Early Science Cycle 3

ALMA Simulations

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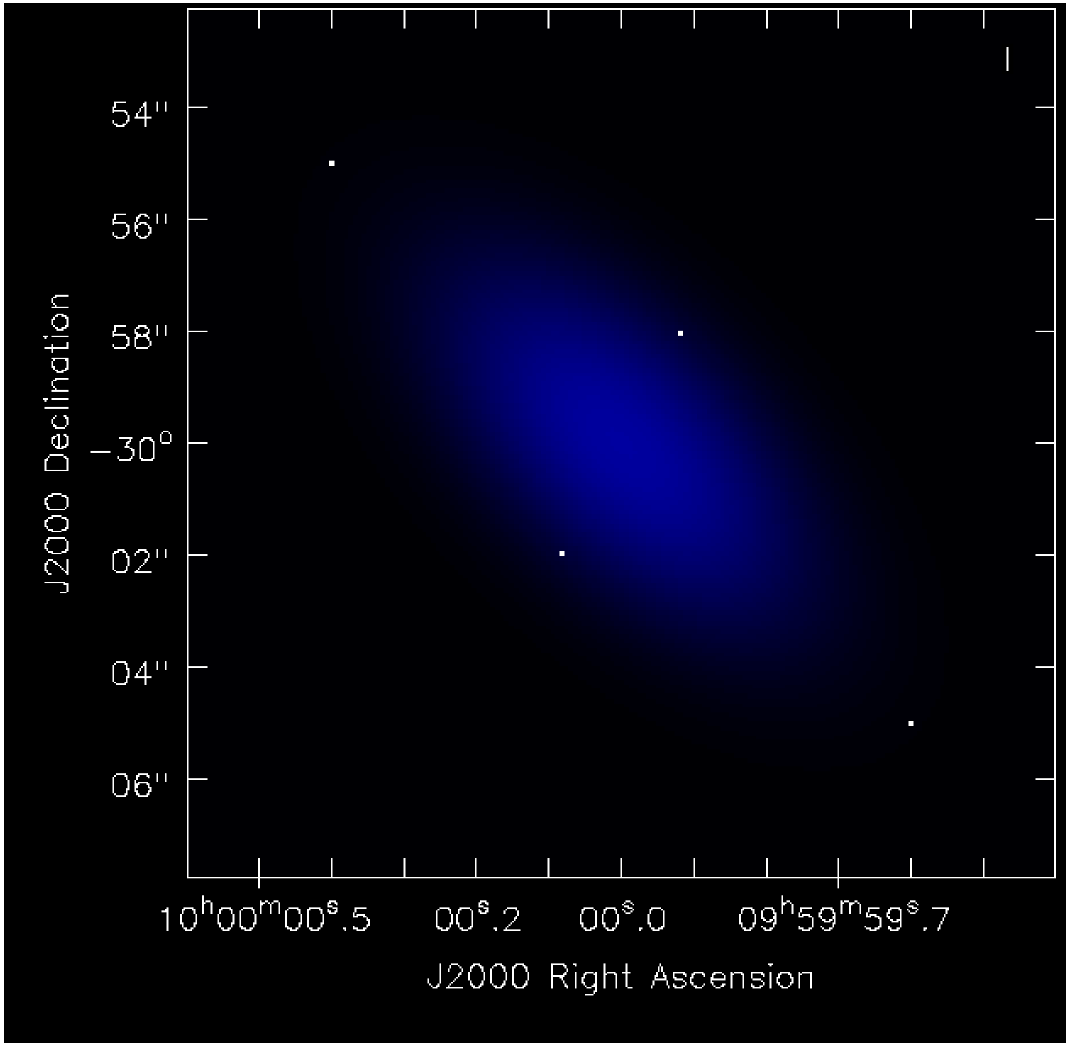
Why simulate ALMA observations

Interferometers do not sample all spatial frequencies on the sky, so the image obtained from interferometric observations does not necessarily represent the full brightness distribution.

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.

Why simulate ALMA observations



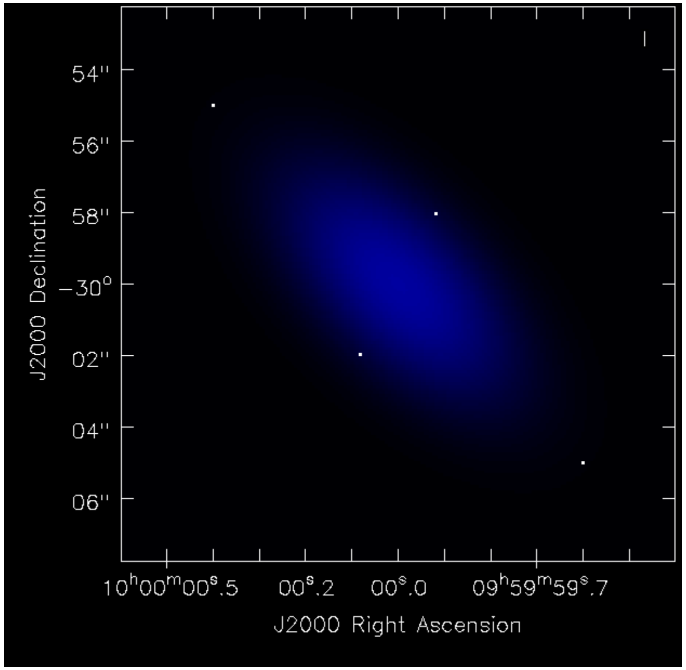
Assume this is our target field:

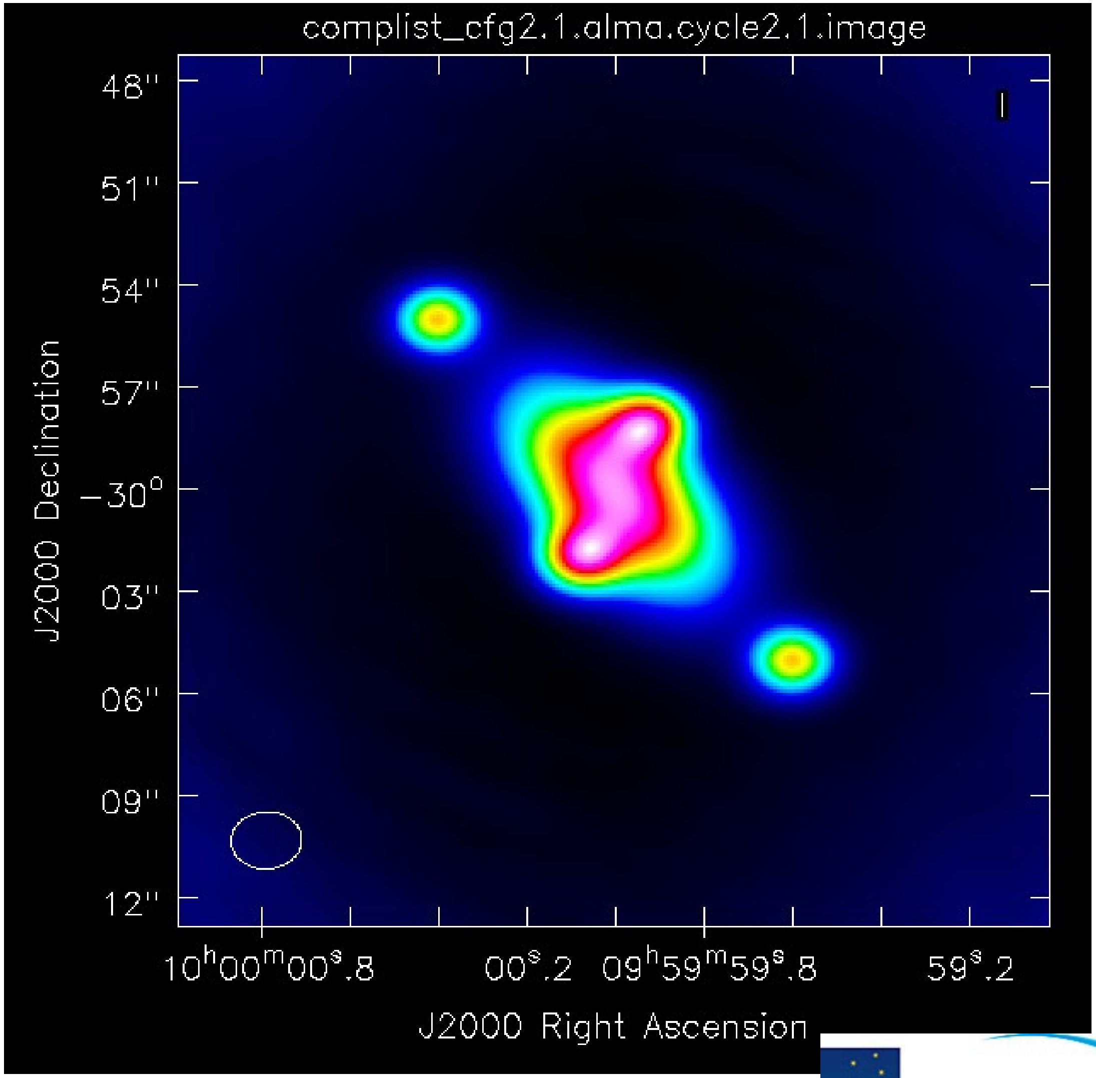
4 point sources

1 central gaussian

Why simulate ALMA observations

ALMA Cycle3 **most compact cfg**
8hrs observations 1 pointing





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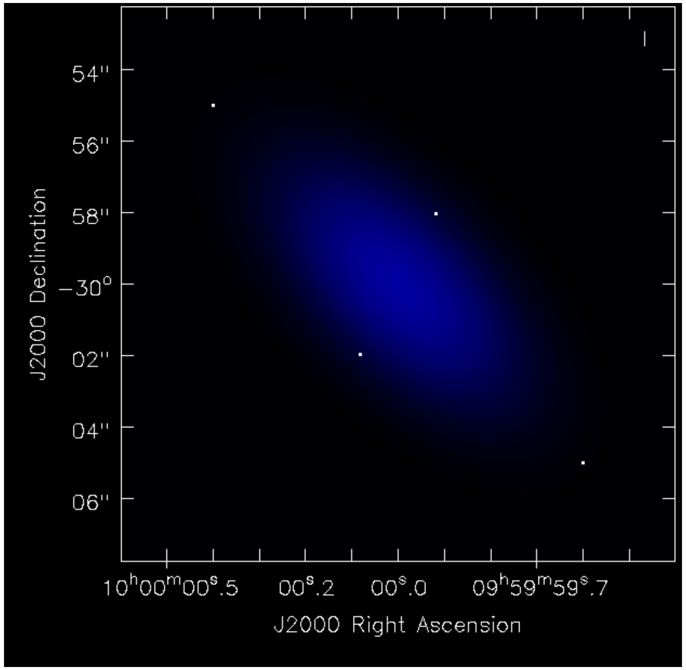
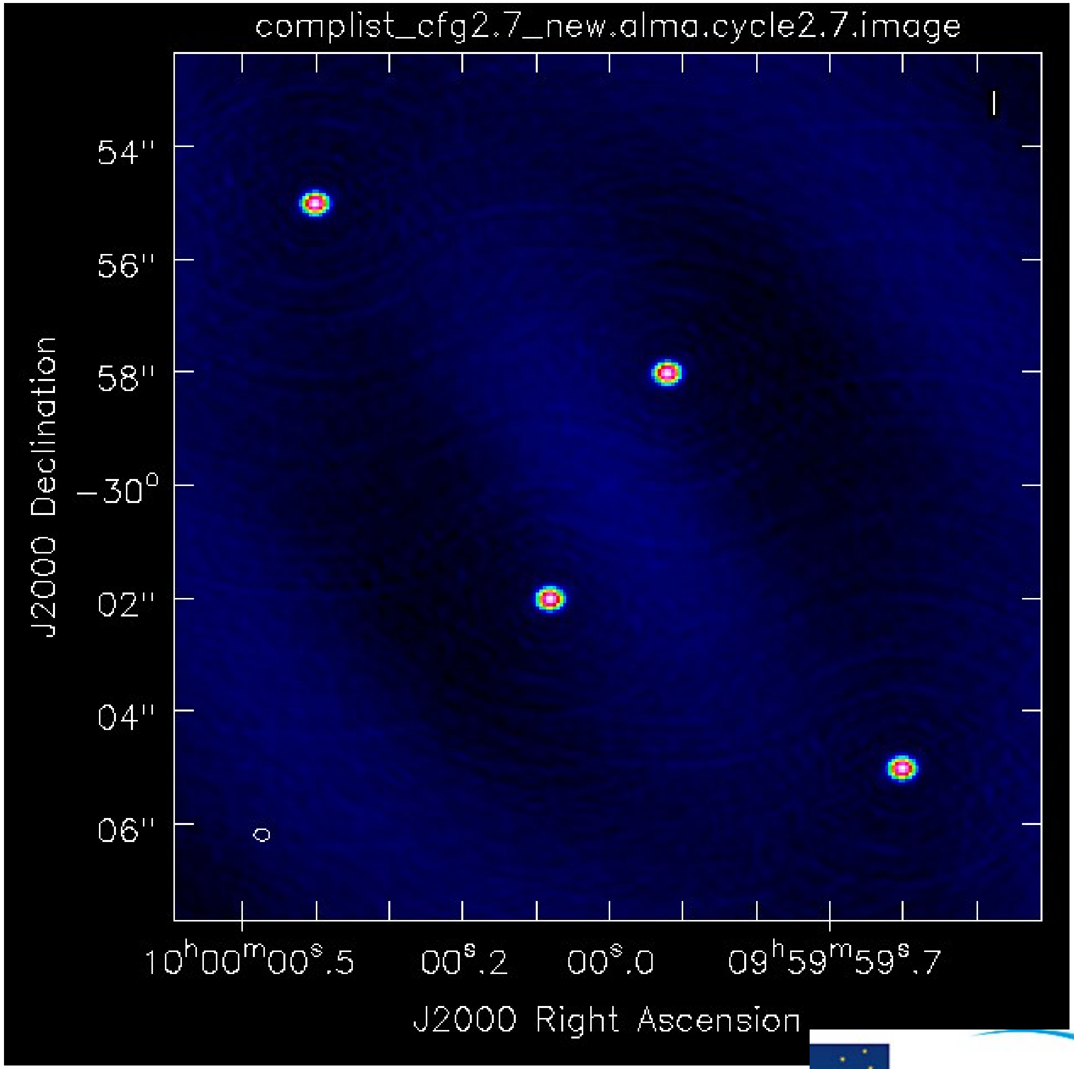
Why simulate ALMA observations



