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Investigating Radio Transients with VLBI

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Abstract. The technique of Very Long Baseline Interferometry (VLBI) can provide accurate localization and unique physical information about radio transients. However, it is still under-utilized owing to difficulties inherent in VLBI data analysis, and also to practical difficulties of organizing observations at short notice. We present here a catalogue of the VLBI arrays currently available, with a brief decription of each. The catalogue is also available on-line [PAGE:HTML]. We also list types of object known to generate transient radio events.

Keywords. techniques: interferometric, radio continuum: general, stars: neutron

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1. An Overview of VLBI Arrays

The majority of arrays listed below offer at least part of their observing time as 'open sky' (any astronomer can apply), and also accept requests on the basis of 'targets of opportunity'. Note: the list does not include some telescopes which are capable of VLBI but are dedicated either to space geodesy (Schuh & Behrend, 2012) or to deep space communication.

The Very Long Baseline Array (VLBA; Napier, 1994) was the first instrument to be dedicated fully to VLBI. It includes ten 25-m telescopes spread across the continental United States, the US Virgin Islands and Hawaii. It operates full-time at frequencies of 0.3–96 GHz and is 'frequency agile', meaning that it may switch between receivers in about one minute. The VLBA may be combined with the GBT 100-m, the phased VLA 27x25-m, the Arecibo 305-m, the Effelsberg 100-m and/or the LMT 50-m, to form *the High Sensitivity Array.*

The European VLBI Network (EVN; Zensus & Ros, 2015) is a collaboration of 10–15 diverse stations (including 60–100-m class telescopes). The number of participating stations depends on the observing band (1–43 GHz range) and station availability. Most EVN stations are not frequency agile. Observations are performed during three sessions per year; there is also a limited number of pre-planned out-of-session observations. The EVN routinely includes stations from the regional VLBI arrays in Korea, Italy, China and Russia. The EVN may be requested together with the US stations as *the Global Array.*

The e-EVN is a subset of the EVN that is capable of real-time correlation, a feature that was specifically introduced for transient observations (Paragi, 2016). There is one 24 hr e-EVN observing session per month. Additional Target-of-Opportunity observations are also possible.

The Global mm-VLBI Array (GMVA; Hodgson et al. 2014) includes Effelsberg 100-m, the GBT 100-m, the NOEMA interferometer 7x15-m, the VLBA and other mm-band telescopes in Europe. The observations are performed at 86 GHz during two sessions per year.

The Event Horizon Telescope (EHT; e.g. Lu et al. 2014) is a heterogeneous VLBI array operating at 230 GHz. It has one observing session per year. The first open call for proposals for VLBI observations with the EHT together with the Atacama Large Millimeter/submillimeter Array (ALMA) was issued in 2018.

RadioAstron (Kardashev et al. 2013) combines ground stations with the 10-m radio telescope aboard a dedicated satellite in a high elliptical orbit (apogee – 326000 km) to form a Space–VLBI array. The observing frequencies are 0.3, 1.7, 4.8 and 22 GHz. Observations at 22 GHz may reach a higher angular resolution than can the EHT at 230 GHz (Gómez et al. 2016). The first observation of a transient source with RaioAstron was made during the search for radio emission from SN2014J in M82 (Sokolovsky et al. 2014).

The Long Baseline Array (LBA; Edwards & Phillips, 2015) has its core stations in Australia (the largest are the ATCA interferometer 6x22-m, the Parkes 64-m and the Tidbinbilla 70-m) but also provides intercontinental - baselines to the Hartebeesthoek 26-m in South Africa. This is the only VLBI array operating in Southern hemisphere. The observing frequency range is 1.4–22 GHz, but not all telescopes are available at all bands. The observations are conducted in 3–4 sessions per year. Test observations of GRB 080409, by combining a few LBA stations with the telescopes in China and Japan in the e-VLBI mode, were performed by Moin et al. 2016.

