Reports

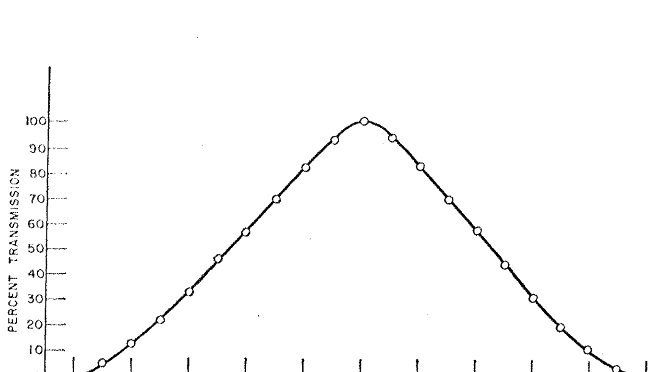
Cosmic X-ray Sources, Galactic and Extragalactic

Abstract. *Instruments carried aboard an Aerobee rocket in April 1965 provided evidence for x-ray emission from the directions of the radio galaxies Cygnus A and M-87 and from the galactic supernova remnant Cassiopeia A. A survey of the Cygnus region revealed a marked decrease in the flux of x-rays from Cygnus XR-1, which was identified in June 1964 as the second brightest object in the first Naval Research Laboratory list of x-ray sources. The detection sensitivity was improved over previous surveys and several new sources were detected at lower flux levels.*

For the past few years, the x-ray survey program of the Naval Research Laboratory has employed large-area Geiger counters carried aloft in unstabilized rockets. The spin and precession of the rocket permit the detectors to scan slices of the sky and thus to map a grid whose fineness depends on the rate of roll and precession. Relatively fast roll and precession produce a more detailed map at the expense of poorer counting statistics in each traverse of a source. In the flight that produced the present results, the roll period was 15 seconds, as compared to 8 seconds and 4 seconds on previous flights. As a result, the detection sensitivity for a single transit was improved, but the scans were fewer and more loosely spaced. Further improvement in the detector sensitivity was attained from the rejection of cosmic-ray background count, through the use of anticoincidence counters. With the enhancement of signal-to-noise ratio, it was possible to detect sources approximately four times weaker than in earlier surveys. For the first time, signals have been detected from the directions of individual radio galaxies. The identifications, however, are still uncertain to the extent of about 1.5 deg, which is the positional accuracy derived from the aspect solution and the location of peak responses in the telemetry record.

Previous surveys have identified approximately a dozen sources. Naval Research Laboratory (NRL) observations (*1*) in 1964 produced a list of ten sources, six of which were grouped in the general vicinity of the galactic center, two in the Cygnus region, and one in Scorpius. The tenth source was identified with the Crab Nebula. Surveys by Fisher *et al.* (*2*) of the Lockheed Corporation and by Clark *et al.* (*3*) have confirmed and refined some of the positions, disputed others, and identified some new positions. The NRL survey of April 1965 again covered the galactic center region. It is clear that this region is more complex than previously indicated and that higher instrumental resolution is essential to isolate the individual sources. In this report we discuss only the observations of the Cygnus region, Cassiopeia, and the scan of M-87 and neighboring regions at high galactic latitude.

The honeycomb baffle used to define the field of view of the Geiger counter in the April 1965 flight was identical with that used in June 1964. Figure 1 shows the angular transmission pattern in the pitch direction. The width at half-maximum was 8 deg. In theory, a perfect hexagonal honeycomb should give a triangular transmission curve with small wings at the edge of the field of view. The rounding of the peak is a result of slight imperfections and irregularities over the large collimator area. The results reported here were obtained from two counters, mounted one above the other in the same plane of the instrument section, parallel to the long axis of the rocket. The center of the field of view was normal to the roll direction. Each counter provided an effective window area of 453 cm^2. One was equipped with a window of Mylar ¼ mil (0.0064 mm) thick; the window of the second counter was 1 mil (0.0254 mm) thick. The counting gas mixture was argon-isobutane at atmospheric pressure, and the gas path from window to wall was 2.54 cm. In the 1964 counters, the gas was neon-isobutane. Figure 2 shows the counting efficiencies plotted against wavelength. The use of argon rather than neon greatly enhances the response below 3.9 Å. Each counter was backed by an identical, flat, box-shaped counter which served as an anticoincidence shield against cosmic rays, with rejection efficiency of about 85 percent. The combined counting rates of the two counters were prescaled by a factor of 32, and the time of arrival of every 32nd count was recorded. Pulses from individual



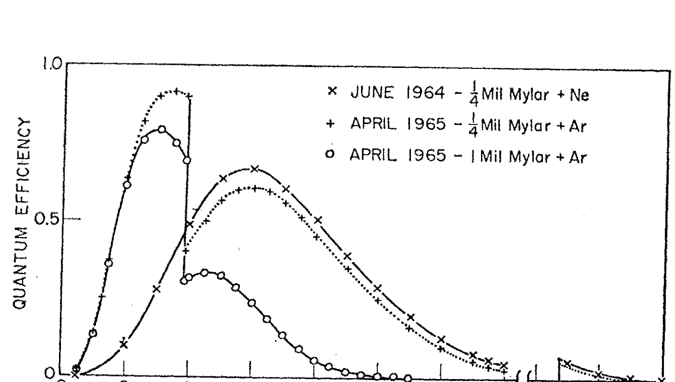


Fig. 1 (left). Angular-transmission curve of hexagonal honeycomb collimator in rocket pitch direction. Fig. 2 (right). Spectral-efficiency curves for Geiger counters used in June 1964 and April 1965.

