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SHORT-TERM X-RAY VARIABILITY OF THE GLOBULAR CLUSTER SOURCE 4U 1820−30 (NGC 6624)

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ABSTRACT

As a part of a large project aimed to better identify the temporal and spectral variability properties of globular cluster and galactic bulge X-ray sources, we present our analysis techniques and their application to a large number of observations of 4U 1820−30 in the globular cluster NGC 6624. The data were obtained with the Monitor Proportional Counter on board the *Einstein Observatory*. At the epoch of the observations the source was in a "high" state, and no burst activity was detected. Timing analysis performed using correlation and power spectrum techniques reveals the presence of shot noise-like variations on a time scale of ~ 17 s. The variations in low- and high-energy bands exhibit 100% correlation at zero time lag and roughly identical autocorrelation functions; however the excess variance is considerably more pronounced at higher energies. This suggests that the spectrum of the "shots" is significantly harder than that of the steady component from the source. Implications of these observations for models of galactic bulge and globular cluster X-ray burst sources are discussed.

Subject headings: clusters: globular — X-rays: bursts — X-rays: sources — X-rays: spectra

I. INTRODUCTION

X-ray spectral and temporal variability studies may be of special interest for galactic bulge and globular cluster X-ray sources, as the nature of these objects has remained unclear despite extensive investigation. Although many of the characteristics of these two classes of sources have been clarified by means of temporal analysis techniques, a systematic study of the short–time scale X-ray variability in different energy ranges and of the associated spectral variations has not yet been conducted.

The most popular model for these sources involves a low-mass binary system containing an evolved neutron star (cf. Clark 1975; Lewin 1980). Several lines of evidence have tended to confirm this general picture in recent years:

1. The spectral evolution of X-ray bursts, suggesting that the source regions are ~ 10 km radius blackbodies and thus consistent with neutron stars.
2. The spectra of low-mass dwarf companions (K dwarfs) for the bursters/transients Aq 1 X-1 and Cen X-4 (see Lewin and Joss 1982 for a review of these arguments).
3. The determination of the mass of globular cluster X-ray sources as a class ($M = 1$–$2\ M_{\odot}$; cf. Grindlay *et al.* 1984) based on the measurement of the source offset from the cluster center.
4. The observation of a 50 minute binary modulation in the X-ray flux from 4U 1915−05 (Walter *et al.* 1982; White and Swank 1982) and, possibly, of a 4.3 hr periodicity in the optical flux from V926 Sco (MXB 1735−44) (McClintock and Petro 1981).

Indirect evidence for the presence of a neutron star in the galactic bulge and globular cluster sources comes also from the reasonably successful nuclear flash model of X-ray bursts (cf. Ayasli and Joss 1982 and references therein). On the other hand, some observations still constitute a challenge to this standard picture:

1. The wide variety of properties of X-ray bursts is not adequately explained by the model. In particular, the short time interval between some bursts, such as the 8 minute interval between two essentially identical bursts recorded from Terzan 5 (Inoue *et al.* 1980), does not allow for the fuel accumulation which is required for a thermonuclear flash.
2. The super-Eddington burst luminosities observed in several sources (e.g., Grindlay *et al.* 1980; Kahn and Grindlay 1984) have not yet been reproduced by the numerical experiments.

It is thus clear that both observational and interpretative efforts are required to yield an insight into these problems. In this context, the X-ray data obtained with the Monitor Proportional Counter on board the *Einstein Observatory* may be of significant value. In particular, a precise characterization of the short-term temporal and spectral properties of the "steady" flux from these sources is now possible thanks to the large number of pointed MPC observations. This study, which is currently in progress, is expected to add to our knowledge of the underlying mechanism of X-ray production and, in turn, to provide new hints and suggestions for more detailed models.

In this paper we describe our analysis techniques as they apply to a large set of observations of the source 4U 1820−30 in the globular cluster NGC 6624. The results are discussed in terms of current models with particular emphasis on recent accretion disk corona models.

