X-661-77-86

PREPRINT

TMX - 71302

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(NASA-TM-X-71302) SPECTRAL CHARACTERISTICS OF 3U1915-05, A BURST SOURCE CANDIDATE (NASA) 13 p HC A02/MF A01 CSCL 03A

N77-24026

Unclas

G3/89 28941

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APRIL 1977

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Spectral Characteristics of 3U1915-05,
A Burst Source Candidate

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ABSTRACT

An X-ray burst source has been discovered near the X-ray source 3U1915-05. The continuum spectra of both the burst source and the quiescent 3U1915-05 are hard, with kT above 20 keV. The spectrum of 3U1915-05 has a feature at 9.1 keV, which, if attributed to absorption by hydrogen and helium-like iron, suggests the presence of a highly ionized cloud surrounding a central X-ray source.

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I. INTRODUCTION

In the last year, over 15 X-ray burst sources have been discovered (Lewin, 1976). The bursts are usually characterized by rise times of $< 1^s$ and decay times of 5-50 sec. In many instances, the error box of the burst source contains a "steady" source of X-rays. During three days in 1975, the GSFC Cosmic X-ray Spectroscopy Experiment on OSO-8 observed a series of eleven bursts (Swank et al., 1976a). During this period, the steady source 3U1915-05 was also in the field of view. This paper will report on the spectra and light curves for both the burst source and 3U1915-05 and discuss the possibility that they are one and the same source.

II. OBSERVATIONS

During the period between April 11-14, 1976, a series of eleven X-ray bursts were observed with a pointed xenon proportional counter with a 5^o FWHM field of view. A description of the experiment is given by Pravdo et al. (1976) and will not be repeated here. The arrival times of the bursts, the interval between bursts, and the center of the detector field of view during the burst are given in Table 1. All the bursts had similar temporal characteristics, with rise times of $\sim$ 0.5 sec and decay times of 5 - 10 secs. The similarity among the events and the fairly regular occurrence of the events suggest that all the bursts have the same origin. If so, then an error box for the location of the burst source can be constructed by taking the intersection of all eleven fields of view.

The observations also indicated that a continuous X-ray source was within the field of view of the detector. The only known source within the field of view during this period was 3U1915-05. We find that the X-ray intensity from 3U1915-05 varies by as much as a factor of 3 within 5000 - 10,000 sec. The existence of these rapid variations do not depend on the assumed location of the source because the orientation of the detector was changing little over such time intervals. The average intensity of 3U1915-05 during the observation was 10.0 ± .6 x 10^{-11} ergs/cm^2-sec between 2 - 6 keV and 28.5 x 10^{-11} ergs/cm^2-sec between 2-20 keV. UHURU detected a varying intensity for 3U1915-05 with a range between 8 - 40 x 10^{-11} ergs/cm^2-sec (Giacconi et al., 1974). The average spectrum of 3U1915-05 is shown in Figure 1.

The statistics for a single burst are inadequate to produce a meaningful spectrum, so that we have combined that data from all the bursts to generate an average burst spectrum. This result is also shown in Figure 1 and has been normalized to the peak burst intensity of 5.2 ± 1.0 x 10^{-9} ergs/cm^2 sec between 2 - 6 keV, approximately 50 times the steady intensity of 3U1915-05.

Attempts to fit the spectra of 3U1915-05 with simple power law and thermal bremsstrahlung models did not result in acceptable χ^2 values. However, the inclusion of an absorption edge at 9.1 ± 0.4 keV into either model resulted in acceptable fits. This feature is significant at the 5σ level. The edge was represented by the analytic form

