Calibration basics

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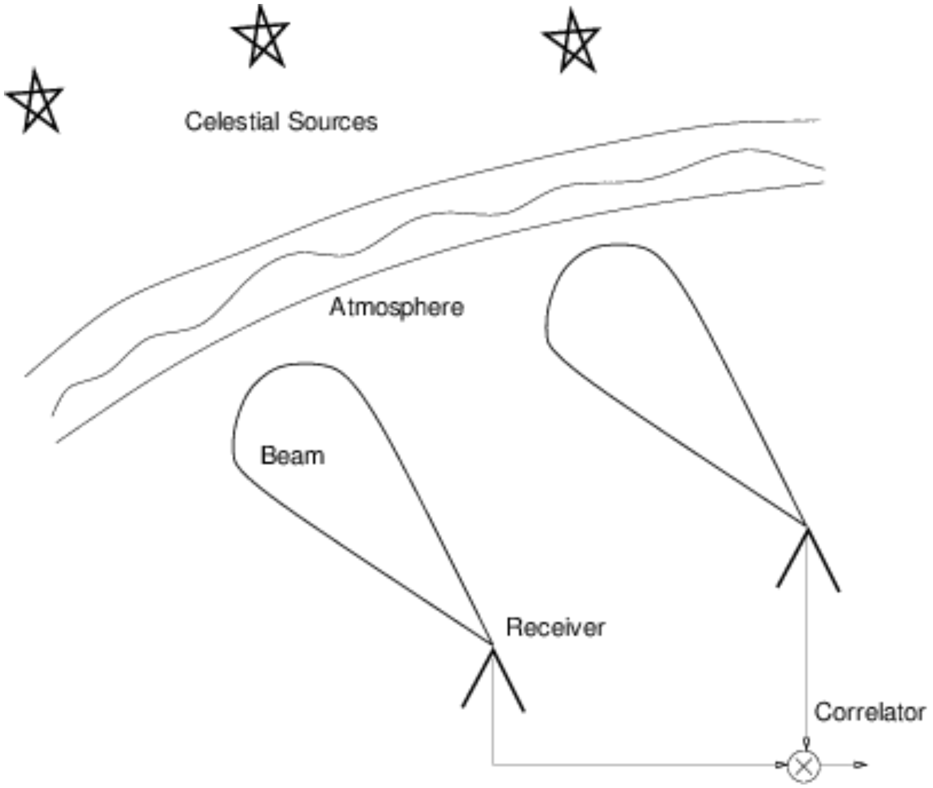
Why is calibration needed?

What are the main assumptions and limitations?

How is calibration done?

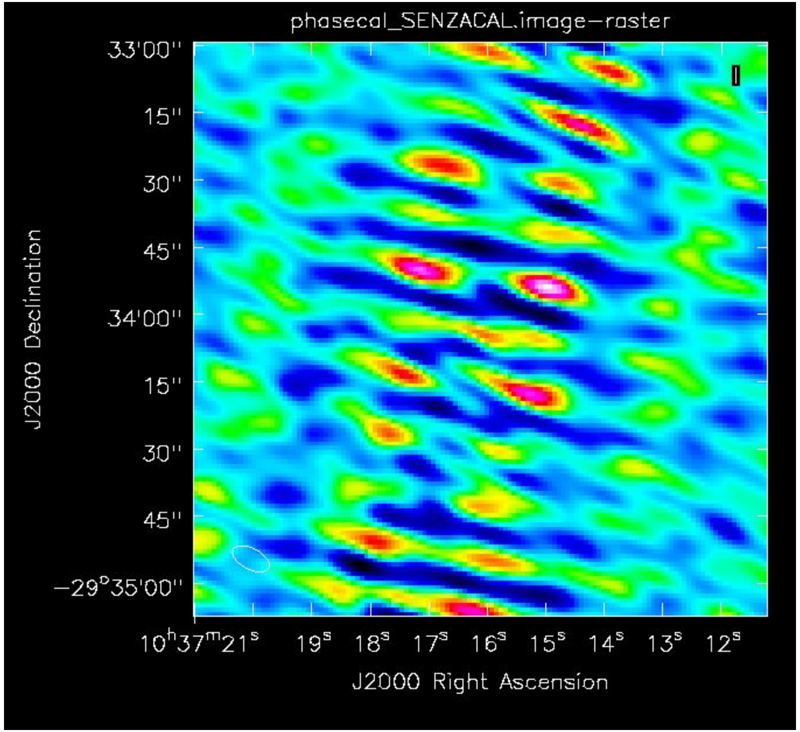
Where are calibration results in the archive?



Observed visibilities differ from true visibilities

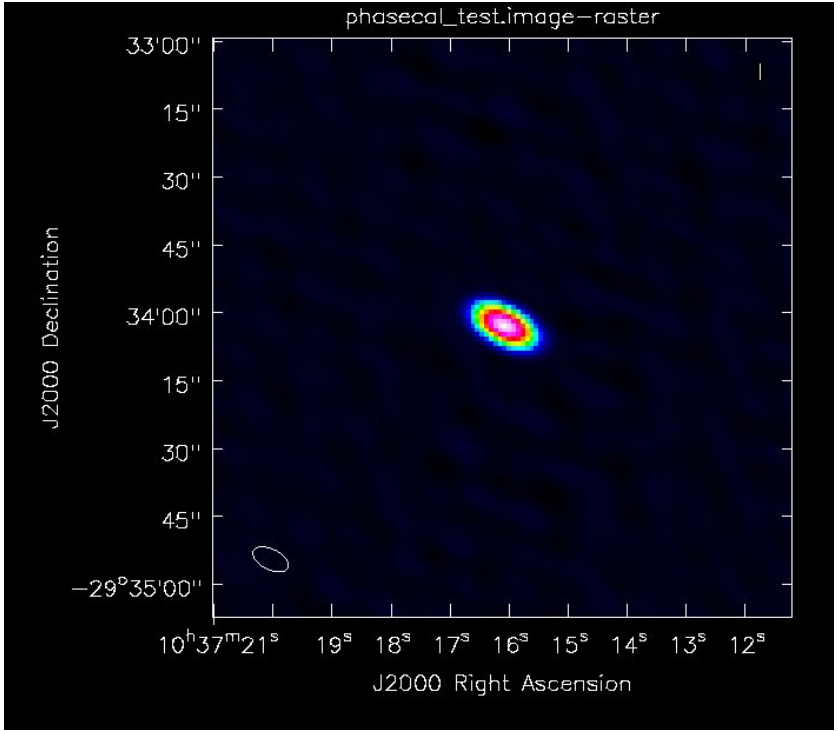
- atmosphere
- electronics

The Fourier transform of raw visibilities of a point source



The Fourier transform of raw visibilities of a point source

look far from what it should



The calibration consists in

- measuring the effects of the various corruptions on the observed visibilities

$$V^{ij}_{obs}(\nu,t) = G^{ij}(\nu,t) \quad V^{ij}_{true}(\nu,t)$$

corruptions

G = B J D E P T

T=troposphere
P=parallactic angle (alt-az mounting)
E=antenna voltage pattern
D=polarization leakages
J= electronic gains
B=bandpass response

The calibration consists in

- measuring the effects of the various corruptions on the observed visibilities
- some factors can be predicted or directly measured

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The calibration consists in

- measuring the effects of the various corruptions on the observed visibilities
- some factors can be predicted or directly measured
- others can be determined by observing a calibration source during the observing period

$$V^{ij}_{obs}(\nu,t) = G^{ij}(\nu,t) \quad V^{ij}_{true}(\nu,t)$$

corruptions

G = B J D E P T

T= troposphere
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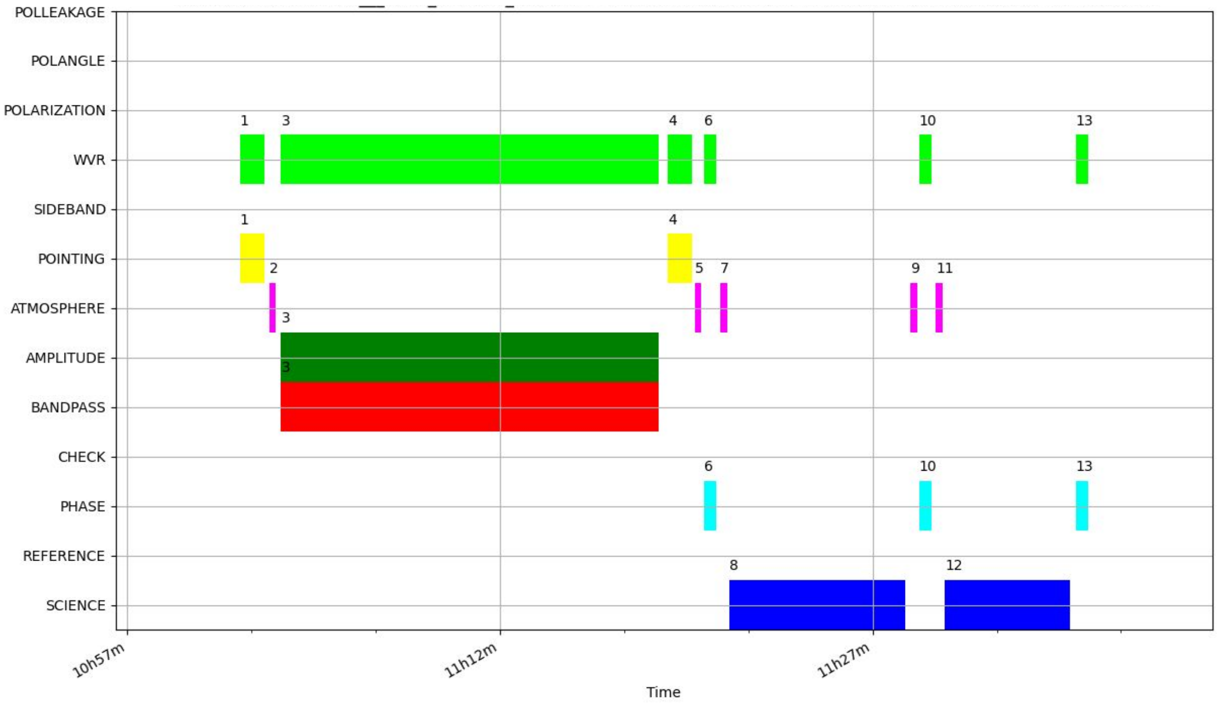
Typical execution structure



