Error recognition

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CSIRO ASTRONOMY AND SPACE SCIENCE
www.csiro.au

Content heavily borrowed from previous radio schools – thanks to Emil Lenc, Ron Ekers, Allison Peck + lots more I found online.

How to recognize and diagnose errors?

Some are easy to fix

Others less so…

(slide stolen shamelessly from Emil Lenc)

U,v plane vs. image plane

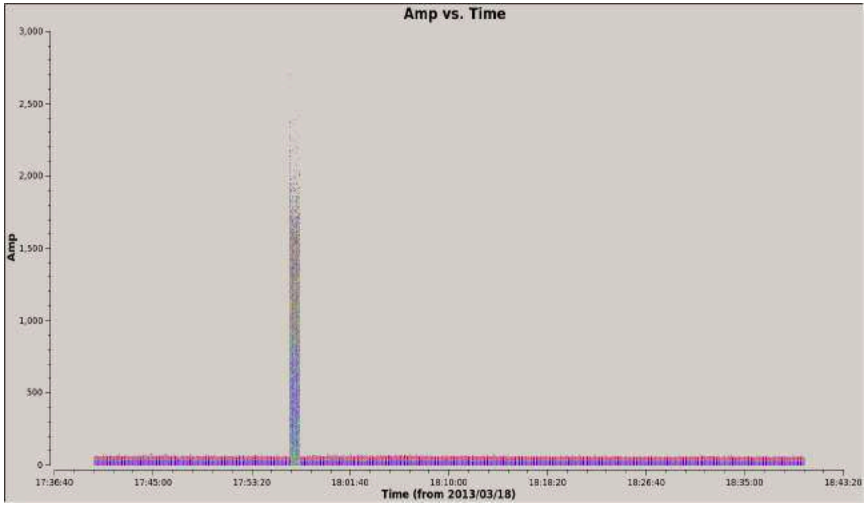
- Check both - errors may be more obvious in one plane compared to the other

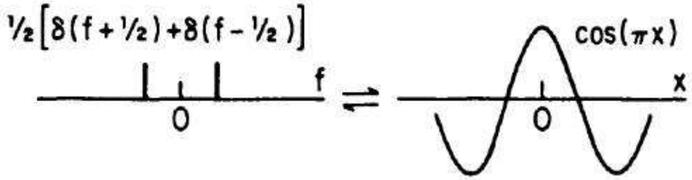
- Errors also obey the Fourier transform relation – use this to your advantage!
  - Large errors in the u,v plane can be virtually insignificant in the image plane
  - Likewise, small undetectable defects in the u,v plane can be very obvious in the image plane

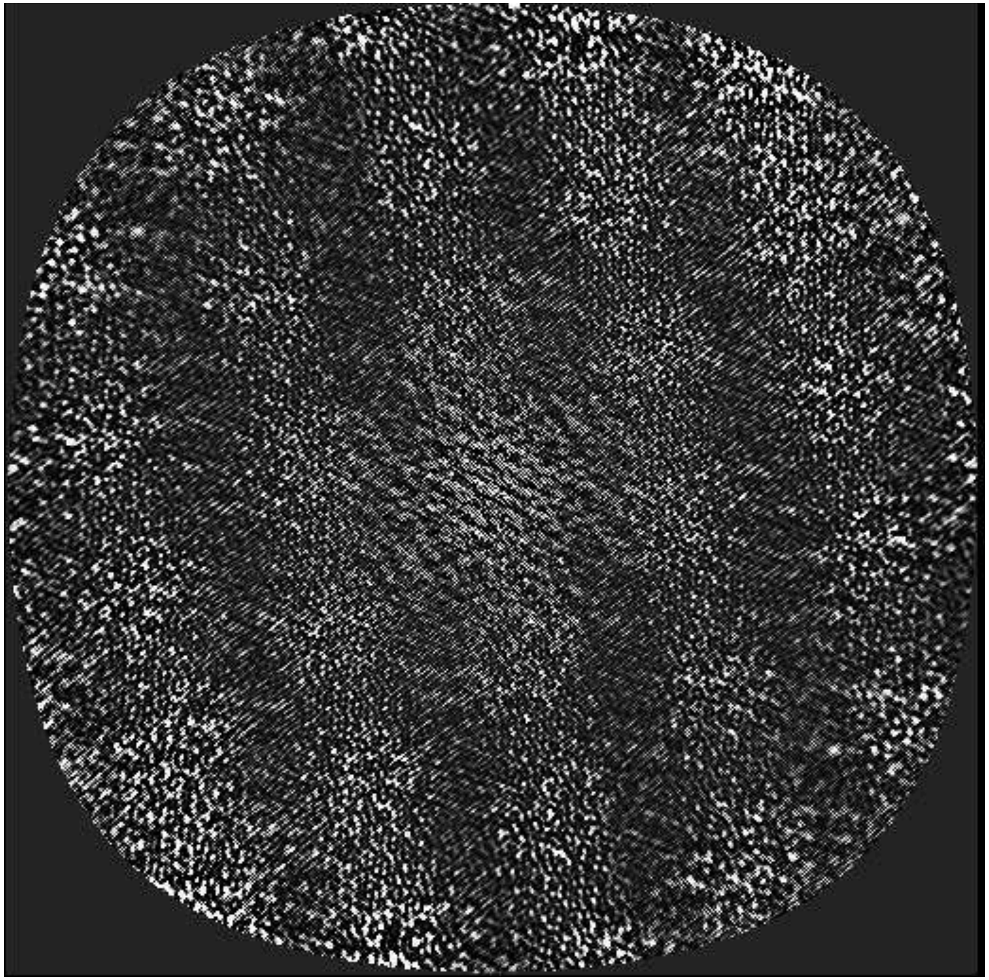
- Additive errors (out-of-field sources, RFI, cross-talk, baseline-based errors, noise)
  - $V + \varepsilon \Rightarrow I + F[\varepsilon]$
- Multiplicative errors (uv-coverage effects, gain errors, atmospheric effects)
  - $V \bullet \varepsilon \Rightarrow I \star F[\varepsilon]$
- Convolutional errors (primary beam effect, convolutional gridding)
  - $V \star \varepsilon \Rightarrow I \bullet F[\varepsilon]$

- Goal is to get good image – not always worth being a perfectionist about the u,v data…

RFI in the image plane







Sidelobes from nearby bright sources

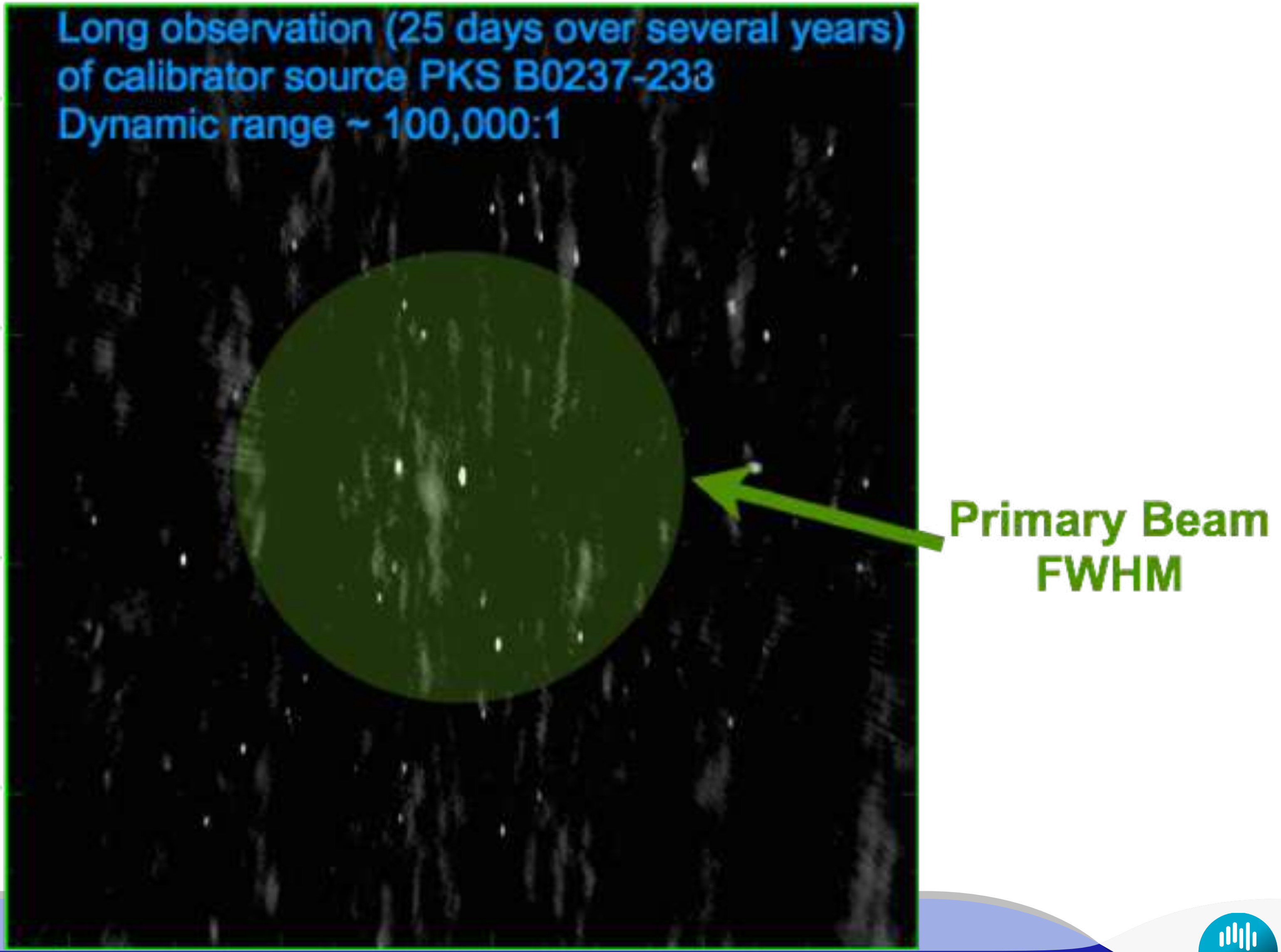
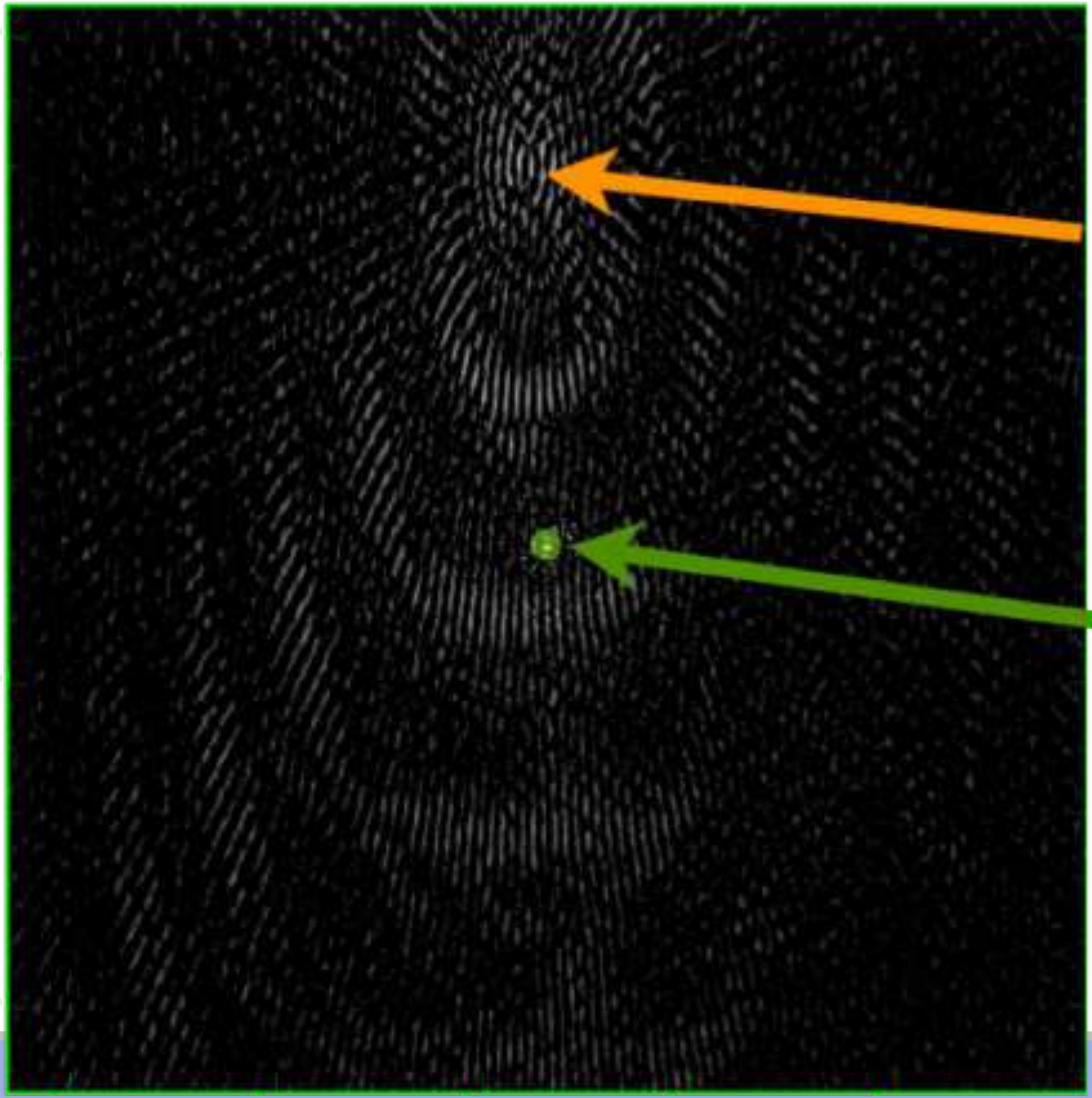


Image: Emil Lenc

Sidelobes from nearby bright sources



The Sun was "near" the calibrator during one of the observing days.

