Simulating ALMA observations

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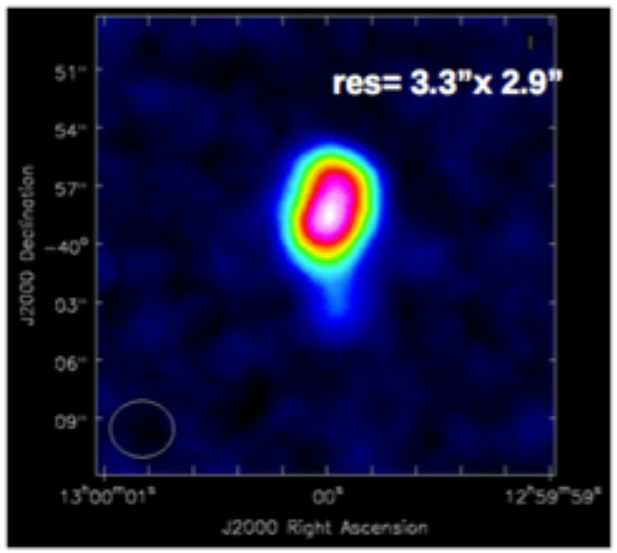
IT-ARC

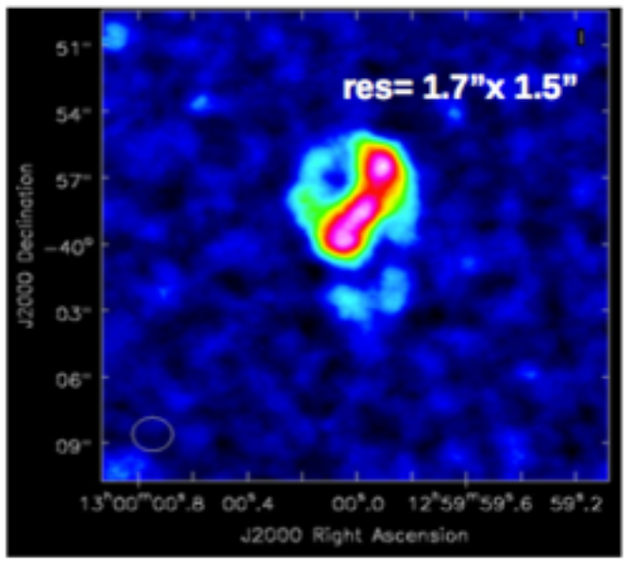
Outline

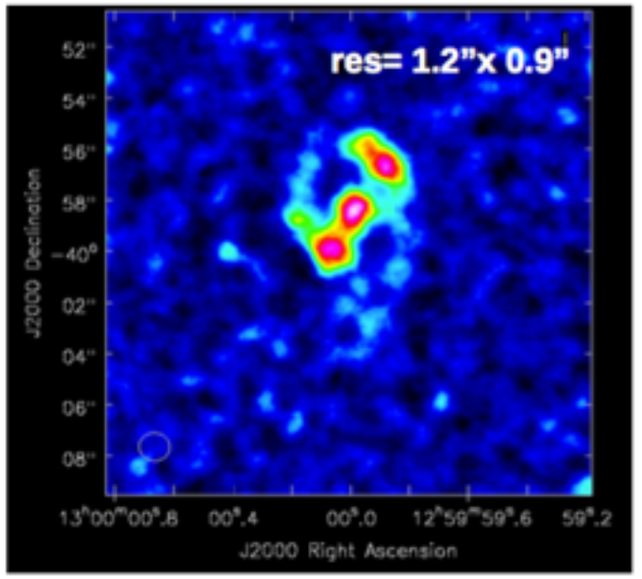
- Why do we need to simulate ALMA observations?
  - SIMALMA
  - OST

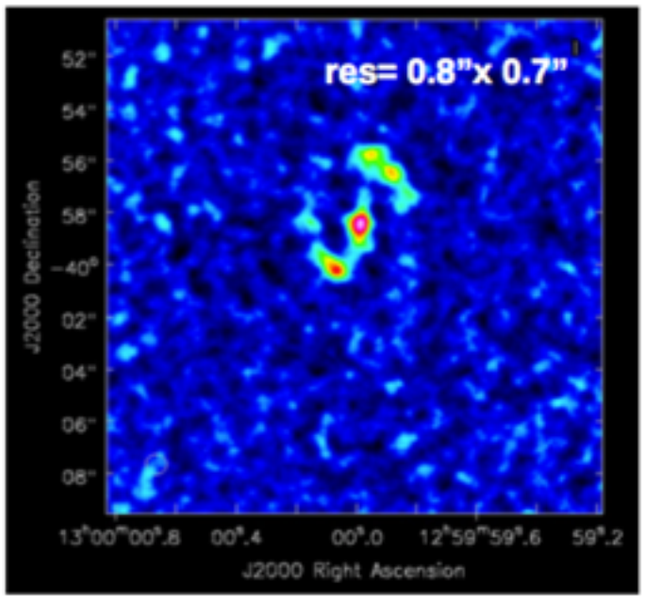
AIM: make PIs familiar with simulation to strengthen their proposal request, if needed

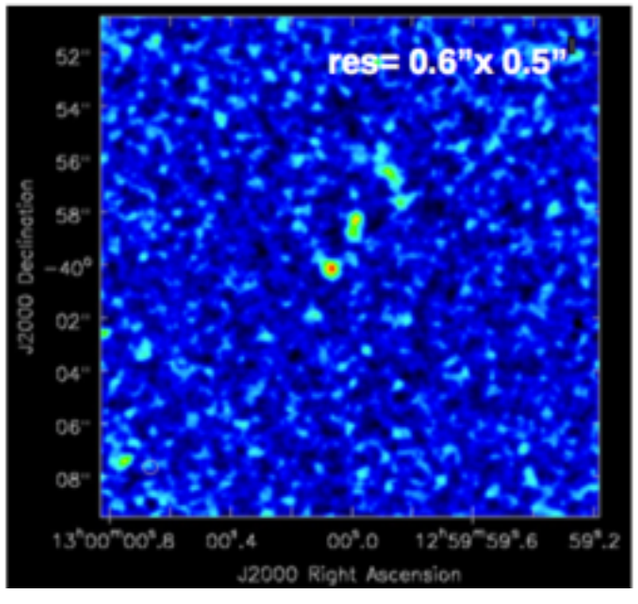
Same source, different ALMA configurations

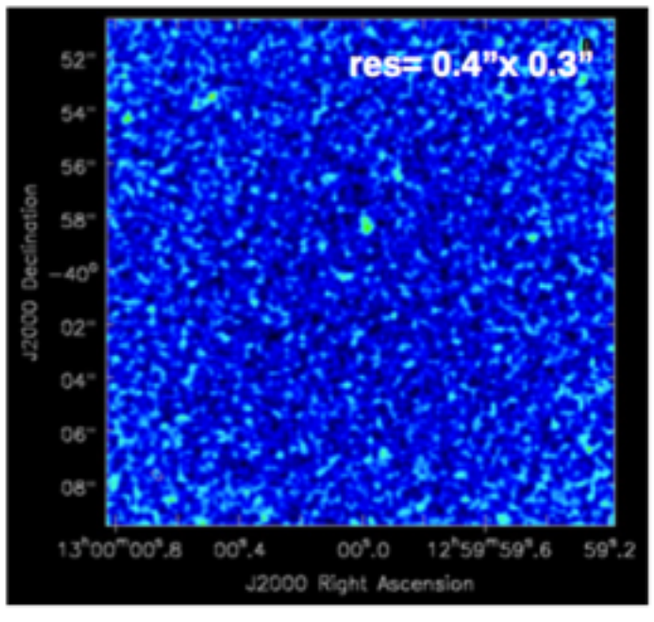




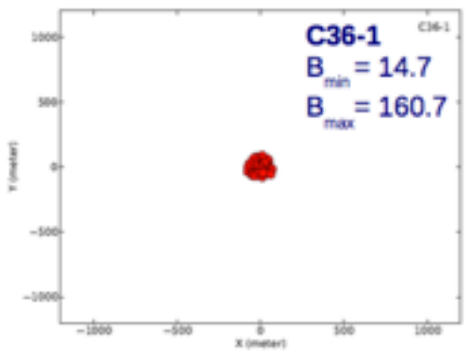


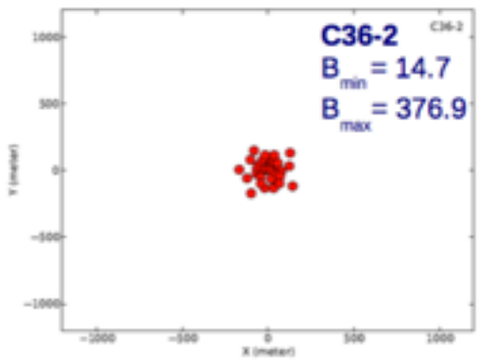


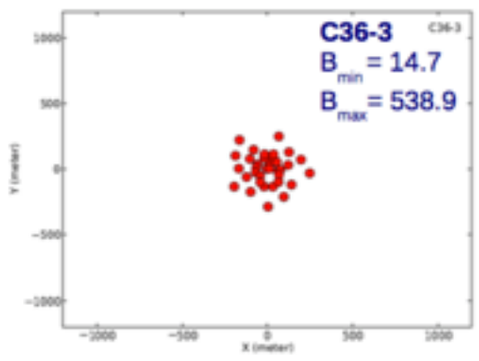


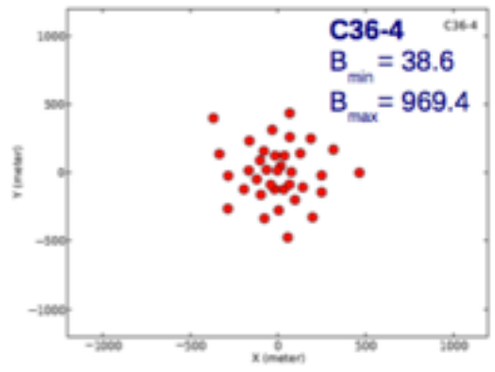


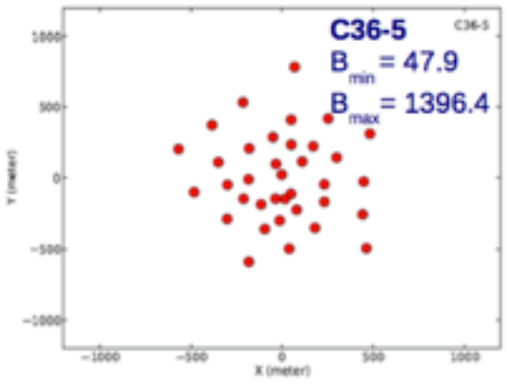
Same source, different ALMA configurations

