Self-calibration

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Outline

What is self-calibration?

- how is different from regular calibration?
- under what circumstances can it be helpful

How to solve for and apply self-calibration

- choosing calibration parameters
- inspecting calibration solutions
- assessing results and next steps

What is self-calibration

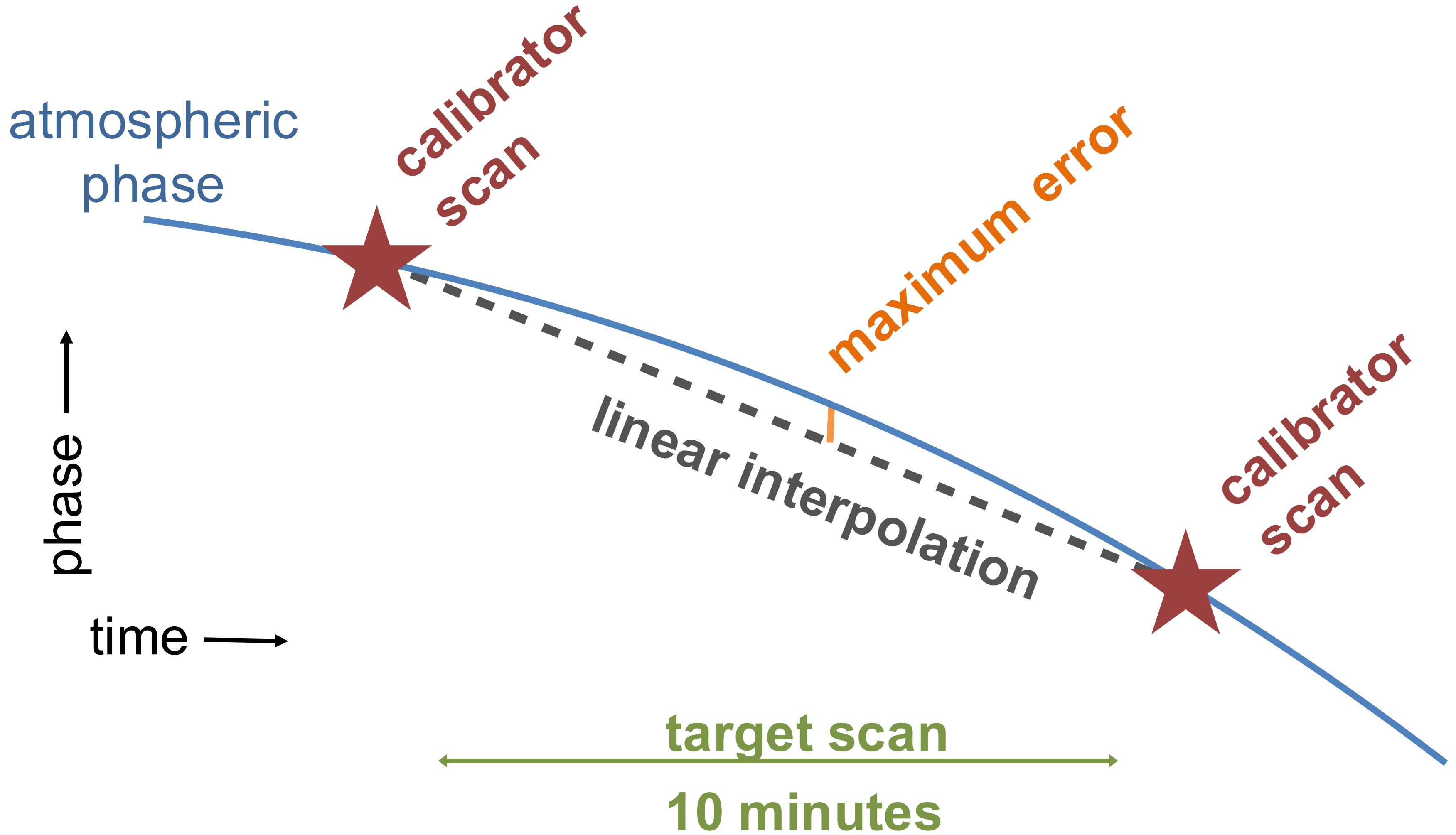
Self-calibration (selfcal) is an incremental refinement to the standard calibration solutions

Solutions are typically expressed using the G Jones (electronic gain) matrix but can absorb uncorrected F (ionosphere) and T (troposphere) terms

