tclean: CASA task for Radio Interferometric Image Reconstruction

```
CASA <x>: inp tclean
vis                 = ''            # Name of input visibility file(s)
selectdata          = True          # Enable data selection parameters
     ...
specmode            = 'mfs'         # Spectral definition mode
     ...
gridder             = 'standard'    # Gridding options
     ...
deconvolver         = 'hogbom'      # Minor cycle algorithm
     ...
weighting           = 'natural'     # Weighting scheme
     ...
niter               = 0             # Maximum number of iterations
     ...
usemask             = 'user'        # Type of mask(s) for deconvolution
```

Before you clean: Imaging Preparation

1. **Inspect your data**
   a. **Inspect the weblog** - see I-TRAIN #4: ALMA WebLog inspection
   b. `listobs`: spw & field information
   c. `plotms`: check *uv* coverage, check for spectral lines, telluric lines, etc.
2. **Prepare your measurement set**
   a. If needed, `split` science source from calibrated measurement set(s)
   b. If continuum imaging, optional: `split` out continuum-only MS
   c. If line imaging: *uv* continuum subtraction with `uvcontsub` if continuum > 3 sigma per channel

Resources:

ALMAGuides & General Imaging Tutorials: casaguides.nrao.edu
Video tutorial on imaging: https://youtu.be/yuLKAfroHu4

Material preparation & Let's launch CASA!

In YOUR analysis directory (analysis/USERNAME/):
mkdir imaging
cd imaging
cp -r ../../../scripts/Imaging_*.py ./

Scripts involved in this tutorial:

(a) Imaging_1_basic.py - setting up all tclean parameter in interactive style

(b) Imaging_2_basic_scripted.py - scripted version of (a)

(c) Imaging_3_uvcontsub.py - basic steps to perform continuum subtraction

(d) Imaging_4_uvtaper_scripted.py - tclean script including tapering specification (uvtaper and the associated parameters)

(you can copy below from the script "Imaging_1_basic.py")
cp -r ../../../archive/DRT2023/TW_hydra/sis14_twhya_calibrated_flagged.ms.contsub/ ./

nice +10 env -u PYTHONPATH -u LD_LIBRARY_PATH casapy-660

tclean: data selection

```
CASA <x>: inp tclean
vis                 = 'sis14_twhya_calibrated_flagged.ms.contsub'
selectdata          = True       # Enable data selection parameters
   field            = 'TW Hya'      # field(s) to select
   spw              = '0'        # 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)
     ...
```

Or go to casa documentation:
https://casadocs.readthedocs.io/en/stable/api/tt/casatasks.imaging.tclean.html

tclean: get spw & field information from `listobs`

```
CASA <x>: vis = 'sis14_twhya_calibrated_flagged.ms.contsub'
CASA <x>: listobs(vis)
CASA <x>: listobs(vis, listfile='listobs.txt')
```

View `listobs` output in logger or in file

Information includes:

- Observation information (time, field observed, intents)
- Field information (field IDs, coordinates)
- Spectral window information (spw IDs, frequencies, bandwidth, spectral resolution)
- Antenna information (Names, stations, dish diameter, coordinates)

tclean: get spw & field information from `listobs`

Output:

```
================================================================================
           MeasurementSet Name:  /yourDirectory/sis14_twhya_calibrated_flagged.ms.contsub      MS Version 2
================================================================================
   Observer: cqi     Project: uid://A002/X327408/X6f
Observation: ALMA
Data records: 53161       Total elapsed time = 4268.11 seconds
   Observed from   19-Nov-2012/07:56:23.5   to   19-Nov-2012/09:07:31.6 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  19-Nov-2012/07:56:23.5 - 08:02:11.3    12      0 TW Hya                   8514   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:08:09.6 - 08:13:57.3    16      0 TW Hya                  10360   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:19:53.9 - 08:25:41.7    20      0 TW Hya                  10321   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:32:00.5 - 08:37:48.2    24      0 TW Hya                  10324   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:43:45.6 - 08:49:33.4    28      0 TW Hya                   9462   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              09:05:15.6 - 09:07:31.6    36      0 TW Hya                   4180   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
            (nRows = Total number of rows per scan)
Fields: 1
  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
  0    none TW Hya              11:01:51.796000 -34.42.17.36600 J2000   0          53161
Spectral Windows:  (1 unique spectral windows and 1 unique polarization setups)
  SpwID  Name                           #Chans   Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
  0      ALMA_RB_07#BB_2#SW-01#FULL_RES    384   TOPO  372533.086       610.352    234375.0 372649.9688        2  XX  YY
```

