Technical Justification and CASA Simulator

Town hall meeting for ALMA Cycle 4
2016 March 28

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Technical Justification

what cube data for your science

- Sensitivity
- Imaging
- Correlator configuration
- Choices to be justified

Sensitivity

- Multiple sources: most restrictive values
- Continuum and/or line flux
- Line: bandwidth for sensitivity ≲ 1/3 of line width
- Spectral dynamic range: both spectral line properties and a continuum flux put in <continuum>/<line rms>

Imaging

- Imaging goals of a proposal
- Requested angular resolution
- Requested Largest Angular Structures (LAS)
  0 (zero): any 12-m configuration could be used so angular resolution might be much better
- Change OT's recommendation (ACA, default Nyquist sampling for rectangular mosaics)
  => explicitly justify

Correlator configuration

- Number of spectral resolution elements (including Hanning smoothing and spectral averaging) per line width
- Bandwidth of the Representative Window
- Example: We use the default continuum polarimetric correlator set-up.

Choices to be justified

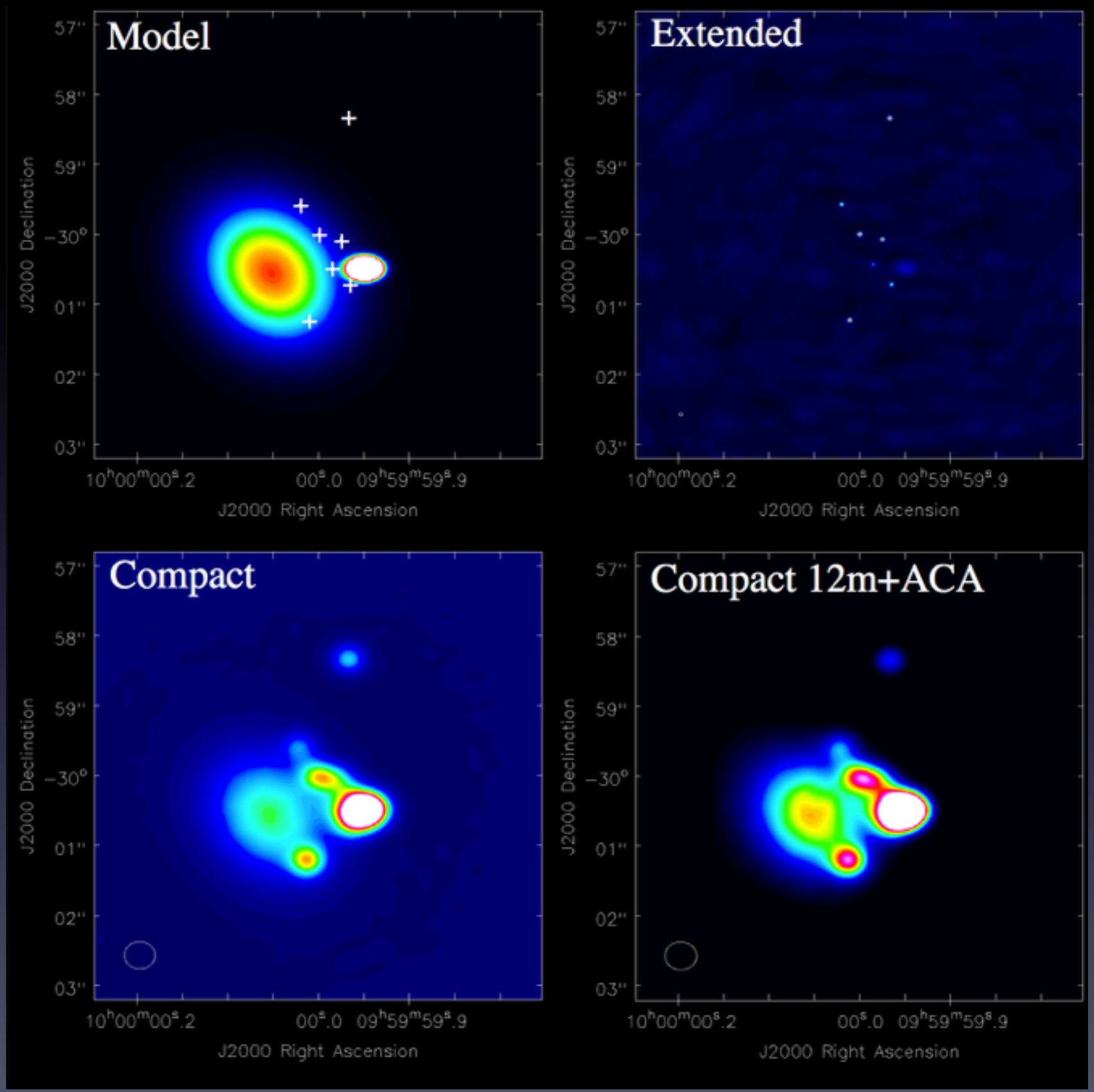
- **Non-Nyquist mosaic sampling**: large field without large-scale structures
- **Single polarization**: e.g., for highest spectral resolution
- (**High data rate**: due to many high spectral-resolution spectral windows, easiest way-spectral averaging)
- **Low max elevation**: large atmospheric attenuation, limited time above the horizon
- **User-defined calibration**: must be rigorously justified
- (**ACA choice overridden**: depending on LAS, ACA recommended)
- **Override of OT's sensitivity-based time estimate**: e.g., monitor a source over a certain time span, sufficient uv coverage for imaging complicated structures => detailed justification for the time override and how the new time was estimated (including calibrations and overheads)
- **Time-constrained observing**: significant constraints on the scheduling of all ALMA projects

CASA simulator

Why?

