Mem. S.A.It. Vol. 86, 48
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Opportunities for radio observations of southern sources

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Abstract. This is intended as a "rough guide" for high energy astrophysicists who may not have experience in radio astronomy but who want to undertake centimetric radio observations of a southern high energy source. Properties of the source and of the available telescopes are assessed in order to assist in selecting an appropriate radio telescope and frequency band for the observations.

Key words. Radio continuum: general – Instrumentation: miscellaneous

1. Introduction

The radio telescope best suited to observing a source of interest may be interrogated through a series of questions such as:

- What is the declination of the source?
- Is it Galactic or extra-Galactic?
- Is it an Active Galactic Nucleus (AGN)?
- What observing cadence is wanted?
- What radio frequencies would be best for observing it?
- What is its radio flux density likely to be?
- What angular scale is needed for observing it?

These questions are addressed in the following sections. This paper focuses on radio continuum emission and other possibilities such as spectroscopy and observing rapid transient sources are not discussed.

2. What is the declination of the source?

Sources with declinations north of about $-30^{\rm o}$ are observable with northern radio telescopes as well as those in the southern hemisphere. This declination limit is an approximate rule-of-thumb and can be slightly exceeded by some northern telescopes. For these sources, the largest of the single-dish telescopes such as the Effelsberg and Greenbank 100-m class telescopes could be used. Several northern telescopes have AGN monitoring projects, e.g.

- Effelsberg 100-m telescope "Fermi-GST AGN Multifrequency Monitoring Alliance" (F-GAMMA) project since 2007 (Angelakis et al. 2012; Fuhrmann et al. 2014)
- Owens Valley Radio Observatory (OVRO) 40-m telescope since 2007 (Richards et al. 2014)
- Medicina 32-m telescope "Simultaneous Medicina-Planck Experiment" (SiMPlE) project since 2004 (Procopio et al. 2011)

– University of Michigan 26-m telescope monitored over 900 sources from 1965 to 2012 (Aller et al. 2003).

If high-resolution imaging is wanted for sources with declinations north of about -30^{o} then the Jansky Very Large Array (JVLA) provides resolution comparable to the best optical telescopes. Much higher resolution is possible with Very Long Baseline Interferometry (VLBI). The Very Long Baseline Array (VLBA), and the European VLBI Network (EVN) are available and provide high sensitivity. The two can combine to form the "Global Array". The Russian Radioastron orbiting radio telescope, combined with Earth-based telescopes, currently provides the highest resolution (Fig. 1). The VLBA is used for an AGN monitoring project, "Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments" (MOJAVE) (Lister et al. 2009).

If the source is suitable for observation between 151 MHz and 1.4 GHz, then the Giant Metre-Wave Radio Telescope (GMRT) in India can observe down to a declination of -53^{o}.

Otherwise, below $\sim -30^{o}$ declination, only southern hemisphere radio telescopes are available. Single-dish telescopes in use include, in Australia, the Parkes 64-m telescope operated by the CSIRO, the Ceduna 30-m telescope, see "Continuous Single-Dish Monitoring of Intraday Variability at Ceduna" (COSMIC) (McCulloch et al. 2009) and the Hobart 26-m telescope, both operated by the University of Tasmania, and in South Africa the Hartebeesthoek 26-m telescope (Nemenashi, Gaylard & Ojha 2013). These telescopes typically have receivers covering bands from 1.4 or 1.6 GHz up to 22 GHz.

The Ceduna and Hobart telescopes have also been used as a two-element interferometer for AGN flux measurement (Blanchard et al. 2012). The Hobart 26-m and 12-m telescopes can be used in the same way at 2.3 and 8.4 GHz, and it is planned to test this with the HartRAO 26-m and 15-m telescopes at 8.4 GHz (Fig. 2).

Two radio telescope arrays are available in the southern hemisphere. The first is the Australia Telescope (AT) which could be used in its Compact Array (ATCA) form with baselines up to 6 km, or with extra telescopes as the Long Baseline Array (AT-LBA) providing VLBI resolution. The AT-LBA, with other southern telescopes, is used for the "Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry" (TANAMI) project monitoring AGNs at 8.4 and 22 GHz (Ojha et al. 2010). The six 22-m AT telescopes operate in four bands up to 105 GHz. The second array is KAT-7 in South Africa, comprising seven 12-m antennas equipped with L-band receivers covering 1.4 - 1.9 GHz.

