ALMA simulations

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& the Italian ARC

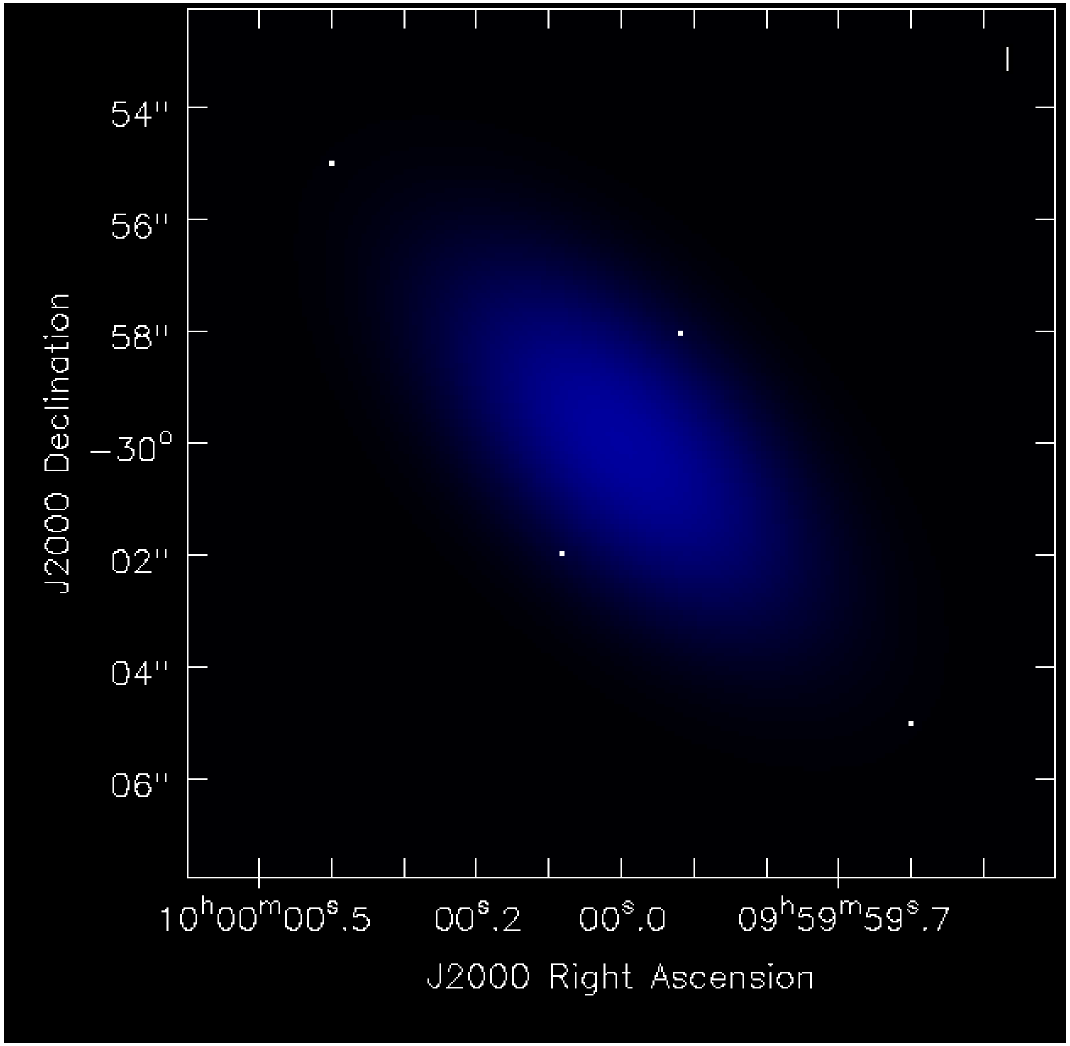
Why simulate ALMA observations

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



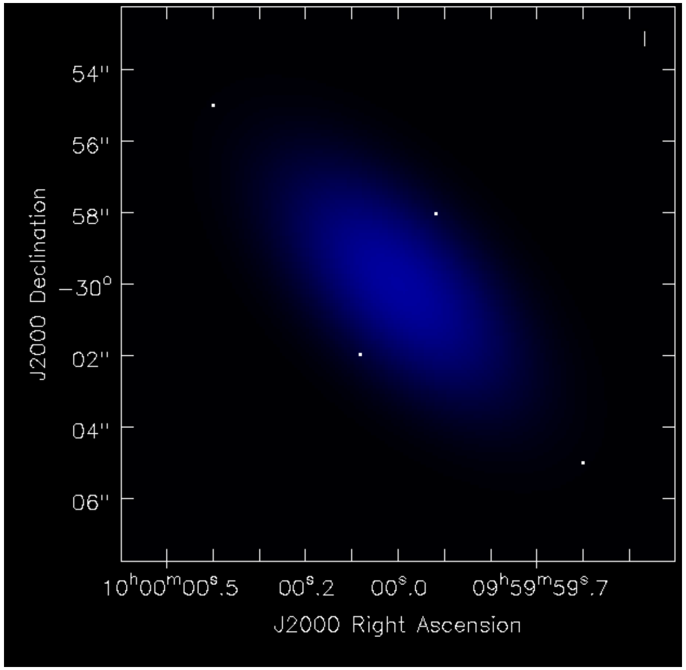
Assume this is our target field:

