ALMA Manual Imaging

Dominic Ludovici | 21st Synthesis Imaging Workshop| May 28th, 2026

National Radio Astronomy Observatory

Learning Objectives

At the end of this tutorial, participants should be able to…

1. Demonstrate using the CASA task Tclean to create an image from ALMA visibilities.
2. Use Plotms to identify line and continuum regions in a spectrum
3. Utilize immoments to make moment maps from spectral line data.
4. Use CARTA to visualize Radio Astronomy data.

Tutorial Guide

- I will use Active Learning techniques to keep you engaged.
  - We will often stop for discussion and questions.
  - Please sit near someone else. Help each other and check your work against your neighbors.

- Your understanding is important to us!
  - I will be walking around the room to help while you work.
  - We have many others here to help as well.

- Ask us questions! Raise your hand and someone will come to help!

Your CASA tutorial team

Dominic Ludovici
NRAO NAASC

Natalie Butterfield
NRAO NAASC

Tristan Ashton
NRAO NAASC

Michael Sanchez
NRAO NAASC

Ed Starr
NRAO NAASC

Your CASA tutorial team

Maria Galloway-Sprietsma
ALMA Ambassador
University of Florida

Carla Cornil-Baïotto
ALMA Ambassador
Instituto de Física y Astronomía

Jess Speedie
Former ALMA Ambassador
MIT

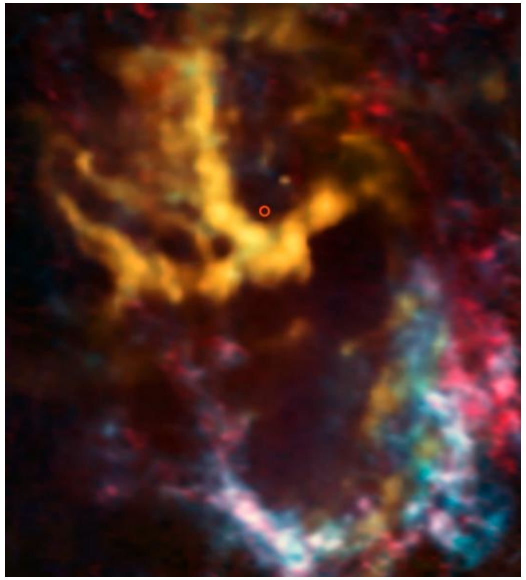
Data Description

Today's data is from the ALMA Atacama Compact Array (ACA) filler projects observed during cycle 6.

Data Description

We will examine the heart of our own galaxy: SGR A*!

- Sgr A* is a variable source of radiation from the Radio up to gamma rays.
- During the observing campaign, ALMA cooperated with Spitzer, Chandra, and NuStar to observer our central black hole.
- The data contain both continuum and spectral line observations, allowing us to examine the emission from Sgr A* as well as the Circumnuclear Disk!



Sgr A* as seen by ALMA in multiple bands.

Data Description

We will image the continuum emission and CO line emission observed at Band 6.

- Link to paper:
- https://iopscience.iop.org/article/10.3847/1538-4357/ac2d2c/pdf and
- https://iopscience.iop.org/article/10.3847/1538-4357/ac6104/pdf

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

In **ALMA_manual_imaging_tutorial.tar** you should have:

- **SgrAstar.ms**(the calibrated measurement set file containing data)
- **imaging.py** (the script we will work through together to begin imaging the data)
- analysis_scripts

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

CASA (Common Astronomy Software Applications)

- CASA is the offline data reduction package for ALMA and the VLA (data from other telescopes usually work too, but not primary goal of CASA)
- Code is C++ (fast) bound to Python which provides ease of use and scripting
- Provides data import/export, inspection, editing, calibration, imageing, viewing, and analysis
- Also supports single dish data reduction
- We have a lot of documentation (CASA docs), reduction tutorials (CASA guides), and a helpdesk.

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Start CASA.

Lets make sure everyone can start CASA!

On Linux: Start CASA 6.6.6 or 6.7.5

On OSX: Start CASA 6.7.5

If you put CASA in your path, you should be able to start it by typing “`casa`” on the command line.

If not, give the full path:
</path/to/casa/install>/bin/casa

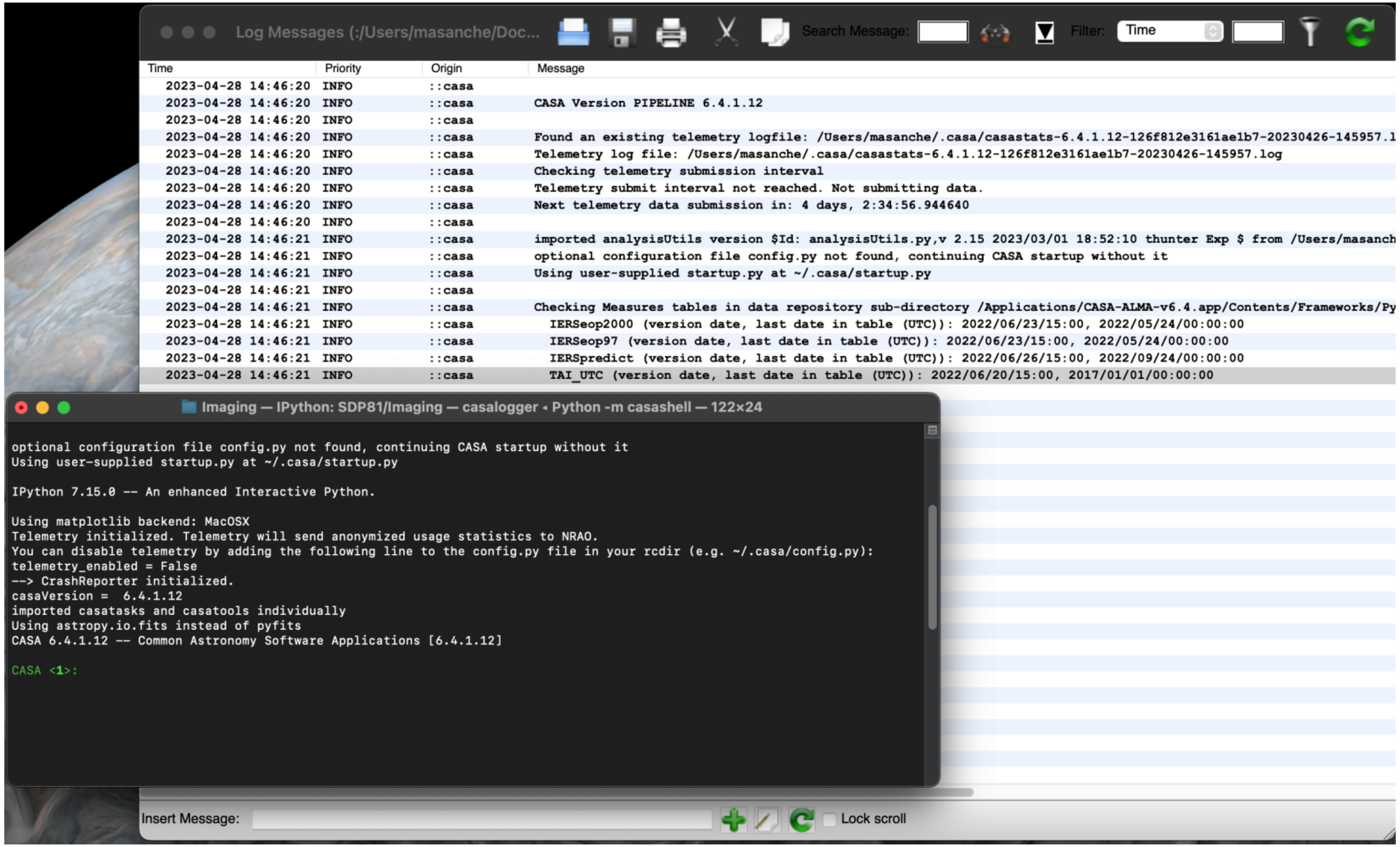
Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks



Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Why a different version of CASA for OSX?

- Interactive Tclean does not function on OSX in CASA 6.6.6 (and earlier)
- New iclean task is available in CASA 6.7

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

CASA runs within pythons scripts or through the interactive *IPython* (ipython.org) interface

- IPython Features:
  - shell access
  - auto-parenthesis (autocall)
  - Tab auto-completion
  - command history (arrow up and “hist [-n]”)
  - session logging
  - casaTIME.log – casa logger messages
  - numbered input/output
  - history/searching

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Tasks - high-level functionality

- function call or parameter handling interface
- these are what you should use in tutorials

Tools - complete functionality

- **tool.method()** calls
- they are internally used by tasks or can be used on their own sometimes shown in tutorial scripts and CASAGuides

Applications – some tasks/tools invoke standalone apps

- e.g. **casaviewer, mpicasa**

Shell commands can be run with a leading exclamation mark

- **!du –ls** or inside **os.system("shell command")**
- (some key shell commands like "ls" work without the exclamation mark
- We will use **os.system()** exclusively within this tutorial.)

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

taskhelp

Calibration — IPython: SDP81/Calibration — casalogger ‹ Python -m casashell — 110×50

```
CASA <1>: taskhelp

==================================================================
CASA tasks
------------------------------------------------------------------
> analysis
------------------------------------------------------------------
    imcollapse : Collapse image along one axis, aggregating pixel values along that axis.
     imcontsub : Estimates and subtracts continuum emission from an image cube
         imdev : Create an image that can represent the statistical deviations of the input image.
         imfit : Fit one or more elliptical Gaussian components on an image region(s)
        imhead : List, get and put image header parameters
     imhistory : Retrieve and modify image history
        immath : Perform math operations on images
     immoments : Compute moments from an image
       impbcor : Construct a primary beam corrected image from an image and a primary beam pattern.
          impv : Construct a position-velocity image by choosing two points in the direction plane.
       imrebin : Rebin an image by the specified integer factors
     imreframe : Change the frame in which the image reports its spectral values
      imregrid : regrid an image onto a template image
      imsmooth : Smooth an image or portion of an image
        imstat : Displays statistical information from an image or image region
    imsubimage : Create a (sub)image from a region of the image
       imtrans : Reorder image axes
         imval : Get the data value(s) and/or mask value in an image.
       listvis : List measurement set visibilities.
         rmfit : Calculate rotation measure.
       specfit : Fit 1-dimensional gaussians and/or polynomial models to an image or image region
      specflux : Report spectral profile and calculate spectral flux over a user specified region
    specsmooth : Smooth an image region in one dimension
        spxfit : Fit a 1-dimensional model(s) to an image(s) or region for determination of spectral index.
------------------------------------------------------------------
> calibration
------------------------------------------------------------------
         accor : Normalize visibilities based on auto-correlations
      applycal : Apply calibrations solutions(s) to data
      bandpass : Calculates a bandpass calibration solution
         blcal : Calculate a baseline-based calibration solution (gain or bandpass)
       calstat : Displays statistical information on a calibration table
      clearcal : Re-initializes the calibration for a visibility data set
        delmod : Deletes model representations in the MS
    fixplanets : Changes FIELD and SOURCE table entries based on user-provided direction or POINTING table, op
tionally fixes the UVW coordinates
     fluxscale : Bootstrap the flux density scale from standard calibrators
     fringefit : Fringe fit delay and rates
            ft : Insert a source model as a visibility set
       gaincal : Determine temporal gains from calibrator observations
        gencal : Specify Calibration Values of Various Types
   initweights : Initializes weight information in the MS
```

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Task Execution:

Write the full parameter set in a line:

- taskname(arg1=val1, arg2=val2, ...)
- e.g. tclean(vis='input.ms',imagename='galaxy', robust=0.5, imsize=[200,200])

unspecified parameters will be set to their default values (globals not used; i.e. not to previously set variables)

Useful in scripts, but also in 'pseudo-scripts':

- To keep a record, it is frequently a good idea to write down the full line as above in an editor, then cut and paste into CASA.
- When changes are needed, change in editor and cut and paste again. That is good practice to keep a record of the exact input.
- But note that the logger is also repeating the full task command

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Scripts can be run with the following:

execfile(‘<yourscript.py>’)

Python 3 removed the execfile built-in function. CASA provides a convenience function that attempts to reproduce the behavior of the Python 2.7 built-in execfile function.

Getting Started

Navigating to Your Data
Starting CASA
Task Help
Running Tasks

CASA also has an asking interface, similar to AIPS, MIRIAD, etc.

- parameter manipulation commands
  - inp, default, saveinputs, tget, tput
- use parameters set as global Python variables
  - <param> = <value>
  - (e.g. vis = ‘ngc5921.demo.ms’)
- execute
  - <taskname> or go (e.g. tclean())
- return values (except when using “go”)
  - some tasks return Python dictionaries, assign a variable name to get them, e.g. myval=imval()
  - Very useful for scripting based on task outputs

Getting Started

Navigating to Your Data

Starting CASA

Task Help

Running Tasks

Calibration — IPython: SDP81/Calibration — casalogger ◂ Python -m casashell — 110×50

```
[CASA <3>: inp tclean
# tclean -- Radio Interferometric Image Reconstruction
vis                 = ''                        # Name of input visibility file(s)
selectdata          = True                      # Enable data selection parameters
   field            = ''                        # field(s) to select
   spw              = ''                        # spw(s)/channels to select
   timerange        = ''                        # Range of time to select from data
   uvrange          = ''                        # Select data within uvrange
   antenna          = ''                        # Select data based on antenna/baseline
   scan             = ''                        # Scan number range
   observation      = ''                        # Observation ID range
   intent           = ''                        # Scan Intent(s)
datacolumn          = 'corrected'               # Data column to image(data,corrected)
imagename           = ''                        # Pre-name of output images
imsize              = [100]                     # Number of pixels
cell                = []                        # Cell size
phasecenter         = ''                        # Phase center of the image
stokes              = 'I'                       # Stokes Planes to make
projection          = 'SIN'                     # Coordinate projection
startmodel          = ''                        # Name of starting model image
specmode            = 'mfs'                     # Spectral definition mode (mfs,cube,cubedata, cubesource)
   reffreq          = ''                        # Reference frequency
gridder             = 'standard'                # Gridding options (standard, wproject, widefield, mosaic,
                                                # awproject)
   vptable          = ''                        # Name of Voltage Pattern table
   pblimit          = 0.2                       # PB gain level at which to cut off normalizations
deconvolver         = 'hogbom'                  # Minor cycle algorithm
                                                # (hogbom,clark,multiscale,mtmfs,mem,clarkstokes)
restoration         = True                      # Do restoration steps (or not)
   restoringbeam    = []                        # Restoring beam shape to use. Default is the PSF main lobe
   pbcor            = False                     # Apply PB correction on the output restored image
outlierfile         = ''                        # Name of outlier-field image definitions
weighting           = 'natural'                 # Weighting scheme (natural,uniform,briggs,
                                                # briggsabs[experimental], briggsbwtaper[experimental])
   uvtaper          = []                        # uv-taper on outer baselines in uv-plane
niter               = 0                         # Maximum number of iterations
usemask             = 'user'                    # Type of mask(s) for deconvolution: user, pb, or
                                                # auto-multithresh
   mask             = ''                        # Mask (a list of image name(s) or region file(s) or region
                                                # string(s) )
   pbmask           = 0.0                       # primary beam mask
fastnoise           = True                      # True: use the faster (old) noise calculation. False: use
                                                # the new improved noise calculations
restart             = True                      # True : Re-use existing images. False : Increment imagename
savemodel           = 'none'                    # Options to save model visibilities (none, virtual,
                                                # modelcolumn)
calcres             = True                      # Calculate initial residual image
calcpsf             = True                      # Calculate PSF
   psfcutoff        = 0.35                      # All pixels in the main lobe of the PSF above psfcutoff are
                                                # used to fit a Gaussian beam (the Clean beam).
```

Getting Started

Navigating to Your Data

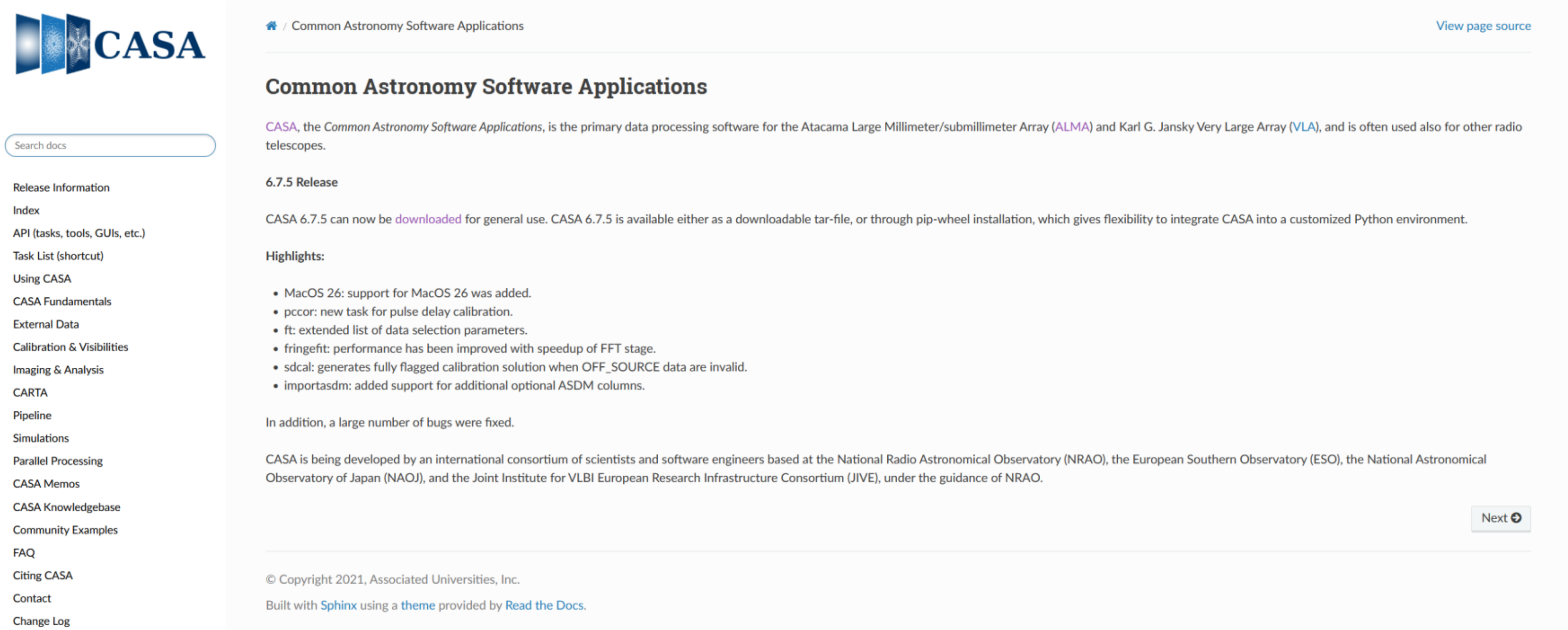
Starting CASA

Task Help

Running Tasks

Getting Help:

https://casadocs.readthedocs.io/en/stable/


CASA

Search docs

Release Information
Index
API (tasks, tools, GUIs, etc.)
Task List (shortcut)
Using CASA
CASA Fundamentals
External Data
Calibration & Visibilities
Imaging & Analysis
CARTA
Pipeline
Simulations
Parallel Processing
CASA Memos
CASA Knowledgebase
Community Examples
FAQ
Citing CASA
Contact
Change Log

/ Common Astronomy Software Applications — View page source

Common Astronomy Software Applications

CASA, the *Common Astronomy Software Applications*, is the primary data processing software for the Atacama Large Millimeter/submillimeter Array (ALMA) and Karl G. Jansky Very Large Array (VLA), and is often used also for other radio telescopes.

6.7.5 Release

CASA 6.7.5 can now be downloaded for general use. CASA 6.7.5 is available either as a downloadable tar-file, or through pip-wheel installation, which gives flexibility to integrate CASA into a customized Python environment.

Highlights:

- MacOS 26: support for MacOS 26 was added.
- pccor: new task for pulse delay calibration.
- ft: extended list of data selection parameters.
- fringefit: performance has been improved with speedup of FFT stage.
- sdcal: generates fully flagged calibration solution when OFF_SOURCE data are invalid.
- importasdm: added support for additional optional ASDM columns.

In addition, a large number of bugs were fixed.

CASA is being developed by an international consortium of scientists and software engineers based at the National Radio Astronomical Observatory (NRAO), the European Southern Observatory (ESO), the National Astronomical Observatory of Japan (NAOJ), and the Joint Institute for VLBI European Research Infrastructure Consortium (JIVE), under the guidance of NRAO.

Next

Built with Sphinx using a theme provided by Read the Docs.

Data Inspection

Data Inspection

Viewing Observation Information

Plotting UV Coverage

We are going to inspect our data to learn about the observation.

We are still following the imaging.py script if you want to copy the commands and follow along.

Jim Torson analyzes data from the Very Large Array in its computer room in 1983. (Image Credit: NRAO)

Data Inspection

Viewing Observation Information

Plotting UV Coverage

Lets start by looking at a summary of the measurement set.

Use the task `listobs()`

From imaging.py:

```
listobs(“SgrAstar.ms")
```

Question: Listobs

After taking a look at the listobs output in the logger window, what information do you see that you think may be useful during imaging?

You can write your listobs to a file using:

```
listobs(vis = ‘SgrAstar.ms',
 listfile = ‘SgrAstar.ms.listobs')
```

Data Inspection

Viewing Observation Information

Plotting UV Coverage

Lets start by looking at a summary of the measurement set.