3. Is the source Galactic or extra-Galactic?

Confusion with other sources may complicate radio observations. The first point of relevance is whether the source is within $\sim 2^{o}$ of the Galactic plane or not. For single dish observing, confusing sources in the beam are detected together with whatever radio emission may be coming from the source of interest. By contrast, with synthesis imaging using interferometers comprising multiple radio telescopes, diffuse emission is resolved out and only compact sources will remain.

For sources close to the Galactic plane, there is a diffuse background of synchrotron radio emission with a steep radio spectrum so that its brightness falls off rapidly with increasing frequency. There are also discrete sources, particularly HII regions (flat spectrum if optically thin, rising spectrum if optically thick) and supernova remnants (mainly steep spectrum). There is of course also a background of extragalactic sources seen through the Milky Way, but sources in the Milky Way generally dominate within 2^{o} of the Galactic plane.

The HartRAO 26m telescope was used to map the whole southern sky at 2.3 GHz (Jonas, Baart & Nicolson 1998). The Parkes telescope was used to make surveys at large single-dish resolution along the southern Galactic Plane at 0.408 GHz (Haslam et al. 1982), 1.4 GHz (Hill 1968), 2.4 GHz (Duncan et al. 1995), 2.7 GHz (Day, Caswell & Cooke 1972) and 5 GHz (Haynes, Caswell & Simons 1978). The

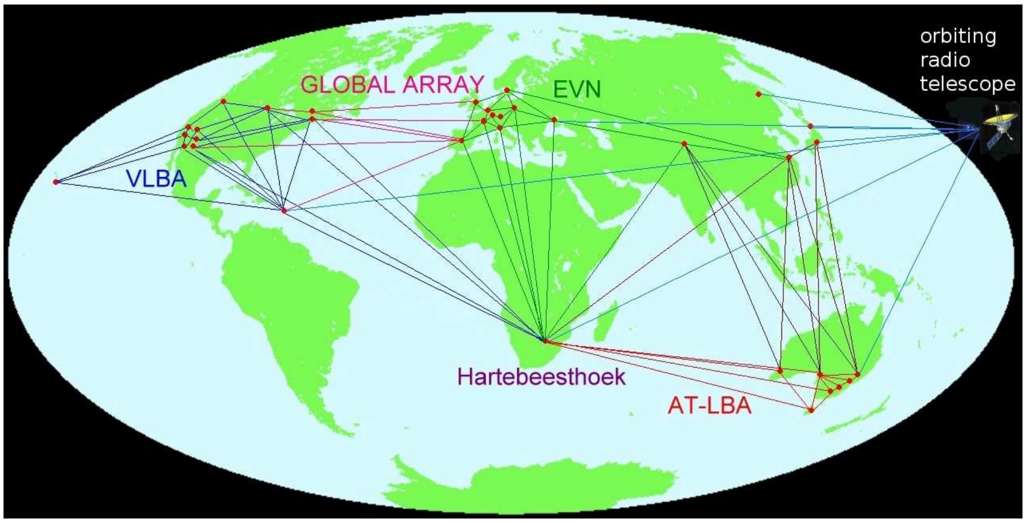

Fig. 1. VLBI networks of radio telescopes currently include the Radioastron orbiting radio telescope.

Fig. 2. The 26m and 15m telescopes at the Hartebeesthoek Radio Astronomy Observatory.

Effelsberg 100m telescope was used to make maps along the first quadrant of the Milky Way at 1.414, 2.695 and 5.000 GHz (Altenhoff et al. 1970) and again at 4.875 GHz (Altenhoff et al. 1979).

For sources that are extragalactic (and away from the Milky Way), there is a background of radio galaxies and Active Galactic Nuclei. The 5 GHz PMN survey (Griffith et al. 1994) and 20 GHz AT20G (Murphy et al.

2010) survey provide valuable lists of southern sources.

Thus both classes of object have the issue of source confusion of different types to be considered.

4. Is the source an AGN?

Many distant AGNs can appear as unresolved fixed point sources, which has made them attractive as reference sources for astrometry with milli-arcsecond precision. The International Celestial Reference Frame version 2 (ICRF-2) (Ma et al. 2009) made use of the positions of 3414 AGNs. These sources, and new candidates, are regularly observed at 2.3 and 8.4 GHz by the radio telescopes participating in the International VLBI Service for Geodesy and Astrometry (IVS), including Hartebeesthoek. The IVS data are available on the internet. HartRAO is leading new VLBI campaigns of additional southern astrometric observations of AGNs at 1.6 and 22 GHz.

5. What observing cadence is needed?

Short-lived events may provide only a single chance at detection, or permit the possibility of several events over several days. The most sensitive telescopes, usually radio telescope arrays, would then be requested for target of opportunity observations.

