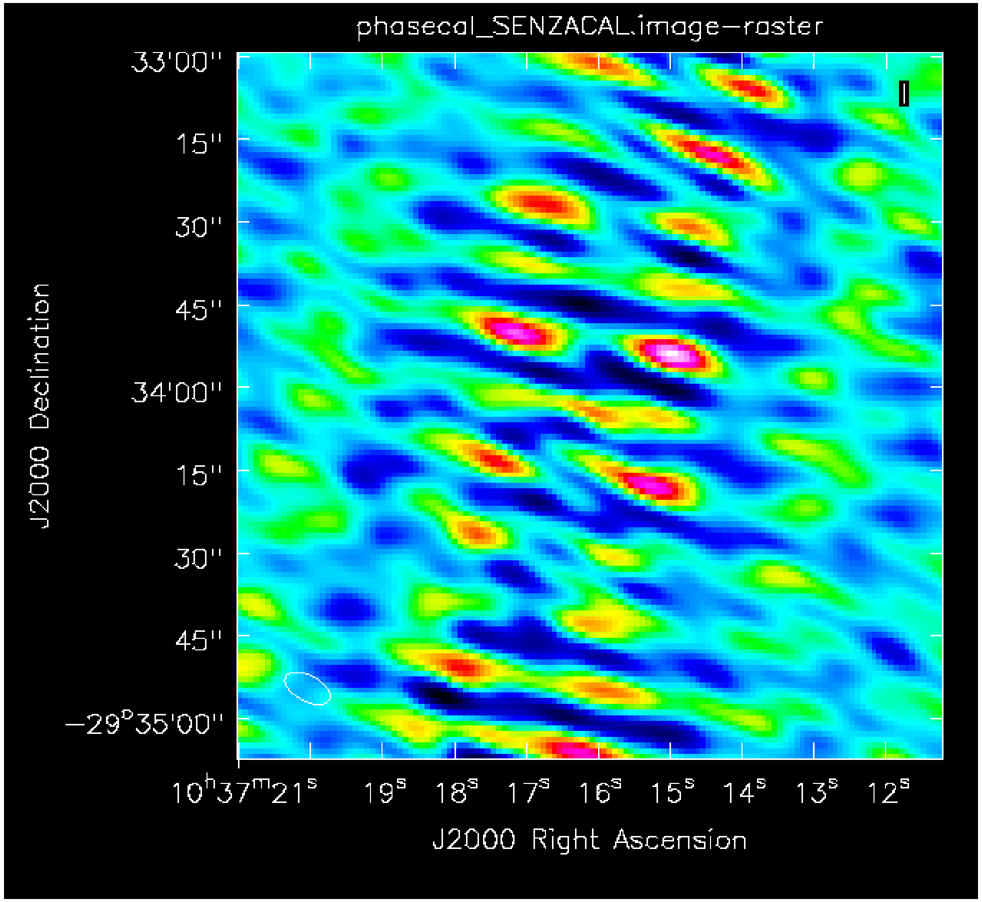
# Calibration

**Rosita Paladino**
Italian Node of ALMA Regional Center

Slides & contributions from
**Arturo Mignano**

**http://www.alma.inaf.it/index.php/Courses**

# If no calibration is applied....




**This would be the image of 1037-295 the calibrator of your dataset**

**deconvolving $V^{ij}_{obs}$**

## *Real interferometry:*

*An interferometer samples the Visibility Function as* ***transmitted*** *by the* ***atmosphere*** *and the* ***instrumentation*** *(antenna, receiver, electronics, cables, correlator, etc.)*

$$V^{ij}_{obs} = V^{ij}_{true} G^{i} G^{j}$$

*With a number of fair assumptions, CALIBRATION is the process to determine $G^i$ aiming at transforming the observed quantities to the proper scale.*

*All the quantities are* ***COMPLEX****, and therefore we need to find two values,* ***AMPLITUDE*** *and* ***PHASE****, for each antenna, polarization, sub-band, channel, ....*
*possibly as a function of time*

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*All the quantities are **COMPLEX**, and therefore we need to find two values, **AMPLITUDE** and **PHASE**, for each antenna, polarization, sub-band, channel, ....*
*possibly as a function of time*

**Most of the effects are antenna-based (pointing, focus, atmosphere, receiver noise, receiver bandpass)**

## *Real interferometry:*

$$V^{ij}_{obs} = V^{ij}_{true} G^{i} G^{j}$$

*The complex gain G can be generally split into two terms:*

*Amplitude* $a$

*Phase* $\theta$

*and the new relationship can be written as:*

$$A^{ij}_{obs} e^{i\,\theta^{ij}_{obs}} = A^{ij}_{true} a^{i} a^{j} e^{(i\,\theta^{ij}_{true} + \theta^{i} - \theta^{j})}$$

***Calibration means to find appropriate $a$ and $\theta$ for the raw data.***

Observing a source with known model $\mathbf{V}^{ij}_{mod}$

$$\mathbf{V}^{ij}_{obs} = \mathbf{G}^{i} * \mathbf{G}^{j}\ \mathbf{V}^{ij}_{mod}$$

Since number of baselines is N(N-1)/2 is larger than the number of gains, we have a over determined system of equation to solve!!!

