# Introduction to Imaging in CASA

**Megan Ansdell**

**With contributions from Amanda Kepley, Crystal Brogan, David Wilner, Urvashi Rau, and others**

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Very Long Baseline Array

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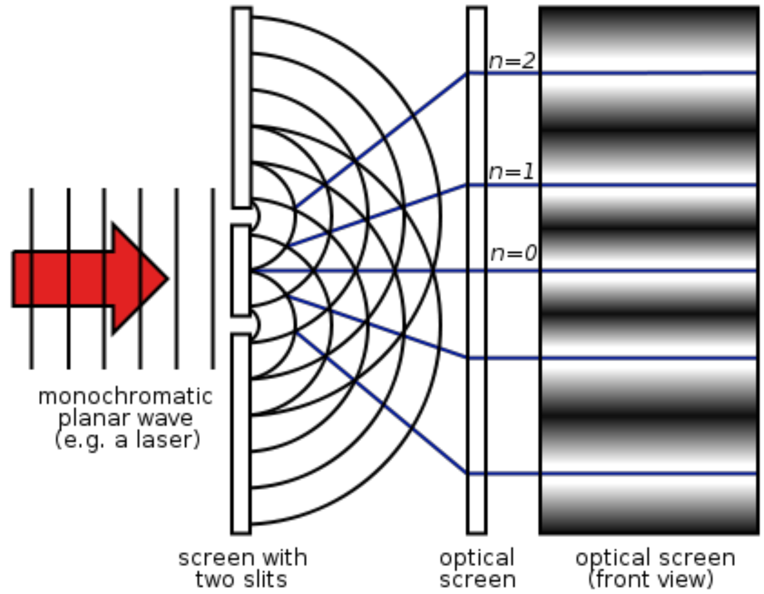
# Introduction to Imaging in CASA

- ☐ Review of interferometric imaging
- ☐ Tour of CASA's "clean" task for imaging
- ☐ Introduction to ALMA simulations
- ☐ Hands-on time

# Radio interferometers measure interference patterns between pairs of antennas

An **interferometer** measures the interference pattern produced by multiple apertures, much like a two-slit experiment



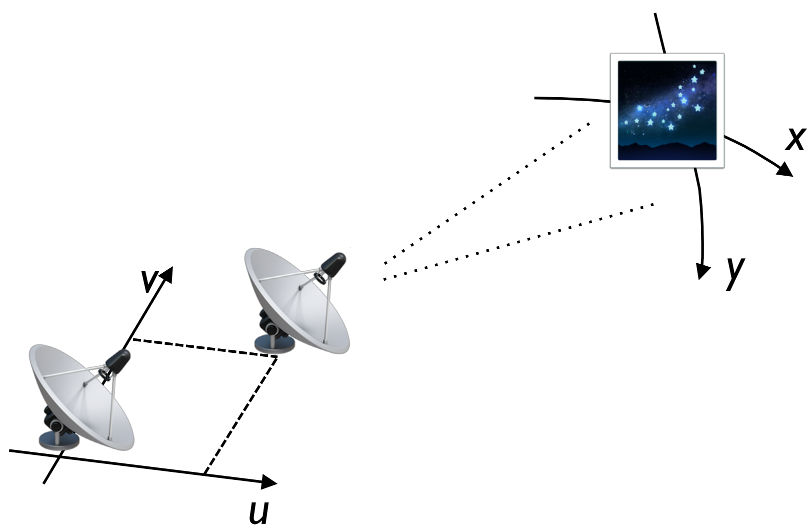

In radio astronomy, the apertures are the individual radio **telescopes/antennas** and the signals are multiplied (not added)

# Fourier transforms [FT] allow us to translate interference pattern measured at telescope into radio brightness on the sky

$$V(u,v) \overset{\text{FT}}{\rightleftarrows} T(x,y)$$

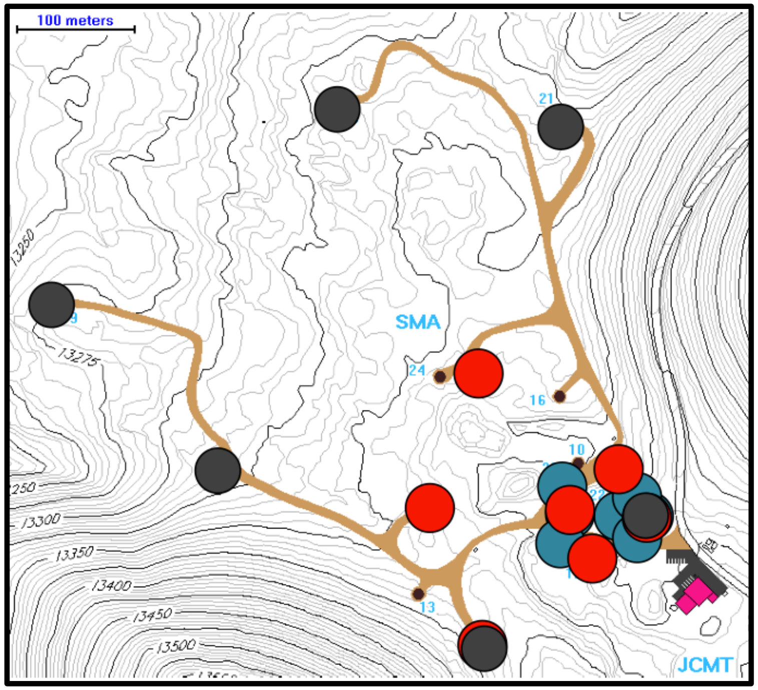
***Complex visibilities***
*(what we measure at telescope; Fourier space)*

