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EXTENDED SOURCE OF ENERGETIC COSMIC X RAYS

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We report here on evidence for an extended source of x rays in a region near the direction of the north galactic pole. This result is based upon data collected during two recent balloon flights launched from Holloman Air Force Base in New Mexico.

The x-ray telescope was suspended vertically so that the detector axis had celestial coordinates given by a right ascension equal to the sidereal time at the local meridian and a declination given by the latitude of the balloon. The stability of the attitude was established to within $\frac{1}{2}$ deg by a camera that continuously photographed the horizon on infrared sensitive film. During the major portion of the flight of 6 December 1965 the detector axis was well out of the galactic plane, riding at a declination of +31 deg, and passed near the north galactic pole. The flight of 13 January 1966 carried the telescope across the galactic plane at a declination of +34 deg, intercepting the x-ray source Cygnus XR-1. The residual atmosphere during the ceiling coverage of these flights was 2.6-2.8 g/cm^2.

Figure 1 shows the main elements of the x-ray telescope. The central x-ray detection element is a cesium-iodide (thallium activated) scintillation crystal that is used to measure x rays in the interval 20-100 keV partitioned by 64 channels. The plastic scintillator (CH) serves as an anticoincidence detector of charged particles and also as the innermost section of a three-element graded x-ray shield consisting of tin on the outside and copper sandwiched between. The light from the cesium iodide is distinguished from that of the plastic scintillator by its longer decay time. The entrance port is a krypton gas proportional counter that serves as an anticoincidence detector and is also used to measure x rays in the approximate interval 10-30 keV, again partitioned by 64 channels. The transmission of the gas counter exceeds the 50% level at 25 keV (K x ray for Sn^{119m}). At this energy, the proportional counter exhibits a resolution of about 20% full width at half-maximum (FWHM) for both the primary and escape peaks. The resolution for the cesium-iodide crystal is about 30% FWHM at 74 keV (K x ray of Bi^{207}).

A structured response pattern was achieved

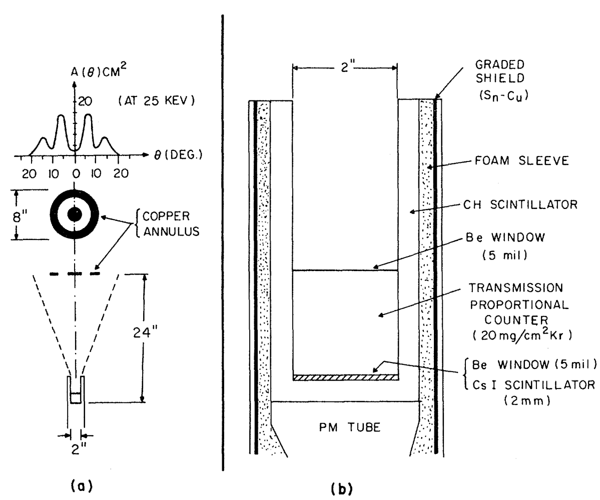

FIG. 1. (a) The x-ray spectrometer telescope utilizes the occultation scheme outlined; the detector appears at the bottom. (b) The essential features of the detector.

through the use of a copper occultation disk and annulus placed well above the detector [see Fig. 1(a)]. The effective detection cross section (A) as a function of the zenith angle (θ) is shown in Fig. 1(a). This was obtained by measuring the counting rate due to a Sn^{119m} source placed at positions corresponding to several values of θ for a fixed radial distance of 12 ft.

At the ceiling altitude, the minimum counting rate encountered was $\approx 1\ \text{sec}^{-1}$ for the proportional counter and $\approx 5\ \text{sec}^{-1}$ for the cesium-iodide crystal. For a reference base line we note that the absolute minimum counting rate occurred shortly after the launch, at about 10 000-ft altitude, and was $\approx 0.3\ \text{sec}^{-1}$ for the proportional counter and $\approx 1\ \text{sec}^{-1}$ for the cesium-iodide crystal.

A stroboscopic location of Cygnus XR-1 is shown in Fig. 2(a). The observed counting rate (dN/dt) of the proportional counter is here folded with the response function (F) of the detector as follows:

$$\langle\text{folded rate}\rangle \equiv \frac{[\int_t^{t+\Delta t}(dN/dt)F dt]}{(\int_t^{t+\Delta t}F dt)}. \qquad (1)$$

The response function (F) at any time (t) is determined by the zenith angle (θ) between the hypothetical celestial object under consideration and the actual axis of the telescope at that time. It is proportional to the effective detection cross section $A(\theta)$ depicted in Fig. 1(a). When, in fact, no localized sources contribute to the observed count, then the folded counting rate (1) exhibits the necessary feature that, independent of the assumed source location, its expectation value remains constant at a level equal to the average counting rate. As a measure of correlation then, we take the difference between the folded counting rate and the average counting rate for the same interval of data, viz.,

$$(\text{Strobe function}) \equiv \frac{\int_t^{t+\Delta t}(dN/dt)F dt}{\int_t^{t+\Delta t}F dt} - \frac{\int_t^{t+\Delta t}(dN/dt)dt}{\Delta t}. \qquad (2)$$