factors that can be predicted or directly measured

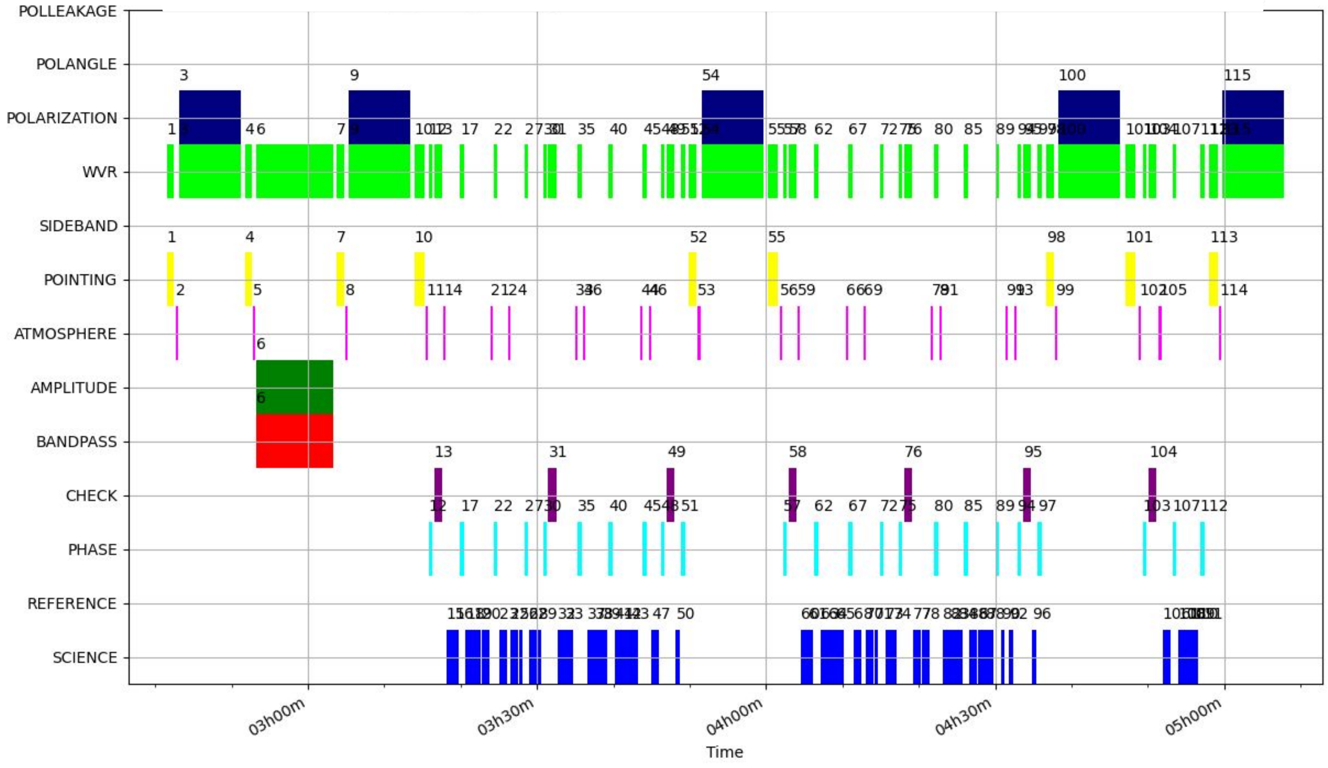
wvr

Pointing

Tsys

Typical execution structure

factors that can be predicted or directly measured



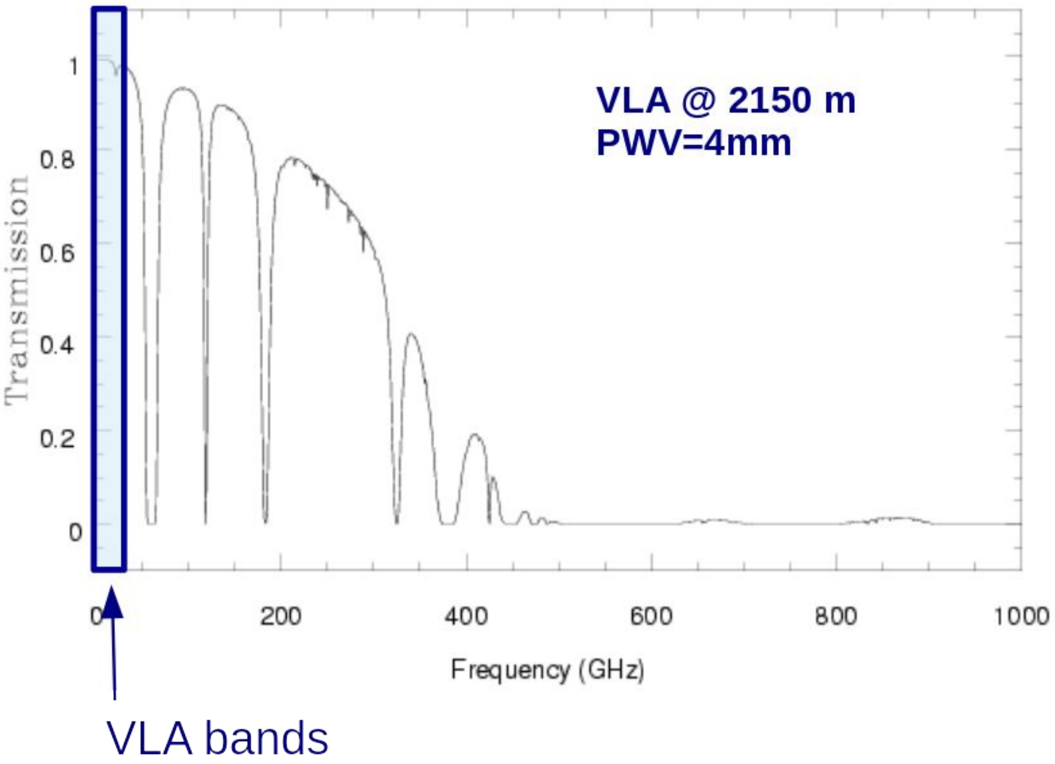
wvr

Pointing

Tsys

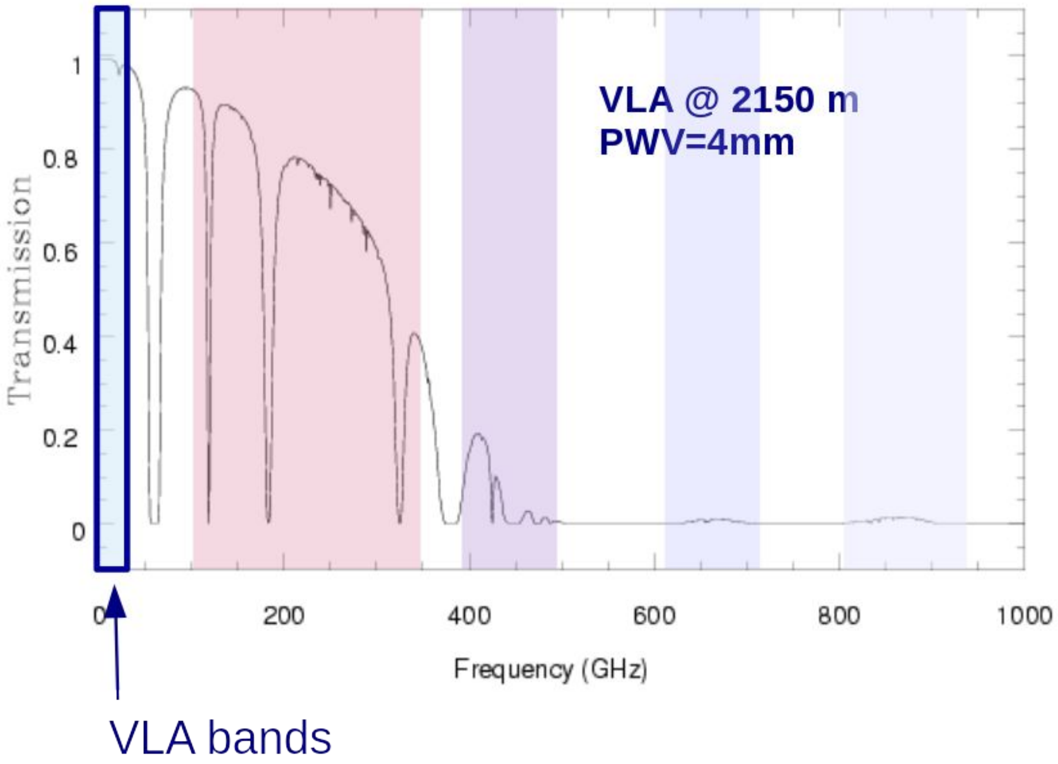
Troposphere

- Tropospheric opacity depends on the altitude



Atmospheric transmission is not a cm problem @ λ > cm

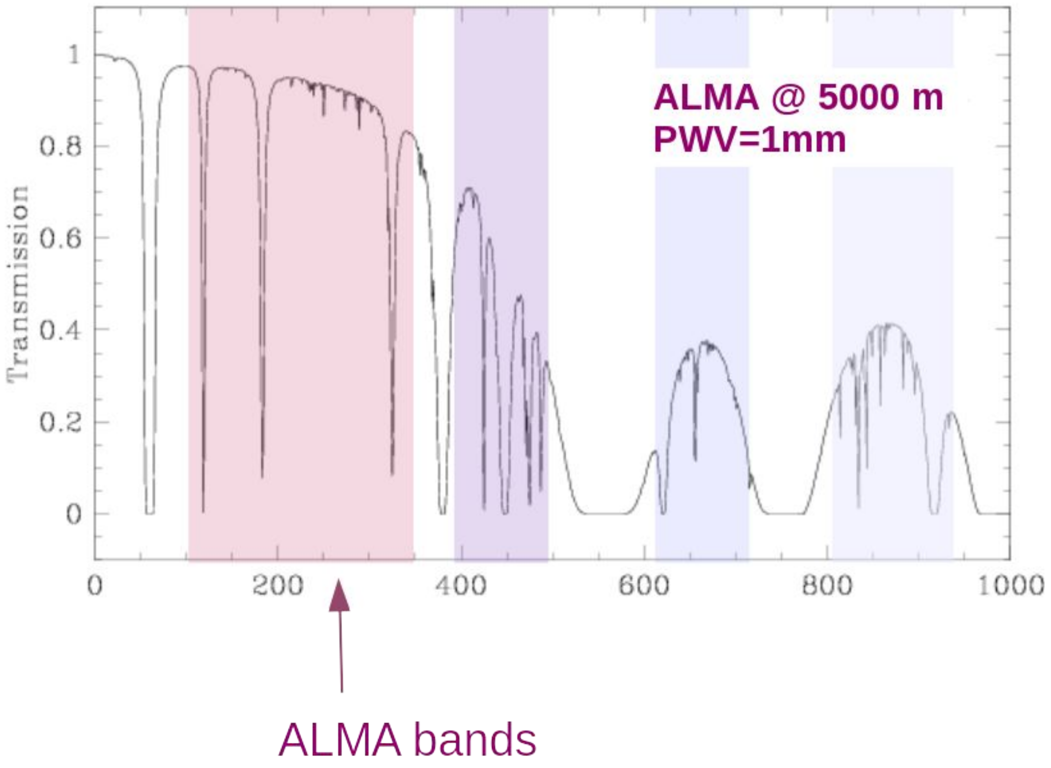
Troposphere



Atmospheric transmission is not a problem @ λ > cm

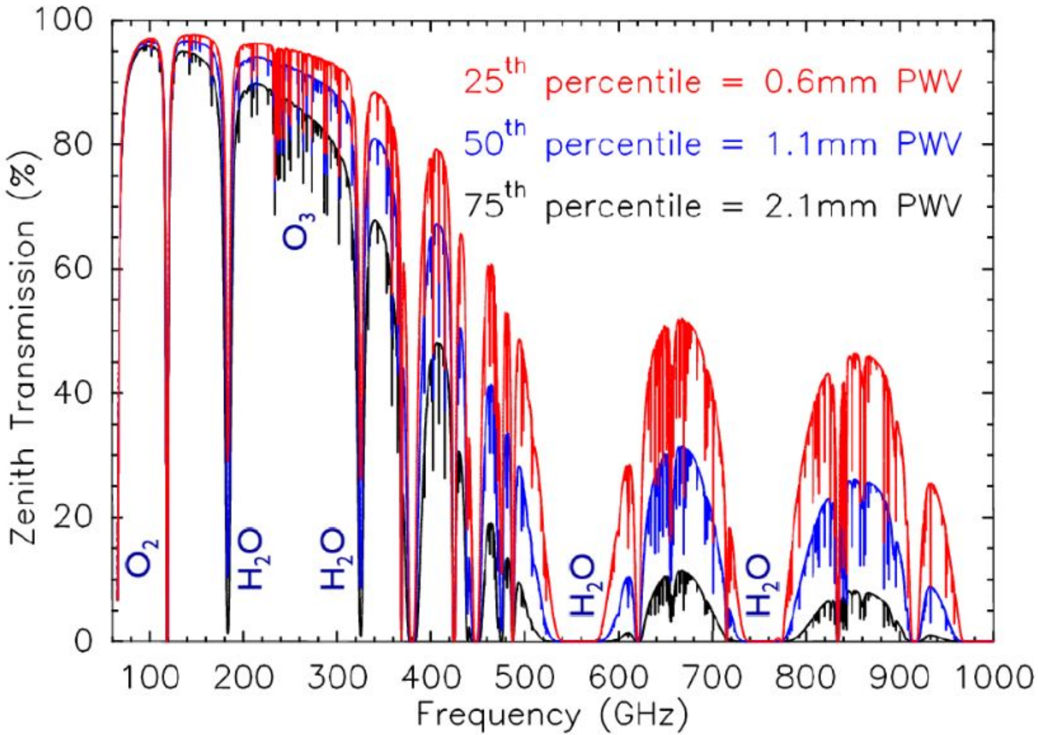
but it would be @ ALMA bands in the VLA site

Troposphere



At the ALMA site
