ASKAP Update

August 2015

Providing the latest news about commissioning and early science with CSIRO's Australian SKA Pathfinder (ASKAP) telescope. The ASKAP Update is online at www.atnf.csiro.au/projects/askap

Commissioning observations with the first six antennas of CSIRO's Australian SKA Pathfinder (ASKAP), installed with first-generation phased array feed (PAF) receivers, have already achieved significant initial scientific results.

The potential that PAFs offer radio astronomy was acknowledged with two awards in the 2014 *Australian Innovation Challenge*, validating ASKAP as a project that keeps Australia on the global innovation map.

The development and production of CSIRO's innovative chequerboard PAFs has also accelerated; the first of the second generation PAFs are now deployed to the Murchison Radio-astronomy Observatory (MRO) and installed on ASKAP antennas (see back page for more).

Coming up ACES

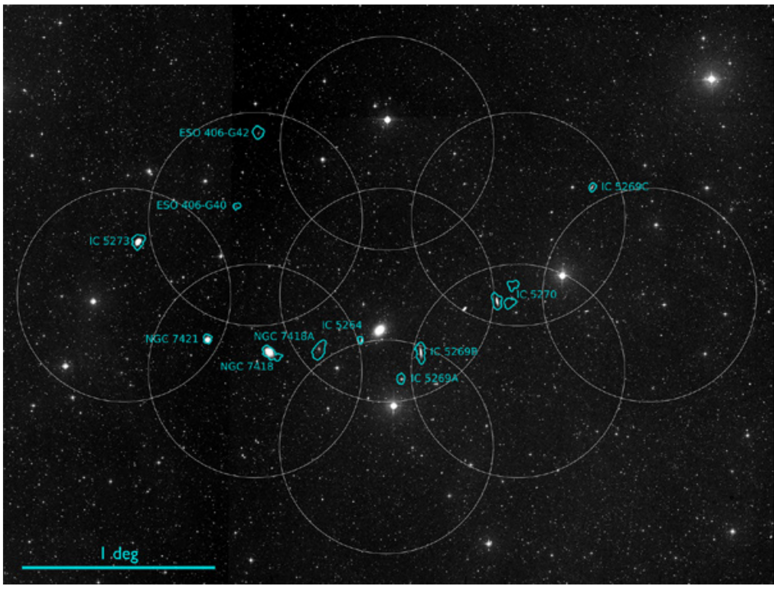
The ASKAP Commissioning and Early Science (ACES) team have been using the Boolardy Engineering Test Array (BETA) – comprising the first six ASKAP antennas installed with Mk I phased array feed (PAF) receivers at the MRO – for commissioning activities and early science demonstration projects.

BETA is a six-element radio interferometer constituting a vital development tool for the researchers and engineers working on ASKAP.

The current focus of commissioning is measuring the properties of formed beams and exploring calibration and imaging techniques.

Now in publication, some of the findings included in this Update, are 'proof of concept' for ASKAP and lay the groundwork for some of the ten Survey Science Projects (SSPs) planned for the first five years of ASKAP operation.

The results would not have been possible without the features that make ASKAP unique, namely a wide field of view and resultant rapid survey capability, and the radio-quiet environment of the MRO.



> In the first science paper from ASKAP (Serra et al), the team has, for the first time, imaged large fields at high angular resolution.

Neutral gas surrounds galaxies

Commissioning work with BETA has taken the team to a new level of understanding of some of the basic performance features of the telescope, whilst delivering interesting scientific results.

In what is the first scientific ASKAP paper accepted for publication (Serra et al. 2015), BETA commissioning data was used to map the 21-cm line of neutral hydrogen (HI) in the IC 1459 galaxy group, resolving the HI emission in eleven galaxies and discovering three previously unknown HI clouds, each containing approximately 1 billion solar masses of gas.

This first large-scale map of hydrogen emission with BETA, covering more than six square degrees, shows that at least 10% of all the gas detected in the IC 1459 group resides outside galaxies.

The clouds' detection adds to the body of evidence suggesting significant interactions between galaxies and their environment. Furthermore, all galaxies known to be in this area from the HI Parkes All Sky Survey (HIPASS) were detected, but with 15 times better angular resolution.

As the first early wide-field HI imaging performed with BETA, the paper demonstrates the excellent capability of PAFs and what the full ASKAP telescope will be able to do across much larger areas of the sky and to much greater distances.

It is also a promising indication for the ASKAP Science Survey Project, WALLABY (the ASKAP HI All-Sky Survey), which will require both sensitivity and resolution to establish how galaxies change over time.

Widefield pilot survey spies transient

To demonstrate the rapid, wide-area survey capability of ASKAP, a pilot continuum imaging survey in the Tucana constellation was made using BETA at 711 – 1015 MHz. The resulting image covers over 150 square degrees and contains more than 2000 sources brighter than 5σ.

The survey, led by Ian Heywood, was able to effectively mimic a traditional 108 x 1 hour pointing survey, covering 150 square degrees, in just 12 hours of observing time.

