

WIDE FIELD IMAGING WITH THE BDA

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ABSTRACT

Imaging the sky with better sensitivity and resolution is the mainstay of all astronomy. While radio maps of the sky do exist at various radio frequencies, astronomers continue to image the sky for various reasons -the improved capabilities of the new instruments, improved analysis and imaging software, variability of the sources in the sky and new questions generated by our improved understanding of the physics of sources. The availability of images of large sources or regions of the sky is a valuable tool in these days of multi wavelength studies of astronomical sources. While the Northern sky has been well studied at radio wavelengths by a variety of modern radio telescopes, the study of the sky south of declinations of -45 degrees has been relatively limited, though a number of new telescopes are being planned. While many of the interesting objects have been imaged with the Australia Telescope, the BDA with its large field of view and better short spacing coverage would do a better job at mapping the extended diffuse features. An all sky survey at 5.8 GHz going down to a few milli Janskies, the southern equivalent of the NVSS catalog would be a valuable contribution and would generate interesting science when combined with the Molongolo survey at 843MHz and surveys at different bands. The wide field of view and good short spacing coverage of the BDA can be used for relatively new areas of research like detection and study of transient radio sources, magnetic fields in the ISM by studying filamentary structures seen in polarization, etc. Some of these projects, along with the science drivers and the effort involved will be discussed.

The construction of a new telescope is expected to produce a flurry of scientific activity and since every new telescope is generally built to fill a niche and address some specific question better than any previous telescope. The niche of the Brazilian Decameter Array (BDA) is solar physics where there is a need for a dedicated, high resolution radio telescope at decameter wavelengths to complement the various planned telescopes at other wavelengths. However, since the sun is up in the sky only during the day and radio telescopes can operate twenty four hours, it is of interest to examine what else it can do after the sunset. This is of special interest if the telescope has to be used by astronomers outside the solar community.

The primary purpose of a radio telescope is to image sky as efficiently as possible so that the entire sky can be mapped, within the geographical constraints of the instrument, as rapidly as possible. For this the BDA is well suited since it is designed to image the sun which is large and variable on short time scales. All high resolution radio telescopes around the world are earth rotation aperture synthesis telescopes that consist of an array of single dishes with complex electronic backends that form N(N-

$1/2$ pairwise interferometers between the N elements in the array. In modern synthesis arrays N can be large (27 for the VLA¹, 30 for the GMRT², 26 for the BDA and even larger values for various proposed radio telescopes). Each interferometer pair measures one spatial fourier component of the patch of sky seen by the individual antennas and as the earth rotates, the geometry of the array with respect to the source changes, leading the same interferometer pair to measure different fourier components. At the end of a full synthesis (observing a source from rise to set) a synthesis radio telescope upwards of a few hundred thousands fourier components (visibilities) and forming an image of the field of view of the telescope consists of fourier inversion on a computer of the observed visibilities and complex image processing to remove artifacts caused by the incomplete measurement of the fourier space and possible errors in calibrating the observed data.

The properties of the telescope that are of direct concern to the astronomer are:

1. its sensitivity which is a function of N , the size of the antennas, the bandwidth and quality of the electronics and the integration time;
2. its angular resolution which is inversely proportional to the longest baseline;
3. its field of view which is inversely proportional to the size of the individual elements of the array;
4. its speed for imaging to a given sensitivity which depends on the array configuration (one dimensional versus two dimensional arrays);
5. the ease of analysing data from from the instrument.

Ideally, the astronomer would like all these quantities to be high, but this is not easily achieved since many of them are contradictory. For instance, increasing antenna sizes to increase the sensitivity leads to leads to smaller fields of view. Increasing the bandwidth increases the complexity of the electronics and the analysis. Increasing the angular resolution and field of view in two dimensional arrays leads to complexities due to the breakdown in the simple fourier relationship between the observed visibilities and the image of the sky. Any radiotelescope has to optimise these various parameters to maximise its impact.

In trying to examine what science can be done with a telescope, its performance has to be compared with existing and planned instruments. From the point of view of an astronomer, the Brazilian Decameter Array has both strengths and weaknesses. The strengths are its large field of view for a telescope in its frequency range, its two dimensional configuration that provides good instantaneous u - v coverage, the relative ease of data analysis since it is unlikely to be affected by w -term and ionospheric problems and its access to the entire southern sky which has till recently been relatively understudied in radio astronomy since most of the radio telescopes are in the northern hemisphere and can see only down to declinations of 45 degrees south. At present, the only major synthesis radiotelescopes that can study the sky south of 50 degrees declination are the Australia telescopes and the Molongolo Radio Telescopes, both of which are east-west arrays. The weaknesses are its relatively poor sensitivity since it was designed for studying the sun which is very bright, its poor angular resolution, its limited bandwidth and the fact that a number of radiotelescopes are being built or planned in the southern hemisphere which could be competitors to the BDA.

