Basic Imaging

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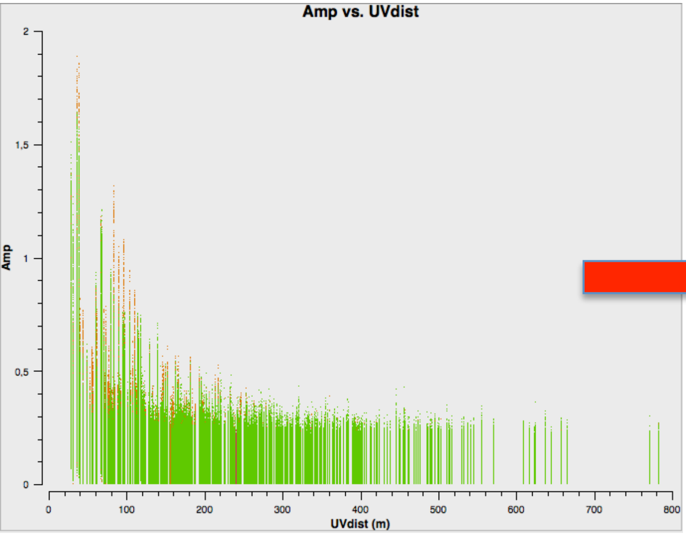
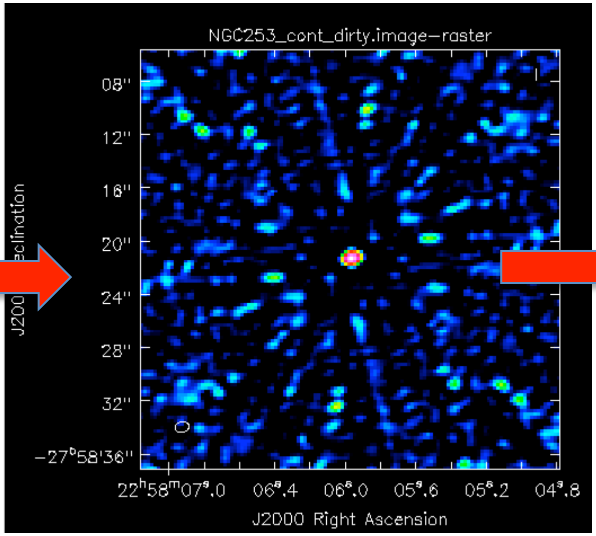
Visibilities



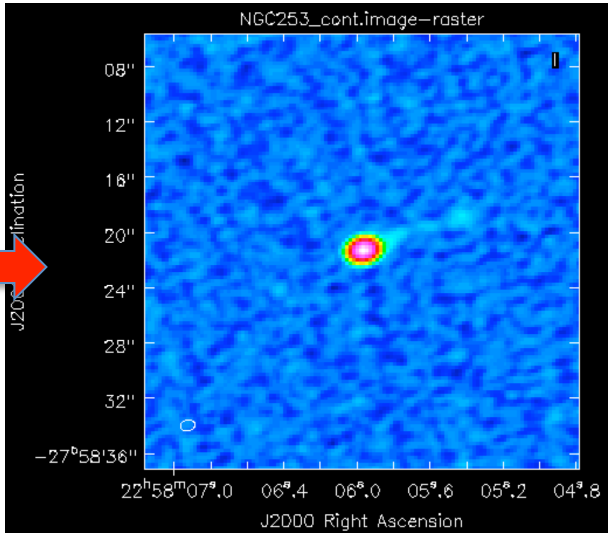
Amp vs. UV-dist

Fourier Transform



Dirty Image

Deconvolution



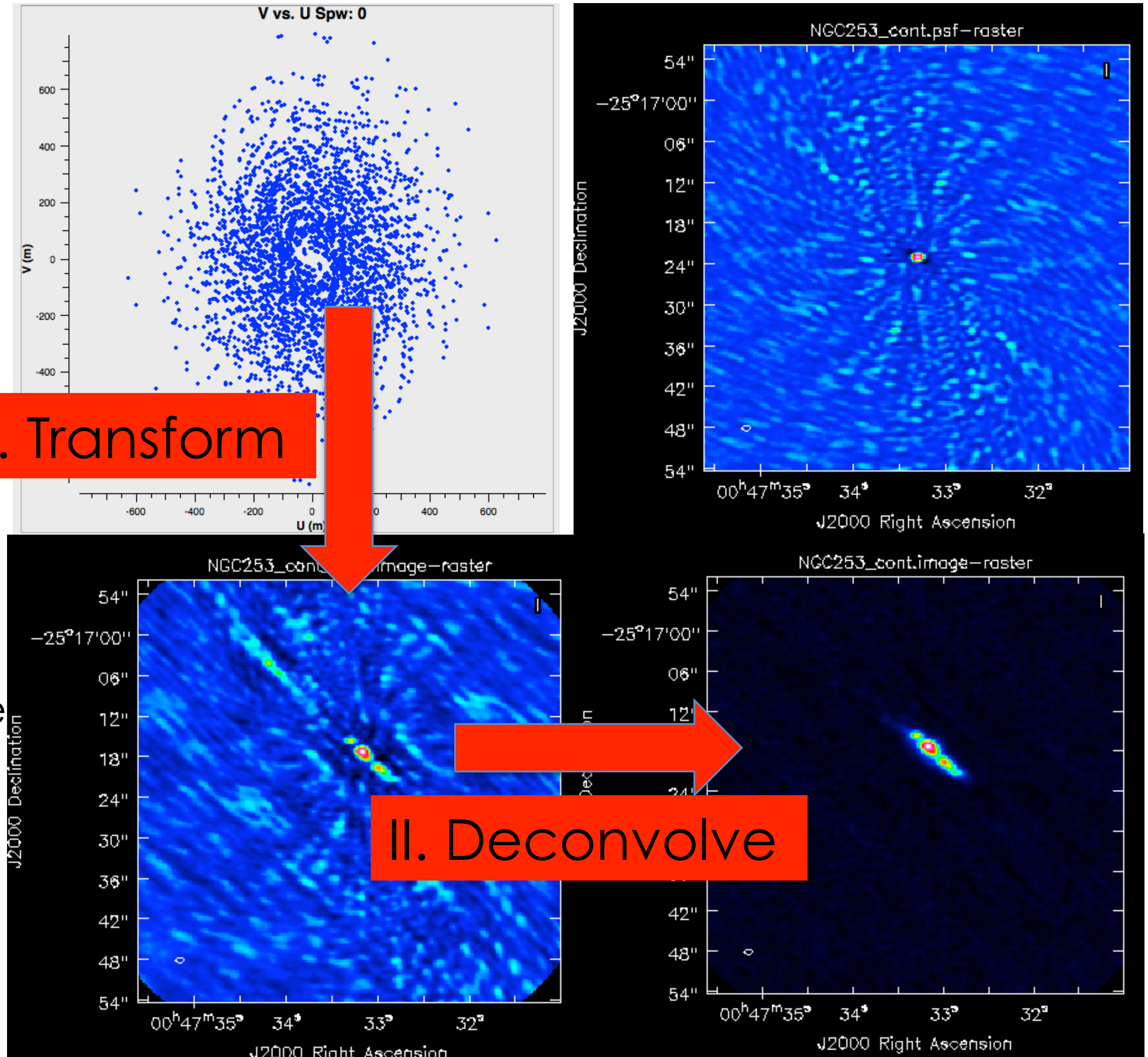
Clean Image

RadioNet

RadioNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562

Imaging Process

V(u,v)
Visibility



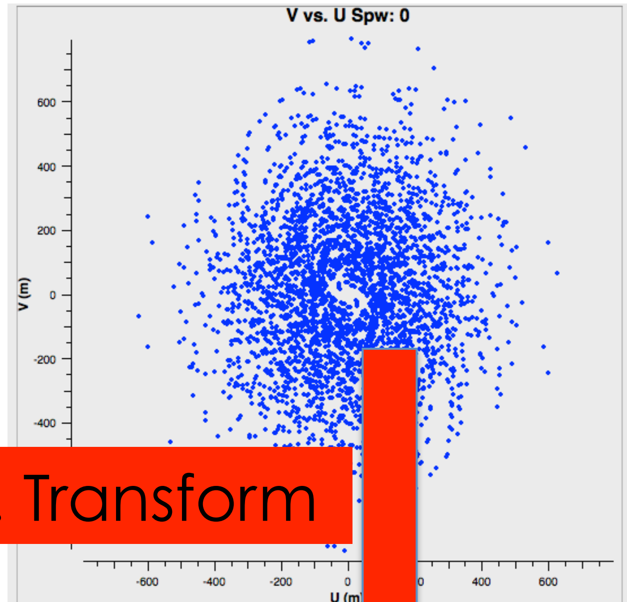
B(x,y)
Dirty Beam
Or
PSF
Point
Spread
Function

I_D(x,y)
Dirty Image

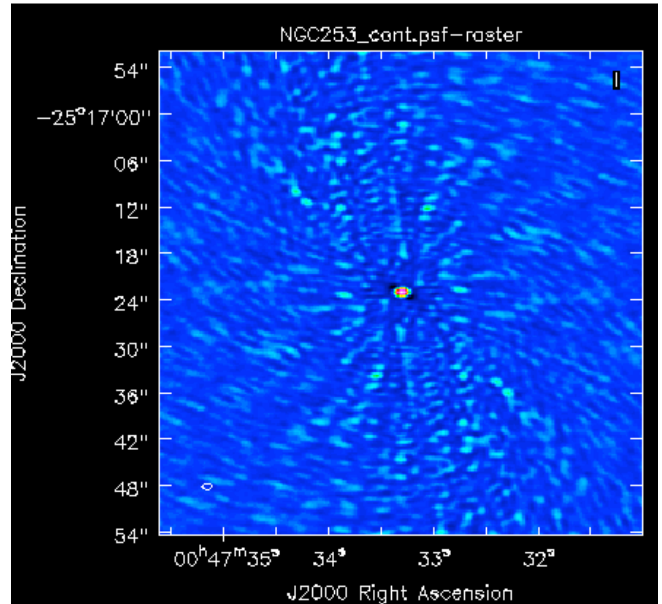
I(x,y)
True Image

Imaging Process

V(u,v)
Visibility

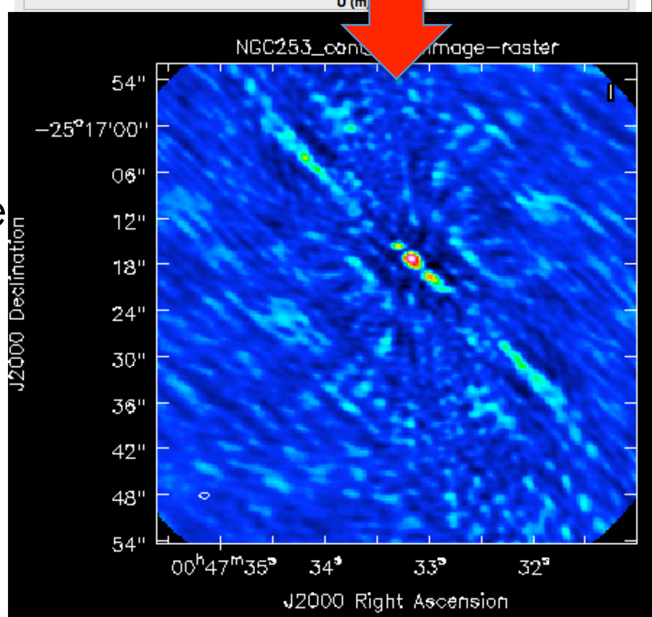


I. Transform



B(x,y)
Dirty Beam
Or
PSF
Point
Spread
Function

I_D(x,y)
Dirty Image



Fourier Transform:

$$V(u,v) = \iint I(x,y) e^{2\pi i(ux+vy)} dx dy$$

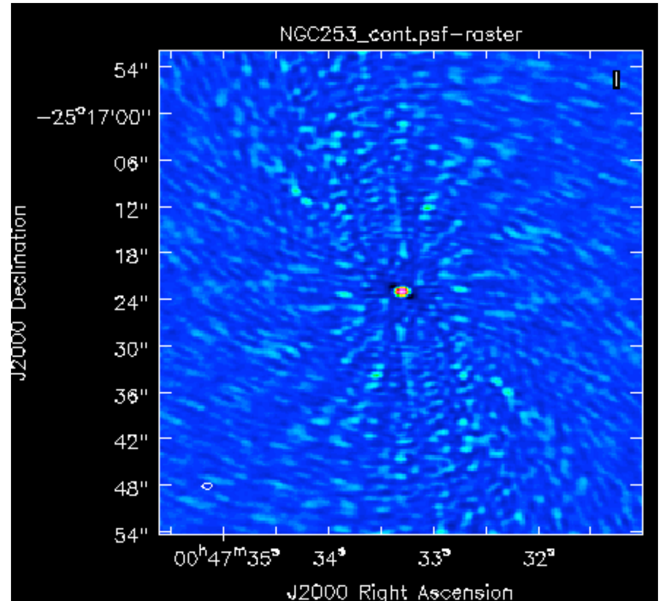
I. $V_{obs}(u,v) \rightarrow I_{dirty\_image}(x,y)$

