Self-calibration

Overview and line-continuum case study

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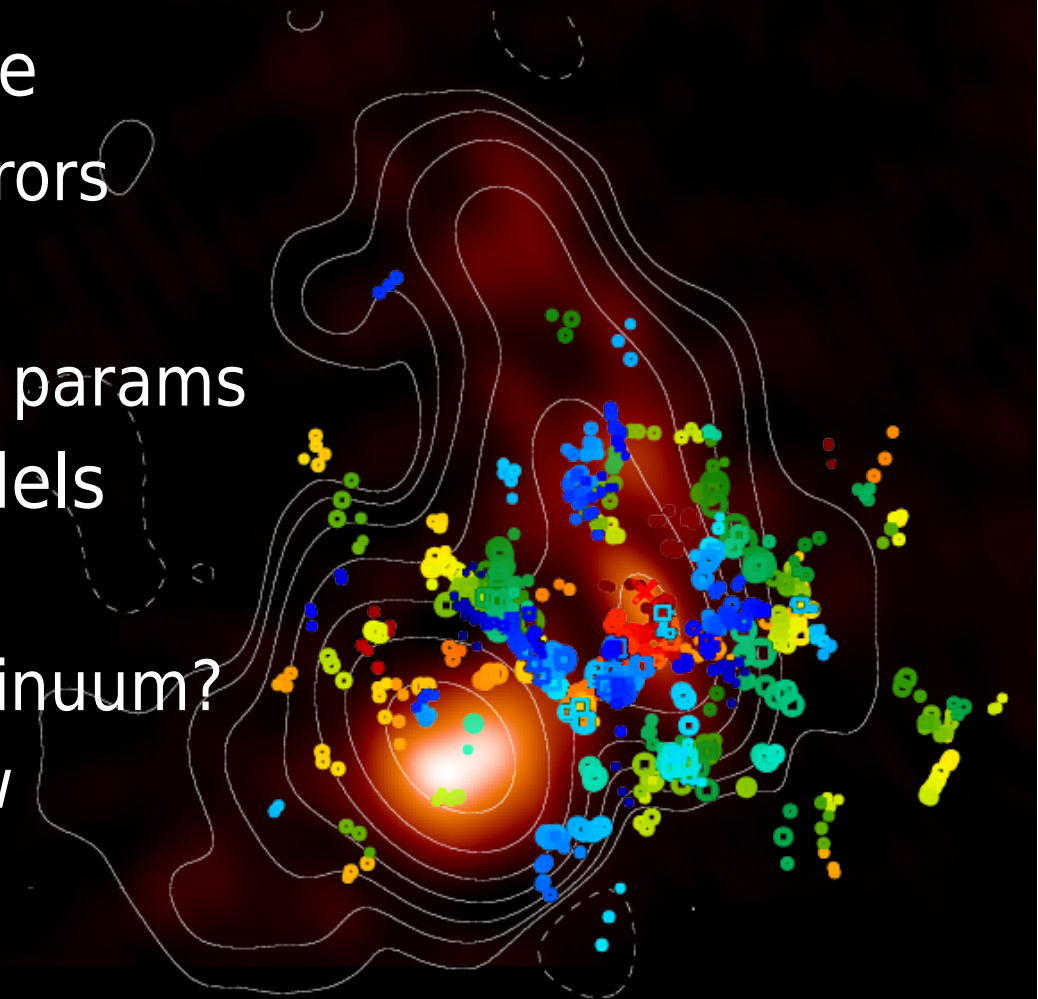
Fomalont, Muxlow, Laing, ALMA, e-MERLIN, DARA teams & '*Synthesis Imaging*

- 'Principles' and practice
  - Effects of ϕ & amp errors
- Whento self-calibrate
  - Strategies for setting params
- Clean Component models
- VY CMa SV data
  - Use line peak or continuum?
  - Transfer between spw



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Why self-calibration?

- Improve the image signal-to-noise ratio and fidelity (response to extended/faint structure)
- The atmosphere is similar, not identical, above the target and above the phase-ref
  - Offsets in distance and time
    - 1^{o} angular separation ≡ 4 min time (4^{m} RA at low Dec)
- The phase-ref model may not be perfect
- The phase-ref may be fainter than the target, so solutions are less accurate
- There may be no phase-reference at all!
- Maybe aligning data sets taken at different times
  - Position, flux scale (subtract variable components!)

When to self-calibrate

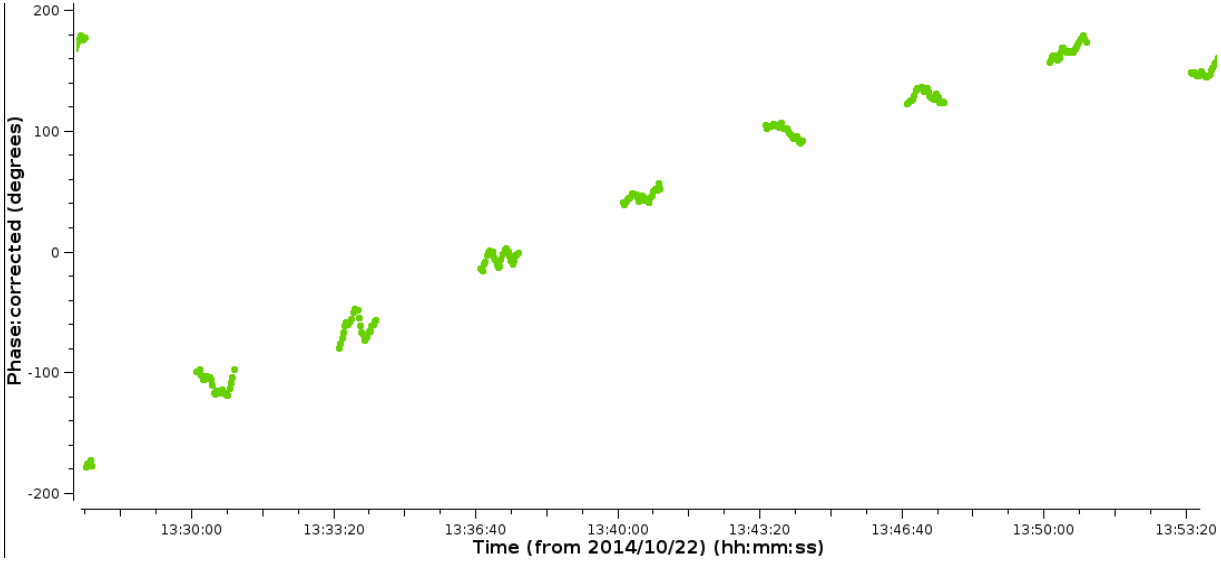
- What noise expected for actual duration & conditions?
  - Should you self-calibrate even if you have reached it?
  - Maybe!
    - See discussion on aligning astrometry/photometry
    - Low-level phase errors may add negligible noise but distort flux distribution, obscurring detail
      - ALMA LB 'basket-weave' background
  - What dynamic range is possible?
    - VLA, WSRT, (e-)MERLIN >1 000 000 (*Perley, Smirnov, Laing, Muxlow*)
    - ALMA ~100 000 (*Fenech*)? Anyone got better?
- More usually, expect e.g. 500, start from 100...
  - The fewer antennas, the more potential improvement

Prior calibration

- Apply instrumental corrections
  - T_{sys}, WVR etc.
- Edit obvious bad data
- Derive and apply frequency- and time-dependent corrections from astrophysical sources
  - Bandpass, flux scale
  - Phase-ref. phase and amp. corrections
    - Phase-ref close to target
      - Sky ***almost*** the same
        - But not quite!

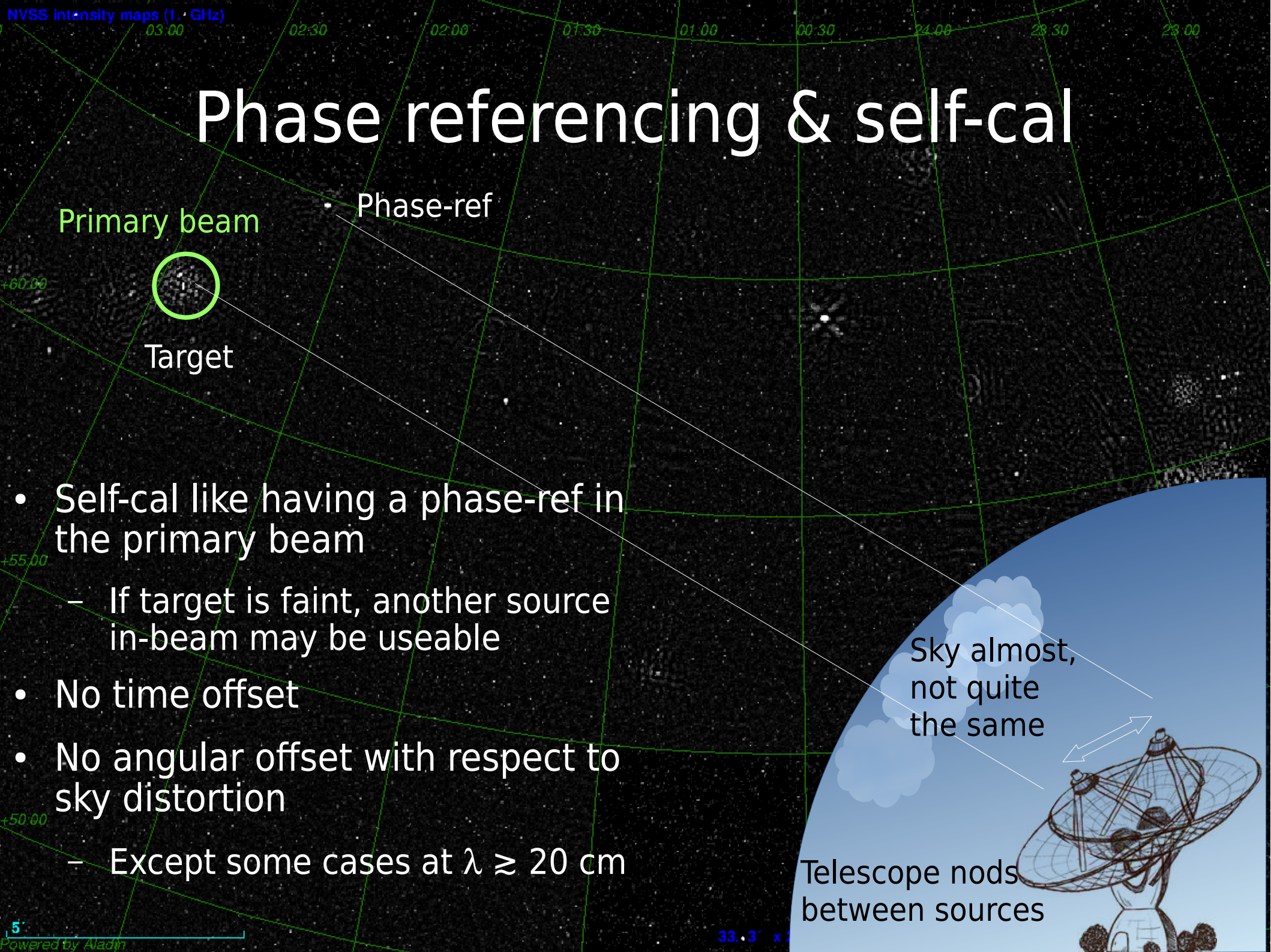
Phase transfer accuracy

- Sky separation
  - Raw calibrator phase change $d\phi_{atm}$ ~π per ~20 min



- Assume Dec 0^o
- Phase-ref: target separation, say $d\theta$ = 2^o = 120 arcmin
  - Convert θ in degrees to 'R.A.-like' units of time
    - ($d\theta$/360^o) x cos(Dec.)x 24hr ~7.5 min at Dec. 20^o
- In 7.5 min, $d\phi_{atm}$ gives π/8 ~65^o phase change
  - Phase corrections from the phase-ref may have up to ~65^o error when applied to the target

Phase referencing & self-cal



- Self-cal like having a phase-ref in the primary beam
  - If target is faint, another source in-beam may be useable
- No time offset
- No angular offset with respect to sky distortion
  - Except some cases at $\lambda \gtrsim 20$ cm

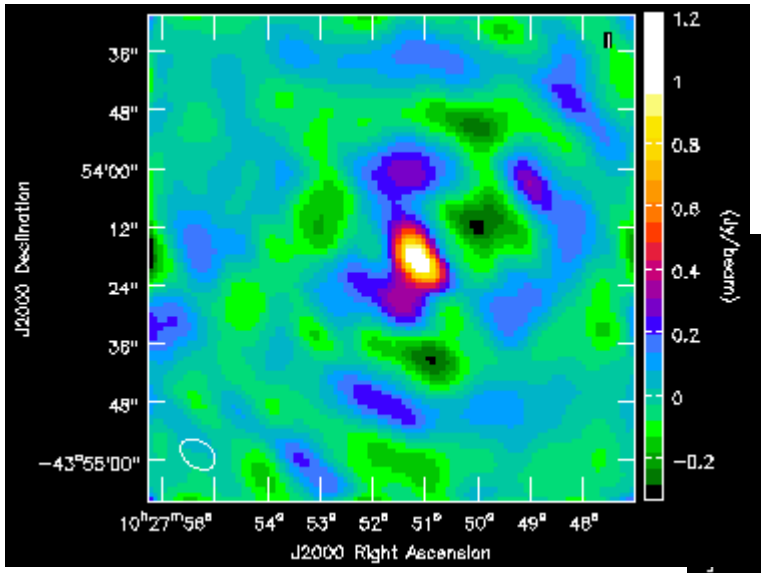
Calibration errors and dynamic range

- Dynamic range $D_{\mathrm{B}}(\phi_{\varepsilon})$ due to phase errors ϕ_{ε} (in radians) on all baselines, per scan for N antennas ~ N / ϕ_{ε}
  - e.g. radians (5°)~0.09 e.g. N 40 gives $D_{\mathrm{B}}(\phi_{\varepsilon})$~440
- Dynamic range $D_{\mathrm{B}}(\varepsilon)$ due to fractional amplitude errors ε on all baselines, per scan ~ N / ε so $D_{\mathrm{B}}(\varepsilon)$~400
- **A phase error of 5° is as bad as a 10% amp error**
- **Phase errors are sin (odd), amp are cos (even)**
- Phase errors are asymmetric (mirror) function in image
- Amp errors are symmetric function in image
- See *Perley* in NRAO 'Synthesis Imaging'

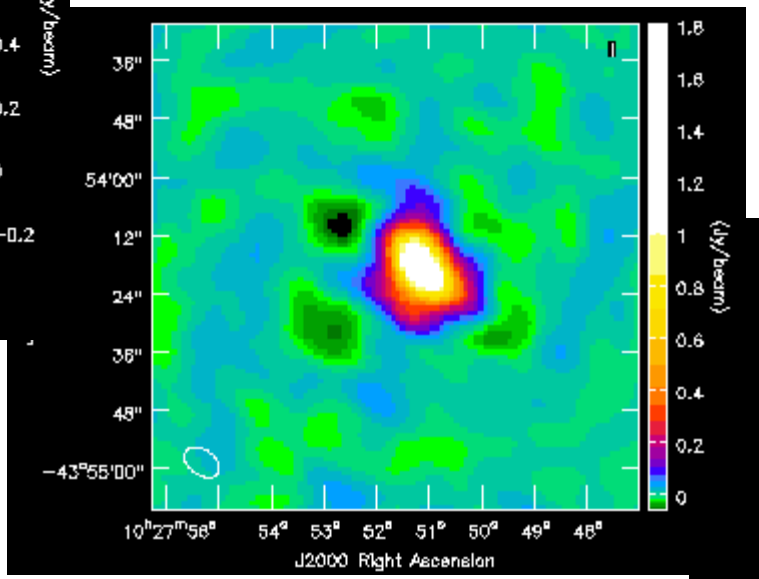
Phase effects in many scans

- Averaging phase fluctuations causes amp decorrelation
  - Visibility $V = V_o e^{i\phi}$ so $\langle V \rangle = V_o \langle e^{i\varphi} \rangle = V_o e^{-(\varphi_{rms}^2)/2}$
- Δt is interval after which phase errors independent
  - $\Delta t >$ scan (phase-ref:target cycle)
    - $\Delta t \sim$ duration of EB, ~30 min? Shorter on long baselines
- Phase errors ϕ_ε affecting all baselines limit dynamic range of M intervals Δt to $\sim \sqrt{M}\, N / (\sqrt{2}\, \phi_\varepsilon)$
  - e.g. M=2, N=35
  - $\phi_\varepsilon = 20^o = \pi/9$ (~0.35) rad ~ 6% amp decorrelation
    - Dynamic range D_B(all)<few100 (typical ALMA limit pre-selfcal)

