Hands-On Activity: Simulating ALMA Observations

ALMA Community Day at Northwesternv University
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Goal: Determine the required observing time and configuration to image the HD 10647 debris disk in Band 6 (1.3 mm), and then simulate ALMA observations.

Some information on the target:

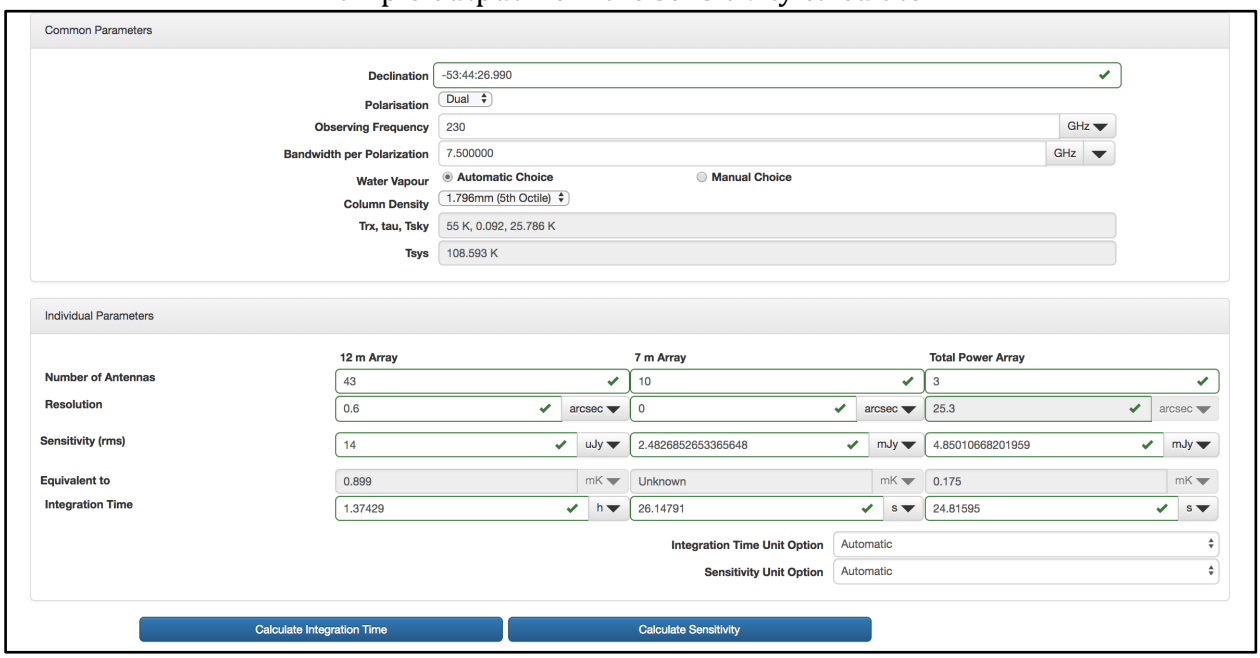
- RA = 01 42 29.315
- DEC = -53 44 26.99
- Total flux density at 1.3 mm = 6 mJy
- Desired resolution = 0.6''
- Largest angular scale = 7''
- Required rms for >10 sigma detection around the entire ring = 14 μJy/beam

Task #1: Use the online sensitivity calculator to determine how long we need to observe with the 12 m array in order to achieve the required rms.

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

Required observing time = _____ hours

Example output from the sensitivity calculator:



Task #2: Use Table A-1 from the ALMA Cycle 6 Proposer's Guide to determine the best observing configuration given our desired resolution and largest angular scale.

Best configuration = _____

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Table A-1 from the ALMA Cycle 7 Proposer's Guide:

Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	183 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m Array	45 m	AR	12.5"	8.4"	6.8"	5.4"	3.6"	2.7"	1.9"	1.4"
	9 m	MRS	66.7"	44.5"	36.1"	29.0"	19.3"	14.5"	10.3"	7.7"
C43-1	161 m	AR	3.4"	2.3"	1.8"	1.5"	1.0"	0.74"	0.52"	0.39"
	15 m	MRS	28.5"	19.0"	15.4"	12.4"	8.3"	6.2"	4.4"	3.3"
C43-2	314 m	AR	2.3"	1.5"	1.2"	1.0"	0.67"	0.50"	0.35"	0.26"
	15 m	MRS	22.6"	15.0"	12.2"	9.8"	6.5"	4.9"	3.5"	2.6"
C43-3	500 m	AR	1.4"	0.94"	0.77"	0.62"	0.41"	0.31"	0.22"	0.16"
	15 m	MRS	16.2"	10.8"	8.7"	7.0"	4.7"	3.5"	2.5"	1.9"
C43-4	784 m	AR	0.92"	0.61"	0.50"	0.40"	0.27"	0.20"	0.14"	0.11"
	15 m	MRS	11.2"	7.5"	6.1"	4.9"	3.3"	2.4"	1.7"	1.3"
C43-5	1.4 km	AR	0.54"	0.36"	0.30"	0.24"	0.16"	0.12"	0.084"	0.063"
	15 m	MRS	6.7"	4.5"	3.6"	2.9"	1.9"	1.5"	1.0"	0.77"
C43-6	2.5 km	AR	0.31"	0.20"	0.16"	0.13"	0.089"	0.067"	0.047"	0.035"
	15 m	MRS	4.1"	2.7"	2.2"	1.8"	1.2"	0.89"	0.63"	0.47"
C43-7	3.6 km	AR	0.21"	0.14"	0.11"	0.092"	0.061"	0.046"	0.033"	0.024"
	64 m	MRS	2.6"	1.7"	1.4"	1.1"	0.75"	0.56"	0.40"	0.30"
C43-8	8.5 km	AR	0.096"	0.064"	0.052"	0.042"	0.028"	N/A	N/A	N/A
	110 m	MRS	1.4"	0.95"	0.77"	0.62"	0.41"			
C43-9	13.9 km	AR	0.057"	0.038"	0.031"	0.025"	0.017"	N/A	N/A	N/A
	368 m	MRS	0.81"	0.54"	0.44"	0.35"	0.24"			
C43-10	16.2 km	AR	0.042"	0.028"	0.023"	0.018"	0.012"	N/A	N/A	N/A
	244 m	MRS	0.50"	0.33"	0.27"	0.22"	0.14"			

Download the FITS file image of the HD 10647 debris disk to use with 'simobserve' in CASA:

https://tinyurl.com/y3mgz5yg

Start CASA and make sure that you are in the directory where you saved the FITS file you downloaded. Then, use

tget simobserve

inp

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to list the possible parameters for 'simobserve'.

Task #3: Set-up 'simobserve' to simulate our ALMA observations of HD 10647.
Example set-up for 'simobserve' in CASA:

```
#  simobserve :: visibility simulation task
project             =  'hd10647'        #  root prefix for output file names
skymodel            = 'hd10647_model.fits' #  model image to observe
     inbright       =         ''        #  scale surface brightness of brightest pixel
                                        #   e.g. "1.2Jy/pixel"
     indirection    =         ''        #  set new direction e.g. "J2000 19h00m00
                                        #   -40d00m00"
     incell         =         ''        #  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        =   '7.5GHz'        #  set new channel width e.g. "10MHz" (required
                                        #   even for 2D model)

complist            =         ''        #  componentlist to observe
setpointings        =      False
     ptgfile        = 'ptgfile.txt'     #  list of pointing positions
     integration    =      '10s'        #  integration (sampling) time

obsmode             =      'int'        #  observation mode to simulate [int(interferom
                                        #   eter)|sd(singledish)|""(none)]
     antennalist    = 'alma.cycle7.3.cfg' #  interferometer antenna position file
     refdate        = '2019/09/01'      #  date of observation - not critical unless
                                        #   concatting simulations
     hourangle      =  'transit'        #  hour angle of observation center e.g.
                                        #   "-3:00:00", "5h", "-4.5" (a number without
                                        #   units will be interpreted as hours), or
                                        #   "transit"
     totaltime      =    '4928s'        #  total time of observation or number of
                                        #   repetitions
     caldirection   =         ''        #  pt source calibrator [experimental]
     calflux        =      '1Jy'

outframe            =     'LSRK'        #  spectral frame of MS to create
thermalnoise        = 'tsys-atm'        #  add thermal noise: [tsys-atm|tsys-manual|""]
     user_pwv       =      1.796        #  Precipitable Water Vapor in mm
     t_ground       =      269.0        #  ambient temperature
     seed           =      11111        #  random number seed

leakage             =        0.0        #  cross polarization (interferometer only)
graphics            =     'both'        #  display graphics at each stage to
                                        #   [screen|file|both|none]
verbose             =       True
overwrite           =       True        #  overwrite files starting with $project
```

In this case, we are using a pointing file 'ptgfile.txt' in order to specify the phase center for our observations, instead of letting CASA decide automatically. You can download this pointing file from the same place as the FITS image file.

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*Note: If you downloaded the most recent version of CASA, you should have the Cycle 7 configuration files. But, if CASA can't find them, you can just use the corresponding Cycle 6 file: 'alma.cycle6.3.cfg' (It's the same!). In the future, you can download the Cycle 7 configuration files using this link:

https://almascience.nrao.edu/tools/documents-and-tools/cycle7/alma-configuration-files

Task #4: Run 'simobserve.' Once you have set all of the parameters, type

go

and then press <enter> to run the task.

Task #5: Once the task completes, move into the project directory to see the output

cd hd10647/

You should have a number of files, including two measurement sets (model visibilities):

hd10647.alma.cycle7.3.ms/
hd10647.alma.cycle7.3.noisy.ms/

The first one does not include model noise and the second one does.

Task #6: Image both the noiseless and noisy measurement sets with natural weighting using the 'tclean' task in CASA.