the chances to observe at
Band 10 increase!

Troposphere



The transmission curve changes with Precipitable Water Vapor content in the atmosphere!

Troposphere's double effect

- attenuation

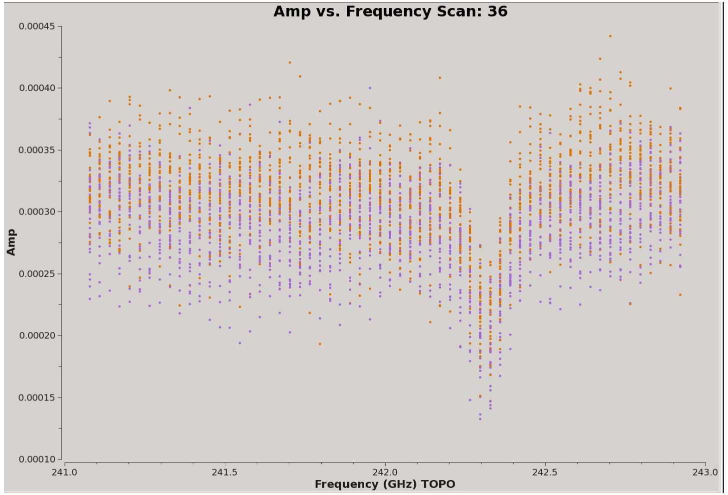
Effective system noise temperature

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

opacity

emission from atmosphere

Tsys factors below atmosphere



Troposphere's double effect

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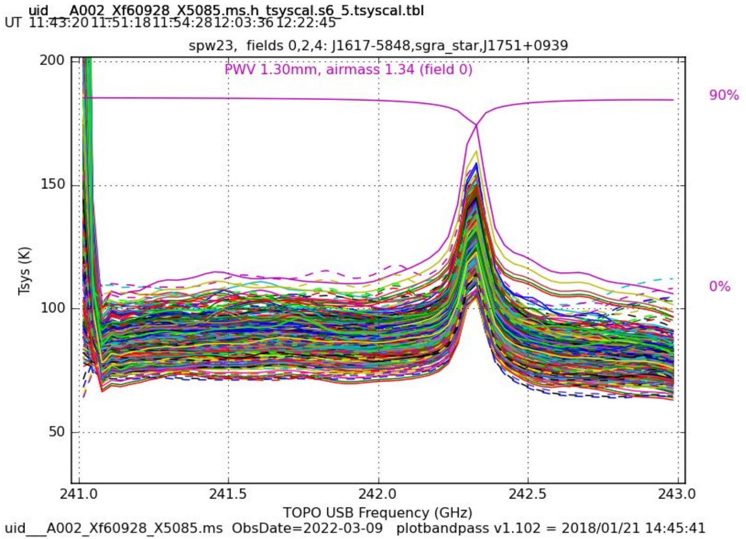

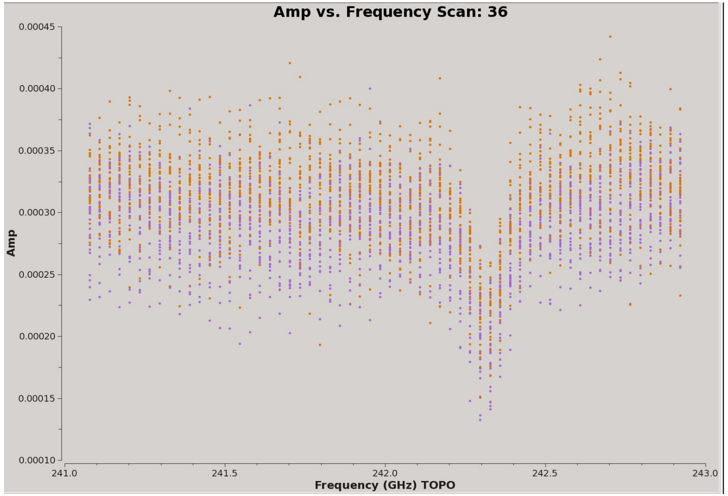

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Effective system noise temperature

