It was a pleasure to participate in the working group on Turbulence and non-linear wave phenomena in plasmas. Almost everyone in the group (including the students) took an active part in the discussions which were quite informal and uninhibited. These discussions were so fruitful that the third working group on Experimental Plasmas, decided to join this group for a couple of days. The major credit for this goes to Dr. D. Montgomery of University of Iowa and Dr. A. Hasegawa of Bell Laboratories. Dr. K. Longren, though an electrical engineer, prefers to work in theoretical nonlinear plasma physics problems ; he opted to join this group. Of the three groups, this was the biggest group ; this turned out to be so because the two groups (Turbulence and Nonlinear Wave Phenomena) which were initially supposed to be separate groups, because of the common interest of the scientists had to be combined at the last minute. Any way, the number of participatns was still not that large that it could be unmanagable.

The third working group dealt with the experimental aspects of plasmas in general and in particular with the problems on relativistic beams and ring which is one of the prospective candidates for the future nuclear fusion programme. Since, at present, in India we do not have many centres which are involved in Laboratory Plasmas, this group had the Indian participation only from PRL and from Saha Institute at Calcutta. The U.S., however, was represented by Professors I. Alexeff of University of Tennessee, C. B. Wharton of Cornell University, K. Kristiansen of Texas Tech. and R. Bengtson of University of Texas. The experimental group at PRL, which is just out of its infancy stage, benefited a great deal from the experts in this field.

Professor Montgomery did a magnificent job of reviewing the subject of Two-dimensional MHD Turbulence and Plasma Turbulence. Dr. M.R. Gupta (presently at Calcutta University) talked about the Binary Correlations and Phase Space Granulation in a turbulent plasma. The technique of self-similar-solutions is widely applied in fluid dynamics but is still not very popular in plasma physics. Professor Longren, by means of a number of examples from plasma physics, illustrated the use of this powerful technique of reducing the partial differential equations to the ordinary differential equations. Dr. Hasegawa, because of his clear exposition, could easily convince the audience that, contrary to the general belief, Alfven wave under certain conditions could act as a kinetic wave and gave its applications to heating of plasmas. Nonlinear Schrödinger equation which describes the envelope behaviour of nonlinear plasma waves, because of mathematical complexity, is usually discussed in one dimension. The three dimensional analogue ot this equation, for nonlinear ion acoustic and Langmuir waves was discussed by Dr. Buti of Physical Research Laboratory. She elaborated on the consequences of the multi-dimensions on the stability of the plasmas and in particular discussed the problem of collapse. Dr. Malik of Punjab University showed that the presence of some neutrals in a plasma could drastically affect the nonlinear stability of a plasma in a nonuniform magnetic field. Dr. B. Das Gupta of Saha Institute presented an alternative method of deriving the one-dimensional nonlinear Schrödinger equation for plasmas. Coming to the laset plasmas, Dr. Forslund gave a couple of lectures on nonlinear processes in laser light absorption. With the help of particle simulation techniques used by him, he very nicely illustrated the important processes involved in the absorption of intense laser light by a plasma. Dr. S. Krishan, of Indian Institute of Science, talked about the anomalous absorption and emission from laser-produced plasmas whereas Dr. A.K. Sundaram of PRL discussed the effects of coherent and turbulent spectrum of waves on trapped particle modes.

On the experimental side, Professor Alexeff gave a critical survey of ion acoustic waves and Professor Bengtson, besides discussing about the plasma heating in the Texas turbulent torus, also talked about the concept of a turbulently heated reactor. The senior most participant, Professor Wharton gave a really authoritative account of plasma heating by intense relativistic electron and ion beams. Professor Kristiansen devoted one lecture in explaining the part played by lasers in the problem of heating of magnetized plasmas. In the second lecture, he completely dwelt upon the fusion reactor technology. Lastly Dr. Y.C. Saxena reviewed the activities of experimental plasma physics group of PRL.