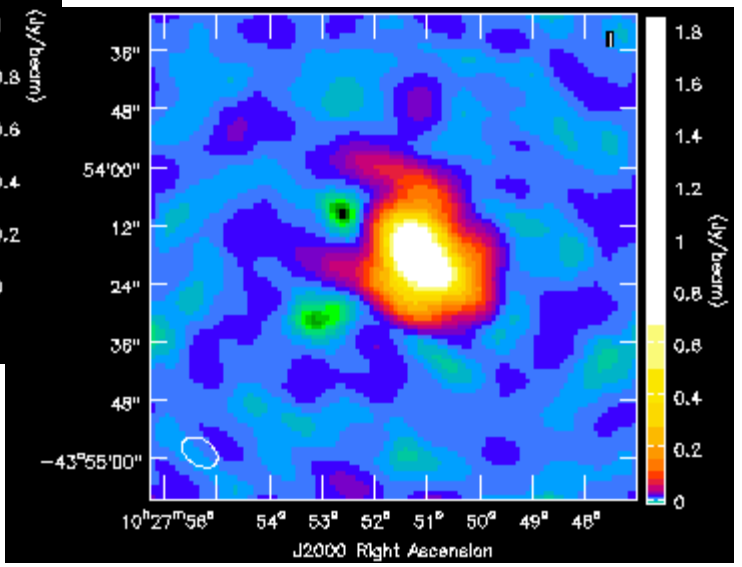
NGC 3254 phase & amp errors



Phase-ref solutions only
Anti-symmetric (phase) errors dominate

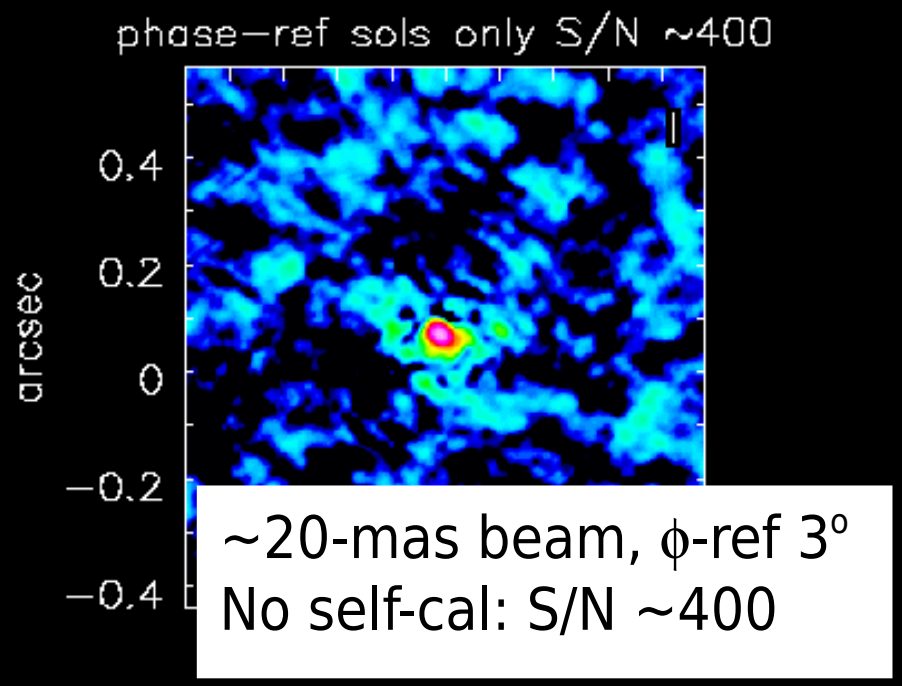


Phase self-cal only
Symmetric (amp) errors dominate

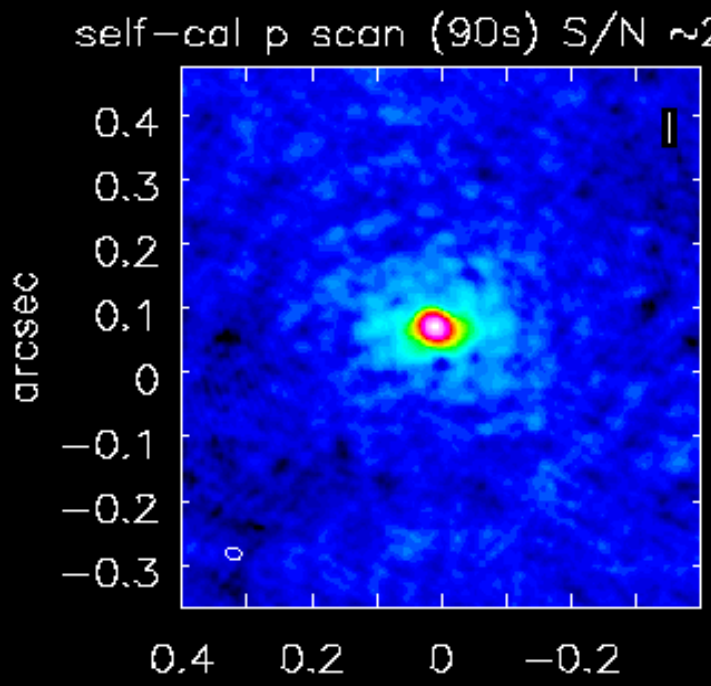


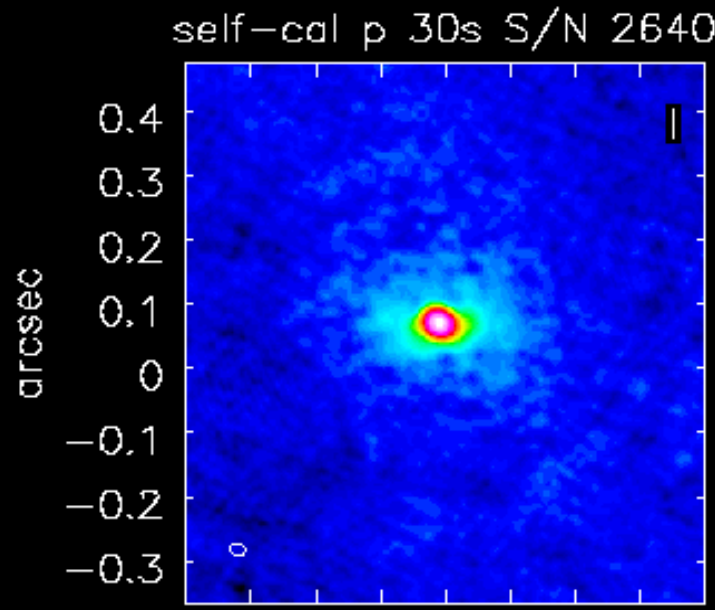
Phase and amp self-cal
Residual errors (model deficiencies?)

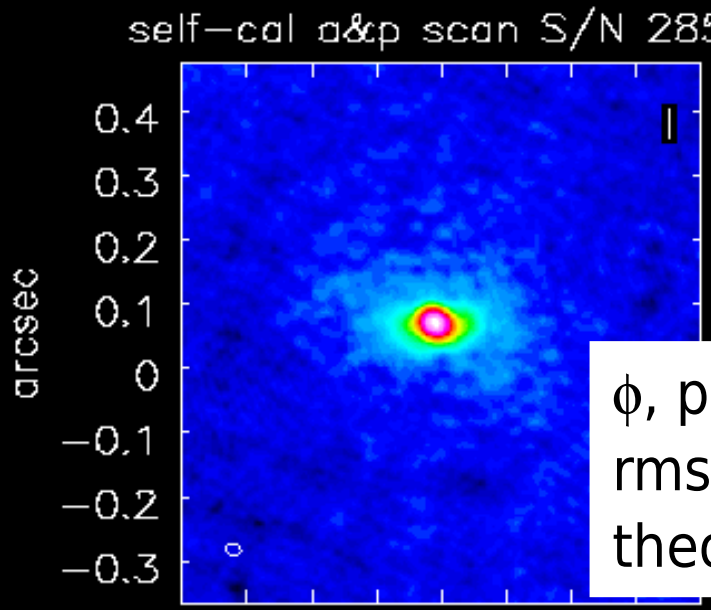
L2 Pup before & after self-cal

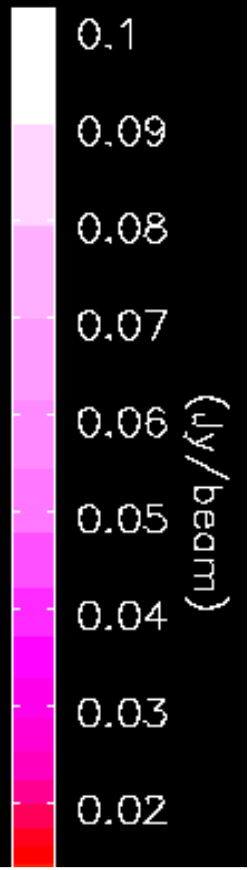


~20-mas beam, ϕ-ref 3°
No self-cal: S/N ~400





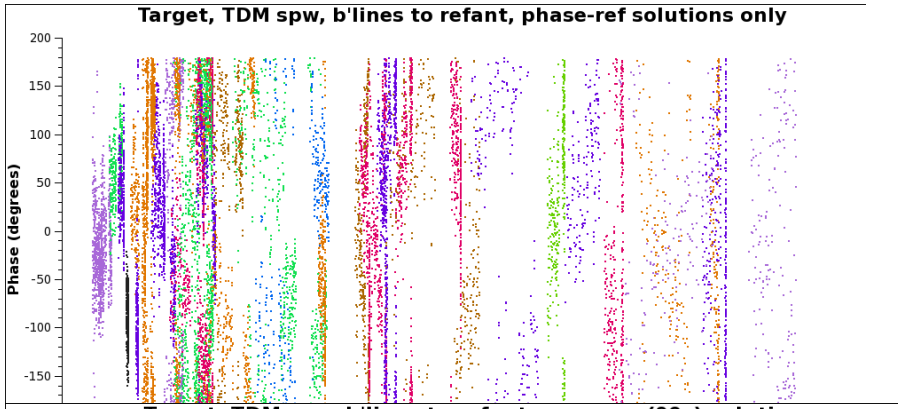


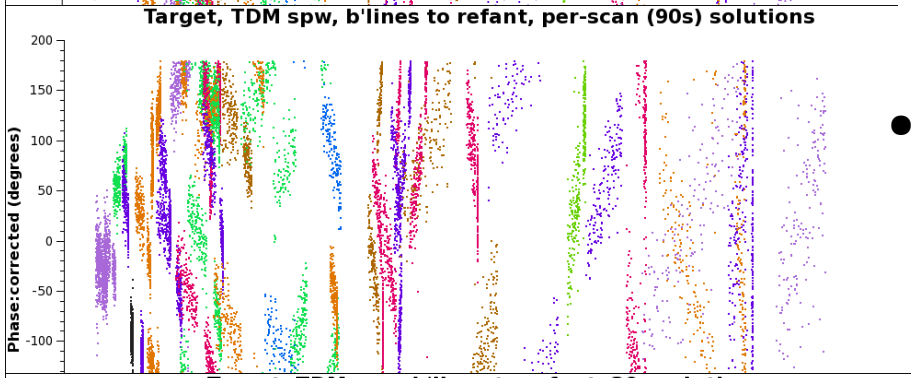


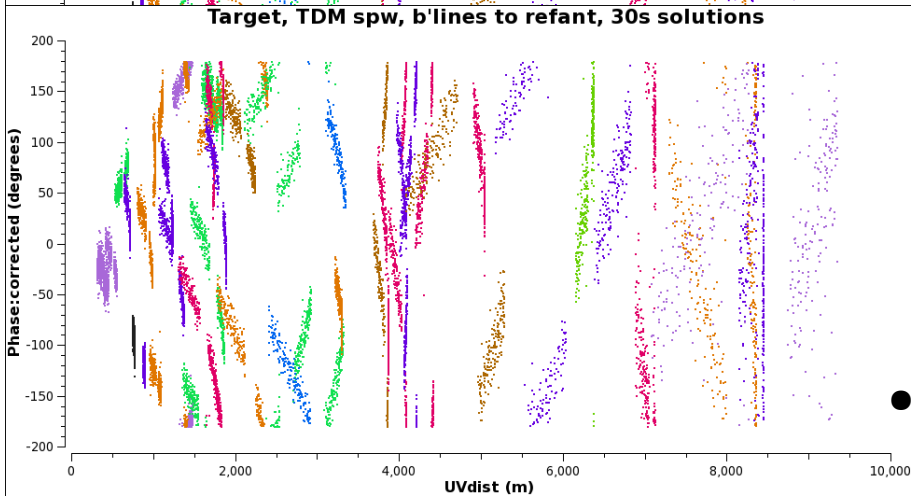
ϕ, p self-cal S/N 2850
rms 35 μJy
theoretical 22 μJy

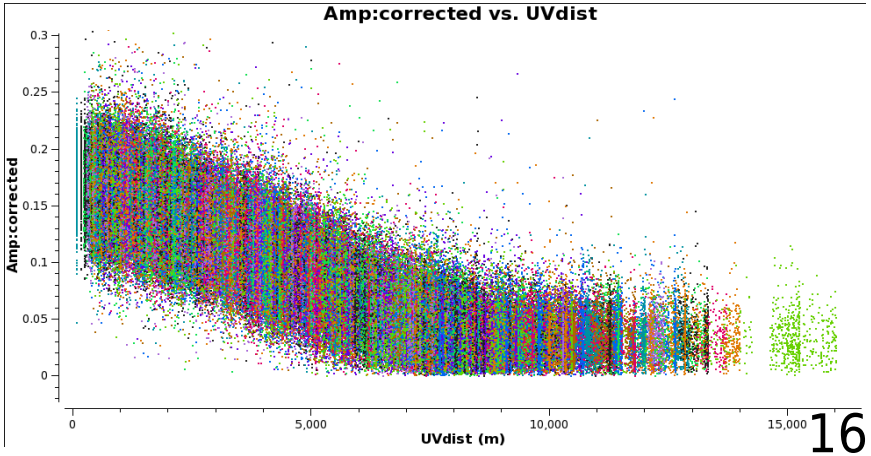
Target phases selfcal

TDM spw



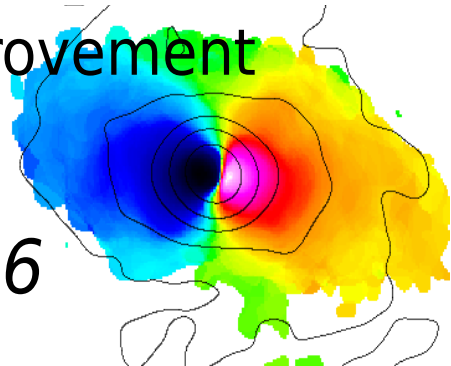






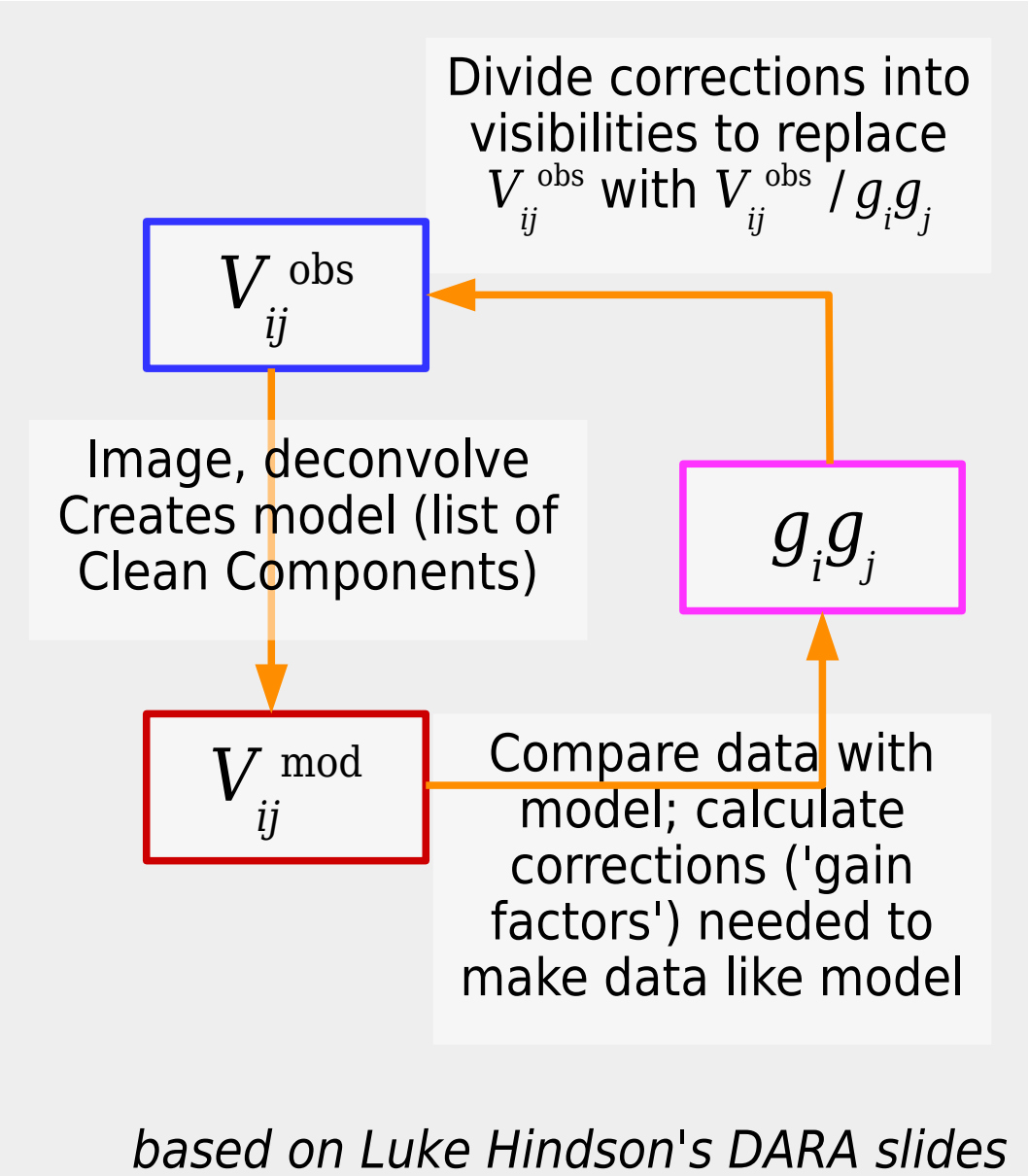
16 km

- Initial per-scan phase solution improves S/N 500%
  - 30s phase solutions
  - per-scan amp & phase
    - another 40% improvement
  - Lines benefitted
- L2 Pup B *Kervella+'16*



Self-calibration overview

- Visibility data, phase-ref etc. corrections applied
  - Initial model:
    - First image from V
- Compare data with model
  - Derive gain correction factors per antenna using χ^2 minimisation
- Apply gain corrections to data and image again
- Repeat cycle until image reaches noise/dynamic range limit and model matches data (allowing for noise)



based on Luke Hindson's DARA slides

What solution interval? minimum

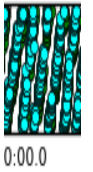
- Require S/N ≥3 per solint dt_{min} per antenna
  - $\sigma_{ant} \leqq P/3$ in dt_{min} where P is peak on longest baselines
  - $\sigma_{array} = \sigma_{baseline} / \sqrt{[N(N\text{-}1)/2]}$
    - Each antenna has (N-1) baselines
    - Two additional degrees of freedom:
      - phase (or amp) correction; origin of phase (or flux scale)
    - $\sigma_{ant} = \sigma_{baseline} / \sqrt{[(N\text{-}3)]}$
  - $\sigma_{ant}(dt_{min}) \leqq \sigma_{array}(tot.t) \sqrt{[tot.t / dt_{min}]} \sqrt{[(N(N\text{-}1)/(2(N\text{-}3))]}$
- $dt_{min} \geq [\sigma_{array}(tot.t)/P/3]^2 \; tot.t \;\; [(N(N\text{-}1)/(2(N\text{-}3))]$
  - NB S/N improves with calibration

What solution interval? maximum

- Solint $\mathrm{d}t_{\mathrm{max}}$ < timescale for significant changes
  - Amp & ϕ change due to source structure as well as errors ε
    - Fast phase rate if peaks far from centre
  - Usual 'upper limit' for phase rate is $\mathrm{d}\phi < \pi/4$ per $\mathrm{d}t$
    - Inspect visibility phases for rate and for scatter
  - S/N (amplitude/σ_{rms}) per antenna usually must be >3
    - Including longest baselines to refant (plot amp v. uvdist)
    - Noise σ_{rms} *estimate from sensitivity calculator or image???*
      - Can you reach S/N > 3 in $\mathrm{d}t_{\mathrm{max}}$?

In practice...

