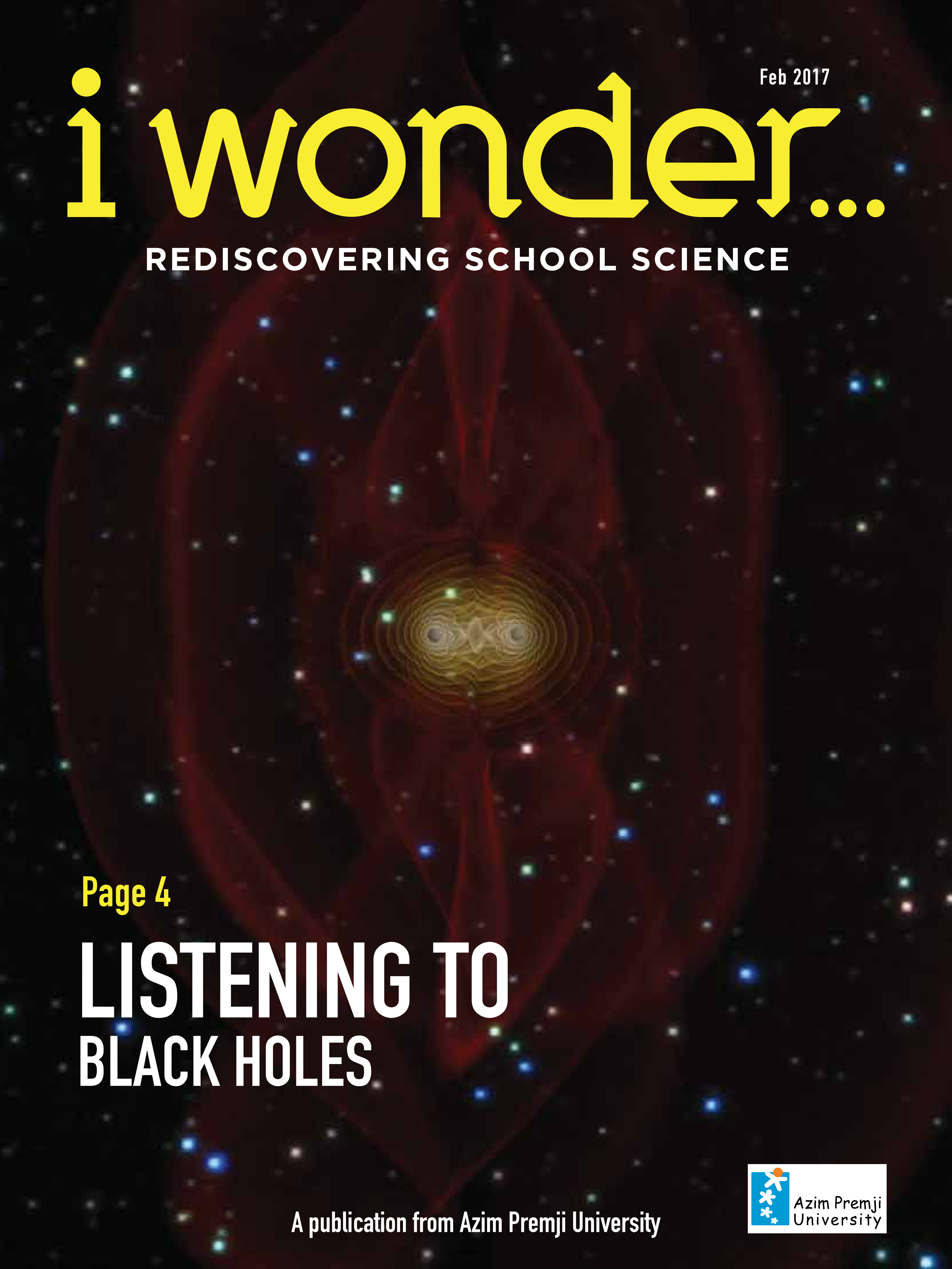
Feb 2017

i wonder...

REDISCOVERING SCHOOL SCIENCE



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LISTENING TO BLACK HOLES

A publication from Azim Premji University

Azim Premji University

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i wonder...
REDISCOVERING SCHOOL SCIENCE

Editor's Desk

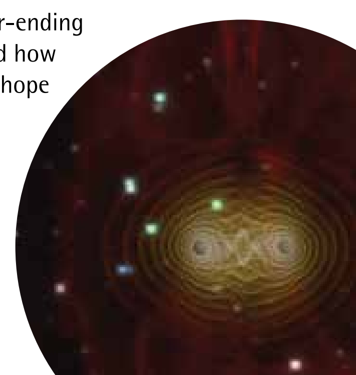
Propelled by science, humanity is at the cusp of becoming a spacefaring civilisation, with 'eyes' firmly set on distant stars and feet taking the first baby steps towards other planets in the Solar system. At this juncture, it is important to remember that science education can no longer be limited to telling students a plethora of facts, as if they are a given. Rather, the role of science education, as emphasized in the article **Why Science Matters**, is to enable children understand and appreciate the scientific process that has led to the most plausible hypotheses being proven with hard data and then being presented as theories. It is also about encouraging children to make use of this process, not only in scientific quests, but also in their day-to-day life. Effective science teachers can convey the beauty of this process and share the wonder it brings with their students. Because, often, each of these 'facts' is the culmination and coming together of work done by many scientists, spanning decades, and at times, even centuries. Frequently, they have benefited from the work of many other scientists – some of whom have come up against blank walls in an attempt to prove their hypotheses. What's more - many of these scientists have worked in seemingly unrelated streams of science, seeking answers to possibly unrelated questions!

The most plausible answers to the most fundamental questions – questions regarding the origins of time and space, of matter and energy, or the very existence of our Earth and life itself – have all benefited from this collaborative nature of science. Often, hundreds of scientists from across the globe have contributed individual jigsaw pieces that together unveil the whole grand picture. We have tried to capture this in the theme section on **Origins.** Any student of science cannot help but appreciate each of these hundreds of jigsaw pieces just as much as the final picture that emerges.

When one examines how these answers were arrived at, what one also realises is the role of technology in new discoveries. Each advancement in technology presents scientists with additional 'senses' to perceive nature, and hence, make available vastly improved and completely new data. Sometimes this new data upends existing 'facts' and sends scientists scrambling to develop and prove new hypotheses that fit all new known observations. Many sections of this issue, including **Emerging Trends in Physics, Annals of History, Indian Science Facilities** and **I am a Scientist**, highlight how technology has helped us reach our current understanding of the universe and nature around us.

The beauty of science is that there is no absolute truth. As newer technologies develop and newer discoveries are made, newer mysteries emerge, requiring more collaborative work and even more advanced technologies to solve them. Thus, science is a never-ending quest to understand the nature of the universe and how best humanity can tap its unlimited resources. We hope that this issue of '**i wonder...**' ignites the spark to embark on that quest in each of our readers.

RamG Vallath
Editor



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LISTENING TO BLACK HOLES

PARAMESWARAN AJITH

The recent discovery of gravitational waves not only confirms Albert Einstein's century old prediction, but also opens up a completely new way of observing the Universe. This article describes the exciting story of this discovery, what went behind it, and what lies ahead.

Around 1.3 billion years ago, in a distant galaxy, two massive black holes moving at speeds close to the speed of light merged to form an even more massive black hole. This powerful event released an energy equivalent to the mass of three Suns, in a fraction of a second. If this energy was converted into light, this flash of light would have outshined the entire visible universe – that is, all the stars in the universe put together – for a fraction of a second. However, this merger did not produce any light. Instead, it produced powerful ripples in spacetime, called gravitational waves.

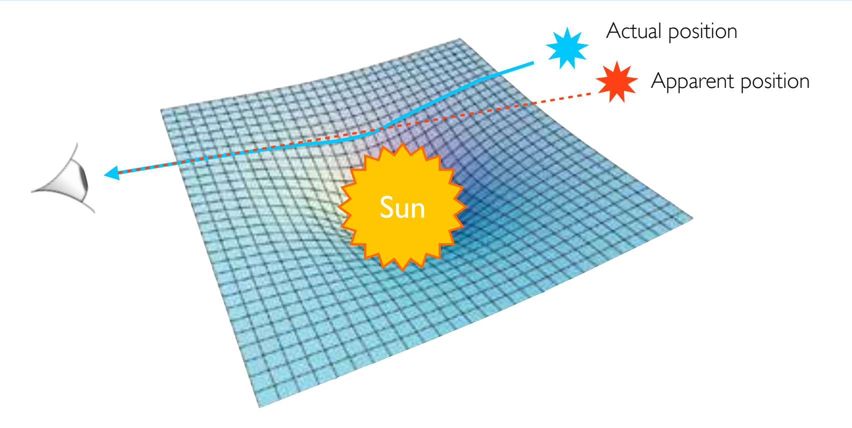
These ripples reached the Earth on 14th September 2015, having travelled a distance of 1.3 billion light years. Two marvelous instruments of the Laser Interferometric Gravitational-wave Observatory (LIGO) in the USA detected these tiny ripples in spacetime. When scientists announced this discovery on 12 February 2016, it produced even greater ripples in the popular imagination. The New York Times described it as "the chirp heard across the universe." What scientists detected in LIGO was a phenomenon called the General Theory of Relativity that was theoretically predicted by Albert Einstein, almost a century before, as a consequence of his theory of gravity.

Gravitational waves

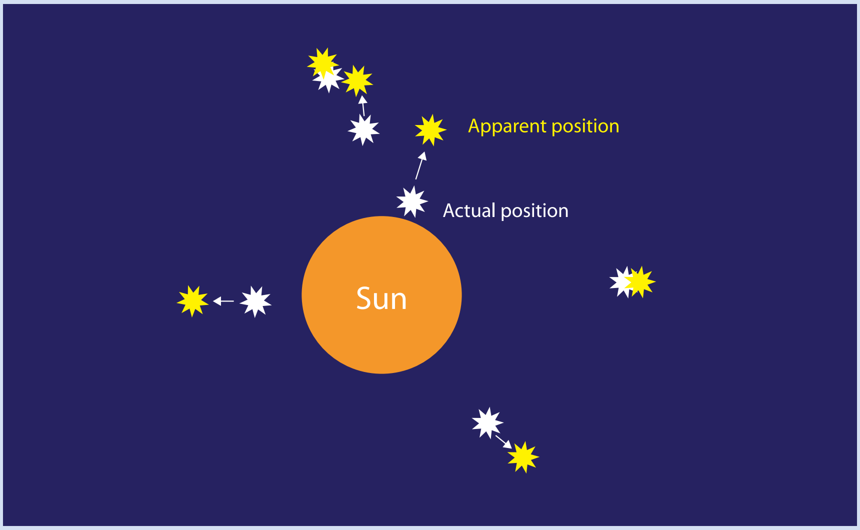
The existence of gravitational waves is one of the most intriguing theoretical predictions of Einstein's General Theory of Relativity (1915). Regarded as one of the pillars of modern physics, the General Relativity is the most accurate theoretical description of gravity available to us today. According to this theory, any massive object (or other forms of energy, such as electromagnetic radiation) curves the spacetime around it. Following this curvature of spacetime, light, which travels in a straight line in flat spacetime, starts to bend near a massive object.

This effect was first observed by the British astronomer Arthur Eddington during the total solar eclipse in 1919. The bending of starlight caused a shift in the apparent position of the stars near the Sun, as compared to their original position, that Eddington found to be consistent with Einstein's prediction (see Box 1). Einstein's theory also predicts that gravity warps time. That is, time runs slower near a massive object. This effect is not only observed in a number of astronomical phenomena and laboratory tests; the Global Positioning System (GPS) needs to take this effect into account for it to function (see Box 2).

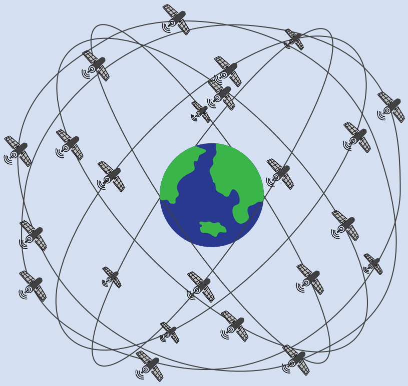
Box 1. Gravitational bending of light



In this cartoon, spacetime is schematically represented as a two-dimensional surface crisscrossed by parallel lines. The Sun curves the spacetime around it so that the shortest path between the star and the observer is no longer a straight line. Since the starlight takes the shortest path between the source and the observer, it bends in the curved spacetime, thus shifting the apparent position of the star. The starlight passing close to the limb of the Sun would be deflected most (by about 1.75/3600 degrees). Thus, stars closest to the Sun suffer the greatest shift in their apparent position.

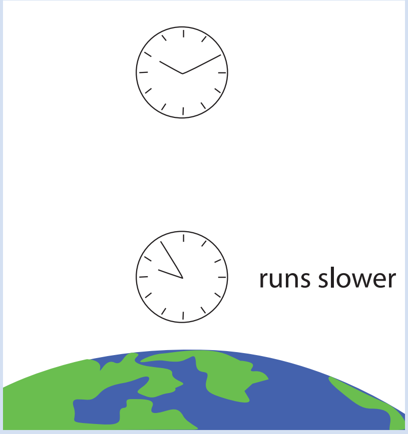


Box 2. The global positioning system and gravitational time dilation



The global positioning system (GPS) relies on a system of satellites orbiting the Earth, which acts as a reference. These satellites have precise atomic clocks onboard, and constantly transmit their location and time. If we receive radio signals from at least four satellites at a time, we can make use of the known constant speed of light to compute our three dimensional position, and the time as measured by a reference clock. The GPS allows us to locate our position on the Earth with an accuracy of up to 10 meters.

However, according to General Relativity, gravity slows time. As a result, a clock on the Earth's surface would tick slower than a similar clock onboard the satellite by about 3 microseconds per day. Note that this is much larger than the time taken by light to travel 10 meters. Thus, the GPS receivers have to factor in this subtle effect if they have to locate their position accurately.



This is one way General Relativity has made its way into our daily lives!

The amount of the warpage of the spacetime outside a gravitating object depends on its mass (or energy) and the distance from it. For example, the warpage of spacetime due to the mass of the Earth is tiny, but precision timekeeping mechanisms such as the GPS still need to account for these effects. In contrast, enormous warpage of spacetime can be observed in the neighborhood of extremely massive and compact astrophysical objects, such as black holes and neutron stars. Expected to be produced by the gravitational collapse of massive stars at the end of their lifetime (when they run out of nuclear fuel), a black hole that is as massive as the Sun, for example, has a radius of only a few kilometers (remember that the Sun's radius is about 700,000 km)!

When a massive and compact object accelerates, it not only causes the spacetime curvature to follow its movement, but also produces oscillations in this curvature that detach from the source and propagate outwards. The process of gravitational waves being produced in this way is analogous to the generation of electromagnetic waves by the acceleration of charged particles. Only, for gravitational waves, the oscillations are in the geometry of spacetime itself.

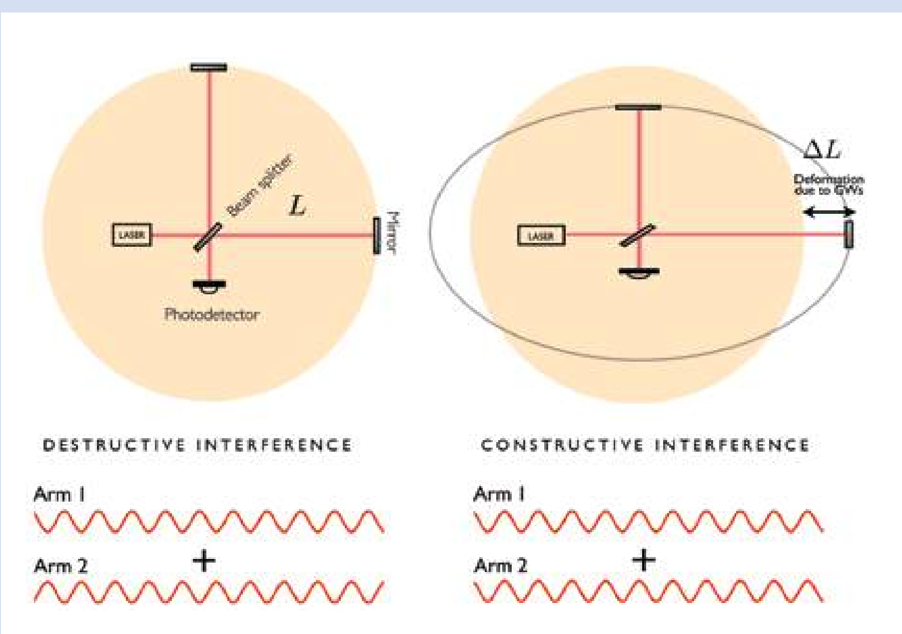
While examining field equations of General Relativity in 1916, Einstein discovered that they admitted mathematical solutions that describe waves travelling at the speed of light. However, whether these are phenomena that exist in the physical world or not remained controversial until the 1950s. There were times when Einstein, himself, doubted their existence. However, a large body of theoretical work from the 1950s and 1960s established that gravitational waves have real physical existence. They could, for instance, carry away energy from their source, much like electromagnetic waves. Then, in 1975, Russell Hulse and Joseph Taylor discovered a binary pulsar system through radio observations. This is a system of two neutron stars orbiting each other with a period of about 8 hours. If the system radiated gravitational waves, the loss of energy would cause the orbital separation to decrease. Measurements using a few years of radio observations showed a corresponding decrease in the orbital period, agreeing precisely with the prediction of General Relativity. This was a remarkable triumph of the theory and settled, beyond any reasonable doubt, that gravitational waves are real. Hulse and Taylor were awarded the 1993 Nobel Prize in Physics for the discovery of this binary pulsar.

Catching the wave

While binary pulsars allow us to observe the effect of gravitational waves, we have not observed the gravitational waves from them. The success of binary pulsar observations prompted scientists to give serious thought to the possibility of directly detecting gravitational waves.

Theoretical calculations showed that astrophysical phenomena involving massive and compact objects moving with very high velocities will produce gravitational waves that are potentially detectable from the Earth. Examples include the collapse of massive stars at the end of their lifetime, binary systems of black holes or neutron stars, fast rotating deformed neutron stars, and the Big Bang itself. There was also compelling observational evidence of the existence of such phenomena. Experimental efforts to detect gravitational waves started in the 1960s itself, with Joseph Weber using resonant bar detectors. However, what revolutionized this endeavor was the idea of using large-scale laser interferometers as gravitational wave antennas.

Far away from their source, gravitational waves can be thought of as time-dependent distortions in the curvature of space. They distort space in a way that is characteristic of tidal forces. Just like the Moon creates tides, deforming the Earth from its spherical shape, gravitational waves would deform a ring of "test particles" into ellipses (except that the tidal deformation produced by gravitational waves is purely transverse, i.e., perpendicular to the direction of wave propagation). It is this key idea that makes a laser interferometer the ideal instrument for detecting gravitational waves (see Box 3).



Box 3. Detecting gravitational waves using laser interferometers:

In a Michelson interferometer, a laser beam is split and sent to two orthogonal arms, which are reflected by two mirrors, and then allowed to recombine.

Initially the length of the two arms are adjusted in such a way that the two light beams interfere destructively (left). When a gravitational wave passes perpendicular to the plane of the interferometer, it will lengthen one arm and shorten the other. Since the speed of light is a universal constant, this will introduce a relative change in the time taken by light to make this round trip in the two arms. The interference between the two light beams will change the output power of the light, which can be read out using a photo-detector.

Invented by Albert Michelson in the late nineteenth century, interferometry is a well-established technique. The problem with using it as a gravitational wave detector is that the distortions in the arm-length of the interferometer due to the passage of gravitational waves are tiny. For example, the merger of two neutron stars in Virgo, a neighboring galaxy cluster, will only make a fractional change of ~ 10^{-21} in the arm length of the interferometer! This means that to detect this phenomenon, we will need to measure length changes as small as 10^{-21} meters. No wonder, then, that detecting gravitational waves is a difficult task! One way of addressing this problem is by using interferometers with arms much longer than that of a 1-meter table-top device – with longer arms, the absolute change in the arm length produced by the gravitational wave would be larger. Thus, modern gravitational wave detectors are kilometer-scale Michelson interferometers. However, we still have to measure changes in their arm length that are much smaller than 10^{-18} meters – much smaller than the size of an atomic nucleus! Interferometers are nominally designed to measure the distance between the 'dark' and 'bright' fringes, that is, length scales comparable to the wavelength of light used. However, with advances in the last three decades, modern gravitational wave detectors measure a much smaller fraction (~10^{-12}) of the wavelength by detecting tiny changes in the brightness of the light coming out of the interferometer.

Although an interferometer is most sensitive to gravitational waves arriving perpendicular to its plane, it is also sensitive to signals coming from almost all other directions. It is an antenna that can detect signals coming from essentially the full sky. This is different from a telescope, which can be pointed to a small part in the sky to observe a star or a galaxy. On the one hand, this allows us to observe the full sky using a small number of antennas. On the other hand, this makes it difficult to identify the location of the source using a single antenna. Instead, the location of the source is identified by combining data from multiple, geographically-separated detectors. Since gravitational waves travel at the speed of light, the difference in the arrival time of the signal in multiple detectors across the globe allows us to reconstruct the location of the source in the sky. This is analogous to an owl identifying its prey by processing the time of arrival of the sound in its two ears. This makes it evident that the larger the distance between different detectors, the better is the accuracy with which the source of a gravitational wave can be localized. In this context, current plans to establish a LIGO observatory in India will be an important addition to the existing international network of gravitational wave detectors. Since the site for LIGO-India is at a significant distance from the existing detectors in USA and Europe, it will greatly improve the accuracy with which gravitational wave sources can be localized in the sky.

While examining field equations of General Relativity in 1916, Einstein discovered that they admitted mathematical solutions that describe waves travelling at the speed of light. However, whether these are phenomena that exist in the physical world or not remained controversial until the 1950s. There were times when Einstein, himself, doubted their existence. However, a large body of theoretical work from the 1950s and 1960s established that gravitational waves have real physical existence.

A new "sense" to perceive the universe

Large interferometric gravitational wave detectors have been constructed at many different parts of the globe.

After a major upgrade over the past few years, two of these detectors, at the LIGO observatory in the USA, started operating with a significantly improved sensitivity since September 2015. On 14th September, 2015, both these Advanced LIGO detectors, separated by about 3000 kilometers, observed a coincident gravitational wave signal. A careful analysis of this data revealed that the signal was produced by the merger of two massive black holes that were about 1.3 billion light years away. Apart from being the first direct detection of gravitational waves, this is the first discovery of a binary system consisting of two black holes. These black holes were significantly more massive than any other stellar-mass black holes that astronomers have observed so far – in fact, each of these black holes were about 30 times more massive than our Sun! The merger produced an energy equivalent to the mass of three Suns ($E = 3 Mc^2$) that was radiated as gravitational waves over a fraction of a second, reaching a peak power emission of 10^{49} watts! This is the most powerful astronomical phenomena ever observed by humankind. On 26th December 2015, a second signal, from yet another black hole merger was observed. Based on the rate of observed signals, scientists expect observations of gravitational waves from black hole binaries to become routine in the coming years.

The history of astronomy presents a story full of surprises. Looking at the heavens through his telescope, Galileo saw that far from being a translucent and perfect sphere as thought by the ancients, the Moon was full of large mountains and deep craters; Venus had phases like that of the Moon; and Jupiter had satellites orbiting it. Since then, radio, microwave, infrared, ultraviolet, x-ray and gamma-ray telescopes have extended astronomy to invisible wavelengths of the electromagnetic spectrum and presented different windows to the universe. Cosmic ray and neutrino observations have extended astronomy to messengers that are entirely different from electromagnetic waves. LIGO has opened up the newest branch of observational astronomy – its observations of gravitational wave signals have frequencies in the audio band. Thus, gravitational wave astronomy is more like listening to the Universe rather than looking at the Universe. One may say that gravitational wave observations gave astronomy yet another "sense" with which to perceive the Universe.

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Further reading

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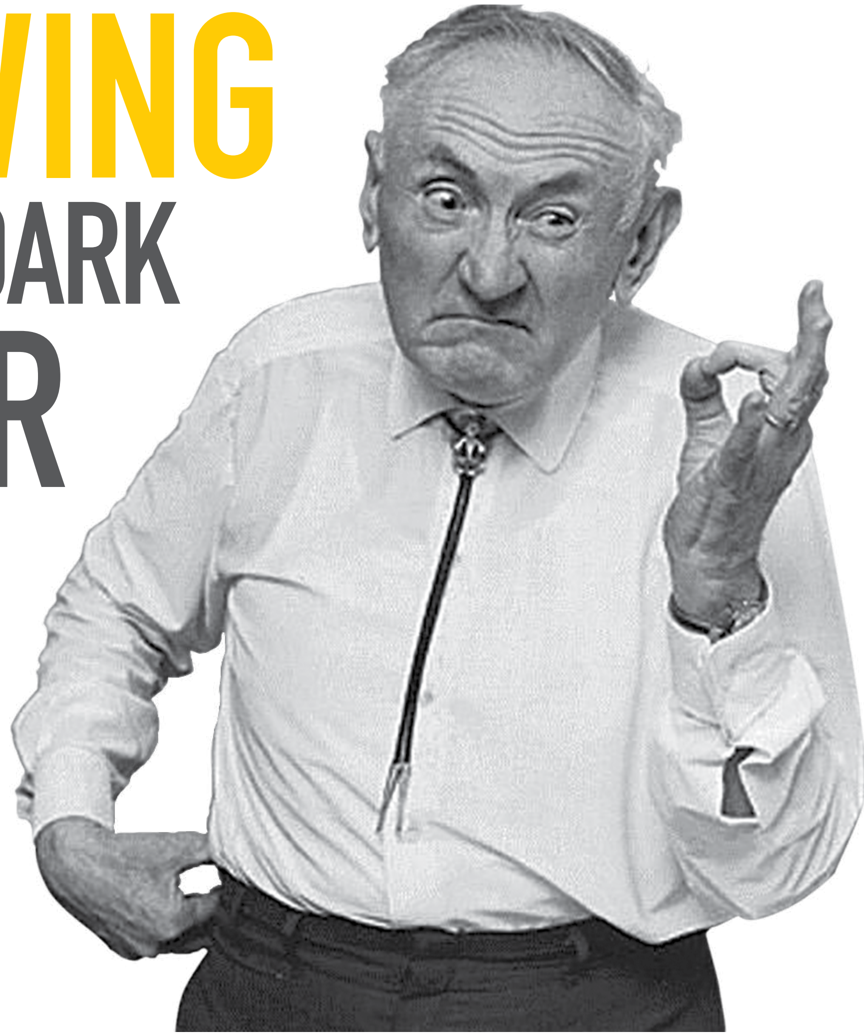
THROWING LIGHT ON DARK MATTER



AMITABHA MUKHERJEE

What is dark matter? How do we know it exists? Where is it found? This article explores such questions, showing how the study of the largest structures in the Universe tells us something about the smallest constituents of matter.

If we look at the universe as a whole, we see many objects that emit light. Obvious examples are stars, such as our Sun. In addition, there are enormous glowing clouds of gas and other mysterious objects, such as quasars. Collectively, these are referred to as luminous or bright matter.

However, not everything in the universe emits light. Examples include our own Earth, and indeed all the planets in the solar system. Such objects are collectively called Dark Matter. The solar system has very little dark matter – all the planets, asteroids, comets etc., put together make up only about 0.14% of its mass. Why then should we worry about dark matter, and why should it be a subject of study? The reason is that the solar system is very small when seen on the scale of the universe as a whole; there is a lot of dark matter of other kinds 'out there'.

Detecting dark matter

Before we widen our discussion, let's take a look at how dark matter can be detected. While planets as distant as Saturn are visible to the naked eye by the sunlight that they reflect, this method is unlikely to work for more distant objects.

One way to find more dark matter is illustrated by the discovery of Neptune in the 19th century. Irregularities in the orbit of Uranus indicated an unexplained gravitational pull on the planet – perhaps by another, as yet undiscovered, planet. Neptune was discovered, telescopically in 1846, close to this predicted position. In other words, even when an object emits no light, its presence can be inferred from its gravitational effects. Since gravitation is universal, other kinds of dark matter, on different distance scales, are

Fig. 1. A recent image of the Andromeda Galaxy.
Source: Adam Evans, Wikimedia Commons. License: CC-BY. URL: https://en.wikipedia.org/wiki/File:Andromeda_Galaxy_(with_h-alpha).jpg.

also likely to make their presence felt through their gravitational effects.

Another piece of evidence for the existence of dark matter comes from spiral galaxies. Our Milky Way is an example of a spiral galaxy. So is the Andromeda galaxy, also known as M31, whose spiral arms are beautifully visible in Figure 1. As we can see, the galaxy appears to be flat, with the stars distributed close to the central plane, forming a bulge in the centre. This is how most spiral galaxies look.

Now comes the interesting part. The stars in a galaxy exert gravitational forces on one another, while they rotate about the centre of the galaxy. Newton's law of gravitation allows us to calculate how the rotation speed of a star depends on its distance from the centre. A simple calculation shows that the rotation speed should decrease with the distance from the centre (think of our solar system: the innermost planet Mercury whizzes around the Sun at 47.87 km a second while Neptune moves at a sedate 5.43 km/s). Thus, we can actually measure how fast the stars are rotating in nearby galaxies, such as M31. In M31, and hundreds of other similar galaxies, however, something quite different is observed. As we move out towards the edge of the galaxy, the speed of the stars remains constant rather than decreasing.

There are two main ways to account for this discrepancy. The first is to say that Newton's Law of Gravitation does not hold at galactic scales. While some scientists believe that the solution to the problem lies in this direction, we will not be discussing this any further in this article. The second way is to assume that Newton's Law holds, but that the mass in a galaxy is distributed in a much more uniform manner than it seems to be. Moreover, the mass of the galaxy appears to be much more than the total mass of the stars in it. In other words, the galaxy is full of dark matter. A picturesque way to put it is to say that, apart from the visible disk, the galaxy has a halo, which, unlike the disk, is not flat but more or less spherical.

You may wonder if this holds for non-spiral galaxies. Measurements of the speeds of stars in the other important type of galaxies – elliptical galaxies – leads to the same conclusion: most galaxies are full of dark matter.

Box 1. What is a black hole?
A black hole is a place in space where the pull of gravity is so strong that even light cannot get out. This pull of gravity is because matter has been squeezed into a tiny space. This can happen when a star is dying. And it is because no light can get out that people can't see black holes – they are invisible!

Estimates for our own galaxy, the Milky Way, indicate that over 80% – perhaps even as much as 95% – of its total mass is in the form of a dark matter halo.

Dark matter in galactic halos

What is the precise nature of the dark matter in galactic halos? This is still an open question. One possibility is that the halo is made of planet-like objects, or stars that are still in the process of formation. Black holes are another possibility.

Such massive astrophysical compact halo objects or MACHOs (scientists like to make up such acronyms) have one common feature: they are made up of 'ordinary' matter. As we know, ordinary

Box 2. Supersymmetry: In the 1970s, some theorists suggested that Nature may possess a new symmetry, called supersymmetry, which connects existing elementary particles to other, as yet undiscovered, ones. For example, the electron, which has spin half, would have a superpartner with spin zero. All the superpartners would have to be very heavy, since they haven't shown up in particle collisions so far. If we extend the standard model to include supersymmetry, we get models with many undiscovered massive particles, including WIMPs.

matter consists basically of protons, neutrons and electrons, with the last being much lighter than the others. Protons and neutrons belong to a type of elementary particles called baryons (from Greek *barys*, meaning heavy), so ordinary matter is called baryonic matter. Now if the proposed MACHOs are planet-like objects made of baryonic matter, they will reflect the starlight falling on them. Since our galaxy is presumably full of MACHOs, they should show up in our telescopes. Searches specifically designed to look for them have failed to find any. There are other arguments too, which together, lead to the conclusion that MACHOs, if they exist at all, contribute only a small amount of mass to our galaxy.

We are led to the inescapable conclusion that galactic dark matter, unlike the dark matter in our solar system, is composed of something exotic. A favoured category of candidates is weakly interacting massive particles, or WIMPs (acronym-coining again!). Many times heavier than protons and neutrons, WIMPs interact through weak nuclear forces and gravitation. The Standard Model of particle physics, which has enjoyed great success starting with the discovery of W bosons in 1983 to that of the Higgs boson in 2012, simply does not have place for such particles. Thus, if galactic halos are largely made up WIMPs, particle physics has to go beyond the standard model. What makes this field of study so exciting is the interplay between the very large and the very small: galactic halos that are typically hundreds of thousands of light years in size suggesting that we need to rethink laws of physics at scales smaller than the radius of a proton! Interestingly, theorists have, for completely different reasons, also been suggesting that we need to go beyond the standard model. A popular idea, in this context, has been that of supersymmetry, and supersymmetric models indeed naturally lead to WIMPs.

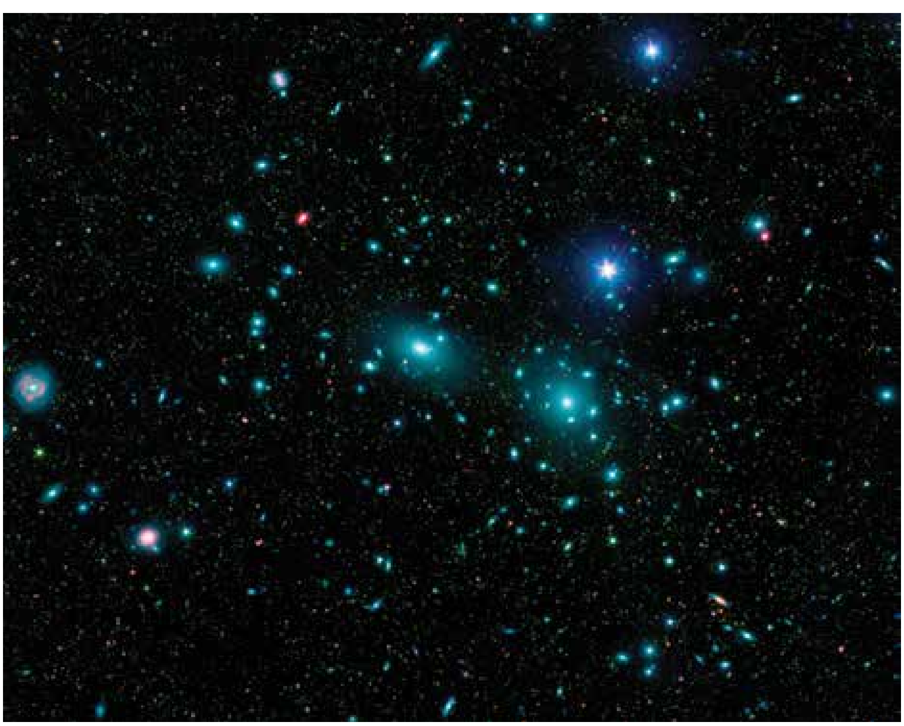


Fig. 2. A composite image of the Coma Cluster.

Source: NASA / JPL-Caltech / L. Jenkins (GSFC), Wikimedia Commons. License: Public Domain. URL: https://commons.wikimedia.org/wiki/File:Ssc2007-10a1.jpg.

Dark matter in galaxy clusters

While galaxies are very big, they are not the largest structures in the universe. Most galaxies lie in clusters consisting of 100–1000 galaxies, held together by their mutual gravitational attraction. The distance scales are mind-boggling: a typical cluster size is 10–20 million light years. Figure 2 shows the Coma Cluster, whose centre is about 320 million light years away. Note that each star-like object in the picture is actually a galaxy, typically consisting of a billion stars or more.

Now when a system of objects interacting through gravitation has been around for a long time, we expect the average energy of motion of its members to be roughly the same as the energy of interaction. In fact, it can be shown that the average kinetic energy is one-half of the magnitude of the average potential energy. But we see something quite different: the galaxies in most clusters appear to be moving much faster than expected. By now you must have guessed the explanation: there are invisible sources of gravitational attraction distributed through the cluster – in short, dark matter. In fact, the term Dark Matter was first used by the Swiss astronomer Fritz Zwicky, way back in 1933, in connection with his studies of the Coma cluster, whose modern image we saw in Figure 2. Zwicky concluded that the mass of this cluster was 400 times the sum of the masses of its galaxies, indicating that the cluster was made mostly of dark matter. The modern estimate is somewhat lower, but 90% of the total mass of clusters such as these is typically believed to be contributed by dark matter.

To conclude

Clearly, since dark matter is spread out over such immense scales in the universe, it seems likely that it plays an important role in our understanding of the universe as a whole – its structure as well as its evolution. And it does – with a majority of cosmologists now believing that dark matter has played a crucial role in the origin of complex structures in the universe. The microwave background radiation that permeates the whole universe shows tiny wiggles. These, as well as the formation and evolution of galaxies and their clusters, is consistent with the model that dark matter makes up about 85% by mass of the total matter in the universe.

According to the latest data available from the Planck satellite, whose mission was to study the wiggles in the microwave background radiation, the energy content of the universe is as follows: baryonic matter 4.9%, dark matter 26.8%, and dark energy 68.3%. The last quantity may come as a surprise, since we have not spoken about it so far. However, since media reports often talk of dark matter and dark energy, it is important to note that the two are quite distinct.

In summary, dark matter of various kinds is found at various distance scales in the universe. Our Earth, and we ourselves, are part of the dark matter story. However, planets etc. are composed of baryonic matter, while most of the dark matter 'out there' is non-baryonic. Its precise nature is a subject of current study, and connects our understanding of the very large – cosmology – to that of the very small – particle physics. This is something no one would have imagined a hundred years ago. We are lucky to be living in exciting times!

Amitabha Mukherjee is a Professor at the Department of Physics and Astrophysics, University of Delhi. Email: amimukh@gmail.com.

LOOKING FOR OTHER WORLDS OUT THERE

SUMA N MURTHY

Are there worlds outside our Solar System? How do we look for them? What can we learn from them? In this article, the author shows how recent advances in technology have made the search for exoplanets more exciting than ever before!

Questions regarding the uniqueness of the solar system, and more particularly that of Earth, have haunted the human mind for ages. The possibility that planetary systems outside our own existed in the universe was first suggested in the sixteenth century, by the Italian philosopher Giodano Bruno. According to Bruno, distant stars could just be like our own Sun, in hosting planets, and even life. Voicing similar thoughts, Sir Isaac Newton referred to exoplanets towards the end of the 1713 edition of his celebrated work, Principia, stating that:

"...this most beautiful System of the Sun, Planets, and Comets, could only proceed from the counsel and dominion of an intelligent and powerful being. And if the fixed Stars are the centers of other like systems, these, being formed by the likewise counsel, must be all subject to the dominion of One; especially since the light of the fixed Stars is of the same nature with the light of the Sun, and from every system light passes into all the other systems ..."

An extrasolar planet, or an exoplanet – as it is called today, is defined as a planet that orbits a star other than the Sun. While many people claimed to have detected exoplanets, the first such claims to be confirmed were in 1992, when the astronomers Aleksander Wolszczan and Dale Frail observed 3 planets revolving around a pulsar – a rapidly rotating star almost at the end of its lifetime, called PSR B1257+12. Three years later, the Swiss astronomers Didier Queloz and Michel Mayor discovered another exoplanet, one that was revolving around a yellow star, called 51 Peg, which was similar to our own Sun. This was followed by the discovery of two more exoplanets, in 1996, by a team of American astronomers, led by Paul Butler and Geoff Marcy. This team went on to discover around 70 of the 100 exoplanets known by the end of the subsequent decade. The launch of the Kepler Space Telescope in 2009 has brought about a revolution in this field. This telescope has been used to collect enormous amounts of data, keeping astronomers busy mining it for clues to other exoplanets.

Box 1. A slice of history

The world famous Arecibo telescope was shut down for repair in the early 1990s and became unavailable for normal use by the general astronomy community. The astronomer Wolszczan made use of this rare opportunity by using this telescope to search for pulsars. This search led to the discovery of the pulsar PSR B1257+12, and later revealed the existence of planets around it.

At almost the same time, another group of astronomers led by Prof. Matthew Bailes claimed that they had discovered a planet around the pulsar PSR 1829-10. The American Astronomical Society convened a meeting at Atlanta, in January 1992, to discuss these two exciting discoveries.

However, before the meeting could convene, the group led by Bailes found out that their discovery was an error caused by ignoring certain effects caused by the interstellar medium. In a fantastic display of scientific ethics and honesty, deeply appreciated by the scientific community, Bailes publicly acknowledged this mistake in the meeting. Consequently, Wolszczan and Frail were acknowledged as the discoverers of the first set of exoplanets.

(To read a detailed description of this entire episode in Wolszczan's own words, go to www.sciencedirect.com/science/article/pii/S1387647311000418).

How do we find exoplanets?

Astronomers use a variety of methods to detect exoplanets. Many of these are indirect and determine the presence of exoplanets by looking at how they affect their host star and its actions. This is because, except in certain cases, the host stars are so far away and so bright, that they outshine their planetary companions.

This is similar to our own solar system where the Sun's brightness at visible wavelengths is a billion times greater than Jupiter. In other words, if we were to observe the solar system from a distance, for every 1,000,000,000 light particles we receive from the Sun, we would be able to see about 1 light particle from Jupiter. In contrast, if we were to observe the Sun and Jupiter from a distance of even 15 light years away, the two would seem to be separated from each other by only 1/3600th of a degree, which is about the width of a strand of hair! As you can see from this analogy, imaging even a large planet under these circumstances is as challenging as photographing a fire-fly fluttering very close to a flood light!

To be able to really "see" those worlds (and their inhabitants, if any) in their entirety, we will need far-better technology than what exists today. Till the time these improvements happen, we will continue to infer the presence of exoplanets, studying them in all the ways permitted by current technology! Some of the most common detection methods we use for this purpose are described below.

Radial Velocity Tracking

This is a very successful method for hunting down exoplanets. It was in fact used by the astronomers Queloz and Mayor to detect the first exoplanet revolving around a normal (non-pulsar) star. If an orbiting planet is massive, its gravitational pull on the parent star can cause the star to wobble. This slight movement of the host star, facilitated by the Doppler effect (refer Box 2), can be used to detect the presence of exoplanets.

Big gas giant planets, like Jupiter, induce wobble velocities of several tens of meters per second on their host stars. Current technology allows us to detect wobble velocities as small as half a metre per second (this is how fast we walk on a leisurely stroll). Every improvement in this technology will increase the possibility of detecting much smaller and rockier planets, like the Earth, in other planetary systems.

Box 2. Doppler effect

Have you noticed the sudden change in pitch in the sound of an ambulance siren or a speeding motorbike as it speeds towards you and then passes you to speed away? This effect, called the Doppler effect, is described as an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move towards (or away from) each other. Astronomers use this effect to determine the speed with which stars or galaxies approach or move away from us on Earth, identified as the degree of shift in frequency of the light that we receive from them. Thus, stars moving away from us show a shift to longer wavelengths of light – called red shift, while those moving towards us show a shift towards the shorter wavelengths – called blue shift.

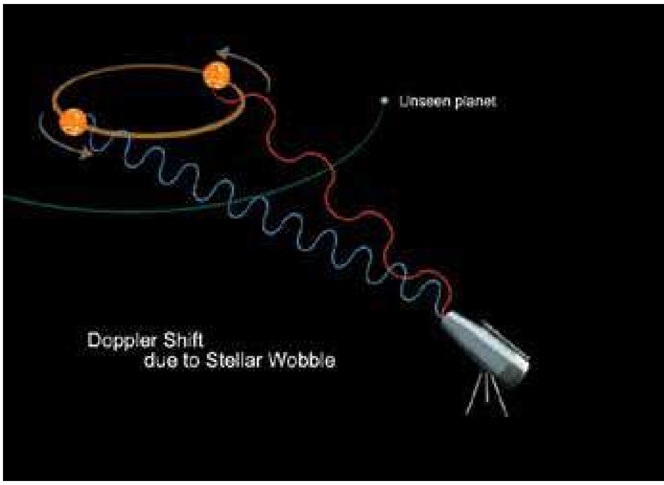


Fig.1. Catching a moving star. The star orbits about the planetary system's center of mass. As it moves towards us, the light from it is 'blue-shifted' and as it moves away from us, it is 'red-shifted'.

Credits: NASA, Night Sky Network. URL: https://nightsky.jpl.nasa.gov/news-display.cfm?News_ID=682. License: Public domain.

Astrometry

Astrometry is a process that involves measuring the positions of stars in the sky as precisely as possible. As we've seen earlier, the presence of a planet causes its star to wobble slightly. This wobble is reflected as a subtle change in the position of the star in the sky. As this change can be very slight, we need high precision measurements to detect it. It is for this reason that the presence of exoplanets was not confirmed through this method until 2009.

Astrometry gained importance in 2013, when the European Space Agency launched a space observatory called Gaia, purely for astrometric purposes. In its lifetime of about 10 years, Gaia is expected to enable us to detect and characterise the orbits of around 70,000 exoplanets!

Transit Method

We use the transit method to detect exoplanets when a star and its planet are aligned towards us in such a way that the planet eclipses the star as it passes by.

The brightness of the star drops ever so slightly during the eclipse. This drop can be detected through observations by high-resolution telescopes trained on it over a period of time. This method works best for large planets with orbits close to the parent star, as this causes a greater and, thus, more easily detectable drop in the star's brightness.

This method has yielded the maximum number of exoplanet detections till date – especially of Earth-like planets, the kind we are most interested in! The main reason behind this huge number of detections is the launch of the space-based Kepler mission in 2009. This mission surveys certain portions of our galaxy to discover planets of the size of Earth and smaller, by using the transit method. Kepler has so far aided in the discovery of 4706 exoplanet candidates, of which 2330 have already been confirmed. That the Kepler mission is space-based is the main reason behind its spectacular success.

Box 3. Why go to space?

The Earth's atmosphere distorts images of outer space, limiting how accurately we can carry out measurements. Placing a telescope outside the atmosphere removes this constraint. As space provides a stable observing platform, it becomes possible to obtain the very fine measurements required to carry out precision astronomy (see figure 2 for comparison).

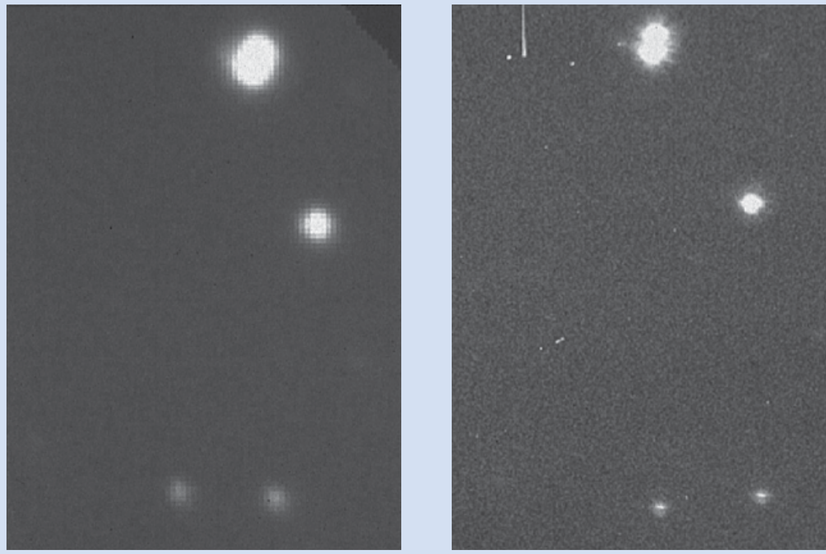


Fig. 2. Ground vs. Space. Here is a comparison between the images of a region of the sky taken by Las Campanas, Chile, Observatory (to the left) and the Hubble Space Telescope (to the right). Did you notice that, in addition to improved clarity, there are also more stars seen in the Hubble image?!

Source: NASA. URL: https://www.nasa.gov/content/hubbles-first-light. License: Public domain.

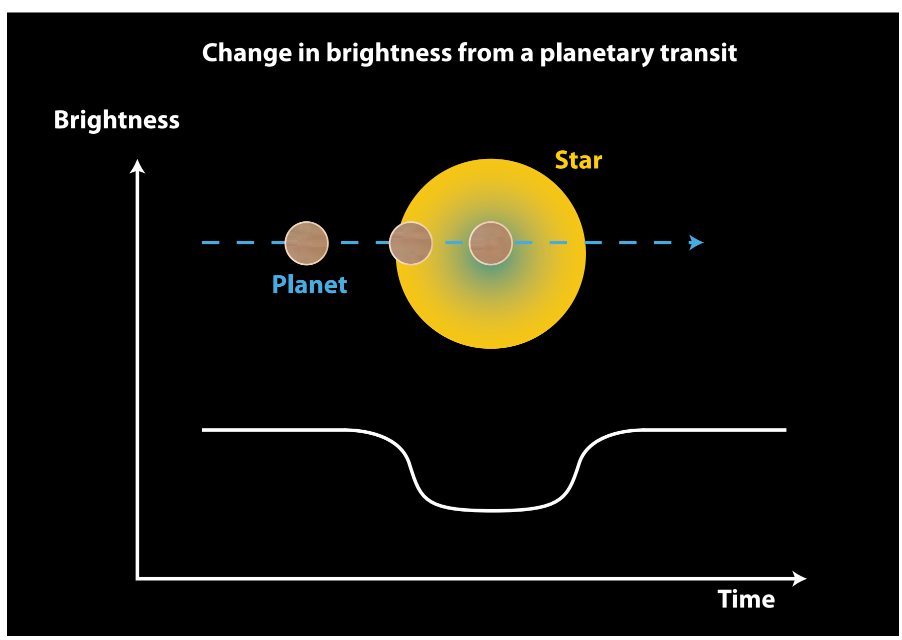


Fig. 3. Caught while transiting! This figure demonstrates how the brightness of a star varies as the planet moves across it. As the planet starts eclipsing the star, we see a gradual drop in brightness which then remains constant as long as the planet is in front of it and later gets back to its original brightness.

Credits: SuperWASP, NASA. URL: http://www.superwasp.org/how.htm. License: Public domain.

Box 4. Tabby's Star!

The star KIC 8462852 is better known by its nickname–Tabby's star, after the scientist Tabetha S Boyajian, who was the first to study it. This star was picked up by the Kepler telescope, which also found that it showed very strange brightening and dimming episodes. This strange behaviour of the star kept extra-terrestrial life enthusiasts on their toes for a while. When attempts to explain these variations through natural causes remained unsuccessful, scientists suggested that they were caused by structures called Dyson swarms, built by an advanced civilization to harness the star's energy. A search for signals from intelligent extra-terrestrial life around this star by the Search for Extra Terrestrial Intelligence (SETI) team has, however, yielded negative results.

Gravitational Micro-Lensing

The general theory of relativity tells us that massive objects can bend light around them. Called gravitational lensing, this effect magnifies the light of a distant star when a nearby faint star moves across it. This is analogous to the effect we see by placing the foot of a wine glass in front of a candle (as seen in Fig. 5).

The brightness of the distant star in the background increases at first, then decreases steadily as the invisible foreground star moves past it, and finally reverts to its usual constant value once the star in the foreground has moved away completely. If the invisible star in the foreground has a planet orbiting around it, then there will be a short time interval during which this planet will also contribute to the lensing effect of the star in the background (see Fig.6). This can be detected and used to infer the presence of exoplanets.

