The University of Manchester

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Introduction to Calibration:

General Calibration

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RadioNet

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A reminder of the measurement equation

$$V_{ij} = M_{ij}B_{ij}G_{ij}D_{ij}\int E_{ij}P_{ij}T_{ij}F_{ij}SI_{\nu}(l,m)\,e^{-i2\pi(u_{ij}l+v_{ij}m)}\frac{\mathrm{d}l\mathrm{d}m}{\sqrt{1-l^2-m^2}} + Q_{ij}$$

V_{ij} = What we measure
I_{ν} = What we want
Q_{ij} = additive baseline errors
S = maps I to polarisation
i,j = telescope pair
M_{ij} = Multiplicative baselines errors
B_{ij} = Bandpass reponse
G_{ij} = Gerenalised electronic gain
D_{ij} = polarisation leakage
E_{ij} = Antenna voltage pattern
P_{ij} = paralatic angle
T_{ij} =Tropospheric effects

Green= vectors
Blue= Scalars
Red= Part of the Jones Matrix

Slide cribbed from A.M.S.Richards

A reminder of the measurement equation

$$V_{ij} = M_{ij} B_{ij} G_{ij} D_{ij} \int E_{ij} P_{ij} T_{ij} F_{ij} S I_\nu(l,m)\, e^{-i2\pi(u_{ij} l + v_{ij} m)} \frac{\mathrm{d}l\mathrm{d}m}{\sqrt{1 - l^2 - m^2}} + Q_{ij}$$

What we have

What we want

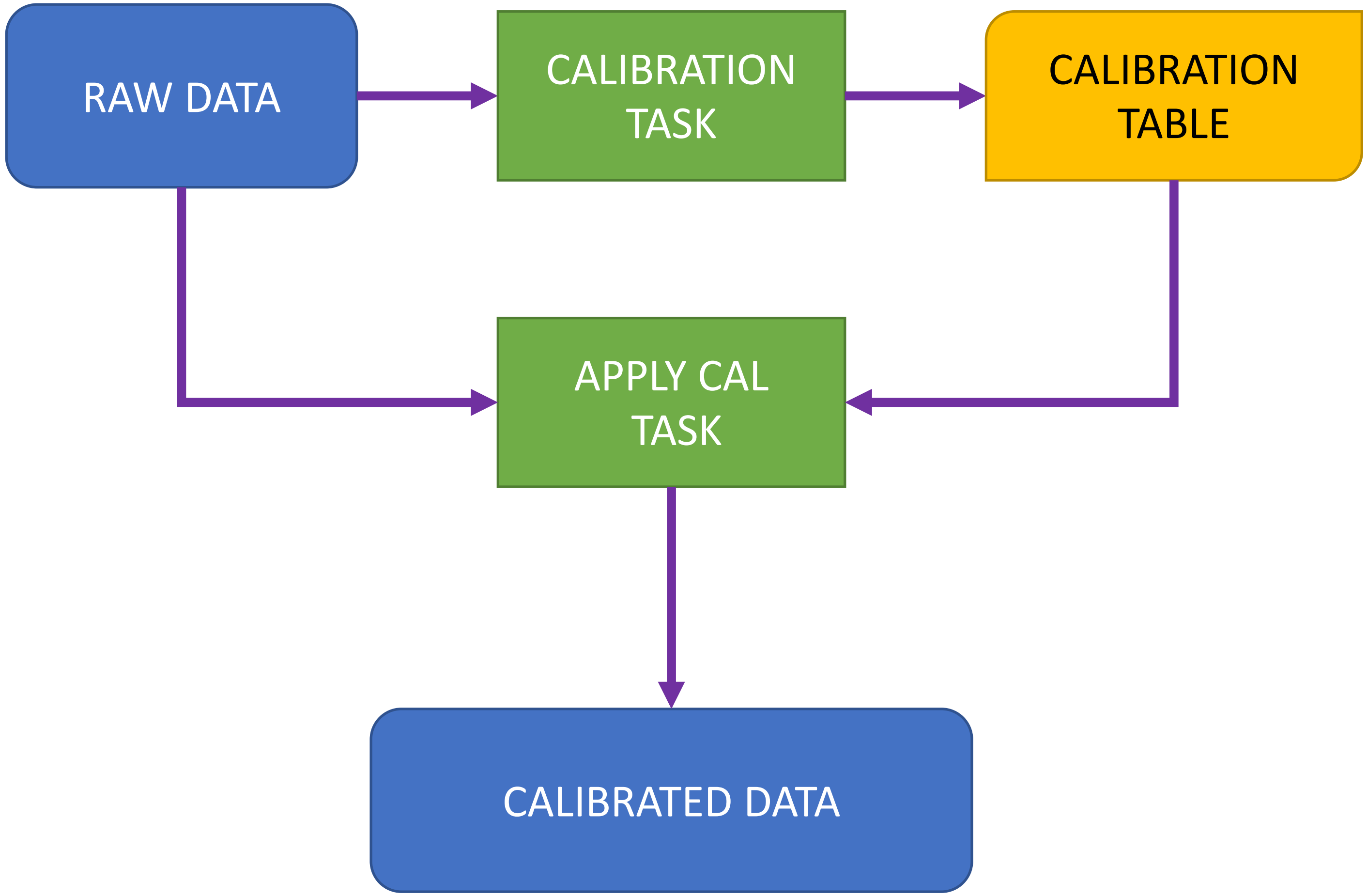
Outline

- Calibration workflow
- Useful Calibrator properties
- Flux Scaling
- Bandpass Calibration
- Phase/amplitude Calibration

