I-TRAIN #6: Advanced Self-Calibration Topics

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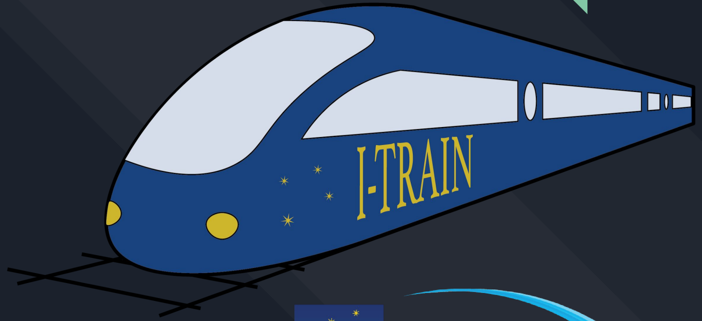
with thanks to Perley, Fomalont, Kloeckner and others; *Taylor et al. Synthesis Imaging 1999* and *Brogan et al. 2018*



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Advanced Topics & Background Explanations

1. Choosing a solution interval
2. When not to self-calibrate
3. Other aspects of self-calibration
4. How to choose a line
5. How to recover poorly-calibrated data
6. Sources of error
7. Bright sources
8. Methods for implementing self-cal
9. Why phase first?
10. Image accuracy

Warning: Expressions are mostly oversimplification or approximations. See references at end for more detailed derivations.

(1a) How to Choose a Solution Interval (Solint): Theory

Choosing the solution interval - phase

- Start cautiously, e.g. scan length, to avoid freezing-in imperfect model
  - See previous talks
  - Can compare S/N to optimise solint (also see VLA self-calibration CASA guide)
    - Maybe harder if sensitivity or signal changes a lot with frequency or baseline length
- Can estimate analytically integration time giving required S/N per antenna
  - S = peak flux in Jy/beam, ideal σ_{rms}, N antennas

$$\sigma_{\mathrm{rms}} \propto \frac{T_{\mathrm{sys}}}{\sqrt{N(N-1)/2 \times \Delta\nu \times \Delta t}}$$

  - $\Delta\nu$ total bandwidth (used in image), Δt total time on target
    - Initial actual image σ_{rms} higher, atmospheric as well as thermal noise
      - Actual σ_{rms} should decrease as self-calibration progresses
- Each antenna has (N-1) baselines
  - Degrees of freedom also reduced by refant, arbitrary origin of phase
  - Noise per antenna $\sigma_{\mathrm{rms,ant}} = \sigma_{\mathrm{rms}} \times \sqrt{\frac{(N(N-1)/2)}{(N-3)}}$

Minimum solution interval for phase calibration

- e.g. Require S/N ≥ 3 per antenna, per polarization (X, Y), per spw*, per solint *dt*
  - Noise in solint (all baselines) $\sigma_{\mathrm{rms},dt} = \sigma_{\mathrm{rms}} \times \sqrt{\Delta t/dt \times NP \times N\mathrm{spw}}$
  - Take *N*=20, two polarizations *NP*=2, total *Nspw*=2
  - Want S/N per antenna per solint $\sigma_{\mathrm{rms,ant},dt} = \sigma_{\mathrm{rms},dt} \times \sqrt{(N(N-1)/2)/(N-3)} = S/3$
  - So $\sigma_{\mathrm{rms}} \times \sqrt{\Delta t/dt \times NP \times N\mathrm{spw} \times (N(N-1)/2)/(N-3)} = S/3$
  - Minimum solution interval, for peak *S*, without spw or polarization avg.

$$dt = \frac{(N(N-1)/2)/(N-3) \times NP \times N\mathrm{spw} \times \Delta t}{(S/3\sigma_{\mathrm{rms}})^2}$$

- If the full observation had **more** antennas, more spw, a longer time on source, thus lower σ_{rms}, then the minimum solution interval is **longer** for a given peak flux

* For continuum, spw ~equal sensitivity; use appropriate spectral widths for different spw or for line self-cal

What is signal peak? What is noise? Why $3\sigma_{rms}$?

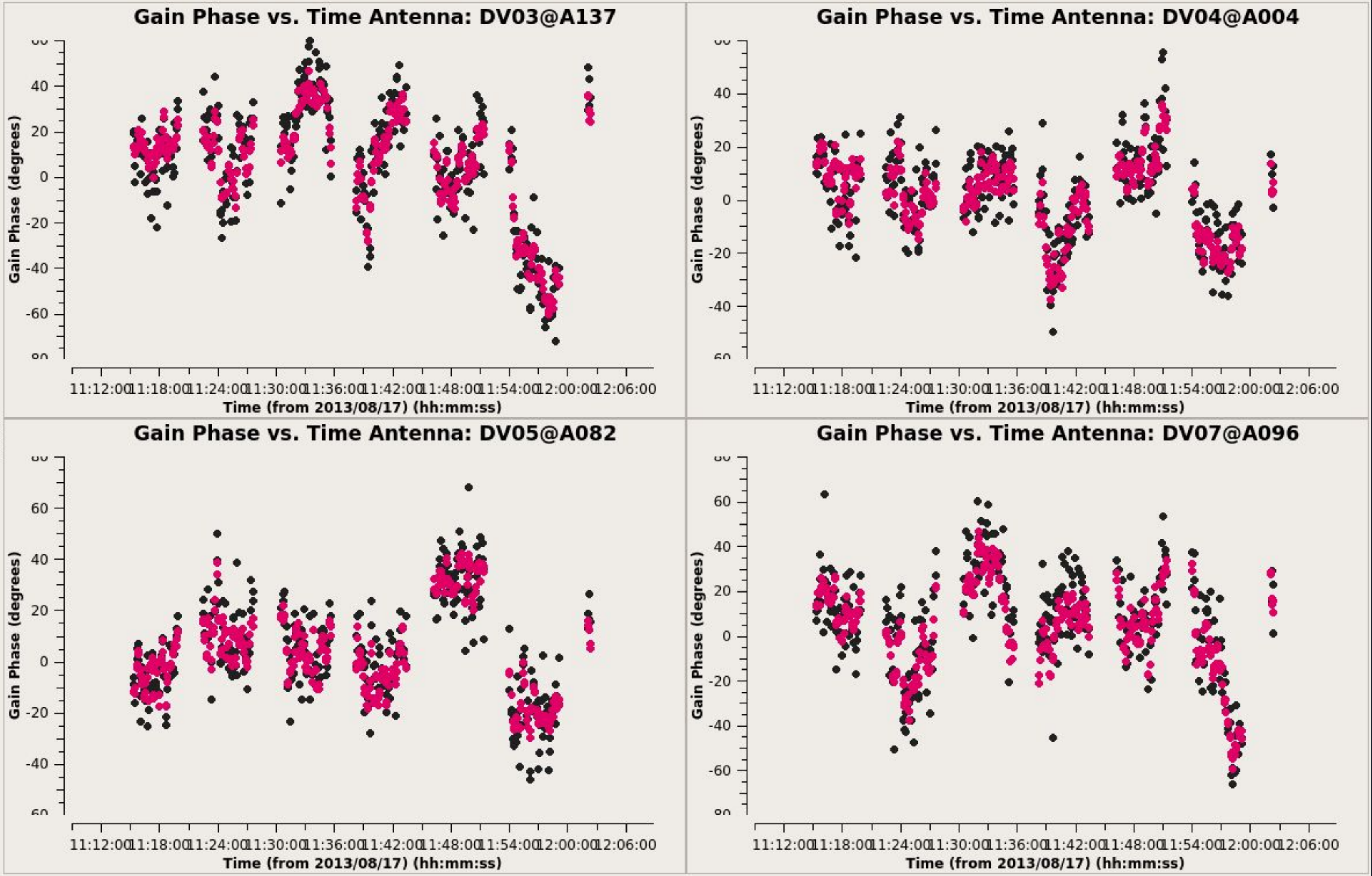
- First image peak is probably lower and noise is higher than ideal
  - Why use peak (not total) flux in estimating S/N? To ensure that long baselines are calibrated
  - Don't calibrate weights until last self-cal cycle (usually)
    - Model needs to include contributions from antennas most in need of correction
    - Exceptions e.g. mixed 7m-12m antennas, i.e. real difference in sensitivity
- Using initial image S/N gives longer dt (plus you should allow for imperfect model)
  - As S/N improves, minimum dt shrinks (can estimate optimum σ_{rms} from sensitivity calculator)
- In map, off-source, a few pixels per 1000 have values outside $3\sigma_{rms}$
  - NB map noise has non-linear relationship with visibility phase errors
    - Nonetheless, usually ensuring S/N $3\sigma_{rms}$ *per antenna per solint* produces good solutions
  - Could start with $< 3\sigma_{rms}$ to avoid failing solutions due to a poor model rather than bad data
  - Or $> 3\sigma_{rms}$ if there are bad data, or for large data sets and potential high dynamic range

(1b) How to Choose a Solution Interval (Solint): Method S/N

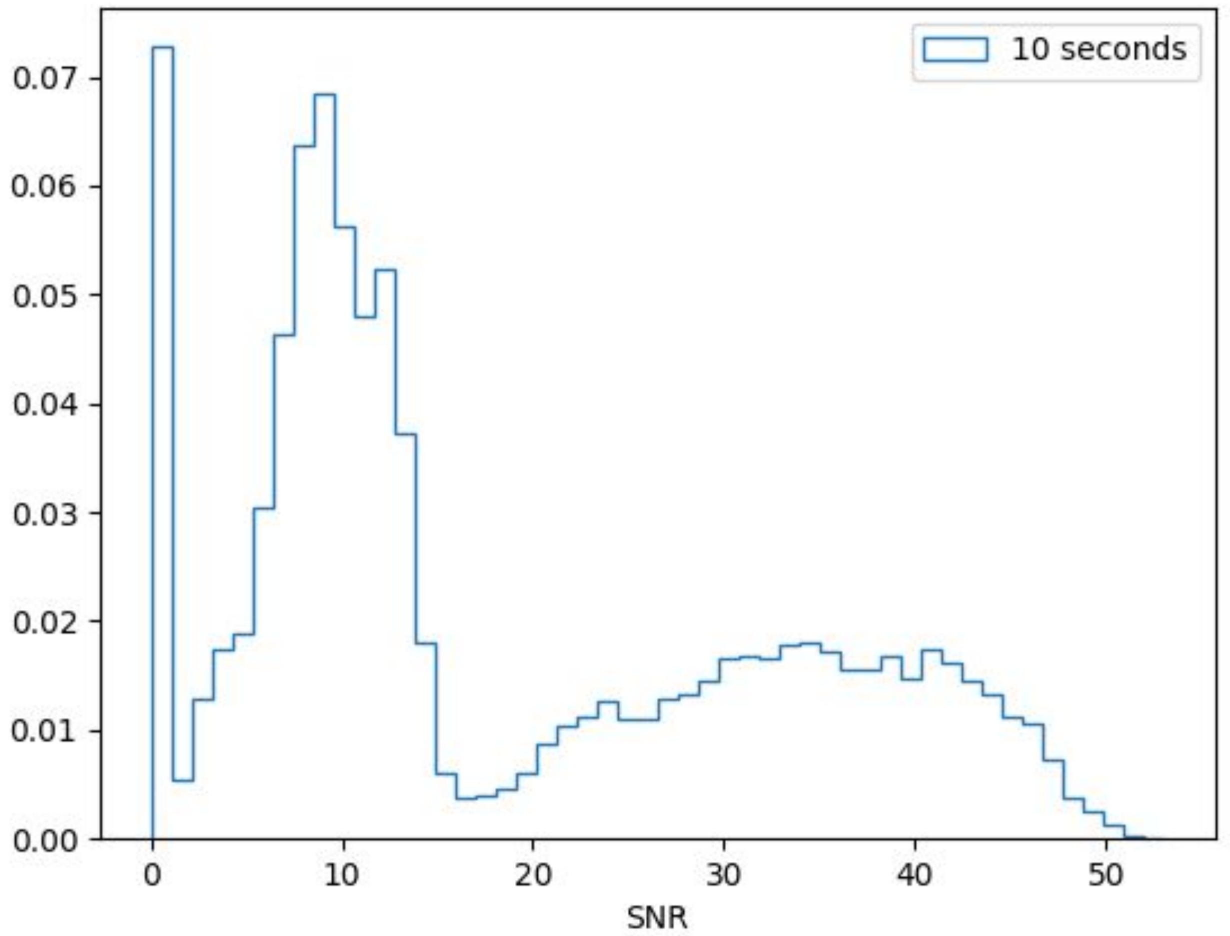
Goal: choose a solint that captures the variations and flags minimal solutions