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opacity

emission from atmosphere

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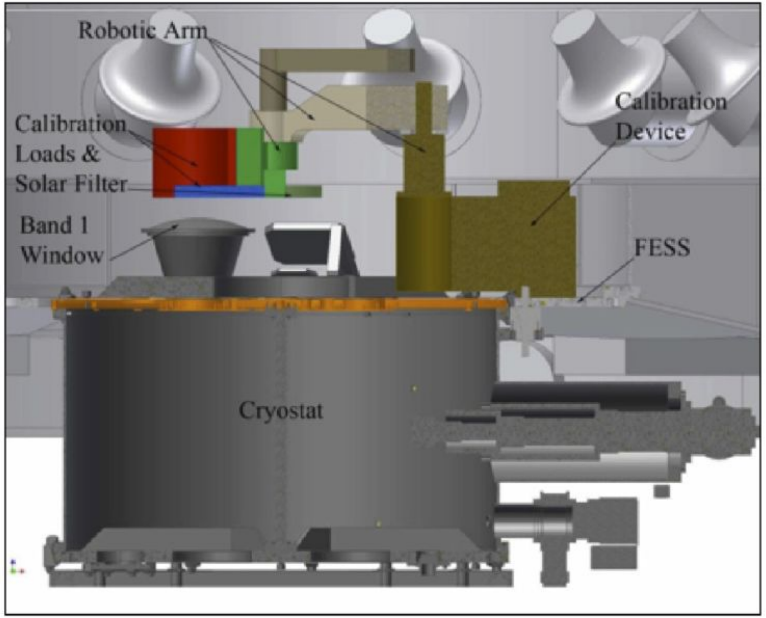
—> Amplitude Calibration Device



Measure T_{sys} and T_{rx} for each antenna

Troposphere's double effect

- attenuation

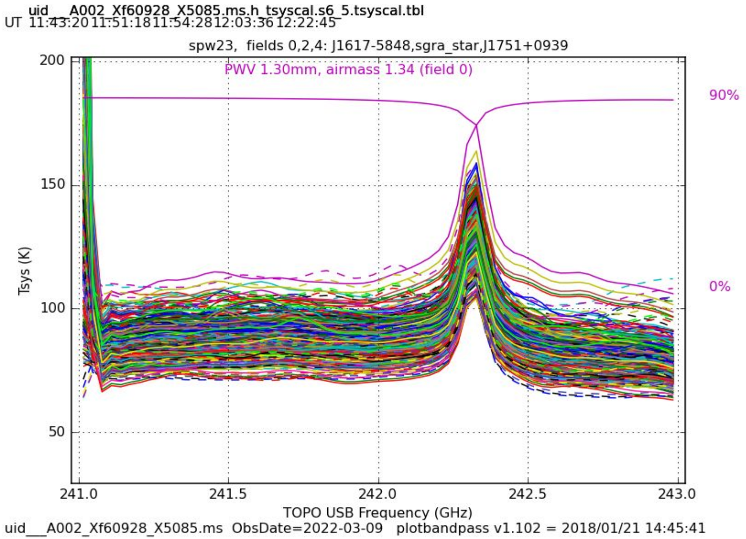
Effective system noise temperature

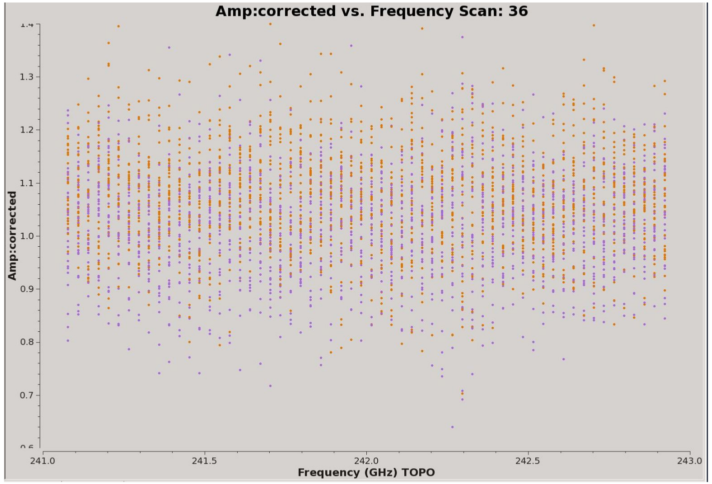
$$T_{sys} \sim e^{\tau} \, [T_{atm} \, (1- e^{-\tau}) + T_{rx} \,]$$

opacity

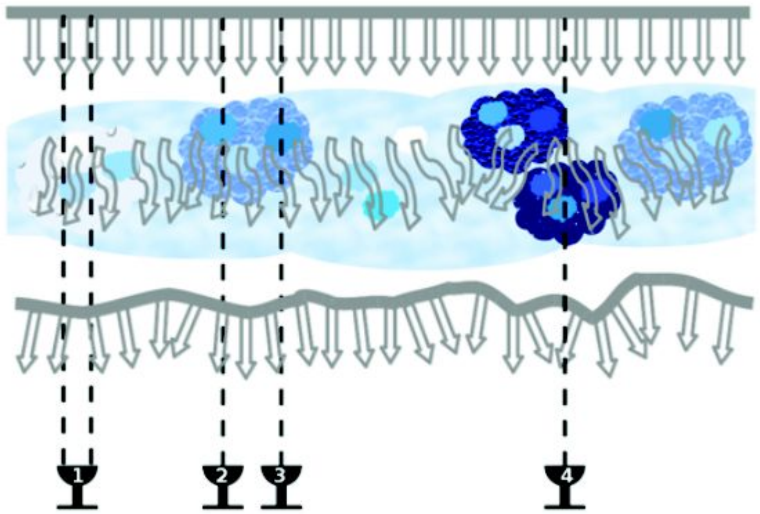
emission from atmosphere

Tsys factors below atmosphere





Troposphere's double effect



- **phase noise**

PWV variations cause phase fluctuations resulting in:

- phase shift

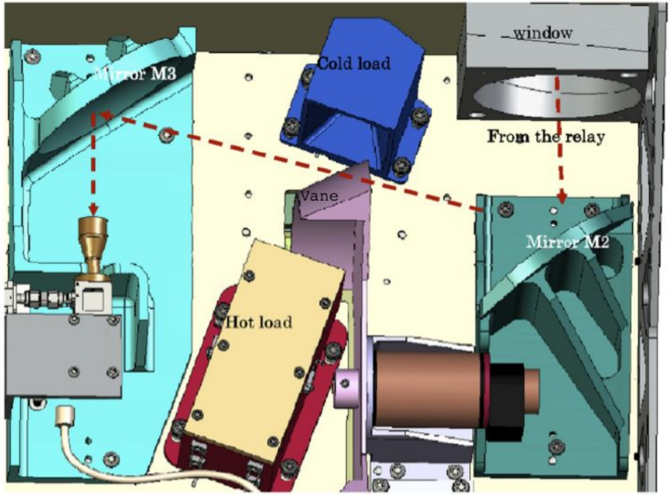
$$\varphi_e \approx \frac{12.6\,\pi}{\lambda} \cdot pwv$$

- low coherence

$$\varphi_{rms} = \frac{K\,b^{\alpha}}{\lambda}$$

Troposphere's double effect

water vapor radiometer



Only on 12m antennas
Allow to measure pwv

- **phase noise**

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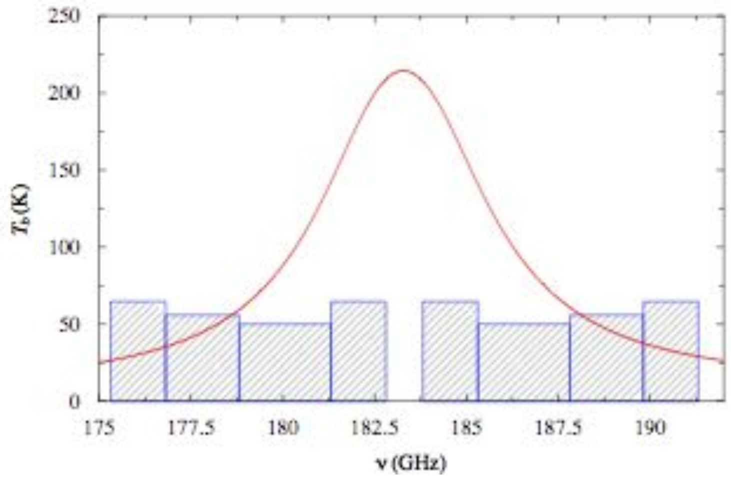
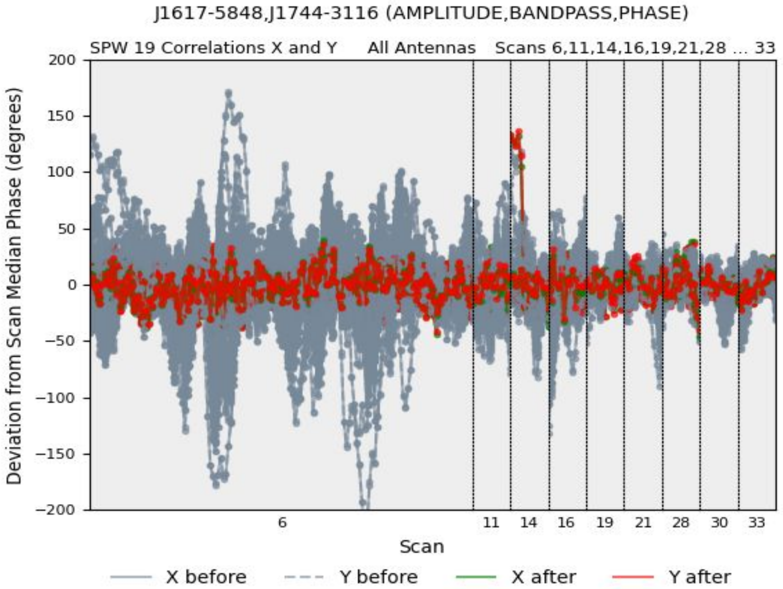
$$\varphi_{rms} = \frac{K\, b^{\alpha}}{\lambda}$$

