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X-RAY SPECTRAL STUDY OF TWO X-RAY BINARIES: 4U 1957+11 AND 2S 1543−624

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ABSTRACT

The X-ray observations of two binary systems, 4U 1957+11 and 2S 1543−624, by the *EXOSAT* satellite are analyzed. The continuum spectra are best fitted by a superposition of a blackbody spectrum ($kT \sim 1$ keV) and emission from a Comptonized region, consistent with the spectra of low-mass X-ray binary systems. The Comptonization parameters found for 4U 1957+11 are observed to change significantly from $kT_e > 12.5$ keV and $\tau < 4.5$ in the higher intensity state to $kT_e \sim 1.3$ keV and $\tau \sim 22$ in the lower intensity state. The values of kT_e and τ derived for 2S 1543−624 are limited to be >4 keV and <4.8, respectively. A broad line ascribed to be due to the fluoresence of iron is detected in both the objects with an equivalent width of ~60–200 eV. The blackbody radius is ~3.3 km for 2S 1543−624 and ~4.9 km in the case of 4U 1957+11 in its higher intensity state. In an observation of 4U 1957+11 with ~20% lower intensity, the blackbody component was not detected. Some possible interpretations of the results are discussed, and an estimate of $\sim 10^8$ G is derived for the magnetic field on the surface of the neutron star in 4U 1957+11.

Subject headings: binaries: close — stars: individual (4U 1957+11, 2S 1543−624) — X-rays: stars

1. INTRODUCTION

Low-mass X-ray binaries (LMXRBs) are complex systems which exhibit a variety of interesting phenomena. Short-term (minutes to hours) temporal changes include a Z-shaped hardness ratio variation, quasi-periodic oscillations (QPO), and X-ray bursts (van der Klis 1989). On longer timescales, these sources also undergo a change of state. The X-ray and optical spectra can change substantially on timescales of a few hours or days. Several LMXRBs have been studied in detail, but the understanding of the above phenomena remains poor.

There is a subclass of LMXRBs, which have large X-ray to optical flux ratios, featureless optical spectra, UV excesses, and are not known to emit X-ray bursts. These are sometimes referred to as "Sco X-1" types (Mason et al. 1976; Bradt & McClintock 1983). More recently, on the basis of their behavior in a color-color diagram, some of them have been divided into subclasses such as "Atoll sources," "Banana sources," etc. (Hasinger & van der Klis 1989). However, a better insight into the nature of the physical processes occurring in LMXRB can be obtained only by a detailed spectral study and identifying the spectral parameters associated with the changes of intensity. It is also necessary to study the details of as many of these objects as possible and their relationship to the general class of LMXRBs.

In this paper, we have chosen two "Sco X-1" type X-ray sources, 4U 1957+11 and 2S 1543−624, for spectral study. Very few X-ray spectral measurements have been reported for these objects. An accurate position of the object 4U 1957+11 was given by Doxsey et al. (1977). Its optical counterpart was identified as a $V = 18.7$ star by Margon, Thorstensen, and Bowyer (1978). By studying the colors and spectrum of the object, in particular its UV excess, and comparing it with other stars they classified it as a "Sco X-1" type object. Thorstensen (1987) used CCD photometry to find a sinusoidal variation of the optical intensity with a period of 9.3 hr. The amplitude of variation is similar to V818 Sco, the optical counterpart of Sco X-1. By considering various possibilities, he concludes that the observed periodicity is an orbital period. He derives the mass of the companion of the X-ray object as 1 $M_\odot$. White & Marshall (1984) analyzed the X-ray data obtained by the *HEAO 1* A-2 experiment and the Solid State Spectrometer (SSS) aboard the *Einstein Observatory*. In the narrow band of 3–10 keV (*HEAO 1* A-2) the data is fitted with a thermal bremsstrahlung spectrum to yield a $kT = 3.0 \pm 0.3$ keV with an absorption hydrogen column density $N_{\rm H} = (2 \pm 1) \times 10^{21}$ cm^{-2}. A very broad iron line with a width (FWHM) of 2 ± 1 keV and having an equivalent width 200 ± 22 eV was also reported. The SSS observation in the energy range 0.5–3 keV was fitted with a power-law spectrum yielding an energy index, $\alpha = 0.7 \pm 0.2$. Assuming a distance of 7 kpc, they obtained an X-ray luminosity of 5×10^{36} ergs s^{-1}. In the case of the *HEAO 1* observation, the flux beyond 10 keV does not show any hardening. They classified this source along with LMC X-1 and LMC X-3 as an unusually soft X-ray source.

The X-ray source 2S 1543−624 was accurately positioned by Apparao et al. (1978), resulting in an optical identification of the object with a $B \simeq 20$ mag star (McClintock et al. 1978). Further reduction of the error box by the *HEAO 1* modulation collimator confirmed the identification (Reid et al. 1980). This object has not been well studied owing to its optical faintness, but the colors indicate that it could be a "Sco X-1" type. Its X-ray spectrum has been reported by Jones (1977), based on *Uhuru* observations, who fitted a thermal bremsstrahlung model with a kT in the range of 5–7 keV or, alternatively, a power law with α in the range of 0.8–1.8.

In this paper, we present analysis of the *EXOSAT* archival data obtained from two observations of 4U 1957+11 and one observation of 2S 1543−624. In § 2 we present the data, and in § 3 we give our analysis procedure. The results are presented in § 4, followed by a discussion in § 5.

