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Adaptive e-VLBI observations of radio emitting X-ray binaries

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A group of northern radio emitting X-ray binaries, known to have radio emissions from past observations, have been observed with the new 'adaptive e-VLBI' mode of the e-EVN. We exploit the 'real-time' correlation of e-EVN data, to adapt the observing schedule of the telescopes to follow the transient sources. Two epochs were spaced by ~ 48 hours, with the target(s) of the latter epoch determined by the image results of the former epoch. During the first epoch we imaged, using phase referencing, 16 X-ray binaries with a sensitivity of $\sim 100\ \mu$Jy r.m.s. None of the targets were however above the detection limit and thus the second epoch was not necessary. These upper limits are compared with X-ray data from the RXTE All Sky Monitor.

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There are around 50 known radio emitting X-ray binary stars (REXRBs). All types of objects are included – high and low mass X-ray binaries, neutron star and black-hole compact accreting objects. However only a few objects have been well studied in the radio (mainly the persistently stronger ones) since REXRBs are generally in quiescence and flares are often short lived. ATCA, VLA, MERLIN and VLBI observations have shown that several of the strong sources have radio jets (in particular GRO1655-40, GRS1915+105, SS433, Circ X-1, CygX-3, Sco X-1 e.g. (Mirabel & Rodriguez, 1994; Fender, 2006) where collimated ejection of radio emitting knots occurs during a radio flare. The apparent velocities are high, in cases superluminal, hence leading to the term 'microquasar'. In addition there are objects, such as Cyg X-1 (Stirling et al., 2002) and also GRS1915+105 in the plateau state (Dhawan et al., 2000) where there is a persistent compact jet on the scale of a few ten's of AU. Radio spectra of these objects are often flat, as predicted by the Blandford & Konigl (1979) model, but the model also predicts a maximum brightness temperatures in the order of 10^{12}K, which is not observed in microquasars. This results from partial synchrotron self-absorption but also free-free absorption may play a role, whereas the flare events result in relatively steep spectral index ($S \propto \nu^{-\alpha}$) of $\alpha \sim 0.6$. Several of the weaker objects have not been studied by VLBI and do not have known resolved jets, however the mere presence of radio emission has generally led to these objects being classified as microquasars with radio jets. Neutron star binaries have a lower radio luminosity than black-hole candidate sources, but some also have apparently superluminal jets.

The aim in these observations is to prove that the less well studied objects also show collimated jets when flaring. However since flare events are rare, we need to survey all the available objects in order to catch any in the act. There are (at least) two kinds of flaring events. GRS1915+105 has short duration flares (< 1-2 days) where the cm-wavelength radio emission drops to the pre-flare level in a short time, and longer duration events characterised by a short rise time (hours) and a slow decay over several days – such events enable the proper motion of the jets to be studied in detail, e.g. in MERLIN observations (Fender et al., 1999; Miller-Jones et al., 2005). Cygnus X-3 also has short and long duration flares (Newell et al., 1998; Spencer et al., 1986).

1. Observations and results

This was the first 'adaptive e-VLBI' observation mode used to exploit the scientific advantages of e-VLBI over locally recording VLBI. In February 2007 two e-EVN epochs were closely spaced apart by ~48 hours. This experiment intented to test the unique e-VLBI capability, in which the observing schedule of a second run could be changed in response to results from earlier e-VLBI observations.

During the first epoch, on 2007 February 1st, the 16 X-ray binaries with known radio components listed in table 1. were observed at 4.994 GHz. The observation was scheduled to interleave between the sources to provide the best uv-converage with the available GST range of the sources. The observations were placed around 3-4 hrs before transit, to avoid long drive times for the high declination sources, and also any cable wrap problems.