Look at multiples of int (1,2,3,4,5,etc.) (2,4,8,16,etc) -- int from listobs

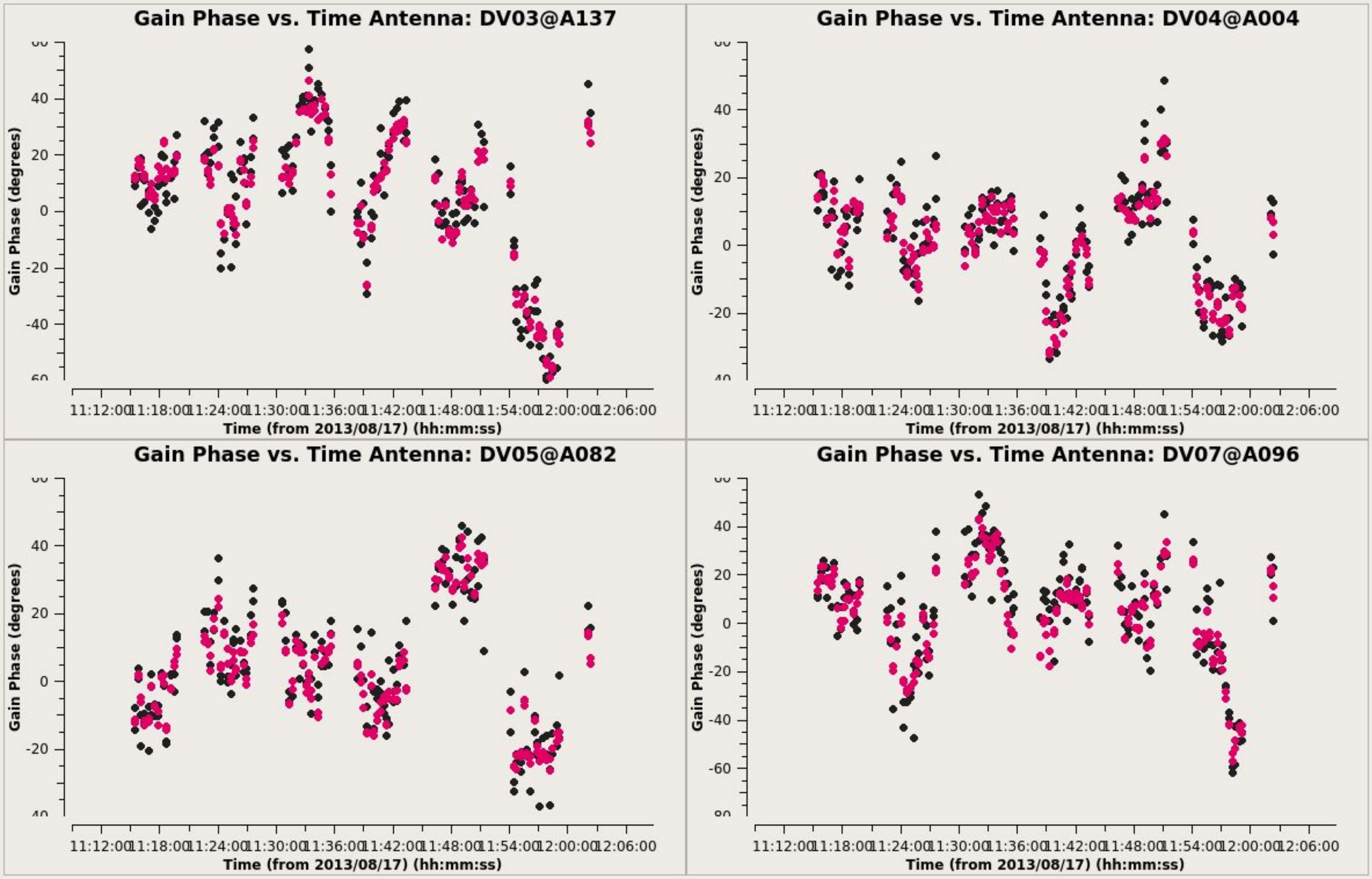
Multiples of inf (inf, inf/2,inf/4) -- scan length from listobs solint=int~10s



S/N of SOLUTIONs in GAINTABLES NOT the IMAGE

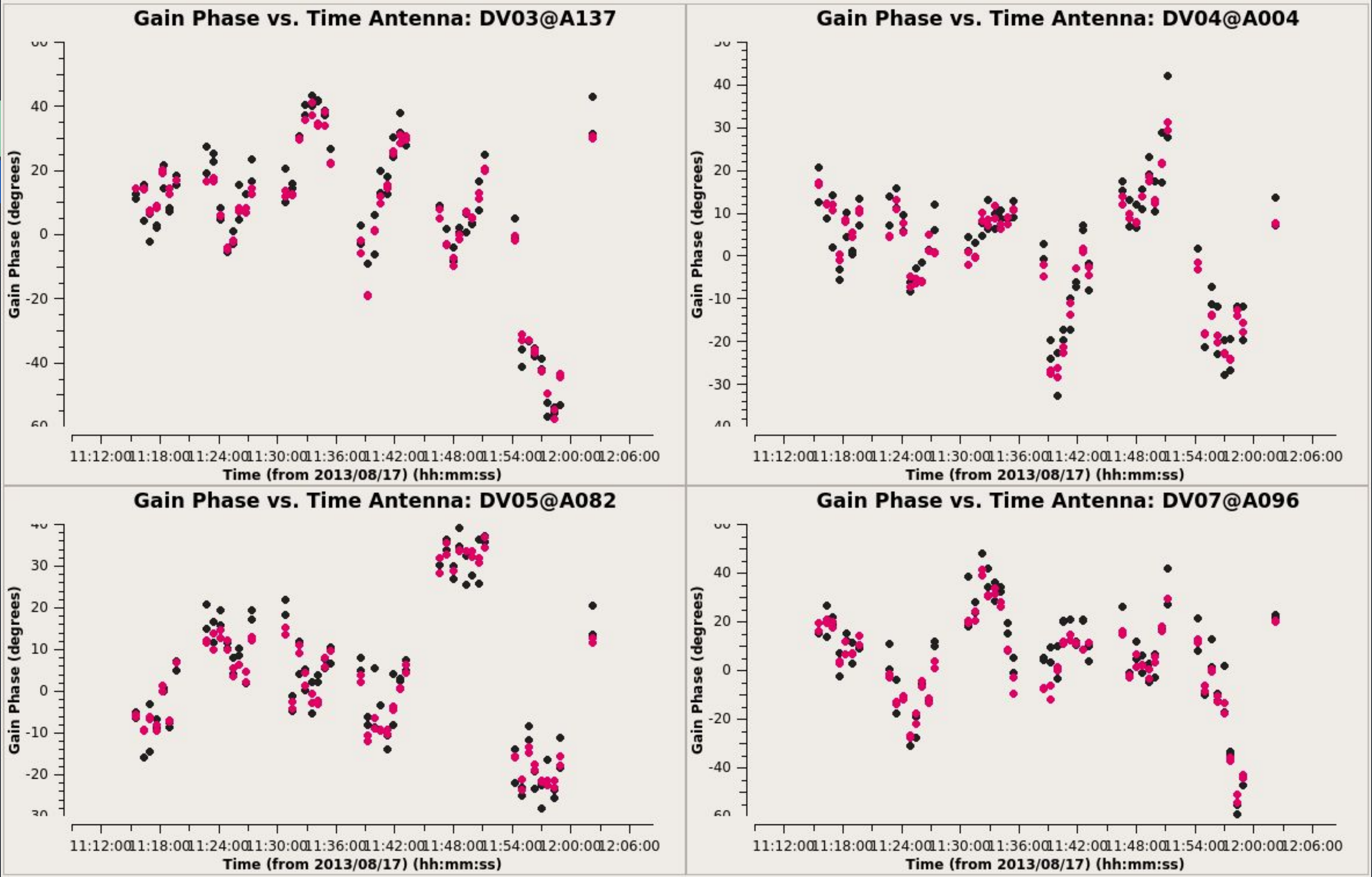


solint=20s



Gain Phase vs. Time Antenna: DV03@A137
Gain Phase vs. Time Antenna: DV04@A004
Gain Phase vs. Time Antenna: DV05@A082
Gain Phase vs. Time Antenna: DV07@A096
Gain Phase (degrees)
Time (from 2013/08/17) (hh:mm:ss)
11:12:00
11:18:00
11:24:00
11:30:00
11:36:00
11:42:00
11:48:00
11:54:00
12:00:00
12:06:00
40
20
0
-20
-40
-60

solint=40s


Gain Phase vs. Time Antenna: DV03@A137
Gain Phase vs. Time Antenna: DV04@A004
Gain Phase vs. Time Antenna: DV05@A082
Gain Phase vs. Time Antenna: DV07@A096
Gain Phase (degrees)
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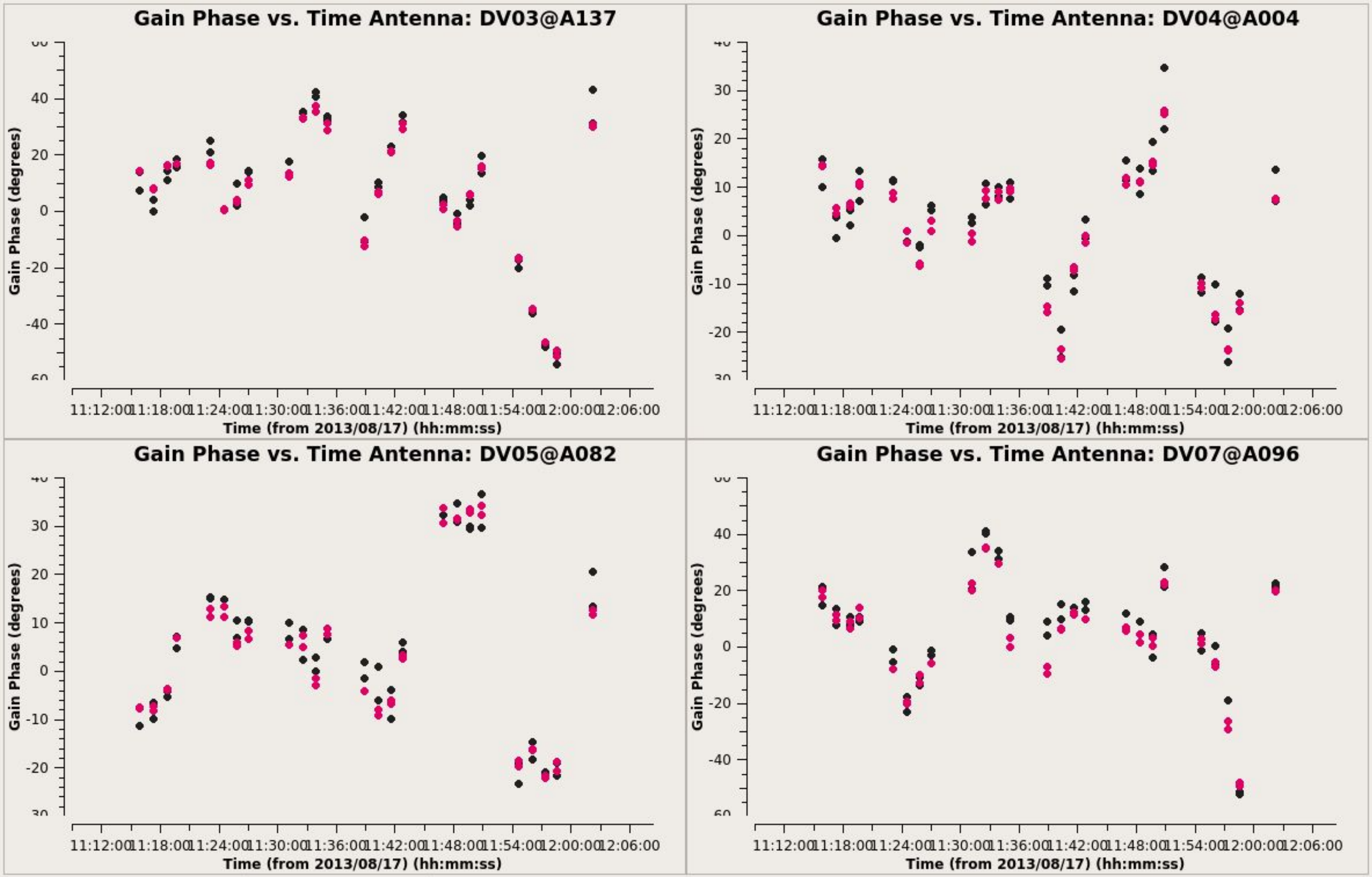
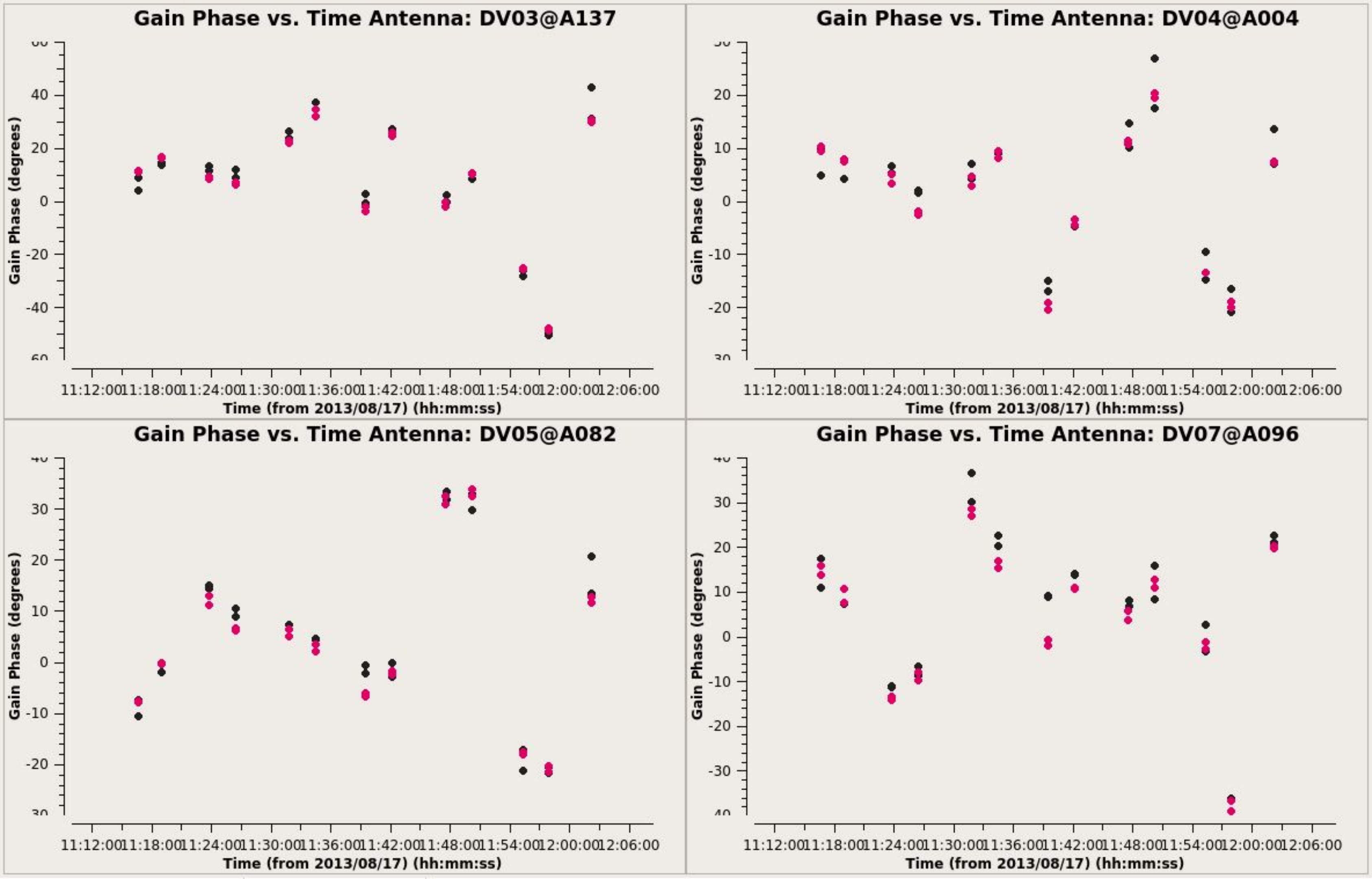
11:12:00
11:18:00
11:24:00
11:30:00
11:36:00
11:42:00
11:48:00
11:54:00
12:00:00
12:06:00