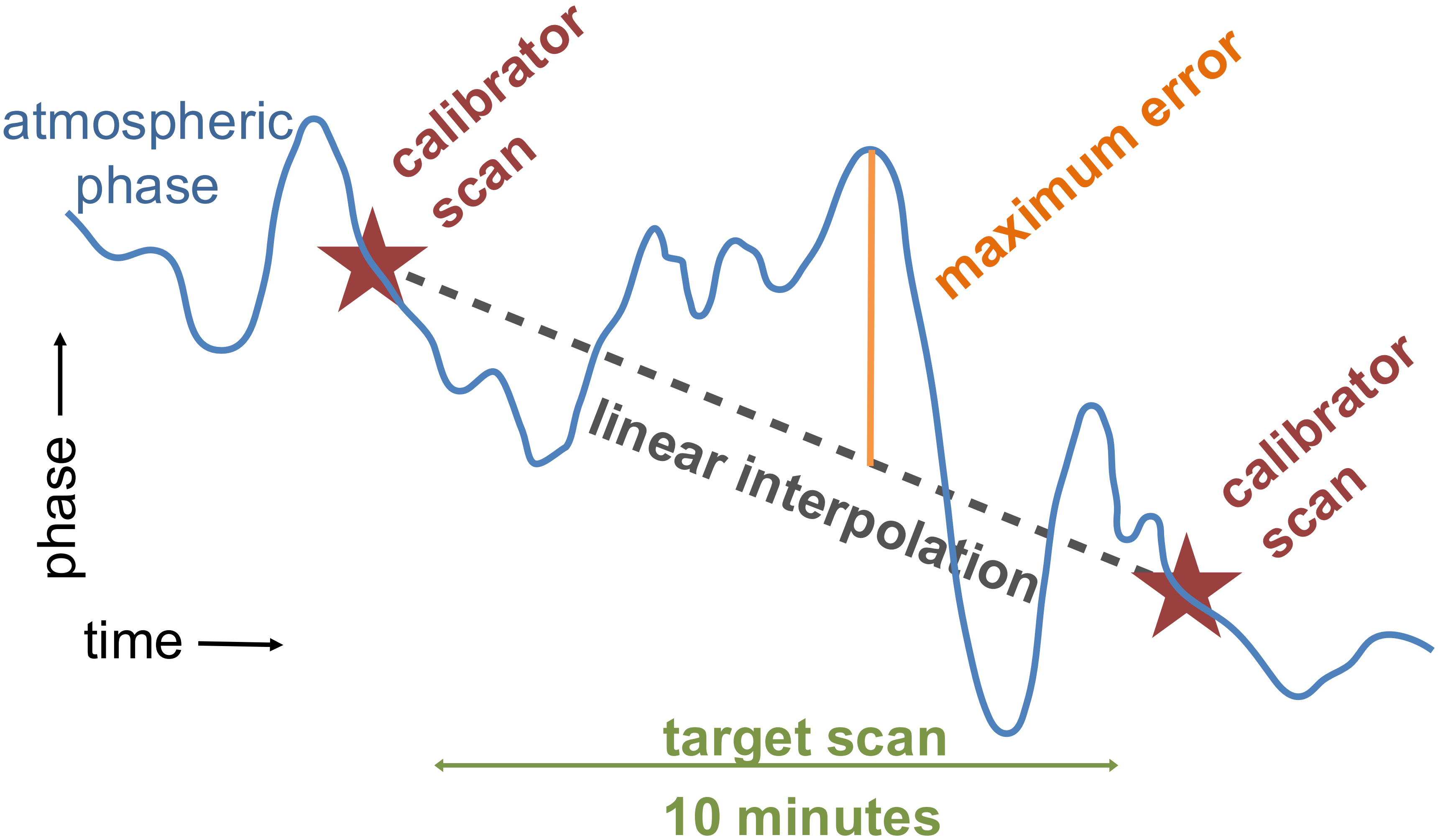
$$\overleftrightarrow{J}_i = \overleftrightarrow{K}_i \overleftrightarrow{B}_i \overleftrightarrow{G}_i \overleftrightarrow{D}_i \overleftrightarrow{E}_i \overleftrightarrow{X}_i \overleftrightarrow{P}_i \overleftrightarrow{T}_i \overleftrightarrow{F}_i$$

$$\overleftrightarrow{G}^{pq} = \begin{pmatrix} g^p & 0 \\ 0 & g^q \end{pmatrix} \qquad V_{ij}^{obs} = J_i J_j^* V_{ij}^{true} \quad \square \quad V_{ij}^{cor} = J_i^{-1} J_j^{*-1} V_{ij}^{obs}$$

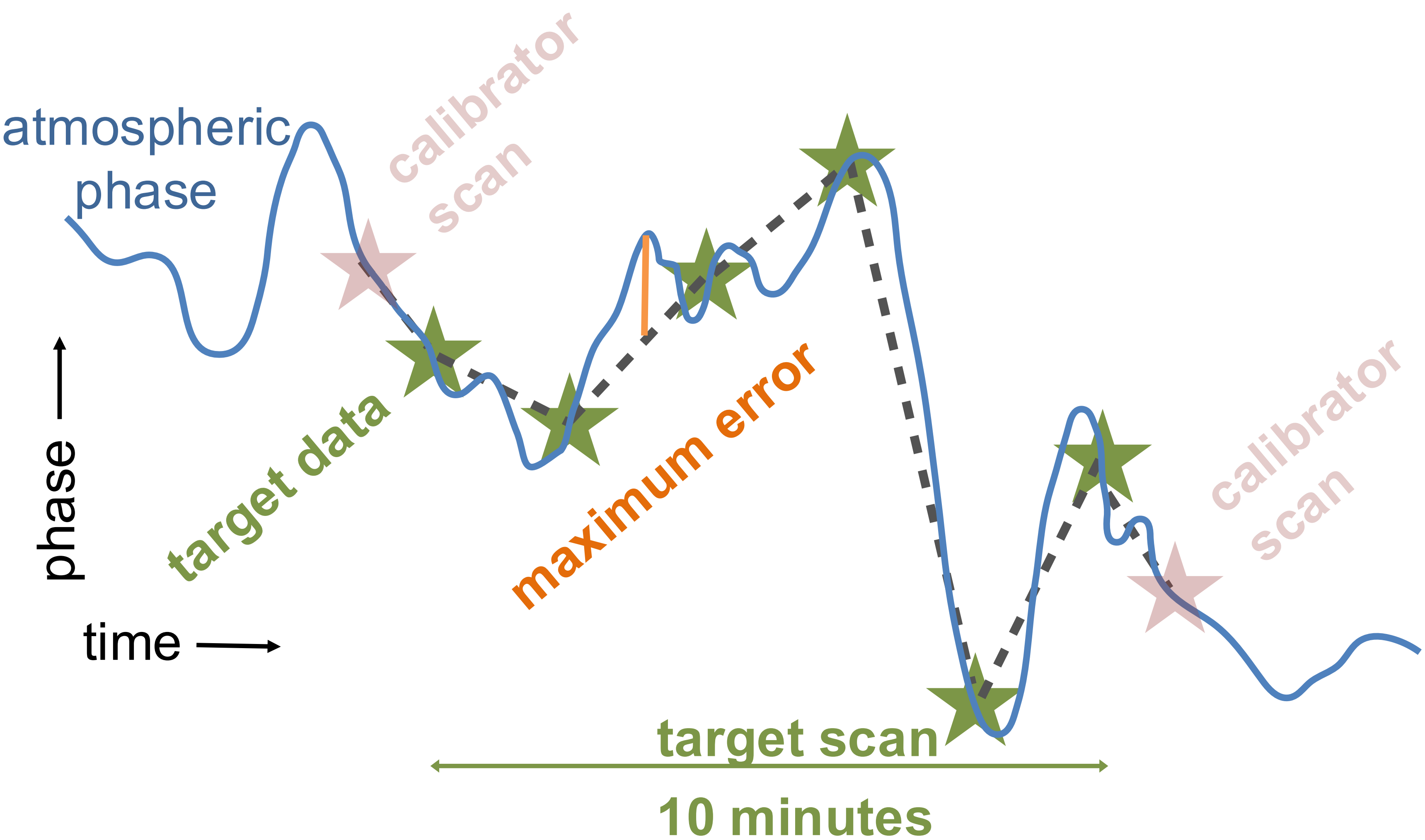
Standard Calibration (good conditions)



