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Spectral Variability in the X-Ray Pulsar GX 1+4

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Abstract

Observations of the galactic center region, hard x-ray source GX 1+4 by the GSFC x-ray spectroscopy experiment on OSO-8 confirm that GX 1+4 is a slow x-ray pulsar. The amount of absorption by cold matter in the spectrum of GX 1+4 varies significantly within a 24 hour period, behavior typical of many x-ray binary systems. The light curve for the pulsations from GX 1+4 appears to be energy dependent.

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The x-ray source GX 1+4 (3U 1728-24) was first identified by Lewin et al (1971). The source was observed to have a hard spectrum and there was a suggestion that it pulsed with a period of ~138 seconds. More recently, Thomas et al., (1975) have indicated that GX 1+4 is the dominant high energy x-ray source in the galactic center region, and therefore it is probably the same x-ray source observed in 1966 by Boldt et al. (1968). GX 1+4 has been observed by SAS-3 and was found to pulsate with a period of 122.6 seconds (Lewin et al., 1976). This paper will report on data from a two day observation of GX 1+4 by the GSFC X-ray spectroscopy experiment on OSO-8 during September, 1975.

Experiment

The observations were made on September 16-17, 1975 with a pointed argon-filled proportional counter. The detector has an effective area of 36.7 cm^2 and an energy range from 2-20 keV divided into 63 channels. The detector has 3° collimation which isolated GX 1+4 from the nearby galactic center sources. During the two day observation, counting rates from the detector had a time resolution of 160 ms while spectral data were restricted to time resolution of 40 seconds. Only about 10 per cent of the data are available at this time

Analysis

Periodicity in the x-ray intensity of GX 1+4 was searched for by folding the observed rates over a large number of trial periods. The resulting light curves were tested against a constant intensity using the χ^2 technique. The period resulting in the highest χ^2 value was taken as the best estimate of the pulsation period. The validity of the procedure was tested by examining individual light curves produced when the data is folded.

The procedure used for analyzing the spectral data has been described in previous papers (Serlemitsos et al., 1975; Pravdo et al., 1976). In general, after background subtraction, a numerical incident photon spectrum is inferred from the data using a spectrum-dependent channel-by-channel efficiency. Efficiencies for a best fit to the data are obtained after several iterations.

The data available for analysis are limited to sets of data which span ~15,000 and ~20,000 seconds respectively and are separated by ~66,000 seconds.

Results

Our observations of GX 1+4 confirm the results of Lewin et al., (1976) that the source's x-ray intensity pulses with a period of ~122 seconds. Combining data over a time span of 24 hours, our best estimate of the pulsation period is 122.46 $\pm$ .03 seconds. This estimate is based on the assumption that the principal peak in the pulsation light curve does not move in phase during the duration of the observation. This value for the period does not agree with the previously reported periods of 138 seconds in October, 1971 (Lewin et al., 1971) and 122.607 $\pm$ .003 seconds in December, 1975 (Lewin et al., 1976).

The spectrum of GX 1+4 shows significant variability during our observation. On September 16, 1975, GX 1+4 was in a relative high state with an energy flux of ~8.8×10^{-10} ergs/sec-cm^2 between 2 and 6 keV. On September 17, 1975 the energy flux was down to ~5.8×10^{-10} ergs/sec-cm^2

in the same energy range. Figure 1 shows the spectra for these two days. As an indication of the difference between the two spectra, we determined a hardness ratio for the two spectra by taking the ratio of the number of photons below 4.6 keV to the number of photons above 4.6 keV. For the high and low state, we find hardness ratios of $1.03 \pm .08$ and $0.79 \pm .05$ respectively. These values indicate that the high and low state spectra are different with a 99.5 percent confidence level. In terms of the spectra in Figure 1, it is clear that the low state spectrum shows a low energy turn-over which is not present in the high state spectrum. The change in the hardness ratio is consistent with a three-fold increase in low energy absorption due to cold matter along the line of sight.