The highlight of the workshop was the panel discussion on 'Present Status of Nuclear Fusion'. It was exceedingly encourgaing to see the lively discussions on different aspects of fusion e.g. tokomak, mirror machines, stellarator, relativistic beams and lasers. The general conclusion was that the nuclear fusion is indeed the most promising source of power in future but it should not be expected, on commercial level, before the end of the century.

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REPORT OF THE SYMPOSIUM ON RELATIVISTIC ASTROPHYSICS

The Eighth Texas Symposium on Relativistic Astrophysics jointly sponsored by the American Astronomical Society and the American Physical Society was held between December 13-17, 1976 at Boston, Massachusetts, USA. The scientific program of the symposium consisted essentially of about 50 invited critical status reports on a variety of "hot topics" in astronomy astrophysics and cosmology each followed by brief discussions for about 5 minutes. A number of informal sessions were organised in the evenings on topics of specialised interest to smaller groups of participants.

It is evident that it will not be possible to condense in a few pages all that was presented in a symposium which covered a wide spectrum of experimental and and theoretical work in relativistic astrophysics. We have therefore attempted in the following to focus attention on those aspects which according to us are new and exciting; we also confess that there is a definite bias of presentation stemming from our own interest and expertise.

From a profusion of new and often unexpected experimental findings made in X-ray astronomy during recent years using novel detecting instruments carried in high flying balloons, rockets and satellites, certain trends and order are now emerging. Much of this has been realised in the brief period of the last 2-3 years because of the opportunities of prolonged observations for months and even years now possible with sophisticated instruments on earth satellites such as UHURU, Ariel-5, Copernicus, SAS-3 and OSO-8. Some of these can be commanded continuously from ground to point the X-ray telescopes towards any part of the sky of interest thus rendering the space station one of considerable flexibility for observations. These observations in turn have been greatly responsible for triggering a variety of new and exciting work in relativistic astrophysics related to binary systems, neutron stars, black holes, supernova explosions and supernova remnants. It is therefore not surprising that at this symposium the organisers rightly laid emphasis on these topics on which there were as many as 29 presentations. On the subject of radiogalaxies and quasars there were 9 reports and on gravitation, cosmology and related topics 8.

1. X-Ray Observations :

1.1 X-ray Bursters: This is a new class of X-ray emitting objects recognised to be important and studied seriously only during the last two years or so. Though the first X-ray burst event was observed in 1971 from a Soviet satellite followed by more from the US satellite Vela-5, it is only after 1975, burst arrival directions could be determined with adequate accuracy necessary for source identifications. These X-ray bursts have a rise time of 1-2 sec and last for period varying between a few seconds and few minutes. Such events have a a tendency to recur from the same object. So far 20-25 such objects, now named as X-ray Bursters, have been discovered.

H. Gursky of the Centre for Astrophysics at Harvard Smithsonian summarised the data on a total of 24 Bursters of which, according to him, 6 are associated with globular clusters (NGC 1851, NGC 6440, NGC 6441, NGC 6624, NGC 6388 and NGC 6541), some with binaries and other with steady X-ray emitting objects. In the last category, there is an indication that the association is correlated to the X-ray luminosity of the source ($\sim 10^{36}$erg s^{-1}). He then referred to the similarity of the time structure of X-ray and γ-ray bursts of which the later though discovered earlier still await source identification because of the large errors in the determination of their arrival directions. Nevertheless, the available information on the arrival directions of γ-ray bursts seem to be isotropic in nature indicating thereby that they represent a relatively nearby phenomenon (or extragalactic origin). Whether there is any real relation between the two is still an open question.

