TRANSIENT X–RAY SOURCES OBSERVED with the RXTE ALL-SKY MONITOR after 3.5 YEARS

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ABSTRACT.

We present light curves of a sample of “transient” sources observed with the All-Sky Monitor (ASM) of the Rossi X-ray Timing Explorer (RXTE). The light curves extend over 3.5 years. They are presented in three groups: six neutron-star systems, eight black-hole-candidate systems, and an additional diverse set of six objects that are either transient sources (in the sense of usually being undetectable) or persistent sources showing transient behavior. The outburst profiles of these sources show reproducible characteristics within one source and from source to source, as well as large variations. These profiles together with the profiles of the hardness ratios from the ASM are a valuable resource for the understanding of accretion instabilities. We summarize briefly some recent work by observers on these somewhat arbitrarily selected sources.

1. Overview

For a period of 3.5 years (at the time of this workshop), the All-Sky Monitor (ASM; Levine et al. 1996) on RXTE has been monitoring the entire sky for new (uncataloged) transient x–ray sources while also recording the intensities of the known (cataloged) sources. The current catalog contains about 325 source positions of which about 180 have yielded positive detections. The monitoring of a given source has been reasonably continuous except for times when the sun is relatively close to the source and except for a period of ∼7 weeks shortly after launch when the detectors were turned off due to a temporary breakdown problem. The detected sources include many well known persistent sources as well as a substantial number of ‘transient’ sources. Some of these are recurrent and others are in their first known outburst. Most of the latter have been discovered in the RXTE era, either with other satellites, e.g. CGRO and BSAX, or with RXTE. A few were discovered prior to the launch of RXTE.

Some of the RXTE discoveries have been made during scans with the highly-sensitive, but narrow-field-of-view, PCA instrument while the others have been made with the ASM. In almost all of these cases, whether the transient is new or recurrent or whether it was discovered with RXTE or not, the PCA has carried out pointed observations, and the ASM data have been analyzed to provide a light curve (including upper limits) of the source that extends back to early 1996. The exceptions are faint sources (<25 mCrab) discovered with the PCA during scans of the crowded galactic-center region. Source confusion renders some of these inaccessible to the ASM.
The number of transient sources thus far observed by RXTE (PCA and ASM) now exceeds 40, excluding Be star systems. We consider a transient to be a source that, for significant periods, has been below the detection level of the proportional-counter experiments (a few millicrabs) and which shows at least an order of magnitude change of intensity that exceeds the one-day ASM threshold (~15 mCrab at 3σ for a cataloged source). A more precise definition will be required for quantitative studies of transient occurrence rates. Also, a complete search to these levels requires care because our thresholds vary with position on the sky and with time because of variable source density and variable sky exposure.

Our most recent tabulation (November 1999) shows 23 ‘new’ transients studied with RXTE during the first known outburst, or series of outbursts. Among these, sixteen were discovered with RXTE (9 with the ASM and 7 with the PCA). In addition there are 19 recovered transients, i.e., previously known sources recovered after a period of quiescence. The RXTE/ASM has played a substantial role in the recoveries of these transients. A recovery often leads to the discovery of important new characteristics of the source. An earlier (1997) tabulation of transient sources observed with the RXTE/ASM may be found in Remillard (1999). An updated version will be released later.

The occurrences or reoccurrences of transients and also the changes of state of persistent sources provide valuable opportunities for the study of the processes that modulate x-ray emission. The early detection and study of these events require a relatively sensitive all-sky monitor together with a highly sensitive narrow-field x-ray instrument that can be pointed rapidly to any point in the sky. The RXTE combines these capabilities for the first time in the history of x-ray astronomy. Thus new progress on the understanding of the accretion processes in these variable sources is now becoming possible.

2. ASM Light Curves

Light curves of transient sources from RXTE/ASM data show examples of repetitive behavior as well as considerable variation within the same source, e.g. from outburst to outburst. There are ‘failed outbursts’ interspersed with ‘normal’ outbursts. There are outbursts that usually turn completely ‘off’ (less than a few mCrab), but sometimes remain luminous at a low level for long periods. Outburst profiles include ‘fast rise with slow exponential-like decay’ sometimes interspersed with flat-topped and more irregular profiles. These light curves provide a quantitative challenge to models of accretion disk instabilities and of the capture of stellar wind from the companion.