All targets were phased referenced with a nearby bright compact source, with approximately 40 minutes of time on each target. The phase referencing observations consisted of 5 minutes on source and 3 minutes on the calibrator. Each station sustained a transfer rate of 256 Mbps data rate across the e-VLBI network. The data was transferred from the telescope to the correlator using Mark5A VLBI data systems (Whitney, 2003). These units have been fitted with 1 Gbps Network Interface Cards which allow the units to transfer the telescope data to the correlator over the internet.

The initial post-correlator data processing was performed by the JIVE support team. The NRAO software package AIPS was used to perform the initial data reduction. An estimated of the system temperature and a gain calibration was performed by the EVN pipeline, written by Cormac Reynolds, based on the PARSELTONGUE interface (Kettenis et al., 2005). The AIPS task FRING was used to solve for the delay across the basebands with the fringe finder. Then, combining the basebands to give a better signal to noise, the phase, rates and delay of the phase calibrator were solved again using FRING. A self-calibrated image of the phase reference source was produced for each target. The calibrated *uv* data of the targets were then Fourier transformed, this gave a calibrated image field for each source with a sensitivity of $\sim 100\mu$Jy.

None of the X-ray binaries were detected above a 3σ level of the current e-EVN noise level. Therefore as the first epoch did not detect any of the targets and a second epoch was not required.

1.1 RXTE monitoring

The RXTE All Sky Monitor (ASM) (Levine et al., 1996) covers an energy band of approximately 3 - 12 keV, with 90 second point observations allowing $\sim$ 80% of the sky to be monitored every 90 minutes. The X-ray spectral behaviour is measure by the hardness radio (HR2), defined as 5 - 12 keV (“hard”) / 3-5 keV (“soft”). Measurements of the Crab give $\sim$ 75 counts/s over the ASM spectral range.

Presented in figure 1 are the daily averages of the 90 second pointing observations of Cygnus X-2, Ser X-1 and V1055 Ori. The rest of the XRBs in table 1 were below the ASM sensitivity limit ($<$ 2counts/s) during the adaptive e-VLBI experiment. Cygnus X-2 was in a low state, although it had a large X-ray flare $\sim$ 15 days before the e-EVN epoch, reaching a peak intensity of 75 counts/s. This flare was preceded by a period ($\sim$ 10 days) of steady emission at 30 counts/s in a hard state and then a sharp spectral softening with a HR2 of less than 0.8.

Ser X-1 and V1055 Ori showed a fairly constant X-ray emission of 18 and 3 counts/s respectively over the last year. The peak ASM intensity over the last 10 years of the RXTE mission has shown Ser X-1 and V1055 Ori have only reached 30 and 12 counts/s respectively.

2. Discussion

The detection of radio emission in the first epoch of the e-VLBI observations was to be used as an indication that a flare was taking place (quiescent emission of sources in the list is generally $\ll$ 1 mJy). Follow up imaging observations 48 hours later on from a flaring source would show either that the flare has decayed to sub-detectable levels or that the flare was associated with the ejection of a collimated jet. Typical proper motions of components in the well studied microquasars are $\sim$10 mas per day (corresponding to 0.5c at 10 kpc), so we would expect the components to have moved by $\sim$3 beams in 48 hours.

RXTE data from the ASM showed all but three of the XRBs were detectable above the ASM noise level of 0.3 counts/s (0.004 Crab). The three targets with detectable emission are believed to be neutron stars (Liu et al., 2000). It has been established that the radio emission from the Atoll and Z-type neutron star sources are at least 30 times less ‘radio loud’ than their black hole counterparts. Given the radio-X-ray correlation found for black-holes and neutron star XRBs (Migliari & Fender, 2006), then perhaps it is not surpising that we did not detect radio emission.