▪▪▪

tclean: get spw & field information from `listobs`

Output:

```
================================================================================
           MeasurementSet Name:  /yourDirectory/sis14_twhya_calibrated_flagged.ms.contsub      MS Version 2
================================================================================
   Observer: cqi     Project: uid://A002/X327408/X6f
Observation: ALMA
Data records: 53161       Total elapsed time = 4268.11 seconds
   Observed from   19-Nov-2012/07:56:23.5   to   19-Nov-2012/09:07:31.6 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)     ScanIntent
  19-Nov-2012/07:56:23.5 - 08:02:11.3    12      0 TW Hya                   8514   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:08:09.6 - 08:13:57.3    16      0 TW Hya                  10360   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:19:53.9 - 08:25:41.7    20      0 TW Hya                  10321   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:32:00.5 - 08:37:48.2    24      0 TW Hya                  10324   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              08:43:45.6 - 08:49:33.4    28      0 TW Hya                   9462   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
              09:05:15.6 - 09:07:31.6    36      0 TW Hya                   4180   [0]   [6.05] [OBSERVE_TARGET#ON_SOURCE]
          (nRows = Total number of rows per scan)
Fields: 1
  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
  0    none TW Hya              11:01:51.796000 -34.42.17.36600 J2000   0          53161
Spectral Windows:  (1 unique spectral windows and 1 unique polarization setups)
  SpwID  Name                           #Chans   Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
  0      ALMA_RB_07#BB_2#SW-01#FULL_RES    384   TOPO  372533.086       610.352    234375.0 372649.9688        2  XX  YY
```

▪▪▪

tclean: image parameters

```
CASA <x>: inp tclean
     ...
datacolumn                     = 'data'              # Data column
imagename                      = 'twhya_n2hp43'      # Pre-name of output images
imsize                         = [240,240]           # Number of pixels
cell                           = '0.1arcsec'         # Cell size
phasecenter                    = 0                   # Phase center of the image
stokes                         = 'I'                 # Stokes Planes to make
projection                     = 'SIN'               # Coordinate projection
startmodel                     = ''                  # Name of starting model
    ...
```

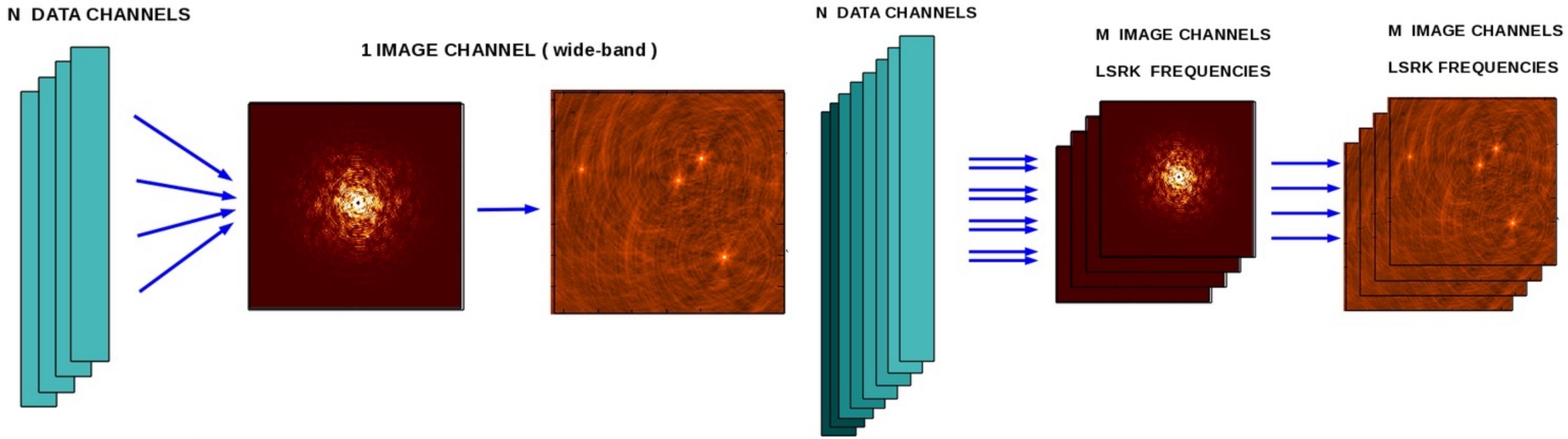
Spectral Modes

The spectral mode determines whether all channels are:

