Technical Justification and CASA Simulator

ALMA Class
Seoul National University
2018 March 12
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ALMA proposals

- [OT] Cover page: abstract, names, obs. hours, science goals (targets)
- Science Case (justification): up to 4 pages
- [OT] Technical Parameters
- [OT] Technical Justification

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 Scale (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

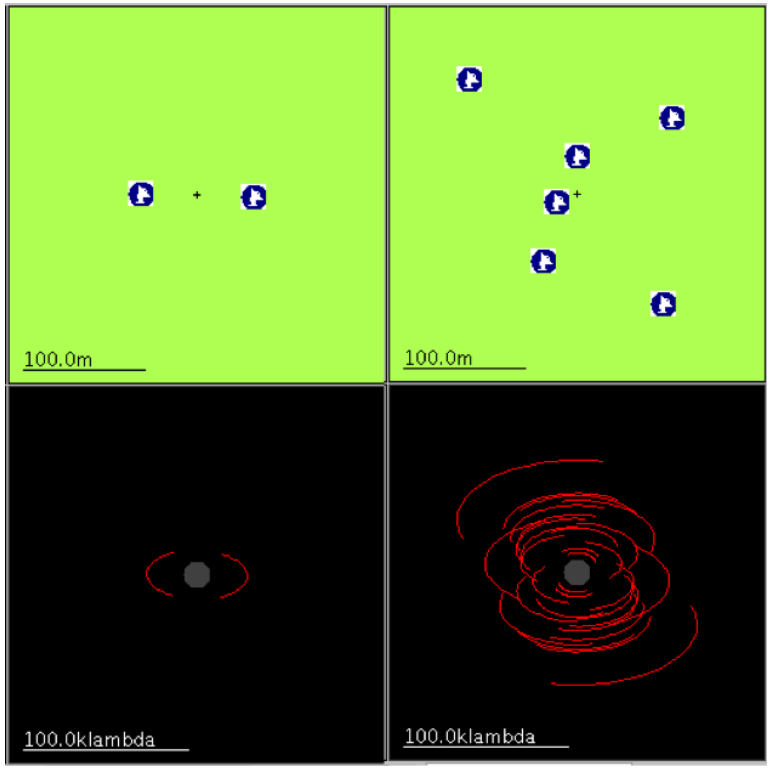
Basics of Interferometry

- 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

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

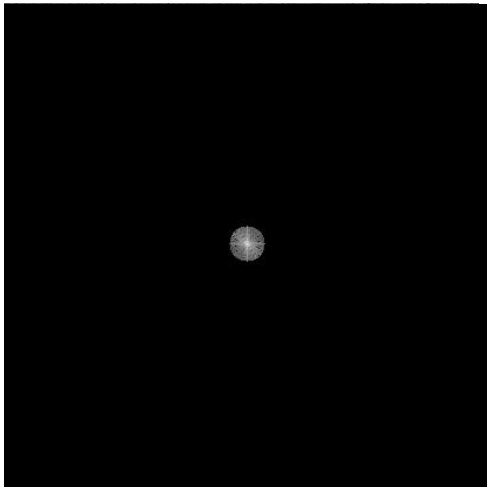
$$S(u,v)V(u,v) \rightleftarrows FT^{-1}[S(u,v)] * FT^{-1}[V(u,v)]$$
$$B_D(l,m) * [A_N(l,m)I(l,m)].$$