Standard Calibration (poor conditions)



Self- Calibration
(poor conditions)



Comparison with standard calibration

Standard Calibration

- data from observations of calibrator sources
- models from observatory database
- solutions applied to target fields

Self-Calibration

- data from observations of the target fields
- models created from the target data
- solutions applied back to the same fields

When Self-cal might help

There are artifacts from the source of interest due to calibration errors

There are artifacts from a background source due to direction-independent calibration errors

Typical sources of these errors:

- **atmospheric density fluctuations**
- **antenna-based gain changes**

When Self-cal will not help

Errors in creating the image (e.g., ignoring the W-term)

Errors in deconvolution (e.g., ignoring wide-band effects)

Insufficient UV coverage (e.g., missing short spacings, snapshot synthesis)

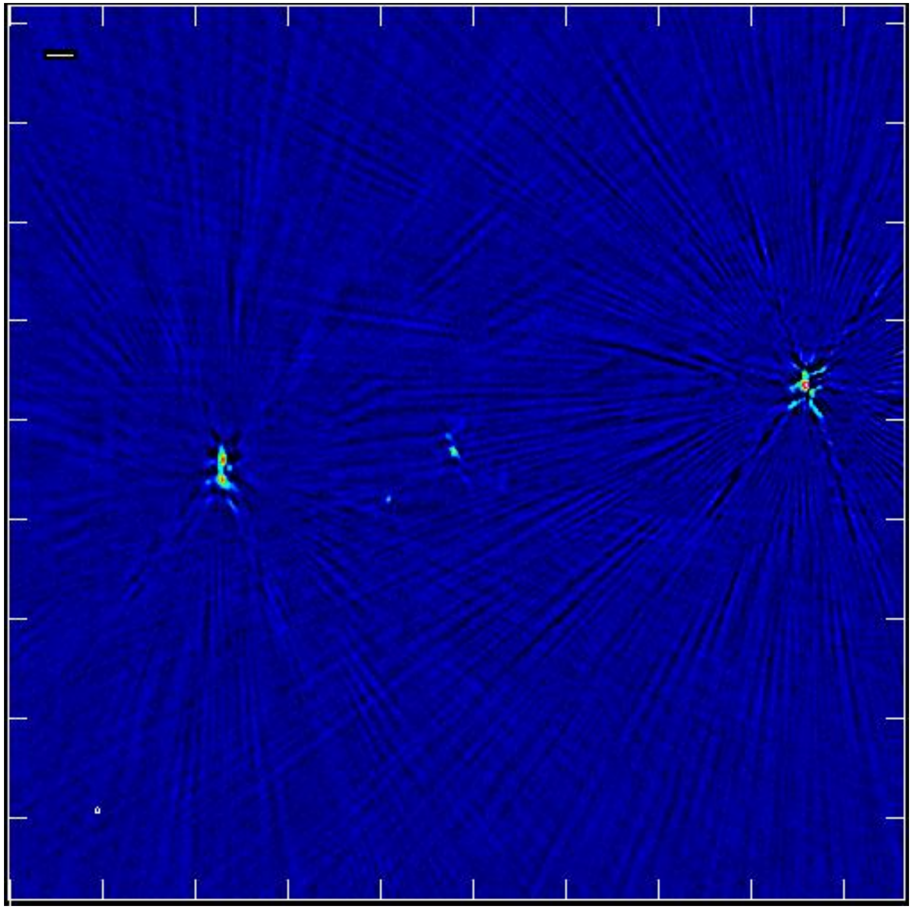
Unflagged RFI in the target visibilities

Source(s) are too weak to achieve sufficient signal-to-noise in the self-calibration solutions