Primary Beam FWHM

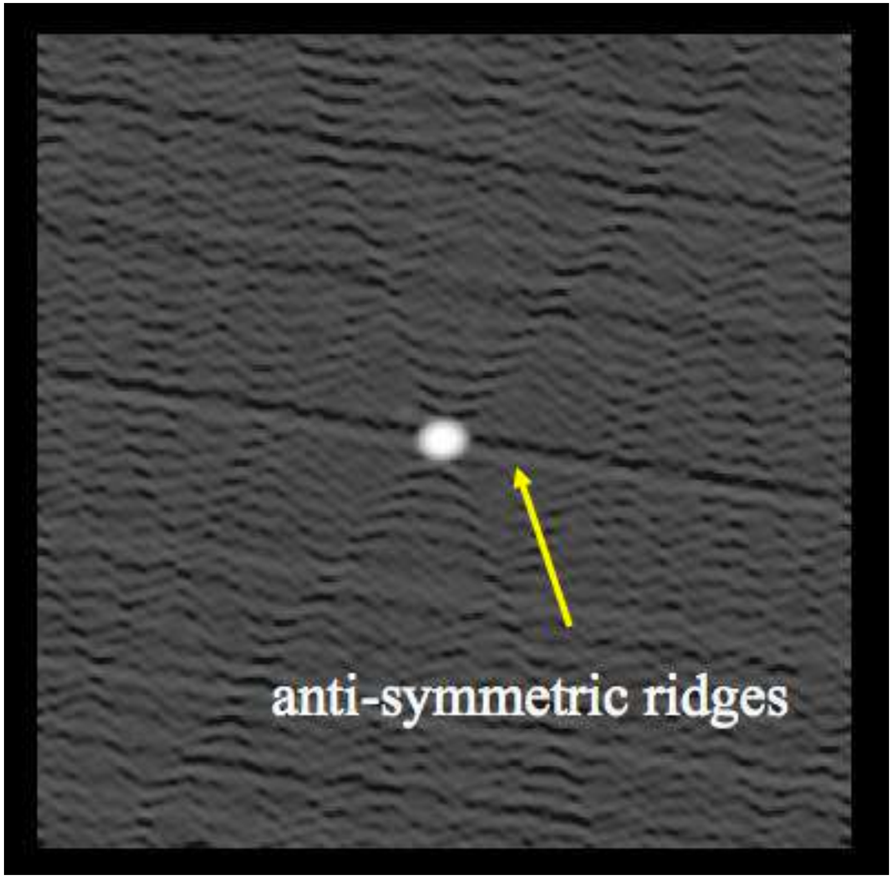
Image: Emil Lenc

Sidelobes from nearby bright sources

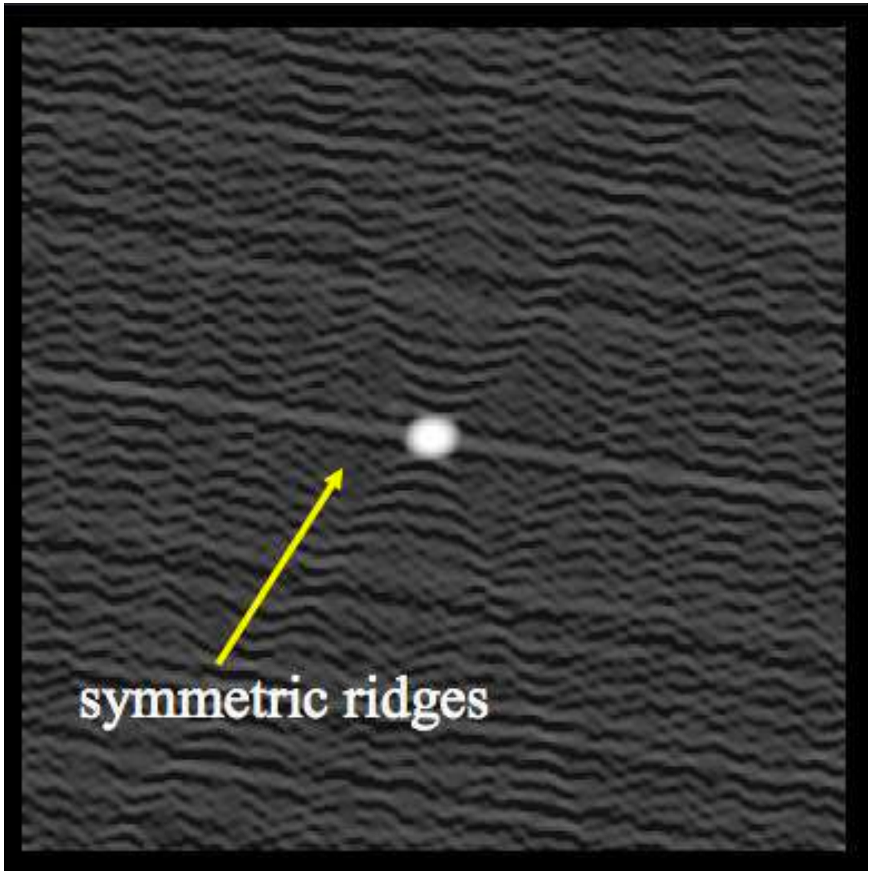
Image: Emil Lenc

Calibration errors in the image plane

10 deg phase error for one antenna at one time



20% amplitude error for one antenna at one time

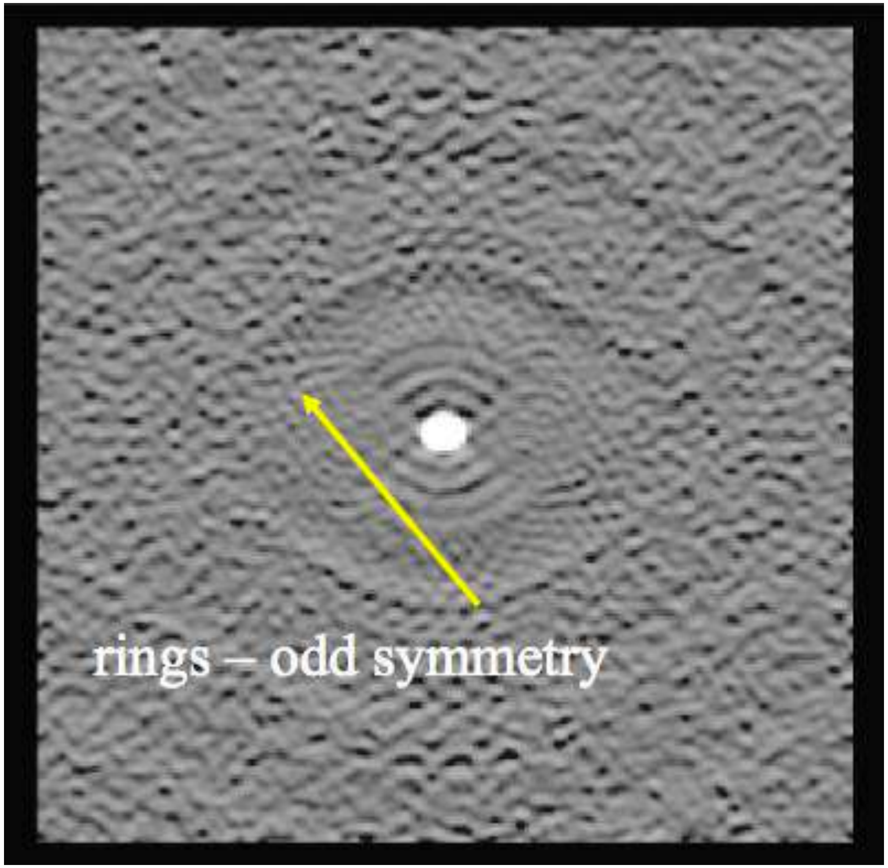


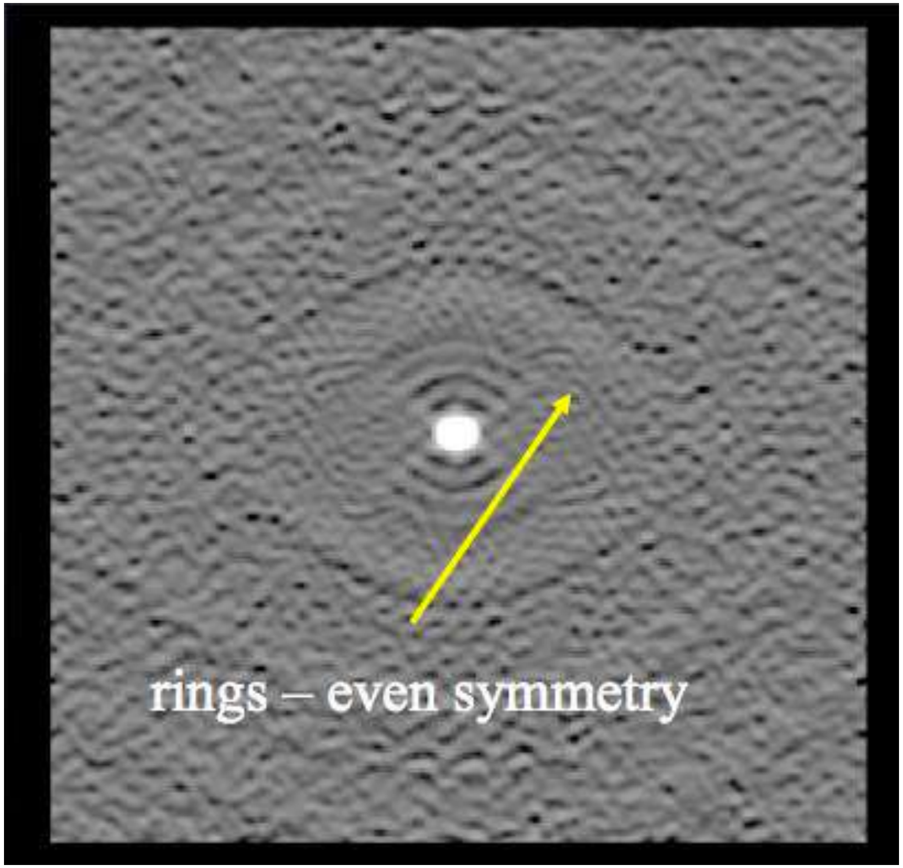
2014 NRAO synthesis imaging workshop

Calibration errors in the image plane

10 deg phase error for one antenna at all times

20% amplitude error for one antenna at all times

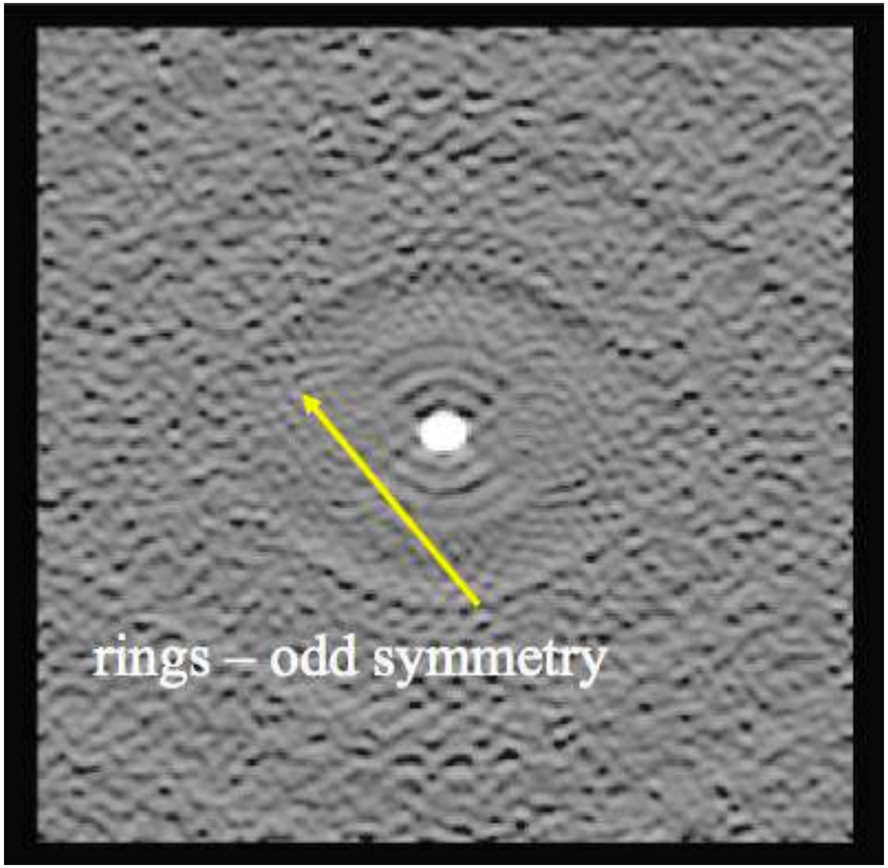


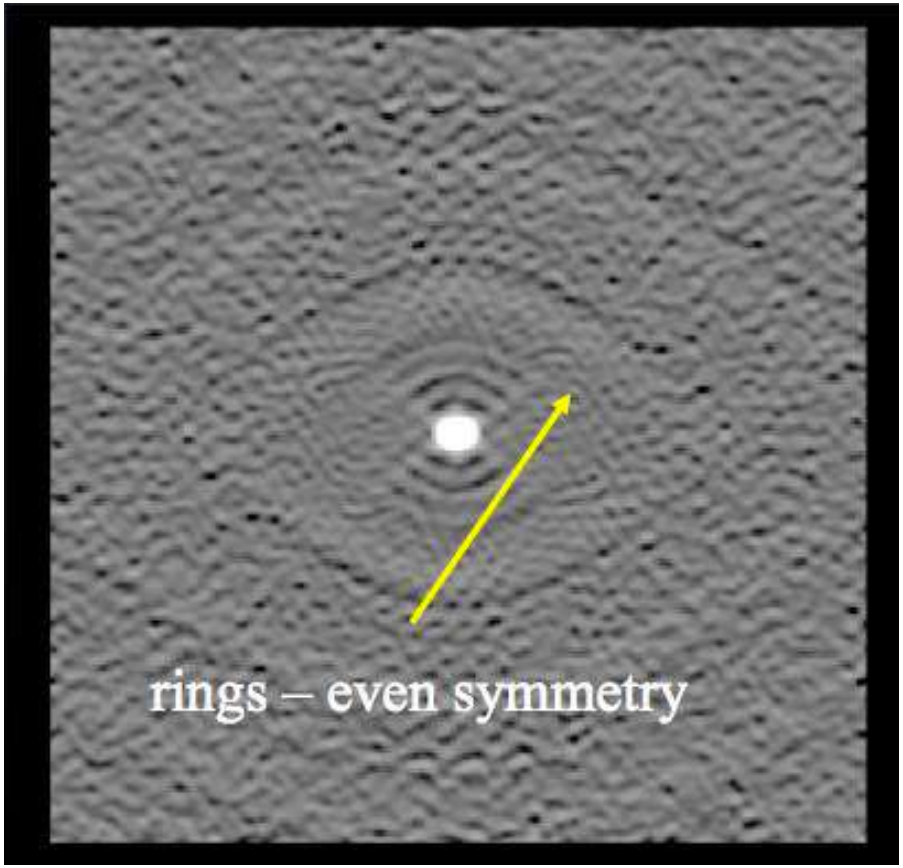


2014 NRAO synthesis imaging workshop

Calibration errors in the image plane

A 10 deg phase error is as bad as a 20% amplitude error





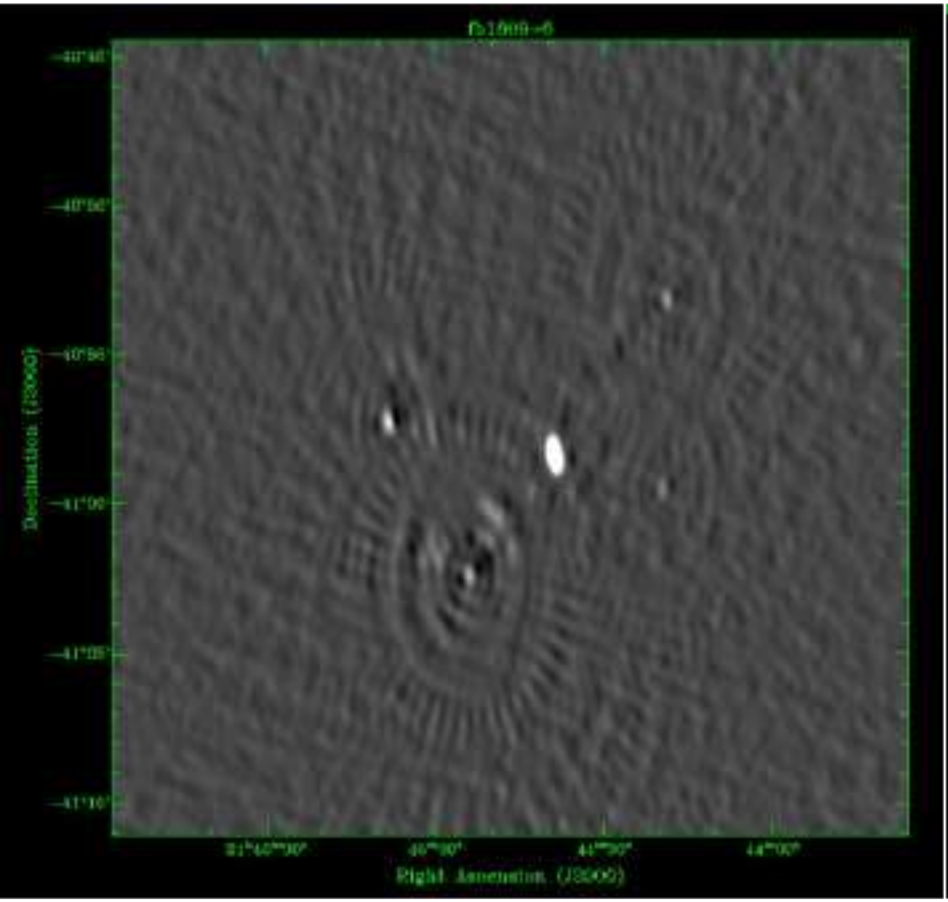
2014 NRAO synthesis imaging workshop

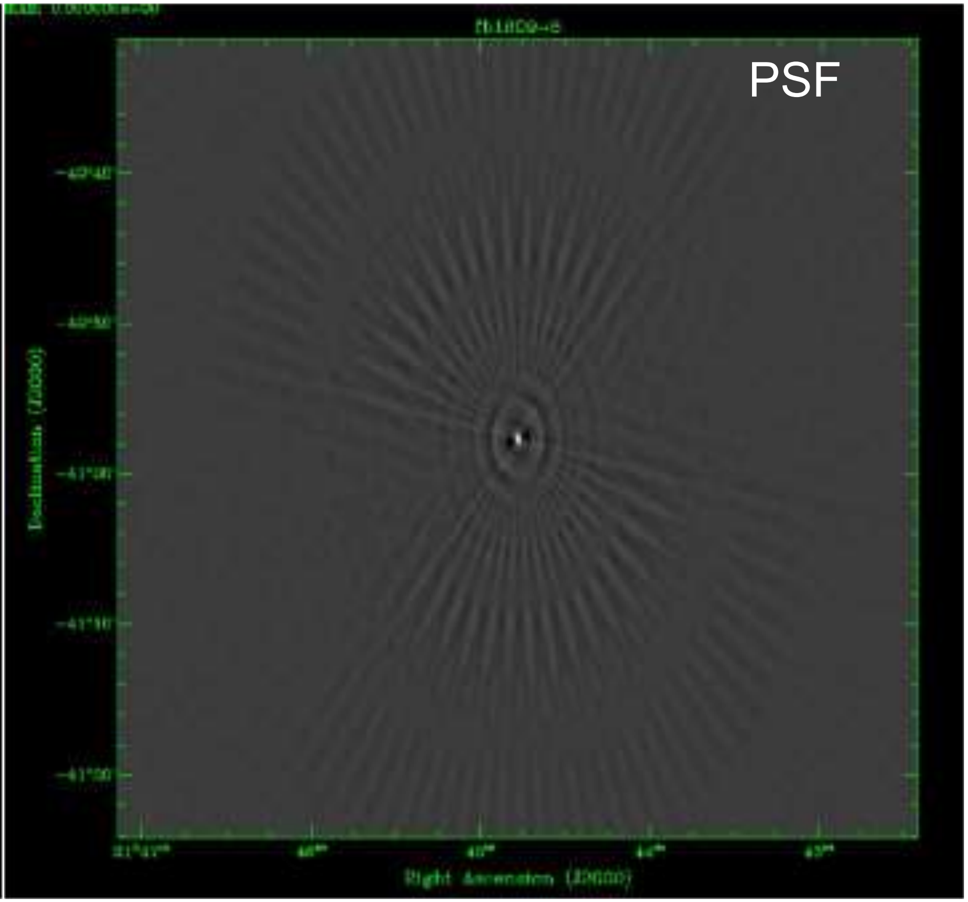
Convolution errors

- Generally associated with deconvolving your image
  - CLEAN wisely… use appropriate parameters/algorithms to suit your instrument, science target etc.
- How to tell if you have CLEANed deep enough?
  - Do your artefacts look similar to the psf/dirty beam? -> Not enough.
  - Are there spurious sources in the image? -> Too much, cleaning noise peaks.
  - Use clean masks around sources to only CLEAN where you need to.
- Are you using the appropriate parameters?
  - How much diffuse emission is there? Are you using the best weighting scheme according to your science?

How to tell if you have CLEANed deep enough?

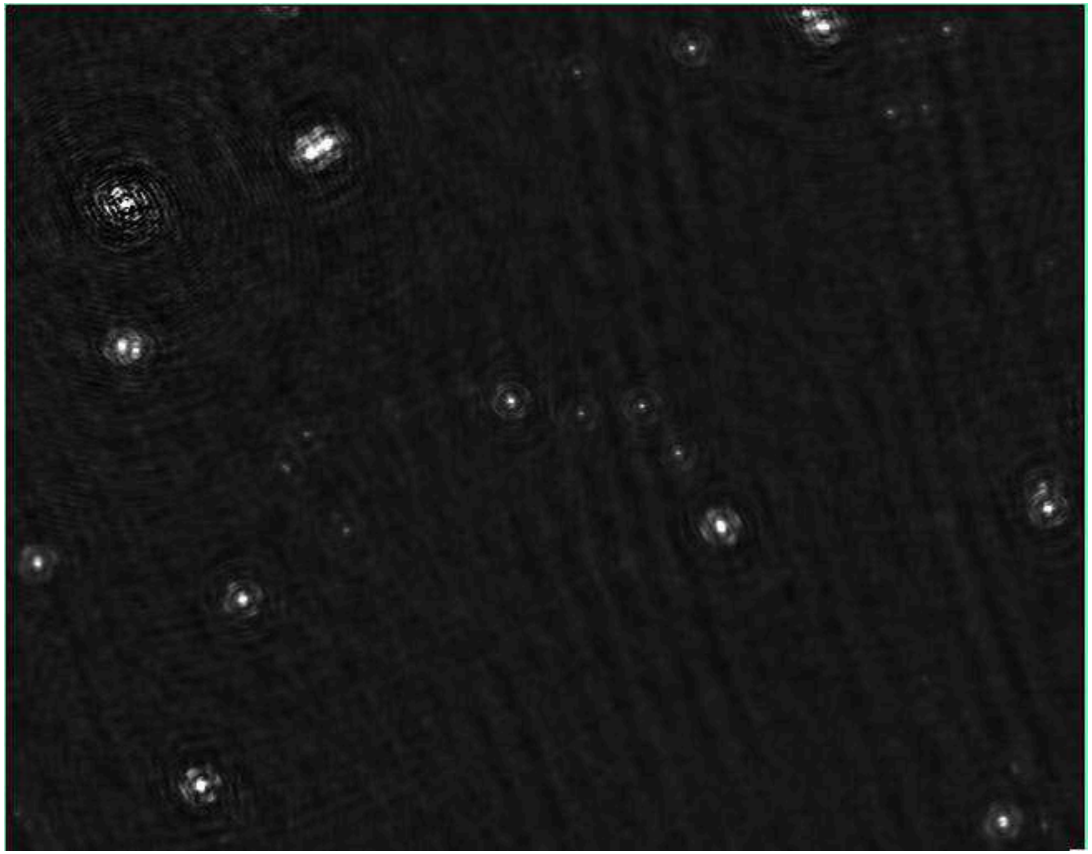
- Do your artefacts look similar to the psf/beam? -> Not enough.

