Activites of the Dominion Radio Astrophysical Observatory

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Abstract

The Dominion Radio Astrophysical Observatory (DRAO) carries out world-class research in radio astronomy science and engineering, with a focus on science and technologies relevant to the planned International Square-Kilometre Array (SKA). DRAO staff operate three on-site telescopes, and participate in international science projects, with recognized expertise in the theory and practice of wide-field imaging and polarimetry. Active engineering programs include digital signal processing (correlators and beam-forming), phased-array feeds, and high performance composite reflector antennas.

1 Introduction

The Dominion Radio Astrophysical Observatory (DRAO) is a Canadian national facility for radio astronomy, operated by National Research Council Canada (NRC) via the Herzberg Institute of Astrophysics (NRC-HIA). The Director is Sean Dougherty.

DRAO is located in a 2000 hectare radio-quiet reserve near the city of Penticton, in the southern interior of British Columbia, Canada. Opened in 1960, and hence celebrating its 50th anniversary in 2010, DRAO has conducted radio astronomy science and engineering research and development work throughout its history. The focus of this work today is on science and technology relevant to the International Square-Kilometre Array.

2 Science Facilities

Staff at DRAO have diverse interests in many fields of radio-astrophysics, ranging from studies of the Sun to cosmology, using both on-site and off-site telescopes. A particular strength is studies of the interstellar medium in the Milky Way.

DRAO maintains and operates three on-site radio telescopes in decimetre bands:

1. **Synthesis Telescope**: a 7-element interferometer with three simultaneous correlators: 408 MHz continuum with 3.5 MHz bandwidth; 1420 MHz 4-band polarimeter with 30 MHz total bandwidth; and 256-channel neutral-hydrogen spectrometer with bandwidths from 0.125–4 MHz, tunable from -1100 to $+3000\,\mathrm{km\,s^{-1}}$. The 9 m antennas have a maximum baseline of 0.6 km, yielding a resolution of $1'$ over a $2\overset{\circ}{.}65$ field (to 20%) at 1420 MHz, and $3'$ over an $8\overset{\circ}{.}22$ field (to 20%) at 408 MHz [1].

   From 1995–2009 the primary user of the Synthesis Telescope was the Canadian Galactic Plane Survey (CGPS [2]) consortium, which imaged the northern Galactic Plane over longitudes $55^\circ < l < 190^\circ$ in the latitude range $-3\overset{\circ}{.}6 < b < 5\overset{\circ}{.}6$. Over 450 fields were observed and "mosaicked" together to form unprecedented panoramic images of key ISM components.

   All observations on the Synthesis Telescope are now scheduled based on a peer-review process. Enquires about applying for telescope time should be made to this author.

2. **26-m Telescope**: a 25.6 m single-antenna telescope that can operate from 408 MHz to 6.7 GHz. It saw considerable use in supporting the CGPS observations on the Synthesis Telescope, providing information on short baselines that the interferometer cannot measure [3].

The primary user at present is the Galactic Magneto-Ionic Medium Survey (GMIMS [4]), an international consortium that has since 2008 been gathering data for all-sky rotation-measure synthesis mapping in three 500-MHz bands spanning 300–1800 MHz. The 26-m Telescope is mapping the northern sky in the highest band using a 2048-channel polarimeter designed specifically for this project. Observations for this phase of the project are 90% complete. Observations in other bands are in various stages of completion at Parkes and Effelsberg, using receivers and polarimeters designed and built at DRAO.

3. **Solar Radio Flux Monitor**: two independent 2-m antennas are devoted to daily horizon-to-horizon observations of the Sun at 10.7 cm wavelength (2.8 GHz) for long-term monitoring purposes. This work is the continuation of a project that has run since 1947. Both continuous records of the integrated flux from the Sun and thrice-daily calibrated measurements are disseminated freely to a broad client base, and are also promptly made available on `www.spaceweather.ca` . This project is a partnership between NRC, Natural Resources Canada (NRCan), and the Canadian Space Agency (CSA).

   Plans are currently well advanced for the Next Generation Solar Flux Monitor, which will employ a 4-m antenna, and monitor the solar radio flux at 6 discrete frequencies from 1–18 GHz, as well as recording dynamic spectra across that range with millisecond resolution. The antenna should be in place at DRAO in mid-2011, and be fully operational by the end of 2013. This is a joint project of the aforementioned partners, the Royal Observatory of Belgium, and other organizations.

3 Research and Development

Research and development activities at DRAO are primarily directed towards providing technology solutions for the International Square Kilometre Array (SKA) project. Projects being undertaken include digital signal processing for correlation and beamforming, phased-array feeds, wide-field imaging simulations, and composite antenna fabrication.

3.1 Digital Signal Processing

DRAO has a strong Digital Signal Processing (DSP) group that had internationally recognized expertise in radio astronomy correlators. Recent successes include a correlator for the Japanese VLBI Space Observatory Programme (VSOP) Space-VLBI mission (which operated from 1997–2003), and the Auto-Correlation Spectrometer and Imaging System (ACSIS) correlator delivered in 2004 to the James Clark Maxwell Telescope (JCMT) in Hawaii.

