First e-VLBI observations of GRS1915+105

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ABSTRACT

We present results from the first successful open call e-VLBI run of the X-ray binary GRS1915+105. e-VLBI science made possible the rapid production of VLBI radio maps within hours of an observation rather than weeks, facilitating a decision for follow-up observations. Six telescopes observing at 5 GHz across the European VLBI Network (EVN) were correlated at the Joint Institute for VLBI in Europe (JIVE) in real time. Data rates of 128 Mbit s⁻¹ were transferred from each telescope, giving 4 TB of raw sampled data over the 12 hours of the whole experiment. Throughout this, GRS1915+105 was observed for a total of 5.5 hours, producing 2.8 GB of recorded visibility of correlated data. A weak flare occurred during our observations, and we detected a slightly resolved single component of 2.7 by 1.2 milliarcsecond was detected at a position angle of 140° ± 2°. The peak brightness was 10.2 mJy per beam, with a total integrated radio flux of 11.1 mJy.

Key words: ISM: jets and outflows - X-ray binaries: individual (GRS1915+105)

1 INTRODUCTION

The use of the Internet for VLBI data transfer offers a number of advantages over conventional recorded VLBI, including improved reliability due to real-time operation and the possibility of a rapid response to new and transient phenomena. Decisions on follow up observations can be made immediately after the observation rather than delayed by potentially weeks due to problems in shipment of tapes/discs to the correlator. The first open call with a suitable GST range for observations of GRS1915+105 using the e-VLBI (European VLBI Network), gave us the opportunity to test e-VLBI under operational conditions. A number of test runs over the past few years have shown that (28 Mbit sec⁻¹ data rates can be obtained reliably to the 6 telescopes: Cambridge, Jodrell Mk2, Medicina, Onsala, Torun and Westerbork, within Europe, currently connected via national and international research networks to the Joint Institute for VLBI in Europe (JIVE) correlator. Currently Effelsberg is not connected to the e-VLBI network, limiting the sensitivity and resolution of the current array. Steps are currently being taken to improve the reliability of 256 and 512 Mbit sec⁻¹ connection with EXPRESS-G goal to develop a stable 1 Gbit sec⁻¹ production capacity network.

Microquasars are ideally suited for study by e-VLBI real-time technique since they often have flares associated with the ejection of radio emitting clouds in the form of jets. Time-scales are in the range of hours to days at cm wavelengths, and decisions about subsequent observations, for instance an injection has been detected, need to be taken quickly.

GRS 1915+105 was first discovered in 1992 (Castro-Tirado et al. 1992) by the WATCH instrument on the GRANAT satellite. The system has a low mass, K-MIII star (Greiner et al. 2001b) companion and 14 (+4) M☉ black hole (Greiner et al. 2001a). It was the first Galactic source to display superluminal motion, and is well known for its rapid

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variability and strong variable radio flux. It spends the majority of its time in relative radio-quietness, with low radio and X-ray brightness, and with a characteristic low/hard X-ray spectrum. In such state the source is thought to be 'jet-dominated' (Fender et al. 2003), with a \( \sim 50 \) AU scale inner radio jet (Dhawan et al. 2003) present. Transitions to the soft state are often accompanied by strong radio flares with the ejection of a high velocity component out to distances of several hundred milliarcseconds \( \sim 10^{11} \) AU; these transitions have been studied by the VLA and MERLIN (Mirabel & Rodriguez 1994; Fender et al. 1999; Miller-Jones et al. 2005). Long-term high sensitivity VLBI monitoring of motions in the core is necessary to understand how the inner jets relate to the larger scale ejections. This is not possible without the strategy in place for a rapid decision of future VLBI observations.

The large scale ejections have apparent superluminal knots or clouds with velocities of \( > 0.9c \) (Miller-Jones et al. 2005). Observations with MERLIN in March/April and July 2001 at 5 GHz gave support for the internal shock model (Kaiser et al. 2000); an increase in the velocity of the jet material forms shocks in the outflow and superluminal knots are observed. Ideally observing the source during a state change would reveal the greatest information.

Over the last few months GRS 1915+105 has been consistently flaring in radio (figure 1). A \( 300 \) mJy (at 4.8 GHz) steep spectrum, optically thin flare was detected by the RATAN on 2006 Feb 23, suggesting that the source may have undergone a transition to the high soft state. This triggered a MERLIN ToO on transient sources which detected another outburst on March 2003 (Miller-Jones et al. in prep). A major goal of the project aim was also to develop a strategy for rapid response ToO VLBI observations for when this technique is more mature.
2 OBSERVATIONS AND RESULTS

On 2006 April 20 - 21 the e-EVN observed the X-ray binary GRS 1915+105 at 4.994 GHz. This observation was scheduled to be interleaved with a companion project on Cyg X-3 (Tudose et al. in prep.) to allow a better u-v distribution for both objects in the available observation period. GRS 1915+105 and its phase-reference source were observed between 23:39 and 10:45 UT for a total time on source of **** hours. HOW MANY HOURS TONY???????

In this e-VLBI experiment, the data is transferred from the telescope to the correlator using the Mark 5A end systems. These units have been fitted with 1 Gbit/s network Interface Cards which allow the units to transfer the telescope data to the correlator over the Internet and private optical networks. Production Internet connections for institutions within each participating country are provided and controlled by the local and national network providers. Most of the telescopes connect to the national networks, and then are connected to the GÉANT 2 network allowing pan-European multi-gigabit connectivity. The exception here is the Westerbork Synthesis Radio Telescope (WSRT) which has its own direct fibre connection to JIVE, and Jodrell Bank who transmits data over a private optical network.