- Mock observations of ALMA
- Not necessary, however:
- Show if your science can be done by ALMA
- Verify what you need for your science goals
  e.g., which configurations

- Comparison of different array configurations



http://casaguide.nrao.edu

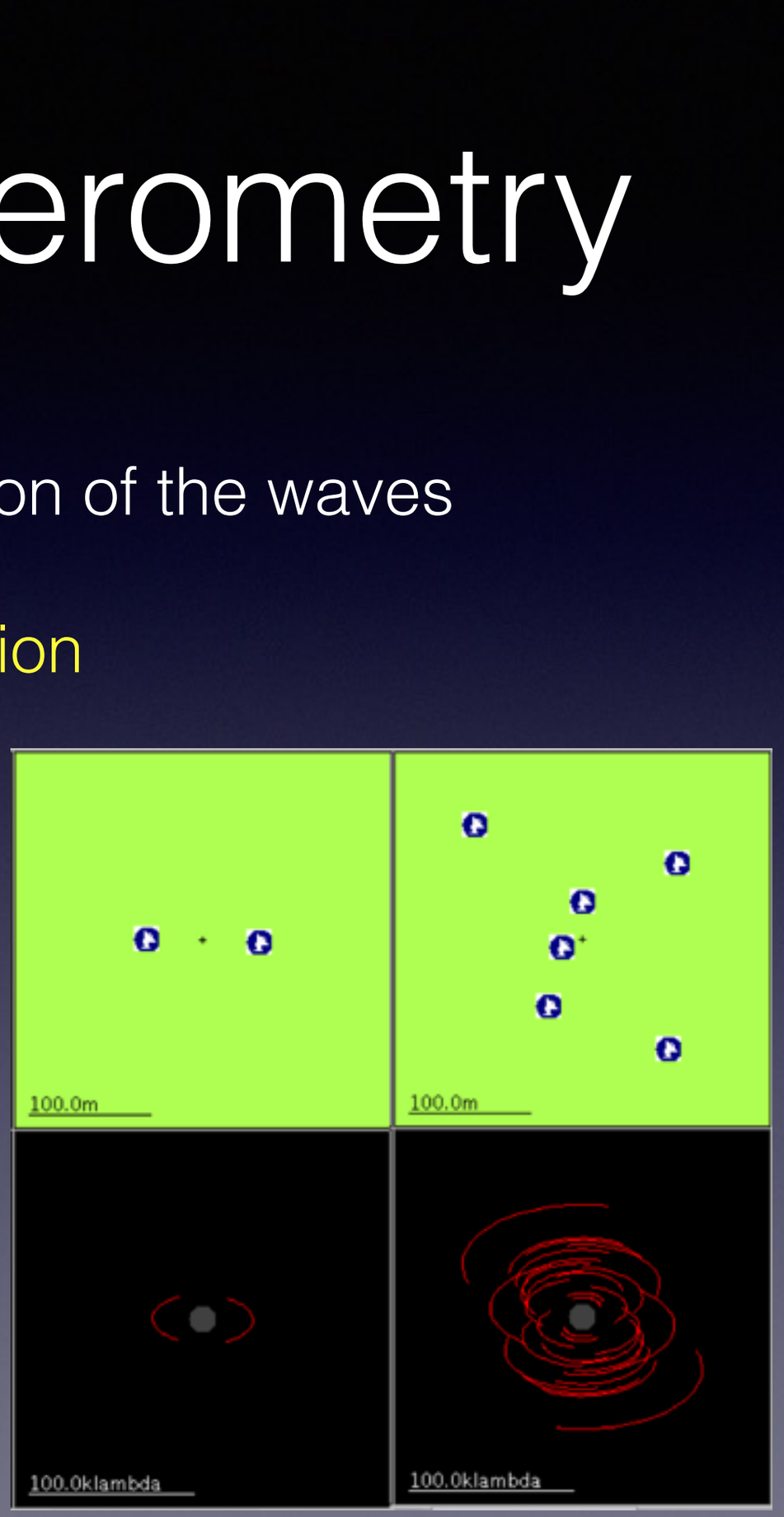
Basics of Interferometry

- Interferometer data: uv visibility
  - Power corresponding to the correlation of the waves received at two antennas
  - FT relation with sky intensity distribution
  - (u, v) coordinates

$$V(u,v) \rightleftarrows A_N(l,m)I(l,m).$$

$$S(u,v)V(u,v) \rightleftarrows FT^{-1}[S(u,v)] * FT^{-1}[V(u,v)]$$
$$B_D(l,m) * [A_N(l,m)I(l,m)].$$