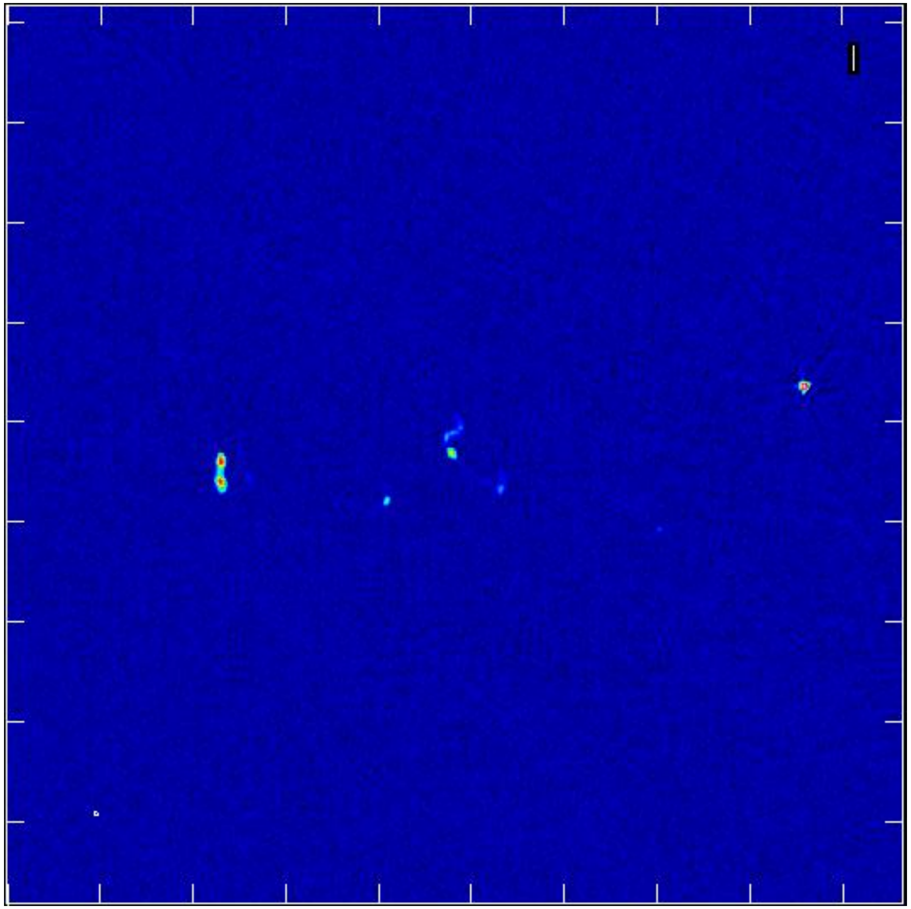
There is a bright outlying source with artifacts due to direction-dependent errors

Example Observation

Before selfcal



After selfcal



Example Observation

from the VLA self-calibration CASA guide:

casaguides.nrao.edu/index.php?title=VLA_Selfcalibration_Tutorial

- Target is z~1 galaxy cluster with high radio activity
- VLA B-configuration; C-band (~5 GHz); 2 GHz bandwidth
- 1024 spectral channels in 16 spectral windows
- 3 target scans of ~10 minutes each
- Multiple radio sources, peak flux ~ 7 mJy
- Initial calibration with the VLA CASA pipeline
- Strong artifacts remained after cleaning

