ALMA Data Reduction Workshop

Presented by Allegro Fellows

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Outline

This hands-on workshop will follow the following topics:

1. Inspection of data
2. First look at imaging

   - Break -

3. Self-calibration
4. Continuum subtraction & line imaging
5. Analysis tools

To follow along with the presentation slides:
https://www.alma-allegro.nl/alma-data-reduction-training-day-nov-2021/

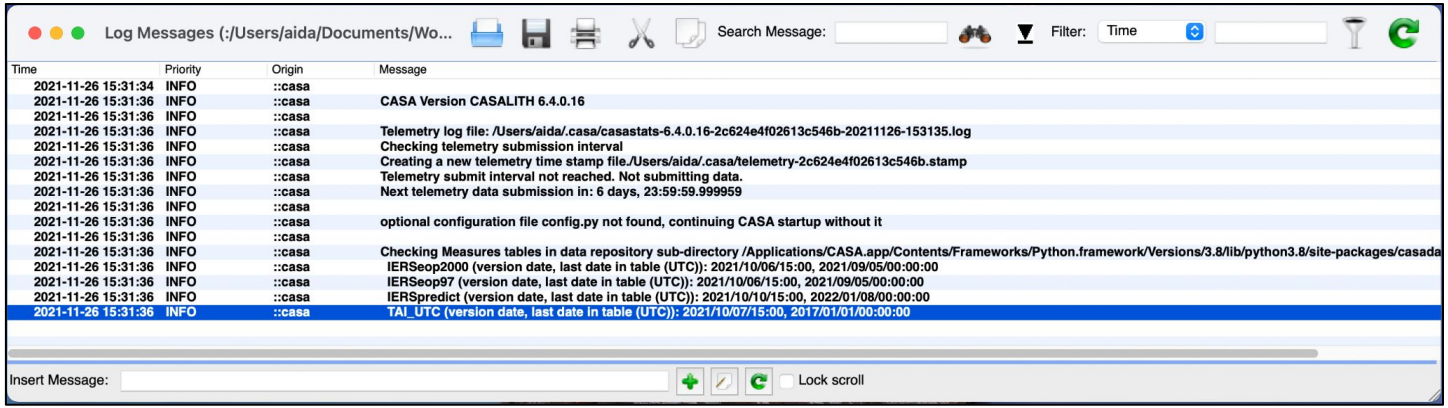
Mostly based on 'First Look' CASA Guides:
https://casaguides.nrao.edu/index.php?title=ALMAguides

Let's get started

- We will be using the TW Hya dataset that is used in most CASA Guides
- If you are using the Allegro computers:
  - Go to the following path:
    - cd /allegro5/allegro/home/**your_username**/open_2021_Training
  - Copy over the data to your dedicated folder:
    - cp -RL archive/* analysis/**your_username**/.
  - Go to your analysis folder:
    - cd analysis/**your_username**/TWHya_Tutorial
  - Start CASA:
    - tcsh: nice +10 /data1/allegro/bin/casapy-570
    - bash: nice -n 10 /data1/allegro/bin/casapy-570
- Otherwise:
  - Download the data from https://bit.ly/AllegroDR21-data
  - Install CASA from https://casa.nrao.edu/casa_obtaining.shtml

CASA Basics

Starting CASA will open a logger (and a log file):



Time	Priority	Origin	Message
2021-11-26 15:31:34	INFO	::casa	
2021-11-26 15:31:36	INFO	::casa	CASA Version CASALITH 6.4.0.16
2021-11-26 15:31:36	INFO	::casa	
2021-11-26 15:31:36	INFO	::casa	Telemetry log file: /Users/aida/.casa/casastats-6.4.0.16-2c624e4f02613c546b-20211126-153135.log
2021-11-26 15:31:36	INFO	::casa	Checking telemetry submission interval
2021-11-26 15:31:36	INFO	::casa	Creating a new telemetry time stamp file./Users/aida/.casa/telemetry-2c624e4f02613c546b.stamp
2021-11-26 15:31:36	INFO	::casa	Telemetry submit interval not reached. Not submitting data.
2021-11-26 15:31:36	INFO	::casa	Next telemetry data submission in: 6 days, 23:59:59.999959
2021-11-26 15:31:36	INFO	::casa	
2021-11-26 15:31:36	INFO	::casa	optional configuration file config.py not found, continuing CASA startup without it
2021-11-26 15:31:36	INFO	::casa	
2021-11-26 15:31:36	INFO	::casa	Checking Measures tables in data repository sub-directory /Applications/CASA.app/Contents/Frameworks/Python.framework/Versions/3.8/lib/python3.8/site-packages/casada
2021-11-26 15:31:36	INFO	::casa	IERSeop2000 (version date, last date in table (UTC)): 2021/10/06/15:00, 2021/09/05/00:00:00
2021-11-26 15:31:36	INFO	::casa	IERSeop97 (version date, last date in table (UTC)): 2021/10/06/15:00, 2021/09/05/00:00:00
2021-11-26 15:31:36	INFO	::casa	IERSpredict (version date, last date in table (UTC)): 2021/10/10/15:00, 2022/01/08/00:00:00
2021-11-26 15:31:36	INFO	::casa	TAI_UTC (version date, last date in table (UTC)): 2021/10/07/15:00, 2017/01/01/00:00:00

And the terminal prompt:

```
optional configuration file config.py not found, continuing CASA startup without it

IPython 7.15.0 -- An enhanced Interactive Python.

Using matplotlib backend: MacOSX
Telemetry initialized. Telemetry will send anonymized usage statistics to NRAO.
You can disable telemetry by adding the following line to the config.py file in your rcdir (e.g. ~/.casa/config.py):
telemetry_enabled = False
--> CrashReporter initialized.
CASA 6.4.0.16 -- Common Astronomy Software Applications [6.4.0.16]

CASA <1>:
```

Common Astronomy Software Applications

CASA Basics

List of available tasks
tasklist() -> Get an overview of available tasks, organized by category (removed in CASA 6)
taskhelp -> A more exhaustive list of tasks with descriptions
More information about the tasks: https://casa.nrao.edu/casadocs/casa-5.0.0/global-task-list

Getting help on a task
help <taskname>

Executing a task
Interactively:
tget <taskname> -> set the task
inp -> determine the input parameters needed for the task that was set
(set individual parameters using a Python <parameter>=<value> syntax)
go -> run the task
Programmatically:
taskname(parameter1='', parameter2='', ...)

Based on: https://casaguides.nrao.edu/index.php?title=Getting_Started_in_CASA

CASA Basics

Parameters

grey: parameter has sub-parameters

green: sub-parameters

red: invalid value

blue: parameter altered from its default

Data selection syntax

spw='0:5~30;40~55,1:10~25;45~58,2'

Running scripts

execfile('script_name.py')

```
CASA <39>: inp tclean
# tclean -- Radio Interferometric Image Reconstruction
vis                 = 'data/sis14_twhya_calibrated_flagged.ms'
                                        # 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          = ''                # Data column to image(data,corrected)
imagename           = ''                # Pre-name of output images
imsize              = [100]             # Number of pixels
cell                = []                # Cell size
phasecenter         = ''                # Phase center of the image
stokes              = 'I'               # Stokes Planes to make
projection          = 'SIN'             # Coordinate projection
startmodel          = ''                # Name of starting model image
specmode            = 'mfs'             # Spectral definition mode (mfs,cube,cubedata, cubesource)
   reffreq          = ''                # Reference frequency
gridder             = 'standard'        # Gridding options (standard, wproject, widefield, mosaic, awproject)
   vptable          = ''                # Name of Voltage Pattern table
   pblimit          = 0.2               # PB gain level at which to cut off normalizations
deconvolver         = 'hogbom'          # Minor cycle algorithm (hogbom,clark,multiscale,mtmfs,mem,clarkstokes)
restoration         = True              # Do restoration steps (or not)
   restoringbeam    = []                # Restoring beam shape to use. Default is the PSF main lobe
   pbcor            = False             # Apply PB correction on the output restored image
outlierfile         = ''                # Name of outlier-field image definitions
weighting           = 'nat'             # Weighting scheme (natural,uniform,briggs, briggsabs[experimental], briggsbwtaper[experimental])
niter               = 0                 # Maximum number of iterations
usemask             = 'user'            # Type of mask(s) for deconvolution: user, pb, or auto-multithresh
   mask             = ''                # Mask (a list of image name(s) or region file(s) or region string(s) )
   pbmask           = 0.0               # primary beam mask
fastnoise           = True              # True: use the faster (old) noise calculation. False: use the new improved noise calculations
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
   psfcutoff        = 0.35              # All pixels in the main lobe of the PSF above psfcutoff are used to fit a Gaussian beam (the Clean beam).
parallel            = False             # Run major cycles in parallel
```

Based on: https://casaguides.nrao.edu/index.php?title=Getting_Started_in_CASA

CASA Basics

<u>Measurement sets:</u>

- Measurement sets (ms) are directories

```
CASA <1>: ls sis14_twhya_calibrated_flagged.ms/
ANTENNA/          DATA_DESCRIPTION/ POINTING/         STATE/          table.f10*      table.f16*       table.f20*       table.f23*       table.f7*
ASDM_ANTENNA/     FEED/             POLARIZATION/     SYSCAL/         table.f11*      table.f17*       table.f20_TSM0*  table.f23_TSM1*  table.f8*
ASDM_CALWVR/      FIELD/            PROCESSOR/        SYSPOWER/       table.f12*      table.f17_TSM1*  table.f21*       table.f3*        table.f9*
ASDM_RECEIVER/    FLAG_CMD/         SORTED_TABLE/     WEATHER/        table.f13*      table.f18*       table.f21_TSM1*  table.f4*        table.info*
ASDM_STATION/     HISTORY/          SOURCE/           table.dat*      table.f14*      table.f19*       table.f22*       table.f5*        table.lock*
CALDEVICE/        OBSERVATION/      SPECTRAL_WINDOW/  table.f1*       table.f15*      table.f2*        table.f22_TSM1*  table.f6*
```

- To copy or remove them you need to use the recursive option
  - ➢ cp -r this_data.ms that_data.ms
- Safest way to remove a dataset in CASA:
  - ➢ **rmtables('this_data.ms')**
  - ○ Alternatively:
    - ➢ rm -rf this_data.ms
  - ○ Or if within a script:
    - ➢ os.system('rm -r this_data.ms')

Common Astronomy Software Applications

Based on: https://casaguides.nrao.edu/index.php?title=Getting_Started_in_CASA

1. Data Inspection

Main Tasks for Data Inspection:

- listobs: lists the contents of measurement set
- plotants: plot the location of antennas
- plotms: inspect/flag data interactively

listobs: lists the contents of measurement set

Can select a subset of the measurement set

```
CASA <11>: inp listobs
# listobs -- List the summary of a data set in the logger or in a file
vis             = ''                    # Name of input visibility file (MS)
selectdata      = True                  # Data selection parameters
spw             = ''                    # Selection based on spectral-window/frequency/channel.
field           = ''                    # Selection based on field names or field index numbers. Default is all.
antenna         = ''                    # Selection based on antenna/baselines. Default is all.
uvrange         = ''                    # Selection based on uv range. Default: entire range. Default units: meters.
timerange       = ''                    # Selection based on time range. Default is entire range.
correlation     = ''                    # Selection based on correlation. Default is all.
scan            = ''                    # Selection based on scan numbers. Default is all.
intent          = ''                    # Selection based on observation intent. Default is all.
feed            = ''                    # Selection based on multi-feed numbers: Not yet implemented
array           = ''                    # Selection based on (sub)array numbers. Default is all.
observation     = ''                    # Selection based on observation ID. Default is all.
verbose         = True                  # Controls level of information detail reported. True reports more than False.
listfile        = ''                    # Name of disk file to write output. Default is none (output is written to logger only).
listunfl        = False                 # List unflagged row counts? If true, it can have significant negative performance impact.
cachesize       = 50.0                  # EXPERIMENTAL. Maximum size in megabytes of cache in which data structures can be held.
```

Optionally can write the output to a file

listobs

listobs(vis='sis14_twhya_calibrated_flagged.ms')

sequence of observations

```
##########################################
##### Begin Task: listobs          #####
listobs( vis='sis14_twhya_calibrated_flagged.ms', selectdata=True, spw='', field='', antenna='', uvrange='', timerange='', correlation='', scan='', intent='', feed='', array='', observation='', verbose=T
================================================================================
           MeasurementSet Name:  /Users/aida/Documents/Work/Leiden/Allegro/Events/202111_Data_Reduction_Day/data/sis14_twhya_calibrated_flagged.ms      MS Version 2
================================================================================
   Observer: cqi     Project: uid://A002/X327408/X6f
Observation: ALMA
Computing scan and subscan properties...
Data records: 80563       Total elapsed time = 5647.68 seconds
   Observed from   19-Nov-2012/07:36:57.0   to   19-Nov-2012/09:11:04.7 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  19-Nov-2012/07:36:57.0 - 07:39:13.1     4      0 J0522-364              4200  [0]  [6.05] [CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            07:44:45.2 - 07:47:01.2     7      2 Ceres                  3800  [0]  [6.05] [CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            07:52:42.0 - 07:53:47.6    10      3 J1037-295              1900  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            07:56:23.5 - 08:02:11.3    12      5 TW Hya                 8514  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            08:04:36.3 - 08:05:41.9    14      3 J1037-295              1900  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            08:08:09.6 - 08:13:57.3    16      5 TW Hya                10360  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            08:16:20.6 - 08:17:26.2    18      3 J1037-295              2100  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            08:19:53.9 - 08:25:41.7    20      5 TW Hya                10321  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            08:28:17.1 - 08:29:22.6    22      3 J1037-295              2100  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            08:32:00.5 - 08:37:48.2    24      5 TW Hya                10324  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            08:40:11.9 - 08:41:17.4    26      3 J1037-295              2100  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            08:43:45.6 - 08:49:33.4    28      5 TW Hya                 9462  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            08:51:57.1 - 08:53:02.6    30      3 J1037-295              1900  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            08:58:12.0 - 09:00:28.1    33      6 3c279                  3402  [0]  [6.05] [CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            09:01:35.7 - 09:02:41.2    34      3 J1037-295              1900  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
            09:05:15.6 - 09:07:31.6    36      5 TW Hya                 4180  [0]  [6.05] [OBSERVE_TARGET#ON_SOURCE]
            09:09:59.1 - 09:11:04.7    38      3 J1037-295              2100  [0]  [6.05] [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
        (nRows = Total number of rows per scan)
```

listobs

listobs(vis='sis14_twhya_calibrated_flagged.ms')

List of fields & spectral windows

Fields: 5

ID	Code	Name	RA	Decl	Epoch	SrcId	nRows
0	none	J0522-364	05:22:57.984648	-36.27.30.85128	J2000	0	4200
2	none	Ceres	06:10:15.950590	+23.22.06.90668	J2000	2	3800
3	none	J1037-295	10:37:16.079736	-29.34.02.81316	J2000	3	16000
5	none	TW Hya	11:01:51.796000	-34.42.17.36600	J2000	4	53161
6	none	3c279	12:56:11.166576	-05.47.21.52464	J2000	5	3402

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

Sources: 5

ID	Name	SpwId	RestFreq(MHz)	SysVel(km/s)
0	J0522-364	0	-	-
1	Ceres	0	-	-
2	J1037-295	0	-	-
3	TW Hya	0	-	-
4	3c279	0	-	-

Antenna names & positions

Antennas: 21:

ID	Name	Station	Diam.	Long.	Lat.	Offset from array center (m) East	North	Elevation	ITRF Geocentric coordinates (m) x	y	z
1	DA42	A050	12.0 m	-067.45.16.2	-22.53.29.3	43.0352	-744.9713	21.6702	2225079.880016	-5440041.377534	-2481724.598031
2	DA44	A068	12.0 m	-067.45.20.6	-22.53.25.7	-82.4232	-631.7828	23.5810	2224981.097784	-5440131.250387	-2481621.066374
3	DA45	A070	12.0 m	-067.45.11.9	-22.53.29.3	166.1833	-743.4934	19.8811	2225193.450167	-5439993.764157	-2481722.540534
4	DA46	A067	12.0 m	-067.45.12.7	-22.53.27.2	142.4097	-678.7318	20.1280	2225181.070532	-5440026.290790	-2481662.975103
5	DA48	A046	12.0 m	-067.45.17.0	-22.53.29.3	21.4267	-742.7987	21.6757	2225060.202580	-5440050.344436	-2481722.598651
6	DA49	A029	12.0 m	-067.45.18.2	-22.53.25.8	-12.9134	-636.4552	22.1350	2225044.239583	-5440102.022535	-2481624.808405
7	DA50	A045	12.0 m	-067.45.17.9	-22.53.30.1	-5.4183	-767.4398	22.6034	2225032.051652	-5440052.426015	-2481745.660003
9	DV02	A077	12.0 m	-067.45.10.1	-22.53.25.9	217.6299	-637.5333	15.8376	2225255.259272	-5440008.987869	-2481623.352052
11	DV05	A082	12.0 m	-067.45.08.3	-22.53.29.2	269.0433	-740.9521	15.7832	2225287.593766	-5439952.243679	-2481718.605314
12	DV06	A037	12.0 m	-067.45.17.5	-22.53.28.8	6.7403	-727.3003	21.2086	2225048.729287	-5440061.085777	-2481708.139136
14	DV08	A021	12.0 m	-067.45.17.2	-22.53.27.0	14.3196	-672.8108	21.3420	2225063.814715	-5440077.948261	-2481657.992572
15	DV10	A071	12.0 m	-067.45.19.9	-22.53.23.5	-60.7887	-563.2541	23.3799	2225011.141945	-5440147.560932	-2481557.855663
16	DV13	A072	12.0 m	-067.45.12.6	-22.53.24.0	147.1742	-580.5887	18.1825	2225199.254375	-5440058.161494	-2481571.803699
17	DV15	A074	12.0 m	-067.45.12.1	-22.53.32.0	161.8159	-828.6196	18.7688	2225176.483514	-5439963.820451	-2481800.529842
18	DV16	A069	12.0 m	-067.45.21.3	-22.53.30.2	-101.4797	-770.1047	23.2972	2224942.993176	-5440088.421459	-2481748.384855
19	DV17	A138	12.0 m	-067.45.17.1	-22.53.34.4	19.1461	-901.2603	26.0137	2225036.269025	-5439997.853009	-2481870.267607
20	DV18	A053	12.0 m	-067.45.17.3	-22.53.31.2	12.5939	-802.9941	21.5281	2225043.111690	-5440031.889497	-2481777.995870
21	DV19	A008	12.0 m	-067.45.15.4	-22.53.26.8	67.5592	-667.6872	20.9574	2225113.709955	-5440059.310545	-2481653.122797
22	DV20	A020	12.0 m	-067.45.17.8	-22.53.28.0	-2.9649	-703.4389	21.6629	2225043.419055	-5440073.737929	-2481686.333574
24	DV22	A011	12.0 m	-067.45.14.4	-22.53.28.4	95.9131	-716.5005	21.0898	2225132.810230	-5440031.115405	-2481698.143589
25	DV23	A007	12.0 m	-067.45.15.1	-22.53.27.3	74.0152	-681.2926	21.3231	2225117.809276	-5440052.280005	-2481665.799049

Task listobs complete. Start time: 2021-11-29 22:42:19.113889 End time: 2021-11-29 22:42:19.209607

