WIDE FIELD H I IMAGING WITH THE AUSTRALIA TELESCOPE

N. M. McClure-Griffiths[1], Snezana Stanimirovic[2], John M. Dickey[3], B. M. Gaensler[4], A. J. Green[5]

[1]***Australia Telescope National Facility, CSIRO, PO Box 76, Epping NSW 1710 Australia***
e-mail: naomi.mcclure-griffiths@csiro.au

[2]*National Astronomy and Ionosphere Center, Arecibo Observatory, HC 3 Box 53995, Arecibo, Puerto Rico 00612*
e-mail: sstanimi@naic.edu

[3]*Department of Astronomy, University of Minnesota, 116 Church St SE, Minneapolis, MN 55455 USA*
e-mail: john@astro.umn.edu

[4]*Harvard-Smithsonian Center for Astrophysics, 60 Garden St MS-6, Cambridge, MA 02138 USA*
e-mail: bgaensler@cfa.harvard.edu

[5]*Astrophysics Department, School of Physics, Sydney University, NSW 2006, Australia*
e-mail: agreen@physics.usyd.edu.au

ABSTRACT

Over the past seven years several large mosaicing projects have been conducted with the Australia Telescope Compact Array (ATCA), including the neutral hydrogen (H I) surveys of the Large and Small Magellanic Clouds and the H I Southern Galactic Plane Survey. These surveys combine data from the Parkes 64m single-dish with ATCA mosaics for sensitivity to angular scales spanning more than two orders of magnitude. Here we focus on the combination of ATCA and Parkes data and discuss results from the SGPS and Small Magellanic Cloud surveys that rely on a wide range of angular scales.

INTRODUCTION

Surveys of Galactic neutral hydrogen (H I) had largely reached a plateau by the 1970's. At the time, single dish telescopes limited H I surveys to an angular resolution of 1/4 to 1/2 degree. Simultaneously, synthesis imaging with interferometers was improving the resolution of radio telescopes, but mapping large regions with an interferometer was both inefficient and unsatisfying. For large-scale distributions like the Galactic H I or the nearby Magellanic Clouds the inability of interferometers to recover information on the largest angular scales limited the usefulness of these surveys.

Some of these obstacles can be overcome with the process of mosaicing, whereby many different pointing centers are combined, enabling a large object to be observed efficiently with high spatial resolution. However, an interferometer still cannot recover information about angular scales larger than those sampled by the shortest projected separation between antennas. This lack of information on very large spatial scales (or very low spatial frequencies) in an interferometric observation is usually referred to as the '*short-spacings problem*'. An absence of the largest spatial scales, corresponding to the central, short, frequencies from the *u*-*v* plane, results in the presence of image artifacts such as deep negative 'bowls' around emission regions (see left panel in Fig. 1). In 1979 Ekers & Rots [4] showed that mosaicing can actually fill in more of the *u*-*v* plane, allowing a mosaiced observation to recover a wider range of spatial scales than a single pointing observation. Mosaicing effectively reduces the shortest projected baseline so that the largest angular scale observed increases from $\theta/d_{\min}$ to $\theta/(d_{\min} - D/2)$, where θ is the observed wavelength, $d_{\min}$ is the minimum separation between antennas, and D is the diameter of an individual antenna. Since 1979 extensive work on mosaicing by Cornwell [2], Sault et al. [7], and others has improved the efficiency with which mosaicing can be undertaken, especially with regard to the large amount of data obtained with this technique.

MOSAICING WITH THE ATCA

Mosaicing has been commonly practiced at the Australia Telescope Compact Array (ATCA) since the telescope was commissioned. The ATCA is a six element, east-west synthesis instrument located near Narrabri, New South Wales, Australia. It consists of six 22 m diameter antennas with a maximum baseline of 6 km. The ATCA was designed as a compact array, so the coverage of short baselines is excellent. By observing in two array configurations, EW 352 and EW

