X-ray Transients Observed with the RXTE All Sky Monitor
1996-1997

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ABSTRACT. Highlights from the RXTE All Sky Monitor (ASM) during 1996 and 1997 are reviewed with particular attention to X-ray transients. The ASM has detected 117 sources. These include 12 recurrent transients and 10 new X-ray sources, some of which began their outbursts before the launch of RXTE. The majority of the outburst profiles are strikingly different from the classical form, with its fast rise and slow decay. Some of the light curves appear quasi-persistent, which suggests that they are associated with secular changes in the accretion rate from the donor star rather than with a cyclic instability in the accretion disk. The nature of the compact object is uncertain in many cases, but there is a likelihood that the majority of new sources are black hole systems, while the majority of recurrent transients contain neutron stars. There is a correlation between the gross shape of the energy spectrum, as seen in the ASM hardness ratio \( HR_2 \), and the accretion subclass. These data, with important contributions from SAX, CGRO, and Granat, provide a deeper probe of the X-ray sky than has been available previously. However, there are important systematic effects to be investigated before a meaningful evaluation of transient occurrence rates can be derived.

1. Introduction
The All Sky Monitor (ASM) on the Rossi X-ray Timing Explorer (RXTE) has been regularly observing bright celestial X-ray sources since 1996 February 22. Detector problems had been encountered during the first days of operation (1996 January 5-12), but the instrument has remained stable under an observing plan restricted to low-background regions of the RXTE orbit (580 km altitude). The ASM currently operates with 20 of the original 24 detector anodes, and the typical observation duty cycle is 40%, with the remainder of the time lost to the high-background regions of the orbit, spacecraft slews, and instrument rotation or rewinds. The net yield from the ASM exposures is about 5 celestial scans per day, excluding regions near the Sun. The ASM instrument calibration, construction of the data archive, the derivation of source intensities, and efforts to locate new X-ray sources are all carried out with integrated efforts of the PI team at M.I.T. and the RXTE Science Operations Center at Goddard Space Flight Center.

The ASM instrument consists of three scanning shadow cameras (SSC) attached to a rotating pedestal. Each camera contains a position-sensitive proportional counter, mounted below a wide-field collimator that restricts the field of view (FOV) to \( 6^\circ \times 90^\circ \) FWHM and \( 12^\circ \times 110^\circ \) FWZI. One camera (SSC3) points in the same direction as the ASM rotation axis. The other two SSCs are pointed perpendicular to SSC3. The latter cameras point toward a common direction, but the long axes of their collimators are
tilted by $+12^\circ$ and $-12^\circ$, respectively, relative to the ASM rotation axis. The ASM can be rotated so that the co-pointing SSCs are aligned with the larger instruments of RXTE (i.e. the PCA and HEXTE). The top of each collimator is covered with an aluminum plate perforated by 6 parallel (and different) series of narrow, rectangular slits. These slits function as a coded mask by casting a two-dimensional shadow pattern onto the position-sensitive anode wires in the detector. The histograms of accumulated counts from the anodes represent the superposition of shadows from each X-ray source in the collimator’s field of view. Further information on this instrument is given by Levine et al. (1996).

The ASM raw data includes 3 types of data products that are tabulated and formatted for telemetry by the two ASM event analyzers in the RXTE Experiment Data System. In the current observing mode, position histograms are accumulated for 90 s “dwell” in which the cameras’ FOVs are fixed on the sky. Each dwell is followed by a $6^\circ$ instrument rotation to observe the adjacent patch of sky. The rotation plans for ASM dwell sequences are chosen to avoid having any portions of the Earth in the FOVs of SSCs 1 and 2. The position histograms are accumulated in three energy channels: 1.5–3.0, 3–5, and 5–12 keV. The second ASM data product consists of various measurements from each camera binned in time. These data are useful in studying bright X-ray pulsars, bursters, $\gamma$-ray bursts, and several other categories of rapid variability. The “good events” from each camera are recorded for each energy channel in 0.125 s bins, while 6 different types of background measures are recorded in 1 s bins. Finally, 64-channel X-ray spectra from each camera are output every 64 s. These data provide a means of monitoring the detector gain, since we may integrate the spectra over long time scales to observe the 5.9 keV emission line from the weak $^{55}$Fe calibration sources mounted in each collimator. In addition, ASM spectra may be useful in investigations of spectral changes in very bright X-ray sources.