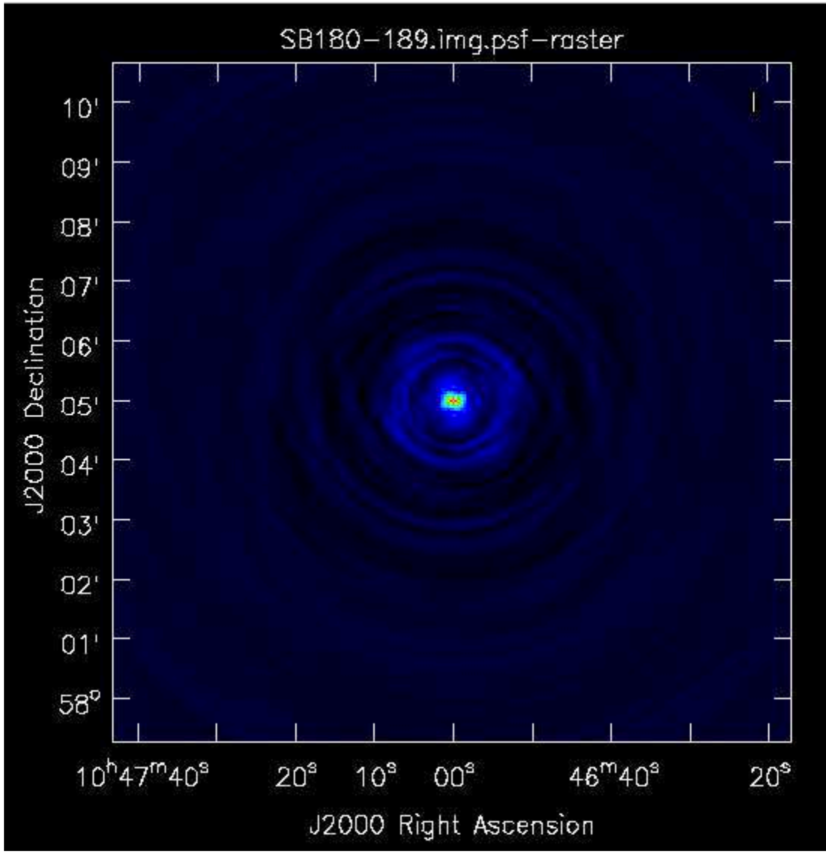




How to tell if you have CLEANed deep enough?

- Do your artefacts look similar to the psf/beam? -> Not enough.





How to tell if you have CLEANed deep enough?

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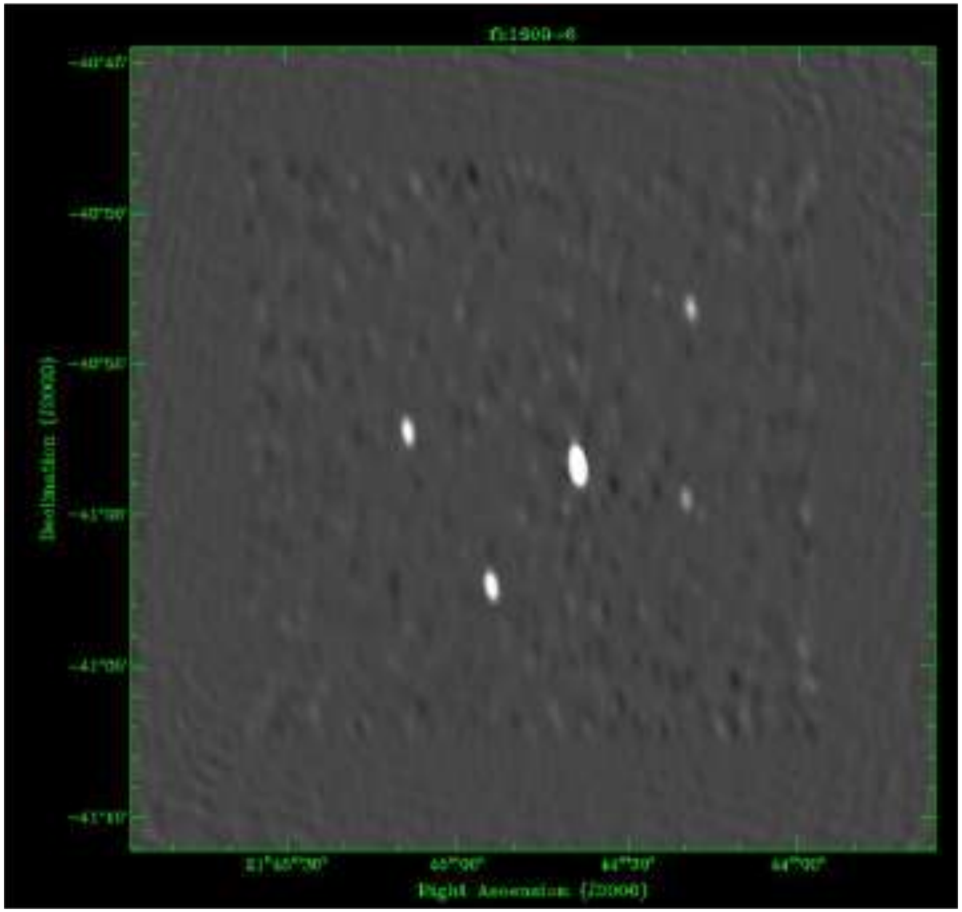
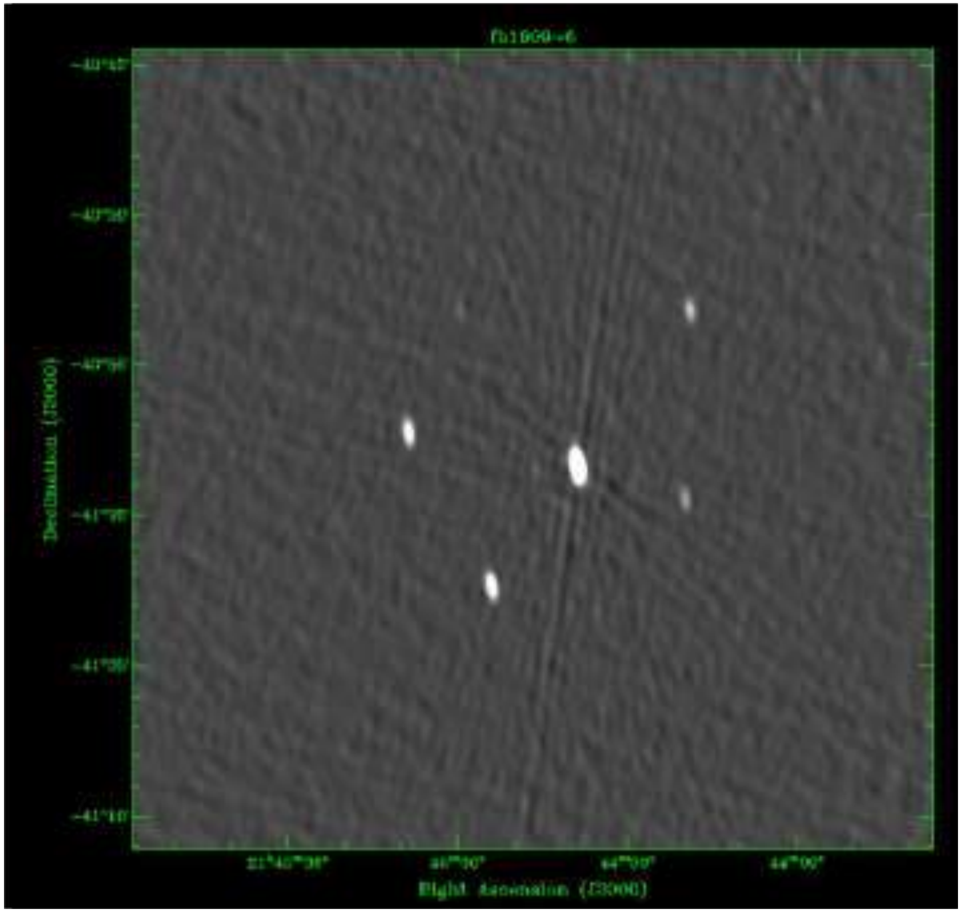


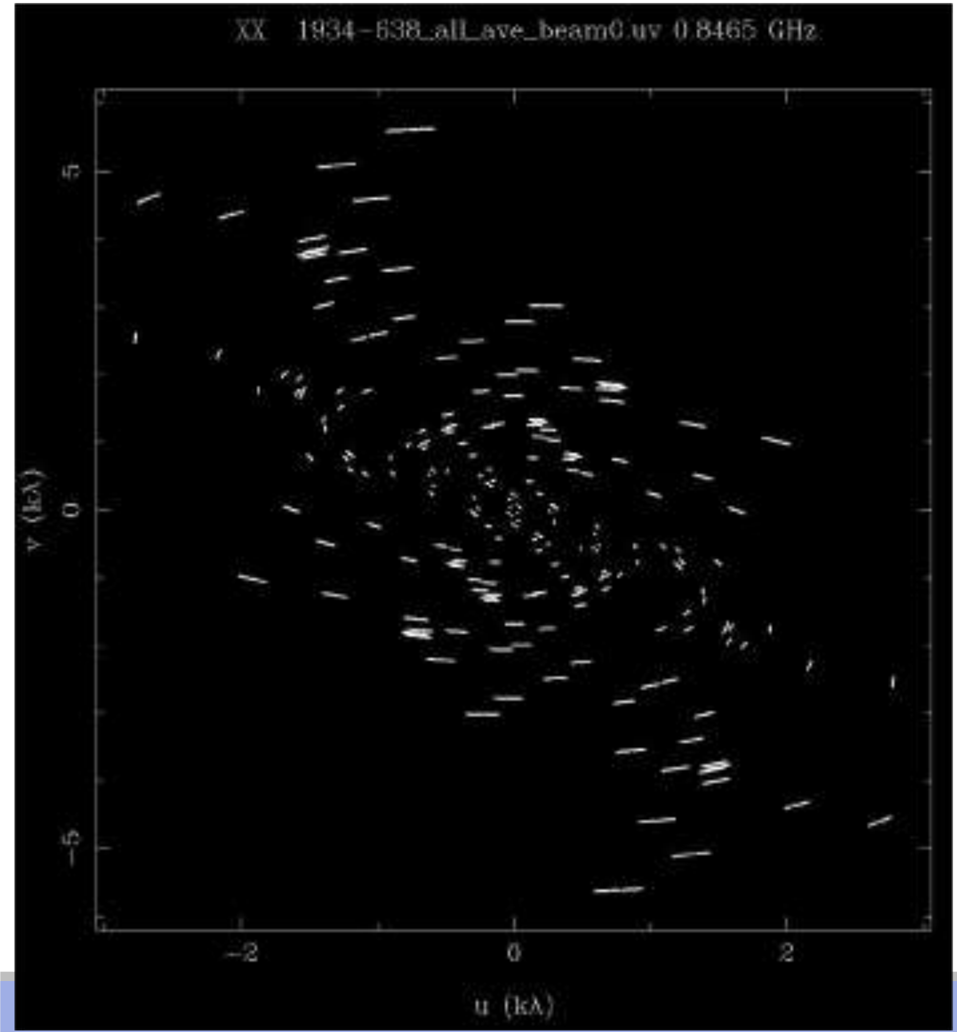
How to tell if you have CLEANed deep enough?

- Use clean masks around sources to only CLEAN where you need to.

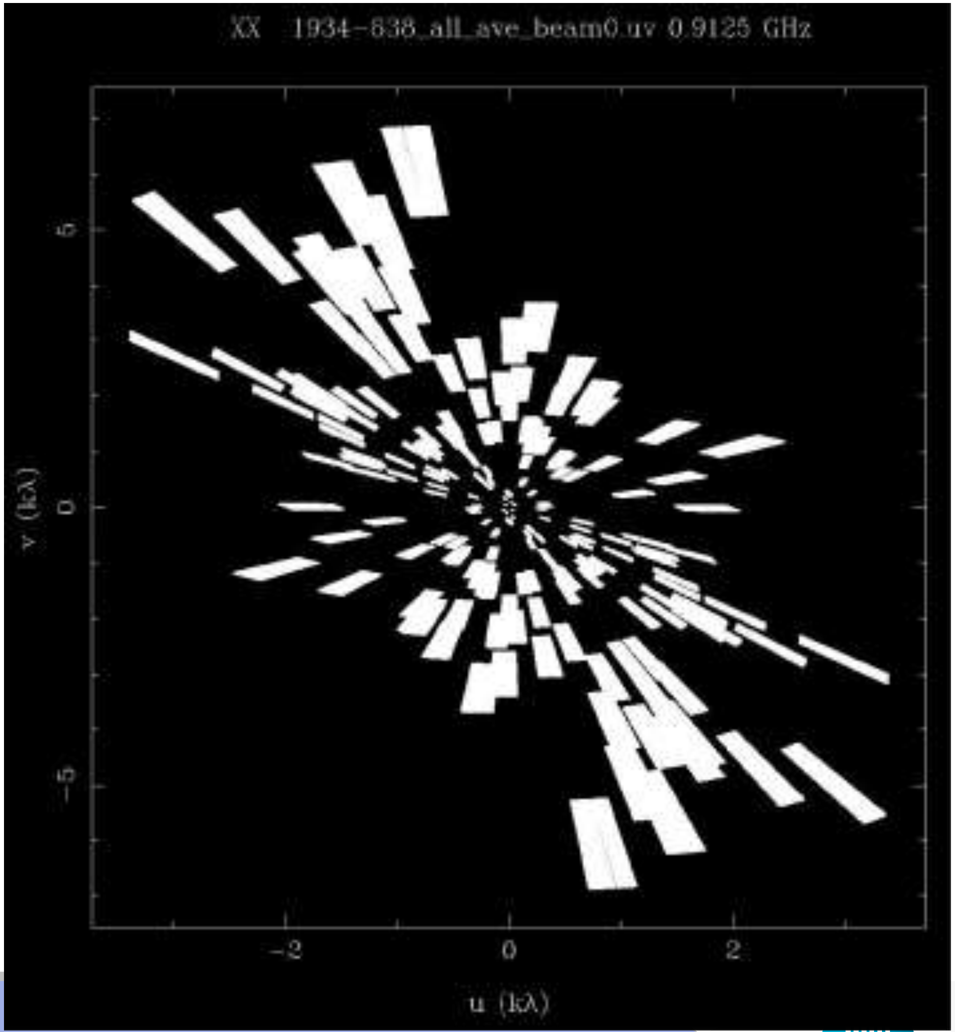


Imaging with wide bandwidths

ASKAP-16, 10min scan, central freq.

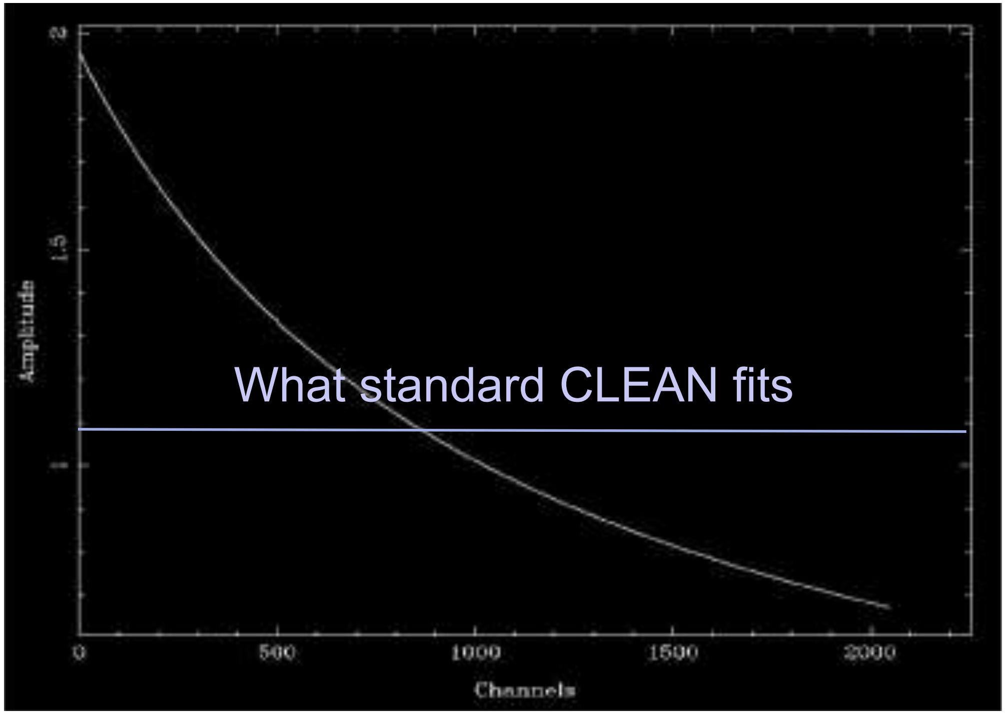


ASKAP-16, 10min scan, 240MHz BW

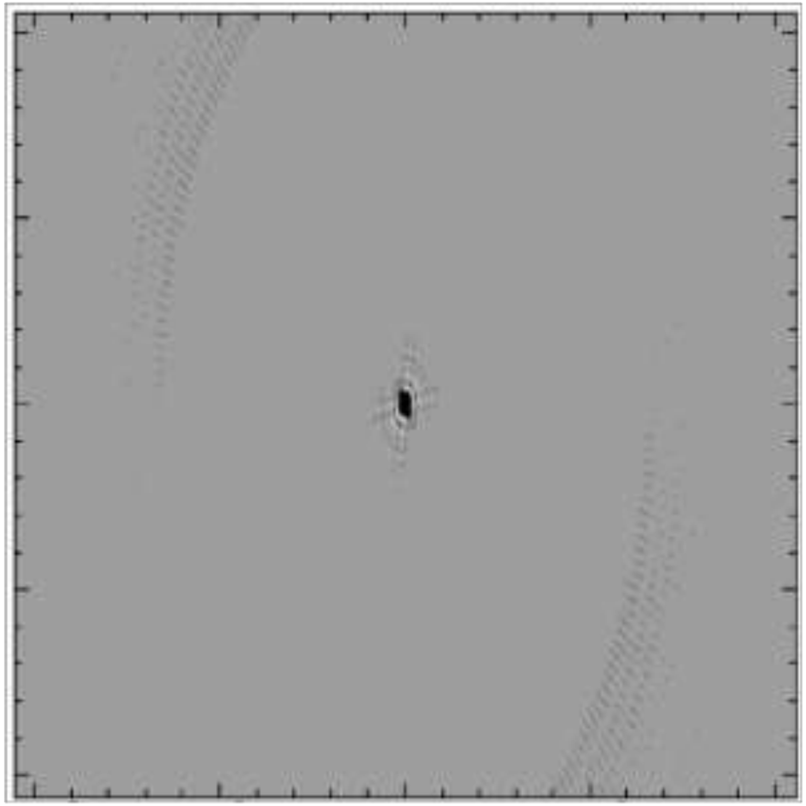


Imaging with wide bandwidths

- Use multi-frequency synthesis (mfs) to account for the spectral index of the source



