Imaging and Self-Calibration

Hands-on CASA introduction

Whoever

North American ALMA Science Center

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Imaging in CASA

- CASA exposes imaging and deconvolution via the `clean` task
  STARTING POINT: CALIBRATED MS ("CORRECTED" COLUMN, IF PRESENT)

- Can be run interactively (using the viewer) or automatically
  INTERACTIVE ALLOWS ON-THE-FLY CLEAN BOXING AND STOPPING

- Key decisions:
  - How to grid the data (image, cell size)
  - How to handle the frequency axis
  - What (if any) deconvolution to carry out
  - Selection and weighting of visibility data

clean

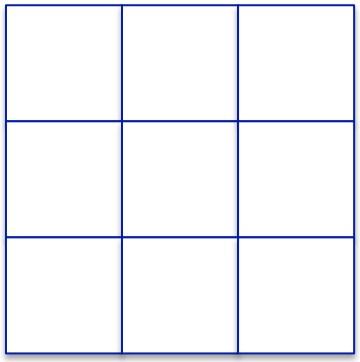
```
--------> inp(clean)
#  clean :: Invert and deconvolve images with selected algorithm
vis                 =          ''        #  Name of input visibility file
imagename           =          ''        #  Pre-name of output images
outlierfile         =          ''        #  Text file with image names, sizes, centers for outliers
field               =          ''        #  Field Name or id
spw                 =          ''        #  Spectral windows e.g. '0~3', '' is all
selectdata          =       False        #  Other data selection parameters
mode                =       'mfs'        #  Spectral gridding type (mfs, channel, velocity, frequency)
nterms              =           1        #  Number of Taylor coefficients to model the sky frequency dependence
reffreq             =          ''        #  Reference frequency (nterms > 1),'' uses central data-frequency

gridmode            =          ''        #  Gridding kernel for FFT-based transforms, default='' None
niter               =         500        #  Maximum number of iterations
gain                =         0.1        #  Loop gain for cleaning
threshold           =     '0.0mJy'       #  Flux level to stop cleaning, must include units: '1.0mJy'
psfmode             =       clark        #  Method of PSF calculation to use during minor cycles
imagermode          =          ''        #  Options: 'csclean' or 'mosaic', '', uses psfmode
multiscale          =          []        #  Deconvolution scales (pixels); [] = standard clean
interactive         =       False        #  Use interactive clean (with GUI viewer)
mask                =          []        #  Cleanbox(es), mask image(s), region(s), or a level
imsize              =   [256, 256]       #  x and y image size in pixels. Single value: same for both
cell                =   ['1.0arcsec']    #  x and y cell size(s). Default unit arcsec.
phasecenter         =          ''        #  Image center: direction or field index
restfreq            =          ''        #  Rest frequency to assign to image (see help)
stokes              =          'I'       #  Stokes params to image (eg I,IV,IQ,IQUV)
weighting           =    'natural'       #  Weighting of uv (natural, uniform, briggs, ...)
uvtaper             =       False        #  Apply additional uv tapering of visibilities
modelimage          =          ''        #  Name of model image(s) to initialize cleaning
restoringbeam       =         ['']       #  Output Gaussian restoring beam for CLEAN image
pbcor               =       False        #  Output primary beam-corrected image
minpb               =         0.2        #  Minimum PB level to use
calready            =        True        #  True required for self-calibration
allowchunk          =       False        #  Divide large image cubes into channel chunks for deconvolution
async               =       False        #  If true the taskname must be started using clean(...)
```

- (Visibility) data selection
- Treatment of spectral axis
- Deconvolution (actual CLEANing)
- Basic image (gridding) parameters
- Weighting

clean: Imaging

- image size
  TYPICALLY ~ PRIMARY BEAM AREA UNLESS IN SPECIAL CASE



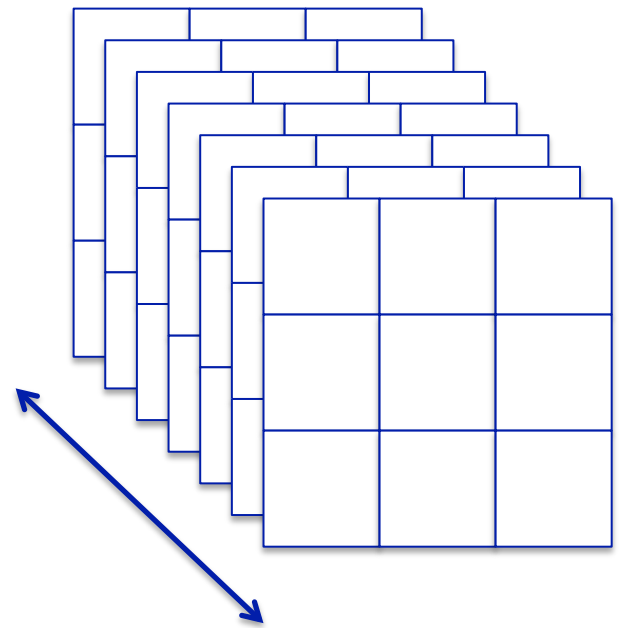
- cell size
  SET THIS TO PLACE ~4-5 PIXELS ACROSS YOUR PSF CORE

- Weighting ("uniform", "robust", "natural")
  USED TO ASSEMBLE VISIBILITIES INTO IMAGE, AFFECT PSF/SENSITIVITY

- Optionally "taper" (smooth) the data to target resolution

`clean`: Imaging

- Handling of spectral axis for **cube**:
  START, STOP, WIDTH OF PLANE
  - Define planes by channel
  - Define planes by velocity
  - Define planes by frequency

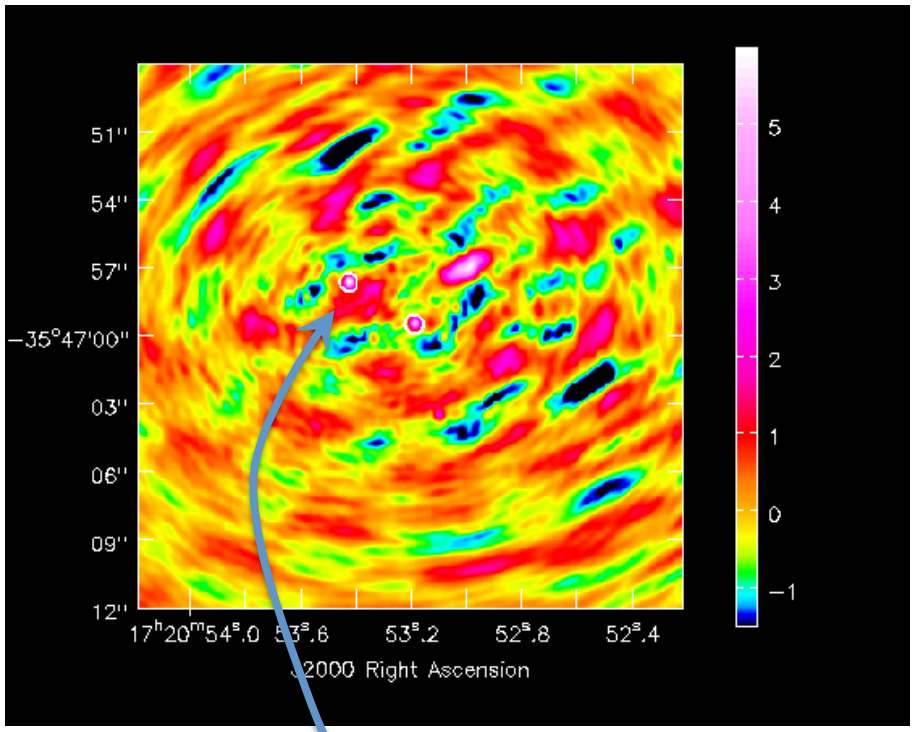


- Handling of spectral axis for **image**:
  - "multifrequency synthesis" accounts for u-v position vs. frequency
  - (Optional) Deconvolution components can have spectral index
    I.E., INTENSITY DEPENDENT ON FREQUENCY

`clean`: Deconvolution

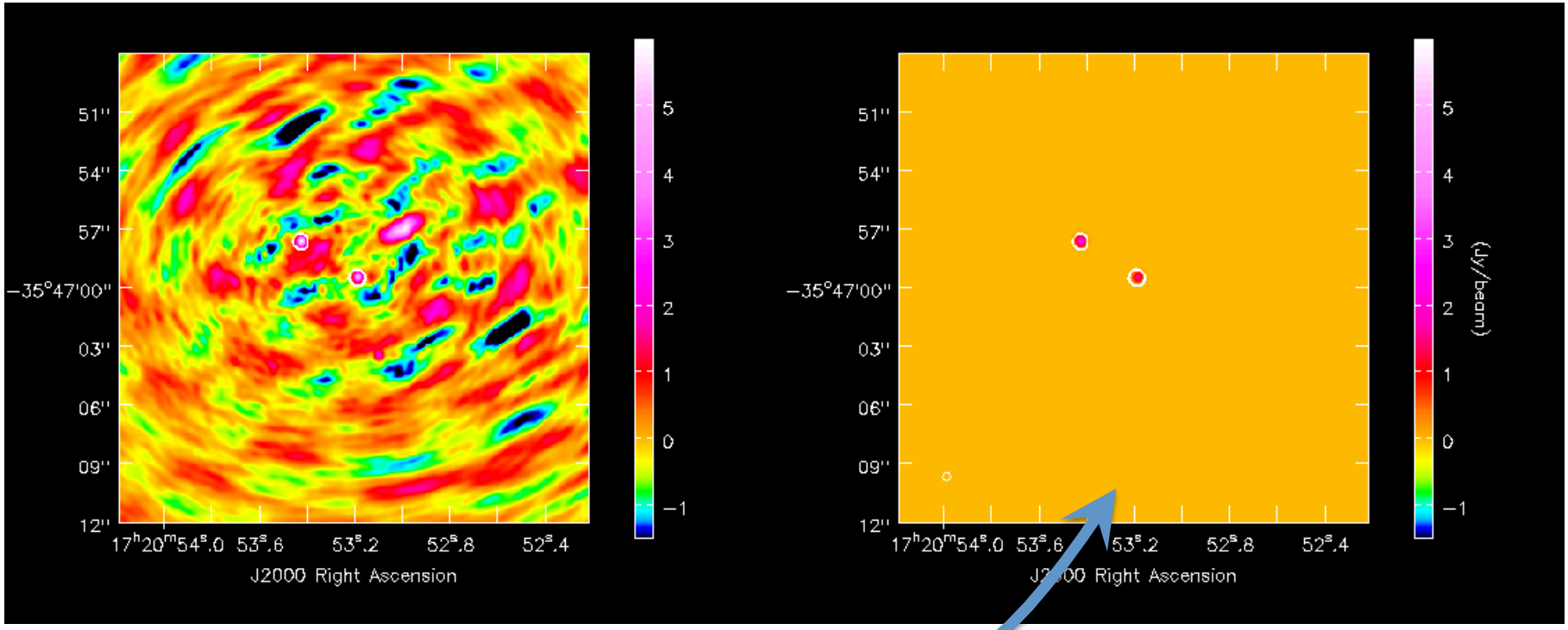
- Image reconstruction to account for imperfect u-v coverage
- Basic Procedure:
  - Identify brightest spot in image
  - Subtract a point source with some fraction of that intensity
  - Add a corresponding point source to a "model" image
  - Proceed until no signal left in image
  - Convolve model with "clean beam" and add to residuals

Deconvolution Illustrated



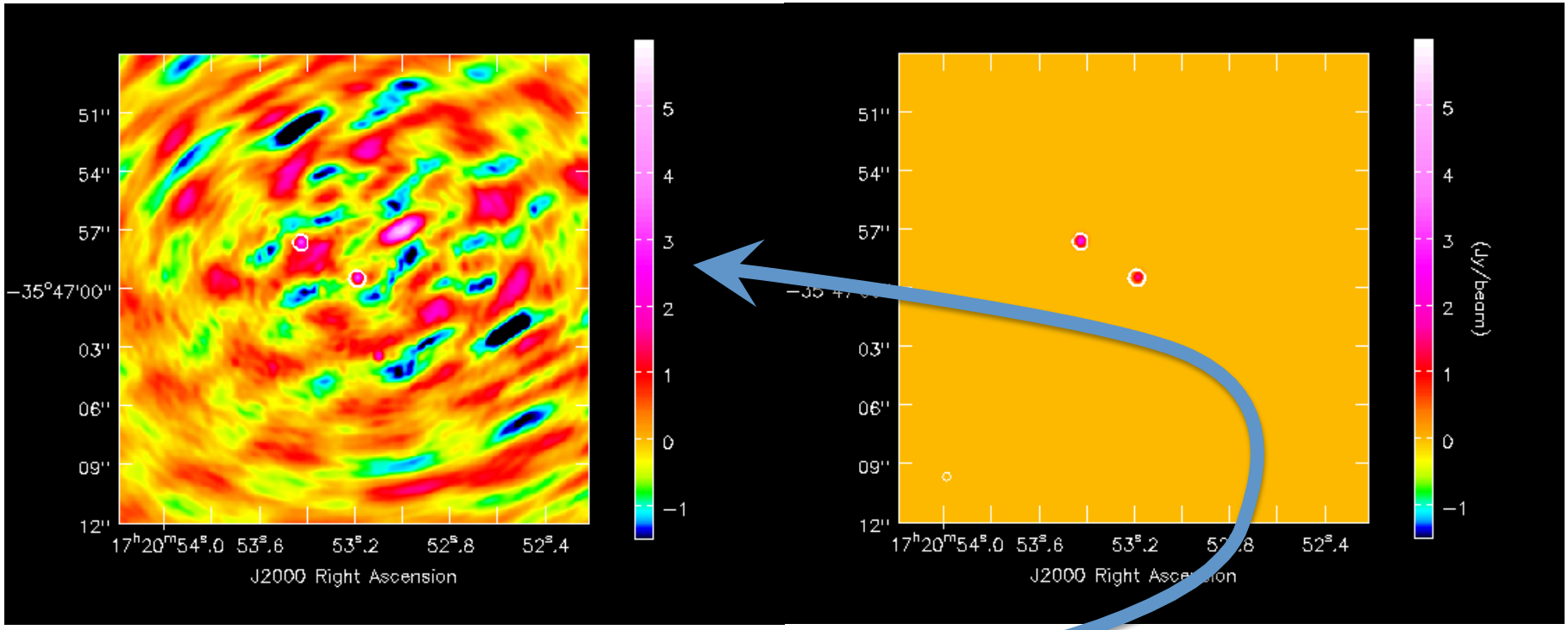
- Find brightest points in "dirty" image

Deconvolution Illustrated

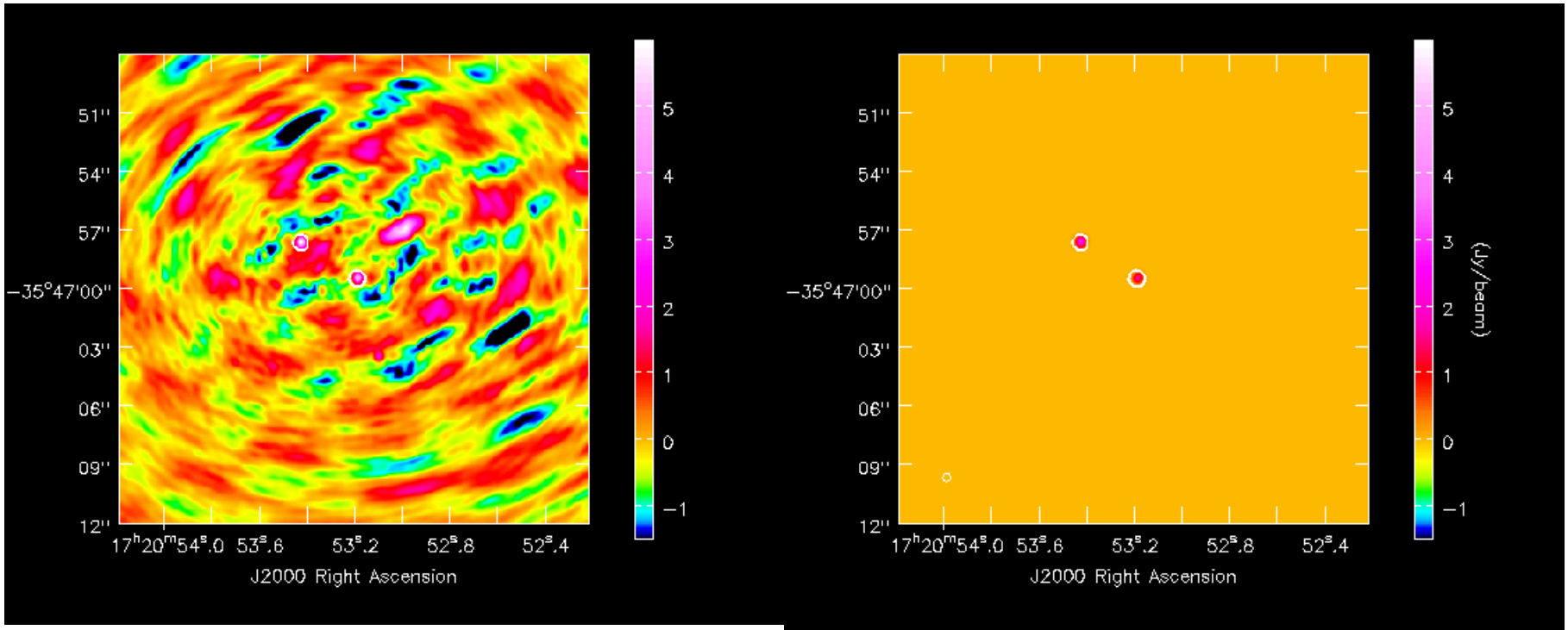


- Find brightest points in "dirty" image
- Create model image containing a fraction of those flux points

