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VARIATIONS IN THE SPECTRA AND PULSE PERIOD OF GX301-2

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ABSTRACT

Spectra from observations of GX301-2 (3U1223-62) by the Goddard X-ray spectroscopy experiment on OSO-8 show an absorption edge due to cool iron with column densities of a few x 10^{19} cm^{-2}. A decrease in intensity was associated with increased absorption and a spectrum similar to those of binary X-ray sources in absorption dips. Observed variations of the pulse period are consistent with Doppler shifts for reasonable orbit parameters.

I. INTRODUCTION

The source GX301-2 or 3U1223-62 has been noted for both spectral and temporal properties. McClintock et al. (1971) discovered a 15-50 keV flux comparable to the Crab, while Giacconi et al. (1972) reported a comparatively low intensity for 3U1223-62 in the 2-6 keV range, so that the identification with GX301-2 (Ricker et al. 1973) suggested high absorption of low energy X-rays. This high absorption was verified

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by Lewin et al. (1975). The high degree of variability reported in the first observations is now known to include 11.6 min pulsations (White et al. 1975) as well as changes in average intensity level.

Data from OSO-8 show that changes in the average intensity of GX301-2 occurr(. ... July, 1975, and again in January, 1976. During both observations the source was in the field of view for 8 days, although not always isolated from nearby sources. We present here spectra obtained from an initial 10% of the data from the January observation for both a high level of intensity observed on several days and a low level observed at least once during each observation. Even when the intensity was high the spectrum was very absorbed and a significant absorption edge due to iron appears to be present. The spectrum when the intensity was low shows much greater absorption and it has features that are similar to those in spectra of Cen X-3 and Vela X-1 in absorption dips. These binary sources are also sometimes heavily absorbed in long transitions to and from eclipse (Schreier et al. 1976; Charles et al. 1976). Similar binaries viewed at inclination angles too small for eclipse should show absorption varying with the orbit phase. Thus the association of the intensity changes with this type of spectral variability suggests the presence of a binary companion, although our data have not yielded a binary period. Analysis of the pulse period does indicate changes on the time scale of days.

II. SPECTRA

The detectors used in the observations and the method of obtaining inferred spectra have been described before (Serlemitsos, 1976; Pravdo et al., 1976). The January 1976 observations of GX301-2 were made with a xenon-filled proportional counter pointing along the spin axis of the satellite. Background was obtained when pointing to nearby regions within 15° of the galactic plane. The July 1975 observations were made with a xenon proportional counter scanning around the negative spin axis at a 5° offset. For this detector spectra are obtained every quarter of a satellite spin period of approximately 10s, and background is taken from off source quarters.

The spectra from the pointed xenon detector are obtained every 40 s, sufficient to determine the spectra of GX301-2 for different phases of the approximately 700 s pulse. Although there appear to be some variations in the absorption with pulse phase the spectra are qualitatively similar and we use the average over the data interval, postponing consideration of the dependence on pulse phase until better statistics are available.

The pulse height spectra for a high and a low intensity interval are shown in Fig. 1. From the fits to be discussed below, the flux at high intensity from 18 to 36 keV was 3.1 keV/cm^{2}s. The low intensity flux in the same energy interval was 1.2 keV/cm^{2}s. These values are in the range of those previously reported (Ricker et al. 1973). Both pulse height spectra show a feature near 7 keV, where the detector efficiency varies slowly with energy. Especially in the low intensity case the feature appears as a sharp drop just above the K edges of neutral or only slightly ionized iron. We interpret the feature in both cases as an iron edge. We cannot exclude the presence of some iron line emission, but the spectral shape is dominated by the pronounced effect of absorption.

If $f(E)$ is an underlying spectrum from a hot source and if the observed counts were simply $f(e)e^{-\tau(E)}$, where $\tau(E)$ is the optical depth of intervening material, the drop in the pulse height spectra from the high channel to the low one ending at 7.3 keV would imply column densities of Fe of $.7\times10^{19}/cm^2$ and $2.1\times10^{19}/cm^2$, respectively, for the high intensity and the low intensity spectrum. Because of the approximately 1 keV detector resolution at 7 keV, these are lower limits.