*The complex gain $G_i$ contains many components (along the signal path):*

*$F$ = ionospheric Faraday rotation*

*$T$ = tropospheric effects*

*$P$ = parallactic angle (altaz-mounts)*

*$E$ = antenna voltage pattern*

*$D$ = polarisation leakage*

*$J$ = electronic gain*

*$B$ = bandpass response*

*$K$ = geometric compensation*

$$G^i = K^i B^i J^i D^i E^i P^i T^i F^i$$

*They are either additive (phases) or multiplicative (amplitudes).*

*In most cases, **when performing calibration we can forget the origin of the contribution to be removed**. Some of them are specific to each type of observation (VLBI, Spectral line, wide field) and of the observing frequency.*

$$G^i = K^i B^i J^i D^i E^i P^i T^i F^i$$

Geometry: antenna position...

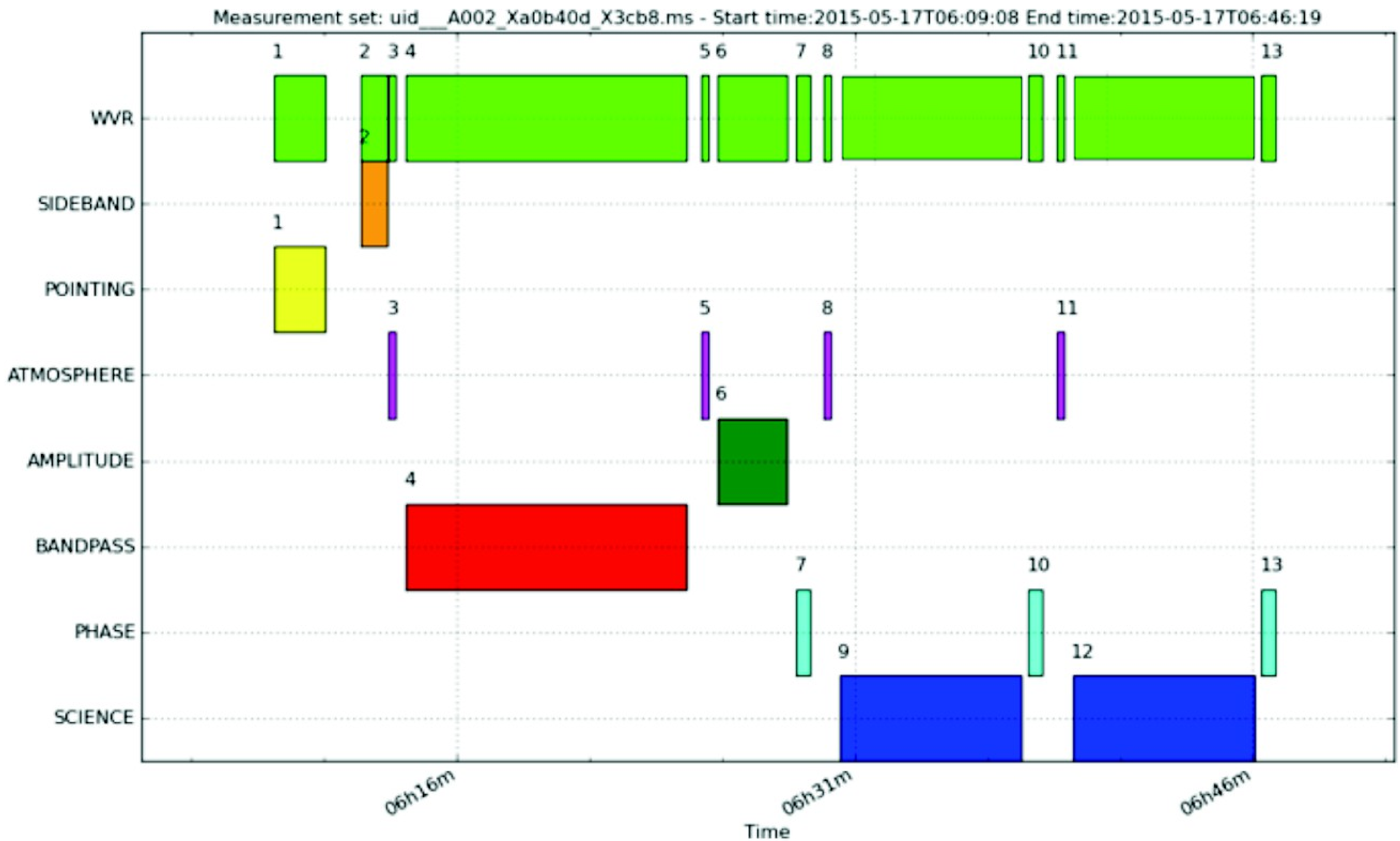
Antenna voltage pattern

Tropospheric effect: **wvr**

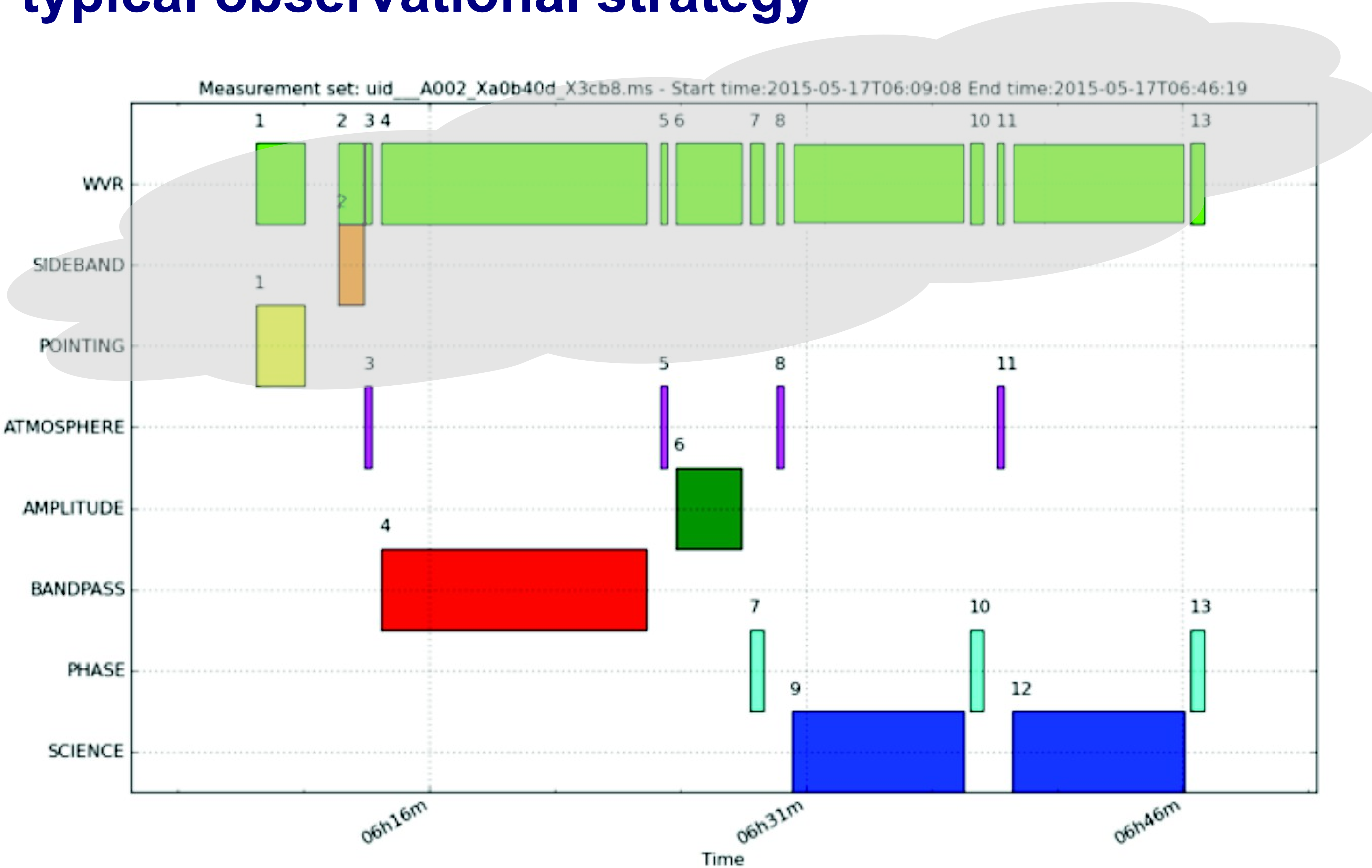
$$G^i(\nu,t) = B^i(\nu)\, J^i(t)$$

**Temporal dependence and frequency dependence are only lightly coupled so their variations can be determined independently or at least iteratively**

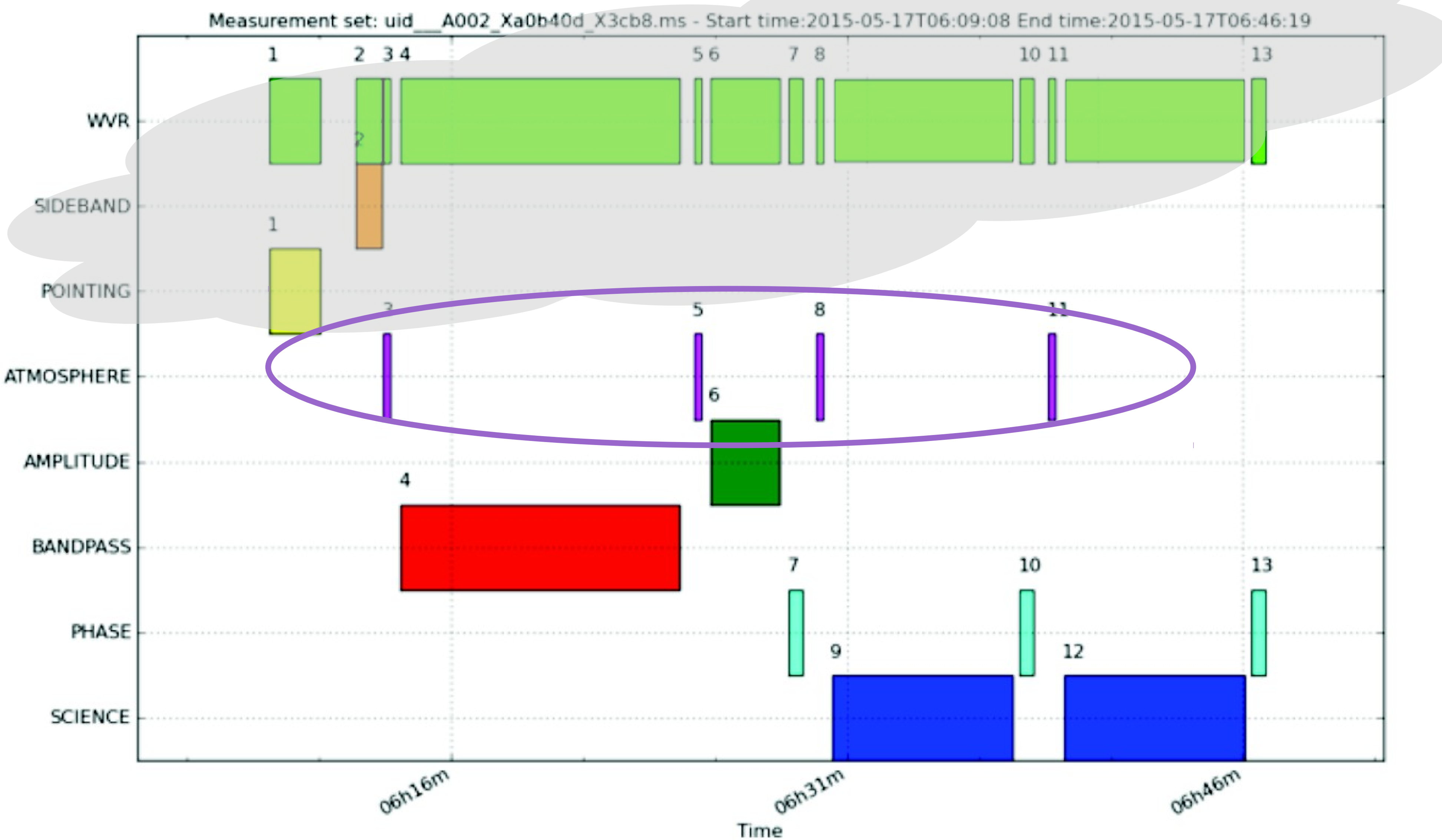
# Calibration in ALMA: typical observational strategy