In the talk by W. Lewin of MIT on the same subject he defined an X-ray Burster as an object which gives rise to X-ray bursts recurring from the same object in some regular pattern with rise times $\lesssim 2$ sec and total duration of not more than few minutes. With these criteria, he accepts only 17 Bursters compared to the 24 of Gursky. Furthermore, he claims from an analysis which is free from selection effects that there is a clustering of Bursters around the galactic center and a dearth of high galactic latitudes (b) and longitudes (l). Indeed from the UHURU satellite there are 54 bursts with $l \lesssim 60°$, 32 with $l = 60°$-$120°$ and only 15 with $l = 20°$-$180°$. He also presented the following interesting observations. (i) A total of 24 bursts have been seen from NGC 6624 which is a bright globular cluster. The average burst interval is about 2.6 hours. The tail of the burst shrinks with increasing burst number untill the bursts cease; the steady emission then slowly builds up and the object starts bursting again. (ii) Within an area of 2°x2° toward the galactic center there are 3 Bursters which give rise to about 3 bursts per day per source. Of the 8 bursts seen from one of them, all have double peak structure; the tail in the burst is softer, and the steady emission after the burst is significantly higher than before the burst. (iii) The Small Astronomical Satellite SAS-3 observations on MXB 1730-335 reveal rapid bursts of the order or 5000 per day perhaps a category different from the other bursts. It is also found that after a large burst the waiting time for the next is longer. Occassionally an anomalously small pulse is seen between regular pulses and so far 13 such events have been seen. Lewin also summarised some of the general properties of X-ray bursts and Bursters. (a) Burst intervals range from hours to days; (b) there are active and inactive periods of bursts; (c) the energy from burst to burst does not vary much; (d) the luminosity in the steady X-ray emission is roughly 100 times that in the bursts : (e) the mean burst spectrum is harder than the associated steady spectrum; (f) the peak intensity is 10^{-8}—10^{-7} erg cm $^{-2}$s $^{-1}$; and (g) the spatial distribution of Bursters is unlike that of globular clusters and also unlike X-ray sources though the Bursters may be a such set of X-ray sources.

It was generally noted that more observations are needed before agreement can be reached between different groups particularly on important aspects such as the Burster association with globular clusters. Also there was no satisfactory understanding and explanation offered at the meeting for the various observations.

J. Ostriker of the Princeton University, made a statistical analysis to find whether there is any correlation between properties such as galactic distribution, luminosity, variability, colour-colour relation, high energy tail and radio emission of X-ray Bursters, globular cluster X-ray sources, galactic center X-ray sources, low and high mass binaries and black hole candidates, and found no significant correlation. Probably, the available statistics is too small for such a study.

1.2 Millisecond X-ray bursts: E. Boldt of Goddard Space Flight Center (GSFC) described from their rocket experiment observations on another class of X-ray bursts lasting periods of milliseconds only using large area detectors with time resolution of 160μs. With this instrument they detected from Cyg X-1 four clear events which are consistent with square bursts lasting ≈ 1 ms. A statistical analysis of their data is also suggestive of a periodicity of 9.9 ms for the bursts. If this periodicity is ascribed to the last orbit before the matter plunges into a black hole, it will indicate a black hole mass of 15M⊙. These inferences must be treated with caution at this stage but they highlight the potentialities of such lines of investigation in X-ray astronomy.

1.3 Extragalactic X-ray sources: The increasing sensitivity and directionality of X-ray telescopes have now made it possible to look for X-ray sources beyond our Galaxy. Such observations on extragalactic X-ray objects were reported by H. Schnopper of the Center for Astrophysics from SAS-3, K.A. Pounds of the University of Leicester from Ariel 5, P. Sanford of the University College, London, from Ariel 5 and Copernicus and E. Boldt of GSFC from OSO-8. A total of about 30 extragalactic sources have so far been well identified of which about 20 seem to be in Abel clusters (Pounds). From a statistical study of 12 X-ray emitting Seyfert galaxies and 3 X-ray emitting quasars, Pounds says that there is support for the inference that quasars probably lie in the continuation of the plot of luminosity versus redshift Z of Seyfert-1 galaxies. The following are some of the interesting observations on individual objects. (a) The Cen A X-ray source has a position coincident with the infrared component at the nucleus of the galaxy with an accuracy of 15″ and perhaps 3″. The source has shown variability between 1969 and 1976. There is also some evidence for an extended component from which 25% of the emission originates. (b) The X-ray source in NGC 1275, which is a Seyfert galaxy, is a composite of a point like and extended sources. Its position coincides with the nucleus of the galaxy within 10″. (c) 3C 120 and 3C 273 have also been identified as X-ray sources. (d) Finally, observational evidence was provided for the emission of the Fe line at 6.7 KeV from Perseus, Virgo and Como clusters, and probably from Cen A and Cyg A.