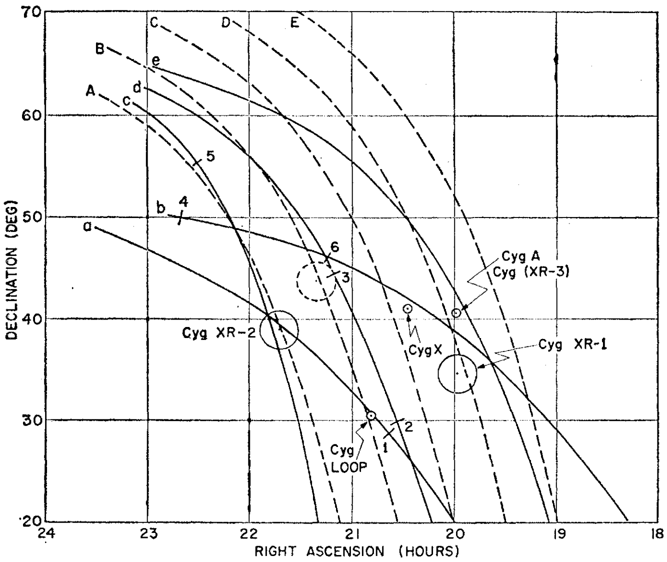


Fig. 3 (above). Scans of Cygnus region. Dashed lines, scans A, B, C, D, and E, are tracks of June 1964 survey. Solid lines, scans a, b, c, d, and e, are tracks of April 1965 survey. Numbered positions correspond to signals shown in Figs. 6 and 7.

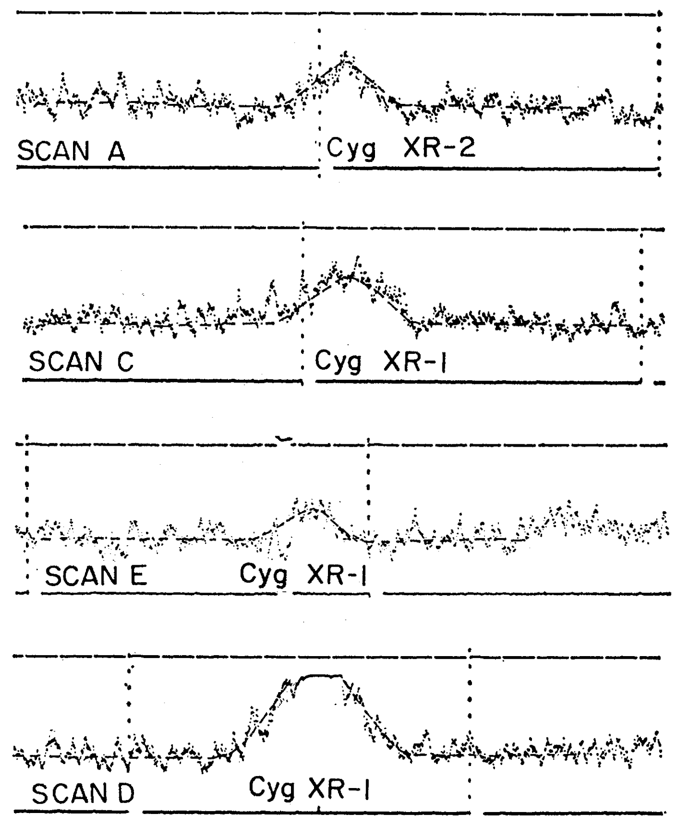


Fig. 4 (right). Telemetry records of scans of Cygnus region in June 1964. Output of rate meter covers 0 to 2000 count sec^{-1}. Scans are labeled to match Fig. 3. Signal on scan D is saturated.

counters were also presented directly to rate meters, whose integrated signals were separately recorded.

Figure 3 is a map of scans across the Cygnus region. The dashed curves are the paths of the scans of the June 1964 flight; the solid curves are the tracks of the April 1965 scans. Figure 4 shows the telemetry records of the rate-meter signals observed in the 1964 survey. Full scale was 2000 counts per second. The signal on scan D was saturated. The relative strengths of the three signals on scans C, D, and E indicated that the source had passed nearly through the center of the field on scan D but was displaced by 1 deg in pitch toward greater right ascension. The position obtained was, within an estimated uncertainty of 1.5 deg, at the center of the error circle on the diagram. The computed counting rate for the source, after correction for displacement from the center of the field of view, was 3.6 counts cm^{-2} sec^{-1}. Cygnus XR-2 was observed on scan A but was not detectable on adjacent scans. Its true position was therefore taken to be on the path of scan A and the observed counting rate was 0.8 count cm^{-2} sec^{-1}.

