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UNUSUAL X-RAY BURST PROFILES FROM 4U/MXB 1636–53

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ABSTRACT

During a 1 day *EXOSAT* observation we observed eight X-ray bursts from 4U/MXB 1636–53. Four of these were very unusual. Their peak fluxes were relatively low, and they showed a distinct double peak in their *bolometric* flux profiles. These new double-peaked bursts are unexplained by presently available models of X-ray bursts. It is possible that the energy release in these bursts proceeds in two “steps.” The burst profiles are not the result of an expansion and subsequent contraction of the photosphere of the neutron star. Thus, they are very different from previously observed bursts which do show a double peak in certain energy ranges but not in their bolometric flux profiles; these are satisfactorily explained in terms of photospheric radius expansion and contraction. We discuss the anticorrelation between the apparent blackbody radius and blackbody temperature in terms of the non-Planckian character of burst spectra and conclude that the model calculations reported by London, Taam, and Howard in 1984 give a reasonable first-order description of the observed *apparent* radius changes in X-ray bursts.

Subject headings: radiation mechanisms — stars: neutron — X-rays: bursts

I. INTRODUCTION

Lewin *et al.* (1976) detected nine bursts from MXB 1743–29, at 35 hr intervals. The bursts had nearly identical double-peaked profiles at high-energy X-rays. Subsequently, similar double-peaked X-ray bursts were observed from other sources (Hoffman, Cominsky, and Lewin 1980; Grindlay *et al.* 1980; Matsuoka 1980). However, in all cases (except for MXB 1743–29) the double-peaked bursts were extremely rare (e.g., only one such burst out of 96 was detected from MXB 1728–34; Basinska *et al.* 1984).

The double-peaked structure is not apparent in the energy-integrated bolometric burst flux profiles. Blackbody fits to the burst spectra showed an anticorrelation between the blackbody temperature and the blackbody radius during the peak of the bursts, where the double-peak structure occurs (Hoffman, Cominsky, and Lewin 1980; Grindlay *et al.* 1980; Matsuoka 1980).

These double-peaked bursts are probably related to the fast transients with “precursors” (Hoffman *et al.* 1978; Tawara *et al.* 1984; Lewin, Vacca, and Basinska 1984). These are believed to be the result of a major expansion (due to radiation pressure) and subsequent contraction of the photosphere of the neutron star at approximately constant bolometric luminosity. The decrease of the effective temperature accompanying the photospheric radius increase gives rise to a temporary shift of the burst emission to lower energy photons. During the subsequent photospheric contraction the effective temperature increases again, and the burst emission shifts back to higher energy photons. In moderate cases this causes a dip in the observed hard X-ray flux (and thus two peaks occur in the burst profile). When the radius expansion is much larger, it causes a complete disappearance of the X-ray emission, and the first peak becomes disconnected from the rest of the burst,

i.e., it becomes a precursor (Tawara *et al.* 1984; Lewin, Vacca, and Basinska 1984).

An alternative explanation of these double-peaked bursts (and in extreme cases a burst with a precursor) has been proposed by Schweizer (1985). He argues that scattering of photons in a radiation-dominated medium of moderate optical depth (e.g., a neutron star wind generated by a super-Eddington luminosity) has to be described by a hyperbolic diffusion equation. This would, in a natural way, give rise to two time scales: (i) a diffusion time scale, and (ii) a “precursor” time scale, connected to a front of forward-scattering photons. In this way an originally single-peaked energy release profile in the neutron star envelope is transformed into a final double-peaked profile of X-rays as observed outside the neutron star’s atmosphere. Since only the temporal aspect of the transfer has been studied by Schweizer (1985), his calculated profiles are independent of energy. However, the observed double-peak burst profiles are strongly energy dependent in a way entirely consistent with the above model of photospheric expansion and contraction. It is not clear that this observation fits Schweizer’s model. The diffusion in energy-space is an essential aspect of the problem, which has not yet been addressed by Schweizer (1985).

Completely independent of the phenomenon of radius expansion believed to give rise to double-peaked bursts is an apparent change in blackbody radius due to deviations of X-ray burst spectra from a Planck function. Because of the dominant contribution of electron scattering to the opacity in a hot neutron star atmosphere, one expects the burst spectrum to be “harder” than a blackbody spectrum at the same effective temperature. This spectral hardening becomes more pronounced at higher temperatures (van Paradijs 1982; Czerny and Sztajno 1983; London, Taam, and Howard 1984). Evidence for the expected anticorrelation between the apparent blackbody radius and blackbody temperature has been found by Inoue *et al.* (1984).

