Introduction to Imaging

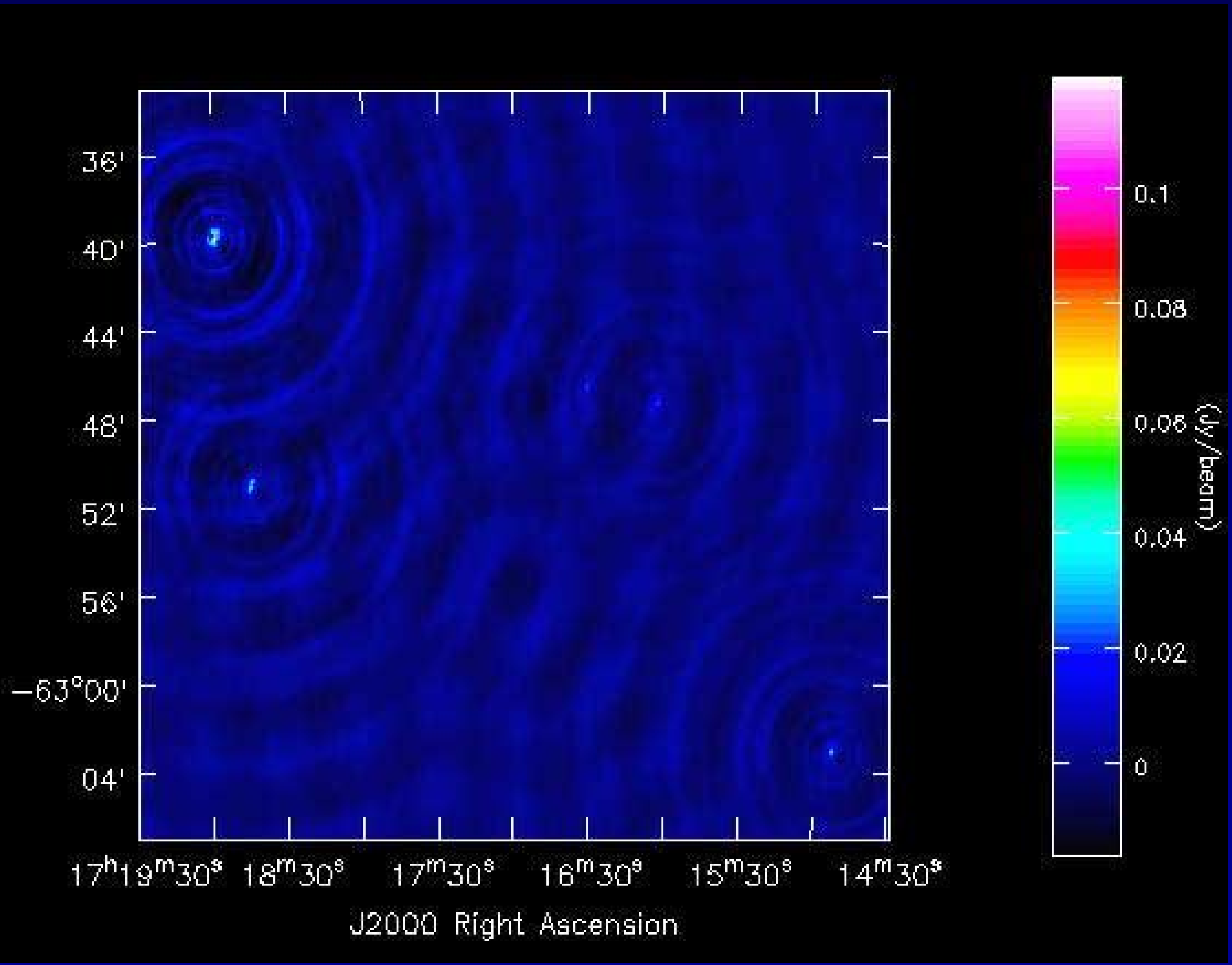
Mark Wieringa - ATNF

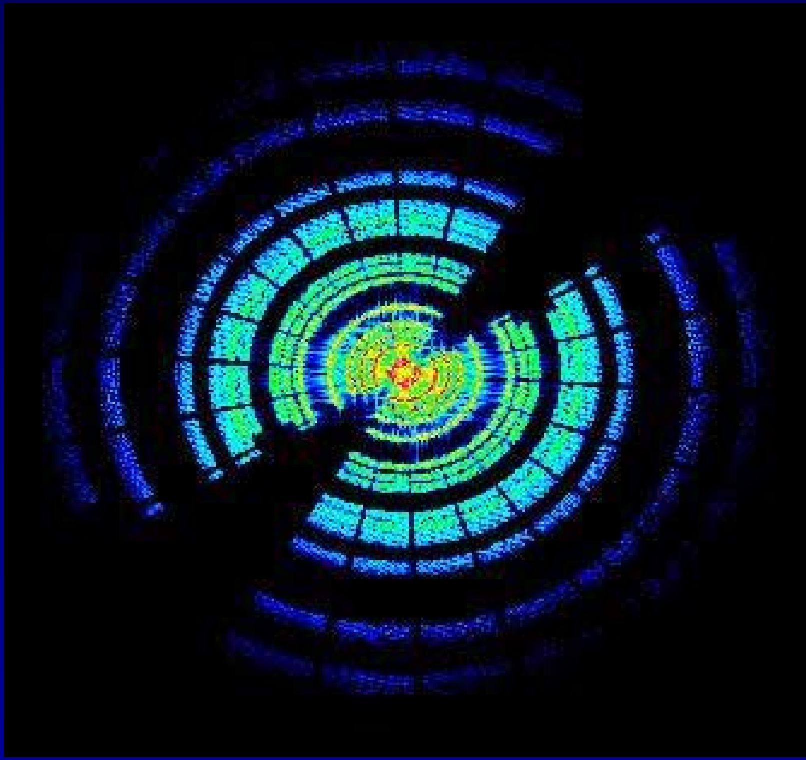
Fourier Basics
Image plane and uv-plane
Imaging decisions
Image estimation
Image errors

Fourier Basics

f(x)		F(s)
Large f(ax)	⟷	Small F(s/a)
Real		Hermitian (F(s)=F(-s)*)
Multiply f g		Convolve F*G
Shift f(x+a)		Phase Gradient
Add f+g		Add(F+G)
Rotate		Rotate

Image Plane and UV plane





UV plane features

- Dense rings
  - Baselines – track in uv plane
- Low level in between rings
  - Gaps in coverage, missing information
- Hole in center
  - No information on low 'spatial frequencies', i.e., no info on large scale structure
- Outer boundary
  - No info on small scale structure – resolution limit