2. THE DATA

The data were obtained from the *EXOSAT* archives on the final observation tapes (FOTs) and contained two long obser-

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vations of 4U 1957+11 performed on 1983 August 27 (1983 day 239, henceforth referred to as 1983/239) and 1985 May 28 (1985/148), and one of 2S 1543−624 on 1984 August 25 (1984/238). The sources were observed using both the medium-energy (ME) detectors and the gas scintillation proportional counter (GSPC) simultaneously. The ME argon (Ar) detectors are sensitive to X-rays in the energy range of 1–20 keV, the ME xenon (Xe) detectors to 5–50 keV X-rays, and the GSPC to 2–16 keV X-rays. The details of the instrument used are given by Turner, Smith, and Zimmermann (1981) for the ME detectors and by Peacock et al. (1981) for the GSPC.

The ME data are normally acquired from Ar- and Xe-filled detectors divided into two half-arrays. The observation of 4U 1957+11 on 1983/239 used only the Argon detectors in one half-array, and the pulse height (PH) data were accumulated using 32 channels. The background data were, therefore, obtained from one half-array while it was "slewing in" and "slewing-out" from the source. The second observation (on 1985/148) utilized both the arrays by swapping the two halves for the source and background measurements. Both the Ar and the Xe spectral data were available in 64 PH channels. The ME observations of 2S 1543−624 were performed similarly using both the halves.

The GSPC data with higher energy resolution were, in all cases, obtained in 256 PH channels. The background was determined from slew data before and after the observation. The energy scale was calibrated using the two instrumental background line features at 10.5 and 12.7 keV (White & Peacock 1988) and by fitting Gaussians to them.

The details of observations, dates and times, effective exposure times, and the detected count rates in different detectors and energy ranges are given in Table 1. The count rate for 4U 1957+11 increased by ~17% in the 1985 observation as compared to the count rate in the 1983 observation. The two observations will be referred to as the "high" and "low" states of 4U 1957+11.

3. ANALYSIS

The data reduction and analysis were performed using the XANADU (X-ray Analysis and Data Utilization) software package. The data were examined for contamination due to non X-ray events and selected suitably. No variations were observed in any given observation on timescales of 50–10,000 s. We have determined the hardness ratios corresponding to the "high" and "low" states of 4U 1957+11 (see § 2). The count ratio (3–6 keV)/(1–3 keV) changes from 0.82 ± 0.01 in the "low" state to 1.16 ± 0.01 in the "high" state, whereas the count ratio (6–17 keV)/(3–6 keV) changes from 0.202 ± 0.008 to 0.215 ± 0.006 in these two states, signifying a harder spectrum in the "high" state. This is further demonstrated by the detailed spectral analysis below.

We have carefully checked the energy scale and mutual calibration of the three detectors (Ar, Xe, and GSPC) as described in detail by Rajeev et al. (1994). The Ar and Xe detectors have been intercalibrated using the Crab Nebula (Smith & Parmar 1985). The gain of the GSPC has been determined accurately by using two background line features at 10.5 keV and 12.7 keV due to the fluorescence in the lead collimator and the radioactive decay of residual plutonium in the beryllium window, respectively (White & Peacock 1988). Small residual discrepancies in the relative calibration of the different detectors were taken care of by applying a systematic error of 1% to the Xe and the GSPC data. No systematics were applied to the Ar data with the best signal-to-noise ratio, as Ar detectors are the best understood of all the *EXOSAT* instruments. The "difference" corrections (see White & Peacock 1988) to the PH spectra were applied where needed, and an excellent background subtraction was obtained in all cases. Additionally, the data from different halves of the ME were kept separate for spectral fitting to avoid any further systematic errors and were combined only for the purposes of plotting them.

The response matrices for the Ar, Xe, and GSPC detectors were made using their gain values on the day of observation. *The data from all the detectors were fitted jointly* by convolving the spectral models with the corresponding response functions. The data were also analyzed for individual detectors, using a combination of Ar and GSPC alone. The addition of Xe data was found to have very little effect on spectral results and served only as a consistency check for the final spectral models. The final results for the best spectral model are based on Ar and GSPC data only. The 90% confidence errors were determined using the $\chi^2_{\rm min} + 7.78$ criterion for four free parameters of interest (Lampton, Margon, & Bowyer 1976).

Simple spectral models, such as power-law, thermal bremsstrahlung, blackbody, and the modified blackbody accretion disk models of Shakura & Sunyaev (1973) and also of Stella & Rosner (1984) failed to provide an adequate fit to the spectral data and were rejected using the χ^2 statistic. A multiplicative absorption model (Morrison & McCammon 1983) for low-energy X-ray absorption due to intervening medium was used

TABLE 1

DETAILS OF OBSERVATIONS

Source Name	Observation Start Time: Year	Day	UT	Effective Exposure (s)	Detector	PH Channels[a]	Count Rate (10^{-2} cm^{-2} s^{-1})
4U 1957+11	1983	239	05:16:38	17738	Ar	2–31	8.40 ± 0.045
	1983	239	04:10:38	24890	GSPC	30–150	3.73 ± 0.043
4U 1957+11	1985	148	17:56:30	33477	Ar	1–60	9.80 ± 0.015
	1985	148	17:56:30	24327	Xe	2–61	0.57 ± 0.037
	1985	148	17:56:44	37039	GSPC	29–143	4.34 ± 0.040
2S 1543−624	1984	238	22:20:00	33345	Ar	1–60	9.96 ± 0.015
	1984	238	22:20:00	33345	Xe	2–61	0.52 ± 0.044
	1984	238	21:40:20	37806	GSPC	29–147	4.36 ± 0.040

[a] The PH channels correspond to energy range of 1–20 keV for Ar, 5–30 keV for Xe, and 2–10 keV for GSPC detectors, respectively.

