

# Calibrating ALMA

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# Long- and short-term calibration

Two basic types of calibration:

- *long-term effects*: no need to calibrate before a given science observation – done periodically by ALMA staff
- *short-term effects*: need to be measured before/during the science observations – involvement of many people

# Long-term effects

- All-sky pointing (correcting overall antenna and pad imperfections)
- Focus models
- Baseline vectors (actual relative telescope positions: they move !)
- Cable delay (errors in the signal delay from receiver to correlator)
- Antenna characteristics (surface errors, beam patterns)

ALMA staff will carry out periodic measurements of these long-term effects and apply the required corrections to the ALMA system so that they are shared by all observational projects.

# Short-term effects

- Offset pointing (residual pointing errors with respect to the all-sky pointing model)
- System and receiver temperature fluctuations
- Sideband ratio leakage
- Absolute flux calibration (weather, elevation, etc.)
- Bandpass (calibrating spectral response of the combined atmosphere and receiving system)
- Gain (amplitude & phase) fluctuations, due to atmospheric fluctuations in the troposphere at various timescales

Some of these calibrations are done at the beginning of a 'Scheduling Block' (basic unit of observation), some during the SB.

# Two topics ...

- WVR corrections

**Recent paper:**

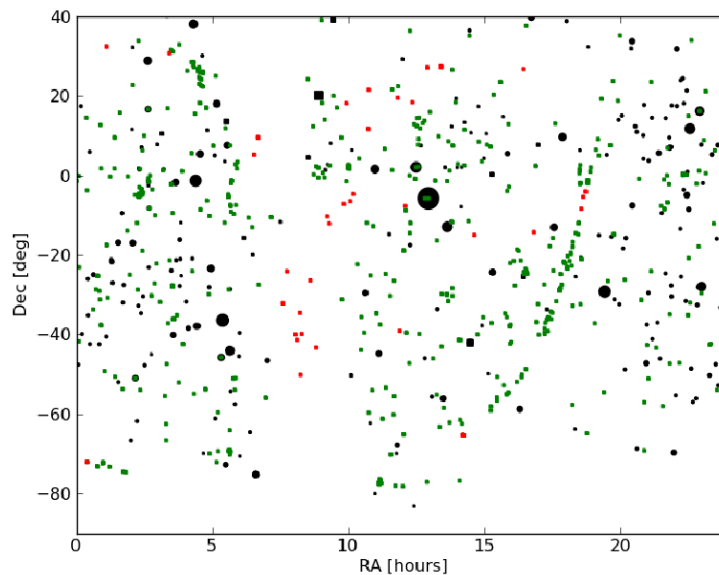
Nikolic et al. (2013), A&A, in press

(arXiv:1302.6056)