solint=80s

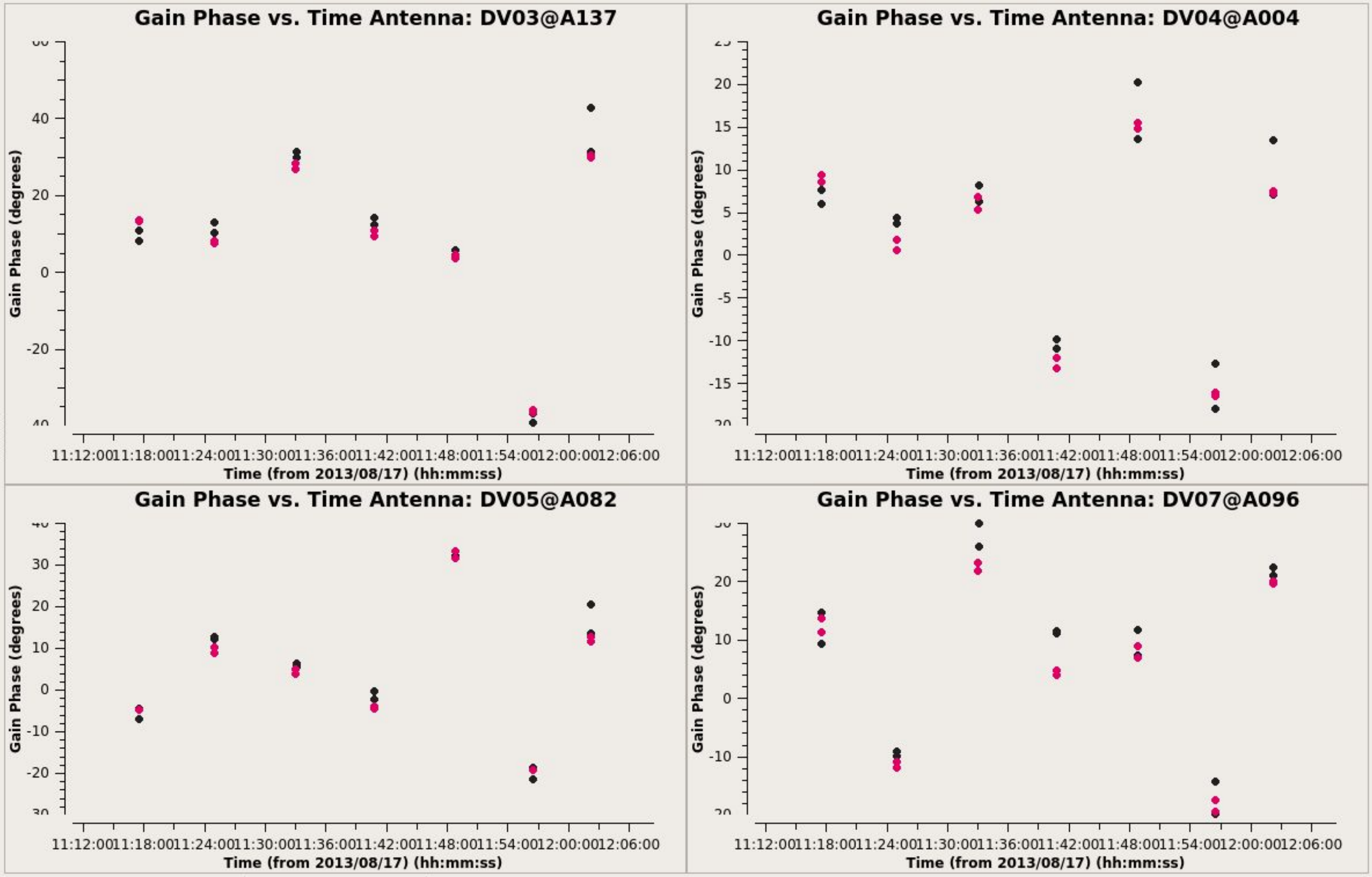


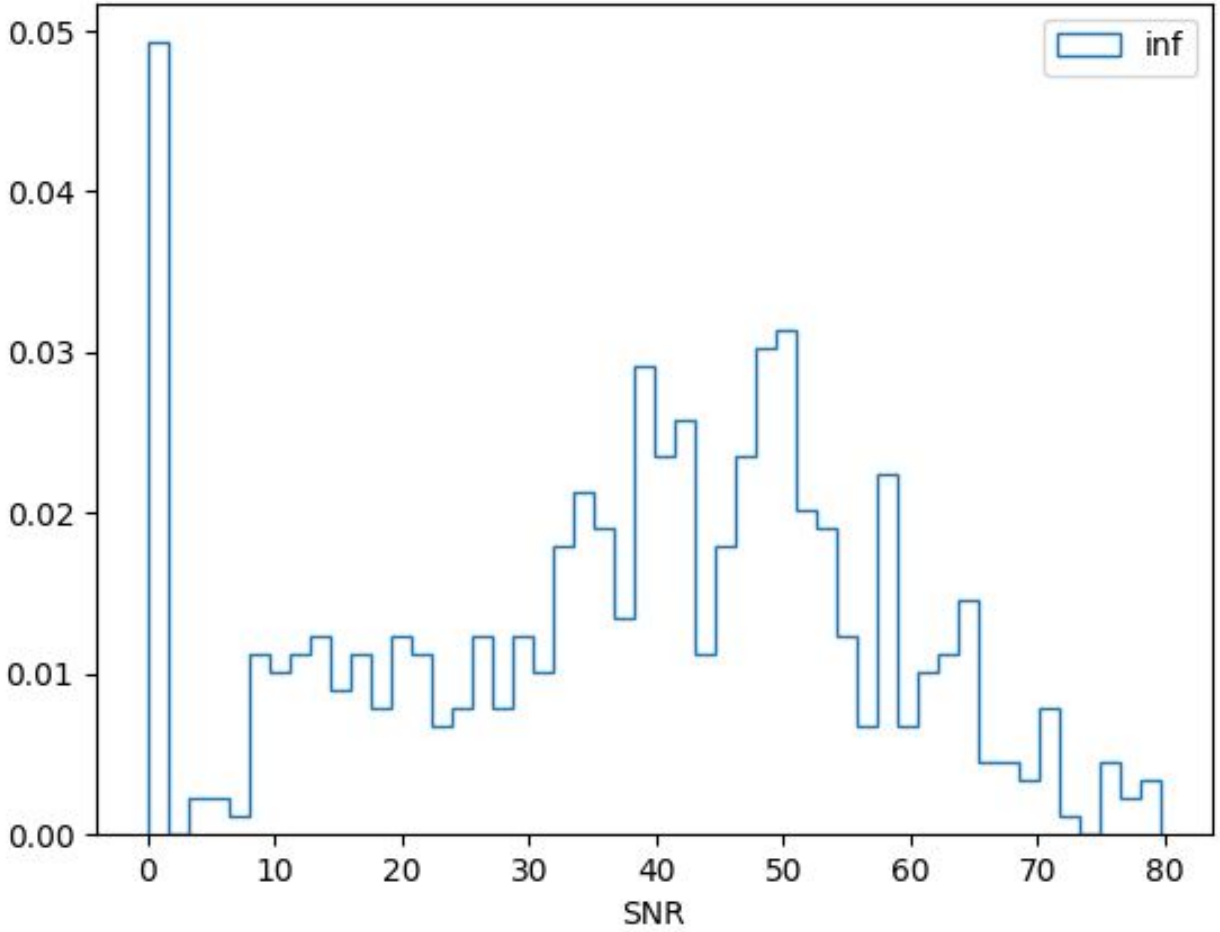
Gain Phase vs. Time Antenna: DV03@A137
Gain Phase vs. Time Antenna: DV04@A004
Gain Phase vs. Time Antenna: DV05@A082
Gain Phase vs. Time Antenna: DV07@A096
Gain Phase (degrees)
Time (from 2013/08/17) (hh:mm:ss)
11:12:00 11:18:00 11:24:00 11:30:00 11:36:00 11:42:00 11:48:00 11:54:00 12:00:00 12:06:00