TABLE 2

ESTIMATE OF SPECTRAL PARAMETERS AND THEIR 90% CONFIDENCE RANGE

	4U 1957+11		2S 1543−624
	1983/239	1985/148	1984/238
N_H (10^{21} cm^{-2})	4.4 (1.6, 7.3)	3.8 (2.4, 5.0)	13.4 (12.8, 14.1)
Blackbody temperature (keV)	...	1.03 (1.02, 1.04)	1.59 (1.57, 1.62)
Blackbody radius[a] (km)	...	4.9 (4.8, 5.0)	3.25 (3.18, 3.33)
kT_e (keV)	1.30 (1.23, 1.37)	34.0 (> 12.5)	37.0 (> 4.0)
Opacity τ	22.3 (19.5, 26.0)	2.1 (< 4.5)	1.16 (< 4.8)
K_{th} (photons cm^{-2} s^{-1} keV^{-1})	0.25 (0.19, 0.32)	0.32 (0.30, 0.34)	1.4 (1.2, 1.6)
Line energy (keV)	...	6.3 (5.9, 6.6)	7.0 (6.5, 7.0)
Width (σ) of line (keV)	...	0.9 (0.5, 1.5)	0.7 (0.1, 1.3)
K_{line} (10^{-4} photons cm^{-2} s^{-1})	...	8.3 (5.7, 13.0)	9.5 (5.6, 13.5)
EW (eV)	...	101 (57, 191)	110 (60, 200)
χ^2_ν (dof)	1.089 (277)	1.38 (377)	1.16 (266)
$F^{b,c}_{total}$ (10^{-9} ergs cm^{-2} s^{-1})	1.0	1.29	1.3
	(1.17)	(1.41)	(2.3)
Blackbody L^a	...	3.5	9.0
$L^{a,b}_{total}$	6.9	8.3	27.5

NOTE.—The 90% confidence range for the parameter values is based on χ^2 + 7.78. K_{th} is the normalization for the CompST component. K_{line} is the peak line flux. F refers to the X-ray flux, and L refers to X-ray luminosity in units of 10^{36} ergs s^{-1}.

[a] Assuming a distance of 10 kpc for 2S 1543−624 and 7 kpc for 4U 1957+11.

[b] For 1–20 keV range.

[c] Flux values in parentheses are corrected for absorption.

throughout. The reduced χ^2, henceforth χ^2_ν, was generally in the range 3 to 20 (or even larger) when any one of these models was used for the data on the objects considered here. An examination of the residuals from a single-component fit pointed very clearly to the requirement of at least two continuum components to improve the χ^2_ν. We adopted a blackbody as one of these components, which has been used quite successfully as one of the spectral components present in many LMXRBs (see White, Stella, & Parmar 1988). For the second component we again tried all the models mentioned above and also the Comptonization model of Sunyaev & Titarchuk (1980) (hereafter CompST), characterized by electron temperature kT_e and opacity τ. We assumed common low-energy absorption for both the components. Combinations of a blackbody with any one of the modified blackbody accretion disk models generally gave very high χ^2 and were unacceptable. In all cases, the best fits were obtained only when the second component was either a power-law model or the CompST model, the two being indistinguishable and equally acceptable based on the χ^2 statistic. There was one exception, however, and that was the 1983/239 observation of 4U 1957+11, which required either a two-component model consisting of a blackbody ($kT \sim 1$ keV) and a very steep power law (energy index $\alpha = 2.6$) or a single-component model consisting of CompST, the latter giving a slightly better fit with $\Delta\chi^2 = 7.6$. We adopted the single-component (CompST) fit as the final result in this case.

The addition of a Gaussian feature, representing line emission, further improved the fits significantly for the 1985/148 data on 4U 1957+11 ($\Delta\chi^2 = 20$) and 1984/238 data on 2S 1543−624 ($\Delta\chi^2 = 22$). Using the F-statistic, we find that the improvements in the χ^2 are significant at better than 99% confidence level. A similar change in the χ^2 is obtained even when other continuum models (see above) are used. Therefore, an emission-line feature near 6 keV has been detected clearly in the two data sets, with the exception of the "low" state data on 4U 1957+11, which did not show any improvement on inclusion of a similar feature. The final results from the spectral fitting are given in Table 2, were the values derived for the model parameters are displayed along with their 90% errors.

The PH data from the two observations of 4U 1957+11 and from the 1984/238 observation of 2S 1543−624 are shown in the top panel of Figures 1, 2, and 3, respectively. The data from the ME and GSPC detectors that were fitted jointly are shown here. The best-fit model is shown as a histogram in these figures. The best-fit model is CompST and multiplicative absorption in Figure 1, and a blackbody+CompST+Gaussian and common multiplicative absorption in Figures 2 and 3. The residuals from this fit are shown in the middle panel of Figures 1, 2, and 3. The residuals testify to the goodness of the fits. The presence of the line feature is shown in the bottom panels of Figures 2 and 3, using the ME data alone for clarity and after subtracting the best-fitted continuum model from the joint fit. The line is at 6.25 ± 0.35 keV for 4U 1957+11, and close to 7 keV for 2S 1543−624.

The deconvolved X-ray spectra from 4U 1957+11 and 2S 1543−62 are shown for all the observations in Figures 4, 5, and 6, respectively. For clarity, the data are based on Ar detectors in the case of 1985 and 1984 observations and on the GSPC detectors in the case of 1983 observations where the ME channels were too few. The model used is, however, based on the joint fitting to data from Ar and GSPC detectors. These figures show the relative contribution of all the spectral components identified in the above analysis.