Use the task `listobs()`

```
listobs("SgrAstar.ms")
```

```
Fields: 5  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
0     none J1337-1257          13:37:39.782778 -12.57.24.69339 ICRS    0          33000
1     none J1700-2610          17:00:53.154063 -26.10.51.72542 ICRS    1         117216
2     none SgrAstar            17:45:40.038000 -29.00.28.06900 ICRS    2         355872
3     none J1924-2914          19:24:51.055956 -29.14.30.12106 ICRS    3          99000
5     none J1733-3722          17:33:15.193076 -37.22.32.39955 ICRS    3          39072

Spectral Windows:  (4 unique spectral windows and 1 unique polarization setups)  SpwID  Name
Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs

16  X67236705#ALMA_RB_07#BB_1#SW-01#FULL_RES   1024   TOPO  344997.260     1953.125   2000000.0 345996.2837        1  XX  YY
18  X67236705#ALMA_RB_07#BB_2#SW-01#FULL_RES   1024   TOPO  346872.240     1953.125   2000000.0 347871.2636        2  XX  YY
20  X67236705#ALMA_RB_07#BB_3#SW-01#FULL_RES   1024   TOPO  334995.365    -1953.125   2000000.0 333996.3419        3  XX  YY
22  X67236705#ALMA_RB_07#BB_4#SW-01#FULL_RES   1024   TOPO  336870.365    -1953.125   2000000.0 335871.3419        4  XX  YY
```

Data Inspection

Viewing Observation Information

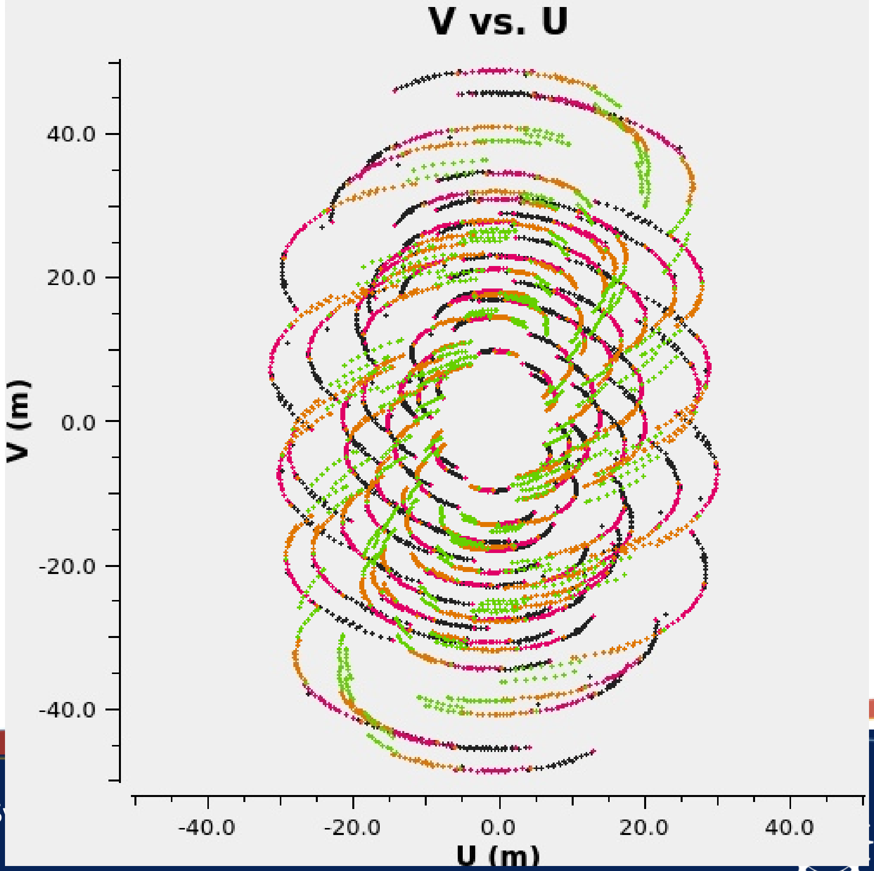
Plotting UV coverage

Now, we will plot the uv coverage with plotms()

There is unfortunately an error in the script! Delete the .listobs.

From imaging.py:

```
plotms(vis='SgrAstar.ms.listobs', xaxis='u',
    yaxis='v',avgchannel='10000', avgspw=False,
    avgtime='1e9',
    avgscan=False,coloraxis="observation")
```



Question: UV Coverage

- Why is the UV coverage different for each EB? (There are multiple possible reasons!)

Imaging

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

We want to image our data! Where do we start?

Most of this section is going to be familiar. You should have seen it in the imaging talks earlier in the workshop!

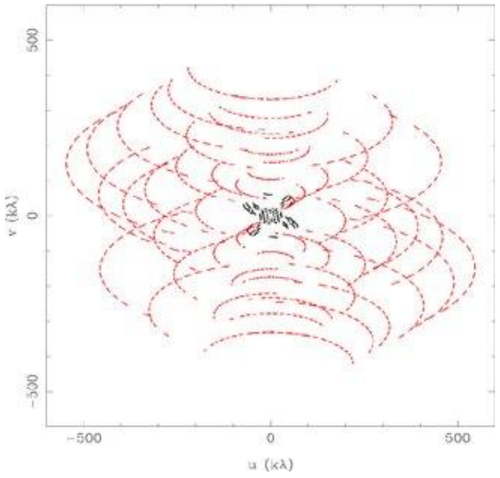
- Thursday:
  - Introduction to imaging and deconvolution (*Joshua Marvil*)
  - Self Calibration (*Joshua Marvil*)
- Friday:
  - Wide-field imaging (*Preshanth Jagannathan*)
  - Wide-band imaging (*Urvashi Rau*)
  - Special Topics: Spectral Lines (*Brian Svoboda*)

  - We will perform a quick review!

Dirty beams and images

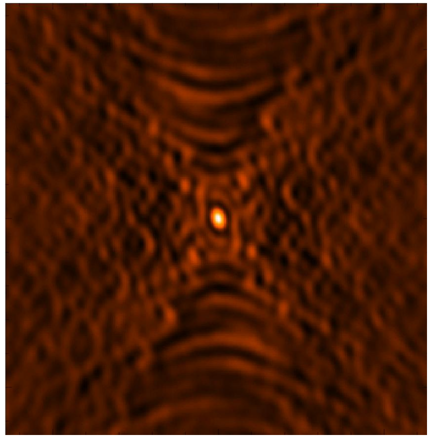
T(x,y)
(True sky brightness)

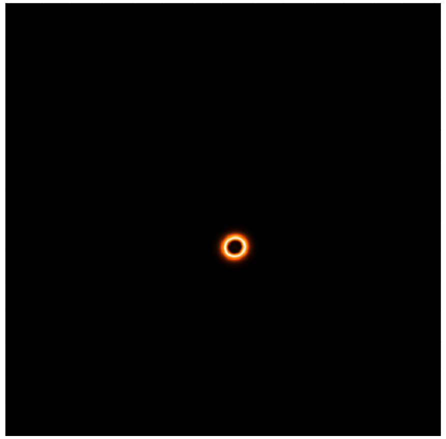
B(u,v)
(sampled visibilities)



(F. Transform) ⇌

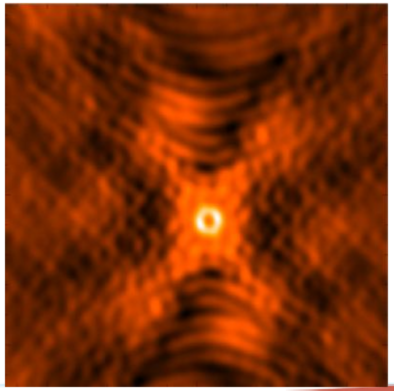
b(x,y)
(dirty beam or psf)



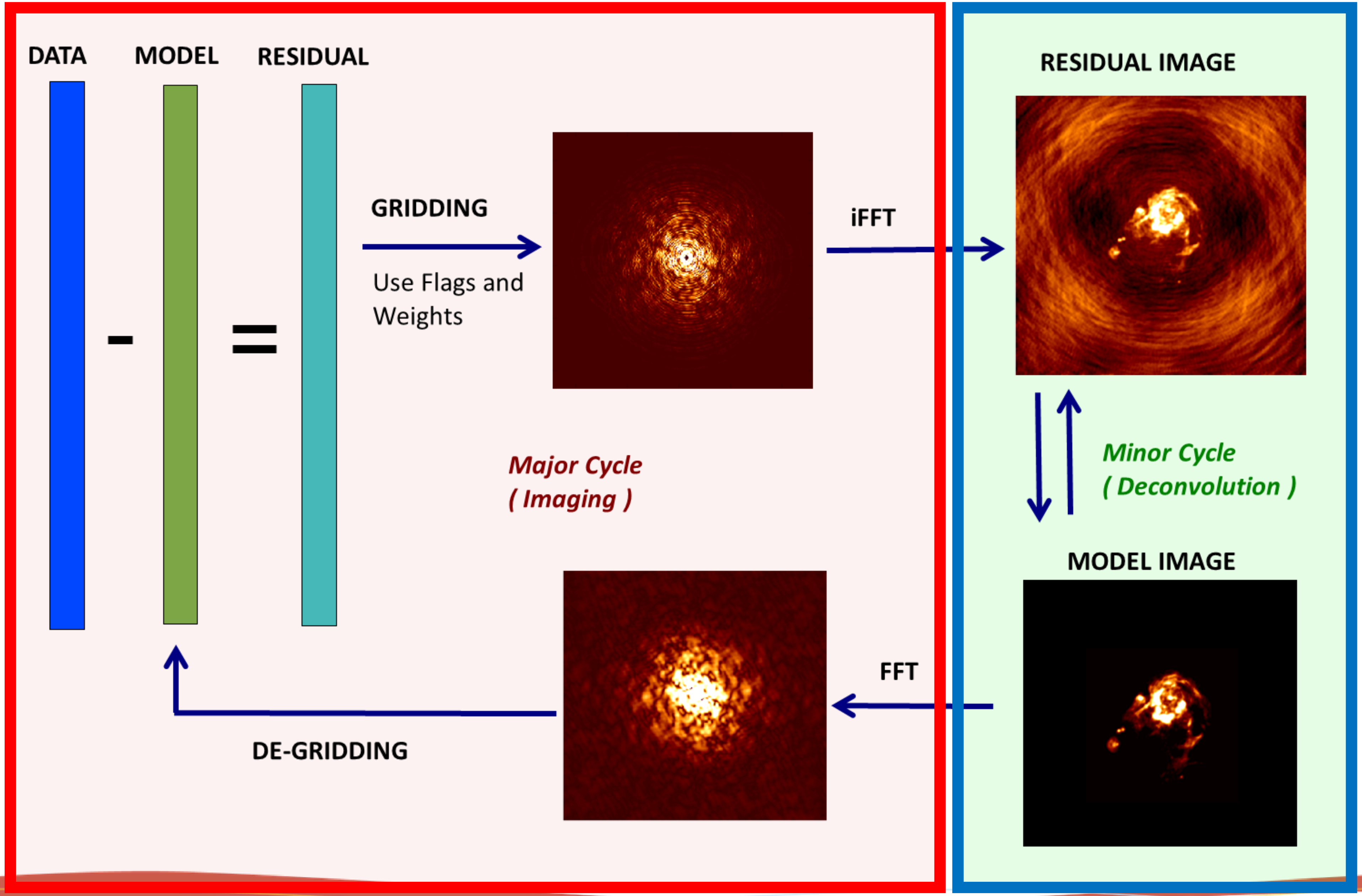


Convolve → $\otimes$ ←

↓



TD(x,y)
(dirty image)


DATA
MODEL
RESIDUAL
-
=
GRIDDING
Use Flags and Weights
iFFT
RESIDUAL IMAGE
Major Cycle
(Imaging)
Minor Cycle
(Deconvolution)
MODEL IMAGE
FFT
DE-GRIDDING

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Stopping criteria:

- *residual* map max < multiple of rms (when noise limited)
- *residual* map max < fraction of dirty map max (dynamic range limited)
- max number of clean components reached (no justification)

loop gain

- good results for g ~ 0.1 to 0.3
- lower values can work better for smoother emission, g ~ 0.05

easy to include *a priori* information about where to search for clean components (“clean boxes”)

Weighting Options

Natural

- Better sensitivity, lower resolution
- $W(u, v) = 1/\sigma^2$
- With ALMA, more weight to shorter baselines
- (More short baselines, more weight)

Uniform

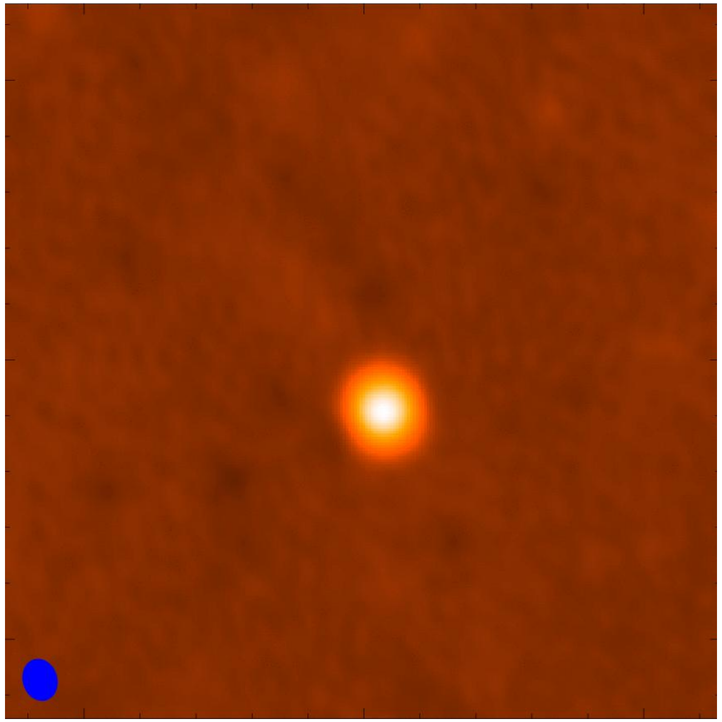
- Worse sensitivity, better resolution.
- Note: can cause problems with sparse (u,v) coverage as cells with few samples have the same weight as cells with many.
  - Think 7m ACA observations.
- Weight all the same.

Robust ("Briggs")

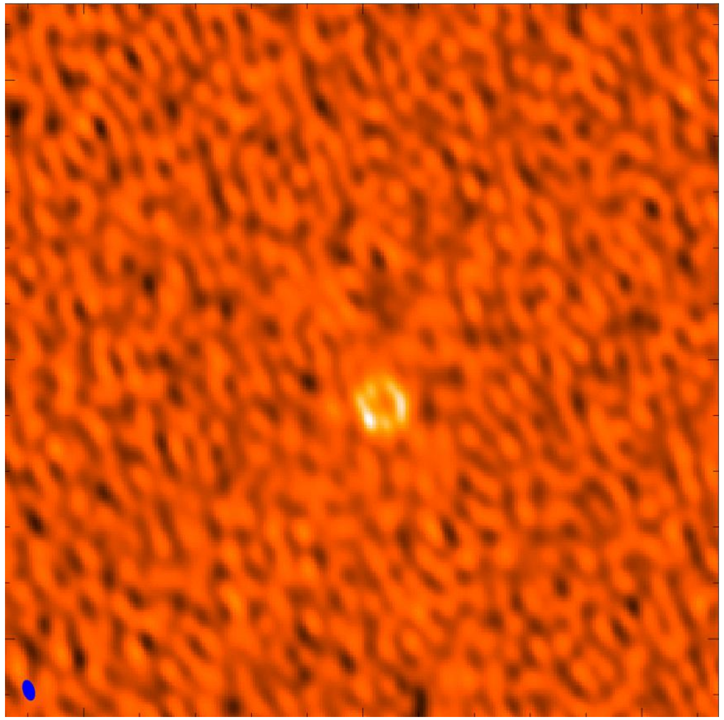
- Compromise. Can recover most of the sensitivity and resolution.
- Variation of Uniform that avoids giving large weights to cells with small natural weigh.
- Robust = -2 => Uniform
- Robust = 2 => Natural
- Stick to robust ≥ 0.0
- Imaging uses robust =0.5 by default in ALMA pipeline.

Weighting Options

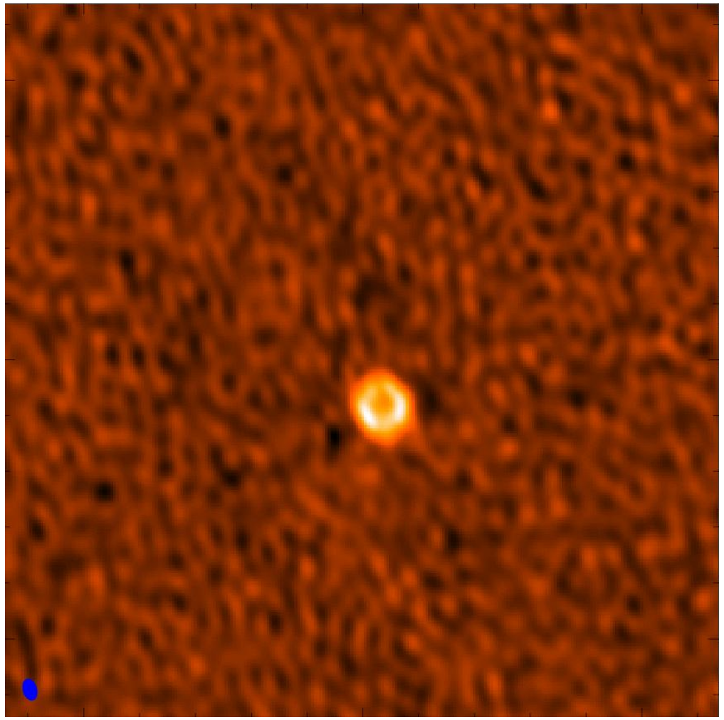
Natural



Uniform



Robust = 0



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

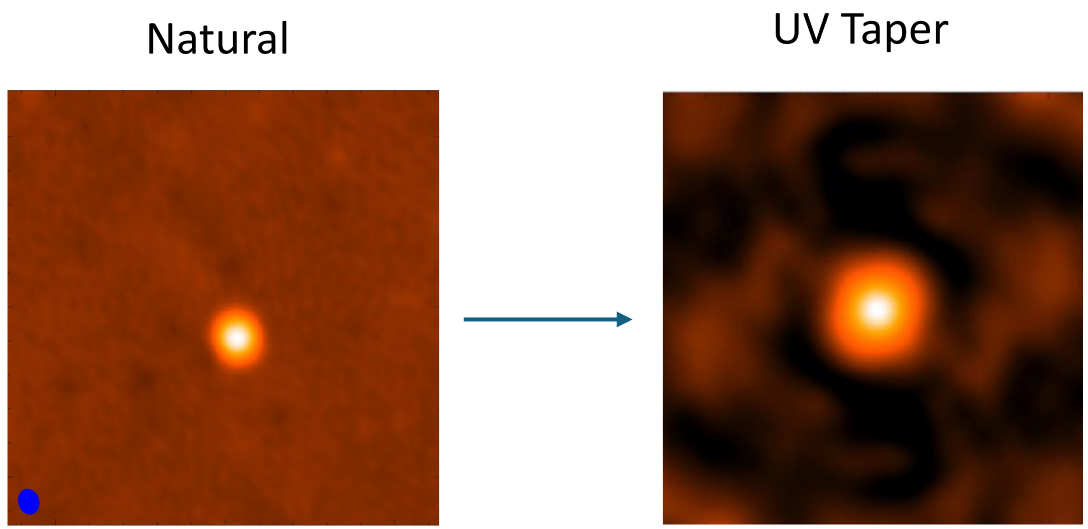
Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

UV Tapering is similar to convolving the image by a Gaussian

Added weight to short baselines degrades resolution

May improve sensitivity to extended structure.



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Clean Boxes:

- Because we do not fully sample the uv-plane in our imaging, there is generally no unique solution to the deconvolution process
- We use clean ‘boxes’, or masks, to identify regions of the image or cube with real emission
- Clean boxes are a way to create the best possible model for your source – particularly sources with complex emission
- As a first step, include bright features in your mask, drawing a close contour around the emission
- For cubes, you can mask channel-by-channel, or all channels
- As tclean progresses, strong residuals that do not appear to be due to sidelobes (i.e., do not disappear in subsequent cycles) can be added iteratively
- Be careful when masking – adding a mask around noise or beam sidelobes can create features in your final image that are not real

Imaging

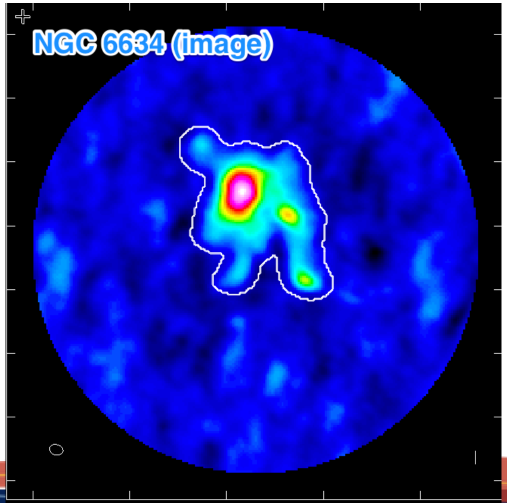
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Automasking (auto-multithresh):

- Algorithm developed by A. Kepley,
  T. Tsutsumi (+Yoon, Indebetouw, Brogan)
  - parameterized in terms of fundamental image parameters (S/N, fraction of beam, sidelobe level) ⇒ instrument independent
  - Masks are re-calculated every major cycle within tclean ⇒ follows evolution of image
- **Available in tclean since CASA 5.1**
  - usemask='auto-multithresh'
- Deployed in ALMA Cycle 5 pipeline
- CASA guide: https://casaguides.nrao.edu/index.php?title=Automasking_Guide
- Be careful if you have poor UV coverage.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Tclean!