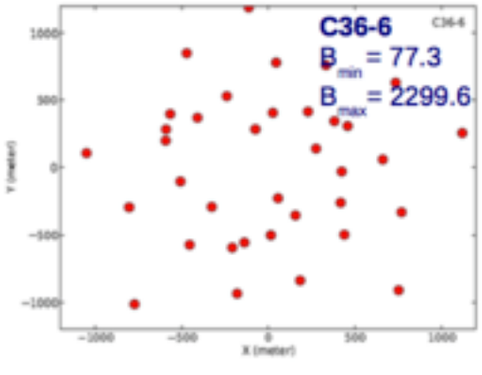


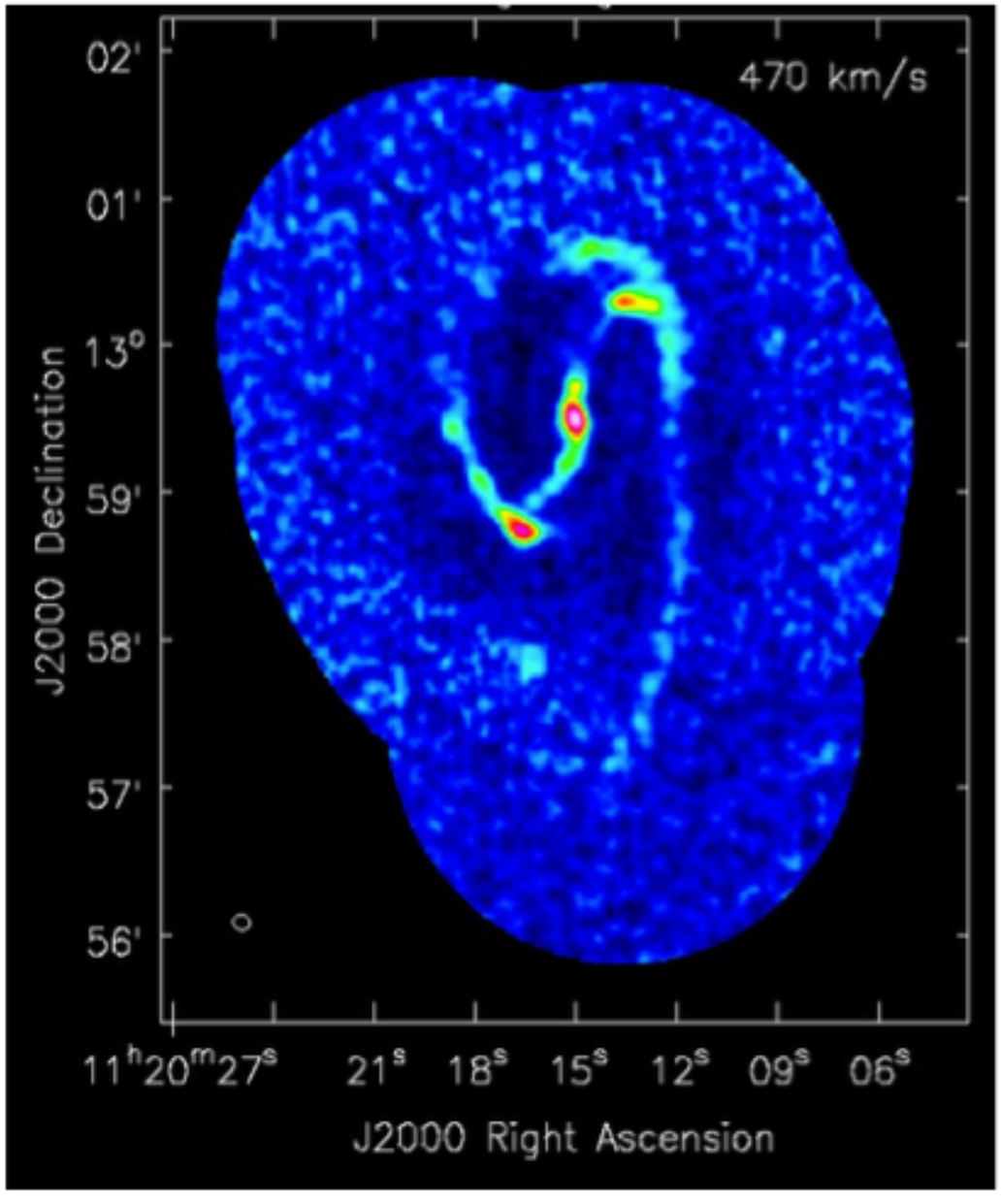












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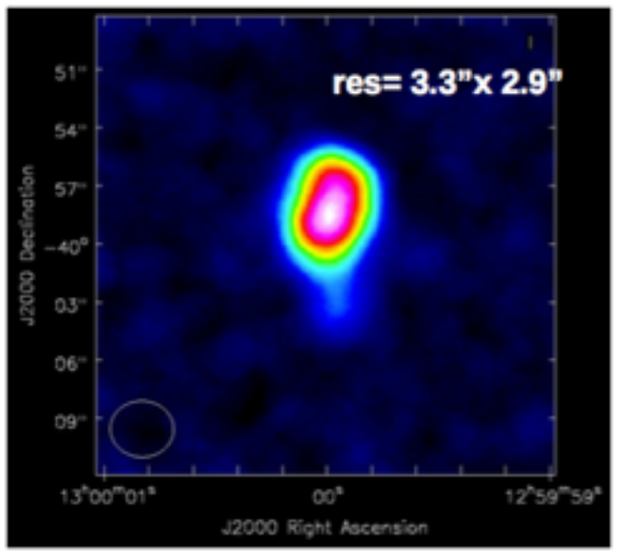
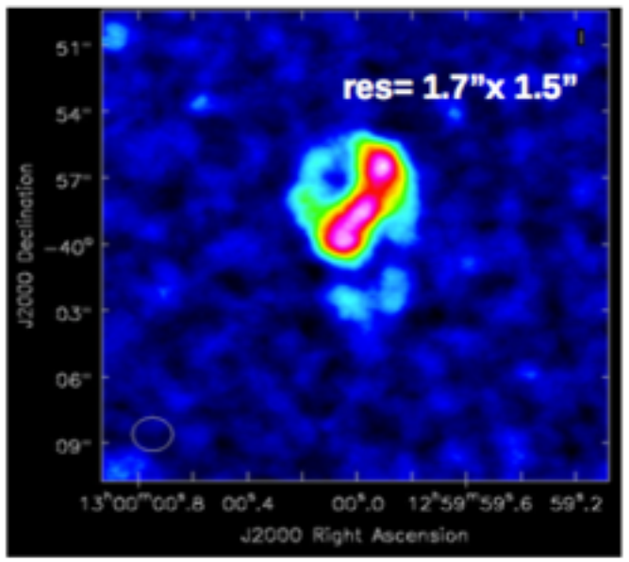
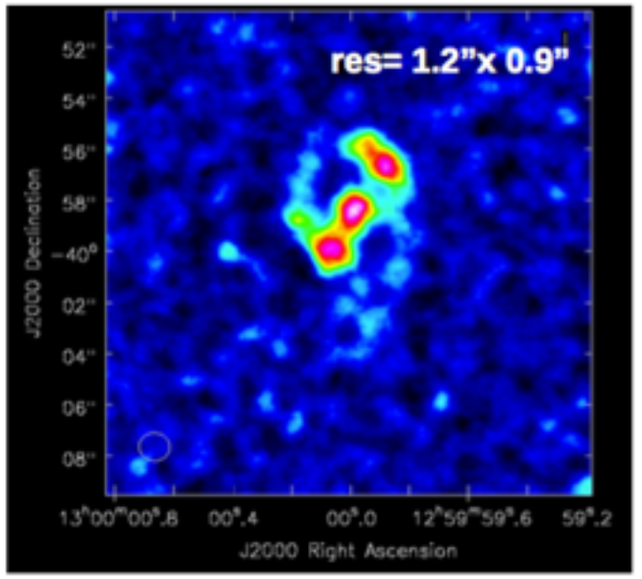
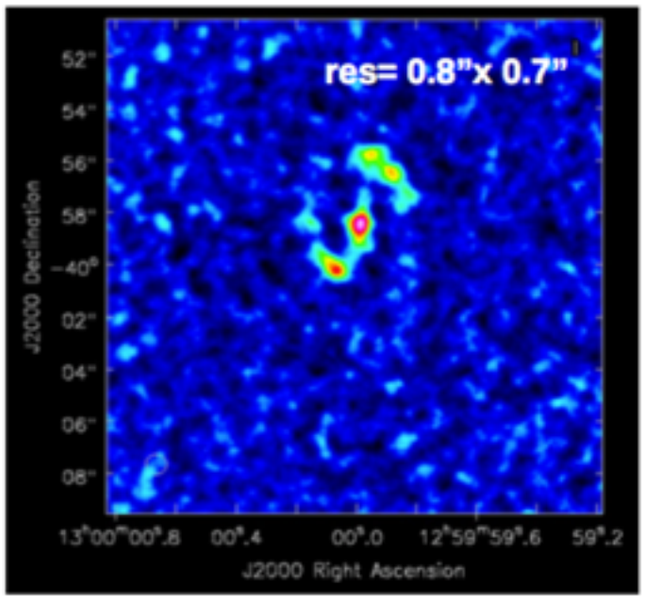
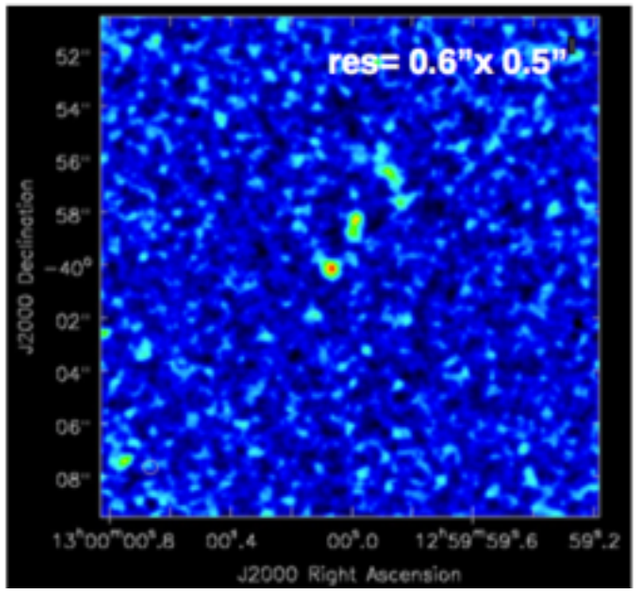
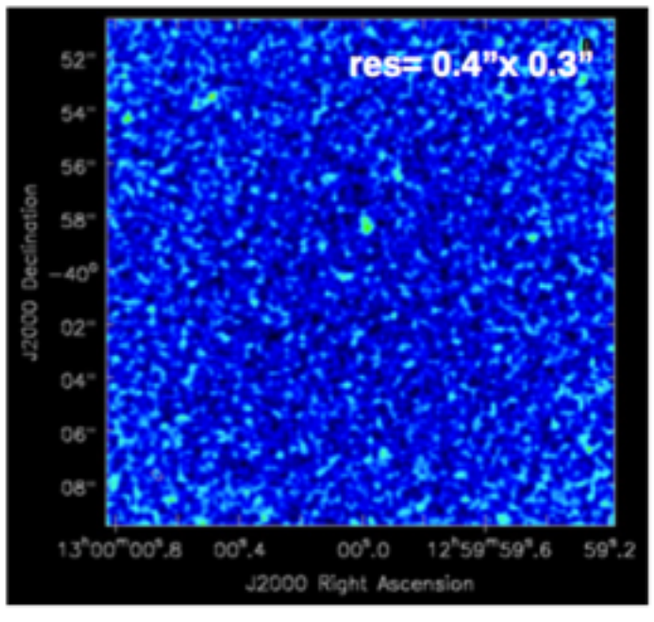








