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X-RAY FLUX FROM CENTAURUS X-2 IN THE ENERGY RANGE 2–20 keV

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ABSTRACT

Two rocket flights carrying X-ray payloads were conducted from Thumba Equatorial Rocket Launching Station (TERLS), Trivandrum, India, on November 3, 1968, and November 7, 1968, respectively. The first evidence for the existence of low-energy X-ray flux in the energy range 2–20 keV from the Cen X-2 source since its reported extinction in May 1967 is presented. The observed flux has the same energy spectrum as that observed in the high-energy range by Lewin *et al.* in October 1967.

In this Letter we report the rediscovery of the Centaurus X-2 X-ray source in the energy range 2–20 keV. Since the first discovery of the intense X-ray source Cen X-2 by Harries *et al.* (1967), several attempts have been made to look at this source. All the observations made in the last two years have indicated that Cen X-2 is a highly variable X-ray star, very much like a nova emitting in the visible spectrum. It was not detectable in October 1965; was observed as a time-varying object during April–May 1967; and was again undetectable in September 1967. The only evidence for the existence of this source since September 1967 is that of the balloon observations of Lewin, Clark, and Smith (1968), which showed that the spectrum as observed in October 1967 was much harder and was consistent with the lack of detectable X-ray emission in the range 2–20 keV observed during September 1967 (Chodil *et al.* 1967). In this Letter we report the observations of two rocket flights conducted from the Thumba Equatorial Rocket Launching Station (TERLS), Trivandrum (76°51′ E., 8°32′ N.), India.

Two identical X-ray payloads were launched from TERLS: one at 0319 U.T. on November 3, 1968, and the second at 0305 U.T. on November 7, 1968, almost toward the zenith (85° elevation), with the X-ray detector mounted so that its axis was perpendicular to the spin axis of the rocket. The launch time was chosen so that Sco X-1, Cen X-2, and Tau X-1 were all in the rocket horizon. The detector consisted of a proportional counter with a useful area of 60.8 cm^2 filled with xenon (90 percent) and methane (10 percent) at 1 atm pressure and having a 2-mil beryllium entrance window. The counters had a resolution of 15 percent (FWHM) for the 6.0-keV line from Fe^{55} and 22 percent for the 22-keV line from Cd^{109}. A slat-type collimator mounted in front of the proportional counter defined a field of view $8\overset{\circ}{.}7 \times 17\overset{\circ}{.}2$ (FWHM), with the long axis parallel to the spin axis. The attitudes of the rockets were determined by using suitably oriented magnetic sensors with Sco X-1 sightings. In-flight calibration was accomplished by measuring the pulse height of the 6.0-keV line from the Fe^{55} radioactive source attached to the nose cone of the rocket up to an altitude of 70 km, at which altitude the nose cone containing the source was explosively ejected.

The spin-stabilized Centaure rocket was launched on November 3, 1968, with a spin rate of about 8 rps, with its axis centered at right ascension 10^h18^m and declination $+15\overset{\circ}{.}0$. Consequently the X-ray detector was able to observe Sco X-1 and Cen X-2 sources during the entire duration of the flight (about 200 sec from 90-km altitude to the time of entry into the atmosphere). The Nike-Apache rocket, however, launched on November 7, 1968, went into precession after the ejection of the nose cone at 70 km, and its spin rate, which was initially about 9 rps, changed to about 2.8 rps after the

nose-cone ejection. The precession axis of the rocket, as derived from the attitude sensors and the Sco X-1 sightings, is centered at right ascension 10^h8^m and declination $+36°$, the half-cone precession angle being 54°. In the seven precessions, each containing ninety-three spins, Sco X-1, Tau X-1, and Cen X-2 sources were all scanned for about eight or nine consecutive spins. The details of the detector, the aspect analysis, and the results for other X-ray sources during these two flights will be published elsewhere (Rao *et al.* 1969). In this Letter we present only the data on the Cen X-2 X-ray source obtained during the two flights.