For longer-term monitoring single-dish observations may be suitable if the source is sufficiently bright in the radio. Single-dish telescopes do not generally resolve the radio source and so they measure the total flux density in the radio band used. For a relatively small single dish such as the Hartebeesthoek 26m telescope, as a general rule a flux density of several hundred mJy would be the minimum for useful monitoring, although with care lower levels could be monitored. This telescope can provide near daily cadence for long term monitoring. The closely spaced observations of two radio flares in the interacting binary system Circinus X-1, which has a period of 16.6 days, provide examples of what can be achieved with the HartRAO 26m telescope and with KAT-7 at L-band (Armstrong et al. 2013). Larger telescopes of course provide more sensitivity. For fainter southern sources (south of -30° Dec.) ATCA could be a good solution, providing reasonable sensitivity over a wide frequency range.

6. What are the best radio frequencies to use?

The answers here are governed by the characteristics of the source and of available telescopes and their receivers. There is a move to increase the bandwidth of receivers so as to cover as much as possible of the centimetric radio spectrum, and this can be seen with the new-generation receivers installed on the JVLA and ATCA. However, for practical purposes we will split the centimetric wavelength regime into three bands:

- Low frequency - below 2.5 GHz - for steep spectrum objects such as radio-bright supernovae, rapid transient sources and AGNs
- Mid frequency - 5 to 18 GHz - for AGNs, gamma-ray bursts, interacting binary stars
- High frequency - 22 GHz and upwards - for AGNs.

22 GHz is widely available but is affected by the broad atmospheric water vapour absorption line centered on 22.235 GHz and several GHz wide. Below -30° Dec only ATCA goes higher than 22 GHz, and overlaps in frequency coverage with the Atacama Large Millimetre Array (ALMA), whose lowest band is at 84 GHz.

7. What is the likely radio flux density of the source?

The likely flux density of the source is governed by the emission mechanism, optical depth effects in the source, evolution of the emission, and its distance. This list gives initial guidance:

- AGNs - from Janskys downwards
- Interacting binary stars - from Janskys downwards
- Radio transients - from Janskys downwards

- Gamma-ray bursts - from milliJanskys downwards
- Radio-bright supernovae - from milliJanskys downwards.

8. What angular scale is needed?

For single-dish radio telescopes the resolution (in radians) approximately equals 1.2 times the wavelength divided by the diameter. As examples, the 26m telescope has an angular resolution (half-power beamwidth) at 1.6 GHz of 30 arc minutes, but at 22 GHz this shrinks to 2 arc minutes.

For interferometers, the resolution (in radians) is approximately given by the wavelength divided by the maximum baseline length, so a guide for connected element interferometers is:

- KAT-7 at 1.7 GHz with 192 m maximum baseline gives $\sim$ 2 arc minutes resolution
- ATCA with 6 km maximum baseline gives 10 - 0.2 arc second resolution
- GMRT, 151 MHz up to 1.4 GHz with 25 km maximum baseline gives 15 - 1.5 arc second resolution
- JVLA, with 27 km max. baseline and 1 - 50 GHz frequency coverage using 8 receiver bands gives $\sim$ 10 - 0.1 arc seconds resolution.

For VLBI networks such as the EVN, VLBA, AT-LBA and IVS, with baselines up to $\sim$ 10 000 km, the typical resolution is of order 1 milli-arc second. This resolution is better than that available with any other observing technique, so it allows the precise location and extent of radio-emitting regions to be identified. Regular VLBI imaging provides a direct measure of the apparent motions in AGN jets.

9. What will be available in the future?

The MeerKAT array comprising of 64 13.5-m antennas is in construction and will become available in a few years. Initial receivers are planned to be wide L-band, but extra receivers are proposed to later cover lower and higher bands. The antennas use efficient offset Gregorian optics and will provide a big step up in sensitivity for the Southern hemisphere. The array will provide baselines of up to about 10 km. This is a precursor to the mid-band dish Phase 1 of the Square Kilometre Array (SKA), which will add hundreds of antennas and provide great sensitivity.

As another SKA precursor, the South African SKA Project, HartRAO and African SKA partner countries are working on the conversion of obsolete large satellite antennas in several countries into radio telescopes. The lead country is Ghana. The aim is for these to work with existing VLBI networks such as the EVN, and MeerKAT and SKA Phase 1 in future. If sufficient antennas become available, they can form an African VLBI Network capable of independent operation.

10. Conclusions

While not as richly endowed with radio telescopes as the Northern hemisphere, effective radio observations of high energy sources are quite possible in the Southern hemisphere, and this capability is set to grow rapidly in the coming decade.

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