RADIO EMISSION FROM THE X-RAY TRANSIENT XTE J1550−564

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ABSTRACT

We report multifrequency radio observations of XTE J1550−564 obtained with the Molonglo Observatory Synthesis Telescope and the Australia Telescope Compact Array at the time of its discovery and subsequent hard and soft X-ray outburst in 1998 September. A large radio flare was observed, peaking about 1.8 days after the X-ray flare. In addition, we present Australian Long Baseline Array images obtained shortly after the maximum of the radio flare which show evolving structure. The apparent separation velocity of the two outermost components is $v > 2c$.

Key words: stars:individual:XTE J1550−564; radio continuum:stars; X-rays:stars.

1. INTRODUCTION

The soft X-ray transient XTE J1550−564 was discovered by the All-Sky Monitor (ASM) on board the Rossi X-ray Timing Explorer (RXTE) on MJD 51063 (1998 Sept 7; MJD=JD−240000.5) with an intensity of ∼0.07 Crab in the 2–12 keV range (Smith 1998) and by the Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory in the 20–100 keV range at a flux level of 1.26×10^{-8} erg s^{-1} cm^{-2} (Wilson et al. 1998). The RXTE/ASM intensity increased steadily over the next few days, reaching ∼1.7 Crab on MJD 51071 (Remillard et al. 1998). XTE J1550−564 flared to 6.8 Crab on MJD 51075–51076, making it the brightest X-ray nova observed with RXTE to date (Remillard et al. 1998). An optical counterpart with a magnitude of V=16 was identified on MJD 51065 (Orosz, Bailyn & Jain 1998), and an orbital period of ∼1.54 days was attributed to the system (Jain et al. 2000). A radio counterpart was discovered at the optical position with a flux density of 10±2.5 mJy on MJD 51065 (Campbell-Wilson et al. 1998). Evolving QPOs (Cui et al. 1999) and hard lags (Wijnands et al. 1999) typical of black hole binaries were observed from XTE J1550−564.

In this paper we introduce briefly the radio emission from XTE J1550−564 at the time of the 1998 outburst. A more detailed analysis will be presented in Hannikainen et al. (2001, in preparation).

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2. OBSERVATIONS

XTE J1550−564 was observed at multiple radio frequencies during the September 1998 outburst. The Molonglo Observatory Synthesis Telescope (MOST) made twelve observations of the source at 843 MHz between MJD 51065 and 51092, while the Australia Telescope Compact Array (ATCA) made observations at 1.4, 2.3, 4.8 and 8.6 GHz between MJD 51073 and 51085. In addition, Very Long Baseline Interferometry (VLBI) images were obtained with the Australian Long Baseline Array (LBA) at 2.29 GHz. The MOST 843 MHz and ATCA 4.8 and 8.6 GHz lightcurves are shown in the upper panel of Figure 1 along with the epochs of the VLBI observations.

2.1. MOST & ATCA

Following the initial detection of XTE J1550−564 on MJD 51065, the MOST monitored the source at 843 MHz over the next 27 days (Figure 1). Between MJD 51065 and 51073, the source flux density remained between 10 and 30 mJy. After MJD 51073 the flux density began to increase, reaching 168 mJy on MJD 51076, and peaking on MJD 51078 with a flux density of 375 mJy. The flux density then declined to 120 mJy over the next three days, with a continuing decline to 14 mJy on MJD 51092, after which the monitoring ceased.

