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A HARD X-RAY OBSERVATION OF THE 1979 OUTBURST OF CENTAURUS X-4 WITH THE FRANCO-SOVIET SIGNE 2 MP (*PROGNOZ 7*) SATELLITE EXPERIMENT

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ABSTRACT

In 1979 May, a collimated detector in the Signe 2 MP experiment aboard the *Prognoz 7* satellite, viewing the antisolar direction, detected intense 13–163 keV X-ray emission from the source Centaurus X-4. This was the first time that high-energy X-ray emission was observed from this object, which up to now has been categorized as a type I soft X-ray burster. The light curve of the outburst is presented, as well as the hard X-ray spectrum at various times during the outburst. A source model involving accretion onto a neutron star is proposed.

Subject headings: X-rays: bursts — X-rays: sources

I. INTRODUCTION

An intense outburst from the transient X-ray source Centaurus X-4 was observed in 1979 May over a period of 15 days, by means of a collimated lateral detector in the Signe 2 MP (*Prognoz 7*) detector viewing the antisolar direction. This event was observed at lower energies (3–6 keV and 1.5–12 keV) at the same time by the *Ariel 5* A11 Sky Monitor (Kaluzienski, Holt, and Swank, 1980) and by the *Hakucho* satellite (Matsuoka *et al.* 1980). The only other event known to come from Cen X-4 occurred in 1969 July (Evans, Belian, and Conner 1970; Kitamura *et al.* 1971) and was also observed at low energy.

Cen X-4 is associated with an optical counterpart which increases from magnitude 19 before the outburst to magnitude 13 during the outburst (Canizares, McClintock, and Grindlay 1980), displaying emission lines characteristic of a K star, whose distance is estimated to be about 1 kpc. The source is probably part of a binary system, of which one component is a neutron star.

II. OBSERVATIONS

The collimated antisolar detector of the Franco-Soviet Signe 2 MP (*Prognoz 7*) experiment is similar to that of the Signe 2 MP (*Prognoz 6*) experiment, described by Chambon *et al.* (1979). It consists of an 11 cm^2 NaI(Tl) scintillator in an active CsI(Na) anticoincidence well which defines a field of view of 16° FWHM. The data used for the study of Cen X-4 were, first, the 13–163 keV integral count rates measured with 10.24 s time resolution, and second, six channel energy spectra covering the 13–163 keV energy range with 164 s resolution. The experiment was placed aboard the Soviet *Prognoz 7* spacecraft, in an eccentric (200,000 × 500 km), 65° inclination Earth orbit with a period of 95 hr. The spacecraft was spin stabilized, with the rotation axis pointed in the solar direction, and updated every 4 days. Thus the antisolar detector swept along the ecliptic plane, observing Cen X-4 in 1979 May. The axis of the solar and antisolar detectors aboard *Prognoz 7* were displaced by 9°.5 with respect to the rotation axis of the satellite. The spin period was about 120 s.

The 9°.5 displacement between the detector and spin axis gives rise to a roll modulation of the source fluxes for sources in the field of view. Using this modulation, observed in the 10.24 s integral count rates, source positions may be found with an accuracy of about 1° for strong sources like the Crab and Sco X-1, even though the field of view is 16° FWHM (Bouchacourt 1982). In this case, it was first determined that two sources were present in the detector field of view: Sco X-1 and a source whose position was unknown. (For the viewing directions considered here, the galactic center was outside the field of view.) No *a priori* assumptions were made about the fluxes of the two sources, which are both calculated for every assumed position of the unknown source, in order to find the best agreement between the fluxes measured as a function of roll phase and the theoretical fluxes calculated from the detector angular response.

Figure 1 shows the most probable position of the unknown source, obtained by varying the coordinates (α, δ) until a minimum χ^2 was found for the measured and calculated fluxes.