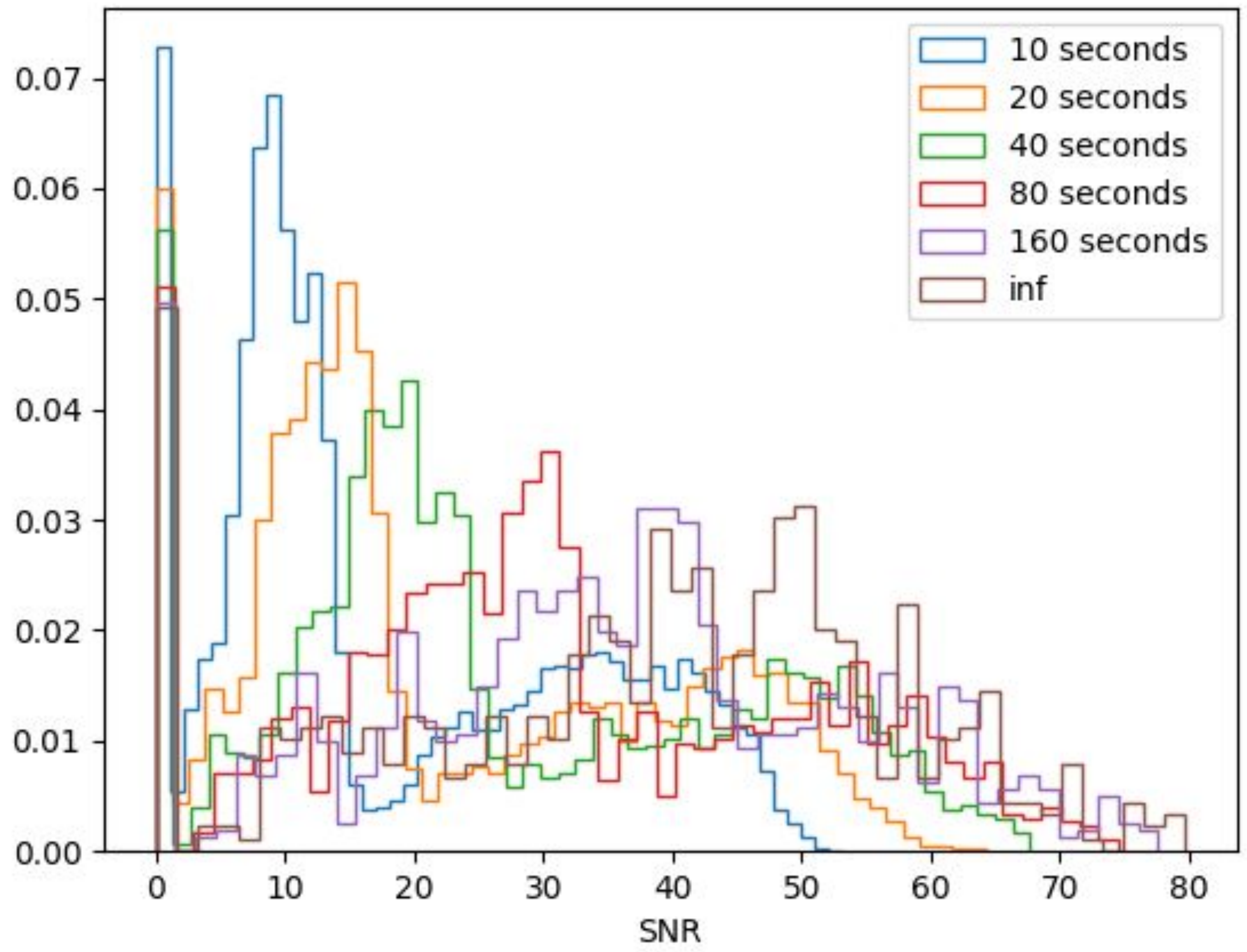
solint=160s


Gain Phase vs. Time Antenna: DV03@A137
Gain Phase vs. Time Antenna: DV04@A004
Gain Phase vs. Time Antenna: DV05@A082
Gain Phase vs. Time Antenna: DV07@A096
Gain Phase (degrees)
Time (from 2013/08/17) (hh:mm:ss)
11:12:00 11:18:00 11:24:00 11:30:00 11:36:00 11:42:00 11:48:00 11:54:00 12:00:00 12:06:00

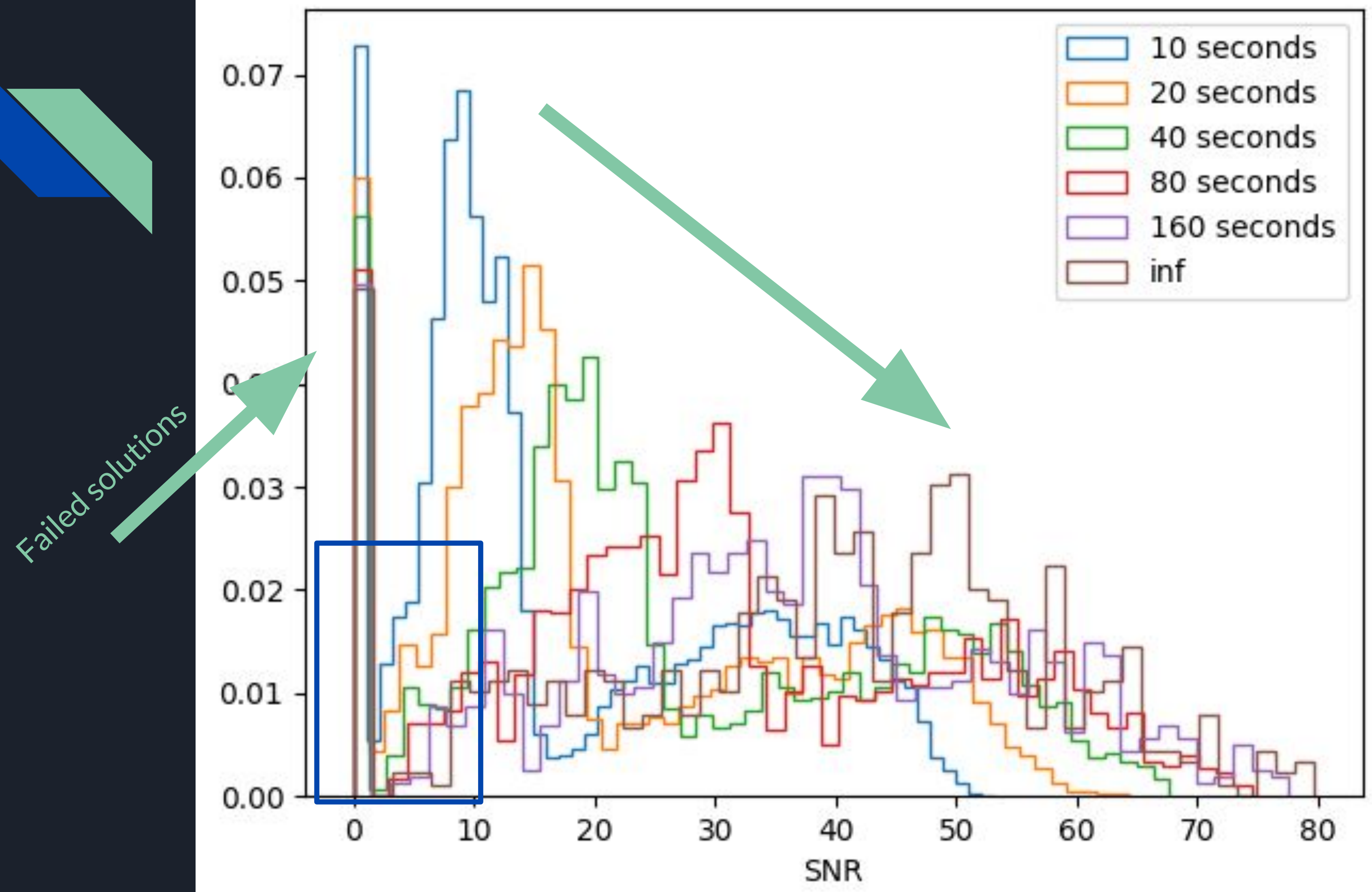
solint=inf~285s

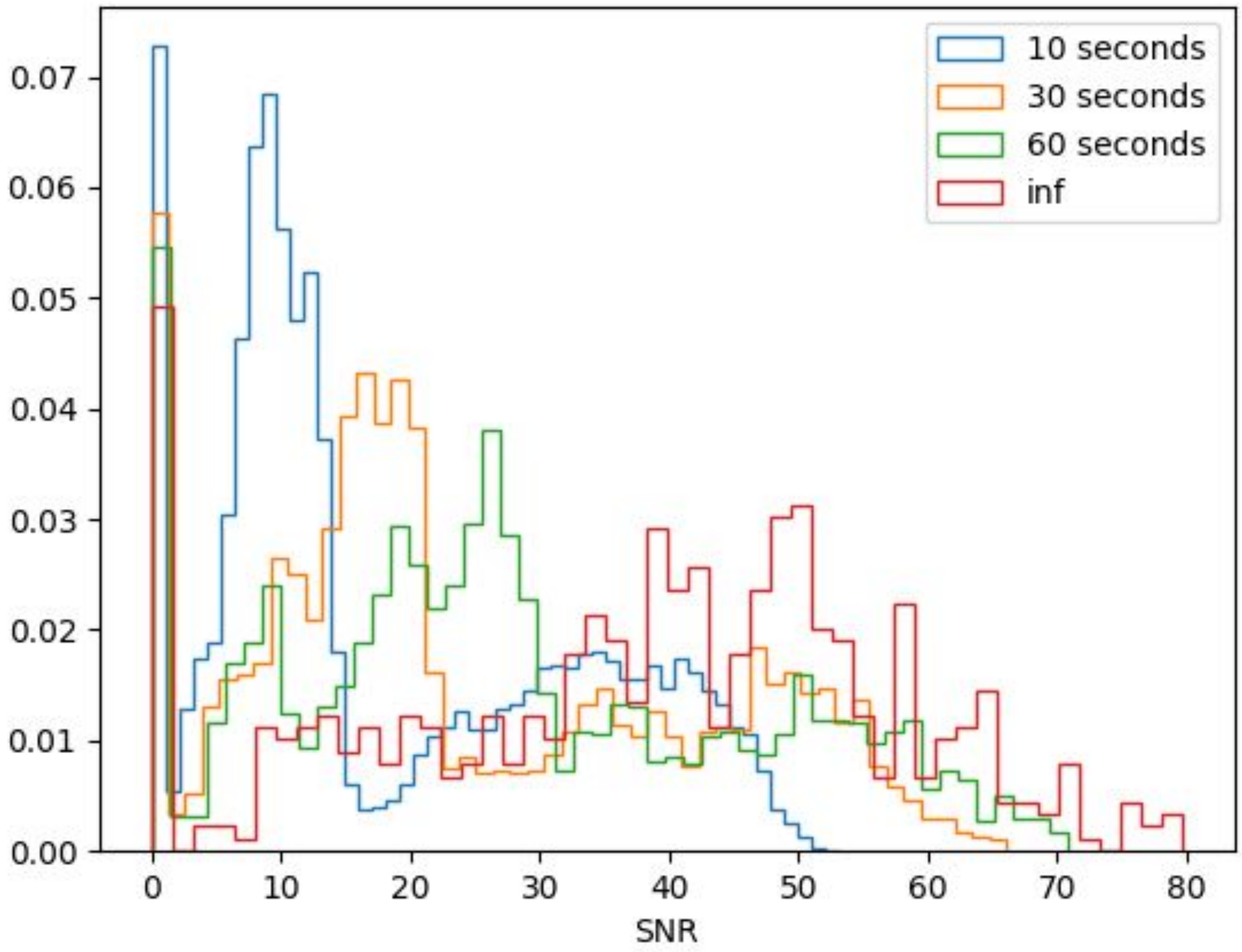



0.05
0.04
0.03
0.02
0.01
0.00
inf
0
10
20
30
40
50
60
70
80
SNR



10 seconds
20 seconds
40 seconds
80 seconds
160 seconds
inf
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
10
20
30
40
50
60
70
80
SNR


10 seconds
20 seconds
40 seconds
80 seconds
160 seconds
inf
0.07
0.06
0.05
0.03
0.02
0.01
0.00
0
10
20
30
40
50
60
70
80
SNR
Failed solutions


