ATCA WVRs

Report to ATUC for their May 2008 meeting by Phil Edwards & Balt Indermuehle

1.1. Primary objective

Water Vapour Radiometers (WVRs) will be used to improve the imaging capabilities of the Compact Array at millimetre wavelengths, by correcting for the phase changes caused by water vapour in the atmosphere. This will allow mm observations with the ATCA to be made on longer baselines, increasing the angular resolution, enabling new science.

The "customers" are the mm observers at the ATCA. At present, observing in the 3mm band is only conducted on baselines of ~350m or less (with the exception of sources like eta Carina, which is bright enough to allow observations up to 3km baselines since it can be self-phase calibrated). Thus, the angular resolution of 3mm observations in 350m configurations is poorer than 12mm observations on 3km baselines. The correction of raw interferometric phases with WVR data has the potential to allow 3mm, and likely at 7mm, observations on longer baselines, improving the angular resolution by a factor of up to 10. On shorter baselines the improved phase stability will improve the signal to noise of mm-wave observations.

Observing at mm wavelengths is largely restricted to the winter months, although WVRs may allow the mm season to start earlier and end later. In 2006, 33% of proposals in the April semester involved observations at 3mm: in 2007 the figure was 25%. In 2008, 37% of ATCA proposals requested 3mm observing, and fully 45% requested 3mm and/or 7mm observations. The interest in mm observing is likely to increase, possibly dramatically, with the installation of CABB later this year. We also note the number of Mopra proposals increased by almost 50% for this winter, again reflecting a growing interest in mm observing with ATNF telescopes.

The ATCA is currently the only mm-wave interferometer operating in the southern hemisphere. This will change in 2012 with the completion of ALMA (Atacama Large Millimetre Array). ALMA will work largely at shorter wavelengths than the ATCA, in the sub-millimetre bands. There is a window of opportunity to maximise the science productivity of the ATCA at mm wavelengths before ALMA is completed, which this project seeks to exploit – to obtain the best imaging quality the telescope is capable of at millimetre wavelengths. Furthermore, the science conducted with the ATCA will then directly feed into many of the projects that ALMA will tackle. The best opportunities for Australian scientists to participate in ALMA are through active collaboration in the projects that will feed the new telescope. This is best served by maximising the capabilities of the ATCA today. Particular science investigations that would benefit from the increased spatial resolution that the provision of WVRs include the study of proto-planetary disks around infant stars, the examination of the natal dust cores in which stars form, and facilitate the search for biologically-relevant molecules in space.

These are considered in some detail in the Millimetre White Paper, available at http://www.atnf.csiro.au/management/atuc/2006jun/docs/8_mmwhitepaper.pdf .

1.2. Technical details

The water vapour radiometer (WVR) project aims to reduce atmospheric water vapour induced path delays by equipping each of the 6 antennas of the ATCA with a WVR colocated with the millimetre receiver package. The output of the WVR's will be recorded along with the receiver data and can be applied as a path length correction to each individual antenna's signal during processing of the data with miriad.

The water vapour radiometer (WVR) project has successfully secured a $231k LIEF grant, which is complemented by a $110k contribution by participating institutions (UNSW, James Cook, Sydney, Swinburne, and ATNF).

1.3. Preliminary work

1.3.1. Phase noise quantization

In a first step, we need to quantify the phase noise conditions at ATCA as a function of frequency and baseline, through measurements of bright standards. We need to verify that the Taylor screen hypothesis is valid, and determine the size scales for transition from thick to thin screen approximation, as well as the outer scale of turbulence.

1) Basic characterisation by mid 2008
2) longer-term site characterisation based on
   a) analysis of archival calibrator data phase noise
   b) implementation of routines to record phase noise from each observation, to enable the site statistics to be determined (e.g. quartiles of phase noise levels as a function of wavelength and baseline).

1.3.2. Demonstrate validity of WVR measurements

We need to demonstrate the validity of WVR measurements to determine phase fluctuations using the currently installed WVRs. This Requires

1. modification of monitoring software to provide WVR measurements at least as often as the cycle time of the ATCA (i.e. 10s), and more frequently if possible
2. re-application of Bob Sault's analysis algorithms to the calculation of the phase fluctuations, with comparison to simultaneous measurements of a calibrator source of the fluctuations. This requires the following stages:
   a. retrieval of meteorological data nearest each data timestamp, and the determination of T_{atm} for the frequencies of the WVR filters, based on application of an atmospheric model. Involves application of the miriad routine "opacget" (or an equivalent routine).
   b. determination of the gain and bias factors for each WVR filter to convert measurement to T_{atm}, through least squares matrix minimisation.
   c. determination of gain and bias drifts with time of one WVR with respect to another, again through least squares matrix minimisation.
   d. determination of any residual terms describing the time variation of the gain/bias between the WVRs
   e. application of these gains/biases to determine T_{atm} for each filter.
   f. determination of path length change through weighted combination of T_{atm} at each frequency.
   g. All the above steps to be incorporated into a single algorithm which takes WVR data and meteorological data to calculate phase corrections. The aim is to provide this as a single routine, which can then apply phase corrections to the data during reduction, and to allow the user the option of whether to accept the phase correction or to ignore it at the reduction stage.

3. Use of the noise diodes to calibrate WVRs directly, and so derive T_{atm} directly for each WVR. This needs to be evaluated as an alternative, direct means of determining the phase fluctuations. The stability of the WVRs might not be sufficient for this but this needs to be determined through measurement.

1.3.3. Filter optimization

In this step we determine the optimal filter set to measure the strength of 22 GHz water vapour line and the resulting weighting coefficients to calculate the path difference between two antennae. This involves application of atmospheric modelling code to determine an optimal filter set for measurement of line strength, separating this from the continuum. It involves re-applying Bob Sault's optimisation algorithm, adapting it to include filter band bass response. The result will provide filter specifications for WVRs, as well as the weighting functions needed to combine these to determine path differences between the antennae due to water vapour fluctuations.

1.4. Hardware implementation

Following the previous steps, the WVRs will be ordered. We anticipate CSIRO being sub-contracted to provide some parts for each WVR. The aim is to refurbish the current two WVRs, and provide 1 for each ATCA dish.

Hardware implementation on the antennas will not commence before CABB installation has been completed, and thus will not remove any resources or interfere with CABB.

1.5. Software implementation

Miriad will require a processing module that reads the WVR data and offers application of path length corrections to the data reduction process. There is an existing code currently used for CARMA (wvcal) which can be used as a starting point about a week's worth of development time. Along with two weeks of testing with real data, it will be possible to offer the observers a specific miriad task to correct for water vapour path length variations.

Data interfacing requires wiring the WVRs to the datasets on each antenna as well as addition of the monitoring data points in the monitoring software package (MoniCA) and slight modification of the existing atwvrmon package. Neither would take more than a day to implement.

The physical mounting of the feedhorn, waveguides and WVR require modifications on the mm package dewar top plate and are the main contributors to the allotted work time to mount the WVRs.

1.6. Goals

- To increase the useable baseline for 3mm interferometry beyond the current 300m, to make 7mm and 12mm observations on 3km(+) baselines a regular occurrence, and to improve phase noise on all baselines at mm wavelengths.
- The ability to observe on a 3km baseline at 3mm would improve resolution by a factor 10 from the current 300m baseline. 3km at 3mm can only be achieved at present when there is a bright phase calibrator already in the primary beam of the telescope