44. ASTRONOMY FROM SPACE
(L'ASTRONOMIE A PARTIR DE L'ESPACE)

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Introduction

Yoji Kondo

The tragic loss of Space Shuttle Challenger and her 7 crew members in January 1986 has seriously affected the astronomical research from space in the U.S.A. and, to a lesser extent, in Western Europe. The incident has caused setbacks in a number of space projects, including the delay in the launching of the Hubble Space Telescope. Nevertheless, the field of space astronomy remained active during the present reporting period (1984 July through 1987 June).

The orbiting astronomical telescopes that were productive during the trienneial period include IUE, EXOSAT, Tenma, Ginga, and several experiments aboard Mir. Five interplanetary probes to Comet Halley and Voyagers 1 and 2 also returned important astronomical data. In addition, a number of rocket, balloon and airplane payloads yielded valuable astronomical results.

In 1984-1987, we witnessed two extraordinary astronomical events, i.e., the bright supernova 1987a that exploded in our sister galaxy, Large Magellanic Cloud, and the perihelion approach of Comet Halley in 1985-6. Astronomical observations from space played important roles in both of these events.

At the time of Comet Halley's perihelion passage, five interplanetary probes, the European Giotto, the Russian Vega, the Japanese Sakigake and Suisei, and the American ICE intercepted the comet for in-situ observations. The first space observation of Comet Halley was obtained with the geosynchronous ultraviolet satellite observatory International Ultraviolet Explorer (IUE), which monitored the comet for about a year. Many advances in our understanding of the comet have resulted from those space observations.

The brightest supernova since Johannes Kepler's naked-eye observations of a galactic supernova in 1604 was detected on 1987 February 24. Within a few hours of the notification of the discovery, the first far-ultraviolet spectrum of the supernova was obtained with IUE. Because of its advantageous geo-synchronous orbit, IUE was the only telescope available to observe the supernova during the early hours of the crucial first day after the discovery. Aided by the results of the sophisticated analysis of the pre-explosion photographic plate of the supernova field, the progenitor of the supernova was identified as a blue supergiant from the IUE spectrum.

X-ray emission from the supernova was detected in August by the Japanese satellite Ginga and also from the Soviet space station Mir, which carried the West German and British X-ray telescopes.

1. GAMMA RAY ASTROPHYSICS BEYOND THE SOLAR SYSTEM

C. E. FICHTEL

A. INTRODUCTION

There have been several interesting new results, interpretations, and theoretical developments in gamma-ray astrophysics over the last three years, although the pace has slowed as the analysis of the data from previous satellites is being finished, and new spacecraft are not yet launched. Some of the new data are related to the nature of the central galactic region, SS433, the detection of a different type of gamma ray burst than detected previously, the large high energy emission of Cygnus X-3, and gamma radiation from galaxies. Regarding the future, the Soviet satellites GAMMA I and GRANAT will be launched in 1988, and the U.S. NASA Gamma Ray Observatory (GRO) is now planned for 1990. There will also be high altitude balloon flights over the next few years that will be of interest both for their potential new scientific results and the demonstration of new instrument techniques.

B. OUR GALAXY

From the earliest satelite measurements, it was clear that the gamma ray sky was dominated by the galactic plane. Although these data did not have the angular accuracy to separate the diffuse galactic radiation from that of point sources, the theoretical analyses of the time (Bignami and Fichtel, 1974, and Bignami et al., 1975) suggested that the majority of this galactic radiation was diffuse, coming from cosmic ray interactions with the galactic matter (e. g., Stecker, 1970) and photons. Although there was some later speculation that point sources might make a quite large contribution, recent studies with improved matter distribution estimates (e. g., Strong et al., 1987) support the original view, and Simpson and Mayer-Hasselvander (1987) even show that the number of detectable point sources at a given sensitivity level is probablly notably less than some of the larger numbers proposed. Strong et al. also conclude that, on the average, there is a variation of the cosmic ray intensity with galactic radius, as several earlier studies had suggested. This gradient is consistent with the galactic cosmic-ray-matter coupling hypothesis of Bignami and Fichtel.

