Simulating ALMA observations

Swiss ALMA Community Days 2017

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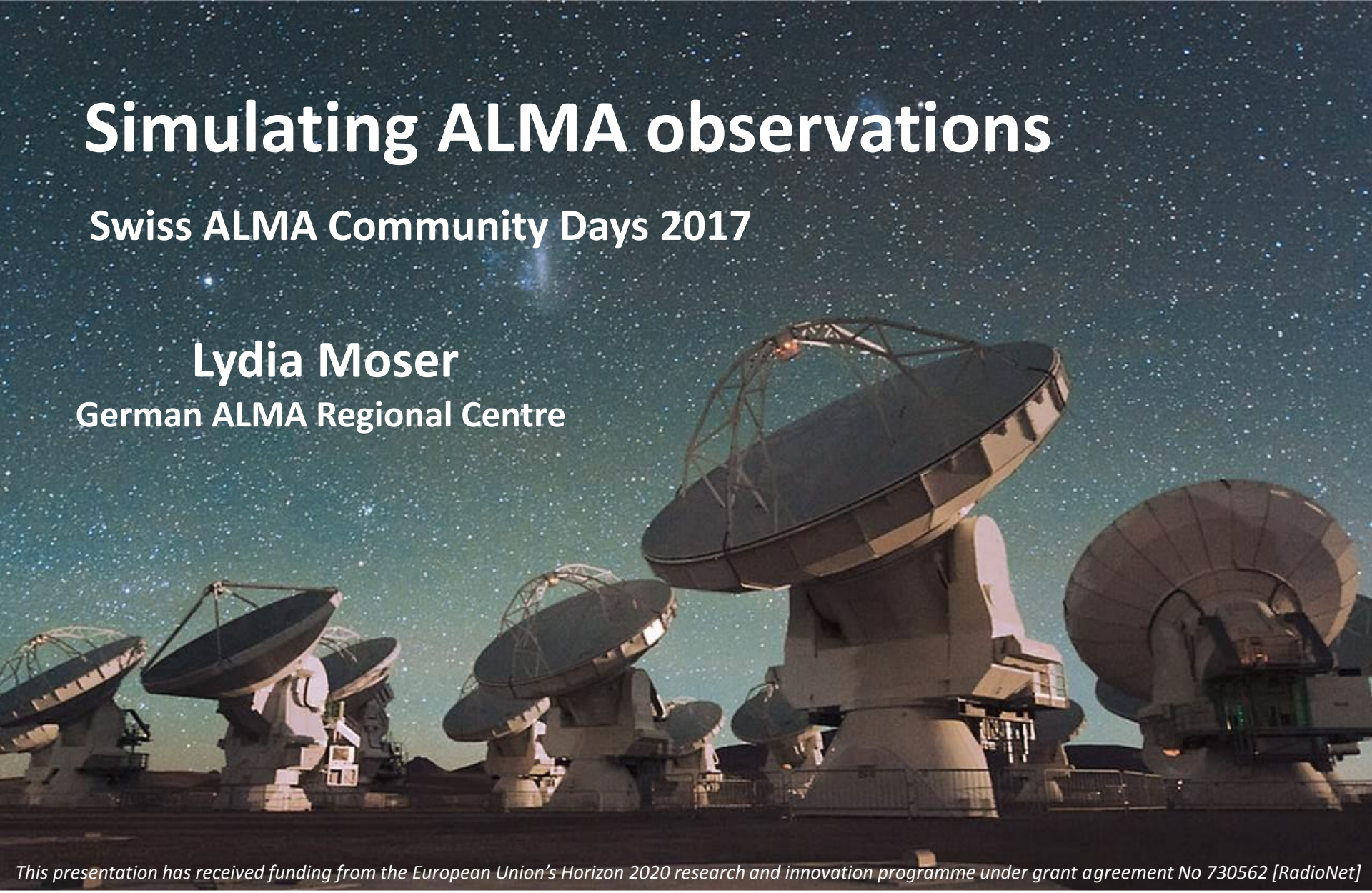
German ALMA Regional Centre



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ALMA EUROPEAN ARC ALMA Regional Centre || Germany

