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Wide-band Imaging with e-MERLIN

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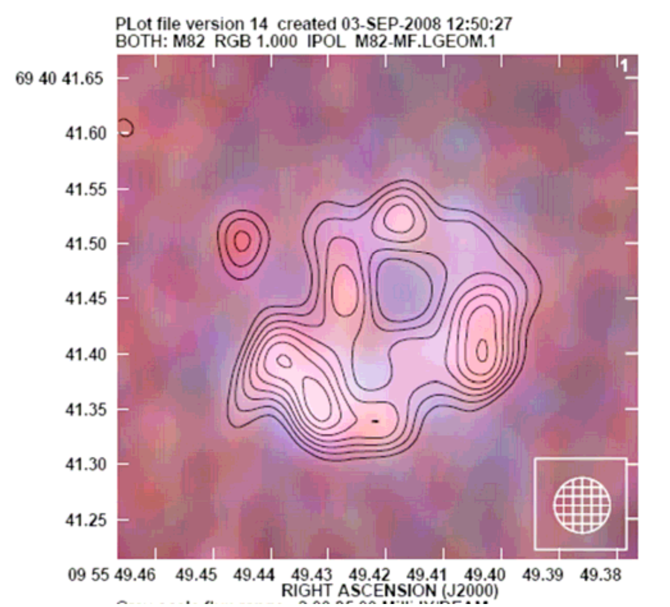
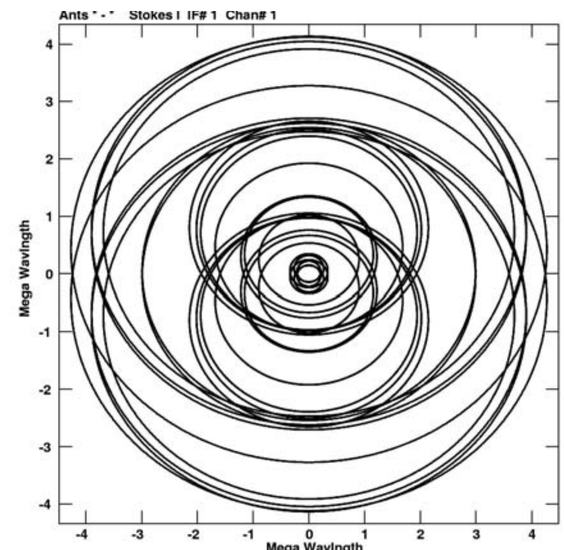
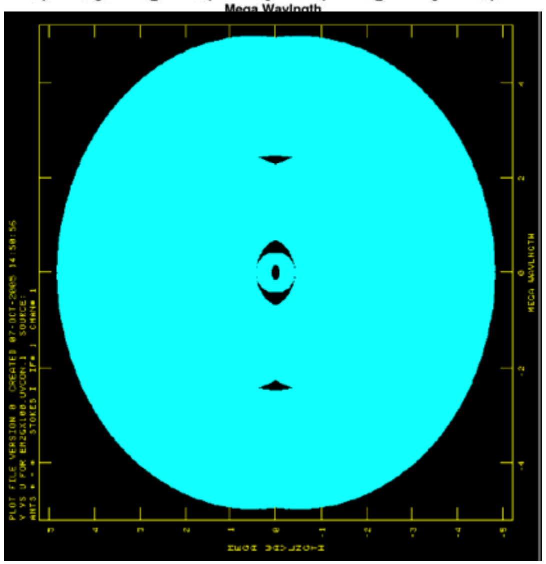
- Motivation
- e-MERLIN
- Background
- Simulations
- M82 data
- Parseltongue implementation
- e-MERLIN data processing



Motivation

- Golden Age of Radio Astronomy: new technology (DSP, TB disks, optical fibres) → much greater bandwidth → increased sensitivity (continuum)
- Typically few% → 50% bandwidth
- Fills aperture plane for sparse arrays like MERLIN, EVN
  - Reduce sidelobes to 10^{-3} to 10^{-4}
- Provides free spectra & RMs
- But introduces new problems for imaging.
- Solutions (and some implementations) exist, but rarely used…
  - Artifacts at $\Delta\alpha/200$
- Will be required for e-MERLIN, EVLA (wide bandwidths, high dynamic range)





e-MERLIN

- Major upgrade to MERLIN
  - 7 antennas; 220km max baseline
  - 50 mas resolution at 5 GHz
- 4 GHz bandwidth
  (2x2GHz or 2+2 GHz)
- New optical fibre network installed
- New/upgraded receivers
  - 1.3-1.8 GHz, 4-8 GHz, 21-24 GHz
- New IF, samplers,…
- New correlator (DRAO)
  - Starting to commission now

e-MERLIN Capabilities

- uJy sensitivity in 12 hrs
- 10 – 150 mas resolution
- L (1.3-1.8 GHz), C (4-8 GHz) K (21-24 GHz)

  Tsys 25-40K

  Rapid change (1 min) between bands
- 16 sub-bands
  - 0.25 MHz channels at all Stokes, full bandwidth (128 MHz)
  - <kHz resolution; mix bandwidths
- Combination with EVN
  - EXPReS

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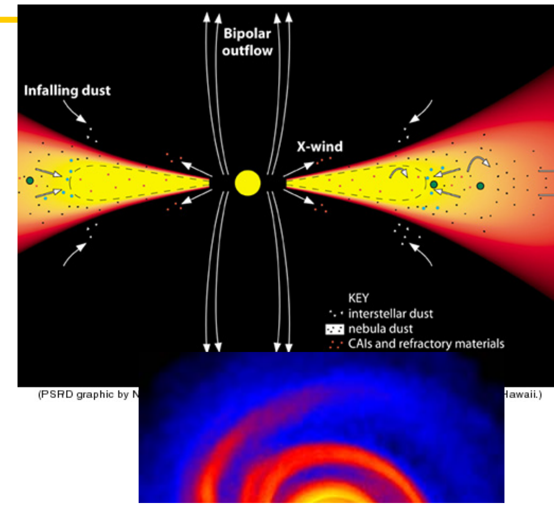
e-MERLIN Science

Open Time + ‘Legacy Programme’

- Stellar magnetic fields
- Massive star formation
- Stellar mass loss
- Pulsar astrometry
- Planet-forming disks
- YSO jets
- XRBs; transients
- Jet physics
- Galaxy substructure, environments
- Starformation & AGN in nearby galaxies
- Galaxy evolution