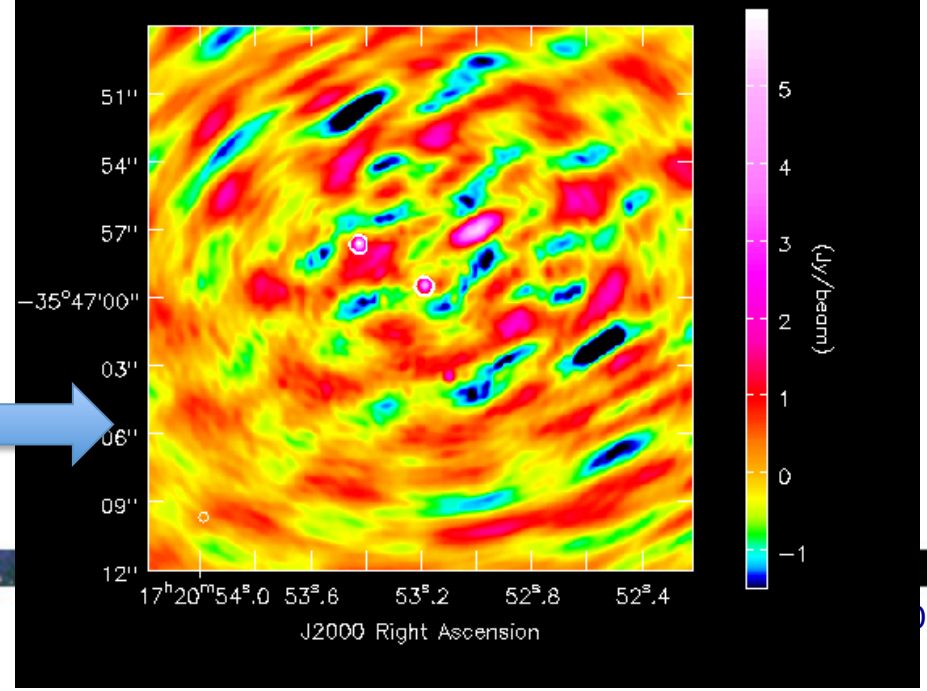
Deconvolution Illustrated

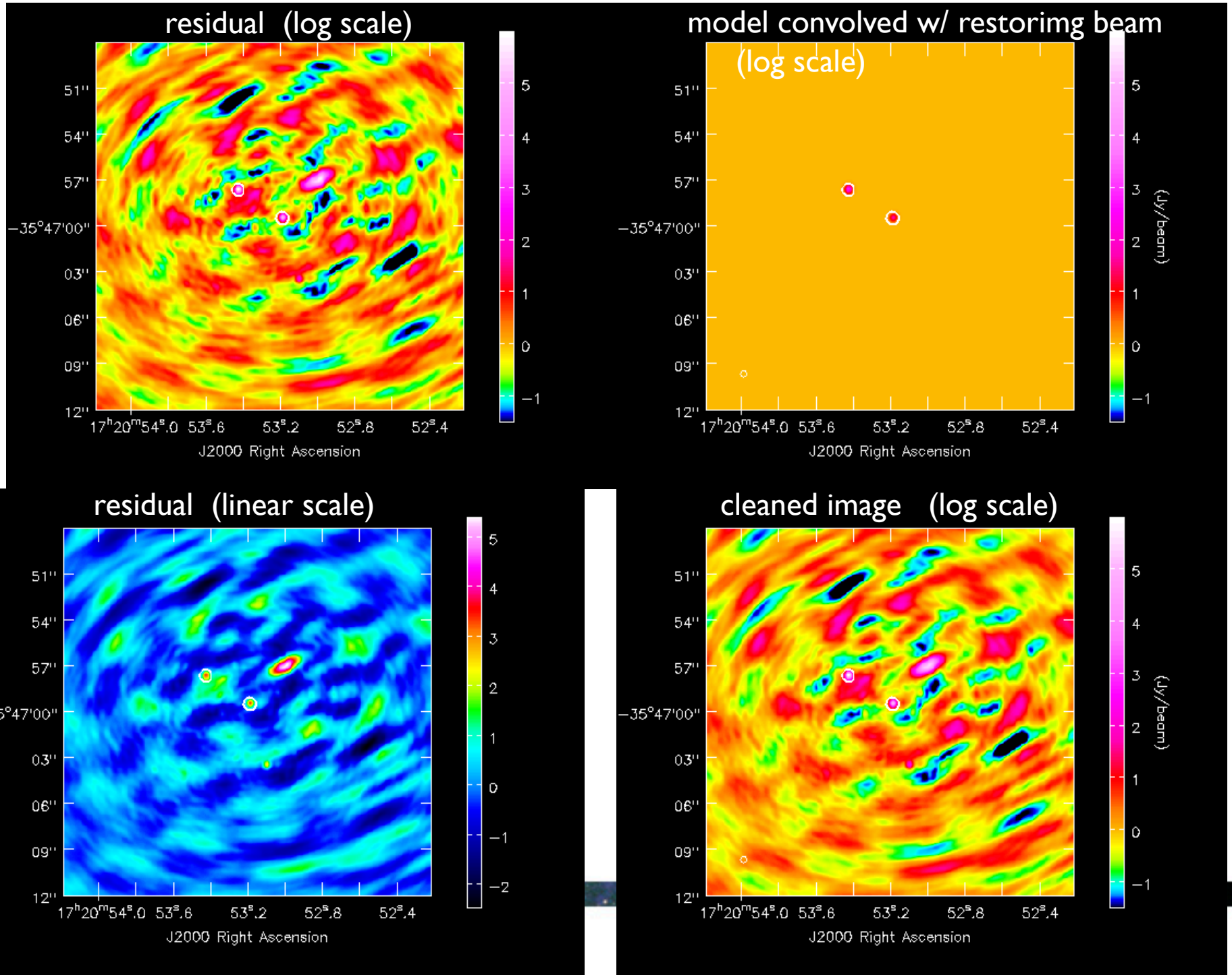


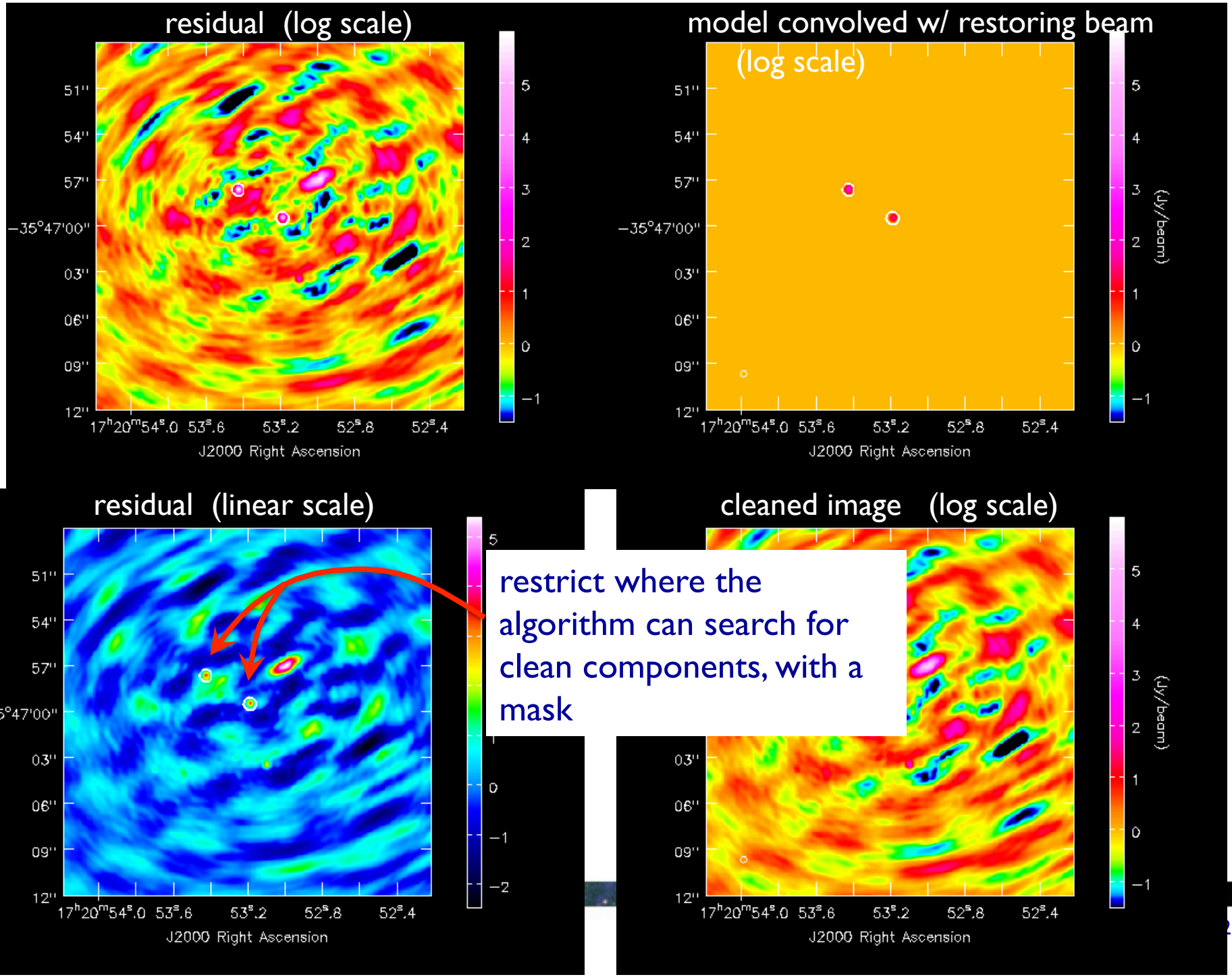
- Find brightest points in dirty image
- Create model image containing a fraction of those flux points
- Subtract model from data, leaving a residual

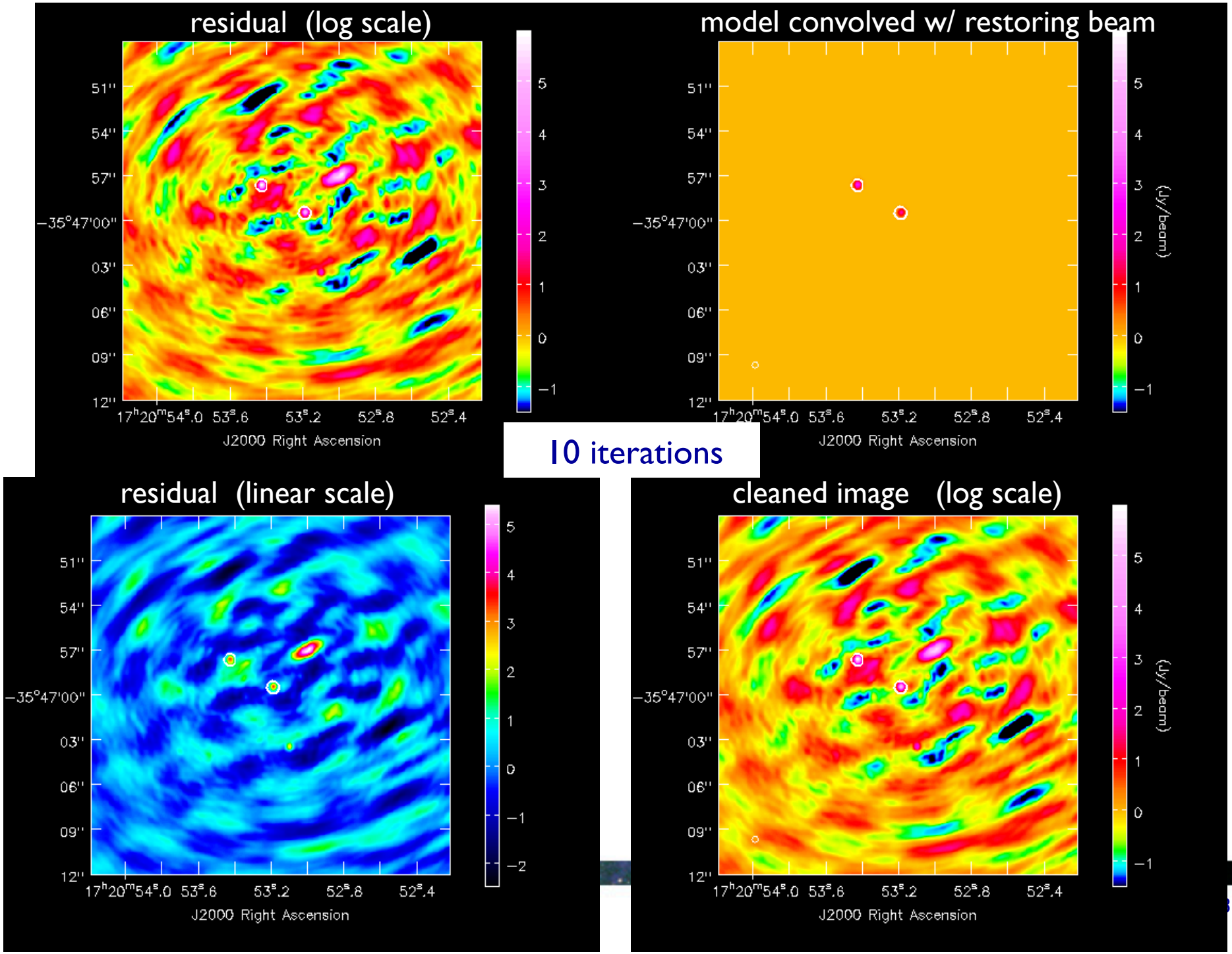


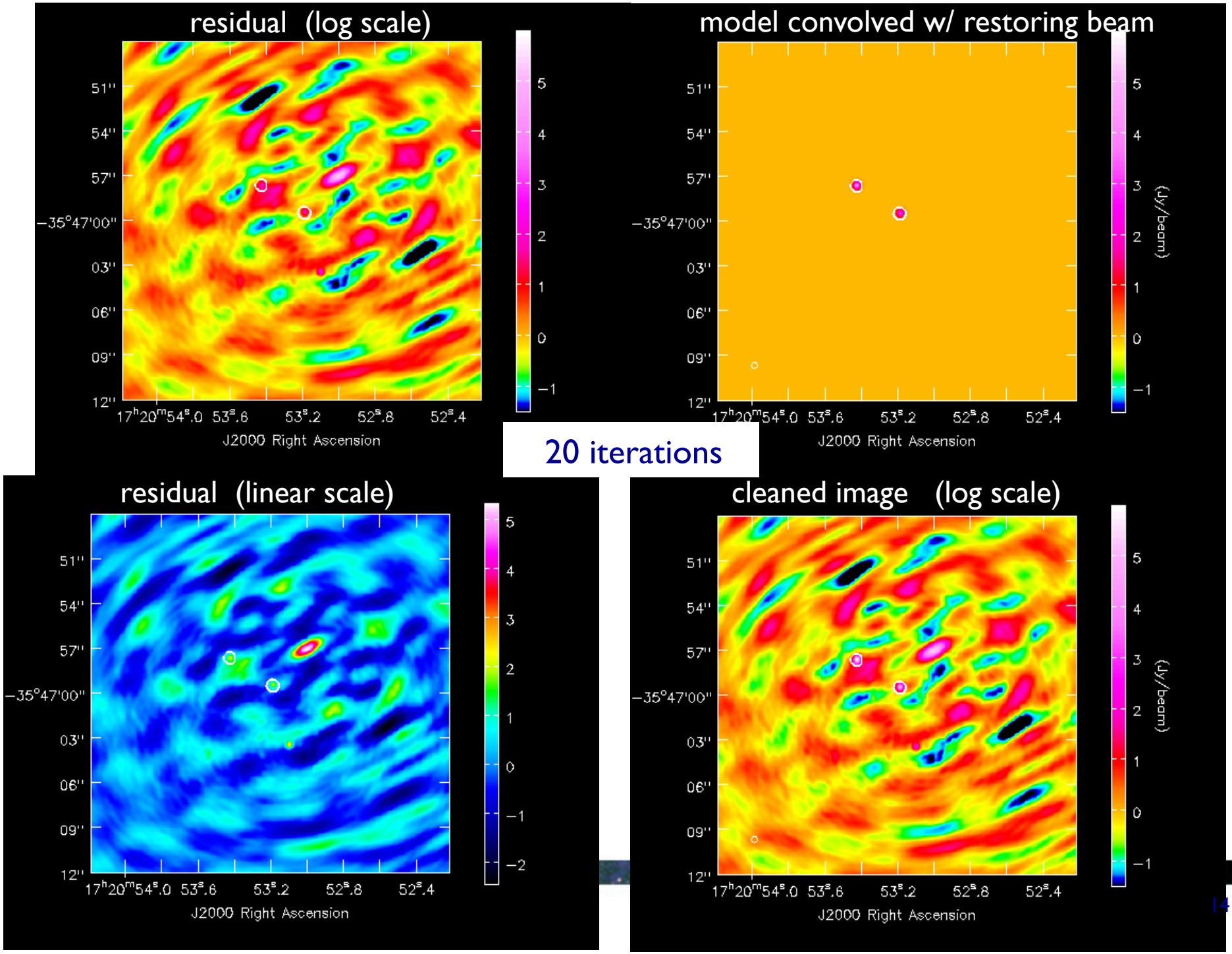
- Find brightest points in dirty image
- Create model image containing a fraction of those flux points
- Subtract model from data, leaving a residual
- Final product = residual + model (convolved with restoring Gaussian beam)

