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PATTERN OF RESEARCH IN INDIA ON THEORETICAL ASTRONOMY AND ASTROPHYSICS DURING THE PERIOD 1990-1980

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The most outstanding work in the field has been the theory of thermal ionisation and its application to astrophysics by Saha in early twenties. Related to it was work on pressure ionisation by Kothari in the late thirties. Although remarkable for their applications in astrophysics, both these works were basically in statistical thermodynamics. In the forties, i.e. the years immediately before independence, one finds a fairly large number of papers, notably from Calcutta and Allahabad, on the problem of pulsation of stars in different conditions, Bethe's law of energy generation and static configuration of rotating stars. There were some works on cosmology also in the pre-independence period, the interest being on the question of stability of cosmological models.

In the post-independence period, the investigations on equilibrium and pulsation of stars were continued; the notable change was the introduction of complicating factors like magnetic fields and viscosity. There was some work also on the configuration of rotating stars. In the field of cosmology, exact solutions of Einstein's equations representing situations different from the Friedmann universe as also the problem of big bang singularity attracted attention. Some interest in the red shift of light from collapsing object is also noticeable.

As the survey is confined to work done in India, a number of important contributions by Indians working outside had to be left out.

I begin with a word of apology, as I feel that I am really not quite competent to give a survey of the researches in theoretical astrophysics in India during the period 1900-1980. My incompetence arises from two reasons. Firstly, I am not myself an astrophysicist in the strict sense of the term. Secondly, most of the researches done in India in olden days were not able to make much impact on the community of astrophysicists abroad in the sense that one fails to find adequate reports of these works in standard books and reviews. Hence, to present a survey, one has to delve into old journals and try to imbibe the spirit of those works. This is not an easy task and in any case demands considerable time. Frankly, I have not been able to devote such time and labour. Besides, the library conditions here are not quite enviable and it is pretty difficult to get hold of old journals.

As a consequence of these limitations, I am not in a position to say anything about the researches in the field that might have been done in the first two decades. The earliest work that I can report happens to be also the most important contribution to astrophysics from India – I mean the outstanding contribution of Saha in the early twenties. Using the principles of statistical thermodynamics, Saha calculated the degree of ionization of an element as a function of the temperature and its ionization potential. Saha showed that many peculiarities of stellar spectra could be understood

on the basis of his ionization formula. In particular, observations revealed a puzzling sequence of changes in the spectra of stars. One wondered whether this indicated the presence of quite different elements in different stars. Saha could correlate these changes in spectra with the change in the degree of ionization due to difference in surface temperature of the stars.

Saha had assumed the electrons to obey Maxwellian distribution formula. This was but natural, for at that time one had no idea about quantum statistics, not to speak of the range of validity of classical statistics. As we now know, in the case of ordinary stars to which Saha applied his formula, the conditions are such that there is no significant difference between classical and quantum distributions. However, the discovery of white dwarf stars on the one hand and quantum statistics on the other demanded a new consideration of the ionization problem in conditions of electron degeneracy. This led to the theory of pressure ionization by Kothari in late thirties, about two decades after the pioneering work of Saha. It is rather interesting to note that both these works were essentially applications of statistical thermodynamics to atomic physics, although their importance arose from application in astrophysics. Perhaps this explains the somewhat indifferent attitude of Saha to astrophysics in his subsequent activities.