II. DATA AND PRELIMINARY ANALYSIS

The source 4U 1820−30 in the globular cluster NGC 6624 plays a particular role in the history of X-ray astronomy, as it was the first source observed to emit X-ray bursts (Grindlay *et al.* 1976). It is the brightest globular cluster X-ray source and one of the most intense "spots" of the X-ray sky. Variations in the "steady" flux were reported up to a factor ~ 5 on time scales of days or months and up to a factor ~ 2 in tens of minutes (Canizares and Neighbours 1975). The fairly slow burst activity (typical recurrence time ~ 4 hr) was observed to

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stop in the transition from the "low" to the "high" state (Clark *et al.* 1976).

The *Einstein* MPC data reported here were acquired during a series of 31 separate observations, each of length ~ 1200 s, performed in 1979 March and October. The detected counts were accumulated in 8 pulse height channels spanning the energy range 1.2–14.4 keV, and binned in 2.56 s contiguous time bins with occasional small gaps associated with telemetry "drop-outs." During the observations, the source was always in its "high" state, and no burst activity was detected. The long-term behavior of the source flux did not show any regular variation. Through the entire observation period, the X-ray flux was relatively more steady than previously reported, the largest variation having only a 30% amplitude on a time scale of 1 day. The X-ray spectrum in the 1.2–14.4 keV band was well fitted ($\chi^2 = 3.9$ for 4 degrees of freedom) by a 13 keV thermal bremsstrahlung fit with a 0.6 keV low-energy cutoff, corresponding to an absorbing column density $N_{\rm H} \approx 1.2 \times 10^{21}$ cm^{-2}. No obvious long-term spectral variability was observed. We note that the X-ray-determined value for $N_{\rm H}$ is in reasonable agreement with that derived from the optical extinction of $A_v \approx 0.9$ mag toward NGC 6624 (Liller and Carney 1978). On the basis of this bremsstrahlung fit, the X-ray luminosity of the source was estimated to be L_x(1–15 keV) $= 8.5 \times 10^{37}$ ergs s^{-1} (assuming the 8.3 kpc distance of Liller and Carney). This value is quite close to the Eddington limit for a 1 $M_\odot$ object. A search for spectral variations associated with long-term luminosity variations gave inconclusive results.

Our investigation of the short-term behavior of 4U 1820$-$30 began with a characterization of the variability as a function of energy. For each pulse height channel and for each of the 31 observations, we measured the intrinsic source variability by means of the expression $(\sigma^2 - \sigma_{\rm cs}^{\ 2})^{1/2}/\bar{C}$. Here, $\bar{C}$ is the number of source counts per 2.56 s bin averaged over the observation, $\sigma^2 = (1/N) \sum_{i=1}^{N} (C_i - \bar{C})^2$ is the total variance (where C_i is the number of source counts in the ith bin), and $\sigma_{\rm cs}^{\ 2} = \bar{C} + \bar{B}$ is the expected variance due to counting statistics fluctuations (where $\bar{B}$ is the number of background events per time bin, again averaged over the observation). This expression is count-rate independent in the sense that the measured value should be independent of the source distance and the details of the detector response. The positive (negative) determination of the square root was used for $\sigma^2 > \sigma_{\rm cs}^{\ 2}(\sigma^2 < \sigma_{\rm cs}^{\ 2})$. The values for the 31 separate observations are then averaged for each pulse height channel, and the results are displayed in Figure 1. An evaluation of the χ^2 values indicates that the source variability is statistically significant in seven of the eight MPC channels. A striking property of the source is apparent from Figure 1: the variability increases dramatically toward higher pulse height bins. This feature strongly suggests that the mechanism responsible for the short-term variability operates mostly at energies higher than the energies observed in the burst activity or in the underlying persistent component of the X-ray emission (see discussion below).

We have further investigated the possible energy dependence of this process, by calculating a hardness ratio $R_i = C_{Hi}/C_{Li}$ as a function of the total intensity as estimated by C_i. The quantities C_i, C_{Li}, and C_{Hi} represent the background subtracted counts in the energy ranges 1.2–14.4 keV, 1.2–3.5 keV, and 3.5–14.4 keV respectively, binned in the ith 10.24 s interval. The binning was chosen so as to maximize the signal-to-noise ratio while still preserving the short-term variability. The values obtained in this way were then averaged in several intensity steps. The results of this analysis are given in Figure 2. A linear trend is clearly visible in the figure. A fit to the form $R = aC_i + b$ yields a slope $a = (1.12 \pm 0.16) \times 10^{-4}$ (counts per 10.24 s)$^{-1}$, inconsistent with zero at a $\sim 7\ \sigma$ significance level. Thus the source spectrum is apparently dependent on intensity.