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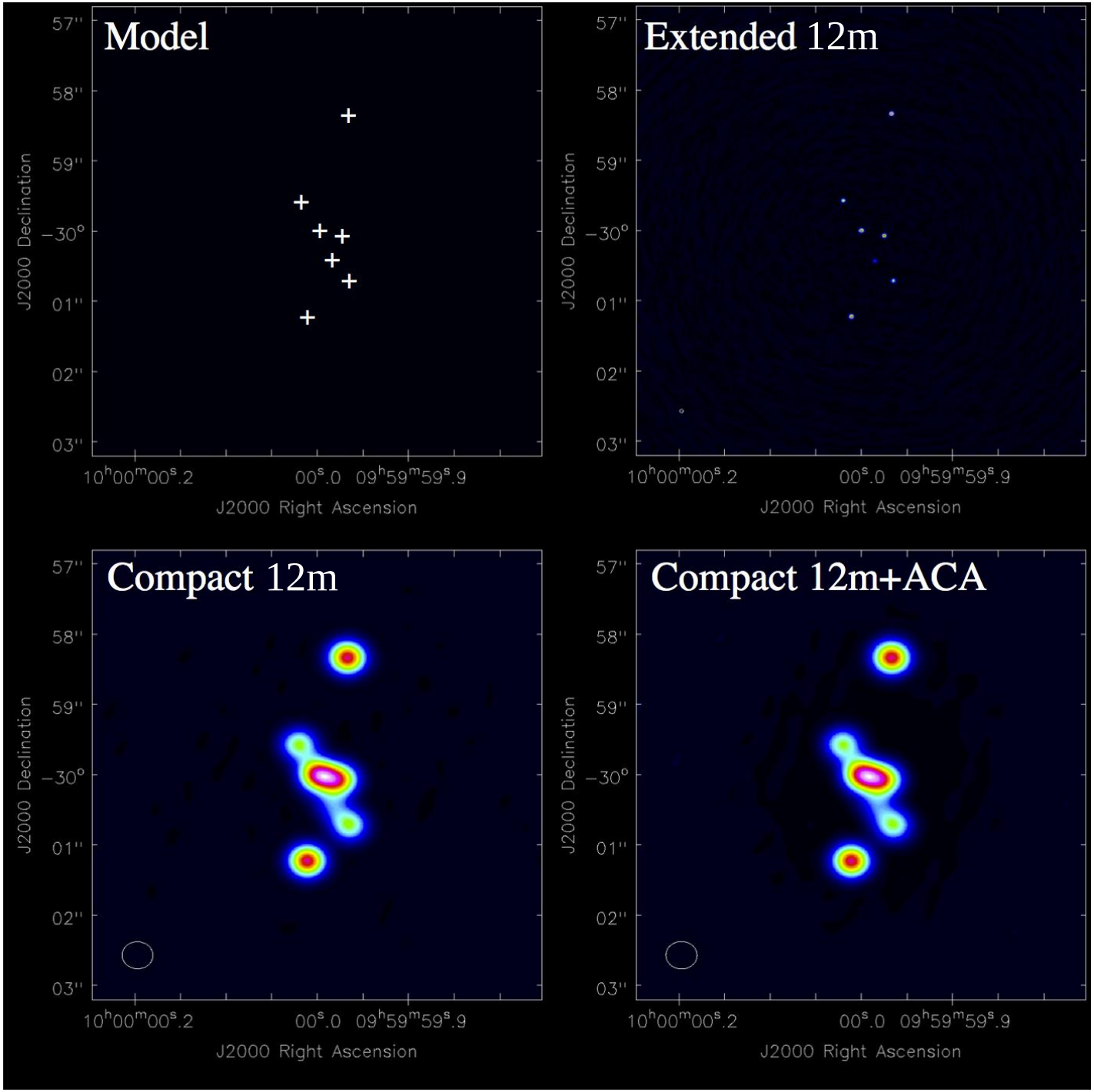
Argelander-Institut für Astronomie

Why simulations ?

- beginners: get familiar with spatial filtering effects
- advanced: test scenarios, mock data

Proposal preparation:

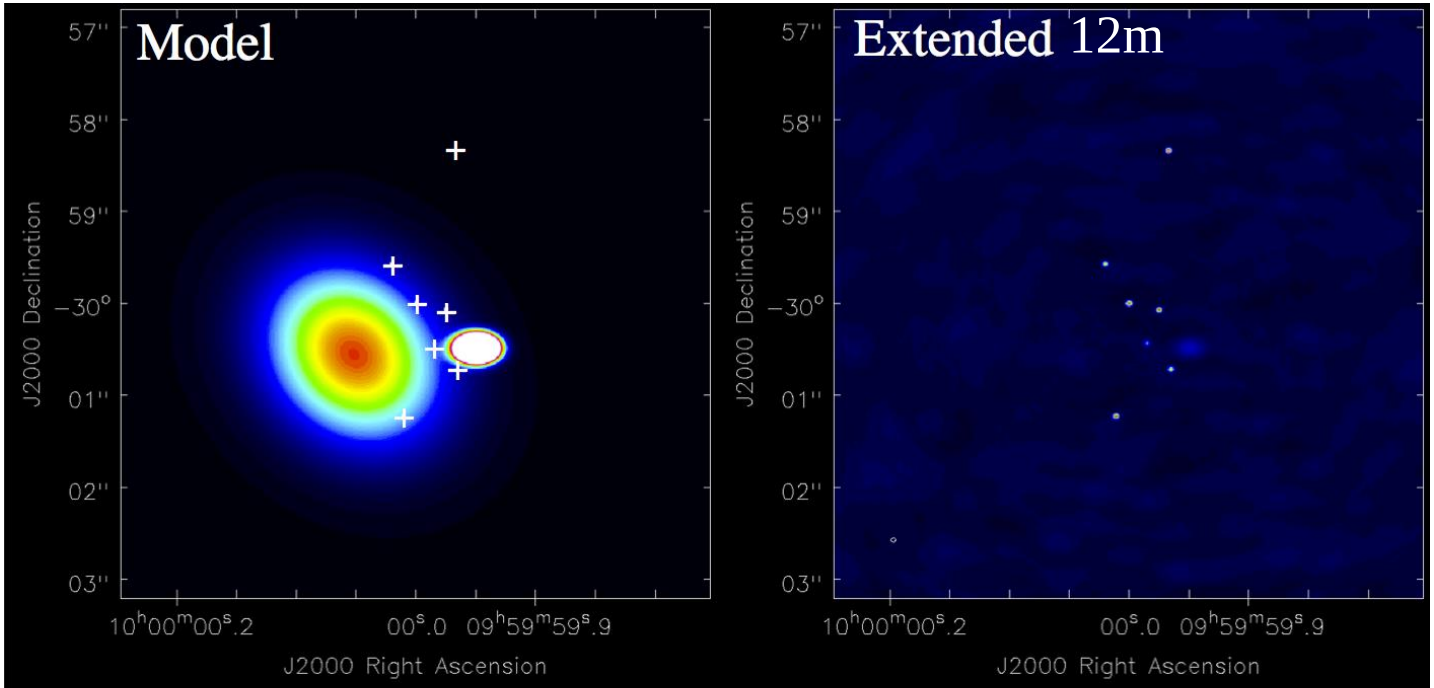
- Get relevant angular scales
    - Angular resolution (beam size) necessary
    - Largest angular scales (LAS) / Maximum Recoverable Scales (MRS)
    - ALMA compact array (ACA), i.e. 7m and/or total power (TP) ?
- Qualitative noise study – effect of artefacts, poor uv-sampling, source structure
- Test special observation setups – feasibility -> use results for technical justification in proposal



