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

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Introduction
M. Oda

A rapid and dramatic change in our views of the Universe which we have witnessed during the past two decades or so is often compared with what happened at the time of Galileo. Revolutionary role of the optical telescope then may be analogized with that of space-astronomy today which has drastically opened the new observational window to the Universe. The revolution is ongoing with a rapid pace or even being accelerated.

Astronomy that is the oldest of the sciences which inspire imagination of mankind has two aspects; one is the exploration of unknown and the other is understanding what is going on in the Universe. Today the frontiers of astronomy extend more and more deeply into the domains of fundamental physics. Space science is now an essential element of astronomy to ask basic questions about the nature of the observational universe.

Recently deep relationships have been developing between astrophysics and elementary particle physics through studies in cosmology and grand-unified-theory. One of the key problemes in this context now is the hidden mass (unidentified matter) in the Universe. It is not an imaginative existence in theoretical cosmologies but now has become a realistic object for observational astronomy to search for.

Today the existence of neutron stars is not anymore the question to be asked but they are subjects of observational studies for physics of extreme environments: extremely strong gravity, high matter density, high temperature, superfluid interior and strong magnetic field. The collapses of stars which produce the neutron stars are origins of dynamic processes in our Galaxy. We now suppose that the interstellar space is the place where such dynamic processes work continuously. We know that in some of the supernova remnants, at least in the Crab Nebula, the spinning neutron star is the cause of all activities of the nebulae.

The black hole is an extremely unusual state of matter. It is of greatest interest to study this in the context of general relativity. X-ray astronomers now believe that they observe black holes in some of the X-ray sources. Intriguing suggestion from observations of active galactic nuclei are that supermassive black holes may sit there.

Infrared astronomy, which had grown its value in all fields of astrophysics over the past decade with relatively modest means, marked a large step by a launch of the Infrared Astronomy Satellite (IRAS). Among fascinating discoveries IRAS has revealed physical processes in active nebulae that are candidate places for star formation and discovered clouds of small particles surrounding stars which are possible origins of the planets.

Among the scheduled space astronomy missions which were listed in the previous commission report, IRAS, ASTRO-B (renamed TENMA), and EXOSAT have been launched. These missions have been extremely rewarding and the results will be

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presented in this report.

The following missions are to be launched in the near future:

- ROSAT, the German X-ray reflective telescope, scheduled for 1987;
- Space Telescope, scheduled for launch in 1986
- GRO, the gamma-ray observatory to be launched in 1988
- HIPPARCOS, the European astrometry satellite, to be launched in 1988
- ASTRO-C, the Japanese X-ray and gamma-ray burst mission under collaboration with UK and US scientists, scheduled for 1987
- GIRL, the German infrared observatory in SPACELAB.

The missions which have been proposed or are under plan include: XTE (X-ray Timing Explorer), AXAF (Advanced X-ray Astronomy Facility), SIRTF (Shuttle Infrared Telescope Facility), ASO (Advanced Solar Observatory). Mission for the next solar maximum are under consideration in Japan and US. Orbiting VLBI has been discussed on various occasions in USSR, US, ESA and Japan.

The Halley's Comet will be observed in March 1986 under the international cooperation by VEGA 1, 2 (USSR), GIOTTO (ESA), MS-T5 and PLANET A (Japan) and ICE and ASTRO-1 (US).

While the scale of space astronomy programmes tends to increase, it appears that small or moderate missions remain valuable. It looks important to maintain a healthy balance between major programmes and modest ones from viewpoints of generating new and progressive ideas for the following decades and producing a powerful new generations of astronomers.

We observe every year more extensive and deeper international collaboration of a wide variety of modes in various disciplines. Commission 44 should continue to provide opportunities to extend international cooperation and collaboration for ASTRONOMY FROM SPACE.

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1. GAMMA RAY ASTROPHYSICS BEYOND THE SOLAR SYSTEM

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A. INTRODUCTION

The promise of high energy ($\gtrsim$ 10 MeV) astrophysics as a valuable new avenue for the exploration of the universe is now beginning to be realized, as the results discussed here will show. Even considering these achievements, γ-ray astronomy is still a young, growing science, and the potential for fundamental contributions to astrophysics in the future is very large. With the study of γ-rays, the forces of change, the formative process in the Galaxy and interstellar clouds, rapid expansion processes, explosions, the largest energy transfers, and very high energy particle acceleration are all examined directly. If the mission opportunities that are discussed here come into being, the results that will be obtained, particularly in combination with those from other areas of astronomy, will provide an entirely new look at the Universe.

