Observing Modes and Real Time Processing

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Outline

Observing Modes

- Interferometry Modes
- Interferometry Calibrations
- Single-Dish

Real Time Data processing

- Scheduling and Control of the Array
- Data Flow and data contents
- On line calibrations
- Array Calibrations

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Interferometry Modes

- Single Field Interferometry
  - All emission to be mapped is in the primary beam ($\sim 60''$ at band 3, $\sim 8''$ at band 9))
  - Already tested
- Pointed Mosaics
  - The emission is extended so several pointings are needed to cover the field
  - The integration time per field is long enough (several seconds)
  - Classical mode, but not yet tested in ALMA commissioning.
- On The Fly Mosaics
  - For many fields and short integration per field: do continuous motion of antennas
  - More complex mode, barely tested
  - Data reduction not operational yet.

Single-side band observing

- Frequency offset method is used to cancel one of the side bands
- Essential at band 9, as interference between the 2 side bands would modulate phase and amplitude as the atmosphere phase fluctuates.
- More accurate calibration in other bands as well
- Can be done independently for the 4 basebands.
- For a dual side band system (bands 9, 10), one will later use 90-degree phase switching to separate the sidebands, doubling the effective bandwidth.

Phase Calibration

- Used to transfer the phase from one (or more) phase calibrators to the science target (phase referencing), usually at the same frequency
- Can be performed at a lower frequency when the observing frequency is high (e.g. band 9) and this direct phase calibrators are scarce (not yet fully tested).
- The cycle time can vary from tens of seconds to several minutes.
- Shorter term fluctuations are removed by water vapor radiometry (WVRs); this is not currently done in real time, but can be done off-line.

Amplitude Calibration

- Used to correct for instrumental gain changes in amplitude
- The amplitude calibrator flux need to be measured again a flux reference source (usually a planet or solar system object; but strong quasars should be monitored as well, as primary calbrators are not available 100% of the time).
- One needs to calibrate atmosphere transmission as the amplitude calibrator and references flux sources will be at different elevations when observed (Temperature Scale Calibration).

Bandpass Calibration

- Needed to correct the spectral response in amplitude and phase in each antenna
- Relative positioning of spectral features is limited by the accuracy of the phase bandpass.
- Measure a strong source in all spectral setups used, to derive antenna bandpass solutions.
- Also need a measurement of side band ratios, necessary for atmosphere (temperature scale) calibrations (and single dish data reduction).

Pointing and Focus

- Pointing Calibration
  - Blind pointing to 2" rms (pointing model)
  - Could be enough at 3mm, but better check...
  - Needed at high frequencies to guarantee a good pointing
  - A good pointing accuracy is required for mosaics
  - Done a low frequency (band 3) where point sources are strong enough
  - The relative pointing of receiver bands is measured by the observatory
- Focus Calibration
  - Focus dependence on elevation is known
  - Temperature dependence appears complex
  - Model can probably be trusted at low frequencies
  - Checking the Z focus may well be required in SBs for high frequency observations.

Single Dish

- Spectral line observations will be done using on-the-fly scanning (little tested however so far)
- Single-dish continuum is not available (no nutator)
- Fast scanning modes are considered as a replacement (testing planned)
- Zero and short spacings will be done in the long run using ACA
- Single-dish calibrations (e.g. pointing and focus) should be done interferometrically.

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Scheduling

- Manual mode:
  - the observations are controlled through a script;
  - mostly used for commissioning tests
- Interactive mode:
  - The observations are made using scheduling blocks;
  - Which is the next SB to execute is decided by the operator and they are manually executed one by one
- Dynamically scheduled:
  - An intelligent algorithm picks up the SB to be executed, depending on actual conditions;
  - 30-60 min SBs for good flexibility
  - Not yet commissioned

Control (1)

- Control of the array is done by using a Control Command Language (CCL) script (written in python language)
- At a low level all hardware devices can be controlled and tested this way; these devices form a hierarchy, from individual hardware devices (e.g. WCA, LO2, FLOOG, ACD, DGCK, SAS, DRX, ...) to the higher level (e.g. Antenna, Array).
- At a higher level, astronomical observations are performed using methods specific to, for instance, TotalPower observations, Holography, ... and (of course) Interferometry.

