ASTRONOMY AND ASTROPHYSICS AT PRL PAST, PRESENT AND FUTURE

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INTRODUCTION:

The fundamental discoveries of Evershed in observational astronomy at Kodaikanal and of Meghnad Saha in theoretical astrophysics ushered this science into the modern times as a continuation of our ancient traditions. With the new developments both in instrumentation as well as in theory, it was found necessary for an organised and concerted effort in attacking the various problems that faced the scientific community. It was also realised that divisions such as seismology, meteorology, aeronomy etc. were all artificial and that they were all the different facets of the same science-astrophysics. This has become much more apparent in the recent developments of planetary sciences. This was realised at the very early stages when Physical Research Laboratory was started with two branches of studies such as Cosmic rays and Ionosphere.

Physical Research Laboratory has come a long way from 1947 when it was started, and today it tackles some of the most front-ranking problems in this discipline. It was realised early enough that any programme in Astronomy and Astrophysics will not be complete without a strong group in plasma physics since 90% of matter in the Galaxy is in the form of ionised gas called "plasma" and hence strong plasma physics groups both on theoretical and experimental side exist in the laboratory. While the theoretical group gives a strong backup to the observational astronomers in the laboratory, the experimental plasma group tries to simulate some of the conditions existing in the interplanetrary space especially solar wind, to have a better understanding of the observations under controlled conditions.

The main thrust at PRL today is on the Sun, the nearest star and its various effects on the members of its family viz. the solar system. The most obvious choice amongst the members of the family is the earth, the planet we are living in. Therefore an elaborate study of the ionospheric conditions and the control of the Sun on the ionosphere as manifested in drifts as well as geomagnetic variations are some of the subjects which are of interest in the laboratory. We are singularly placed in the fact that the geomagnetic equator passes through the southern tip of this subcontinent and hence a study of the phenomena of electrojet has enabled this laboratory to make positive contributions in understanding its nature.

We have an elaborate experimental programme in the investigation of Sun in a wide range of wavelength bands ranging from extreme ultra violet (EUV) to metre wavelength. Solar Radio bursts at 40-240 MHz, polarization characteristics such as Faraday rotation at 35 MHz are some of the problems under investigation in the laboratory with the help of the radio telescope. With the newly developed high resolution spectrograph Type II and Type III bursts are recorded and we are planning to study the fine structures in these bursts. The high resolution that we have achieved enables us to study "Stria Bursts". The ultra violet and EUV emission from the solar flare enables one to study the dynamics of solar flare. The interplanetary scintillations have been used to study the irregularities in solar wind as well as structure of compact sources in the southern skies.

Another young discipline we have added to the many pronged attack is the comparatively young branch of Geocosmophysics. In this group, some of the most exciting work is being done in the study of lunar samples brought by the Apollo and Luna missions to throw light on the evolutionary history of the solar system. This is a joint programme with NASA and USSR. Nuclear oceanography and mass spectrometry are other fields of interest to this group.

Study of Galactic Sources using X-ray astronomy as well as cosmic rays form yet another discipline in the PRL programmes. The meteorite and lunar studies also give fossil data on the prehistory of cosmic rays. An ambitious future is planned for PRL wherein we are proposing to start laboratory astrophysics and also take up work in the infrared region which we have left uptill now in the study of the universe.

SOLAR RADIO-WAVES

Solar radio spectroscopy in the range of 40-240 MHz was begun in this laboratory in 1967 and investigations of the physics of solar flares as well as radio bursts have been carried out since. A 35 MHz fine frequency—time resolution spectrograph has recently been commissioned to study the fine structures both in frequency and time in solar bursts. In addition to this, Faraday rotation due to interaction with the intervening plasma between the flare spot and the observer, has been measured: the rotation is observed to be about two orders of magnitude less than the theoretically expected value. The explanation of this observation seems to be connected with the generations of type III bursts at the second harmonic of the local plasma frequency. Theoretically this can be treated as a non-equilibrium process and many of the features such as stria bursts could be treated as due to collective effects of the plasma.

