

- STOCKMAN, H. S., SCHMIDT, G. D., ANGEL, J. R. P., LIEBERT, J., TAPIA, S., BEAVER, E. A., 1977, *Ap. J.*, **217**, 815.
- STOCKMAN, H. S., FOLTZ, C., TAPIA, S., SCHMIDT, G. and GRANDI, G., 1982, *IAUC*, **3696**.
- SWANK, J., LAMPTON, M., BOLDT, E., HOLT, S., SERLEMITSOS, P., 1977, *Ap. J.*, **216**, L17.
- TAPIA, S., 1977a, *Ap. J. Letts*, **212**, L125.
- TAPIA, S., 1977b, *IAUC* 3054.
- TAPIA, S., 1979, *IAUC* 3327.
- TAPIA, S., 1982, *IAUC* 3683.
- TRUBINIKOV, B. A., 1961, *Phys. Fluids*, **4**, 195.
- TRUMPER, J., PIETSCH, W., REPPIN, C., SACCO, B., KENDZIORRA, E. and STAUBERT, R., 1977, 8th Texas Symposium on Relativistic Astrophysics (Boston, 1976).
- WARNER, B., 1976, *IAU Symposium No. 73* (Eds. Eggleton, P., Mitton, S., Whelan, J.).
- WHITE, N. E., 1981, *Ap. J.*, **244**, L85.
- WICKRAMASINGHE, D. T. and BESSELL, M. S., 1976, *Ap. J. Letts*, **203**, L39.
- WICKRAMASINGHE, D. T., HINTZEN, P., STRITTMATTER, P. A. and BURBIDGE, E. M., 1975, *Ap. J.*, **202**, 191.
- WICKRAMASINGHE, D. T. and MARTIN, B., 1979, *MNRAS*, **188**, 65.
- WICKRAMASINGHE, D. T. and MEGGITT, S. M. A., 1982, *MNRAS*, **198**, 975.
- WICKRAMASINGHE, D. T., STOBIE, R. and BESSELL, M. A., 1982, *MNRAS*, **200**, 605.
- WICKRAMASINGHE, D. T. and VISVANATHAN, N. W., 1980, *MNRAS*, **191**, 589.
- YOUNG, P. and SCHNEIDER, D. P., 1979, *Sp. J.*, **230**, 502.

## INPUTS INTO FUNDAMENTAL STUDIES FROM ASTRONOMY

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### Introduction

The organizers of the Inaugural Seminar have kept an open mind towards the question 'What comes in the domain of fundamental studies?' Thus various sciences as well as religions and philosophy, are represented here through distinguished speakers. You will therefore excuse me for feeling somewhat diffident in this august company.

In my talk today I have decided to present a few instances of the important contributions that astronomy has made to fundamental studies. Since by training I am a physicist specializing in astronomy, my main emphasis will be on fundamental physics. However, I would also like to make a few forays outside this area in which I feel at home, largely because the scope of the seminar is not limited to fundamental physics.

I am not exaggerating when I say that of all sciences astronomy is probably unique in forcing man to widen the horizons of his thoughts and concepts beyond his immediate local environment. In its most primitive form, through simply observing the passage of the Sun, the Moon, the planets and the stars across the sky man was led to religion, philosophy and poetry. In its modern form the scientist is confronted with spectacular phenomena which demand extrapolation of scientific laws far beyond the experience of the laboratory scientist.

In tracing the inputs of astronomy into human thoughts at the fundamental level I shall try to adopt a chronological approach. Starting from Vedic times I will work towards the present day and end with a few speculations for the future.

### Antiquity of the Vedas

The Vedas hold a key place in ancient Indian culture. Unlike other scriptures of the Hindus or of other religions, the Vedas are claimed to be without any author(s). The form of Sanskrit language in the Vedas is different from the Sanskrit of the classics which is more commonly known today. The difficulty of following and interpreting Vedic Sanskrit has added to our present difficulty in assessing the antiquity of the Vedas and also in gauging the depth of information contained in those ancient volumes.

Thus experts differ in their views on both these counts. Some say that the Vedas represent the earliest known evidence of human thought and endeavor

our, containing sophisticated science and technology and expressed in code language. At the other extreme the skeptics doubt if the Vedas are all that old or that they contain anything over and above that expected from a primitive civilization.