Imaging Process

II. Deconvolution

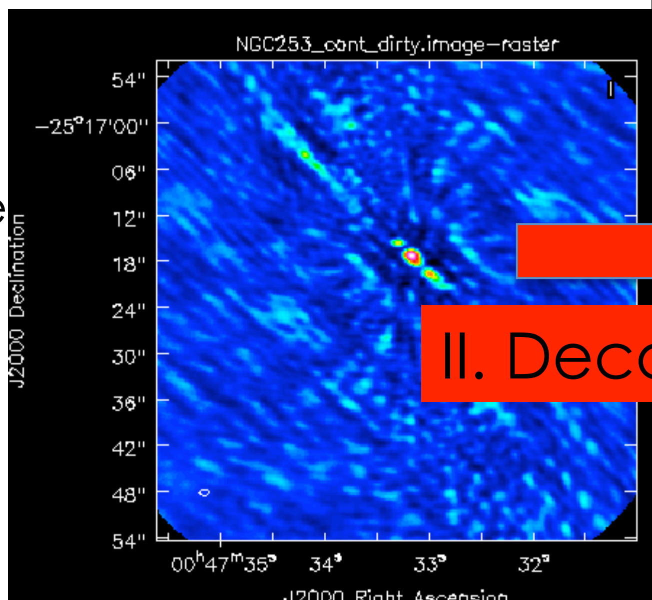
$I_{dirty\_image}(x,y)$ ➔

$I_{clean\_image}(x,y) \sim \mathbf{I_{true}\ (x,y)}$

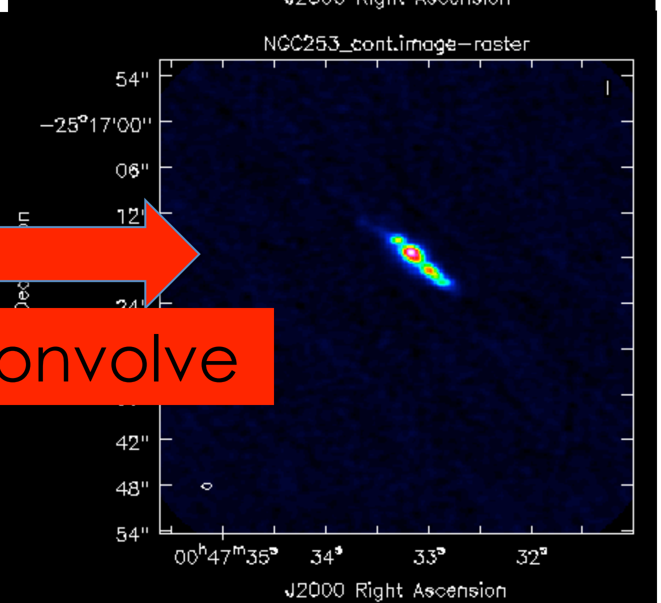


B(x,y)
Dirty Beam
Or
PSF
Point
Spread
Function

I$_D$(x,y)
Dirty Image



II. Deconvolve



I(x,y)
True Image

Cleaning Process

Interferometry (visibility) data are converted into images via a process called "cleaning".

Cleaning performs the 2 operations described earlier:

1. It converts the visibility (phases and amplitudes) into intensity distribution on the sky plane (Fourier Transform)

2. It restructures the beam (point spread function) of the data so that the beam is Gaussian in shape (Deconvolution)

Cleaning Cycles

- The classic algorithm to deconvolve visibility data is the **`clean`** algorithm, which uses delta functions to make a model for the source.
- The `clean` algorithm has the following steps:

1. Performs a Fourier Transform of the visibility data to make an initial Dirty Image of the source
2. Identify the surface brightness peak in the map.
3. Fit a delta function to this position that has a value of the peak surface brightness * gain factor.
4. Subtract the delta function from the image.
5. Identify the next brightness peak and repeat steps 2 and 3 (Minor Cycle).
6. Subtract the collection of delta functions from the uv-data and re image.
7. Repeat steps 1-5 until some threshold is reached.

Cleaning Settings

To make an image by taking the fast Fourier transform (FFT) of the visibility data involves projecting the sky surface brightness distribution onto a regular grid of pixels.

There are a number of choices to make in cleaning

1. Image plane settings
   - Image field-of-view / Pixel size
2. Deconvolution options
   - Weighting of visibility points
   - Maximum number of iterations and/or Stopping threshold
3. Spectral settings
   - Continuum (map) vs. spectral channels (cube)
   - Restframe for frequency/velocity
4. And many others.....

Image plane settings
Size of the image

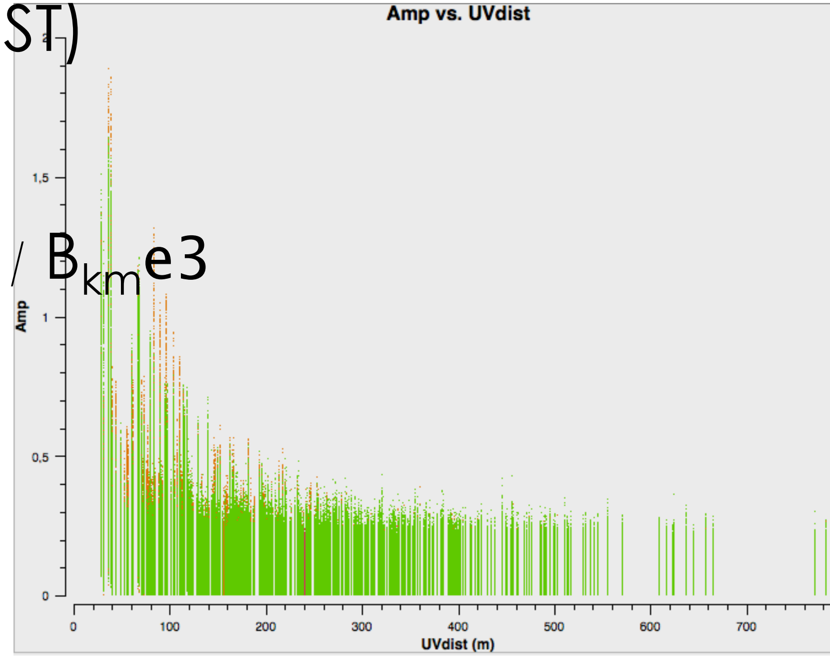
- The visibilities contain information from all of the sources in the field-of-view.

- Technically we should make an image that is equal to this field-of-view: FOV = (c / ν) / D

- ALAM antennas are 12m in size, so
  - FOV = (c / ν) / D * (rad->deg) in arcsec =
  - $(3e^8 / \nu_{GHz}e^9) / 12 * (3600*(180 / pi))=$
  - For ν=100 GHz, FOV ~50 arcsec

Image plane settings
Pixel size

- We need to Nyqvist sample the data when we project it onto a regular grid so that we do not lose information (Pixel = Beam/4)
- We can estimate beam-size by considering the longest baseline in our data set (e.g. using `plotms` and plotting AMP versus UVDIST)



Beam: $\Theta = \lambda / B = c / \nu * B =$

$= 3600 * (180 / pi) * (3e8 / \nu_{GHz} e9) / B_{km} e3$

For ν=100 GHz, $B_{longest}$~0.6 km:

Θ = 1 arcsec

➔pixel size = 0.25 arcsec
(1/4 sampling)

Deconvolution options
Weighting

Three standard options are used in radio interferometry

1. **Natural**:
   - Visibilities are weighted by the data weights (the weights of data points in the uv plane are not altered)
   - gives the best signal-to-noise ratio and the worst angular resolution

2. **Uniform**:
   - Alters the weights to account for the lack of data on long baselines in the uv plane (thus making the uv plane appear "uniform").
   - Makes the resolution finer, but this will increase the noise

3. **Briggs**:
   - Intermediate weighting which allows for adjusting between these two extremes, depending on the value of the robust.
   - Robust = -2 is equivalent to uniform
   - Robust = 2 is equivalent to natural
   - Robust = 0.5 is used in most ALMA QA2 imaging.

Deconvolution options
Weighting

Fourth option

4. Tapering:
- Outer tapering only supported, which will reduce the weight of the longest baselines, thus increasing the sensitivity to the large-scale emission.
- It will increase the noise

Spectral Settings

- Number of spectral channels in the cube
- Width of spectral cube channels (MHz or km/s)
- Velocity frame
- Rest frequency of reference line

N.B.

- Doppler *setting* is done in the project preparation within the OT (where reference line and systemic velocity of the target are set)

- Doppler *tracking* is done by the `clean` task in casa

Hands-on Session

So What do we do now with the calibrated visibilities?

Setup: Input data

- Input: calibrated MS
  data='uid___A002_X87544a_X25eb.ms.split.cal'

- Make sure you have ~120 Gb of HD space
  - 40 Gb input uv-file,
  - 30x2 Gb to create continuum subtracted uv-file,
  - a few tens of Gb to make images

Setup: script

ScriptForImaging.py

```python
thesteps = []
thespws = []

step_title = {0: 'Inspect the data: list of scans and sources',
              1: 'Inspect the data: identify line-free channels',
              2: 'Image the continuum',
              3: 'Imaging spw fully to identify lines',
              4: 'Subtract the Continuum',
              5: 'Image the emission lines : SO',
              6: 'Image the emission lines : HC3N',
              7: 'Image the emission lines : 13CO',
              8: 'Image the emission lines : CN 1-0',
              9: 'Make fits files'}
################### define input parameters #####################
data='uid___A002_X87544a_X25eb.ms.split.cal'
sourcename = 'NGC253'
#Identify the range of channels with continuum
spwcont='0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000'   # For
spwcontsub=spwcont # For continuum subtraction  (assessed in step = 3)
################### ################### ################### ###################
```

What the script does in steps

The input parameters

Edit this file as we go using your favourite text editor

Start casa and Launch script

```
Last login: Mon Dec  4 08:06:12 on ttys001
ciriacos-MacBook-Pro-5:~ cgoddi$ casa
==>
=========================================
The start-up time of CASA may vary
depending on whether the shared libraries
are cached or not.
=========================================


IPython 5.4.0 -- An enhanced Interactive Python.

CASA 5.3.0-47  5.3.0-7-feature-CAS-10684-10 -- Common Ast

--> CrashReporter initialized.
Enter doc('start') for help getting started with CASA...
Using matplotlib backend: TkAgg

CASA <1>: mysteps = [0,1,2]

CASA <2>: myspw = [0,1]

CASA <3>: execfile('scriptForImaging.py')
```

- start casa
- Set the steps you'd like to run
- Set the spw you'd like to process
- Launch the script

