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XTE J1739−302: AN UNUSUAL NEW X-RAY TRANSIENT

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ABSTRACT

A new X-ray transient, designated XTE J1739−302, was discovered with the proportional counter array on the *Rossi X-Ray Timing Explorer* in data from 1997 August 12. Although it was the brightest source in the Galactic center region while active (about 3.0×10^{-9} ergs cm^{-2} s^{-1} from 2 to 25 keV), it was only observed on that one day; it was not detectable 9 days earlier or 2 days later. There is no known counterpart at other wavelengths, and its proximity to the Galactic center will make such an identification difficult due to source confusion and extinction. The X-ray spectrum and intensity suggest a giant outburst of a Be/neutron star binary, although no pulsations were observed and the outburst was shorter than is usual from these systems.

Subject headings: accretion, accretion disks — stars: neutron — X-rays: stars

1. INTRODUCTION

Most bright X-ray transients lasting days or weeks come from two kinds of systems: black hole binaries with a low-mass companion (X-ray novae) and neutron star binaries with a high-mass, Be-type companion (Be/NS). In the latter systems, the neutron star is in a relatively wide, often eccentric orbit, and the outburst occurs at the orbital phase when the neutron star passes through the dense equatorial wind of the Be star, accreting wind material. These systems can be distinguished from each other and from rarer kinds of transients by neutron star pulsations (if present), by optical observations of the companion (if available), by regularity of recurrence (which indicates a Be/NS binary), by a weak secondary outburst peak (which is a signature of an X-ray nova), or by their X-ray spectra (see §§ 5 and 6).

We report a new X-ray transient in the Galactic center region. This source, XTE J1739−302, was discovered in an observation of the black hole candidate 1E 1740.7−2942 with the proportional counter array (PCA) on the *Rossi X-Ray Timing Explorer* (*RXTE*). The transient was initially reported in an IAU Circular (Smith et al. 1997a), with a corrected position reported later (Smith 1997), unfortunately after radio observations of the original field (Hjellming 1997).

On 1997 August 12 at 16:58 UT, the PCA scanned its 1° FWHM field of view toward a weekly observing position near 1E 1740.7−2942, approaching almost exactly along a line of constant right ascension. The count rate, instead of rising smoothly from the background level as 1E 1740.7−2942 entered the field of view, instead rose much higher just before the end of the scan, came back down, and leveled off at a rate over twice that expected for 1E 1740.7−2942 after background subtraction (Fig. 1). This indicated a bright source positioned just before 1E 1740.7−2942 in the scan direction but still within the field of view of the PCA once it came to rest.

Two days later, on 1997 August 14, another scan passed within 0°.55 of XTE J1739−302, but no peak was seen. This sets a 3 σ flux upper limit of about 4% of the flux on August 12 at 16:58 UT. The limit for August 3 can be derived from Figure 1: the rms variation from week to week in the observed flux from 1E 1740.7−2942 (not counting the August 12 data point) is 8 counts s^{-1}. Since the August 3 observation is, in fact, lower than average, the upper limit for XTE J1739−302 on this day is even stricter than the 3 σ variation of 24 counts s^{-1}, or 14% of the August 12 flux of XTE J1739−302.

Data from the Wide-Field Camera on *BeppoSAX* show no detection of the source on September 6, with an upper limit of 20 mCrab from 2 to 10 keV, roughly 30% of the outburst flux.

2. SOURCE LOCATION

A single scan allows good determination of source position along the scan direction but not in the perpendicular direction. Fortunately, another *RXTE* investigation (F. Marshall 1998, private communication) had scanned along the Galactic plane at a Galactic latitude of 0°.25 earlier the same day (14:25 UT). Figure 2 shows the two scans, the positions of some well-known X-ray sources, and the position we eventually fitted for the new source. Figure 3 shows the count rates during each scan. Together, the two scans provide a good localization.