I. synthesized into a single image using **`specmode = 'mfs'`** (multi-frequency synthesis), i.e. continuum imaging

or

II. imaged separately using **`specmode = 'cube'`**, i.e. spectral line imaging



Figures from CASA Docs

Spectral Modes

For this tutorial, we use:

```
CASA <x>: specmode = 'cube'
```

`nchan`, `start`, and **`width`** can be in terms of channel number, frequency, or velocity

```
CASA <x>: nchan = 30
CASA <x>: start = 230
CASA <x>: width = 1
```

for *z<0.2*, can use rest frequency of line (look up with e.g. Splatalogue)

```
CASA <x>: restfreq = '372.67250900GHz' # N2H+ J=4-3
```

Set velocity parameters:

```
CASA <x>: outframe = 'lsrk' # LSR as a kinematical (radio) definition
CASA <x>: veltype = 'radio' # produces channels of fixed velocity width
```

See CASA Docs for more options and precise definitions

Spectral Modes

```
CASA <x>: inp tclean
    ...
specmode                = 'cube'                # Spectral definition mode (mfs...
   nchan                = 30                    # Number of channels...
   start                = 230                   # First channel (e.g. start=3...
   width                = 1                     # Channel width (e.g. width=2...
   outframe             = 'lsrk'                # Spectral reference frame...
   veltype              = 'radio'               # Velocity type (radio...
   restfreq             = '372.67250900GHz'     # List of rest frequencies
   interpolation        = 'linear'              # Spectral interpolation...
   perchanweightdensity = True                  # whether to calculate weight…
    ...
```

Gridder

The gridder resamples imaging weights and weighted visibilities onto a uniform *uv* grid

Recommended:

`gridder = 'standard'`

- operations applied in image-domain to correct for direction-dependent effects
- use for single pointings

`gridder = 'mosaic'`

- direction-dependent, time-variable and baseline-dependent corrections during gridding in the visibility-domain
- use for mosaics

For this tutorial:

`CASA <x>: gridder = 'standard'`

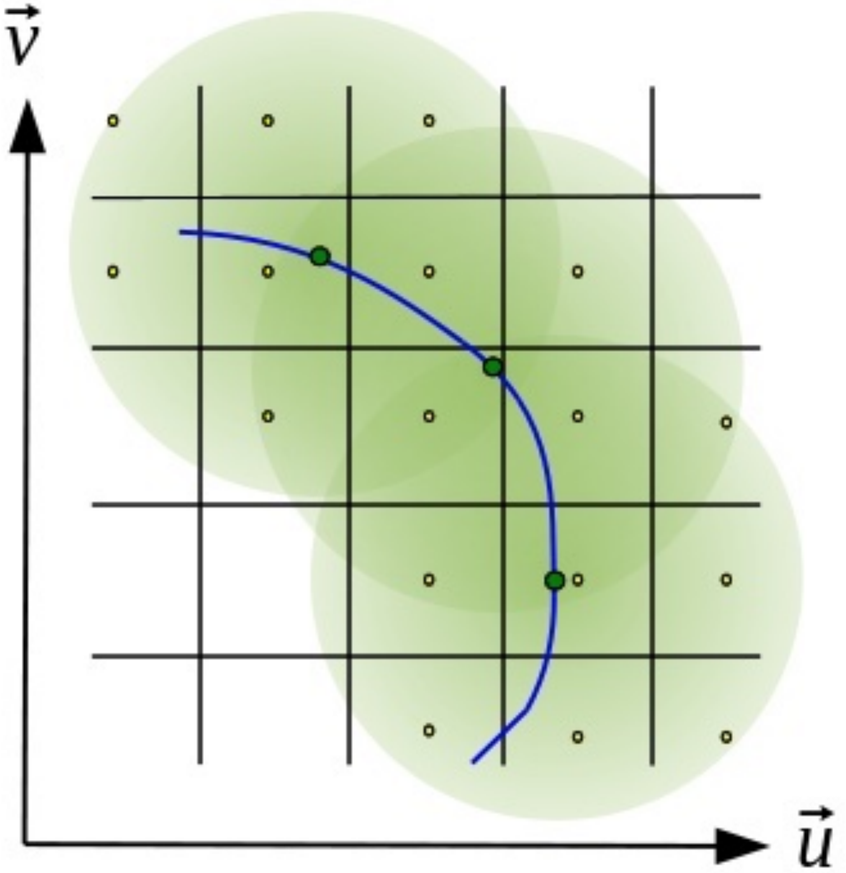


Figure from CASA Docs

Minor-cycle clean algorithms

Recommended:

`deconvolver = 'hogbom'`: adapted version of Hogbom Clean [Hogbom, 1974]
- assumes point source model of source brightness distribution
- → most appropriate for fields of isolated point sources
- compute intensive

`deconvolver = 'multiscale' (or 'mtmfs')`: MultiScale Clean [Cornwell, 2008]
- scale-sensitive clean, can specify multiple scales
- assuming sources extended, tapered 'paraboloids'
- `scales = []`: list of scales (in pixels)
  - use scales up to the smaller of the largest extent of the emission
  - recommended to include a point source scale (pixel size 0)
- `smallscalebias = 0.0`: value from -1 (biases towards larger scales) to 1 (biases towards smaller scales)

For this tutorial:

```
CASA <x>: deconvolver = 'multiscale'
CASA <x>: scales = [0,5,10]
```

Weighting Schemes

Visibility weights alter the synthesised beam and dynamic range of output image

`weighting = 'natural'`

visibilities are weighted by data weights
lower rms noise, lower resolution

`weighting = 'uniform'`

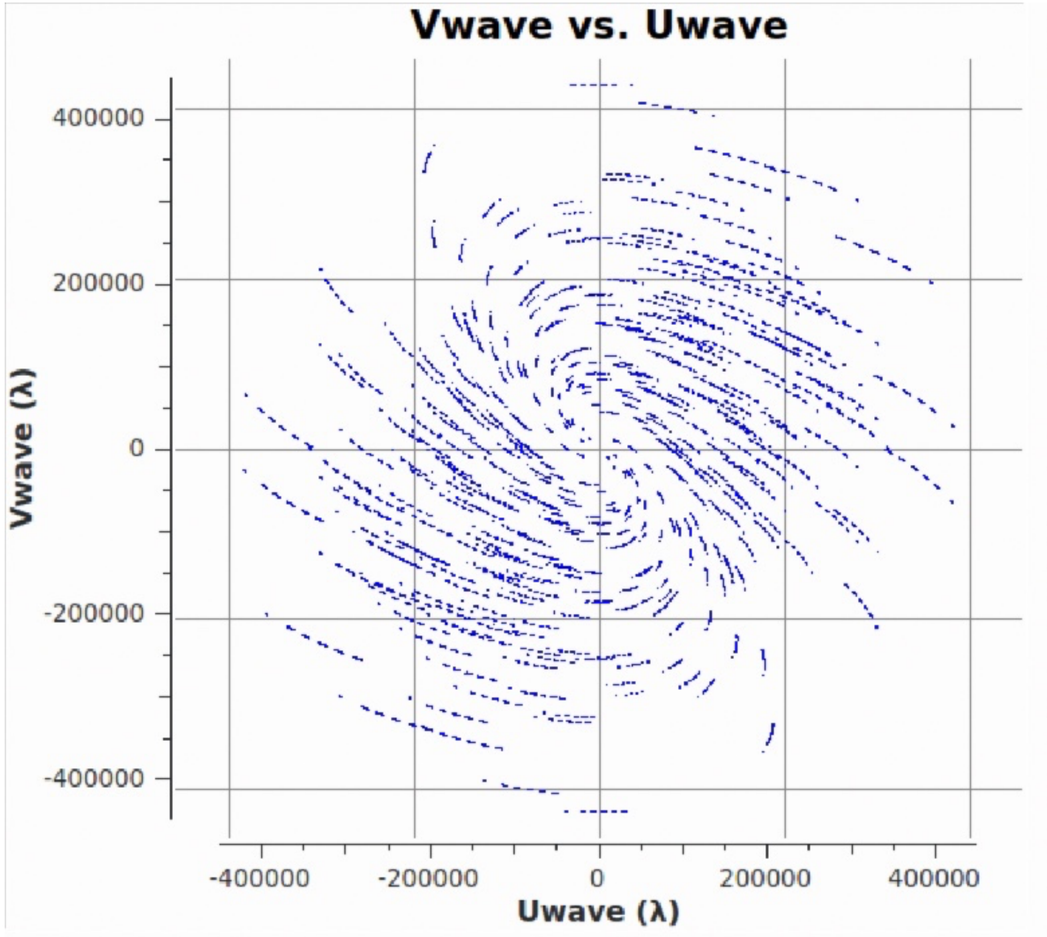
Visibilities in same *uv* cell are weighted 'uniformly'
reduces sidelobes, higher rms noise