The data from all the spins of the Centaure rocket launched on November 3, 1968, have been summarized. Figure 1 shows the observed counting rate in the energy range

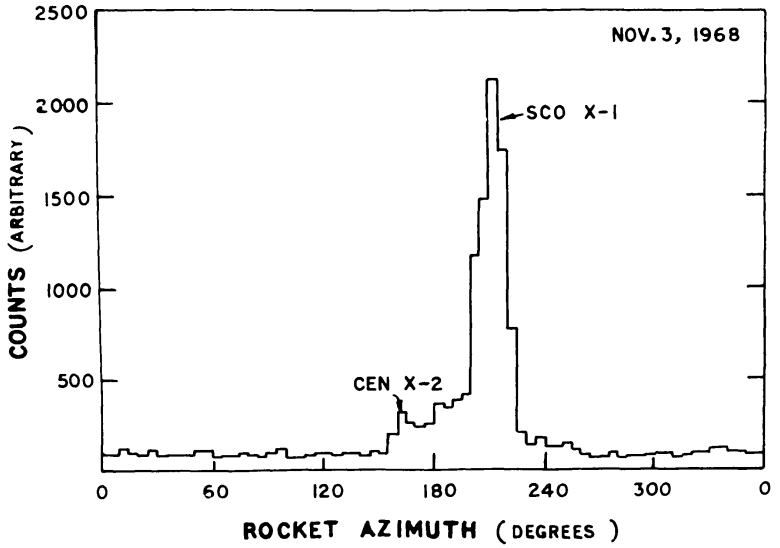

FIG. 1.—Counting rate in the energy range 2–6 keV as a function of rocket azimuth for the flight of November 3, 1968.

2–6 keV, as a function of rocket azimuth. For the flight of November 7, 1968 (Nike-Apache), the data for all the scans during which the source could be observed have also been summarized and are presented in Figure 2. The absolute flux has been obtained by fitting the observed data to a triangular response appropriate to the collimator used. Both flights unambiguously indicate the presence of a flux of low-energy X-rays from Cen X-2, the level of detection on the November 3 flight being more than 10 standard deviations and that on the November 7 flight about 5 standard deviations. The best estimate of the position of Cen X-2 as determined from our experiment is right ascension $201° \pm 2°$ and declination $-62°.5 \pm 2°$, which is consistent with the position of Cen X-2 observed by Harries *et al.* (1967) and Chodil *et al.* (1967). The observed fluxes of Sco X-1 and Tau X-1 during the same flights in the energy range 2–5 keV, which are $(1.1 \pm 0.2) \times 10^{-7}$ erg cm^{-2} sec^{-1} and $(1.6 \pm 0.3) \times 10^{-8}$ erg cm^{-2} sec^{-1}, respectively, in reasonable agreement with the observations of other workers, adds further support to the data on Cen X-2.

In Figure 3 is plotted the energy spectrum of the X-ray intensity for the two flights. Although the data from both flights could be fitted to an exponential spectrum with a characteristic temperature of about 5.4 keV ($T = 6.3 \times 10^7$ °K), a power-law spectrum fits the data better. The X-ray flux on November 3, 1968, can be represented by the spectrum

$$f(E) = 5.8E^{-1.2\pm0.2}\,dE$$

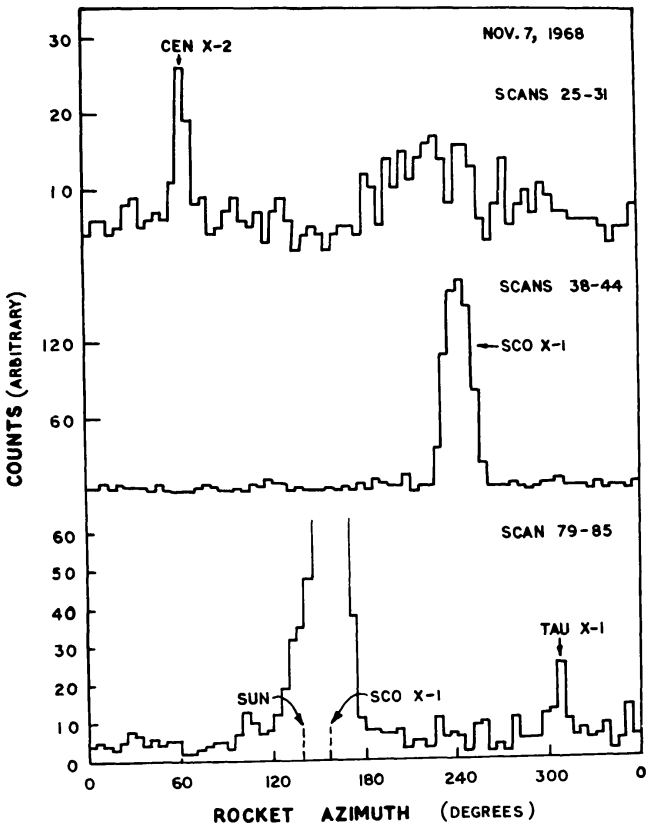

FIG. 2.—Counting rate in the energy range 2–6 keV as a function of rocket azimuth for the flight of November 7, 1968.

