Error Recognition

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With thanks to Greg Taylor, Amy Kimball, Aaron Lawson, Sergio Garza, Devaky Kunneriath, Ilsang Yoon, Todd Hunter, Sumit Sarbadhicary, Ryan Loomis, Erica Keller, Drew Medlin

Understanding your data is key for doing good science!

- Most ALMA/VLA data today is run through a calibration (and potentially imaging) pipeline and QA process.
- It's still useful to be able to recognize issues in your data.
  - The pipelines and QA are very good, but sometimes issues sneak through.
  - You may have more stringent science requirements than what is checked by standard QA.
  - Sometimes you have to calibrate the data from scratch, so you need to be able to ID problems on your own.
- Your data = your responsibility.
  - Don't just blindly accept results!

Focus will be on VLA and ALMA data and CASA

CASA

- These techniques are generally applicable for all interferometric data.
- Other data reduction packages have similar plotting functionality.

Many useful plots are in pipeline weblogs!

VLA Weblog

Home | By Topic | By Task

Task

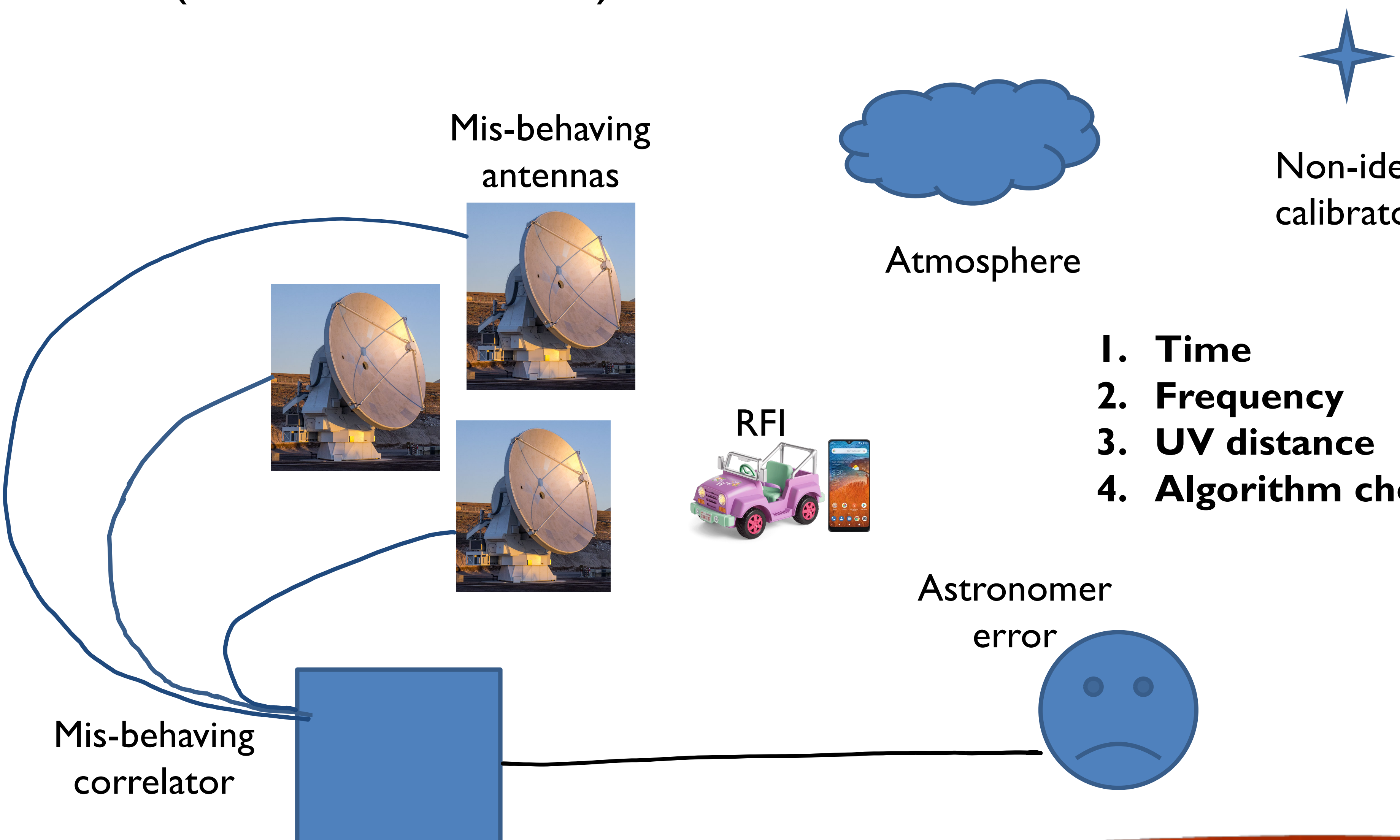
1. hifv_importdata: Register VLA measurement sets with the pipeline
2. hifv_hanning: VLA Hanning Smoothing
3. hifv_flagdata: VLA Deterministic flagging
4. hifv_vlasetjy: Set calibrator model visibilities
5. hifv_priorcals: Priorcals (gaincurves, opacities, antenna positions corrections, rq gains, and switche
6. hifv_testBPdcals: Initial test calibrations
7. hifv_checkflag: Checkflag summary
8. hifv_semiFinalBPdcals: Semi-final delay and bandpass calibrations
9. hifv_checkflag: Checkflag summary
10. hifv_solint: Determine solint and Test gain calibrations
11. hifv_fluxboot: Gain table for flux density bootstrapping
12. hifv_finalcals: Final Calibration Tables
13. hifv_applycals: Apply calibrations from context
14. hifv_checkflag: Checkflag summary
15. hifv_targetflag: Targetflag
16. hifv_statwt: Reweight visibilities
17. hifv_plotsummary: VLA Plot Summary
18. hif_makeimlist: Set-up parameters for bandpass calibrator & phase calibrator imaging
19. hif_makeimages: Make calibrator images

ALMA Weblog

Home | By Topic | By Task

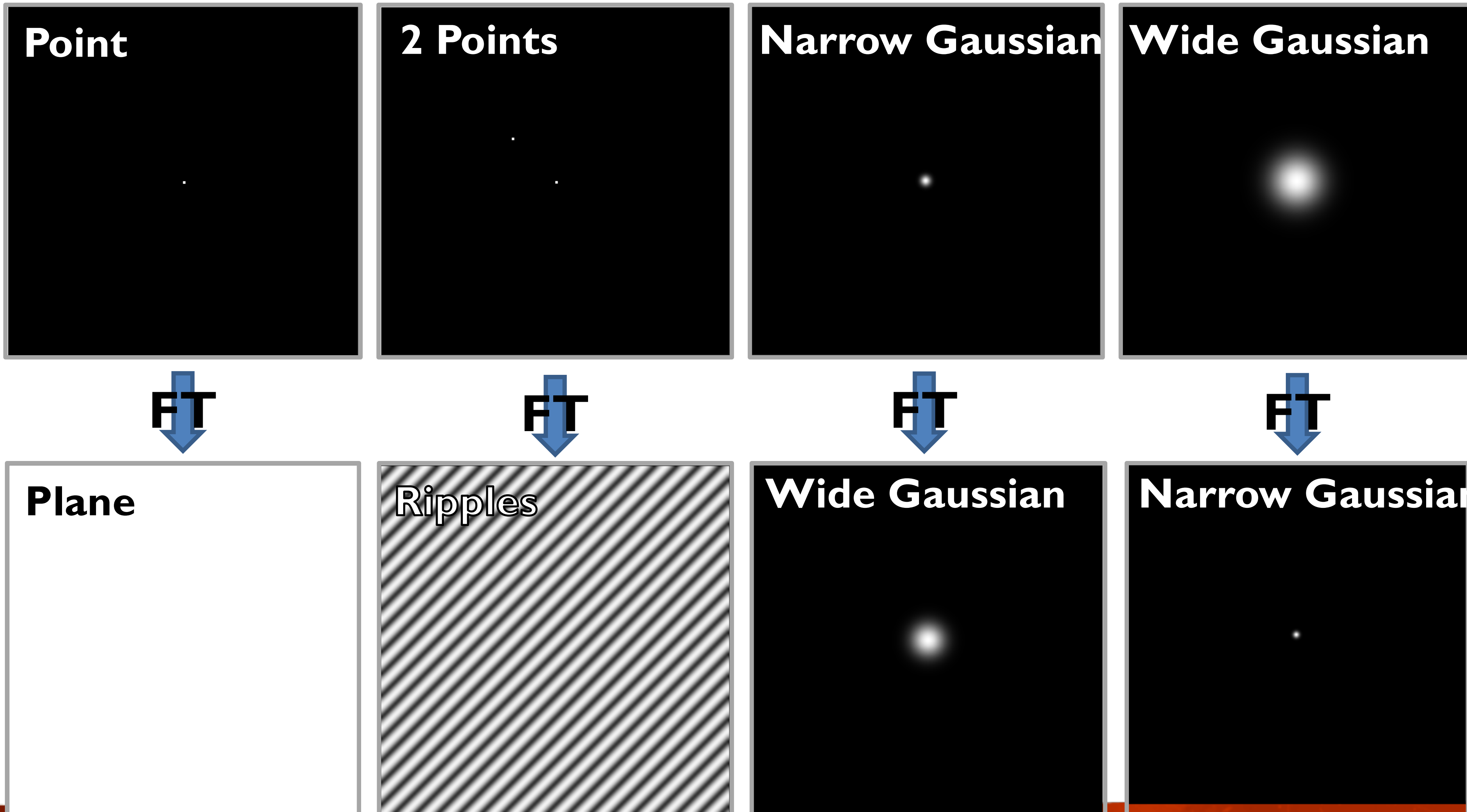
5. hif_refant: Select reference antennas
6. h_tsyscal: Calculate Tsys calibration
7. hifa_tsysflag: Flag Tsys calibration
8. hifa_antpos: Correct for antenna position offsets
9. hifa_wvrgcalflag: Calculate and flag WVR calibration
10. hif_lowgainflag: Flag antennas with low gain
11. hif_setmodels: Set calibrator model visibilities
12. hifa_bandpassflag: Phase-up bandpass calibration and flagging
13. hifa_bandpass: Phase-up bandpass calibration
14. hifa_spwphaseup: Spw phase offsets calibration
15. hifa_gfluxscaleflag: Phased-up flux scale calibration + flagging
16. hifa_gfluxscale: Transfer fluxscale from amplitude calibrator
17. hifa_timegaincal: Gain calibration
18. hifa_targetflag: Target outlier flagging
19. hif_applycal: Apply calibrations from context
20. hif_makeimlist: Set-up parameters for bandpass calibrator & flux calibrator & phase calibrator imaging
21. hif_makeimages: Make calibrator images
22. hif_makeimlist: Set-up parameters for check source imaging
23. hif_makeimages: Make check source images

Common sources of issues with interferometric data (not exhaustive)



1. **Time**
2. **Frequency**
3. **UV distance**
4. **Algorithm choices**

Looking at both visibility data and images can help uncover issues.



Calibrator sources have known properties and thus are good for identifying problems.

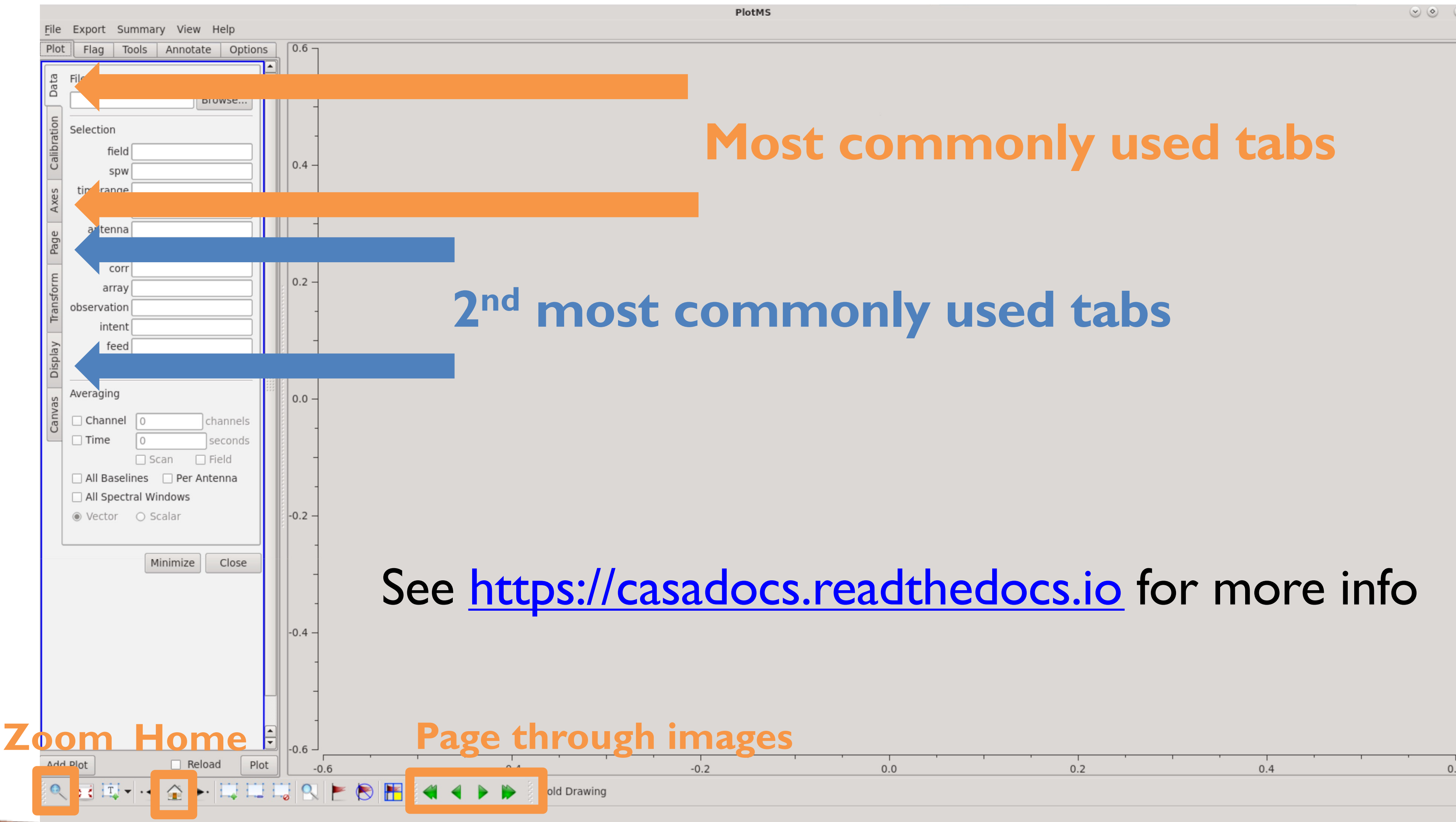
- Flux calibrator:
  - Used to set flux scale of observations (i.e., Jy).
  - Source with a well-known flux density.
  - Source may be extended and thus require the use of models to derive an accurate flux calibration.
- Bandpass calibrator:
  - Used to calibrate frequency response of the system.
  - Brighter the better.
  - Often the same as the flux calibrator, but not always.
- Gain calibrator (also known as phase or secondary calibrator)
  - Used to derive complex gains (amplitude and phase) vs. time.
  - Located near (~few degrees) the target.
  - Point sources strongly preferred.

What does an ideal calibration look like?

e.g., Josh Marvil's talk on calibration

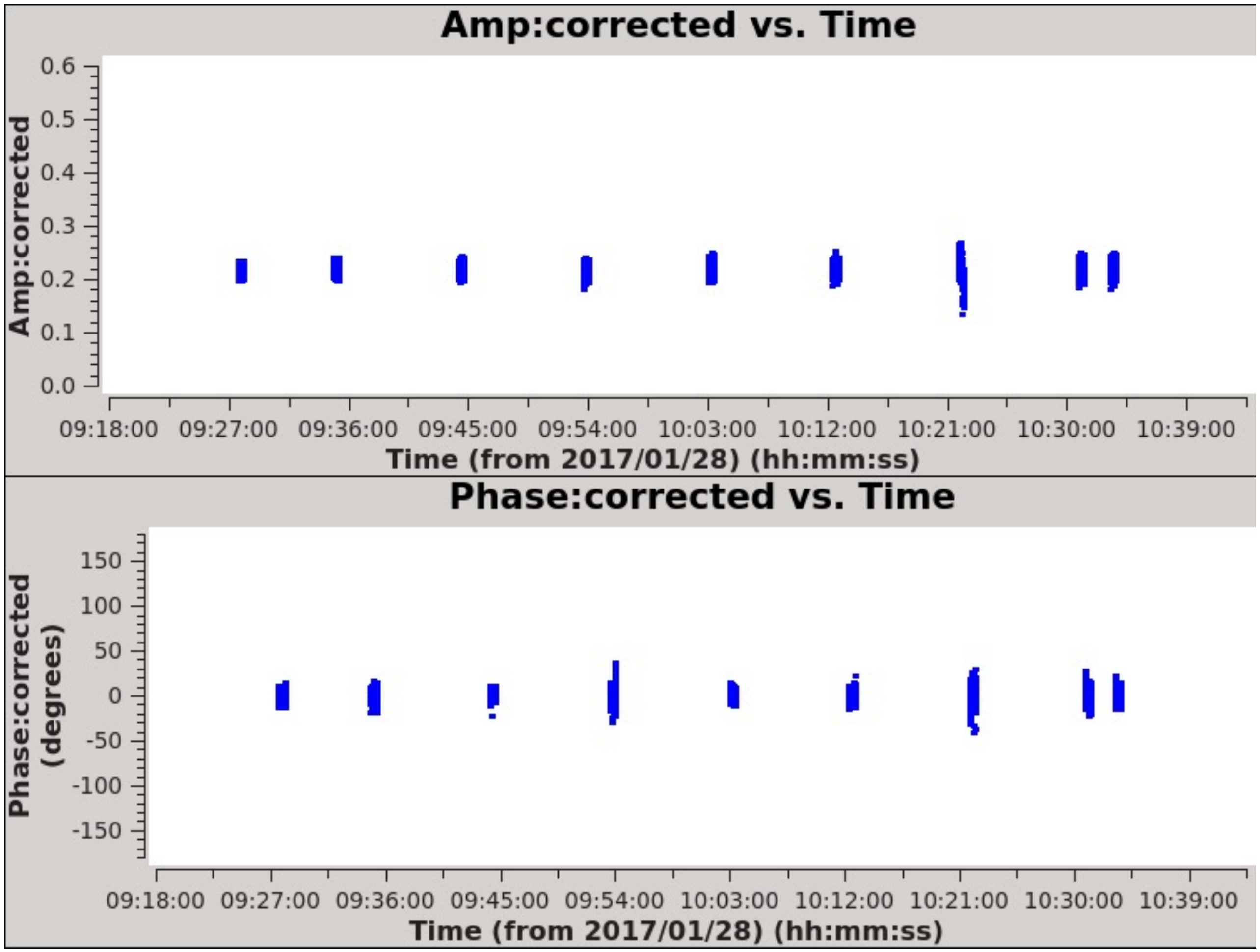
- **Visibility domain:**
  - Bandpass amplitude changes smoothly with frequency and phases are close to zero.
  - Gain calibrator has consistent amplitude with time with phases close to zero.
  - Flux calibrator amplitude should be consistent with expected value. May have structure.
- **Image domain**
  - Calibrated images have the structure you expect.
  - High S/N detections of calibrators
  - Lack of artifacts and sidelobes
  - Flux density of calibrators is as expected.