4. RESULTS

The X-ray continuum is generally best fitted with a two-component model consisting of blackbody radiation and emission from a Comptonized region with a common low-energy absorption, as has been found for many other low-mass X-ray binaries (White et al. 1986, 1988). The blackbody is not detected along with the CompST component in the "low" state of 4U 1957+11. Forcing a 1.0 keV blackbody along with the CompST resulted in the blackbody flux being at least a factor of 4 lower than in the "high" state, which implies

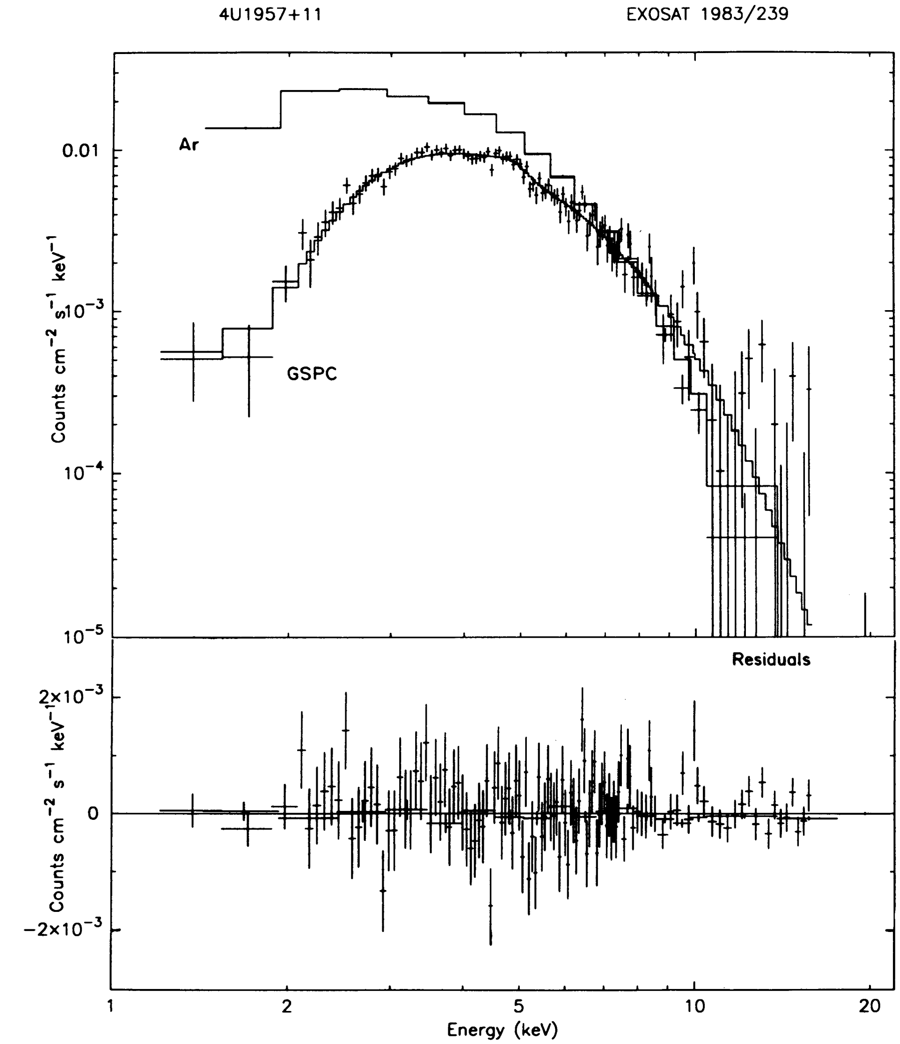

FIG. 1.—*EXOSAT* ME Ar and GSPC data from the 1983 August 27 observation of 4U 1957+11 are shown in the top panel. The best-fit model consisting of a Comptonization model (see text) convolved with the different response functions of the detectors is shown as a histogram. Residuals from the above fit are shown for data from all the detectors in the lower panel.

a strong variability of the blackbody component. The blackbody temperature is 1 keV for 4U 1957+11 and 1.6 keV for 2S 1543−624. The equivalent hydrogen column density, $N_{\rm H}$, responsible for the low-energy X-ray absorption is found to be nearly 10 times higher than the 21 cm value (Stark et al. 1992) in the case of 2S 1543−624. For 4U 1957+11, however, the corresponding value deduced by us is slightly higher but within a factor of 2 of the 21 cm value (Stark et al. 1992) and consistent with the previous measurements by White & Marshall (1984). The distance of 4U 1957+11, given by reddening measurements (Margon et al. 1978), is about 7 kpc, whereas the distance of 2S 1543−624 is unknown, but we have adopted a value of 10 kpc. With these values for the distance, the total X-ray luminosities are estimated to be (6.9–8.3) × 10^{36} ergs s^{-1} for 4U 1957+11 and 2.7 × 10^{37} ergs s^{-1} for 2S 1543−624. Their blackbody radii are then estimated to be 5 km and 3 km, respectively. The ratio of the blackbody luminosity to the total luminosity is ∼0.42 for 4U 1957+11 in its "high" state and <0.10 in the "low" state, whereas it is ∼0.33 for 2S 1543−624.

The parameters for the Comptonized plasma, kT_e and τ, are not constrained too well due to the poor sensitivity at very high energies but do show a significant change in the "high" and "low" states of 4U 1957+11. The kT_e is higher in the "high" state, but the τ is lower. The resulting Comptonization parameter, $y = 4kT_e \tau^2/m_e c^2$, is, however, ≤2 in the "high" state and 5 in the "low" state. This trend is similar to that found in Cygnus X-3 (Rajeev et al. 1993), where the "high" and "low" states are more sharply defined. These results also imply saturated Comptonization in 4U 1957+11. The value for the y parameter, in the case of 2S 1543−624, is ≤0.7 and indicates that Comptonization is less saturated than found in 4U 1957+11.