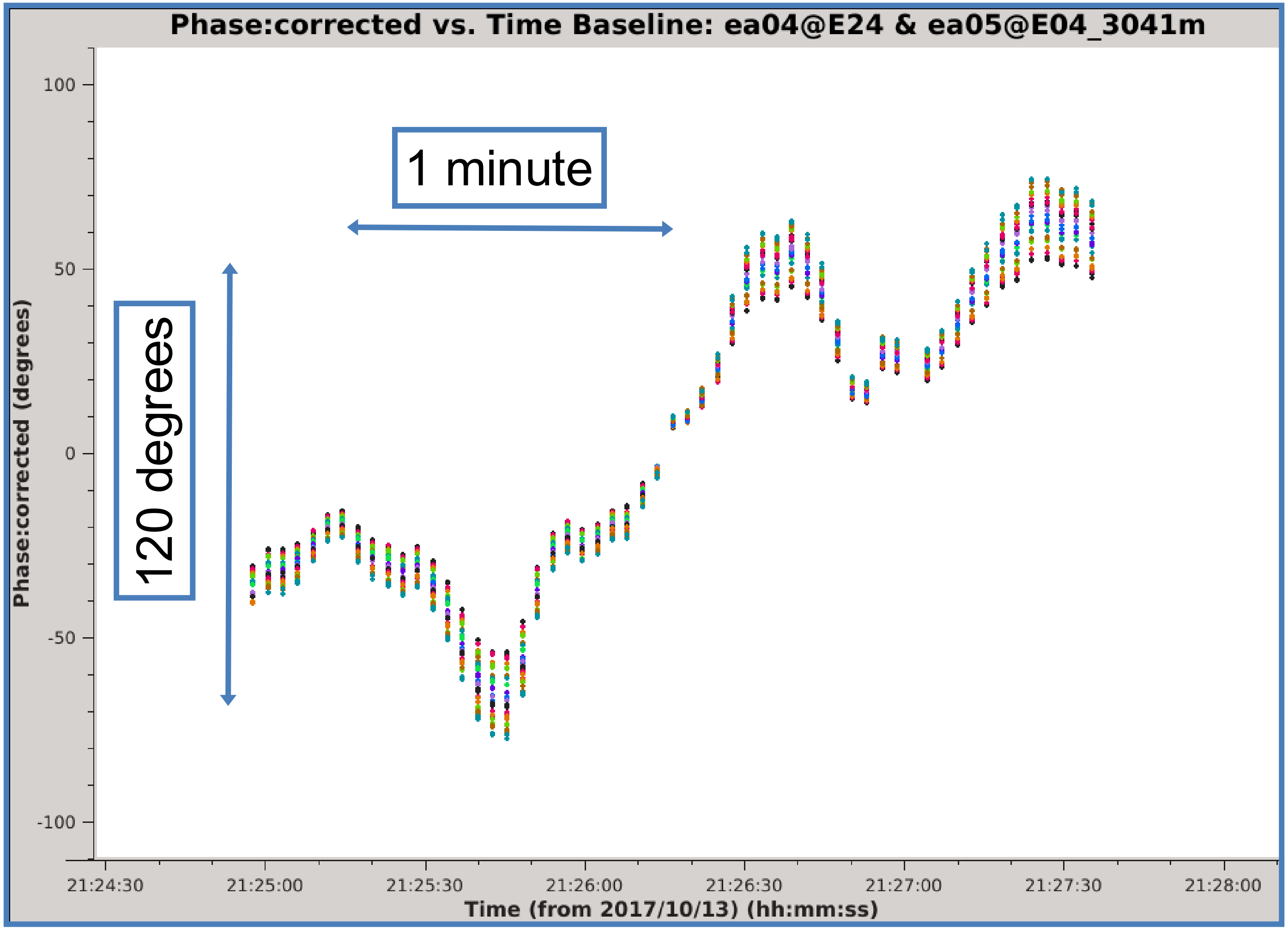
Phase Stability

Our first goal with self-calibration will be to improve the image by correcting phase errors in the target visibilities

Before we do this, it may be insightful to learn more about the observing conditions (i.e., phase stability)

One way to do this is to identify a long scan on a bright calibrator (e.g., bandpass) and plot the phase vs. time for a single baseline

Phase Stability



Phase Stability

The atmospheric phase stability for this observation is not good

The time it takes for the visibility phase to change by a radian, i.e., the ***coherence time***, is $\lesssim$ 1 minute

This is much shorter than the calibrator cycle time of 10 minutes

Standard calibration may have left large residual phase errors in the target data

We should aim for self-calibration solutions $\lesssim$ 1 minute if possible

Self-cal requires an initial model

$$V_{ij}^{obs} - J_i J_j^* V_{ij}^{mod} = 0$$

In order to solve for ***J*** we first need to create a model of our target field

Here we use the model image created by deconvolution

- use appropriate imaging techniques (e.g., wide-band, wide-field) so as not to create additional image errors
- clean all sources that contribute significantly to the visibilities, even those far away from the target of interest
- clean conservatively to avoid artifacts becoming part of the model

The model image is used to predict the model visibilities (degridding)

The initial image

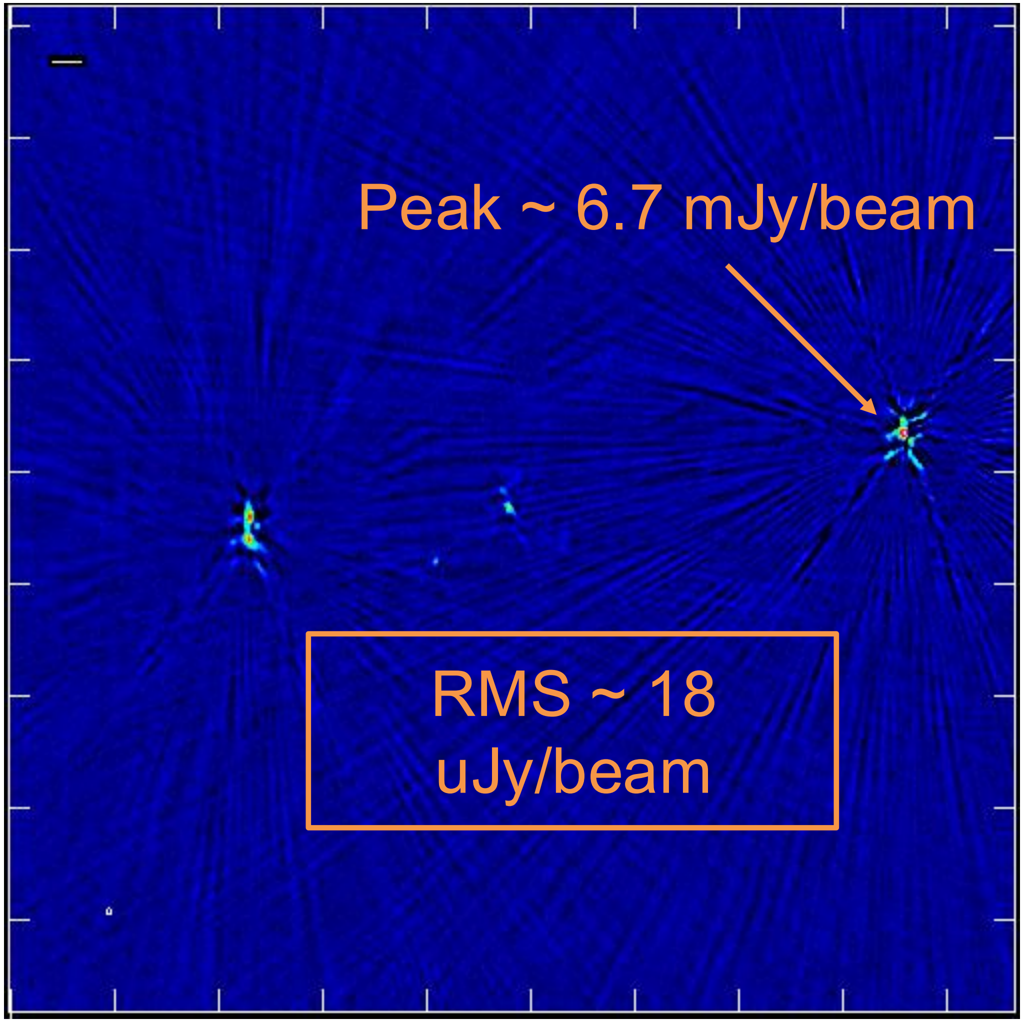
This is the image we get after cleaning

The sensitivity is not thermal noise-limited

Artifacts from the bright sources dominate the noise floor

We measure a **dynamic range** of:

Peak / RMS ~ 370



Choosing self-cal parameters

Should ***J*** include only Amplitude, only Phase or both?

