EVIDENCE FOR A NEW VARIABILITY IN HARD X-RAY EMISSION OF CYG X-1

(*Letter to the Editor*)

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Abstract. From a systematic analysis of the available balloon data for searching variabilities in the time-scales of days for Cyg X-1, the first evidence for the existence of a distinct phase dependence of intensity at 30 keV, corresponding to a period of 5.6 days, is presented. Additionally, the existence of a two-state X-ray emission at these energies is also indicated. Implications of these variabilities on the existing models of Cyg X-1 are discussed.

1. Introduction

In the past, there have been several reports on Cyg X-1 regarding short-term flares and spectral changes in the time-scale of a few minutes using balloon data (Jain *et al.*, 1976; Matteson *et al.*, 1976; Agrawal *et al.*, 1971; Fuligni and Frontera, 1973; Frontera and Fuligni, 1975). However, attempts to search for systematic long-term variabilities with durations of days or months have not been successful. In view of the present ideas that X-rays of energy greater than 10 keV originate from the inner portion of the accretion disk around the compact object which is suspected to be a black hole (Shapiro *et al.*, 1976; Ichimaru, 1977), a study of the time variability of the hard X-ray component should give valuable clues about the morphology of the emitting region in the immediate vicinity of the black hole. The results presented in this note are the outcome of an attempt to search systematic variabilities in hard X-ray emission using the available balloon data. In this note we report the discovery, we believe for the first time, of a distinct 5.6 day X-ray intensity modulation and the existence of a two-state emission for Cyg X-1 at energies $\sim$30 keV.

2. Data Analysis

For the purpose of the present analysis, we have included the data on hard X-rays from all the available observations at our disposal, dating back from 1965 and having a level of statistical significance better than 3 σ. Figure 1 shows intensity of Cyg X-1 at 30 keV for these observations as a function of phase of the binary system at the time

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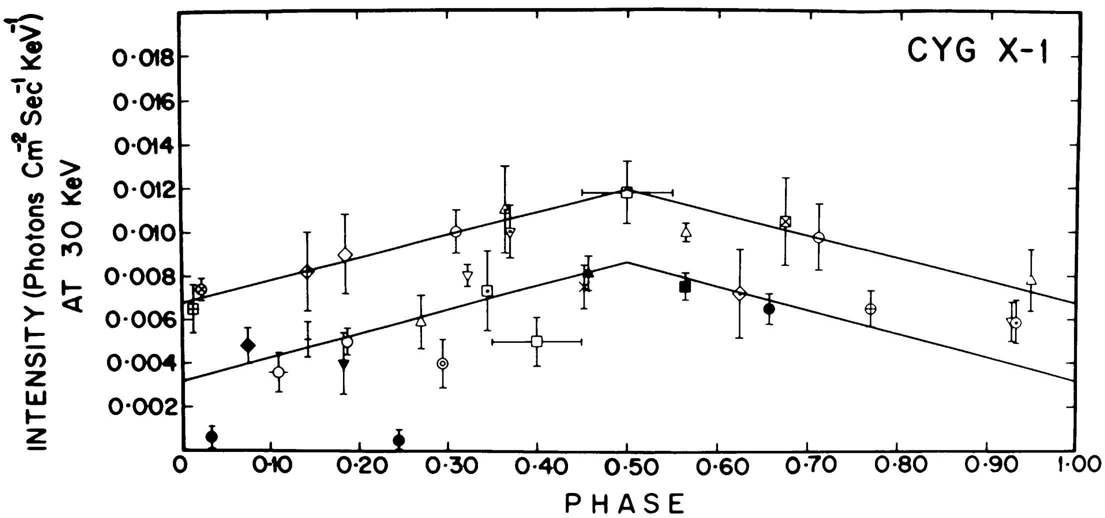

Fig. 1. X-ray intensity at 30 keV plotted as a function of the phase of Cyg X-1 binary system for all available observations.