Line emission is clearly detected near 6 keV in the "high" state data of 4U 1957+11, and near 7 keV from 2S 1543−624. For the "low" state observation of 4U 1957+11, we derive a 90% confidence upper limit for the line flux of 6 × 10^{-4} photons cm^{-2} s^{-1}. The uncertainty in the line energy allows us to place its origin in the fluorescence of cold iron in the case of 4U 1957+11 and the fluorescence of ionized iron (Fe XX to

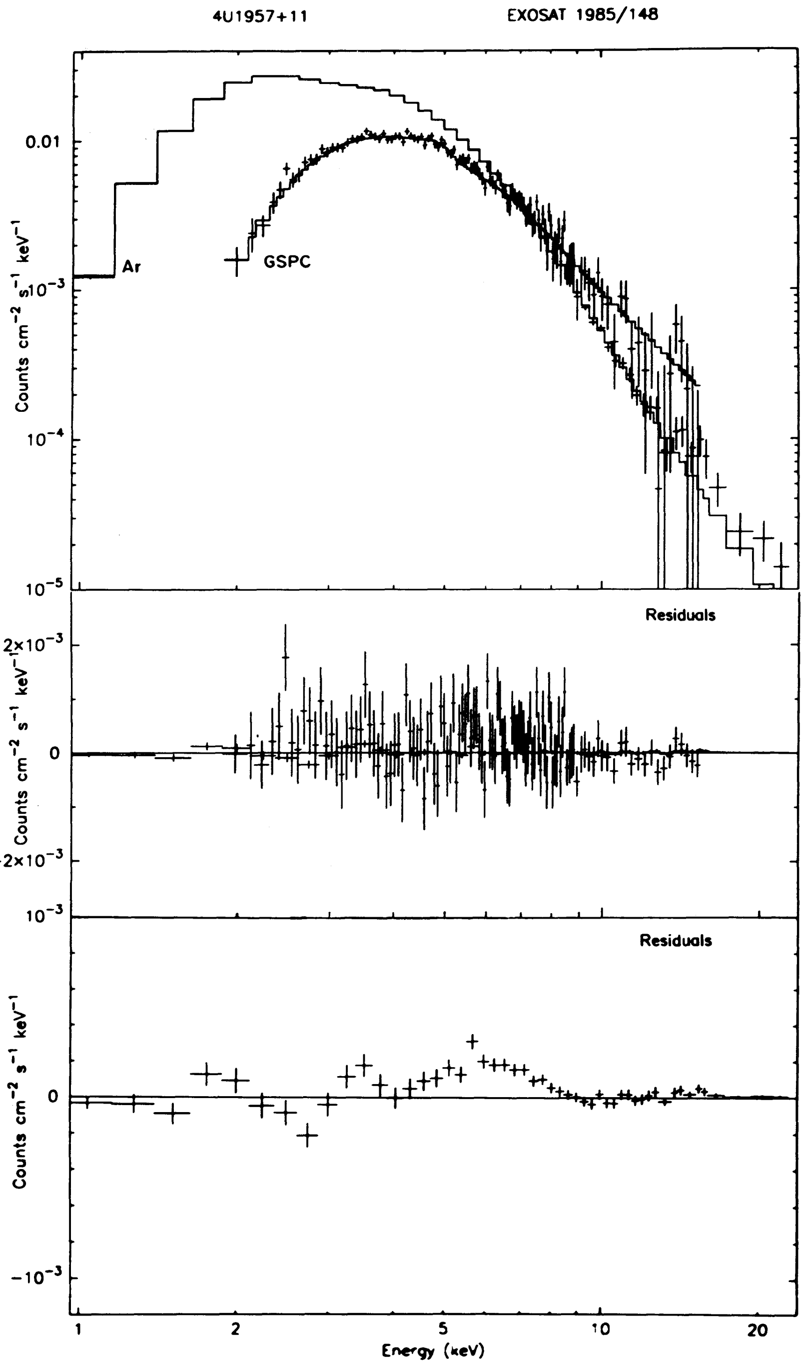

FIG. 2.—*EXOSAT* ME Ar and GSPC data from the 1985 May 28 observation of 4U 1957+11 are showin in the top panel. The best fit model consisting of two continuum components (see text) and a Gaussian line, convolved with the different response functions of the detectors, is shown as a histogram. Residuals from the above fit are shown for data from all the detectors in the middle panel. The bottom panel shows residuals from the best-fit continuum model for the ME Ar detector, to display the line feature clearly.

XXVI) in 2S 1543−624. This implies a very high value ($\simeq 10^3$) for the ionization parameter in 2S 1543−624 (Kallman & McCray 1982). The equivalent width of the lines is ~100–200 eV in both the sources. The lines are very broad, the FWHM being $\simeq$1.0–3.0 keV (90% confidence range) for 4U 1957+11 and 0.25–2.8 keV (90% confidence range) for 2S 1543−624. The large width in the case of 4U 1957+11 is, however, consistent with the value of 2 ± 1 keV reported by White & Marshall (1984) based on the *HEAO 1* data.