To find the position, we set up a grid of candidate positions spaced 0°.01 apart. For each candidate position, we used the standard PCA data analysis tool "pcaclrsp" to find the collimator response versus time for each scan. The same tool was used to find the response to 1E 1740.7−2942. Since the Galactic plane emission is more complicated, we used a different approximation for each scan. For the scan along right ascension, we modeled the Galactic plane emission as decaying exponentially in Galactic latitude with an adjustable scale height (Yamasaki et al. 1996). For the scan along Galactic longitude, we are only concerned with the excess at the Galactic center compared to the rest of the plane emission (Yamauchi et al. 1990). We modeled this as a Gaussian with an adjustable FWHM.

For each scan, we fitted the data with the sum of a constant background (a good approximation) and multiples of the model light curves for 1E 1740.7−2942, the Galactic emission, and the new source. This gave four normalization parameters for each scan. By fitting these separately, we allowed the sources to vary in intensity between the two scans without affecting the final result. Although the Galactic diffuse emission is not

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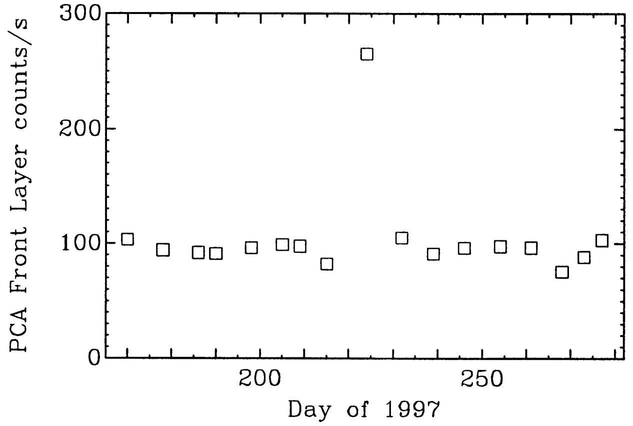

FIG. 1.—Count rates from weekly PCA pointings toward 1E 1740.7−2942. Both instrumental and Galactic diffuse background have been subtracted. The high point is the August 12 observation. Statistical errors are smaller than the symbols used for the data points.

variable, it also had to be fitted separately because it was treated differently for the two scan directions. Repeating this process for each point on the grid of candidate positions, we found the best-fit position for the new source to be right ascension $17^h39^m00^s$, declination $-30°16'.2$ (J2000).

The 99% statistical confidence interval for this fit is an oval with radii 1'.5 in right ascension and 2'.2 in declination (both in true minutes of arc and calculated assuming two parameters of interest). There are, however, two sources of systematic error: the modeling of the diffuse emission and intensity fluctuations in the source.

As modeled, the FWHM of the Galactic center Gaussian was 1° and the scale height of the Galactic Plane exponential was 3°. The best-fit position of XTE J1739−302 is very insensitive to these parameters and varies by less than 1′ even as the Gaussian width varies from 0° to 2° and the exponential scale height varies from 1° to 5°.

Because the source shows low-frequency noise (see below), a fluctuation of the same timescale as the scan across the source could distort its apparent position. To estimate the size of this effect, we used the relatively long (1300 s) stretch of data after the scan to 1E 1740.7−2942 had reached its observing position (see Fig. 4) to represent the likely "population" of fluctuations. This light curve was smoothed to eliminate the high-frequency

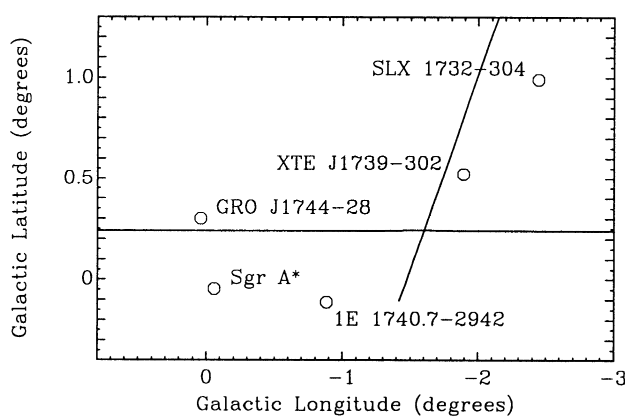

FIG. 2.—Map of the Galactic center region showing well-known X-ray sources, the two scans from 1997 August 12, and the resulting position fitted for XTE J1739−302. GRO J1744−28 (the bursting pulsar) and SLX 1732−304 (an X-ray burster in Terzan 1) were not active at this time.