Workflow

Typically calibration follows a simple workflow

1. You have raw data
2. You calibrate to an expected behaviour/model, generating a calibration table of solutions
3. Inspect solutions
4. Apply calibration table when you're happy

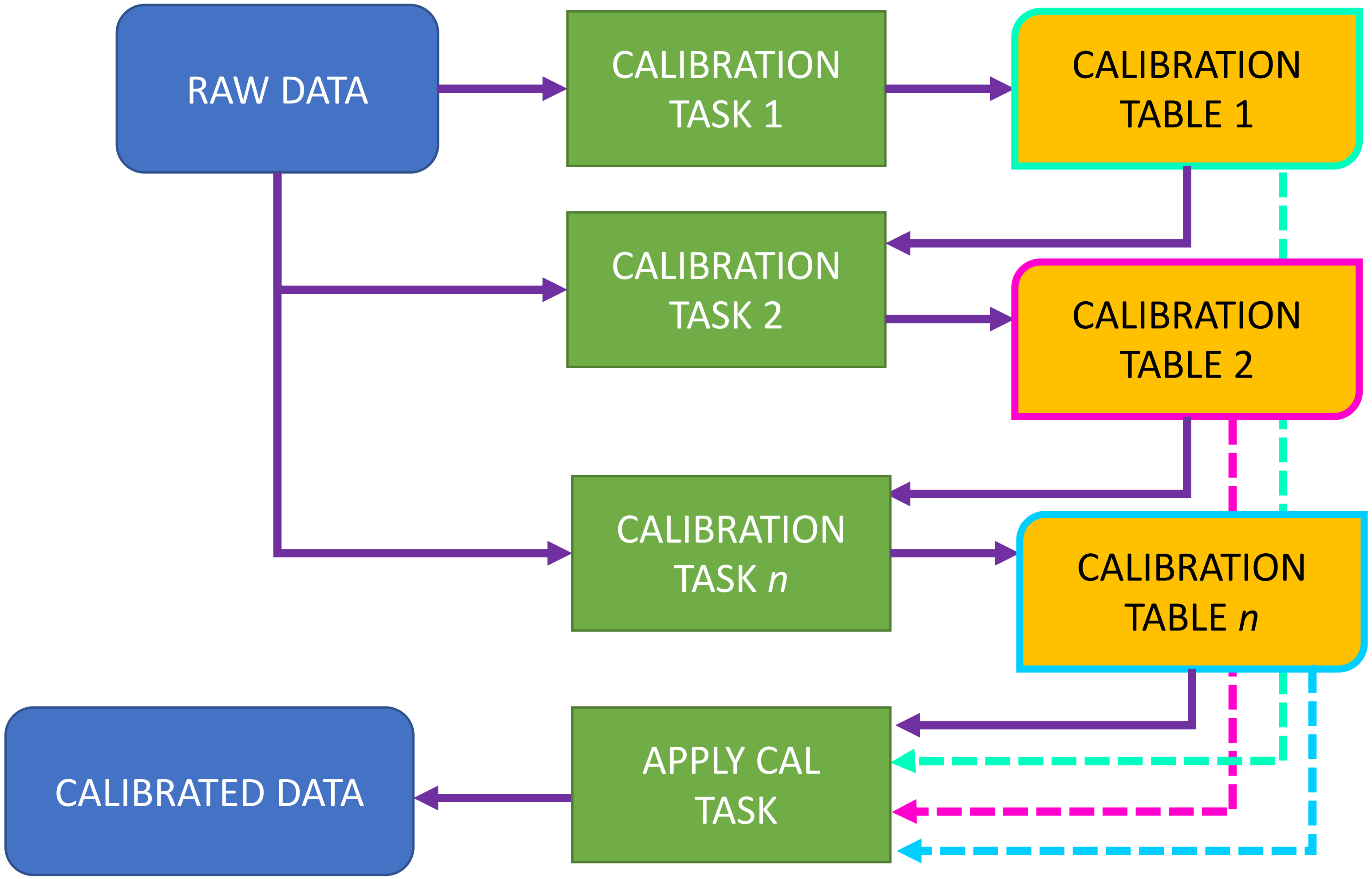


Workflow

Sometimes however it is more efficient to utilise 'on-the-fly' calibration to aide with later calibration steps.

This type of approach will be encountered during this workshops tutorials.

In this talk I'll be showing only the 'Raw' and 'Calibrated' data, you'll see the calibration tables during the tutorials.