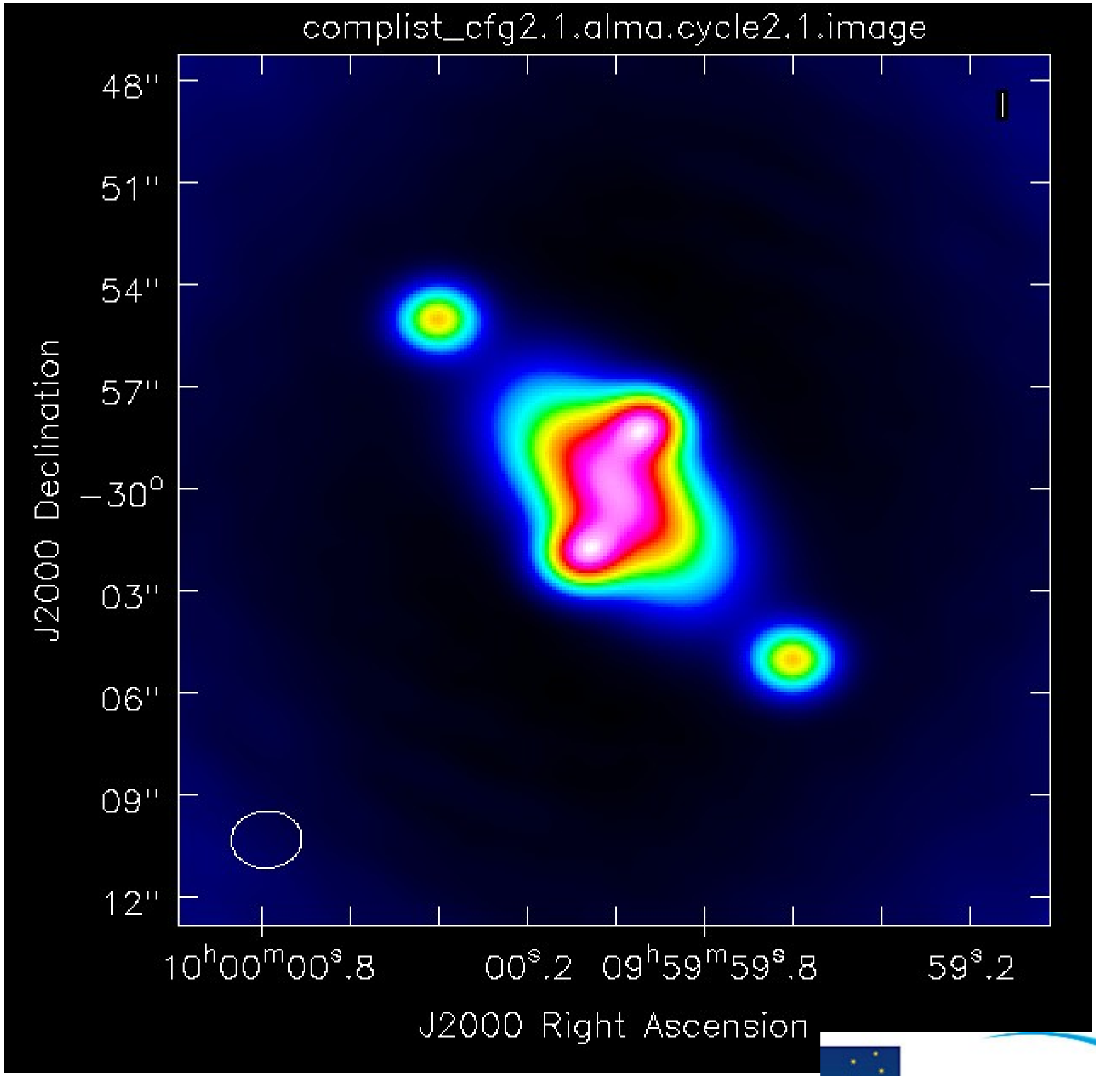
4 point sources

1 central gaussian

Why simulate ALMA observations

ALMA Cycle2.1 cfg **most compact**
8hrs observations 1 pointing





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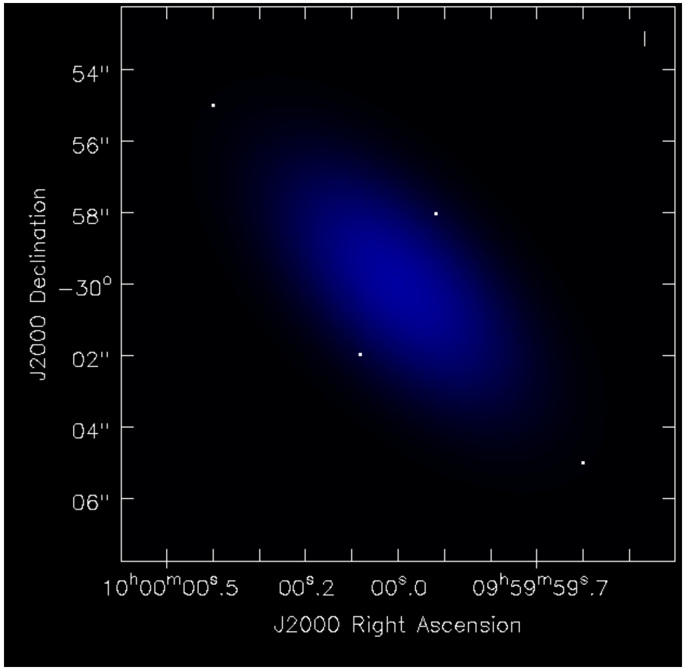
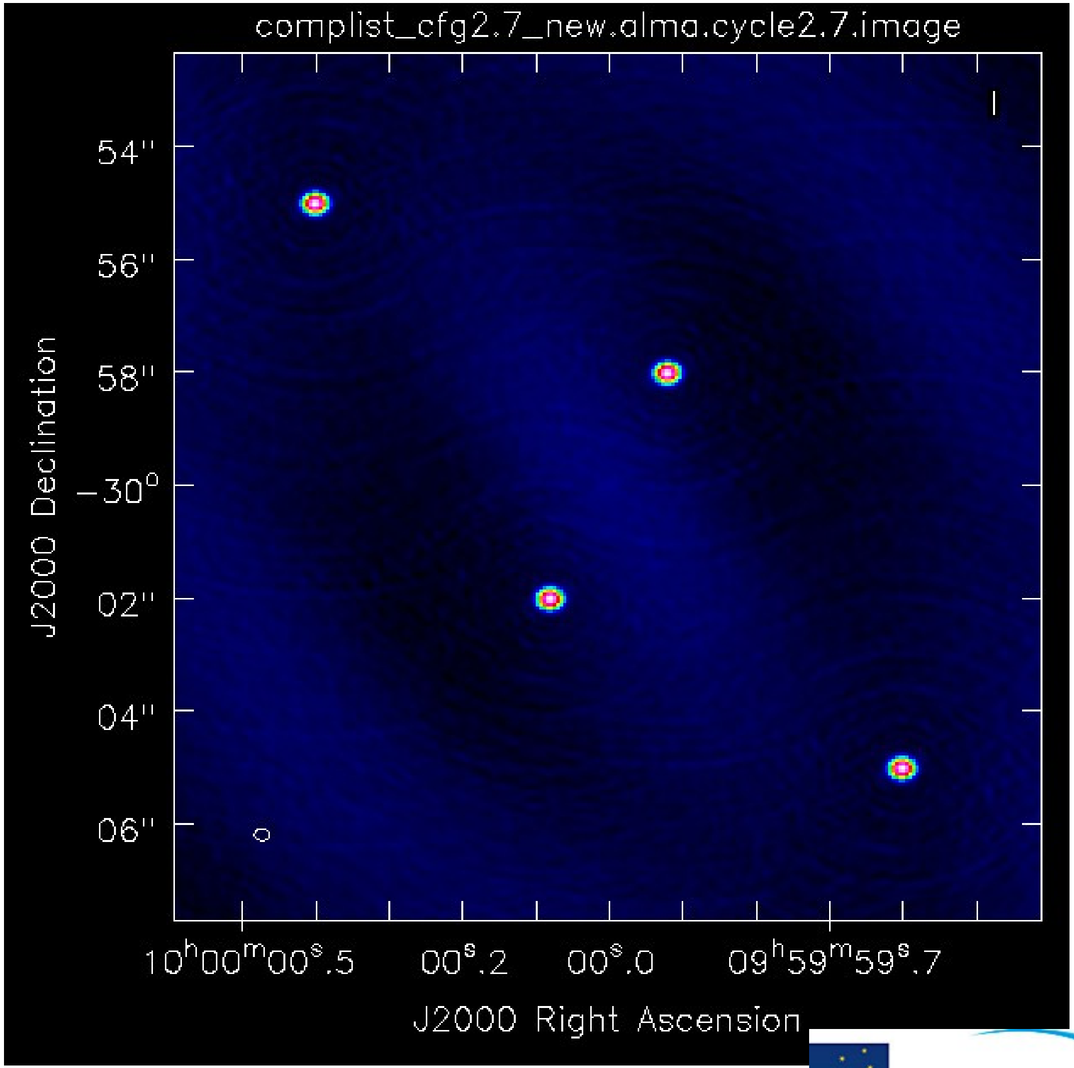
Why simulate ALMA observations

ALMA Cycle2.7 cfg **most extended**
8hrs observations 1 pointing





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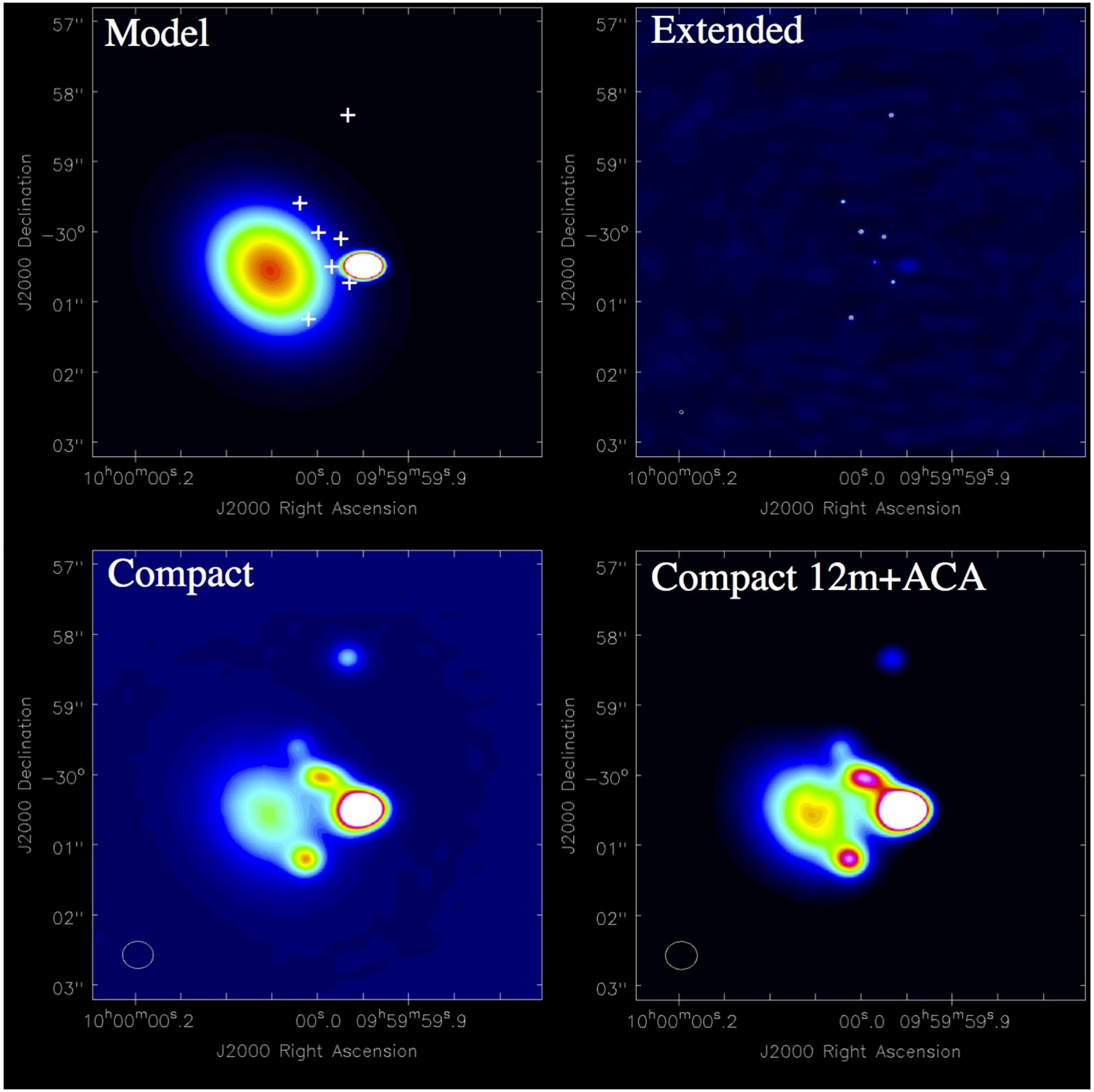
Why simulate ALMA observations