`weighting = 'briggs'`

Compromise between natural & uniform
`robust` parameter can be adjusted from -2 (uniform-like) to 2 (natural-like)

`uvtaper = []`

Applies a Gaussian taper in addition to the weighting scheme
Only outertaper → can clip inner *uv* data using `uvrange`
Should use with `natural` or briggs with `robust = 2`



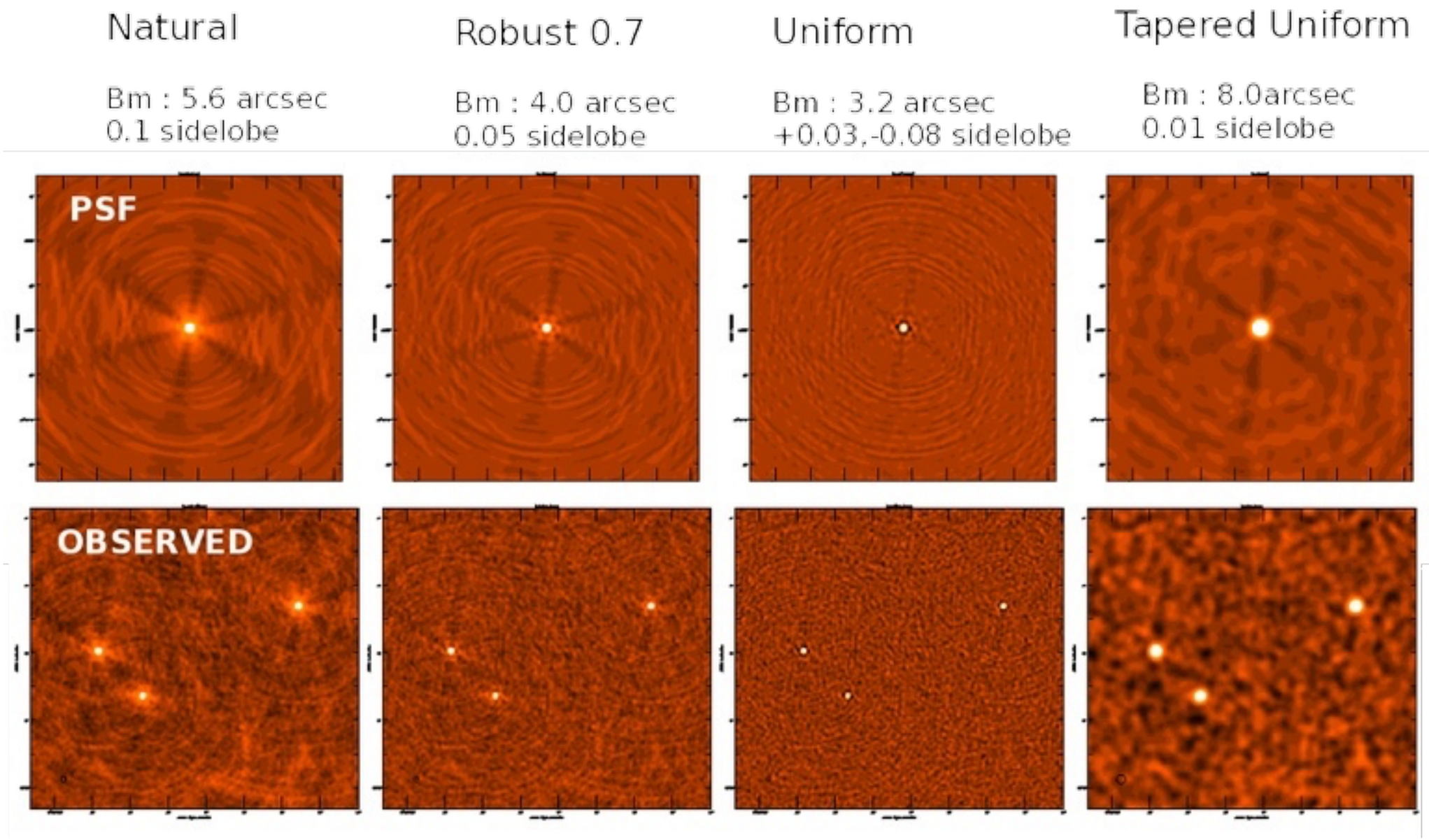


Figure from CASA Docs

Weighting Schemes

For this tutorial we will use:

```
CASA <x>: weighting = 'briggs'
CASA <x>: robust = 0.5

CASA <x>: inp tclean
gridder                     = 'standard'       # Gridding options...
   vptable                  = ''               # Name of Voltage Pattern table
   pblimit                  = 0.2              # PB gain level…
deconvolver                 = 'multiscale'     # Minor cycle algorithm...
   scales                   = [0, 5, 10]       # List of scale sizes (in pixels)
