Report of Meetings, 19, 20, and 21 November 1985

PRESIDENT: Riccardo Giacconi

INTRODUCTION

The Scientific sessions of Commission 48 at the XIX General Assembly of the International Astronomical Union in Delhi, India, were focussed on "High Energy Galactic Phenomena". The three sessions, which were held on November 19, 20, and 21, dealt with "Cosmic Rays", "Very High and Ultra High Energy Gamma-rays from Compact Objects", and "X-rays and High Energy Gamma-rays". Each session consisted of invited discourses and contributed papers. Below a list of the invited discoursers is given:

COSMIC RAYS:

Contemporary Problems and Perspectives in the Origin of Cosmic Rays. Dr. Ramanath Cowsik, TATA Institute of Fundamental Research

Cosmic Rays Above 10 to the Power of 15 EV: Their Origin and Propagation. Dr. Arnold Wolfendale, University of Durham

Cosmic Ray Acceleration by Shock Waves. Dr. Catherine Cesarsky, Service D'Astrophysique Institute de Recherche Fondamentale

VERY HIGH AND ULTRA HIGH ENERGY GAMMA RAYS FROM COMPACT OBJECTS:

Model of Theories of High Energy Sources. Dr. Kenneth Brecher, Goddard Space Flight Center

Experimental Observations of Gamma Rays. Dr. P.V. Ramana-Murthy, TATA Institute of Fundamental Research

Production of Neutrinos and Other Particles. Dr. Thomas Gaisser, Bartol Research Foundation

X-RAY AND HIGH ENERGY GAMMA RAYS:

Nonthermal Processes in X-Ray Binaries and AGNs. Dr. Jonathan E. Grindlay, Harvard Observatory Center for Astrophysics

EXOSAT Observations of the Structure of Low Mass X-Ray Binaries. Dr. Nicholas White, European Space Agency (ESA)

High-Energy Gamma Rays from Non-Compact Active Sources and Compact Objects. Dr. Wim Hermsen,

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In what follows, an abstracted version of the invited discourses is given.

Session 1 - Cosmic Rays.

a) Dr. Ramanath Cowsik reviewed contemporary problems in the study of cosmic rays with particular emphasis on their origin. According to the author:

> The problem of cosmic ray origin centers around finding an explanation for the relativistic corpusular radiation which permeates the galactic environment with an energy density of $\sim 10^{-12}$ erg cm^{-3} comparable to other forms of energy and as those associated with turbulence and thermal motions of the interstellar gas.
>
> The weight of the observational evidence (Proc. ICRC, La Jolla, 1985, eds. Jones, Adams and Mason) and the theoretical studies suggest that bulk of the cosmic rays up to $\sim 10^{4}$ GeV/nucleon, originate in numerous compact sources distributed in a thick disc.
>
> The current discussion and debate is around the basic set of questions: a) where are the particles accelerated, in the general interstellar space or in compact sources? b) what is the region of storage, a thick disc or an extended halo? c) are the decreases in the ratio of primaries to secondaries with energy to be interpreted as indicative of sources shrouded with matter (nested leaky-box) through which the particles of higher energy pass with increasing facility before entering the general interstellar medium, or in terms of energy dependent transport out of the galactic volume (simple leaky-box)? d) what is the source material for the cosmic rays? e) how are the chosen particles injected efficiently into the accelerators? and f) what fraction is extragalactic?

Dr. Cowsik presented a summary of the current status of observational evidence and theory regarding the first two questions.

b) Dr. Arnold Wolfendale devoted his contribution mainly to the general problem of galactic vs extragalactic cosmic ray origin. The author pointed out that although a strong case exists for supernova remnants being responsible at energies below about 10^{10} eV, conventional models indicate a near impossibility of SNR being efficient above about 10^{14} eV and at these higher energies objects epitomised by Cygnus X-3 (which produces

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γ-rays to some 10^{16} eV, and thus protons to 10^{17} eV or so) are likely sources. At still higher energies no good candidates exist, as yet.