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

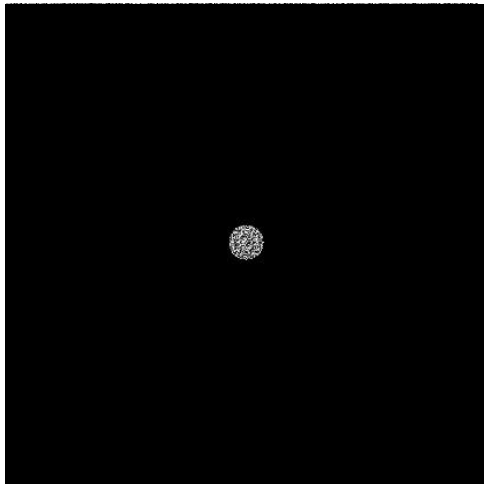


Inner and Outer (u,v) Boundaries

V(u,v) amplitude



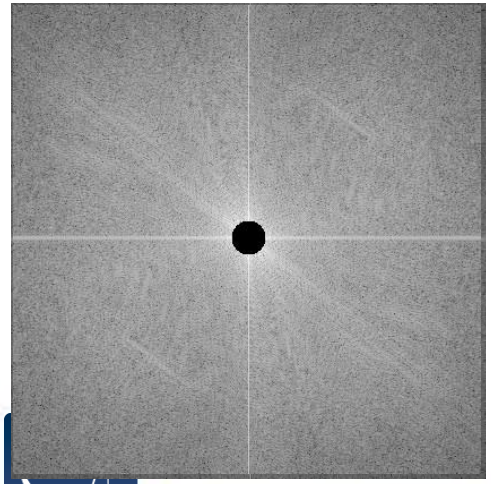
V(u,v) phase



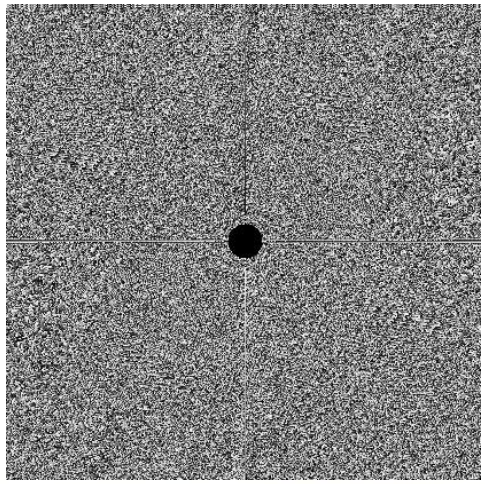
$\mathcal{F}$ $\rightarrow$

T(l,m)

V(u,v) amplitude



V(u,v) phase



$\mathcal{F}$ $\rightarrow$

T(l,m)

	Band	3	4	5	6	7	8	9	10
	Frequency (GHz)	100	150	185	230	345	460	650	870
! Configuration									
7-m	θ_{res} (arcsec)	12.5	8.35	6.77	5.45	3.63	2.72	1.93	1.44
	θ_{MRS} (arcsec)	66.7	44.5	36.1	29.0	19.3	14.5	10.3	7.67
C43-1	θ_{res} (arcsec)	3.38	2.25	1.83	1.47	0.98	0.735	0.52	0.389
	θ_{MRS} (arcsec)	28.5	19.0	15.4	12.4	8.25	6.19	4.38	3.27
C43-2	θ_{res} (arcsec)	2.3	1.53	1.24	0.999	0.666	0.499	0.353	0.264
	θ_{MRS} (arcsec)	22.6	15.0	12.2	9.81	6.54	4.9	3.47	2.59
C43-3	θ_{res} (arcsec)	1.42	0.943	0.765	0.615	0.41	0.308	0.218	0.163
