International Symposium on Solar Terrestrial Physics
ASI Conference Series, 2013, Vol. 10, pp 131 – 135
Edited by N. Gopalswamy, S. S. Hasan, P. B. Rao and Prasad Subramanian

Imaging the Sun with the Murchison Widefield Array

D. Oberoi[1,2*], L. D. Matthews[2], I. H. Cairns[3], S. J. Tingay[4], L. Benkevitch[2], A. Donea[5], S. M. White[6], W. Arcus[4], D. Barnes[5], G. Bernardi[7], J. D. Bowman[8], F. Briggs[9], S. Burns[10], J. D. Bunton[11], R. J. Cappallo[2], B. E. Corey[2], A. Deshpande[12], L. deSouza[11], D. Emrich[4], R. Goeke[13], B. M. Gaensler[14,15], L. J. Greenhill[7], B. J. Hazelton[16], D. Herne[4], M. Johnston-Hollitt[17], D. L. Kaplan[18], J. C. Kasper[7], B. B. Kincaid[2], R. Koeing[11], E. Kratzenberg[2], C. J. Lonsdale[2], M. J. Lynch[4], S. R. McWhirter[2], D. A. Mitchell[15,19], M. F. Morales[16], E. Morgan[13], S. M. Ord[4], J. Pathikulungara[11], T. Prabu[12], R. A. Remillard[13], A. E. E. Rogers[2], A. Roshi[20], J. E. Salah[2], R. J. Sault[19], N. Udaya-Shankar[12], K. S. Srivani[12], J. Stevens[11], R. Subrahmanyan[12,15], M. Waterson[4], R. B. Wayth[4], R. L. Webster[19,15], A. R. Whitney[2], A. Williams[21], C. L. Williams[13] and J. S. B. Wyithe[19,15]

[1]*National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune, India*
[2]*MIT-Haystack Observatory, Westford, MA, USA*
[3]*The University of Sydney, Sydney, Australia*
[4]*ICRAR-Curtin University, Perth, Australia*
[5]*Monash University, Melbourne, Australia*
[6]*Air Force Research Laboratory, Kirtland, NM, USA*
[7]*Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA*
[8]*Arizona State University, Tempe, AZ, USA*
[9]*The Australian National University, Canberra, Australia*
[10]*Burns Industries, Nashua, NH, USA*
[11]*CSIRO Astronomy and Space Science, Australia*
[12]*Raman Research Institute, Bangalore, India*
[13]*MIT Kavli Institute for Astrophysics and Space Research, Cambridge, MA, USA*
[14]*Sydney Institute for Astronomy, The University of Sydney, Sydney, Australia*
[15]*ARC Centre for Excellence for All-sky Astrophysics (CAASTRO)*

*email: `div@ncra.tifr.res.in`

[16]University of Washington, Seattle, WA, USA
[17]School of Chemical and Physical Sciences, Victoria University of Wellington, New Zealand
[18]University of Wisconsin-Milwaukee, Milwaukee, WI, USA
[19]The University of Melbourne, Melbourne, Australia
[20]NRAO, Green Bank, WV, USA
[21]ICRAR-University of Western Australia, Perth, Australia

Abstract. The Murchison Widefield Array (MWA) is a new generation low-frequency radio (80–300 MHz) array. The MWA design exploits recent advances in digital hardware capabilities and affordability of computational capacity to meet the needs of low-frequency radio astronomy. Solar and coronal imaging and studies of the heliosphere and the ionosphere via their propagation effects on low-frequency radio waves comprise one of the four key science goals of the MWA. Here we present some early solar science results to highlight the exceptional imaging dynamic range and fidelity of the MWA and its high time and frequency resolution, ahead of commencement of the regular observing scheduled for mid 2013.