$$\exp -(y/E)^{+3} \quad \text{for } E \geq E_{EDGE}$$

and zero for $E < E_{EDGE}$. The best fit power-law is $\alpha = 1.60 \pm 0.15$ and $N_H = 2.5^{+1.5}_{-1.2} \times 10^{22}$ atoms/cm^2 with $\chi^2 = 16.8$ for 13 degrees of freedom. The thermal bremsstrahlung model requires a $kT > 35$ keV with the best fit value of 50 keV and $N_H = .87^{+1.5}_{-0.4} \times 10^{22}$ atoms/cm^2 giving a $\chi^2 = 16.0$ for 13 degrees of freedom. In both cases, $y = 6.8 \pm 1.4$. The errors represent the range of values of each parameter within the 4-dimensional 90% confidence contour which is found by allowing χ^2 to increase by 7.8 over the best fit. If the absorption edge is due to hydrogen-like iron ions, the implied column density of hydrogen-like iron is $1.4 \pm .3 \times 10^{19}$ ions/cm^2. If the absorption is due exclusively to helium-like iron the column density would be roughly a factor of two less. An upper limit for the equivalent width of any iron line emission at 7 keV is 176 eV at the 90% confidence level.

Spectral fits to the burst spectrum did not result in acceptable χ^2 values. Since burst spectra have been observed to vary over a burst, it is not surprising that the time averaged spectrum can not be well-represented by a simple model. The best fit power-law for the average burst spectrum is $\alpha = 1.7$ and $N_H = 8.7 \times 10^{22}$ atoms/cm^2. The best fit thermal bremsstrahlung resulted in $kT = 31$ keV and $N_H = 7.5 \times 10^{22}$ atoms/cm^2. The addition of an absorption edge at 9.1 keV did not improve the fit.

III. DISCUSSION

The bursts occur at intervals of 15,000 - 22,000 sec or multiples thereof, similar to sequences of bursts observed from 3U1820-30, MXB 1837+05, MX 1906+00, and MXB 1728-34 (ref. in Lewin, 1976). The bursts are also similar in intensity and duration to those of previously discovered burst sources, so that the phenomenology reported here seems typical.

On the other hand, the spectral character of 3U1915-05 is unique among published X-ray spectra. The source has a hard spectrum modified by an apparent absorption edge at 9.1 keV but with relatively little low energy absorption. Absorption edges at 7.1 keV have been observed in several X-ray binary sources (for example, Becker et al., 1977; Swank et al., 1976b) and have been attributed to photoelectric absorption due to neutral iron. The presence of these edges are always accompanied by substantial low energy absorption. The K-absorption edge energy for iron depends on the ionization state of the iron and for hydrogen-like and helium-like iron the edge energy is 9.3 and 8.8 keV, respectively. Therefore the edge seen in the spectrum of 3U1915-05 can be attributed to the K-absorption edges of either hydrogen or helium-like iron. The high ionization of the absorbing material naturally explains the lack of substantial low energy absorption, as all the more abundant lighter elements would be fully ionized. Therefore, the spectrum of 3U1915-05 is consistent with a hard X-ray source ($\geq$ 35 keV) enveloped in a highly ionized cloud of material. The depth of the absorption edge can be explained by a column density of hydrogen-like iron of $1.4 \pm .3 \times 10^{19}$ ions/cm^2. If the abundance of iron in the cloud is near the photosphere-coronal average of 3.9×10^{-5} of hydrogen by number (Withbroe, 1971), the column density of equivalent hydrogen atoms is $\geq 3.5 \pm .8 \times 10^{23}$ cm^{-2} since some iron may be fully ionized.

If the cloud as a whole is in statistical equilibrium there will be as many recombinations as photoionizations. Some fraction (.3 - .7) depending on T will recombine to the ground state resulting in an emission edge which will tend to fill in the absorption edge. Of those which recombine to an excited state, approximately 2/3 will result in a Lyman α photon at 7 keV. Hence, the depth of the edge only gives a lower limit to the column density of iron and furthermore, there should be 2/3 as many Lyman α photons as there are photons missing due to the edge. Therefore, if the cloud is spherically symmetric and all the Lyman α photons escape, we should observe a line of $\sim$ 300 eV equivalent width, substantially larger than the observed upper limit.