ALMA Cycle3 **most extended** cfg
8hrs observations 1 pointing



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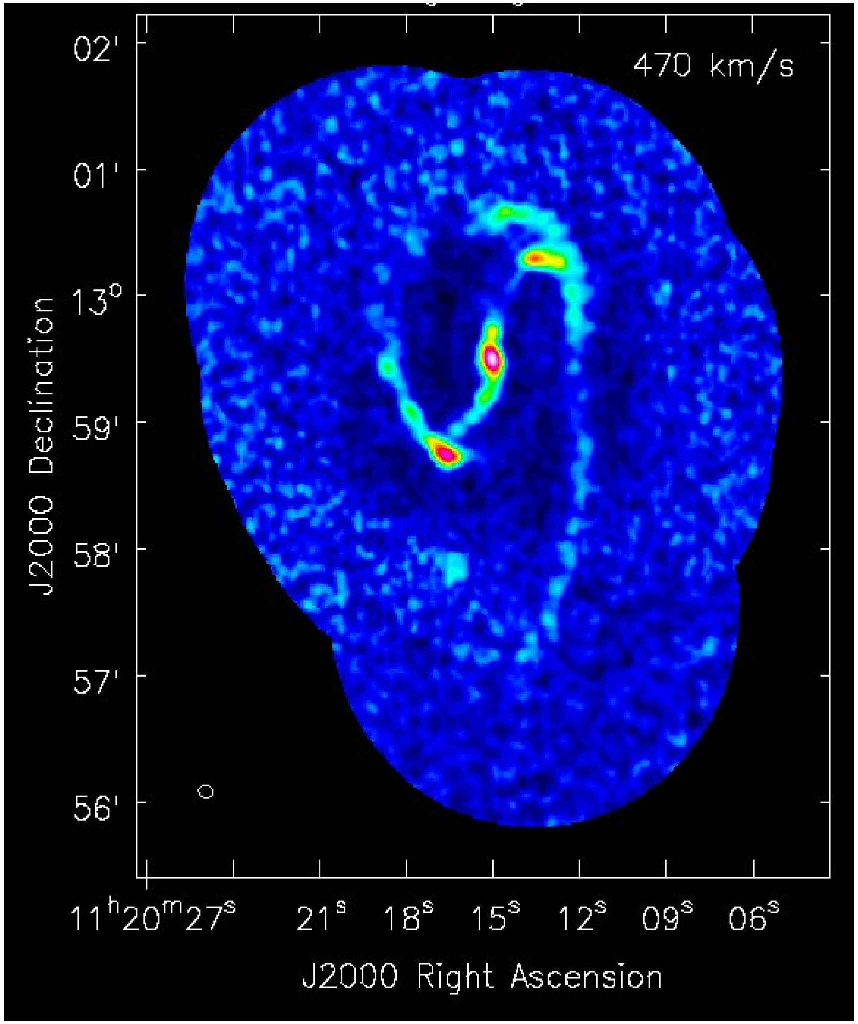
Why simulate ALMA observations

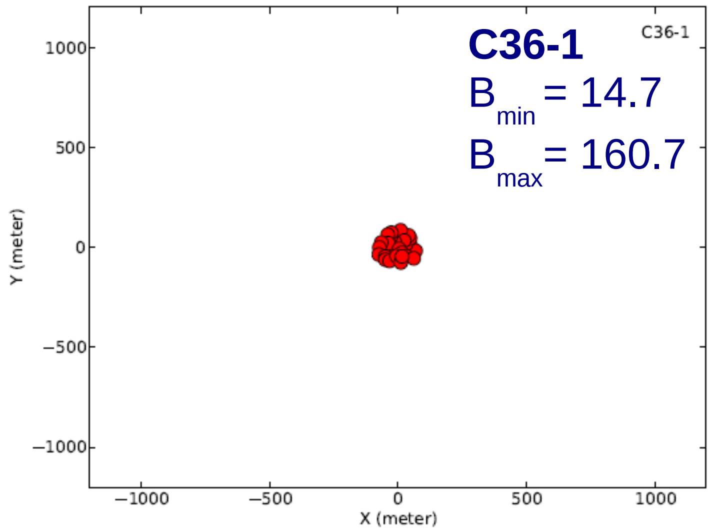


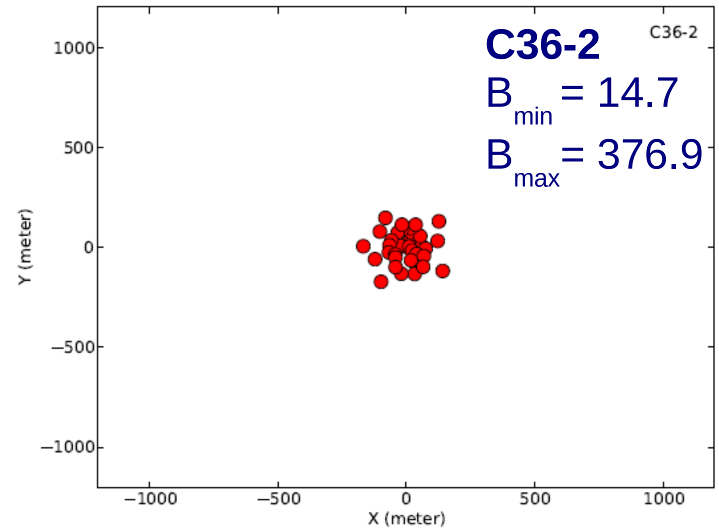
Simulation of a complex source with extended structure and point-like regions.

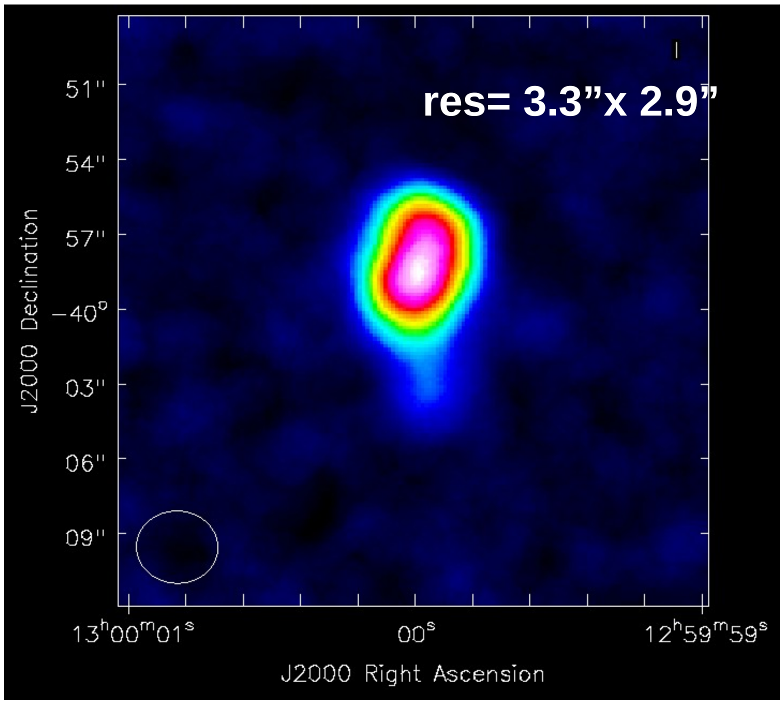
BIMA CO image @ 6”
of NGC3627
rms ~ 30mJy/beam in 10 km/s

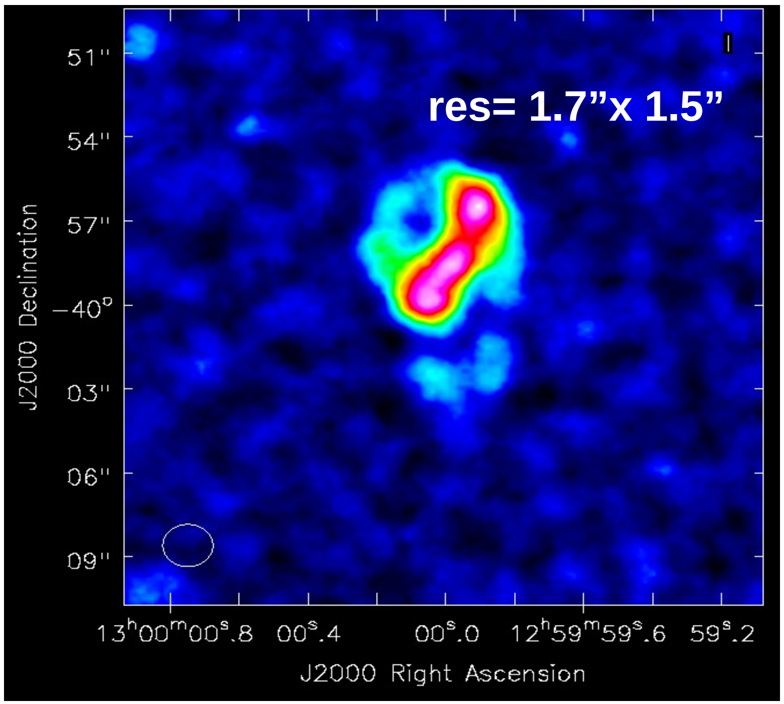
Target scaled to z=0.03
J2000 13:00:00 -40:00:00
CO (1-0) @ 112.10 GHz
peak flux 0.041 mJy/pix

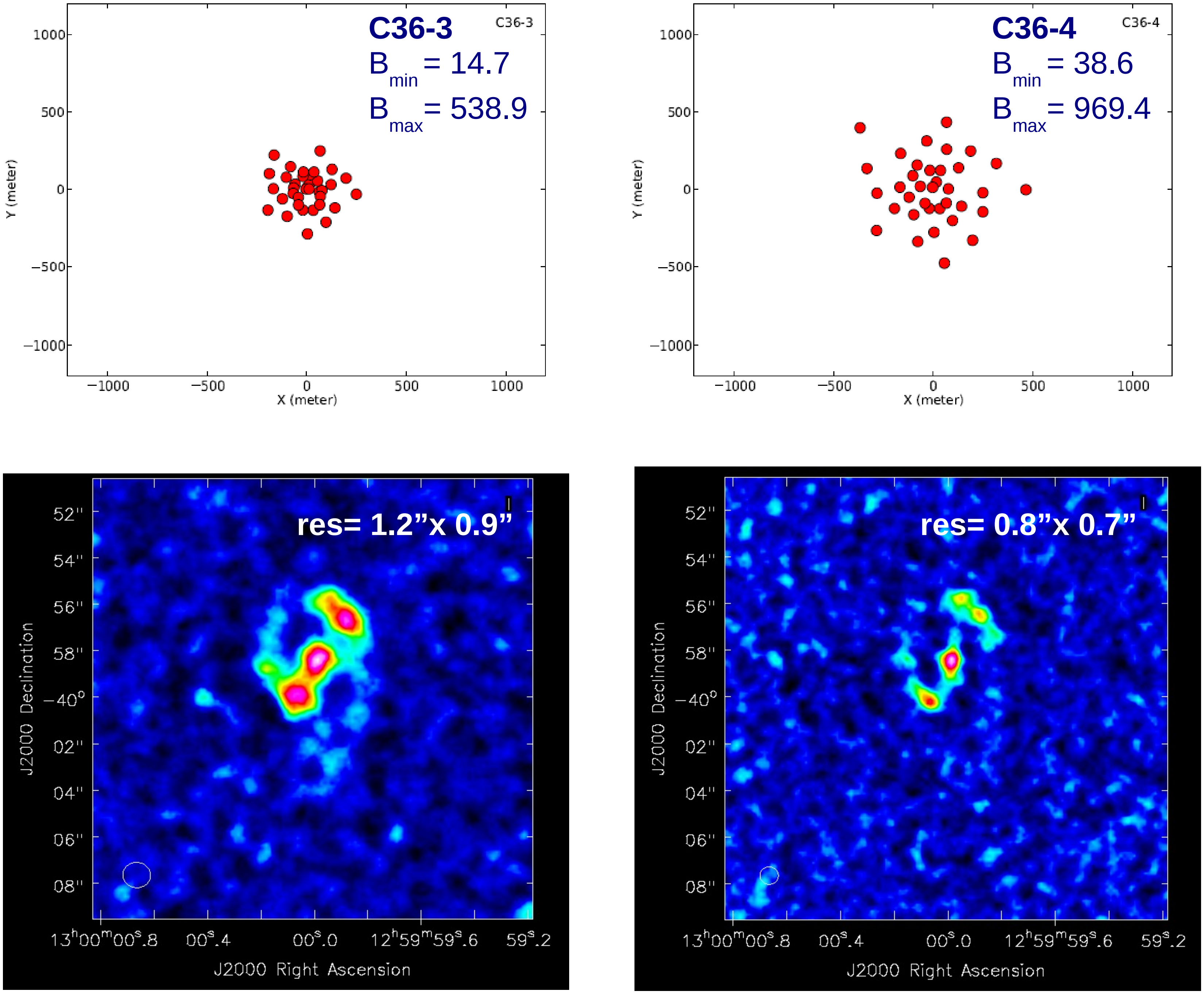
ALMA 12-m configurations available during Cycle 3