Point sources

- Extended: point sources
- Compact: smears
- Compact + ACA: same

Beam size < ½ source distance



Point sources + elliptical Gaussians

- Extended: point sources
- Compact: missing large Gaussian
- Compact + ACA: better

All scales needed

Available simulators

CASA simulator
shell

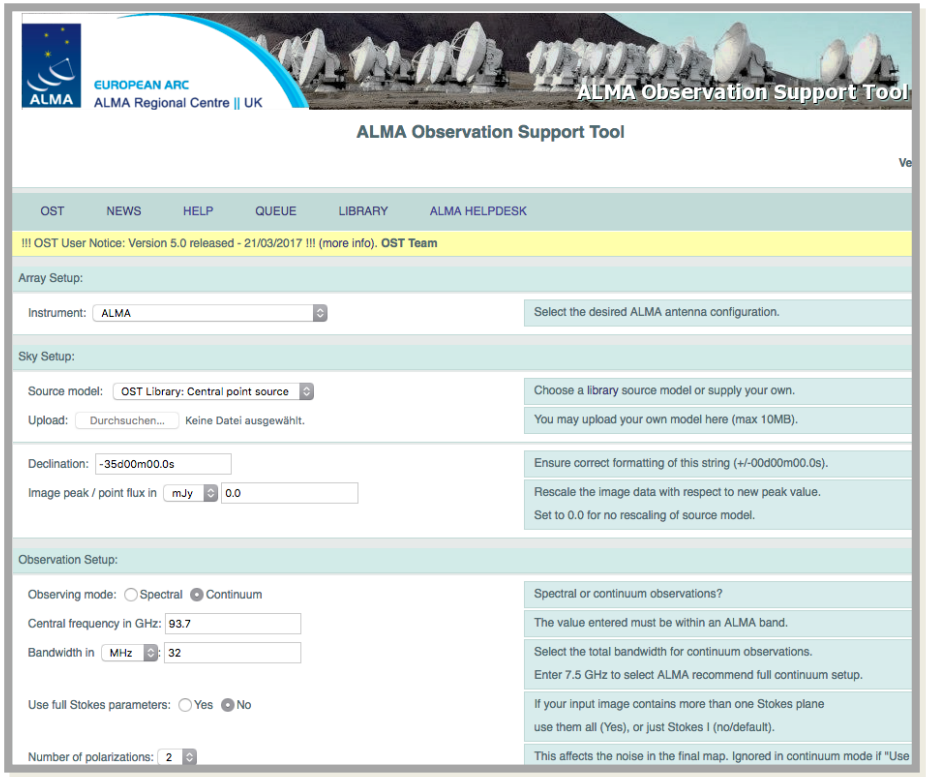
```
CASA <134>: inp simobserve
----------> inp(simobserve)
#  simobserve :: visibility simulation task
project             = 'simobs-M51Ha'     #  root prefix for output file names
skymodel            = 'M51Ha.fits'       #  model image to observe
     inbright       =    '0.004'         #  scale surface brightness of brightest
     indirection    = 'J2000 23h59m59.96s -34d59m59.50s' #  set new direction e.
     incell         = '0.1arcsec'        #  set new cell/pixel size e.g. "0.1arcs
     incenter       = '330.076GHz'       #  set new frequency of center channel e
     inwidth        =    '50MHz'         #  set new channel width e.g. "10MHz" (r

complist            =         ''         #  componentlist to observe
setpointings        =       True
     integration    =      '10s'         #  integration (sampling) time
     direction      =         ''         #  "J2000 19h00m00 -40d00m00" or "" to c
     mapsize        =  '1arcmin'         #  angular size of map or "" to cover mo
     maptype        =      'hex'         #  hexagonal, square (raster), ALMA, etc
     pointingspacing =  '9arcsec'        #  spacing in between pointings or "0.25

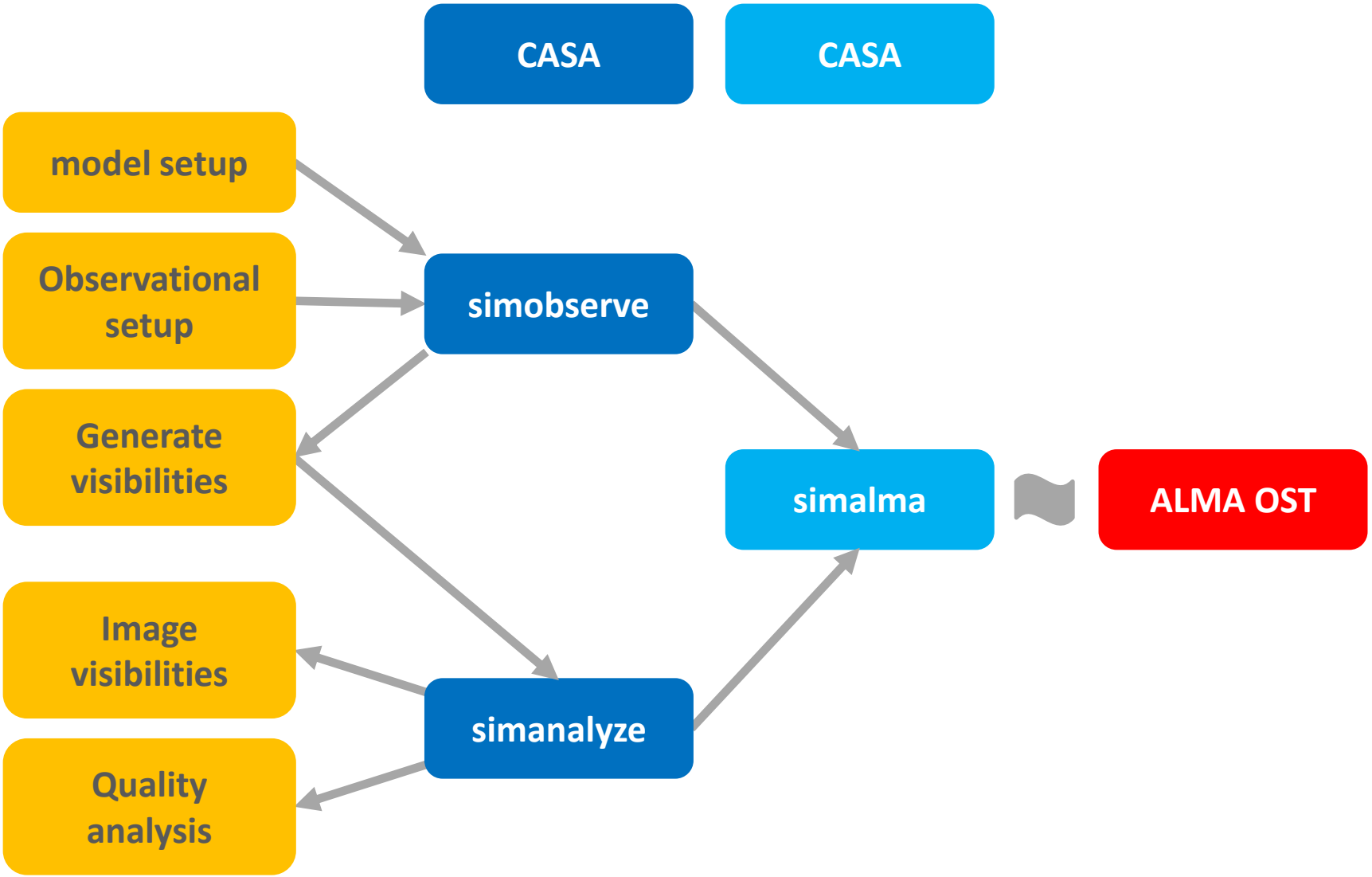
obsmode             =       'int'        #  observation mode to simulate [int(int
     antennalist    = 'ALMA;0.5arcsec'   #  interferometer antenna position file
     refdate        = '2012/12/03'       #  date of observation - not critical un
     hourangle      =  'transit'         #  hour angle of observation center e.g.
                                         #   hours), or "transit"
     totaltime      =    '3600s'         #  total time of observation or number o
     caldirection   =         ''         #  pt source calibrator [experimental]
     calflux        =      '1Jy'

thermalnoise        =         ''         #  add thermal noise: [tsys-atm|tsys-man
leakage             =        0.0         #  cross polarization (interferometer on
graphics            =     'both'         #  display graphics at each stage to [sc
verbose             =      False
overwrite           =       True         #  overwrite files starting with $projec
```