# Calibration in ALMA:
# typical observational strategy



# Calibration in ALMA:
## Tsys calibration



# Calibration in ALMA:
## Tsys calibration

$$T_{sys} \sim T_{atm}\,(e^{\tau} - 1) + T_{rx} e^{\tau}$$

- ALMA front end are equipped with an Amplitude Calibration Device (ACD)

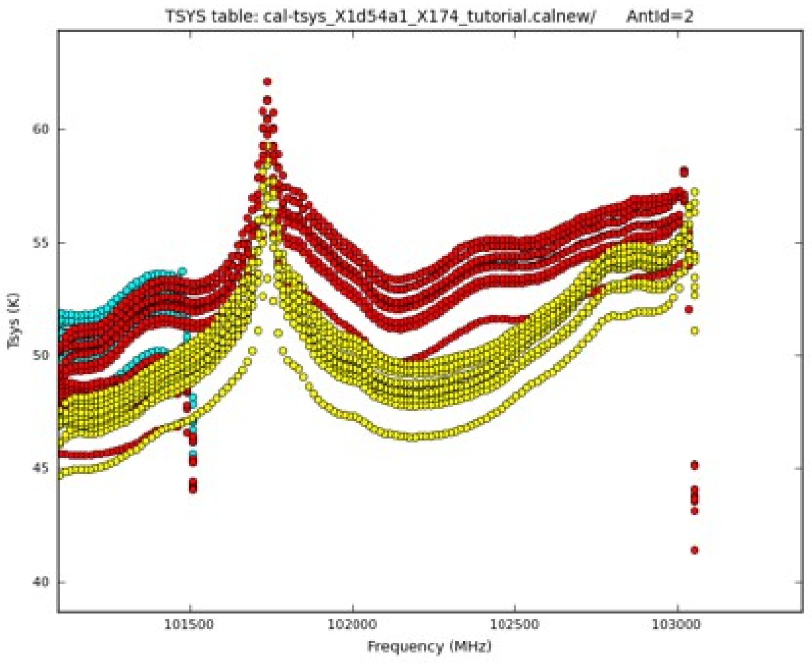
→ $T_{sys}$ and $T_{rx}$ **stored in SYSCAL table**

- Tsys observations are taken **always** with the lower spectral resolution (128 channels per polarization)
- In principle, every scan could have a system temperature measurement.
  At frequencies below 400 GHz, where Tsys are ~ constant over 10 min or 10 deg, measurements can be limited in time and among sources.

