IN TOUCH WITH MWA

Murchison Widefield Array

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MWA Collaboration Meeting in Hawaii

– *Colin Lonsdale, MIT Haystack Observatory*

From December 4th to 7th, 38 members of the MWA global team converged on Waikoloa on the big island of Hawai'i for a project collaboration meeting. The venue was every bit as spectacular as the technical progress reported, and the scientific prospects discussed. And significantly more spectacular than the administrative and programmatic issues tackled behind closed doors. Despite unseasonable and frustratingly persistent clouds and rain, participants showed evidence of being content with their surroundings, particularly those escaping from a Bostonian December. A few foolish souls, craving a climactic reality check, ventured to the summit of Mauna Kea at nearly 14,000 feet in search of freshly fallen, deep snow. It was indeed picturesque, in a surreal, oxygen-deprived sort of way.

The participants at the MWA Meeting in Kona Hawaii.

The meeting started on Tuesday December 4th with a review of the status of the project and its various constituent subsystems and workpackages. Despite a wide variety of problems over the past 6 months, the rate of technical progress has clearly been impressive on all fronts. The hardware systems are maturing quickly, and confidence is running high that within several months, working hardware will be available for all major subsystems, in preparation for replication and rollout of the full 512-tile system. An issue with the antenna response at ~200 MHz was revealed by tests during the X1 expedition, leading to extensive discussion during the meeting. The current state of affairs on this front is summarized elsewhere in this newsletter.

On Wednesday the 5th, MWA science took center stage, with a series of morning presentations on specific science topics. During the afternoon, each of the major science collaborations convened targeted sessions, during which plans and science opportunities were discussed in more depth. The SHI group held a review of their plans with outside experts providing critical comments. This review went extremely well, and the SHI group is moving forward with a compelling set of achievable goals.

Thursday morning was devoted to both near-term and longer-term future planning, and in the afternoon a series of parallel breakout sessions focused on a variety of pressing issues, and provided forums for brainstorming sessions of various kinds. The overall project status and plans were reviewed in open session on Friday morning, and a Board meeting closed out the meeting in the afternoon.

The meeting agenda is available on Knowledge Tree, and a variety of photos from the meeting can be found both on KT and the Twiki.

Overall, it was a very productive and successful meeting, superbly organized by the Melbourne group. Special thanks are due to Lisa Lansfield, Bob Sault and Rachel Webster.

The MWA at External Meetings

– *Colin Lonsdale, MIT Haystack Observatory*

The MWA was well-represented at the 211th AAS meeting, held from January 7th-11th in Austin, Texas. Four posters were presented in session 11 (Instrumentation) on Tuesday 8th, by Colin Lonsdale, Steve Ord, Daniel Mitchell and Randall Wayth, covering the overall project, surveys, the calibration system, and the use of GPU computing. There was considerable interest both during the session, and via informal discussions with many individuals throughout the rest of the conference. Progress is being keenly monitored by various members of the US radio astronomy community. The MWA was also mentioned in multiple presentations as part of a suite of next-generation radio observatories capable of opening new windows on the universe. There was particular interest in radio transient sources and the potential for important new discoveries, with repeated reference to the Lorimer at al. transient described in the previous MWA newsletter. There were a number of papers at the meeting dealing with EoR studies scattered across a variety of sessions. A paper by Judd Bowman on the global-step EDGES experiment was very well received.

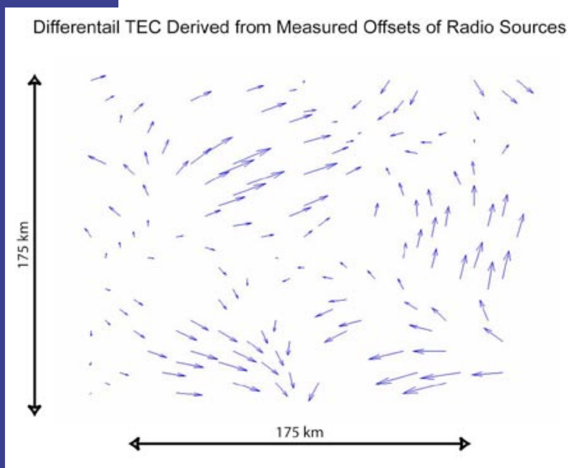
The overall funding climate for astronomy in the US was a major topic at the AAS meeting, and there was discussion of decadal survey planning. Recent actions in Washington have damaged science funding prospects in the US over the coming year, with sudden, steep budget cuts in NASA and NSF. We must hope that the broader MWA effort weathers the resulting lean times, and redouble efforts to provide adequate funding for our science objectives.

