48. HIGH ENERGY ASTROPHYSICS
(ASTROPHYSIQUE DE GRANDE ENERGIE)

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This report concentrates on three observational areas where progress during the last 3 years has been especially noteworthy. These are: X-ray astronomy (reviewed by H. Gursky), γ-ray astronomy (reviewed by G. Fazio) and Cosmic rays (reviewed by M. Shapiro and R. Silberberg). Gratitude is expressed to these contributors, and to Dr J. D. Kurfess, for their help in preparing this report.

H. FRIEDMAN
President of the Commission

1. X-RAY ASTRONOMY

H. Gursky

I. *Introduction*

The period 1970–1972 marked for X-ray astronomy a transition from observations using sounding rockets and balloons to observations from satellites. One satellite experiment in particular, UHURU, which was launched on 12 December 1970 (Giacconi *et al.* (**1**)), has provided so much new X-ray data compared to what was available in the preceding ten years, that we are literally confronted with a new field of astronomy. The other significant aspect of this period is the greater connection, being made with optical and radio observations, and the development of specific models for the X-ray emission in which there is some confidence. Much of the new material was presented at the IAU Symposium on X- and γ-Ray Astronomy in Madrid during May 1972 (Bradt and Giacconi (**2**)).

The essential observational result has been the preparation of the 2U Catalog of discrete X-ray sources based on observations by UHURU (Giacconi *et al.* (**3**)). The Catalog, which still only uses a fraction of the ultimately available data, lists 125 sources of which 60 are most likely in the Galaxy and the remainder are most likely extragalactic. Detailed studies of single objects have led to characterization of specific classes of X-ray sources.

The UHURU instrumentation is sensitive in the range 2–20 keV. The low energy domain, below 1 keV, is still studied with sounding rocket instrumentation and the results in this area are still very tentative. What is revealed at the lower energies is a complex, diffuse background, apparently associated with the galaxy. Several supernova remnants are bright at low energy; however, there are few if any other X-ray sources which are not also seen at the higher X-ray energies.

II. *X-rays from the Galaxy*

In the medium X-ray energy range (>2 keV) there are a large number of discrete sources observed in the galaxy that can be divided into several distinct categories; namely, supernova remnants, transient sources, and galactic X-ray sources. The latter, which have yet to receive a distinctive name, comprise the bulk of the observed sources and may divide into several additional categories.

A. *Supernova remnants*

X-ray emission is seen from the Crab Nebula, Cas A, Tycho SN, Vela X, Y, Z, Puppis A and

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the Cygnus Loop. In the case of Vela SN and Puppis A (Seward *et al.* (**4**)), the bulk of the power is below 1 keV. Vela SN is seen to be extended by at least 5°, and it seems to resolve into several enhanced regions which may coincide with Vela X, Y, Z (Gorenstein *et al.* (**5**), Kellogg *et al.* (**6**)). Puppis A is seen as a point source. The Cygnus Loop is seen only below 1 keV (Grader *et al.* (**7**), Gorenstein *et al.* (**8**)) and is extended with about the same size as the optical-radio object. There are also reports of X-ray emission from IC 443 and MSH15–52 (Giacconi *et al.* (**3**)) and from the Lupus Loop (Bunner *et al.* (**9**)); however, the emission in these cases is very weak and the results are not confirmed by other observers. Emission from the Crab Nebula Pulsar, NP 0532, is reported at energies around 1 MeV (Kurfess (**10**)), 50 MeV (Kinzer *et al.* (**11**)) and 10^{11} eV (Grindlay (**12**), Fazio *et al.* (**13**)). However at the higher energies the results are not of great statistical significance.

The net conclusion regarding supernova remnants is that X-ray production is a natural accompaniment of the activity following the initial explosion. There seems to be a dependence of the spectral content of the radiation on the age of the remnant; the older remnants – the Cygnus Loop in particular – do not radiate significantly above 1 keV. The fact that more supernova remnants are not seen is likely to be the result of the limited sensitivity of present surveys. The general characteristics of the supernova remnants have been reviewed by Woltjer (**14**).

