Hands on Tutorial: ALMA Imaging

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This tutorial will consist of a talk from the speaker in between hands on work with a CASA Guide.

Topics:

- **A first look at tclean**
- **Continuum imaging**
- **Self-Calibration**
- **Linecube imaging**
- **Image Analysis**

A Note: There are a lot of terminal commands and parameters to set in CASA in this talk. These commands are also on the CASA Guide webpages we will be using.

https://casaguides.nrao.edu/index.php/ALMAguides
https://casaguides.nrao.edu/index.php/First_Look_at_Imaging_CDE

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CASAGuides: First Look at Imaging

- Check out the ALMA Guides at

https://casaguides.nrao.edu/index.php/ALMAguides

- Today we'll look at the first look guides

https://casaguides.nrao.edu/index.php/First_Look_at_Imaging_CDE

- There are also guides for:
- Automasking
- Pipeline Image reprocessing
- NA Imaging Template
- Science Verification data reductions

CASAGuides: First Look at Imaging

https://casaguides.nrao.edu/index.php/ALMAguides

Introduction [edit]

This page contains tutorials to guide new ALMA users through some common types of data imaging and analysis using example ALMA datasets. In addition, we provide detailed guides to the calibration and imaging of some of the publicly-available ALMA Science Verification data that illustrate several different ALMA capabilities.

If you are a new user of CASA, take a look at Getting Started in CASA.

If you are new to CASAguides, start with How to use these CASA Tutorials.

General Imaging Tutorials [edit]

The following tutorials use example ALMA datasets to guide new CASA users through the basic steps required for imaging and self-calibration. ALMA data are delivered with standard calibrations applied and they are ready for imaging.

These guides have been updated to work in CASA 5.4.0, and to use tclean rather than clean. To understand the differences between clean and tclean, please see the guide: Examples for using the new tclean CASA task for ALMA Imaging.

- A first look at imaging in CASA: This guide gives a first look at imaging and image analysis in CASA.
- A first look at self-calibration in CASA: This guide demonstrates continuum self-cal.
- A first look at spectral line imaging in CASA: This guide shows imaging of a spectral line.
- A first look at image analysis in CASA: This guide demonstrates moment creation and basic image analysis.

Community Development Day Tutorials:

- A first look at imaging in CASA: This guide gives a first look at imaging and image analysis in CASA.
- A first look at self-calibration in CASA: This guide demonstrates continuum self-cal.
- A first look at spectral line imaging in CASA: This guide shows imaging of a spectral line.
- A first look at image analysis in CASA: This guide demonstrates moment creation and basic image analysis.

New!

- A guide to automasking: This guide demonstrates the automasking functionality of tclean.

You can find archived versions of the first look guides for older versions of CASA here.

About the Sample Data:

The data for this example comes from ALMA Project 2011.0.00340.S, "Searching for H2D+ in the disk of TW Hya v1.5", for which the PI is Chunhua Qi. Part of the data for this project has been published in Qi et al. 2013.

The original observation had three scientific objectives:

1. Image the submm continuum structure in TW Hydra
2. Image the H2D+ line structure (rest frequency 372.42138 GHz)
3. Image the N2H+ line structure (rest frequency 372.67249 GHz)

- This data is already calibrated and we have reduced it in size by averaging in time and frequency.
- Our goal will be to image the continuum emission and the N2H+ spectral line, which is bright and well suited for demonstrating the imaging techniques.

Prepare the Sample Data

Go to your NRAO Socorro Cluster to access the data:

tar –xvf sis14_twhya_calibrated_flagged.ms.tar

First Look at Imaging

- Inspecting the data (listobs, plotms)
- First look at TCLEAN (parameters)
- Experiment with TCLEAN (robust,cell &imsize)
- Image the science target
- Non-interactive clean
- How to apply PB correction

CASAGuides: First Look at Imaging

- clean is the original imaging task.
- tclean (i.e., test clean) is a new version of clean that has been refactored to make it easier to maintain and add new options.
- Both tasks
  - take the calibrated visibilities
  - grid them on the UV-plane
  - perform the FFT to a dirty image
  - deconvolve the image
  - restore the image from clean table and residual
- The task tclean is used by Cycle 5 pipeline and all development including bugfixes is only being done in tclean.
- Major syntax and usage changes from clean → tclean are summarized here: https://casaguides.nrao.edu/index.php/TCLEAN_and_ALMA

Key tclean parameters

vis = ms file (can be multiple ms'es)

imagename = whatever you want

```
CASA <6>: inp tclean
--------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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)
     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,m
                                        #   ultiscale,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               =          0        #  Maximum number of iterations
usemask             =     'user'        #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, 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

CASA <7>:
```

Key tclean parameters

imsize = size of image in pixels = typically primary beam (i.e., FOV)

cell = size of pixels in angular units = typically 5-8 pixels across synthesized beam (resolution)

```
CASA <6>: inp tclean
---------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =          ''        #  Name of input visibility file(s)
selectdata          =        True        #  Enable data selection parameters
     field          =          ''        #  field(s) to select
     spw            =          ''        #  spw(s)/channels to select
     timerange      =          ''        #  Range of time to select from data
     uvrange        =          ''        #  Select data within uvrange
     antenna        =          ''        #  Select data based on antenna/baseline
     scan           =          ''        #  Scan number range
     observation    =          ''        #  Observation ID range
     intent         =          ''        #  Scan Intent(s)

datacolumn          = 'corrected'        #  Data column to image(data,corrected)
imagename           =          ''        #  Pre-name of output images
imsize              =       [100]        #  Number of pixels
cell                = ['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)
     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,m
                                         #   ultiscale,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               =           0        #  Maximum number of iterations
usemask             =      'user'        #  Type of mask(s) for deconvolution
                                         #   (user, pb, auto-thresh, auto-
                                         #   thresh2, 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

CASA <7>:
```

Key tclean parameters

Weighting = visibility weighting scheme

- Natural- More weight given to short baselines-Angular resolution degraded, better sensitivity
- Uniform- More weight give to long baselines-Angular resolution enhanced, sensitivity is degraded
- Briggs-Provides Robust parameter for scaling between Natural and Uniform

robust = -2.0 maps to uniform weighting. robust = +2.0 maps to natural weighting.