Figures 5, 6, and 7 show the April 1965 observations of the same region. In Fig. 5, the vertical lines, marked Cyg XR-2, on scans a and c show the times of closest approach to the positions of June 1964. The peaks of the two signals are within the 1.5-deg error circle of the 1964 position. The fluxes were 0.9 and 1.0 count cm^{-2} sec^{-1} on scans a and c, respectively. After correcting for distance from the center of the collimator field, the averaged flux was 0.97 count cm^{-2} sec^{-1}. Without considering, for the moment, any difference in sensitivity of the 1965 counters from those of the 1964 flight, we conclude that the Cyg XR-2 source had remained essentially unchanged from June 1964 to April 1965.

In contrast to Cyg XR-2, Cyg XR-1 showed a remarkable change between 1964 and 1965. It is clear from scans b and e (Fig. 6) that the observed signal was an unresolved composite of two major sources, with just a suggestion of a weak contribution from still another component on scan b. The vertical lines marked Cyg XR-1 give the times of closest approach to the position of that source in the 1964 survey. The lines marked Cyg A give the times of closest pointing toward that radio galaxy. Correcting for pitch displacement, the computed counting rates for Cyg XR-1 were 0.94 and 0.87 count cm^{-2} sec^{-1}, respectively, and the average was 0.91 count cm^{-2} sec^{-1}. Again, without regard for any difference in counter efficiency, the new fluxes for Cyg XR-1 are only one-fourth as great as in 1964.

From Fig. 6, it can be seen that a satisfactory fit of the second component corresponds with the position of Cyg A. The counting rates are 0.45 and 0.40 count cm^{-2} sec^{-1} on scans b and e, respectively (Fig. 6). Following our notation of x-ray sources according to brightness, Cyg A would be Cyg XR-3 in the NRL list.

The detectability of the signal from Cyg A in the April 1965 flight was made possible by the near disappearance of the flux from Cyg XR-1. If Cyg XR-1 were as strong as in June 1964, it would have still masked the weak signal from Cyg A in the April 1965 survey.

Only one other observation of the Cyg region is relevant to the present discussion. The Lockheed group surveyed the region including Cyg XR-1 and Cyg A in October 1964 with a fan-beam collimator. The length of the fan was parallel to the long axis of the rocket. As the rocket rolled, the positions of sources in the roll direction were determined, but the elevations relative to the roll axis were ascertained only within the wide band of sky accepted by the fan. A signal corresponding to the roll position of Cyg XR-1 was observed and yielded a counting flux about one-fifth of that

