# BIGCAT data reduction using CASA

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The BIGCAT upgrade on the ATCA will allow users to observe with a total of ~8 GHz simultaneous bandwidth. This is achieved using four 2 GHz-wide basebands (IFs). In the first phase of the upgrade, users have access to 4 GHz total bandwidth. Each IF band is composed of 15 128 MHz oversampled sub-bands that are stitched together to form the ~2 GHz IF bandwidth. In this guide we will give users a very basic workflow to reduce BIGCAT observations using the Common Astronomy Software Application (CASA). Note that this guide is based on the tutorial "Basic CABB continuum data reduction with CASA", which you can access via this link: https://www.atnf.csiro.au/research/radio-school/2023/casa_basic_continuum_tutorial.pdf.

## Data format and structure

The BIGCAT correlator output is written as ASDM files. These are then converted to CASA Measurement Sets (MS) using a bespoke CASA install (this is likely to change in the near future when appropriate updates will be released for the standard CASA installs). For more details on how to convert ASDM files into MS data sets please refer to the following document on observing and accessing BIGCAT observations: https://confluence.csiro.au/x/q5-leQ

As mentioned above, each IF consists of 15 128 MHz wide sub-bands. These will be written out as separate spectral windows in the output ASDM/MS files. This document gives a brief run-down of processing BIGCAT observations in CASA using standard CASA tasks.

## Software requirements

If working on personal machines, users will need to install CASA. Please refer to the following link for more information on how to install and run CASA on your machine:
https://casa.nrao.edu/casa_obtaining.shtml

Once properly installed, you can simply run CASA by typing (assuming you have made CASA available in your path) in the terminal:

```
> casa
```

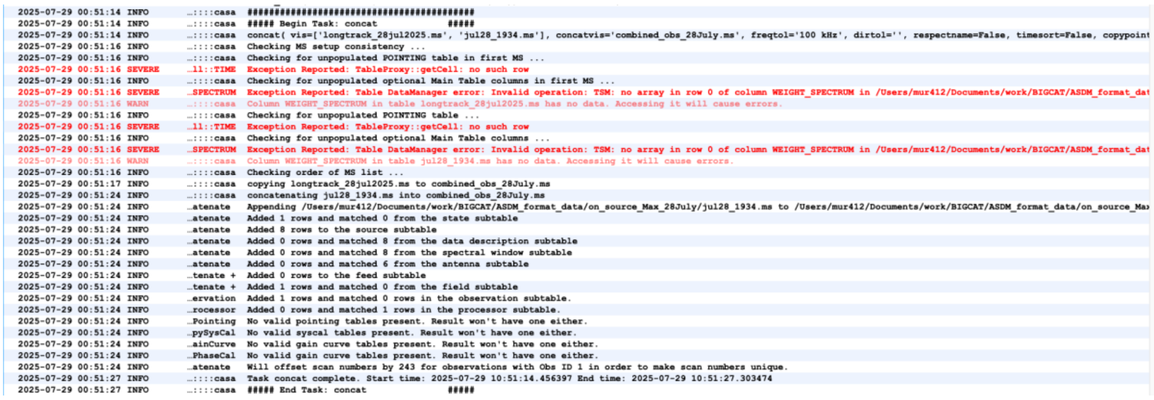
This should load-up the CASA shell/environment and open a logger window. All the following commands in this guide are run within the CASA environment.

## Loading and examining the data

Typically, observations are made in such a way that observations on the primary calibrator are stored as a separate MS data set and one (or more) file(s) containing the target and secondary calibrator observations. While not a necessity, it is easier to process data in CASA if all observations are concatenated into a single file. In the first step we will concatenate the data sets containing observations of the primary calibrator and the target + secondary. One can concatenate multiple datasets if there are many datasets. This can be done using the '***concat***' task in CASA. Here is an example where we concatenate two datasets, one with the target and the phase calibrator and another containing observation of the primary (flux) calibrator. Run this within the active CASA environment.

```
> concat(vis = ['1934-638.ms', 'target.ms'], concatvis = 'combined.ms', freqtol = '100kHz', respectname = False)
```