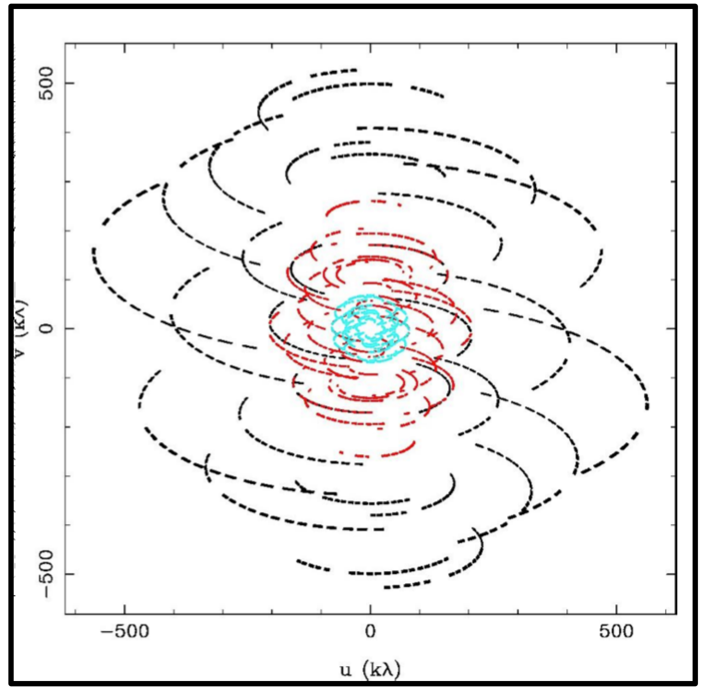
***Sky brightness distribution***
*(what we want to know; image space)*



# Problem of finite (u,v) plane sampling

***1 antenna pair = 1 baseline = 2 (u,v) points***




**Interferometers only discretely sample the (u,v) plane**
**Combine configurations to get most "(u,v) plane coverage"**

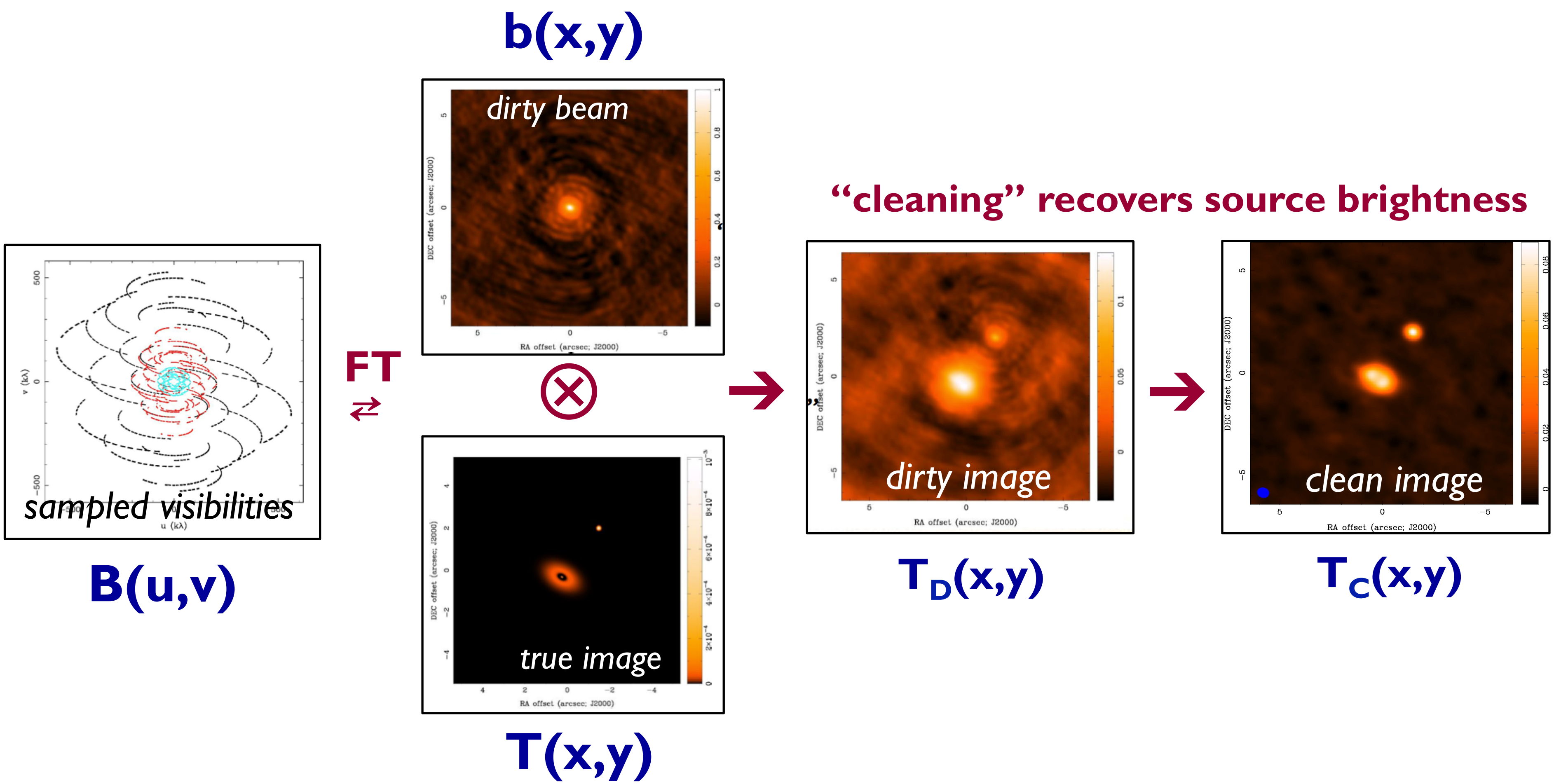
# This is known as "aperture synthesis"