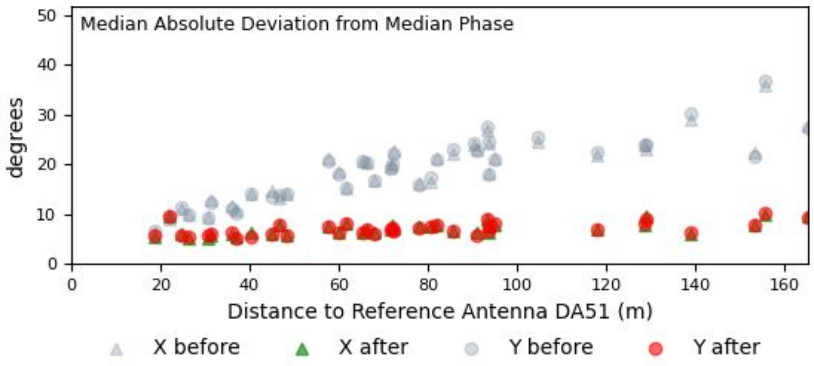
Troposphere's effects corrections

- wvr radiometer



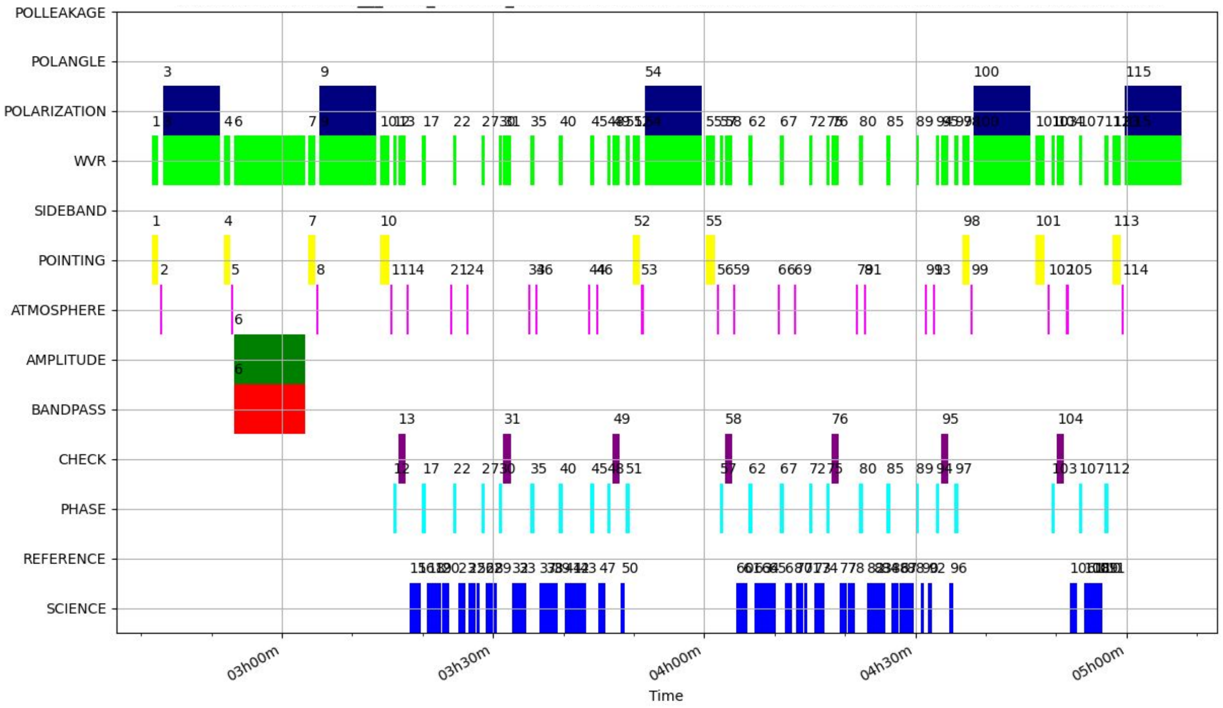


Four "channels" flanking the peak of the 183 GHz water line



Data taken every second

Typical execution structure



factors determined observing a calibration source

Polarization

Amplitude

Bandpass

Check

Phase

Basic assumptions of calibration

$$V^{ij}_{obs}(\nu,t) = G^{ij}(\nu,t) \quad V^{ij}_{true}(\nu,t)$$

- The complex gains $G^{ij}(\nu,t)$ can be approximated by the product of the two associated antenna-based complex gains

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- Visibilities and gains are complex numbers so we need to determine **amplitudes a** and **phases θ** of gains

$$A_{ij}^{obs} e^{i\phi_{ij}^{obs}} = A_{ij}^{true} a_i a_j e^{i(\phi_{ij}^{true} + \theta_i - \theta_j)}$$

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$$A_{ij}^{obs} e^{i\,\phi_{ij}^{obs}} = A_{ij}^{true}\, a_i\, a_j\, e^{i(\phi_{ij}^{true}+\theta_i-\theta_j)}$$

- The frequency and time dependence of the gains are independent of each other

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

How calibration works

- To solve this equation we observe sources for which we know the true visibilities **amplitudes A_{model}** and **phases θ_{model}**

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

- Observing a point source at the phase center

$$\theta_{model} = 0$$

- Consider a normalized amplitude

$$A_{model} = 1$$

Calibrators – The ALMA observatory selects the most appropriate for each project

Amplitude

Target with known flux density
Anywhere in the sky. (Solar System objects in the past, now grid sources)
One scan only, typically at the beginning of observations

Bandpass

Bright object (typically quasar) with no spectral features
Within ~30 deg of the science target
One scan only, typically at the beginning of observations

Phase

Close to the target in the sky.
Within few deg of the target (<5 deg in Band7 — <3 deg in Ban 10)
observed before and after the target (**cycling time depends on freq and baseline length)**

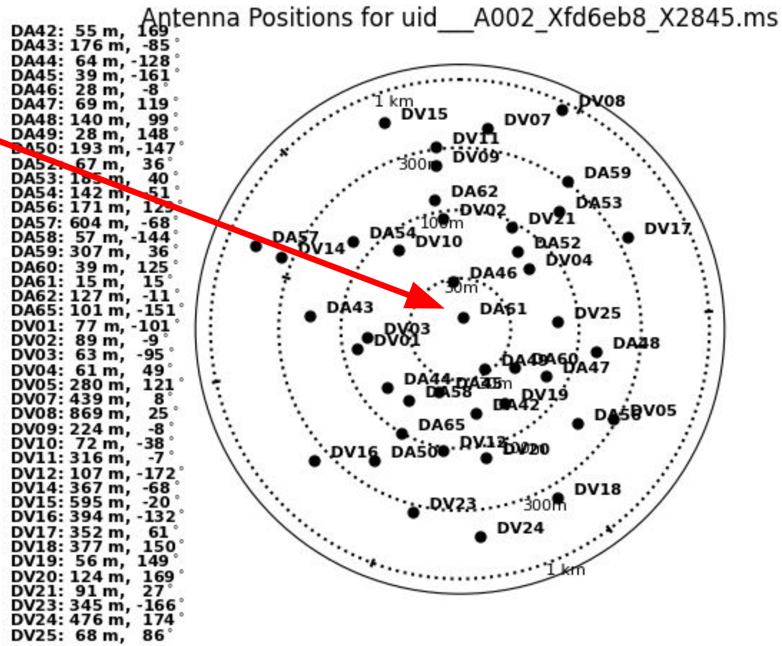
Check

For observations with angular resolution < 0.25" or freq > 400 GHz
Bright source, at a similar distance from the phase calibrator as the target.
Observed two or three times per EB.

Reference antenna

- No absolute phases are measured but differences between the phases of antennas in a baseline
- A reference antenna need to be chosen. It will have by definition **phase zero at all times**

It must be chosen
at the center of the array



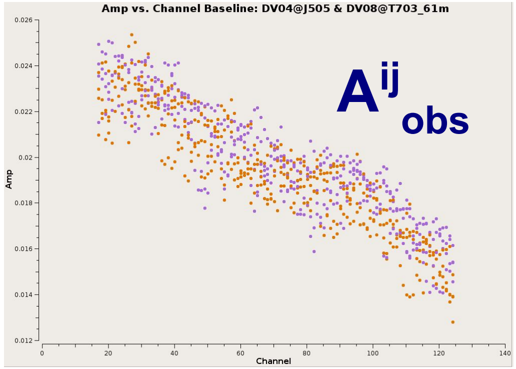
Bandpass calibration

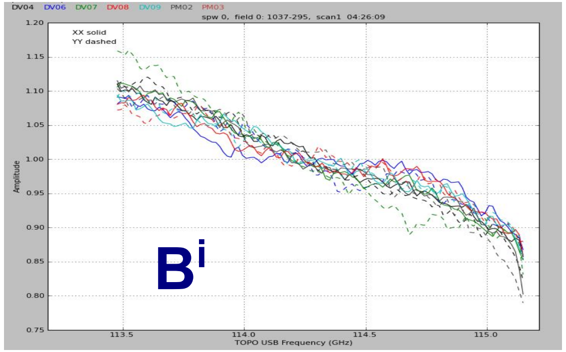
$$A_{mod}(\nu) = 1 \quad \text{and} \quad \theta_{mod}(\nu) = 0$$