1.4 Polarisation measurements : R. Novick of the Columbia University reported the following preliminary observations from the 2 X-ray polarimeters mounted on OSO-8. (a) Definite evidence for polarisation from the Crab has been obtained. At 2.6 KeV it is $22.6 \pm 1.5\%$ and at 5.2 KeV it is $24.5 \pm 5.7\%$ compared to 19% in the optical region. This confirms the synchrotron origin of X-ray emission from the Crab nebula. (b) A 5% polarisation at 2.6 KeV with a 95% confidence level has been seen for Cyg X-2. (c) For Cyg X-1 a poorer evidence at 2-3% level has been found at 2.6 KeV.

1.5 Gyroline emission from Her X-1 : J Trumper of the Max Planck Institute at Garching reported from a balloon experiment the first possible evidence for the gyroline emission from Her X-1 at 53 ± 3 KeV. The observed line or shoulder in the X-ray spectrum has a 7 σ level of significance. If this line is of cyclotron frequency origin, the associated magnetic field will have an intensity of $4.6 \pm 0.3 \times 10^{12}$ Gauss assuming that it is the first harmonic. The intensity of the line is 1.4×10^{-3} cm $^{-2}$s^{-1} and at 6 Kpc will correspond to the emission of 5×10^{35} ergs s^{-1}. They claim to have looked into all possible alternate explanations and find none which is satisfactory. However, the experimental evidence and the interpretation should be considered as tentative until further verification is made.

2. Binary Systems :

Because of the significant association of X-ray sources with binary stellar systems, great attention is being given to the study and understanding of close binary systems. A. Cowley of the University of Michigan reviewed the data on low mass X-ray binaries Her X-1, Cyg X 2, SCO X 1, Cyg X 3 and 3U 1809 + 50 (AM Her) and discussed them in the light of low mass binaries which are not X-ray emitters. It is found that in the H-R diagram, the last category of binaries do not lie on the main sequence but along a distinct black body relation. They exhibit an optical continuum and strong emission lines like old novae. A model to understand the observations with mass transfer between a cool dwarf star and a degenerate star was also discussed.

The mass transfer and evolution of X-ray binaries was dealt with by a number of speakers; much of this is in the published literature. In order to understand the low period pulsars Her X-1, Cen X 3 and SMC X 1, E. Van den Heuvel of the University of Amsterdam proposed a model in which pulsars are born in massive X-ray binaries as rapid rotators and spin down in a weak main sequence stellar wind and remain in slow spin state for a period of $\sim 10^6$ years. When the companion leaves the main sequence the X-ray pulsar spins up depending on V_W the wind velocity. The expectation is that for $V_W \approx 500$ Km s^{-1}, the spin up time is $\sim 10^4$ years where as for $V_W \approx 200$ Km s^{-1}, it is only a few years. However, an application of this model to the known slow binaries does not lead to a satisfactory understanding (see paper by Van den Heuvel and Heise in *Nature Phys. Sci.*, **239**, 67, 1972).

B. Flannery of the Center for Astrophysics has made extensive computer studies of mass transfer in close binaries. An important result from his study is that in certain systems mass can leave through the outer Lagrange point to form a cocoon around the system This may be the case in some systems like Cyg X-3.