- Robust=0.5 is used for ALMA QA2

```
CASA <6>: inp tclean
--------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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)
     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,m
                                        #   ultiscale,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               =          0        #  Maximum number of iterations
usemask             =     'user'        #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, 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

CASA <7>:
```

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Key tclean parameters

The **specmode** parameter controls whether you image the continuum or line emission.

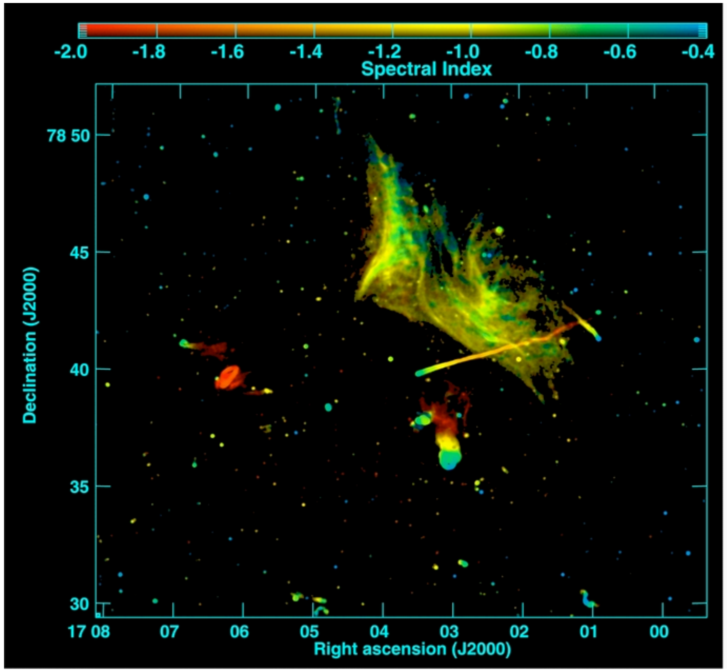
The **gridder** option is used to specify what sort of gridding you will be doing (standard, mosaic, widefield, wproject, or awproject). The first two are most common with ALMA. The rest more common with the VLA.

The **deconvolver** options gives you access to different deconvolution options (hogbom, clark, mtmfs, multiscale, clarkstokes)

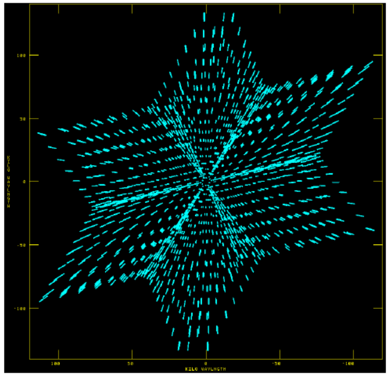
```
CASA <23>: inp
---------> inp()
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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)
     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         =    'mtmfs'        #  Minor cycle algorithm (hogbom,clark,m
                                        #   ultiscale,mtmfs,mem,clarkstokes)
     scales         =         []        #  List of scale sizes (in pixels) for
                                        #   multi-scale algorithms
     nterms         =          2        #  Number of Taylor coefficients in the
                                        #   spectral model

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               =          0        #  Maximum number of iterations
usemask             =     'user'        #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, 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
```

Specmode options: Continuum Imaging

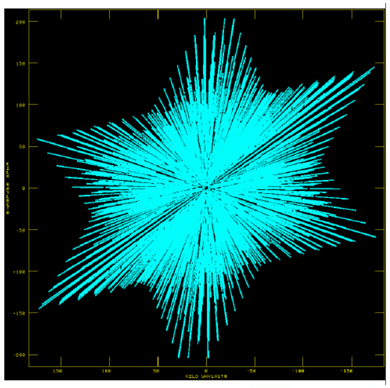
- specmode='mfs' if narrow bandwidth
- add deconvolver='mtmfs' if you have a fractional bandwidth for the aggregate continuum greater than 10% to use multi-term multi-frequency synthesis.
  - Only in ALMA Band 3 and the lower end of Band 4 can have fractional bandwidths of greater than 10% and only when both sidebands are employed.
  - nterm=2 compute spectral index, 3 for curvature etc.
  - tt0 average intensity, tt1 alpha*tt0, alpha images output
  - takes at least nterms longer (image size dependent)



Abell 2256; Owen et al. (2014)



Narrow BW



wide BW

(better uv-coverage)

Stopping parameters

- Setting niter>0 exposes stopping parameters
- tclean stops when it completes the maximum number of iterations or when residuals go below the threshold level, whatever comes first.
    - Set niter to a large, but not too large, number
        - 1000 is a decent starting point
        - The more complex your image is the larger niter you will need
    - threshold='3mJy'
        - Usually some multiple of your noise level (1-3 sigma)
- Interactive=True
    - Allows you interactive control of tclean through the viewer
    - Choice of niter and threshold can be controlled through viewer

```
CASA <21>: inp
---------> inp()
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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)
     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,m
                                        #   ultiscale,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               =          1        #  Maximum number of iterations
     gain           =        0.1        #  Loop gain
     threshold      =        0.0        #  Stopping threshold
     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    =      False        #  Modify masks and parameters at
                                        #   runtime

usemask             =     'user'        #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, 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
```

Get Oriented with CASA and the data

- https://casaguides/nrao.edu/index.php/First_Look_at_Imaging_CDE
  - Start CASA
  - CASA Basics
  - Learn 2 ways to run tasks
  - Get oriented with the data
    - listobs()
    - plotms()

