Populations of Transient Galactic Bulge X-Ray Sources

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Abstract. Starting in 1999, the Rossi X-ray Timing Explorer (RXTE) has monitored the central bulge region of the Galaxy with the Proportional Counter Array (PCA), resolving about 50 binary X-ray sources, including 18 sources discovered by RXTE and BeppoSAX. The accretion rates that RXTE observed from these sources ranged from highs approaching Eddington limits to lows that may correspond to mass exchange for a binary period near the minimum of 80 minutes. Several neutron star binaries with low peak luminosity have outburst or cycle time-scales which are shorter than those of brighter and better known counterparts. We compare the characteristics of the binaries with low rates of mass exchange to predictions of their evolution.

1. Introduction

The bright Galactic bulge populations were among the first known compact X-ray sources. The neutron star binaries are the “Z sources” and the “Atoll sources”. While many sources of Type I bursts (thermonuclear flashes) are Atoll sources, there are others that have low persistent fluxes which have not been well studied. Of course there are also the transient black hole candidate sources such as Nova Ophiuchus and XTE J1748-280.

Transients have been seen by BeppoSAX and RXTE which have peak luminosities of 100 mCrab rather than 1-10 Crab. Some are probably intrinsically bright, but situated on the other side of the galaxy. For others however there is distance or other evidence that they are of lower luminosity.

A famous low luminosity neutron star source is SAX J1808.4-3658, the transient burster that is a coherent 2.5 msec pulsar in a 2 hour binary (Chakrabarty & Morgan 1998). The BeppoSAX Wide Field Camera (WFC) has identified 17 new burst sources (in’t Zand 2000, Heise et al. 1999, Sidoli et al. 1999). Heise et al. suggested that a new class of sources with low peak luminosities was present in the bulge region. King (2000) pointed out that evolution of low-mass neutron star binaries would be expected to lead to small systems with low peak luminosities and short time-scales similar to those of SAX J1808.4-3658.

Among low luminosity black hole candidates, GRS 1737-31 had a spectrum similar to that of Cyg X-1 in the low state and aperiodic variability producing a similar percentage variability of ≈ 30%. These characteristics provide less secure identifications than Type I bursts provide for neutron star sources.

Some sources have been present throughout the observing period and are long-lived, some variable, some steady. The sources which have fluxes less than
Figure 1. Light-curves of four of the monitored sources.

a mCrab may be bright for Chandra and XMM-Newton and more sensitive observations and identifications will develop a more complete picture.

2. RXTE Observations

Although the PCA is not an imaging instrument, the 1° collimators, when scanned in a pattern across the galactic bulge, generate a response that can be fit to a model of point sources plus diffuse emission associated with the center of the galaxy. The region scanned is a $16^\circ \times 16^\circ$ square with a diagonal along the galactic plane. There is a gap of coverage when the sun is within 30° of the region and a smaller gap when the sun in the Galactic anticenter. At a scan rate of 6° per minute, a typical source is in the PCA field of view only 20 seconds. However, RXTE operations require us to hold the attitude briefly (3 minutes) between scans. We chose our scan paths to stop on interesting sources. New sources have been reported in I.A.U. Circulars 7103, 7120, and 7300.

There are several characteristic temporal behaviors. Examples are shown in Figure 1. There are fast-rise/slow-fall transients (9 of them have been observed) which take less than about 3 days to rise and about 3 weeks to decay. In the first two years of this monitoring program a number of sources had one such outburst (XTE J1734–234, XTE J1739–285, EXO 1745–248, SAX J1747–2853, and SAX J1808.4–3658). Some, like GRS 1747–312 in Terzan 6 and the Rapid Burster, have recurrence times, (about 160 and 180 days, respectively) which have allowed observation of multiple outbursts. XTE J1739–285 is starting a second outburst after 580 days and all but XTE J1734–234 (with peak flux of only 2.2 mCrab) have been seen to have previous outbursts. Among the Atoll
bursters, irregular cyclic variations like the high and low states of 4U 1820–30 occur in 4 of the sources we have monitored. In some cases time-scales are similar to the outbursts of the transients, but with a much greater duty cycle, as in KS 1731–26. Several of the sources seen in the galactic bulge region have a high level of irregular variability. With count rates of 10-200 counts s$^{-1}$ (scaled to 5 PCU) (about 1-20 mCrab), the large variations from observation to observation were very significant for 9 additional sources resolved. The light curve for SLX 1735–269 is one of the most peculiar. Occultation for 10 days is an improbable interpretation. Dispersal of an accretion disk may have occurred, with re-formation following within a month. At least 5 of the sources had a flux with an average steady level (and superposed variations) until the flux dropped precipitously within a week. Figure 1 shows the light-curve of XTE J1819–254 = SAX J1819.3–2525. It was identified as V4641 Sgr when it exhibited dramatic optical, X-ray (up to 12 Crab), and radio fireworks in September 1999. These took place entirely between the monitoring observations near MJD 51460.

