An Introduction to Simulating ALMA Observations

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Why Simulate Observations?

- Helps you interpret or plan interferometric observations.
  - But, not a requirement for a proposal.
- Interferometers observe an incomplete sampling of the FT of the sky image, according to the UV coverage. Difficult to gain an easy intuition!
- Both ALMA and the VLA offer multiple configurations, providing a "zoom lens" capability.
- Need to worry about "Largest Angular Scale", gaps in UV coverage, dirty image artifacts, noise levels, multi-configuration data, ACA inclusion

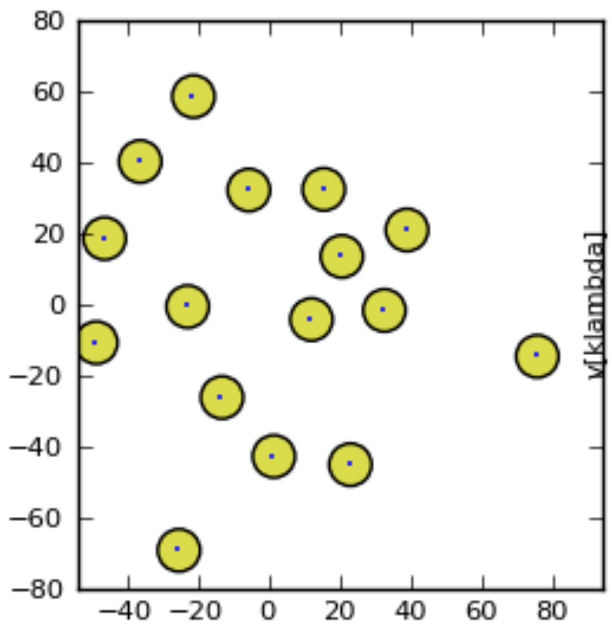
Simulations

Shows how a "model image" would look if observed with an interferometer

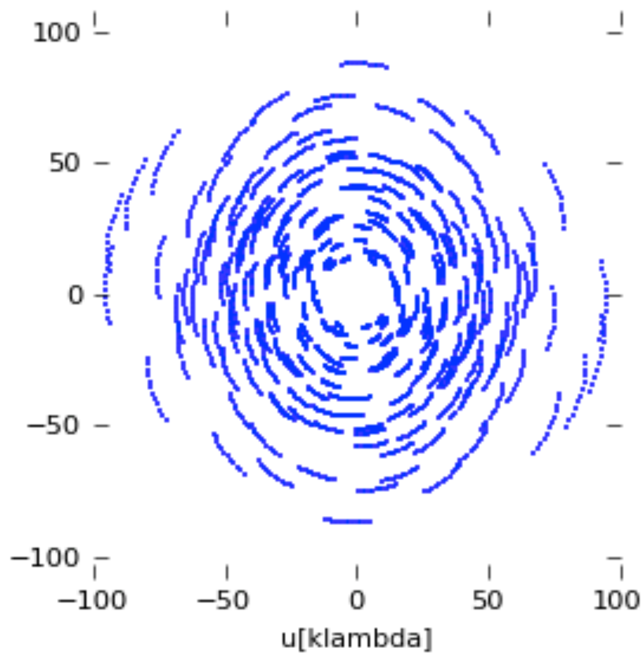
- Number of antennas
- Antenna configuration
- Length of observation
- Noise* ←
  - Thermal Noise
  - Phase Noise

Scales Measured in Compact Early Science

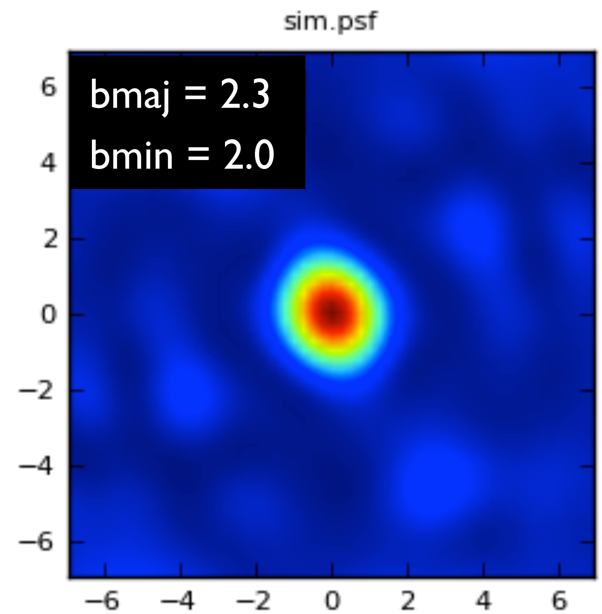
Antenna Placement



uv-coverage



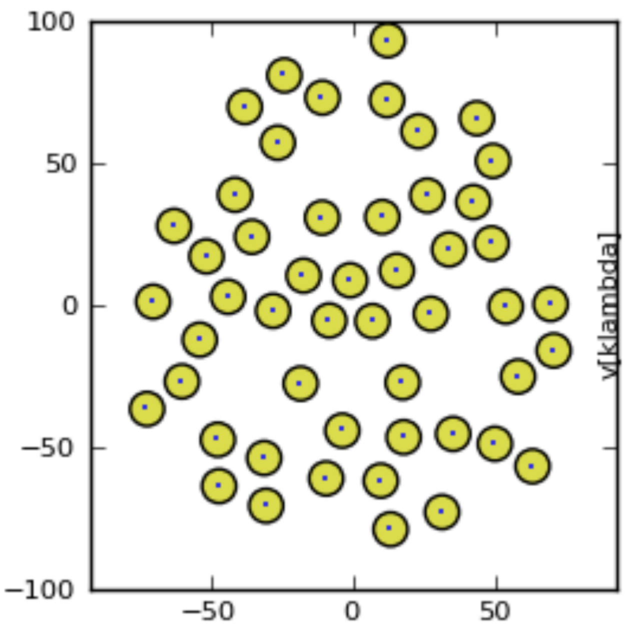
Point Spread Function



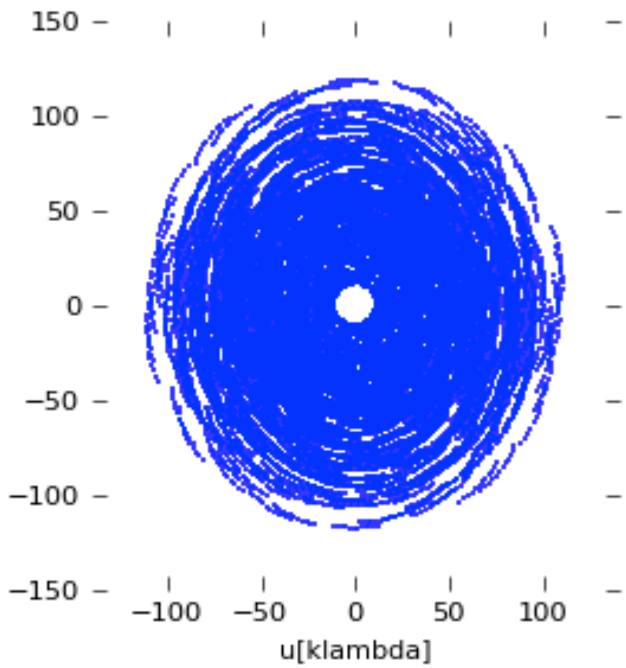
2 hour observation in Compact Configuration