Attempts to fit the spectra in Figure 1 with simple power-law and thermal bremsstrahlung models did not result in acceptable χ^2 values. The best fit power-law for both days had a number index of -1.3 with absorption due to an equivalent column density of hydrogen of 7.9×10^{21} atoms/cm^2 and 2.3×10^{22} atoms/cm^2 for the high and low states respectively (Brown and Gould, 1966). The best fit thermal bremsstrahlung requires kT $\geqslant$ 35 keV for both days with absorption due to an equivalent column density of hydrogen of 1.3×10^{22} atoms/cm^2 and 3.2×10^{22} atoms/cm^2 for the high and low states respectively. It is clear from Figure 1 that the low state spectrum shows considerably more structure than the high state spectrum. The structure in the low state spectrum at 3 keV could possibly be due to an absorption edge and is reminiscent of features observed in the spectra of other binary sources such as Cyg X-3 (Bleach et al., 1972).

Light curves for GX 1+4 for both the high and low states are shown in Figure 2. Lewin et al., 1976 reported that the light curve is energy dependent and shows greater modulation at energies above 8 keV. This is supported by our observations. The modulation in the high state light curve is 19.0 $\pm$ 2.0% while the modulation in the low state is 31.6 $\pm$ 1.5% where we define modulation as the difference between the maximum and minimum intensity of the light curve divided by the minimum intensity. The low state light curve is more indicative of high energy x-rays due to the increase in low energy absorption. It is also interesting that the secondary maximum present in the high state is not present in the low state light curve suggesting that the secondary maximum is a low energy feature. Additional observations are needed to confirm this.

Discussion

The "low state" of GX 1+4 is suggestive of the variable absorption seen to occur in several x-ray binary systems, e.g. Cen X-3, Vela XR-1 and Cyg X-3. In Cen X-3 and Vela XR-1, is is not unusual to observe column densities as high as 10^{24} atoms/cm^2 (Swank et al, 1975; Rothschild et al, 1976), considerably higher than the column density we observe for GX 1+4. Also, while sources such as Cen X-3 and Vela XR-1 have well-defined eclipses, GX 1+4 might be similar to Cyg X-3 which never undergoes eclipse. A possible explanation for the behavior of GX 1+4 is that it belongs to a binary system which we observe at a low inclination. The amount of mass away from the plane of the binary system would be relatively small, resulting in the modest absorption we see on September 17, 1975. The presence of the "low state" may be the first evidence that GX 1+4 belongs to a binary system.

There is an apparent discrepancy between the pulsation period we measured in September 1975 and the value measured by Lewin et al., 1976. The difference of 0.14 seconds between the two 1975 measurements may be explainable in terms of a doppler shift due to a yet undiscovered binary motion. This effect could not explain the ~16 second period change between 1971 and 1975 without requiring an orbital velocity >0.06 c. On the other hand, $\dot{P}/P$ would need to be -0.032/year for a spin-up in the rotation of the compact object of 16 seconds over four years. For comparison, $\dot{P}/P$ for Cen X-3 is approximately -3×10^{-4}/year (Gursky and Schreier, 1975). If the spin-up of these compact objects results from a transfer of angular momentum from material falling onto an accretion disk, $\dot{P}/P$ would be proportional to

$$P\left[\frac{2\pi}{P} - \left(\frac{GM}{r_A{}^3}\right)^{0.5}\right] \times \frac{5\dot{m}r_A{}^2}{4\pi MR^2}$$

as adapted from Pringle and Rees (1972), where M is the mass of the compact object, r_A is the Alfven radius, $\dot{m}$ is the rate of mass accretion onto the compact object, and R is the radius of the compact object. For the case of a spin-up of the compact object, the term in brackets is negative, so that $\dot{P}/P$ will decrease as P increases. Since the pulse period of GX 1+4 is ∿25 times that of Cen X-3, a ratio of ∿100 between $\dot{P}/P$ for the two sources is reasonable in the context of a transfer of angular momentum as described by conventional accretion models.