**Sample V(u,v) at a enough (u,v) points using distributed small antennas to synthesize large antenna of size ($u_{max}$,$v_{max}$)**

For **N antennas**, we get **N(N-1) samples** at each observation

*Fill out the rest of the (u,v) plane using 1) Earth's rotation and 2) physically reconfiguring antennas*

# Observed ("dirty") images are the true sky brightness convolved with the interferometer's PSF ("dirty beam")



# "Cleaning" is process of deconvolving the "dirty beam" from the "dirty image" to reconstruct the true image

*Assumes the dirty image can be modeled as collection of point sources:*

(1) Construct observed (dirty) image and dirty beam (PSF)

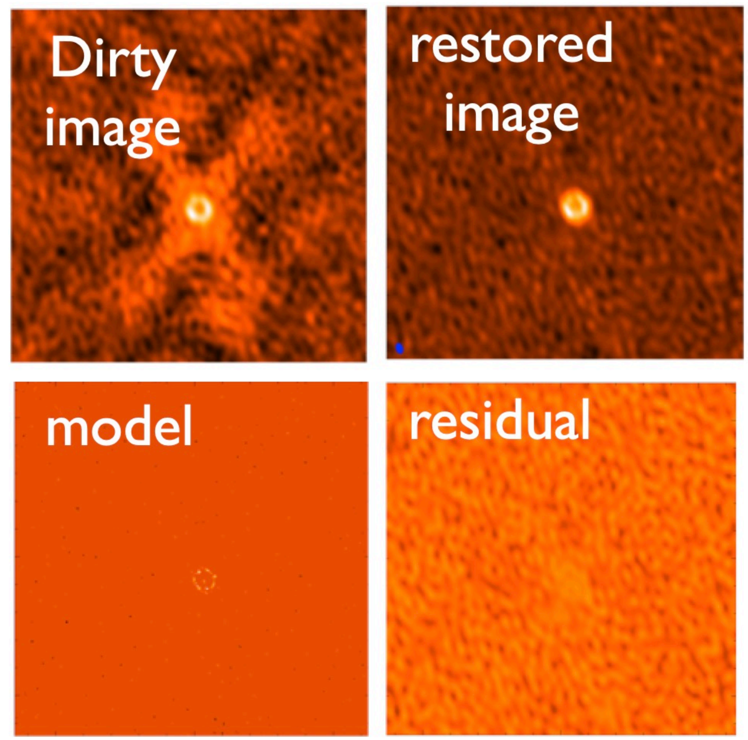
(2) Search for peak of dirty image (within a given mask)

(3) Add a delta-function at peak location to the model

(4) Subtract the contribution of this component (low-amplitude version of the PSF) from the dirty image

Repeat steps (2), (3), (4) until residuals meet stopping criteria

(5) Restore: smooth model with 'clean beam' & add residuals




*This is an iterative process with several important parameter choices…*

# Some parameter choices during cleaning

## Pixel Size

- *5-8 pixels across the dirty beam (to satisfy sampling theorem for longest baselines)*
- *Beam size (arcsec) = 206265 / [longest baseline in wavelength units]*

  (e.g., ALMA 870 microns at 500m max. baselines ➔ pixel size < 0.1 arcsec)

## Image Size

- *Natural choice is often the full primary beam (dictated by wavelength + antenna size)*

  (e.g., ALMA 870 microns for 12m antennas ➔ image size ~10 arcsec)

## Visibility Weighting

- *Emphasizes certain baselines to change the dirty beam*
- *Can choose weight depending on science goals (e.g., sensitivity vs. resolution)*
- *Common choices: Briggs, natural, uniform*

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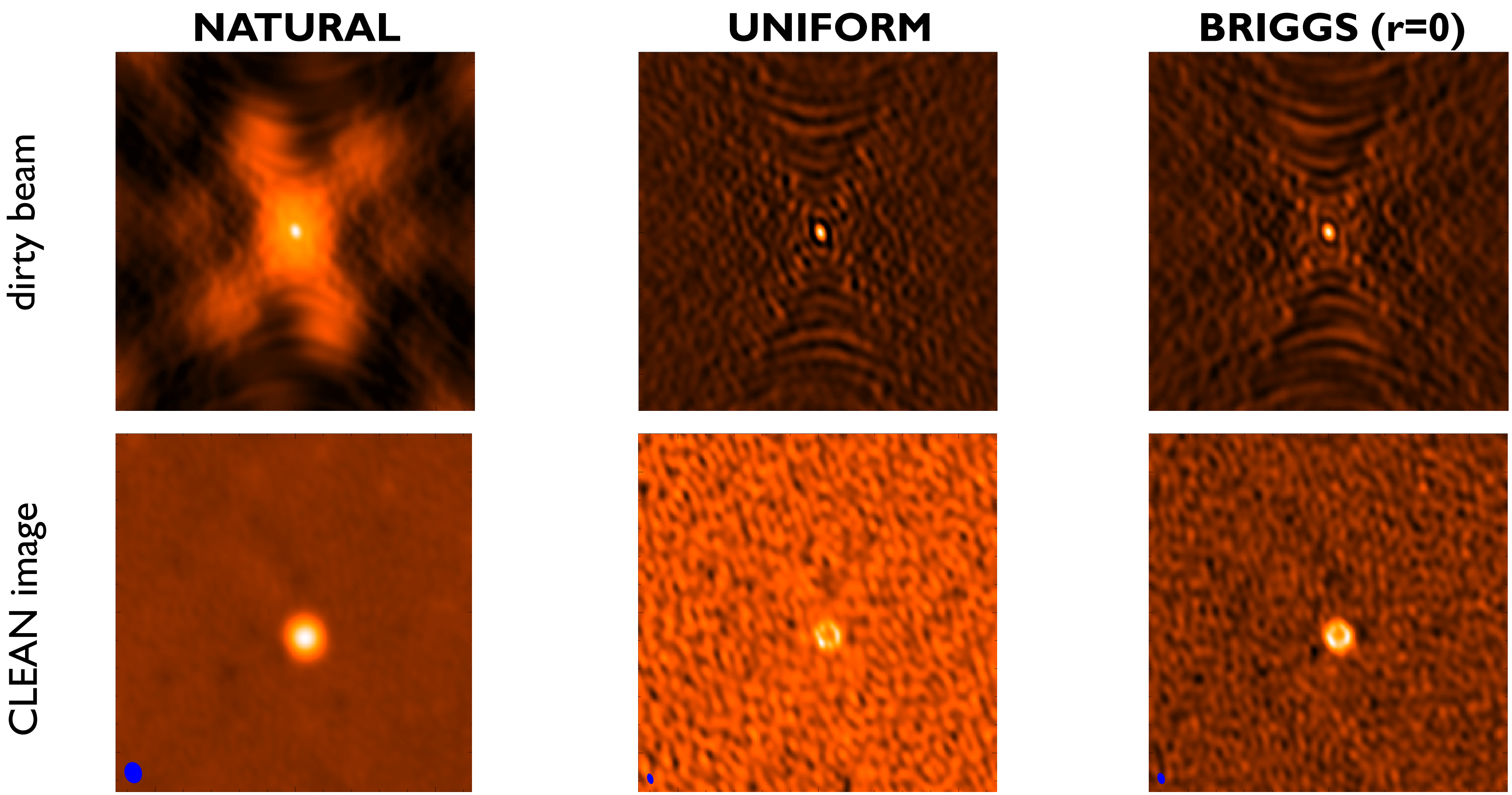
# Choose visibility weighting depending on science goals