The author considers that the main problem above 10^{15} eV is the determination of the transition energy at which extragalactic particles start to predominate. Data from extensive air showers experiments show an increasing concentration of arrival directions from the general direction of the Galactic Plane with increasing energy. This work has been updated recently by Szabelski and collaborators with the inclusion of the latest results from Sydney and Haverah Park. The analysis appears to show a termination of the increased concentration at a little above 10^{19} eV, strongly pointing towards an extragalactic origin above this energy. It is likely that M87, with its dramatic jet is an important source of these extragalactic particles.

c) Dr. Catherine Cesarsky discussed the latest theoretical developments in the study of galactic cosmic ray acceleration by shock wave.

This attractive acceleration mechanism was introduced, a few years ago, and simultaneously, by several groups from all over the world (Krymsky, 1977; Axford et al., 1977; Bell, 1978; Blandford and Ostriker, 1978). The basic ideas are:

1) every time a relativistic particle of energy E crosses a shock of velocity V, it suffers an energy increase proportional to EV/c;

2) if particles can be retained for a long time in the shock vicinity by a scattering mechanism, they can cross the shock a large number of times, and their energy can be boosted by a large factor. Under some general conditions and with some first-order approximations (e.g. test particle approximation for the cosmic rays), the processes predicted a power law spectrum of index (-2) similar enough to that observed.

It seemed that, at last, the acceleration of galactic cosmic rays had been understood: it was the result of the interactions of cosmic rays and supernova shocks in the interstellar medium (Blandford and Ostriker, 1980; Axford, 1980).

It was also immediately realized that, for s.n. shocks in the interstellar medium, the test particle approximation is not valid, and the work on the non-linear case started immediately.

The most recent work by Eichler and Ellison (1985) shows that taking into account more realistic conditions prevailing in the interstellar medium a similar spectrum can be obtained with an efficiency of acceleration of 25%. Unfortunately however, the author points out, the great drawback of the shock acceleration mechanism is that it is slow. Consequently, when applied to realistic shocks, which have a finite lifetime, the theory predicts a high energy cut off. Since non linear effects slow down the acceleration, an upper limit to the maximum energy can be derived with the linear theory. In the case of the acceleration of cosmic rays by a supernova shock, the most optimistic assumptions on the diffusion coefficient lead to a maximum proton energy of about 10^5 GeV. Using a self-consistent theory, where the scattering is due to cosmic ray-generated waves, the maximum proton energy decreases to values as low as 2000 GeV. This is the major problem encountered by this theory in the context of galactic cosmic ray acceleration. It cannot be solved by invoking acceleration of supernova shocks in the galactic halo (Lagage and Cesarky, 1985).

Session 2 - Very High and Ultra High Energy Gamma-Rays from Compact Objects

a) Dr. Ramana-Murthy *reviewed the observations of very high and* ultra high energy gamma-rays from compact objects. His summary is given in Table I.

b) Dr. Kenneth Brecher reported on the cosmic-ray acceleration in UHE and VHE gamma-ray sources.

VHE ($>10^{12}$ eV) and UHE ($>10^{15}$ eV) γ-ray emission has been reported from the X-ray source Cygnus X-3, as well as several known X-ray binaries, including Her X-1, LMC X-4, Cen X-3 and 4U 0115 + 63. These observations, if subsequently found to be statistically significant, imply the acceleration of high energy cosmic rays in these sources. Any model of the acceleration of these particles would have to satisfy several criteria:

(1) Gamma-rays with energies of up to 10^{16} eV have been detected, implying initial particle energies (hadrons) of 10^{17} eV. assuming that the gamma-rays arise from pion decay.

(2) The total cosmic-ray luminosity of these sources must be at least 10^{38} erg/sec, perhaps as high as 10^{39} erg/sec in the case of Cygnus X-3.

(3) UHE particle production may be the major energy loss mechanism for these sources (though non-relativistic bulk gas ejection may also be important.)

(4) The spectrum of accelerated particles could be mono-energetic, even though the gamma-ray spectrum has an E^{-2} power law photon distribution.