It is likely that a number of galactic x-ray sources belong to binary systems which we observe at low inclinations. As a result of their low inclination, we would not expect to observe eclipses. Likewise, the magnitude of any doppler shift resulting from binary motion will be reduced by a factor sin i. We therefore expect that it is necessary to search for more subtle effects to discover the binary nature of these sources. The variations in the low energy absorption observed in GX 1+4 may be one such effect.

Figure Captions

Figure 1 Incident x-ray spectra for GX 1+4 from observations made on September 16, 1975 (high state) and on September 17, 1975 (low state). The solid line in each graph represents the best fit power-law with absorption due to cold matter along the line sight.

Figure 2 Light curves for GX 1+4 from observations made on September 16, 1975 (high state) and on September 17, 1975 (low state). The vertical scale represent the observed rates uncorrected for satellite aspect. The background counting rate is 0.98 cts/sec.

References

Bleach, R. D., Boldt, E. A., Holt, S. S., Schwartz, D. A., and Serlemitsos, P. J. 1972, Ap. J. 171, 51.

Boldt, E., Doong, H., Serlemitsos, P. and Riegler, G. 1968, Canadian J. Phys., 46, S444.

Brown, R. L., and Gould, R. J. 1970, Phys. Rev., D1, 2252.

Gursky, H., and Schreier, E. 1975, Neutron Stars, Black Holes, and Binary X-ray Sources, Gursky, H., and Ruffini, R. (eds) D. Reidel Publishing Co., Dordrecht - Holland, p. 175.

Lewin, W. H. G., Hoffman, J., and Doty, J. 1976, presented at the meeting of the High Energy Astrophys. Div. of the AAS on "X-ray Astronomy" Cambridge, MA.

Lewin, W. H. G., Ricker, G. R., and McClintock, J. E. 1971, Ap. J. (Letters) 169, L17.

Pravdo, S. H., Becker, R. H., Boldt, E. A., Holt, S. S., Rothschild, R. E., Serlemitsos, P. J., Swank, J. H. 1976, submitted to Ap. J. (Letters) 1976.