The Korean VLBI Network (KVN; Lee et al. 2014) consists of three dedicated 21 m stations capable of observing simultaneously at 22, 43, 86 and 130 GHz (Han et al. 2013, Rioja et al. 2015). The possibilities of installing similar receiving systems at VLBI stations outside Korea were investigated by Jung et al. (2015).

The VLBI Exploration of Radio Astrometry (VERA; Kobayashi et al. 2003, Honma et al. 2012) array includes four 20-m telescopes in Japan. Its main focus is parallax and proper motion measurements of Galactic maser sources. VERA observes at 6.7 GHz (methanol), 22 GHz (water) and 43 GHz (SiO masers) using a unique dual-beam system that allows simultaneous observations of the target maser source and an extragalactic continuum source serving as the phase calibrator.

KaVa combines KVN and VERA, observing at 22 and 43 GHz (e.g. Hada et al. 2017).

The Italian VLBI network (Stagni et al. 2016) includes the Sardinia 64-m and the two 32-m telescopes at Medicina and Noto. It is capable of observing in the 1–22 GHz range. Sokolovsky et al. (2013) searched for radio emission from SN2013ej in M74, using Medicina and Noto as a two-element VLBI.

The Japanese VLBI Network (JVN; Doi et al. 2006) combines VERA with other VLBI-capable telescopes, including the Usuda 64-m deep space communication antenna. There is no call for observing proposals from outside the JVN collaboration.

The Russian VLBI Network “Quasar” (Finkelstein, Ipatov, & Smolentsev, 2008) includes three 32-m telescopes in Svetloe, Zelenchukskaya and Badary observing in the 1–22 GHz range. The main focus of the network is geodetic VLBI, but it also performs astronomical observations with EVN and RadioAstron. There is no open call for proposals, but proposals for astronomical observations submitted directly to the Director may be considered.

The Chinese VLBI Network (CVN; Zheng, 2015) includes the Tianma 65-m, the Miyun 50-m, the Kunming 30-m and the 25-m telescopes in Seshan and Urumqi. The network is used for spacecraft navigation, geodesy and astronomy. There is no open call for proposals.

Future facilities include the *East Asia VLBI Network* (Wajima et al. 2016, An, Sohn, & Imai, 2018), which will combine the national networks of China, Japan, Korea and the African VLBI Network (Gaylard et al. 2011, Copley et al. 2016).

Other facilities that should be mentioned are *LOFAR* and *e-MERLIN*. Although not exactly VLBI arrays in the same sense as the ones listed above, they should be included as there are important technical similarities to VLBI.

LOFAR, with its international stations, is a VLBI array operating at frequencies ∼ 50 MHz (Morabito et al. 2016) and ∼ 150 MHz (Varenius et al. 2016). Its angular resolution is comparable to that of connected interferometers operating at GHz frequencies.

e-MERLIN (Spencer, 2009) is a 7-station array (including the Lovell 76-m instrument) observing at 1–22 GHz. It provides baselines approaching those of regional VLBI arrays, while it is technically a connected interferometer. It was used recently to study Galactic transients (among others) by Chomiuk et al. (2014), Healy et al. (2017).

2. Types of Radio Transients

Radio transients can be divided broadly into two classes (Bhat, 2011): *fast* transients, probably related to neutron stars (and flares on low-mass stars) and appear on subsecond time-scales, and *slow* transients, related to various explosive astrophysical events that evolve on a time-scale of days to months.

Fast transients include:

The enigmatic *Fast Radio Bursts* (FRBs; Petroff et al. 2016). Recent EVN+Arecibo observations enabled Marcote et al. (2017) to establish spatial coincidence of the repeating FRB 121102 with a persistent extragalactic radio source, providing new constraints on the physical interpretation of the (repeating) FRB phenomenon. VLBI was used to investigate the suspected host of FRB 150418 (Giroletti et al. 2016, Bassa et al. 2016).

Rotating radio transients (RRATs; Karako-Argaman et al. 2015).

Giant pulses from pulsars (Mickaliger et al. 2012, Takefuji et al. 2016).

A connection between the above three classes of fast transients is suspected (Popov, Postnov, & Pshirkov, 2018), but is not yet established.