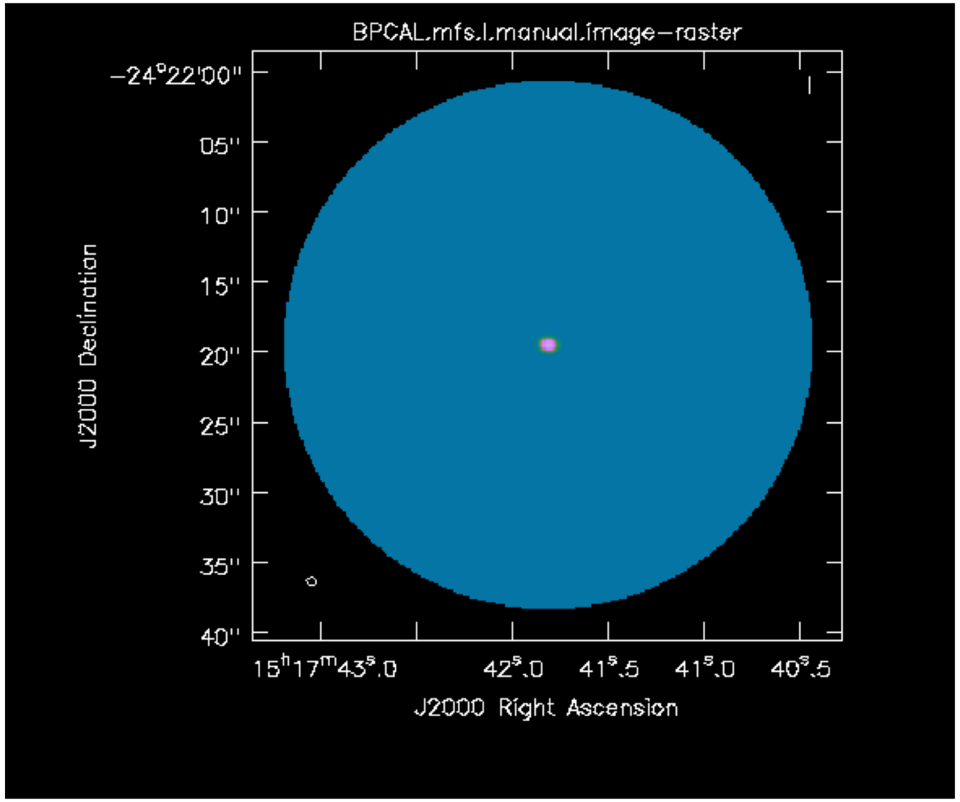


Useful calibrator properties

- Typically at least 3 calibration source are used per interferometric observation.

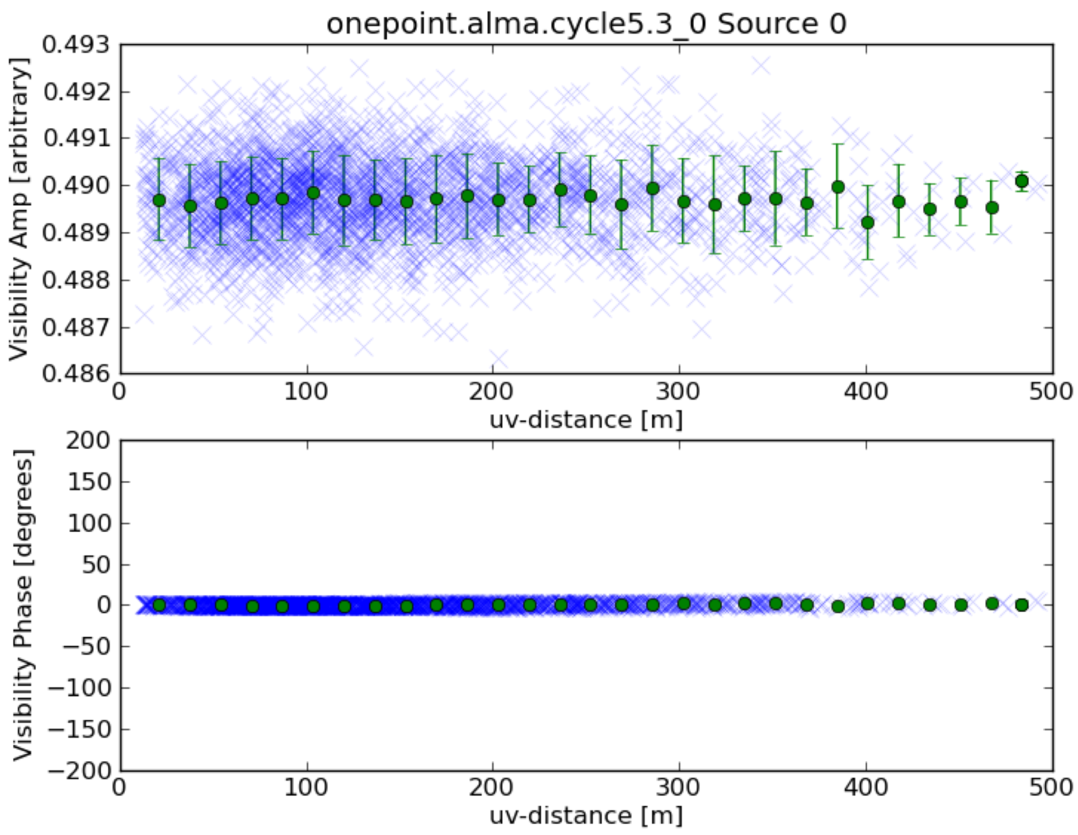
- A flux calibrator (S cal).
- A bandpass calibrator (BP cal).
- A phase calibrator (ϕ cal).

- In the simplest case each of these sources is chosen to be a *point like, bright quasar*.



Useful calibrator properties

- Point sources have the following properties:
  - Unresolved on ALL baselines, meaning their amplitude/flux density is the same on all baselines.
  - ALL the sky brightness comes from a single point, so the phases are flat/zero as a function of baseline & time.
  - Quasars have known spectral indices and few/no line emission at radio/sub-mm frequencies.
- Deviations from this allow us to calibrate out various instrumental/environmental effects.
- We choose *bright* sources so that we can achieve high SNR in a small integration time.



