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NOVA-LIKE BEHAVIOR OF THE X-RAY SOURCE CENTAURUS XR-2*

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This letter compares the results of six observations of Cen XR-2. These observations were made over a period of two years and indicate that Cen XR-2 emits X-rays with a time dependence very much like that of a nova emitting in the visible spectrum.

Proportional counters were used on all these flights to detect the X-rays. Other cosmic X-ray sources of known intensity were also observed on each of these flights. Therefore, meaningful intensity comparisons can be made for Cen XR-2. The six observations are summarized briefly in the following paragraphs and in Table 1 and Figure 1.

Flight 1.—October 28, 1965 (Grader *et al.*, 1966). A thin-window (0.15-mil aluminum-coated Mylar), argon-methane–filled proportional counter was used to detect the X-rays. Total intensity measurements for several well-known sources were obtained (Sco XR-1, Tau XR-1). The detector scanned the region of the sky containing Cen XR-2, and no counts above background were observed. From these data, the upper limit of the X-ray flux from this object was 0.25 photon cm^{-2} sec^{-1} between 2 and 10 keV.

Flight 2.—April 4, 1967 (Harries *et al.* 1967; Francey *et al.* 1967). Xenon-methane–filled proportional counters with 3-mil beryllium windows were employed in this investigation. Photons from Cen XR-2 and Sco XR-1 were observed in the energy intervals 2–5 and 5–8 keV. The intensity of Cen XR-2 was nearly as strong as that of Sco XR-1, but the spectrum was softer. The data agreed with a thermal bremsstrahlung spectrum with a temperature of $4.2^\circ \times 10^{7\,\circ}$ K.

Flight 3.—April 10, 1967 (Cooke *et al.*, 1968). Large-area, argon-methane–filled proportional counters with $\frac{1}{4}$-mil Melinex windows were used. During this investigation Sco XR-1 and Tau XR-1 were observed. In addition, Cen XR-2 was observed to have a slightly higher intensity than Sco XR-1, and the Cen XR-2 spectrum was softer than that of Sco XR-1.

Flight 4.—April 20, 1967 (Harries *et al.* 1967; Francey *et al.* 1967). This flight was very similar to Flight 2. However, the detectors used on this flight had better resolution. Cen XR-2 was found to be nearly half as strong as Sco XR-1, and the Cen XR-2 spectrum could be approximated by thermal bremsstrahlung with $T = 2.7^\circ \times 10^{7\,\circ}$ K.

Flight 5.—May 18, 1967 (Chodil *et al.* 1967*b*). Xenon-methane–filled proportional counters with thin beryllium windows were used in this investigation. The flux measured was 5.4 ± 0.7 photons cm^{-2} sec^{-1} between 2 and 9 keV, and the spectrum was found to be consistent with thermal bremsstrahlung with $T = 1.8^\circ \times 10^{7\,\circ}$ K.

Flight 6.—September 28, 1967.[1] The region of the Cen XR-2 source was scanned again during this flight. The equipment used was similar to that used for Flight 5. No counts above background were observed from the Centaurus region, although Sco XR-1, Cyg XR-1, and the Sun were detected. An upper limit to the flux from Cen XR-2 is 0.5 photon cm^{-2} sec^{-1} between 2 and 10 keV.

The unequivocal conclusion to be drawn from the data presented here is that at some time between October 1965 and April 1967 an intense source of X-rays appeared in the constellation Centaurus. The intensity of this source diminished rapidly, and in

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[1] The results of this flight will be described in more detail in a future publication concerning Sco XR-1.

September 1967, six months after it was first observed, it was again below background. This decrease in intensity between April and May and its disappearance by September are in apparent agreement with the expanding constant-mass plasma model proposed by Manley (1967). Manley's calculations are based on early reports of the measurements of April 20 and May 18, 1967.

The authors wish to point out the similarity between the time behavior in Figure 1 of the X-ray intensity of Cen XR-2 and the time behavior of the optical intensity of novae (Payne-Gaposchkin 1958). It has apparently been possible to determine the optical characteristics of Sco XR-1 (Gursky *et al.* 1966) and Cyg XR-2 (Giacconi *et al.* 1967; Chodil *et al.* 1967*a*) by extrapolating the observed X-ray spectrum to the visible wavelengths. If it is valid to apply this extrapolation procedure to Cen XR-2, then it was a blue, 12.4-mag object on April 20, 1967, and a 12.8-mag object on May 18, 1967. The average change in visual magnitude was 0.02 ± 0.01 mag per day. This rate of intensity decrease is within the range observed for optical novae.