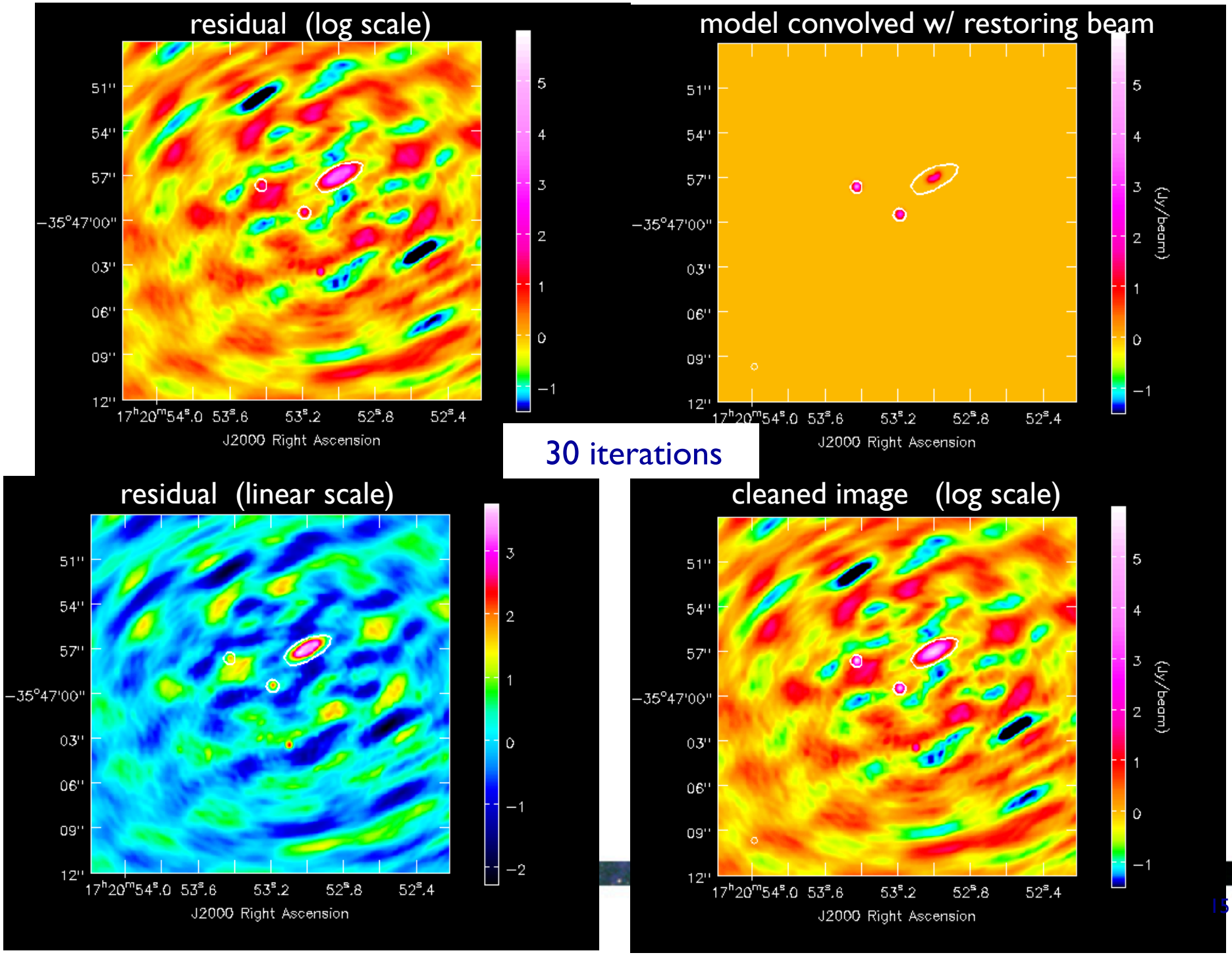


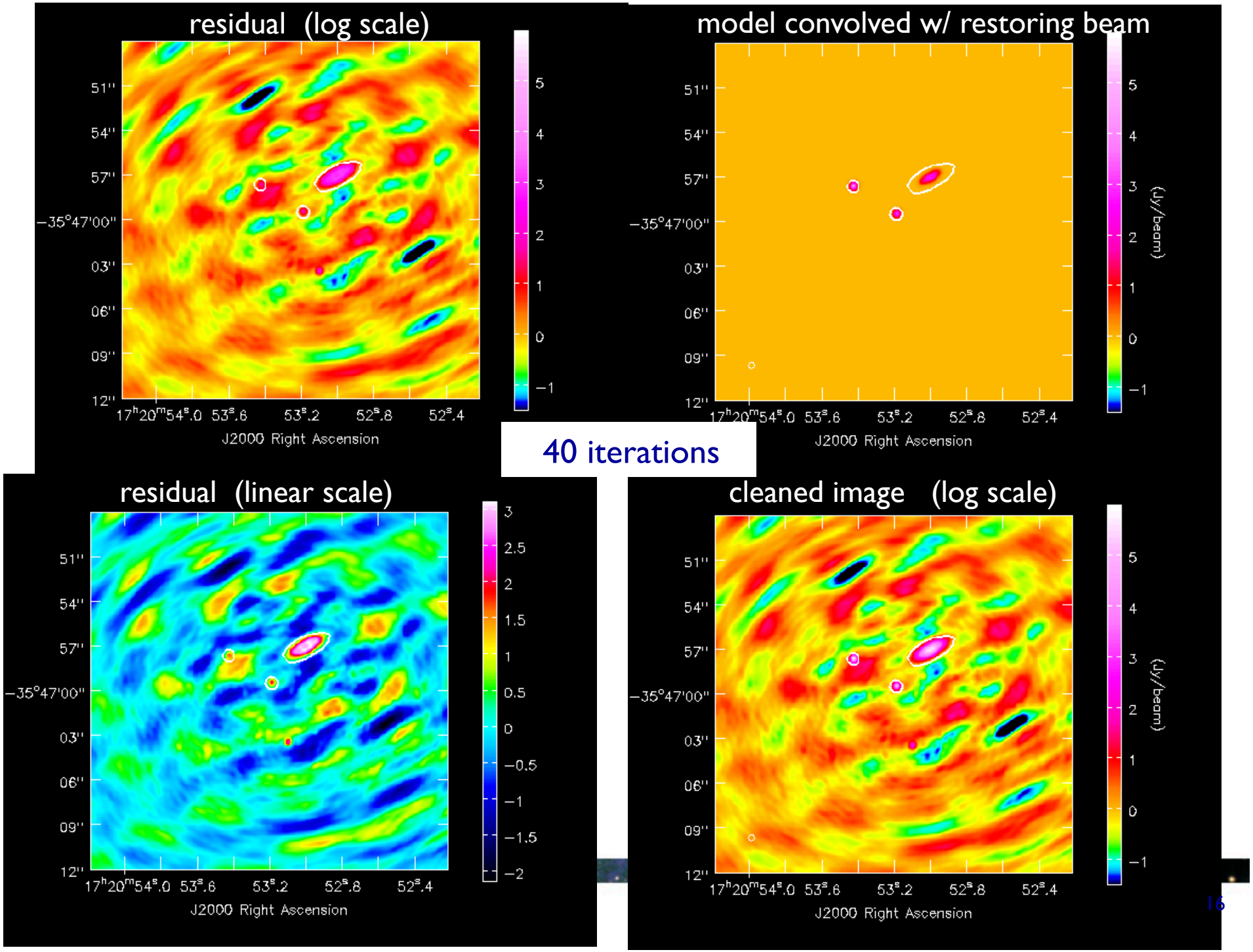

residual (log scale)
model convolved w/ restorimg beam
(log scale)
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)
5
4
3
2
1
0
−1
−2

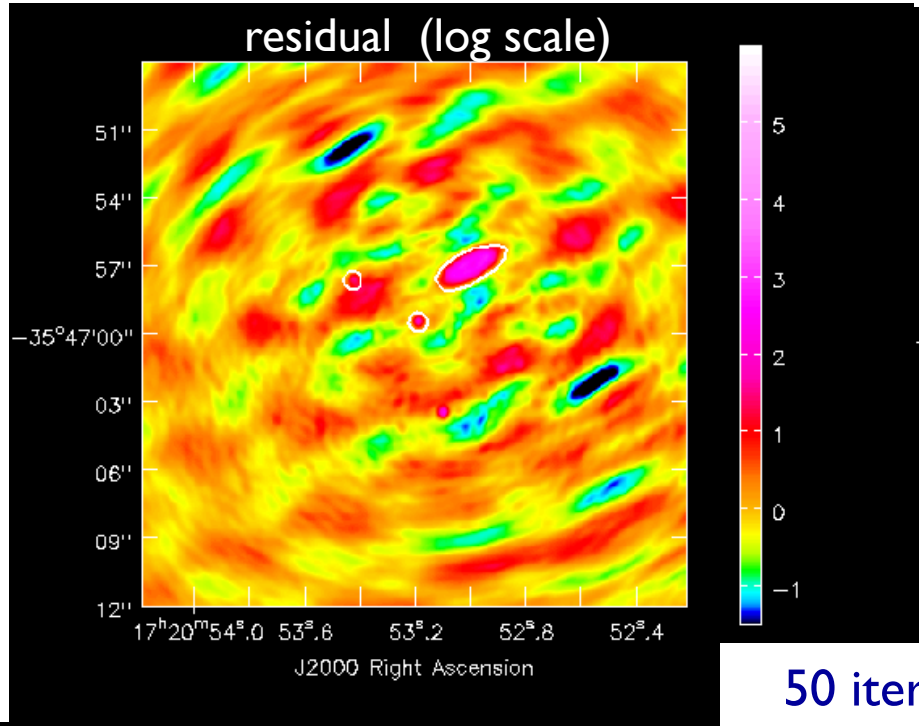

residual (log scale)
model convolved w/ restoring beam
(log scale)
residual (linear scale)
cleaned image (log scale)
restrict where the algorithm can search for clean components, with a mask
J2000 Right Ascension
(Jy/beam)

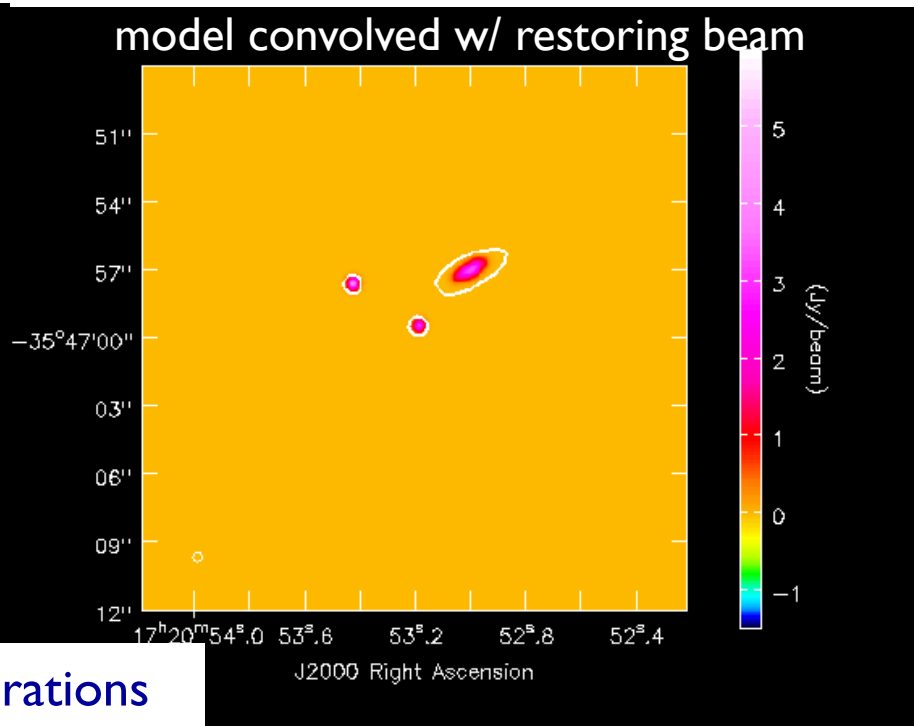

residual (log scale)
model convolved w/ restoring beam
10 iterations
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)


residual (log scale)
model convolved w/ restoring beam
20 iterations
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)
5
4
3
2
1
0
−1
−2

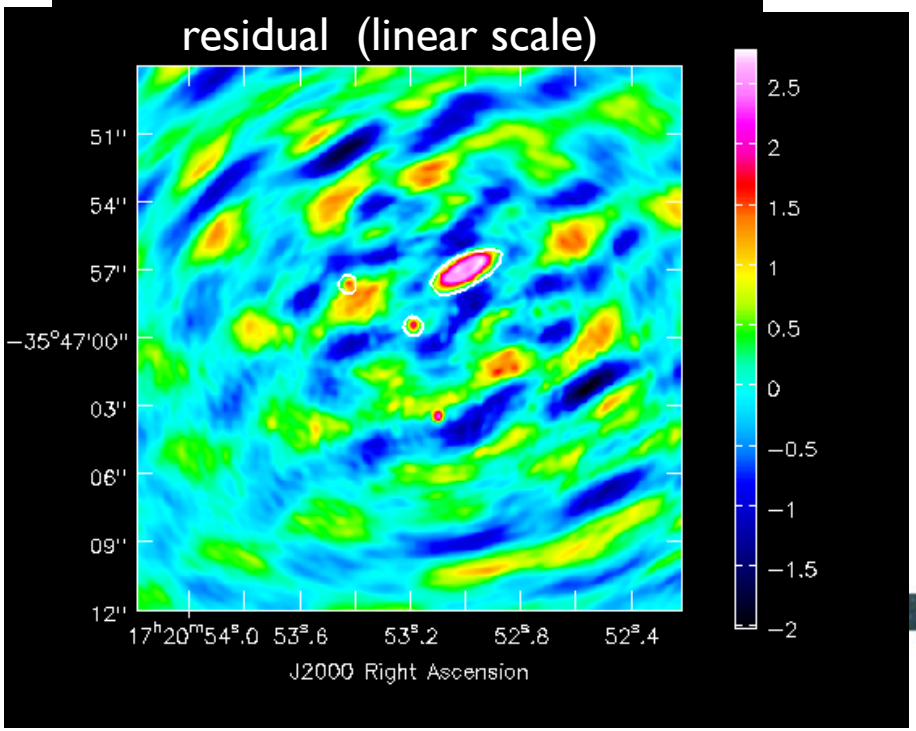

residual (log scale)
model convolved w/ restoring beam
30 iterations
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)

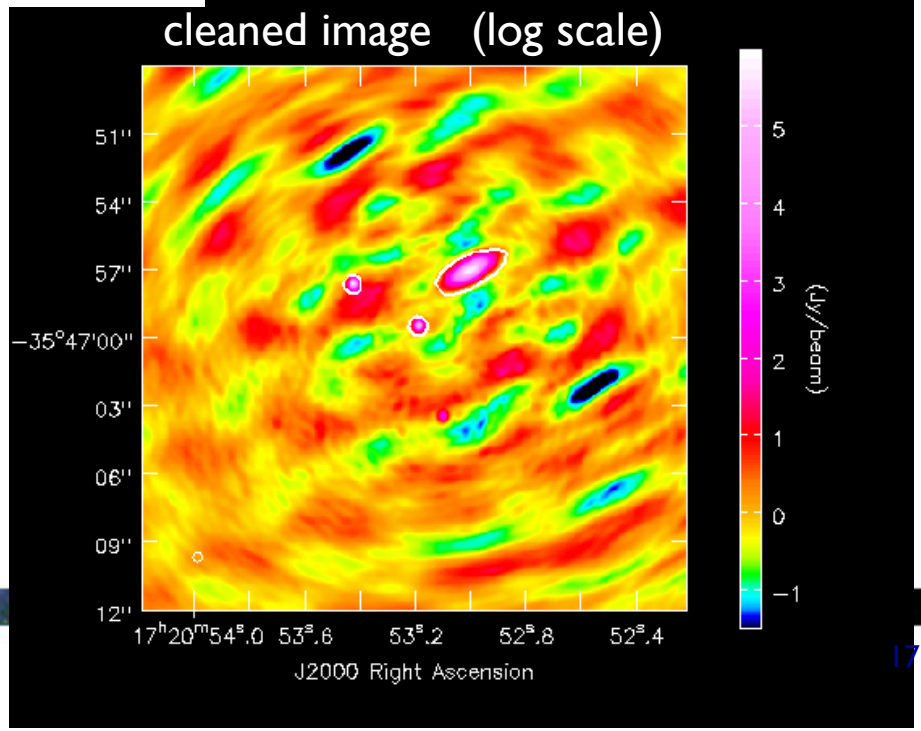

residual (log scale)
model convolved w/ restoring beam
40 iterations
residual (linear scale)
cleaned image (log scale)
J2000 Right Ascension
(Jy/beam)

