THE EUROPEAN VLBI NETWORK: A SENSITIVE AND STATE-OF-THE-ART INSTRUMENT FOR HIGH-RESOLUTION SCIENCE

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ABSTRACT. The European VLBI Network (EVN) is an array of 18 radio telescopes located throughout Europe and beyond that carry out synchronized very-long-baseline-interferometric (VLBI) observations of radio-emitting sources. The data are processed at a central facility located at the Joint Institute for VLBI in Europe (JIVE) in the Netherlands. The EVN is freely open to any scientist in the world based on peer-reviewed proposals. This paper outlines the current capabilities of the EVN and procedures for observing, highlights some recent results that have been obtained, and puts emphasis on the future development of the array.

1. INTRODUCTION

The European VLBI Network (EVN)[1] was formed in 1980 by a consortium of five of the major radio astronomy institutes in Europe (the European Consortium for VLBI). Since then, the EVN and the Consortium has grown to include 12 institutes in Spain, UK, the Netherlands, Germany, Sweden, Italy, Finland, Poland and China (Table 1). In addition, the Hartebeesthoek Radio Astronomy Observatory in South Africa and the Arecibo Observatory in Puerto Rico are active Associate Members of the EVN.

The EVN members operate 18 individual antennae, which include some of the world's largest and most sensitive telescopes (Fig. 1). Together, these telescopes form a large scale facility, a continent-wide radio interferometer with baselines ranging from 200 km to 9000 km. The angular resolution of the array is 5 mas at 1.6 GHz and 0.3 mas at 22 GHz, hence providing astronomers with the sharpest view of the observed target sources.

The Joint Institute for VLBI in Europe (JIVE), located in Dwingeloo (Netherlands), was formed by the EVN in 1993 to build and operate the current 16-station EVN data processor (also referred to as the EVN correlator) and to provide central support for EVN users. The new EVN correlator has been operational since 1999, increasingly taking most of the load of EVN data processing. A small portion of the EVN data is also processed by the 9-station correlator of the Max-Planck Institut für Radioastronomie in Bonn.

The overall policy of the EVN is set by the *Consortium Board of Directors* (CBD) whose membership consists of the Directors of the member institutes of the EVN. It meets twice a year to discuss operational, technical and strategic issues.

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[1] See http://www.evlbi.org/

Table 1: Member institutes of the European Consortium for VLBI.

Institute	Name	Location	Country
<u>Full members</u>			
Nether. Found. for Research in Astronomy	ASTRON†	Dwingeloo	Netherlands
Istituto di Radioastronomia	IRA†	Bologna	Italy
Jodrell Bank Observatory	JBO†	Jodrell Bank	UK
Joint Institute for VLBI in Europe	JIVE	Dwingeloo	Netherlands
Max-Planck Institut für Radioastronomie	MPIfR†	Bonn	Germany
Metsähovi Radio Observatory	MRO	Espoo	Finland
Observatorio Astronómico Nacional	OAN	Alcalá de Henares	Spain
Onsala Space Observatory	OSO†	Onsala	Sweden
Shanghai Observatory	SHAO	Shanghai	China
Toruǹ Centre for Astronomy	TCfA	Toruǹ	Poland
Urumqi Astronomical Observatory	UAO	Urumqi	China
Bundesamt für Kartographie und Geodäsie	BKG	Wettzell	Germany
<u>Associate members</u>			
Hartebeesthoek Radio Astron. Observatory	HartRAO	Hartebeesthoek	South Africa
National Astronomy and Ionosphere Center	NAIC	Arecibo	Puerto Rico

†Founding institutes.

2. EVN OBSERVING

The EVN observes for three periods per year known as "VLBI sessions". Each of these sessions is approximately 3–4 weeks long and typically involves 3–4 different observing frequencies[2]. The EVN is also linked on a regular basis to the 7-element MERLIN interferometer (located in the southern half of the UK) to create a very sensitive "regional network", and to the US NRAO Very Long Baseline Array (VLBA) and the NASA Deep Space Network (DSN) to create a "Global Network". The EVN in stand-alone or global mode, also observed together with the orbiting radio telescope HALCA launched in February 1997 by the Institute of Space and Astronautical Science (ISAS) in Japan as part of the first dedicated Space VLBI mission VSOP (VLBI Space Observatory Programme).