The CASA task plotms can be used to examine visibility data and calibration tables.



See https://casadocs.readthedocs.io for more info

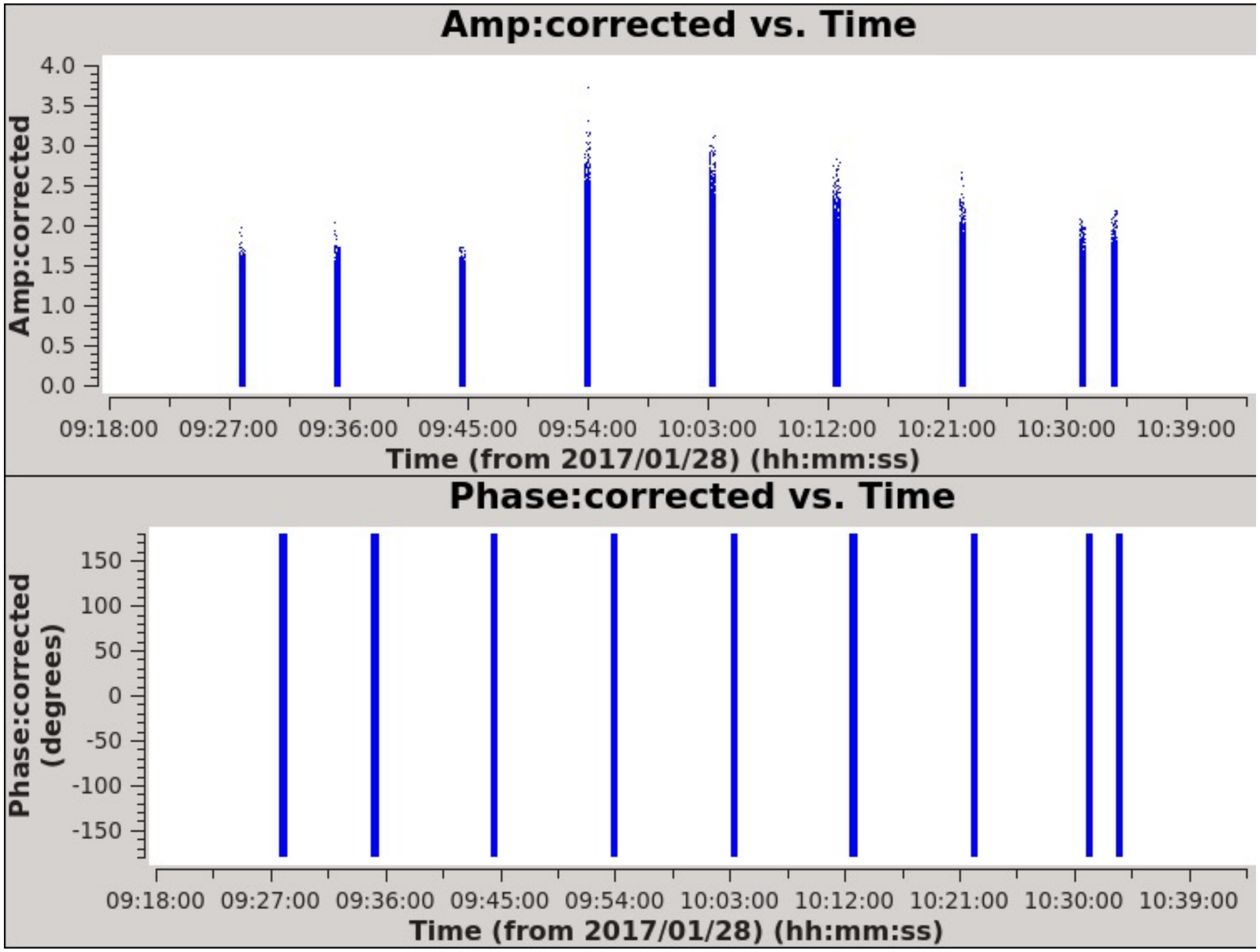
Amplitude and phase vs. time



- Good to check for time-based issues:
  - Telescope not quite on source
  - Misbehaving antennas
  - Shadowing
  - RFI
- Calibrations should have a constant amplitude with time that is consistent with the known flux density.
- Phases should be zero (point source).
- Averaging by antenna and channel suggested.

A word about averaging

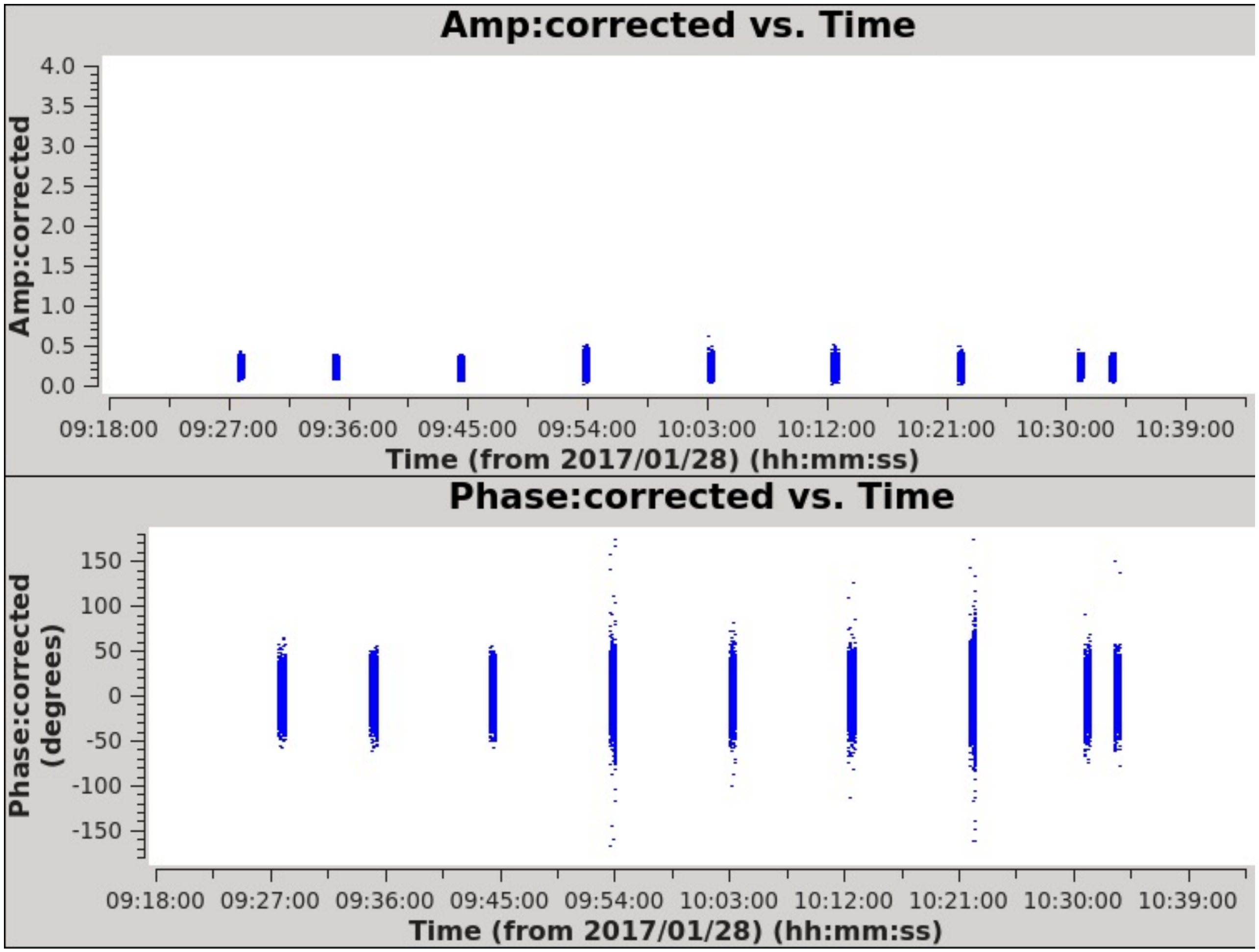
Often will need to average data to increase S/N



No averaging

A word about averaging

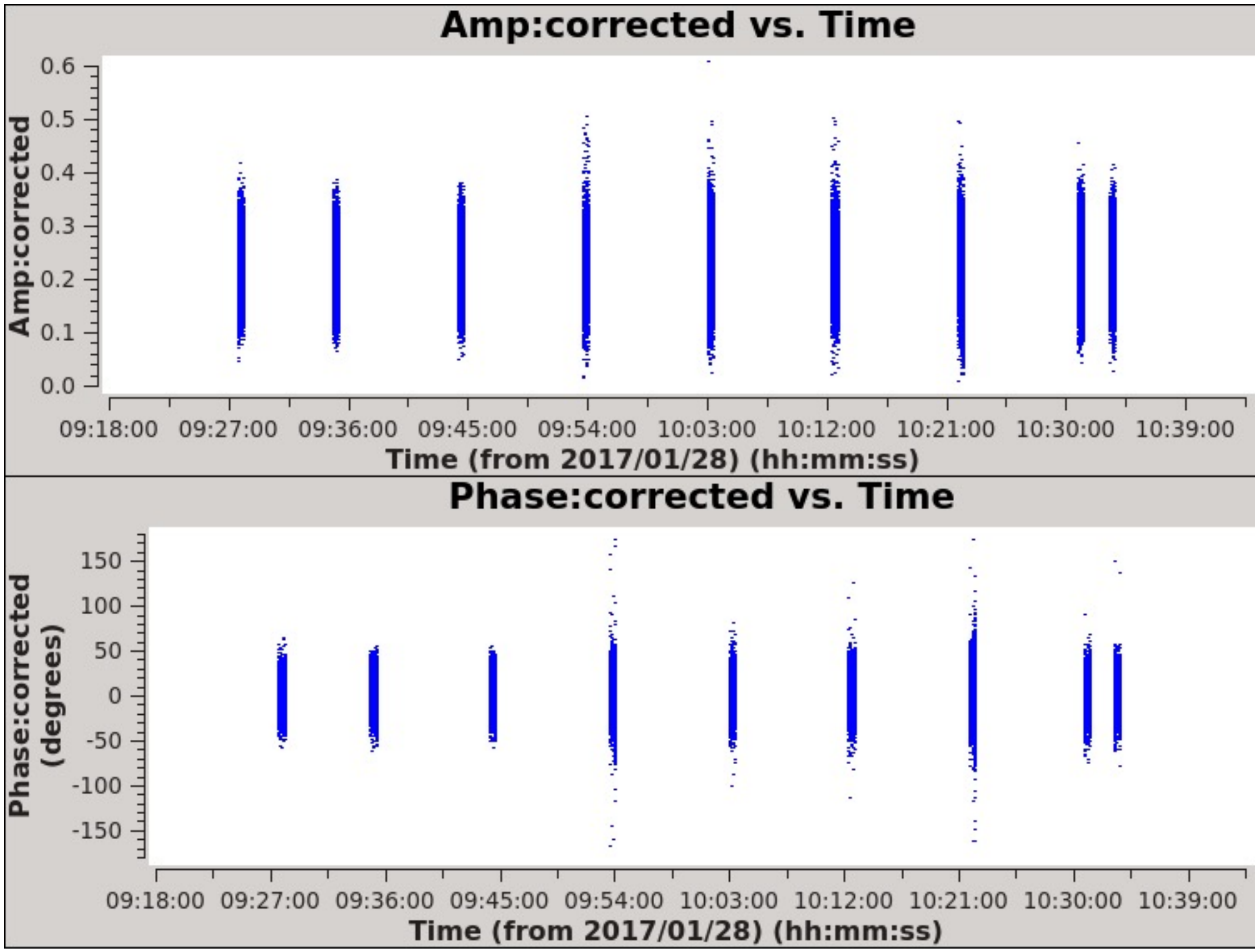
Average on axes orthogonal to the plot



X-axis is time, so averaging over all channels

A word about averaging

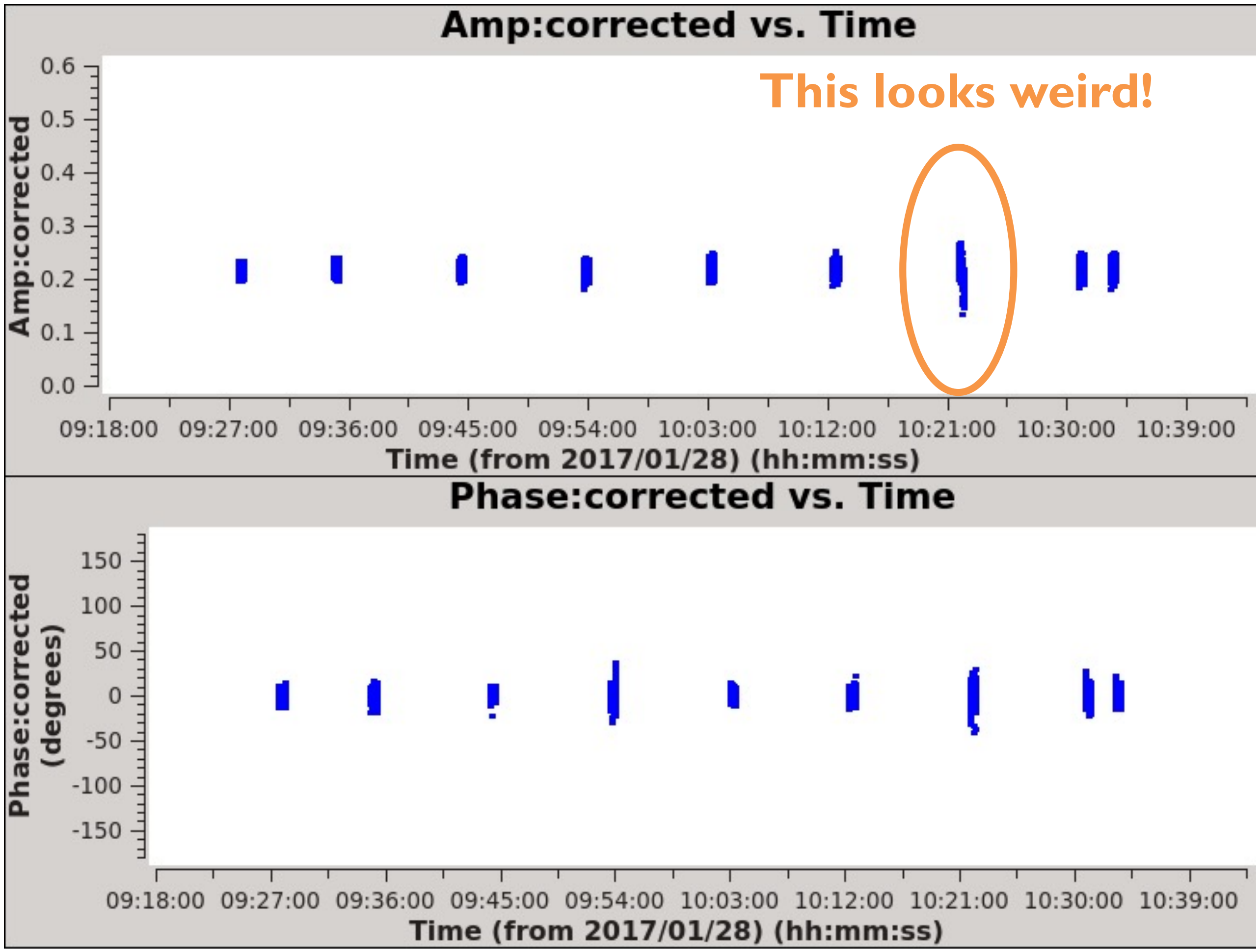
Average in the orthogonal direction to the plot



Averaging over all channels (zoom in)

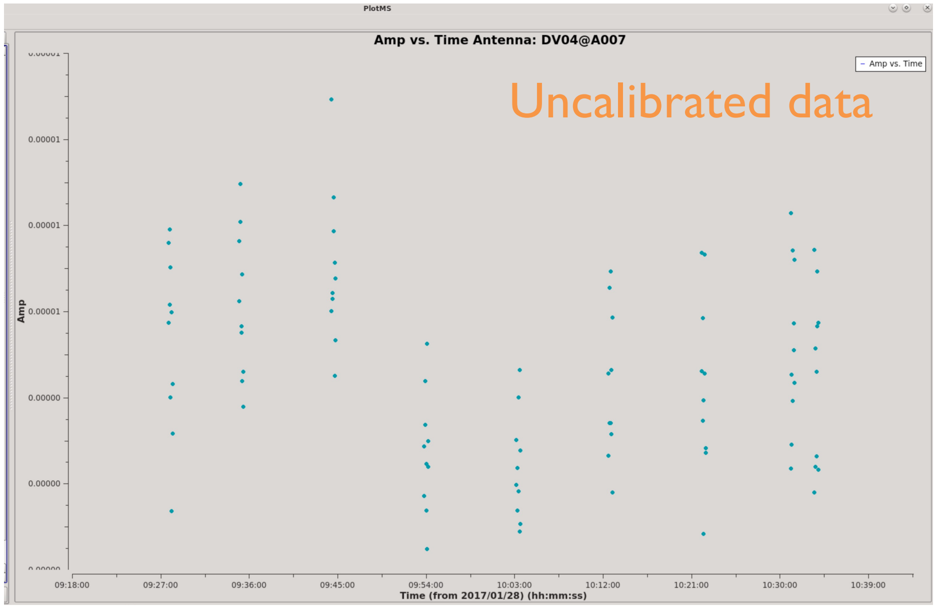
A word about averaging

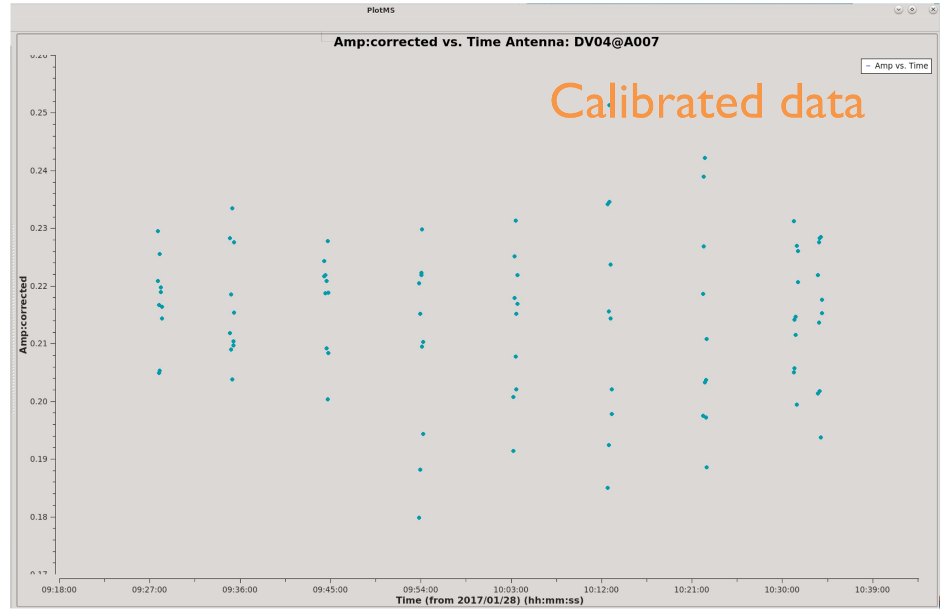
Average by antenna (fundamental calibration quantity)