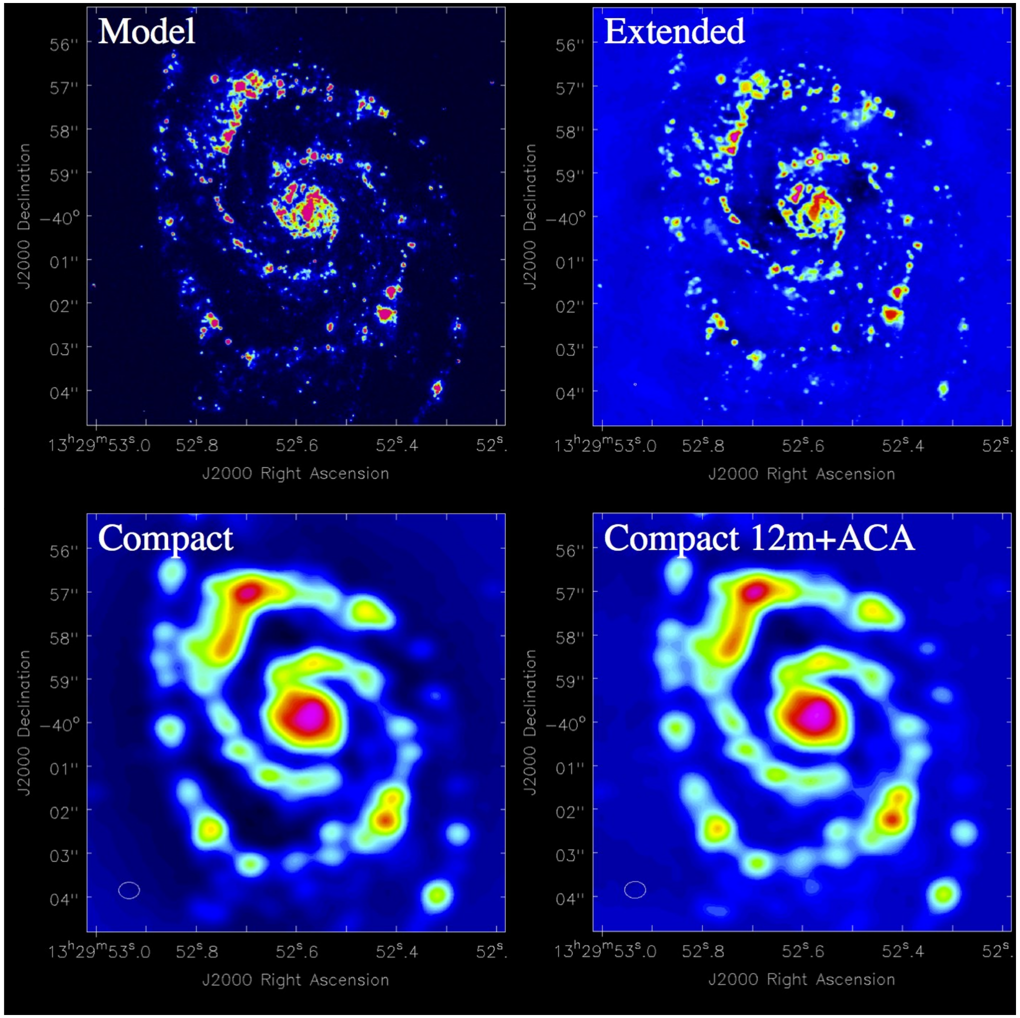


A more complex model:
many point sources and many gaussians

The extended configuration misses completely the emission from the largest gaussian component.
The compact cfg recovers the extended emission.
Adding ACA gives a more precise representation of the flux.

To recover both extended and point sources the combination of multiple 12 m array cfg and ACA are needed.

Why simulate ALMA observations



Simulation of a M51-like galaxy

The extended configuration reproduces well the model since most of the emission is on small angular scale.

The compact array gives the information on larger scales, and adding ACA the short spacings are recovered and the flux density recorded is closer to the model one.

The extended configurations cannot be combined directly with ACA because the large difference in uv-coverage would produce negative holes in the final image

ALMA configurations available during Cycle 2

	Band	3	4	6	7	8	9
	Frequency (GHz)	100	150	230	345	460.	650
Configuration							
7-m	θ_{res} (arcsec)	19.26	12.84	8.38	5.58	4.19	2.96
	θ_{MRS} (arcsec)	41.7	27.8	18.1	12.1	9.1	6.4
7-m-NS	θ_{res} (arcsec)	18.80	12.53	8.17	5.45	4.09	2.89
	θ_{MRS} (arcsec)	44.2	29.4	19.2	12.8	9.6	6.8
C34-1	θ_{res} (arcsec)	3.73	2.49	1.62	1.08	0.81	0.57
	θ_{MRS} (arcsec)	26.1	17.4	11.4	7.6	5.7	4.0
C34-2	θ_{res} (arcsec)	2.04	1.36	0.89	0.59	0.44	0.31
	θ_{MRS} (arcsec)	26.3	17.5	11.4	7.6	5.7	4.0
C34-3	θ_{res} (arcsec)	1.40	0.93	0.61	0.40	0.30	0.21
	θ_{MRS} (arcsec)	18.0	12.0	7.8	5.2	3.9	2.8
C34-4	θ_{res} (arcsec)	1.11	0.74	0.48	0.32	0.24	0.17
	θ_{MRS} (arcsec)	18.0	12.0	7.8	5.2	3.9	2.8
C34-5	θ_{res} (arcsec)	0.75	0.50	0.33	0.22	0.16	0.12
	θ_{MRS} (arcsec)	14.4	9.6	6.3	4.2	3.1	2.2
C34-6	θ_{res} (arcsec)	0.57	0.38	0.25	0.16	0.12	0.09
	θ_{MRS} (arcsec)	9.1	6.1	4.0	2.6	2.0	1.4
C34-7	θ_{res} (arcsec)	0.41	0.27	0.18	0.12	-	-
	θ_{MRS} (arcsec)	9.1	6.1	4.0	2.6	-	-

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_{MRS} (arcsec)	Array combinations for a specified $\{\theta_{res},\theta_{MRS}\}$	Time ratios	Total Time
0.41-0.57	< 9.1	C34-7	1	$1.0 \times \Delta_{extended}$
0.41-0.57	9.1-18.0	C34-7 + C34-3	$1 : 0.5$	$1.5 \times \Delta_{extended}$
0.41-0.57	18.0-41.7	C34-7 + C34-3 + 7-m	$1 : 0.5 : 2$	$3.5 \times \Delta_{extended}$
0.41-0.57	> 41.7	C34-7 + C34-3 + 7-m + TP	$1 : 0.5 : 2 : 4$	$5.5 \times \Delta_{extended}$

Table 7.4 ALMA cycle-2 Technical Handbook

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Desired angular resolution

Largest angular structure

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Table 7.4 ALMA cycle-2 Technical Handbook

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The most extended configuration is enough!