   smallscalebias           = 0.0              # Biases the scale...
   ...
weighting                   = 'briggs'         # Weighting scheme
   robust                     = 0.5              # Robustness parameter
   npixels                  = 0                # Number of pixels to determine uv-cell
   uvtaper                  = []               # uv-taper on outer baselines in uv-plane
   ...
```

Masks for Deconvolution

Masks are used to restrict the regions over which clean components are found (used to speed up the cleaning)

`usemask = 'user'`

this option can be selected to define regions by hand in the GUI when using `interactive = True`

Alternatively, the `mask` subparameter can be specified as an image file, a region file, or a region string

`usemask = 'auto-multithresh'`

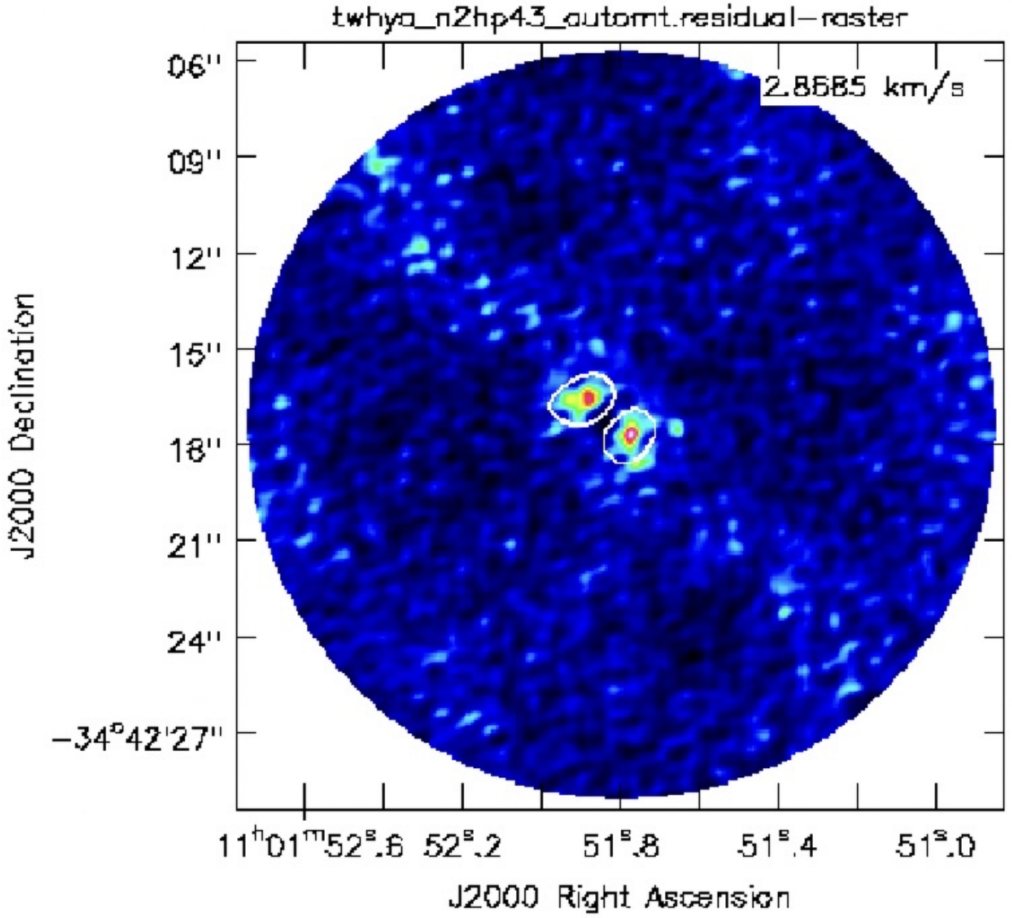
Available in CASA versions 5.1 and later