There have been several reports of lines being detected from the general region of the galactic center in the last few years. Since the low energy detectors that have flown have wide fields, typically from 15° to 35°, precise location of the orgin of this radiation is not possible. The most extensive recent results related to the half MeV line from this general direction are those of Share et al. (1987), who reported a series of measurements using a telescope on SMM over the period from 1981 to 1986 consistent with the several earlier results, but of higher statistical weight in total. Other recent reports (Leventhal et al., 1982; Paciesas et al., 1982; and MacCallum and Leventhal, 1985) give only upper limits just consistent with the positive results if the emission is diffuse. With the exception of the Bell Sandia results (Leventhal, 1985, and earlier papers), all appear now to be consistent with a constant, diffuse galactic emission. The 1.81 MeV line, presumed to be ^{26}Al originally seen by HEAO-3 (Mahoney et al., 1982) has now also been seen by instruments flown on SMM (Share et al., 1985) and on a balloon (von Ballmoos, Diehl, and Schonfelder, 1986). If this line comes from the debris of supernovae as suggested by Ramaty and Lingenfelter (1977), its distribution should be broad. Hence, better positional accuracy is greatly to be desired.

The HEAO-3 gamma ray group (Lamb et al., 1983) reported gamma ray lines at 1.5 and 1.2 MeV during the period of 1979 and 1980 from SS443. More recent attempts to detect these lines during the period from 1980 to 1985 by MacCallum,

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et al. (1985) and Geldzahler et al. (1985) have led only to upper limits, in some cases well below the previously reported intensity.

A new type of burst phenomena seems to have emerged, which in photon energy seems to be about an order of magnitude larger than the soft x-ray bursts, but much lower than the now well known gamma-ray bursts. Thus far, three, and possibly four, have been observed. The most distinctive feature of these soft gamma bursts is that they are repetitive; they are also relatively brief and free of the complex temporal structure often seen with the hard gamma ray bursts. The most recently discovered series of bursts seen by instruments on PROGNOZ-9, the International Comet Explorer and the Solar Maximum Mission (Hurley et al., 1987; Laros et al., 1987; Kouveliotou et al., 1987) have a source consistent with an earlier January, 1979 event in the direction of the central part of the galaxy. The other two seen with gamma-ray burst type instrumentation consisted of at least twelve bursts. One was in the plane of the Galaxy (Golenski et al., 1983; Mazets et al., 1981) and the other in the direction of N49 in the Large Magellanic Cloud (Mozets and Golenski, 1979). It is also possible that an unusual transient series seen by other instruments (Babushkina et al., 1975) may belong to this class. The properties of these bursts have been summarized by Cline, Kouvelitou, and Norris (1987).

Several reports of very high energy gamma rays from Cygnus X-3 in the last several years (See, e.g., Weekes, 1987) have stimulated considerable theoretical study of the interesting question of how can a source that is approximately ten kiloparsecs from the Earth produce energetic particles of very high energy in sufficient quantity to lead to this gamma ray emmission. Cygnus X-3 which is a remarkable highly variable source is the only gamma ray source that has been seen by more than one observation team in the high energy region (>30 MeV), the very high energy range (>10^{11} eV), and the ultra high energy realm (>10^{14} eV). Three different groups (Danaher, 1981; Lamb, 1982; and Dowthwaite, 1983) have all reported evidence for activity in the TeV gamma ray energy region centered on the 0.6 to 0.7 phase of the 4.8 hour period seen in the x-ray resion. A reexamination of the SAS-2 high energy gamma ray data (Fichtel et al., 1987) confirmed the 4.8 Hour periodic emission, but indicated no evidence of the ten minute type bursts seen both at very high energy gamma ray energies (Dowthwaite et al., 1983; Weekes, 1983) and at infrared Wavelengths (Mason, Cordova, and White, 1986). A further study of the COS-B high energy gamma ray data (Hermsen et al., 1987) obtained at a later time than the SAS-2 data, which was collected just after a large radio flare, again gave only an upper limit to the high energy gamma radiation. One theory that seems to be able to explain the very high energy gamma ray emission reasonablly well is that of Chanmugam and Brecher (1985) who suggest that the high energy particles which produce the gamma rays are accelerated in an accretion disk, surrounding the neutron star, by the unipolar induction mechanism. Thus, in this model accretion is the ultimate source of energy.