Fits to the high intensity spectrum were attempted with functions of the form $f(E)\ e^{-n\sigma_{BG}-N_{Fe}\ \sigma_{Fe}}$ with $f(E)$ a blackbody spectrum or of the form $e^{-E/kT}E^{-\alpha}$. σ_{BG} is the cross section with Brown and Gould (1970) abundances and N is the column density of equivalent hydrogen atoms. σ_{Fe} is the cross section for absorption by cold iron (Storm et al., 1967) and N_{Fe} is the column density of the absorbing iron. The best fits, still unacceptable with χ^2 = 90 for 19 degrees of freedom, were obtained for a blackbody of kT $\sim$5 keV with the iron absorption beginning at an edge between 7.2 keV and 7.7 keV. Fig. 1 shows the histogram obtained by folding through the detector resolution the fit with an edge at 7.7 keV and at the edge a jump $\Delta\tau$ of .8 in the optical depth $\tau(E)$. The inferred spectrum based on it is shown in Fig. 2.

For the low intensity spectrum we assumed the same underlying spectrum $f(E)$ as for the high intensity spectrum and fit the parameters describing absorption and the normalization (which could be interpreted as an indication of electron scattering). For this case χ^2 rose sharply from 80 for edge energies outside the range 7.1 - 7.25 keV. The histogram predicted by the fit of the low intensity spectrum with the edge at

7.2 keV and $\Delta\tau$ = 2.6 is also shown in Fig. 1 and the inferred spectrum in Fig. 2. As expected, for both spectra the $\Delta\tau$ of the best fits are larger than the drops in the pulse height spectra. But again the low intensity spectrum requires $\Delta\tau$ larger than does the high intensity spectrum by more than a factor of 3.

GX301-2 is 2.6° from 3U1210-64 and this source was in the field of view. 3U1210-64 is listed as a 6 ct/s Uhuru source (Giacconi et al. 1974). At that intensity we estimate that it could have produced ∿10% of the 2-6 keV counts when GX301-2 was at high intensity and ∿25% when it was at low intensity. Forman et al. (1976) have also reported a 3 ct/s source at ℓ_{II}= 302.6°, which could have also been in the field of view. If these sources were contributing a smooth background spectrum near 7 keV, the effect on the conclusions is to increase the required column densities of absorbing material.

III. DISCUSSION OF THE SPECTRA

The discontinuity in cross section at the K photoionization edge varies less than 10% from .4 x 10^{-19} cm^2 for ionization states with thresholds between 7.1 and 7.7 keV. The discontinuities in optical depths in the best fits then imply column densities of 2 x $10^{19}/cm^2$ and 6.5 x $10^{19}/cm^2$ respectively for the high and low intensity spectra. Because of uncertainty about the underlying spectrum the edge due to iron should be a more reliable indicator of absorbing material than the amount of other absorption. If the abundance of iron is near the photosphere-coronal average of 3.9 x 10^{-5} of hydrogen by number (Withbroe, 1971), the column densities of equivalent hydrogen atoms were $5 \times 10^{23}/cm^2$ and $1.7 \times 10^{24}/cm^2$. The amounts of cool material other than iron that gave the best fits were significantly less than this, so that in this model iron is overabundant or the effective cross section of other material is reduced by ionization. The positions of the iron edges indicate responsible iron ionization states below Fe^{XX}. In the photoionization models of Hatchett, Buff, and McCray (1976) most of the elements like Si and S would probably not be stripped of K electrons, but further work is needed on comparison of the observations with particular models of radiation from a hot source absorbed and reprocessed by wind material.

The low intensity level persisted for at least an hour on January 28, but not more than 2 days, since the level was high on the preceeding and succeeding days. A decrease in intensity associated with an increased absorbing column density on the order of 10^{24} cm^{-2} of equivalent hydrogen atoms and with a duration on the order of hours suggests the presence of a binary companion either nearly eclipsing the X-ray source or providing cool material which collects in a wake or a disk and obscures the source at binary phases well away from eclipse. Absorption dips have been seen in Cen X-3, Vela X-1, and 3U1700-37 (Jones et al., 1973). OSO-8 observed both Cen X-3 and Vela X-1 in absorption dips (Swank et al., 1976; Rothschild et al., 1976). In both cases the spectra are best fit with an edge due to cool iron in a column density of $2.6 \times 10^{19}/cm^2$. A binary companion would provide an obvious source of changing absorption by cool matter.