Plans are afoot to simulate radio emissions from solar plasma in the laboratory and study the dynamics of type II and type III bursts under controlled conditions. It is also proposed to study the existence of complex molecules in the interplanetary medium by using these techniques. Faraday rotation measurements may be carried out to obtain valuable information about the Jovian radio bursts ; it is important to note here that the magnetic field of Jupiter is of the order of 10 Gauss.

SOLAR WIND

Some of the discontinuities, which have been identified in the solar wind near the orbit of the earth are found to be nonuniform with gradients in temperature and magnetic field. These gradients, give rise to drift instabilities. The resonant electron instability has growth rates of $\sim 0.1\ \Omega i$, Ωi being ion cyclotron frequency. These instabilities give rise to turbulent dissipation which may lead to destruction of some of the discontinuities.

The observations at 1 AU, show that the proton and α - particles of the solar wind move with equal speeds but at different temperatures. In the vicinity of the sun, however, due to different charge to mass ratios, U_{α} should be smaller than U_p resulting in a relative streaming. Our investigations as to whether this relative streaming could give rise to instability showed that the solar wind just escapes the threshold of this instability, leaving these observations unaccounted for.

The interaction of distant solar wind ($r > 5$ AU) with interplanetary neutral gases, can give rise to magnetoacoustic instability in the region $r < r_c$. The critical distance r_c for the solar wind can be in the range $5 < r_c < 20$ A.U. This will throw some light on the problem of termination of the Solar Wind.

INTERPLANETARY SCINTILLATIONS

Using Ooty Radio Telescope at 327 MHz, Interplanetary scintillations (IPS) of several compact radio sources have been made since 1971. The data were used to derive the properties of the interplanetary medium and structure of the compact sources in the southern sky.

EVOLUTIONARY HISTORY OF MOON AND METEORITES

Cosmic rays induce appreciable changes in meteorites and in lunar surface materials. In both these samples, the two primary effects are (i) nuclear interactions leading to production of stable and radioactive nuclei, and (ii) solid state damage of the crystalline structure of the target matrix. In the former class of materials, the observed effects are deduced to have been produced both during the early history of the solar system before accumulation of the " parent " bodies which are sources of the meteorites, as well as in the later history, i.e. after ejection of meteorites from the parent body and prior to their capture by the earth. Exposure ages can be deduced as well as the chemical composition and the energy spectrum of heavy nuclei can be studied by an analysis of cosmic ray produced radioactivity and fossil tracks in meteorites. The same holds good for the lunar samples but there are very important differences in the irradiation patterns which is generally observed. One of the differences arises from the fact that the low energy records of meteorites are usually destroyed due to atmospheric ablation ; lunar samples are abundant in tracks and readioactivity produced by low energy particles.

Based on the extensive studies of fossil tracks and radioactivity by the Geocosmophysics Group, originally at TIFR, it has become possible to study the time scales involved in the breakup of meteorites from parent bodies. In the case of lunar samples the evolutionary history of the top few meters of the regolith has been derived on the basis of study of soil grains from long cores and a few dozen rock samples ; the lunar regolith is found to be extremely dynamic and simple minded exposure models, as employed for meteorites, are found to be inadequate.

A very interesting result of lunar regolith studies has been the confirmation of the cosmic ray irradiation model proposed for certain gas rich meteorites prior to their compaction.

Future work is now planned to pinpoint conditions under which the parent bodies of meteorites formed in the early history of the solar system.

GALACTIC SOURCES :

Rocket launching and Balloon flight facilities in South India are being used by PRL towards comprehensive X-ray astronomy programme. Telescope with proportional counters as detectors on board of rockets for low energy X-rays and telescopes on oriented platforms deployed with high flying balloons for high energy X-rays have been employed for X-ray astronomy studies. The first Indian Scientific Satellite to be launched in December 1974 is also to have an experiment in X-ray Astronomy.