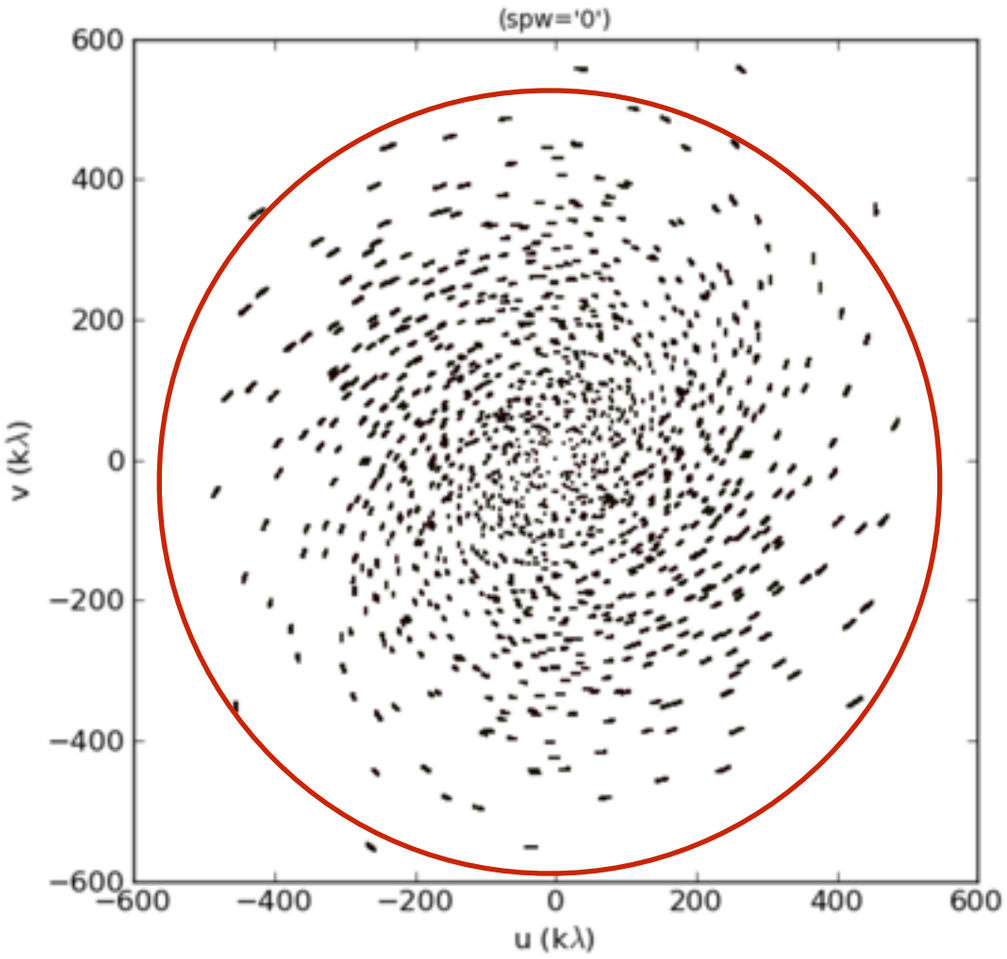




why? Interferometers filter source information…

- Interferometer “synthesize” a large single antenna with a PSF depending on λ/D_{max}

- but not continuous, not uniform —>gaps to minimize
  - increasing observation time
  - increasing number of antennas
  - different configuration
  - different λ

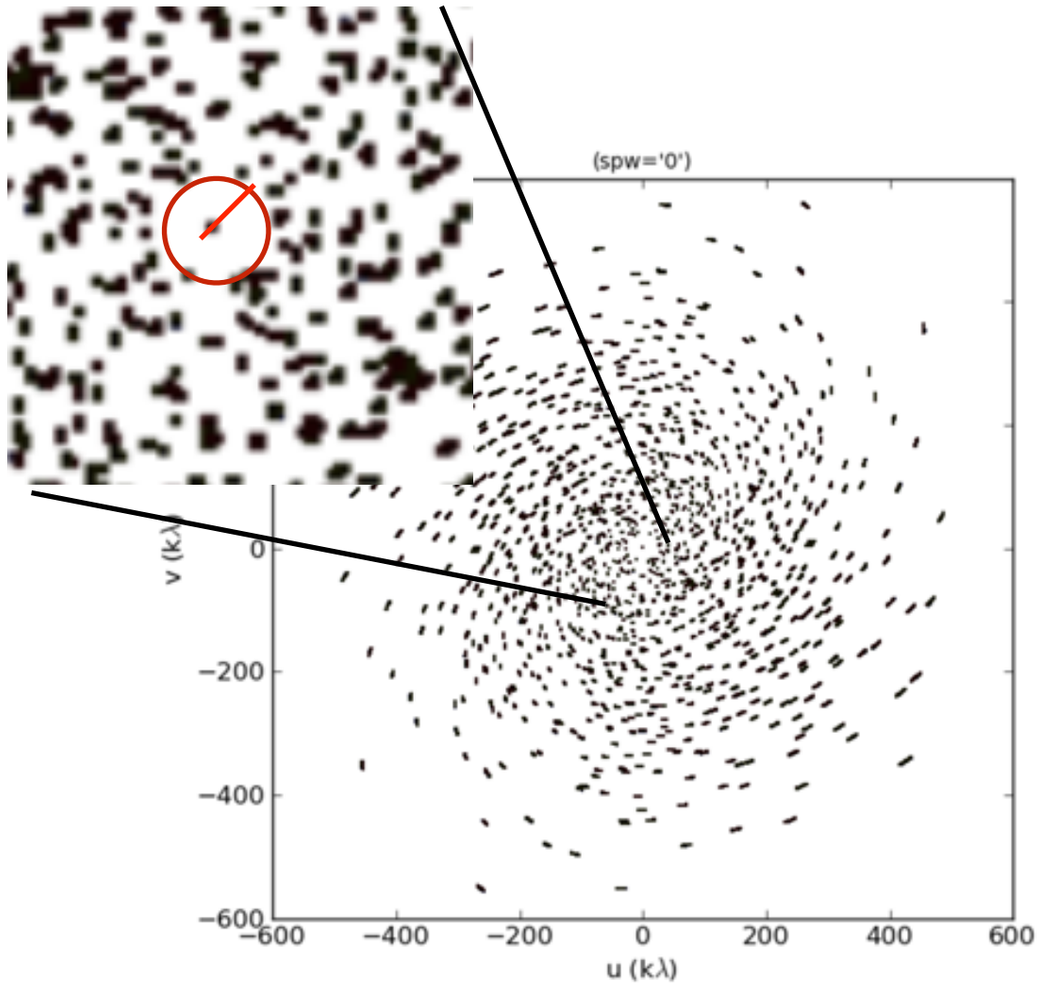


why? Interferometers filter source information…

- Interferometer “synthesize” a large single antenna with a PSF depending on λ/D_{max}

- … but there will be always a hole responsible of filtering large scale structures… MRS~λ/D_{min}

- if you deal with extended sources, may need for ACA/TP observation (OT suggest this! see Kazi’s talk)



