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VLBI OBSERVATIONS OF THE SHORTEST ORBITAL PERIOD BLACK HOLE X-RAY BINARY

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The X-ray transient MAXI J1659-152 was discovered by Swift/BAT and it was initially identified as a GRB. Soon its Galactic origin and binary nature were established. There exists a wealth of multi-wavelength monitoring data for this source, providing a great coverage of the full X-ray transition in this candidate black hole binary system. We obtained two epochs of EVN/e-VLBI and four epochs of VLBA data of MAXI J1659-152 which show evidence for some extended emission in the early phases but –against expectations– no major collimated ejecta during the accretion disk state transition. This might be related to the fact that, with a red dwarf donor star, MAXI J1659-152 is the shortest orbital period black hole X-ray binary system.

Keywords: ISM: jets and outflows; X-rays: binaries; stars: individual (MAXI J1659-152).

1. Introduction

Swift/BAT discovered a new source on 25 September 2010, which was designated as GRB 100925A[1]. A hard X-ray transient positionally coincident with the GRB candidate was identified by the MAXI/GSC team, MAXI J1659-152[2]. Optical spectroscopy by the ESO/VLT X-shooter showed broad emission and absorption lines

*We report our results for a bigger collaboration at zero redshift, indicating that the source is likely a Galactic X-ray binary[3]. Our group initiated Westerbork Synthesis Radio Telescope (WSRT) observations and detected MAXI J1659-152 at the 5 mJy level at 5 GHz just ∼1.5 day after the initial trigger[4]. This was followed by a series of European VLBI Network (EVN) e-VLBI[5] and VLBA observations at 5 GHz.

2. VLBI observations

The first VLBI observations were carried out on 30 Sep. 2010 with the EVN in real-time e-VLBI mode at 1 Gbps data rate. Within this first run we targeted MAXI J1659-152 and a nearby NVSS source as well. This latter was found to be compact and was subsequently scheduled in all follow-up observations with the measured accurate coordinates as a secondary phase-reference source – this demonstrates the flexibility of real-time VLBI observations of ToO events. The phase-reference check source turned out to be very useful during the data analysis because of the low declination of the target. Further observations were on 4 Oct. with the EVN, and 2, 6, 14 and 19 Oct. with the VLBA. MAXI J1659-152 was detected at all except the last epoch (see Fig. 1). At the first two epochs the source was clearly resolved: the VLBI peak brightness was ∼50% or lower of the total flux densities measured by the WSRT and EVLA (while the check source did not show evidence for a severe loss of coherence in the data), but the distribution of the extended emission remain uncertain. On 4 and 6 Oct. only a compact (or partially resolved) component was detected with practically all flux density recovered; on 14 Oct. we achieved a SNR∼7 detection only and at the last epoch the source was undetected.

3. MAXI J1659-152: a black hole X-ray binary candidate

The X-ray properties of MAXI J1659-152 agree well with that of black hole binary candidates. The source followed the typical evolutionary track on the hardness-intensity diagram (HID) and had the usual variability/timing properties, in particular type-B and type-C QPOs[6]. In addition, there are regular dips seen with a period of about 2.4h in RXTE, XMM-Newton and Swift data which make it the shortest orbital period system in all known Galactic black hole X-ray binary candidates[7−8] (BHB). The two groups that reported this results also show that the companion star is most likely an M5 dwarf, and the system is likely located at a distance of 7 kpc. In addition, using the scaling relation between the spectral index and the QPO frequency, the mass of the BH is estimated to be 20 ± 3 $M_\odot$. If this estimate is correct, then MAXI J1659-152 would be the most massive stellar BH known in the Galaxy[9].

4. Radio structure and X-ray evolution

The RXTE lightcurve and HID (6−15 keV/2−6 keV) are shown in Fig. 2, black points show measurements closest to the VLBI epochs. The source was first observed