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2 main array configurations are needed!

Table 7.4 ALMA cycle-2 Technical Handbook

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2 main array configurations are needed!

Time scaling assumed for the observations

Table 7.4 ALMA cycle-2 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

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2 main array configurations + ACA are needed!

Time scaling assumed for the observations

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2 main array configurations + ACA are needed!

Time scaling assumed for the observations

Table 7.4 ALMA cycle-2 Technical Handbook

In spectral line mode (in band 3 to 8) the Total Power array is also available.

The OT, when the use of ACA is needed assumes that TP is also needed and gives an increased estimate of the observing time.
If you don't need TP you have to explicitly say so!

Desired angular resolution

Largest angular structure

θ_{res} (arcsec)	θ_{MRS} (arcsec)	Array combinations for a specified $\{\theta_{res},\theta_{MRS}\}$	Time ratios	Total Time
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0.41-0.57	> 41.7	C34-7 + C34-3 + 7-m + TP	1 : 0.5 : 2 : 4	$5.5 \times \Delta_{extended}$

The OT assumes you need TP in both cases!

Time scaling assumed for the observations

Table 7.4 ALMA cycle-2 Technical Handbook

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

Simulations with CASA tasks
simobserve & simanalyze (suggested CASA 4.2)
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

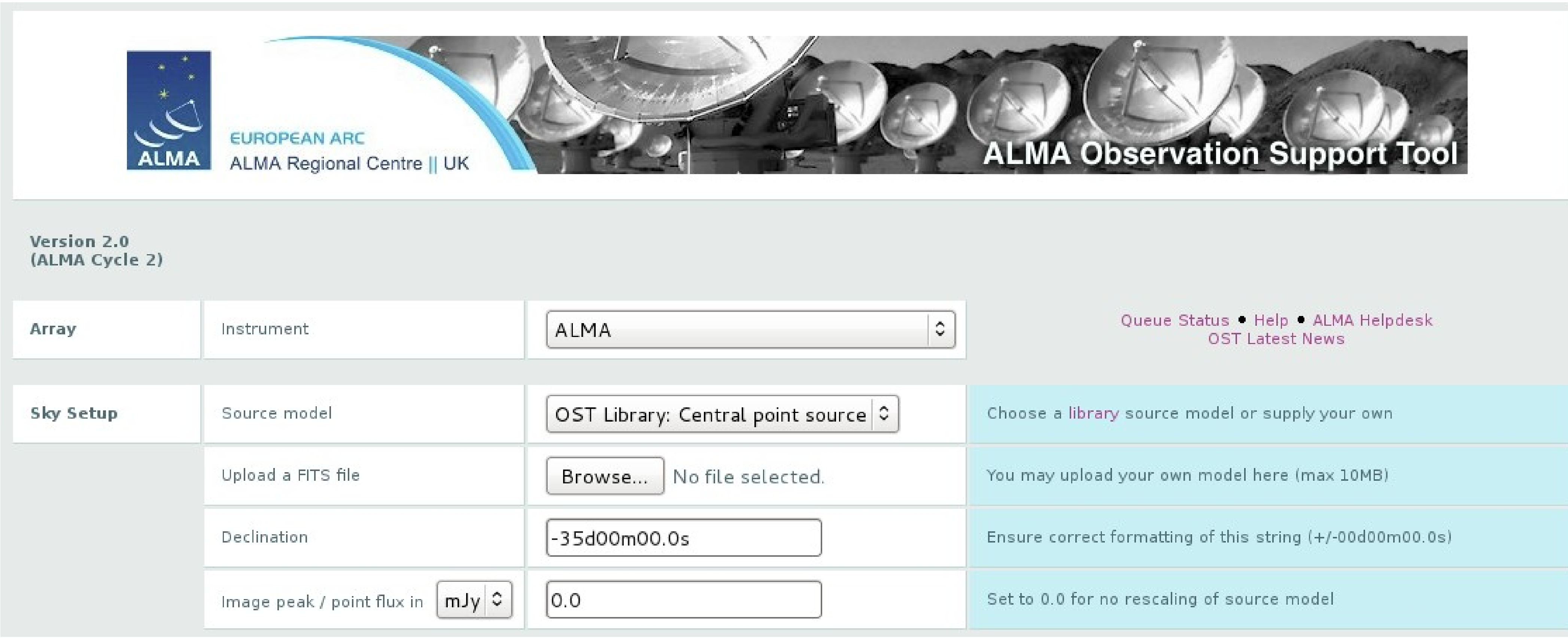
Simulations with CASA

- 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**

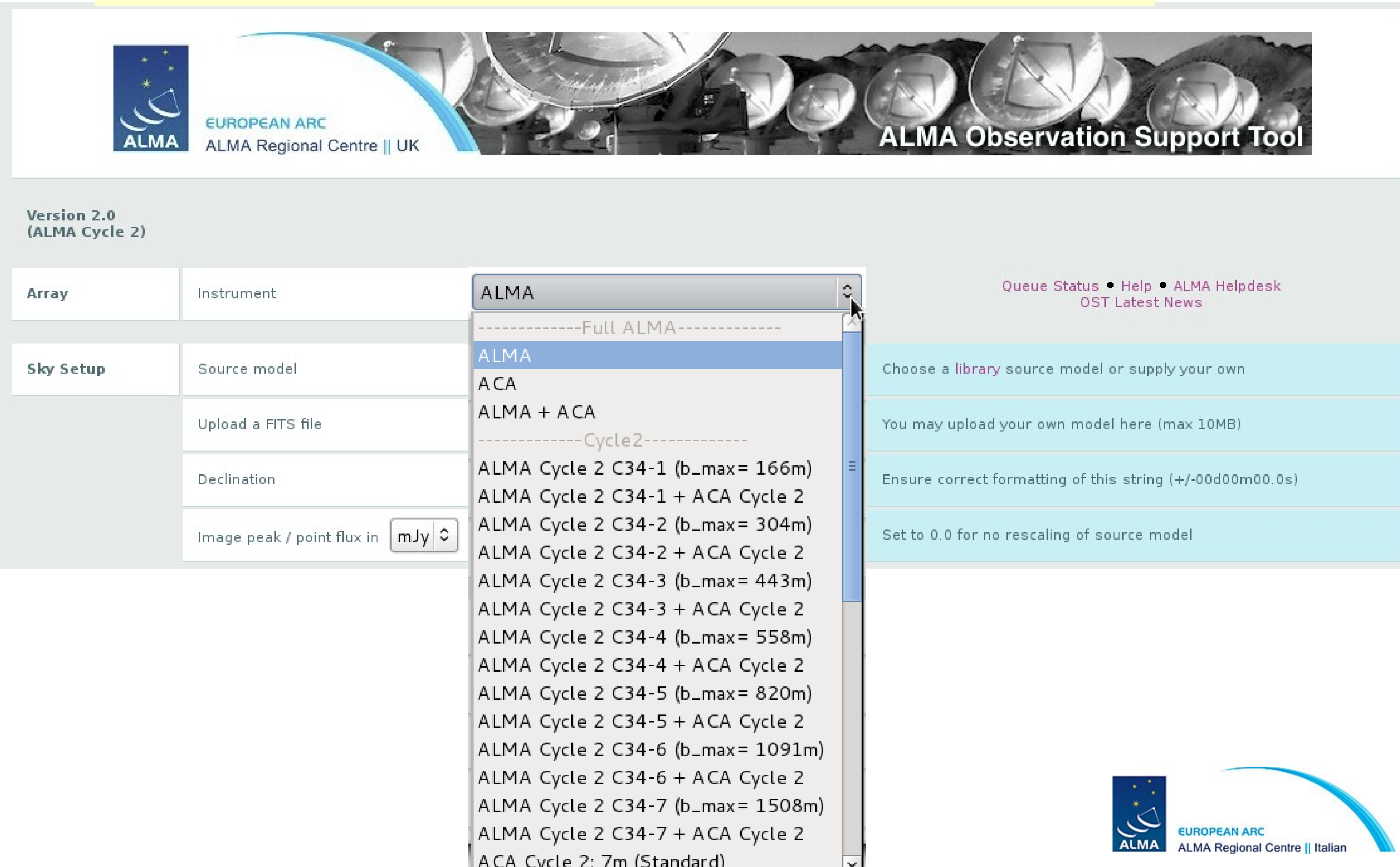
- **If you need CASA simulations we can help you running CASA scripts during this afternoon session or some other time.**