- Inspect phase (refant & *) you want to correct
  - What interval shows systematic drift?
    - Not just noise - that can't be calibrated away!
  - Average by channel as appropriate (see next slide)
    - Maybe average pols &/or spw?
      - Can be offsets
        - Phase-ref refant issues, atmospheric transmission differences
    - Try longer solint, per spw/pol first
      - Apply solutions, shorter solint, average in other dimensions
- Longer solint does not always improve solution accuracy
  - Shorter solint may fail less often
    - e.g. bright but offset target



Noise in initial choice of solint?

In practice...

- Inspect phase (refant & *) you want to correct
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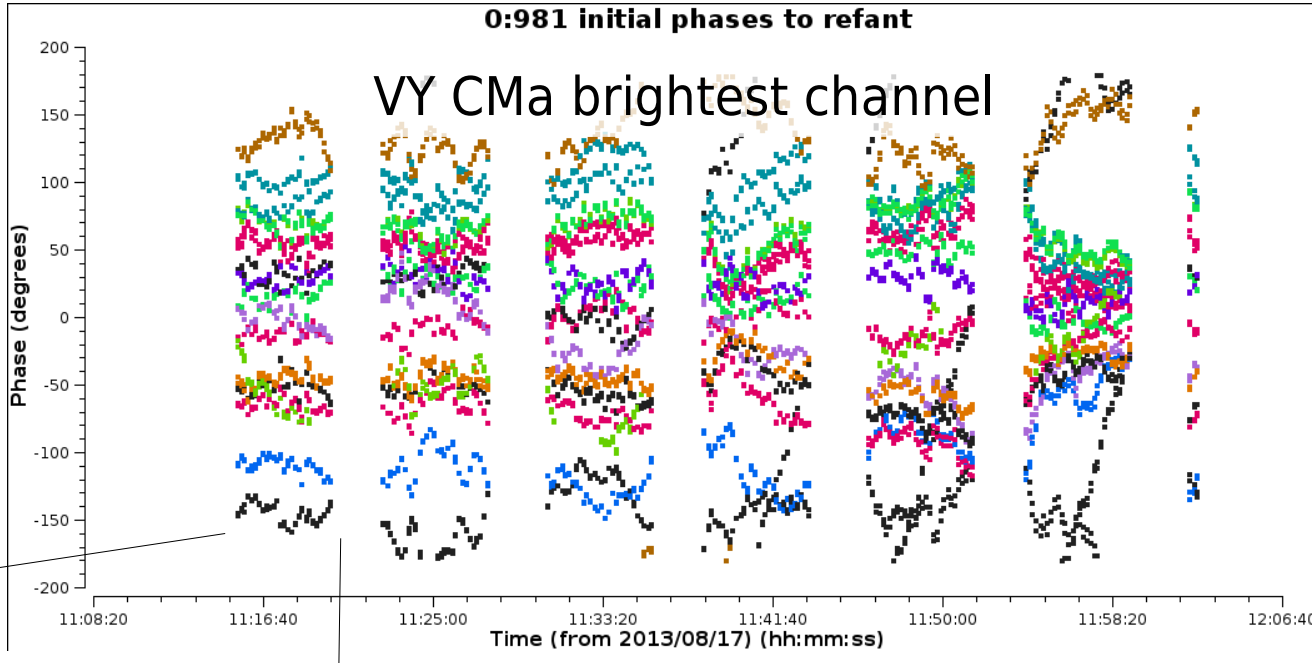
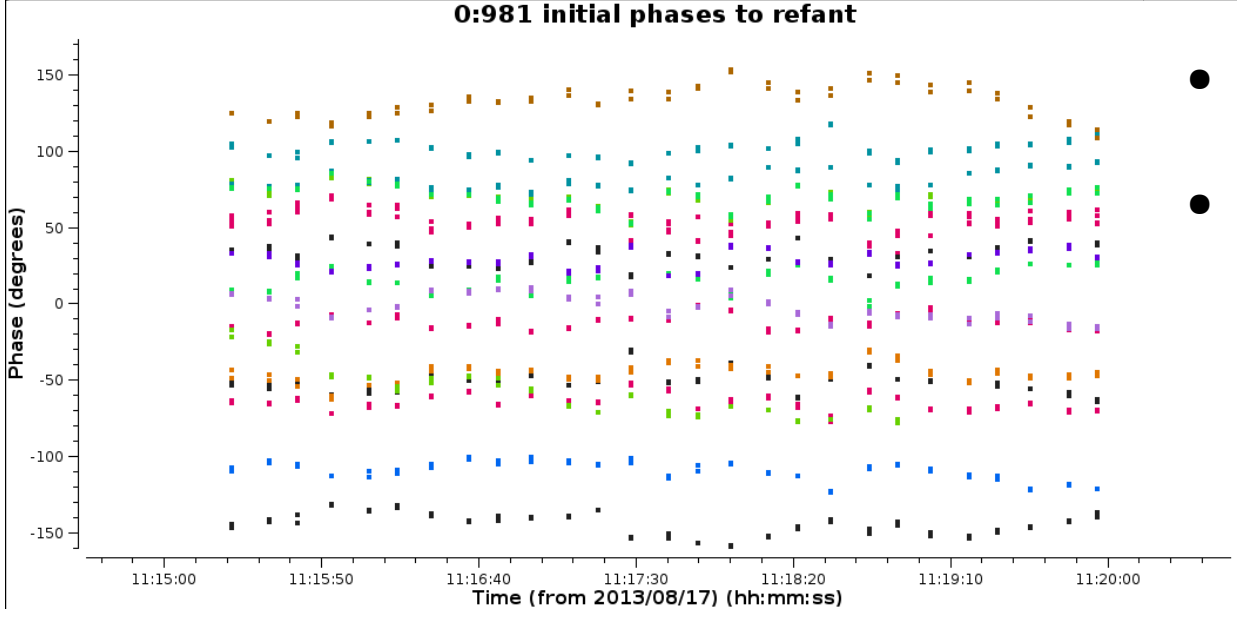
Inspect phase v. time

- Zoom in on one scan
  - 12-s averaging
- Mostly ~1 min drifts
  - Small scatter

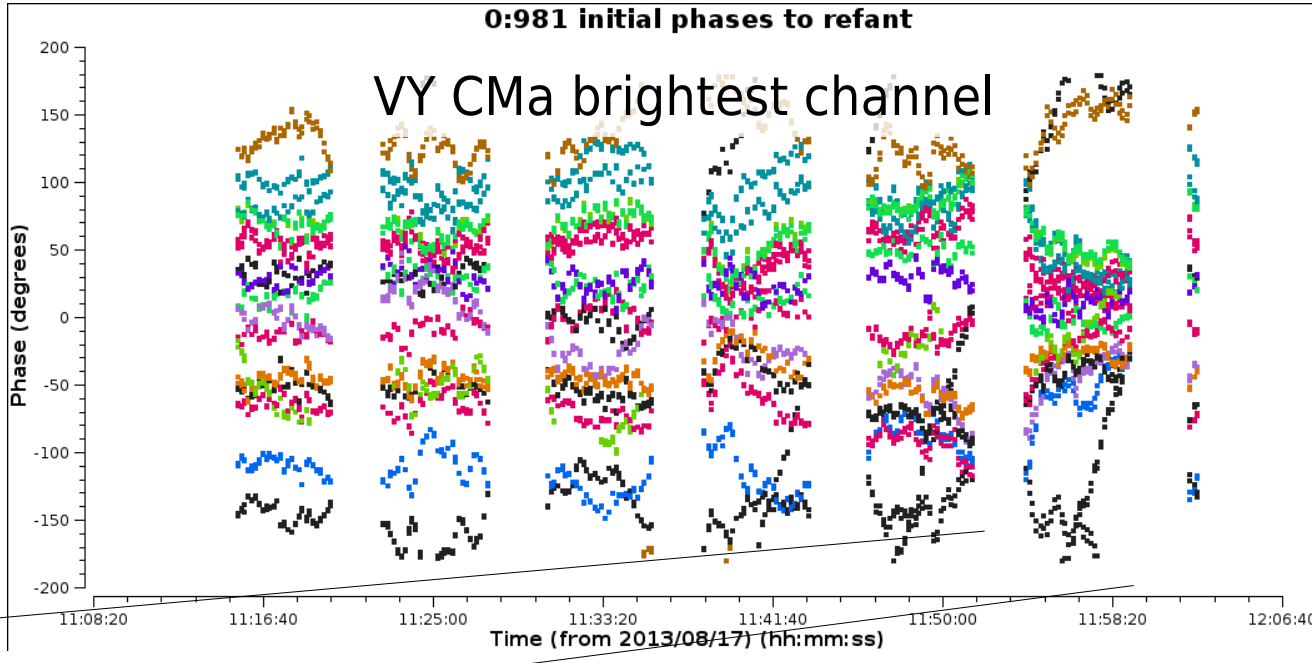


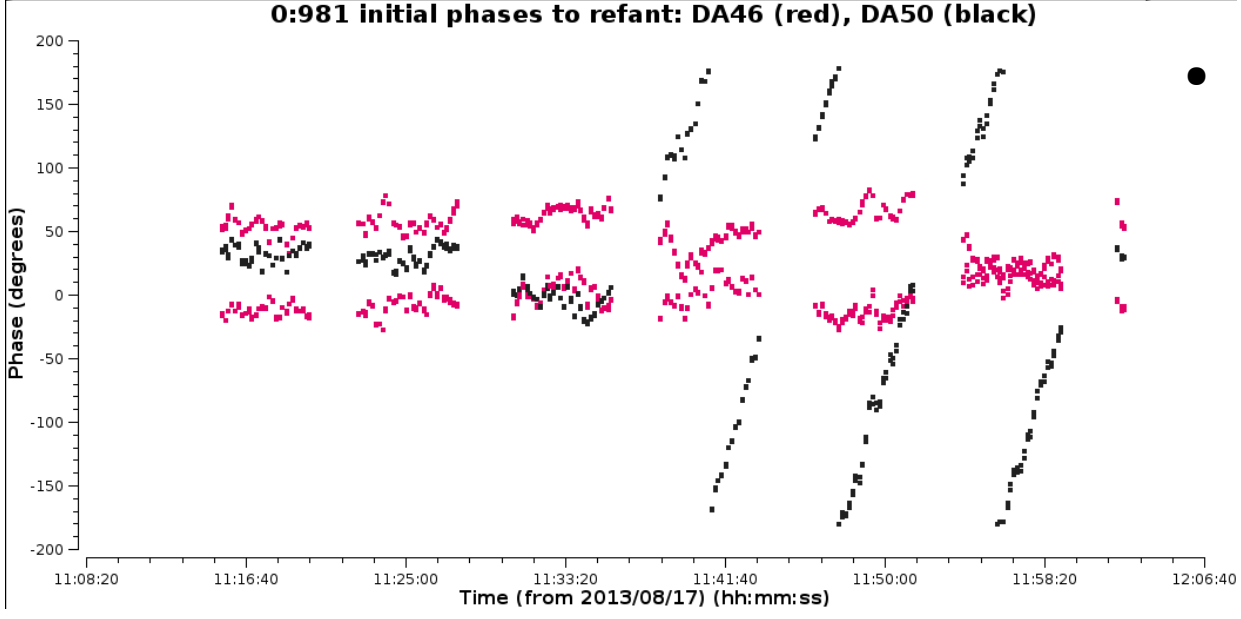


- Faster rate in last scans?
- Plenty of S/N

Inspect phase v. time

- Zoom in on one scan
  - 12-s averaging
- Mostly ~1 min drifts
  - Small scatter

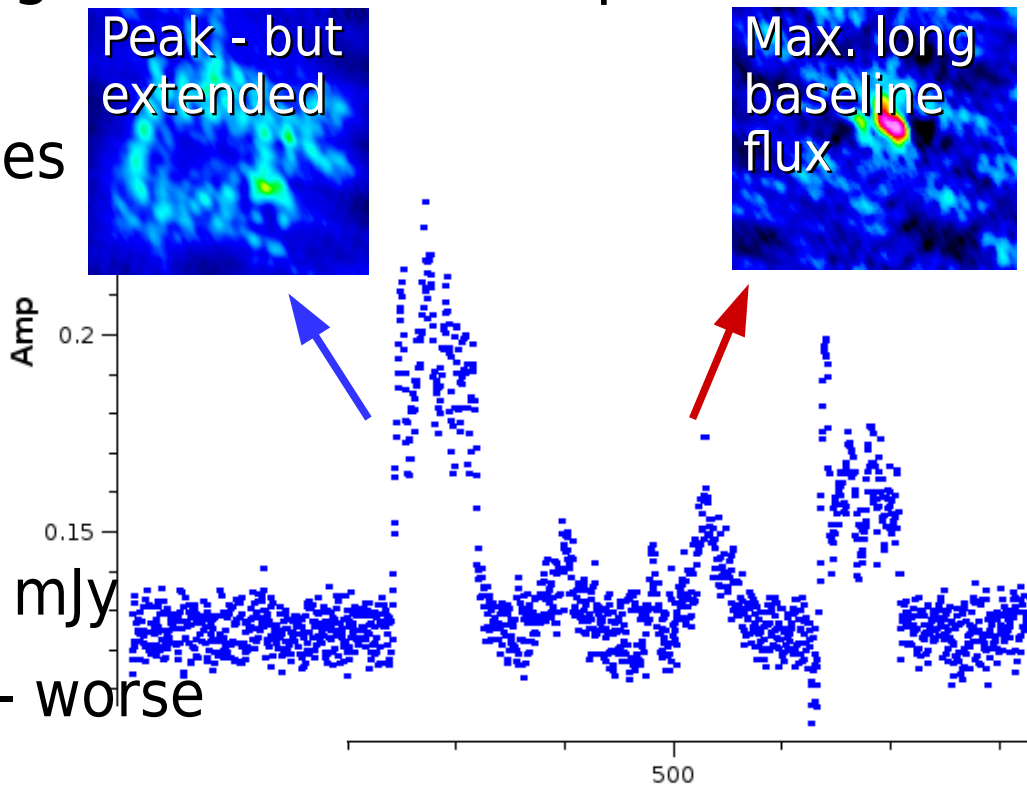




- Faster rate in last scans?
  - Sudden change
    - One antenna
  - Exclude at first
    - Then calibrate
      - Shorter solint

Channel averaging gotcha's

- Line: best S/N on all baselines
  - Highest peak may be extended spatially
    - Broad twin-peaked line probably optically thin, diffuse
  - Narrow inverted-V peakhigh-excitation, compact, accelerating transition
    - Highflux on long baselines
- Don't over-average
  - Peak chan 1 Jy, S/N 100
    - Narrow line
    - Σ(3-chan)=(1+0.2+0.2) mJy
    - S/N = 100x1.4/√3 = 68 - worse



Model constraints

- Parameterised model (FT in visibility plain)
  - Traditional (delta function) Clean Components
  - Multiscale Clean may work
    - Beware artefacts around elongated narrow features!
- Can self-calibrate in full polarization
  - Get total intensity phases right first
    - Also OK to calibrate total intensity amps first?
- Is target spectral index α significant?
  - Check correct phase-ref α (or normalisation) used
  - Generally, use nterms=1 for initial ϕ-only self-cal
    - Use nterms ≥2 for image *before* & during amp self-cal!

Model constraints

- Usually, applycal calwt=False during self-cal
  - Noisiest antennas are most important to correct
    - Usually best to use natural weighting or robust ≥0.5
- If necessary start with low minsnr e.g. 2
  - applycal applymode='calonly' will pass failed solutions
    - Avoid flagging salvagable data due to poor model
  - Or, if failed solutions are really bad data, 'calflag'
- Include all significant flux
  - but build up slowly, iteratively, if in doubt
    - Real source details will reappear if not included at first
    - Artefacts can become frozen in to model
      - less of a risk if *uv* coverage is good
- Don't apply primary beam correction until finished!

Iterative self-calibration

- Usually, phase-only first
  - You may need to do a number of rounds of self-cal
    - Improve model and/or shorten solint
  - Aim is to get morphology right - total extent of source
    - If channel selection, check spectrum/another line image
- Then, if enough S/N, amp and phase
  - Start with a longer solint than for phase-only
    - Occasionally, an antenna is very mis-scaled (e.g. bad T_{sys})
      - Make model excluding bad antenna if possible
      - Try initial v. long-time, amp self-cal, normalise if necessary
- Iterate only if model improved or parameters changed
- Cumulative or progressive?
  - Keep track of calibration tables

Calibration table consistency

Image_0
Gaincal caltable=p5min, gaintable=[]
Applycal gaintable=[p5min]

Discard this table after making better model

Image_p5min
Gaincal caltable=p0.5min, gaintable=[]
Applycal gaintable=[p0.5min]

Accumulate these tables

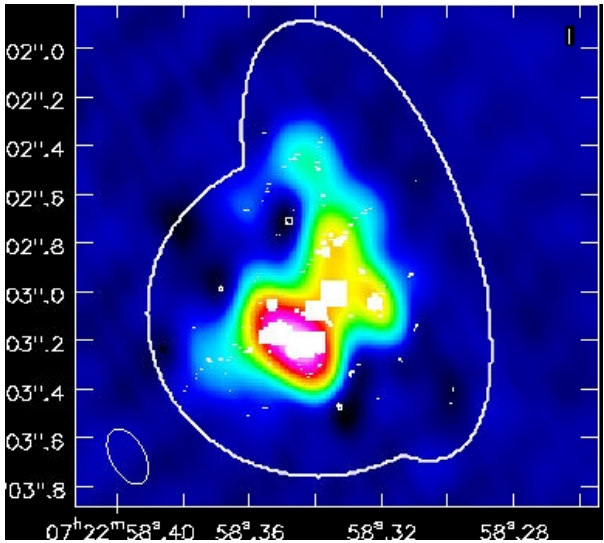
Image_p0.5min
Gaincal caltable=ap5min, gaintable=[p0.5min]
Applycal gaintable=[p0.5min, ap5min]

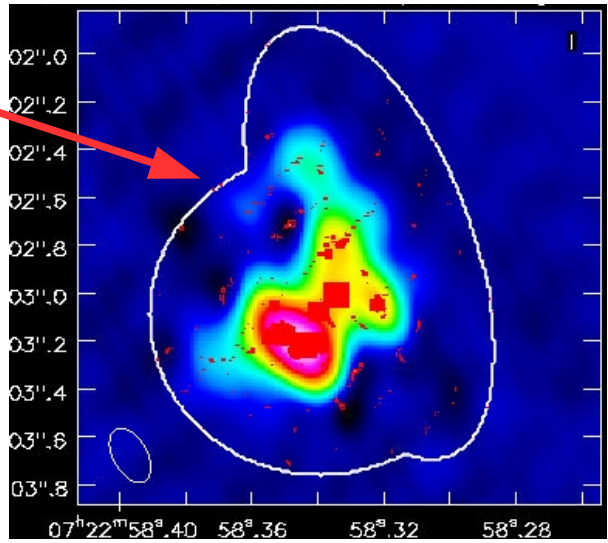
Image_p0.5min_ap5min
Gaincal caltable=ap1min, gaintable=[p0.5min, ap5min]
Applycal gaintable=[p0.5min, ap5min, ap1min]

Final image (final applycal calibration all in **corrected** column)

Preparing model for self-cal

- Take care in setting mask (clean boxes)
  - Clean Components to be used as model
- Mask conservatively for initial models for phase self-cal
  - CC should trace emission
    - but -ives are part of data
      - Beware 'pile-ups' at mask edges
- Make sure all flux is in model for amplitude self-cal
  - If in doubt, normalise solutions
    - Flux might go up (~10% at most) as phase improves
      - Should never go down!