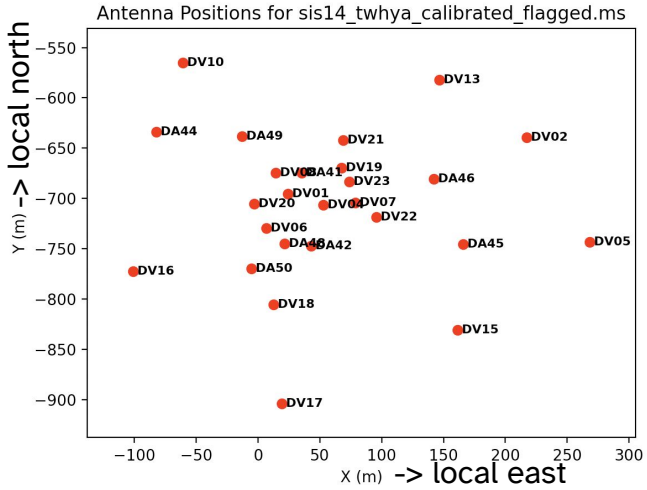
End Task: listobs

##

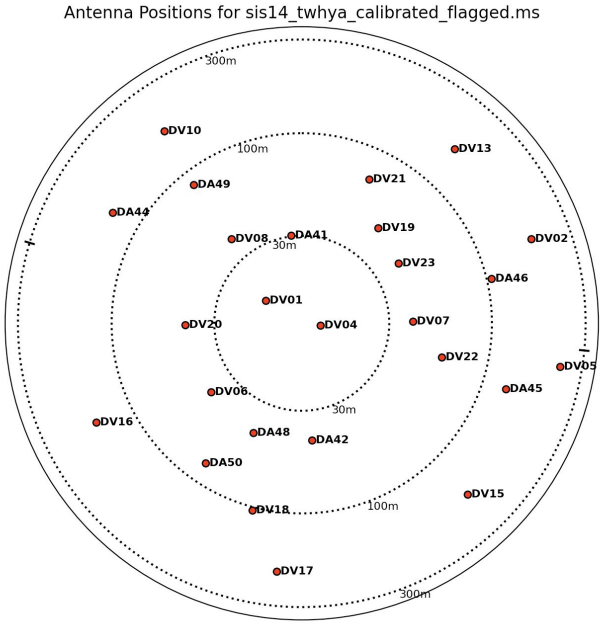
##

Plotant: plot the location of antennas

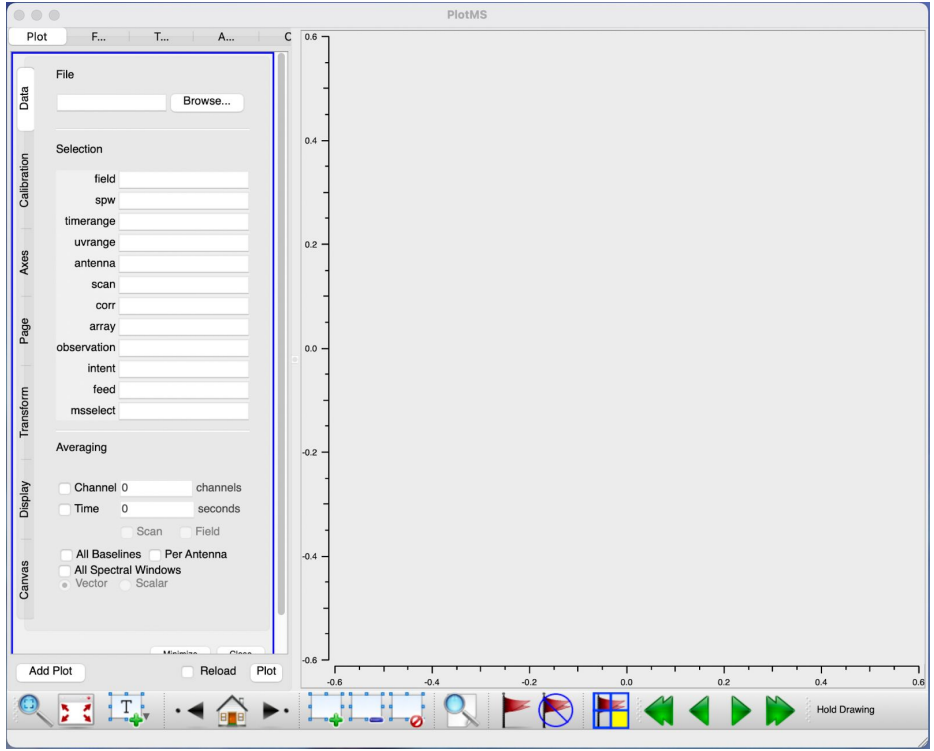
plotants(vis='sis14_twhya_calibrated_flagged.ms', showgui=True, logpos=True)



Plotting logarithmic positions helps display the center of the array

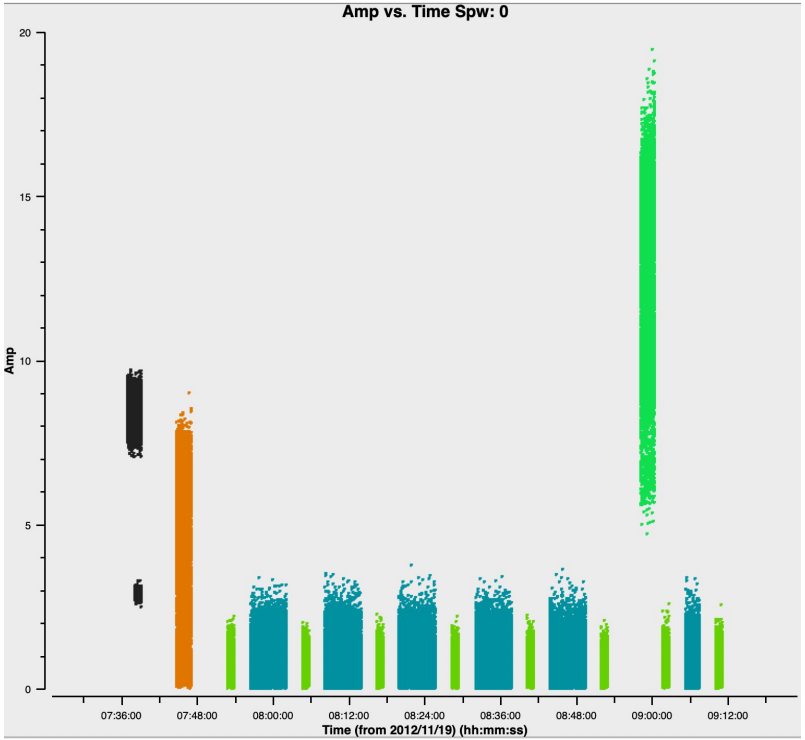


plotms: inspect/flag data interactively



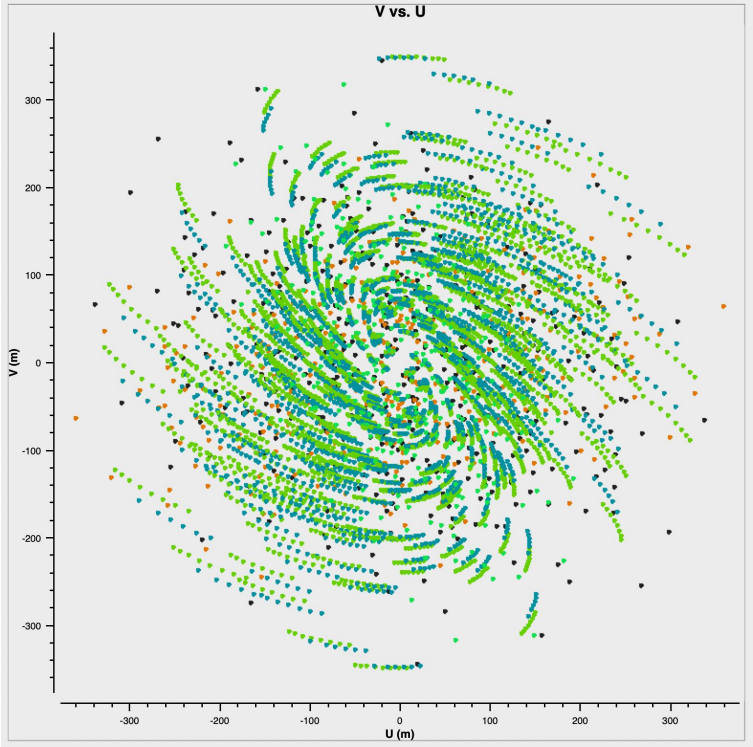
plotms - get familiar with your data

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='time',
yaxis='amp',
avgchannel='10000',
avgspw=False,
avgscan=False,
coloraxis="field",
showgui=True)
```



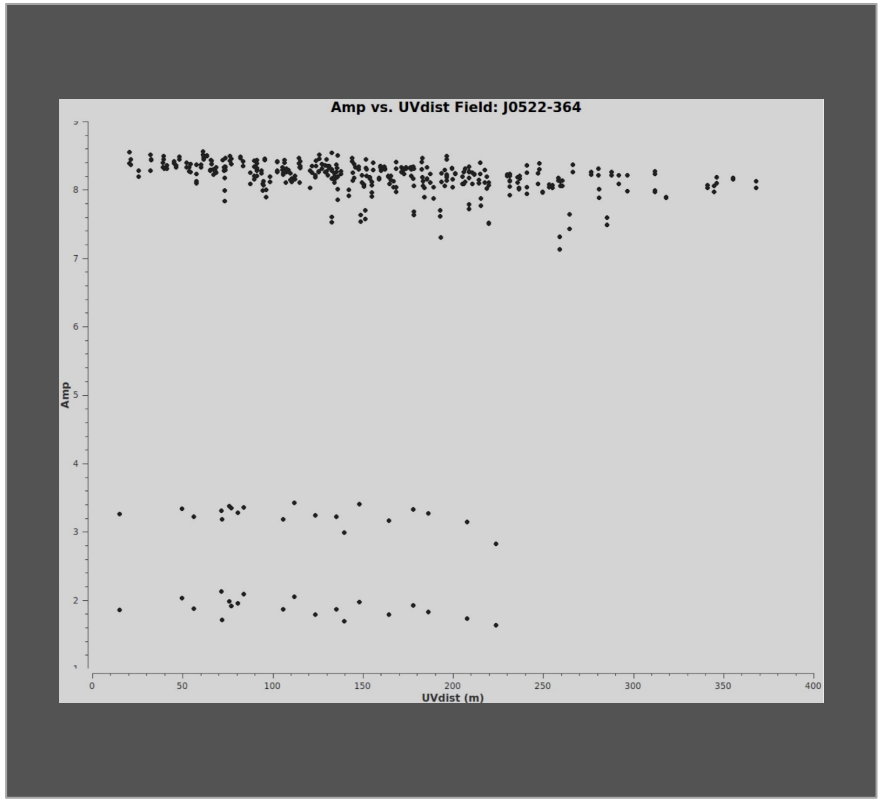
Plotms - V vs U

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='u',
yaxis='v',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
showgui=True)
```



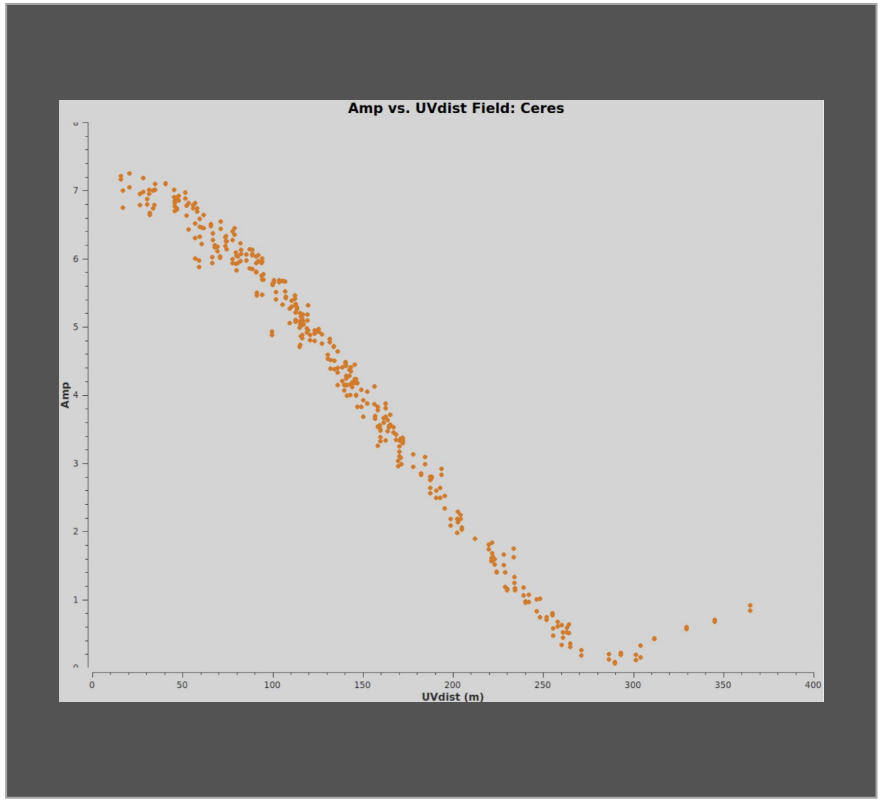
Plotms - Amp vs UV distance

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='UVdist',
yaxis='amp',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
iteraxis = "field",
showgui=True)
```



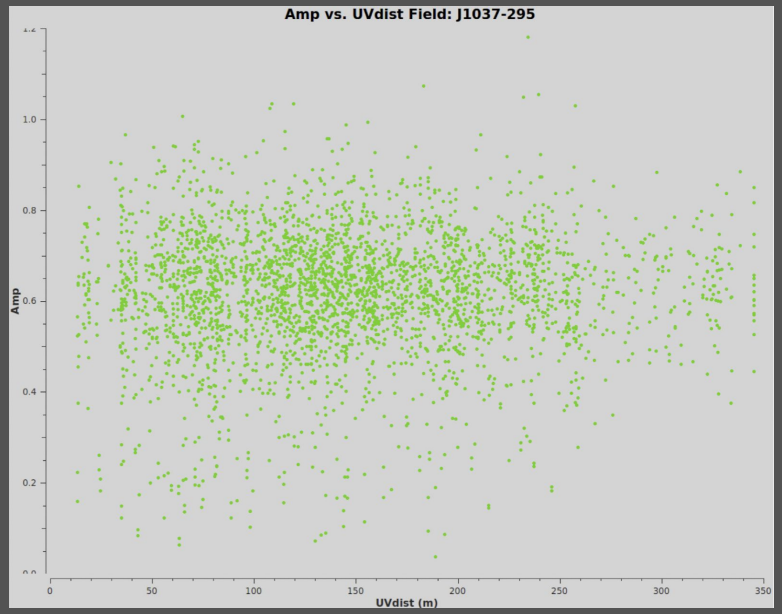
Plotms - Amp vs UV distance

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='UVdist',
yaxis='amp',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
iteraxis = "field",
showgui=True)
```



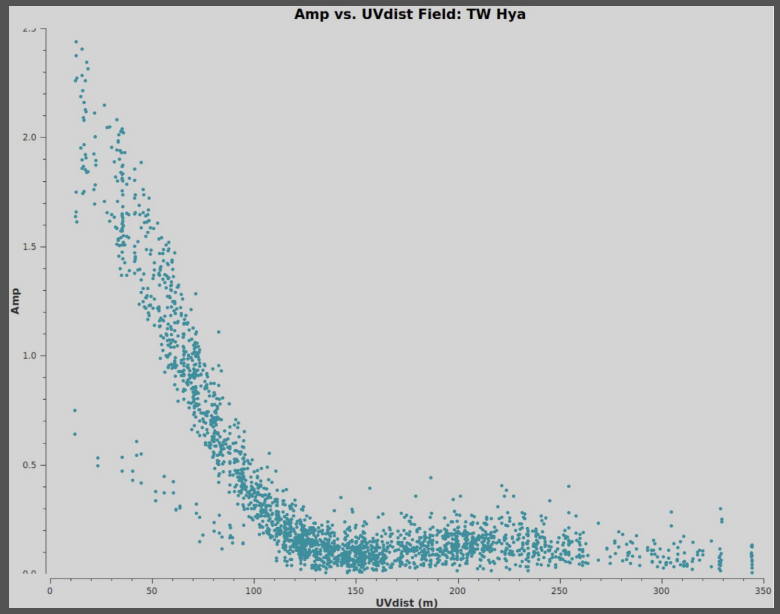
Plotms - Amp vs UV distance

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='UVdist',
yaxis='amp',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
iteraxis = "field",
showgui=True)
```



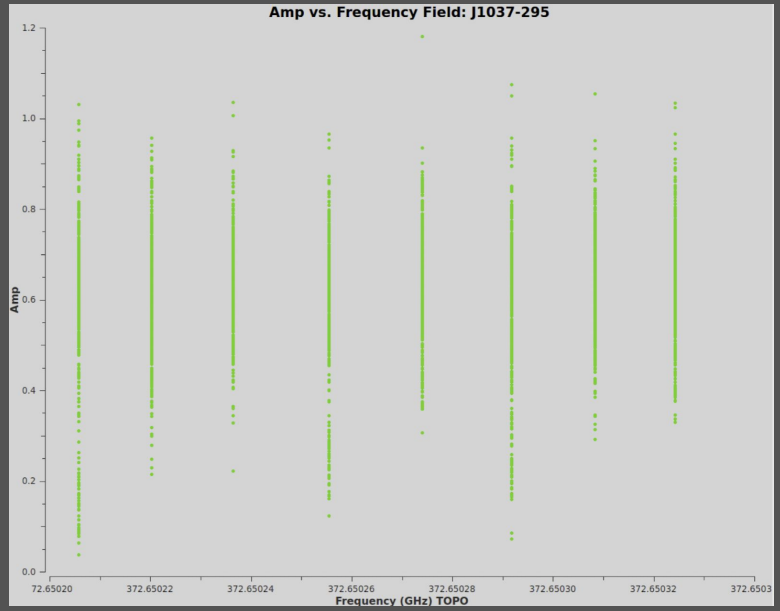
Plotms - Amp vs UV distance

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='UVdist',
yaxis='amp',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
iteraxis = "field",
showgui=True)
```



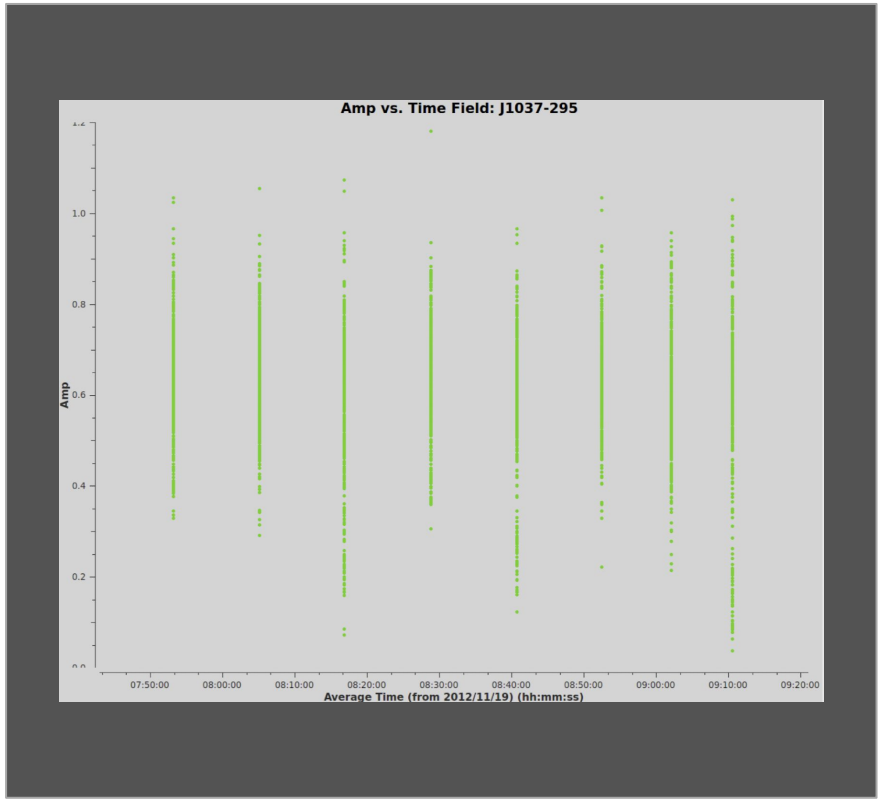
Plotms - Amp vs Frequency

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='freq',
yaxis='amp',
field = 'J1037-295',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
showgui=True)
```



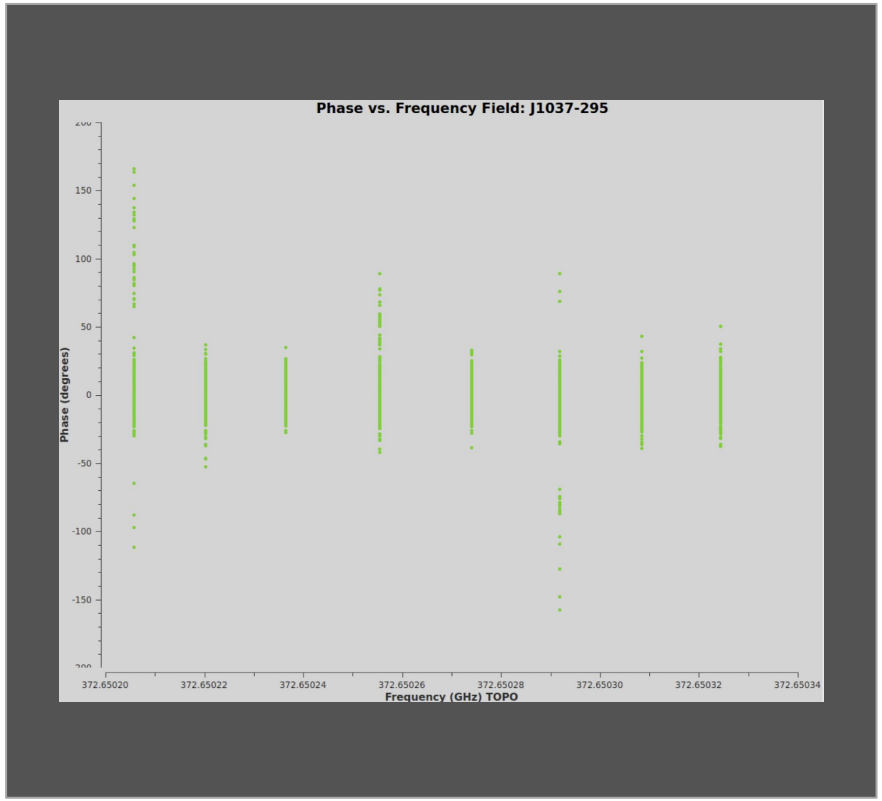
Plotms - Amp vs Time

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='time',
yaxis='amp',
field = 'J1037-295',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
showgui=True)
```