Control (2)

- Both in manual mode observations and scheduled mode observations, an observing script is executed that sends these high level methods.
- Specific python objects are provided to execute science target observations and calibration targets (e.g. Phase calibration)
- In scheduled observations, these target objects are built according to the parameters set in the Scheduling Blocks.
- These parameters are structured in:
  - Spectral setup (frequencies, correlator setup)
  - Field Source (coordinates and systems, reference positions, mapping strategy...)
  - Observation parameters (integration times, cycle times, ...)
- The typical user will only have to set these parameters in the Observing Tool

Total Power Data

- has been very useful for:
  - verification of antennas at OSF
  - early commissioning
- will be extended for science continuum measurements in the future.
- cannot be mixed with interferometry at this point.

Correlator Data

- Produces correlation data and autocorrelation data simultaneously
- Can provide 1,2 or 4 polarisation products (XX, YY, XY, YX)
- Online processing for Baseline Correlator:
  - Correction for quantization
  - Time domain windowing (apodization)
  - Fourier transform to spectral domain
  - Side band separation
  - Residual delay correction
  - Pathlength correction from water vapour radiometry
  - Normalization by autocorrelations
  - Channel averaging (in one or more spectral regions)
  - Time averaging (integration duration)
- Similar processing for ACA data
- Archiving as binary files (3 for every subscan) in BDF format.
- Data rate limit 6 MB/s average, 60 MB/s peak.

WVR Data

- Collected from WVR radiometers by correlator subsystem software
- The radiation temperatures of atmosphere in 4 frequency channels, on the center ans wings of the 183GHz water line
- Sent to Archive as binary files (BDF format)
- Conversion to pathlength in correlator software, using coefficients provided by TelCal
- Applied to correlation data
- Archive both corrected and uncorrected data in correlator binary files.

Metadata

- Collected-on line by 'DataCapture' component
- ASDM data model:
- Set of linked XML documents containing:
  - Data contents description
  - Observation intents
  - Relevant auxiliary data
  - Links to binary data
- On-line calibration results are inserted
- At present only saved at the end of an ExecBlock (SB execution)
- Incremental Saves
- A Filler converts ASDM data to Measurement Set format for data processing in Casa

Observing Objects

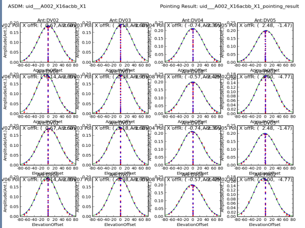
By decreasing time granularity:

- **Correlator dump** minimum anout of data produced by the correlator ($\sim$ 96ms)
- **Sub-integration** time granularity for channel-averaged data
- **Integration** time granularity for spectral data *(science)*
- **Subscan** correspond to a control command, about 30-60 s.
- **Scan** grouping of subscans by intent (e.g. pointing calibration, or science target)
- **ExecBlock** single execution of a Scheduling Block

On-line calibrations

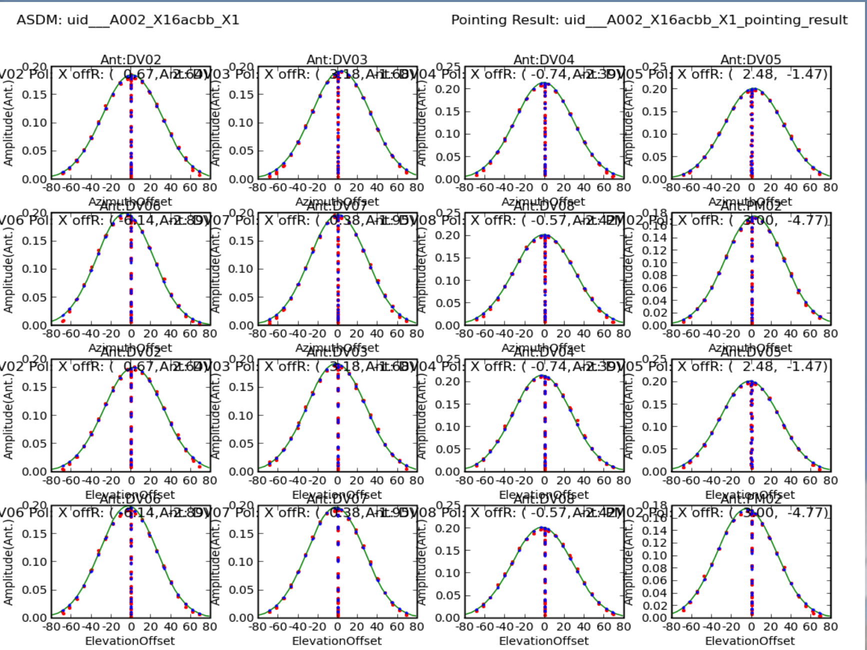
- Goals are to provide:
  - on line results to improve data taking (e.g. apply pointing, focus corrections)
  - data for dynamic scheduling (system temperatures, seeing, ...)
  - feed-back to on-duty operator and astronomer; aka QA0
- TelCal software subsystem (developed by IRAM).
- Use asdm input directly from on-line subsystems (Correlator, Data Capture)
- Results displayed on-line (Quick Look)
- Results are inserted in the ASDM metadata.
- Results can be re-calculated off-line for commissioning and testing.

