

Challenges and Benefits of Studying Astronomy

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INTRODUCTION

Let me first of all convey my greetings and good wishes to the Swami Ramanand Teerth Marathwada University on the occasion of its Foundation Day. I am confident that under the able stewardship of Vice-Chancellor Professor Waghmare this new university will scale great heights before long.

I am particularly happy that the University has chosen astronomy and astrophysics as thrust areas to be developed specially. Since astronomy and astrophysics are increasingly assuming greater and greater importance in the field of science I thought of devoting this article for **New Vision** to astronomy and astrophysics. These subjects not only provide excitement of research into uncharted territory, they also have beneficial fall-outs for the society at large.

Indeed, astronomy began as a science as much through human fascination about the cosmos as through the realization that observing the sky can bring in knowledge that is *useful* to the society. For, the stars and constellations change their position on the sky as the time passes, and by observing these patterns one can make calendars. The observed changes in the position of the sun and the moon were thus used to tell how the march of time was measured. And it was observed that these changes were cyclical, with the period of what became known as *one year*.

To the agriculturist, it was important to know how the seasons progressively change through the year, so that the different activities of sowing, growing and harvesting could be carried out at the right time. Even today the *nakshatras* guide the farmer in such operations.

To the Indian society, of course, astronomy provided information on determining the so called 'auspicious' times for performing the various rituals, as these time were linked to the positions of heavenly bodies in the sky. In fact considerable progress of mathematics in the early times is linked to the rituals like *yajnas*. Astronomy made its own contributions to these events.

FROM KEPLER TO THE MODERN TIMES

However, let us move on to later epochs and consider the motions of planets. More than two millennia ago the Greeks used the word 'planet' in the sense of its meaning: **wanderer**, because they did not, or could not, see a prima-facie pattern in their motions. Guided as they were by the natural philosophy of Aristotle, they tried to fit the heavenly bodies into a pattern of circular motions because Aristotle believed that all *natural motions*

are circular and any departure from circular path indicates that there is a disturbing agency. He termed this latter type of motion as *violent motion*.

Star trajectories across the sky fell into neat circular arcs from East to West. This was consistent with Aristotle's natural motions. The planets, however, did not show such simplicity. Relative to stars or relative to the path of the Sun, their paths were twisted, sometimes reversing, sometimes going up or down. The planets, therefore, were *wanderers in the sky*.

It is probably because of this extraordinary nature of planetary tracks that belief grew that the planets possessed extraordinary powers which they wielded on the mortals on the Earth. The age-old belief in astrology may be understood this way. I will return to this aspect later in this article.

To their credit, the Aristotelians did not content themselves with this belief and sought to fit the wayward planetary trajectories into the circular pattern. Thus grew the concept of *epicycles*. Instead of a single circle, the planet, so it was argued, moved on a circle whose centre moved on another circle, whose centre moved on still another circle, and so on... It depended on the skill of the geometer and the required accuracy of the model vis-a-vis observations as to how far this sequence would go! These circles came to be known as epicycles and the theory the *epicyclic theory*.

In short, to understand the somewhat arbitrary motions of planets was a challenge to the Greek astronomers and they tried to meet it through the intricate geometric constructions of epicycles. In the terminology of the modern theoretical physicist, their theory had epicycles as parameters and to achieve the desired accuracy the number of parameters had to be increased.

The Greek obsession with circles, looked at this way, was conditioned by the wrong Aristotelian belief in circular motion. It was further complicated by the geocentric theory that supposed that the Earth is fixed in space and that all planets and the Sun move around it. Nicolaus Copernicus got rid of the latter but retained the former. That is, although he assumed that the Earth, along with other planets goes round a fixed Sun, he still retained the epicycles. This made his geometrical constructions somewhat simpler but still not elegant: the epicycles were a reminder that this was a wrong way of looking at reality.

This is where we appreciate the contributions of Johannes Kepler. He was keen to work on planetary trajectories to look for an underlying simplicity of their construction. He was aware that this required detailed observational studies and such observations had been carried out by the Danish astronomer Tycho Brahe. So he enrolled with Tycho as an assistant. Tycho himself was convinced that the heliocentric theory of Copernicus was wrong and hoped that his own data would disprove it. He was in need of an assistant and was glad to enrol Kepler as one.