Tclean has many options. You should check out the tclean page on the CASAdocs to see what it is capable of!

```
tclean(vis, selectdata=True, field='', spw='', timerange='', uvrange='', antenna='', scan='', observation='', intent='', datacolumn='corrected', imagename='', imsize=[100], cell='"1arcsec"', phasecenter='', stokes='I', projection='SIN', startmodel='', specmode='mfs', reffreq='', nchan=-1, start='', width='', outframe='LSRK', veltype='radio', restfreq='', interpolation='linear', perchanweightdensity=True, gridder='standard', facets=1, psfphasecenter='', wprojplanes=1, vptable='', mosweight=True, aterm=True, psterm=False, wbawp=True, conjbeams=False, cfcache='', usepointing=False, computepastep=360.0, rotatepastep=360.0, pointingoffsetsigdev='', pblimit=0.2, normtype='flatnoise', deconvolver='hogbom', scales='', nterms=2, smallscalebias=0.0, fusedthreshold=0.0, largestscale=-1, restoration=True, restoringbeam='', pbcor=False, outlierfile='', weighting='natural', robust=0.5, noise='1.0Jy', npixels=0, uvtaper=[''], niter=0, gain=0.1, threshold=0.0, nsigma=0.0, cycleniter=-1, cyclefactor=1.0, minpsffraction=0.05, maxpsffraction=0.8, interactive=False, nmajor=-1, fullsummary=False, usemask='user', mask='', pbmask=0.0, sidelobethreshold=3.0, noisethreshold=5.0, lownoisethreshold=1.5, negativethreshold=0.0, smoothfactor=1.0, minbeamfrac=0.3, cutthreshold=0.01, growiterations=75, dogrowprune=True, minpercentchange=-1.0, verbose=False, fastnoise=True, restart=True, savemodel='none', calcres=True, calcpsf=True, psfcutoff=0.35, parallel=False)    [source]
```

Radio Interferometric Image Reconstruction

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

iclean!

Iclean is the upcoming interactive clean! We will use this today if you have OSX. (Recommended for linux users too!)

Interactive Clean

The new `iclean` task uses the `cubevis` package (formerly casagui) to display the interactive clean graphical interface in a web browser. The `cubevis` package and its dependencies (e.g. `bokeh`, `astropy`), together with a new task `iclean`, is available in CASA versions >= 6.7.2. This page describes the features of the interactive clean graphical user interface (GUI). For a description of the interactive clean (`iclean`) task interface please refer to the iclean API.

The `iclean` task was developed as a replacement for the interactive cleaning capabilities present in the current `casaviewer`, and as such only contains the functionality necessary for interactive deconvolution. It is **not** meant as a replacement for an image viewer such as CARTA.

iclean GUI

The `iclean` GUI is designed to support interactive image viewing, mask drawing and iteration control.

Usage

- **Masking** : To add or modify the mask, select a drawing tool, draw a region, and then add or subtract the region from the image mask (using the toolbar buttons or keyboard shortcuts).
- **Deconvolution** : Setup the deconvolution parameters using the input text boxes in the default iteration control tab. Then click the “Run a single major cycle” button (single circular arrow) or “run multiple major cycles” button (double looping arrows).
  - The “run multiple major cycles” button will continuously execute the deconvolution loop until a user interrupt, or until a convergence criterion is reached.

Pixel and Image Size

Pixel (cell) Size

- Satisfy sampling theorem for long baselines
    - In practice, 5 to 8 pixels across dirty beam main lobe.
- $\theta_{res} \approx \frac{k\lambda}{L_{max}} [radians]$
    - L_{max} is the longest baseline [meters]
    - λ is the wavelength in meters
    - $0.7 < k < 1.2$ (typically) depends on weighting choice

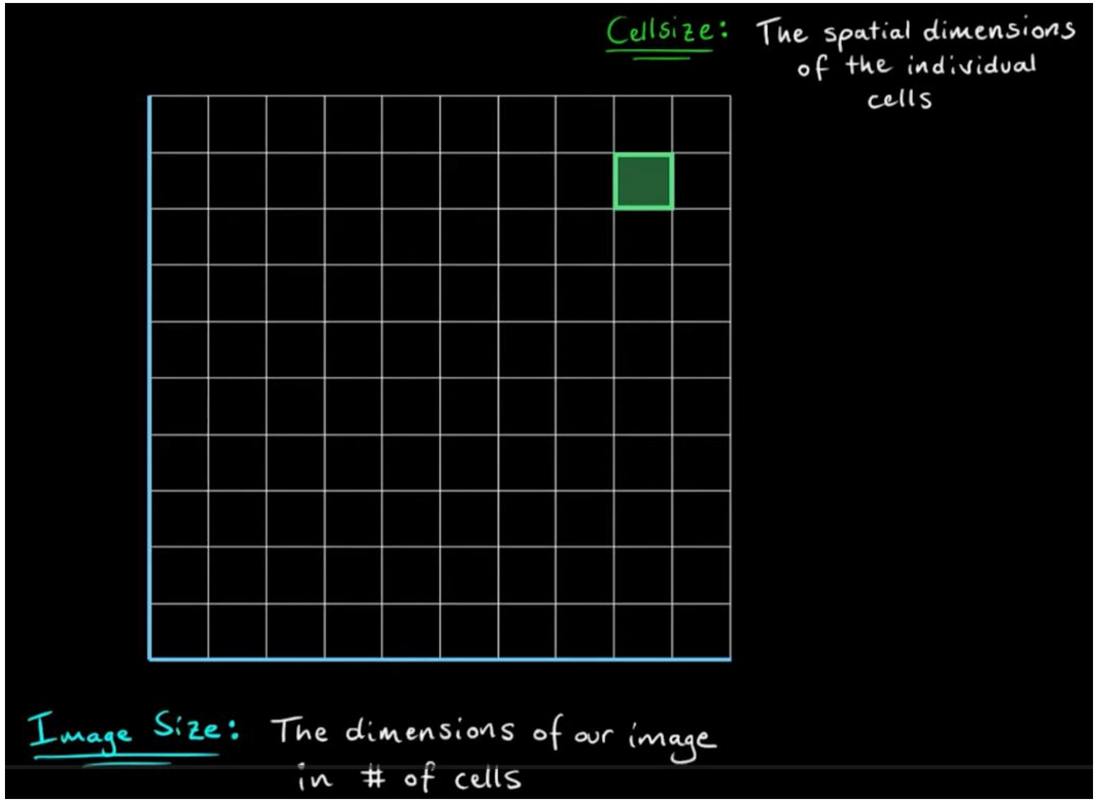
Image Size

- Avoid aliasing from targets outside your image.
- Usual choice is the primary beam.
- 12m : $FOV[arcsec] = \frac{6300}{\nu[GHz]}$
- 7m: $FOV[arcsec] = \frac{10608}{\nu[GHz]}$

Question: Image Parameters

- Before we begin imaging, we need to determine a cell size and image size. Split these tasks up among your group!
- What is Lmax?
- What is ν?

- Calculate the pixel size
- Calculate FOV in arcsec
- Calculate FOV in pixels



Screenshot from the ALMA Primer Youtube Series Video “ALMA Primer Series: Image and Cell Size”

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Best Image sizes

- Image sizes should be factorizable by 2, 3, and 5 only for optimum performance.
- Should usually make the image a little bigger than required
- SQUARE images process much faster than rectangular images.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Largest Angular Size

- **Range** from synthesized beam to maximum angular scale (MAS)
- **Smooth** structures larger than LAS begin to be resolved out.
- All flux on scales larger than $\frac{\lambda}{B_{min}} \sim (2 \times MAS)$ completely resolved out.

Band	Frequency (GHz)	Primary beam (")	Range of Scales (")
3	100	106	12.7 – 66.7
6	230	46	5.52 – 29.0
7	345	30	3.68 – 19.3
9	650	16	1.95 – 10.3

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Output files from tclean (additional files made for some modes)

***.pb**

Relative sky sensitivity - shows the primary beam response

***.image**

Cleaned and restored image

***.mask**

Clean “boxes” shows where you cleaned

***.model**

Clean components - the model used by clean (in Jy/pixel)

***.psf**

Dirty beam - shows the synthesized beam

***.residual**

Residual shows what was left after you cleaned (the "dirty" part of the final image)

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

- Since the Bandpass calibrator is a point source, we are going to experiment a little bit with options in clean!

```
tclean(vis = ['SgrAstar.ms’],
  imagename = 'J1924-2914_bp.spw16_18_20_22.mfs.I.manual',
   field = 'J1924-2914',
   stokes = 'I',
   spw = '16,18,20,22',
   outframe = 'LSRK',
   specmode = 'mfs',
   nterms = 1,
   imsize = [60, 60],
   cell = '0.81arcsec',
   deconvolver = 'hogbom',
   niter = 100,
   weighting = 'briggs',
   robust = 0.5,
   mask = '',
   gridder = 'standard',
   pbcor = True,
   threshold = '1.5mJy',
   restoringbeam = 'common’,
   Interactive = True)
```

Imaging

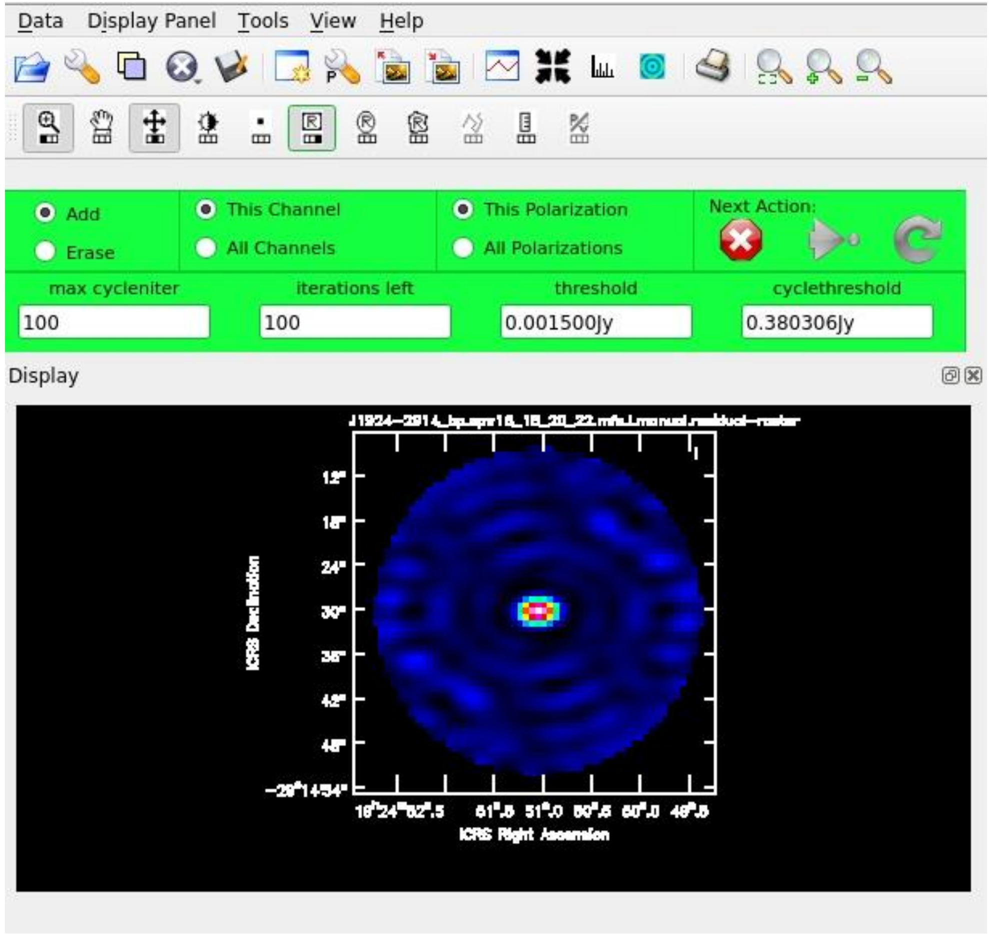
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



This is the dirty image of our calibrator.

Imaging

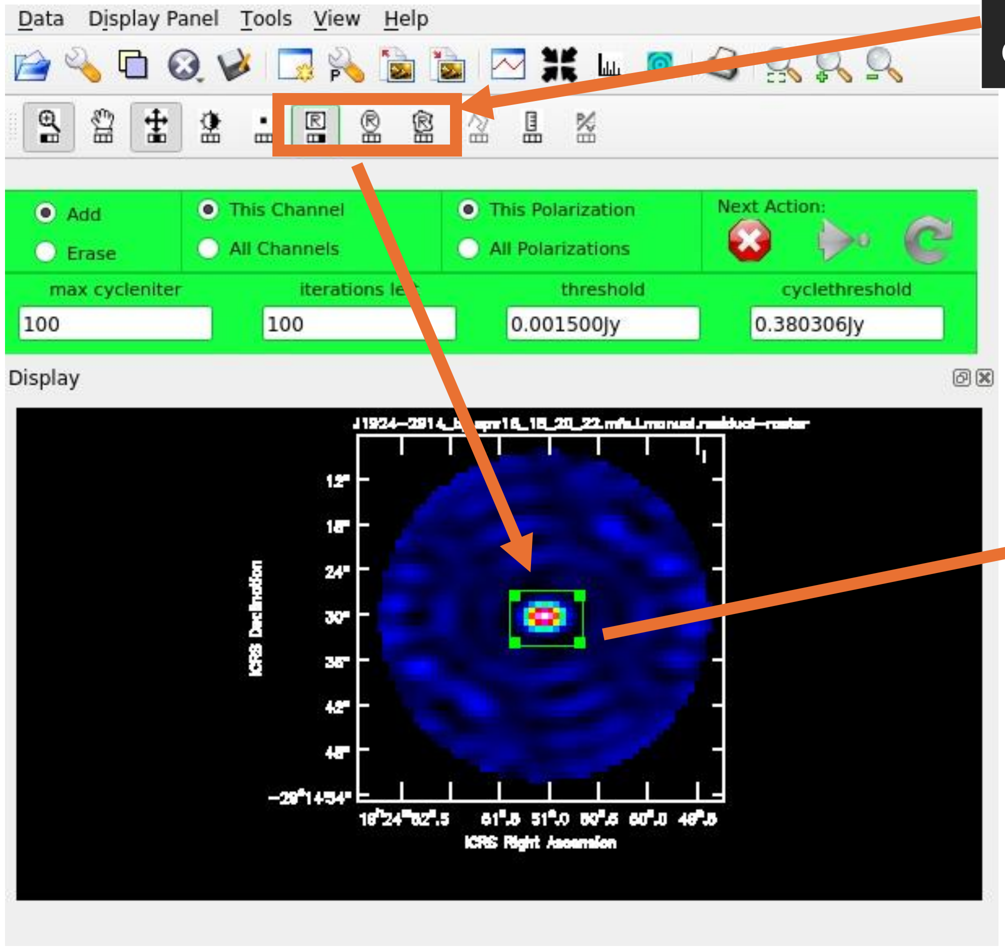
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

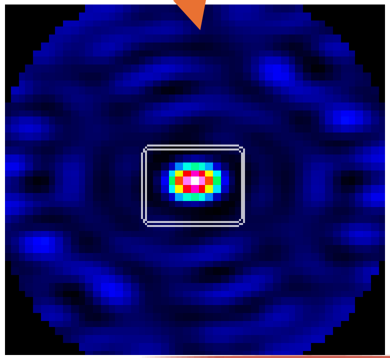
Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Click on a region tool and draw a mask around the emission you know is real.

Double click region to confirm mask. The mask outline will turn white.



Imaging

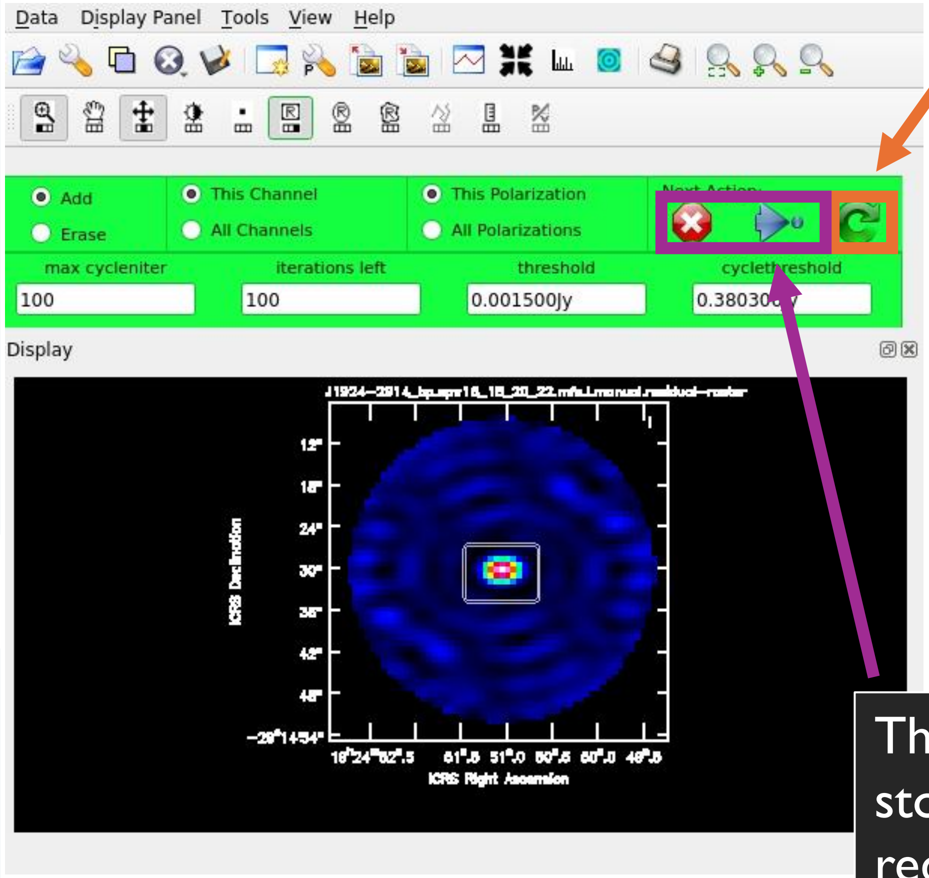
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



After masking all emission that you are confident is real, click the green circular arrow to run the next major cycle.

The blue arrow will run until stopping criteria are met. The red octagon with a white X stops cleaning. We won't use these yet.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

- Since the Bandpass calibrator is a point source, we are going to experiment a little bit with options in clean! Remove the extra comma in your script for iclean command!

```
iclean(vis = ['SgrAstar.ms’],
  imagename = 'J1924-2914_bp.spw16_18_20_22.mfs.I.manual',
   field = 'J1924-2914',
   stokes = 'I',
   spw = '16,18,20,22',
   outframe = 'LSRK',
   specmode = 'mfs',
   nterms = 1,
   imsize = [60, 60],
   cell = '0.81arcsec',
   deconvolver = 'hogbom',
   niter = 100,
   weighting = 'briggs',
   robust = 0.5,
   mask = '',
   gridder = 'standard',
   pbcor = True,
   threshold = '1.5mJy',
   restoringbeam = 'common',
            )
```


National Radio Astronomy Observatory

Imaging

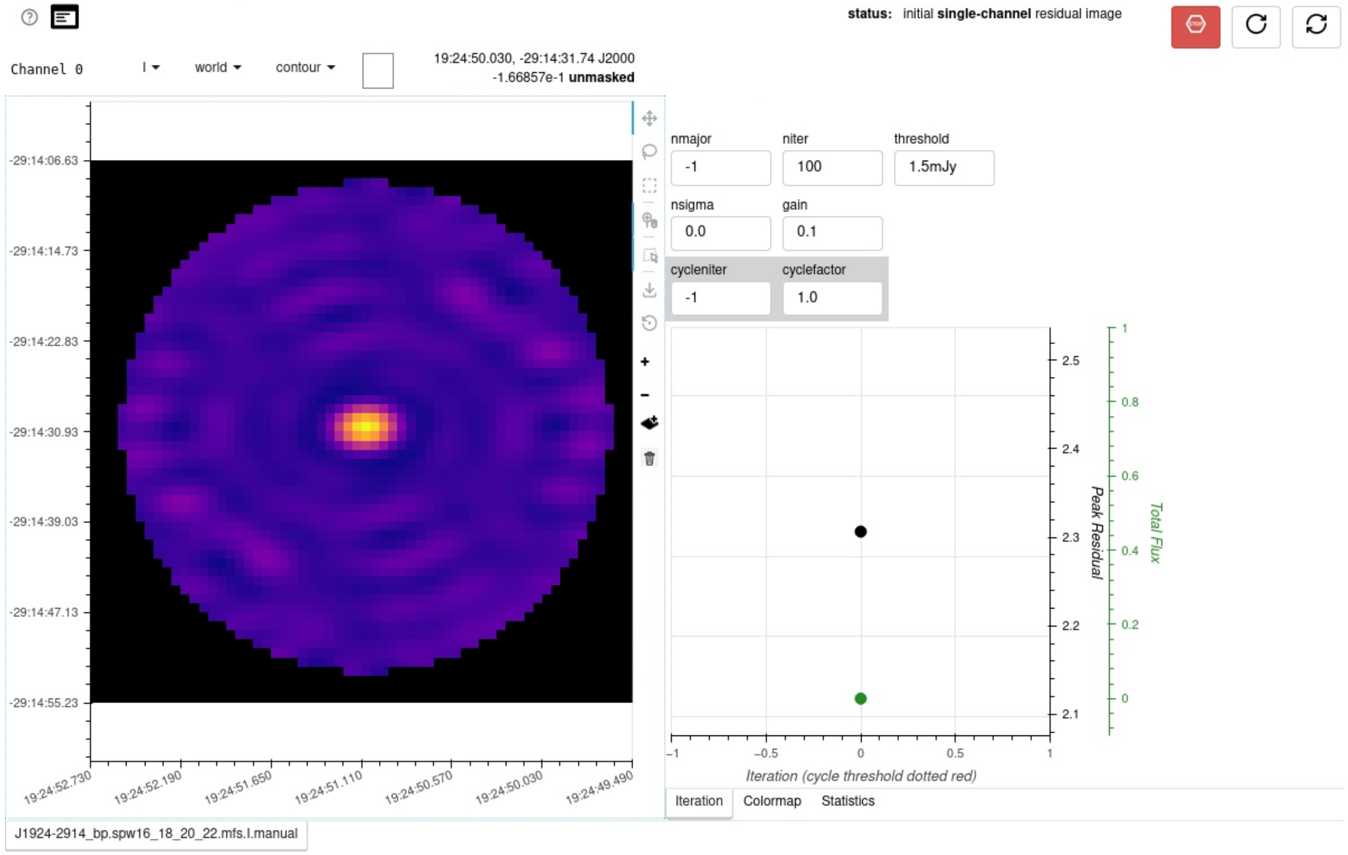
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



This is the dirty image of our calibrator.