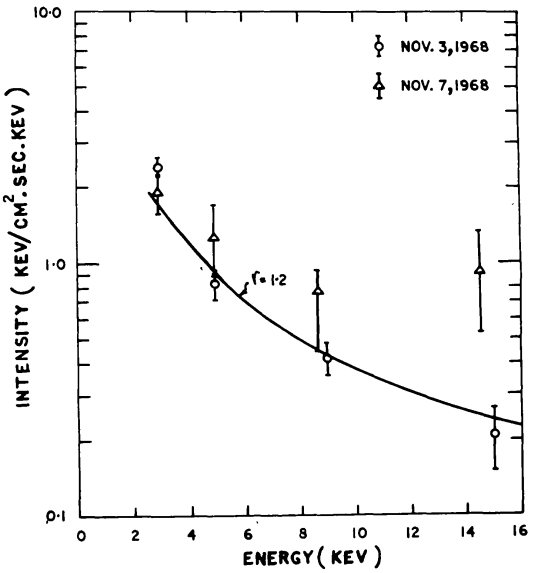

FIG. 3.—Energy spectrum of Cen X-2

and that on November 7, 1968, by the spectrum

$$f(E) = 5.1E^{-0.9\pm0.2}\,dE\,.$$

We conclude that the energy spectra of the X-ray flux measured on November 3 and November 7 are the same within the statistical error. If the time variation of the Cen X-2 flux is truly represented by an exponential with a time constant of about 25 days (Harries *et al.* 1967), then a change of 15 percent in the flux should have been observed in 4 days; such a change, however, cannot be ruled out in our experiments, because of the statistical uncertainties.

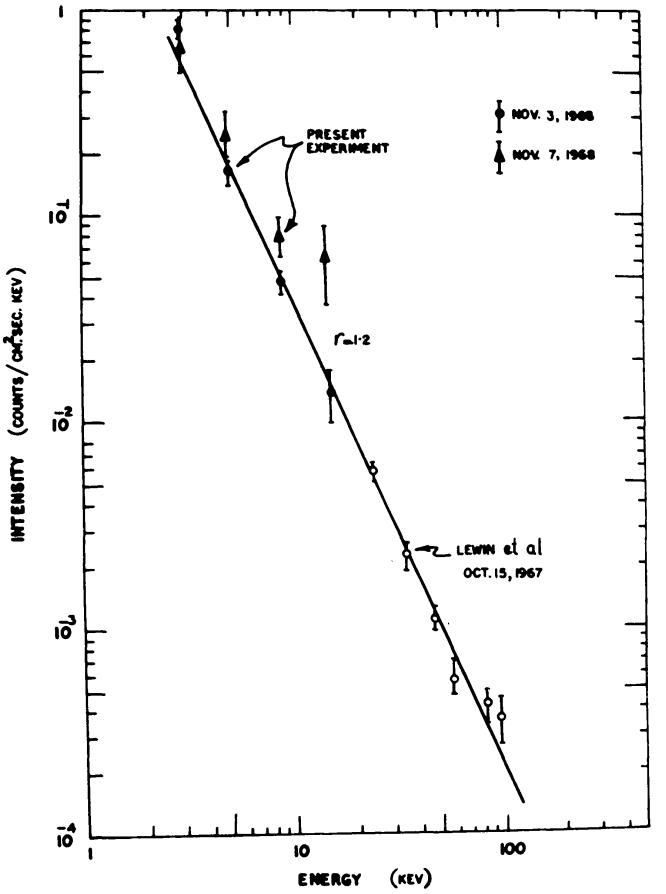

FIG. 4.—X-ray flux from Cen X-2 in low and high energies

The balloon observations on October 15, 1967, of Lewin *et al.* (1968) in the energy range 20–100 keV showed that the energy spectrum of the Cen X-2 source can be fitted to a power-law spectrum with an index of 1.2. In Figure 4 the X-ray flux observed by us in the low-energy region during the two flights is plotted as a function of energy. In the same diagram the balloon observations of Lewin *et al.* are also shown. It is evident from the figure that the observations of both the low- and the high-energy X-rays from Cen X-2 over an interval of 1 year can be fitted to a single power-law spectrum with an exponent of 1.2.