> A field in Tucana (Heywood, et al) imaged with BETA over 12 hours, covering 150 square degrees (an area approximately four times the size of the Southern Cross) and containing more than 2000 sources brighter than 5σ. The image shows the rapid survey capability of the first generation PAFs and the stability of the system when performing wide-area surveys, highlighting the potential value of PAFs in studying variable sources .

*"BETA has proven itself to be **highly competitive** in searching for red-shifted HI in the frequency range 0.7 - 1.0 GHz."*

The pilot project also revealed a significantly variable source within the survey data, indicating the possibilities for the Survey Science Project called VAST (an ASKAP survey for Variable and Slow Transients).

VAST will take advantage of the wide-field survey capabilities of the PAF in order to discover variable and transient phenomena, from the local to the cosmological.

This was a successful demonstration of the viability and clear potential for using PAFs to rapidly and accurately conduct broadband continuum imaging of the radio sky.

Comparisons with data from the SUMSS survey showed a close match with BETA data in angular resolution, depth and observing frequency, verifying the survey mode performance and stability of BETA.

Gas reservoir discovered in distant galaxy

A team led by James Allison conducted a search for the 21cm HI line between $z = 0.4 - 1.0$ against bright background radio sources.

This redshift range had, until now, remained largely unexplored. A new source of HI absorption was detected at $z = 0.44$ towards the radio source PKS B1740-517, and confirmed by optical spectroscopy to be intrinsic to the early-type host galaxy.

The results (Allison et al. 2015) are also a great demonstration of the science possible with FLASH (First Large Absorption Survey in HI), which is expected to find hundreds of galaxies up to ten billion light years away and determine how much hydrogen gas they contain.

This information will help astronomers understand why star formation, which is fuelled by hydrogen gas, has dropped off in the Universe since its peak 10 billion years ago.

Monitoring a distant OH megamaser

BETA has been used to observe a hydroxyl megamaser in a luminous infra-red galaxy undergoing a merging event at a redshift of $z = 0.129$.

The BETA spectrum, made by Lisa Harvey-Smith, confirmed the presence of broad-line emission in IRAS 20100-4156 spanning several hundreds of kilometres per second as well as a few brighter, narrower spectral lines.

The broad line is thought to originate from a large-scale ensemble of circumnuclear gas. The narrower peaks in the spectrum are thought to originate from a much more compact region of molecular gas located close to the galactic nucleus.

The BETA spectrum indicates that the brightness of the OH megamaser has declined significantly since it was observed previously in 1989 and 1995.

Follow up observations were made with CSIRO's Australia Telescope Compact Array (ATCA) to confirm these findings and to reveal additional morphological information based on the radial velocities of the broad and narrow-line components of the maser emission.

These results are currently being prepared for submission to MNRAS.

BETA Commissioning Highlights

Optimising beam shape

ASKAP's ability to form multiple electronic beams is what will make this telescope such a high-speed, flexible survey instrument, and is one of the new and very complex technologies in the telescope.

However, to take full advantage of this capability – and to produce the highest quality scientific images – the shape, sensitivity, and polarisation characteristics of these beams must be carefully optimised.

Investigations of new beamforming approaches have been underway to improve the characteristics of beams used by the BETA telescope.

The team has implemented a new beamforming algorithm which weights the signals from each PAF element in a way that constrains the shape of the beam.

This indicates that a shape-constrained approach to beamforming is a feasible alternative to the algorithm currently in use: capable of producing a symmetric beam with low sidelobes and good signal-to-noise.

Further, the flexibility of these new algorithms mean they can also be used to apply other constraints, and optimise characteristics such as spectral stability and polarisation purity.

This will allow both BETA and ASKAP to offer astronomers flexible beamforming options, customised to a variety of scientific purposes.

Polarimetric performance

To understand some of the characteristics of the widefield polarimetric response of BETA, a standard observation was made in March 2015 of the flux calibrator 1934-638 (see Sault, *ASKAP memo 005*).

The ASKAP antennas and BETA hardware were found to have a stable and consistent polarimetric response, which will simplify the processing needed for widefield polarimetric imaging.