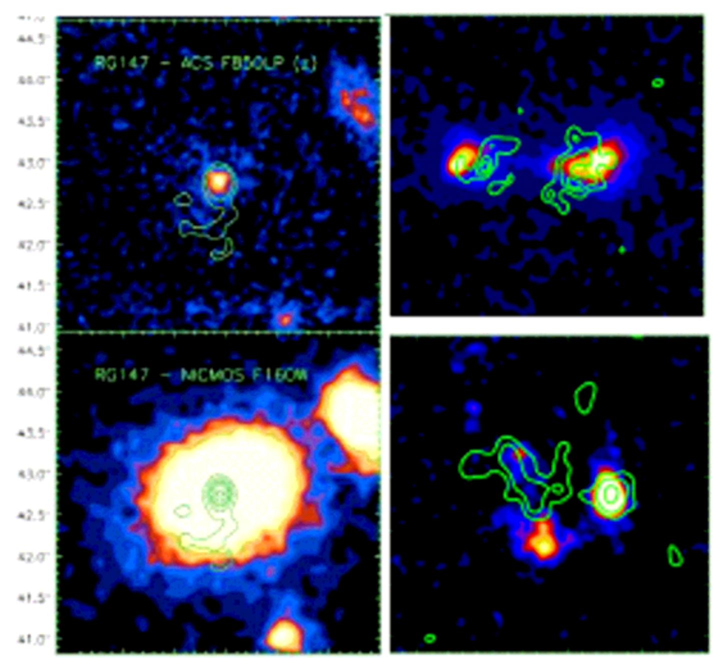


Proposals being evaluated now

3x oversubscribed; >300 scientists

Programme put to Steering Committee before end of year

Projects should remain open



Wide-band imaging
Multi-frequency Synthesis

For no spectral variation

Dirty map: $I'(x,y) = I(x,y) * B_0(x,y)$

For i different frequencies & spectral variation (α) across map

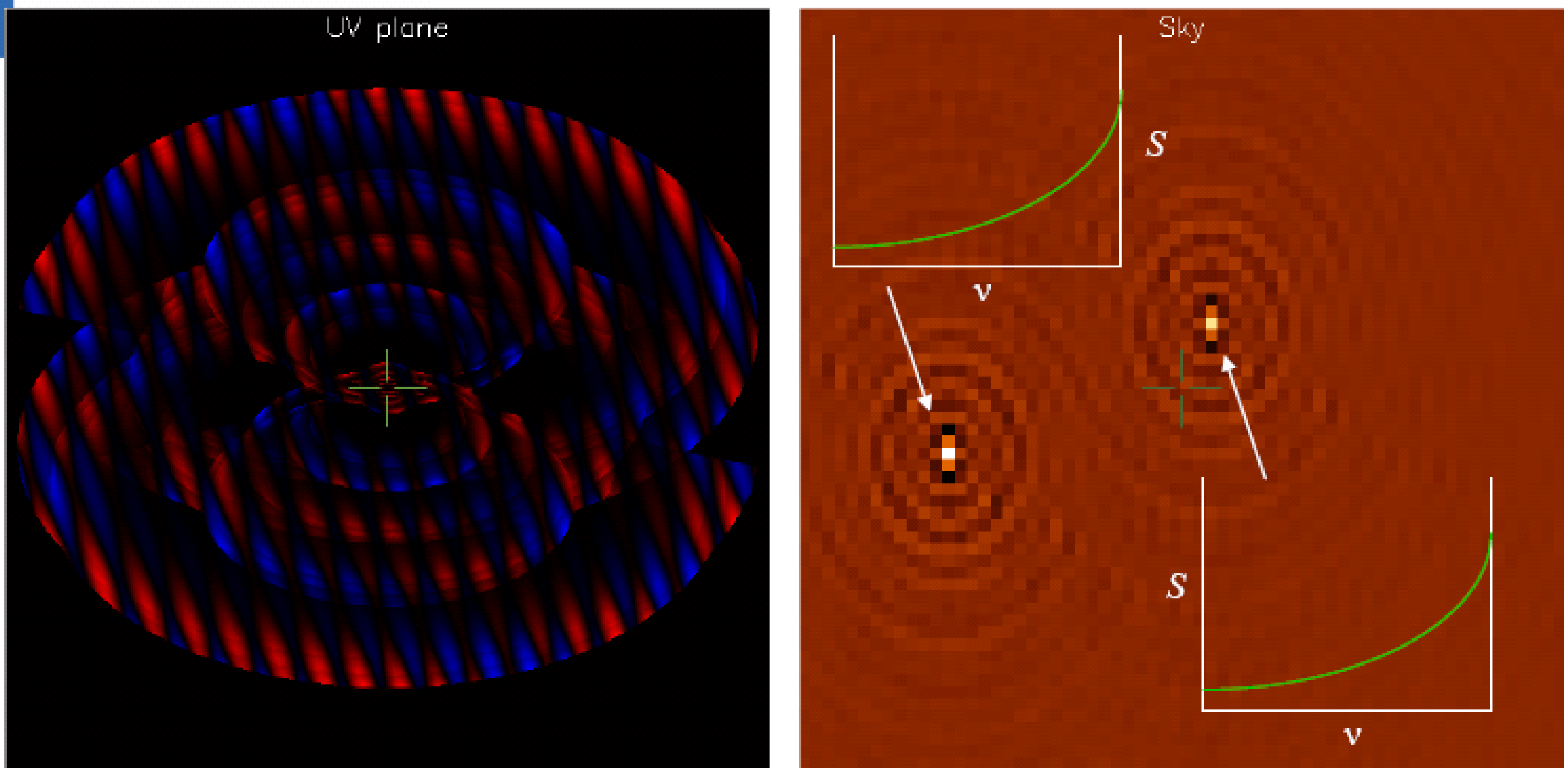
Dirty map: $I' = I * B_0 + I\alpha * B_1 + \ldots$

$B_0 \Leftrightarrow S(u,v)$

$B_1 \Leftrightarrow \sum(\Delta\nu_i/\nu_0) S_i(u,v)$

Wide-band example

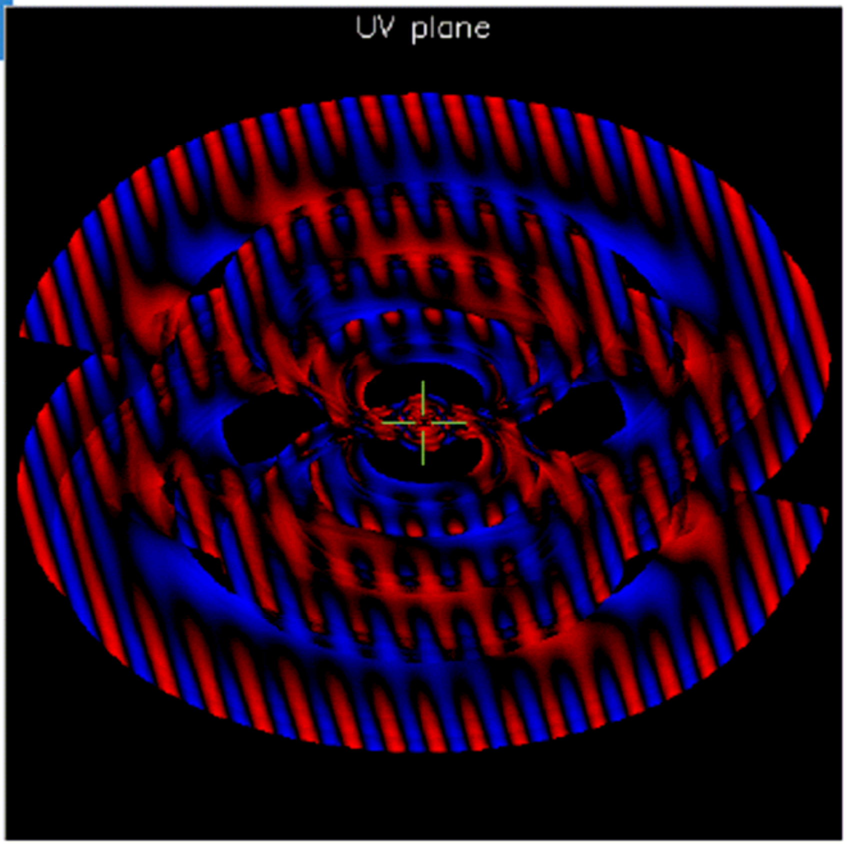
Where both point sources have identical spectra:

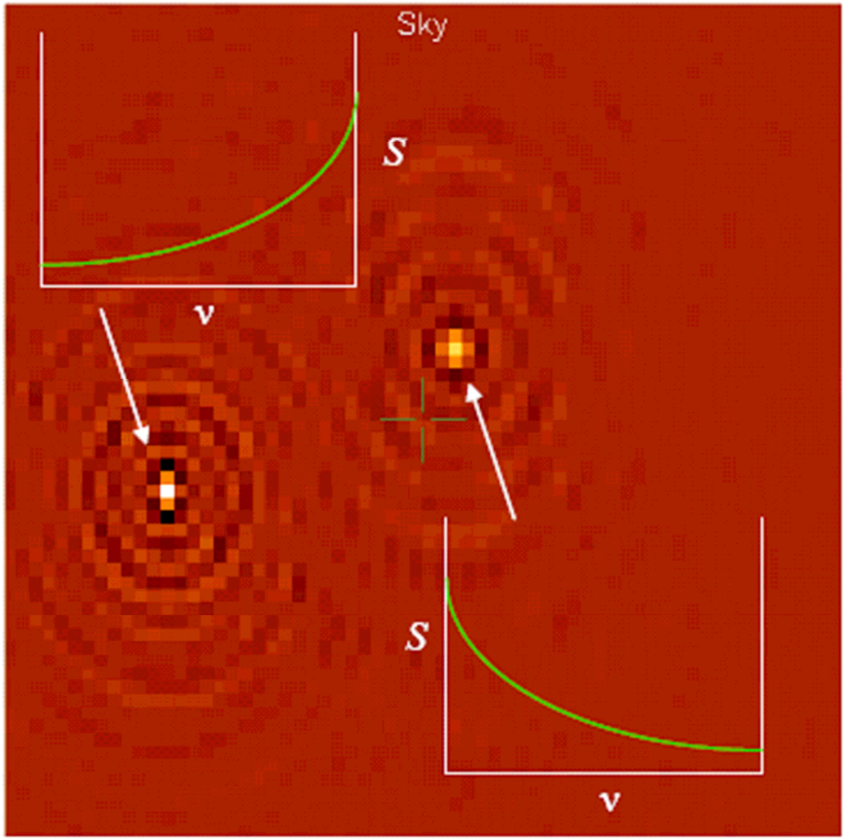


Spectral indices both +10.0 (!!!)

Wide-band example

More realistic: different spectra:





This will **not** clean away.

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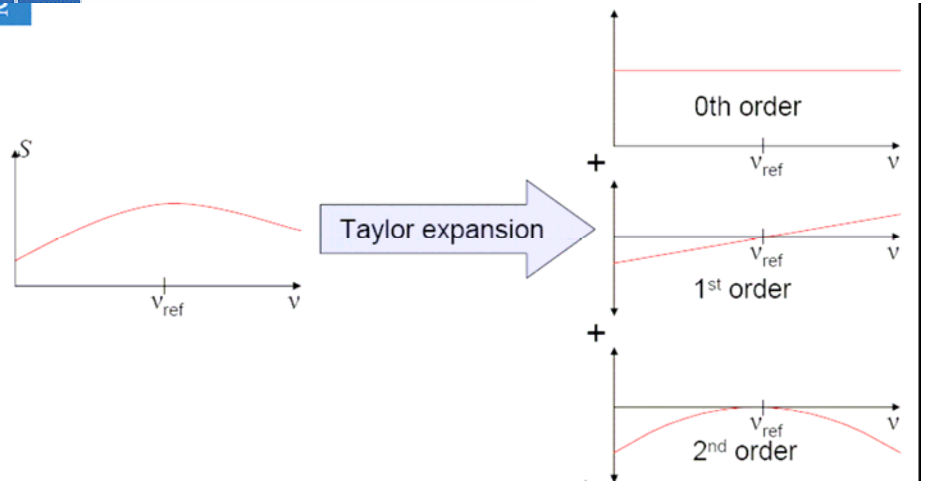
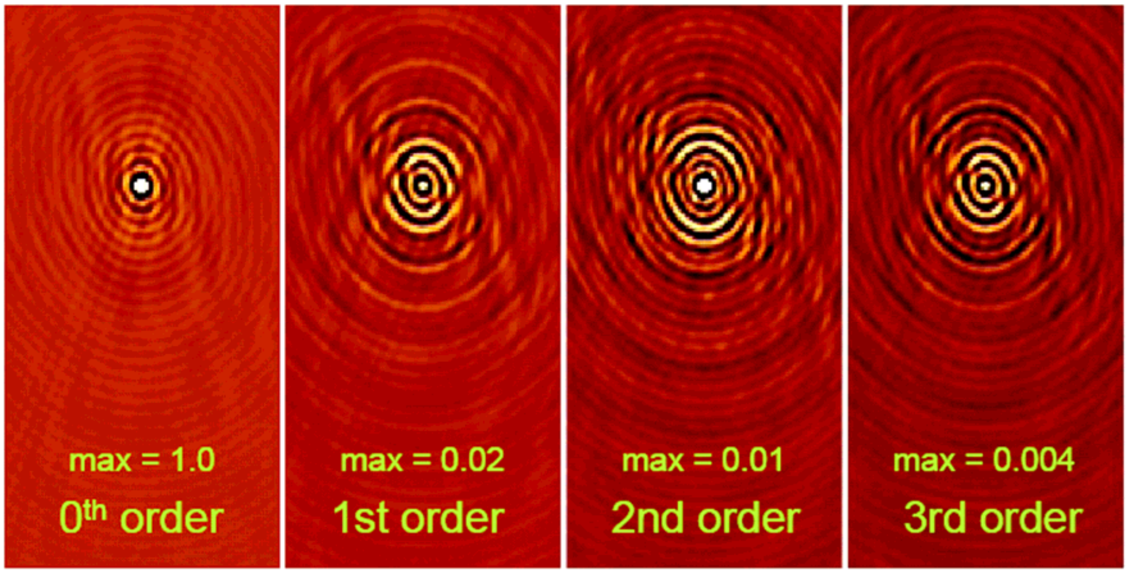
‘Spectral beams’





Sault-Wieringa algorithm

- Form dirty image $I(x,y)$ and a beam $B_k(x,y)$ for each Taylor order k

- Perform correlations for k, l = 1 to N:
  - $A_{kl} = B_k * B_l$
  - $R_k = I * B_k$

Sault R J & Wieringa M H: A&A Suppl. Ser. 108, 585 (1994)