In this paper we report the detection of four X-ray bursts from 4U/MXB 1636–53 with a double-peak structure. These

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bursts are relatively weak and, unlike in the case of the previously reported double-peaked bursts (see above), these double peaks are present in their bolometric flux profiles. We discuss these double-peaked bursts in the context of the correlation between the apparent blackbody radius and black body temperature, due to the non-Planckian shape of the X-ray burst spectra, and conclude that they are not the result of an expansion and subsequent contraction of the photosphere of the neutron star.

II. OBSERVATIONS AND DATA ANALYSIS

The observations of 4U/MXB 1636–53 were made between 1984 May 8, 09:10 UT and May 9, 10:40 UT, with the X-ray observatory *EXOSAT* (Taylor *et al.* 1981). In the present analysis we use only data obtained with the Medium Energy (ME) proportional counter array (Turner, Smith, and Zimmermann 1981). Half of the ME array was offset from the source by 2° , in order to monitor the X-ray background. The background monitor indicated no solar activity during the observations. Energy spectra were recorded every 0.31 s in 32 channels with the argon detector in the energy range from 1 to 20 keV.

III. GENERAL BURST AND PERSISTENT PROPERTIES OF

4U/MXB 1636–53

The average persistent X-ray flux from 4U/MXB 1636–53 was 1.6×10^{-9} ergs cm^{-2} s^{-1} (0.9–10.7 keV). The source flux was within the previously observed brightness range (Hoffman, Lewin, and Doty 1977; Ohashi 1980; Forman *et al.* 1978; Warwick *et al.* 1981). During the observations the persistent flux underwent a gradual decrease of about 30% and showed variations on time scales of hours with an amplitude of about 10%.

Eight X-ray bursts were detected during the ~ 25 hr of continuous observation, at intervals between ~ 1.5 and 11 hr (see Fig. 1). Each burst was divided into a number of time intervals, with typical durations between 1 and 4 s, depending on the corresponding burst count rate. All count rates were corrected for dead time.

The persistent count rate, derived from 2000 s of data before a burst, was subtracted from the burst data. The resulting net burst data could be successfully fitted with blackbody func-

tions, which include a blackbody temperature T_{bb} , a low-energy cutoff (represented by an equivalent hydrogen column density N_{H}), and a normalization constant I_0 as parameters. Typical reduced χ^2 values for these fits are between 0.5 and 1.5 for 15 degrees of freedom. In the large majority of these fits we found only an upper limit to N_{H} , typically less than 2×10^{22} cm^{-2} . The average value for N_{H} from all blackbody fits is 5×10^{21} cm^{-2} , corresponding to $A_V \approx 2$ mag (Gorenstein 1975). In view of the large uncertainties in the individual values of N_{H} we consider the good agreement with the interstellar extinction (determined from an analysis of a correlated X-ray/optical [multi-color] burst from 4U/MXB 1636–53 [$A_V = 2.4 \pm 0.3$ mag; Lawrence *et al.* 1983]) as probably fortuitous. The 1σ error in the blackbody temperature T_{bb} was found from χ^2 contours in the (T_{bb} , I_0) plane at a 68% confidence level, with N_{H} fixed at zero. In these calculations of χ^2 values we included a 1% systematic error in the calibration of the argon detectors.

The X-ray burst flux in each time interval was calculated by integration over the energy interval between 0.9 and 10.7 keV. In the conversion of count rates to fluxes we assumed an incident blackbody spectrum at the fitted temperature. The bolometric flux F_{bol} was obtained by multiplying this observed flux by a bolometric correction factor, equal to $\int_0^\infty F(E)dE / \int_{0.9}^{10.7} F(E)dE$, which (because of the blackbody assumption) is a function of the blackbody temperature only. This correction factor ranges between 1.03 and 1.30 over the temperature ranges encountered.