5. DISCUSSION

The nature of the X-ray spectra of several binary X-ray sources was considered by White, Stella, & Parmar (1988). The binaries included bursters, LMXRBs, and black hole candidates. In the case of the bursters, the persistent emission was studied. They divided the sources into low-luminosity and high-luminosity systems. The best fits to all the spectra were obtained. They found that the low-luminosity systems and the

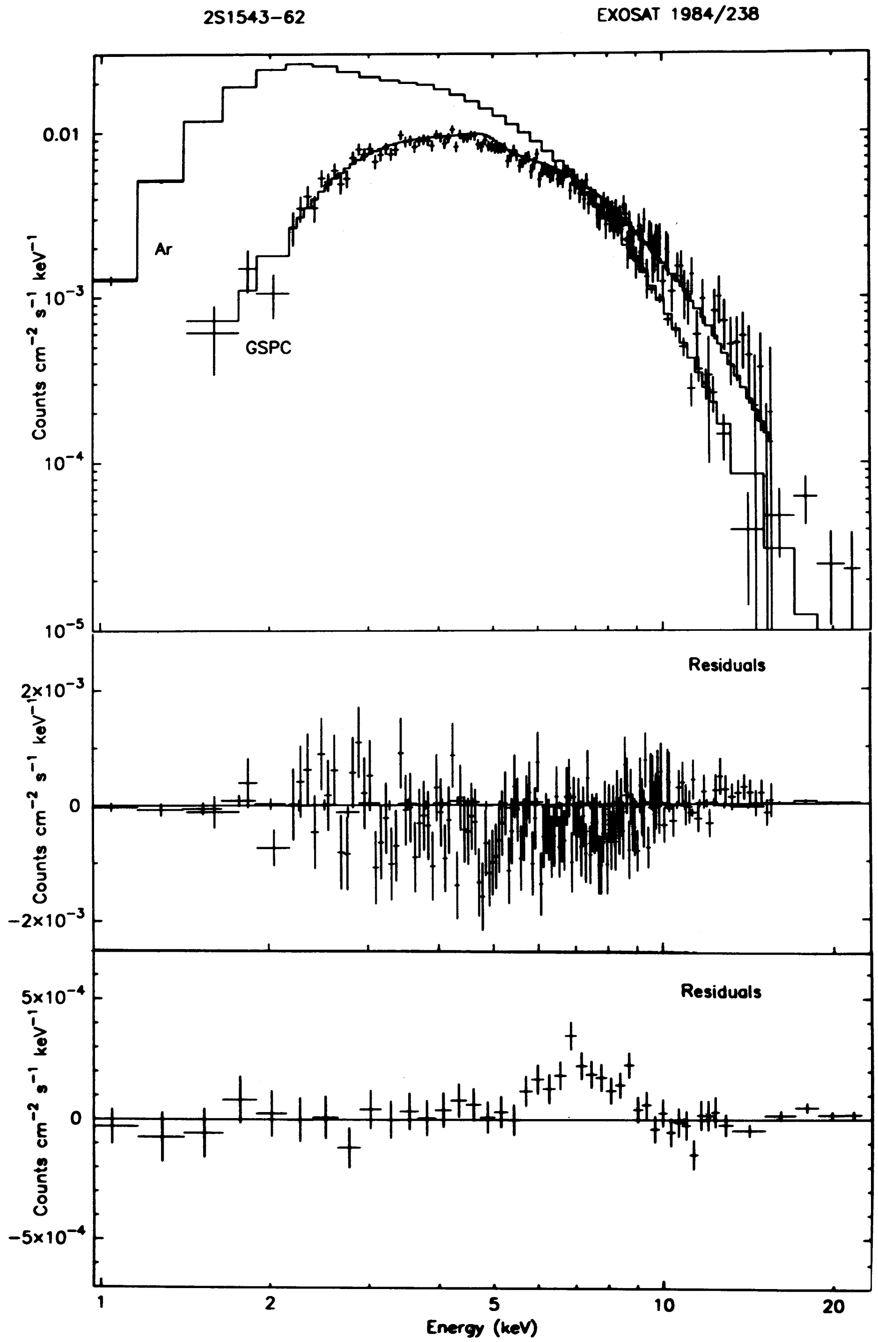

FIG. 3.—Same as in Fig. 2 for the 1984 August 25 observation of 2S 1543−624

black hole candidates could be best fitted with a CompST spectrum (Sunyaev & Titarchuk 1980). The high-luminosity systems needed two components—a blackbody emission and a CompST component. In the case of some high-luminosity systems, the strengths of the two components depended on the intensity of X-ray emission (high-low states). White, Stellar, & Parmar (1988) suggest that the CompST is the result of a two-temperature disk (Shapiro, Lightman, & Eardley, 1976) which is thick in the inner regions. The blackbody component is suggested to be due to a hot region produced in a boundary layer, where the disk meets the neutron star. A possible interpretation in this picture is that in the case of a low-luminosity system the magnetic field, though considered small in LMXRBs, is enough to keep the disk away from the surface of the neutron star, resulting in no blackbody emission. In the case of the high-luminosity systems, the higher accretion rate results in the disk reaching all the way to the surface. This picture is in agreement with the fact that black hole candidates need only a CompST component to fit their spectra.