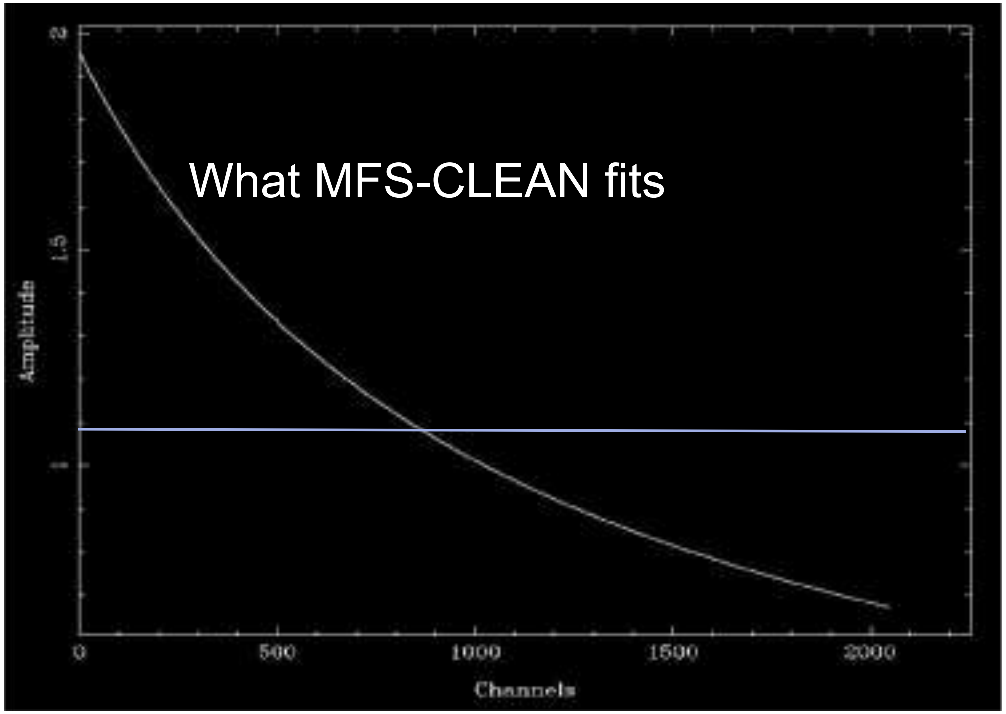
CLEAN (no n-terms)

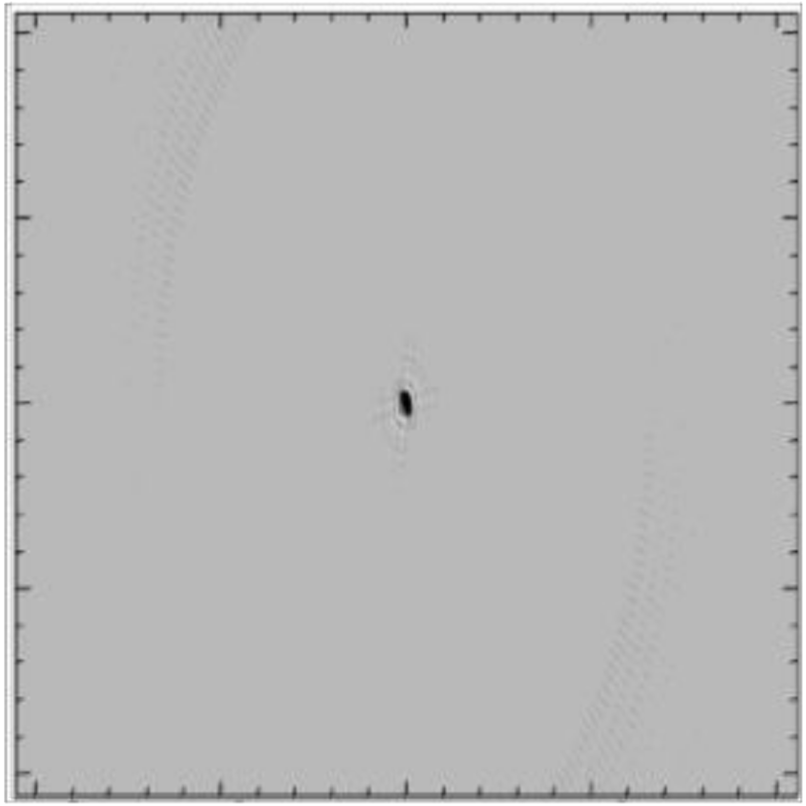


Imaging with wide bandwidths

- Use multi-frequency synthesis (mfs) to account for the spectral index of the source

MFS-CLEAN (n-terms=2)

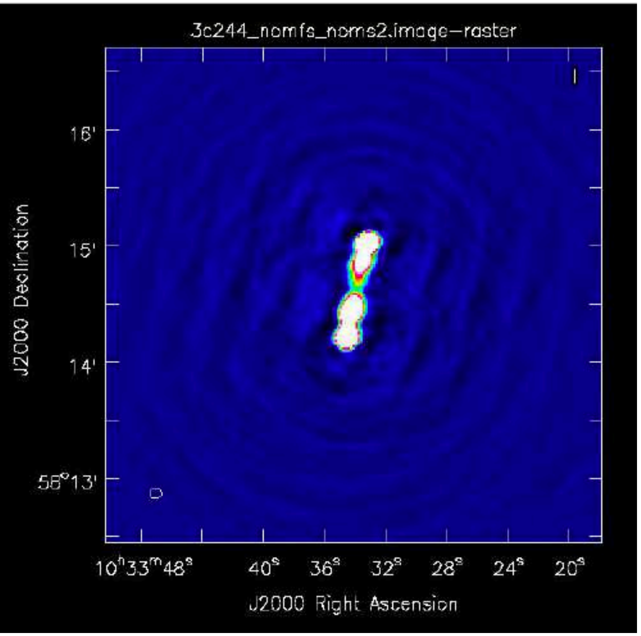




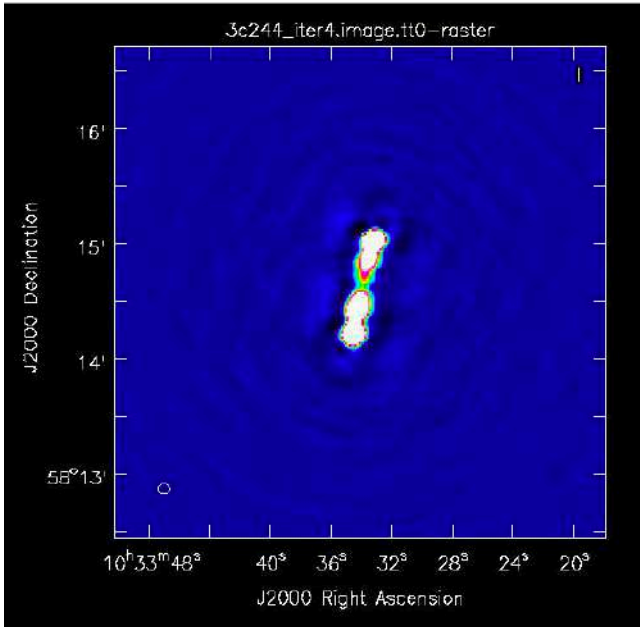
Using MS-MFS CLEAN

- If imaging more complicated structure want to deconvolve using different scales – use multiscale CLEAN

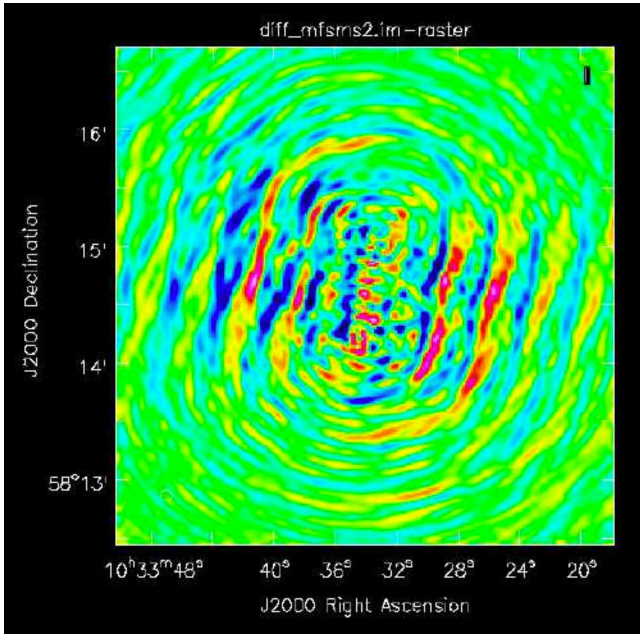
Normal CLEAN



ms-mfs CLEAN

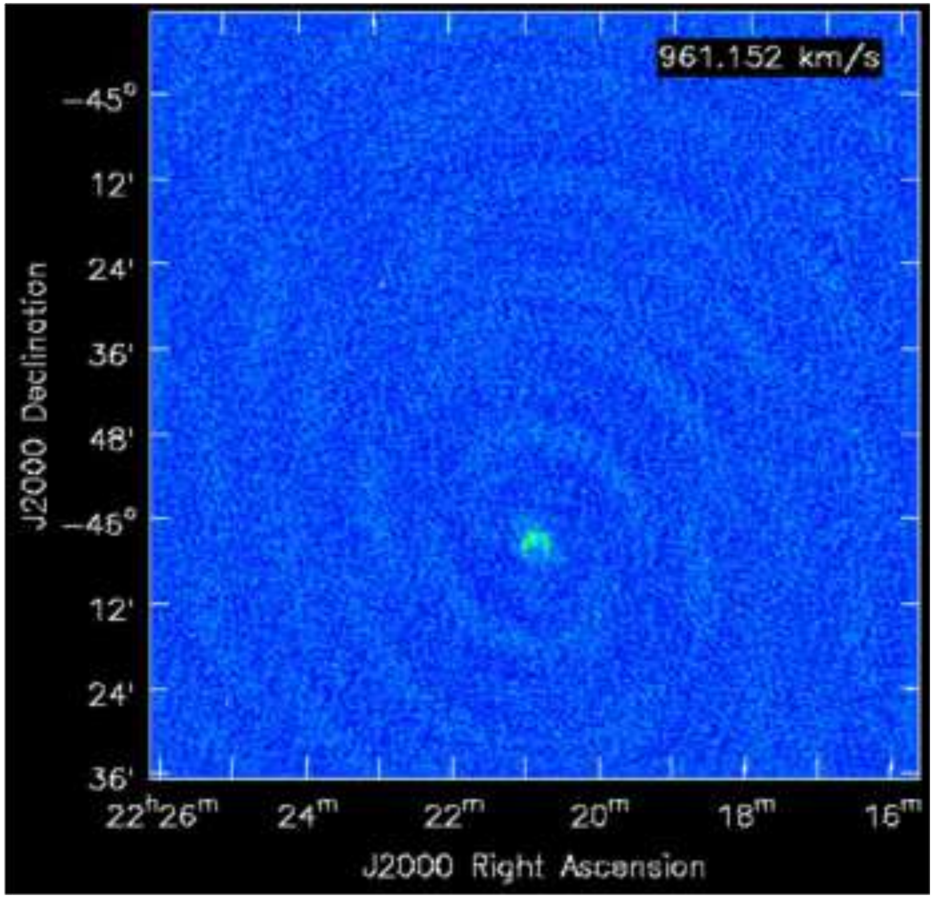


Difference image

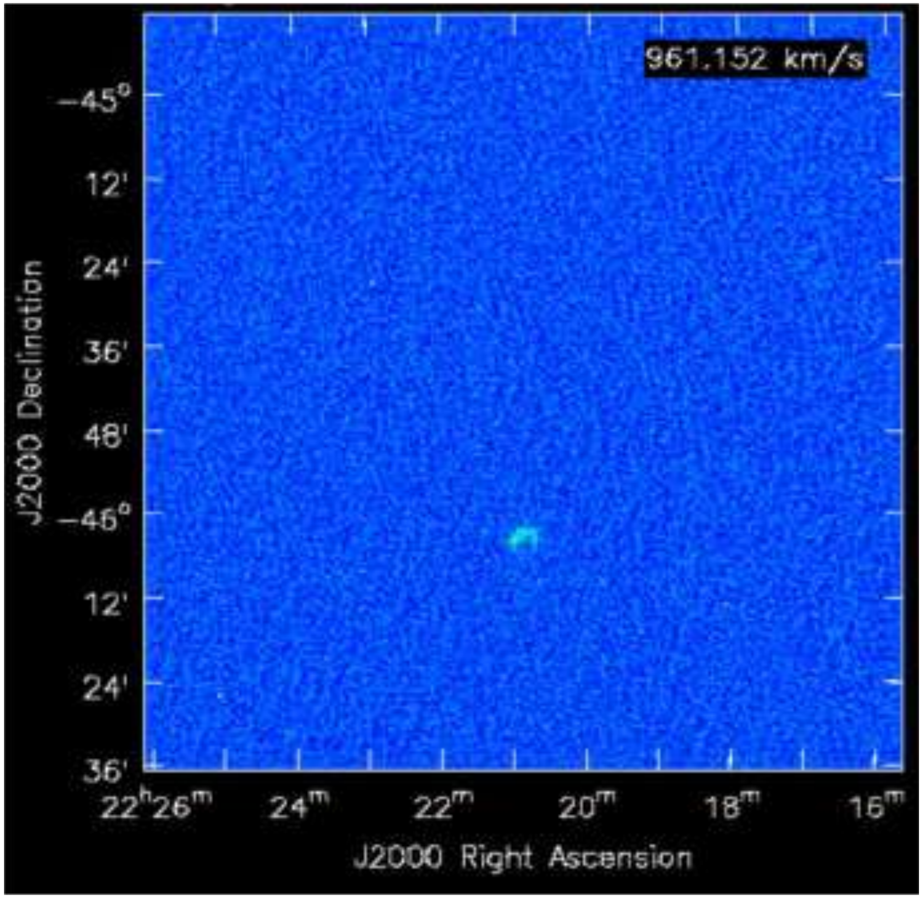


Using MS-MFS clean

Normal CLEAN



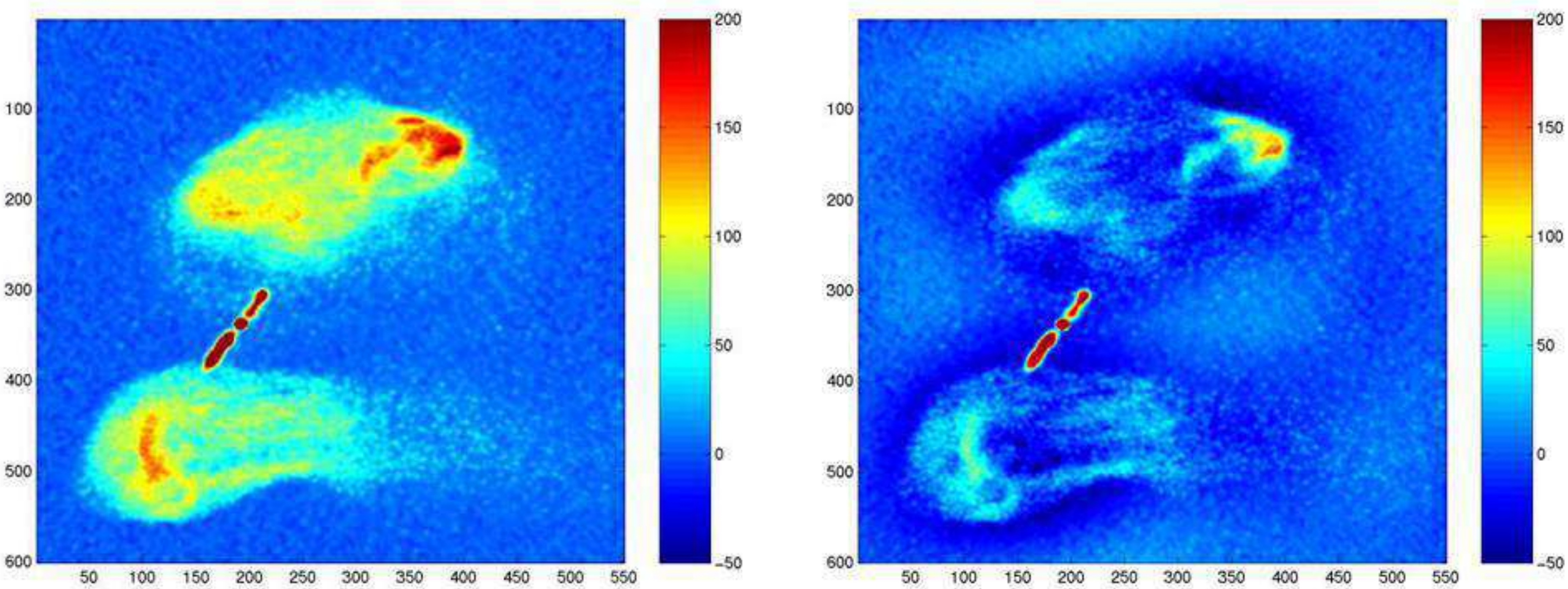
Multi-scale CLEAN



Dane Kleiner + ASKAP WALLABY team

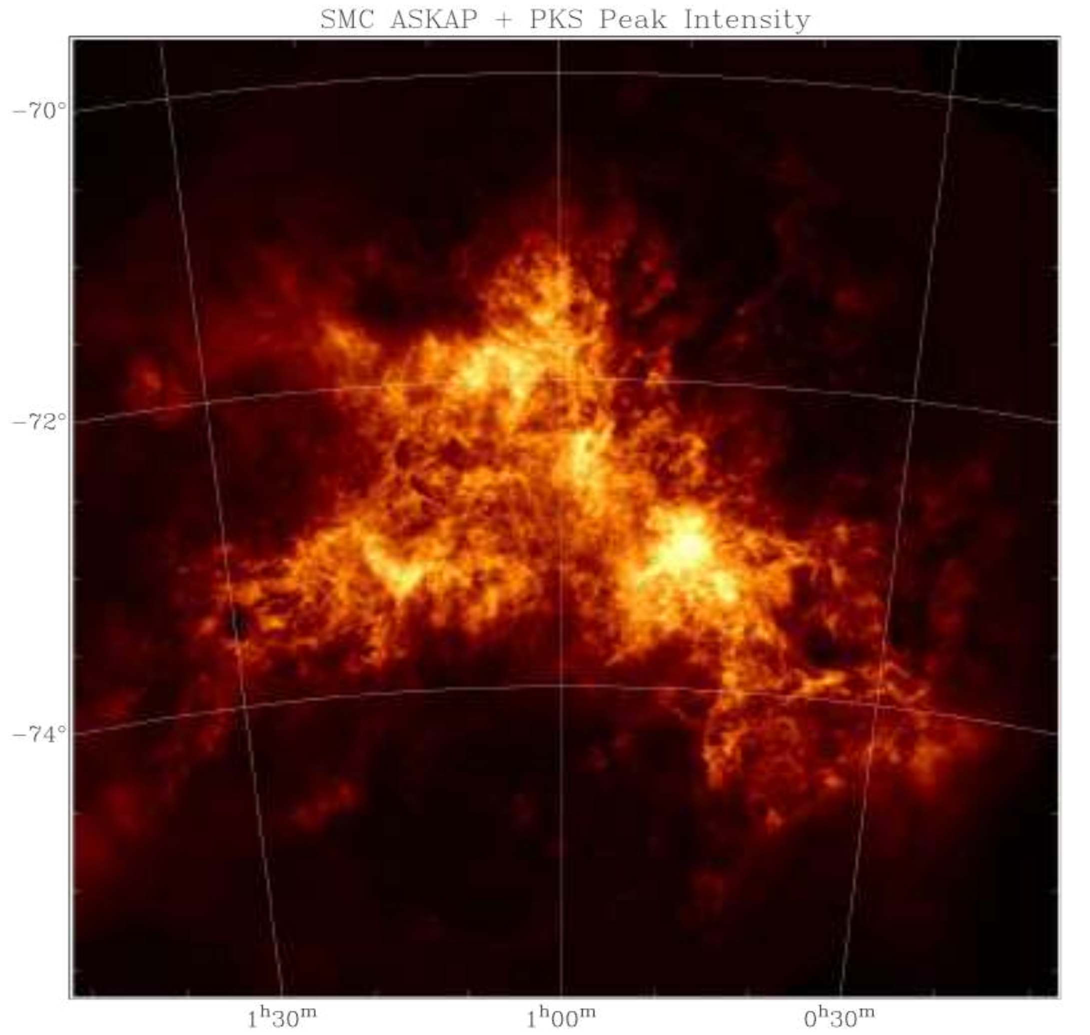
Missing short spacings

- Sensitive to extended, diffuse emission on short baselines
  - Therefore missing information if only observed on long baselines