This section will concentrate on the γ-ray astrophysics results beyond the solar system with the latter subject being included in the section on the solar system. Gamma ray bursts will be discussed elsewhere and will not be considered here. The remainder of this section will be divided into three parts: our galaxy, extragalactic radiation, and future prospects for γ-ray astrophysics.

B. OUR GALAXY

The γ-ray sky is dominated by radiation from the galactic plane, which is generally assumed to be the sum of diffuse radiation and unresolved point sources. The point source contribution would for the most part appear diffuse to the high energy γ-ray satellite instruments that have flown thus far because the angular resolution of these instruments for individual photons has been only one to a few degrees, or poorer, depending on energy. The source of the true diffuse radiation has been assumed to be cosmic ray interactions since, assuming cosmic rays pervade the Galaxy, they necessarily produce high energy γ-rays as they interact with the interstellar matter and photons. Substantial work has been performed on the calculation of the source functions for these various γ radiations and the intensity to be expected in the vicinity of the solar system. (For a general review see Chapter 5 of Fichtel and Trombka 1981.) Several recent important developments have occurred to aid in the study of this problem, including the detailed results of high energy galactic γ-radiation obtained with the COS-B satellite (Mayer-Hasselwander et al., 1982), the medium energy results of Agrinier et al., (1981), Graser and Schonfelder (1982), and Bertsch and Kniffen (1983), further evaluations of the 21 cm radiation in the galaxy, and hence the atomic hydrogen density distribution, additional CO line observations from which molecular hydrogen column densities are deduced, the high photon density estimate for the inner galaxy which affects the Compton radiation and the electron spectrum in this region, the current longer estimate of the galactic cosmic ray lifetime, further evidence supporting the galactic arm concept, and improved theoretical calculations on the nucleon-nucleon source function. It should be noted that the difficulty in normalizing the molecular hydrogen column density deduced from the CO measurements in an absolute manner remains a problem, but one which can at least be constrained.

The variations of the cosmic ray density in the galactic plane with position in the galaxy is a complicating factor. However, for galactic latitudes where the local contribution may be expected to dominate, $|b|$ greater than 10 or 15, the cosmic ray density as a function of position in the galactic plane presumably does not vary much. For this case, since the scale height of the cosmic rays is expected to be large compared to that of matter, a good approximation for the cosmic ray, matter interaction contribution to the γ-ray diffuse radiation is

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probably obtained by using a constant cosmic ray density, which allows the direct use of atomic and molecular hydrogen column densities. If the point source contribution is small and if account is taken of the Compton contribution, it should be possible to obtain a good agreement using the matter column densities directly as shown by Strong et al., (1982), and Lebrun et al., (1982). It should also be possible to use this simplified approach successfully at intermediate longitudes (~ 60 to ~ 100 and ~ 250 to ~ 280), where regions which are at galactic radii similar to the Earth are predominantly being viewed as shown, for example, by Arnaud et al., (1982) and Lebrun and Paul (1983), for the ($60 < l < 100$) region. Other attempts to correlate the γ radiation with matter include Issa et al., 1981, Lebrun et al., (1983), and Riley et al., (1983), with generally reasonable results. The more general case wherein the cosmic ray density is assumed to be variable is treated by Fichtel and Kniffen (1984). They show that within uncertainties the present γ-ray results are in agreement with a coupling of the cosmic ray density in the plane with the broad galactic features as predicted by theory. Other analyses which support at least a general galactic radial gradient of the cosmic ray density include those of Dodds et al., (1975), Kniffen et al., (1977), Issa et al., (1981), and Hermsen et al., (1982).

With regard specifically to the galactic center, Blitz et al., (1984) show that the γ-ray flux from the central few hundred parsecs of the Milky Way is nearly an order of magnitude smaller than the value expected from the H_2 masses generally estimated to be present from CO emission data. This result implies that in the galactic center, either the cosmic ray density is very anomalously low or that molecular hydrogen is much less abundant than estimated. These authors argue that circumstantial evidence favors a low H_2/CO abundance as the source of the γ-ray deficiency.

A recent summary of the COS-B γ-ray results by Hermsen (1983) lists about 25 localized excesses as potential point sources, in addition to the Orion and ρ Oph clouds (Bloemen et al. 1984). In spite of considerable effort, there are no new clear identifications of galactic sources as point sources, as opposed to broad localized sources such as clouds, beyond those known a decade ago, namely the Crab and Vela pulsars, Cygnus X-3, and very likely Geminga (195, 5). New observations are needed to determine if these point-like excesses are objects, such as neutron stars, supernovae, or even black holes, or broad features.