Full Science 12m Array - Compact

Antenna Placement

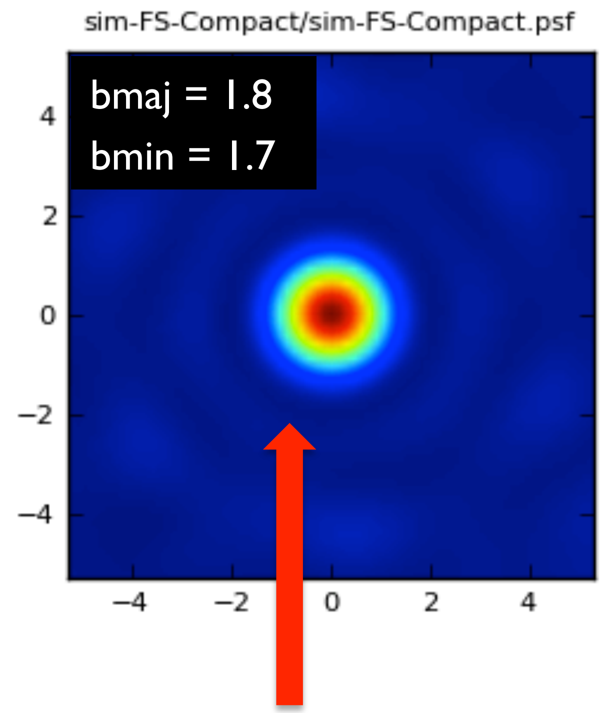


uv-coverage



2 hour observation

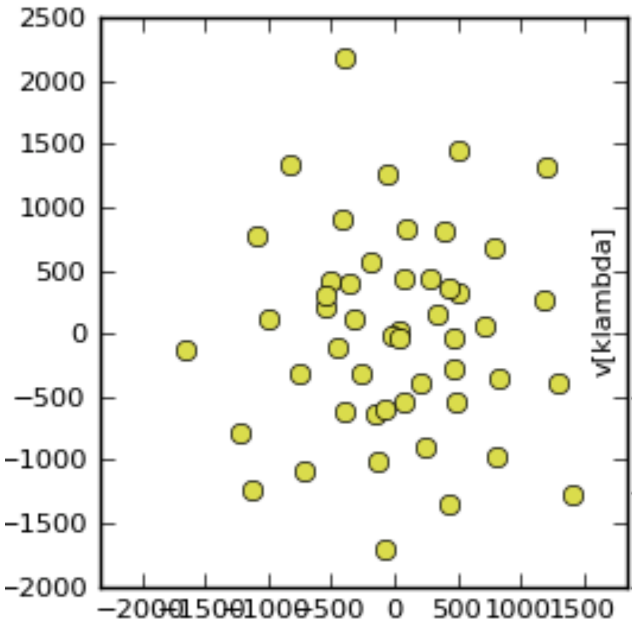
synthesized beam



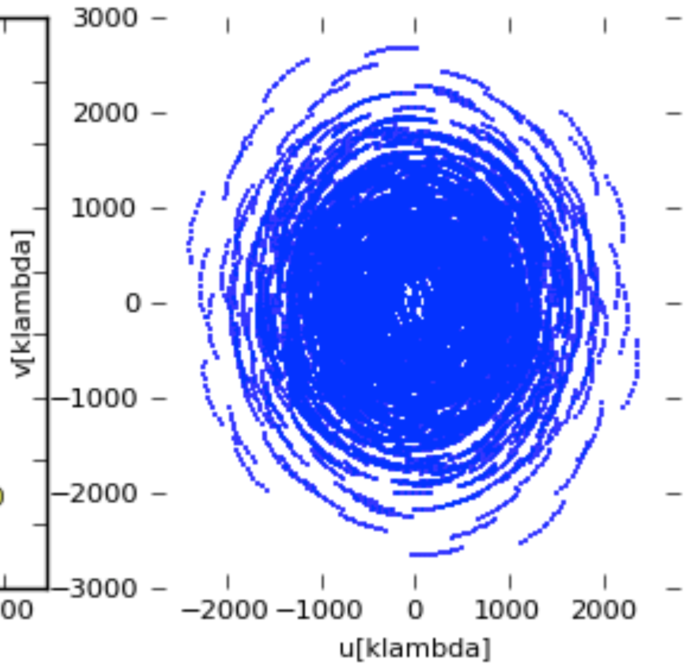
Note lower sidelobes

Full Science 12m Array – More Extended

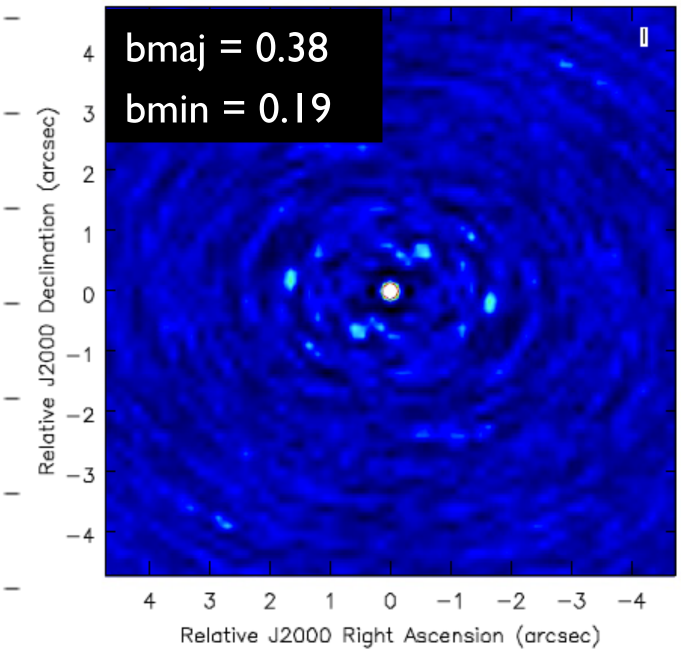
Antenna Placement



uv-coverage



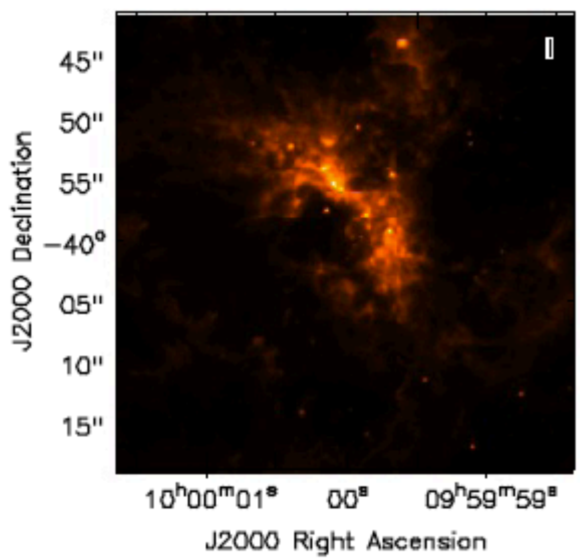
synthesized beam



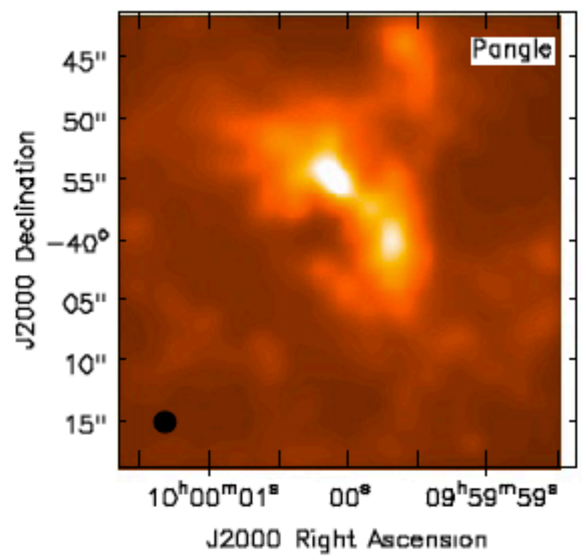
2 hour observation

Model: Full Science Main Array - Compact

Model Image

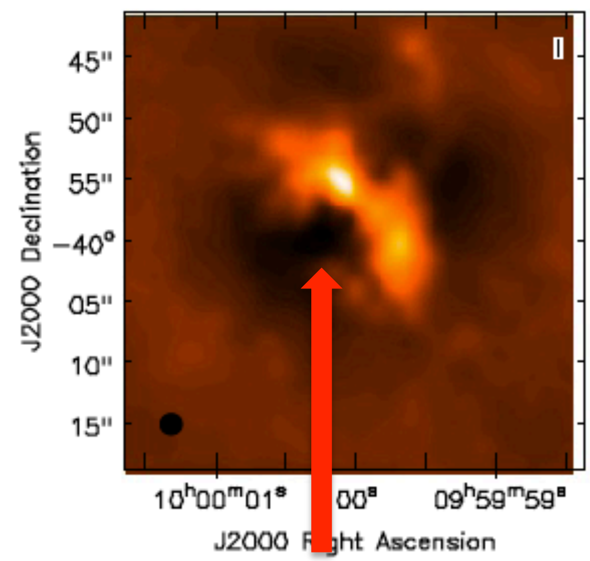


Convolved Model



2 hour observation

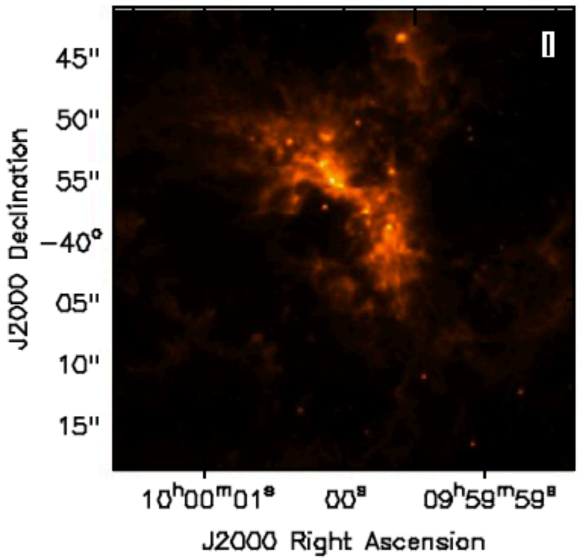
"Observed" Image



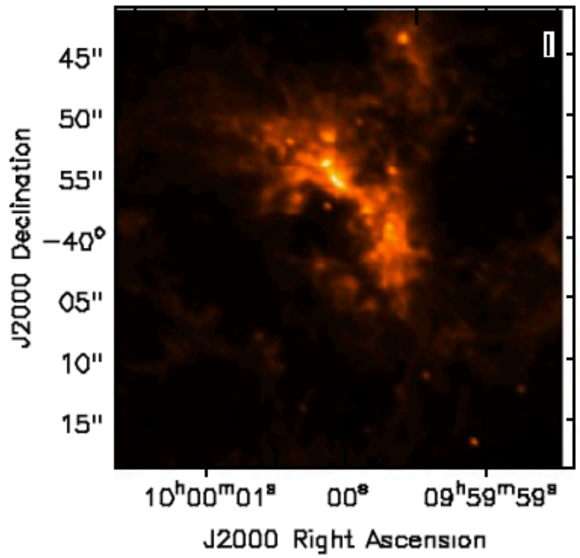
Large scale emission: Observe with ACA and possibly TPA

Model: Full Science Main Array - Extended

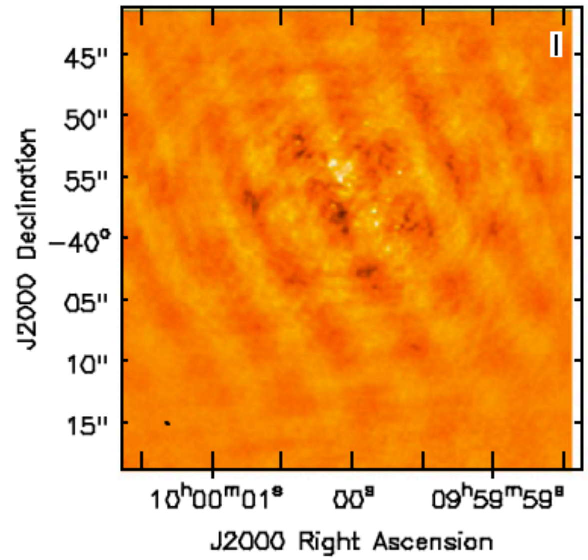
Model Image



Convolved Model



"Observed" Image



2 hour observation

ALMA Simulation Tools

- Two tools: OST and CASA
- Observation Support Tool (OST):
  - A batch service accessible through a web site
  - http://almaost.jb.man.ac.uk/
  - Useful for straightforward simulations, includes C3 configurations with the main 12-m array and ACA

EUROPEAN ARC
ALMA Regional Centre || UK

ALMA Observation Support Tool

Version 3.0

OST | NEWS | HELP | QUEUE | LIBRARY | ALMA HELPDESK

Updated: Important information on the new OST version.