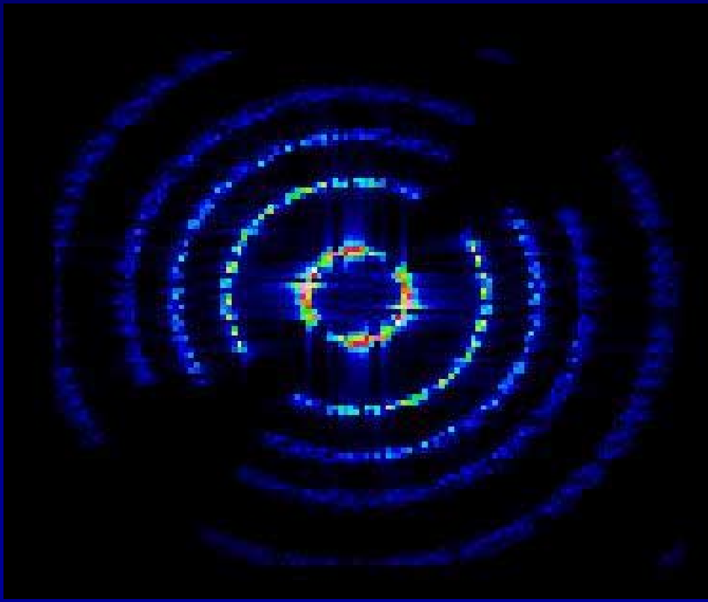
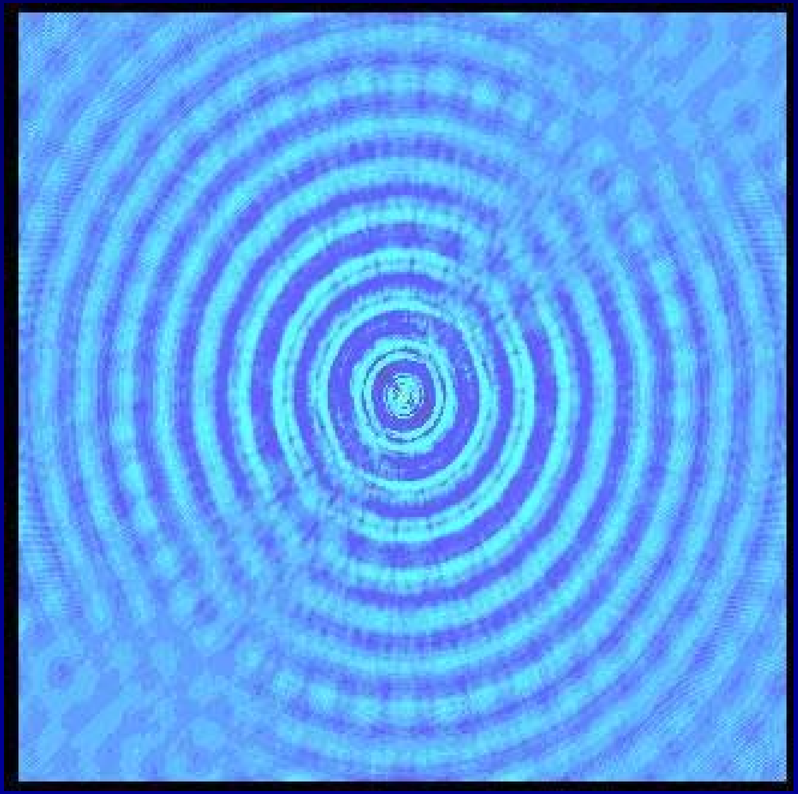
