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EVIDENCE FOR WEAK X-RAY BURST EMISSION FROM CYGNUS X-2 AND GX 17+2

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ABSTRACT

Events resembling weak X-ray bursts have been detected from the two strong persistent sources, Cygnus X-2 and GX 17+2. Both events exhibit rise times less than 2.56 s and 1.2–14.4 keV decay times of approximately 5–10 s. The event from Cyg X-2 is similar to a type I burst in terms of blackbody temperature and peak luminosity, and we show that it can be plausibly interpreted as a thermonuclear flash from an accreting neutron star. The GX 17+2 event exhibits a considerably harder X-ray spectrum which makes it unlikely to be a thermonuclear flash. We suggest that this event arises from an accretion instability as in type II bursts.
Subject headings: X-rays: binaries — X-rays: bursts

I. INTRODUCTION

Cygnus X-2 and GX 17+2 are persistent bright X-ray sources believed to be members of low-mass binary systems with late-type companions (Bradt and McClintock 1983, and references therein). Both exhibit relatively soft X-ray spectra ($kT \sim$ few keV) and erratic short-term variability, but show no consistent evidence for short-term coherent X-ray periodicities (Branduardi *et al.* 1980; White *et al.* 1978). Such properties are characteristic of a large subclass of galactic X-ray emitters which includes the globular cluster sources, the Sco X-1 type sources, the galactic bulge sources, soft X-ray transients, and X-ray bursts (Parsignault and Grindlay 1978; Lewin and Joss 1981; Oda 1983; Lewin and Joss 1983).

In this paper, we report the detection of events resembling X-ray bursts from these two sources.[1] The events are, however, unusually weak in relation to the persistent emission from each source. We discuss possible interpretations of such phenomena within the context of prevailing models for X-ray burst emission.

II. OBSERVATIONS

The observations were performed with the monitor proportional counter (MPC) of the *Einstein Observatory* (see Gaillardetz *et al.* 1978 and Grindlay *et al.* 1980 for experiment description). The detector consisted of two collimated proportional counters sensitive to X-rays in the range 1–20 keV. It was coaligned with the *Einstein* telescope so that it could continuously monitor sources which were being observed simultaneously by the focal plane instruments (Giacconi *et al.* 1979). The total geometric area of the experiment was 720 cm^2, and the field of view was $\frac{2}{3}° \times \frac{2}{3}°$ FWHM.

Eight-channel pulse-height spectra were accumulated by the MPC in 2.56 s bins. A background spectrum was estimated for each bin on the basis of the count rate in the coincidence counter using relations derived during periods when no detectable source was in the field of view (Halpern 1982). The gain of the detector was calibrated to approximately 3% accuracy using in-flight data from the Crab nebula and other standard sources.

These investigations were carried out as part of a general program of time variability studies of aperiodic, strong galactic sources. Roughly 2×10^5 s of MPC data were surveyed covering a variety of objects including GX 340+0, GX 3+1, 4U 1705−44, GX 9+1, GX 17+2, GX 9+9, GX 349+2, GX 5−1, and Cygnus X-2. One "burstlike" event each was detected from Cygnus X-2 and GX 17+2 (see Fig. 1). The total observing durations for these two sources were 1.3×10^5 s and 1.9×10^4 s respectively.

In order to test for the possibility that these events were spurious (e.g., detector related, terrestrial magnetospheric phenomena, particle flares), we examined MPC data on extended X-ray sources: the Virgo and Perseus clusters of galaxies and the supernova remanant Cassiopeia A. Nothing similar was observed in 5×10^5 s of observations. If the events were of noncosmic origin, then the probability that two or more would be detected during observations of compact galactic X-ray sources and that none would be detected in extended source observations 2.5 times longer is less than 2%. We thus conclude that the observed phenomena most probably are associated with the bright cosmic sources being observed.

The profiles of the Cyg X-2 and GX 17+2 events are displayed in three separate energy bands in Figure 1. As can be seen in both cases, the rise time is ≤ 2.56 s (1 bin) and the decay time (in each band shown) is approximately 5–10 s. These parameters are typical of X-ray bursts which have been observed from other sources (Lewin and Joss 1983). The peak flux in the 1–20 keV band from the Cyg X-2 event (after subtraction of the steady emission) was $1.9 \pm 0.8 \times 10^{-8}$ ergs cm^{-2} s^{-1}. For the GX 17+2 event, the peak flux was 9.1 ± 10^{-8} ergs cm^{-2} s^{-1}. At the time the burstlike events occurred, the steady components of the

[1] A preliminary report for the GX 17+2 burst was given by Kahn *et al.* (1981). Additional bursts from GX 17+2 were discovered simultaneously and independently using the *Hakucho* satellite. See preliminary announcement by Oda *et al.* (1981).