Imaging

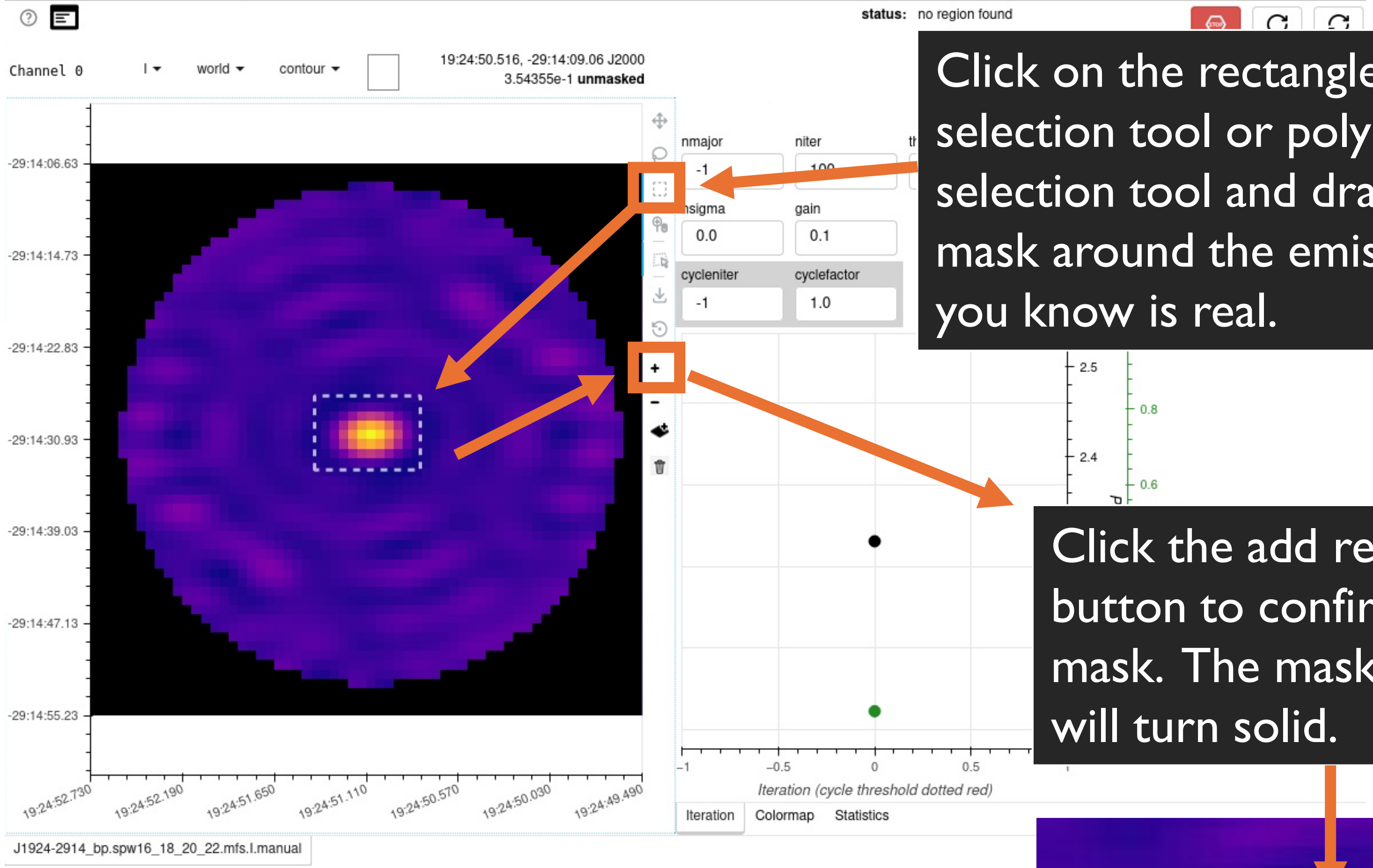
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

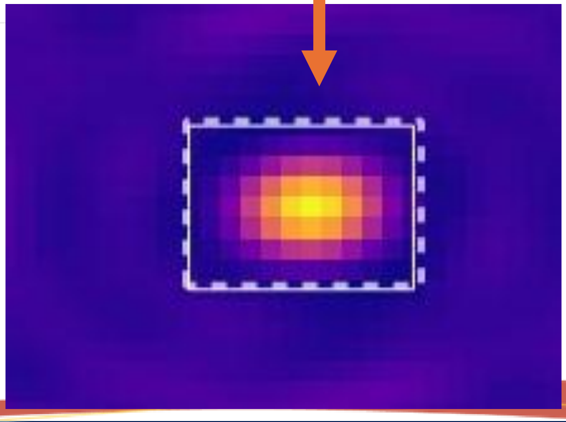
Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



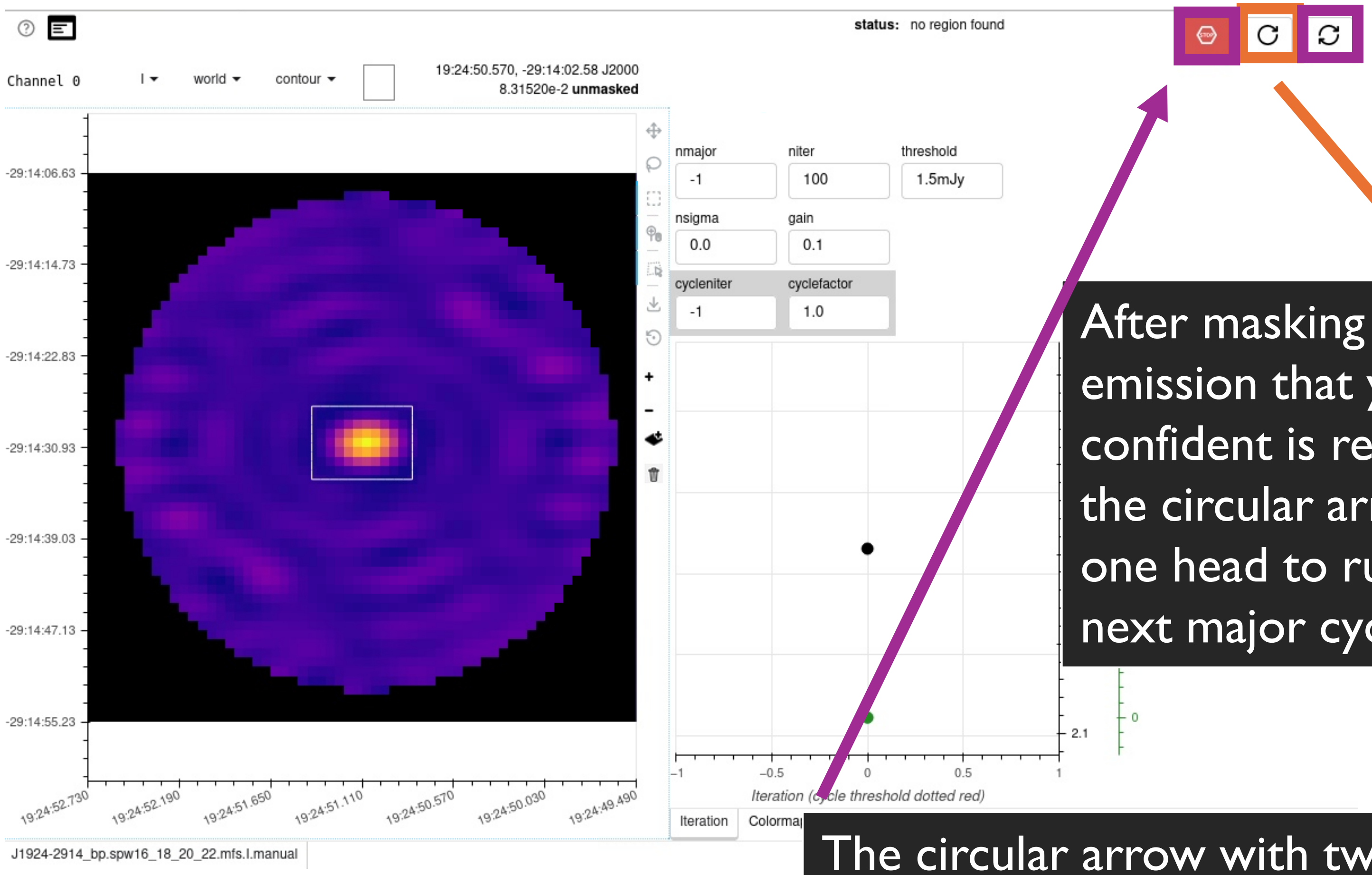
Click on the rectangle selection tool or poly selection tool and draw a mask around the emission you know is real.

Click the add region button to confirm mask. The mask outline will turn solid.



Imaging

- Basics of Imaging Review
- **Bandpass Calibrator Imaging**
- CARTA
- Sgr A* Continuum Imaging
- Sgr A* CO Line Imaging



After masking all emission that you are confident is real, click the circular arrow with one head to run the next major cycle.

The circular arrow with two heads will run until stopping criteria are met. The red stop button stops cleaning. We won't use these yet.

Imaging

Basics of Imaging Review

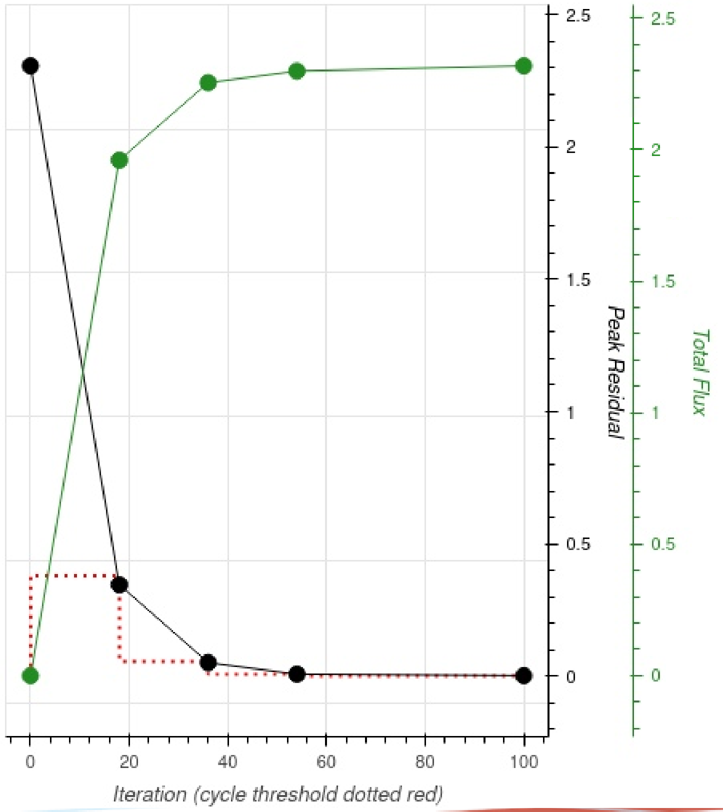
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

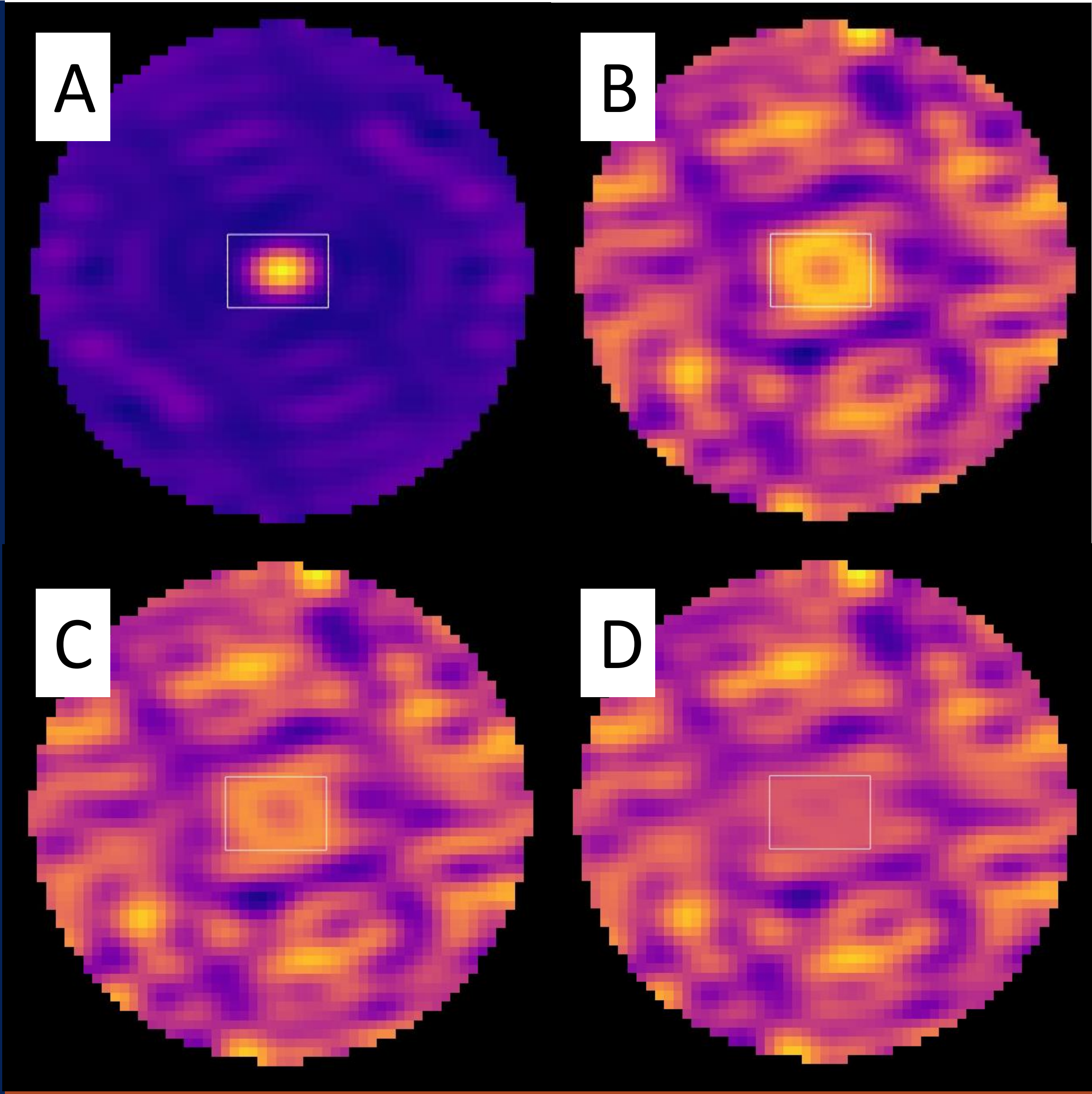
Sgr A* CO Line Imaging

- Bonus: Residual Plot
  - With iclean, you can watch your residuals decrease and your recovered flux increase!



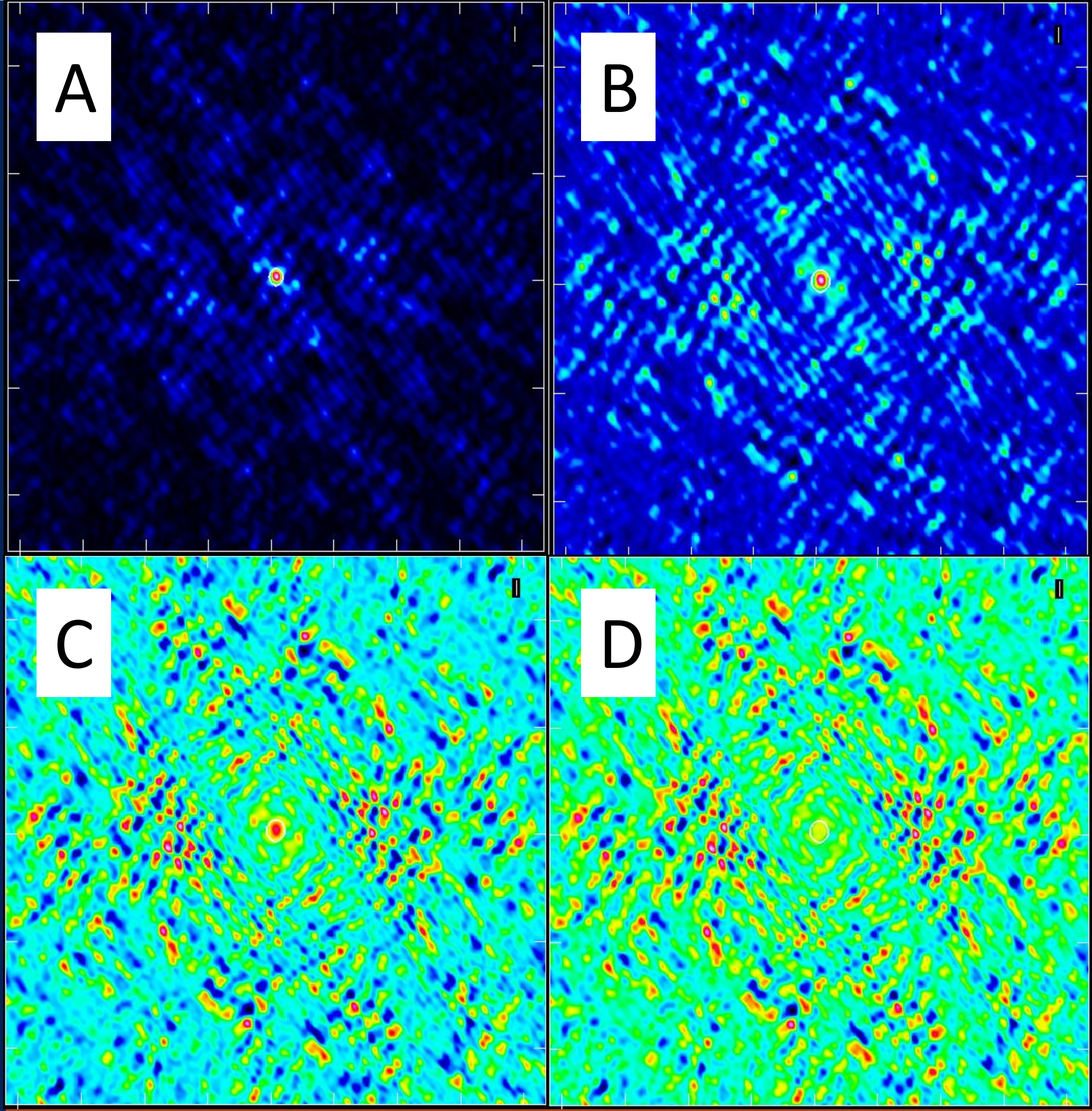
Question:

- How clean is clean enough?
- "Clean until the residuals from the source are comparable to the residual noise outside the source."
- What does this mean to you? Select an image on the right and prepare to vote on where you would stop.



Question:

- How clean is clean enough?
- "Clean until the residuals from the source are comparable to the residual noise outside the source."
- What does this mean to you? Select an image on the right and prepare to vote on where you would stop.



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

How deep should you clean?

- Not a simple answer. Depends on UV coverage / dirty beam, SNR, structure of the emission, and what you are trying to accomplish.
- Science imaging:
  - If low SNR and good UV coverage, dirty beam residuals will be buried in the noise. No cleaning needed.
  - If data is well behaved, and source structure is well determined with the clean model, clean until the noise looks like thermal (non-patterned) noise.
  - Sources where you don't know the structure ahead of time, clean until residual source is comparable to the noise.
  - Data with calibration errors, clean until residual source is comparable to the noise.
- Self-Calibration
  - Phase self-cal: clean shallow to ensure only real structure is included.
  - Amplitude self-cal: Clean deep to ensure all flux included in model.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Image viewing with CARTA!

CARTA should be launched, as we will need it going forward.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

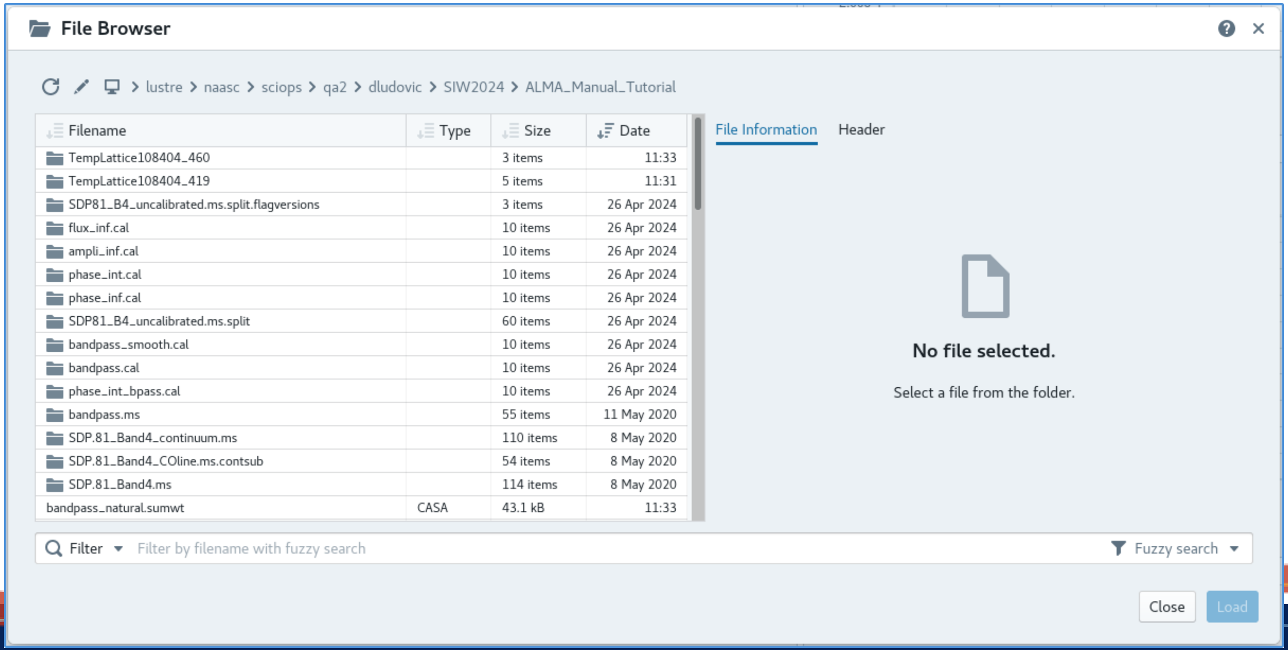
Opening your images in CARTA

If you installed with...