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TABLE I. VERY HIGH AND ULTRA HIGH ENERGY GAMMA RAYS FROM COMPACT OBJECTS: OBSERVATIONS

Ser. No.	OBJECT	COORDINATES R.A. h-m	COORDINATES DECL. DEG.	APPROX. DIST. kpc	APPROX. PERIOD	V.H.E.G.R. TIME AVG. INTEGRAL FLUX (≥1 TeV) cm^{-2} s^{-1}	V.H.E.G.R. TIME AVG. LUMINOSITY (≥ TeV) ergs s^{-1}	U.H.E.G.R. TIME AVG. INTEGRAL FLUX (≥1 PeV) cm^{-2} s^{-1}	U.H.E.G.R. TIME AVG. LUMINOSITY (≥1 PeV) ergs s^{-1}
1.	CRAB PULSAR	05-32	+ 22	2.0	33.3 ms	4.10^{-12}	6.10^{33}	?	?
2.	VELA PULSAR	08-34	- 45	0.5	89.2 ms	3.10^{-12}	3.10^{32}	?	?
3.	PSR 1937+21	19-37	+ 21	5	1.56 ms	2.10^{-11}	2.10^{35}	?	?
4.	PSR 1953+29	19-53	+ 29	3.5	6.13 ms	$1.2.10^{-12}$	6.10^{35}	?	?
5.	CYG X-3	20-31	+ 41	$\gtrsim$ 11.4	4.8 hr 12.6 ms	5.10^{-11} ?	$\gtrsim 3.10^{36}$?	2.10^{-14} ?	$\gtrsim 10^{36}$?
6.	HER X-1	16-56	+ 35	5	1.24 s	3.10^{-11}	3.10^{35}	$3.3.10^{12}$*	$1.6.10^{37}$*
7.	4U0115+63	01-15	+ 63	5	3.61 s	7.10^{-11}	6.10^{35}	?	?
8.	CEN-A	13-22	- 43	4400	Steady flux	4.10^{-12}	3.10^{40}	?	?
9.	CRAB NEBULA/ PULSAR	05-32	+ 22	2.0	DITTO	10^{-11}	$1.6.10^{34}$	1.10^{-13}	$1.5.10^{35}$
10.	M 31	00-40	+ 41	670	DITTO	$2.2.10^{-10}$	4.10^{40}	?	?
11.	VELA X-1	09-00	- 40	1.4	8.96 d	?	?	$9.3.10^{-15}$**	$2.3.10^{34}$**
12.	LMC X-4	05-32	- 66	50	1.41 d	?	?	$4.6.10^{-15}$***	10^{38}***

* Flux and Luminosity about 5.10^{14} eV.
** Flux and Luminosity above 3.10^{15} eV.
*** Flux and Luminosity above 10^{16} eV.

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(5) Particle acceleration must be fast (seconds or less), in order for the particles to escape the acceleration region without major energy loss before hitting the presumed gas target giving rise to the observed VHE and UHE gamma-rays.

The author discussed the three different kinds of models proposed to date to account for the cosmic ray flux from these sources.

Pulsar Acceleration. Pulsars are known to accelerate particles to high energies, in the case of the Crab nebula, electrons with energies of at least 10^{11} eV. A similar mechanism may apply to Cygnus X-3, a source with a 4.8 hour gamma-ray periodicity, but with a possible shorter underlying (pulsar?) periodicity in the 1 - 100 ms range. While such a model could be made to fit the properties of Cygnus X-3, it cannot fit the observed luminosity of the four other reported VHE and UHE gamma-ray sources because of their longer observed pulse periods. At least for these sources an alternative energy source, derived from accretion rather than rotational energy, is required.

Shock Acceleration. Since we are dealing with accreting binary systems, the ultimate energy for the accelerated particles comes from accretion, rather than rotation, thus allowing for a long lived source. A standing shock near the polar cap can accelerate protons to high energies. However, these particles suffer severe energy losses by synchrotron radiation and other processes. The maximum accelerated particle energy is achieved by equating the acceleration to loss times and, for reasonable parameters, gives $\gamma_m \lesssim$ few $\times 10^7$.

Unipolar Induction. This model in a sense combines some of the features of pulsar acceleration models with the shock acceleration model, in that the particles are accelerated by a parallel electric field, but the ultimate energy source is from accretion. For weak enough magnetic fields ($B \lesssim 10^9$ gauss) and strong enough accretion rates ($L \gtrsim 10^{39}$ erg/sec), a potential drop of 10^{17} volts can develop. If the Alfven surface lies just above the neutron star surface, the accelerated particle luminosity can equal the accretion luminosity. Since particles, not photons, carry off the energy, the total accretion luminosity can excede the normal (photon) Eddington luminosity by a factor of 10 - 100, thus allowing for the high observed non-thermal luminosity of Cygnus X-3.