There is enough evidence, however, to show that astronomy was an important discipline in the Vedic era. Narada's statement

वेदस्य निर्मलं चक्षुर्ज्योतिःशास्त्रमनुत्तमम् ।

(Vedasya nirmalam chakshurjyotihshāstramanuttamam)

means that 'astronomy, an unexcelled science is a clear eye of the Veda'. Astronomy in Vedic times seems to be in three parts, Siddhānta, Samhitā and Horā. Of these the first part is straightforward astronomy while the other two have astrological connotations.

It is not my purpose today to describe Vedic astronomy. Rather I want to describe to you an attempt made at dating the Vedas with the help of the astronomy contained therein. The attempt was made by Bal Gangadhar Tilak, a distinguished nationalist leader in the British India at the turn of the century. Although Tilak is well known as a freedom fighter he was also a Sanskrit scholar with interest in mathematics and astronomy. It was while writing his famous commentary on Gita (known as the Gitarahasya) that a verse in that volume set him thinking.

In chapter 10 of the Gita, Lord Krishna identifies himself with excellence in all things in nature, living or non-living. The line which attracted Tilak's attention was

मासानां मार्गशीर्षोऽहम् ऋतूनां कुसुमाकरः ।

(Māsānām mārgashirshoham rutunām kusumākarah).

meaning that amongst the months he is 'mārgashirshā' while in seasons he is 'spring'.

According to the present Hindu calendar, the month of mārgashirshā (identified with 'mrigashiras' or the Orion) does not come in spring but in the autumn. Why this apparent discrepancy?

Tilak's argument which is given in detail in his monograph 'The Orion' rests on the premise that the above reference was correct at the epoch it was made. Because of the precession of equinoxes the 'first' month of the year (which was identified with the spring equinox) happened to be mārgashirshā then; but it is not so now. Going further in his researches Tilak looked for references to seasons and constellations in the Vedas and argued that to reconcile the apparent discrepancies therein one has to assume a substantial precession of the equinoxes. And from these astronomical inputs one can estimate the epoch when the references in the Vedas were written. Tilak's

calculations set the antiquity of the Vedas and the initial Aryan period as far back as 6000 B.C.

Other scholars dispute this estimate which, they claim, makes the Vedas far more ancient than estimated by other methods based on evolution of literature, history and anthropology. On astronomical grounds, however, Tilak's approach is hard to fault. Its weakness lies in how clear cut are the astronomical references on which the theory rests. As I mentioned earlier Vedic language is neither easy nor unambiguous. Perhaps more systematic search along Tilak's lines is needed to improve the estimates given in 'The Orion'.

### The Law of Gravitation

From the Vedic times I make a jump to the era of Galileo, Kepler and Newton. By questioning the validity of the then established Aristotelean mechanics Galileo laid the foundations of modern mechanics. Newton quantified mechanics with his three laws of motion. The most telling demonstration of the Newtonian system came, however, in the astronomical settings of the Solar System. This is where Kepler's work on planetary astronomy played the key role.

That planets do not move in straight lines with uniform velocities was known to the early Greeks. That the deviation from uniform velocity implies the existence of force became clear after Galileo. How did this force act?

From the three laws of planetary motion derived empirically by Kepler it is possible to deduce the answer to this question. The acceleration of the planet is directed towards the Sun and varies inversely as the square of its distance from the Sun. Using Newton's laws of motion one can then deduce the magnitude and direction of the force. This result was responsible for the famous inverse square law of gravitation.

The remark that Newton arrived at the law of gravitation by watching the fall of an apple does injustice to the above role of astronomy. Without the astronomical inputs it would have been impossible for Newton (or any other scientist) to arrive at the inverse square law. Even today, the demonstration of the inverse square law in the laboratory requires all the resources of modern technology.

Newton's law of gravitation can be said to be the first modern theoretical attempt to understand the natural phenomena in terms of a basic interaction. By saying 'Hypotheses non-tingo' (I do not frame hypotheses) Newton refused to analyze the law of gravitation in terms of anything more basic. With all the later attempts through general relativity and super-gravity we are still nowhere near solving the mystery of gravitation or relating it to a wider and unified framework of all basic physical interactions.