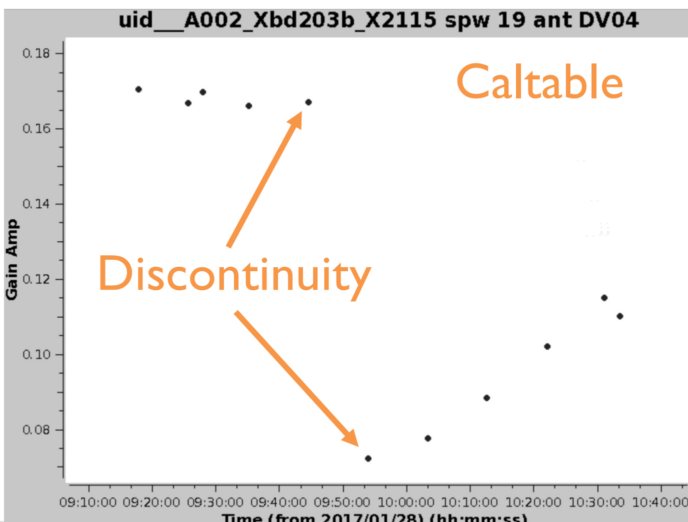
Averaging over all channels and per antenna (zoom in)

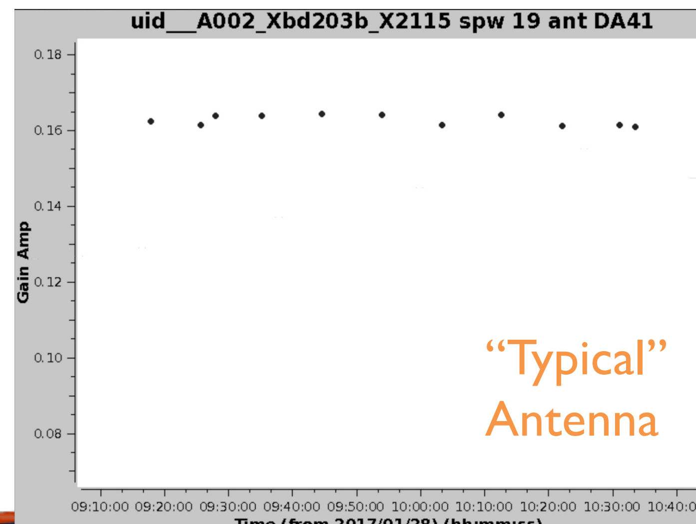
Looking at calibration tables can be helpful!



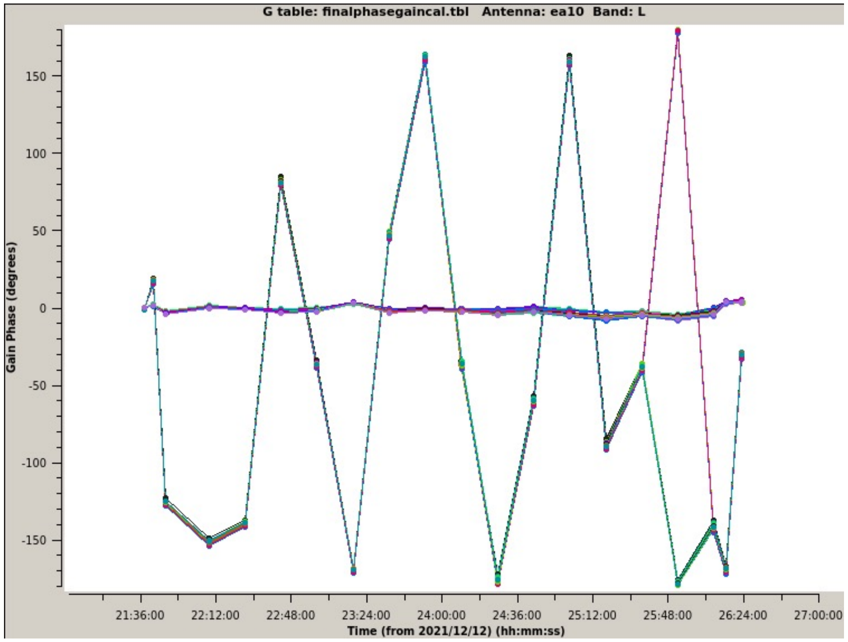


Looks like DV04 has something funny going on





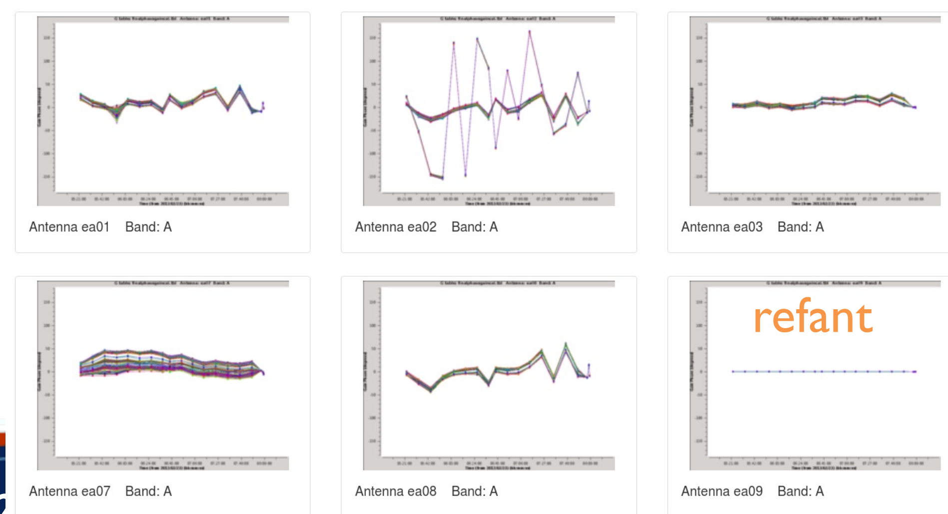
Amplitude and phase vs. time



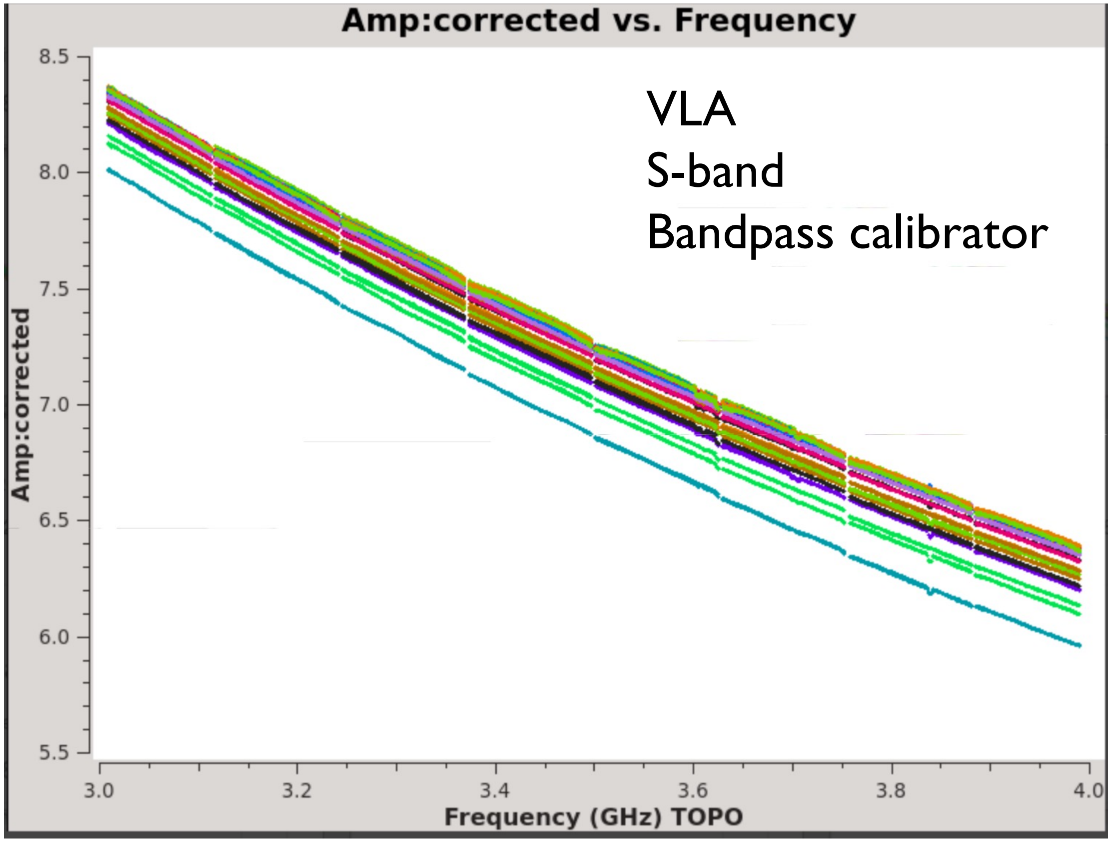
- Sometimes antenna phases will change too rapidly due to hardware issues
- Prevents phase vs. time solution.
- If that antenna is your reference antenna, then these bad solutions can propagate to the other antennas.
- Solution: flag bad antenna and exclude it as a refant

Bad antenna as refant

Changed refant to good antenna

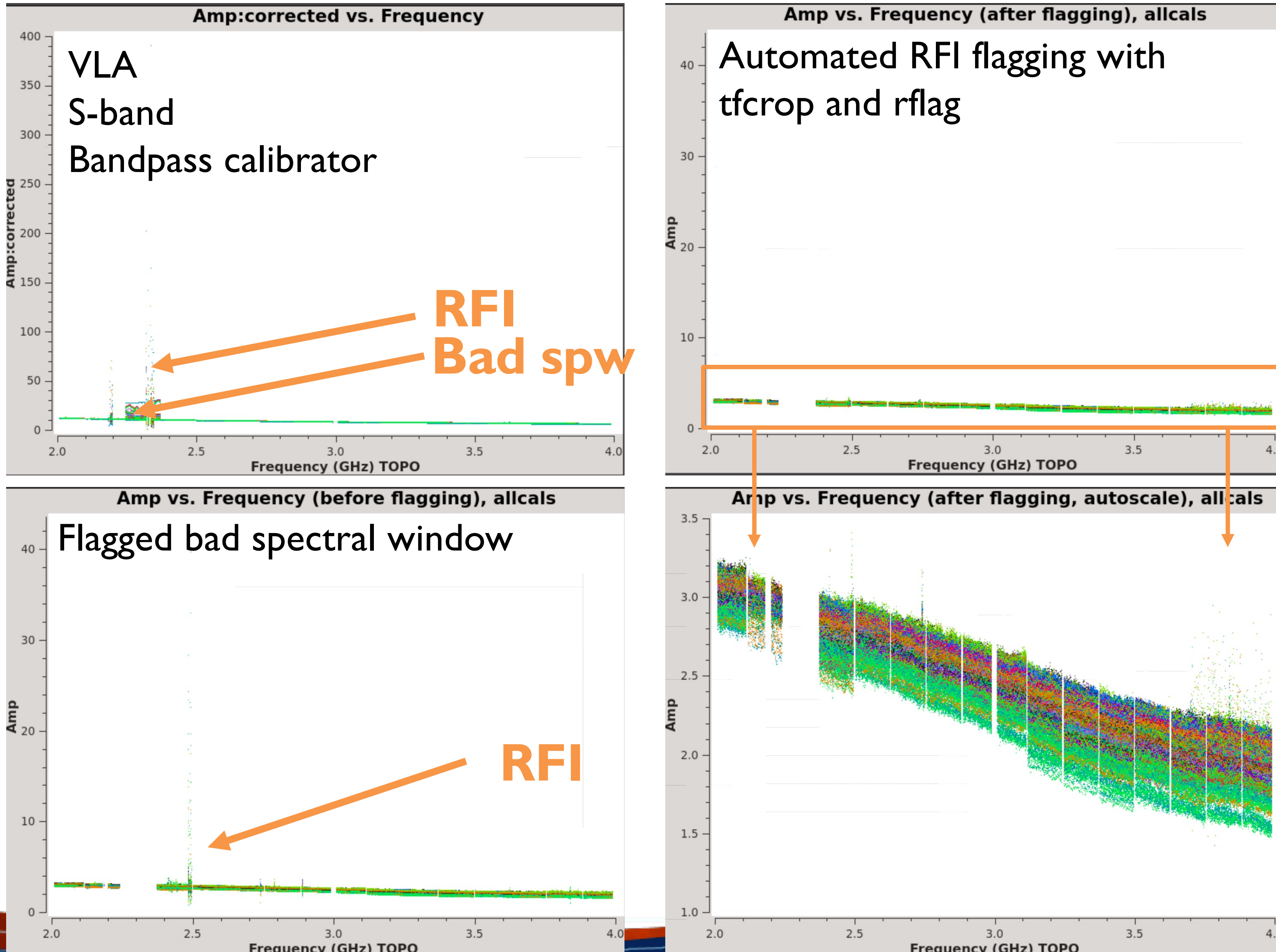


Amplitude and phase vs. frequency plots

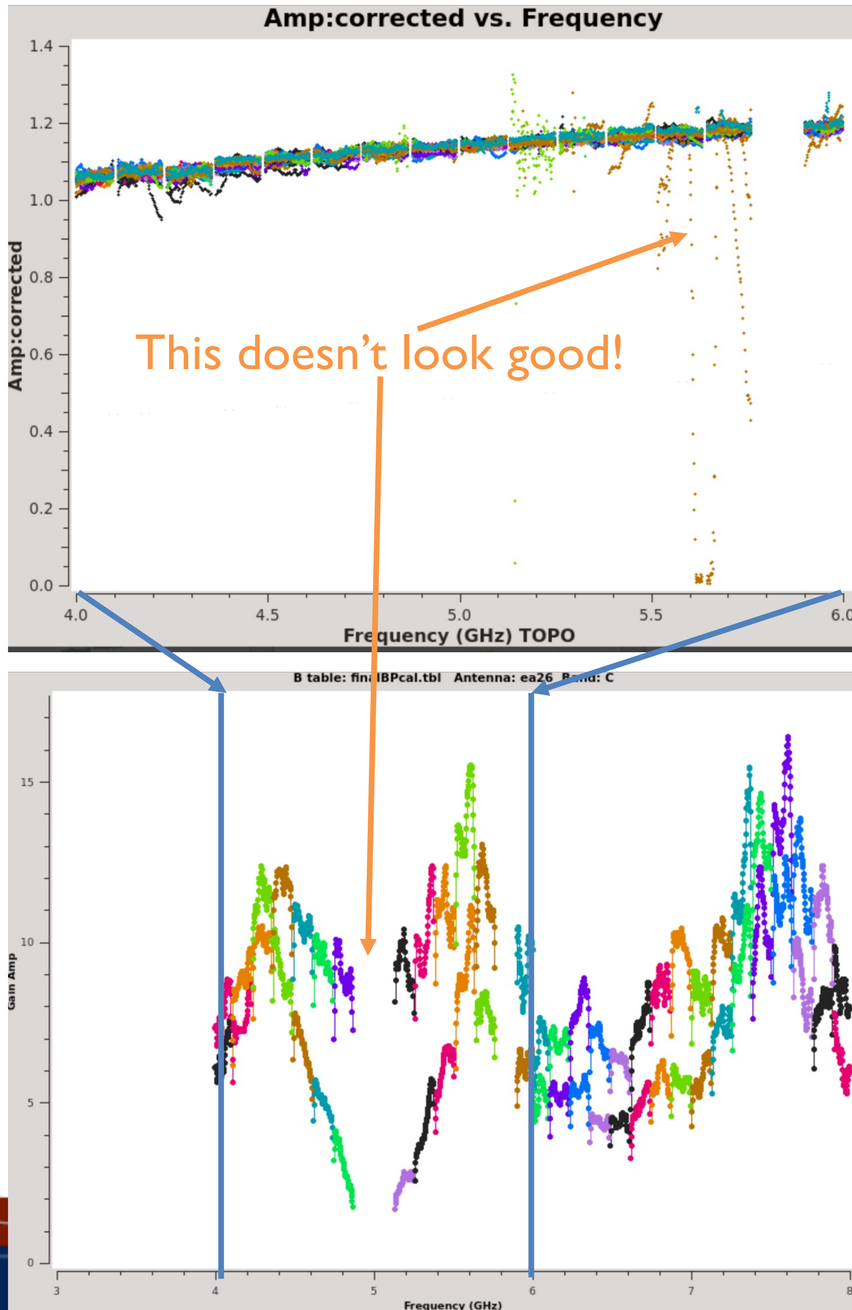


- Good to check for frequency-based issues:
    - RFI
    - Correlator issues
    - Spectral lines (either atmospheric or science lines)
- Suggested averaging by all scans and either per antenna or all baselines.
- Calibrators should have the correct amplitudes.
    - But older flux density measurements may no longer be accurate due to changes in calibrator flux densities.
- Phases generally near zero, although flux calibrators may show structure.

Amplitude and phase vs. frequency plots



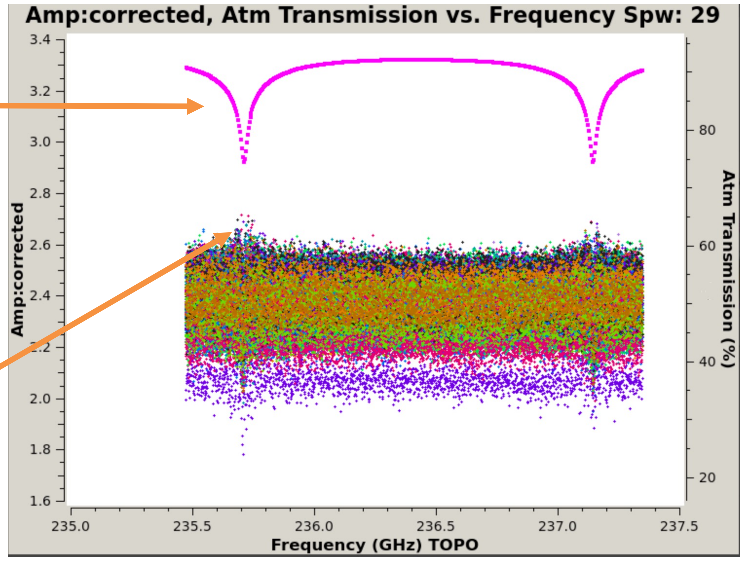
Amplitude and phase vs. frequency plots



- Correlator issues show up particularly well in amplitude/phase vs. frequency plots.
- Example of one type of deformatter issue at the VLA.
    - At the telescope the electronic signal is converted to an optical one to go down the optical fibers.
    - At the correlator the signal is deformatted to an electronic signal.
    - Some times this doesn't happen as it should and you get strong amplitude/phase slopes with frequency.
- Features like this are generally caught by telescope support teams or QA.