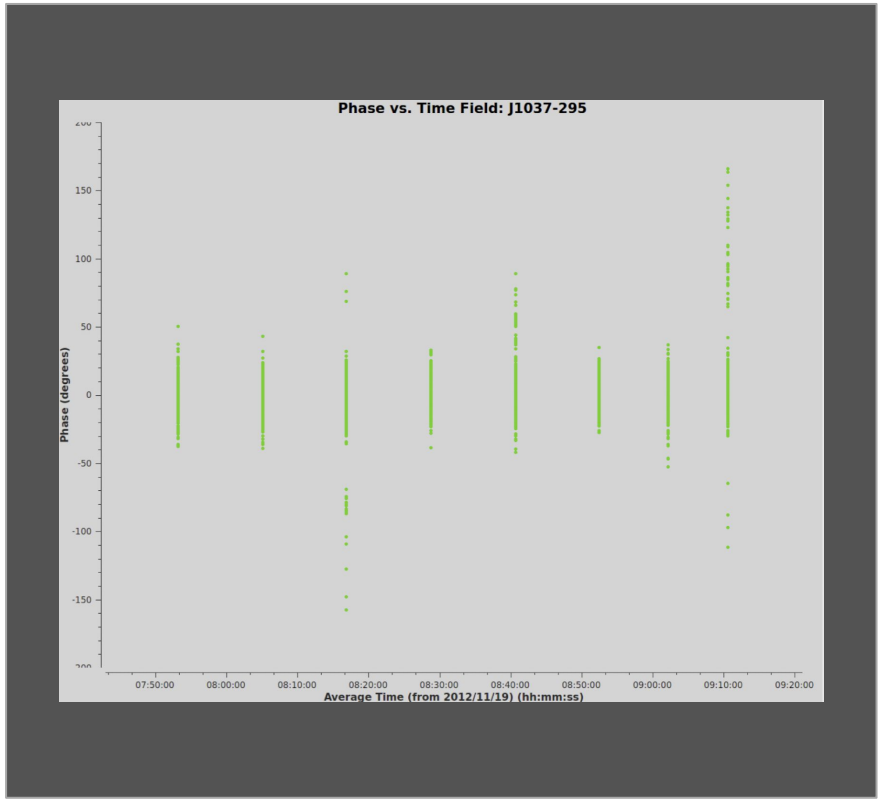
Plotms - Phase vs Frequency

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='freq',
yaxis='phase',
field = 'J1037-295',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
showgui=True)
```



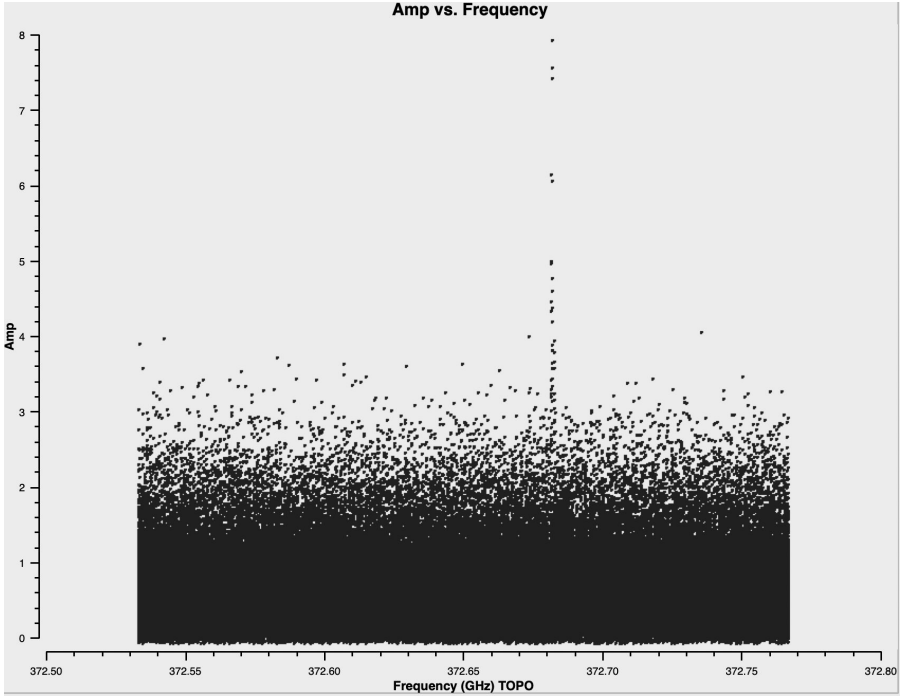
Plotms - Phase vs Time

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='time',
yaxis='phase',
field = 'J1037-295',
avgchannel='10000',
avgspw=False,
avgtime='1e9',
avgscan=False,
coloraxis="field",
showgui=True)
```



Plotms - Amp vs Frequency

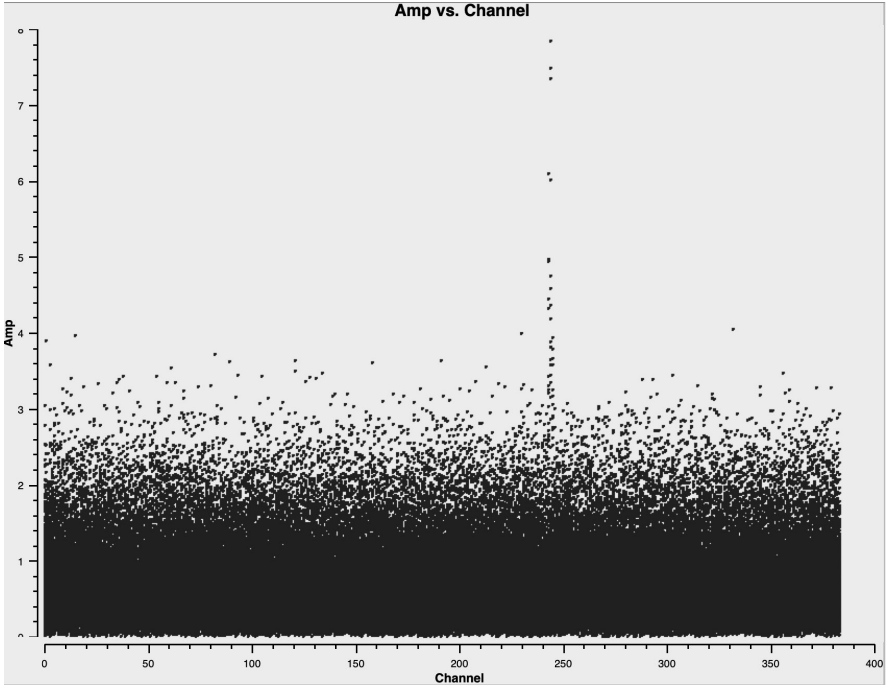
```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='freq',
yaxis='amp',
field = 'TW Hya',
avgspw=False,
avgtime='1e9',
avgscan=True,
coloraxis="spw",
showgui=True)
```



Plotms - Amp vs Channel

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='channel',
yaxis='amp',
field = 'TW Hya',
avgspw=False,
avgtime='1e9',
avgscan=True,
coloraxis="spw",
showgui=True)
```

Optional:
avgchannel='10'

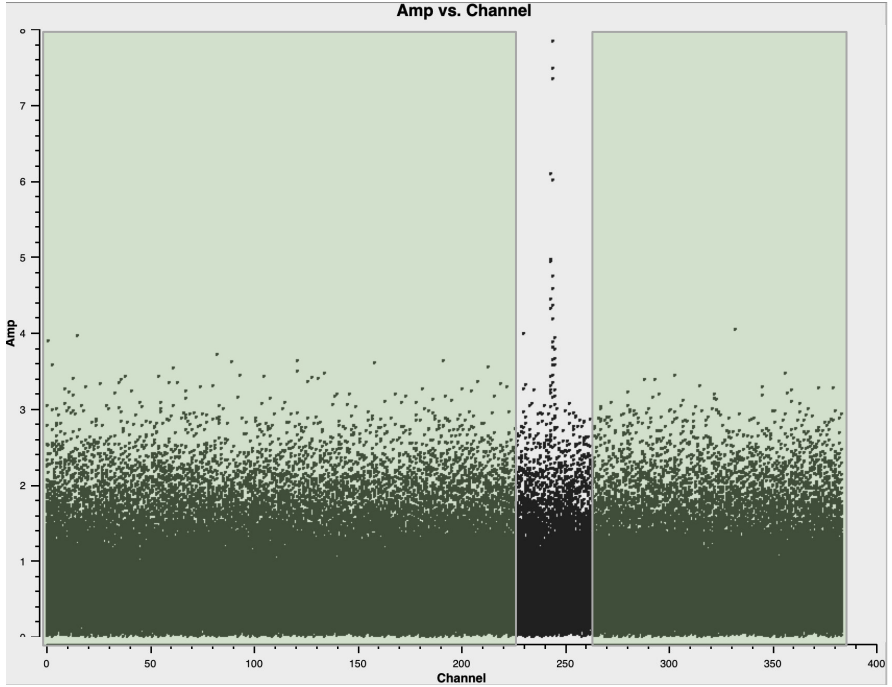


Determining line-free channels

Two common methods:

1) a channel vs. amplitude plot of the visibilities

- Here we see channels 0-239 and 281-383 are free of lines and can be used to create the continuum (shown later)



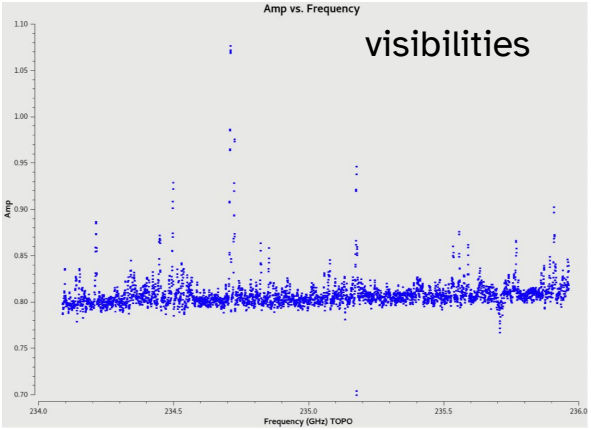
Determining line-free channels

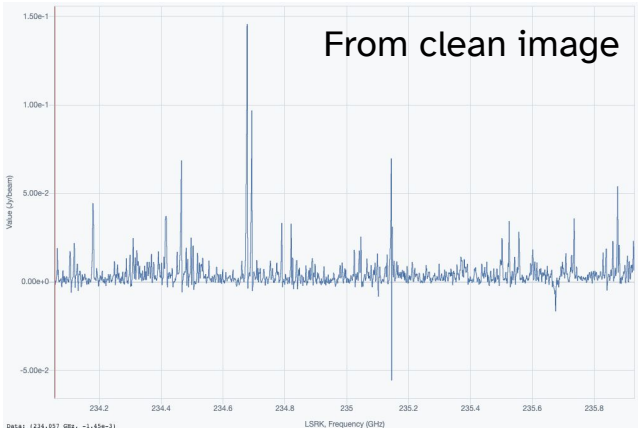
Two common methods:

2) a dirty image of the cube (tclean with niter=0)

Or better yet, if available: the products cubes from the pipeline

Especially for chemically-rich sources:





Better statistical tools

For sources that are extremely rich in lines better statistical tools are needed to determine the continuum level. Two options:

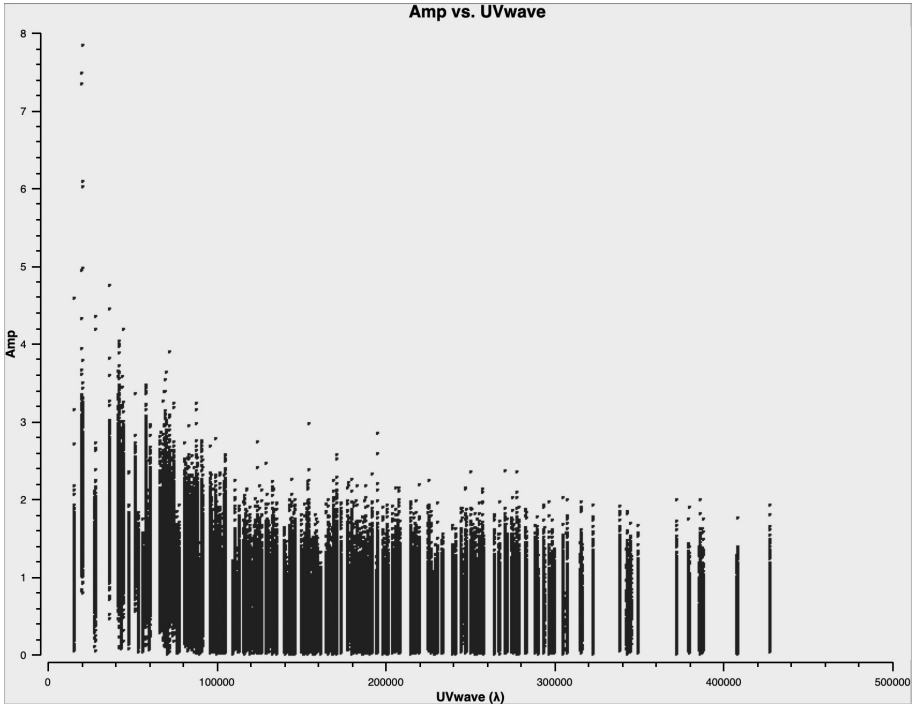
1. **STATCONT**: https://hera.ph1.uni-koeln.de/~sanchez/statcont
   - Can produce continuum fits files and continuum-subtracted line cubes. It can also handle single spectra in ASCII format.
   - See upcoming I-TRAIN (#11) on Dec. 10: https://almascience.eso.org/tools/eu-arc-network/i-train
2. **Lumberjack**: CASA task that determines line-free channels: https://github.com/adam-avison/LumberJack

Imaging parameters

- Determine the **beam size:**
  - **Resolution(arcsec) ~ 206265.0/(longest baseline in wavelengths)**
  - Make a dirty image, or
  - Use product images as a starting point
  - See parameters on the weblog

Determine longest baseline

```
plotms(
vis='sis14_twhya_calibrated_flagged.ms',
xaxis='UVwave',
yaxis='amp',
field = 'TW Hya',
avgspw=False,
avgtime='1e9',
avgscan=True,
coloraxis="spw",
showgui=True)
```



Imaging parameters

- Determine the **beam size:**
  - **Resolution(arcsec) ~ 206265.0/(longest baseline in wavelengths)**
  - Make a dirty image, or
  - Use product images as a starting point
  - See parameters on the weblog

↓

206265.0/427600 ~ 0.5”

- Determine the pixel size -> **cellsize:**
  - Rule of thumb: ~5 pixels across the smallest direction of an elliptical beam

↓

0.5” / 5 = 0.1”

Imaging parameters

- Determine the image size -> **imsize:**
  - Rule of thumb: ~1.5-2 times the HPBW primary beam (~λ/D)
    - 12m primary beam in arcsec scales as 6300 / nu[GHz]
    - 7m primary beam in arcsec scales as 10608 / nu[GHz]

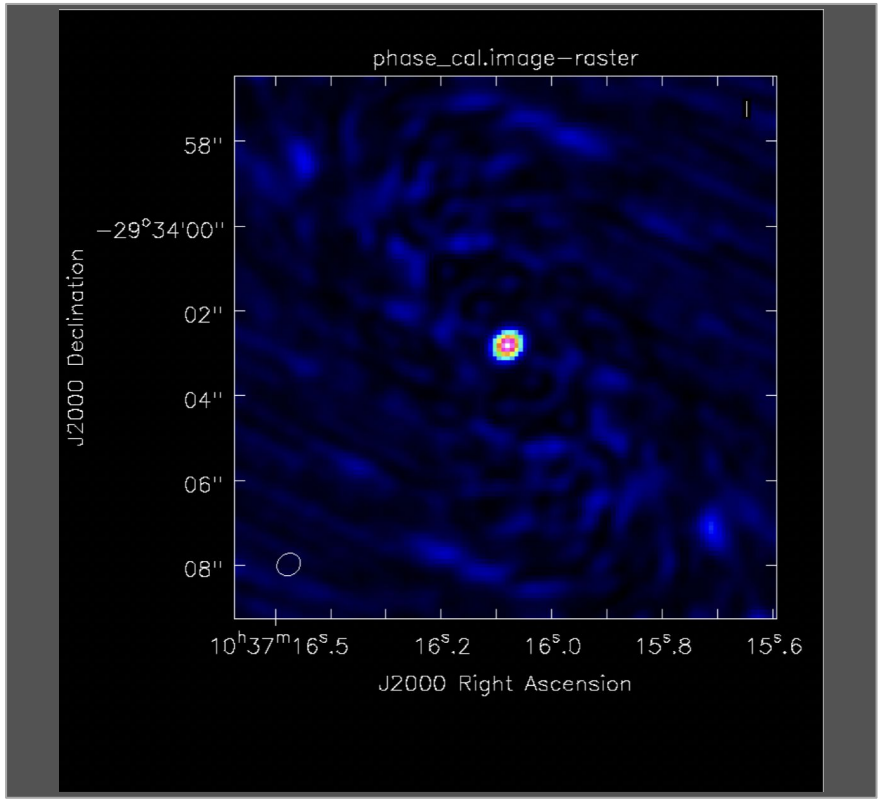
→ **6300 / 372.6 GHz = 17" @ 0.1" per pixel -> 170 pixels**
You can afford to make smaller images if target is compact at the phase center. We will choose 128 pixels.

- Remember to set the 'field' parameter to your target (select all fields for mosaics)

2. First look at imaging

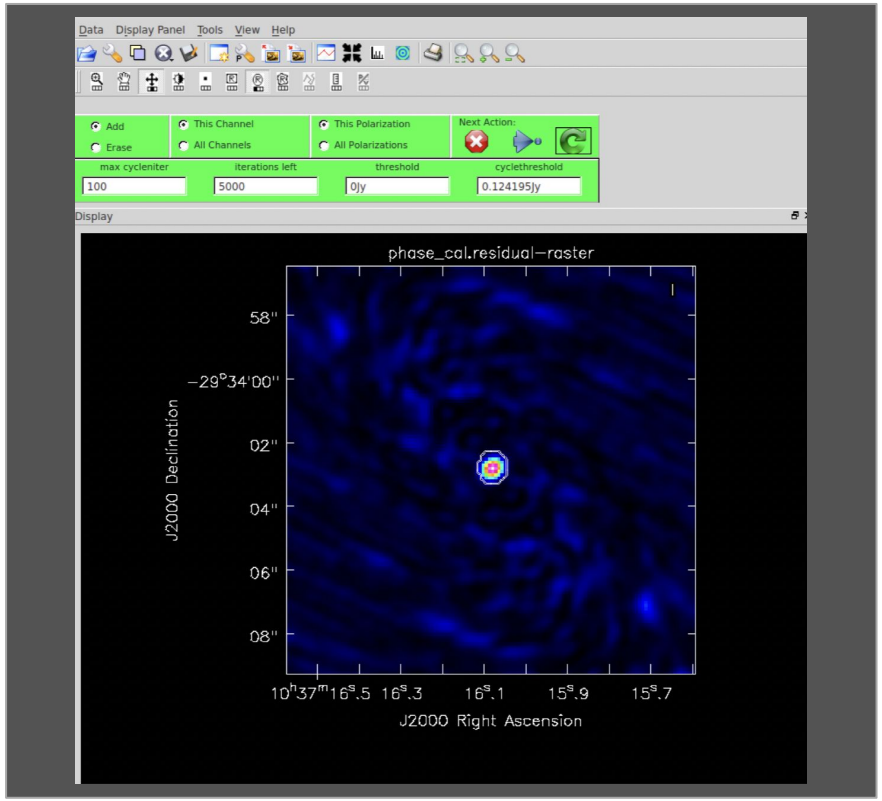
Tclean - Dirty image

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       interactive=True)
```