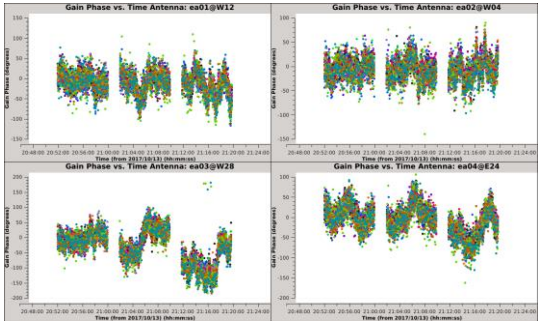
- It is recommended to begin in phase-only mode because phase corrections can boost the amplitude by reducing decorrelation

Other key self-cal parameters to consider:

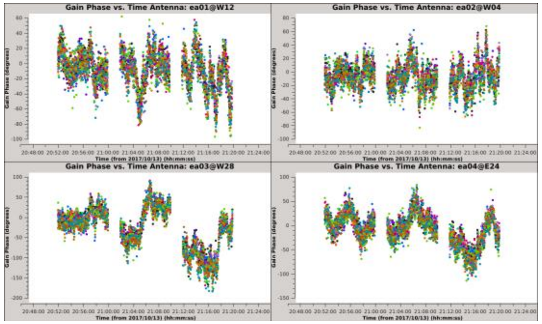
- how much time averaging (solution interval)
- should I average polarizations?
- how much frequency averaging to use?
- solution signal-to-noise ratio