The southern sky has a number of unique objects that have yielded interesting results whenever they are observed. The center of our galaxy with all its associated objects, many of which vary with time, is almost overhead for the BDA. The Magellenic clouds, our nearest neighbour galaxies are also easily accessible to the BDA.

Given its large field field of view, any observation of these regions by the BDA would cover a very large number of individual objects which increases the probability of discovering interesting objects. There are also many interesting and unique extended extragalactic sources in the southern sky

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like Centaurus-A, Pictor-A and Fornax-A which would benefit from high quality low resolution images since most of the modern synthesis radiotelescopes have limited fields of view and poor short spacing coverage of the fourier plane. Combining the BDA data with existing high resolution data and redoing the imaging analysis would generate high quality images that could provide interesting insight on the physical processes in the source. The same is true of the galactic center complex and the various extended supernova remnants and HII regions like 40Doradus that lie in the southern galactic plane.

Besides imaging individual sources, a project to map the southern sky down to a flux limit of a few milliJanskys should be undertaken by the BDA since it will be very sensitive to low surface brightness objects that are often missed in high resolution studies. The Sydney University Molonglo Sky Survey (SUMSS)² has surveyed the southern sky at 843MHz with a resolution of 50". A BDA survey at 5.6 GHz would have a similar resolution and would yield valuable scientific results by identifying interesting object by studying the radio spectra between these two frequencies. Many interesting objects that are often ignored as not reliable when they are near survey limits, get studied when they are detected independently in a different study. An all sky survey would consume a lot of telescope time and would also involve large volumes of data and analysis. Such a survey should be undertaken only after the instrument is reasonably debugged and astronomer are confident of undertaking the effort. A major limitation of the BDA for such studies is its relatively poor sensitivity, because of which the time required for the survey could become prohibitive. One hour observation with the BDA Phase III will produce images with noise of 3 milliJansky rms enabling detection of sources stronger than 10 milliJansky. Increasing the bandwidth of the BDA by a factor of 10, which is not too difficult with today technology would increase the sensitivity by a factor of 3 and bring the observing time for the survey to acceptable values.

One of the most active areas in astronomy is the study of transient and variable sources which are seen in all wavelengths bands - gamma rays, X-rays, optical and radio.

The prototype for such objects is the sun which shows variability in all wavelength bands and at all time scales, from millisecond bursts to secular variations over years. With modern telescopes, variable sources are detected from all distances, ranging from the edge of the universe (gamma ray bursts), through objects at extragalactic distances like active galactic nuclei and supernovae, to galactic objects like Xray binaries, optical variable and flare stars and radio pulsars and transients. A proper understanding of the nature of any source requires studying its properties in the different wavelength bands which is often a challenge since it requires coordinated observations from different telescopes across the world and in space, which is often difficult to arrange at short notice during the short life of a transient source. Every observatory routinely gets hundreds of requests for observations of a newly discovered transient but only a few can be handled given the various other planned observations at the observatory. This is a field that is growing and the BDA would benefit from participating in this area of research since many of these transients are within the sensitivity range of the BDA. Even when not detected, the upper limits set by the BDA would provide useful constraints while modeling the sources.

However, acting as a service facility and adding one or two points in somebody else's project is no doubt, a useful scientific activity, it is not very glamorous and would not excite younger astronomers. More exciting would be to discover new transient sources, initiate observations at different observatories and carry out the modeling and interpretation of the sources. This could be achieved by regularly monitoring interesting fields in the sky where the density of stars and hence the probability of detecting such transients is high. Possible regions to monitor are the galactic center region, the Magellenic clouds and regions at galactic longitude 90/270 degrees. A program to routinely monitor a few selected fields in such regions, combined with near real time analysis of the data, would

enable detection of new transients and would trigger the associated follow up activity. For this, the contacts developed by acting as a radio facility to users in other wavelength bands would come in handy.

Astronomy is evolving rapidly and new areas of research keep cropping up. The filamentary structures seen in polarization by the Westerbork Radio Telescope, which are believed to be due to structure in the foreground rotation measure screen is one example. A new telescope brings in new people and new perspectives which generally leads to a period of enhanced scientific activity.

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