energy comparable to that of an entire galaxy might well be coming out of a source no greater than a light year across. Here then was the very example of the kind of objects conjectured by Hoyle and Fowler.

This discovery opened up a new field in astrophysics, called *relativistic astrophysics*, which dealt with the astrophysical phenomena in strong gravitational fields, in situations where Newtonian gravity must be replaced by Einstein's general theory of relativity. So great was the excitement amongst the astronomical community that an international symposium was held in December 1963 in Dallas to discuss the implications of theories and observations in this emerging field. Both Hoyle and Fowler were the lead speakers in this meeting on the theoretical side. These meetings now continue to be held biennially under the title 'Texas Symposia'. Much of the present black hole bandwagon in astrophysics has its origin in the Hoyle–Fowler work of 1963

Another of Willy's seminal contributions came in the big bang cosmology when in 1967 he along with Fred Hoyle and Robert V. Wagoner carried out a revised and updated version of Gamow's primordial nucleosynthesis The Wagoner–Fowler–Hoyle paper in the *Astrophysical Journal* (**148**, p. 3) again turned out to be a trendsetter for future work in big bang nucleosynthesis. It is interesting to recall that this work was carried out in a shed in the Cambridge Observatories while Hoyle's new institute building was under construction.

It was during the first six years of the Institute of Theoretical Astronomy at Cambridge that Willy was a frequent visitor during the summer months. He and Fred would sometimes take off to the Scottish Highlands for hiking, a practice that Willy continued till late in his life.

For his work in nuclear astrophysics Willy Fowler shared the 1983 Nobel Prize with S. Chandrasekar. It was the second time that a Nobel award was given for theoretical astrophysics, the previous occasion being in 1967 when Hans Bethe was honoured for his work on stellar structure models with nuclear energy generation. The 1983 award, however, brought both surprise and disappointment at the omission of Fred Hoyle from the list.

Willy was known for his thoroughness in all the work he did, a fact which was belied by his informality and jolly demeanour. He would be the life and soul of a party discussing (over a martini) either the world series, or the Scottish terrain, or one of his long train journeys (he was a train buff), or nuclear cross-sections all with equal ease. Amongst his many honours, his Indian connection was with IUCAA as one of its Honorary Fellows, and several of us recall his jokes and anecdotes as he talked about his latest work in cosmology in March 1990. As a personality he will be greatly missed but his work will continue to guide the succeeding generations of astrophysicists.

Willy Fowler is survived by his wife Mary Dutcher Fowler and two daughters by his first wife Ardienne (deceased).

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Who should look at stars*

Ashok S. Ganguly

In January 1994, I met Jayant Narlikar on a flight from Calcutta to Bombay. He then reminded me of an earlier occasion when (in a weak moment), I had agreed to deliver a Foundation Day lecture at his Institute in Pune. I tried to wriggle myself out of the commitment, firstly, by reminding Jayant that I would have nothing meaningful to say to what was likely to be a distinguished gathering of scholars, and secondly, because my daughters were discouraging me from being typecast as a Foundation Day fixture. Both attempts failed, as you will notice from my presence here today.

Having made the commitment to speak, I spent many agonizing evenings trying to focus on a suitable topic. Finally, I drew inspiration from my association with Narlikar as a member of the Science Advisory Council to the Prime Minister (1986–89) and settled on a 'blue sky' approach. More of that shortly.

A few recent events spurred me to put down some initial thoughts on paper before I lost track of them. A very close friend and his wife were visiting us in London. While we were driving to Glyndebourne to attend a performance of the Opera, Don Giovani, I shared with them my dilemma about the Foundation Day lecture. My friend's wife, a well-known physician from Bombay in her own right, asked me, 'Why should a poor country like India, with its impoverished millions, fund research to watch stars?' For the best part of the two-hour car ride, we had a series of disagreements on the subject. These disagreements ranged from the concept of curiosity, through the nature of the Indian mind and the need to be part of the international community in leading-edge science, to the origins of the universe and life on Earth. I could not convince her that curiosity-driven exploration was at the heart of human civilization, starving or otherwise. Finally, the arguments ended inconclusively when I raised a rhetorical question, 'What was the level of poverty and deprivation in Italy in the days of Galileo Galilei?', I asked, feeling that would end the debate amicably. Neither

*This was the subject of the Foundation Day Lecture delivered at Inter-University Centre for Astronomy and Astrophysics, Pune, India, on 29 December 1994

of us knew for sure, but she promptly shot back that it really did not matter, since Galileo's star gazing was not funded by the State.