Pointing

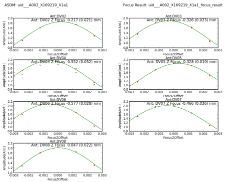


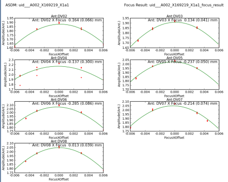
- Normally 5-point scans, using interferometry, at band 3 or 6
- Offsets between reference band and other bands are measured
- All antennas are moved simultaneously (for the time being)
- Cross-scans more stable to large errors ($\sim$ 0.5 beam)
- Check about every hour (more often at high frequency)

Pointing


ASDM: uid___A002_X16acbb_X1
Pointing Result: uid___A002_X16acbb_X1_pointing_result
Ant:DV02
Ant:DV03
Ant:DV04
Ant:DV05
Ant:DV06
Ant:DV07
Ant:DV08
Ant:PM02
X offR: (2.48, -1.47)
Amplitude(Ant.)
AzimuthOffset
ElevationOffset

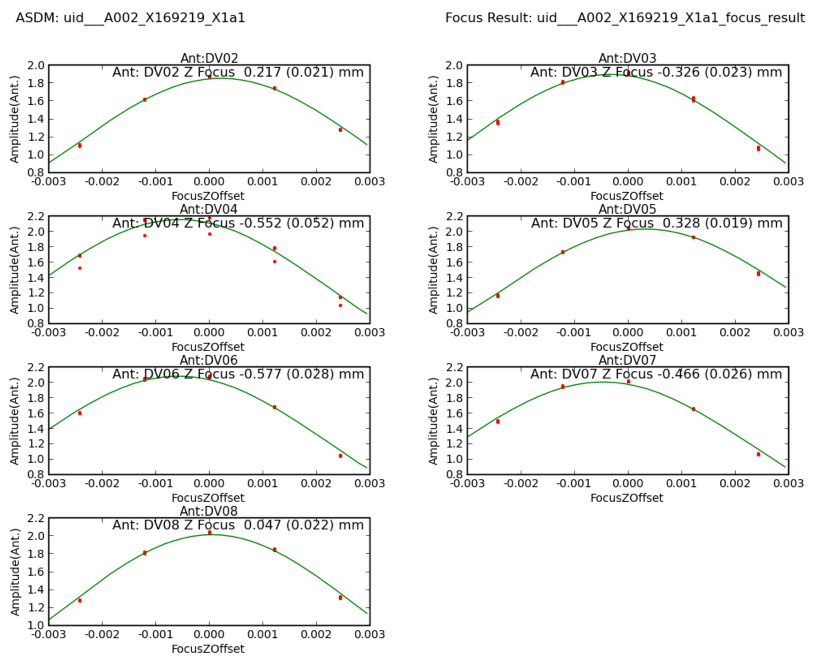
Focus





- 5-point scans, moving Z focus
- optimizing axial interferometric gain
- all antennas moved simultaneously
- also available in X and Y (though less critical)