In Table 1 we have listed for the eight bursts the occurrence times (to the nearest minute), the maximum and total integrated bolometric fluxes, and the parameter α , which is defined as the ratio of the total energy in the persistent emission during the time interval since the previous burst, to that emitted in the burst. From the data in this table it appears that during our observations the overall burst behavior of 4U/MXB 1636–53 was rather normal. The maximum and integrated burst fluxes varied between 1.0×10^{-8} and 5.6×10^{-8} ergs cm^{-2} s^{-1} , and between 0.9×10^{-7} and 4.3×10^{-7} ergs cm^{-2} , respectively. These values are within the range previously observed and follow the correlation seen in the *Hakucho* data for this source (Ohashi 1980; Ohashi *et al.* 1982). Also with respect to the

FIG. 1.—Variation of the 3.4–6.0 keV X-ray intensity (counts per second per detector) of 4U/MXB 1636–53 during our 1 day *EXOSAT* observation, averaged in bins of 300 s. The discontinuity in the count rate before the first X-ray burst is the result of a small change in the pointing direction of the satellite.

TABLE 1
BURSTS FROM 4U/MXB 1636-53

Burst Number	Date (1984 May/UT)	$F_{\max}$ (10^{-8}) (ergs cm $^{-2}$ s $^{-1}$)	E_b (10^{-7}) (ergs cm $^{-2}$)	$E_b/F_{\max}$ (s)	α
1.....	8/11:01	$1.81^{+0.14}_{-0.11}$	1.53 ± 0.03	$8.5^{+0.5}_{-0.7}$	...
2.....	8/12:28	$1.88^{+0.15}_{-0.11}$	1.61 ± 0.03	$8.6^{+0.5}_{-0.7}$	54
3.....	8/14:36	$2.01^{+0.13}_{-0.11}$	2.60 ± 0.02	$12.9^{+0.7}_{-0.8}$	135
4.....	8/16:23	$1.66^{+0.10}_{-0.09}$	1.03 ± 0.03	$6.2^{+0.4}_{-0.4}$	102
5.....	8/17:50	$1.04^{+0.05}_{-0.03}$	1.19 ± 0.02	$11.4^{+0.6}_{-0.6}$	71
6.....	8/19:32	$2.04^{+0.13}_{-0.13}$	1.06 ± 0.03	$5.2^{+0.4}_{-0.6}$	96
7.....	9/06:30	$5.59^{+0.23}_{-0.23}$	4.29 ± 0.07	$7.7^{+0.3}_{-0.4}$	133
8.....	9/08:15	$1.56^{+0.10}_{-0.09}$	0.94 ± 0.03	$6.0^{+0.4}_{-0.4}$	105

ratio α , which varies between ~ 55 and ~ 135 , the burst properties of 4U/MXB 1636-53 during our observations were normal (Ohashi 1980; Waki *et al.* 1984; van Paradijs *et al.* 1979).

IV. SPECTRAL ANALYSIS OF THE BURSTS

The blackbody radius of the burst-emitting region (identified with the surface of the neutron stars) follows directly from

$$R_{bb} = d(F_{bol}/\sigma T^4)^{1/2}.$$

Here d is the source distance, which we have assumed to be 10 kpc in all subsequent discussions. In the estimates of the errors of R_{bb} we took the correlation between the (asymmetric) errors in T_{bb} and F_{bol} into account.

In Figure 2 we show the variation of the bolometric flux, blackbody temperature, and blackbody radius during the eight bursts. This figure shows that with the exception of the one large burst in our sample (burst 7) the bursts seem to follow a common pattern. Initially the blackbody radii are about 8 km, they then rise to a value around 16 km within ~ 8 s, after which they remain nearly constant (see Fig. 3). This apparent initial radius increase has been reported previously (Inoue *et al.* 1984; Turner and Breedon 1984).

It is conceivable that this phenomenon reflects a real increase of the burst-emitting area, e.g., due to a spreading of the thermonuclear flash region over the surface of the neutron star. If this were the case, then the initial stages of such X-ray bursts may provide favorable conditions to attempt a search for possible periodic modulations of the X-ray flux due to the rotation of the neutron star. The rotation periods for these old neutron stars could be as small as milliseconds.