Working with Tycho was not, however, a pleasant experience, what with his whim-

sicality and derogatory behaviour towards his assistant. But Kepler stuck to it, as Tycho's data was a veritable goldmine. As luck would have it, Tycho died not long after Kepler joined him and on his deathbed enjoined his assistant to do his best to disprove Copernicus.

After Tycho's death, while his relatives were arguing over his possessions, Kepler quietly took hold of the valuable data and spent the next two decades carefully analysing it. And out of these efforts emerged the three laws of planetary motion that are now named after him. In a sense Kepler kept his promise to Tycho: he proved Copernicus wrong. But not in the sense that Tycho had intended. Kepler verified that the heliocentric theory was correct, although the Copernican epicyclic approach was wrong.

Kepler's first law of motion sets this out clearly. It tells us that a planet goes round the Sun in an *elliptical* trajectory. The Sun is at the focus of the ellipse. Thus the series of epicycles represented an approximation to the reality of an ellipse. Kepler's second law describes *how* a planet moves along its path: the line joining it to the Sun sweeps out equal areas in equal intervals of time. And his third law relates the period for the planet to complete one orbit to the size of the orbit.

I have gone into these details because the emergence of these simple looking but *quantitative* rules demonstrate the result of Kepler's persistent efforts. He had picked up the real signal out of the noise which all his predecessors had missed. **He had discovered the pattern of planetary motion.** More importantly, the stage was now set for asking the question '*Why do the planets move around the Sun in this way?*'

It required the genius of Isaac Newton to answer this question. We read the story of how Newton discovered the law of gravitation when an apple fell on him while sitting in his orchard at Woolsthorpe Manor during his *anni mirabilis*, 1664-1666. Could the fall of an apple inspire an inverse square law? The story, if true, may go so far as suggesting that it let Newton to think of a force of attraction between the Earth and the apple. But nothing more. Even the most sensitive instruments of today's technology cannot tell us that the fall of an apple implies the inverse square law of attraction. For this quantitative deduction, Newton needed more detailed data and those were available to him in Kepler's work.

Today a mathematics undergraduate can deduce the inverse square law of gravitation from the three Keplerian laws. For Newton, it was the work of genius, as he used the calculus newly invented by himself for this work. Later he demonstrated the converse problem, that given the law of gravitation and the laws of motion, the Keplerian laws follow. The Sun is the prime-mover for all the planets.

Thus by the end of the seventeenth century, the riddle of how the planets move and why they so move had been fully understood. Far from being wanderers moving at their own will, the planets were inert masses forced to move in well-defined trajectories by the Sun's force of attraction. If there was any justification for believing that planets wielded any influence on us humans, that should have disappeared by this demonstration. Yet such is human mind, that many still believe in that myth today, three centuries later.

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Let me move on to the next step in the evolution of thought. Newtonian law of gravitation was inspired by Kepler's laws of planetary motion and received further confirmation through more astronomical observations, like Halley's comet, the discovery of planet Neptune, the motions of binary stars, and so on. Although the famous experiment by Henry Cavendish measured the strength of the gravitational force in the laboratory, the confidence in the validity of the Newtonian law grew solely because of astronomical data.

Having said this we now come to the recent years of space technology. That we can launch satellites around the Earth or can send spacecraft to the Moon and the planets like Mars, Mercury or Jupiter, all in highly precise trajectories, is because of the validity of Newton's law. So the benefits we enjoy today from space technology, be it remote sensing of Earth resources, or sending a fax or an e-mail message or watching the World Cup live on TV, all owe their existence to the law of gravitation; and the law of gravitation itself owes its genesis to the data from astronomy.

This brings me to the point I wish to underscore in this article, that astronomy may appear esoteric and remote from everyday life, but its pursuit adds to human storehouse of knowledge and brings benefits to human societies.

THE SOURCE OF SOLAR ENERGY

I now turn to another example, to the age-old problem of what keeps the Sun shining. This question has been a major challenge to astrophysicists whose job is to understand the behaviour of celestial bodies in terms of the laws of physics. Although the problem has now been solved, it is interesting to take a look at its history.