Array Setup:

Instrument: ALMA	Select the desired ALMA antenna configuration.

Sky Setup:

Source model: OST Library: Central point source	Choose a library source model or supply your own.
Upload: Browse... No file selected.	You may upload your own model here (max 10MB).
Declination: -35d00m00.0s	Ensure correct formatting of this string (+/-00d00m00.0s).
Image peak / point flux in mJy 0.0	Rescale the image data with respect to new peak value. Set to 0.0 for no rescaling of source model.

Observation Setup:

Observing mode: ○ Spectral ◉ Continuum	Spectral or continuum observations?
Central frequency in GHz: 93.7	The value entered must be within an ALMA band.
Bandwidth in MHz: 32	Select the total bandwidth for continuum observations. Enter 7.5 GHz to select ALMA recommend full continuum setup.
Number of polarizations: 2	This affects the noise in the final map.
Required resolution in arcseconds: 1.0	OST will choose array config based on this value if *instrument* is set to ALMA.
Pointing strategy: Mosaic	Selecting single will apply primary beam attenuation.
On-source time in hours : 3	Per pointing for mosaics.

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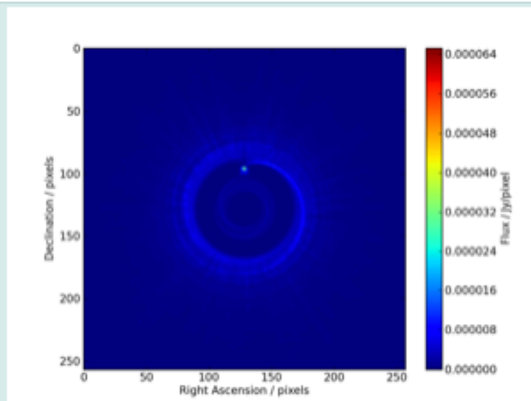
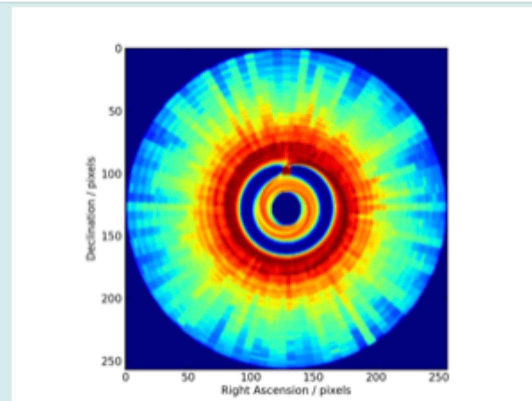
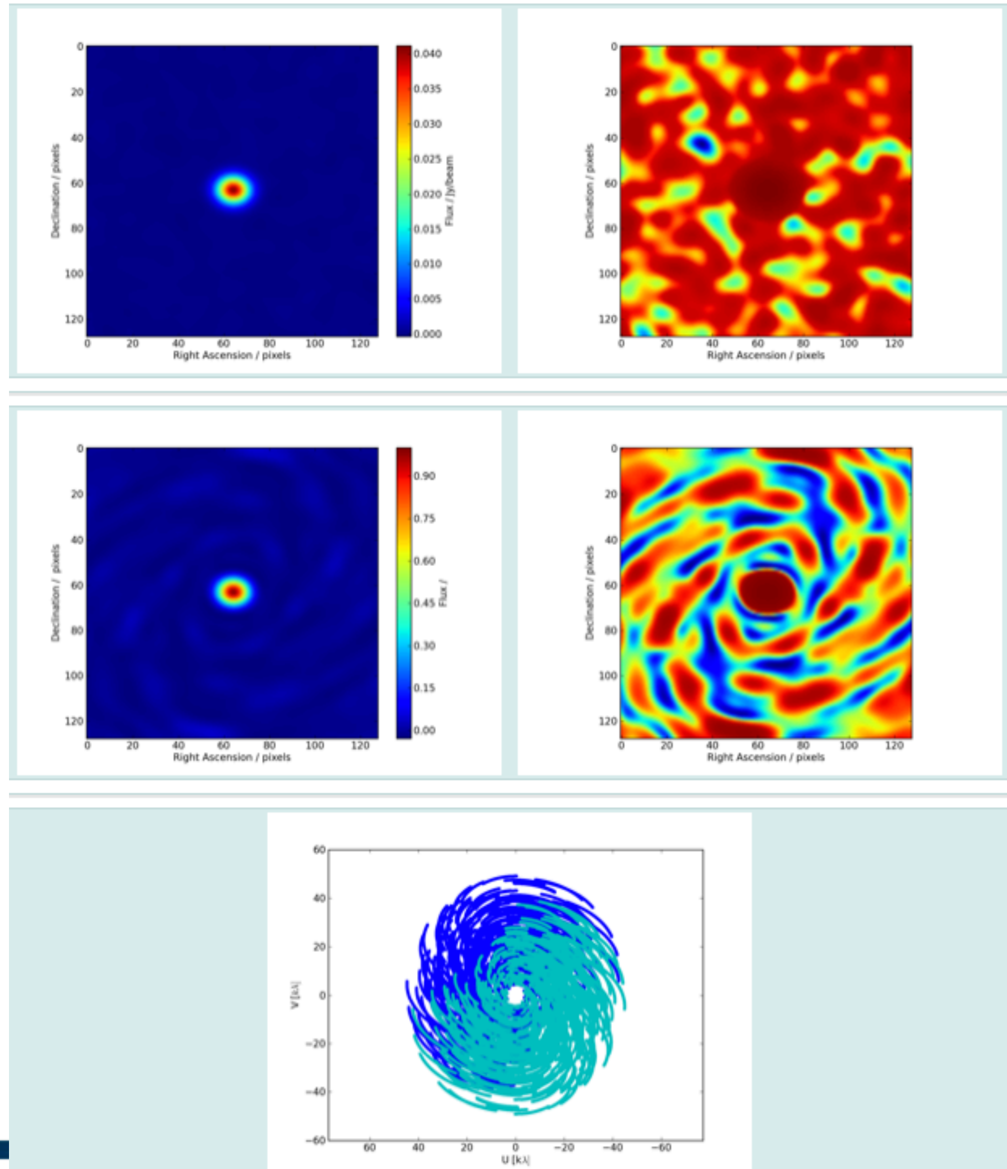
Overview	
Click thumbnails to view full-size images. Left: linear colour scale, right: with histogram equalization.	
Array configuration:	ALMA Cycle 3 C36-1n (160 m baseline)
Source model:	Simulation of Jupiter mass planet orbiting a 0.5 solar mass star in a disk
Input image:	 

C3 Compact


Declination / pixels
Right Ascension / pixels
Flux / Jy/beam
Flux /
V [kλ]
U [kλ]

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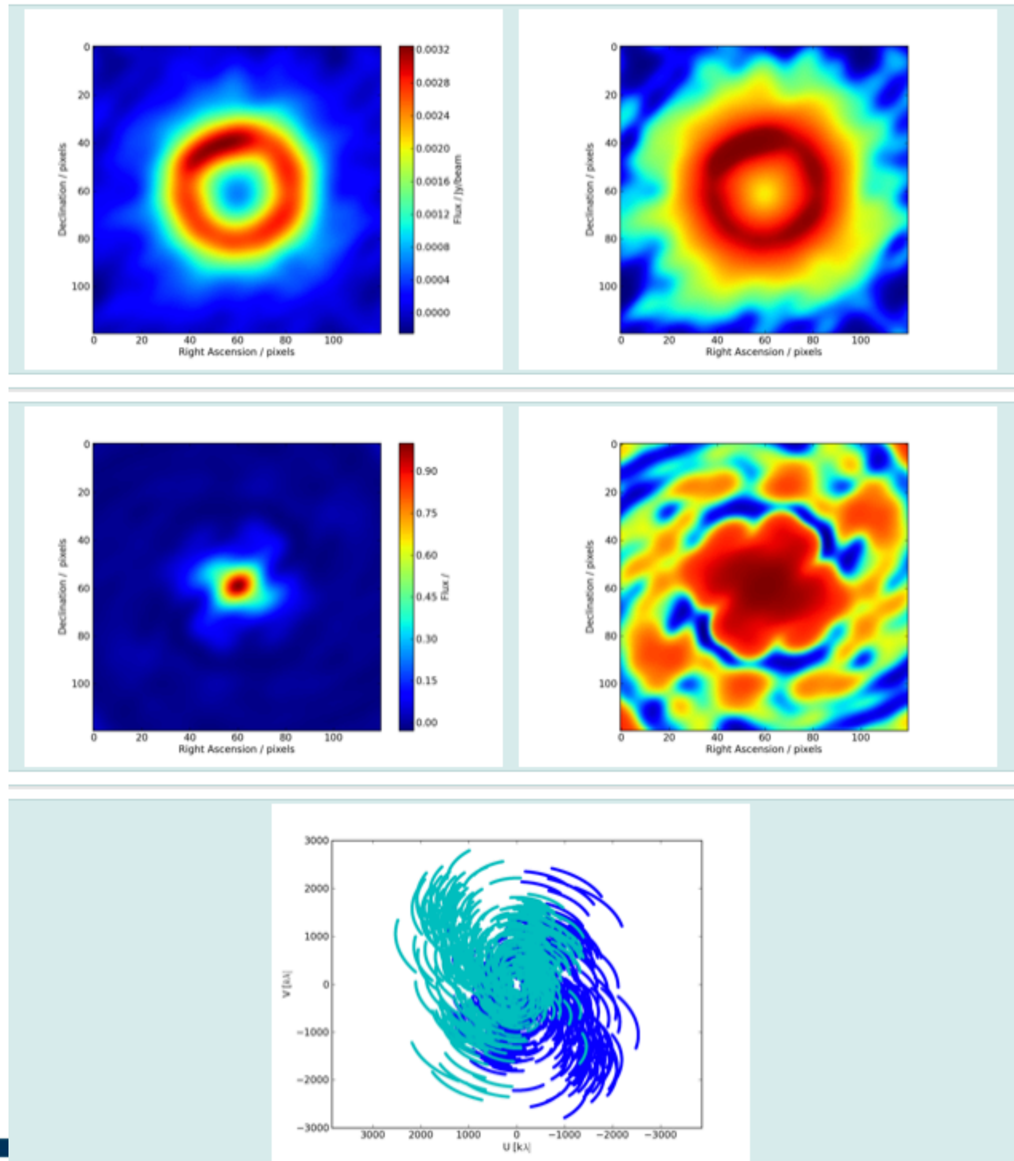
C3 Extended