ALMA Observation Support Tool

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



Array selection



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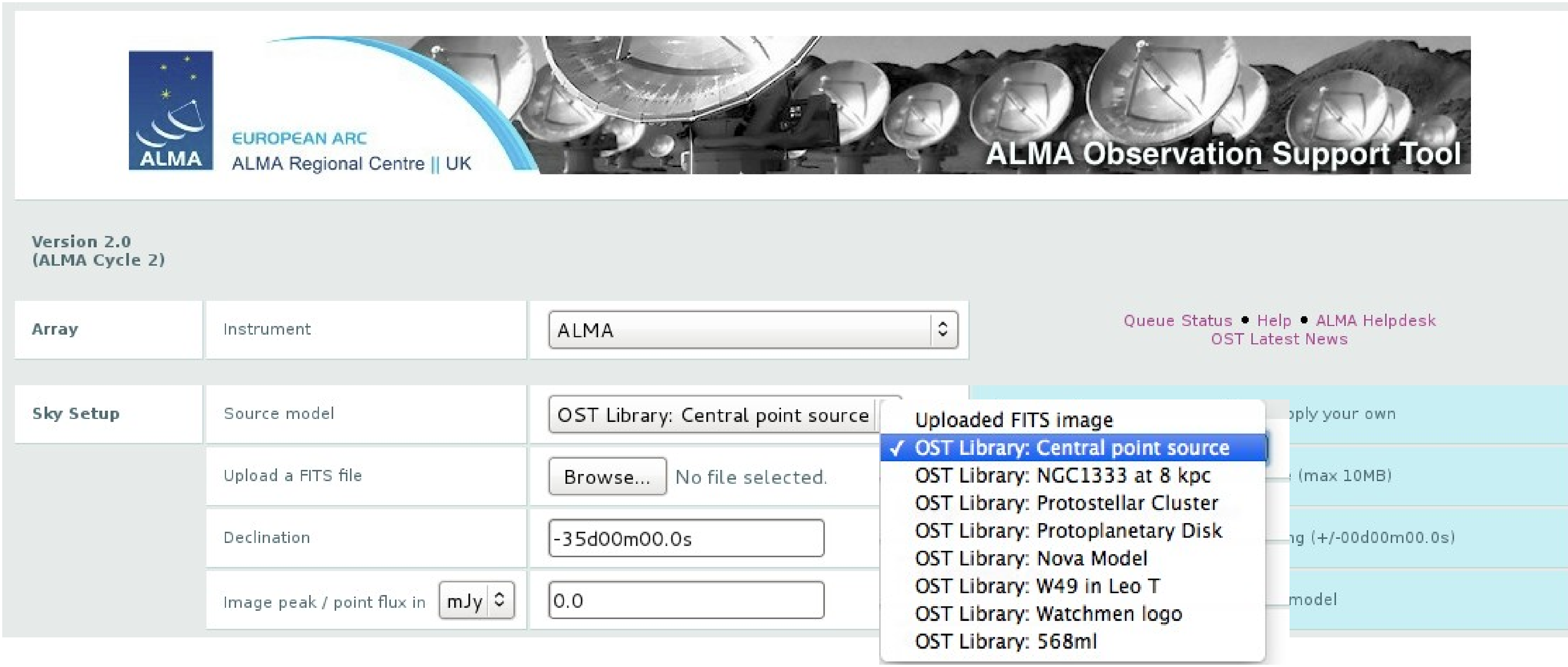
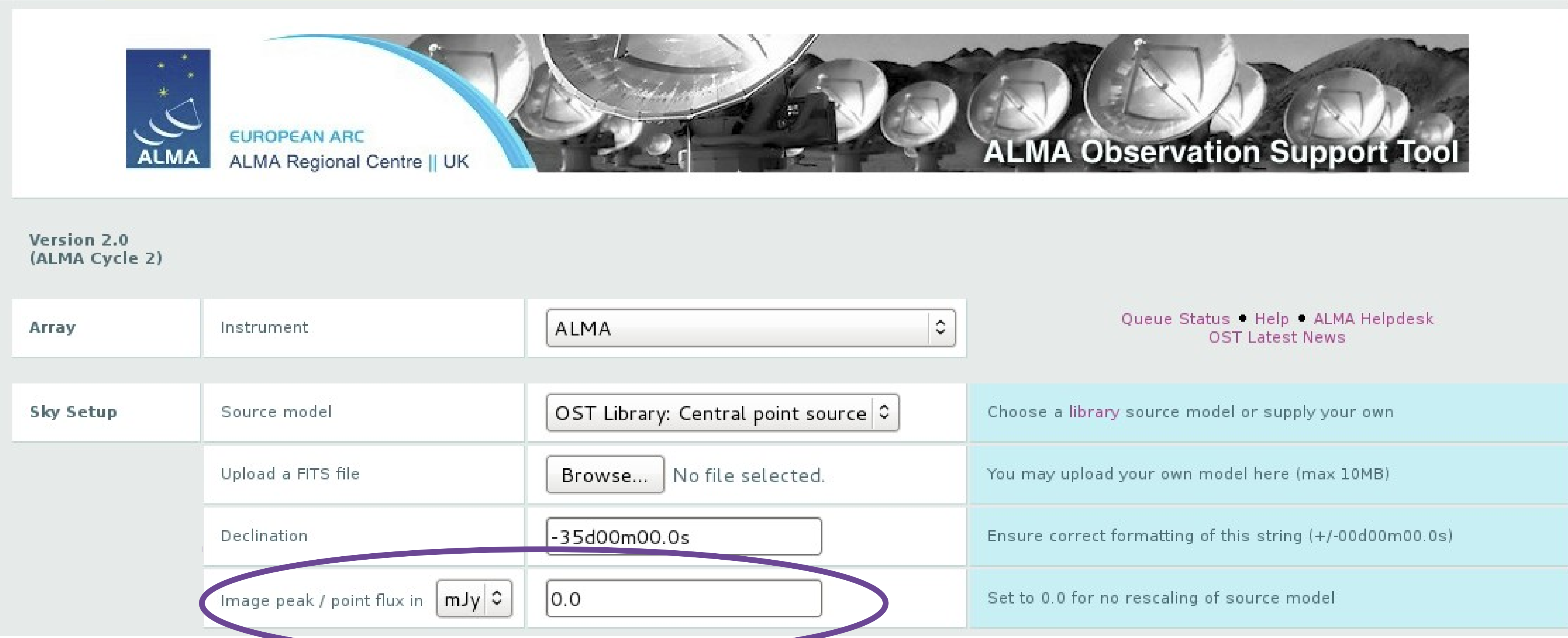
Source model



Source model



The original image I_{xy} will be scaled according to
(M is the original maximum value of the image)
0 means no scaling

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

If point source model is chosen this sets the flux of the source

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Observation setup

Observation Setup	Central frequency in GHz	90	The value entered must be within an ALMA band
	Bandwidth in MHz	32	Use broad for continuum, narrow for single channel
	Use recommended continuum setup?	(•) No ( ) Yes	If Bandwidth = 7.5GHz use the ALMA recommended spectral window spacing for continuum simulations.
	Required resolution in arcseconds	1.0	OST will choose config if instrument is set to ALMA
	Pointing strategy	Mosaic	Selecting single will apply primary beam attenuation
	Start hour angle	0.0	Deviation of start of observation from transit
	Phase Cycle in seconds	0.0	The length of time between cutting to a phase calibrator. Currently limited to either 0s **or** between 300s and 600s.
	On Phase Calibrator in seconds	0.0	The length of time spent observing phase calibrator (including slewing time). Currently limited to either 0s **or** between 30s and 120s.
	On-source time in hours	3	Per pointing for Mosaics.
	Number of visits	1	How many times the observation is repeated
	Number of polarizations	2	This affects the noise in the final map

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

Observation setup

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Use recommended continuum setup?
YES (only if bandwidth is 7.5GHz): it will use ALMA recommended spw for continuum observations

Observation setup

Observation Setup	Central frequency in GHz	90	The value entered must be within an ALMA band
	Bandwidth in [MHz]	32	Use broad for continuum, narrow for single channel
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	Number of polarizations	[2]	This affects the noise in the final map

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

Observation Setup			
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	Number of visits	1	How many times the observation is repeated
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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

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Observation setup

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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.

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Phase cycle
between 300 and 600 s. Indicates the on source time between cuts of hypothetical phase calibrator.
On phase calibrator time spent on the hypothetical phase calibrator after each on source cut.