10 seconds
30 seconds
60 seconds
inf
0.00
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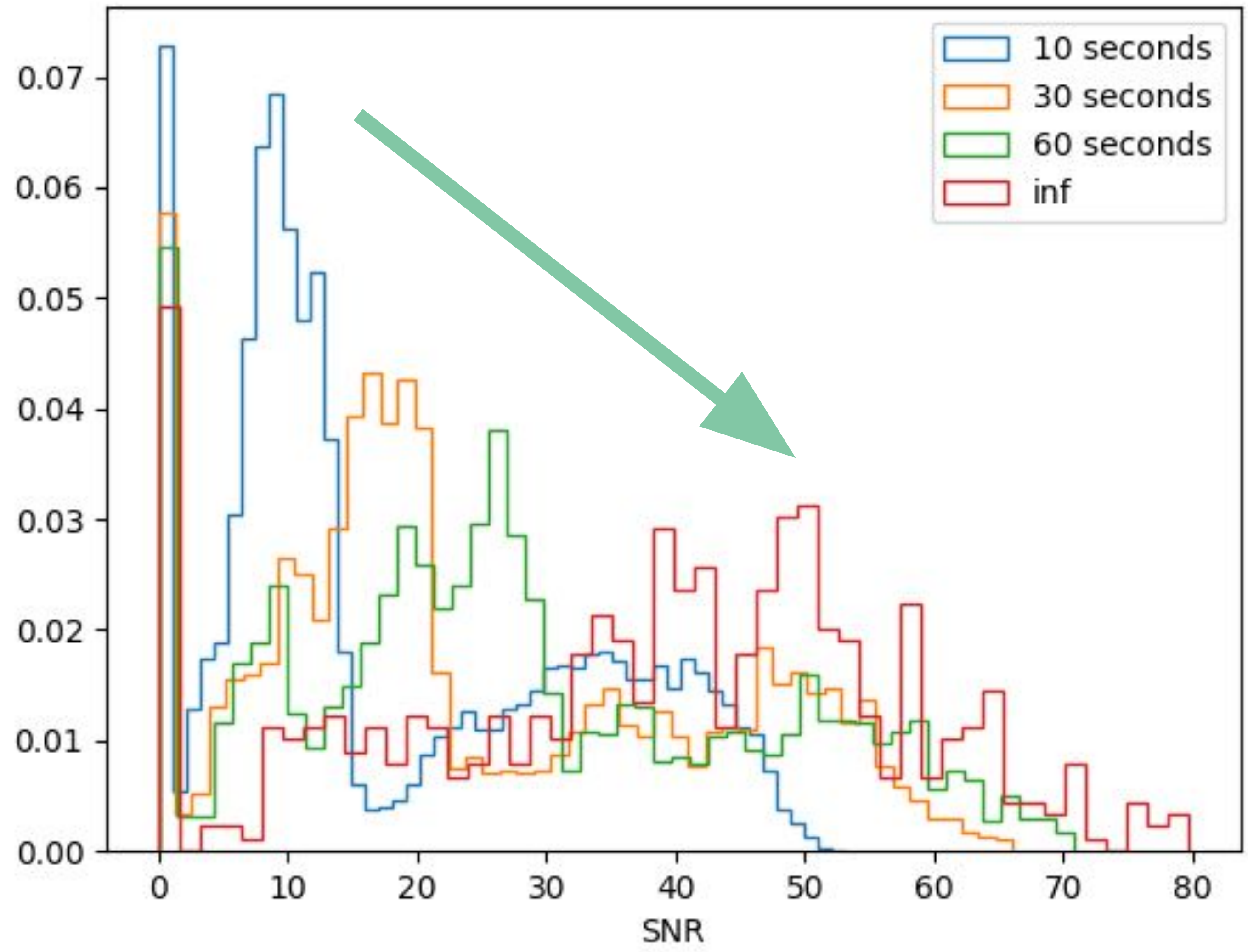
10
20
30
40
50
60
70
80
SNR


10 seconds
30 seconds
60 seconds
inf
0.00
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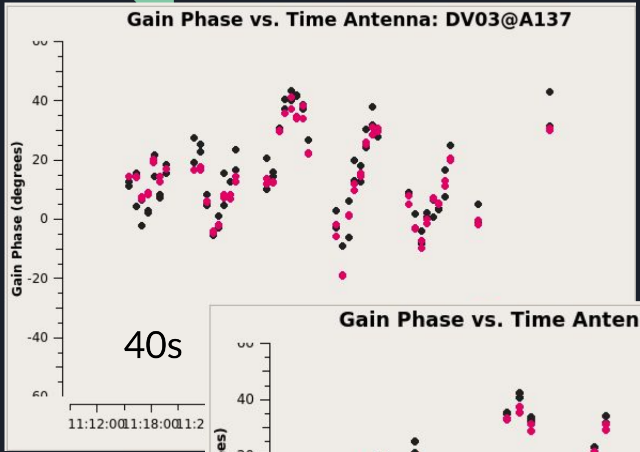
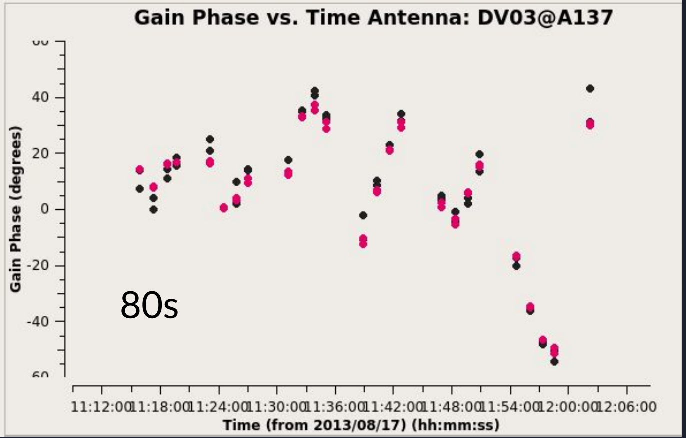
0.02
0.03
0.04
0.05
0.06
0.07
0
10
20
30
40
50
60
70
80
SNR

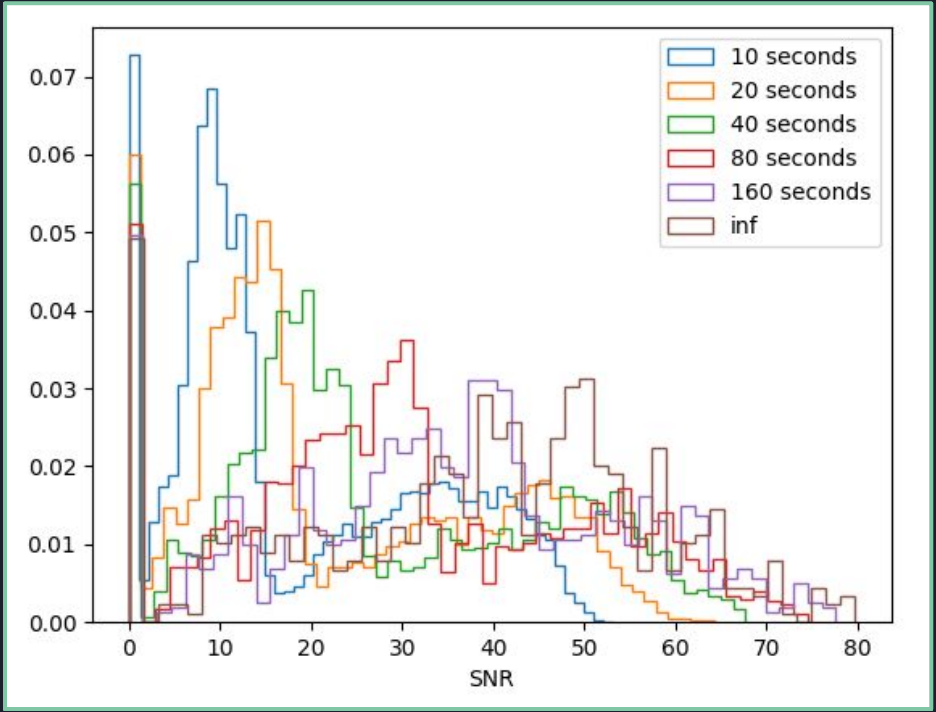
What you want in a solution interval

The shortest solution interval that balances (1) sampling the variations in the solutions, and (2) flagging the least amount of solutions.

solint~40-80s and minsnr~5

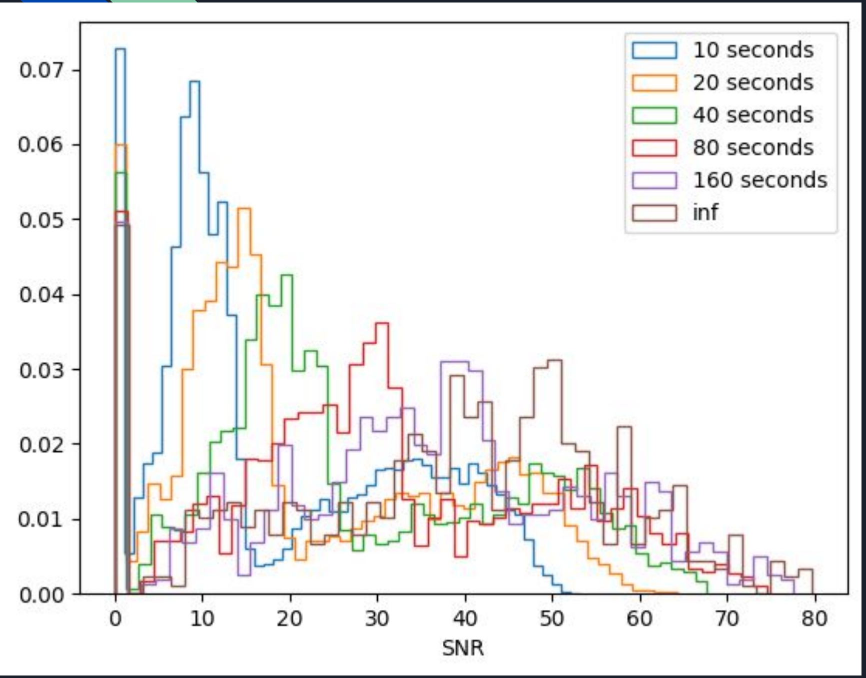




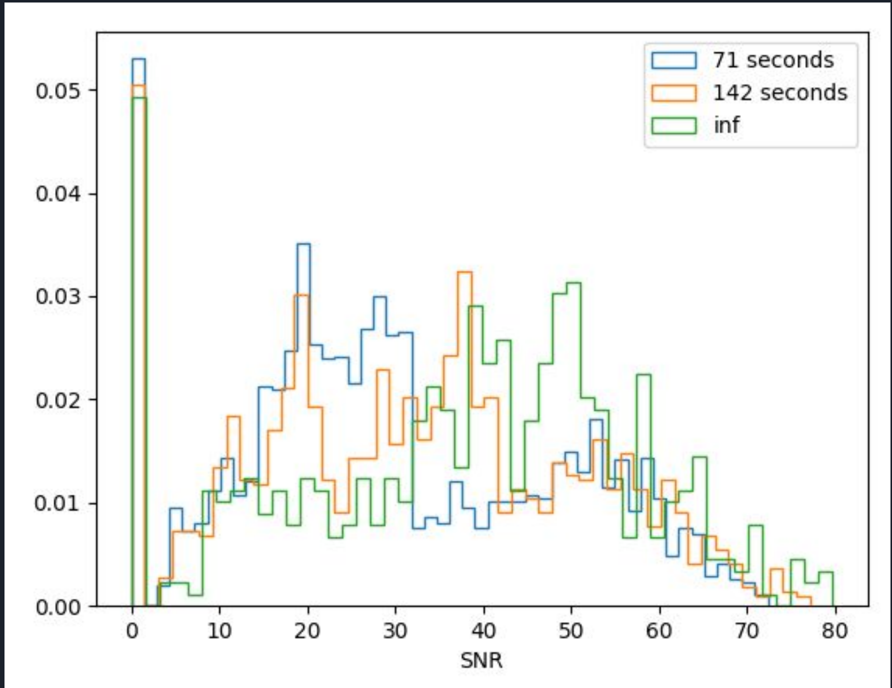


Inspiration from: https://casaguides.nrao.edu/index.php?title=VLA_Self-calibration_Tutorial-CASA5.7.0

Ways of applying solution intervals with rounds of self-calibration



- Reduce solution intervals from inf (naturally improving model and increasing S/N) (inf, inf/2, inf/4, etc.) (conservative approach way to do left)



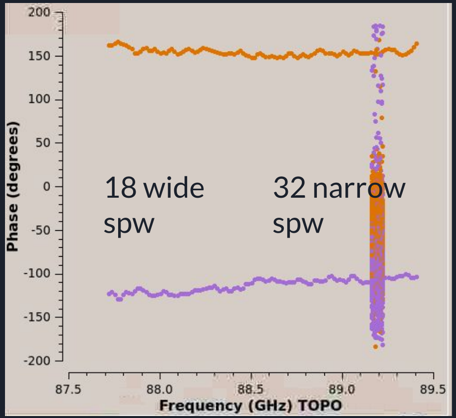
- Find optimal solution interval using S/N plots (higher S/N and flagged minimal solutions) apply and look at histograms again to find optimal solution interval and apply again

Increasing SNR in your gaintables

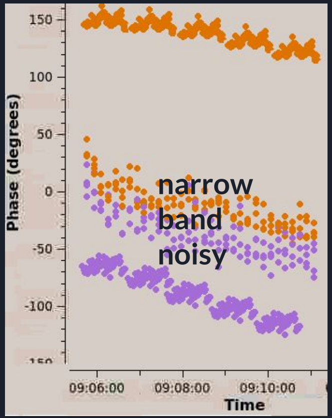
- Combine
  - Spectral Windows (e.g. 4 x equal spw doubles S/N)
    - If gain solutions are quite similar
    - gaincal(combine='spw') -> applycal(spwmap='[0,0,0...number of spw]')
    - Some spw normal-broad and others very narrow? Apply good solutions from broad windows to all spw (bandwidth switching)
    - **check if the spws have offsets (anything more than scatter in phase solutions ~10deg)
      - by plotting previous solutions and if so, will have to derive phase solution w bandpass calibrator with long solint (reach out to colleagues for help with this)
  - Polarizations
    - If gain solutions are quite similar
    - gaincal(gaintype='T')