B. *Transient sources*

On three occasions very bright X-ray sources were found where none was previously reported. The sources subsequently decayed to unobservability. With regard to their intensity variations, the transient sources are similar to optical nova, to which they have been compared.

The most recent transient X-ray source seen was discovered by UHURU in the constellation Lupus (Matilsky *et al.* (**15**)). At its peak intensity it was comparable in brightness to the Crab Nebula, the second brightest X-ray source in the sky. The degree of brightening in this source must have exceeded 10^3. This source persisted for at least one year, which is much longer than other X-ray transient sources. No optical candidates have been found for this or other transient sources.

In contrast, X-ray emission has not been found associated with reported optical novae or supernovae in external galaxies.

C. *Galactic X-ray sources*

The great majority of the X-ray sources in the galaxy can not be identified with known classes of stars or stellar systems. In the 2 UHURU Catalog, as an example, out of 60 galactic sources, 5 are supernova remnants and 1 is a transient source. The remainder apparently comprise hitherto unrecognized stellar systems, although by now a number of them have been identified optically. A few individual sources, as discussed below, provide most of the information we have about these sources.

1. *Sco X-1.* This source was subject to extensive joint study during Spring, 1972, by radio, optical and X-ray astronomers using facilities at NRAO, Westerbork, Cerro Tololo, in conjunction with X-ray observations from UHURU. The analysis of these data is still in progress. Other work on Sco X-1 include attempts to measure spectral line emission (Kestenbaum *et al.* (**16**), Griffiths *et al.* (**17**)) and study of short time variability (Kestenbaum *et al.* (**18**), Angel *et al.* (**19**)). While these observations have added a fair amount of information regarding this object, nothing has been revealed that uniquely points to the nature of the system.

2. *Cyg X-1.* This source along with Hercules X-1, described below, may prove to be as important to X-ray astronomy as the Crab Nebula was to radio astronomy. Cyg X-1 was found to possess intensity 'pulsations' on a time scale of less than one second that appeared to be periodic (Oda *et al.* (**20**)). It was subsequently determined that the intensity variations were not periodic (Rappaport *et al.* (**21**), Shulman *et al.* (**22**)); however, significant variations in intensity are found to occur on a time scale of about 0·1 sec, which indicate the presence of an extremely small X-ray emission region. Then, a variable radio source was found by Hjellming and Wade (**23**) within the newly determined

position (Rappaport *et al.* (**24**)). The radio source is coincident with the 9th mag B0I, HDE 226868 (Webster and Murdin (**25**), Bolton (**26**)) which was found to be a spectroscopic binary with a 5·6 day period. The X-ray emission shows no evidence of the 5·6 day binary motion (Tananbaum *et al.* (**27**)) in spite of earlier claims that it did (Dolan (**28, 29**)). Later spectroscopic studies revealed at least one other spectral line, He II-4686, out of phase with the remainder (Brucato and Kristian (**30**)). Assuming this line to be produced at the optically, unseen X-ray source and that the B0I has a normal mass of around 20 $M_{\odot}$, the X-ray source becomes an object of about 13 $M_{\odot}$. Since the X-ray emission region must be small (< 0·1 light second), it is argued that this object must be a black hole since neither white dwarfs or neutron stars can exist with such large masses. This is probably the best evidence to date for the existence of a black hole.

3. *Hercules X-1*. This X-ray source is one of two observed to have periodic intensity variations in the range of seconds, and one of five which seem to eclipse in X-rays. The pulse period is 1·24 seconds and the eclipse period is 1·7 days. The pulse period is seen to undergo a Doppler shift that is synchronous with the eclipse period, which proves the binary nature of the system (Tananbaum *et al.* (**31**)). In addition the X-ray intensity shows an on-off alteration of 35 days which may also be periodic. During this interval the intensity is on for 12 days; during the remaining 23 days there is no evidence of any X-ray emission. The envelope of the X-ray intensity during this time interval shows reproducible features which must eventually relate to the intrinsic nature of the source. The X-ray emission shows a sudden onset followed by a gradual increase. The intensity reaches a peak about 3–4 days after the turn-on, and this is followed by a gradual decrease until disappearance.