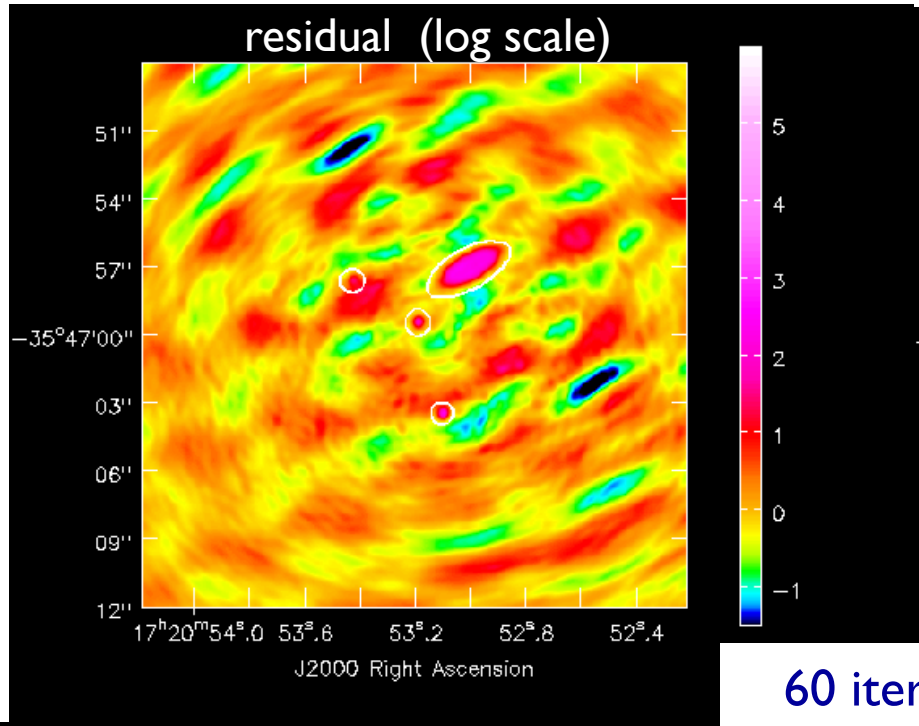


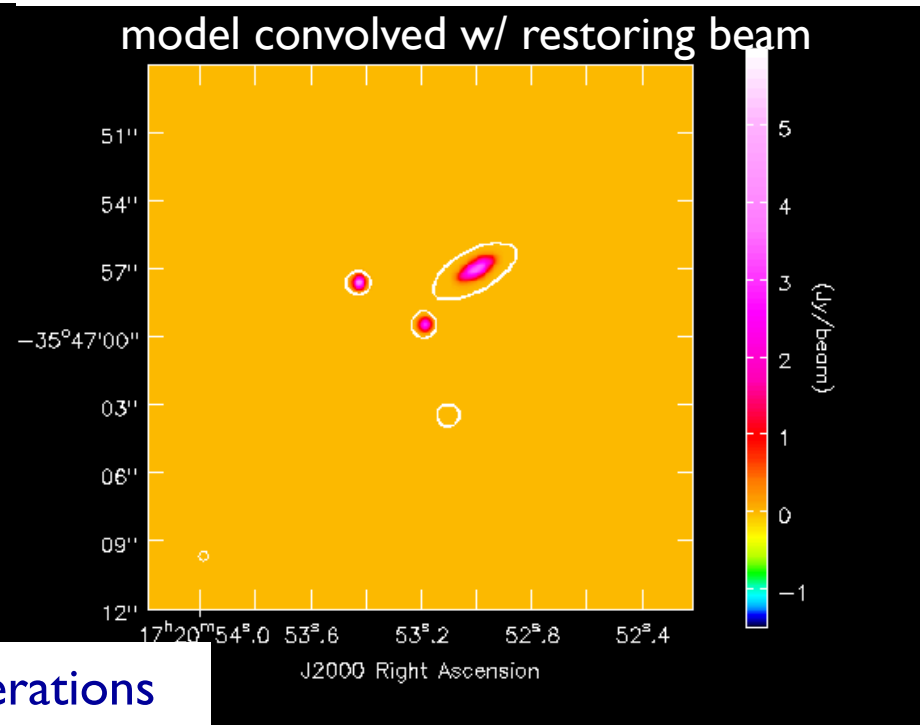


50 iterations

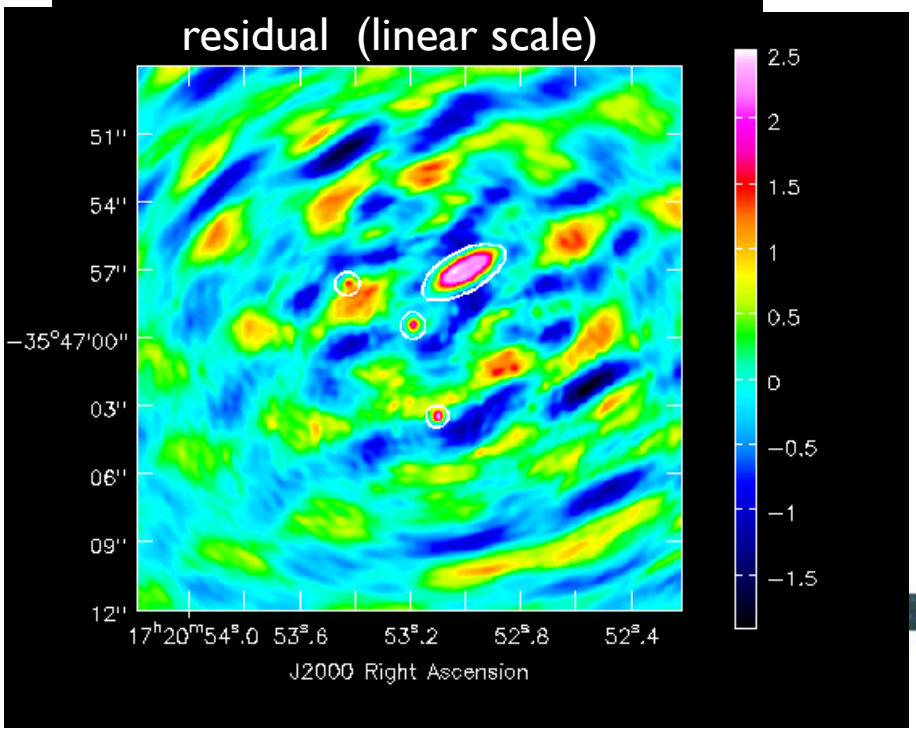


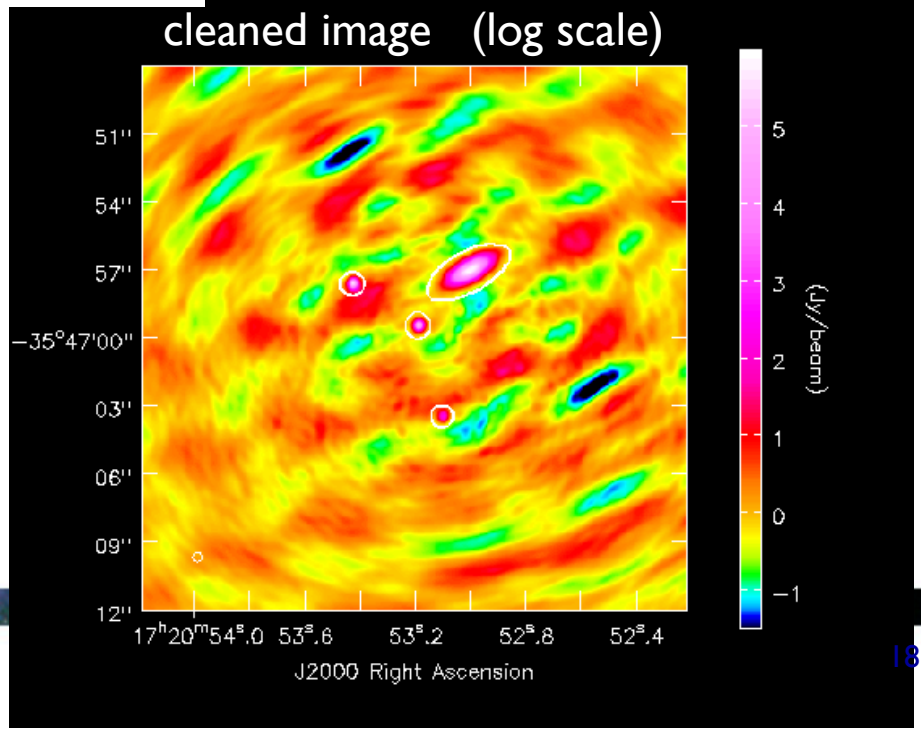


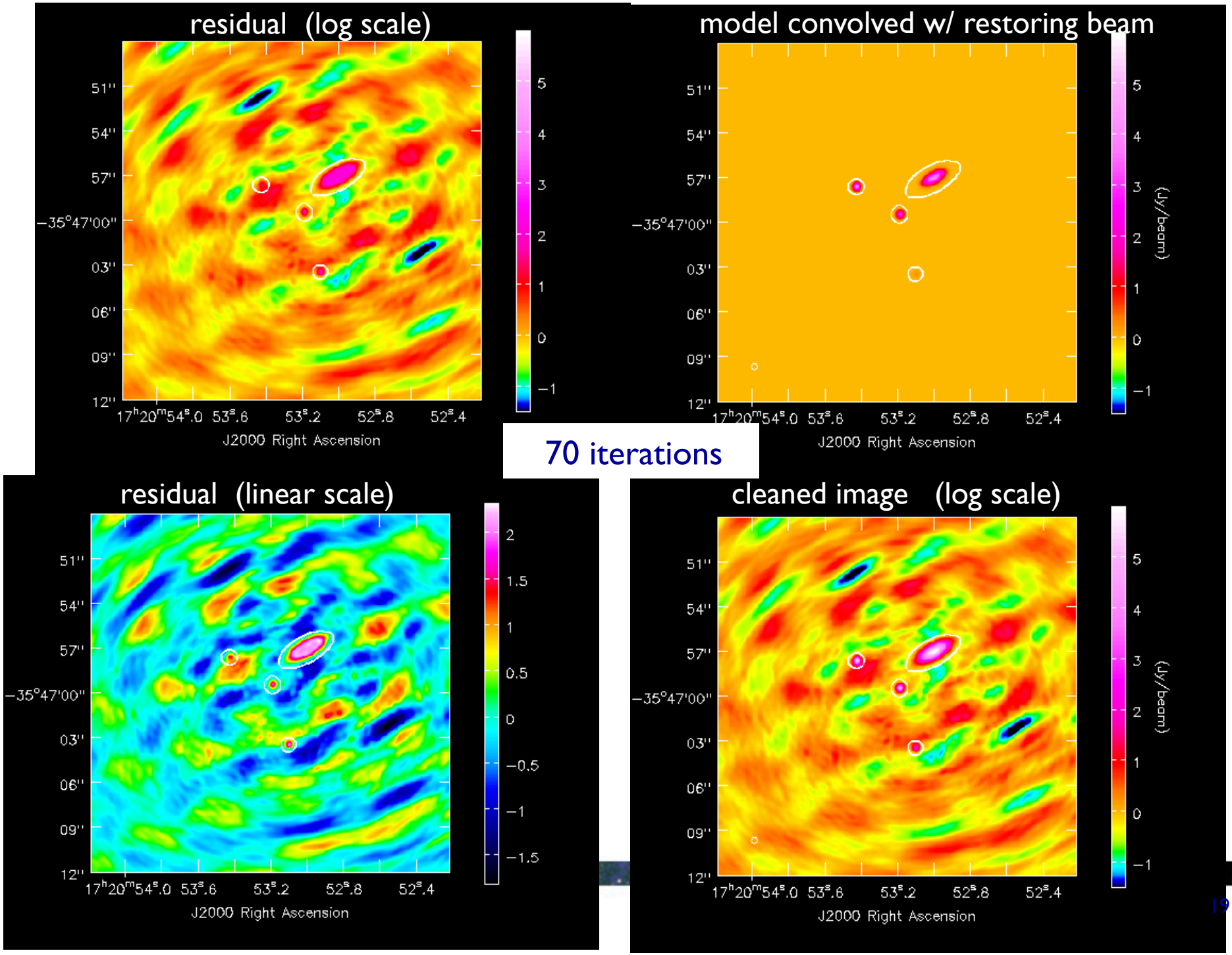


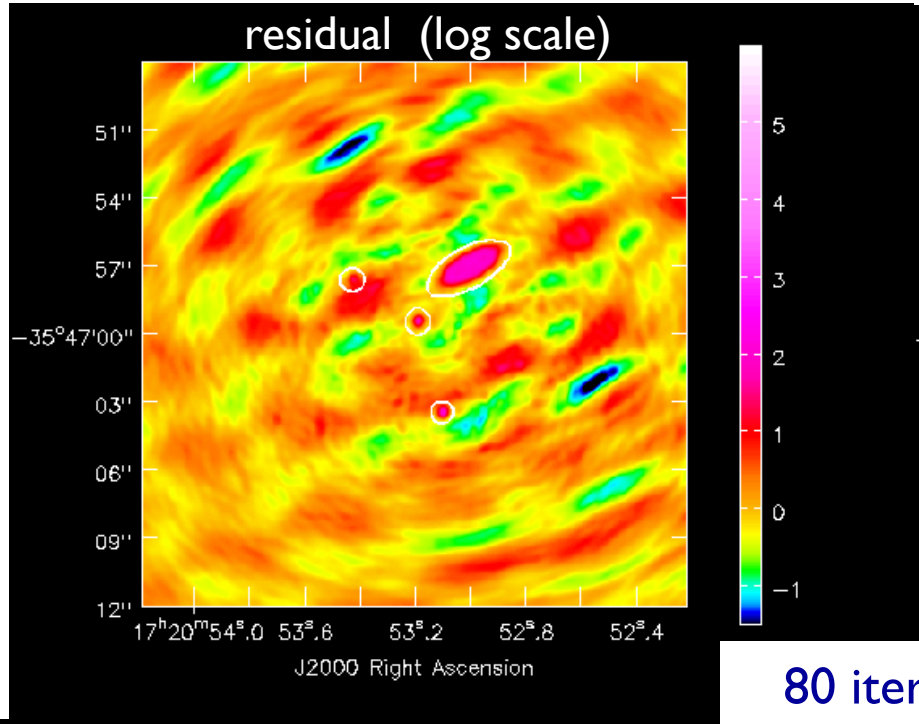


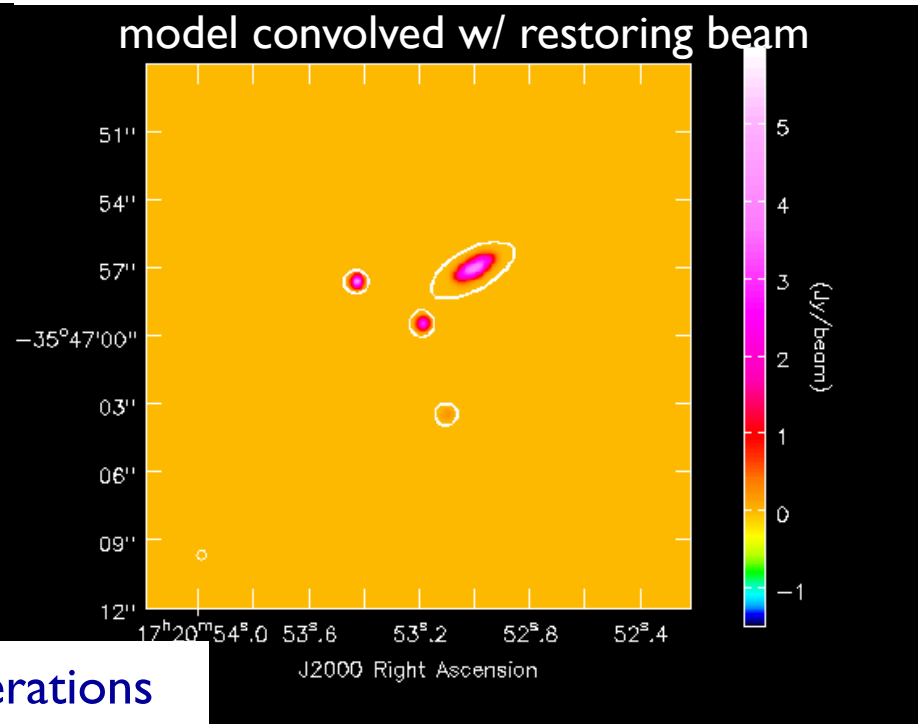
60 iterations



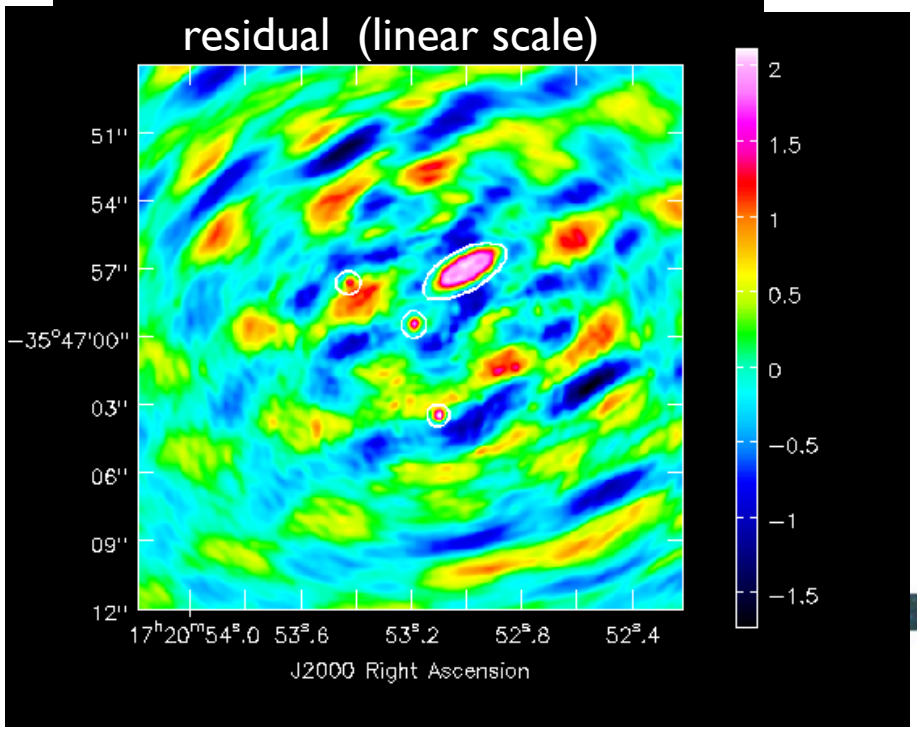


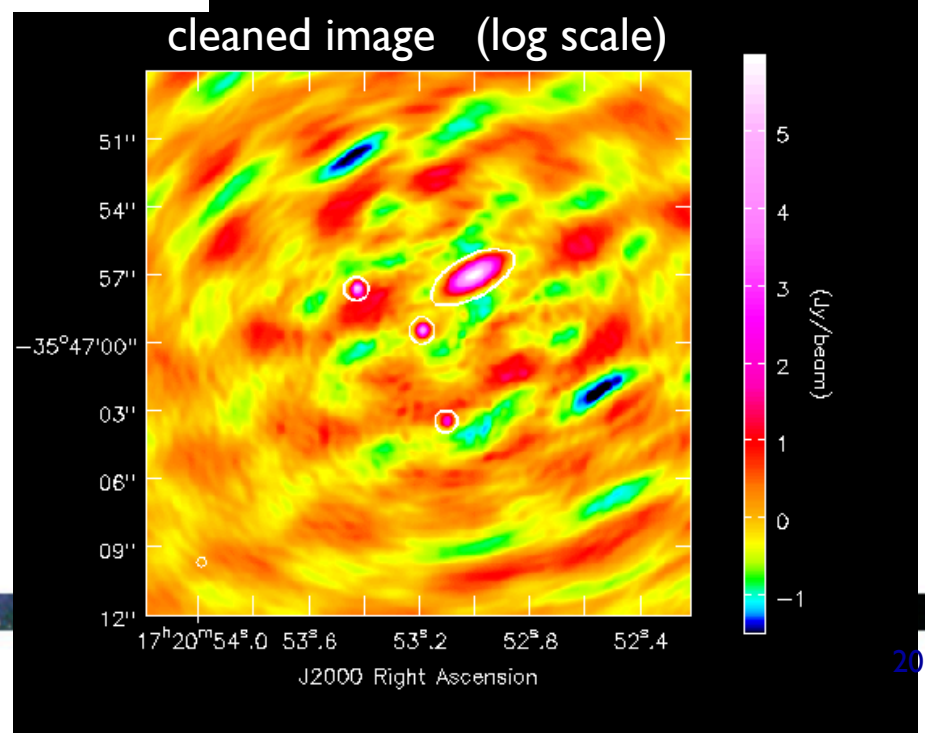

residual (log scale)
model convolved w/ restoring beam
70 iterations
residual (linear scale)
cleaned image (log scale)
J2000 Right Ascension
(Jy/beam)