CASA intro

- CASA is the post-processing package for ALMA and the VLA
- CASA in active community use since October 2007
- Latest Release: 4.3.1
- Linux and Mac OS

http://casa.nrao.edu

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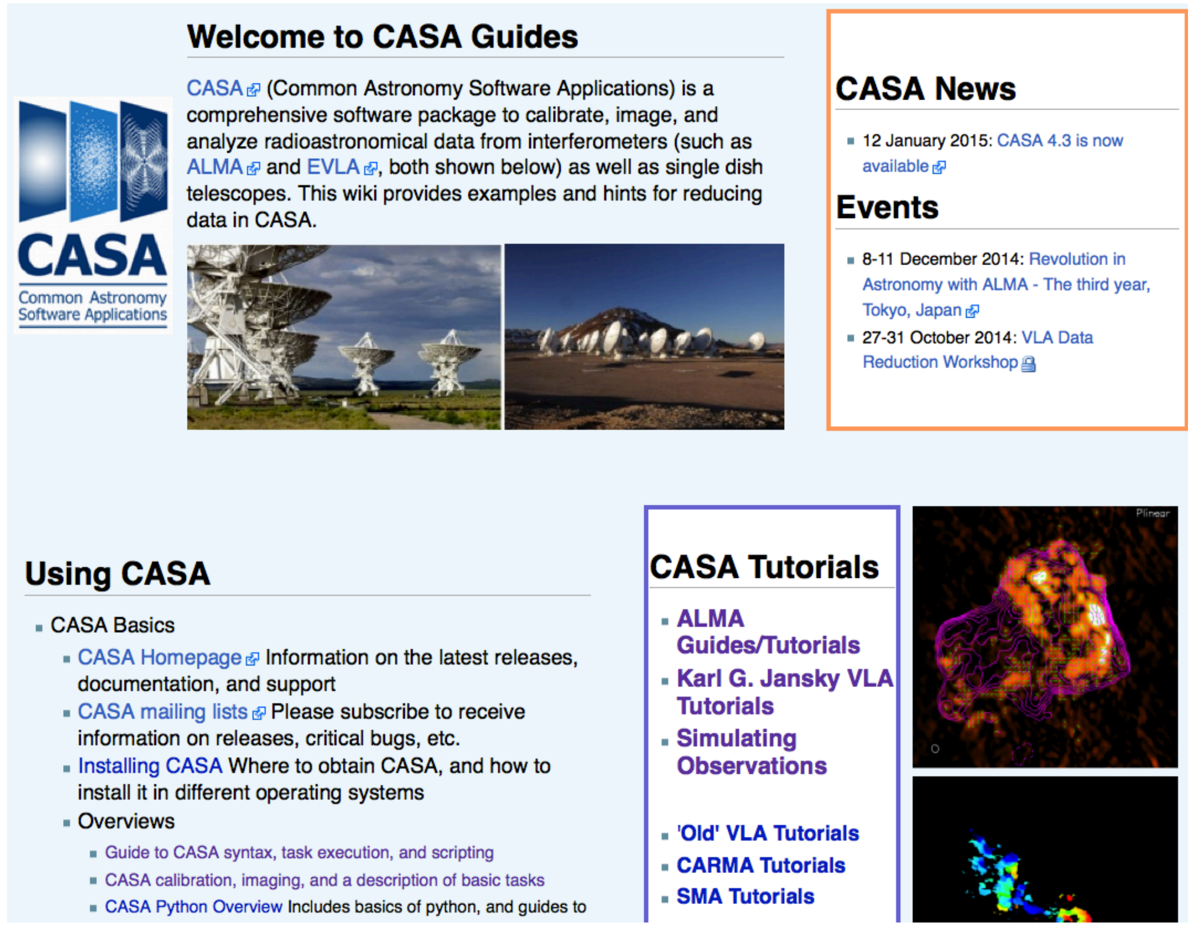
CASA Documentation and Web Resources

- There is a comprehensive CASA user manual and reference material
- CASA guides
  - Fully annotated scripts with screen shots
  - Imaging Tutorials
  - ALMA Science Verification data


Welcome to CASA Guides

CASA (Common Astronomy Software Applications) is a comprehensive software package to calibrate, image, and analyze radioastronomical data from interferometers (such as ALMA and EVLA, both shown below) as well as single dish telescopes. This wiki provides examples and hints for reducing data in CASA.

CASA
Common Astronomy Software Applications

CASA News
- 12 January 2015: CASA 4.3 is now available

Events
- 8-11 December 2014: Revolution in Astronomy with ALMA - The third year, Tokyo, Japan
- 27-31 October 2014: VLA Data Reduction Workshop

Using CASA
- CASA Basics
  - CASA Homepage Information on the latest releases, documentation, and support
  - CASA mailing lists Please subscribe to receive information on releases, critical bugs, etc.
  - Installing CASA Where to obtain CASA, and how to install it in different operating systems
  - Overviews
    - Guide to CASA syntax, task execution, and scripting
    - CASA calibration, imaging, and a description of basic tasks
    - CASA Python Overview Includes basics of python, and guides to

CASA Tutorials
- ALMA Guides/Tutorials
- Karl G. Jansky VLA Tutorials
- Simulating Observations
- 'Old' VLA Tutorials
- CARMA Tutorials
- SMA Tutorials

CASA tasks

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- CASA <2>: tasklist

Will show an organized list of all currently available tasks

Visualization	Simulation	Single dish	Utility
clearplot	simanalyze	asap_init	browsetable
imview	simobserve	sdaverage	caltabconvert
msview	(simalma)	sdbaseline	clearplot
plotants		sdbaseline2	clearstat
plotbandpass		sdbaselineold	concat
plotcal		sdcal	conjugatevis
plotms		sdcal2	find
plotuv		sdcal2old	help par.parameter
viewer		sdcalold	help taskname
(plotweather)		sdcoadd	imview
		sdfit	msview
		sdfitold	plotms
		sdflag	rmtables
		sdflag2old	startup
		sdflagmanager	taskhelp
		sdflagold	tasklist
		sdgrid	testconcat
		sdgridold	toolhelp
		sdimaging	virtualconcat
		sdimagingold	
		sdimprocess	

CASA tasks

- CASA <2>: inp simobserve — Show inputs and set to current
- CASA <3>: simobserve — Run the task
- CASA <4>: help simobserve — Show help
- CASA <5>: default simobserve — Reset parameters to defaults
- CASA <6>: tget simobserve — Get parameters from last execution
- CASA <7>: tput simobserve — Save parameters without running

- CASA <8>: simobserve(project='sim',skymodel='30dor.fits',integration='600s')

Basic Workflow for CASA Simulations

- Make a model image (FITS)
- Simulate observations with *simobserve*
  - You can repeat this step with multiple configurations
- Image the simulated observation with *simanalyze*