Example of solution intervals

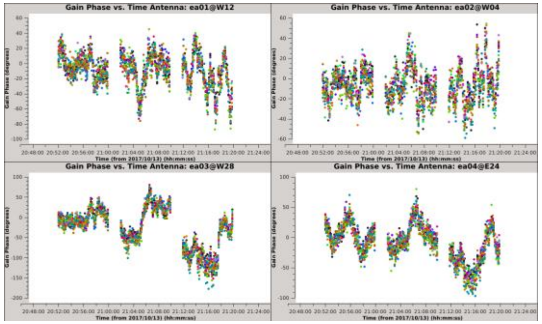
3s



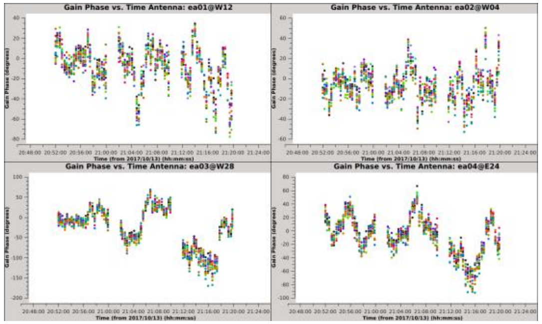
6s



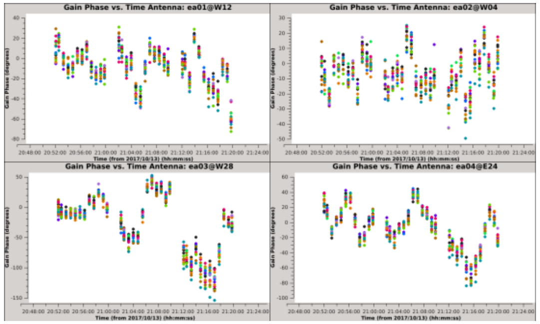
12s



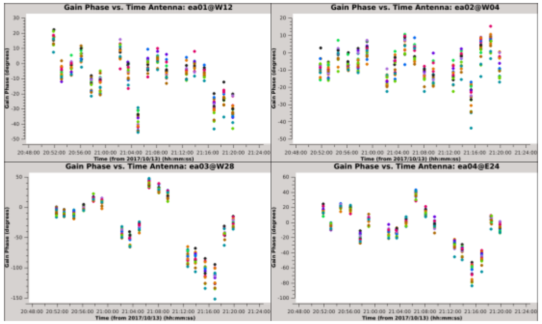
24s



48s



96s

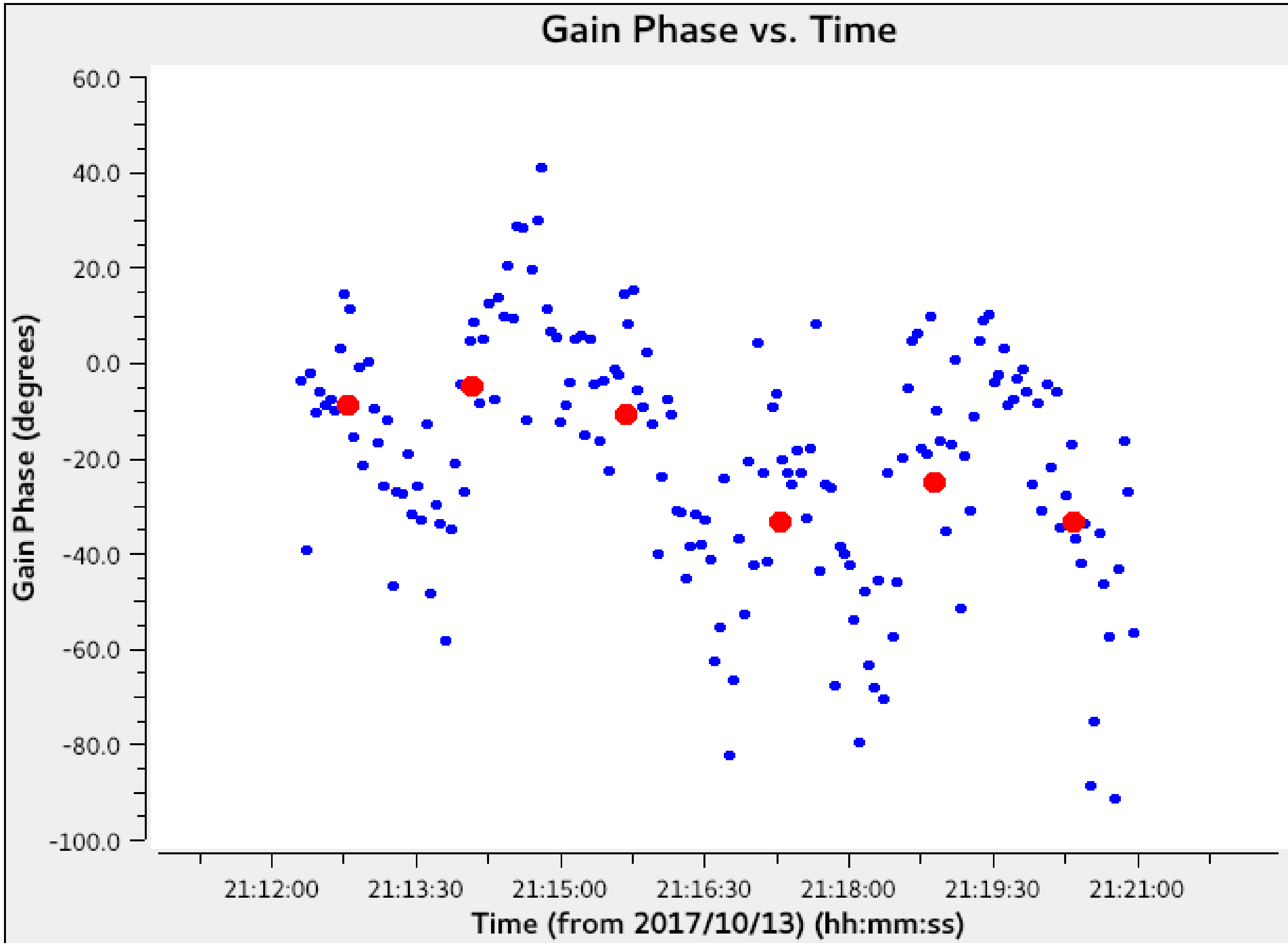


Example of solution intervals

Comparison of 3s (blue) to 96s (red) solution intervals.

The 3s solutions show significant structure but also a lot of noise.

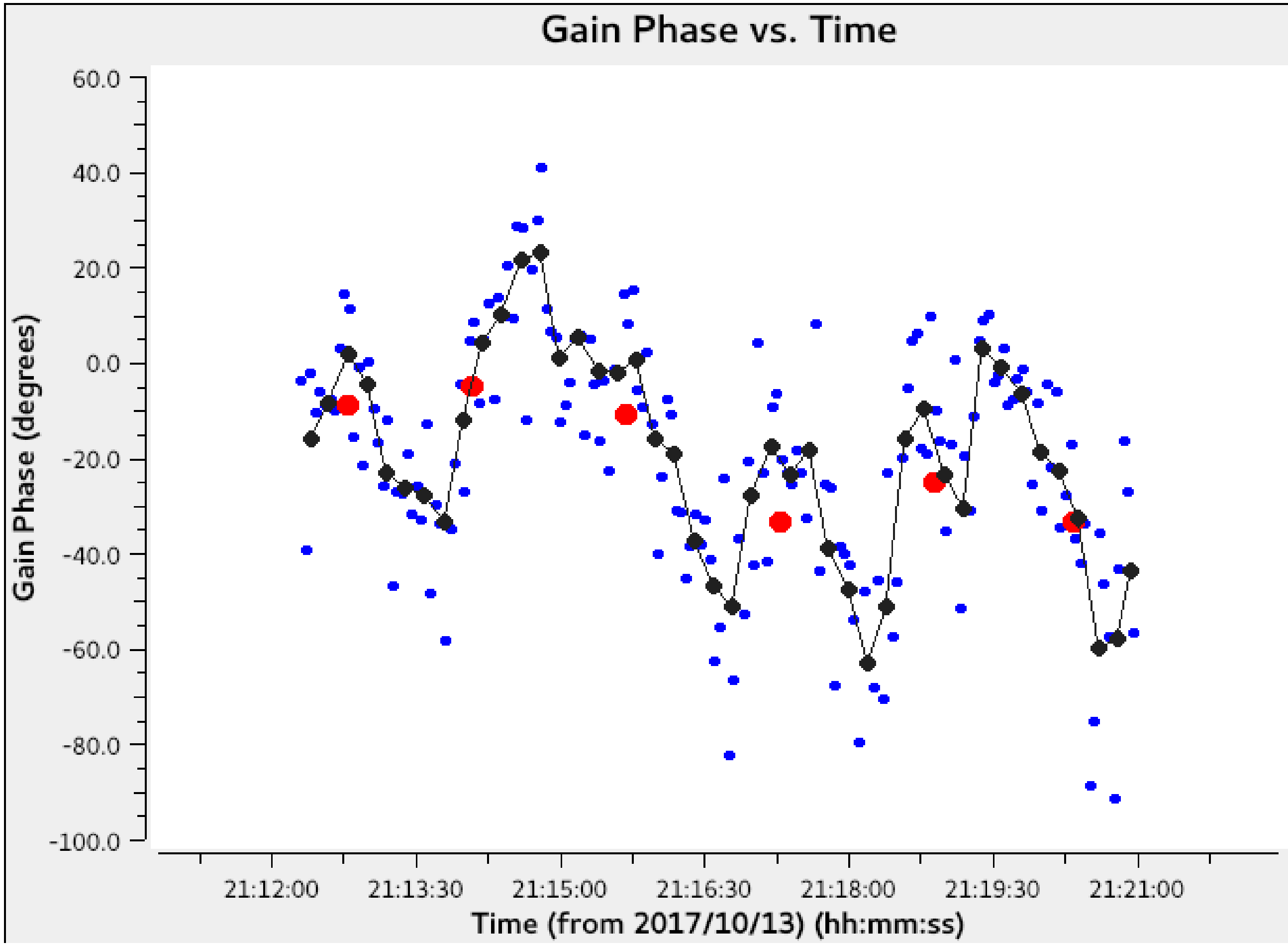
The 96s solutions are unable to sample the large, fast phase changes.