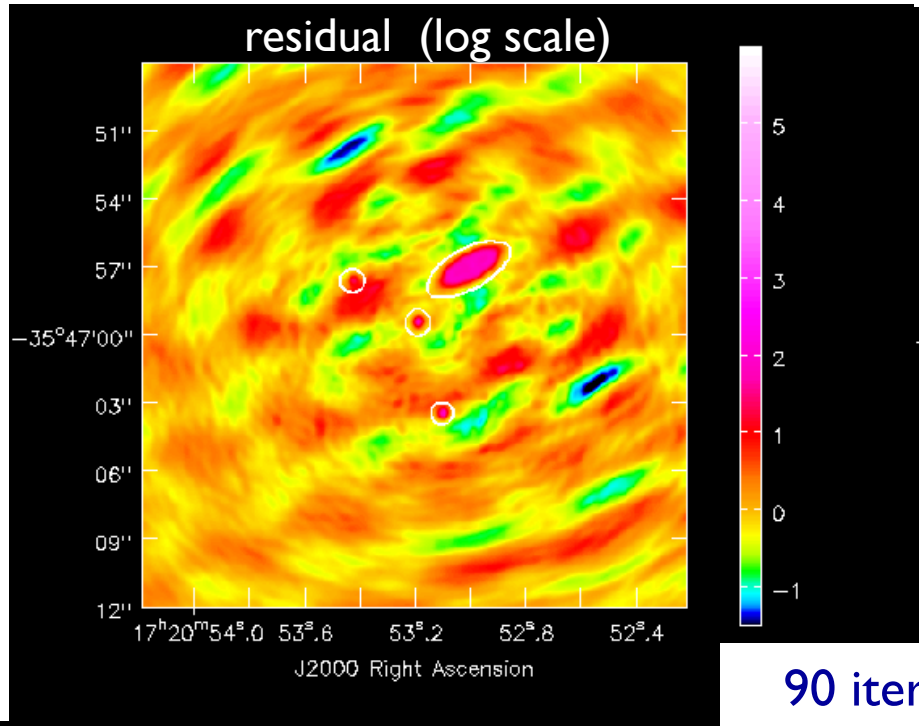


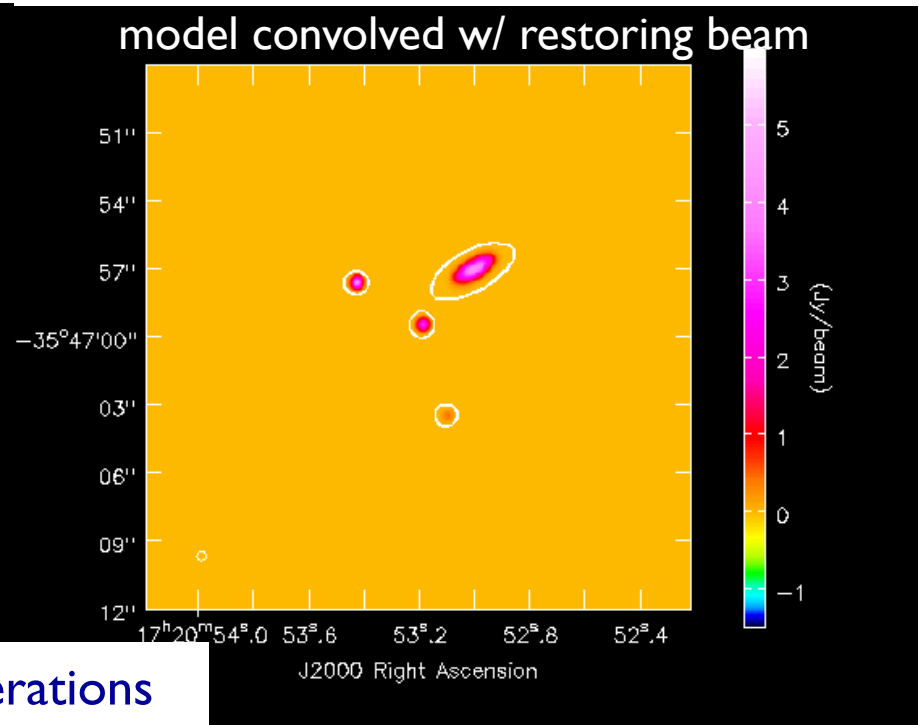


80 iterations

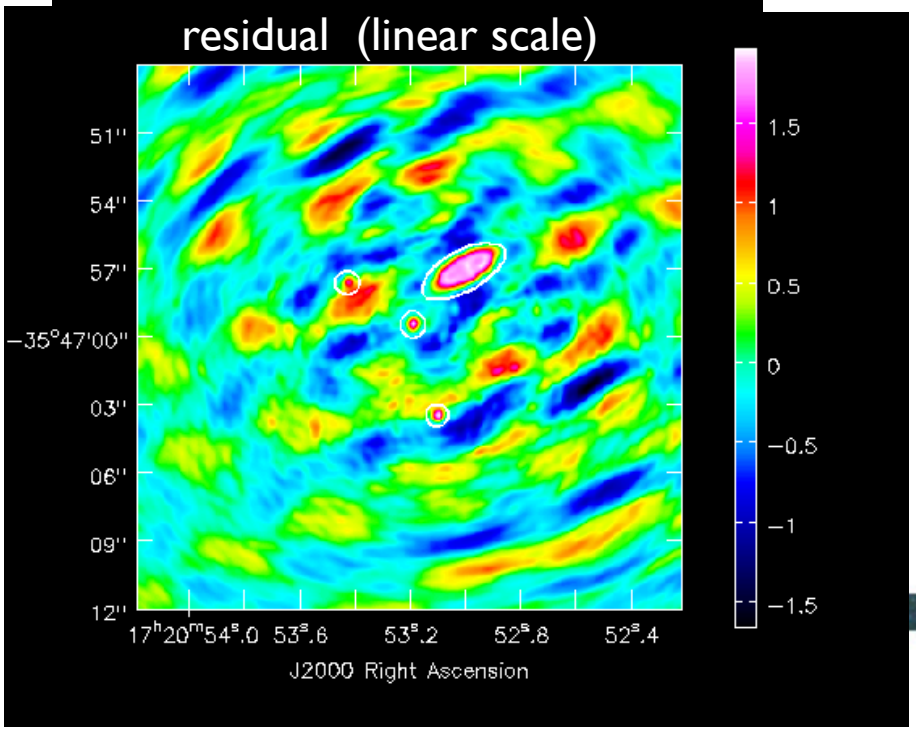


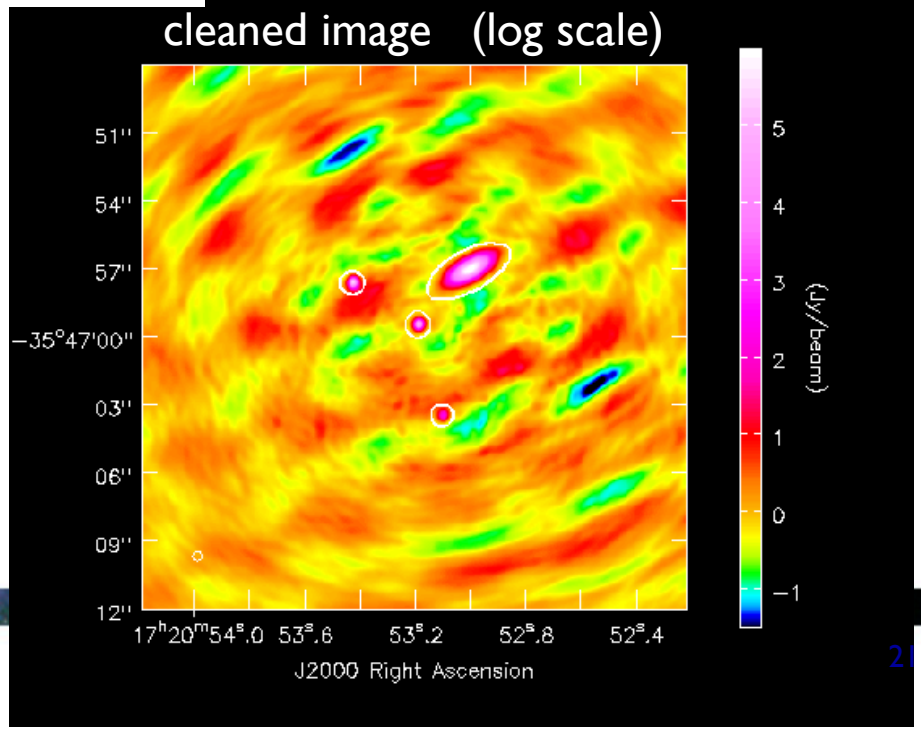


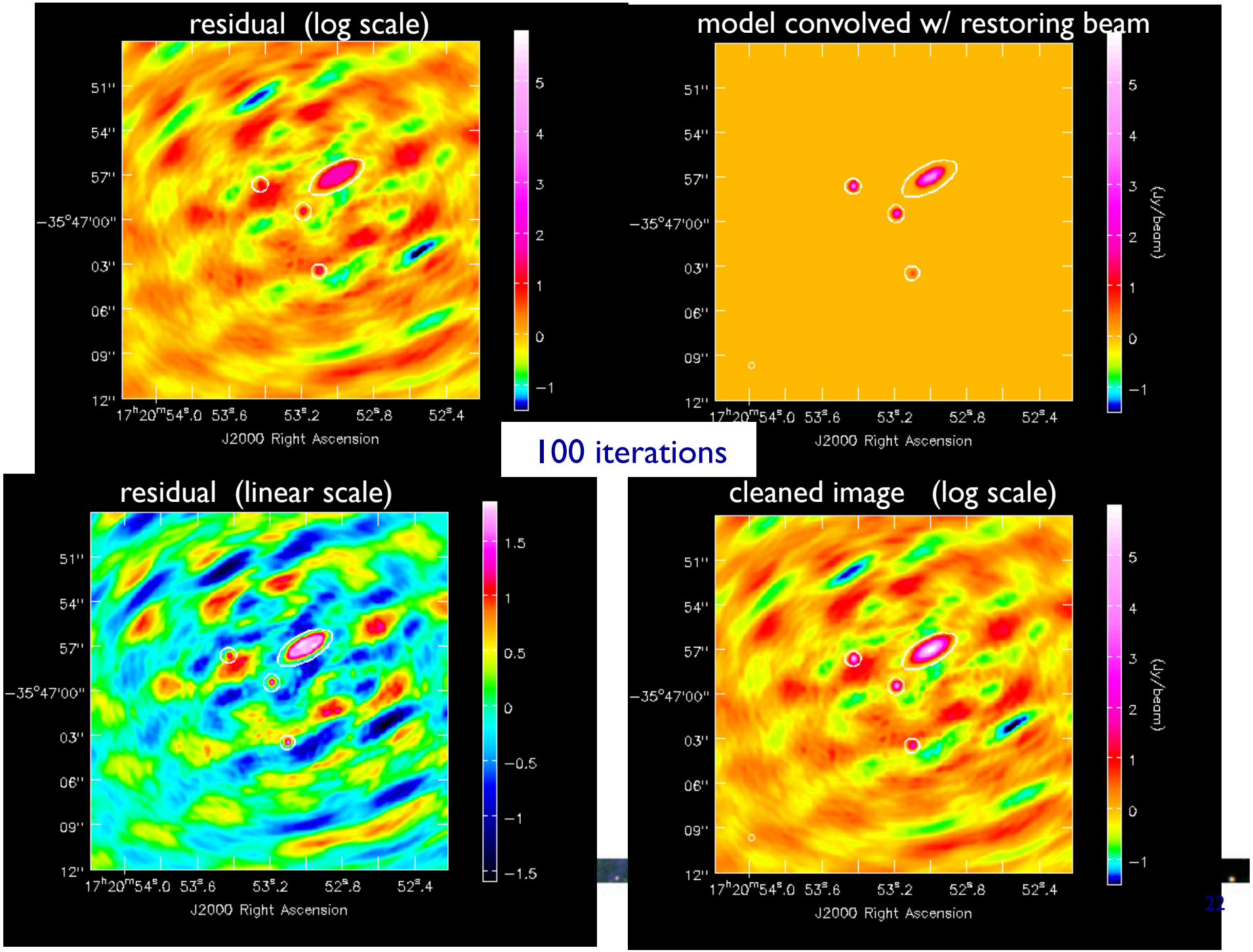


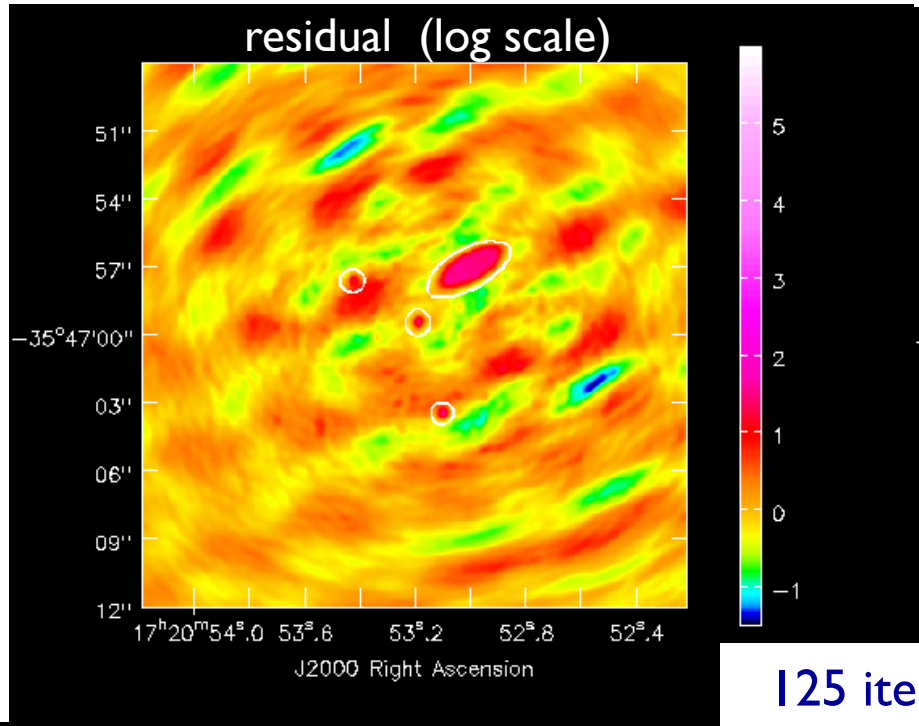


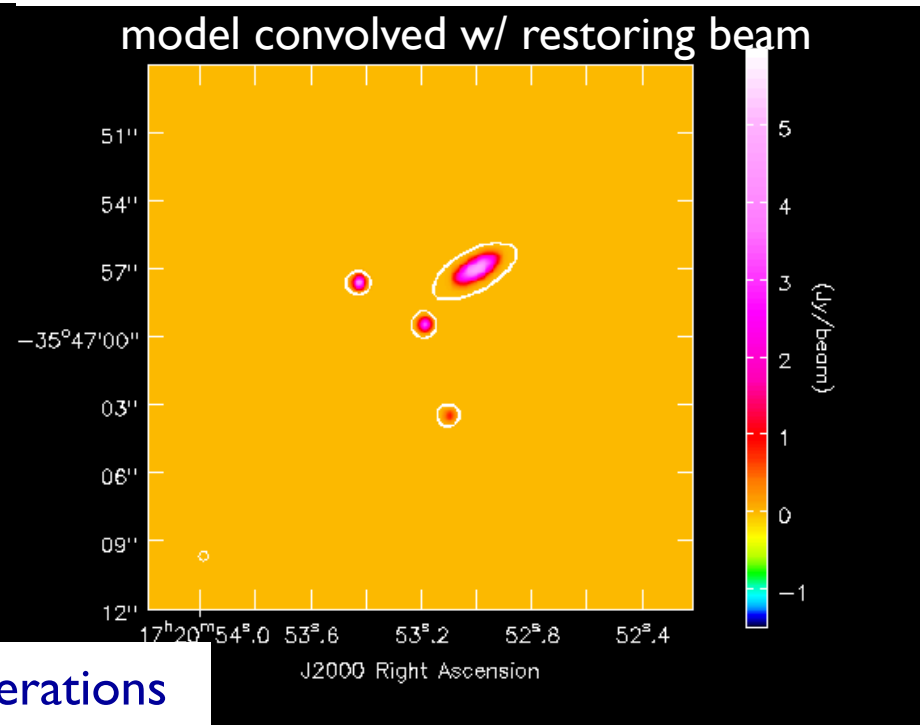
90 iterations



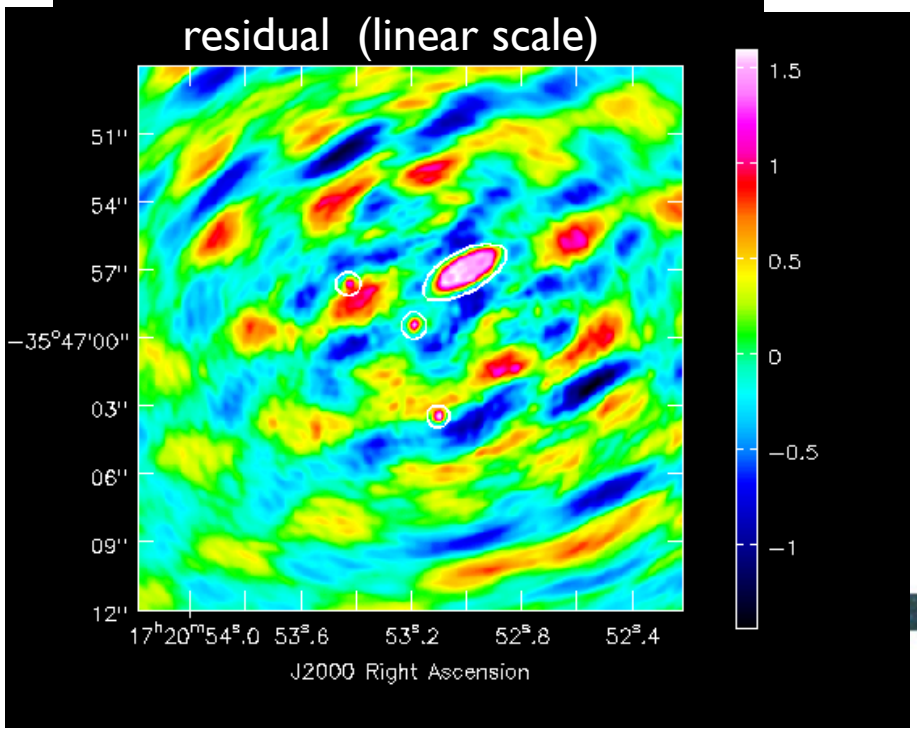


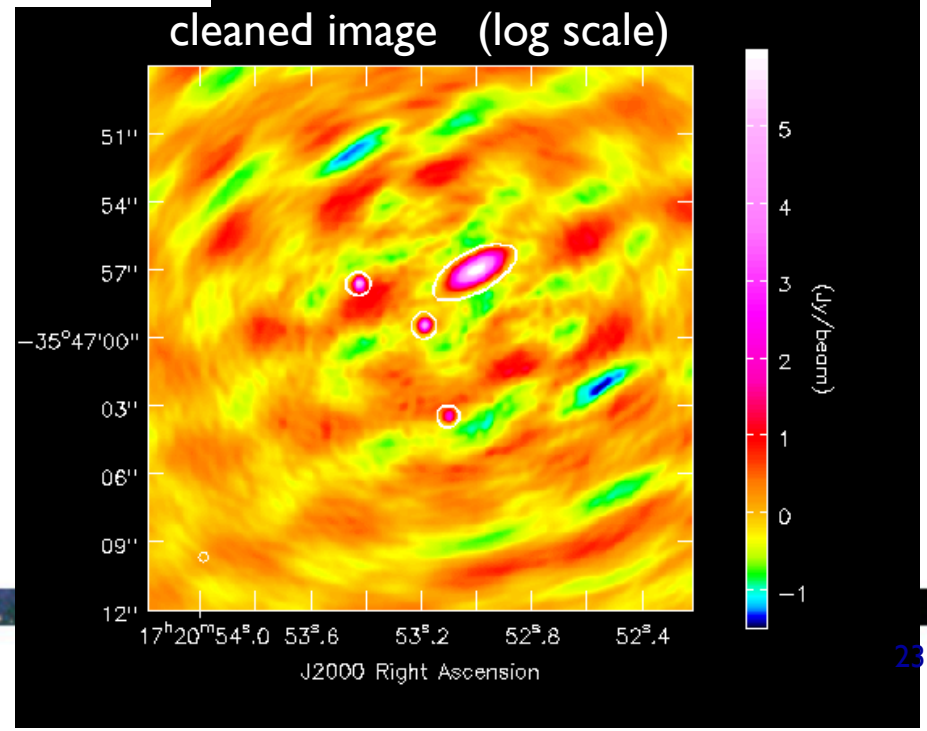

residual (log scale)
model convolved w/ restoring beam
100 iterations
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)