Step 0: Inspect the data

LISTOBS: List of scans and sources

```
================================================================================
           MeasurementSet Name:  /Volumes/HD_RU/data/alma/2017_tutorial_portugal/imaging/uid___A002_X87544a_X25eb.ms.split.cal      MS Version 2
================================================================================
   Observer: stakano     Project: uid://A001/Xa0/Xf75
Observation: ALMA
Data records: 678300       Total elapsed time = 2169.07 seconds
   Observed from   21-Jul-2014/05:52:54.9   to   21-Jul-2014/06:29:04.0 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  21-Jul-2014/05:52:54.9 - 05:58:11.1     4      0 J2258-2758             119000  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_BANDPASS#ON_SOU
              06:00:12.1 - 06:02:49.5     6      1 Neptune                 59500  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_AMPLI#ON_SOURCE
              06:03:15.3 - 06:03:45.5     7      2 J0038-2459              11900  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE
              06:04:54.5 - 06:11:46.1     9      3 NGC_253                154700  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              06:12:03.6 - 06:12:33.9    10      2 J0038-2459              11900  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE
              06:12:53.7 - 06:19:45.2    11      3 NGC_253                154700  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              06:20:01.7 - 06:20:32.0    12      2 J0038-2459              11900  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE
              06:21:57.7 - 06:28:17.5    14      3 NGC_253                142800  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [OBSERVE_TARGET#ON_SOURCE]
              06:28:33.7 - 06:29:04.0    15      2 J0038-2459              11900  [0,1,2,3]  [6.05, 6.05, 6.05, 6.05] [CALIBRATE_PHASE#ON_SOURCE
           (nRows = Total number of rows per scan)
Fields: 4
  ID   Code Name               RA               Decl           Epoch   SrcId      nRows
  0    none J2258-2758         22:58:05.962880 -27.58.21.25670 J2000   0          119000
  1    none Neptune            22:35:54.303104 -09.40.13.13552 J2000   1           59500
  2    none J0038-2459         00:38:14.735510 -24.59.02.23520 J2000   2           47600
  3    none NGC_253            00:47:33.300000 -25.17.23.00000 J2000   3          452200
Spectral Windows:  (4 unique spectral windows and 1 unique polarization setups)
  SpwID  Name                           #Chans   Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
  0      ALMA_RB_03#BB_1#SW-01#FULL_RES   3840   TOPO  100366.192      -488.281   1875000.0  99428.9366        1  XX  YY
  1      ALMA_RB_03#BB_2#SW-01#FULL_RES   3840   TOPO  100667.018      -488.281   1875000.0  99729.7621        2  XX  YY
  2      ALMA_RB_03#BB_3#SW-01#FULL_RES   3840   TOPO  109933.503       488.281   1875000.0 110870.7590        3  XX  YY
  3      ALMA_RB_03#BB_4#SW-01#FULL_RES   3840   TOPO  111932.075       488.281   1875000.0 112869.3306        4  XX  YY
Sources: 16
  ID   Name                SpwId RestFreq(MHz)  SysVel(km/s)
  0    J2258-2758          0     99500          0
  0    J2258-2758          1     99800          0
  0    J2258-2758          2     110950         0
  0    J2258-2758          3     112950         0
  1    Neptune             0     99500          0
  1    Neptune             1     99800          0
```

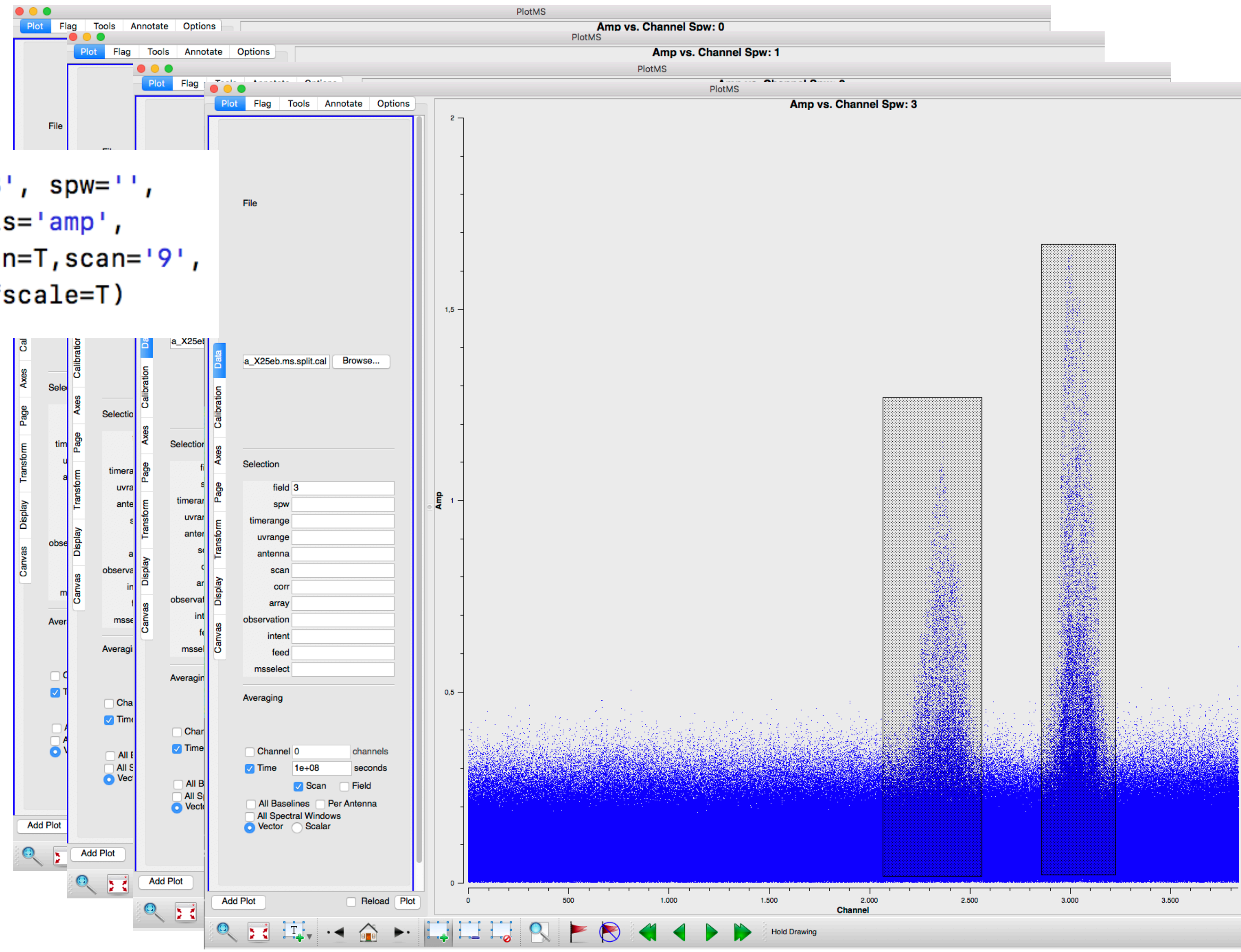
target

Step 1: Inspect the data

PLOTMS: Identify line-free channels I

```
plotms(vis=data, field='3', spw='',
    xaxis='channel', yaxis='amp',
    avgtime='1e8', avgscan=T,scan='9',
    iteraxis='spw', xselfscale=T)
```

- Good for continuum imaging
- For line imaging, a more carefully analysis needs to be carried out in the imaging plane



Imaging Algorithm

CLEAN

- Normal clean used widely on other interferometers
- It was used for ALMA data till recently

TCLEAN

- CASA own clean algorithm
- faster and more robust than CLEAN for ALMA data
- N.B. NOT FULLY DOCUMENTED YET

Step 2: Image the continuum

We will use the `tclean` algorithm

Useful `casa` commands:

```
CASA <7>: tget tclean
--------> tget(tclean)
Restored parameters from file tclean.last

CASA <8>: default tclean
--------> default(tclean)

CASA <9>: help tclean
--------> help(tclean)
Help on instance of tclean_cli_ in module tclean_cli:

tclean = class tclean_cli_
 |  Methods defined here:
 |
 |  __call__(self, vis=None, selectdata=None, field=N
```

Step 2: Image the continuum

```
tclean(vis=data,                           # Input filename
  imagename = sourcename+'_cont',          # Output filename
  spw = spwcont,                           # Spectral windows to image
  field='3',                               # Field to be imaged: NGC253
  cell = '0.25arcsec',                     # Pixel size
  imsize = [500, 500],                     # Image size in pixels
  niter=1000,                              # Maximum number of iterations
  threshold='0.08mJy',                     # FLux threshold to stop (noise)
  weighting='briggs',                      # Cleaning weights
  robust=0.5,                              # Weighting parameter
  specmode = 'mfs',                        # Imaging mode (continuum)
  outframe = 'LSRK',                       # Velocity frame of image
  uvrange = '',                            # uv-range of baselines to use
  mask= '',                                # input file with masks
  pbcor=True,                              # primary beam correction
  nterms=1,                                # Nr of Taylor coeff. in spectral slope
  deconvolver='hogbom',                    # Cleaning algorithm
  chanchunks=-1,                           # Chunking for gridding
  gridder='standard',                      # Projection method
  interactive=True)                        # Interactive mode setting
```

Step 2: Image the continuum

```
CASA <23>: spwcont='0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000'
```

```
tclean(vis=data,
  imagename = sourcename+'_cont',
  field='3',
  phasecenter=3,
  gridder='standard',
  cell = '0.25arcsec',
  imsize = [500, 500],
  spw = spwcont,
  specmode = 'mfs',
  outframe = 'LSRK',
  niter=5000,
  threshold='0.07mJy',
  weighting='briggs',
  robust=0.5,
  deconvolver='hogbom',
  nterms=1,
  uvrange = '',
  mask= '',
  chanchunks=-1,
  pbcor=True,
  interactive=True)
```

Select only line-free data!
(but never flag the line channels)

Field or coordinates

set to "standard" for single pointings and "mosaic" for multiple pointings

Pixel size should be ¼ or less of beam

The size of the image have to be at least twice the size of your primary beam

number of interactions (trial & error)

Measured (or as requested)

set robust parameter to 0.5
Brigg weighting (intermediate between natural and uniform weighting)

You could also try setting instead:
robust= 2 #(natural weighting)
robust= -2 #(uniform weighting)

Always true

Step 2: Image the continuum

```
Message
Step 2 Image the continuum

##########################################
##### Begin Task: tclean         #####
tclean(vis="uid___A002_X87544a_X25eb.ms.split.cal",selectdata=True,field="3",spw="0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000",t
        uvrange="",antenna="",scan="",observation="",intent="",
        datacolumn="corrected",imagename="NGC253_cont",imsize=[500, 500],cell="0.25arcsec",phasecenter="",
        stokes="I",projection="SIN",startmodel="",specmode="mfs",reffreq="",
        nchan=-1,start="",width="",outframe="LSRK",veltype="radio",
        restfreq=[],interpolation="linear",gridder="mosaic",facets=1,chanchunks=-1,
        wprojplanes=1,vptable="",aterm=True,psterm=False,wbawp=True,
        conjbeams=True,cfcache="",computepastep=360.0,rotatepastep=360.0,pblimit=0.2,
        normtype="flatnoise",deconvolver="hogbom",scales=[],nterms=1,smallscalebias=0.6,
        restoration=True,restoringbeam=[],pbcor=True,outlierfile="",weighting="briggs",
        robust=0.5,npixels=0,uvtaper=[],niter=1000,gain=0.1,
        threshold="0.08mJy",cycleniter=-1,cyclefactor=1.0,minpsffraction=0.05,maxpsffraction=0.8,
        interactive=True,usemask="user",mask="",pbmask=0.0,maskthreshold="",
        maskresolution="",nmask=0,sidelobethreshold=3.0,noisethreshold=5.0,lownoisethreshold=1.5,
        negativethreshold=0.0,smoothfactor=1.0,minbeamfrac=0.3,cutthreshold=0.01,growiterations=75,
        restart=True,savemodel="none",calcres=True,calcpsf=True,parallel=False)
Verifying Input Parameters
MS : uid___A002_X87544a_X25eb.ms.split.cal | Selecting on fields : 3 | Selecting on spw :0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~
  NRows selected : 452200
Define image coordinates for [NGC253_cont] :
Impars : start
Shape : [500, 500, 1, 1]Spectral : [1.06144e+11] at [0] with increment [1.35188e+10]
Set Gridding options for [NGC253_cont] with ftmachine : mosaicft
Using default Voltage Patterns from the VPManager
Temporary alert : The state of the vpmanager tool has been modified by loading these primary beam models. If any of your scripts rely on the vpma
PB used ALMA
Automatically calculate chanchunks using imshape : [500, 500, 1, 1]
Required memory 0.0201166
Available memory 12.8 (rc: memory fraction 80% rc memory -0.000976562)
1 other processes on node
Setting chanchunks to 1
Set imaging weights : Briggs weighting: sidelobes will be suppressed over full image
Normal robustness, robust = 0.5
Set Deconvolution Options for [NGC253_cont] : hogbom
Set Iteration Control Options
----------------------------------------------------------- Make PSF ---------------------------------------------
```

Here are our
Input Parameters

Step 2: Image the continuum

Cleaning is an iterative process in which three steps are done in each iteration:

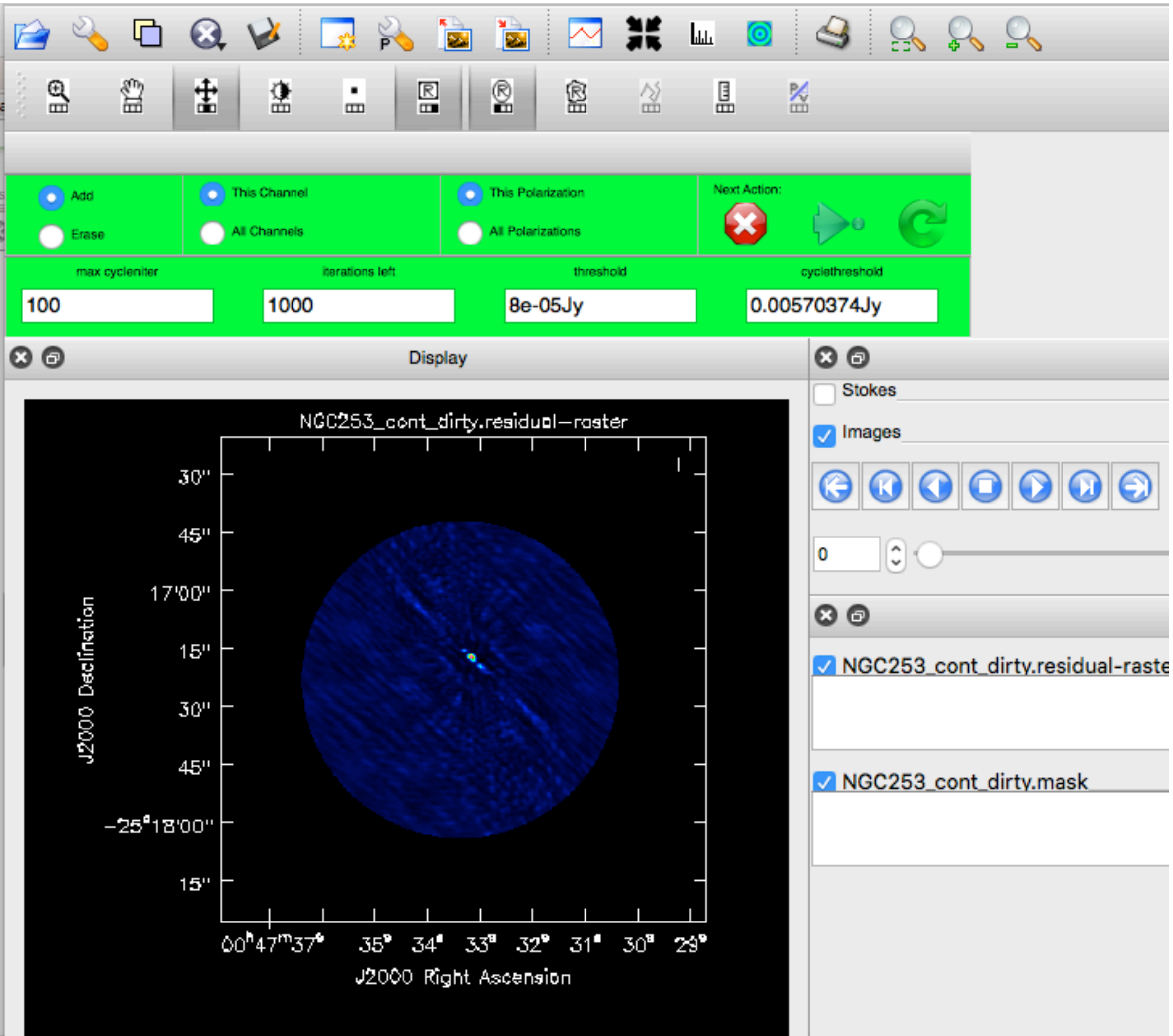
- An image is displayed.

- Either the user or the program identifies sources and masks them.

- Using the identified sources, the algorithm models and removes them from the image, producing a residual image that is used at the beginning of the cycle.

Step 2: Image the continuum

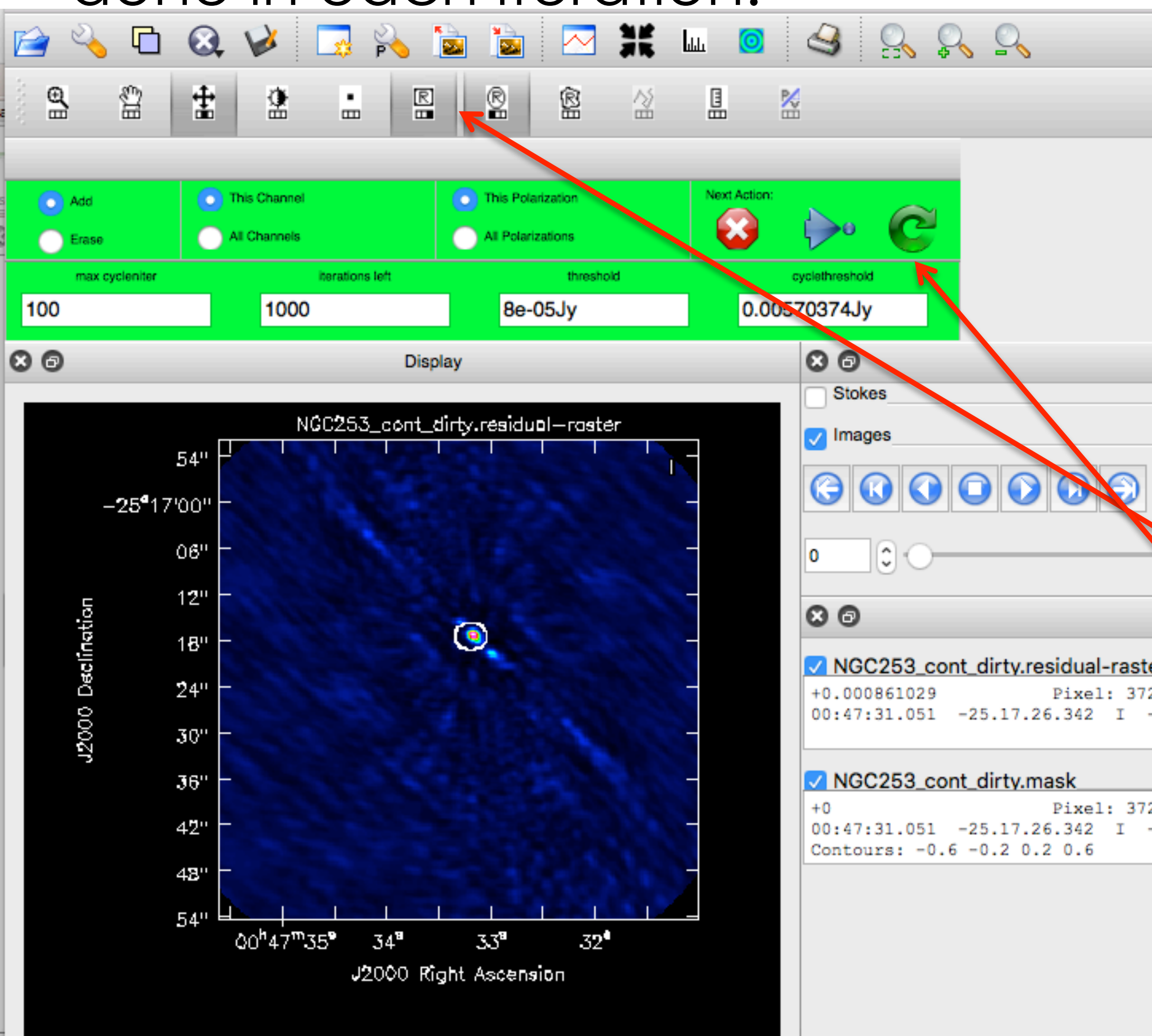
Cleaning is an iterative process in which three steps are done in each iteration:



a) An image is displayed

Step 2: Image the continuum

Cleaning is an iterative process in which three steps are done in each iteration:



a) An image is displayed

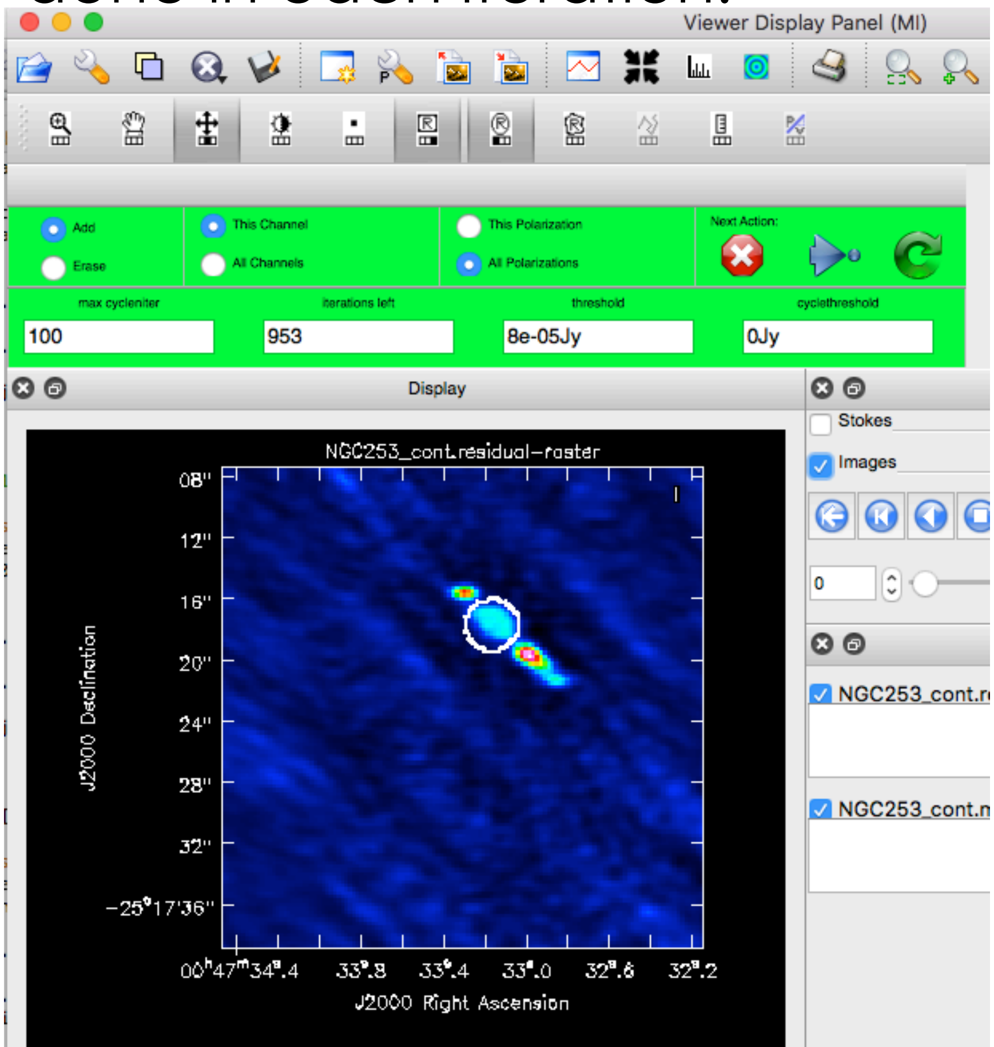
b) Either the user or the program identifies sources and masks them

Set your clean box

Proceed to clean (interactively)

Step 2: Image the continuum

Cleaning is an iterative process in which three steps are done in each iteration:

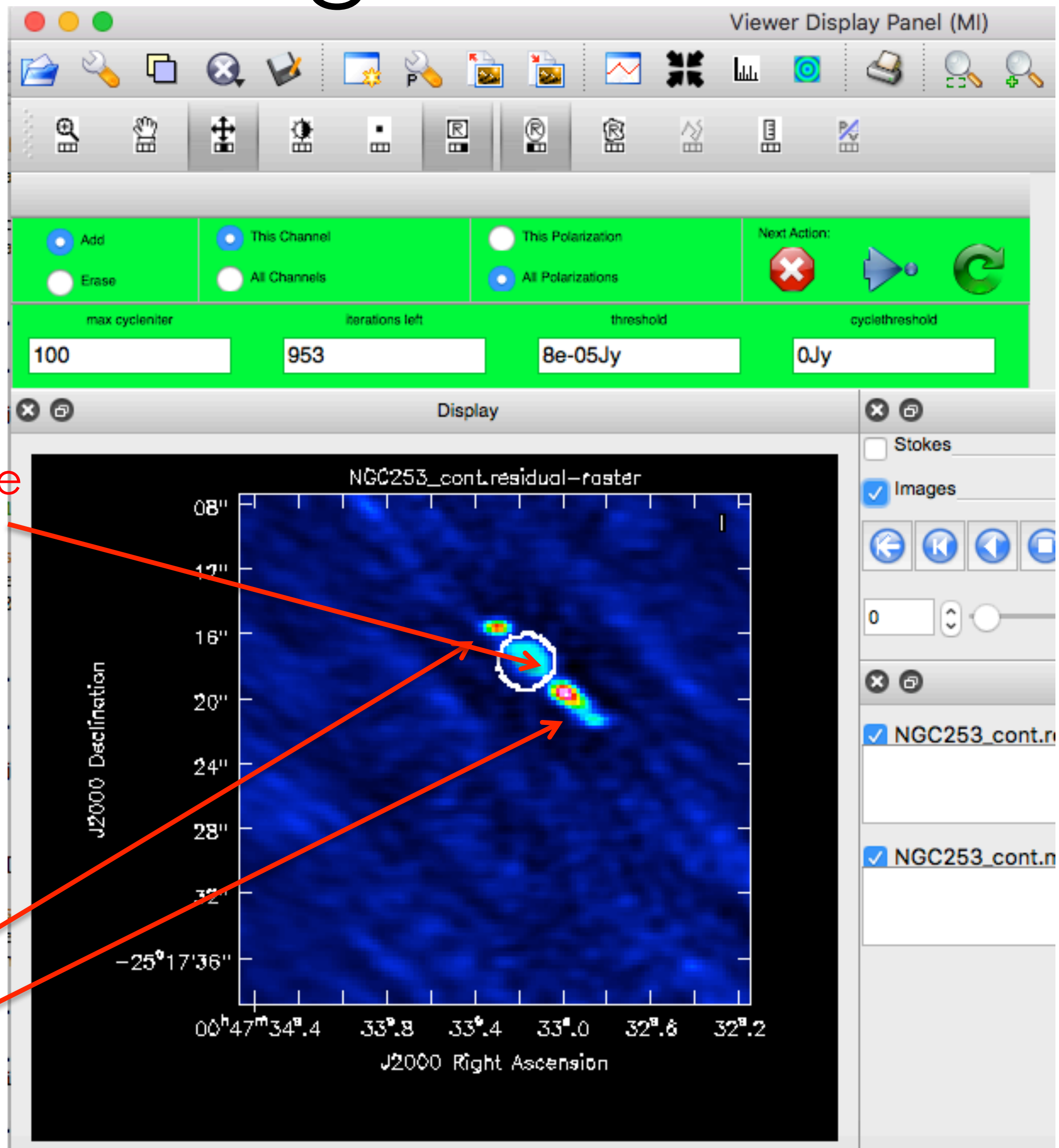


a) An image is displayed

b) Either the user or the program identifies sources and masks them

c) Using the identified sources, the algorithm models and removes them from the image, producing a residual image then used at the beginning of the cycle

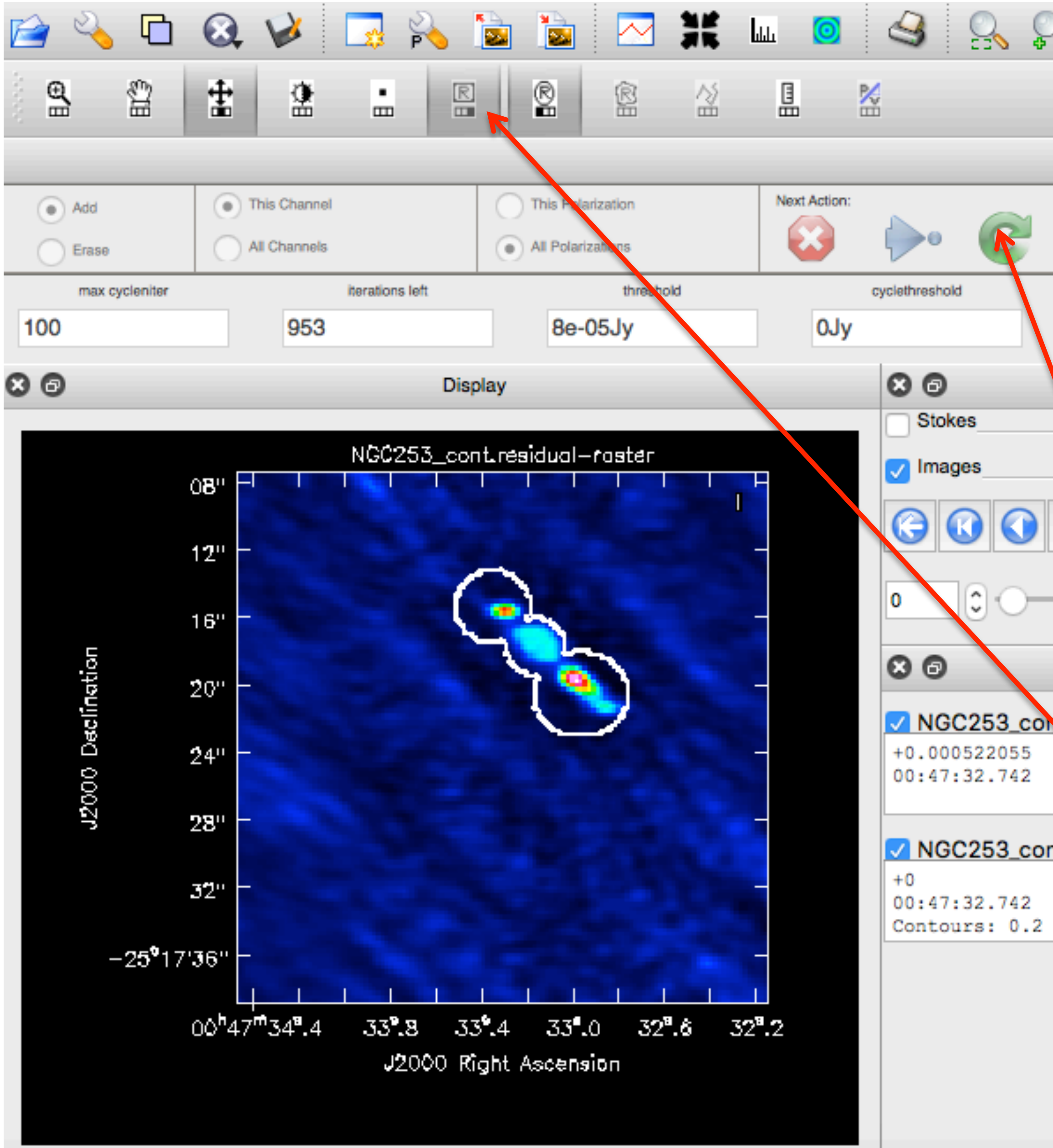
Step 2: Image the continuum



parts of the source CLEANed away

More (weaker) emission to clean pops up

Step 2: Image the continuum

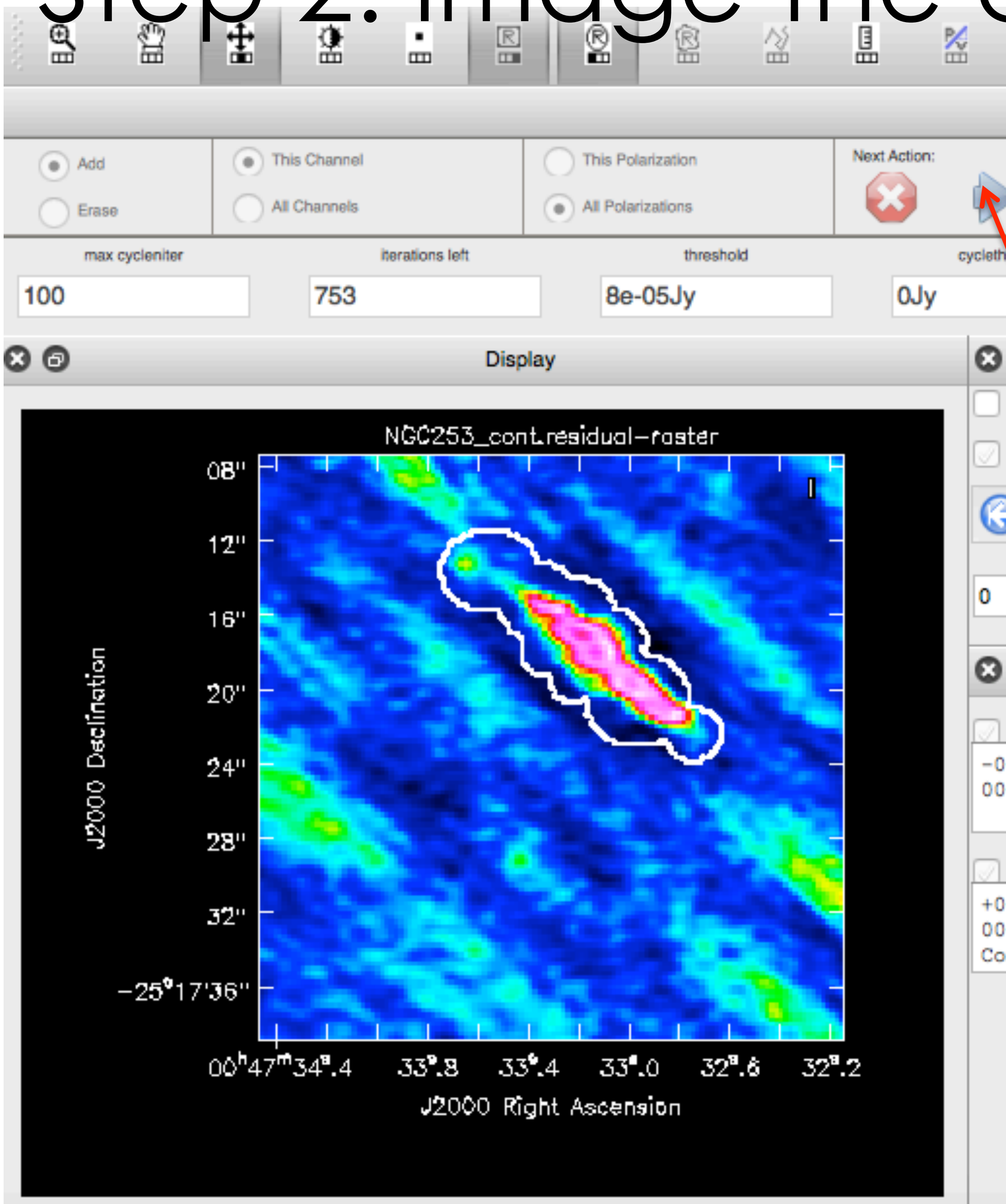


...and then another cycle begins......

Set your clean box

Proceed to clean (interactively)