In Figures 1–6, we present sample light curves (1.5 – 12 keV) for the 3.5–year period of RXTE’s operations. The intensities are given in ASM ct/s where 75 ct/s corresponds to the x-ray intensity of the Crab nebula. Most of the light curves are displayed in the form of 1–day averages of the 10 to 30 intensity measures typically obtained per day. The dates are given in MJD where:

1996 Jan. 0.0 = MJD 50082.0
1997 Jan. 0.0 = MJD 50448.0
1998 Jan. 0.0 = MJD 50813.0
1999 Jan. 0.0 = MJD 51178.0.
Figure 1 shows the light curves for six neutron-star binary sources. Figures 2, 3, and 4 show the light curves for eight black-hole-candidates, while Figs. 5 and 6 show six additional sources of diverse types. Most of these sources are transients in the classic sense that they are not detectable above some threshold for long periods of time. Figure 5 includes sources that we would not label as transients, but which do exhibit transient behavior in some sense of the word.

The light curves shown are for the entire bandwidth of the ASM detectors, namely 1.5 – 12 keV. In fact, the data are telemetered and stored in three energy channels, 1.5 – 3 keV, 3 – 5 keV, and 5 – 12 keV, which can serve as a further tool in the study of transient sources. The curves are shown here on a rather compressed scale; larger scales reveal substantially more detail. The intensities are available in both graphical and numerical form on the internet sites at MIT and GSFC, e.g., [http://heasarc.gsfc.nasa.gov/xte_weather/](http://heasarc.gsfc.nasa.gov/xte_weather/) and [http://space.mit.edu/XTE/ASM_lc.html](http://space.mit.edu/XTE/ASM_lc.html).

Here, we point out features in the light curves of selected transients that should be pertinent to the classification of transient types. The characteristics of the previously known sources are well documented in van Paradijs (1995). The discovery references for a number of the new or recovered sources are listed in Remillard (1999).

We also point the reader to papers that can serve as an introduction to the more recent literature for the sources we have selected for illustration. This serves to give the reader a flavor of the research carried out by RXTE in the past few years. Much of this research has been stimulated by results from the ASM, e.g., because it provides notice of a changing state. This presentation is intended to point out the potential of such data for the understanding of accretion processes.

### 3. Neutron-star binaries; Fig. 1

4U 0115+63. This HMXB (high-mass x-ray binary) is a 3.6–s pulsar. Recently its optical counterpart has been reclassified as an O9e (Unger et al. 1999). In 1999 at MJD ~51250 (hereafter simply 51250), it underwent a major outburst. Studies with BSAX and RXTE during this event led to the discoveries of high-harmonic cyclotron lines (Heindl et al. 1999; Santangelo et al. 1999). The outburst profile in the ASM light curve is quite symmetric. In addition, there were several weak outbursts in 1996 (50300) whose peaks are spaced by multiples of the 24–d orbital period. In larger scale plots they appear to have profiles similar to the larger outbursts.

X 1608–522. This well known LMXB (low-mass x-ray binary) is an x-ray burster as are many LMXBs. The source was in outburst when RXTE was launched and erupted again at 50850. The profile of the latter outburst shows a remarkably very fast rise, a rapid initial descent, a hesitation at about half maximum followed by a less rapid fall to the lower quiescent level. The source was undetectable ($<10$ mCrab) for almost a year (50500 – 50800) before the latter outburst. In contrast, it exhibited a sustained, variable low–level flux at 0.03 – 0.1 Crab for a year or more after each of the outbursts. This could be an indicator that the source is intrinsically unstable between on and off states. This low level (for the ASM) is several orders of magnitude greater than the quiescent luminosity of $\sim 10^{34}$ erg/s. See Rutledge et al. (1999) for a discussion of the quiescent state.
3A 1942+274. This Ariel source was recovered for the first time in many years by the ASM in late 1998. It was found to be a 16-s pulsar in RXTE PCA observations immediately upon its recovery (Smith & Takeshima 1998). The previously suggested optical counterpart (Israel, Polcaro & Covino 1998) is now considered to be an unlikely candidate (Israel, pvt. comm.). The irregularly spaced multiple peaks in the light curve may represent enhanced accretion near periastron in an ∼80-d elliptical orbit (Campana, Israel & Stella 1999). The source remains active through at least mid November 1999.