The author concludes that any of these models is at least plausible.

c) Dr. Thomas Gaisser reported on the production of neutrinos in close binaries.

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If a compact object in a binary system accelerates protons to high energies, it is natural to expect production of high energy secondaries when the accelerated particles collide with target nucleons in the system. The secondaries will include high energy photons from decay of neutral pions produced in the collisions.

Charged pions will also be produced. These will either interact and contribute further to the cascade or decay to muons and neutrinos. Therefore, if this model correctly explains very high energy gamma rays from binaries, then these systems should also be potent neutrino sources. The author made two points:

1) The expected neutrino flux is large, but (because of the small cross section for neutrino interaction) the neutrino-induced signal is too small to explain the reported underground signals from the direction of Cygnus X-3. Neutrino signals may, however, be large enough to show up in underground detectors of large area ($\gtrsim 1000\ m^2$), and they would likely be detectable in an area as large as proposed for a deep underwater muon and neutrino detector ($\sim 10^5\ m^2$).

2) Absorption of neutrinos with energies $\gtrsim$ 2 TeV deep in the companion star is likely to be very significant and may give rise to upper limits on the total cosmic ray luminosity of the system and to mechanism for quenching the high energy signals periodically.

Session 3 - X-Rays and High Energy Gamma-Rays

a) Dr. Jonathan Grindlay discussed nonthermal phenomena in X-ray binaries and AGNs. He pointed out that:

Whereas it is customary to think of the primary processes occurring in and around compact X-ray binaries as being thermal ones, many of these same systems show striking non-thermal behavior in the form of variable radio emission, jets and high energy spectra. In this sense, the physics of these objects may closely resemble that in active galactic nuclei (AGN). Although the possible similarities have been pointed out many times before, particularly for sources such as SS433, work carried out in collaboration with L. Molnar and D. Band points out more directly the possible links between Cygnus X-3, SS433 and AGN.

The peculiar X-ray binary Cygnus X-3 produces relatively intense radio flares with an apparent period of 4.95 hours, which is significantly displaced from the 4.8 hour X-ray period. These flares constitute the normal "quiescent" radio emission from the source and are probably the low end of a size spectrum which extends up to the giant radio outbursts which the source seems to produce each September-October. The radio

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flares show a striking frequency versus time dependence which strongly suggests an expanding synchrontron source and indeed our recent VLBI observations at 1.3 cm wavelength directly measure the expansion of the source to be 0.4 mas/hr with an axial ratio of about 2:1 in the north-south direction (refs. 2,3). This shows that the binary is ejecting relativistic electrons into jets roughly once each binary orbit, although during the giant flare events the injection is strong enough to be directly resolved in the jets even a month after the outburst. The total energy in relativistic electrons in each "quiescent" radio flare is probably in excess of 10^{41} ergs, so that the total luminosity in non-thermal particles is at least 10^{37} erg/ sec, or comparable to the total observed accretion luminosity of the system. An underlying hard X-ray spectrum (non-thermal) with spectral index comparable to the radio index (0.6) should therefore accompany the flares; Compton-synchrotron models for the source are being calculated.

SS433 shows radio flares which also inject relativistic electrons into the jets and which do in fact accompany apparently non-thermal X-ray flares of the system. The more luminous central-most X-ray source is apparently buried so that only the surrounding non-thermal emission region is seen during flares and the additional thermal emission (producing Doppler-shifted iron line emission) from hot plasma entrained in the jets. Recent calculations for the origin of the non-thermal X-ray emission show that it may be produced by inverse Compton scattering of electrons in a central synchrotron source on the thermal IR and optical photons produced in the accretion disk or companion star and surrounding dust. The detailed calculations show that the non-thermal X-ray flares cannot arise from the same extended region in the jets as the observed radio emission without gross violations of equipartition; instead the X-ray flares arise in a central optically thick synchrotron source from which the plasmons in the jets are probably ejected.

A very similar Compton-synchrotron model for the X-ray emission (as well as far-IR through optical spectrum) for radio-quiet QSOs and AGN (e.g. Seyfert 1s) has been developed.

b) Dr. Nicholas White described EXOSAT Observations of the Structure of Low Mass X-ray Binaries.