Step 2: Image the continuum

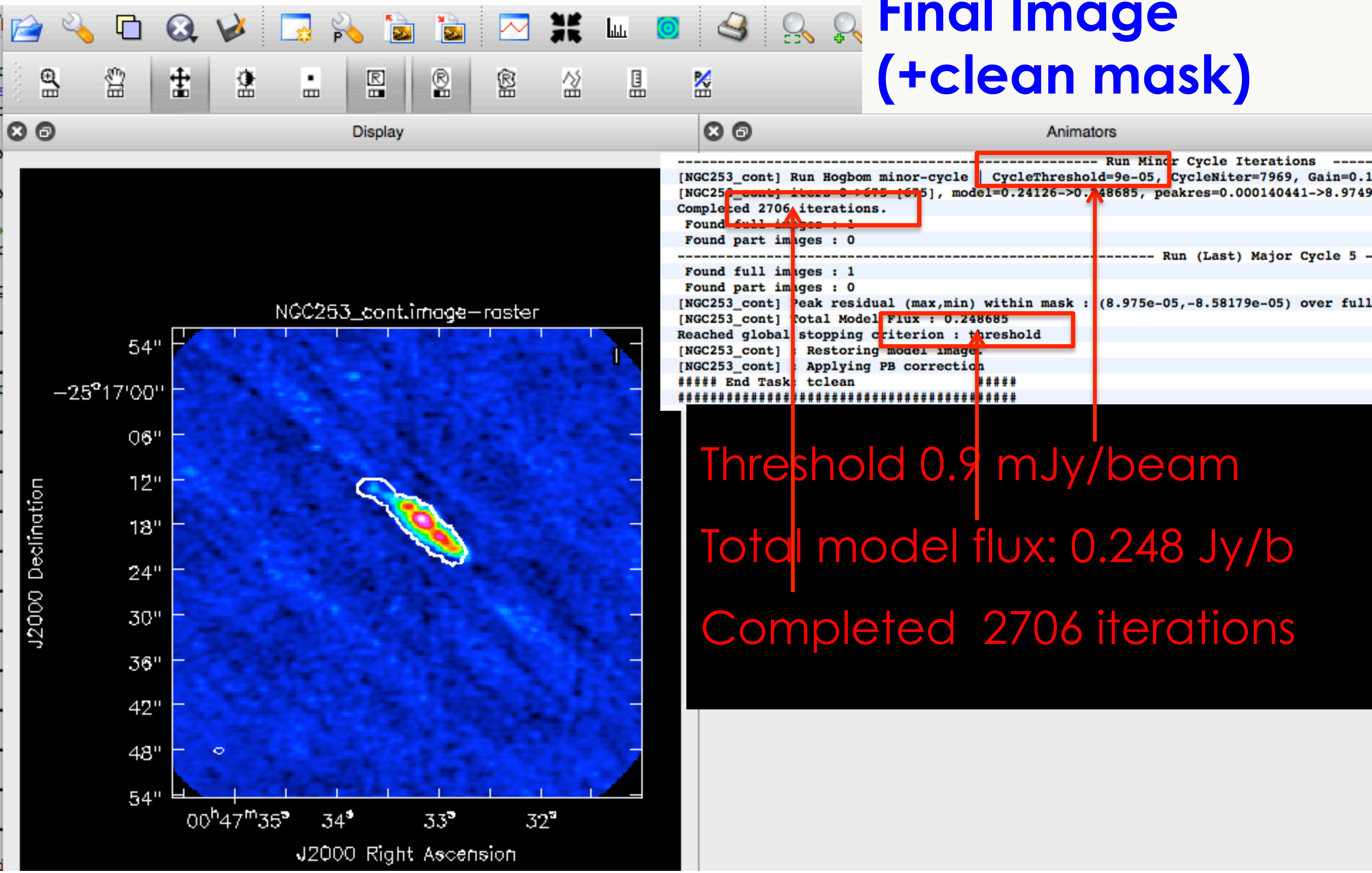


Proceed to clean (non-interactively)

Keep cleaning till you hit the noise level……

Step 2: Image the continuum

Final Image (+clean mask)



Threshold 0.9 mJy/beam

Total model flux: 0.248 Jy/b

Completed 2706 iterations

Step 2: Image the continuum

Output of `tclean`:

- NGC253_cont.image # 'deconvolved' image
- NGC253_cont.image.pbcor # Primary beam corrected image
- NGC253_cont.mask # mask created while cleaning
- NGC253_cont.model #image containing your model components (eg. delta functions)
- NGC253_cont.pb (renamed NGC253_cont.flux) # expected primary beam response (area where the telescope is sensitive)
- NGC253_cont.psf # point spread function (FFT of the uv-sampling function): Beam before cleaning
- NGC253_cont.residual # Residuals after the final iteration of Cleaning (visibility – model)
- NGC253_cont.sumwt
- NGC253_cont.weight

Step 2: Image the continuum

Output of `tclean`:

- NGC253_cont.image
- NGC253_cont.image.pbcor
- NGC253_cont.mask
- NGC253_cont.model

- NGC253_cont.pb

- NGC253_cont.psf

- NGC253_cont.residual
- NGC253_cont.sumwt
- NGC253_cont.weight

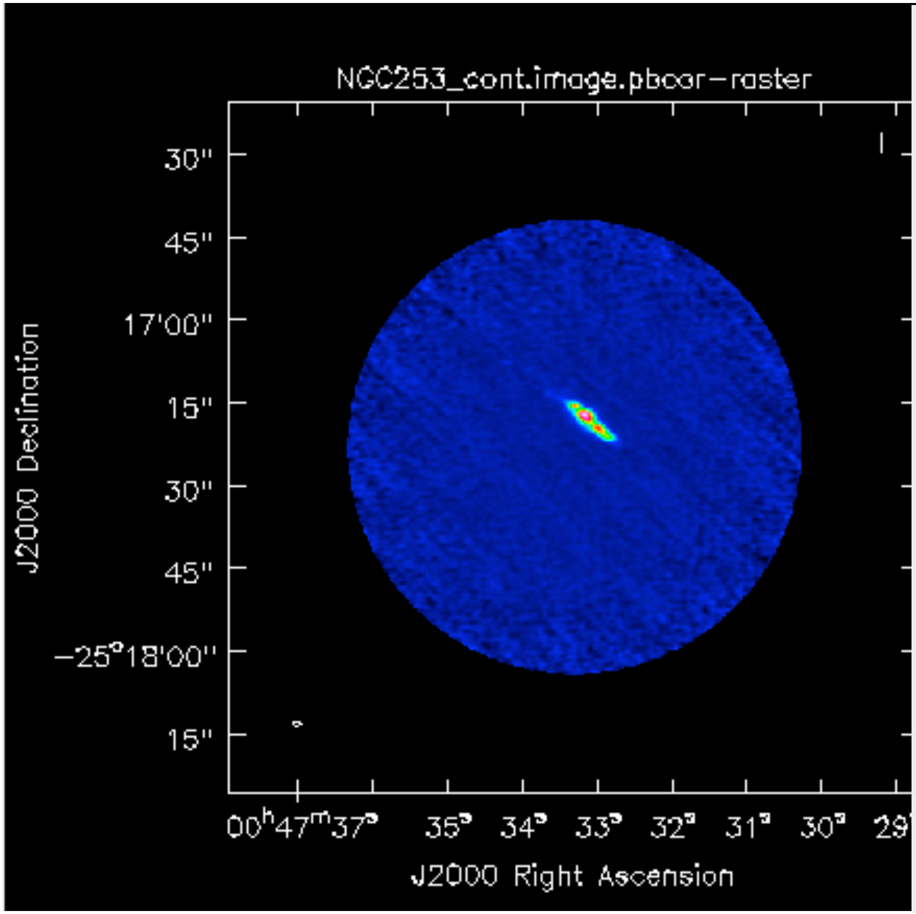
We can look at each of these images using the CASA VIEWER

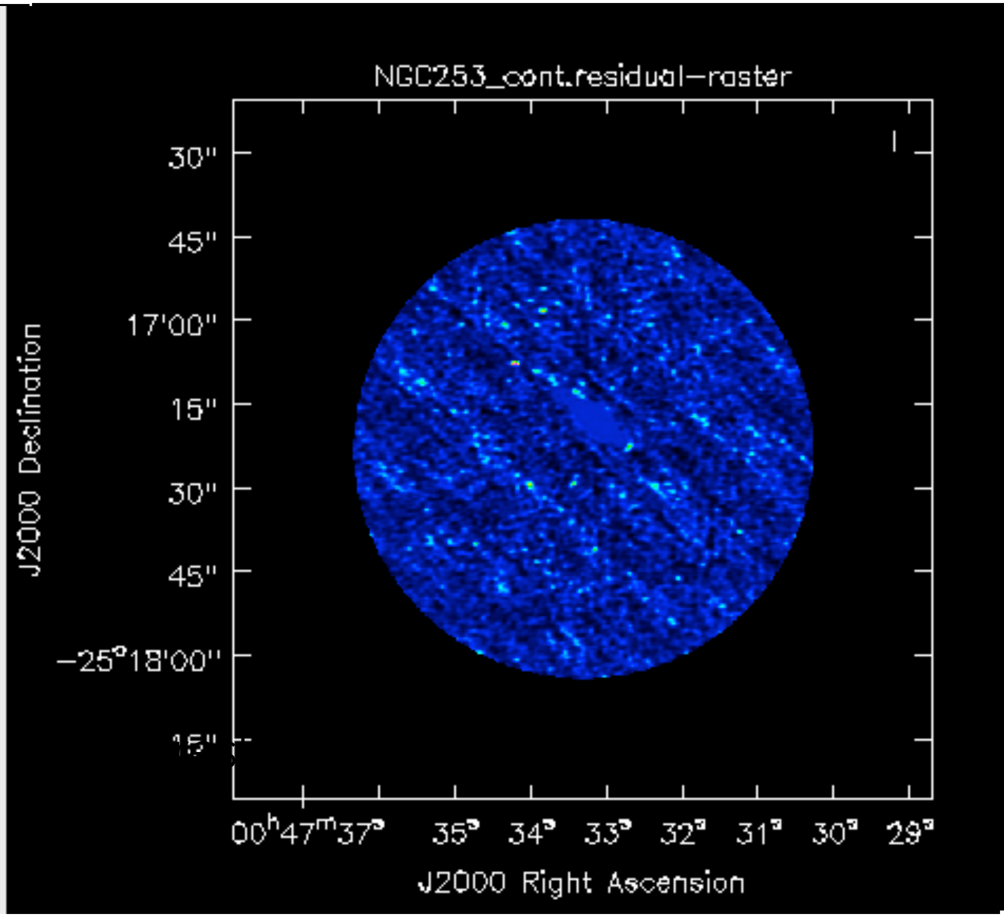
- `viewer` # start the viewer GUI and DATA MANAGER # within CASA
- `casaviewer` #from the shell command line