XTE J2123–058. This previously unknown source at high galactic latitude (−36 deg) was discovered in ASM data (Levine, Swank & Smith 1998). It is an atoll LMXB with twin x-ray kHz oscillations and x-ray bursts (Homan et al. 1999). An optical counterpart with V = 17 and a 6–h orbit was immediately discovered (Tomsick et al. 1999a) with orbital modulations that continued beyond the x-ray outburst (Soria, Wu & Galloway 1999). The outburst at 51000 is quite weak (85 mCrab); it exhibits the same hesitation during the decay seen in 1608–522. Possible precursor activity ∼100 d before the peak is apparent at ∼15 mCrab, but may be an artifact from x-ray Solar contamination.

Rapid Burster. The ASM data show 6 outbursts of activity since the RXTE launch. They reaffirm the ∼200-d previously-noted quasi-periodicity of these outbursts, but for the first time show the extent and evolution of each outburst. Each outburst lasts about 5 weeks and, in PCA data, exhibits two phases, the first of which is characterized by Type I (thermonuclear) bursts and the second by Type II (accretion) bursts (Guerriero et al. 1999).

Aql X-1. This well-known atoll, bursting, LMXB recurring transient has recently had its optical identification (V1333 Aql) clarified. The counterpart is the western component of a 0.5-arcsec double with V= 21.6 in quiescence and with a late K-star classification (Chevalier et al. 1999). ASM detections of outburst states made possible studies of kHz oscillations in the active state that include demonstrations of (1) a sudden decrease in frequency and flux after an x-ray burst (Yu, Zhang & Zhang 1999) and (2) low-energy lags of ∼1 radian consistent with a Doppler-delay model (Ford 1999).

The ASM light curve of Aql X-1 shows 5 outbursts, including those at the beginning and the end of the plot and another two “failed” bursts at 50270 and 51200. The intervals between these events range from 200 to 300 d. Two of the outburst light curves (50700 and 50900) are roughly symmetric in shape with comparable rise and fall times. The other two have faster rises than decays. The failed outbursts may indicate that the conditions for outburst are marginal, as we suggest for the low-level persistent flux from x1608–522. Aql X-1 lies on the thermal-viscous instability boundary derived by van Paradijs (1996) for neutron stars.

4. Black-hole candidates; Figs 2, 3, 4

4U1630–47. This long-known transient and black-hole candidate (from soft-hard spectral components) exhibits outbursts roughly in accord with the reported ∼600–700 d intervals (Kuulkers et al. 1997). Three outbursts are seen in the ASM data with separations ∼700 d and ∼450 d. The longer interval follows the outburst with the largest integrated flux. All three outbursts exhibit sharp maxima at the leading and trailing edges of the profile, and the leading edges rise faster than the trailing edges decay. In spite of this,
the latter two outbursts have different shapes; they appear to have failed to attain the full profile of the first outburst. The flux remains markedly above threshold after the second outburst. Again this behavior could be an indicator of marginal instability.

The 1996 outburst (50200) revealed deep narrow (minutes) x-ray absorption dips in RXTE/PCA data (Kuulkers et al. 1998). This outburst is included in the historical review of outburst behavior in 4U 1630–47 (Kuulkers et al. 1997). This review points out the heretofore unrecognized complexity of the outburst behavior of this source. The evolution of the x-ray spectral components of the 1998 outburst (50850) from BeppoSAX are presented by Oosterbroek et al. (1998).

GRO J1655–40. This is a well established black-hole system with a dynamical mass for the collapsed object of ∼6–7 solar masses (Orosz & Bailyn 1997, Shabaz et al. 1999). It exhibits superluminal radio jets which establish it as a “microquasar” (Tingay et al. 1995). First discovered in 1994, it was solidly below threshold prior to and after the ∼450–d 1996–1997 outburst. The optical turn-on was found to precede the x-ray emission by ∼5 days (Orosz et al. 1997). Observations with the PCA exhibited several QPOs including 300 Hz when the source spectrum was particularly hard (Remillard et al. 1999b). The evolution of x-ray spectral components is given by Mendez, Belloni & van der Klis (1998), Tombesi et al. (1999b), and Sobczak et al. (1999a). Echo mapping (x-ray to optical) locates the reprocessing region to be in the accretion disk rather than the mass donor star (Hynes et al. 1998).