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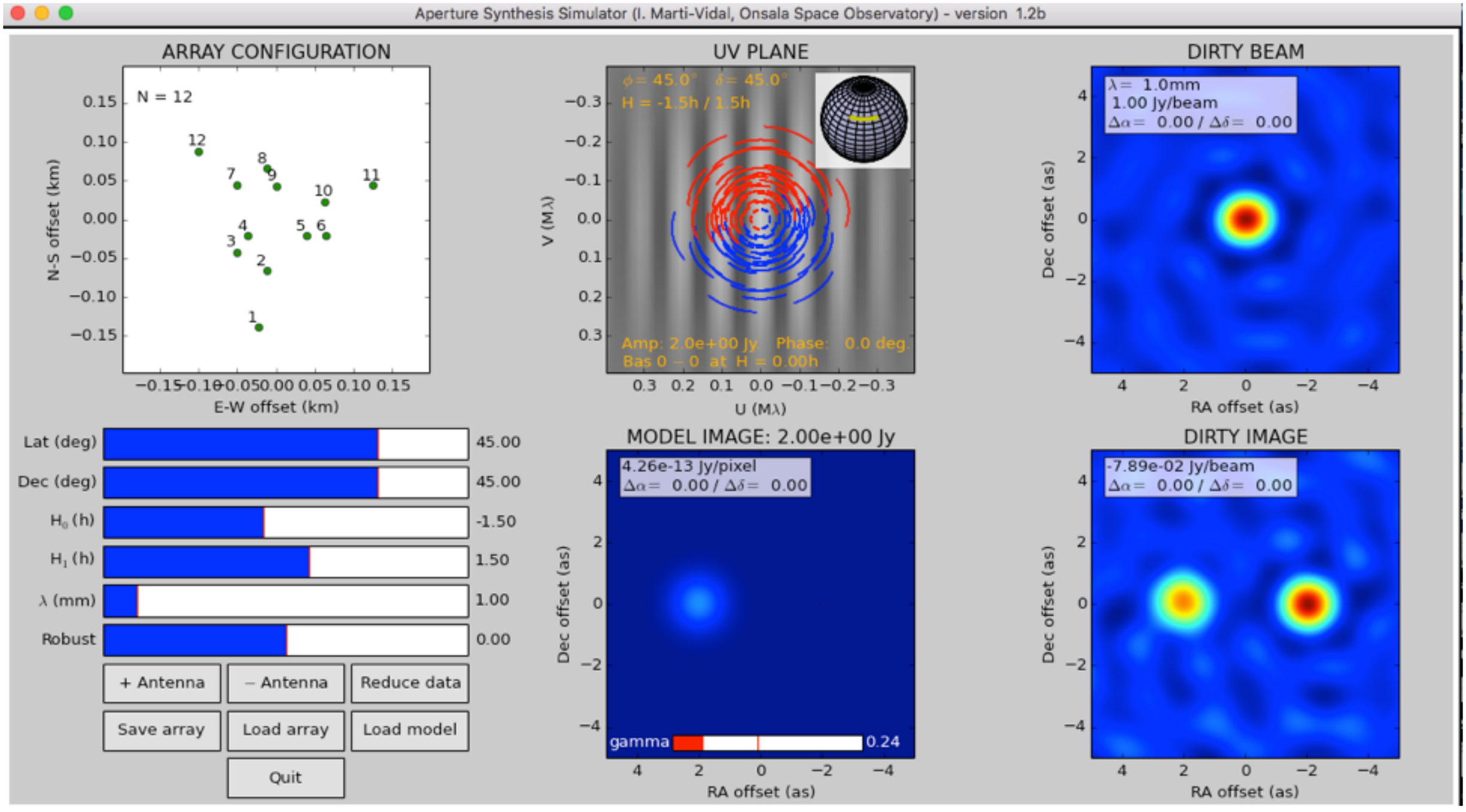
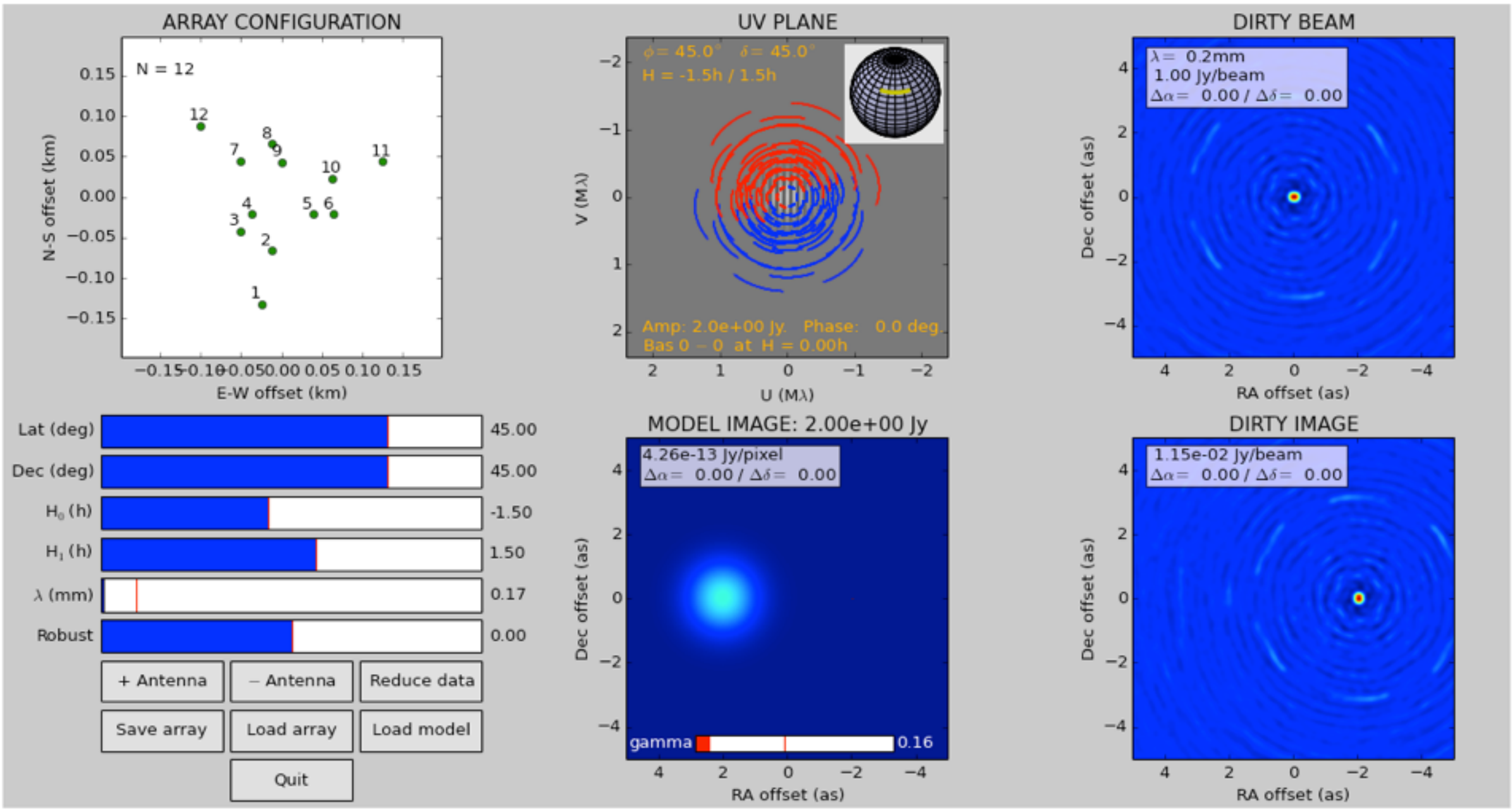


Marti Vidal Simulator

https://launchpad.net/apsynsim

why? Interferometers filter source information…



Marti Vidal Simulator

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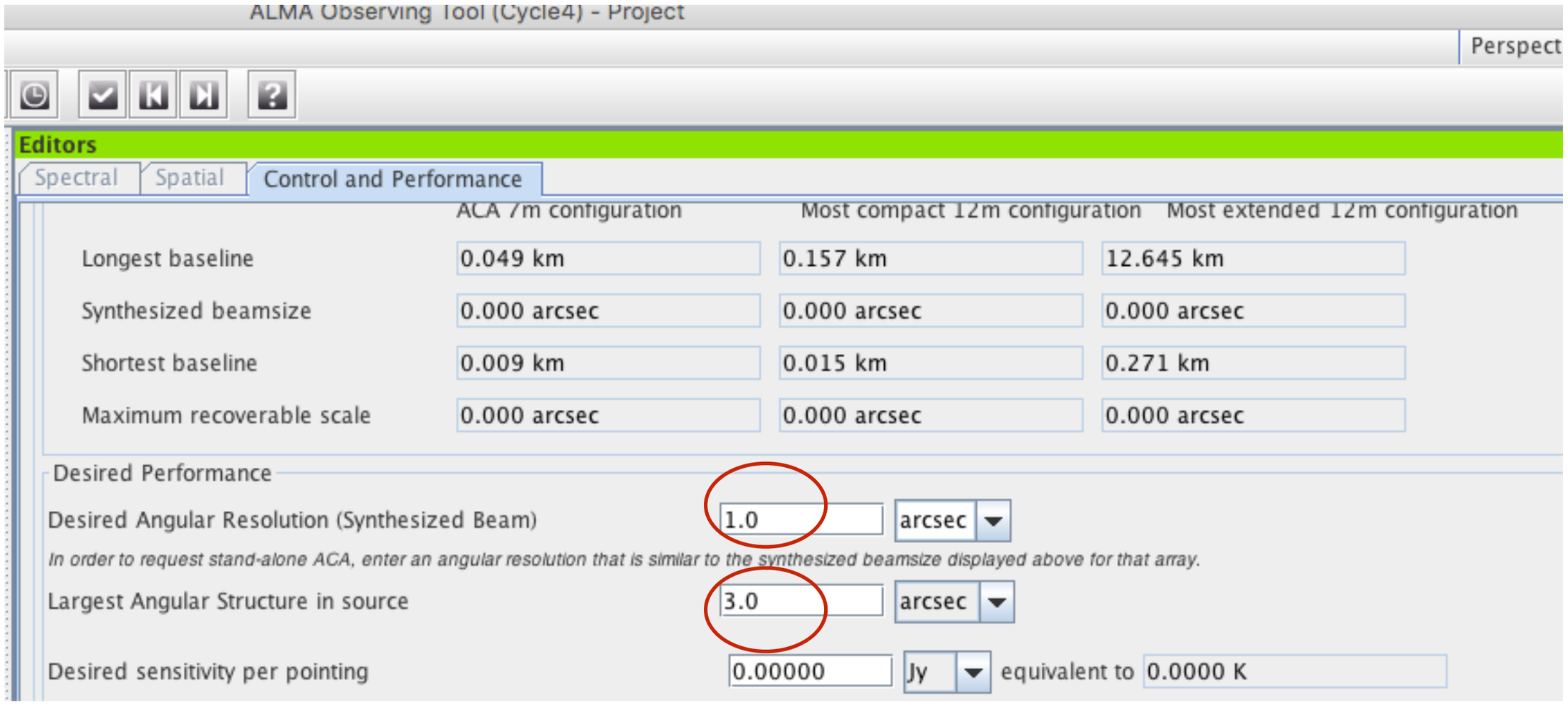
Simulation help to understand the way ALMA "sees" our source of interest!

- Simulations of ALMA observations are **not required** for a proposal, but they can strengthen it in some cases.



Array combination (https://almascience.eso.org/documents-and-tools/cycle4/alma-technical-handbook)

Input:
desired resolution and LAS

Output:
configuration,
observing time constraints

@100GHz

… useful for simulations

θ_{res} (arcsec)	θ_{LAS} (arcsec)	Array combination	Time ratios	Total Time
0.066	< 0.78	C40-9	1	$1.0 \times \Delta_{extended}$
0.066	0.78-3.1	C40-9 + C40-6	1 : 0.3	$1.3 \times \Delta_{extended}$
0.066	> 3.1	-	-	-
0.12	< 1.3	C40-8	1	$1.0 \times \Delta_{extended}$
0.12	1.3-6.0	C40-8 + C40-5	1 : 0.3	$1.3 \times \Delta_{extended}$
0.12	> 6.0	-	-	-
0.21	< 1.8	C40-7	1	$1.0 \times \Delta_{extended}$
0.21	1.8-8.9	C40-7 + C40-4	1 : 0.3	$1.3 \times \Delta_{extended}$
0.21	> 8.9	-	-	-
0.35	< 3.1	C40-6	1	$1.0 \times \Delta_{extended}$
0.35	3.1-13.7	C40-6 + C40-3	1 : 0.3	$1.3 \times \Delta_{extended}$
0.35	13.7-66.7	C40-6 + C40-3 + 7-m	1 : 0.3 : 0.4	$1.7 \times \Delta_{extended}$
0.35	> 66.7	C40-6 + C40-3 + 7-m + TP	1 : 0.3 : 0.4 : 0.68	$1.98 \times \Delta_{extended}$
0.54	< 6.0	C40-5	1	$1.0 \times \Delta_{extended}$
0.54	6.0-22.1	C40-5 + C40-2	1 : 0.3	$1.3 \times \Delta_{extended}$
0.54	22.1-66.7	C40-5 + C40-2 + 7-m	1 : 0.3 : 1.4	$2.7 \times \Delta_{extended}$
0.54	> 66.7	C40-5 + C40-2 + 7-m + TP	1 : 0.3 : 1.4 : 2.38	$3.68 \times \Delta_{extended}$
0.93	< 8.9	C40-4	1	$1.0 \times \Delta_{extended}$
0.93	8.9-29.0	C40-4 + C40-1	1 : 0.3	$1.3 \times \Delta_{extended}$
0.93	29.0-66.7	C40-4 + C40-1 + 7-m	1 : 0.3 : 3	$4.3 \times \Delta_{extended}$
0.93	> 66.7	C40-4 + C40-1 + 7-m + TP	1 : 0.3 : 3 : 5.1	$6.4 \times \Delta_{extended}$
1.5	< 13.7	C40-3	1	$1.0 \times \Delta_{extended}$
1.5	13.7-66.7	C40-3 + 7-m	1 : 1.4	$2.4 \times \Delta_{extended}$
1.5	> 66.7	C40-3 + 7-m + TP	1 : 1.4 : 2.38	$3.38 \times \Delta_{extended}$
2.4	< 22.1	C40-2	1	$1.0 \times \Delta_{extended}$
2.4	22.1-66.7	C40-2 + 7-m	1 : 5	$6.0 \times \Delta_{extended}$
2.4	> 66.7	C40-2 + 7-m + TP	1 : 5 : 8.5	$9.5 \times \Delta_{extended}$
3.7	< 29.0	C40-1	1	$1.0 \times \Delta_{extended}$
3.7	29.0-66.7	C40-1 + 7-m	1 : 5	$6.0 \times \Delta_{extended}$
3.7	> 66.7	C40-1 + 7-m + TP	1 : 5 : 8.5	$9.5 \times \Delta_{extended}$
12.5	< 66.7	7-m	1	$1.0 \times \Delta_{extended}$
12.5	> 66.7	7-m + TP	1 : 1.7	$1.7 \times \Delta_{extended}$

Simulation help to understand the way ALMA "sees" our source of interest!