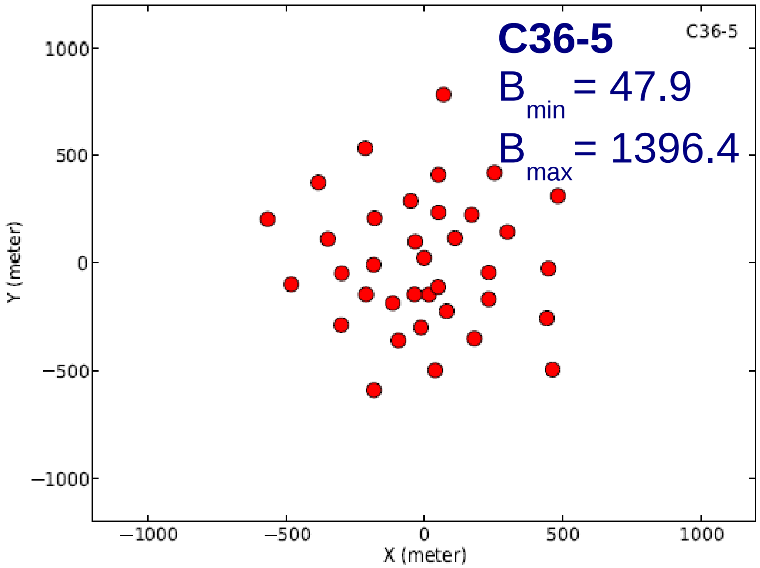


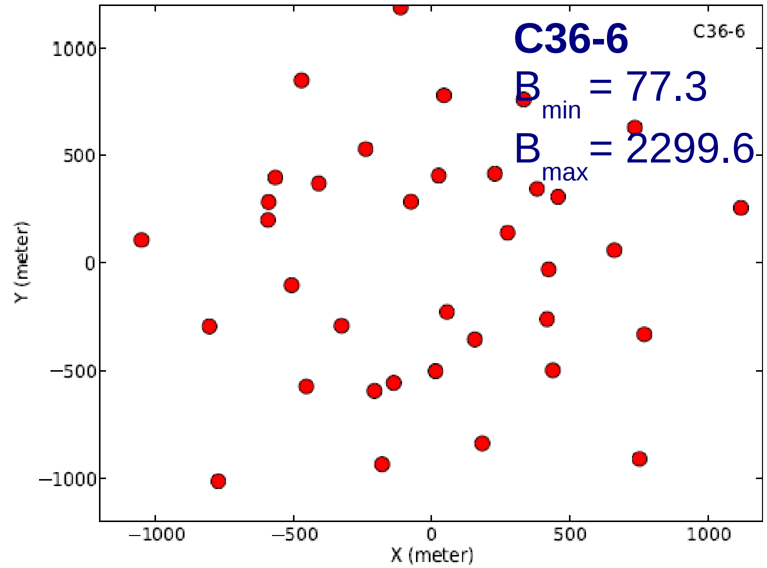


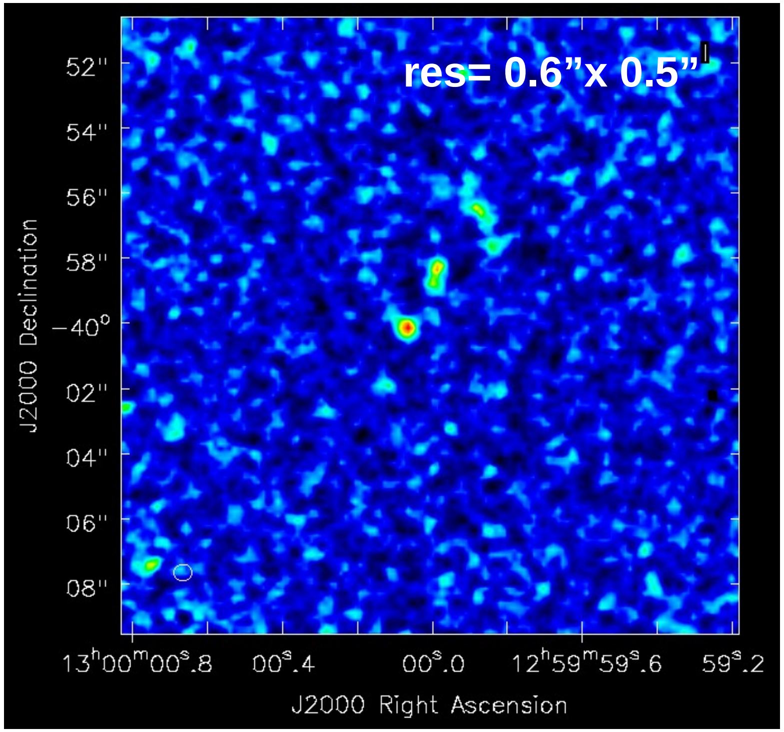


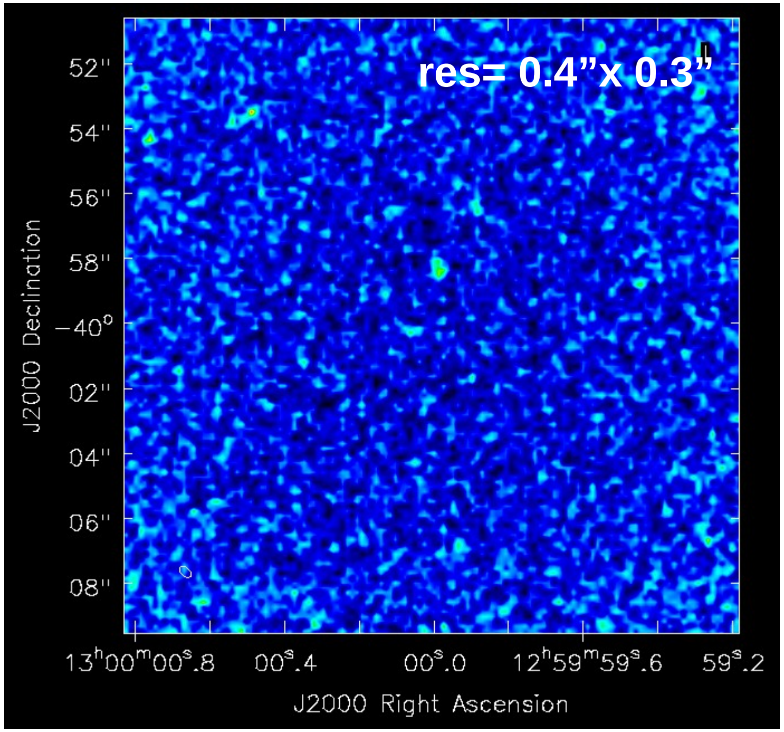



C36-3
B min = 14.7
B max = 538.9
Y (meter)
X (meter)
C36-4
B min = 38.6
B max = 969.4
Y (meter)
X (meter)
res= 1.2”x 0.9”
J2000 Declination
J2000 Right Ascension
res= 0.8”x 0.7”
J2000 Declination
J2000 Right Ascension

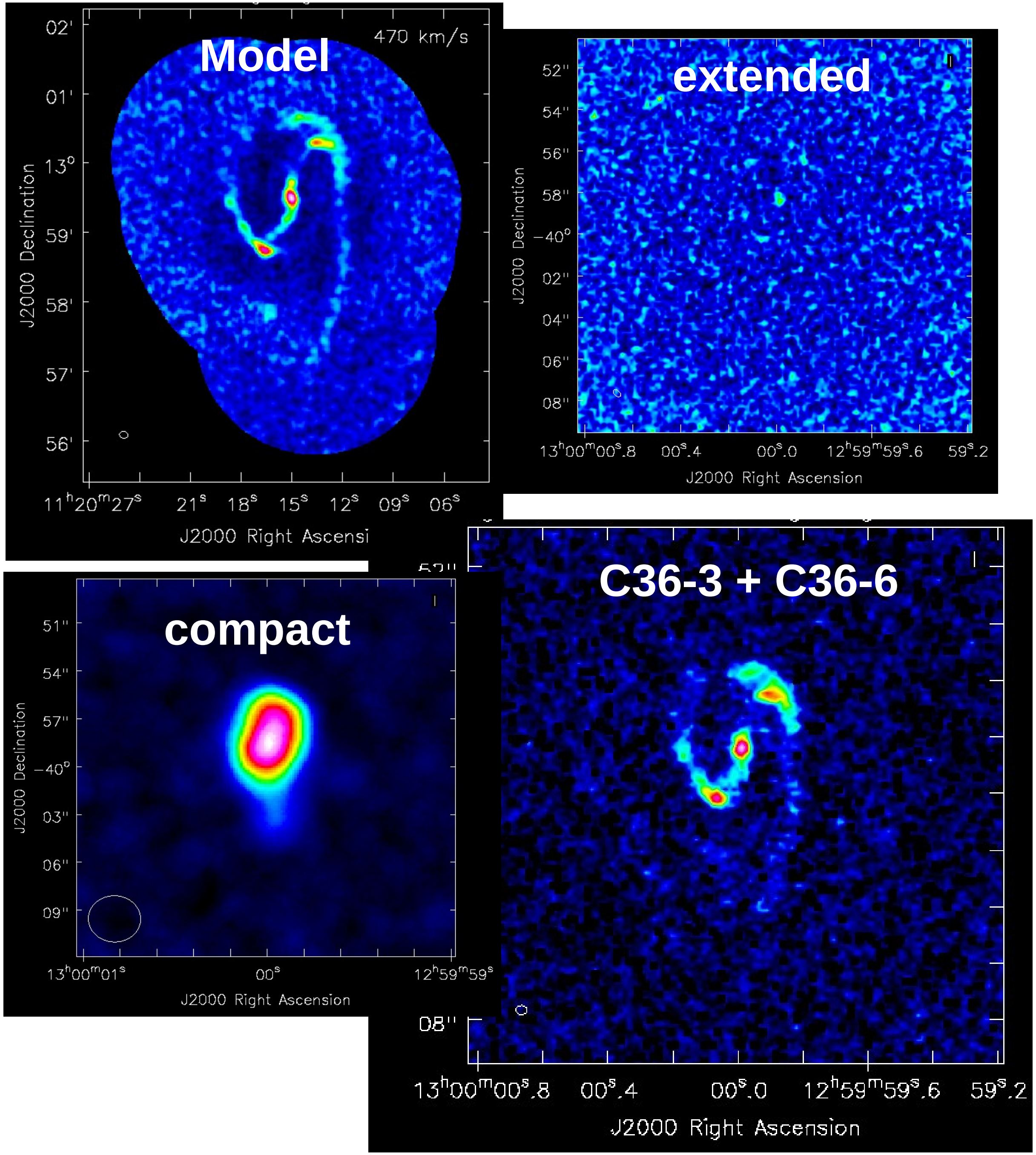

C36-5
B min = 47.9
B max = 1396.4
C36-5
Y (meter)
X (meter)


C36-6
B min = 77.3
B max = 2299.6
C36-6
Y (meter)
X (meter)


res= 0.6"x 0.5"
J2000 Declination
J2000 Right Ascension


res= 0.4"x 0.3"
J2000 Declination
J2000 Right Ascension

Why simulate ALMA observations



The extended configuration misses completely the emission from the largest components.
The compact cfg recovers the extended emission without resolution.
Adding ACA would give a more precise representation of the flux.