This X-ray source is positively identified with the irregular variable HZ Hercules based on the observation of optical variations with the same period as the X-ray intensity (Liller, Forman and Jones (**32**), Bahcall and Bahcall (**33**)). The light curve does not show deep, sharply delineated 'eclipses' as is seen in X-rays; the ratio of maximum to minimum light is about 1·5 magnitude, and minimum light corresponds to the middle of the X-ray eclipse. Both Liller *et al.* and the Bahcalls interpret the light curve as originating on a stellar surface illuminated by the short wavelength radiation of the X-ray source; thus, it is maximum when the X-ray source is in front of the star (phase = 180°). At zero phase, only the fainter stellar radiation is seen. The spectrum is rich in spectral lines, both emission and absorption, and it should be possible to determine the structure and dynamics of this enormously interesting system by classical methods of studying the line velocities and intensities as a function of the integrated light curve.

4. *Cen X-3*. This was the first eclipsing, pulsing X-ray source to be observed (Giacconi *et al.* (**34**)). The pulse period is 4·8 sec and the eclipse period is 2·1 days. As in Her X-1, the pulse period is seen to be a Doppler shift in phase with the eclipse period (Schreier *et al.* (**35**)). The source also 'disappears' from time to time for periods of days, but in an apparently erratic fashion.

There is no optical candidate available for this object; however, it is located right on the galactic plane in the direction of a spiral arm and may be badly obscured.

5. *Cyg X-3*. A great deal of interest was focussed on this X-ray source when the radio source that may be its counterpart (Braes and Miley (**36**), Hjellming *et al.* (**37**)) flared up by 2–3 orders of magnitude compared to its 'quiescent' state which itself is highly variable. Observations of this flare are summarized in a number of papers in the 20 October 1972 issue of *Nature*, and the 23 October 1972 issue of *Nature, Physical Science*. In X-rays, no significant change was observed during the radio flare. In X-rays, the intensity of this source undergoes a 4·8 hr. periodic variation. The shape of the intensity variations is roughly periodic and the minimum intensity is about a factor of two below the peak intensity. This source does not appear to exhibit very rapid pulsations characteristic of Cygnus X-1 or the periodic pulsing characteristic of Her X-1 or Cen X-3.

There is no optical candidate for Cyg X-3; however, the source is centered in the Cygnus X radio complex and thus is directly along the projection of the Cygnus spiral arm. If the distance to the source is more than 1 or 2 kpc, the obscuration could account for the failure to find the optical object.

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C. *Other eclipsing X-ray sources*

At least three other X-ray sources exhibit time variability that can best be interpreted as being the result of the eclipse by a large, unseen object; the characteristic signature being a sharp on/off transition of the X-ray intensity. These are 2U(0900-40), 2U(1700-37) and 2U(0115-73) with eclipse periods of 7days, 3·4 days and 4 days respectively. The latter object is in the Magellanic Clouds. Both 2U(0900-40) and 2U(1700-37) are associated with 6^m early type stars. The star associated with 2U(0900-40) has been found by Hiltner *et al.* (**38**) to be a spectroscopic binary.

D. *Summary*

If one is forced to summarize the characteristics of the galactic X-ray sources in a few words, he would conclude that the objects are close binary systems with the X-ray emission occurring on a collapsed star, either a neutron star or a black hole, with mass transfer from the larger component providing the energy. The basis for this is the following:

1. A large number of X-ray sources are seen to be members of binary systems and many of these are seen to be eclipsing.
2. Time variability and X-ray spectral data require small objects, certainly no larger than white dwarfs.
3. Mass accretion onto collapsed objects appears to be an extremely efficient means of generating the energy that goes into X-rays.
4. A number of the X-ray sources are associated with bright, early type stars.
5. At least in two systems, Cyg X-1 and Her X-1, there is direct evidence that all of the above elements are combined. In Cyg X-1, the data are most directly interpreted in terms of the presence of a black hole in a binary system.