The conclusion then is that the source spectrum becomes harder during the rapid intensity increases. This feature of 4U 1820$-$30 is quite common in bright galactic sources (e.g., Sco X-1 and "Sco X-1 like" sources; cf. White, Charles, and Thorstensen 1980 and references therein), although there are clear exceptions such as Cyg X-1 (cf. Priedhorsky *et al.* 1979), where the hardness ratio is virtually constant.

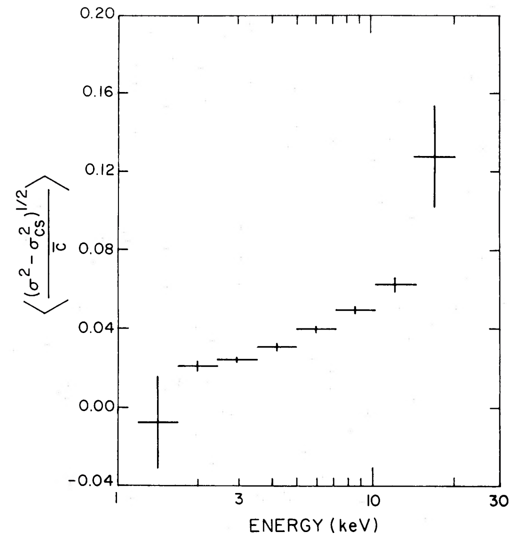

FIG. 1.—Variability in excess of the counting statistics noise as function of energy. The estimate is based on the count rate independent expression $(\sigma^2 - \sigma_{\rm cs}^{\ 2})^{1/2}/\bar{C}$. Values referring to different data sets have been averaged and the errors computed from the scatter of the individual values. In all the figures error bars are 1 σ.

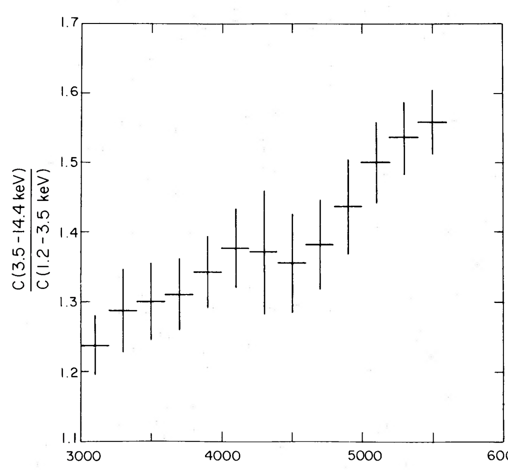

FIG. 2.—Hardness ratio vs. total count rate for 10.24 s binning time. Mean hardness ratios for different intensities have been obtained by averaging the values of all bins falling in the intensity step ($C \pm 100$) counts per 10.24 s.

III. DETAILED ANALYSIS

a) *Autocorrelation Function*

The partially unbiased autocorrelation function (Sutherland, Weisskopf, and Kahn 1978)

$$\tilde{\rho}_u' = \frac{\tilde{R}_u'}{\tilde{R}_0} = \left[\tilde{R}_u + \frac{(N-u)}{N(N-1)} \tilde{R}_0 \right] \Big/ \tilde{R}_0$$

$$\tilde{R}_u = \frac{1}{N} \sum_{i=1}^{N-u} (C_i - \bar{C})(C_{i+u} - \bar{C}) \qquad (1)$$

was used to investigate the coherence time of the short-term variability in different energy ranges. This formula has the advantage of partially removing that part of the bias that depends only on the finite length of the data set. The autocorrelations were calculated separately for the 31 intervals of data in the two energy ranges 1.6–4.9 keV and 7.1–14.4 keV. Since our emphasis is on the short term-behavior of the source, we removed weak long-term trends, present in several intervals, by dividing the data by a third-order polynomial fit. This procedure, which is often applied in the analysis of stochastic time series, is justified by the fact that the time scale of interest is much shorter than the time scale of the trend (in the present case by a factor of ~10–100). The autocorrelations referring to individual intervals were then averaged and the errors computed by the scatter in the measurement. This estimate of the errors is more appropriate here than the propagation of the counting statistics errors through the autocorrelation formula, since the measured scatter of $\tilde{\rho}'$ is largely due to the random character of the shot noise process rather than the white noise errors associated with counting statistics.