Package manager: type `carta`

Download AppImage: type `/<path to carta>/<carta_version>.appimage`

You should see the following prompt in your web browser:



Imaging

Basics of Imaging Review

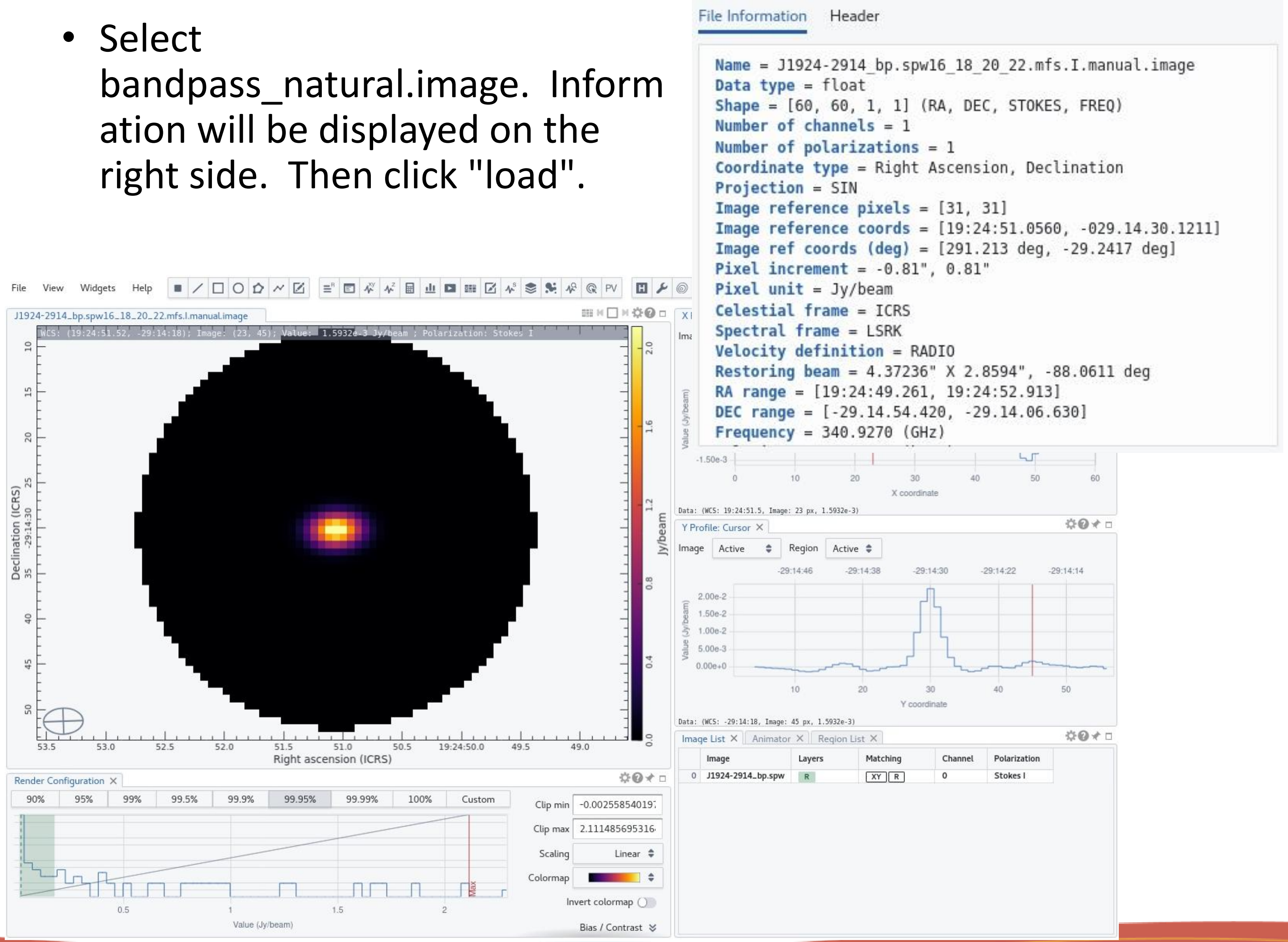
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

- Select bandpass_natural.image. Information will be displayed on the right side. Then click "load".



Imaging

Basics of Imaging Review

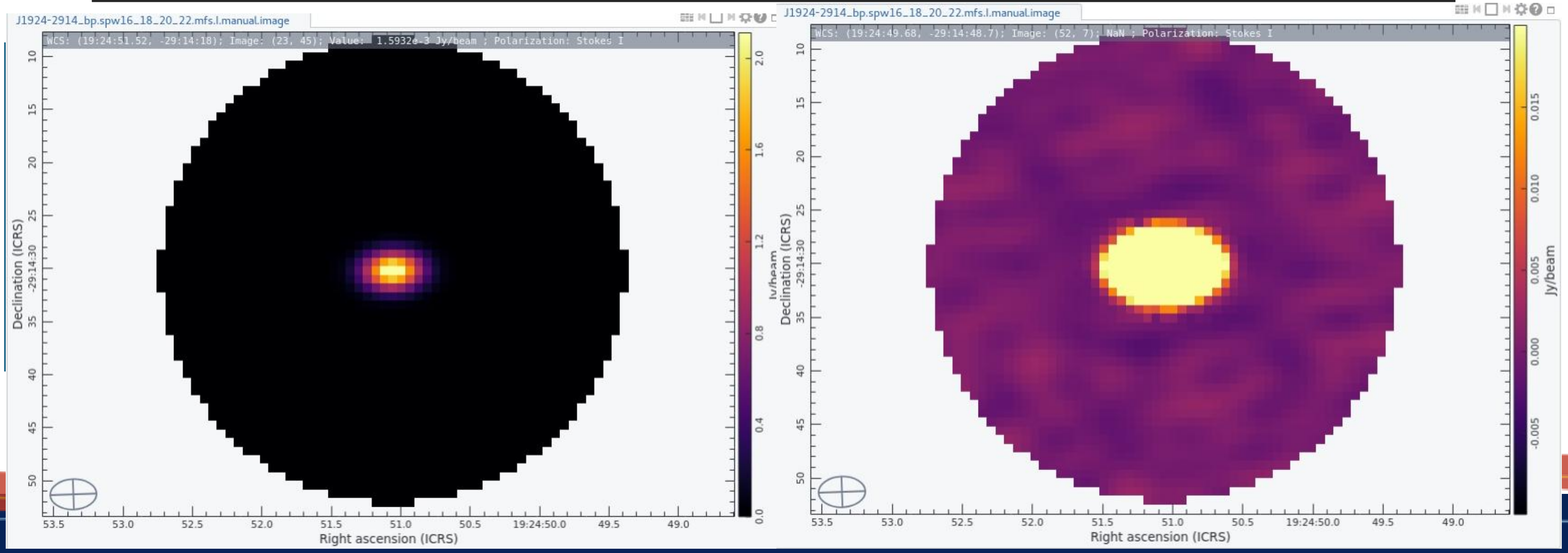
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

The render configuration allows you to adjust the histogram for the display. Try adjusting using the buttons, and using a custom range by clicking and dragging the min and max bars on the plot.



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

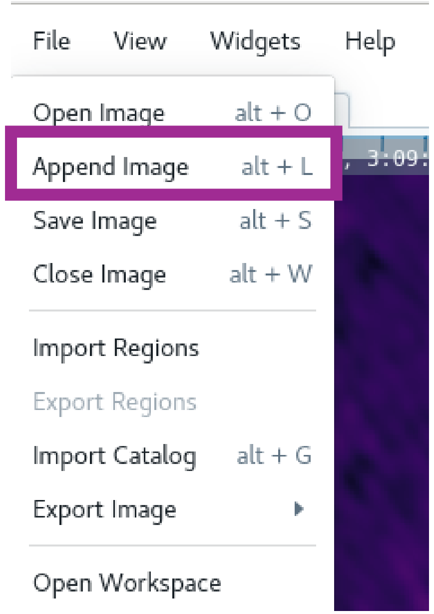
- What happens if we change our weighting?
- Copy and then edit your command
  - Change your imagename
  - Change your Robust to -2 or +2
  - Go ahead and clean it yourself!

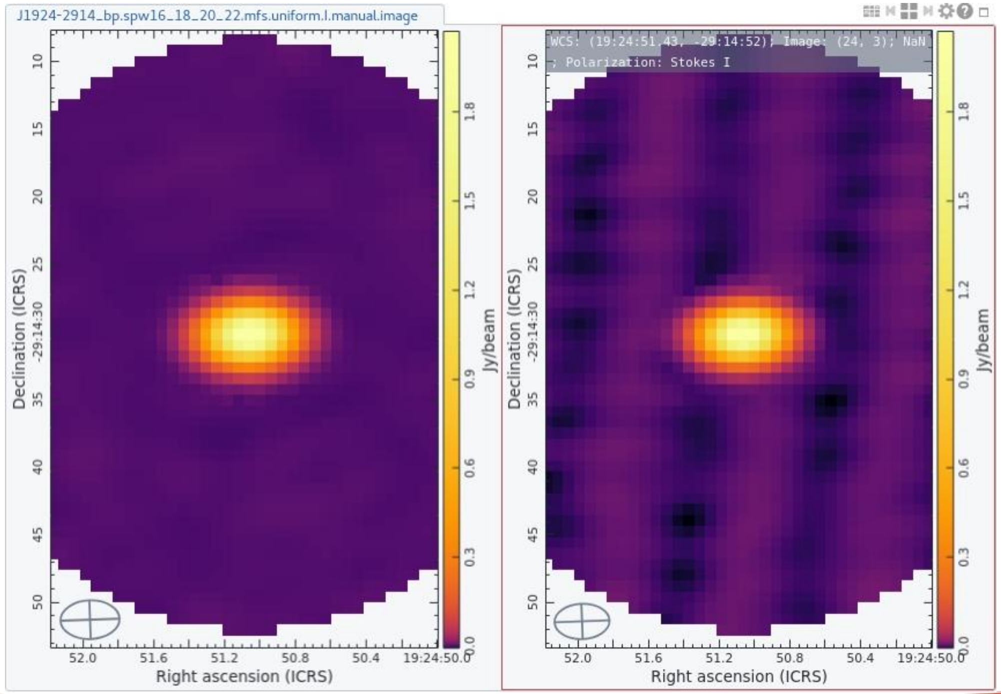
```
iclean(vis = ['SgrAstar.ms’],
  imagename = 'J1924-2914_bp.spw16_18_20_22.mfs.I.manual',
   field = 'J1924-2914',
   stokes = 'I',
   spw = '16,18,20,22',
   outframe = 'LSRK',
   specmode = 'mfs',
   nterms = 1,
   imsize = [60, 60],
   cell = '0.81arcsec',
   deconvolver = 'hogbom',
   niter = 100,
   weighting = 'briggs',
   robust = 0.5,
   mask = '',
   gridder = 'standard',
   pbcor = True,
   threshold = '1.5mJy',
   restoringbeam = 'common')
```

Imaging

Basics of Imaging Review
Bandpass Calibrator Imaging
CARTA
Sgr A* Continuum Imaging
Sgr A* CO Line Imaging

- After cleaning is finished. Go to CARTA.
- Click File > Append Image
- Choose your new bandpass image





Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

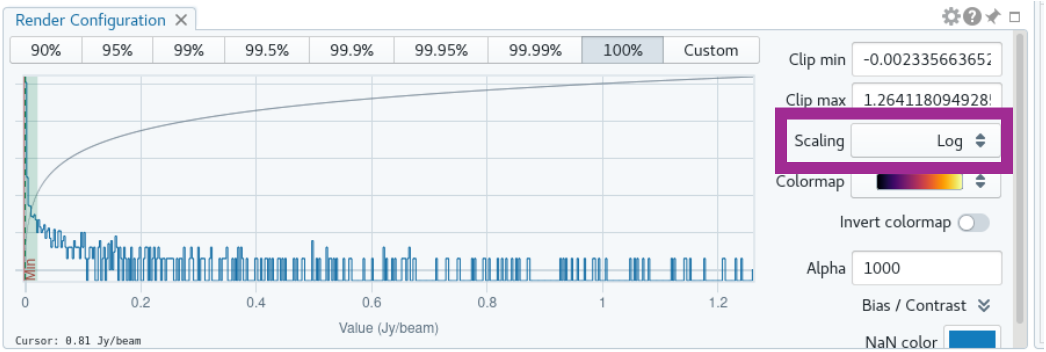
CARTA

Sgr A* Continuum Imaging

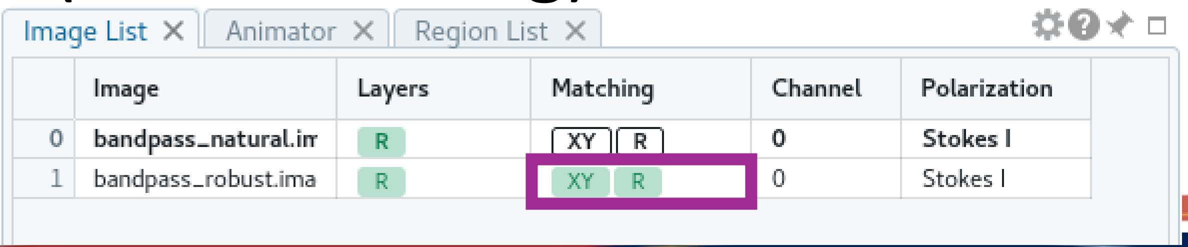
Sgr A* CO Line Imaging

Let's prepare to compare images.

1. Set scaling to log so we can see the full range of structures in the image.



2. In the Image List, set matching on image 2 for XY (Coordinates) and R(Render Config)



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

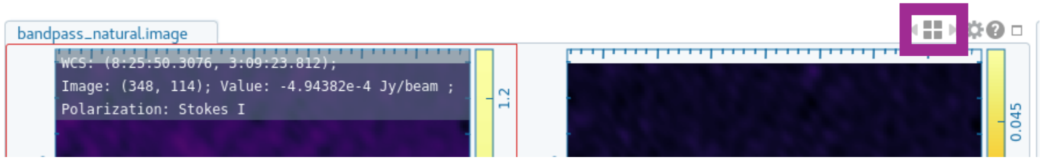
CARTA

Sgr A* Continuum Imaging

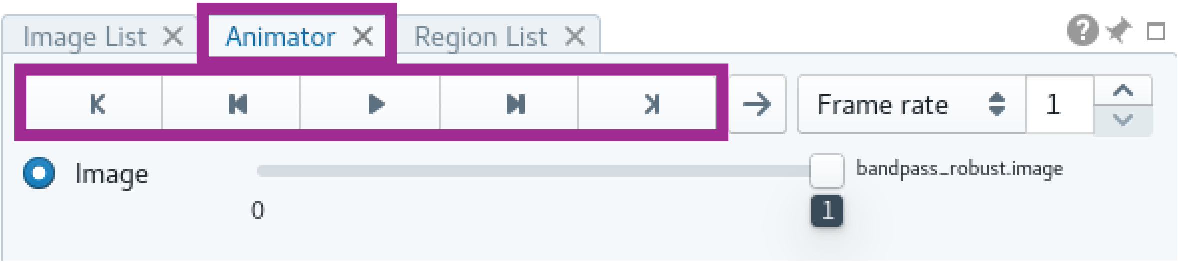
Sgr A* CO Line Imaging

Blink the images!

- On the top of the image window, click the button to switch to a single image.



- Click on the animator tab beside the image list tab. Use the tools to switch between images or blink.



Imaging

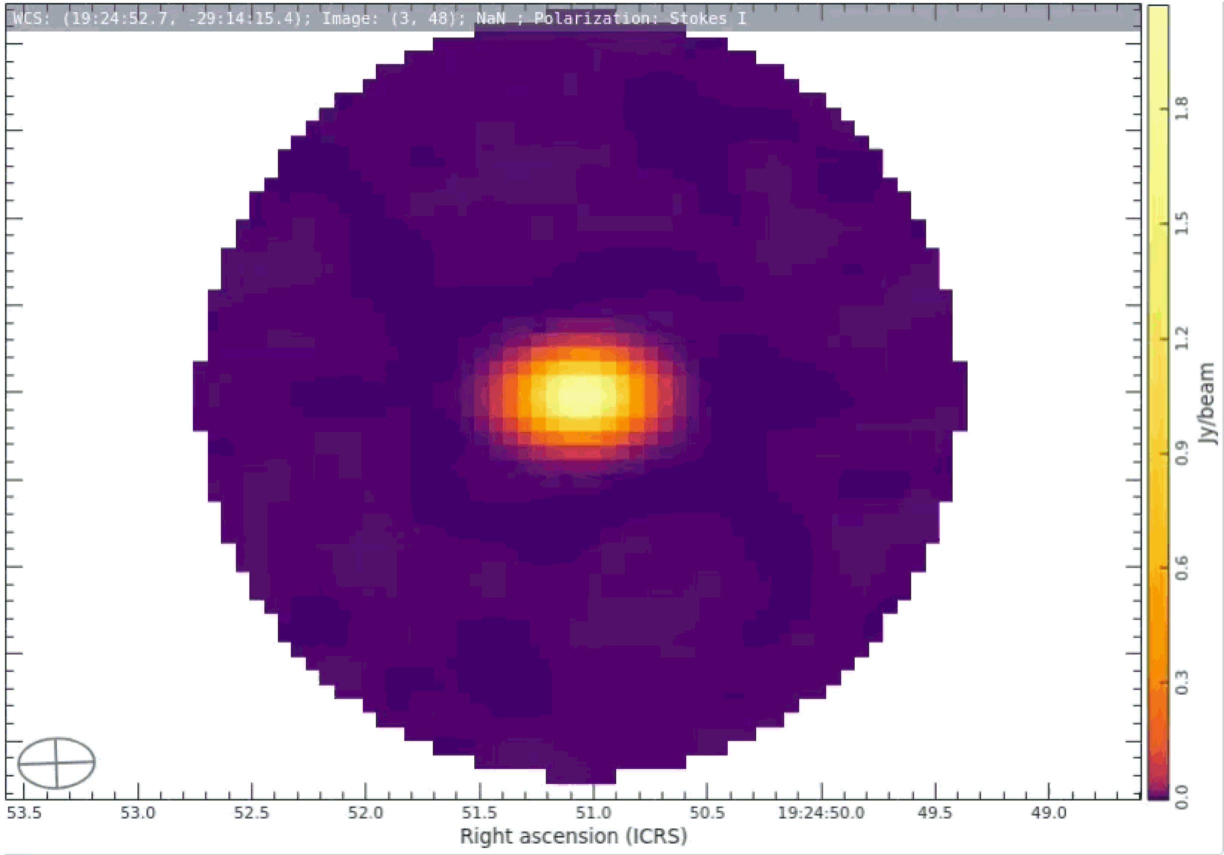
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Let's make an image incorrectly.