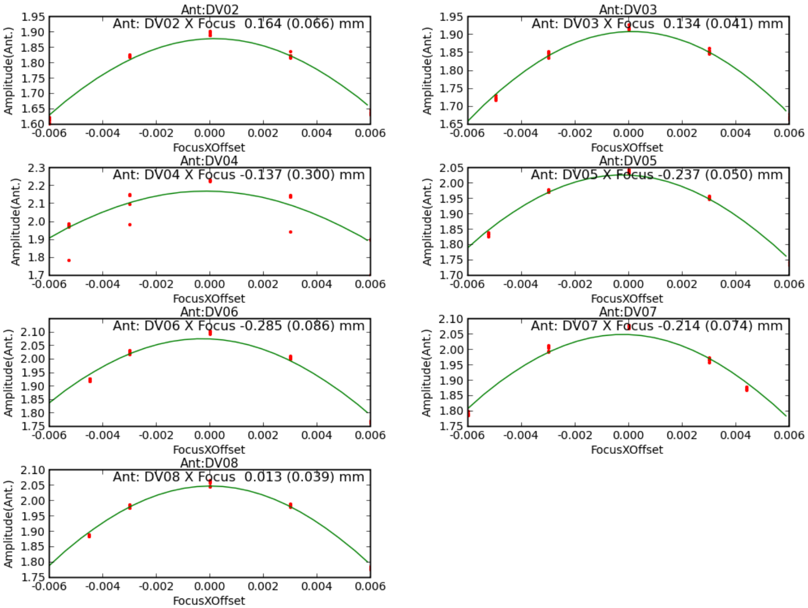
Focus


ASDM: uid___A002_X169219_X1a1
Focus Result: uid___A002_X169219_X1a1_focus_result
Ant:DV02
Ant: DV02 Z Focus 0.217 (0.021) mm
Ant:DV03
Ant: DV03 Z Focus -0.326 (0.023) mm
Ant:DV04
Ant: DV04 Z Focus -0.552 (0.052) mm
Ant:DV05
Ant: DV05 Z Focus 0.328 (0.019) mm
Ant:DV06
Ant: DV06 Z Focus -0.577 (0.028) mm
Ant:DV07
Ant: DV07 Z Focus -0.466 (0.026) mm
Ant:DV08
Ant: DV08 Z Focus 0.047 (0.022) mm
Amplitude(Ant.)
FocusZOffset

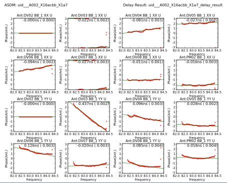
Focus

ASDM: uid___A002_X169219_X1a1

Focus Result: uid___A002_X169219_X1a1_focus_result

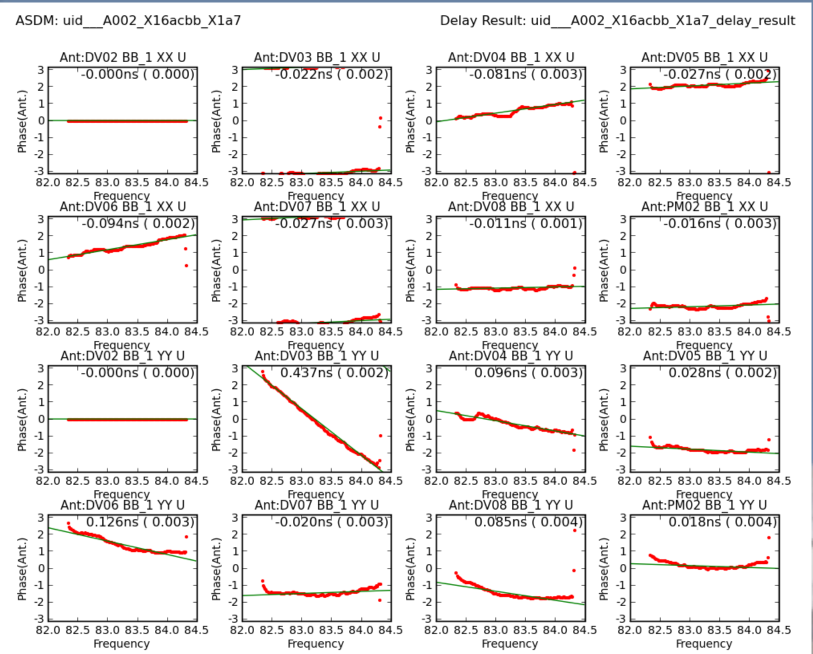


Delay



- Compute delay offsets using frequency dependence of antenna phases
- Done independently for each baseband and polarization
- Delay offsets compensated in correlator for baseband `BB_1` and polarization `XX`, for receiver band in use
- Delay offsets compensated in correlator for all basebands and polarizations (R8; for easier bandpass calibration); using a data base of delay offset measured for each contibuting part of the IF chain.