- Keywords
  uv coverage, uv distance,
  synthesized beams, primary beam…



$$V(u,v) \rightleftarrows A_N(l,m)I(l,m).$$

$$\begin{aligned} S(u,v)V(u,v) &\rightleftarrows FT^{-1}[S(u,v)] * FT^{-1}[V(u,v)] \\ &\quad B_D(l,m) * [A_N(l,m)I(l,m)]. \end{aligned}$$

- Simulating interferometric data (visibilites)
  1. sky intensity distribution (model): I(l,m)
  2. primary beam correction: A_N(l,m) I(l,m)
  3. FT: V(u,v)
  4. sampling over S(u,v): S(u,v) V(u,v)

- Interferometric data reduction
  1. data: S(u,v) V(u,v)
  2. IFT
  3. de-convolution of B_D(l,m) to fine A_N(l,m) I(l,m)

Two Approaches

- CASA simulation tools
- Observation Support Tool (OST)
  EU ARC, University of Manchester
  Web-based
  http://almaost.jb.man.ac.uk

CASA 123

- Common Astronomy Software Applications
  http://casa.nrao.edu
- Install CASA - version 4.3.1 (latest: version 4.5.2)
- > casapy
  : tasklist
  : taskhelp
  : inp(<task>)
  : project = 'sim' (example of putting in a parameter value)
  .....
  : go (or a task name)

CASA simulation tools

- CASA version 4.3 http://casaguides.nrao.edu/index.php?title=Simulating_Observations_in_CASA_4.3
- Simobserve
  generate visibilities
- Simanalyze
  produce a cleaned image
- (Simalma)
  particular cases: e.g., combining 12-m array and ACA data

Caveats

- RMS noise should not be used for proposals
- 20% underestimates for both surface brightness and total flux in single dish maps

