BALLOON OBSERVATIONS OF FAST INTENSITY FLUCTUATIONS AND FLARE-LIKE ENHANCEMENTS OF X-RAY EMISSION FROM CYGNUS X-1*

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Abstract. The paper presents the results of the investigation on the short term X-ray emission characteristics of Cyg X-1 in the 20–150 keV range. The observations were made with balloon-borne oriented scintillation telescope and the flights were conducted from Hyderabad, India. The source was tracked over a duration of 1 hr that enabled detailed observations with time resolution of the order of 1 min. Fluctuations in the intensity of Cyg X-1 with time scales of the order of minutes have been detected besides short-term flare-like enhancements. The spectral characteristics of the flare emission features are discussed and their relationship to the phase of the binary is examined.

1. Introduction

The X-ray source Cyg X-1 is now believed to be one of the eight known X-ray sources belonging to binary stellar systems. Based on the considerations of the mass transfer apparently taking place between the primary and the secondary (Webster and Murdin, 1972) and the velocity measurements of the primary (Bolton, 1972), the secondary X-ray emitting object is conjectured to be a black hole.

The Cygnus X-ray source has been shown to exhibit considerable intensity fluctuations over time scales of a few milliseconds to tens of seconds, specially at energies less than 10 keV (Oda *et al.*, 1971, 1974; Rothschild *et al.*, 1974). At energies above 20 keV, balloon observations have revealed the existence of fast intensity fluctuations (Agrawal *et al.*, 1971), flare-like enhancements (Matteson, 1971; Frontera and Fuligni, 1975) and possibly long-term variations (Dolan, 1970).

In view of the considerable interest in the intensity variations of the X-ray emission from Cyg X-1 that could give a clue to its emission mechanism as well as the nature of the source itself, we have carried out a number of balloon flights to make observations on this source at energies greater than 20 keV. This paper deals with the specific aspects of a flare-like enhancement that was recorded in one of the flights. The charac-

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teristic features of this flare-like enhancement are discussed and compared with those detected by other workers to derive conclusions about the specific properties of Cyg X-1.

2. Balloon Flights and Results

Table I gives a summary of the three balloon flights with which observations on Cyg X-1 were carried out. The details of the detector system have been described elsewhere (Jain *et al.*, 1973). In all cases, the source was tracked continuously for durations of the order of an hour by pre-programmed azimuth and elevation controls of the oriented platform on which the X-ray telescopes were mounted. In all the flights energy measurements were carried out using an eight channel pulse height analyzer, within the energy range which was typically 20–150 keV.

The computation of flux enhancement and its energy spectrum during the X-ray flare event has been carried out using standard techniques involving the evaluation of the excess rates due to the source, computing the normalized rates corresponding to the effective exposure areas of the detector, correction for the K_α and K_β escape effects in the crystal and the atmospheric absorption effects (Sharma, 1974).

In all the three flights, the spectral nature of the source during its 'quiet' nature is well represented by a power law function with an index typically of -1.9 to -2.0. Figure 1 shows the spectral characteristics of this source derived from the data obtained from the three flights corresponding to the quiet state of the source.

In the 29 March, 1972 flight, where Cyg X-3 was also observed in the initial phase of the observations, we estimate its contribution to the observed counting rates to be less than 25% at the time of maximum exposure based on the counting rate profile at different times. In the same flight, at 1045 IST, the intensity registered by the detector suddenly increased by a factor of 2 in about 3 minutes. This enhancement subsequently persisted for about 5 min after which it decreased to its normal pre-enhancement value. The time intensity profile observed during this flight is shown in Figure 2