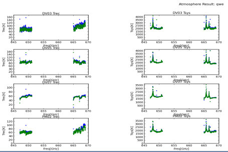
Delay


ASDM: uid___A002_X16acbb_X1a7
Delay Result: uid___A002_X16acbb_X1a7_delay_result
Ant:DV02 BB_1 XX U
-0.000ns (0.000)
Ant:DV03 BB_1 XX U
-0.022ns (0.002)
Ant:DV04 BB_1 XX U
-0.081ns (0.003)
Ant:DV05 BB_1 XX U
-0.027ns (0.002)
Ant:DV06 BB_1 XX U
-0.094ns (0.002)
Ant:DV07 BB_1 XX U
-0.027ns (0.003)
Ant:DV08 BB_1 XX U
-0.011ns (0.001)
Ant:PM02 BB_1 XX U
-0.016ns (0.003)
Ant:DV02 BB_1 YY U
-0.000ns (0.000)
Ant:DV03 BB_1 YY U
0.437ns (0.002)
Ant:DV04 BB_1 YY U
0.096ns (0.003)
Ant:DV05 BB_1 YY U
0.028ns (0.002)
Ant:DV06 BB_1 YY U
0.126ns (0.003)
Ant:DV07 BB_1 YY U
-0.020ns (0.003)
Ant:DV08 BB_1 YY U
0.085ns (0.004)
Ant:PM02 BB_1 YY U
0.018ns (0.004)
Phase(Ant.)
Frequency
82.0 82.5 83.0 83.5 84.0 84.5
3 2 1 0 -1 -2 -3

WVR

- *on line* TelCal:
  - calculates a priori temperatures to pathlength conversion coefficients based on ATM model;
  - gives the precipitable H_2O content.
  - This may be applied off-line to the ASDM data.
- *off line* `wvrgcal` (based of FP6 development) calculates coefficients based on recorded WVR data (more costly in computing time, uses data before and after the fact)
- Results of both methods being compared (longer baselines needed however)

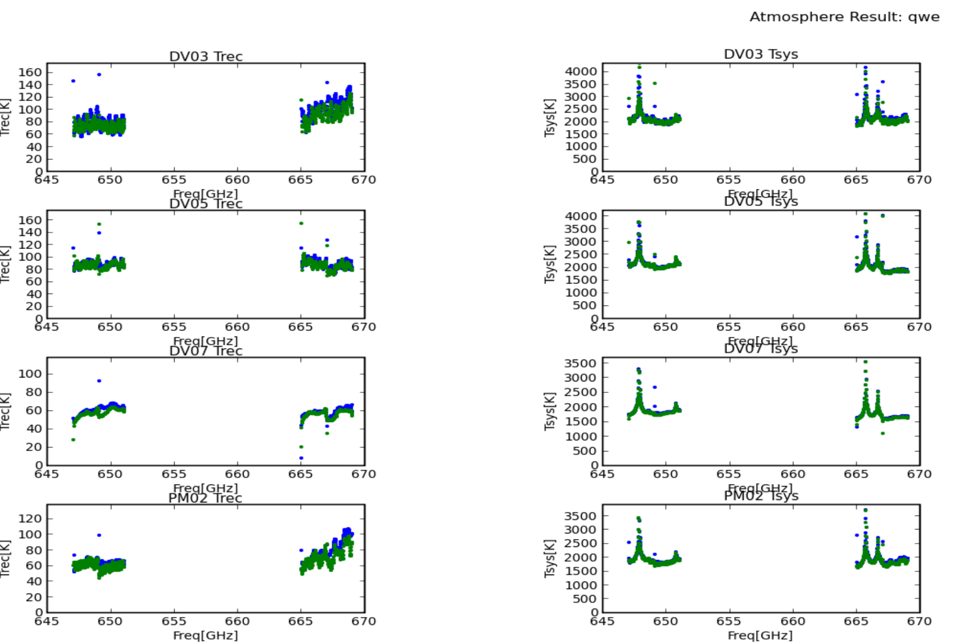
Temperature Scale



- Calculate T_{SYS} in order to scale the data to T_{A}^{*} temperature scale
- Ambient ($\sim$ 300K) and hot ($\sim$ 360K) loads available
- Different methods being tested:
  - Use two loads and sky (α method in CalExamples document)
  - Use two loads for T_{REC}, and WVR data as input to ATM model to get T_{SYS}
- Also considered:
  - Use emission from ambient load and sky (sky temperature from ATM model computed using WVR)
  - Use emission from both loads and sky (sky temperature from ATM model computed using WVR); may evaluate saturation

Note: we are late on this (difficulties to control those loads...).