Spend about 5 minutes getting oriented

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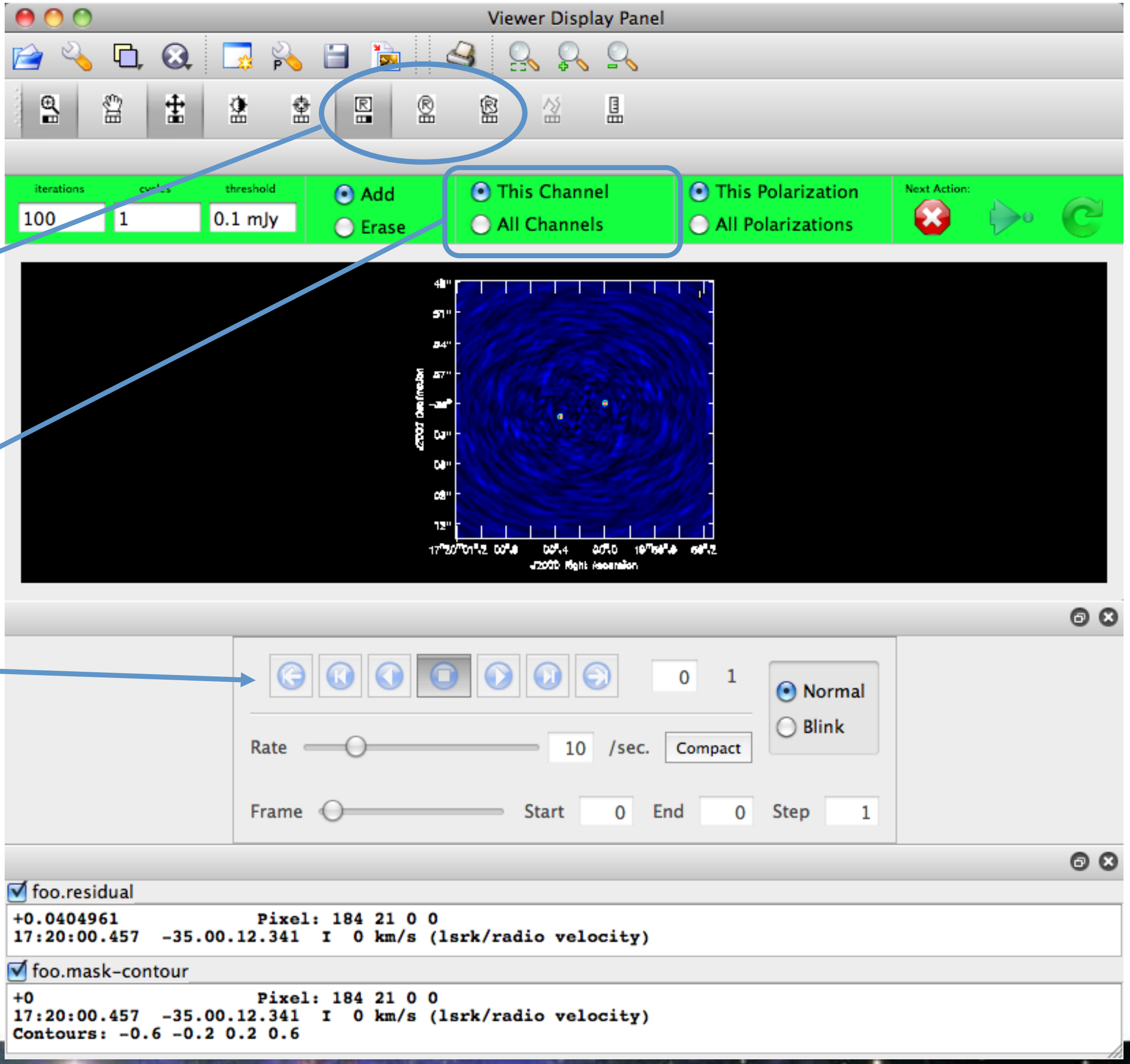
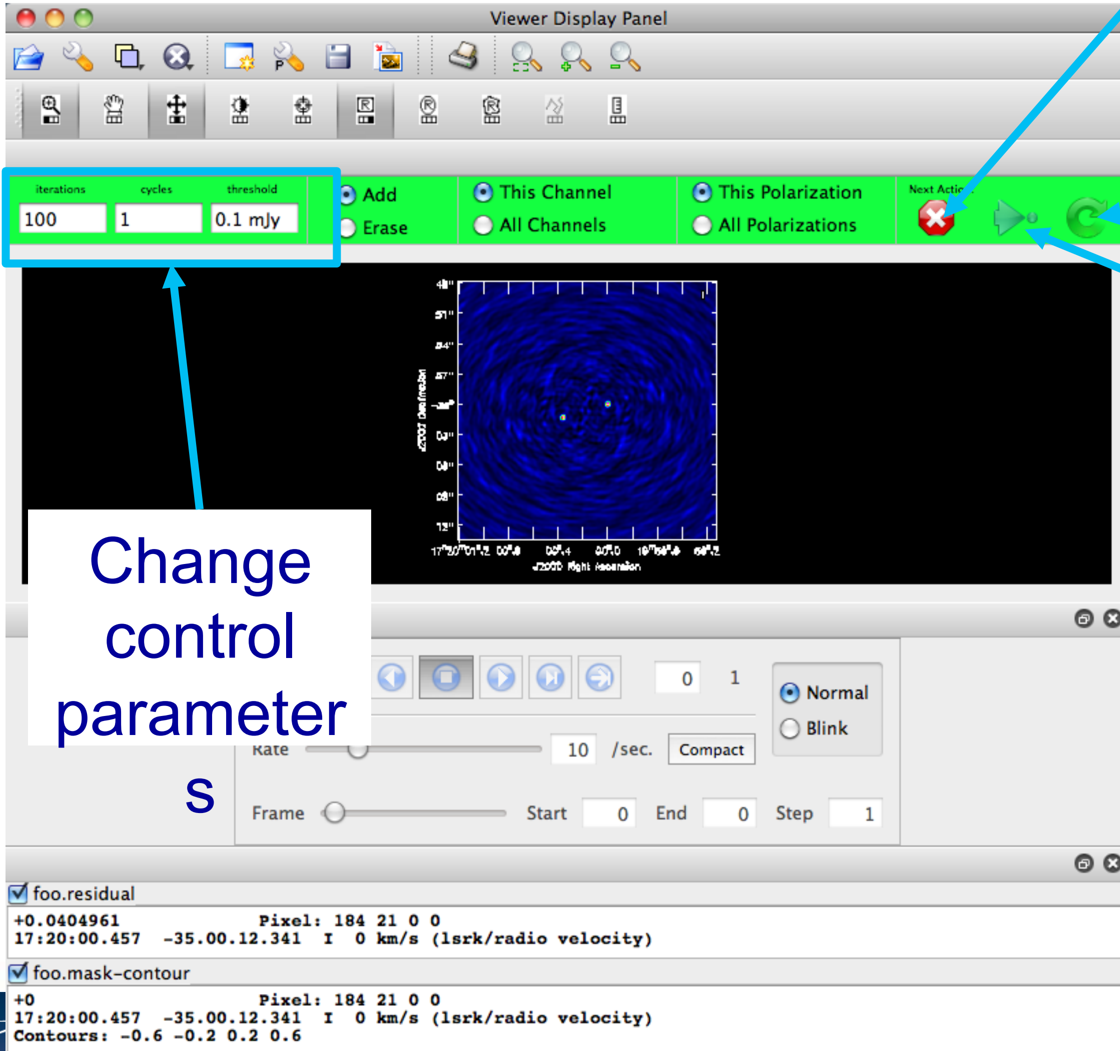
Running TCLEAN interactively