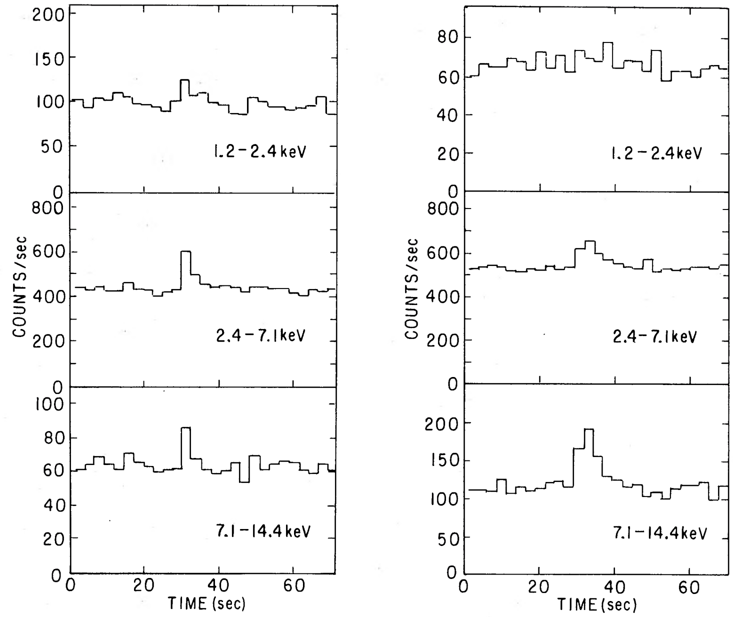

FIG. 1.—The MPC background-subtracted count rate as a function of time in three pulse-height bands for the (*left*) Cygnus X-2 (*right*) GX 17+2 burstlike events.

emission from Cyg X-2 and GX 17+2 yielded fluxes of $1.07 \pm 0.02 \times 10^{-8}$ ergs cm^{-2} s^{-1} and $1.56 \pm 0.02 \times 10^{-8}$ ergs s^{-1} respectively. These values lie toward the low end of the previously observed ranges of intensity for those two sources (Bradt, Doxsey, and Jernigan 1978).

We have derived spectra for the two events by first subtracting the persistent flux and then comparing the pulse-height data with standard functional representations of the incident spectrum folded through the instrument response. For Cyg X-2, the first two 2.56 s bins of data were used in the fits, whereas for GX 17+2, the first three were used. The derived spectra are thus averaged over the burst profile. Trial spectral models included power-law, thermal bremsstrahlung (exponential with a Gaunt factor), and blackbody functional forms modified to allow for absorption by neutral intervening material. In both bursts, best fits are achieved with blackbody spectra, although the data are not of sufficient quality to rule out the other two models. In Figure 2, we provide 90% confidence contours for the relevant spectral parameters of each model for each of the two events. Here kT_{BB} is a blackbody spectral temperature, kT_{Br} is a bremsstrahlung spectral temperature, α is a power-law energy spectral index, and E_A is an absorption energy, approximately related to the absorbing column density by $N_H = 5.08 \times 10^{21}$ $E_A^{2.72}$ cm^{-2}, were E_A is in keV.

The dashed lines in Figure 2 indicate 90% error limits on E_A derived by fitting bremsstrahlung models to the steady component spectra which are of much higher statistical quality and hence better constrained. As can be seen, this allowed range in E_A is inconsistent with that required by the spectrum of GX 17+2 for the bremsstrahlung model and just barely consistent for the power-law model. Thus, if either of these spectral models is applicable to that event, then substantial intrinsic absorbing material must have been present in this source at the time the burst occurred.

For the blackbody spectral fits to the burst emission, the allowed range in E_A from the steady component is consistent, in both cases, with the 90% contours, and allows us to derive reduced ranges in burst blackbody temperature. For Cyg X-2, we find $1.2 \leq kT_{BB} \leq 2.5$ keV. Ignoring possible general relativistic effects (Marshall 1982), the corresponding range in blackbody emitting area, A_{BB}, is 0.55–4.7 $\times 10^{13}$ $(D/10\ \mathrm{kpc})^2$ cm^2, where D is the distance to the source. For GX 17+2, we find $3.8 \leq kT_{BB} \leq 9.3$ keV and $0.56 \leq A_{BB} \leq 3.2 \times 10^{12}$ $(D/10\ \mathrm{kpc})^2$ cm^2. Given this range in kT_{BB}, a blackbody interpretation of the GX 17+2 burst would imply a vastly super-Eddington burst luminosity (see discussion below).

