Single-dish Radio Astronomy

Andrew Wright
Originally submitted for the Astronomy Online course at Swinburne University of Technology

1. Introduction

The radio astronomy world is abuzz with talk of huge interferometer projects such as the Square Kilometer Array, the Low Frequency Array, the Atacama Large Millimeter Array and others. Yet, single-dish telescopes have, and continue to, play a vital role in radio astronomy. This essay will compare the strengths of single-dish telescopes to interferometers and take a look at the research which is performed using these tools.

2. Single-dish telescopes and interferometers

2.1 Single-dish radio telescopes

A single-dish radio telescope basically consists of a a parabolic reflector which focuses incoming radio frequency energy on to a receiver/detector. Variations on this theme exist, including the use of sub-reflectors and different mountings for receivers. Single-dish telescopes range in size from metre diameter satellite-class antennas up to the world's largest steerable dish, the 100 metre Green Bank Telescope (GBTWeb) and the huge, but fixed, 305 metre Arecibo Observatory.

Figure 1 The Green Bank Telescope (Courtesy of NRAO)

2.2 Interferometry

The resolution of a telescope is limited by its collecting area (Storey 2002). Interferometry is a technique for combining multiple radio antennas to effectively form single antenna with a far greater collecting area than the individual components. The distance between the antennas and the rotation of the Earth leads to differences in the observed path length from the object under observation. When the data from each of the antennas is combined an interference pattern is generated, which can be reconstructed to form an image of the observation (NRAOweb).

Some major interferometer telescopes are listed in the table below. The wavelengths under observation by interferometer arrays range from the submillimetre (ALMA - under construction) to metre wavelengths (GMRT). Further interferometers are in the planning stage, including the Low Frequency Array (LOFAR), which should observe down to 30 metre wavelengths (LOFARweb) and the Square Kilometre Array (SKA), with which it is hoped that astronomers will get their first glimpses back into the Era of Reionization (Ekers, 2003).

Name	Antennas	Location	Reference
Atacama Large Millimeter Array (ALMA)	64 x 12m	Chile	ALMAweb
Australia Telescope Compact Array (ATCA)	6 x 22m	Australia	ATCAweb
Giant Metrewave Radio Telescope (GMRT)	30 x 45m	India	GMRTweb
Very Large Array (VLA)	27 x 25m	USA	VLAweb
Westerbork Synthesis Radio Telescope (WSRT)	14 x 25m	The Netherlands	WSRTweb

Figure 2 The GMRT (Courtesy of GMRT)

It is also possible to combine telescopes across thousands of kilometres, or even into space, using a technique called Very Long Baseline Interferometry (VLBI) (NRAOweb). The individual antennas may be of a heterogenous nature. For instance, the Australian Long Baseline Array

(LBA) utilises the 64 metre dish at Parkes, the 70 metre dish at Tidbinbilla, the ATCA's 22 metre dishes and other various other facilities in Hawaii, South Africa, Tasmania and South Australia (LBAweb).

Each antenna is equipped with a data recorder and in the case of the LBA, data is recorded on to high quality video tape (Ohja, R., private communication). Precise timing pulses for the data are provided by hydrogen maser clocks at each of the observatories, which then allows the data to be recombined in a machine called a correlator (NRAOweb). This data is then analysed for interference fringes.

2.3 Advantages of Single-dish Telescopes

It may appear that interferometers would be the ideal tool for performing radio astronomy, and in some cases this is true. However, single-dish telescopes have a number of disadvantages when compared with interferometers.

Sensitivity

Generally speaking, the large the collecting area of a antenna, the greater the sensitivity. The greater the collecting area of a radio antenna, the more radio energy that is focused on to the receiver. So, a large dish such as Parkes should be able to detect a fainter source than, say, a single dish of the ATCA. Furthermore, this will be true of an array of smaller antennas. While the total collecting area of an array may be larger, their sensitivity is dependent on the signal collected by each dish. It should also be noted, however, that the sensitivity will also be dependant on other factors, such as the system noise in the receiver's electronics (Burke & Graham-Smith 1997).