We will make an image with pixels that are too large. Make them ~3x larger

```
iclean(vis = ['SgrAstar.ms’],
  imagename = 'J1924-2914_bp.spw16_18_20_22.mfs.I.manual',
  field = 'J1924-2914',
  stokes = 'I',
  spw = '16,18,20,22',
  outframe = 'LSRK',
  specmode = 'mfs',
  nterms = 1,
  imsize = [60, 60],
  cell = '0.81arcsec',
  deconvolver = 'hogbom',
  niter = 100,
  weighting = 'briggs',
  robust = 0.5,
  mask = '',
  gridder = 'standard',
  pbcor = True,
  threshold = '1.5mJy',
  restoringbeam = 'common')
```

Imaging

Basics of Imaging Review

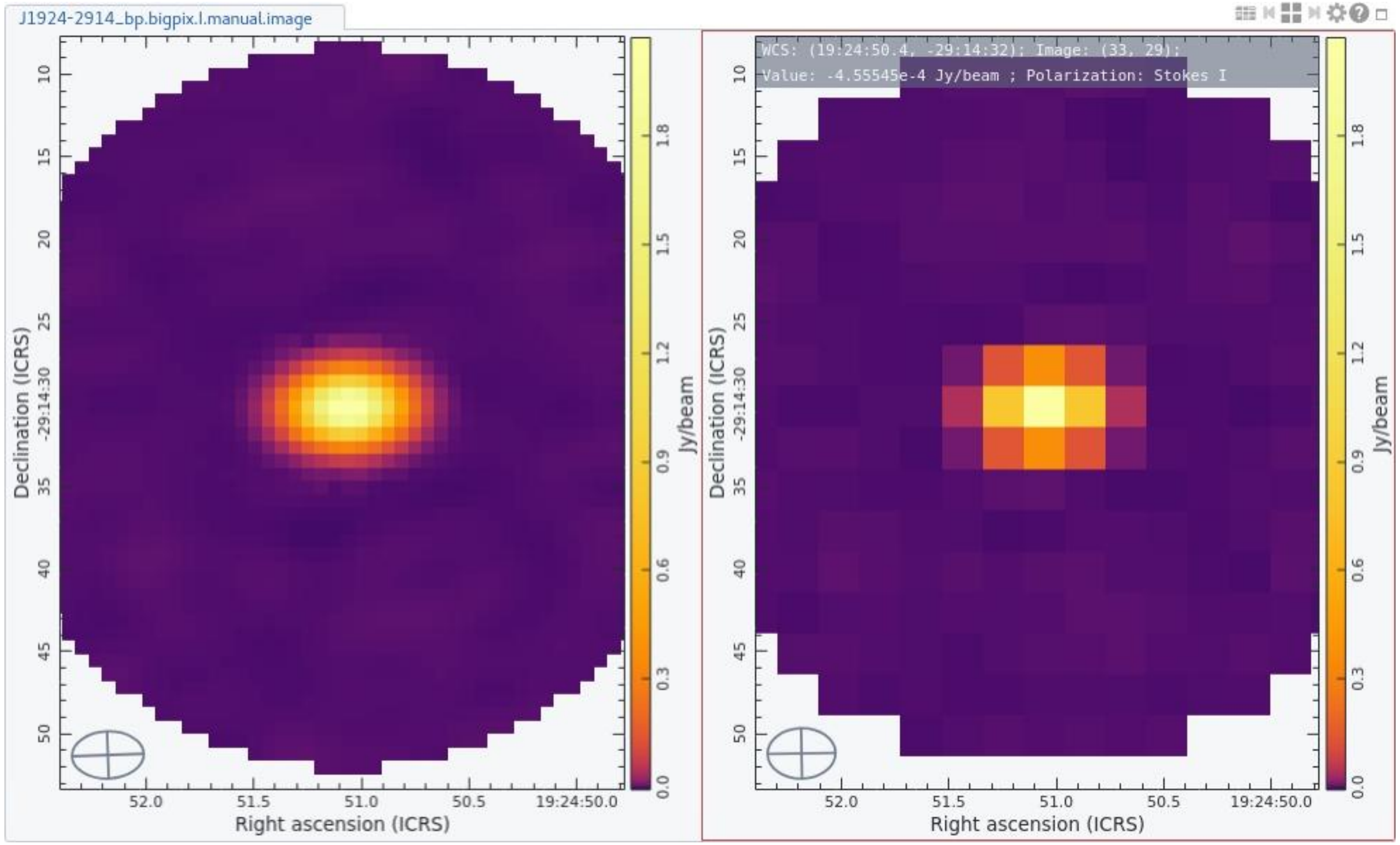
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

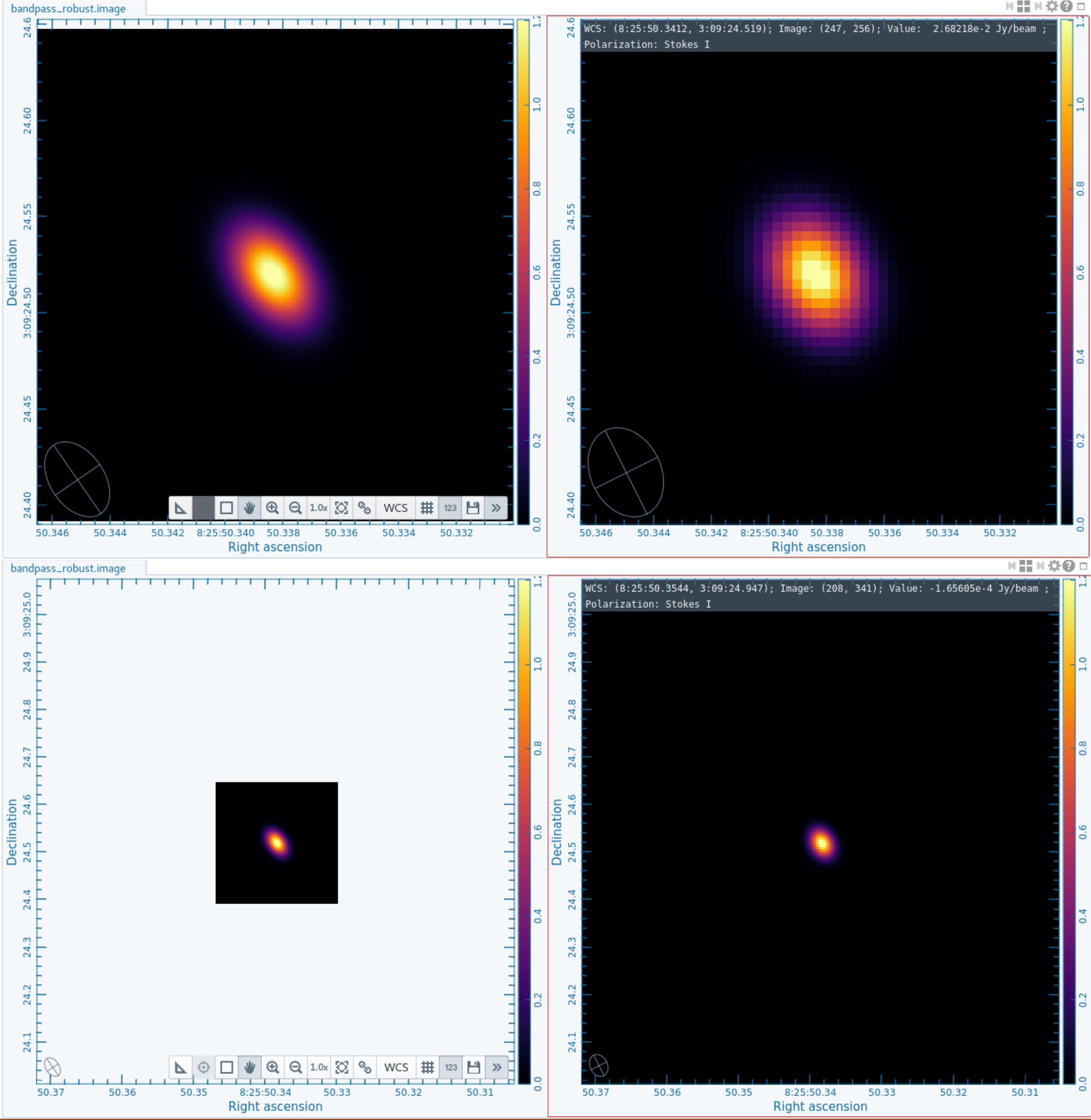
Comparing big pixels to correct pixels



Question: Pixels

- What about really small pixels?

- Why would we want to avoid really small pixels?



Sgr A* Continuum Imaging

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Imaging Sgr A Continuum

We will image the continuum emission in Sgr A. In the interest of time, I want you to make a change to the code I sent you.

Below the next set of imaging commands, there is a command to flag out spectral lines in your data. Run these before running the imaging command. (We don't need to compare before and after spectral line removal today.)

Adding the averagedata and avgtime keywords will speed up plotting.

```
plotms(vis="SgrAstar.ms",
      xaxis="frequency",
      yaxis="amp",
      iteraxis="spw",
      freqframe='LSRK',
      averagedata=True,
      avgtime="1e8")
```

Imaging

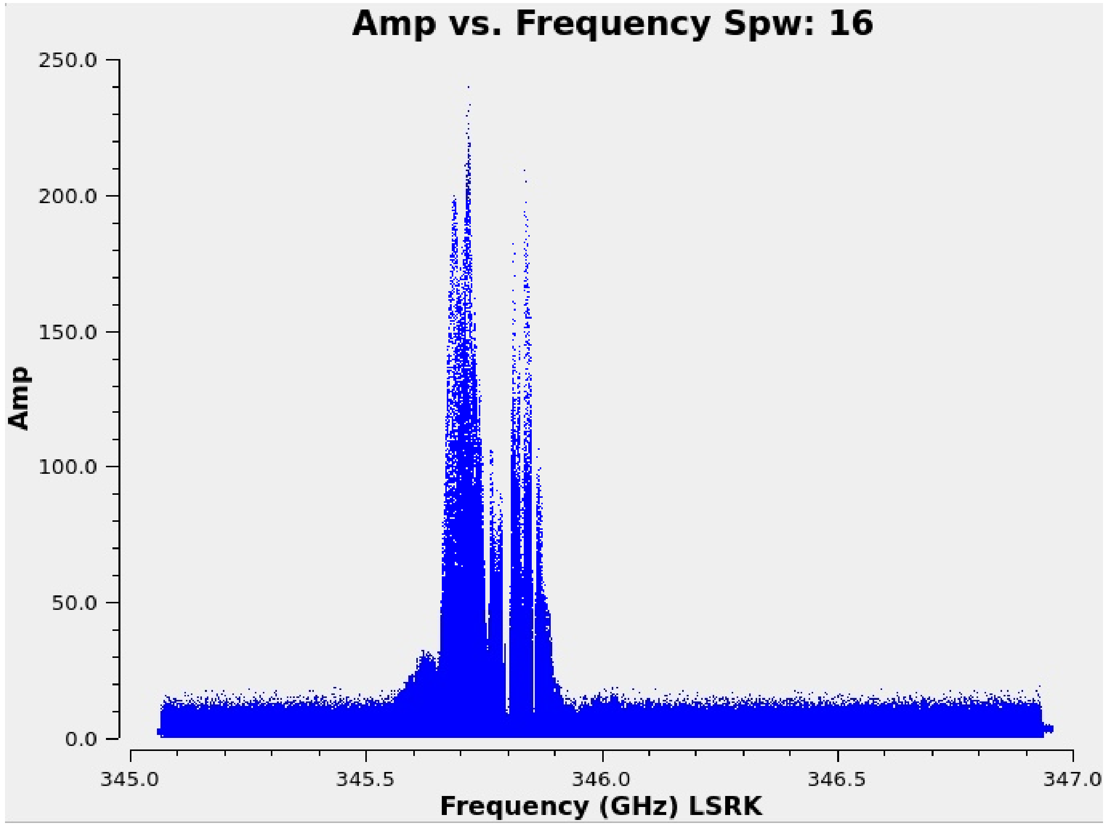
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

This command will take a snapshot of the state of flags of SgrAstar.ms. The saved flag table, Original.flags, can be restored at any time using mode='restore'

```
if os.path.exists('SgrAstar.ms.flagversions/Original.flags')==False:
  flagmanager(vis = 'SgrAstar.ms',
    mode = 'save',
    versionname = 'Original')
```

Now we will flag the data using the ranges we have identified from plotms.

```
flagdata(vis='SgrAstar.ms',
  mode='manual',
  spw='16:260~546',
  flagbackup = False)
```

This command will take a snapshot of the state of flags of SgrAstar.ms again. The saved flag table, continuum_only.flags, can be restored at any time using mode='restore'. You can use flagmanager with mode restore to re-flag the spectral lines.

```
if os.path.exists('SgrAstar.ms.flagversions/continuum_only.flags')==False:
  flagmanager(vis = 'SgrAstar.ms',
    mode = 'save',
    versionname = 'continuum_only’)
```

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Now, we can run the Tclean / Iclean command.

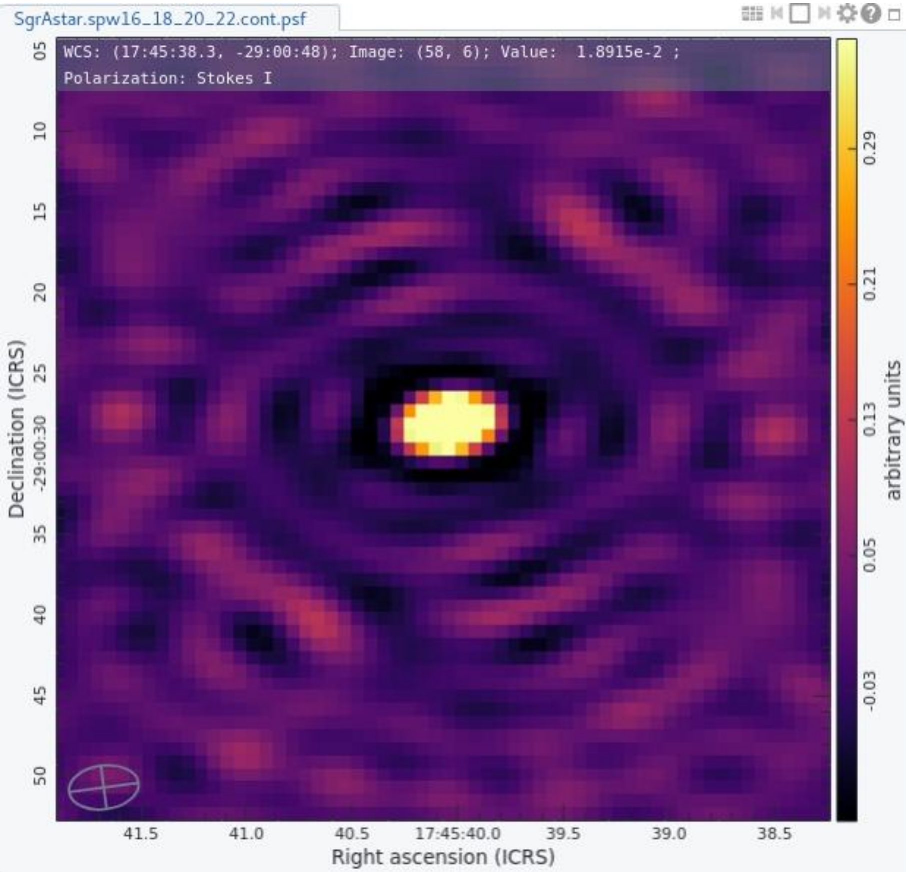
NOTE: After clean starts, immediately press the red stop button. This will create a dirty image.

To convert the tclean command to iclean, simply remove the interactive=True and change tclean to iclean. Do this yourself in your code!

```
iclean(vis = 'SgrAstar.ms',
       imagename = 'SgrAstar.spw16_18_20_22.cont',
       field = 'SgrAstar',
       stokes = 'I',
       spw = '16,18,20,22',
       outframe = 'LSRK',
       specmode = 'cont',
       nterms = 1,
       imsize = [60, 60],
       cell = '0.81arcsec',
       deconvolver = 'hogbom',
       niter = 100,
       weighting = 'briggs',
       robust = 0.5,
       mask = '',
       gridder = 'standard',
       pbcor = True,
       threshold = '0.1 mJy',
       restoringbeam = 'common')
```

Question:

- How would you classify this PSF? Are the side lobes high or low?



PSF from the Sgr A* observation. Robust = 0.5

Imaging

Basics of Imaging Review

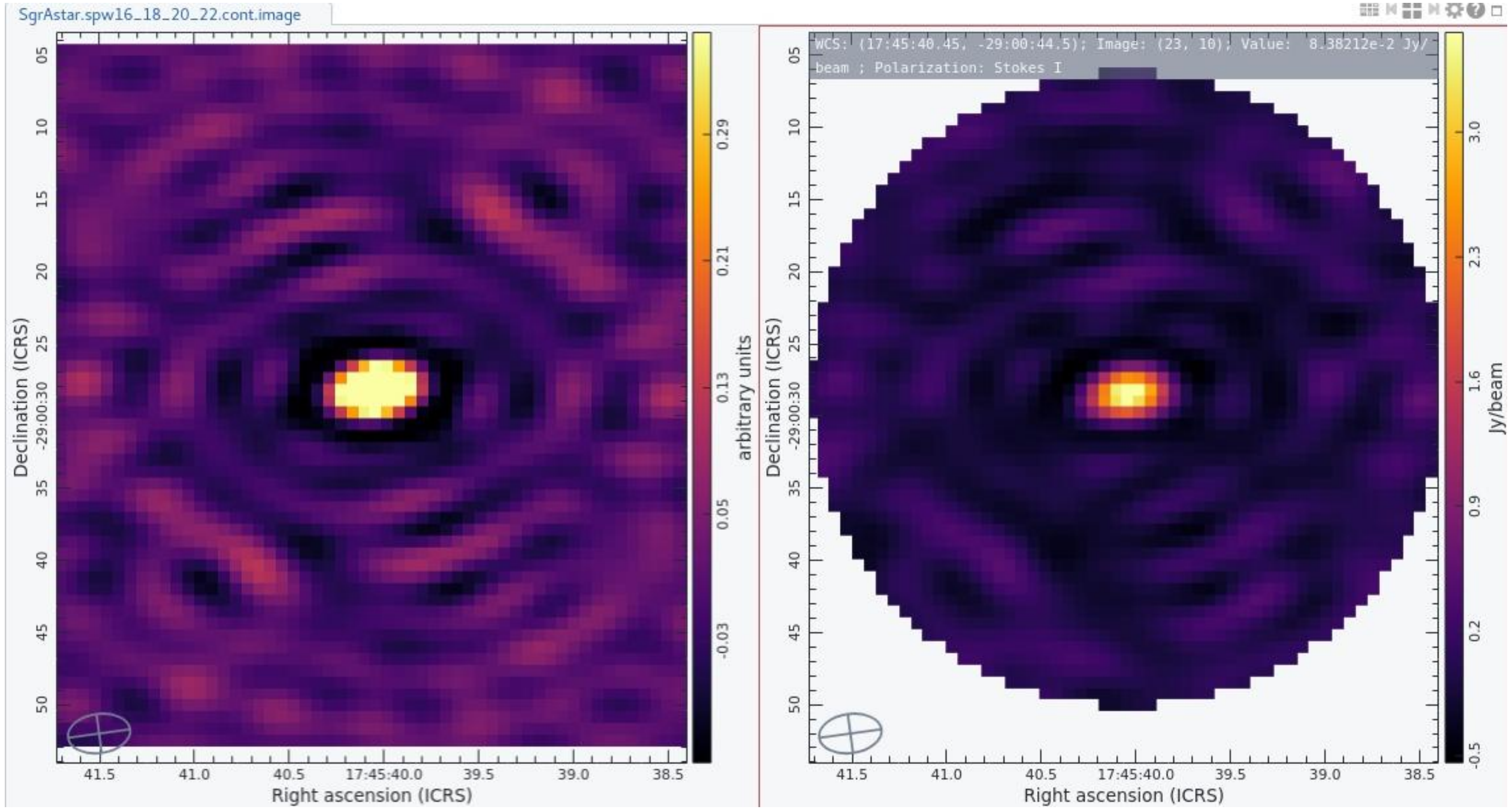
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Rerun the previous command. Tclean/iclean will pick up where you left off. Finish cleaning the image.



Imaging

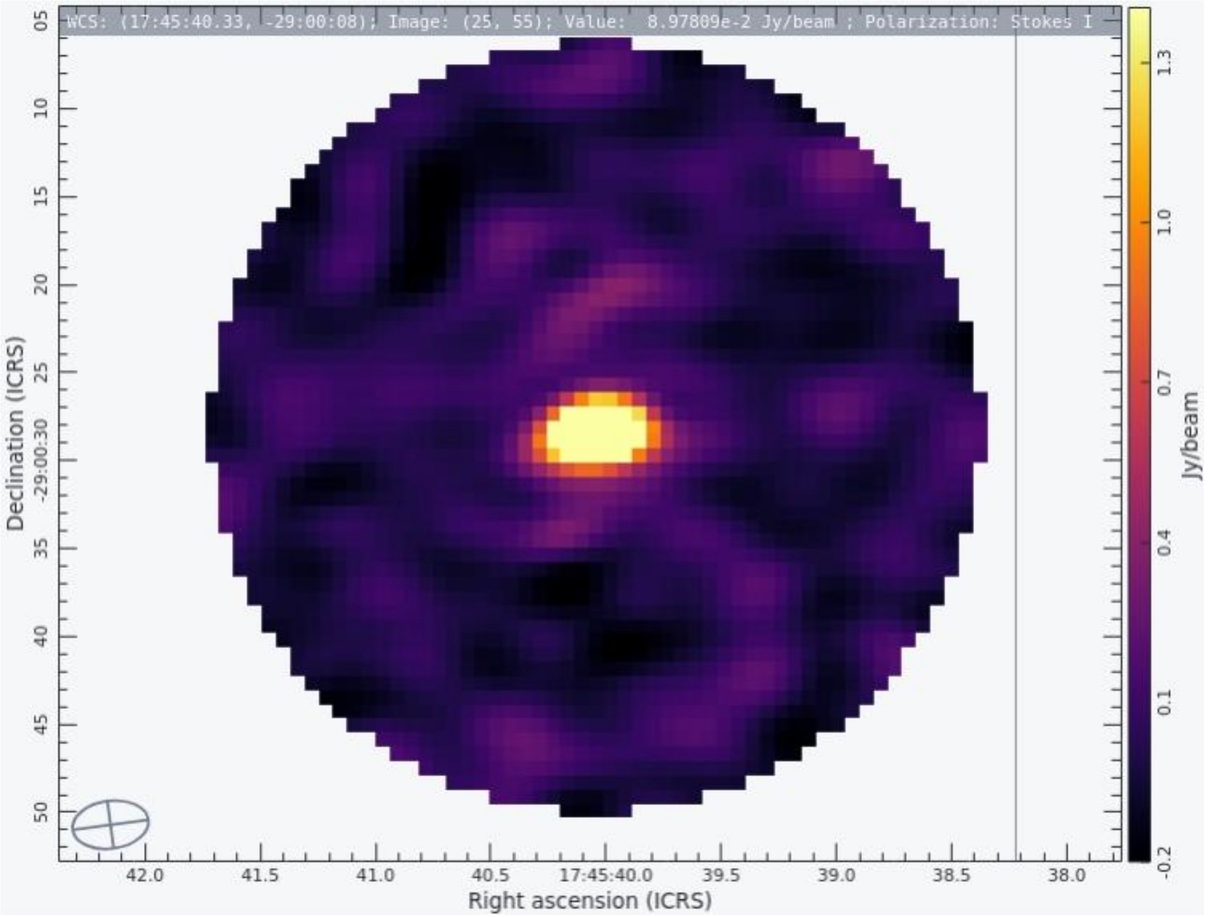
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



National Radio Astronomy Observatory

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

The spectral line we want to image today is CO(3-2) [rest frequency = 345.7959899 GHz].