To recover both extended and point-like structures the combination of multiple 12 m array cfg is needed.

Combination: C36-3+ C36-6
Observation 8hrs long.

The OT will decide automatically how many 12 m array configurations are needed, based on the values of **Desired Angular resolution** and **Largest angular structure** you give as input.

Desired angular resolution

θ_{res} (arcsec)	θ_{LAS} (arcsec)	Array combination	Time ratios	Total Time
0.3	< 4.8	C36-6	1	$1.0 \times \Delta_{extended}$
0.3	4.8-25.2	C36-6 + C36-3	1 : 0.5	$1.5 \times \Delta_{extended}$
0.3	25.2-42.8	C36-6 + C36-3 + 7-m	1 : 0.5 : 2	$3.5 \times \Delta_{extended}$
0.3	> 42.8	C36-6 + C36-3 + 7-m + TP	1 : 0.5 : 2 : 4	$5.5 \times \Delta_{extended}$

Table 7.4 ALMA cycle-3 Technical Handbook

The OT will decide automatically how many 12 m array configurations are needed, based on the values of
Desired Angular resolution and
Largest angular structure
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Desired angular resolution

Largest angular structure

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The most extended configuration is enough!

Table 7.4 ALMA cycle-3 Technical Handbook

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Largest angular structure

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2 main array configurations are needed!

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2 main array configurations are needed!

Time scaling assumed for the observations

Table 7.4 ALMA cycle-3 Technical Handbook

The OT will decide automatically how many 12 m array configurations are needed, based on the values of
Desired Angular resolution and
Largest angular structure
you give as input,
and suggests the use of ACA if needed.

Desired angular resolution **Largest angular structure**

θ_{res} (arcsec)	θ_{LAS} (arcsec)	Array combination	Time ratios	Total Time
0.3	< 4.8	C36-6	1	$1.0 \times \Delta_{extended}$
0.3	4.8-25.2	C36-6 + C36-3	1 : 0.5	$1.5 \times \Delta_{extended}$
0.3	25.2-42.8	C36-6 + C36-3 + 7-m	1 : 0.5 : 2	$3.5 \times \Delta_{extended}$
0.3	> 42.8	C36-6 + C36-3 + 7-m + TP	1 : 0.5 : 2 : 4	$5.5 \times \Delta_{extended}$

2 main array configurations + ACA are needed!

Time scaling assumed for the observations

The OT suggests to add ACA. If you decide to go against this recommendation you need to adequately justify your decision.

The OT will decide automatically how many 12 m array configurations are needed, based on the values of

Desired Angular resolution and

Largest angular structure

you give as input,

and suggests the use of ACA if needed.

Desired angular resolution

Largest angular structure

θ_{res} (arcsec)	θ_{LAS} (arcsec)	Array combination	Time ratios	Total Time
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2 main array configurations + ACA + TP are needed!

Time scaling assumed for the observations

The largest angular structure can have a strong impact on a proposal since it can multiply by a factor of 5 the total time needed.
A strong scientific motivation for it should be provided when multiple configurations are required.

Two software tools available to help users simulate images resulting from an ALMA observations:

Simulations with CASA tasks
simalma or simobserve & simanalyze
Tasks to produce ALMA data from an input sky model (theoretical model or previous observations)

Observation Support Tool
The OST is a webtool hosted by the UK ARC with a website acting as a simple GUI to set parameters and run the simulations

Simulations with CASA

- Allow you to simulate observations starting from images or component list.
- 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
- New simple task **simalma**

- **If you need CASA simulations we can help you running CASA scripts during this afternoon session or some other time.**

simalma

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

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)
```

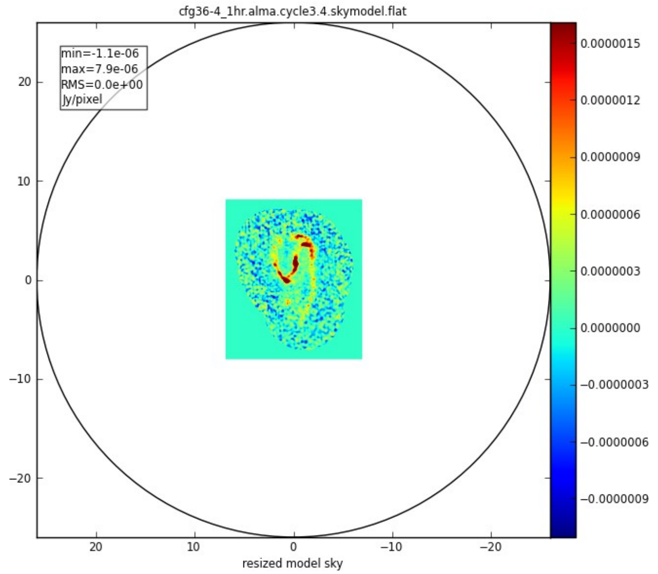
simalma

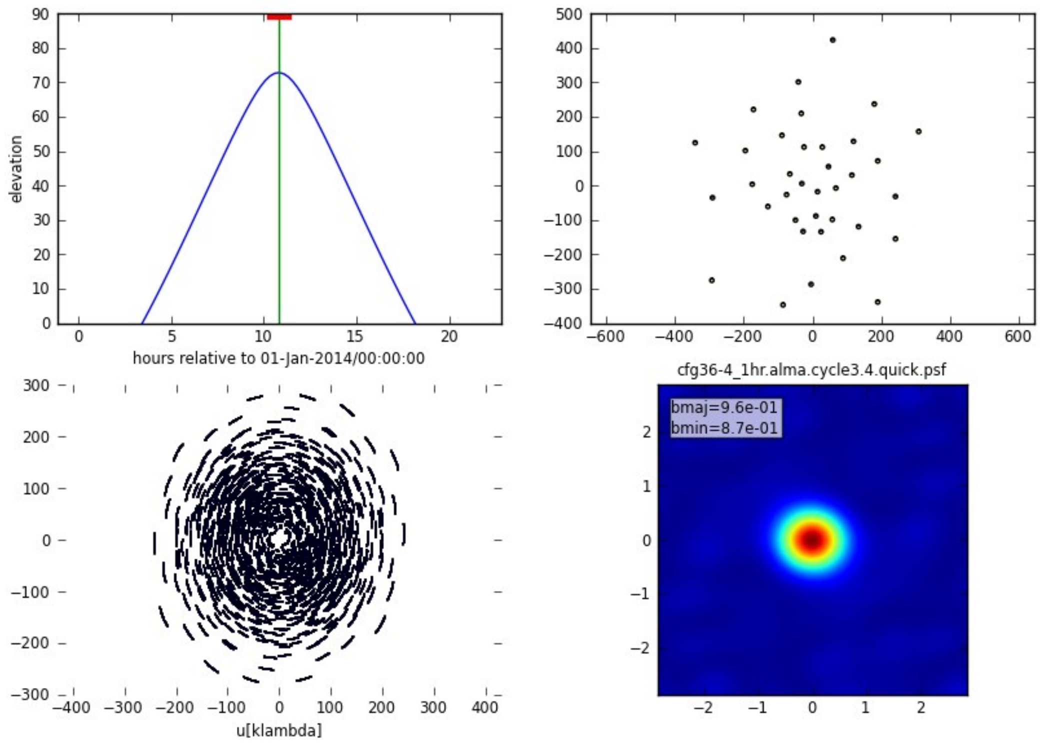
imsize in pixels = dimension of the image in spatial pixels
cell = cell size dimension of a pixel in arcsec
threshold = flux level to stop cleaning (2 -3 times the expected rms)
niter = number of cleaning iterations (0 for dirty image)