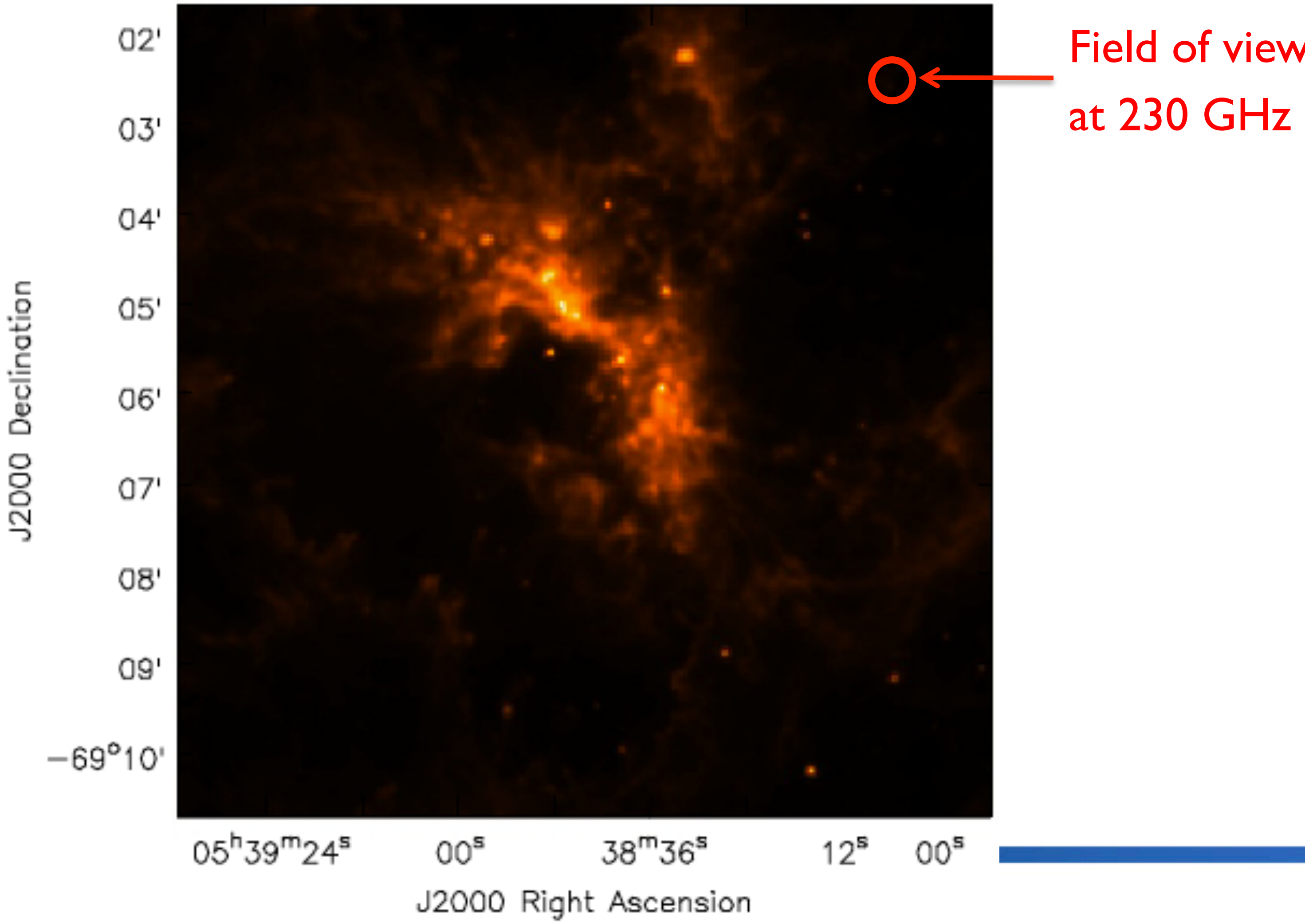
Making a Model Image

- Start from an existing FITS image
  - The simobserve task allows you to adjust the peak flux density, sky coordinates, pixel size, frequency, and channel width

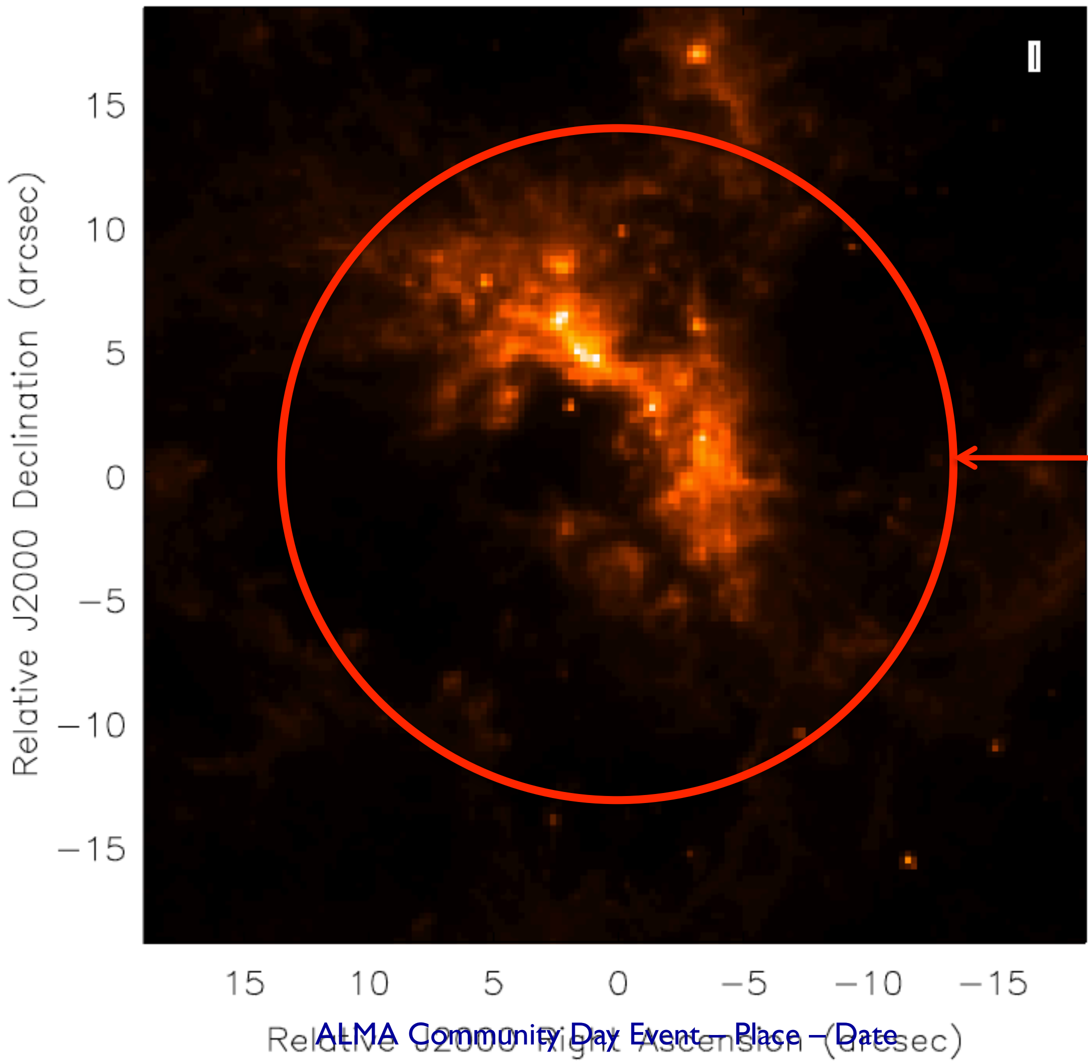
- Make an image from a "component list"
  - A combination of points, gaussians, disks, and limb-darkened disks

- Start with a GIF or JPEG
  - Use unix tools like *convert* to make FITS
  - Use CASA to set data type and image header (see example …)

Model Image
30Dor Spitzer IRAC 8um image from SAGE



Model Image
Resized and now at 230 GHz



Now ~15 times more distant!

Field of view at 230 GHz

Simobserve inputs

```
CASA <22>: inp
---------> inp()
#  simobserve :: visibility simulation task
project              =      'sim'        #  root prefix for output file names
skymodel             = '30dor.fits'      #  model image to observe
     inbright        = '0.06mJy/pixel'   #  scale surface brightness of brightest pixel e.g. "1.2Jy/pixel"
     indirection     = 'J2000 10h00m00 -40d00m00' #  set new direction e.g. "J2000 19h00m00 -40d00m00"
     incell          = '0.15arcsec'      #  set new cell/pixel size e.g. "0.1arcsec"
     incenter        =   '230GHz'        #  set new frequency of center channel e.g. "89GHz" (required even for 2D model)
     inwidth         =     '2GHz'        #  set new channel width e.g. "10MHz" (required even for 2D model)

complist             =         ''        #  componentlist to observe
setpointings         =       True
     integration     =     '600s'        #  integration (sampling) time
     direction       =         ''        #  "J2000 19h00m00 -40d00m00" or "" to center on model
     mapsize         =    ['', '']       #  angular size of map or "" to cover model
     maptype         =     'ALMA'        #  hexagonal, square (raster), ALMA, etc
     pointingspacing =         ''        #  spacing in between pointings or "0.25PB" or "" for ALMA default INT=lambda/D/sqrt(3), SD=lambda/D/3

obsmode              =      'int'        #  observation mode to simulate [int(interferometer)|sd(singledish)|""(none)]
     antennalist     = 'alma.cycle3.1.cfg' #  interferometer antenna position file
     refdate         = '2014/05/21'      #  date of observation - not critical unless concatting simulations
     hourangle       =  'transit'        #  hour angle of observation center e.g. "-3:00:00", "5h", "-4.5" (a number without units will be interpreted as
                                         #   hours), or "transit"
     totaltime       =    '7200s'        #  total time of observation or number of repetitions
     caldirection    =         ''        #  pt source calibrator [experimental]
     calflux         =      '1Jy'

thermalnoise         =         ''        #  add thermal noise: [tsys-atm|tsys-manual|""]
leakage              =        0.0        #  cross polarization (interferometer only)
graphics             =     'both'        #  display graphics at each stage to [screen|file|both|none]
verbose              =      False
overwrite            =       True        #  overwrite files starting with $project
```