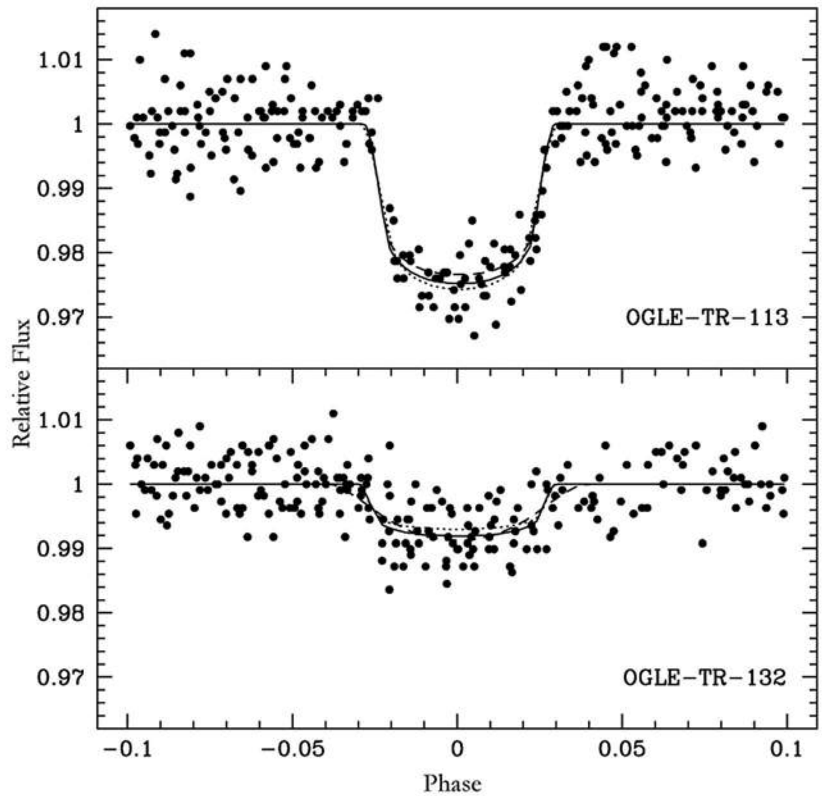


Fig. 4. Science in the real world. The black dots in this image demonstrate how the varying brightness of a star hosting planets appears in reality.

Credits: ESO. URL: https://www.eso.org/public/news/eso0415/. License: Public domain.

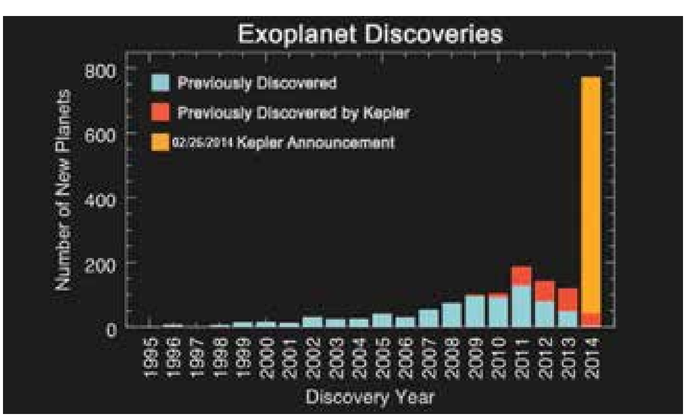


Fig. 5. Kepler steps in with a bang! This histogram shows the number of exoplanets discovered since 1995. Note the sudden jump in the number of discoveries after the Kepler team announced the discovery of about a thousand planets.

Credits: NASA. URL: https://www.nasa.gov/content/exoplanet-discoveries. License: Public domain.

Fig. 6. A model gravitational lens: The way a wine glass distorts the candle light in the background is almost similar to how a massive object distorts light.

Credits: KIPAC, Kavli Insitute of Particle Physics and Cosmology. URL: http://kipacweb.stanford.edu/research/gravitational_lensing. License: Public domain.

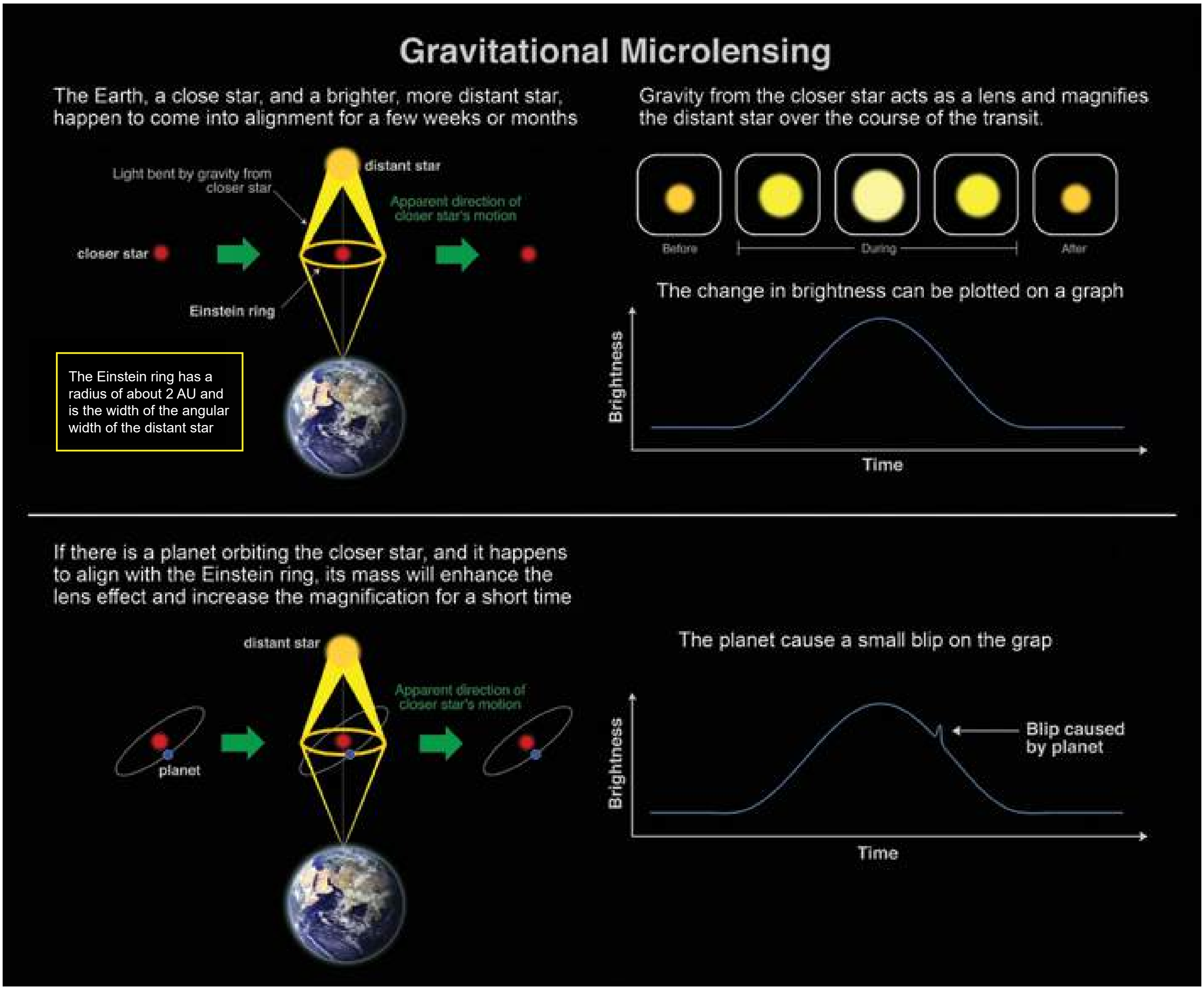


Fig. 7. Microlensing in detail. This is how the gravitational microlensing technique works.

Credits: LCOGT, IFLSCIENCE. URL: https://lco.global/files/spacebook/Gravitational%20Microlensing%20timeline.png. License: Public domain.

Direct Imaging

As mentioned earlier, at visible wavelengths, our Sun is around one billion times brighter than Jupiter. However, at infrared wavelengths – wavelengths longer than the visible light, our Sun is only a hundred times brighter. Provided the circumstances are favourable, we can image the planetary system at these wavelengths. For example, if a planet is very far from its star, and we block the light that we receive from the star, the fainter planet will show itself. This direct imaging method has taken off only recently, enabling us to discover around 33 planets so far.

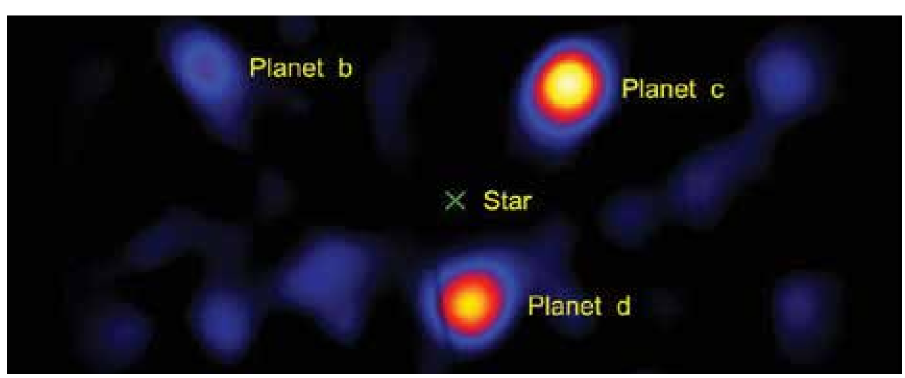


Fig. 8. Photographing the neighbours! This image shows the light we receive from three planets – called HR8799b, c and d - all orbiting a single star, called HR8799. The star is located at the spot marked with an "X." The three planets, are thought to be gas giants like Jupiter, but more massive.

Credits: NASA/JPL-Caltech/Palomar Observatory. URL: http://www.nasa.gov/topics/universe/features/exoplanet20100414-a.html. License: Public domain.

Making large strides!

Since the life span of our solar system is unimaginably longer than our own lifetimes, studying its origin and evolution is not possible even with many generations of continuous research. The best way to go about this is to study similar systems at different stages of evolution, and then piece together the evidence we gather from them.

As we have just seen, other planetary systems are not uncommon at all, and we should be able to study them if only we can detect them in sufficient numbers and diversity. In fact, we have come a long way from the discovery of the first exoplanet, in 1992. Current technology, including the famous Hubble telescope and the Kepler mission, has already helped us detect thousands of planets outside our solar system, and with every advance, we may learn of many more.

Box 5. See them work!

If you want to 'see' how all the detection techniques described here work, please visit https://exoplanets.nasa.gov/interactable/11/.

NASA hopes to launch a Transiting Exoplanet Survey Satellite (TESS) sometime in 2017. The aim of this survey will be to discover planets ranging from those the size of the Earth to those much greater than Jupiter, and with host stars of varied types. Similarly, the James Webb Space Telescope, scheduled to be put into orbit later in 2018, will study the atmospheres of exoplanets and shed light on the ambient conditions in those worlds.

We can now look at the systems just born and understand the early stages of planetary formation; systems slightly older will tell us about the interaction among the planets; and extreme planets orbiting dead stars tell us of the different evolutionary paths possible. We can put to test theories on the formation of our own solar system based on all that we see. We can even study the atmospheres of exoplanets and determine their habitability to a large extent. But more importantly, the study of exoplanets is a major stride towards satiating our own curiosity regarding the existence of habitable worlds and intelligent life out there!

Box 6. Be a citizen scientist!

Probed by mega projects like the Kepler mission, the Milky Way is only too happy to give away the whereabouts of exoplanets. Huge amounts of data have been collected, but now a huge amount of human resource is needed to make sense of this. Planet Hunters is a citizen project which makes use of the human capability of pattern recognition to extract signals betraying the presence of exoplanets. This project has around 300,000 volunteers, and many planet discoveries to its credit, including the weirdness of Tabby's star! So, if you are dying to join the search for exoplanets, the Planet Hunters group will certainly be very happy to take you into their fold! Visit www.planethunters.org and help scientists discover new worlds!

Note: Credits for the image used in the background of the article title: Kepler Mission Overview, NASA Ames/ W Stenzel, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:NASA-KeplerSpaceTelescope-ArtistConcept-20141027.jpg. License: Public Domain.

Want to know more?

1. A (very) technical paper on the detection techniques: http://www.mpia.de/homes/ppvi/chapter/fischer.pdf.
2. About Kepler mission: http://kepler.nasa.gov/ and http://www.nature.com/nature/journal/v513/n7518/pdf/nature13781.pdf.
3. About Gaia mission: http://sci.esa.int/gaia/ and https://arxiv.org/pdf/1411.1173v1.pdf.
4. Some websites to tell you all about the recent gossip in the field: http://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html and https://exoplanets.nasa.gov/newworldsatlas/.
5. About some of the upcoming missions: https://tess.gsfc.nasa.gov/overview.html and http://www.jwst.nasa.gov/.

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HUMAN SETTLEMENT ON MARS

INTERVIEW WITH MARS ONE

About 70,000 years ago, Homo sapiens moved out of Africa and eventually spread across the globe. Today, humanity is ready to take the next big leap – to land on, and explore other planets. Because of its proximity and similarity to Earth, Mars is the obvious choice to start with. Many people believe that eventually, humanity is destined to be a spacefaring, multi-planetary species, spreading across the galaxy and the universe. This decade has witnessed several proposals from various agencies for exploring Mars – ranging from manned Mars missions to establishing permanent settlements on Mars. What is significant is that many of these are from private companies or foundations. This entry of private players into the fray has substantially ramped up the excitement around Mars colonisation. Mars One is one such organisation that has unveiled a plan to colonise Mars in the coming decades. The following is an interview with the Mars One team. The purpose of this interview is not to endorse Mars One's plan, but to bring out the fascinating lessons that their efforts in colonisation hold for us. – The Editor.

Tell us something about the overall vision of Mars One?

Mars One is a not-for-profit foundation that works towards establishing a permanent human settlement on Mars. This settlement will consist of a carefully selected and trained crew. The departure of this crew will be preceded by several unmanned missions to Mars. Starting in 2020, these unmanned missions will carry planetary rovers, supplies, life support systems, and all the cargo needed to establish a habitable settlement for humans. When the outpost is fully operational, the first crew of four astronauts will depart for

Fig. 1. **A view of the planned settlement.**
Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

their one-way journey to Mars. They will not simply visit the planet, but live, explore and create a second home for humanity on Mars.

How long will it take to establish a large-scale human population on Mars?

Starting in 2026, a new crew will depart every 26 months. With only four individuals to start with, the settlement will at first be very small, but with new crews of four arriving every 26 months, the community will steadily grow larger.

What challenges does the Mars One mission face in the technology and engineering of space vehicles and human spaceflights to Mars?

Establishing a permanent settlement allows Mars One to use technology that is not substantially different from existing systems. While this technology already exists, the hardware that is specifically needed for this mission still needs to be designed, built, and tested extensively. As Mars One is not an aerospace company, it will not design or manufacture mission hardware. Instead, all this equipment will be developed by third party suppliers, and integrated in established facilities of the Mars One mission.

Mars One's mission design is currently in the early concept phase. The main requirements for the mission have been identified and discussed with established aerospace companies around the world. Possible solutions have been identified and rough cost figures discussed. In the first phase, Mars One will finance conceptual design studies by established aerospace companies for every major system required for the permanent settlement mission. The Mars One mission design will be updated according to the results of the conceptual design studies. The first studies have already been completed by Paragon Space Development Corporation and Lockheed Martin.

How do you plan to create a sustainable ecological system on Mars – both at the macro and the micro level?

Mars One will take specific steps to ensure that the Mars environment (which we will study, and on which we will depend) will not be harmed. The Mars base will be forced to recycle just about everything, pay close attention to energy use, and minimize the leakage of materials and energy. Nutrients are scarce on Mars. They need to either be imported from Earth, or extracted from the ground or atmosphere. Solar panels, which will also be launched from Earth, will generate the settlement's electricity. All of this means that a Mars resident will have a much smaller ecological footprint than the average person on Earth.

In addition, the development and operation of the settlement itself can greatly improve our sustainability efforts on Earth. The necessity to recycle everything on Mars will provide a high-profile boost to our recycling industry, as will the demand for lightweight solar panel technology. New methods of cultivating crops and growing plants on Mars can also teach us, on Earth, a great deal about how to improve our environment from experiences on another planet.

How do you plan to achieve self-sufficiency of air, water and food on Mars?

Breathable air is made up of several things. About 20% of what we breathe on Earth is made up of oxygen, almost 80% is the element nitrogen, and there are also very small amounts of other gases, like argon. On Mars, oxygen can be produced by splitting water into

Fig. 2. Mars Lander.

Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

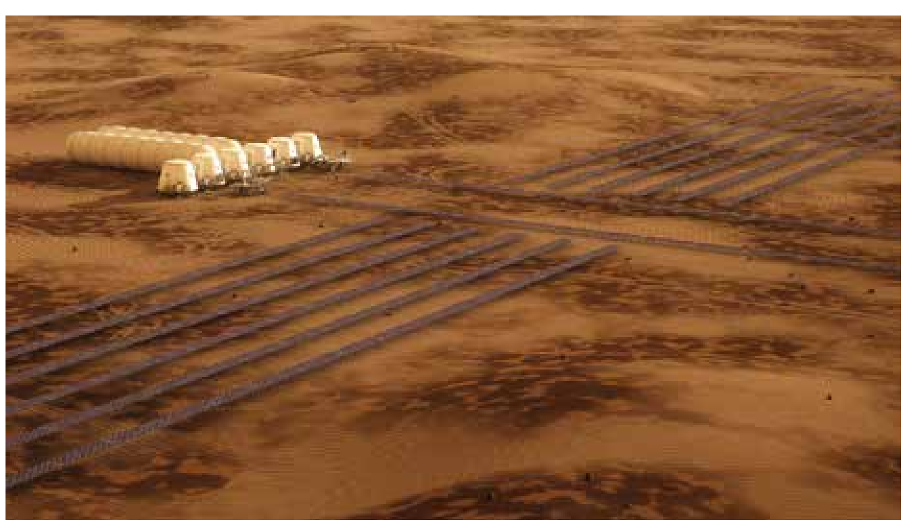


Fig. 3. Solar panels.

Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

hydrogen and oxygen. This oxygen will be used to provide a breathable atmosphere in the living units. Since the settlement uses solar panels to generate power, a portion of oxygen will be stored in reserve for conditions when there is less power available, for example at night and during dust storms. Nitrogen and argon will be extracted from the atmosphere of Mars and injected as inert gases into the habitable space for humans.

Water can be extracted from Martian soil. Mars One will send a rover to a certain area where there is water in the soil, and the rover will select the exact location for the settlement based primarily on the amount of water content in this area. We expect this region to be at latitude between 40 and 45 degrees North. The rover will scoop up soil with water ice in it, and deposit it into a water extractor in the life support units that generate energy, water, and breathable air for the settlement. The water extractor will heat the soil until the water evaporates. The evaporated water will be condensed and stored, the dry soil expelled, and the process repeated to extract more water. About 1500 liters of reserve water will be stored in each life support unit, to be consumed during periods of low power availability. Since Mars has gravity, water can be used in the same way as on Earth. Each astronaut will be able to use about 50 liters of water per day. The water will be recycled, which takes much less energy than extracting it from the Martian soil. Only water that cannot be recycled will be replaced by water extracted from the soil.

The astronauts on Mars will be able to produce their own food, in a greenhouse. Mars One will investigate the volume requirements for food production in a simulation outpost on Earth where all crew members will be trained to operate greenhouse equipment. To ensure that the first crew has food waiting for them when they arrive on Mars, stored food will be sent from Earth on a supply mission, before human landings. This stored food will be used sparingly to ensure that a large part of it can serve as emergency rations. Approximately 80m^2 of the habitat will be available for plant growth. The first crew will also be able to use the habitat of the second crew to grow food because the hardware for the second crew lands only a few weeks after the first crew lands. Food production will occur indoor under artificial lighting. A thick layer of Martian soil on top of the habitat will protect the plants (and the astronauts) from radiation. CO_2 for the plants will be available from the Martian atmosphere, and water will be available through extraction from the soil on Mars, or recycling from other purposes. Nutrients for the plants could be imported from Earth or from recycling human waste. Non-edible parts of plants will be recycled, or stored until more advanced recycling equipment is shipped from Earth. Apart from fresh crops, it is likely that algae and insects will also be part of the regular human diet on Mars. Any plant production surplus will be stored along with food shipped from Earth as emergency rations to survive until the next supply mission arrives.

Fig. 4. Mars-One Farm.
Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

What are the physical and health challenges thrown up by low gravity, and how do you plan to address these?

Astronauts will face the effects of reduced gravity both during spaceflight missions and upon landing on Mars (62% less gravity than Earth). The reduced gravity during spaceflight missions of extended duration can result in astronaut de-conditioning – including a decrease in muscle mass and performance, reduced aerobic capacity and losses in bone density – in addition to several other physiological changes. When Mars One astronauts first arrive on Mars, they will, in theory, be stronger than an astronaut returning to Earth's gravity after a mission on Mars. A recent study of International Space Station (ISS) astronauts, with mission durations ranging from 4–6 months, showed a maximum loss of 30% muscle performance (and maximum loss of 15% muscle mass).

Mars One aims to lower these numbers through a program of well-structured and scientifically valid countermeasures, including but not limited to exercise, pharmaceuticals and nutrition that have been shown to mitigate these effects. Continued research and advancements in this area will surely produce even more effective countermeasures within the ~10 year period of preparation prior to the first human launch. Mars One will also take advantage of the decade prior to

A great example of the effectiveness of in-flight exercise countermeasures in maintaining astronaut health and performance is illustrated by American astronaut Shannon Lucid's 188 day stay aboard the Russian MIR space station, during which time she relied heavily upon the use of exercise countermeasures. When her mission came to an end, she was able to walk unassisted within 24h.

Source: NASA, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Shannon_Matilda_Wells_Lucid_1978.jpg. License: Public Domain.

the launch of the first colonization mission to observe and select the most suitable astronauts and counter-measures to ensure a safe and successful mission. Once on Mars, astronauts will be able to take advantage of the force of gravity to assist them in the reconditioning and adaptation process, resulting in bone re-modeling to help strengthen their bones.

Will there be any psychological impacts of loneliness on the initial colonisers? How do you plan to mitigate these?

The men and women that will make this journey will need more than technological advances to see them through: while technology will get them there, teamwork will be what ensures they survive the journey and that they will be able to successfully start building a society on Mars.

We have discussed our plan with experienced and respected psychologists. One of Mars One's team members is Dr. Norbert Kraft, who has worked on astronaut selection at NASA and JAXA (Japan Aerospace Exploration Agency). His primary area of expertise is developing physiological and psychological countermeasures to combat the negative effects of long-duration spaceflight.

The key to successful survival on Mars will involve a very careful selection procedure and extensive training program where group training will play a very important role. Mars One isn't looking for the best individuals, but for the best crew. There are many people who would not be suitable for a Mars mission. During the journey to Mars and upon arrival, they will spend 24 hours a day with each other. It is during this time that the simplest things may start to become bothersome. It takes a specific team dynamic to be able to handle this and it is Mars One's job to find and prepare those that are best suited for this challenge.

On Mars, it will help to keep the crew busy – and it is certain that they will be. They will improve their habitats, and extend it with new units sent from Earth and with local materials. They will be involved in research – both their own, and the gathering of data for the research of others (for example, universities). They will also prepare the settlement for the second crew that lands two years later. Additionally, recreation will be important, this can be mental, physical or creative, such as sports, arts, games, etc. With a new crew arriving every two years, the settlement will slowly become a small village and an attractive place to live, for more and more people.

Are there any interesting scientific experiments that are planned in the low gravity, low atmospheric pressure conditions on Mars?

There will be a great deal of research conducted on Mars. For example, the astronauts will research how their bodies respond and change by living in a 38% gravitational field, or how food crops and other plants grow in reduced gravity using hydroponic plant production units or other technologies. Research will also include extra- settlement explorations

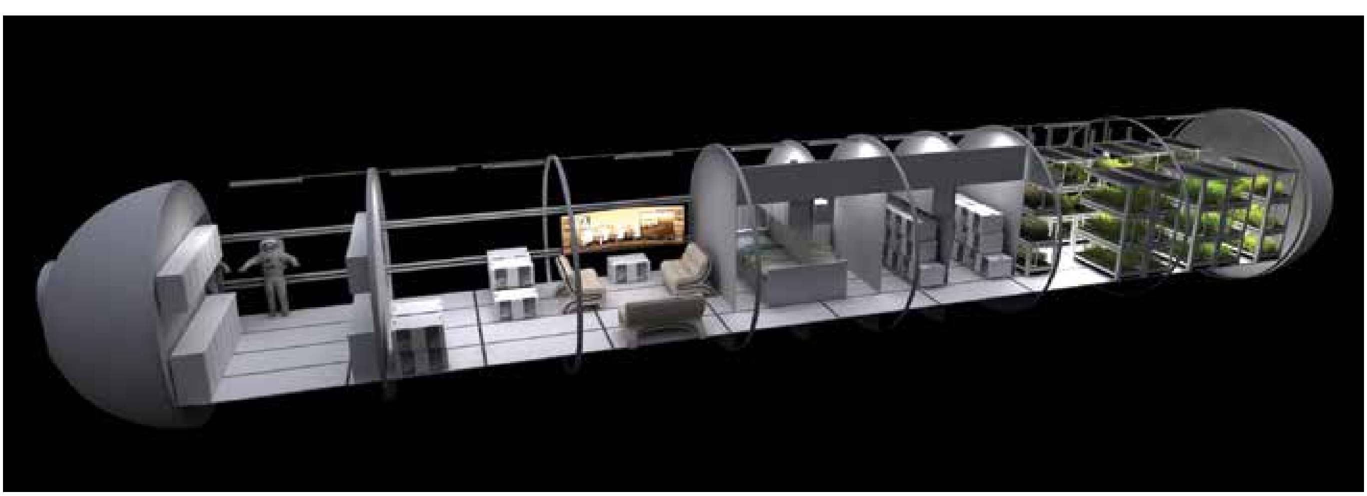


Fig. 5. Mars-One habitat.

Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

Fig. 6. Mars-One Habitat – a closer look.
Source: Bryan Versteeg, Mars One, URL: http://www.mars-one.com/

to learn about the ancient and current geology of Mars. Of course, much research will be dedicated to determine if life was once present, or currently exists on Mars.

If the colonisation of Mars succeeds, eventually babies will be born on Mars. Will conditions on Mars cause health issues in these children?

The human ability to conceive in reduced gravity is not known; neither is there enough research on whether a fetus can grow normally under these circumstances. Additionally, the Mars settlement will certainly not be a suitable place for children to live. The group of astronauts living on Mars will be very small, all of whom will be very busy with the necessary work on the outpost; and the human settlement will have very basic medical facilities. Therefore, Mars One will advise the first inhabitants of the settlement to not attempt to have children. However, in order to establish a true permanent, self-sustaining settlement on Mars, Mars One recognises that having children will be vital. Therefore, this will be an important area of research.

Is there a plan to make Mars One commercially viable?

Establishing the first human settlement on Mars is likely to be the defining moment of the 21st century and the most exciting event in our lifetime. People from around the world would like to support this mission and are contributing by donating to our human mission to Mars. Mars One receives donations from over 100 countries every month. Although we expect revenues from donations received till our first unmanned mission lands on Mars to contribute substantially to our mission, this will not be enough to finance the entire mission. This is why a large part of Mars One's mission will be financed by investments from the private sector. In order to accept investments, the Mars One Foundation has established Mars One Ventures which is a for-profit entity that allows investors to buy shares. Mars One Ventures holds the exclusive media and intellectual property rights to Mars One's mission and will monetize it to enable the mission and to provide shareholders a return on their investment. That return on investment will come from several revenues streams, including media exposure, brand partnerships, intellectual property rights, merchandise, and several other business cases.

Any partnerships with national space research organizations?

At this moment, there aren't any partnerships with national or international space organizations, but we've had several initial discussions with NASA about potential future partnerships.

How can a school teacher in India help this initiative?

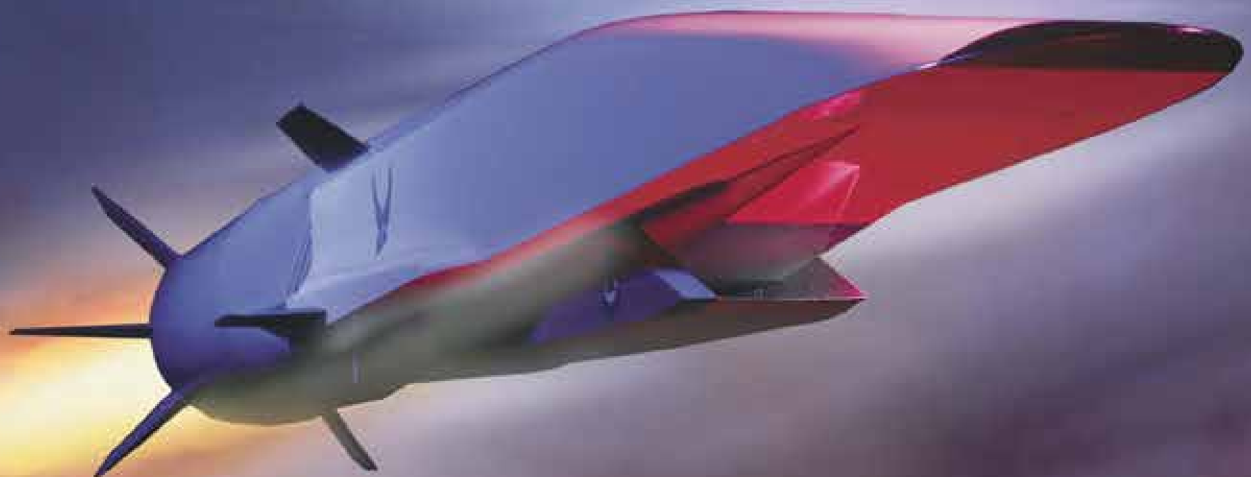
School teachers in India can help by discussing Mars One's mission plans in class. This will help spread the word and create awareness. This is not only important for Mars One but for developments in the space industry in general. Teachers can have a very positive impact on the development of students and can inspire young boys and girls to chase their dreams and become engineers, scientists, and astronauts themselves!

Note: Credits for the image used in the background of the article title: Settlement camera, Bryan Versteeg, Mars One, URL: http://www.mars-one.com/.

SCRAMJET: ISRO'S FUTURISTIC TECHNOLOGY TO REDUCE COSTS OF SPACE TRAVEL

What are Scramjet engines? How are they different from conventional one time use-and-throw rocket launch vehicles? This article introduces readers to this new technology, exploring its use in providing low cost space launch in low earth orbits.

T V VENKATESWARAN



On 28th August, 2016, the Indian Space Research Organisation (ISRO) successfully demonstrated its indigenously produced Dual Mode Ramjet (DMRJ) ScramJet engines in-flight. India now belongs to an elite club – with USA, Russia and Europe – leading the quest to design reliable, safe, affordable and reusable space launch vehicles to place space assets, like satellites, in a low earth orbit.

Box 1. What is a low earth orbit?

Most communication satellites are placed in what is known as the Geosynchronous Orbit (GSO), about 36,000 km above the surface of the Earth. A satellite at that height would take approximately 23 hours 56 minutes and 4 seconds to complete one revolution around the Earth, matching the Earth's sidereal rotation period.

In contrast, the Global Positioning System (GPS), Russian Glonass and a few other space environment research satellites are placed in what is called the Medium Earth Orbit (MEO), about 1200 – 35790 km from the surface of Earth. The orbital periods of MEO satellites range from about 2 to nearly 24 hours.

However, if you wanted to build a space station and ship people to and fro, you'd prefer its location to be much nearer to the Earth. This would also be true for a remote sensing satellite, if you were planning to use it to take close-up pictures of the Earth's surface. Thus satellites such as these are typically placed in what is called the Low Earth Orbit (LEO), which is about 200 – 1200 km from the surface of Earth. These satellites take about 80 to 130 minutes to go around Earth once.

Limitations of current technology

Current launch vehicles are mainly multi-stage, expendable, and carry oxidiser, making them costly, risky and bulky.

About 85-90% of rocket mass before lift-off is propellant, and only about 1% is the mass of the satellite that orbits the earth. The rest, which includes the supporting structure, tanks, pumps, engines etc. are useless once the fuel is burnt. To avoid having to carry all that excess weight into space, rockets often have several stages, or sections, each of which drops away after use. Typically, once the fuel in one stage-section is consumed, that stage of the rocket, its shell and motors are jettisoned into the ocean.

As each stage burns out, it has to be de-coupled from the vehicle, and the next stage has to ignite. This must occur with each stage, in sequence, without fail or delay, making current technology both expensive and risky. The greater the number of stages, the higher the chances of failure – even a tiny lag or mishap in this sequence can spell disaster. The accident, in Jan 1986, on NASA's space shuttle – Challenger – that killed seven astronauts and shocked the world, was caused because the rubber-O-rings joining two stages failed to seal properly.

Except during its final stages, when a rocket travels to the edge of Earth's atmosphere, it is surrounded by abundant oxygen. In spite of this, many rockets carry both their own fuel and an oxidiser for burning it. This makes their design bulky and inefficient, with more than half of the thrust generated by the rocket going into lifting the oxidiser.

If we could build a launch vehicle with a re-usable engine that could somehow use atmospheric oxygen, at least during most of its flight inside the Earth's dense atmosphere – the cost of space travel would be reduced considerably. Little wonder then, that space-faring nations around the world are in quest of such a technology.

What is a dual mode Ramjet-Scramjet engine?

An ordinary jet engine works on the same principle as a rocket – with two important exceptions. Jet engines are re-usable, and use atmospheric oxygen to burn fuel.

The design of a jet engine is quite simple. Atmospheric air, rich in oxygen, is compressed by rotary blades and brought to the combustion chamber. Fuel is injected into the hot compressed air to make it burn, causing the whole mixture to expand considerably. This gas comes out of the exhaust nozzle at high speed, generating thrust (based on Newton's third law) that pushes the jet upward.

Ramjet and scramjet are advanced models of jet engines that can be used for space travel. The fastest jet plane can cruise at speeds of about 0.8 km per second, while space travel requires one to achieve speeds of 8 km per second. Jet engines that can provide such an impulse are called ramjets. In other words, ramjets are more advanced air-breathing engines that do not need rotary blades to ingest compressed air into the combustion chamber. Instead, compressed air is sucked in through specially designed inlets, even as the vehicle moves at supersonic speeds. A scramjet, or a "supersonic combusting ramjet", is an improved novel variant of a ramjet that uses the same principle, but operates optimally at hypersonic speeds.

The challenge of a scramjet!

Although the design of a scramjet seems pretty simple, operationalizing it is difficult and technologically demanding.

In the absence of rotary blades to compress the air, both ramjet and scramjet engines use their relative velocity to compress the air entering through their inlets. On ground, the air entering the inlets will not have any appreciable relative velocity. Therefore, much like the way we start the engine of a car whose battery is down by giving it a push, we use conventional rockets to propel scramjet/ramjet crafts into space. These rockets help the crafts quickly achieve an initial velocity greater than Mach 4. Once they reach the relative velocity required to compress air, their scramjet/ramjet engines can be ignited. This ignition is quite tricky – it must

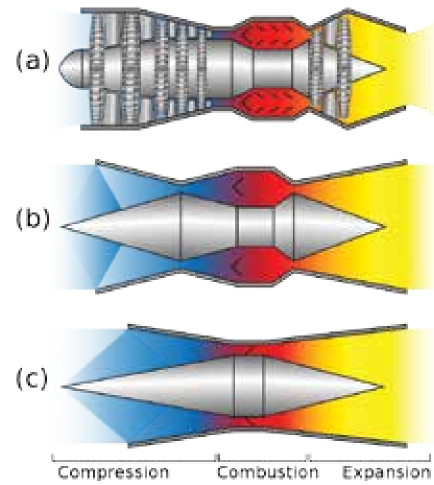


Fig. 2. Ramjet and scramjet are two types of advanced jet engines. Unlike a jet engine, ramJets and scramJets have no movable parts and, hence, are safe. All three types of jet engines use atmospheric oxygen for combustion.

Credits: GreyTrafalgar, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Turbo_ram_scramjet_comparative_diagram.svg. License: Public Domain.

Fig. 1. Launch of the ScramJet engine

Credits: Scramjet engine gallery, ISRO. URL: http://www.isro.gov.in/launchers/scramjet-engine-td-gallery. License: Public Domain.

Box 2. Mach number

Mach number is defined as the ratio of the speed of a body to the speed of sound in the surrounding medium. It is often used with a numeral (as Mach 1, Mach 2, etc.) to indicate the speed of sound, twice the speed of sound, etc.

Supersonic speed is a rate of travel of an object that exceeds the speed of sound (Mach 1).

Hypersonic speed is highly supersonic – since the 1970s, this term has generally been assumed to refer to speeds of Mach 5 and above.

occur within the next few milliseconds. Given the riotous flow of air into the combustion chamber of a spacecraft moving at a velocity of Mach 5 or 6, experts liken this ignition to lighting a matchstick in the midst of a hurricane.

Even if the mixture can be ignited, sustaining the flame for the duration of time taken to burn the fuel is an arduous task – almost like holding a lighted candle in your hand while running at top speed!

This is not all. As a scramjet moves through the atmosphere at hypersonic speeds, the relative velocity of the air is high enough to interfere with its ability to continue ingesting air. Imagine putting your face through a fast moving bus window –the gush of wind blowing across your nose will leave you breathless. The design of the scramjet has to ensure that the inlets continue to suck in air, even at such velocities.

These challenges were addressed by developing, testing and perfecting the design of ramjet-scramjet engines stage-by-stage. ISRO chose to use its time-tested, indigenously designed, three tonne Rohini class rockets RH 560 for the initial propulsion. First tested in March 2010, and designated ATV-D01, this rocket maintained a Mach 6 velocity for seven seconds. While this analysis was conducted with scramjet modules strapped on to the rocket, these modules were not ignited. The test showed that Rohini class rockets could provide the dynamic pressure of around 80 kilopascals required to initiate ignition of ramjet/scramjet engines. Then, in the wee hours of 28th August 2016, two indigenously built dual mode ramjet-scramjet engines were strapped on to the Rohini class two-stage RH-560 rocket, along with a solid booster. Once the rocket attained an altitude of 20 km, the scramjet engines were ignited, and the flame sustained for five seconds. A preliminary examination of the test showed that the propulsion system maintained the desired flight condition, both in terms of Mach number (6+0.5) and dynamic pressure (80+35kPa). Also, as planned, the burn out of booster rocket stage and activation of scramjet engines took 5 seconds, occurring between the 55th-60th seconds of flight and at 20 km height. This was followed by a burn out of the second stage. Together, these imply that ISRO's dual mode ramjet-scramjet engines can be expected to function well in flight mode.

What lies ahead?

Although this test has been successful, we have miles to go before these ScramJet engines are used to carry payloads to space.

Some key challenges facing ISRO include the design and development of a supersonic combustor, computational tools to simulate hypersonic flow, and new materials capable of withstanding the huge oscillations and the very high temperatures likely to happen at higher speeds. Others involve ensuring hypersonic engine air intake, performance and operability of the engine across a wide range of flight speeds, proper thermal management, and ground testing of the engines. For example, while analysis of the current test was done only at about Mach 6 speed, the engine needs to be tested at various speeds between Mach 2-12. Also, with computational fluid dynamic tools having matured only recently, improvements in the design of scramjets have to be tested by trial-and-error. This is complicated by the fact that other countries are unwilling to share their technical knowledge of scramjets, as it is thought of as strategic technology. This means that ISRO has to embark upon an indigenous programme to develop its own reusable launch vehicle.

An ISRO project called AVATAR is aimed at developing a rocket to launch the scramjet engine into space. This rocket should be able to lift off vertically from a launch pad (with the assistance of conventional chemical booster rockets), soar at supersonic speeds, initiate a scramjet engine and propel it to low earth orbits to deliver space

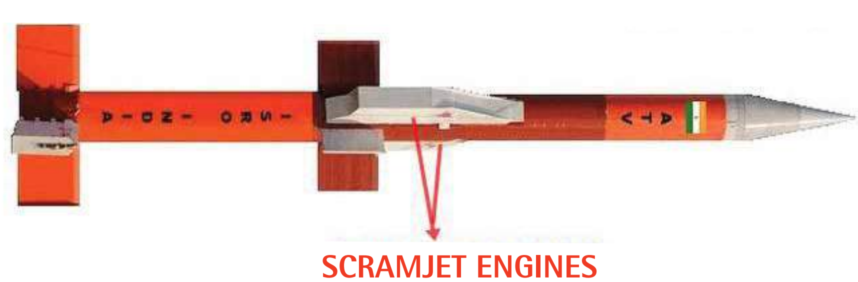


Fig. 3. Two ScrameJet engines were strapped to Rohini Class rockets and test fired by ISRO.

Credits: MarcRic, Wikimedia Commons. URL: https://te.wikipedia.org/wiki/%E0%B0%A6%E0%B0%B8%E0%B1%8D%E0%B0%A4%E0%B1%8D%E0%B0%B0%E0%B0%82:ISRO_Advanced_Technology_Vehicle_shape-01_(rotated).jpg. License: CC-BY-SA.

payloads, and then land on a runway like an ordinary plane. The estimated development cost of this entire project is 35 cores, of which about three cores were spent on the test conducted in August 2016.

While ISRO aims to use a single-stage-to-orbit (SSTO) launch vehicle ultimately, it is settling for a two-stages-to-orbit (TSTO) launcher in the interim, with an air-breathing first stage. In the second stage, a cryogenic motor will be used to take the payload to the desired low earth orbits. ISRO proposes to make the first stage of the TSTO re-usable, halving the costs of launching satellites.

On 23rd May 2016, ISRO conducted a Hypersonic Flight Experiment or HEX1 in which the performance of a Reusable Launch Vehicle (RLV), dubbed 'Swadeshi space shuttle', was experimentally launched, and the performance of guiding computers on-board and heat-resistant tiles affixed to the RLV were tested. At the end of the test-flight, the spaceship splashed down into the Bay of Bengal. In the next experiment, named landing experiment (LEX), ISRO will attempt to land an RLV on a custom runway, to be constructed at SHAR (Sriharikota High Altitude Range). Thereafter, RLV and Rohini-Scramjet modules will be integrated into a single

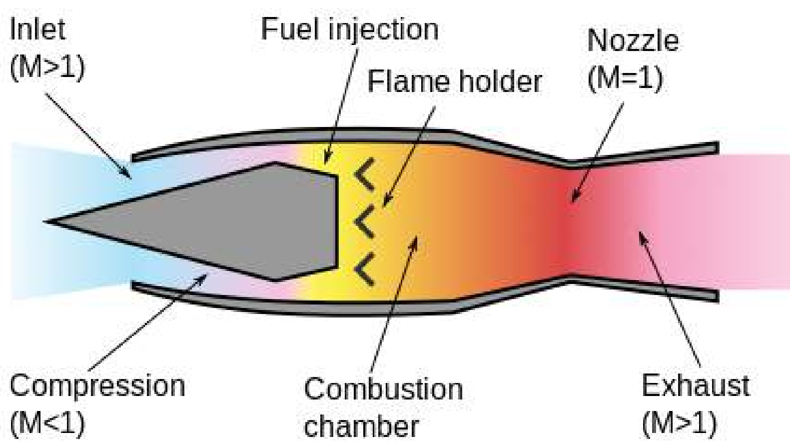


Fig. 4. Ignition, sustaining the flame, and ensuring compressed air inflow are some of the major technological challenges of ScramJet design.

Credits: Cryonic07, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Ramjet_operation.svg. License: CC-BY-SA.

mission, and actively powered by the scramjet engines for Return Flight Experiment (REX)s. For propulsion beyond the atmosphere, the RLV will be fitted with five semi-cryogenic engines. It is only after all these different stages have been tested and integrated flawlessly that the system will be used for commercial launch. Estimates by ISRO indicate we will be ready for space missions using a TSTO launch vehicle with scramjet engines, around the year 2030.

A scramjet-fired RLV can take a payload of about 10,000 – 20,000 kg to low earth orbit; while the most advanced conventional ISRO launch vehicle GSLV Mk-III is designed to take only 8,000 kg, and SpaceX's rival Falcon 9 rocket is expected to lift 13,000 kg to the

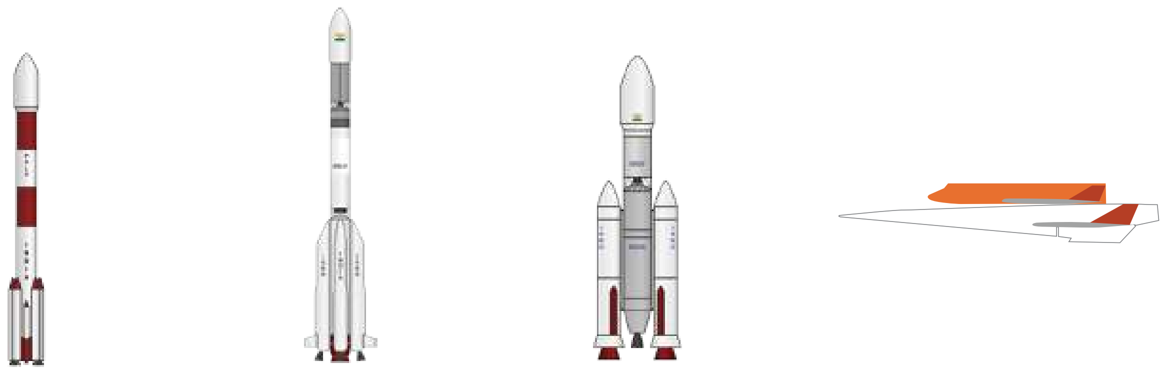
Box 3. Cryogenic Rocket Engines

A cryogenic rocket engine is one that uses a cryogenic fuel or oxidizer, that is, its fuel and/or oxidizer are liquefied gases stored at very low temperatures.

same orbit. These futuristic re-usable launch vehicles, with their air-breathing propulsion will enable cost-efficient space launch. While the launch of one kg of payload currently costs about US$ 5000; ISRO estimates that its RLV will cause a drop in rates to US$ 2000 per kg.

However, some experts question ISRO's elation, and claim that the cost-benefit analysis is not that clear. A 2006 NASA technical document warns that "The general conception is that the choice between a reusable and an expendable launch vehicle is essentially a trade-off between lower recurring costs of the former and lower non-recurring costs of the latter". On average, the reliability of throwaway launchers is about 95% – which means that on average, 1 in every 20 launches fails. However, the reusable launcher has to be fail-safe if it has to justify the higher investment needed to develop and build it. Also, as the RLV will take-off, cross into space and re-enter the Earth's atmosphere many times, it will require advanced heat shields – making the project technologically more challenging. The NASA document goes on to assert that a "decades-long debate over reusable launch vehicles (RLVs) versus expendable launch vehicles (ELVs) has been less a reasoned debate than a sustained argument for the building of reusable launchers instead of the standard throwaway rockets."

The economics of developing reusable hybrid vehicles that use expendable boosters and a reusable vehicle, like the one proposed by ISRO, is rather different. A.S. Kiran, the ISRO chief, remains optimistic, stating that, "in principle, even if the cost comes down by 50%, it is worth it. After factoring in the logistics of recovering it, etc., whatever it can bring down is worth it."



PSLV	GSLV	GSLV MK3	ABLV-TSTO (FULLY REUSABLE)
TIME FRAME	TODAY	10 YEARS	40-50 YEARS
LAUNCH COST	20,0000 $/kg	5,000 $/kg	500 $/kg
FLIGHTS/YEAR	4-6	20-30	300
TURN AROUND TIME	FEW MONTHS	FEW WEEKS	FEW DAYS
.... UP TO 2010 + ...		2010 +	2040/50

Fig. 5. The Scramjet engine is a worthy addition to ISRO's slew of existing launch vehicles.

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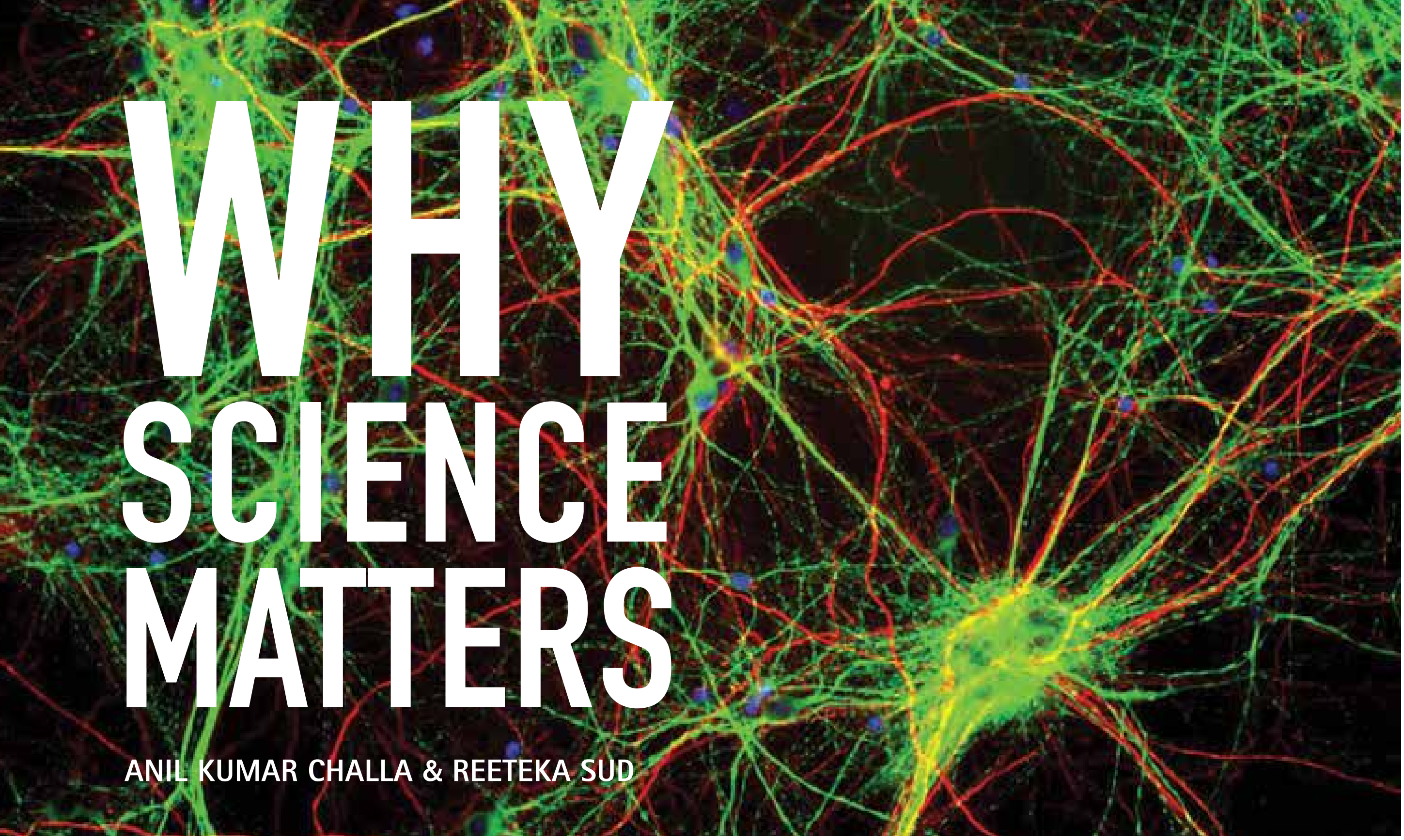

WHY SCIENCE MATTERS

ANIL KUMAR CHALLA & REETEKA SUD

Science is more than a body of knowledge; it is a way of thinking. Our aim, above all else, should be to foster scientific thinking in students. If students seem bewildered about the need to study science, our response to them has to go beyond the cool gadgets and ease of life that scientific advancements have brought us.

The modern usage of the word 'science' refers to a systematic study of the natural world in its many facets. Perhaps the best example of this can be seen in the San, hunting tribes indigenous to South Africa. Their hunt for an animal starts with an observation (pug marks in sand, etc), a hypothesis is formulated (direction the animal went), a course of action is decided (the equivalent of research methods), and pursued till conflicting evidence is found (overlapping pug marks) – at which point an alternate hypothesis is formed. Even though the San are miles away (literally and metaphorically) from the schooling you and I see in the "civilized world", we can see their actions follow the same thread as any scientific investigation: observation → hypothesis → experimental methods (to test the hypothesis) → record results → analyse results (whether they support or contradict the hypothesis) → in case of contradictory results, develop alternate hypothesis and follow-up accordingly.