The MWA was also represented at the Fall AGU meeting in San Francisco, Dec 10-14, 2007. A paper was presented on the MWA solar-heliospheric-ionospheric science goals, as well as on the results of the calibration tests conducted with the MWA GPS receivers and the MIT Millstone Hill incoherent scatter radar.

Ionospheric Science Applications

– Anthea Coster, MIT Haystack Observatory

The Murchison Widefield Array (MWA) offers a tremendous new opportunity for ionospheric science. The MWA observations combined with total electron content (TEC) measurements from a network of GPS receivers can be used to monitor ionospheric effects at a level of detail that has not been hitherto possible. The offset of the geographic and geomagnetic poles in Western Australia places the MWA at a special longitude for investigating ionospheric space weather disturbances. Recent studies indicate that this offset has important consequences for the development of storm enhanced density (SED) in the American sector (Coster et al., 2007; Foster and Coster, 2007; Foster and Erickson, 2007). SED is associated with steep electron density gradients, which at times have been observed to be greater than 100 TEC units/degree, and is associated with some of the most severe mid-latitude space weather effects ever observed. [One TEC unit is defined as 10^{16} electrons/m^2].



Example of Differential TEC map (relative scale) estimated from measured offset in position of 300 radio sources. Arrows represent magnitude and direction of the TEC gradient. In this example 300 radio sources were used as calibrators. In MWA operations ~ 1000 radio sources will be used providing substantially more detail. (Doeleman, 2007).

The MWA observations are also uniquely suited for the exploration of ionospheric irregularities and scintillation. The MWA will provide VHF scintillation measurements at multiple positions across an ionospheric region of about 175 km sq. In addition, the MWA will be capable of measuring TEC spatial gradients on a 1 km resolution grid over this region. These measurements will be made on short temporal (~10 sec) scales and with very fine amplitude resolution (<0.01 TEC units). An example of the type of differential TEC map that will be produced on an on-going basis at the MWA is shown in Figure 1 (Doeleman, 2007). This map was generated using a simulated ionosphere based on a simple Chapman Profile with an imposed Kolmogorov turbulence (16 km to 43 km) level with rms swings in the TEC of 4%. In this simulation, only 300 calibrator sources were used, versus the 1000 that will typically be used at the MWA. The addition of approximately 3 times as many calibrator sources will provide significantly more detail in the differential TEC map produced as a regular MWA product.

The MWA observations will be augmented by data from three specially designed GPS receivers at the MWA site which can measure L-band scintillation statistics. These receivers were provided by Dr. Keith Groves (AFOSR) and are operational as of this writing. GPS TEC data from these receivers, when combined with data from a large number of newly deployed GPS receivers on the Australian continent, will provide important contextual information about the regional distribution of TEC around the MWA site.

By combining MWA observations with those from GPS, we will be able to examine how energy cascades from larger to smaller scale sizes within the plasma. We will be able to observe the TEC gradients associated with SED in Australia with unsurpassed precision and detail, enhancing our understanding of this phenomenon both locally and globally. We will be able to associate plasma irregularities with causative features such as large TEC gradients associated with SED. We will be able to monitor the speed, direction, and amplitude of traveling ionospheric disturbances (TIDs) as they move across the array. Finally, we will be able to monitor which background irregularity conditions produce VHF scintillation and which produce L-band scintillation. All of these capabilities will allow us to significantly advance the state of knowledge on ionospheric structuring and space weather

References

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Galactic and Extragalactic Science with the MWA

– Bryan Gaensler, The University of Sydney

While most of the scientific focus within the MWA consortium has been on frontier topics such as reionization and transients, the project also marks a return to the early years of radio astronomy. In the 1940s and 1950s, astronomers in Australia built some of the first radio dishes and interferometers, which they used to map out the bright low-frequency radio emission from the diffuse Milky Way, and from individual discrete sources.