- Dynamic calibrators

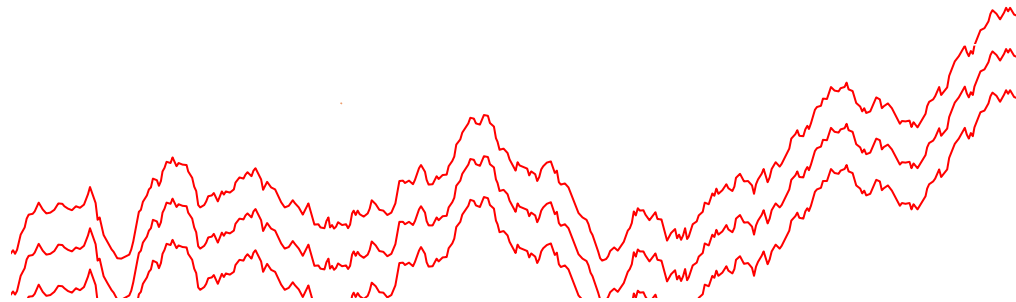
**New in Cycle 1**



# ALMA's sky is dry ... but not perfect



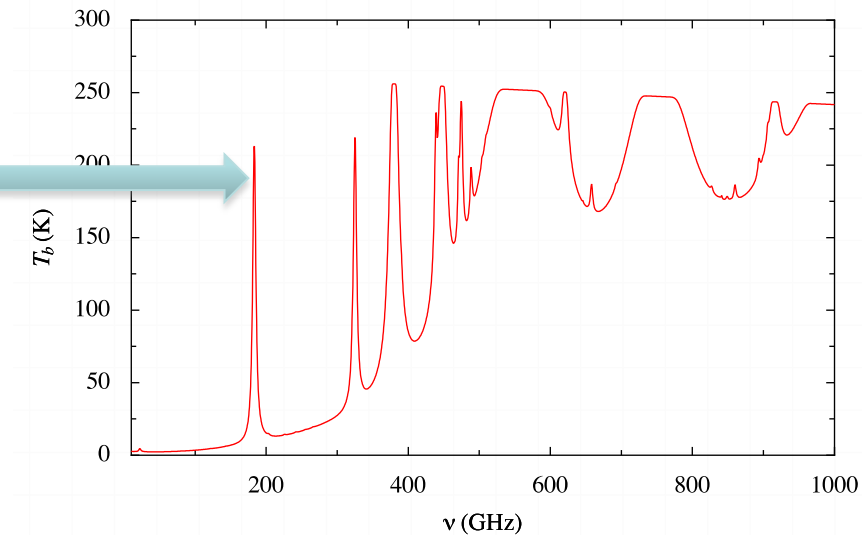
# Atmospheric phase fluctuations



*Figure: Bojan Nikolic*

# ALMA WVR system

The Water Vapour Radiometry system on ALMA uses the 183 GHz water line



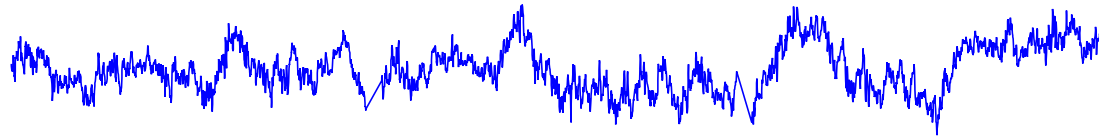
Each antenna has its own WVR receiver





# WVR correction for a long (600m) baseline

Red: uncorrected phase; Blue: corrected phase



# Running ALMA observations

- Observations are prepared using the 'Observing Tool' (see the talk by Suzanna Randall tomorrow)
- This tool saves all the observing parameters in a structured 'project file', which is read by the telescope control software
- The basic unit of observation in a project is a Scheduling Block (SB), which is usually executed multiple times

Special for ALMA Cycle 1: dynamic calibrator selection

# SBs are full of calibrators ...

- ◆ Group 1: Calibration Group (with non-cyclic calibrators)
  - ◆ Pointing (e.g. near amplitude/bandpass calibrator) in B3/B6
  - ◆ Bandpass calibrator
  - ◆ Amplitude calibrator
  
- ◆ Group 2: Science Group (with cyclic calibrators)
  - ◆ Pointing (e.g. on phase calibrator) in B3/B6 (every hour)
  - ◆ Phase calibrator (every five minutes or so)
  - ◆ Science Target (rest of the time ...)

# Calibrator selection in Cycle 0

Do dust holes in transitional disks still contain cold gas? v1.9 - Observing Tool for ALMA, version Cycle1-PhaseII(RC6)

File Edit View Tool Search Help

Perspective 1

**Project Structure**

- Proposal
  - Program
    - Do dust holes in transitional disks still contain cold gas? v1.9
      - Science Plan
        - ScienceGoal (CO 6-5 & continuum) - generated
          - General
          - Field Setup
          - Spectral Setup
          - Calibration Setup
          - Control and Performance
          - Oph IRS 48-SI
            - Oph IRS 48[12m Array SB]
              - Group 1 : Calibrators
              - Group 2 : Science
              - 16 Targets
                - Titan Primary Amplitude (Amplitude)
                - 3c279 Primary Bandpass (Pointing)
                - 3c279 Primary Bandpass (Bandpass)
                - Titan Primary Amplitude (Atmospheric)
                - 3c279 Primary Bandpass (Atmospheric)
                - [R] Oph IRS 48 Primary: (Science)
                - Oph IRS 48 Primary: (Atmospheric)
                - Juno Secondary Amplitude (Amplitude)
                - Juno Secondary Amplitude (Atmospheric)
                - J1924-292 Secondary Bandpass (Bandpass)
                - J1924-292 Secondary Bandpass (Pointing)
                - J1924-292 Secondary Bandpass (Atmospheric)
                - J1733-130 First Phase (Phase)
                - J1733-130 First Phase (Atmospheric)
                - J1625-254 Second Phase (Phase)
                - J1733-130 First Phase (Pointing)
              - Resources
                - 7 Field Sources
                  - Primary: Oph IRS 48
                  - Primary Amplitude Titan