Observation setup

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Number of visits

If the observation is longer than 24 hours, or occupies a limited range of hour angles is needed.

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

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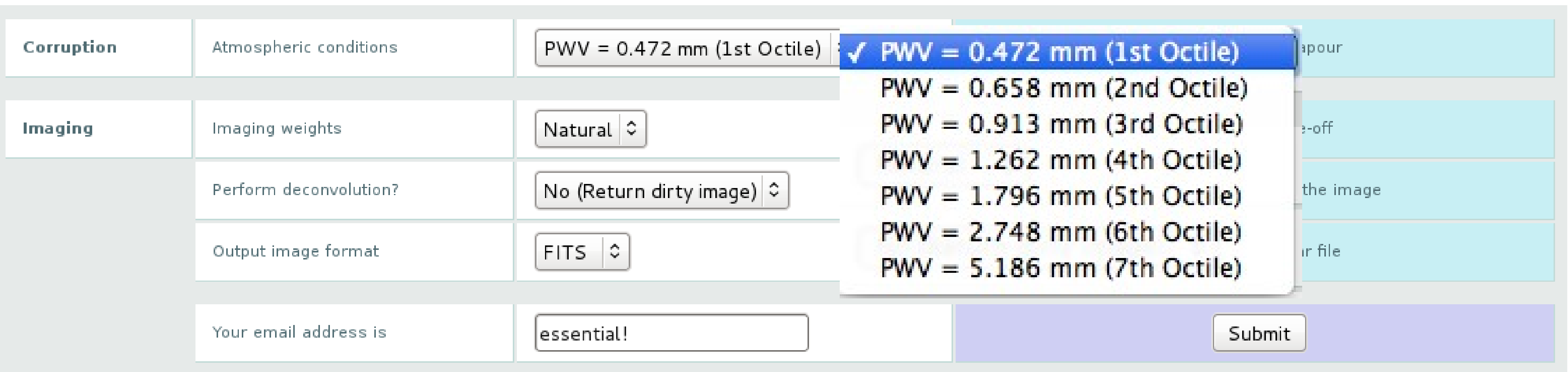
Corruption and imaging

Corruption	Atmospheric conditions	PWV = 0.472 mm (1st Octile)	Determines level of noise due to water vapour
Imaging	Imaging weights	Natural	This allows a resolution / sensitivity trade-off
	Perform deconvolution?	No (Return dirty image)	Apply the CLEAN algorithm to deconvolve the image
	Output image format	FITS	CASA format images are returned as a tar file
	Your email address is	essential!	Submit

Corruption



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

Imaging

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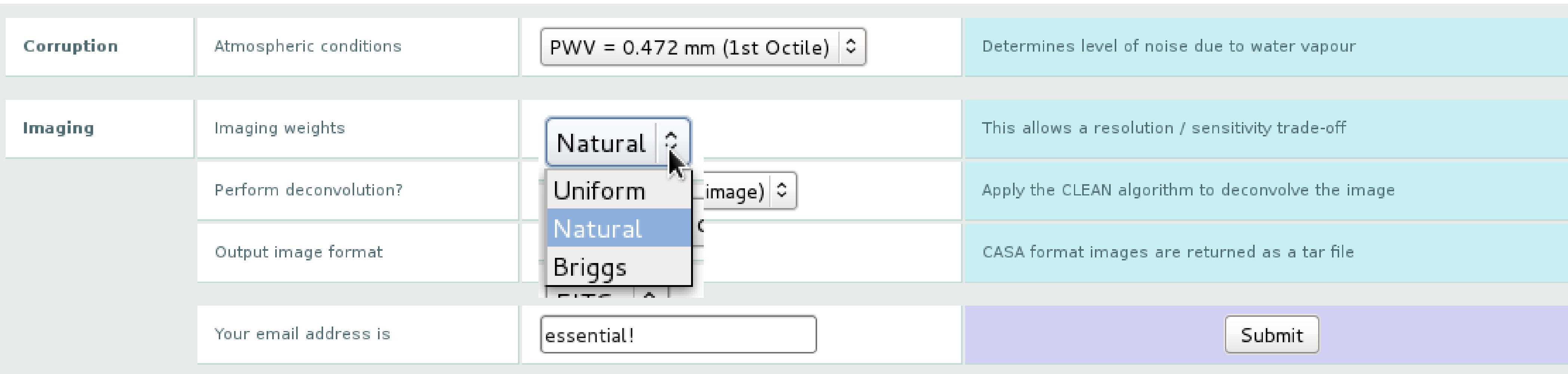
Imaging



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.

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Imaging

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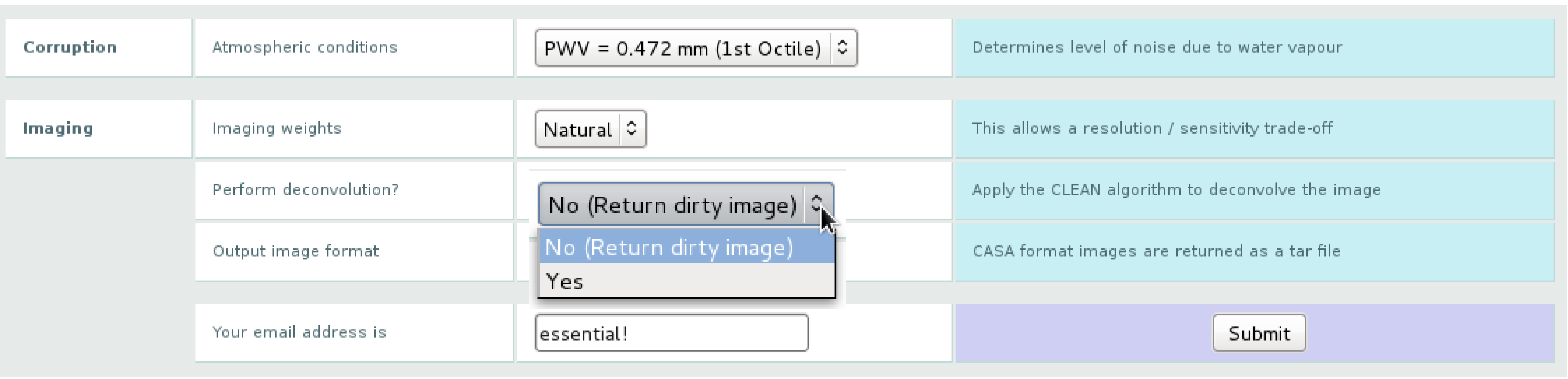
	Your email address is	essential!	Submit

Imaging



Deconvolution
If required the OST performs it using the CLEAN algorithm.
The CLEAN cycle stops when the theoretical noise limit in the map is reached.

Imaging

Corruption	Atmospheric conditions	PWV = 0.472 mm (1st Octile)	Determines level of noise due to water vapour
Imaging	Imaging weights	Natural	This allows a resolution / sensitivity trade-off
	Perform deconvolution?	No (Return dirty image)	Apply the CLEAN algorithm to deconvolve the image
	Output image format	FITS FITS CASA	CASA format images are returned as a tar file
	Your email address is		Submit

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email

Corruption	Atmospheric conditions	PWV = 0.472 mm (1st Octile)	Determines level of noise due to water vapour
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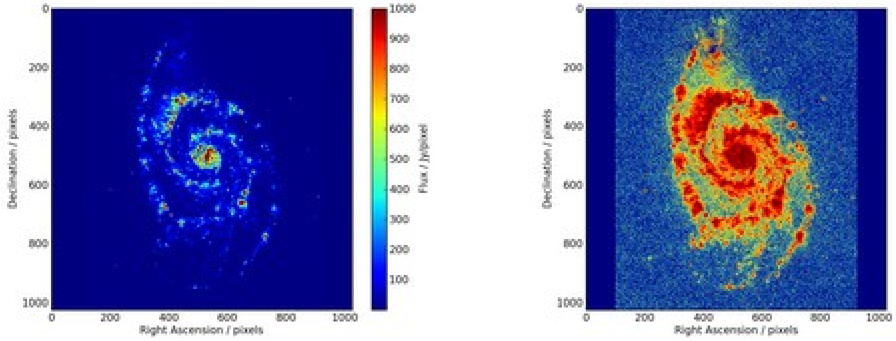
	Output image format	FITS	CASA format images are returned as a tar file
	Your email address is	essential!	Submit

Your email address is essential!

You will be notified via email when the simulation is complete.