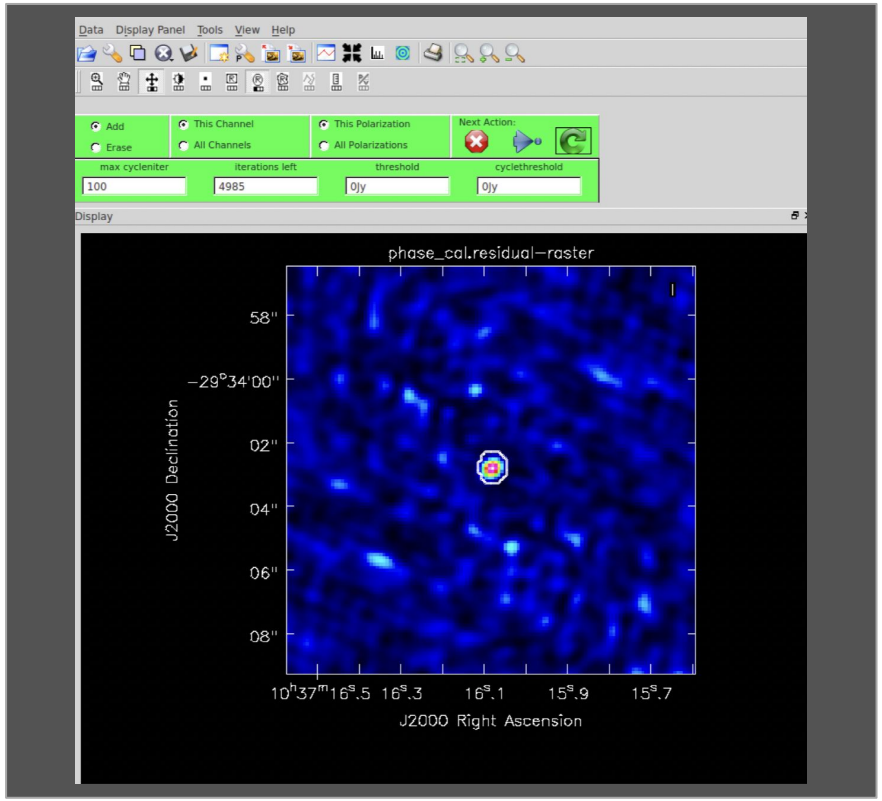
Tclean - Clean image - Phase calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```



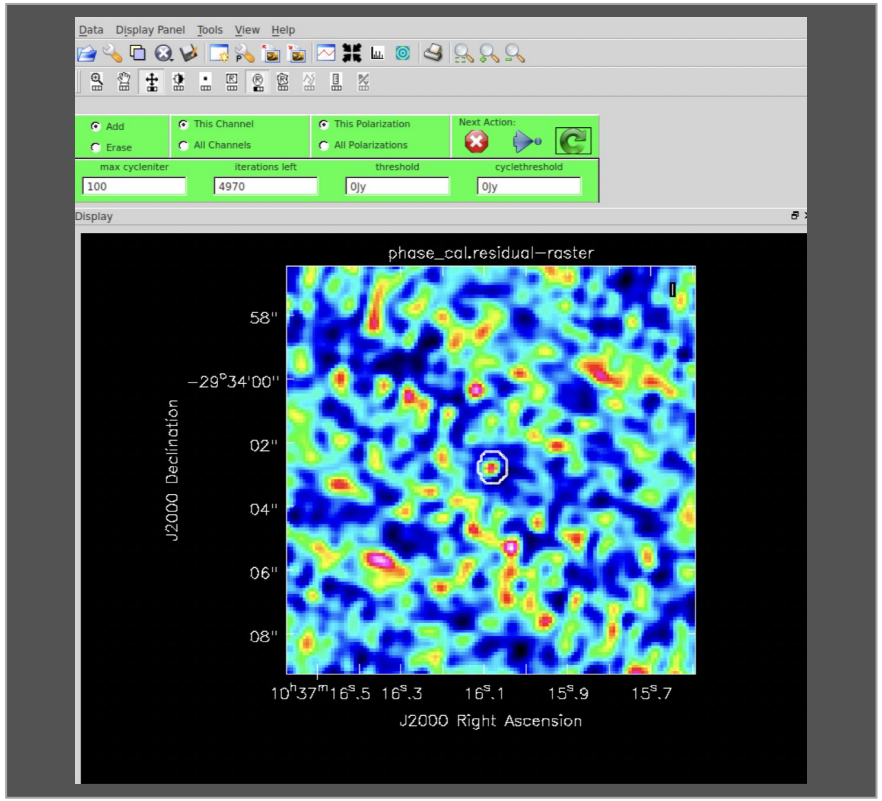
Tclean - Not cleaned enough

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```



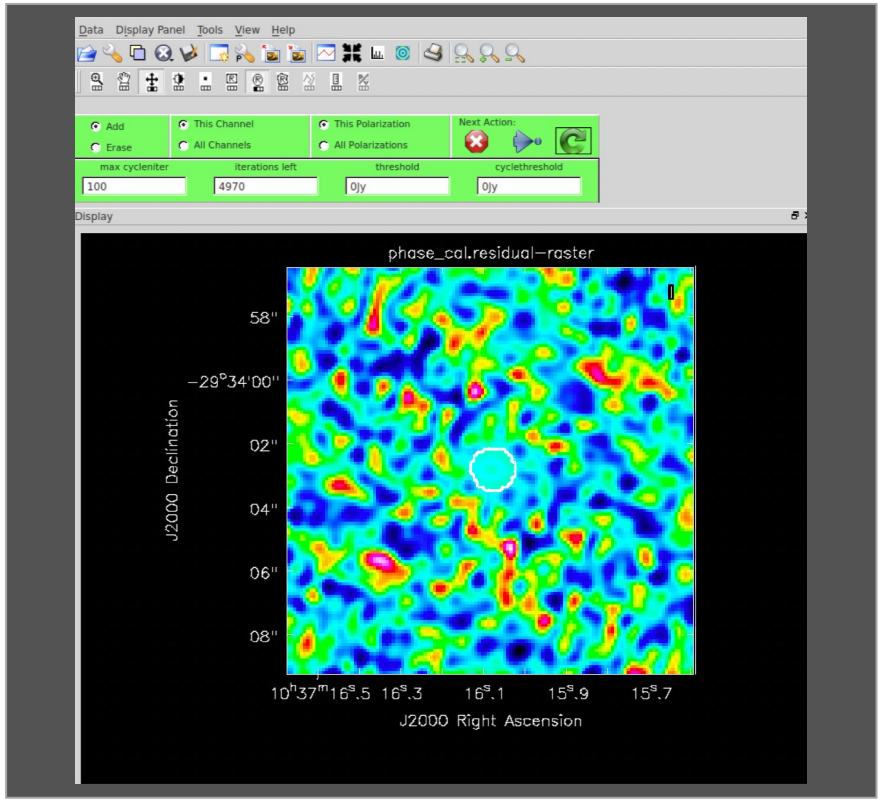
Tclean - Cleaned just right

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```



Tclean - Cleaned too much

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```

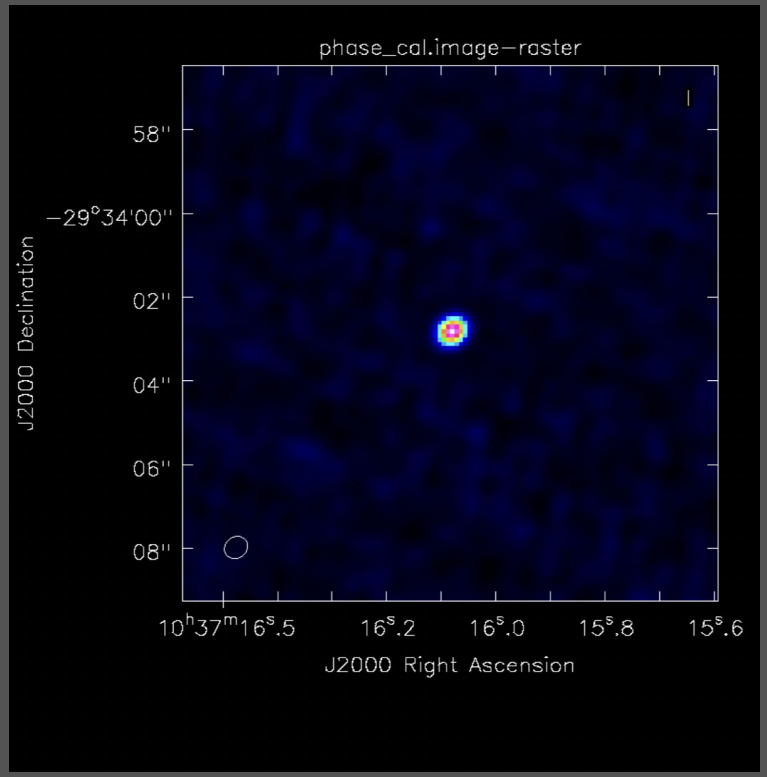


Tclean - Clean image - Phase calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```

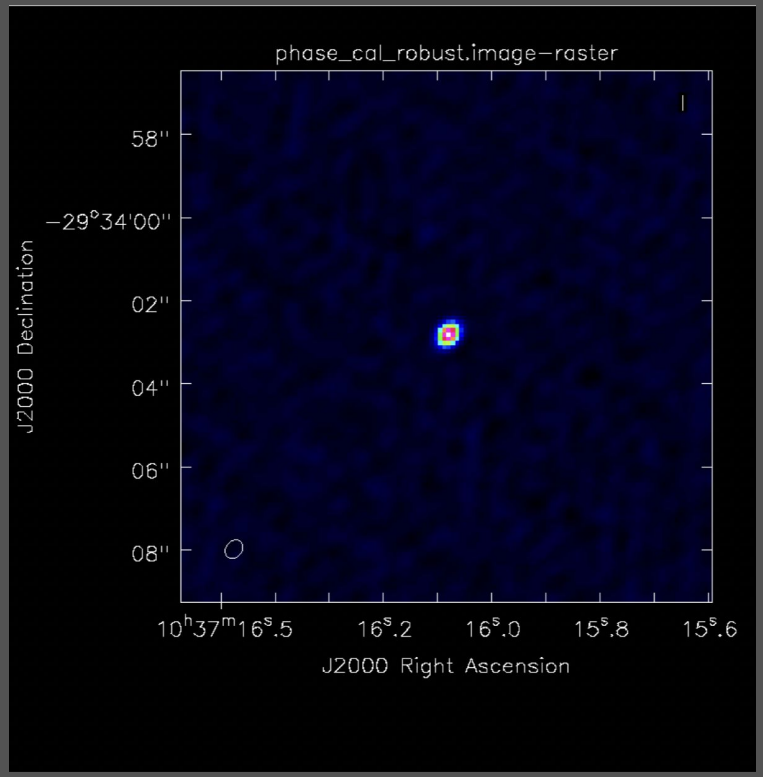
Tclean - Clean image - Phase calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal',
       field='3',
       spw='',
       specmode='mfs',
       deconvolver='hogbom',
       gridder='standard',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0.0mJy',
       niter =5000
       interactive=True)
```



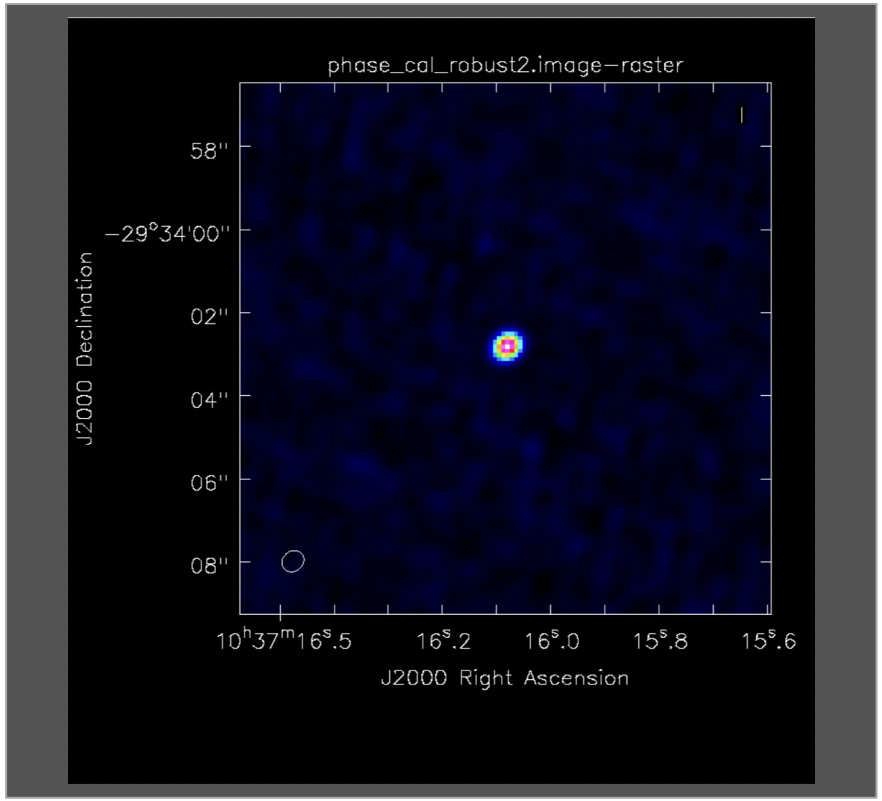
Tclean - Clean image - Phase calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal_robust',
       field='3',
       spw='',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='briggs',
       robust=-1.0,
       threshold='0mJy',
       niter=5000,
       interactive=True)
```



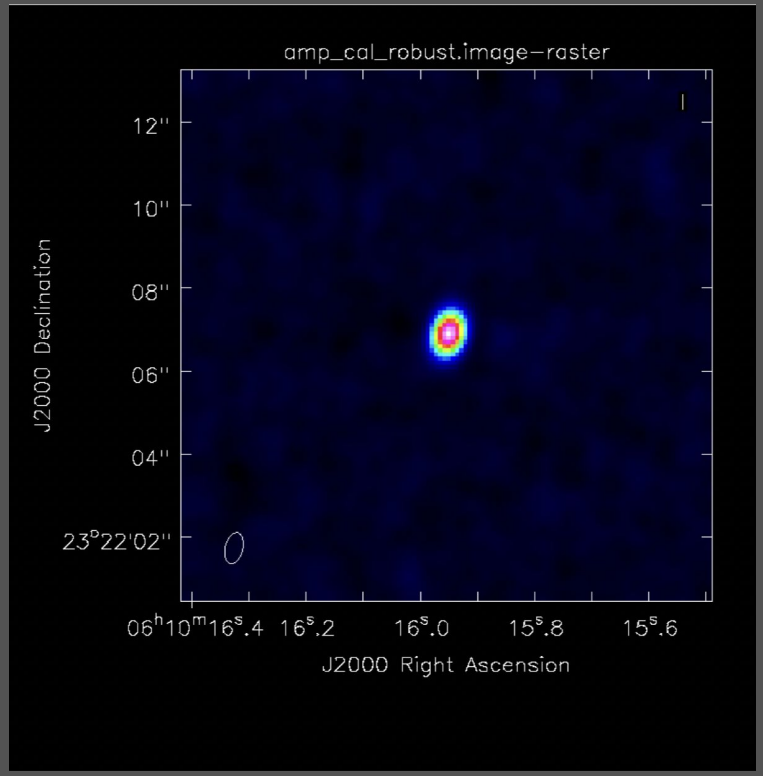
Tclean - Clean image - Phase calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='phase_cal_robust',
       field='3',
       spw='',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='briggs',
       robust=1.0,
       threshold='0mJy',
       niter=5000,
       interactive=True)
```



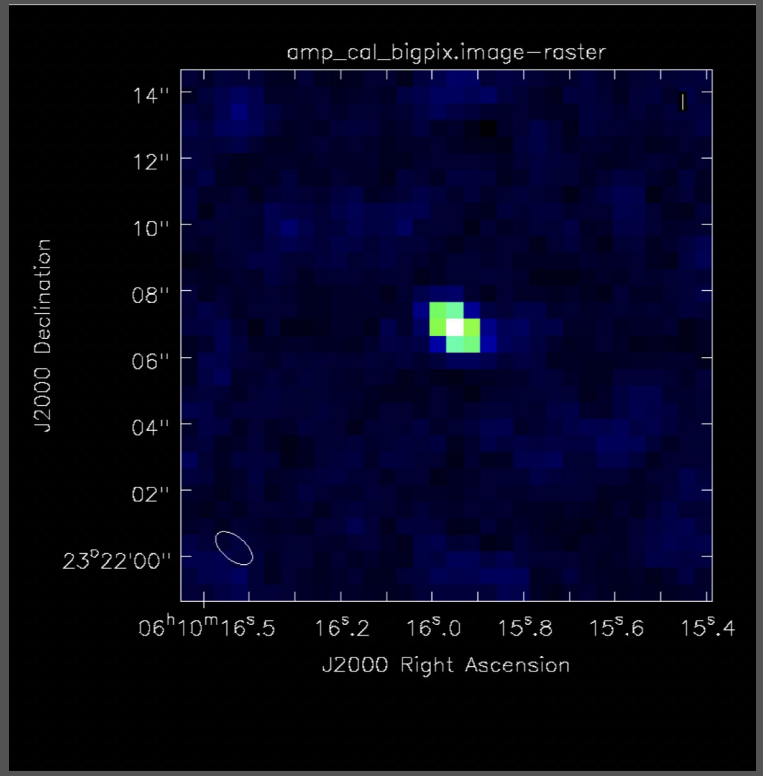
Tclean - Clean image - Amp calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='amp_cal_robust',
       field='2',
       spw='',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[128,128],
       cell=['0.1arcsec'],
       weighting='natural',
       threshold='0mJy',
       niter=5000,
       interactive=True)
```