```
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 output

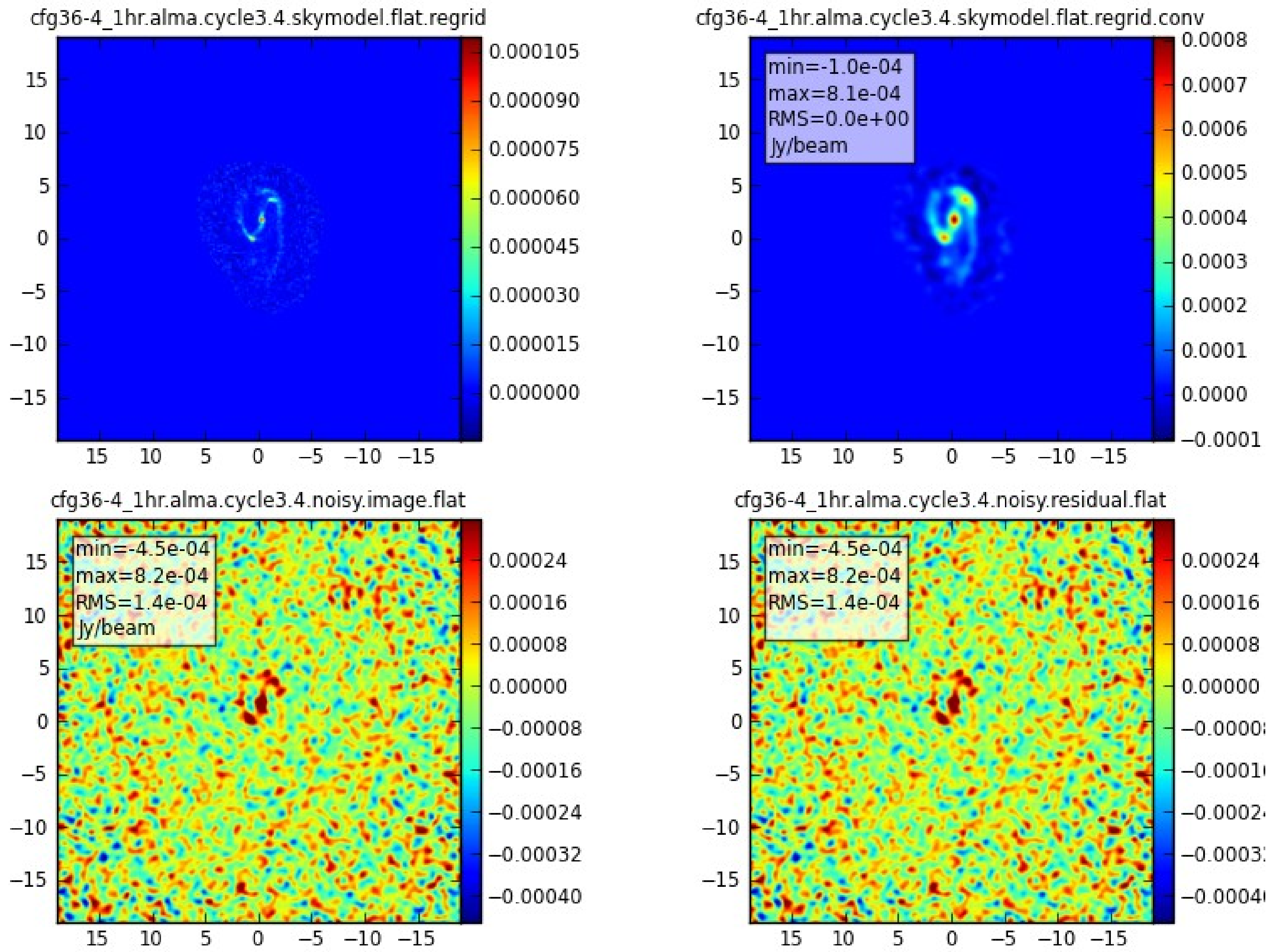




Sky model

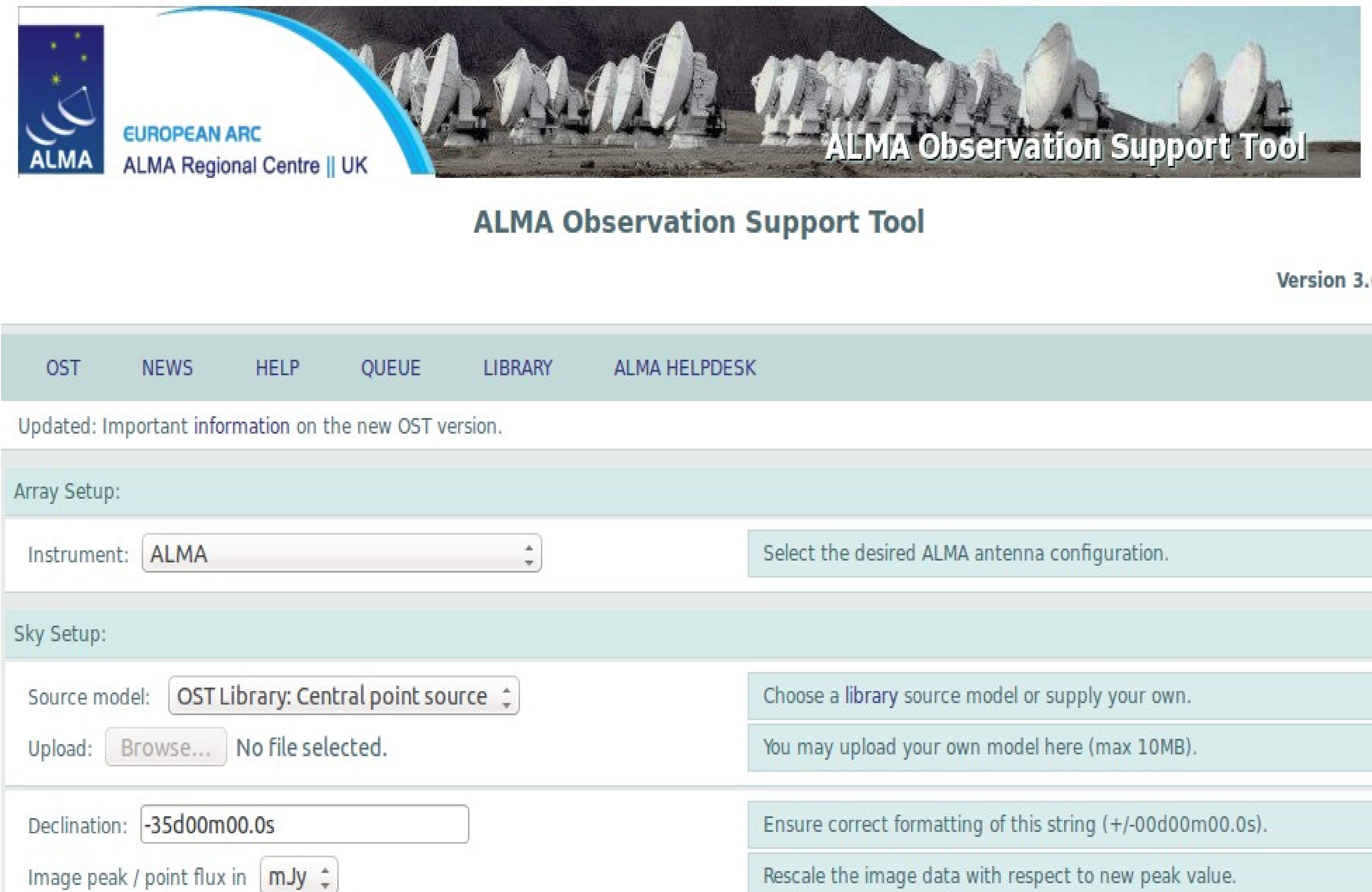
Observing details:
Elevation plot
Antenna configuration
UV-coverage
PSF

Simalma output

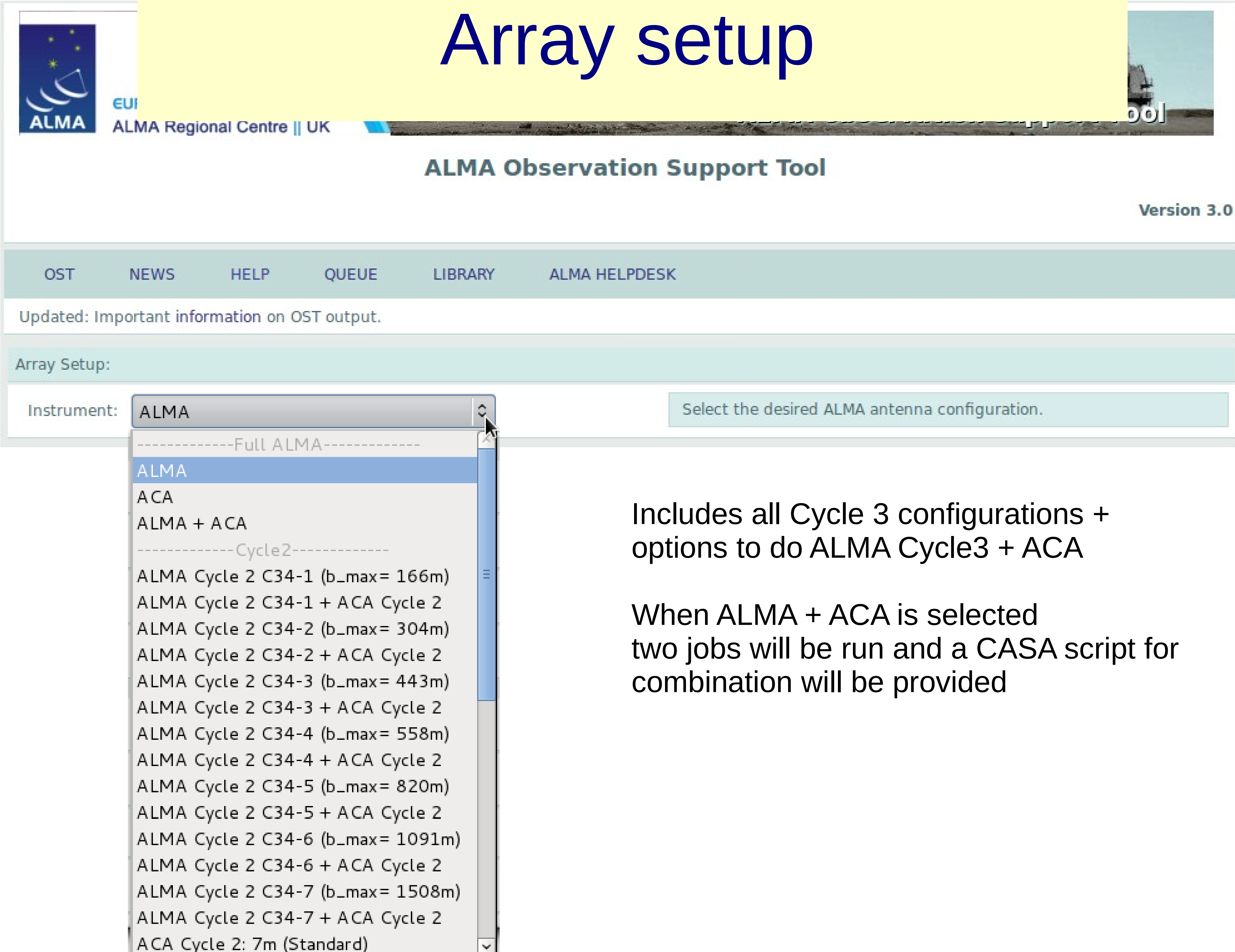


ALMA Observation Support Tool

(http://almaost.jb.man.ac.uk/)



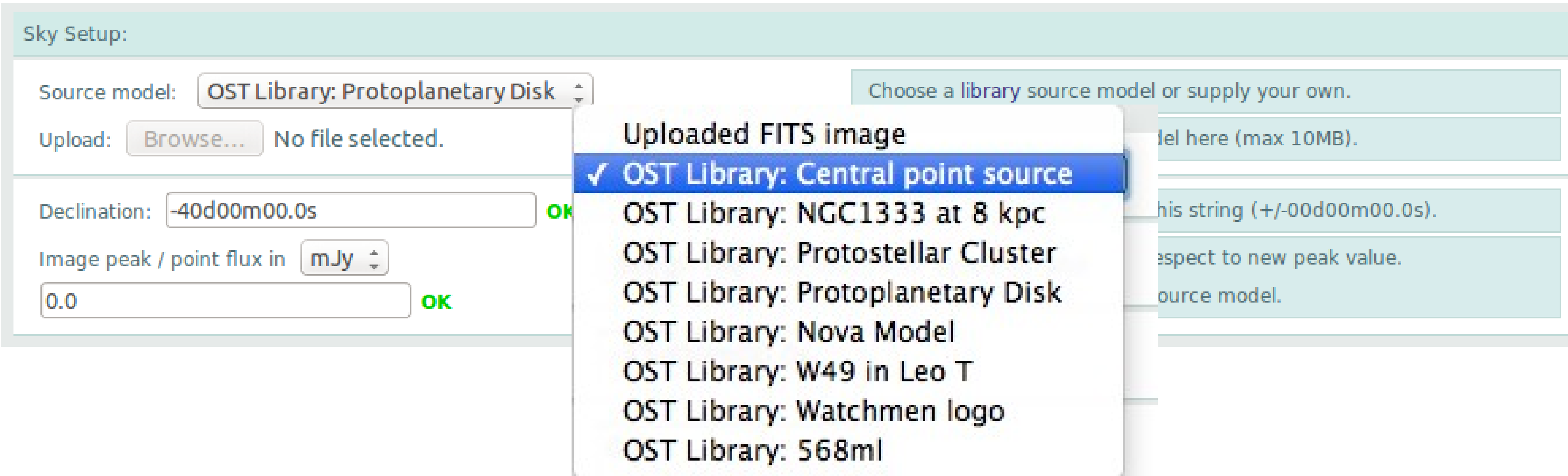
Array setup



Includes all Cycle 3 configurations + options to do ALMA Cycle3 + ACA

When ALMA + ACA is selected two jobs will be run and a CASA script for combination will be provided

Sky setup



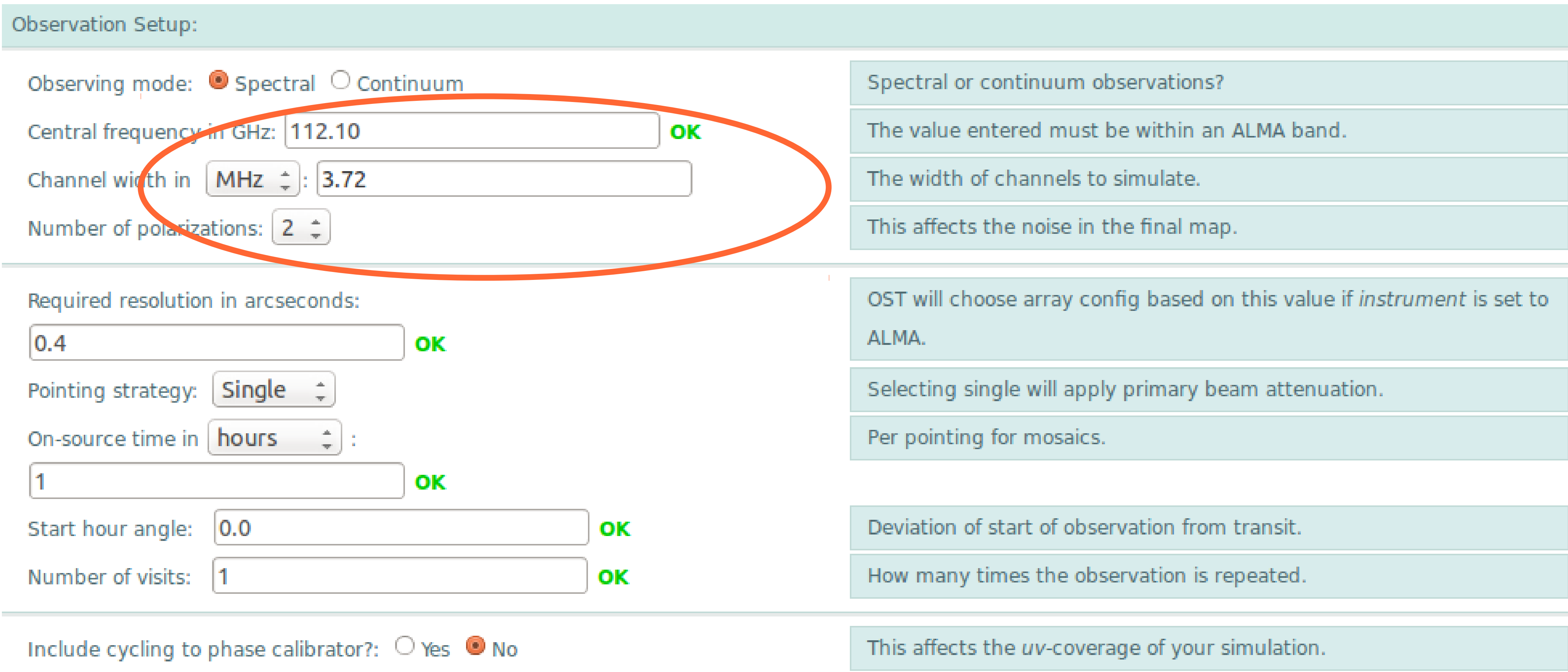
You can upload a FITS image or a model
(max size 10 MB)
OST library available