The ASM data archive is a public resource available for both planning purposes and scientific analysis. The source histories are available in FITS format from the RXTE guest observer facility at [http://heasarc.gsfc.nasa.gov/docs/xte/xte_ist.html](http://heasarc.gsfc.nasa.gov/docs/xte/xte_ist.html). The ASM archive is also available in ASCII table format from the RXTE web site at M.I.T., [http://space.mit.edu/XTE/XTE.html](http://space.mit.edu/XTE/XTE.html).

The majority of scientific applications for ASM data can be organized into four categories:

- Locating and Monitoring X-ray Transients,
- Measuring Intensity and Spectral Variations in Persistent X-ray Binaries,
- Long Term Behavior of Bright AGNs,
- Positions and X-ray Properties of $\gamma$-Ray Bursts.

This paper briefly reviews the ASM results in the first category, with consideration of results obtained during 1996 and 1997.
2. X-ray Transients 1996-1997

There has been a remarkable diversity of X-ray transients during 1996 and 1997. Table 1 summarizes 22 cases detected with the RXTE ASM; these include both new sources and recurrent transients. We have selected these to emphasize intrinsic (rather than geometric) variations in accretion, and so we have excluded transients associated with active coronae and X-ray sources with periodic (or nearly periodic) recurrence intervals, such as systems with B-e type donor stars in eccentric orbits. Table 1 lists the known transients observed with a peak X-ray flux above 20 mCrab (2–12 keV) during 1996 and 1997. This group includes recent discoveries from RXTE, SAX, CGRO, and Granat. One of the strengths of the ASM program is the frequent all-sky coverage and the relative ease with which historical light curves may be extracted from the survey database in response to discoveries from various researchers in the astronomical community.

Table 1 - ASM Observations of X-ray Transients 1996-1997

| New and Continuing Transients | Source          | type | profile | peak | HR2 | start  | ΔT | comments |
|------------------------------|-----------------|------|---------|------|-----|--------|----|----------|
| XTE J1716-389                | ns?             | qp   | 66      | 0.9  | pre XTE | –   | ASM detection |
| GRS 1737-31                  | bhc             | qp   | 26      | 1.6  | pre XTE | –   | Cui 97    |
| GRS 1739-278                 | bhc             | frsd | 805     | 0.6  | 1/96   | 270 | radio source |
| XTE J1739-302                | bhc             | qp   | 34      | 1.3  | pre XTE | –   | Smith 97  |
| SAX J1750-29                 | ns              | frsd | 117     | 1.3  | 3/10/97 | 33  | q?, Bazzano |
| XTE J1755-324                | bhc             | frsd | 188     | 0.3  | 7/24/97 | 105 | Remillard 97 |
| SAX J1808-3658               | ns              | frsd | 108     | 0.9  | 9/07/96 | 19  | int’Zand 98 |
| XTE J1842-042                | ns?             | qp   | 21      | 1.2  | pre XTE | –   | PCA detection |
| XTE J1856+053                | bhc             | sym  | 75      | 0.4  | 4/16/96 | 27  | Marshall 97a |
|                         |                 |      |         |      |       |      |              |