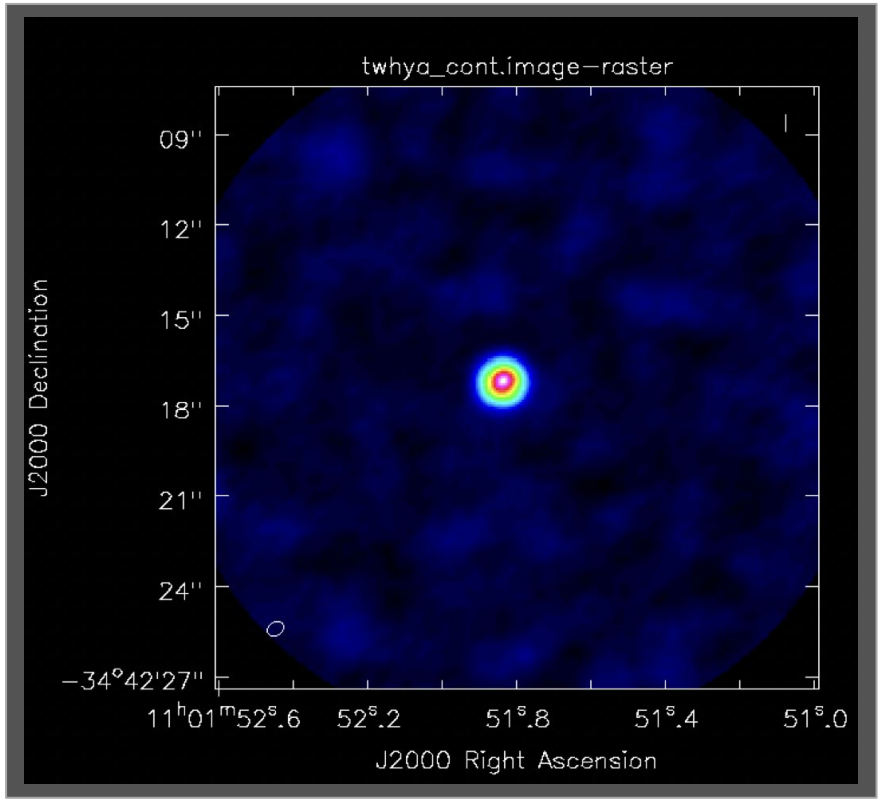
Tclean - Clean image - Amp calibrator

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='amp_cal_bigpix',
       field='2',
       spw='',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[32,32],
       cell=['0.5arcsec'],
       weighting='natural',
       threshold='0mJy',
       niter=5000,
       interactive=True)
```



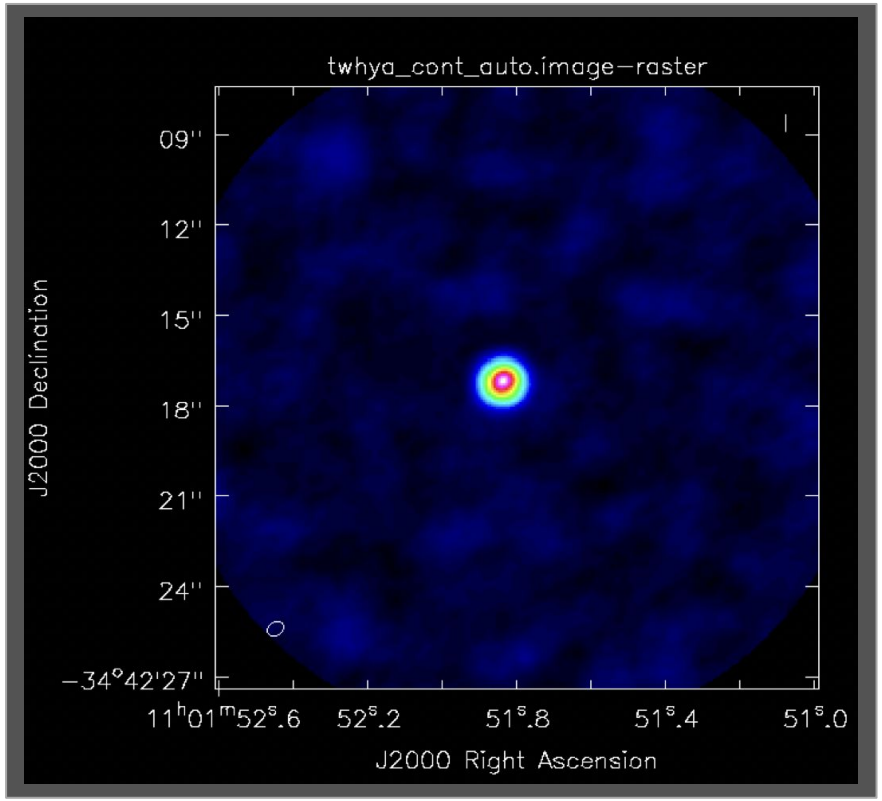
Tclean - Target

```
tclean(vis='sis14_twhya_calibrated_flagged.ms’,
       imagename='twhya_cont',
       field='5',
       spw='0:0~239;281~383',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[250,250],
       cell=['0.08arcsec'],
       weighting='briggs',
       robust=0.5,
       threshold='0mJy',
       niter=5000,
       interactive=True)
```



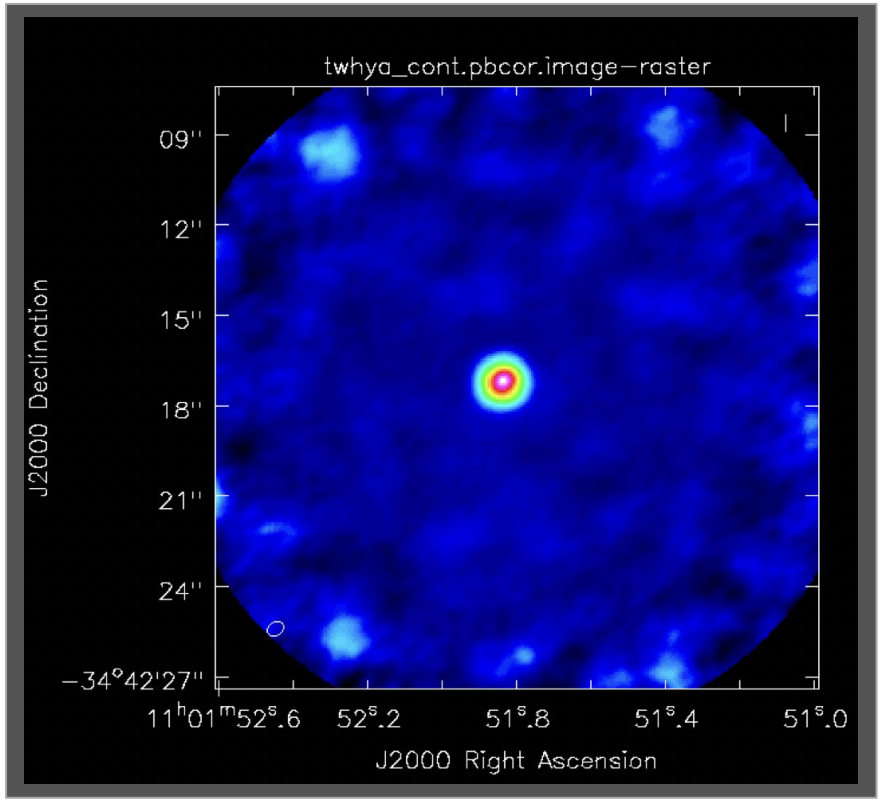
Tclean - Target - Non-interactive clean

```
tclean(vis='sis14_twhya_calibrated_flagged.ms',
       imagename='twhya_cont_auto',
       field='0',
       spw='0:0~239;281~383',
       specmode='mfs',
       gridder='standard',
       deconvolver='hogbom',
       imsize=[250,250],
       cell=['0.08arcsec'],
       mask='box [ [ 100pix , 100pix] , [150pix, 150pix ] ]',
       weighting='briggs',
       robust=0.5,
       threshold='15mJy',
       niter=10000,
       interactive=False)
```



Primary beam correction

```
impbcor(imagename='twhya_cont.image',
        pbimage='twhya_cont.pb',
        outfile='twhya_cont.pbcor.image')
```



3. First look at Self-calibration

```
# List of steps executed by this script
thesteps=[]
step_title = {0:  'List the data set and plot antennas and visibility spectrum',
              1:  'Make dirty image of continuum',
              ### INITIAL MODEL
              2:  'Make an initial, conservative cleaning',
              3:  'Check and save model',
              ### FIRST ROUND OF SELF-CALIBRATION - PHASE
              4:  'Calculate gain solution table - phase-only, solution interval = scan-length',
              5:  'Explore different solution intervals',
              6:  '[ADVANCED] Calculate SNR of the different solution intervals',
              7:  'Apply calibration table',
              8:  'Make second, conservative cleaning and save model',
              ### SECOND ROUND OF SELF-CALIBRATION - PHASE
              9:  'Explore different solution intervals',
              10: '[ADVANCED] Calculate SNR of the different solution intervals',
              11: 'Calculate gain solution table - phase-only, solution interval = 60s applying round 1 table on-the-fly',
              12: 'Apply calibration tables',
              13: 'Make image of continuum and save model',
              ### THIRD ROUND OF SELF-CALIBRATION - AMPLITUDE & PHASE
              14: 'Calculate gain solution table - amplitude and phase, long solution interval',
              15: 'Apply calibration tables',
              16: 'Make image of continuum and save model',
              ### FOURTH ROUND OF SELF-CALIBRATION - AMPLITUDE & PHASE
              17: 'Calculate gain solution table - amplitude and phase, short solution interval',
              18: 'Apply calibration table',
              ### FINAL CONTINUUM IMAGE
              19: 'Make image of continuum and save model',
             }
```

Script written by Dr. M.C. Toribio

https://almascience.eso.org/tools/eu-arc-network/i-train

Initial step

Dataset: **sis14_twhya_calibrated_flagged.ms**
Selfcal Script: **twhya_selfcal.py**

Open the script in a terminal.
(gedit, vi, emacs)

Define the variable:
mysteps = [0]
Save it and open CASA.

helada [1] > nice +10 casapy-560

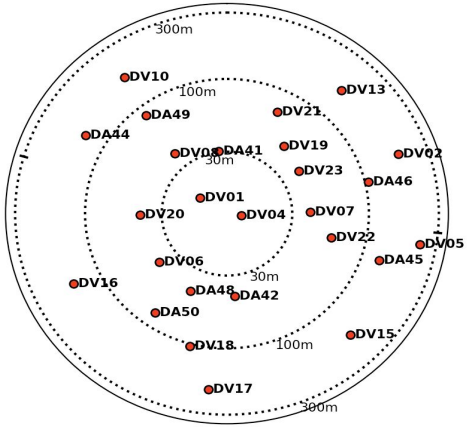
```
==========================================
The start-up time of CASA may vary
depending on whether the shared libraries
are cached or not.
==========================================

IPython 5.1.0 -- An enhanced Interactive Python.

CASA 5.6.0-60   -- Common Astronomy Software Applications

Found an existing telemetry logfile:
/home/perezsanchez/.casa/casastats-560-60-1e02b0110e82a43e6-20211125-184523.log
Telemetry initialized. Telemetry will send anonymized usage statistics to NRAO.
You can disable telemetry by adding the following line to your ~/.casarc file:
EnableTelemetry: False
--> CrashReporter initialized.
Enter doc('start') for help getting started with CASA...
Using matplotlib backend: TkAgg

CASA <1>: mysteps=[0]
CASA <2>: execfile('twhya_selfcal.py')
```

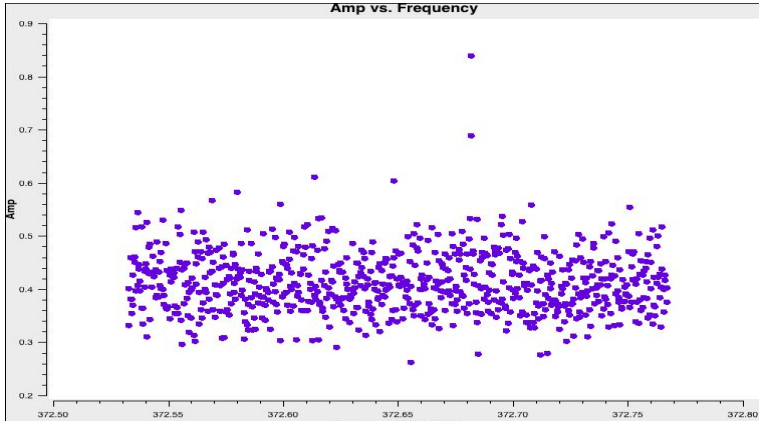
0: 'List the data set and plot antennas and visibility spectrum',

1: 'Make dirty image of continuum'.

sis14_twhya_calANDflag_listobs.txt

```
================================================================================
           MeasurementSet Name:  /Users/aperez/Allegro/Work/2021SciDay-II/sis14_twhya_calANDflag.ms      MS Version 2
================================================================================
   Observer: cal     Project: uid://A002/X327408/X6f
Observation: ALMA
Data records: 80563       Total elapsed time = 5647.68 seconds
   Observed from   19-Nov-2012/07:36:57.0   to   19-Nov-2012/09:11:04.7 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
  19-Nov-2012/07:36:57.0 - 07:39:13.1     4      0 J0522-364               4200   [0]   [6.05]  [CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              07:44:45.2 - 07:47:01.2     7      2 Ceres                   3800   [0]   [6.05]  [CALIBRATE_AMPLI#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              07:52:42.0 - 07:53:47.6    10      3 J1037-295               1900   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              07:56:23.5 - 08:02:11.3    12      5 TW Hya                  8514   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              08:04:36.3 - 08:05:41.9    14      3 J1037-295               1900   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              08:08:09.6 - 08:13:57.3    16      5 TW Hya                 10360   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              08:16:20.6 - 08:17:26.2    18      3 J1037-295               2100   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              08:19:53.9 - 08:25:41.7    20      5 TW Hya                 10321   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              08:28:17.1 - 08:29:22.6    22      3 J1037-295               2100   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              08:32:08.5 - 08:37:48.2    24      5 TW Hya                 10324   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              08:40:11.9 - 08:41:17.4    26      3 J1037-295               2100   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              08:43:45.6 - 08:49:33.4    28      5 TW Hya                  9462   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              08:51:57.1 - 08:53:02.6    30      3 J1037-295               1900   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              08:58:12.0 - 09:00:28.1    33      6 3c279                   3402   [0]   [6.05]  [CALIBRATE_BANDPASS#ON_SOURCE,CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              09:01:35.7 - 09:02:41.2    34      3 J1037-295               1900   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
              09:05:15.6 - 09:07:31.6    36      5 TW Hya                  4180   [0]   [6.05]  [OBSERVE_TARGET#ON_SOURCE]
              09:09:59.1 - 09:11:04.7    38      3 J1037-295               2100   [0]   [6.05]  [CALIBRATE_PHASE#ON_SOURCE,CALIBRATE_WVR#ON_SOURCE]
           (nRows = Total number of rows per scan)
Fields: 5
  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
  0    none J0522-364          05:22:57.984648 -36.27.30.85128 J2000   0           4200
  2    none Ceres              06:10:15.950590 +23.22.06.90668 J2000   2           3800
  3    none J1037-295          10:37:16.079736 -29.34.02.81316 J2000   3          16000
  5    none TW Hya             11:01:51.796000 -34.42.17.36600 J2000   4          53161
  6    none 3c279              12:56:11.166576 -05.47.21.52464 J2000   5           3402
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
Sources: 5
  ID   Name                SpwId RestFreq(MHz)  SysVel(km/s)
  0    J0522-364           0     -              -
  1    Ceres               0     -              -
  2    J1037-295           0     -              -
  3    TW Hya              0     -              -
  4    3c279               0     -              -
Antennas: 21:
  ID   Name  Station   Diam.    Long.         Lat.                Offset from array center (m)                ITRF Geocentric coordinates (m)
                                                                       East         North     Elevation               x               y               z
  1    DA42  A050      12.0 m   -067.45.16.2  -22.53.29.3          43.0352     -744.9713        21.6702  2225079.880016 -5440041.377534 -2481724.598031
  2    DA44  A060      12.0 m   -067.45.20.6  -22.53.25.7         -82.4232     -631.7828        23.5810  2224981.097784 -5440131.250387 -2481621.066374
  3    DA45  A070      12.0 m   -067.45.11.9  -22.53.29.3         166.1833     -743.4934        19.8811  2225193.450167 -5439993.764157 -2481722.540534
  4    DA46  A067      12.0 m   -067.45.12.7  -22.53.27.2         142.4097     -678.7318        20.1280  2225181.070532 -5440026.290790 -2481662.975103
  5    DA48  A046      12.0 m   -067.45.17.0  -22.53.29.3          21.4267     -742.7987        21.6757  2225060.202580 -5440050.344436 -2481722.598651
  6    DA49  A020      12.0 m   -067.45.18.2  -22.53.25.8         -12.9134     -636.4552        22.1350  2225044.230583 -5440102.022535 -2481624.808405
  7    DA50  A045      12.0 m   -067.45.17.9  -22.53.30.1          -5.4183     -767.4398        22.6034  2225032.051652 -5440052.426015 -2481745.660003
  9    DV02  A077      12.0 m   -067.45.10.1  -22.53.25.9         217.6299     -637.5333        15.8376  2225255.259272 -5440008.987869 -2481623.352052
  11   DV05  A082      12.0 m   -067.45.08.3  -22.53.29.2         269.0433     -740.9521        15.7832  2225287.593766 -5439952.243679 -2481718.605314
  12   DV06  A037      12.0 m   -067.45.17.5  -22.53.28.8           6.7403     -727.3083        21.2086  2225048.729287 -5440061.085777 -2481708.139136
  14   DV08  A021      12.0 m   -067.45.17.2  -22.53.27.0          14.3196     -672.8108        21.3420  2225063.814715 -5440077.948261 -2481657.992572
  15   DV10  A071      12.0 m   -067.45.19.9  -22.53.23.5         -60.7887     -563.2541        23.3799  2225011.141945 -5440147.560932 -2481557.855663
  16   DV13  A072      12.0 m   -067.45.12.6  -22.53.24.0         147.3742     -580.5087        18.1825  2225199.254375 -5440058.161494 -2481571.803699
  17   DV15  A074      12.0 m   -067.45.12.1  -22.53.32.0         161.8159     -828.6196        18.7688  2225176.403514 -5439963.820451 -2481800.529842
  18   DV16  A069      12.0 m   -067.45.21.3  -22.53.30.2        -101.4797     -778.1047        23.2972  2224942.993176 -5440088.421459 -2481748.384855
```

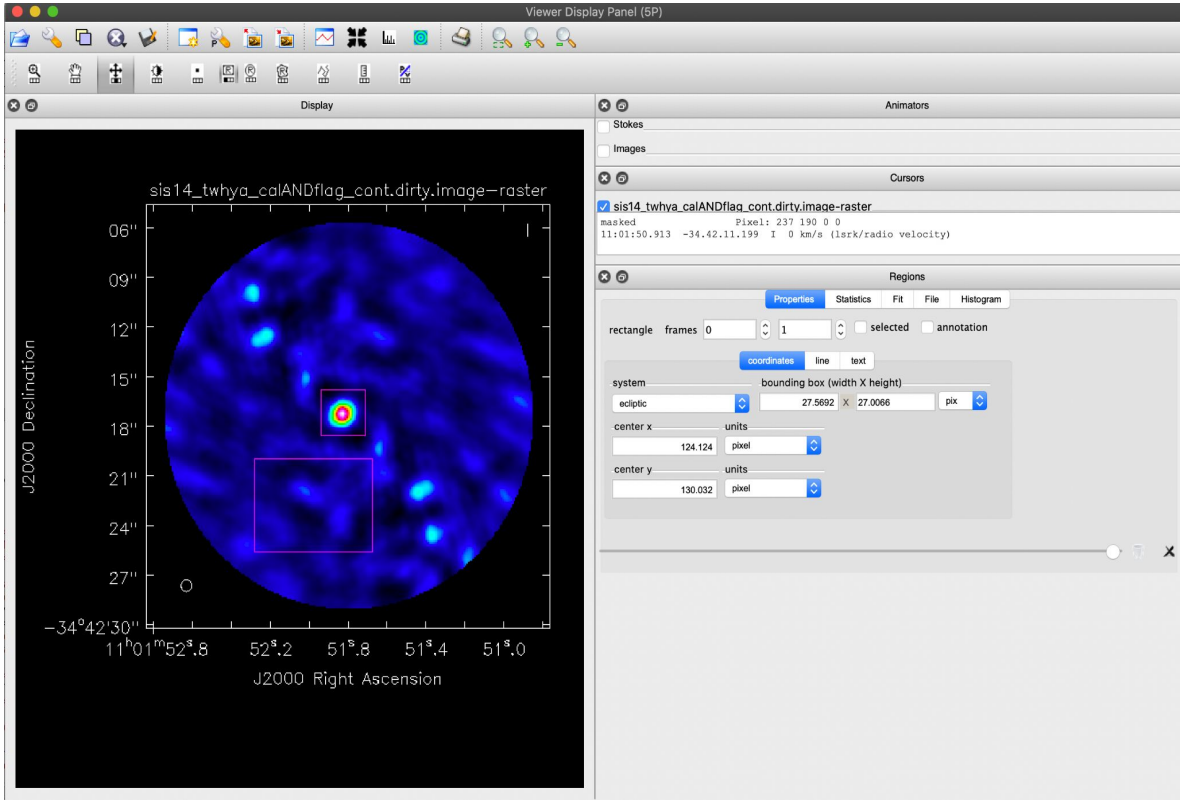




0: 'List the data set and plot antennas and visibility spectrum',

1: 'Make dirty image of continuum'.