**Editors**

Spectral Spatial J1733-130 First Phase (Phase)

⚠ This FieldSource is used by 3 targets. Edit Only This

-Query Status ?

Select target from ALMA calibrator catalogue at execution time

Field Source ?

Field Source Name: First Phase

Source Name: J1733-130 Resolve

Choose a Solar System Object?  Select Object Unspecified

System: J2000 Sexagesimal display?

Parallax: 0.00000 mas

Source Coordinates

RA: 17:33:02.7058 PM RA: 0.00000 mas/yr

Dec: -13:04:49.548 PM DEC: 0.00000 mas/yr

Source Radial Velocity: 0.000 km/s topo z: 0.000000000 Doppler Type: RADIO

Source Properties

| Frequency              | Flux    | Diameter   |
|------------------------|---------|------------|
| 99.9308193333333 GHz   | 2.6 Jy  | 0.0 arcsec |
| 230.00000000000003 GHz | 3.7 Jy  | 0.0 arcsec |
| 352.697009411765 GHz   | 1.51 Jy | 0.0 arcsec |
| 1.4989622900000001 GHz | 5.2 Jy  | 0.0 arcsec |
| 4.996540966666667 GHz  | 5.0 Jy  | 0.0 arcsec |

Add Delete

Visible Magnitude:

Use Reference:

Reference Position (Offset): ? -

Reference0

# Calibrator selection in Cycle 1

The screenshot displays the 'Observing Tool for ALMA' interface, version Cycle1-PhaseII(RC6). The window title is 'Spatially resolved wide band spectroscopy in ULIRG obscured nuclei - Observing Tool for ALMA, version Cycle1-PhaseII(RC6)'. The interface is divided into several panels:

- Project Structure:** A tree view on the left showing the project hierarchy. The selected path is:
  - Spatially resolved wide band spectroscopy in ULIRG obscured nuclei
  - Science Plan
  - ScienceGoal (Band 6 low) - generated
  - General
  - Field Setup
  - Spectral Setup
  - Calibration Setup
  - Control and Performance
  - SG OUS (Band 6 low)
  - Group OUS
  - Member OUS (Arp220)
  - Arp220\_B6\_low\_1[12m Array SB]
    - Group 1 : Calibrators
    - Group 2 : Science
    - 7 Targets
      - query Pointing Template (Cal Group)
      - query Pointing Template (Science Group)
      - query Amplitude (Amplitude)
      - query Phase (Phase)
      - query Check source (Delay)
      - query Bandpass (Bandpass)
      - [R] Arp220 Primary: (Science)
    - Resources
      - 7 Field Sources
        - Pointing Template (Cal Group) query
        - Pointing Template (Science Group) query
        - Amplitude query
        - Phase query
        - Check source query
        - Bandpass query
        - Primary: Arp220
      - 2 Instrument Setup

- Editors:** A panel on the right with tabs for 'Spectral', 'Spatial', and 'query Phase (Phase)'. The 'query Phase (Phase)' tab is active.
- Query Status:** 'This FieldSource is used by 1 target.' Below it, a checkbox 'Select target from ALMA calibrator catalogue at execution time' is checked.
- Source Catalog Search Parameters:**
  - Instructions:
    - Set a non-zero value to enable a filter
    - A maximum of 100 results can be returned
  - Search criteria:
    - Cone Search: RA: 15:34:57.2710, Dec: 23:30:10.479, Radius ("): 15.0
    - Flux: Min: 0.00000 Jy, Max: 0.00000 Jy
    - Frequency: Min: 0.00000 GHz, Max: 0.00000 GHz
    - Max Results: 40
  - Buttons: 'Convert Dynamic Calibrator to Fixed Calibrator...'
  - Field Source: (empty)
  - Reference Position (Offset): (empty)

# Calibrator query

Main selection criteria:

- ◆ distance to science target
- ◆ signal to noise ratio and maximum integration time
- ◆ minimum elevation (to prevent shadowing)
- ◆ range in frequency

All calibrators are selected before actually taking data.

