CHALLENGES AND BENEFITS OF STUDYING ASTRONOMY

Jayant V. Narlikar*

I feel greatly honoured by this prestigious award of the Indian Science Congress Association, a distinguished organization that has played an umbrella role for science in India. It gives me special happiness that the award commemorates a person who was not only a great freedom fighter and social leader, but who essentially sowed the seeds of Indian scientific infrastructure at a stage when our nation had just gained its independence. I humbly accept the award and use this occasion to talk about my subject in the general context of science and society.

I am an astronomer and astrophysicist by profession and I thought that I can use this award lecture to share with you the thrill and excitement of working in this field, to show how new unexpected challenges appear along the way and how they are met. Also, to those who are not in this field and who wonder what is the use of star gazing and trying to understand cosmic phenomena, I would like to convey how an apparently esoteric field like this one can bring benefits, not only to the scientist but to 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 passage of time was measured and monitored. And its 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 times 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. For, Aristotle believed that all *natural motions* were circular ;

* Inter-University Centre of Astronomy and Astrophysics, Ganeshkhind, Pune—411007

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and any departure from circular path indicated that there was a perturbing agency. This latter type of motion be termed *violent motion.*

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

It is probably because of this extraordinary nature of the 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 talk.

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 geometor 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 whimsicality 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 respresented 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 demonstrates the result of Kepler's persistent efforts. Out of the noise he had picked up the real signal 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 sotry, if true, may go so far as suggesting that it led 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 a 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 wield 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!

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 rceived further confirmation thorugh 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 spacecrafts 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 lecture, 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 it 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 enegy 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 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 electorns have been stripped off and kept as a separate entity), which was held in equilibrium under the opposing forces of its own gravity and the 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 Celsius, but its central temperature could well exceed ten mlillion 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 the 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 enrgy 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.

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 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 achieve 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 : for the heavy water available from the seas around us could be used as fuel.

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 possiblity 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 of craters are confused with volcanic ones. Two examples of craters believed to have formed 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 or vapourized 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 geophysicists. Meteorites have been extremely useful in dating and estimating the age of the Solar System, as well as for getting infomration on its chemical composition.

However, larger meteorites can be devastating in their impact. For example, the meteorite whose impact caused the 'hole' at Lonar was about 60 metres 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 centruy.

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 spacercraft 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 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 metres 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 1 km 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 Hiroshimas'*. 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 life elsewhere on the planet impossible to sustain. 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 exmaple 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. Planets around other stars, possibly possessing atmospheres have been found.

- Millimetre-wave astronomy has revealed several giant molecular clouds in the interstellar space, 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 makes 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 extra-terrestrials.

- 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 spacecrafts currently available to us makes 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 Kolkata 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 recepients 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!

People ask, need we confine our searches only to advanced life-forms? What about life more primitive than ours? Evidently, the above method of interstellar communication would not work in such cases. But if we are less ambitious, can we confine our searches to our doorstep, to the outer reaches of the Earth's atmosphere ?

It is commonly believed that life on the Earth originated here. However, this popular hypothesis was challenged about twenty-five years ago by two British scientists, Fred Hoyle and Chandra Wickramasinghe, who argued that life on the Earth was seeded from outside, through micro-organisms being dumped on the Earth from comets. The Hoyle Wickramasinghe hypothesis assumes that the interstellar space has not only complex organic molecules, but it also has bacteria and viruses, some of which should be found in the cometary material. If therefore the tail of a passing comet brushes the Earth's atmosphere, it may deposit some micro-organisms on it. These would gradually descend to the surface in a few months to a year or so. Hoyle and Wickramasinghe have argued that such 'panspermia' may have started the life-cycle on the Earth.

To test this hypothesis some of us undertook an experiment funded by the Indian Space Research Organization (ISRO), in which a balloon was flown up to a maximum height of around 41 km with a cryogenic payload in the form of sterilized evacuated cylinders. At different heights the cylinders were opened by remote control and air sucked in through a cryo-pump. The samples were brought down and are being carefully examined. Preliminary indications are that there are living cells, possibly bacteria at heights ranging from 20 to 41 km. It would be very hard to think of them as terrestrial contaminants ; on the contrary, their estimated number density matches the distribution we would expect if these microorganisms were being injected from outside the Earth's atmosphere. Biologists are in the process of examining the evidence critically as it has sweeping implications for our ideas on how life on the Earth began.

With this exciting prospect, I end this lecture and thank the Indian Science Congress Association for giving me the opportunity of presenting these ideas. In any case I hope that I have succeeded in a modest way in convincing you why it is so exciting and worthwhile to work in the science of astronomy.

DO YOU KNOW ?

Q3. Thanks to Julius Ceasar we know "veni, vidi, vici." One college student wrote on his desk, veni, vidi, vermi".—What did he mean ?

Q4. How fast does the elephant's heart beat ?

Q5. Which element is most abundant in the earth's crust ?

Q6. What makes ape different from monkey ?