The studies carried out at PRL ivolve the determinations of energy spectrum, flux and time variation of known discrete sources and scanning of the sky for unknown ones. The balloon and rocket experiments on Sco X-1, have indicated that thermal mechanisms are responsible for X-ray emission. Balloon flight observations have shown the existence of flares in Cyg X-1. Using earth's occultation the flux and energy spectrum of the diffuse X-ray background in the 2-20 keV range were determined in a rocket flight. The few balloon flights conducted to measure the flux and spectrum of diffuse X-ray background in the 20-500 keV range did not reflect the exact nature of the spectrum and only on applying corrections for multiple Compton-Scattering of X-rays in atmosphere, a unique spectral exponent for the energy spectrum in 2 keV-1 MeV was established.

Very recently this Laboratory has reported interesting observations concerning the effect of celestial X-ray sources on terrestrial phenomena. Some of the powerful sources such as Sco X-1, Tau XR-1 seem to cause significant enhancement in the ionisation of the D-region ionosphere at night time and also excess night air glow emissions. Theoretical studies have conclusively proved these effects on ionosphere with the transit of X-ray stars.

The Laboratory envisages an intensive programme in X-ray Astronomy in the near future. The current development work on the highly sensitive X-ray balloon telescope is to be completed soon. This is expected to give very useful information on time variations, pulsations in stars such as Her X-1 and Cyg X-1 at high energies. In addition one would be able to study faint stars and discover new sources. The programme in soft X-ray astronomy aims at investigation of supernovae remnants and extragalactic objects.

COSMIC RAYS—SOLAR AND GALACTIC:

(i) *Ground and Satellite Studies*:

The earlier attempts in PRL were mainly centred on the study of electromagnetic conditions of the interplanetary medium in the neighbourhood of the earth. The experiments were done at sea level at Ahmedabad and Trivandrum and at high altitude stations such as Gulmarg and Kodaikanal. Detectors made in this laboratory such as GM and proportional BF_3 counters were used to measure the intensity of charged particles and neutrons respectively. The problem was tackled with more sophisticated and larger detectors and the data from various other stations were also analysed along with our own data.

The studies of cosmic ray anisotropy have been noticeably fruitful. The possibility of a 22 year variation in the diurnal anisotropy was established in our laboratory for the first time from the data supplied by the Carnegie Institution, Washington. A paper on the cause of diurnal variation of cosmic ray intensity from our laboratory started a series of papers which ultimately led to the (more or less) complete understanding of the anisotropy.

The diurnal variation is now understood to be the result of two processes: one a radial convection of cosmic rays outwards from the sun and the other a diffusive process towards the sun, with the diffusion being constrained to be along with interplanetary magnetic field. This was very clearly brought out by the study of data from the widely spaced Pioneer spacecrafts 6-9 and Explorer 34-41 observations. The satellite data studies further brought out information on physical processes such as near sun particle storage, diffusion and secondary injection which are triggered by distant solar flares. The propagation of solar cosmic rays in the interplanetary space is found to be essentially governed by the changing electro-magnetic conditions of the interplanetary medium and therefore cosmic rays serve as space probes.

(ii) *Contemporary Cosmic Radiation in the Vicinity of the Earth—Experiments on Skylab*

An experiment to study low energy galactic cosmic ray nuclei in the energy region—(10-150) MeV/n, based on studies of tracks in a stack of Lexan sheets, exposed on the Skylab for 72 days, is being carried out in collaboration with Tata Institute of Fundamental Research.

As in the case of lunar rock and soil samples, the passage of charged particles in the Lexan plastic produces solid state damage which can be enlarged and seen under an optical microscope.Lexan records nuclei of atomic number exceeding 5, whereas the corresponding threshold in the case of lunar samples is 20. Thus the present experiment, because of its long exposure in free space is expected to provide statistically significant data on the charge and energy spectrum of low energy galactic cosmic ray nuclei near the earth. Fairly large statistics is expected both for the lowest energy and the very heavy nuclei; results so far are very encouraging.