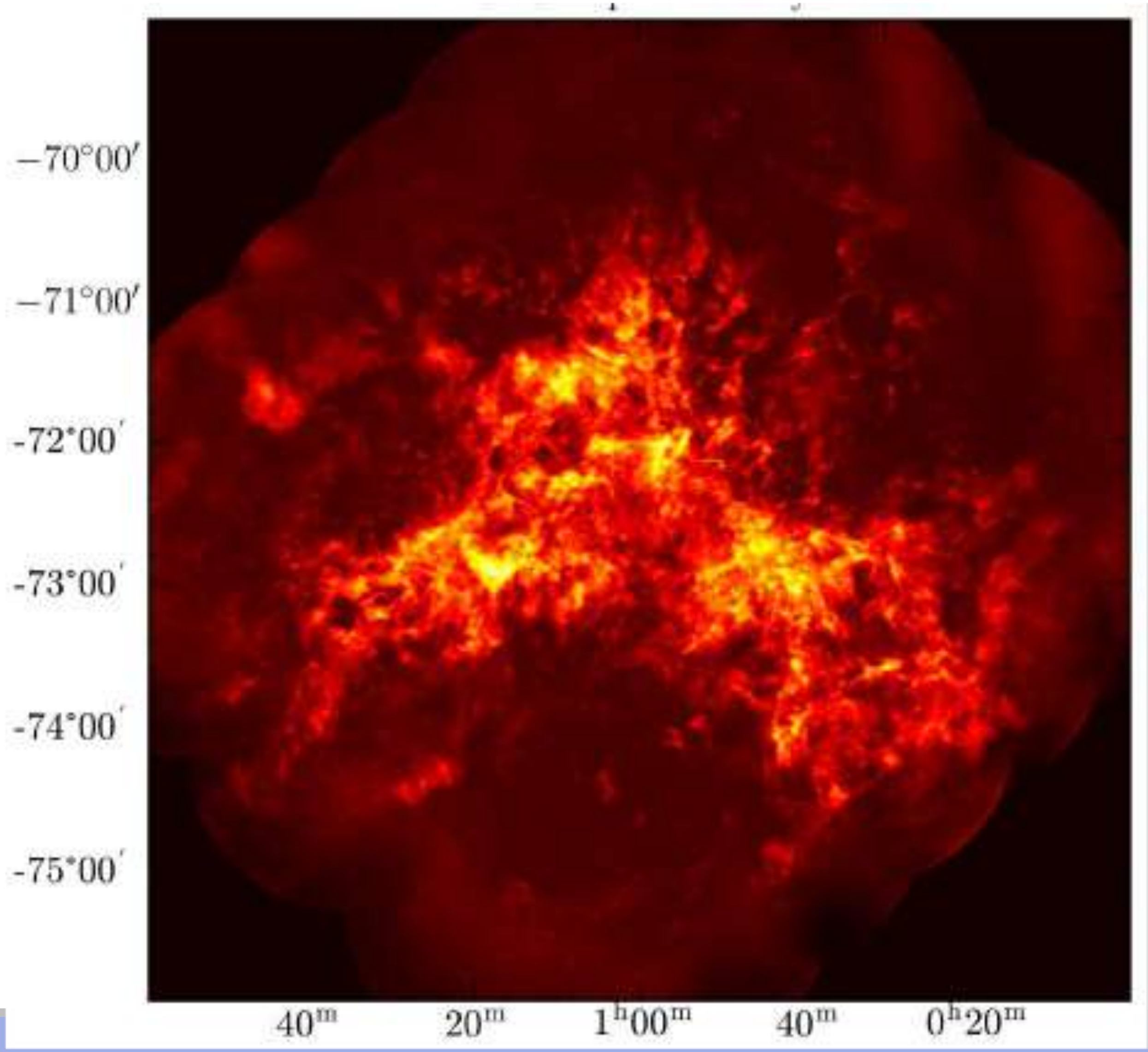
Paul Rayner 2001

ASKAP + Parkes



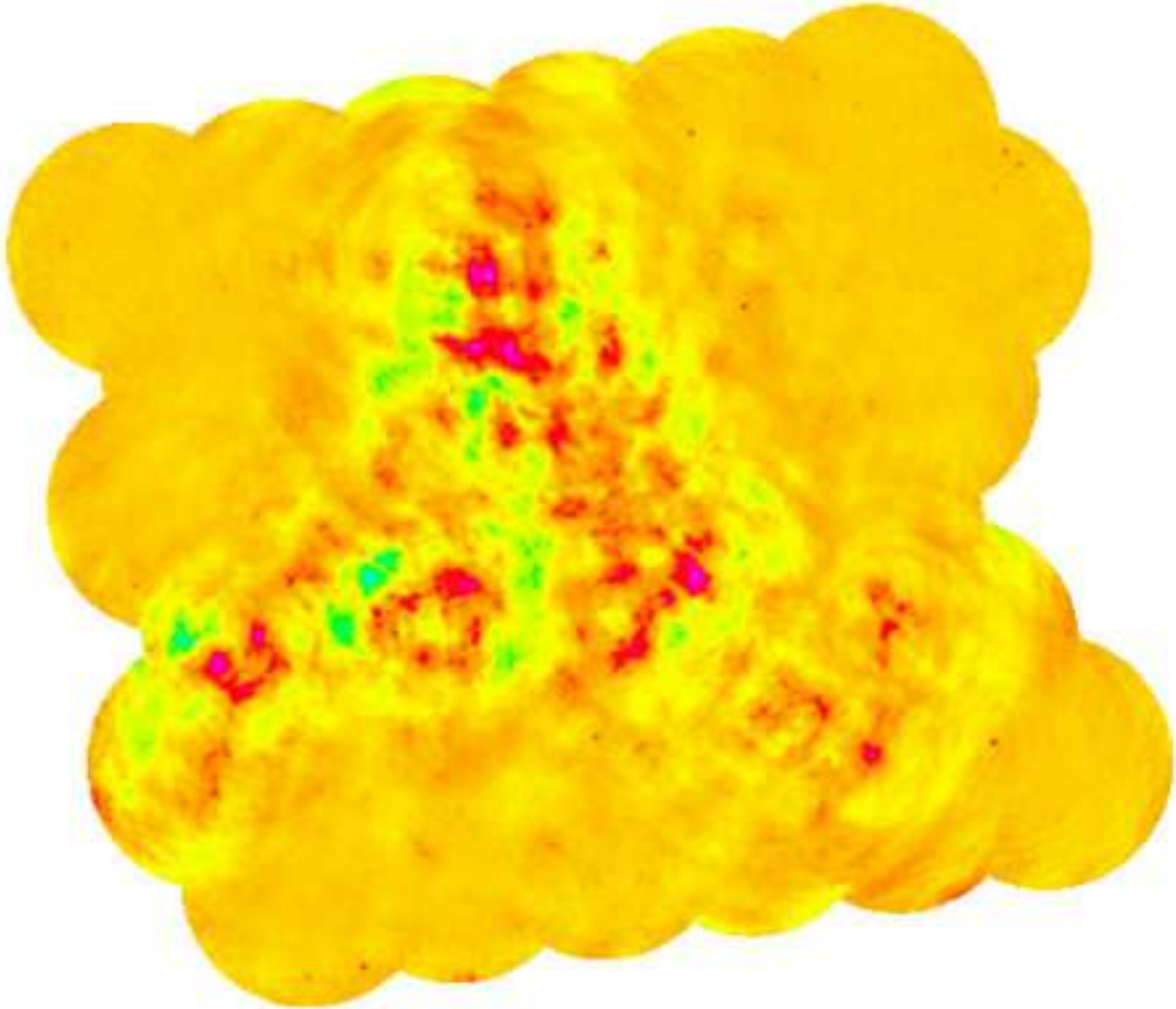
McClure-Griffiths, Denes, Dickey + GASKAP team

ASKAP incl. short baselines



McClure-Griffiths, Denes, Dickey + GASKAP team

ASKAP without short baselines



McClure-Griffiths,
Denes, Dickey +
GASKAP team

Wide-field effects

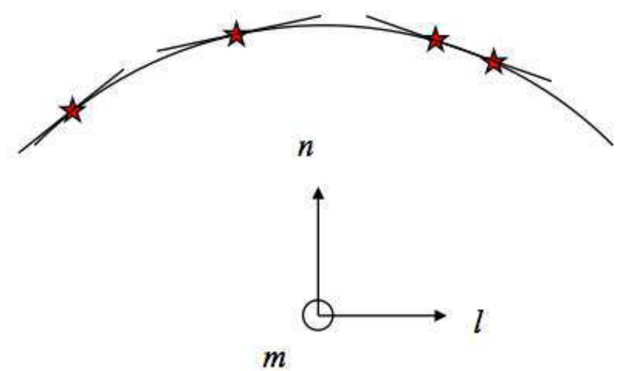
- Many of the difficulties associated with imaging ASKAP/MWA data are due to the large field of view.
- Contribution of many sources can sometimes make it hard to diagnose issues in u,v plane
  - Also a LOT of baselines to inspect manually.
- Extra things to worry about for wide-field imaging:
  - includes non-coplanar array (w-term) effects
  - Also have wide bandwidths – need to be careful of bandwidth and time-averaging smearing
  - Direction dependent effects, particularly important at low frequencies!
  - Requires enormous computing power
- All of these issues will limit the dynamic range and image fidelity if not accounted for properly!

The w-term

- The w-term describes the deviation from a plane:

$$V(u,v,w) = \int \int I(l,m) e^{-2\pi i [ul+vm+\boxed{w(\sqrt{1-l^2-m^2}}-1)]} dl dm$$

- When imaging large fields, 2-d approximation is not valid (i.e. can no longer assume the sky is flat)

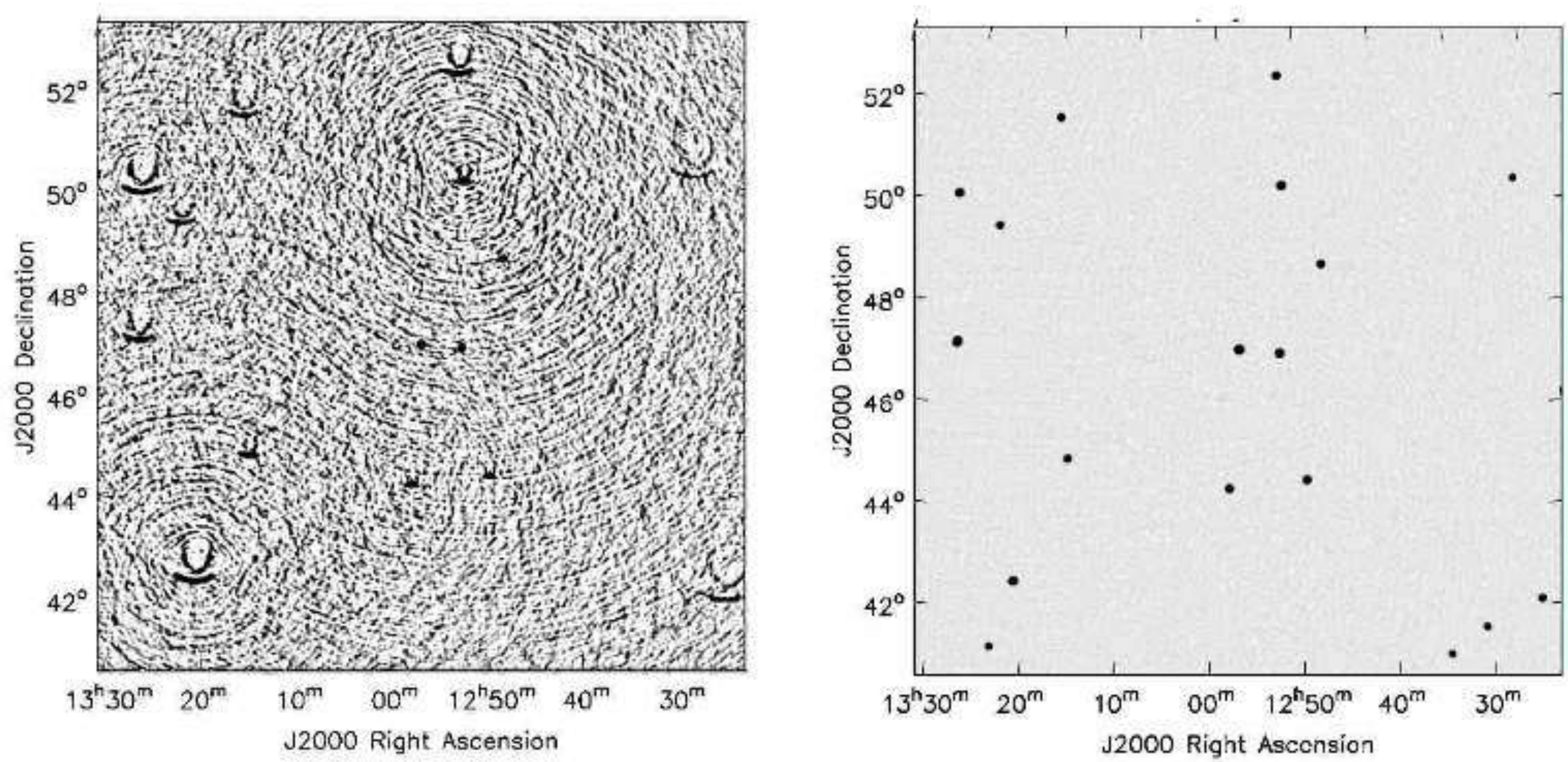


- Different imaging algorithms exist to take the w-term into account

  (e.g. w-projection, w-stacking, w-snapshot imaging)

Imaging using w-projection

- Smearing of sources away from phase centre



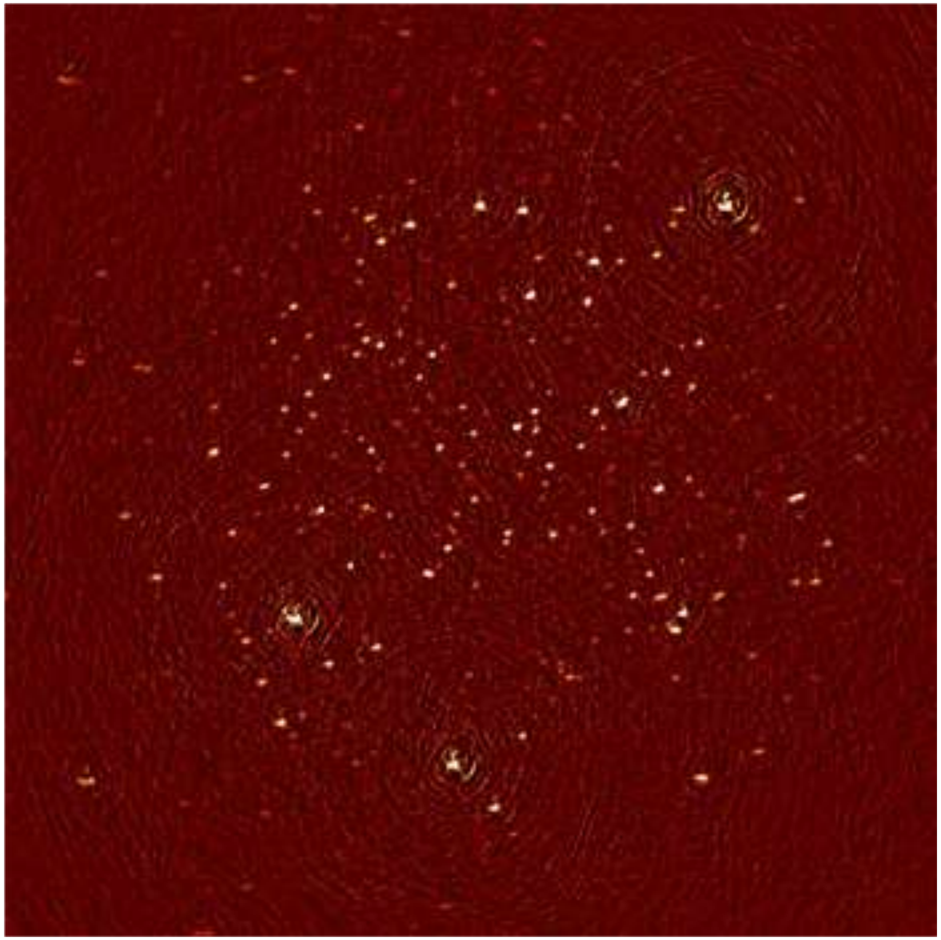
(a) standard Fourier transform

(c) W-projection (128 $\tilde{G}_T$ planes)