Galileo – the star gazer

Her reply had me stumped, until just a few days later when I came across a review by A. C. Grayling of GALILEO: A LIFE, a new book by James Reston Jr. If any one man acted as a doorman to the modern world, Galileo Galilei has an excellent claim to the title. The publication of his latest biography is timely because Reston has hooked his tale firmly to events in the contemporary world: the flight of the spacecraft Galileo to Jupiter, still taking place as I speak to you, and the decision of the Vatican in 1992 to acknowledge its fault in ill-treating Galileo three-and-a half centuries ago by dragging him before the Inquisition, humiliating and imprisoning him.

Indeed, Galileo's story is a microcosm of the epic struggle between science, religion and society. Galileo was inquisitive, inventive and mathematically adept. He was fascinated by the view above him in the clear Italian night sky. He perfected the telescope, and terrified the Church by revealing more stars than had been guessed before, hitherto unseen satellites orbiting other planets, valleys and mountains on the surface of the moon.

Because Christian scriptures taught that the Earth sits immovably in the centre of the Universe, whose celestial spheres are driven around by angels, the Church could not tolerate this new cosmology.

By threats and intimidation, Pope Urban VIII forced Galileo to recant his espousal of the Copernican system. That the Church should come to its own recantation in 1992 speaks volumes for the conflict between faith and reason. Therefore, I cannot consider my friend's wife's question of whether astronomy research is really needed in a poor country like India unusual.

Galileo not only made discoveries of prime importance in astronomy and physics – especially in the laws of motion, thus breaking the stranglehold of Aristotelian ideas – he was also an inventive genius. He devised, amongst other things, pendulums for clocks, ways of improving telescopes and instruments for measuring pulse rates and temperatures. Despite disgrace by the Inquisition, his telescopic discoveries made him a star all over Europe.

While I have not been able to locate evidence of State support for his experimental pursuits. I am reliably informed that there were many poor people in Italy at the time Galileo gazed at the stars

From star-gazing Galileo to the man behind the comet, Edmund Halley

Soon after the book on Galileo, I came across an excellent piece by Allan Chapman of Wadham College, Oxford, on a remarkable man.

Chapman avers that scientific research has always been expensive, but in the past, the real cost was not so much the hardware, as paying for the scientists' time. This is why so many discoveries between the 17th and the 19th centuries have been made by clergymen, semi-retired professionals and businessmen, and people of private means – individuals who were in command of their own time. But while the cash was not entirely certain, if one had the ability to wear many hats and cultivate friends across the whole spectrum of potential influence, then one might enjoy a career similar to that of Edmund Halley (1656–1742). This immediately brought to my mind some eminent Indians who fit parts of this description, like Ramanujam, C. V. Raman and Homi Bhabha, to name just three.

Edmund Halley's work was funded by, to begin with, family money. When that ran out, he worked as a clerk at the Royal Society, then took a job with the Royal mint, and later joined the Royal Navy. At the age of 48, he became a professor at Oxford and at 64 the Astronomer Royal. Edmund Halley was clearly capable of living with uncertainty.

Though primarily an astronomer, what is most impressive about Halley's approach to science is his awareness of how the great 'systems' of nature are interconnected. Geomagnetism was such a system. Halley published major papers in 1683 and 1692 in which he collected and analysed a growing body of data on the subject. He created the geomagnetic chart and then in 1716 he was the first to recognize the interconnection between the Earth's magnetic field and the aurora borealis.

Halley was a man of vast interests, ranging from pure science to a whole series of practical applications in marine engineering.