The first step is to continuum subtract the data. This can take some time to run.

- If you don’t have much time, just run the command in the script.
- If there is lots of time left, we will go though it together.

Either way, we will talk about the command and how to generate it yourself.

First, you can use plotms to try to plot the data and locate the location of the line.

Imaging

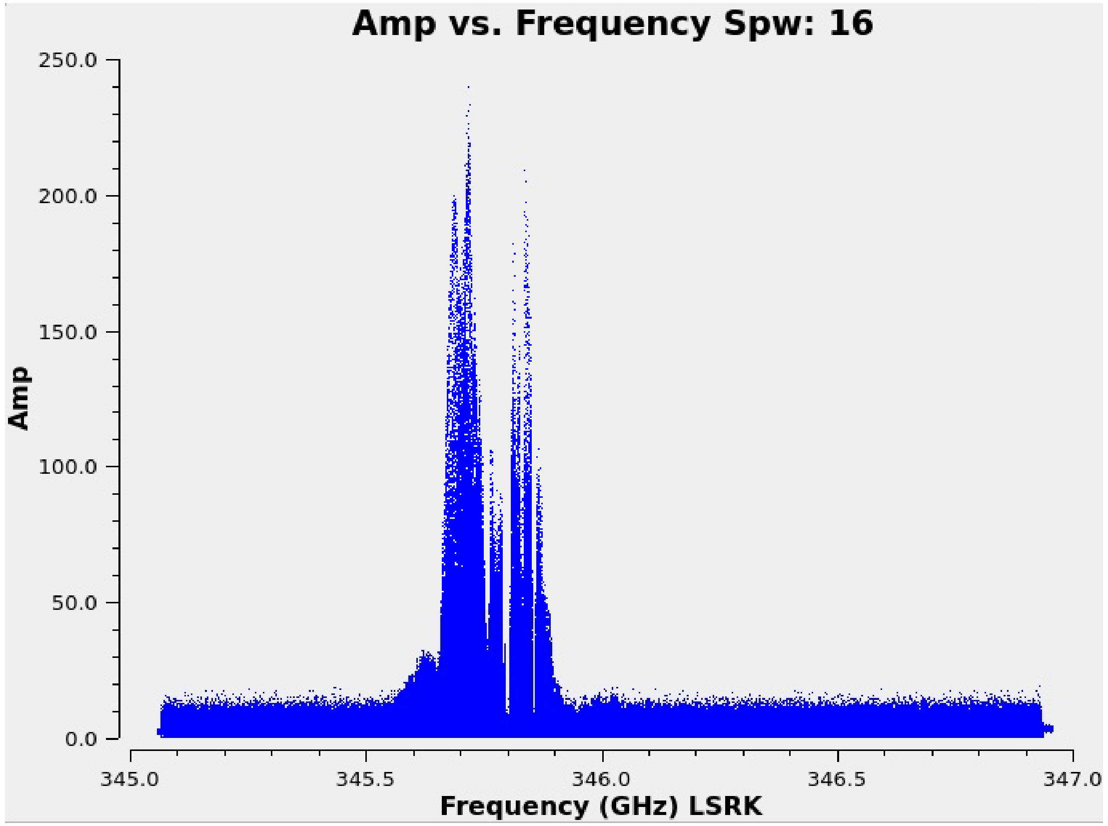
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

After locating the line channels, split out a new MS, and run uvcontsub:

```
split(vis='SgrAstar.ms’,
      outputvis='SgrAstar_COline.ms',
      spw='16’,
      datacolumn='data’,
      field='SgrAstar’)

uvcontsub(vis='SgrAstar_COline.ms’,
      outputvis='SgrAstar_COline.ms.contsub’,
      fitorder=1,
      fitspec='0:50~200;600~950')
```

The fitspec selection avoids edge channels, as well as the spectral lines.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Cleaning the cube! DON’T RUN THIS YET!!!

```
iclean(vis = 'SgrAstar_COline.ms.contsub’,
    imagename = 'SgrAstar.spw16.CO_line',
    field = 'SgrAstar',
    stokes = 'I',
    spw = '0',
    outframe = 'LSRK',
    restfreq = '345.7959899GHz',
    specmode = 'cube',
    imsize = [60, 60],
    cell = '0.81arcsec',
    deconvolver = 'hogbom',
    niter = 100,
    weighting = 'briggsbwtaper',
    robust = 0.5,
    mask = '',
    gridder = 'standard',
    pbcor = True,
    threshold = '0.05mJy',
    width = '3.386 km/s’,
    start = '-300 km/s',
    nchan = 177,
    restoringbeam = 'common’,
    perchanweightdensity = True )
```

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

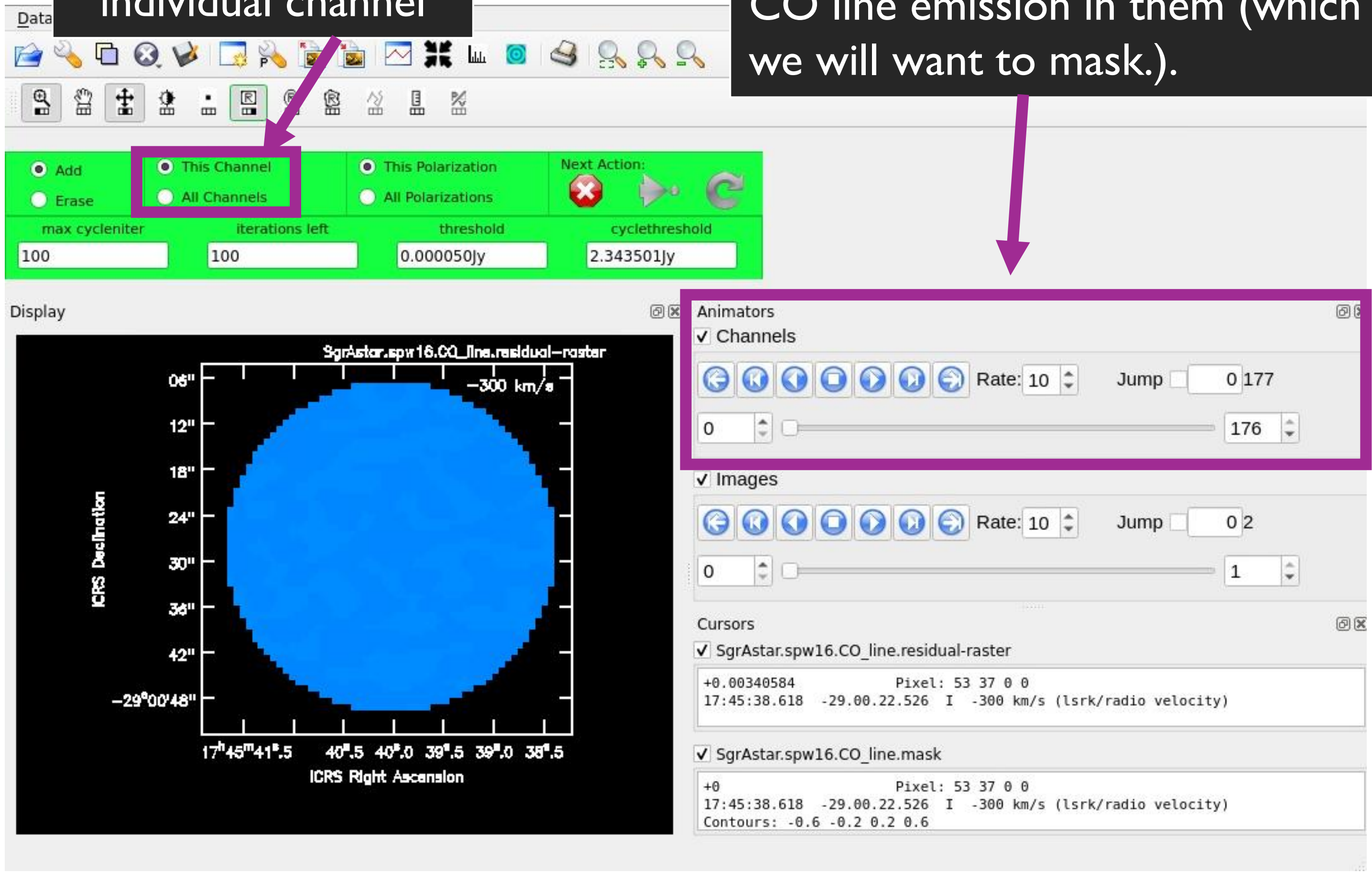
CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Can mask all channels or each individual channel

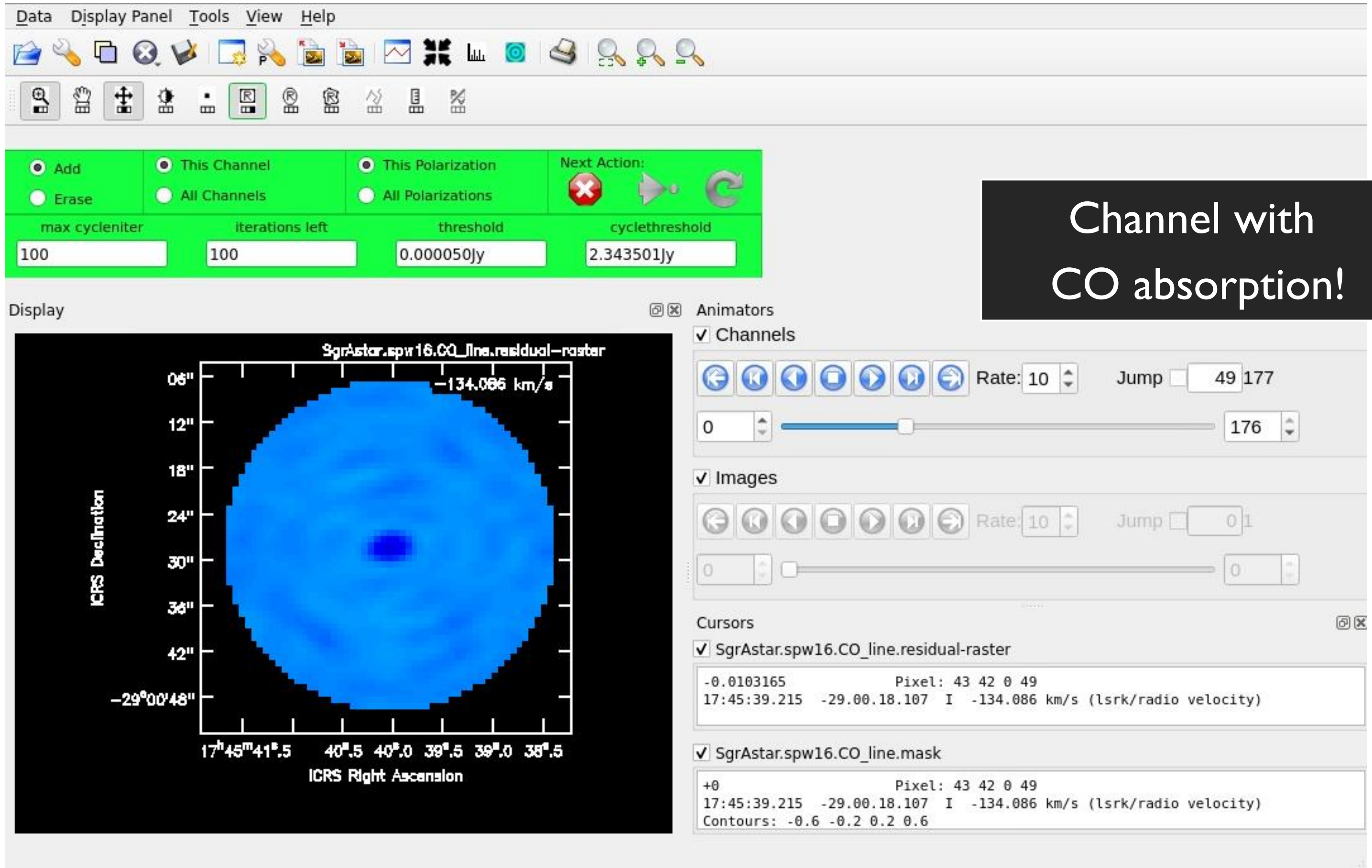
Moving through channels using the arrows shows which channels have CO line emission in them (which we will want to mask.).



Channel with no CO emission

Imaging

- Basics of Imaging Review
- Bandpass Calibrator Imaging
- CARTA
- Sgr A* Continuum Imaging
- **Sgr A* CO Line Imaging**



Channel with CO absorption!

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

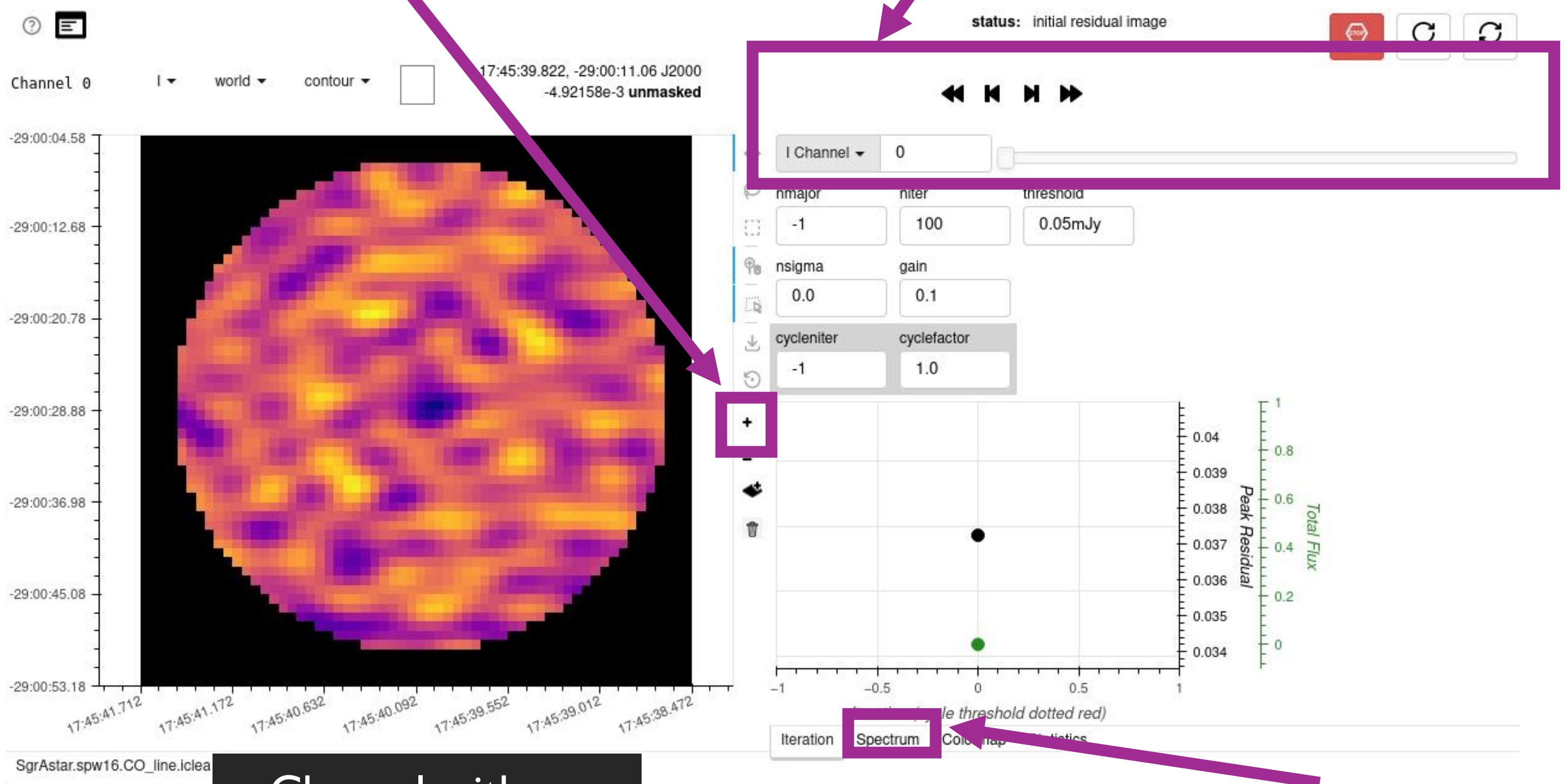
CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Can mask current channel, or apply mask to all channels using by holding shift while clicking

Moving through channels using the arrows shows which channels have CO line emission in them (which we will want to mask.).



Channel with no CO emission

View Spectrum

Imaging

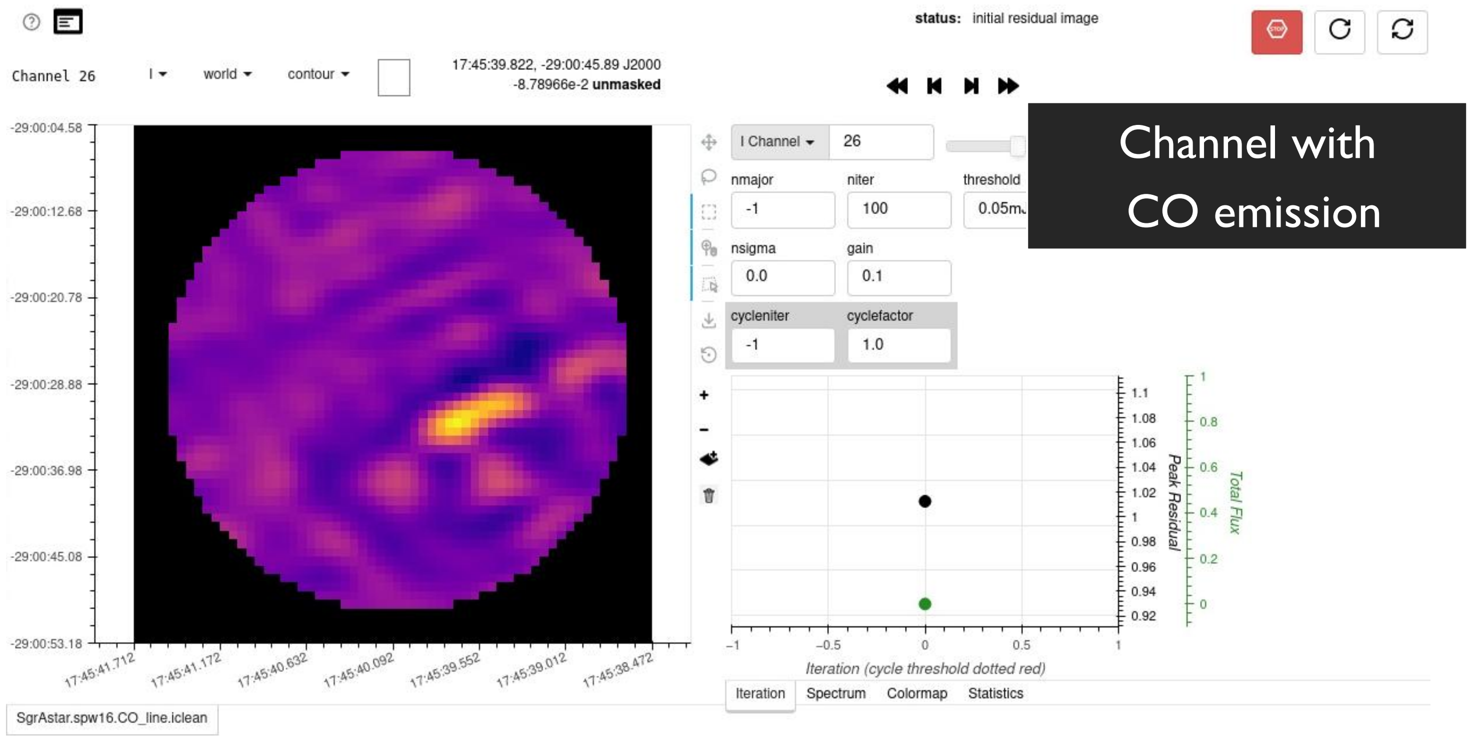
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Channel with CO emission

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Automasking:

No one wants to spend the time to mask that cube…

I highly suggest automasking.