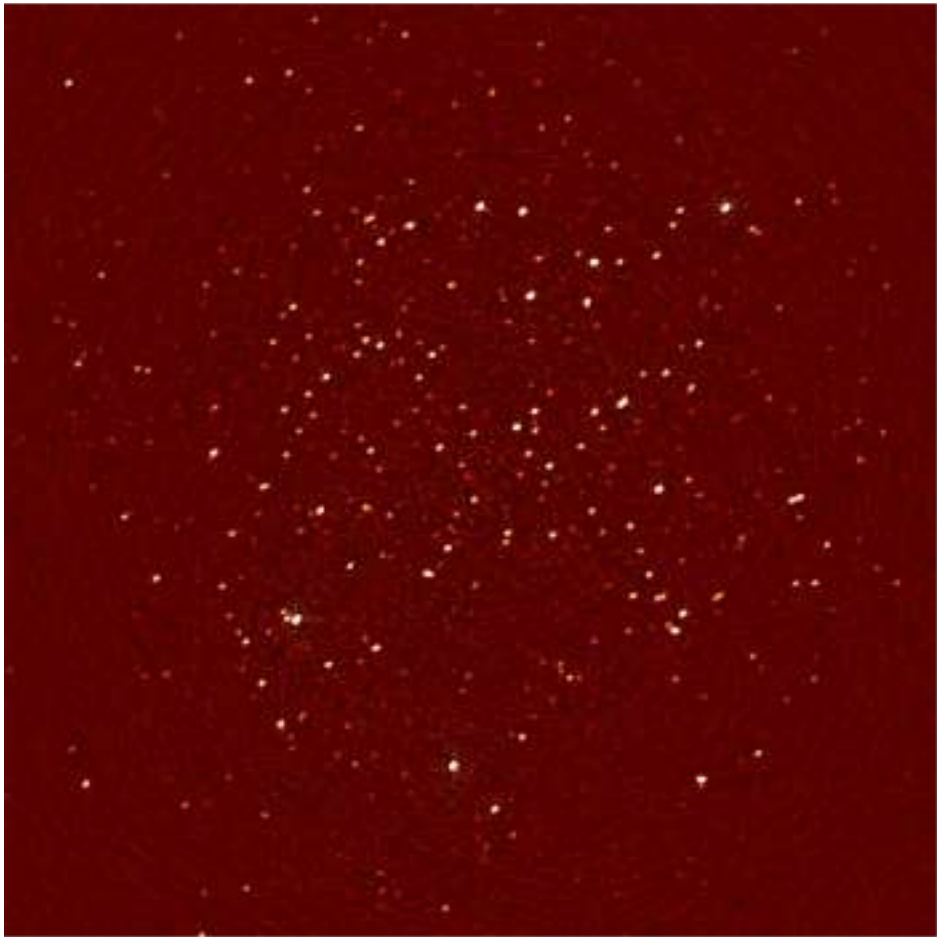
Cornwell et al. 2008

Imaging using w-stacking: LOFAR 3C196 field

No w-term correction



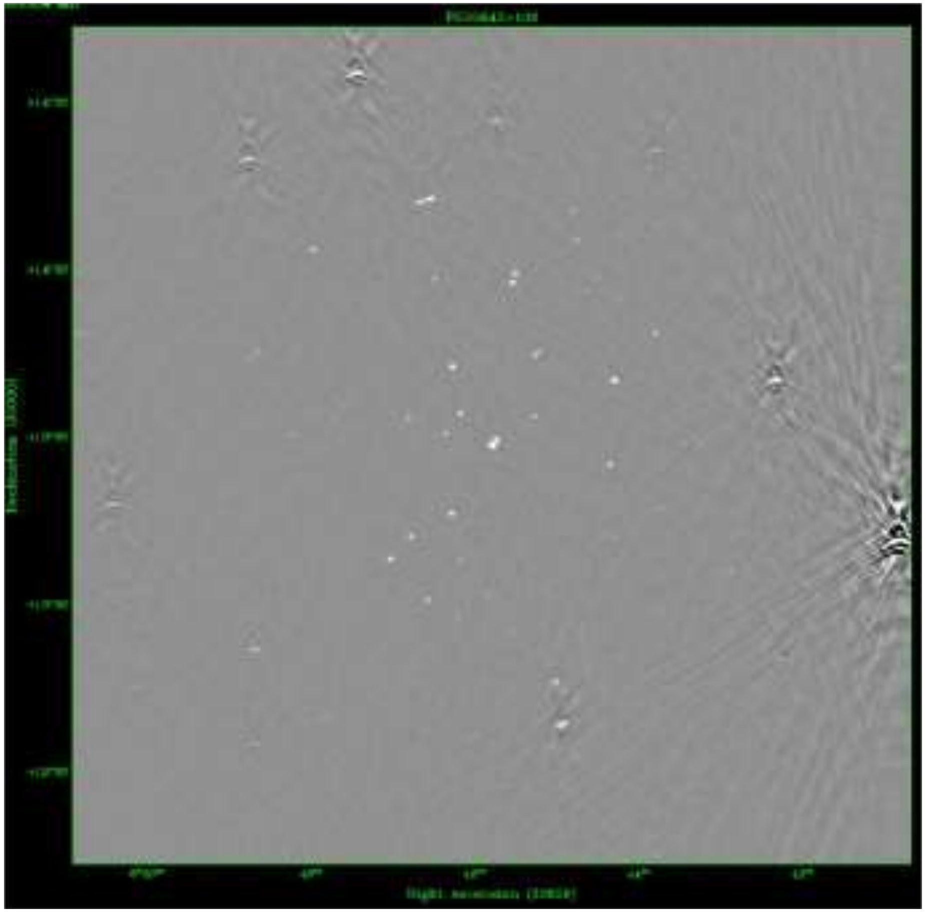
Using w-stacking



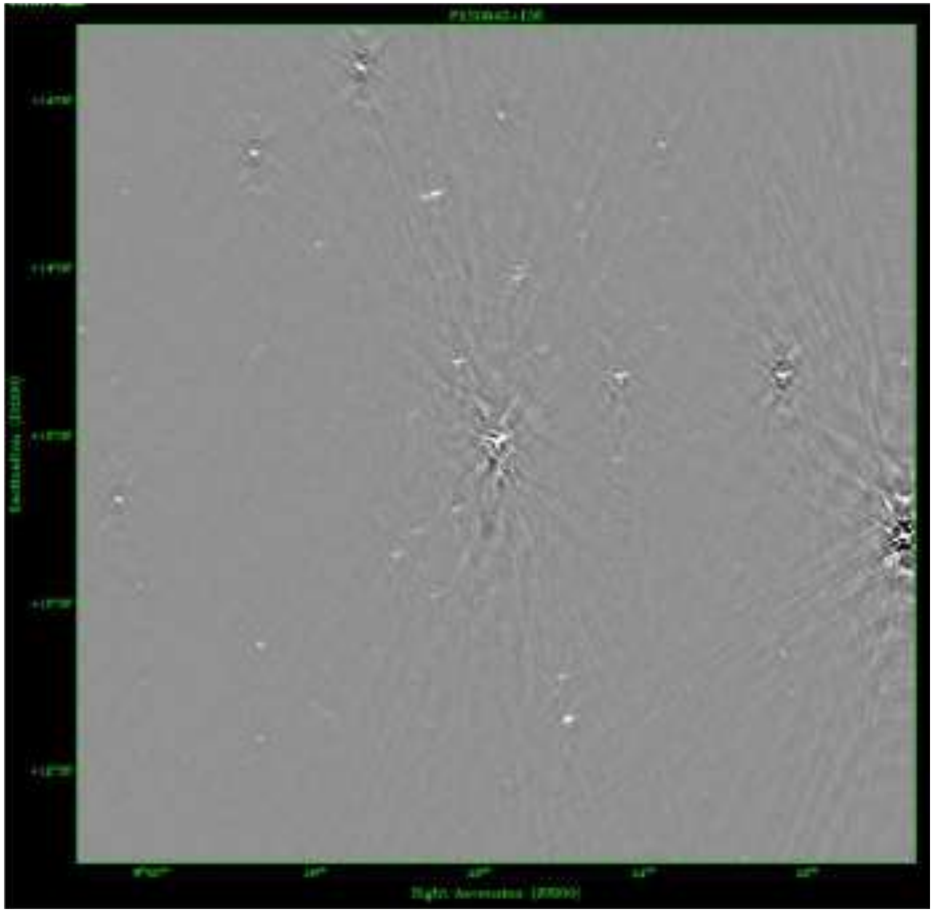
Images: Andre Offringa

An ASKAP example

No w-term correction



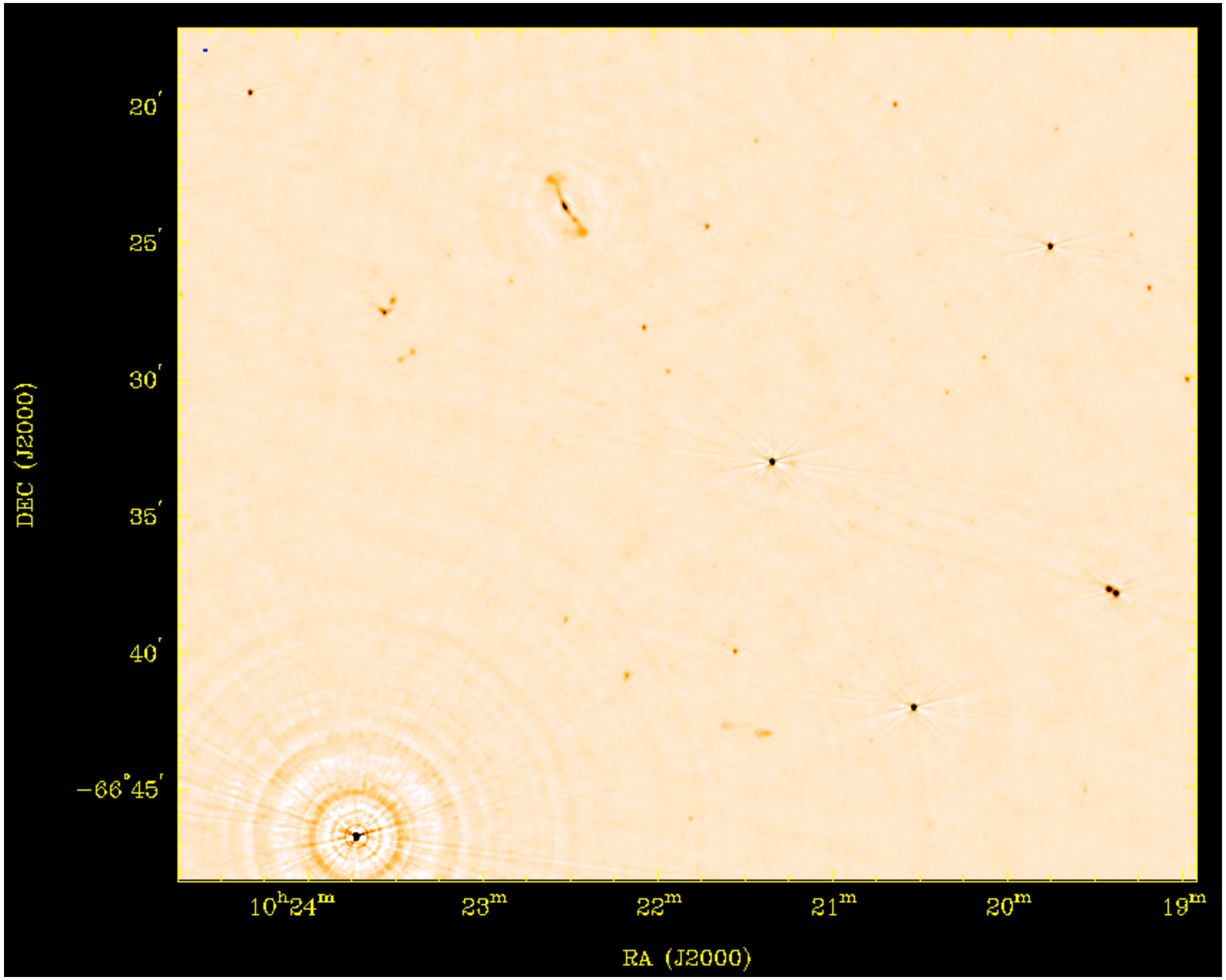
No w-term correction + selfcal



Bandwidth smearing + Time smearing

- When making an image, the visibilities are gridded as if they were monochromatic (i.e. all same frequency)
  - This means that if we average too much, sources will be smeared in the radial direction
  - Leads to reduction in peak flux
  - This effect gets larger the further the sources are from the phase centre

Bandwidth smearing + Time smearing



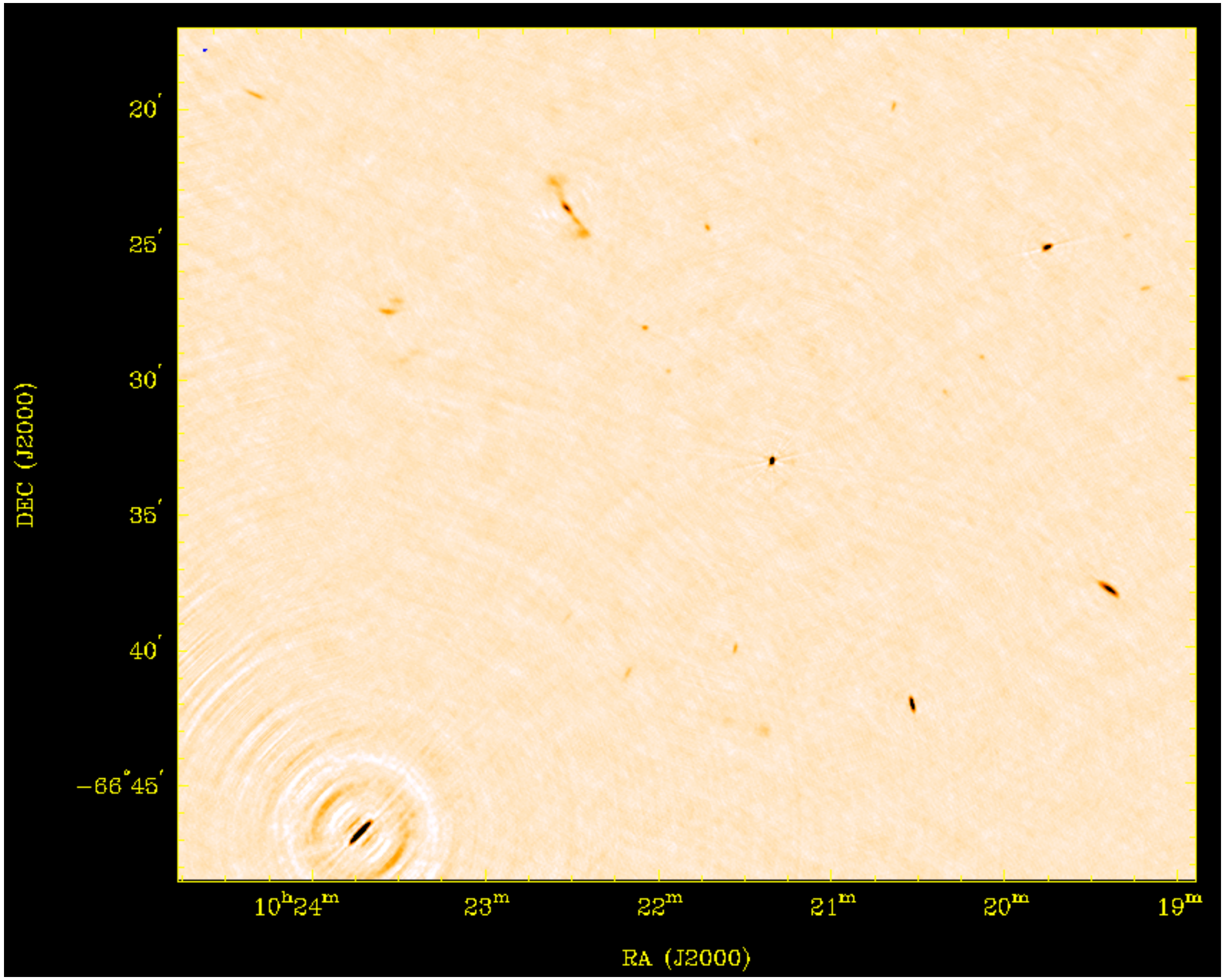
ATCA image

2048 channel bandwidth (~2 GHz)

2048 x 1 MHz channels

Image: Jamie Stevens

Bandwidth smearing + Time smearing



ATCA image

2048 channel bandwidth (~2 GHz)

32 x 64 MHz channels

Image: Jamie Stevens

Bandwidth smearing + Time smearing

- The same thing happens if you average too heavily in time, but instead the sources are smeared in the tangential direction

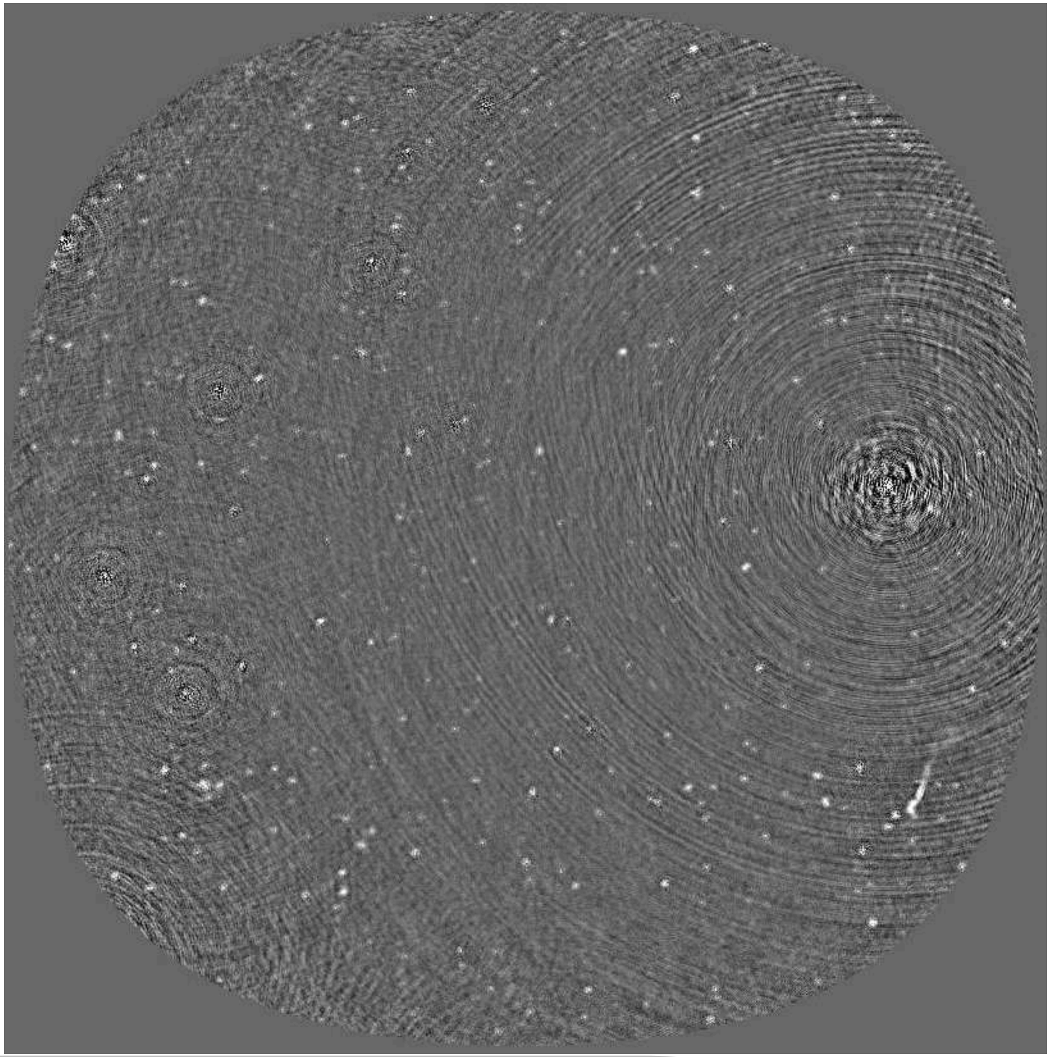
- Bandwidth smearing and time-averaging smearing aren't unique to wide-field imaging, but effects become more pronounced as you move away from the phase centre

- A large field of view means we have to be careful of both these effects
  - Need small channel widths (to avoid bandwidth smearing)
  - Need rapid correlator dumps (to avoid time smearing)

  -> this is why data rates are so huge!