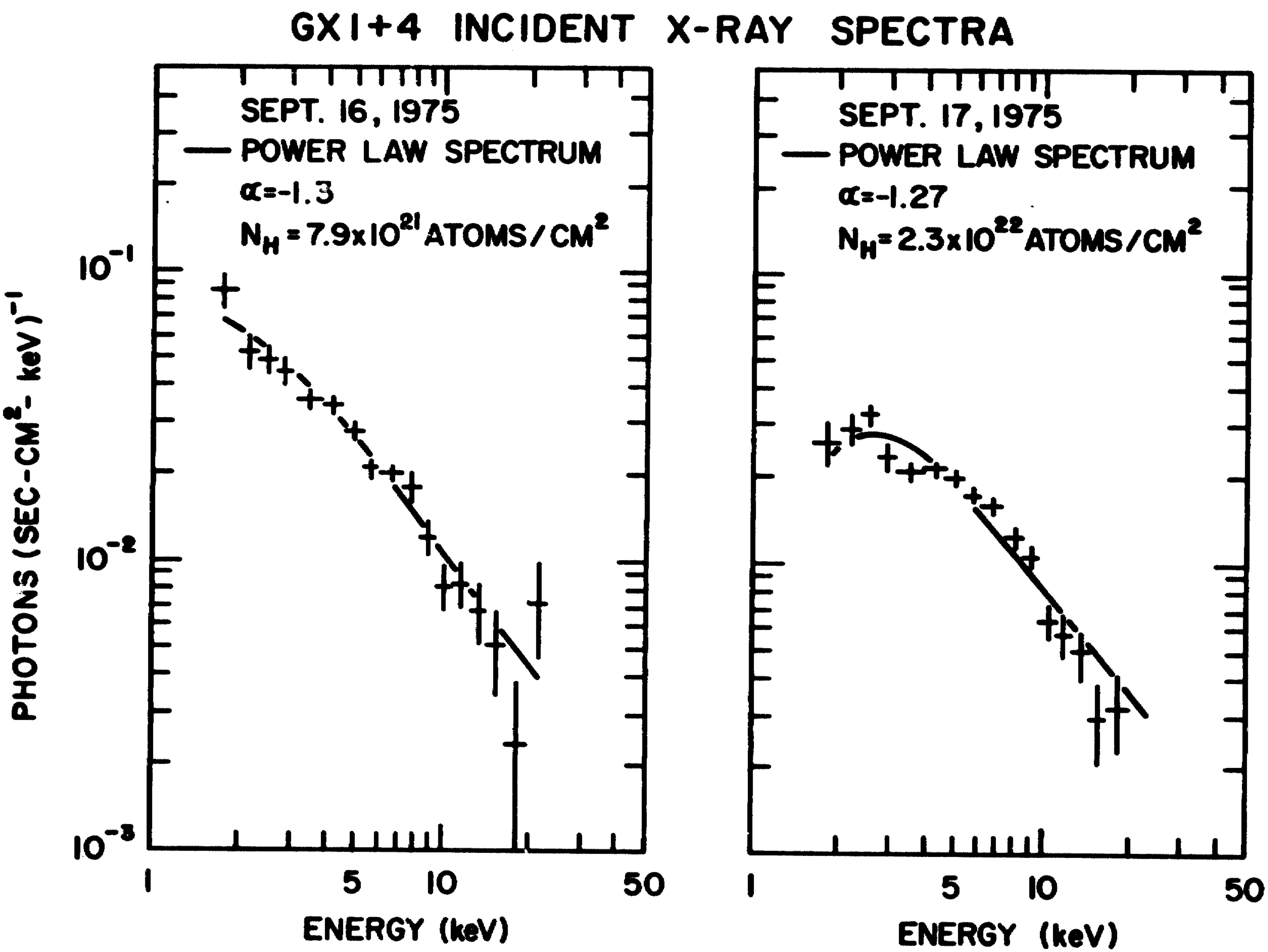
Pringle, J. E., and Rees, M. J. 1972, Astron. Astrophys. 21, 1.

Rothschild, R. E., Boldt, E., Holt, S., Serlemitsos, P., Becker, R., Swank, J., Pravdo, S. 1976, presented at High Energy Astrophys. Div. of AAS on "X-ray Astronomy" Cambridge, MA.