However, we suggest that a more plausible explanation for this apparent initial radius increase is the breakdown of the blackbody assumption (see also Inoue *et al.* 1984). This results in a systematic difference between the effective temperature T_{eff} of the hot neutron star atmosphere and the color temperature T_c (only the latter is obtained from the spectral fits). The X-ray energy distribution is expected to correspond to a color temperature which is higher than the effective temperature (van Paradijs 1982; Czerny and Sztajno 1984; London, Taam, and Howard 1984, hereafter LTH), i.e., the ratio T_c/T_{eff} is larger than 1. According to the model atmosphere calculations of LTH, the ratio T_c/T_{eff} is an increasing function of T_{eff} . The apparent radius will be affected by a factor $(T_c/T_{eff})^{-2}$. Thus, for an assumed constant radius of the neutron star, one will find apparent blackbody radii, which will become smaller (larger) as the observed color temperature increases (decreases).

In Figure 4 we show the observed relation between the

blackbody radius and color temperature based on all individual time intervals in the eight bursts. (We wish to reiterate that, since the source distance has been arbitrarily fixed to 10 kpc, this figure contains only the relative variation of the blackbody radius with temperature). With the exception of the data (*open circles*) from the peak of the one large burst 7 (in this burst a photospheric radius expansion apparently did occur), all points in this diagram follow a relation with the radius decreasing with increasing color temperature, in agreement with the above described expectations based on models. For each data point in the diagram (excluding burst 7) we have determined the ratio of the difference ΔR with respect to the average (T, R) relation, to the error σ_R in the determination of R . We find that the quantity $(1/N) \sum (\Delta R/\sigma_R)^2 = 0.95$ (where N is the number of data points in the summation), i.e. the data are consistent with a single relation between radius and temperature.

In order to pursue these qualitative considerations we have made a more detailed comparison with the models of LTH, who give the expected variation of the ratio (T_c/T_{eff}) as a function of T_{eff} for $\log g = 14.0$ and 15.0 . Since R_{bb} varies as $(T_{eff}/T_c)^2$ we can use their results to derive an expected relation between the observed values of R_{bb} and T_{bb} , for an assumed constant value of the radius of the neutron star photosphere.

In Figure 5a we have plotted the observed average values of R_{bb} in several color temperature intervals, together with similar results for 4U/MXB 1636-53 obtained by Inoue *et al.* (1984) using *Tenma*. The agreement between these results, obtained with different satellites, is quite satisfactory. In addition this figure contains the theoretical relation obtained from the models of LTH. Since the distance to 4U/MXB 1636-53 is not well known, this theoretical relation (independently for the two values of g) has been arbitrarily shifted vertically so as to agree with the average of the observed radii (here ~ 15 km) at a color temperature of 1.3 keV (corresponding to $kT_{eff} = 1.0$ keV, according to LTH).

The calculated spectra of LTH refer to the reference frame of the neutron star surface. However, photons emitted from a neutron star surface undergo a substantial redshift by a factor $(1+z) = [1 - (2GM/Rc^2)]^{-1/2}$. As a consequence, the blackbody temperature and blackbody radius, as observed at infinity, are related to the corresponding values at the neutron star surface (subscript 0) by $T_{bb} = T_0/(1+z)$ and $R_{bb} = R_0(1+z)$ (van Paradijs 1979; Goldman 1979). Therefore, in the theoretical relation between T_{bb} and R_{bb} the temperatures have to be decreased by a constant redshift factor (for an assumed constant photospheric radius). The redshift factor in the radii can be "absorbed" in the vertical shift due to the uncertain distance to the burst source.

FIG. 2.—Variations of the bolometric luminosity (for an assumed distance of 10 kpc), the blackbody (color) temperature and the apparent blackbody radius during the eight X-ray bursts observed from 4U/MXB 1636—53.

FIG. 2—Continued

FIG. 3.—Superposition of the radius variations observed during the eight X-ray bursts. With the exception of the strong burst 7 (*open symbols*), all bursts show an initial increase of the apparent blackbody radius.

A provisional estimate of the gravitational redshift factor of 4U/MXB 1636–53 may have been obtained from the discrete absorption features at 4.1 and 5.7 keV in the spectra of some X-ray bursts from this source, reported by Waki *et al.* (1984). They suggest that the 4.1 keV feature is due to the 6.7 keV resonance line of Fe xxv, which would imply a redshift factor $(1 + z) = 1.63$. This value is surprisingly high but is perhaps

still consistent with presently viable models of neutron stars (see Joss and Rappaport 1984).

In Figure 5b the observed relation between R_{bb} and the color temperature T_{bb} is compared with the theoretical relation, derived from the models of LTH, redshifted along the color temperature axis by a factor 1.63. To first order, the agreement between the theoretical and observed trends with color tem-

FIG. 4.—Apparent blackbody radius plotted as a function of the blackbody (color) temperature. Except for the strong burst 7 (*open symbols*), the data are consistent with a single relation between these two quantities.