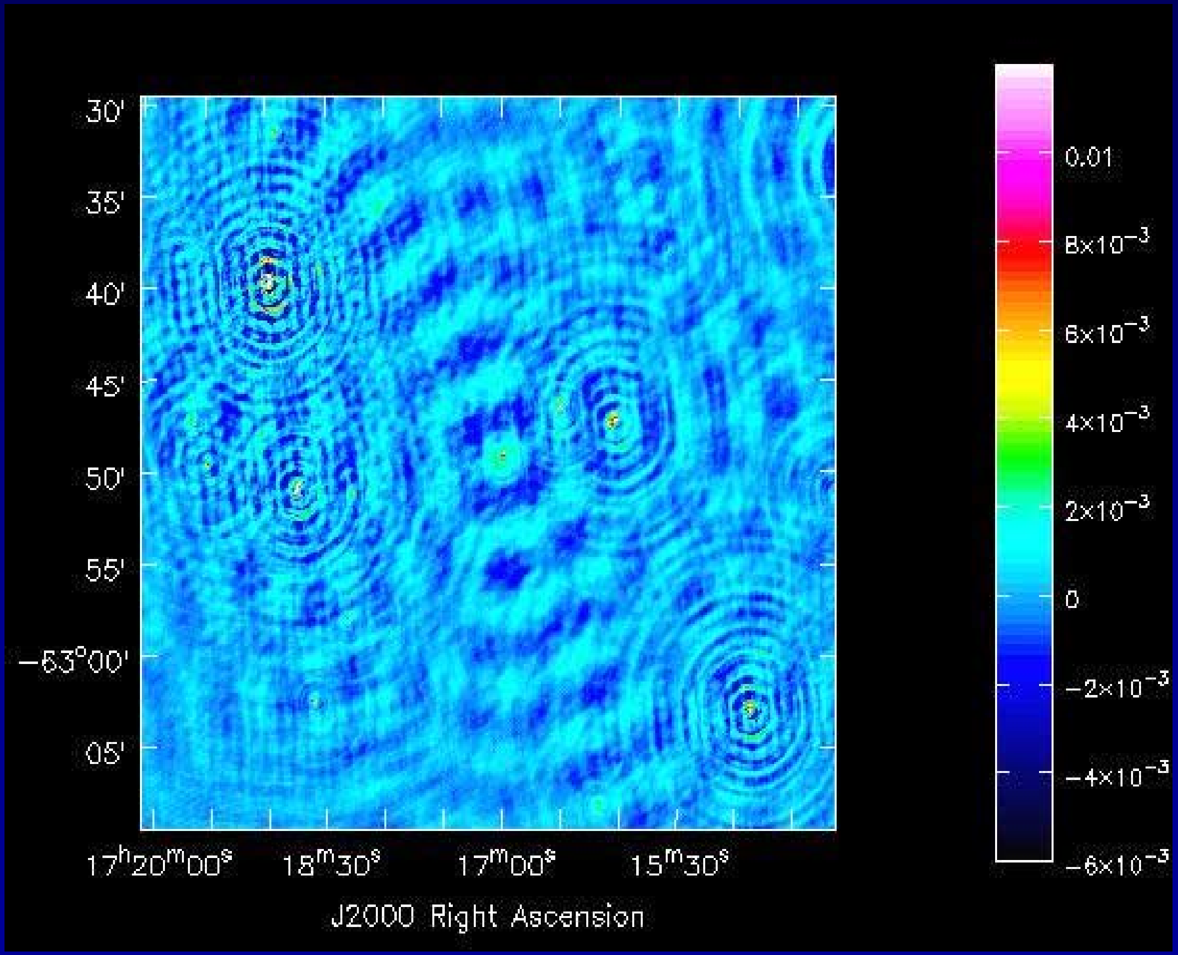