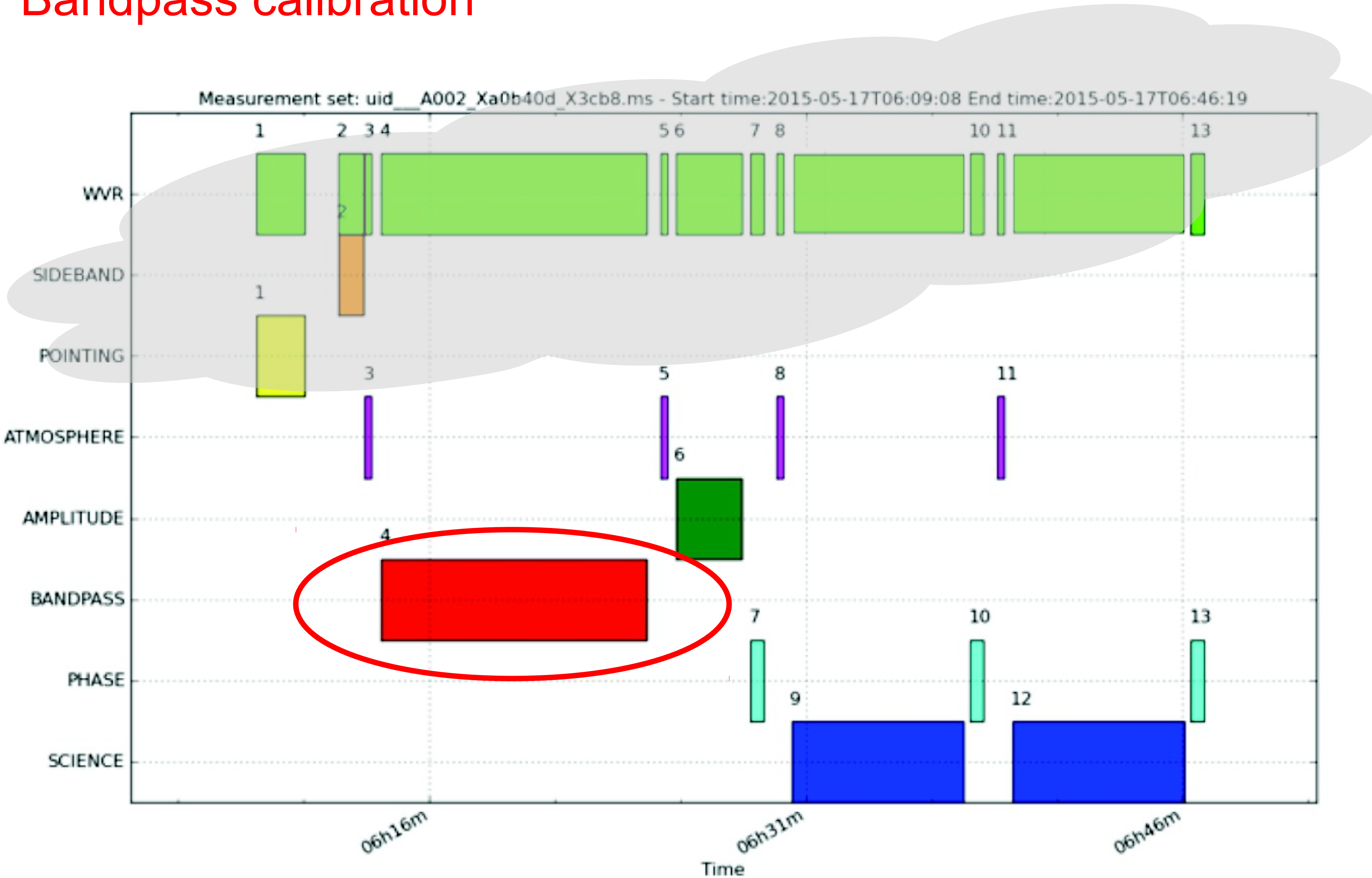
# Calibration in ALMA:
## Tsys calibration

- Assuming correlated data are in units of percentage correlation, multiplication by the Tsys  will change the units in **Kelvin**.

- Inspecting Tsys tables is important to identify possible “bad” antennas which need to be flagged.



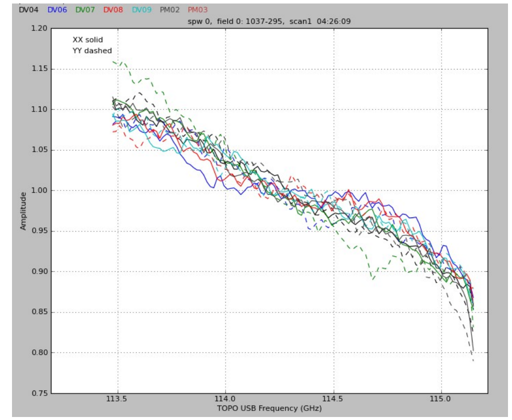
# Calibration in ALMA:
## Bandpass calibration



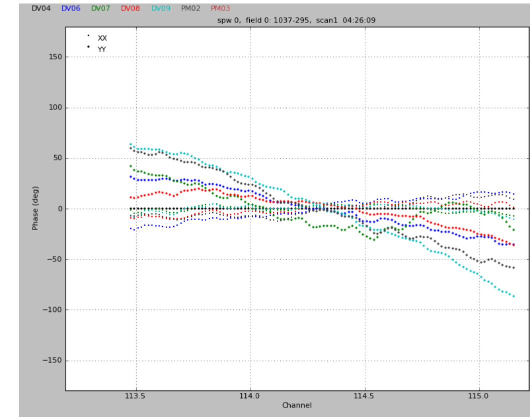
# Calibration in ALMA:

## Bandpass calibration

$$G^i(\nu,t) = B^i(\nu)\, J^i(t)$$




amplitude




phase

- Calibrate for the response of each antenna
  ...basically, electronics
- Observations of a bright QSO (typically at the beginning of the observation)
- Amplitude constant within the band
- Observing time long enough to reach high S/N on each channel

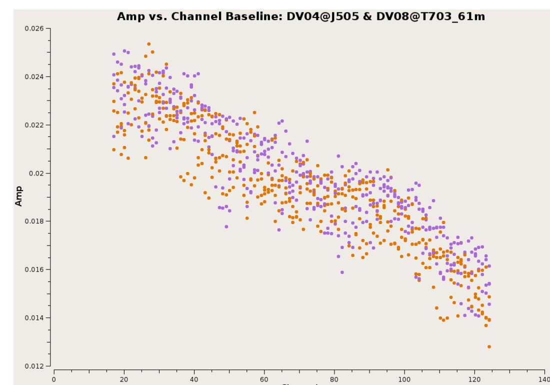
# Calibration in ALMA:

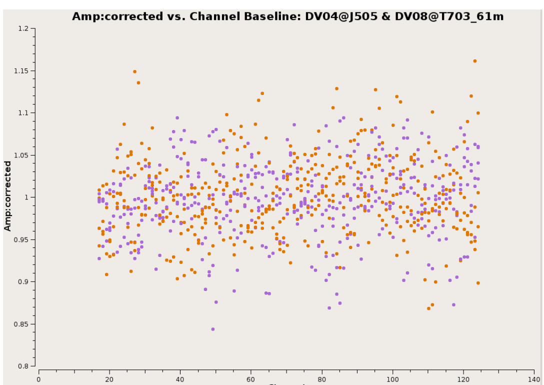
## Bandpass calibration

Observing a source with known model

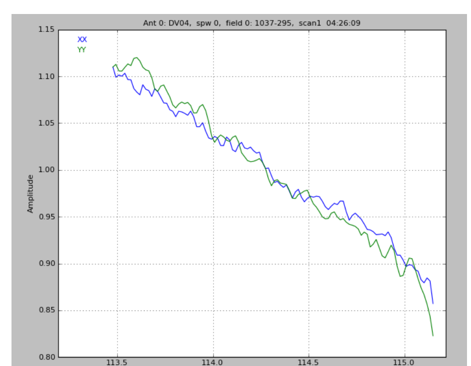
$$A_{mod}(\nu) = 1$$

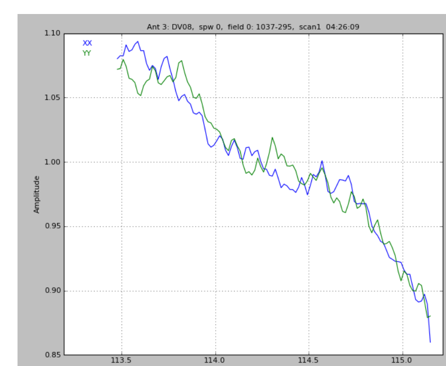
$$A^{ij}_{obs} = B^{i} * B^{j} \; A^{ij}_{mod}$$