3. Neutron Stars :

F. Lamb of the University of Illinois reviewed the processes occuring near neutron stars in binaries. As a possible solution to understand the spin up puzzle (between the observed and calculated spin up time periods) of slow rotators such as the Vela pulsar, he suggested that rotators are born slow. He also suggested that the complex shapes of X-ray pulses in some of the pulsars is probably due to multipole structure of the magnetic field near the surface of the pulsar. E. Schreier of the Center for Astrophysics on the other hand tried to relate $\dot{P}$, the rate of change of period to luminosity changes and finds that though there seems to be a general correlation, there is a large wandering for the average spin up rate. Lamb interprets this wandering as possibly due to the transfer of angular momentum to the core of the neutron star.

S. Rappaport of MIT described in detail an attempt to estimate from the known observational data, the masses of neutron stars in binary systems associated with

X-ray and radio pulsars 3U0900-40, Her X-1, PSR 1913 + 16, Cen X 3 and SMC X-1 and came to the conclusion that the allowed mass range of the neutron star is rather narrow namely 1.4-1.9 $M_\odot$ if the companion is a white dwarf and $\lesssim 1.9\ M_\odot$ for other types of companions. (For further reading see Joss and Rappaport, *Nature*, **264,** 219, 1976). K. Brecher of MIT reviewed the calculations on masses of neutron stars. He showed that while under usual general relativity considerations, neutron star masses should be below $5M_\odot$, with theories such as Brans-Dicke theory the limit can be very much higher. He therefore cautioned drawing conclusions about the presence of black holes purely on the basis of mass. V. Canuto of NASA at New York reviewed the topic of neutron star structure using various equations of state. One important development in this area is the study of the contribution of quarks to the structure of neutron stars (quark stars?).

4. Black Holes :

The most important contribution in this field was due to S.W. Hawking of the University of Cambridge, England. He reviewed his pioneering work wherein he has been able to show that while according to classical theory of general relativity, the intense gravitational field around a blackhole would prevent any particle or light signal from the singularity to escape from the black hole, they are really not completely black: quantum effects allow particles and radiation to tunnel out of them. In the case of these particles emitted by a black hole neither position nor velocity can be definetely predicted. All one can do is to give the probabilities that particles will be emitted in certain modes. The reason for this break-down in predictability is that information about the quantum state of the system, like baryon number, is being lost down the black hole. Equivalently one can say that new random information is enteing our universe from regions (either singularities or wormholes leading to other universes) about which we have no knowledge (see Hawking, *Scientfiic American*, Jan. 1977 and Sciama, *Vistas in Astronomy*, **19**, 385, 1976).

5. Supernovae and Supernova Remnants :

G. Tammann of the University of Basel has studied the six historical supernova (SN) of our galaxy (Lupers, 1006 AD; Crab, 1054 AD; 3C 58, 1181 AD; Tycho, 1572 AD; Kepler, 1604 AD; and Cas A, 1725 AD) and finds that all of them are at positions with Z, the distance above the galactic plane, greater than 100 pc and are within a galactic longitude of ± 25 °. On the other hand it is known that supernova remnants (SNR) have a Z dependence which is very much peaked at small values of Z. If corrections are therefore made for the *l* and Z distances of historical SN seen in our galaxy since 1000 AD, the rate of SN explosions in the Galaxy works out to be one in 11^{+15}_{-4} years. (we will like to recall here that estimates made by other authors in the past have ranged between 30 and 150 years). He also stressed the overall similarity of the spectra of Type I and Type II SN though there are significant differences such as the exponential part of the light curve in blue for Type I has a value of $\tau_{\frac{1}{2}} \approx 44$ days which it is ≈ 190 days in the case of Type II.

J. Taylor of the University of Massachusetts spoke about the relationships of pulsars to SN. While there are 150 known radio pulsars and 120 SNRs, the association between them is very poor (only 2 associations so far). Also while on the average pulsars are about 10^6 years old, SNRs are relatively very young. The poor association between them is thought to be due to luminosity problems though no quantitative explanation is possible yet. He also summarised some of the gross features of pulsars assuming that they belong to a galactic population. (a) The total number of pulsars in the galaxy is expected to be about 7×10^5. However, beaming is not important this number may have to be reduced by about 5. (b) Pulsar life expectancy is about 4×10^6 years. (c) Their birth rate is about one in 6-15 years. (d) They have a scale height of $Z \approx 250$ pc. (e) The luminosity function can be written as $\phi(L) = 350\ L^{-1.1}$ where $L = S_{400}\, d^2$. Here S_{400} is the flux at 400 MHz in Jy and d is distance in Kpc. This relation corresponds to 90 ± 15 pulsars per kpc^2 in the neighbourhood of the sun.