| Recurrent Transients | Source          | type | profile | peak | HR2 | start  | ΔT | comments |
|----------------------|-----------------|------|---------|------|-----|--------|----|----------|
| 4U1210-64            | ns?             | qp   | 30      | 1.2  | pre XTE | –   |          |
| X1354-644            | bhc             | sym  | 52      | 1.3  | 10/23/97 | >85 |          |
| X1630-472            | bhc             | irr  | 336     | 1.1  | 3/11/96 | 150 | flat top |
| RX J1655-40          | bh              | irr  | 3138    | 0.6  | 4/25/96 | 484 | var. spectra |
| RX J17095-266        | ns?             | frsd | 210     | 0.9  | 12/31/96 | 86  | Marshall 97b |
| KS1731-260           | ns              | qp   | 356     | 1.1  | pre XTE | –   | msec pulsar |
| Rapid Burster        | ns              | frsd | 377     | 1.5  | multiple | 25  | 3 outbursts |
| GRO J1744-28         | ns              | frsd | 1291    | 2.5  | 12/95 12/96 | >120 | complex |
| GX 1826-238          | ns              | qp   | 120     | 1.2  | pre XTE | –   | Bazzano 98 |
| X1845-024            | ns              | sym  | 24      | 2.6  | 9/96 5/97 | 21  | 2 outbursts |
| EXO 1846-031         | bhc             | sym  | 30      | 1.5  | 12/19/97 | ?   |          |
| AQL X-1              | ns              | sym  | 370     | 0.9  | multiple | 60  | 4 outbursts |
In col. 4 of Table 1 we list the peak X-ray flux compiled using daily ASM averages (mCrab at 2–12 keV), and in col. 3 the profile of the outburst is described as either quasi-persistent (qp), irregular (irr), symmetric (sym), or the more common shape with a fast rise and slow decay (frsd). The starting date of the outburst is given (or limited) in col. 6, while col. 7 lists the duration (days) for which the X-ray emission is above the ASM threshold, which is near 10 mCrab at \(3\sigma\) per one day time bin.

As indicated in col. 2, the X-ray transients of 1996-1997 include 1 confirmed black hole system (bh), 9 black hole candidates (bhc), 8 accreting neutron stars (ns), and 4 suspected ones (ns?). All of the confirmed neutron stars are bursters except for the pulsars GRO J1744-28 and X1845-024. There are interesting correlations between the X-ray spectrum and the type of accreting system, despite the coarse energy resolution available from the ASM and the randomizing effects of substantial differences in the amount of interstellar column density among these sources. The ASM hardness ratio, \(HR_2\), is defined as the flux in the 5–12 keV band relative to the flux in the 3–5 keV band, and the mean value for each source is given in col. 5. Both pulsars (with \(HR_2 \sim 2.5\)) are significantly 'harder' than the other sources. The confirmed neutron star systems lie in the range \(0.9 \leq HR_2 \leq 1.5\), while the black hole candidates have a bimodal distribution, \(HR_2 \leq 0.6\) or \(HR_2 \geq 1.1\). Since the accreting black hole systems are known to exhibit composite spectra consisting of a soft, thermal component and a hard, power-law component (e.g. Tanaka & Lewin 1995), the bimodal distribution in \(HR_2\) values for the bhc can be understood as the optional dominance of the soft or hard spectral component, respectively.

3. Light Curves of Selected X-ray Transients

In Figure 1 we show the ASM light curves for four examples among the group of new X-ray transients. The first source was located with the ASM during March of 1997. The detection was gained from ASM sky maps that are constructed on a weekly basis from the residuals of our data analysis effort. For each camera - dwell, we fit the ASM position histograms for the superposition of mask shadows of sources in the camera’s FOV, and then we compute the residuals from this fit. The residuals histograms are then back-projected onto position cells fixed on the celestial sphere. In each sky cell, the X-ray flux is computed by cross correlating the residuals histograms against the modeled shadow pattern for that particular cell during a given observation. In the case of XTE J1716-389, the superposition of such residual flux (while the source was unknown) yielded a significant detection at a position (J2000) 259.10°, -38.90°, with an uncertainty radius (90% confidence) of 0.12°. We then re-analyzed the ASM database with routine inclusion of this new source position and extracted the light curve shown in the top panel of Figure 1. This source is one of 7 quasi-persistent transients listed in Table 1. These cases exhibit long-term (i.e. years) secular changes in the accretion rate, and they appear very different from the transients associated with the classical disk instability mechanism, which produces a wave of accretion that generally causes an X-ray outburst of 1-6 months duration (e.g. Cannizzo et al. 1995; Chen et al. 1997).