On empirical grounds, however, astronomy has continued to provide settings for the study of the law of gravitation. Laplace's 'Mecanique Celeste' provided, in five volumes, a sound description of the complex

motions of the planets and satellites of the Solar System in terms of the inverse square law. The predicted arrival of Halley's comet and the discovery of Neptune are other examples from astronomy which generated confidence in the law of gravitation.

It was astronomy again which played the key role when the Newtonian theory was supplanted by general relativity. The anomaly in the motion of planet Mercury, known for several decades, became explainable when in 1915 Einstein proposed his radically new theory of gravitation. The dramatic confirmation of the predicted bending of light by the Sun in the 1919 Solar eclipses at Sobral and Principe went a long way towards gaining credibility for the general theory of relativity.

In the Solar System the differences between Newtonian gravity and general relativity are minute and we need well planned experiments to distinguish between the two theories. Earlier I mentioned the difficulties of laboratory experiments on the law of gravitation. These difficulties become magnified if we look for a general relativistic effect in the laboratory.

Take the example of gravitational radiation. This is a consequence of general relativity just as the electromagnetic radiation is a consequence of Maxwell's electromagnetic theory. However, electromagnetic waves were generated and detected by Hertz in the laboratory within two decades of their prediction by Maxwell. A laboratory detector-emitter system for gravitational waves is out of the question. To give an example imagine a gravitational wave emitter in the form of a cylindrical steel beam of radius 1 metre, length 20 metres with a mass of around 500 tons. Rotate this beam about its middle with an angular speed so high that the beam is barely able to maintain its shape. This implies about 250 revolutions per minute. Such a revolving system would emit gravitational waves. But the energy radiated is so small that 100 billion billion billion such systems together would radiate 1 watt of power. Because of such impossibly high numbers, the generation of gravitational waves has to be left to heavenly bodies like a binary star system or a supernova explosion. With luck combined with superior technology such waves may be detected by a laboratory detector one of these days.

The other creature of general relativity, the black hole also requires such esoteric circumstances for its formation that the only hope of establishing its existence lies in astronomy. As its name implies the black hole is a highly collapsed object whose strong gravitational pull prevents light from escaping its surface. How collapsed must a black hole be? If the Earth were to shrink to a ball of diameter 1.6 centimetre it would become a black hole!

Improbable though such an outcome is, the formation of black holes in the vast cosmos is not considered unlikely. Massive stars, after burning their nuclear fuel collapse and could very well become black holes. It would not be an exaggeration to say that the concept of the black hole has generated far larger number of research papers in astronomy and astrophysics than any other single concept of recent origin.

### Physical Interactions in Stars

The examples given so far illustrate the wide gulf that separates the astronomer from the laboratory physicist. This gulf often manifests itself through the suspicion which the laboratory physicist displays towards any astronomical result or any astrophysical theory. Despite the valuable inputs from astronomy into the development of our understanding of gravitational phenomena, an impression is created that whatever the astronomers and the astrophysicists talk about could not possibly be of any relevance to laboratory science.

Nothing could be more misleading! Take for example the observations which led to the quantum theory. Three phenomena contributed towards the early evolution of quantum theory: the black body spectrum, the emission and absorption lines and the photoelectric effect. Of these the last one belongs to laboratory physics while astronomy has provided valuable information towards the first two phenomena. The continuum radiation from stars approximates the black body radiation and surface temperatures of 4,000 K–10,000 K are quite common amongst the different types of stars. Stars of different colours and intensities provide ready made testing grounds for Planck's formula of black body radiation.

The discovery of dark lines in the spectrum of the Sun by Fraunhofer in 1814 first indicated the possibility that the classical electromagnetic theory developed from the time of Coulomb may not provide the whole truth. The discreteness implied in these spectral lines was to pose problems for the nineteenth century physicists. Even Lord Kelvin who contributed so much to the science of electromagnetism and thermodynamics felt at a loss towards the end of his life when confronted with such phenomena.

Just as the outer surface of the stars provided inputs into atomic physics, the stellar interiors gave insight into sub-atomic physics. The equations which describe the internal equilibrium and the energy transport within a star led to the conclusion that the central temperature in the star is related to its mass and could range from ten to forty million degrees. This was the conclusion first arrived at by the Cambridge astronomer A. S. Eddington.