(iii) *Prehistory of Cosmic Rays: Fossil Evidence Based on Studies of Radioactivity and Tracks*

With the development of the fossil track method the scope of extraterrestrial samples for providing information on the history of cosmic radiation has consderably increased. The natural detectors in rocks, mostly crystalline silicates, have begun to provide very high resolution cosmic ray information about heavy nuclei in the kinetic energy region (1-1500) MeV/n, thanks to the development of sophisticated techniques in India for the study of the solid state damage produced in the natural detectors. Observations of fossil tracks in meteorites and lunar samples allow one to deduce the chemical composition and energy spectrum of nuclei of $Z > 20$ for the (1—3) AU space and for time periods of the order of (10^6-10^7) yrs. during the recent time period, (0-100) m.y. as well as during the early history of the solar system. Comparison with the contemporary cosmic ray data, wherever possible reveals that there have been no dramatic changes in the past, either in the energy spectrum or in the chemical composition for both solar and galactic cosmic ray nuclei. One of the important features of cosmic ray studies using the meteorites and lunar samples is that long term averages can be obtained for solar flares for which contemporary data are obviously limited.

Future emphasis will be to obtain shorter term averages for the chemical composition and the energy spectrum at different epochs in the past in order to study secular and spatial changes in the cosmic rays as the solar system sweeps through different parts of the galaxy. This information should be extremely useful for understanding the nature of sources responsible for acceleration of heavy ions and diffusion length and time scales for cosmic rays in the galaxy.

STUDIES IN ASTROPHYSICS DURING NEXT FIVE YEARS:

Solar Physics:

Line emissions in the solar atmosphere give important clues to the dynamics of the solar atmosphere. Many features of the short-term and long-term variations of the solar EUV spectrum are yet obscure and the flare time behaviour in these wavelength regions is also not clearly known. In view of this, it is proposed to make measurements on hydrogen Lyman alpha and beta lines (1216Å and 1026Å), helium I and II lines (584Å and 304Å) as well as in the silicon continuum (1540-1680Å) using thin film filters and ionization chambers. Studies would include the short-term and long-term variations in these emission-intensities. The total flare time enhancements of these intensities would also be measured. The experiment has been proposed for the Solar Maximum Mission to be launched during 1978.

It is also planned to make Lyman alpha maps of the solar atmosphere during flares. This would be accomplished by obtaining an image of the sun with a Cassegranian type of telescope, dividng it into many zones and then measuring the Lyman alpha emissions from each zone separately by means of channel electron multiplier arrays. This experiment has been proposed for the Solar Maximum Mission to be launched in 1978.

Planetary Atmospheres:

The atmopsheres of the planets, Mars, Venus and Jupiter have been found to be amenable to studies from a balloon platform. The solar infrared radiation reflected from these planets can be conveniently detected by baloon-borne Ebert-Fastie spectrometers. These spectrometers are made to look at the planetary disc with altitude controlled devices. The balloon heights assure the minimum telluric absorption and hence better sensitivity. Such a study would be undertaken by us in the near future.

Laboratory Astrophysics:

The atmospheres of different planets exhibit many interesting phenomena due to interaction of solar radiations and charged particles with its neutral constituents. These interactions give rise to phenomena like photo-absorption, total and partial photionization, ionic fluorescence, elastic and inelastic collision of charged particles, etc. The study of these phenomena in the laboratory is conventionally named as 'Laboratory Astrophysics'.

The study of photon interactions with planetary gases has already been undertaken in this laboratory. It is planned to start work on photoelectron spectroscopy of atomic oxygen in the near future.

FUTURE PROGRAMME IN INFRARED ASTRONOMY:

Infrared astronomy continues to be an expectant area and PRL has plans to use the existing facilities in India to study the universe from ground based observations and also to create new observational facilities. Interferrometry, fast Fourier transform spectroscopy etc. are some of the tools which will be used to study stars and hot gas clouds.

EPILOGUE

Physical Research Laboratory has passed its 25 years of existence and is entering into its adulthood. The programmes at PRL in the field of astronomy and astrophysics were conceived and fostered by Dr. K. R. Ramanathan and late Prof. V. A. Sarabhai. With man landing on the moon and spacecrafts spanning the solar system, new themes are emerging in the area of space sciences and new challenges are thrown every day. We are confident that we shall look ahead and shoulder the responsibilities that science and society bestow on us.