FIG. 5a

FIG. 5b

FIG. 5.—(a) Comparison of the observed average (color) temperature dependence of the blackbody radius of 4U/MXB 1636–53 with that expected from the models of London, Taam, and Howard (1984), for different values of the surface gravity of the neutron star. The data points have been derived from the present EXOSAT observations and from similar *Tenma* observations by Inoue *et al.* (1984). The theoretical relations have been shifted vertically by an arbitrary amount, so as to coincide with the average of the observed radii at a color temperature $kT_{bb} = 1.3$ keV (corresponding to $kT_{eff} = 1.0$ keV). (b) Same as for Fig. 5a, with the theoretical color temperatures divided by a gravitational redshift factor 1.63 (see text).

perature of the blackbody radius of 4U/MXB 1636–53, displayed in Figures 5a and 5b, is encouraging, and this gives some confidence in the prospects of future model atmosphere studies of X-ray bursts. The results of London, Taam, and Howard (1984) indicate that such studies should preferably be based on a representation of theoretical spectra in terms of more than a single parameter (i.e., color temperature). One way to proceed, which would do justice to both the accuracy of present observations and the level of detail of recent theoretical spectra, would be to use predicted ratios of count rates in a number of energy bands (these are, of course, detector dependent), analogous to classical color-index studies of normal stars.

V. DOUBLE-PEAKED X-RAY BURSTS

The results collected in Figure 2 show that in four of the eight bursts (number 1, 2, 3, and 5) there appears a second maximum in the bolometric flux profile. The separation of this second maximum from the first maximum varies between 4 and 7 s. In particular, in bursts 1, 2, and 5, the second peak rises substantially above the extrapolation of the initial decay part of the burst, following the first peak. The rise times of the second peaks, defined as the time interval between initial rise over the previous decay and the second maximum, ranges from 1.9 to 3.5 s, not much different from the rise times of the first peak (similarly defined), which lie between 2.0 and 4.0 s. In these four double-peaked bursts the second peak is always smaller than the first one, but its relative size varies substantially. In bursts 1, 2, and 5, it reaches a maximum flux about half that of the first peak; in burst 3 it appears as a slight bump on the decay part of the first peak. This suggests that these double-peaked bursts form a “tail” of a continuous sequence of burst profiles (covering both the single- and the double-peaked bursts) and not a completely separate class of bursts. There is no evidence for a radius expansion accompanying the minimum in the burst profiles between the two maxima. In the case of burst 2 the apparent increase of the blackbody radius is

largely accounted for by the general anticorrelation between radius and temperature, which (as discussed above) is most likely the result of the non-Planckian shape of the burst spectra. If we take this general trend of the blackbody radii into account, the apparent radius excess during the flux minimum in burst 2 amounts to only three points deviating upward by 1.3σ .

In addition to the absence of a radius expansion these four double-peaked bursts are also different from the “classical” double-peaked bursts in other respects. In the first place the two maxima are clearly visible in the bolometric flux profile. In the previously observed double-peak bursts, the two maxima are present in the flux profiles observed in a limited energy range (most clearly at the higher energy X-rays), but not in the bolometric burst profiles. Furthermore, the previously observed double-peaked bursts (and the associated fast transients with a precursor; see Tawara *et al.* 1984; Lewin, Vacca, and Basinska 1984) were very energetic, reached a very high maximum luminosity, and it appeared that they occurred after a long waiting time since the previous burst (see, e.g., Hoffman, Cominsky, and Lewin 1980). The four bursts from 4U/MXB 1636–53 all occurred after a moderate waiting time (between 1.3 and 2.3 hr) and they are all rather weak. Their maximum fluxes are between a factor of 3 to 5 lower than that of burst 7 which, parenthetically, is the only burst we observed which does show evidence of an initial radius expansion; it occurred after a long waiting time of 11 hr. It is therefore highly unlikely that in these double-peaked weak bursts we encounter the high radiation pressure which is believed to cause the radius expansion (and lowering of the effective temperature) required to give rise to a double-peaked burst (see, e.g., Tawara *et al.* 1984; Lewin, Vacca, and Basinska 1984, and references therein). The low peak luminosity of these bursts may also create a problem for the model proposed by Schweizer (1985).