If the low intensity state is analogous to absorption dips in other X-ray binaries the line-of-sight may need to be close to the orbital plane and observation of an eclipse and Doppler shifts would be probable. However, the large column density of iron at the highest level of intensity is probably associated with the binary system itself rather than an interstellar cloud and the absorption behavior observed could be possible even for low inclination angles. Cen X-3 makes long transitions in and out of eclipse while recovering from long term low states. It has been suggested that wind conditions are then preventing the X-ray source from completely ionizing the region around itself (Pringle, 1973; Schreier et al. 1976). Under such conditions the inclination angle could be too small for eclipse, but the source still show much greater absorption during the part of the orbit when it is most distant. We have suggested this interpretation of a smaller change in absorption in the spectrum of GX 1+4 (Becker et al. 1976). The behavior of the known binary sources implies the wind conditions change, so the effect may not always be present. When it is, it could show the binary periodicity.

The star Wray 977 was suggested as a possible optical counterpart of 3U1233-62 (Jones et al. 1974) and the recent observation of optical pulsations (Mauder, 1976) confirms this identification. If the reddening is due to interstellar absorption, the relation $\frac{N_H}{E_{(B-V)}} = (6.8\pm1.6)\times10^{21}/cm^2$ (Ryter et al. 1975) and Vidal's value $E_{B-V} = 1.8$ (1973) imply $N_H = (1.2\pm.3)\times10^{22}/cm^2$ in that direction and $N_{Fe} \sim 5\times10^{17}/cm^2$, more than an order of magnitude below the amount indicated by the edge in the high intensity spectrum. If Wray 977 is a binary companion, the additional absorption shown by the X-ray object is due to material too hot or too limited in extent to cause additional abrorption of the optical radiation from the star.

IV. PULSE PERIOD

Since our observations spanned 8 days, evidence for binary periods in the likely range of 2 to 20 days can be sought in the pulse average light curves and in shifts in the measured pulse period. The January 1976 observations should yield the better results, but the majority of that data is not yet accessible. During the July 1975 observation the scanning detector usually had other sources (notably 3U1145-61) in view as well. Factor of 2 variations in pulse averaged intensity did occur which were due to GX301-2, but although no periodicity was found, the interpretation is difficult. However, we can determine the pulse period over 2 to 3 days with an accuracy of a fraction of a second, comparable to the magnitude of correction that periods around 10 days would produce for a mass function of about 20 $M_\odot$.

The results of our estimates of the pulse period are shown in Fig. 1. For the periods given the folded data gives the maximum χ^2 when compared to the average flux. The errors quoted are the deviations in period required for χ^2 to fall by the expected root mean square deviation of χ^2. The July values suggest a shift in period consistent with binary periods $\gtrsim$8 days, although these data cannot make a significant test of the hypothesis that binary Doppler shifts cause the change. The intensity decreased and absorption increased at the end of this observation, while the pulse period was relatively high. Whereas for the July intervals gaps in data were less than 1/4 day, for each of the January values intervals of data a day apart were used. A shift in phase between the 2 intervals, as would be given by a different average time delay due to binary motion, could shift these values by a fraction of a second. The January values again suggest that variations in period do occur on time scales of days. Our values for July 1975 are slightly larger than the value of 698.4±1.2 s reported for Ariel V observations 6 months before (White et al. 1976a). Our values for January 1976 are consistent with the value 696.6±1.5 s reported for December, 1975 by White et al. (1976b) and slightly smaller than the value 696.4±.5 s reported by Hoffman et al. (1976) for December 14-17, 1975. The period data accumulated so far indicate a non-uniform behavior of the pulse period on time scales of 6 months.

A more complete record of the spectral behavior and corresponding pulse period should determine whether the increases in absorption of GX301-2 can be understood as absorption dips or near eclipses of a binary source. The absorption for this source is greater than for the known binaries. The iron edge provides a probe of the conditions in the atmosphere causing it.