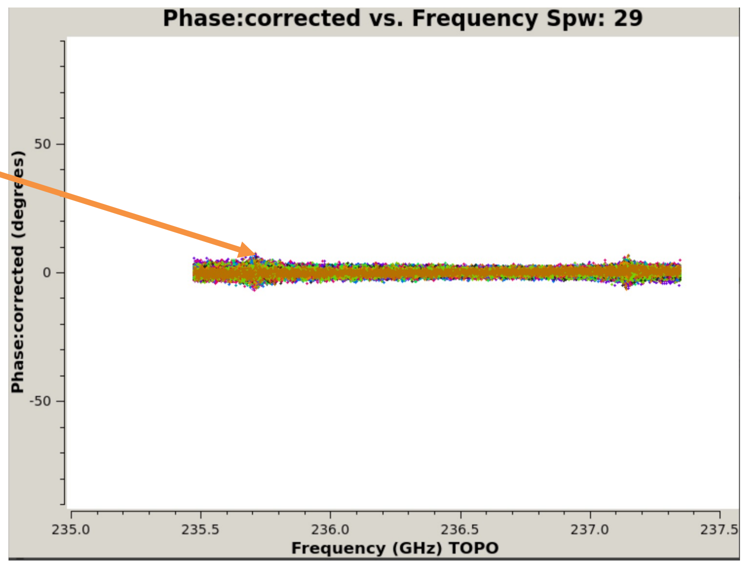
Amplitude and phase vs. frequency plots

Atmospheric model

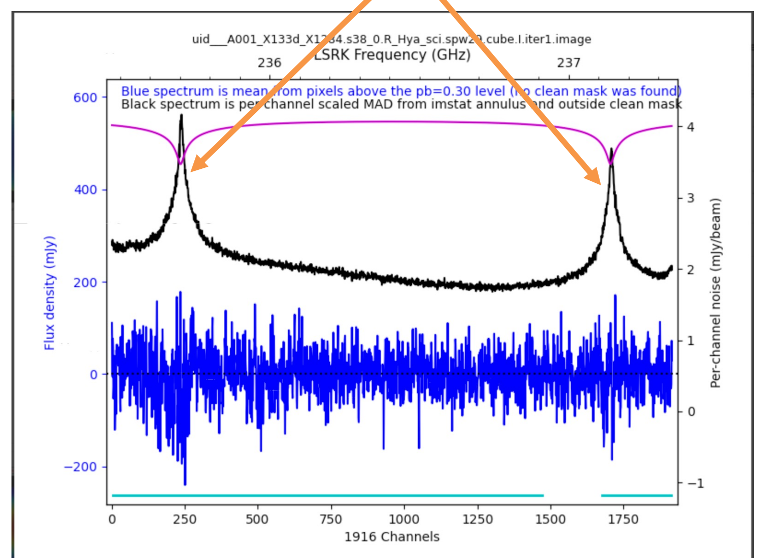


- Can also reveal the effects of atmospheric lines
- More important for ALMA than VLA

Noise higher near atmospheric line

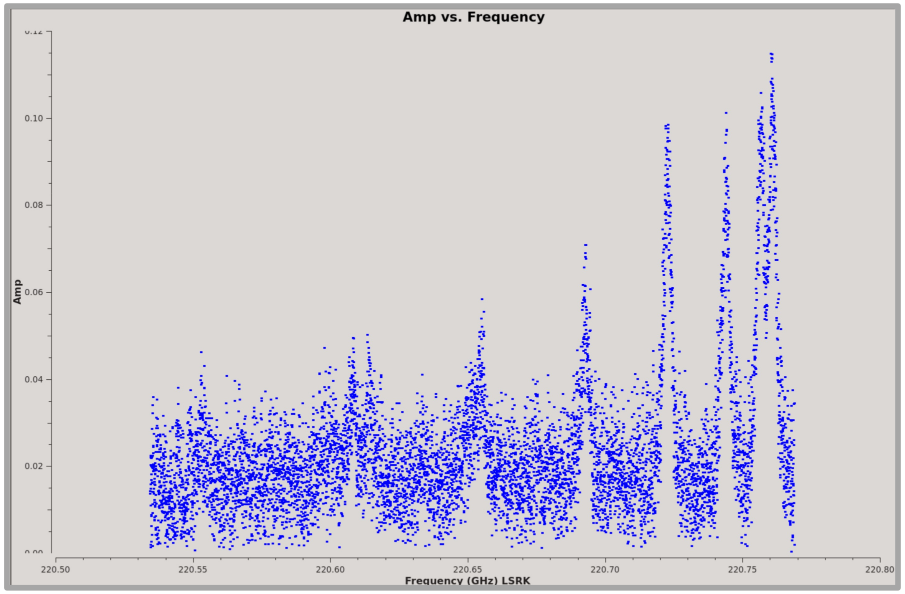


Science cube shows higher noise there as well.



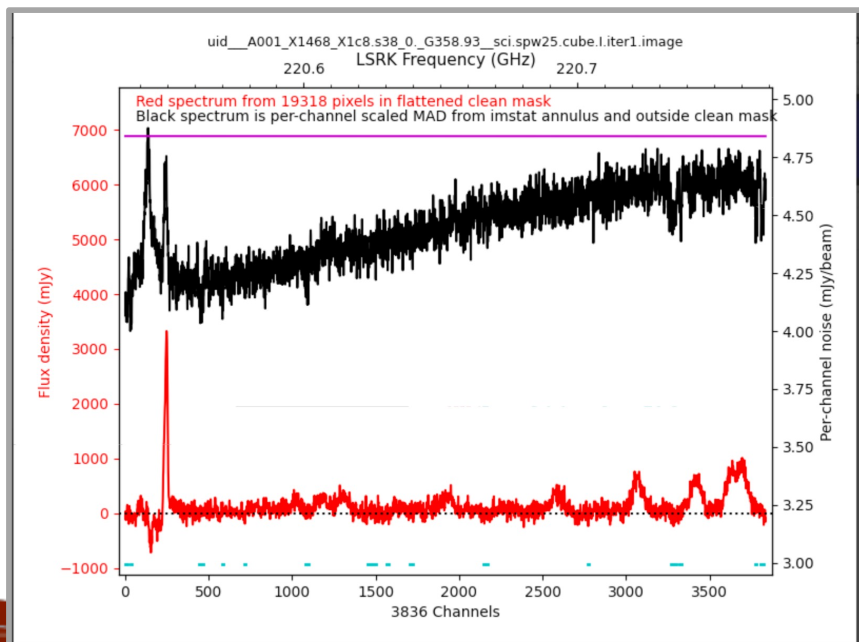
Amplitude and phase vs. frequency plots

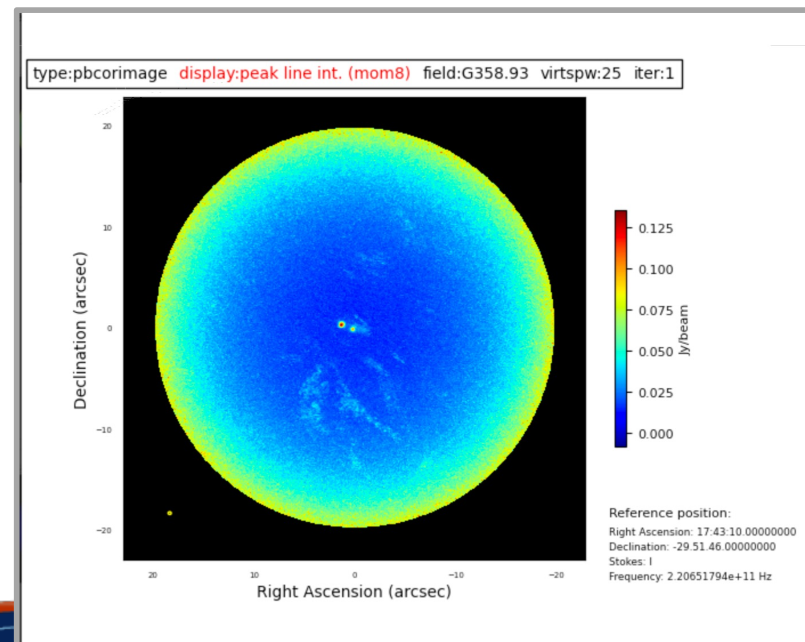
Averaged visibilities



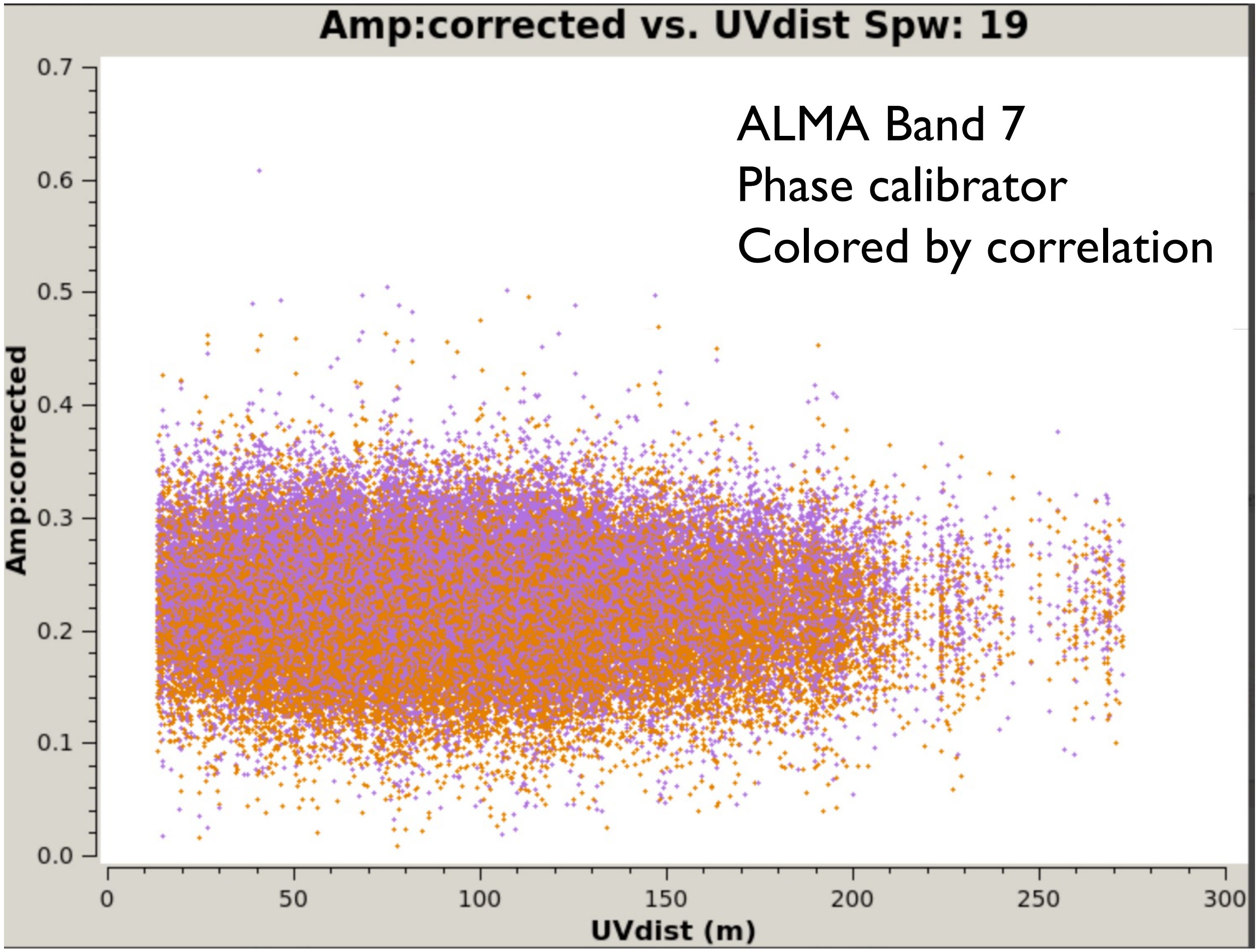
- You can average target source visibilities together to see if you have line emission and determine continuum subtraction ranges.
- Faster than imaging the cube.
- The visibility spectrum won't correspond exactly to the line cube spectrum except for point sources at phase center.

Spectrum From cube



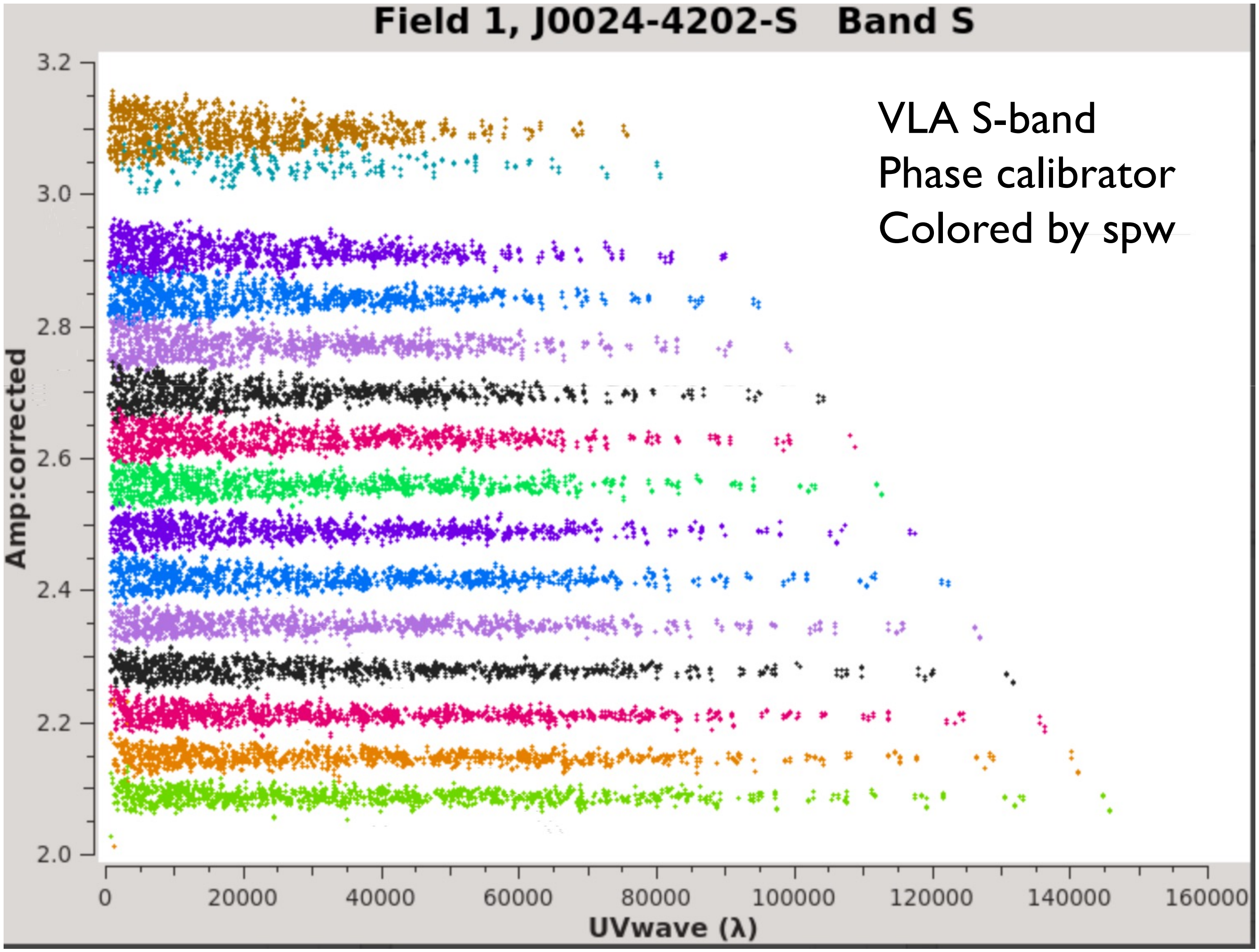


Amplitude vs. uvdistance plots



- Good to check for baseline-based issues:
  - RFI
  - Source structure
- Averaging by channel and time (possibly over scans) suggested.
- Calibrators should have the correct amplitudes.
- Point sources should be straight, horizontal lines (recall your FT pairs).
  - Amplitude = source flux density
  - Phase = 0deg

Amplitude vs. uvdistance plots



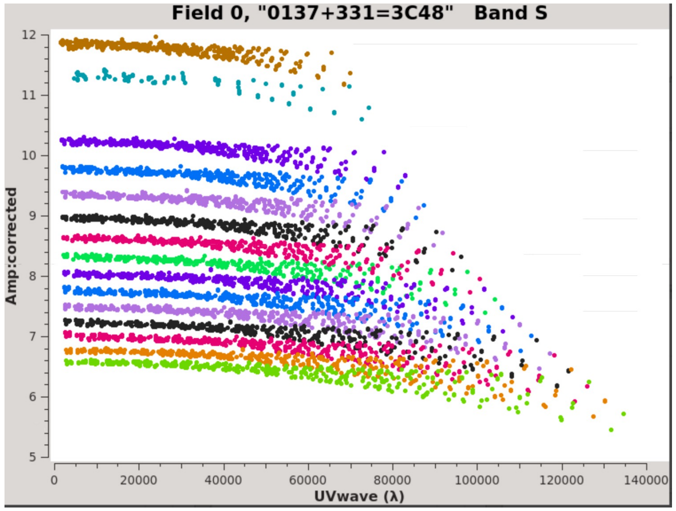
- If source flux changes across band, can have different amplitudes for different spectral windows.
- But phase calibrator still looks point like (i.e., straight horizontal line)

NB: UVwave is just the UVdistance expressed as number of wavelengths.