The results of this analysis are shown in Figure 3. Nonzero time lag autocorrelations have been corrected for the effects of counting statistics (Weisskopf, Kahn, and Sutherland 1975). The exponential decrease of the autocorrelation function, which is immediately seen in Figure 3, suggests the presence of exponential shots as discussed by Sutherland, Weisskopf, and Kahn (1978). We derive a decay time ~17 s which we interpret as the physically interesting time scale for 4U 1820−30. We have tested for an energy dependence in the autocorrelation by fitting an exponential to the first 20 bins of the soft- and high-energy curves independently. We find $\tau_{\text{soft}} = 16.8 \pm 0.1$ s and $\tau_{\text{hard}} = 17.4 \pm 0.9$ s, so that the two are consistent. For comparison, the decay time of Cyg X-1 is ~30 times shorter and exhibits a definite energy dependence in the sense that the curve decays slower at lower energies (Kahn 1980 and references therein).

The determination of other shot parameters for 4U 1820−30 (like the shot fraction, the shot rate, and the number of counts per shot) is prohibited by the very large uncertainty in the estimate of the third moment for the data set that we have analyzed.

b) *Cross-Correlations*

Cross-correlations were used in order to investigate the degree of correlation and the possible time delay in the shots from the low- and the high-energy bands. The partially unbiased cross-correlation function

$$\tilde{x}_u' = \frac{\tilde{K}_u'}{\tilde{K}_0} = \left[\tilde{K}_u + \frac{(N-|u|)}{N(N-1)} \tilde{K}_0 \right] \Big/ \tilde{K}_0$$

$$\tilde{K}_u = \frac{1}{N} \sum_{i=\max(1,1-u)}^{\min(N,N-u)} (C_{Li} - \bar{C}_L)(C_{Hi+u} - \bar{C}_H) \qquad (2)$$

was derived in analogy to the partially unbiased autocorrelation function (1). It can be shown that expression (2) partially removes that portion of the bias due to the finite length of the observation that is independent of any true correlation in the data. C_L and C_H represent, respectively, the 2.56 s count rate in the low- (1.4–4.9 keV) and the high- (7.1–14.4 keV) energy bands. The other aspects of the cross-correlation analysis, namely the trend removal and the estimate of the errors, are identical to the ones we used for the autocorrelations. Figure 4 shows the results for the average cross-correlation function, corrected for the effects of counting statistics. The time lags u are defined with respect to the low-energy data.

An almost 100% correlation in the data at zero time lag is immediately seen in the figure. The exponential behavior of the