The EVN *scheduler* ensures that all telescopes follow the same observing schedule during the VLBI sessions. Engineering issues related to EVN operations are considered by the *Technical and Operations Group* (TOG) whole role is to ensure that all telescopes are delivering good quality data during VLBI observing. At each EVN telescope, the data are recorded on disks with data rates up to 1 Gb/s using the Mark V recording system (which replaced traditional VLBI magnetic tape recording two years ago). After each observing programme is completed, the disks are shipped to JIVE where the data are replayed and combined at the EVN correlator to produce the VLBI observables.

Astronomers who wish to use the EVN must submit observing proposals to the EVN *Programme Committee* (PC). A *Call for proposals* is distributed three times a year with proposal deadlines of 1st February, 1st June and 1st October. The EVN PC is an independent body appointed by the CBD to assess all EVN, joint EVN plus MERLIN and Global VLBI requests for

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[2] The available frequencies are 0.3, 0.6, 1.2–1.6, 2.3, 5.0, 6.7, 8.4, 22 and 43 GHz, including the standard dual-frequency observing setup (simultaneous 2.3 and 8.4 GHz) used in astrometry and geodesy. The 6.7 GHz frequency (tracing methanol maser emission) is unique to the EVN. Not all frequencies are available at all telescopes.

Figure 1: Pictorial representation of the 18 telescopes of the European VLBI Network.

observing time. The EVN is an open facility and the PC awards observing time based only on scientific merit and technical feasibility.

EVN users can obtain assistance and support from JIVE via its support scientists. These scientists are funded through the European Commission's IHP Programme *Access to Research Infrastructures* and are able to advise on many different aspects of EVN observations and data analysis, including the technical feasibility of a proposed observing programme, the creation of EVN and Global VLBI experiment schedules, support of observations and data correlation, data calibration and image analysis at JIVE.

3. SCIENCE WITH THE EVN

The range of scientific projects carried out with the EVN covers a wide variety of areas, reflecting the growing applications of the VLBI technique. These include studies of masers in star forming regions, individual stars and X-ray binaries, pulsars and interstellar scattering, supernovae remnants in nearby galaxies, weak Seyfert nuclei, environment of active galaxies through OH and HI absorption lines and megamasers, the "classical" monitoring of jets in active galactic nuclei, and extragalactic and galactic astrometry.

Two recent highlights of the EVN are illustrated by the images in Figs. 2 and 3. Figure 2 shows the spatial distribution of the methanol maser emission in the candidate high-mass protostar G23.657–0.127 (Bartkiewicz et al. 2005). The striking nearly-circular ring structure seen in this image suggests a common origin for the maser components. A possibility is that the methanol maser emission arose in a shock initiated by a young, massive star at the centre of the ring, which yields a new perspective on the problem of the origin of methanol masers and star formation. Figure 3 shows a sequence of 24 images of the supernova 1993J obtained with the Global VLBI