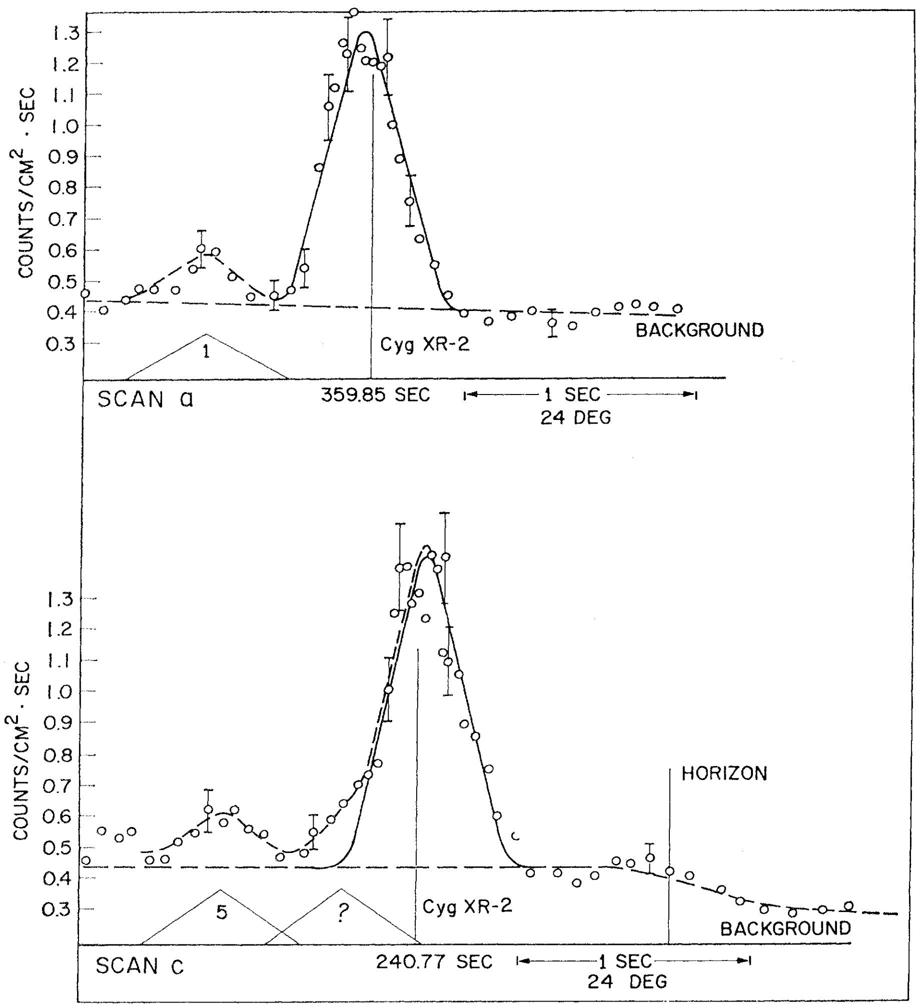


Fig. 5 (left). Scans of Cyg XR-2 in April 1965. Numbered positions identified on Fig. 3. Solid-line envelopes match transmission pattern for a discrete source, Fig. 1. Original data are time intervals for every 32 counts. Plotted points are averages of counting rates computed for 92 counts spaced every 32 counts. Each point, therefore, retains 2/3 of its information from preceding and following points.

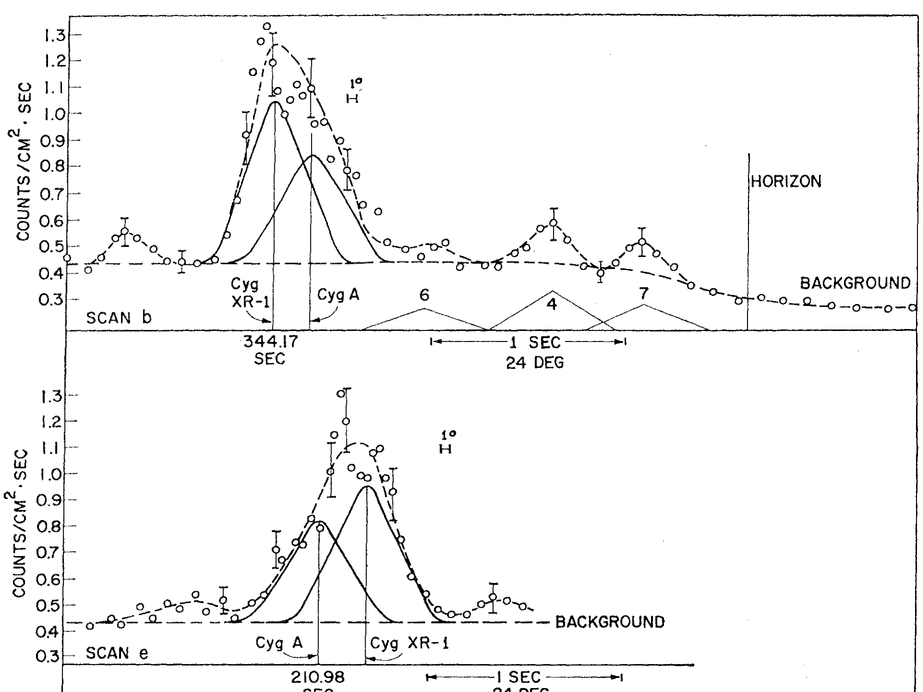


Fig. 6. Scans of Cygnus XR-1 and Cygnus A, April 1965. Solid curves match transmission pattern for a discrete source, Fig. 1. Positions 4 and 6 are shown on Fig. 3.

observed by the NRL survey. The Lockheed group remarked that the difference in measured count fluxes could be due to the much greater bandwidth of the NRL detectors. No signal was observed from Cyg A; Cyg XR-2 was outside the limits of the fan beam.

Scan d, Fig. 7, clearly shows a source at position 3 which we shall list as Cyg XR-4. Another source is indicated at positions 1 and 2 near the Cygnus loop but appears not to be coincident with it. Signals 1 and 2 were studied to see if they could be fringing responses to Cyg XR-1, but it would be necessary to displace Cyg XR-1 in pitch by more than 1 deg, and the roll discrepancy would be 2 deg on trace d. Finally, signal 1 is stronger than signal 2, implying a true source position toward greater right ascension. Signals 4, 5, 7, and 8 are equal to or greater than 3 standard deviations (σ) of the background. It is clear that several additional sources are indicated in the Cygnus region, but it will be necessary to scan in finer detail before reliable positions can be assigned.