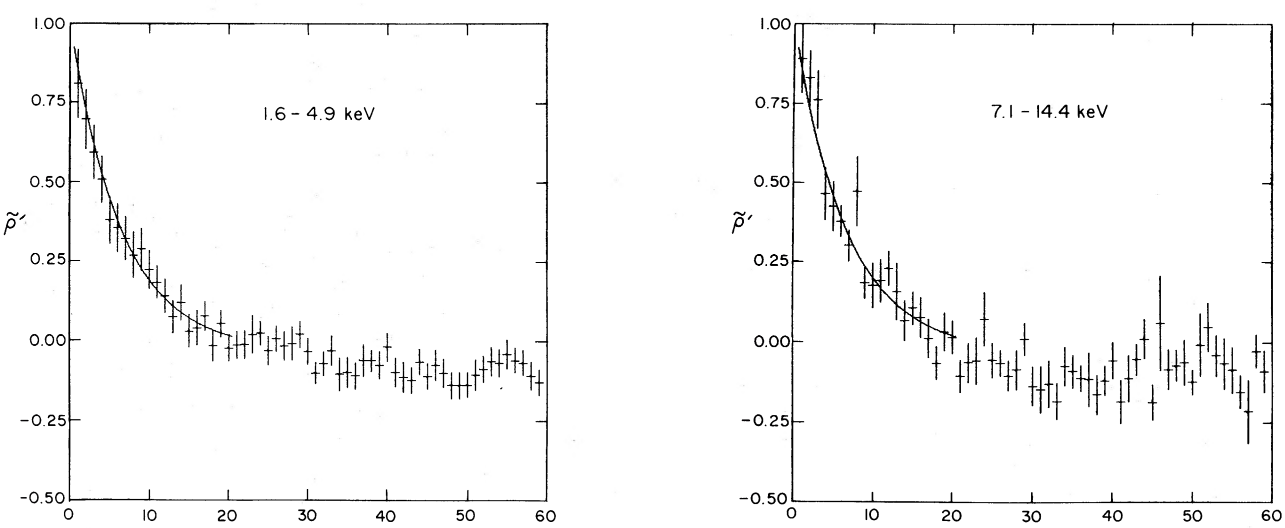

FIG. 3a FIG. 3b

FIG. 3.—Mean partially unbiased autocorrelation function in the energy ranges 1.6–4.9 keV and 7.1–14.4 keV. Delays τ are in units of 2.56 s. Best fit curves for exponential shots are shown. The fit includes the first 20 points of the autocorrelation function and, by definition, $\tilde{\rho}_0' = 1$.

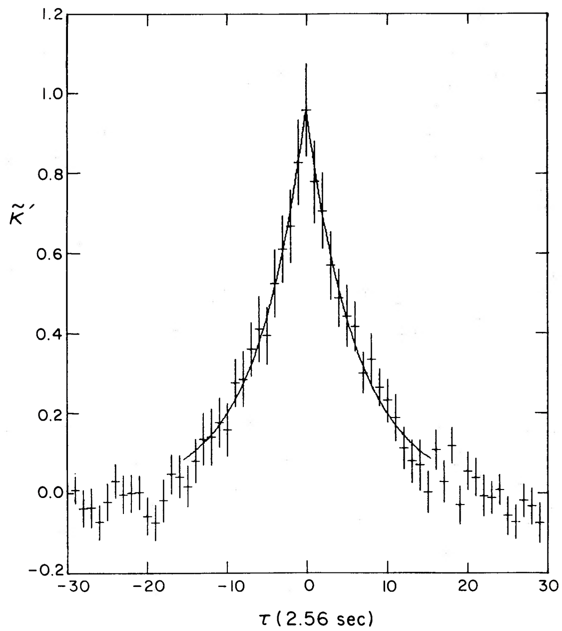

FIG. 4.—Mean partially unbiased cross correlation function between counts in the 1.6–4.9 keV and 7.1–14.4 keV energy bands. Delays τ are measured with respect to the low-energy band in units of 2.56 s. The best fit curve, based on eq. (4), is shown.

cross-correlation function for positive and negative time lags is characterized, within the errors, by the same decay time of the autocorrelation function (~ 17 s) and shows a remarkable symmetry with respect to zero time lag. These features are all suggestive of strongly correlated shots with essentially no delay time between the low- and the high-energy bands. An accurate upper limit to this delay time was obtained by fitting the values of the cross-correlation function for time lags between -38.4 s and $+38.4$ s to the functional form

$$\tilde{K}(\tau) = \beta \exp(|\Delta\tau/\tau_D|) \exp\left(-\left|\frac{\tau - \Delta t}{\tau_D}\right|\right) \tag{3}$$

expected for the cross-correlation of exponential shots with equal decay time τ_D in the low- and high-energy bands and delay time Δt (Priedhorsky *et al.* 1979). The limit obtained in this way is $\Delta t = (0.01 \pm 0.03)$ s.

c) *Time Skewness Function*

The autocorrelation and cross-correlation analysis techniques that we used suggest the shot noise character of the short-term variability of 4U 1820−30. Our conclusions regarding the independence of the typical autocorrelation time on the energy and the absence of a delay time between the low- and the high-energy shots are virtually independent of the particular shot-noise model.