Instrumentation

Specialised instrumentation may only be available on a single dish, rather than each of the antennas in an interferometer, possibly due to the cost of the equipment. For example, the ALFA receiver recently mounted on the Arecibo receiver was valued at A$1.4 million (MBWeb). ALFA, and other multibeam receivers like it, are available for single dish antennas such as Arecibo, Parkes and Jodrell Bank rather than interferometers.

Availability

There are simply more single dish antennas available for use by astronomers than arrays, especially in the Southern Hemisphere, where currently the only (dish based) interferometer of note is the Australia Telescope Compact Array. In part this is because a single medium sized antenna is naturally cheaper to build than an array of similar sized antennas and does not require support equipment such as correlators. Another reason is that, in cases such as Hartbeesthoek (HartWeb) and the University of Tasmania (TasWeb), the antennas are surplus from NASA or telecommunications.

Ease of use

Data obtained from a single-dish experiment does not require correlation. Furthermore, there is no need to plan for and coordinate multiple antennas. This problem is especially evident in planning VLBI observations, which must take into account factors such as the visibility of objects from different locations and the slew rate of the individual antennas, or how quickly they can point to a new position in the sky. (Ohja, R., private communication)

3. Single-dish Research

In general, interferometers excel at performing high resolution studies of objects, including mapping extended sources such as jets from active galaxies (eg, JetWeb) and even planetary nebula formation (NebWeb). However, for tasks that do not require such high resolution, or where other factors, such as the availability of a telescope and receivers come into play, single-dish telescopes are usually used.

Listed below are examples of areas where single-dish telescopes have, and continue to, play an important role in astronomy.

3.1 HI Surveys and High Velocity Clouds

All-sky HI surveys have been primarily the domain of single-dish telescopes. Of particular note is the work performed by single-dish telescopes such as Parkes, Dwingeloo, Effelsberg and Villa Elisa in the discovery and investigation of High Velocity Clouds (HVCs) of HI (Wakker 2004). These clouds have been attributed to both galactic (eg Putman & Gibson 1999) and extragalactic (Blitz et al. 1999) regions, although the former argument appears to have more support (Wakker 2004).

Figure 3 The Parkes Radiotelescope (Courtesy of the ATNF)

HVCs are a good illustration of the relative strengths of single-dish and interferometer facilities. For example the HI Parkes All-Sky Survey (HIPASS) utilised a multibeam receiver and was responsible for substantially increasing the number of known HVCs (Putman et al. 2002). However, for more detailed studies of HIPASS objects other instruments, including the Australia Telescope Compact Array (ATCA) have been used (eg Kilborn, V. A. et al. 2000). Similarly, HIPASS also helped to illustrate the overall shape of the Magellanic Bridge, a tidal stream of HI between the Magellanic Clouds, while the ATCA filled in the details (Muller 2003)

3.2 Pulsars

One of the major uses of single-dish instruments and a very active area of research is the search for and study of pulsars. Facilities that are heavily involved in Pulsar research include the Parkes, Jodrell Bank and Arecibo radio telescopes (PulsarWeb). This research has been ongoing since pulsars were discovered in 1967 by Jocelyn Bell.

Pulsars are effectively point sources, so there is usually little need to use interferometry to resolve structure. Instead, research is focused on initial detection and the timing of pulses to detect variations and glitches, which can provide information about the nature of the underlying neutron stars.

Russell Hulse and Joseph Taylor were awarded the 1993 Nobel Prize in Physics for their discovery of a pulsar binary system using the Arecibo telescope and for the use of the timing to show that energy was being lost from the system in the form of gravity waves (NobelWeb). Work is also under way to precisely measure multiple millisecond pulsar timings using the Parkes radio telescope in the hope of detecting the passage of a gravity wave (HobbsWeb).

3.3 Radar

Single-dish telescopes have also been used in an active role to bounce radar signals off the upper atmosphere, solar system planets and the Sun. In fact, the giant Arecibo radiotelescope was originally designed in the 1960's as a tool to study the ionosphere using radar (Alschuler). The rotation periods of Mercury and Venus were determined using the radar signals from Arecibo (Dyce et al.). Today, radar from Arecibo is still used to image asteroids (Alschuler).