ALMA Observation Support Tool (OST)
http://almaost.jb.man.ac.uk/



Simulation procedure



Simobserve

```
#  simobserve :: visibility simulation task
project             = 'simobs-M51Ha'    #  root prefix for output file names
skymodel            = 'M51Ha.fits'      #  model image to observe
     inbright       =    '0.004'        #  scale surface brightness of brightest pixel e.g. "1.2Jy/pixel"
     indirection    = 'J2000 23h59m59.96s -34d59m59.50s' #  set new direction e.g. "J2000 19h00m00 -40d00m00"
     incell         = '0.1arcsec'       #  set new cell/pixel size e.g. "0.1arcsec"
     incenter       = '330.076GHz'      #  set new frequency of center channel e.g. "89GHz" (required even for 2D model)
     inwidth        =    '50MHz'        #  set new channel width e.g. "10MHz" (required even for 2D model)

complist            =         ''        #  componentlist to observe
setpointings        =       True
     integration    =      '20s'        #  integration (sampling) time
     direction      =         ''        #  "J2000 19h00m00 -40d00m00" or "" to center on model
     mapsize        =  '1arcmin'        #  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/sqr
                                        #   SD=lambda/D/3

obsmode             =      'int'        #  observation mode to simulate [int(interferometer)|sd(singledish)|""(none)]
     antennalist    = 'Cycle5-cfg/C43-2.cfg' #  interferometer antenna position file
     refdate        = '2017/12/02'      #  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      =     '0.5h'        #  total time of observation or number of repetitions
     caldirection   =         ''        #  pt source calibrator [experimental]
     calflux        =      '1Jy'

thermalnoise        = 'tsys-atm'        #  add thermal noise: [tsys-atm|tsys-manual|""]
     user_pwv       =        0.5        #  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             =      False
overwrite           =       True        #  overwrite files starting with $project
```