- residual image in viewer
- define a mask with defining a mouse button on shape type
- define the same mask for all channels
- or iterate through the channels with the tape deck and define separate masks



Running TCLEAN interactively



Change control parameters

Stop cleaning

Continue for next major cycle and display residual

Exit interactive mode, but continue cleaning. Dangerous if control parameters not set sensibly!!

Using Ctrl+C can corrupt your ms!

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Output of TCLEAN

Minimally:

• my_image.pb	Primary beam model
• **my_image.image**	Cleaned and restored image (Jy/clean beam)
• my_image.mask	Clean "boxes"
• my_image.model	Clean components (Jy/pixel)
• my_image.psf	Dirty beam
• my_image.residual	Residual (Jy/dirty beam)
• my_image.sumwt	Sum of weights

Wide-field imaging, multi-term, and parallel imaging will produce additional products.

Together images can be used in subsequent tclean runs if necessary. It's good practice not to delete subsets of images.

First Look at Imaging

Start working on the First Look at Imaging CASA Guide
~ 20 Minutes Hands on

What you should expect to learn:

- Become familiar with basic TCLEAN parameters
- Be familiar with TCLEAN GUI
- How to image non-interactively
- How to add a primary beam correction

https://casaguides.nrao.edu/index.php/First_Look_at_Imaging_CDE

CASAGuides: First Look at SelfCal

- Repeats the last step of a First Look at Imaging - Image the continuum of the science target
- A look at the steps of selfcal (clean, gaincal, plot, apply, repeat)

- Best Template to use for your science can be found:

https://casaguides.nrao.edu/index.php/Self-Calibration_Template

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https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration

Doing selfcalibration on continuum image

Iterative process with decreasing solution interval

- clean and save the clean model (tclean)
- use the model to solve gain solution (gaincal)
- apply the solution to the data (applycal)

Rule of Thumb:

1. With more than 25 antennas, if image S/N is 20, try phase only selfcal
2. Do clean conservatively
3. Be cautious on amp-selfcal (with extended emission)

https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration

Doing selfcalibration on continuum image

Make sure to set savemodel='modelcolumn' if self-calibrating!

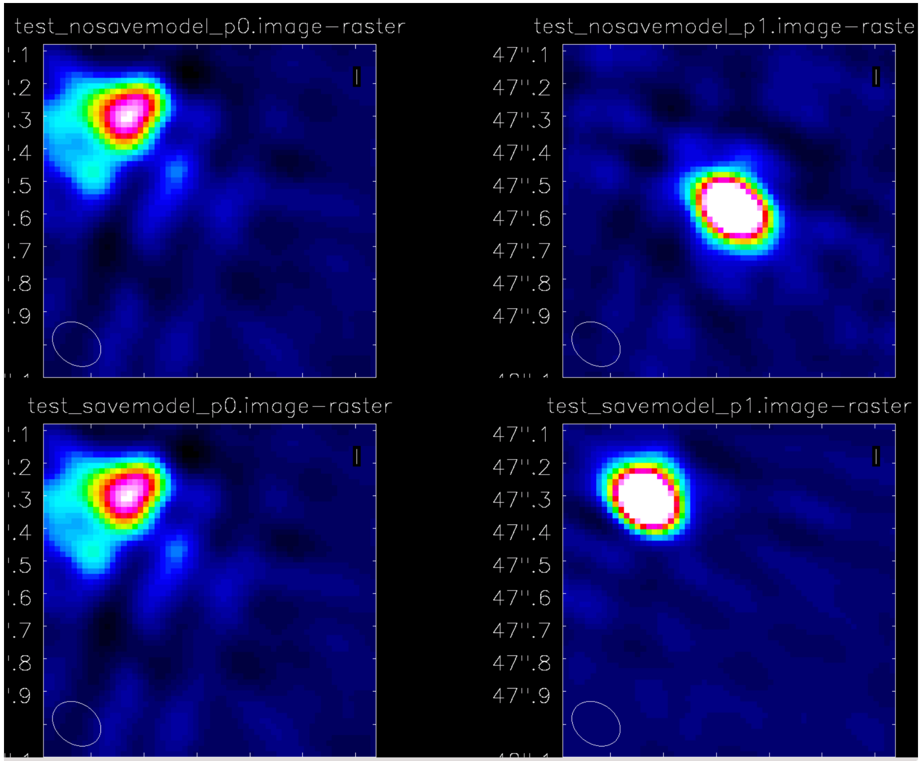
- CASA measurement sets nominally have three columns (data, model, corrected) data
- tclean does not save model by default to save disk space.
- However if you are self-calibrating, you need the model.
- If you don't do this, gaincal will use the default model (point source at the phase center).
- The end result is your source appearing to move to the center of the image and possibly becoming more point-like.