Image plane

PSF or ‘dirty beam’



Partially Cleaned Image



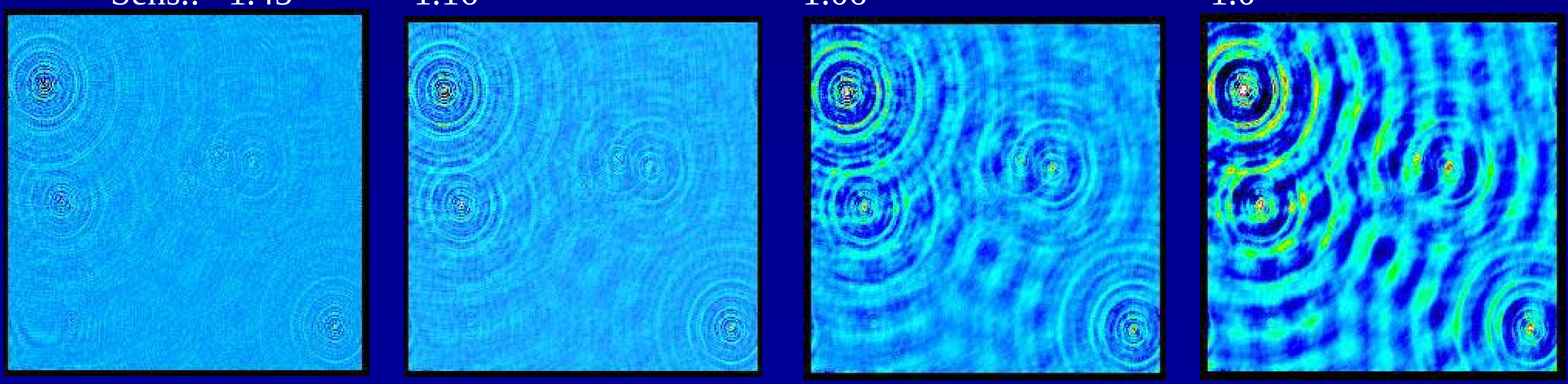
Imaging Decisions

- Field of view (FOV)
  - Based on primary beam size, mosaicing(multiple fields)
    - 20cm – 33' beam, 3mm – 30" beam
  - may need to image larger field to remove sidelobes from distant sources
- Resolution/tapering, cell size (>2 pixels/beam)
  - Many observations do NOT want maximum resolution because sensitivity to extended structure is low
    - Many short baseline configurations: EW352, H75
  - may elect not to include long baselines (e.g., deselect CA06)
    - Only adds high frequency ripple to image with mostly short baselines

Imaging Decisions(2)

- Weighting scheme
  - Uniform (min. sidelobe level)
  - Natural (min noise level)
  - Robust (optimal combination of above two)