What you need

- Possible starting points: a model image in FITS

  e.g.,

  images taken at a different wavelength

  numerical simulation results

  knowledge on object size and total flux

Simobserve

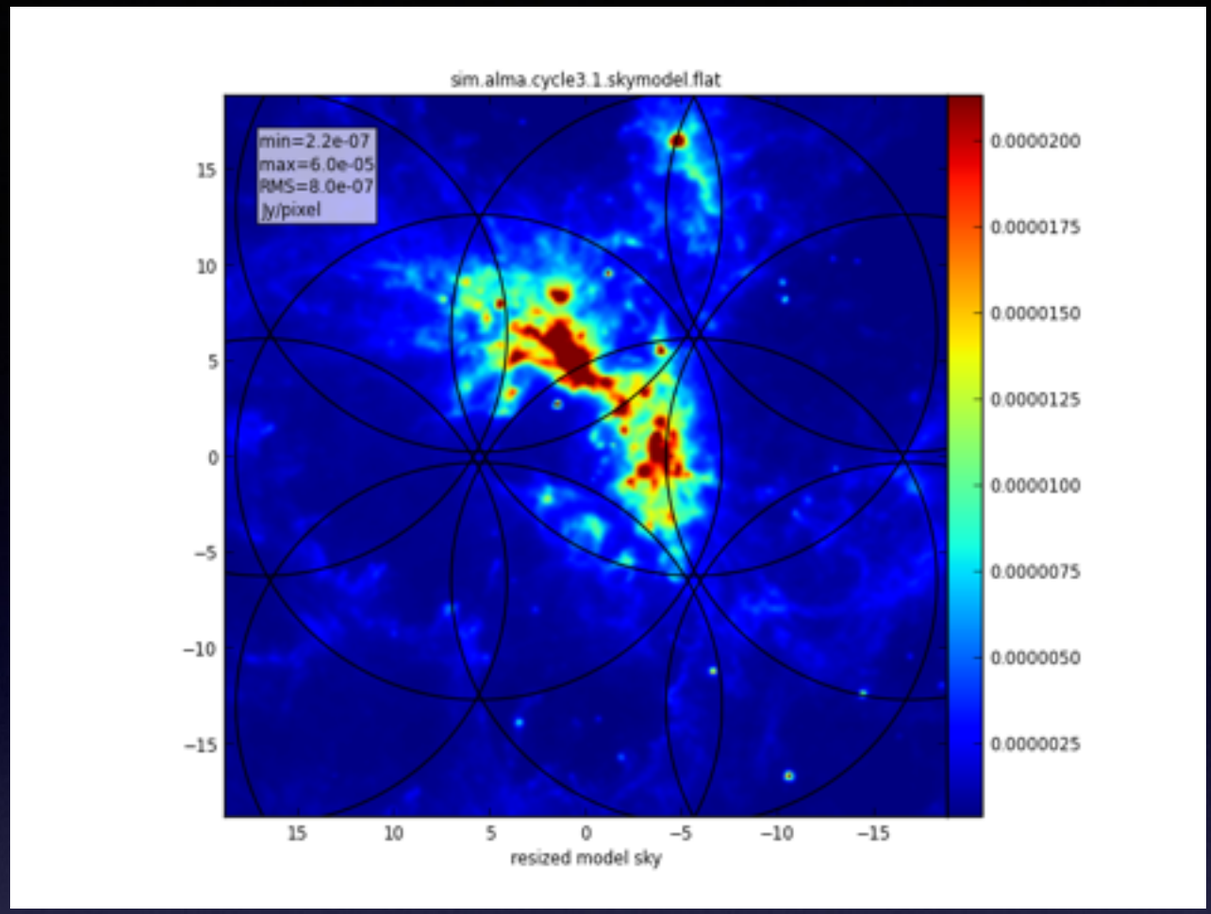
- Generate visibilities: 30 Doradus

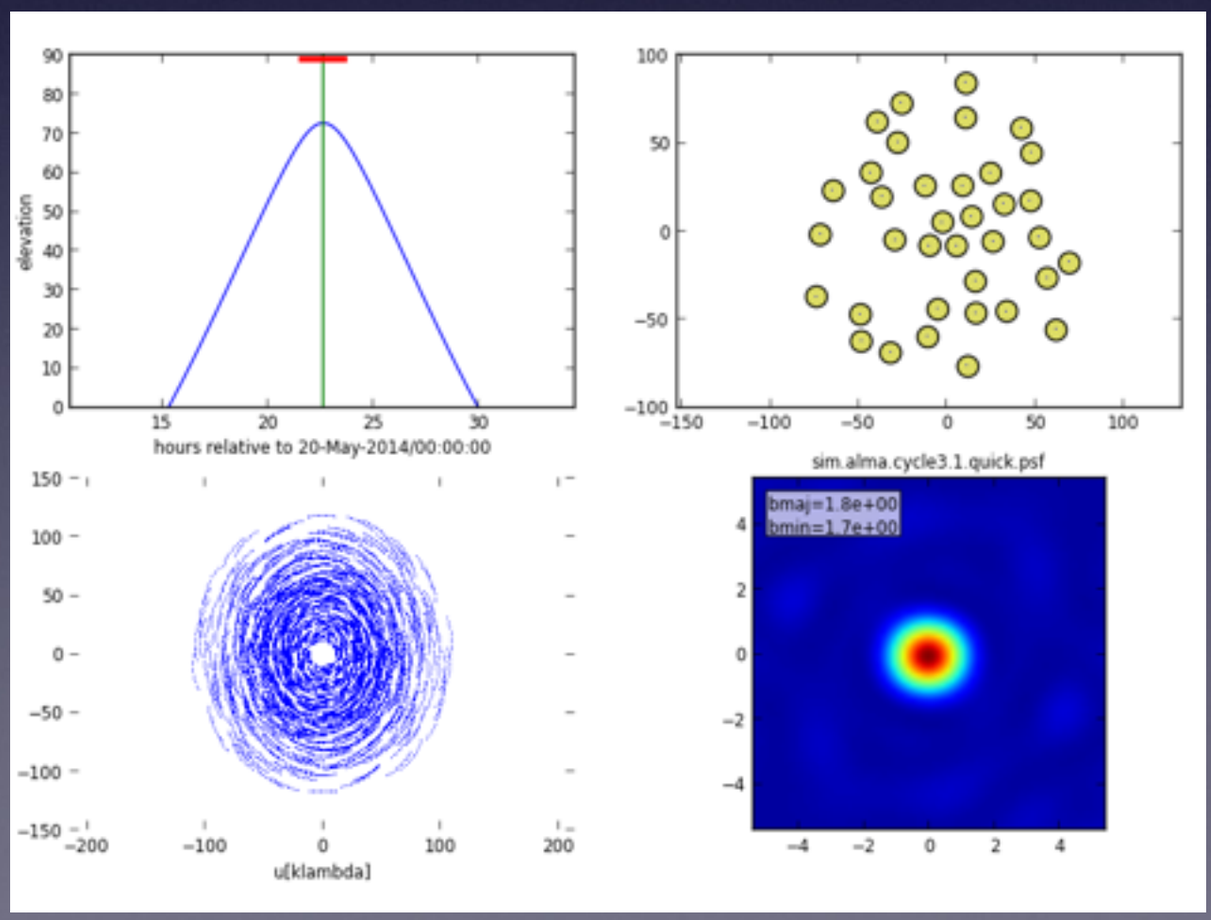
```
CASA <46>: inp
---------> inp()
#  simobserve :: visibility simulation task
project             =      'sim'        #  root prefix for output file names
skymodel            = '30dor.fits'      #  model image to observe
     inbright       = '0.06mJy/pixel'   #  scale surface brightness of brightest
                                        #   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
                                        #   erferometer)|sd(sin
                                        #   ]
     antennalist    = 'alma.cycle3.1.cfg' #  interferometer ant
                                        #   file
     refdate        = '2014/05/21'      #  date of observation
                                        #   unless concatting s
     hourangle      =  'transit'        #  hour angle of observ
                                        #   "-3:00:00", "5h", "
                                        #   without units will
                                        #   hours), or "transit
     totaltime      =    '7200s'        #  total time of observ
                                        #   of repetitions
     caldirection   =        ''        #  pt source calibrator
     calflux        =      '1Jy'

thermalnoise        = 'tsys-atm'        #  add thermal noise: [
                                        #   manual|""]
     user_pwv       =       0.5        #  Precipitable Water V
     t_ground       =     269.0        #  ambient temperature
     seed           =     11111        #  random number seed

leakage             =       0.0        #  cross polarization (
                                        #   only)
graphics            =     'both'       #  display graphics at
                                        #   [screen|file|both|n
verbose             =     False
overwrite           =      True        #  overwrite files star
                                        #   $project
```