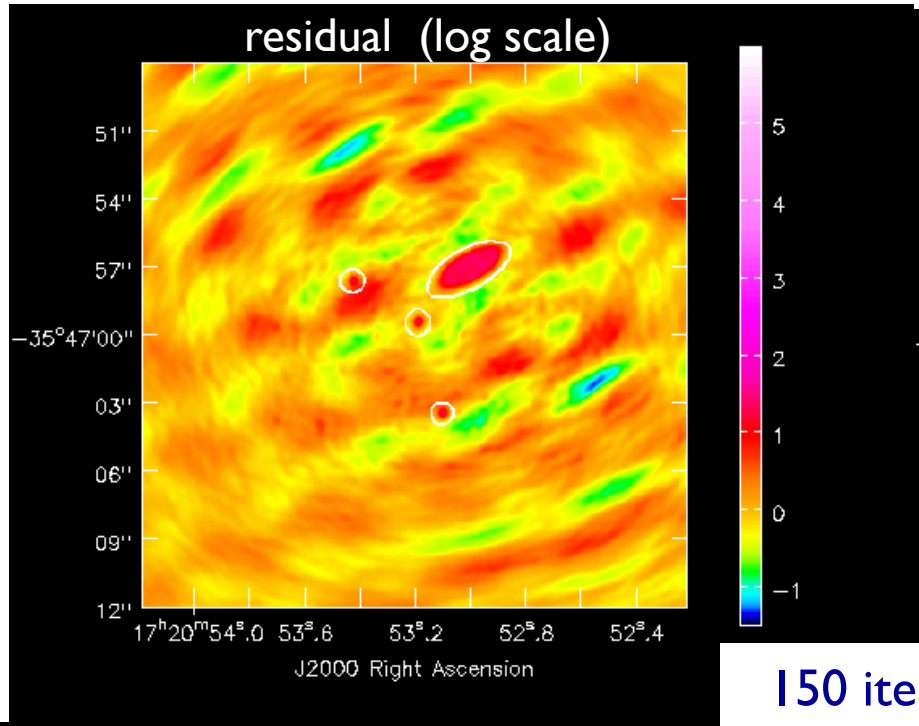


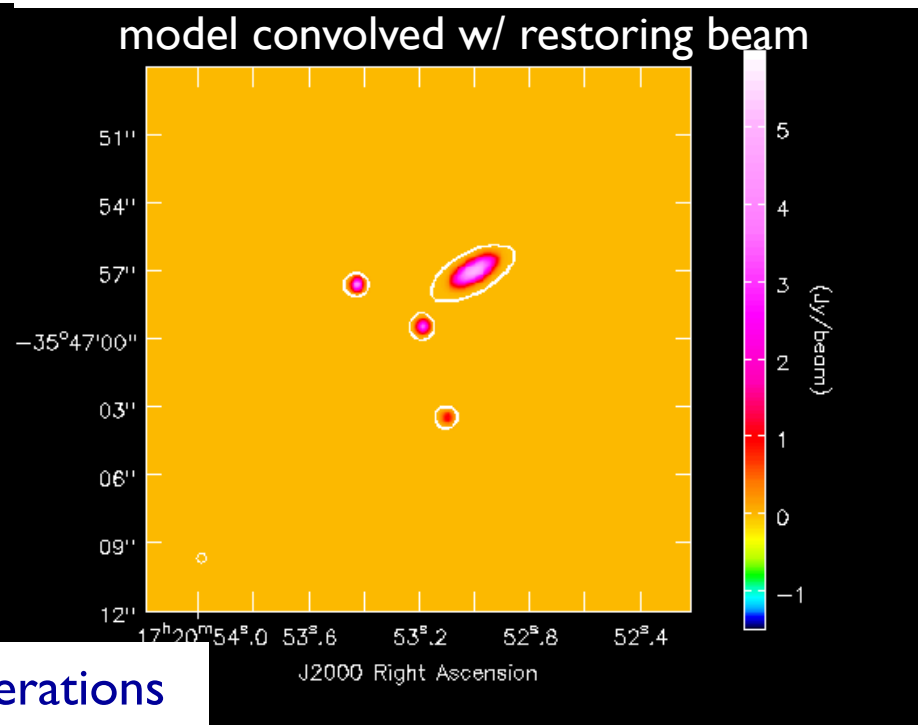


125 iterations

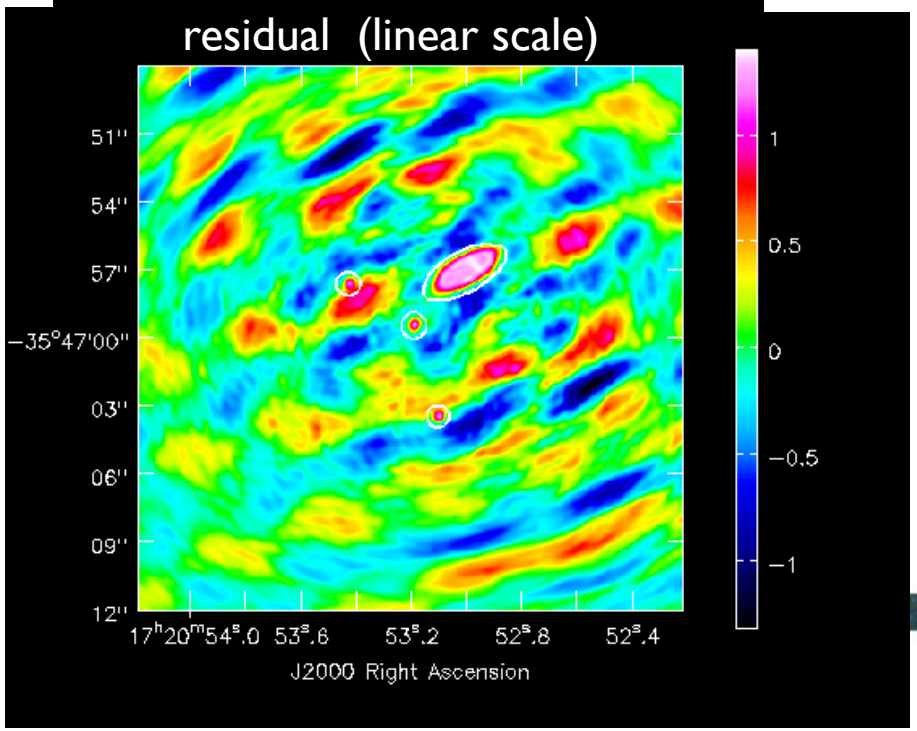


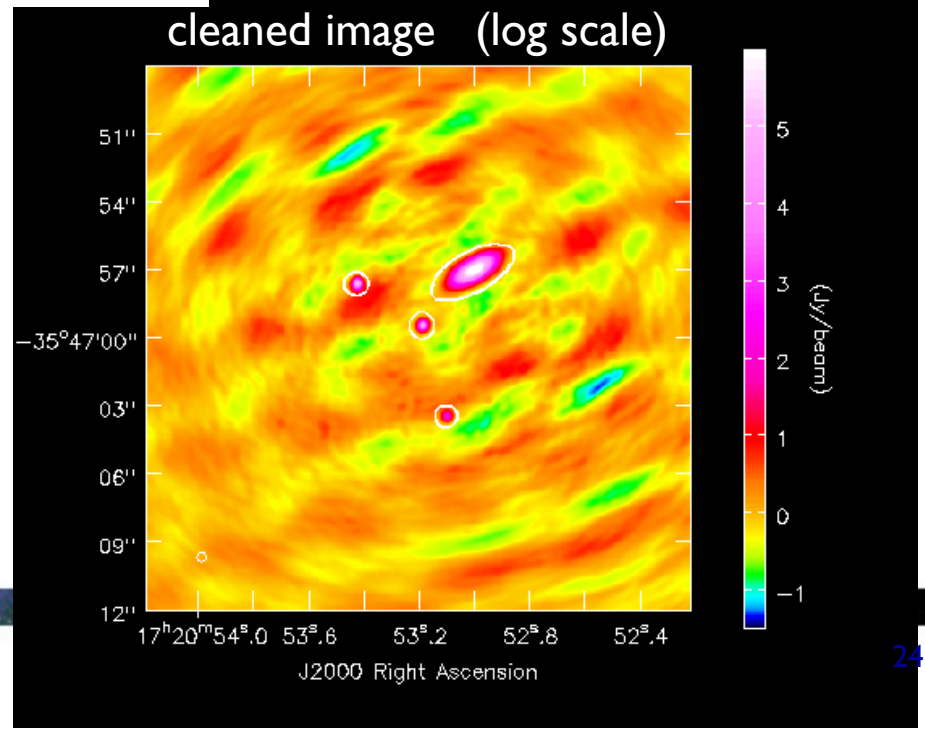


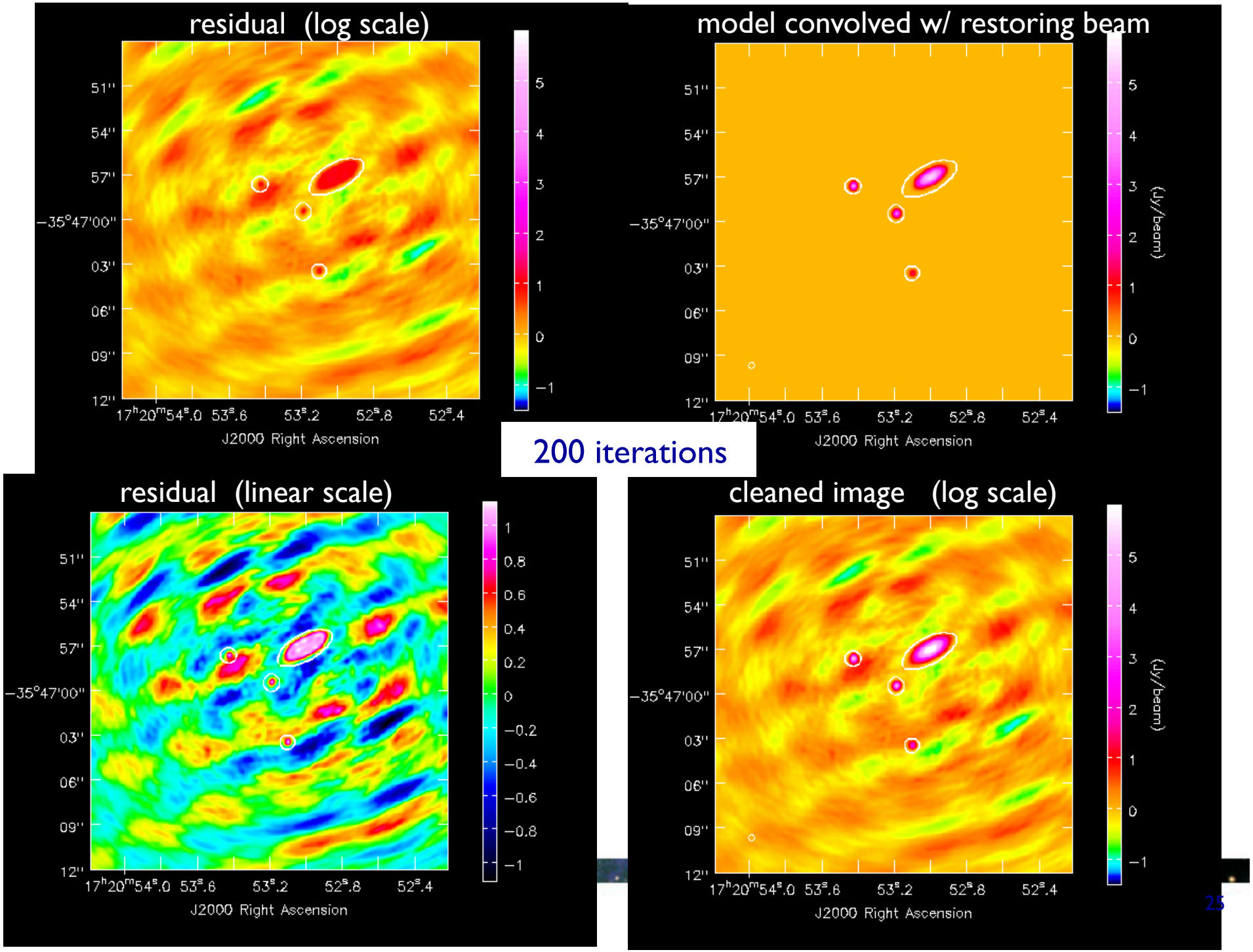


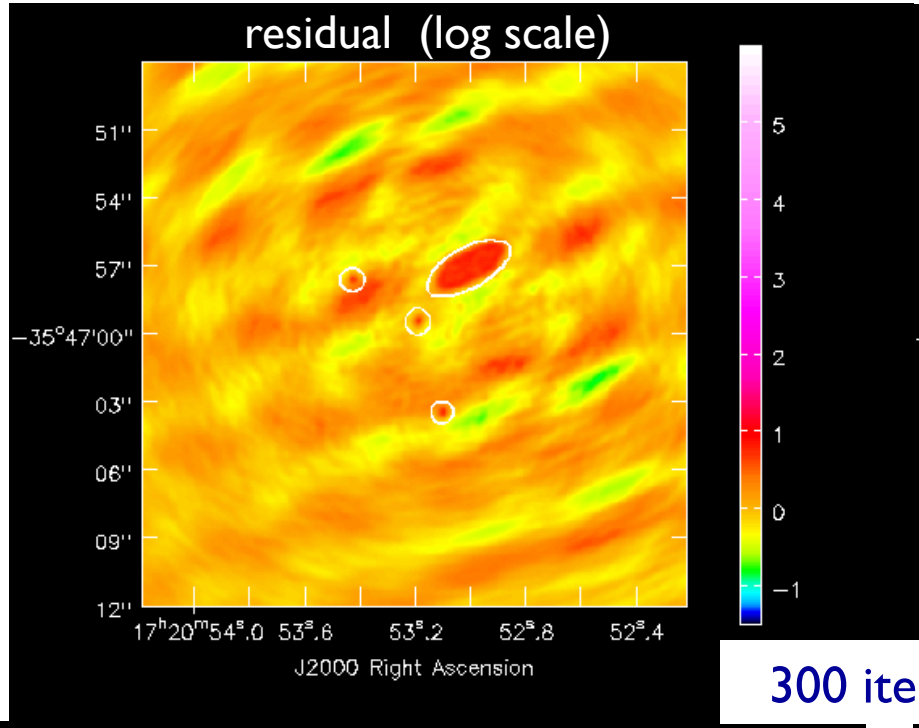


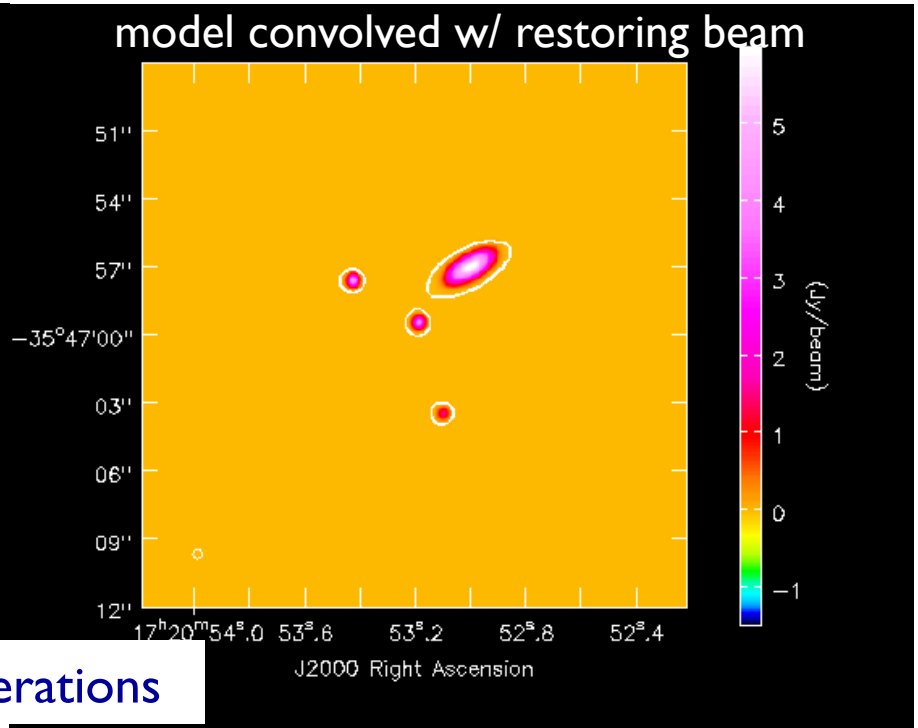
150 iterations



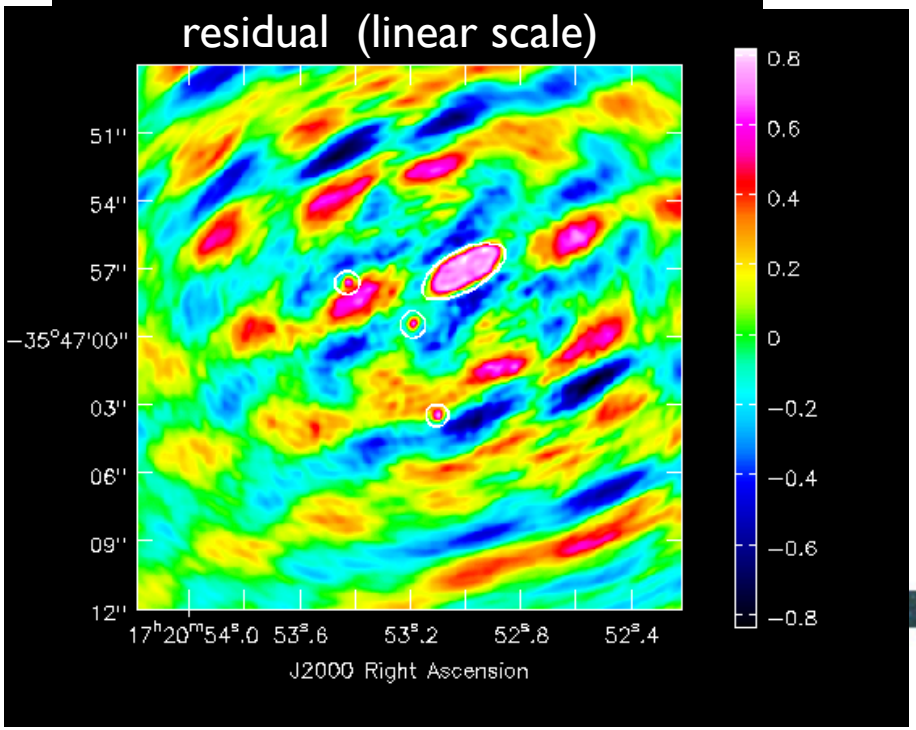


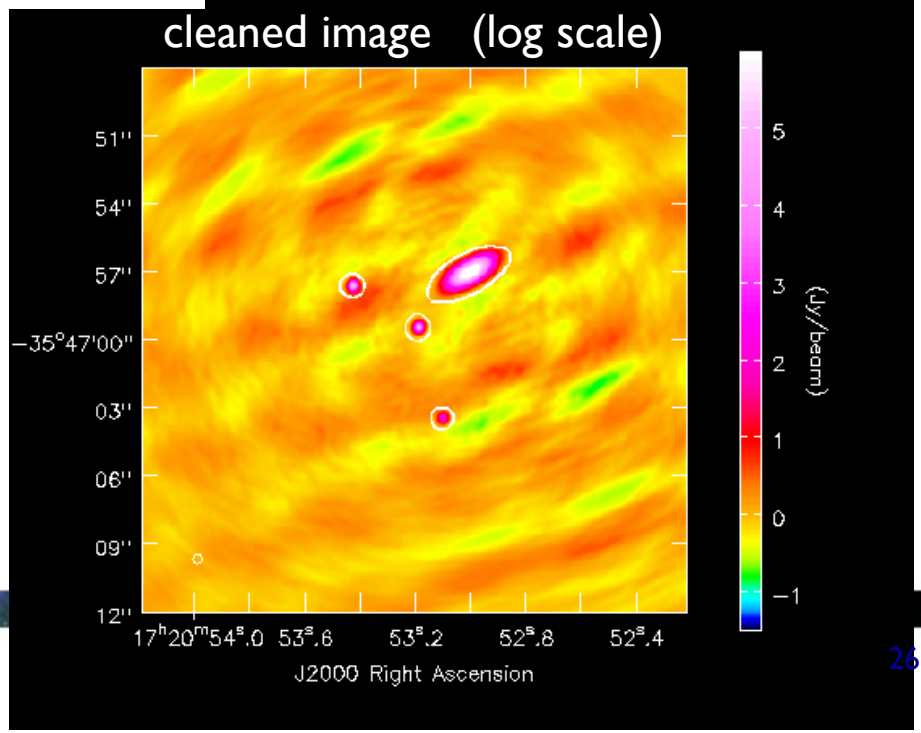

residual (log scale)
model convolved w/ restoring beam
200 iterations
residual (linear scale)
cleaned image (log scale)
51''
54''
57''
−35°47'00''
03''
06''
09''
12''
17h20m54s.0 53s.6 53s.2 52s.8 52s.4
J2000 Right Ascension
(Jy/beam)