In the current standard version (6.6) of CASA, you might see an error reported in the logger similar to the one shown in Fig.1. At this stage this is probably OK to be ignored.



```
2025-07-29 00:51:14 INFO    …::::casa   ############################################
2025-07-29 00:51:14 INFO    …::::casa   ##### Begin Task: concat           #####
2025-07-29 00:51:14 INFO    …::::casa   concat( vis=['longtrack_28jul2025.ms', 'jul28_1934.ms'], concatvis='combined_obs_28July.ms', freqtol='100 kHz', dirtol='', respectname=False, timesort=False, copypoint
2025-07-29 00:51:16 INFO    …::::casa   Checking MS setup consistency ...
2025-07-29 00:51:16 INFO    …::::casa   Checking for unpopulated POINTING table in first MS ...
2025-07-29 00:51:16 SEVERE  …ll::TIME   Exception Reported: TableProxy::getCell: no such row
2025-07-29 00:51:16 INFO    …::::casa   Checking for unpopulated optional Main Table columns in first MS ...
2025-07-29 00:51:16 SEVERE  …SPECTRUM   Exception Reported: Table DataManager error: Invalid operation: TSM: no array in row 0 of column WEIGHT_SPECTRUM in /Users/mur412/Documents/work/BIGCAT/ASDM_format_dat
2025-07-29 00:51:16 WARN    …::::casa   Column WEIGHT_SPECTRUM in table longtrack_28jul2025.ms has no data. Accessing it will cause errors.
2025-07-29 00:51:16 INFO    …::::casa   Checking for unpopulated POINTING table ...
2025-07-29 00:51:16 SEVERE  …ll::TIME   Exception Reported: TableProxy::getCell: no such row
2025-07-29 00:51:16 INFO    …::::casa   Checking for unpopulated optional Main Table columns ...
2025-07-29 00:51:16 SEVERE  …SPECTRUM   Exception Reported: Table DataManager error: Invalid operation: TSM: no array in row 0 of column WEIGHT_SPECTRUM in /Users/mur412/Documents/work/BIGCAT/ASDM_format_dat
2025-07-29 00:51:16 WARN    …::::casa   Column WEIGHT_SPECTRUM in table jul28_1934.ms has no data. Accessing it will cause errors.
2025-07-29 00:51:16 INFO    …::::casa   Checking order of MS list ...
2025-07-29 00:51:17 INFO    …::::casa   copying longtrack_28jul2025.ms to combined_obs_28July.ms
2025-07-29 00:51:24 INFO    …::::casa   concatenating jul28_1934.ms into combined_obs_28July.ms
2025-07-29 00:51:24 INFO    …atenate    Appending /Users/mur412/Documents/work/BIGCAT/ASDM_format_data/on_source_Max_28July/jul28_1934.ms to /Users/mur412/Documents/work/BIGCAT/ASDM_format_data/on_source_Max
2025-07-29 00:51:24 INFO    …atenate    Added 1 rows and matched 0 from the state subtable
2025-07-29 00:51:24 INFO    …atenate    Added 8 rows to the source subtable
2025-07-29 00:51:24 INFO    …atenate    Added 0 rows and matched 8 from the data description subtable
2025-07-29 00:51:24 INFO    …atenate    Added 0 rows and matched 8 from the spectral window subtable
2025-07-29 00:51:24 INFO    …atenate    Added 0 rows and matched 6 from the antenna subtable
2025-07-29 00:51:24 INFO    …tenate +   Added 0 rows to the feed subtable
2025-07-29 00:51:24 INFO    …tenate +   Added 1 rows and matched 0 from the field subtable
2025-07-29 00:51:24 INFO    …ervation   Added 1 rows and matched 0 rows in the observation subtable.
2025-07-29 00:51:24 INFO    …rocessor   Added 0 rows and matched 1 rows in the processor subtable.
2025-07-29 00:51:24 INFO    …Pointing   No valid pointing tables present. Result won't have one either.
2025-07-29 00:51:24 INFO    …pySysCal   No valid syscal tables present. Result won't have one either.
2025-07-29 00:51:24 INFO    …ainCurve   No valid gain curve tables present. Result won't have one either.
2025-07-29 00:51:24 INFO    …PhaseCal   No valid gain curve tables present. Result won't have one either.
2025-07-29 00:51:24 INFO    …atenate    Will offset scan numbers by 243 for observations with Obs ID 1 in order to make scan numbers unique.
2025-07-29 00:51:27 INFO    …::::casa   Task concat complete. Start time: 2025-07-29 10:51:14.456397 End time: 2025-07-29 10:51:27.303474
2025-07-29 00:51:27 INFO    …::::casa   ##### End Task: concat             #####
```

*Figure 1Current error in CASA when concatenating datasets (not sure if this is BIGCAT-specific)*

Next, we can examine the content of the combined dataset using the '***listobs***' task. Note the output will be written in the logger window.

```
> listobs(vis = 'combined.ms', verbose = True)
```

You should see an output similar to the one shown below in Fig. 2. The output will list all the fields, scans, spectral windows (sub-bands), sources and details of all the antennas.

## Examining the data

It's a good idea to look at the UV coverage as well as the amplitude/phase Vs time, and amp/phase Vs frequency etc. to get an idea about the RFI and other issues in the observations. These can then be flagged accordingly.