- Look at https://casaguides.nrao.edu/index.php/Automasking_Guide_CASA_6.6.6

Parameter	7m (continnum/line)	12m (b75 < 300m)	12m (300m < b75 < 400m)	12m (b75 > 400m)	12m + 7m combined *TENTATIVE*
noisethreshold	5.0	**4.25**	5.0	5.0	4.25
sidelobethreshold	1.25	**2.0**	2.0	2.5	2.0
lownoisethreshold	2.0	**1.5**	1.5	1.5	1.5
minbeamfrac	0.1	**0.3**	0.3	0.3	0.3
negativethreshold	0.0	**0.0 (continuum) 15.0 (line)**	0.0 (continuum) 7.0 (line)	0.0 (continuum) 7.0 (line)	0.0
fastnoise	False	**False**	False	True	False

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

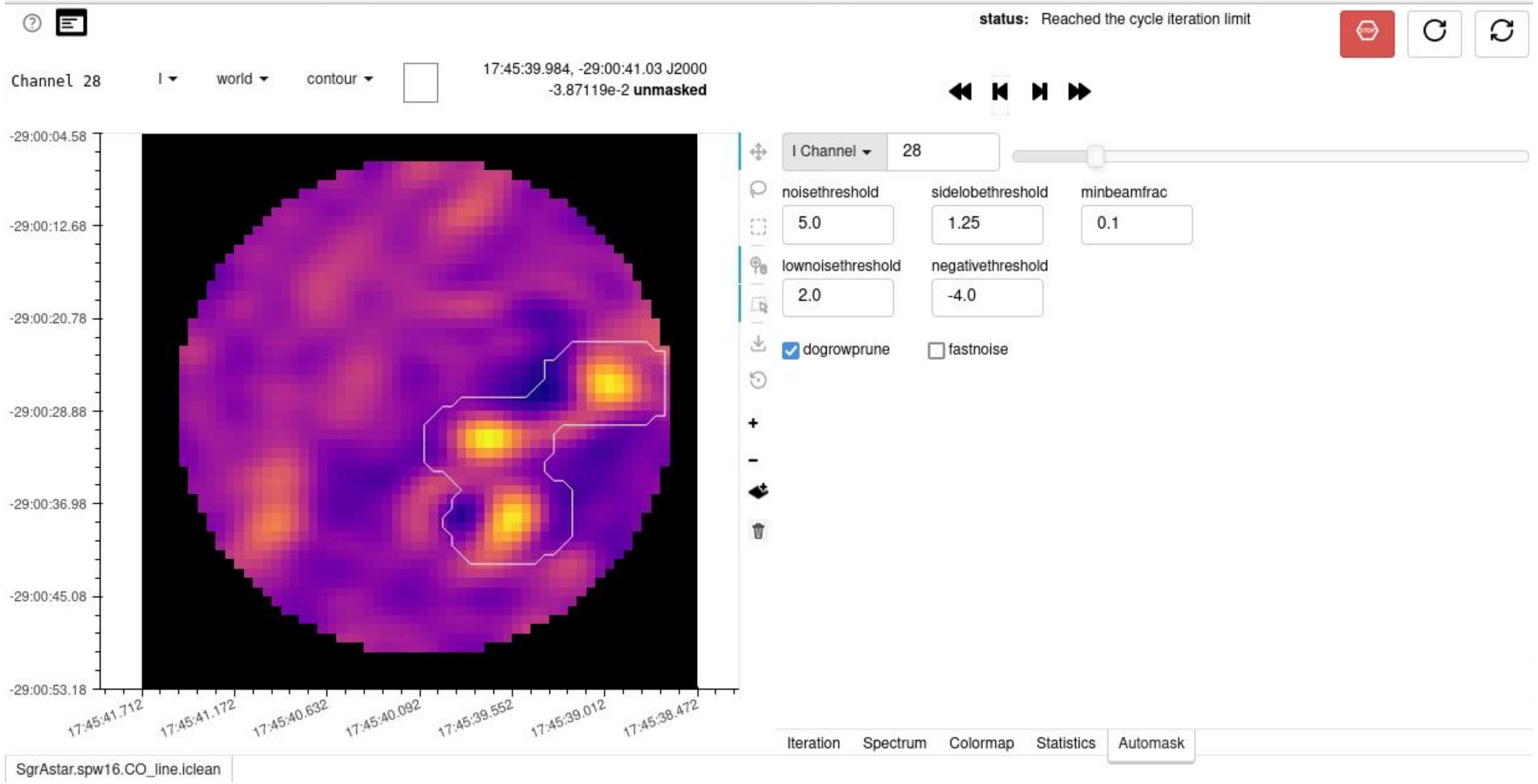
Sgr A* CO Line Imaging

```
iclean(vis = 'SgrAstar_COline.ms.contsub’,
    imagename = 'SgrAstar.spw16.CO_line',
    field = 'SgrAstar',
    stokes = 'I',
    spw = '0',
    outframe = 'LSRK',
    restfreq = '345.7959899GHz',
    specmode = 'cube',
    imsize = [60, 60],
    cell = '0.81arcsec',
    deconvolver = 'hogbom',
    niter = 100,
    weighting = 'briggsbwtaper',
    robust = 0.5,
    mask = '',
    gridder = 'standard',
    pbcor = True,
    threshold = '0.05mJy',
    width = '3.386 km/s’,
    start = '-300 km/s',
    nchan = 177,
    restoringbeam = 'common’,
    perchanweightdensity = True
    usemask='auto-multithresh’,
    noisethreshold=5.0,
    sidelobethreshold=1.25,
    lownoisethreshold=2.0,
    minbeamfrac=0.1,
    negativethreshold=0.0,
    fastnoise=False)
```

Channel 28 of the CO cube

Imaging

- Basics of Imaging Review
- Bandpass Calibrator Imaging
- CARTA
- Sgr A* Continuum Imaging
- **Sgr A* CO Line Imaging**



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

The mask will change between major cycles to pick up missing emission while cleaning the image.

My iclean seems to have a bug and would not display channels higher than channel 59.

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Moment maps can be created from spectral line images.

- moments = -1 - mean value of the spectrum
- moments = 0 - integrated value of the spectrum
- moments = 1 - intensity weighted coordinate; traditionally used to get “velocity fields”
- moments = 2 - intensity weighted dispersion of the coordinate; traditionally used to get “velocity dispersion”
- moments = 3 - median value of the spectrum
- moments = 4 - median coordinate
- moments = 5 - standard deviation about the mean of the spectrum
- moments = 6 - root mean square of the spectrum
- moments = 7 - absolute mean deviation of the spectrum
- moments = 8 - maximum value of the spectrum
- moments = 9 - coordinate of the maximum value of the spectrum
- moments = 10 - minimum value of the spectrum
- moments = 11 - coordinate of the minimum value of the spectrum

Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

```
immoments(imagename='SgrAstar.spw16.CO_line.image’,
  chans=‘’,
  moments=[0],
  outfile='SgrAstar.spw16.CO_line.image.mom0')

immoments(imagename='SgrAstar.spw16.CO_line.image’,
  chans=‘’,
  moments=[1],
  includepix=[4*1.49e-2,100],
  outfile='SgrAstar.spw16.CO_line.image.mom1_4sigma')
```

These commands will create the moment maps. We are making a integrated intensity map and an intensity weighted velocity map (velocity dispersion)

While this gives a first draft, depending on your science you may need to add channels to limit what emission is included. This field contains a lot of emission.

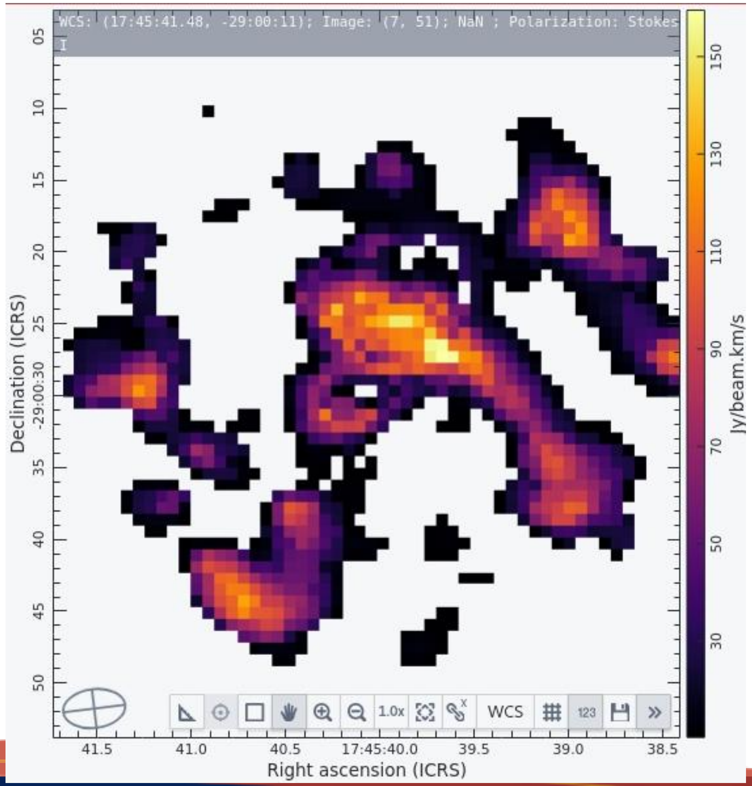
You can try limiting this to chans = ’80~108’ and includepix = [3,100]

Question

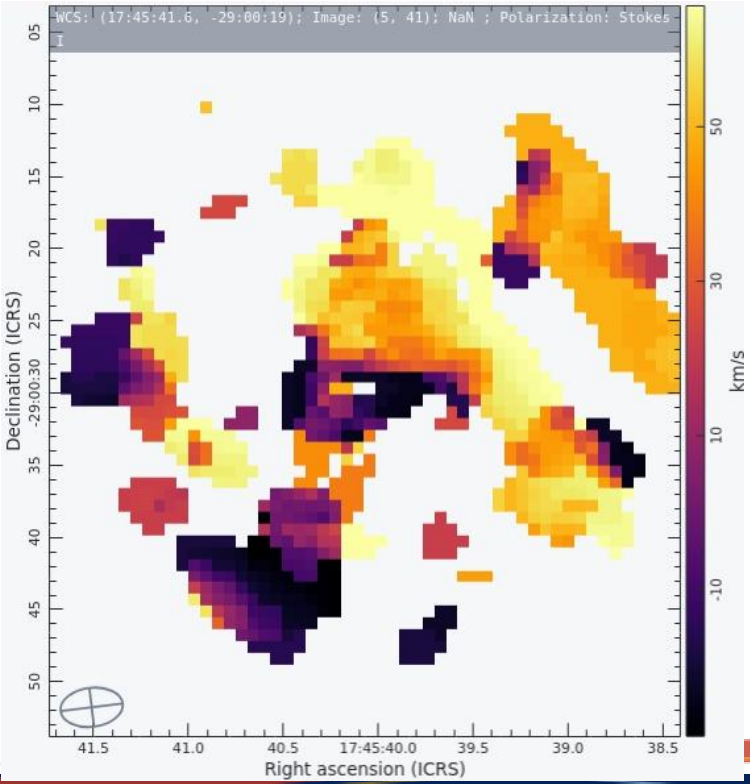
- Why did we set limits for includepix? Why not include all data?

Moment Maps for Sgr A*

Moment zero map



Moment 1 map



Imaging

Basics of Imaging Review

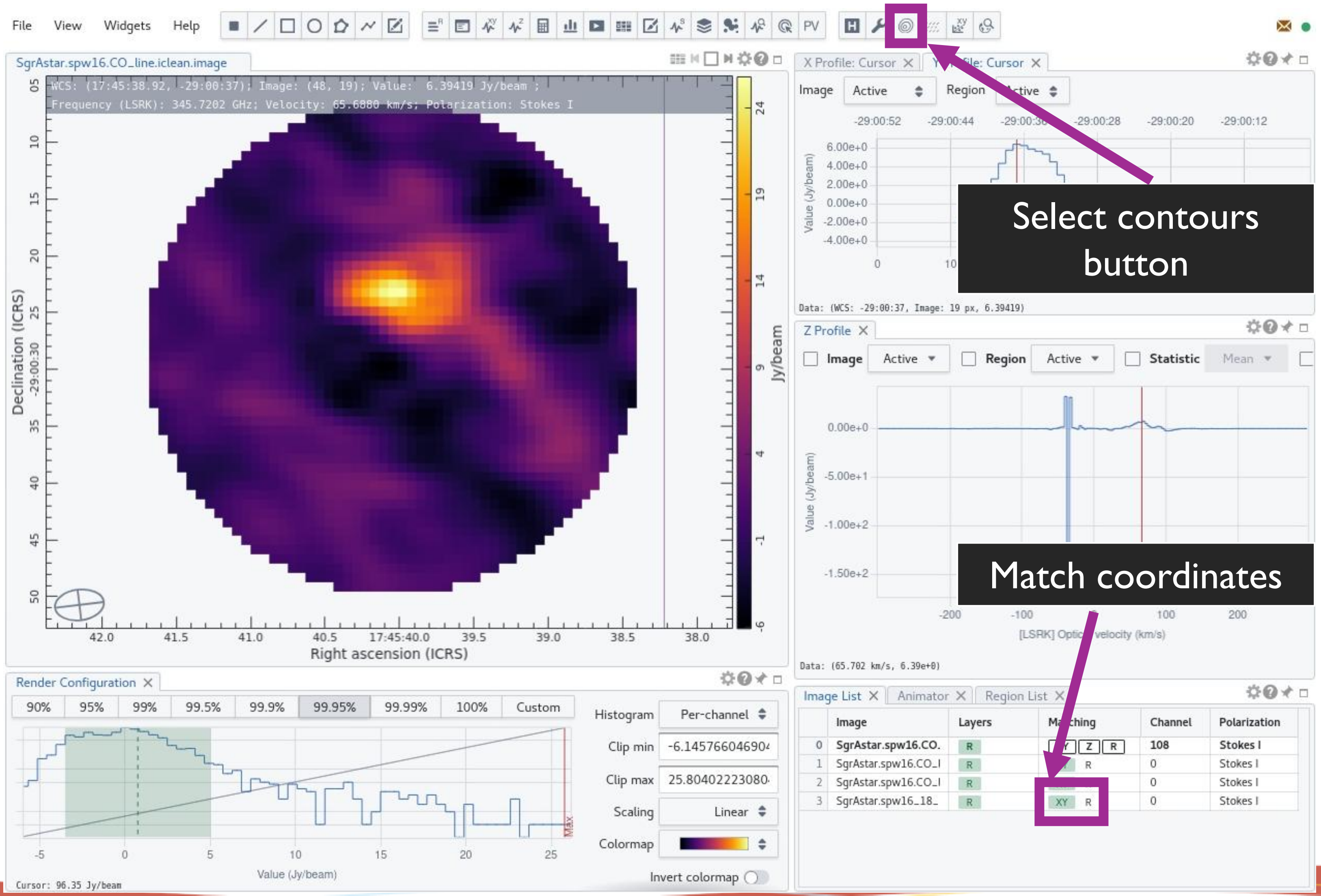
Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Lets add continuum contours to the spectral lines.



Imaging

Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging

Select Continuum Image

Generate / set your contour levels.

Clear contours from image

Apply contours to image

Imaging

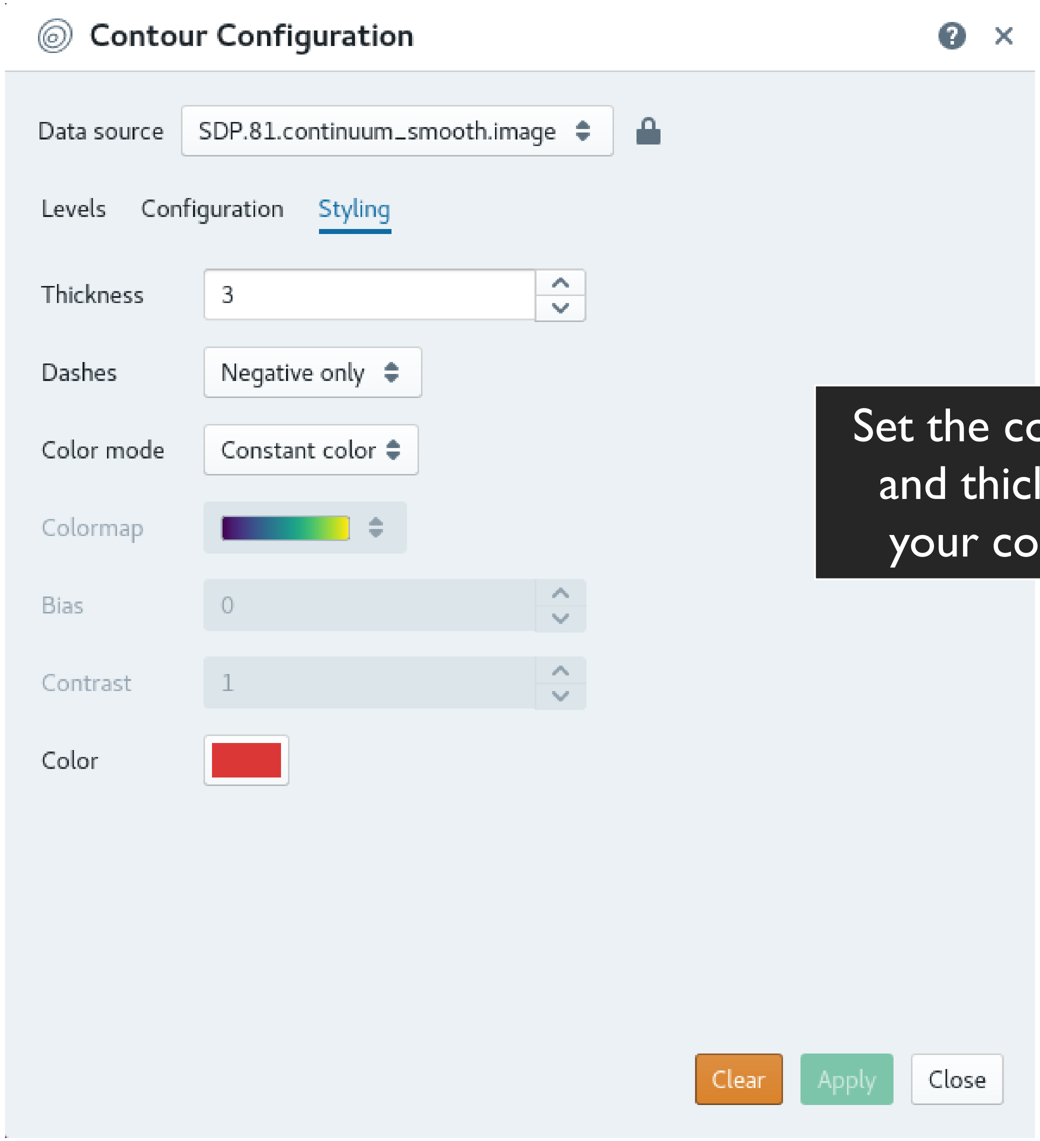
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



Set the color, style, and thickness of your contours!

National Radio Astronomy Observatory

Imaging

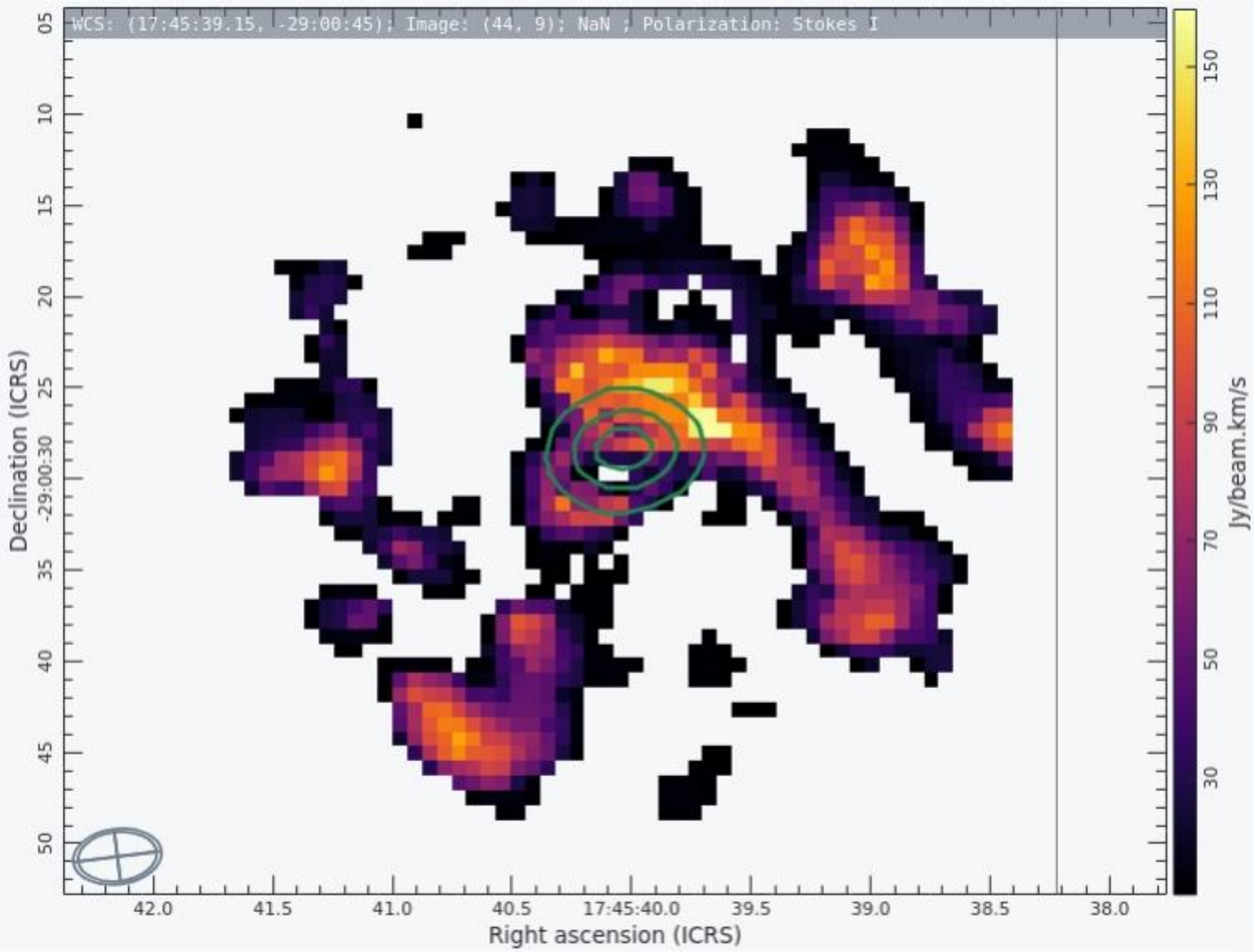
Basics of Imaging Review

Bandpass Calibrator Imaging

CARTA

Sgr A* Continuum Imaging

Sgr A* CO Line Imaging



And we are finished!

- Thanks for sticking with me though that long workshop!
- If you have any further questions, feel free to ask!

- If you have problems or need to ask questions later, contact us at the ALMA help desk! We are happy to help with your technical questions!

Additional Resources:

- ALMA CASA Guides:
  - https://casaguides.nrao.edu/index.php?title=ALMAguides
- ALMA Documentation
  - https://almascience.nrao.edu/documents-and-tools
- ALMA Helpdesk:
  - https://help.almascience.org/

Thank You!