Figure 5 shows the remarkable variability of the X-ray flux from Cen X-2, the numerical data being given in Table 1. The extrapolated energy flux of X-ray emission in the range 2–5 keV based on the balloon observations by Lewin *et al.* (1968) is also shown

in the diagram. The decrease in X-ray flux during the period April–May 1967 can be represented as an exponential decay with a time constant of 23.4 days. This decrease was also accompanied by a softening of the spectrum. Even though Cen X-2 was observed in the high-energy range in October 1967, Pounds (1969) detected no low-energy flux from the source in June 1968. He provides an upper limit of 0.15 photon cm^{-2} sec^{-1} for the flux in the energy range 2–5 keV, which is more than an order of magnitude below the low-energy flux we detected in November 1968. We present the first evidence for the existence of the low-energy X-ray flux from Cen X-2 in the range 2–20 keV since May 1967. Our observations, together with those of others, indicate that the Cen X-2 source gives recurring X-ray outbursts, each outburst lasting probably for a short period of time. In order to explain this behavior, Manley (1967) proposed an expanding, constant-mass plasma model for the source, according to which a dense plasma cloud of radius $\sim 10^{14}$ cm was heated at constant volume to nearly 2×10^{7} ° K and then proceeded to expand isothermally and cool off. The recurring short-lived outbursts like the one observed by Lewin *et al.*, and more recently our low-energy observations, can be attributed to a shock wave from the nova outburst expanding into the circumstellar medium. Such a shock could accelerate and heat the gas to a high temperature as it propagates into a medium of decreasing density.

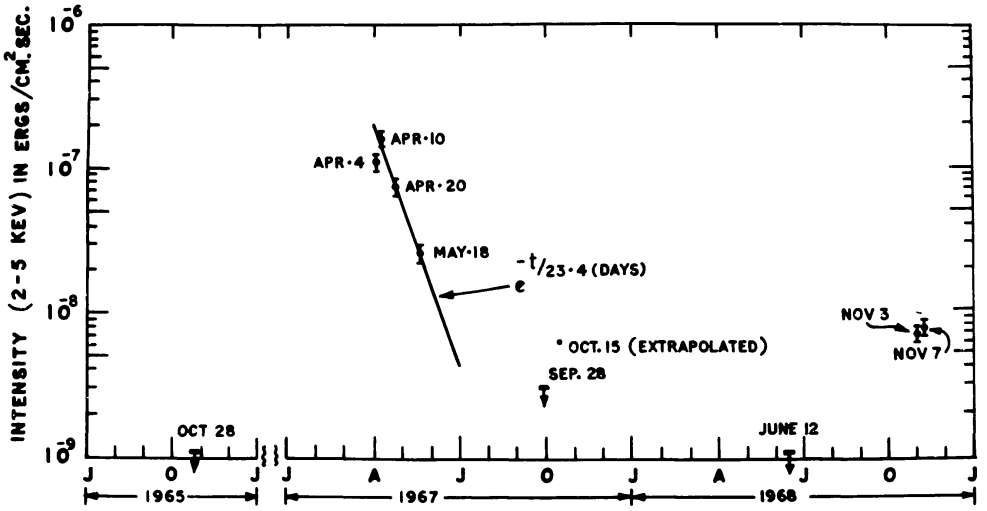

FIG. 5.—Time variation of X-ray flux from Cen X-2

TABLE 1

TIME VARIATION OF X-RAY INTENSITY FROM CEN X-2

Experimenter	Flight Date	Energy in 2–5-keV Range (10^{-8} erg cm^{-2} sec^{-1})
Grader *et al.* (1966)	October 28, 1965	< 0.25
Harries *et al.* (1967)	April 4, 1967	11.0 ±1.0
Cooke *et al.* (1967)	April 10, 1967	16.0 ±1.0
Francey *et al.* (1967)	April 20, 1967	7.5 ±1.0
Chodil *et al.* (1967)	May 18, 1967	2.6 ±0.4
Chodil *et al.* (1968)	September 28, 1967	< 0.3
Lewin, Clark, and Smith (1968)	October 15, 1967	0.62 (extrapolated)
Pounds (1969)	June 12, 1968	< 0.1
Rao *et al.* (present experiment)	November 3, 1968	0.68±0.08
Rao *et al.* (present experiment)	November 7, 1968	0.83±0.14

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