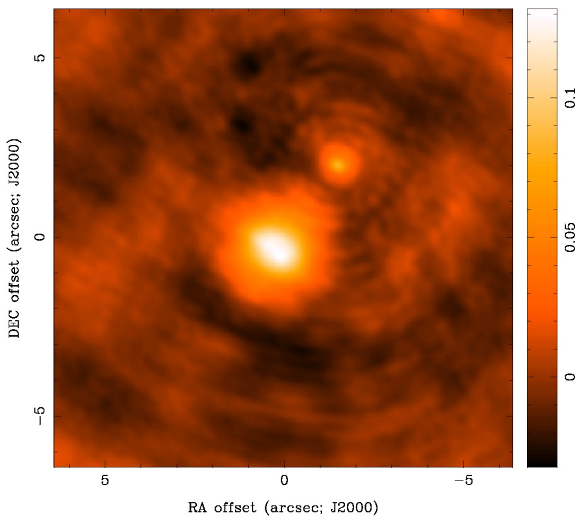

maximizes point-source sensitivity by weighting short baselines (minimizes rms at cost of resolution)

fills (u,v) plane uniformly so weights longer baselines more (higher resolution but this comes with problems)

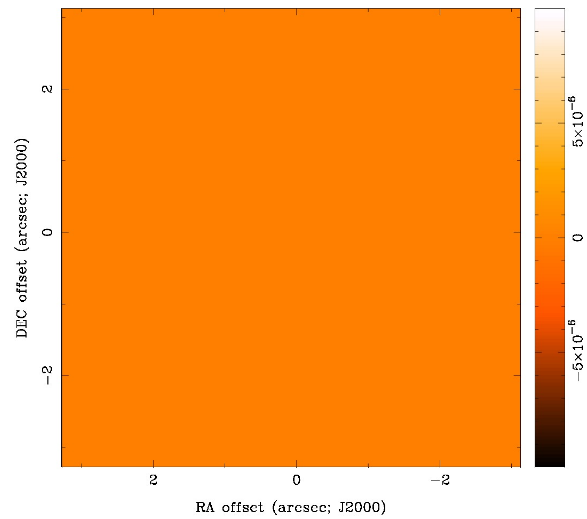
Variant of uniform weighting with adjustable "robust" parameter (typically used with $r = 0.5$; do not use $r < 0$)