Combining spw/polarizations? Things to check:

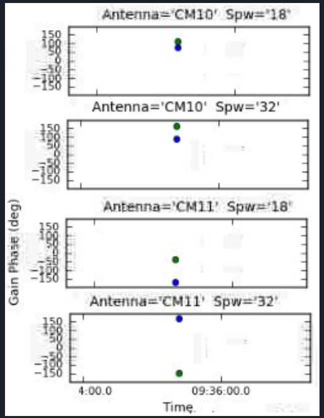
- Some spw OK, others very narrow?
- Apply good solutions to all spw (bandwidth switching, use spwmap)
  - Usually phase-referencing removes phase offsets between spw, correlations.
  - Plot phase-time to check (b). If offsets >5-10 deg, use bright source to remove
  - Exaggerated example:



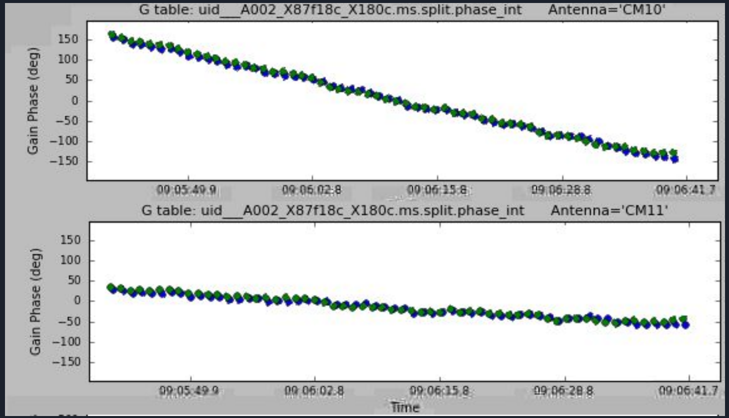
(a) Bandpass calibrator
Polarizations XX, YY
Use as DiffGainCal (could, alternatively, use target itself)



(b) Target to self-calibrate. WVR, Tsys, BP solutions applied.
spw, poln phases have similar slopes, ~constant time offset



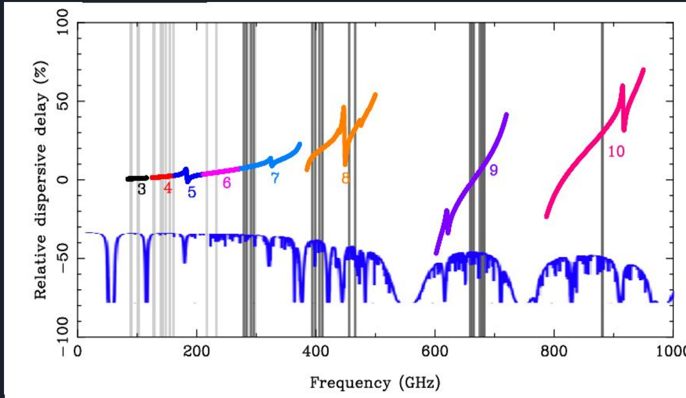
(c) DGC: average all times, solve for phase
One correction per poln, per spw



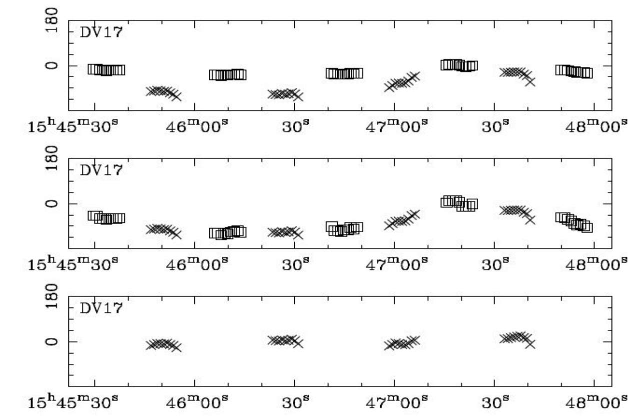
(d) Apply DGC solns to target, derive time-dependent phase solutions for **wide spw 18**, p1
Corrections have same slope for X, Y, average about 0
Applycal DGC solutions and p1 to spw 18 & 32

Transferring phase across large frequency intervals

- In ALMA bands, atmosphere mostly has refractive index ~1
  - Phase delays (cause of error) scale linearly with frequency
    - e.g. 45° correction at 220 GHz ⇒ 55° at 270 GHz
  - **P**hase**D**elay suffix in CASA scales solutions by frequency
    - e.g. `applycal interp='linearPD'`
  - Usually negligible within one tuning,
    - Significant if frequency changes by ≳20%



Normalised atmospheric delay (colours), absorption (blue), v. frequency



- Phase solutions: band 3 squares □, band 7 crosses x
- Scale band 3 phases to band 7 frequency
- Apply to band 7; residuals ~0

Additional 'phase up' needed for Band to Band, see *Asaki et al. 2019*

(2) What can't be cured by self-calibration?
(ALMA examples) (data might *also* need self-cal)

- Targets with S/N too low or where thermal noise is already reached
  - Although small phase errors can smear flux with negligible off-source noise - might be worth a try
- Bad data (maybe identified from failed solutions)
  - Pure noise (phase incoherent on all scales), spikes, very low amplitudes - **flag it!**
- 'Basket-weaving' /negative bowl - too few intermediate spacings/missing short-spacing flux
  - Reduce weight of long baselines with `uvtaper`, consider multiscale (`mtmfs`)
    - May need additional more compact array or Total Power data
- Target variability - spottiness around compact source gets worse with self-cal
  - Inspect uv amps v. time, possibly image in time chunks and/or `uvsub` variable core
- (unknown) Antenna position, pointing errors can be mitigated for compact, central sources
- Baseline-dependent errors (i.e. not antenna effects) need great care
  - `gaincal` solves per-antenna; `blcal` solves per baseline - need perfect model and high S/N
- Broad stripes shifting over planes of cube may be bandpass/delay errors
  - Can original bandpass/delay calibration be improved?
    - BP self-cal needs v. v. high S/N, smooth continuum, perfect model, spectral terms

Q: When do I stop doing rounds of self-cal?
A: When things stop getting better (recap)

- Carry on while you estimate something can be improved: Phase
    - If no/v. few solutions failed in the last gaincal, and the target phase still have errors (not just noise)
        - Try a shorter solint?
    - If you compare image with model and the mask you used and there is emission not in the model
        - Continue to improve model
    - Usually, want to get phase corrections as good as possible first
        - This reduces noise, improves image fidelity and may increase flux as correlation improves
    - Stop (or try something different) if S/N does not increase or target flux falls
        - Check improvements are realistic… beware forcing extended flux into a point
- For good S/N (here, ~100) try Amplitude self-cal applying phase solutions
    - Make an image+model including spectral index with deconvolver='mtmfs', nterms=2
        - Clean down close to the noise to make sure all the target flux is in the model
    - Examine visibility amplitudes - usually errors change more slowly than phase
        - Usually start with longer solint than the final phase solint
            - If, after amp self-cal, image flux is lower, try solnorm=True
                - Do another round improving model? Or maybe data are not bright enough
    - Stop (or try something different) if S/N does not increase or target flux falls

(3) More aspects of self-calibration

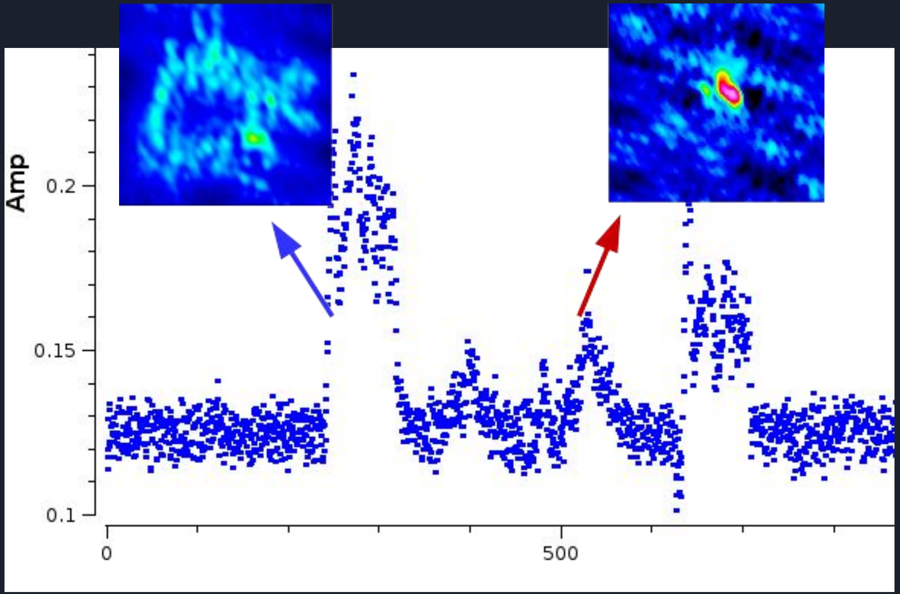
- As with any imaging, include **all significant sources in the field of view** to prepare model for self-calibration
- Check visibilities, after applycal, for bad data appearing as S/N increases
- For **mosaics** use field with brightest peak, apply to all fields (`gainfield` parameter in `gaincal/applycal`)
- For (weak) **polarization**: ALMA observes in X and Y receiver polarizations:
  - Make I (total intensity) model image
  - `gaincal gaintype ='T'` (average correlations), real X -- Y differences are preserved
- For **extended objects** can use multiscale clean to produce model
- Amp self-cal to make **flux scale consistent** (assume no time variability!)
  - Flux scale offsets between observations at different times, and between spw (e.g. atmospheric effects)
    - Use continuum, may need to allow for **spectral index** α (tclean `deconvolver='mtmfs'`)
      - Flux density at freq ν_1 is related to that at ν_0 by $S_1 = S_0\,(\nu_1/\nu_0)^{\alpha}$
      - e.g. S_0= 9 mJy, ν_0 = 86 GHz, ν_1 = 100 GHz, α= 2, so $(S_0 - S_1)$ = 3.2 mJy
        - If change in flux $(S_0 - S_1)$ is more than ~$3\sigma_{rms}$ **in each spw**:
  - Use `nterms=2` in making image model, `ft *tt0` and `*tt1` models

(4) Calibrate on line or continuum?

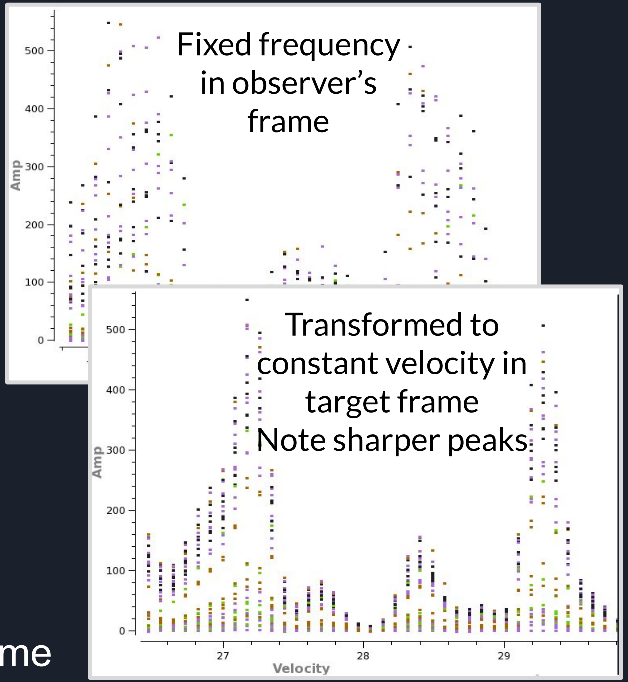
- Start with continuum if possible to make multiple observations consistent (point (3))
  - Is S/N of brightest line peak much higher than for continuum?
  - Or, is line but not continuum bright enough to self-cal?
- Might be possible to self-calibrate on line brightest channel(s)

- Even after self-calibration on continuum, S/N on a line might be higher
  - Here, VY CMa best continuum S/N ~200
  - Potential maser peak S/N ~1000
    - After continuum self-cal, improve line S/N