XTE J1748–288. This RXTE/ASM-discovered transient (Smith, Levine & Wood 1998) exhibited a single outburst at 51000 with a very rapid rise (∼2 d) and slow exponential-like decay. It was above threshold for 60 d and was detected to at least 100 keV with BATSE. (Harmon et al. 1998). PCA observations showed QPO at 0.5 and 32 Hz (Fox & Lewin 1998). The spectral and QPO evolution has been studied by Revnivtsev, Trudolyubov & Borozdin (1999). Transient radio emission (Hjellming et al. 1998, Fender & Stappers 1998) became extended after 10 days. The jet motion at >20 mas/d indicated an apparent speed > 0.93c for a ≥8 kpc distance. Later the speed decreased and the leading edge of the radio jet brightened due to a shock in the interstellar medium, the first such shock known in a galactic source. There is no reported optical counterpart; its galactic coords. are 0.7, –0.2).

XTE J1755–324. This source, also ASM discovered (Remillard et al. 1997), was noteworthy for its extremely soft color in the ASM (HR2 = 0.3) which suggests black-hole candidacy. (HR2 is the harder color of the two ASM x-ray energy colors.) The intensity profile was similar to XTE J1748–288 in that it rose in ∼2 d and decreased quasi-exponentially. However, unlike 1748–288, but reminiscent of the neutron-star system 1608–522 (Fig. 1), it halted its descent after about 50 days, increased slightly to a second maximum and then descended to non-detectability after a total time of ∼105d. The temporal and spectral evolution is described by Revnivtsev, Gilfanov & Churazov (1998) who find it to be a “canonical” x-ray nova such as Nova Muscae 1991. Again there is no reported optical identification at this writing; galactic coords. 358.0, –3.6.

XTE J2012+381. This transient, discovered with the ASM (Remillard, Levine & Wood 1998), had a hard initial spike and also reached a very low hardness ratio (HR2 = 0.4). In ASCA data it had an ultrasoft spectrum with a hard tail suggesting a black hole (White et al. 1998). A radio counterpart was detected (Hjellming & Rupen 1998a, Pooley
A V = 21.3 star (1.1 arcsec from a foreground 18th magnitude star) lies within 0.4 arcsec of the radio source and is tentatively identified as the optical counterpart (Hynes et al. 1999). The light curve is strongly double peaked with an additional low maximum 150 d after the onset.

GX 339–4. This long-known black-hole candidate with a persistent x-ray flux entered a bright and soft (HR2 ~0.3) state beginning at ~50800 and returned to its low state ~400 d later. It is not generally considered a “transient”; nevertheless the infrequent high soft states could be considered so. The ASM high/soft state is accompanied by a low high-energy (BATSE) flux and a marked reduction of radio emission (Fender et al. 1999a). The transition is reminiscent of the 1996 Cyg X-1 transition to its high/soft state (Wen et al. 1999 and refs. therein). The temporal and spectral characteristics during the rise and at maximum showed a “typical” high/soft state (Belloni et al. 1999). See also the multiwavelength (radio, optical, x-ray) studies in a 3-paper series (e.g., Smith, Filippenko & Leonard 1999).

XTE J1915+105 (Fig. 3). This remarkable “microquasar” (Mirabel & Rodriguez 1994) has been active continuously since the launch of RXTE. The x-ray light curves show what is probably the most dramatic variability of any known x-ray source. Extensive PCA observations (vertical-line markers at top) have permitted the definition of a number of distinct accretion states (e.g., Greiner, Morgan & Remillard 1997). This source also exhibits superluminal radio jets (e.g., Fender et al. 1999b). A dynamical mass does not exist for this source, but its high luminosity strongly implies a black-hole compact object. The object is replete with unusual x-ray oscillatory modes that repeat on time scales of tens to thousands of seconds (e.g., see Muno et al. 1999). One such mode has been associated with micro-radio outbursts with high confidence (Pooley & Fender 1997, Eikenberry et al. 1998, Mirabel et al. 1998), thus linking specific accretion configurations with jet creation. These events appear to be associated with the loss via accretion of the inner portion of the accretion disk (see Belloni et al. 1997, Pooley & Fender 1997). The radio-x-ray association is also seen on longer time scales in Fig. 3 where increased radio fluxes are sometimes associated with low hard x-ray states, e.g., at 50750, with, in addition, bright flaring at the onset and end of such low states. The source is replete with low frequency x-ray QPOs at frequencies that vary with time and also a 67-Hz QPO that reappears when the spectrum is hard (Morgan, Remillard & Greiner 1997). Recent work has addressed the interplay of the QPOs and the variation of the spectral components, e.g., Muno et al. (1999) and Markwardt, Swank & Taam (1999).