In view of the possible physical interpretation, it is desirable to obtain some information about the evolution of the individual shots. The time symmetry of the autocorrelation function does not allow one to specify the time sense of the shots. In the particular case in which the decay time of the shots is different in the low- and high-energy bands, the rising or decaying behavior of the shots can be inferred from the asymmetry of the cross-correlation function (Kahn 1980). Unfortunately, this technique cannot be used in the case of 4U 1820−30, as the shot decay time is virtually identical in the two energy bands. Another way of getting information about the direction of the shots involves the use of time skewness functions (Katz 1977). The definition that we have used for the time skewness function is

$$\tilde{\phi}_u = \frac{1}{M_3 N} \sum_{i=1}^{N-u} [(C_i - \bar{C})^2 (C_{i+u} - \bar{C}) - (C_i + \bar{C})(C_{i+u} - \bar{C})^2] , \tag{4}$$

where M_3 represents the third moment of the data. It can be shown that this definition does not contain any bias that is due only to the finite length of the data set and is thus "partially unbiased" in the same sense of definitions (1) and (2). Exponentially decaying (rising) shots would produce positive (negative) time skewness functions on time scales comparable with the shot time constant. This analysis of the 4U 1820−30 data was carried out following the same procedure described in the two previous sections. The results that we obtained were always consistent with zero time skewness function and due to the very large errors the analysis was inconclusive. No firm conclusion on the direction of the shots can thus be obtained on the basis of the present data, but our results are consistent with exponential shots. It is important to point out however, that the expected time skewness function becomes severely "flattened" if one allows a distribution in shot widths (Kahn 1980).

d) *Erratic Periodicities and Pulse Trains*

At least four of the 31 intervals of data that we have analyzed show evidence for erratic periodic variability on time scales ~ 2–5 times longer than the shot decay time. That the appearance of intermittent or drifting periodicities can be simulated by an underlying completely random shot-noise process was pointed out by Terrell (1972) in relation to the conflicting periods reported in those years for Cyg X-1. Shot-noise numerical simulations have shown that the probability of random occurrence of a ~ 5–7 pulses long train over a duration comparable to data interval corresponds to a few percent (Kahn 1980). As the pulsations we detected are quasi-coherent over 5–8 cycles, it seems natural to interpret in this way the conflicting periodicities of 4U 1820−30. However in one striking case the pulsations remain coherent for 16 cycles of 47 s before becoming undetectable. The corresponding autocorrelation function and the power spectral density are shown in Figure 5. The power spectral density was calculated as the Fourier transform of the (biased) autocorrelation function. The fluctuations in the spectrum were smoothed by the use of Tukey lag window whose width was chosen with the "window closure" technique described by Jenkins and Watts (1968). The shape of the autocorrelation function and the very high peak of the power spectrum at 0.02 Hz leaves little doubt about the coherency of the phenomenon. The probability of a random occurrence due to the presence of the shot noise is difficult to evaluate, but it seems very small. Quite likely a transient periodic phenomenon, rather than shot noise, is responsible for this episode. The physical reality of this kind of event, if confined, could be relevant in better specifying the model for 4U 1820−30.

IV. DISCUSSION

The observations of 4U 1820−30 that we have analyzed provide the first evidence for shot-noise variability in a globular cluster X-ray source. The possibility that background varia-