TABLE I

Date and time of experiment	Balloon volume	Ceiling altitude	Detector area	FWHM of collimator	Nature of observation
29 March, 1972 0500 UT	3×10^6 ft^3	6.5 g cm^{-2}	72 cm^2 NaI(Tl) with plastic antishield	18°	Cyg X-1 was tracked 1 hr and 15 min
18 January, 1973 0500 UT	3×10^6 ft^3	4.5 g cm^{-2}	81 cm^2 of NaI(Tl) with plastic antishield	13.5°	Cyg X-1 was tracked for about 1 hr
11 February, 1975 0530 UT	3×10^6 ft^3	4.8 g cm^{-2}	$\sim$150 cm^2 of NaI(Tl)	13.5°	Cyg X-1 was tracked for about 3 hr

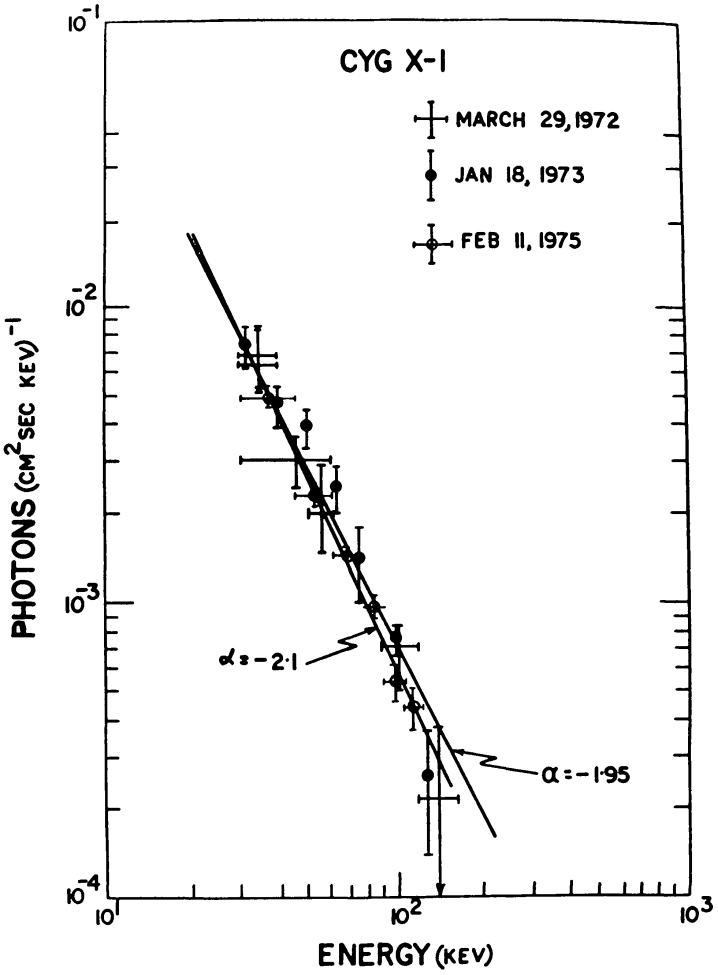

Fig. 1. The spectra of the flux received from Cyg X-1 during the three different flights are shown. For 29 March, 1972, the spectrum during quiet condition only is shown.