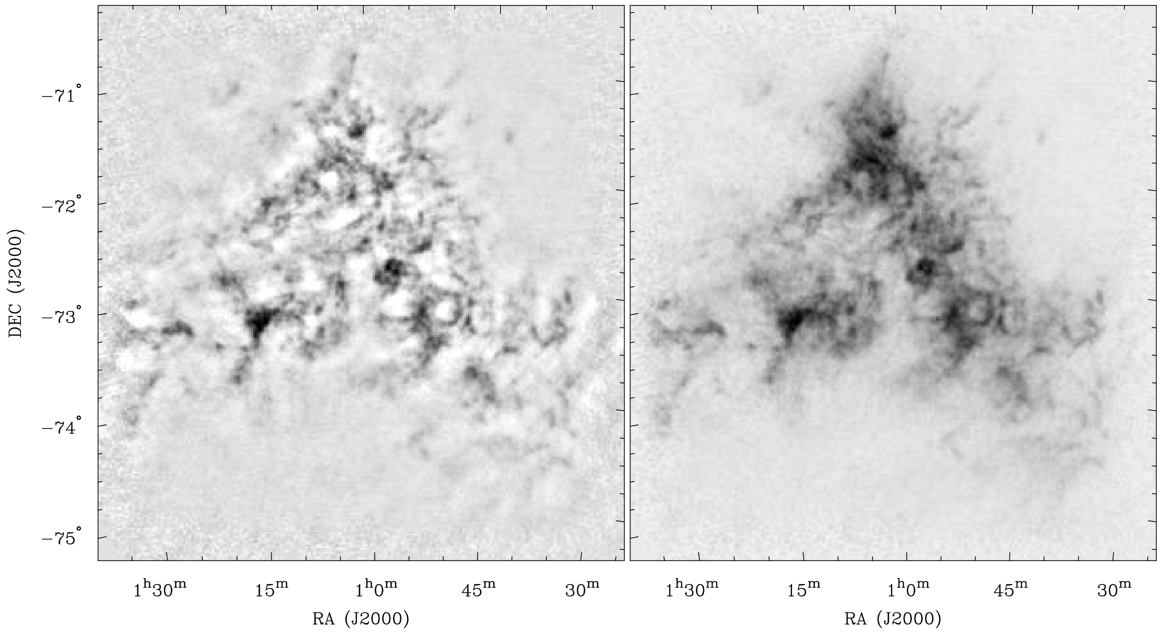

Figure 1: H I image of the Small Magellanic Cloud obtained with the ATCA (left) and by combining Parkes and ATCA data (right).

367, it is possible to cover all baselines from 30m to 168m in multiples of 15m. The ATCA is also optimally designed for mosaicing; both because of its non-parabolic dish surface, which under-illuminates the secondary, and its fast drive motors. The ATCA antennas can slew and settle to a new position 20 arcmin away in less than 3 seconds, sacrificing very little time to overhead. Additionally, the observing software is well-equipped for mosaicing, greatly simplifying mosaicing observations.

WIDE FIELD IMAGING WITH PARKES

Another component of the Australia Telescope is the Parkes Radio Telescope, a 64m single dish near Parkes, New South Wales, Australia. In 1997 the telescope was equipped with a thirteen beam 21 cm receiver package at prime focus [11]. The thirteen beams are arranged in a hexagonal pattern with 29.1 arcmin separation between adjacent feeds. In addition to pulsar observations, the primary use of the multibeam for large-scale H I imaging projects (e.g. HIPASS [1] and the SGPS). These surveys use the multibeam to map "on-the-fly", scanning continually to sample the sky at the Nyquist rate. The multibeam and software developed for use with it, has significantly increased the effectiveness of imaging large areas with a single dish. It is now possible to cover a 20 deg^2 region to an rms of about 300 mK per $1\ \mathrm{km\ s}^{-1}$ channel in 1 hour.

COMBINING SINGLE DISH AND INTERFEROMETER DATA

Though mosaicing allows one to recover information on angular scales larger than the minimum interferometer baseline, there remains a hole at the center of the *u*-*v* plane, corresponding to the largest angular scales. To overcome this limitation, one can combine the interferometer mosaics with images obtained with a single-dish. The resultant images contain information for total flux values, H I masses, and statistical information on spatial scales ranging over several orders of magnitude.

The constituents of the Australia Telescope, the Compact Array and Parkes, are ideal for combination. The minimum baseline of the ATCA is 30m, whereas Parkes is 64m in diameter, so the overlap in the *u*-*v* plane is maximized. This allows for simple cross calibration of the two datasets over the *u*-*v* range sampled by both. There are a number of different methods used to combine single-dish and interferometer data. It is beyond the scope of this paper to present a full analysis of all methods, for a full treatment see [8]. We will focus, therefore, on a method that is often preferred because of its simplicity and robust results. In this technique the single dish and interferometer data are imaged and deconvolved separately and then combined. The deconvolved images are Fourier transformed and re-weighted so that lowest spatial frequencies are weighted heavily in the Parkes data and down-weighted in the ATCA data. The single dish image is then