In addition to Cygnus X-3, detection of very high energy gamma radiation by ground level detectors has now been reported for the Crab pulsar, the Vela pulsar, PSR 1953+29, PSR 1802-23, PSR 1937+21, Hercules X-1, 4U0115+63, and Vela X-1 in our galaxy (See Weekes, 1987, for a summary). In addition, ultra-high gamma radiation has been reported from three of these sources.

A recent analysis of the entire set of COS-B data from the Crab pulsar and Nebula (Clear et al., 1987) showed that the spectrum of the pulsar emission can be represented by a single power law of index 2.00 ± 0.10 over the entire energy range of the instrument, 50 to 3×10^{3} MeV. Unpulsed emission was measured up to 5×10^{2} MeV with a spectral index of 2.7 ± 0.3, which supports the steepening of this spectrum observed in the hard X-ray region.

C. EXTRAGALACTIC GAMMA RADIATION

Looking beyond our galaxy, no new sources beyond those known three years ago have been added to the observed list. The extragalactic gamma ray sources that are generally accepted as detected are the Sefert galaxies NGC 4151 and MCG 8-11-11, the quasar 3C 273, and Centaurus A (NGC 5128), although other marginal posibilities are candidates for further future study. There have been two new confirmations of the low energy continuum from Centaurus A (Gehrels et al. 1984 and Ballmoos et al., 1985), but no confirmation of the very high energy radiation. The new low energy data strengthen the already established dramatic drop in intensity between about 15 and 40 MeV, with there being only the severe upper limits established by SAS-2 and COS-B existing above about 40 MeV.

In addition to expanding our knowledge of active galaxies with the larger satellite instruments to fly in the future, several calculations (e.g. Fichtel and Trombka, 1981; Houston, Riley, and Wolfendale, 1983; and Ozel and Berkhuijsen, 1987) show that several of the closest normal galaxies should be visible in gamma rays. The large Magellenic Cloud and the Andromeda galaxy M 31 should be of particular interest because their level of intensity and proximity may permit at least a crude study of their structure in the gamma ray realm.

One of the most interesting considerations for nuclear gamma ray spectroscopy is that it should be possible to detect gamma ray lines from material synthesized in a supernova explosion under certain conditions. Among other considerations, including of course the correctness of the model, the ability to see the gamma ray lines depends on how soon the overlying material becomes transparent to the gamma rays being omitted at any particular level and on how far away the supernova occurs. For the recent supernova 1987A in the Large Magellenic Cloud, the line most likely to be seen is the one at 0.847 MeV from Co^{56} with the next most likely line being 0.511 MeV (See, e.g., Clayton, Colgate, and Fishman, 1968). Lines from nuclei decaying more quickly probably will not escape at detectable levels; even the lines just mentioned will probably not be at observable levels if they cannot be seen in the first three years from the time of the explosion in early 1987.

There have been no new measurements on the isotropic diffuse radiation. More detailed information on this subject of potentially very significant cosmological implications will probably have to await results from GRO.

D. FUTURE PROSPECTS FOR GAMMA RAY ASTRONOMY

The satellite opportunities for γ-ray astronomy in the near future are the Soviet GAMMA-I and GRANAT planned to be launched in 1988 and the NASA Gamma Ray Observatory, currently scheduled for launch in 1990. The information to be obtained from these satellites will be supplemented by that from instruments carried on high altitude balloons and ground based very high energy telescopes.

i. GAMMA-I and GRANET

The next gamma ray satellite expected to fly is GAMMA I. The major instrument on GAMMA-I is Galper, which is similar to SAS-2 and COS-B in the sense that its central element is a multilayer spark chamber system, triggered by a directional counter telescope, and surrounded on the upper end by an anticoincidence system. The upper spark chamber system is a twelve-level wide gap Vidicon system. The directionality of the electrons is determined by a time-of-flight system rather than a directional Cerenkov counter. The sensitive area is about 1400 cm^2 or about 2½ times that of SAS-2 or COS-B. The area solid angle factor is about the same, because the viewing angle is smaller. The gamma-ray arrival direction measurements are expected to be an improvement over those of SAS-2 and COS-B. GAMMA-I will also carry a 0.2 to 20 MeV NaI telescope using a modulated anticollimator. GRANAT is primarily an x-ray satellite, but will carry