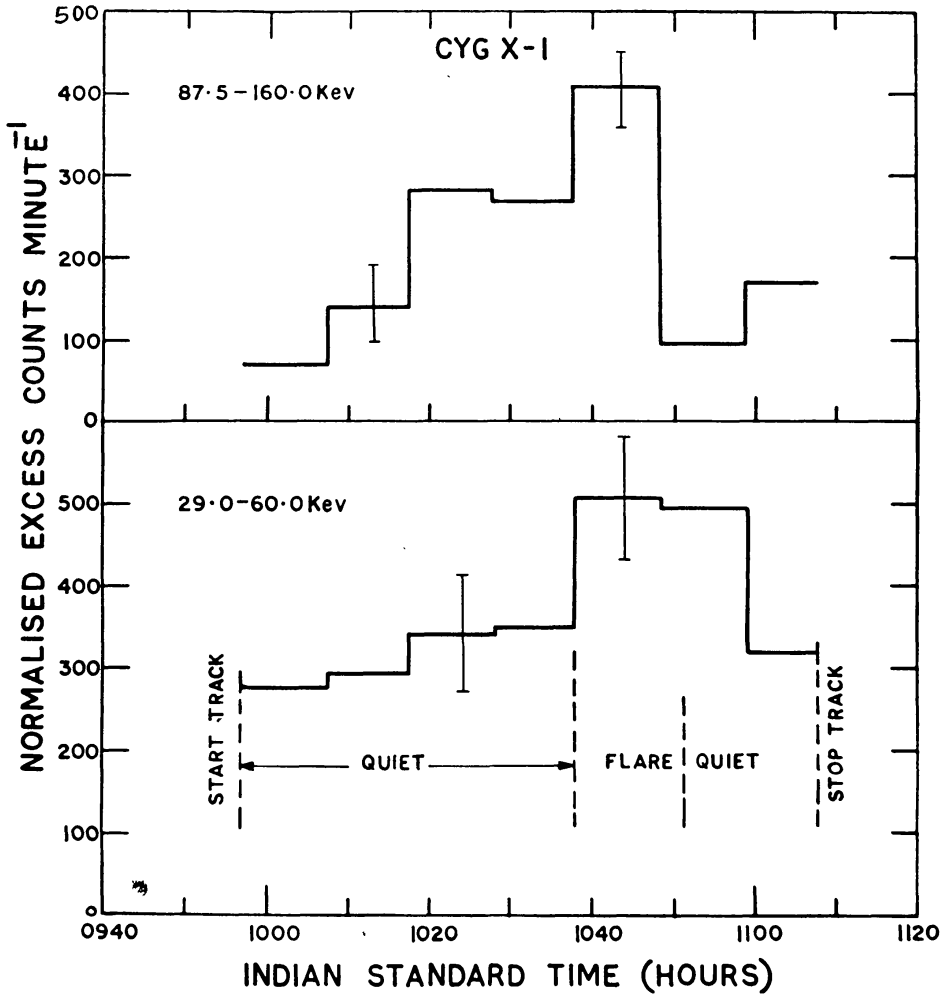

Fig. 2. The counts deposited in the detector during the tracking of Cyg X-1 on 29 March, 1972 and corrected for transmission efficiency through the atmosphere and collimator shown over the background. The data is averaged over a 10 min time scale.

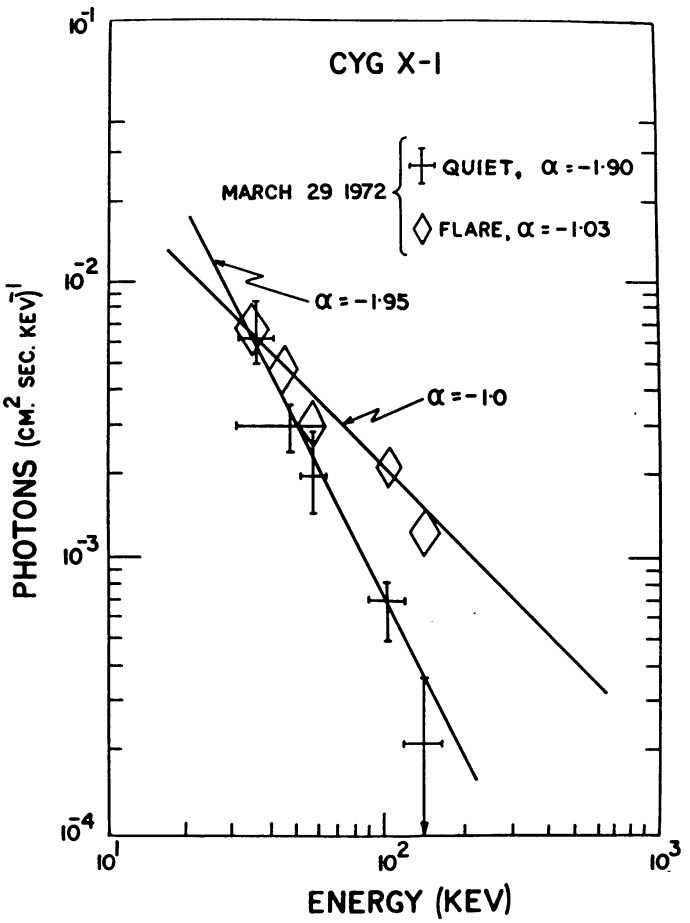

Fig. 3. The spectra of Cyg X-1 emission observed during the 29 March, 1972 flight. The spectra during quiet as well as flare-like enhancement are shown. The points during quiet and flare conditions are best fitted by power law exponents $\alpha = -1.9$ and -1.0 respectively.