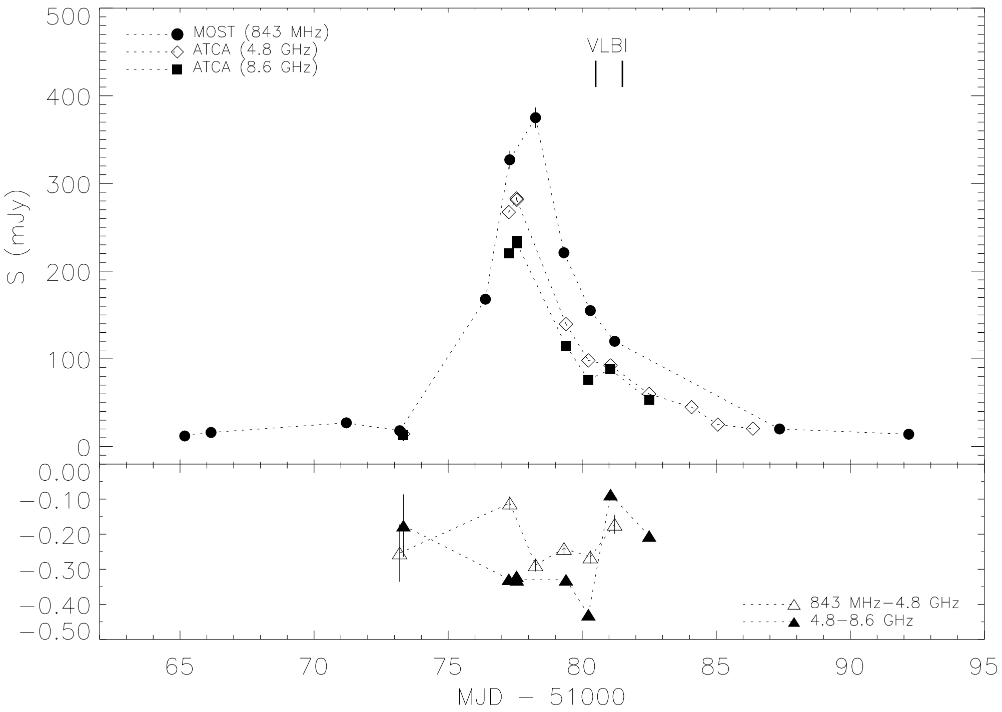

Figure 1. The upper panel shows the MOST 843 MHz lightcurve (filled circles) along with the ATCA 4.8 GHz (open diamonds) and 8.6 GHz (filled squares) lightcurves. The two vertical lines denote the epochs of the VLBI observations. The bottom panel shows the 2-point spectral indices derived from the 843 MHz–4.8 GHz data (open triangles) and from the 4.8–8.6 GHz data (filled triangles).

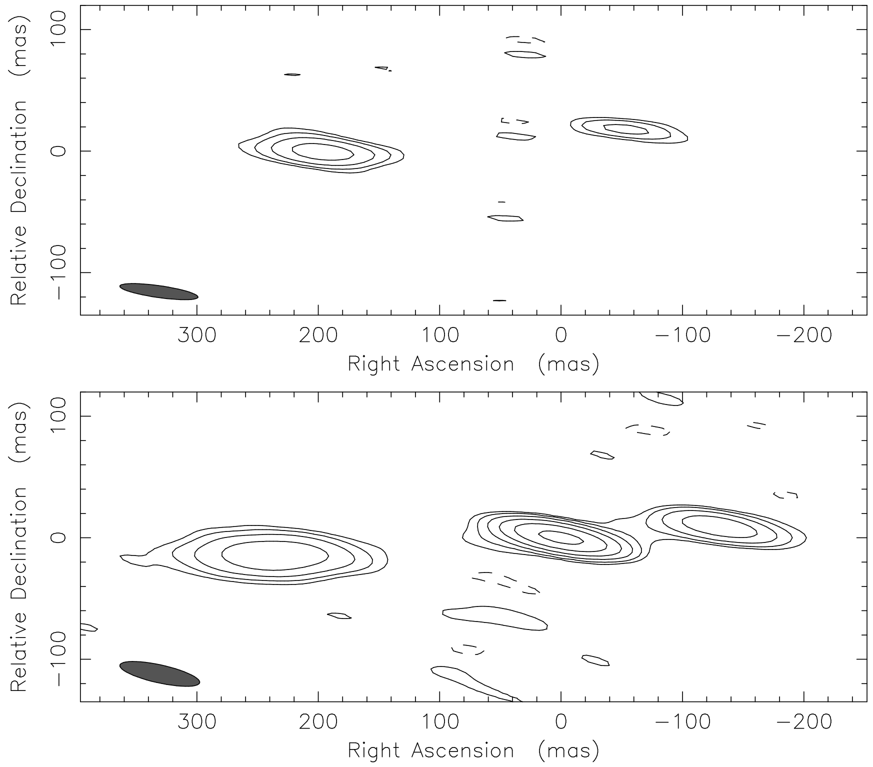

Figure 2. The 2.29 GHz VLBI images from MJD 51080.5 (top) and MJD 51081.5 (bottom). The flux densities in the components, from east to west, are: 71 mJy and 20 mJy (top); 19 mJy, 25 mJy and 8 mJy (bottom). The beam is shown in the lower left-hand corner.