When your calibrator isn’t point like

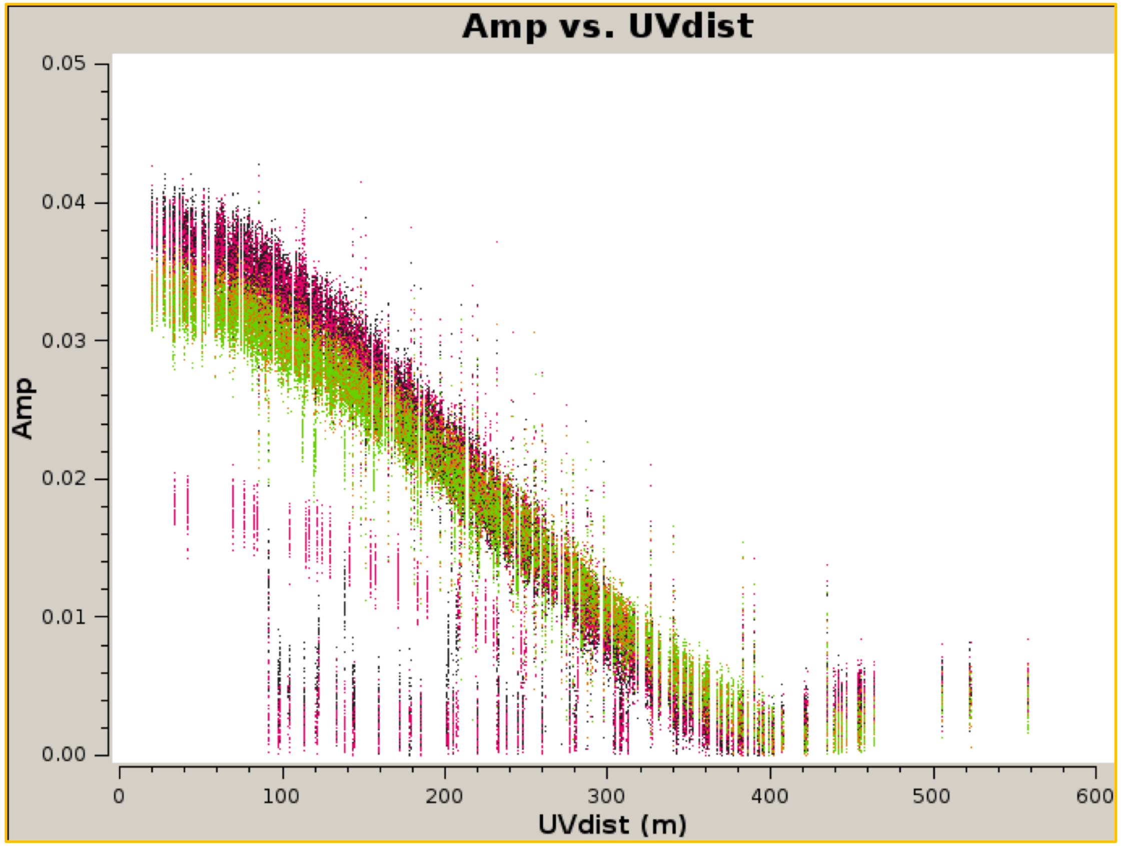
- Applicable only to flux calibration, (unless you want to make you’re life really difficult).

- ALMA often uses planets, moons and other minor Solar system bodies as flux cals. Some quasars have e.g. jets but are used by the VLA.

- We can flux calibrate using a model of the target as a function of baseline length.

Flux scaling

- The visibility amplitudes which come out of the correlator are have an arbitrary scaling.
- To convert these into physically meaningful value we observe a source of known flux to which we can “bootstrap” the amplitudes values to.
- Calibrator needn’t be close to the source. (But should avoid being low in the sky).



ALMA data of Titan for a given dataset *(some bad data here!)*.