Outputs

- sim.alma.cycle3.1.ms/
- sim.alma.cycle3.1.noisy.ms/
- sim.alma.cycle3.1.observe.png
- sim.alma.cycle3.1.ptg.txt
- sim.alma.cycle3.1.quick.psf/
- sim.alma.cycle3.1.skymodel/
- sim.alma.cycle3.1.skymodel.flat/
- sim.alma.cycle3.1.skymodel.png





Simanalyze

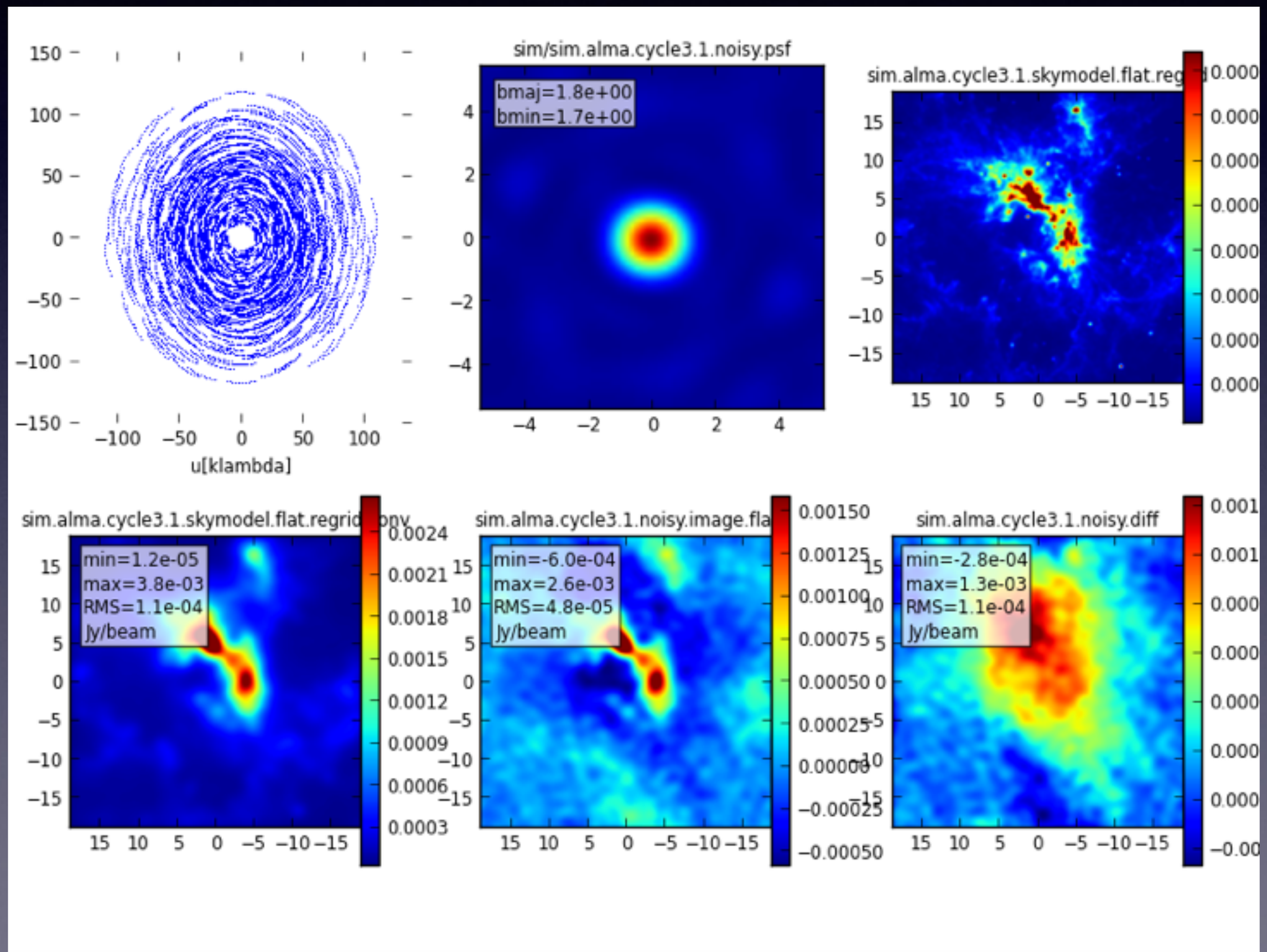
- Generating (cleaned) image

```
CASA <57>: 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              =          0       #  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 output
                                       #   be displayed)
     showuv         =       True       #  display uv coverage
     showpsf        =       True       #  display synthesized (dirty)
                                       #   (ignored in single dish sim
     showmodel      =       True       #  display sky model at origina
                                       #   resolution
     showconvolved  =       True       #  display sky model convolved
                                       #   output clean beam
     showclean      =       True       #  display the synthesized imag
     showresidual   =      False       #  display the clean residual i
                                       #   (ignored in single dish sim
     showdifference =       True       #  display difference between o
                                       #   cleaned image and input mod
                                       #   image convolved with output
                                       #   beam
     showfidelity   =      False       #  display fidelity (see help)

graphics            =     'both'       #  display graphics at each sta
                                       #   [screen|file|both|none]
verbose             =      False
overwrite           =       True       #  overwrite files starting wit
                                       #   $project
dryrun              =      False       #  only print information [expe
                                       #   only for interfermetric dat
logfile             =         ''

CASA <58>:
```