Several scans passed the position of Cassiopeia A near the x-ray horizon. On each scan, evidence for x-ray emission from the vicinity of Cas A was observed. Figure 8 shows the signals along three scans that passed within 3 deg of Cas A. Curve 4 was obtained by adding the observed fluxes at corresponding angular displacements from the direction to Cas A. The resultant plot indicates a source within 1 deg of roll in the direction of closest approach to Cas A. Signals observed at pitch angles larger than 3 deg get progressively weaker, indicating that the source is indeed closer to Cas A than the 3-deg displacements of the closest scans.

The celestial sphere was loosely scanned at high galactic latitudes. Only two sources were observed above the 3-σ level. These are indicated in Fig. 9. The stronger is very close to M-87, which lay within 1 deg of the scan track. The maximum pitch-angle un-

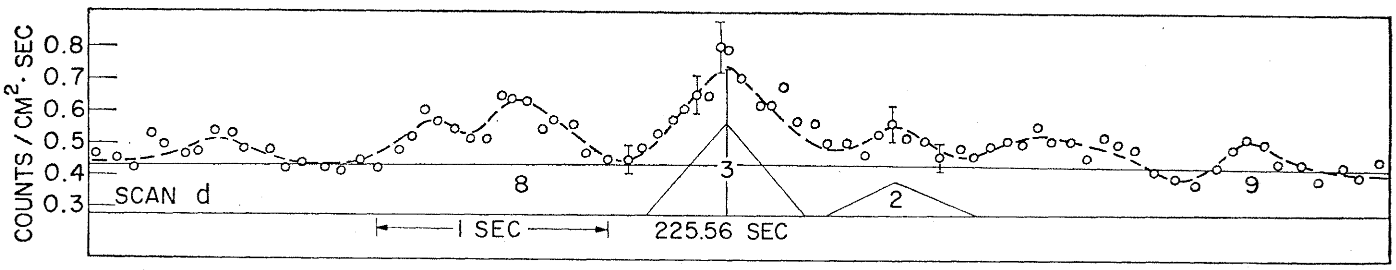


Fig. 7. Scan d (Fig. 3), April 1965. Peak at position 3 is Cyg XR-4.