- Simulations of ALMA observations are **not required** for a proposal, but they can strengthen it in some cases.

- They can demonstrate the need for specific configurations, or combinations of configurations, to resolve certain structures or meet specific goals.

- If they are discussed to justify any technical aspects of the observation their results should be included in the science case and in the technical justification.

Two Softwares for simulating ALMA observations

- **SIMALMA** (CASA software): Task to produce ALMA data from an input sky model (theoretical model/previous observations)

- **Observation Support Took (OST)**: a web tool hosted by UK ARC with a website acting a simple GUI to set parameters and run simulation

SIMALMA (CASA)

- Allow you to simulate observations starting from images (***with higher resolution respect to ALMA obs***).
- You can scale the spatial axes and the flux of your model to shift the data to what would be observed for a similar target at a different distance.
- You can combine observations taken with different configuration and with the ACA / TP

SIMALMA (CASA)

dryrun = T prints an informational report including the required calls to other CASA tasks
You can check it before actually running the simulation

simalma requires a **CASA or fits image**. You can set the appropriate input parameters, scaled if needed. This simply changes the header values, does not perform any regridding.

```
-----------> inp(simalma)
#  simalma :: Simulation task for ALMA
project             = 'cfg36-6_1hr'     #  root prefix for output file names
dryrun              =     False         #  dryrun=True will only produce the
                                        #   informative report, not run
                                        #   simobserve/analyze
skymodel            = 'N3627-song'      #  model image to observe
     inbright       = '0.000041Jy/pixel' #  scale surface brightness of
                                        #   brightest pixel e.g. "1.2Jy/pixel"
     indirection    = 'J2000 13h00m00 -40d00m00' #  set new direction e.g.
                                        #   "J2000 19h00m00 -40d00m00"
     incell         = '0.039376arcsec'  #  set new cell/pixel size e.g.
                                        #   "0.1arcsec"
     incenter       = '112102678873.933456Hz' #  set new frequency of center
                                        #   channel e.g. "89GHz" (required even
                                        #   for 2D model)
     inwidth        = '3724187.351539Hz' #  set new channel width e.g. "10MHz"
                                        #   (required even for 2D model)
```

SIMALMA (CASA)

Integration time default = 10 s. Simulations are faster using larger values
antennalist : antenna position files available in CASA, or you can also use the string
antennalist='ALMA;0.5arcsec' and CASA will use the appropriate full ALMA configuration

```
complist             =          ''          #  componentlist to observe
setpointings         =        True
     integration     =     '100s'          #  integration (sampling) time
     direction       =          ''          #  "J2000 19h00m00 -40d00m00" or "" to
                                            #   center on model
     mapsize         = '18.900470arcsec'    #  angular size of map or "" to cover
                                            #   model

antennalist          = ['alma.cycle3.6.cfg'] #  antenna position files of ALMA
                                            #   12m and 7m arrays
hourangle            =  'transit'           #  hour angle of observation center e.g.
                                            #   -3:00:00, or "transit"
totaltime            =    '3600s'           #  total time of observation; vector
                                            #   corresponding to antennalist
tpnant               =         0            #  Number of total power antennas to use
                                            #   (0-4)
```

user can specify a list of ALMA cfg

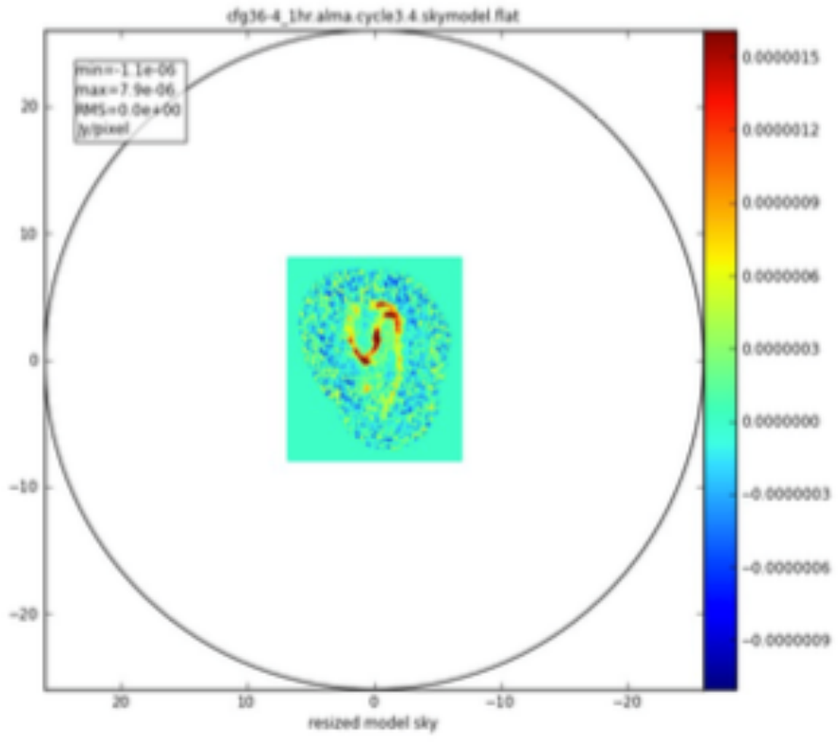
SIMALMA (CASA)

imsize in pixels = dimension of the image in spatial pixels
cell = cell size dimension of a pixel in arcsec
threshold = flux level to stop cleaning (2 -3 times the expected rms)
niter = number of cleaning iterations (0 for dirty image)

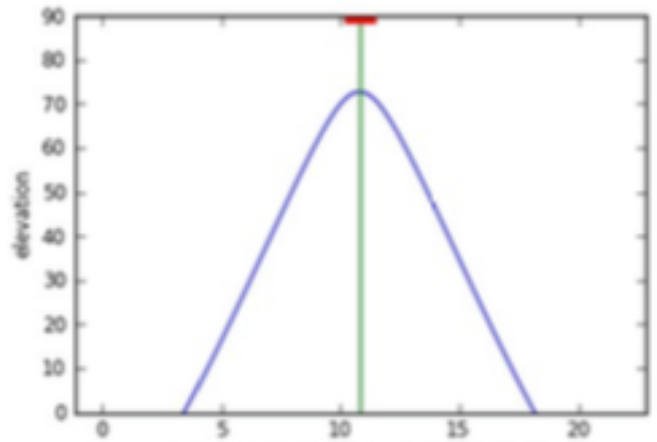
```
image                =         True       #  image simulated data
     imsize          = [256, 256]         #  output image size in pixels (x,y) or
                                          #   0 to match model
     imdirection     =         ''         #  set output image direction,
                                          #   (otherwise center on the model)
     cell            = '0.148000arcsec'   #  cell size with units or "" to equal
                                          #   model
     niter           =          0         #  maximum number of iterations (0 for
                                          #   dirty image)
     threshold       =   '1.0mJy'         #  flux level (+units) to stop cleaning

graphics             =     'both'         #  display graphics at each stage to
                                          #   [screen|file|both|none]
verbose              =       True
overwrite            =       True         #  overwrite files starting with
                                          #   $project
```

SIMALMA (CASA)- outputs

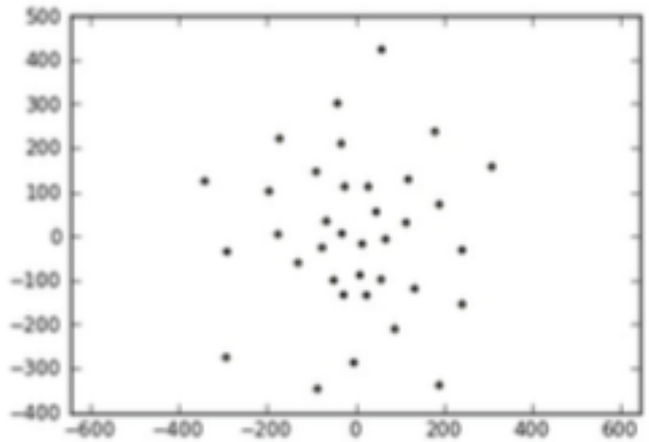
Model Image

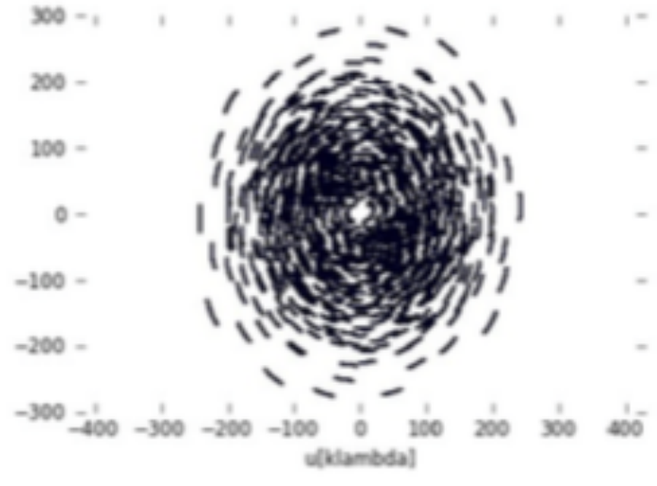


Elevation

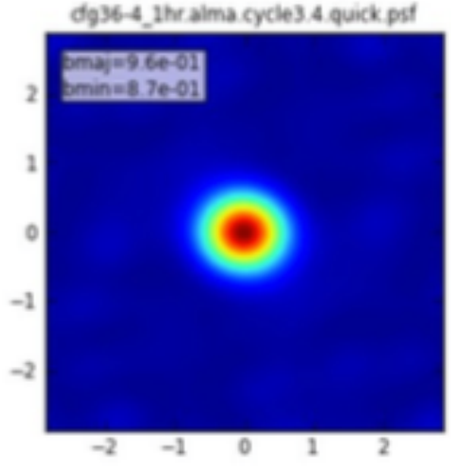


Antenna Conf.