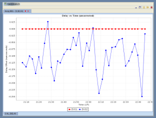
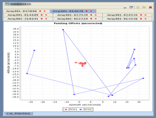
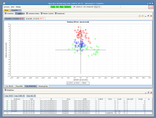
Temperature Scale



Amplitude / Flux

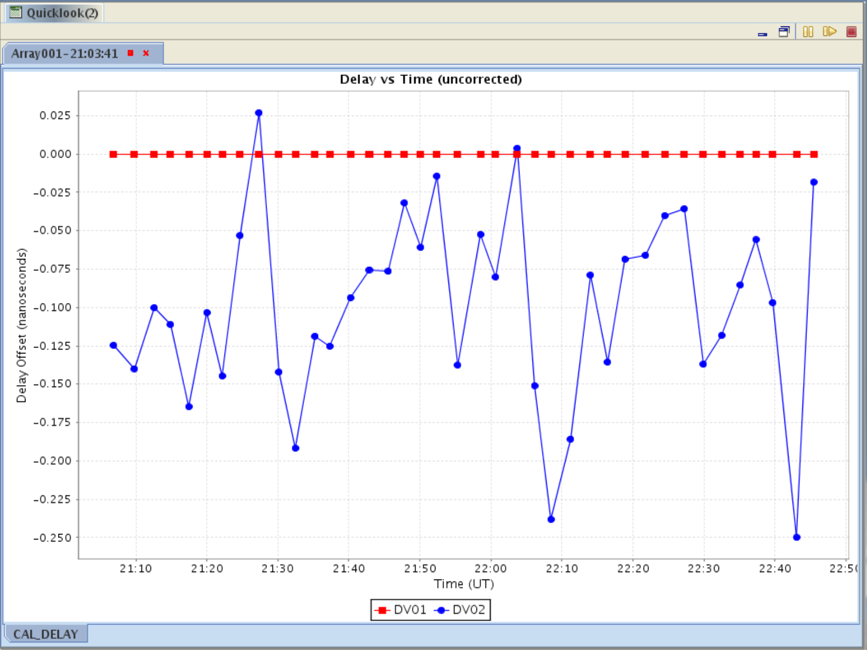
- Check the antenna efficiencies when observing a source of known flux
- Provide a flux estimate assuming the antennas are well pointed and well focused (known antenna efficiencies)
- As many antennas are available both methods can be combined
- Will allow to check WVR performance by comparing corrected and uncorrected results
- Will allow to spot misbehaving antennas (poor efficiency)

Quick look monitoring

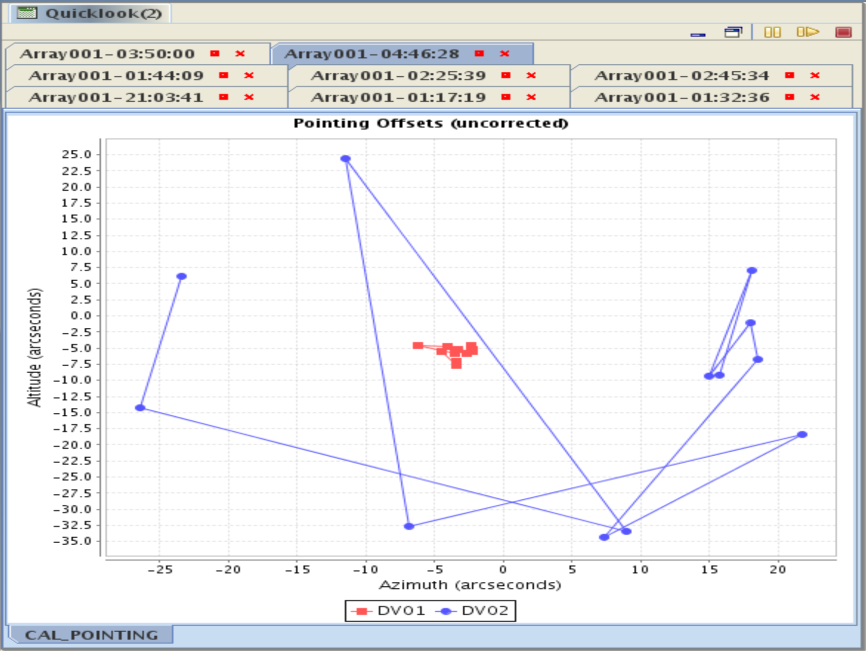




- Quick look produces a display of several calibration results, to allow trends to be evaluated
- Provides a useful feedback to operator and on-duty astronomer (QA0).
- Need to design modes of display that scale well with many antennas
- Will also display science results (raw images) in quasi real-time (processing MS data converted by a real-time filler)