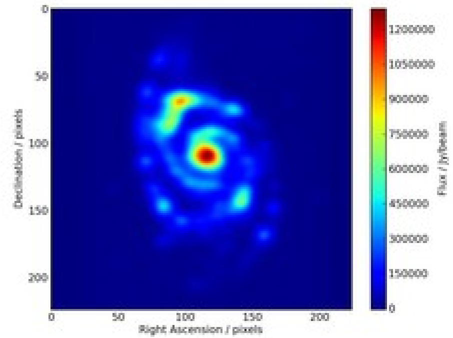
Results overview

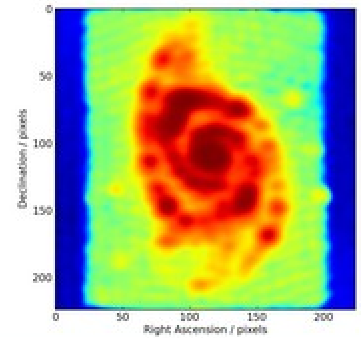
Overview	
Click thumbnails to view full-size images. Left: linear colour scale, right: with histogram equalization.	
Array configuration	ALMA Cycle 2 C34-7 (1508 m baseline)
Source model	M51 originally observed in H_alpha
	
Maximum elevation	77.89 degrees
Central frequency	90 GHz = Band 3
Bandwidth	0.00749999999999 GHz
Track length	8 hours × 1.0 visits
Hexagonal mosaic pointings	1 required to cover requested sky area with uniform sensitivity
System temperature	Tsys = 67.5701719499 K
PWV	0.475 mm
Theoretical RMS noise	0.000126651276648 Jy (in naturally-weighted map)
Restoring beam (resolution)	Major axis = 0.474 arcsec, minor axis = 0.376 arcsec, PA = 93.255 deg

Data products

Image
with and without
histogram equilization

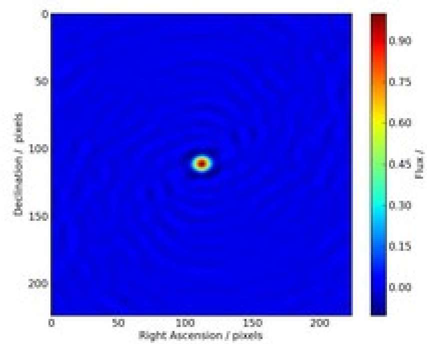
Your simulated image
Download FITS file

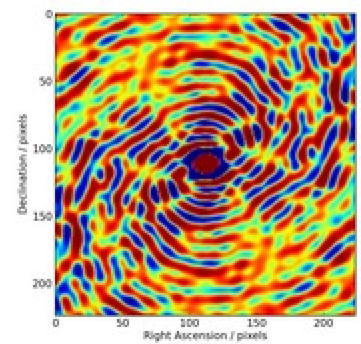




Dirty Beam
(Point Spread Function)

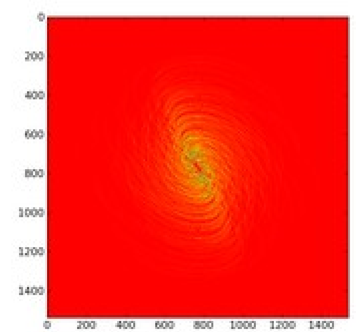
synthesyzed beam
PSF

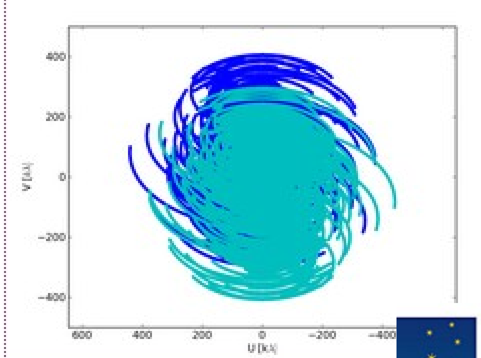




Coverage in the *uv*-plane

uv-plane coverage





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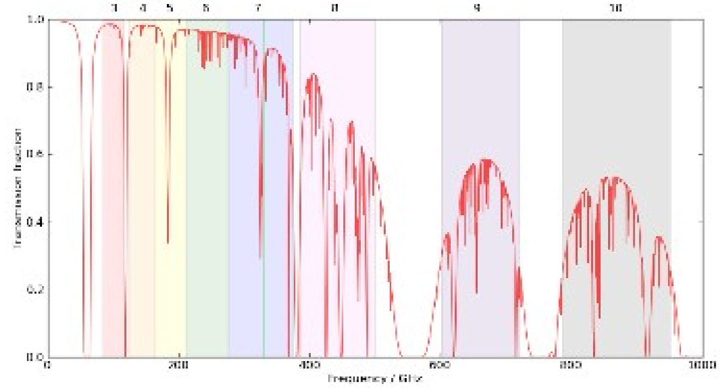
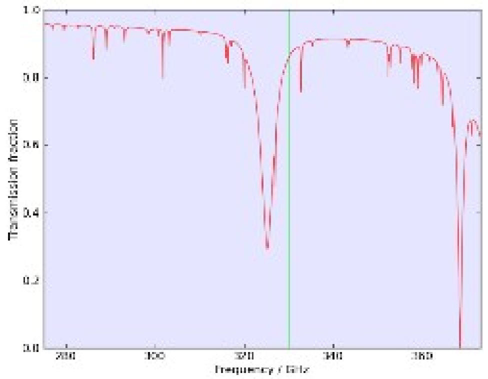
Data products

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

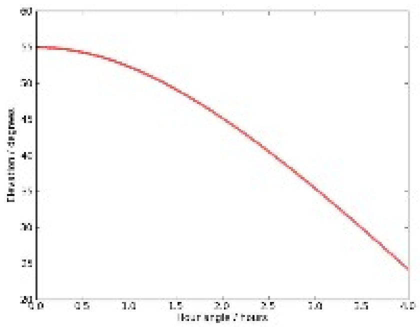
Atmospheric transmission for all bands (left) and the selected band (right)





Elevation vs time

Source elevation vs time

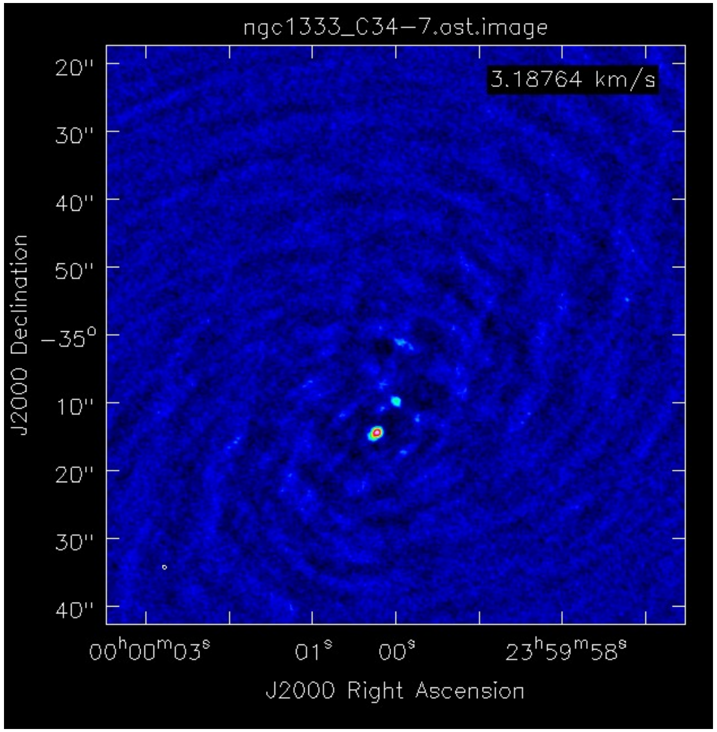


Data combination

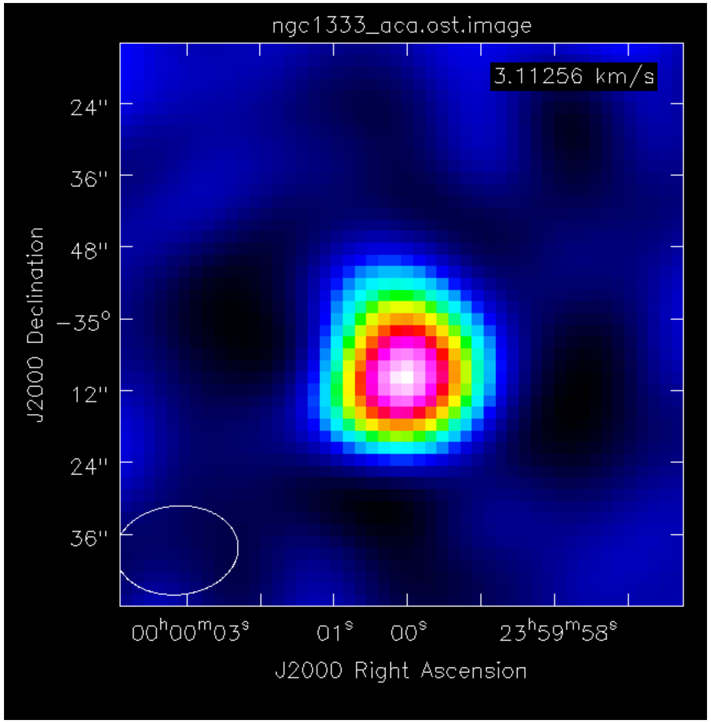
You can simulate observations taken with one 12 m array configuration and the ACA selecting it from the array selector.