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References

Blandford, R. D., & Konigl, A. 1979, ApJ, 232, 34

Dhawan, V., Mirabel, I. F., & Rodríguez, L. F. 2000, ApJ, 543, 373

Fender, R. P., et al., 1999, MNRAS, 304, 865

Fender, R. 2006, Compact stellar X-ray sources, 381

Gallo, E., Fender, R. P., & Pooley, G. G. 2004, NuPhS, 132, 363

Gallo, E. 2006, ArXiv Astrophysics e-prints, arXiv:astro-ph/0611413

Kettenis M., et al., 2005, ADASS XV, ASP Conf series ParselTongue: AIPS Talking Python

Levine, A. M., et al., 1996, ApJL, 469, L33

Liu, Q. Z., van Paradijs, J., & van den Heuvel, E. P. J. 2000, A&AS, 147, 25

Migliari, S., & Fender, R. P. 2006, MNRAS, 366, 79

Miller-Jones et al., 2005, MNRAS, 363, 867

Mirabel, I. F., & Rodriguez, L. F. 1994, Nat, 371, 46

Newell, S. J., Garrett, M. A., & Spencer, R. E. 1998, MNRAS, 293, L17

Rushton, A., et al. 2007, MNRAS, 374, L47

Spencer, R. E., Swinney, R. W., Johnston, K. J., & Hjellming, R. M. 1986, ApJ, 309, 694

Stirling, A. M., et al., 2002,MNRAS, 337, 657

Tudose, V., et al. 2006, ArXiv Astrophysics e-prints, arXiv:astro-ph/0611054

Whitney, A. R., 2003, Mark 5 Disk-Based Gbps VLBI Data System, available at http://www.haystack.mit.edu/tech/vlbi/mark5/index.html