Makes masking spectral line emission easier and faster

"AUTO-MULTITHRESH: A General Purpose Automasking Algorithm"

Kepley et al., 2020 PASP **132** 024505

Automasking Guide: casaguides.nrao.edu/index.php/Automasking_Guide



Masks for Deconvolution

For this tutorial we will use:

```
CASA <x>: usemask = 'auto-multithresh'

CASA <x>: inp tclean
    ...
usemask                 = 'auto-multithresh'    # Type of mask(s)
   pbmask               = 0.2                   # primary beam mask
   sidelobethreshold    = 2.0                   # sidelobethreshold *...
   noisethreshold       = 4.25                  # noisethreshold * ...
   lownoisethreshold    = 1.5                   # lownoisethreshold * ...
   negativethreshold    = 0.0                   # negativethreshold * ...
   smoothfactor         = 1.0
   minbeamfrac          = 0.3                   # minimum beam fraction ...
   cutthreshold         = 0.01
   growiterations       = 75
   dogrowprune          = True
   minpercentchange     = -1.0
   verbose              = False
    ...
```

Setting clean stopping thresholds

```
CASA <x>: inp tclean
    ...
niter                       = 100000                # Maximum number of iterations
    gain                    = 0.1                   # Loop gain
    threshold               = ''                    # Stopping threshold
    nsigma                  = 2.0                   # rms-based threshold stopping
    cycleniter              = -1                    # Max minor-cycle iterations
    cyclefactor             = 1.0                   # Scaling on PSF sidelobe...
    minpsffraction          = 0.05                  # PSF fraction max depth...
    maxpsffraction          = 0.8                   # PSF fraction min depth...
    interactive             = True                  # Modify masks and parameters...
    ...
```

Also see
Imaging_2_basic_scripted.py

Summary of tclean inputs

```
CASA <x>: inp tclean
vis = 'sis14_twhya_calibrated_flagged.ms.contsub'
selectdata                = True
   field                  = 'TW Hya'
   spw                    = '0'
    ...
datacolumn                = 'data'
imagename                 = 'twhya_n2hp43'
imsize                    = [240,240]
cell                      = '0.1arcsec'
phasecenter               = 0
      ...
specmode                  = 'cube'
   nchan                  = 30
   start                  = 230
   width                  = 1
   outframe               = 'lsrk'
   restfreq               = '372.67250900GHz'
      ...
```

```
gridder                   = 'standard'
deconvolver               = 'multiscale'
   scales                 = [0, 5, 10]
                ...
weighting                 = 'briggs'
   robust                       = 0.5
        ...
usemask                   = 'auto-multithresh'
   sidelobethreshold      = 2.0
   noisethreshold         = 4.25
                ...
niter                     = 100000
   nsigma                 = 2.0
   interactive            = True
                ...
```