Outputs

- uv coverage, dirty beam, model,
  convolved model image, clean image, differences



Observation Supporting Tool

- Web-based
- Results can be delayed depending on job load
- http://almaost.jb.man.ac.uk

ALMA Observation Support Tool

Version 3.0

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

OST Report: OST usage statistics during the ALMA Cycle 3 Call.

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: Choose File No file chosen — 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.

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 = 0.472 mm (1st Octile) — Determines level of noise due to water vapour.

Imaging Product:

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

Submission:

Your email address is essential! — Submit

EUROPEAN ARC
ALMA Regional Centre || UK

Job ID: 20160317125744WnlRv / Submitted by: wkwon@kasi.r

Messages

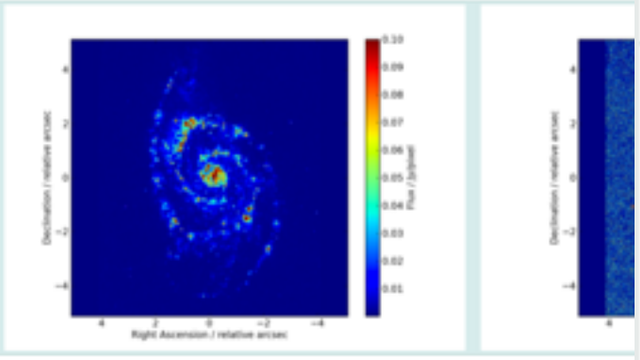
- **The brightness unit of your uploaded sky model was not recognised and has been adjusted to Jy/pixel.**

You should carefully check that your sky model remains sensible, and consider tuning the rescaling value to compensate for any

- The peak pixel of your model image has been rescaled to 100 mJy

Overview

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

Array configuration:	ALMA Cycle 3 C36-3n (538 m baseline)
Source model:	M51 originally observed in H_alpha
Input image:	
Maximum elevation:	77.88 degrees
Central frequency:	93.7 GHz (ALMA Band 3)
Total Bandwidth:	7.5 GHz
Track length:	3 hours × 1.0 visits
Hexagonal mosaic pointings :	1 required to cover requested sky area with uniform sensitivity
System temperature:	Tsys = 68.8274779127 K
PWV :	0.942 mm
Theoretical RMS noise:	5.63260725958e-06 Jy (in naturally-weighted map)
Restoring beam (resolution):	Major axis = 1.937 arcsec, minor axis = 1.578 arcsec, PA = 81.624 deg

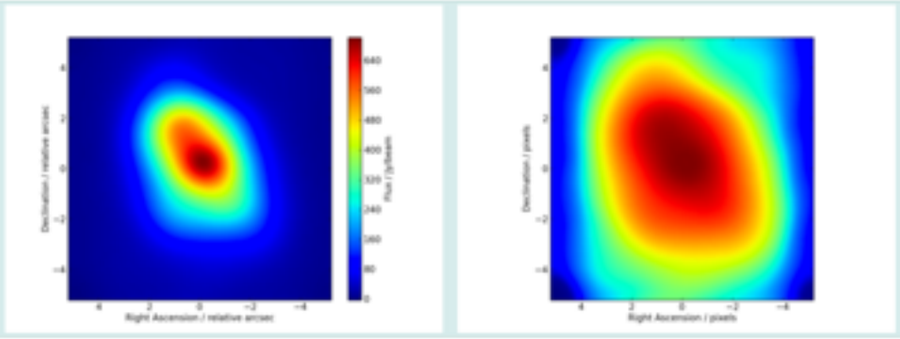
For use with CASA simdata

Input sky model:	Download processed model in FITS format
Download CASA simobserve/analyze file:	20160317125744WnlRv.simdata.last
Download pointing file:	20160317125744WnlRv.ptg.txt