	Uniform	Robust=0.5	Robust=1.0	Natural
Beam:	7x5”	8x6.5"	9.6x7.5"	12x8"
Sens.:	1.45	1.16	1.06	1.0



Imaging Decisions (3)

- Continuum vs Spectral line imaging
  - Continuum
    - » combine channels (ATCA continuum obs. has 32x 4MHz channels)
    - » possibly combine multiple center frequencies (MFS)
      - E.g. for max. sensitivity at 6cm use 4800 & 5824 MHz each with 32 channels over 128 MHz.
  - Line
    - » Check velocity frame, doppler correction
    - » Specify spectral resolution & velocity range
    - » Remove continuum emission
- Polarization
  - Choice of Stokes I,Q,U,V

Some details

- Imaging uses FFT – works on sampled data
  - Need to grid the uv data (choice of gridding methods)
    - » Specify gridding convolution function
    - » Suppresses aliasing
- Tapering (gaussian taper applied to vis weights)
  - Another form of weighting to influence beam size
- Non-coplanar baselines (e.g.VLA at low freq)
  - Small field approx fails, do e.g., facet imaging + joint deconvolution

Image estimation

Imaging is estimating the sky brightness distribution from incomplete information

- The imaging process can be generalized into a minimization process – minimize discrepancy between model of sky and the visibility data
  - » Some effects are easy to correct in image plane
    - e.g. Primary beam
  - » Others are easily corrected in visibility data
    - eg. atm. Gain, phase calibration
- But when e.g. Primary beam varies with time or phase varies with position in the sky an iterative approach is needed.

Improving the Image

- We need to:
  - Fill in the gaps in the uv-coverage (deconvolution)
  - Correct the instrumental responses (calibration)
    - » Filter response (bandpass correction)
    - » Polarization response (leakage terms)
  - Measure and Correct the atmospheric & instrumental responses that vary rapidly
    - » Mainly atmospheric path length (phase errors) and attenuation (gain vs. elevation)

(latter two require calibration observations of known sources)

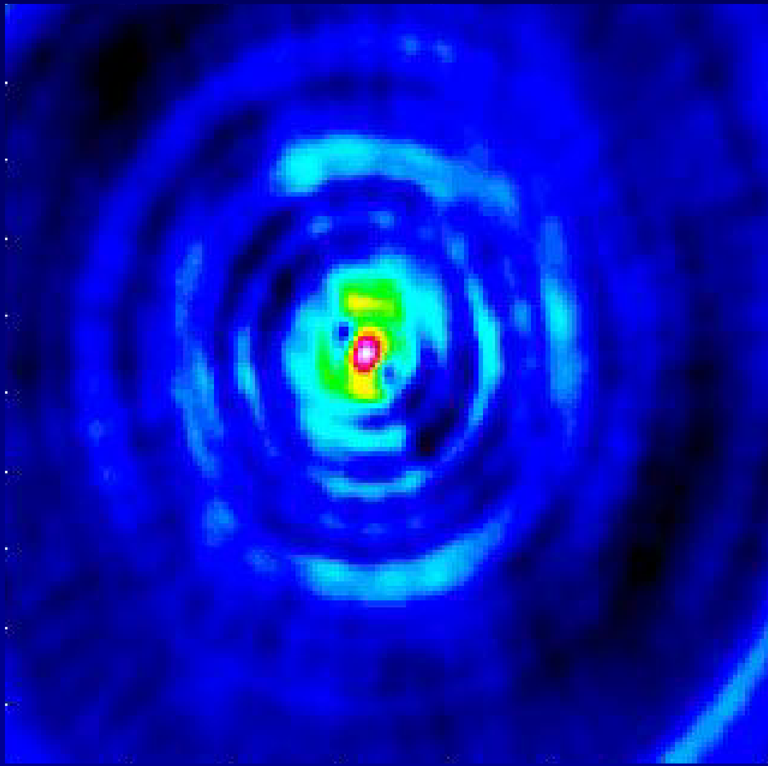
Deconvolution

- Need to make assumptions to get a realistic estimate
- Different algorithms make different assumptions, e.g.,
- CLEAN –
  - Sky is mostly empty, with occasional peaks
  - Works well for field with point sources, poor for extended emission
- MEM
  - Sky is uniform
  - Works well for very extended sources, poor for point sources
- Many variations on each basic scheme available
  - e.g., multi-scale clean, sdi clean