How does this process lead to progress in science? The history of scientific pursuit somewhat resembles the ancient parable of six blind men describing an elephant[1]. Each one is trying to figure out what an elephant is, by touching one part of it. In so doing, one of the men likens the elephant to a fan (by touching its ear), another to a pole (its legs), a third to a rope (its tail), and so on. Similarly, different scientists, in different countries or even in different eras, pursuing differing questions have followed essentially this same process, and continue to do so. Through this process, a body of knowledge is generated over time. The progression from first observations is hardly ever linear, unlike what textbooks will have you believe (and this is where confining ourselves to science textbooks can be misleading!).

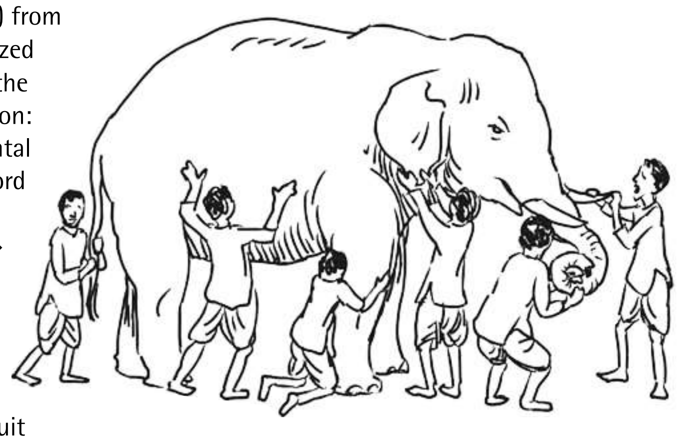

Fig. 1. The six blind men and the elephant.

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Why should we care about this iterative nature of science? When students are quizzed on their understanding of topics in the Biology curriculum, the Cell Theory for instance, they can recite the core principles of the Theory, but are unaware that it is the culmination of more than 300 years of research (refer 'The wacky history of Cell Theory' at http://ed.ted.com/lessons/the-wacky-history-of-cell-theory), with contributions from scientists in many branches of science (Botany, Zoology, Physics, Chemistry and Maths). A failure in understanding the nature of the scientific process can have many consequences on the way students perceive the practice of science – ranging from general distrust to the outright denouncement of scientists. Distrust of scientists by the general public raises its head frequently enough, on a variety of issues – from climate change and genetically modified crops to vaccination in children. In every one of these cases, hearing opposing sides of the same issue can be (and often is) misinterpreted as a "lack of knowledge" among experts. Our contention in this article is that this distrust is linked to the lifelong learning of science as a "compilation of facts", with no effort devoted to how these facts, as we know them, come to be. Interpretation of new knowledge is frequently debated before being accepted by the scientific community. If we only think of science as being a list of answers (or facts), then open questions can be unsettling, as has been the case with climate change. Is the current crisis of global warming natural? Or are humans causing it? Which of these is true?

Science is more than a body of knowledge; it is a way of thinking. Our aim, above all else, should be to foster scientific thinking in students. Folklore and anecdotes can make their way as "immutable facts" instead of testable ideas into students' lives. Time spent in the science classroom ought to give them tools to critically analyse the stories they hear. They ought to question "common wisdom" in things like "cold weather makes you catch a cold", or "the human body is designed for a vegetarian lifestyle". Science classrooms should give them the tools for doing so, along with skills of critical analysis.

The history of science is also replete with examples pointing to the limits of our knowledge and underscoring how factual knowledge in science is subject to the tools available at a given point. An interesting case from the history of neuroscience offers an excellent example of how improvements in tools lead to an enhancement of knowledge. Italian scientist Camillo Golgi has

Fact or myth:

Does the cold weather make you catch a cold?

The virus that causes common cold infects the mucus lining the insides of the nose. In the 60s, scientists found that the virus multiplies much faster at cooler temperatures. But why this is so wasn't known until 2015, when a team of Japanese scientists reported that this is not because the virus adapts better but because our immune system falters at cooler temperatures. Why our immune system falters at lower temperatures remains an open question.

Should you take antibiotics when you have a cold?

Antibiotics (anti = against; bios = life), also called anti-bacterials, only work against bacteria. Common cold is caused by a virus, and antibiotics cannot destroy viruses[2].

Fig. 2. Cajal and Golgi. (A) Santiago Ramón y Cajal in the library of the "Laboratorio de Investigaciones Biológicas" (ca. 1930). In the left-upper part there is a picture of the Helmholtz gold medal, one of the more renowned prizes and one of which he was especially proud. Cajal was very popular in his country as can be seen by the use of his portrait on a 50 pesetas bill (paper currency, bottom-left). (B) Picture of a microscope, some colorants and some histological tools used by Camillo Golgi, conserved in the Museum of Pavia University, Italy (upper-left). Golgi also was a very popular scientist in his own country. This can be seen by the commemorative stamp produced by the University of Pavia tocelebrate the centenary of the discovery of his impregnation method, the "reazione nera" (bottom-left).

Credits: Juan A. De Carlos, José Borrell from the article - A historical reflection of the contributions of Cajal and Golgi to the foundations of neuroscience. Brain Research Reviews 55 (2007) 8-16.
URL: http://hobertlab.org/wp-content/uploads/2013/03/DeCarlos_2007.pdf. License: Used with permission of the rights owner.

made innumerable contributions to the development of Biology, including a technique to visualise brain tissue that he was the first to develop in 1873. Although the postulates of the Cell Theory were widely known (since 1838-39), no one realized that it applies to cells of the nervous system too. An alternative explanation, called reticular theory, was gaining ground instead. According to this theory, the nervous system was formed from continuous fibres that formed an intricate network. Golgi's method allowed him to visualize nerve cells in their entirety. But seeing highly branched membranes, he too concluded that the reticular theory held merit (we know these branched parts as dendrites today). It wasn't until later that a Spanish scientist by the name of Santiago Ramon y Cajal made significant improvements in Golgi's method. Consequently, the anatomic features of nerve cells, and their organization in different parts of the brain, became distinctly clear to him. He first published his results in 1888, supporting "neuron theory", which stated that brain tissue was made up of distinct cells, like every other tissue in the body; and was no exception to the Cell Theory as the proponents of reticular theory (including Golgi himself) thought. In spite of their interpretations being polar opposites of each other, both Golgi and Cajal laid the foundations of neuroscience, and were jointly awarded the Nobel Prize in Medicine in 1906.

By incorporating stories of *how* discoveries are made[3], students also become familiar with the broader context into which the syllabus fits. What better way of stimulating their curiosity than by stories of key discoveries coming from [a scientist] following their curiosity! This strategy offers the added advantage of hooking student attention, since our brains relate to stories much better than they do to facts read from books.

Another way of exposing students to the process of science is by organising visits to research laboratories. Students are not only able to look at the practice of science but can also interact with scientists— ask them questions about what they do, why, why this particular problem, and the like. The point isn't to get all of them to grow into future scientists, but to help them develop into scientifically literate citizens of the future. Science education can enhance students' perception of themselves, their immediate surroundings, their communities and ecosystems, and the planet at large.

Thus science can help students when they confront real-life questions – is genetically-modified food safe for us? Should Indians be worried about contracting infection from drug-resistant bacteria? Is climate change man-made or does it happen in the natural course of earth's history?

The clarity of our perception depends on the quality of tools at our disposal. As young minds engage with life and learn about how things work around them, it makes sense to have effective tools. The question is – are we giving today's students the best tools to help them deal with challenges of tomorrow? Science is critical in enabling human perception through continuously improving and evolving tools. And that is why science matters.

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Further readings:

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TREASURES FROM TRASH:
THE GOLDMINE IN YOUR GARDEN

RADHIKA PADMANABHAN

With waste disposal problems gripping cities as well as towns and an increasing recognition of the role of organic fertilizers to combat the growing food crisis, how do we learn about the inter-linkages between these two? Can waste become a resource? In this article, the author shares insights on how her school adopted the time tested technique of recycling waste into food through composting.

Population explosion, rapid industrialization and consumption - driven lifestyles have caused huge changes in the quantity as well as the composition of waste generated at both industrial and household levels. Finding sustainable and efficient ways of managing our waste has become a significant challenge. With an enormous increase in the amount of waste generated, we are quickly running out of energy, land and water for disposal, with most landfill sites already overflowing with accumulated and rotting waste. This is complicated by a significant increase in the use of non-biodegradable material, like plastic and glass, in the last three decades. The percentage of plastics alone in household waste, for example, has risen from 0.7% in 1971 to 9.22% in 2005.

It is in this context that composting becomes relevant. Simply expressed, composting refers to the process of biological decomposition of organic waste, such as plant material, by bacteria, fungi, worms and other organisms under controlled aerobic (occurring in the presence of oxygen) conditions. Compost, the end result of this process, can be used as manure to replenish the fertility of garden soils and grow safe, healthy food. Thus, a system of decentralized

Fig. 1. Landfills – polluting land and water.

Credits: Ted Mathys, 2009 AP Fellow. Location: Delhi, India. Partner: Chintan. URL: https://www.flickr.com/photos/advocacy_project/3638204454. License: CC-BY -NC-SA.

Fig. 2. Food 'waste' is a resource, not a waste at all!

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Did you know that modern methods of composting originated in India?

Interestingly, the seeds of composting were sown in India. Sir Albert Howard, a British agronomist, came to India in 1905, and spent almost 30 years experimenting with organic gardening and farming. He found that the best compost consisted of three times as much plant matter as manure, with materials initially layered in sandwich fashion, and then turned during decomposition (known as the Indore method). He published the results of his work in 1943, in a book titled, 'An Agriculture Testament'. This book renewed interest in organic farming methods, earning him recognition as the 'modern day father of organic farming and gardening'.

composting, coupled with efforts to spread general awareness on its necessity, has the potential to provide a more sustainable solution to tackle the organic, bio-degradable component of household waste.

Educational institutions have a key role to play in today's changing world. Teaching science is no longer sufficient in itself; there is a need for schools to also act as spaces for students to learn how to use this knowledge in more practical ways so as to build a more sustainable future for themselves and others. Involving them in hands-on composting efforts in school helps students arrive at an understanding of the interconnections between their actions and its impacts on their immediate environment. They begin to see, for example, how disposing organic waste pollutes, but recycling it through composting generates a valuable resource. Students, often, also contribute to greater general awareness on composting by sharing what they learn from being part of this process at school with their families and communities that they are part of.

Fig. 3. The composting process: (a) Crates with aluminum meshes. (b) Bed of green coconut shells. (c) Soil with earthworms. (d) A cover of dried leaves.

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Composting in the school premises

We, at Pawar Public School, Bhandup, Maharashtra, have initiated a vermicomposting project in the school garden using the green waste generated in the school canteen and the leaf litter from the school garden. This model has been successful, cost effective and, more importantly, sustainable.

We compost our waste in two crates – with aluminum mesh bodies (to allow aeration) and metal lids. Within each crate, we prepare a bed with green coconut shells, layer it with some soil with earthworms, and cover it with dried leaves from the school garden. The crates are kept covered with a green cloth to prevent excessive drying of its contents in sunlight. In addition, a little water is added each day to the contents in the crate to ensure that the soil remains moist enough to allow microbes and earthworms to act effectively.

Composting is part of our daily routine. Each day's green waste (canteen waste as well as the leaves and flowers from the garden) is added to these crates, after it is weighed and the weight is recorded. We remove compost from the two crates in a staggered manner, again weighing and recording the amount of compost obtained in each cycle. By involving students in weighing green

Role of Earthworms

Many of us know that earthworms improve soil structure, increasing its water and nutrient holding capacities. But that's not all! Did you know that they are also voracious eaters, consuming all kinds of biodegradable matter? Part of what they eat is excereted as partially digested matter, called vermi-castings. Turns out, these vermi-castings are rich sources of manure, providing plants with many growth-enhancing hormones and essential nutrients.

waste and compost, we provide them with the opportunity to see, first-hand, how the volume and weight of organic waste is reduced tremendously as a result of composting. For example, in our first phase, 250 kg of green waste was converted into 40 kg of chemical free, organic manure. In the next phase, we obtained 50 kg of compost.

As a result of this activity, our school gardeners no longer spend money on buying chemical fertilizers – they get superior quality manure, without any polluting effects, absolutely free of cost within the school premises. We've also started a 'Garden Club' where students, under the guidance of a gardening expert, use the compost prepared in the school to grow ornamental as well as food crops in the school garden. School staff and parents are also allowed to purchase this compost at the rate of Rs. 30 per kg. Staff members who have purchased our compost vouch for the enhanced quality – in terms of colour, size, flavor and taste – of the flowers and vegetables in their gardens. Parents often make a beeline to our compost-selling stalls on Open Day.

Above all, the knowledge that we've managed to recycle waste derived from food to obtain food again is most satisfying! As a community of students, teachers and parents, this initiative has made us realize that the organic waste that we generate daily is actually a resource and not 'waste'. Visitors are very appreciative of the fact that we have managed to set up a composting project in the meager garden space available within our school premises. Added to this is the advantage that once the process of composting is initiated, it is very easy to carry it forward as the labour and the cost of maintenance involved is minimal. This self- sustaining model has given us a much needed impetus in organizing other ecologically-sensitive activities in school.

Fig. 4. Students engaged in composting. (a) Students, along with school gardener, adding green waste and flowers to the compost bin. (b) Weighing the compost.

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Fig. 5. Compost - a gardener's delight!

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Fig. 6. Uses of compost. (a) Using compost in the school garden. (b) Growing food crops from food waste.

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FIVE REASONS TO RECYCLE AND COMPOST!

1. **Recycle waste!** On average, each of us generates about 200kg of solid waste each year - that is a lot of garbage! Remember 40% of residential waste is made up of compostable matter. By composting organic waste, we help contribute to a more responsible and sustainable way of managing a significant bulk of the waste we produce.
2. **Save money!** No need to buy chemical fertilizers. Compost is free!
3. **Improve your soil!** Compost returns valuable nutrients to the soil to help maintain soil quality and fertility. As a mild, slow-release natural fertilizer that won't burn plants like chemical fertilizers, compost also improves texture and air circulation in heavier soils and water retention in sandy soils. By providing organic matter, compost improves plant growth and leads to better yields.
4. **Reduce your negative ecological impact!**
   - Reduce green-house gases (GHG's) from: (a) vehicles used to transport waste to landfills emit carbon dioxide (CO_2); and (b) anaerobic (without oxygen) break down of organic waste in landfills that produce methane gas, a greenhouse gas twenty one times more harmful than CO_2.
   - Reduce water pollution by: (a) runoffs of chemical fertilizers into rivers, lakes and streams; and (b) groundwater pollution by toxic leachates produced by the reaction of metals with buried organic wastes in landfills.
5. **Save Resources!** By composting, you:
   - Reduce costs and fuel use for waste collection and transportation to landfills.
   - Keep valuable resources out of the landfill and extend the life of existing landfills
   - Return wastes back to the soil to help you grow more food!
   - Conserve water since compost helps with moisture retention in soil.

Conclusion

Composting is an art and science in itself. Engaging students in the practice of composting at the school-level helps them develop into more responsible and ecologically aware individuals. In the world that we live in today, students can no longer say, “No, not in my backyard”; instead they must learn to say, “Yes, in my backyard!”

Note: Credits for the image used in the background of the article title: Still life on composter, allispossible.org.uk. URL: https://www.flickr.com/photos/wheatfields/2257331369. License: CC-BY.

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Teaching as if the Earth Matters

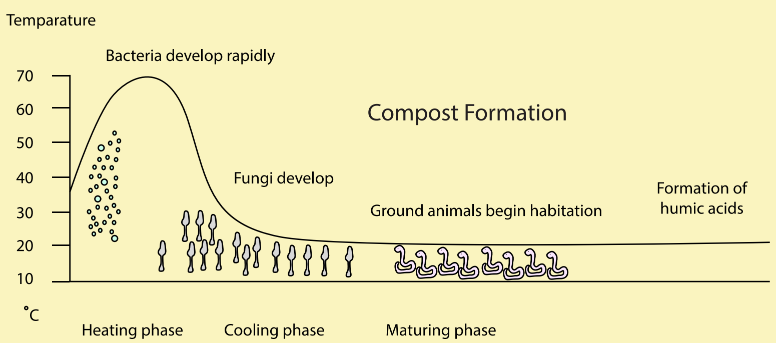
Origins of Composting

Author: Radha Gopalan

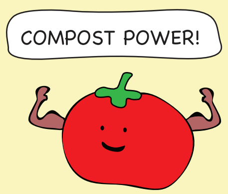
"All the human and animal manure which the world wastes, restored to the land instead of being cast into the water, would suffice to nourish the world…" – *Les Miserables*, Victor Hugo

What is composting?

Composting is the human regulated transformation of animal dung, leftover foods and other organic waste carried out by microorganisms, insects and worms. The compost produced, as a result, completes the cycle of life – living vegetative matter dies, and is broken down by other organisms to produce more living matter.



Why compost?

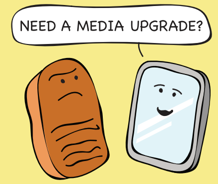


We began composting as a way to enrich soils to grow safe, healthy food. Thus, the origin of composting mirrors the origin of agriculture – dating back to about 10,000 years ago. In fact, till synthetic fertilizers were manufactured in the 18th century, soil was fertilized only with manure – so all food was organic!

Today, the benefits of composting are not limited to agriculture. By providing a powerful way of converting degradable waste into food, composting offers a way of ridding our cities of rotting vegetable and animal waste.

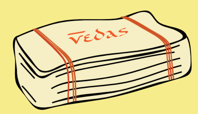
How do we know the origins of composting?

Since composting and manuring are such integral parts of agriculture, knowledge about them was unique to each location and often shared by word of mouth. Recorded works on composting are therefore sparse and often in the form of recollections of people's experiences and practices. This broad timeline has been pieced together from anecdotal information and reported archaeological records.



2320 BCE - 2120 BCE: Earliest written accounts of composting were found in a set of clay tablets carved during the Akkadian Dynasty that ruled Mesopotamia (modern day Iraq). Not much is known about the complete contents of these tablets.

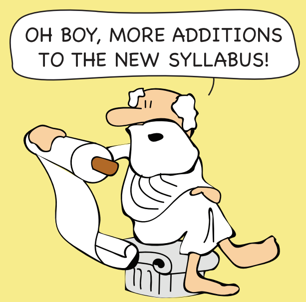
3000 BCE - 2000 BCE: Archaeological evidence from Hamoukar, one of the largest 3rd millenium centres in North-East Syria, provides evidence of household level composting of animal waste, soiled bedding, and spoiled fodder in sump like structures outside the main house.



1500 BCE - 400 BCE: In ancient India, the *Rigveda* and *Atharvaveda* contain references to the practice of throwing some items onto the ground to increase soil fertility, and the value of the manure prepared from straw of barley and sesame plants in improving land productivity. The Atharvaveda also mentions the use of dry cow-dung as manure.

1000 BCE – 1500 BCE: The Native Americans planted uneaten fish parts or other animal parts with seeds as a nutrient source. They also pioneered the use of seed balls to enhance growth. These balls consisted of seeds, rolled in clay and compostable materials. When thrown on soil, the seeds were protected by the clay balls which kept them moist, while the compost provided nutrients as they germinated and grew.

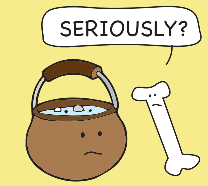
Native American seed balls.



362 BCE: Xenophon's *Oeconomicus*, a treatise on the science of the household, is among the earliest accounts of composting among the Greeks. Translations of the treatise indicate that agricultural residues were composted to form manure.

350 BCE: Carthaginian writer Mago, called the Father of Farming by the Greeks and Romans alike, wrote a vast treatise on agriculture in 28 books which reportedly contained information regarding Punic manuring practices. This is known through ~40 citations found primarily in works by other Roman and Greek scholars.

160 BCE: A retired Roman General Marcus Porcius Cato described composting in his book *De Agri Cultura* (Concerning the Culture of the Fields). According to him, goat, sheep, cattle and other dung were composted with plant wastes such as straw, chaff, bean stalks, husk, oak leaves etc. These different types of animal manure were ranked differently - whilst favouring goat, sheep and ox dung, all of which must be stored carefully, pigeon dung was the most highly prized, to be spread on pastures, gardens and arable farms. Street sweepings and other organic waste were also mixed to produce compost. This book is also the first to describe composting using worms.



100 BCE: Archaeological records from Neolithic sites in Northern China and the first century BCE Agricultural Manual authored by the Chinese scholar Fan Sheng-Chih Shu indicate that the ancient Chinese enriched soils by recycling a variety of organic matter, including cooked bones, leather, manure, silkworm remains and human waste!

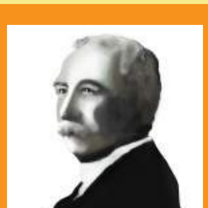
77 AD: Pliny's *Naturalis Historia* from the medieval world put together advice on manure and manuring provided by earlier authorities.

50 BCE: Cleopatra reportedly made worms sacred after observing their composting abilities, enacting laws to make the removal of earthworms from Egypt a crime punishable by death!

450 AD - 510 AD: Palladius's fourth-century text *De re rustica* and the tenth-century Byzantine compilation of agricultural instructions known as *Geoponica* laid the foundations for western manuring practices in the nineteenth century.

200 AD - 1200 AD: In India, Tamil people carried out systematic ploughing, manuring, weeding, irrigation and crop protection for sustained agriculture.

Archaeological evidence of structures and isotopic nitrogen analysis shows that compost making in various forms was practiced in the Indus Valley. Straw from animal stalls, dung and urine were buried in cultivated fields to increase soil fertility.



Basis of Modern Composting

Most modern methods of composting are based on the Indore method, developed by the renowned agriculturist Sir Albert Howard while he was stationed in India (1905 onwards). It was inspired by Howards's observation that just as "The forest manures itself. It makes its own humus and supplies itself with minerals", peasants in India and China fertilized their soils: "cultivators of the Orient have followed Nature's method as seen in the primeval forest."

Howard tested this method for several years in India. In the late 1930s and early 1940s, it was successfully adopted in several African countries, the United Kingdom and the United States of America. Today, in spite of the domination of the industrial method of agriculture, the Indore Method continues to be the basis of composting methods all over the world.

Poster Design: Vidya Kamalesh

i wonder…
Rediscovering school science

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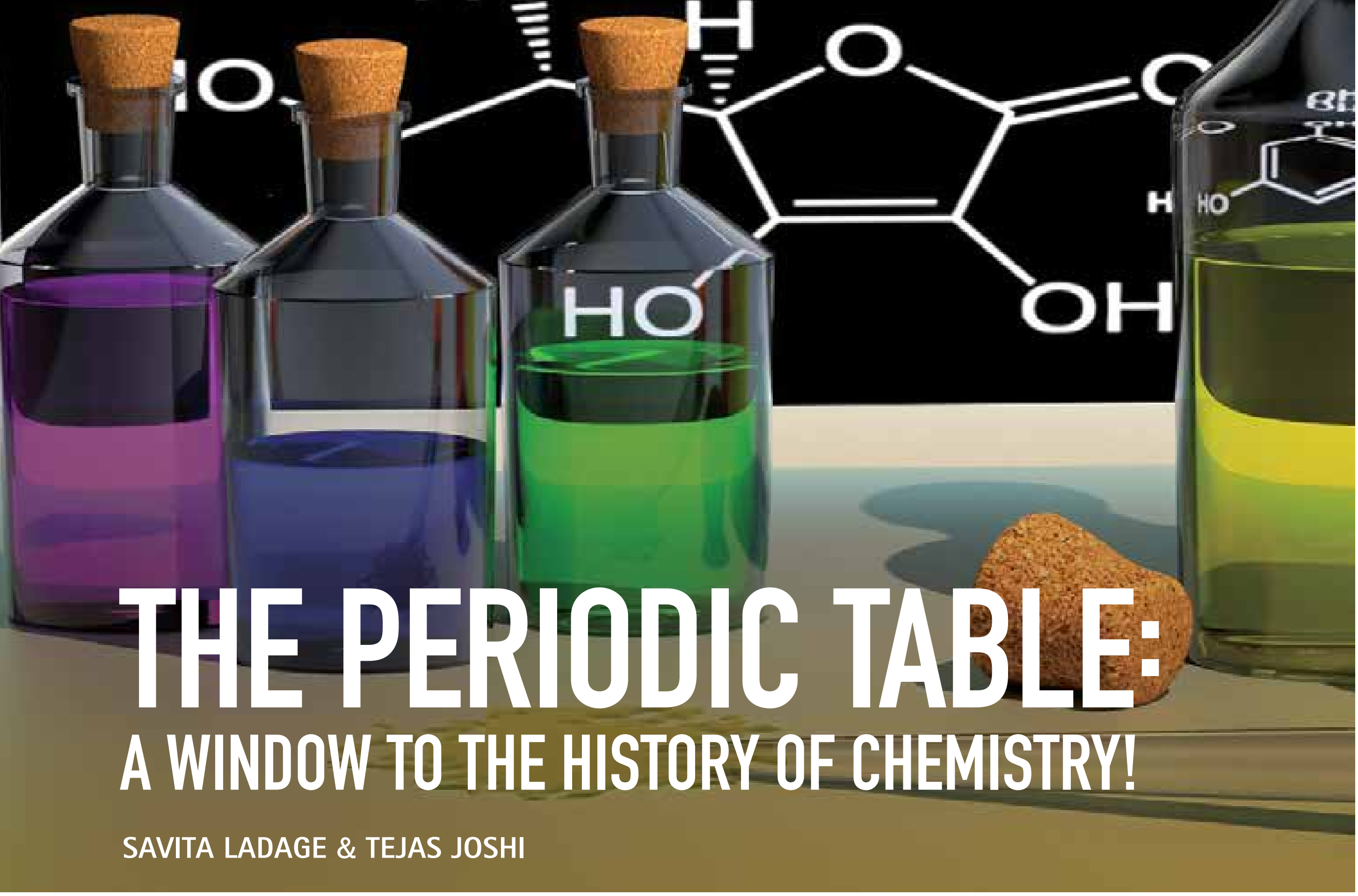
Azim Premji University



THE PERIODIC TABLE: A WINDOW TO THE HISTORY OF CHEMISTRY!

SAVITA LADAGE & TEJAS JOSHI

The periodic table is central to chemistry education, and it can be just as central in exploring the inspiring history and evolution of chemistry as a subject. This article embarks on this historical journey, with the objective of showcasing its value for both teachers and students.

The periodic table is an integral part of the chemistry we study today. But, have you ever wondered how elements were discovered? Or, how the periodic table has evolved to its present structure and format – especially in the absence of advanced analytical techniques, instruments or accessible literature? The answers to these questions lie in the unflinching human quest for knowledge, a logical approach, and a great deal of foresight. As lucid and organized as it may appear today, the periodic table is in fact a reflection of the challenging and uphill evolution of the very subject of chemistry. Thus, learning about its history is as invaluable for a teacher as it is for a learner...

Early attempts to identify natural elements

The belief that all matter in the world around us is made up of a limited pool of building blocks has persisted since ancient times. This has led to numerous attempts, from different civilisations, to identify these building blocks.

One such attempt identified four elementary substances – Water, Air, Fire and Earth. Aristotle added one more element – 'Aether', the element of the heavens, to this list. These finite building blocks were put together in a preliminary, but convincing, 'table' – becoming one of the first efforts to classify elements. Even back then, these elementary substances were used to make sense of natural phenomena (refer Fig1)!

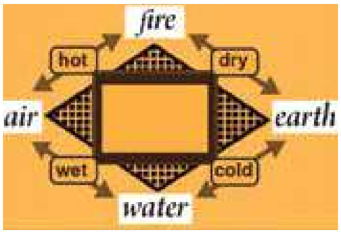


Fig. 1. A preliminary table of natural elements. This very old precursor, by Aristotle, to the modern periodic table might have been a modest beginning, but it worked well in explaining natural phenomena. For example, the presence/absence of fire explained hot and cold respectively. The absence of water implied a solid. Thus observing ash and experiencing heat following the burning of wood, wood was believed to be made up of earth and fire.

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This simple, but reasonably rational, classification prevailed for many centuries. However, beginning with the work of alchemists (ancestors of modern chemists), and later as a result of progress in experimental sciences, the concept of chemical elements began witnessing a considerable change.

What are chemical elements?

The discovery of chemical elements dates back to prehistoric times, when humans observed charcoal (Carbon) being left behind from the burning of wood in forest fires.

An awareness of as many as seven metals – Gold, Silver, Copper, Lead, Iron, Tin and Mercury, and the non-metal Sulphur (apart from Carbon) – can be traced back to ancient times. This may have been because many of these elements occur naturally, either in free (elemental) forms or in ores like sulphides and oxides, and are easily decomposed by simple heating or heating in the presence of charcoal. It is also possible that once they were discovered, their utility or importance to humans may have driven their further identification. However, we have little documentation of either – their discovery, or their recognition as elements.

In this context, the history of Gold is particularly significant. Due to its attractive lustre, Gold (along with Silver) became a symbol of wealth (ornaments) and beauty, gradually assuming significance as a medium of exchange and international trade. Consequently, many alchemists began to seek this 'Philosopher's Stone' by attempting to convert other base metals, like Iron, into Gold. It was these attempts by alchemists from the Middle Ages that led to the discovery of many other elements, like Antimony, Arsenic and Bismuth. It also led to the development of a variety of glassware as well as the discovery of three major acids – sulphuric, hydrochloric and nitric, all of which have been crucial for subsequent experimental research.

However, the first written record documenting the discovery of an element dates back to 1669. The element it describes is Phosphorus, discovered from urine, a natural source of phosphates.

While it is possible that many more elements were discovered in this period, it is difficult for us to establish the existence of this knowledge. Alchemists of this period relied heavily on trial and error. Also, given the potential economic benefits that their discoveries might bring them, they tended to refrain from disclosing their learning. This meant that knowledge was more likely to remain isolated, and its development did not progress methodically.

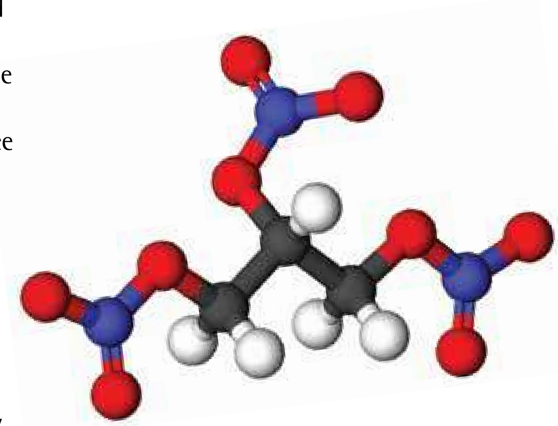
Experimental science and the new concept of the element

The first significant shift in our ideas about elements came from the work of Robert Boyle in the seventeenth century. Boyle defined an element as being a substance that could not be broken down into simpler constituents, and could combine with other elements to form a mixture (today's compound). Extensive work by scientists like Henry Cavendish, Joseph Priestley and Antoine Lavoisier in the eighteenth century demonstrated this concept experimentally.

Cavendish discovered a flammable gas (produced by the reaction of acid and metal), christened Hydrogen, at around the same time that Priestley discovered a gas, christened Oxygen, which supported burning. Lavoisier's milestone synthesis of water using the two was the first major blow to Aristotle's choice of elements. Lavoisier also established the conservation of mass in chemical reactions and provided a basis for writing chemical reactions.

An invention that played a vital role in the discovery of new elements was the construction of the Volta's cell in 1800. The Volta's cell provided a steady source of electricity and, thereby, a unique means of decomposition. It was successfully deployed by Sir Humphry Davy to isolate the extremely reactive Sodium and Potassium in 1807 and other alkaline earths like Calcium, Magnesium and Barium subsequently. The reducing ability of potassium, in turn, helped Jöns Jacob Berzelius discover Selenium, Silicon, and Zirconium etc.

The gradual increase in the number of known elements was accompanied by the evolution of ideas regarding the atom and atomic mass in the early nineteenth century. Both these aspects became important stepping stones in subsequent attempts to classify elements. The atomic theory proposed by John Dalton in the beginning of the nineteenth century is particularly significant in this context. Dalton suggested that elements were made up of indivisible particles, called 'atoms'. His idea that all atoms of a particular element were identical – in terms of their mass, size and properties – focussed attention on the important concept of atomic mass. According to Dalton, the exact value for the atomic mass of an element could be thought of as being the signature of that element. This idea led to the question: how do we calculate the atomic mass of an element? Dalton displayed remarkable foresight in calculating this value relative to another element whose mass was known (i.e. Hydrogen as a reference element to predict relative masses of other elements).



Box 1. **Atoms or molecules?**

Remarkably, at this point of time, the chemical formulae of compounds was not known, nor was the concept of valence. However, the law of conservation of mass (Lavoisier) and the law of constant proportion (Proust) had already been established. The law of constant proportion by Proust states that irrespective of its source, a particular compound (say water) is made up of the same elements (hydrogen and oxygen) present in a constant mass ratio (1:8) throughout. Keeping hydrogen as a reference, and assuming the simplest formula of water to be HO, Dalton concluded the atomic mass of oxygen to be 8.

Gay-Lussac was working with chemical reactions in gaseous phase, and suggested that atoms need not be the smallest particles in an element to have independent existence. Gay-Lussac's results were in conflict with Dalton's postulate of the indivisibility of an atom. This conflict was finally resolved by Avogadro who proposed the idea of 'molecules'.

The concept of atomic mass and its determination was further developed in the period between 1800 and 1860 by Gay-Lussac, Amedeo Avogadro, Berzelius, Jean Stas and Stanislao Cannizzaro. Berzelius changed the reference element from Hydrogen to Oxygen, broadening the canvas of chemical assays by making use of readily available oxides. This historic notion of using some reference for calculating atomic masses is still very much in use – with the 12C isotope being the standard today.

Box 2. **Developing the idea of atomic weights.**

The development of the idea of atomic weights is an amazing story in itself, which has been discussed in detail in an article titled – The Saga of Atomic Weights (Pg. 78) in the first issue (Nov 2015) of **i wonder...** We'd recommend a quick read!

Thus, by the mid-nineteenth century, almost 60 elements had been discovered, and their atomic masses had been calculated. However, this knowledge was still largely unknown within the scientific community, and wasn't particularly accessible to everyone. As a result many conceptual ambiguities regarding valence, molecular masses, equivalent masses continued to prevail.

The necessity for contemporary chemists to come together to resolve these ambiguities resulted in the first international Congress held at Karlsruhe, Germany in 1860. Cannizzaro's values of atomic masses and his rationale for calculating them, based on Avogadro's hypothesis, was presented at the Congress. This landmark gathering thus laid the foundation for serious and concerted efforts to reflect on existing knowledge about elements and their properties.

Box 3. **Triads of elements.**

Even though most attempts at classifying elements happened after the Karlsruhe Congress, there were some noteworthy attempts prior to it, notably Dobereiner's work. Dobereiner's categorization of elements was based on their chemical similarity: he arranged a group of three similar elements in an increasing order of (their then known) atomic masses. When this was done, he noticed that the atomic mass of the middle element was close to the average of the mass of the other two. He published his 'Law of Triads' in 1829, leading to the subsequent identification of ten such triads by 1843.

Fig. 2. Examples of some triads of elements.

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However, this preliminary classification could not be used to organize all known elements; neither was this grouping perfectly robust: for example, some tetrads, and even one pentad, were identified later!

Periodicity in chemical properties of elements

Following the 1860 Congress, the considerable number of known elements (63) and clarifications about their atomic masses, valence etc. provided the appropriate reference points needed to organize this information.

John Newlands was the first to identify a certain 'periodicity' in the chemical properties of elements. Newlands observed that when arranged in order of their increasing atomic masses (as calculated by Cannizzaro), every eighth element to appear in sequence from a given starting element in his arrangement was similar to each other (refer Figure 2). He called this peculiar property the 'Law of Octaves' given its similarity to the musical octave.

The fact that Newlands relied more on atomic masses of elements, rather than their physical and chemical properties, resulted in some limitations in his arrangement. This was partly because some of the atomic mass values that were in use at that time were incorrect, leading to their incorrect placement. Additionally, Newland did not leave gaps for undiscovered elements in his table.

Mendeleev solves the puzzle

Even though Newlands identified periodicity, his attempt at classifying elements was not taken seriously by chemists, and thus he did not pursue his ideas further. It was Dmitri Mendeleev, who in 1869, and later in 1871, published his version of a periodic table. This elegant system of classification not only established the periodic law convincingly; but, also anticipated some undiscovered elements by virtue of logical foresight, accommodating them by actually leaving gaps!

What makes Mendeleev's efforts, in the development of the perioidic table, transformational?

Li^{2} 7	Be^{3} 9	B^{4} 11	C^{5} 12	N^{6} 14	O^{7} 16	F^{8} 19
Na^{9} 23	Mg^{10} 24	Al^{11} 27.5	Si^{12} 28	P^{13} 31	S^{14} 32	Cl^{15} 35.5

Fig. 3. A portion of Newlands' periodic table. Newland's brave attempt in arranging elements and identifying periodicity is evident in this portion. Chlorine (Cl), the eighth element to appear in sequence from F (Fluorine) exhibits similar chemical properties to it. That they both belonged to the same group – of halogens – was established much later.

1. Mendeleev's arrangement did not rely only on the atomic mass values calculated by Cannizzaro. Instead, he pursued his own analysis of compounds, identifying chemically similar or 'analogous' elements, and prioritised this chemical similarity in his arrangement. In fact, he used this information to question the atomic masses of several elements.

2. Mendeleev seemed to have taken knowledge available to him as a challenge –somewhat like a jigsaw puzzle that was supposed to be assembled. He, therefore, prepared individual cards for each element, attempting to sort them through multiple arrangements. While considering these arrangements in the vertical and horizontal directions, that we are familiar with (in today's table), he chose to use family likeness vertically, and increasing atomic masses horizontally.

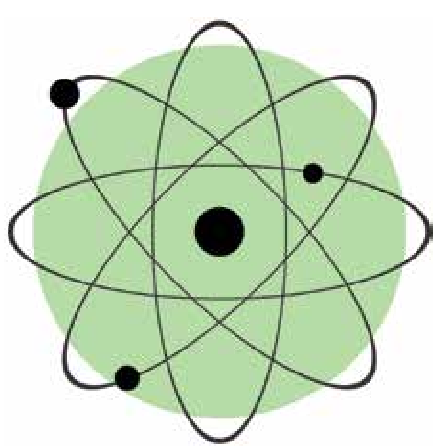
3. Mendeleev's conviction enabled him to confidently question existing knowledge (for example, incorrect atomic masses) and he resorted to re-calculating or re-positioning apparently incorrectly placed elements. This conviction and foresight were proved correct subsequently.

4. Possibly the most salient feature of Mendeleev's table are its blank spaces that were aimed at accommodating some undiscovered elements. But these were not just spaces, they were also accompanied by predictions of the properties these yet undiscovered elements were likely to exhibit (for example, having anticipated properties similar to aluminium, Mendeleev predicted the presence of an element that he called eka aluminium, and was later discovered and named Gallium). This visionary, and rather audacious, provision in Mendeleev's table allowed more elements to be incorporated. In fact, it also guided the search for new elements!

Amazingly, a strikingly similar periodic table was independently devised at around the same time by Lothar Meyer, a scientist who was later given almost equal credit for his contribution to the development of the periodic table as Mendeleev. Meyer's table drew more attention towards a progression in physical properties of elements, such as their atomic volumes.

A bigger problem: the surge in new elements and accommodating them!

Even as Mendeleev's periodic table offered a formidable organization of the 60-odd elements known at the time, it was soon threatened by the discovery of many new elements.



The first of these challenges came with the discovery of rare earths, i.e. lanthanides, using a spectroscope, invented by Robert Bunsen and Gustav Kirchoff in 1859. The spectroscope is an instrument that allows us to detect very small quantities of elements in any substance, without chemically isolating them. For the rare earths, which were chemically very similar and difficult to separate, therefore, the spectroscope was apt. As many such rare earths were being discovered post 1870, placing them in Mendeleev's periodic table was proving to be a challenge. Their chemical similarity was at odds with the fact that one of the main attributes of Mendeleev's classification was a progression in chemical properties. In 1905, Alfred Werner successfully resolved this problem by placing the rare earths between alkaline earth metals and transition elements in his very long periodic table, comprising 33 columns! Isn't it remarkable that Werner was able to rightly place the rare earths without any knowledge of their electronic configuration?

Another challenge came with the discovery of the first inert gas – Argon, in 1894, by William Ramsay and Lord Rayleigh. This discovery was unwelcome to most chemists, as chemically unreactive Argon seemed to threaten all that we had discovered and understood about elements. The subsequent discovery of other inert gases like Helium, Neon, Krypton and Xenon, amplified this complication – culminating in the creation of a unique group in the table, placed between the halogens and alkali metals.

In 1898, Marie Curie and her husband, Pierre, discovered Polonium and Radium, and by 1911, almost 30 radioactive elements were known. These discoveries presented yet another challenge to the conceptual understanding of elements – mainly because some of them had identical chemical properties, but different atomic masses. This naturally

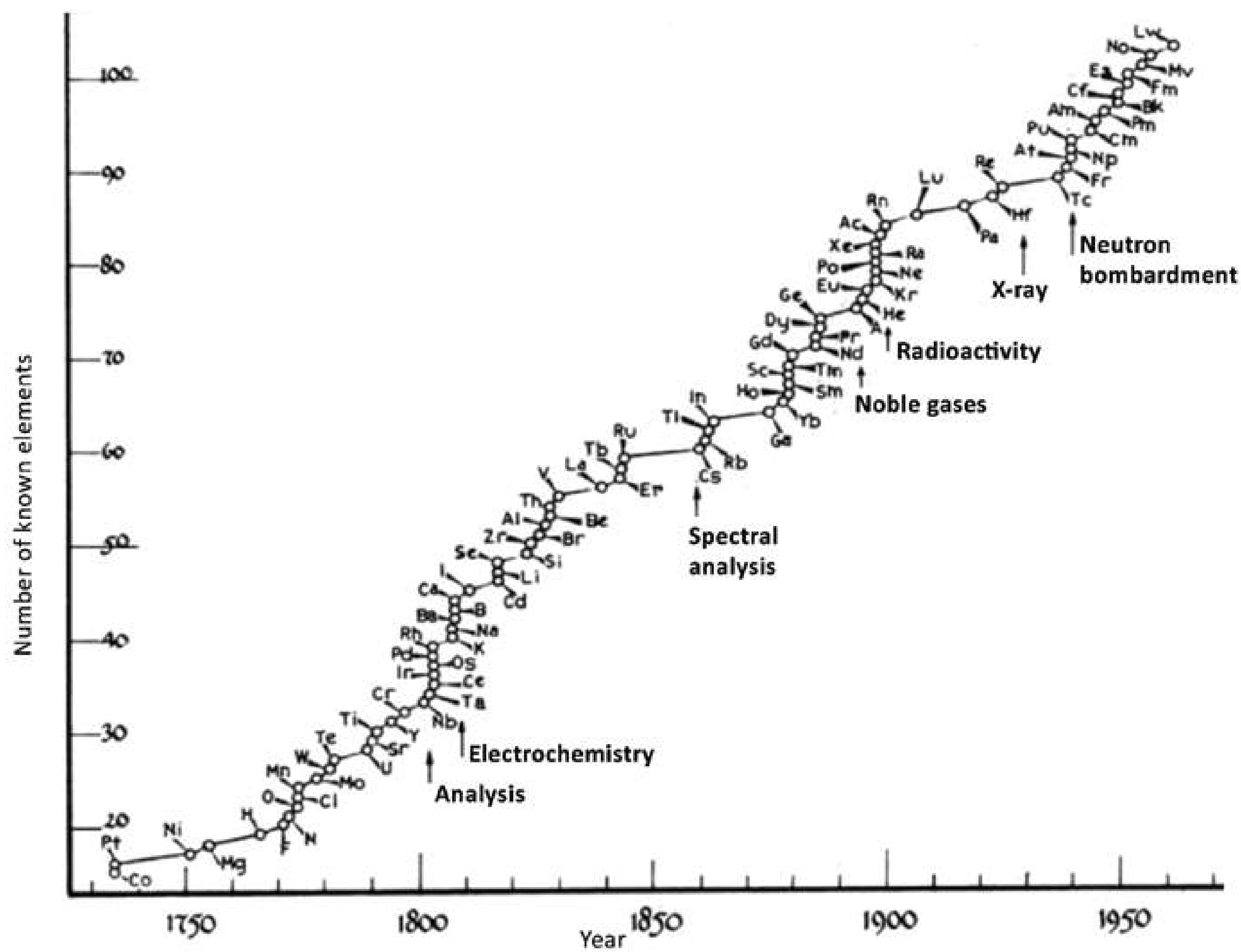


Fig. 4. An overview of the discovery of the elements.

Credits: Adapted by Tejas Joshi from Goldwhite, H., & Adams, R. C. (1970). Chronology of the discovery of elements. Journal of Chemical Education, 47(12), 808.

led to the problem of how and where to place these new elements in the periodic table. Frederick Soddy and Kazimierz Fajans resolved this problem by suggesting that all isotopes (elements with identical chemical properties) of an element must be placed along with it, in one single place, despite having different atomic masses.

Atomic number: the new signature of an element

Henry Moseley's work in 1913 showed that there exists a systematic mathematical relationship between the placement number of an element in the periodic table and X-rays produced by the element. Thus, he could measure the atomic numbers of several elements for the first time. Because of his work, atomic number (that is, number of protons present in the nucleus of the atom), instead of atomic mass, is now considered the signature of an element. Moseley's work also conclusively showed that there were 14 rare earths, with the two, till then missing, elements Hafnium and Rhenium being discovered soon after, by the X-ray method.

The latest addition to the periodic table is that of new elements created by humans. As a result, the concept of elements evolved from being limited to naturally occurring ones to including those created in laboratories by the transformation of matter on nuclear bombardment. Neptunium was the first element to be synthesized. The creation of this trans-uranium element in 1940 by Edwin McMillan and Philip Abelson, at the Berkeley Radiation Laboratory was followed by extensive syntheses of transuranium elements by Glenn Seaborg and his co-workers. Accommodating these newly created elements in the periodic table was yet another challenge, as nobody had anticipated them! By 1944, Seaborg, who christened this set of elements as the 'Actinide' group, had developed an updated version of the table with these elements placed below the rare earths (Lanthanides). This was based on the discovery that the actinide group of elements were analogous to their corresponding lanthanides, and subsequently aided the identification of many more synthetic elements.

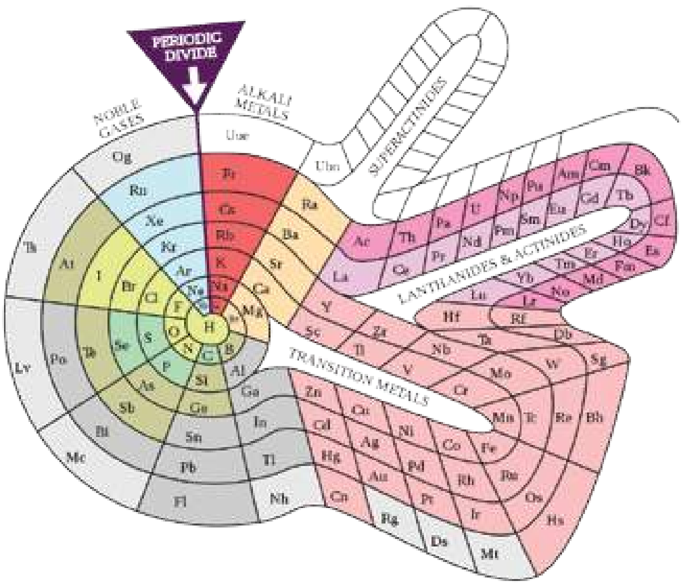


Fig. 5. Could the periodic table look different? Presented in this image is one example of a significantly unusual format – a spiral table developed by Theodor Benfey. With hydrogen placed at the centre of the spiral, the emergent spirals expand into eight segments, housing transition elements, lanthanides and actinides. The spiral and helical models are not new – the Telluric Screw model proposed by Chancourtois in 1862 was a prominent example of a helical model. To explore other such formats, collected from across the world, visit Mark Leach's online collection at http://www.meta-synthesis.com/webbook/35_pt/pt_database.php.

Credits: DePiep (Own work), Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Alternative_periodic_tables#/media/File:Elementspiral_(polyatomic).svg. License: CC-BY-SA.

1. The first resource is an infographic flyer presenting the milestones in the development of the periodic table and introduces scientists who contributed to it. This article is inspired by this resource.
2. But this flyer opens up (unfolds) into a large, incomplete activity-based periodic table with hints and spaces, which the reader completes!
3. The second resource is a pack of 114 visual information cards, one for each element.
4. Color-coded and illustrated, each card has the element 'talk' to the reader, sharing myriad information about itself across themes, details of which are available on the portal.

The portal **www.bit.ly/lmtce** takes you to a detailed description about these resources, and hyperlinks to many useful sources of information for you to pursue.

Fig. 6. Resources developed at the Homi Bhabha Centre for Science Education.

Credits: Tejas Joshi. License: CC-BY-NC.

Box 4. Resources

An extensive list of print and web-based resources on the periodic table that we have referred to for this article, as well as some teaching resources developed by us, are openly accessible online at www.bit.ly/lmtce under the 'Important References and Resources' section on the portal.

We recommend visiting the portal, which was built to make available educational resources for multiple audiences, some of whom might not be able to access teaching aids or international books in print. We are sure that some of these resources will inspire and support you in your practice – whether it is through designing activities for your students, directing them towards self-learning, or encouraging them to question and seek answers. We also offer print versions of a set of learning resources designed to act as lucid starting points for inculcating an appreciation for the periodic table and its elements among your students. These resources are available on purchase, and details for the same can be obtained by writing to us.

The periodic table as an educational tool

So here we are today, with the widely recognized long-form of the periodic table. A lengthy journey, right? And one that has not yet ended – efforts to improve the functionality and format of the periodic table continue (refer Figure 4 for one such example)!

All revisions in the periodic table are documented and updated by a global body called the International Union of Pure and Applied Chemistry (IUPAC). These revisions could involve changes in technical information, or the addition of new elements. The most recent version of the table (January 2016), a standard reference for educators, incorporates four new elements that have been in the news, and are known simply as 113, 115, 117, and 118.

What makes the periodic table invaluable for chemistry, and science education in general, is its extraordinary depiction of the dynamic but gradual process by which scientific knowledge progresses, and how pushing this progress is a constant human endeavour.

We present this historical journey in the hope that it broadens your perspective on the periodic table (or anything that you study in science for that matter). Rather than seeing it as a completed product, we hope you can now see the periodic table as the result of an on-going, and rather captivating, story with characters who were curious, hard-working, and pursued questions with no obvious answers through logical contemplation.