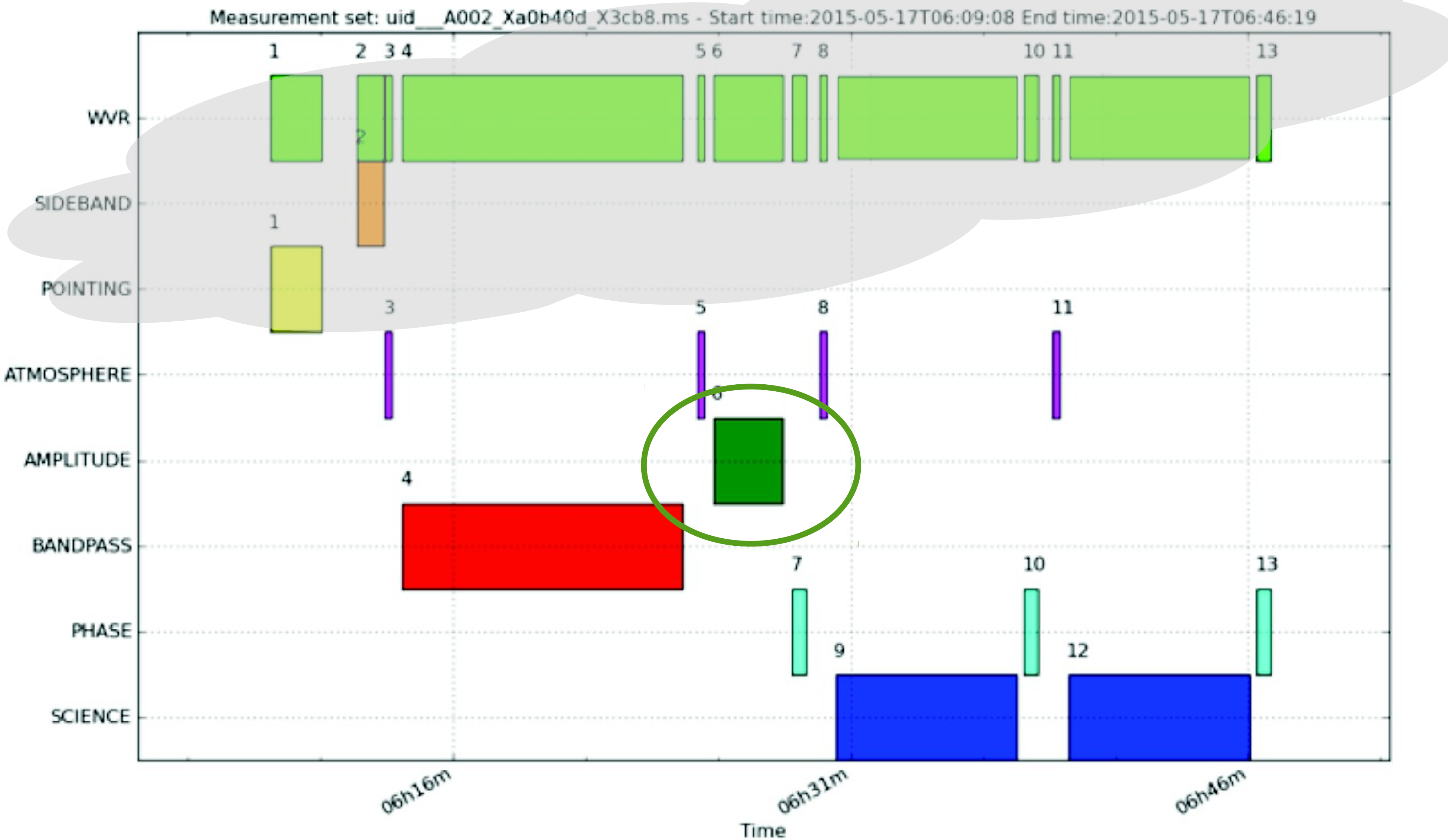




$$A^{48}_{corr} = \frac{A^{48}_{obs}}{B^{4} * B^{8}}$$



# **Calibration in ALMA:**
## Amplitude calibration

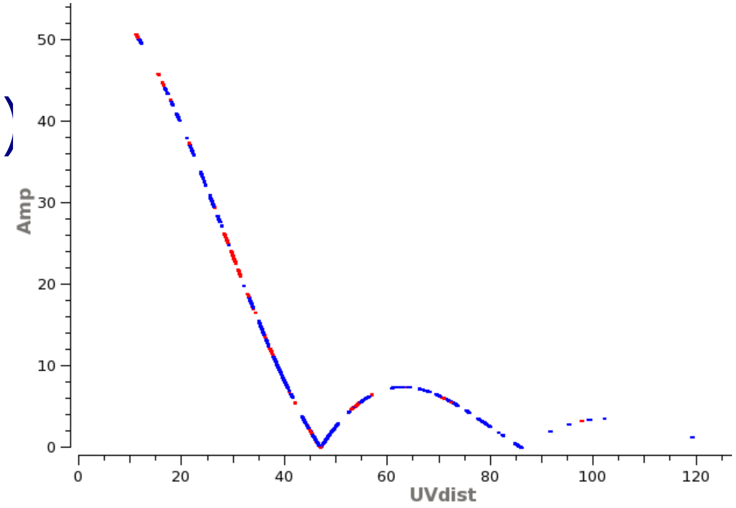


# Calibration in ALMA:
## Amplitude calibration

- Define the Jy/K scale
  basically antenna efficiency (~40 Jy/K, once Tsys corrected)

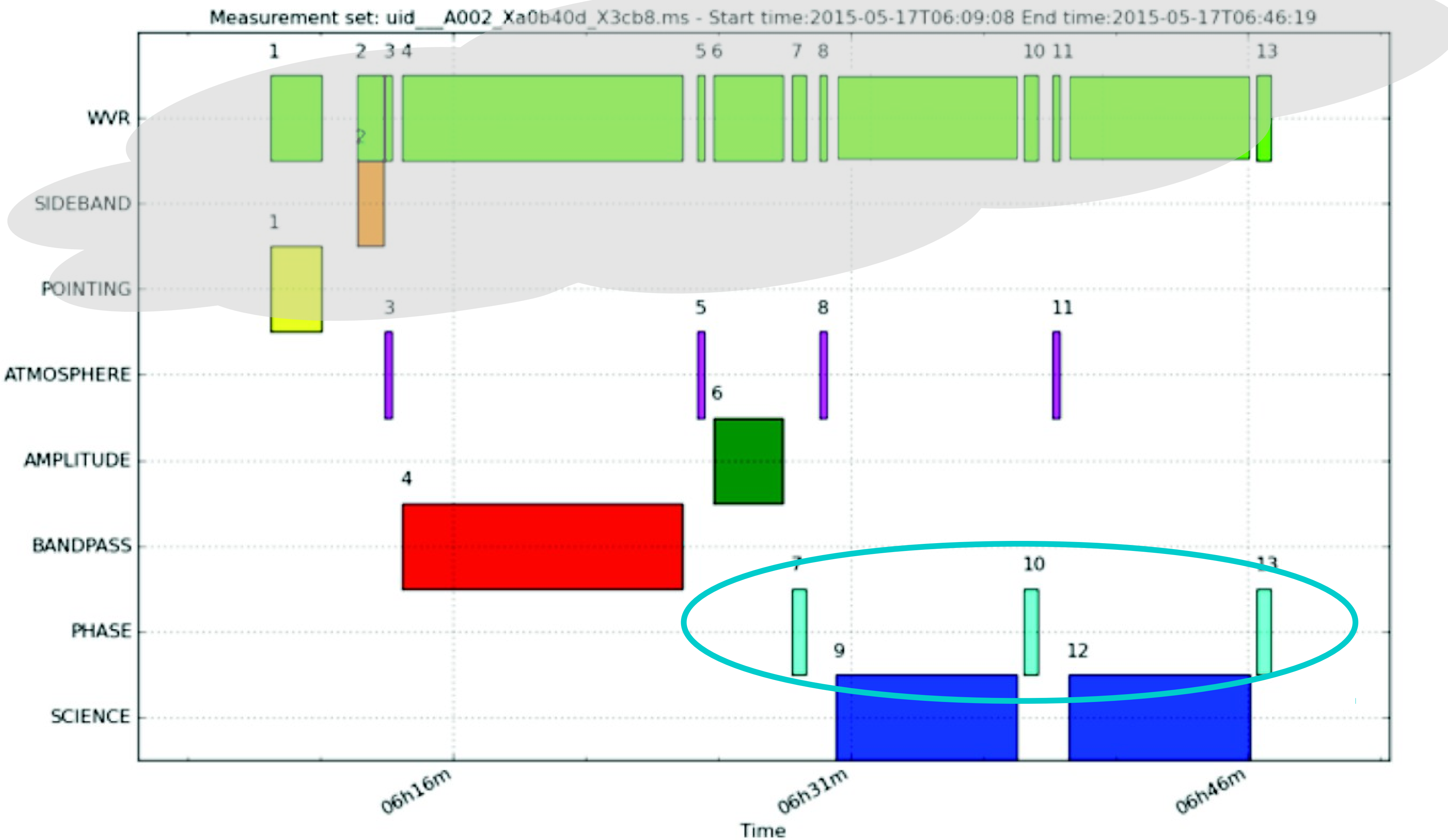
- Observations of a non variable object
  (typically at the beginning of the observation)