Image peak is the **scaling factor**, defined as:

$$I'_{xy} = \frac{I_{xy} \cdot P}{M}$$

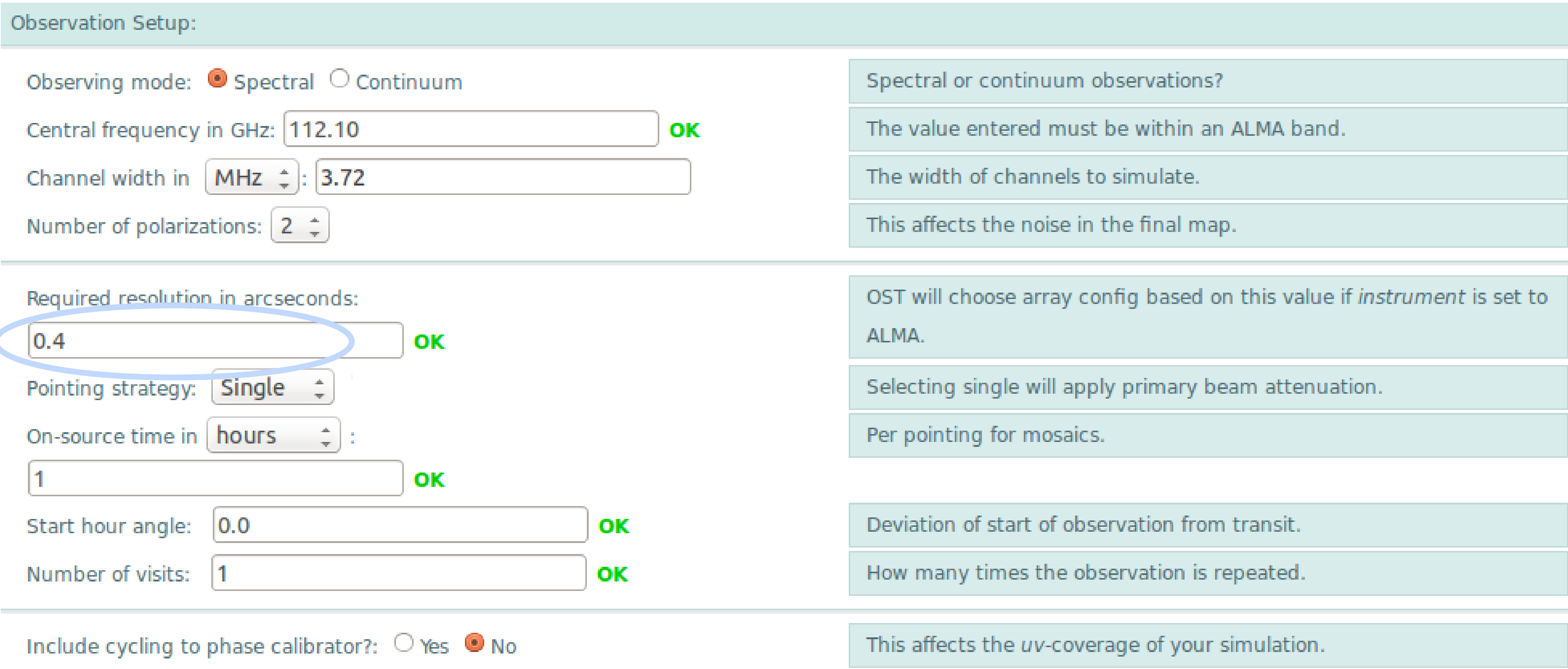
0.0 means no scaling

Observation setup



Central frequency within the range of available ALMA bands.
Bandwidth of observations:
Narrow for lines, broad for continuum

Observation setup

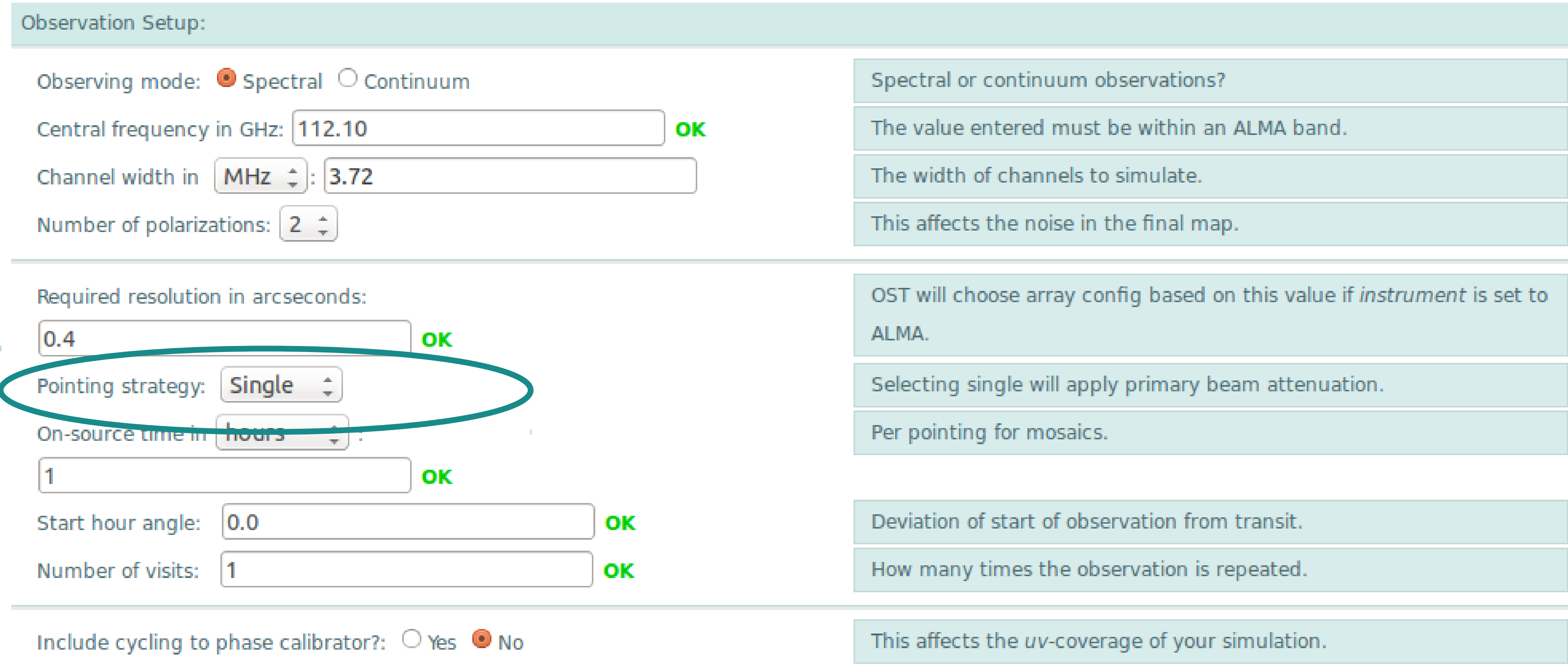


Required resolution

Not needed if you select a specific Cycle 2 configuration

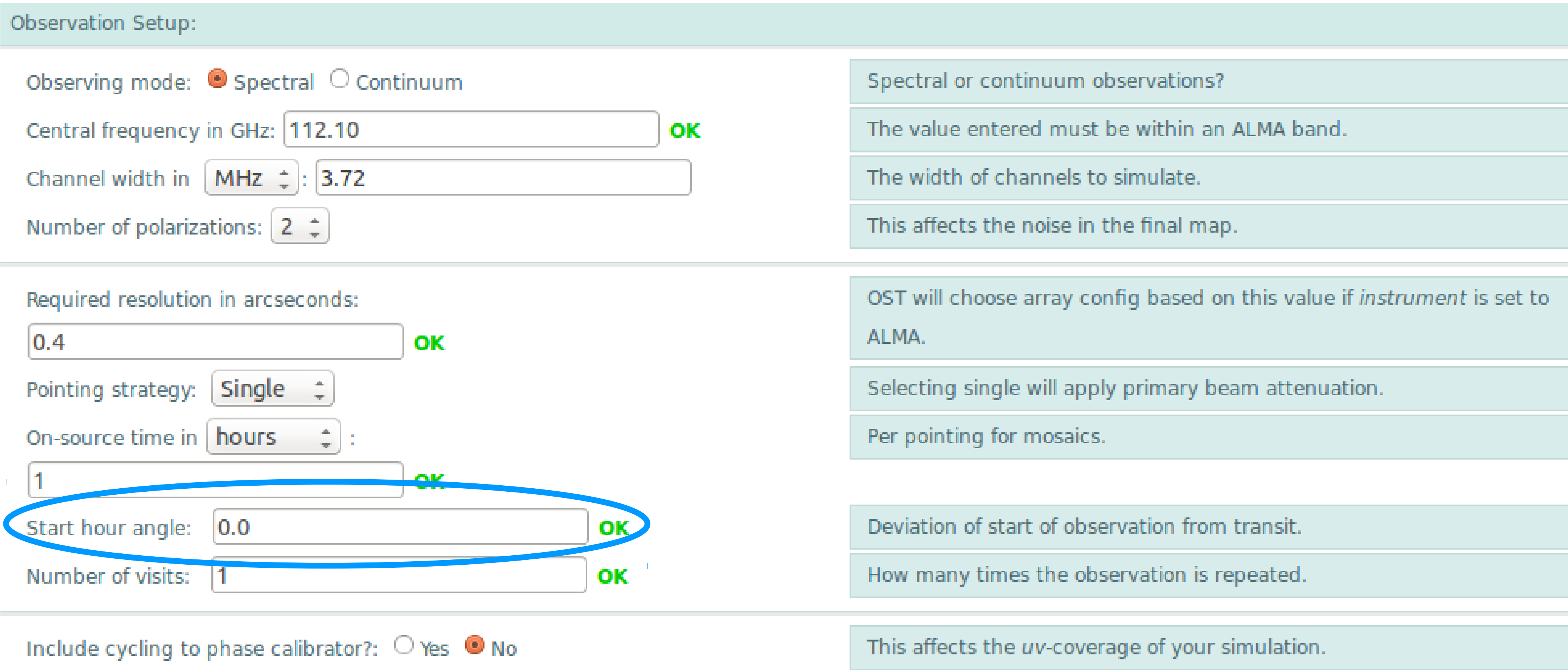
If you select ALMA in the array selection, the OST will select the appropriate configuration given the frequency requirement.

Observation setup



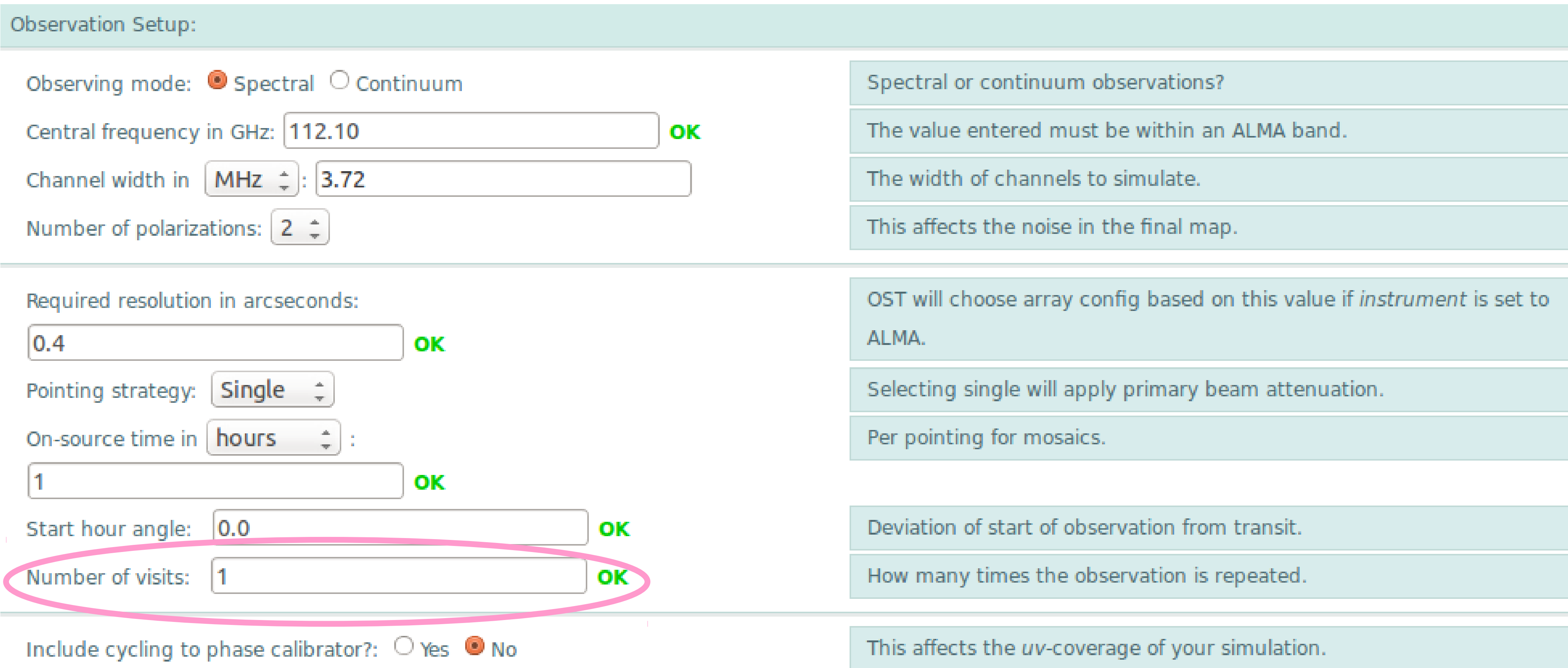
Pointing strategy
Single pointing or
Mosaic: it will examine the sky area which is to be simulated and return the number of pointings needed to cover the entire field

Observation setup



Start hour angle
this value indicates the time before/after the transit the observation starts.
ex. -1.5 with time on source 3 hrs means the source transits in the middle of the observation.