III. LIGHT CURVE

After establishing the presence of Cen X-4 in the detected flux, the time variation of the flux was determined using a model in which the positions of the two sources (Sco X-1 and Cen X-4) were assumed to be known. The method is the same as that described above, except that only the fluxes of the two sources are taken as variables. In this manner, the 13–163 keV flux from Cen X-4 was calculated every day (Fig. 2). The light curve displays a rapid increase in flux from May 12 to May 14, an equally rapid decrease between May 14 and May 16, and a slow but significant increase from May 26 to May 28. Figure 2 also shows the variation of the flux in the 3–6 keV energy range (Kaluzienski, Holt, and Swank 1980). It can be

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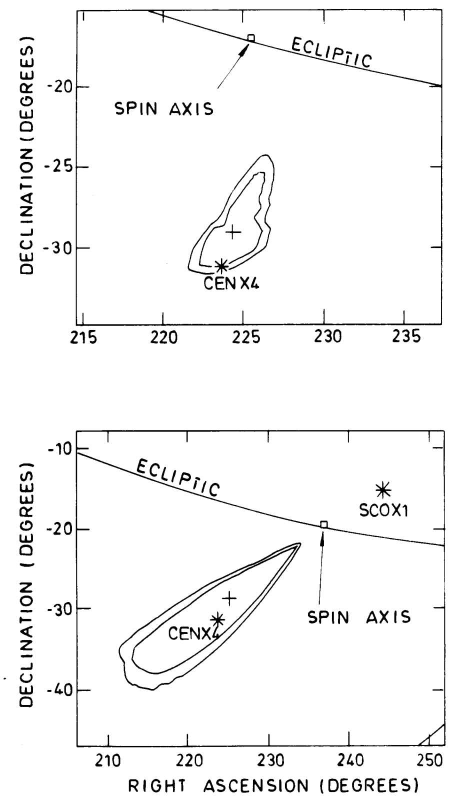

FIG. 1.—Localizations of Cen X-4 using the Signe 2 MP data for two different orientations of the *Prognoz* satellite (method of Lampton *et al.* 1976). The cross indicates the minimum χ^2 localization of the source.

seen that hard X-ray emission is present mainly at the start and the end of the outburst.

The hard X-ray maximum is located around May 14 at 2300 hours; this corresponds to the premaximum identified by Kaluzienski, Holt, and Swank (1980) in the 3–6 keV *Ariel 5* data. In addition, the 13–163 keV increase on 1979 May 28 corresponds to the small recovery maximum at lower energies during the end of the event (Kaluzienski, Holt, and Swank 1980).

IV. PERIOD SEARCH

A fast Fourier transform showed no evidence for periodicity in the 10 s–10 hr range, with an upper limit of 4% for the pulsed fraction. Thus the period of 8.2 ± 0.2 hr found by Kaluzienski, Holt, and Swank (1980) was not confirmed in these data. However, it should be noted that those authors observed the periodicity at low energies, and only during the decreasing phase of the flare-up, where the high-energy component falls back near the background level, making analysis of this phase impossible for the data considered here.

V. ENERGY SPECTRA

The energy spectra during the outburst were measured with 163 s resolution in six channels: 13–20, 20–29, 29–48, 48–72, 72–114, and 114–163 keV. The Cen X-4 contribution in each energy range was obtained by comparing the count rates during the outburst to comparable count rates obtained in the absence of an outburst for the same orientation of the satellite, and taking into account the decay in each separate channel due to the detector environment activation after peri-