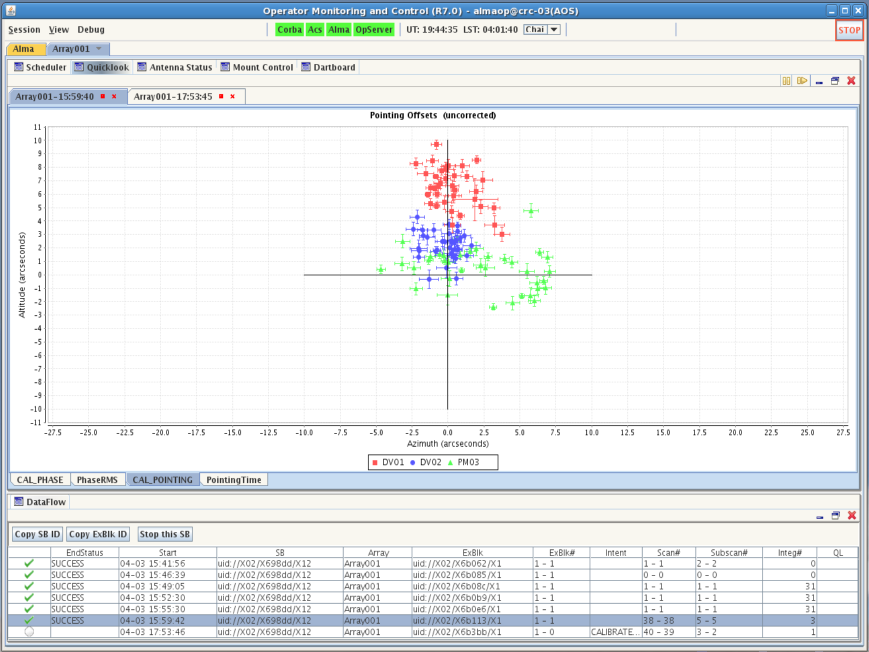
Quick look monitoring



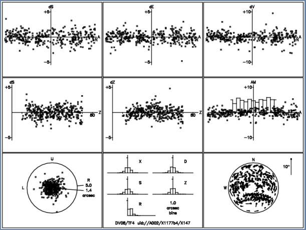
Quick look monitoring



Quick look monitoring

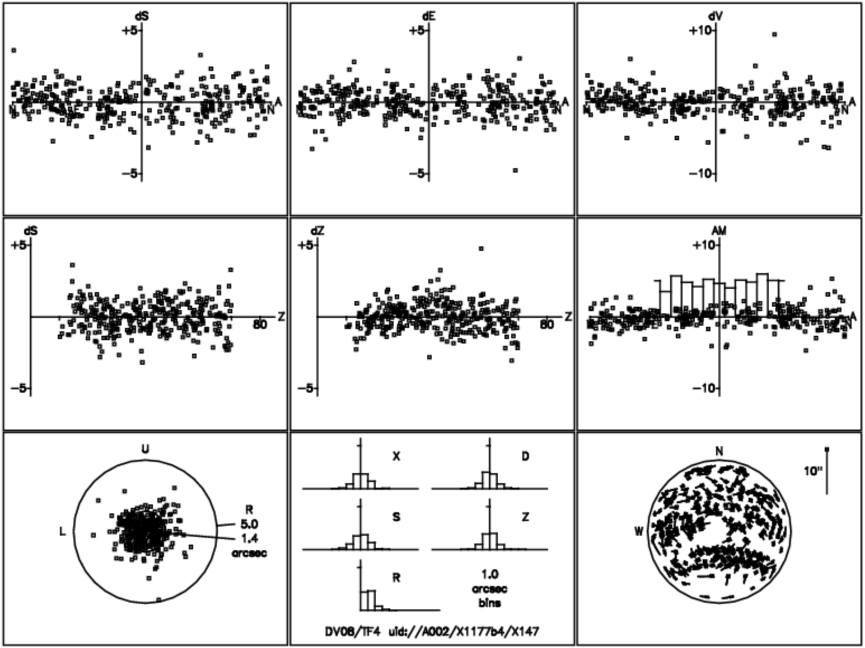


Pointing models

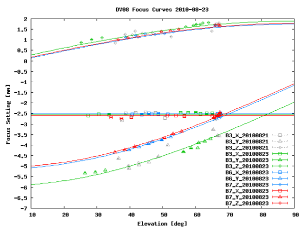


- Use `tpoint` to fit the pointing model ($\sim$ 15 coefficients)
- include some 3-order azimuth terms.
- Pointing models are re-measured each week to check for time variations.