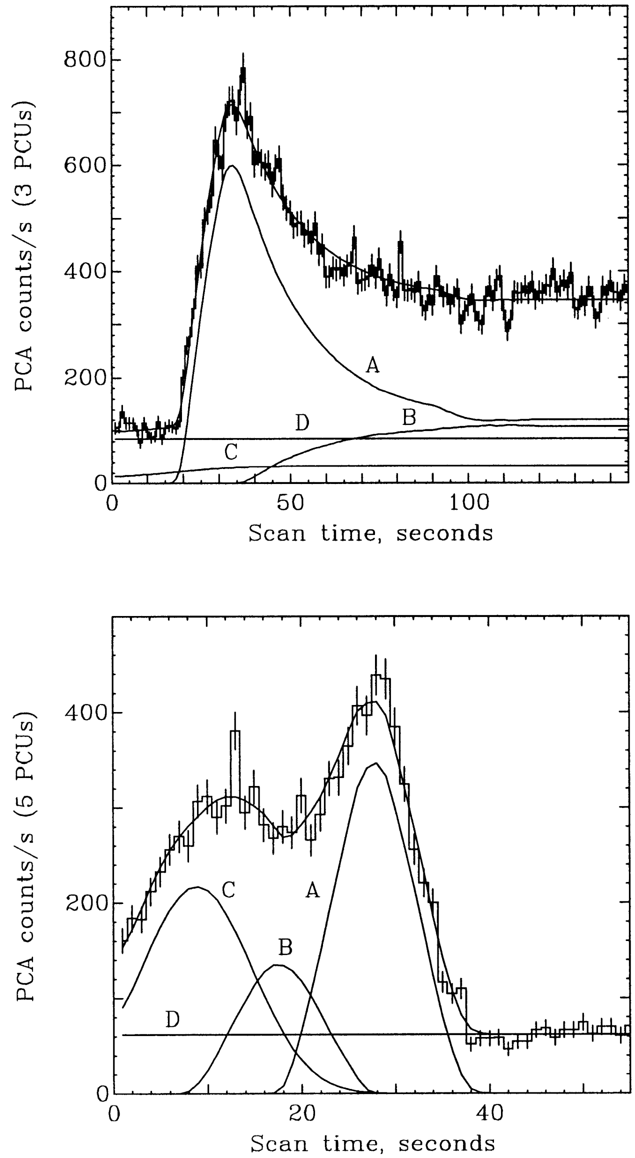

FIG. 3.—PCA count rates during the two scans over XTE J1739−302. *Top:* Scan at nearly constant right ascension. *Bottom:* Scan at constant Galactic latitude. The best-fit curve for each is made up of a sum of four contributions, each in the form of a collimator response times an intensity. The four components are also shown and labeled as follows. Line A: XTE J1739−302 in its best-fit position; line B: 1740.7−2942; line C: Galactic center diffuse emission (a different component in each plot—see text); line D: a constant instrumental background.

(mostly statistical) noise and sampled at random positions to provide percentage fluctuations that could be introduced to each of the two short stretches of scan data. This process was repeated many times to get a distribution of best-fit positions. The contour that encloses 99% of these trials has radii 4'.5 in right ascension and 4'.2 in declination, which shows that this is the dominant source of uncertainty. Adding in quadrature the three contributions from statistics, modeling, and fluctuations, we find an overall 99% confidence contour that is almost perfectly circular, with a radius of 4'.8.