Flare stars produce outbursts of non-thermal radio emission (Osten & Bastian, 2008).

The following types of events may produce slow radio transients:

Supernovæ are the most-studied class of radio transients (Bartel, Karimi, & Bietenholz, 2017). Over 50 radio supernovæ are known (Lien et al. 2011). VLBI observations provide expansion velocity measurements of the shell independently of optical spectroscopy, and reveal the mass-loss history of the progenitor star (e.g. Bietenholz et al. 2018).

γ-ray bursts produce afterglows that may be detected (e.g. Moin et al. 2013, Michałowski et al. 2016, Nappo et al. 2017) and resolved (Pihlström et al. 2007) with VLBI.

Novæ and symbiotic stars may appear as radio sources observable with VLBI, e.g. Sokoloski, Rupen, & Mioduszewski (2008), Giroletti et al. (2012). The source of the radio emission may be the nova shell and possibly a non-relativistic synchrotron-emitting jet (Rupen, Mioduszewski, & Sokoloski, 2008). VLBI imaging of the γ-ray-emitting classical nova V959 Mon, by Chomiuk et al. (2014), suggested that the synchrotron emission is produced at the interface between the fast polar outflow and the slow thermally-emitting outflow escaping the binary system in the orbital plane. Understanding the structure of the shocks in nova ejecta is important, as the shocks are found to be responsible not only for γ-ray, X-ray and radio emissions (Weston et al. 2016) but they also contribute significantly to the optical emission of the novæ (Li et al. 2017).

Dwarf novæ may also be transient radio sources (Körding et al. 2008). The mechanism causing their radio emission is unclear.

Tidal disruption events (TDE) in galactic nuclei, such as Swift J164449.3+573451, may be detected at radio frequencies. This is interpreted as evidence of a relativistic jet forming in the matter lost by the disrupted star (Berger et al. 2012). Surprisingly, Yang et al. (2016) were able to place an upper limit of 0.3 c to the ejection speed in this source.

Active galactic nuclei (AGN) are known to be sources of variable radio emission, and may appear as transients rising above the threshold of previous radio observations.

Microquasars (Gallo, 2010) can flare by several orders of magnitude within days. Some, when in the quiescent state, are also sources of radio emission. Recent VLBI results include observations of the expanding jets in XTE J1908+094 by Rushton et al. (2017), and of the giant flare in Cygnus X-3 by Egron et al. (2017).

Maser sources associated with star-forming regions and late-type stars may show flares of orders of magnitude in intensity (Matveenko, Graham, & Diamond, 1988, Rudnitskij et al. 2007).

References

An, T., Sohn, B. W., & Imai, H. 2018, *Nature Astron.*, 2, 118

Bartel, N., Karimi, B., & Bietenholz, M. F. 2017, *ARep*, 61, 299

Bassa, C. G., et al. 2016, *MNRAS*, 463, L36

Berger, E., et al. 2012, *ApJ*, 748, 36

Bhat, N. D. R. 2011, *BASI*, 39, 353

Bietenholz, M. F., et al. 2018, *MNRAS*, 475, 1756

Chomiuk, L., et al. 2014, *Nature*, 514, 339

Copley, C. J., et al. 2016, *arXiv:*1608.02187

Doi, A., et al. 2006, *Proc. 8th EVN Symp.,* p. 71

Edwards, P. G., & Phillips, C. 2015, *PKAS*, 30, 659

Egron, E., et al. 2017, *MNRAS*, 471, 2703

Finkelstein, A., Ipatov, A., & Smolentsev, S., 2008, *Proc. 9th EVN Symp.,* p. 53

Gallo, E., 2010, *LNP*, 794, 85

Gaylard, M. J., et al. 2011, *Proc. 56th Annual SAIP Conference*, p. 473

Giroletti, M., et al. 2012, *Proc. 11th EVN Symp.*, p. 47

Giroletti, M., et al. 2016, *A&A*, 593, L16

Gómez, J. L., et al. 2016, *ApJ*, 817, 96

Hada, K., et al. 2017, *PASJ*, 69, 71

Han, S.-T., et al. 2013, *PASP*, 125, 539

Healy, F., O'Brien, T. J., Beswick, R., Avison, A., & Argo, M. K. 2017, *MNRAS*, 469, 3976