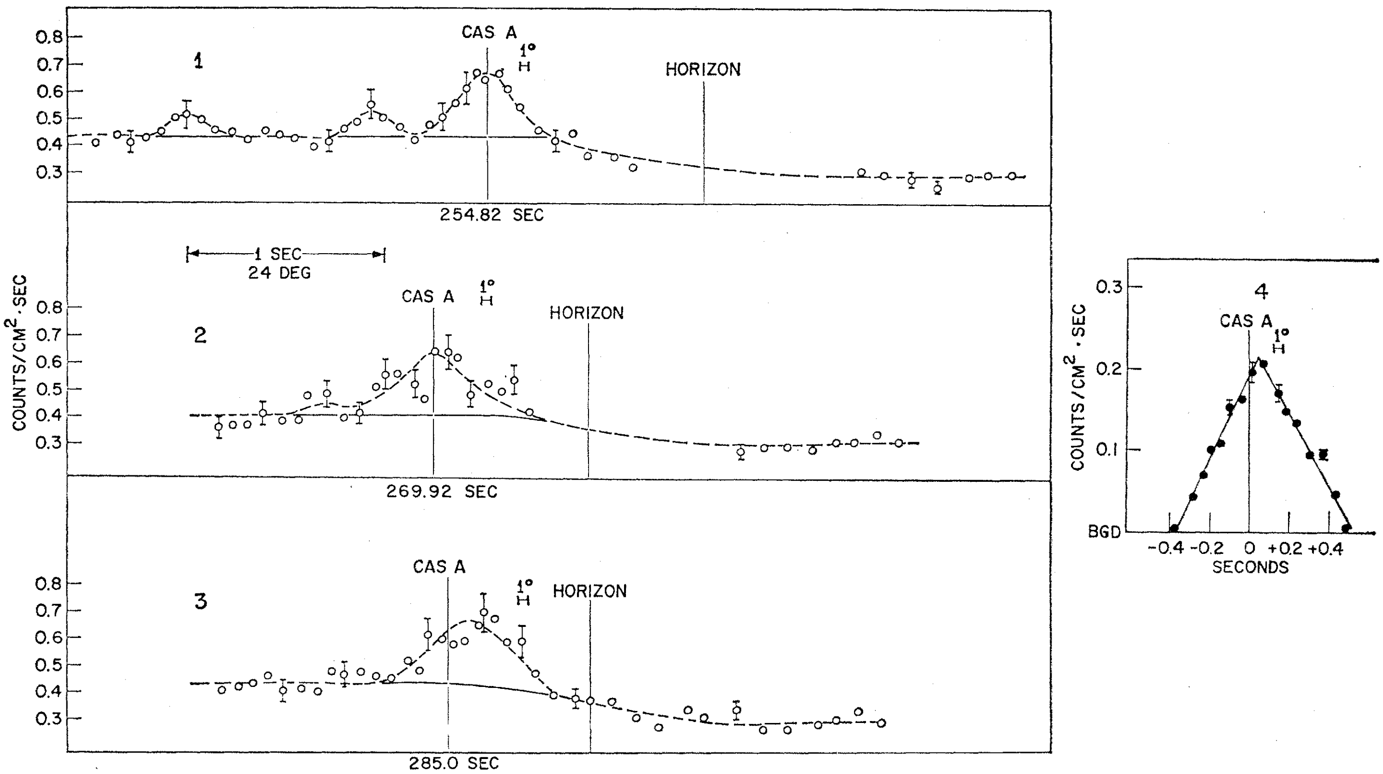


Fig. 8. Scans of region near Cassiopeia A, April 1965. Scans 1, 2, 3 each passed within 3 deg of Cas A in pitch direction. Curve 4 is the sum of scans 1, 2, and 3 plotted relative to the direction of closest approach to Cas A.

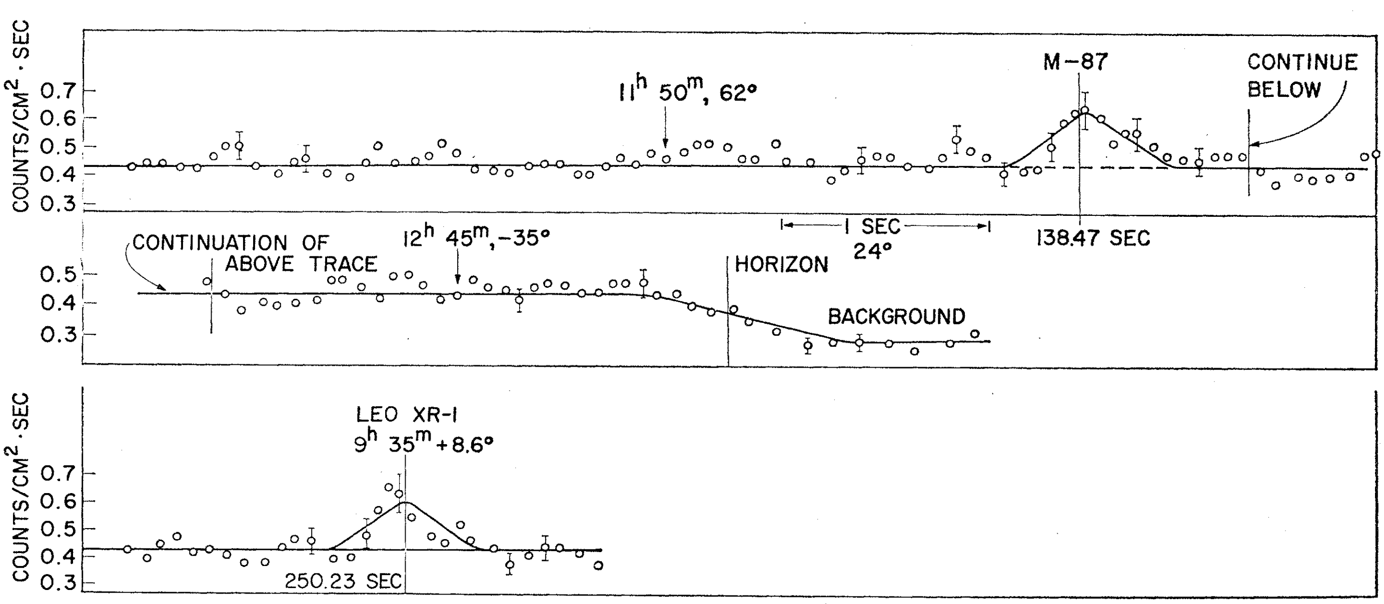


Fig. 9. Scans through M-87 and Leo XR-1.

Table 1. Relative efficiencies of counting equipment used in April 1965 (combination of two counters, ¼- and 1-mil-thick Mylar windows, argon-isobutane) and June 1964 (single counter ¼-mil-thick Mylar window, neon-isobutane). Figures are ratios of efficiency of 1965 to 1964 equipment.

Synchrotron index			Free-free (deg K)		
0.5	1.0	1.5	10^8	5×10^7	3×10^7
1.1	0.9	0.7	1.2	1.0	0.9

certainty is ± 3 deg, since the source is not observed on two adjacent scans separated about 6 deg from the track on which the signal was observed. The second source, which we designate Leo XR-1, is displaced 2 to 4 deg from the nearest radio galaxy, 3C-222. The indicated coordinates are for a position on the scan track; the uncertainty in pitch may be (+6 deg −9 deg).

As in previous surveys, a diffuse background of x-rays was observed. This background is distinguished from cosmic-ray background by subtracting the counting rate when the instruments are pointing downward from that observed when they are pointing above the horizon. The average x-ray background flux measured this way was 0.75 count cm^{-2} sec^{-1} $steradian^{-1}$.