```
#---------
mystep = 1
if(mystep in thesteps):
  casalog.post('Step '+str(mystep)+' '+step_title[mystep],'INFO')
  print('Step ', mystep, step_title[mystep])

  ## Make a first dirty imaging of the continuum to get a sense of the
structure of the object
  imagename = visname + '_cont.dirty'
  os.system('rm -rf '+imagename+'.*')
  tclean(vis = vis,
            imagename = imagename,
            field = field,
            spw='0',
            specmode='mfs',
            cell='0.1arcsec',
            imsize=256,
            deconvolver='hogbom',
            weighting='natural',
            niter=0,
            interactive=False)

  # view image
  imview(imagename+'.image')
```

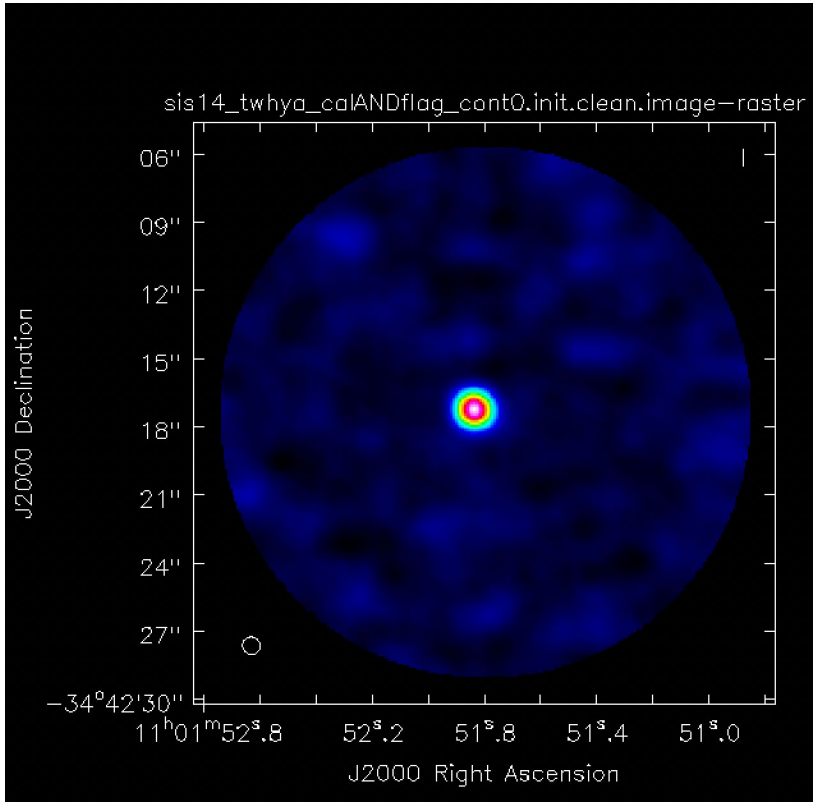


2: 'Make initial, conservative clean',
3: 'Check and save model'.

```
tclean(vis = vis,
        imagename = imagename,
        field = field,
        spw='0',
        specmode='mfs',
        cell='0.1arcsec',
        deconvolver='hogbom',
        weighting='natural',
        imsize=256,
        niter = 200,
        interactive=True)
```

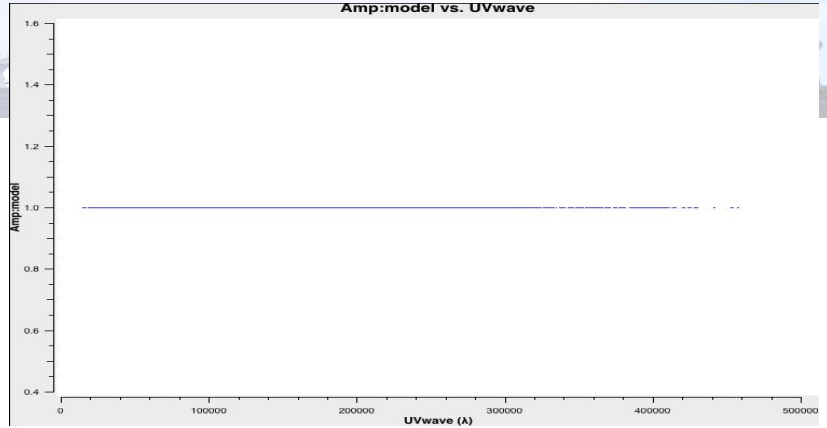
```
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
```

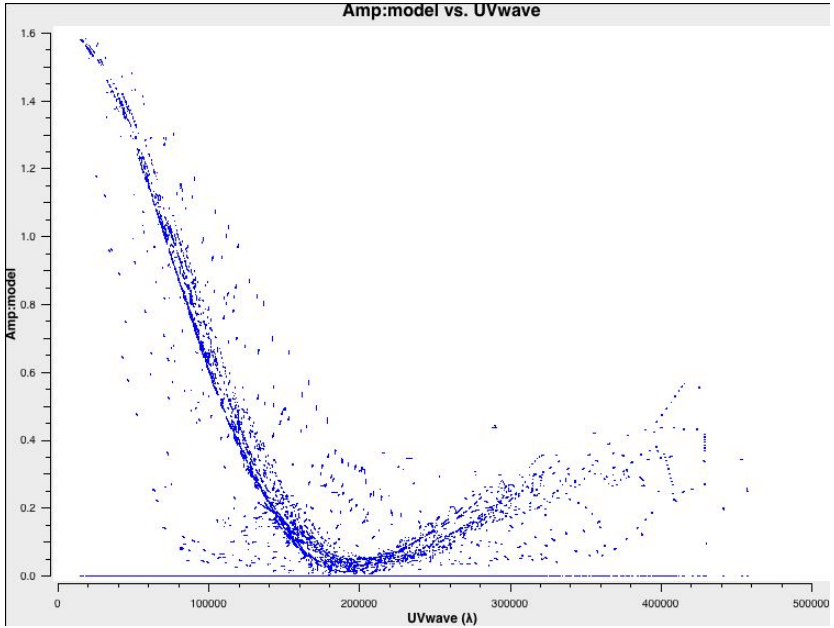
rms 0.015, peak 0.584, snr 40



2: 'Make initial, conservative clean',
3: 'Check and save model'.

```
# check that model has saved
 plotms(vis=vis,
        xaxis='UVwave',
        yaxis='amp',
        ydatacolumn='model',
        showgui=False,
        plotfile=modelname+'.png')

 # force model to save
 ft(vis=vis, model=modelname, usescratch=True)
```



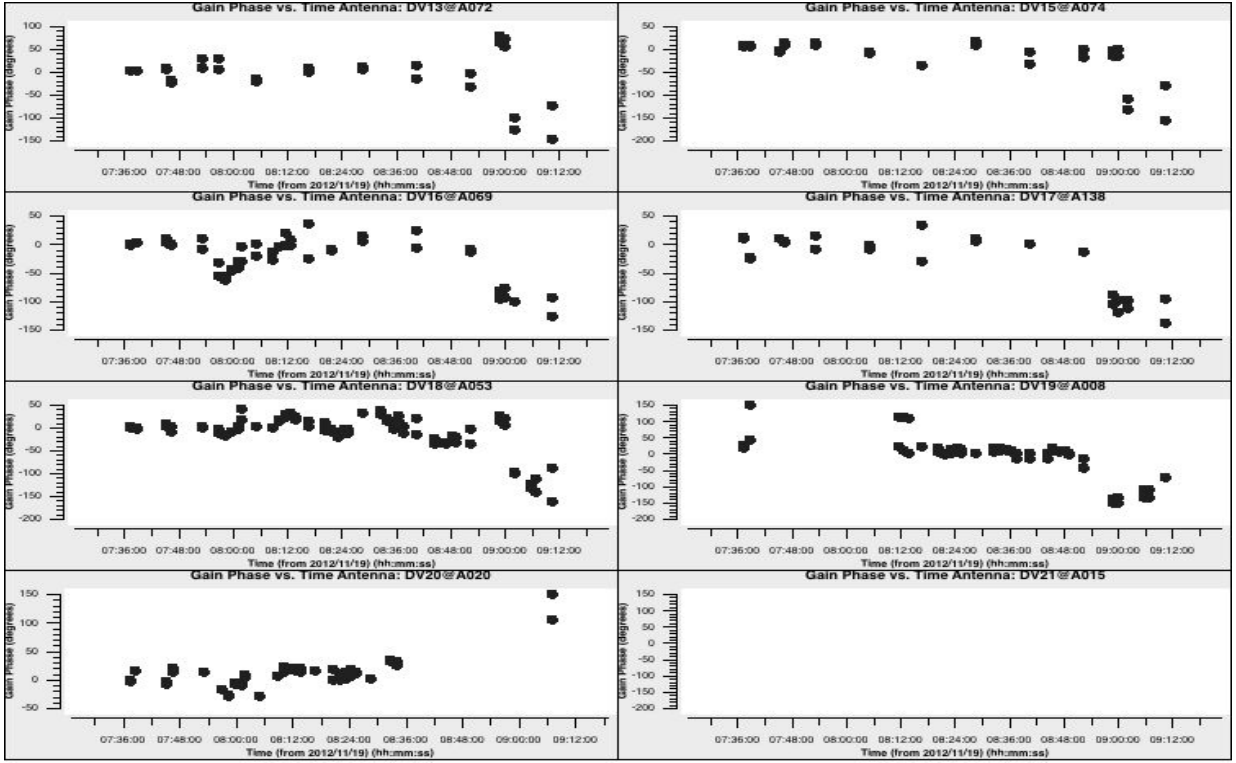


4: 'Calculate gain solution table - phase-only, solution interval = scan-length',

5: 'Explore different solution intervals'.

```
solint='inf'
caltable=visname+'_cont.ph1.solint_'+solint+'.tb'

gaincal(vis = vis,
        field= 'TW Hya',
        refant=refantenna,
        caltable=caltable,
        spw='0',
        calmode='p',
        solint=solint,
        gaintype='G',
        minsnr=3)

plotms(vis=caltable,xaxis='time',yaxis='phase',
        iteraxis='antenna',gridrows=3,
        gridcols=3,coloraxis='spw')
```

Tables saved in the ph1_check folder!

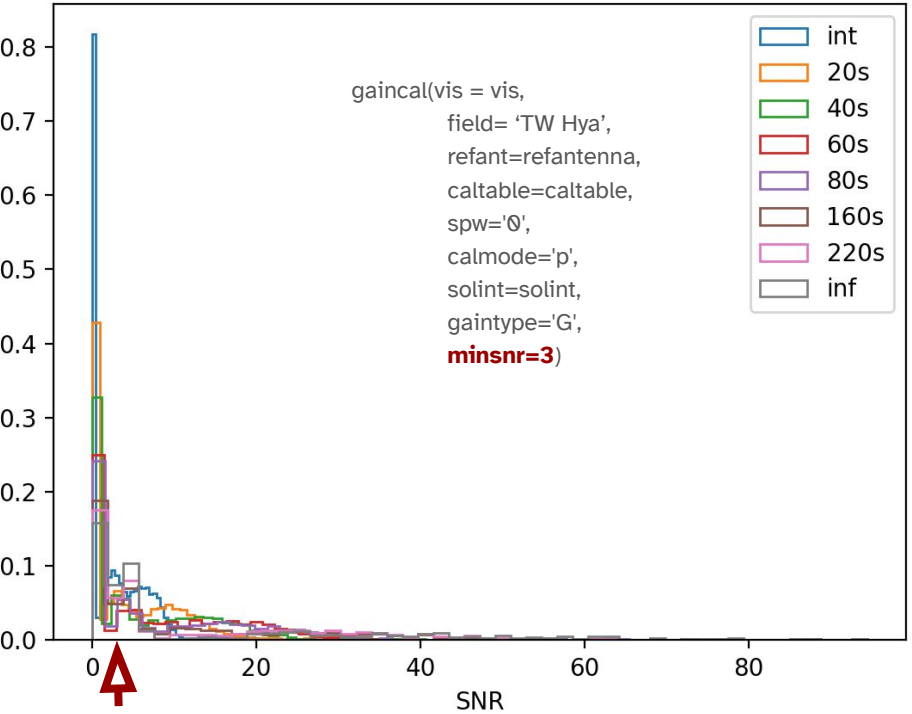


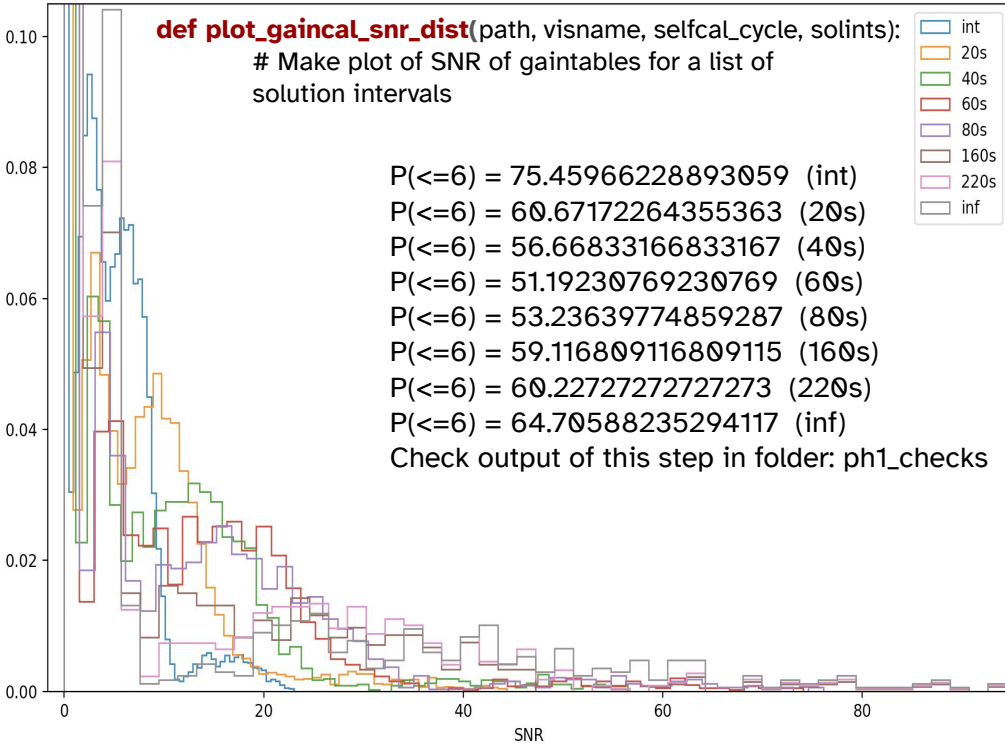
4: 'Calculate gain solution table - phase-only, solution interval = scan-length',

5: 'Explore different solution intervals'.

```
# The following loop calculates gaincal solutions for a list of intervals and makes corresponding plots
# The output is saved in a separate folder
selfcal_cycle = 'ph1_checks'
solint_all = ['int', '20s', '40s', '60s', '80s', '160s','220s', 'inf']
for solint in solint_all:
    print('Solint:', solint)
    caltable = visname+'.'+selfcal_cycle+'.solint_'+solint+'.tb'
     gaincal(vis=vis,
            caltable=caltable,
            solint=solint,
            refant=refantenna,
            spw='0',
            calmode='p',
            gaintype='G',
            minsnr=3)