Simobserve

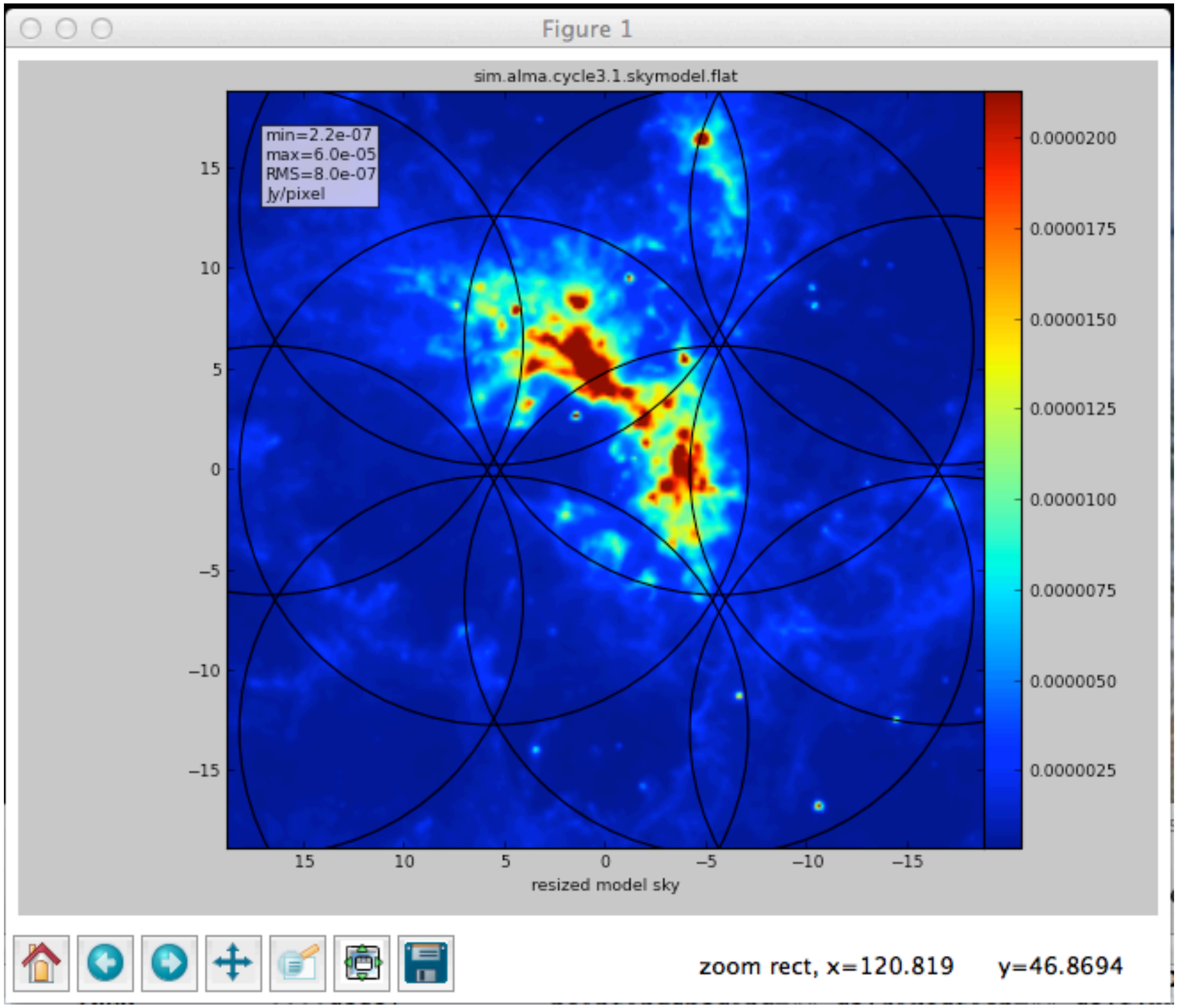


Figure 1
sim.alma.cycle3.1.skymodel.flat
min=2.2e-07
max=6.0e-05
RMS=8.0e-07
Jy/pixel
15
10
5
0
−5
−10
−15
0.0000200
0.0000175
0.0000150
0.0000125
0.0000100
0.0000075
0.0000050
0.0000025
resized model sky
zoom rect, x=120.819 y=46.8694

Simobserve

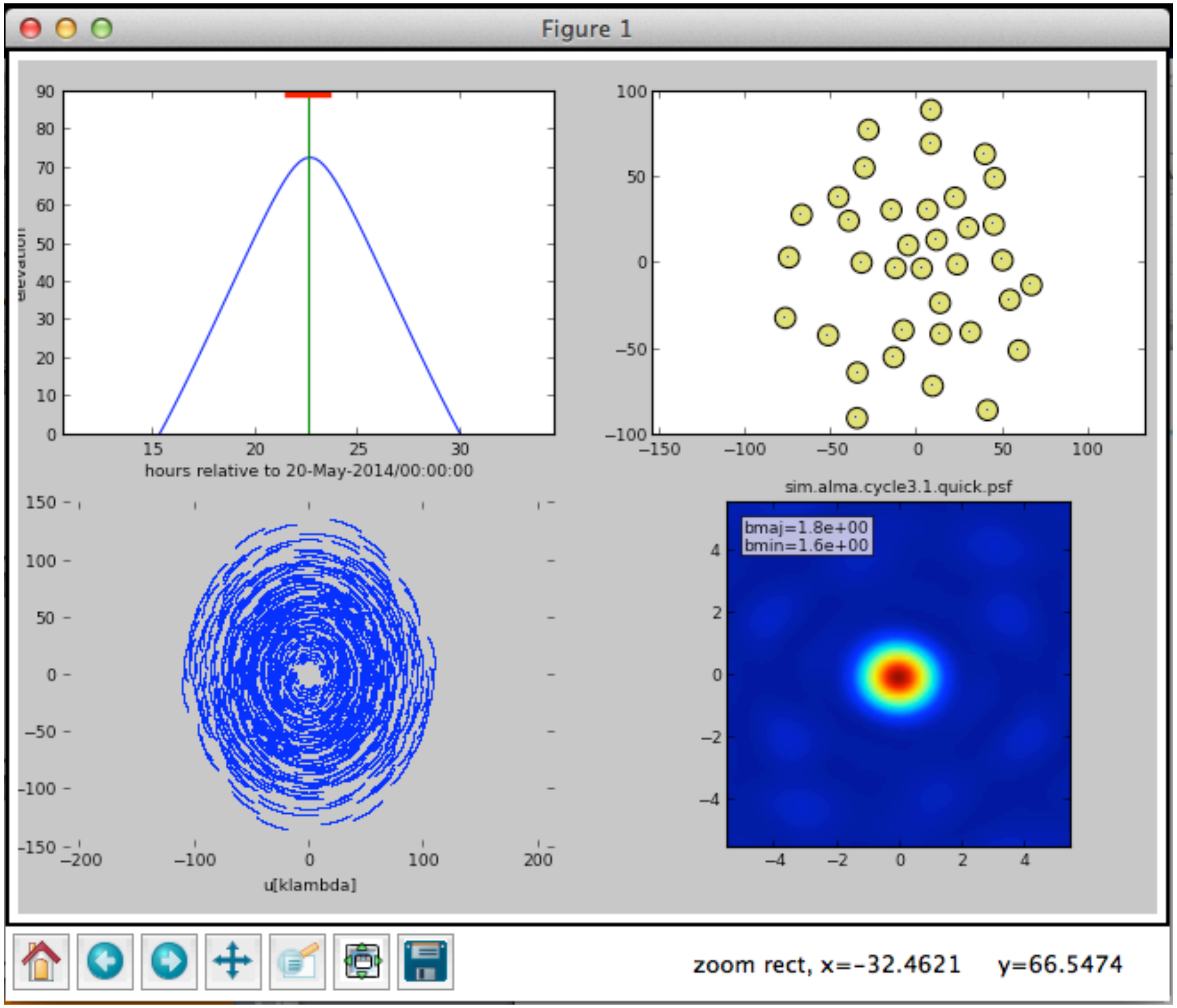


Figure 1
hours relative to 20-May-2014/00:00:00
sim.alma.cycle3.1.quick.psf
bmaj=1.8e+00
bmin=1.6e+00
u[klambda]
zoom rect, x=-32.4621 y=66.5474