I imagine in modern parlance one would find comparable traits in the venture entrepreneurship of many famous American academics and Nobel Laureates. But where are the young Bhabhas and Ramans, I wonder

Fred Hoyle – the astrobiologist

No address in an institute headed by Jayant Narlikar would be complete without reference to his Guru, Fred Hoyle, the astrobiologist.

Being somewhat of an amateur biologist myself, Hoyle's 'origin of life' hypothesis intrigues me. In his autobiography, *Home Is Where The Wind Blows*, Hoyle is sanguine about the chances of acceptance of his idea that life began in the vast expanses of space. 'Finding glycine is about 5% of the way to proving the idea', says Hoyle. 'It's the right way, but it's only 5%'.

The glycine discovery certainly bolsters Hoyle's thesis that the first organic matter rained down on Earth from space. According to Hoyle, it was such a comet which struck Earth about four billion years ago, depositing its cargo of primitive cells – the forerunners of all life today.

It is a rather controversial view, although the idea that organic material – the 'feedstock of life' – came from space is gaining wider acceptance. One is, however, faced with the moral and philosophical dilemma about the true origin of the living form Hoyle acknowledges that the riddle will not be solved in his lifetime. However, he has been proved right before. In 1940 he had suggested that molecular hydrogen was widespread in space and was greeted with wide disbelief He subsequently published his views in a science fiction book, *The Black Cloud*. Since the publication of the book, more than 100 molecules have been detected in space, including molecular hydrogen, which is now known to be the most abundant molecule in the Universe

Marcus Chown (*New Scientist*, 10 September 1994) writes, 'Hoyle believes that, if a problem has an orthodox solution, the scientific community would already have found it, so he looks for the unorthodox solution'.

This unorthodox approach has proved Hoyle right on a number of predictions and wrong in just as many, such as the making of the sun or the explanation of binary stars.

But as the saying goes, 'If you have not made mistakes, you have really not tried'. I hope the adage applies to this Institute also.

I was pleased to learn that since 1988 Hoyle has developed the 'quasi-steady-state theory' jointly with Burbridge and Jayant Narlikar. The three of them believe that the creation tap opened in one part of the Universe 15 billion years ago, unleashing a flood of matter and causing the expansion of galaxies we observe all about us. Who knows they may be right!

Finally, I feel much comforted by Hoyle's view that 'a little bit of god operates in all of us. We are his observing instruments. He observes the Universe through us'. No matter where you are, whether in Cambridge or California or Pune, it all happened together.

Has science lost its way?

While I was warming up to the theme of science for curiosity's sake, I was crestfallen to read Bernard Levin's essay titled 'Has science lost its way?' (Even if I were to ignore Levin's levity, in the UK, observations on science such as his fall under the classification of 'Have you beaten your wife today?'.) Like it or not, some of this reflects contemporary lay thinking.

Bernard Levin's motto seems to be 'Beware of scientists claiming breakthroughs'. He then goes on to observe that 'If the boffins do have a fault, it is their conviction that any amount of money required for their work should be immediately provided'. In this essay, Levin chose the quarks as his centrepiece to criticize the nature of scientific enquiry and quotes a neat example of his odd but touching belief from a recent breakthrough in science. The last quark had been spotted (or rather not spotted. The thing is invisible). Aric Bodek from Chicago said that his discovery had saved scientists from an intellectual crisis 'since failure to discover the top quark would have shattered decades of research worth billions of pounds'. Levin asks, if the quark cannot even be seen, 'What is in it for us?'. The moot question is, what can discovery of quarks do for the common man? To Levin's queries, the only response he was able to elicit is that there are six quarks named UP, DOWN, CHARM, STRANGE, TOP and BOTTOM, and that 493 scientists were enlisted to find the last quark, going about the search 'smashing protons and antiprotons in a four-mile circular accelerator' and on top of that 'the two particles annihilate each other as they collide'.

Bernard Levin then moves on to compound his confusion by relating the discovery of a new planet 7000 trillion miles away. Hitherto 'in every case, the putative planets had either proved impossible to confirm, turned out to be something else, or shown to be a product of error'. Now, however, Wolszczan's team 'has bolstered its original findings with three more years of even more finely nuanced data designed to eliminate any explanation other than planets'. And this statement is backed by Kulkarni, a pulsar expert at the California Institute of Technology, who says, 'It should convince even die-hard sceptics that planets exist outside the solar system'.