S-W implementation

- Calculate matrix elements $M_{kl} = A_{kl}(0,0)$ and invert M
- For each clean component (ie ‘point source’ j):
- Evaluate ‘equation 22’:
  - $E22(x,y) = \Sigma_k \Sigma_l M^{-1}_{kl} R_k R_l$
- Find (x_{max}, y_{max}), location of maximum in E22
- Coeffs $a_{j,k,l}$ given by matrix expression (equ 14)
  - $\mathbf{a}_j = \mathbf{M}^{-1}\mathbf{R}(x_{max}, y_{max})$
- Subtract scaled and shifted A_{kl} from the beam-correlated residuals R_k:
  - $R_k = R_k - \lambda\Sigma_l\, a_{j,k,l}\, A_{kl}(x-x_{max}, y-y_{max})$
- Implemented to first order in Miriad (ATNF)

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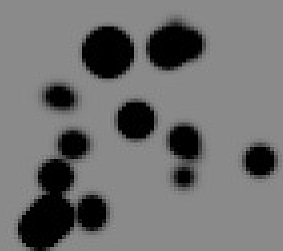
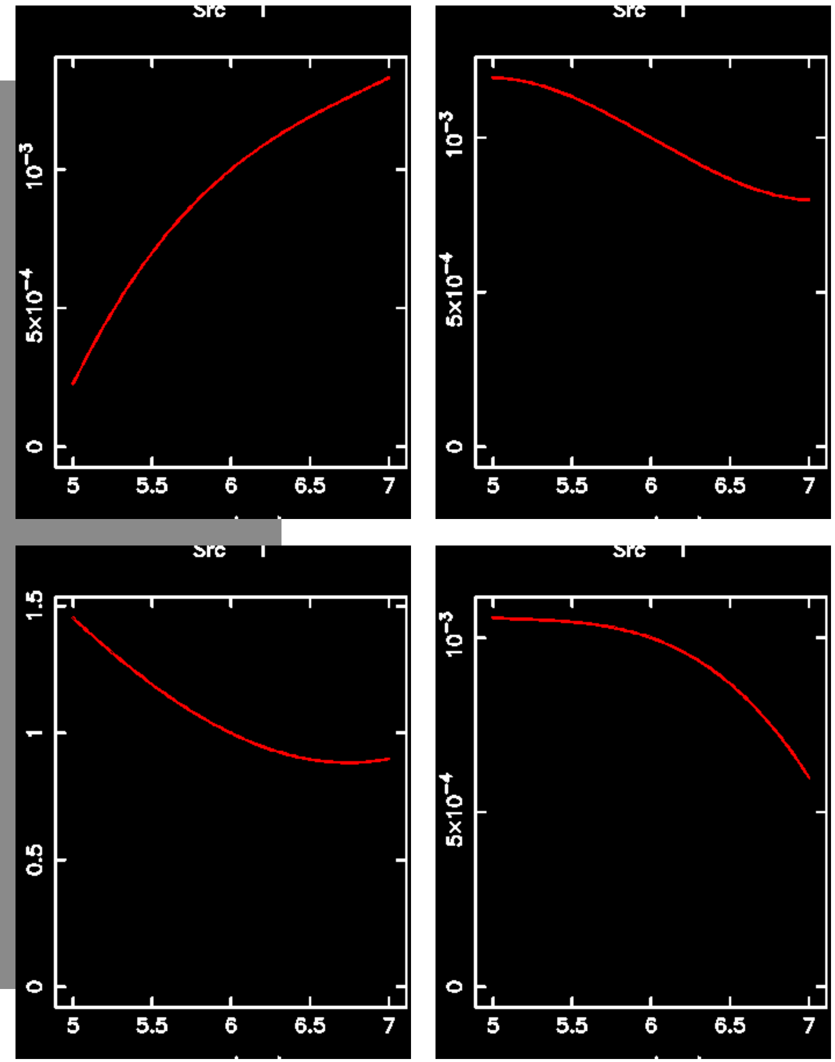
Tested simulation

19 point sources from 0.001 to 1 Jy



Spectra: cubics, with random coefficients.

eg

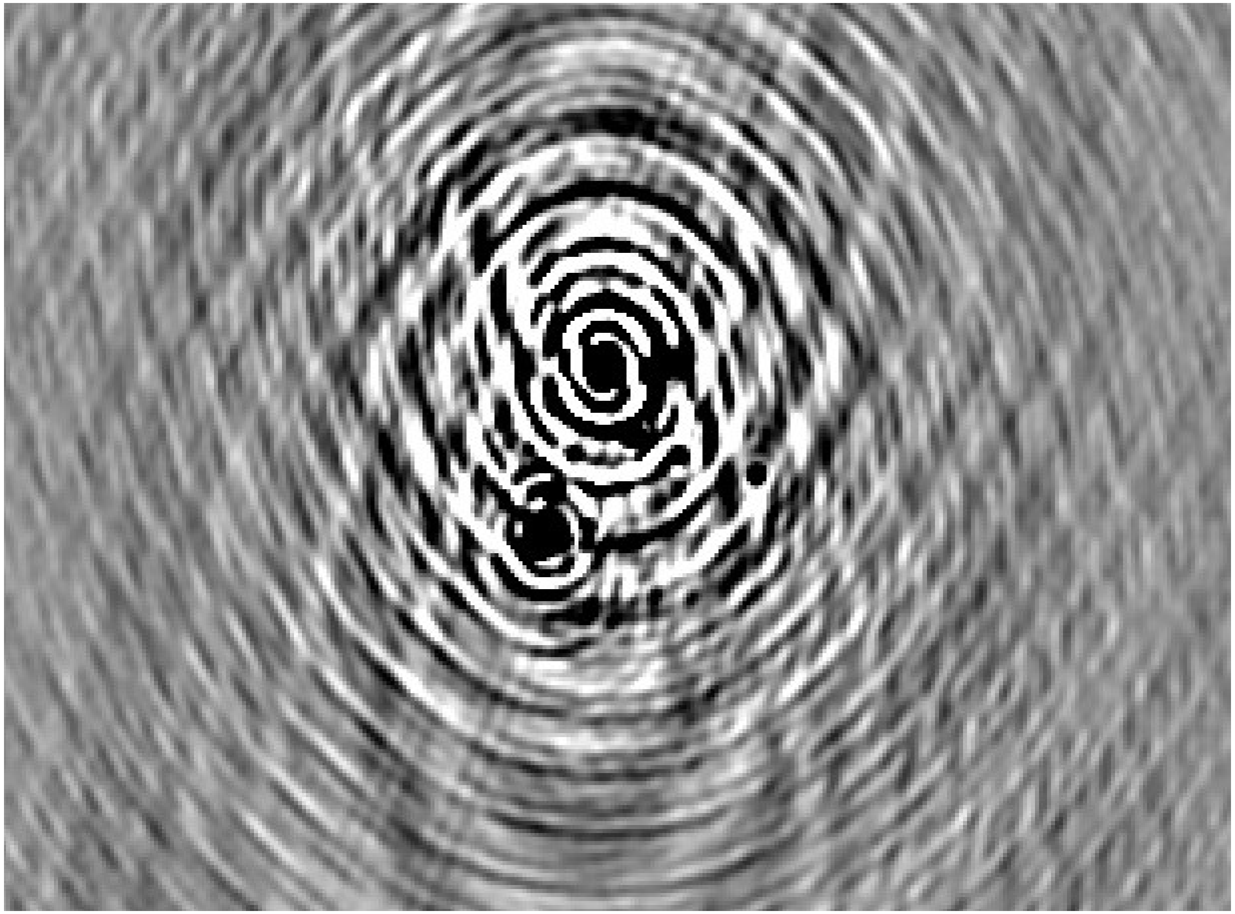


f (GHz)