5.1. *Comparison with Other LMXRB*

A comparison of results here with the results for the various systems reported by White et al. (1988) and others based on a similar analysis is quite interesting. The CompST parameters

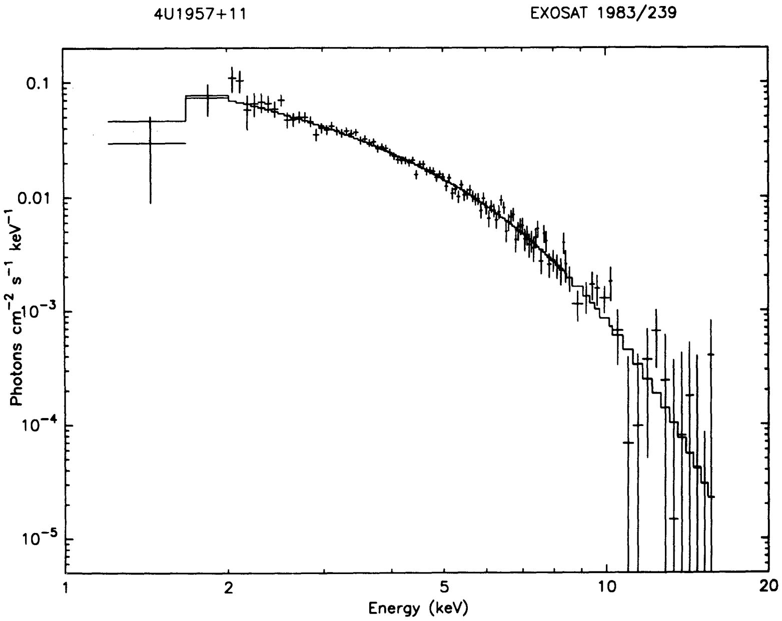

FIG. 4.—Deconvolved best-fit spectrum for 4U 1957+11 based on a joint fit to Ar and GSPC data from the 1983 August 27 observation, but shown using GSPC data only for clarity.

for 4U 1957+11 (low kT_e and high τ) in the "low" state are remarkably similar to those of black hole candidates LMC X-3 and X1755−33, and its earlier spectral measurements by White & Marshall (1984) suggested it to be a potential black hole candidate even though it is ~30 times fainter than the above mentioned candidates. The detection of a blackbody in the "high" state, however, makes this possibility unlikely. The limits for kT_e and τ derived for 4U 1957+11 and 2S 1543−624 imply much higher values when compared to the values derived by White et al. (1988) for all but one of the systems, viz., XB 1608−52, studied by them. Similar high values for kT_e and τ have, however, been found for high-luminosity systems Cyg X-1 (Done et al. 1992) and Cyg X-3 (Rajeev et al. 1993). The blackbody temperature radius, and luminosity fraction obtained for 4U 1957+11 and 2S 1543−624 are similar to that found in Sco X-1 and many other LMXRBs (see White, Peacock, & Taylor 1985; White et al. 1986).

5.2. 4U 1957+11

A significant result obtained here is the change in the spectral parameters in the two different states of 4U 1957+11. In the higher intensity state there is a blackbody component

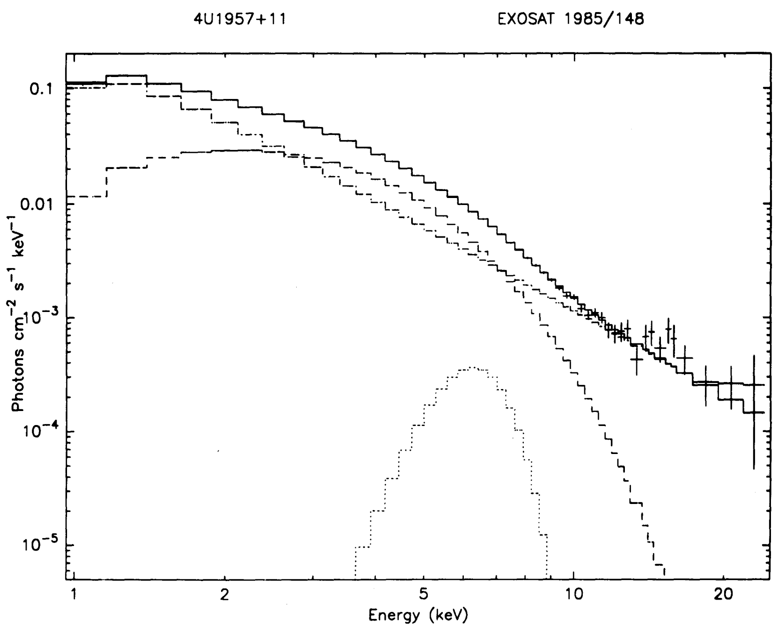

FIG. 5.—Deconvolved best-fit spectrum for 4U 1957+11 based on a joint fit to Ar and GSPC data from the 1985 May 28 observation, but shown using Ar data only for clarity. The contribution from the individual model components, blackbody (*dashed lines*), CompST (*dash-dot lines*) and Gaussian (*dotted lines*) are shown.

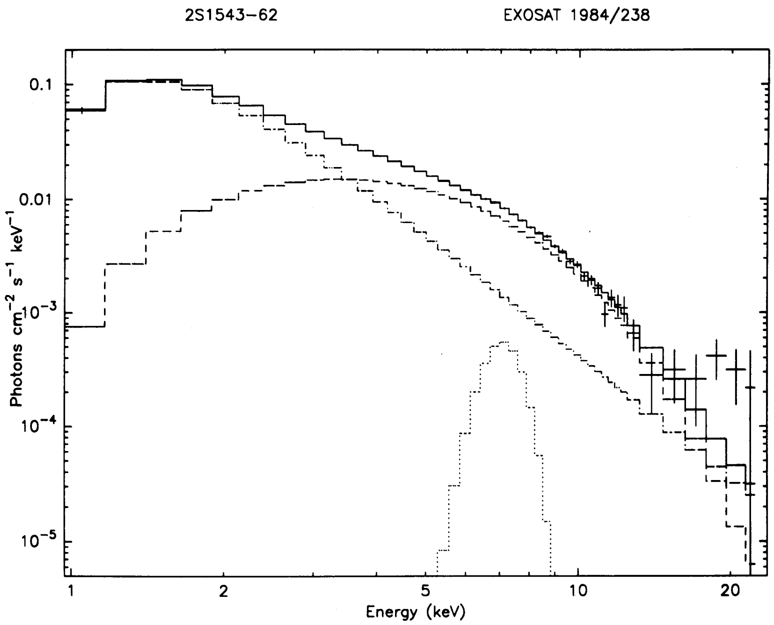

FIG. 6.—Same as in Fig. 5 but for 2S 1543 – 624 from the 1984 August 25 observations