# Iterative cleaning example

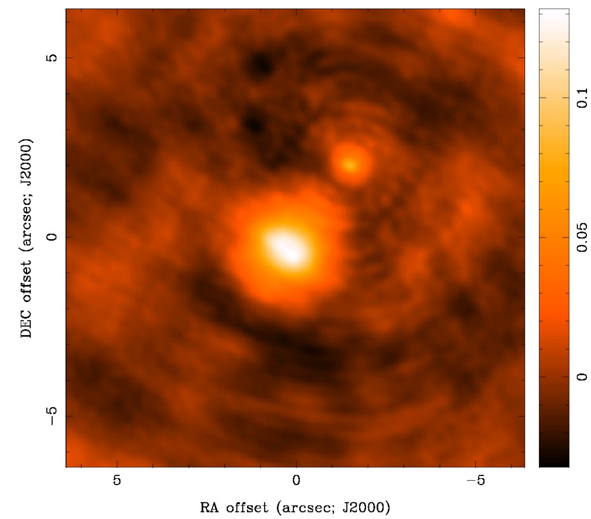
*dirty image*




*0 clean components*

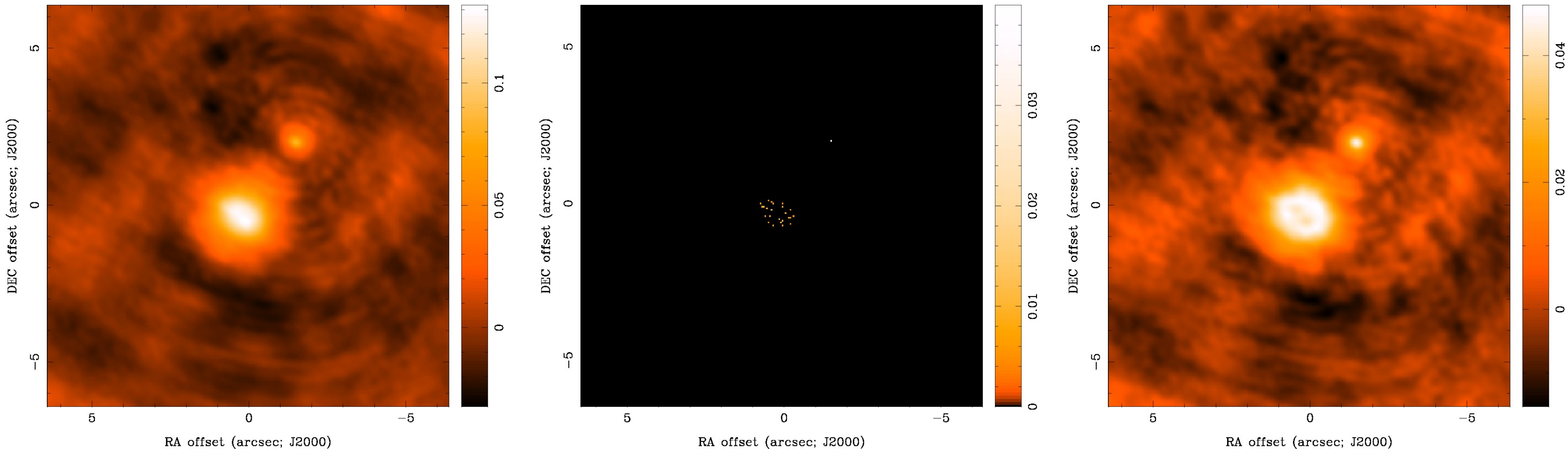



*residual map*



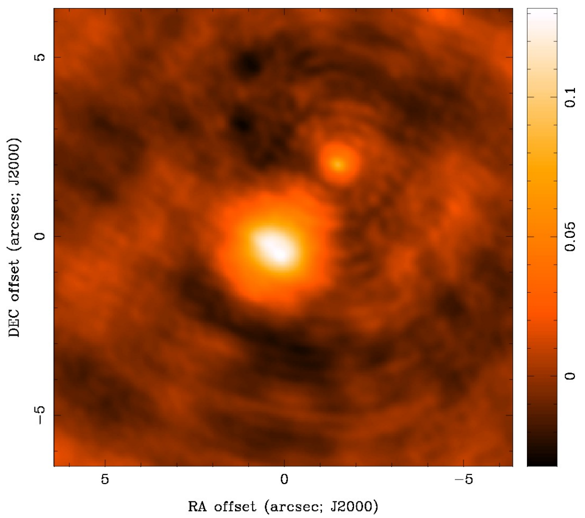
# Iterative cleaning example

*dirty image* | *30 clean components* | *residual map*

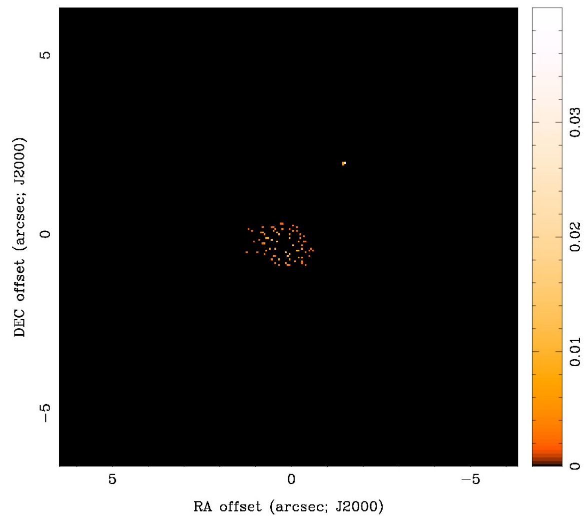


# Iterative cleaning example

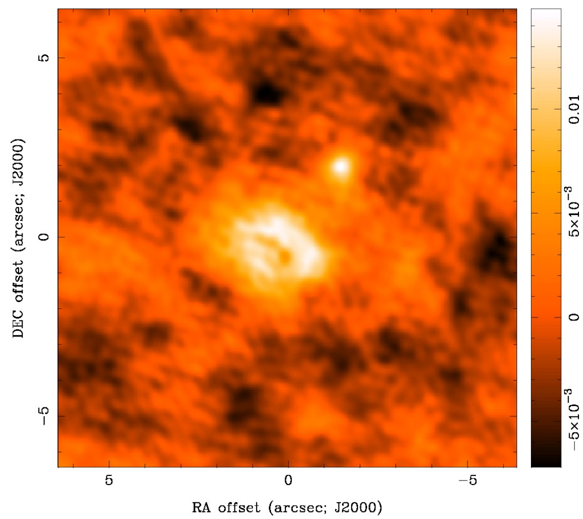
*dirty image*