	θ_{MRS} (arcsec)	16.2	10.8	8.73	7.02	4.68	3.51	2.48	1.86
C43-4	θ_{res} (arcsec)	0.918	0.612	0.496	0.399	0.266	0.2	0.141	0.106
	θ_{MRS} (arcsec)	11.2	7.5	6.08	4.89	3.26	2.44	1.73	1.29
C43-5	θ_{res} (arcsec)	0.545	0.363	0.295	0.237	0.158	0.118	0.0838	0.0626
	θ_{MRS} (arcsec)	6.7	4.47	3.62	2.91	1.94	1.46	1.03	0.77
C43-6	θ_{res} (arcsec)	0.306	0.204	0.165	0.133	0.0887	0.0665	0.0471	0.0352
	θ_{MRS} (arcsec)	4.11	2.74	2.22	1.78	1.19	0.892	0.632	0.472
C43-7	θ_{res} (arcsec)	0.211	0.141	0.114	0.0917	0.0612	0.0459	0.0325	0.0243
	θ_{MRS} (arcsec)	2.58	1.72	1.4	1.12	0.749	0.562	0.398	0.297
C43-8	θ_{res} (arcsec)	0.096	0.064	0.0519	0.0417	0.0278	-	-	-
	θ_{MRS} (arcsec)	1.42	0.947	0.768	0.618	0.412	-	-	-
C43-9	θ_{res} (arcsec)	0.057	0.038	0.0308	0.0248	-	-	-	-
	θ_{MRS} (arcsec)	0.814	0.543	0.44	0.354	-	-	-	-
C43-10	θ_{res} (arcsec)	0.042	0.028	0.0227	0.0183	-	-	-	-
	θ_{MRS} (arcsec)	0.496	0.331	0.268	0.216	-	-	-	-