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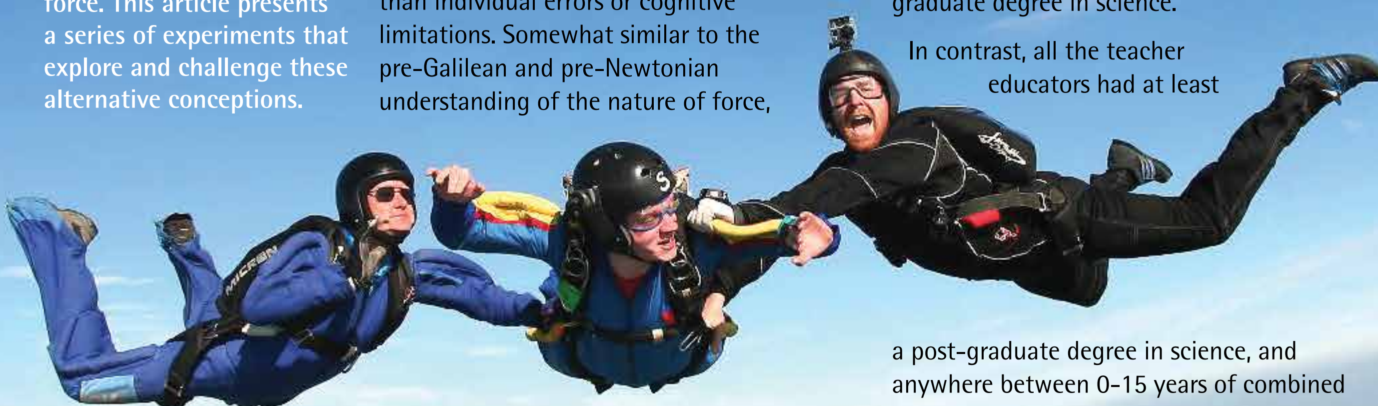
EXPLORING ALTERNATIVE CONCEPTIONS OF FORCE

SAURAV SHOME

Force is a fundamental concept in Newtonian mechanics that teachers and teacher educators are expected to understand well. However, even when teachers and teacher educators are familiar with Newton's laws of motion and gravitation, they continue to hold several misconceptions about force. This article presents a series of experiments that explore and challenge these alternative conceptions.

Understanding force and concepts of Newtonian mechanics is fundamental to elementary physics. However, this is also an area where many alternative conceptions (or misconceptions) abound among not only students, but also teachers and teacher educators [1, 2, 3, 4,] and [5]. Often, even practicing scientists tend to lack conceptual clarity in this area[6].

Most misconceptions about force arise mostly out of real life experiences rather than individual errors or cognitive limitations. Somewhat similar to the pre-Galilean and pre-Newtonian understanding of the nature of force,



they are so deeply ingrained that it unlikely that merely pointing out mistakes or sharing the correct response will change them. Instead, it is important to explore the individual's conceptual framework, and then challenge the framework by situations designed to create cognitive conflicts[4].

In this article, the author presents his experiences from engaging with teachers and teacher educators in a workshop session designed to address some of their most common misconceptions about the way forces act.

About the workshop

Participants

The session on forces was attended by nineteen teachers and eight teacher educators, all working in a single district of a state in North India.

All the teachers had been teaching science and/or Environmental Studies in primary, middle and high school for at least ten years. Some of them had an under/post-graduate degree in science.

In contrast, all the teacher educators had at least a post-graduate degree in science, and anywhere between 0-15 years of combined experience in school teaching and teacher education.

Overview of session structure

The session was structured in order to create cognitive conflict among the participants. A schematic diagram of the process cycle is shown in Fig. 1.

The general format of the session consisted of introducing a problem context to the participants, and then asking them a question. Participants were encouraged to choose their answers from a list of

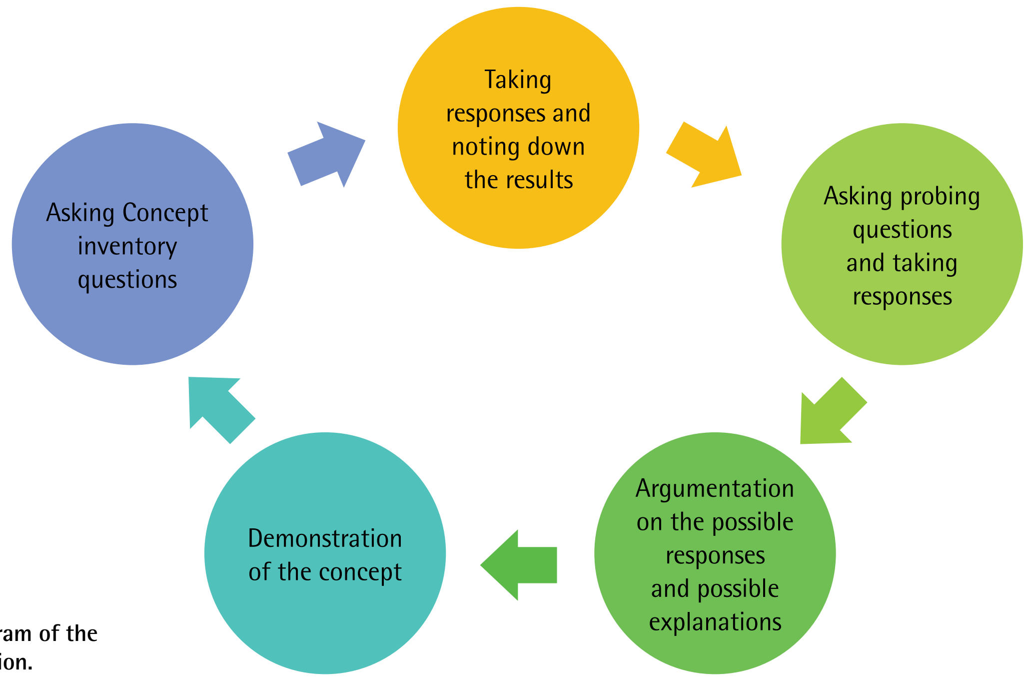


Fig. 1. **A schematic diagram of the process cycle of the session.**

Credits: Saurav Shome. Licence: CC-BY-NC

multiple options shared orally and in writing on the board. For each question, participants would indicate their option by writing it down on a chit of paper. The author would collect the chits and note down the frequencies of different responses. This method was used to protect the identity of the respondents.

Except the first question, all other questions were adapted from the Force Concept Inventory or FCI[7]. The questions as well as responses were rephrased in order to simplify and make them more context-relevant for the participants. Also, slight modifications were made in the language and order of the multiple options, mainly to allow these questions to be presented orally in Hindi (the language that participants were most familiar with).

After noting down the frequency of responses, the author would ask the participants probing questions in order to initiate discussions and arguments. In some cases, the author would introduce new concepts while discussing different types of responses. It was only after a question was thoroughly discussed and the participants demonstrated a reasonable degree of understanding of it that the author would move onto the next question.

How well do we understand force?

No motion no force!

Question 1: There are two identical chairs, A and B, facing the same direction. A man sits on chair A and places his hand on the back of chair B. Suddenly, the man pushes chair B. Observe the result of the push. In this situation, which of the following statements would be correct?

a) Neither the man nor chair B exerts a force on the other.

b) The man exerts a force on chair B, but the chair does not exert any force on the man.

c) Both the man and chair B exert force on the other, but the chair exerts a greater force on the man.

d) Both the man and chair B exert force on the other, but the man exerts a greater force on the chair.

e) The man and chair B exert the same amount of force on each other.

Responses: 22 (81%) participants opted for option b, while five (19%) of the participants opted for option e.

What option would you choose?

Fig. 2. Man sitting on chair A, pushing chair B.

Credits: Saurav Shome. License: CC-BY-NC

Answer 1: The correct answer to question 1 is that stated in option (e). Why did most participants choose option b then?

Participants observed practically no motion in chair A and, in contrast, a considerable amount of motion in chair B. They associated application of force with the motion of an object, in this case, the moving of a chair. Citing Newton's first law of motion, the participants argued that as chair A remained at rest, there was no force acting on it.

Why is this incorrect? It is crucial to note that in choosing this option, the participants neglected two important considerations: the violation of Newton's third law of motion, and the force of friction. In accordance with Newton's third law of motion, when the man sitting on chair A exerts a force on chair B, chair B also exerts an exactly equal force on the man on chair A. But as the two chairs experience this force and move, a second force – the force of friction comes into play, acting in the direction opposite to the rotation of each chair's wheels. The difference in the weights of the two chairs means that although they both experience the same force of push, they don't experience the same force of friction. Since chair A carries the additional weight of the man sitting on it, it experiences a greater force of friction than that acting on chair B. This causes the two chairs to move different distances.

Interestingly, when asked about Newton's third law, all the participants were able to state it – "Every action has an equal and opposite reaction", but knowing this had not influenced their responses

Greater the motion greater the force!

Question 2: Imagine the same scenario as in Question 1. Only, now, a man sits on chair B too. The mass of the man sitting on chair B is about 1.5 times that of the man sitting on chair A. The man sitting on chair A gives a sudden push to the chair B. Take a look at what happens, and choose the correct explanation for it from the statements given below:

a) Neither the man on chair A nor chair B exerts a force on the other.

b) The man on chair A exerts a force on chair B, but the chair does not exert a force on the man.

c) Both chair B and the man on chair A exert force on the other, but the chair exerts a greater force on the man.

d) Both chair B and the man seated on chair A, exert force on the other, but the man exerts a greater force on the chair.

e) Chair B and the man seated on chair A exert the same amount of force on the other.

f) Chair B exerts a force on the man on Chair A, but the man in chair A does not exert a force on chair B.

Responses: Fifteen (56%) of the participants opted for (c), five (18%) for (e), three (12%) for option (f), two (7%) for option (b), and one (4%) for option (a).

What option would you choose?

Fig. 3. Man in chair A pushing chair B with the other man sitting in it.

Credits: Saurav Shome. License: CC-BY-NC.

Answer 2: The correct answer to question 2 is that stated in choice (e). Why were the responses of the participants so varied then?

It is evident that those choosing option (c) overlooked Newton's second law of motion. Simply comparing the distance travelled or acceleration produced is not sufficient to conclude that the amount of force acting on the two bodies is unequal. We must also know the mass of each body. Similarly participants who chose option (f) ignored the motion of chair B, as it was much less than that of chair A. In both these cases, respondents tried to estimate the amount of force acting on the two bodies by taking into consideration the distance travelled by the chairs, but ignoring their respective masses. The two participants who chose option (b) made the erroneous assumption that only animated objects or objects having intention to push can apply force. One of the participants even mentioned that neither the man nor the chair was exerting any force on the other - option (a).

At this stage, participants were asked to compare their responses to Questions 1 and 2. Although, in many cases, the responses received from the two demonstrations were contradictory, both of them stemmed from the same misconceptions of force. A majority of participants had explained the first demonstration by suggesting that only the man in chair A was applying force on chair B. And in the second demonstration, most participants had suggested that both the man in chair A and the chair B were applying force on each other, although the two forces were unequal in magnitude. In the first case chair B was empty, and in the second, the chair was occupied by a motionless man, heavier than the one seated on chair A.

It was pointed out that in responding to both these questions, most of the participants had associated only the amount of motion of objects with the force acting on that object. Hearteningly, this initiated a discussion among participants, where they began acknowledging and reflecting on these contradictions, although they were still not able to apply Newton's third law to either situation.

No attempt was made, even at this juncture, to mention or explain the correct responses to the two questions. Instead, to help participants understand the unequal motion of the chairs, the author introduced them to Newton's law of gravitation. Attention to the connection between Newton's three laws of motion and Newton's law of gravitation was drawn by specifically stating that the force exerted by Earth on any object is exactly equal to the force exerted by the object on Earth.

Both heavier and lighter objects land at the same time.

Question 3: In each of three scenarios given below, two objects are dropped from the same height. Which of them will fall faster to the ground?

Scenario 1: An empty bottle versus a bottle completely filled with water.

Scenario 2: A purse versus a sheet of paper.

Scenario 3: A notebook versus a sheet of paper from it.

Which objects would you pick?

Answer 3: Presented with the **first scenario,** the participants predicted that the two bottles would fall to the ground at the same time. To confirm this, this experiment was performed with two water bottles. As suggested by the participants, the two bottles were dropped from increasingly greater heights. As predicted, in every case, the two bottles touched the ground at almost the same time.

In response to the **second scenario,** the participants predicted that the purse would fall faster than the sheet of paper. A demonstration confirmed this prediction. When asked the reason for this observation, the participants indicated that the paper falls slower due to greater air resistance, caused by its larger surface area.

To present the **third scenario,** a notebook and a piece of paper from he same notebook were taken to ensure that both objects had the same surface area. When the objects were dropped from a height, keeping the faces of the objects horizontal, the paper fell slower than the note book. It was pointed out how this was because the paper, being lighter, could not overcome air resistance as easily as the heavier notebook. In contrast, when the two objects were dropped keeping their faces vertical, both of them fell almost at the same time.

From these demonstrations, all the participants agreed that all objects, irrespective of their mass, fall to the ground at almost at the same time, if they are released from the same height.

Gravitational force is the same on all objects!

Question 4: Imagine two iron balls of the same size rolling on a horizontal table with identical uniform velocity. One of the balls is hollow, while the other is solid. The solid ball is 10 times heavier than the hollow ball. Both the balls slip from the edges of the table at the same time. The hollow ball touches the ground at a horizontal distance of DH from the base of the table while the solid one traverses a horizontal distance of DS from the base. Which of the following statements best describes the relation between DH and DS?

a) DH > DS

b) DH < DS

c) DH = DS

Responses: Seventeen (65%) of the participants opted for (a), one (4%) for (b), and eight (31%) for option (c).

What option would you choose?

Answer 4: The correct answer to this question is that stated in option (c). Why were the majority of responses of the participants so different then?

In an effort to get the participants to apply their understanding of gravitational force to this situation, the author asked them to name the forces that were acting on the balls when they left the table surface. While some of the participants named gravitational force, one participant argued that gravitational force was also acting on the balls when the balls were moving on the surface of the table. Justifying choosing option (a), participants compared this situation with their real life experiences of throwing lighter and heavier objects, arguing that even when thrown with the same force, lighter objects traveled further than heavier ones.

It is interesting to note that in spite of being aware of Newton's law of gravitation, participants continued to hold the view that the magnitude of gravitational force is independent on the mass of the object it acts upon. The demonstrations, of different objects falling to the ground simultaneously, conducted prior to posing this question did not challenge this misconception. All objects fall towards earth with equal rapidity due to equal acceleration produced in the objects and not due to the equal gravitational force acting on the objects. The participants wrongly equated equal acceleration with equal force.

Responses to this question brought to light three more aspects of forces that are difficult to appreciate:

1. A force acting perpendicular to the direction of motion does not do any work.
2. Newton's laws of motion help predict the resolution of different forces acting simultaneously on an object.
3. No impetus force is required to sustain the motion of an object.

Motion due to impetus force!

Question 5: A student throws a cricket ball, as shown in Figure 4. What force(s) act on the ball during its flight at the points A, B and C. Please do not consider the effect of air resistance on the ball.

How would you answer this question?

Answer 5: The responses given by the participants were varied and interesting. All the participants opined that two forces acted on the ball at point A. One was the force of gravity, and the other was the force with which the ball was thrown. Some also rightly said that the force of air friction also acted upon the ball.

However, the participants had differing views regarding the nature of forces acting on the ball at points B and C. Ten (38%) participants had the view that the force of the throw would become zero at point B, and by the time the ball reached point C only the force of gravity continued to act upon it. In contrast, 16 (62%) participants held the view that the force of throw would remain in the ball till it touched the ground. However, the magnitude of the force of the throw would continue to reduce at every point in its trajectory. Thus, at point B, it would be equal to force of gravity and at point C, it would be much weaker than the force of gravity.

At this point, the trajectory of a ball when hit with a bat was demonstrated, and the participants were asked to predict how long the force of hitting would continue to act on the ball. All participants responded that the force would remain in the ball till it reached the ground. Pointing out that the person hitting the ball was not traveling along with the ball; the participants were asked how the force with which the ball was hit would travel along with the ball? Also, if the force of hitting was travelling with the ball, why did the ball stop after traveling a certain distance, rather than continue to move further? And how was the force of hitting transferred to the ball, even when contact between the ball and the bat no longer existed?

To further clarify this point, the participants were asked to reflect upon the same situation under circumstances where there was no force of gravity acting upon the ball. According to Newton's first law of motion, what would happen to a ball thrown in a gravity-free environment? What would be the trajectory of the ball? By applying Newton's first law to this situation, participants could predict that the ball would continue moving in a straight line. They also explained that this would be due to the inertia of motion and not due to the force of hitting. However, in the presence of the force of gravity, the ball follows a curved path. This led them to conclude that once the ball was hit, only one force continued to act on it and this force was that of gravity.

Interestingly, some participants expressed their dissatisfaction with this explanation. For example, one participant said "How is it possible that the ball makes a trajectory under the influence of the force of gravity without having any force continuing to act in the direction of motion?"

The discussion was then steered back to question 3, reminding the participants that irrespective of their mass, all objects fall to the earth with the same acceleration. Hearing this, some of the participants concluded that both balls in Question 3 would take the same time to reach the ground. By the end of this session, many of the participants started appreciating the fact that Newton's third law meant that forces exist in pairs and that freely falling objects are acted upon only by the force of gravity. However, the answer to the third question continued to remain unresolved.

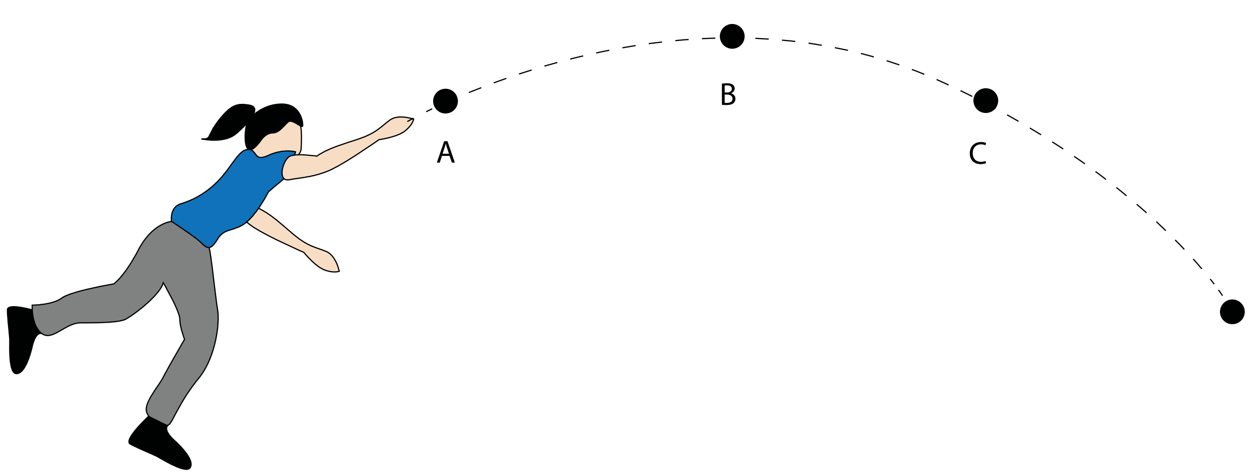


Fig. 4. Different forces act upon a ball thrown by a student. Credits: Saurav Shome. License: CC-BY-NC

Conclusion

Many science students and teachers find it difficult to differentiate between force, energy and momentum.

Even when reminded that energy and momentum are conserved quantities and properties of the object that are carried with it as opposed to force that is neither carried with the object nor conserved, these statements alone are not sufficient to bring about conceptual change. For example, although participants of the workshop session were able to state Newton's laws of motion and the theory of gravitation, they showed inadequate understanding of both. They tended to associate force with motion, rather than inertia with motion, an idea similar to motive/impetus force.

Similarly, experiments to demonstrate the workings on force may also not be sufficient in helping students develop a conceptual understanding of force in Galilean and Newtonian mechanics. For example, despite elaborate demonstrations that all objects in free fall move towards ground with equal rapidity, participants adhered to their initial understanding that the mass of objects influences the horizontal distance traversed by the same object after it has reached the ground. Their alternative conceptions seemed to stem from their inability to differentiate between physical quantities at least at three levels: a) mechanical force and gravitational force, b) energy and force, c) velocity and acceleration.

From our survey with teachers, it seems likely that questions around counter intuitive examples may be a great way for teachers to help rid students of learning misconceptions. We have illustrated a few such examples. However, these could be changed in a variety of ways. For example, while discussing the responses in Question 1 and 2, other sets of demonstrations could be included. These could take the form of exchanging the students; or putting the heavier student in chair A and lighter student in chair B with the heavier student pushing the chair B; or, equalizing the mass on each chair; and comparing the relative distances traveled by the chairs in each case. The sequences and intermediate questions could be structured in alignment with the conceptual pitfalls that appear in discussions. The situation in Question 4 could be demonstrated, by allowing hollow and solid balls to fall from increasing heights.

Now it's your turn - try out some of these experiments with your students today. You may find yourself surprised at their responses!

Note: Credits for the image used in the background of the article title: Accelerated freefall. Tony Danbury. Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:AFF_Level_1_-_Skydive_Langar.jpg. License: CC-BY.

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POLLINATORS: THE PLANT PROPAGATORS

MEENAKSHI PANT

Plants court a variety of animal pollinators to ensure their own genetic diversity. This article explores the diversity of mechanisms that plants use to attract specific pollinators, showing how these co-evolving mutualistic relationships matter to life on Earth.

"Life did not take over the globe by combat, but by networking" – Lynn Margulis.

The famous evolutionary biologist Lynn Margulis held the view that life evolved on this planet not through a competition for survival but by collaboration between life forms in order to survive. What better example of this than the process of pollination, where plants and animals interact for mutual benefit!

Pollination is vital to the survival and propogation of a variety of plant species on Earth, especially those that reproduce by sexual means. Such plants have evolved to minimize self-fertilisation by separating their mature male and female reproductive cells in space or time (or both). One example of this is seen in plant species where mature male and female reproductive organs are located in different flowers on

Fig. 1. Lynn Margulis.

Source: Javier Pedreira, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Lynn_Margulis_2005.jpg. License: CC-BY.

Origins of pollination studies:

Our understanding of pollination by animals is based on the work of many scientists.

Joseph Gottlieb Kölreuter (1733-1806) played a pioneering role in this field. He published a "preliminary report" called Vorläufige Nachricht in 1761. This report described different modes of animal-mediated pollination, the sexual characters of flowers, as well as the hybridization of plant species. Kölreuter's work was based on a series of experiments where plants secluded from insects failed to produce fruit.

His initial findings were subsequently supported by the results of extensive studies conducted by scientists like Sprengel (1793), Vogel(1996), Charles Darwin (1859), Hermann Müller(1873) and Grant(1952) among others.

Fig. 2. Joseph Gottlieb Kölreuter.

Source: Materialscientist, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Josef_Gottlieb_Koelreuter.jpg. License: CC-BY.

the same or two different plants. The only way fertilization can occur in such plants is through a mediator, one that is capable of transferring the pollen from one flower (called the pollinizer) to the stigma of another. These mediators, indispensable to cross-fertilisation, are what we commonly call pollinators.

Current estimates suggest that about 200,000 species of animals pollinate about 75% of all flowering plants! Animal pollinators come in different sizes and shapes – ranging from insects and birds to mammals and reptiles. It is no wonder, then, that plants have evolved a variety of features to attract a particular type of pollinators. Ranging from bright colours for those with great eyesight to fragrance for those who don't – these features are called pollination syndromes. This coevolution of flowering plants and their pollinators shows one of nature's most conspicuous examples of adaption and specialization.

It also reveals how the interaction between two groups of organisms can be a font of biodiversity.

Let's take a look at some interesting examples of pollinizer-pollinator associations, exploring how these mutualistic relationships shape both interacting partners.

Insects as pollinators

Insects constitute the largest community of pollinators. As Joseph Gottlieb Kölreuter said *"und wahrscheinlich leisten[Insekten]wo nicht den allermein pflanzen, dochwenigstens einem sehr großen Theil derselben, diesen ungemein großen Dienst"* meaning, *"Insects probably provide this uncommonly great service, if not to most plants, then at least to a very large portion of them."* Prominent among them are bees, butterflies, moths, beetles, wasps, flies and ants.

The idea of co-evolution:

This idea of coevolution was first proposed by Charles Darwin who predicted that a long-spurred Madagascar orchid, *Angraecum sesquipedale*, must be pollinated by a hawkmoth with an extraordinarily long tongue.

This idea was supported by naturalists like Alfred Wallace, and a hawkmoth matching the expected tongue-length profile was finally discovered in Madagascar during the early twentieth century.

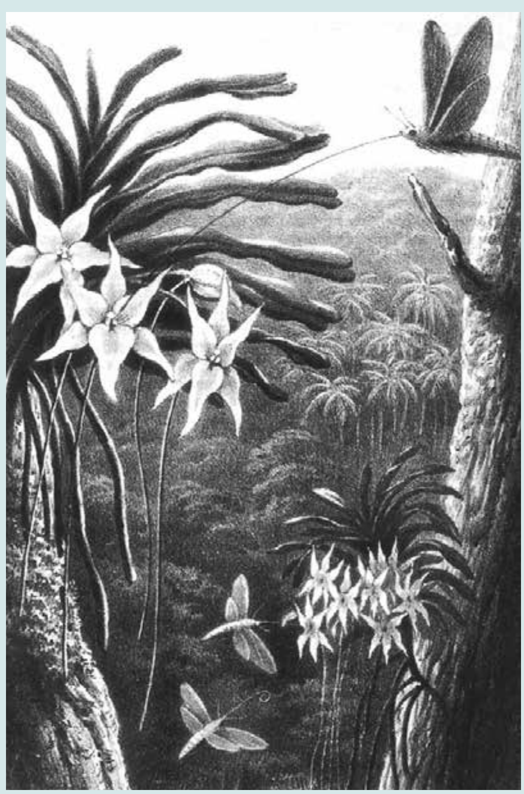

Fig. 3. An illustration by Thomas William Wood, based on Alfred Russel Wallace's description, showing a moth pollinating *A. sesquipedale*. Remarkably, this was drawn in 1867, before the moth was even discovered.

Source: Wallace, Alfred Russel (October 1867). "Creation by Law". The Quarterly Journal of Science 4 (16): p. 470. London: John Churchill & Sons. Retrieved on 2009-07-30. Uploaded by Dmitriy Konstantinov, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Wallacesesquipedale.jpg. License: CC-BY.

Fig. 4. Pollen baskets on pollinating honey bees.

Source: Fifamed, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Honeybee_pollen_basket.JPG. License: Public Domain.

With about 20,000 species involved in plant pollination, bees are some of the most important insect pollinators. Bees depend on plants not only for the nectar they provide – their main food source, but also for pollen – which they use to feed their larvae. The "intelligence" of these pollinators is evident in their ability to perceive, differentiate between, and remember the appearance of flowers they visit. On each visit, bees rub their bodies against the anthers of the flower they land upon. The pollen from these anthers sticks to dense hairs on their hind legs, referred to as a pollen basket, and is transferred to the next flower the bee visits. Bee-pollinated plant species use a variety of mechanisms to look appealing to these insects. Since bees rely heavily on their sense of smell, flowers of these plants often have a strong fragrance. Their flowers are bright yellow or blue in colour, attracting bees even from a distance. This is because bees have trichromatic vision, with their eyes containing pigments sensitive to green, blue, and ultraviolet light, but blind to red colour (which appears black to them). Many floral species offer a special landing platform, in the form of a broad lower lip, to their bee pollinators. Thus, bee-pollinated flowers generally show bilateral rather than radial symmetry. Often, flowers have lines or other distinct markings, with special UV reflection patterns, which may function as honey guides or nectar guides. Ostensibly, these may seem to have evolved to lead bees to nectar; in reality, they ensure that bees reach the places that the flower 'wants' them to reach. Bee pollinated flowers also offer large amounts of nectar and pollen to their visitors. In fact, the pollen collected by a single honeybee colony may amount to more than 28 kg per year.

Fig. 5. UV-reflective nectar guides on flowers of *Potentilla reptans* visible to bees.

Source: Wiedehopf20, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Flower_in_UV_light_Potentilla_reptans.jpg. License: CC-BY-SA.

Although bees are the most talked about insect pollinators, beetles comprise the largest set of pollinators, responsible for pollinating about 85% of all flowering plants, including species like spicebush and magnolia. Since beetles don't have good sense of vision, flowers pollinated by them are usually white or dull coloured. Some beetle-pollinated flowers don't produce nectar; instead they provide these insects with pollen, or have food present on the petals in special storage cells, which pollinating beetles consume. Beetles often eat their way through floral parts, and even defecate within flowers – they are hence nicknamed as 'mess and soil' pollinators.

Although the sight of their colourful bodies perching on flowers is always a treat to the eyes, butterflies are less efficient than bees at transferring pollen between plants. Not only do they not

Fig. 6. An example of beetle pollination – a scarab beetle on *Encelia californica*.

Source: Marshal Hedin (uploaded by Jacopo Werther), Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Scarab_beetle_on_Encelia_californica_(3376142862).jpg. License: CC-BY.

possess any specialized structures to collect pollen; with their slender bodies held high on their long thin legs, not much pollen sticks to their bodies. Butterflies are often found hovering around bright yellow, blue or orange flowers, and sometimes red flowers too, for nectar. The nectaries of these flowers are at the bases of their spurs or corolla tubes that are accessible to only moths and butterflies with long proboscis. Night-flying moths visit flowers that are white- or pale-colored and stand out against their darker backgrounds in moonlight or starlight.

Fig. 7. An example of a butterfly pollinator – the Dark Blue Tiger.

Source: Jeevan Jose (Jkadavoor), Wikimedia Commons. URL: https://commons.wikimedia. org/wiki/File:Dark_Blue_Tiger_tirumala_septentrionis_by_kadavoor.JPG. License: CC-BY-SA.

Other insects like short-tongued flies pollinate flowers, like the Stapelias of Africa, that smell like rotten meat. These flowers are dull red or brown and are, often, called carrion flowers due to their pungent odour and appearance.

Fig. 8. An example of night-flying moth pollination – *Manduca sexta* (Carolina sphinx moth) feeding from a *Datura wrightii* flower.

Source: Kiley Riffell Photography. For use with credit by Henry Art Gallery. URL: https://www.flickr.com/photos/115381928@N03/14255320758. License: CC-BY-NC.

Fig. 9. *Stapelia gigantea* being pollinated by flies.

Source: Ton Rulkens, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Stapelia_gigantea_-_fly_pollination_(5587930978).jpg. License: CC-BY-SA

The orchid family, with about 35,000 species, is visited by all these types of insect pollinators. The pollen grains of most orchids are produced in tiny sac like structures called pollinia that have special sticky pads at the bases. When an insect visits such a flower, the pollinia stick to its head. The 'glue' of the sticky pads dries immediately, causing the pollinia to attach strongly. In some orchids, the pollinia are forcibly slapped onto the pollinator through a trigger mechanism within the flower. *Ophrys*, a genus of orchids found in North

Africa and Europe, has a modified petal resembling a female bumblebee or wasp. Male bees or wasps that emerge from their pupal stage a week or two before the females, mistake the orchid flowers for potential mates. While they are trying to mate with the flowers, pollinia get attached to their heads. When they move on to another flower, the pollinia gets caught in the sticky stigma. On every visit by a pollinator, the pollinia removed from one flower is replaced by the pollinia it has collected from the previous flower it has visited. The pollinia of orchids that are pollinated by butterflies and moths get attached to their long proboscis with sticky clamps instead of pads.

Fig. 11. Bog orchids are pollinated by mosquitoes.

Fig. 10. ***Ophrys speculum*** **or bee orchids which get pollinated by pseudo-copulation.**

Source: Carsten Niehaus, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Ophrys_speculum_d.JPG. License: CC-BY-SA.

Some bizarre pollination mechanisms have also been observed in orchids. In some bog orchids, for example, pollinia get attached to the eyes of their pollinators – female mosquitoes. Thus, with repeated visits, these mosquitoes get blinded. In another weird mechanism, the pollinator gets plunged in a pool of watery secretion produced by the orchid. The only way the pollinator can escape from this pool is by pushing itself through a trapdoor, the route to which is such that contact with pollinia and the surface of the stigma is ensured. Some orchids produce very strong narcotic scents intoxicating pollinators before slowly attaching their pollinia to them. As soon as the transfer of pollinia is completed, the fragrance of the orchid fades abruptly. The temporarily dazed insect comes back to its senses and flies away, carrying the pollinia along with it.

Birds as pollinators

Birds do not have a strong sense of smell, but they have exceptional vision. They visit flowers that are bright red or yellow in colour, with mild or no odour. Bird-pollinated flowers are usually large, in the form of an inflorescence (flower cluster) and, in some cases, grow on tree trunks. They also produce large

Unusual Pollinators:

The role of lizards in pollination has only been recognized recently. Studies have revealed that lizards help the survival of many plant species, particularly on islands, by pollinating them. This unusual behavior can be attributed mainly to the high population densities of island lizard species, an excess of floral food, and relatively low risk of predators as compared to the lizards on the mainland. Island lizards often drink nectar from flowers and eat the pulp of fruits of many plant species, even though the protein content of both these food sources is quite low.

Fig. 12. A lizard pollinating a flower.

In New Zealand, Hoplodactylus geckos are only attracted to the nectar in flowers, not the pollen. Strongly scented flowers are another important attraction as lizards have an acute sense of smell. Also, flowers must be robust enough to support the weight of the pollinator while feeding.

A more intricate pollination system suggesting a common evolutionary history is that between *Phelsuma* geckos and the many different plants found on the islands in the Indian Ocean. In 1998, Olesen and co-workers reported that the puzzling blood-red nectar produced in the flowers of the endemic Mauritian plant species, *Nesocodon mauritianus* and *Trochetia boutoniana*, and the yellow nectar in *Trochetia blackburniana* acted as an attractant for *Phelsuma* geckos, who preferred visiting flowers with coloured nectar rather than those with colourless nectar.

Fig. 13. Hummingbird pollinating *Fuchsia*.

Source: Togzhan Ibrayeva, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Hummingbird_in_search_for_nectar.jpg. License: CC-BY-SA.

amounts of nectar, often in long floral tubes that keep most insects out.

Some birds, like the sunbirds of Africa and hummingbirds of America, are uniquely adapted to the flowers they pollinate. Hummingbirds are attracted to many types of flowers, including Hibiscus, Cannas, honeysuckles, Salvia, Fuchsia, etc. Some Fuchsia have long threads projecting from each pollen grain. When a hummingbird inserts its typically elongated bill into such a flower, the pollen grain threads stick on to the short, stiff hairs located toward the base of its bill. In this way, the bird unsuspectingly transfers pollen from one flower to another.

Bats as pollinators

Most bat species that act as pollinators are found in Southeast Asia, Africa and the Pacific islands. Plants pollinated by bats often have white or pale flowers that bloom at night and are large or have ball-like inflorescences. Many of these flowers have large amounts of nectar, and emit a strong fruity or musky odour that attracts bats. This smell is produced due to the presence of sulphur-containing compounds, specially found in those flowers that are pollinated by bats. Bats use these chemical signals to locate these flowers.

This relationship is of great significance as about 500 tropical plant species, including mangoes, litchi, bananas, and guavas, depend – either partially or completely – on bats for pollination. Pollination by bats has also greatly influenced the genetic diversity of plants in these regions.

Fig. 14. Mexican long-tongued bat pollinating Agave flowers.

Source: U.S. Fish and Wildlife Service Headquarters (uploaded by Dolovis), Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Choeronycteris_mexicana,_Mexican_long-tongued_bat_(7371567444).jpg. License: CC-BY.

Conclusion

Although we've explored only a few plant-pollinator associations as examples, these are sufficient to show how strongly these mutualistic associations influence the propagation of plant species, and thus play a pivotal role in the survival of all life on this planet.

The significance of pollinators is aptly highlighted in these words of E. O. Wilson, an American biologist, researcher, theorist, naturalist and author, *"If we were to wipe out insects alone on this planet, the rest of life and humanity with it would mostly disappear from the land. Within a few months."*

Note: Credits for the image used in the background of the article title: Bee pollinating a rose, Debivort, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Bee_pollinating_a_rose.jpg. License: CC-BY-SA.

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ART AND ECOLOGY

ABHISHEKA KRISHNAGOPAL

Art is a powerful medium to teach students about the importance of nature as it stimulates them to think and feel. This article explores a few simple art based activities that can be used to sensitize children to their local ecology and environment.

Our increasing disconnection with nature is an important cause of many of the negative impacts that humans have on their environment. Thus, it is now widely believed that in order to live more sustainably, we need to create educational experiences that help children develop greater sensitivity and appreciation for the natural world.

Most national and state education boards approach this objective by making environmental education a compulsory part of the school curriculum. For a variety of reasons, however, this seems to have little influence on the minds of young learners. The curriculum for environmental education focuses on topics like environmental pollution, global warming, ozone layer depletion etc, which young students cannot relate to easily. Many teachers, and students, feel overwhelmed by the burden of teaching (and learning) yet another subject in an already packed syllabus. Often this 'subject' is neglected or treated like any other subject that has to be studied and 'memorized' to get through exams. Quite naturally, the teaching methods used in environmental education seem to have little influence on the minds of young learners. In contrast, there is a need for students to not just learn scientific facts about our natural world, but also enhance their sensibility towards nature and understand the environmental issues in their immediate surroundings. To do this, we need to explore and experiment with methods and mediums that can awaken and nourish the sensibility of children to the natural world.

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Throughout the history of humankind, art and education have been interrelated. Indeed, knowledge was often transmitted through art. Now, however, the two are completely dissociated in many educational systems of the world. Using art as a tool for teaching stimulates children to think, feel, and become more sensitive. Sensitivity towards nature can also be achieved through a variety of art-inspired activities, particularly when we work closely with nature. In fact, when it comes to learning about the natural world, art has an ability that conventional approaches lack.

To use art to teach children about nature, one need not be a trained artist or an expert in the subject. Individuals with a curious, exploratory and creative mind can experiment using the medium of art to come up with innovative art-based activities. School teachers can easily teach ecology and environment through some simple art-based activities. These activities need not be too complicated or highly creative. Even simple experiments can make a difference to the quality of learning in children. In this article, we will explore a few such simple activities and experiments that have been used to sensitize children about their environment.

Observing through art builds confidence!

One experiment on teaching children about the natural world through art was conducted with students living at the foothills of a Tiger Reserve. Before plunging into art-based activities, we used a questionnaire based survey to get an estimate of the average knowledge level of students about their local biodiversity. Surprisingly, the survey revealed that these students were unaware of the diversity of wildlife that existed right in their backyard. Although it would have been ideal to take students into the forest and give them some authentic experience of this wildlife, it was not possible to obtain permission to do so. Instead an attempt was made to teach students to learn to identify wildlife in a classroom session using art. Students were shown photographs of the most important mammals known to exist in the tiger reserve, and asked to differentiate between species belonging to the same family. They were divided into two groups – with one group assigned the task of just watching the photos, and the other group asked to sketch the key differences between the various species they were seeing. Since the forest had five species of primates, two species of big cats, and three species of ungulates, the children had to learn to remember the main characteristics of each of these species in order to differentiate between them. A post-workshop survey revealed that the level of knowledge was distinctly higher among the students who sketched the mammals as compared to students who only observed their photographs. Sketching helped students remember features of even animals that were otherwise unfamiliar to them. Significantly, this increase in knowledge level was also evident among those female students who chose to draw. This demonstrates that art can be a useful tool for children with limited opportunities to spend time outdoors, especially in villages where girls are kept indoors after a certain age.

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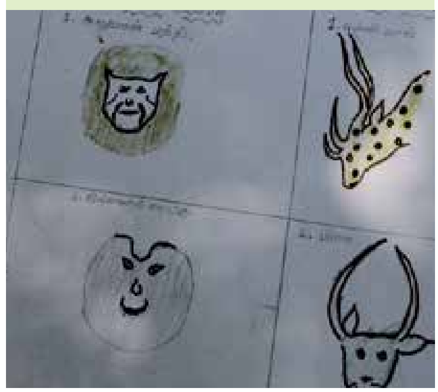

Fig. 1. Sketching helped children remember the distinguishing features of unfamiliar animals.

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Similarly, children were tested to see if they could remember the characteristics of a tree better by just observing it, or by drawing it. Each class was divided into two groups. One group was asked to simply observe the different trees that grew in their school campus, while the other was asked to sketch different parts – like leaves, fruits and flowers – of each tree they observed. They were also encouraged to study the pattern of tree barks by taking an impression of the bark on a sheet of paper using crayons. Observations recorded by both groups in data sheets provided to them after this activity clearly showed that those who had sketched the trees they'd observed, were able to remember differences like those in the shape of the leaves or their barks better and longer. They were also able to draw the leaves or fruits on the black board without referring to their sketches from the field. It was also noticed that when children were asked to select trees for this activity, the students who were asked to just observe trees chose species that they were already familiar with, like Tamarind, Papaya or Fig. These students were already unsure of being able to remember all that they saw and therefore choose trees that they already had some knowledge about. In contrast, students who were asked to sketch their observations often chose trees unfamiliar to them. Art helped increase their confidence to explore and learn the distinguishing characteristics of new trees, which in turn increased their knowledge levels.

Fig. 2. The excitement of outdoor sketching.

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Similarly sketching can be used to learn to identify birds, insects, and other life forms. Though nature trails helps students look at life forms that they may have ignored before, sketching helps them keenly observe and retain what they learn from these observations. For example, when a group of village students were challenged to find animal-homes and sketch them, students spent a long time observing the details of different animal homes, and the animals that made them (if present). To draw these, the students paid great attention to some of the minutest details of these homes; details that they may have missed if they had just briefly glanced at the homes while on a nature trail.

This activity can be conducted even within a school premises. Teachers can ask students to look for animal-homes.

Fig. 3. Drawing an ant nest, hidden under the blade of grass.

Credits: Abhisheka K. License: CC-BY-NC.

Drawing their attention to how spider webs or wasp nests are also examples of these, may help ensure that children don't focus only on bird nests, which is something many of them tend to do. Teachers may also have to give students enough time to observe and sketch the different animal homes they discover. The sketches made during this activity can be displayed at the end of the session, and used to initiate a discussion to ensure that the entire group gets to learn about a variety of animals and their building skills. This group discussion could also be used to bring out the uniqueness of these animals, requirements for their homes, and the threats these homes must protect them against, etc.

Encouraging nature-inspired art

During my experience as a nature educator, I have faced many situations where students have shied away from sketching. The pressure from teachers and parents to create beautiful looking art work; judging the art work based on how closely it resembles the object being drawn; and other such factors discourage several children from engaging with art and exploring their creativity. Nature-inspired art helps students break such mental barriers as they are allowed to work with natural material, without any expectation of seeing any specific or defined form as an end product. What matters is the experience that the child goes through while engaging with art, and not how the art work looks after completion.

Fig. 4. Nature-inspired art by a group of middle school students of a tribal school.

Credits: Abhisheka K. License: CC-BY-NC.

In schools where children are never exposed to drawing, students have expressed fear of drawing or painting. In such cases, given limitations of time, I have preferred to work with natural materials to create art. In this way, students are not limited to using pencils, papers and colors. Instead, they learn to explore the various colours and textures of the natural world. When students are asked to collect material from their natural surroundings to create an art work, it opens them to all that nature can offer – from mud and stones, to leaves, seeds, fruits and broken pieces of wood, dried grass, dead insects and what not! They suddenly discover new things in nature that they had never bothered to look at before. They also get an opportunity to feel these objects with their hands. Allowing students to create an art work without any theme helps them to feel free to explore their own creativity. They learn to play with color, texture and design without any inhibitions, and create some extraordinary art work in the process! Since these works of art are ephemeral by nature, they are recycled into the earth without causing any detrimental effects, and the children take back the experience with them, learning to look at nature in a new way. This is just one enjoyable way of encouraging children to

Nature-inspired art helps students break such mental barriers as they are allowed to work with natural material, without any expectation of seeing any specific or defined form as an end product. What matters is the experience that the child goes through while engaging with art, and not how the art work looks after completion.

develop or improve their relationship with the natural world.

Environmental awareness

Art can also be used as a medium to share environmental messages and to create awareness about critical ecological issues specific to their villages/towns/cities.

Art-based activities can also be used to make students more aware of their own role in shaping local ecology. For example, I asked students from a village, who were in the habit of pulling down bird nests, to build nests of their own. To do this, the students were first asked to collect materials like grass and leaves that they had observed birds using to make nests. Then, they were to use these materials in any way they chose to construct nests that could hold eggs. After working on this task for several hours, some of the children managed to come up with nests that were strong enough to meet these criteria. However, many others had nests which were flaccid. This simple activity helped students realize that while they could destroy nests in no time at all, it takes birds a lot of time and effort to build them. When the students were told that the nests they had built so painstakingly would be discarded after the activity, they were horrified, voluntarily promising to never destroy a bird nest again!

Waste management is another important issue that children need to be exposed to as early as possible in life. Art was used differently in this context. A typical session, for example, would start with discussions about waste management, reducing and recycling waste, and preparing compost pits; gradually leading up to the up-cycling of discarded waste using art. Then, children were asked to bring discarded stuff from their homes and turn these

Fig. 5. Bird nests created by students in Relli Village, Kalimpong.
Credits: Abhisheka K. License: CC-BY-NC.

Fig. 6. Discarded carton boxes being upcycled at Relli Village, Kalimpong.
Credits: Abhisheka K.
License: CC-BY-NC.

things into utilitarian products. The transformation of waste into a beautiful product is always an eye opener for students, getting them to think more carefully before discarding anything!

Conclusion

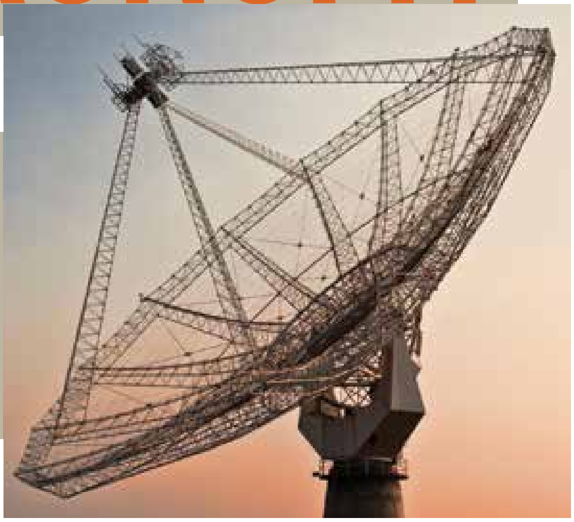
Many other art forms – ranging from literature, poetry and music, to dance, sculpture and theatre are embedded in Indian culture, and can be used as a means to help children develop awareness and a sense of connection to 'nature'. For example, even the performing arts can be a great form of teaching, with students encouraged to take on the role of raising awareness about the necessity of nature conservation to other, children and adult, audiences. Art allows us to reach out to even some of the most underprivileged and marginalized communities, when all other forms of communication with them fail.

Using art to teach ecology, however, requires us, as teachers, to develop a certain sensitivity, playfulness and creativity. This article only explores 'some' ways in which art can make the process of teaching and learning about nature more enjoyable. I hope that it encourages you to use art more often and more creatively in your classrooms!

Fig. 7. Holders made out of discarded water and shampoo bottles. These were decorated with sketches of animals that people are often scared of or think of as bad omens.

Abhisheka Krishnagopal is an ecologist, artist (visual and performing) and nature educator. She uses her experience in field ecology and the medium of art to create awareness about nature conservation. She also has several years of experience rehabilitating injured and abandoned urban wildlife. Abhisheka can be contacted at: abhishekagopal@gmail.com.

RADIO ASTRONOMY AND THE GIANT METRE-WAVE RADIO TELESCOPE



JAYARAM N CHENGALUR

The cosmos is strange and beautiful, full of unanticipated objects. The only way to understand it is to observe it – in as many different ways as possible. In this article, we take a look at the wonders revealed upon observing radio emissions from celestial objects through the Giant Metrewave Radio Telescope (GMRT), near Pune, India.

More than two decades ago, one of Carl Sagan's science fiction novels, Contact, was made into a major Hollywood motion picture starring Jodie Foster as the protagonist, Dr. Eleanor "Ellie" Arroway. Based on the Search for Extra-terrestrial Intelligence (or SETI, as it is popularly known), Contact is the story of a determined astronomer managing, against heavy odds, to make radio contact with an extra-terrestrial civilisation. An abiding image from the movie is of Jodie Foster with a pair of headphones clamped to her ears, and a massive antenna array in the background, listening intently to this extra-terrestrial signal. For many people of that generation, this is likely to have been their first, and most likely only, exposure to radio astronomy. In some ways, however, what is more surprising is that the general public has some exposure to radio astronomy at all, let alone through a major Hollywood film.

Fig. 1. Jodie Foster as Dr. Eleanor Arroway in the film Contact. The radio telescope in the background is the Very Large Array in the USA. As described in greater detail in the article, radio astronomers don't usually "listen" to extra-terrestrial signals, with headphones or otherwise. Image adapted from a still from the film.

Radio astronomers form a small and esoteric community – the radio astronomy commission of the International Astronomy Union has only a few hundred members. In India, the numbers are smaller still, but there is at least one work of fiction featuring Indian radio astronomers – Manu Joseph's award winning novel, Serious Men. For a small community, radio astronomy has certainly received a disproportionate amount of representation in popular culture! This is caused, at least partly, by the allure of space exploration and the Search for Extra- terrestrial Intelligence. But what does radio astronomy have to do with the SETI? If you go by the small fraction of radio astronomers involved with SETI – very little. But in order to understand radio astronomy, exploring its connections with SETI is as good a place to start as any other.

Radio Astronomy and the Search for Extra-terrestrial Intelligence

Broadly speaking, radio astronomy involves the observation of radio-waves from celestial objects. Radio-waves are one kind of electromagnetic waves; the most familiar kind of electro-magnetic waves being light waves (see Box 1). All of us use radio-waves every day, even if we are not aware of it (see Box 2). But what is the connection between these waves and astronomy?

Astronomy has traditionally used visible light, because that is the only kind of electromagnetic wave that the human eye is sensitive to. Stars and other celestial objects, however, emit all kinds of electro-magnetic radiations – from gamma-rays to radio-waves. In principle, with instrumentation that is sensitive enough, one could study the sky at all of these wavelengths. Which, again, begs the question – why (on earth) would anyone want to do so? It turns out (as we will see below) that studying the universe only in light waves gives us a very limited understanding of all that is out there. Very much as in the story of the blind men and the elephant, one could come away with a completely wrong picture of the universe. To understand the universe in all its richness and variety, one has to observe it in as many different ways as one can. Which brings us to the next question – if it is necessary to observe the universe at all possible wavelengths, what is so special about radio astronomy?

Box 1: Electromagnetic waves are of many different kinds

These range from the metres-long radio-waves to the very short gamma rays. Visible light, the electro-magnetic wave that we are most familiar with, occupies only a small portion of the entire spectrum.

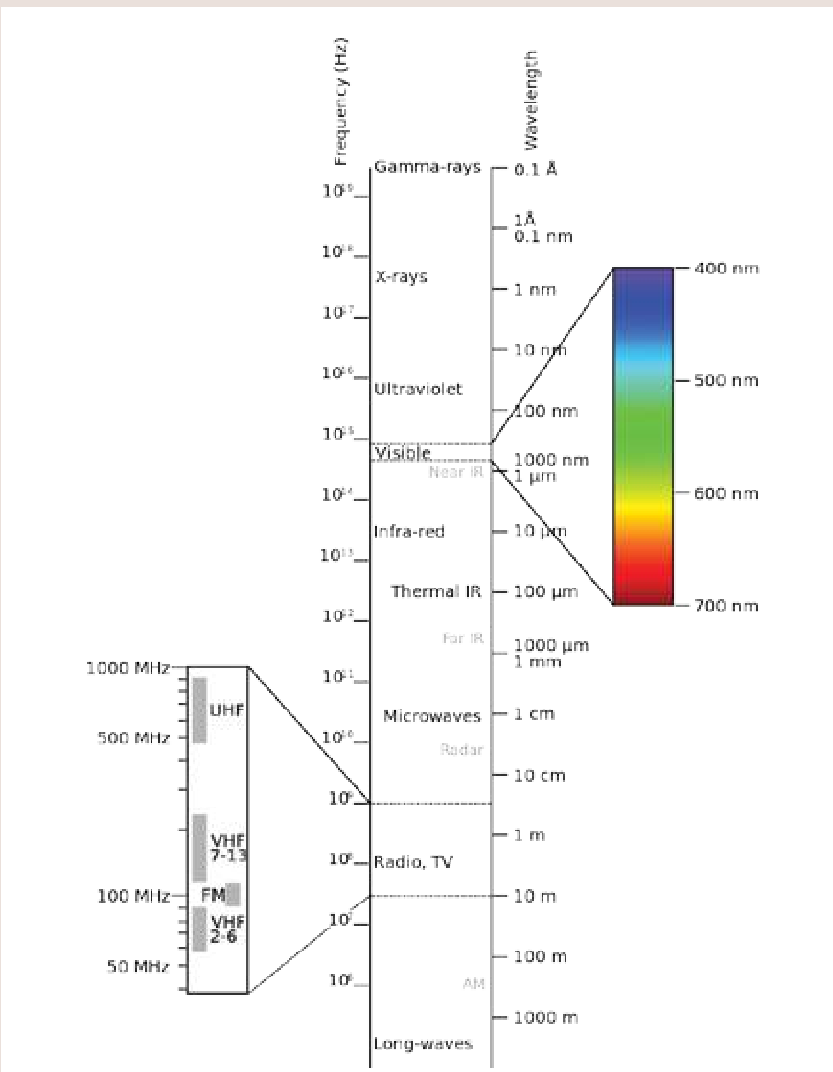


Fig. 2. The electro-magnetic spectrum. All electromagnetic waves travel at the speed of light, but the energy of each type of wave varies inversely with its wavelength. Thus, radio-waves with the longest wavelengths are the least energetic, while gamma-rays with their short wavelengths are the most energetic. X-rays, with relatively short wavelengths, are energetic enough to penetrate through skin and flesh, but not bones. This is why the bones in an X-ray image cast shadows on the photographic plate.