Each station sustained a transfer rate of 128 Mbit/s across the e-VLBI network. This record rate supports two 8 MHz dual-polarisation baselines channels, providing a total bandwidth of 32 MHz. The observations were made using the phase-reference mode with a cycle of 5 minutes on source and 3 minutes on the phase reference, J1925+1227. A bright compact radio source, J2002+4725, used as a fringe finder, is scheduled at the beginning and toward the end of the run. The JIVE correlator used an integration time of 1 sec, to give a 0.55 arcsec field of view.

The initial data reduction was performed using the NRAO software package AIPS. The system temperature and gain calibration was initially calculated using the EVN PIPELINE (Kettenis et al. 2005) pipeline written in PYTHON by Cormac Reynolds. The AIPS task FRING was used to solve for the delay across the baselines with the fringe finder. Then, combining the baselines to give a better signal to noise, the phase, rates and delays of the phase calibrator were solved for again using FRING. A self-calibrated image of the phase calibrator was produced using the Caltech VLBI Software Package DIFMAP (Shepherd 1997), enabling further calibration using AIPS to be performed. The calibrated uv data of GRS 1915+105 was then Fourier transformed and a CLEAN algorithm was applied using the AIPS task IMAGR.

The radio image of GRS 1915+105 on 2006 20 - 21 April is shown in Fig. 2 using a uv weighting robustness parameter of 0 (Briggs 1995). The source had a position of R.A. 19 15 11.548 ± 0.001 and Declination 10 56 44.71 ± 0.01 (J2000). The position is consistent with that expected from the known proper motion (Miller-Jones et al. 2005).

The detected source has a major and minor axis of 9.8 X by 6.9 mas, observed with a beam size of 9.8 by 6.5 mas, respectively. This was deconvolved with the beam using the AIPS task JMFIT, which revealed an extended component of 2.7 X by 1.2 mas at a position angle of 140 ± 6°. This is similar to the P.A. of the large scale jets (e.g. Fender et al. 1999). The total integrated radio flux was 11.1 ± 0.6 mJy.

2.1 Ryle telescope and RXTE monitoring of GRS1915+105

The Ryle Telescope and the RXTE all sky monitor regularly observes GRS1915+105. Fig. 1 shows the XRB flux density between 2005 Jan - April at 15 GHz and 2 - 10 keV in the bottom and middle plots respectively. The top plot in Fig. 1 shows the X-ray spectral hardness ratio (X:1keV - 2:1:5keV). The date of the e-VLBI observation (53846 MJD), is marked. The flux enter a period of relative radio quietness in the two weeks before the e-VLBI observation. During the observation, the ASM count was at ≈ 40 counts per second, which is ≈ 0.5 crab (Lyne et al. 1996). The X-ray spectral hardness changed just before the epoch of the observation to a slightly softer state.

3 DISCUSSION

Fig. 3 shows the Ryle telescope data on 2006 April 21 between 01:27 - 08:32 UT. A flare of 40 mJy was detected, which quickly decayed to ~ 20 mJy within 4.5 hours. Assuming that the flare expands isotropically, the minimum energy in the magnetic field and energetic electrons can be calculated assuming equipartition within a synchrotron radiation field (Fender 2006). For a distance of 11 kpc (Fender et al. 1999) the minimum energy is 2 × 10^41 ergs. Using the deconvolved size from the image rather than assuming spherical expansion, we find a minimum energy of 1 × 10^40 ergs, a lower value due to the source being collimated.

The radio emission for this and similar weak flares (see Fig. 1) decays rapidly (~ 1day). This is unlike the major flares studied by the VLA and MERLIN (Fender et al. 1999; Mirabel & Rodriguez 1994; Miller-Jones et al. 2006) where the decay is over several days and the ejecta can be followed for up to 2 weeks after the flare. The behaviour of the strong flare is consistent with the shock-in-jet model (Miller-Jones et al. 2005); however the short flares seem to show the characteristics of an expanding source without continuous ejection of relativistic electrons.

The relationship between the radio and X-ray flare is consistent with that for other black holes with hard state (Gallo et al. 2003). Such sources have compact jets and flat spectra. The spectrum measured in our observations

2 GÉANT 2 is the seventh generation of pan-European research and education network - see www.geant2.net

3 quick look results provided by the ASM/RXTE team
between 5 and 15 GHz is flat or slightly inverted, and further
more the source is aligned with the P.A. of major ejections
observed by Mirabel & Rodriguez (1994). This gives extra
support to the idea that radio jets are present when X-ray
binaries are in the low/hard state.

The use of e-VLBI enabled us to obtain images within a
day of the VLBI run, rather than the weeks needed
for conventional recording based observations. It is possible
to shorten the time between observations and image
production even further, so that strategic decisions on future
observations can be made for rapidly changing sources. The
correlator needs to be stopped before correlated data can be
off-loaded. Suitable gaps on the observing schedule could
enable this to happen rather than waiting until the end of
the run. The time to convert the data to an AIPS data file could
be improved by software improvements and finally avoidance
of weekends would help.

This initial e-VLBI observation showed that the work
load at observatories is decreased, while the load on corre-
lator staff is increased considerably. Due note of this should
be taken for resource allocation.

This work clearly shows the ability of the e-EVN to pro-
duce high resolution radio maps in real time, hence elimin-
ating the need of tape/disc recording. In future e-VLBI data
rates will keep increasing with network development, yielding
higher sensitivities and longer baseline will be achieved with
the addition of more telescopes to the network.

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