Table 7.1: Resolution (θ_{res}) and maximum recoverable scale (θ_{MRS}) for the 7-m Array and 12-m Array configurations available during Cycle 6 as a function of a representative frequency in a band. The value of θ_{MRS} is

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

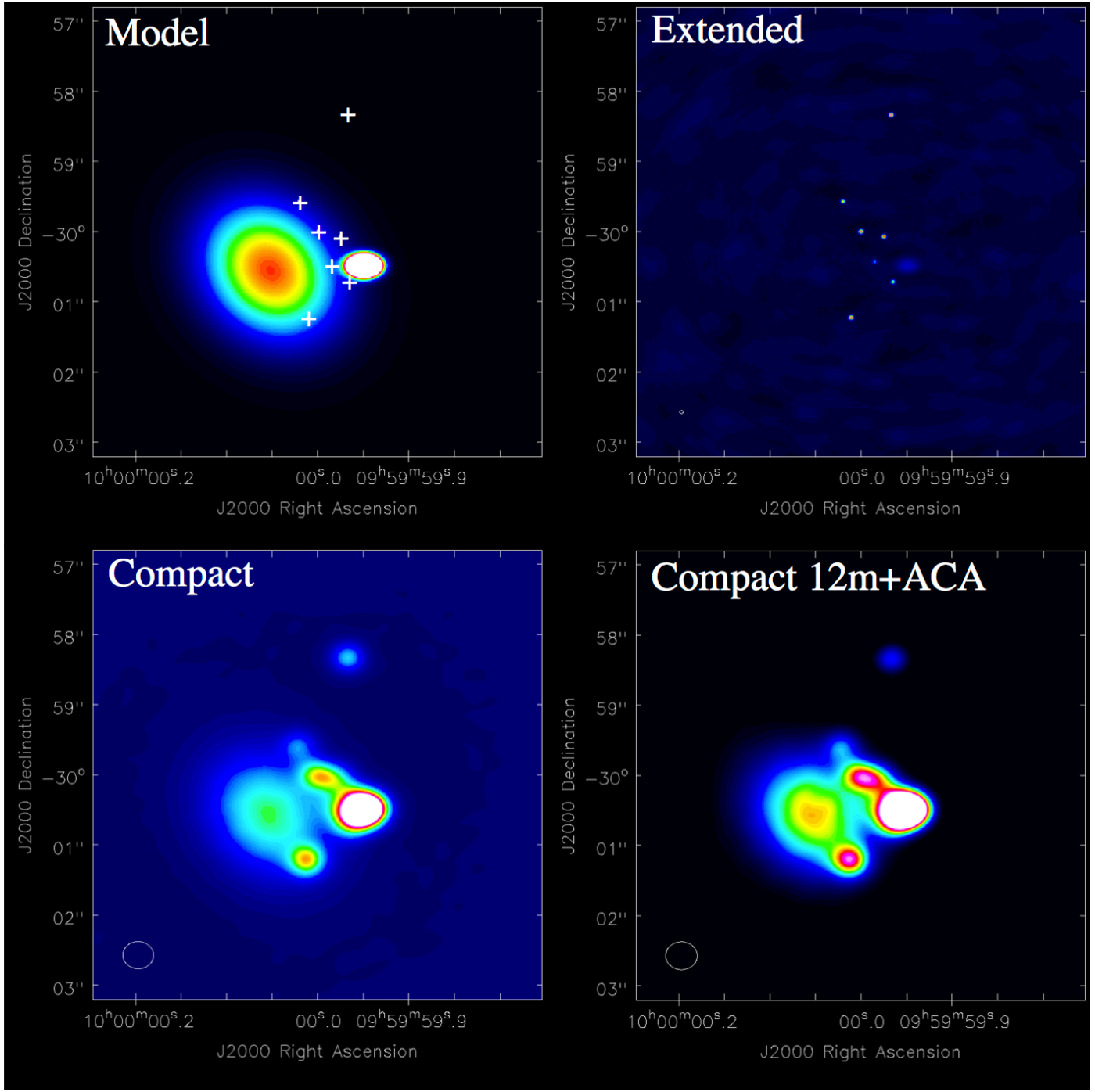
- **Non-Nyquist mosaic sampling**: for a large field without large-scale structures
- **Single polarization**: e.g., for highest spectral resolution
- **Low max elevation**: large atmospheric attenuation, limited time above the horizon
- **User-defined calibration**: must be rigorously justified
- **Override 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
- Flux loss by interferometry?