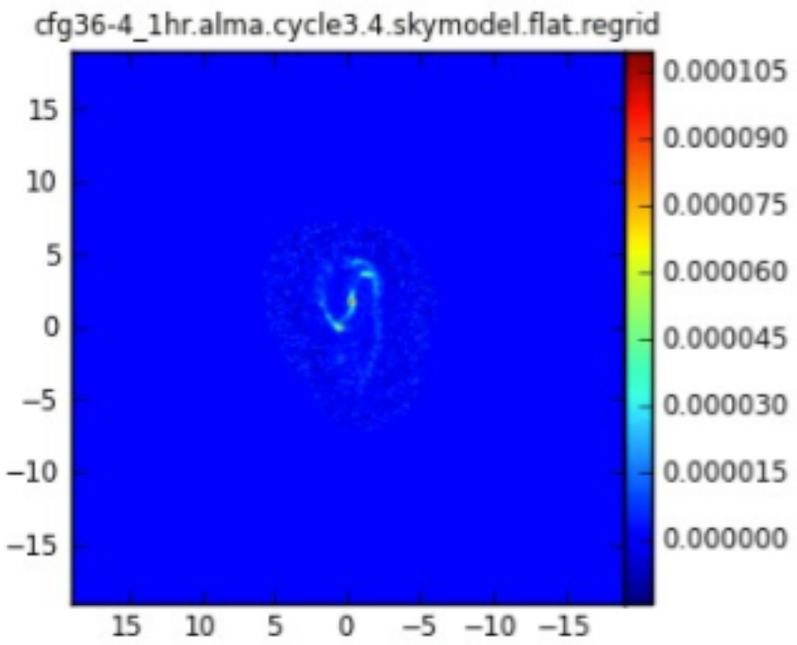


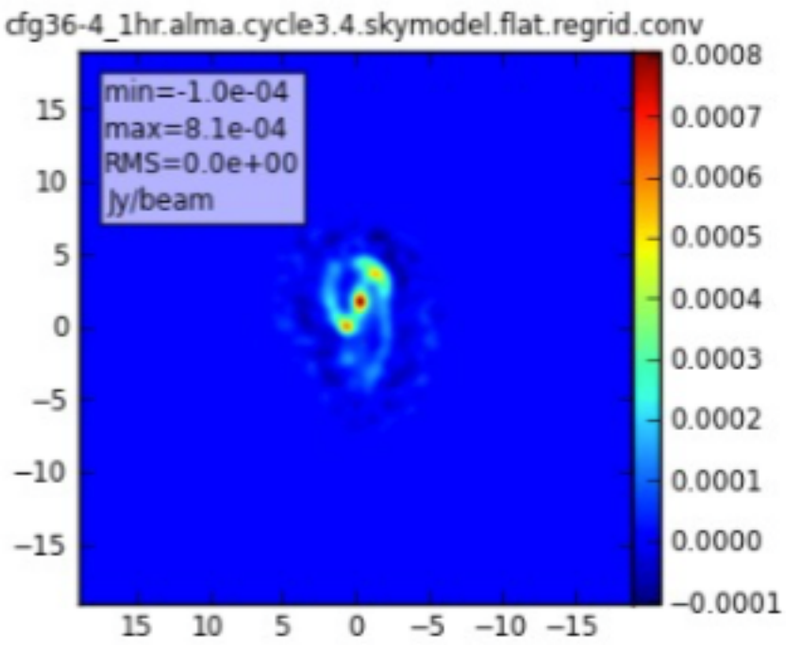
UV plane

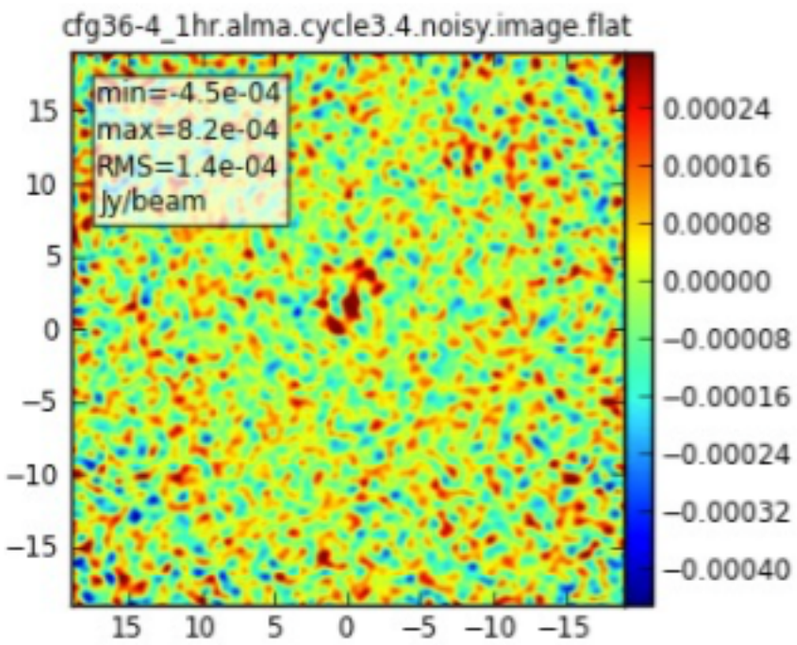


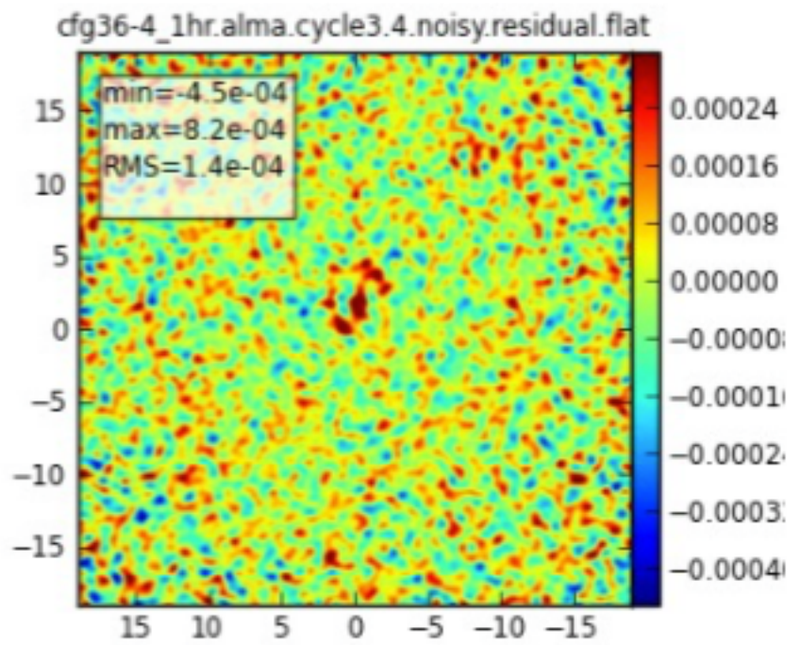
PSF

SIMALMA (CASA)- outputs









ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

ALMA Observation Support Tool

Version 4.0

OST NEWS HELP QUEUE LIBRARY ALMA HELPDESK

rray Setup:

Instrument: ALMA — Select the desired ALMA antenna configuration.

ky Setup:

Source model: OST Library: Central point source — Choose a library source model or supply your own.

Upload: Scegli file Nessun file selezionato — You may upload your own model here (max 10MB).

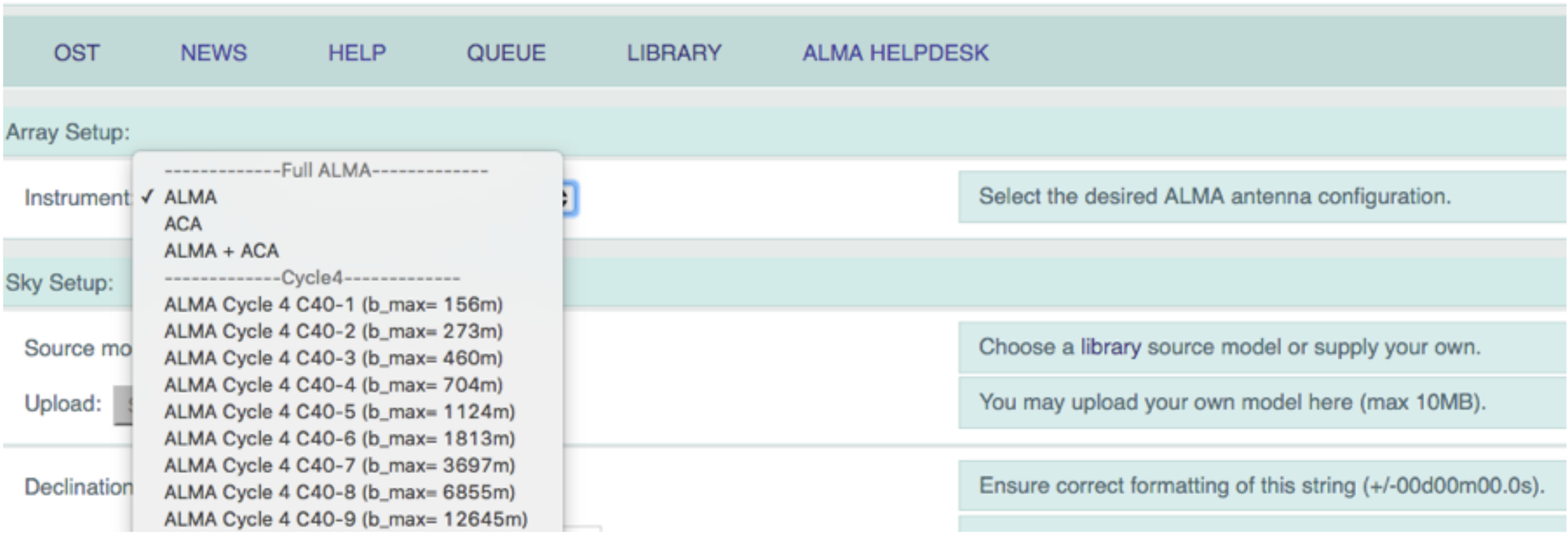
Declination: -35d00m00.0s — Ensure correct formatting of this string (+/-00d00m00.0s).