In Fig. 2(a) we strobe in declination for sources at a fixed right ascension of 299 deg. The maximum correlation occurs at a declination of +34 deg, which is close to that reported[1] for Cygnus XR-1. The negative correlation for hypothetical sources that are about 9 deg away from Cygnus XR-1 in declination is indicative that the observed counting rate structure followed the response pattern of the occultation scheme. This could have masked any contribution to the counting rate from Cygnus-A,

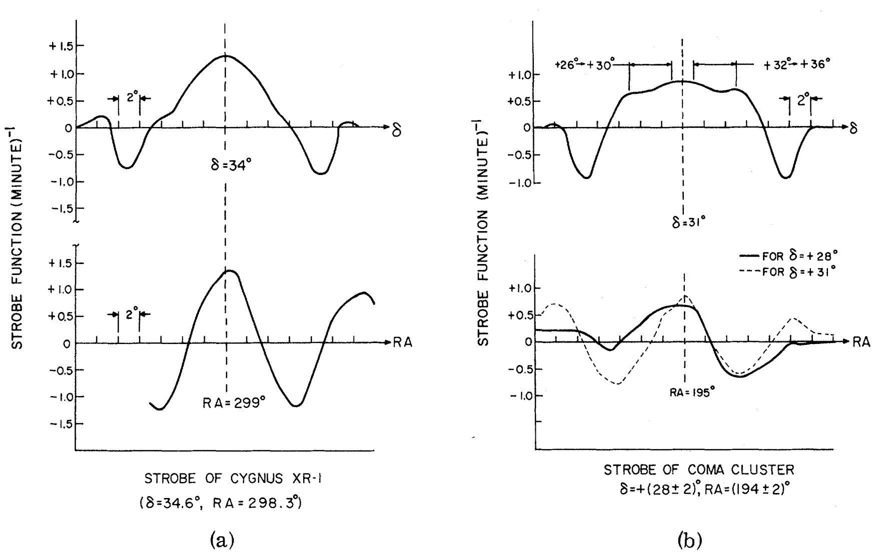

FIG. 2. (a) The strobe function [Eq. (2)] for the proportional-counter data of 13 January 1966 for the vicinity of Cygnus XR-1 (Ref. 1). (b) The strobe function for the proportional-counter data of 6 December 1965 for the vicinity of the Coma cluster (Ref. 2).

which is at about the same right ascension considered here, but is about 7 deg higher in declination. It does permit us to state that any flux from Cygnus-A above 20 keV is smaller than that from Cygnus XR-1 during the time of this observation (~19 h U.T., 13 January 1966).

Also shown in Fig. 2(a) is a strobe in right ascension for hypothetical sources at a declination of +34 deg. This was restricted in right ascension to those hypothetical sources that would have passed both into and out of the telescope's field of view during the ceiling coverage of the flight. The pronounced lobes in this pattern are characteristic of a scan in right ascension for a source that passes near the telescope axis. The principal maximum occurs at about 299 deg, close to the right ascension reported[1] for Cygnus XR-1.

The net spectrum from Cygnus XR-1 collected during a 30-min period of maximum yield is shown in Figs. 3(a) and 3(b). The response function for an object located at Cygnus XR-1 was used to establish the effective exposure during this period. The exposure for a 30-min interval of partial occultation bracketing this period of maximum yield was also obtained. By subtracting the occultation exposure value from the maximum yield value we obtain a net exposure which for the CsI crystal turns out to be 27×10^3 cm^2 sec and for the proportional counter is 22×10^3 cm^2 sec. The net spectrum shown here corresponds to this net exposure. The spectrum given by the CsI crystal was used to infer the magnitude expected for the peak interval indicated for the proportional counter; that is shown as a dotted region on Fig. 3(b). In the interval of spectral overlap for the two detectors, near 25 keV, we have referred the flux to the top of the atmosphere and obtained an incident primary flux value of $\sim10^{-2}$ (cm^2 sec keV)$^{-1}$.