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

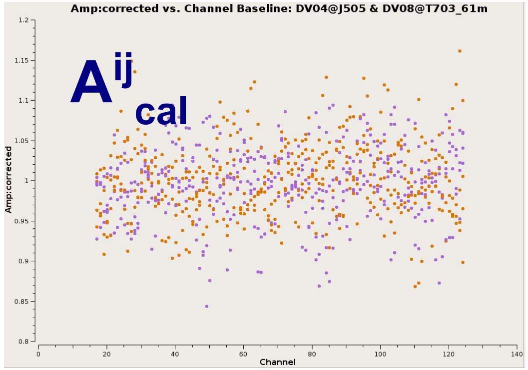
$$A^{ij}_{cal} = \frac{A^{ij}_{obs}}{B^i \, B^j}$$

amplitude





frequency



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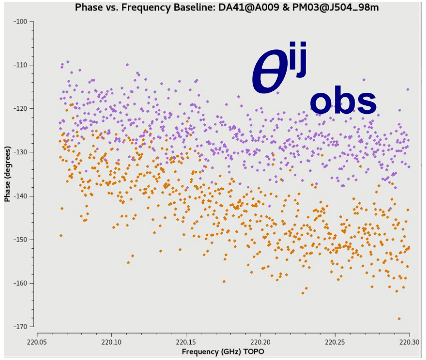
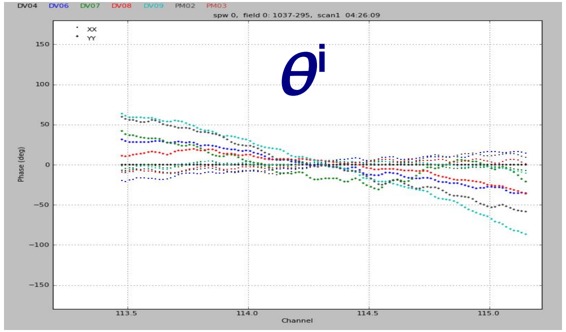
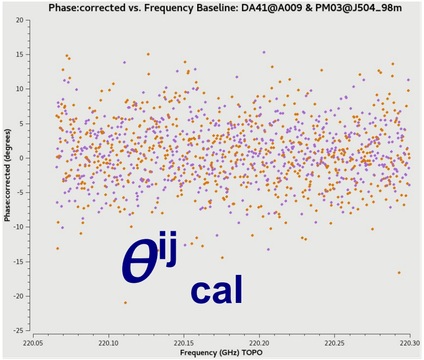


$$\theta^{ij}_{obs} = \theta^{i} + \theta^{j} + \theta^{ij}_{mod}$$

$$\theta^{ij}_{cal} = -\theta^{i} - \theta^{j} + \theta^{ij}_{obs}$$

phase

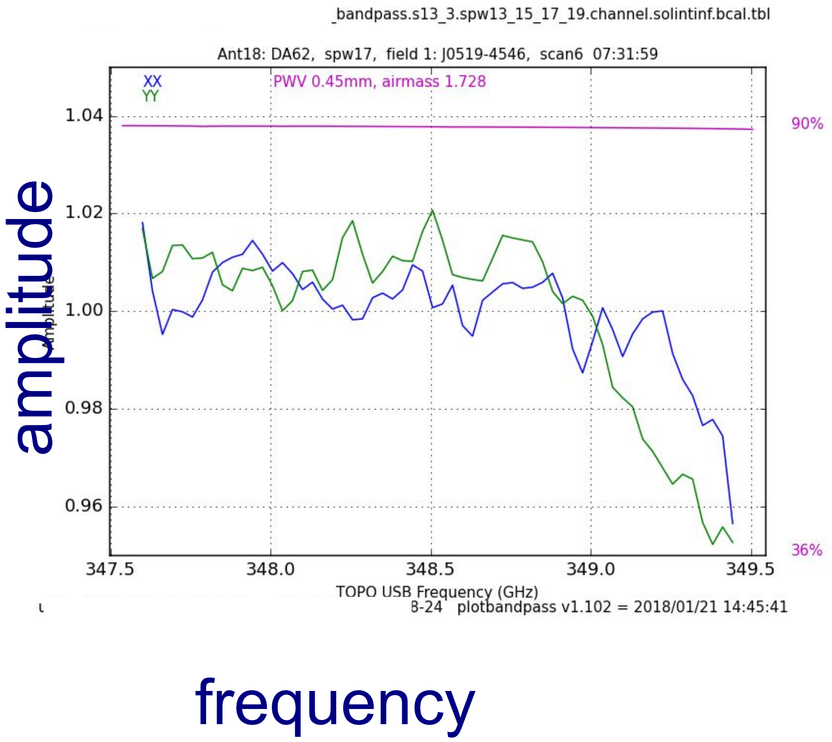


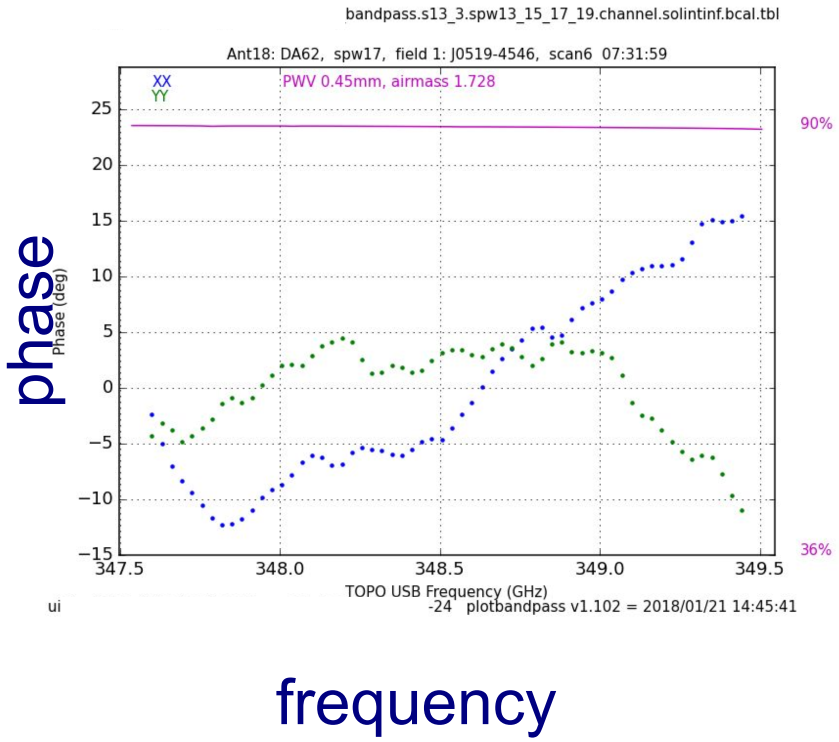


frequency

Bandpass calibration

- In the weblog you can see the gains for each antenna and each spw





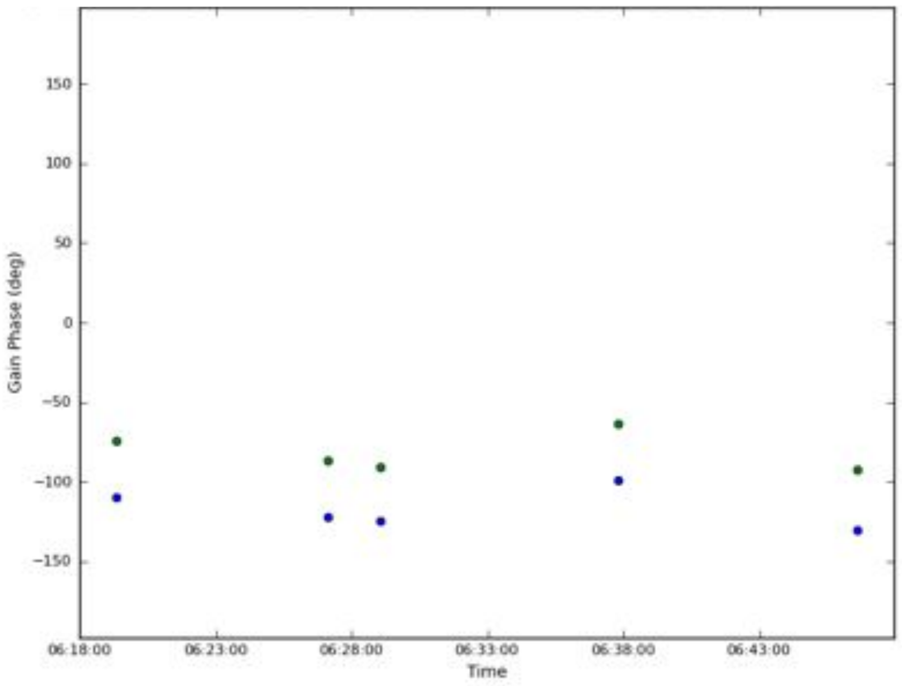
Time-dependent gain calibration

- Observed regularly before and after target scans

As for the bandpass
The calibrator is observed
at the **phase center**

$\mathbf{A_{mod}(t) = 1}$ **and** $\boldsymbol{\theta_{mod}(t) = 0}$

We can determine **for each scan** on the calibrator the amplitude correction J^i_A and the phase correction J^i_θ

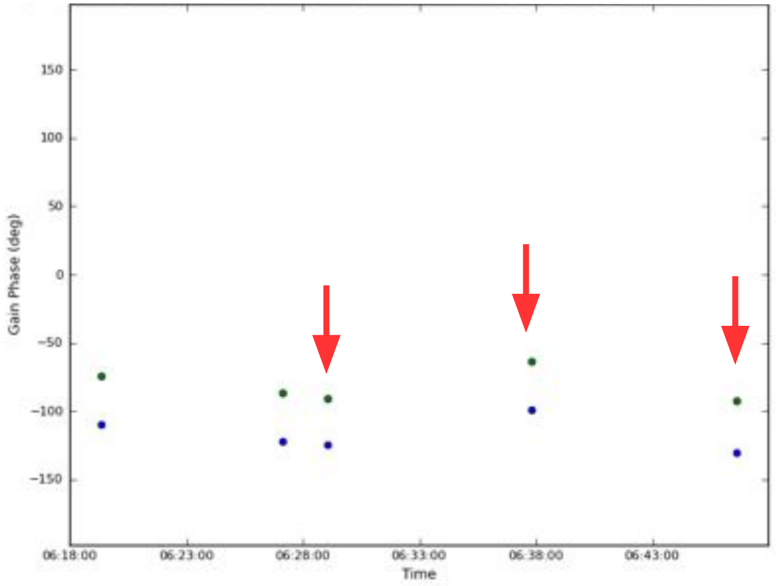


Time-dependent gain calibration

- Calibrator observed regularly before and after target scans

- **Coherence time**

is the time between each phase calibrator's observation.
Shorter at higher freq
and longer baselines