Source: Victor Blacus, Wikimedia Commons. URL: https://commons.wikimedia.org/wiki/File:Electromagnetic-Spectrum.svg. License: CC-BY-SA.

Box 2: We use radio-waves in our daily lives.

Radio-waves are used primarily for communication – from carrying FM radio signals (using waves with a wavelength of about 3m) and mobile phone signals (with waves of a wavelength of about 30cm), to TV signals (typically waves of a wavelength of about 50cm for ground-based TV stations to a few centimetres for satellite TV). Incidentally, microwave ovens also use radio-waves (with a wavelength of a few centimetres) to heat food.

One of the major advantages of using radio-waves to observe the sky stems from the fact that the Earth's atmosphere is transparent to these waves. This means that radio emissions from extra-terrestrial objects can reach telescopes built on the surface of the Earth. In contrast, other electro-magnetic waves, like X-rays, are absorbed before they reach the Earth's surface (see Fig. 3). This is a good thing for us because many of these rays are harmful to life. For astronomers, on the other hand, this is a mixed blessing – the Earth can host astronomers because energetic rays don't reach the Earth's surface; however, these same astronomers need fairly expensive satellites to realize just how lucky they are to have the protection of the atmosphere and ionosphere!

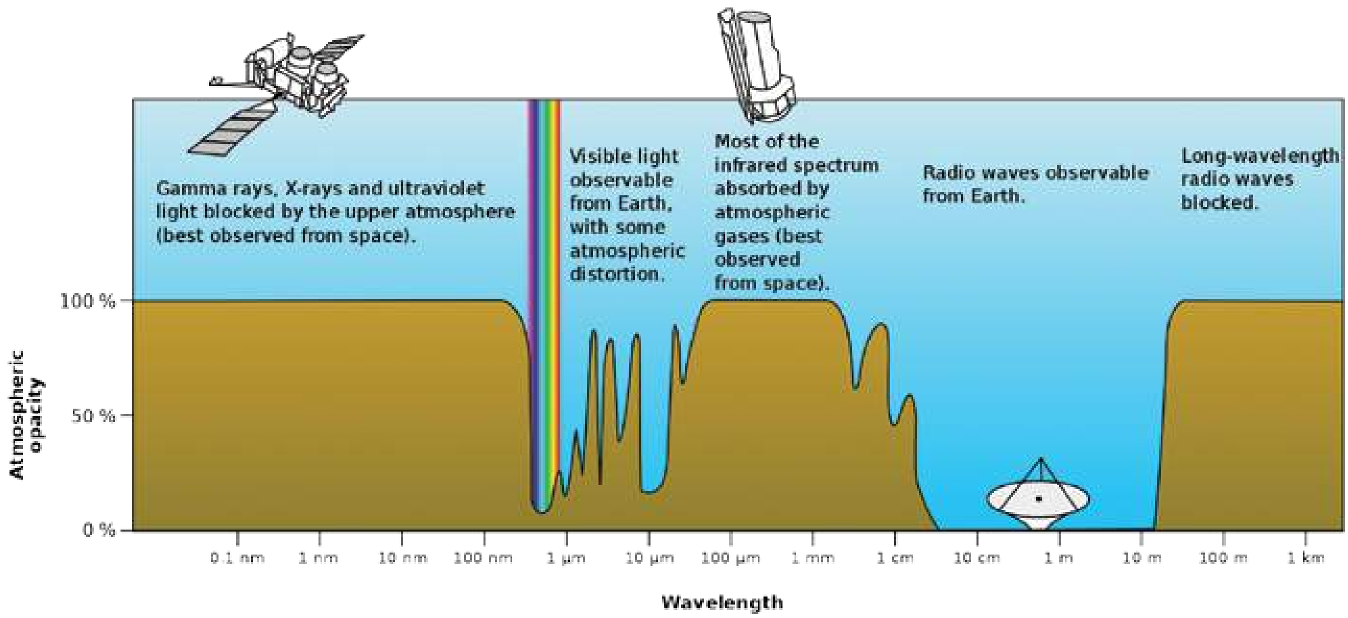


Fig. 3. Atmospheric opacity is a function of wavelength. The atmosphere (and ionosphere) is almost completely opaque in most parts of the electro-magnetic spectrum. It is only in the optical (i.e. ordinary visible light which human eyes are sensitive to) and radio (at which wavelength radio telescopes work) windows where the atmosphere is transparent. Since radiation from distant celestial sources does not reach the surface of the Earth at other wavelengths, they can be observed only by satellites launched into space. This is, in general, much more expensive than building a telescope on Earth.

Source: Mysid, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/Optical_window#/media/File:Atmospheric_electromagnetic_opacity.svg.
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It turns out that it's not just the Earth's atmosphere that is transparent to radio-waves; much of the galaxy is also transparent to radio-waves. The same cannot be said of light waves. The space between stars contains fine dust particles, which scatter and absorb light, but don't affect radio-waves. This means that radio-waves allow one to peer into regions of deep space which are completely opaque to star light. This is one of the major reasons why SETI uses radio-waves: they allow one to look for tell-tale signs of a technological civilisation in regions of the sky that no other tracer would allow one to probe. So, for example, if we were to try and eavesdrop on the internal communication in some other civilisations, our best chance of "hearing" something would be at radio wavelengths. Being the least energetic of the electromagnetic waves, radio-waves are also the cheapest forms of communication signals. This is another reason why SETI focuses on radio-waves. Indeed, long-distance communication on Earth really took off only after the discovery of radio-waves. It is not surprising, then, that communications engineering played a central role in establishing radio astronomy.

Radio communication and the birth of radio astronomy

During the 1930s, transatlantic communication using radio-waves was in its infancy. Companies involved in transatlantic communication were looking for ways to identify different sources of noise ("static") picked up by radio receivers and, if possible, eliminate them. The Bell telephone company, a pioneer in this field, assigned the job of characterizing noise in radio communications to one of its engineers, Karl Jansky. Janksy turned out to be an extremely systematic observer, and through careful, painstaking effort, he classified the noise he was receiving into 3 different categories: (i) static generated by nearby thunderstorms; (ii) static generated by distant thunderstorms; and, (iii) static of unknown origin. From a careful follow-up, he discovered that the third class of static had a periodicity of 23 hours and 56 minutes – the time taken for the Earth to complete one rotation. This indicated that its source was far, far away from the solar system (see Box 3). More careful observations, and comparison with what is known from optical observations, allowed Jansky to determine that the radio-waves he was receiving were strongest in the direction towards the centre of the galaxy.

Box 3: The Earth takes a little less than a day to complete one rotation.

We are used to thinking of a day as being 24 hours long, and regarding this as the time taken for the Earth to complete one rotation. But, in addition to rotating around its axis; the Earth is also revolving around the Sun. Thus, strictly speaking, a day (or, more accurately, a solar day) is defined as the time period between one mid-day (i.e. the time at which the Sun is at its maximum height from the horizon) and the next. This takes slightly more time (about 4 minutes) than that required for one rotation (see Fig.4). A periodicity of 23 hours and 56 minutes (called a sidereal day) is, hence, characteristic for stars and other distant celestial objects.

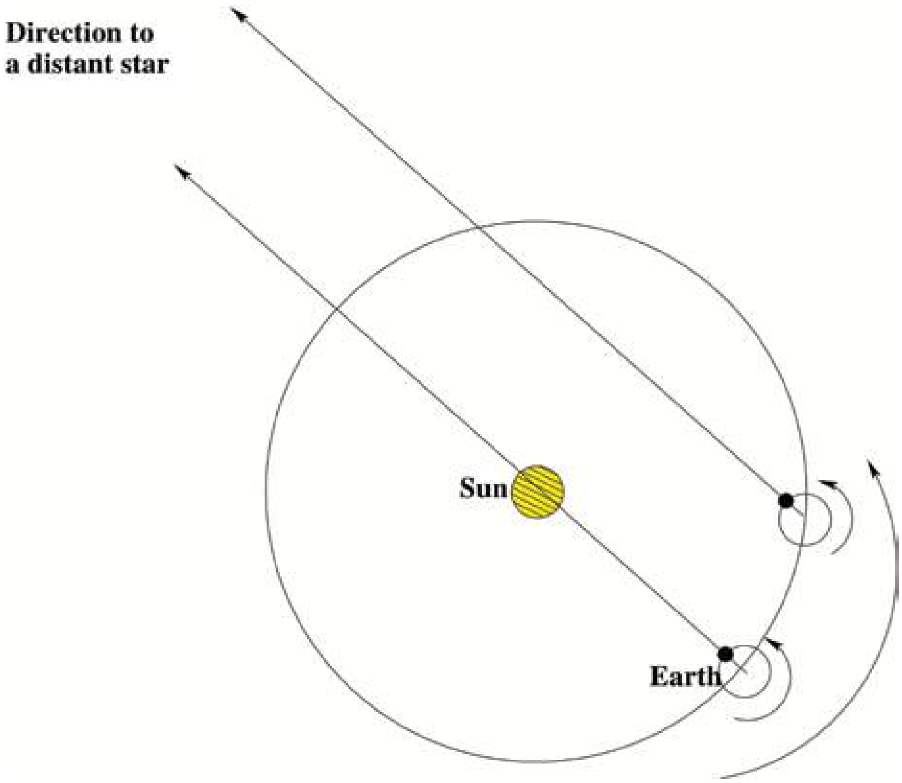

Fig. 4. The Earth is both rotating around its own axis and revolving around the Sun.

One can see that at each of the two instants of time indicated, the Earth has completed one full rotation (since the location marked is pointing, again, to the original direction). While the direction at the first time instant is towards the Sun, this is no longer the case in the second time instant. This difference is because, by the second time instant, the Earth has moved in its orbit around the Sun and would have to rotate a little more to reach a position where the Sun is directly overhead. A solar day is, therefore, slightly longer than the rotation period of the Earth. This phenomenon allows one to distinguish between emissions coming from distant objects (which will have a periodicity equal to that of the rotation of the Earth, viz. 23 hours, 56minutes) to that coming from nearer objects.

Credits: Jayaram N Chengalur.

This was the first detection of radio-waves from an extra-terrestrial object, and received a lot of public attention, including front page coverage in the New York Times and other newspapers. However, it was several years before professional astronomers paid attention to this discovery partly because the technology required for radio astronomy was completely different from that used by optical astronomers. For the optical community to retrain themselves to become radio astronomers would have required a huge effort (in fact, the divide between optical and radio astronomers persists to this day, with radio astronomy remaining a highly specialized sub-field of astronomy). But, this was also partly because Jansky's discovery came during the Great Depression in the US, when funding for new and risky initiatives was difficult to find. During the Second World War, however, there was a sudden explosion in the development of radio technology, driven primarily by the need to have powerful radar defence systems. After the war, some of these radar facilities were used by radio engineers for astronomy. This quickly led to the discovery that the Sun was one of the brightest sources of celestial radio-waves, and that the sky is, in fact, full of radio sources.

Unveiling the cosmos – what do Radio Telescopes "see"?

The most striking thing about the night sky is the tapestry of stars scattered across it. This coupled with the fact that the Sun is a strong source of radio-waves, suggested the possibility that these new observations were detecting some kind of stars, referred to as radio-stars. But, it turns out that radio emissions from stars are very, very faint (see Box 4); and almost none of the sources detected in these early observations correspond to that of stars known to us. If not stars, then what were these objects that radio telescopes were discovering?

The answer to this question remained unclear for a long time. Early radio telescopes had very poor angular resolution (see Box 7), making it very difficult to cross identify radio sources with sources seen in optical images. In 1962, however, the precise location of one of the brightest radio sources, called 3C273, was determined using radio observations from the Parkes radio telescope. The Parkes radio telescope, like all other telescopes of that era, had fairly poor resolution. But, it turns out that 3C273 is occasionally eclipsed (or, occulted) by the moon. Careful observations of the way in which the radio brightness of 3C273 changed during the eclipse allowed astronomers

Box 4: Stellar radio emissions are much fainter than those from the Sun.

This difference is related to our distance from the Sun versus that from other stars. The nearest star is almost 300,000 times further away from us than the Sun, which means that if it was intrinsically as luminous as the Sun in radio-waves, it would appear to be about a ninety billion times less bright. This was too faint for the early radio telescopes to detect.

to determine the precise time at which the edge of the moon had just crossed the source. This allowed identification of the source of the mysterious radio-waves from archival optical images. Surprisingly, the source appeared to be a fairly nondescript star-like object. So, were radio-telescopes discovering some kind of stars after all?

To answer this question, an astronomer named Marteen Schmidt observed the spectrum (see Box 5) of the star-like 3C273. The type of spectrum a star produces helps determine its composition. For example, the Sun's spectrum has a characteristic sharp colour (called a spectral line) arising from the element Helium (which gets its name from being first identified from observations of the solar spectrum). The spectrum of 3C273 also had several spectral lines, but of wavelengths that did not match with those expected for any of the elements known to us.

Box 5: Luminous objects can be identified by the kind of spectrum they produce.

White light consists of a blend of different coloured lights, which one can see by breaking it up into its constituent colours (as you may have noticed while handling a CD or DVD) using a prism. This decomposition of light into its constituent colours (or wavelengths, since light of different colours corresponds to light of different wavelengths) is called a spectrum. The spectrum of a luminous object carries information about its composition. For example, the different colours that one sees in fireworks arise from the different elements that are mixed into its powder, with each element emitting light of a different wavelength.

Puzzling over this, Marteen Schmidt suddenly realized that the lines did indeed correspond to those of the known elements, but they had all been shifted to wavelengths that were longer by 15.8%! Such shifts of light from celestial sources towards longer wavelengths (called redshifts) had been observed for several decades by then, and were understood to arise from the expansion of the universe. It was only because the shift in wavelengths in the 3C273 spectrum was so enormous compared to all other redshifts observed before that it took some time for its spectral lines to be recognized as those from a redshifted system. This was, by far, the most distant object discovered till 1962 and, therefore, also one of the most luminous objects known to us. It was, in fact, enormously more luminous than any known star. We now know that 3C273 is not a star; but a black hole – with a mass that is billions of times more than that of the Sun! Matter swirling around a black hole gets heated up to enormous temperatures before it is swallowed, producing bright jets shot out at speeds close to that of light. It is the material in these jets that produce the radio emissions detected by telescopes. So, radio astronomers had found a completely new kind of object, now called by the generic name of radio-galaxies. This is just one example of how observing the universe at a different wavelength can lead to startling new discoveries. This has, indeed, turned out to frequently be the case, with the opening of new observational windows generally leading to the discovery of strange new objects.

Box 6: Shifts in wavelengths from celestial sources arise from the expansion of the universe.

As the universe expands, wavelengths of light emitted by distant sources also expand along with it. So, what you finally receive on Earth is a longer wavelength that what was originally emitted. This is referred to as a redshift, since it involves a shift towards longer wavelengths or reddish colours in the electromagnetic spectrum.

Super massive black holes at the heart of radio galaxies are not the only new objects discovered by radio astronomy. Early discoveries also included pulsars (objects with a density similar to that of atomic nuclei, but with radii of a few kilometres, and masses similar to that of the Sun) and the Cosmic Microwave Background Radiations (relic radiations left over from the time after the Big Bang when the universe cooled sufficiently for electrons and protons to combine together to form neutral atoms). The diffuse gas that is found between stars is also a strong emitter of radio-waves. In general, optical telescopes show us where stars are, while radio telescopes show us the distribution of this gas. These can be quite different (see Fig. 5), once again driving home the point that one needs multiple kinds of observations to fully understand the world around us.

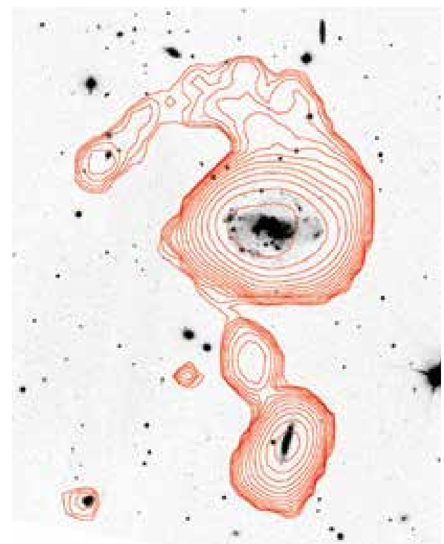

Fig. 5. Optical and radio telescopes show us different aspects of the universe

The black and white image is an optical (i.e. visible light) image. Stars are bright in visible light, so what one sees in this image is the location of stars in two nearby galaxies. The image has been inverted (like a film negative) so darker regions in the image are actually brighter. In visible light, these two galaxies look fairly regular, and don't seem to be interacting with each other. In contrast, the super-imposed red lines are from an image made at radio wavelengths using the GMRT. The red lines, showing the concentration of (Hydrogen) gas arund these galaxies, tell us a very different story. In addition to being concentrated around each galaxy, the gas also forms a bridge joining the two galaxies, and a long tail pulled out of the larger galaxy. This indicates that the two galaxies are clearly interacting, and are likely to merge in the future (see for example, the article "Interactions in Outer Space", by Anand Narayanan, in the June 2016 issue of **i wonder....**

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The Giant Metre-wave Radio Telescope (GMRT)

The 1960s – India joins the Radio Astronomy Club

Built in the late 1960s, the Ooty Radio Telescope (ORT), located in the hills near Udhgamandalam, is India's first major radio telescope. This cylindrical telescope is 530m long and 30m wide. It was designed and constructed by a group led by Prof. Govind Swarup of the Tata Institute of Fundamental Research (TIFR), Mumbai.

The ORT has been used for a number of influential studies, including determinations of radio source sizes using lunar occultation, observations of spectral line emissions from ionized gas in our galaxy, and measurements of the propagation of energetic plasma emitted by the sun. These last type of observations (generically called studies of "space weather") are growing increasingly important in an era where much of our communications depends on satellites, and can be badly disrupted by energetic solar events. Despite being over 30 years old, the ORT remains one of the most sensitive telescopes in the world at the frequencies at which it operates. The experience of building, maintaining, and using the ORT has also led to the growth of a healthy radio astronomy community in India.

The 1990s and A Seriously Big Telescope

In the mid-1980s, it began to become clear that the ORT, while still a sensitive telescope, was not as versatile as the next generation of radio telescopes, such as the Very Large Array (VLA) in the US, or the Australia Telescope Compact Array (ATCA) in Australia. TIFR's radio astronomy group at Ooty, again headed by Prof. Govind Swarup, began work on the design of a much larger radio telescope, called the Giant Metrewave Radio Telescope (or GMRT).

Large telescopes are quite expensive to build, and as a consequence, very few countries in the world invest in building them. Optical telescopes face the additional problem of requiring a site that has to be dark, at a high altitude, and as free from rain as possible. There are very few locations on Earth which satisfy these criteria, exceptions being Mauna Kea in Hawaii, and the high mountains in Chile. Consequently, many countries end up building optical telescopes at these sites.

Radio telescopes (particularly those working at longer wavelengths), on the other hand, need not be located at such high altitudes, and can thus be constructed at many more parts of the world. The main criterion in choosing a site for a radio-telescope is to ensure that it is protected from man-made interference (such as, mobile phones and towers, TV and radio stations, etc). The TIFR group identified a number of such sites in India, including one near Khodad village, about 80 kilometres from Pune. The site was near enough to a major city (Pune) to have access to a manufacturing base to support the construction of a large telescope. At the same time, the proposed site was far enough (and also protected by encircling hills), to shield it from the interference produced by the industry, TV and radio in Pune and Mumbai. The cost of this facility, however, remained a challenge.

Frugal Engineering and the "SMART" design

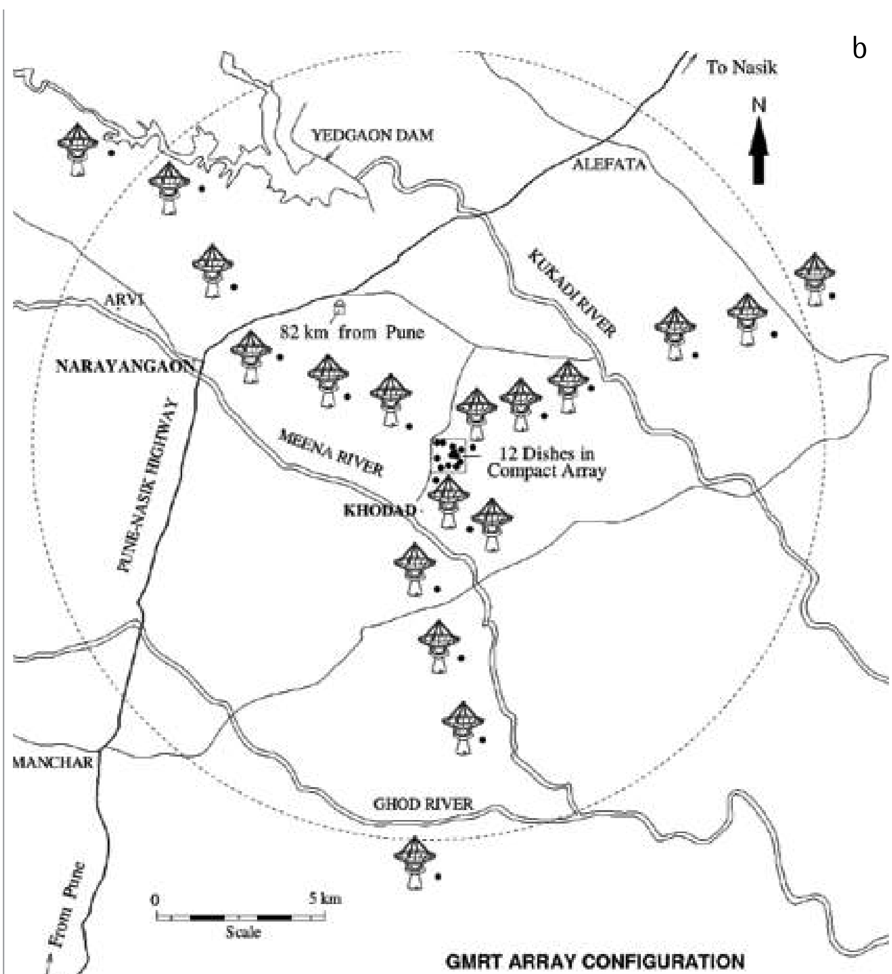
The problem of cost was finally resolved by an innovative design proposal from Prof. Govind Swarup to build a much cheaper type of antenna than has traditionally been used for radio astronomy.

Most radio-telescopes, even newer ones like the VLA and ATCA mentioned before, work at short radio wavelengths that require expensive solid reflecting surfaces. However, since the Indian radio-astronomy group has been working largely at long radio frequencies, it made sense to build a large long-wavelength radio telescope that would also occupy a unique global niche. Prof. Swarup's design proposal took advantage of precisely this difference. It was based on the fact that imperfections in a mirror that are smaller than its wavelength of operation have a negligible effect on its performance. For example, rough rock cliffs echo sound (which has a long wavelength) very well, but do not reflect light (which has a shorter wavelength) at all. So, long-wavelength radio telescopes did not need the finely polished reflecting surfaces that would be needed at short wavelengths.

The quality of the reflecting surface in a radio telescope has a multiplicative effect on its cost. Smooth surfaces require material that can be finely shaped and polished, which means that they are generally solid. These are preferred in cold countries, where these surfaces would need to be able to withstand the significant load of snow in winters. This translates into a need to have strong back-up structures to support the reflecting telescope, and hence a huge cost. At low frequencies, and at a sub-tropical location like Pune, all of these considerations become irrelevant. Prof. Swarup conceived a design where the reflecting surface was a simple wire mesh, worked into a parabolic shape by connecting thousands of wires to a light back-up structure, with each wire tensed by just the right amount so that the entire mesh takes the shape that one wants. He dubbed this new design SMART, for Stretched Mesh Attached to Rope Trusses. The SMART design led to a dramatic decrease in cost, allowing one to think of building a large telescope for a relatively modest amount of money.

The GMRT was a bold step forward for TIFR's radio astronomy group, and promised to place India at the forefront of radio astronomy research. Constructed through the nineties, the GMRT was dedicated to the nation in 2001, by Shri Ratan Tata. The design and construction of the telescope is entirely indigenous, with most of its systems being designed in-house at TIFR's National Centre for Radio Astrophysics (which was established specifically in the context of the GMRT), and some of the sub-systems being designed and

LOCATIONS OF GMRT ANTENNAS (30 dishes)



built by the Raman Research Institute (RRI), Bangalore.

The telescope consists of 30 separate antennas – each of which is a parabolic dish, 45m in diameter. The 30 dishes of the GMRT are spread over an area 25km in diameter. The antennas are all connected together by optical fibre, and operate in unison, to produce images with a resolution of a telescope 25km across (see Fig.6). The signals from these antennas are combined by a technique that is generally called interferometry or aperture synthesis (see Box 7). The GMRT is one of the largest operational interferometric arrays in the world, and India is one of a handful of countries operating such a facility. Like other such facilities, like the VLA and ATCA (operated by the USA and Australia respectively), allocation of observing time at the GMRT is independent of the nationality of the proposer. All proposals go through a process of international peer review, and the highest ranked ones are allocated time. The GMRT runs about a hundred different projects every year, observing a variety of objects, ranging from planets in our solar system to emissions from diffuse gas in very distant parts of the universe. Over the last several years, about half of all of the observing time at the GMRT has ended up being allocated to astronomers from India, while the other half goes to astronomers from across the world.

Fig. 6. Antennae of the Giant Metrewave Radio Telescope (GMRT) located at Khodad Village, near Pune. The GMRT is one of the largest radio interferometers in the world, and also one of the most sensitive telescopes at its wavelengths of operation. Spread across an area of 25km, its antennae operate synchronously to produce images with an angular resolution comparable to a mirror that is 25km in size. (a) A view of some of its antennae. The GMRT has 30 such antennae, each of which is 45m in diameter. (b) The location of the GMRT antennae. 12 dishes, arranged in a compact array, are located at Khodad village near Pune. The remaining antennae are spread along 3 roughly Y-shaped arms, each about 14km long. The antennae that are most far apart from each other are separated by a distance of about 25km.

Credits: B. Premkumar, NCRA-TIFR.

Box 7. Signals from the 30 antennae of the GMRT are combined through a process called Aperture Synthesis.

It may seem natural to think that a bigger telescope would be better than a smaller one. But in what specific ways is a bigger telescope better?

There are two different criteria by which we judge the performance of a telescope. The first is the ability to see fine details in a distant object (for example, can one distinguish between two nearby stars, or is the image so blurred that you can only see what looks like one?). This is called the resolution of the telescope. The second is the ability to detect faint objects. The further a source is, the fainter it appears, so this also translates into the ability to observe a radio source as it moves further and further away. This parameter is generally called the sensitivity of the telescope.

In parabolic telescopes, all the light that falls on the aperture is concentrated at the focus (see Fig. 7). Clearly, the larger the telescope, the more light it will gather, with the telescopes acting like a giant light bucket. It is easy to see that the larger the telescope, the more light it will gather, and the more sensitive it will be. What is less obvious is that larger telescopes also have better resolution. This happens through diffraction (observed for all kinds of waves), which causes the resolution of a telescope at a fixed wavelength to improve as its mirror size increases. Similarly, for a fixed size of reflector, the resolution improves as the wavelength decreases (a related phenomenon, which may be more familiar to readers is that blu-ray DVDs which work with shorter wavelength blue light can pack more information into the same geometric area as compared to normal DVDs).

The wavelength of optical light is about a million times smaller than that of the radio-waves to which the GMRT is sensitive to. To have a radio telescope with a resolution that matches that of an optical telescope a few centimetres in size, one would need to build a telescope that is tens of kilometres across – a formidable challenge! How do we build a telescope which has the resolution of a mirror that is tens of kilometres in size?

Let us step back and see what it is that a mirror does to the light that falls on it. As can be seen in Fig. 7, all the reflected light is concentrated at the focus. We could achieve the same effect by building a collection of small mirrors, collecting the radiation that is concentrated at each of their foci, and adding all of these signals together. This combined signal would be like one from a giant mirror (i.e. a mirror with a size equal to that of the largest separation between the small mirrors); except that this mirror is not complete, it has large holes in it. This is because light is collected only from the regions covered by the small mirrors, and the light falling on the regions in between (or the 'holes') is lost. So, a telescope formed by properly putting together the signals from a collection of small mirrors would have the resolution of a mirror with a size corresponding to the largest separation between the mirrors, but with a sensitivity corresponding to that of a mirror with an area equal to the sum of the areas of the smaller mirrors.

If we went one step further, we could look at what happens when we track a radio source from rise to set. From the point of view of this distant source, what is happening is that because of the Earth's rotation, these small mirrors are being carried around in space. Equivalently, these small mirrors sweep out large areas of the hypothetical large mirror as one observes a source from rise to set. The resultant mirror (i.e. the aperture that one has synthesized) is significantly closer to a perfect mirror than that obtained by a snapshot produced by individual small mirrors (see Fig. 8). This is what is called Earth rotation aperture synthesis, and is the technique that the GMRT and other such telescopes employ to take high resolution images of the sky.

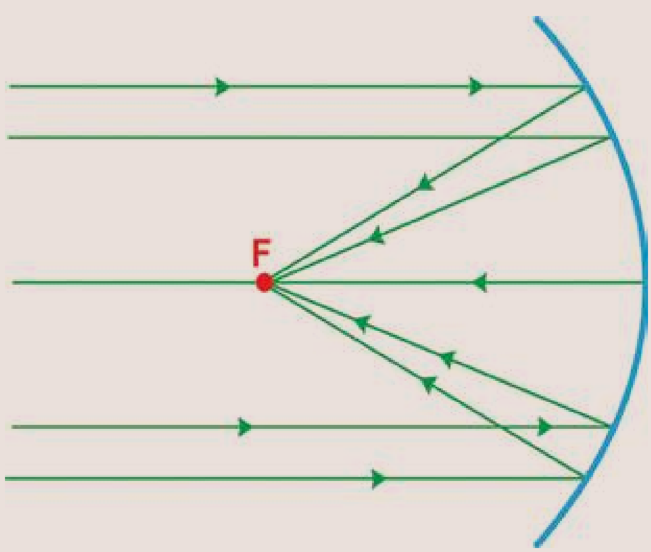


Fig. 7. Light rays falling on a parabolic mirror get concentrated at the focus. Parabolic mirrors act like light buckets, collecting all the energy falling on their surface, and concentrating it at their focal point. Clearly, larger telescopes will collect more light, or are more sensitive, capable of detecting fainter objects. It turns out that larger telescopes also have better resolution, or are better able to distinguish finer details in the source.

Credits: S. Meshra, NCRA-TIFR. License: CC-BY-NC.

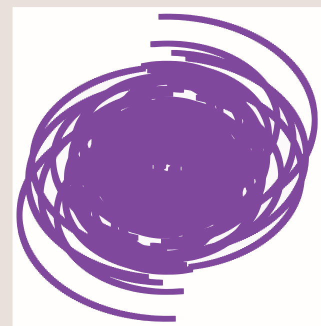


Fig. 8. The tracks traced out by the GMRT antennae in the central part of its array when following a source from rise to set. As can be seen from this image, even with a small number of antennae, the rotation of the Earth results in a fairly good coverage of the 'mirror' that one is trying to synthesize.

Credits: Jayaram N Chengalur. License: CC-BY-NC.

One issue that has been brushed under the carpet in this description is how exactly one 'combines' the signals of the small mirrors together to get the signal of a large mirror scanning the sky. This, unfortunately, is a highly detailed technical issue, and discussion of this would take us too far afield. However, one thing that is probably worth making clear is that it involves very sophisticated digital electronics and software algorithms – radio astronomers do not listen to the signals coming out of their telescopes using headphones!

Conclusion

Since the first instruments that came into service after World War II, radio telescopes have taken giant leaps. The most sensitive telescopes today, amongst which is the GMRT, have much greater sensitivities than those of the first generation of telescopes. Modern telescopes are extremely versatile. The GMRT, for example, has been used to search for a variety of emissions – from those of hydrogen that filled the universe 12 billion years ago (i.e. just before the first stars and black holes converted all of the intergalactic gas into a hot plasma) to those from other planets in the solar system. Three Nobel prizes have so far been awarded for discoveries made by radio astronomers. Although the radio astronomy community is small, it has clearly had a disproportionate impact on society, and not just via films and novels. Being a small community, it has also been relatively collaborative and forward-looking. Radio astronomers are one of the few research communities, for example, that allow free use of their telescopes. As described before, the GMRT can be used by anyone in the world whose proposal is judged to be good enough (by an international panel of experts). Similarly, Indian astronomers can use radio-telescopes built by other countries. In an environment of growing insularity and isolationism, radio astronomers provide not just a broader perspective with which to view our place in the universe, but also a practical example of the advantages of working together.

Note: Credits for the image used in the background of the article title: One of the antennae of GMRT telescope, Pune, India. Photographer: Rohit Gowaika. URL: https://www.flickr.com/photos/18419987@N00/3119728744. License: CC-BY-SA.

Further Reading and useful links:

1. A brief introduction to radio astronomy and SETI can be found at: http://www.bigear.org/guide.htm.
2. The Australia Telescope National Facility has some interesting material on radio astronomy and radio telescopes: http://www.atnf.csiro.au/outreach/education/everyone/radio-astronomy/index.html.
3. More about the GMRT at Pune can be found at: http://www.ncra.tifr.res.in/ncra/.
4. A very readable account of the discovery of pulsars can be found at: http://www-outreach.phy.cam.ac.uk/camphy/pulsars/pulsars_index.htm.
5. More about galactic interactions and mergers can be found in the article titled – Interactions in Outer Space, by Anand Narayan, **i wonder...**, Issue 2, June 2016, Page 4.
6. A popular account of radio astronomy can be found in the book, The Invisible Universe, by Gerrit Verschuur, Springer Publishing.

Jayaram N Chengalur is a radio astronomer working at the National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Mumbai. Trained as an engineer, he blundered into this field by accident, and stayed on because it seemed like fun.

WHY SCIENCE TEACHERS SHOULD CARE ABOUT SOCIAL JUSTICE

DAY GREENBERG

This article explores the need for social justice teaching in science education, and what it can accomplish, especially for students who come from communities that have been excluded from science learning and careers. It also presents important lessons learned from one case of science teaching for social justice.

"There is a need to prepare teachers and students for the new roles that they must play… Our vision of schooling, and by extension science education, is more aligned with participatory democracy where citizens actively collaborate… for future generations."
– Mike Mueller.

"I used to probably think, well I thought that, um, school wasn't that important, but then this program made me feel that I belonged in the school, that I made a change, so I had to go to school, cause it helped me and it helped the school, a lot."
– Fatima, an elementary student who did "action research" in school.

As our world continues to change along multiple dimensions – socially, politically, ecologically, medically, digitally, and economically – it is increasingly important for science teachers to provide students with the skills, knowledge, and opportunities to apply their learning to the world around them. They should seek to empower their students with the agency and tools to confidently meet challenges of the present and the future. Far too often, however, teachers assume that their students are not capable of accomplishing big things as young people. This is especially true for students who come from communities that have been excluded from mainstream science learning and careers (e.g., students who are members of immigrant or ethnic minority communities, and students from low-resource schools and neighborhoods).

What is social justice science education?

Social justice (oriented) science education involves using science knowledge and skills to make the world a fairer and more just place for everyone. Integrating social justice into their classroom practice offers teachers the tools they need to accomplish this goal.

Science teachers who work for social justice use their classroom practice as a tool of social, political, and academic empowerment for their students. Students learn to question existing systems of power – systems that oppress students and their communities. Science teachers empower students by

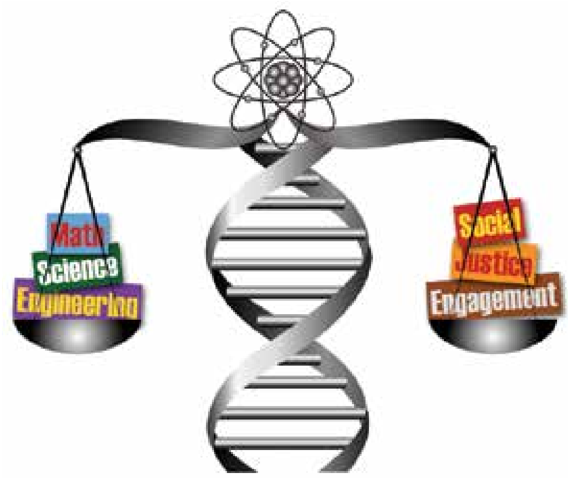


Fig. 1. Science and social justice – finding the balance!

making their science classroom a place where students can build skills and use knowledge in ways that mirror and/or speak back to what the real world already asks of them (and will continue to ask of them in the future). They show their students how to navigate socio-scientific issues and challenges – issues that involve science knowledge and practices, and critically question/examine related social factors. They also build spaces that encourage their students to make change for themselves and their world, in partnership with others. Ultimately, such students learn to use science as a tool to act for positive change and greater justice, in partnership with others. This can benefit science learning, because the shared desire to make a specific positive change as a class can motivate students to reach related science learning goals. Then, students can activate their ownership of content (not just absorption) to take action themselves and/or convince others in positions of power to create positive change. For example, students who live in a flood zone could work towards physics learning goals to inform a student-organized public communications campaign to educate local community members on how to design stronger flood control structures. In this example, relevant physics content (e.g., energy, force, speed, weight, etc.), can become more directly important and meaningful when students recognize it as a tool to inform and protect their families and friends.

What does the research say?

How can science teachers make science matter for their students? How can they provide students with the tools to become leaders who take educated and meaningful action with science?

Educational researcher Alexandra Schindel Dimick studied a case of high school environmental science teaching that was organized around the goal of community action for greater social justice. Her study focused on science teacher Mr. Carson, who introduced social justice actions into his high school environmental science curriculum. He discussed local environmental problems with students, and allowed them to form three separate working groups to address these problems. His students learned about pollutants in their local waterway and conducted lab experiments related to water chemistry. They then created posters to educate the public on science topics related to water. Finally, they completed group action projects to solve problems in their local waterfront environment.

In her observations on the work done by the students, and her interviews with some of them (9 from a total of 24 students in the class), Alexandra found that students felt an increased sense of power when their learning was directed towards social justice. Mr. Carson explained:

> *... [the students] are feeling empowered to change something that affects them and they're not depending on other people to make the change. They're the ones who are being affected; they're the ones that are trying to make the change.*

However, it should be noted that not all of Mr. Carson's students felt that the project was a complete success. Social justice science education must empower students socially, politically, and academically. Alexandra's study showed that the students noticed when one of these dimensions was missing, and they shared their disappointment in not receiving the support they needed to succeed as action-takers in science. It should also be noted that although Mr. Carson taught environmental science, **social justice action can be integrated into every type of science classroom.**

How can teachers become social justice science teachers?

What can we learn from this study about the successes and failures of implementing ideas of social justice in science classrooms? Here are three components that appear to be important to enact in order to successfully teach science for social justice:

Fig. 2. Participatory engagement in a classroom context.

Guide 1: Support Student Leadership and Collaboration (The Social Component)

Mr. Carson had students divide themselves up into three separate groups after they voted to narrow down their ideas for taking action. He did not, however, provide group members with any specific strategies or guidelines for making group decisions and sharing discussion time. As a result, group dynamics affected individual actions, decreasing speed and efficiency.

How to implement: Allow students to choose their own working groups based on the topic, but provide them with tools to navigate group dynamics. Give them opportunities to practice healthy teamwork and compromise, within a supportive structure of group social rules that students can agree on together. Have students create a social contract together that dictates how to behave in groups and how to resolve conflicts. Empower your students to work well together by helping them create shared expectations and the tools to solve problems themselves.

Recommended Articles to Learn More

1. Birmingham, D., & Calabrese Barton, A. (2014). Putting on a green carnival: Youth taking educated action on socioscientific issues. Journal of Research in Science Teaching, 51(3), 286–314. http://doi.org/10.1002/tea.21127
2. Vakil, S. (2014). A Critical Pedagogy Approach for Engaging Urban Youth in Mobile App Development in an After-School Program. Equity & Excellence in Education, 47(1), 31–45. http://doi.org/10.1080/10665684.2014.866869.

Guide 2: Prepare Students to Take Action (The Political Component)

Mr. Carson removed himself from classroom interactions after students formed groups. His students lacked the support they needed to transition from understanding action in terms of daily, personal responsibilities to understanding action in terms of larger, more transformative, active participation in change. As a result, some students came to a larger understanding of action with science themselves, but other students ended the project without knowing how to take further, larger, or more complex action for social justice with science.

How to implement: Be an active part of student interactions to make changes that matter to them and their community. Discuss the difference between individual action and collective action, and help students to critically question structures of power that cause pain to people or destruction to environmental systems. Help them discover the "root causes of problems" that often relate to social injustice but can also be better understood through scientific investigation. For example, science teachers could support their students in asking: How does a local school building's mold infestation relate to political debates on education budget proposals? How has genetics been used to marginalize existing populations? Who profits from the use of coal energy and mining? How have the contributions of women to computer science been neglected in histories of computing?

Fig. 3. The dove with an olive branch, a symbol of peace. Made from icons representative of science, flies against a word-cloud created from all the words in the Wikipedia page on "Social Justice." Credits: Photograph and Illustration by Punya Mishra, 2016.

Guide 3: Help Students Use Knowledge as a Tool (The Academic Component)

Student empowerment can align with teaching and learning science education when social justice is the goal and science knowledge and practice is the tool. In order for students to feel empowered with scientific knowledge, teachers must actively facilitate experiences and provide supportive resources and information. It is not enough to give students the opportunity to lead – science teachers must also arm students with the scientific skills and knowledge to take the action that they desire.

How to implement: Each component of this model is important, but teachers must use all three to support social justice actions with science knowledge.

Help students learn about the ways in which actions they want to take can be supported with science learning and practice. Once they have a big goal in mind, help students break that down into smaller, accessible goals and have them lead a discussion together about what scientific information and skills they need to learn in order to reach each smaller goal. As they achieve the small goals, continually check in with them to discuss how their step-by-step progress is bringing them closer to their larger goal of big change (at the same time, help them see and feel proud about how their collection of knowledge and skills is growing in size and depth).

Conclusion

Science teachers must offer their students the resources and support to combine social, political, and academic growth in order to take action for social justice with science. When Mr. Carson did not combine and equally address all three components, his students were disappointed. They described their socially and politically informed actions as not being supported enough with academic knowledge and connections to their classroom learning. When, however, all three aspects work together, the results are positive. As Janis, a 13-year-old student in another social justice science teaching project explained:

"We know what we are doing.
We know how to make a difference.
We know how to save energy and how to convince other people of better ways to do things with electricity. That is one way that we are experts."

Teachers should empower their students with science, in ways that provide students with the tools to solve real problems that affect them and the people and surroundings they love and depend on. This requires more than simply giving student's permission to be powerful actors. It requires supporting students as they work to complete each step along the way towards addressing bigger and more complex issues, with scientific, social, and political knowledge and tools.

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URL: https://commons.wikimedia.org/wiki/File:Cudrefin-justice.jpg. License: CC-BY-SA.

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1. Calabrese Barton, A., Birmingham, D., Sato, T., Tan, E., & Calabrese Barton, S. (2013). Youth As Community Science Experts in Green Energy Technology. After school Matters. Retrieved from http://eric.ed.gov/?id=EJ1016811.
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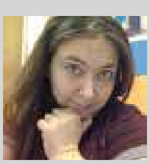

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A WEEK IN MY LIFE

AFTAAB DEWAN

When I introduce myself as a researcher, people often ask me "what do you do as a researcher?" With research being an open-ended endeavour, this is often not an easy question to answer. For example, over the last week, I have made some calculations, aligned a new laser path in the laboratory I work in, been involved in troubleshooting problems in an electronic system, and read academic papers by other researchers to keep abreast of the latest happenings in my field. However, none of these truly answer the question 'what I do'.

Let's take the first of those: the calculations. One part of my work involves the capture of atoms in a magnetic trap. You could think of a magnetic trap as being something like a porcelain bowl holding atoms, except that instead of porcelain, the bowl's made of magnetic field lines. These magnetic field lines are often generated using two circular electrical coils (loops of wire) that are held apart at a fixed distance from each other. Calculating the magnetic field in any part of the bowl is a rather difficult task, but it is easier to compute in the part nearest the atoms – which is at the centre of the bowl. I made this calculation mostly to help me understand what a typical magnetic trap looks like.

The primary tools we use in our labs are lasers. These laser beams are used to trap, probe and manipulate atoms according to the requirements of our experiments. My lab's recently acquired a new laser system, which needs to be aligned accurately to ensure that its beams hit atoms at the precise spot that we want them to. Since both the size of a laser beam and a cloud of atoms is less than a tenth of a millimetre, reaching this alignment is a delicate process. My work this week involved aligning this new laser system using two different mirrors, one to point the beam at the right spot, and the other to align the pointing of the beam.

Working with electronic systems is almost a requirement for an experimental physicist. For example, our experiments involve the use of lasers that are beamed at specific frequencies. These frequencies are stabilised using lock boxes. While we only need one lockbox to run our experiments, it's always handy to have a couple of spare ones. Since we routinely use about six to ten laser frequencies in our lab you can see why we need a lot of lockboxes. So, when we recently acquired a couple of new lock boxes and found that they were not functioning properly, I spent some time diagnosing the problem and fixing them.

What is a laser beam?

A laser beam is a highly focused and collimated beam of light. It can travel a long distance without changing its shape.

I should probably explain what exactly I mean by 'locking' a laser, or in more general terms, locking a signal. Imagine you have a laser beam and you would like to use it at a particular power or frequency – for example, I may want to use the beam at a constant output of 500 mW at a particular point. The actual power of the laser beam I use in my experiment may vary for a variety of reasons, including changes in temperature or humidity, mechanical vibrations, air currents etc. And these variations can change the power of my laser beam by as much as 10-20%. How do I ensure that the laser beam remains at the exact power/frequency that I require it to be? I do this by locking the laser at that power. To do this, I measure the power of the laser signal at its intended destination. Let's call this signal A, and compare it with the signal I want, call it signal B (=500mW in this case). What a lockbox does is that it feeds a signal (let's call this the lock signal, or L) to a laser controller that changes the

What is a Bose-Einstein Condensate?

We are all taught about matter existing in three states: solid, liquid and gas. For most of our lived experience, knowing just three phases is sufficient. However, in physics, matter may (and indeed does) have many more states (or more properly written as phases). A Bose Einstein Condensate is one such phase of matter that occurs when particles of a particular type (i.e. bosons) get cold enough to all condense to the same quantum state. What is important to remember is that this phase is a configuration that is energetically most favourable to the condensing particles, given the environment.

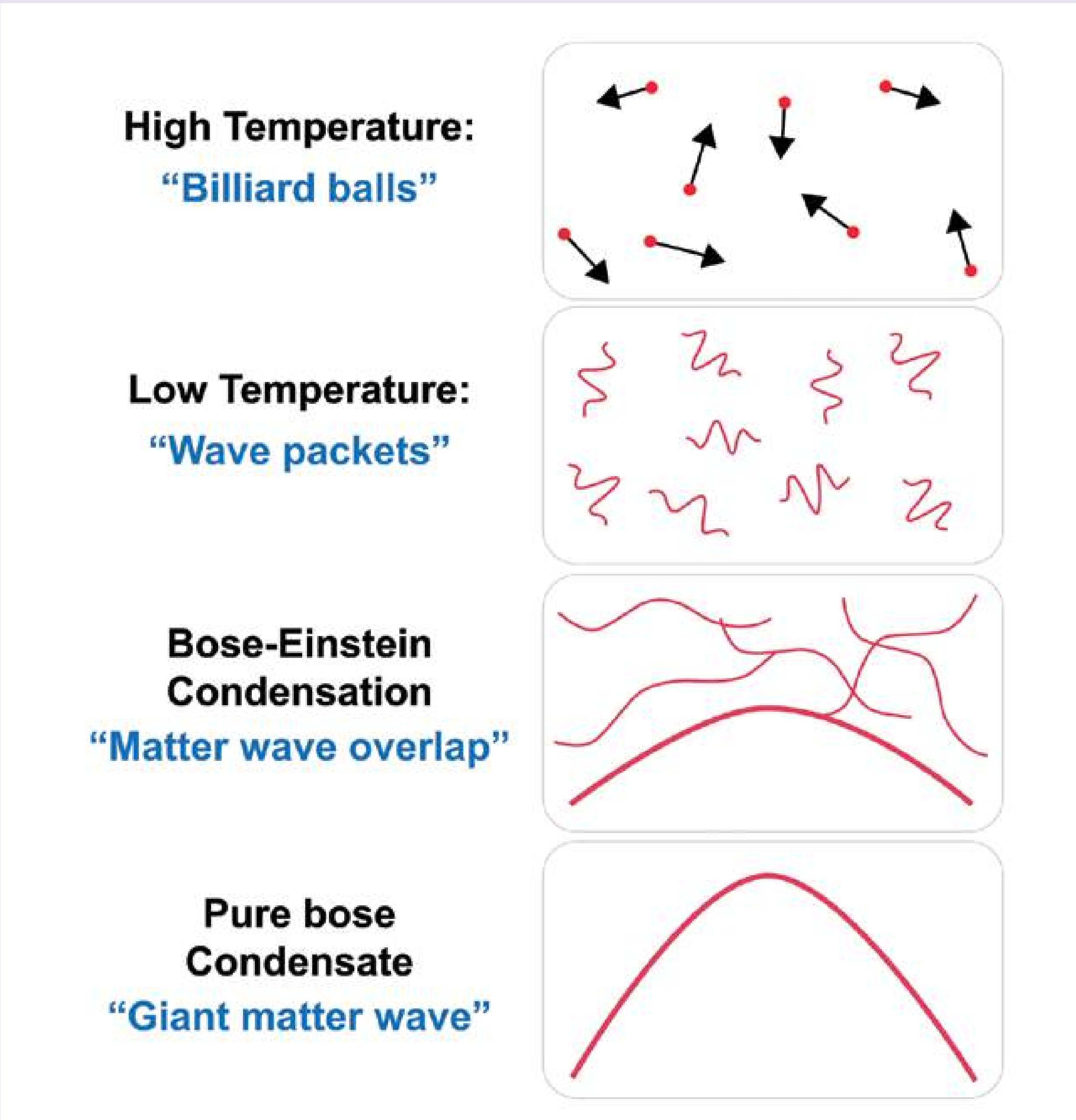

Fig.1. Recipe for a BEC. What makes a BEC particularly interesting as a phase is that it is a really good example of a macroscopic quantum state. Therefore, by manipulating a BEC, we are actually manipulating a particular macroscopic state; in ways that are specific to the nature of phenomena we are interested in investigating.