The MPC observation of GX 17+2 was performed when the high resolution imager (HRI) was at the focal plane of the *Einstein* telescope. No significant excess signal was observed in the HRI at the time the burst occurred, either at the position of GX 17+2 or anywhere else in the field. However, given the burst spectral parameters derived from the MPC (particularly the high values of E_A), no statistically significant signal is expected in the HRI bandpass. At the time of the Cyg X-2 observation, the focal plane crystal spectrometer (FPCS) was in position at the focus of the telescope. No statistically significant burst signal is expected for the FPCS observation either.

III. DISCUSSION

Our observations demonstrate the existence of weak "burstlike" events (with temporal profiles similar to X-ray bursts from other sources) from the two strong steady sources, Cyg X-2 and GX 17+2. Since Cyg X-2 and GX 17+2 are also similar to the X-ray bursters in terms of their steady component X-ray spectra (cf. Parsignault and Grindlay 1978; Lewin and Joss 1981, 1983), it is useful to investigate the relation between these weaker events and the well-studied "classic" X-ray bursts.

As first pointed out by Hoffman, Marshall, and Lewin (1978), X-ray bursts can in general be classified into two categories: those thought to be associated with thermo-

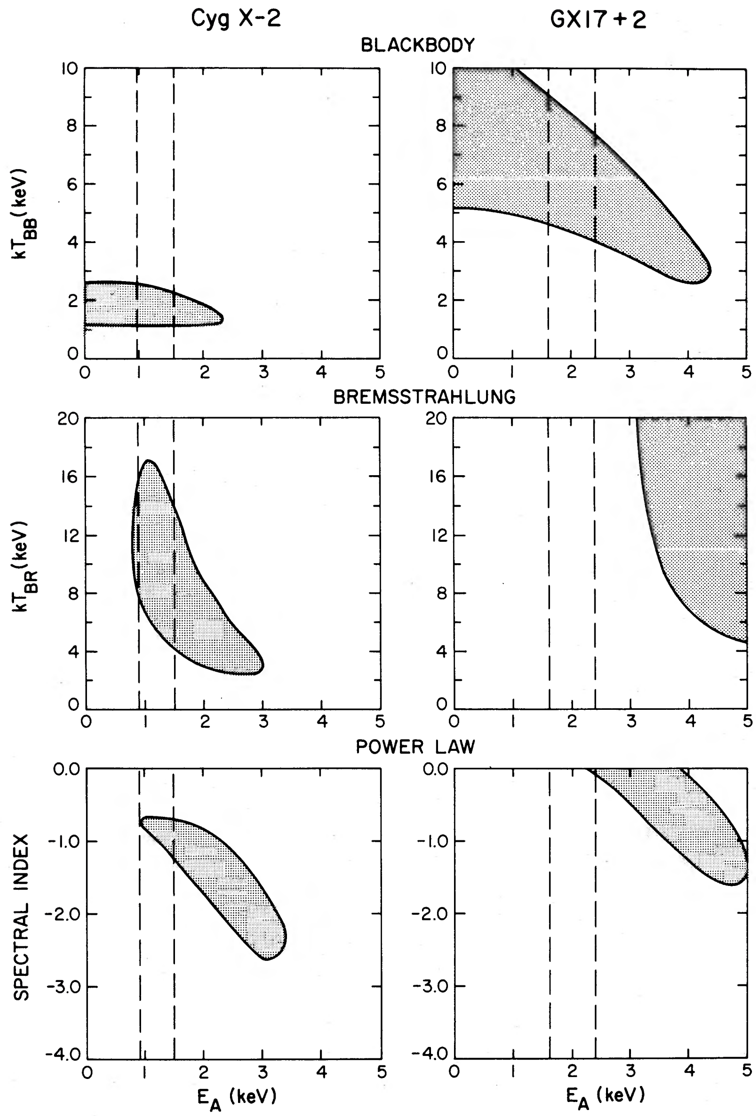

FIG. 2.—The confidence contours in spectral parameters for the (*left*) Cygnus X-2 and (*right*) GC 17+2 burstlike events. Shading indicates the allowed regions. Results are shown for the (*upper*) blackbody fits, (*middle*) bremsstrahlung fits, and (*lower*) power-law fits. The dashed lines in each case provide the 90% confidence limits on E_A obtained by fitting the spectrum of the steady emission from the source.

nuclear flashes on accreting neutron stars (type I) and those thought to be associated with accretion instabilities (type II). The two are observationally distinguished by the presence of spectral "softening" during the decay of type I bursts and the apparently significantly shorter recurrence times of type II bursts. The events which we have observed from Cyg X-2 and GX 17+2 are not of sufficient statistical quantity to allow us to measure the spectrum as a function of time during the burst decay. Therefore, it is not possible to classify these events according to the first criterion mentioned above. Moreover, the recurrence times of these bursts are apparently considerably longer (relative to the persistent emission intensity than the recurrence times associated with either type I or type II bursts. Since the physics associated with the accretion instability responsible for type II burst activity is not well understood, it seems premature to argue against that mechanism on the basis of recurrence times.