XTEJ1550–564 (Fig. 4). This was the first previously-unknown very-bright transient found in the RXTE era. It was discovered in ASM data with new triggering software soon after its onset (Smith 1998). This permitted PCA observations during the rise, the times of which are marked in the figure. The x-ray light curve with its narrow peak, flat plateau and second maximum is not typical of a prototype x-ray nova, e.g., 0620–00. It reaches 6.8 Crab brightness in the dramatic brief flare at ~51050. X-ray emission was observed to 200 keV with BATSE (Wilson et al. 1998). The evolution of the x-ray spectral components in the PCA and ASM data were tracked by Sobczak et al. (1999b). The source was found in the very high, high/soft, and intermediate canonical outburst states of black-hole x-ray novae. X-ray QPOs were abundant from 0.05 to 185 Hz (Cui et
al. 1999; Remillard et al. 1999a). An optical counterpart brightened about 4 magnitudes over the quiescent $B \approx 22$ state (Jain et al. 1999). The extinction $E(B-V) = 0.7$ indicated a distance of 2.5 kpc and a luminosity consistent with a K0–K5 star (Sanchez-Fernandez, et al. 1999). A likely radio counterpart was found (Campbell-Wilson et al. 1998).

5. Various sources; Fig. 5

Here we illustrate the diversity of x-ray variation in a few other selected sources. Most would not be deemed transients under the conventional definition. However they all exhibit transient behavior in the broader sense.

CI Cam. Here we see the remarkably brief outburst from the symbiotic star CI Cam, discovered with the ASM (Smith et al. 1998). The rise took place over a few hours, and the exponential-like fall (Fig. 6) showed a time scale that began at $\sim 0.5$ d and later became $\sim 2.3$ day (Belloni et al. 1999a). It was above the ASM threshold for only 9 days. The ASM detection enabled studies with ASCA, BSAX and the RXTE PCA as well as in the radio and optical. This object was reported to have corkscrew radio jets reminiscent of SS433 (Hjellming & Mioduszewski 1998). Belloni et al. (1999a) suggest this is a Be-star + neutron-star binary system but do not exclude a black-hole; see Belloni et al. for references to several studies of this outburst.

GS 2138+568 (=Cep X-4?). This source was discovered in 1972 with OSO–7. It was rediscovered with Ginga which found it to be a 66-s pulsar. It is believed to be a Be-star system with a total of four recorded outbursts. A study with BATSE and RXTE (Wilson, Finger & Scott 1998) of outbursts in 1993 and 1997 also serves as a review of the literature. In the ASM data, the source remained above threshold for about 40 days. It is among the fainter sources ($\sim 30$ mCrab) detectable with the ASM in 1–day averages.

4U 1705–44. This modestly bright LMXB burster with no known optical counterpart exhibits large intensity variations that have rise and fall times that quite consistently are on the order of 50 days. This source has historical ‘off’ states but has essentially always been detectable since Feb. 1996 in the ASM data. It also exhibits radio emission. Kilohertz QPO have been discovered with RXTE (Ford, van der Klis & Kaaret 1998). The fast timing behavior at lower frequencies based on the EXOSAT archive are reported by Berger & van der Klis (1998).

SMC X-1. This well-known high-mass system with an eclipsing (3.9 d) x–ray pulsar (0.71s) reveals itself conclusively to have a quasi 60-d period in the ASM data. It is probably a precessing disk system (Wojdowski et al. 1998). The pulsar continues to show a steady spin-up rate (Kahabka & Li 1999).

Cyg X-3. This unusual binary, with a 4.8-h x–ray period (probably orbital) exhibits spectacular radio flares. Its ASM x–ray light curve exhibits one sustained flaring interval and several shorter ones. Bright radio flares occur during the sustained active period, with peak intensities of 3 to 9 J at wavelength 13 cm at 50465, 50485, and 50610 (Ogley et al. 1998). The orbital period evolution has recently been revisited by Matz (1997).

