Atmospheric Phase Correction for ALMA using 183 GHz Water Vapour Radiometers


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183 GHz water vapour line

The brightness temperature of 1 mm of water vapour as a function of frequency in the centimetre to sub-millimetre bands.

Water Vapour cm/mm/sub-mm lines

The brightness temperature of the 183 GHz water vapour line for a precipitable water vapour column density of 1 mm (red line) and the four double sideband channels of the Dicke-switched prototype ALMA WVR system (rectangles) with heights scaled in inverse proportion to bandwith to illustrate their relative sensitivity.

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The 183 GHz water vapour line (red line) and the filters specified the production ALMA water vapour radiometers (rectangles, see above for full description).

The retrieved marginalised distributions of the three main atmospheric parameters: precipitable water column (c), pressure (P) and temperature (T). The input information were the absolute sky brightness temperatures of the four channels of the radiometers and priors the distributions of the model parameters.

Bayesian estimation of differentials of sky brightness wrt excess path to antenna:

The distribution of estimated values of the four differentials of sky brightness with respect to the excess path to the antennas. These are the quantities that are used to translate observed fluctuations in the WVR signal to actual phase correction to be applied to each visibility sample.

Current status:

Two prototype WVRs built by a collaboration between the Onsala Observatory and the University of Cambridge.

Prototype tested at the SMA (see right)

The contract for the approximately 60 production WVRs let to a partner in industry

Production design currently in review

Delivery of first production units to Chile expected in December 2008

Algorithms for analysis of WVR data are being developed at IRAM, Grenoble (as a part of the TeCal ALMA package) and at the University of Cambridge (as an European Union FP6 ALMA-enhancement project)

Top-level goal

Challenges

1. Planetary will have baselines up to 15km in length

2. ALMA will observe at frequencies up to 950 GHz

3. Phase correction using 183 GHz water vapour radiometers (correct fluctuations on 1 second timescale)

Combine:

• Fast-switching to nearby quasars (calibration cycles from 300 to 10 seconds)

• Imaging with resolution as fine as 0.005". E.g.: Physics of AGN

• Proto-planetary disks

GOALS FOR RADIOMETRIC PHASE CORRECTION:

• Correction on one-second timescales

• Effective phase correction in wide range of precipitable water vapour conditions

• Specification for residual 'wet' path errors: $\delta p_{\text{uncorr}}/p(\mu\text{m}) = (1 \pm 0.1)\% + 0.02 \times \delta p_{\text{corr}}$ (r.m.s.

• Correction of phase errors due to phase transfer from calibration quasars to science targets

SPECIFICATIONS FOR THE PRODUCTION WVRs:

• WVR will be separate units next to the science Front-end cryostats, with an optical relay picking off incoming radiation from centre of the focal plane

• Four double-sideband channels with bandwidths between 1.5 and 2.5 GHz

• RMS sensitivity 0.1 K (least sensitive channel) to 0.07 K (most sensitive channel)

• Absolute calibration: better than 2 K

• Stability: better than 0.1 K over 10 minutes + 10 degree tilt

CTOS:

Continuous calibration

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Advanced WVR algorithm development:

As part of a European Union FP6 ALMA enhancement project, we are currently developing advanced algorithms for WVR-based phase corrections. The aim is to make optimal use of all available information, including:

• Absolute sky brightness temperatures from WVRs

• Observed meteorological conditions at ground level at the site

• Information on the vertical temperature profile from an OZone monitor while observing a quasar (GHz)

• Observed differentials of sky brightness with respect to excess path to antenna:

We are approaching task by developing a Bayesian-framework for analysing this information; some preliminary examples of results from this framework are shown below.

Efficient estimation of differentials in the correlation example above between each of the pairs of model parameters.

The correlation in the retrieval example above between each of the pairs of model parameters.

Imaging with resolution as fine as 0.005". E.g.: Physics of AGN

• Proto-planetary disks

Sample radiometer data

The sky brightness temperature as a function of time as observed by the Dicke-switched ALMA WVR prototype mounted on the SMA and tracking an astronomical source. The eight traces represent the four double-sideband frequency channels from the two receivers in the prototype system (the production system is expected to have a single receiver). The drift of the observed sky brightness with time is due to the decreasing elevation of the source being tracked.

Change in conditions, short time scale fluctuations

Interferometer phase (red line) while observing a quasar and the best fitting prediction from the radiometers (blue line), both with the five-minute running average subtracted.

Tracking long time-scale fluctuations

Interferometer phase (red line) while observing a quasar and the best fitting prediction from the radiometers (blue line). As on the left but with the five-minute running average removed from both the interferometer and the radiometer data.