Keywords : Sun: corona; Sun: activity; instrumentation: intereferometers

1. Introduction

The Murchison Widefield Array (MWA) is a radio frequency array with an innovative design, operating in the 80–300 MHz range. Its location at the Western Australian site chosen for the Square Kilometer Array (SKA) gives it the unique status of a low-frequency SKA precursor. A prototype array, comprising 32 elements, was constructed and operated on site for a period of about 3 years, with the objective of refining and verifying the engineering design, achieving end-to-end system integration, obtaining useful field operations experience, and doing some early science. The MWA has now reached the point of practical completion and formal observing cycles are scheduled to commence from mid 2013. The details of MWA design and hardware capabilities are available in Tingay et al. (2013a), the complete science case is presented in detail in Bowman et al. (2012) and the solar and heliospheric science case, with greater emphasis on heliospheric science, is presented in Oberoi & Benkevitch (2010). The MWA will follow an "Open Skies" policy and the details about proposing and observing with the MWA are available on `http://www.mwatelescope.org`. Here, we briefly discuss the suitability of the MWA for solar and coronal science and present some early results.

2. Solar and coronal science with the MWA

Solar radio emission is characterised by complex morphology with structures spanning a large range of angular sizes, rapid temporal evolution, spectral features at a

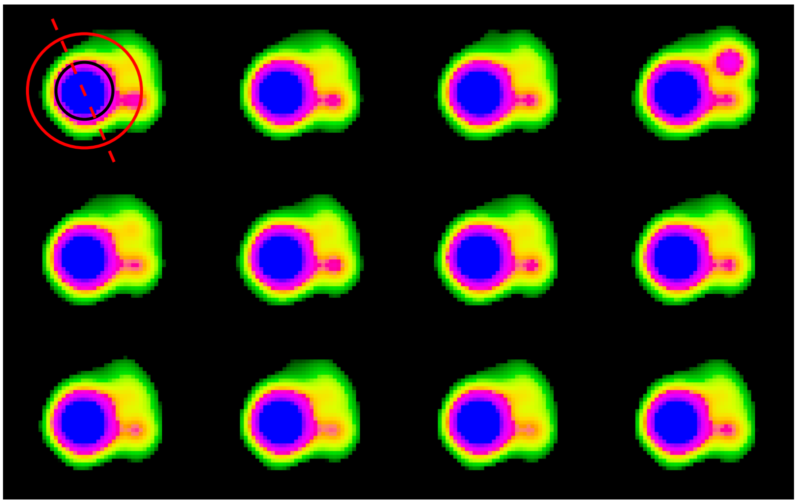

Figure 1. A set of solar images from the MWA Prototype using data taken on 25 Sep. 2011. The black circle on the first panel represents the optical disc of the Sun, and the red concentric circle marks 2 solar radii. Astronomical north is to the top and the red dashed line marks the solar axis of rotation. These images have integration times of 1 s, consecutive frames are arranged row wise and span the time range 04:12:10.6 UT to 04:12:22.6 UT. Evolution from one frame to the next is readily evident. The central frequency is 152.3 MHz and the bandwidth is 80 kHz. A log colour scale has been chosen to highlight the off disc emission which is at a few percent level of the peak and the dynamic range is greater than 1100. The variable emission feature in the southwest comes from the location of a recent Coronal Mass Ejection (CME) liftoff (Fig. 2). The variable emission feature in the northwest is coincident with a helmet streamer present at that location. A few different physical phenomenon can give rise to the dynamic off-limb emission seen here. Possible iterpretations include emission from the often seen noise-storms; streamer interactions; and the locations of the CME footpoints, as expected for a loop model for a CME. A more detailed analysis is currently underway to distinguish between possible interpretations.

fractional bandwidth of order a percent, and emission features spanning many orders of magnitude ($\gtrsim$5) in their intrinsic brightness temperatures. High dynamic range high fidelity imaging of the Sun, spanning a broad spectral range, but with a short cadence ($\lesssim$1 s), and good spectral and angular resolution, is therefore needed to simultaneously track the spatial and spectral evolution of solar emission. This is quite a challenge for radio interferometers, which usually rely on techniques like time and frequency synthesis to achieve high dynamic range imaging.