Pointing models

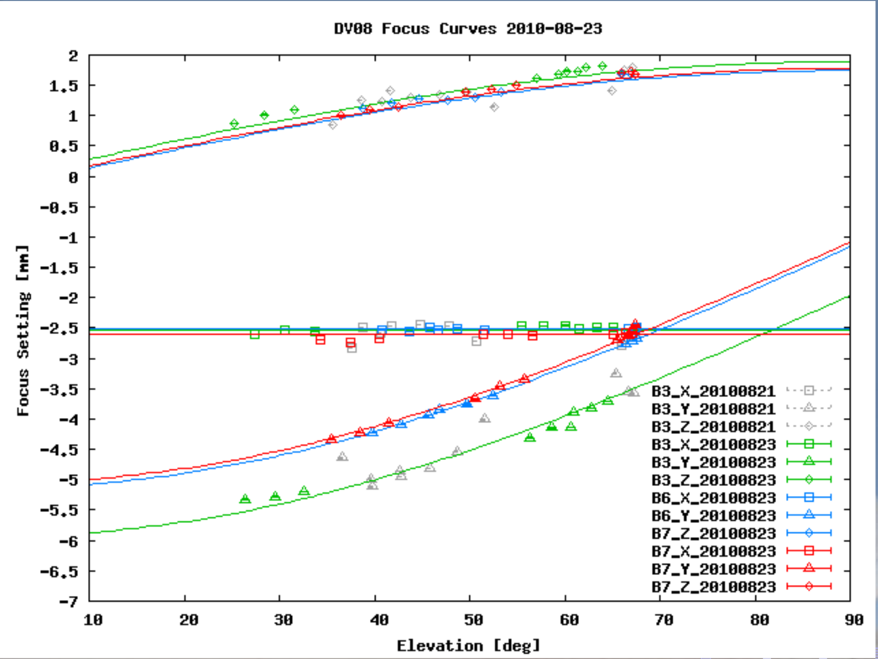


Focus models

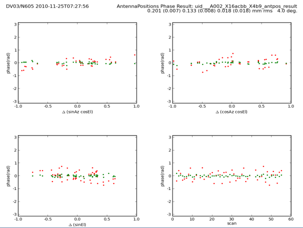


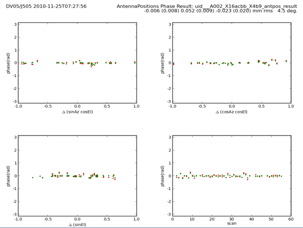
- For each antenna, fit a simple elevation dependent model
- The offset is dependent of the frequency band
- Also fit a temperature model, but this is less simple (non linear?)

Focus models



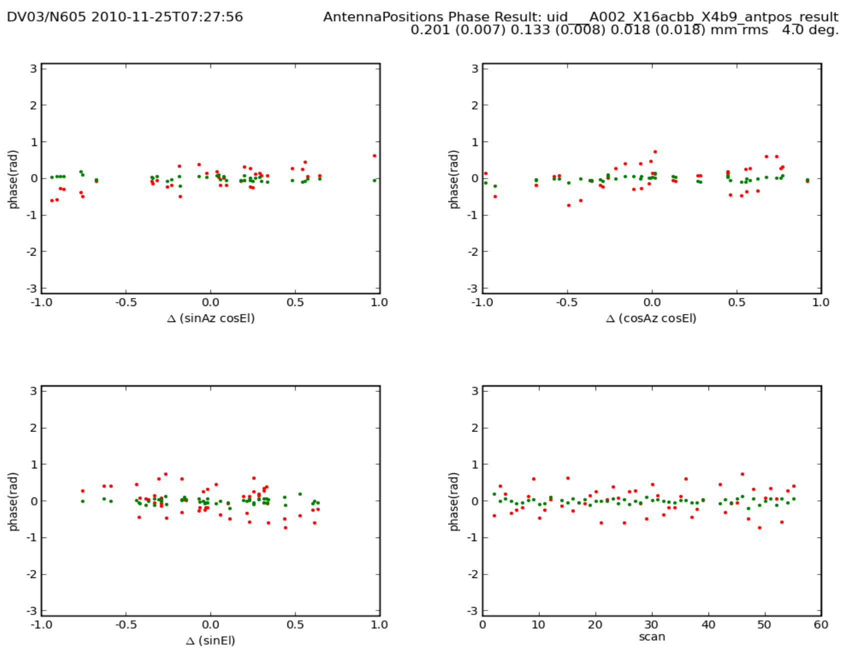
Antenna positions





- Use delays for a new pad (no 2π ambiguities)
- Use phase differences between sources for accurate, routine measurements
- Antenna positions are re-measured each week to check for time variations; accuracy $< 20\mu$m (hor.) or $< 40\mu$m (vert.)
- Current effort to check variations with temperature and weather conditions

Antenna positions



Antenna positions