Amplitude vs. uvdistance plots

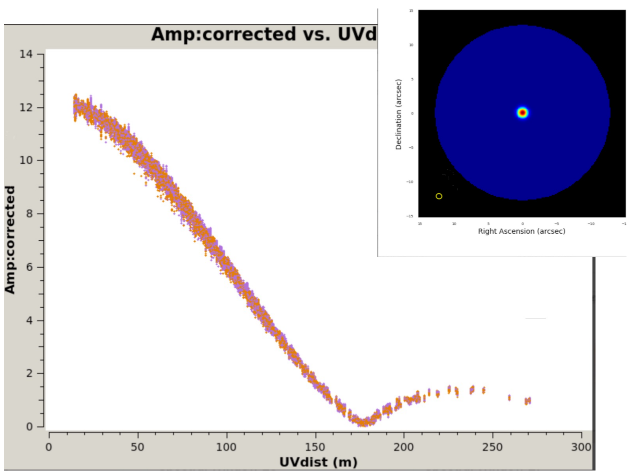
Flux calibrator
slightly extended

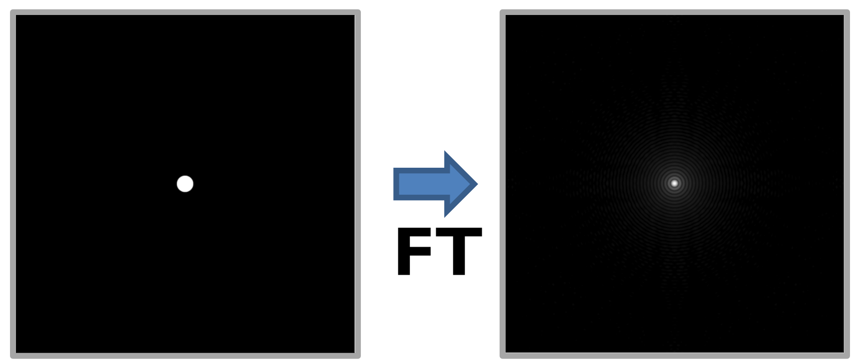
VLA S-band
Flux calibrator
Colored by spw



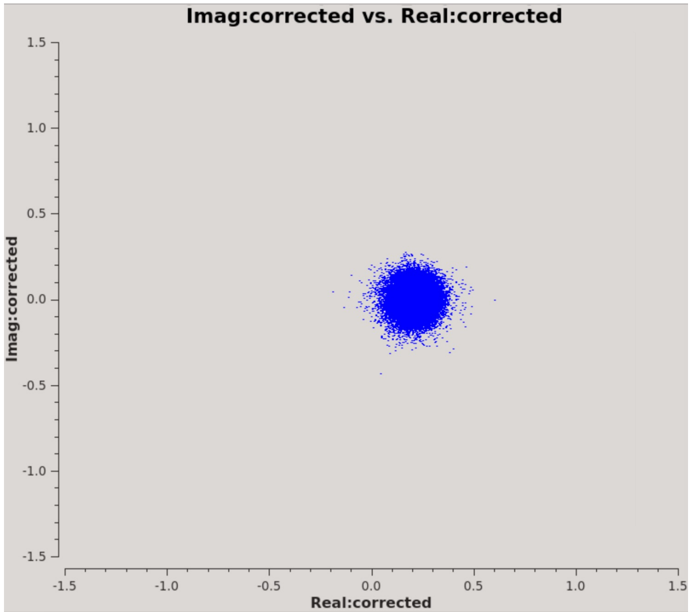
Flux calibrator
is a resolved disk

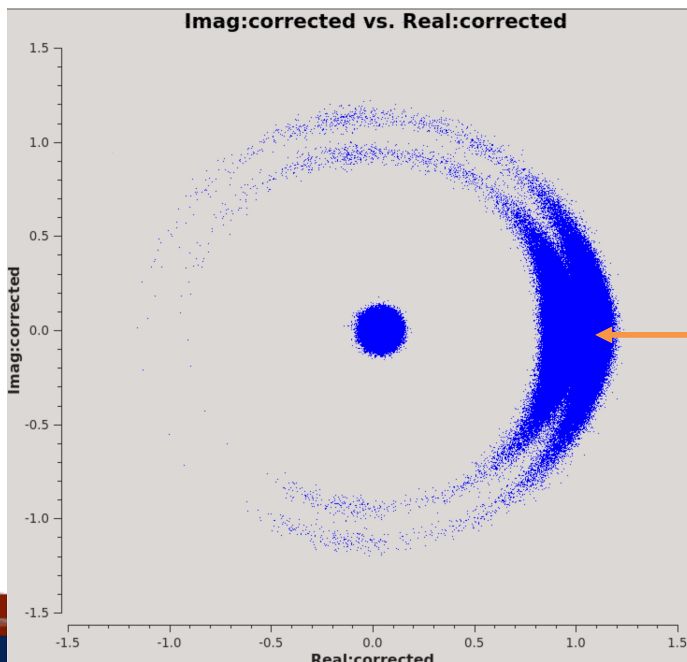
Band 7 ALMA
Callisto
Disk!





Real vs. imaginary



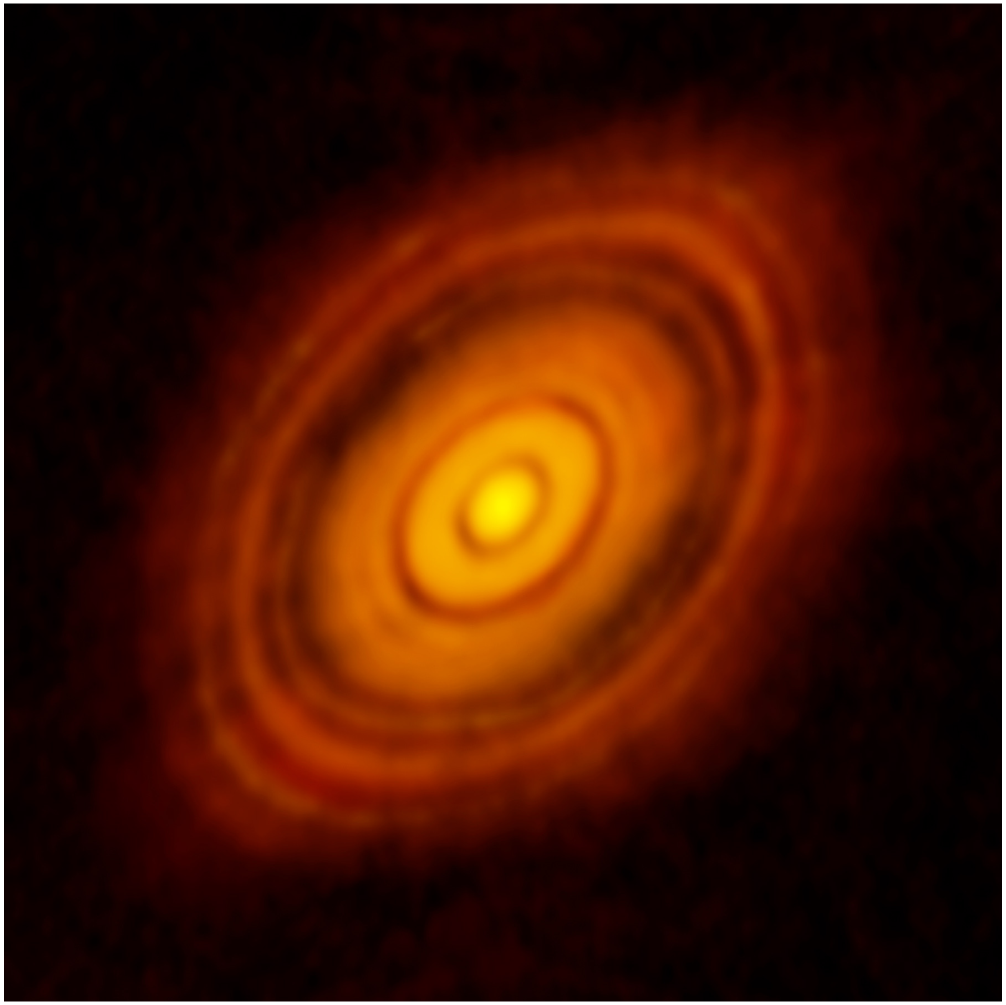


- Gain calibration should be point source at phase center.
    - Assuming picked good calibrator and calibration is good.
- Real component ~ amplitude of gain calibrator
- Imaginary component ~ 0 (since it's a point source)

Bad antenna!

Now let's switch to the imaging side!

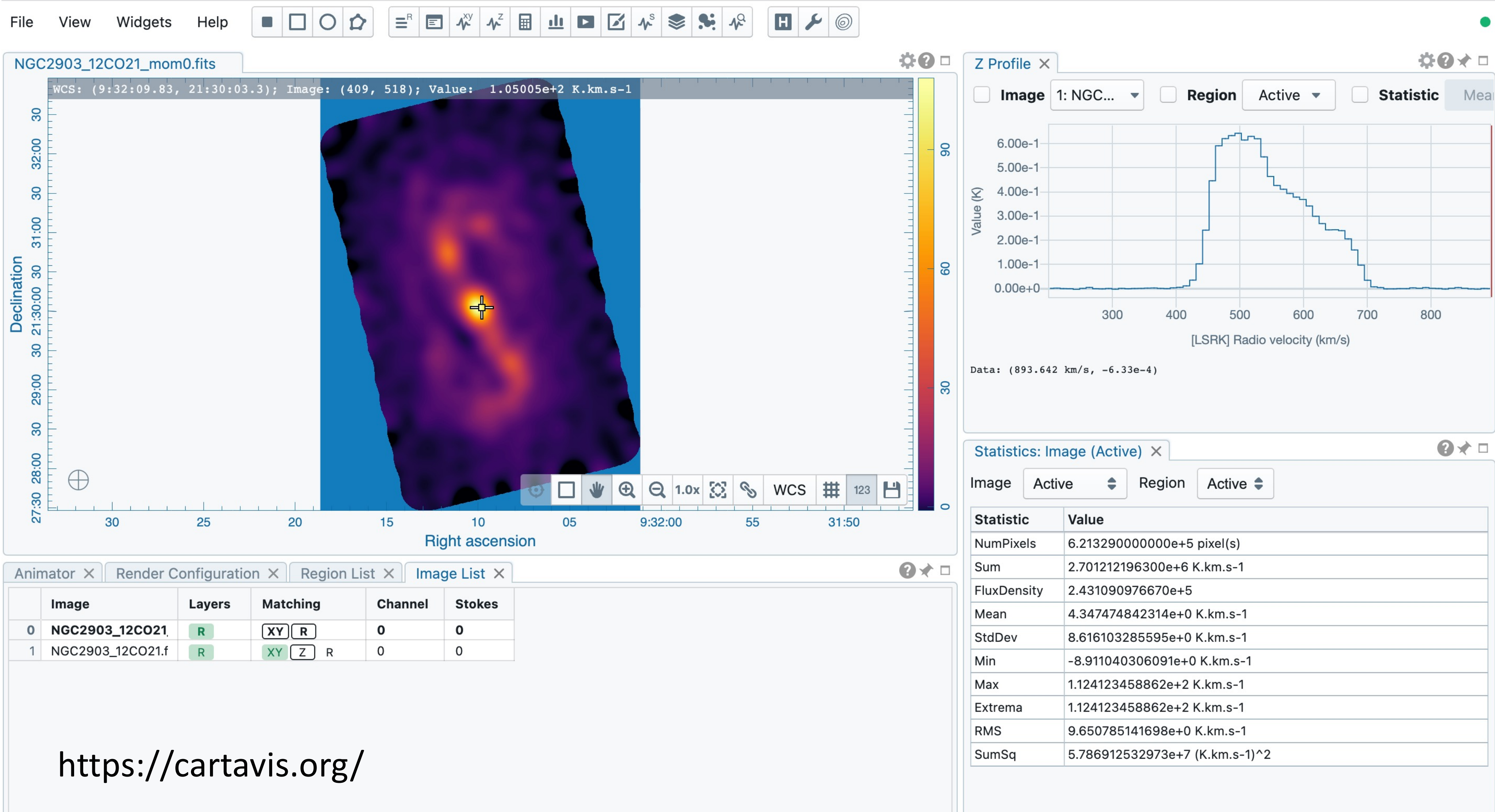
Credit: Pasetto et al., Sophia Dagnello, NRAO/AUI/NSF.



Credit: ALMA(ESO/NAOJ/NRAO); C. Brogan, B. Saxton (NRAO/AUI/NSF)

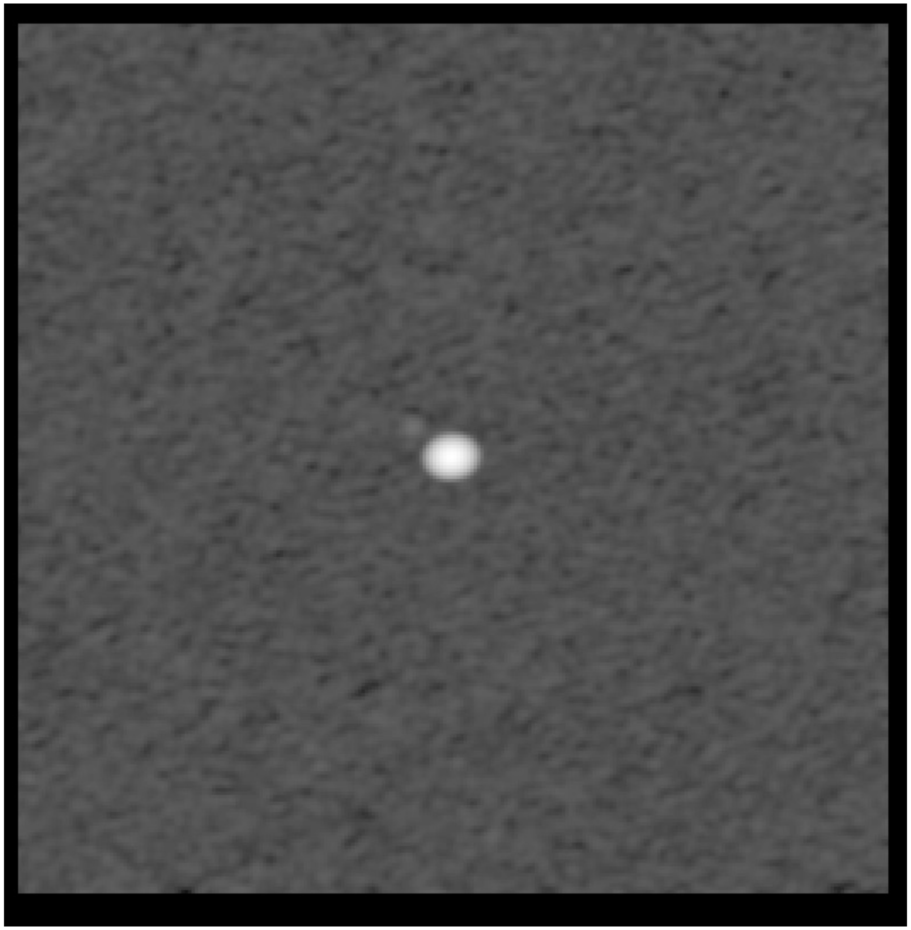
CARTA can be used to examine images.

See Juergen Ott's upcoming talk!



https://cartavis.org/

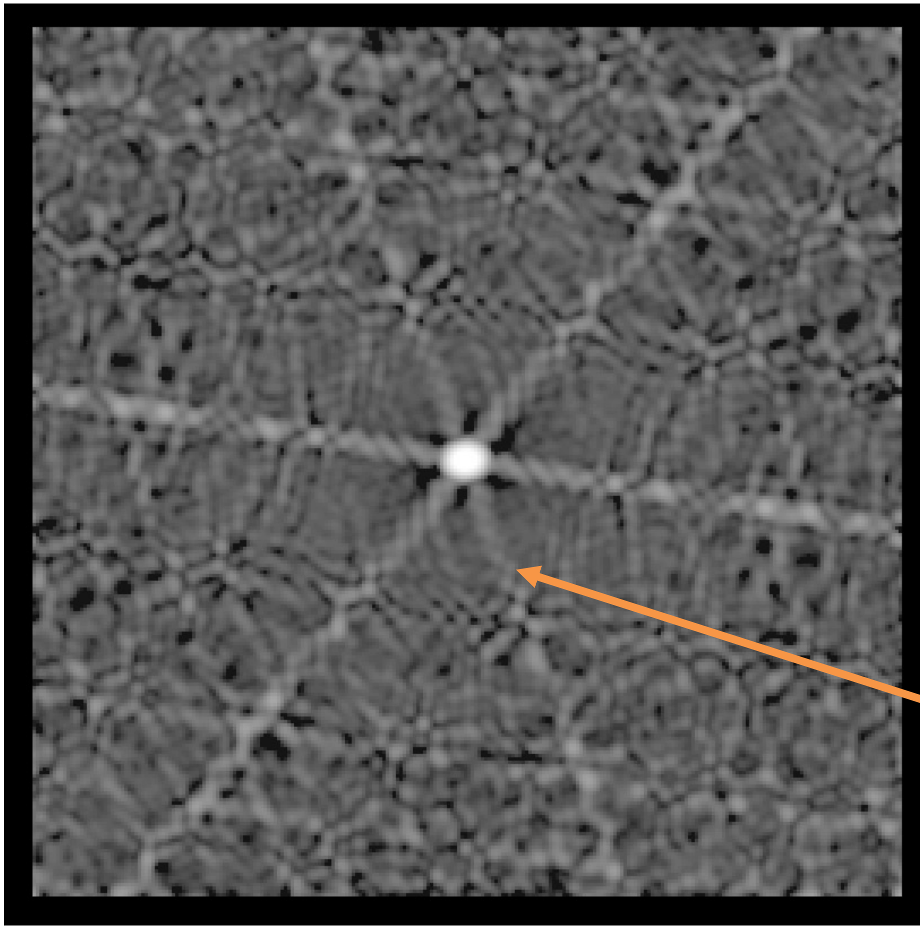
Calibration errors can affect your images.



- Point source observed with VLA
- 13x5min observation over 10 hrs

no errors:
max 3.24 Jy
rms 0.11 mJy

Calibration errors can affect your images.