New results on the Crab γ-ray source have been reported, e.g., Graser and Schonfelder (1982), Wills et al., (1982), and Mahoney et al., (1984), the latter two showing a definite interpulse flux. The Crab γ-ray results are summarized in detail in an article by Schönfelder (1983).

During the last two years, Samorski and Stamm (1983), Lloyd-Evans et al., (1983), and Dowthwaite et al., (1983), have reported the strongest evidence yet for γ-rays from Cygnus X-3 with energies in the 10^{15} to 5×10^{16} eV range from ground level detector systems. The source shows the same 4.8 hr period reported by Lamb et al., (1977) in the 35 MeV to several hundred MeV range from SAS-2 data. These results suggest a continuous spectrum from the soft γ-ray range to over 10^{16} eV with an integral power-law index of about -1.1. Although the COS-B γ-ray detector did not detect the source (Bennett et al., 1977), those observations were during a period of low X-ray intensity. The positive detection of γ-rays with energies $> 10^{16}$eV from Cygnus X-3 could be very important to the understanding of the acceleration and supply of cosmic rays.

There have been reports of discrete γ-ray absorption or emission lines from Hercules X-1, SS433, and γ-ray bursts and of the half MeV annihilation line from the general direction of the galactic center. (For a summary, see Ramaty 1984). Because of the difficult nature of the experiments, the low intensities, differences between the results, and the sensitivity of the data to analysis

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assumptions, most of these reports should probably be viewed as needing confirmation. The two most recent attempts to measure the galactic center half MeV line (Leventhal et al., 1982, and Paciesas et al., 1982), set upper limits below any reported positive result (Haymes et al., 1975, Leventhal et al., 1978, Albernhe et al., 1981, and Riegler et al., 1981). There is, of course, the possibility of time variability.

Jacobson (1983) has reported the detection of the 1.809 MeV ^{26}Al line from the more intense central part of the galactic plane with an intensity of $(4.7\pm1.0)\times10^{-4}$ photons cm^{-2}s^{-1}rad^{-1}. Because of the long half-life of 7.4×10^{-5} years, this emission would be expected to be diffuse rather than associated with a source region since the nuclei would have had time to spread through the interstellar medium. Ramaty and Lingenfelter (1983) had predicted the presence of this line on the basis of ^{26}Al being synthesized in supernovae and estimated the intensity from the direction of the galactic center region to be 10^{-4} photons cm^{-2}s^{-1}rad^{-1}. In view of the uncertainty of some of the parameters and the likelihood that novae make a similar contribution, the agreement between the prediction and observation is reasonable. This observation may thus represent direct evidence of nucleosynthesis in our galaxy within the last million years.

In general, the study of astrophysical γ-ray lines outside the solar system, at present, seems to require more definitive measurements with greater sensitive and lower background before many firm conclusions are possible.

C. EXTRAGALACTIC RADIATION

Beyond our Galaxy, γ-ray emission has already been seen from four active galaxies, two Seyfert galaxies, one radio galaxy, and a quasar. For at least two of these, 3C273 and NGC 4151, more energy is emitted in the γ-ray region (E >0.1 MeV) than in the X-ray, optical, or radio regions. The photon intensities are still relatively low, of course, because of the large energy per photon in the γ-ray region. No normal galaxy, other than our own, has been seen in γ-rays, but this result is not surprising on the basis of the emission level of our own Galaxy. The γ-rays observed from the Seyfert galaxies NGC 4151 and MCG 8-11-11 are in the low-energy γ-ray region (Auriemma et al., 1978; Coe et al., 1980; Gursky et al., 1971; Ives et al., 1976; Meegan and Haymes 1979; Mushotsky et al., 1978; Paciesas et al., 1977; Perotti et al., 1979; Perotti et al., 1981; Schönfelder et al., 1980; White et al., 1980) and only upper limits to the high energy γ-radiation exist (Bignami et al., 1979). The spectra are similar in that both show a very marked increase in the spectral slope in the energy region near 1 MeV. The several measurements in the γ-ray region for NGC 4151 were made at different times, and, assuming no significant errors in the data, clearly show a time variability. For five other Seyferts (and also several other emission-line galaxies) upper limits derived from the SAS-2 γ-ray data (Bignami et al., 1979) are substantially (more than an order of magnitude) below an extrapolation of the power law X-ray spectra (Mushotsky et al., 1979), suggesting that a sharp spectral change in the low-energy γ-ray region may be a general feature of these galaxies. Pollock et al., (1981) come to a similar conclusion.