S-W clean to various orders

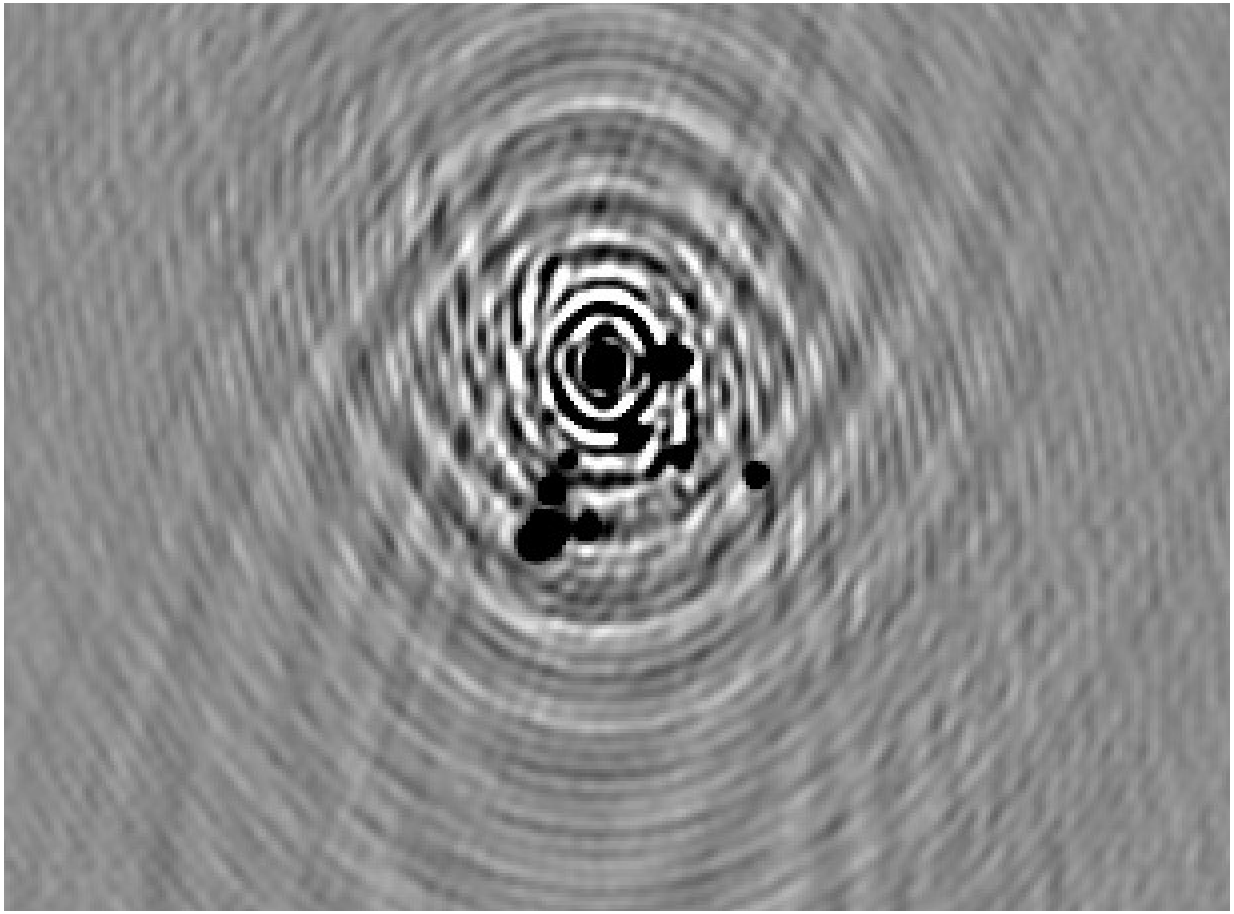
(All 1000 cycles with gain = 0.1)

0th order (equivalent to Högbom clean)