III. *Extragalactic X-ray sources*

The UHURU satellite has seen a large number of sources that are likely to be extragalactic in addition to M 87, NGC 5128 and the Magellanic Clouds which were reported as sources before the UHURU launch. Many of the UHURU results have been summarized by Kellogg (**39**) at the Madrid Meeting.

The essential results can be summarized as follows. A number of discrete sources are seen in the Magellanic Clouds (Leong *et al.* (**40**)). If these are taken to be representative of discrete sources seen in our galaxy, it sets the upper limit to the luminosity of the galactic X-ray sources; namely, 10^{38} erg s^{-1}.

Several different kinds of active galaxies are found to be X-ray sources; namely, a quasar 3C 273, a giant radio galaxy NGC 5128, and a Seyfert Galaxy NGC 4151. These are the only examples of these classes of objects seen as X-ray sources; however, each is or is close to the nearest example of the class which it represents and each is seen in X-rays at close to the limiting intensity of UHURU. Thus, it is likely that these three classes of objects are in fact X-ray sources.

In each case the X-ray spectrum shows a low energy turnover typical of absorption in a column density of 10^{23} atoms/cm^2 of H. Because of the high galactic latitude of these objects this absorption can not be taking place in our own galaxy and the most straightforward explanation is that the X-ray emission region is relatively compact and located near the central region of the galaxy in which it is located.

A number of X-ray sources are found to be associated with rich clusters of galaxies and these seem to represent a distinct class of objects (Gursky *et al.* (**41**)). Included in this class are X-ray sources in the Virgo Cluster (M 87), the Coma Cluster and the Perseus Cluster. Each of these sources is extended – and in two cases (M 87 in Virgo and NGC 1275 in Perseus) the X-ray emission is centered on a galaxy which exhibits a high level of non-thermal activity. Except for the Virgo source, these sources are found only in richness 2 clusters. It is possible that this X-ray emission is related to other new observations of rich clusters including radio trails (Miley *et al.* (**42**)), low frequency radio emission (Bridle and Feldman (**43**)) and optical halos around giant elliptical galaxies (Welch and Sastry (**44**)).

About $\frac{2}{3}$ of the high latitude sources are unidentified; however, as discussed by Matilsky *et al.* (**45**) they are likely to be extragalactic based on their l and b distribution and their intensity distribution. The presence of large numbers of discrete extragalactic sources makes it likely that a significant fraction of the diffuse background in the 2–10 keV energy range is just the superposition of fainter, unresolved examples of these same objects, as has been discussed by Gursky *et al.* (**46**).

IV. *Soft X-rays*

One basic characteristic of 'soft' (i.e., below 2 keV) X-ray astronomy is that the sky looks very different. This must be expected because the interstellar gas very strongly absorbs in this energy range, and in fact, imposes a low energy cutoff of about 100 to 200 eV for this data channel. Generally, different discrete sources are detected in this energy range than above 2 keV. Experimentally, the X-ray focusing techniques which will be an important part of future satellite payloads are being developed and utilized on rocket payloads to study soft X-rays.

A. *Extragalactic component*

The problem of establishing the flux of soft X-rays external to our galaxy has received major attention. Some such flux is expected based simply on extrapolation of the X-ray background above 2 keV, known to be primarily extragalactic from its isotropy. Any excess over this extrapolation has important implications regarding the conditions of a possible intergalactic gas as reviewed recently by Field (**47**). In particular, detection of thermal bremsstrahlung from a hot gas of sufficient density to close the universe has been attempted. The basic technique has been to correlate the intensity measured as a function of galactic latitude with the intensity distribution expected due to attenuation by gas having the hydrogen column density shown by the 21 cm measurements (Davidsen *et al.* (**48**), Bunner *et al.* (**49**)). Although the correlation is qualitatively reasonable, with the soft X-ray intensity decreasing from galactic pole to equator, the rate of falloff is not rapid enough, and the intensity does not become zero as expected at the galactic equator. Thus a diffuse, galactic component of emission is required. Simple models of galactic emission still result in the lack of quantitative, point-to-point agreement between the soft X-rays and the hydrogen density.