- Comparison of different array configurations



http://casaguide.nrao.edu

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

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

- **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 5.1.1)
- > 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

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

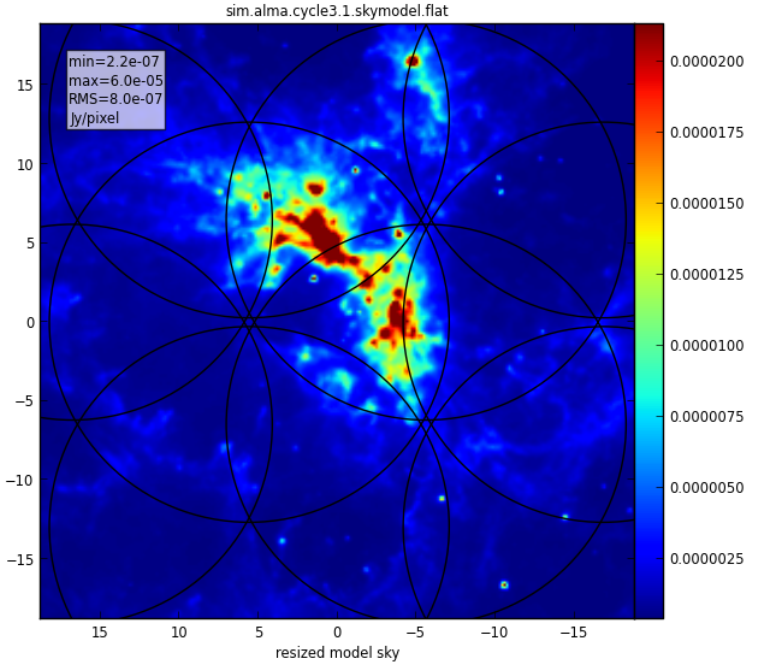
Simobserve

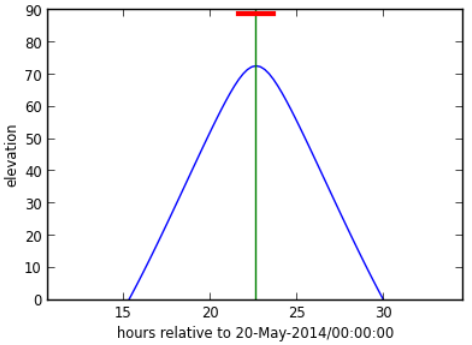
- Generate visibilities: 30 Doradus

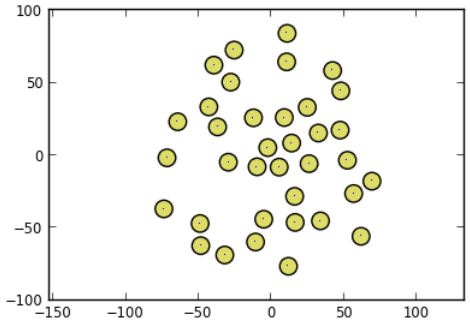
```
CASA <46>: inp
---------> inp()
#  simobserve :: visibility simulation task
project             =      'sim'       #  root prefix for output file names
skymodel            = '30dor.fits'     #  model image to observe
     inbright       = '0.06mJy/pixel'  #  scale surface brightness of brightest
                                       #   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
```

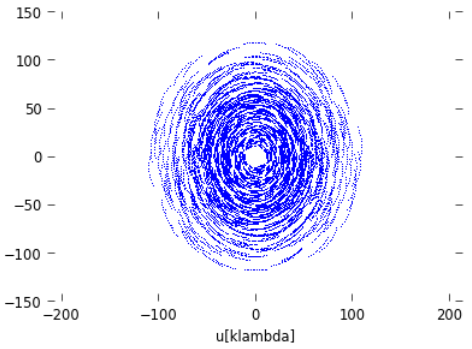
Outputs

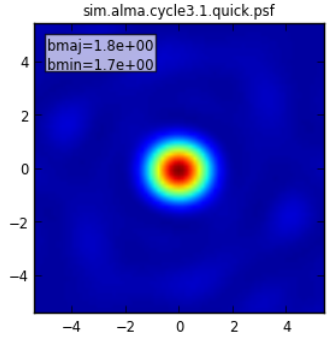
- sim.alma.cycle3.1.ms/
- sim.alma.cycle3.1.noisy.ms/
- sim.alma.cycle3.1.observe.png
- sim.alma.cycle3.1.ptg.txt
- sim.alma.cycle3.1.quick.psf/
- sim.alma.cycle3.1.skymodel/
- sim.alma.cycle3.1.skymodel.flat/
- sim.alma.cycle3.1.skymodel.png