*100 clean components*

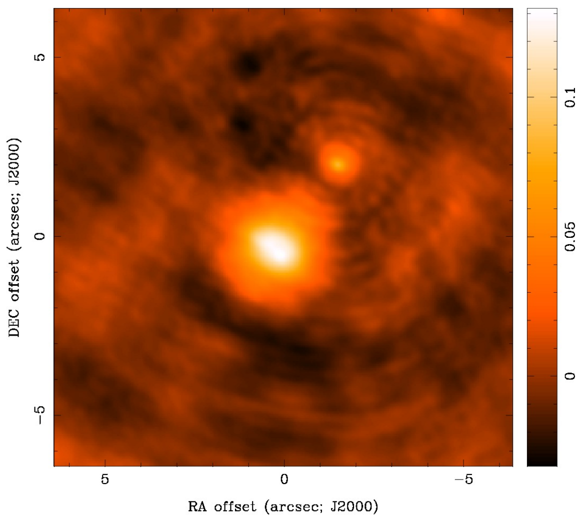



*residual map*

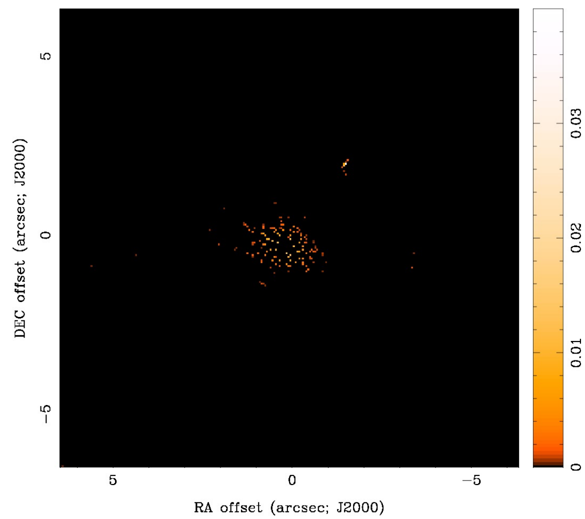


# Iterative cleaning example

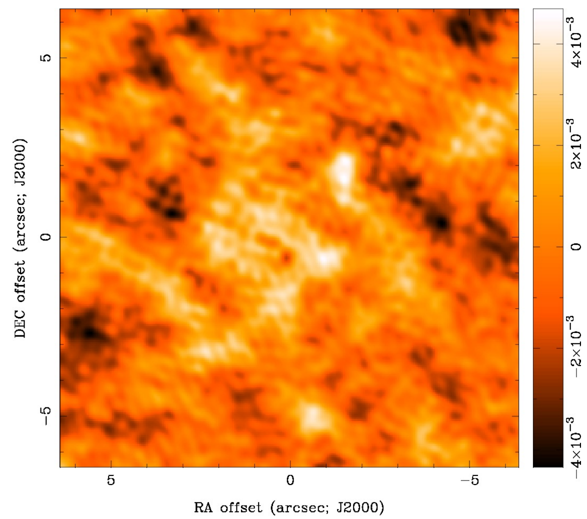
*dirty image*




*300 clean components*




*residual map*

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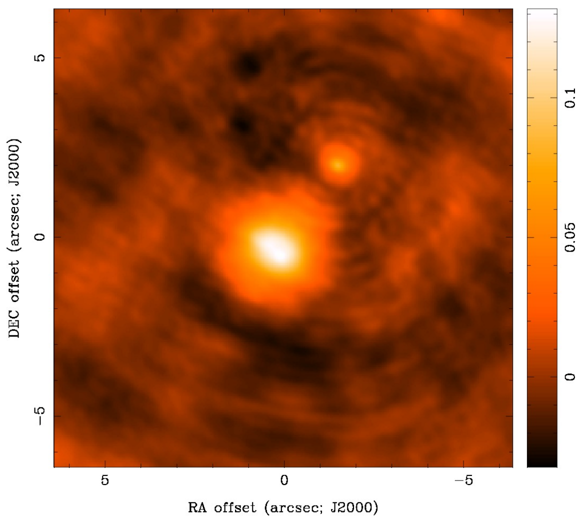
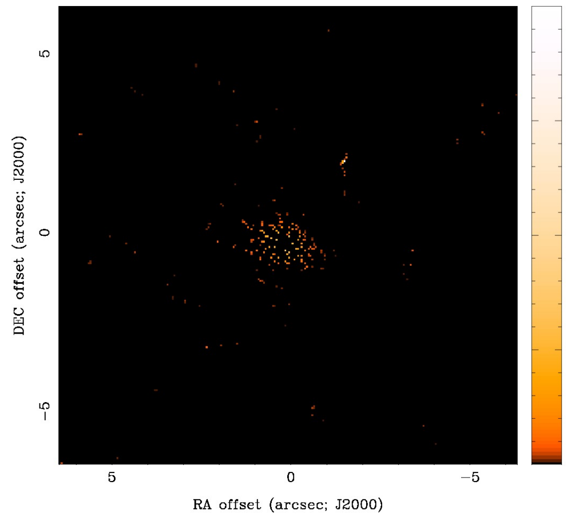
# Iterative cleaning example