Astrophysics in its standard form seems to have found a place in India from the early forties. Thus, following the work of Bethe on energy generation of stars in 1939, we find a few papers elucidating Bethe's law of energy generation and applying it to the study of stellar models, notably by Sen and Burman in Calcutta. However, in the following years, interest in theoretical astrophysics was mainly concentrated on the dynamics of bounded fluid distributions – this took the shape of the study of equilibrium configurations, pulsations (harmonic and anharmonic) of stellar bodies assuming usually polytropic equations of state introducing complicating factors like rotation, viscosity and magnetism. In particular, there were investigations on meridional circulation, and an axi-symmetric model with a specific density distribution was put forward by Ghosh which had equatorial acceleration, as is actually observed for the sun. So far as pulsation problems were concerned, the inadequacy of both the Roche model with its central singularity and the homogeneous model led to the consideration of the so-called composite models in which there were two distinct regions of different density and/or different adiabatic index (i.e. the ratio of the two specific heats). Mention should also be made of the investigation on the influence of rotation on the mass limit. One finds in the field now a host of workers, to name some of them – Banerji, Bandyopadhyaya, Bhatia, Bhatnagar, Burman, Chandrika Prasad, Chatterji, Das, Ganguli, Ghosh, Gurtu, Kushwaha, Roy, Sen, Sinha, Singh, Tandon and Trehan. Within this broad outline, one finds an attempt by Banerji to put forward a novel idea about the origin of the solar system – it was envisaged that at one time, the sun was radially pulsating and instability was brought about by an encounter with another star. All these works which began in the early forties continued right up to the late sixties and in some cases isolated works can be found even in early seventies.

Somewhat distinct from the above trend, but belonging to the same period, was

a series of papers by Das of Kodaikanal, who attempted an explanation for numerous solar phenomena, including sun spots on the basis of the assumption that a fast rotating central core of the sun is throwing out matter. However, the mechanism of ejection of matter was left obscure. Also, in this period we note the work on collision of galaxies by Alladin and coworkers. In the forties, Saha put forward a theory of the solar corona based on the idea that there were some fission reactions occurring in the sun.

In the late sixties and seventies, following the discovery of quasars and pulsars, astrophysical research took a new turn. In India also, we find investigations on the equation of state of ultra-dense matter, as also the dynamics of accretion discs and the mechanism of radiation from these objects. Another related subject was the high red shift from collapsed or collapsing bodies. There was also investigation of upper mass limits to equilibrium configurations. Participating in these researches one finds many researches from different parts of the country, although the TIFR group appears to be playing the dominant role.

I am rather hesitant to include cosmology in astrophysics, as its position in astrophysics has been duly recognised only recently. However, it is gratifying to note that a significant contribution in the field came in India after the discovery of expanding cosmological solutions by Friedmann. Dutta of Presidency College, Calcutta studied non-homogeneous spherically symmetric solutions – unfortunately this pioneering worker is completely forgotten and nothing is known about his subsequent career. A few years earlier, the stability of cosmological models was studied by Sen and reported in a series of papers. In one of these papers, Sen sought to explain the expansion of the universe as a consequence of a condensation in an originally static Einstein universe. This paper was highly appreciated by Eddington, as it agreed with his ideas at that time.

Interest in general relativity and cosmology was revived throughout the world in the post-war period. (Recall the sensational idea of continuous creation and steady state theories of Bondi, Gold and Hoyle in 1947.) In India also, we find some good work in relativity and cosmology coming out in the fifties, which is of astrophysical interest. Vaidya presented his solution of the Einstein equations which could be interpreted as due to a radiating star (in early fifties). A little later, interested in the problem of the big bang, i.e. a singular beginning of the universe in a state of infinite density and vanishing volume, the present author gave an equation which showed clearly the effects of shear, acceleration and vorticity on the temporal history of the universe. This equation, since named after the author, has played a crucial role in all subsequent investigations on the singularity problem, including, in particular, the proof of the singularity theorems of Hawking and Penrose.

Quite a different attitude to the singularity problem is evident in the work of Kembhavi of TIFR who showed that in the conformally invariant theory of Hoyle and Narlikar, there is no geometrical singularity in common cosmological models.

Some other problems in cosmology like embedding of different metrics (like the Schwarzschild, the Vaidya, the Kerr) in a homogeneous universe, the problem of perturbation of homogeneous universes, the red shift in a cosmological background, the so-called anomalous red shift and apparent superluminal velocities, gravitational lens and screens have engaged researchers at different places like Bombay, Calcutta, Gorakhpur and Gujarat. Valiant and persistent attempts have been made by the TIFR group to challenge the generally held belief that the microwave radiation background is primeval and the group tried to explain its thermalisation by scattering processes in not so distant past.