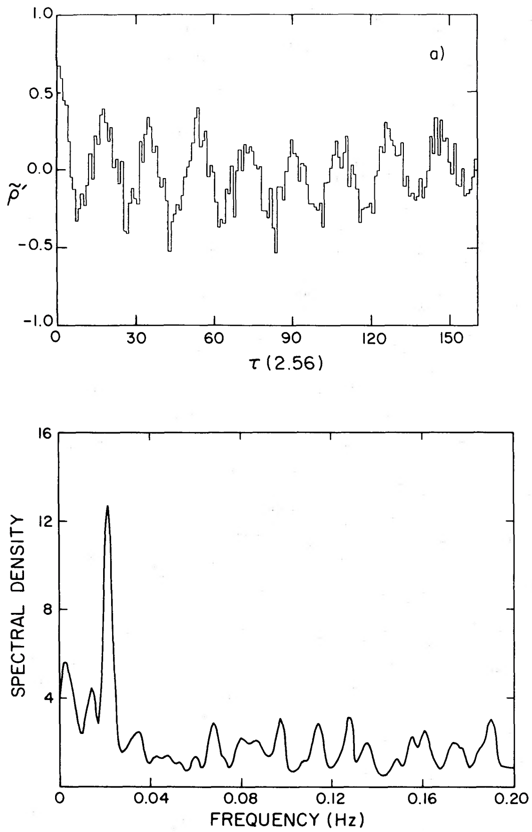

FIG. 5.—Partially unbiased autocorrelation function and power spectral density in the 1.2–14.4 keV energy band for the 16 cycle periodic event that we have revealed. The power spectral density, obtained from the Fourier transform of the autocorrelation function, has been smoothed with a 512 s Tukey lag window (cf. Jenkins and Watts 1968).

tions could give rise to the shot noise was excluded by the analysis of a large number of background and steady source[3] MPC fields. The results that we obtained following the same technique we have described above were always consistent with the absence of any variability. No doubt is thus left about the reality of the processes that our analysis revealed for 4U 1820−30.

The fact that the autocorrelation function is apparently independent of energy suggests that the shots exhibit no significant spectral evolution. However, since the variations in source flux are more pronounced at higher energies (see Fig. 1), the shots cannot be responsible for all of the persistent emission from 4U 1820−30. Instead it appears there must also be an underlying quiescent emission component with a spectrum softer than that of the shots. Unfortunately the limited spectral resolution and coverage of the MPC do not allow us to estimate the fractional luminosity in this component.

A search for a possible dependence of the variability of the source on the X-ray luminosity was performed. Within the errors, the shot decay time in the different energy bands was found not to depend on the luminosity of the source. The results of this analysis are, however, limited by the small luminosity excursions in the data that we have analyzed ($\sim$30% at most). Further observations of the source in its "low state" are required to establish whether the shot noise is present also in the "steady" flux of the burst-active state.

At the present stage, the interplay of the burst and shot noise activity is quite uncertain. While the similarity of the decay times of bursts and shots could suggest some connection of the two phenomena, the spectral hardening associated with the shot noise strongly contrasts with the typically soft burst spectra. In the following discussions we neglect any possible connection of the two phenomena, and we focus on the possible physical origin of the shots.

As several models of X-ray burst sources involve the presence of an accretion disk, it seems natural to investigate the shot production mechanism in the framework of accretion disk models. Discussion of the shot origin in Cyg X-1 has focussed mainly on hydrodynamical and thermal instabilities of the inner radiation pressure–dominated region of the disk, where most of the X-ray flux is supposed to be emitted (e.g., see Piran 1978 and references therein). Since the shot time scales in Cyg X-1 ($\sim$0.5 s) was recognized to be slow in comparison to the dynamical timescales of the inner region ($\sim$1–10 ms), only unstable traveling modes with growth rates $\sim$1 s were left as possible cause of the shots within the accretion disk (Kahn 1980). These instabilities supposedly originate close to the radius where the radiation pressure becomes comparable to the gas pressure and the instabilities propagate inward in the disk, possibly up to the outer edge of the two-temperature inner region (Shapiro, Lightman, and Eardley 1976).

The same picture can be adapted to the shot-noise behavior we have found for 4U 1820−30. As the growth rate for traveling modes scales like $\alpha^{6/7}M^{-8/7}L_x^{-8/7}$ (at the radius where $P_{\rm gas} = P_{\rm rad}$), for M(NGC 6624)/M(Cyg X-1) ≈ 0.1 and L_x(NGC 6624)/L_x(Cyg X-1) ≈ 5, the $\sim$20 s shot time scale would require the viscosity parameter α to be $\sim 10^{-2}$. The picture above strictly refers to an accretion disk around a black hole. If the compact object in 4U 1820−30 is instead an old neutron star (as is much more likely), modifications to the disk structure would be required to take into account the different rate of angular momentum deposition at the inner edge of the disk and a significant fraction of the X-ray flux could be emitted from the surface of the neutron star. However, our conclusions are not expected to be modified qualitatively.