Nevertheless, for the case of Cyg X-2 at least, the burst properties are consistent with those expected for type I bursts, and the association of that event with the thermonuclear flash model has interesting consequences. In particular, the model predicts that the bursts should exhibit blackbody spectra and that the emission should arise essentially from the entire surface of the neutron star. If we make these assumptions, then we can use the observed best fit blackbody temperature and peak burst intensity to derive a distance estimate for the source. We find $D = 6.7$–20 kpc, which is consistent with the 8 kpc distance derived from optical studies of the companion of Cyg X-2 by Cowley, Crampton, and Hutchings (1979) but not consistent with the degenerate dwarf interpretation (Branduardi *et al.* 1980) of Cyg X-2. It is interesting to note that, at 8 kpc, the peak burst luminosity is 1.4×10^{38} ergs s^{-1}, close to the Eddington limit, L_E, for a 1.4 $M_\odot$ neutron star. Peak burst luminosities close to L_E have been inferred for a number of type I

X-ray bursters and are predicted by the thermonuclear flash model (Lewin and Joss 1981, 1983).

The event observed for Cyg X-2 is, in fact, only unusual compared to typical type I bursts in that it is "weak" in relation to the persistent intensity. In particular, the parameter γ, defined as the ratio of persistent X-ray flux to maximum burst flux, is approximately 0.6, or more than double the maximum value of γ ever previously reported. The high γ value is undoubtedly related to the high intrinsic luminosity of this source which implies a high accretion rate. There is also substantial observational evidence for a connection between such high accretion rates and burst suppression, which suggests that such weak bursts may be rare events. Van Paradijs *et al.* (1979), in particular, have pointed out the fact that the high luminosity galactic bulge sources generally do *not* burst even though in terms of most other observational properties, they strongly resemble the X-ray bursters. In addition, for several sources, variations in the persistent intensity have been explicitly associated with transitions in burst activity (Clark *et al.* 1977; Lewin 1978; Makishima *et al.* 1982).

That burst activity should be rare at high accretion rates is also expected theoretically for the thermonuclear flash model. Numerical calculations (Joss 1978; Ayasli and Joss 1982) have shown that bursts associated with helium flashes disappear when the accretion rate exceeds a critical value of approximately 2×10^{18} g s^{-1}. This results from the high temperatures produced at the base of the helium burning layer (due to steady hydrogen burning and heating caused by gravitational compression) and the consequent weak temperature dependence of the helium burning reactions (Ayasli and Joss 1982). If a significant fraction of the accreting helium burns in the steady state, then high γ values are expected. The critical value of the accretion rate necessary for burst suppression may also be a function of other parameters, particularly the neutron star core temperature (Ayasli and Joss 1982). It seems possible that, if the accretion rate is close to this critical value, small perturbations may occasionally excite flashes which burn off a fraction of the accreting nuclear fuel. Such a process might give rise to weak rare events such as that observed for Cyg X-2. Further observational work on this source might thus be fruitful for the study of the effects of high accretion rates on the thermonuclear flash process.

For the case GX 17+2, interpretation of the observed event as a type I burst is far more problematic. In particular, the high blackbody temperature observed requires that the luminosity be super-Eddington by at least a factor of 20 if the emission arises from the entire surface of a neutron star. Super-Eddington luminosities have been observed for other X-ray bursts (Grindlay *et al.* 1980; Oda 1983) but not by such a large factor. In addition, the bursts observed from this source by the *Hakucho* satellite (Oda *et al.* 1981) were a factor of approximately 10 brighter than that observed here which may make the energetic problem even more severe if those events were also type I phenomena.

Therefore, for GX 17+2 it appears more likely that the observed events were type II bursts related to accretion instabilities. If that is the case, then the power-law or bremsstrahlung spectral models may be more appropriate and would seem warranted considering the rather small emitting area required by the blackbody fit. As discussed in § II, our spectral fits then require an increase in the intrinsic photoelectric absorption at the time the burst occurred. This might be expected since small, but apparently significant, variations in E_A have been observed from the persistent emission of GX 17+2 (Grindlay and Hertz 1984). An increase in E_A might be expected during accretion instabilities since, if our line of sight intercepts the accreting flow at all, then an increase in the accretion rate must be accompanied by an increase in the line-of-sight column density of accreting material. Further study of "burstlike" events from this source may thus be useful as a probe of unstable accreting flow around compact objects.

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