Initial self-cal image

Phase-only self-cal

Savemodel= ''none'

Savemodel= 'modelcolumn'



- For self-cal and other imaging examples see the NA ALMA imaging script template: https://github.com/aakepley/ALMAImagingScript

https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration

Doing selfcalibration on continuum image https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration_CDE

```
tclean(vis=contvis,
      imagename='twhya_cont_p0',
      field='0',
      spw='',
      specmode='cont',
      gridder='standard',
      deconvolver='hogbom',
      imsize=[250,250],
      cell=['0.08arcsec'],
      weighting='briggs',
      robust=0.5,
      threshold='0mJy',
      niter=5000,
      savemodel='modelcolumn',
      interactive=True)
```

```
gaincal(vis=contvis,
      caltable='pcal1',
      field='0',
      gaintype='G',
      refant='DV22',
      calmode='p',
      solint='30s')
```

30 second solution intervals

```
applycal(vis=contvis,
      field='0',
      gaintable=['pcal1'],
      interp='linearperobs')
```

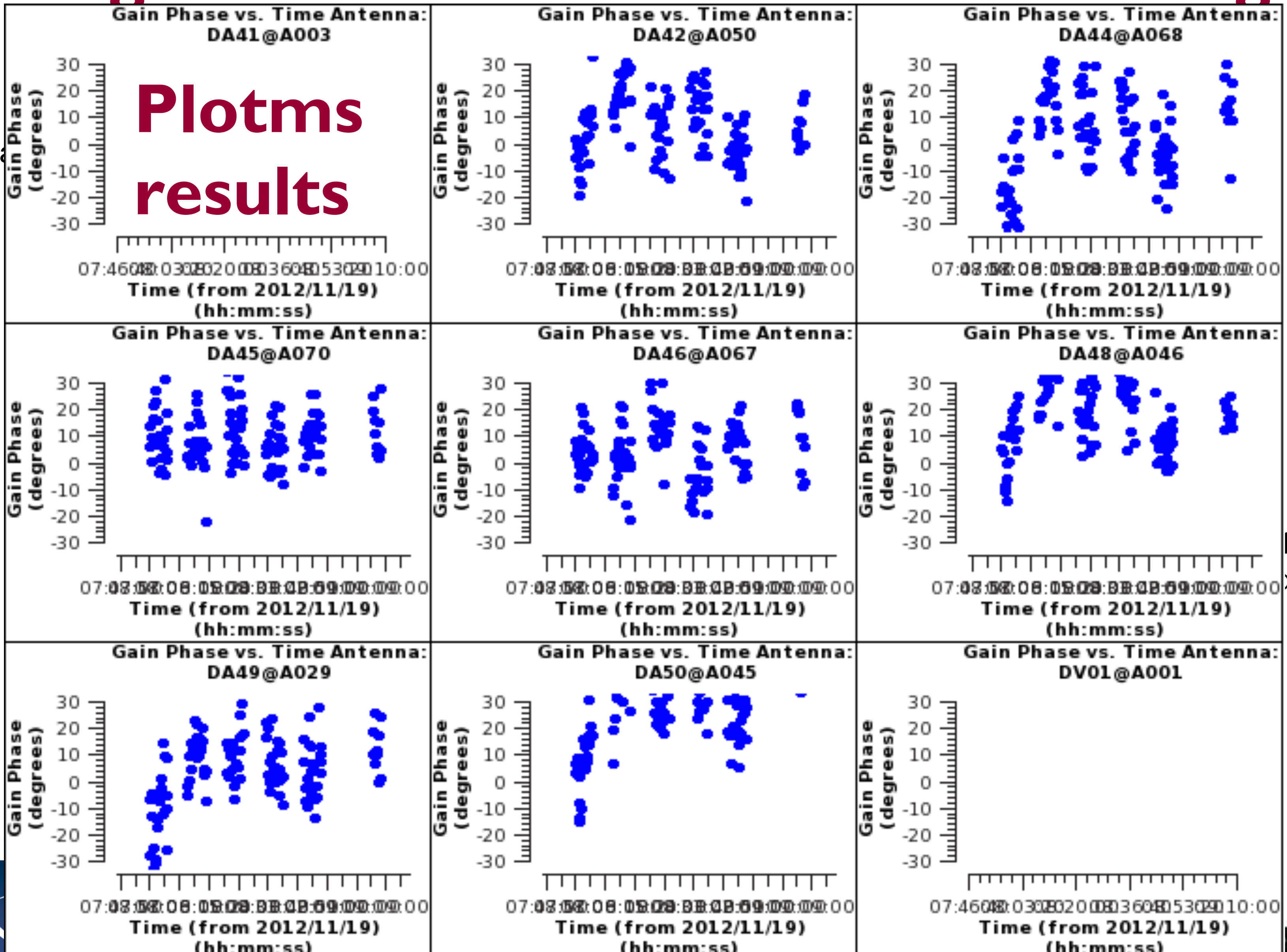
```
plotms(vis='pcal1',
      xaxis='time' yaxis='phase',
      iteraxis='antenna')
```

```
split(vis=contvis,
      outputvis=contvis+'_p1',
      datacolumn='corrected')
```

https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration

Doing selfcalibration on continuum image

tclea



Plotms results

l',
d')

https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration_CDE

CASAGuides: First Look at SelfCal

Start working on the First Look at Self Calibration Guide
30 Minutes Hands On

What you should expect to learn:

- The steps in the iterative process of selfcal
- Experimenting with gaincal averaging options
- How to measure progress of selfcal (comparing residuals)

https://casaguides.nrao.edu/index.php/First_Look_at_Self_Calibration_CDE

CASAGuides: First Look at Spectral Line Imaging

- Continuum Subtraction
- Imaging a cube

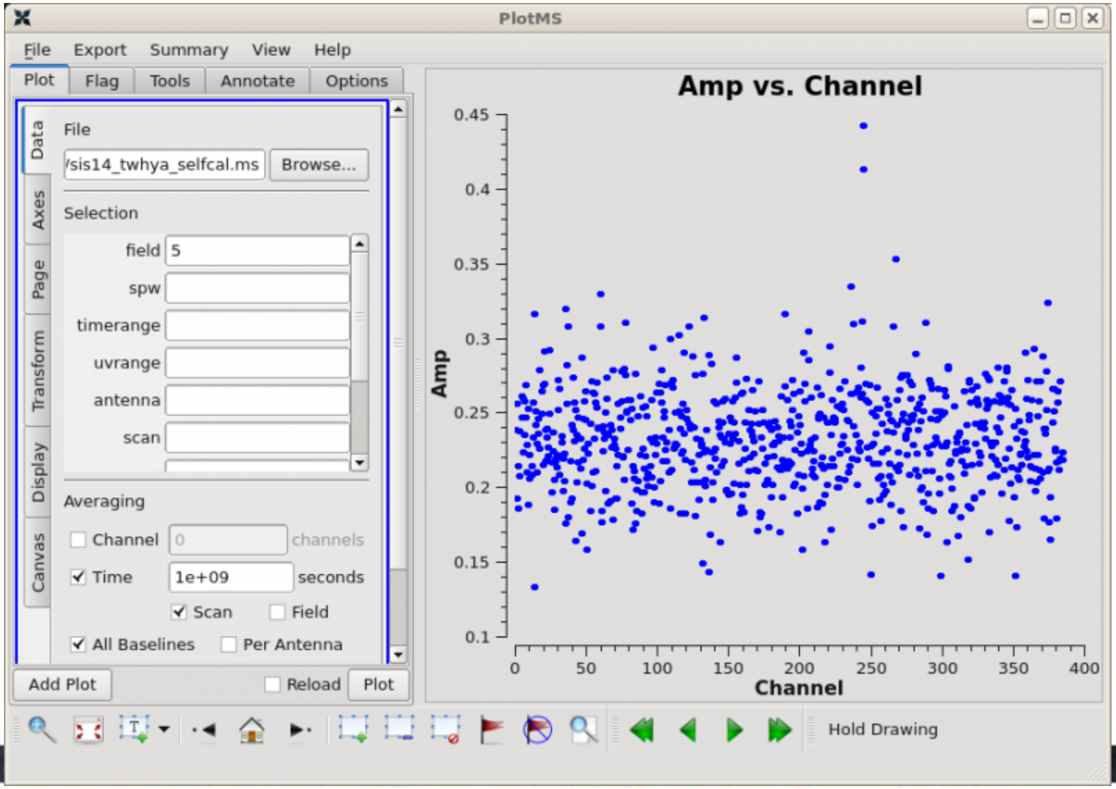
- Continue with same ms sis14_twhya_selfcal.ms

https://casaguides.nrao.edu/index.php/First_Look_at_Line_Imaging_CDE

Continuum Subtraction

Find the Continuum with Plotms

plotms(vis='sis14_twhya_selfcal.ms', xaxis='channel', yaxis='amp', field='5', avgspw=False, avgtime='1e9', avgscan=True, avgbaseline=True, showgui = True)



https://casaguides.nrao.edu/index.php/First_Look_at_Line_Imaging_CDE

Continuum Subtraction

```
uvcontsub(vis ='sis14_twhya_selfcal.ms',
    field = '5', fitspw = '0:0~239;281~383',
    excludechans = False, fitorder = 0, solint='int')
```

https://casa.nrao.edu/casadocs/casa-5.4.0/global-task-list/task_uvcontsub/about

Specmode options: Imaging spectral lines

specmode='cube'

- Set the dimensions of the cube
- Set Rest frequency
- Set Velocity Frame (LSRK, BARY, …)
- If imaging large cubes, set chanchunks=-1. Default (1) tries to put entire cube in memory, which can fail for large cubes.

tclean will calculate the Doppler corrections for you!
No need to realign beforehand.

```
CASA <40>: inp tclean
---------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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            =     'cube'        #  Spectral definition mode
                                        #   (mfs,cube,cubedata)
     nchan          =        100        #  Number of channels in the output
                                        #   image
     start          =  '100km/s'        #  First channel (e.g. start=3,start='1.
                                        #   1GHz',start='15343km/s')
     width          =   '10km/s'        #  Channel width (e.g. width=2,width='0.
                                        #   1MHz',width='10km/s')
     outframe       =     'lsrk'        #  Spectral reference frame in which to
                                        #   interpret 'start' and 'width'
     veltype        =    'radio'        #  Velocity type (radio, z, ratio, beta,
                                        #   gamma, optical)
     restfreq       =         []        #  List of rest frequencies
     interpolation  =   'linear'        #  Spectral interpolation
                                        #   (nearest,linear,cubic)
     chanchunks     =         -1        #  Number of channel chunks
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,m
                                        #   ultiscale,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               =          0        #  Maximum number of iterations
usemask             =     'user'        #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, 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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Specmode options: Imaging spectral lines

- nchan=Number of channels in output image
- start=First channel of output image specified by channel number, velocity, or frequency
- width= Width of output image channels, specified by number of channels, velocity, or frequency
- outframe=Spectral Reference frame in which to interpret start and width parameters
- restfreq=Specify rest frequency to use