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.

bservation Setup:

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Array configuration

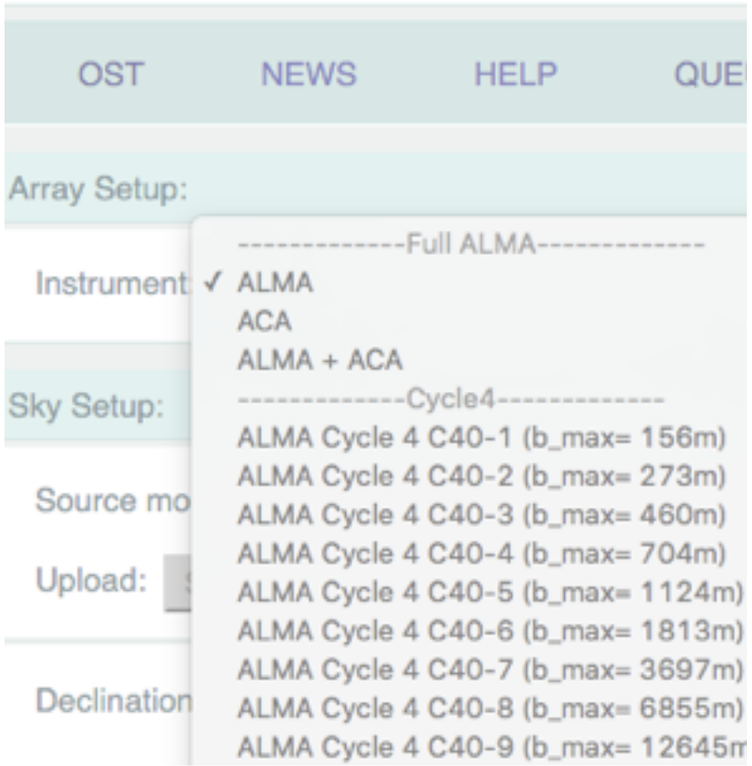


includes ALMA Cycle 4 (*3,2…*) configuration.

ALMA + ACA separately+CASA script for combination

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Array configuration



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0.066	> 3.1	-	-	-
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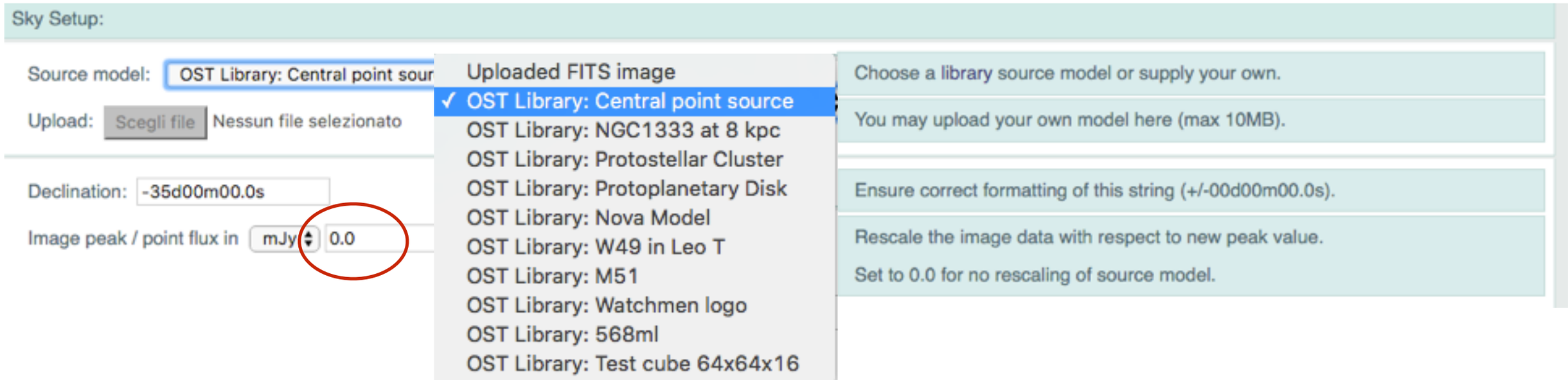
0.12	1.3-6.0	C40-8 + C40-5	1 : 0.3	$1.3 \times \Delta_{extended}$
0.12	> 6.0	-	-	-
0.21	< 1.8	C40-7	1	$1.0 \times \Delta_{extended}$
0.21	1.8-8.9	C40-7 + C40-4	1 : 0.3	$1.3 \times \Delta_{extended}$
0.21	> 8.9	-	-	-
0.35	< 3.1	C40-6	1	$1.0 \times \Delta_{extended}$
0.35	3.1-13.7	C40-6 + C40-3	1 : 0.3	$1.3 \times \Delta_{extended}$
0.35	13.7-66.7	C40-6 + C40-3 + 7-m	1 : 0.3 : 0.4	$1.7 \times \Delta_{extended}$
0.35	> 66.7	C40-6 + C40-3 + 7-m + TP	1 : 0.3 : 0.4 : 0.68	$1.98 \times \Delta_{extended}$
0.54	< 6.0	C40-5	1	$1.0 \times \Delta_{extended}$
0.54	6.0-22.1	C40-5 + C40-2	1 : 0.3	$1.3 \times \Delta_{extended}$
0.54	22.1-66.7	C40-5 + C40-2 + 7-m	1 : 0.3 : 1.4	$2.7 \times \Delta_{extended}$
0.54	> 66.7	C40-5 + C40-2 + 7-m + TP	1 : 0.3 : 1.4 : 2.38	$3.68 \times \Delta_{extended}$
0.93	< 8.9	C40-4	1	$1.0 \times \Delta_{extended}$
0.93	8.9-29.0	C40-4 + C40-1	1 : 0.3	$1.3 \times \Delta_{extended}$
0.93	29.0-66.7	C40-4 + C40-1 + 7-m	1 : 0.3 : 3	$4.3 \times \Delta_{extended}$
0.93	> 66.7	C40-4 + C40-1 + 7-m + TP	1 : 0.3 : 3 : 5.1	$6.4 \times \Delta_{extended}$
1.5	< 13.7	C40-3	1	$1.0 \times \Delta_{extended}$
1.5	13.7-66.7	C40-3 + 7-m	1 : 1.4	$2.4 \times \Delta_{extended}$
1.5	> 66.7	C40-3 + 7-m + TP	1 : 1.4 : 2.38	$3.38 \times \Delta_{extended}$
2.4	< 22.1	C40-2	1	$1.0 \times \Delta_{extended}$
2.4	22.1-66.7	C40-2 + 7-m	1 : 5	$6.0 \times \Delta_{extended}$
2.4	> 66.7	C40-2 + 7-m + TP	1 : 5 : 8.5	$9.5 \times \Delta_{extended}$
3.7	< 29.0	C40-1	1	$1.0 \times \Delta_{extended}$
3.7	29.0-66.7	C40-1 + 7-m	1 : 5	$6.0 \times \Delta_{extended}$
3.7	> 66.7	C40-1 + 7-m + TP	1 : 5 : 8.5	$9.5 \times \Delta_{extended}$
12.5	< 66.7	7-m	1	$1.0 \times \Delta_{extended}$
12.5	> 66.7	7-m + TP	1 : 1.7	$1.7 \times \Delta_{extended}$

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Sky Setup

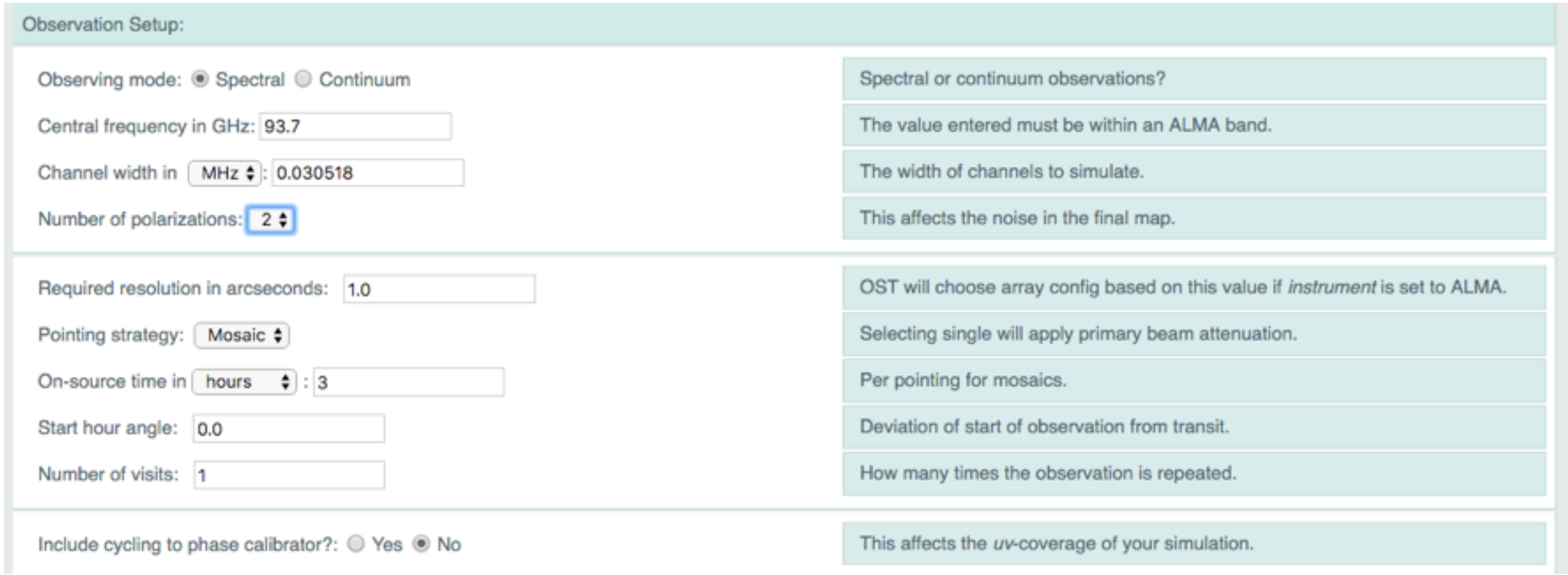


Peak flux value *(if you want to rescale)*

0 —> no rescale

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Observation Setup (spectral)



ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Observation Setup (continuum)

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Observation Setup and Atmospheric Corruption

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 OK	Per pointing for mosaics.
Start hour angle: 0.0	Deviation of start of observation from transit.
Number of visits: 1	How many times the observation is repeated.
Include cycling to phase calibrator?: Yes No	This affects the *uv*-coverage of your simulation.
Atmospheric Corruption:	
Atmospheric conditions: PWV = 0.913 mm (3rd Octile)	Determines level of noise due to water vapour.

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Image Product

Imaging Product:

Imaging weights: Briggs — This allows a resolution / sensitivity trade-off.

Perform deconvolution?: Yes — Apply the CLEAN algorithm to deconvolve the image.