An inevitable by-product of any MWA observation will be new, high quality images of all these familiar classes of sources (in fact, the Milky Way and background galaxies will serve as the main foreground contaminant in the EoR experiment, and as a crucial set of background sources for studying the heliosphere and ionosphere). To take advantage of these rich data sets, a Galactic and Extragalactic (GEG) science team has now been assembled. The GEG team will carry out a diverse set of experiments aimed at obtaining a better understanding of supernova remnants (SNRs), HII regions, the diffuse interstellar medium, Galactic magnetic fields, and the energetics of external galaxies and clusters.

Most of these projects will capitalize on three main advantages of low-frequency astronomy: non-thermal sources will be very bright; Faraday rotation and depolarization will be very strong; and along some sightlines free-free absorption will be significant. The combination of wide fields, good sensitivity and reasonable angular resolution will allow us to simultaneously study both small objects and large-scale structure. An example of the sort of GEG science we hope to obtain, even at the earliest stages of the project, is presented above, where we show a recent VLA 300 MHz survey of 40 deg^2 of the inner Galaxy, as published by Brogan et al., ApJL, 639, L25 (2006). Comparison with infrared data to separate out thermal and non-thermal sources reveals 35 new SNRs, an increase of 300% in the SNR population of this well-studied region. The MWA will produce a similar return over a huge swathe of the inner Galaxy (much more than can be seen by LOFAR or the LWA), providing manyhundreds of SNRs. This large sample will allow us to characterise the production and energy density of Galactic cosmic rays, to study turbulence and triggered star formation in the interstellar medium, and to increase the sample of SNRs that are very young or that otherwise have unique properties.

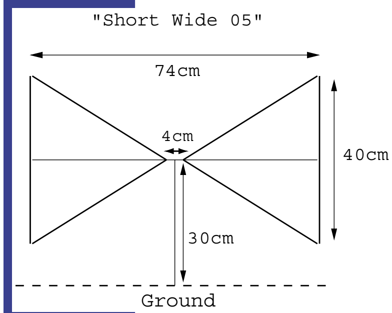
This and most other GEG projects will not require dedicated campaigns or observing modes, but will be able to be carried out using the multi-frequency all-sky survey maps that will be produced as part of the calibration pipeline. Some specific exceptions to this could be areas of deep polarization mapping (for which the confusion limit will be ~20-30 times below that encountered in total intensity) and recombination line surveys (which require very high spectral resolution). The recently formed GEG collaboration is in the process of setting up science teams and defining survey specifications for each sub-project. Information on this and other aspects of GEG science will appear soon on the MWA Twiki. Please contact Bryan Gaensler (bgaensler@usyd.edu.au) for more information, or to join the GEG mailing list.

Aerial view of the 32T system.

Update on Antenna Design

—Brian Corey, MIT Haystack Observatory

A problem with the MWA antenna design was discovered in 2007, through a combination of lab and field measurements. A fix is already in the works, with field-testing of an improved design anticipated soon.



Schematic of new Antenna

Antenna tile patterns measured at the MIT Lincoln Laboratory antenna range and Galactic plane drift scan data acquired at the site during the 32T-X1 expedition both showed anomalous tile performance around 190-210 MHz. Outside this range, the performance of the existing tiles appears to be nominal, and 32 T system tests will simply avoid the affected frequencies.

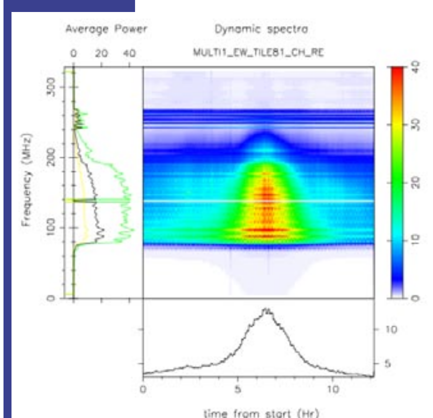
At the problem frequencies the zenith gain is low by 4-5 dB, and the effective receiver noise temperature estimated from the drift scan data is much higher than at nearby frequencies when the antenna models used in the analysis assume canonical dipole patterns with no mutual coupling. Both effects are related to the emergence of very strong sidelobes near the horizon in that frequency range. The presence of such sidelobes would seriously degrade the MWA, at those frequencies, if left uncorrected.