It is easy to construct models to explain the lack of iron emission line. If a spherical cloud was divided by an optically thick, planar disk, the expected iron emission would be halved. In addition, the optical depth at the line center for iron Lyman α is $\gtrsim 10^3$ times the optical depth in the continuum. This results in long path lengths through the cloud, increasing the probability that the line radiation will be absorbed.

The high ionization of the absorbing material could result from either collisional ionization or photoionization. Hydrogen-like iron will be the dominant species of iron in a cloud of 10^8 K temperature. The continuum intensity from a constant density cloud of 10^8 K temperature at a distance d with a radius r and a hydrogen column density 7×10^{23} cm^{-2} (at 10^8 K, iron is $\sim$ 50% fully ionized) is given by 5×10^{25} r/d^2 ergs/sec-cm^2. It is unlikely that 3U1915-05, located at

$\ell^{II} = 31.3$ $b^{II} = -8.3$, is more distant than 10 kpc. Therefore, if we assume that less than .2 of the observed intensity is from the 10^8 K absorbing material and that the region is spherical, then the radius must be less than 1.4×10^{10} cm and the density greater than $4 \times 10^{13}/\mathrm{cm}^3$. In the limiting case where all the observed intensity comes from the 10^8 K cloud, then $r \leq 7 \times 10^{10}$ cm and $n_e \geq 1.0 \times 10^{13}$ cm^{-3}.

These results are sensitive to the degree that iron is fully ionized. Therefore, higher values of T lead to smaller limits on r. If T is greater than 5×10^8, almost all iron will be fully ionized and no edge would be observed.

Alternatively, the absorbing material could be photoionized by X-rays from the hard central source. Hatchett et al. (1976) have shown that the ionization state and temperature of a gas in photoionizational equilibrium can be determined from the single parameter $\xi \equiv L_x/nr_x^2$ if the spectrum of the incident X-rays is specified. Here L_x is the luminosity of the X-ray source, n is the local atomic density, and r_x is the distance to the X-ray source. For a 50 keV incident spectrum, hydrogen and helium-like iron will be the dominant species for $\log \xi \simeq 3$. Using N_H calculated from the absorption edge as a lower limit to $n\, r_x$, we can solve for r_x. If 3U1915-05 is nearer than 10 kpc, then $L_x \leq$ 3.4×10^{36} ergs/sec between 2-20 keV and therefore, $r_x \leq 10^{10}$ cm if the cloud is photoionized. In this model, the kT of the electrons at a radius where iron is 50% fully ionized is < 2 keV for an incident spectrum like that observed for 3U1915-05.

Canizares (1976a, 1976b) has suggested that the time evolution of spectra from the bursters NGC 6624 and MXB 1728-34 can be understood in terms of scattering in a cloud of 10^8 K. Our data indicate that 3U1915-05 is surrounded by a highly ionized cloud. If this cloud is in collisional equilibrium, it would have to be very similar to the cloud postulated by Canizares. If the cloud is in photoionization equilibrium, the temperature of the absorbing material is substantially cooler. However, this would not exclude the presence of higher temperature material closer to the source of ionizing radiation.