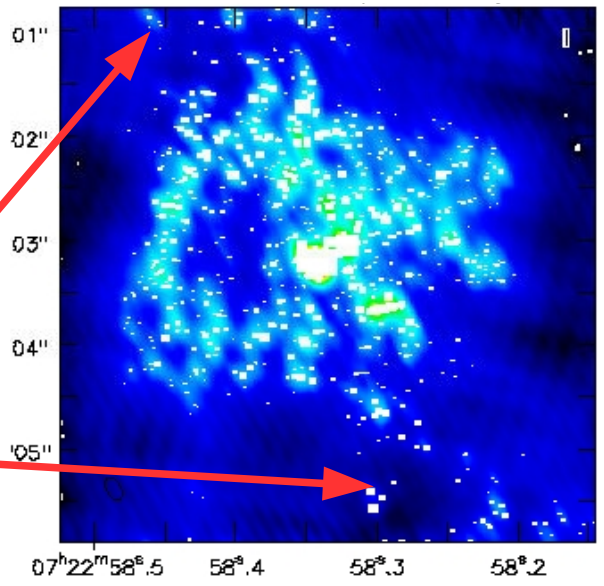




Difficulties in starting model

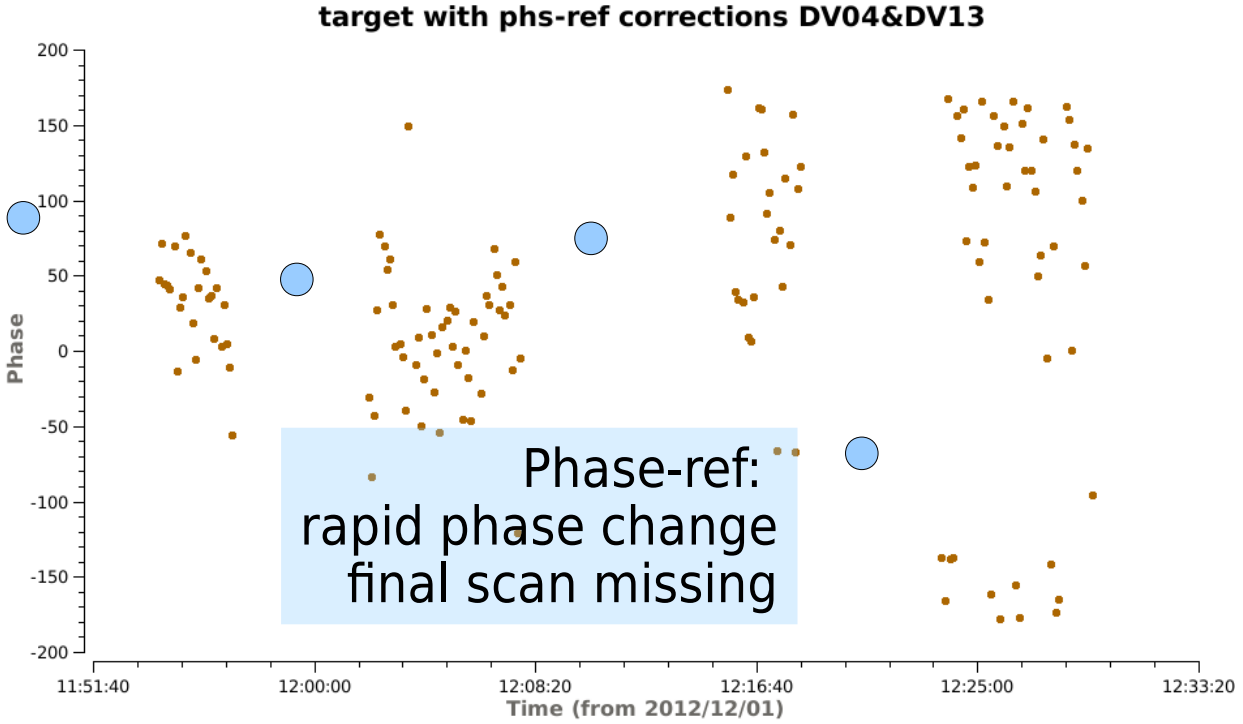
- Not easy to edit CC in CASA (need toolkit)
  - Get mask right
    - NB negatives genuine part of an interferometry image!
- No phase-referenced model?
  - Ready-made image CC from other obs?
    - e.g. shorter baseline, higher freq.
    - Use for initial phase self-cal for structure
      - More similar than exact flux
  - Start with point model, build up slowly
    - Select uvdist based on prior knowledge
      - Long b'lines if point(s)-dominated
      - Taper if complex/extended

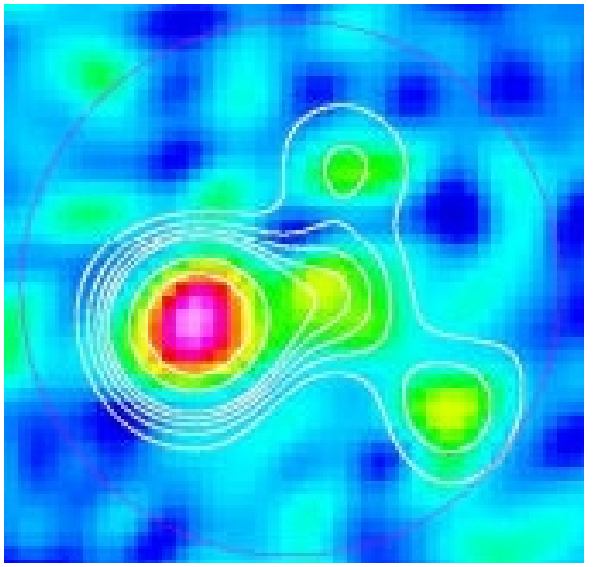
No mask - spurious CC
Faint, so probably not serious



Difficulties in starting model

- Bad phase referencing at some times/baselines?
  - Cycle 0 B9 IRC+10216 phase wrap between ϕ-ref scans
    - Mickey Mouse self-cal model contaminated all data
  - Exclude bad data for starting model
    - Use as model for all target data

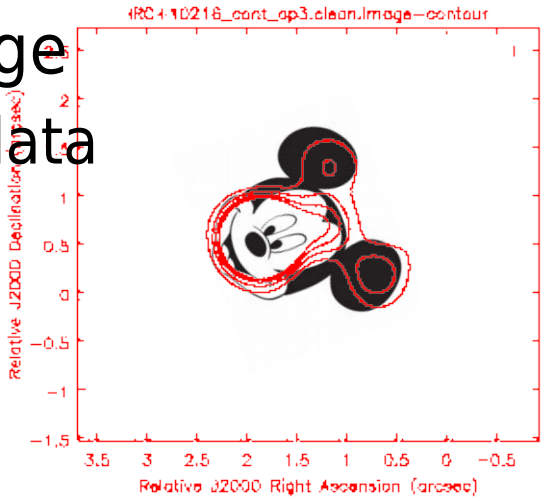


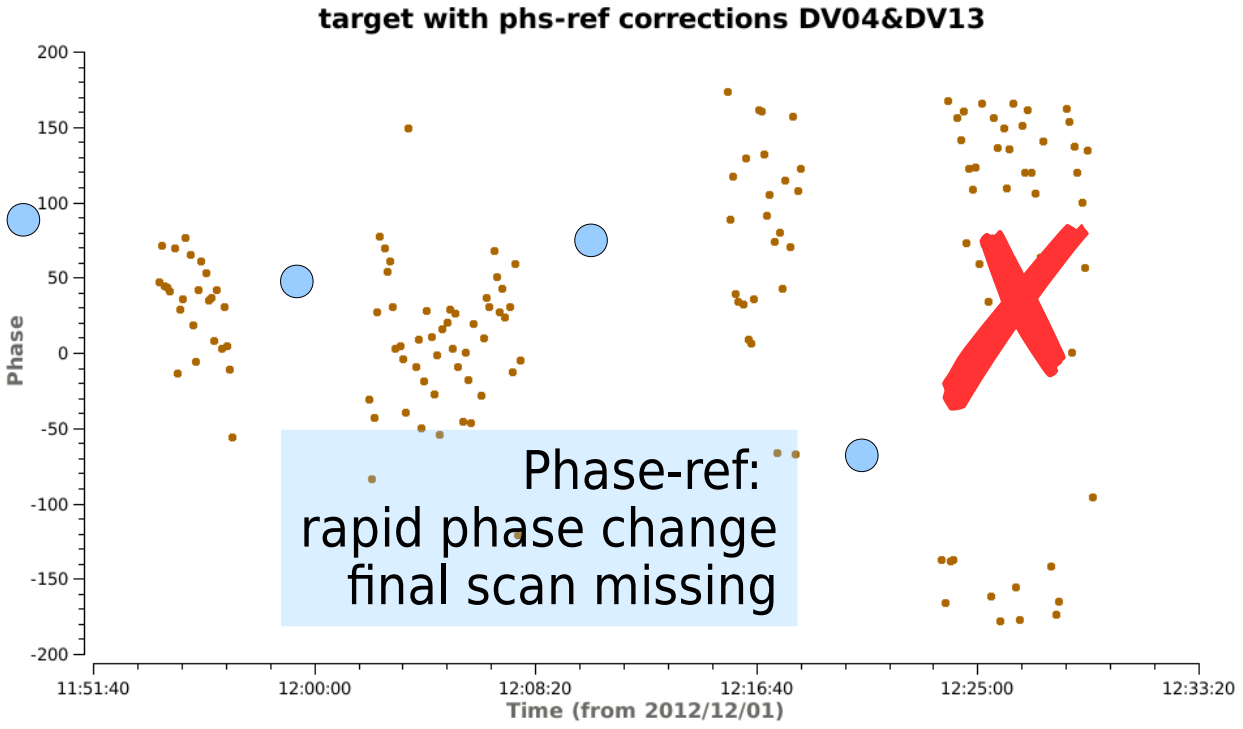


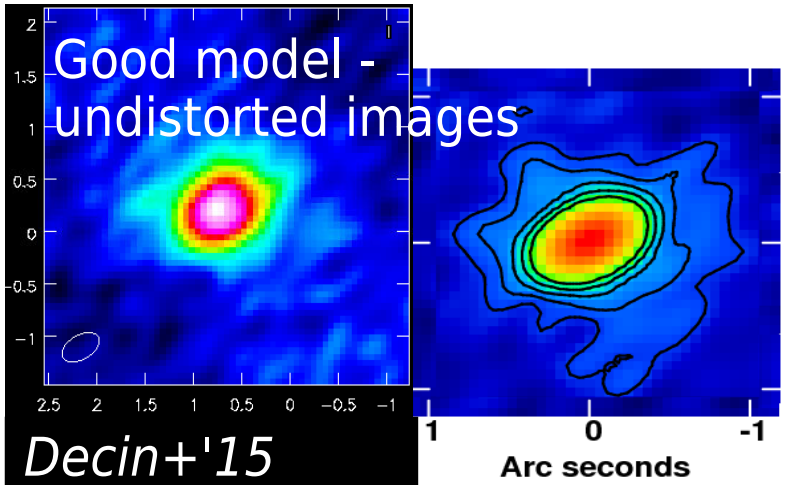
Initial continuum contours over ^{29}SiS total intensity
All lines same shape????

Difficulties in starting model

- Bad phase referencing at some times/baselines?
  - Cycle 0 B9 IRC+10216 phase wrap between ϕ-ref scans
    - Mickey Mouse self-cal model contaminated all data
  - Exclude badly-calibrated data for 1st image
    - Use first 2 scans for model for all target data
      - Add last scans to later self-cal rounds

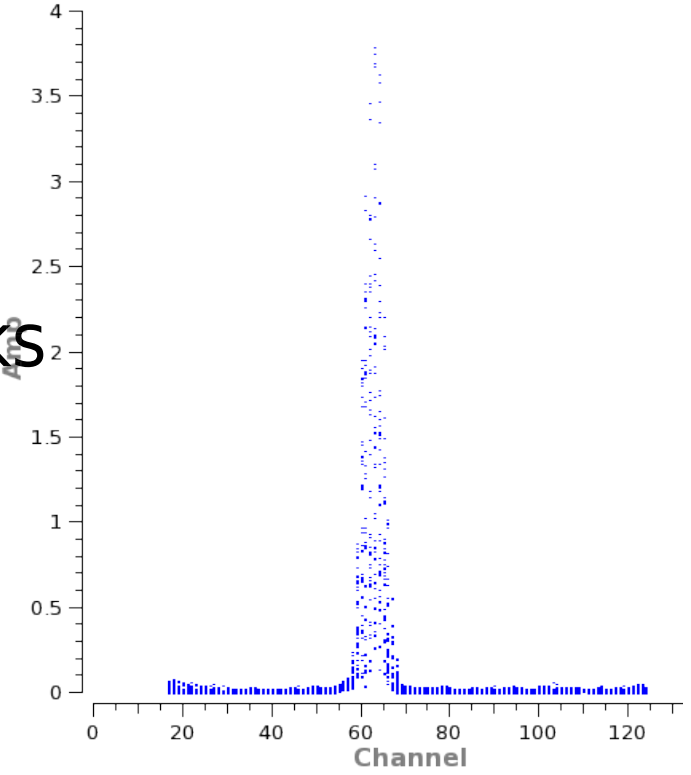






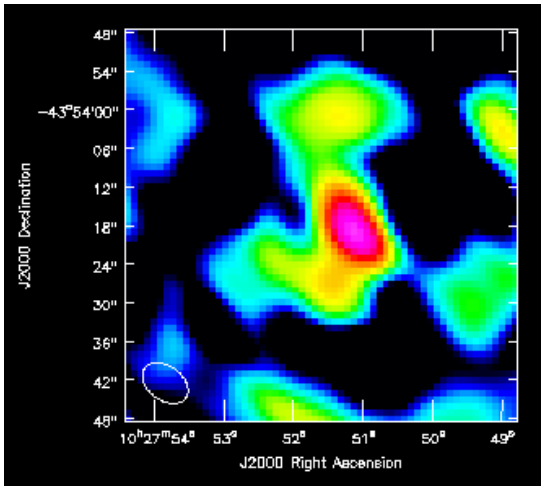
CASA Guide ALMA self-cal

- NGC3256 (δ -44º) Band 3: Continuum, CO and HCN
  - CASA Guide uses continuum
  - Can also use CO peak to self-cal and apply to all data
- Apply instrumental, bandpass, fluxscale, phase-ref cal.
- ~180 min on-target
- 7 antennas on average
- Plot visibility spectrum, identify peaks
  - CO peak spw 0:63~64, ~4 Jy
  - 2 chans = 31.25 MHz @~114 GHz
  - Sens. Calc. σ_{rms} ~0.9 mJy/bm