The query script searches the 'live' calibrator database, and rates each possible calibrator with a weighting scheme for the search parameters. The top choice is then selected for observation for the whole SB. This does not have to be the same choice for a repeat execution of the SB.

Data will not be taken if suitable calibrators can not be selected.

# Dynamic calibrator selection

## Phase calibrator selection example

Top five sources from selection script:

| sname      | sep<br>(deg) | rating | flux<br>(mJy) | fl_err<br>(mJy) | last<br>(yr) | number<br>obs | FR   |
|------------|--------------|--------|---------------|-----------------|--------------|---------------|------|
| J2253+1608 | 9.8          | 0.22   | 2761          | 936             | 1.1          | 9             | 1.04 |
| J2225+2118 | 11.3         | 0.07   | 125           | 12              | 0.5          | 1             | 1.06 |
| J2217+2421 | 12.5         | 0.06   | 396           | 39              | 0.5          | 1             | 1.06 |
| J2212+2355 | 13.7         | 0.05   | 239           | 23              | 0.5          | 1             | 1.06 |
| J2219+1806 | 14.1         | 0.05   | 93            | 9               | 0.5          | 1             | 1.06 |

# Dynamic calibrator selection

## Bandpass calibrator selection example

Top five sources from selection script:

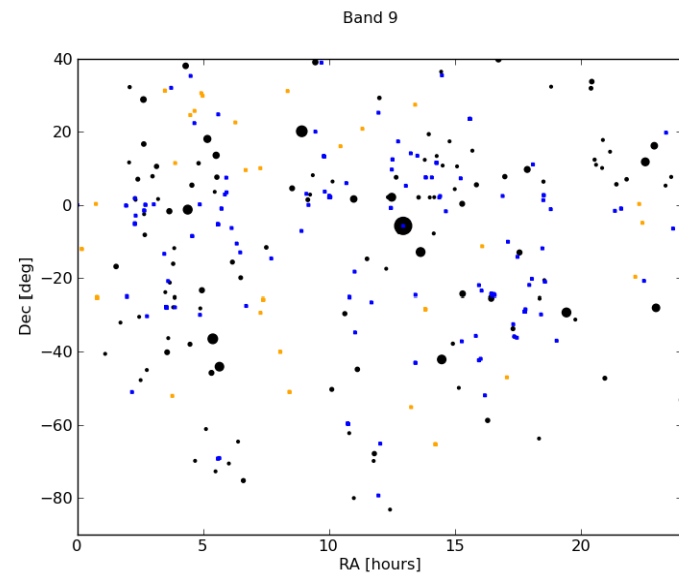
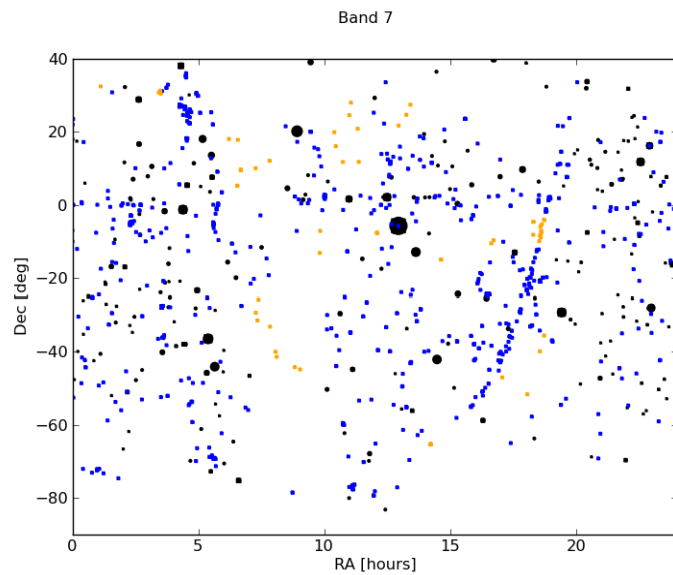
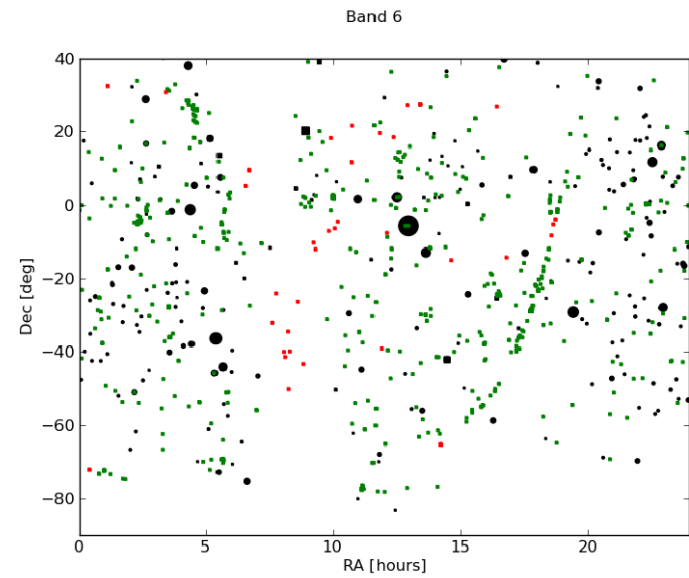
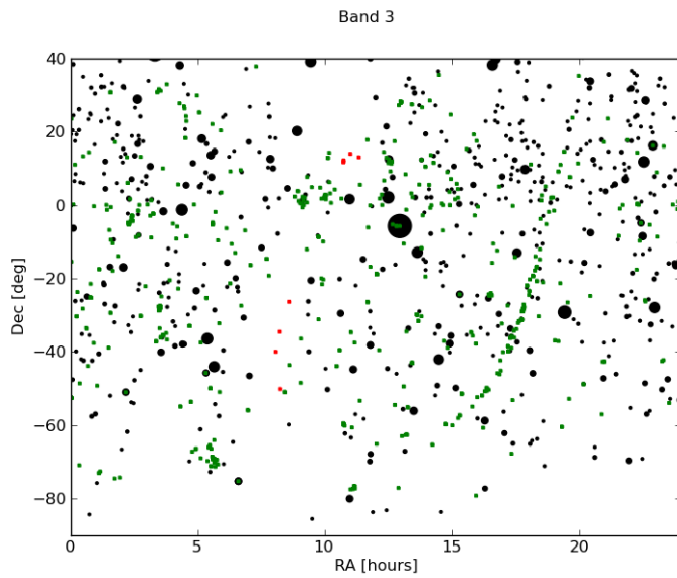
| sname      | sep<br>(deg) | rating | flux<br>(mJy) | fl_err<br>(mJy) | last<br>(yr) | number<br>obs | FR   |
|------------|--------------|--------|---------------|-----------------|--------------|---------------|------|
| J2232+1143 | 16.2         | 1.12   | 3827          | 1181            | 0.2          | 14            | 1.04 |
| J2253+1608 | 9.8          | 0.98   | 2761          | 936             | 1.1          | 9             | 1.04 |
| J2323-0317 | 28.4         | 0.22   | 829           | 88              | 1.1          | 6             | 1.04 |
| J2334+0736 | 18.2         | 0.15   | 526           | 86              | 0.3          | 2             | 1.06 |
| J2217+2421 | 12.5         | 0.14   | 396           | 39              | 0.5          | 1             | 1.06 |