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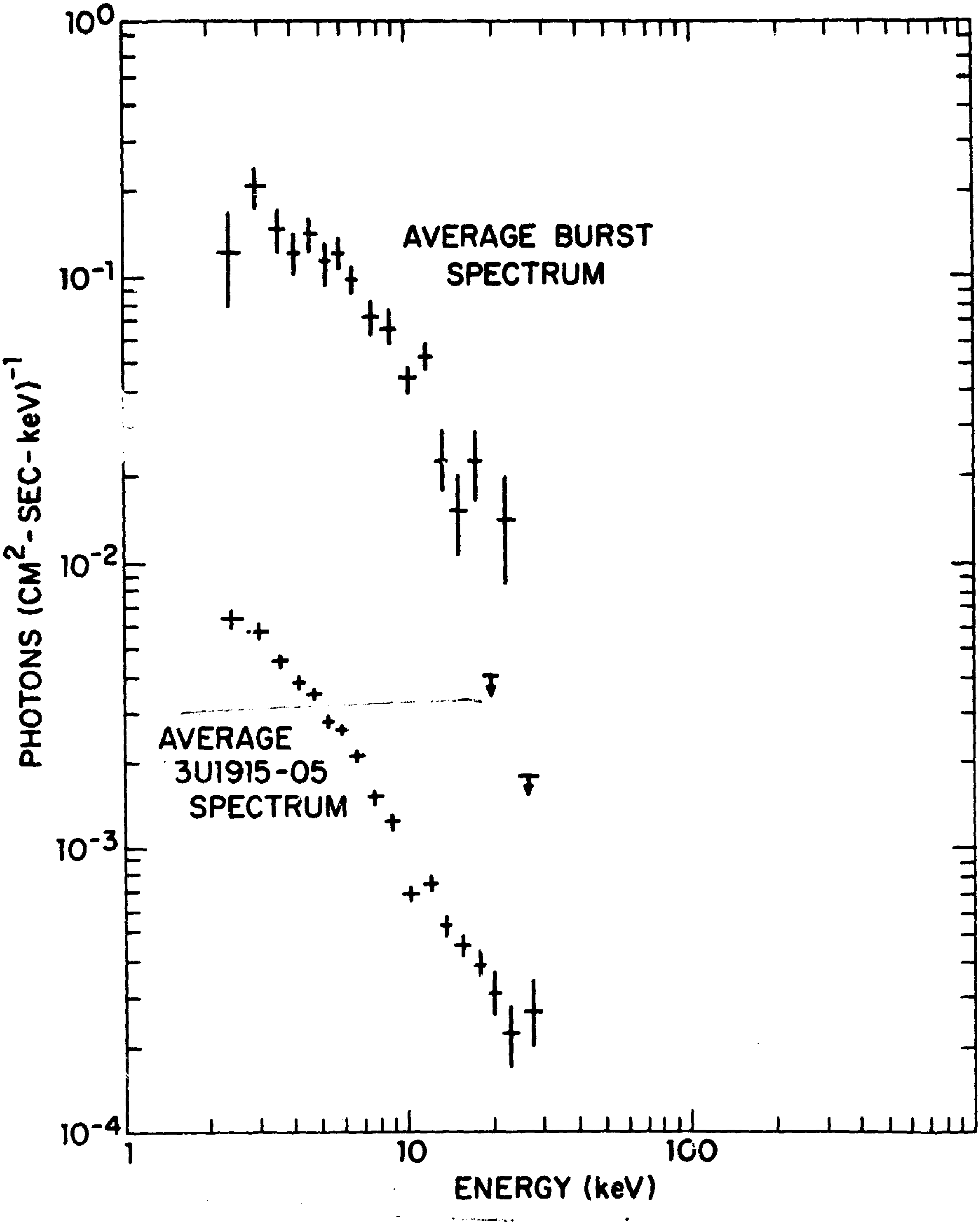
TABLE I

Time of Burst		Time Interval	RA(1950)	Dec(1950)
Day (1975)	Sec	to previous burst (sec)		
102	73487		287.5	-8.54
103	16482	29373	288.6	-7.88
	32860	16421	289.3	-7.36
	68120	35228	289.6	-6.68
	82119	14043	289.7	-6.44
104	26787	31017	290.0	-5.60
	44157	17384	290.3	-4.89
	62013	17323	290.6	-4.54
	82922	21457	290.8	-4.05
105	38770	42203	291.2	-2.85
	59188	20520	290.9	-2.40

FIGURE CAPTIONS

Figure 1. The inferred incident spectra for the X-ray source 3U1905-05 and for the X-ray bursts originating from the vicinity of 3U1905-05.



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