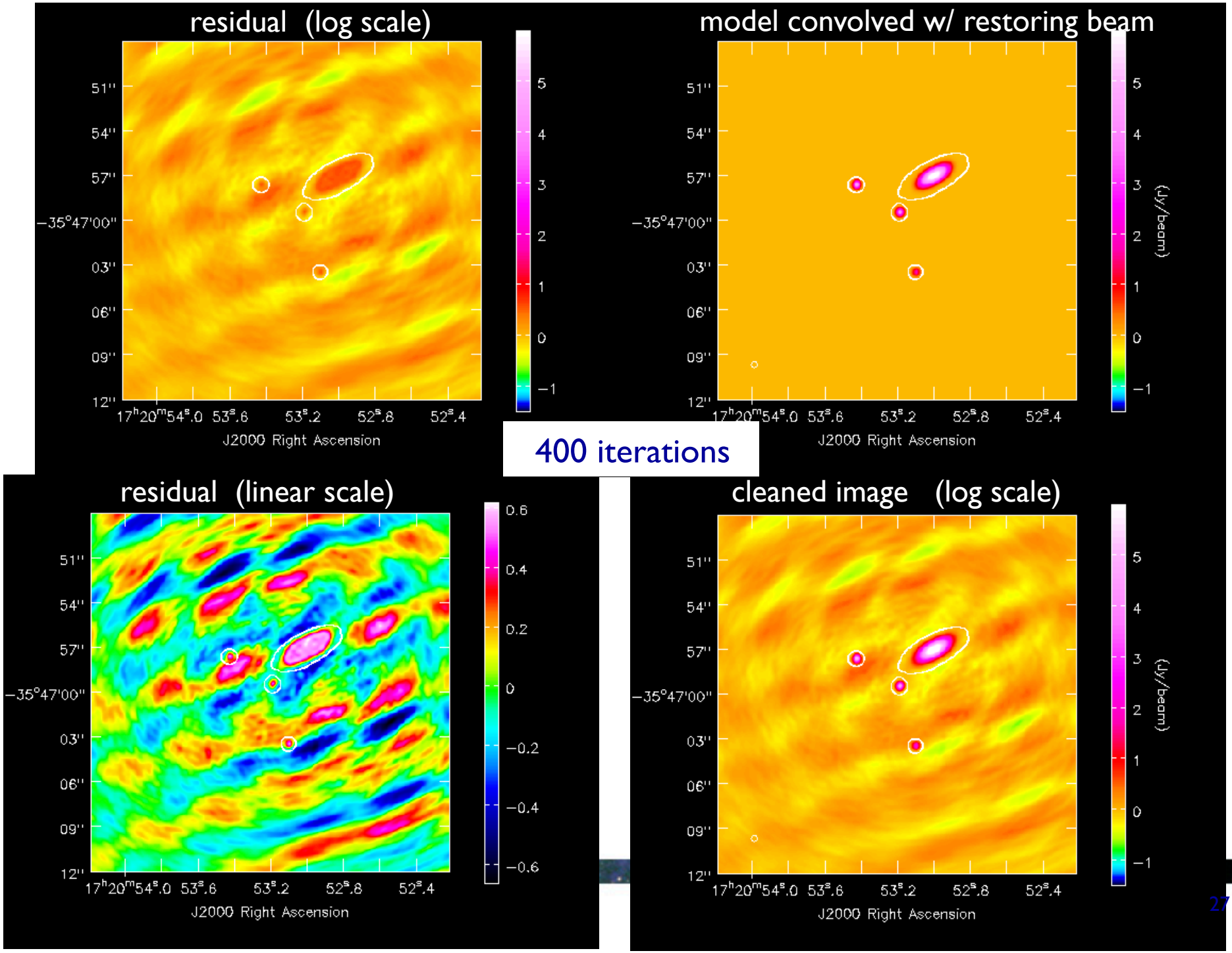


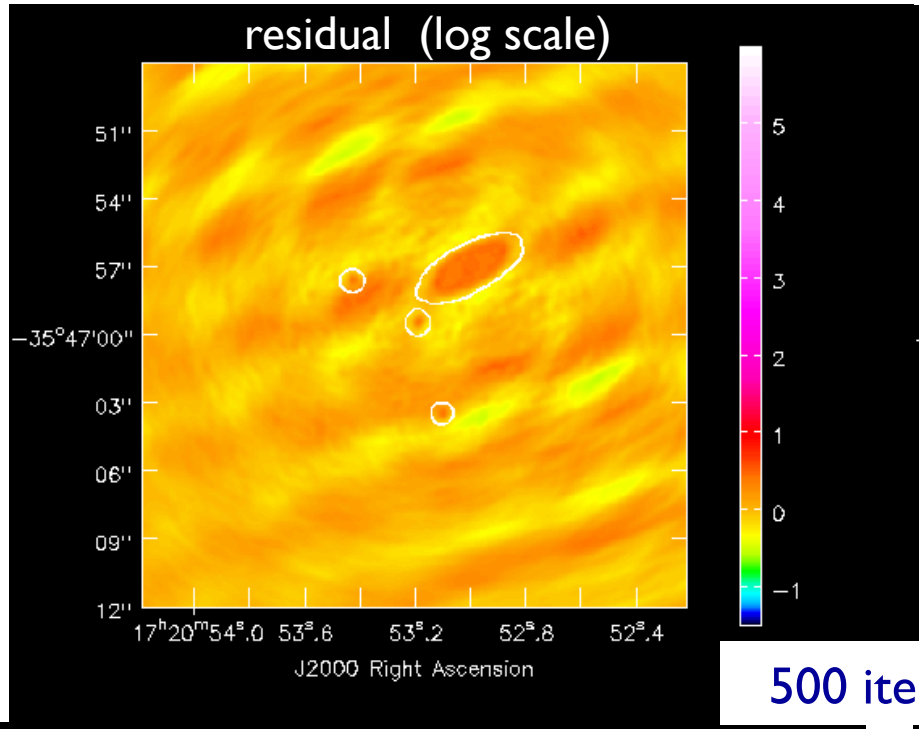


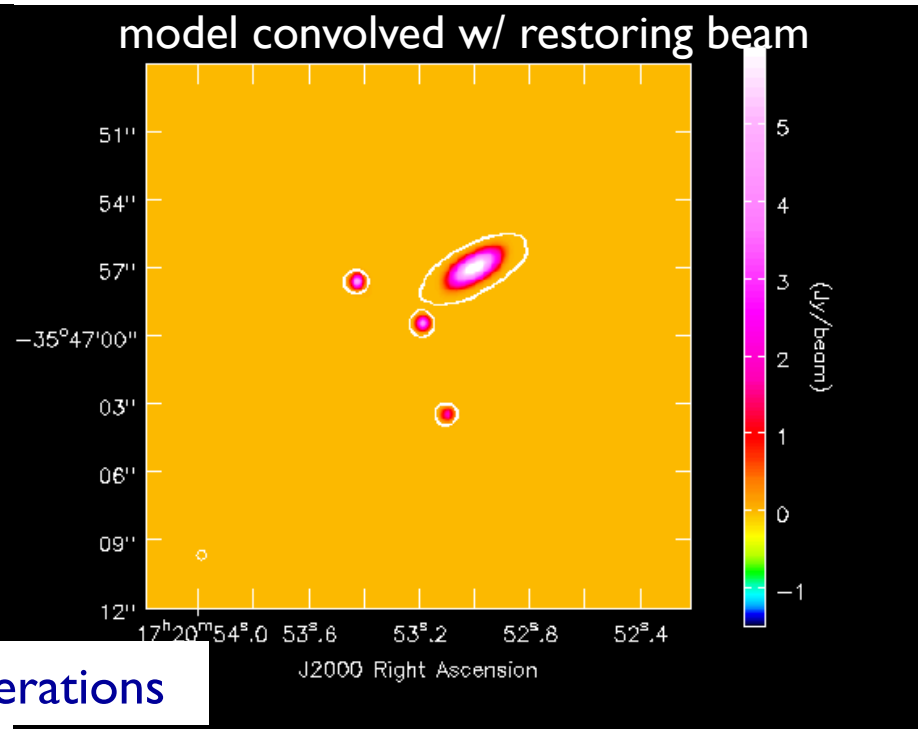
300 iterations



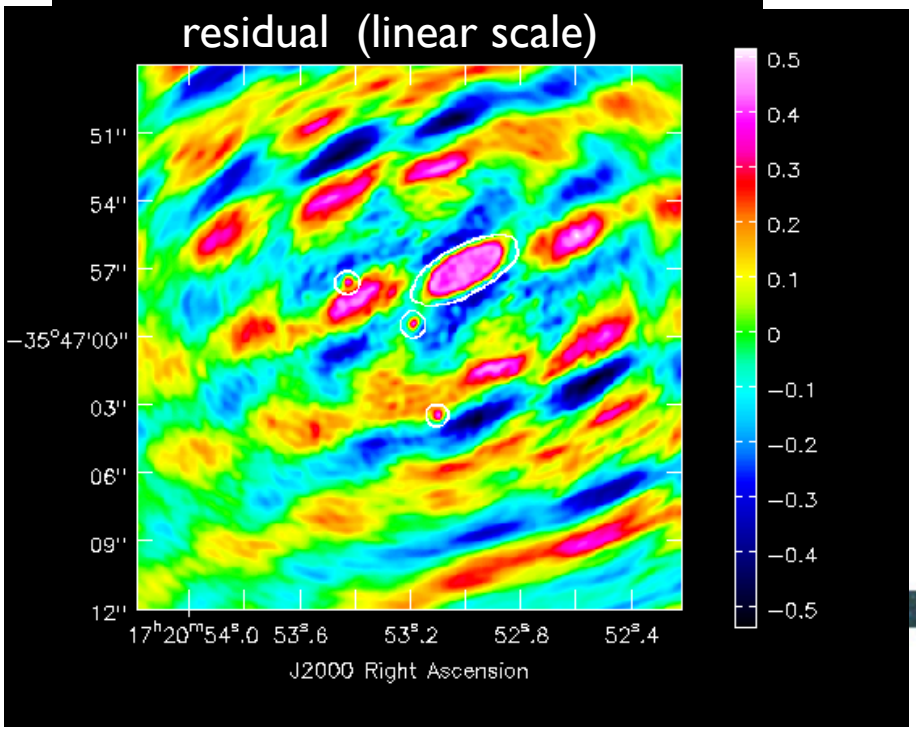


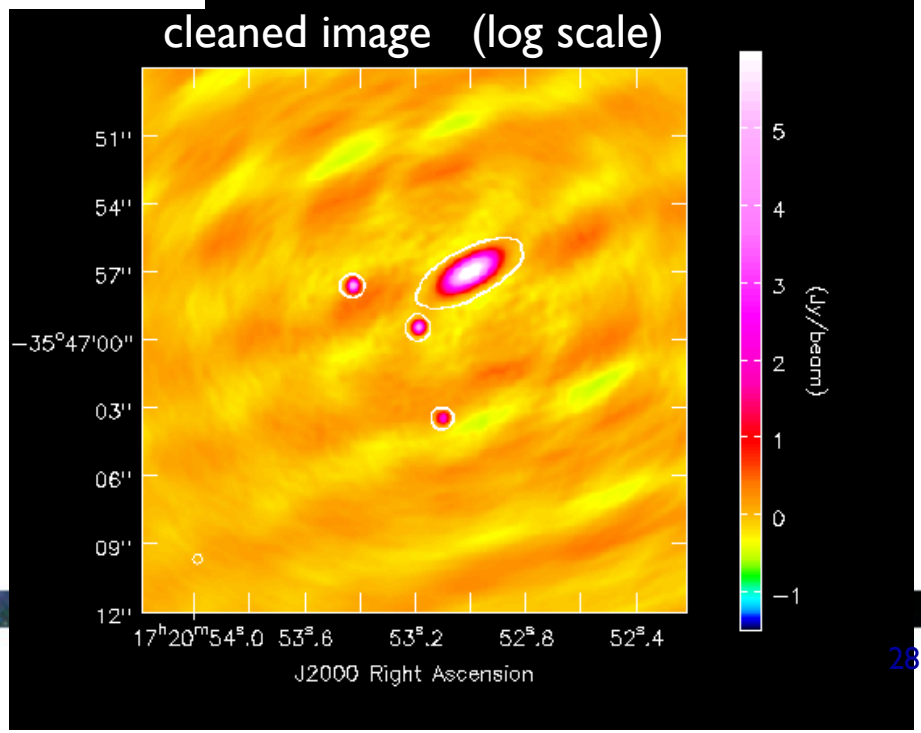

residual (log scale)
model convolved w/ restoring beam
400 iterations
residual (linear scale)
cleaned image (log scale)
J2000 Right Ascension
(Jy/beam)