Common errors in Image plane

Problems remaining after deconvolution

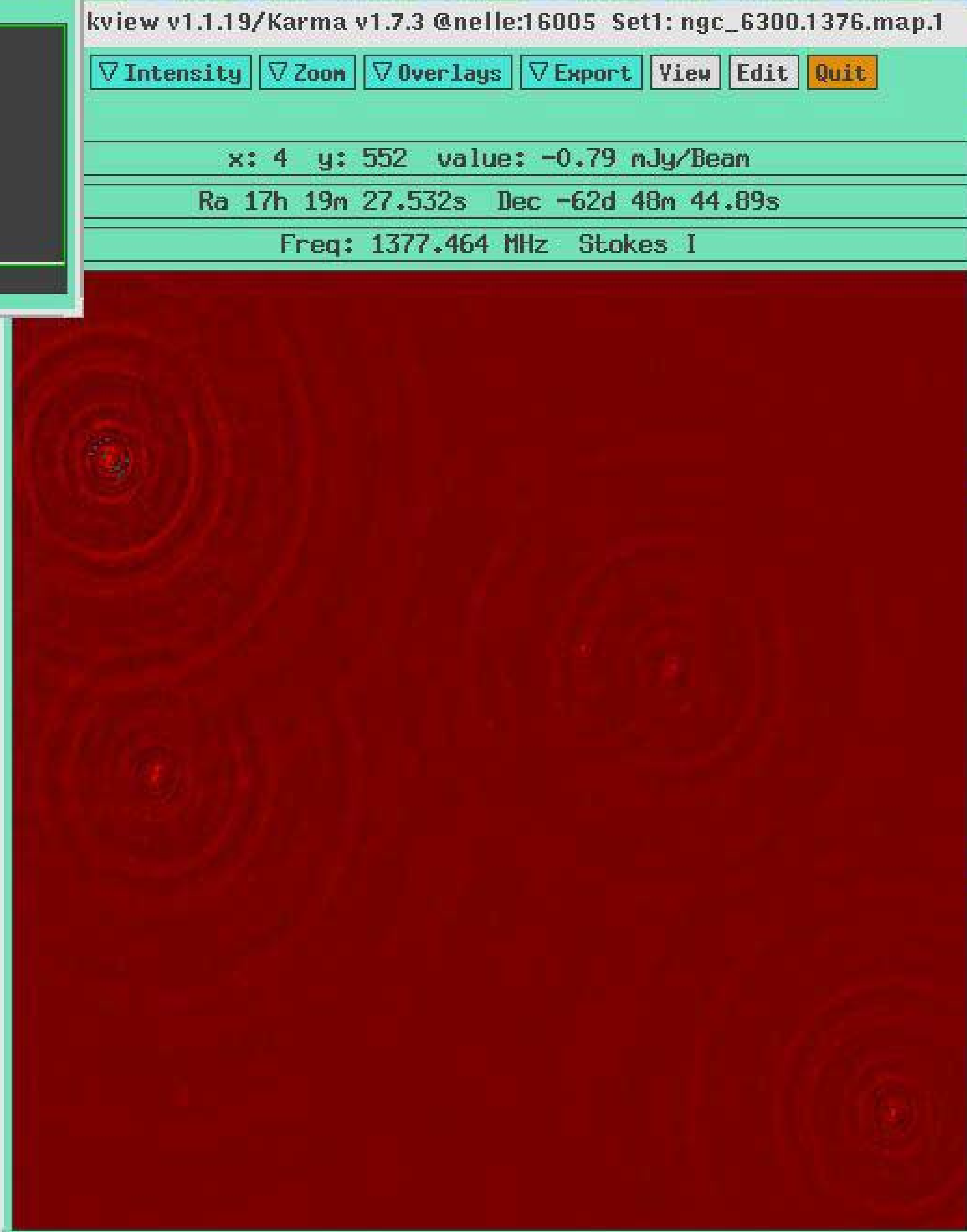
- (grating) rings ⇔ uv tracks
  - Improve by calibrating slowly varying gain&phase
- Radial spokes ⇔ short times
  - Improve by calibrating fast varying gain & phase
- 'Fuzzy' sources ⇔ outer tracks bad
  - decorrelation/bad phase errors (common at high frequency)