3. LUMINOSITY

The luminosity of XTE J1739−302 is also obtained from the fits for each scan. For the scan at 16:58 UT, the counting rate at the peak of the collimator response to XTE J1739−302

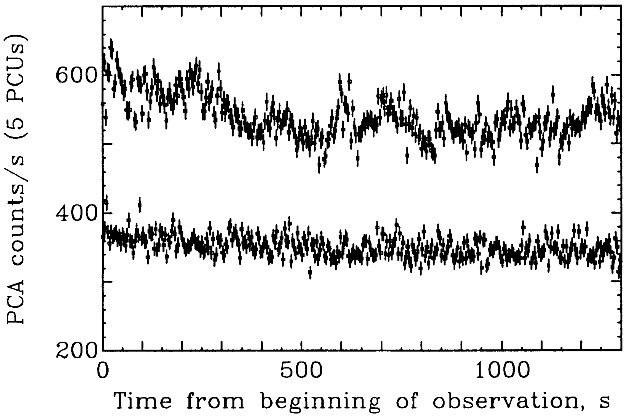

FIG. 4.—Raw count rates in 4 s intervals during the pointings toward 1E 1740.7−2942 on August 12 (*top*, including XTE J1739−302) and August 20 (*bottom*, typical of all 1E 1740.7−2942 pointings). Unlike Fig. 1, these rates include instrumental and Galactic diffuse background.

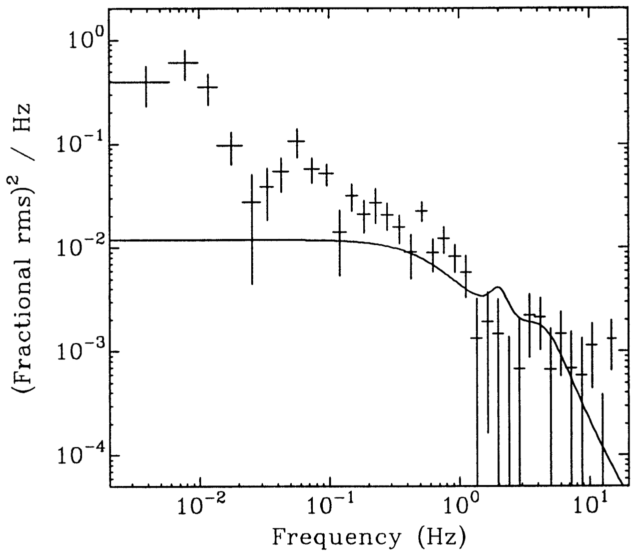

FIG. 5.—Power spectrum of the August 12 observation. Fractional rms is expressed relative to the count rate due to XTE J1739−302 alone. Poisson noise has been subtracted. The curve shown is the power spectrum of 1E 1740.7−2942 from Smith et al. (1997b) rescaled so that it could be directly subtracted.

is 600 counts s^{-1} using three of the five detectors of the PCA (the other two were not turned on until the scan ended). For the best-fit position, this represents a collimator response of 91%; thus, the PCA count rate for all five detectors pointed directly at the source would have been 1100 counts s^{-1}. During the Galactic plane scan only 2.55 hr earlier, the flux was only 56% of this value. We cannot know if we caught the source turning on or if it had large-amplitude variations during a longer active period.

Assuming a thermal bremsstrahlung spectrum (see below), the X-ray flux from 2.5 to 25 keV is 3.0×10^{-9} ergs cm^{-2} s^{-1}. Removing the effect of the absorption column, this becomes 3.6×10^{-9} ergs cm^{-2} s^{-1}, or 2.1×10^{-9} ergs cm^{-2} s^{-1} from 2 to 10 keV and 4.8×10^{-9} ergs cm^{-2} s^{-1} from 2 to 100 keV. Both the position and absorption column (see below) support a location near the Galactic center, so assuming a distance of 8.5 kpc, the 2–100 keV luminosity is 4.2×10^{37} ergs s^{-1}.

4. TIMING

Figure 4 shows the light curve of the August 12 1E 1740.7−2942 observation once the scan ended, with the August 20 observation shown for comparison. It is apparent that the source contributing the additional flux has significant low-frequency noise. Figure 5 shows the August 12 power spectrum along with a fit to the power spectrum from a long observation of 1E 1740.7−2942 alone (Smith et al. 1997b). The total rms variability of XTE J1739−302, removing the effects of Poisson statistics and the usual variability of 1E 1740.7−2942, is 13%, integrated from 0.003 to 10 Hz. We have examined the power spectrum with fine frequency resolution from 0.01 to 1000 Hz and find no statistically significant periodicities or quasi-periodic oscillations. We can exclude with at least 99% confidence pulsations with an amplitude above 2% for any period shorter than 300 s.