○ Overbeck and Tananbaum, 1968a, b
-○- Brisken, 1973
⊕ Haymes and Harnden, 1970
⊗ Frontera and Fuligni, 1975
⊙ Clark *et al.*, 1968
◎ Webber and Reinert, 1970
● Matteson *et al.*, 1976
□ Dolan *et al.*, 1977
⊞ Rocchia *et al.*, 1969
⊠ Chodil *et al.*, 1968
⊡ Lewin *et al.*, 1968
■ Haymes *et al.*, 1968
◇ Bleeker *et al.*, 1967
◇ Riegler, 1969
◇ Boldt *et al.*, 1966
◆ Peterson *et al.*, 1968
△ Jain, 1979
△ Bingham and Clark, 1969
▲ Glass, 1969
▽ Agrawal *et al.*, 1972
▽ Reinert, 1969
▼ Sommer *et al.*, 1976
– Overbeck *et al.*, 1967
× McCracken, 1966

of observation. This figure clearly shows a correlation between intensity at 30 keV and phase of the binary, intensity being maximum at phase 0.5. Whereas a single line fit to all the data is poor, a striking feature emerges on separating the intensities into two sets of points and fitting best fit lines to these two sets as shown in Figure 1. Only two points, corresponding to the observations of Matteson *et al.* (1976), lie significantly away from the best fit lines; this is interpreted as due to the anomalously low intensity state of the source at the time of observation. The correlation coefficient for a single line fit to all the data points is ~0.43, whereas a two-line fit gives a correlation coefficient of ~0.93 for both lines. Similarly, χ^2 for a single line fit is ~5 per degree of freedom, whereas it is only ~0.4 for a two-line fit. This points to the fact that the source normally remains in one of the two distinct states of emission. Observations of Agrawal *et al.* (1972), Clark *et al.* (1968) and Jain *et al.* (1976), which lie between the two lines, were most probably taken when the source was undergoing a transition from one state to another.

The following points emerge from the present analysis:

1. Distinct phase variability of intensity at energies ~30 keV is seen – intensity at phase 0.5 being greater by a factor of ~2 compared to that at phase 0.0.

2. There is clear evidence for the presence of two distinct states of emission for Cyg X-1 at these energies.

3. Variation of intensity with phase has the same slope for low and high states and is, thus, independent of the state of emission of the source. The variation of intensity with phase for two states can be represented by

$$I = (0.0109 \pm 0.0015)P + (0.0032 \pm 0.0006) \quad \text{low state,}$$
$$I = (0.0103 \pm 0.0013)P + (0.0068 \pm 0.0005) \quad \text{high state,}$$

where I is the source intensity (photons $cm^{-2}\,s^{-1}\,keV^{-1}$) at 30 keV and P is the phase of the binary system.

4. The source spends almost equal time in the two states at these energies.

It should be emphasized that the deduction regarding the existence of two states is neither an artifact of the analytical or experimental procedures nor due to the presence or absence of Cyg X-3 in the detector field of view of the different experiments for the following reasons:

(a) Observational results obtained at different times using same instruments and data reduction techniques (Overbeck and Tananbaum, 1967; Overbeck and Tananbaum, 1968a, b; Jain, 1979) clearly reveal the existence of different intensity levels that belong to one of the two states identified here.

(b) Our analysis shows that the intensity levels deduced for Cyg X-1 neither bear direct correlation with the reported intensity levels of Cyg X-3 and its variabilities, nor with the collimation angles employed for the various detector systems.

3. Discussion and Conclusion

The low and high states at hard X-ray energies, in which the source approximately spends equal times, are not analogous to those observed at low energies since the source spends only 10% of the time in the high state at low energies (Oda, 1977). Also, there are two reported observations of hard X-rays concurrent with the low-energy high states (Sommer *et al.*, 1976; Dolan *et al.*, 1977) – see Figure 1. Both points lie below the low state line drawn in the figure. This indicates that the intensity transitions reported at low energies may be those involving changes on a larger scale than reported here and may occur less frequently. In the light of our current understanding of the Cyg X-1 source, we suggest that the characteristic fundamental property of the source is the two-state emission of high energies emanating from the inner disk, the two states having equal probability of occurrence. The normal state at low energies emitted from the outer disk is the one corresponding to the low state in intensity for almost 90% of the time. On rare occasions, when the low-energy emission flips to the high state, the high-energy X-ray component shows a further decrease which could be interpreted as a third state of emission at high energies.

It is interesting to note that the variability we found at high energies exhibits a linear dependence of intensity on phase, unlike the results of Holt *et al.* (1976) from the

Ariel V satellite revealing an abrupt minimum in intensity, in phase with the superior conjunction of the binary system at lower energies. The behaviour observed is very unusual and quite unlike the eclipsing type of pattern normally expected for a binary system. It should be interesting to investigate the nature of the orbital configurations, the structure of the accretion disk and the geometry of the accretion flow that could explain the features reported in this paper.

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