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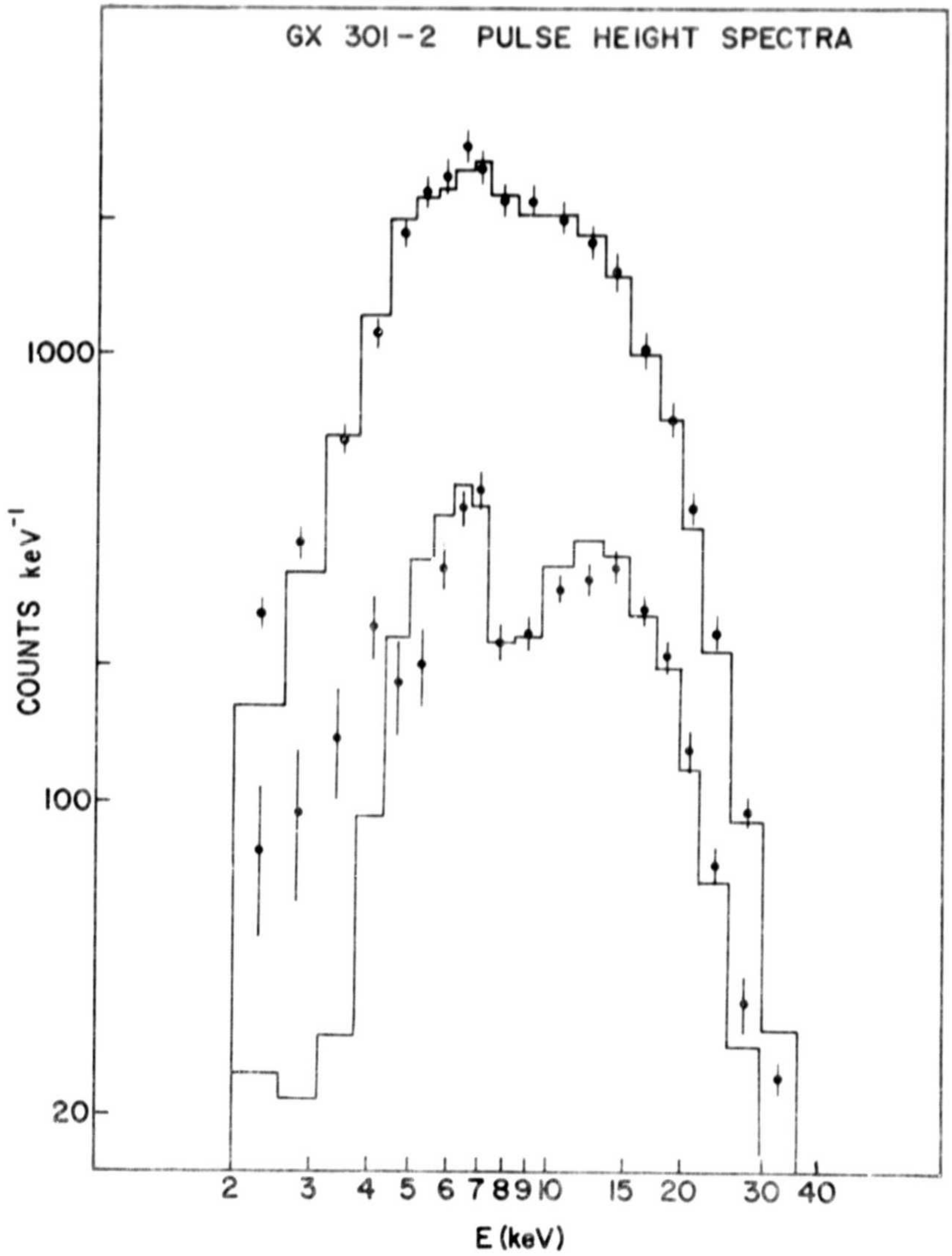