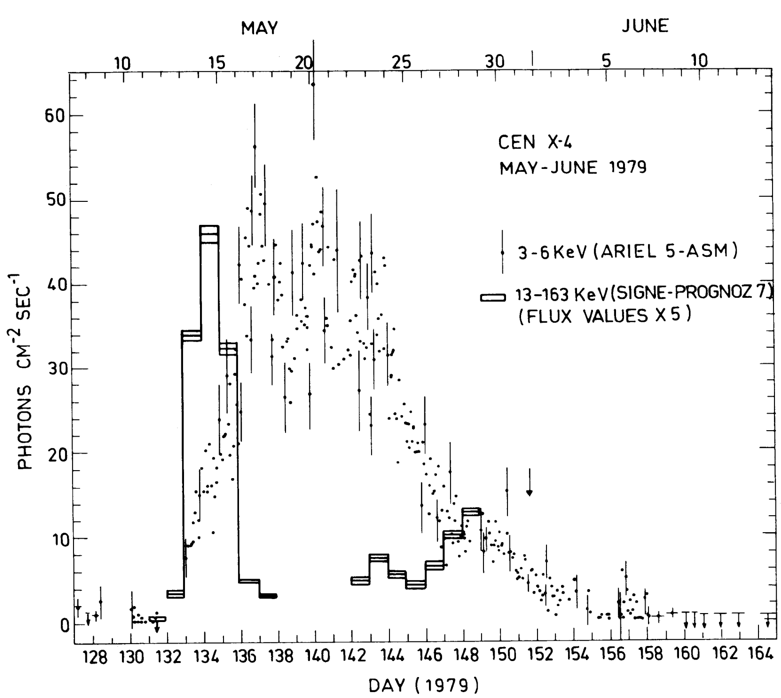

FIG. 2.—Signe 2 MP (*Prognoz 7*) and *Ariel 5* light curves of the 1979 outburst of Cen X-4. Arrows denote times of spectra shown in Fig. 3. Our data represent 1 day averages of the 13–163 keV flux. For clarity, the error bars on *Ariel 5* data have been indicated only where typical.

gee crossing (Bouchacourt 1982; Violes 1981). The spectra at various times (denoted A, B, and C) during the outburst are shown in Figure 3. The 13–163 keV points are well represented by a thermal bremsstrahlung law of the form $AE^{-1}\exp(-E/kT)$ The best fit value of kT decreases monotonically from May 13 to May 15 as follows: 70(−50, +80) keV on May 13 at 0700 hr for spectrum A, 45(−15, +85) keV on May 13 at 2100 hr for spectrum B, and 31(−11, +45) keV on May 15 at 1200 hr for spectrum C (the uncertainties are given at a 68% confidence level). We note that a blackbody spectrum also gives a good fit to the data.

VI. DISCUSSION

The 3–6 keV *Ariel 5* points are shown on spectra A, B, and C of Figure 3. They lie above the extrapolation of the 13–163 keV best fit spectra, implying that the entire spectrum cannot be described by a simple law during the hard X-ray peak at the start of the event. On the other hand, with the exception of the initial phase of the event, only soft X-ray emission is present, which can be described by a free-free law

$$gE^{-1}\exp(-E/kT - n_{\rm H}\sigma), \qquad (1)$$

where σ is the absorption cross section of Brown and Gould and g is the Gaunt factor (Matsuoka *et al.* 1980). This spectrum is essentially in agreement with that measured in 1969 by Kitamura *et al.* (1971). Moreover the constancy of the hardness ratio (6–10 keV/3–6 keV) during the 1969 outburst following the initial phase was noted by Kitamura *et al.* (1971) and by Evans, Belian, and Conner (1970), while the latter clearly observe an increase in this ratio at the start and the end of the event, suggesting that hard X-ray emission analogous to that which we observed in 1979 was present for the 1969 event. A spectrum of the form (1) is shown in Figure 3, by a dotted line, after normalization to the point of *Ariel 5* which corresponds to measurements taken simultaneously with those of the Signe 2 MP (*Prognoz 7*) experiment. A comparison shows that the spectrum observed at the start of the event between 13 and 163 keV is quite different from that observed with *Hakucho* during the rest of the event between 3 and 10 keV. Note that for spectrum B, the energy flux in the 13–163 keV range is 2.5 times that observed by *Ariel 5/Hakucho* in the low-energy component.

X-ray nova events of the type reported here have been widely attributed to binary systems with a compact component such as a neutron star. The emission is either produced at the surface of this component by a thermonuclear explosion in layers of accreted matter, or by rapid accretion onto the surface, or in an accretion disk corona (ADC) (White and Holt 1982). The time between the two flares (1969–1979) is too short for the former process. A thermonuclear explosion would require the source to radiate at least 10^{36} ergs s^{-1} in the X-ray range, making it a steady X-ray source (Kaluzienski, Holt, and Swank 1980). On the other hand, if emission from an accretion disk corona is a plausible explanation for the soft component, it will be more difficult to explain the production of photons above 70 keV (which are significant at a 6 σ level when integrating over the whole outburst). A Comptonization of the soft X-ray component in the ADC itself is a plausible explanation for the hard photon production, but it would require a hot plasma at a temperature about 50 keV, which is somewhat higher than the temperature currently assumed in an accretion disk around a neutron star. Thus it seems to us more likely that the hard emission is due to strong accretion.