Mkn 501. This blazar exhibits a year-long period of x–ray activity in the ASM data from 50400 to 50800. This active period was accompanied by dramatic flux variations and a high average flux ($\sim 1.4$ Crab) at TeV energies (Quinn et al. 1999; Aharonian et al.
1999). It was on MJD 50607 that an intense rapid (hour scale) TeV flare was detected (Quinn et al.). Aharonian et al. report an intensity correlation with ASM data with zero time lag during this active period. In 1998 the TeV flux had decreased to ~20% of the Crab. The ASM data serve to guide TeV observers in target selection. The light curve (4-day averages) shows the capability of the ASM for the study of the brighter AGN sources which, even so, are quite weak in the ASM. Mkn 501 reaches 35 mCrab in this plot.

6. Conclusion

The light curves shown here are illustrate the richness of the ASM data and improve the prospect for better understanding of the accretion processes underlying transient behavior. The outburst profiles, the marginally-on states, the durations of on and off states, and the hardness parameters should all serve as diagnostics of these processes. A planned reanalysis of the entire data base with improved procedures should provide a uniform search for transients sources down to ~7 mCrab at positions away from the galactic center. With good fortune the RXTE/ASM will continue to provide comprehensive light curves to the community for at least several more years.

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References

Aharonian, F. et al.: 1999, Astron. Astrophys. 342, 69.
Belloni, T., Mendez, M., van der Klis, M., Lewin, W., Dieters, S.: 1999b, Astrophys. J. Lett. 519, L159.
Belloni, T. et al.: 1999a, Astrophys. J., in press; astro-ph 9907124.
Belloni, T., Mendez, M., King, A. R., van der Klis, M. & van Paradijs, J.: 1997, Astrophys. J. Lett. 488, L109.
Berger, M. & van der Klis, M.: 1998, Astron. Astrophys. 340, 143.
Campana, S. Israel, G. & Stella, L.: 1999, Astron. Astrophys., in press; astro-ph 9911145.
Campbell-Wilson, D. et al.: 1998 IAUC 7010.
Chevalier, C., Ilovaisky, S. Leisy, P. & Patat, F.: 1999, Astron. Astrophys. Lett. 347, L51.
Cui, E., Zhang, S. N., Chen, W. & Morgan, E. H.: 1999, Astrophys. J. Lett. 512, L43.
Eikenberry, S.S., Matthews, K., Morgan, E. H., Remillard, R. A. & Nelson, R. W.: 1998, Astrophys. J. Lett. 494, L61.
Fender, R. P. & Stappers, B. W.: 1998, IAUC 6937.
Fender, R. P. et al.: 1999a, Astrophys. J. Lett. 519, L165.
Fender, R. P. et al.: 1999b, Mon. Not. R. Astr. Soc. 304, 865.
Ford, E. C.: 1999, Astrophys. J. Lett. 519, L73.
Ford, E. C., van der Klis, M. & Kaaret, P.: 1998, Astrophys. J. Lett. 498, L41.
Fox, D. & Lewin, W.: 1998, IAUC 6964.
Greiner, J., Morgan, E. H. & Remillard, R. A.: 1997, Astrophys. J. Lett. 473, L79.
Guerriero, R. et al.: 1999, Mon. Not. R. Astr. Soc. 307, 179.
Harmon, B. A., McCollough, M. L., Wilson, C. A., Zhang, S. N. & Paciesas, W. S.: 1998, IAUC 6933.
Heindl, W. A., et al.: 1999, Astrophys. J. Lett. 521, L49.
Hjellming, R. M. & Mioduszewski, A. J.: 1998, IAUC 6872.
Hjellming, R. M. & Rupen, M. P.: 1998, IAUC 6924; see also IAUC 6932.