A few questions to keep in mind when defining the parameters for the task:

1. If the expected rms noise in our final image is 14 μJy/beam, what is the right threshold to set for 'tclean'?

2. What should our cell (pixel) size be if we want to have about 5-6 pixels across the synthesized beam?

3. What size (in pixels) should we make the image if we want to cover the primary beam of the telescope? (Hint: At 1.3 mm, the primary beam has a FWHM of ~23'')

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Example set-up for 'tclean' in CASA:

```
#  tclean :: Radio Interferometric Image Reconstruction
vis                 = 'hd10647.alma.cycle7.3.noisy.ms' #  Name of input visibility file(s)
selectdata          =      False        #  Enable data selection parameters
datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           = 'hd10647_natrual_cycle_7' #  Pre-name of output images
imsize              = [250, 250]        #  Number of pixels
cell                = '0.1arcsec'       #  Cell size
phasecenter         =         ''        #  Phase center of the image
stokes              =        'I'        #  Stokes Planes to make
projection          =      'SIN'        #  Coordinate projection (SIN, HPX)
startmodel          =         ''        #  Name of starting model image
specmode            =      'mfs'        #  Spectral definition mode (mfs,cube,cubedata, cubesource)
     reffreq        =         ''        #  Reference frequency

gridder             = 'standard'        #  Gridding options (standard, wproject, widefield, mosaic, awproject)
     vptable        =         ''        #  Name of Voltage Pattern table
     pblimit        =        0.2        #  >PB gain level at which to cut off normalizations

deconvolver         =   'hogbom'        #  Minor cycle algorithm (hogbom,clark,multiscale,mtmfs,mem,clarkstokes)
restoration         =       True        #  Do restoration steps (or not)
     restoringbeam  =         []        #  Restoring beam shape to use. Default is the PSF main lobe
     pbcor          =      False        #  Apply PB correction on the output restored image

outlierfile         =         ''        #  Name of outlier-field image definitions
weighting           =  'natural'        #  Weighting scheme (natural,uniform,briggs)
     uvtaper        =         []        #  uv-taper on outer baselines in uv-plane

niter               =       1000        #  Maximum number of iterations
     gain           =        0.1        #  Loop gain
     threshold      = '0.042mJy'        #  Stopping threshold
     nsigma         =        0.0        #  Multiplicative factor for rms-based threshold stopping
     cycleniter     =         -1        #  Maximum number of minor-cycle iterations
     cyclefactor    =        1.0        #  Scaling on PSF sidelobe level to compute the minor-cycle stopping threshold.
     minpsffraction =       0.05        #  PSF fraction that marks the max depth of cleaning in the minor cycle
     maxpsffraction =        0.8        #  PSF fraction that marks the minimum depth of cleaning in the minor cycle
     interactive    =       True        #  Modify masks and parameters at runtime

usemask             =     'user'        #  Type of mask(s) for deconvolution:  user, pb, or auto-multithresh
     mask           =         ''        #  Mask (a list of image name(s) or region file(s) or region string(s) )
     pbmask         =        0.0        #  primary beam mask

restart             =       True        #  True : Re-use existing images. False : Increment imagename
savemodel           =     'none'        #  Options to save model visibilities (none, virtual, modelcolumn)
calcres             =       True        #  Calculate initial residual image
calcpsf             =       True        #  Calculate PSF
parallel            =      False        #  Run major cycles in parallel
```

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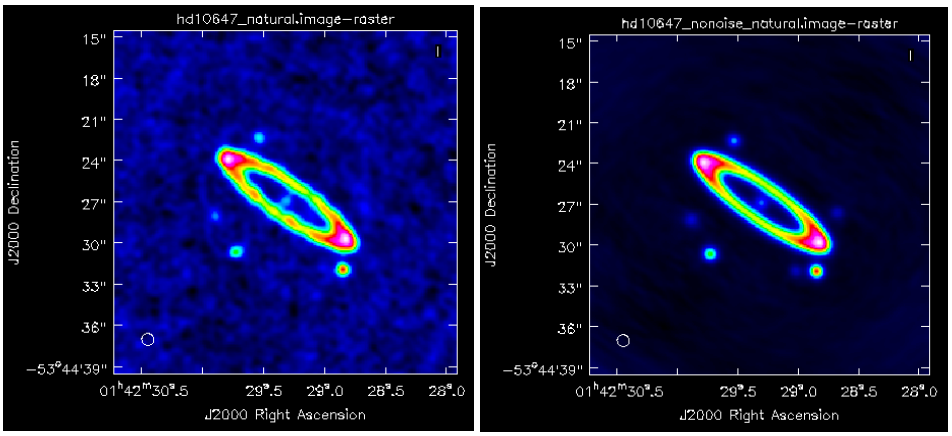
Example images from 'tclean' of noisy (left) and noiseless (right) measurement sets:



Once you have made natural weight images, try other weighting schemes (e.g. briggs, uniform, and uvtaper) to see what the differences are. You can even try using the 'imstat' task to measure the noise level in the images.