Credits: Adapted from image used in Experimental studies of Bose-Einstein condensation, by Dallin S. Durfee and Wolfgang Ketterle, in Opt. Express 2, 299-313 (1998).

power of the laser in real time. When we tell the lockbox to lock a signal at a particular power, it tries to make signal A as close as possible to signal B by changing signal L, and it does all of this incredibly quickly, over the course of a few microseconds. This is what keeps the laser power/frequency from changing during an experiment. More generally, this can be used to lock any signal to a particular value with a high degree of precision.

Behind all these different tasks is a larger goal, one that leads to the research project I am part of. The goal of this project is to use all the tools I have just described to cool atoms to extremely low temperatures of about -273°C or almost 0 K and explore their behaviour at these low temperatures. However, getting this near 0 K is not a small feat in itself and requires multiple steps that have to all work together in conjunction. The atoms we use are from an isotope of Rubidium, Rubidium 87. A block of this rubidium isotope is converted to its gaseous form by baking it in an oven. The gas produced contains atoms that are very hot and, therefore, move extremely fast. To capture and hold these atoms in a magnetic trap, they need to be cooled down, and the way to cool them is to make them go as slow as possible. We do this in a series of steps. The first step is to use a laser beam propagating in the opposite direction of their travel. The collisions between the atoms and the photons that constitute the laser slow down the atoms to a velocity where they can be held in magnetic trap. This is much like trying to run headlong into the wind or a stream of water – the frictional force will slow you down. Once the atoms are in a magnetic trap, we use a a magnetic field and a combination of lasers to slow them down to about 400 mK. The principle of this step is the same as the first one, with the only difference being that it brings the temperature of the atoms down to a much higher degree. Once this is completed, the atoms are transferred to an optical trap, where they are held in place by a pair of laser beams. The final step in this process involves exposing the atoms in the optical trap to evaporation which allows the higher energy atoms to leave the trap. With a lot of fine-tuning, one can eventually obtain a Bose-Einstein condensation, or a BEC for short. A BEC is a new phase of matter, where whole groups of atoms behave like a single entity. This means that in this phase, there is no way to distinguish between the 100,000 or so individual atoms that make up the condensate – they all appear the same. This happens because, in some sense, they all occupy the same space. And since they are all atoms of the rubidium isotope, it becomes impossible to tell them apart if they are all in the same space.

The physical phenomena we are currently investigating in our lab is how a stack of these BECs behave in different scenarios. To explain this in simpler terms, imagine the BEC to be a giant watermelon that we slice vertically into many different pancakes. We then investigate what happens when we move the different pancakes apart, twist them a little bit, and bring them back together. Do they still form a watermelon? Or do they form something different?

But this is not all. After we are done with this experiment, we can do another, looking at something completely different. Over time, the cumulative results of these experiments, gradually contribute to an increase in our knowledge of the natural world and, therefore, to the greater project of human knowledge. This is what our research is about, but doing it requires wearing multiple hats. This is also why there is no easy answer to the question 'what do you do?' The answer is often – many different things!

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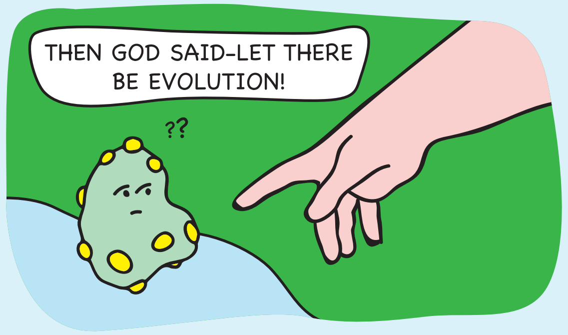
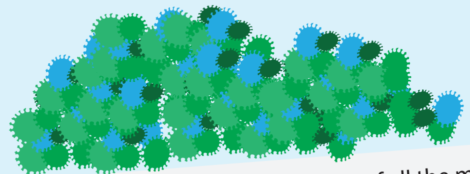
Ten Things You Didn't Know About **Ocean Microbes**

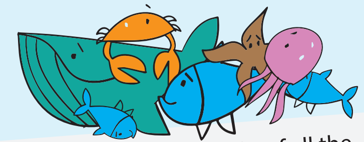
Author: Mahira Kakajiwala

Millions Of Microbes In The Sea, Too Small For Us To See!



1. It is most likely that life originated in the oceans about 3.5 billion years ago. And marine microbes accounted for all known life forms for nearly 50 to 90% of Earth's history! Since they emerged, ocean microbes have continuously changed the environmental conditions on earth, greatly influencing the development of all other forms of life.

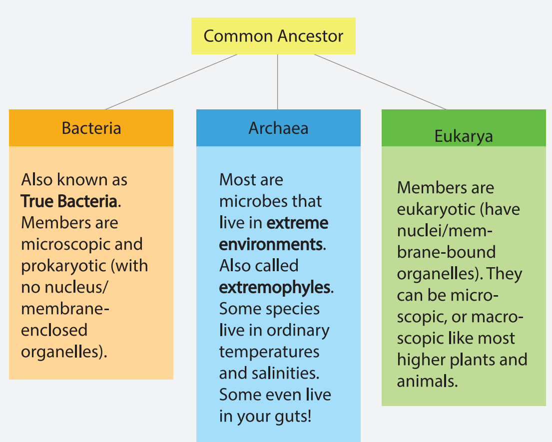




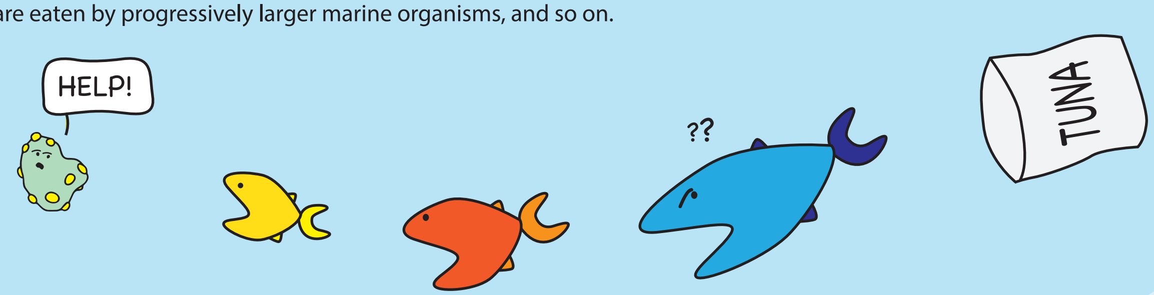
2. If you were to add up the weights of all the marine microbes, it would be way more than the combined weight of all the mammals, sharks, fish and other life-forms in the ocean. In fact, estimates suggest that sea water contains up to 1,00,000 microorganisms per millilitre. In other words, there are more marine microbes in the oceans than there are people living on earth!

3. Microbes are found in every kind of marine environment possible – from the open ocean to the shores; from the equator to the poles; in the ice-covered polar regions of the Arctic and Antarctic to the boiling hydrothermal vents in the depths of the sea. They can be found as plankton (free-floating organisms) at the surface, as symbionts in corals, on the outer surface of marine organisms, or even in the sediments at the bottom of the sea!

4. Marine microbes are a very diverse group! They consist predominantly of bacteria and archaea, but also include microbial eukaryotes and viruses (which some don't even consider as being alive and hence won't be found in the tree of life).

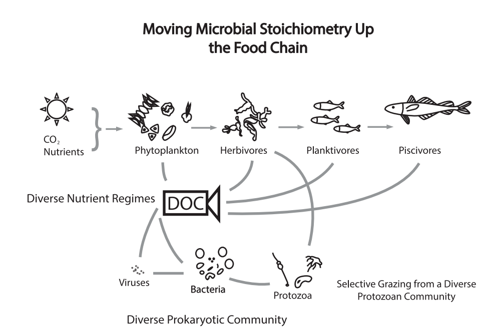


5. Marine microbes – whether, autotrophic, chemotrophic or hetero-trophic – can be said to form the bottom of the oceanic food chain! They get eaten by zooplanktons (free-floating animals) which are eaten by small fish that are eaten by progressively larger marine organisms, and so on.



6. Autotrophic microbes or phytoplanktons are like land plants – they rely on the process of photosynthesis to live and grow. In fact, half of the primary production on Earth occurs in the ocean, and half of this oceanic production is carried out solely by autotrophic marine bacteria! This also means that the autotrophic bacteria and single-celled algae in oceans together produce as much oxygen as that produced by all the land plants combined!

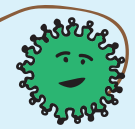
Diatoms (single-celled algae) and cyanobacteria (procholorococus and syenoschoccus) are responsible for the production of half the oxygen we breathe!



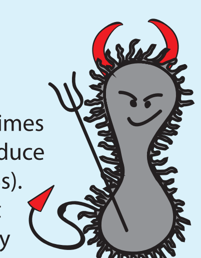
8. Heterotrophic marine microbes are unable to make their own food. Some live in symbiotic association with coral polyps. Still others, such as viruses, are parasitic on a wide variety of hosts to get the food and energy they need to grow and reproduce. Free-living heterotrophic bacteria play a vital role in carbon cycling in the ocean through what is known as the microbial loop. These bacteria are the only organisms capable of using dissolved organic carbon (DOC), which was once part of living organisms, as a food source. This organic matter is then passed up the food chain, even as other, larger, organisms excrete waste and or die, making carbon and other nutrients available to these microbes again.

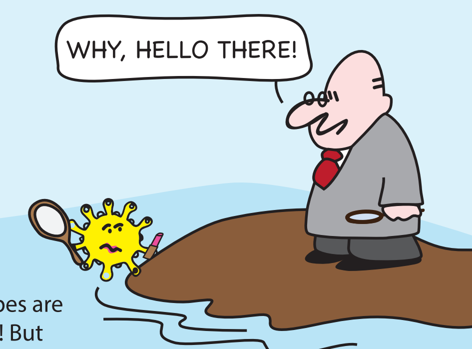
ENERGY

7. The deep seas have many chemotrophic marine microbes that do not need sunlight or oxygen to survive. Instead, they grow by capturing energy from a wide range of chemical processes, like the hydrogen sulfide emitted from oceanic vents. Using carbon from carbon dioxide, they act as a source of food for larger creatures – making these microbes the equivalent of primary producers at these deep, dark depths!



9. Most marine microbes are beneficial to us, but a small percentage can sometimes cause harm. For example, in highly polluted waters, marine microbes can reproduce rapidly thanks to their short life cycles resulting in harmful algal blooms (HABs). Because some algae produce toxins, they can be harmful to organisms that consume them. Even if they are not toxic, HABs can impact fish and plants by depleting the oxygen in the water and by blocking sunlight from reaching them.





10. New marine microbes are being discovered daily! But not many of them can be grown in a laboratory, making them difficult to study. This is why microbiologists (scientists who study microbes) are constantly looking for better methods, especially ones based on sampling genetic material, to correctly identify new microbes and ultimately improve our understanding of their role on Earth!

Poster Design: Vidya Kamalesh

i wonder... Rediscovering school science

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Azim Premji University

THE BIG BANG

ANAND NARAYANAN

The Big Bang theory currently occupies the center stage in modern cosmology. And yet, half a century ago, it was only one among a few divergent world views, with competing claims to the truth. This article highlights a few trail-blazing events in the journey of the Big Bang model from the fringes to the centerfold of astrophysics, a journey that is ongoing and far from over.

"Who really knows, who can declare?
When it started or where from?
From when and where this creation has arisen
Perhaps it formed itself, perhaps it did not."

– Rig Veda (10:129), 9th century BCE.

These words were written over 2000 years ago. And yet, if they sound contemporary, it is because they echo a trait that is distinctly human; the highly evolved ability of our species to look at the world around us and wonder how it all came to be. How often have you asked these very same questions?

We assume that all things have a beginning. Could this be true for this vastly complex universe as well? If so, what was that moment of origin, and what could have triggered it? Also, does a beginning, in some way, mean that our universe will someday cease to exist?

Humans have always pondered about the origins of things around us – from the atomic to the cosmic. Poets and philosophers, theologists and scientists have all, in their own unique ways, tried to fathom the universe. But, it is only in the last 120 years or so, that science has made it possible for us to get closer to answering some of these long-standing questions.

The scientific study of the origin and evolution of the universe is called cosmology. From the early years of the 20th century, the observational aspects of scientific cosmology began to gather wide attention. This was because of a small series of startling discoveries made by scientists like Edwin Hubble that changed the way we understood the physical universe.

Hubble had an advantage which few astronomers in the early 20th century had – access to the Mount Wilson Observatory in California. This particular observatory housed the largest telescopes of that time and yielded high quality data. With the help of Milton Humason, a fellow astronomer who was adept at using the Mount Wilson telescope Hubble began observing nearly two dozen galaxies in the neighbourhood of the Milky Way.

Hubble and Humason had already calculated the distance from the Earth to each of these galaxies through a set of scrupulous observations. Now, they began recording the spectra (see Box 1)

Fig. 1. Edwin Hubble looks through the eyepiece of the 100-inch telescope at the Mount Wilson Observatory in California, USA. It was using this telescope that Hubble made his many seminal discoveries in the field of cosmology.

of each of these galaxies. Pouring over these observations, Hubble observed two striking trends. Barring a few exceptions, nearly every galaxy that he looked at

Fig. 2. A view of the Hooker Telescope at the Mount Wilson Observatory. It was this telescope, having a mirror with a diameter of 100 inches, which was used by Edwin Hubble to discover the expansion of the universe.

Source: Ken Spencer, Wikimedia Commons.
URL: https://commons.wikimedia.org/wiki/File:100_inch_Hooker_Telescope_900_px.jpg.
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exhibited a redshift, suggesting that it was moving away from us. This implied that the universe is not stationary. If it were, either none of the galaxies would show any movement relative to us, or an equal number of galaxies would be moving closer to our own. That the vast majority of galaxies are receding from us can only be true for an expanding universe. This important revelation was in stark contrast to the view held by many leading scientists of the period, including Albert Einstein (see Box 2), that the universe was stationary, neither expanding nor contracting.

Hubble noticed the second interesting trend when he plotted the velocity of recession of each galaxy against its distance from us (see Fig.4). These plots showed that the farther away a galaxy was from us, the faster it was receding. The relationship between the two quantities is almost linear (see Box 3). Hubble & Humason formalized this linear relationship, by writing it in the form of a mathematical expression:

$$v = H \times d$$

Where, **v** is the velocity of any galaxy relative to us, and **d** the distance to that galaxy. The two quantities are related to each other by a constant, represented by the symbol **H.** Astronomers started calling this constant, the Hubble's constant. Its value could be obtained

Box 1. Red and Blue Shifts in Spectra:

We know that when white light passes through a prism, it splits into several different colours, corresponding to the different energies of photons (light particles) it contains. Astronomers measure the brightness of the light across this rainbow of colours to obtain the **spectrum** of the object emitting it.

The spectrum of a luminous object is a gold mine of information. The spectrum of a star, galaxy or a nebula, for example, helps in determining its temperature, chemical composition, pressure and

Fig. 3. White light passing through a prism produces a spectrum of colours.

Source: Vilisvir, Wikimedia Commons.
URL: https://commons.wikimedia.org/wiki/File:Optical-dispersion.png. License: CC-BY-SA.

density. It also allows the measurement of the object's velocity, if the object is moving relative to us. So, if an object emitting light is moving away from us, its spectrum will show a shift towards longer wavelengths and lower energies, called a **redshift**. If, instead, the object is moving towards us, its spectrum would show a shift towards shorter wavelengths and higher energies, called a **blueshift**. The greater the velocity of the object relative to us, the greater will be its shift in energy.

Consequently, recording the spectrum of astronomical objects has become a routine part of astronomy. This is done using an instrument called a spectrograph – with older models using a prism to split light into different energies of photons, and newer models replacing this with an optical device called a grating.

by calculating the slope of the linear trend between velocity and distance in Hubble's plots.

As it turns out, Hubble's constant is not just any other number. For over 90 years, astronomers have been trying to measure its value as accurately as possible because it can tell us something very important about the universe. We will come back to that in the section titled – Age of the Universe.

Understanding the expansion of the universe

Hubble's pioneering observations, taken at face value, can lead to a gross misconception about our universe. The spectra of galaxies show all of them moving away from us. Does this mean that we are the centre of this expansion? Intuitively, one may be tempted to say "yes", but such an assumption harks back to an old human folly.

There was a period in history, when even the greatest minds believed that the Earth was the centre of the cosmos. On hindsight, it may appear as a ludicrous notion. But realizing that it is so hasn't been easy. The Earth feels stationary to us, whereas the Sun, the Moon, and all the stars, appear as if they are going around the Earth. It took years of observation and much thought to hit upon the fact that it is the Earth, along with other planets, that is circling the Sun. The fact that even the Sun is not stationary was discovered much later. The Sun occupies a corner of our galaxy, and with billions of other stars, circles the galaxy's centre.

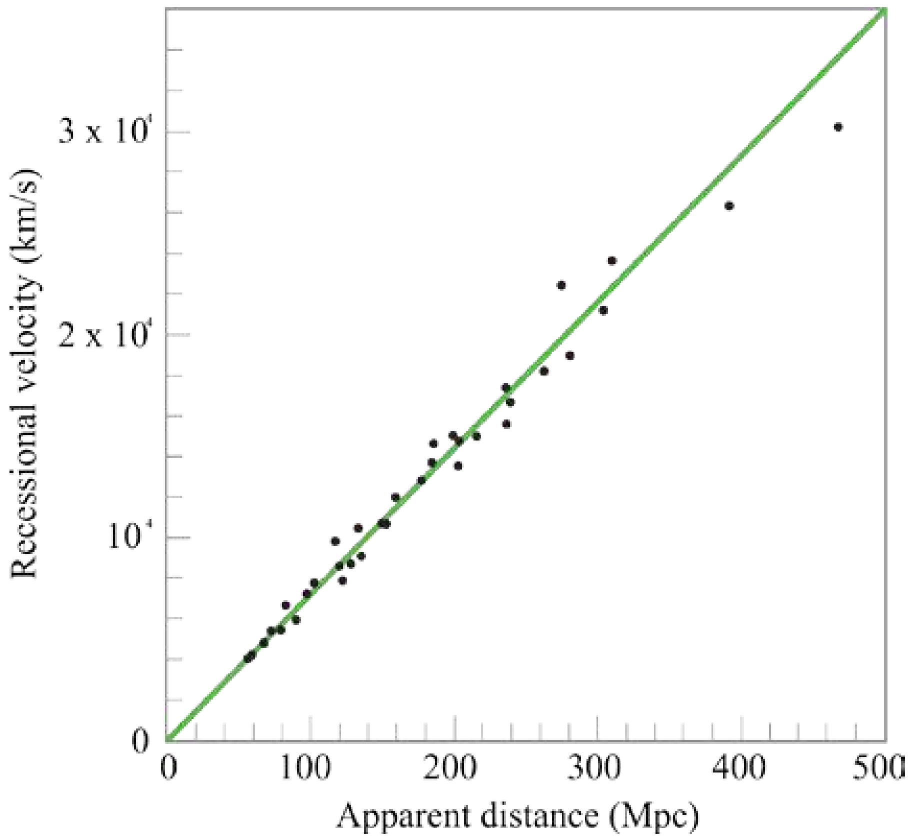

Fig. 4. A graph showing the velocity–distance relationship for galaxies, similar to the one plotted by Hubble and Humason. On the vertical axis is the velocity in units of kilometers per second. On the horizontal axis is the distance of these galaxies from the Milky Way in million parsecs (1 parsec corresponds to 3.26 light years). The black dots correspond to each individual galaxy in this sample. As one can see, the galaxies that are farther away from us also have higher velocities with respect to us. The spread of data in this plot suggests a linear relationship between relative velocity and distance. This linear relationship is represented by the thick green line. The slope of that line is Hubble's constant.

History is replete with such examples of science displacing us from our imagined significance in the cosmos. As a consequence, most astronomers were extra cautious about interpreting Hubble's results. To conclude that the Milky Way is the centre of the expansion would be the repetition of an old mistake. Instead, astronomers came up with a radical new idea that no matter which galaxy we look at the universe from, we should see the other galaxies rushing away from us. So, if an alien astronomer from some other galaxy were to do the same experiment that Hubble and Humason did, it would

Box 2. The biggest blunder of my life!

In 1916, nearly a decade before Hubble and Humason's path-breaking observations, Einstein had derived a set of mathematical equations that described gravity from a fresh perspective. One of the logical outcomes of these equations on general relativity was a universe that kept growing in size. In other words, the equations predicted a non-static universe. Einstein himself was appalled by this outcome, and did not know how to make sense of it. The prevailing notion of those times was that the universe was stationary; and there was no evidence to imagine it being otherwise. Einstein assumed that his model was imperfect. To correct for this, and to set the equations straight, he introduced a constant in his equations, upon learning of Hubble's discovery, Einstein happily threw away the constant, calling its forced insertion to his general relativity equations, "the biggest blunder" of his life.

Interestingly, some of Einstein's contemporaries, like Willem de Sitter, Alexander Friedmann and Georges Lemaitre, had used Einstein's general relativity equations to mathematically arrive at the same conclusion – the universe is expanding. Although they published their results in a various scientific journals, it was taken seriously by the scientific community only after Hubble & Humason's observations were widely replicated and proven.

Box 3. Linear relationships:

The relationship between two quantities that looks like the Hubble velocity–distance diagram is called a linear relationship. When one quantity doubles in its value, the other quantity also doubles. Similarly, when one quantity is halved, the other is also halved. Whenever such a trend is observed between two quantities, scientists try to codify it with the help of a straight line.

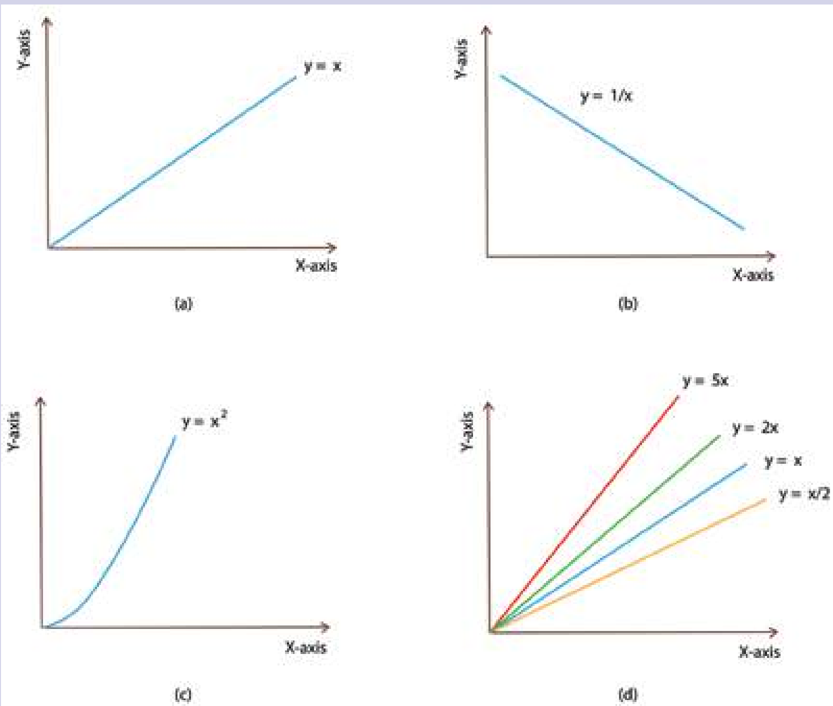

Fig. 5. Identifying a linear relationship. (a) This graph shows a positive linear correlation between the quantities along the horizontal and vertical axes. (b) This graph shows a negative linear correlation between the quantities along the horizontal and vertical axes. (c) This graph shows a non-linear relationship, where the quantity along the vertical axis varies faster than the quantity along the horizontal axis. (d) Four examples of positive linear correlation, with slopes of 5, 2, 1 and 0.5 respectively.

also arrive at the conclusion that the universe is expanding. In other words, there are no preferred locations in the universe. The universe would look the same at large physical scales, no matter where we observe it from. This notion, referred to as the **homogeneity** of the universe, has since become a central idea in cosmology.

The only way that the homogeneity of the universe can be explained is by concluding that space itself is expanding. As incredible as it may sound, this is exactly how astronomers understand the expansion of the universe. While the expansion of space is a dramatic idea that is beyond the scope of this article, one can get a conceptual handle on it through the following analogy. Imagine the three dimensional universe that we live in as being represented by a two dimensional grid system (see Fig. 6). While two galaxies would start out by being close to each other (see Fig. 6a), after some time, our fictitious universe would look different (see Fig. 6b). Seen from each galaxy, it would appear as if the other galaxy has moved away from it. The universe **has** expanded. And yet, if we were to ask where the centre of this expansion is, we would not be able to point our finger at any specific location. The moving apart of galaxies is a consequence of the expansion of space between them, and not so much due to the galaxies themselves travelling through space.

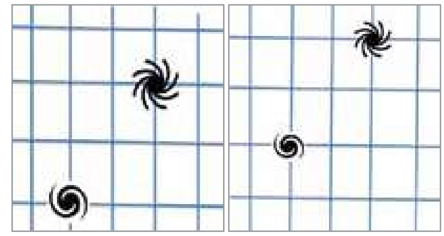

Fig. 6. Expansion of space.

Expansion as evidence of a beginning

The expansion of the universe was a landmark discovery in cosmology because it points in the direction of the universe having an origin. Our observations show us that at present, galaxies are moving away from each other. What would happen if we rewound time? Obviously, we should see space shrinking, galaxies coming closer to each other, and eventually everything collapsing to a single point of infinite density, encompassing the entire mass energy of the universe. This notion of an infinitesimally small entity, from which the entire universe of matter, energy, space and time emerged, was first proposed by a Belgian astrophysicist Georges Lemaitre. From that primordial state, the universe must have started expanding by some means. Astronomers refer to this beginning of the universe's expansion as the "Big Bang", to indicate that it could have been kicked off by an explosion.

The Big Bang has now become a commonly accepted term to refer to the origin of the universe. But the truth is, no one really knows what triggered the expansion, or whether it did, in fact, all start with a bang. With the means of observation available to us and our understanding of the laws of physics, it is very difficult to probe time periods close to the origin of the universe. What is certain, however, is that at present the universe is growing in size, and therefore it must have been smaller in the past.

The Age of the Universe

If the universe had a beginning, the obvious question is – how old is it?

Again, observations of the expansion of the universe provide an answer. To understand how, consider the following analogy:

> Imagine that you are rushing to a race course to witness a motorcar race. It's a busy day and pushing your way through heavy traffic, you finally arrive at the venue to find that the race has already begun. There are two teams competing, and as you take your seat in the gallery, you see that one of the cars has already advanced 80 km from the START line, while the other is lagging behind at 40 km. The display board shows the speeds of the two cars as 80 km/h and 40 km/h respectively (see Fig. 7). It would not take you too long to conclude that the race must have started about an hour ago. To arrive at this conclusion, however, you have to make the crucial assumption that the two cars have been travelling at a steady speed, without accelerating or decelerating at any point of time.

Let us apply this analogy to galaxies. Hubble found that a galaxy that had a relative velocity of 1400 km/s was at a distance of 6 million light years from us, whereas a galaxy that was moving with half that relative velocity had only travelled half that distance away from us. We can, therefore, calculate when the Big Bang must have occurred:

Age of the universe =

$$\frac{\text{distance of any galaxy from us}}{\text{velocity of the galaxy relative to us}} = \frac{1}{H}$$

This explains why calculating the value of Hubble's constant is so important. It offers a means to estimate the age

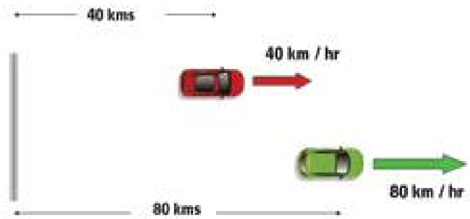

Fig. 7. When did the race between the two cars begin?

of the universe. Of course, by doing so we make the crucial assumption that the universe has always been expanding at the same rate as what we measure today. The current best estimates of the velocities of the galaxies indicate that the universe is about 14 billion years old. That's how far back in time the Big Bang must have happened.

Beginning or no beginning

By the middle of the 20th century, there were two competing theories about the universe. The steady state theory, put forward by astrophysicists Hermann Bondi, Thomas Gold and Fred Hoyle, suggested a universe that was infinite in space and time. According to this theory, the universe has always existed and, therefore, it was meaningless to talk about an origin. The alternative to this was the Big Bang theory, developed by George Gamow,

Fig. 8. George Gamow and Ralph Alpher, who along with Robert Hermann, developed the Big Bang Theory. Gamov was born in the Soviet Union. He moved to the US in the 1930s after spending a brief period in Europe. He later joined the faculty at the George Washington University in the US. Along with his student Ralph Alpher and co-worker Robert Hermann, Gamow worked a great deal on the Big Bang theory, also predicting the presence of the cosmic microwave background radiation.

Ralph Alpher and Robert Herman (see Fig. 8), which favoured the notion of a universe with a beginning.

The discovery that the universe is constantly expanding posed a serious threat to the steady state model. If the universe is expanding, and if it has been doing so for an infinitely long period of time, then individual galaxies should have moved so far away from each other that we should not be seeing any of them in the night sky at all. Clearly, that is not the case. Irrespective of which direction we orient our telescopes; we end up seeing many other galaxies.

Those who favoured the steady state theory tried to resolve this embarrassing contradiction by suggesting that even as the universe was expanding, matter was being spontaneously created from empty space. This is not a trouble-free idea. It violated the law of conservation of matter, for example, which suggests that whenever matter is spontaneously created out of an energy field, an equal amount of anti-matter is also formed. In reality, we see much less anti-matter than matter in the universe. In addition, the rate at which matter would need to be created to compensate for the expansion of the universe is so tiny (one hydrogen atom every trillion years) that it would be difficult to directly observe this phenomenon as it happens.

In science, ideas that cannot be experimentally or observationally verified have short lives. Such ideas do not qualify as scientific theories. Instead, they are called **hypotheses**, which, put simply, are educated guesses. Hoyle's hypothesis of the spontaneous generation of matter was met with only marginal enthusiasm in the broader scientific community. With the expansion of the universe becoming firmly established through repeated observations, the future prospects of the steady state theory started looking grim.

The strength of any scientific model lies in being able to make a prediction which can be observationally tested and verified. In one of the most sensational

Box 4. The Big Bang!

Ironically, the term 'Big Bang' was coined by the astronomer Fred Hoyle, who found the idea that the entire universe had started off from an infinitesimal point, ridiculous. While Hoyle remained a staunch critic of the Big Bang theory till the end of his life, the name he gave it was too awesome to be ignored!

tales in the modern history of science, the Big Bang theory would go on to do just that, triumphing over the steady state cosmology a second time. The prediction was made in 1948, by George Gamow and his collaborators, in a scientific paper based on the Big Bang cosmology. It was observationally confirmed as being true, nearly 20 years later, and interestingly, by a sheer stroke of luck.

The discovery of the oldest light in the universe

According to the Big Bang theory, a few seconds after it was formed, the universe was an extremely dense sea of highly energetic photons and fundamental particles. The photons in this sea were a billion times more energetic than the ones our eyes perceive as light. This early universe was also expanding. Physics tells us that expansion is a type of work. Any physical system that is isolated from everything else can do work only if it is willing to expend its own energy, called **internal energy**. This fact is fundamental to a branch of physics called thermodynamics. Our universe is also an isolated system. As far as we can tell, there is nothing outside of the universe for it to interact with, or borrow energy from. If it has to do any work, such as expand and become bigger, it has to use up its internal energy. This means that the photons that filled the universe, immediately after it was born, would have to lose their energy.

Following this train of thought, George Gamow and his collaborators predicted that if the Big Bang were true, the radiation (i.e., photons) from the earliest moments of its existence should be detectable even today. But, in the 14 billion years of expansion that followed the Big Bang, the energy of this radiation would have declined significantly. Gamow and his group suggested that this radiation

David Wilkinson (1935 – 2002) | **Robert Dicke (1916 – 1997)** | **Jim Peebles (b.1935)**

Fig. 9. Robert Dicke, David Wilkinson, and Jim Peebles from the Princeton University. These astronomers started an experimental campaign to detect the cosmic microwave background radiation predicted by George Gamow and his group.

would most likely be in the form of microwave photons, which are a thousand times less energetic than the light that our eyes perceive. If it existed, this radiation would pervade the universe, and therefore should be detectable from all directions in the sky. Gamow and his group called this the **cosmic microwave background radiation**, or CMBR for short.

Intrigued by the possibility of detecting the CMBR, a group of researchers at the Princeton University, headed by Robert Dicke, started fabricating a radio antenna-receiver system sensitive enough to detect photons of very low energies. This antenna would act like a bucket, collecting any radiation (photons) pouring in from the direction to which it is pointed. The receiver, which is typically tuneable to different energies, records the signal collected by the antenna. Simultaneously, Dicke and his colleagues David Wilkinson and Jim Peebles (see Fig. 9), started the long and rigorous calculations needed to estimate the kind of intensity one could expect from the CMBR at different energies. Even as Dicke and his group were making arrangements to test Gamow's prediction, the CMBR was discovered serendipitously by two young radio engineers from a place not far from Princeton.

In the 1960s, the American electronics research and product development company Bell Labs had built a 20-foot radio antenna meant to collect and amplify radio signals to send them across long distances. But, in a few years, due to the launch of new satellites, the radio antenna system became obsolete and was given away for research. Two radio astronomers – Arno Penzias and Robert Wilson, started using this Bell Labs antenna to measure the brightness of the Milky Way, and several other galaxies near it, at radio photon energies (see Fig. 10). Penzias and Wilson were unaware of Gamow's prediction of the CMBR, or the efforts at Dicke's lab to detect it.

As they began recording their observations, Penzias and Wilson were

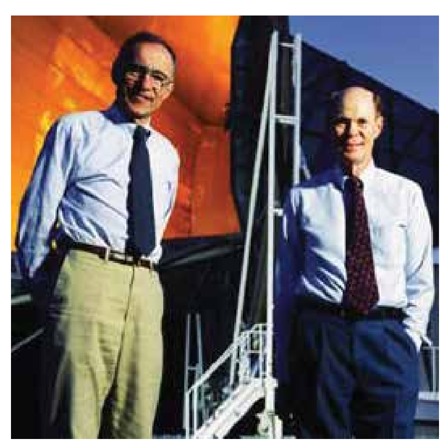

Fig. 10. Arno Penzias and Robert Wilson. They stand in front of the 20-feet long horn-shaped antenna and receiver system they used to discover the cosmic microwave background radiation.

confronted with a problem. Their antenna kept picking up a steady but faint source of noise, in the form of microwave photons, which was disturbing their measurements. The noise was persistent and seemed to be coming from all directions. It did not go away no matter which direction they pointed the antenna at. Assuming that it could be due to some problem with the electronic components of their instruments, Penzias and Wilson tried every means to improve the antenna set-up. To their great chagrin, the "noise" persisted. Nearly a year went by with no means to either explain or get rid of this problem.

Till one day, Arno Penzias heard of Gamow's work from one of his colleagues. Soon after, he and Wilson got in touch with Robert Dicke's group at Princeton. It didn't take Dicke and his colleagues much time to recognize that Penzias and Wilson had accidently discovered the cosmic microwave background radiations predicted by the Big Bang model. These radiations had the exact same properties that the model had predicted, thus becoming the ultimate cause for the triumph of the Big Bang theory. Arno Penzias and Robert Wilson went on to win the Nobel Prize in physics for the discovery of the CMBR.

The CMBR represents the oldest photons in the universe – the fossil relics of the Big Bang. There are hundreds of those photons in every cubic centimetre of space, and each one of them is nearly 13 billion years old. Although we are constantly being bombarded by the CMBR, we do not feel their presence (like the way we feel the heat from Solar photons), because of their very low energies. And yet, these whispers from the Big Bang hold precious information about the early universe – on what seeded the formation of galaxies, galaxy clusters, and similar large-scale structures that we see in the present universe. Because of their importance, we continue making observations of the CMBR, both from the ground, as well as from high-flying balloon experiments, and satellites.

A story far from over

The scientific awareness of the universe having a beginning is only a century old. From the discovery of the expansion of the universe, to the detection of cosmic microwave background radiation, the Big Bang theory has stood the test of many observations. Yet, there are many big gaps in our understanding of the physical universe. We do not really know what triggered the Big Bang, or the physical state the universe had at the very beginning. In one version of the Big Bang cosmology, the universe underwent a very rapid phase of expansion, called inflation, for a tiny fraction of a second. The inflationary model was invoked by scientists to explain certain problems posed by the cosmic microwave background radiation. But whether such a rapid growth phase truly existed; and if it did, what could have powered it is unclear.

And then, there are some even bigger questions. The cosmology of the last three decades has exposed two previously unknown components to the universe – Dark Matter and Dark Energy. Together, these two ingredients account for nearly 96% of the energy density of the present universe. In comparison, the ordinary matter that you, I, and all that we see around us – the planets, the billions of stars in our Galaxy, the trillions of galaxies in our universe, the cosmic microwave background photons – is composed of measure up to only 4% of the known universe. Science has no inkling what dark matter and dark energy are, or how they were generated in the first place. But with their discovery, our view of the universe has changed in ways that were unimaginable before. It has made us realize that in all these years of exploring the universe, we have only been scraping its surface. There is a lot more to the universe than what meets the eye. Scientists hope that astronomy of the 21st century will address and answer these big unknowns. What new challenges the answers might pose for the Big Bang theory remains to be seen.

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THE ORIGINS OF ELEMENTS

SRINIVASAN KRISHNAN

This article explores the origin of chemical elements as a process occurring inside stars, as well as in terms of what they mean to people.

It is an obvious fact that different substances make up the world as we know it. We look at the world through our senses and use our powers of deduction and inference (dependent largely on existing technology and robustness of intellectual structures) to aid in the discovery of new substances and categorise known ones in ever more suitable ways. Given the robust engineering capacities that humans display, it is clear, even from antiquity, that we could also make new kinds of substances by a suitable combination or distillation of existing ones, i.e. cooking a dish, mixing medicines and beverages, constructing buildings and tools, and so on. To make ever more complex substances and systems with properties that we desire, the following question must have been considered over the ages, "What are the basic substances out of which all other substances are made?"

Different civilizations have attempted to answer this question, and all of them seem to have postulated the existence of 'elements'. Believed to be created when the universe itself was created, elements have been thought of as being the unique and fundamental building blocks out of which all other existing structures are made. The Indians and Greeks thought that the world was made up of five elements which were Ether, Air, Water, Fire and Earth; the Chinese postulated that wood, metal, earth, water and fire made up all the substances of the world, and so on.

Atoms, on the other hand, were thought to be indivisible particles of the elements. For example, Kanada, founder of the Vaisheshika philosophy in 6th century BC, thought that the world was composed of atoms, which were of four basic kinds corresponding to the four elements – earth, water, fire and air. Each of these different kinds of atoms had other qualities assigned to them; and there were complex rules governing how these atoms could combine to produce all the substances seen on Earth. Similarly, the Buddhist, Jain, Islamic and Greek schools of thought also constructed the concept of atoms as representing elements, and being the origin of all matter, but their descriptions and qualities varied (see 'The Atom in the History of Human Thought' by Bernard Pulman[3] for a comprehensive account). All schools, however, agreed that atoms were eternal, indestructible and indivisible; and, importantly, atoms of any one kind were all identical.

This makes it evident that elements and atoms were inextricably linked in the ancient world – this is so even in the modern world. Today, we know of 92 naturally occurring elements, but can also artificially produce many more, with atomic numbers greater than 92. This is possible only because the relationship between atoms and elements is robust enough to allow such creation. So, according to modern scientific wisdom, how were these naturally occurring elements formed? The most widely accepted theory for the origin of the universe, which is somewhat similar to some of the theories propounded in the ancient world, is called the Big Bang theory. This event, occurring about 14 billion years ago, is believed to have created a large quantity of the primordial element hydrogen (which is made of one proton and a corresponding electron) along with very small quantities of helium, and trace amounts of other elements and isotopes. This is quite exciting, given that the Big Bang theory has arisen almost entirely out of observations made of the cosmos and experiments carried out in the laboratory.

Since old theories on the relationship between elements and atoms have not been able to withstand the scrutiny of modern scientific rigor, we will look afresh at the questions, 'How is an element defined?' and, 'What are atoms and how are they related to elements?' We begin our journey into the origin of elements by starting with the first of these questions.

Defining an element

Historically, elements have been defined in a variety of ways. For example, one, now 'obsolete', definition states that: *"An element is a substance that cannot be decomposed into simpler substances"*. This was possibly the first useful definition of an element, because it allowed one element to be experimentally distinguished from another. If a substance could be broken down into two or more new elements, which when recombined formed the original substance, the original substance was definitely not an element. Of course, it is impossible to use this definition to conclusively prove that a substance **is** actually an element because a substance which couldn't be decomposed using existing technology in one century could be decomposed in the next, when more advanced technologies became available.

Look at another, also obsolete, but more useful definition: *"An element is a substance composed of identical atoms"*. This definition was one of the cornerstones of the (John Dalton's) atomic theory, but it was made obsolete by the discovery of **isotopes.** This discovery also made the previous definition of elements as non-decomposable substances untenable because an element

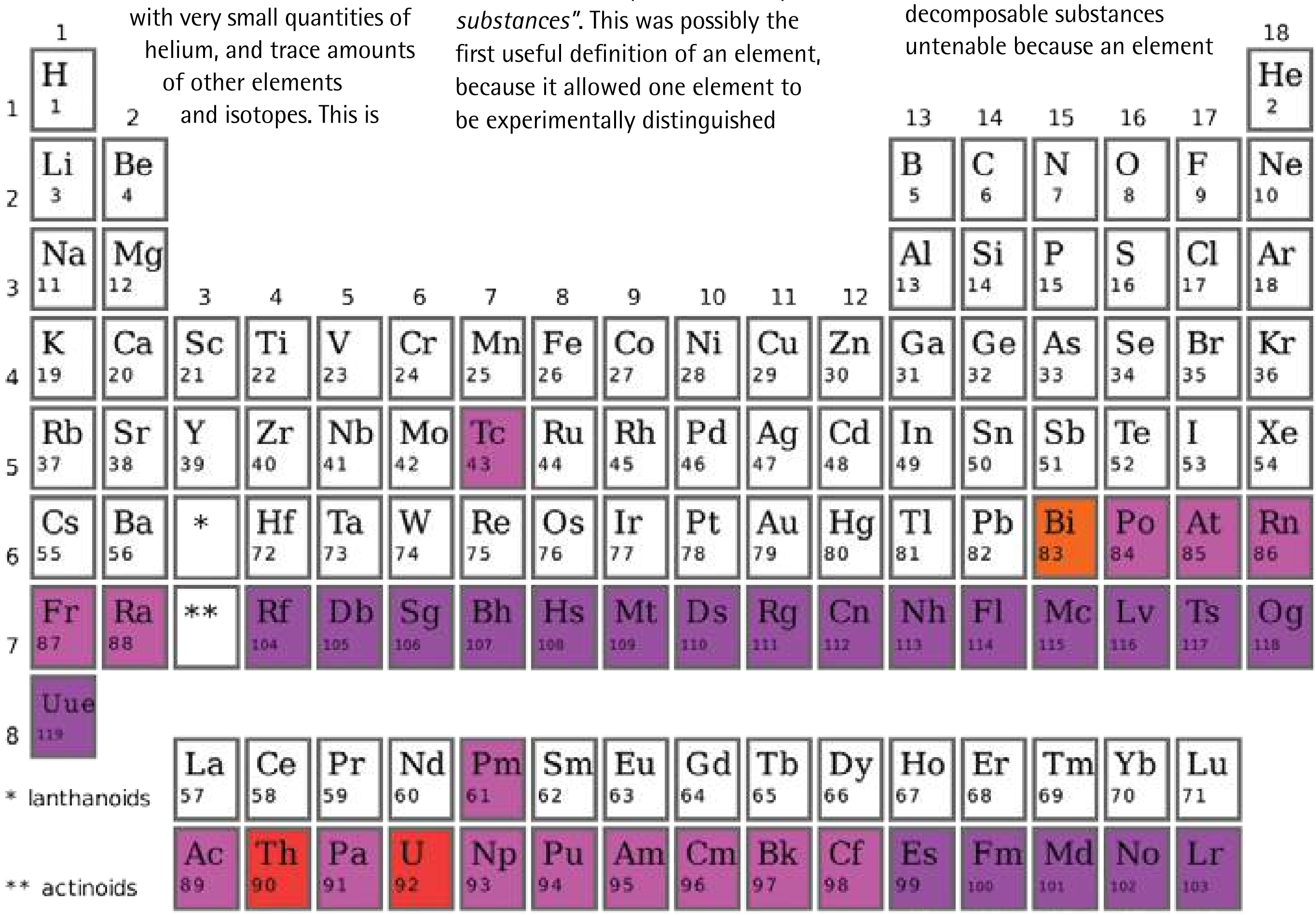

Fig. 1. The periodic table with all known elements.

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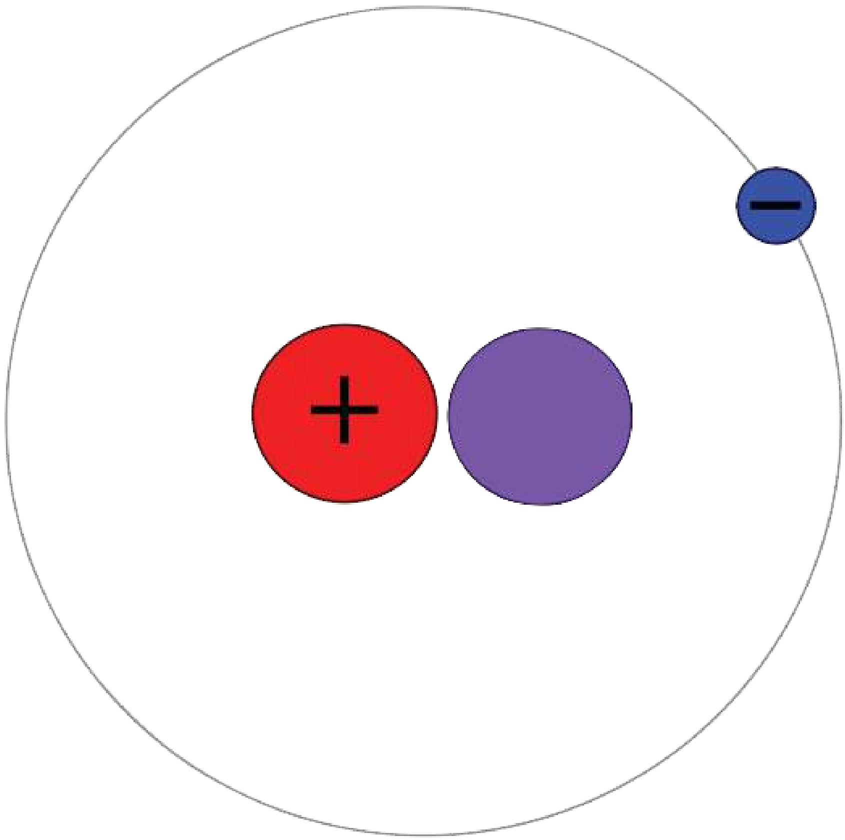

Fig. 2. A deuterium atom.

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can be decomposed into its isotopes, which have slightly different properties than those of the original element. This means that a given element's atoms can exist in different forms, contradicting Dalton's definition. Further, recombining its isotopes gives back the original sample, and so, by the previous definition, any element that consists of more than one isotope cannot be a true element. One striking example of this is seen in the existence of heavy water. Normal water has the usual form of hydrogen, with one proton in its nucleus; while heavy water has Deuterium, which is an isotope of hydrogen with one extra neutron present in it. This makes molecules of heavy water significantly heavier (one mole of heavy water can be around 2 grams heavier than one mole of normal water) – its freezing point is about 4^{0}C, and it is about 11% more dense. Heavy water has unusual nuclear and biological properties and is extensively used in nuclear reactors as a neutron moderator, i.e. to absorb neutrons. Isn't it amazing that the mere presence of an isotope can cause such a difference in properties?!

The modern era of chemistry probably started around 1789, when the 'father of chemistry', Antoine-Laurent de Lavoisier (1743–1794), attempted to classify elements. Lavoisier defined a chemical element as a substance that could not be further divided by any known method of **chemical analysis**. This was a very precise definition – remarkable because in retrospect it seems as if by restricting this definition to objects that were 'indivisible by chemical analysis', Lavoisier was suggesting that other methods, that came to be known about 150 years later, could succeed in splitting an element or making it (see Box 1).

Let us now look at the second question 'What are atoms and how are they related to elements?' Many amazing scientific discoveries in the 19th and 20th centuries, including advances in nuclear physics, astrophysics and so on, have clearly shown that all the different types of elements are made up of atoms. We also know that atoms are made up of essentially three stable particles – positively charged protons, neutrons with no net charge, and negatively charged electrons. The atoms of any element have a specific number of protons and neutrons that together form a small nucleus, with electrons orbiting around this central core. Keeping these three particles in mind, we can now arrive at a rigorous, unambiguous definition of an 'element' in terms of its atoms:

'An element is composed of atoms of one kind, all of which have the same number of protons (called its atomic number)'.

This definition makes it clear that a single free neutron, or other sub-atomic particles like neutrinos, pions, kaons, photons, and so on, cannot be thought of as elements.

Box 1. Experimental Deduction: Getting to know an element as an element. Why is it definitely not a compound or a mixture?

If you put two graphite rods (you could use thick pencil leads) into a glass of tap water, and connect these rods to an 18V battery, you'll see bubbles arising at both electrodes. The gases given off at these two electrodes can be easily collected into test tubes. Now we know, from textbooks and other sources, that these two gases are elements i.e. hydrogen and oxygen - but how does one prove that experimentally?

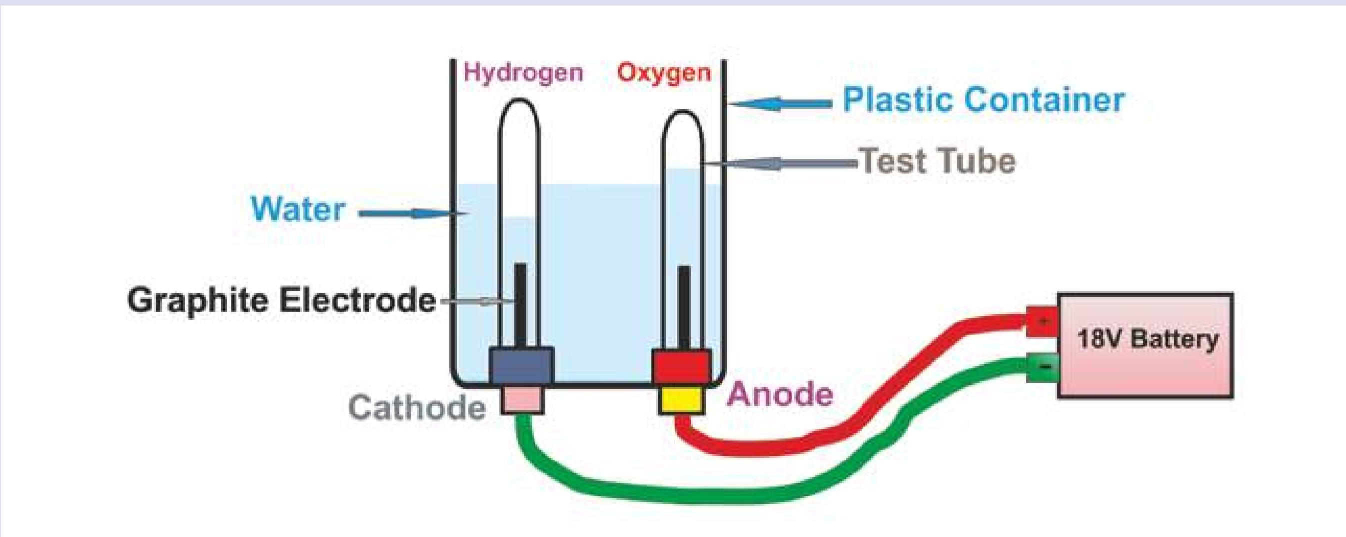

Fig. 3. The electrolysis of water: Oxygen and hydrogen gases collect in the test tubes.