Example miriad imaging

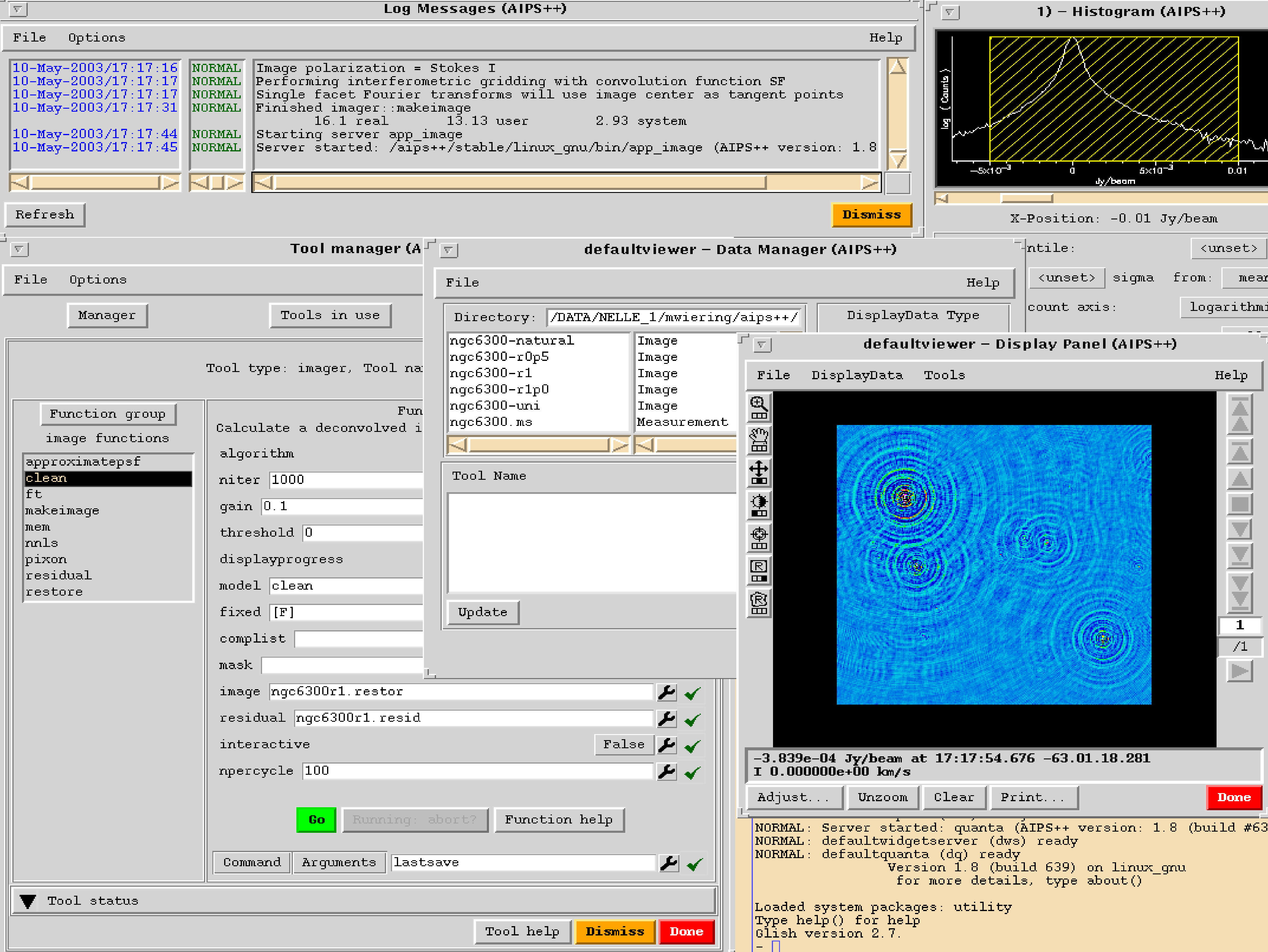
- Use task invert with following parameters:
  - vis, line, select to specify the data included
  - imsize, cell, options(mfs) to specify image (or cube)
  - sup, robust, fwhm, options(systemp) to specify weighting
  - Produces dirty image and beam
  - Use clean and restor to deconvolve the image
  - Use xmtv, kview to look at the image


```
Miriad shell version 1.0 26-Oct-99
miriad% inp invert
  Task:   invert
  vis       = ngc_6300.1376
  map       = ngc_6300.1376.map.1
  beam      = ngc_6300.1376.beam.1
  imsize    = 1024
  cell      = 2
  offset    =
  fwhm      =
  sup       =
  robust    = 0.5
  line      = channel,14,1,1
  ref       =
  select    =
  stokes    = i
  options   = mfs,double,systemp
  mode      =
  slop      =
invert% go
Invert: version 1.0 1-Jul-99
Reading the visibility data ...
Making MFS images
Visibilities accepted: 312676
### Warning:  Visibilities rejected: 25844
Mean Frequency(GHz):      1.38
Sidelobe suppression area is 4096x4096 arcsec
 ... this corresponds to uniform weighting
Calculating the weights ...
Applying the weights ...
Theoretical rms noise: 4.192E-05
Forming the beam ...
Finished gridding  50% ...
Forming Stokes I  image ...
Completed 100% !
invert% kview &
[1] 28388
invert% Port allocated: 16005
```