The DSP group has, for the past decade, been responsible for the design and construction of the correlator for the Expanded VLA (EVLA [5]). The correlator employs patented Wideband Interferometric Digital ARchitecture (WIDAR) technology. All correlator boards have now been delivered and installed at the VLA site. The old correlator was disconnected on March 2, 2010, and the WIDAR correlator has since been used exclusively. Improvements in available capability and bandwidth are being added through on-going commissioning activity, and with the forthcoming availability of 3-bit 4-Gs/s samplers. WIDAR technology is also being supplied to the eMERLIN VLBI array in the United Kingdom.

Currently the DSP group is working on beam-forming hardware for the AFAD phased-array feed project (see below), using general purpose FPGA compute blades (discussed elsewhere at this symposium [6]).

3.2 Phased-Array Feeds: PHAD and AFAD

The phased-array feed project is developing technologies leading to astronomy-capable phased-array feeds. Successful work on an engineering demonstrator, the PHased-Array Demonstrator (PHAD), is now progressing to an astronomy-capable array, the Advanced Focal Array Demonstrator (AFAD).

PHAD was designed to explore the capabilities of phased-array feeds (PAFs). It consists of a dual-polarized array of 180 Vivaldi elements operating between 1 and 2 GHz. The signals from 84 elements (42 in each polarization) are converted to baseband and digitized with a signal bandwidth of 8 MHz per element. PHAD does not have a real-time beamformer, but takes snapshots (up to several seconds in length) that are stored for off-line beamforming. This approach has a number of benefits including facilitating rapid algorithm development, providing versatile diagnostics, and allows a data set to be processed multiple times using different beamforming schemes. The main drawbacks of software beamformers are limited bandwidth and lengthy processing time.

PHAD has been tested on a 10-metre axi-symmetric reflector antenna constructed as part of the Composite Applications for Radio Telescopes (CART) program (see below). It was used to successfully demonstrate calibration and the determination of beamformer weights to form images of bright radio sources. PHAD is also the first PAF with full polarization capability from front-end to beamformer. This capability was used to study polarization calibration and the effects of errors on polarimetry performance. Results from this work are reported in a manuscript accepted for publication [7].

Work has now commenced on AFAD. The goals of this second-generation demonstrator are to have an astronomy-capable system, with low system temperature, a wide bandwidth (500 MHz), and real-time beamforming. Related work is being undertaken in collaboration with the University of Calgary to explore uncooled low-noise amplifiers, low-power, high-speed analogue-to-digital converters, and novel beam-forming techniques.

3.3 Wide-field Imaging Simulations

Work on simulating wide-field imaging uses the MeqTrees calibration and imaging software package to simulate various aspects of beam behaviour when phased-array feeds are used to observe the sky mounted on either Azimuth-Elevation or Equatorially-mounted interferometer telescopes [8].

Simulations to date have demonstrated that Az-El telescopes equipped with phased-array feeds will require a third mechanical axis of rotation (such as those being used in the Australian SKA Pathfinder or ASKAP) to compensate for rotation of the antenna beam relative to the sky, if the system is to achieve the performance required for the Square Kilometre Array without requiring significant post-processing of the data to remove artefacts. This is particularly true for polarization imaging, as instrumental polarization properties will be time-dependent if parallactic-angle dependent beamformer weights are used instead to compensate for sky rotation.

Another area being investigated is the performance of off-axis beams. Beams that deviate from the boresight of the antenna suffer from comatic aberration, an inherent property of telescopes using parabolic mirrors. Comatic aberration increases with distance from the boresight and also varies as a function of frequency. A consequence of this is that each phased beam will have unique instrumental polarization characteristics. Sky models provided by the University of Calgary are being used to simulate the response of the ASKAP array to the polarized sky. These simulations will be used to determine whether the ASKAP beams can be described by parametrized mathematical functions or whether interpolation schemes will be necessary to correct the data that come from the telescope.

3.4 Composite Reflector Antennas

The Composite Applications for Radio Telescopes (CART) project has focussed on the design and fabrication of low-cost, high-performance, small-diameter (< 15 m) reflector telescopes using composite materials. Two prototype 10-m axi-symmetric reflectors have been produced to date, each with sub-mm surface accuracies straight off the mold [9].

The project has now entered a new phase of development, in the form of a joint effort with the US SKA Technology Development Program (TDP) group to design a complete mid-frequency SKA prototype antenna. Known as Dish Verification Antenna 1 (DVA-1), it is a 15-m Gregorian offset design with shaped optics, and a composite thin-shell reflector mounted on a rim-supporting tubular back-structure. A successful Conceptual Design Review was held during 2011 Feb 3–4 in Socorro, New Mexico, and a Preliminary Design Review is scheduled for 2011 August.

The CART group is responsible for the design and construction of everything above the DVA-1 elevation axis, while the TDP group is responsible for everything from the ground up to the elevation axis. The current schedule has construction on the one-piece $15\,\text{m} \times 18.5\,\text{m}$ reflector surface starting in Socorro in the first quarter of 2012, with completion of the whole telescope expected in the 3rd quarter of 2012.

Based on experience with reflectors fabricated over the last few years at DRAO, DVA-1 promises to offer an exceptional cost/performance ratio. A very stiff overall structure coupled with a unique rim supported design and low thermal expansion composite materials work together to produce a high precision telescope with a wide range of operating conditions (including insolation, temperature, and wind factors).

4 References

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