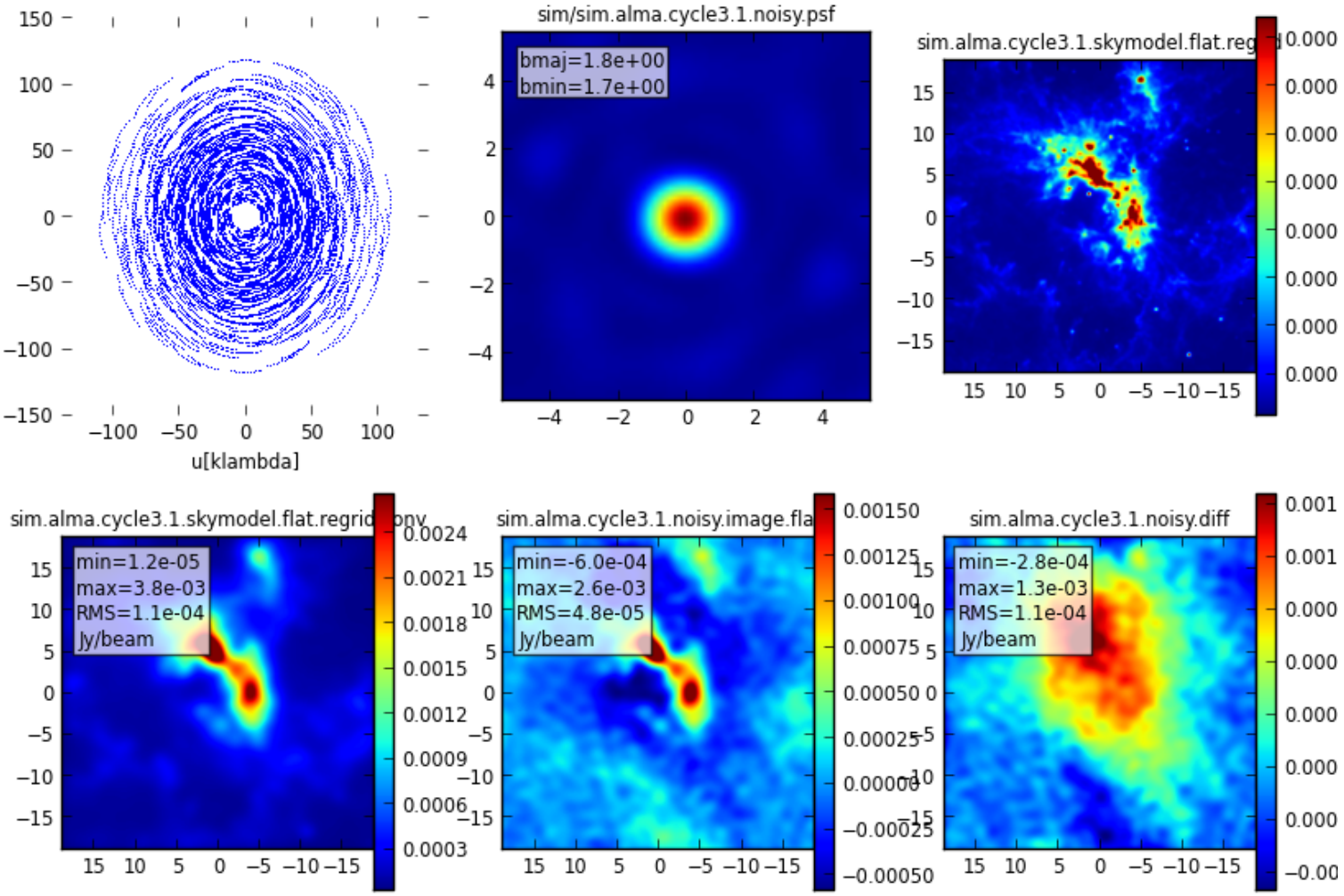
Simanalyze

- 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) b
                                         #   (ignored in single dish simu
     showmodel      =        True        #  display sky model at original
                                         #   resolution
     showconvolved  =        True        #  display sky model convolved w
                                         #   output clean beam
     showclean      =        True        #  display the synthesized image
     showresidual   =       False        #  display the clean residual im
                                         #   (ignored in single dish simu
     showdifference =        True        #  display difference between ou
                                         #   cleaned image and input mode
                                         #   image convolved with output
                                         #   beam
     showfidelity   =       False        #  display fidelity (see help)
graphics            =      'both'        #  display graphics at each stag
                                         #   [screen|file|both|none]
verbose             =       False
overwrite           =        True        #  overwrite files starting with
                                         #   $project
dryrun              =       False        #  only print information [exper
                                         #   only for interfermetric data
logfile             =          ''