Example aips++ imaging

- Use imager tool:
  - setdata() to select the data to use in the image
  - setimage() to specify the image parameters and how to combine the data (mfs or spectral cube)
  - weight() to apply a weighting scheme
  - makeimage() to make a 'dirty image' or
  - clean() to make a deconvolved image
  - Use the viewer to look at the image


Log Messages (AIPS++)
File Options Help
10-May-2003/17:17:16 NORMAL Image polarization = Stokes I
10-May-2003/17:17:17 NORMAL Performing interferometric gridding with convolution function SF
10-May-2003/17:17:17 NORMAL Single facet Fourier transforms will use image center as tangent points
10-May-2003/17:17:31 NORMAL Finished imager::makeimage
16.1 real 13.13 user 2.93 system
10-May-2003/17:17:44 NORMAL Starting server app_image
10-May-2003/17:17:45 NORMAL Server started: /aips++/stable/linux_gnu/bin/app_image (AIPS++ version: 1.8
Refresh
Dismiss
1) – Histogram (AIPS++)
log (Counts)
Jy/beam
X-Position: -0.01 Jy/beam
ntile: <unset>
<unset> sigma from: mear
count axis: logarithmi
Tool manager (A
File Options
Manager
Tools in use
Tool type: imager, Tool na
Function group
image functions
approximatepsf
clean
ft
makeimage
mem
nnls
pixon
residual
restore
Calculate a deconvolved i
algorithm
niter 1000
gain 0.1
threshold 0
displayprogress
model clean
fixed [F]
complist
mask
image ngc6300r1.restor
residual ngc6300r1.resid
interactive False
npercycle 100
Go
Running: abort?
Function help
Command
Arguments
lastsave
Tool status
Tool help
Dismiss
Done
defaultviewer – Data Manager (AIPS++)
File Help
Directory: /DATA/NELLE_1/mwiering/aips++/
DisplayData Type
ngc6300-natural Image
ngc6300-r0p5 Image
ngc6300-r1 Image
ngc6300-r1p0 Image
ngc6300-uni Image
ngc6300.ms Measurement
Tool Name
Update
defaultviewer – Display Panel (AIPS++)
File DisplayData Tools Help
-3.839e-04 Jy/beam at 17:17:54.676 -63.01.18.281
I 0.000000e+00 km/s
Adjust...
Unzoom
Clear
Print...
Done
NORMAL: Server started: quanta (AIPS++ version: 1.8 (build #63
NORMAL: defaultwidgetserver (dws) ready
NORMAL: defaultquanta (dq) ready
Version 1.8 (build 639) on linux_gnu
for more details, type about()
Loaded system packages: utility
Type help() for help
Glish version 2.7.

VRI

- VRI, the virtual radio interferometer
  - http://www.narrabri.atnf.csiro.au/astronomy/vri.html
  - Lets you experiment with Fourier transforms and ATCA configurations