Take oxygen for example. Let us imagine at first that it is actually made up of a mixture of two or more gases. Assuming that we can use all known gas separation techniques, we ought to be able to get these gases by **at least one** method. This will prove that oxygen is actually a mixture of gases. In the real world, however, we have only managed to separate the different isotopes of oxygen, all of which are very similar to each other in their physical and chemical properties.

One could, however, argue that our inability to separate oxygen into two significantly different gases is because we don't yet have the technology to do so. So we could hypothesize that the **chemical properties** of oxygen might be able to reveal the presence of many different gaseous components that are probably all similar in weight to each other, which is why they could not be separated by our separation techniques in the first place. One way of testing this hypothesis would involve reactions between oxygen and specified quantities of pure alkali metals (like sodium and potassium) for example. We avoid using transition elements as they can have different oxidation states, forming different sorts of compounds when reacted with the same substance. If we get two or more compounds **in any one** given reaction that we can clearly distinguish by sight, smell, touch or other chemical properties, it will prove our hypothesis. Another way we can test this hypothesis is to get oxygen from other sources, like by heating mercury oxide or some nitrates. If this reacts with the hydrogen obtained from splitting of water, after discarding the oxygen produced during the split, then we should get water as a result. If we do, **(and we actually do)** then it shows that the simplest explanation is that oxygen is **not a mixture of gases**. Whew! That is a lot of work just to show that a given substance is not a mixture!

However, our proof of oxygen's elemental nature is not yet conclusive. What if we consider the possibility that oxygen is actually a compound, rather than a mixture? The situation, then, becomes much more complicated. Firstly, because we may not yet have discovered the tools to split this compound apart chemically, and till someone does so, oxygen will continue to be considered an element. Once we do, and we use these tools to split oxygen into its components, these components will be regarded as elements if they cannot be further divided by any known chemical means. This has never been done as of now, and so we "know" that oxygen is an element and not a compound. Look at the flow chart that indicates a possible scheme of investigation when you encounter a substance that is new to you

It is interesting (and amusing) to note that Lavoisier included **all entities** he could not split using chemical means in his list of elements. This included **light, heat,** and metal oxides. Metal oxides could be broken down only when the use of electric current became wide spread in the nineteenth century. Light and heat, of course, are not substances, and so are not classified as elements now.

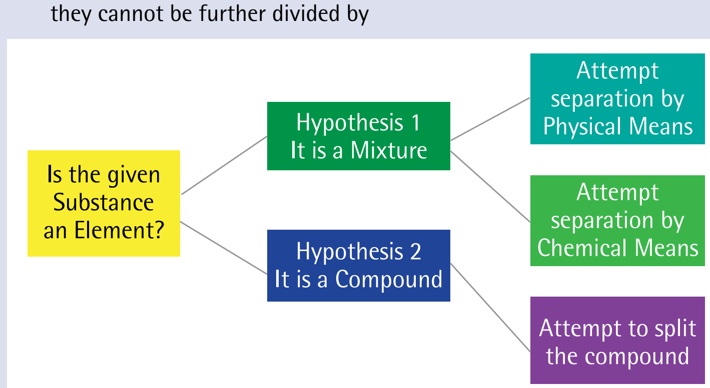

Fig. 4. Flow chart showing a scheme of investigation to show that a substance is an element.

Box 2. Are atoms real?

We have seen that any discussion on the origin of elements ought to begin with the notion of atoms – since elements are composed of atoms. But, are atoms real? Intriguingly, even long after they were conceived of (and after the birth of the modern science of chemistry), no one could actually see atoms in any way. In fact, it is only since late last century that we have come close to actually seeing atoms (see https://www.youtube.com/watch?v=ipzFnGRfsfE for an illuminating idea of the history of atoms and how they can be seen and manipulated).

In spite of this, the idea of atoms has been of immense importance. As the famous physicist Prof. Feynman wrote, *"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the* ***atomic hypothesis*** *(or the atomic* ***fact****, or whatever you wish to call it)* ***that all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.*** *In that one sentence, you will see, there is an* ***enormous*** *amount of information about the world, if just a little imagination and thinking are applied."*

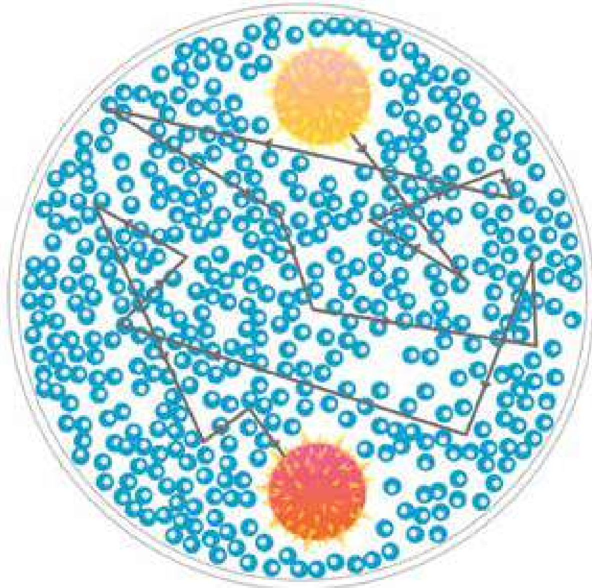

Fig. 5. The random motion of pollen is a result of the Brownian motion of atoms in water.

Experiment: 'Seeing' atoms indirectly through Brownian motion.

Put some pollen from a grass flower into a drop of water and observe using a microscope. If the size of the pollen is right (neither too heavy nor too light), you will see it move or jiggle in a **random manner** as opposed to showing continuous smooth motion. This random movement is called "Brownian Motion", after Robert Brown who discovered (but could not explain) it in 1827.

In a path-breaking paper, published in 1905, Einstein showed that this random motion unequivocally proved the existence of atoms. That Einstein received the Nobel Prize in Physics in 1921 for this discovery indicates how significant it was perceived to be.

In this experiment, the random motion of pollen actually **proves** that the drop of water is made up of atoms. How does it do that? If the drop of water were continuous, the suspended pollen grains could only bob and move smoothly in different directions as the water jiggled and moved about. But their random motion indicates that each pollen grain is actually being hit randomly. This random hitting can only be possible if the water is made up of atoms which are doing the hitting as they move around.

A harder experiment to conduct is to shine a bright light through some smoke particles captured in a glass cell and observe this through a microscope. Amidst swirling masses of smoke, one may occasionally spot smoke particles, which look like bright spots of light, showing Brownian motion.

See https://en.wikipedia.org/wiki/Brownian_motion for an accurate motion picture of Brownian motion.

Observations of atoms

Let us now consider the meaning of constructing an atomic theory. Do we need it at all? What are the benefits of doing so? But, first, let's begin by considering much simpler questions – are atoms real? If yes, can they be seen (see Box 2)?

Now that the setting is clear and we are sure about the reality of atoms even though they cannot be directly seen, we move onto how people envision the creation of all the elements out of the primordial element, hydrogen, which was created during the Big Bang.

Dynamics within a cloud of gaseous hydrogen

As the universe cooled down after being created, hydrogen atoms condensed into massive clouds held together mainly due to gravitational attraction (see the article on the 'Origins of the solar system' in the same issue, for a detailed account of how these clouds condense). Notice that although a cloud of gas has no walls for the gas molecules to bump against, it does have pressure, volume and temperature – all of which change as the cloud is compressed (see Box 3). Thus while these quantities may or may not have been the same everywhere within a cloud, a more condensed cloud definitely had greater internal pressure and temperature.

Amazing things happen when a cloud of hydrogen has enough internal-gravity to begin contracting (see Box 4). Note that we are thinking of a gas cloud with an

Box 3. Experiment: Squeezing a gas

You will need a 20ml syringe for this experiment. Use some araldite to plug the hole where the needle fits. Before closing this hole, pull the piston all the way up making sure that there is enough air inside. After the araldite dries, try to squeeze the piston of the syringe to the maximum extent and make a note of your observations. Clearly, the air seems to push back. How does it do that?

What is happening here is that the air molecules bump against the walls of the container, and as the volume of the syringe reduces, the frequency of bumping increases. At every position within the piston, the pressure applied by the air matches yours, and if you relax, the piston comes back to its original position.

When this experiment is done using a bigger piston-cylinder system like a cycle pump, the air within the pump definitely gets warmer, i.e. its temperature increases.

enormous amount of mass. It is so large that it can condense to ignite nuclear reactions and produce a star. Some of these clouds are much smaller, and stop condensing after a point as they do not possess enough gravitational potential energy, but we will not discuss these clouds here.

When the temperature at the core of a contracting gas cloud reaches a few million degrees centigrade, the atoms in it cease to exist and become just a dense soup of separately moving electrons and protons. When two protons in this state collide against each other, they are able to overcome their strong electrostatic repulsion (both are positively charged), and come close enough to exert nuclear forces of attraction. This happens because of a phenomenon that we know as quantum tunnelling. Quantum tunnelling brings two protons close enough to bind even at relatively low temperatures – it was realised in the 1920s itself that the temperature at the core of a star, which is a few million degrees centigrade, is about a **1000 times smaller** than what is actually required to bring two protons close enough to bind. What is interesting is that we came to this realisation even before the neutron was discovered (which was in 1932). At that time, the possibility that elements with larger atomic weights were formed by fusion was pure conjecture, with no plausible evidence as to how it could take place.

When protons come close enough to each other to be able to **quantum mechanically tunnel** into each other, the nuclear forces i.e. the strong and weak forces, come into play and the whole game immediately changes. The protons can now change into neutrons; other protons can join in to form larger nuclei, and so on. The energy given off in these nuclear reactions is immeasurably larger than the heat radiation energy that was given off till now. A star, as we know it, is now actually born, and generates energy by nuclear fusion. This slows its contraction, with the star beginning to

Box 4. Stretch of reason: the dynamics inside a cloud

What are the things that can possibly happen inside a condensing cloud of gas? I've listed some of my questions about its fate below. You could add your own questions to this list.

- When a cloud of gas condenses, why does it get hotter? We should keep in mind that the standard gas laws ($PV = nRT$ and so on) that hold for ideal gases are applicable to much of this contraction.
- What happens to the contraction when it gets hotter?
- What quantity of gas is needed for condensation to occur due to internal gravity?
- Does the temperature inside the core of the gas increase as it condenses?

Regarding questions one and two, the gas gets hotter simply because its molecules are confined to a smaller space, much like in the case of a gas in a cycle pump which is compressed and not allowed to escape. On Earth, the contraction of a gas stops once its temperature rises to a certain level, usually because of the walls surrounding the gas. In contrast, in a massive gas cloud, contraction produces warming which stops it from contracting any further. However, this warming ensures that heat in the gas cloud is radiated away from its surface. This cools the gas, and once it has cooled sufficiently, the contraction and clumping begin with renewed vigour, and the cloud becomes smaller. **This is clearly a runaway effect – this cycle of events continues endlessly, stopping only if the amount of matter in the cloud is small.**

There are several answers to the third question. One of them gives us an idea of how stars are formed. Usually atoms cannot get too close to each other. Therefore, squeezing a solid, liquid or a gas gets progressively harder beyond a certain point. For a gas to condense due to its **own gravity** there needs to be a lot of it; given that gravity is the weakest force in the universe. Also, according to **Pauli's exclusion principle**, which states that one just cannot put two electrons or protons or neutrons on top of each other, a cloud can be gravitationally compressed only if its mass exceeds a certain limit of about 4×10^{32} grams. Thus, the greater the mass of a gas cloud, the hotter the stars formed from it. For the record, our sun has a mass of about 2×10^{33} grams, which is obviously greater than the minimum mass required for condensation to occur.

For the last question, it turns out that the temperature at the core of the gas cloud does increase, and its value depends on the mass of the cloud. This is reasonable because the contraction would be faster for a gas cloud with higher mass, and so the gas ought to get hotter. Connecting this to the answers of the first and second questions, we can deduce that the core of the gas cloud should just keep getting progressively hotter. How hot can it become? In fact, once it reaches a few million degrees centigrade, **nuclear reactions begin**, i.e. the energy of the protons begins to gradually overcome the repulsive electromagnetic force between the positively charged protons. As we will see later, this means that the internal temperature of a gas cloud can increase by much more.

Box 5. The mysterious Quantum Mechanics & Quantum Tunnelling

What is quantum mechanics? To explain it simply, you need to imagine a system with a limited number of states of existence. To understand this, imagine a particle put inside a "box" which is somewhat penetrable (if the particle has enough kinetic energy). The "states" of this particle are clearly that of being anywhere inside the box and those of being outside it. An example of a state could be the position of the particle at, say, a point in the middle of the box at a particular time and moving along a given direction with some speed. This is different from a state where the particle can be 10cm outside of the box at a particular time and going with the same speed along some other direction. Clearly, the particle does keep changing states as its position and velocity keep changing.

Now, imagine that all of these states can occur, each with some **probability**. If we can somehow conceive of a **superposition of states**, where instead of the electron or particle being in any one state, it can potentially be in a **mix of all their possible states** (how it is mixed is decided using mathematical rules and cannot be stated easily in ordinary language), then you would have a model of a quantum mechanical system. The last thing we need to add is that **when we make a measurement**, the particle or electron **can only be** in some specific state. For the particle in the box, the states it can be in are either somewhere inside or somewhere outside the box.

Now comes the amazing part. Even if we started out with the particle having less energy than that required to penetrate the box, there is a slight chance that it can jump out, or, in other words, it can still **tunnel through to the outside**. The rules that govern the superposition of states somehow allow for this possibility, and every once in a while the particle does just that. This has been observed experimentally in various situations and is uniquely a quantum phenomenon. There is no classical analogue to this effect.

It was in 1929 that George Gamow (1904–1968m), Ronald Gurney (1898–1953) and Edward Condon (1902–1974) discovered the phenomenon of quantum tunnelling. It would be hard to overestimate the importance of the tunnelling phenomenon in many disciplines, especially astrophysics. This one discovery essentially kick-started the entire field of nuclear astrophysics. The tunnelling phenomenon is one of the crucial factors required for the existence of life in the cosmos. It provides both the energy and a suitably long time-scale for its release in stars. What is interesting is that for several years before this discovery, Condon, who eventually explained how nuclear reactions can occur in stars, had believed that mass annihilation was the source of stellar energy and explained their long life. However, no reason was found to explain why mass annihilation should generate energy at the rate it does inside the Sun. Tunnelling gives a much better explanation for both the quantity of energy produced and how quickly it is produced. This tunnelling effect is also the phenomena behind the workings of the ever-present solid-state devices, the diode and transistor, which are literally the backbone of the electronics industry.

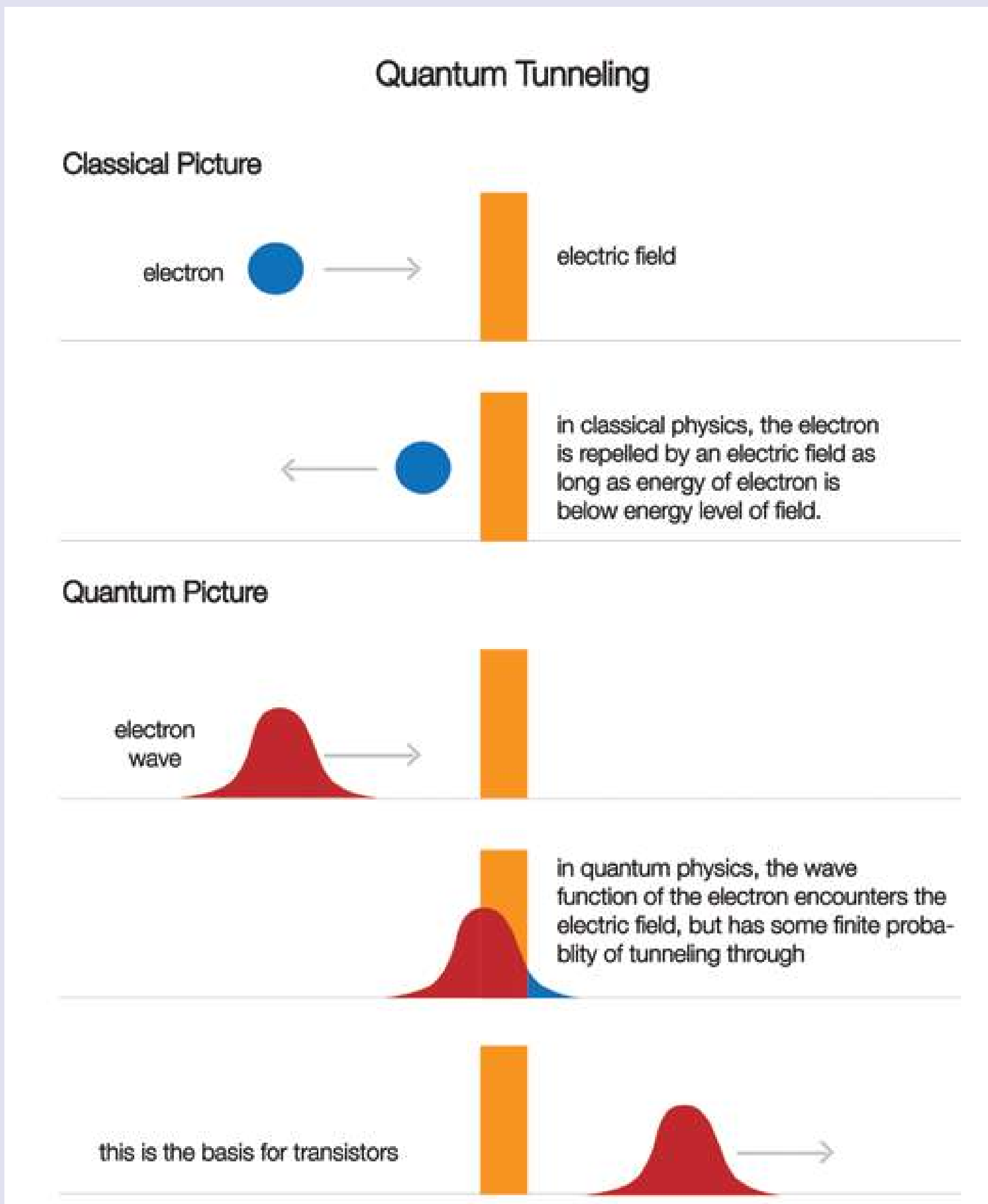

Fig. 6. Quantum Tunnelling.

Credits: Dr. James Shombert, University of Oregon.

generate heat which is radiated away from its surface. These two processes of energy generation and radiation ensure that the star remains a certain size for a long time.

The temperature within stars is sufficiently low to allow nuclear reactions to proceed slowly enough to provide energy over the long time scales needed for the evolution of planets, and indeed, life itself. If the temperature at the core of stars had been higher, the reactions would have proceeded faster, the energy generated would have been greater, and their lifetimes would have been shorter.

Creation of the heavier elements

Before we get into the details of the creation of heavier elements, let us just take a quick look at the notation for the nuclei of the elements that will be used from this point onwards.

We use the notation $^{Z}_{A}S$ to denote an atom S, with an atomic number (or number of protons in the nucleus) of A, and a mass number (number of protons plus the number of neutrons) of Z. We will normally omit the atomic number as it can be rather cumbersome, and stick with ^{Z}S when convenient. If you have access to a periodic table, and know the symbol for an atom, you can always find its atomic number. For example, ^{8}Be would be the nucleus of the Beryllium atom with an atomic **mass** of 8 (its atomic number is 4).

Going back to the events happening within stars, there are two basic nuclear reactions that produce helium from hydrogen. The first, called the proton-proton chain reaction, accounts for about 94% of the energy produced in an ordinary star (see Fig. 7).

In these reactions, ^{1}H stands for the **hydrogen** nucleus which is just a single proton, ^{2}H stands for the Deuterium nucleus which is made up of one proton and a neutron bound together, e^{+} is the positron (experimentally discovered in 1932) or anti particle of an electron, ν_e is the electron neutrino (existence postulated in 1930 and experimentally discovered only in 1956), ^{3}**He** is an isotope of the Helium nucleus consisting of two protons and one neutron,^{4}**He** is the standard Helium nucleus which consists of two protons and two neutrons, and γ is the radiant energy released.

First, notice that the pp chain is actually a **cycle** – one that starts off with two protons interacting, and ends with a helium nucleus and two more protons. The very first reaction of this chain, which shows two protons interacting to give a Deuterium nucleus (with a positron and neutrino), is the **deciding factor** for the entire chain. The time scale for its occurrence is around a billion years. That means that it can take **over a billion years** for a given

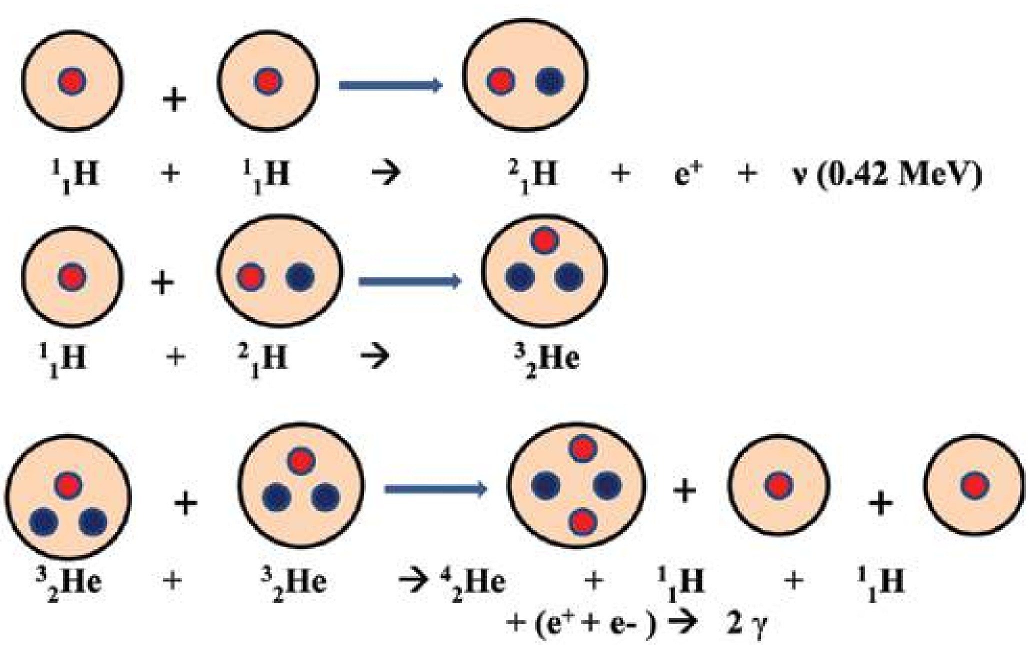

Fig. 7. The proton-proton chain (or pp chain) reaction.

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pair of protons to combine to form a Deuterium, even under the conditions of pressure and temperature found at the core of the sun. In most collisions between protons, they just come together and break up again. The chances of fusion occurring remain really small, because **weak nuclear forces** decide this reaction. The other reactions in the chain are comparatively fast because they are controlled by the **strong nuclear force**, which is much more powerful than the weak force.

The other important reaction to generate helium and, hence, energy in the Sun, is that of the CNO cycle. As the name suggests, this reaction involves the presence of the elements carbon, nitrogen and oxygen, but we will not describe this here.

Let us now consider reactions in which helium is burnt to form the heavier elements. These reactions do not happen to a significant extent in the Sun or similar-sized stars, which still predominantly burn hydrogen.

Going back to the dynamics within a gas cloud, we know that once hydrogen is converted to helium, and the extra heat generated is radiated off, the star cools down a bit, and then slowly starts to contract again. This contraction raises the temperature of the core of the star to about a hundred million degrees centigrade. At these temperatures, helium nuclei fuse to produce heavier elements.

The first reaction in this Helium burning is:

$$^{4}He + {}^{4}He \longrightarrow {}^{8}Be$$

This reaction is **endothermic**, i.e. it needs energy to form. However, the next crucial stage in Helium burning, involving the conversion of ^{8}Be to ^{12}C, is **exothermic**

$$^{8}Be + {}^{4}He \longrightarrow {}^{12}C + \gamma$$

The combination of these two reactions results in to the formation of one carbon nucleus from three helium nuclei. The net reaction releases energy, as the second reaction releases more energy than is used up in the first. However, this reaction is highly temperature sensitive, implying that as a fuel, **helium is much more explosive** in a nuclear reaction than hydrogen. Once ^{12}C is formed, further reactions forming oxygen and neon nuclei begin occurring:

$$^{12}C + {}^{4}He \longrightarrow {}^{16}O + \gamma$$

$$^{12}O + {}^{4}He \longrightarrow {}^{20}Ne + \gamma$$

These processes – similar to that of Helium burning – lead to the burning of heavier elements such as carbon, neon, oxygen, silicon, etc. Such reactions become more probable only at temperatures of a **billion degrees** or more. Most of these reactions are fairly complex, and can proceed through very many **channels**, i.e. can give more than one sort of product based on chance (recall Box 5). As an example, consider the reaction of two carbon atoms, which can produce either magnesium, or sodium, or neon, or oxygen:

$$^{12}C + {}^{12}C \longrightarrow {}^{24}Mg + \gamma$$
$$\longrightarrow {}^{23}Mg + n$$
$$\longrightarrow {}^{23}Na + p$$
$$\longrightarrow {}^{20}Ne + {}^{4}He$$
$$\longrightarrow {}^{16}O + 2\,{}^{4}He$$

The relative probabilities for each of these channels are very different, and depend on the temperature at the core of the star. Similarly, we can have different reactions involving oxygen nuclei, with the reactions ending up with ^{28}Si, ^{31}S, and ^{31}P.

At these very high temperatures, some of the radiation produced can actually break the newly created nuclei apart into smaller nuclei, a process aptly named **photo-disintegration**. The existence of such reactions complicates matters at these high temperatures. For example, the reaction:
$^{20}Ne + \gamma \longrightarrow {}^{16}O + {}^{4}He$, can produce helium by the photo-disintegration of neon. Such a helium nucleus will again combine in a sequence of reactions to give a pool of ^{16}O, ^{24}Mg, and ^{28}Si.

When the temperature in a star's core is higher than three billion degrees, several complex sequences of nuclear reactions and photo-disintegration can occur. These processes gradually build up heavier nuclei, such as ^{27}Al and ^{24}Mg, working all the way up to ^{56}Fe. The formation of nuclei with masses lower than ^{56}Fe release energy, but those of nuclei with masses higher than ^{56}Fe require energy to make.

But, how are these heavier elements synthesised? One set of such reactions relies on the capture of neutrons by nuclei. This is a process that is not

Box 6. A short time-line of Deuterium (^{2}H) formation

Around the 1930's, nuclear physics was coming up with crucial results, and plenty of important isotopes and elements were being discovered. Two scientists – Robert d'Escourt Atkinson and Charles Critchfield, played key roles in developing our understanding of the proton-proton chain reaction.

1919: The astrophysicist Eddington suggested that the **synthesis** of hydrogen to Helium might be the source of energy in the Sun, but he had no idea how this could work. People thought that the Helium nucleus contained 4 protons and 2 electrons, so as to have a net positive charge of two (recall that the neutron was discovered only in 1932). Also, no nuclei with atomic masses of 2 or 3 were known to exist in nature. Hence, the only way Eddington's hypothetical synthesis could happen would be for 4 protons and 2 electrons to come together simultaneously, release energy, and then stay together as a Helium nucleus. This was known to be a hopelessly complicated and extremely rare process.

1931: "The situation was", as Atkinson remarked, "that so much observational data had accumulated that it was no longer possible to **construct an arbitrary hypothesis without producing a contradiction**." At this point of time, many nuclear experiments were being carried out, and it was also recognised that hydrogen was the **first and probably only** chemical element to have existed at the beginning of the universe. The difficulty lay in finding how fusion could start with just pure hydrogen. All the scenarios that researchers came up with assumed the **pre-existence of elements heavier than hydrogen**, but without any explanation for how these heavy elements could have been formed.

1936: Atkinson re-examined his scenarios from 1931 in view of the recent discoveries of the neutron, Deuterium (^2H), and the positron. It was believed that nuclear reactions with neutrons do not face the problem of repulsion with protons (neutrons have a net charge of zero) and hence can operate at any temperature. The question was whether neutrons could be produced in sufficient amounts in stars. Checking all possible neutron production reactions seen in laboratory conditions revealed that such reactions were very slow, producing insignificant quantities of neutrons. For example, the reaction $^1H + e \rightarrow n$, namely, the absorption of an electron by a proton resulting in a neutron was not seen at all. The only alternative left, and suggested by Atkinson, was to generate neutrons by first producing plenty of Deuterium (^2H) via the reaction: $^1H + {}^1H \rightarrow 2\ {}^2H + e^+$, and then splitting the Deuterium. In this way, Atkinson discovered the first reaction of the pp chain. However, Atkinson expected this reaction to produce Deuterium, and from it, neutrons. He also expected it to be easy to see and measure the rate of this reaction in the laboratory. In this, he was mistaken, because **this is the most famous nuclear reaction in stars** – one that cannot be measured in the laboratory because of its extremely low yield, i.e. it hardly ever happens. Also, it is only after the difficult process of formation of Deuterium occurs, that the road to other, faster, nuclear fusion reactions opens.

1938: Charles Critchfield (1911–1994) was a Ph.D student at George Washington University, working under the guidance of the scientists Teller and Gamow. The subject of his thesis, suggested by Gamow, was to calculate how quickly the first pp reaction happens in stars. When Critchfield finished the calculation, Gamow suggested that he should present the calculation to the 'high priest' of nuclear physics, a scientist named Hans Bethe, and try to get his approval. Bethe found the calculation to be correct, and so in 1938 Bethe and Critchfield published the calculation. The authors gave no credit to Atkinson, although it was Atkinson who had come up with the idea of the pp reaction.

This was how the first reaction of the pp chain was found. Much of this investigation was done in laboratories, and checked with observations of the energy output of the sun to ensure accuracy.

Fig. 8. Robert d'Escourt Atkinson and Charles Critchfield played key roles in developing our understanding of the proton-proton chain reaction.

affected by the strong repulsion that exists among positively charged nuclei. So a nucleus with an atomic mass of Z and atomic number A will change to one of Z + 1 when it absorbs a neutron, and this can continue till the resulting nucleus decays by emitting an electron to give a new element with atomic number A + 1. In this way, elements higher than iron are also synthesised. Note that elements not found in nature are also produced in a similar manner in the laboratory i.e. through the absorption of neutrons.

Conclusion

We've looked at the story of how elements are generated in stars in brief here. As stars grow older and turn into supernovae, they explode and seed the cosmos with the elements that they have created. These elements often end up in gas clouds which can condense to form new stars and planets that can harbour life.

Much of this story could not have been discovered if nuclear physics had not developed to the point of being able to generate reactions by throwing particles at each other and observing what new nuclei form, how they decay through their collisions and noting the probabilities with which these reactions occur. New channels, new ways of looking at radioactivity, and understanding the stability of nuclei have been crucial to deciphering how stars cook up elements. With many, many questions still remaining unanswered, this remains a thriving field of study offering plenty of surprises.

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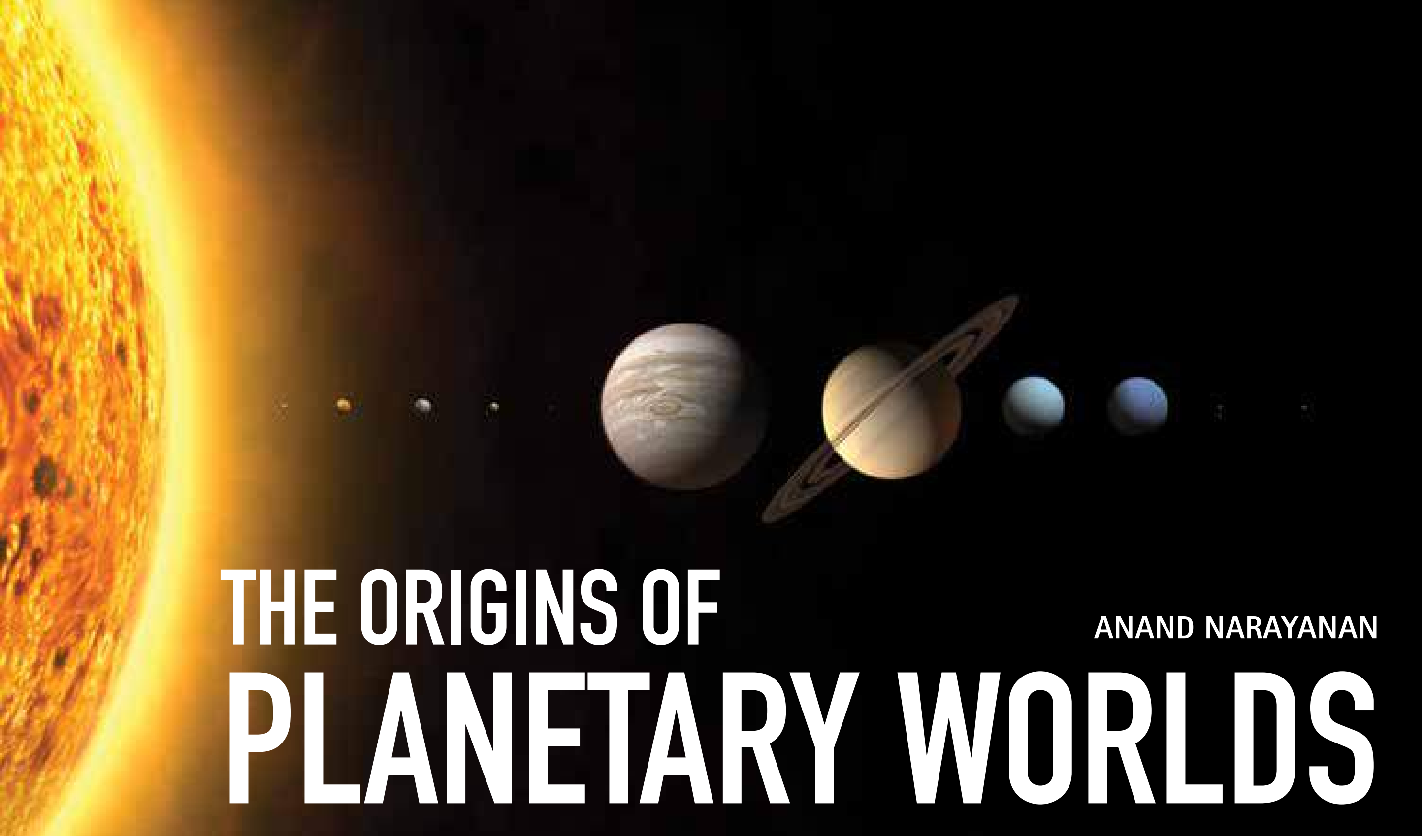

THE ORIGINS OF PLANETARY WORLDS

ANAND NARAYANAN

The solar system is the only place in the entire cosmos that we have surveyed directly using spacecrafts. Years of long and fascinating collaborative efforts between many different disciplines have helped us understand its origins and subsequent evolution. This article narrates this scientific story, discussing how our understanding of planetary systems has been altered by new findings from within and beyond the solar system.

Within the vastness of the universe, with its billions of galaxies and thousands of trillions of stars, there is only one place we can truly call home. The planet Earth is a tiny world compared to the astonishing scale of everything else in outer space. And yet, this rocky world is a special place. It is the only planet we know of that supports life.

Have you ever wondered how the Earth came to be? When and how it was formed? What was there before the birth of the solar system? Underlying such questions is a more fundamental and perennial urge – to know whether we are alone in this universe. We have always wondered about the possibility of life outside Earth. After all, the Earth is just one planet among many others orbiting the Sun, and the Sun a typical star in a universe of countless stars. What are the odds of finding another planet like the Earth circling another star? Is life is a one-time chance event, an extremely rare occurrence, or a ubiquitous phenomenon?

The Birth of the Solar System

The birth of the solar system is a thing of the past. We cannot go back in time and witness how it happened. Our best hope to understand the origins of the solar system lies in carefully formulating hypothesis on possible pathways through which planet formation could have happened. We can then corroborate our hypothesis against some hard scientific evidence. Fortunately, we do not have to do this entirely in the dark. The architecture of the solar system itself holds many crucial clues to its formation.

Patterns of a Common Origin

There are several lines of evidence that suggest that all the components of the solar system have a common origin. For example:

1. All planets orbit the Sun in the same direction. Seen from any point high above the Earth's North Pole, they all revolve around the Sun in counterclockwise direction.
2. The Sun rotates on its axis in the same direction as the planet's revolution around the Sun. This is called **prograde rotation.**
3. The orbits of all planets and a vast majority of minor bodies are nearly circular.
4. All planetary orbits lie along nearly the same plane.

Since, these would be unlikely to occur if individual components had come into existence independently, they seem to strongly suggest the origin of the entire solar system from a single event.

Age of the solar system

If the birth of the solar system was a single event in the history of the universe, how far back in time did it happen?

Scientists have attempted to answer this question by trying to estimate the age of very old rocks – not just here on Earth, but also from outer space. Age estimates of the oldest rocks on Earth done using a technique called radiometric dating, yield a value close to 4.5 billion years (see Figure 1). This is supported by the radiometric dating of several meteorite samples recovered from different locations on Earth, which also suggest an age close to 4.5 billion years. So that's when it must have all happened – about 4.5 billion years ago. To put that number in perspective,

Fig. 1. Fragments of a meteorite collected on April 24, 2012, two days after they fell on Earth. Meteorites are chunks of rock, small and big, that fall onto Earth from outer space. As left-over rocks from the early days of the solar system, they are of great interest.

Credits: © NASA / Eric James.

the first forms of life appeared about a billion years after the Earth formed, and early humans, according to some estimates, only around 600,000 years ago!

4.5 billion years ago

What existed before the solar system? Astronomers have put together a more or less coherent model, in keeping with the known facts and theories. To understand this model, we need to shift our attention away from the stars, to the space between them.

When we gaze at the night sky with our naked eyes, we see the shimmering stars and the darkness of the empty space separating them. But the space between stars is far from empty! What our eyes fail to perceive are large columns of gas and dust that pervades most of the space between stars. This is called the **interstellar medium** or ISM for short. In long-exposure photographs, like the one in Figure 2, the ISM is visible as a thick dark lane.

The primary ingredients of the ISM are atoms of hydrogen and helium,

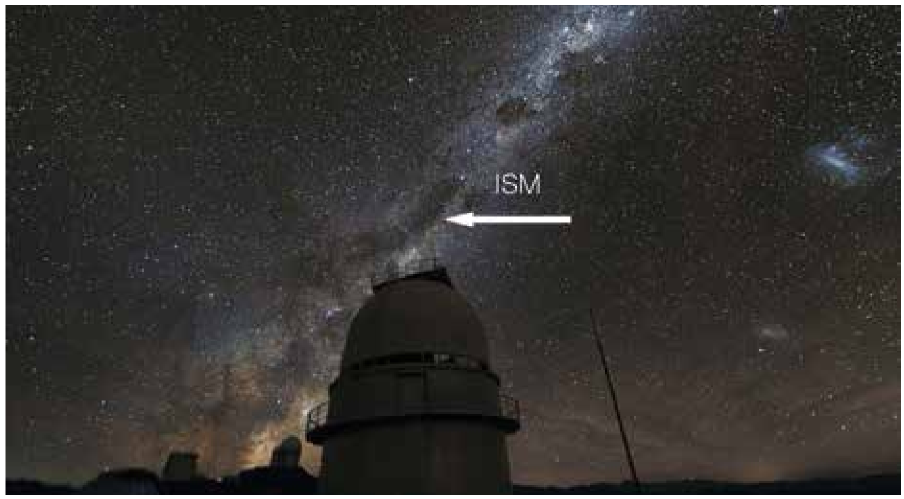

Fig. 2. A long-exposure photograph of the night sky, taken from a location in the Earth's Southern hemisphere. In the background, we see stars as tiny dots of light. Observing this image closely, one may also see dark patches or dark lanes that seem to hide the light from the stars. This is the interstellar medium (ISM), which is made up of gas and very tiny dust particles, spread over vast regions of our Galaxy, in between the stars. In the foreground is an astronomical observatory. Only from such very dark locations like this can the ISM be photographed from Earth with such clarity.

Credits: © European Southern Observatory/Z.Bardon. URL: http://phys.org/news/2016-11-magellanic-clouds.html.

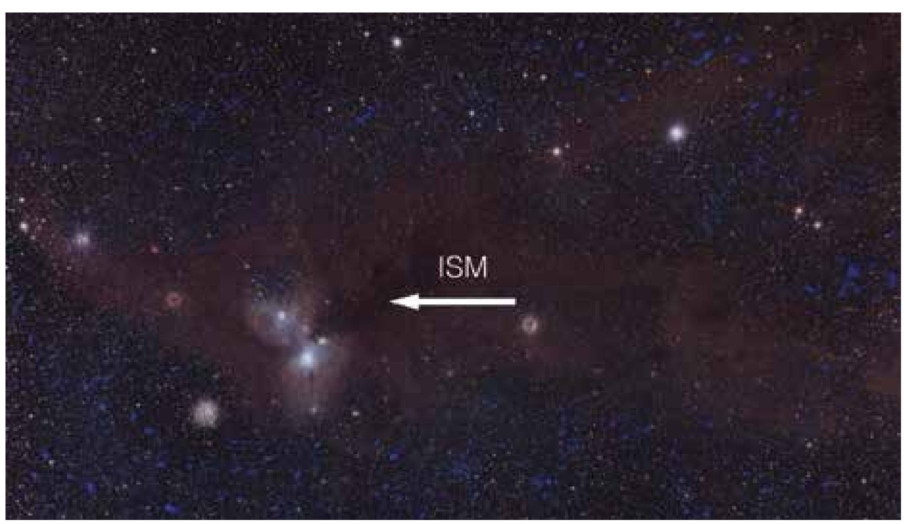

Fig. 3. A zoomed-in photograph of a region within our Galaxy. The diffuse dark cloud is the interstellar medium, which is a mixture of gas and dust grains. Such ISM clouds tend to dim the light coming from stars behind them.

Credits: © Loke Kun Tan / StarryScapes. URL: http://www.deepskywatch.com/Photography/starry-scapes.html.

(a) (b)

Fig. 4. Photographs of star-forming regions taken by the famous Hubble Space Telescope. (a) The famous Orion Nebula, one of the many current sites of star formation in our Galaxy (Milky Way or Akashganga). This particular nebula is very well studied by astronomers because of its relative proximity to us (approximately 1350 light years). It can be spotted in the sky as a faint glow if you look in the direction of the constellation Orion. The Orion Nebula contains enough gas to give birth to thousands of stars. The region that you see in this photograph is a few light years across. (b) The star-forming region in a nebula called NGC 346, within our Milky Way galaxy. The blue and dark coloured columns of gas are the dense ISM gas clouds. Most of the stars at the centre of this image are relatively young, born out of fragments in the gas cloud.

Credits: © NASA/ESA/HST.

with some trace amounts of heavier elements such as carbon, nitrogen, oxygen, and so on. In addition there are very tiny grains of dust. These dust grains, believe it or not, are very similar in composition and structure to the dust grains here on Earth.

Much of this ISM is wispy, with densities of 1 atom per cubic centimetre or even lesser. Although very diffuse, the ISM makes up about 15% of the total visible mass of our Galaxy. This is because there is a lot of space between stars, and the ISM occupies nearly all of it. Certain regions of the ISM are a 100 – 1000 times denser than the average. These denser clouds of gas are loosely referred to as **nebulae.** Very cold and dense nebulae, called **molecular clouds**, are the sites of birth of new stars (see Fig. 4).

Dense interstellar regions, like the Orion Nebula, are huge clouds of gas with enough mass to form hundreds or thousands of stars. The birth of an individual star happens through fragmentation. Studied with great interest in astronomy, fragmentation refers to a process where

Visible • WFPC2 Infrared • NICMOS

(a) (b)

Fig. 5. Two images of the same region, called the Trapezium cluster, within the Orion Nebula, showing a large column of interstellar gas. The two images of this cluster, which is roughly 1300 light years from us, were captured by two different cameras connected to the Hubble Space Telescope. (a) In this image taken at visible light (the same light that our eyes perceive), we can see the gas columns within the cluster. But, as photons of visible light are easily scattered by dust particles, this photo does not show us the inner regions of the nebula. (b) This is a photograph of the same region, taken with a different camera on Hubble that collects infrared photons. Since infrared photons are scattered much less by dust, we are able to peer through the diffuse gas clouds and see what is inside the nebula.

Credits: © NASA/ESA/HST.

Box 1. Sequential snapshots from a supercomputer simulation

Supercomputers help in simulating very slow but complex processes, like the birth of planetary systems, by allowing us to see the sequence of events at a very fast rate. This is very much like watching a movie in fast-forward.

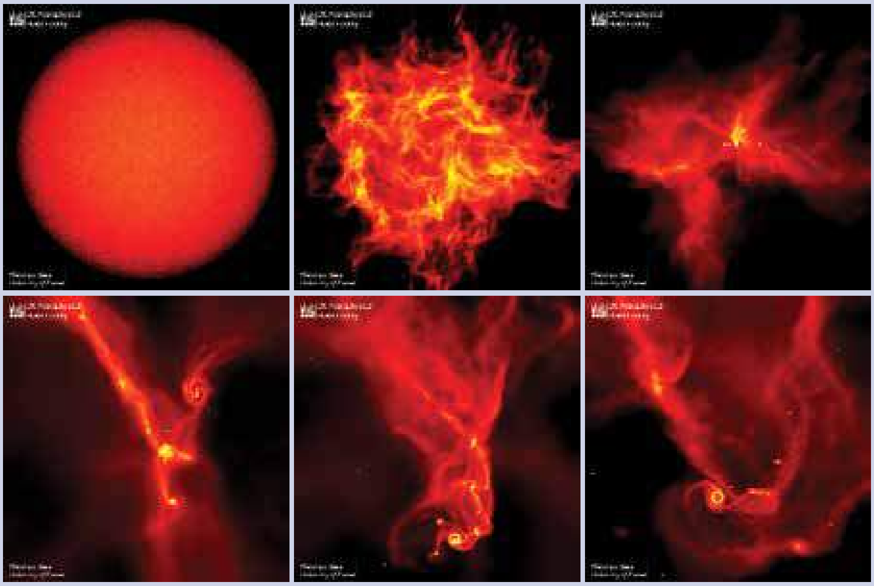

Fig. 6. A super-computer simulation of a star-forming nebula. This simulation begins with the visualization of a giant spherical nebula. It then adds some non-uniform turbulence to this gas cloud, causing parts of it to slowly fragment and collapse. The fragmentation process alters the shape of the nebula, giving it a more filamentary structure. The individual fragments continue to collapse, eventually forming stars. You can watch a full blown animation of this process here: https://www.youtube.com/watch?v=YbdwTwB8jtc.

Credits: © Mathew Batte, University of Exeter.

smaller segments break away from a bigger entity and begin to evolve independently. Many different processes – such as an external shock from an exploding star, a pressure wave propagating through a galaxy, or internal turbulence – can trigger the fragmentation process in an interstellar nebulae. These processes are extremely complex and can only be understood with the help of supercomputers.

It's likely that our Sun, like the newly born stars in the Orion Nebula (see Fig. 7), was also formed from a small fragment within a big nebula about 5 billion years ago. Let's call this fragmented bit the **presolar nebula.** Once fragmented, the presolar nebula started collapsing under its own gravity, shrinking in size every step of the way.

Fig. 7. Fragments within the Orion nebula collapsing under their own gravity. This image, taken by the Hubble Space Telescope, shows several fragments embedded within a cloud in the Orion Nebula. Each fragment has started collapsing under its own gravity and is well on its way to becoming one or more stars. It is possible that our own solar system was formed out of a fragment similar to this.

Credits: © STScI/NASA and ESA.

As it continued to collapse, the temperature of the presolar nebula started rising. This is because the gravitational energy in the collapsing star gets converted first to kinetic energy, and then to thermal energy (which is heat). The collapsing nebula was hottest at its center where most of its mass was concentrated into a big ball of gas (see Fig 8).

Fig. 8. An artist's impression of what a young Sun must have looked like, soon after it formed. In its early phase, the glow of the Sun would have come from the conversion of gravitational energy into thermal energy. Nuclear fusion reactions would have started only after a million years or so, when the density and temperature at the centre of the Sun had reached high values.

Credits: © NASA Goddard Media Studios.

This ball of gas was destined to become the Sun, but not immediately, because conditions were not conducive for the onset of nuclear fusion reactions at its core. Astronomers call such blossoming stars **protostars.** Although nuclear fusion had not yet begun, the conversion of gravitational energy would have been enough to set the proto-Sun ablaze.

Protoplanetary disks – A key milestone in planet formation

According to the current model of planet formation, as the proto-Sun was born, something very interesting took shape around it. A part of the collapsing nebula flattened out, forming a thick disk of material around the proto-Sun. This disk of material is called the **circumstellar disk**

Fig. 9. An artist's impression of a protoplanetary disk around a nascent star.
Credits: NASA/JPL-Caltech. URL: https://www.flickr.com/photos/nasablueshift/7610034044. License: CC-BY.

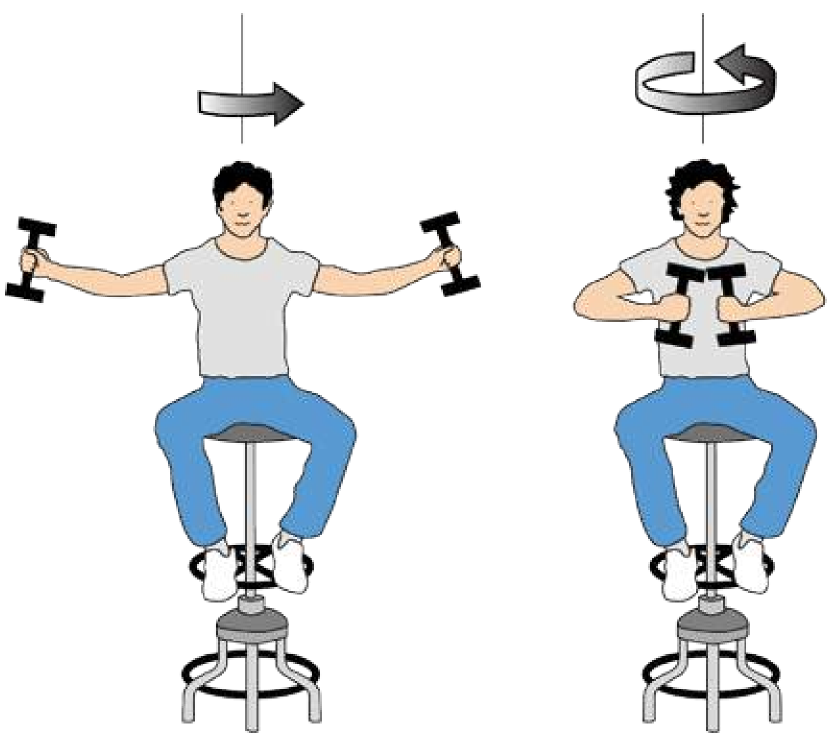

Fig. 10. Spinning on a swirling chair – an example of the principle of conservation of angular momentum. You will notice that when your weight is spread out, you tend to rotate slower. As you shrink by pulling hands and legs inwards, your speed of rotation automatically increases. The principle of cconservation of angular momentum tells us that the angular momentum of a system, which is the product of how mass is distributed within that system and its spin velocity (also called angular velocity), will remain a constant. Thus, if the mass of the system is more concentrated, then the system will spin faster. If the mass gets more distributed, the spin will slow down. Here is a nice video that demonstrates this concept: https://www.youtube.com/watch?v=_eMH07Tghs0.