Turning to quasars, 3C 273 is the brightest X-ray quasar and is the only quasar which has been clearly identified as a source of γ-rays (Swanenburg et al., 1978). The differential energy spectrum of 3C 273 steepens sharply from the X-ray range to the γ-ray region, with the slope of the differential energy spectrum changing from 1.4 in the hard X-ray region to 2.7 in the high-energy (E>50 MeV) γ-ray region. The change in spectral shape between the hard X-ray and γ-ray region seen for 3C 273 is similar to that suggested for the Seyfert galaxies for which data exist. The COS-B instrument has observed 3C 273 in γ-rays in July 1976, June 1978, and June-July 1980, and no significant variation in the γ-ray fluxes among the observation was observed (Bignami et al., 1981).

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Centaurus-A (NGC 5128), generally believed to be the closest radio galaxy, is the only radio galaxy that has been seen in γ-rays. It has now been observed in all frequency bands from radio through low-energy γ-rays (e.g., Baity et al., 1981) and, although γ-ray emission is not seen in the 30 to 10^3MeV region (Bignami et al., 1979 and Pollock et al., 1981), a strong indication of very high energy ($E>3x10^{11}$ eV) γ-ray emission has been found (Grindlay et al., 1975). The observations of the radiation from CEN-A in the X-ray region through the very high energy γ-ray region again suggest a steepening of the spectral slope similar to NGC 4151, MCG 8-11-11, and 3C 273.

A diffuse celestial radiation, which is isotropic at least on a coarse scale, has been measured from the soft X-ray region to about 150 MeV, at which energy the intensity falls below that of the galactic emission for most galactic latitudes. The first indication that diffuse celestial radiation extended from the X-ray region into at least the low-energy γ-ray (1 MeV) portion of the spectrum was reported by Arnold et al., (1962). At energies above 10 MeV, the first measurements related to an extragalactic diffuse radiation were those of Kraushaar and Clark (1962), whose upper limits from Explorer 11 provided an experimental refutation of the steady-state theory of cosmology. The first suggestion of a diffuse high-energy flux came from the OSO-3 satellite experiment (Kranshaar, et al., 1972); however, it was data from the SAS-2 high-energy γ-ray experiment that clearly established a high-energy extension of the diffuse radiation with a steep energy spectrum above 35 MeV (Fichtel et al., 1977). A recent reanalysis of the SAS-2 data which included galaxy counts as a tracer of the interstellar matter has been performed by Thompson and Fichtel (1982) and has added support to the concept of the spectrum being quite steep (having a power low index of about 2.4) in the energy region above 35 MeV.

A large number of theories predicting a diffuse γ-ray background have appeared in the literature over the years. With the measurements of the spectrum and intensity which now exist, most of these seem not to be likely candidates for the majority of the diffuse radiations (see, for example, Fichtel and Trombka, 1981). Two possibilities seem to remain at present. One of these involves a baryon-symmetric universe, containing superclusters of galaxies of matter and others of antimatter. The annihilation of nucleons and antinucleons at the boundaries (Stecker, Morgan, and Bredekamp, 1971) produces the γ-rays. The other possibility is the sum of the radiation from point sources, and particularly active galaxies, integrated over cosmological times (e.g., Strong and Worrall, 1976; Bignami et al., 1978; Schönfelder, 1978; and Grindlay, 1978). Using the data on the few known objects, Bignami et al., (1979) and Fichtel and Trombka (1981) conclude that it is quite conceivable that Seyfert galaxies and Quasars could account for the diffuse γ radiation using conservative evolutionary models. Leiter and Boldt (1982) and Boldt and Leiter (1984) have proposed a model based on supermassive Schwarzschild black holes with accretion disks radiating near the Eddington luminosity limit. The authors believe that, if this theory is correct, there would be detectable variations in the diffuse radiation in small elements of the sky (10 deg^2) over several days in the 1/2 to 3 MeV region, giving a specific test for this theory.

D. FUTURE PROSPECTS FOR GAMMA RAY ASTRONOMY

The major satellite opportunities for γ-ray astronomy in the 1980's are the GAMMA-I and the Gamma Ray Observatory. The information to be obtained from these instruments may be supplemented by results from γ-ray balloon flights and from yet to be approved spacelab and small satellite opportunities. In the more distant future, the NASA Space Station should provide opportunities to fly quite large γ-ray instruments which might be refurbished or reconfigured in space.