Figure 2 shows the counting efficiencies of the Geiger counters flown in the June 1964 and April 1965 flights. The argon-filled counters are much more sensitive than the neon-filled counters at wavelengths shorter than the argon-K absorption edge. Table 1 lists the relative counting efficiencies based on exposures to assumed synchrotron and free-free x-ray spectra. All the data plots shown here for the April 1965 flight are based on the combined responses of two counters fitted with ¼-mil and 1-mil Mylar windows, respectively. Comparison of the responses of these two counters provides a "two-color photometry" of the x-ray sources. Here it suffices to mention that the ratios indicate a spectrum as hot or hotter than a 50-million-degree bremsstrahlung distribution. Accordingly, we conclude that the ratio of counter efficiencies appropriate to comparison of the ratio of 1965 to 1964 counting rates is unity, or slightly greater.

Tables 2 and 3 list the counting rates from several sources and the diffuse background. Comparison is made between the radio, optical, and x-ray emission rates. The ratios of x-ray to radio fluxes from the discrete sources Cygnus A and M-87 and of the diffuse background compared to the integrated flux of radio galaxies are of the same magnitude. This comparison suggests that the x-ray background is composed of a multitude of discrete sources, at present below the limit of x-ray resolution and detection.

The observational results may be summarized as follows:

1) Comparison of two surveys of the Cygnus region, about 1 year apart, shows that Cyg XR-1 has decreased in brightness about 75 percent.

2) X-ray sources were observed in the directions of Cas A, Cyg A, and M-87. The x-ray emission rates for these three sources were between 1 and 2 orders of magnitude greater than the combined radio and optical emissions.

3) The unresolved x-ray background showed a degree of random variation indicative of many unresolved discrete sources. The ratio of x-ray background brightness to integrated radio brightness was of the same magnitude as the ratios observed for Cyg A and M-87.

Cygnus XR-1 is the first clear example of an x-ray variable. It cannot be specified how rapidly the variation occurred, only that it occurred between the observations in June 1964 and April 1965. At present one can only speculate about possible interpretations. It is well known that light ripples are observed in the Crab Nebula, which indicate that even in this ancient supernova very energetic processes are still occurring. If the x-radiation is synchrotron in origin, the lifetime of the high-energy electrons may be of the order of a year and the source may undergo a large variation due to a statistical lapse in generation of relativistic electrons. Perhaps Cyg XR-1 was in a relative "flare" condition at the time of observation in 1964. Some neutron-star models of an x-ray source indicate a cooling time of the order of a year. Although a careful analysis of observations of the remaining nine sources isolated in 1964 has not yet been completed, a preliminary examination shows no very marked variations comparable to the decay of Cyg XR-1. The need to monitor the fluxes of x-ray sources at frequent intervals is clearly indicated.

Although Cyg A is the brightest extragalactic radio source and was discovered in 1946, 5 years passed before Baade and Minkowsky (*4*) identified it with a weak optical galaxy about 700 million light-years distant. The central portion of the galaxy appeared to consist of two bright condensations separated by about 2 seconds of arc, and it was proposed that these were two galaxies in collision. Subsequent studies indicated that the radio emission came from two vast regions whose centers lie about 100 seconds apart. The radio flux is 4×10^{46} erg sec^{-1}, about four times as great as the optical flux; and even at its great distance, Cyg A appears as bright as the sun on meter wavelengths. The radio evidence indicates that Cyg A is a synchrotron source and that the original idea of colliding galaxies is not valid.

Table 2. X-ray fluxes and emission rates.

Source	Count (cm^{-2} sec^{-1})	Flux (1 to 10Å) (10^{-8} erg cm^{-2} sec^{-1})		Distance (parsecs)	Emission rate (erg sec^{-1})				Ratio of x-ray (synch) to radio
		Free-free, 5×10^7 deg K	Synchrotron $\alpha = 1$		X-ray (1 to 10 Å) Free-free, 5×10^7 deg K	X-ray (1 to 10 Å) Synchrotron $\alpha = 1$	Radio	Optical	
Cyg A	0.4	0.5	0.4	220×10^6	3×10^{46}	2×10^{46}	4.4×10^{44}	4×10^{44}	45
M-87	.2	.2	.2	11×10^6	3×10^{43}	3×10^{43}	3×10^{41}		100
Cas A	.3	.4	.3	3.4×10^3	5×10^{36}	4×10^{36}	2.6×10^{35}		15
Tau A	2.7*	3.2	2.6	1.1×10^3	4.5×10^{36}	3.6×10^{36}	8×10^{33}	10^{36}	450
Cyg XR-1	3.6*	4.3	3.6						
	0.9	1.1	1.0						
Cyg XR-2	.8*	1.0	.8						
	1.0	1.2	1.1						

* June 1964. All other data refer to April 1965.

Table 3. Background fluxes.