NGC1333 model from the OST template

ALMA C34-7



ALMA ACA



You get two different simulated datasets.
The OST provides a python script to combine them.
You have to run it in CASA:

CASA> execfile('ost_combine.py')

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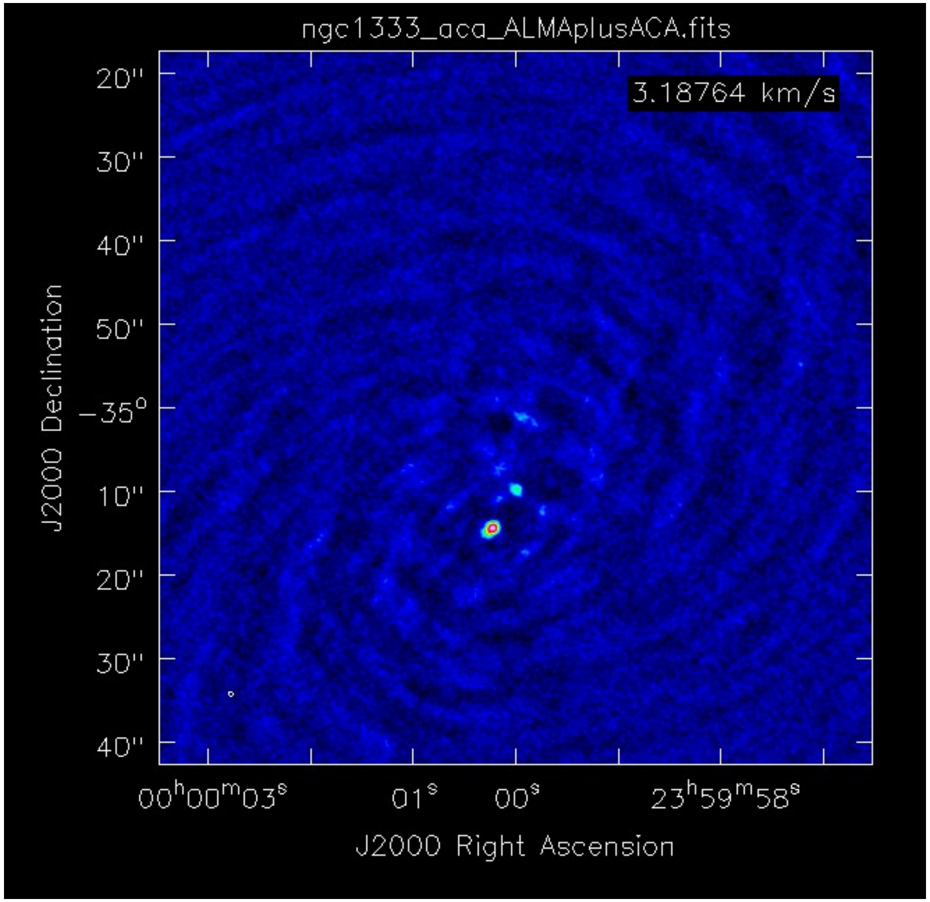
Data combination

ALMA C34-7 + ACA



In this case the combination does not show a clear improvement in the image because we are combining a very extended configuration with the ACA.

In summary

Simulations can provide informative results on the feasibility of proposed observations. They can provide information on the fraction of the flux that is resolved out by a given configuration.

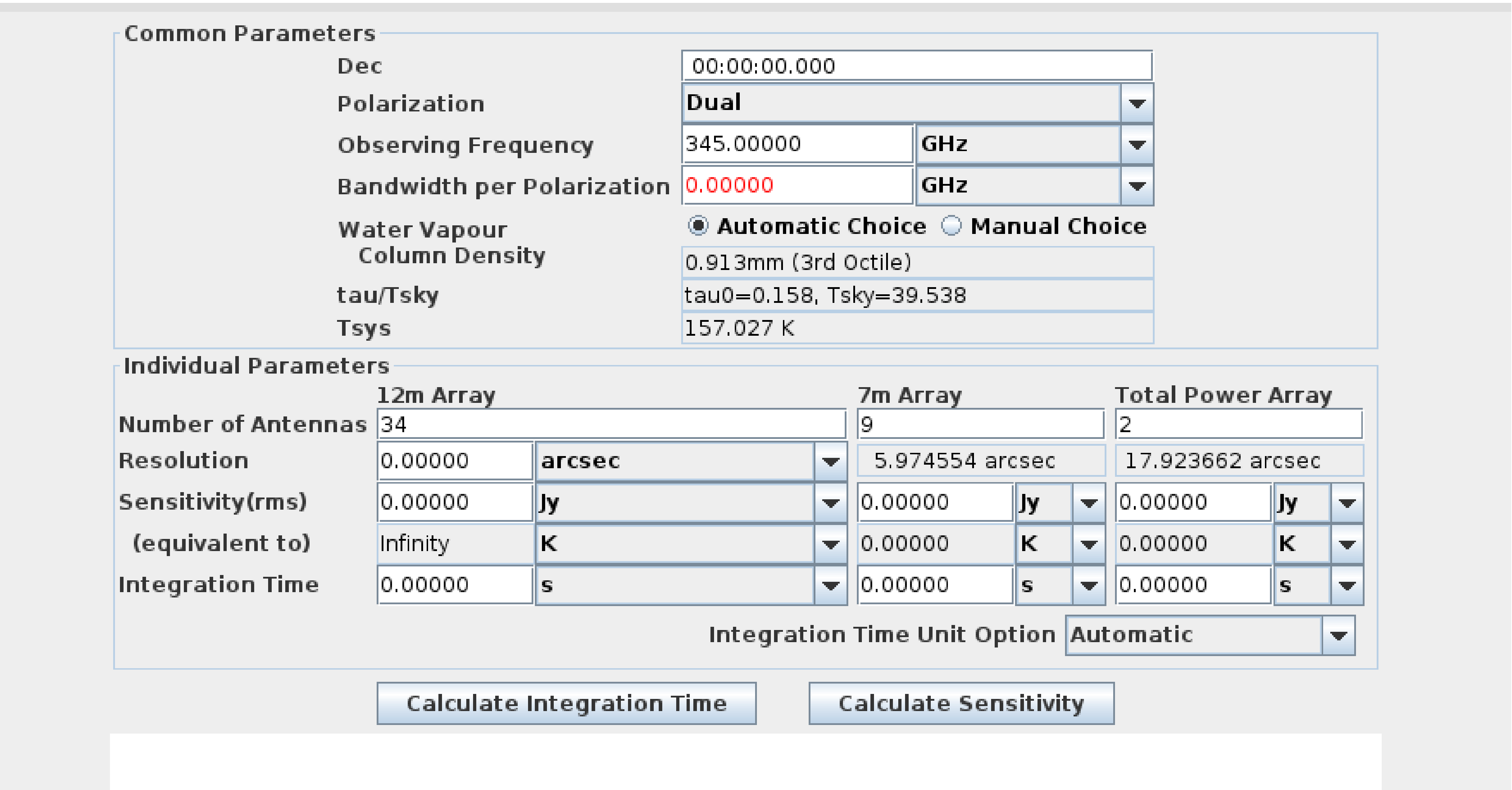
BUT

Significant differences exist sometimes between the noise predicted by the ALMA sensitivity calculator and the measured RMS in the simulated images.
Simulations should only be used to qualitatively assess the sensitivity.

Expected sensitivity (proposed observing time) should only be based on the sensitivity calculator.

ALMA sensitivity calculator

http://almascience.eso.org/proposing/sensitivity-calculator



Grazie