5. SPECTRUM

We were able to remove the spectral contributions from Galactic diffuse emission and 1E 1740.7−2942 with high confidence by subtracting a spectrum constructed from six of the pointings shown in Figure 1, three before and three after the August 12 event. Both the intensity and spectral shape of 1E 1740.7−2942 have been quite stable over the last 2 yr.

Despite the lack of pulsation, the energy spectrum of XTE J1739−302 is well fit by the models that have been historically used for X-ray pulsars. The one most commonly used (e.g., White, Swank, & Holt 1983) has been a power law with energy index α and an exponential cutoff (i.e., $E^{-\alpha-1}\exp[(E_c - E)/E_f]$ photons cm^{-2} s^{-1} above E_c and just the power law below E_c). We find $\alpha = (0.38 \pm 0.12)$ (i.e., a photon index of −1.38), $E_c = (6.6 \pm 0.8)$ keV, and $E_f = (21.4 \pm 4.5)$ keV. The very low reduced χ^2 (0.78) indicates that five parameters may not be needed. Figure 6 shows the count spectrum from 2.5 to 25 keV and an optically thin thermal bremsstrahlung (OTTB) model from XSPEC (Arnaud 1996) that has only three parameters (temperature, normalization, and absorption column). The XSPEC model is taken from Kellogg, Baldwin, & Koch (1975). The fit is very good ($\chi_r^2 = 1.075$ for 49 degrees of freedom). The fit temperature is (21.6 ± 0.8) keV. A common approximation to a bremsstrahlung spectrum at high energies is $E^{-1}\exp[-E/kT]$. This also fits well ($\chi_r^2 = 1.054$), giving $T = (12.4 \pm 0.3)$ keV. Each model included an absorption column; the values were (5.3 ± 0.7), (6.2 ± 0.2), and $(5.1 \pm 0.2) \times 10^{22}$ cm^{-2}, respectively, which is consistent with the position near the Galactic center.

Other spectral forms can be excluded. A power law is a poor fit ($\chi_r^2 = 2.347$), as is a multicolored disk model ($\chi_r^2 = 3.072$). We also tried the sum of these two, as representative of a typical black hole spectrum. The fit is good ($\chi_r^2 = 0.674$), but this is to be expected when using a five-parameter model for a spectrum that was fitted well by a three-parameter model (OTTB). The resulting parameters are not typical of black hole candidates: the power-law photon index (1.0) and disk blackbody temperature (3.3 keV) are both harder than any ever seen. We therefore do not consider this fit physically meaningful.

6. DISCUSSION

Most bright Galactic X-ray transients are either black hole candidates or binaries consisting of a Be star and a neutron star (Be/NS). We tentatively identify XTE J1739−302 as a Be/NS binary because its spectral shape is similar to that of these systems: a gradual steepening over the 2–25 keV range. In this