The net situation is that one may hypothesize an extragalactic flux, and create an ad hoc model of galactic emission for consistency with the 21 cm results. Alternatively, one may invoke clumpiness in the galactic hydrogen distribution. Clearly, no proof is provided for the existence of an extragalactic component. On the contrary, McCammon *et al.* (**50**) show that the direction of the Small Magellanic Cloud does not show a reduced soft X-ray intensity as expected due to absorption by the gas in that galaxy. They place an upper limit of 25% to the fraction of the measured intensity which might originate beyond the Small Magellanic Cloud. This is consistent with extrapolation of the power law measured for diffuse X-rays above 2 keV.

B. *Galactic sources*

Other than the extended supernova remnants discussed in Section II, A, at most, one or two new point sources are seen in a galactic plane survey below 2 keV (Hill *et al.* (**51**), Burginyon *et al.* (**52**)). However, the sensitivity is only to about 10% of the flux of the Cygnus Loop ($\sim 10^{-8}$ erg cm^{-2} s^{-1}), therefore the dynamic range of sensitivity relative to the strongest source is much smaller than available in the 2–10 keV range with the UHURU satellite. Some of the diffuse background features noted above might be extended galactic sources. Bunner *et al.* (**9**) have discussed identification of a region of enhanced emission with the North Polar Spur. Gorenstein and Tucker (**53**) have defined parameters of a discrete galactic source distribution which would provide the measured diffuse intensity.

Low energy spectral data can be used to estimate distances to X-ray sources. The spectra must fall off below some energy, providing a measure of the effective column density of hydrogen between the sun and the source, which can be divided by a volume density of hydrogen to give the distance. This method has been applied to make a statistical statement about source distances (Seward *et al.* (**54**)); however, any given X-ray source may have significant intrinsic absorption which obviates any conclusions.

V. *Hard X-rays*

This energy region might be defined by the use of scintillation crystals as the X-ray detectors. Most results are obtained from balloon flights, where the atmosphere imposes a low energy cutoff at roughly 20 keV, although some data down to 8 keV are available from satellites. Since photon fluxes all decrease rapidly with energy, many fewer sources are seen in hard X-rays, and probably no sources which are not detected between 2 and 10 keV. In the study of one problem, the diffuse background X-rays, this proves an advantage because discrete sources serve as a contamination. Data from the OSO-III satellite covering most of the sky has shown the background between 8 and 40 keV to be isotropic within a few percent over angular scales of $\sim$ 400 sq. degrees (Schwartz (**55**)). The diffuse spectrum cannot be fit with a single power law between 8 and 100 keV, but rather seems to show a much steeper slope above 30–40 keV (Schwartz *et al* (**56**)).

The basic significance of hard X-rays is that the spectrum, combined with the 2–10 keV results, can help distinguish between models of emission mechanisms. Many of the results on hard X-rays have recently been summarized by Peterson (**57**). A great deal of time variability has been found on scales from minutes to months (Lewin *et al.* (**58**); Lewin *et al.* (**59**); McClintock *et al.* (**60**)); however, regularities have not yet emerged comparable to the results on Cen X-3 and Her X-1. Cyg X-1, Cyg X-3 and Sco X-1 have all been detected to at least 100 keV. The high energy components of these sources vary in both intensity and spectrum in a manner not apparently correlated with the 2–10 keV emission.

VI. *Observational facilities*

The preceding three years have witnessed a qualitative change in our understanding of X-ray astronomy based on the launch of the first satellite, UHURU, exclusively devoted to X-ray astronomy. The next decade will see a number of other satellite programs come to fruition, some of about the same overall capability of UHURU but with different instruments and other with much larger, more powerful instruments. The various satellite programs under development in December 1972 are listed in Table 1.