In the last century, two distinguished physicists, Lord Kelvin in Britain and Baron von Helmholtz in Germany offered a solution to the problem. They argued that the source of solar energy lies in its vast gravitational energy reservoir. In a gravity dam, water falling from a great height can run electric turbines and thereby transfer its gravitational energy to electric one. In the same way, Kelvin and Helmholtz demonstrated that as a massive ball of matter like the Sun slowly shrinks, it releases gravitational energy which can be converted to light energy.

On the face of it the calculation was impressive as it showed that the Sun could draw on this energy for about twenty million years if it were to keep shining at its present rate. However, the idea did not work! For, by the turn of the century, it was becoming clear that the Earth and the Solar System was considerably older than twenty million years. Today we know that the age of the Solar System may be close to five *billion* years. Thus the gravity reservoir of the Sun is not adequate for keeping it shining for so long.

In the third decade of this century, the problem of solar energy was tackled anew by the Cambridge astronomer Arthur Stanley Eddington. Eddington had set up equations describing the internal structure of a star like the Sun. These equations visualized the Sun as a ball of hot plasma, (that is, a system of atoms of gas from which the outer electrons

have been stripped off and kept as a separate entity) which was held in equilibrium under the opposing forces of its own gravity and pressures of gas and radiation. They also showed how to describe the passage of radiation from deep interior to the outer layers of the star, eventually escaping from the surface as starlight.

Using these equations, Eddington was able to estimate the march of pressure, density and temperature of the gas from the outer layers all the way towards the centre. All these physical measures rise rapidly as we proceed inwards. For example, a star like the Sun may have an outer surface temperature of 5500 degrees, but its central temperature could well exceed ten million degrees!

Now, normally the nucleus of an atom is a tightly bound entity. In a typical chemical reaction the nucleus is not affected. However, at energies considerably in excess of chemical energies, at energies of particles in a gas of ten million degrees temperature, even the identity of a nucleus is threatened. In particular, it may be possible for two smaller nuclei to combine into a bigger one. This process is known as *nuclear fusion*.

Eddington believed that nuclear fusion would operate in the core of a star and in particular, the process would result in the formation of the nucleus of helium from the fusion of hydrogen. This possibility had earlier been suggested by J. Perrin. When four nuclei of hydrogen combine to form one nucleus of helium, *some mass is lost*. Using the law of conservation of matter and energy via the celebrated Einstein equation $E = Mc^2$, Eddington argued that the mass loss would be compensated by energy which is what the star radiates.

There was one snag, however. The science of nuclear physics was in a very primitive state in the twenties. Based on what they knew, the atomic physicists felt that Eddington's ideas will not work. For, the hydrogen nuclei are positively charged and any two of them would repel each other. Unless the nuclei are hurtled towards each other very fast they would not fuse together. Now in a hot gas the nuclei do move very fast. While they move at random, there are cases where two nuclei may approach each other. Could they not collide and fuse? But, according to the atomic physicists, at the temperatures of the order of ten million or more that Eddington was talking about, the speeds of these nuclei would not be high enough for the fusion process to work.

Eddington was, however, confident that he was right. In his book *The Internal Constitution of the Stars*, he wrote:

....We do not argue with the critic who urges that the stars are not hot enough for this process. We tell him to go and find a hotter place...

A decade later Eddington was proved right. By mid-1930s, the science of nuclear physics had advanced to a stage where scientists had become better acquainted with the force of nuclear binding. In 1939, Hans Bethe used the ideas of nuclear fusion of hydrogen to helium to generate realistic models of the Sun and stars.

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Here we have another example where astronomy has shown the way to basic science. I should mention that the fusion that operates in the Sun is the same thermonuclear process that operates in a hydrogen bomb, a process that was tested at Pokharan on May 11 this year by our scientists. The only difference is that the process operates in the Sun in a *controlled* fashion, whereas it does so in an *explosive* fashion in a bomb.

This brings me to the last question in the present context. Can we carry out this process in a controlled fashion on the Earth? That the process can operate in a controlled fashion in the Sun has been demonstrated over the last five billion years or so. The challenge now lies in repeating on the Earth what has been demonstrated in an astronomical setting. It is easy for the Sun to do this because of its strong gravity. In a terrestrial experiment, the controlling agency cannot be gravity (which is very weak on the Earth). The present attempts revolve round containing hot plasma under a magnetic force. If the process succeeds, it may provide cheap ways of generating energy as the heavy water available from the seas around us could be used as the fuel.