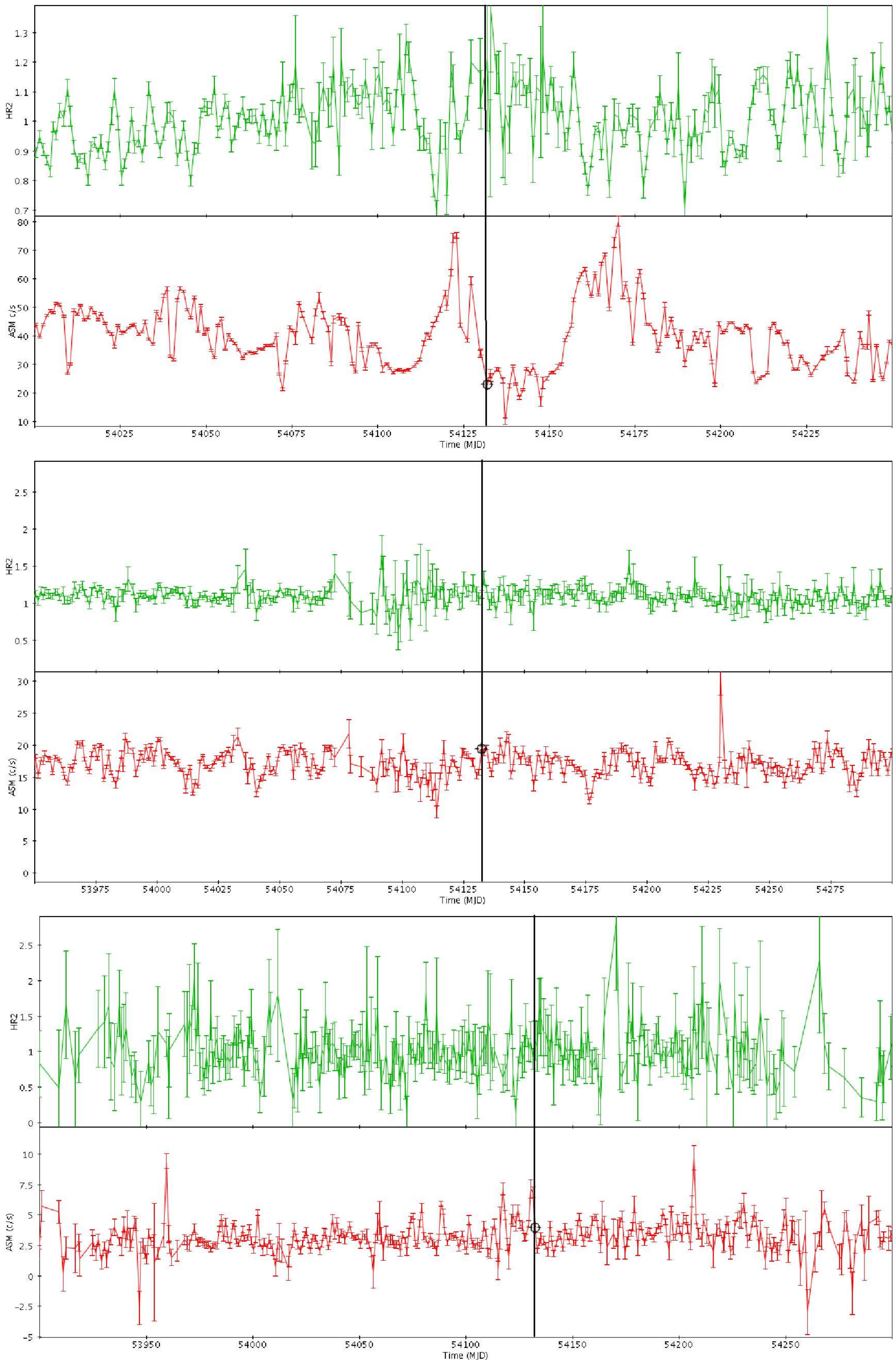

Figure 1: RXTE ASM lightcurves and hardness ratio (HR2). The data of the adaptive e-VLBI observation, MJD 54132 (01 Feb 2007), is marked for each source. **TOP:** Cygnus X-2 had a value of 26.6 ± 1.6 counts/s and a HR2 value of 0.9 ± 0.2 during the e-EVN experiment. **MIDDLE:** Ser X-1 had a value of 19.3 ± 0.3 counts/s and a HR2 value of 1.11 ± 0.05 during the e-EVN experiment. **Bottom:** V1055 Ori had a value of 3.9 ± 0.4 counts/s and a HR2 value of 1.1 ± 0.2 during the e-EVN experiment.

Name	AKA	Right ascension (J2000)	Declination (J2000)	ASM X-ray Intensity (count/s)	ASM error (counts/s)
2 S 0053+603	Gamma Cas	00:56:42.318	+60:43:00.06	0.496	0.28
CI Cam		04:21:42.2	+55:55:57.8	0	0.28
GRO J0422+32	V518 Per, Nova Persei 1992	04:21:42.77	+32:54:26.7	0.16	0.512
V725 Tau		05:38:54.601	+26:18:56.85	0.028	0.356
V1055 Ori	X 0614+091	06:17:07.31	+09:08:13.5	3.927	0.379
A 0620+00	V616 Mon	06:22:44.53	-00:20:44.5	-0.38	0.3
XTE J1118+480		11:18:10.85	+48:02:12.9	0.387	0.335
Ser X-1		18:39:57.51	+05:02:08.58	19.343	0.34
4U 1850-08	NGC 6712	18:53:04.87	-08:42:19.9	-0.1	0.33
XTE J1859+226		18:58:41.58	+22:39:29.4	0.195	0.258
Aql X-1	4U 1908+00, V1333 Aql	19:11:16.01	+00:35:06.3	0.004	0.355
GS 2000+25	QZ Vul	20:02:49.58	+25:14:11.3	0.577	0.644
XTE J2012+381		20:12:37.8	+38:11:01.1	1.012	0.802
V404 Cyg	GS 2023+338	20:24:03.81	+33:52:03.32	0.421	1.05
M15 AC 211	NGC7078	21:29:58.31	+12:10:00.06	0.853	1.279
Cyg X-2		21:44:41.3	+38:19:18	26.562	1.457
GT 2318+620		23:20:34.13	+62:17:33.37	0.08	0.289

Table 1: The target objects (J2000) and the RXTE ASM intensity value (counts/s) in the energy range 2-12 keV.