- No matter where in the sky




- The scale is calculated for the flux calibrator and transferred
  to bandpass and phase calibrator

# Calibration in ALMA:
## Phase calibration



## Calibration in ALMA:
## Phase calibration

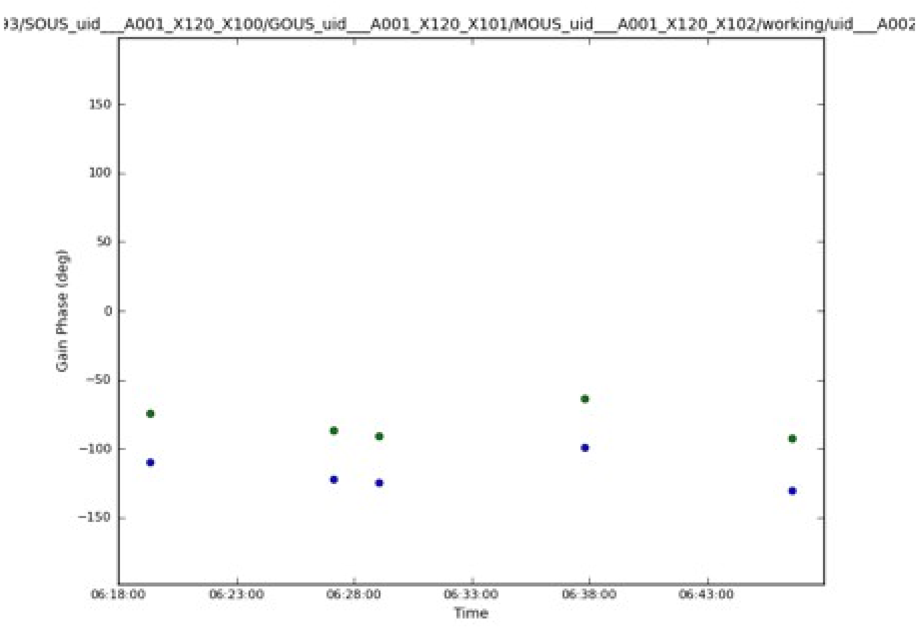
$$G^i(\nu,t) = B^i(\nu)\, J^i(t)$$

- Calibrate for the long time scale dependent response of each antenna
  ...basically, atmosphere
- Observations of a point like source (QSO)
- As close as possible to the target (< 4 deg)

# **Calibration in ALMA:**
## Phase calibration

$$G^i(\nu,t) = B^i(\nu) J^i(t)$$

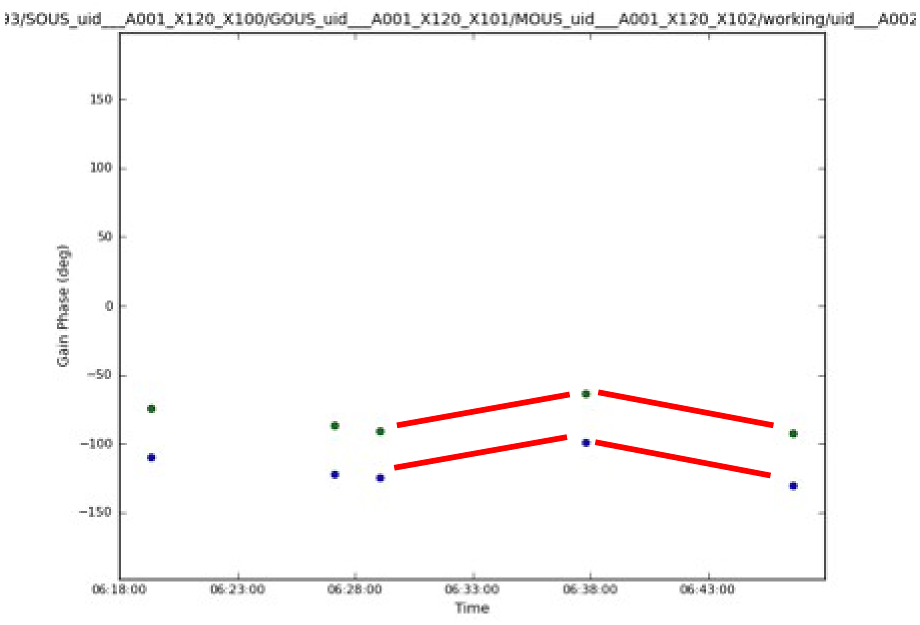
- Observed regularly before and after target scans



# Calibration in ALMA:
## Phase calibration

$$G^i(\nu,t) = B^i(\nu)\,J^i(t)$$

- Observed regularly before and after target scans
- Solutions applied to the target using a linear interpolation



# Calibration in ALMA:

Apply all the calibrations
and NOW make the image!!!