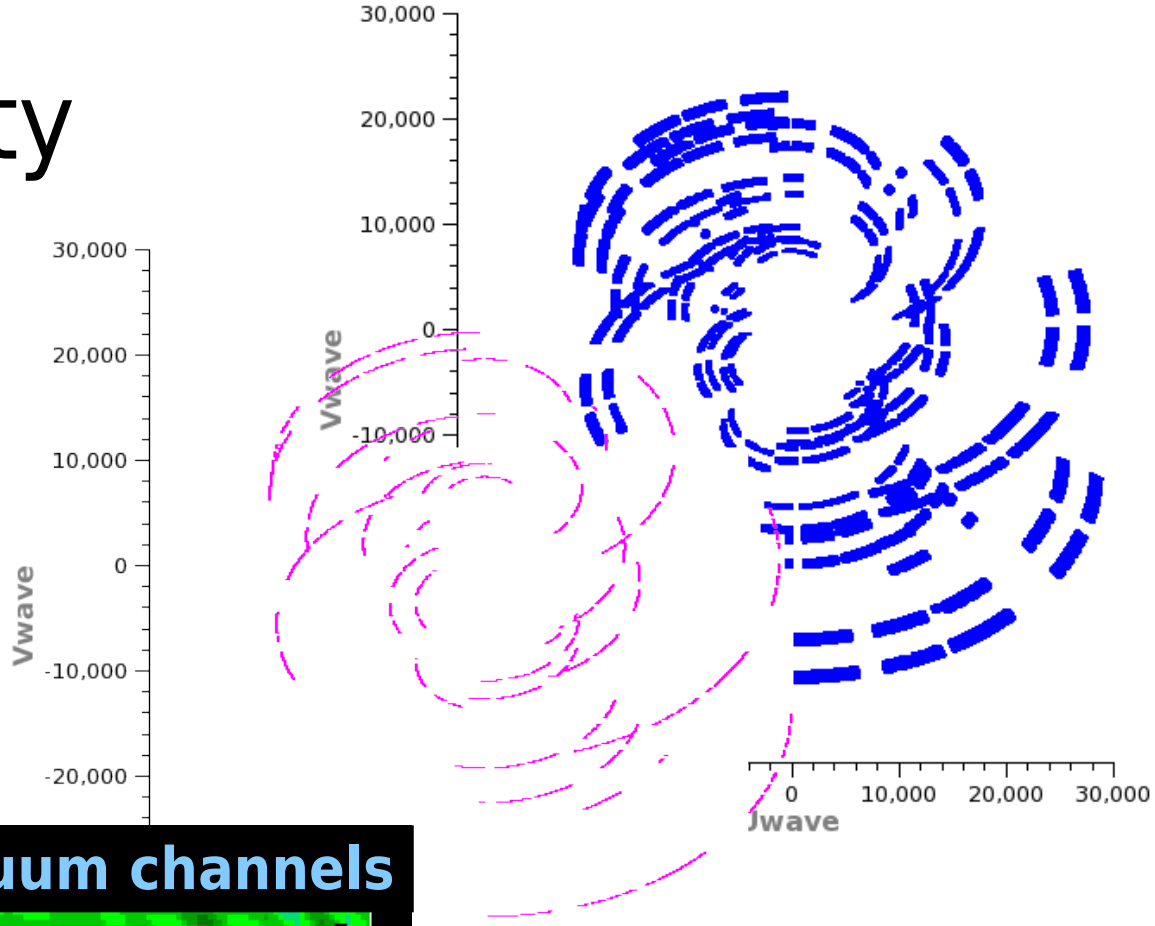
CO peak self-cal solint

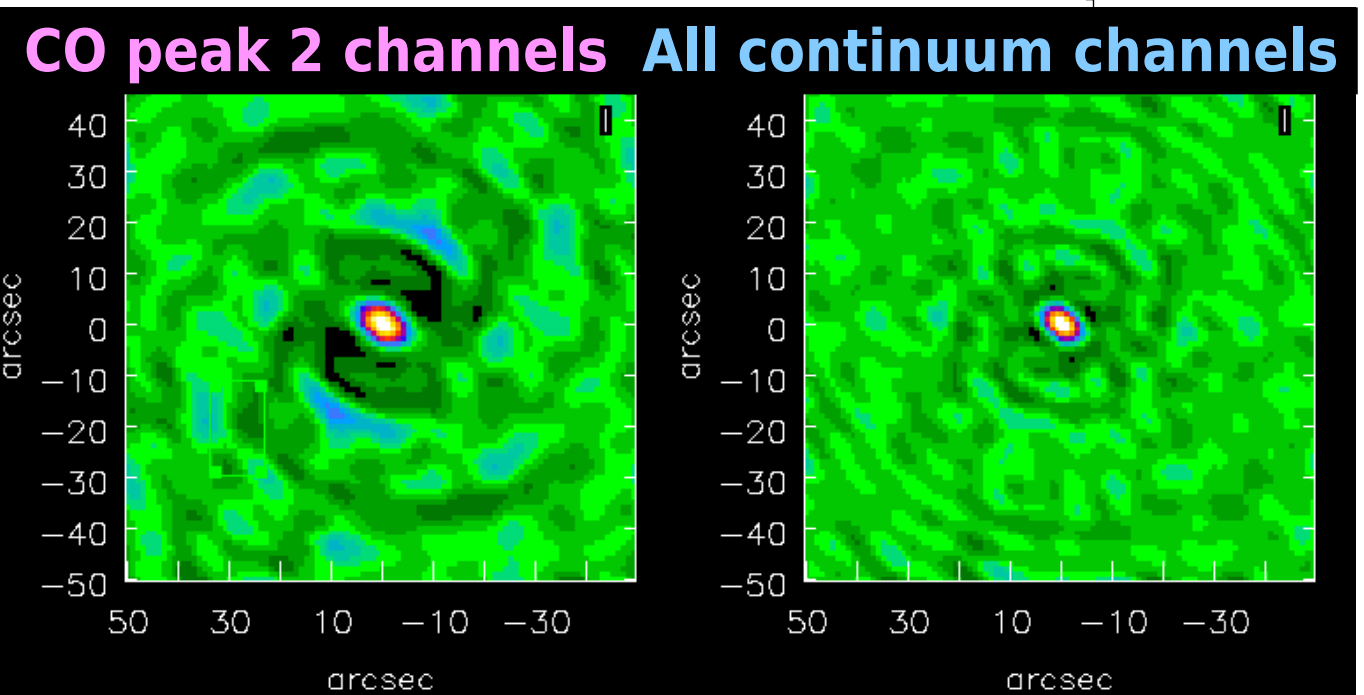
- $dt \geq [\sigma_{array}(tot.t)/P/3]^2\ tot.t\ \ [(N(N\text{-}1)/2(N\text{-}3)]$
  - $\sigma_{array}(tot.t)$ ~ 0.9 mJy/bm (s. calculator)
    - In $tot.t$ ~180 min
  - $N = 7$; P ~ 500 mJy/bm
  - dt ≥2 sec (in practice, t_{int} 6 sec)
- In this instance, other factors limit dt
  - First map noise ~90 mJy
    - ~100 x $\sigma_{array}(tot.t)$ (theoretical)!
  - Dynamic range limitations
  - Inspect actual phase and amplitude rates of change



Spectral sensitivity

- Beware dynamic range limit in narrow channels
  - Poorer *uv* coverage means worse sidelobes

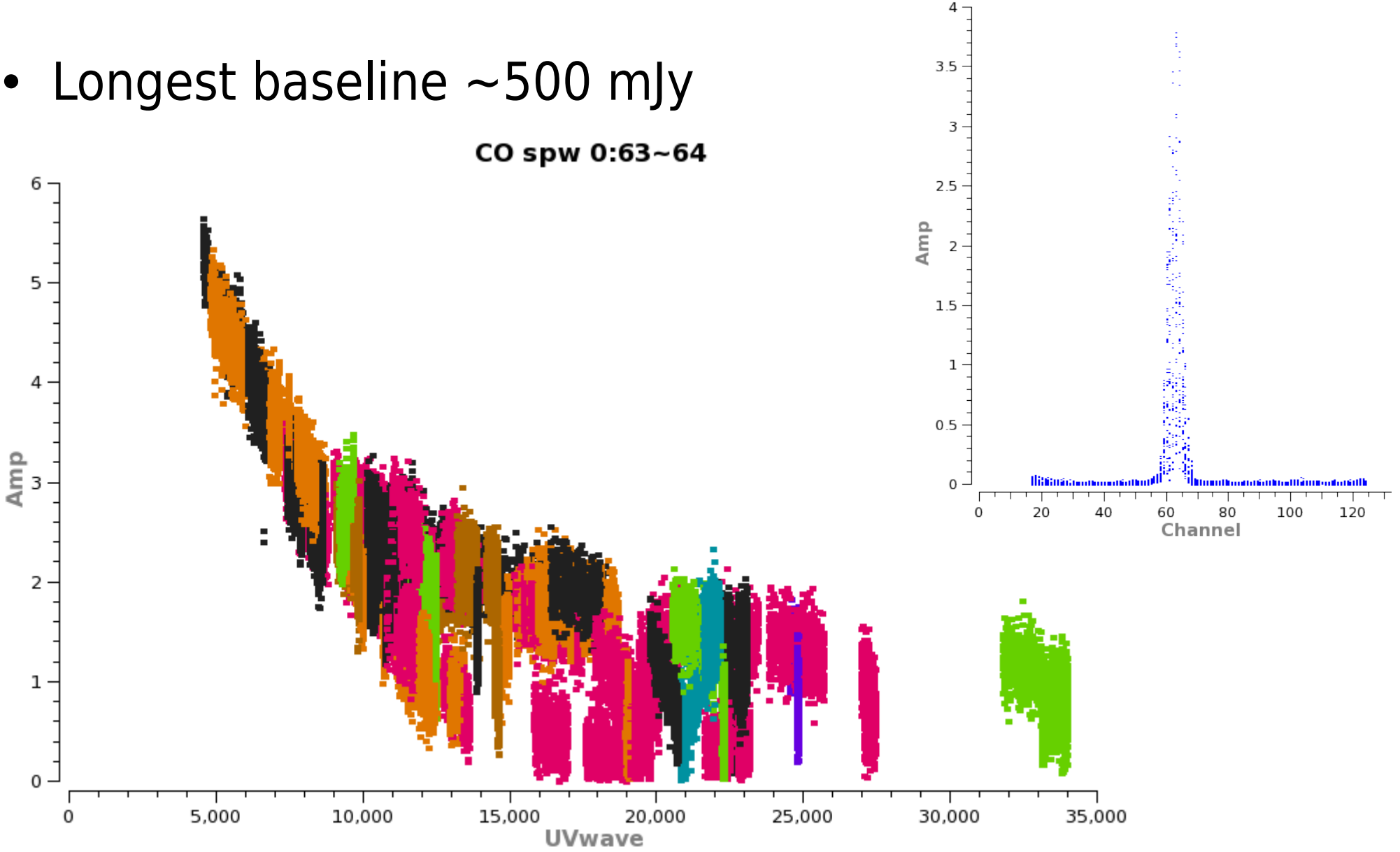


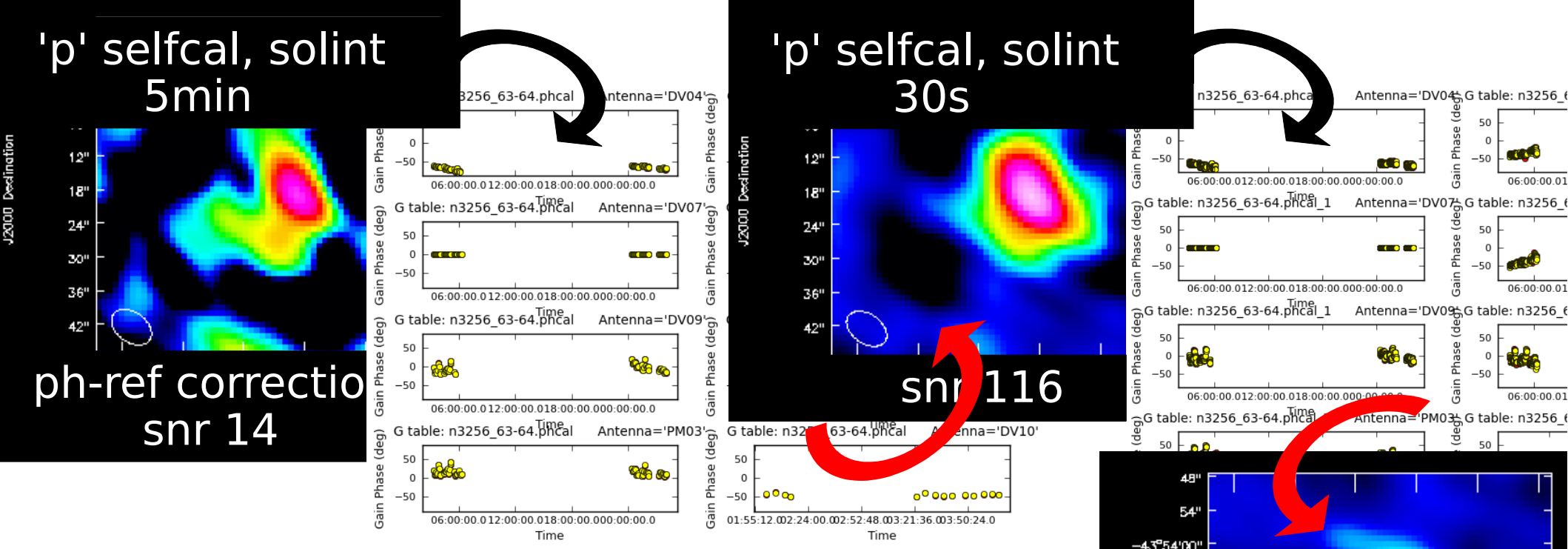


- Dirty maps
  - Color scale of each is relative to peak

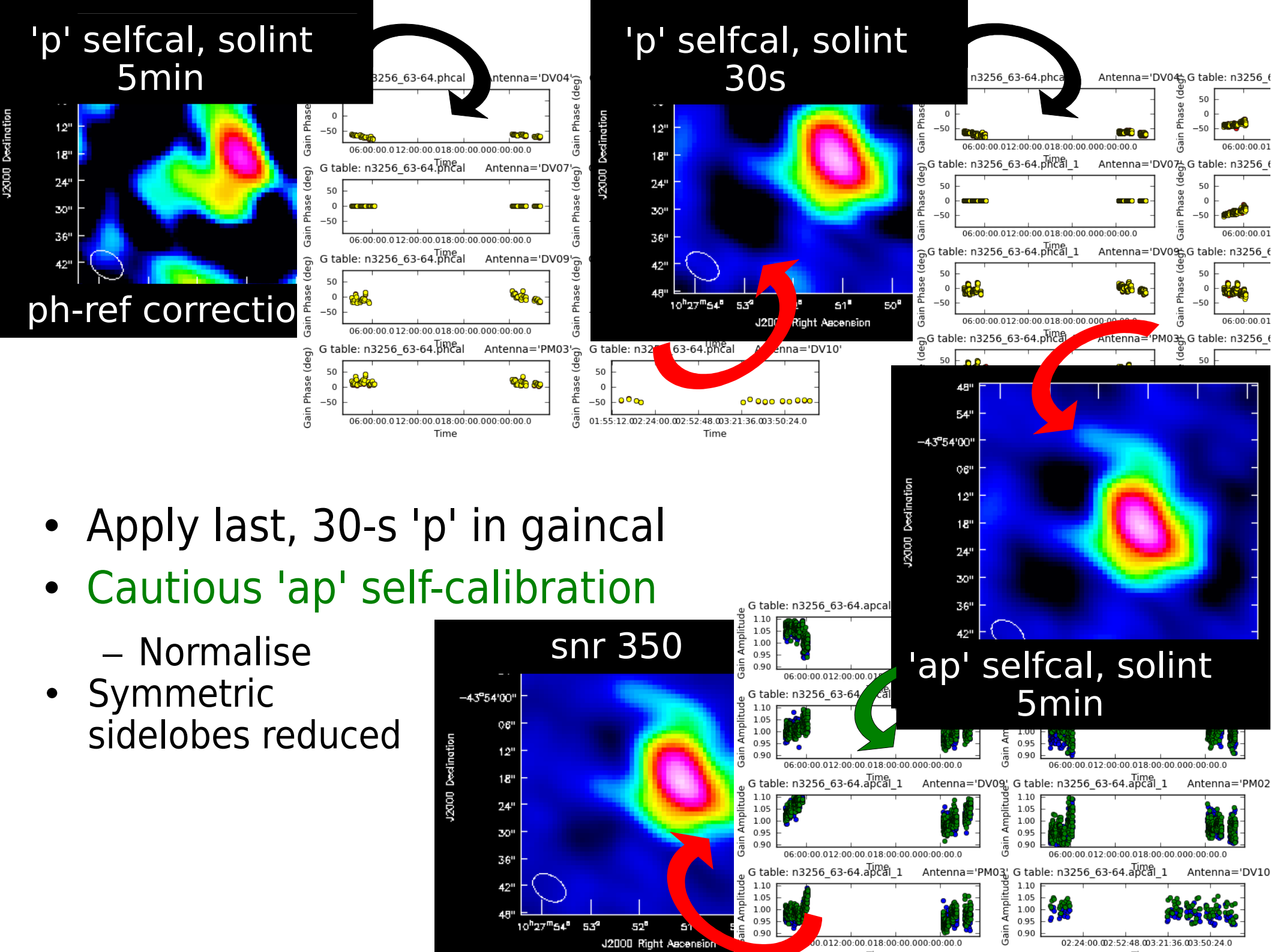
CO peak is spatially extended

- Longest baseline ~500 mJy

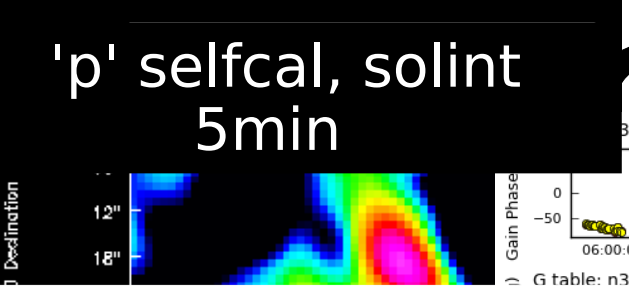


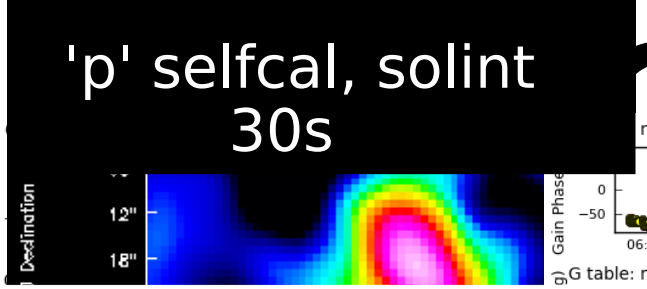


- Apply phase-ref etc. corrections, image
  - FT of image CC is left in MS
  - Model for 5-min phase-only self-cal
- Apply, image again
  - Better model so shorter solint next time
- Apply, image again
  - Symmetric errors
    - snr high enogh for amplitude self-cal

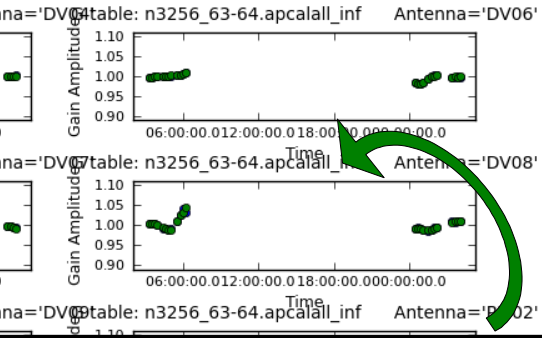


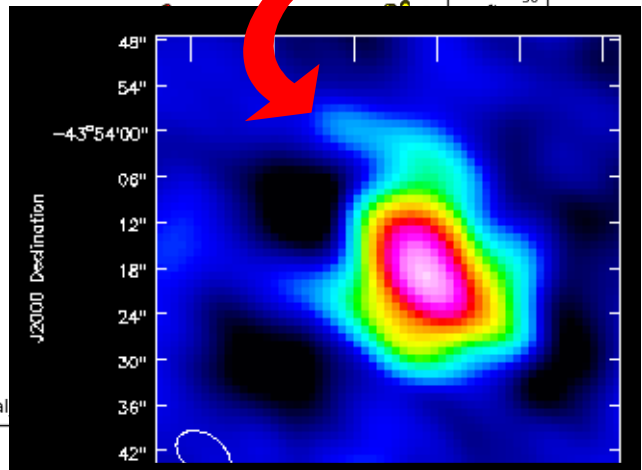
- Apply last, 30-s 'p' in gaincal
- Cautious 'ap' self-calibration
  - Normalise
- Symmetric sidelobes reduced