Step 2: Image the continuum

Final Cleaned Image

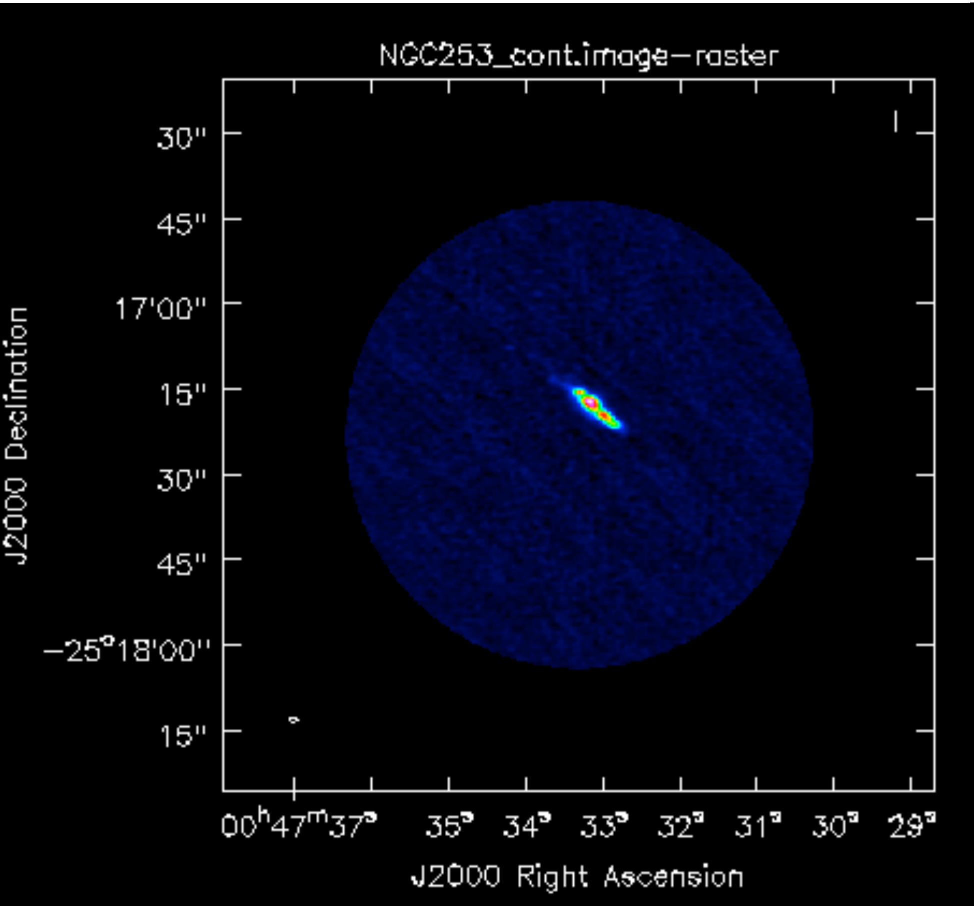
Residual Image



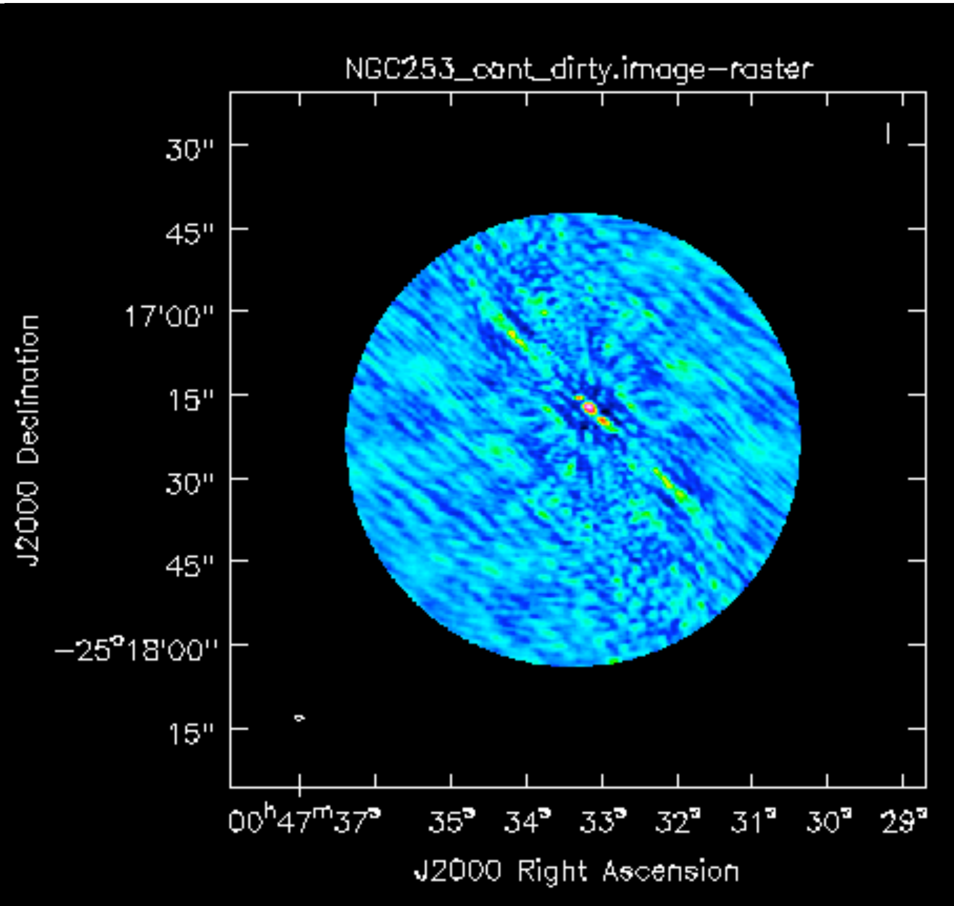


Step 2: Image the continuum

Final Cleaned Image

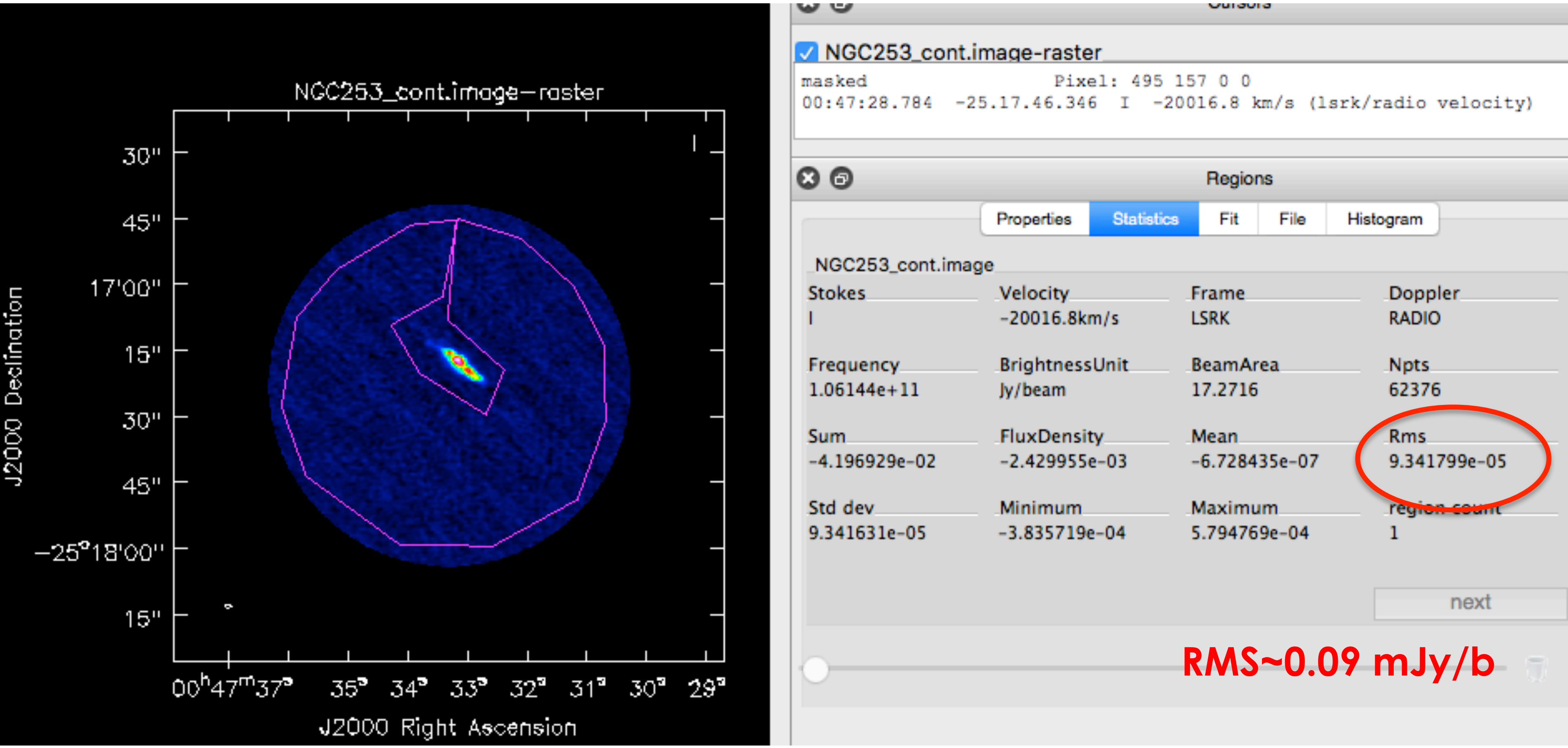


Dirty Image



Step 2: Image the continuum

Image properties



Spectral lines imaging settings

```
tclean(vis = data+'.contsub',
  imagename = sourcename+'_SO',
  spw = '0',
  field='0',
  restfreq = '99.3GHz',
  specmode = 'cube',
  outframe = 'LSRK',
  nchan = 35,
  start = '-50km/s',
  width = '20km/s',
  threshold='1.5mJy',
  niter=1000,
  deconvolver='hogbom',
  gridder='mosaic',
  pbcor=True,
  chanchunks=-1,
  interactive=F,
  imsize=[500, 500],
  cell = '0.25arcsec',
  weighting='briggs',
  robust=0.5)
```

- Specmode ="cube" instead of "mfs" as for continuum (only options in tclean)
- older clean had multiple options ("frequency", "velocity", "channel")
- tclean only supports "lsrk" (for clean, "lsrk" is recommended for galactic objects and "bary" for
- extragalactic objects)

Step 3: Image a full spw

- Necessary for careful identification line-free channels (for continuum subtraction)
- Useful to identify spectral lines in a given spw
- The resulting cube will have line+continuum signal

```
tclean(vis = data,
  imagename = sourcename+'_spw0',
  spw = '0',
  field='3',
  specmode = 'cube',
  outframe = 'LSRK',
  nchan = -1,
  width = 10,
  threshold='1.5mJy',
  deconvolver='hogbom',
  gridder='mosaic',
  pbcor=True,
  interpolation='linear',
  chanchunks=-1,
  interactive=F,
  imsize=[500, 500],
  cell = '0.25arcsec',
  weighting='briggs',
  robust=0.5)
```

Select all data in the spw

Select the target field

Integrate across 10 channels
To reduce size and time
(3840 chans in tot!)

 # Feel free to try this step in another spw

Spectral dimension settings

- spw Spectral windows to image
- specmode Spectral imaging mode (mode in clean)
- start Staring point of spectral cube
- nchan Number of spectral cube channels
- width Width of spectral cube channels
- outframe Velocity frame
- restfreq Rest frequency of reference line
- (optional)

Step 3: Image a full spw

```
##########################################
##### Begin Task: tclean            #####
tclean(vis="uid___A002_X87544a_X25eb.ms.split.cal",selectdata=True,field="3",spw="0",timerange=""
        uvrange="",antenna="",scan="",observation="",intent="",
        datacolumn="corrected",imagename="NGC253_spw0",imsize=[500, 500],cell="0.25arcsec",phasec
        stokes="I",projection="SIN",startmodel="",specmode="cube",reffreq="",
        nchan=-1,start="",width=10,outframe="LSRK",veltype="radio",
        restfreq=[],interpolation="linear",gridder="mosaic",facets=1,chanchunks=-1,
        wprojplanes=1,vptable="",aterm=True,psterm=False,wbawp=True,
        conjbeams=True,cfcache="",computepastep=360.0,rotatepastep=360.0,pblimit=0.2,
        normtype="flatnoise",deconvolver="hogbom",scales=[],nterms=2,smallscalebias=0.6,
        restoration=True,restoringbeam=[],pbcor=True,outlierfile="",weighting="briggs",
        robust=0.5,npixels=0,uvtaper=[],niter=0,gain=0.1,
        threshold="1.5mJy",cycleniter=-1,cyclefactor=1.0,minpsffraction=0.05,maxpsffraction=0.8,
        interactive=False,usemask="user",mask="",pbmask=0.0,maskthreshold="",
        maskresolution="",nmask=0,sidelobethreshold=3.0,noisethreshold=5.0,lownoisethreshold=1.5,
        negativethreshold=0.0,smoothfactor=1.0,minbeamfrac=0.3,cutthreshold=0.01,growiterations=7
        restart=True,savemodel="none",calcres=True,calcpsf=True,parallel=False)
Verifying Input Parameters
MS : uid___A002_X87544a_X25eb.ms.split.cal | Selecting on fields : 3 | Selecting on spw :0 | [Ope
  NRows selected : 113050
Define image coordinates for [NGC253_spw0] :
 phaseCenter='Direction: [0.884764, 0.186268, -0.427196]'  *** Encountered negative channel width
 Channels equidistant in freq
 Central frequency (in output frame) = 9.94237e+10 Hz
 Channel central frequency is decreasing with increasing channel number.
 Width of central channel (in output frame) = 4.88255e+06 Hz
 Number of channels = 384
 Total width of SPW (in output frame) = 1.8749e+09 Hz
 Lower edge = 9.84862e+10 Hz, upper edge = 1.00361e+11 Hz
Impars : start
Shape : [500, 500, 1, 384]Spectral : [1.00359e+11] at [0] with increment [-4.88255e+06]
Set Gridding options for [NGC253_spw0] with ftmachine : mosaicft
Using default Voltage Patterns from the VPManager
Temporary alert : The state of the vpmanager tool has been modified by loading these primary beam
PB used ALMA
Automatically calculate chanchunks using imshape : [500, 500, 1, 384]
Required memory 7.72476
Available memory 12.8 (rc: memory fraction 80% rc memory -0.000976562)
1 other processes on node
Setting chanchunks to 1
Tuning frequency data selection to match image spectral coordinates
MS : uid___A002_X87544a_X25eb.ms.split.cal | Selecting on fields : 3 | Selecting on spw :0 | [Ope
  NRows selected : 113050
Set imaging weights : Briggs weighting: sidelobes will be suppressed over full image
Normal robustness, robust = 0.5
Set Deconvolution Options for [NGC253_spw0] : hogbom
----------------------------------------------------------- Make PSF --------------------------
```