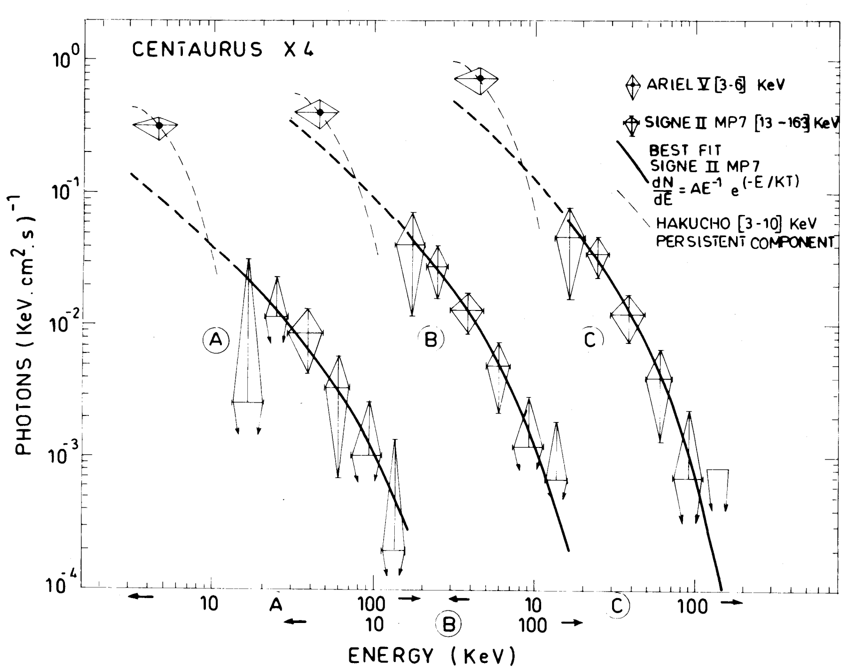

FIG. 3.—Energy spectra obtained during the 1979 outburst of Cen X-4. Spectrum A: 1979 May 13, 0700 UT. Spectrum B: 1979 May 13, 2100 UT. Spectrum C: 1979 May 15, 1200 UT.

If this is the case, this accretion must occur on a small surface of the neutron star (for instance, a magnetic polar cap) in order to produce 100 keV photons. The absence of modulation could then be explained if the rotation axis of the star coincides with the magnetic axis or with the line of sight.

The probability of the latter alignment, however, is quite small, of the order of 10^{-3}. Moreover, the former alignment has been predicted as a consequence of magnetic and/or gravitational forces upon the star (Curtis and Goldwire 1970; Chau and Henriksen 1970).

So, in addition to the previously proposed models explaining the soft X-ray emission, we propose a model for the hard component that may occur at a quite different place than the softer one. Thus we have assumed that an accretion column exists at the surface of a neutron star and have studied its opacity. At the beginning of the event, the mass inflow is small, and the column is transparent. A hot spot forms at the surface of the star, radiating roughly as a blackbody at about 10 keV, consistent with the hard spectral component. We have calculated that in the adopted conditions (bulk of emission of 30 keV photons), the Compton scattering was predominant over free-free processes. Under classical assumptions for the neutron star ($\sim 1\ M_{\odot}$ and 10^{10} cm^2 hot spot area), the opacity of the accretion column can be expressed as $\tau \approx 1.6 \times 10^{-16}\ \dot{M}$, where $\dot{M}$ is the accretion rate onto the star in g s^{-1}.

It can be seen that the column becomes opaque when the accretion rate exceeds 6×10^{15} g s^{-1}, corresponding to a luminosity of 8×10^{35} ergs s^{-1}. Thus at the beginning of the outburst, when the accretion rate and consequently the luminosity are small compared to these values, the column is transparent, and the bulk of emission is due to the interaction of the accreted matter with the surface, corresponding to a radiation temperature of 30 keV. When the luminosity increases, and reaches a maximum value of 5×10^{36} ergs s^{-1}, the column becomes opaque and the bulk of emission occurs in the column itself, or in the disk/corona with lower characteristic energies. This would explain the absence of the hard component at times other than the start and the end of the event, as shown by our observation.

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