RELATIONSHIP TO FUNDAMENTAL PHYSICS

The examples cited so far also demonstrate an important fact, namely the contributions astronomy makes to fundamental physics. The law of gravitation and controlled thermonuclear fusion came to physics via astronomy. Indeed the universe is a grand laboratory for science, with dimensions far exceeding that of any terrestrial laboratory. The laws of science that were first discovered and tested on the Earth also receive a more severe testing in the cosmic laboratory. A few examples will suffice by way of demonstration:

- The cosmic radio sources emit energies of the order of 10^{60} ergs or more, that is about a hundred billion billion billion billion times the energy released in a one megaton H-bomb.
- The rapidly pulsating radio sources called *pulsars* send signals with such regularity over periods as short as a few milliseconds that they more than match in stability and accuracy the best man made atomic clocks.
- The highest energy cosmic rays showering the Earth contain particles of energies a billion times that produced in the most advance accelerator on the Earth.
- Neutron stars contain matter with a density as high as a million billion times the density of water, far exceeding density of any macroscopic form of terrestrial matter.
- The large scale structure of the universe, as revealed through the best telescopes of today, extends out to distances which a light ray would take ten billion years to traverse. For a comparison, light takes only a second and quarter to come here from the Moon. Thus we have ways of testing physical laws over very long spans of space and time.

Several more such examples can be given. What do they indicate? That the physicist is looking to astronomy to provide confirmation that the laws of physics discovered *here and now* were also applicable *there and then*.

A very daring extrapolation of this idea appears in the studies of the *very early universe*. As per the popular belief (- which I myself don't subscribe to!) the universe originated in a *hot big bang* which took place some ten billion years ago. If we go right to the big bang instant, it supposedly lies beyond the scope of physics, because it describes a situation when physical quantities like density, temperature, etc. were infinite, when all mathematical operations broke down. However, the physicist's clock begins to tick immediately after this *singular epoch*. For example, as time elapses the universe cools down and its temperature drops.

We have already seen that the temperature of gas is indicative of its dynamical activity. The higher the temperature, the higher is the energy of the typical particle of the gas. In the very early stages after the big bang, the particle energies were extremely high. This circumstance excited the high energy particle physicists into using the very early universe as testing space for their theories of unification.

I should state that the goal of unification of all basic interactions was first conceived by Albert Einstein who tried to look for a *unified field theory* of gravitational and electromagnetic interaction. His goal was to seek a description wherein the apparently separate phenomena of gravity and electricity and magnetism (electromagnetism) are seen as different manifestations of the same basic law of nature. His efforts were inconclusive and failed to excite the community of theoretical physicists. Wrote Wolfgang Pauli: *Let no man put together what God has put asunder*.

However, fashions change in science as they change in the world of dress designers! A few decades later physicists began to search for a unified framework that included not only the two phenomena Einstein was seeking to unite but also the other basic interactions (the so-called *strong* and *weak interactions*) that operate in the microworld of atomic nuclei and subatomic particles. A partial success in this direction was achieved when Abdus Salam and Steven Weinberg produced a successful theory unifying the electromagnetic theory with the weak interaction. Successful, because its predictions were verified in the powerful particle accelerator at CERN, near Geneva.

However, the next rung on the unification step-ladder is far steeper. For the so-called *Grand Unified Theory* (GUT in brief), the currently accepted standard model requires energies a *thousand billion times* than those achievable in the present accelerators. In other words, by 1980, the particle physicists had reached a stage where their theory *could not be tested experimentally*. And in science, a theory that cannot be tested is no more than a speculation.

It was against this background that the big bang cosmology offered a way out to particle theorists. As we just saw, in the early epochs, the typical constituent particles of the universe were indeed highly energetic and so could serve as targets for testing the

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GUT predictions. Of course, for reaching the desired energies the epochs would have to be very early. *How early?* Calculations suggest that barely a *billion-billion-billion-billionths part of a second* had elapsed for the universe to have particles of the requisite energy! Beyond that, as the universe continued to expand, the particles slowed down. In other words, the particle theorists have in the universe itself a high energy particle accelerator, which only for a fleeting moment produced particles of high enough energy for testing their theories.