Subsequent E&M simulations of a complete tile by Alan Rogers and Randall Wayth in December 2007 have uncovered the cause and potential solutions. Strong parasitic coupling between the vertical spars of the bowties in a tile creates a "resonance" at ~200 MHz with peak response along a row of bowties, i.e., toward the horizon. (In a similar fashion, the reflectors and directors added to a simple dipole create the highly directional Yagi antenna.) With the guidance of this insight, many new antenna designs have been created, simulated and evaluated as potential replacements for the current design. Several exhibit little or no resonant behavior in their simulated impedances and patterns. From among these we have selected one design for fabrication and field-testing: a vertical bowtie, like the current design, but with reduced height and a slightly wider span. A set of 16 crossed bowties is presently being manufactured by Burns Industries, and they will be tested at the site during the upcoming 32T-X3 expedition in late February 2008.

The X2 Expedition

—Colin Lonsdale, MIT Haystack Observatory

An expedition to the MWA site was conducted between December 14th and 19th, with the goal of testing the signal path from antenna through the digital receiver. This expedition, labeled X2, was led by Anish Roshi of RRI, and included Gopala Krishna (RRI), Prabu Thiagaraj (RRI), Eric Kratzenberg (Haystack), Jamie Stevens (U. Tasmania) and David Herne (Curtin). Several new components were included in the tests. Analog systems included a new beamformer unit developed at Haystack with all 16 delayline channels for a single polarization on one board, plus a new control board, and the analog signal conditioning (ASC) unit developed by Mark Waterson at ANU. Digital processing receiver components included the samplers and coarse polyphase filterbank on the CSIRO designed ADFB board, and a data aggregation and formatting (AgFo) board, both developed by RRI. Data were recorded for later analysis using a custom RRI capture system.



Raw spectral data from the MWA digital receiver system, gathered during the X2 expedition at relatively low time and spectral resolution. This is a drift scan with a single tile pointed at the zenith, and the transit of the galactic plane can be clearly seen. A number of analog system artifacts are visible, and are well-understood. The solid band from 240-270 MHz is the military satellite downlink band, and the data gap at 140 MHz is due to a marker signal deliberately injected into the system for these tests. Figure courtesy of Avinash Deshpande, RRI.

The tests represent "first light" from the MRO low frequency sky and RFI environment, through production prototype antenna and beamformer hardware, and MWA receiver node hardware, to spectral data on disk. Such data can be correlated in software to yield detailed information on the response of the system to the MRO sky and environment. The X2 equipment was tested and integrated into an end-to-end system at the ANU lab in Canberra, prior to the site expedition.

The X2 expedition faced significant challenges, not only in terms of getting a complex and untried system to work, and then taking successful field measurements with that system, but also in physically getting to the site at all. Severe thunderstorms blew through the region only days before the planned arrival of the X2 team. These storms were accompanied by strong winds, large hail and torrential (but localized) rain. There was extensive damage to the homestead, and the roof was torn off the visiting scientist's quarters. Several hundred head of livestock were lost to flooding, and roads were impassable until the morning that the X2 team were scheduled to travel. Fortunately, the MRO site itself was spared the worst of the weather, and all equipment was found to be undamaged in any way.

Congratulations and kudos to Anish and the X2 team for a highly successful expedition, and to the supporting teams at RRI, ANU and Haystack for all the hard work getting the systems built and tested in a short time. Thanks are also due to Merv Lynch and the Curtin team for helping to overcome logistical challenges and make the expedition a success. Both the preparatory work and the field work have laid a solid foundation for continued rapid progress with the upcoming X3 and X4 trips.

The "X3 Site Trip"

—Frank Briggs, The Australian National University

An MWA team is planning to install and test prototype electronics at the site of the "32T Array," arriving during the last week of February and working into the first week of March. As there are 32 antennas tiles already on the ground (having been constructed during the November X1 trip) the goal of X3 will be to set up a prototype of the first Receiver Node electronics, with the capability of acquiring data from an 8 tile sub-array.

During the same period, we expect to perform further testing of the batwing designs for the crossed dipoles on the tiles. The geometry of the batwings is being tuned to improve the frequency response of these novel antenna arrays. The tests on site in the radio quiet Murchison environment will be straightforward and conclusive.