Observation setup



Number of visits

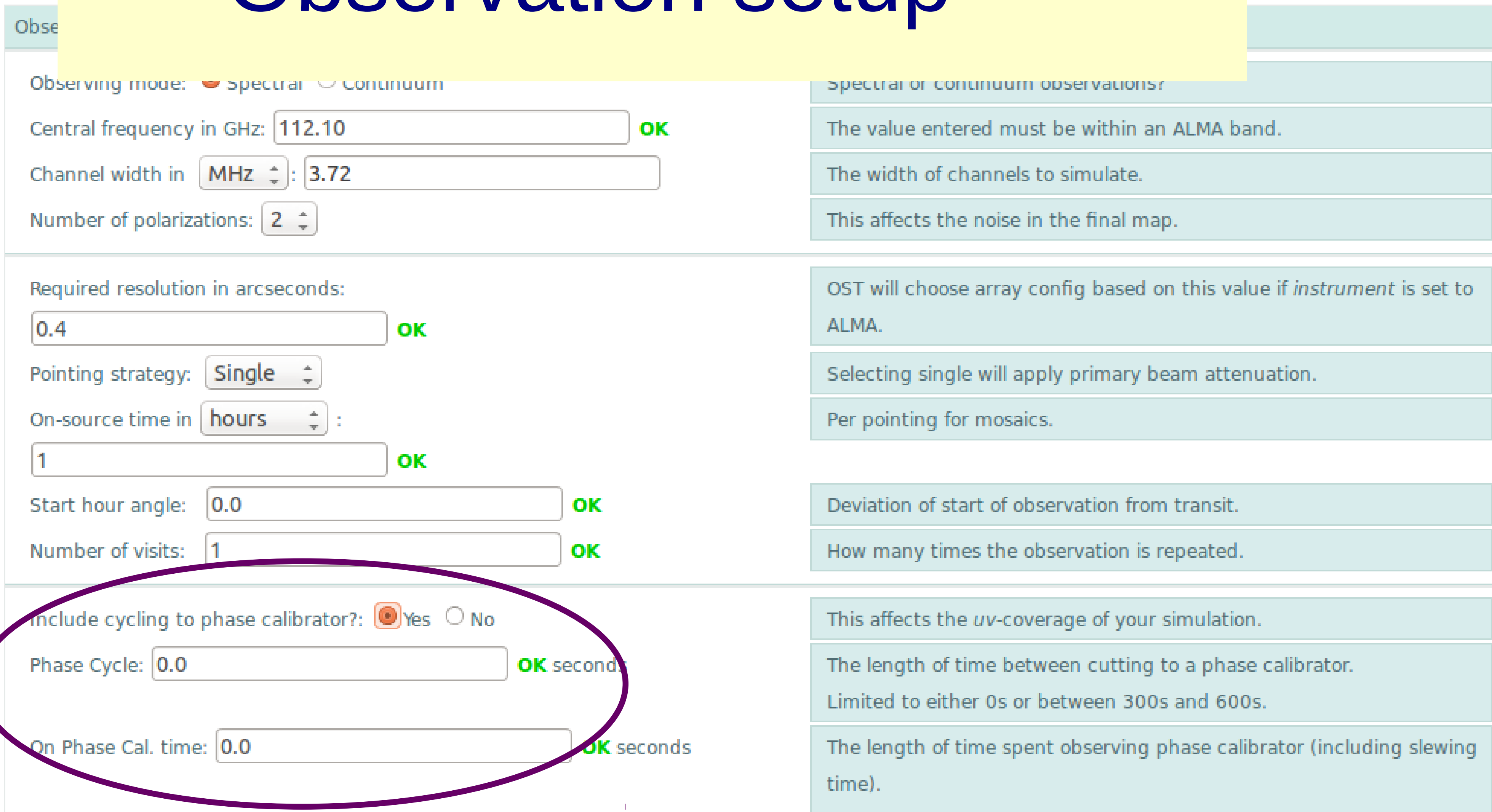
A long observation requiring a limited range of hour angle can be repeated, more than once.

ex. only **hour angle +/- 1 is acceptable but 20 hours on source** are needed:

start hour angle must be set to -1, time on source to 2,

and number of visit to 10

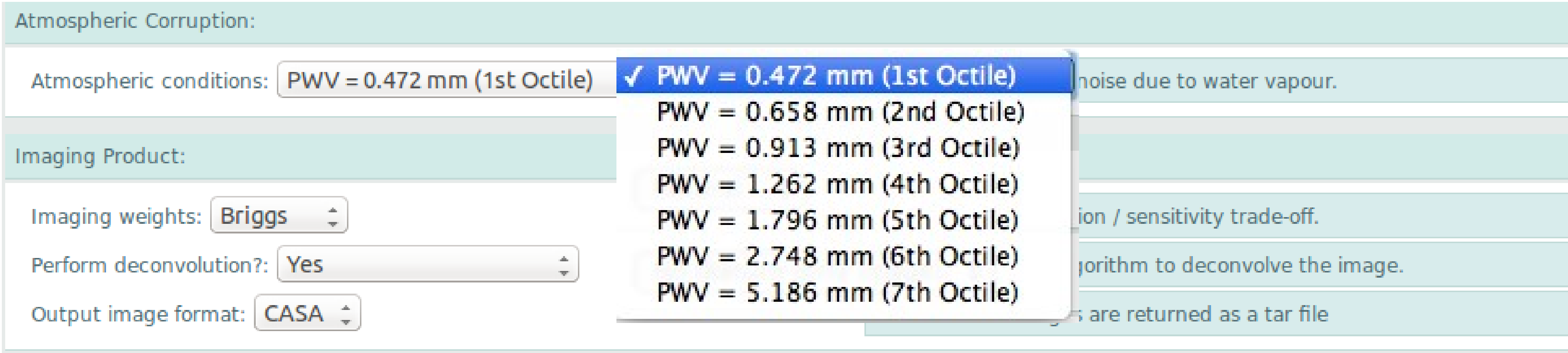
Observation setup



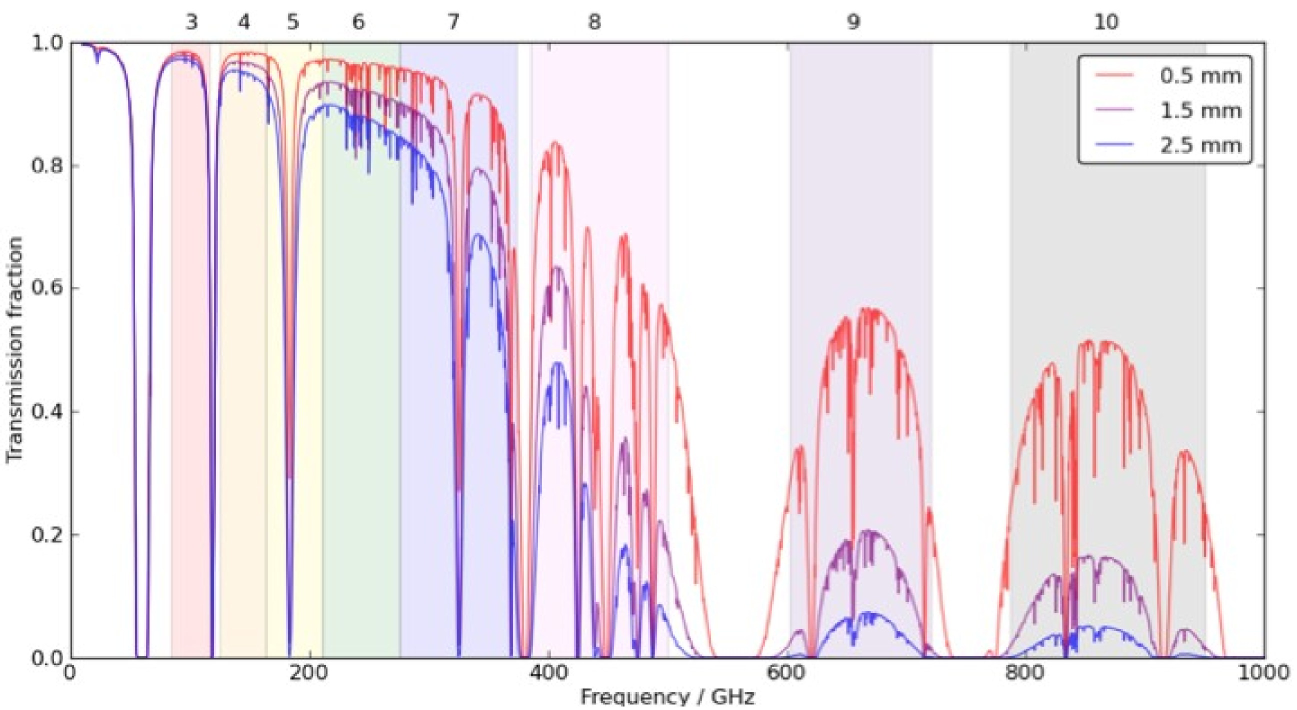
Include cycling to phase calibrator

If YES includes in the simulation time off source, spent on a hypotetical calibrator.
Phase cycle is the time between scans on the calibrator
On Phase cal time is the time spent on the calibrator

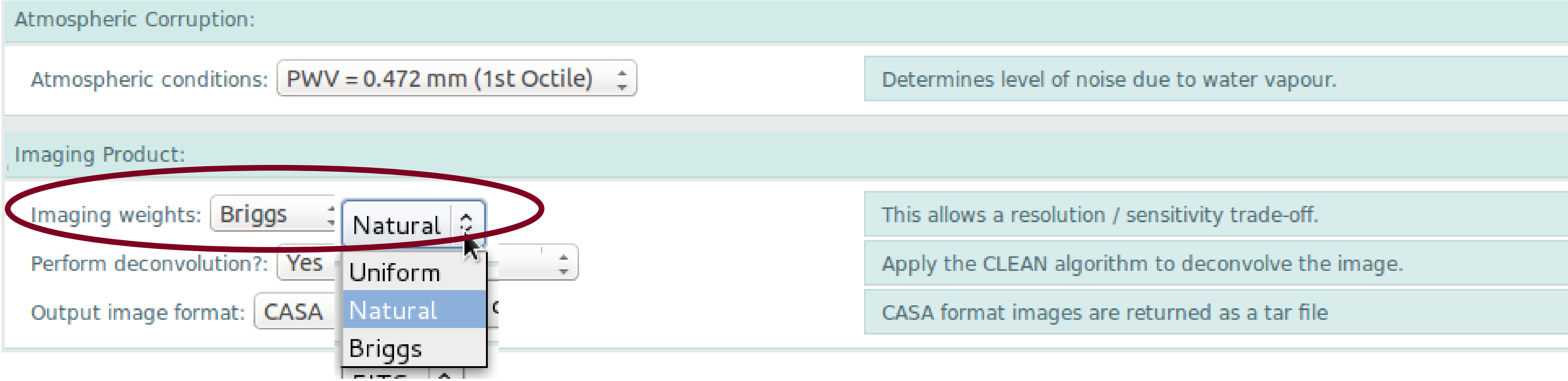
Atmospheric corruption



Add noise to the simulated observations due to water vapor in different weather conditions

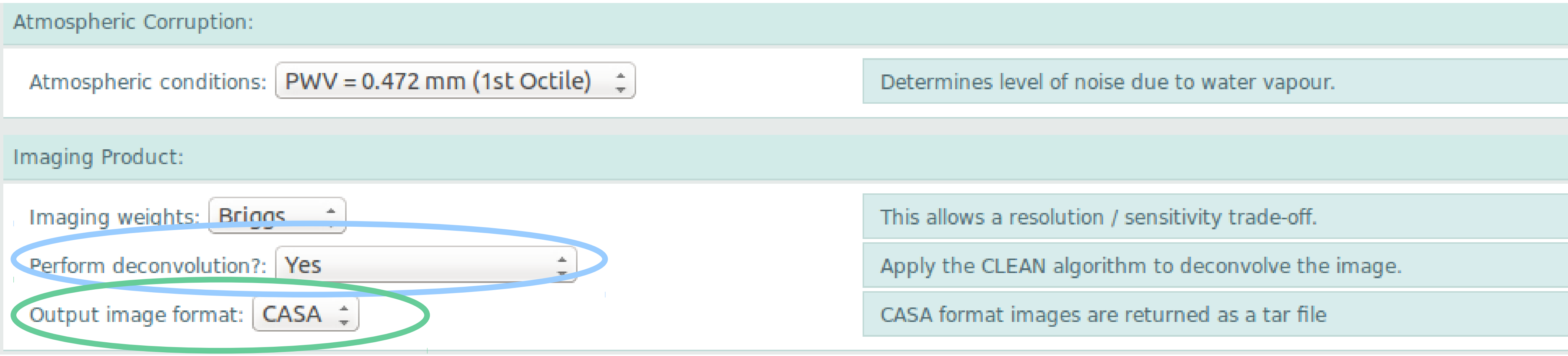


Imaging products



Weighting
Natural: visibilities are weighted according to the number of measurements within a given region of the u-v plane. **Maximum sensitivity but lower resolution than that offered.**
Uniform: applies equal weighting to all visibilities. **Maximum resolution.**
Briggs: intermediate approach.