Amongst other things, Levin concludes by noting that, whereas the common man may not very much begrudge the scientists the millions and millions of pounds needed to peep beyond the solar system 'where God resides!' while millions and millions may starve and suffer from malnourishment around the world, surely the tax-payers have a right to understand better where all these discoveries are leading.

Well, there we go! In quick succession, the wife of one of my best friends from India and the well-known columnist Bernard Levin, two persons from two totally different societies, asking very similar questions. Then interesting events started happening in July.

Shoemaker Levy 9

My interest perked up on reading the news that the comet Shoemaker Levy 9 was moving as a funeral procession of 21 fragments of ice and rock after its break up two years ago. Their eventual collision with Jupiter was being described by astronomers as a 'once in a millennium opportunity'. The subsequent pictures and descriptions of the collision were widely reported around the world by the media. I am told that it will take years before the explanation of the events leading to this collision are well understood. But the pictures and descriptions of the events started making sense to the common man as to why we stare at the night sky. This has been further encouraged by the fact that, unlike the Shoemaker couple who are professional astronomers, Levy is an amateur.

Suddenly Big Bang is back on the agenda and the question on every one's lips is, 'If it could happen to Jupiter, can it not happen to Earth?'.

Comets are celestial bodies, believed to be the relics of the birth of the solar system. A thousand or so of them have had their orbits well plotted. But for every comet which is confirmed to exist, there are thought to be at least ten others that have eluded detection. And billions more may reside in a halo beyond Pluto. Comets have collided with Earth before, and scientists insist that more collisions are probable, making it vital to overcome complacency about the threat to Earth from cosmic debris.

If a comet, streaming along at 50,000 miles per hour, were to crash into Earth in the wrong place at the wrong time – London, Bombay or New York at rush hour – it could cause a disaster of monstrous proportions. These thoughts were expressed in the editorials of the serious *London Times*. There is a school of serious astronomers, aptly known as 'catastrophists', which is convinced that within the celestial procession of comets lie the seeds of Armageddon. They attribute the death of the dinosaurs, 65 million years ago, to a comet which ploughed into the planet triggering either a nuclear-style winter or uncontrollable fires. The serious question is: If the comet could wipe out the mighty *Tyrannosaurus rex*, what chance do puny *Homo sapiens* have?

Thus, contemplating the impact of the 21 fragments of Shoemaker Levy 9 on collision with Jupiter in our lifetime has raised modern astronomy from the preoccupation of the specialists to a concern for all living and thinking mankind, starving or not.

Such an extraordinary astral event then starts stretching the mind and arouses the interest of the layman in astronomy, as indeed it did mine. I then began to think that although man has the technology needed to detect and track threatening celestial objects, there is yet no global chain of telescopes. And research has still to be aimed at defending the Earth from 'asteroid attack', including the possible redeploy-

ment of nuclear warheads to shatter incoming projectiles and the use of propulsion units to divert or steer them away. None of these, however, will protect us from every conceivable threat, nor can they whet our awe at the immensity of space. The 'black that remains beyond our blue' seems destined to remain a mystery to all but our telescopes

The social relevance

No matter how awestruck I am, I cannot avoid relating all of this to developments in India. I hope I have provided a reasonable, layman's support to the need for the pursuit of the planets even in Pune. The statistical probability is that, next to China, India should have the largest number of curious people. This does not necessarily mean that we should have the second largest population of astronomers peeping through a chain of telescopes across the Indian subcontinent. However, in astronomy we have a history of interest as recorded in the Puranas, through the Middle Ages, and now this world-class centre in Pune. There is, thus, a tradition in mathematics and physics which links the ancient with the leading edge in India.

This, unfortunately, is not the case in most other areas of modern science and technology. Although we talk of modernizing and globalizing India, in lay terms what we really mean is a growth in production and consumption in our lifetime rather than a change in the fundamentals of looking and doing for a better future. I am, therefore, proud that India is considered to be a world player in astronomy and astrophysics, if not in any other sphere of science and technology.