The MWA is exceptionally well-suited to meet the challenges of solar imaging. Its 128 interferometer elements, distributed over a comparatively small area (3 km diameter), lead to a dense instantaneous sampling of the Fourier components in every spectral channel enabling high fidelity, high dynamic range imaging with every tem-

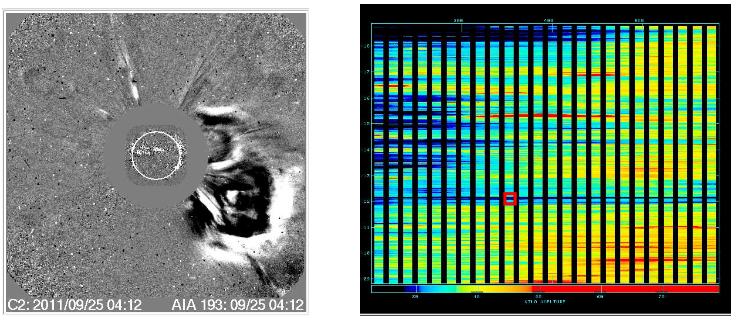

Figure 2. The left panel shows the running difference image from the white light LASCO C2 coronagraph taken at 25 Sep. 2011, 04:12 UT. Each C2 image represents an integration over at least 19 s, while the images shown in Fig. 1 span only 12 s. The steady streamer alluded to in Fig. 1 caption is not seen in the running difference image. The right panel shows the radio dynamic spectrum (auto-correlation), spanning the range 140.19 MHz – 170.91 MHz on the x axis and 10 min on the y axis. The small red box approximately marks the part of these data used for making the images shown in Fig. 1. The ubiquitous presence of short lived and comparatively narrow band features are signatures of non-thermal emission processes.

poral and spectral slice of the data. Its digital design can provide time and spectral resolution of up to 0.5 s and 10 kHz, respectively.

The MWA prototype, when it existed, represented the state-of-the art in many aspects of solar imaging Oberoi et al. (2011). Figs 1 and 2 show an example of solar imaging from the MWA prototype derived from data taken on 25 September 2011. A more recent example showing a higher resolution image from data taken during the MWA commissioning phase is available in Tingay et al. (2013b).

Acknowledgments

This scientific work makes use of the Murchison Radio-astronomy Observatory. We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site. Support for the MWA comes from the U.S. National Science Foundation (grants AST-0457585, PHY-0835713, CAREER-0847753, and AST-0908884), the Australian Research Council (LIEF grants LE0775621 and LE0882938), the U.S. Air Force Office of Scientific Research (grant FA9550-0510247), and the Centre for All-sky Astrophysics (an Australian Research Council Centre of Excellence funded by grant CE110001020). Support is also provided by the Smithsonian Astrophysical Observatory, the MIT School of Science, the Raman Research Institute, the Australian National University, and the Victoria University of Wellington (via grant MED-E1799 from the New Zealand Ministry of Economic Development and an IBM Shared University Research Grant). The Australian Federal government provides additional support via the National Collaborative Research Infrastructure Strategy, Education

Investment Fund, and the Australia India Strategic Research Fund, and Astronomy Australia Limited, under contract to Curtin University. We acknowledge the iVEC Petabyte Data Store, the Initiative in Innovative Computing and the CUDA Center for Excellence sponsored by NVIDIA at Harvard University, and the International Centre for Radio Astronomy Research (ICRAR), a Joint Venture of Curtin University and The University of Western Australia, funded by the Western Australian State government.

References

Bowman J. D., Cairns I., Kaplan D. L., et al., 2012, ArXiv e-prints 1212.5151
Oberoi D., Benkevitch L., 2010, Sol. Phys., 265, 293
Oberoi D., Matthews L. D., Cairns I. H., et al., 2011, ApJ. Let., 728, L27
Tingay S. J., Goeke R., Bowman J. D., et al., 2013a, Pub. Ast. Soc. of Aus., 30, 7
Tingay S. J., Oberoi D., Cairns I., et al., 2013b, ArXiv e-prints 1301.6414