Example of solution intervals

A 12s solution interval (black circles) provides a reasonable compromise between time resolution and signal-to-noise

Linear interpolation (black lines) is used to correct the target visibilities

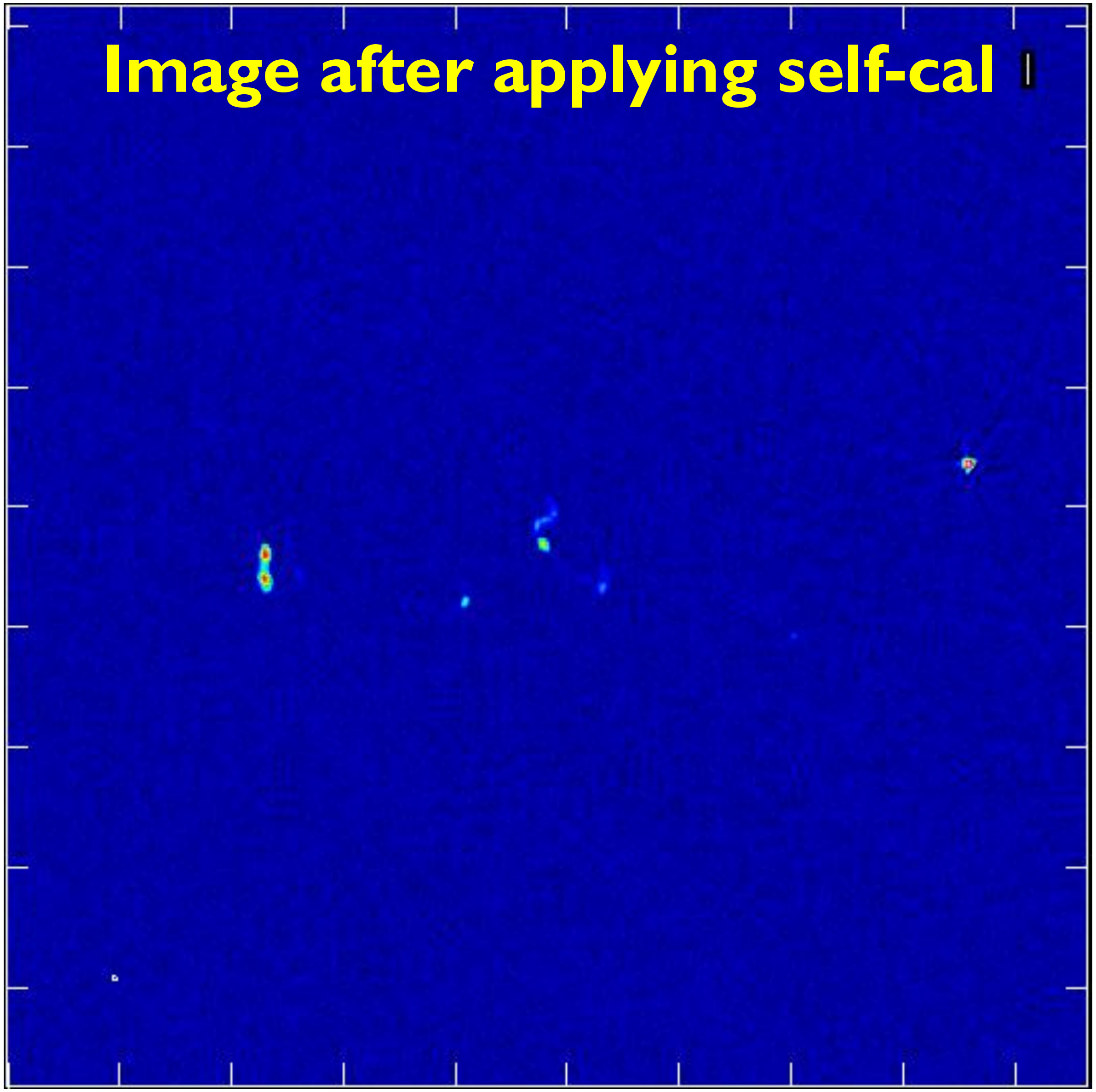


Peak flux has **increased** from 6.7 to 9.1 mJy

Background RMS has **decreased** from 18.2 to 8.2 uJy and noise looks more Gaussian

Dynamic range has **improved** by a factor of 3, from 370 to 1100!

Science target (central source with bent tail) is more clearly visible



Next steps

Decide to stop: the new image may now be good enough to meet your science goals, so there may be no need to go further

Reassess image artifacts: the new image may now be limited by one or more issues that self-cal can not improve

Iterate on Selfcal Parameters: it's easy to undo selfcal and try again

Additional Rounds of Phase-only Self-calibration: sometimes it may take several iterations to reach a satisfactory result

Amplitude Self-calibration: after taking phase-only selfcal as far as possible, you may want to try including amplitude corrections.

Direction-dependent Self-calibration: standard self-calibration is direction-independent. More advanced techniques exist when the calibration varies over the field of view (e.g. peeling, pointing selfcal)

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