(meaning, a disk circling the star), or the **protoplanetary disk** (meaning, a disk that is a precursor to planet formation).

This disk forms as a result of the need to conserve the angular momentum of the system. The principle of conservation of angular momentum is rather simple. We regularly experience it in our lives. Have you ever sat on a swirling chair? Next time you do so, ask your friends to spin you around. Extend your arms outwards (see Fig. 10). If you want, you can also spread your legs apart. After a few spins, pull both hands and legs inwards. Repeat this and see what happens to your spin speed.

When the pre-solar nebula shrank in size, it started rotating faster. This increase in velocity of rotation ensured that the entire cloud did not collapse into the central proto-sun. Instead some of it formed a circumstellar disk. Estimates suggest that about 99% of the mass of the collapsing nebula must have gone into the Sun, and only 1% settled into the disk. This 1% mass lead to the formation of the planets, their moons, asteroids and everything else that we see in the solar system.

From Disks to Planets – The Pivotal Few Millions Years

Imagine constructing a whole planet as big as the Earth or Jupiter by piecing together particles the size of sand. As absurd and as far-fetched as it may seem, this is exactly what seems to have happened in the case of our solar system. The formation of planets from the swirling gas and dust around the young Sun was an unhurried process that took several million years to complete. These years are likely to have been very dramatic as there were many ways things could have gone differently, retarding the formation of planets and their long-term stability in the solar system.

In the sequence of events that unfolded, the first was the slow condensation of material in the rotating proto-planetary disk to form small lumps of the order

Box 2. Activity zone: Order out of Chaos. The formation of a proto-star with a circumstellar disk is a slow process, lasting several million years. What is interesting, and perhaps counter-intuitive, is that irrespective of the size or shape of a gas fragment in a nebula, after a few million years into its collapse, it will change shape. Its new shape will consist of central spinning big blob of gas, with a disk of matter rotating around it in the same direction. This is an example of order emerging out of chaos.

To see a similar phenomenon in action, try out this simple experiment. Quickly stir in a pinch of coloured powder or turmeric into a bowl of water in a random manner. Leave it for a few seconds and watch what happens. No matter how randomly you stir the water, the powder will almost always settle into a slow rotation, in one direction or the other.

Fig. 11. The formation of dust balls (also called dust bunnies) in our houses is an example of accretion in action.

of size of a few centimetres. When they encountered each other, these lumps got glued together due to electrostatic force (see Box 3). Once the lumps grew to rocks that were a few centimetres in size, gravitational forces became central to the story. Through gravitational attraction, smaller rocks gathered more matter and gradually grew bigger. This process of smaller objects acting under some force to collate together and grow bigger is called **accretion.** You can find an example of accretion in your own house. You may have noticed that when corners and edges of furniture or walls are not cleaned regularly, the dust in these places tends to gather into balls (see Fig. 11). This is an example of **accretion** – smaller objects acting under some force to collate together and grow bigger.

The rocks formed through accretion are called **planetesimals** (meaning very tiny planets). Planetesimals are not planets. We can think of them as flakes of condensed material that can gradually acquire more mass, and in the very distant future become planets. The kind of chemical compounds that would condense to solid planetesimals depended largely on the temperature in the protoplanetary disk. The temperature in any region of the protoplanetary disk was dictated by its distance from the central proto-Sun. While the temperature of the protoplanetary disc was highest near its centre, due to the Sun's fierce heat, it eased out in a slow manner from the centre of the protoplanetary disk to its outskirts (see Fig. 12).

Astronomers who study the formation and evolution of proto-planetary disks often talk about the **frost-line,** a boundary beyond which easily volatile compounds, like water, can exist as solids. At distances closer than the frost line, these volatile compounds will only exist in their vapour forms. For water and several other hydrogen based compounds, like methane and ammonia, a temperature of about 200 K is a good approximation for transition from solid to vapour form. Given that different volatile compounds have different melting points, the frost line is more likely to be a zone rather than a sharp line. The frost line in today's solar system lies between the orbits of Mars and Jupiter. In the distant past, when the Sun was not so bright, the frost line must have been closer.

In the high temperature regions (500 K – 1500K) inner to the frost line, non-volatile materials, like silicates, and metallic compounds made of iron, nickel, and aluminium, condensed into hard grains. These hard grains first grew into rocky planetesimals, and then to the rocky planets of the inner solar system (i.e., Mercury, Venus, Earth and Mars). Beyond the frost line, hydrogen compounds condensed into grainy ices. Silicates and metals were also still present in the outer solar system, but they were outnumbered by the hydrogen compounds. Thus, the planetesimals that grew in the outer regions of the solar system were primarily icy rocks made of hydrogen compounds with trace amounts of silicate grains and metals engrained in them.

The lightest elements, hydrogen and helium, initially remained as gases, dispersed everywhere in the collapsed

Box 3. What force would have initiated the growth of planets from grains of dust? Gravity would be the common guess. While gravity did play a major role in the formation of the solar system, it was not the first and the most decisive force to seed the growth of planets. The small dust particles in the protoplanetary disk were too small and too light for gravity to be significant between them. Have you ever seen how a balloon that is rubbed on a woollen or cotton material sometimes sticks to the wall? Or how your hair stands up when you bring a ruler that is rubbed on some surface close to it. The main attractive force acting in these cases is electrostatic force, the force between charged particles. The same electrostatic force caused small grains and lumps in the protoplanetary disk to stick together and grow bigger in size.

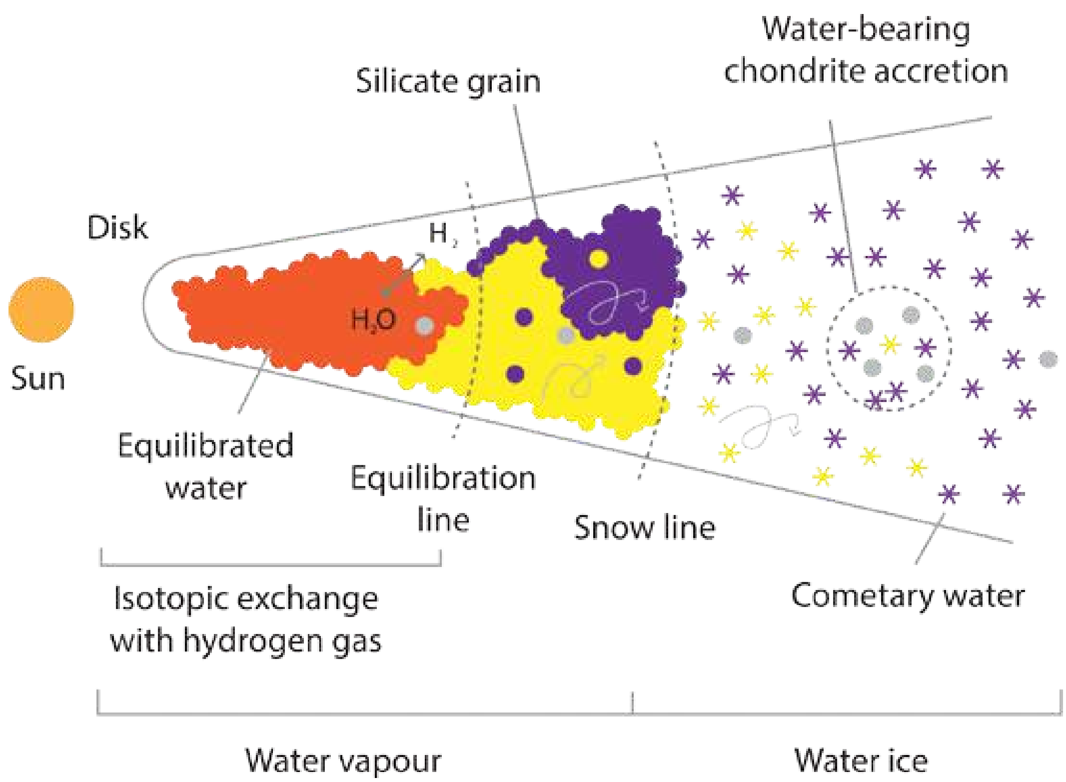

Fig. 12. The temperatures in the protoplanetary disk decide which chemical elements condense at a given location. Close to the newly formed Sun, grains made of heavier metals, with their very high melting points, could remain as solids. Icy materials were easily vaporized because of these high temperatures. They would condense as solids only at a distance from the Sun. The pressure from the Sun's radiation would also sweep the gases into the outer regions of the solar system, mostly beyond the orbit of Mars. This sorting of material in the protoplanetary disk eventually led to the diversity that we come across between the inner terrestrial planets and the outer gas giants of the solar system.

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solar nebula without ever condensing into solids. These gases were slowly pushed from the inner to the outer regions of the protoplanetary disk by the pressure of the light radiated by the newly-born Sun, in much the same way as wind steers the sails of a boat. Scientists call this pressure from light – **radiation pressure.** Most of the hydrogen and helium gas thus settled in the outer regions of the solar system. There the icy planetesimals accrued them in large measures, growing gradually in size to become gas-giants, like Jupiter or Saturn. According to this scenario, we expect the cores of these gas-giant planets to be icy, but as of now, these claims remain speculative. For planetary scientists, finding out what the inner regions of a big planet like Jupiter or Saturn is made of from spacecraft observations has been very tricky. Some of the hydrogen and helium gas was also drawn in by terrestrial

	Examples	Typical Condensation Temperature	Relative Abundance (by mass)
Metals	Iron, Nickel, Aluminium	1000-1600 K	0.2 %
Rock	Various minerals	500-1300 K	0.4 %
Hydrogen Compounds	Water (H_2O), Methane (CH_4), Ammonia (NH_3)	<150 K	1.4 %
Hydrogen and Helium Gas	Hydrogen, Helium	Do not condense in nebula	98 %

Fig. 13. Materials in the solar nebula. A summary of the four types of materials found in the solar nebula – with examples of each type and their typical condensation temperatures. The squares represent the relative proportions of each type (by mass).

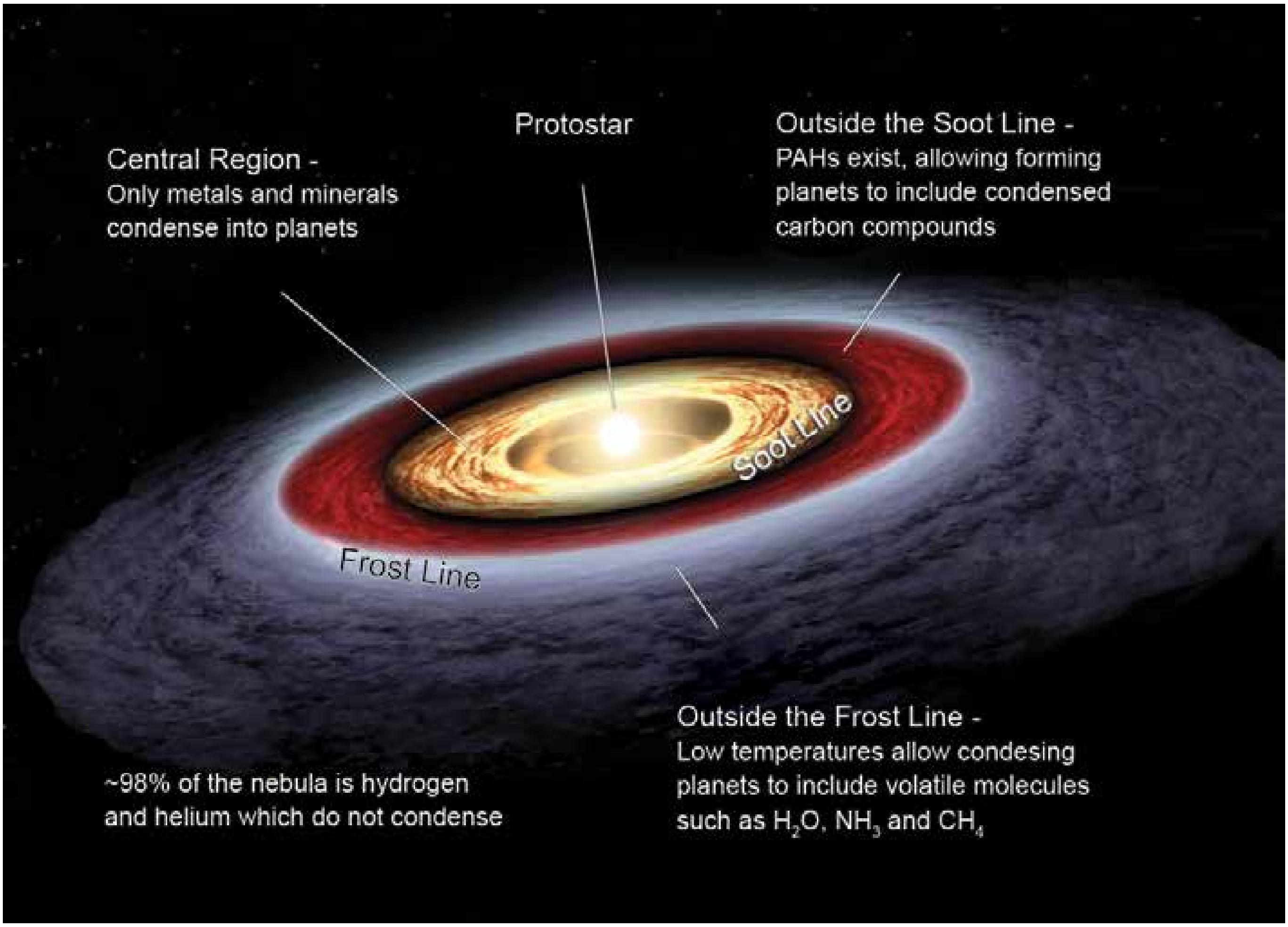

Fig. 14. An artist's impression of the proto-Sun and the disk around it. Metals and minerals with high melting points condensed in the inner regions of the solar system to form the terrestrial planets. In contrast, it was only beyond the frost line that easily volatile compounds could become solid. The temperature gradient across the protoplanetary disk is the key reason for the differing chemical compositions of terrestrial planets and gas giants.

Credits: © NASA/JPL-Caltech.

planets, and formed their early atmosphere.

As this process neared its end, many planetesimals remained scattered between the newly formed planets. These leftovers became comets and asteroids. Their material compositions were similar to the planets: i.e., asteroids made of hard rock and metal in the inner solar system, and icy fragile comets in the outer solar system. The leftovers must have had nearly circular orbits in the same plane as the orbits of planets. But in due course of time, as these planetesimals moved close to large planets, gravitational forces must have toppled their orbits into arbitrary directions, like a pellet released from a sling shot. A good number of these planetesimals must have escaped the confines of the solar system through this process. Many others ended up in much-elongated orbits that took them in and out of the solar system. The planets on the other hand, with their significantly higher mass, remained unperturbed by such encounters, eventually settling into dynamical stable orbits.

Evidence from Afar

This account of the formation of the solar system (planetary systems in general) goes by the name **Nebular Hypothesis.** A hypothesis is a suggested explanation for something based on reason. It is not a theory, because all aspects of it are not fully proven. But it is not a wild guess either. First proposed in a very crude form in the late 18th century, the Nebular Hypothesis has been refined and reworked from time to time, based on fresh insights into the process of planet formation.

One may wonder how much of the Nebular Hypothesis is backed by evidence. As already mentioned, the birth of the solar system is an event from a past that we have no direct access to. But it is only reasonable to assume that the same forces that drove the formation of our solar system might be acting elsewhere in the universe. In fact, there must be some planetary systems taking shape around other newly born stars at this very moment! Through very high resolution photography of star forming regions within the Milky Way, astronomers have found several instances of the birth of planetary systems. The Orion nebula, described earlier (see Fig. 4a), contains many examples of this. Nestled within its vast columns of gas, are several thousands of newly born stars. Such observations strongly affirm the view that stars are born out of the gravitational collapse of dense fragments within gas clouds in interstellar space. Today we know of hundreds of such sites of star formation, or stellar nurseries, within the Milky Way.

Through its high resolution cameras, the Hubble Space Telescope has also found that quite a few of the infant stars in the Orion nebula have extended disks around them (see Fig. 15 and 16). These proto-planetary disks stretch out to radii of more than 100 astronomical units (an astronomical unit, or AU, is the distance between the Sun and Earth ~ approximately 150 million kilometres). If we could roll back time to a period somewhere between 4 – 5 billion years ago, our solar system, from a distance of a few hundred light years, would have looked like any one of these.

An important aspect in the validation of the Nebular Hypothesis is to discover fully formed planets around other stars. From the 1990s onwards, astronomers have been routinely discovering planetary systems around other stars. These extrasolar planet (**exoplanets**, for short) discoveries have been made using several different techniques. The most successful of these techniques, at present, is biased towards finding big planets, of the size of Jupiter and Saturn, circling their host stars. Only very recently have these techniques reached the level of sophistication required to discover planets that are smaller, but still a few times the mass of the Earth. Astronomers call such planets the **super-Earths**. The Holy Grail, no doubt, is to find a planet of the size and mass of the Earth around a Sun-like star, at a distance where the heat from the Sun is just right enough to ensure the presence of liquid water – a prerequisite for life as we know it. If such a planet exists, we may not have to wait too long for its discovery, given the very rapid pace at which the field of extrasolar planet research is evolving.

Thus, our best hope of finding answers to the origins of our solar system lie not only in investigating objects within the confines of the Sun's gravity, but also those worlds that are far away from us. By looking into the far reaches of space, we are in a way searching for answers to our own origins.

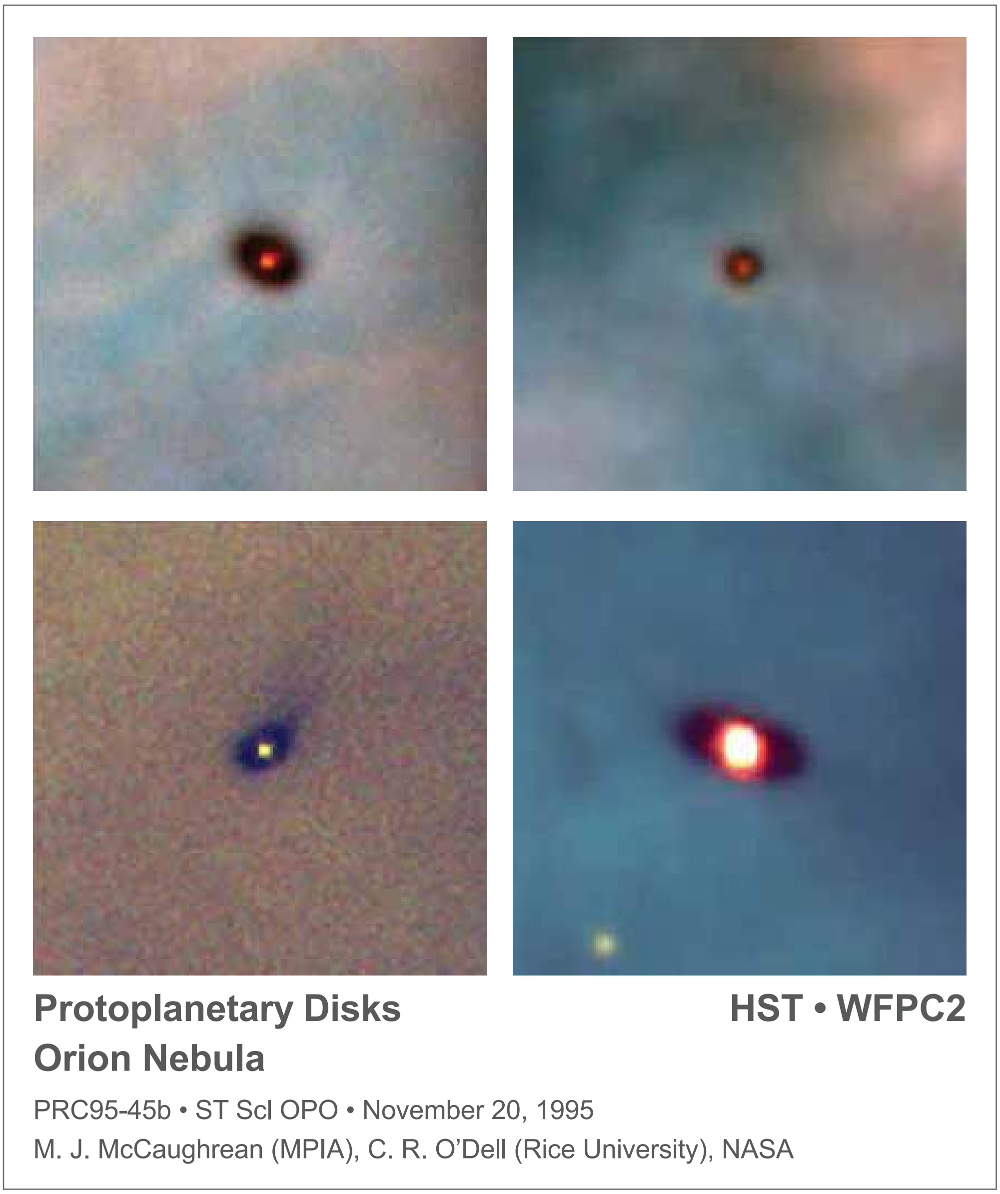

Fig. 15. Four examples of protoplanetary disks around young stars in the Orion Nebula. The bright object in the centre of each image is a newly born star (a protostar), surrounding which is an extended disk of material that may eventually give birth to planets, asteroids and comets.

Credits: © STScI / NASA and ESA.

Fig. 16. An assortment of newly born stars in the Orion Nebula. There are thousands of examples of on-going star and planet formation within the Orion Nebula. Look closely and you will notice the presence of protoplanetary disks around some of these young stars.
Credits: © NASA/ESA and L.Ricci (ESO).

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Resources

1. A Lunar and Planetary Institute designed activity for the classroom to help students understand the sequence of events in the formation of the solar system- http://www.lpi.usra.edu/education/timeline/activity/.
2. A short video that takes one through the formation of the solar system - https://www.stem.org.uk/elibrary/resource/26893.
3. This page from the Big History Project has a wonderful timeline on the formation of the solar system - https://www.bighistoryproject.com/home. Look under the link "Earth &The Solar System".
4. This page from the University of Colorado has several activities, appropriate for students from classes 4 – 8, to help understand the solar system - http://lasp.colorado.edu/education/outerplanets/solsys_planets.php.

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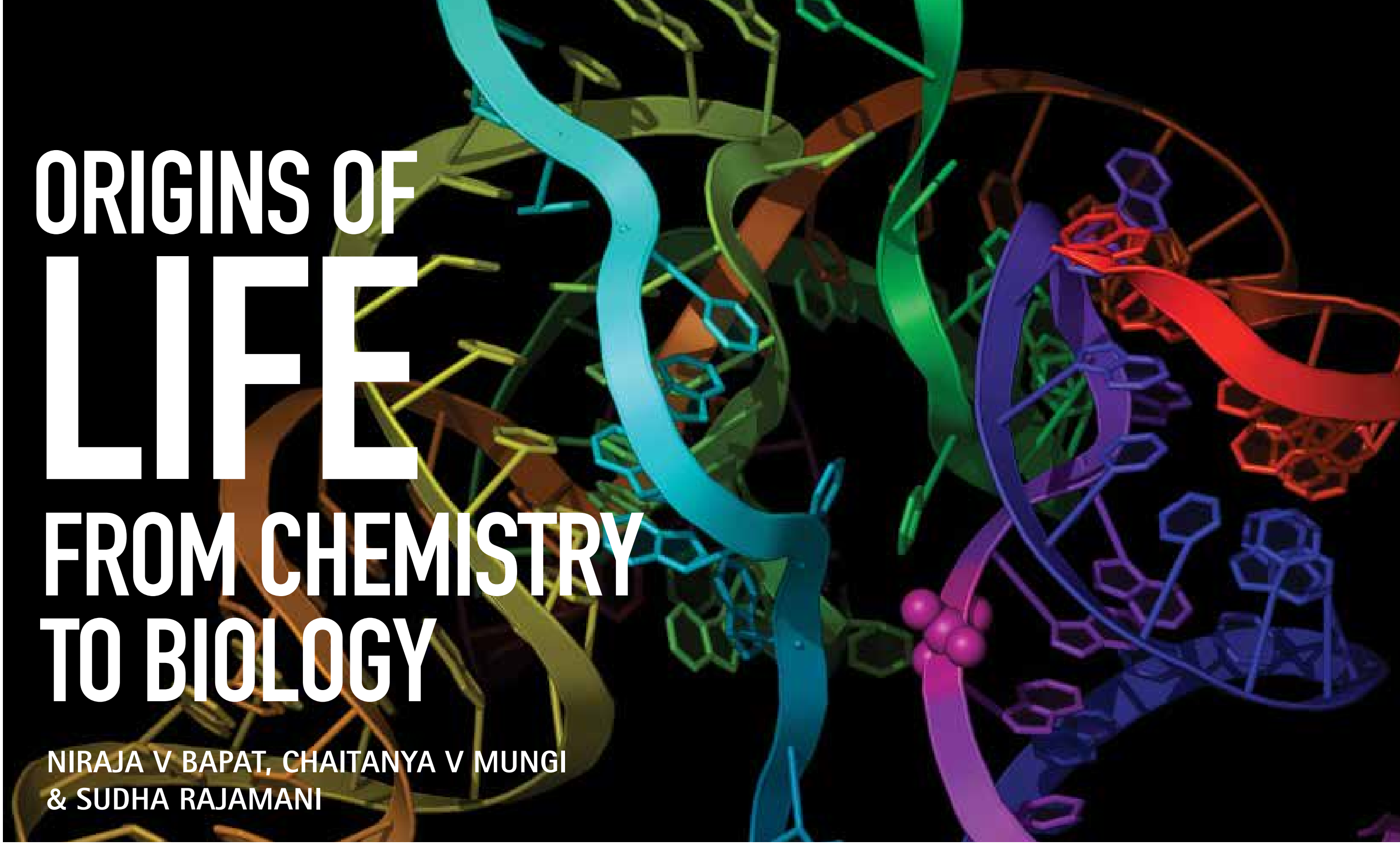

ORIGINS OF LIFE FROM CHEMISTRY TO BIOLOGY

NIRAJA V BAPAT, CHAITANYA V MUNGI & SUDHA RAJAMANI

Understanding how life started on Earth is a long-standing mystery. This article explores the sequence of events that may have led a mixture of simple chemicals to transform into the first living cells; showing how, in recent years, ribonucleic acid (RNA) has emerged as an important clue to this mystery.

Humans have long wondered about the origins of life. The popular view was that a living being could spontaneously arise from non-living matter. Most people believed this to be true, despite their religious beliefs or the lack of it, since they could see life forms, such as fleas and maggots, arise from inanimate matter (dust) or dead animals. Many philosophers tried to explain this phenomenon of spontaneous generation using various hypothetical means, including the "five elements" or "vital heat" etc. However, experiments conducted by Louis Pasteur in the mid-19th century conclusively disproved these unscientific ideas.

Pasteur used meat broth and special type of flasks, called swan-necked flasks, to demonstrate that life could not originate from non-living matter without contamination (see Figure 1). The swan-necked flask has a long downward-

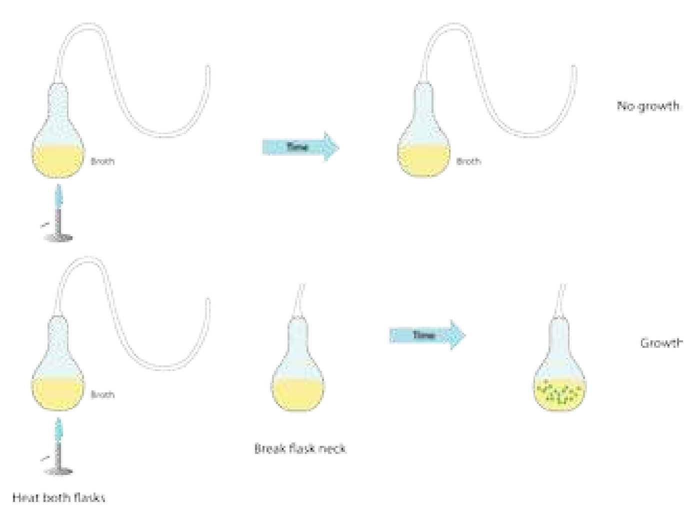

Fig. 1. Pasteur's swan-necked flask experiment. Sterilised meat broth does not show growth if the curved neck of the flask is intact. In contrast, when the neck of the flask is broken, the broth is exposed to dust and air, and shows microbial growth. Adapted from study.com.

curving neck, which prevents particles like dust or spores from falling into the broth. Pasteur boiled meat broth in two flasks, one with its neck intact and the second with its neck removed. Microorganisms were found growing in the flask without the neck whereas the control flask remained sterile. This result demonstrated that complex life arises only from other living organisms. This phenomenon is known as *'Omne vivum ex vivo'* that means "all life (is) from life".

Today, we know this to be true of all life-forms – every living being arises from other beings by means of reproduction. For e.g. the eggs of flies in dead meat give rise to maggots, the spores of microbe and fungi result in their growth in stale food/broth, and complex organisms reproduce by sexual reproduction to give rise to future generations. However, this begs the question of how the very first living being would have come into existence. What chemical mixtures would have allowed life to emerge? What sources of energy did the earliest life-forms use? Finding conclusive answers to a plethora of such questions regarding the origin of life on Earth remains a huge challenge.

To understand the steps that may have led to the origins of life, we need to reduce all living organisms into their most fundamental functional units. A cell is considered to be the basic unit of all life. A cell is fully functional, even on its own, as demonstrated by single-celled organisms such as bacteria, amoeba, paramecium, yeast etc. In fact, each cell can be thought of as a miniature factory – producing energy that is required for living, moving around, absorbing food from its surroundings, and reproducing to form more copies of itself. It achieves this marvellous feat by employing tiny machines called proteins, with each protein doing a specific job in the cell. Proteins are produced by an elaborate process, called translation, of joining amino acids in a sequence dictated by the genetic material of the cell. The genetic material of a cell, in the form of Deoxyribonucleic Acid (DNA), stores all the information required for various cellular processes. In this way, it acts like a blueprint of life! DNA itself is produced by the action of a variety of enzymes, all of which are proteins. In other words, the information stored in DNA is used to synthesize proteins and proteins are required in the process of making DNA. It is the interdependent production of these two important categories of biological molecules that gives rise to the mystery around the origins of life. Similar to the "chicken and egg dilemma", which of these bio-molecules came first – DNA or proteins; information or function (catalysis)?

While there are many different ways in which scientists have tried answering this question, one possible answer is – neither! Instead, Ribonucleic Acid (RNA), a chemical cousin of DNA, may have been the first important biomolecule to emerge. RNA is a unique biomolecule – it can perform functions of both DNA and protein – storing genetic information (as in RNA viruses) as well as catalysing metabolic reactions (in the form of ribozymes, i.e., RNA sequences that act as enzymes). Since RNA alone could acquire both these properties (under exceptionally rare circumstances), it is possible that early life-forms consisted of specific molecules of RNA working together as a network (similar to metabolism). The subsequent evolution of such RNA networks may have led to the complexity of life that we know of today. But, if this is how early life evolved on Earth, how did these RNA molecules come together to form a living organisms? What environmental conditions would have shaped this process?

Several fossil records have shown us that the diversity of life that we see today has evolved from simple unicellular entities giving rise to increasingly complex multi-cellular organisms, over a period of billions of years. This suggests that the first living organisms would have had to be very simple, even simpler than a single cell. In fact, the oldest fossil records of life on Earth, uncovered recently from some rocks in Greenland, are in the form of some simple layered structures called stromatolites. Formed by the activity of microorganisms like cyanobacteria, stromatolites assume different morphological shapes – ranging from the branched to the conical. These structures are about 3.7 billion years old. Cell-like structures from periods pre-dating this would have most likely been much simpler. These older structures are usually referred to as "protocells". National Aeronautics and Space Administration (NASA) defines a protocell as "membrane-encapsulated genetic material capable of growth, replication and Darwinian evolution". To imagine this structure, think of a protocell as consisting of only two basic components *viz.* an outer membrane enclosing some sort of functional molecular machinery, like proteins or nucleic acids. The presence of just these two components would have made the protocell capable of evolving into more complex living forms.

All modern living cells are also bound by membranes. These membranes allow the selective movement of molecules in and out of cells, while also protecting their metabolic networks and genetic material from the external environment. And while the exact composition of this cellular boundary varies with cell types, it mainly consists of complex lipid molecules. In contrast, protocells would not have had the elaborate machinery that modern cells use for the synthesis of complex lipid molecules and their

Box 1. Amphiphiles

Derived from two Greek words, *'amphis'* meaning 'both' and *'philia'* meaning 'love', amphiphiles are compounds that contain both water-loving (polar/hydrophilic) and water-repelling (non-polar/hydrophobic) chemical groups. Thus, in aqueous solutions, amphiphilic molecules assume shapes that allow their non-polar groups to stay away from water. Some examples of amphiphiles that we use in our day-to-day life include soaps, detergents, butter and oils.

maintenance (integrity). Thus, it is likely that their encapsulating membranes would have been composed of some very simple amphiphilic molecules (see Box 1), like fatty acids. Studies show that not only can simple and complex amphiphiles self-assemble to form membrane-like structures; they can also divide under certain conditions to produce more such structures. Other experiments have demonstrated that these interesting molecules are capable of spontaneous encapsulation of entities like nucleic acids and proteins inside compartments called vesicles. The main role of these encapsulating membranes would have been to protect genetic material. However, much like modern cell membranes, membranes composed of fatty acids have also been shown to compete for the selective absorption of resources from the surrounding environment – a property crucial to evolution.

Box 2. Prebiotic chemistry

As the name suggests, prebiotic chemistry is the study of chemical events before the emergence of life on Earth. It explores processes like the formation of biological monomers, the construction of polymers from these monomers, and viable assemblies of polymers that could ultimately gave rise to life. A highly inter-disciplinary field, prebiotic chemistry draws insights from a variety of disciplines, including chemistry, geology, computer simulations, astronomy, physics, and biology etc.

On the other hand, primitive genetic material is believed to have been capable of passing on its encoded information to the next generation without the help of proteins. This fact has been clearly demonstrated by several prebiotic chemistry (refer Box 2) experiments in the last several decades. Although the synthesis of organic molecules (*viz.* Urea) from inorganic reactants (*viz.* Ammonium cynate) was first demonstrated by Friedrich Wöhler in the early 19th century, the stage for the field of prebiotic chemistry was truly set by the famous Urey-Miller experiment. In the 1950's, biochemists Stanley Miller and Harold Urey, demonstrated that complex organic compounds like amino acids could be formed spontaneously from very simple chemicals like water, methane, ammonia and hydrogen, under simulated atmospheric conditions of the young Earth.

Over the past several years, many origins of life researchers have begun favouring RNA as the molecule of choice for the earliest genetic material (see Figure 2). This choice is supported by what we are discovering about the functions of RNA within living cells. As we have seen before, RNA can act not only as an information storage molecule, but also as a catalyst for protein synthesis in modern cells. That it performs all core functions in the protein-making factory in modern cells also strengthens the likelihood of a putative 'RNA World' existing during the early stages of evolution on life on Earth. Scientists have shown that ribonucleotides can self-assemble into RNA polymers in an all-chemical environment, without the aid of biological (proteinaceous) enzymes. They have also been successful in showing the evolution of RNA molecules with enzymatic activity (or ribozymes) in the lab. Scientists across the world are now working on simulating the faithful chemical replication of RNA as well as similar nucleic acid molecules. Considering the fact that the replication of nucleic acids in modern cells requires many proteins to work together in a tightly controlled manner, achieving this entirely by chemical means is no small feat!

The main focus of research in our lab is to understand the basis of the chemical emergence and replication of nucleic acids that can occur in the absence of enzymes under conditions simulating that of early Earth. We seek to understand the process by which RNA polymers are formed from its monomers in the presence of prebiotic molecules like lipids, clay particles etc. We are also working towards understanding the rate and accuracy of enzyme-free copying of information-carrying molecules, especially those from a putative RNA world. These studies are aimed at understanding the emergence and evolution of protocells on early Earth.

In conclusion, it seems likely that the emergence of simple primitive cells marked the transition from complex chemistry to biology during the early history of life on Earth. However, some crucial challenges remain in our understanding of this process. One of which is to demonstrate multiple self-replication cycles of RNA (or similar

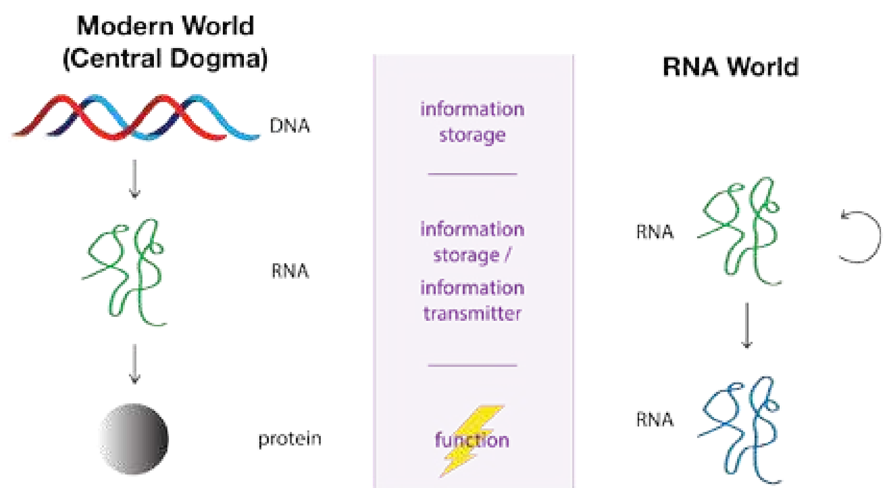

Fig. 2. A putative RNA world may have existed in the early stages of evolution of life on Earth. RNA is believed to have acted both as information-carrying molecules and as catalysts in a putative RNA world. Adapted from www.chemistryworld.com.

nucleic acids), a challenge usually referred to as a "Molecular Biologist's Dream". Another challenge has been to demonstrate that self-sustaining protocell-like structures are capable of evolution. Consequently, we still have some way to go to achieve our goal of constructing artificial cells in a test tube. Nevertheless, this is very plausible; and once achieved, will answer some of the most daunting questions about the origins of life on our pale blue dot.

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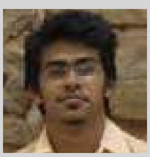

Chaitanya Mungi joined IISER Pune as an integrated PhD student in 2011 after completing his Bachelors in Biotechnology from Jai Hind College, Mumbai. His work centres on understanding the chemical processes that may have led to the synthesis of polymers on early Earth. Chaitanya is also interested in science popularization and communication. He can be reached at cvmungi@students.iiserpune.ac.in.

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THE ASIAN ASSOCIATION OF BIOLOGY EDUCATION'S 26TH BIENNIAL CONFERENCE A REPORT

REETEKA SUD & GEETHA IYER

Held on the 20-23rd September, 2016, the 26th biennial conference of the Asian Association of Biology Education, focused on encouraging communication between educators and researchers on practices in and challenges of current trends in Biology Education. This report captures some of the highlights of this event.

United in the idea that a networked teaching community would be an advantage both for students and teachers, a group of Biology teachers in Philippines started the non-profit organization – Asian Association of Biology Education (AABE). That was 1966. Today, AABE has members in 16 Asian countries. The 26th biennial conference, that marked the beginning of India chapter, was held in September 2016 in Goa. The theme of this year's conference was – Trends in Biology Education and Research: Practices and Challenges. The conference was inaugurated by the Chief Minister of Goa, Lakshmikant Parsekar, who delivered a short but apt talk about the role of a teacher; punctuated with examples from his own life.

Satyajit Rath, faculty at National Institute of Immunology, New Delhi, delivered a talk that was very pertinent to the meeting's theme. He discussed current practices in Biology education, drawing attention to worrying trends that were resulting in significant losses in learning. Being an immunologist, he spoke about how, for example, current practices in biology education were narrowly centered on diseases, when they should actually go beyond diseases to encompass health and its repercussions on society. Like with many other subjects, teaching learning processes in biology appear to be focused not on understanding health, but passing exams. Prof. Rath wondered if this trend could change and the biology syllabus shift its focus from a reductionist view of, say 'hygiene', to a broader one, of say 'health'; and highlight

Objectives of AABE

- Improve teaching of (and promote research in) biology in Asian countries.
- Bring together biology educators of Asian countries at periodically held conferences.
- Establish an agency in Asia to serve as a center for the exchange of teaching materials, journals and research papers, specialists and teachers in the biological sciences, and to open channels of communication between this agency and agencies in different countries doing similar work.
- Promote the creation of biological science teaching centers in each Asian country.

Fig. 1. Satyajit Rath, from the National Institute of Immunology, Delhi, speaking at the AABE conference.
Credits: Reeteka Sud. License: CC-BY-NC.

> *"[This conference] definitely gave me an understanding of the current situation of biology education in India."*
> — A participant.

interconnectedness, for example between the health of individuals and communities they belonged to. Can the purpose of education be "re-purposed" from a job-directed education with information-overload for students, to focus on raising informed citizens who can think on their own?

Rohini Balakrishnan, Professor from the Indian Institute of Science (Bangalore), took the participants through a very enlightening process. Pointing out why Natural History should be an important part of Biology, she drew attention to the fact that today, unfortunately, very little of it makes any appearance in the average Biology classroom. This manifests itself in the process of hiring of new faculty — rarely do departments hire those trained in Natural History. Biology is all around us, and yet sadly 'modern biology' has become all about laboratories and molecular analysis, with no room for learning from simply observing nature. She pointed out how our fisheries, agriculture, pharmaceuticals, health issues, and even the current crisis brought on by climate changes, are all dependent one way or the other on Natural History. Human welfare cannot be driven only by statistical analysis of molecules; it must have a sound basis in natural history. Her point resonated with that of Satyajit Rath, who described the same as a dominance of reductionism in biology education.

No doubt our education system imposes a lot of constraints — the syllabus content is continually growing, and the rush to cover all that before exams can be heavily taxing for teachers and for students. But as Swati Patankar, faculty from IIT Bombay, showed — it is still possible for teachers to "break away from the mould" — there is considerable autonomy that teachers have when they are in class. When managed well, the outcomes of this approach can be extremely impressive. To support her point, she shared examples from her class, where even factual information is taught and asked (in exam questions) in the context of a bigger problem that students can relate to. As a result, facts that they would have otherwise just learned by rote become meaningful to students. Instead of being mere spectators who passively watch the teacher in class, students therefore become active participants in their own learning process.

> *"I was very touched and warmed to meet some very enthusiastic and dedicated school teachers. I would like to make special mention of Mr. Rajesh Patil... Not only were his ideas creative and innovative, he had so much energy and enthusiasm, I walked away thinking that this was the key to being a good educator and was truly inspired".*
> — A participant.

> *"I have also noticed a divide between the flexibility of research-based institutes vs. teaching-only colleges with respect to teaching courses. This came through in Swati Patankar's talk, where she illustrated creative ways in which questions can be asked in the undergrad setting."*
> — A participant.

Being part of the conference definitely made many of us sit up and think more deeply about the pressing need to start the process of improving Biology education. This need is, in fact, a big reason driving the formation of an Indian chapter now, and the Asian association over 50 years ago. The founding members felt that a networked teaching community is more empowered to learn from each other, and make a difference in the overall education system in the process.

"It was nice to see enthusiasm of many teachers who, in spite of challenging situations, are trying their best to make learning exciting." — A participant.

The conference provided a rich platform for the exchange of ideas by bringing together people from different backgrounds, ideologies and practices. Given that it was attended by approximately 100 participants, the conference offered a tremendous opportunity for collaborations. Did it succeed in encouraging teachers to break away from the shackles that limit Biology education? In a very limited way, perhaps, but we see this as a good beginning. Networking opportunities afforded by meetings such as these can go a long way in bringing motivated teachers together. It is only when people with different approaches and philosophies towards Biology education come together, can we expect a serious overhaul.

Teachers in India can join this community by contacting the Executive Director of the Indian chapter, Narendra Deshmukh (nddeshmukh1965@gmail.com). The AABE also publishes a journal – The Asian Journal of Biology Education, which can be accessed online (http://www.aabe.sakura.ne.jp).

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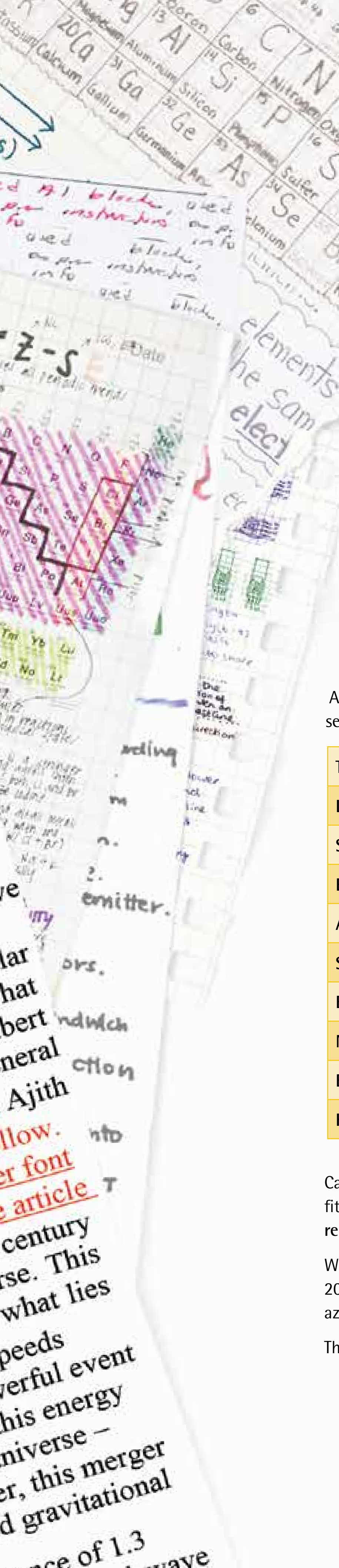


Write for us

i wonder... is a magazine for middle school science teachers. This not-for-profit effort is published twice a year - June and December, and available in free online and print formats. Each issue is originally available in English, and later translated into Hindi and Kannada.

We are always on the lookout for articles that capture new perspectives to the teaching and learning of science, building on concepts covered in middle school curricula. Submissions from practicing science teachers and teacher educators are particularly welcome. We'd like to read more about the methods, activities, and examples you've tried and tested in your classrooms to engage the curiousity and imagination of your young learners.

Send us a science snippet! We are looking for short (200-500 words) science snippets that bring out the funny, fascinating, mysterious and inspiring facets of science and scientists. Send one of these to us, along with a short bio and a photo of yourself - the five best submissions will be published in our next issue!

Apart from a theme section that is unique to each issue, **i wonder...** features many of these non-theme sections that are common across issues:

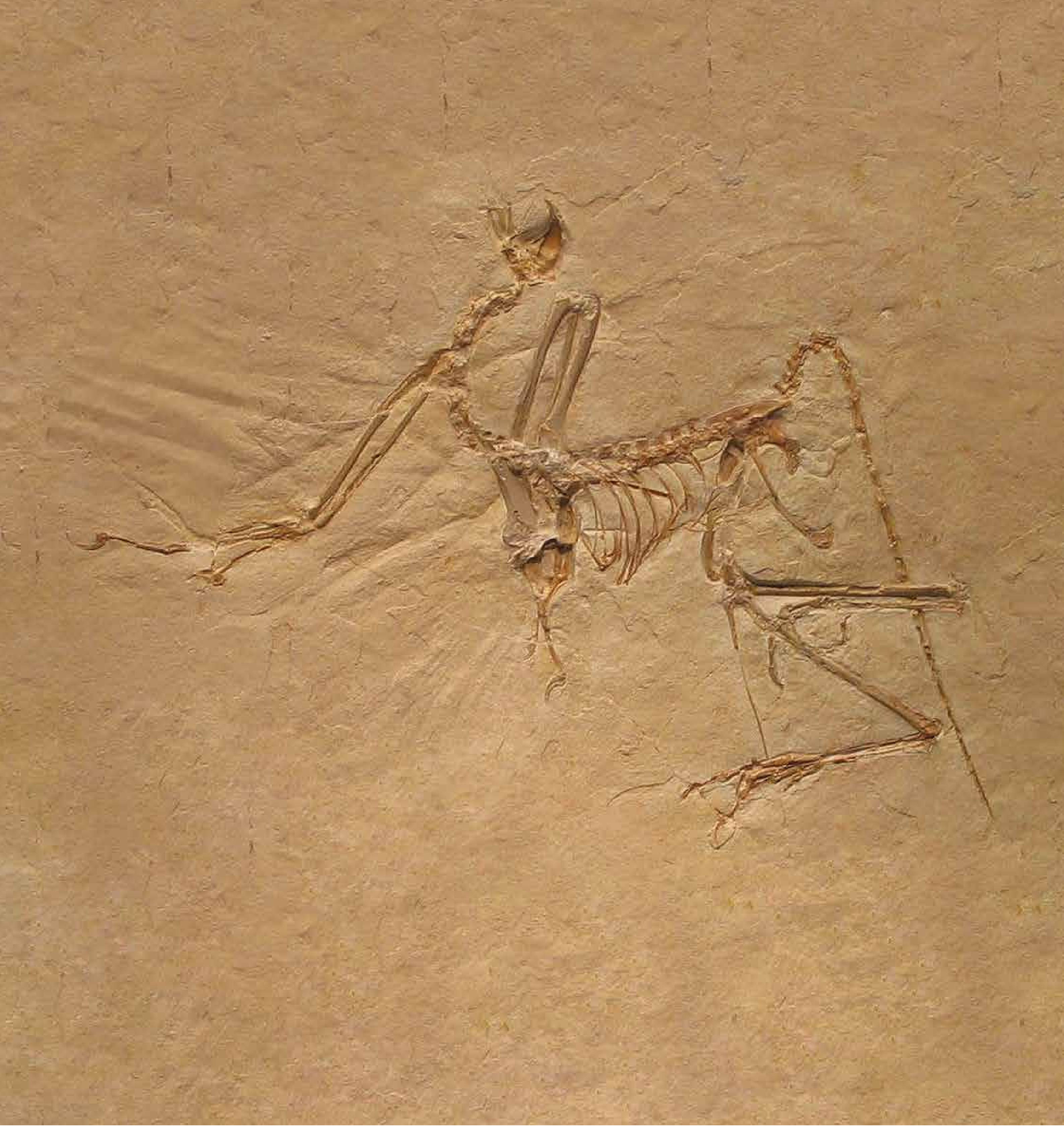
The Science Lab	Tried-and-tested thought/practical experiments to teach a concept.
Life in Your Backyard	Concepts and activities to use immediate surroundings for ecological literacy.
Science Online	Ideas and activities to use an open-access online resource as a teaching aid.
Earth Matters	Ideas, activities and experiments in education for sustainability
Annals of History	The history of one major scientific idea/innovation/concept.
Serendipity	The story of an accidental scientific discovery.
Biography of a Scientist	Her life and times through the prism of her contribution to science.
Myth or Fact	Identifying and addressing common mental models through science.
Book Review	Review of a book that can add to the teaching/learning of science
Hot off the Press	Why recently reported scientific work has grabbed headlines.

Can't find a match? Get in touch with us. We'll help you identify the section that the article you'd like to write fits best. Our word limit for most articles is between 2000-2500 words. **Content and ideas for a poster or resource material that teachers can directly use in their classrooms are particularly welcome!**

We accept submissions throughout the year, but ideas for articles must reach us latest by the 10th March, 2017. So, hurry - please send a brief outline (<500 words) and a bio (<100 words) to iwonder.editor@azimpremjifoundation.org. We'll get in touch with you as soon as possible.

The Editors.

Discovered two years after Charles Darwin published the Origin of Species, the *Archaeopteryx* is a key piece of evidence supporting evolutionary theory.



Catch the next issue of **i wonder...** to explore the **Evolution** of the stars, our planet and the life around us!