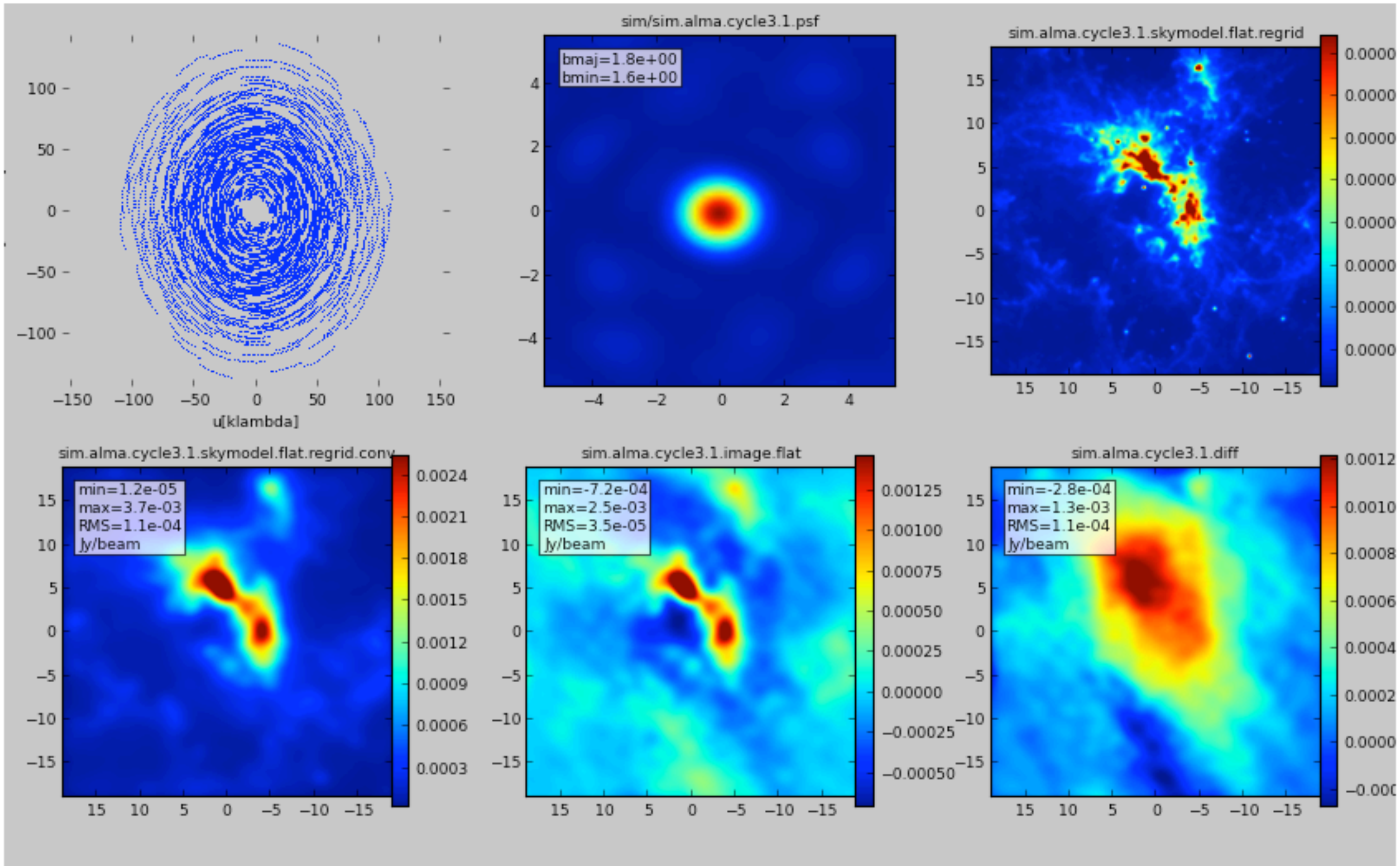
Image it with simanalyze

```
CASA <31>: inp
---------> inp()
#  simanalyze :: image and analyze measurement sets created with simobserve
project             =      'sim'        #  root prefix for output file names
image               =       True        #  (re)image $project.*.ms to $project.image
     vis            =  'default'        #  Measurement Set(s) to image
     modelimage     =         ''        #  lower resolution prior image to use in clean e.g. existing total power image
     imsize         =        252        #  output image size in pixels (x,y) or 0 to match model
     imdirection    =         ''        #  set output image direction, (otherwise center on the model)
     cell           =         ''        #  cell size with units e.g. "10arcsec" or "" to equal model
     interactive    =      False        #  interactive clean?  (make sure to set niter>0 also)
     niter          =          0        #  maximum number of iterations (0 for dirty image)
     threshold      =   '0.1mJy'        #  flux level (+units) to stop cleaning
     weighting      =  'natural'        #  weighting to apply to visibilities.  briggs will use robust=0.5
     mask           =         []        #  Cleanbox(es), mask image(s), region(s), or a level
     outertaper     =         []        #  uv-taper on outer baselines in uv-plane
     pbcor          =       True        #  correct the output of synthesis images for primary beam response?
     stokes         =        'I'        #  Stokes params to image
     featherimage   =         ''        #  image (e.g. total power) to feather with new image

analyze             =       True        #  (only first 6 selected outputs will be displayed)
     showuv         =       True        #  display uv coverage
     showpsf        =       True        #  display synthesized (dirty) beam (ignored in single dish simulation)
     showmodel      =       True        #  display sky model at original resolution
     showconvolved  =       True        #  display sky model convolved with output clean beam
     showclean      =       True        #  display the synthesized image
     showresidual   =      False        #  display the clean residual image (ignored in single dish simulation)
     showdifference =       True        #  display difference between output cleaned image and input model sky image convolved with output clean beam
     showfidelity   =      False        #  display fidelity (see help)

graphics            =     'both'        #  display graphics at each stage to [screen|file|both|none]
verbose             =      False
overwrite           =       True        #  overwrite files starting with $project
dryrun              =      False        #  only print information [experimental; only for interfermetric data]
logfile             =         ''
```

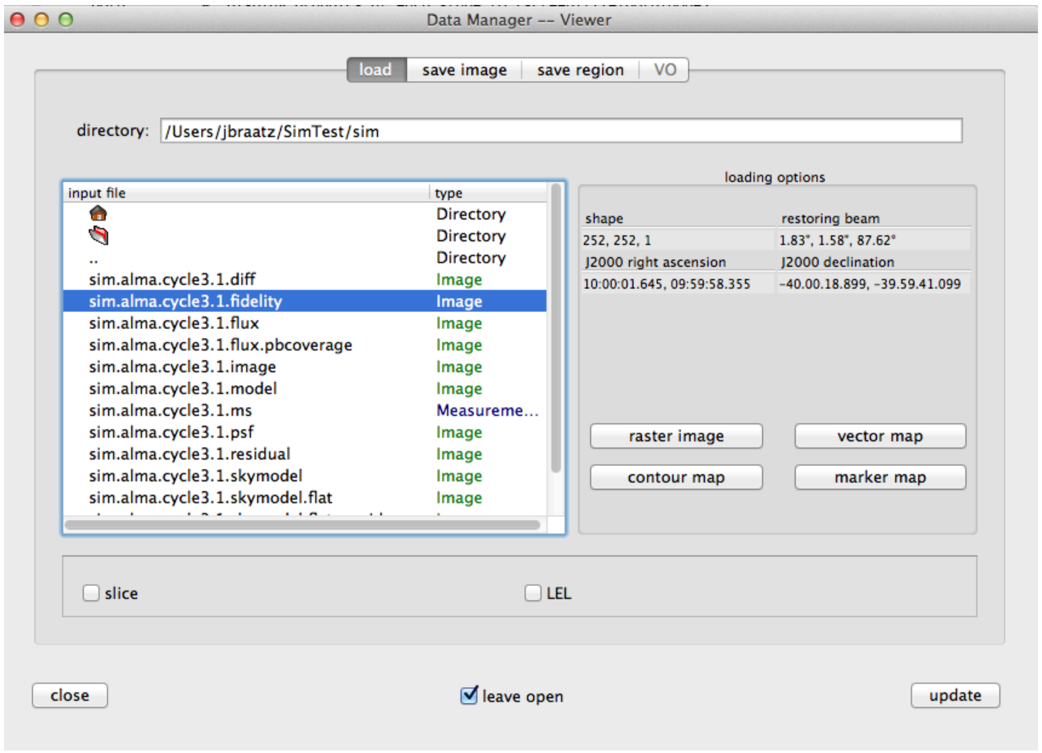
Image it with simanalyze



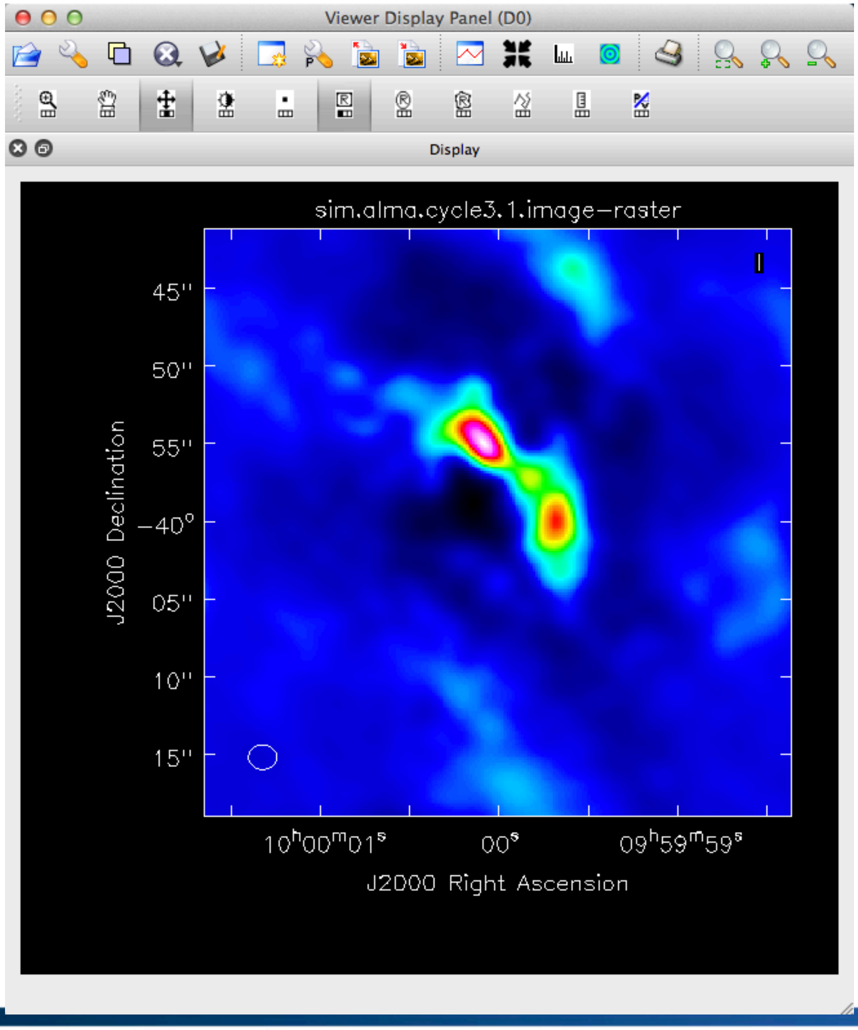
Navigate image products with the viewer

In CASA: viewer

Then navigate the to "sim" directory



Navigate image products with the viewer



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Simanalyze output images

- Most important output images are:
  - $project.skymodel – input image/cube
  - $project.skymodel.flat.regrid.conv – input convolved with synthesized beam
  - $project.image.flat – moment 0 of simulated cube/plane
  - $project.psf – synthesized beam (point spread function)
  - $project.image – output simulated image/cube
  - $project.residual – residuals after cleaning