The study of the X-ray properties of Low Mass X-ray Binaries (LMXRB) has been revolutionized by the capability of EXOSAT to make long uninterrupted observations lasting up to 80 hours and by its fast (up to 5000 Hz) temporal resolution. Five new orbital periods have been established with periods ranging between 2.9 and 4.4 hours and one at 21. hours. These periods manifest themselves as irratic dips in the X-ray flux that recur periodically. They are thought to be caused by a splash of material at the edge of an accretion disk at the point where the gas stream from the companion collides with the disk.

The orbital period distribution of the LMXRB is centered between 2.9 and 7. hours. Orbital modulations have only been convincingly detected in the lower luminosity system (~10^{37} erg/s). The bright galactic bulge sources with luminosities of ~10^{38} erg/s, do not show dips or eclipses indicating their orbital periods are longer than a few days. This supports the view that there is a dichotomy in the properties of the LMXRB with the high luminosity systems driven by the evolution of a giant, whereas, the lower luminosity systems are driven by gravitational radiation/magnetic braking.

Quasi-periodic Oscillations (QPO) have been discovered by EXOSAT, first from GX5-1, and then subsequently from the following six sources: Cyg X-2, Sco X-1, GX17+2, GX349+2, the rapid burster and 4U1820-30. The QPO frequency ranges from 20-35 Hz in GX5-1 to 2-5 Hz from the rapid burster, with the remainder in between.

The frequency-intensity dependence of the QPO comes in two flavors. First, the highest frequency QPO (>10 Hz) show a strong dependence between frequency and intensity (typically to the power 2 or 3). When the QPO are at a lower frequency they are not strongly correlated with intensity and if anything show a slight anti-correlation with intensity. The typical RMS amplitude of the QPO in these seven sources ranges from 1% up to 10%. In the rapid burster the behavior of the QPO is quite different from the other sources. Here QPO appear both during bursts and in persistent emission found between bursts. The frequency seen during a burst is inversely correlated with the peak flux during the burst. In between bursts, the QPO execute an S shaped pattern in frequency from 2 to 4 Hz and then appear in the following burst at the final frequency seen in the S pattern. The most puzzling aspect of this source is that the QPO are not seen all the time, but only during ~50% of the bursts and only very infrequently in between bursts.

The models for QPO are as varied as the number of different properties being found by EXOSAT. The most promising seems to be the beat frequency model where the rapidly rotating magnetosphere of a millisecond pulsar interacts with the inner accretion disk. This model, if correct, fits in with evolutionary models for the millisecond radio pulsars where the pulsar is re-cycled back to a rapid rotation period in a LMXRB. On the other hand non-magnetic models for QPO are also being proposed where the QPO are generated in an inner accretion disk corona or in the boundary layer between an accretion disk and the neutron star.

c) Dr. Wim Hermsen discussed the observation of high energy gamma-rays from non-compact active sources and compact objects.

The detection of localised sources of high energy gamma radiation, first by SAS-2 and later more comprehensively by COS-B, has led to much discussion regarding the physical nature of the objects that number 25 in the 2CG catalog. Only the Crab and Vela pulsars have been unambiguously identified; the ρ-Oph cloud has subsequently been resolved; and 3C273 and the X-ray source 1E0630+178 have also been proposed as counterparts. The status of the remaining sources is much less clear. An exhaustive review has been given by Bignami and Hermsen and additional papers discussing the observations and possible models can be found in the proceedings of the meeting on 'Galactic Astrophysics and Gamma-Ray Astronomy' (Morfill and Buccheri, 1983) organized during the General Assembly of the IAU in Patras in 1982.

Of the gamma radiation observed above 100 MeV only a few percent is due to the cataloged sources which are viewed against intense background emission from the galactic plane. Detailed modelling of the galactic plane emission as being due to the interactions of cosmic rays with atomic and molecular interstellar gas demonstrates that the large angular scale features of the gamma-ray intensity distributions are well reproduced in this way. The analysis has been extended to small angular scales showing which of the 2CG sources might be due to conventional levels of cosmic rays within clumps of gas and which cannot be so explained. A possible scenario for some of the sources is the interaction of SNR's with interstellar clouds. For such a SNR-cloud coincidence Pollock argues for identification of 2CG006+00 and 2CG078+00 with the synchrotron-emitting region behind the shock front. Alternative explanations have been proposed, e.g. contributions of stellar winds or close binary systems.

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