Hodgson, J. A., et al. 2014, *arXiv:*1407.8112

Honma, M., et al. 2012, *Proc. IAUS*, 287, p. 386

Jung, T., et al. 2015, *JKAS*, 48, 277

Karako-Argaman, C., et al. 2015, *ApJ*, 809, 67

Kardashev, N. S., et al. 2013, *ARep*, 57, 153

Kobayashi, H., et al. 2003, *ASPC*, 306, p. 367

Körding, E., et al. 2008, *Sci*, 320, 1318

Lee, S.-S., et al. 2014, *AJ*, 147, 77

Li, K.-L., et al. 2017, *Nature Astron.*, 1, 697

Lien, A., Chakraborty, N., Fields, B. D., & Kemball, A. 2011, *ApJ*, 740, 23

Lu, R.-S., et al. 2014, *ApJ*, 788, 120

Marcote, B., et al. 2017, *ApJ*, 834, L8

Matveenko, L. I., Graham, D. A., & Diamond, P. J. 1988, *SvAL*, 14, 468

Michałowski, M. J., et al. 2016, *arXiv:*1610.06928

Mickaliger, M. B., et al. 2012, *ApJ*, 760, 64

Moin, A., et al. 2013, *ApJ*, 779, 105

Moin, A., et al. 2016, *RAA*, 16, 164

Morabito, L. K., et al. 2016, *MNRAS*, 461, 2676

Napier, P. J. 1994, *IAUS*, 158, p. 117

Nappo, F., et al. 2017, *A&A*, 598, A23

Osten, R. A., & Bastian, T. S. 2008, *ApJ*, 674, 1078-1085

Paragi, Z., et al. 2015, *AASKA14*, p. 143

Paragi, Z. 2016, *arXiv:*1612.00508

Petroff, E., et al. 2016, *PASA*, 33, e045

Pihlström, Y. M., Taylor, G. B., Granot, J., & Doeleman, S. 2007, *ApJ*, 664, 411

Popov, S. B., Postnov, K. A., & Pshirkov, M. S. 2018, *arXiv:*1801.00640

Rioja, M. J., Dodson, R., Jung, T., & Sohn, B. W. 2015, *AJ*, 150, 202

Rudnitskij, G. M., et al. 2007, *IAUS*, 242, p. 330

Rupen, M. P., Mioduszewski, A. J., & Sokoloski, J. L. 2008, *ApJ*, 688, 559-567

Rushton, A. P., et al. 2017, *MNRAS*, 468, 2788

Schuh, H., & Behrend, D. 2012, *J. Geodynamics*, 61, 68

Sokoloski, J. L., Rupen, M. P., & Mioduszewski, A. J. 2008, *ApJ*, 685, L137

Sokolovsky, K., Giroletti, M., Stagni, M., Nanni, M., & Mahabal, A. 2013, *ATel*, 5264

Sokolovsky, K. V., et al. 2014, *ATel*, 6197

Spencer, R. E. 2009, *Proc. 8th International e-VLBI Workshop,* p. 29

Stagni, M., Negusini, M., Bianco, G., & Sarti, P. 2016, in: *New Horizons with VGOS*, *Proc. International VLBI Service for Geodesy and Astrometry*, NASA/CP-2016-219016, p. 132

Takefuji, K., et al. 2016, *PASP*, 128, 084502

Varenius, E., et al. 2016, *A&A*, 593, A86

Wajima, K., et al. 2016, *ASPC*, 502, p. 81

Walker, R. C. 1999, *ASPC*, 180, p. 433

Weston, J. H. S., et al. 2016, *MNRAS*, 460, 2687

Yang, J., et al. 2016, *MNRAS*, 462, L66

Zensus, J. A., & Ros, E. 2015, *arXiv:*1501.05079

Zheng, W. 2015, *IAUGA*, 22, id. 2255896