Y-axis scale in correlator output units

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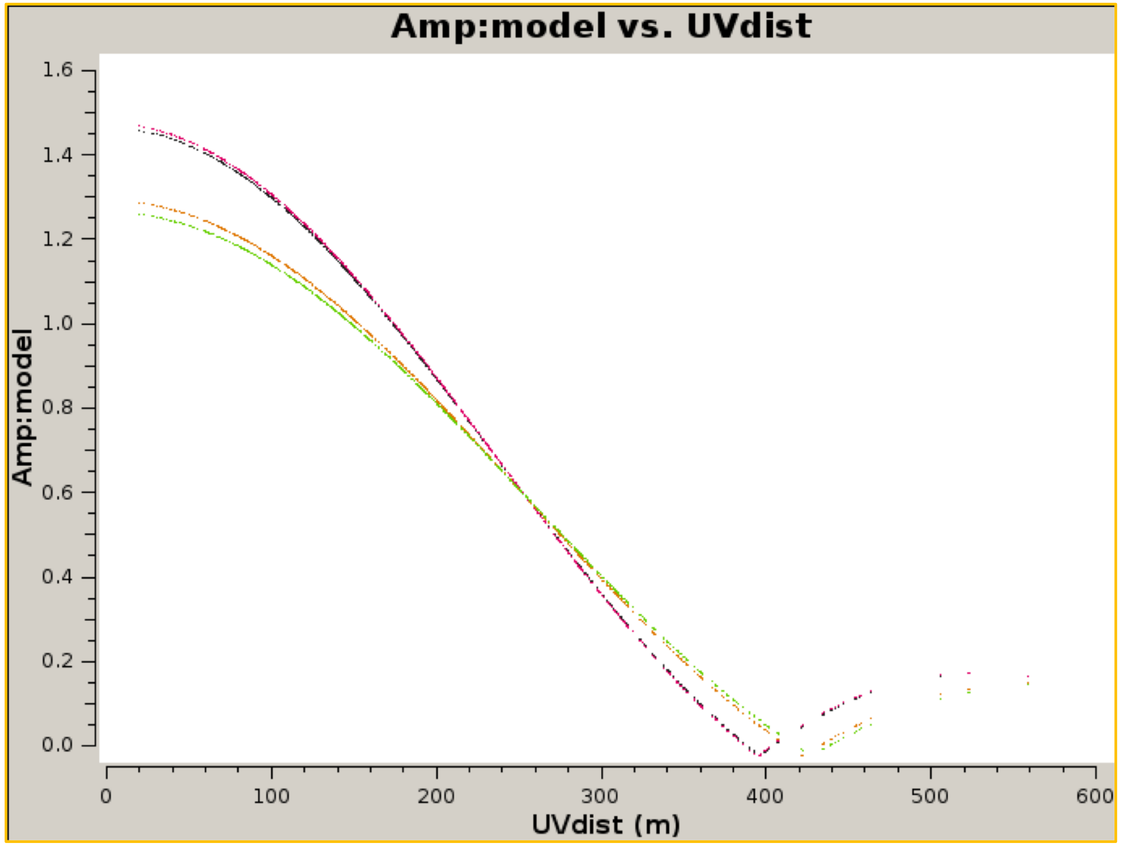
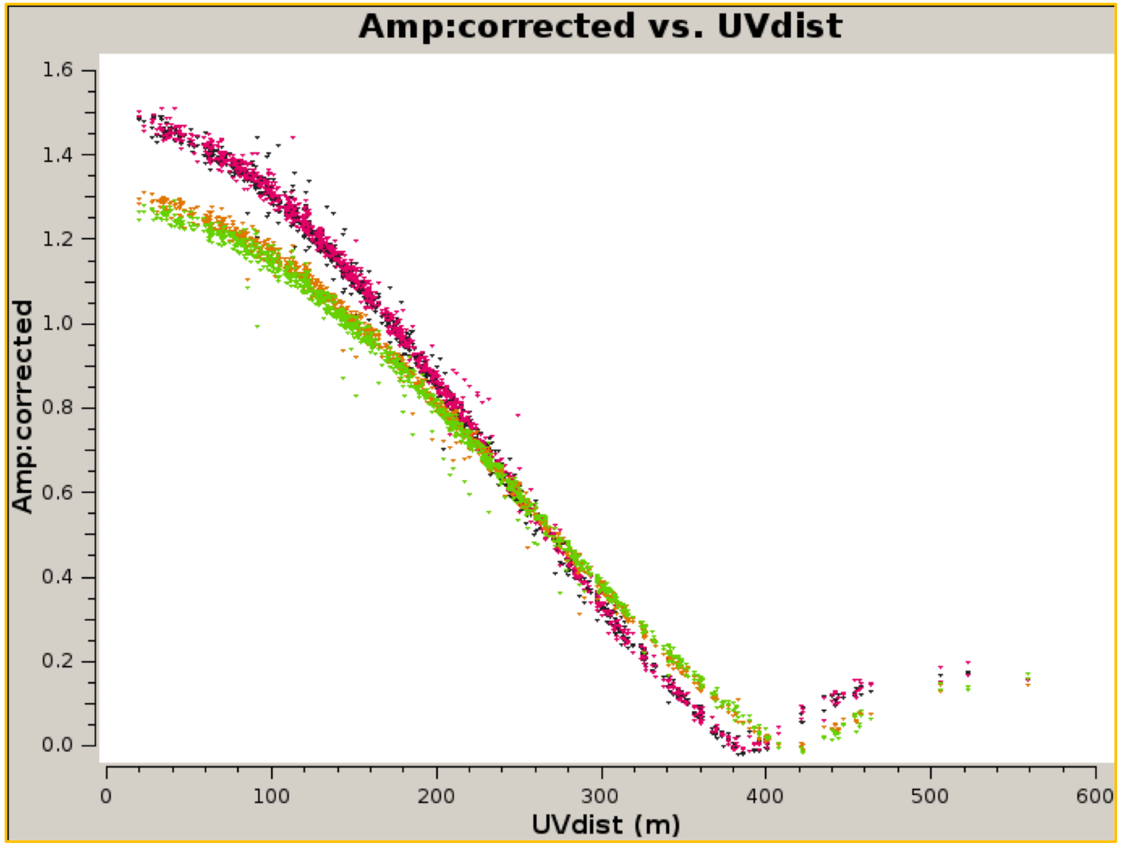


CASA model of Titan for a given dataset
(Notice the y-axis scale)

Flux scaling

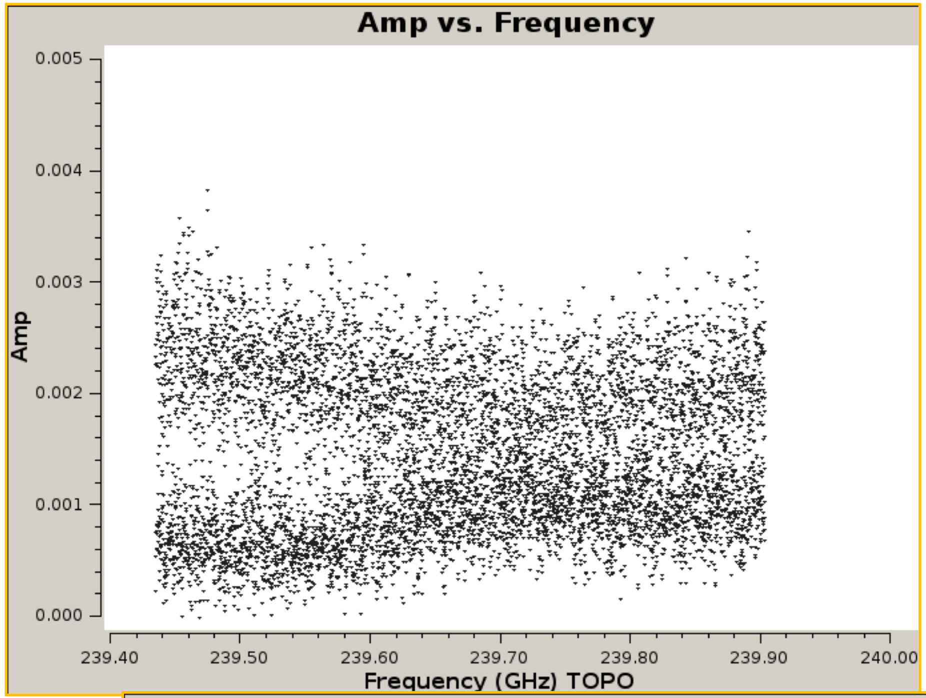
- This is typically a two part process, where by you set your amplitude scales with one task (e.g. setJy in CASA) and then scale the fluxes of other sources with another (e.g. fluxscale in CASA).