I. GAMMA-I

The next γ-ray satellite expected to fly is GAMMA I, which should be launched in about two years on a Soviet satellite. It 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 twleve-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 1600 cm^2 or about 2.7 times that of SAS-2 or COS-B. The area solid angle factor is about the same, because the viewing angle is smaller.

II. The Gamma Ray Observatory

The Gamma Ray Observatory (GRO) is an approved NASA mission with a launch tentatively planned for 1988. There are four instruments covering the energy range from 0.03 MeV to 3×10^4 MeV, with a major increase in sensitivity over previous satellite experiments. It is advantageous to combine the instruments into one mission not only because they place similar requirements on a spacecraft, but also because of the great scientific value of studying the entire γ-ray spectrum of any object at the same time to examine in detail the nature of time variations. The combined compliment of instruments to be incorporated into the Gamma Ray Observatory is expected to have the capability to carry out the following:

i. A survey of γ-ray sources and diffuse emission with sensitivities around 10^{-5} photon cm^{-2} sec^{-1} and energy resolution around 10 percent at energies between 0.1 and 30 MeV.

ii. A survey of high energy γ-ray sources and diffuse emission with a point source sensitivity of 10^{-7} photon cm^{-2} sec^{-1} or better, angular resolution of about 0.1° for strong sources, and energy resolution around 15% at energies above 10^2 MeV.

iii. Detection and identification of nuclear gamma lines with an energy resolution of 4 percent and sensitivity of the order of 5×10^{-5} photon cm^{-2} sec^{-1}.

iv. Observations of γ-ray bursts, including studies of their spectral and temporal behavior.

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 arc minutes. 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. For further information on the instruments to be flown on GRO, see Kniffen et al., (1981).

III. Space Station

NASA is now considering a Space Station which would be a manned spacecraft permanently orbiting the earth and capable of performing a variety of scientific and operational missions. High energy γ-ray astronomy is certainly among the scientific desciplines which would be able to benefit very significantly from such an opportunity. With the γ-ray sky surveyed in some depth with the GRO, it would, for example, be possible to concentrate on the detailed features of discrete sources and to study carefully limited regions such as clouds, galactic arms, and nearby galaxies.