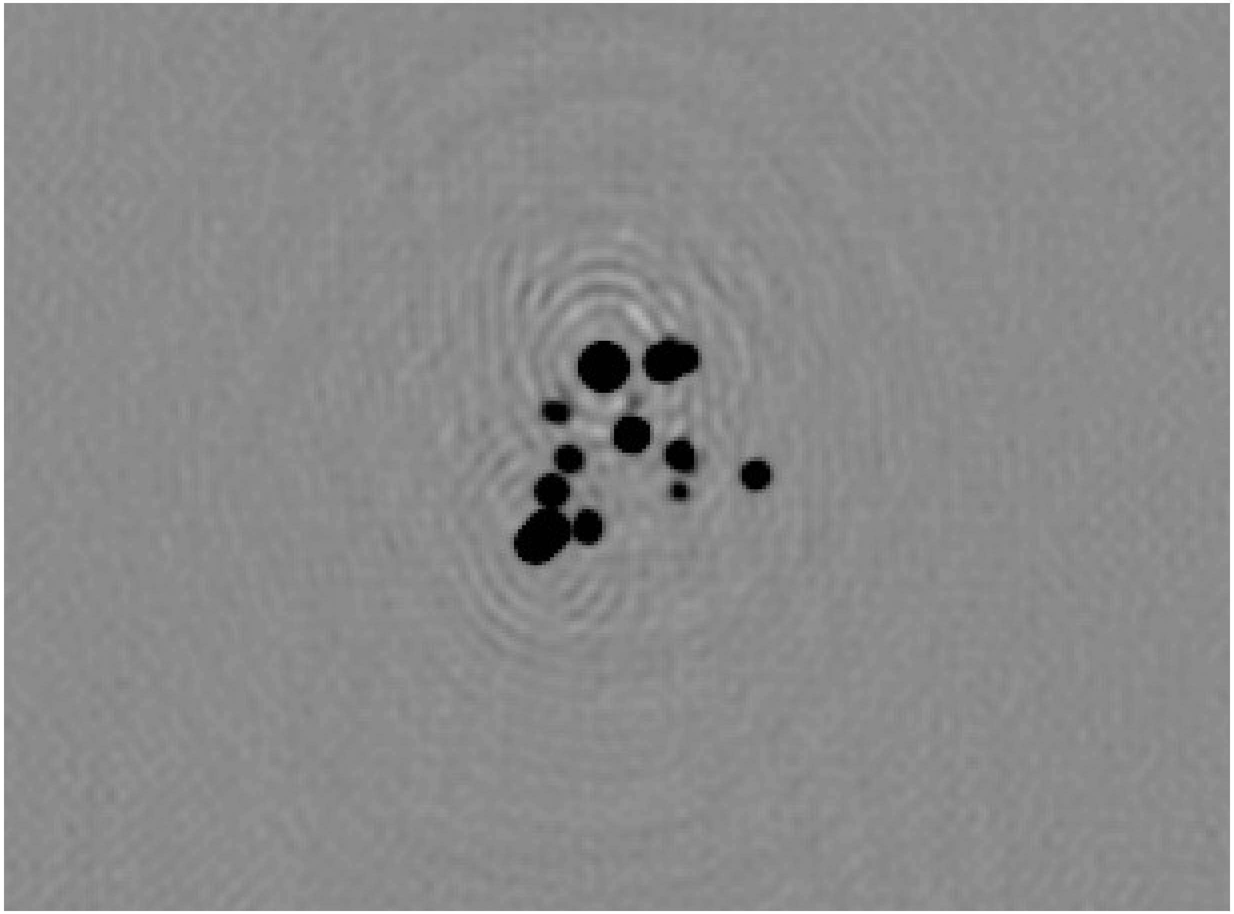
S-W clean to various orders

1st order



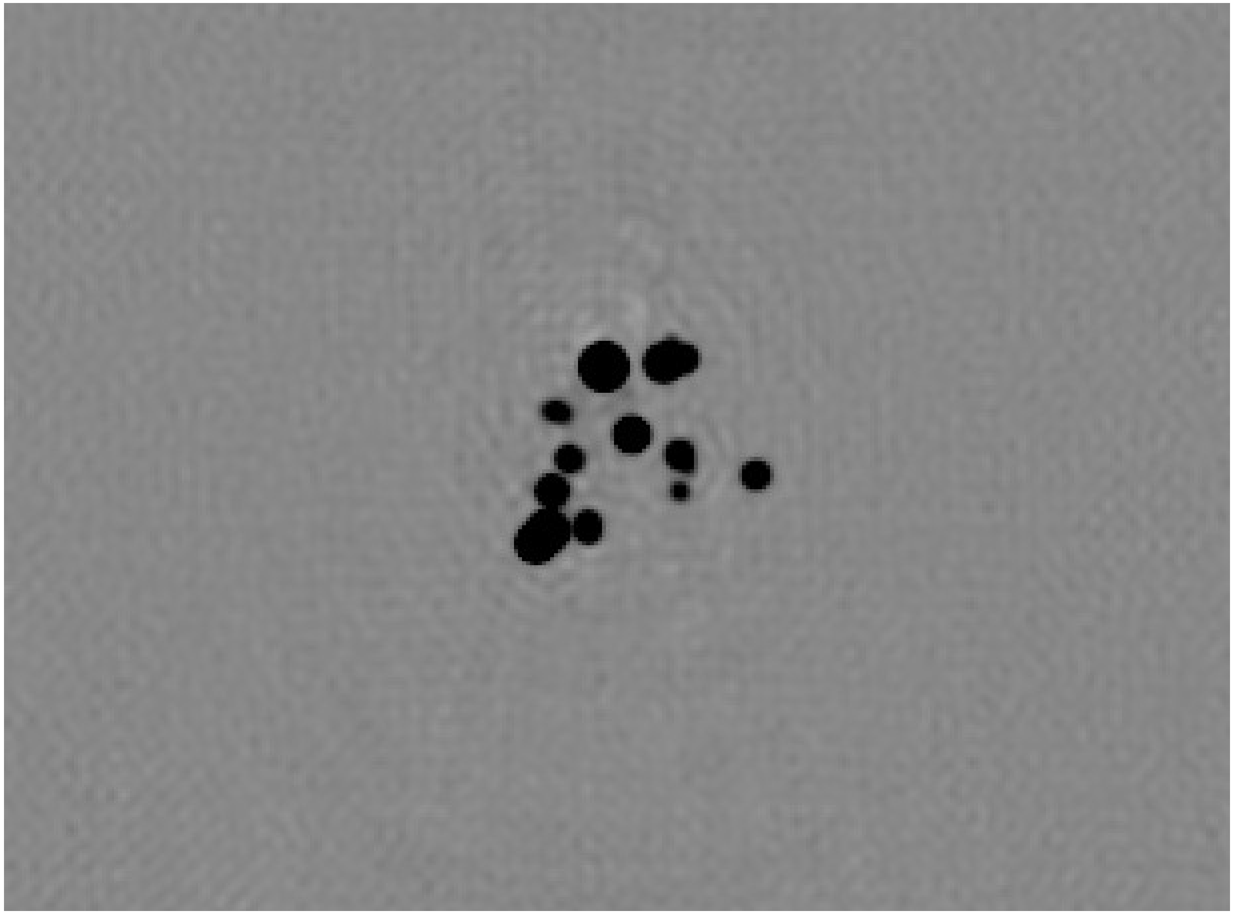
S-W clean to various orders

2nd order



S-W clean to various orders

3rd order



Testing with real data

- Eleven separate observations of nearby starburst M82.
- Range from 4.5 – 6.7 GHz, each 16 MHz bandwidth.
- Provides ideal test for the algorithm - more extended emission with changes in spectral index.
- Also show effects of incomplete aperture.

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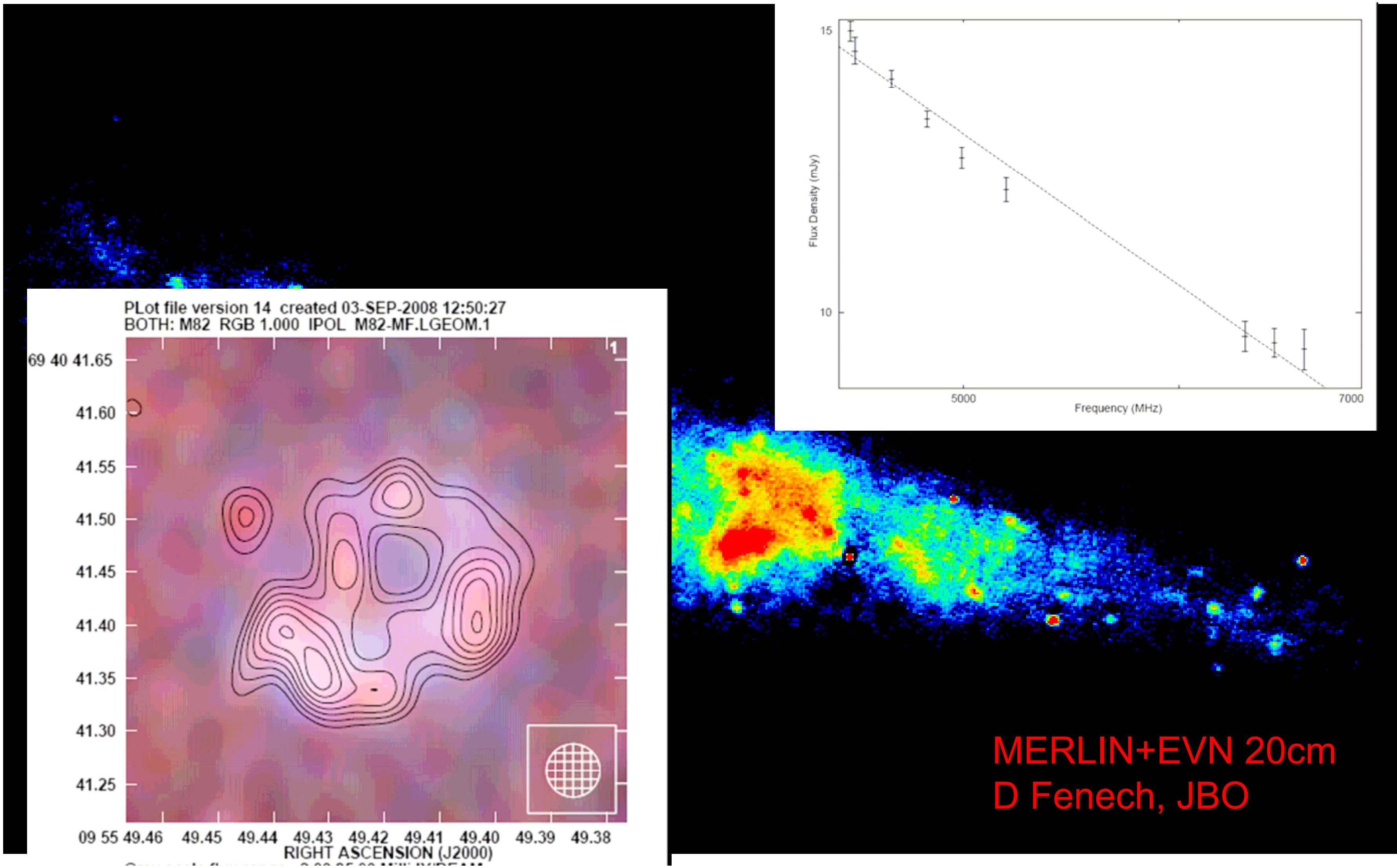
Testing with real data