Hjellming, R. M. et al.: 1998, Paper in preparation; see Abstract #103.08, AAS Mtg #193.
Homan J., Mendez, M., Wijnands, R., van der Klis, M., van Paradijs, J.: 1999, Astrophys. J. Lett. 513, L119.
Hynes, R. I., O’Brien, K., Horne, K., Chen, W. & Haswell, C. A.: 1998, Mon. Not. R. Astr. Soc. 299, L37.
Hynes, R. I., Roche, P., Charles, P. A. & Coe, M. J.: 1999, Mon. Not. R. Astr. Soc. 305, L49.
Israel, G. L., Polcaro, V. F. & Covino, S.: 1998, IAUC 7021.
Jain, R. K., Bailyn, C. D., Orosz, J. A., Remillard, R. A. & McClintock, J. E.: 1999, Astrophys. J. Lett. 517, L131.
Kahabka, P. & Li, X.-D.: 1999, Astron. Astrophys. 345, 117.
Kuulkers, E., Parmar, A. N., Kitamoto, S., Cominsky, L. R. & Sood, R. K.: 1997, Mon. Not. R. Astr. Soc. 291, 81.
Kuulkers, E., Wijnands, R., Belloni, T., Mendez, M., van der Klis, M., van Paradijs, J.: 1998, Astrophys. J. 494, 753.
Levine, A., Bradt, H., Cui, W., Jernigan, J. G., Morgan, E., Remillard, R., Shirey, R., Smith, D.A.: Astrophys. J. Lett. 469, L33.
Levine, A., Swank, J. & Smith, D.A.: 1998, IAUC 6955.
Markwardt, C. B., Swank, J. H. & Taam, R. E.: 1999, Astrophys. J. Lett. 513, L37.
Matz, S. M.: 1997, Proceedings of the 4th Compton Symposium; astro-ph 9708201.
Mendez, M., Belloni, T. & van der Klis, M.: 1998, Astrophys. J. Lett. 499, L187.
Mirabel, I. F. & Rodriguez, L. F.: 1994, Nature 371, 46.
Mirabel, I. F. et al.: 1998, Astron. Astrophys. Lett. 330, L9.
Morgan, E. H., Remillard, R. & Greiner, J.: 1997, Astrophys. J. Lett. 482, L155.
Muno, M. P., Morgan, E. H. & Remillard, R. A.: 1999, Astrophys. J., in press; astro-ph 9904087.
Ogley, R. N., Bell Burnell, S. J., Fender, R. P., Pooley, G. G., Waltman, E. B. & van der Klis, M.: 1998, in 2nd Workshop of Relativistic Jets from Galactic Sources, R. N. Ogley & S. J. Bell Burnell eds, NewAR42, in press, astro-ph 9808019.
Oosterbroek et al.: 1998, Astron. Astrophys. 340, 431.
Orosz, J. A. & Bailyn, C. D.: 1997, Astrophys. J. 477, 876.
Orosz, J. A., Remillard, R. A., Bailyn, C. D. & McClintock, J. E.: 1997, Astrophys. J. Lett. 478, L83.
Pooley, G. G.: 1998, IAUC 6926.
Pooley, G. G. & Fender, R. P.: 1997, Mon. Not. R. Astr. Soc. 292, 925.
Quinn, J. et al.: 1999, Astrophys. J. 518, 693.
Remillard, R. A.: 1999, in Proc. of Frascati Workshop 1997, Vulcano, eds. F. Giovannelli
Remillard, R. A., Levine, A. & Wood, A.: 1998, IAUC 6920.
Remillard, R. A., McClintock, J. E., Sobczak, G. J., Bailyn, C. D., Orosz, J. A., Morgan, E. H. & Levine, A. M.: 1999a, Astrophys. J. Lett. 517, L127.
Remillard, R. A., Morgan, E. M., McClintock, J. E., Bailyn, C. D. & Orosz, J. A.: 1999b, Astrophys. J. 522, 397.
Revnivtsev, M., Gilfanov M. & Churazov, E.: 1998, Astron. Astrophys. 339, 483. See also Astronomy Letters 25 493 and Astrophys. J. 511 847.
Revnivtsev, M. G., Trudolyubov, S. P. & Borozdin, K. N.: 1999, Mon. Not. R. Astr. Soc., submitted; astro-ph # 9903306).
Rutledge, R. E., Bildsten, L., Brown, E. F., Pavlov, G. G. & Zavlin, V. E.: 1999, Astrophys. J. 514, 945.
Sanchez-Fernandez, C. et al.: 1999, Astron. Astrophys. Lett. 348, L9.
Santangelo, A., et al.: 1999, Astrophys. J. Lett. 253, L85.
Sobaz, T., van der Hooft, F., Casares, J., Charles, P. A. & van Paradijs, J.: 1999 Mon. Not. R. Astr. Soc. 306, 89.