Indian research is noticeable in highly speculative fields as well. Thus, Bandyopadhyaya and his coworkers have advanced the hypothesis of a weak coupling between the photon and the neutrino; they investigated the influence of such a coupling in different astrophysical situations. Tachyons too have figured in the researches of a number of workers who have investigated the gravitational interaction of tachyons, the possible metric field due to an isolated tachyon, and the role that tachyons, if present, may play in the career of the universe. Again, these works have come from Calcutta, Gorakhpur, Gujarat and TIFR. An intriguing result has been given that if tachyons actually occur, one can contrive situations such that there is a violation of the second law of black hole physics. There have been some investigations on the extraction of energy from black holes, notably by Dadhich of Poona.

This brings us to the end of our survey, admittedly very defective. It has been rather painful for me to omit all references to the important works of Indians abroad, but that was the constraint set by the sponsors of the present seminar. I have also omitted all works on plasma physics and some other subjects which very often draw inspiration from astrophysical situations. My excuse is that the authors have not indicated the possibility of the application of their results to astrophysical problems.

After concluding this survey, I consider it my duty to say a few words in the light of the aim of the present seminar. To quote the Convenor, the aim is "to emphasise the changing pattern of the growth of science and technology during the pre- and post-independence periods of the twentieth century."

In the whole period of survey, it is remarkable that no work other than that of Saha can be called really fundamental. However, while before the forties, work in astrophysics was scarce, there was a steady flow of papers during the period 1940-80. This transition preceded independence and apparently owed largely to the involvement of stalwarts like Sen in Calcutta and Banerji in Allahabad. Following independence, a number of research institutes sprang up and their impact became perceptible in astrophysical research in the seventies – Narlikar's settling down at the TIFR giving a fillip to astrophysics in that institute. While in the 1940-70 period the universities and affiliated institutions at Allahabad, Calcutta, Delhi, Roorkee and Jodhpur seem to have been dominating the field, in the seventies the universities receded to the background and the epicentre of activity shifted to the research institutes like the TIFR at Bombay, the Indian Indian Institute of Astrophysics at Bangalore and

the Physical Research Laboratory at Ahmedabad. (A very recent addition has been the Raman Research Institute also at Bangalore but its impact began to be felt only after 1980). Geographically, there is a curious shift from the eastern and northern regions to western and southern parts of the country.

An interesting post-independence phenomenon which is specially evident in the case of the research institutes is the existence of a sort of continuous interaction with the scientific community abroad. One finds frequently foreign scientists visiting these institutes and in their turn scientists from these institutes spend periods ranging from a few weeks to a year or two in research centres abroad. This, besides acting as a general tonic, helps the researchers here in identifying and working on problems which really matter. The possibilities of such interaction are rather poor in our universities and it is better not to mention the institutions like the one in which the present author works.

The author cannot resist the temptation of recalling a remark that Professor Kothari made in the concluding portion of his Bhatnagar Memorial Lecture delivered in October 1967. After referring to the great contribution of Professor Saha in astrophysics, he lamented the rather poor quality of later Indian researches in the field ascribing this to "the relative neglect of the study of astrophysics in our country". Professor Kothari's remarks raise two questions – firstly, has the standard of research in astrophysics in our country really gone down? Secondly, if it is indeed so, is "relative neglect" the cause for that? I venture to suggest that in a way the standard has not deteriorated. Saha was like a dazzling meteor, while at present we have a twilight sky. The meteor vanishes in a moment, but is it too much to hope that the twilight is the precursor of dawn? Today we have no Fellow of the Royal Society or prospective candidate for the Nobel Award amongst us, but I sincerely believe that there are at least a dozen workers whose researches are appreciated around the world.

Again for the shortcomings that are present, is "relative neglect" responsible? Frankly I think it is not so – rather I have a feeling that the real reason behind is the failure of two giants that India produced. Saha was basically a physicist, rather than an astrophysicist and his later years were spent more in organisation and administration than training up young researchers, while the other giant, I mean, Chandrasekhar, chose to stay abroad. Would astrophysical research in India not have been a little different if Saha had devoted a good part of his energy to astrophysics and Chandrasekhar settled down in the land of his birth? One does not know – such questions will remain unanswered for ever.