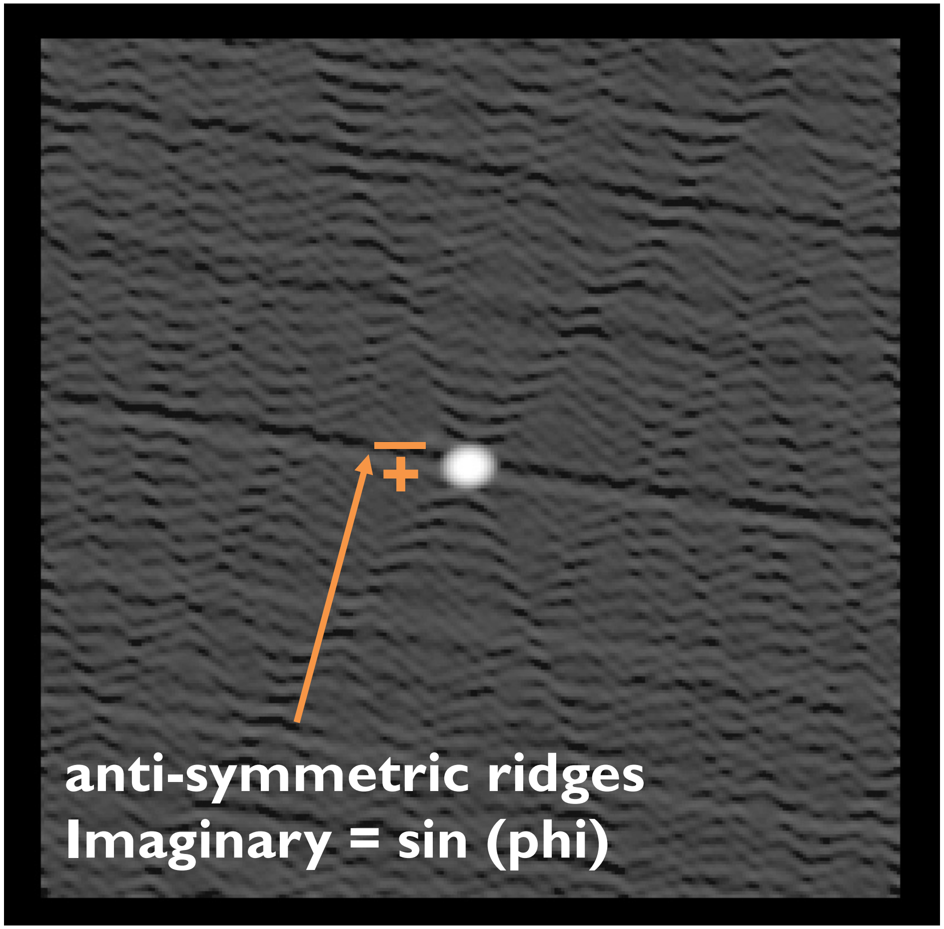
- 10% amplitude error for all antennas for 1 time period
- rms 2.0 mJy

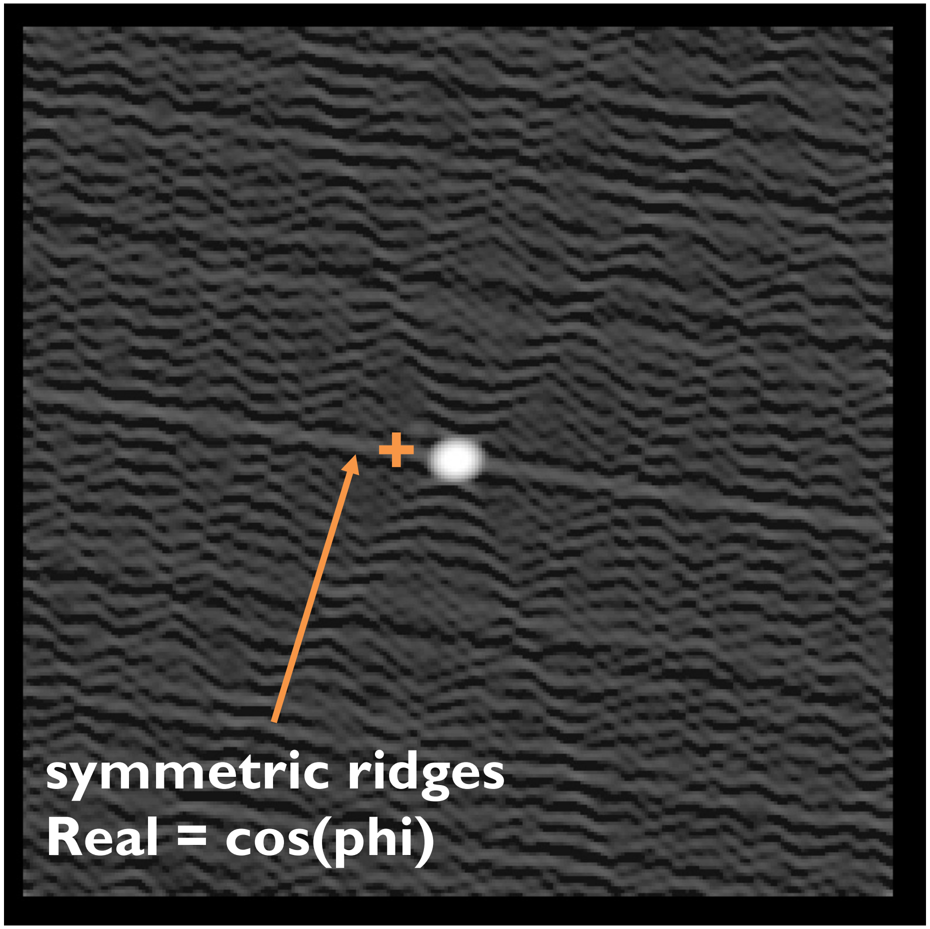
6-fold symmetric pattern due to VLA "Y".
Image resembles dirty beam.

Calibration errors can affect your images.

- **10 deg phase error** for one antenna at one time
- rms 0.49 mJy

- **20% amplitude error** for one antenna at one time
- rms 0.56 mJy

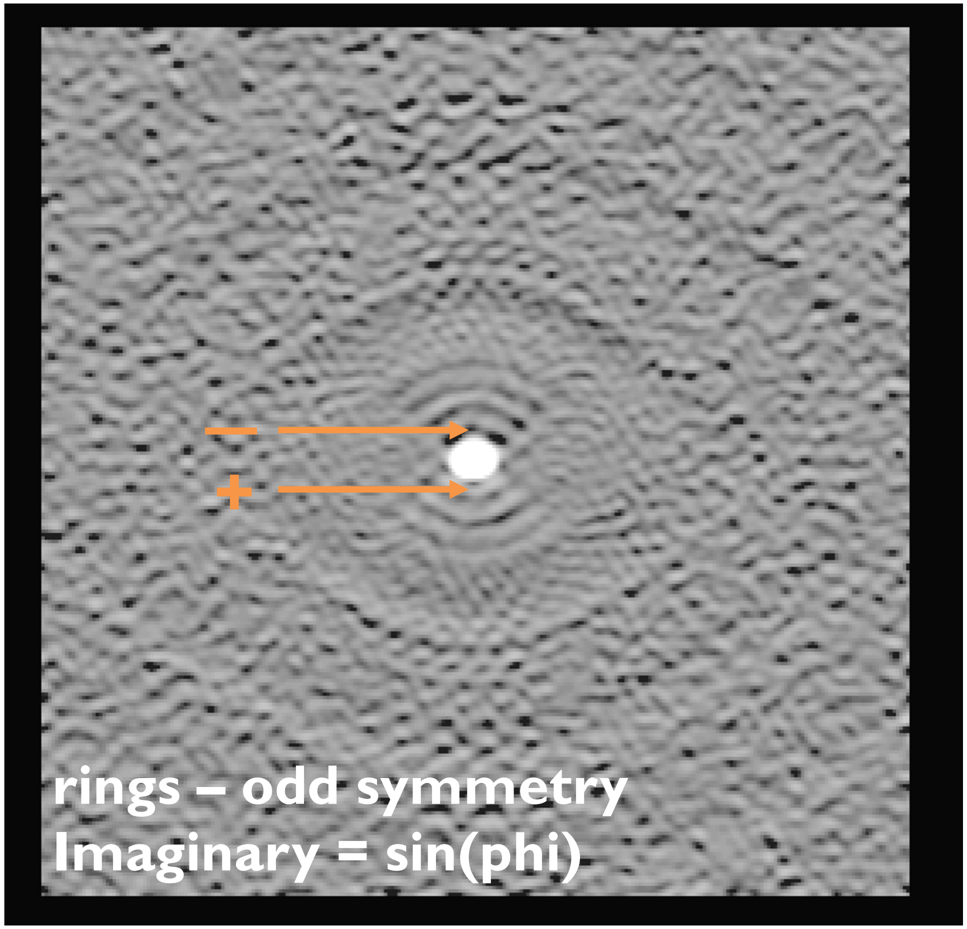


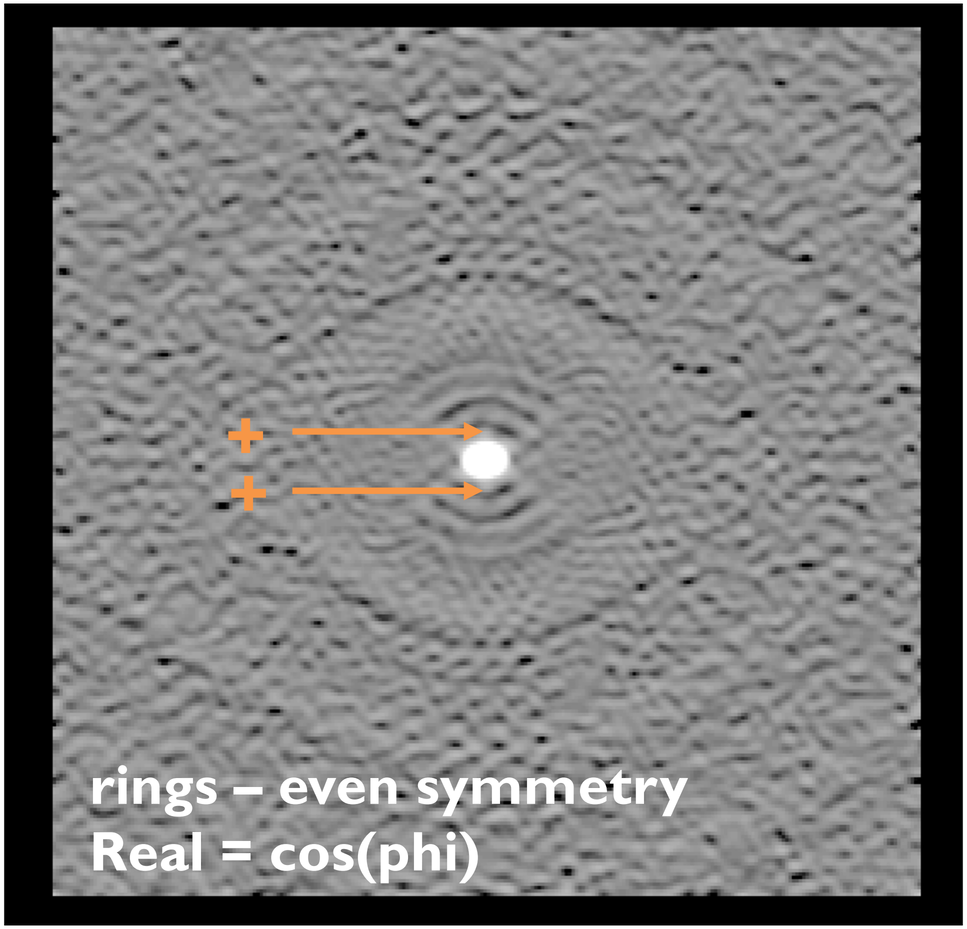


Calibration errors can affect your images.

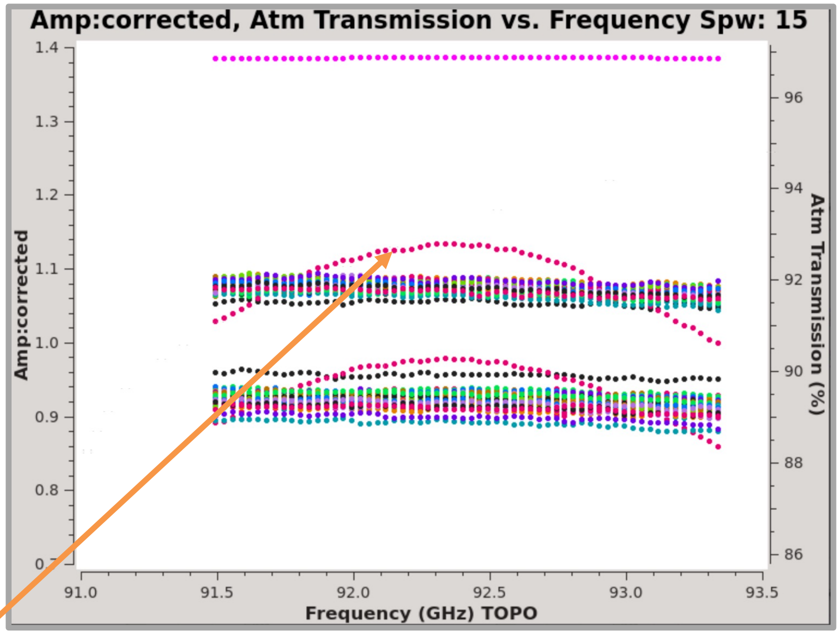
- **10 deg phase error** for one antenna all times
- rms 2.0 mJy

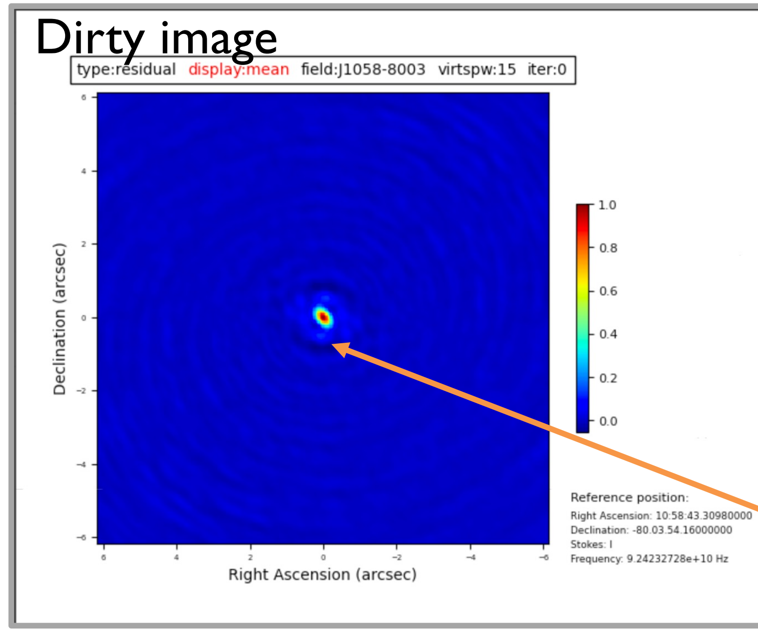
- **20% amplitude error** for one antenna all times
- rms 2.3 mJy