There are two principal reasons for listing these programs. First, they indicate the time scale when new results will be available in this field. Secondly, many of these programs allow for guest investigators to participate in the use of the instruments after launch and thus represent opportunities for investigators other than those who are directly involved with the satellite program to become involved in independent research. In addition to X-ray observatories, advances in X-ray astronomy are becoming increasingly dependent on optical and radio facilities. In fact during the past several years it is likely that more observing time has been spent on radio and optical observations of the X-ray sources than have been utilized in studying the X-rays directly. Furthermore, it is the major ground-based facilities that are being utilized in these studies because of the faintness of the objects being investigated. Thus in the future, there will be increased pressure on ground-based facilities because of new results in X-ray astronomy.

Examples of the kinds of observations that may be conducted include the following:

1. Detailed spectroscopic and photometric studies of identified X-ray stars.
2. Search for optical and radio candidates for unidentified X-ray sources.
3. Correlated X-ray, optical, and radio investigations.
4. Long term radio and optical monitoring of X-ray sources.
5. Detailed studies of X-ray emitting galaxies.
6. Investigations of clusters of galaxies that are also X-ray sources.

As was the case in radio astronomy it is likely that many of the phenomena newly uncovered in X-rays will await detailed information from optical studies to elucidate their true nature.

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Table. 1. Satellite programs

Satellite	Launch	Experiments	Investigating Institutions
Small Astronomy Satellite-A (SAS-A)	Dec. 1970 (UHURU)	X-Ray Sky Survey (2–20 keV)	AS&E
Orbiting Solar Observatory-H (OSO-H)	Sept. 1971 (OSO-VII)	Four-Color X-Ray Survey (1–60 keV)	MIT
		Hard X-Ray Survey (10–500) keV)	UCSD
		Gamma-Ray Survey (0·5–10 MeV)	UNH
Orbiting Astronomical Obs.-C (OAO-C)	Aug. 1972 (OAO-III)	Soft X-Ray Telescope (< 4 keV)	UCL Leicester
United Kingdom-V (UK-V)	Sept. 1973	Low Energy Gamma-Ray Survey (0·01–1·0 MeV)	Imperial College
		Soft X-Ray Modulation Collimator	University College London (UCL)
		X-Ray Source Spectra (2–30 keV)	UCL
		Bragg Spectrometer/ Polarimeter	Leicester
		X-Ray Sky Survey (2–20 keV)	Leicester
		All-Sky X-Ray Monitor (3–6 keV)	GSFC
SAS-C	April 1974	Galactic Source Survey (1·5–50 keV)	MIT
		Extragalactic Sources (1·5–10 keV)	
		Soc X-1 Monitor (0·5–50 keV)	
		Galactic Absorption (0·2–5 keV)	
OSO-I	1974	Soft X-Ray Survey	U. of Wisconsin
		Cosmic X-Ray Spectroscopy (2–60 keV)	GSFC
		Crystal Spectroscopy/ Polarimetry	Columbia
		High Energy X-Rays (0·05–1 MeV)	GSFC
ANS	Aug. 1974	Soft X-Ray Study (2–35 Å, 44–55 Å)	Utrecht
		Medium Energy X-Rays (1–40 keV) (1–5 keV Bragg Spectro-meter)	AS&E
CORSA-II	1975	X-Ray Sources/Variability (0·45-20 keV)	University of Tokyo
HEAO-A	July 1976	AXR-1: Soft X-ray Survey (0·1–2 keV)	Columbia/AS&E/ Cal Tech
		AXR-2: Integrated Modulation Collimator (1–15 keV)	AS&E/MIT
		AXR-3: Large Area Survey (0·1–100 keV)	NRL/U. of Chicago
		AGR-4: Gamma-Ray Sky	UCSD

Table 1 (continued)