Output image format: FITS — CASA format images are returned as a tar file

Submission:

Your email address is amignano@ira.inaf.it

Submit

Job ID: 20160408124007AevDp / Submitted by: amignano@ira.inaf.it

Your result will appear here: 20160408124007AevDp

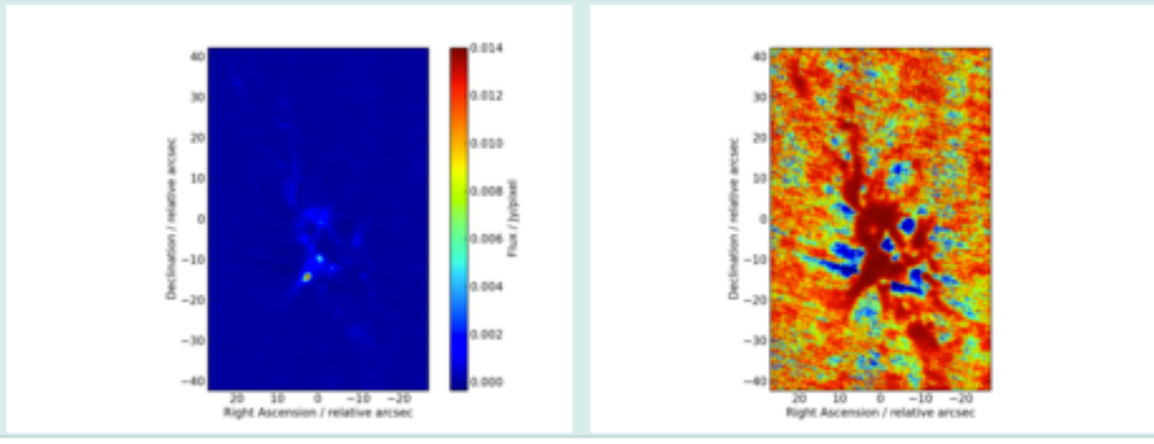
Your simulation has entered the OST queue and has 0 jobs infront of it.

ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Results

Overview

Click thumbnails to view full-size images. Left: linear colour scale, right: with histogram equalization.

Array configuration:	ALMA out10
Source model:	NGC 1333 at 8 kpc
Input image:	
Maximum elevation:	77.88 degrees
Central frequency:	93.7 GHz (ALMA Band 3)
Total Bandwidth:	3.0518e-05 GHz
Channel Width:	0.030518MHz
Track length:	3 hours x 1.0 visits
Hexagonal mosaic pointings :	2 required to cover requested sky area with uniform sensitivity
System temperature:	Tsys = 70.1061277681 K
PWV :	1.796 mm
Theoretical RMS noise (per channel):	0.00204136207821 Jy (in naturally-weighted map)
Restoring beam (resolution):	Major axis = 1.141 arcsec, minor axis = 1.048 arcsec, PA = 56.788 deg

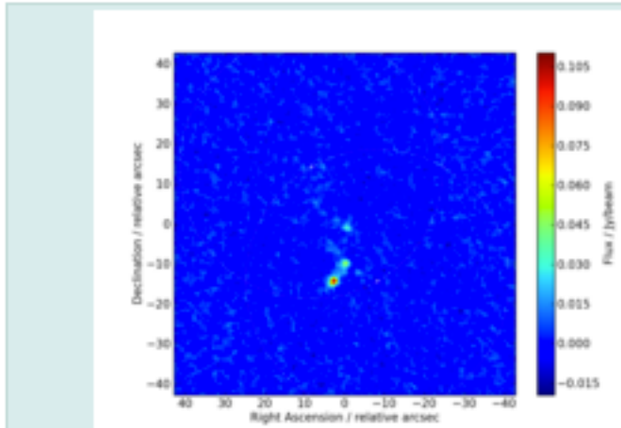
ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

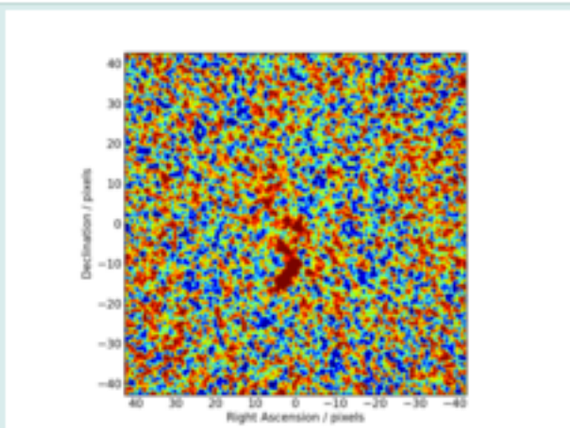
Results

Data products

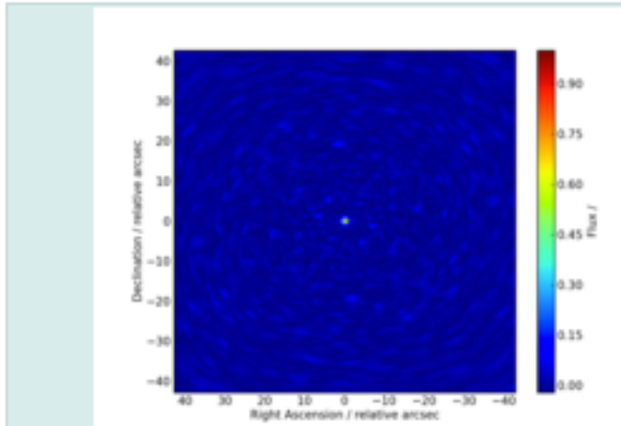
Your simulated image:

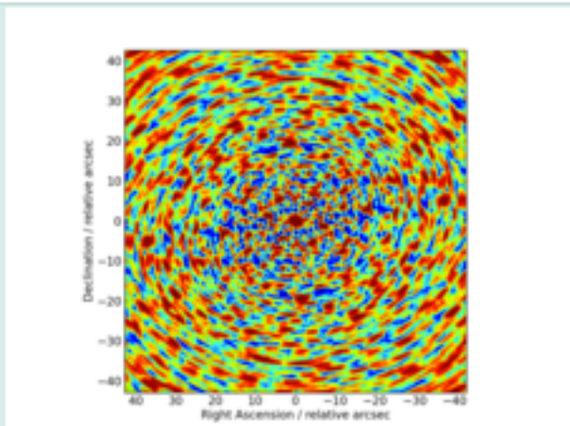
Download FITS file



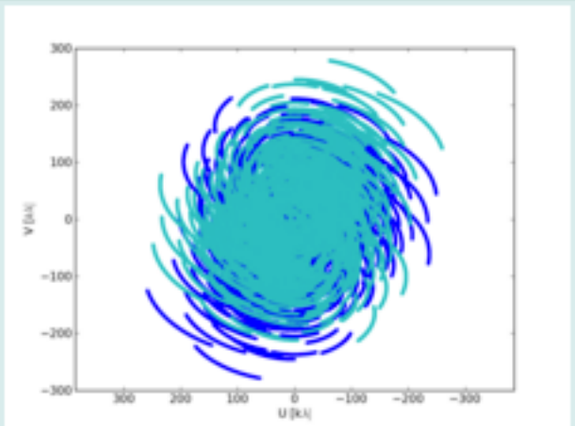


Dirty Beam
(Point Spread Function):





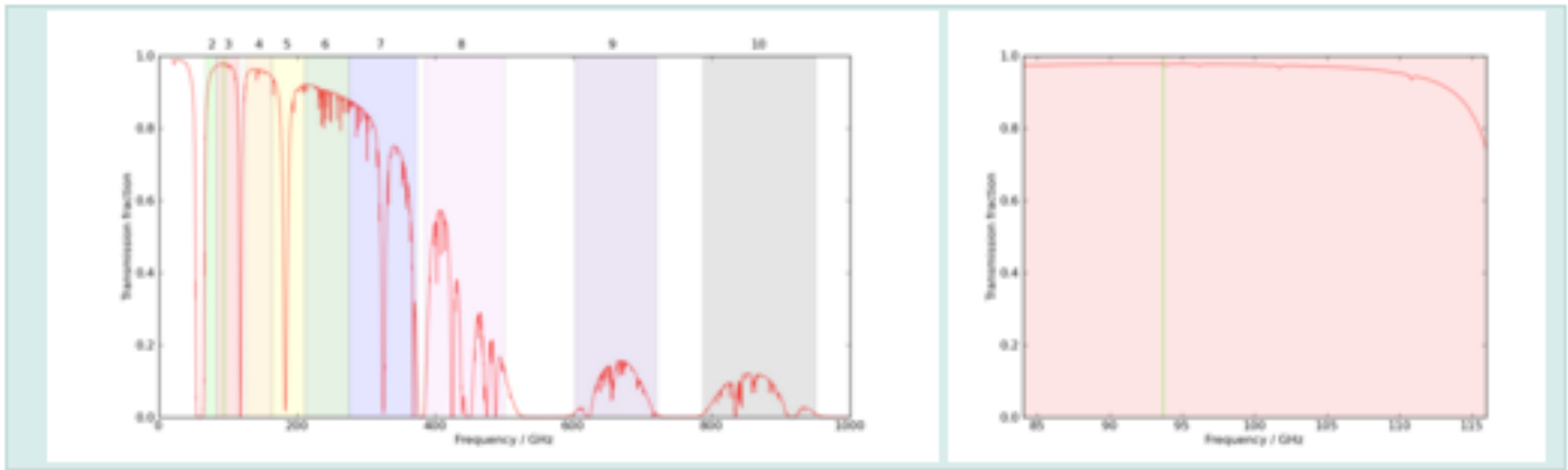
Coverage in the *uv*-plane:



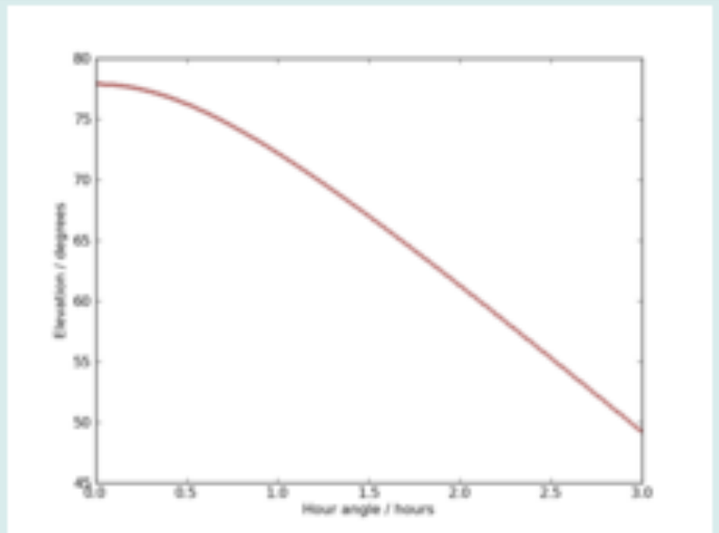
ALMA Observing Tool (OST) http://almaost.jb.man.ac.uk/

Results

Atmospheric transmission for all bands (left) and the selected band (right)



Elevation vs time:



ALMA Observing Tool (OST) vs SimALMA

- **SIMALMA** (CASA software):
  - “move” the source in z
  - combine different Cycle4 configurations
  - combine with ACA+TP
  - more sophisticated treatment of noise

- **Observation Support Took (OST)**:
  - easy (web)
  - no CASA knowledge

Do not use simulator to calculate RMS!
—> use ALMA sensitivity calculator