Final cube with 3840/10 chans

Step 3: Image a full spw

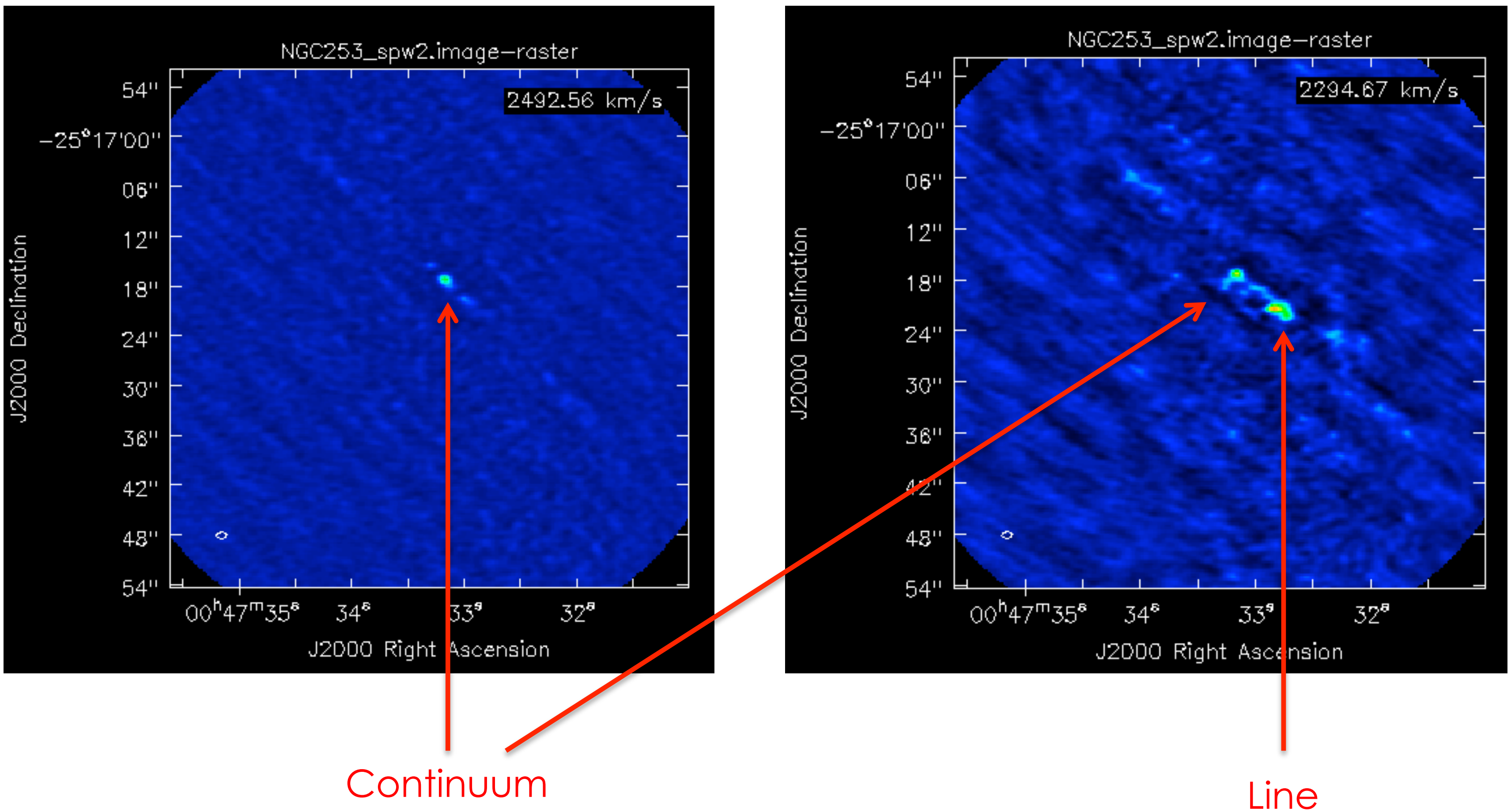
```
…r::makePSF    ------------------------------------------------------------ Make PSF ------------------------------------
…agesOnDisk     Found full images : 1
…agesOnDisk     Found part images : 0
…ensitivity    [NGC253_spw0] Theoretical sensitivity (Jy/bm):c0:0.000932044 c1:0.000885355 c2:0.000886193 c3:0.00088706
…intBeamSet    Restoring Beams
…ntBeamSet +   Pol    Type Chan         Freq     Vel
…ntBeamSet +     I     Max  383 9.848866e+10   3047      1.3690 arcsec x     0.8088 arcsec pa=-88.0781 deg
…ntBeamSet +     I     Min    0 1.003587e+11  -2587      1.3308 arcsec x     0.7923 arcsec pa=-88.5190 deg
…ntBeamSet +     I  Median  192 9.942123e+10    237      1.3246 arcsec x     0.8136 arcsec pa=-86.2968 deg
…agesOnDisk     Found full images : 1
…agesOnDisk     Found part images : 0
…MajorCycle    ------------------------------------------------------------ Run (Last) Major Cycle 1 -------------------
…agesOnDisk     Found full images : 1
…agesOnDisk     Found part images : 0
…e::restore    [NGC253_spw0] : Restoring model image.
… line 1921)   Restoring with an empty model image. Only residuals will be processed to form the output restored image.
…ase::pbcor    [NGC253_spw0] : Applying PB correction
tclean::::     ##### End Task: tclean               #####
tclean::::+    ##########################################
```

Final cube with 3840/10 chans

Beamsize

Step 3: Image a full spw

Identify line emission in the channel maps with the *casaviewer*



Step 2: Subtract the continuum

```
[CASA <23>: spwcont='0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000'

        #  uvcontsub :: Continuum fitting and subtraction in the uv plane
        vis                 = 'uid___A002_X87544a_X25eb.ms.split.cal' #  Name of input
                                                    #   MS.  Output goes to vis + ".contsub"
                                                    #   (will be overwritten if already
                                                    #   exists)
        field               =       '3'             #  Select field(s) using id(s) or
                                                    #   name(s)
[CA! fitspw              = '0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000'
                                                    #   pectral window:channel selection for
                                                    #   fitting the continuum
             excludechans   =      False            #  exclude Spectral window:channel
                                                    #   selection in fitspw for fitting

        combine             =      'spw'            #  Data axes to combine for the
                                                    #   continuum estimation (none, or spw
                                                    #   and/or scan)
        solint              =      'int'            #  Continuum fit timescale (int
                                                    #   recommended!)
        fitorder            =          1            #  Polynomial order for the fits
        spw                 =         ''            #  Spectral window selection for output
        want_cont           =      False            #  Create vis + ".cont" to hold the
                                                    #   continuum estimate.
```

Step 2: Subtract the continuum

NB: You need ~30x2=60Gb!

```
##########################################
##### Begin Task: uvcontsub          #####
uvcontsub(vis="uid___A002_X87544a_X25eb.ms.split.cal",field="3",fitspw="0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000",
        solint="int",fitorder=1,spw="",want_cont=False)
Preparing to add scratch columns.
splitting to /Volumes/HD_RU/data/alma/2017_tutorial_portugal/imaging/uid___A002_X87544a_X25eb.ms.split.cal.contsubHoKIu0 with spw=""
Using DATA column.
452200 out of 678300 rows are going to be considered due to the selection criteria.
CASA Version 5.3.0-47  5.3.0-7-feature-CAS-10684-10

Forcing use of OLD VisibilityIterator.
****Using OLD VI-driven calibrater tool****
Opening MS: /Volumes/HD_RU/data/alma/2017_tutorial_portugal/imaging/uid___A002_X87544a_X25eb.ms.split.cal.contsubHoKIu0 for calibratio
Clearing all model records in MS header.
Adding MODEL_DATA and CORRECTED_DATA column(s).
Initializing MODEL_DATA to (unity).
Initialized 452200 rows.
Initializing nominal selection to the whole MS.
Reseting solve/apply state
Beginning selectvis--(MSSelection version)-------
Reseting solve/apply state
Performing selection on MeasurementSet
 Selecting on spw: '0:50~500;1000~2000,1:50~1000;1700~2500,2:1100~3300,3:50~2000'
Selection did not drop any rows
Frequency selection:
.  Spw 0:50~500 (451 channels, step by 1)
.  Spw 0:1000~2000 (1001 channels, step by 1)
.  Spw 1:50~1000 (951 channels, step by 1)
.  Spw 1:1700~2500 (801 channels, step by 1)
.  Spw 2:1100~3300 (2201 channels, step by 1)
.  Spw 3:50~2000 (1951 channels, step by 1)
chanmode=none nchan=1 start=0 step=1 mStart='0km/s' mStep='0km/s' msSelect=''
Beginning setsolve--(MSSelection version)-------
```

Steps 5-8: Image the emission lines

```
mystep = 7
if(mystep in thesteps):
    casalog.post('Step '+str(mystep)+' '+step_titl
    print 'Step ', mystep, step_title[mystep]

    if(2 in thespws):
        os.system('rm -rf '+sourcename+'_13CO*')

        tclean(vis = data+'.contsub',
          imagename = sourcename+'_13CO',
          restfreq = '110.210GHz',
          spw = '2',
          field='0',
          specmode = 'cube',
          outframe = 'LSRK',
          nchan = 35,
          start = '-50km/s',
          width = '20km/s',
          threshold='1.5mJy',
          niter=100,
          deconvolver='hogbom',
          gridder='mosaic',
          pbcor=True,
          chanchunks=-1,
          interactive=F,
          imsize=[500, 500],
          cell = '0.25arcsec',
          weighting='briggs',
          robust=0.5)
```

Steps 5-8: Image the emission lines

```
Message
Step 7 Image the emission lines : 13CO

##########################################
##### Begin Task: tclean            #####
tclean(vis="uid___A002_X87544a_X25eb.ms.split.cal.contsub",selectdata=True,field="0",spw="2",timerange="",
        uvrange="",antenna="",scan="",observation="",intent="",
        datacolumn="corrected",imagename="NGC253_13CO",imsize=[500, 500],cell="0.25arcsec",phasecenter="",
        stokes="I",projection="SIN",startmodel="",specmode="cube",reffreq="",
        nchan=35,start="-50km/s",width="20km/s",outframe="LSRK",veltype="radio",
        restfreq="110.210GHz",interpolation="linear",gridder="mosaic",facets=1,chanchunks=-1,
        wprojplanes=1,vptable="",aterm=True,psterm=False,wbawp=True,
        conjbeams=True,cfcache="",computepastep=360.0,rotatepastep=360.0,pblimit=0.2,
        normtype="flatnoise",deconvolver="hogbom",scales=[],nterms=2,smallscalebias=0.6,
        restoration=True,restoringbeam=[],pbcor=True,outlierfile="",weighting="briggs",
        robust=0.5,npixels=0,uvtaper=[],niter=100,gain=0.1,
        threshold="1.5mJy",cycleniter=-1,cyclefactor=1.0,minpsffraction=0.05,maxpsffraction=0.8,
        interactive=False,usemask="user",mask="",pbmask=0.0,maskthreshold="",
        maskresolution="",nmask=0,sidelobethreshold=3.0,noisethreshold=5.0,lownoisethreshold=1.5,
        negativethreshold=0.0,smoothfactor=1.0,minbeamfrac=0.3,cutthreshold=0.01,growiterations=75,
        restart=True,savemodel="none",calcres=True,calcpsf=True,parallel=False)
Verifying Input Parameters
MS : uid___A002_X87544a_X25eb.ms.split.cal.contsub | Selecting on fields : 0 | Selecting on spw :2 | [Opened
  NRows selected : 113050
Define image coordinates for [NGC253_13CO] :
 phaseCenter='Direction: [0.884764, 0.186268, -0.427196]'  Channels equidistant in vrad
 Central frequency (in output frame) = 1.10103e+11 Hz == 290000 m/s radio velocity
 Width of central channel (in output frame) = 7.35242e+06 Hz == 20000 m/s radio velocity
 Number of channels = 35
 Total width of SPW (in output frame) = 2.57335e+08 Hz
 Lower edge = 1.09975e+11 Hz, upper edge = 1.10232e+11 Hz
Impars : start -50km/s
Shape : [500, 500, 1, 35]Spectral : [1.10228e+11] at [0] with increment [-7.35242e+06]
Set Gridding options for [NGC253_13CO] with ftmachine : mosaicft
Using default Voltage Patterns from the VPManager
Temporary alert : The state of the vpmanager tool has been modified by loading these primary beam models. If
PB used ALMA
Automatically calculate chanchunks using imshape : [500, 500, 1, 35]
Required memory 0.70408
Available memory 12.8 (rc: memory fraction 80% rc memory -0.000976562)
1 other processes on node
Setting chanchunks to 1
Tuning frequency data selection to match image spectral coordinates
MS : uid___A002_X87544a_X25eb.ms.split.cal.contsub | Selecting on fields : 0 | Selecting on spw :2 | [Opened
  NRows selected : 113050
Set imaging weights : Briggs weighting: sidelobes will be suppressed over full image
Normal robustness, robust = 0.5
Set Deconvolution Options for [NGC253_13CO] : hogbom
Set Iteration Control Options
------------------------------------------------------------ Make PSF ------------------------------------------
 Found full images : 1
 Found part images : 0
```

Steps 5-8: Image the emission lines

Masking (interactive clean) vs. **non-masking** (non-interactive)