```
CASA <40>: inp tclean
---------> inp(tclean)
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =        ''        #  Name of input visibility file(s)
selectdata          =      True        #  Enable data selection parameters
     field          =        ''        #  field(s) to select
     spw            =        ''        #  spw(s)/channels to select
     timerange      =        ''        #  Range of time to select from data
     uvrange        =        ''        #  Select data within uvrange
     antenna        =        ''        #  Select data based on antenna/baseline
     scan           =        ''        #  Scan number range
     observation    =        ''        #  Observation ID range
     intent         =        ''        #  Scan Intent(s)

datacolumn          = 'corrected'      #  Data column to image(data,corrected)
imagename           =        ''        #  Pre-name of output images
imsize              =     [100]        #  Number of pixels
cell                = ['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            =    'cube'        #  Spectral definition mode
                                       #   (mfs,cube,cubedata)
     nchan          =       100        #  Number of channels in the output
                                       #   image
     start          = '100km/s'        #  First channel (e.g. start=3,start='1.
                                       #   1GHz',start='15343km/s')
     width          =  '10km/s'        #  Channel width (e.g. width=2,width='0.
                                       #   1MHz',width='10km/s')
     outframe       =    'lsrk'        #  Spectral reference frame in which to
                                       #   interpret 'start' and 'width'
     veltype        =   'radio'        #  Velocity type (radio, z, ratio, beta,
                                       #   gamma, optical)
     restfreq       =        []        #  List of rest frequencies
     interpolation  =  'linear'        #  Spectral interpolation
                                       #   (nearest,linear,cubic)
     chanchunks     =        -1        #  Number of channel chunks

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,m
                                       #   ultiscale,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               =         0        #  Maximum number of iterations
usemask             =    'user'        #  Type of mask(s) for deconvolution
                                       #   (user, pb, auto-thresh, auto-
                                       #   thresh2, 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
```

Check visibilities after Continuum Subtraction

```
plotms(vis='sis14_twhya_selfcal.ms.cont
sub',
       xaxis='channel',
       yaxis='amp',
       field='0',
       avgspw=False,
       avgtime='1e9',
       avgscan=True,
       avgbaseline=True,
       showgui = True)
```

Linecube imaging

```
tclean(vis = linevis, imagename = 'twhya_n2hp’,
       field = '0’, spw = '0’, specmode = 'cube’, nchan = 15,
       start = '0.0km/s’, width = '0.5km/s',
       outframe = 'LSRK’, restfreq = '372.67249GHz',
       deconvolver= 'hogbom’, gridder = 'standard',
       imsize = [250, 250], cell = '0.08arcsec',
       phasecenter = 0, weighting = 'briggs’, robust = 0.5,
       restoringbeam='common’, interactive = True,
       pbcor=True, niter=5000)
```

https://casaguides.nrao.edu/index.php/First_Look_at_Line_Imaging_CDE

CASAGuides: First Look at Spectral Line Imaging

Start working on the First Look at Spectral Line Guide
20 Minutes Hands On

What you should expect to learn:

- How to image a cube
- Inspect the cube using the Viewer

https://casaguides.nrao.edu/index.php/First_Look_at_Line_Imaging_CDE

CASAGuides: AutoMasking

We will not be going through this guide today.

- **Complicated line emission?**
- **Check out the automasking guide!**

https://casaguides.nrao.edu/index.php/Automasking_Guide

Automasking

- Done at every time when minor cycle starts
- Noise threshold mask (noise vs sidelobe)
- Low noise threshold mask (previous mask grows into low noise region)
- Absorption mask (negative threshold, not growing into low noise region)
- Pruned and smoothed
- Combined to create clean mask
- Multiple threshold parameters control the procedure of creating each mask

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https://casaguides.nrao.edu/index.php/Automasking_Guide

Advanced usage: automasking

- **usemask='auto-multithresh'**
- Used in the ALMA imaging pipeline starting with Cycle 5 (CASA 5.1). Significant improvements to speed in Cycle 6 (CASA 5.4.0)
- Default parameters generally good for ALMA 12m data
- General purpose algorithm so works for ALMA, VLA, ATCA, etc.
- casaguide describing algorithm, recommended parameter values, and how to tune the parameters:

https://casaguides.nrao.edu/index.php/Automasking_Guide

```
CASA <58>: inp
---------> inp()
#  tclean :: Radio Interferometric Image Reconstruction
vis                 =         ''        #  Name of input visibility file(s)
selectdata          =       True        #  Enable data selection parameters
     field          =         ''        #  field(s) to select
     spw            =         ''        #  spw(s)/channels to select
     timerange      =         ''        #  Range of time to select from data
     uvrange        =         ''        #  Select data within uvrange
     antenna        =         ''        #  Select data based on antenna/baseline
     scan           =         ''        #  Scan number range
     observation    =         ''        #  Observation ID range
     intent         =         ''        #  Scan Intent(s)

datacolumn          = 'corrected'       #  Data column to image(data,corrected)
imagename           =         ''        #  Pre-name of output images
imsize              =      [100]        #  Number of pixels
cell                = ['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)
     reffreq        =         ''        #  Reference frequency

gridder             =   'mosaic'        #  Gridding options (standard, wproject,
                                        #   widefield, mosaic, awproject)
     normtype       = 'flatnoise'       #  Normalization type (flatnoise,
                                        #   flatsky)
     vptable        =         ''        #  Name of Voltage Pattern table
     pblimit        =        0.2        #  >PB gain level at which to cut off
                                        #   normalizations
     conjbeams      =      False        #  Use conjugate frequency for wideband
                                        #   A-terms