Simobserve

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#  simobserve :: visibility simulation task
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setpointings        =       True
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     direction      =         ''         #  "J2000 19h00m00 -40d00m00" or "" to center on model
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     pointingspacing =       ''         #  spacing in between pointings or "0.25PB" or "" for ALMA
                                        #   SD=lambda/D/3

obsmode             =      'int'         #  observation mode to simulate [int(interferometer)|sd(sin
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     refdate        = '2017/12/02'       #  date of observation - not critical unless concatting sim
     hourangle      =  'transit'         #  hour angle of observation center e.g. "-3:00:00", "5h",
                                        #   units will be interpreted as hours), or "transit"
     totaltime      =     '0.5h'         #  total time of observation or number of repetitions
     caldirection   =         ''         #  pt source calibrator [experimental]
     calflux        =      '1Jy'

thermalnoise        = 'tsys-atm'         #  add thermal noise: [tsys-atm|tsys-manual|""]
     user_pwv       =       0.5          #  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             =     False
overwrite           =      True          #  overwrite files starting with $project
```

Input model

Spectal setup

Array and pointing setup

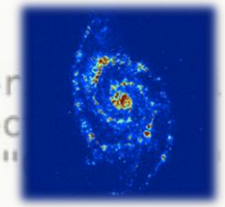
Date and Duration

Noise corruption

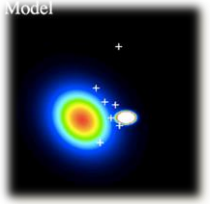
Input model

- fits-file (also cube)

```
skymodel            = 'M51Ha.fits'      #  model image to observe
      inbright      =    '0.004'        #  scale surface brightness of br
      indirection   = 'J2000 23h59m59.96s -34d59m59.50s' #  set new direc
      incell        = '0.1arcsec'       #  set new cell/pixel size e.g. "
```



- create fits-file from GIF or JPG with ImageMagik: `convert myfile.jpg myfile.fits`
- simulate object at higher redshift → rescale brightness and angular scale
  (see https://casaguides.nrao.edu/index.php/M51_at_z_%3D_0.1#Flux_Density_Scaling)



- component list (point sources, disks, Gaussians, ...)

```
complist            =           ''      #  componentlist to observe
```

- See https://casaguides.nrao.edu/index.php/Simulation_Guide_Component_Lists_(CASA_3.3)

Spectral setup

```
      incenter      = '330.076GHz'      #  set new frequency of center channel e.g.
      inwidth       =    '50MHz'        #  set new channel width e.g. "10MHz" (requi
```

Array configuration

- interferometer

```
obsmode                 =       'int'          #  observation mode to simulate [int(interfe
     antennalist        = 'Cycle5-cfg/C43-2.cfg' #  interferometer antenna position file
```

- antennalist:
  - = 'alma; 0.5arcsec'
  - = os.getenv('CASAPATH').split(' ')[0] + '/data/alma/simmos/>choose_a_list<.cfg‘
  - Recent configurations: https://almascience.eso.org/tools/casa-simulator
  - Beam size > model image cell size
  - Array resolution and LAS: https://almascience.eso.org/proposing/proposers-guide#section-59
  - Arrays to combine like in a real ALMA observation: https://almascience.eso.org/proposing/proposers-guide#section-63

- single dish

```
obsmode                 =         'sd'         #  observation mode to simulate [int(interfe
     sdantlist          = 'aca.tp.cfg'         #  single dish antenna position file
     sdant              =            0         #  single dish antenna index in file
```

Pointing setup

- provide a list of pointing positions

```
setpointings          =      False
     ptgfile          = '$project.ptg.txt' #  list of pointing positions
     integration      =      '20s'         #  integration (sampling) time
```

- OT generated pointings cannot be used?

- calculate a map of pointings

```
setpointings          =       True
     integration      =      '20s'        #  integration (sampling) time
     direction        =        ''         #  "J2000 19h00m00 -40d00m00" or "" to cente
     mapsize          =  '1arcmin'        #  angular size of map or "" to cover model
     maptype          =    'ALMA'         #  hexagonal, square (raster), ALMA, etc
     pointingspacing =          ''        #  spacing in between pointings or "0.25PB" c
                                          #   SD=lambda/D/3
```

- If `obsmode = 'sd'` : mapsize <0.5PB larger than for 'int' – avoid edge effects
- $project.ptg.txt generated automatically

Date and Duration

```
integration    =      '20s'        #  integration (sampling) time
```

- time per pointing

```
refdate        = '2017/12/02'      #  date of observation - not critical unless
hourangle      =  'transit'        #  hour angle of observation center e.g. "-3
                                   #   units will be interpreted as hours), or
totaltime      =     '0.5h'        #  total time of observation or number of re
```

- refdate: use different dates for each configuration/data set within your project
- totaltime:
  - also: = # repetion per map
  - Observing time ratios for multiple arrays to combine like in a real ALMA observation:
    https://almascience.eso.org/proposing/proposers-guide#section-63

Noise corruption

- Atmospheric Transmission at Microwaves (ATM) model

```
thermalnoise          = 'tsys-atm'        #  add thermal noise: [tsys-atm|tsys-manual
     user_pwv         =         0.5       #  Precipitable Water Vapor in mm
     t_ground         =       269.0       #  ambient temperature
     seed             =       11111       #  random number seed
```

- Zenith opacity