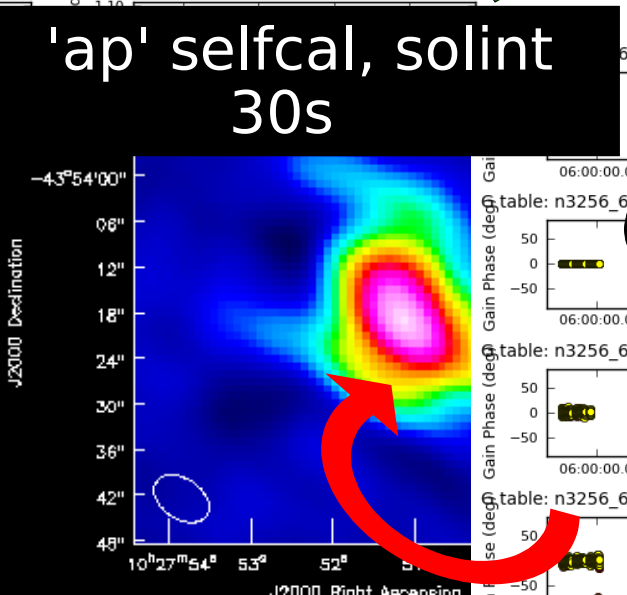


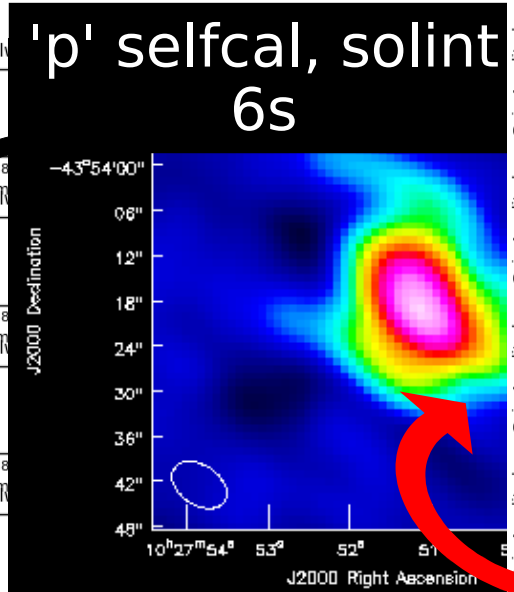


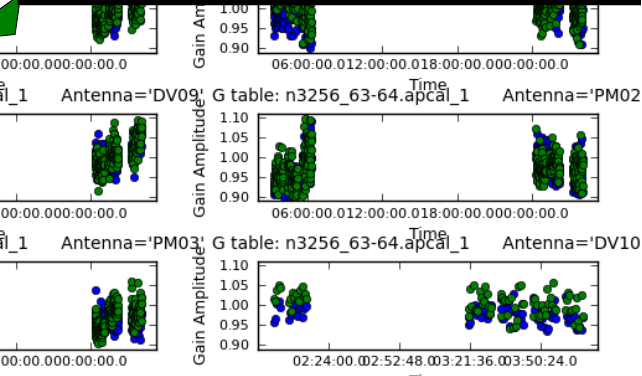
- Apply 30s 'p' and 5min 'ap' gain tables
  - Image improving
- 'p' per integration (6s), image again
- Apply all these tables for final 30s 'ap' cal





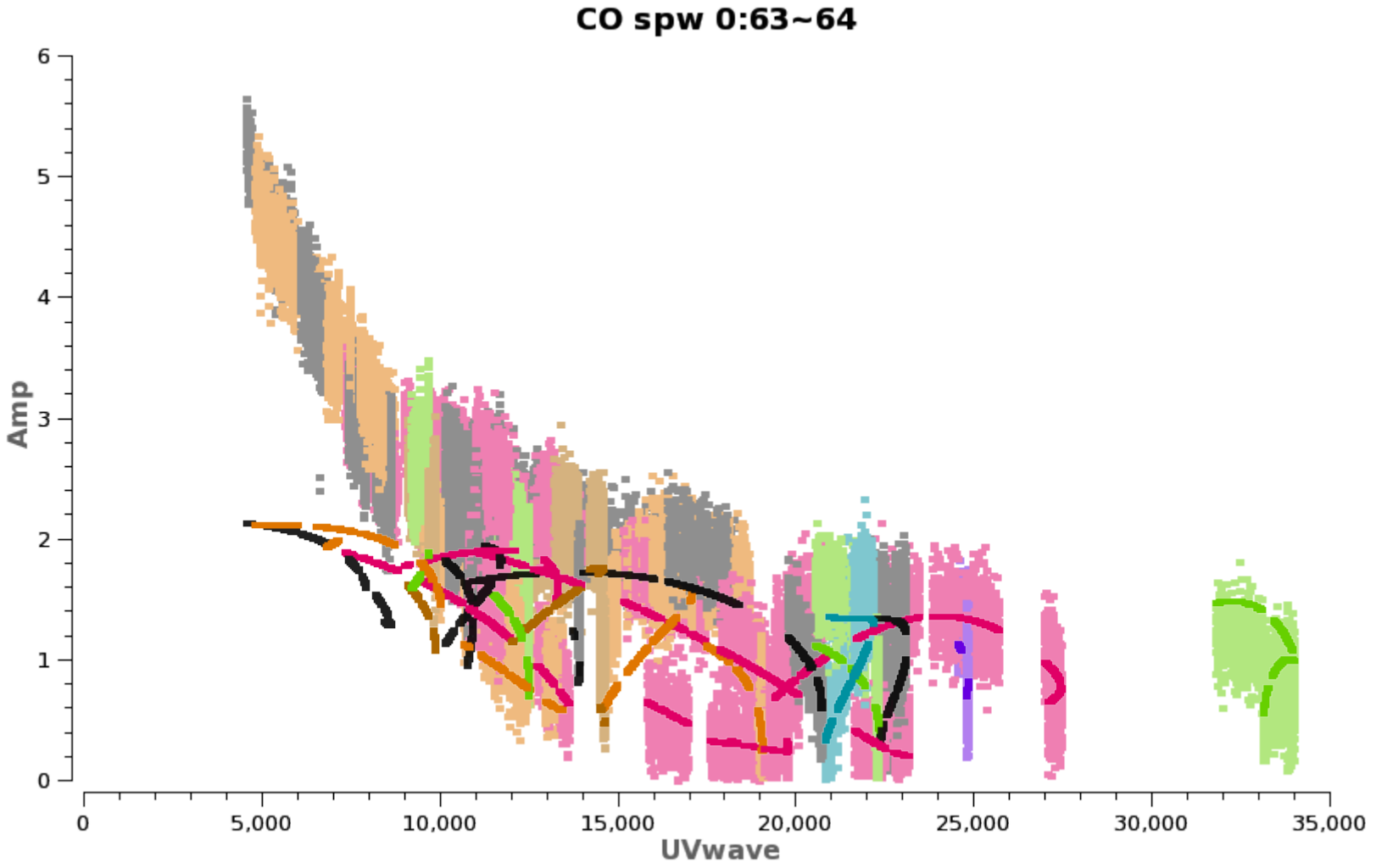






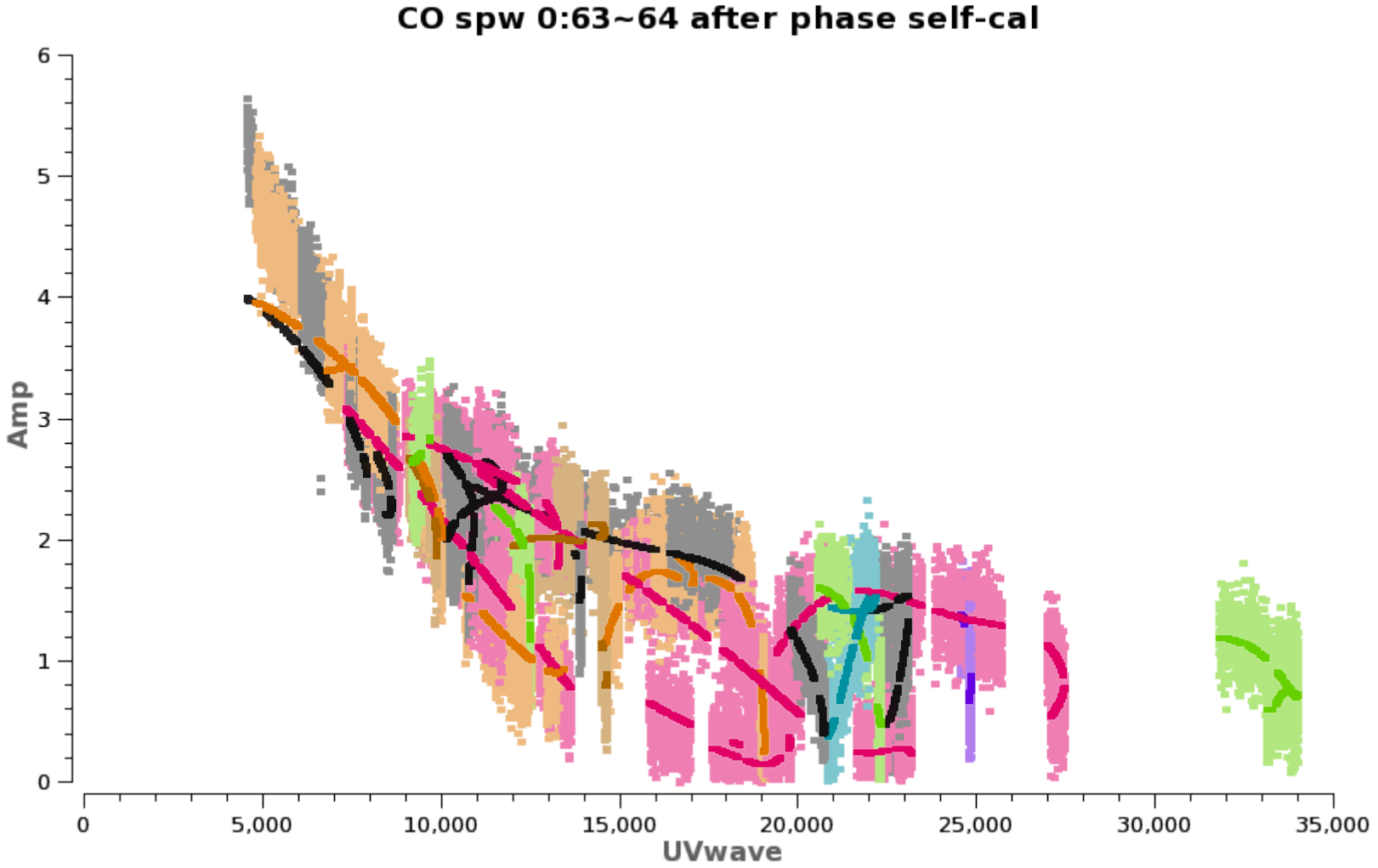
Compare model with data

- First model missing a lot of extended flux
  - Use for phase-only (not amp) selfcal



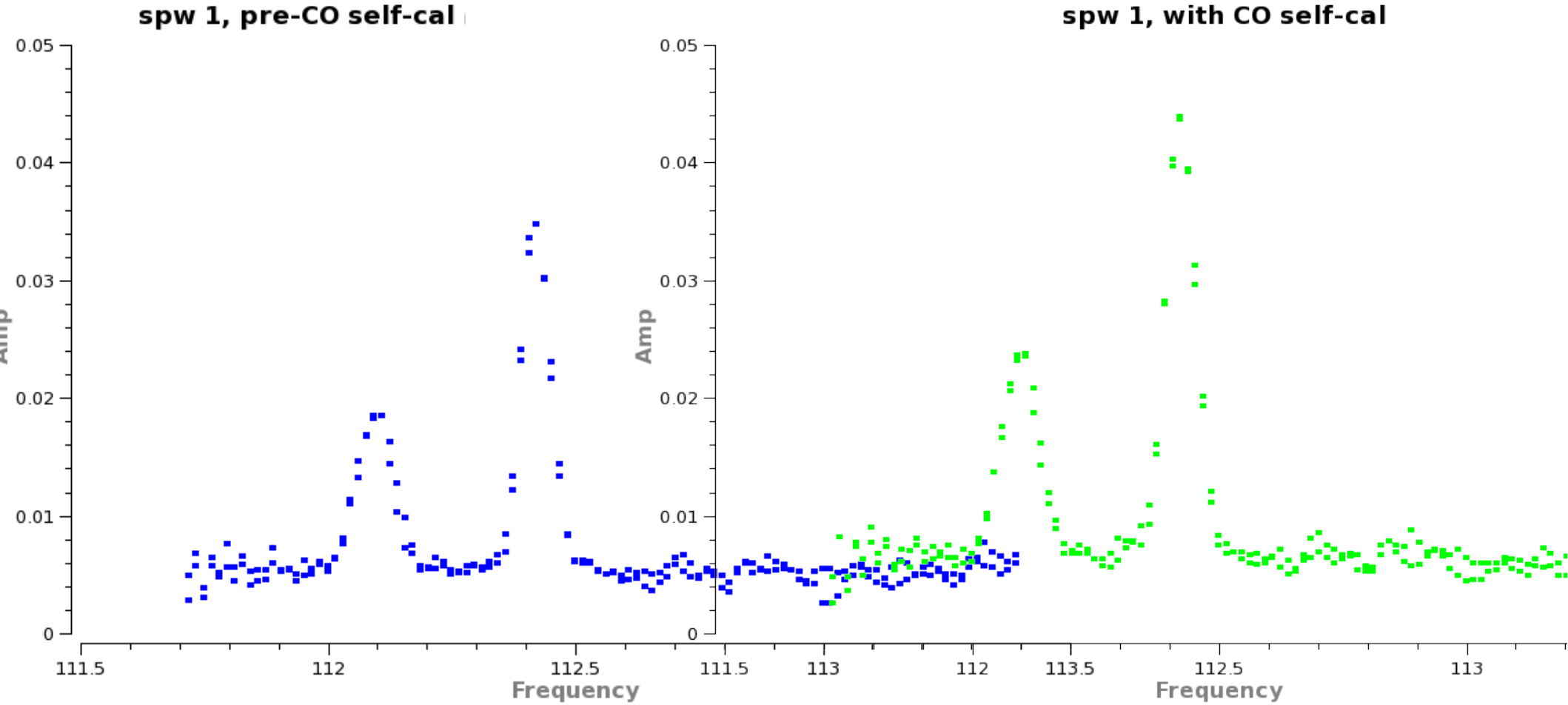
Compare model with data

- Vast improvement after just one round of self-cal



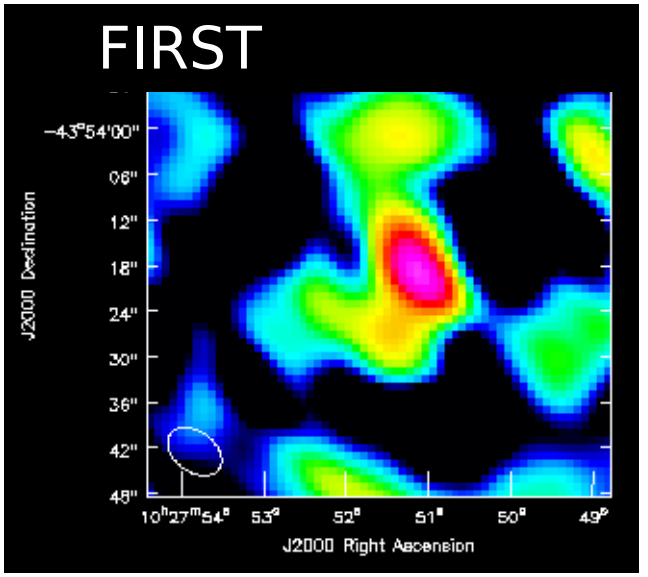
spw 0:63~64 applied to spw 1

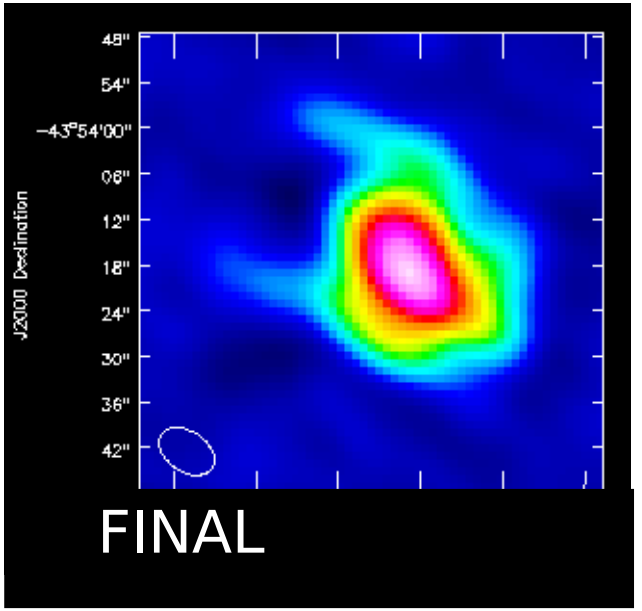
- CN line still there, better snr line and continuum – OK!
  - Need good bandpass to transfer solutions between spw



Complete self-cal of CO peak

- Signal-to-noise improved from 14
  - …. to 550!
  - First σ_{rms} 83 mJy/bm
  - Peak 1212 mJy/bm
- After all calibration:
  - Peak 1866 mJy/bm
  - σ_{rms} 3.3 mJy/bm
    - ~3.5 x theoretical
      - Dynamic-range limited?
      - Could try more editing?
      - Use single channel model?
        - after first phase self-cals





Self-cal of CO line peak

Apply phase-ref etc. corrections, split out corrected target

Identify line peak, clean image

1 gaincal 'p' solint 5min 5min-phcal / 5min-phcal, clean *snr improves*

2 gaincal 'p' 30s-phcal Apply 30s-phcal, clean *snr improves but symmetric artefacts*

3 gaincal 'ap', solnorm T, apply 30s-phcal, make 5m-apcal

Apply 30s-phcal, 5m-apcal, clean *snr improves*

4 gaincal 'p' apply 30s-phcal, 5m-apcal make int-pcal *need v. good model*

Apply 30s-phcal, 5m-apcal, int-pcal, clean *snr improves*

5 gaincal 'ap',solnorm F, apply 30s-phcal, 5m-apcal, int-pcal, make 30s-apcal

Apply 30s-phcal, 5m-apcal, int-pcal, 30s-apcal, clean *snr improves a bit*

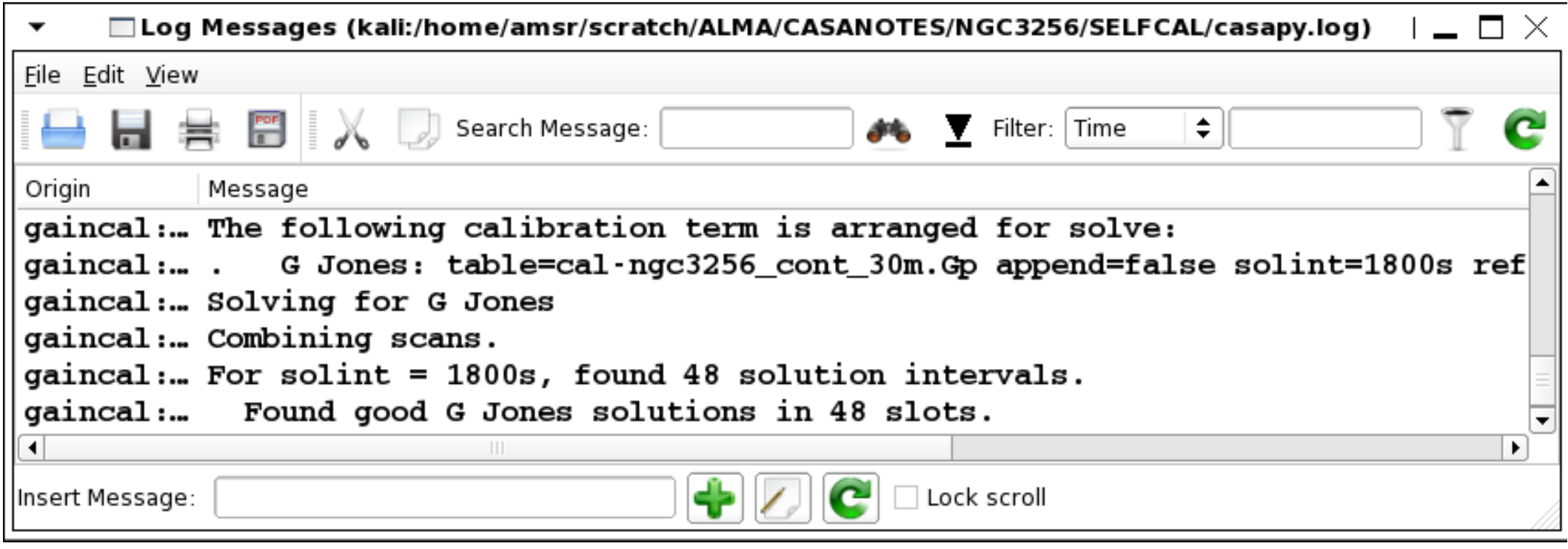
1,2: Replace old solutions with those from better model
3,4,5: Accumulate solutions to optimise amp. calibration