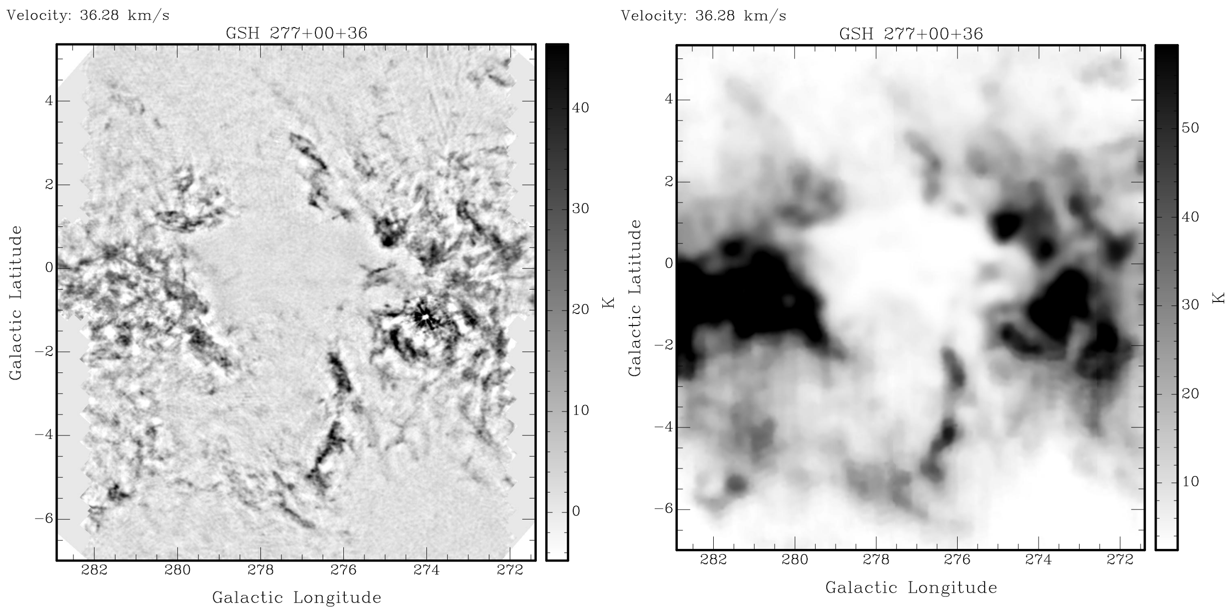

Figure 2: H I images of GSH 277+00+36 at $v = 36.28\ \mathrm{km\,s^{-1}}$. The left image was made with ATCA data and has a resolution of 3 arcmin. The right image is just Parkes data with a resolution of 16 arcmin.

scaled by a calibration factor, the two images are added together and the result is inverse Fourier transformed.

RESULTS

The results of combining single-dish and interferometer data in this manner are striking. This is especially true for H I data, where structure exists on all size scales. Fig. 2 shows the ATCA and Parkes images of a large H I shell in the outer Milky Way, GSH 277+00+36 [6]. The shell is observed as a large void at the center of the images, surrounded by walls of swept-up material. The ATCA data consist of 1025 pointings, with a resolution of 3 arcmin. The Parkes data were obtained with the multibeam. In the ATCA image (Fig. 2 left) the filamentary structure of the walls is visible, and although the void is still apparent, the context of the structure is lost. By comparison, the Parkes image (Fig. 2 right) shows dense concentrations of mass on the edges of the shell with no detail. In Fig. 3 the ATCA mosaic and the Parkes data have been combined to show the fine-scale structure of the shell walls with the dense concentrations of matter along the Galactic plane. Perhaps the most remarkable aspect of the combined image is how it highlights the thin walls of the shell and the vertical extensions. Though the radius of the shell is more than 320 pc, the shell walls are in some places only 5 pc thick. The added resolution also shows that at some velocity channels, the shell walls and chimney extensions are losing their continuity. This is presumably due to motions in the ISM external to the shell, the expected end-cycle of shells.

Another example is provided by the Small Magellanic Cloud data combination. The ATCA mosaic consists of 320 pointing centers while Parkes data were obtained towards 1540 different positions in the SMC. As was done with the SGPS data, the two data sets were cross-calibrated and combined in the image domain. Images before and after short-spacings correction are shown in Fig. 1. The final image has the ATCA's high angular resolution of 98 arcsec and is sensitive to all spatial scales from 30 pc up to the size of the whole SMC, about 4 kpc. The image also contains the total power information which allows reliable flux density and H I mass estimates. The wide range of *continuous* spatial scales provided by the data combination allowed especially employment of the H I spatial power spectrum to probe the existence and properties of the interstellar turbulence in the SMC. It was found that the H I spatial power spectrum closely obeys a power law relation. This suggests the presence of a hierarchy of H I clouds created, most likely, by interstellar turbulence [9]. The power-law index of the 2-D H I power spectra of intensity fluctuations varies with the thickness of velocity slices, which enabled [10] to probe properties of the 3-D density and velocity distributions. Results suggest a slightly more shallow spectrum than predicted for the Kolmogorov type of turbulence.