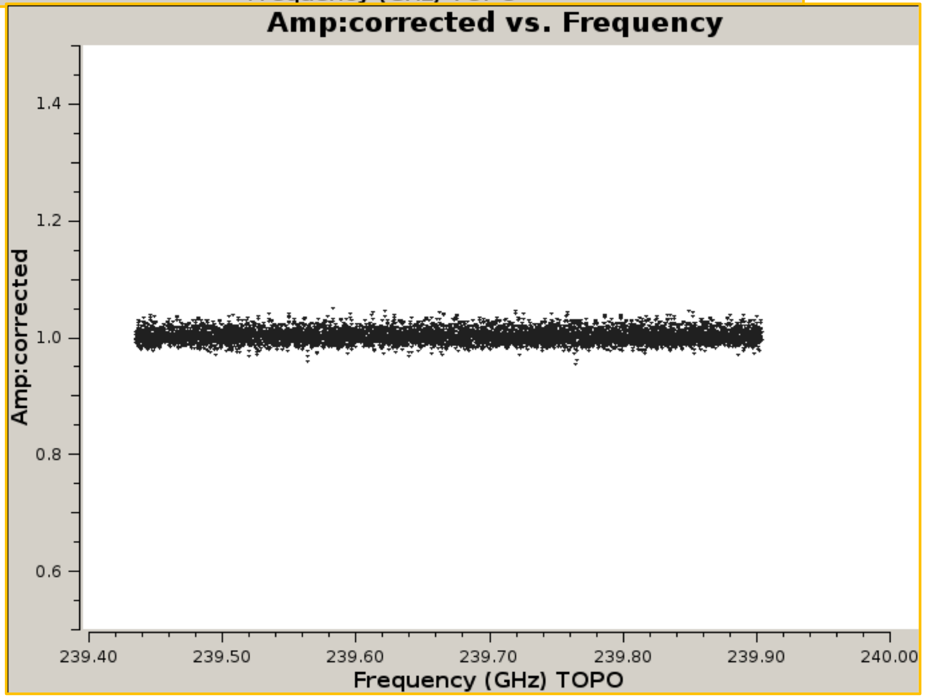


Fully calibrated data for Titan

Bandpass calibration

- Antenna based calibration. So solutions are per antenna w.r.t reference antenna.
- Each receiver will have a unique response to emission at a given ν.
- But we know our BP cal has a flat spectrum (or known spectral index).
- Calibrator needn't be close to target on sky.