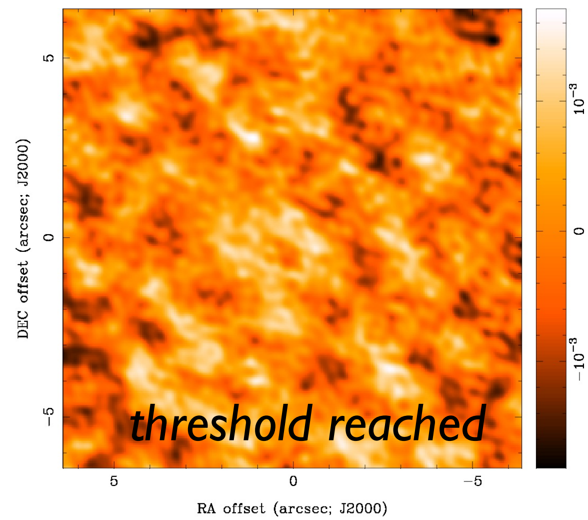
*dirty image*




*583 clean components*




*residual map*

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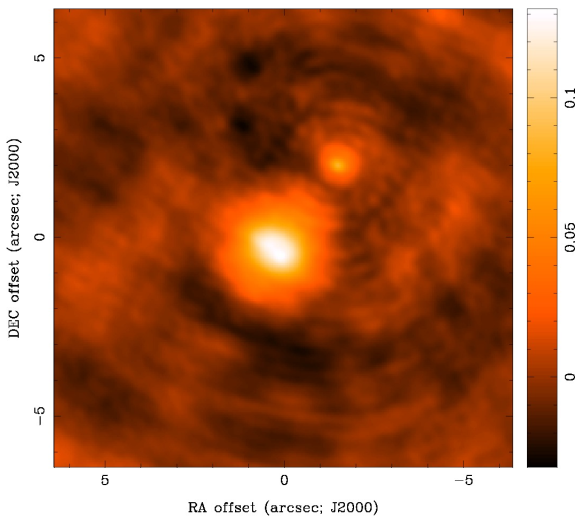
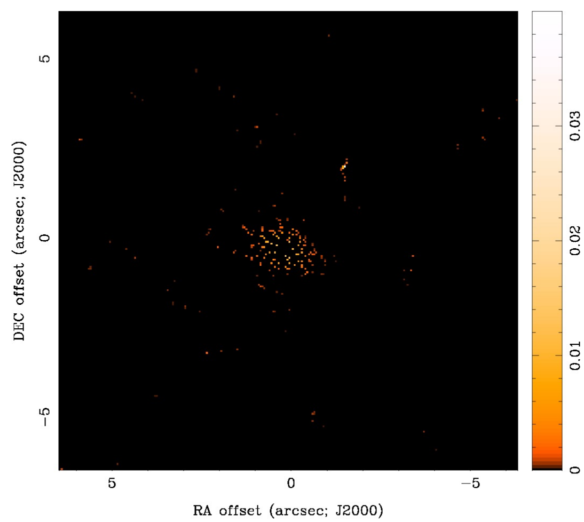
# Iterative cleaning example