Bright sources in the field

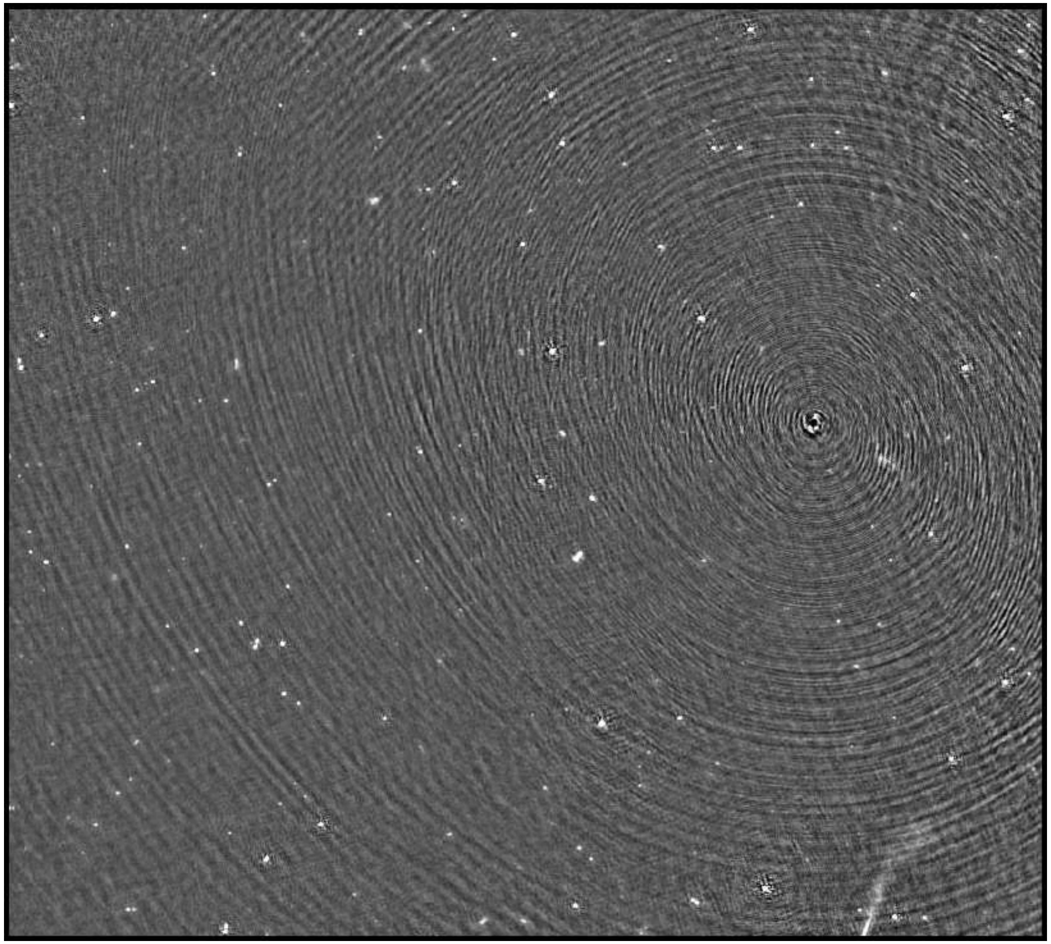
- Peeling 101:
  - Subtract all other sources in the field
  - Direction-dependent calibration towards the bright source (or phase-shift + calibrate bright source)
  - Subtract bright source
  - Add back all other sources
  - Another round of phase calibration



Bright sources in the field

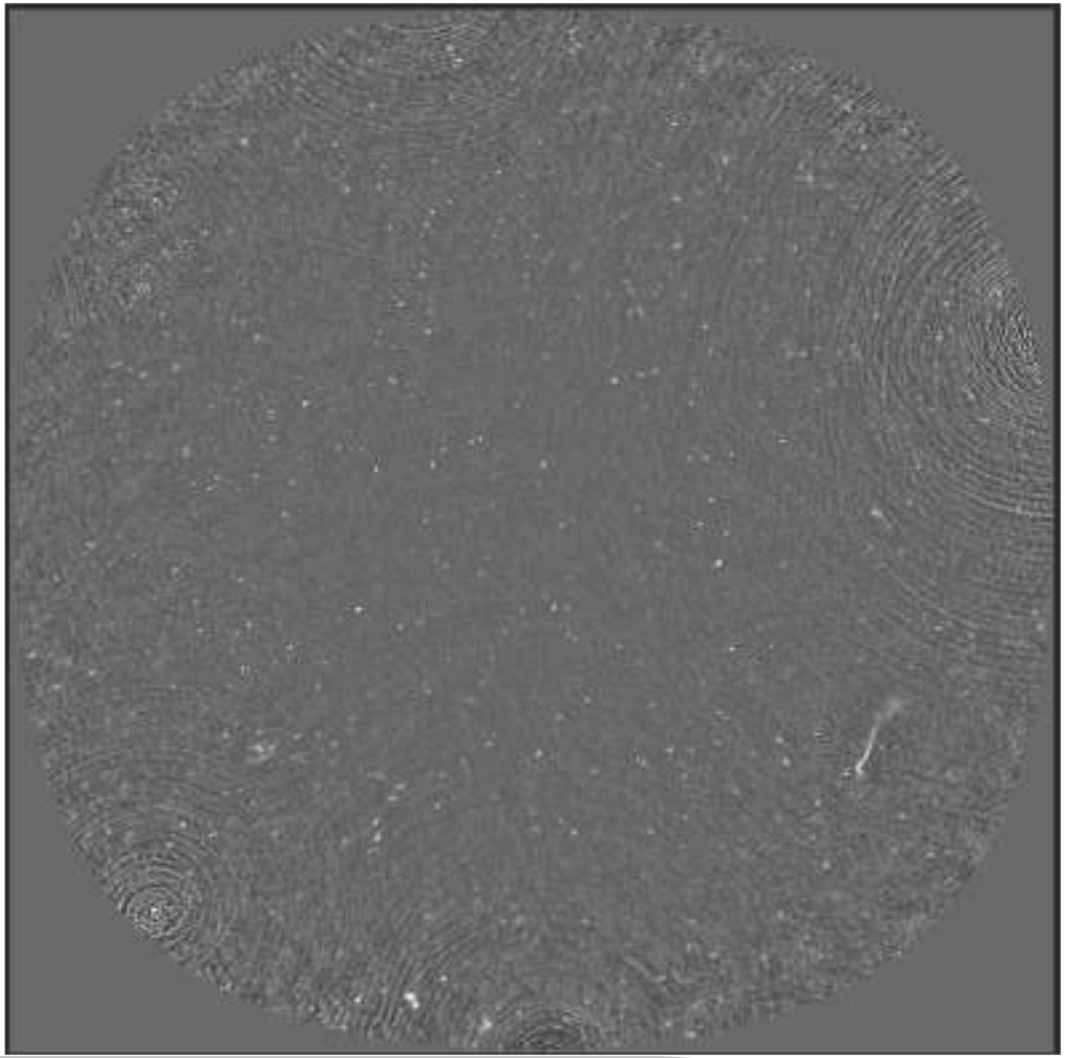
- Good calibration is crucial!
  - Need a good model

- In this case, residual delay offsets on the long baselines meant that the bright source could not be effectively removed

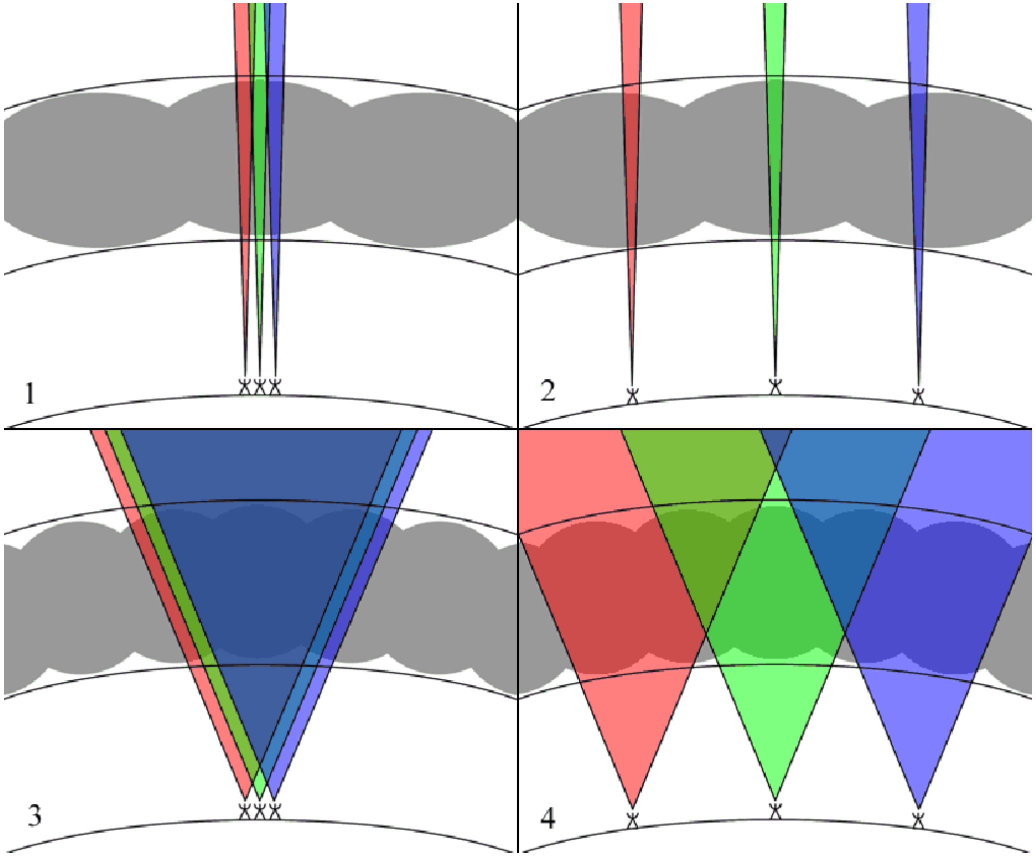


Bright sources in the field

- Removing artefacts often reveals the next problem to deal with…



Direction dependent effects



Intema et al., 2009

- Each antenna looks through different patch of ionosphere
- Phases change across the antenna aperture
- Need to calibrate different directions separately

  -> direction-dependent calibration

Direction dependent effects

After direction-independent calibration and selfcal:

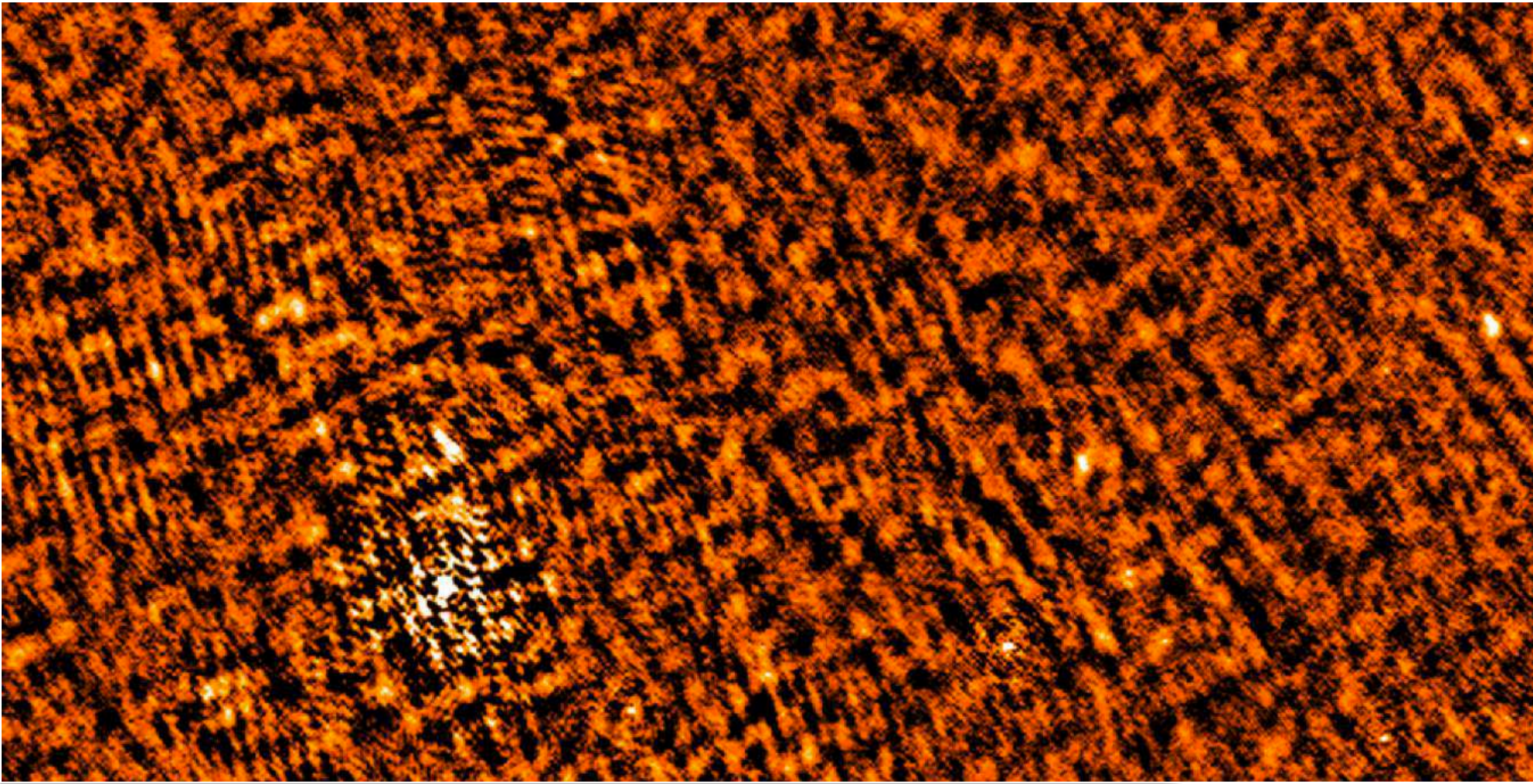


Image credit: R. van Weeren

Direction dependent effects

After direction-dependent calibration:

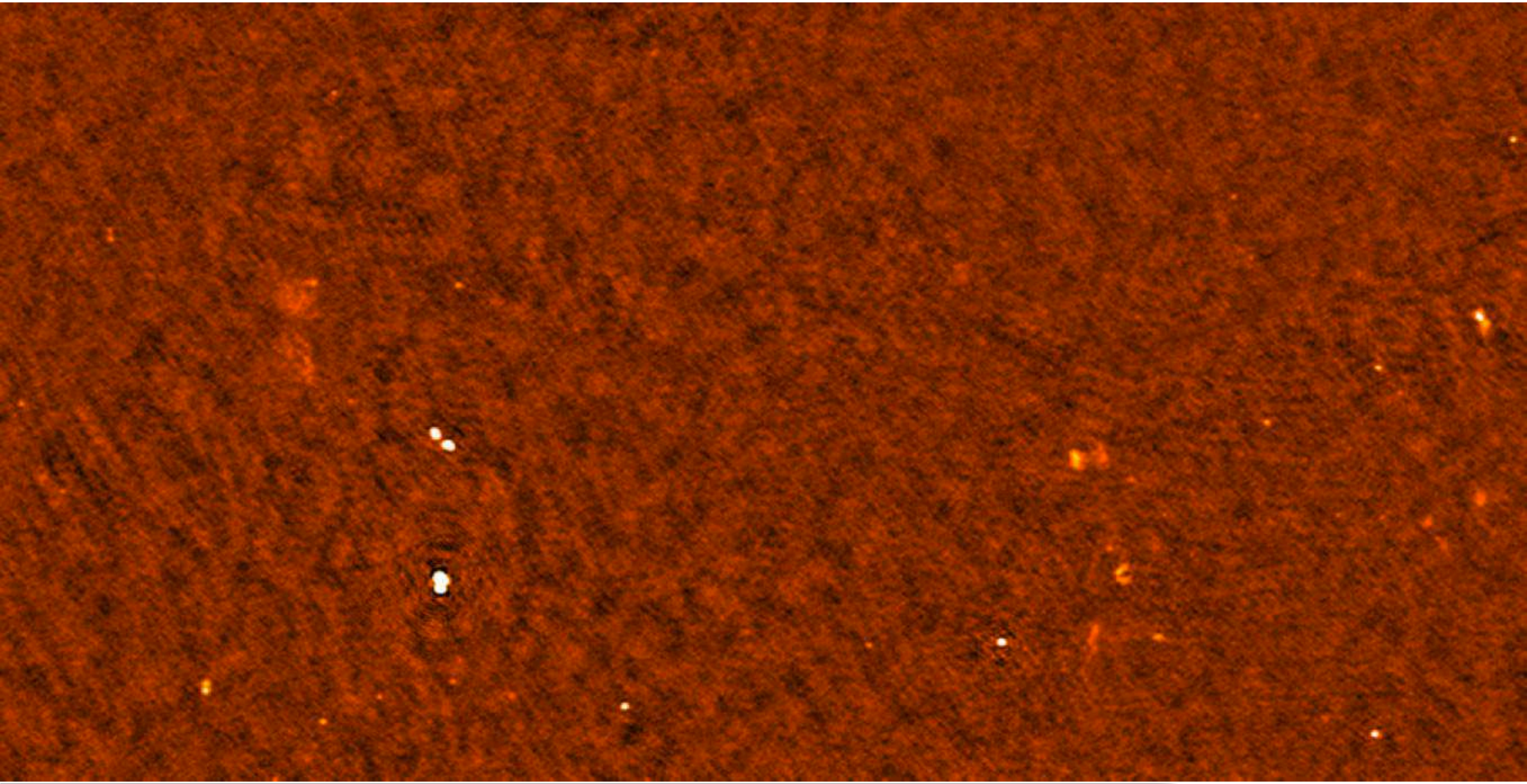
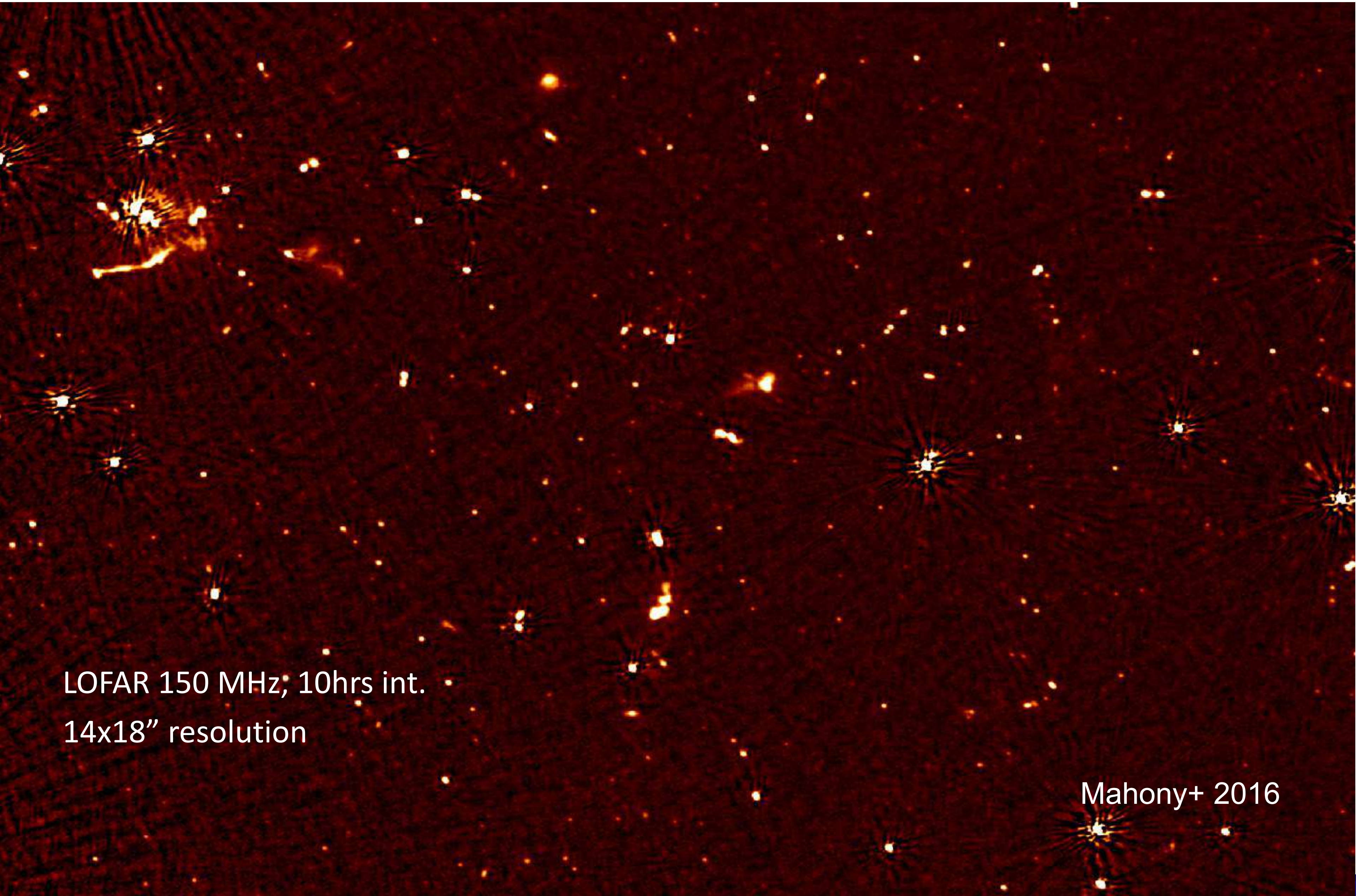
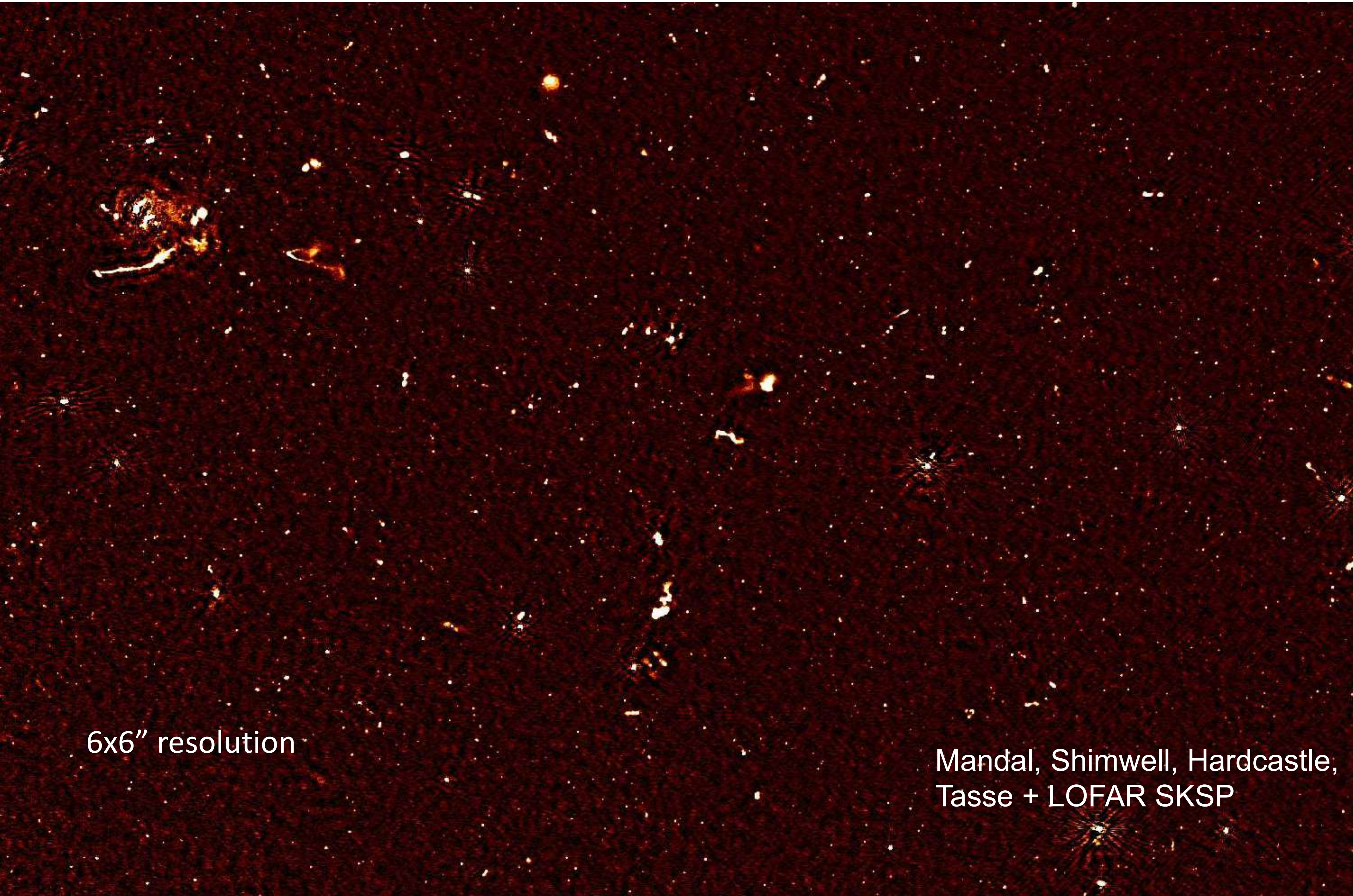


Image credit: R. van Weeren

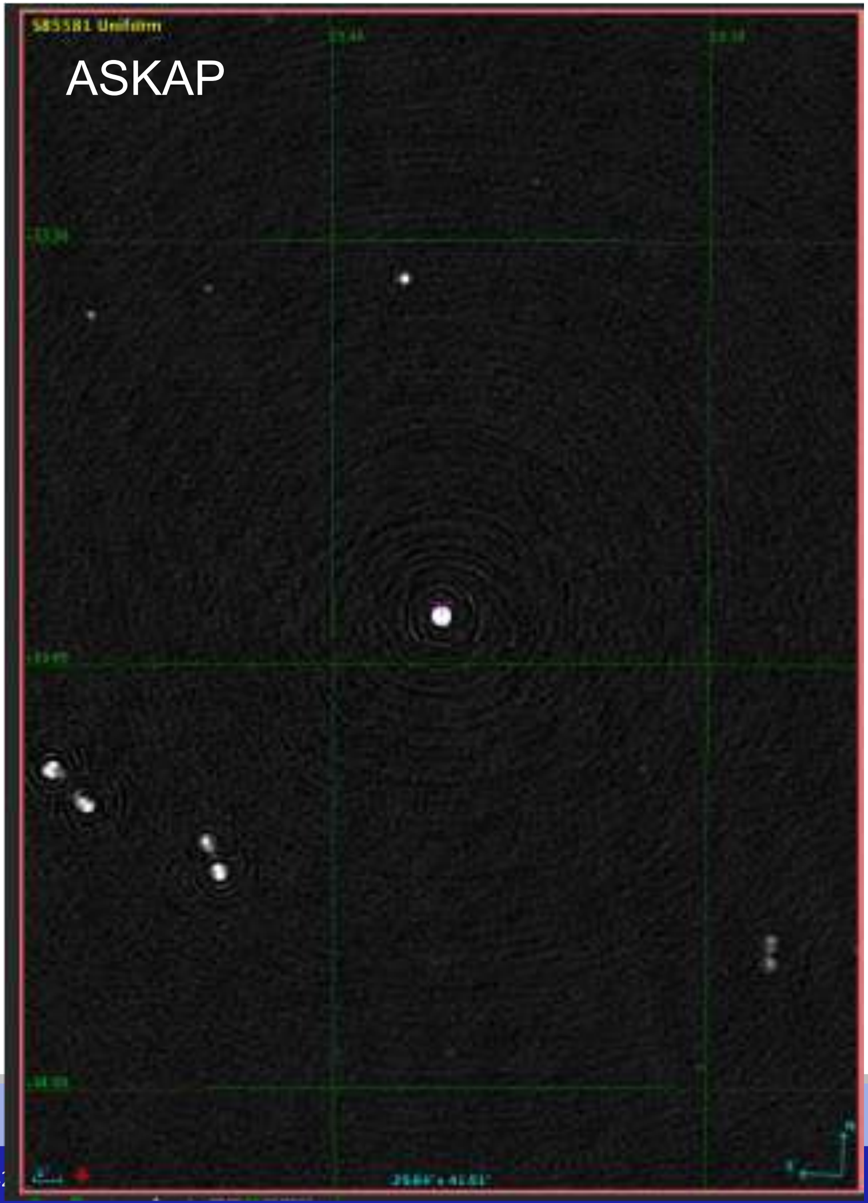
Without direction-dependent calibration



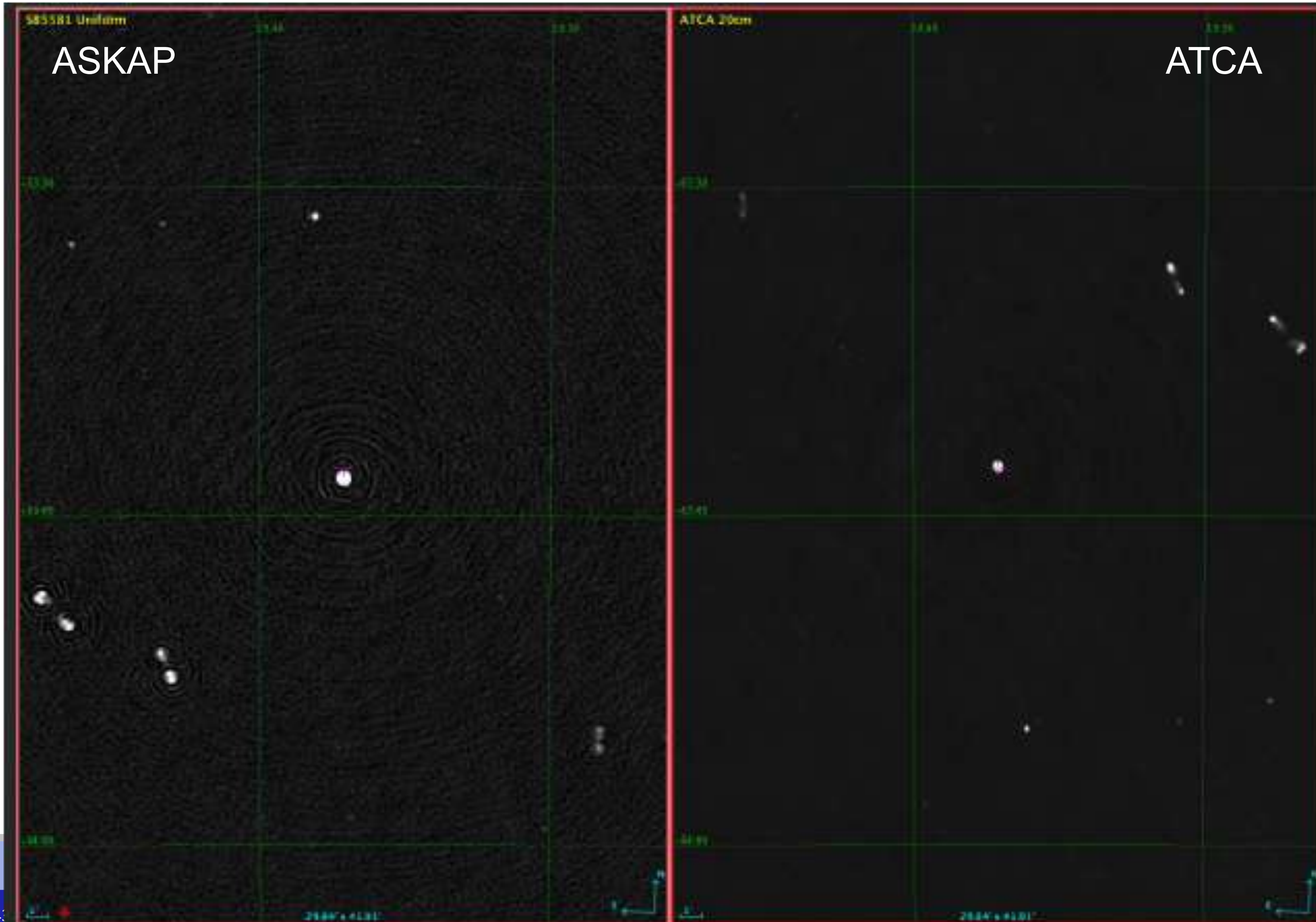
With direction-dependent calibration



Can you do your science with it?

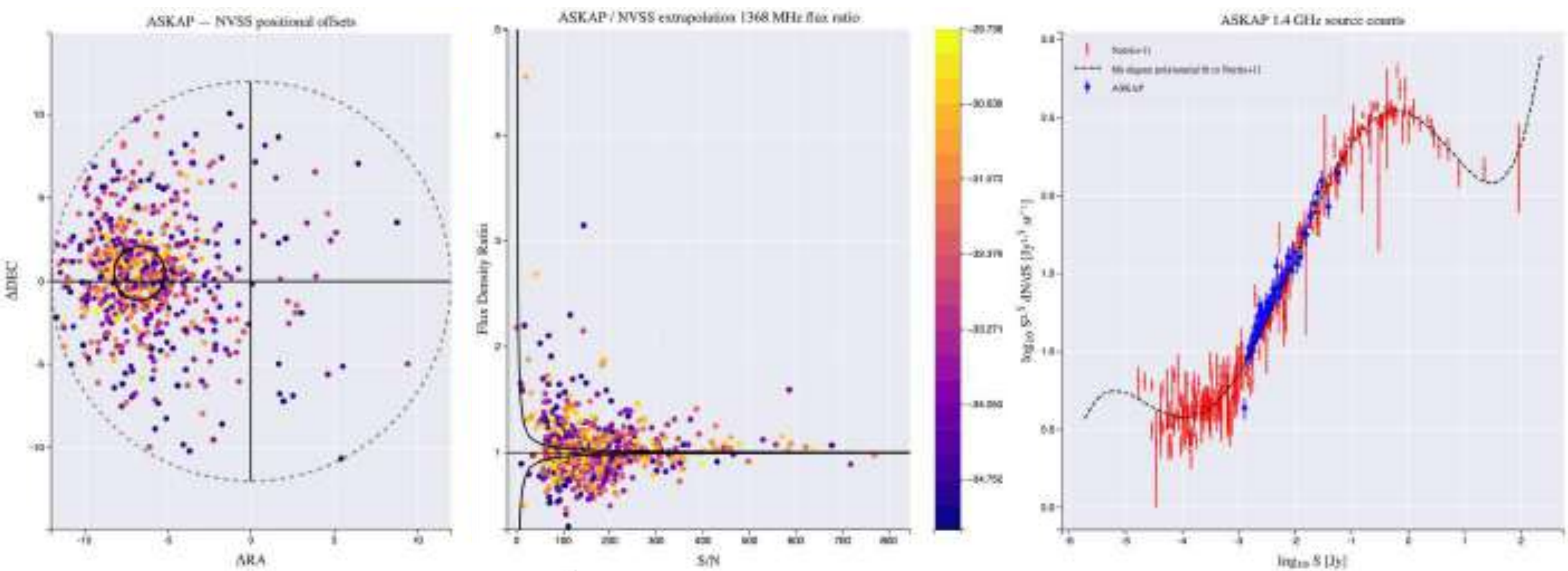


Can you do your science with it?



Can you do your science with it?

- You can make the best looking image in the world, but is it useful?
  - Is the flux scale correct?
  - Are your sources at the right positions?
  - Do you recover reliable spectral indices?



ASKAP validation tool

Summary – some tips on how to spot errors

- Look at your data
  - In u,v, plane:
    – Don't just plot amp vs. time, look at other properties as well

    i.e. real vs. image, amp vs. uvdist, time vs. phase, freq vs. amp

  - In image plane:
    – Look for patterns in any artefacts (know your Fourier transforms!)

    i.e. odd vs. even, ringing, image larger f.o.v

    – Check off source noise – is it what you expected?

  - Try taking your image/model and FT back to u,v, plane – is it what you expected?
- Flag bad data – no data is better than bad data

Summary – some tips on how to spot errors

- Check data after each processing step
  - Much easier to diagnose errors one at a time then if there are multiple errors propagated through the data reduction process
- What is your definition of the 'perfect' image?
  - What is your science goal?
  - Do you need high-dynamic range?
  - Are you focused on a particular target?
- Really look at your data!