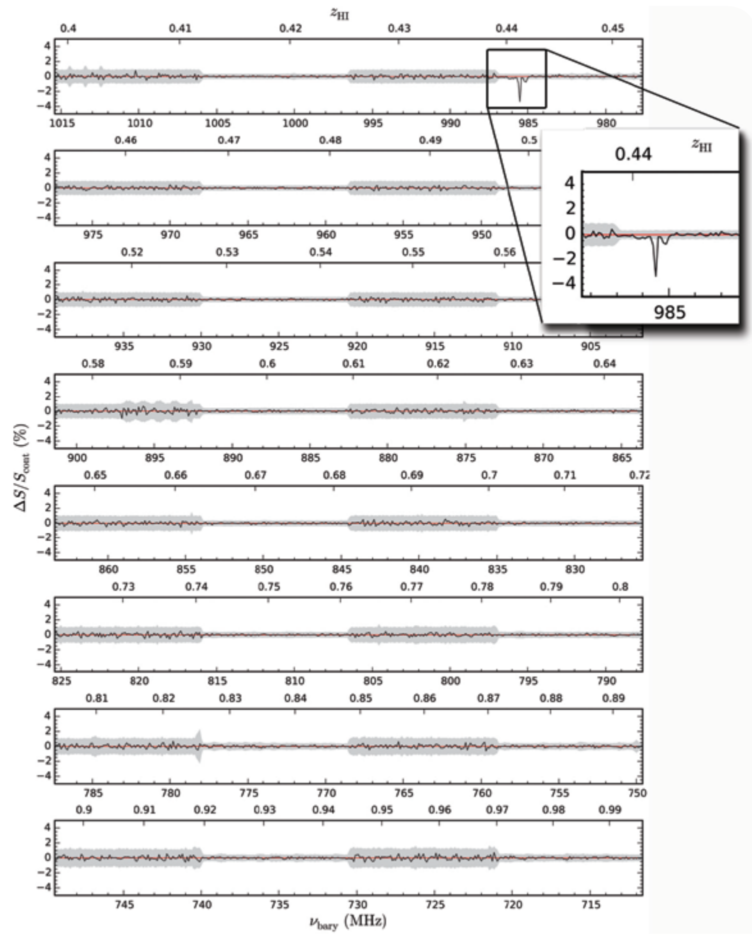
The ability of BETA (and ultimately the full ASKAP telescope) to produce quality widefield polarimetric images is critically dependent on the algorithm used to determine the beamformer weights. Further development of the algorithms to determine the beamformer weights is required.

Survey speed and sensitivity

A technique to independently measure T_{sys} and aperture efficiency (η) of the BETA Mk I PAFs has been developed, in order to understand the sensitivity and likely survey speed of BETA (and ultimately, ASKAP).

Initial data indicates efficiencies in the range 0.68 – 0.76 and mean T_{sys} values of 110 K and 111 K (returning results for T_{sys}/η of approximately 150 K).

It is however important to note that these measurements were made at 1.4 GHz, the part of the band that is expected to improve with transition to the new Mk II systems.



> The 711.5–1015.5MHz BETA spectrum towards PKS B1740-517, averaged over all three observing epochs. For visual clarity the data have been binned from the native spectral resolution of 18.5 kHz to 100 kHz. The barycentric corrected observed frequency is shown on the lower abscissa, and the upper abscissa denotes the corresponding HI redshift. The data (black line) denote the change in flux density as a fraction of the continuum and the grey region gives the corresponding rms spectral noise multiplied by a factor of 5. The detected absorption line is visible in the spectrum at vbary = 985.5 MHz, equal to a redshift of z = 0.4413. Credit: Allison, et al.

The differences between antennas appears significant; raising a question of are the differences intrinsic to the individual PAFs, or are they a consequence of variability in the beam weight determination?

Additional measurements have been made, and further investigations suggest the latter explanation is likely.

The new data give T_{sys} values consistent with the first measurements, and values of η in the range 0.71 – 0.76 with a mean of $\eta = 0.74$.

Performance of second generation PAFs

At time of publication, the first four second generation (Mk II) PAF receivers and associated systems are now installed at the MRO.

The development of the second generation PAF is the result of an effort to increase the efficiency and performance, whilst improving manufacturability and making operational enhancements to the receiver design through the use of new technologies and assembly techniques.

Preliminary on-dish system temperature measurements of the first full-size (prototype) Mk II receiver at the MRO confirmed a low-noise performance across the entire ASKAP frequency band.

Above 1,400 MHz, the new PAFs are more than twice as sensitive as the Mk I receivers, and have four times the survey speed.

The minimum T_{sys}/η is 78 K at 1,230 MHz, and T_{sys}/η is 95 K or better across the 835 – 1,800 MHz range.

Building on lessons learned with the design, development, construction, and testing of the Mk I receiver, the Mk II now incorporates novel components and assembly techniques such as:

- the use of marine composites technology in the PAF casing to manage structural loading, thermal insulation, environmental protection and RFI shielding,
- specially-designed groundplanes that ensure a low and stable operating temperature for increased system reliability.

The installation follows months of site preparation, including the connection of thousands of fibres and cables and the installation of firmware that forms the backend system support.

This preparation has enabled the PAFs to be tested with the newly commissioned backends as soon as they were installed at the MRO.

Phase closure was recently achieved in the labs at the CSIRO Astronomy and Space Science headquarters in Sydney, between three backend systems installed as part of a test system.

Work now continues through commissioning of the Mk II systems (from the PAFs to the digital chains right through to the new correlator) at the MRO, including all the normal data flow, and stability tests, as well as phase and amplitude closure.

Keep an eye on the ASKAP web for the latest status update: www.atnf.csiro.au/projects/askap

> A view of the Murchison Radio-astronomy Observatory, showing an ASKAP antenna installed with a Mk II phased array feed receiver in the foreground.

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