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an instrument called SIGMA using a coded mask system to study the 0.04 to 2 MeV range. It will have an energy resolution of about 7% and an angular resolution between 0.1° and 0.2°.

ii. The Gamma Ray Observatory (GRO)

There are four instruments on GRO covering the energy range from 0.03 MeV to $3x10^4$ MeV, all having a major increase in sensitivity over previous satellite experiments. The Gamma Ray Observatory will be a shuttle-launched, free-flyer satellite. The nominal circular orbit will be about 400 kilometers with an inclination of 28.5°. Celestial pointing to any point on the sky will be maintained to an accuracy of ±0.5°. Knowledge of the pointing direction will be determined to an accuracy of 2 arcminutes. Absolute time will be accurate to better than 0.1 milliseconds to allow precise comparisons of pulsars and other time varying sources with observations at other wavelengths from ground observations and other satellites.

The four instruments to fly on GRO are:

The Gamma-Ray Observatory Scintillation Spectrometer (OSSE)

This experiment utilizes four large actively-shielded and passively-collimated Sodium Iodide (NaI) Scintillation detectors, with a 5° x 11° FWHM field of view. The large area detectors provide excellent sensitivity for both γ-ray line and continuum emissions. An offset pointing system modulates the celestial source contributions to allow background subtraction. It also permits observations of off-axis sources such as transient phenomena and solar flares without impacting the planned Observatory viewing program. The energy range is from below 0.1 to over 30 MeV.

The Imaging Compton Telescope (COMPTEL)

This instrument employs the signature of a two-step absorption of the gamma-ray, i.e., a Compton collison in the first detector followed by total absorption in a second detector element. This method, in combination with effective charged particle shield detectors, results in a more efficient suppression of the inherent instrumental background. Spatial resolution in the two detectors together with the well defined geometry of the Compton interaction permits the reconstruction of the sky image over a wide field of view (~ 1 steradian) with a resolution of a few degrees. The energy range is 1 to 30 MeV.

The Energetic Gamma-Ray Experiment Telescope (EGRET)

The High Energy Gamma-Ray Telescope is designed to cover the energy range from about 20 MeV to over 10^4 MeV. The instrument uses a multi-level magnetic core spark chamber system to detect and record gamma-rays coverted by the electron-positron pair process. A total energy counter using NaI (T1) is placed beneath the instrument to provide good energy resolution over a wide dynamic range. The instrument is capped with a plastic scintillator anticoincidence dome to prevent readout on events not associated with gamma-rays. The combination of high energies and good spatial resolution in this instrument should provide the best source positions of any GRO instrument.

The Burst and Transient Source Experiment (BATSE)

The Burst and Transient Source Experiment for the GRO is designed to continuously monitor a large fraction of the sky for a wide range of types of transient gamma-ray events. The monitor consists of eight wide field detector modules. Four have the same viewing path as the other telescopes on GRO and four are on the bottom side of the instrument module viewing the opposite hemisphere. This arrangement provides maximum continuous exposure to the unobstructed sky. The capability provides for 0.1 msec time resolution, a burst location accuracy of about a degree and a sensitivity of 6×10^{-8} erg/cm^2 for a 10 sec burst.

iii. Other Possibilities

Among the other experiments capable of producing new results in the next several years are those to be flown on balloons. The Compton Telescope instruments appear to hold hope for a better understanding of the spectral region where marked changes in spectral shape are occuring. Several nuclear spectroscopy detectors will be flown over the next few years both to look at supernova 1987A and to study further the gamma ray lines that have already been reported.

At very high energies (above about 10^{11} eV), photons can be detected by instruments at sea level. These measurements are an important extension of the space measurements because the very low intensities at these energies make collection of the photons in space impractical, at least for the present. In the region above about 10^{11}eV, the telescope records the Cerenkov light produced in the atmosphere from a series of interactions initiated by a single incident gamma-ray. A technique using two parallel large reflectors, each equipped with multiple detector channels to provide two images of the shower in Cerenkov light, appears to be one of the more promising approaches for the future (e.g., Weekes and Turver, 1977). In the ultra high energy region ($E \geq 10^{14}$ eV), careful analysis or extensive air showers to pick out point source enhancements due to gamma rays has yielded some indications of gamma rays even at these extreme energies as noted earlier here, and this work will be continued in the future.

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