Satellite	Launch	Experiments	Investigating Institutions
		Survey (0·03–10 MeV)	
		AGR-5: High Energy X-Ray Survey (10–150 keV)	MIT
HEAO-B	~1978	BXR-1: Diffuse X-Ray Survey (0·25–60 keV)	GSFC/CAL Tech/ U.C. Berkeley
		BXR-2: Bragg Crystal Spectrometer (0·5–10 keV)	Columbia/Aerospace
		BGR-3: Cooled Gamma-Ray Spectrometer (0·06–10 MeV)	JPL
HEAO-C	~1979	LOXT: High Resolution Telescope: Imaging, Bragg Spectroscopy; High Efficiency Collector: Imaging, Non-Dispersive Spectrometer, Polarimetry	AS & E/Columbia/ GSFC/MIT
		Long Wavelength Studies	GSFC/UCL/Aero-space/Berkeley.
High Eccentricity Lunar Occulation Satellite (HELOS)	~1978	Source Positions/Structure: High Energy X-Rays (2–20 keV), Low Energy X-Rays (0·1–2 keV); Time Variability	ESRO

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2. GAMMA-RAY ASTRONOMY

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Over the years, gamma-ray astronomy has advanced rapidly, yet it has not enjoyed the spectacular surprises and successes of X-ray astronomy, particularly with respect to the intensity and number of sources detected. In the late 1950's the theoretical outlook for intense gamma-ray sources was promising, but as more sensitive detectors were developed, the early optimistic predictions vanished. Despite the difficulties associated with gamma-ray astronomy, considerable activity still exists and positive results have been produced.

The first evidence for the detection of a gamma-ray flux came from the results of the counter telescope on the OSO-3 satellite (Clark *et al.* (**1**)). Recently, a final summary of their results has been published (Kraushaar *et al.* (**2**)). The experiment detected gamma rays above 50 MeV from the Galaxy, concentrated in a band of directions around the galactic equator with a broad maximum toward the galactic center. The equivalent line-source intensity at the center was $1{\cdot}3 \times 10^{-4}$ photon $cm^{-2}\, s^{-1}\, rad^{-1}$. The gamma-ray intensity away from the galactic center is consistent with a production by π^0-meson decay, the π^0 mesons being produced by high-energy cosmic-ray interactions with the interstellar gas (Cavallo and Gould (**3**), Stecker (**4**, **5**)). The increase in intensity at the center cannot be explained by this mechanism, unless one assumes an increase in the primary cosmic-ray intensity. The fact that the gamma-ray distribution at the center is similar to the non-thermal radio emission suggests a mechanism involving cosmic-ray electrons, most probably Compton scattering. Electron scattering on the large submillimeter radiation (Shen (**6**), Cowsik and Pal (**7**)) is sufficient, but the resulting X-ray intensity is too large. Balloon-flight experiments by Fichtel *et al.* (**8**), Bennet *et al.* (**9**), and Helmken (**10**) seem to have verified the results at the galactic center, and several other groups have evidence, of marginal significance, of gamma radiation from other regions of the galactic plane. However, a serious contradiction to these results has been the balloon-flight experiments of Frye *et al.* (**11**), who failed to detect any excess diffuse radiation above 50 MeV from the galactic center and plane. The problem is complicated by the poor spatial resolution of the detectors, and by the fact that the flux value is obtained from the difference between two large numbers.

One of the most interesting developments over the past few years has been the possible detection of a number of discrete gamma-ray sources in the galactic plane, with some near the galactic center. In contrast to their negative results on a diffuse flux from the galactic center, Frye *et al.* (**12**) and Frye (**13, 14**) have reported evidence for several discrete sources in this region. In fact, two of the sources lie within the region of galactic-center emission reported by OSO-3. Their intensity ($\sim 10^{-5}$ photon $cm^{-2}\, s^{-1}$) is such that they could not have been detected by OSO-3; however, it should be noted that many more discrete sources would be needed to explain the measured OSO-3 flux. Browning *et al.* (**15, 16**) detected three sources in the galactic plane, near the center, and each was associated with an X-ray source. Three of the six most significant sources found by Frye's group may also be associated with X-ray sources. Dahlbacka *et al.* (**17**) also reported evidence for three discrete sources in this region, but only one was in the galactic plane.

The Cygnus region of the galactic plane is another region where discrete sources and enhanced emission have been reported (Browning *et al.* (**15**), Niel *et al.* (**18**)). Dean *et al.* (**19**) have also reported evidence for 0·8- to 10-MeV gamma rays from the region of Cygnus X2 and X4. At energies above