The advent of particle theorists into cosmology was also welcomed by supporters of the big bang theory as it provided 'physics' to discuss the behaviour of matter and radiation in the early epochs. For, cosmologists also have an agenda which includes a theory that explains the formation of large scale structure in the universe from the 'seeds' planted in the early epochs. The hope is that particle theories will tell us what those seeds could have been and how they grew.

Sheldon Glashau has expressed this cosmology-particle physics interaction through the picture of a mythical snake (which also reminds us of our *Shesha Naga*) swallowing its own tail. The head of the snake has the whole universe and the tail the smallest particles, the act of swallowing symbolises a synthesis of the largest and the smallest.

Perhaps a note of caution needs to be interjected in all this excitement of understanding both the largest and the smallest in a joint effort. What we have here are two speculations, one from particle physics, viz. a GUT, the other from cosmology, the Big Bang. Two speculations may not make up certainty: at best they may be fitted into a self consistent scenario. Nor is the scenario a repeatable experiment. For, as we saw, the universe passes through the GUT-phase only very fleetingly and the same conditions are not repeated later. Thus the standard scientific criterion of testing a theory through repeatable experiments is not met.

Nevertheless this example demonstrates how astronomy is proving indispensable to physicists.

PROTECTION FROM ASTEROIDS AND COMETS

I next come to a more down to Earth issue which has recently shown how astronomy may become relevant to our very survival on this planet.

We are aware of the history of Jurassic age when huge beasts like dinosaurs used to dominate this planet. What happened to them? What catastrophe took place that wiped them entirely from the face of the Earth?

Speculations are many. But one possibility that is taken very seriously is that the Earth may have been hit by an extra-terrestrial body of appreciable mass and the impact caused a huge turmoil wiping out all, or at least most life forms from the Earth. What could such a body be?

Judged by the crowded streets in a metropolis, the space in which the Earth moves is remarkably empty. The chance of a collision is very very small. But it is not zero. Let us see a few examples.

The surface of the Moon is pock-marked with craters, showing evidence that outside bodies have hit it on several occasions. The Earth also has such craters, only many of them are filled with water and appear as lakes. Some impact craters may have been confused with volcanic ones. Two examples of craters believed to have arisen from impacts are the Meteor Crater in Arizona, USA and the Lonar Crater (Lake) in the Buldhana district of Maharashtra in India. As the name of the first one suggests, the impacting body in both cases was a huge meteorite.

Meteorites are bodies orbiting within the Solar System, being relatively small bits that did not form into a (much bigger) unit like a planet. Some of them can come close enough to the Earth to be attracted by its gravity. In that case, they 'fall' on the Earth. Smaller bits of a few centimetres or less are usually burnt out by friction as they pass through the atmosphere. They are mistakenly called '*shooting stars*' or '*falling stars*'. Some do land on the Earth and if noticed and collected, they end up as museum pieces and useful tools for geoscientists. Meteorites have been extremely useful in dating and estimating the age of the Solar System, as well as for getting information on its chemical abundances.

However, larger meteorites can be devastating in their impact. For example, the meteorite whose impact caused the 'hole' at Lonar was about 60 meters in diameter, weighing about twenty million tons. The impact caused a hole that today has a diameter of around 1830 metres and a depth of 150 metres. The energy released in the process was equivalent to that coming from a 6 megaton H-bomb. For a comparison, the atom bomb dropped on Hiroshima was of 13 kiloton capacity, about two percent of the strength of the impact on Lonar. We will take the Hiroshima case as a unit of energy released.

There are bigger entities than such meteorites going around in the Solar System. In July 1994, Comet Shoemaker Levy had impacted on Jupiter. The event was witnessed by telescopes on the Earth. On the huge planet the impact of a comet had of course a transient and relatively mild effect. But what if a comet strikes the Earth? Indeed, such a possibility was raised in 1992 in connection with Comet Swift Tuttle. This comet passed by in 1992. At the time it was predicted that in its next visit on August 14, 2126, it will come very close to the Earth. Although it cannot be definitely calculated, the probability of its actually hitting the Earth is not negligible. A better estimate can only be made when the comet is sighted again in the 22nd century.