deconvolver         =    'hogbom'       #  Minor cycle algorithm (hogbom,clark,m
                                        #   ultiscale,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               =          0        #  Maximum number of iterations
usemask             = 'auto-multithresh' #  Type of mask(s) for deconvolution
                                        #   (user, pb, auto-thresh, auto-
                                        #   thresh2, or auto-multithresh)
     pbmask         =        0.0        #  primary beam mask
     sidelobethreshold =        3.0     #  sidelobethreshold *  the max sidelobe
                                        #   level
     noisethreshold =        5.0        #  noisethreshold * rms in residual
                                        #   image
     lownoisethreshold =        1.5     #  lownoisethreshold * rms in residual
                                        #   image
     negativethreshold =        0.0     #  negativethreshold * rms in residual
                                        #   image
     smoothfactor   =        1.0        #  smoothing factor in a unit of the
                                        #   beam
     minbeamfrac    =        0.3        #  minimum beam fraction for pruning
     cutthreshold   =       0.01        #  threshold to cut the smoothed mask to
                                        #   create a final mask
     growiterations =         75        #  number of binary dilation iterations
                                        #   for growing the 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
```

CASAGuides: First Look at Image Analysis

- **This guide uses the continuum and line images previously made:** fourth_image.image & twhya_n2hp.image
- **Imhead gives header information**
- **Statistics with imstat**
- **Moment maps**
- **Export Fits**

https://casaguides.nrao.edu/index.php/First_Look_at_Image_Analysis_CDE

CASAGuides: First Look at Image Analysis: Moment Maps

- A useful product to compute is to collapse the cube into a moment image by taking a linear combination of the individual planes. The **immoments** task will compute basic moment images from a cube.
- The *moments* parameter chooses which moments are calculated.
- Some examples for choices for of operation mode are:

moments=0 - integrated value of the spectrum

moments=1 - intensity weighted coordinate; traditionally used to get 'velocity fields'

moments=2 - intensity weighted dispersion of the coordinate; traditionally used to get 'velocity dispersion’

- See CASADocs for more modes!

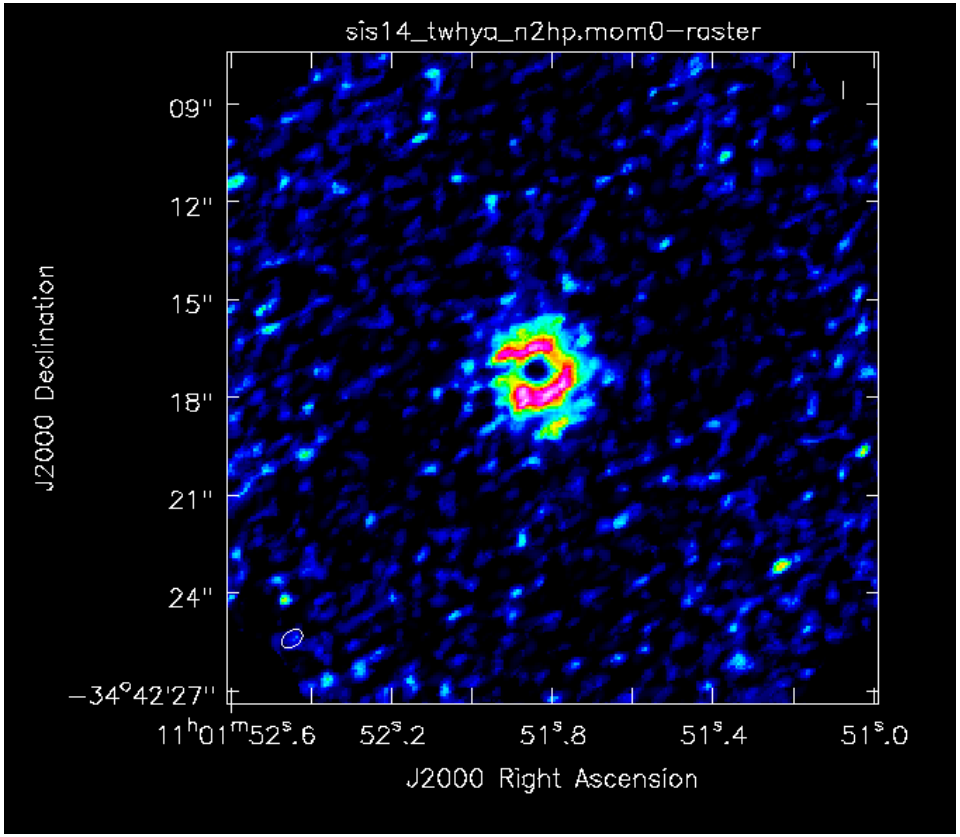
https://casa.nrao.edu/casadocs/casa-5.5.0/global-task-list/task_immoments/about

https://casaguides.nrao.edu/index.php/First_Look_at_Image_Analysis_CDE

CASAGuides: First Look at Image Analysis: Moment Maps

- Here is a moment 0 image clipped at ~1 sigma

- immoments("sis14_twhya_n2hp.image", outfile="sis14_twhya_n2hp.mom0", includepix=[20e-3,100], chans="4~12", moments=0)



CASAGuides: First Look at Image Analysis

Start working on the First Look at Image Analysis Guide
15 Minutes Hands On

What you should expect to learn:

- How to print image header information (IMHEAD)
- How to measure statistics and flux with IMSTAT
- How to create moment maps
- How to export the CASA image to fits (EXPORTFITS)

https://casaguides.nrao.edu/index.php/First_Look_at_Image_Analysis_CDE

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References

CASA documentation:
https://casa.nrao.edu/casadocs/casa-5.4.0/synthesis-imaging

NRAO's 16th Synthesis Imaging Workshop Lectures
https://science.nrao.edu/science/meetings/2018/16th-synthesis-imaging-workshop/16th-synthesis-imaging-workshop-lectures

Thompson, A.R., Moran, J.M., Swensen, G.W. 2017 "Interferometry and Synthesis in Radio Astronomy", 3rd edition (Springer)
http://www.springer.com/us/book/9783319444291

Perley, R.A., Schwab, F.R., Bridle, A.H. eds. 1989 ASP Conf. Series 6 "Synthesis Imaging in Radio Astronomy" (San Francisco: ASP)
www.aoc.nrao.edu/events/synthesis

IRAM Interferometry School proceedings
www.iram.fr/IRAMFR/IS/IS2008/archive.html

Other CASAGuides

- The NA Guide to the imaging template: https://casaguides.nrao.edu/index.php/Guide_to_the_NA_Imaging_Template
- The Guide to imaging with Pipeline tasks: https://casaguides.nrao.edu/index.php/ALMA_Imaging_Pipeline_Reprocessing
- VLA Imaging guide: https://casaguides.nrao.edu/index.php/VLA_CASA_Imaging-CASA5.4.0

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