There was one piece of information missing in Eddington's picture. What is the source of energy which maintains the stellar interior at such a high temperature? It is this mysterious energy reservoir which is ultimately responsible for keeping the star shining. The suggestion had been made by J. Perrin in 1920 that this energy came from atomic nuclei in the stellar interior.

Eddington pressed forward Perrin's idea with the backing of his stellar models. It was his argument that the high temperature in the central region of the star would lead to nuclear reactions which are exothermic, that is, reactions which release energy in the form of heat.

In the 1920s there was hardly any study of atomic nuclei and physicists were largely guided by classical ideas of mechanics and electromagnetic theory. On this experience, laboratory physicists were skeptical of Eddington's ideas, even assuming that the stellar interiors are as hot as he claimed them to be. To such doubters Eddington had this classic rejoinder 'we do

not argue with the critic who urges that the stars are not hot enough for this purpose. We tell him to go and find a *hotter place*' (vide *The Internal Constitution of the Stars*, by A. S. Eddington, Cambridge University Press).

In the end Eddington was vindicated. Thermonuclear reactions leading to the fusion of four hydrogen nuclei into a helium nucleus are indeed possible at the temperatures prevalent in stellar interiors. Further, the fusion process gives rise to energy because the mass of the helium nucleus is less than the combined mass of the four hydrogen nuclei and this difference must manifest itself as equivalent energy according to Einstein's famous relation  $E = Mc^2$ . By late 1930s Hans Bethe was able to construct the complete model for the Sun (and other similar stars) with this input.

The nuclear energy so released is the consequence of the strong interaction and the weak interaction, which operate in the short range of  $\sim 10^{-13}$  cm. Off hand it would seem improbable that interactions operating within atomic nuclei should have relevance to astronomy (and vice versa) to a subject which deals with distances of the order of millions of miles, light years and even longer. However, the example of the Sun shows how false this first impression could be. What is more, the demonstration of a working model of a fusion reactor comes from astronomy—an example which the laboratory physicists have so far been unsuccessful in emulating.

The story of nuclear fusion of hydrogen to helium in the Sun is only the beginning of a long chain of fusion reactions which go on inside stars as they evolve. Thus heavier elements are formed and finally distributed over the cosmos as the stars finally explode. The mineral constitution of the Earth can therefore be traced to stellar nucleosynthesis. Our very existence can thus be linked to the distant stars.

### GUTs and Cosmology

The theory of stellar structure and evolution is thus intimately connected with the structure of atomic nuclei and the forces which bind the nuclear particles. We can pursue this line of study further and ask what about the nuclear particles themselves? How did the proton and the neutron come into existence?

One of the frontier areas in theoretical physics handles questions like these. The so called grand unified theories (GUTs), vigorously pursued by physicists today, are concerned with the unification of three of the four basic interactions of physics—the strong and the weak interactions and the electromagnetic interaction. There is as yet no single grand unified theory—but all GUTs lead to the result that the nuclear particles themselves are not stable, but prone to decay. In particular, the proton, hitherto considered immortal, has a finite lifetime. The predicted lifetime is quite high—in excess of thousand billion billion billion years but that it is finite is important. For, it is related to the question of the unification of basic interactions.

Is there any way of testing the working of grand unified theories? One consequence, the decay of the proton, can be looked for in a terrestrial experiment. The first of such experiments, deep in the Kolar Gold Fields in Southern India does appear to indicate the decay of protons (see Professor

B. V. Sreekantan's talk in this seminar). However, to study the full dynamics of GUTs we need powerful accelerators. How powerful?

The largest man made accelerators generate particles of energies as high as 1000 GeV. The accelerators needed to study GUTs must produce particles a thousand billion times as energetic. There is no foreseeable way in which human technology of the future could produce accelerators so powerful. The case here is different from that of nuclear fusion. Fusion reactors emulating the Sun are not yet ready on the Earth but they are certainly within reach of human technology in the next few decades.

There is another way to highlight the tremendous gap between the technology of thermal fusion and the required technology of accelerators needed for testing GUTs. The temperatures at which nuclear fusion takes place are of the order of millions of degrees. The temperature at which grand unification of all three basic interactions is achieved is of the order of billion billion degrees! And this raises the question: 'Granted that terrestrial environment cannot generate such high temperatures; can even astronomers point to a location where such temperatures exist?'