```
thermalnoise          = 'tsys-manual'     #  add thermal noise: [tsys-atm|tsys-manual|
     t_ground         =       269.0       #  ambient temperature
     t_sky            =       263.0       #  atmospheric temperature
     tau0             =         0.1       #  zenith opacity
     seed             =       11111       #  random number seed
```

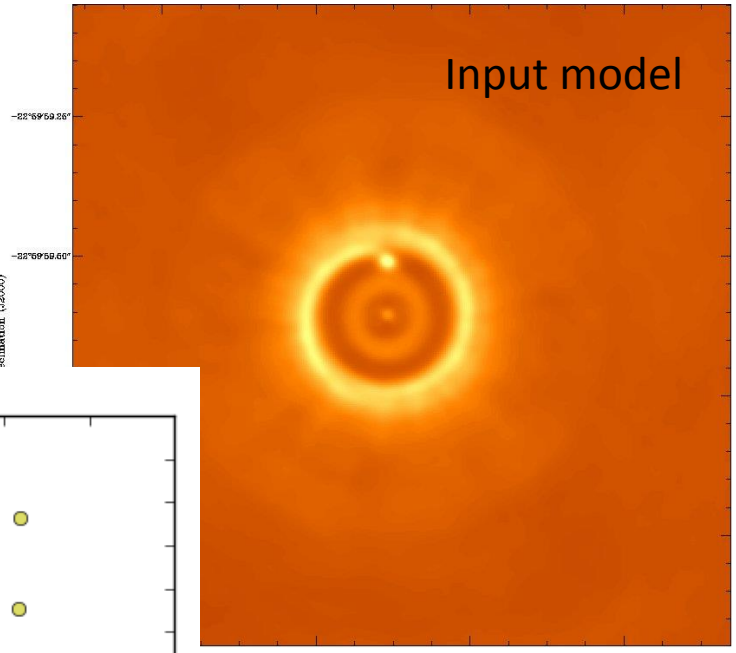
- No noise: thermalnoise= ''
- RMS in the resulting map should not be used in the proposal
- use ALMA sensitivity calculator instead

- **sm tool**: advanced users; apply after simobserve without noise
  - thermal noise, phase delay variations, gain fluctuations and drift cross-polarization, etc. (see https://casaguides.nrao.edu/index.php/Corrupt)
    → more flexibility in adding thermal noise

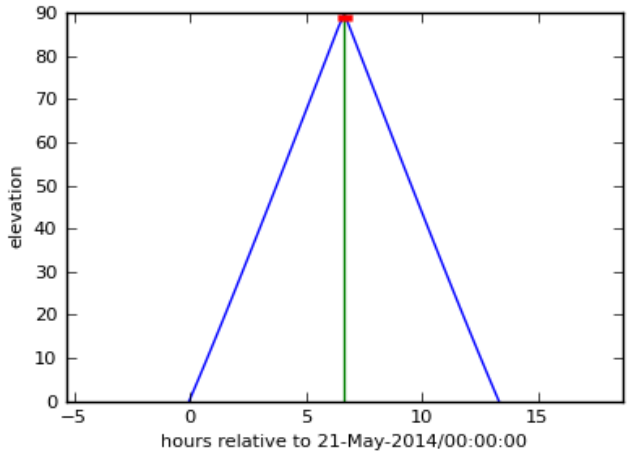
Simobserve

Diagnostic image products

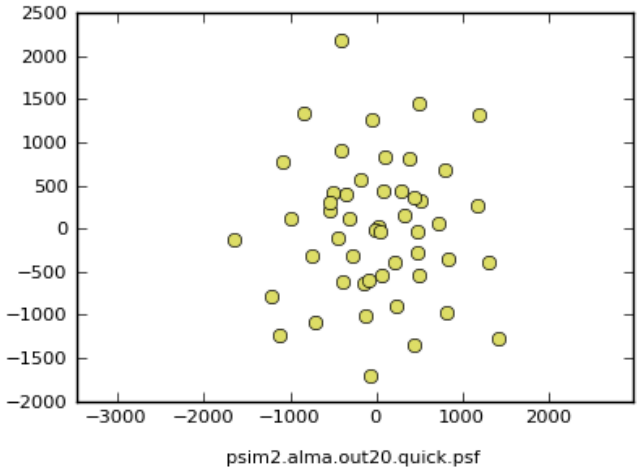
Example: Protoplanetary disk with 12m array

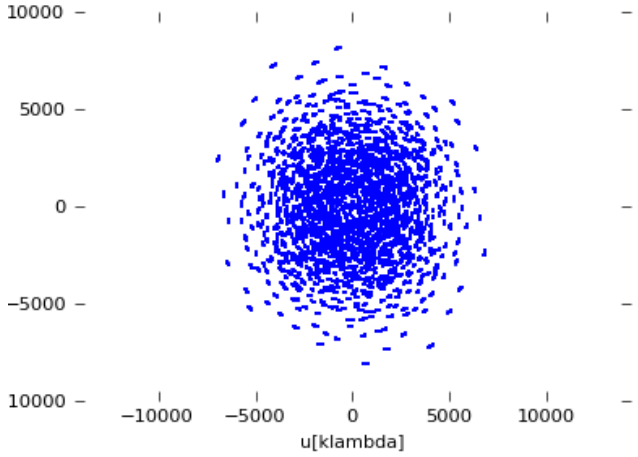


Elevation

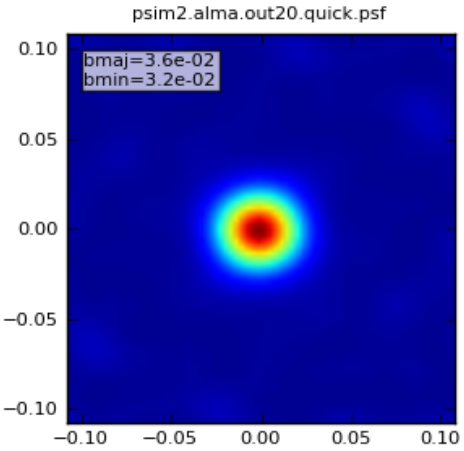


Antenna positions



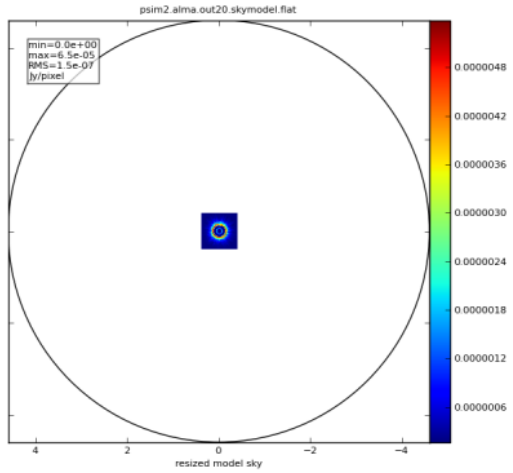


uv coverage



Synthesized beam

skymodel



Simanalyze