for two energy intervals. The enhancement due to flare-like outburst from this source is clearly seen in the figure. The best fit energy spectrum during the flare is well represented by

$$\frac{dN}{dE} = 0.45E^{-1.0\pm0.05} \text{ photons cm}^{-2}\text{ s}^{-1}\text{ keV}^{-1}.$$

The energy spectral characteristics during quiet and flare periods of Cyg X-1 X-ray source are compared in Figure 3. The average integrated energy in the 20–100 keV energy band is about 2.9×10^{-8} erg cm^{-2} s^{-1} which is 1.5 times the normal energy output observed under quiet conditions.

3 Discussion

The flare-like enhancements for Cyg X-1 at energies greater than 20 keV have been observed by a number of workers (Matteson, 1971; Agrawal, 1972; Frontera and

TABLE II

Date and time of observation	Detector field of view (FWHM)	Observation	Spectrum	Reference
10 June, 1969 0926 UT	5.9°	Increase in the intensity in the 17–31 keV range by a factor of 2 observed over time scale of about 5 min. The corresponding high energy channels failed to show increase.	General softening of the spectrum.	Matteson (1971)
2 April, 1971 0058 UT	18°	Increase observed in the 22.5–88 keV channel and 88–154 keV for about 3 min. The rise and fall lasted about 9 min. The intensity increase was about 2.5 times the normal value.	No change in spectrum observed. The flare and pre-flare spectrums are $\alpha = 1.74 \pm 0.2$ and $\alpha = 1.71 \pm 0.25$ respectively.	Agrawal (1972)
30 June, 1972 0046 UT	18°	Increase below 100 keV was about 1.8 times the normal value and lasted about 10 min.	Spectrum softened with an index of 2.5 ± 0.2 compared to the pre-flare value of 1.8 ± 0.7.	Frontera and Fuligni (1975)
7 October, 1972 1010 UT	$4° \times 20°$	Intensity in the 30–70 keV range increased by a factor of 4 and the flare activity was detected for a duration of about 25 min.	The spectrum softened with an index of ~ 3.9 during flare compared to the pre-flare spectral index of ~ -1.7.	Nakagawa *et al.* (1973)
29 March, 1972 0530 UT	18°	Increase was observed in the 29–160 keV interval, the intensity went up by a factor of 2 in the 29–60 keV range. The enhancement lasted for about 8 min.	The spectrum was found to harden with an index of -1.0 compared to the pre-flare value of -1.9.	Present result

Fuligni, 1975; Nakagawa *et al.*, 1973). Table II gives a summary of all the observational results on these flares.

Comparing the various results presented in Table II, it is clear that there is no consistent picture with regard to the spectral variability during flares. The observations of Matteson (1971), Frontera and Fuligni (1975) and Nakagawa *et al.* (1973) indicate that the spectrum softens during the flare whereas that of Agrawal (1972) leads to the conclusion that there is no change in the spectrum. The present observations on the other hand indicate that the spectral hardening occurs during the flare. The picture with regard to the flare phenomena thus appears to be far from complete and calls for a more systematic investigation. It may be noted that the preflare spec-

trum in all these cases are in fairly good agreement with a power law index of -1.8.

Attempts to relate the flare occurrence with the phase of binary seems to indicate that nearly all the flares occurred when the binary phase was between 0.2 and 0.5. Whether such a situation arises in relation to the gas streaming from the primary towards the secondary needs further examination.

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