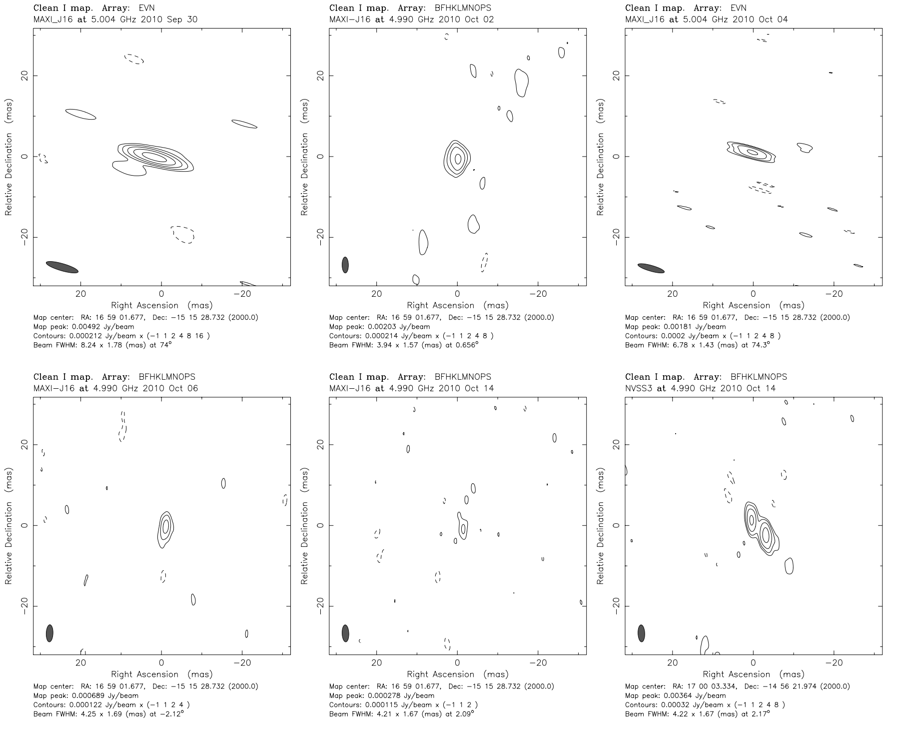

Fig. 1. The VLBI maps of MAXI J1659-152 for 30 September, 2 and 4 October (top row), 6 and 14 October 2010 (bottom row). The last map shows the nearby phase-reference check source on 14 October 2010.

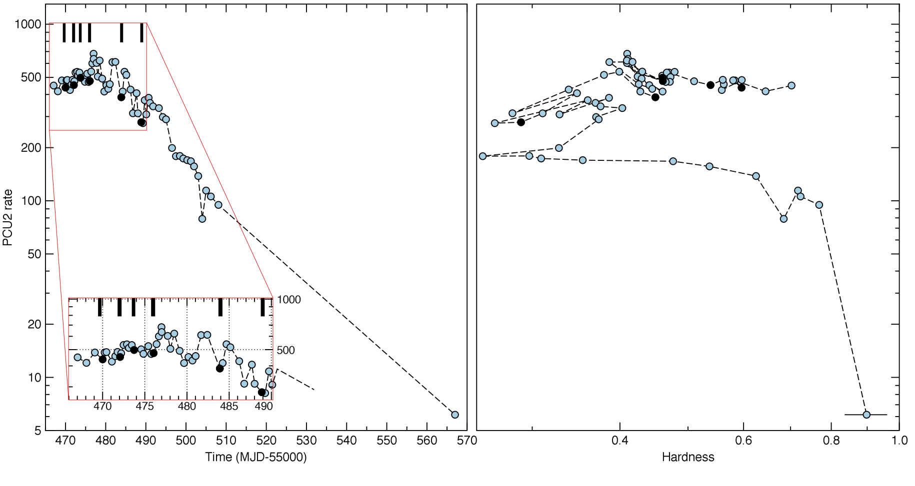

Fig. 2. RXTE PCU2 count rate (left) and hardness-intensity diagram of MAXI J1659-152 during its outburst in 2010. The hardness is defined as the ratio of count rates measured in the 6–15 keV and the 2–6 keV energy ranges. The black bars indicate the times of VLBI observations while the black circles show the RXTE measurements closest in time to the VLBI observations.

with the EVN still in the hard intermediate state (HIMS). It was resolved with a hint of an extension (compact-jet?) in the south-east direction, similarly to e.g. Cyg X-1 in this state. During the evolution to the soft intermediate state (SIMS) radio quenching was reported on 8 October[10] and type-B QPOs appeared on 12 October[11], which are usually followed by relativistic jet ejections. However, we do not see these in MAXI J1659-152, the source was fading below our detection limit by the time it reached the soft state. It is intriguing that the shortest orbital period (and maybe the most massive?) BHB does not produce such ejecta. However we note that while the X-ray state transition was fully completed and the X-ray timing properties also indicated that the "jet-line" region was crossed, the soft state in MAXI J1659-152 appeared to be significantly harder than in most BHBs. A similar result was reported for the June 2010 state transition of Cyg X-1[12], ie. the source did not show bright transient ejecta.

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