```
#  simanalyze :: image and analyze measurement sets created with simobserve
project             = 'simobs-M51Ha'     #  root prefix for output file names
image               =      True          #  (re)image $project.*.ms to $project.image
     vis            = '$project.C43-2.noisy.ms' #  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 outputs will be displayed)
     showuv         =       False        #  display uv coverage
     showpsf        =       False        #  display synthesized (dirty) beam (ignored in single dish simulation)
     showmodel      =        True        #  display sky model at original resolution
     showconvolved  =        True        #  display sky model convolved with output clean beam
     showclean      =        True        #  display the synthesized image
     showresidual   =        True        #  display the clean residual image (ignored in single dish simulation)
     showdifference =        True        #  display difference between output cleaned image and input model sky image cor
     showfidelity   =        True        #  display fidelity (see help)

graphics            =      'both'        #  display graphics at each stage to [screen|file|both|none]
verbose             =       False
overwrite           =        True        #  overwrite files starting with $project
dryrun              =        True        #  only print information [experimental; only for interfermetric data]
logfile             =          ''
```

Simanalyze

```
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project             = 'simobs-M51Ha'     #  root prefix for output file names
image               =      True          #  (re)image $project.*.ms to $project.image
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     modelimage     =          ''        #  lower resolution prior image to use in clean e.g. existing
     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 robus
     mask           =          []        #  Cleanbox(es), mask image(s), region(s), or a level
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     showdifference =        True        #  display difference between output cleaned image and input
     showfidelity   =        True        #  display fidelity (see help)