In the 1970s, I had written a science fiction story in which a comet like this was headed for a collision with the Earth. How did the scientists avert the catastrophe? The solution used in the story involved sending an unmanned spacecraft to rendezvous with the comet, with the provision that close to the comet it would carry out a nuclear explosion generating shock waves that would divert the comet from its original path. The same

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solution is now proposed for saving the Earth from an impending impact by a comet or a meteorite, or, what is now considered more of a threat, an asteroid.

Asteroids form a swarm of bodies moving generally in a belt between Mars and Jupiter. It is believed that these represent a 'failed planet', that is, a planet that did not form! These bodies are thus smaller than a planet like the Earth, ranging in sizes from several hundred meters to around 10 kilometres, although a few of them are larger, even upto 1,000 km in size. These bodies generally lie beyond Mars, although a few of them may occasionally come close to the Earth, thus raising the spectre of an impact. It is estimated that the number of asteroids of upto 1km size may be between 1,000-2,000, while the number of 100-metre size objects may be as large as 1,00,000. Although the impact of a smaller object is less severe, the chance of its taking place is much larger.

How severe is the impact? The Lonar example gives some indication. However, suppose a 10 km size object hits the Earth. What will be the energy released? The answer is a staggering '*One Billion Hiroshima*'. Not only will the area hit by the object get devastated, the overall changes in the Earth's atmosphere will be such as to make it impossible to sustain life elsewhere on the planet. We will share the fate of the dinosaurs.

Keeping such possibilities in view, astronomers in the USA have initiated a *Spacewatch programme*, in which a dedicated 1.8 metre telescope is looking for all asteroids of such appreciable sizes in our neighbourhood. With their trajectories charted out, we can predict if any of them will come dangerously close to the Earth in the future, and take preventive action as needed.

This example again tells us that sky-gazing is not a mere idle activity, it can contribute to human survival.

ARE WE ALONE IN THE UNIVERSE ?

My last example in the list of challenges and benefits points to the future, to perhaps the most exciting discovery in the annals of human history. Who knows, but the twenty first century may bring an affirmative answer to the frequently asked question: *Are we alone in the universe?*

If it does, a major contribution to the quest will have come from astronomy. In fact it is an inter-disciplinary issue but by and large it is the recent developments in astronomy that attracted scientists of several disciplines towards it. We may briefly mention the following highlights:

- The large scale structure of the universe shows that our location on a planet around a star is very commonplace and there can be a large number of similar habitats available for hosting life.
- Millimetre wave astronomy has revealed several giant molecular clouds containing chemical molecules of considerable complexity, including the kind of organic molecules we are made of.

- The evidence of fossilized life in the tiny Alan Hill Meteorite from Mars, although still very tentative, has raised the question whether life exists or existed on our neighbouring planet.
- The techniques of communication using the 21-centimetre wave band have reached the level of sophistication which make interstellar communication possible. This is the natural frequency of neutral hydrogen, the most prevalent element in the Galaxy, and one likely to be best known to extraterrestrials.
- Advances in space technology make it possible in the future to set up a huge antenna in space for interstellar communication.

I have not mentioned the usage of space-ships, most popular with science fiction writers, for the simple reason that the distances in the Galaxy are so vast that use of spacecraft currently available to us make it an impractical proposition. Their speed is so slow that using them to travel to the nearest star, Proxima Centauri, is worse than the case of an ant going from Chennai to Delhi.

Experts agree that the best way of looking for extraterrestrials is through radio signals using wavelengths like that of neutral hydrogen. These waves are less attenuated and are likely to be recognized by the recipients who should have gone through an evolutionary development which makes them familiar with the sciences we know. Indeed they may, hopefully, be far more advanced than us which will make it exciting for our scientists. Perhaps we can receive ready answers to our present scientific puzzles and thereby make sudden leaps of progress!

However, patience is needed, for if we send a query to the extraterrestrials located at a modest distance of, say, ten light-years, our signal will take ten years to reach them and their reply another ten years, making it a twenty-year gap between question and answer. Still the effort would be worth it.

With this exciting prospect for the next century, I end this article.