Data products

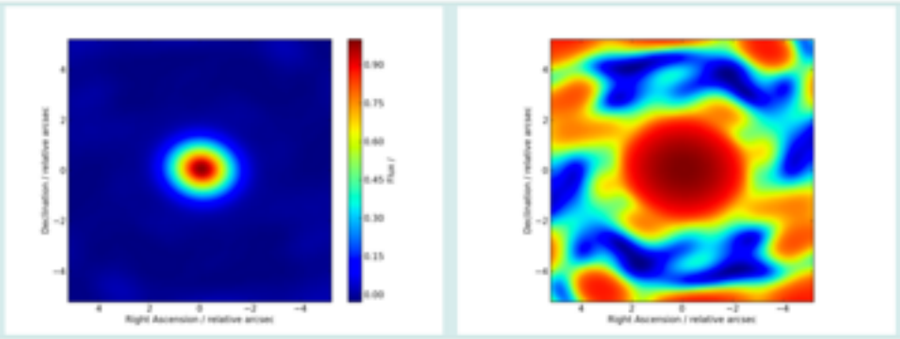
Your simulated image:

Download FITS file

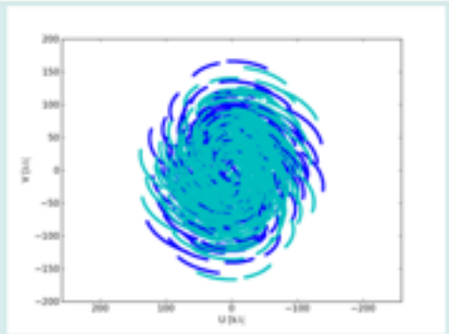


Dirty Beam

(Point Spread Function):



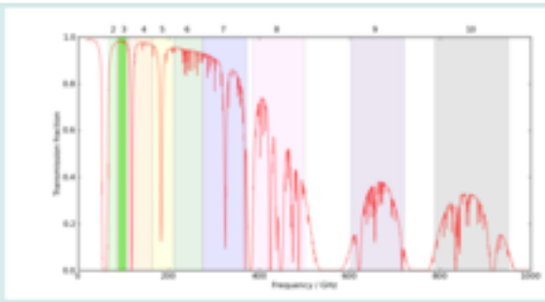
Coverage in the *uv*-plane:

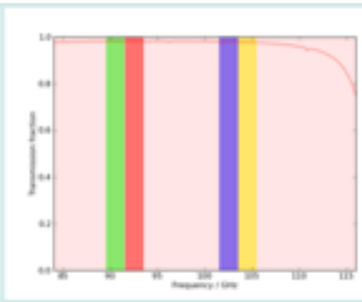


Atmospheric transmission for

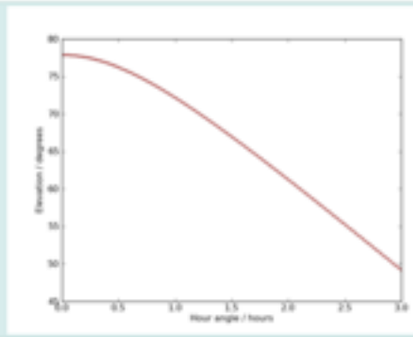
all bands (left) and

the selected band (right)





Elevation vs time:



Diagnostics

Processing time: 37 seconds

EUROPEAN ARC
ALMA Regional Centre || UK

Job ID: 20160317130740ZILNu / Submitted by: wkwon@

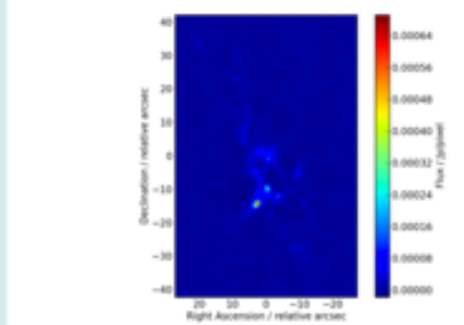
Messages

- The uploaded FITS file appears to have multiple spectral channels or Stokes axes.

Only the central frequency channel or first Stokes axis have been extracted.