Such temperatures do not exist in stellar interiors. Not even Eddington, wishing his critics would go to hotter places, could have conceived of a temperature so high, except in one circumstance. And that circumstance does not obtain now, but might have occurred long back in the history of our universe.

This point brings me to cosmology, the largest setting for the operation of astronomical events. For, cosmology is the subject dealing with the origin, structure and evolution of the universe. Cosmological models are the outcome of physicists' attempts to describe the large scale structure of the universe in terms of basic laws of physics. These models are supposed to simulate the behaviour of the actual universe. If a model is successful in describing the actual universe as it is at present, then the cosmologist feels emboldened to extrapolate it into the past and the future.

The so called big bang models of cosmology arose out of such a procedure. They are based on Einstein's general theory of relativity and on the behaviour of matter according to known physical laws. These models tell us that the universe arose out of a gigantic explosion (the 'big bang') and, from a state of infinite density and infinite temperature, it began to expand. It is still continuing to expand, although the explosive phase is now over and the present temperature of the universe is as low as 3K ( $= -270$  C centigrade). However, in the very early stages it would have been hot enough for grand unified theories to play their full role.

'The early universe is the poor man's high energy accelerator.' This oft quoted remark reflects the growing research activity in the subject of the 'early universe'. This is the only epoch when the universe was hot enough for GUTs to be effective and hence any observable consequences of GUTs have to be related to this epoch. For this reason, particle physicists who had so far derided cosmology as a speculative subject, have resorted to the study of GUTs in the context of the early universe.

How 'early'? Calculation shows that the temperature of the order of  $10^{28}$  K would have existed when the universe was only  $10^{-36}$  seconds old. Are

we justified in pushing our present knowledge to such limits and still 'believe' our conclusions? We should be cautioned here by Landau's remark 'Cosmology is often wrong but never in doubt'. Nevertheless, the speculative nature of the conclusions is often mistaken for the gospel truth.

### Astronomy and Biology

I now leave my familiar territory of physics and turn to biology and to the important question of origin of life. There are others more competent and experienced than I at this seminar to take part in the controversy 'Did life now seen on the Earth originate here?' What I have to say on this subject will therefore be at a superficial level.

For one who has been working as an astronomer the place of the Earth in the overall scheme of the universe appears insignificant. Copernicus showed that Earth has no special place in the Solar System. Shapley showed that the Solar System has no special place in the Galaxy. Finally Hubble demonstrated that our Galaxy is just one amongst millions of galaxies taking part in the expansion of the universe. Against this background the idea that life exists only on the Earth seems to be somewhat far fetched.

It could be argued that the origin of life is such a complicated event that the chance of its coming about spontaneously is extremely small and hence it should not be a very common phenomenon. If so we must have a demonstration as to why the Earth was particularly suitable for so rare an event. Such a demonstration has not been given so far.

The computation of probabilities and the demonstration of the above type can perhaps be attempted when biologists have a better understanding of the basic phenomenon of life. Meanwhile it is instructive to engage in a thought experiment.

Imagine a geologist who is totally unaware of astronomical research. He finds mineral deposits on the Earth and tries to figure out how they got there. Had he been aware of stellar nucleosynthesis he would have known that the metals he has found were cooked in some stars and thrown out, to be subsequently picked up during the process of formation of the planets in the contaminated medium. Not knowing this scenario he has to argue that the metals were formed on the Earth. He will try to look for evidence in the early history of the Earth to support such a theory. Needless to say that he will find it very difficult to make any progress.

Could a similar situation obtain about the existence of life on the Earth? Are most biologists attempting an impossible task when they seek to explain the origin of life on the Earth in entirely terrestrial terms? Are they ignoring the valuable input likely to come from astronomy?

That complex organic molecules exist in interstellar space has been amply demonstrated. Hoyle and Wickramasinghe have argued that interstellar space contains bacteria and or other primitive life forms. They point to astronomical evidence in favour of their hypothesis. Evidence like this would be very valuable in settling the above question. For, if life structures

are seen in outer space it would be difficult to think of the Earth in isolation.

I feel that in the next two decades the improved astronomical techniques in optical, infrared and microwaves will help us assess the importance of astronomy to biology. If history is any guide, the inputs from astronomy would be truly astronomical.

### Concluding Remarks

This seminar is devoted to present attitudes and future prospects. Let me conclude with a few comments on the latter. In fact I have already begun doing so: for I said that the future will bring considerably more input from astronomy to biology, than it has done so far.