# make plots for antenna triplets that will be saved in png files
plot_gaincal_table(caltable)
os.system('rm -r '+selfcal_cycle)
if not os.path.exists(selfcal_cycle):
    os.makedirs(selfcal_cycle)
    os.system('mv *.'+selfcal_cycle+'*tb* '+selfcal_cycle+'/')
    print("Check output of this step in folder: "+selfcal_cycle)
```

6.'[ADVANCED] Calculate SNR of the different solution intervals'.





7. Apply Calculate SNR of the different solution intervals'.

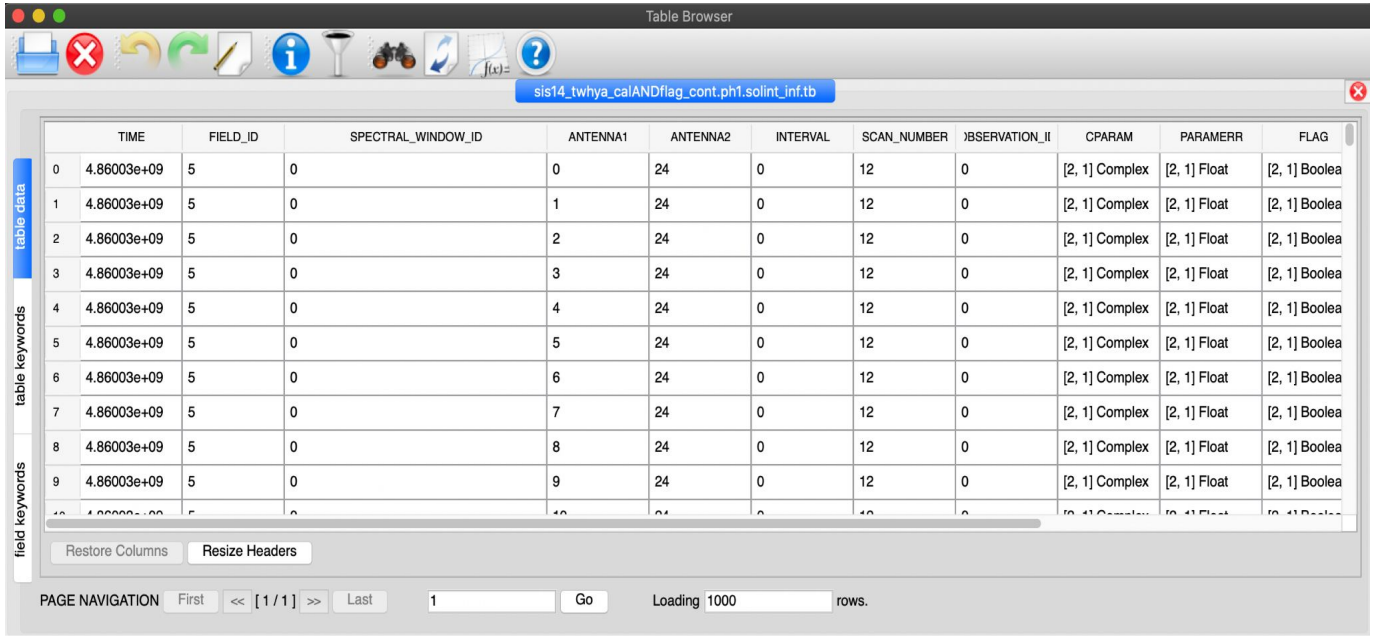
```
# apply the solutions to the MS
caltable=visname+'_cont.ph1.solint_inf.tb'
applycal(vis = vis,
         field= field,
         spw='0',
         spwmap=[0],
         gaintable=caltable,
         calwt = False,
         applymode='calonly',
         flagbackup = False)
```

browsetable(caltable):

SPECTRAL_WINDOW_ID column == [0,1]

If: **spw='0,1,2'**

spwmap = [[0,1],[0,1],[0,1]]



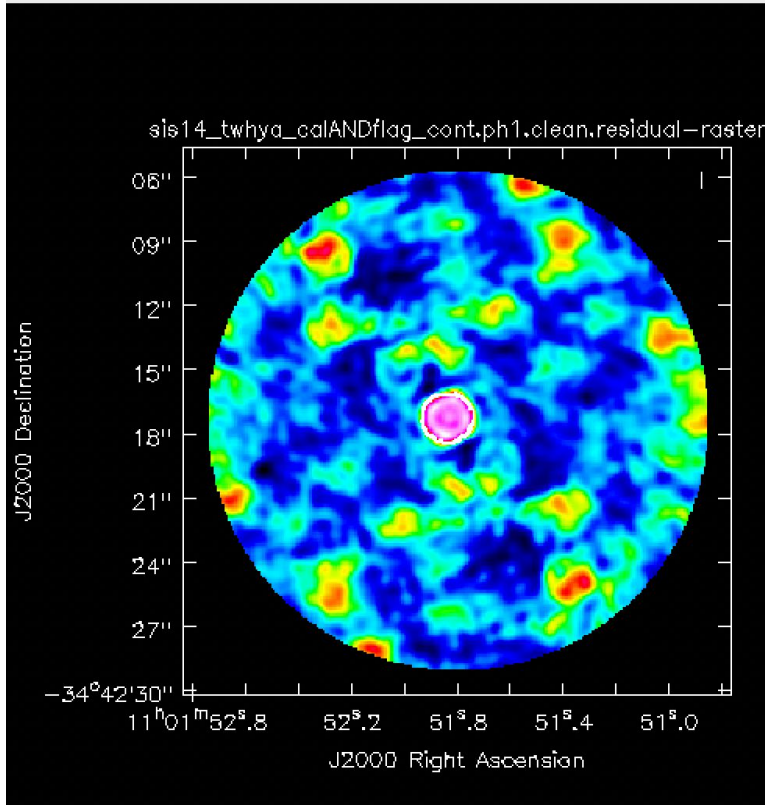
	TIME	FIELD_ID	SPECTRAL_WINDOW_ID	ANTENNA1	ANTENNA2	INTERVAL	SCAN_NUMBER	OBSERVATION_II	CPARAM	PARAMERR	FLAG
0	4.86003e+09	5	0	0	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
1	4.86003e+09	5	0	1	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
2	4.86003e+09	5	0	2	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
3	4.86003e+09	5	0	3	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
4	4.86003e+09	5	0	4	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
5	4.86003e+09	5	0	5	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
6	4.86003e+09	5	0	6	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
7	4.86003e+09	5	0	7	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
8	4.86003e+09	5	0	8	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea
9	4.86003e+09	5	0	9	24	0	12	0	[2, 1] Complex	[2, 1] Float	[2, 1] Boolea

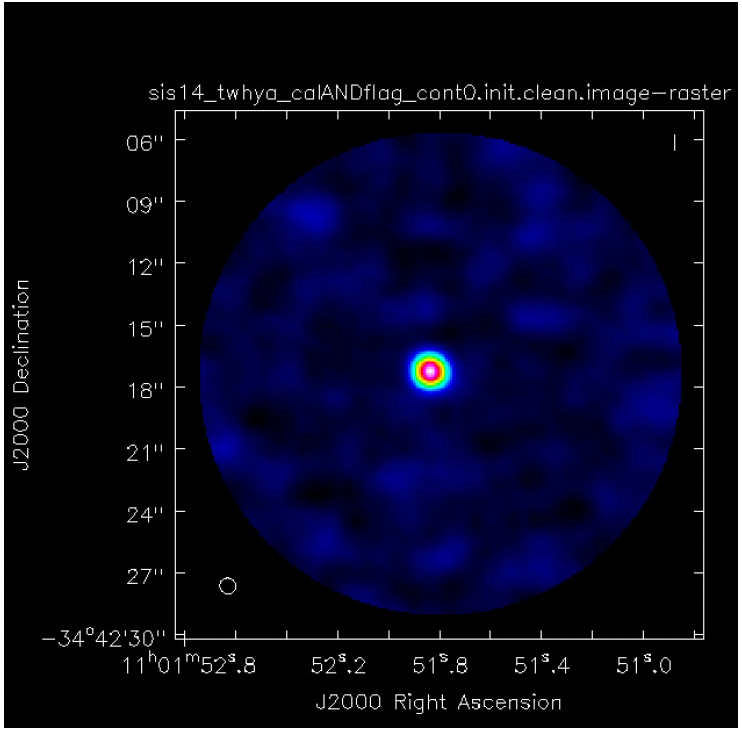
8: 'Make second, conservative cleaning and save model',

```
imagename = visname + '_cont.ph1.clean'
os.system('rm -rf '+imagename+'.*')
tclean(vis = vis,
        imagename = imagename,
        field = field,
        spw=contchans,
        specmode='mfs',
        cell='0.1arcsec',
        deconvolver='hogbom',
        weighting='natural',
        imsize=256,
        niter=200,
        interactive=True)

#Get image statistics for comparison
get_im_stats(imagename+'.image')

#force model to save
modelname=imagename+'.model'
ft(vis=vis,model=modelname,usescratch=True)
```

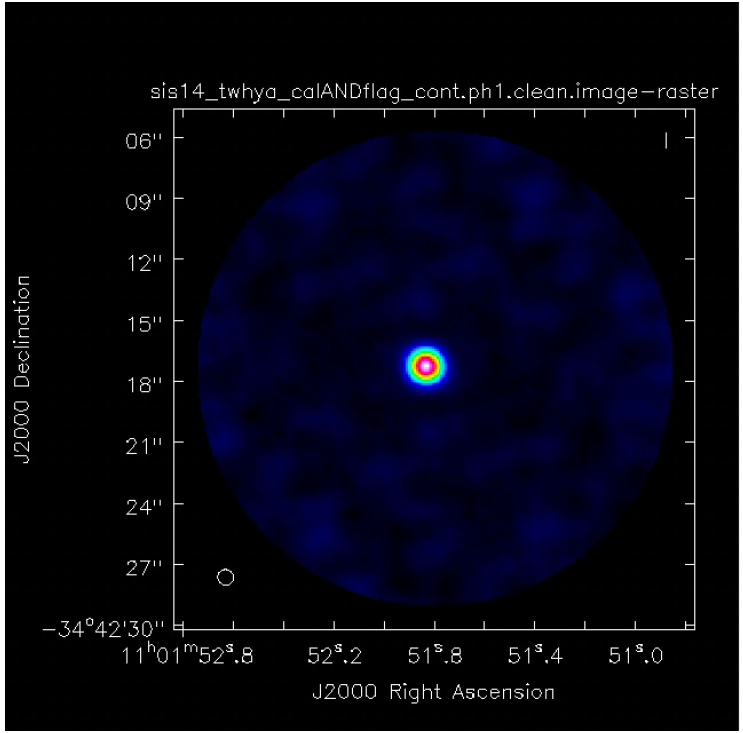
```
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
0%....10....20....30....40....50....60....70....80....90....100%
```

rms 0.008, peak 0.615, snr 81




sis14_twhya_calANDflag_cont0.init.clean.image−raster
06''
09''
12''
15''
18''
21''
24''
27''
−34°42'30''
J2000 Declination
11h01m52s.8
52s.2
51s.8
51s.4
51s.0
J2000 Right Ascension

snr 40


sis14_twhya_calANDflag_cont.ph1.clean.image−raster
06''
09''
12''
15''
18''
21''
24''
27''
−34°42'30''
J2000 Declination
11h01m52s.8
52s.2
51s.8
51s.4
51s.0
J2000 Right Ascension

snr 81

Set mysteps=[9,10,11,12,13]

```
### FIRST ROUND OF SELF-CALIBRATION - PHASE
4:  'Calculate gain solution table - phase-only, solution interval = scan-length',
5:  'Explore different solution intervals',
6:  '[ADVANCED] Calculate SNR of the different solution intervals',
7:  'Apply calibration table',
8:  'Make second, conservative cleaning and save model',
### SECOND ROUND OF SELF-CALIBRATION - PHASE
9:  'Explore different solution intervals',
10: '[ADVANCED] Calculate SNR of the different solution intervals',
11: 'Calculate gain solution table - phase-only, solution interval = 60s applying round 1 table on-the-fly',
12: 'Apply calibration tables',
13: 'Make image of continuum and save model',
### THIRD ROUND OF SELF-CALIBRATION - AMPLITUDE & PHASE
14: 'Calculate gain solution table - amplitude and phase, long solution interval',
15: 'Apply calibration tables',
16: 'Make image of continuum and save model',
### FOURTH ROUND OF SELF-CALIBRATION - AMPLITUDE & PHASE
17: 'Calculate gain solution table - amplitude and phase, short solution interval',
18: 'Apply calibration table',
### FINAL CONTINUUM IMAGE
19: 'Make image of continuum and save model',
}
```

11: 'Calculate gain solution table - phase-only, solution interval = 60s applying round 1 table on-the-fly',
12: 'Apply calibration tables',

```
solint_1='inf'
solint='60s'
caltable = visname + '_cont.ph2.solint_'+solint+'.tb'
os.system('rm -rf '+caltable)
gaincal(vis = vis,
        field= 'TW Hya',
        refant=refantenna,
        caltable=caltable,
        spw='0',
        gaintable = [visname + '_cont.ph1.solint_'+solint_1+'.tb'],
        spwmap=[0],
        calmode='p',
        solint=solint,
        gaintype='G',
        minsnr=3)
```

```
# apply the cumulative solutions to the MS
solint_1='inf'
solint_2='80s'
applycal(vis = vis,
        field= field,
        spw='0',
        gaintable=[visname+'_cont.ph1.solint_'+solint_1+'.tb',
        visname+'_cont.ph2.solint_'+solint_2+'.tb'],
        spwmap=[[0],[0]],
        calwt = False,
        applymode='calonly',
        flagbackup = False)
```

11: 'Calculate gain solution table - phase-only, solution interval = 60s applying round 1 table on-the-fly',
12: 'Apply calibration tables',

```
solint_1='inf'
solint='60s'
caltable = visname + '_cont.ph2.solint_'+solint+'.tb'
os.system('rm -rf '+caltable)
gaincal(vis = vis,
        field= 'TW Hya',
        refant=refantenna,
        caltable=caltable,
        spw='0',
        gaintable = [visname + '_cont.ph1.solint_'+solint_1+'.tb'],
        spwmap=[0],
        calmode='p',
        solint=solint,
        gaintype='G',
        minsnr=3)
```

```
# apply the cumulative solutions to the MS
solint_1='inf'
solint_2='80s'
applycal(vis = vis,
        field= 'TW Hya',
        spw='0',
        gaintable=[visname+'_cont.ph1.solint_'+solint_1+'.tb',
        visname+'_cont.ph2.solint_'+solint_2+'.tb'],
        spwmap=[[0],[0]],
        calwt = False,
        applymode='calonly',
        flagbackup = False)
```

After tclean()... rms 0.008, peak 0.620, snr 80

14: 'Calculate gain solution table - amplitude and phase, long solution interval',
15: 'Apply calibration tables',

```
# long solution interval, applying previous solutions on the fly
solint='inf'
caltable = visname + '_cont.ap1.solint_'+solint+'.tb'
# apply the cumulative solutions to the MS
solint_1='inf'
os.system('rm -rf '+caltable)
gaincal(vis = vis,
      field= field,
      refant=refantenna,
      caltable=caltable,
      gaintable = [visname + '_cont.ph1.solint_'+solint_1+'.tb'],
      spwmap=[[0],[0]],
      spw=contchans,
      calmode='ap',
      solint=solint,
      gaintype='G',
      minsnr=3)
```

14: 'Calculate gain solution table - amplitude and phase, long solution interval',

15: 'Apply calibration tables',

```
solint='inf'
solint_1='inf'
solint_2='80s'
applycal(vis = vis,
      field= 'TW Hya',
      spw='0',
      spwmap=[[0],[0],[0]],
      gaintable=[visname+'_cont.ph1.solint_'+solint_1+'.tb',
                 visname+'_cont.ph2.solint_'+solint_2+'.tb',
                 visname+'_cont.ap1.solint_'+solint+'.tb'],
      calwt = False,
      applymode='calonly',
      flagbackup = False)
```

After final tclean() run

Initial map:

rms 0.015, peak 0.584, **snr 40**

After applying **.ph1** table for solint= ‘inf’:

rms 0.008, peak 0.615, **snr 81** **(+)**

~~After applying **.ph2** table for solint= ‘60s’:~~

rms 0.008, peak 0.620, **snr 80**

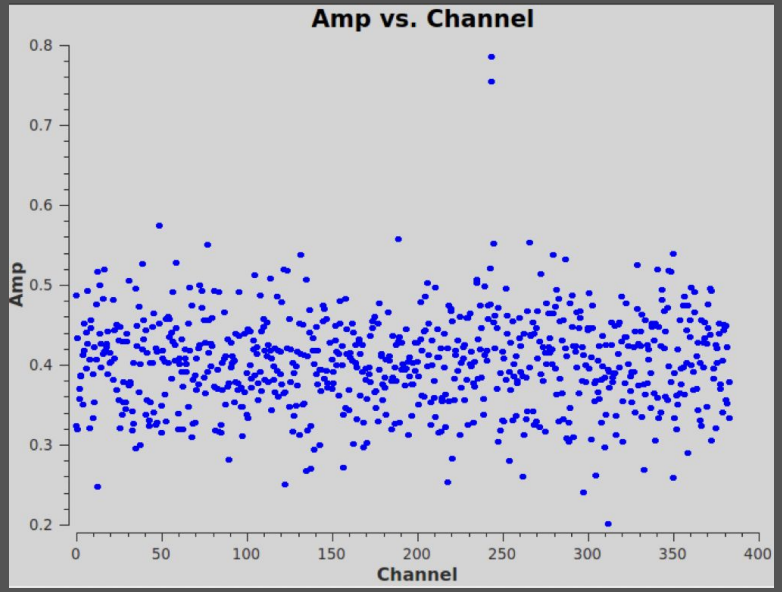
After applying **.ap1** table for solint= ‘inf’:

rms 0.006, peak 0.607, **snr 101**

4. Line imaging

Plotms

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

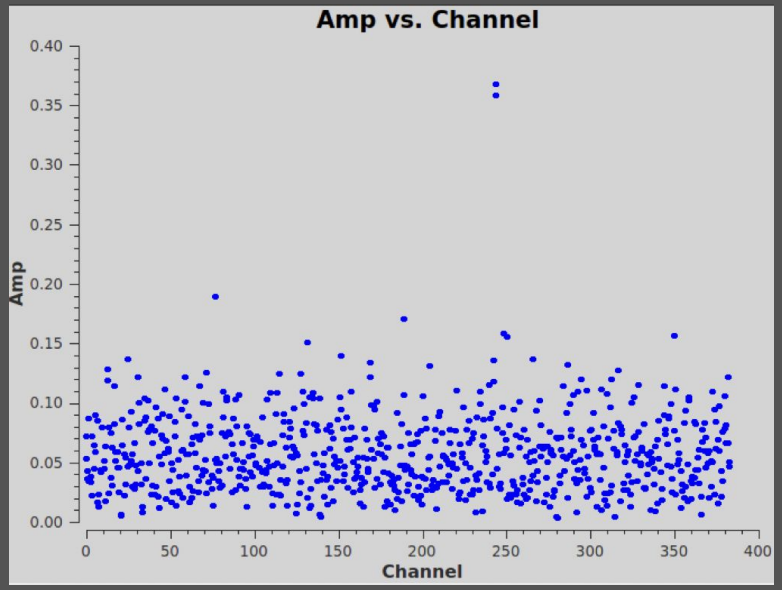


UVcontsub

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

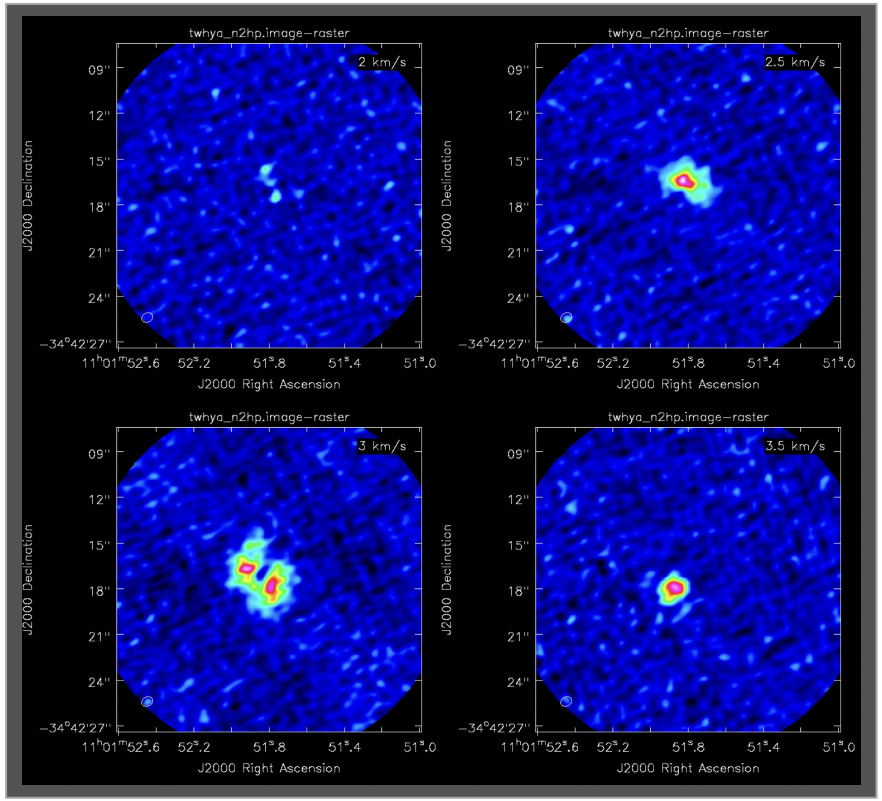
Plotms

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



Tclean - N2H+ line

```
tclean(vis = 'sis14_twhya_selfcal.ms.contsub',
       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,
       niter=5000)
```



5. Image analysis

Imhead

imhead("sis14_twhya_cont.image")

```
##########################################
##### Begin Task: imhead                 #####
imhead(imagename="sis14_twhya_cont.image",mode="summary",hdkey="",hdvalue="",verbose=False)

Image name        : sis14_twhya_cont.image
Object name       : TW Hya
Image type        : PagedImage
Image quantity    : Intensity
Pixel mask(s)     : mask0
Region(s)         : None
Image units       : Jy/beam
Restoring Beam    : 0.830341 arcsec, 0.683704 arcsec, -66.1199 deg

Direction reference : J2000
Spectral  reference : LSRK
Velocity  type      : RADIO
Rest frequency      : 3.72637e+11 Hz
Pointing center     :  11:01:51.796000  -34.42.17.366000
Telescope           : ALMA
Observer            : cqi
Date observation    : 2012/11/19/07:56:27
Telescope position: [2.22514e+06m, -5.44031e+06m, -2.48103e+06m] (ITRF)

Axis Coord Type      Name              Proj Shape Tile   Coord value at pixel        Coord incr Units
-----------------------------------------------------------------------------------------------------
0    0     Direction Right Ascension   SIN   250  250  11:01:51.796   125.00     -1.000000e-01 arcsec
1    0     Direction Declination       SIN   250  250 -34.42.17.366   125.00      1.000000e-01 arcsec
2    1     Stokes    Stokes                    1    1             I
3    2     Spectral  Frequency                 1    1   3.72637e+11     0.00 2.34445114878e+08 Hz
                     Velocity                                      0     0.00     -1.886149e+02 km/s
##### End Task: imhead                 #####
##########################################
```

Imhead

imhead("twhya_n2hp.image")

```
##########################################
##### Begin Task: imhead              #####
imhead(imagename="twhya_n2hp.image",mode="summary",hdkey="",hdvalue="",verbose=False)

Image name        : twhya_n2hp.image
Object name       : TW Hya
Image type        : PagedImage
Image quantity    : Intensity
Pixel mask(s)     : mask0
Region(s)         : None
Image units       : Jy/beam
Restoring Beam    : 0.750766 arcsec, 0.598023 arcsec, -59.397 deg