Extended sources self-calibration

- Start with data with phase-ref etc. corrections applied
- Make first image, box carefully, don't clean too deep
- Estimate minimum possible solution interval t_{min}
  - If t_{min} >scan, use t_{min} as solint
    - If t_{min} < scan:
      - If potential snr >> snr of first image, use scan as solint
        - If initial snr is close to ideal, model good, use t_{int}
  - Start with calmode 'p', usually minsnr 3
  - Improve model, clean more, decrease solint if pos.
- Amplitude cal needs better snr i.e. longer solint
  - Apply 'p' corrections when using calmode 'ap'
  - Normalise solutions unless model is very good
- Stop when no further improvement/ideal snr reached

Self-calibration checks

- Check in logger – not too many failed solutions
- Also see terminal messages
  - May be all failures at just one time interval out of many
  - Or may be just a few but all to the crucial distant antenna…

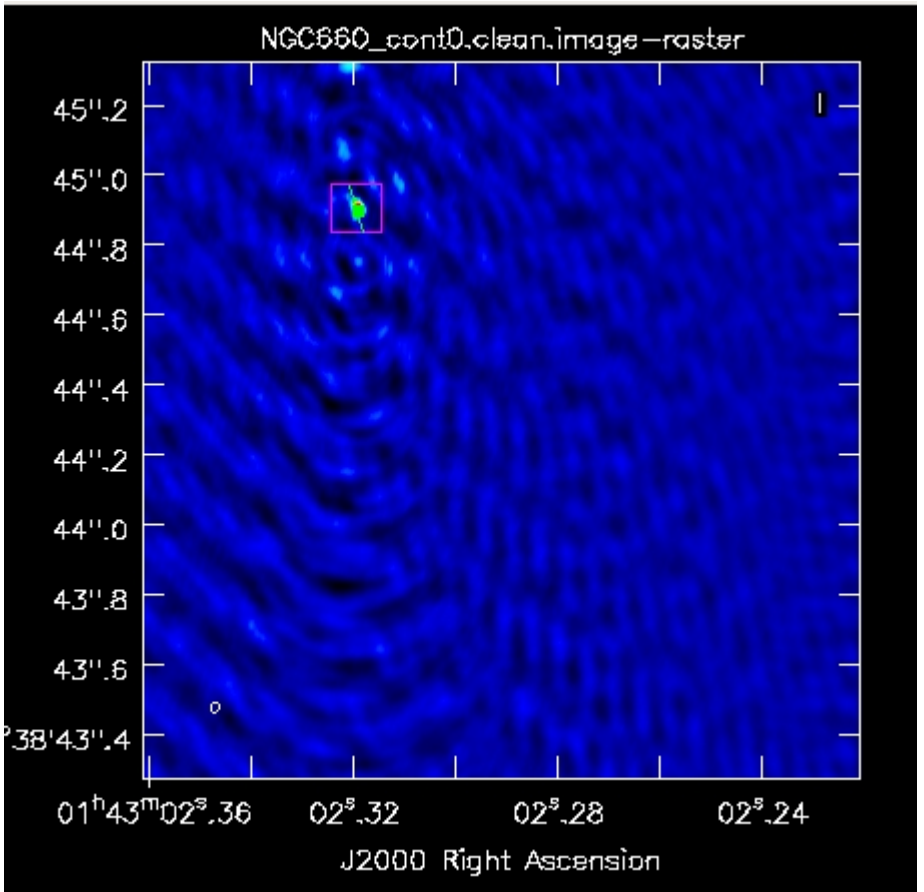


Self-calibration checks

- Plot solutions
  - If they look like noise, don't use!
    - Check you used the right model and any pre-applied cal
    - Edit data if only parts look really bad
    - Increase solint if less than a scan or so, source faint
      - But keep shorter than phase change of $\pi/4$, amp structure
- Succesive rounds of self-cal should improve
  - Phase/amp solutions should approach 0/ 1
    - See above if solutions diverge
- Image, check snr is increasing, position not shifted
- Compare model with data – is it converging?
- Check other spw's etc. also improved if relevant

Astrometry

- Target position is not known accurately?
  - Use **pre-self-cal** image to measure **astrometric** position
    - This is the most accurate position you can measure
  - Limited by ϕ-ref solution & antenna position accuracy, separation on sky, etc. (**Ed's the expert!**).
- Use this image as self-cal model for good astrometry
- Compact target?
  - Reverse roles with ϕ-ref
  - Apparent ϕ-ref offset x -1 gives target position



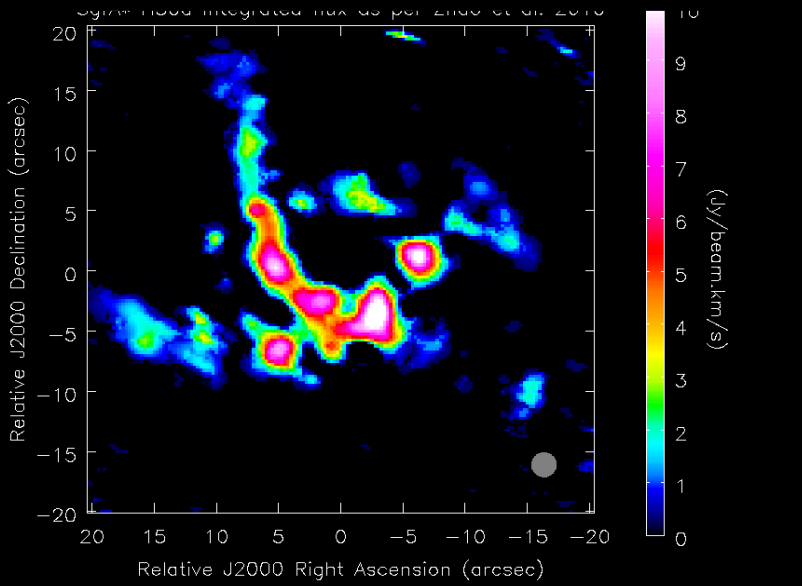
Frequency Dependence

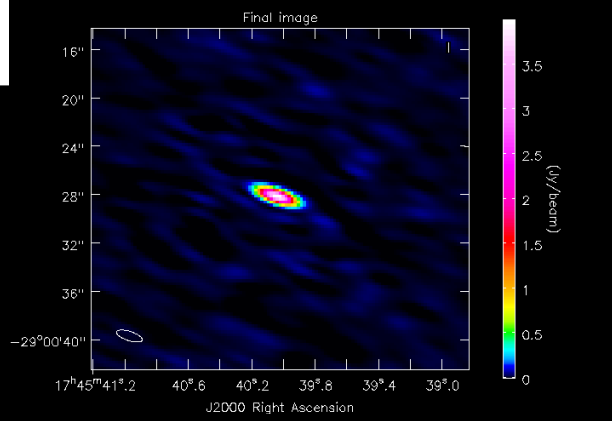
- Continuum source spectral index α in amp self-cal
  - $S_1 = S_0\,(\nu_1/\nu_0)^{\alpha}$
    - $S_0/(S_1-S_0) = 1/[(\nu_1/\nu_0)^{\alpha} - 1]$
      = (flux density / flux density difference between spw)
  - e.g. spw0 @ ν_0 =100 GHz; spw2 @ ν_1 =102 GHz
    - $S_0/(S_1-S_0) = 1/[(102/100)^{\alpha} - 1]$
      - ~ 25 if $\alpha = 2$
  - If S/N > 25, use nterms = 2
- Atmospheric refraction is linear function of frequency
  - interp= 'nearestPD' etc. if extrapolating far in frequency

Mosaics

- Apply brightest-field solutions to whole mosaic
  - Sgr A* compact ~4-Jy central continuum peak
    - In this case, amplitude may be variable
      - Phase-only self-cal
    - Could use other fields and/or subtract variable core

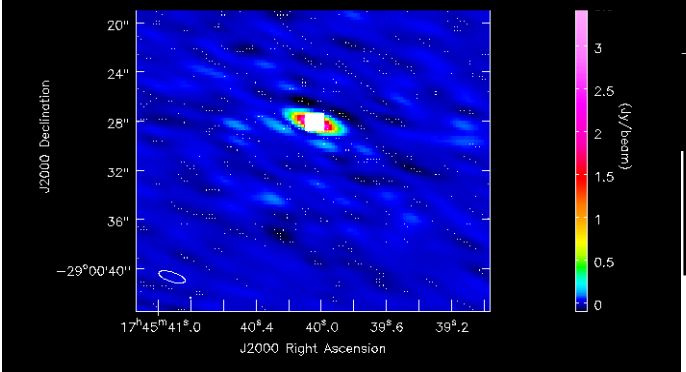
Post selfcal H30α mosaic





Post selfcal
Central continuum

Pre selfcal
Central continuum
field

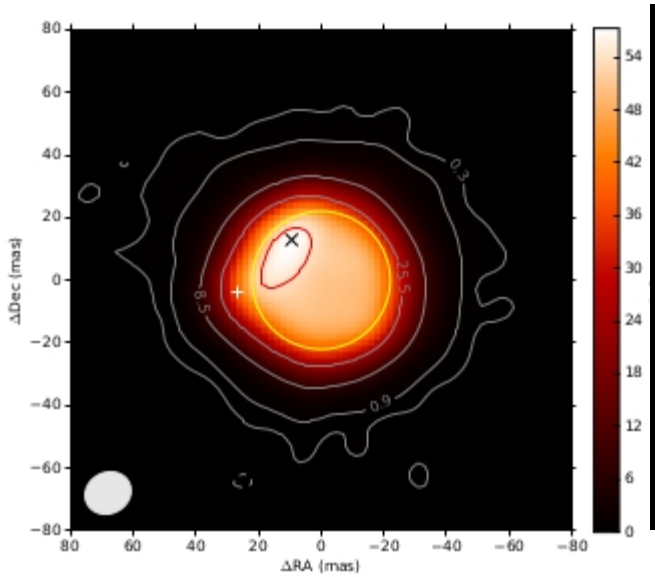


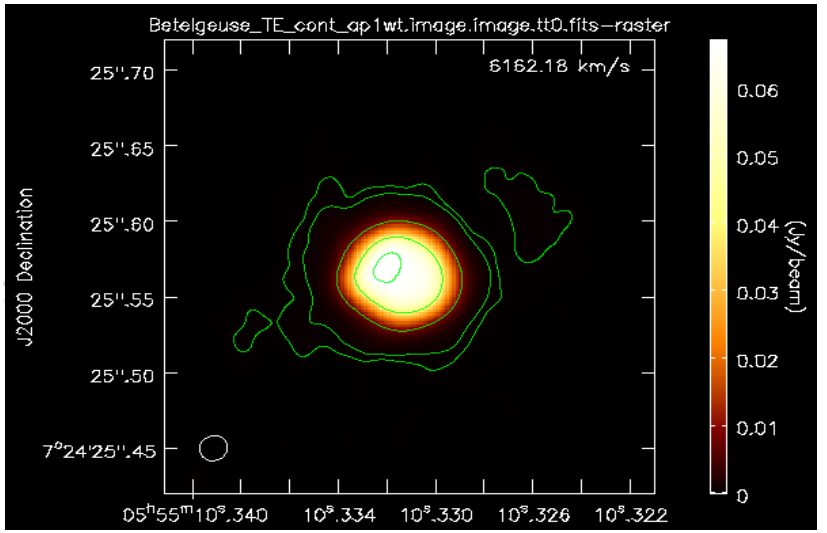
Aligning different observations

- Flux scale
  - Phase-ref variability
  - 5-10% uncertainty (more at higher bands)
    - Model uncertainty/short-term variability of flux standard
    - Transfer of solutions between cal sources
      - CASA optimisation tends to overestimate noisy spw flux
        - Select best spw if necessary in fluxscale
  - Spectral scans
    - If possible, self-calibrate on continuum
      - Check if spectral index and/or gain scaling for atmosperic refraction is required for very wide frequency ranges
    - Tools for alignment e.g. Nordic node `Specscan`
- If self-cal on line use mstransform first to shift to constant velocity
- Use freqtol and dirtol in concat as needed

Combining data and missing spacings

- Betelgeuse (*O'Gorman et al, Kervella et al.*)
  - Star worse with 3 EBs - variability
    - Extended lines better!

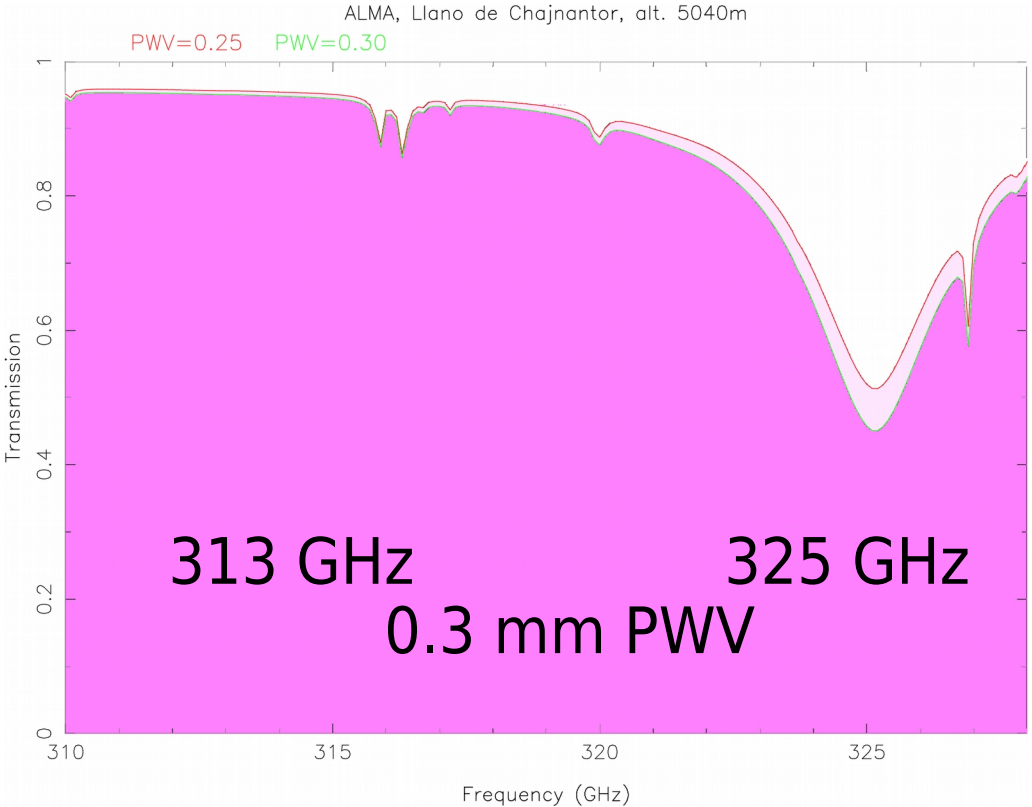




- Missing spacings
  - Can ignor if good image
  - What if artefacts?

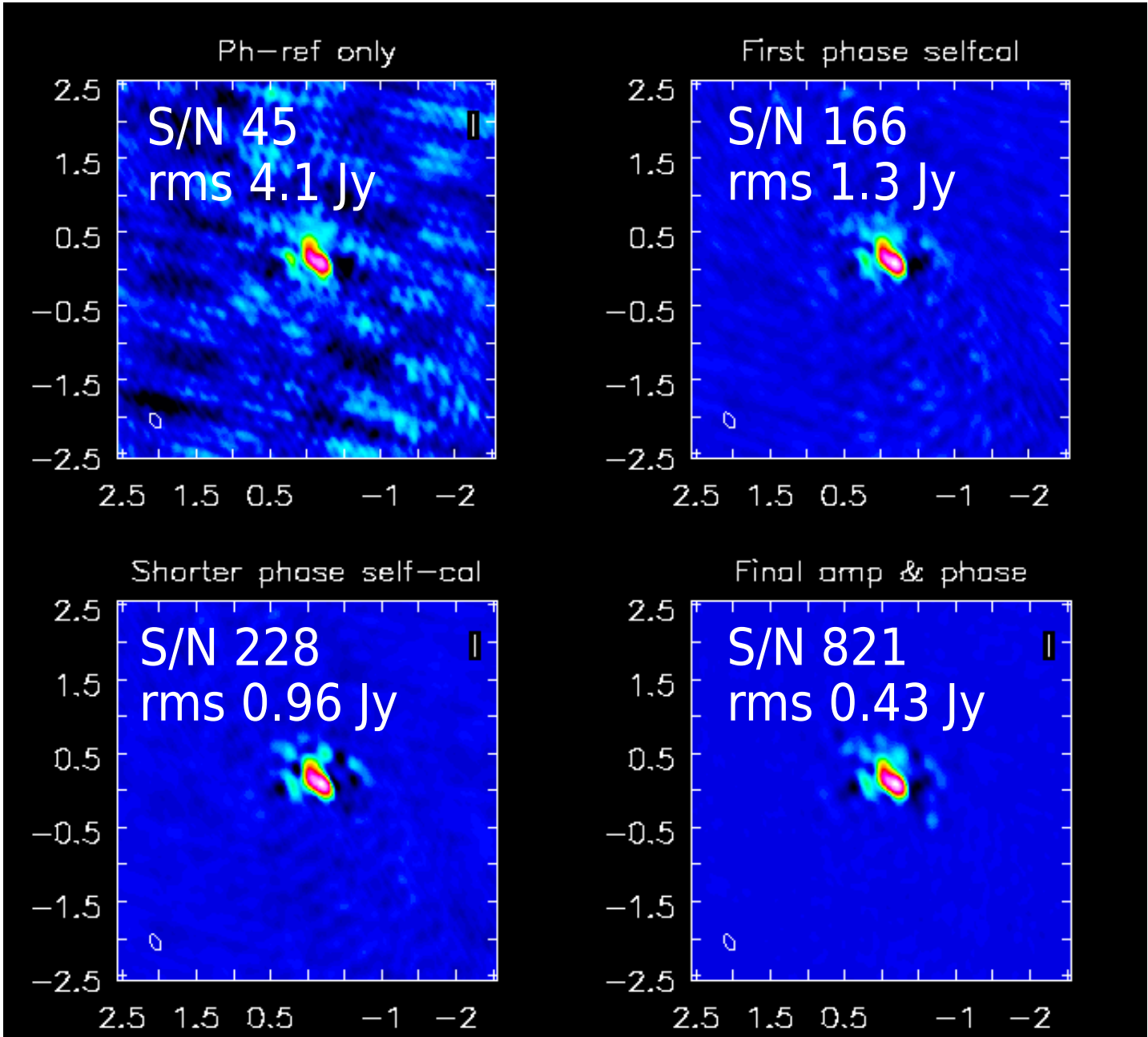
VY CMa SV data

- August 2013, 19 antennas, up to 2.7 km baselines
- Three observations x 3EB around 321, 325, 658 GHz
- Here, just one EB with two spw at 325 GHz, 313 GHz
  - All 'QA2' calibration applied, VY CMa split out
    - Extra averaging
      - 1920 chan/spw
      - 12-s integrations
  - 100s Jy maser at 325 GHz
    - Awful atmosphere
    - Calibrate on maser?
      - continuum?
      - mix?
      - another line?