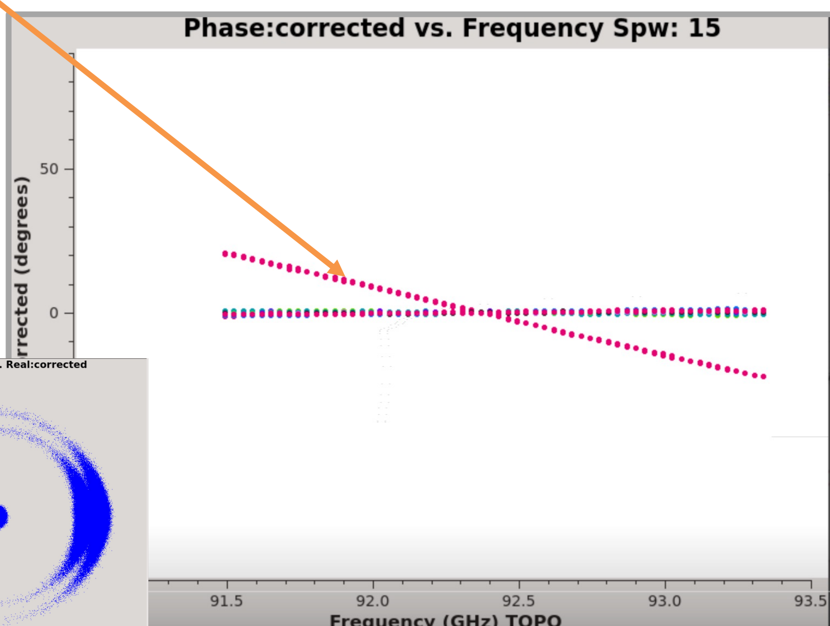
A real life example

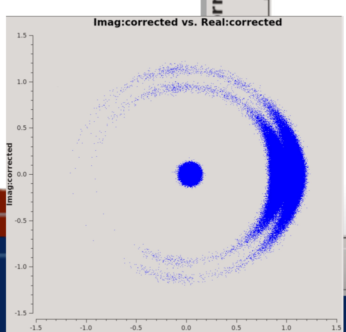


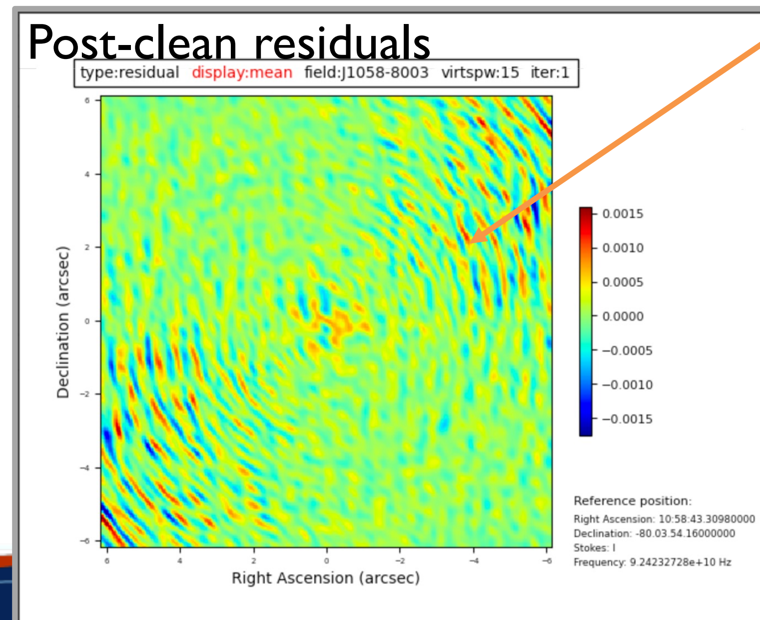


Bad antenna

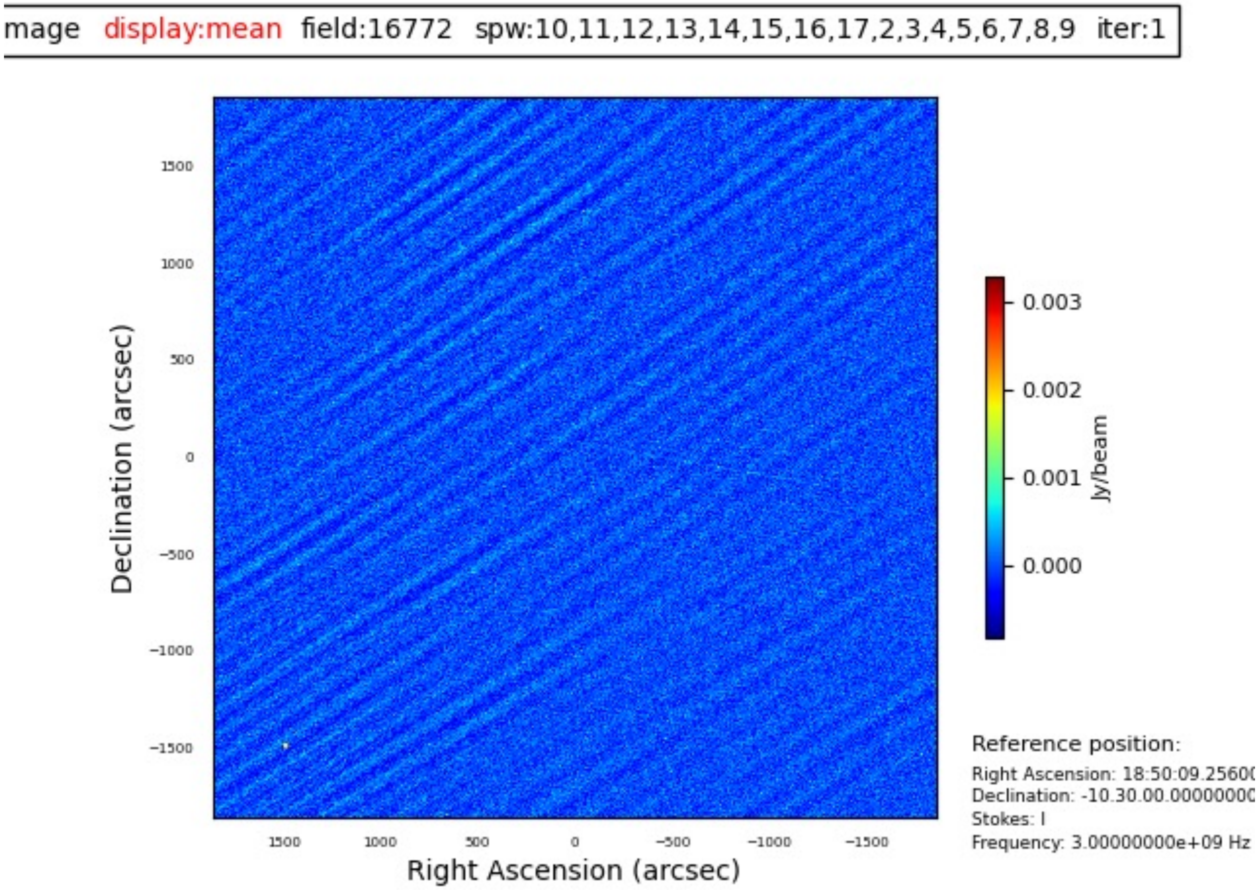
Significant image artifacts





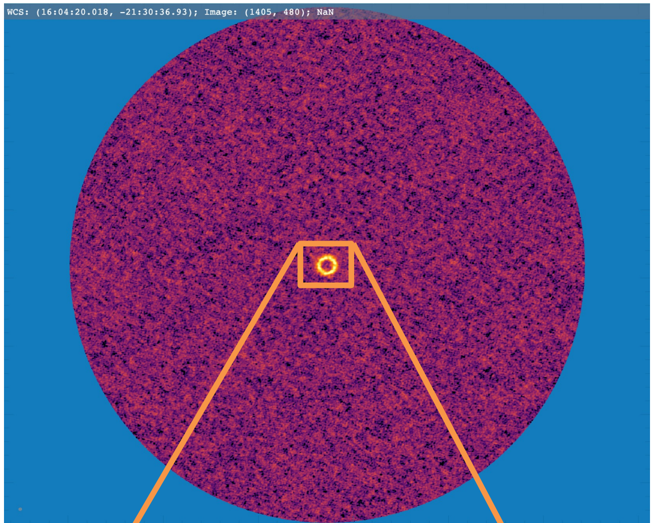


Another real life example



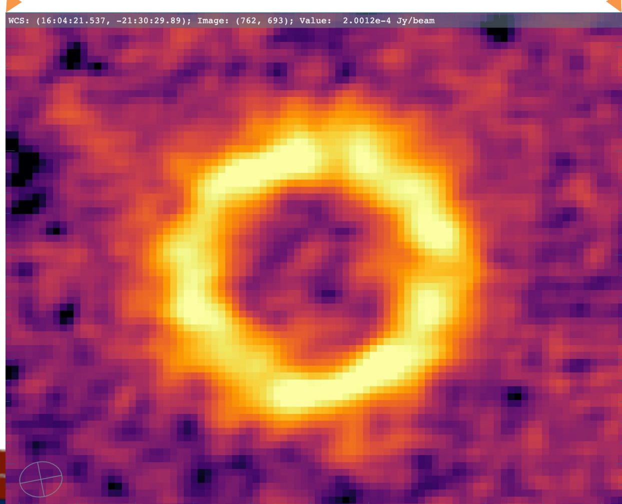
- Bad baseline leading to stripes across VLASS image
- Remember that point source off phase center has a phase.
- Size of ripple inversely related to length of bad baseline.
- Orientation of the ripple related to u-v orientation of baseline.

Non-optimal parameters can affect your images.

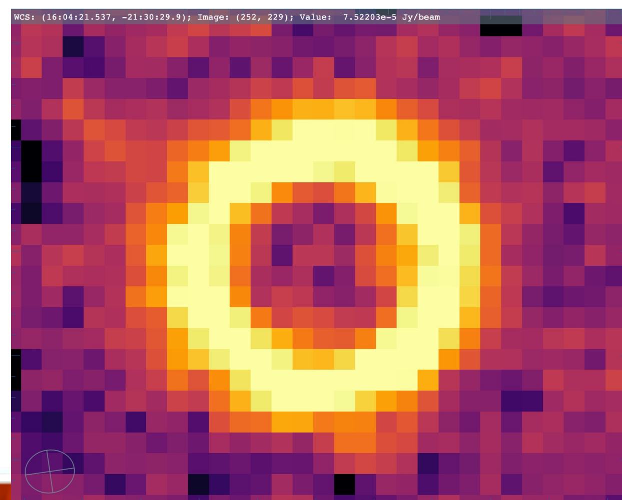


- Non-optimal choices in imaging parameters can affect the resulting image.
- Generally want 5-7 pixels across beam (err on the side of more rather than fewer)
- Image full primary beam (or mosaic).
- For more, see the ALMA Primer Video on cell and image size: https://www.youtube.com/watch?v=OC3IWpRRtEQ

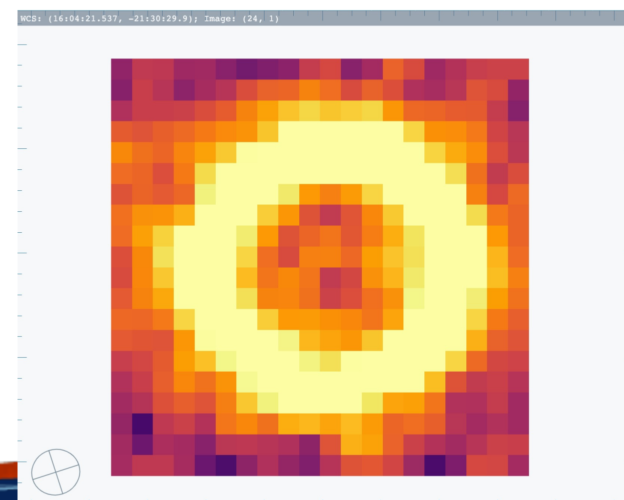
Cell size good.
Image size good.



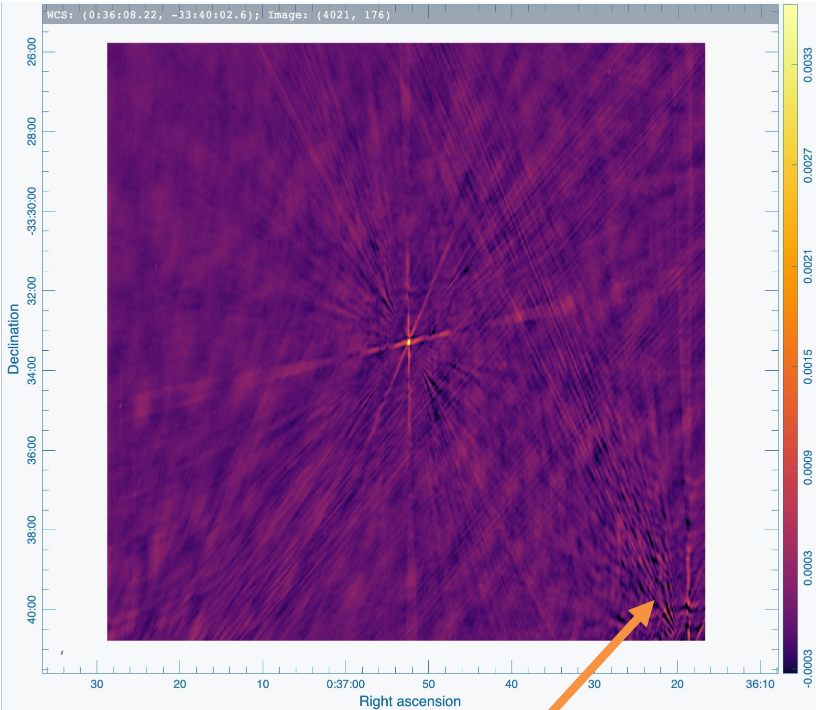
Cell size too big.
Image size good.

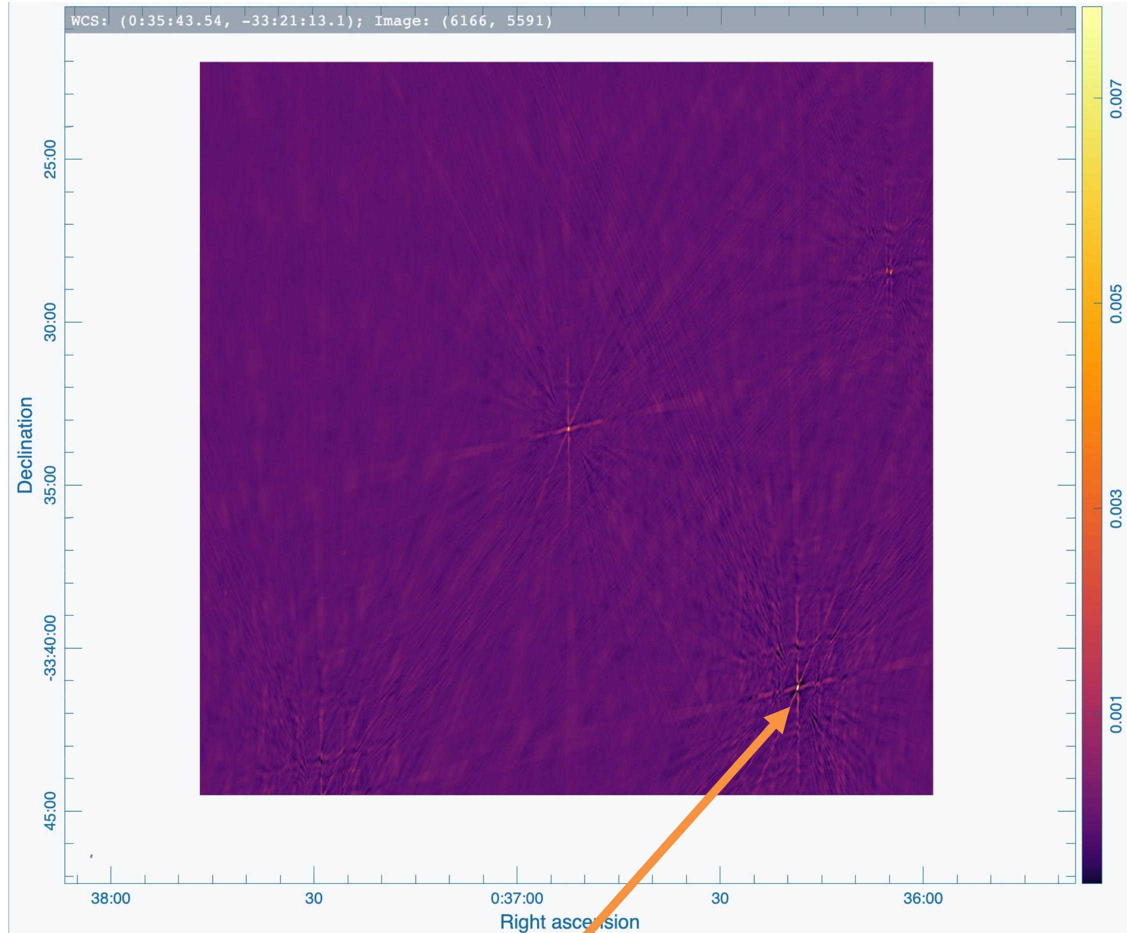


Cell size too big.
Image size too small.



Sources outside primary beam may contribute to image.

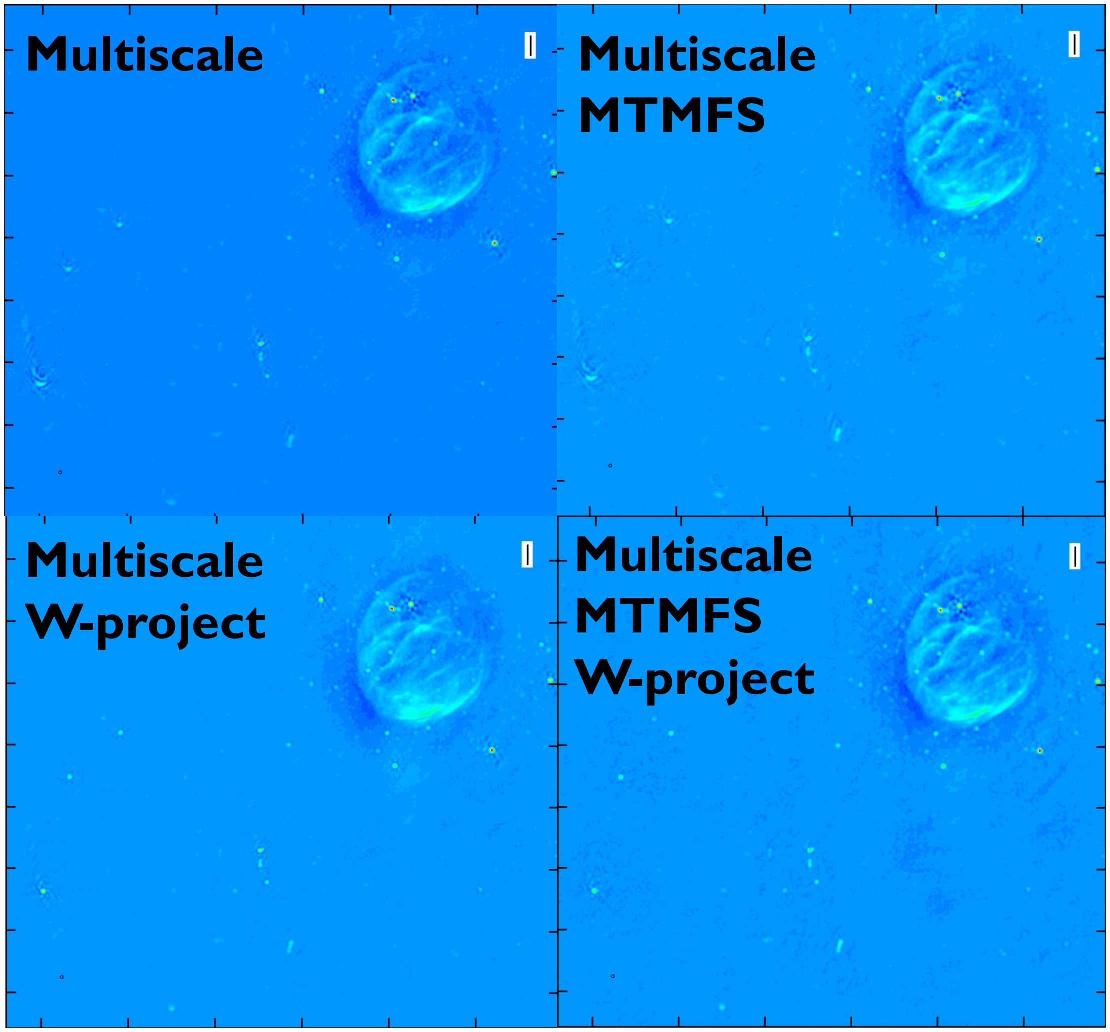




Artifacts from source outside imaged area

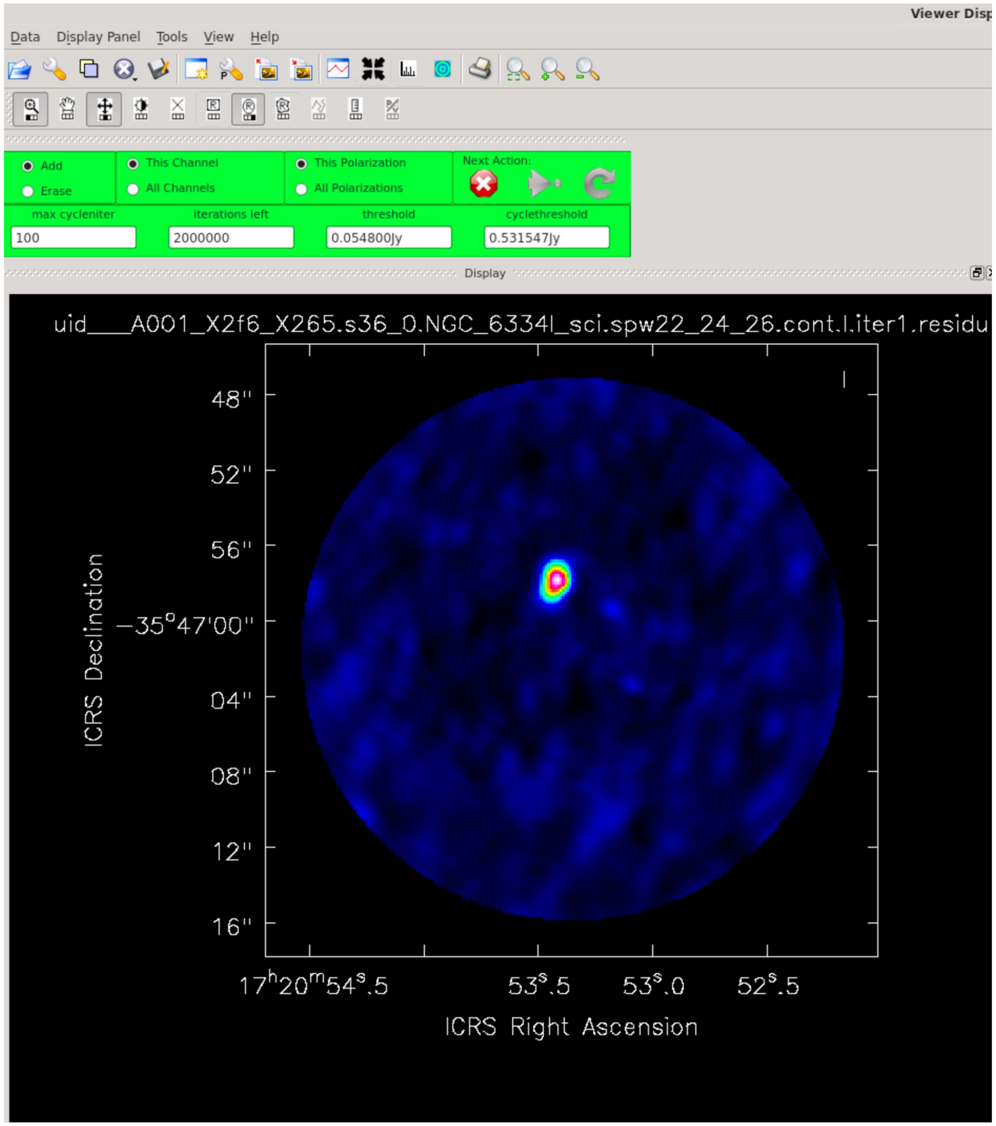
Source now in imaged area and can be cleaned.

Gridder and deconvolver choices depend on the imaging case.