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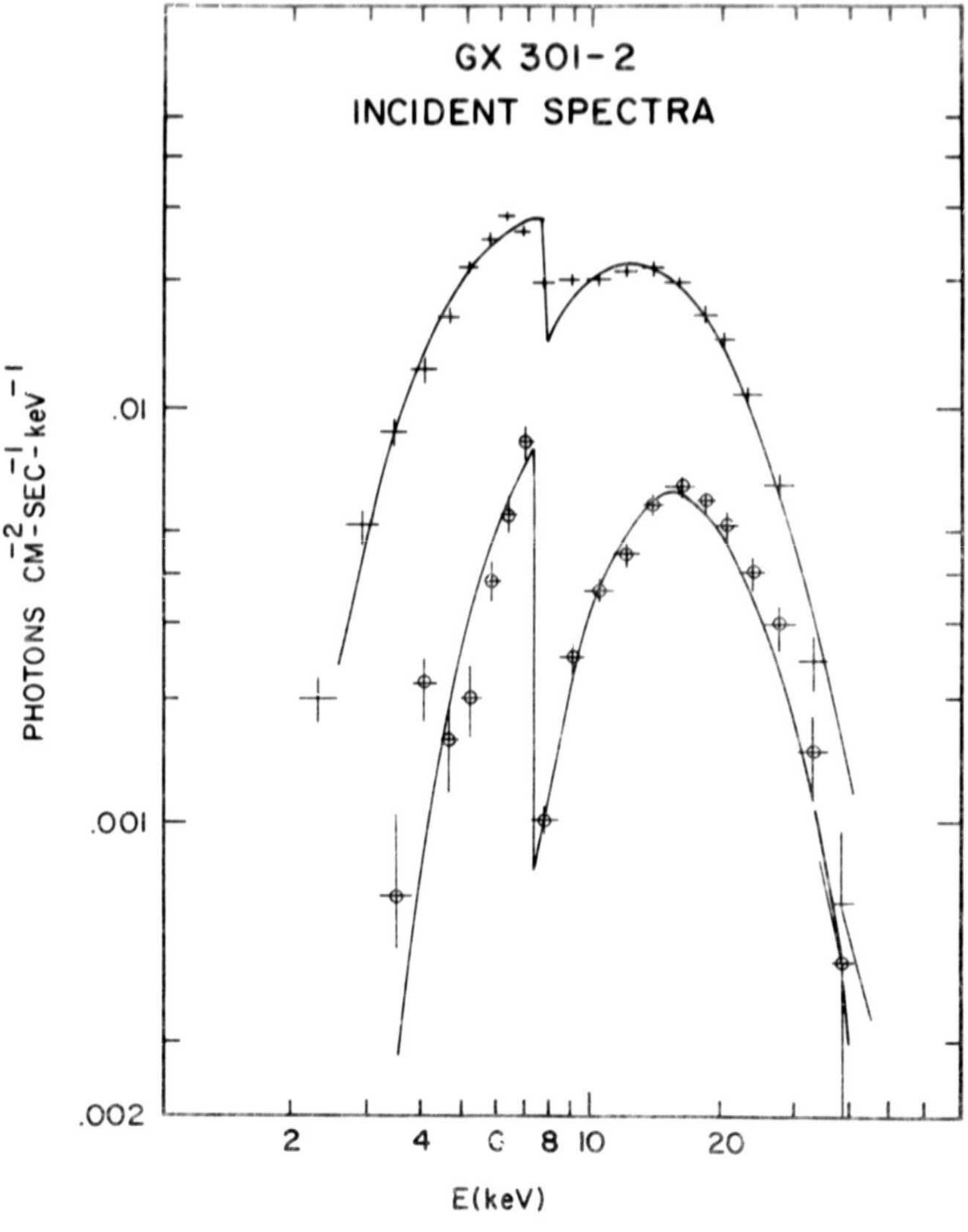

GX 301-2
INCIDENT SPECTRA
PHOTONS CM^{-2}-SEC^{-1}-keV^{-1}
.01
.001
.002
2
4
6
8
10
20
E(keV)

FIGURE CAPTIONS

Fig. 1 Pulse height spectra for GX301-2 on January 28, 1976 (lower) and January 29, 1976 (upper). The histograms are the best fits folded through the detector resolution.

Fig. 2 Inferred incident spectra of GX301-2 on January 28, 1976 (lower) and January 29, 1976 (upper), with efficiencies based on the fitting functions shown by the curves.

TABLE I: PULSE PERIOD

Date (JD-2442412.5)		Period (s)
200.2 - 202.7	July, 1975	699.89±.13
202.4 - 205.0		700.03±.12
205.0 - 207.5		700.49±.20
392.8 - 393.8	January, 1976	696.1± .2
394.8 - 395.8		695.7 ±.15
396.8 - 397.8		695.7 ±.2

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