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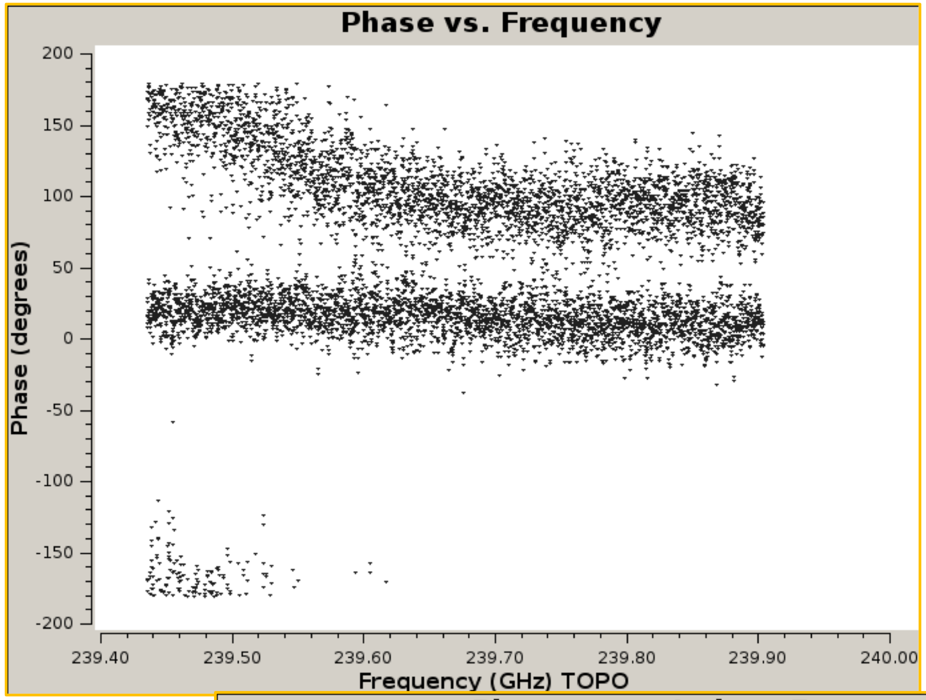
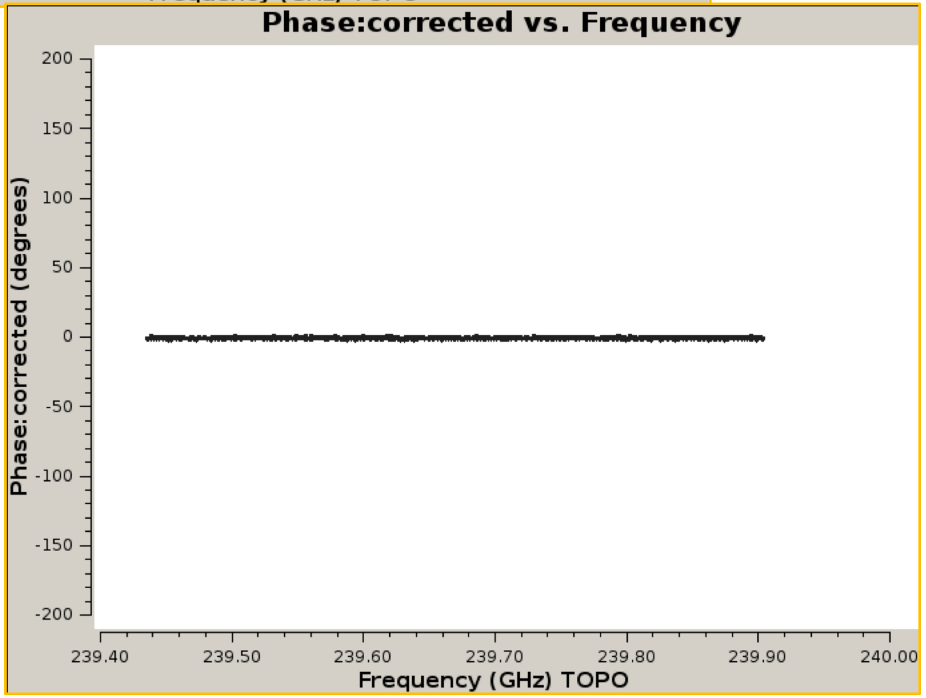
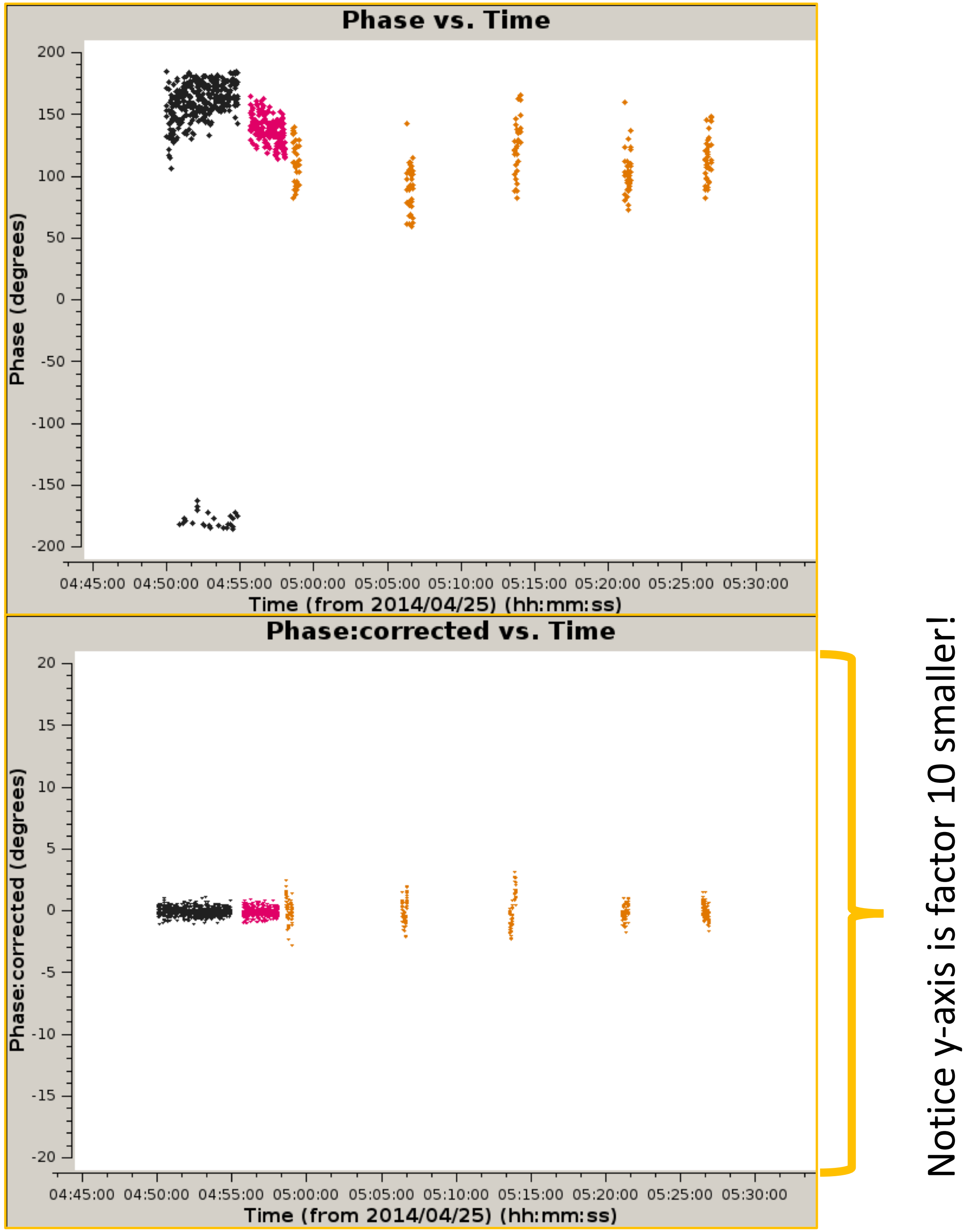