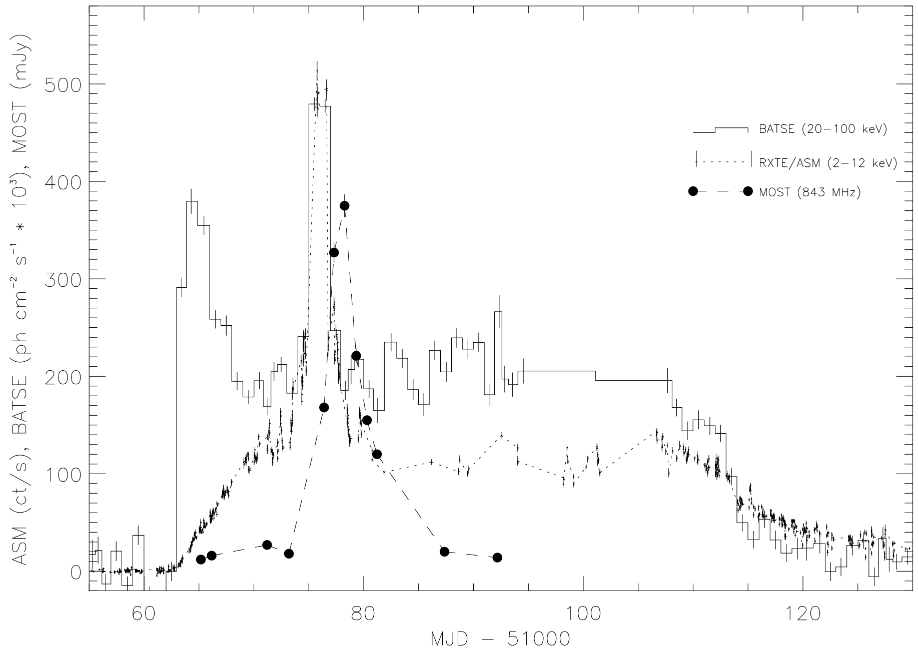

Figure 3. The XTE J1550−564 multiwavelength lightcurves: BATSE 20–100 keV (histogram), RXTE/ASM 2–12 keV (dotted line), MOST 843 MHz (filled circles and dashed line).

The ATCA started observing XTE J1550−564 on MJD 51073 while the flux density was still low − 10 − 12 mJy at 4.8 and 8.6 GHz (Figure 1). After the rise to 168 mJy detected with the MOST, the ATCA resumed observing the source and monitored it over the next ten days. The 4.8 and 8.6 GHz flux densities appear to peak approximately 0.5 days before the MOST peak, with flux densities of 283 and 234 mJy respectively and linear polarization $\sim$ 6%. The ATCA flux densities then followed the same decline as the MOST, reaching a level of around 20 mJy at 4.8 GHz on MJD 51086.5 when monitoring was ceased. The linearly polarized flux also evolved during the outburst (Hannikainen et al., in preparation), reminiscent of the behavior of GRO J1655−40 during the 1994 ejection episodes (Hannikainen et al. 2000a).

2.2. VLBI

The VLBI observations were undertaken on MJD 51080.5 and MJD 51081.5 using the LBA (Hannikainen et al. 2000b). On the first day, the 34-m DSS45, the 26-m Hobart and the 22-m Mopra antennas were used, while on the second day the 70-m DSS43 replaced the DSS45, and the six 22-m dishes of the ATCA were also used.

Figure 2 shows the 2.29 GHz VLBI images obtained on MJD 51080.5 (top) and MJD 51081.5 (bottom).