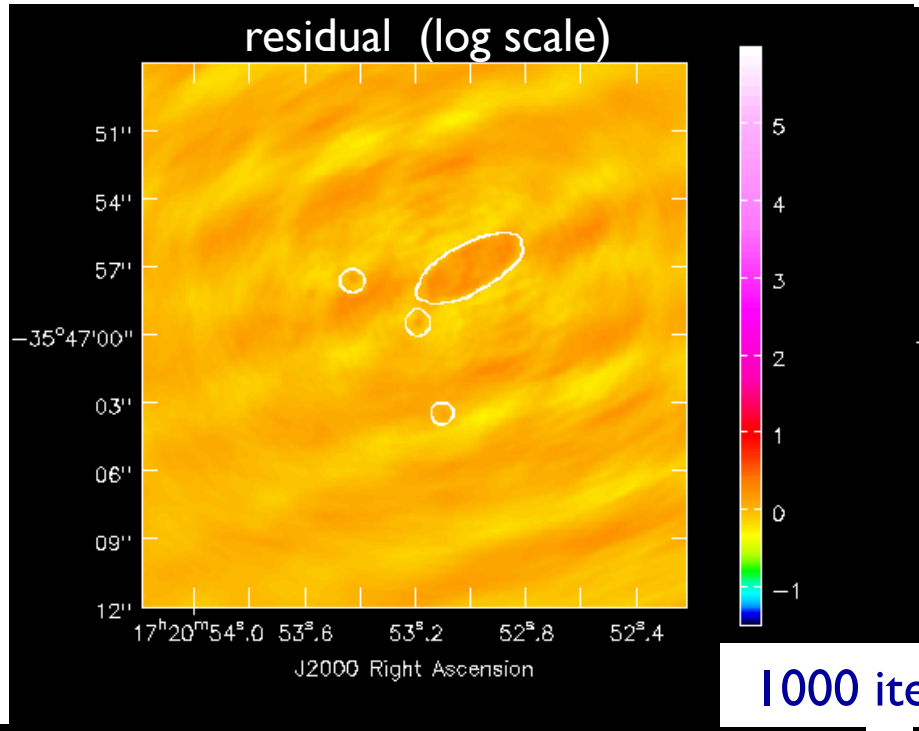


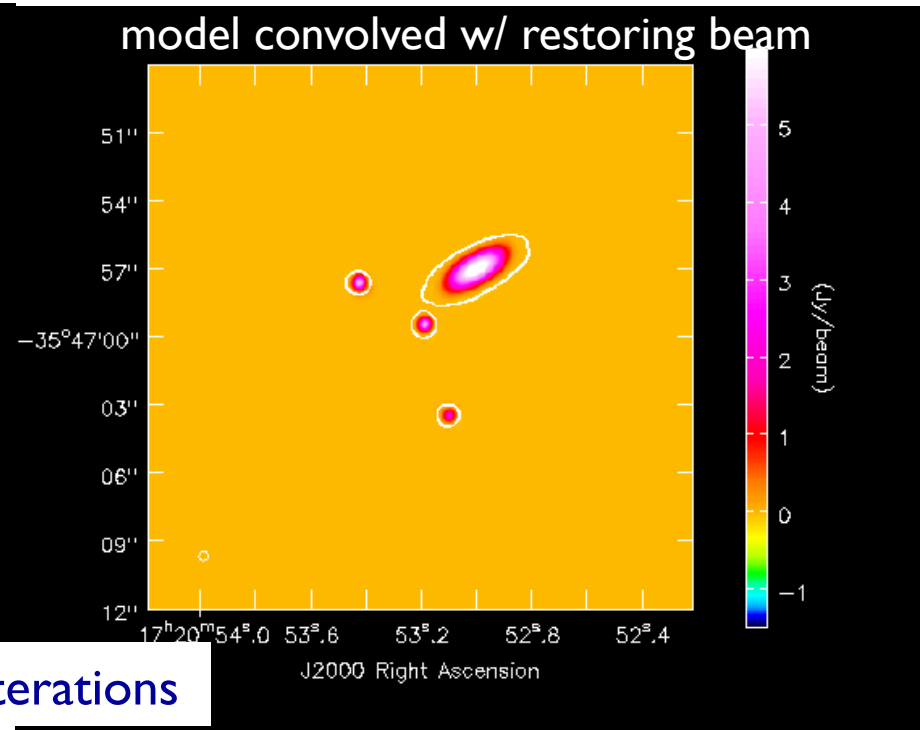


500 iterations

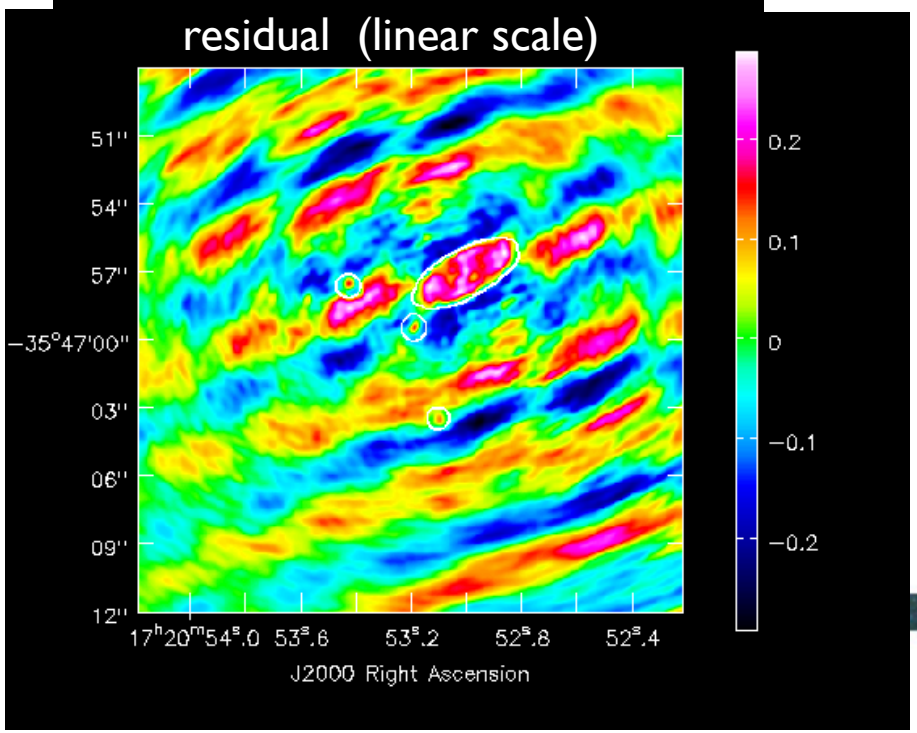


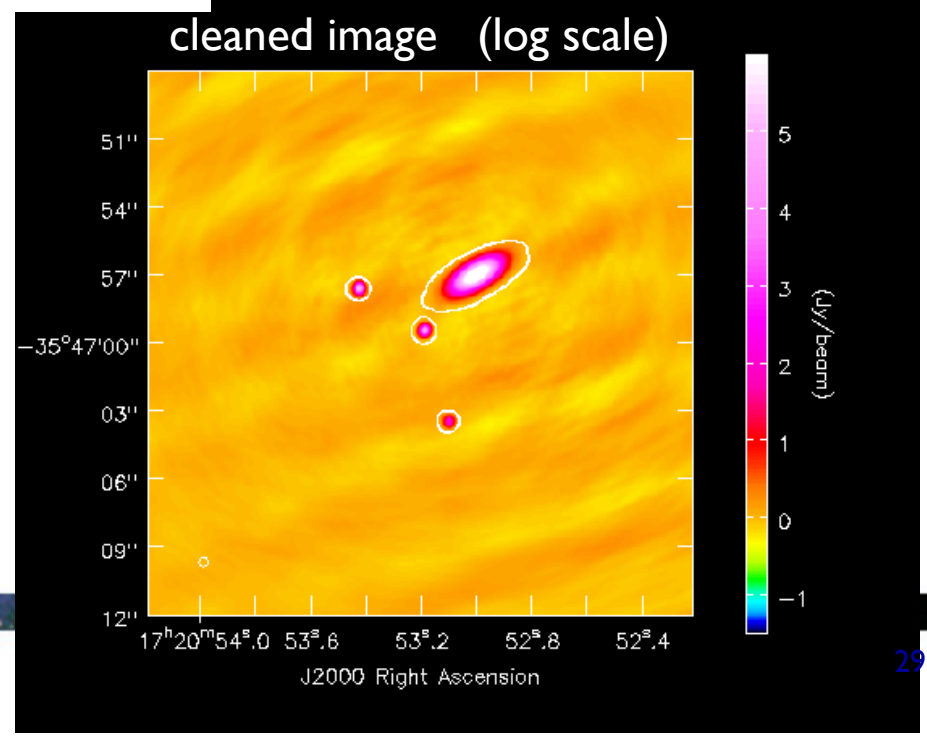


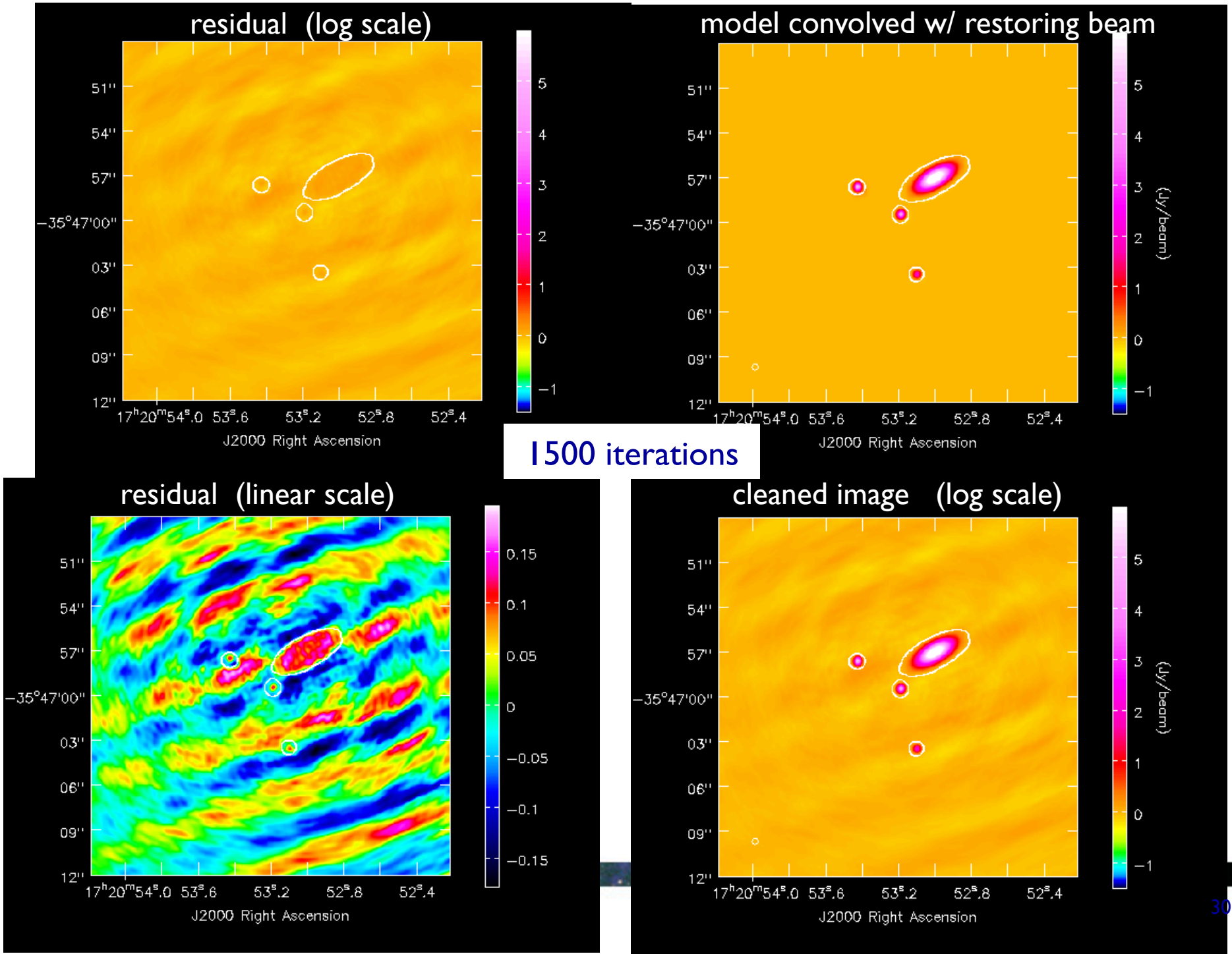




1000 iterations

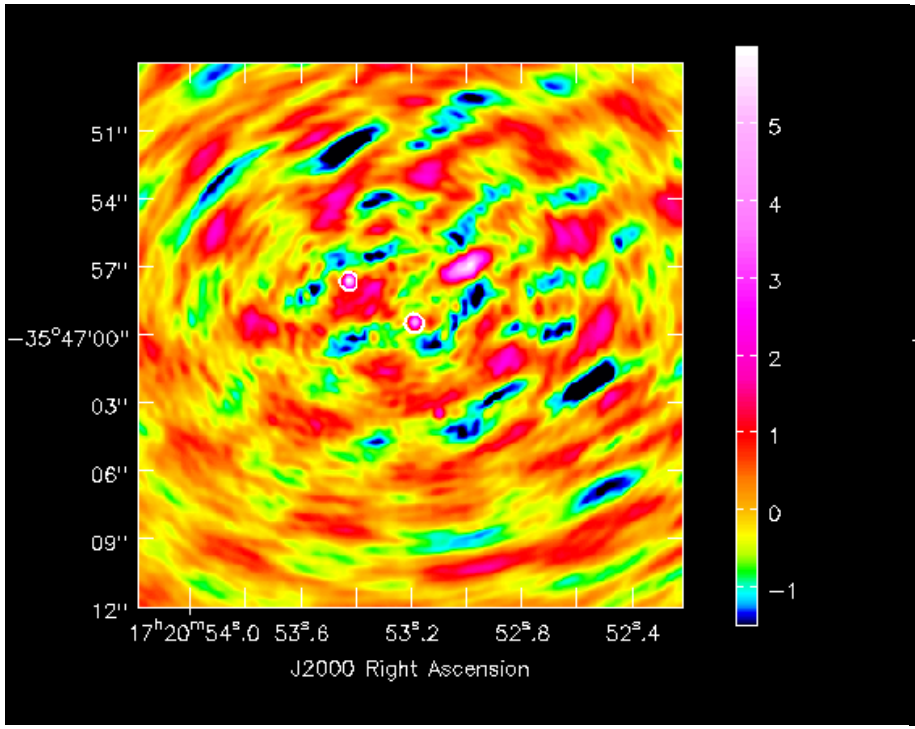




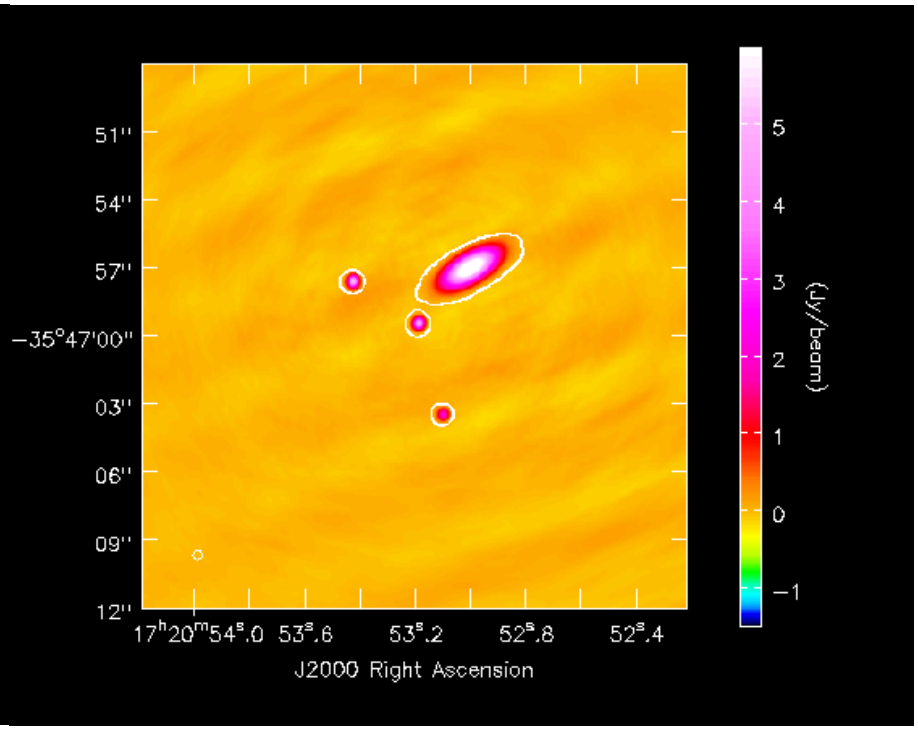

residual (log scale)
model convolved w/ restoring beam
1500 iterations
residual (linear scale)
cleaned image (log scale)
J2000 Right Ascension
(Jy/beam)

clean: Deconvolution

DIRTY IMAGE (LOG SCALE)



CLEANED IMAGE (LOG SCALE)

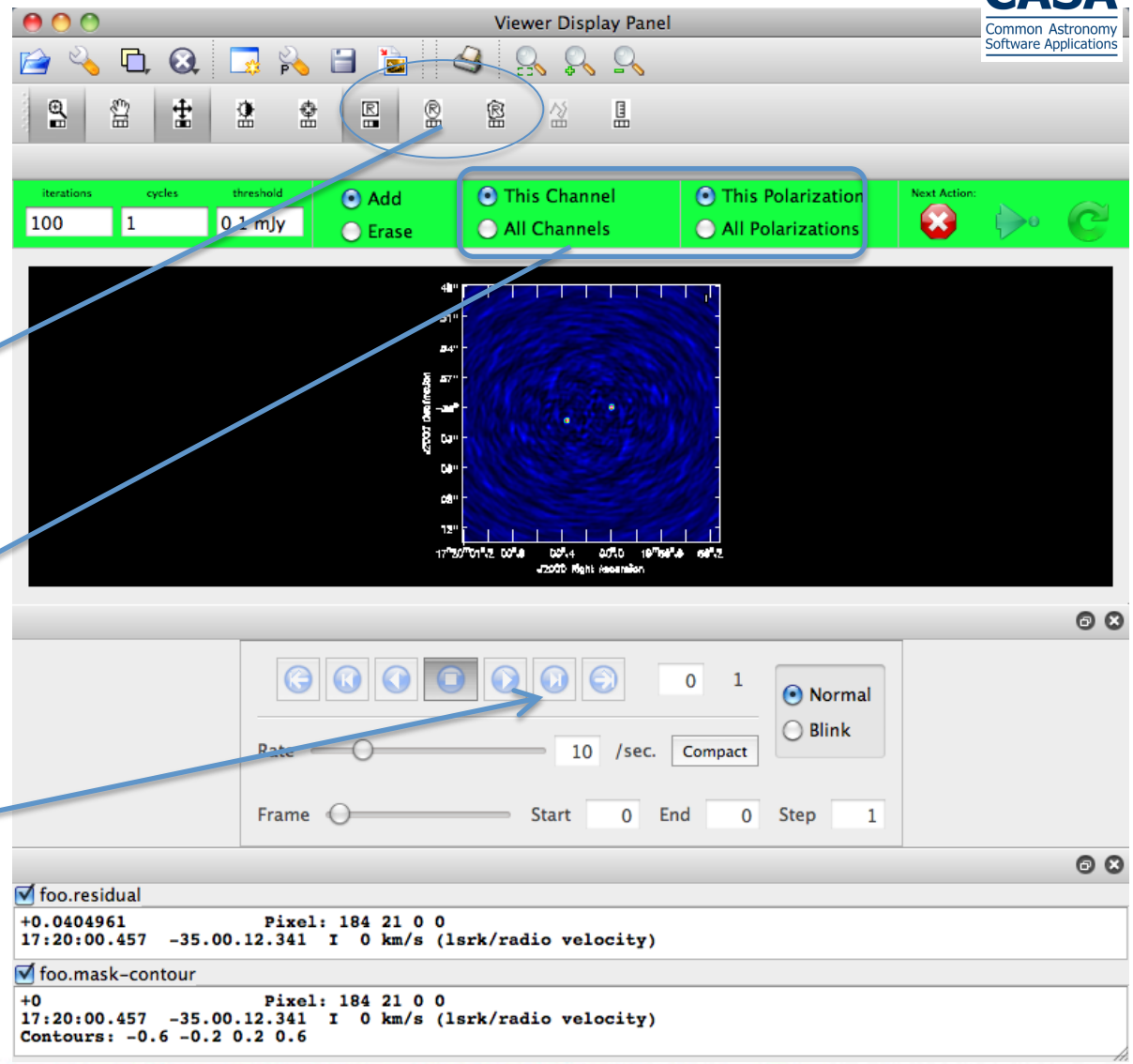


`clean`: Deconvolution

- Key decisions:
  - Constraining where the signal can be (clean boxing)
    MANUALLY USING THE VIEWER OR INPUT AS AN IMAGE OR REGION
  - Setting stopping threshold
    TYPICALLY A SMALL NUMBER TIMES THE RMS NOISE
  - Number of iterations allowed
    NOT USUALLY A GOOD CRITERIA TO STOP
  - Deconvolution algorithm
    BALANCE OF MAJOR/MINOR CYCLES, ETC.

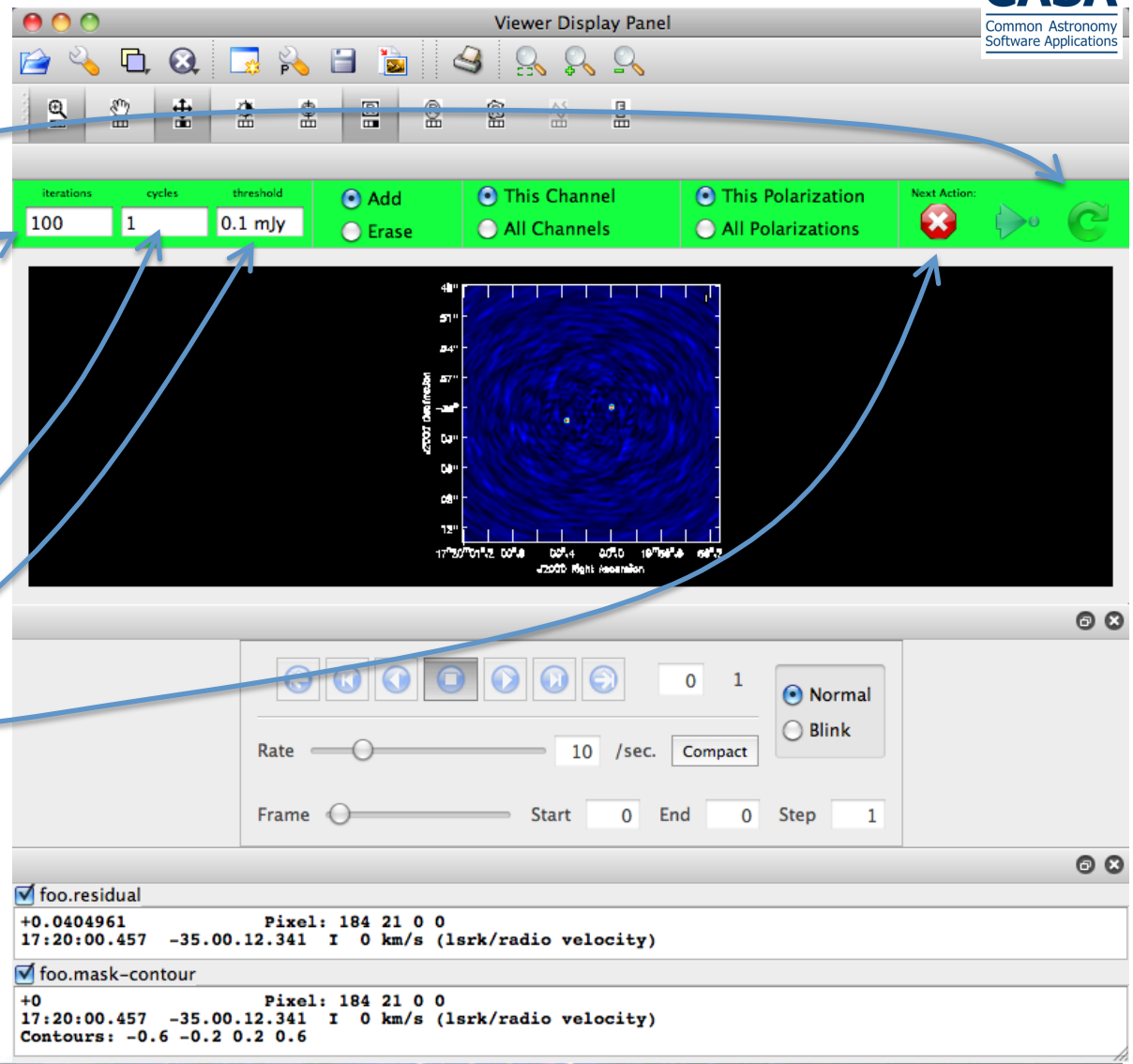
Interactive clean

- residual image in viewer
- define a mask with R-click on shape type
- define the same mask for all channels
- or iterate through the channels with the tape deck and define separate masks



Interactive clean

- perform N iterations
- and return – every time the residual is displayed is a major cycle
- continue until #cycles or threshold reached, or user stop



`clean`: Notes

- `clean` restarts from existing files
  WILL FIRST RECOMPUTE RESIDUALS FROM MODEL

- The mask image, in particular, can be reused
  BE CAREFUL OF IMSIZE – MASK MUST MATCH IMAGE

- don't hit `^C` while imaging – this can do bad things to your MS

Self-Calibration in CASA

- "Self-calibration" is just regular calibration
- With a model of your source, you can calibrate on your source
- Requires that your source is bright enough
  NEEDED TO GET SUFFICIENT S/N; GET SOME S/N BACK TIME AVERAGING.
- Can be iterated as model improves
  USUALLY PHASE-ONLY SELFCAL FIRST, AMPLITUDE SELFCAL LATER (IF AT ALL)

Self-Calibration in CASA

Image your source, deconvolve build a model, place model in MS

`clean`

Initial Image

Measurement Set

Now has associated model.

Calibrate to match data to model

`gaincal`

Phase Calibration Table
Amplitude Calibration Table

Apply the new calibration

`applycal`

Measurement Set

Improved corrected column.

Re-image the better-calibrated data

`clean`

Improved Image

Self-Calibration in practice

- Initial round of cleaning
  CAREFUL NOT TO OVERDO IT: THE SELF CALIBRATION CAN "LOCK IN" ARTIFACTS

- Experiment with solution interval (`solint`)
  S/N USUALLY LIMITING CONCERN, TRY POL. COMBINATION (`GAINTYPE='T'`)

- Inspect resulting solutions
  LOOK FOR SMOOTH TRENDS OF PHASE, AMP. WITH TIME

- May take multiple iterations
  MODEL WILL SUCCESSIVELY IMPROVE, START WITH PHASE, THEN TRY AMPLITUDE

Your Turn

- Follow the imaging CASA guide

http://casaguides.nrao.edu/index.php?title=TWHydraBand7_Im_SS12

- We have provided the full calibrated data set
  NO NEED TO USE THIS MORNING'S DATA, BUT YOU CAN IF YOU LIKE

- Try:
  - CONTINUUM IMAGING
  - LINE IMAGING
  - SELF-CALIBRATION AND RE-IMAGING
  - MOMENT MAP CREATION
  - IMAGING YOUR CALIBRATORS

ASK IF YOU NEED HELP!