Smith, D. A.: 1998, IAUC 7008.
Smith, D.A., Levine, A. & Wood, A.: 1998 IAUC 6932
Smith, D., Remillard, R., Swank, J., Takeshima, T., & Smith, E.: 1998, IAUC 6855.
Smith, D. A. & Takeshima, T.: 1998 IAUC 7014.
Smith, I. A., Filippenko, A. V. & Leonard, D. C.: 1999, Astrophys. J. 519, 779.
Sobczak, G. J., McClintock, J. E., Remillard, R. A., Bailyn, C. D. & Orosz, J. A.: 1999a, Astrophys. J. 520, 776.
Sobczak, G. J., McClintock, J. E., Remillard, R. A. Levine, A. M., Morgan, E. H., Bailyn, C. D. & Orosz, J. E.: 1999b, Astrophys. J. Lett. 517, L121.
Soria, R., Wu, K. & Galloway, D.: 1999, Mon. Not. R. Astr. Soc., in press; astro-ph 9906267).
Tingay, S. J. et al.: 1995, Nature 374, 141.
Tomsick, J. A., Halpern, J. P., Kemp, J. & Kaaret, P.: 1999a, Astrophys. J. 521, 341.
Tomsick, J. A., Kaaret, P., Kroeger R. A. & Remillard, R. A.: 1999b, Astrophys. J. 512, 892.
Unger, S. J. Roche, P., Negueruela, I., Ringwald, F. A., Lloyd, C. & Coe, M. J.et al.: 1998, Astron. Astrophys. 336, 960.
van Paradijs, J.: 1995, in X-ray Binaries, eds. W. H. G. Lewin, J. van Paradijs & E. P. J van den Heuvel (Cambridge: Cambridge Univ. Press), 536.
van Paradijs, J.: 1996, Astrophys. J. Lett. 464, L139.
Wen, L, Cui, W., Levine, A. & Bradt, H.: 1999 Astrophys. J. 525, 968.f
White, N. E., Ueda, Y., Dotani, T. & Nagase, F.: 1998, IAUC 6927.
Wilson, C. A., Finger, M. H., & Scott, D. M.: 1999, Astrophys. J. 511, 367.
Wilson, C. A., Harmon, B. A., Paciesas, W. S. & McCollough, M. L.: 1998, IAUC 7010.
Wojdowski, P. S., Clark, G. W., Levine, A. M., Woo, J. W. & Zhang, S. N.: 1998, Astrophys. J. 502, 253.
Yu, W., Li, P., Zhang, W. & Zhang, S. N.: 1999, Astrophys. J. Lett. 512, L35.
Fig. 1. RXTE/ASM light curves for six neutron-star binary-system transients. The data points represent 1-day averages of the 10–20 (typical) daily measurements in the 1.5–12 keV band. 75 ct/s corresponds to 1.0 Crab. MJD 50082 = 1996 Jan. 0.0.
Fig. 2. RXTE/ASM light curves for six black-hole binary-system transients. GX 339–4 shows a transient bright soft state; it also exhibits “off” states. See also caption to Fig. 1.
Fig. 3. RXTE/ASM x-ray light curve, hardness ratio, and radio fluxes for the “microquasar” GRS 1915+105. The data points for the x-ray light curve are individual 90-s dwells which show the huge variability on short time scales. The hardness ratios $(5 - 12 \text{ keV})/(3 - 5 \text{ keV})$ are one-day averages. The markers at the top indicate times of PCA observations and the less frequent occurrence of the 67-Hz QPO.
Fig. 4. RXTE/ASM light curve and hardness ratio for XTE J1550–564 which reached an intensity of 6.8 Crab. The markers indicate the PCA observation times and the less frequent detections of the 185 Hz QPO. The intensity points are 90-s dwell objects and the hardness ratios are one-day averages.
Fig. 5. RXTE/ASM light curves for six sources of diverse character and diverse transient behavior. The CI Cam points are from individual 90-s dwells, those for Mk 501 are 4-d averages, and the others are 1-day averages. See also caption to Fig. 1.
Fig. 6. RXTE/ASM expanded light curve for CI Cam illustrating its rise in hours and ∼1-d descent.