Diffuse x-ray (1 to 10Å)
7.9 count cm^{-2} sec^{-1} $steradian^{-1}$
9×10^{-8} erg cm^{-2} sec^{-1} $steradian^{-1}$ (synchroton $\alpha = 1$)
Integral of radio galaxies (100 to 10^4 mc sec^{-1})
1.5×10^{-9} erg cm^{-2} sec^{-1} $steradian^{-1}$
Ratio of x-ray flux to radio flux
60

With the synchrotron hypothesis, however, it became necessary to explain how the billion-volt electrons, needed to produce the radio emission, were accelerated and to account for the total energy contained in electrons and magnetic fields. Because the synchrotron process is inefficient, the total energy content must be in excess of 10^{60} erg, and perhaps as great as 10^{62} erg.

In the thermonuclear burning of stars, the efficiency of conversion of mass to energy is of the order of 1 percent, and the burning of 1 sun produces about 10^{52} erg. It would, therefore, take the nuclear conversion of 10^{10} suns, or the entire mass of a medium-sized galaxy, to produce the energy content of Cyg A. Attempts to explain the energy in terms of gravitational collapse of a superstar have thus far failed. The present x-ray observation, which indicates that x-ray emission is more than an order of magnitude greater than radio plus optical emission, correspondingly increases the difficulty of explaining the total content of radio galaxies.

M-87 (Virgo A) is an elliptical galaxy, one of the brightest in the Virgo cluster, at a distance of 11 megaparsecs. It is about 5 minutes of arc in angular size, and the brightness is highly concentrated toward the center. Its total mass may be about 10^{12} solar masses, 10 times the mass of our galaxy. A luminous jet, 20 seconds long (about 1000 parsecs) bursts from its center, and its light is highly polarized. It provided Shklovsky (*5*) with the first evidence for the role of synchrotron radiation in radio galaxies. The radio power of M-87 is about 1000 times weaker than that of Cyg A, but it ranks immediately behind Cyg A and Cen A in flux received at the earth.

The detection of x-rays from the direction of Cas A provides evidence for a second supernova x-ray source in addition to the previously identified Crab Nebula. Cas A is believed to be a Type II supernova, whereas the Crab is Type I. It is estimated from the expansion velocity that the supernova explosion took place in the year 1702, ± 14. Taking the distance to Cas A as 3.4 kiloparsecs, its x-ray power is about equal to that of the Crab.

Several weaker sources were discovered in the April 1965 survey, and it is clear that many more are indicated by signals near the 2-σ background level. A modest increase in sensitivity and resolution should suffice to reveal these sources clearly. The great majority of x-ray sources are still unidentified with optical or radio objects, and the identifications proposed here for Cyg A, Cas A, and M-87 should be accepted with some caution because of the 1.5-deg uncertainty in positions. However, the circumstantial evidence for these identifications is strong. In the history of radio astronomy, Cyg A was the first discrete source detected; the Crab was the first radio source identified with an optical object; and M-87 was the first radio source identified with an optical galaxy. Cas A is the brightest radio source in the sky. It seems more than fortuitous that the first x-ray sources that can be associated with radio sources, within the present uncertainty of the observations, should fit four of the most spectacular radio sources. At the same time, the large number of x-ray sources that do not fit radio supernova remnants or radio galaxies implies the existence of a new type of celestial object observable only in the x-ray spectrum.

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References and Notes

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6. Sponsored jointly by ONR and NSF.

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Polymorphism in Pleistocene Land Snails

Abstract. *Under suitable conditions the colors and patterns of the shells of land snails may be preserved for thousands of years. In a late Pleistocene population of* Limicolaria martensiana *all the major color forms that occur in modern living snails may be distinguished, and the basic polymorphism is at least 8,000 to 10,000 year old.*

Under favorable conditions the colors and patterns of the shells of land snails may be preserved for thousands of years. When the species is polymorphic for shell color and pattern it may be possible to establish how long the polymorphism has persisted and if any evolutionary changes have occurred.

The African land snail, genus *Limicolaria* (Achatinidae), contains a number of species that exhibit conspicuous polymorphism in shell color and pattern. In Uganda one species, *L. martensiana* (*1*), forms well-defined populations, each with a characteristic frequency of the polymorphic forms: Adjacent populations separated by no more than a few meters may differ significantly in the frequency of the forms, provided there is sufficient ecological isolation between them (*2*). The polymorphism, which involves the presence or complete or partial absence of dark streaking and the presence or absence of pigment in the columella, may be detected in late Pleistocene shells. In an earlier report (*3*) the frequencies of streaked and unstreaked fossils were given; these fossils, which are not particularly well-preserved with regard to color and pattern, were obtained from the Kichwamba escarpment and from Equator Road in the Western Rift of Uganda, in areas covered by ash from the Katwe volcanic explosions, estimated to have occurred 8,000 to 10,000 years ago (*4*).

A new fossil site has now been found in Western Uganda; here the colors of the shells are much better preserved and the polymorphic forms can be recognized with greater accuracy. The new site is on Kabazimu Island in northern Lake Edward in the Western Rift. The shells have been washed by floods into a paleosol which is overlaid by a varying thickness (20 to 300 cm) of volcanic ash deposited