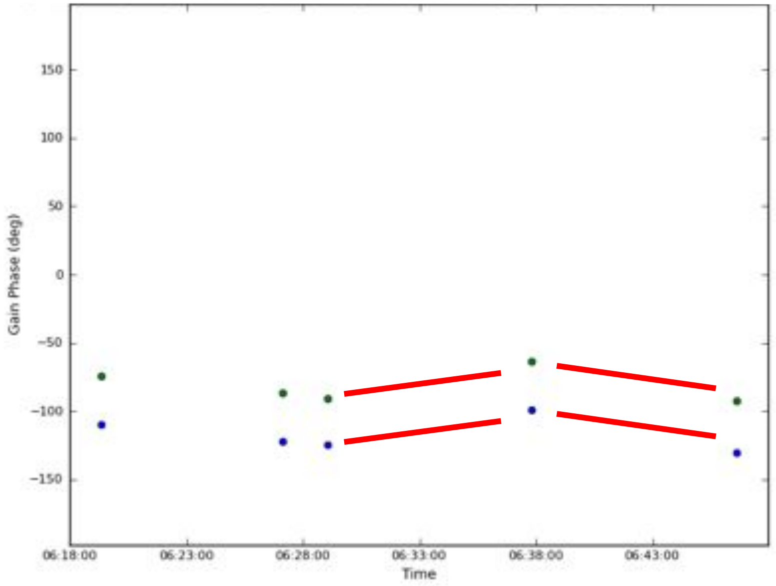


Time-dependent gain calibration

- Calibrator observed regularly before and after target scans

- **Coherence time**
is the time between each phase calibrator's observation.
Shorter at higher freq
and longer baselines

- Solutions J^i_A and J^i_θ
are applied to all the visibilities of the target using a **linear interpolation**



Time-dependent gain calibration

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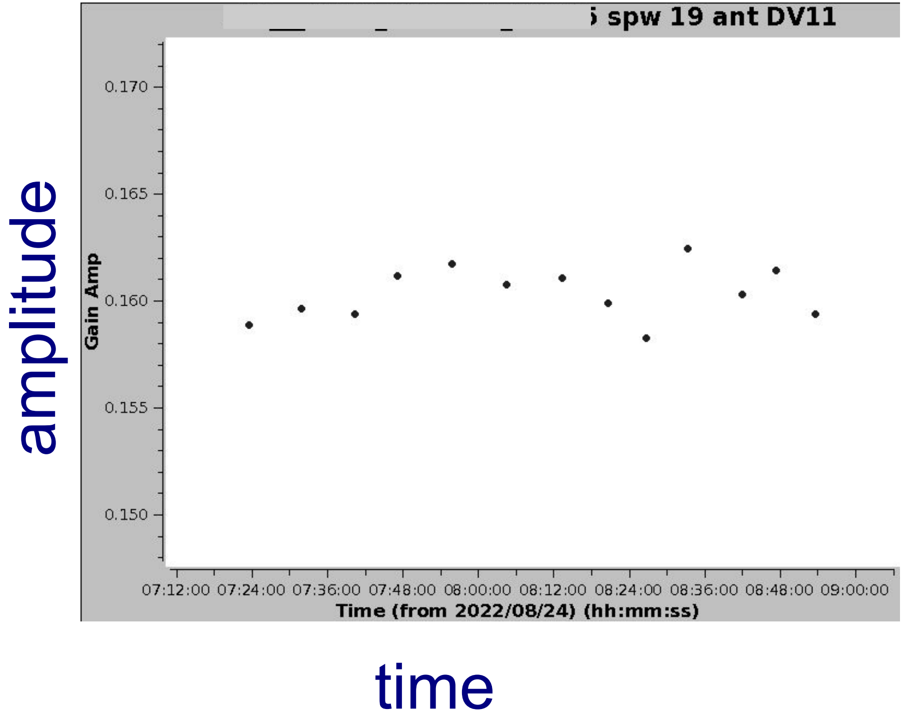
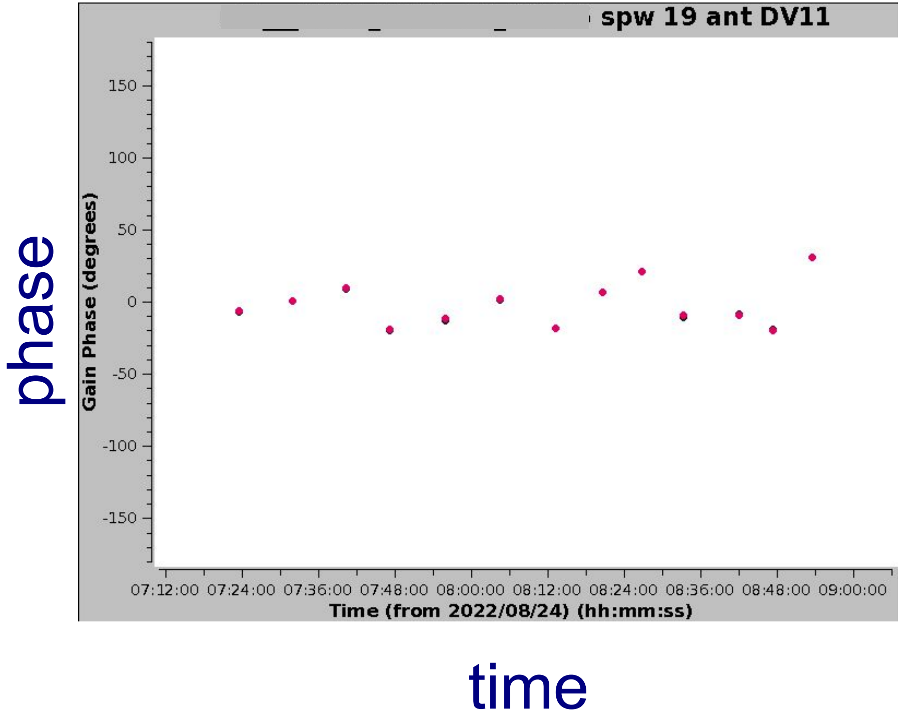
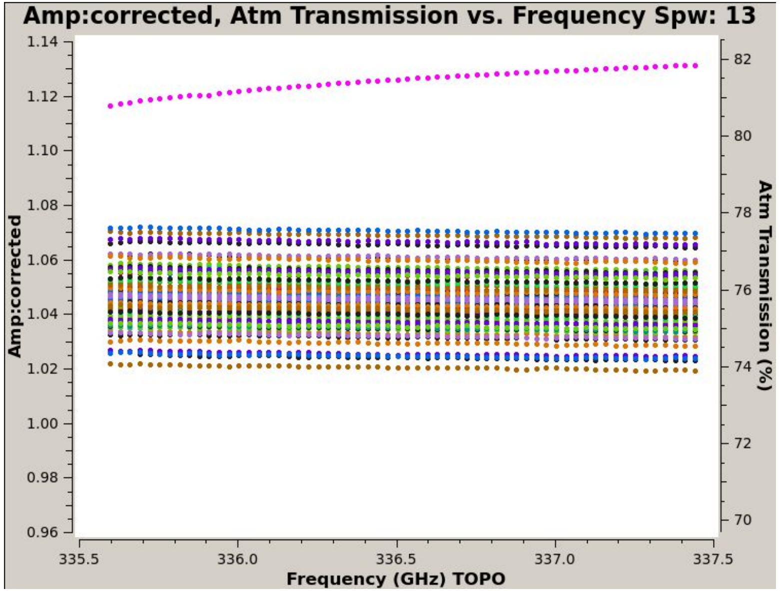




Bandpass and Time-dependent gain applied

- In the weblog you can see the calibrated visibilities for each calibrator for each spw

amplitude



frequency

for all calibrators (in particular the bandpass calibrator) should be **flat**

Bandpass and Time-dependent gain applied

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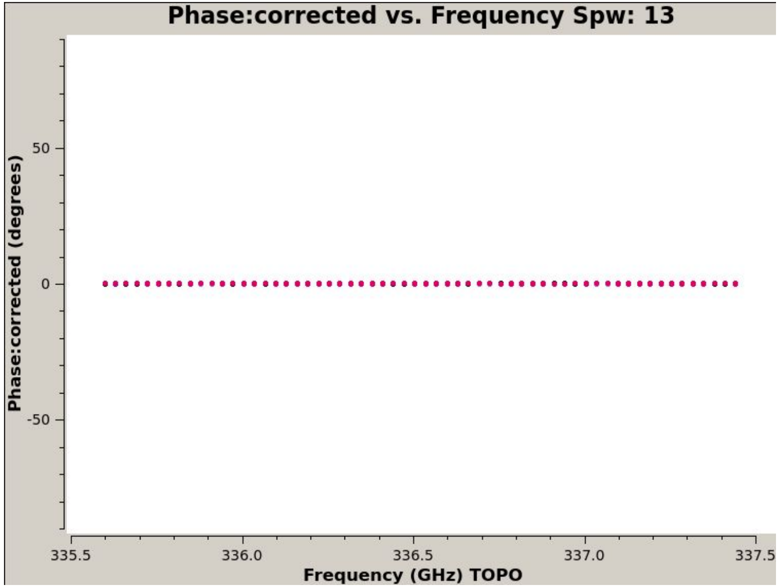
phase