# Example of a simulated SB execution

| $t_{\text{run}}$ | Scan | Source          | $t_{\text{int}}$ | $N_{\text{sub}}$ | BP | AMP | PHASE | SCI | ☉ | ↗ | atm | WVT | Setup |
|------------------|------|-----------------|------------------|------------------|----|-----|-------|-----|---|---|-----|-----|-------|
| 0:00             | 1    | J1427-4206      | 0:50             | 5                |    |     |       |     | • |   |     | •   | A     |
| 0:50             | 2    | J1427-4206      | 1:00             | 2                |    |     |       |     |   | • |     | •   | B     |
| 1:50             | 3    | J1427-4206      | 0:12             | 3                |    |     |       |     |   |   | •   | •   | B     |
| 2:02             | 4    | J1427-4206      | 1:00             | 2                | •  |     |       |     |   |   |     | •   | C     |
| 3:02             | 5    | J1427-4206      | 1:01             | 2                |    |     |       |     |   | • |     | •   | D     |
| 4:03             | 6    | J1427-4206      | 0:11             | 3                |    |     |       |     |   |   | •   | •   | D     |
| 4:14             | 7    | J1427-4206      | 5:03             | 10               | •  |     |       |     |   |   |     | •   | E     |
| 9:17             | 8    | J1445-1629      | 0:50             | 5                |    |     |       |     | • |   |     | •   | A     |
| 10:07            | 9    | Titan           | 0:12             | 3                |    |     |       |     |   |   | •   | •   | B     |
| 10:19            | 10   | Titan           | 2:31             | 5                |    | •   |       |     |   |   |     | •   | C     |
| 12:50            | 11   | J1625-2527      | 0:11             | 3                |    |     |       |     |   |   | •   | •   | B     |
| 13:01            | 12   | J1625-2527      | 0:31             | 1                |    |     | •     |     |   |   |     | •   | C     |
| 13:32            | 13   | IRAS_16293-2422 | 0:11             | 3                |    |     |       |     |   |   | •   | •   | D     |
| 13:43            | 14   | IRAS_16293-2422 | 6:33             | 13               |    |     |       | •   |   |   |     |     | E     |
| 20:16            | 15   | J1625-2527      | 0:31             | 1                |    |     | •     |     |   |   |     | •   | C     |
| 20:47            | 16   | IRAS_16293-2422 | 6:33             | 13               |    |     |       | •   |   |   |     |     | E     |
| 27:20            | 17   | J1625-2527      | 0:30             | 1                |    |     | •     |     |   |   |     | •   | C     |
| 27:50            | 18   | IRAS_16293-2422 | 0:11             | 3                |    |     |       |     |   |   | •   | •   | D     |
| 28:01            | 19   | IRAS_16293-2422 | 6:34             | 13               |    |     |       | •   |   |   |     |     | E     |
| 34:35            | 20   | J1625-2527      | 0:11             | 3                |    |     |       |     |   |   | •   | •   | B     |
| 34:46            | 21   | J1625-2527      | 0:30             | 1                |    |     | •     |     |   |   |     | •   | C     |
| 35:16            | 22   | IRAS_16293-2422 | 6:33             | 13               |    |     |       | •   |   |   |     |     | E     |
| 41:49            | 23   | J1625-2527      | 0:31             | 1                |    |     | •     |     |   |   |     | •   | C     |
| 42:20            | 24   | IRAS_16293-2422 | 0:11             | 3                |    |     |       |     |   |   | •   | •   | D     |
| 42:31            | 25   | IRAS_16293-2422 | 1:31             | 3                |    |     |       | •   |   |   |     |     | E     |
| 44:02            | 26   | J1625-2527      | 0:30             | 1                |    |     | •     |     |   |   |     | •   | C     |

# ALMA Cycle 1 Calibrator database (black points)



# Further reading

## **ALMA Cycle 1 Technical Handbook, chapter 10**

Available on the ALMA Science Portal: <http://almascience.org/>

## **Phase Correction for ALMA with 183 GHz Water Vapour Radiometers**

Nikolic et al. (2013), A&A, in press (arXiv:1302.6056)

## **Phase Correction for ALMA: Adaptive Optics in the Submillimetre**

Nikolic et al. (2008), ESO Messenger vol. 131

## **How ALMA is calibrated: I Antenna-based pointing, focus and amplitude calibration**

van Kempen et al. (2012), ALMA Newsletter vol. 9 (arXiv:1210.1899)

## **Dynamic calibrator selection**

On the ALMA Science Portal, in the near future ...



### **ALMA in-depth**

#### **How ALMA is calibrated:**

I. Antenna-based pointing, focus and amplitude calibration  
by T. van Kempen, S. Corder, R. Lucas and R. Mauersberger.