Complex Gain
(Phase and Amplitude)

- Calibration step to mitigate temporal effects (i.e. the atmosphere) on the phase and amplitude of the target source visibilities.
- Target a bright, *nearby* (few degrees), quasar and intersperse throughout observation of target.
- Needs to be nearby to target the same atmospheric conditions



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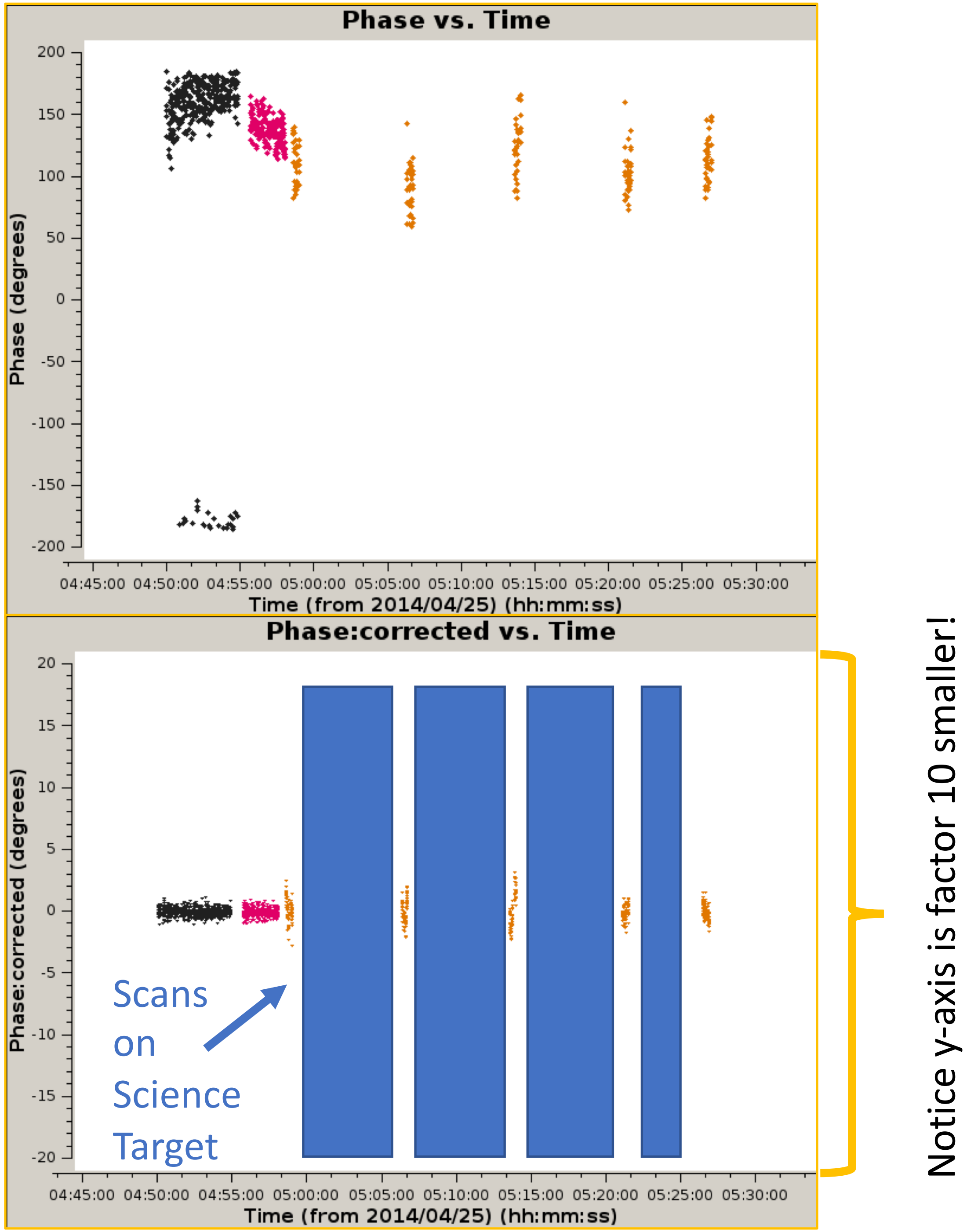

Which source gets which calibration solution?

- Once generating calibration solutions is complete, which source gets which solution applied to it is important.
- Particularly for the target source.
- The next slide tries to show schematically which source gets which solution. *(For the general case... There are always exceptions to the rule!)*

Calibration "Table" \ Calibrator	BP CAL	FLUX CAL	PHASE CAL	TARGET
FLUX SCALING	FLUX CAL (Scaled in fluxscale)	FLUX CAL (Model in setJy)	FLUX CAL (Scaled in fluxscale)	
BANDPASS	BP CAL	BP CAL	BP CAL	BP CAL
PHASE	BP CAL (short interval time solutions)	FLUX CAL (short time interval solutions)	PHASE CAL (long time interval solutions	PHASE CAL (long time interval solutions
AMPLITUDE	BP CAL (short interval time solutions)	FLUX CAL (short time interval solutions)	PHASE CAL (long time interval solutions	PHASE CAL (long time interval solutions

A bit more on applying solutions to the target

- The receiver responses are calibrated against the BP calibrator.
- In all other respects the target calibrated against the phase (ϕ) calibrator.
- Solutions for phase and amp from the ϕ-cal are interpolated in time between the ϕ-cal scans which intersperse observations of the target.
- This corrects the source phase and also correctly scales the visibility amplitudes to the same flux density scale as has been applied to the ϕ-cal.

Ok that’s the theory... Time for the practice...