Following our independence after over a thousand years of enslavement, Nehru, Bhabha, Bhatnagar, Meghnad Saha and many others inspired my generation to believe that science and technology held the key to traverse the path from backwardness to modernity and provide social justice for all. History will record that for the first three decades this promise at least seemed to begin to materialize. The role of science and technology in India achieving self-reliance was indeed significant. India thus achieved a critical mass as a democracy with a viable economy, although the problems of social inequity remained.

At a time when we are ready to integrate India's economic developments with the rest of the world, the same science and technology institutions which helped in achieving self-reliance may now turn out to be the major source of competitive disadvantage. Any attempt to revive them may be futile, as many of them may have outlived their utility. What is necessary is to take drastic steps to restructure and modernize the old and, in addition, create new institutions for the future.

Who should be concerned about this vital problem? The Government, Indian Industry, the non-Government Organization (NGOs), the media, the intellectuals, or whoever? Since 1990 even the interest and vibrancy in the science and technology community that one felt and saw in the 1980s seems to have dangerously waned. Unusual and dangerous priorities have overtaken the nation, such as disputes regarding places of worship, the revival of the caste conflict, the drive for instant gratification and enrichment, multinational baiting, the 'back to primitive roots movement', etc. There is not even lip service paid to the social and economic imperative to modernize our institutes of higher education and those institutions dedicated to advanced research in different areas of S&T. Every country other than India seems to be deeply engaged in addressing these vital issues. China is set to revamp its total research base, from one which had remained isolated and totally dependent on the State, towards one which is more autonomous, modern and globally relevant. There is a similar reassessment of the science base in the USA and Japan. In the UK, the 1993 White Paper on the need to choose areas of science in which to lead and its relevance to that country's global competitiveness was articulated. The key was that not every country could afford to be outstanding in every discipline of science. What a nation needs is a solid foundation in basic and higher education and then the ability to choose areas of science to excel in, by the combined efforts of the Government, Academia and the Industry.

As an Indian it frightens me today that, as we enter the most complex and competitive period in human history, we in India seem to adopt a policy of benign neglect of higher education and leading-edge S&T. Probably, the only other tragedy that this policy can be compared with is the disarray in the once powerful S&T culture of the former Soviet Union with its devastating consequences.

India does not have a choice. All of us must raise our voices against this benign neglect, in which lie the seeds of economic impoverishment and social disarray. Just talking about liberalization, economic development and poverty alleviation will not do. There are limits to foreign investment and export growth. Without overhauling our S&T base India faces a finite economic horizon.

I, therefore, disagree with my friend's wife and with people like Bernard Levin. Just because we are unable to comprehend science-speak or because many mediocre practitioners may have given science a poor image, it does not mean that there are better alternatives to achieving excellence in science. For there are none. More people will die of starvation and malnourishment without scientific advances and more nations will face decline and catastrophe without the pursuit of scientific knowledge. I am, therefore, thrilled that Narlikar and his dedicated colleagues have built this world-class facility in Pune. Could this be the faint glimmer of light at the end of the tunnel? We need a few more of these, and soon. I am encouraged by developments in massive parallel computing, also in Pune, advances in complex materials in the Institute of Science in Bangalore, the modernization of NCL and a few other such developments. They cost very little money. What they need is a few great minds. As an Indian, I am grateful that we have a fair number of excellent minds. Let us create the environment in which they can flourish to prepare India for the next century.

Jayant and I had the privilege of being members of Rajiv Gandhi's Science Advisory Council. In every meeting we had with him, we enjoyed inspirational debates on the choice of blue-sky priorities. True, even then, everyone was aware of India's day-to-day problems, but it was not a question of either/or. Such debates have now waned. I hope Narlikar and his dedicated group will help revive the debates, even beyond blue skies. I sometimes wonder, if only we could divert a fraction of the energy of our people away from breaking down places of worship or participating in caste riots, towards the pursuit of scientific enquiry, could we transform our nation and start realizing our potential?

I am now pleased about the brief encounter Jayant and I had in January 1994.

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