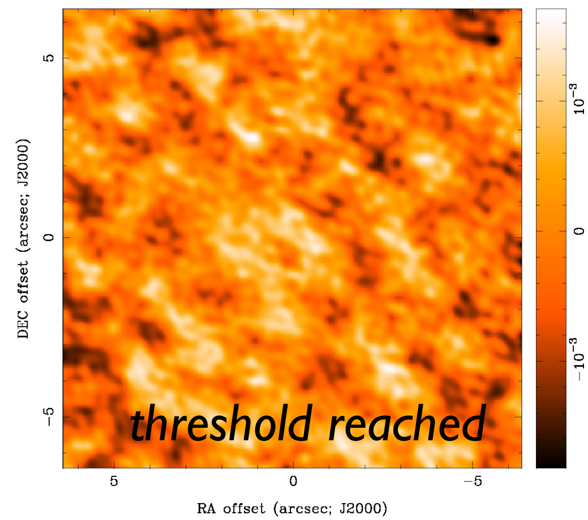
*dirty image*



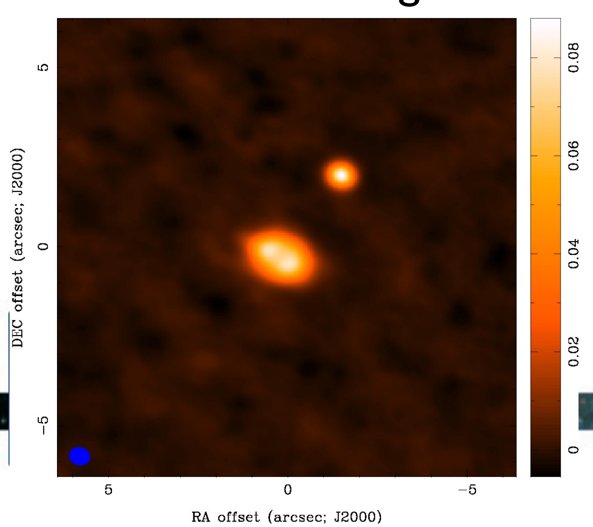

*583 clean components*




*residual map*




*restored image*




***final image depends on:***

*- imaging parameters (pixel size, visibility weighting scheme, gridding)*

*- deconvolution (algorithm, iterations, masks, stopping criteria)*

# In practice, we use the TCLEAN task in CASA

*Many parameters, but don't panic! Start here:*

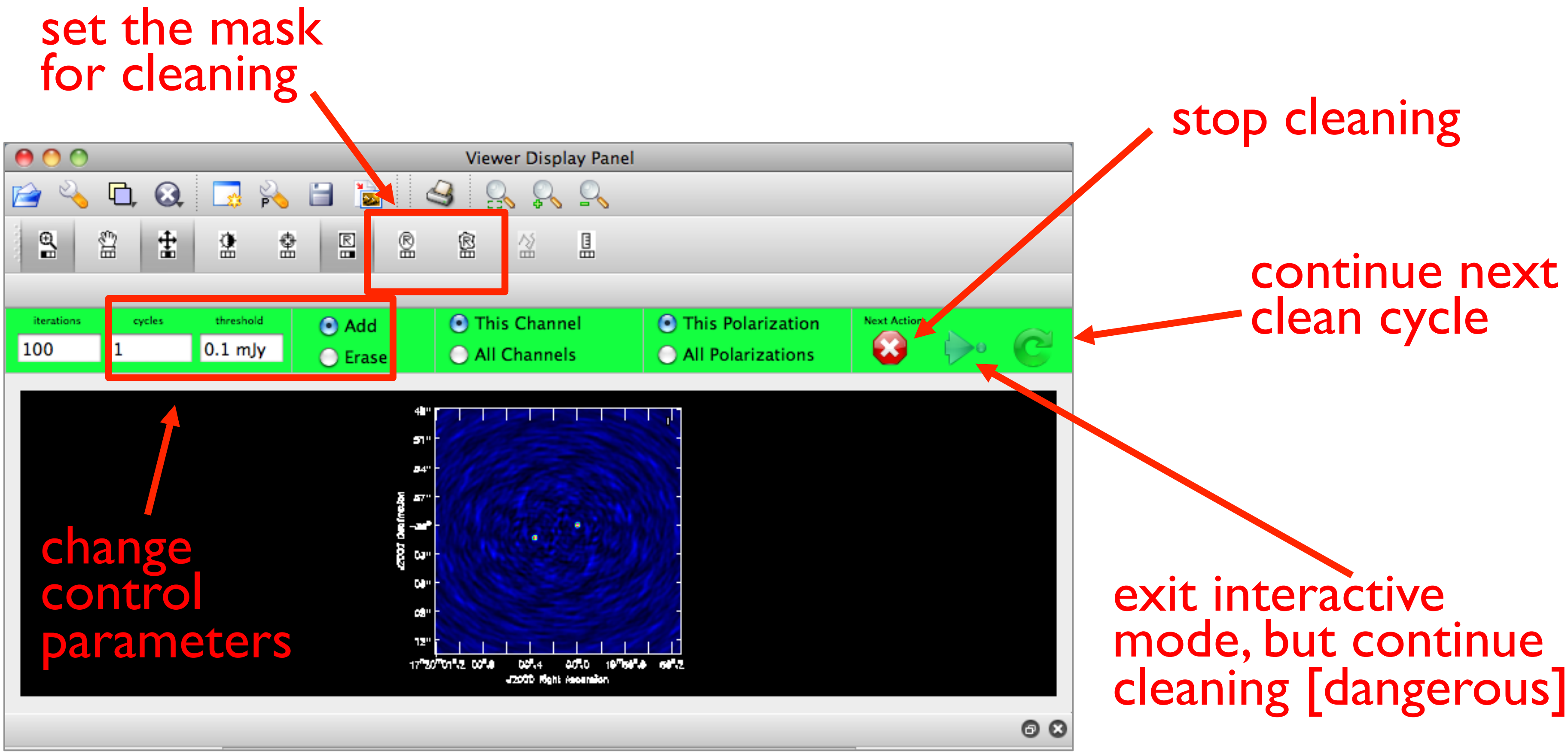
- **vis** = measurement set (can be multiple)
- **imagename** = whatever you want
- **imsize** = size of image in pixels (primary beam)
- **cell** = pixels size (5-8 pixels across synth. beam)
- **specmode** = imaging continuum or line?
- **gridder** = standard or mosaic?
- **deconvolver** = different deconvolution options
- **interactive** = use TLCEAN interactively?
- **niter** = number of iterations before stopping
- **threshold** = residuals limit to stop cleaning

*If you are imaging spectral lines, you must subtract the continuum first (e.g., using **uvcontsub** in CASA)*

```
CASA <6>: inp tclean
--------> 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                = ['1arcsec']       #  Cell size
phasecenter         =         ''        #  Phase center of the image
stokes              =        'I'        #  Stokes Planes to make
projection          =      'SIN'        #  Coordinate projection (SIN, HPX)
startmodel          =         ''        #  Name of starting model image
specmode            =      'mfs'        #  Spectral definition mode
                                        #   (mfs,cube,cubedata)
     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,m
                                        #   ultiscale,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)
     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, auto-thresh, auto-
                                        #   thresh2, 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

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
parallel            =      False        #  Run major cycles in parallel

CASA <7>:
```

https://casaguides.nrao.edu/index.php/TCLEAN_and_ALMA

# Running TCLEAN interactively (recommended)



# Output of TCLEAN

Minimally:

| | |
|---|---|
| my_image.pb | Primary beam model |
| **my_image.image** | Cleaned and restored image (Jy/clean beam) |
| my_image.mask | Clean "boxes" |
| my_image.model | Clean components (Jy/pixel) |
| my_image.psf | Dirty beam |
| my_image.residual | Residual (Jy/dirty beam) |
| my_image.sumwt | Sum of weights |

*these can be used in subsequent tclean; good practice not to delete*

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# Hands-on CASA Imaging Tutorials

**https://casaguides.nrao.edu/index.php/ALMAguides**

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# ALMAguides

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## Introduction

This page contains tutorials to guide new ALMA users through some common types of data imaging and analysis using example ALMA datasets. In addition, we provide detailed guides to the calibration and imaging of some of the publicly-available ALMA Science Verification data that illustrate several different ALMA capabilities.

If you are a new user of CASA, take a look at Getting Started in CASA.

If you are new to CASAguides, start with How to use these CASA Tutorials.

## General Imaging Tutorials

The following tutorials use example ALMA datasets to guide new CASA users through the basic steps required for imaging and self-calibration. ALMA data are delivered with standard calibrations applied and they are ready for imaging.

*These guides have been updated to work in CASA 5.4.0, and to use tclean rather than clean. To understand the differences between clean and tclean, please see the guide: Examples for using the new tclean CASA task for ALMA Imaging.*

- A first look at imaging in CASA: This guide gives a first look at imaging and image analysis in CASA.
- A first look at self-calibration in CASA: This guide demonstrates continuum self-cal.
- A first look at spectral line imaging in CASA: This guide shows imaging of a spectral line.
- A first look at image analysis in CASA: This guide demonstrates moment creation and basic image analysis.

**New!**

- A guide to automasking: This guide demonstrates the automasking functionality of tclean.