Deeper observations have been carried out for some sources. No pulsations have been seen similar to those of SAX J1808.4–3658. For that source 5% pulsations were seen when the source was only 10 mCrab (Wijnands et al. 2001). Limits of high frequency quasiperiodic oscillations were typically a few percent. Observed power at frequencies below 1 Hz was 10-30%. GRS 1747–312 in Terzan 6 (in’t Zand et al. 2000) and XTE J1710–281 (Markwardt et al. 1999) are eclipsing. We do not report on spectral information here. It is difficult to use the spectra to separate black hole candidates from neutron star sources, since both could have similar spectra in certain states. A burst with exponential decay strongly points to a neutron star identification and the WFC has identified bursts from more than half of the sources we have tracked.

3. Discussion

There have been several transients whose outburst characteristics are very similar to those of SAX J1808.4–3658. There have also been additional outbursts by sources which are very much like Aql X–1 and 4U 1608–52. The latter are about 3.5 kpc away and their peak outburst rates of 500-1000 mCrab imply peak persistent luminosities of $2-4 \times 10^{37}$ ergs s$^{-1}$. Thus they reach 0.1-0.2 of the Eddington limit. The less well known GRS 1747–312 and EXO 1745-248 are both at about 7.6 kpc (in’t Zand et al. 2000; Johnston, Verbunt, & Hasinger 1995). Like SAX J1808.4-3658, GRS 1747–312 has a peak outburst luminosity 0.04 of the Eddington limit, while the peak ratio for an outburst of EXO 1745-248 was 0.4. As in’t Zand (2000) has noted, the population is a mixture. Distances are essential for determining whether some of these transients have systematically less flux. A majority of bursts may be standard candles within a factor of 2, but several sources have appeared to be implausibly far if the bursts were assumed that bright (e.g. Gotthelf & Kulkarni 1997).

Binary periods are known for a handful of sources (Aql X–1 19 hr; GRS 1747–312 12 hr; AX J1745.6-2901 8 hr; SAX J1808.4-3658 2 hr). The period of XTE 1710–281 is probably near 3 hr. In many of the binaries the secondary comes into contact long before the minimum period of $\approx 80$ minutes is reached. Consistently, the outburst decay times vary. King (2000) found a 4 day expo-
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nential time-scale in accord with the short orbital period of SAX J1808.4–3658. Others have linear decays of several tens and even hundreds of days. The relation between the orbital period and the decay time-scale needs further study.

The average accretion rates from the companions to the disk that are implied for the recurrent transients are in the range expected to be unstable; that is, they are low enough that the X-ray flux irradiation combined with the viscous dissipation are not enough to keep the outer part of the disk ionized. Some are near the instability line of $L_{\text{ave}}$ versus $P_{\text{orb}}$ estimated by van Paradijs (1996).

While typical transients have a fast rise, a peak of several days, and a manifest decay over many days, we have observed several examples of sources which have flat topped light-curves (with high root mean squared variability), and then fast decay, within a few days. V4641 Sgr is the most dramatic example of how the flux can erratically increase just before the X-ray flux declines. Possibly a disk-like accretion reservoir is blown away, into the radio jet in the case of V4641 Sgr, or completely emptied and not replenished. This source is a black hole system, but bursts from two of the sources which suddenly die away suggest they are neutron stars. Spectra from the decay of GRS 1758–258 show the source declining rather than being swamped (Smith et al. 2001).

For very low average accretion rates, neutron star sources are expected to be transient, with hardly more than thermal radiation from the neutron star (Rutledge et al. 1999), at about $10^{33}$ ergs s$^{-1}$. For more than 2 years we have observed about 15 sources persisting at 0.5-80 mCrab, some varying strongly, others steady within errors. The limiting intensity for the PCA scans is about 0.5 mCrab, $1 \times 10^{35}$ ergs s$^{-1}$ at a galactic center distance of 8.5 kpc, or, for accretion, $1.5 \times 10^{-11}$ $M_\odot$ yr$^{-1}$, at which even short period systems would be transient. At least one source, 2S 1803–245 ≡ XTE J1806–246, is a transient in “quiescence” and more may be. If the magnetic field is as low as $5 \times 10^7$ gauss, implied accretion rates are too high to be inhibited by propeller effects, even for fast rotating neutron stars. Some of the transients may well recede to the levels of thermal emission, but a set of them may keep accreting.

4. References

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