Overview

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

Array configuration:	ALMA out05
Source model:	NGC 1333 at 8 kpc
Input image:	
Maximum elevation:	77.88 degrees
Central frequency:	230 GHz (ALMA Band 6)
Total Bandwidth:	7.5 GHz
Track length:	3 hours x 1.0 visits
Hexagonal mosaic pointings :	24 required to cover requested sky area with uniform sensitivity
System temperature:	Tsys = 85.8582664401 K
PWV :	0.654 mm
Theoretical RMS noise:	5.27516797554e-06 Jy (in naturally-weighted map)
Restoring beam (resolution):	Major axis = 1.207 arcsec, minor axis = 0.967 arcsec, PA = 89.585 deg

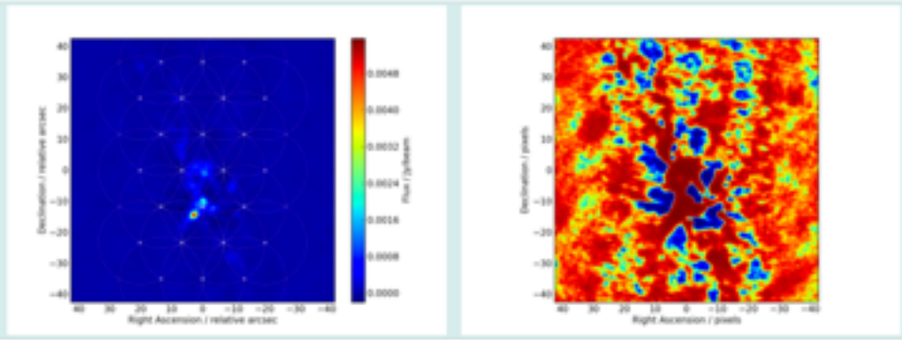
For use with CASA simdata

Input sky model:	Download processed model in FITS format
Download CASA simobserve/analyze file:	20160317130740ZILNu.simdata.last
Download pointing file:	20160317130740ZILNu.ptg.txt

Data products

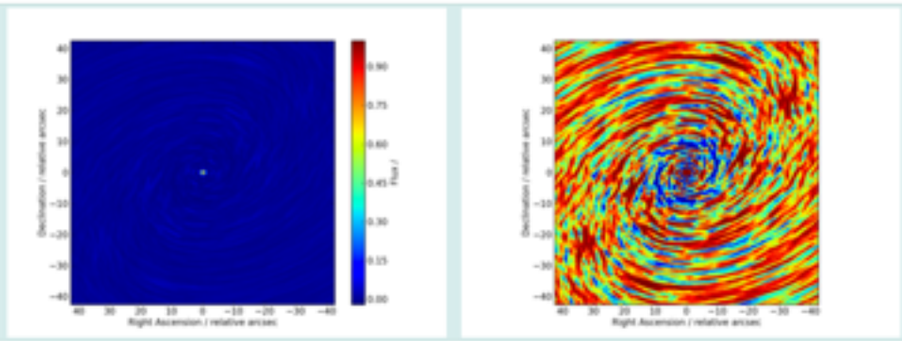
Your simulated image:

Download FITS file

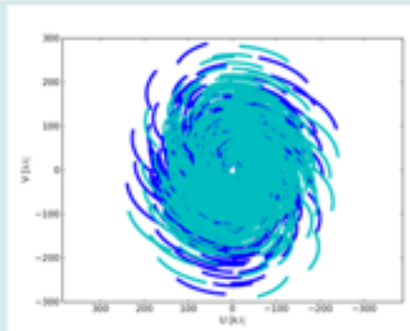


Dirty Beam

(Point Spread Function):



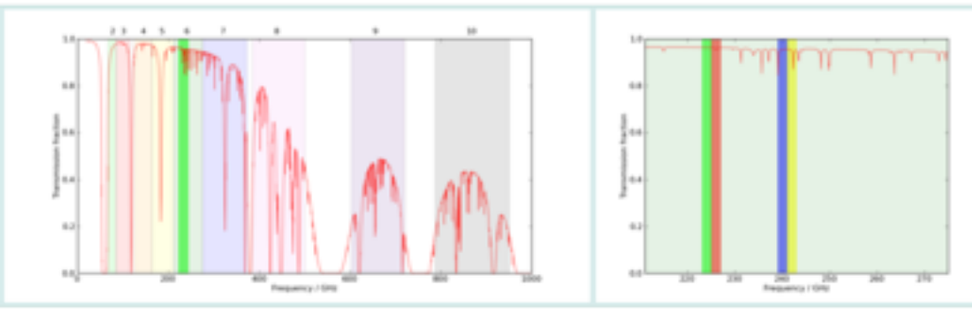
Coverage in the *uv*-plane:



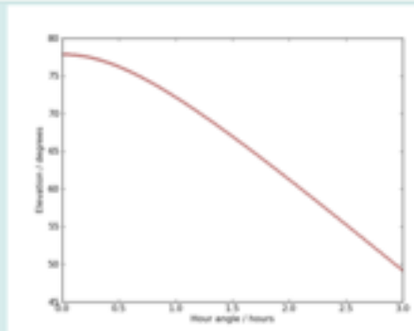
Atmospheric transmission for

all bands (left) and

the selected band (right)



Elevation vs time:



Diagnostics

Processing time: 104 seconds

Summary

- ALMA simulator
- CASA simulation tasks/tools

  http://casa.nrao.edu

  http://casaguides.nrao.edu/index.php?title=Simulating_Observations_in_CASA_4.3

  simobserve

  simanalyze

  (simalma)
- Observation Support Tool

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