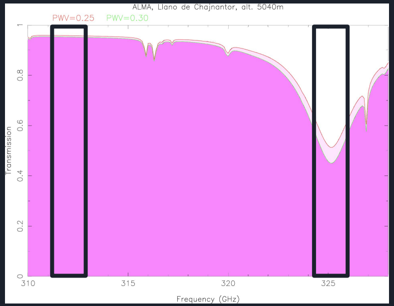
Tip: 'Triangular' lines more likely to have compact emission for self-cal
  - Lower spectral peak but higher Jy/beam



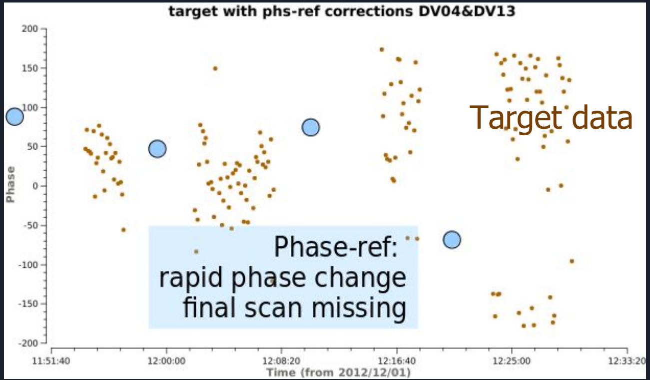
Spectral line for self-calibration



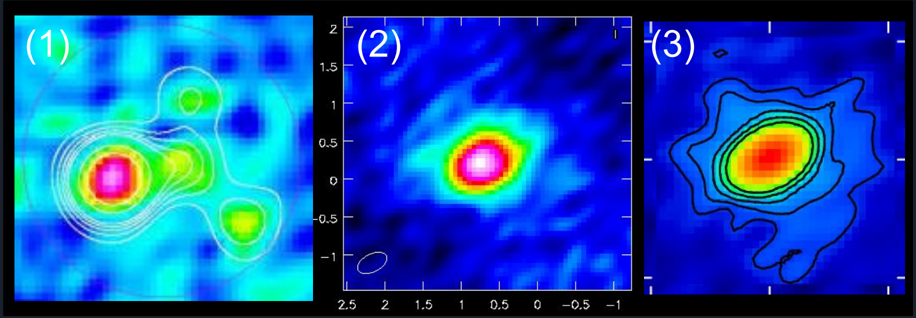
- Combining executions?
  - Earth rotation shifts channel-velocity correspondence
- For each EB, use `mstransform` to split spw's into V_{LSR} frame
  - Calculate start channels at same velocities for each spw for concat
- Select peak channel for imaging
  - If flat-topped maybe a few channels but check position same
    - Take care not to decrease averaged S/N by including weak channels
  - Insert model just for appropriate channel(s)
- Use gaincal just for selected channel(s)
- Apply corrections to all channels
  - Exceptionally, might confine to one sideband if drastic atmospheric differences



(5) Rescuing poor data

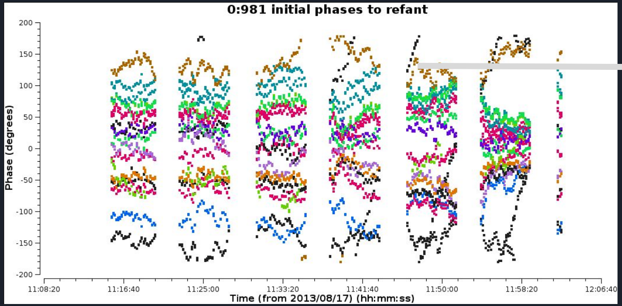


- First image (1) with all target data has 'ears'!
  - 3rd target scan is noisy
  - 4th scan has no phase reference
  - Make image, model from scans 1-2
  - Use to self-calibrate all scans

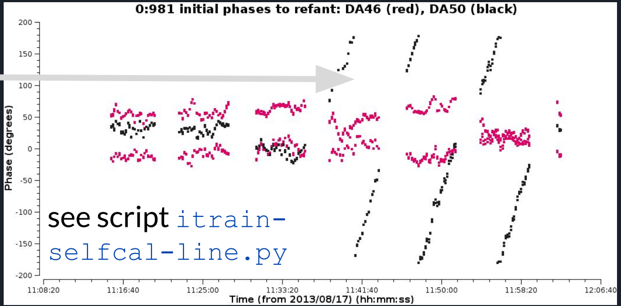


(1) All scans, no self-cal (2) Scans 1-2 first image
(3) All scans after self-calibration
IRC+10216, *Decin et al. 2015*

- VY CMa DA50 phase wraps

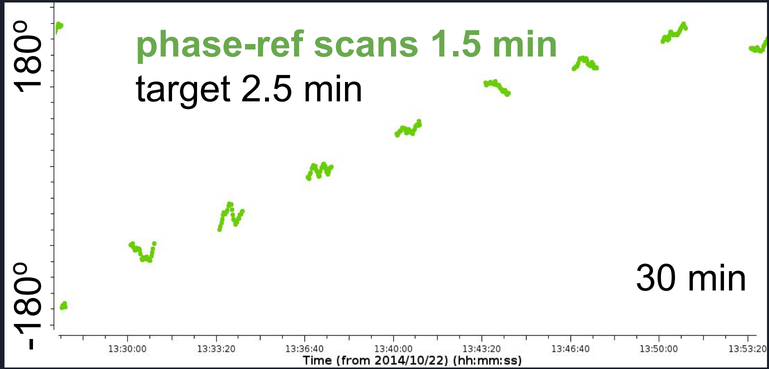


DA50: scan-average would decorrelate
Exclude for self-cal until good model derived
Then include, phase-self-cal with short solution interval



see script `itrain-selfcal-line.py`

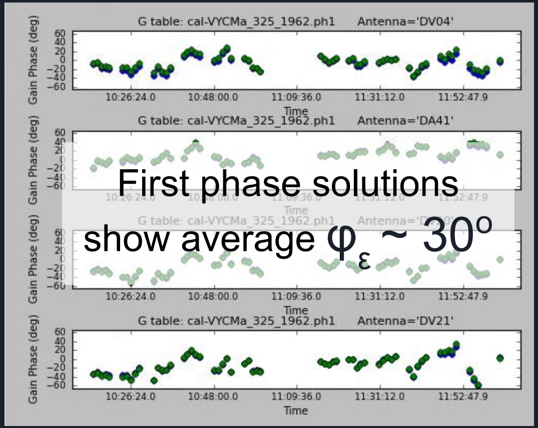
(6) Sources of error
Target-phase ref separation in time and direction

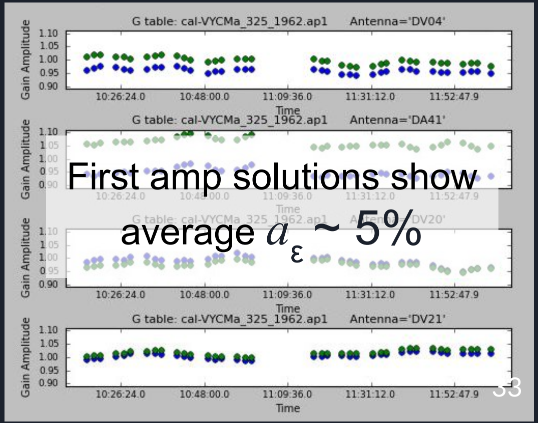


- Phase drift with time: example
  - Raw calibrator phase change $d\varphi_{atm}$ ~ π per ~20 min
  - ~36° phase deviation in each phref-target cycle
- Separation on sky equivalent to time offset
  - Phase-ref: target separation $d\theta$ = 2° = 120 arcmin
    - 1° angular separation ≡ 4 min time (4^m RA)
  - ($d\theta$/360°) x cos(Dec.)x 24hr ~7.5 min at Dec. 20°
  - In 7.5 min, $d\varphi_{atm}$ gives π x 7.5/20 ~65° phase change due to sky separation
  - Phase-ref corrections error ~($\sqrt{(65^2+36^2)}$)/2 ~ (75°)/2 when interpolated across target scans
    - Mitigated if many scans, baselines, with errors in different senses
- Jitter on scales shorter than a scan also remains
  - ~10° in 30 sec
- Averaging phase fluctuations causes amp decorrelation
- Visibility $V = V_o e^{i\varphi}$ so $\langle V \rangle = V_o \langle e^{i\phi} \rangle = V_o e^{-(\phi^2_{rms})/2}$
  - **Phase error φ_ε 10° produces 2% reduction in Visibility amplitude**

(7) Bright Sources: Dynamic Range

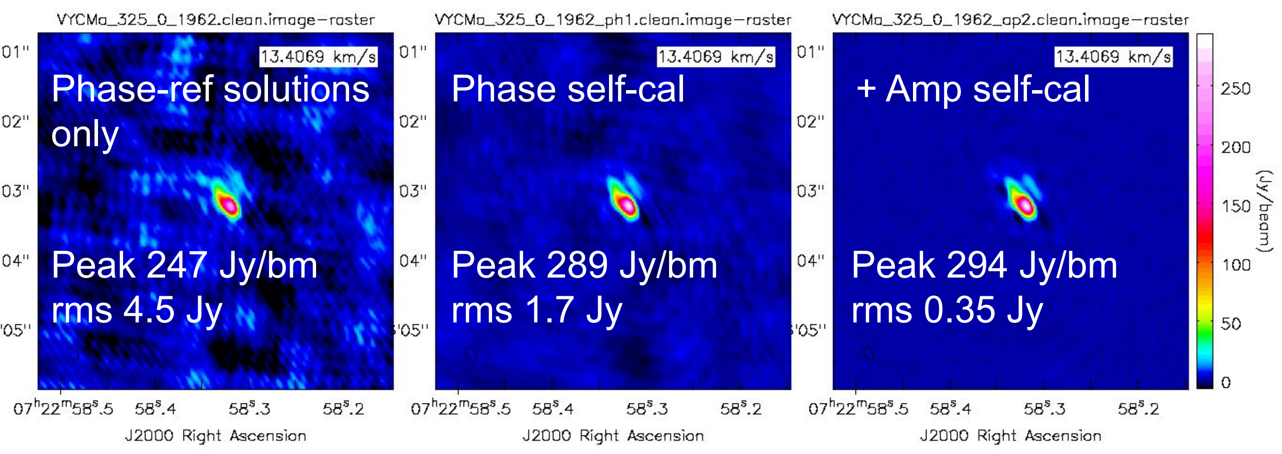
VY CMa brightest 325 GHz maser channel





- Dynamic range DB(φ_ε) due to phase errors φ_ε (rad) on all baselines, per scan for N antennas ~ N / φ_ε
  - M periods when φ_ε independent as atmosphere blows over
    - $\mathrm{DB}(\phi_\epsilon) = \sqrt{M/2} \times N/\phi_\epsilon$
- Similarly for fractional amplitude errors A_ε
    - $\mathrm{DB}(A_\epsilon) = \sqrt{M/2} \times N/A_\epsilon$
- 2 hr obs, 2.7 km b'lines/5 km/h wind~30 min so M=4
  - e.g. φ_ε = radians(30°)~0.5, N = 20 gives **DB(φ_ε)~54**
  - A_ε = 0.05 so **DB(A_ε)~280**
- Even if no errors transferring corrections to target, limited by phase-ref dynamic range *(see Synthesis Imaging ch 13)*

VY CMa maser self-calibration - compact peak



$$V = Ae^{i\phi} = A(isin(\phi) + cos(\phi))$$

Phase errors are sin (odd), asymmetric +ive/-ive in image

Amp errors are cos (even) symmetric function in image

- Dynamic range DB before self-cal 55 (DB 54 predicted from φ_ε 30°)
- After 1st phase self-cal DB 170
- After phase and amp self-cal DB 840
- Phase-ref J0648-3044 0.44 Jy, rms in line-free parts of 325 GHz spw 4 mJy
  - Best dynamic range possible without self-cal 440/4 = 110

(8) Methods of Implementing Self-cal

1. Incremental build-up of corrections more flexible, less increase in data volume
   a. Make model, derive calibration table p1, apply
      i. Applycal always uses the *data* column and (over)writes the *corrected* column
   b. Image again (*corrected* column), calibrate again (p2) applying table p1 in gaincal, applycal with p1+p2
   c. Continue adding tables until no more improvement, then apply all tables and split out calibrated data
      i. You can discard a model or a gain table, for example if the final amplitude cal makes a better model, throw away the last phase table and the amp table and redo those steps
      ii. Always, *whatever table(s) you apply as gaintable in gaincal, apply those plus the new table in applycal*
2. Split corrected column from MS after each correction can be simpler but multiplies data volume
   a. Make model, derive calibration table p1, apply, split out *corrected* column
      i. So in new MS, previous corrections are in *data* column
   b. Image split data, derive calibration table p2, apply just new table p2 to new MS, split that
   c. Continue until no more improvement and final split of calibrated data

(9) Why phase first, then amplitude?