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References

Agrinier, B., et al.: 1981, 17th International Cosmic Ray Conf. 9, p. 72.
Alberne, F., et al.: 1981, Astron. Astrophys. 94, p. 214.
Arnaud, K. Pei, Li Ti, et al.:1982, Mon. Not. R. Ast. Soc. 201, p. 745.
Arnold, J. R., Matzger, A. E., Anderson, E. C., and Van Dilla, M. A.: 1982, J. Geophys. Res. 67, p. 4878.
Auriemma, G., et al., 1978, Ap. J. Letters 221, p. L7.
Bennett, K., et al.: 1977, Astron. Astrophys. 59, p. 273.
Bertsch, D. L., and Kniffen, D. A.: 1983, Ap. J. 270, p. 305.
Bignami, G. F., et al.: 1981, Astron. Ap. 93, p. 71.
Bignami, G. F., Fichtel, C. E., Hartman, R. C., and Thompson, D. J.: 1979, Ap. J. 232, p. 649.
Bignami, G. F., Lichti, G. G., and Paul, J. A.: 1978, Astron. and Astrophys. 68, p. L15.
Blitz, L., Bloemen, J. B. G. M., Hermsen, W., and Binia, T.: 1984, "The Gamma-Ray Deficit Toward the Center", preprint.
Bloemen et al.: 1984, Astron. Astrophys. 139, 37.
Boldt, E., and Leiter, D.: 1984, Ap. J. 276, p. 427.
Coe, M. J., et al.: 1980, M.N.R.A.S.
Dodds, D., Strong, A. W. and Wolfendale, A. W.: 1975, Mon. Not. R. Astr. Soc. 171, p. 569.
Dowthwaite, J. C., et al.: 1983, Astron. Astrophys. 126, p.1.
Fichtel, C. E., et al.: 1977, Ap. J. 217, p. L9.
Fichtel, C. E., and Trombka, J. I.: 1981, "Gamma Ray Astrophysics: New Insight into the Universe", NASA SP-453.
Fichtel, C. E., and Kniffen, D. A.: 1984, Astron. Astrophys. 134, p. 13.
Graser, U., and Schönfelder, V.: 1982, Ap. J. 263, 677.
Grindlay, J. E.: 1978, Nature 273, p. 211.
Gursky, H., et al.: 1971, Ap. J. Letters 165, p. L43.
Haymes, R. C., et al.: 1975, Astrophys. J. 201, p. 593.
Hermsen, W.: 1983, Space Sci. Rev. 36, p. 61.
Hermsen, W., and Bloemen, J. B. G. M.: 1982, Leiden Workshop on Southern Galactic Surveys.
Issa, M. R., Riley, P. A., Strong, A. W., Wolfendale, A. W.: 1981, J. Phys. G. 7, p. 656.
Ives, J. C., Sanford, P. W., and Penston, M. V.: 1976, Ap. J. Letters 207, p. L159.
Jacobson, A.: 1983, Bulletin of the American Physical Society 28, p. 666.
Kniffen, D. A., Fichtel, C. E., and Thompson, D. J.: 1977, Ap. J. 215, p. 765.
Kniffen, D., et al.: 1981, "The Gamma-Ray Observatory Science Plan."
Kraushaar, W. L., and Clark, G. W.: 1962, Phys. Rev. Letters 8, p. 106.
Kraushaar, W. L., et al.: 1979, Ap. J. 233, p. 510.
Lamb, R. C., et al.: 1977, Ap. J. Letters 212, p. L63.
Lebrun et al.: 1982, Astron. Astrophys. 107, 390.
Lebrun et al.: 1983, Ap. J. 274, 231.
Lebrun, F., and Paul, J. A.: 1983, Astrophys. J. 266, p. 276.
Leiter, D., and Boldt, E.: 1982, Ap. J. 260, p. 1.
Leventhal, M., MacCallum, C. J., and Stang, P. D.: 1978, Astrophys. J. 225, p. L11.
Leventhal, M., et al.: 1982, Astrophys. J. 260, p. L1.
Lloyd-Evans, et al.: 1983, Nature 305, p. 784.
Mahoney, W. A., Ling, J. C., and Jacobson, A. S.: 1984, Ap. J. 278, p. 784.
Mayer-Hasselwander, H. A., et al.: 1982, Astron. Astrophys. 105, p. 164.
Meegan, C.A., and Haymes, R.C.: 1979, Ap. J., 233, 510.
Mushotzky, R. F., Boldt, E. A., Holt, S. S., and Serlemitsos, P. J.: 1979, Ap. J. 232, p. L17.
Mushotzky, R. F., Holt, S. S., and Serlemitsos, P. J.: 1978, Ap. J. Letters 225, p. L115.

https://doi.org/10.1017/S0251107X00006659 Published online by Cambridge University Press

Paciesas, W. S., Mushotzky, R. F., and Pelling, R. M.: 1977, N.N.R.A.S. 178, p. 23.
Paciesas, W. S., et al.: 1982, Astrophys. J. 260, p. L7.
Perotti, F., et al.: 1979, Nature 282, p. 484.
Perotti, F., et al.: 1981, Ap. J. Letters 247, p. L63.
Pollock, A.M.T., et al.: 1981, Astron. Astrophys. 94, 116.
Ramaty, R., and Lingenfelter, R. E.: 1977, Ap. J. 213, p. L5.
Ramaty, R.: 1984, 4th Moriond Astrophysics Meeting, LaPlagne, France
Riegler, G. R., et al.: 1981, Astrophys. J. 248, p. L13.
Riley, P. A., et al.: 1984, Mon. Not. R., Ast. Soc. 206, p. 423.
Samorski, M., and Stamm, W.: 1983, Ap. J. 268, p. L17.
Schönfelder, V., 1978, Nature 274, p. 344.
Schönfelder, V., Graml, F., and Penningsfeld, F. P.: 1980, Ap. J. 240, p. 330.
Schönfelder, V.: 1983, Adv. Space Res. 3, p. 59.
Stecker, F. W., Morgan, D. L., and Bredekamp, J.: 1971, Phys. Rev. Letters 27, p. 1469.
Strong, A. W., and Worrall, D. M.: 1976, J. Phys. A: Math. Gen. 9, p. 823.
Strong, A. W., et al.: 1982, Astron. Astrophys. 115, p. 404.
Swanenburg, B. N., et al.: 1978, Nature 275, p. 298.
Thompson, D. J., and Fichtel, C. E.: 1982, Astron. Astrophys. 109, p. 352.
White, R. S., et al.: 1980, Nature 284, p. 608.
Wills, R. D., et al.: 1982, Nature 296, 1.

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