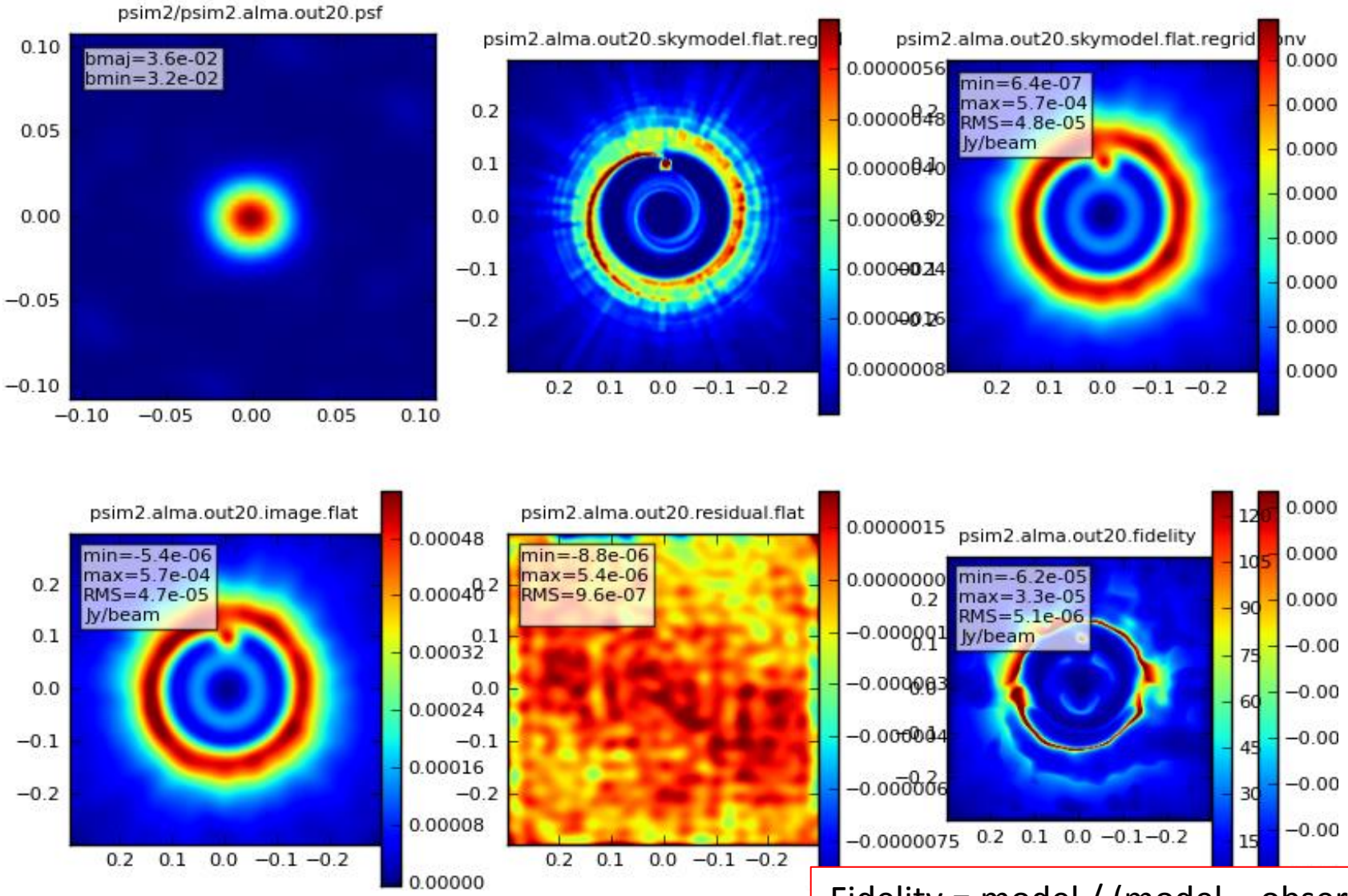
graphics            =      'both'        #  display graphics at each stage to [screen|file|both|none]
verbose             =       False
overwrite           =        True        #  overwrite files starting with $project
dryrun              =        True        #  only print information [experimental; only for interfermetric data]
logfile             =          ''
```

clean

diagnostic products

Simanalyze

Diagnostic image products - Example: Protoplanetary disk with the 12m array

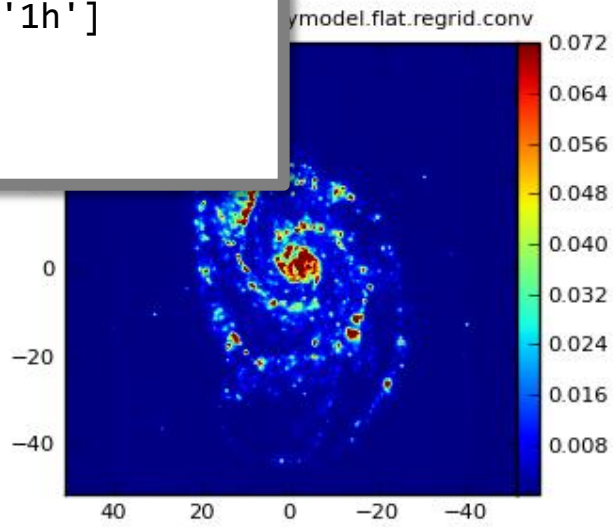


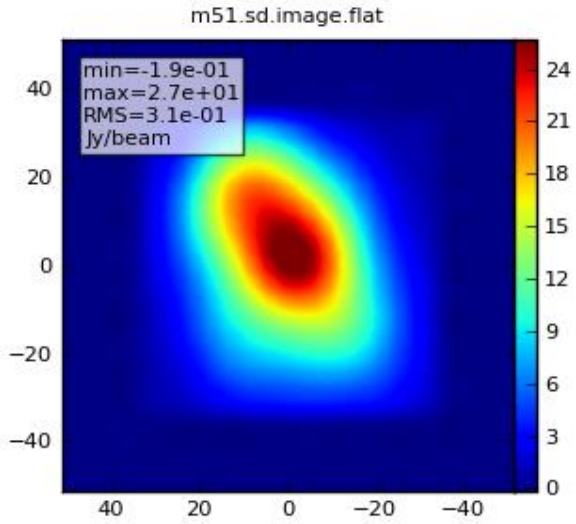
Fidelity = model / (model – observed)

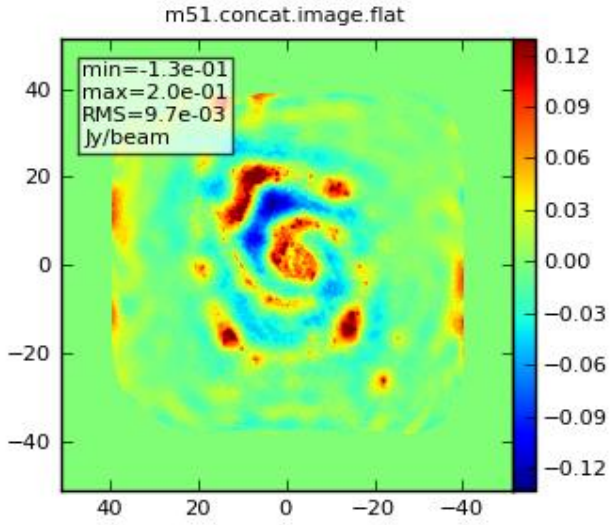
Simalma - generate and combine ALMA 12m, ACA (7m) and TP

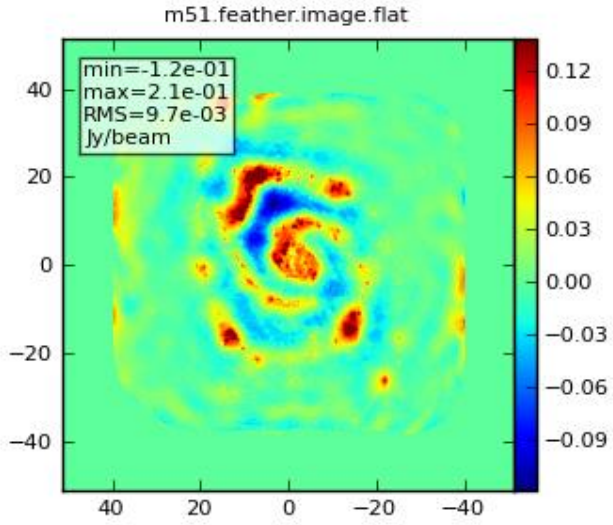
```
mapsize   = "1arcmin"
antennalist= ["alma_cycle1_3.cfg",
               "aca_cycle1.cfg"]
totaltime= ['30min', '1h']
tpnant    = 2
tptime    = '2h'
pwv       = 0.6
```

- Simobserve + simanalyze for each array
- Simanalyze of concatenated interferometic data (weigths!)
- Feather concatenated interferometic image with SD image









Summary

- Simulations – useful tool to study observation setup/ feasibility
- basic simulator procedure demonstrated for CASA simulator
  - Simobserve
  - Simanalyze
  - Simalma
- More details?! → CASA inline help (e.g. `help simobserve`), tutorials, manual, Google

Based on https://casaguides.nrao.edu/index.php/Simulating_Observations_in_CASA_4.4

- https://casaguides.nrao.edu/index.php/Guide_To_Simulating_ALMA_Data
- https://casaguides.nrao.edu/index.php/Protoplanetary_Disk_Simulation_(CASA_4.4)
- https://casaguides.nrao.edu/index.php/ACA_Simulation_(CASA_4.4)
- https://casaguides.nrao.edu/index.php/Simalma_(CASA_4.4)