There are no obvious further characteristics which distinguish the double-peak bursts from the other bursts we have observed. They are all rather weak, but not weaker than the

single-peaked bursts 6 and 8. The persistent emission before the double-peaked bursts is not significantly different from that before the single-peaked bursts; neither are the values of α . Also there does not seem to be a relation between the occurrence of these double-peaked bursts and other characteristics, e.g. the waiting times (both before and after the burst), their rise- and decay times, and their blackbody radii.

VI. DISCUSSION

The properties of the four double-peaked bursts from 4U/MXB 1636–53 suggest that we are here witnessing events in which the energy release proceeds in two steps. To the best of our knowledge this is the first time that double-peaked bursts of this kind have been observed. There are a number of ways in which to envisage the occurrence of such a two-step process.

One possibility, which we consider highly unlikely (see below), is that the double-peaked bursts from 4U/MXB 1636–53 could be the result of a spatial confinement of the nuclear fuel on different parts of the neutron star surface. Such a confinement could perhaps be caused by a weak (but sufficiently strong) magnetic field, or by the separation of the two hemispheres of the neutron star surface by an equatorial region, e.g., due to the rapid rotation of the neutron star (giving rise to a lower effective gravity at the equator) or to an as yet unknown effect of an equatorial boundary layer, where the inner parts of the accretion disk are in contact with the neutron star. If this were the case one would not expect that the second peak is always smaller than the first.

We suggest that these double-peaked bursts are the result of either a variation in the rate at which nuclear energy is released in the flashing layer (in the extreme this could be a complete temporary halt of the flash), or of a variation in the rate at which the nuclear energy, produced at the bottom of the neutron star envelope, is transported to the surface.

Theoretical burst profiles have been calculated by Ayasli and Joss (1982). In their models the presence of hydrogen, and its interaction with helium in the thermonuclear flashes, is taken into account. They find that after the ignition of helium there occurs a phase of rapid proton capture on heavy nuclei, produced in the initial helium flash. This gives rise to a slow increase of the X-ray burst flux following a slight decrease of the initial peak of the burst. However, a comparison between the theoretical and the observed double-peak profiles shows that there is a serious difference in the observed rise times of the second peaks (2–4 s), which are much shorter than the modeled rise times of ~ 20 s. Since the theoretical rise times of the second “peak” are determined by the time scales at which energy is released through the proton capture, it seems likely that the observed phenomenon is unrelated.

A small secondary burst was found to occur in some models

of Woosley and Weaver (1983). This postburst activity is the result of mixing mutually combustible layers produced in previous bursts. However, the time scale for the recurrence of the secondary burst in these models is two orders of magnitude larger than the separation between the observed double peaks.

Thus it appears that these double-peaked bursts are another phenomenon unexplained by presently available models. According to numerical simulations of the evolution of accreting surface layers of nonmagnetic neutron stars, a dominant parameter determining the burst behavior is the mass-accretion rate. Apart from the overall result that at the highest accretion rates X-ray bursts do not occur, the models do not account for the observed large variety in burst characteristics, which often occur without any clear correlated changes in the persistent X-ray properties of the burst source (for recent reviews see Lewin 1984, 1985).

The new double-peaked bursts discussed in this paper reinforce the conclusion that, although the variability of the X-ray burst characteristics could, in principle, be a gold mine of information on the physics of thermonuclear flashes and the surface layers of neutron stars, the models against which to calibrate the variety of observational data have not yet reached the level of sophistication required to interpret those data.

VII. CONCLUSIONS

A time-dependent spectral analysis of eight X-ray bursts from 4U/MXB 1636–53, observed with *EXOSAT*, shows that during these bursts the observed apparent blackbody radius is anticorrelated with the blackbody temperature. This can be understood as the result of the non-Planckian character of burst spectra. The model atmospheres of London, Taam, and Howard (1984) give a reasonable first-order description of the apparent radius changes in X-ray bursts.

We observed four double-peaked X-ray bursts which, unlike the previously observed bursts with double-peaked profiles, have a relatively low maximum luminosity and show double peaks in their bolometric profiles. They are not the result of an expansion and subsequent contraction of the photosphere of the neutron star.

These new double-peaked bursts are another phenomenon left unexplained by presently available thermonuclear flash models of X-ray burst.

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