6. Radio Galaxies and Quasars :

I. Shapiro of MIT summarised the very exciting work on Very Long Base Line (VLBL) observations on quasars with resolutions of ≈ one milliarc second, that have provided evidence for the expansion of quasars at apparantly superrelativistic speeds. Almost all observations made so far on a few dozen quasars show time variation. Of these about 10-15% sources have components that appear to separate at speeds $> c$. The source 3C 279 which was the first to give speeds $> c$ dramatically changed its structure in a period of months. The observed increase of angular size $\dot{\Theta} = 0.67 \pm 0.07 \times 10^{-3}$ arc sec yr^{-1} which corresponds to a velocity of expansion of 25 ± 3c assuming a double component structure for the quasar, $H_0 = 55$ km s^{-1} Mpc^{-1} and $q_0 = 0$. In the case of 3C 345 on which observations are available for a period of 5 years, there is some evidence for an acceleration in the expansion rate during the last 2 years. He also brieflly mentioned the variety of models and theories proposed to understand these observations but none satisfactory.

D. Richstone of the Hale observatories described a study of the optical continuum of about 80 quasars and found the spectral index α in the powerlaw relation $f \propto \nu^{\alpha}$ had values ranging between −3 and + 1/3 with a pronounced peak between 0 and −0.5. His attempts to find any correlation between α and other properties such as optical luminosity and radio spectral index were in vain. He also referred to two broad absorption features at about 2000 Å and 4000 A in the continuum which still await an explanation. M. Rees of the University of Cambridge, England, reviewed theories of quasars and was in favour of central black holes of

$\sim 10^6 M_\odot$ as being the prime movers in these objects. The energy released from these objects is probably due to the tidal disruption of stars and the debris settling in circular orbits around the black hole and providing matter for accretion. He also suggested a mechanism which can explain qualitatively the super-relativistic expansion of quasars. In this the relativistic blast wave impacting on the mass cone along the spin axis, simulates a double source separating apparently with $v > c$.

Van der Laan of Leiden observatory presented an impressive amount of experimental data (based on ~ 100 man years) about radio galaxies. His main thesis is that irrespective of thin sizes (kpc to Mpc) nearly all of them show double structure with rotational symmetry of bridges and even other small features. He argues that they are all driven by the same "engine". There are globules of emission or hot spots within the double structures which suggest in-situ acceleration. The magnetic field shows large scale structures wrapped around the hot spots and the magnetic energy is mainly in stream lined patterned field.

7. Cosmology :

In an attempt to determine the deceleration parameter, q_0, B. Tinsley of Yale University considered various methods used and their drawbacks. It is found that various stellar and galaxy evolution effects introduce corrections to the estimate of q_0. It is then concluded that q_0 determination as of now is inconclusive because of the difficulty in unravelling these evolutionary effects.

The question of the isotropy of the universe was considered by Vera Rubin of the Carnegie Institution. She has made Hubble diagrams in different directions and by a comparison finds that after taking into account the motion of our galaxy with a speed V of about 600 km s^{-1}, the universe is isotropic to within 5% which is of the same magnitude as the error in the analysis.

The study of the anisotropy of the universal 3°K radiation on the other hand yields a limit of $V < 300$ km s^{-1} in disagreement with Rubin's value as reported by R. Weiss of MIT. He discussed various difficulties in determining the high frequency side of the 3°K blackbody curve. His conclusion is that the blackbody nature on the high frequency side of 3°K radiation has not been established yet.

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