TABLE 1

X-RAY INTENSITIES AND LOCATIONS OF CEN XR-2

Date	X-Ray Energy (keV)	Cen XR-2 Intensity (ergs cm^{-2} sec^{-1})	Cen XR-2 Location	Sco XR-1 Intensity (ergs cm^{-2} sec^{-1})
Oct. 28, 1965 (Grader *et al.*)	2–5	$\leq 10^{-9}$	.....	2.6×10^{-7}
April 4, 1967 (Harries *et al.*)	2–5	1.1×10^{-7}	13^{h}9 R.A., −64° decl.	1.3×10^{-7}
	5–8	4.7×10^{-8}		6.9×10^{-8}
April 10, 1967 (Cooke *et al.*)	2–5	1.6×10^{-7}	13^{h}3 R.A., −60° decl.	1.3×10^{-7}
April 20, 1967 (Harries *et al.*)	2–5	7.5×10^{-8}	13^{h}9 R.A., −64° decl.	1.2×10^{-7}
	5–8	2.3×10^{-8}		6.6×10^{-8}
May 18, 1967 (Chodil *et al.*)	2–5	2.6×10^{-8}	13^{h}4 R.A., −62° decl.	1.4×10^{-7}
	5–8	4×10^{-9}		7.2×10^{-8}
Sept. 28, 1967 (Chodil *et al.*)	2–5	$\leq 3\times10^{-9}$	.....	2.2×10^{-7}

Following Manley's model for an expanding plasma in approximate thermal equilibrium, the intensity of the radiation emitted into the energy interval between $h\nu_1$ and $h\nu_2$ is proportional to the following factors:

$$I \propto (\text{volume})(\text{density})^2 (T)^{1/2} \left(\exp \frac{-h\nu_1}{kT} - \exp \frac{-h\nu_2}{kT} \right). \quad (1)$$

Assuming that the mass remains constant, it is possible to obtain the ratio of the plasma radii R_1/R_2 on April 20 (R_1) and on May 18 (R_2) from expression (1), using the measured values of the temperatures and intensities on those dates.

Another relation between R_1 and R_2 exists if it is assumed that the plasma expands at a constant velocity:

$$R_2 = R_1 + V(t_2 - t_1) . \quad (2)$$

The velocity (V) of sound in the plasma, 5.4×10^7 cm sec^{-1}, will be used for the plasma-expansion velocity. This is consistent with Doppler measurements of expansion velocities of novae (Payne-Gaposchkin 1958) and is the upper limit for the quasi-equilibrium model proposed here. Using expressions (1) and (2) results in $R_2 = 8 \pm 3 \times 10^{14}$ cm for the plasma radius on May 18. At maximum, novae have radii in the neighborhood of 10^{13} cm (Payne-Gaposchkin 1958); thus Cen XR-2 would have been at maximum on December 1, 1966, ± 3 months. By extrapolating the apparent visual decrease

of 0.02 mag per day, we find that the apparent visual magnitude of the object should have been between +10 and +5 on December 1, 1966. The absolute magnitudes of typical novae at maximum range from −5.5 to −8.5 (Arp 1956). From these considerations it is possible to estimate the distance to Cen XR-2 as lying between 5 and 14 kpc.

By use of the plasma radiation model, the distance, and the observed X-ray energy flux, an electron density of $3 \pm 1 \times 10^8$ electrons cm^{-3} at a temperature of 1.8×10^7 ° K is obtained, a value consistent with the estimates of Wallerstein (1961) for repeating novae. The arguments outlined above are also consistent with the prediction of Tucker (1966) that novae should emit X-rays during their outburst phase.

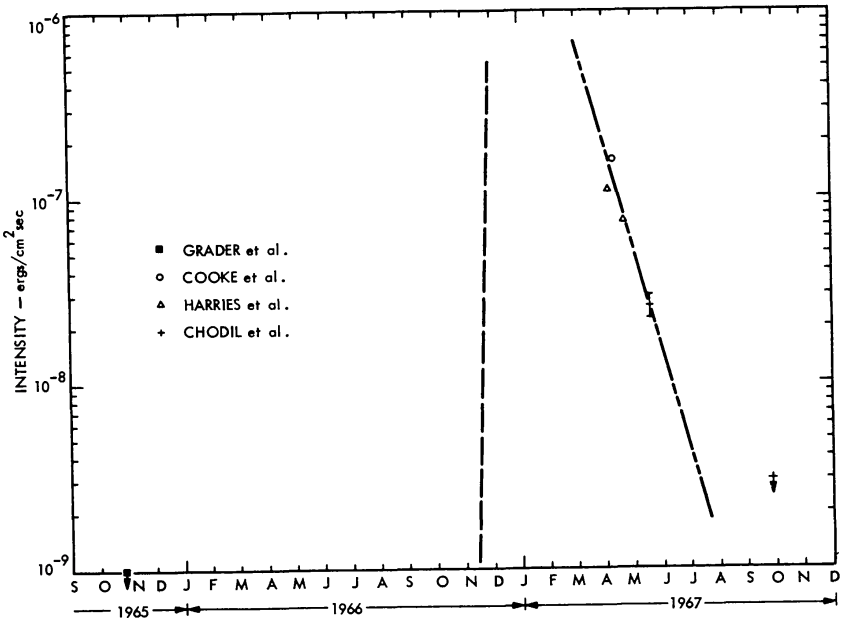

FIG. 1.—Cen XR-2 intensity observed between 2 and 5 keV as a function of date. Observations on October 28, 1965, and September 28, 1967, only set upper limits on intensity. The dashed line in November 1966 is an estimate based on assumption that Cen XR-2 is a nova whose maximum occurred on December 1, 1966, ±3 months.

The occurrence of the phenomenon observed in Cen XR-2 suggests that further searches for nova-like X-ray objects should be conducted. It may eventually be possible to establish a relationship between the absolute intensity and the decay time of X-ray novae similar to the one existing for visual novae (Arp 1956). Also, observations should be made to see whether known visual novae are X-ray sources.

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