CASA <58>:
```

Outputs

- sim.alma.cycle3.1.noisy.analysis.png
  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 5.0

OST NEWS HELP QUEUE LIBRARY ALMA HELPDESK

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.

Use full Stokes parameters: Yes No

If your input image contains more than one Stokes plane
use them all (Yes), or just Stokes I (no/default).

Number of polarizations: 2

This affects the noise in the final map. Ignored in continuum mode if "Use full Stokes parameters" is set to yes.

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 Pointing Strategy = 'mosaic'.
Total time over all pointings Pointing Strategy = 'single' and 'User pointing'
See here for more information.

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.

Job ID: 20180312015923HFPxI / Submitted by: wkwon@kasi.re.k

Messages

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

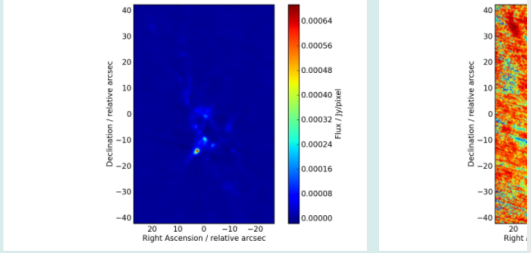
Only the central frequency channel or first Stokes axis have been extracted.

- The uploaded FITS file also appears to have multiple Stokes axes.

Only the first Stokes axis have been extracted.

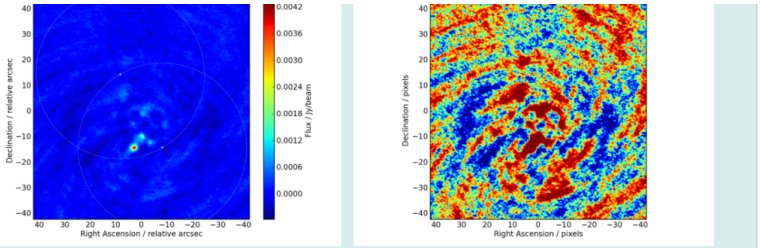
Overview

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

Array configuration:	ALMA Cycle 5 C43-5 (1398 m baseline)
Source model:	NGC 1333 at 8 kpc
Input image:	
Maximum elevation:	77.88 degrees
Central frequency:	93.7 GHz (ALMA Band 3)
Total Bandwidth:	0.032 GHz
Track length:	3 hours × 1.0 visits
Hexagonal mosaic pointings :	2 required to cover requested sky area with uniform sensitivity
System temperature:	Tsys = 67.4355519482 K
PWV :	0.475 mm
Theoretical RMS noise:	7.06283019575e-05 Jy (in naturally-weighted map)
Restoring beam (resolution):	Major axis = 0.835 arcsec, minor axis = 0.711 arcsec, PA = 82.026 deg

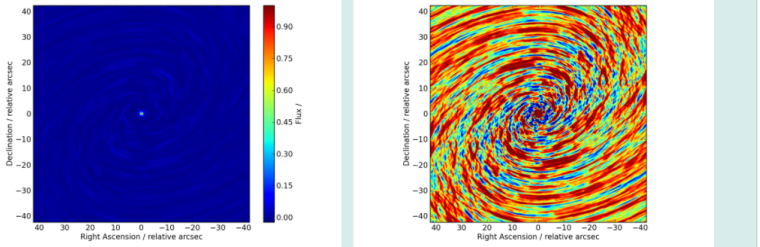
For use with CASA simdata

Download FITS file

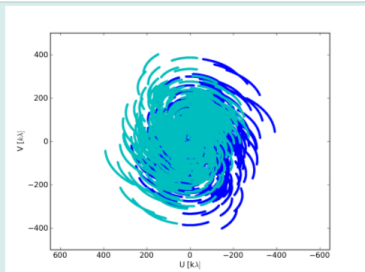


Dirty Beam

(Point Spread Function):



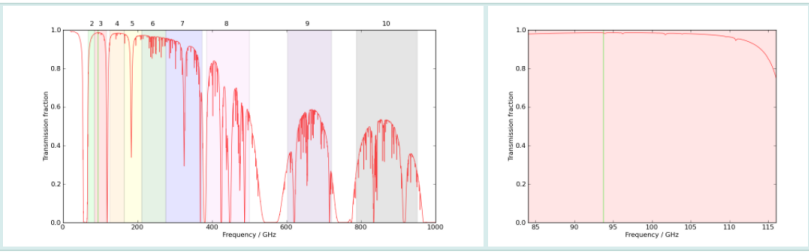
Coverage in the *uv*-plane:



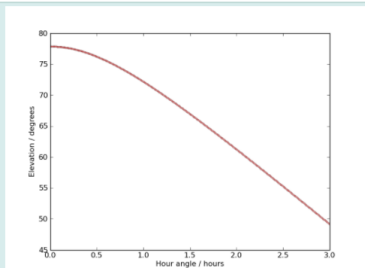
Atmospheric transmission for

all bands (left) and

the selected band (right)



Elevation vs time:



Summary

- ALMA proposals: technical justification
- ALMA simulator: CASA simulation tasks/tools
  simobserve
  simanalyze
  (simalma)

  cf. Observation Support Tool
  http://almaost.jb.man.ac.uk