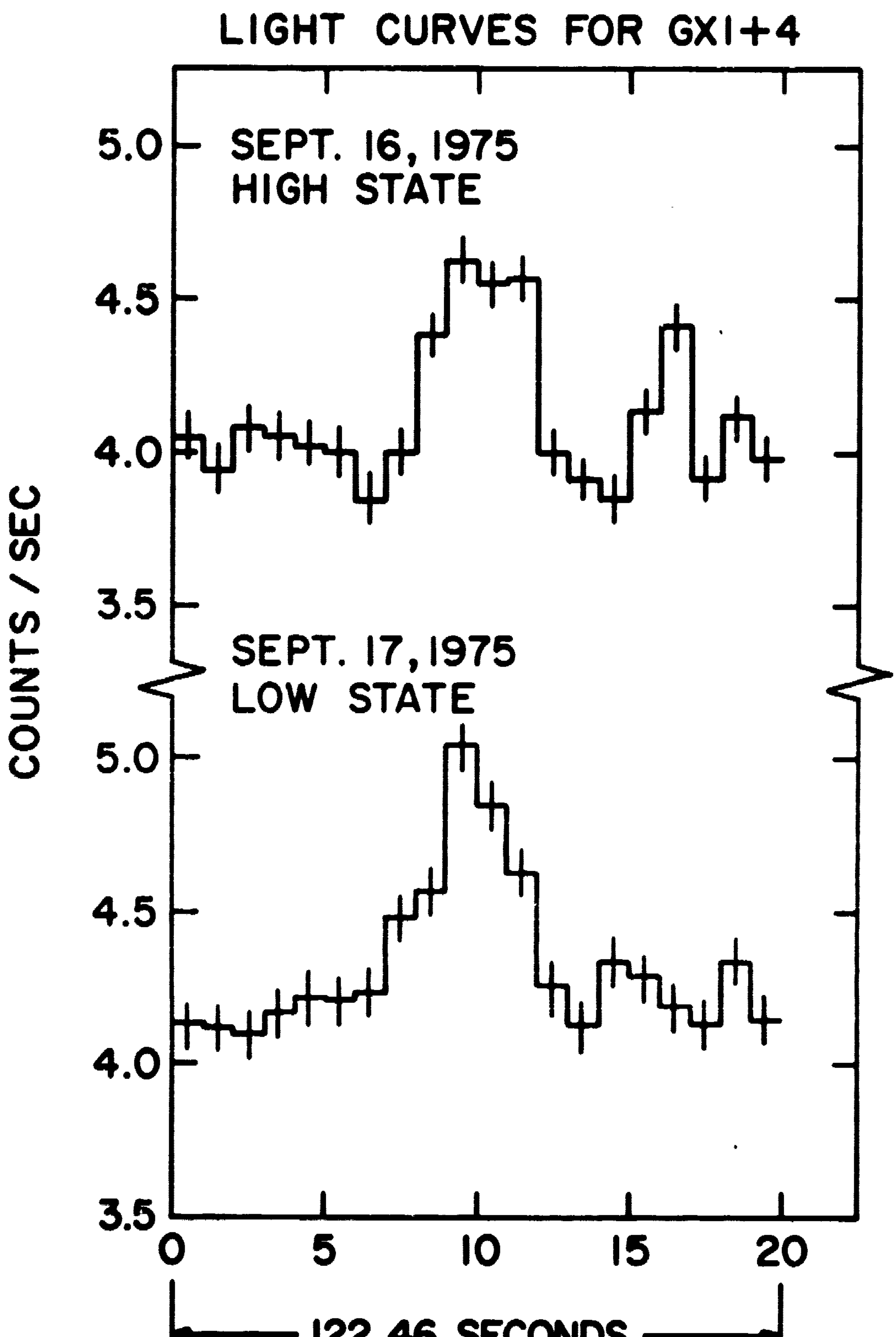
Serlemitsos, P. J., Boldt, E. A., Holt, S. S., and Rothschild, R. E., 1975, Ap. J. (Letters), 201, L9.

Swank, J. H., Becker, R., Boldt, E., Holt, S., Pravdo, S., Rothschild, R., Serlemitsos, P. J. 1975, submitted for publication in Proceedings of Symposium on X-ray Binaries, NASA Goddard Space Flight Center, Greenbelt, Maryland, Oct. 20-22, 1975.

Thomas, R. M., Davison, P. J. N., Clancy, M. C., and Buselli, G. 1975, Mon. Not. R. Astro. Soc., 170, 569.



GX1+4 INCIDENT X-RAY SPECTRA
SEPT. 16, 1975
POWER LAW SPECTRUM
α=-1.3
N_H = 7.9x10^21 ATOMS/CM^2
SEPT. 17, 1975
POWER LAW SPECTRUM
α=-1.27
N_H = 2.3x10^22 ATOMS/CM^2
PHOTONS (SEC-CM^2- keV)^-1
10^-1
10^-2
10^-3
1
5
10
50
ENERGY (keV)
ENERGY (keV)


LIGHT CURVES FOR GX1+4
SEPT. 16, 1975
HIGH STATE
SEPT. 17, 1975
LOW STATE
COUNTS / SEC
5.0
4.5
4.0
3.5
5.0
4.5
4.0
3.5
0
5
10
15
20
122.46 SECONDS