ALMA: Specification of Ancillary Calibration Devices

Initial Draft

Introduction

As with other many other astronomical telescopes, the calibration of ALMA is founded on observations of known objects: sources of known flux provide the basis of the amplitude calibration and sources with accurately known positions provide the phase calibration. (The same applies to a lesser extent to polarisation.) At millimetre wavelengths however the transmission of the atmosphere is a strong function of frequency, zenith angle and atmospheric conditions. The instrumental parameters, such as antenna and receiver gain also vary strongly with frequency and to some extent with time. The ALMA antennas will therefore be equipped with calibration devices whose essential purpose is to transfer the calibration from the known sources to the current observations. These are the "Primary" calibration devices: in the case of are amplitude and polarization these consist of thermal sources ("loads") of known temperature which are installed in the space above the receivers. For the phase there are two systems: a photonic-based system which injects a reference signal to measure instrumental phase, and the 183GHz radiometers which measure the emission from water vapour in the atmosphere along the line of sight to the source, from which the atmospheric phase changes can be estimated. The photonic system has to our knowledge been dropped by the project because of stability problems in early tests.

The specification of these Primary Calibration Devices are dealt with elsewhere (refs?). This document covers the other instruments (the Ancillary Calibration Devices) which will be needed to enable the calibration to be carried out to the desired accuracy. These are focussed on describing the atmosphere above the ALMA site, both statistically and in real time. They are needed because the quantities measured by the primary devices – essentially the brightness temperature of the atmosphere at both the astronomical observing frequency and near the 183GHz water line – can only be related to the quantities required – the atmospheric transmission and phase at the observing frequency – by using a model of the atmosphere. The information required as input to this model includes temperature and water vapour content as a function of altitude as well as parameters describing any water or ice particles present.

At present it is assumed that these Ancillary Devices be housed in a single location near the centre of the array. Since conditions may vary across the site it is possible that, when observations on the longest baselines are fully implemented, it will be worthwhile installing a number of additional devices (presumably a subset of those in the central location) at a few additional locations near the extremities of the array. It will be difficult to asses how beneficial such additional devices would be until more is known about how different conditions can be across the site. A related topic is the *prediction* of atmospheric conditions in the short and medium term which will be important in the context of flexible scheduling. This is addressed in the memo by Otarola and Holdaway: (http://www.cv.nrao.edu/~awootten/mmaimcal/holdawayotarolaproposal.pdf)

Finally it is noted that devices related to the safe operation of the telescopes and of the site as a whole – principally anemometers to warn of high wind speeds and something to indicate the build-up of ice and snow – will also be required but are not covered here.

Instruments under Consideration

1) Temperature profiler
The purpose of this device is to measure the temperature profile in the atmosphere as a function of altitude. The requirements are:
Height resolution: 400m from 5 to 8km and 1km from 8 to 12km (altitude above sea level)
Precision 1K and accuracy of 2K from 5km to 8km and twice these figures from 8 to 12 km.
Time for measurement – 10 minutes.
(Numbers are guesses – need modelling to find real ones.)
It is assumed that this will be done using a radiometer operating on the side of the O2 absorption band at ~60GHz. Probably a single device pointing straight up will be adequate. Some question here about the effect of cloud on this device.

2) Broad-band mm/submm emission monitor
The purpose is to measure as wide a frequency range as possible to get parameters for any water droplets and ice particles. For this purpose only, the requirements would appear to be:
Frequency resolution: 25GHz, perhaps only 50GHz.
Precision: 10K and accuracy 20K.
Time for measurement – 10 minutes.
(Numbers are guesses – need modelling to find real ones.)
If this is done with an FTS then much more resolution and sensitivity will be available. This will presumably require cryogenics so the possibility of using an uncooled device with multiple filters should be considered. In either case it may be worth putting steerable mirrors in front of the device so that the beam can be scanned in 1 or 2 dimensions.

3) Cloud monitor
The purpose is to detect the presence of clouds and if possible give and indication of their nature. For daytimes a TV camera is sufficient but at night an IR camera is presumably required.
Specs: ??
(Note that multiple wide angle cameras would in principle make it possible to estimate the height of the clouds.)

4) Additional water vapour measurement devices
We can use a scanning device in front of a water vapour radiometer (or perhaps a number of radiometers spread over a few hundred metres) to deduce the current scale size and altitude range of the water vapour fluctuations. Essentially one is performing a form of topography by looking along different paths through the atmosphere. Although this could be done with the 183GHz radiometers we might also consider using IR devices for this.

5) Ozone line monitor
We may need to estimate the strength of the line emission from Ozone. This could be provided by a high resolution FTS or perhaps a single mm-wave radiometer tuned to a suitable line or group of lines.
More needed on variability of lines and the numbers of parameters needed to describe them.

6) Phase monitor
It would be possible to use radio interferometers looking a satellites as additional phase monitors. It is not clear what additional information these would provide and there is a concern about ionospheric effects for some fraction of the time.