Imaging



Perform deconvolution
If NO only the dirty image (Fourier transform of the visibilities) is produced.

Output image format: CASA or FITS

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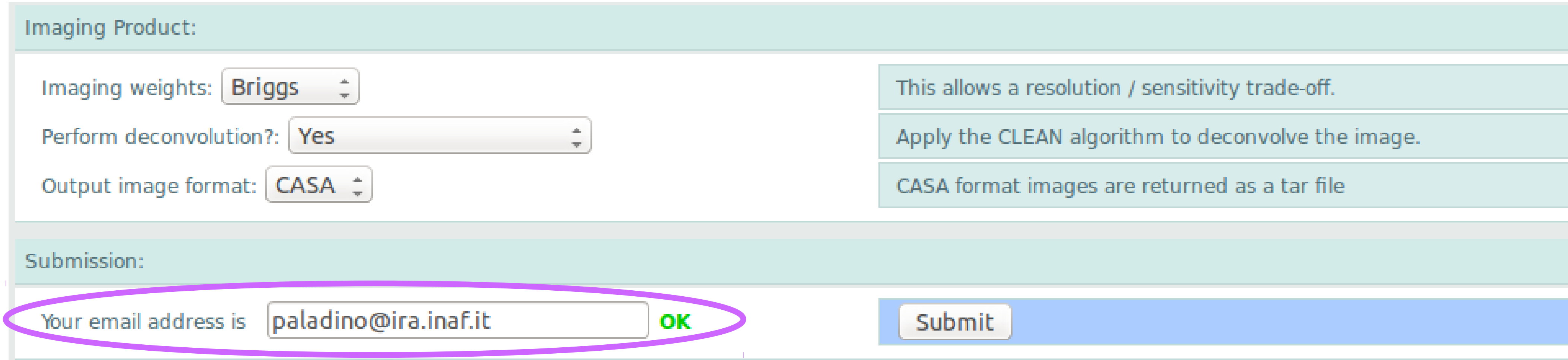
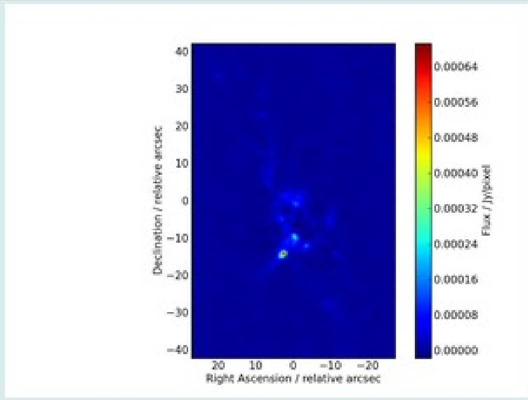
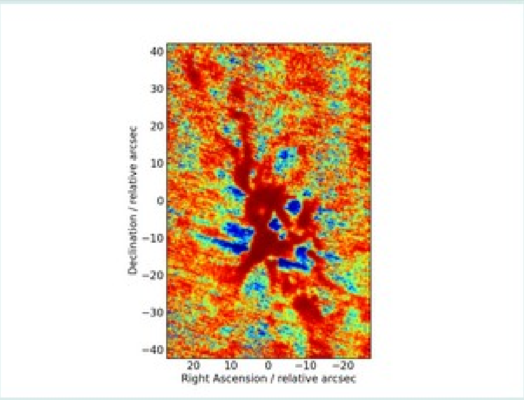
Submission



Your email address is essential!

You will be notified via email when the simulation is complete and be directed to a link:

Results: Overview

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:	72.88 degrees
Central frequency:	112.10 GHz (ALMA Band 3)
Total Bandwidth:	0.032 GHz
Track length:	4 hours × 1.0 visits
System temperature:	Tsys = 80.6330795691 K
PWV :	0.475 mm
Theoretical RMS noise:	6.30543753455e-05 Jy (in naturally-weighted map)
Restoring beam (resolution):	Major axis = 0.685 arcsec, minor axis = 0.607 arcsec, PA = 41.45 deg

Time on source 4 hrs

Theoretical RMS noise
Estimated in a naturally weighted map

Restoring beam
resolution obtained

Results: data products

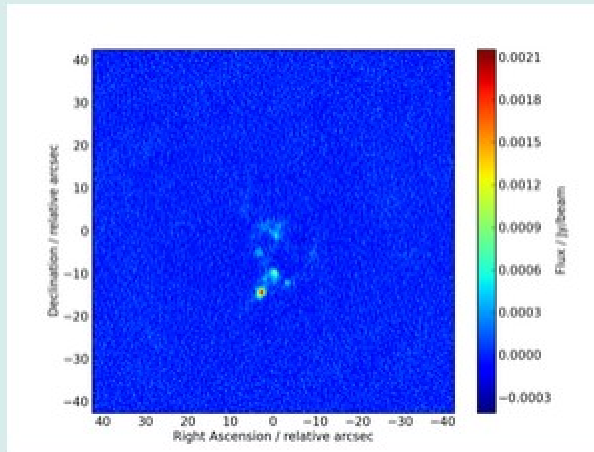
Data products

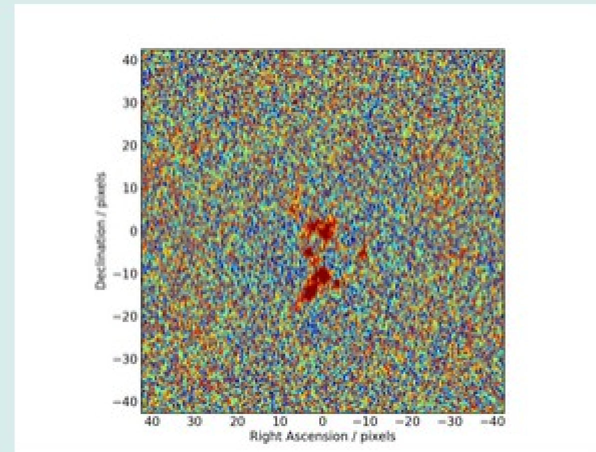
Your simulated image:

Download CASA image

and and with primary beam

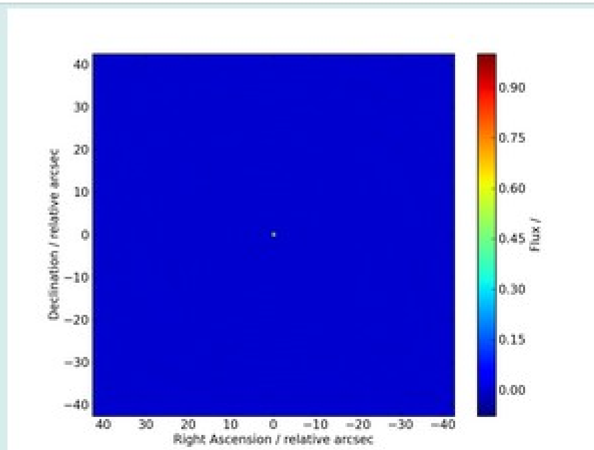
correction

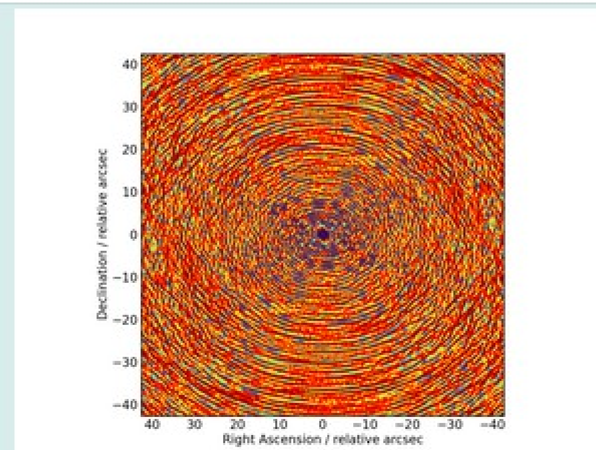




Dirty Beam

(Point Spread Function):





Simulated image and PSF.

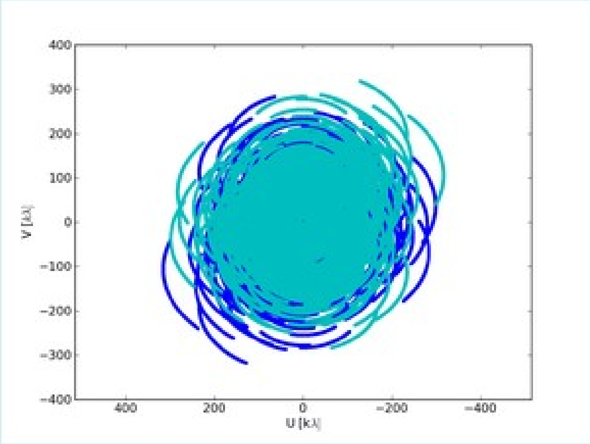
Linear pixel transfer function

Histogram equalization

Results: data products

Coverage in the *uv*-plane:

UV coverage

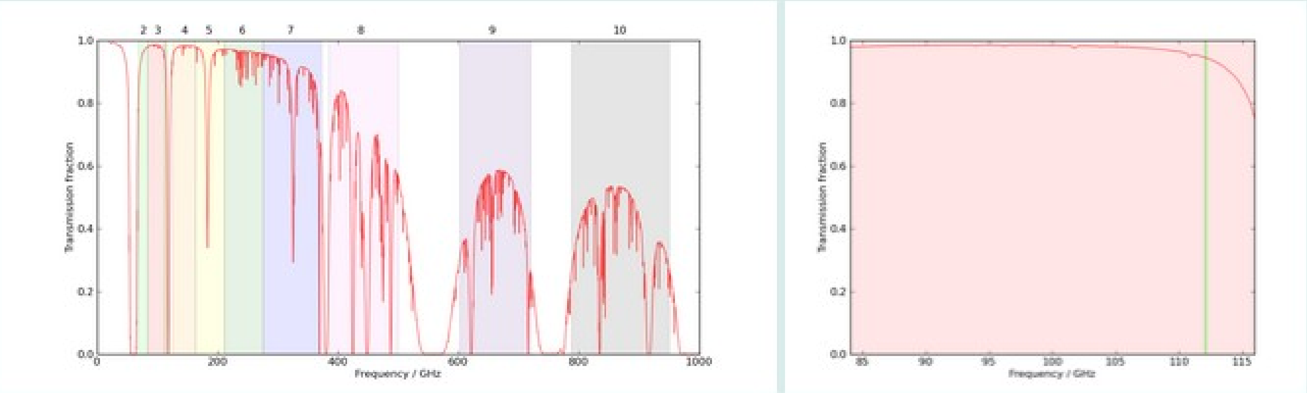


Atmospheric transmission for

all bands (left) and

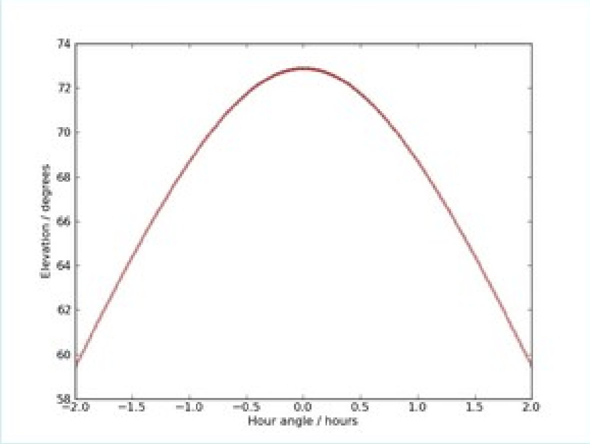
the selected band (right)

Atmospheric transmission and zoom to the band



Elevation vs time:

Source elevation



Comparison between these two methods

Simalma
Needs a little CASA knowledge
Allows more control on the simulation details.
It is possible to move a target to different distances, without producing a fits model image.
Combinations of different configurations and TP can be simulated.

OST
is very easy to use.
Only combinations of one configuration + ACA simulations are possible.
No TP.

Using both methods:

The rms measured in the simulated images can be significantly different from that predicted by the ALMA sensitivity calculator.

Simulations should only be used to qualitatively assess the sensitivity.
Expected sensitivity should only be based on the sensitivity calculator.

Grazie