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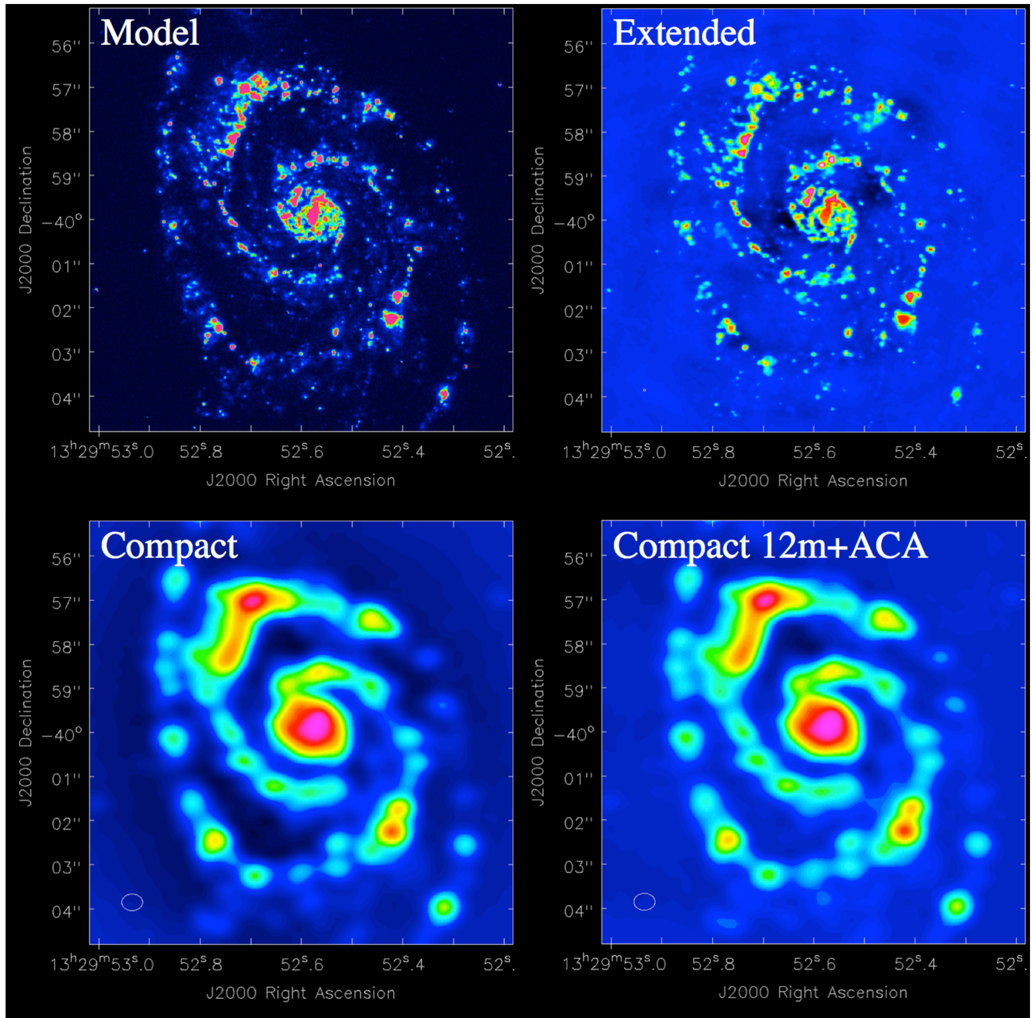
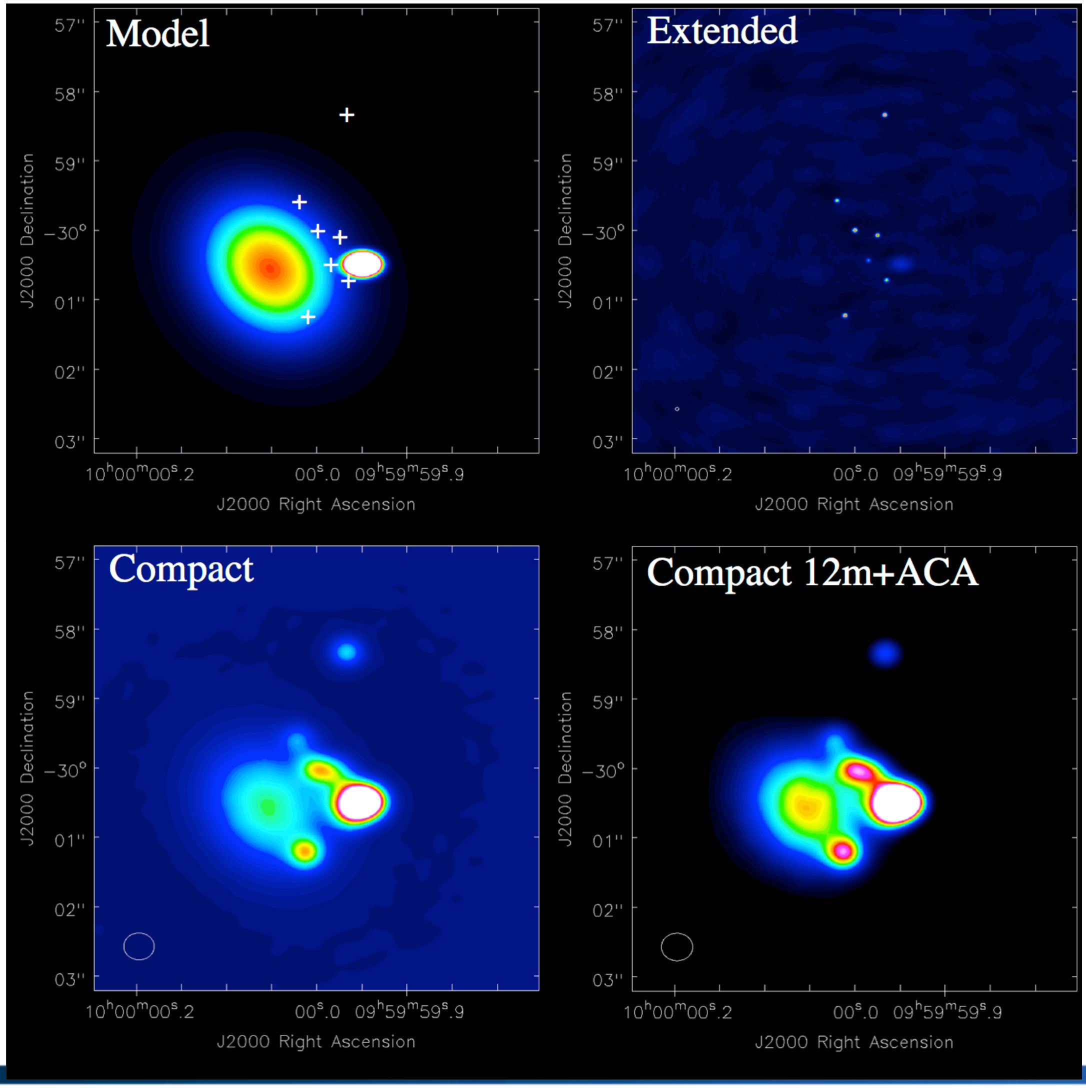
Simulating CO in an M51-like Spiral



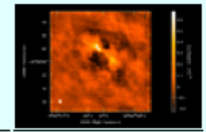
Simulation with a Component List



Your Turn!

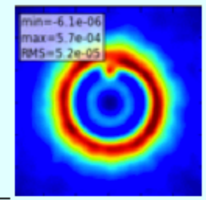
Simulation Guide for New Users (CASA 4.3)

A fully annotated tutorial that uses a Spitzer SAGE 8 micron continuum image of 30 Doradus and scales it to greater distance. A good place for new users to start.



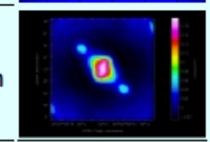
Protoplanetary Disk Simulation (CASA 4.3)

A sky model with a lightly annotated script that simulates a protoplanetary disk. Uses a theoretical model of dust continuum from Sebastian Wolff, scaled to the distance of a nearby star. This is another fairly generic simulation - if you're short on time, you probably don't need to go through this one and the New Users guide, but it can be useful to go through multiple examples.



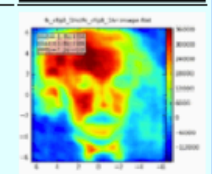
Simulation Guide Component Lists (CASA 4.3)

Tutorial for simulating data based on multiple sources (using both a FITS image and a component list). If you are interested in simulating from a list of simple sources (point, Gaussian, disk), rather than or in addition to a sky model image, then read the considerations here.



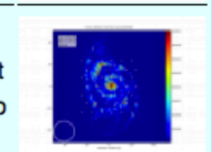
Einstein-Face (CASA 4.3)

A sky model and lightly annotated script that simulates the face of Einstein as seen by ALMA. This simulation is particularly useful for those who wish to better understand spatial filtering by an interferometer, but doesn't demonstrate new capabilities of the simulation tasks beyond those described above.



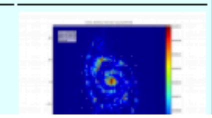
ACA Simulation (CASA 4.3)

A tutorial for simulating ALMA observations that use multiple configurations or use the 12-meter array in combination with the ALMA Compact Array. This tutorial demonstrates combining data from each ALMA component "by hand". This guide is of particular interest to those wishing to explore using the 12-m array in combination with the ACA, and those interested in combining data from multiple 12-m array configurations.



Simalma (CASA 4.3)

This tutorial demonstrates how to use **simalma**, a task that simplifies simulations that include the main 12-m array plus the ACA. Like the



NRAO

First simobserve

default simobserve
skymodel = '30dor.fits'
incell = '0.15arcsec'
indirection = 'J2000 10h00m00 -40d00m00'
incenter = '230GHz'
inwidth = '2GHz'
inbright = '0.06mJy/pixel'
integration = '600s'
antennalist = 'alma.cycle3.1.cfg'
thermalnoise = ''
totaltime = '6000s'
simobserve

Then simanalyze

default simanalyze
imsize = 252
analyze = True
showconvolved = True
showfidelity = False
simanalyze

The End