The moderately bright outburst in GRS1739-278 (panel 2 of Figure 1) displays the more typical 'frsd' outburst profile noted above. However, in this case there are at least
Fig. 1. ASM light curves for 4 new X-ray transients (1996-97). In the 2–12 keV band, the count rate for the Crab Nebula is 75.5 ASM c/s
six decay phases after X-ray maximum, and the sequence of accretion enhancements has extended the outburst interval to \( \sim 9 \) months. In contrast, the outburst duration of SAX J1808.4-3658 (panel 3) is only 19 days. This X-ray burster (in t’Zand et al. 1998) is one of several fast X-ray transients that would likely have gone unnoticed without the current complement of X-ray instruments that monitor the high-energy sky. Finally, a source discovered originally in PCA scans of the galactic plane, XTE J1856+053 (Marshall et al. 1997a) shows diverse decay profiles in two X-ray maxima separated by only 4.5 months. Since this interval is short relative to the subsequent span of X-ray quiescence, it is possible that the two X-ray maxima are best regarded as interrelated portions of a single X-ray nova episode.

Four light curves of recurrent transients are shown in Figure 2. The bhc X1630-472 (top panel) exhibits a peculiar ‘flat top’ profile in which the spectrum slowly hardens. The maximum luminosity occurs \( \sim 110 \) days after the initial X-ray rise, and it is not at all clear how this may be explained employing the accretion disk instability model. Even more peculiar is the light curve of the microquasar, GROJ1655-40. It is considered here as recurrent transient because of the extended period of X-ray quiescence during late 1995 and early 1996. A double wave in X-ray brightness is shown in panel 2 of Figure 2. The strong flares in the first wave are absent in the second wave, and the flares are entirely due to activity in the power-law spectral component. We note that the gap in ASM coverage between these waves, which is an annual feature also seen in other ASM light curves, is caused by the Sun’s passing near a given X-ray source. The microquasars with relativistic radio jets, GROJ1655-40 and GRS1915+105 (see Morgan et al. 1997) display the most complex light curves in the ASM archive.

Panel 3 of Figure 2 shows the outburst in RX J1709.5-266 (Marshall et al. 1997b). Very little had been known about this source apart from a brief detection in the ROSAT survey. The ASM light curve suggests that it is a disk-instability type of X-ray source, and it is a suspected neutron-star system given the shape of its X-ray spectrum. Finally, the most regularly recurring X-ray transient is Aql X-1 (see van Paradijs 1995). Portions of 4 X-ray outbursts have been seen with the ASM, and the average recurrence interval is \( \sim 190 \) days. The second detection interval (MJD 50240–50310) appears to be some type of failed outburst that presents yet another challenge for the disk instability model.

The ASM detection threshold for new X-ray transients (\( \sim 25 \) mCrab in weekly residual maps) is higher than that for recurrent transients (\( \sim 10 \) mCrab per daily average), since the sky mapping technique is substantially less sensitive that the method for determining the X-ray flux for known sources with accurate positions. Since many of the new transients (e.g. the SAX discoveries) have brief outburst duration, the systematic issues pertaining to completeness must be investigated thoroughly in order to use the ASM archive to determine reliable production rates for X-ray transients in the Galaxy. Accordingly we plan to revise our instrument models and conduct archival sky mapping efforts with a goal to understand the completeness level for ASM detections of new sources, as a function of both X-ray brightness and outburst duration.
Fig. 2. ASM light curves (1996-97) for 4 recurrent transients.
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