The image from MJD 51081.5 shows three distinct components, and the structure has clearly evolved compared to the previous day. Phase-referenced observations were not performed on either day so the zero coordinate in the images is arbitrary. However, changes in the spectral index, α ($S_\nu \propto \nu^\alpha$), are consistent with the appearance of a third component (Figure 1). Although the overall 2-point spectral indices, both the 843 MHz–4.8 GHz and the 4.8–8.6 GHz, stay relatively flat throughout the observing period (much flatter, say, compared to GRO J1655−40 which had α of $\sim$ -0.5 to -0.9 during the 1994 ejection episodes; Hannikainen et al. 2000a) the 4.8–8.6 GHz spectral index does flatten from -0.45 to -0.1 just before the VLBI observations. Thus, the central component in Figure 2 (bottom) is tentatively identified with a new optically thick outburst. If this interpretation is correct, then the apparent separation velocity of the outermost components between MJD 51080.5 and 51081.5 is $v > 2c$ (Hannikainen et al. 2000b), based on a distance estimate of 3.5–5 kpc derived from H I observations.

3. MULTIWAVELENGTH LIGHTCURVES

Figure 3 shows the multiwavelength behavior of XTE J1550−564. The significance of the sequence of lightcurve features in each waveband is discussed in Wu et al. (2000) and an in-depth analysis of the multiwavelength data is in Hannikainen et al. (2001, in preparation), so here we shall only summarize the more salient features. The outburst sequence is characterized by an impulsive rise in hard X-rays accompanied by a gradual brightening in the soft X-rays, followed by a period of exponential-like decay in the hard X-ray luminosity, and then a giant flare in all wavebands. The hard and soft X-rays peaked simultaneously, while the radio flare maxima occurred about 1.3–1.8 days later. As the radio emission continued to decline to a low level after the flare, the X-ray intensities settled into a plateau, lingered for another 35 days, and then faded away.

In order to explain the first impulsive BATSE hard X-ray outburst, which does not conform to the standard disk-instability scenario, a model involving a magnetic secondary star is proposed (Wu et al. 2000). In this model, coronal magnetic activity lifts matter above the stellar surface of the secondary (which is presumed to be a G/K subgiant; see also Bildsten & Rutledge 1999), and if this happens near the L_1 point of the Roche lobe, this matter will fall easily into the Roche lobe of the black hole, as gravity is weak near the L_1 point. Provided the magnetic stress/tension is stronger than the gas pressure terms, matter can be trapped there and accumulate over time. Eventually, this magnetic dam may burst leading to field-line breaking and a matter avalanche. The initial angular momentum of the matter with respect to the black hole is insignificant, as the matter is practically in free-fall from zero velocity. This flow will therefore be quasi-spherical, and deviation occurs only when approaching the black hole. An accretion shock forms when the infalling material encounters the centrifugal barrier of the hole, converting a portion of the kinetic energy to thermal energy, giving rise to radiation. These photons are then upscattered by the surging infalling matter to hard X-ray energies, which is observed as the first hard X-ray outburst. As the quasi-spherical flow subsides, the hard X-ray luminosity declines, and at the same time, residual matter with substantial angular momentum begins to condense in the equatorial plane to form an accretion disk – this is seen as the gradual rise in the soft X-rays (see Igumenschev, Illarionov & Abramowicz 1999). Irradiation of the secondary as a consequence of the first hard X-ray outburst will result in an increase of mass transfer, and provoke instabilities, seen in the large fluctuations in the soft X-ray luminosity between MJD 51070 and 51075. As a result, the accretion disk becomes unstable and portions of it collapse, leading to mass ejection, as evidenced by the radio flare and the discrete components observed with the VLBI.

4. SUMMARY

The XTE J1550−564 hard and soft X-ray flare in 1998 September was accompanied by radio emission. The radio outburst, which reached 375 mJy at 843 MHz, lagged the X-ray flare by 1.8 days. There was spectral evolution during the outburst, and polarization was detected at the 6% level. The VLBI images showed evolving structure confirming that there was an outflow from the system. The inferred superluminal separation velocity of the two outermost components, $v > 2c$, strengthens the argument for XTE J1550−564 being a black-hole binary system similar to GRO J1655−40 and GRS 1915+105.

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