Since I began with a reference to the Vedas I will first say something about them. As a scientist of Indian origin I am often asked to comment on the statement that the storehouse of knowledge in the Vedas and other ancient Hindu books contains the latest in science and technology, including further advances to be rediscovered in the future. Because of my incompetence in understanding the Vedic language I can hardly give an informed judgement. The interpretations given by the experts have however failed to convince me so far.

At first sight such interpretations are often very impressive. For example, in a volume 'Dirghatamas and the Sun' published in Marathi in 1970 the author Bhayyasaheb Pant makes a persuasive case that the sage Dirghatamas, in a series of Cantos of Rigveda describes the outer and inner structure of the Sun in a form that closely agrees with the present astronomical knowledge of the Sun. The description is said to include not only the surface phenomena like sunspots and solar flares but it is also supposed to contain a description of thermonuclear fusion. None of the quantitative details are, however, apparent from the cantos—they are read into the apparently simple words through a code. The interpretation therefore smacks of being wise after the event.

Nevertheless, the subject deserves attention from experts who could objectively assess the importance of the astronomical information in the Vedas.

Coming to physics proper what inputs may we expect from astronomy in the future? Astronomy is likely to confront man with more and more unusual phenomena, some of which may force us to add to the existing set of laws of physics. I had no time today to discuss such ideas as Mach's principle, the apparent unidirectionality of time, the possible relationship of quantum mechanical uncertainty to the large scale structure of the universe, the anomalous redshifts of quasars . . . etc. It is possible that what appears anomalous mystifying or incomplete today may receive a perfectly logical explanation with a better understanding of the laws of physics known already. On the other hand, to argue that the end of physics has been reached with grand unified theories and big bang cosmology is to repeat the complacent attitude of the last century. New observing techniques, espe-

cially from space technology such as the forthcoming Space Telescope may well shake the complacent attitude that is gaining ground at present.

Physicists and biologists, beware of the gifts brought by the astronomers!

To sum up, my examples from astronomy merely illustrate the general interconnectedness of knowledge. To achieve progress in any given area, be it physics or biology or any branch of the humanities, inputs from outside are valuable. In research establishments specializing in specific areas such external inputs are often frowned upon. This is where an interdisciplinary institution like the Institute of Fundamental Studies has a crucial role to play.

I wish it success.

## THE PAST, PRESENT AND FUTURE OF COMPUTERS AND COMPUTER SCIENCE

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### Introduction

Thirty years ago the computer was a new invention; a typical computer filled a large room, contained tens of thousands of valves, consumed hundreds of kilowatts of power, performed a thousand or so arithmetic operations a second and broke down every few minutes. Nevertheless, despite its unreliability, the potential of the computer was, if not recognised, at least sensed from quite early on though some of the predictions made concerning it were rather wide of the mark. An early official estimate of the number of computers likely to be built was that 15 would be sufficient to handle all the computing in the world! Today the minicomputer in my Department in Cardiff has the power of several hundred of those early machines. Prophecy is always dangerous unless, like the Oracle at Delphi in Ancient Greece, one can give ambiguous answers, and the example just quoted is not the only celebrated case of a prophecy that was wide of the mark. When the telephone was invented a certain European Postmaster-General said, after seeing it demonstrated, that although it was undoubtedly an interesting invention he could foresee no possible use for such an instrument since the postal and telegraph services were so good that it was unnecessary. This lack of vision was not confined to Europe; the mayor of an American city, with rather more foresight, said that he thought the telephone was a great invention and that he could foresee the day when every American city would have one.

In the light of such unfortunate predictions the inclusion of the word 'Future' in the title of this lecture might appear rather rash. In some ways it is, though I shall only attempt to forecast the relatively near future, but I feel that in lectures to mark the opening of a new Scientific Institute one should not concentrate entirely on the past and the present. So I'll be taking some risk, though not too great, and I hope that I won't mislead you as to where computers and computer science may be going.

Before coming to the future however I must talk about the past and the present, firstly of computer hardware, that is the physical units themselves; secondly of computer software, the programs that control and utilize these machines; and thirdly of Computer Science as an academic subject of great importance which was unknown 30 years ago but which is now taught in most European and American Universities to large classes of enthusiastic young people.