3.4 SETI

Despite the impression given by movies such as Contact and 2010, the VLA and other interferometers are not used to search for signals from extraterrestrials. Instead, single-dish instruments such as the Parkes radiotelescope and the 140-foot dish at Green Bank have been involved with SETI research (Shostak 1998). However, it is likely that, if a detection is ever made, then interferometers would be involved in undertaking high-resolution observations of the source.

4. Conclusions

Single-dish telescopes have played an important part in the history of radioastronomy and continue to do so today, with research in areas such as HI surveys, pulsars, radar and SETI. While the past 30 to 40 years has seen the development of interferometer observatories, often these telescopes complement the surveys performed by single-dishes, providing higher resolution images of features first detected in single-dish surveys. Single-dishes retain a number of advantages over their interferometry counterparts, including their sensitivity, availability, instrumentation and ease of use. While there are plans underway to do the next generation of astronomy with massive arrays such as the SKA, it should also be remembered that the world's largest steerable radiotelescope, the 100 metre Green Bank Telescope, has only just been completed. The future still looks bright for the single-dish!

References

ALMAweb: http://www.alma.nrao.edu/
Alschuler, D., The National Astronomy and Ionosphere Center's (NAIC) Arecibo Observatory in Puerto Rico, available at http://www.naic.edu/about/history/daltschuler_3.pdf
AreciboWeb: http://www.naic.edu/about/ao/discovr.htm
ATCAweb: http://www.narrabri.atnf.csiro.au/
Blitz, L., Spergel, D. N., Teuben, P. J., & Hartman, D. 1999, ApJ, 514, 818
Burke, B. F. and Graham-Smith, F., 1997, An Introduction to Radio Astronomy (Cambridge: Cambridge University Press)
Dyce, B. R., Pettengill, G. H. & Shapiro, I. I. 1967, AJ, 72, 351
Ekers, R. D. 2003, in The Proceedings of the IAU 8th Asian-Pacific Regional Meeting, Volume I, ed S. Ikeuchi, J. Hearnshaw & T. Hanawa (San Francisco: ASP), 21
GBTWeb: http://www.gb.nrao.edu/
GMRTweb: http://www.ncra.tifr.res.in/ncra_hpage/gmrt/gmrt.html
HartWeb: http://www.hartrao.ac.za/other/dss51/dss51.html
HobbsWeb: http://astronomy.swin.edu.au/anita/gravity/talks/ghobbs.ppt
JetWeb: http://www.nrao.edu/pr/1997/cjet/
JIVEweb: http://www.jive.nl/
Kilborn V. A. et al. 2000, AJ, 120, 1342
LBAweb: http://www.atnf.csiro.au/vlbi/documentation/
LOFARweb: http://www.lofar.org/
MBWeb: http://www.atnf.csiro.au/news/press/ALFA/
Muller, E., Staveley-Smith, L. & Zealey, W. 2003, in the Proceedings of the International Astronomical Union Symposium no. 217, ed P.-A. Duc, J. Braine, and E. Brinks. (San Francisco: ASP), p.506
NebWeb: http://www.nrao.edu/pr/2001/k335/
NobelWeb: http://nobelprize.org/physics/laureates/1993/press.html
NRAOweb: How Radio Telescopes Work: http://www.nrao.edu/whatisra/radiotel.shtml
PulsarWeb: http://outreach.atnf.csiro.au/education/everyone/pulsars/
Putman, M. E. & Gibson, B. K. 1999, PASA, 16, 70
Putman, M. E. et al. 2002, AJ, 123, 873
Shostak, S. 1998, Sharing the Universe, (Sydney: Landsdowne Publishing)
SKAweb: http://www.skatelescope.org/
Storey, M., 2002, Introduction to Radio Interferometry, http://www.atnf.csiro.au/education/interferometry/introduction/index.html
TasWeb: http://www-ra.phys.utas.edu.au/physics_telescopes.html
VLAweb: http://www.vla.nrao.edu/
Wakker, B. P. 2004, Ap&SS, 289, 381
WSRTweb: http://www.astron.nl/p/observing.htm

Swinburne Astronomy Online: http://astronomy.swin.edu.au/sao/