Similar behavior of the H I spatial power spectrum was also found for a region in the SGPS data. The power-law slope (-4) is steeper than in the case of the SMC (-3.4) and appears to be a result of density, rather than velocity, dominated

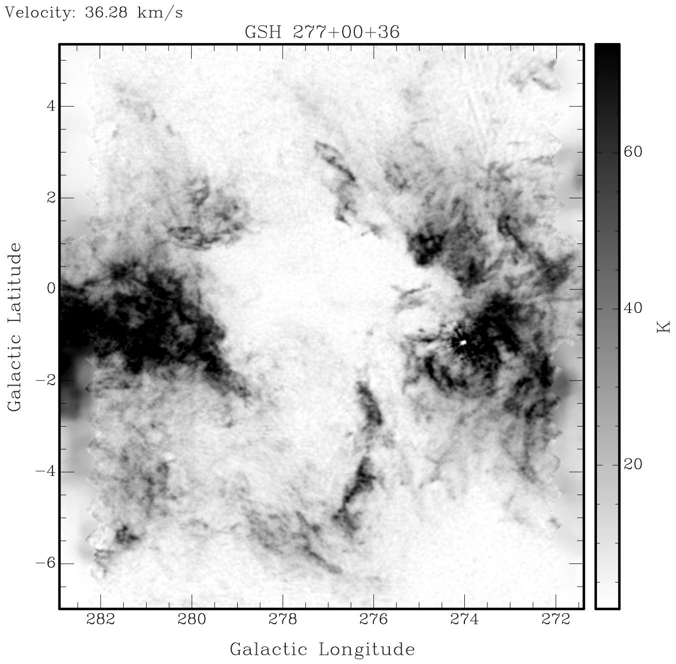

Figure 3: H I image at $v = 36.28~\mathrm{km~s^{-1}}$ of GSH 277+00+36. The image was produced by combining the ATCA and Parkes images shown in Fig 2.

variations [3].

CONCLUSIONS

Many studies of Galactic or nearby (Magellanic) H I require a broad range of angular scales in order to understand the nature of the ISM. In these cases mosaicing alone is insufficient to recover all desired information and it is necessary to combine mosaics with single-dish data. The Australia Telescope provides an ideal pair of telescopes to use for wide-field H I imaging. The thirteen beam multibeam on the Parkes Radio Telescope allows for efficient on-the-fly mapping and the excellent short baseline coverage of the ATCA produces very well sampled images. Combination of the two datasets is simplified by the large overlap in the *u*-*v* plane. The techniques for combining these two data products have been applied with good results for large, fully sampled surveys of H I in the Galactic Plane and Magellanic Clouds. These surveys allow us, for the first time, to explore interstellar processes over more than two orders of magnitude in spatial scale.

REFERENCES

[1] Barnes, D. G. et al. 2001, MNRAS, 322, 486.
[2] Cornwell, T. J. 1988, A&A, 202, 316
[3] Dickey, J. M., McClure-Griffiths, N. M., Stanimirovic, S., Gaensler, B. M., & Green, A. J. 2001, 561, 264
[4] Ekers, R. D. & Rots, A. 1979, in IAU Colloq. 49, Image Formation from Coherence Functions in Astronomy (Dordecht: Reidel), 61
[6] McClure-Griffiths, N. M., Dickey, J. M., Gaensler, B. M., Green, A. J., Haynes, R. F., & Wieringa, M. H. 2000, ApJ, 119, 2828
[7] Sault, R. J., Staveley-Smith, L., & Brouw, W. N. 1996, A&AS, 120, 375
[8] Stanimirovic, S. 1999, PhD Thesis, University of Western Sydney, Nepean
[9] Stanimirovic, S., Staveley-Smith, L., Dickey, J. M., Sault, R. J., & Snowden, S. L. 1999, MNRAS, 302, 417
[10] Stanimirovic, S. & Lazarian, A. 2001, ApJ, 551, L53
[11] Staveley-Smith, L., Wilson, W. E., Bird, T. S., Disney, M. J., Ekers, R. D., Freeman, K. C., Haynes, R. F., Sinclair, M. W., Vaile, R. A., Webster, R. L., & Wright, A. E. 1996, Publications of the Astronomical Society of Australia, 13, 243