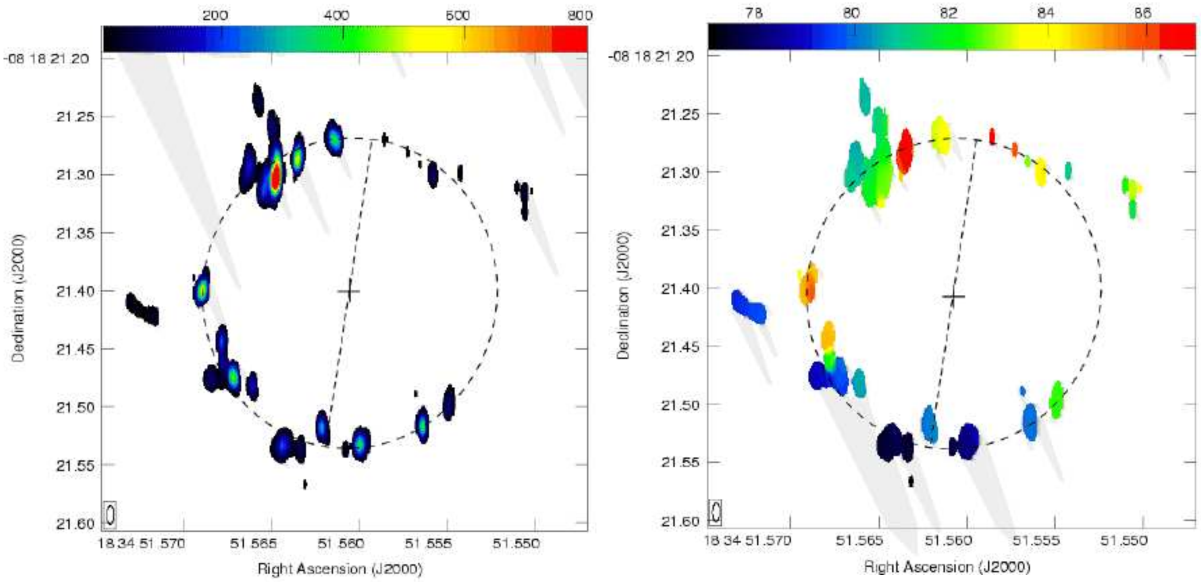

Figure 2: A 6.7 GHz EVN image of the galactic radio source G23.657–0.127 showing the spatial geometry (left panel) and velocity field (right panel) of the methanol maser emission in this young high-mass star (reproduced from Bartkiewicz et al. 2005). (See the website version of Proceedings for the color version of this figure.)

array over a range of 7.5 years starting shortly after the shock breakout in 1993 (Bietenholz et al. 2003). The sequence of images shows the expanding radio shell of the exploded star in detail, permitting a direct measurement of the angular expansion of the shell and studies of the interaction of the ejected material with the circumstellar medium around the progenitor star.

Another recent scientific highlight of the EVN was the precision VLBI tracking of the Huygens probe as it descended on to the surface of Titan on 2005 January 14 (Lebreton et al. 2005). Combined with Doppler data, the VLBI astrometric measurements will provide a full three-dimensional trajectory of the probe during its descent, enabling planetary scientists to study Titan's winds and to put measurements of the physical and chemical structure of the Titan atmosphere in perspective (Bird et al. 2005). The EVN has also been recently used to measure sub-milliarcsecond accurate astrometric positions for 150 new reference frame sources, as part of a project to densify the International Celestial Reference Frame (ICRF) towards weaker sources (Charlot et al. 2004). As noted above, the EVN is especially adapted to observe such weak sources due to its high sensitivity.

4. THE FUTURE OF THE EVN

Looking ahead, future developments will be targeted primarily at increasing further the sensitivity of the EVN. Disk-based recording with the Mark 5 system (yielding data rates up to 1 Gb/s) has already provided a gain by a factor of 4 compared to the standard 256 Mb/s data rate used until a few years ago when recording was still on magnetic tapes. A gain by an additional factor of two will be possible when Mark 5B units are available (two of these used in parallel will support up to 2 Gb/s), while the introduction of modern digital videoconverters opens up hope for recording rates up to 4–8 Gb/s on the longer term. New large antennas that are being constructed, e.g. in Spain (40 m telescope in Yebes to be available by 2006), Italy (64 m telescope in Sardinia planned for 2008) or China (50 m telescope in Miyun and 40 m in