VY CMa 325 GHz long-ish (2.7 km) b'lines

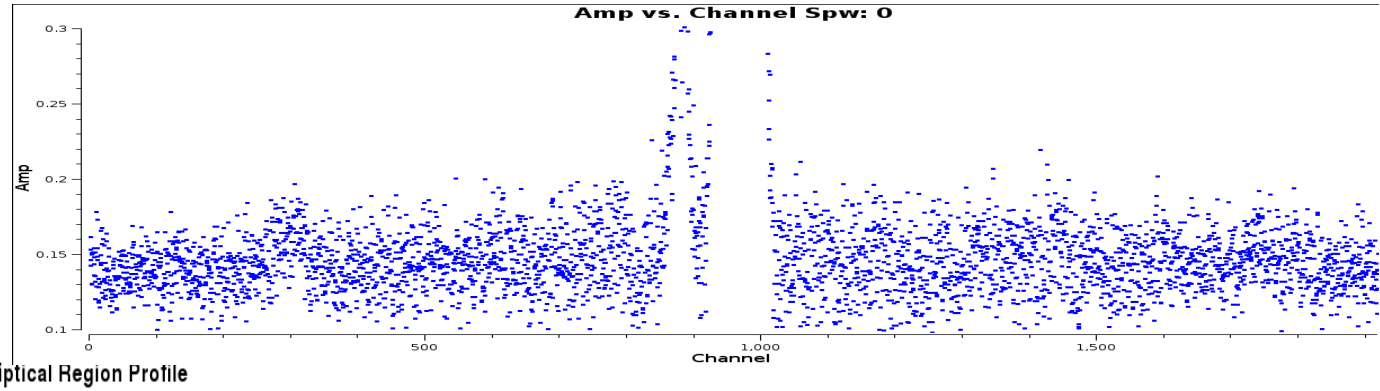
- 'Basket weaving' suggests long baseline errors
  - Usually phase-dominated
  - Peak incr. 184 - 224 Jy
  - S/N x 18 improvement
- Single channel dynamic-range limited



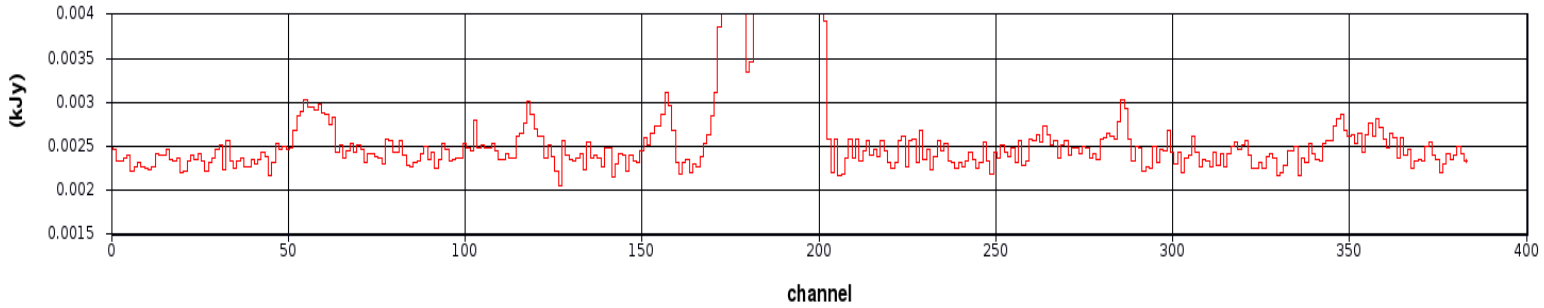
Self-calibration on line

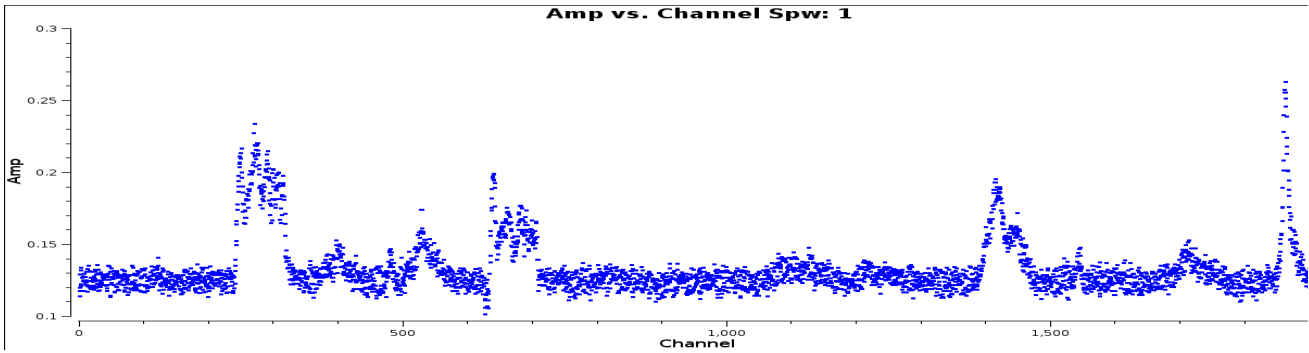
- mstransform to constant velocity after QA2 calibration
  - Multiple EBs combined?
    - Check concat tolerances have combined spw properly
- Select brightest compact line
  - Fewest channels for good S/N if morphology shifts
  - Self-calibrate before continuum subtraction
    - Better continuum selection after calibration
    - More accurate subtraction
- Phase, then ap
  - Periodically check resolved line in other spw
    - Stop when no improvement in model/reduction in solint
- Make low-resolution cube to identify continuum
- Image continuum with multiscale
- uvcontsub, image lines

Spectra: *uv* v. image planes

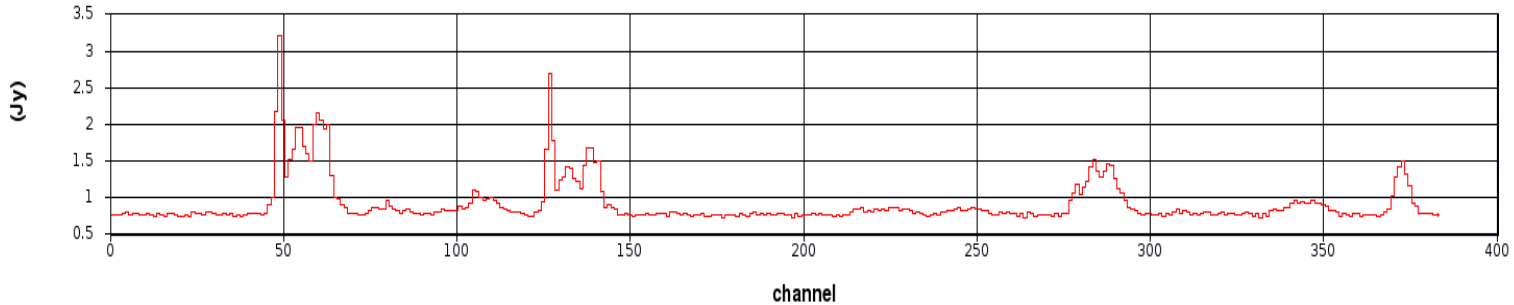


Elliptical Region Profile





Elliptical Region Profile



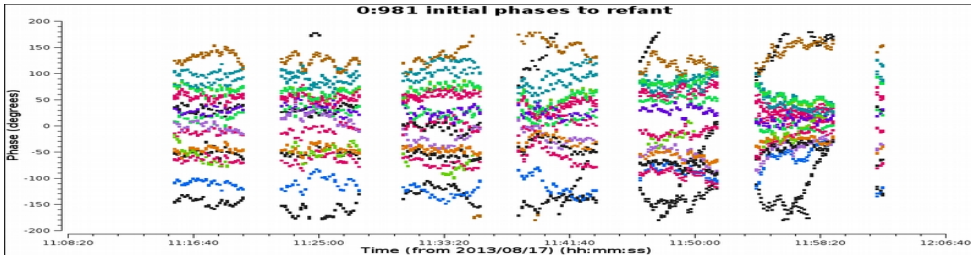
Self-calibration on continuum

- mstransform to constant velocity after QA2 calibration
  - Multiple EBs combined?
    - Check concat tolerances have combined spw properly
- Select continuum
  - Hard to do accurately from uv spectrum
    - Make test cube first?
  - Err on side of rejecting too much for self-cal
    - Avoid lines contaminating flux scale
- Phase, then ap
    - Stop when no improvement in model/reduction in solint
- Make low-resolution cube to identify continuum
- Image continuum with multiscale
- uvcontsub, image lines

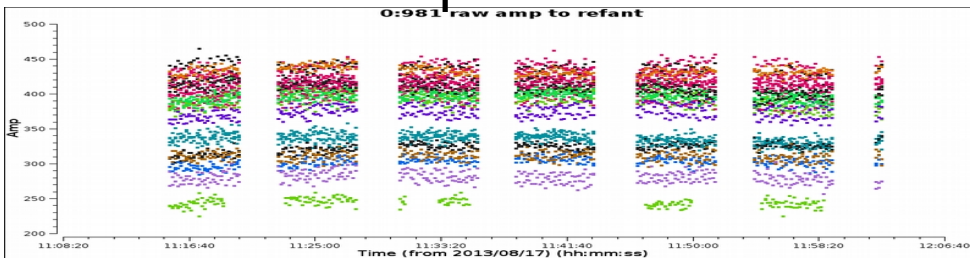
Monitoring progress

Phase

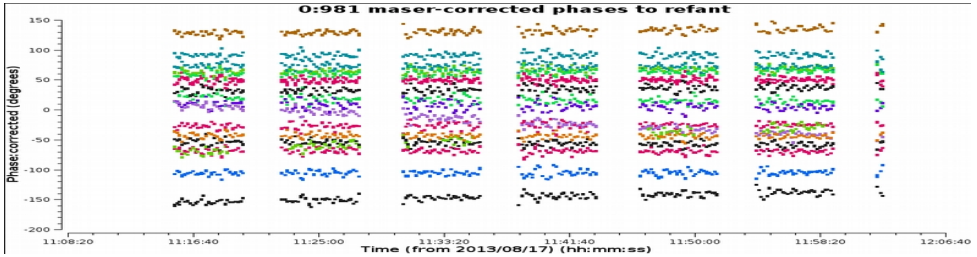
Before

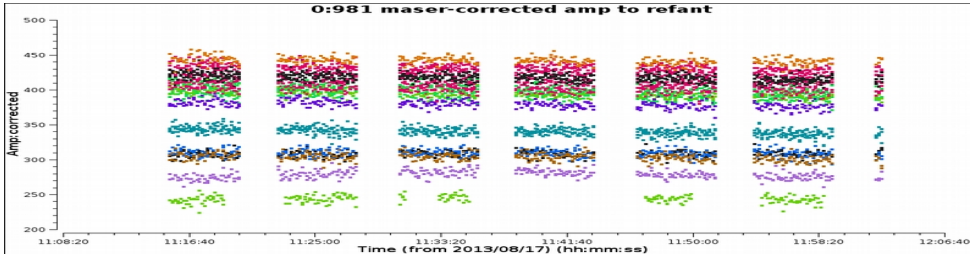


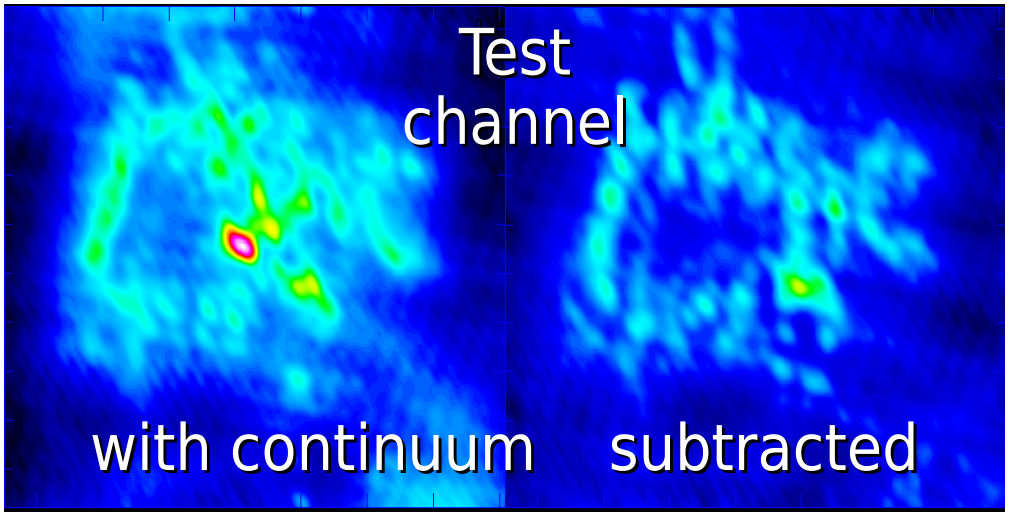
Amplitude



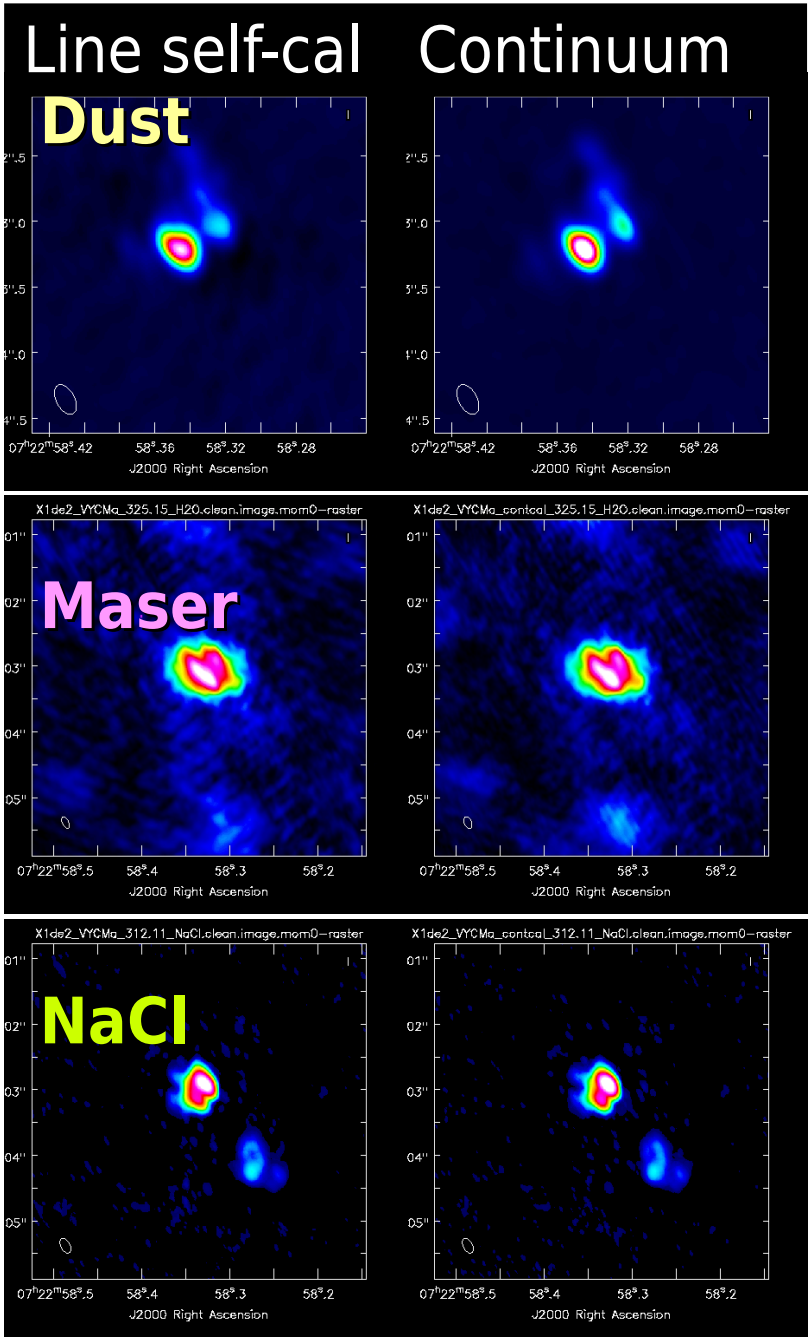
After







Final images - which method wins?



		Line	Continuum
Dust	peak	0.223	0.183
continuum	rms	0.00014	0.0006
Jy	S/N	160	? 305
Maser	peak	1225	1140
mom0	rms	4.6	5.0
Jy	S/N	266	228
NaCl	peak	5.23	5.89
mom0	rms	0.014	0.014
Jy	S/N	374	420

CASA complications

- (t-)clean does not always insert useable model
  - Check savemodel/usescratch parameters
    - If you want a virtual model in tclean:
      - If tclean stopped manually, re-run with savemodel='virtual', calcres=False, calcpsf=False
  - Or use scratch column, or insert model with task 'ft'
    - Safest for complex transfers of calibration anyway
- Want to inspect phase etc. in plotms
  - plotms can't average a complicated continuum selection e.g. spw='0:5~17;34~127,1:3~9;90~127'
    - Could back-up, flag lines and average?
      - If initial image S/N good (e.g. 100) just try anyway?

Your mission, should you choose to accept it...

- Best way to self-calibrate VY CMa
  - May be different for best maser or best thermal images
- Two scripts provided
  - blq.py (self-cal on maser)
  - blq_cont.py (continuum used for self-cal)
    - Solutions applied to all data in both cases
- Improve at will
  - Better models, different solints
  - Could start with line and then use continuum etc.
  - Compare continuum spw separately
    - Solve flux divergence

Thanks

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