frequency

for all calibrators should be **zero**

Bandpass and Time-dependent gain applied

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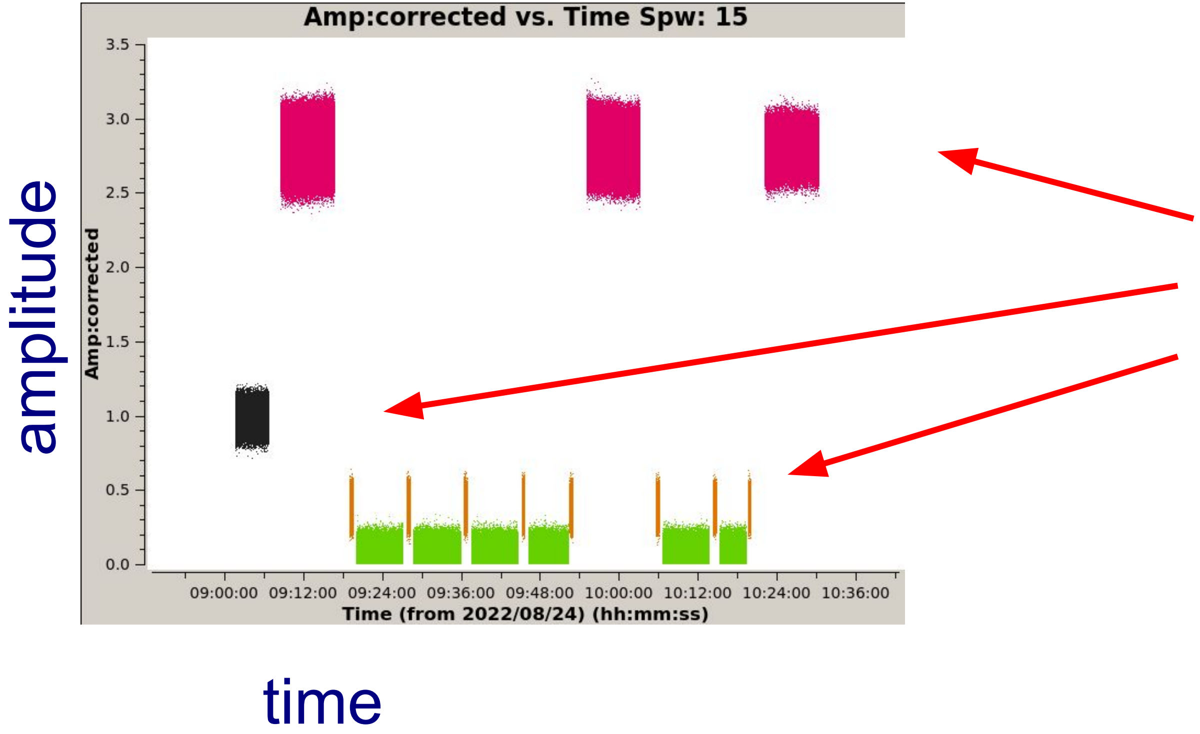

for all calibrators should be **flat**

Bandpass and Time-dependent gains applied

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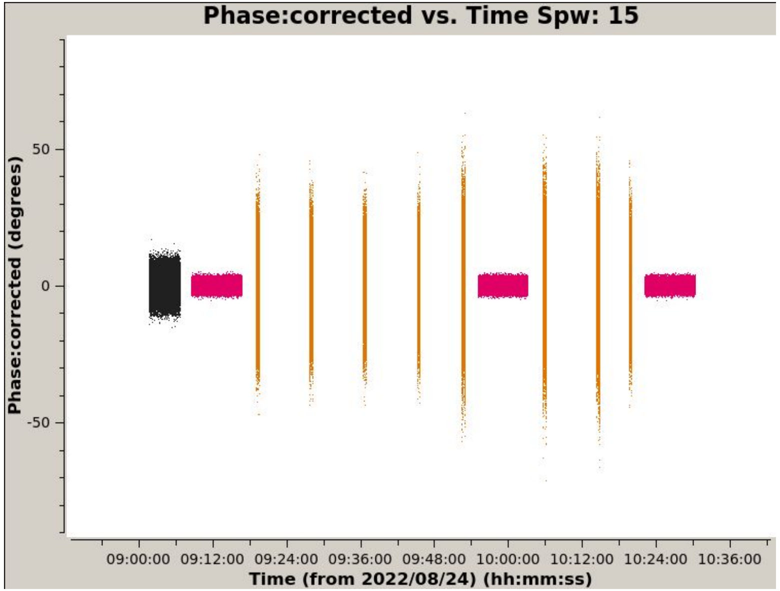
phase



time

for all calibrators should be around **zero**

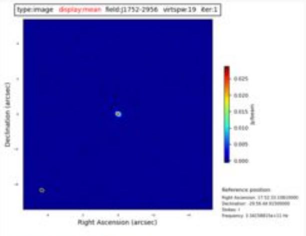
the scatter (< few tens of deg) depends also on the calibrator's brightness

CHECK source

- If a check source is observed in the weblog you find images per spw

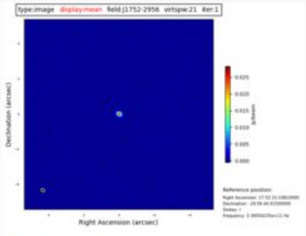
J1752-2956 (CHECK)

19 / X772369088#ALMA_RB_07#BB_1#SW-01



View other QA images...

21 / X772369088#ALMA_RB_07#BB_2#SW-01



View other QA images...

- and fluxes

Field	Virtual SPW	Bandwidth (GHz)	Position offset (mas)	Position offset (synth beam)	Fitted Flux Density (mJy)	Image S/N	Fitted [Peak Intensity / Flux Density] Ratio	gfluxscale mean visibility	gfluxscale S/N	[Fitted / gfluxscale] Flux Density Ratio
J1752-2956	19	1.875	5.73 +/- 0.54	0.03 +/- 0.003	30 +/- 0	234.88	0.97	30.68 +/- 0.17	175.88	0.96
	21	1.875	5.95 +/- 0.52	0.03 +/- 0.003	29 +/- 0	247.87	0.97	30.08 +/- 0.16	191.36	0.97
	23	1.875	4.83 +/- 0.50	0.03 +/- 0.003	29 +/- 0	246.38	0.98	30.09 +/- 0.17	182.25	0.96
	25	1.875	5.37 +/- 0.58	0.03 +/- 0.003	29 +/- 0	216.20	0.96	29.86 +/- 0.19	155.86	0.96

fitted flux density **visibility flux density**

Standard calibration limitations

- Time-dependent gains applied to the target are estimated on the “phase” calibrator observed in
  ≠ position
  ≠ times

  Based on the assumption that atmospheric conditions change linearly in time. **Reasonable but not always true!**

- **Self-calibration may be necessary to improve calibration and image fidelity**

- **For time dependent projects the calibration intervals must be carefully considered**

Where to find the calibration's diagnostic plots

auxiliary

qa

Group OUS uid://A001/X15c6/Xb9			
Member OUS uid://A001/X15c6/Xba	2022-08-08		
SB GLASS-z1_c_06_TM1			
☑	readme	member.uid___A001_X15c6_Xba.README.txt	
☑	product	2021.A.00020.S_uid___A001_X15c6_Xba_001_of_001.tar	
	auxiliary	2021.A.00020.S_uid___A001_X15c6_Xba_auxiliary.tar	
☐	calibration	member.uid___A001_X15c6_Xba.hifa_calimage_renorm.auxproducts.tgz	
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☐	script	member.uid___A001_X15c6_Xba.hifa_calimage_renorm.pipeline_manifest.xml	
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☐	script	member.uid___A001_X15c6_Xba.scriptForPI.py	
☐	log	member.uid___A001_X15c6_Xba.hifa_calimage_renorm.casa_commands.log	
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☐	qa	uid___A002_Xfc69ac_X23ed.qa0_report.pdf	
☐	raw	2021.A.00020.S_uid___A002_Xfc69ac_X1af2.asdm.sdm.tar	

member.uid__bla_bla_bla.**weblog.tgz**

Where to find the calibration’s diagnostic plots

member.uid__bla_bla_bla.**weblog.tgz —> index.html**

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By Task

Task Summaries

Task		QA Score
1. **hifa_importdata**: Register measurement sets with the pipeline		1.00
2. **hifa_flagdata**: ALMA deterministic flagging		0.94
3. **hifa_fluxcalflag**: Flag spectral features in solar system flux calibrators		1.00
4. **hif_rawflagchans**: Flag channels in raw data		1.00
5. **hif_refant**: Select reference antennas		1.00
6. **h_tsyscal**: Calculate Tsys calibration		1.00
7. **hifa_tsysflag**: Flag Tsys calibration		0.98
8. **hifa_antpos**: Correct for antenna position offsets		1.00
9. **hifa_wvrgcalflag**: Calculate and flag WVR calibration	1.11x improvement	0.56
10. **hif_lowgainflag**: Flag antennas with low gain		1.00
11. **hif_setmodels**: Set calibrator model visibilities		1.00
12. **hifa_bandpassflag**: Phase-up bandpass calibration and flagging		0.98
13. **hifa_bandpass**: Phase-up bandpass calibration		1.00
14. **hifa_spwphaseup**: Spw phase offsets calibration		1.00
15. **hifa_gfluxscaleflag**: Phased-up flux scale calibration + flagging		0.99
16. **hifa_polcalflag**: Polcal outlier flagging		1.00

bandpass

Why

Is calibration needed?

Calibration is needed to correct observed visibilities for the electronic and atmospheric effects

What

are the main assumptions and limitations?

- corruptions in time and frequency are independent from each other
- gains are **antenna NOT baseline** - dependent
- atmospheric corruptions estimated using the phase calibrator change linearly in time

How

is calibration done?

- Atmospheric frequency-dependent and short time-dependent corruptions are calibrated a priori
- Calibrators are observed to determine electronic and bandpass gains

Where

are calibration results?

Calibration results are collected in the weblog attached to each dataset