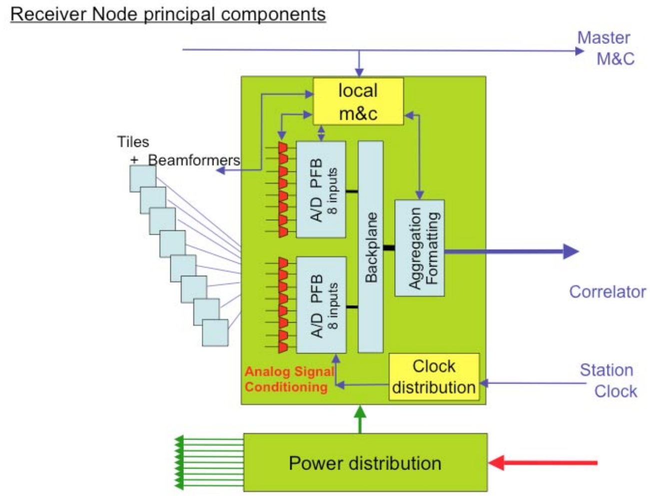
In X3, the receiver components will be located in the central electronics hut, with cables of up to 200m length carrying communications, power and RF signals to and from the antenna tiles. Within the Receiver Node, the main components to be tested will be the high-speed digital boards (ADFB's and AgFo), a small single-board computer (SBC) that serves for local monitor and control, banks of analog signal conditioners (ASC's) and electronics interface boards that serve to interface the Receiver Node to the beamformers that are located adjacent to each antenna tile. Eventually, the 32T Array will be supported by 4 Receiver Nodes.

In each Node, the two ADFB boards carry the analog-to-digital converters and polyphase filter banks that form coarse (1.28MHz wide) channels. A subset of these channels is transmitted to the AgFo board, which is responsible for formatting the data for transmission to the correlator. In the X3-8T test array, the correlator capability will be provided by baseband recorders and off-line correlation in software. The SBC provides local intelligence to manage the ADFB, AgFo, and ASC's, as well as communicating the beam-steering commands to the beamformers. The "clock" to drive the samplers will come from a frequency synthesizer in X3.

The X3 expedition includes integration and laboratory testing of the components developed in the various institutions which will take place at Curtin University in Perth in the week prior to heading to the MRO site.

On-site activities during X3 will place high priority on engineering verification of hardware and firmware functionality. In a distributed system such as the MWA, the automated transmission and acknowledgement of instructions is essential for the precise control and fault-recognition in the instrument that is required to reach the unprecedented sensitivity levels we must achieve.

True astronomical tests using the 8T array will verify basic array calibration, as well as producing astronomical data for use in testing the processing pipeline to be implemented with greater capacity in future expeditions.



Update on 32T Plans

—Colin Lonsdale, MIT Haystack Observatory

Following the X2 trip, the next stage in the development of the 32T system is to deploy a fully functional node receiver, accepting data from 8 dual-polarization tiles (X3 trip led by Frank Briggs - see opposite). All components are being updated with minor fixes for known issues arising from X2 integration and field tests. Two additional receiver node components will be added and integrated, enabling central node control of all receiver and beamformer functions. Data will be recorded using a capable PC-based system provided by Steven Tingay of Curtin, allowing continuous data capture for a single 1.28 MHz channel with all 8 tiles, two polarizations. Pending successful tests during X3, the hardware will be replicated three more times to create a full complement of instrumentation for 32 tiles, yielding 496 simultaneous dual-polarization baselines. This capability is to be installed at the site during the X4 trip led by Roger Cappallo of Haystack, scheduled for early April. The first high-quality 32T images, and incisive tests of hardware and software performance, should follow shortly thereafter.

A detailed plan for the rollout and initial operation of the 32T system is under development, coordinated by Divya Oberoi of Haystack. These plans are being assembled on the Twiki, and will be maintained on a weekly basis.

The 32T program includes opportunities for early science, and one such opportunity may present itself in late March. The solar and space weather community is organizing a coordinated campaign of ground and space-based observations to cover a full Carrington rotation (27 days), from March 20 to April 16, and the partially completed 32T system can potentially generate unique, useful and complementary data as part of this campaign. The feasibility and desirability of MWA participation is being explored.