Technical Justification and CASA Simulator

Town hall meeting for ALMA Cycle 4
2016 March 28
Woojin Kwon
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 $\leq 1/3$ of line width
- Spectral dynamic range: both spectral line properties and a continuum flux put in $\langle$continuum$\rangle/\langle$line rms$\rangle$
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

\[
V(u, v) = A_N(l, m)I(l, m).
\]

\[
S(u, v)V(u, v) = FT^{-1}[S(u, v)] \ast FT^{-1}[V(u, v)]
\]

\[
B_D(l, m) \ast [A_N(l, m)I(l, m)].
\]

- Keywords
  - uv coverage, uv distance, synthesized beams, primary beam…
Simulating interferometric data (visibilities)
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](http://almaost jb.man.ac.uk)
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

- 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

```python
# CASA <46>: inp
--------> inp()

# simobserve :: visibility simulation task
project = 'sim'  # root prefix for output file names
# root prefix for output file names
skymodel = '30dor.fits'  # model image to observe
# model image to observe
inbright = '0.06mJy/pixel'  # scale surface brightness of brightest pixel e.g. "1.2Jy/pixel"
# scale surface brightness of brightest pixel e.g. "1.2Jy/pixel"
indirection = 'J2000 10h00m00 -40d00m00'  # set new direction e.g. "J2000 19h00m00 -40d00m00"
# set new direction e.g. "J2000 19h00m00 -40d00m00"
incenter = '0.15arcsec'  # set new cell/pixel size e.g. "0.1arcsec"
# set new cell/pixel size e.g. "0.1arcsec"
inwidth = '2GHz'  # set new channel width e.g. "10MHz" (required even for 2D model)
# set new channel width e.g. "10MHz" (required even for 2D model)

# componentlist to observe
complist = ''
# integration (sampling) time
integration = '600s'
# integration (sampling) time
direction = ''
# angular size of map or "" to cover model
mapsize = ['', ']
# angular size of map or "" to cover model
maptype = 'ALMA'
# spacing in between pointings or "" for ALMA default
pointingspacing = ''
```
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

```python
# simanalyze :: image and analyze measurement sets created with simobserve
project = 'sim'  # root prefix for output file names
image = True
vis = 'default'  # Measurement Set(s) to image
modelimage = ''  # lower resolution prior image to use
imsiz = 0  # in clean e.g. existing total power
imdir = ''  # output image size in pixels (x,y) or 0 to match model
model = ''  # set output image direction,

interactive = False  # (otherwise center on the model)
cell = ''  # cell size with units e.g. "10arcsec"

niter = 0  # interactive clean? (make sure to set niter>0 also)

threshold = '0.1mJy'  # flux level (+units) to stop cleaning
weighting = 'natural'  # weighting to apply to visibilities.

showuv = True  # flux level (+units) to stop cleaning
showpsf = True  # weighting to apply to visibilities.
showmodel = True  # briggs will use robust=0.5
showconvolved = True  # Cleanbox(es), mask image(s),
showclean = True  # region(s), or a level
showresidual = False  # uv-taper on outer baselines in uv-plane
showdifference = True  # correct the output of synthesis
showfidelity = False  # images for primary beam response?

graphics = 'both'  # Stokes params to image
verbose = False  # image (e.g. total power) to feather
overwrite = True  # with new image
logfile = ''  # Stokes params to image
dryrun = False  # Stokes params to image
```
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

**Array Setup:**
- **Instrument:** ALMA
- **Select the desired ALMA antenna configuration.**

**Sky Setup:**
- **Source model:** OST Library: Central point source
- **Upload:** Choose File, No file chosen
- **Declination:** -35d00m00.0s
- **Image peak / point flux in mJy:** 0.0
- **Choose a library source model or supply your own.**
- **Ensure correct formatting of this string (+/-00d00m00.0s).**
- **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
- **Central frequency in GHz:** 93.7
- **Bandwidth in MHz:** 32
- **Number of polarizations:** 2
- **Required resolution in arcseconds:** 1.0
- **Pointing strategy:** Mosaic
- **On-source time in hours:** 3
- **Start hour angle:** 0.0
- **Number of visits:** 1
- **Include cycling to phase calibrator?:** No
- **Spectral or continuum observations?**
- **The value entered must be within an ALMA band.**
- **Select the total bandwidth for continuum observations.**
- **Enter 7.5 GHz to select ALMA recommend full continuum setup.**
- **This affects the noise in the final map.**

**Atmospheric Corruption:**
- **Atmospheric conditions:** PWV = 0.472 mm (1st Octile)
- **Determines level of noise due to water vapour.**

**Imaging Product:**
- **Imaging weights:** Natural
- **Perform deconvolution?:** No (Return dirty image)
- **Output image format:** FITS
- **This allows a resolution / sensitivity trade-off.**
- **Apply the CLEAN algorithm to deconvolve the image.**
- **CASA format images are returned as a tar file**

**Submission:**
- **Your email address is:** essential
- **Submit**
Job ID: 2016031125744WnlRv / Submitted by: wkwon@kasi.re.kr

Data products
Your simulated image:
Download FITS file

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:

<table>
<thead>
<tr>
<th>Maximum elevation:</th>
<th>77.88 degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central frequency:</td>
<td>93.7 GHz (ALMA Band 3)</td>
</tr>
<tr>
<td>Total Bandwidth:</td>
<td>7.5 GHz</td>
</tr>
<tr>
<td>Track length:</td>
<td>3 hours x 1.0 visits</td>
</tr>
<tr>
<td>Hexagonal mosaic pointings:</td>
<td>1 required to cover requested sky area with uniform sensitivity</td>
</tr>
<tr>
<td>System temperature:</td>
<td>Tsys = 68.8274779127 K</td>
</tr>
<tr>
<td>PWV:</td>
<td>0.942 mm</td>
</tr>
<tr>
<td>Theoretical RMS noise:</td>
<td>5.6326072559e-06 Jy (in naturally-weighted map)</td>
</tr>
<tr>
<td>Restoring beam (resolution):</td>
<td>Major axis = 1.937 arcsec, minor axis = 1.578 arcsec, PA = 81.624 deg</td>
</tr>
</tbody>
</table>

For use with CASA simdata
Download processed model in FITS format
Download CASA simobserve/analyze file: 2016031125744WnlRv_simdata last
Download pointing file: 2016031125744WnlRv_point last

Diagnostics
Processing time: 37 seconds
**Data products**

- Your simulated image:
- Download FITS file

**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:**
- [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:**
- $T_{sys} = 85.8582654401$ K

**PWV:**
- 0.654 mm

**Theoretical RMS noise:**
- $5.27516757554e-06$ 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**

- Download processed model in FITS format
- Download CASA simobserve/analyze file: [20160317130740ZILNu_simdata.leaf](#)
- Download pointing file: [20160317130740ZILNu_ptg.txt](#)

**Diagnostics**

- Processing time: 104 seconds
Summary

- ALMA simulator
- CASA simulation tasks/tools
  http://casa.nrao.edu
  simobserve
  simanalyze
  (simalma)
- Observation Support Tool
  http://almaost.jb.man.ac.uk