A more serious problem for this picture comes from the exponential shape of the spectrum and the increase of the hardness ratio with the intensity. The value of the luminosity of 4U 1820−30 that we have estimated above for the bremsstrahlung emission regime (probably with some contribution due to Comptonization) cannot be achieved by the disk unless the mass of the central object substantially exceeds 10 $M_\odot$ (cf. Eardley *et al.* 1978). An X-ray emitting accretion disk corona seems to be a more plausible environment for the generation of the spectrum (Liang and Price 1977). If this is the case, however, and the shots originate within the disk, it is not easy to explain the spectral hardening associated with the shot activity.

A more plausible scenario is obtained by requiring that the shots are produced in the accretion disk corona as well. Recent investigations have focussed on the central role played by the disk magnetic field for the generation of a hot magnetically confined accretion disk corona (Galeev, Rosner, and Vaiana 1979). Under very general conditions, magnetic fields cannot be retained inside the disk for a time scale comparable with the radial infall time scale (Stella and Rosner 1984): their emergence via bouyancy in the form of looplike structures is thus

[3] In particular we analyzed $\sim$6000 s data from the Crab, which is virtually a steady source on the time scales considered in this paper.

expected to lead to the formation of a hot structured accretion disk corona. In this context it seems natural to associate X-ray shots with the stochastic emergence and heating of coronal loops. The fluctuation time scale for the X-ray emission from a single loop is of the order of the reconnection time scale (cf. Galeev, Rosner, and Vaiana 1979):

$$t_{\rm rec} \approx \frac{l}{1.4 \times 10^{-2} v_{\rm A\mathit{j}}}\,, \tag{5}$$

where l is the loop scale length and $v_{\mathrm{A}j} = (B_j^2/4\pi)^{1/2}$ is the Alfvén velocity associated with the poloidal magnetic field of the loop. If we approximate the length l with the longest Rayleigh-Taylor stable flux tube inside the disk ($\sim 10z_0$, where z_0 is the disk half-thickness; cf. Stella and Rosner 1983) and we use the same procedure described by Galeev, Rosner, and Vaiana (1979) to estimate $v_{\mathrm{A}j}$, we get

$$t_{\rm rec} \approx 14\alpha^{1/28}\left(\frac{M}{M_\odot}\right)^{29/28}\left(\frac{L}{L_{\rm Edd}}\right)^{29/28} \mathrm{s} \tag{6}$$

for the radius at which the accretion disk becomes radiation pressure dominated (cf. Shakura and Sunyaev 1973). The reason for selecting this particular radius for the production of the shots is that in the inner radiation pressure–dominated region the typical flux tube length is expected to decrease by a factor $P_{\rm gas}/P_{\rm rad}$, while for larger radii the power emitted by the emerging flux tubes decreases as a consequence of the reduced magnetic field strength. Most of the variability associated with the stochastic emergence of magnetic flux tubes is thus expected to originate close to the transition region between the gas pressure and the radiation pressure-dominated zones of the disk.

For the most likely parameters of 4U 1820−30 ($M \sim 1\ M_\odot$, $L \sim L_{\rm Edd}$), the agreement of estimate (6) with the measured decay time of the shots is very satisfactory, especially in view of the fact that no free parameter has been adjusted to the data. Moreover, in this scenario the spectral hardening associated with the shots is more easily justified, as individual flux tube reconnection events are expected to produce mostly hard X-rays (Galeev, Rosner, and Vaiana 1979).

This interpretation of the shot origin, while clearly not the only one possible, is strongly suggestive of a model in which the accretion disk magnetic field plays an important role in the production of the X-ray spectrum and variability. Several authors, on the basis of different arguments, have mentioned the possible importance of magnetic field instabilities in X-ray burst sources (Liang 1977; Wheeler 1977; Ruffini 1979). Rather than being connected to the X-ray burst mechanism, the magnetic field activity that we suggest here would be associated with a shot-noise-like type of variability. The validity of this interpretation can be verified to some extent by the extensive study of the short-term temporal and spectral properties of galactic bulge and globular cluster X-ray sources that is now in progress. Since these sources also have luminosities (and masses) similar to the values for 4U 1820−30, shotlike behavior with ~ 10 s time scales may also be expected.

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