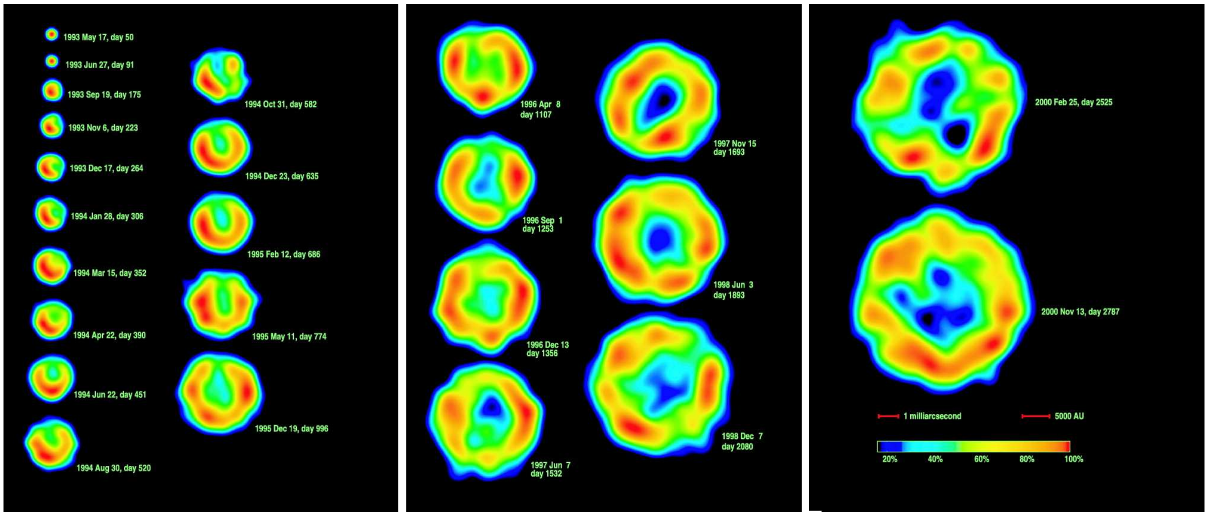

Figure 3: The evolution of the supernova 1993J which exploded on 1993 March 28 in the nearby galaxy M81. The observations were made with the global VLBI array at 8.4 GHz and cover a period from 50 to 2287 days after the explosion (reproduced from Bietenholz et al. 2003). (See the website version of Proceedings for the color version of this figure.)

Kunming to be available within about a year) will also directly and significantly improve the sensitivity of the EVN.

Another rapidly-developing area is the connection of EVN telescopes through high-speed networks (like the Pan-European Research Network GÉANT–2) to transfer and correlate VLBI data in real time. Such real-time experiments are usually referred to as "e-VLBI" experiments. As of September 2005, telescopes at Onsala, Westerbork, Jodrell Bank, Cambridge, Torun and Arecibo have already been connected to JIVE, while the Medicina antenna is expected to be connected soon. Subsequent to technical tests, a first e-VLBI science experiment[3] was conducted on 2004 September 22 and proved to be a great success. Notably, this experiment demonstrated real-time transfer and correlation over a 8200 km baseline between the EVN telescopes in Arecibo and Torun.

In the next 4 years, such e-VLBI developments will be coordinated through the EXPR*e*S (EXpress Production Real-time *e*-VLBI Service) project, an Integrated Infrastructure Initiative (I3) proposal submitted to the European Commission under the 6th Framework Program. This proposal was rated No. 1 out of 43 submitted proposals and was awarded 3.9 Million Euros. The objective of EXPR*e*S is to make e-VLBI an operational instrument by connecting 16 EVN telescopes (including those in China and South Africa) to JIVE at 1 Gb/s (the current e-VLBI transfer is only reliable to about 128 Mb/s), by integrating the antennas from e-MERLIN (an upgrade of the present MERLIN interferometer) transparently within the e-EVN and by offering a Target of Opportunity capability to the EVN users, i.e. a rapid response of the array allowing one to observe transient astronomical phenomenons like flaring stars, gamma-ray bursts,...etc...

With these developments, the EVN is likely to remain a state-of-the-art radio interferometer instrument in the forefront of astronomical research for high-resolution studies of galactic and extragalactic targets through the next decade.

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[3] See http://www.evlbi.org/evlbi/first_science/first_science.html

Acknowledgements. The author wishes to thank Anna Bartkiewicz and Leonid Gurvits for providing material prior to publication. He is also grateful to Mike Garrett for information about the EXPR*e*S project. The European VLBI Network is a joint facility of European, Chinese, South African and other astronomy institutes funded by their national research councils.

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