Direction reference : J2000
Spectral  reference : LSRK
Velocity  type      : RADIO
Rest frequency      : 3.72672e+11 Hz
Pointing center     :  11:01:51.796000  -34.42.17.366000
Telescope           : ALMA
Observer            : cqi
Date observation    : 2012/11/19/07:56:27
Telescope position: [2.22514e+06m, -5.44031e+06m, -2.48103e+06m] (ITRF)

Axis Coord Type      Name              Proj Shape Tile   Coord value at pixel      Coord incr Units
-----------------------------------------------------------------------------------------------------
0    0     Direction Right Ascension   SIN   250  125  11:01:51.796   125.00   -8.000000e-02 arcsec
1    0     Direction Declination       SIN   250   50 -34.42.17.366   125.00    8.000000e-02 arcsec
2    1     Stokes    Stokes                    1    1                I
3    2     Spectral  Frequency                15    5  3.726725e+11     0.00 -6.21550810e+05 Hz
                     Velocity                                      0     0.00    5.000000e-01 km/s
##### End Task: imhead               #####
##########################################
```

Imstat

```
imstat("sis14_twhya_cont.image",
        box="100,100,150,150")
```

```
##########################################
##### Begin Task: imstat              #####
imstat(imagename="twhya_n2hp.image",axes=-1,region="",box="",chans="0~4",
        stokes="",listit=True,verbose=True,mask="",stretch=False,
        logfile="",append=True,algorithm="classic",fence=-1,center="mean",
        lside=True,zscore=-1,maxiter=-1,clmethod="auto",niter=3)
No directional region specified. Using full positional plane.
Using channel range(s)
Using polarizations ALL
Determining stats for image twhya_n2hp.image
Selected bounding box :
    [0, 0, 0, 0] to [249, 249, 0, 4]  (11:01:52.607, -34.42.27.366, I, 3.726725e+11Hz to 11:01:50.992, -34.42.07.446, I, 3.7267e+11Hz)
Statistics calculated using Classic algorithm
Regions ---
         -- bottom-left corner (pixel) [blc]:  [0, 0, 0, 0]
         -- top-right corner (pixel) [trc]:    [249, 249, 0, 4]
         -- bottom-left corner (world) [blcf]: 11:01:52.607, -34.42.27.366, I, 3.726725e+11Hz
         -- top-right corner (world) [trcf]:   11:01:50.992, -34.42.07.446, I, 3.7267e+11Hz
Values ---
         -- flux [flux]:                          -0.168573 Jy.km/s
         -- number of points [npts]:               292095
         -- maximum value [max]:                   0.129122 Jy/beam
         -- minimum value [min]:                   -0.106066 Jy/beam
         -- position of max value (pixel) [maxpos]: [73, 11, 0, 2]
         -- position of min value (pixel) [minpos]: [43, 158, 0, 1]
         -- position of max value (world) [maxposf]: 11:01:52.133, -34.42.26.486, I, 3.726712e+11Hz
         -- position of min value (world) [minposf]: 11:01:52.328, -34.42.14.726, I, 3.726719e+11Hz
         -- Sum of pixel values [sum]:              -26.7995 Jy/beam
         -- Sum of squared pixel values [sumsq]:     205.058 Jy/beam.Jy/beam
Statistics ---
        -- Mean of the pixel values [mean]:         -9.17492e-05 Jy/beam
        -- Variance of the pixel values :           0.000702021 Jy/beam
        -- Standard deviation of the Mean [sigma]:  0.0264957 Jy/beam
        -- Root mean square [rms]:                  0.0264958 Jy/beam
        -- Median of the pixel values [median]:     -0.000341541 Jy/beam
        -- Median of the deviations [medabsdevmed]: 0.0177556 Jy/beam
        -- IQR [quartile]:                          0.035516 Jy/beam
        -- First quartile [q1]:                     -0.0179168 Jy/beam
        -- Third quartile [q3]:                     0.0175991 Jy/beam
Sum column unit = Jy/beam
Mean column unit = Jy/beam
Std_dev column unit = Jy/beam
Minimum column unit = Jy/beam
Maximum column unit = Jy/beam
Npts          Sum           Mean          Rms           Std_dev       Minimum       Maximum
 2.920950e+05 -2.679948e+01 -9.174920e-05  2.649578e-02  2.649567e-02 -1.060663e-01  1.291219e-01
##### End Task: imstat                #####
##########################################
```

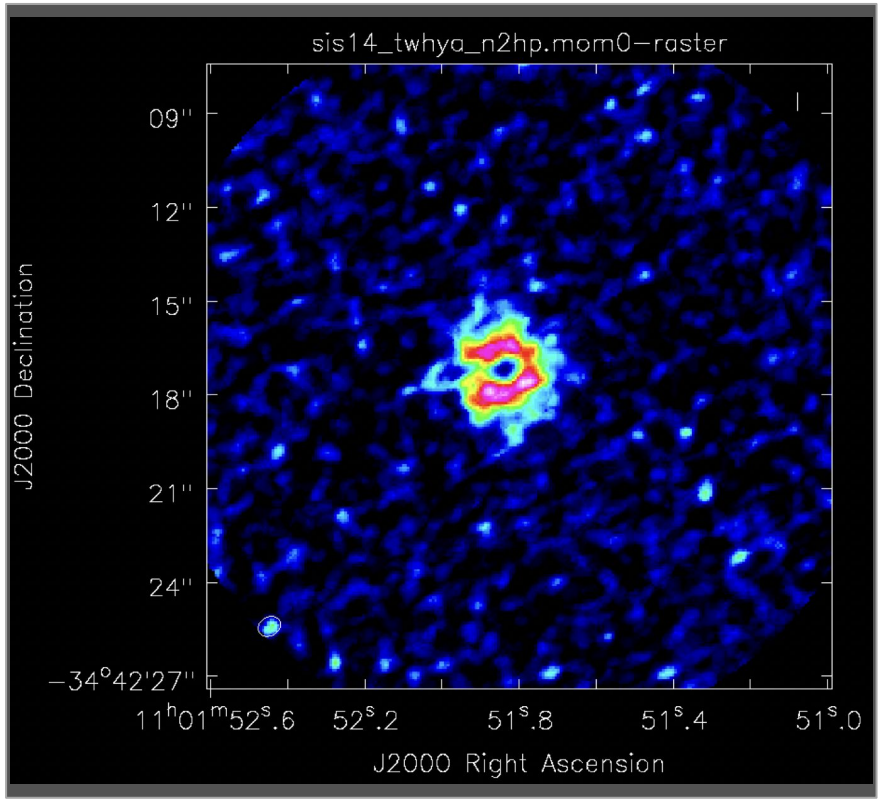
Imstat

```
imstat("sis14_twhya_cont.image",
        box="25,150,225,200")
```

```
##########################################
##### Begin Task: imstat              #####
imstat(imagename="sis14_twhya_cont.image",axes=-1,region="",box="100,100,150,150",chans="",
        stokes="",listit=True,verbose=True,mask="",stretch=False,
        logfile="",append=True,algorithm="classic",fence=-1,center="mean",
        lside=True,zscore=-1,maxiter=-1,clmethod="auto",niter=3)
Using specified box(es) 100,100,150,150
Determining stats for image sis14_twhya_cont.image
Selected bounding box :
    [100, 100, 0, 0] to [150, 150, 0, 0]  (11:01:51.999, -34.42.19.866, I, 3.72637e+11Hz to 11:01:51.593, -34.42.14.866, I, 3.72637e+11Hz)
Statistics calculated using Classic algorithm
Regions ---
         -- bottom-left corner (pixel) [blc]:  [100, 100, 0, 0]
         -- top-right corner (pixel) [trc]:    [150, 150, 0, 0]
         -- bottom-left corner (world) [blcf]: 11:01:51.999, -34.42.19.866, I, 3.72637e+11Hz
         -- top-right corner (world) [trcf]:   11:01:51.593, -34.42.14.866, I, 3.72637e+11Hz
Values ---
         -- flux density [flux]:                        1.86016 Jy
         -- number of points [npts]:                    2601
         -- maximum value [max]:                        0.622676 Jy/beam
         -- minimum value [min]:                        -0.0101302 Jy/beam
         -- position of max value (pixel) [maxpos]: [120, 127, 0, 0]
         -- position of min value (pixel) [minpos]: [136, 135, 0, 0]
         -- position of max value (world) [maxposf]: 11:01:51.837, -34.42.17.166, I, 3.72637e+11Hz
         -- position of min value (world) [minposf]: 11:01:51.707, -34.42.16.366, I, 3.72637e+11Hz
         -- Sum of pixel values [sum]:                 119.658 Jy/beam
         -- Sum of squared pixel values [sumsq]:       37.9836 Jy/beam.Jy/beam
Statistics ---
        -- Mean of the pixel values [mean]:          0.0460044 Jy/beam
        -- Variance of the pixel values :            0.0124919 Jy/beam
        -- Standard deviation of the Mean [sigma]:   0.111767 Jy/beam
        -- Root mean square [rms]:                   0.120845 Jy/beam
        -- Median of the pixel values [median]:      0.00125647 Jy/beam
        -- Median of the deviations [medabsdevmed]:  0.00456389 Jy/beam
        -- IQR [quartile]:                           0.0197377 Jy/beam
        -- First quartile [q1]:                      -0.00179461 Jy/beam
        -- Third quartile [q3]:                      0.0179431 Jy/beam
Sum column unit = Jy/beam
Mean column unit = Jy/beam
Std_dev column unit = Jy/beam
Minimum column unit = Jy/beam
Maximum column unit = Jy/beam
Npts          Sum           Mean          Rms           Std_dev       Minimum       Maximum
 2.601000e+03  1.196576e+02  4.600444e-02  1.208448e-01  1.117670e-01 -1.013024e-02  6.226758e-01
##### End Task: imstat                #####
##########################################
```

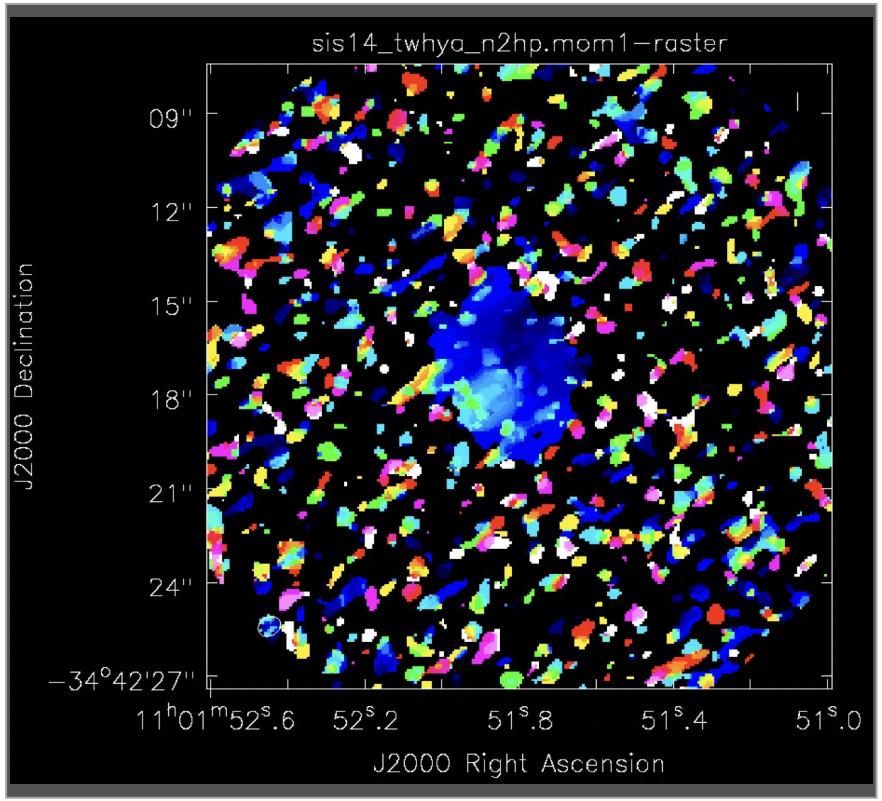
Immoments - Mom0

```
immoments("twhya_n2hp.image",
        outfile="sis14_twhya_n2hp.mom0",
        includepix=[20e-3,100],
        chans="4~12",
        moments=0)
```



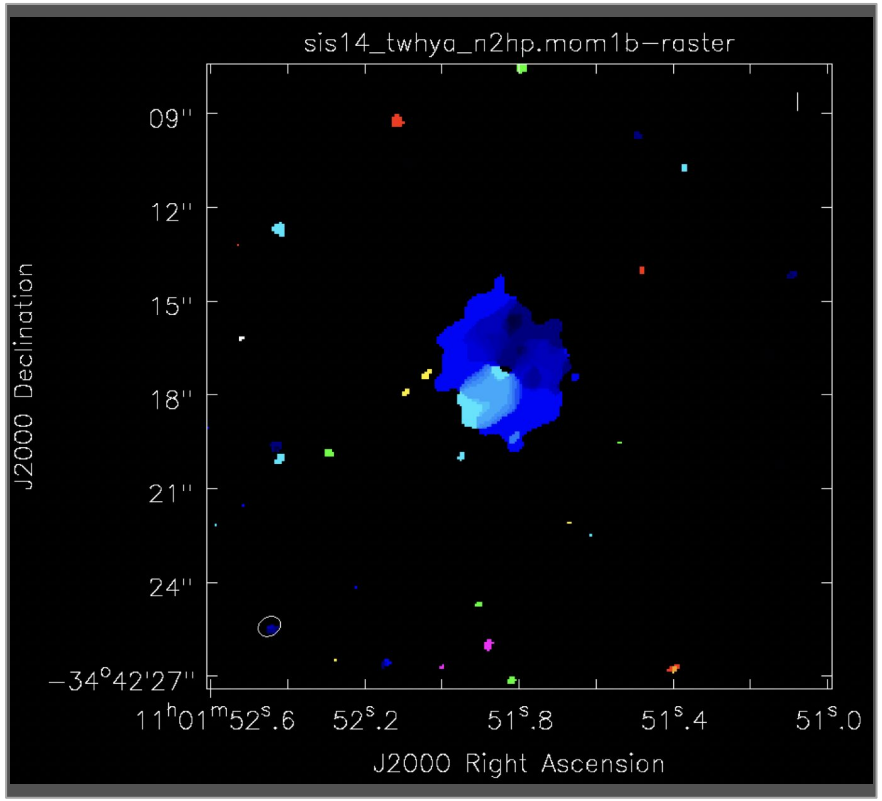
Immoments - Mom1

```
immoments("twhya_n2hp.image",
        outfile="sis14_twhya_n2hp.mom1",
        includepix=[40e-3,100],
        chans="4~12",
        moments=1)
```



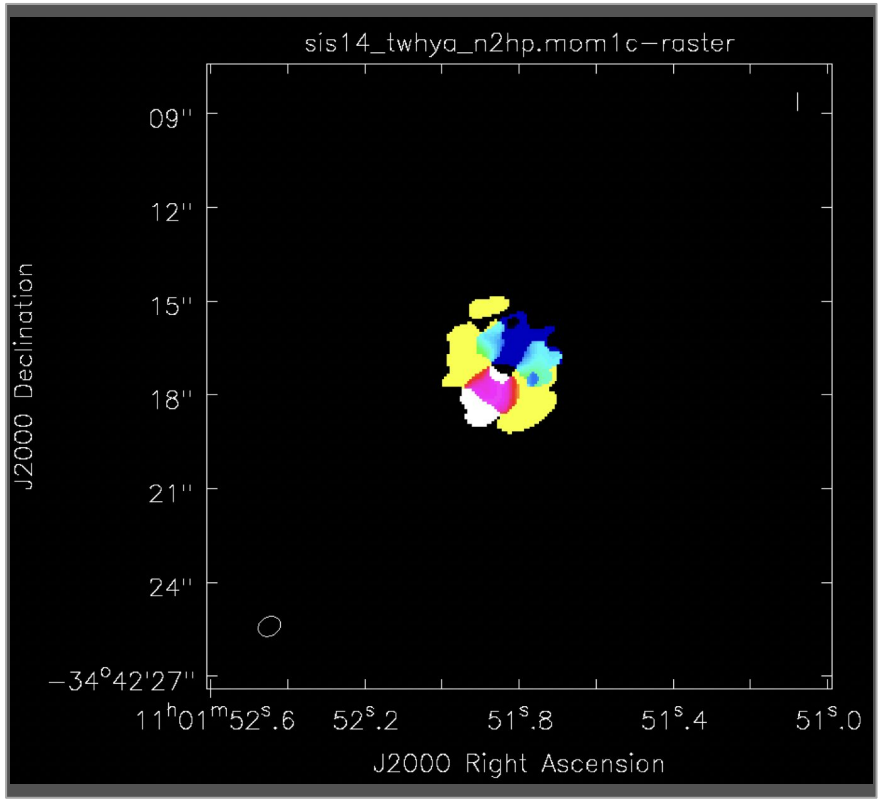
Immoments - Mom1

```
immoments("twhya_n2hp.image",
        outfile="sis14_twhya_n2hp.mom1",
        includepix=[80e-3,100],
        chans="4~12",
        moments=1)
```



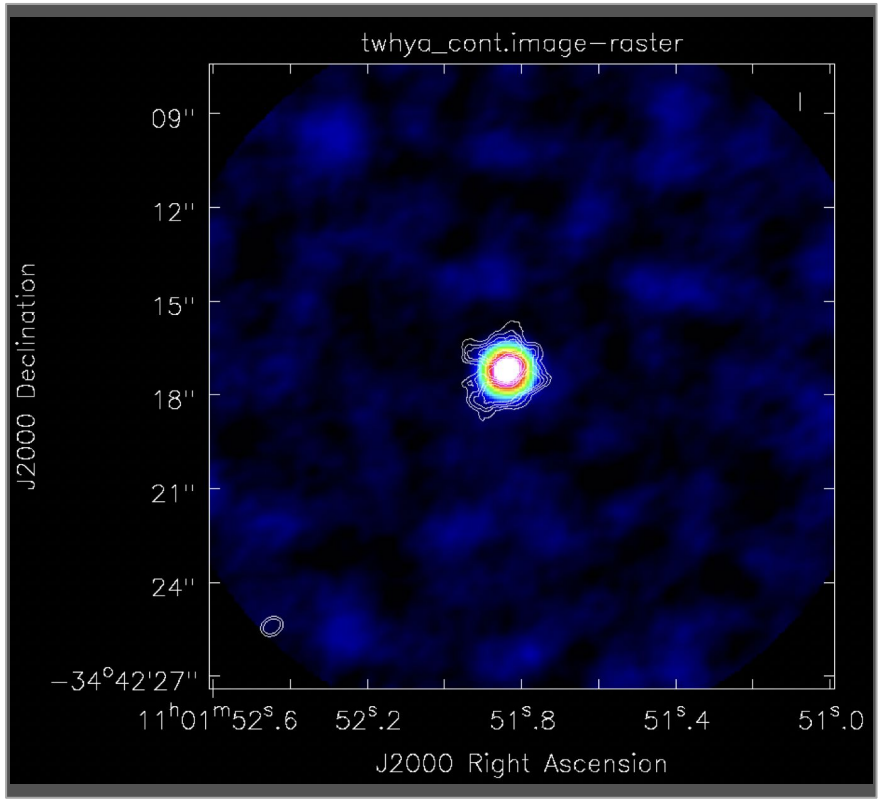
Immoments - Mom1

```
immoments("twhya_n2hp.image",
        outfile="sis14_twhya_n2hp.mom1",
        includepix=[120e-3,100],
        chans="4~12",
        moments=1)
```



imview

```
imview(raster={'file': 'sis14_twhya_cont.image',
'range': [-0.01,0.2]},
contour={'file': 'sis14_twhya_n2hp.mom0',
'levels': [0.5,0.6,0.7,0.8] })
```



Still unsure about something?

Contact us if you have any questions or need help with your data!

Our services include (but are not limited to):

- Reproducing calibrated measurement sets or obtaining calibrated measurement sets from the ARI-L group
- Inspection of data quality
- Guidance with imaging techniques
- Computing resources & access to useful software
- Archive mining
- Proposal preparation

Email us: alma@strw.leidenuniv.nl

Thank you!