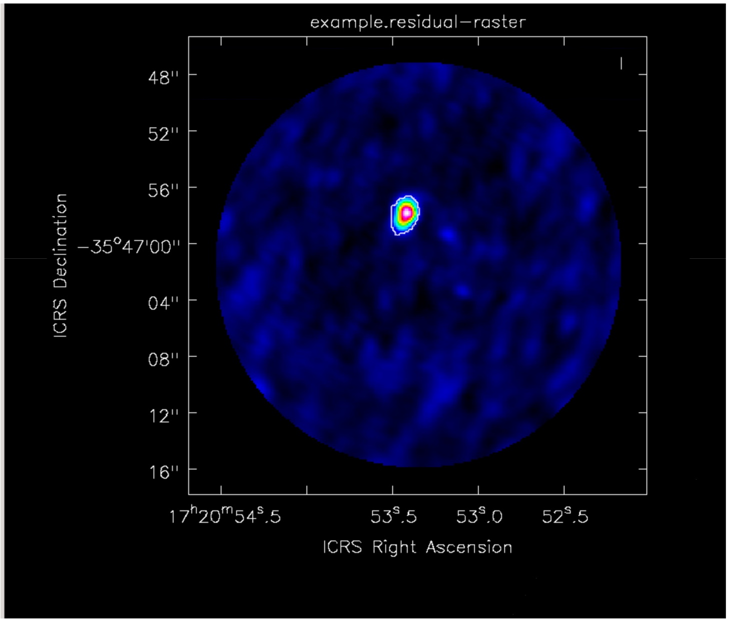
- Generally **wide fields (λB ~ D²) and wide fractional bandwidths (>10%)** require special treatment e.g.
    - Multi-frequency synthesis
    - W-project
    - AW-project
- Sources with extended emission may benefit from multiscale clean.
- See Urvashi and Preshanth's talks for more detail.
- Also see https://casaguides.nrao.edu/index.php?title=VLA_CASA_Imaging-CASA6.2.0

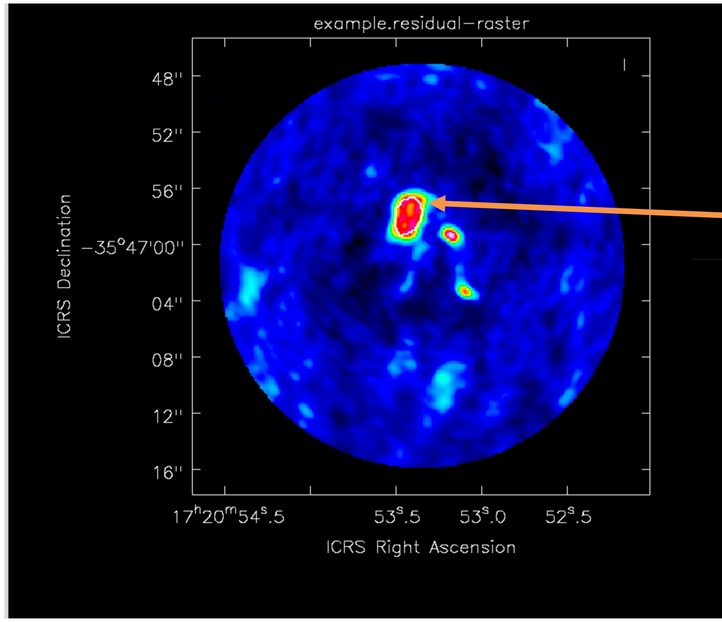
Improper cleaning can produce poor images.



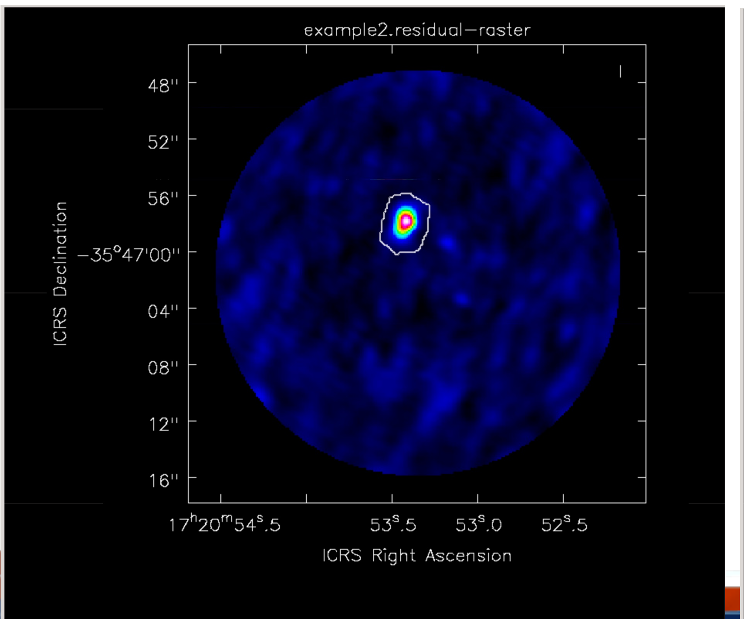
- Clean is an iterative process.
- Masks are often used to guide clean in building a model image.
- A rule of thumb is to include all "real" astronomical features in the clean mask.
- For hogbom clean, you generally want to leave buffer of several beams between the emission and the mask.
  - Other deconvolution methods might benefit from a less restrictive (i.e., broader) mask.
- Stop cleaning when your residuals look noise like.
  - Cleaning too deeply will end up including the noise in your model.
  - Cleaning too shallowly will miss real emission

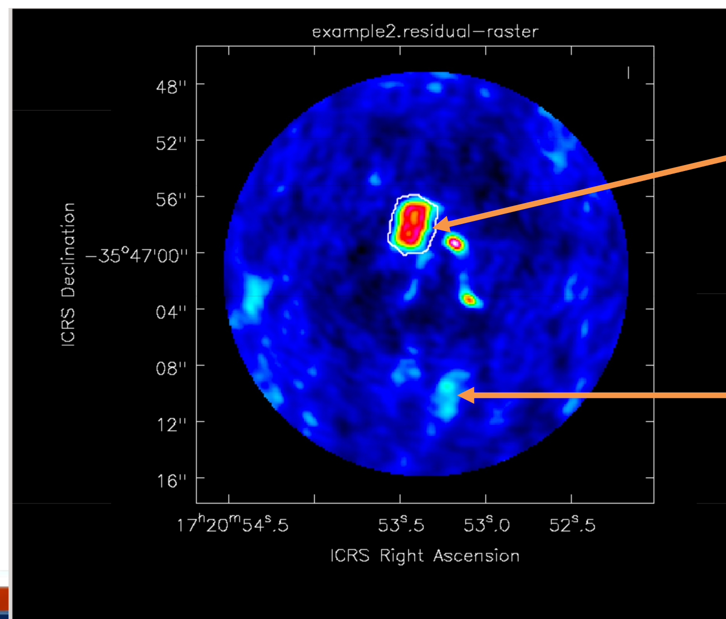
Masking: a Goldilocks (“just right”) approach





Real emission just outside box!

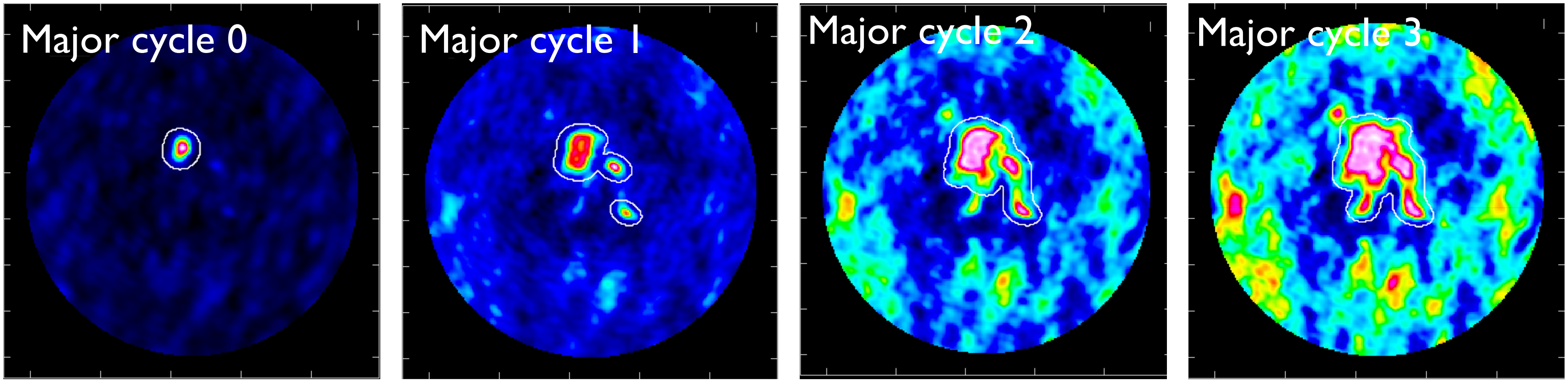


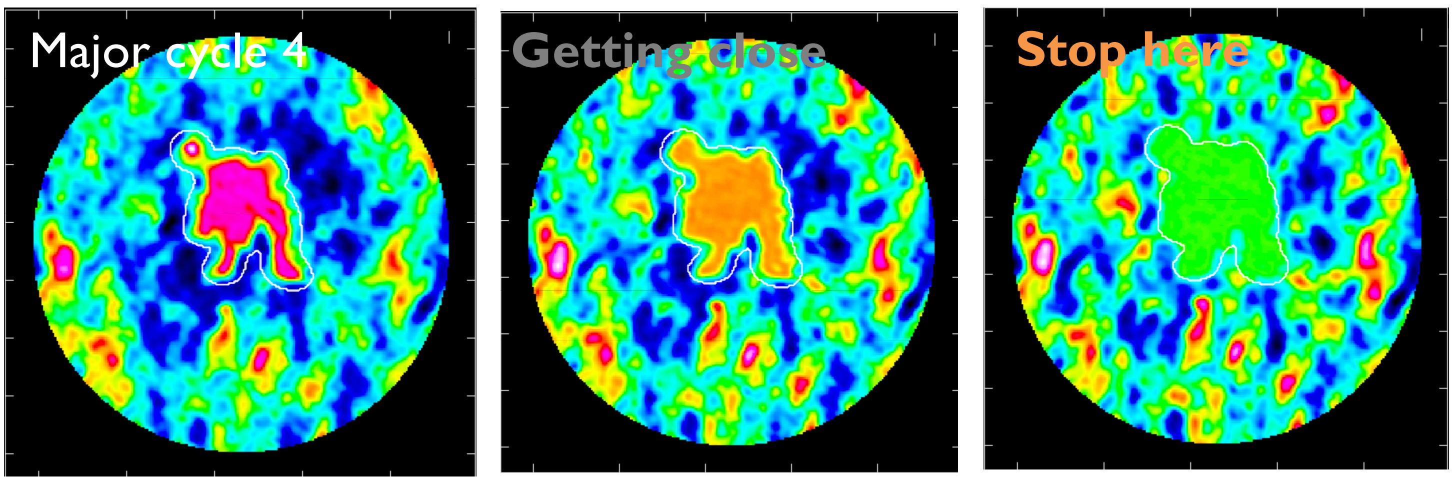


Initial region gets most of the emission.

But a box is needed to avoid picking up sidelobes

Clean depth: another Goldilocks approach

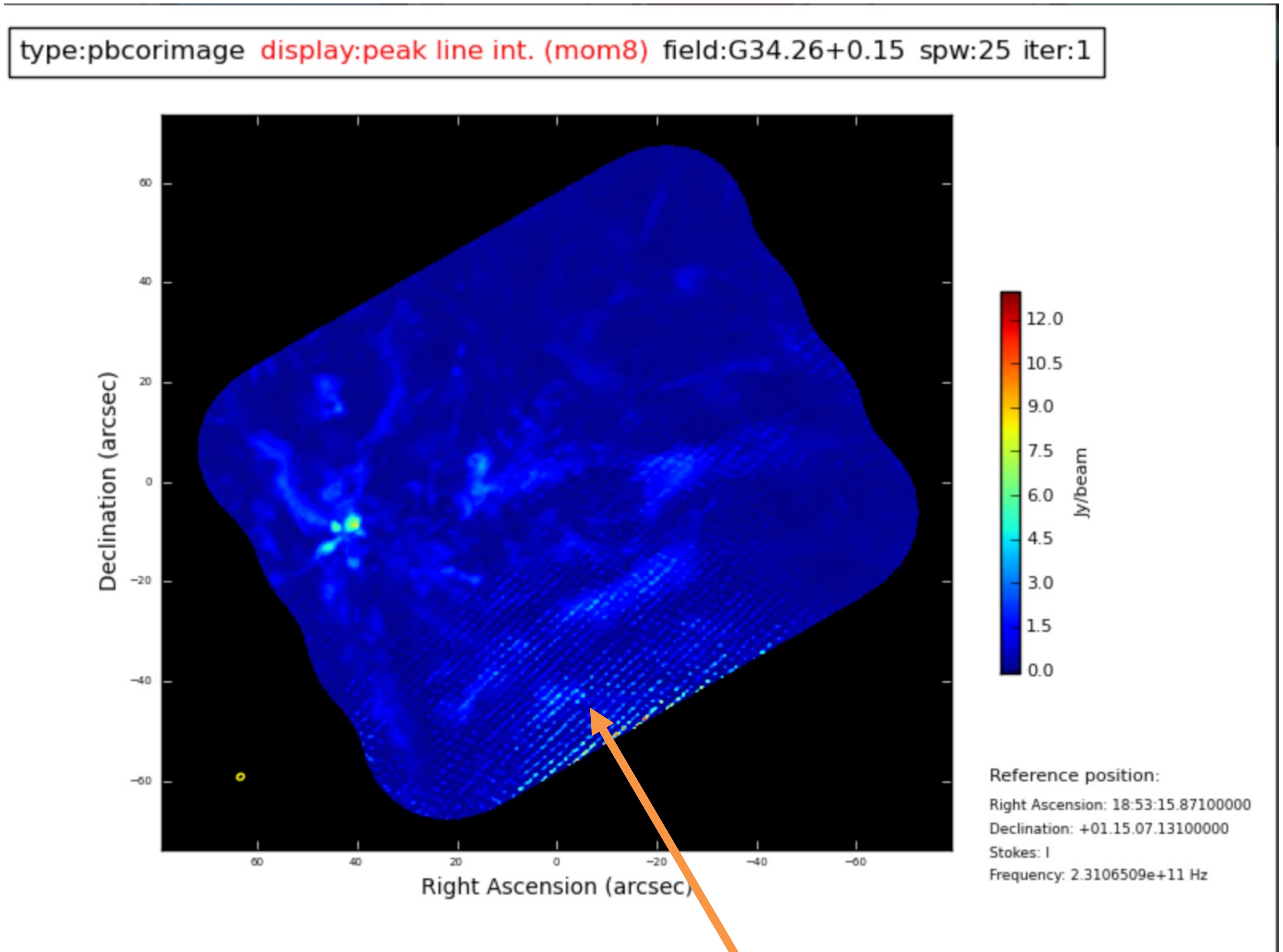




- Stop clean when your residuals ~ the noise.
- But note that this is a case where you would be able to do better using multi-scale.

To automatically mask emission, use AUTO-MULTITHRESH in tclean (Kepley+ 2020, PASP).

Clean can diverge.

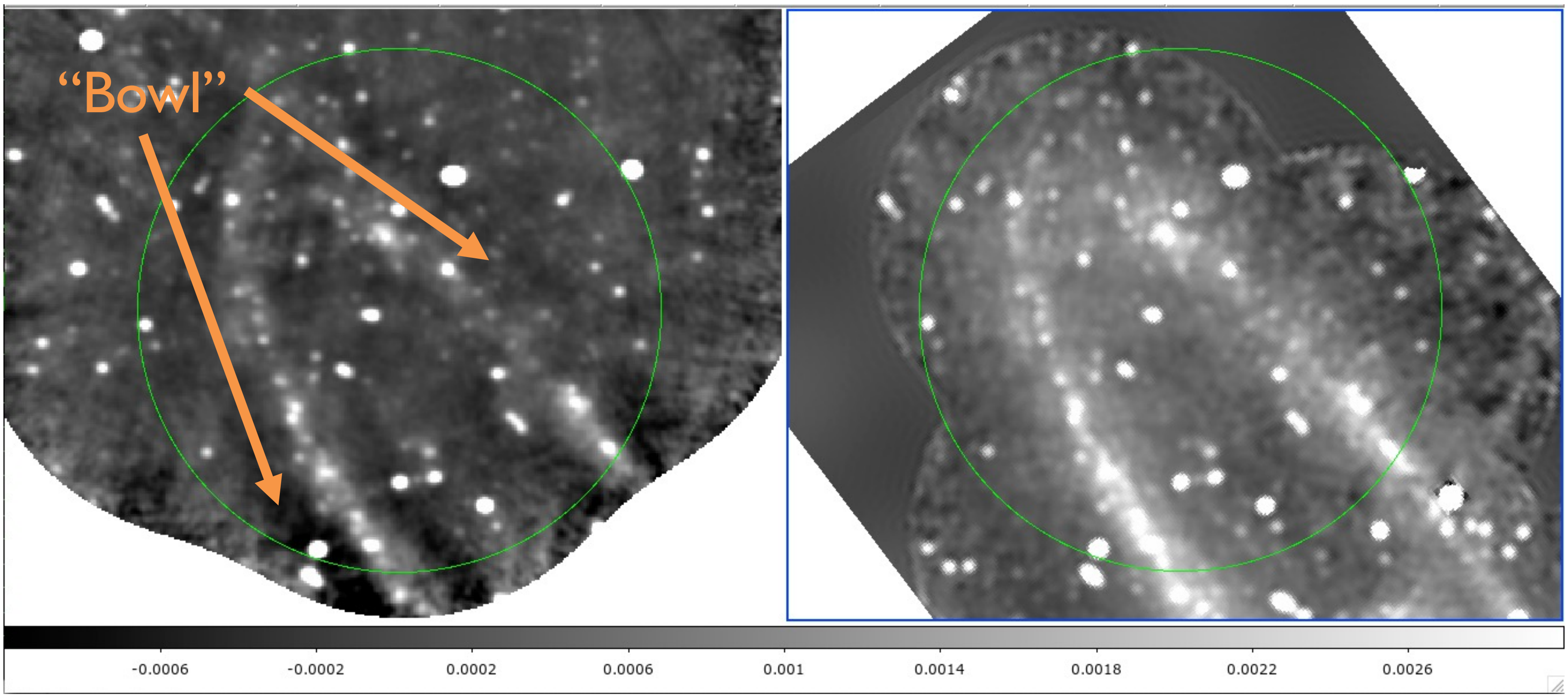


Grating-like artifacts

- More likely for data with high sidelobes and complex emission.
- Will let you know in the log if has diverged.
- Image usually has "grating" like artifacts.
- Check your mask and model. Are you only including believable emission?
- Trigger major cycles more often (using cycleniter or cyclefactor) to reconcile the model and data more frequently.

Missing emission leads to “bowls” in images.

See Brian Mason’s talk for more on how to correct this!



Robust=2 VLA D config

VLA+Effelsberg from Beck (1998)

Preliminary images from the **Local Group L-Band Survey (**https://www.lglbs.org/).

Take-aways

- Doing great science means understanding the underlying data!
- Both the visibility data and images are useful for finding errors.
- Helpful visibility plots:
  - Amplitude/phase vs. time – time dependent problems
  - Amplitude/phase vs. frequency – frequency dependent problems
  - Amplitude vs. uvdistance – structure in sources
  - Real vs. imaginary – bad antennas/baselines
- 10 deg phase error for one antenna = 20% amplitude error.
- Double check your imaging parameters are appropriate, especially: cell, imsize, gridder, and deconvolver.
- VLA and ALMA weblogs have many useful plots.
- Questions about your data? Ask your friendly neighborhood helpdesk.
  - ALMA: help.almascience.org
  - VLA: help.nrao.edu

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