together with a Comptonized component with a high kT_e and small τ. In the lower intensity state the blackbody is either absent or very faint, and the Comptonized component has low kT_e and large τ. A possible interpretation of these observations is as follows. In the higher intensity state, the blackbody component is from a boundary layer, and CompST is due to Comptonization in a two-temperature thick disk (Shapiro et al. 1976). In the lower intensity state, there exists only a thin disk, whose blackbody emission is Comptonized by the corona over the disk, the blackbody component being reduced below the detection level by the large Comptonization thickness τ. The above picture is consistent with the high kT_e and the small τ in the higher intensity state and vice versa in the lower intensity state.

If the above picture is accepted, then the accretion rate in the two observations must be quite close to the critical value, when the inner regions of the disk just overcome the magnetic field pressure and touch the surface of the neutron star. One can then make an estimate of the surface magnetic field strength of the neutron star, B_0. The pressure P_D due to the disk on the inner surface is

$$P_D \simeq \rho v_r v_K 2\pi r h ,$$

where ρ is the density, v_r is the radial velocity of the gas at the distance r, v_K is the Keplerian velocity, and h is the height of the disk. One can substitute $2\pi r \rho v_r h$ by $\dot{m}$, the accretion rate. Also, $v_K = (2GM/r)^{0.5}$, giving

$$P_D \simeq \dot{m}(2GM/r)^{0.5} .$$

The magnetic field interacts with the disk in a region of width δ of the inner disk (see Ghosh & Lamb 1991 and references therein). Then the magnetic pressure opposing the inward movement of the disk is

$$P_M = (\mu^2/8\pi r^6)2\pi r\delta ,$$

where μ is the magnetic moment of the neutron star. Equating P_M and P_D gives

$$\mu^2 = [4\dot{m}r^{9/2}(2GM)^{0.5}]/\delta .$$

We can rewrite this as

$$\mu^2 = [4\dot{m}R_*^{7/2}(2GM)^{0.5}]/(\delta/R_*) ,$$

using $\dot{m} = 8 \times 10^{16}$ g s^{-1} corresponding to the observed X-ray luminosity, $r = R_* = 10^6$ cm (the radius of the neutron star) and $M = 1\ M_\odot$, we get

$$\mu \simeq 7 \times 10^{25}/(\delta/R_*)^{0.5} .$$

The value of (δ/R_*) is estimated to lie between 0.1 and 1.0 (see Ghosh & Lamb 1991 and references therein). The value of μ will then be between 7×10^{25} and 2×10^{26}, yielding a value of $B_0 \sim 10^8$ G. This estimate of the surface field strength of the neutron star is consistent with the expectation that LMXRBs have lower field strengths than X-ray pulsars, where field strengths have a value close to the canonical value of 10^{12} G.

5.3. *Line Emission*

The two sources, 4U 1957+11 and 2S 1523–624, show weak but very broad lines due to iron fluorescence. The line widths and the equivalent widths are similar (within the 90% confidence range) to those seen in Sco X-1 and other systems of the same type (White et al. 1986). The results presented here also confirm the unusually large width for 4U 1957+11 reported earlier by White & Marshall (1984). The large width of the line could be due to blending of lines in a highly ionized region and to electron scattering in the CompST region (Kallman & White 1989). The reduction in the line emission, to undetectable levels, in the "low" state of 4U 1957+11 is perhaps related to the overall softening of the spectrum with fewer photons above 7 keV (see George & Fabian 1991) or to the reduced brightness of the blackbody itself. Although the first explanation is the simplest, the latter is also consistent with the above picture, where the blackbody is shining on the gas away from the neutron star and producing fluorescence of iron. The line photons produced, in the cold disk in the case of 4U 1957+11 and in the hot ionized regions of the disk in the case of 2S 1543–624, are most probably broadened as these traverse through outer zones of the "structured" disk. These outer regions then need to be highly ionized and have sufficient electron temperature and opacity to broaden the line due to Comptonization.

The equivalent width found for the iron line is fairly large in both the systems. The absence of an absorption edge favors a face-on configuration for the disk in both the systems (Vrtilek, Soker, & Raymond 1993).

Finally, we wish to point out that more observations with wide energy bandwidth instruments, such as those planned to be launched on XTE, would be of great value in a better understanding of these binary systems.

6. CONCLUSIONS

1. The two X-ray binaries, 4U 1957+11 and 2S 1543−62, conform to the general spectral classification of LMXRBs, i.e., emission from a blackbody and a Comptonized region give the best fits (White et al. 1988; Rajeev et al. 1993).

2. A significant change in the spectral parameters is found for 4U 1957+11 in two intensity states. In a lower intensity state, a saturated Comptonization spectrum alone gives the best fit.

3. The above change of spectral parameters is interpreted as a transition from a thick disk to a thin disk and used for estimating the surface magnetic field of the neutron star in 4U 1957+11.

More observations with wide energy bandwidth instruments, such as those planned to be launched on XTE, would be of great value in a better understanding of these binary systems.

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