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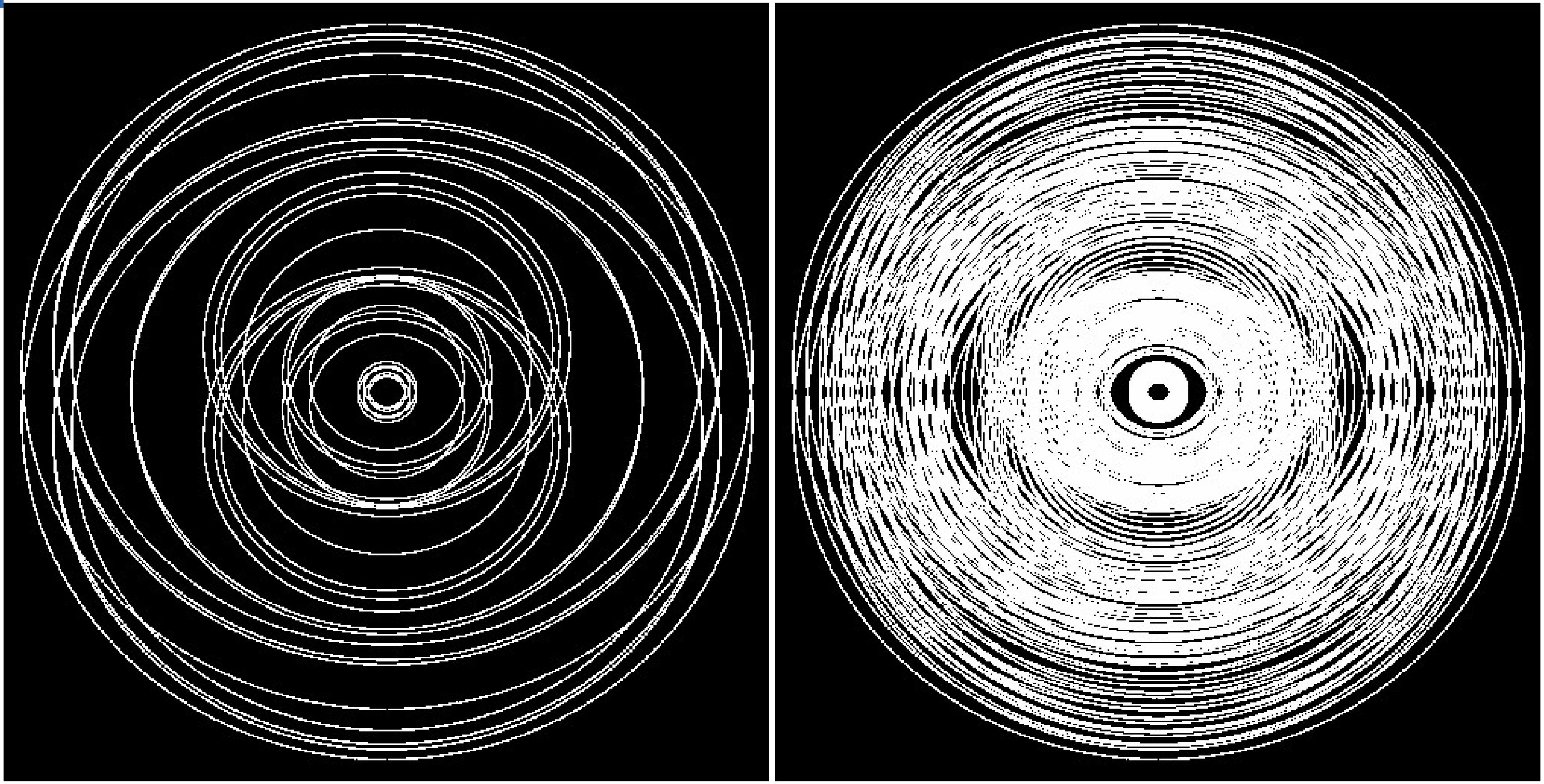
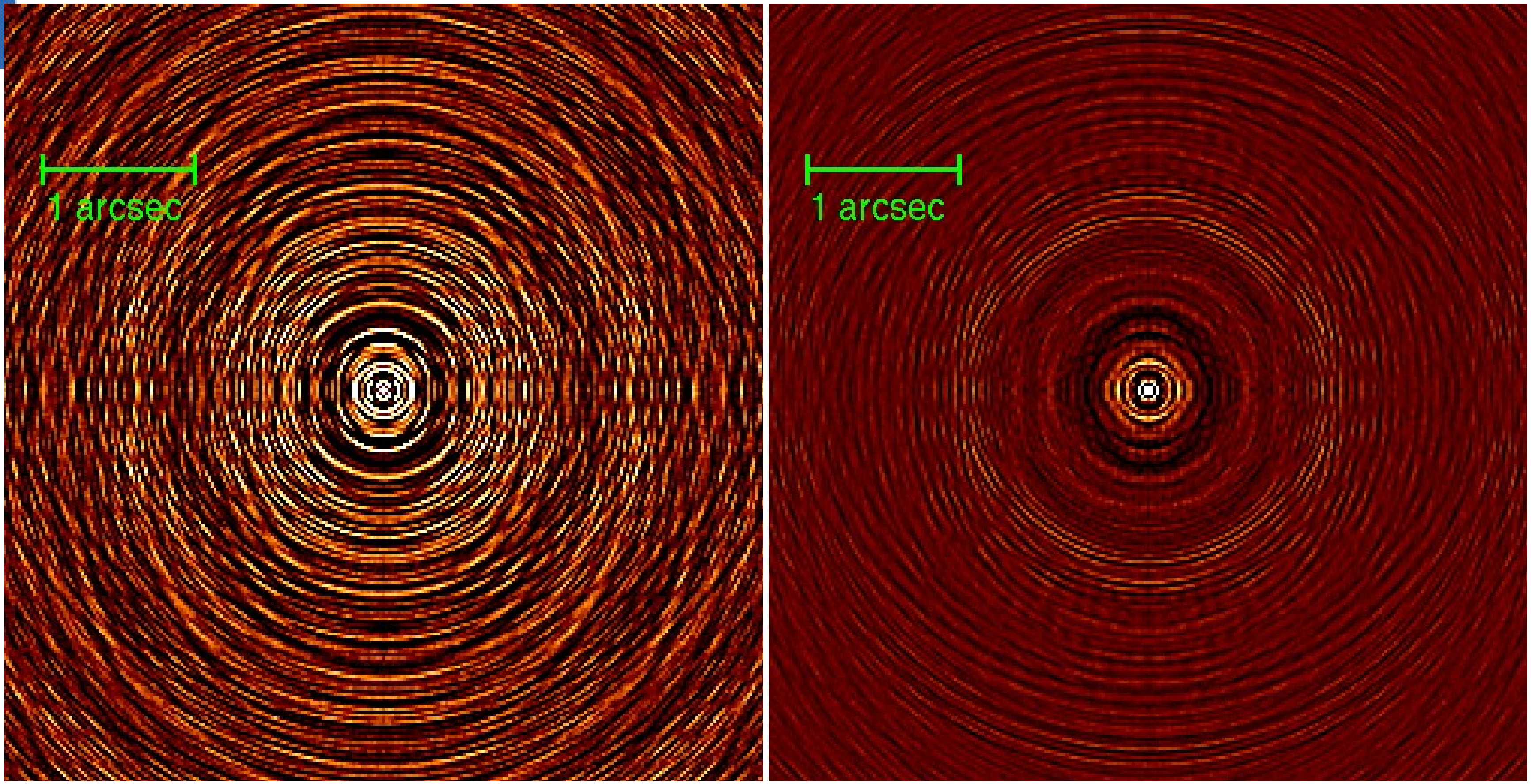
Testing with real data