Figure 2(b) shows a stroboscopic analysis of the proportional-counter counting rate for the flight of 6 December 1965. The strobe in declination is at a fixed right ascension of 195 deg. Since the mean declination of the detector axis during the ceiling coverage of this flight was +31 deg, this procedure examines a region of the sky in the immediate vicinity of the north galactic pole. This pattern is different from that obtained for Cygnus XR-1 in that it exhibits a broad structured central peak with shoulders symmetrically situated about

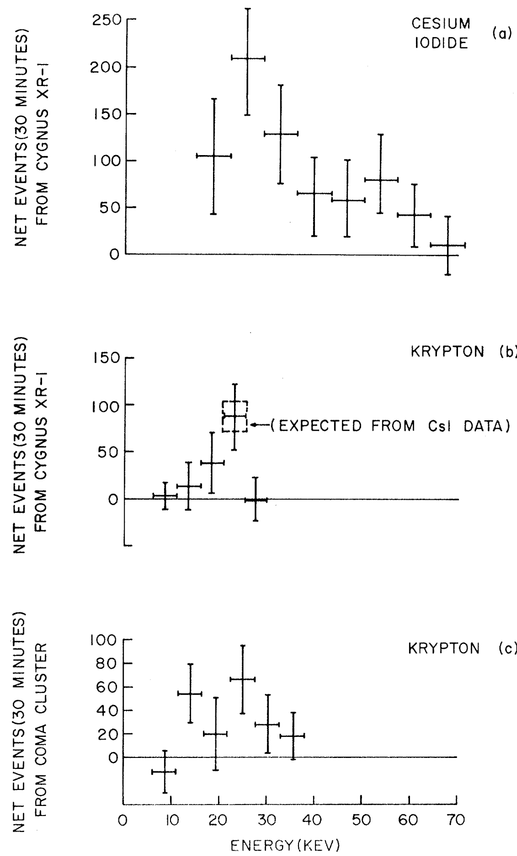

FIG. 3. (a) The net spectrum (background subtracted but with no corrections applied for atmospheric absorption or variations of detector efficiency) from Cygnus XR-1 detected by the CsI scintillator during a 30-min interval on 13 January 1966. (b) The net spectrum detected by the proportional counter (Kr gas) at the same time. (c) The net spectrum from the Coma cluster detected by the proportional counter during a 30-min interval on 6 December 1965.

5 deg on either side of +31 deg. This indicates radiation coming from a declination of +26 deg and/or +36 deg; the ambiguity here is an inherent feature of this scheme. That the correlation does not dip at the axis of symmetry indicates the passage of a source region near the detector declination of +31 deg. We interpret these features as evidence for an extended x-ray source at a mean declination of +28 or +34 deg and with an angular size of 4-5 deg. It is well established[2] that the Coma cluster of galaxies is an extended region of about that size located at a mean declination of +28 deg.

The next step in this procedure is to consider a fixed declination of +28 deg and strobe in right ascension. This is shown on Fig. 2(b) by a solid curve that exhibits a broad peak at a mean right ascension of about 195 deg, consistent with the Coma cluster.[2] If we strobe at +31 deg, which is the declination of the telescope axis, then we obtain the dotted curve shown on Fig. 2(b). We note that here we pick up a multilobed pattern somewhat similar to that obtained for Cygnus XR-1, and we interpret this as evidence that an edge of the Coma cluster source extends to a declination near +31 deg.

The net spectrum from the Coma cluster detected by the proportional counter during a 30-min interval of maximum yield is shown in Fig. 3(c). This corresponds to a net exposure value of 27×10^3 cm^2 sec and exhibits a positive net count of 169 events with an expected statistical standard deviation of 55 counts. A malfunction of the pulse-height analysis for the CsI scintillator channel during the flight of 6 December 1965 prevents an examination of the spectrum much above 30 keV.

The expected total number of events recorded by the proportional counter during a total exposure to the Coma cluster of about two hours was evaluated as 474 ± 113. For comparison, the expected total number of events recorded by the proportional counter during a similar exposure to Cygnus XR-1 was evaluated as 809 ± 121. Since the exposure values for these two sources were essentially the same, this allows us to estimate that the flux from the Coma cluster is comparable to that from Cygnus XR-1 for energies in the vicinity of 25 keV, vix., $\approx 10^{-2}$ (cm^2 sec keV)$^{-1}$ at the top of the atmosphere.

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INTERFEROMETRIC STUDY OF COSMIC LINE EMISSION AT OH FREQUENCIES

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The 18-cm Λ-type multiplet of $O^{16}H^1$ in its ground state has been observed in absorption[1] against strong continuum radio sources, with frequencies that agree well with the laboratory-measured values.[2] The emission lines, on the other hand, have been observed only close to H II regions[3-5] with polarization and intensity anomalies that are not yet understood. Single-antenna measurements[6] have shown that the sources are of small angular size, with surface brightnesses that correspond to radiation temperatures two orders of magnitude greater than the apparent kinetic temperatures derived from the observed linewidths. An improvement in angular resolution has been achieved by using the Millstone (84-ft) and Haystack (120-ft) antennas of the MIT Lincoln Laboratory as an interferometer with a base line of approximately 3800λ at 18 cm, along a line nearly 20° east of north. Most of the observations were made with both antennas circularly polarized in the same sense.

The signals from the two antennas were effectively cross-correlated by a phase-switching scheme. The sum and difference of the i.f. outputs from the two receivers were autocorrelated,[7] and the difference between these autocorrelation functions was taken. A common