- If there are phase errors, the amplitude will decorrelate
- Phase fluctuations due to atmospheric refraction change faster than amplitude drifts due to absorption/emission
  - e.g. ALMA measures PWV every few sec, T_{sys} every few minutes
- Amplitude solutions require higher S/N per antenna - longer solint
- Analogous to closure relations (not actually method used in gaincal):
  - Visibility for baseline between antennas 1 and 2: $V12 = Ae^{i\varphi 12}$
  - Add visibility phases for 3 baselines and phase errors cancel out - phase closure

$$[(\phi 12 + (\phi_{\epsilon 1} - \phi_{\epsilon 2})] + [(\phi 23 + (\phi_{\epsilon 2} - \phi_{\epsilon 3})] + [(\phi 31 + (\phi_{\epsilon 3} - \phi_{\epsilon 1})] = \phi 12 + \phi 23 + \phi 31$$

  - Amplitude closure needs 4 antennas, i.e. more baselines contribute to each solution

$$\frac{[A12 A_{\epsilon 1} A_{\epsilon 2}] \times [A23 A_{\epsilon 3} A_{\epsilon 3}]}{[A34 A_{\epsilon 3} A_{\epsilon 4}] \times [A41 A_{\epsilon 4} A_{\epsilon 1}]} = \frac{A1A2 \times A2A3}{A3A4 \times A4A1}$$

    - Very occasionally, an antenna is totally mis-scaled in amplitude - need to fix it early on

(10) Final image accuracy

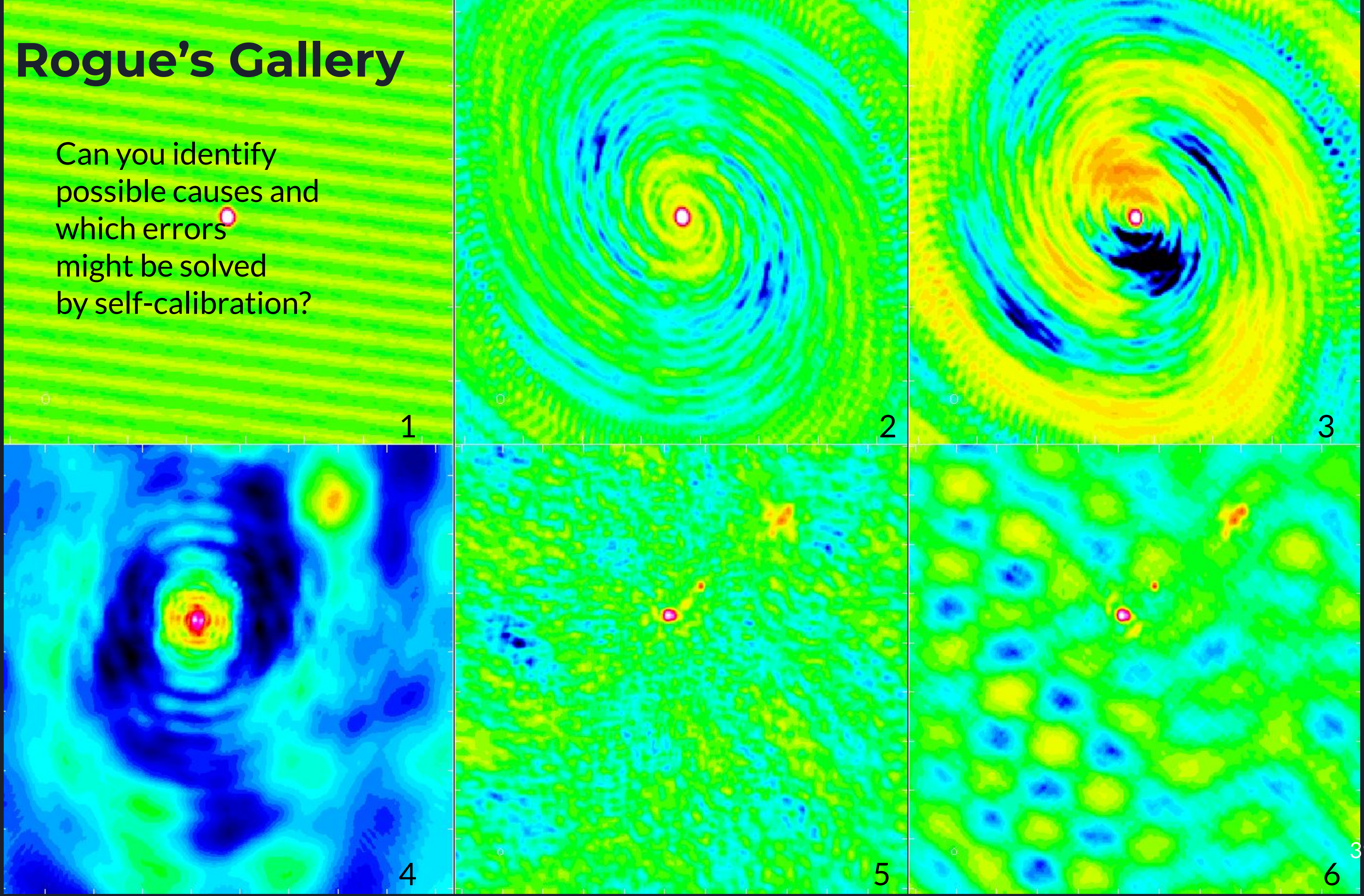
- Astrometry - factors influencing accuracy
        - Antenna positions
        - Phase reference position accuracy
        - Phase correction accuracy: phase rate, offsets in time and angular separation
        - Target S/N
        - Resolution
    - First image after applying phase reference solution gives target position
        - **Using first image as model keeps astrometrically accurate position**
            - But self-cal cannot *improve* absolute position even if target S/N improves
- Flux scale (photometry)
    - Mostly determined by flux standard accuracy and determination of phase reference flux
        - Can be over-estimated (`fluxscale` biased to higher values in noisy data)
        - Target flux may be reduced by phase decorrelation or not all flux in amplitude model
        - More rarely, overcleaning a compact model may pile in too much flux

My image is still awful! Noisy/no source/....

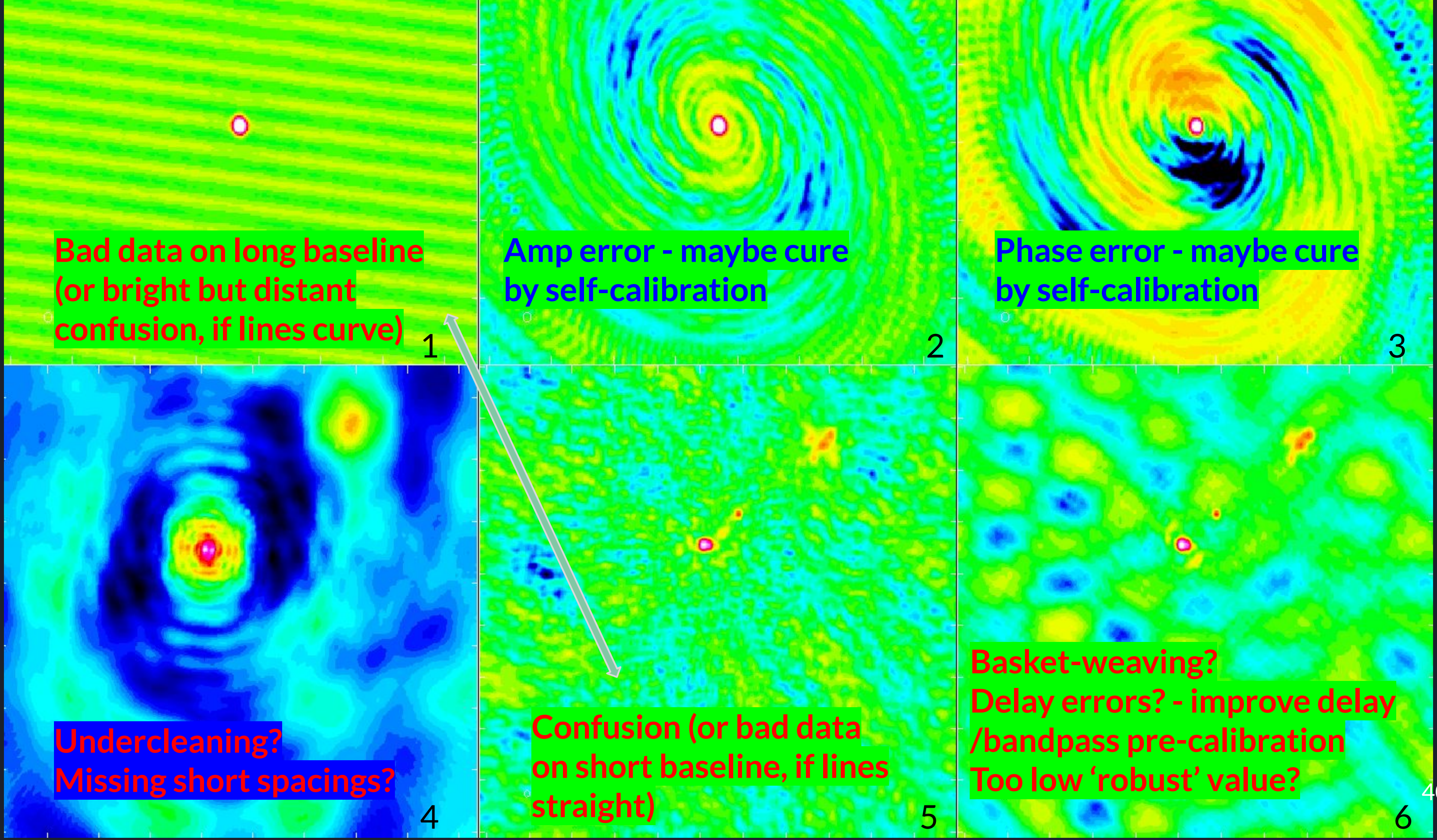
- Check weblogs/QA log, previous calibration - is phase ref OK?
- Check all non-default settings in tclean are appropriate
- Check how much data you have in plotms (so flagged data don't appear)
  - Use sensitivity calculator to predict rms - get PWV from weblog/QA logs
- You've checked for bad data
  - If you tried self-calibration, were the solutions coherent? Applied correctly? Right model?
- Does more channel averaging or tapering the beam improve S/N?
- Is there more emission in the field of view? (especially nearby galaxies, Galactic SFR)
  - Make larger image, inspect uvdistance plot
  - Do you need more compact array/total power data to fill in missing spacings?
    - Already combined? Are positions and flux scale correctly aligned?
- Wide bandwidth continuum? Solve for spectral index (see More Aspects slide)
- Extended emission? `deconvolver='mtmfs'` or `'multiscale'`

Rogue's Gallery

Can you identify
possible causes and
which errors
might be solved
by self-calibration?



Rogue's Gallery



Resources/More information

VLA Self-cal Tutorial (https://casaguides.nrao.edu/index.php?title=VLA_Self-calibration_Tutorial-CASA5.7.0)

ALMA Self-cal Tutorial (https://casaguides.nrao.edu/index.php?title=First_Look_at_Self_Calibration)

Advanced Gain Calibration Techniques (Brogan et al. 2018): https://arxiv.org/abs/1805.05266

INAF (http://www.alma.inaf.it/images/Selfcalibration.pdf)

NAASC (https://science.nrao.edu/facilities/alma/naasc-workshops/nrao-cd-wm16/Selfcal_Madison.pdf)

ALLEGRO (https://www.alma-allegro.nl/wp-content/uploads/2018/10/Allegro_CASAtrainingDay2018_selfcalupdate.pdf)

ERIS (https://www.chalmers.se/en/researchinfrastructure/oso/events/ERIS2019)

DARA (http://www.jb.man.ac.uk/DARA/)

Synthesis Imaging Taylor, Carilli & Perley (http://www.phys.unm.edu/~gbtaylor/astr423/s98book.pdf)

ALMA technical handbook for current cycle

ALMA memos

Additional slides

Advanced script that shows how self-calibrate using a line and how to recover antenna DA50

In this tutorial we provide an example script on how to perform self-calibration of a dataset using a strong maser line (instead of using the continuum):

`itrain-selfcal-line.py`

In this case the antenna DA50 is not flagged in the Measurement Set. Given its suspicious behaviour, the antenna is excluded of the first cycles of self-calibration. In particular, the antenna is excluded at the time of generating new models with `tclean` by specifying `antenna='!DA50'`.

Given its behaviour, we exclude antenna DA50 until a good model is derived and then we include it for a phase self-calibration step with a short solution interval.