Single band at 6.7 GHz

Combination bands between 4.5 and 6.7 GHz



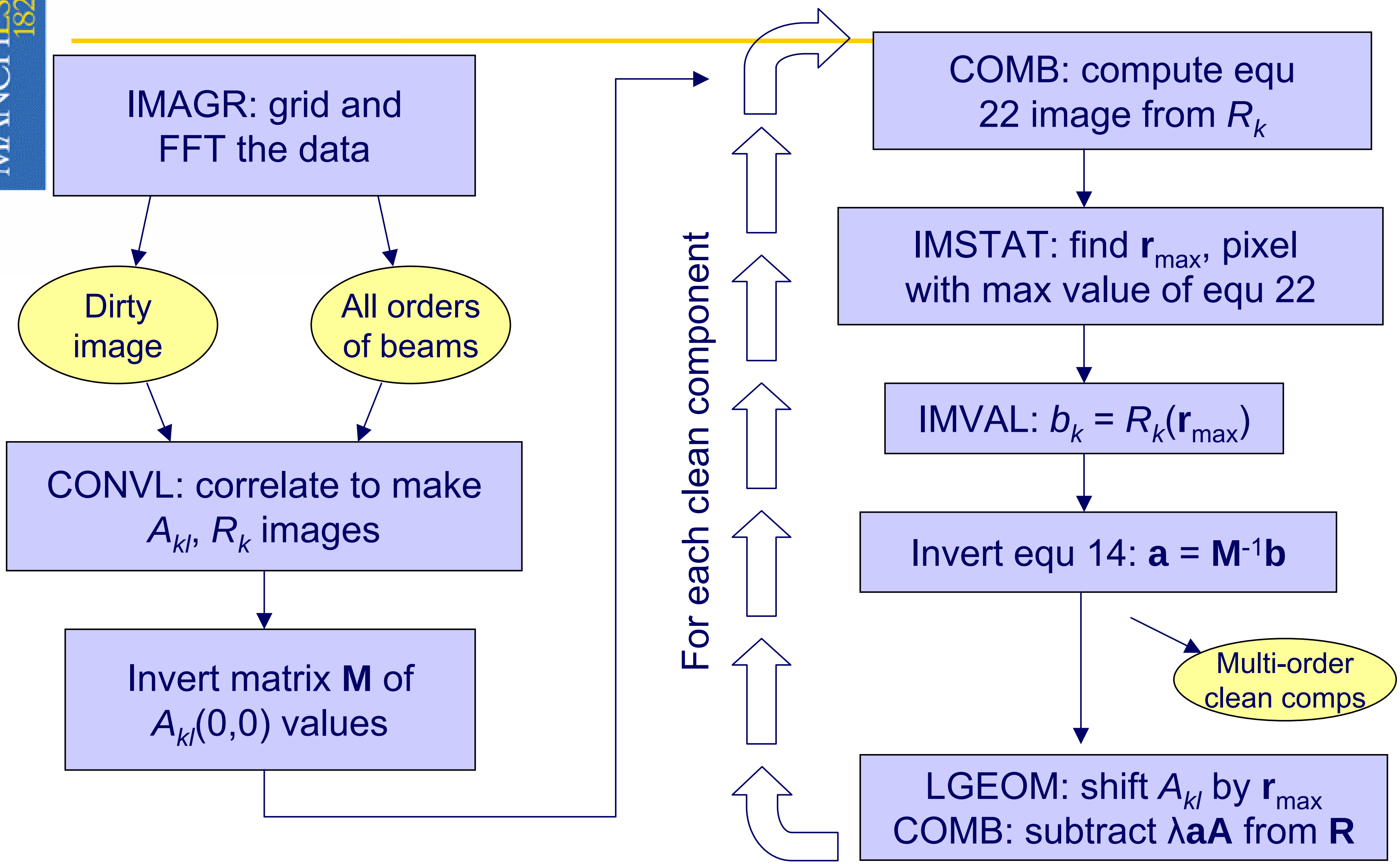
Resulting beams



Testing with real data

- Each observation calibrated individually and then combined.
- AIPS does not know how to do this.
- Use a combination of tasks including DBCON and written/amended tasks to accomplish producing the images and beams required for testing.
- May be used (initially) to split and recombine e-MERLIN data to carry out calibration on sections of the data!

Parseltongue



Parseltongue - SW

- Added a ‘major cycle’ to the code – so will be able to incorporate wide-field faceted imaging.
- Many generic python tools written for image analysis, manipulation
  - Faster, but not as fast as coding at task level
- Need to tidy-up outputs into user-friendly images/information

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e-MERLIN Data Processing

- Data presented as up to 16 sub-bands
  - Similar to largest present-day VLBI data
- Automated flagging
- A priori calibration using Tsys data
- Amplitude calibration – source models <u>necessary!</u>
- Bandpass calibration per sub-band
- Phase calibration (phase cal. source/FRING)
  - Per sub-band
- Initial sub-band imaging
- Removal of brighter confusing sources
  - Peeling, per sub-band
- Initial full-band image
  - Map & stack
- Search for fainter confusing sources
  - Subtraction
- Multi-frequency imaging