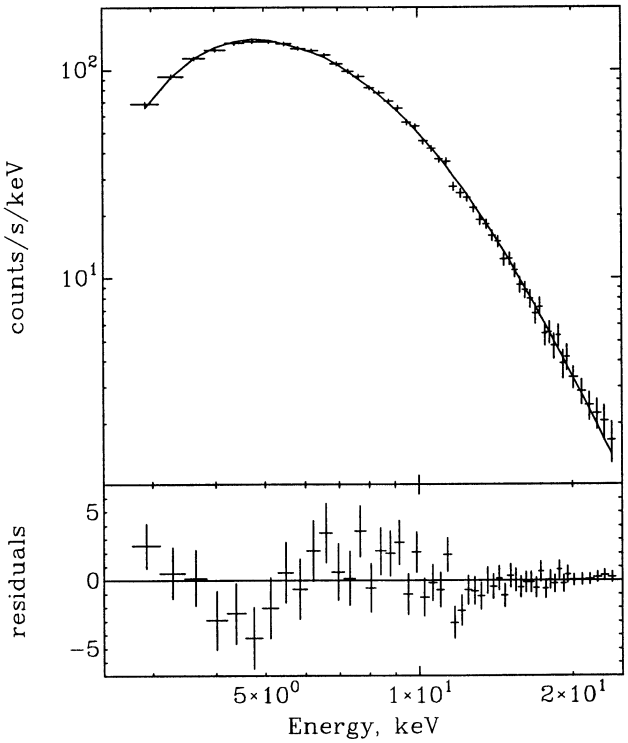

FIG. 6.—XTE J1739−302 count spectrum (1E 1740.7−2942 and background subtracted), best-fit thermal bremsstrahlung spectrum, and residuals from XSPEC. The collimator response has been removed, so this is the equivalent on-axis intensity.

energy range, the black hole candidates show either two distinct components (a very soft thermal component and a power law) or else a single, very hard power law. Our parameters for the cutoff power-law model of the XTE J1739−302 spectrum fall within the ranges of the X-ray pulsars listed in White, Swank, & Holt (1983), which include Be/NS binaries. Our temperature for the exponential approximation to a bremsstrahlung spectrum (12.4 keV) is near the low end of the ranges of GS 0834−430 (12–18 keV; Wilson et al. 1997) and A0525+262 (14–22 keV; Finger, Wilson, & Harmon 1996) measured with BATSE. As noted above, spectral forms typical of black hole candidates were either poor fits or gave parameters far from the usual range.

With the OTTB model used in § 5, the luminosity from 20 to 50 keV (1.05×10^{37} ergs s^{-1}, about one-fourth of the 2–100 keV luminosity) is at the high end of the expected range for a “giant” outburst of a Be/NS binary (Bildsten et al. 1997). The short duration (less than 11 days) would be not be typical for a giant outburst (Bildsten et al. 1997), although one giant outburst of A0535+262 was only 18 days long (Sembay et al. 1990). With no detected pulsations and such a short sample of data, we cannot distinguish between a normal and giant outburst by spin-up rate.

If we caught the source turning on, then at less than 2 days it is not similar to any common class of transient, although the light curve is consistent with that recently observed from XTE J0421+560 = CI Cam (Smith et al. 1998). That bright transient showed a fast rise over hours followed by an exponential decay with a time constant on the order of a day (quick-look results provided by the ASM/*RXTE* team). Otherwise, it behaved very differently from XTE J1739−302, showing a bright Fe-K line and no time variability aside from its smooth decay (Belloni et al. 1998). What the events have in common is that they underscore the need for very frequent monitoring and very fast response in the study of Galactic X-ray transients.

If we are correct in the spectral identification of XTE J1739−302 as a Be/NS binary, the pulse period may simply have been too long (greater than 300 s) to be seen in our short (1300 s) stretch of data, but the lack of detection could also be due to a very low pulsed fraction. A pulsed fraction of only 4%–6% rms was seen in X0331+53 (= V0332+53 = BQ Cam) along with flat-topped noise with a total rms of 25% from 0.01 to 1 Hz (Makishima et al. 1990). Our power spectrum is similar to that of the A0535+262 outburst of 1980 October with its pulsed component removed (Frontera et al. 1985). Although that power spectrum had a broad peak around 0.05 Hz detected with more significance than the similar feature in our spectrum (see Fig. 5), the authors interpreted it as due to imperfect subtraction of the pulsation, so the coincidence should be viewed cautiously. Like ours, their power spectrum showed significant low-frequency noise below 0.02 Hz and little power above 0.1 Hz.

Our best hope to learn more about this object is to catch a subsequent outburst with a longer exposure and multiple instruments. If it is a Be/NS binary, its unusually brief and luminous outburst makes it particularly interesting. We encourage anyone with access to appropriate archival data to look for the 1997 August outburst and any earlier ones, particularly to search for pulsar periods longer than 300 s. We also encourage anyone with new Galactic center data to look at it promptly and call for target of opportunity observations from the various high-energy observatories during any subsequent outbursts of this object.

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