Examine the visibilities using '***plotms***'. Once the *plotms* GUI opens, one can select data for visualisation as per one's convenience.

`> plotms(vis = 'combined.ms', xaxis = 'U', yaxis = 'V')` # to plot the UV coverage

`> plotms(vis = 'combined.ms', xaxis = 'time', yaxis = 'amp')` # to plot the amplitude Vs Time for all baselines, all SPWs

`> plotms(vis = 'combined.ms', xaxis = 'time', yaxis = 'phase')` # to plot the phase Vs Time for all baselines, all SPWs

`> plotms(vis = 'combined.ms', xaxis = 'freq', yaxis = 'amp')` # to plot the amplitude Vs freq. for all baselines, all scans.

`> plotms(vis = 'combined.ms', xaxis = 'freq', yaxis = 'phase')` # to plot the phase Vs freq. for all baselines, all scans. This is particularly useful to look for phase variation, delays etc.

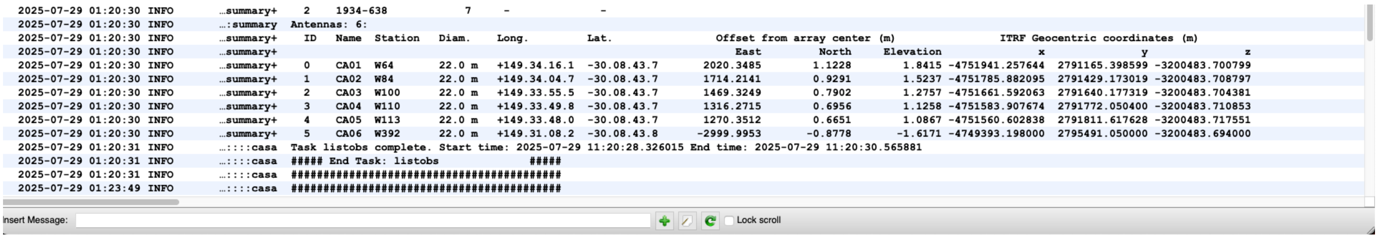
Note, to select only the cross-correlated data, set antenna = `'*&'` (to examine only auto-correlated data set antenna = `'*&&&'`).

Log Messages (:/Users/mur412/Documents/work/BIGCAT/ASDM...

```
Time                 Priority  Origin      Message
2025-07-29 01:20:28 INFO  ...::::casa  ###########################################
2025-07-29 01:20:28 INFO  ...::::casa  ##### Begin Task: listobs            #####
2025-07-29 01:20:28 INFO  ...::::casa  listobs( vis='combined_obs_28July.ms', selectdata=True, spw='', field='', antenna='', uvrange='', timerange='', correlation='', scan='', intent='', feed='', array='',
2025-07-29 01:20:29 INFO  ...:summary  ================================================================================
2025-07-29 01:20:29 INFO  ...summary+            MeasurementSet Name:  /Users/mur412/Documents/work/BIGCAT/ASDM_format_data/on_source_Max_28July/combined_obs_28July.ms      MS Version 2
2025-07-29 01:20:29 INFO  ...summary+  ================================================================================
2025-07-29 01:20:29 INFO  ...summary+     Observer: max     Project: uid://ATCA/X668535054c8/X8aba2b#project
2025-07-29 01:20:29 INFO  ...summary+  Observation: atca
2025-07-29 01:20:29 INFO  ...summary+
2025-07-29 01:20:29 INFO  ...summary+    Telescope Observation Date    Observer       Project
2025-07-29 01:20:29 INFO  ...summary+    atca      [                     5.26031e+09, 0]max           uid://ATCA/X668535054c8/X8aba2b#project
2025-07-29 01:20:29 INFO  ...summary+    atca      [                     5.26035e+09, 0]max           uid://ATCA/X668535054c8/X8aba2b#project
2025-07-29 01:20:29 INFO  ...perties   Computing scan and subscan properties...
2025-07-29 01:20:30 INFO  ...:summary  Data records: 388560       Total elapsed time = 35457.2 seconds
2025-07-29 01:20:30 INFO  ...summary+     Observed from   27-Jul-2025/05:50:03.1   to   27-Jul-2025/15:41:00.2 (UTC)
2025-07-29 01:20:30 INFO  ...:summary
2025-07-29 01:20:30 INFO  ...summary+     ObservationID = 0         ArrayID = 0
2025-07-29 01:20:30 INFO  ...summary+    Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
2025-07-29 01:20:30 INFO  ...summary+    27-Jul-2025/05:50:03.1 - 05:52:08.5     1      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                05:52:24.6 - 05:54:29.6     2      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                05:54:44.7 - 05:56:49.8     3      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                05:57:05.6 - 05:59:10.8     4      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                05:59:26.9 - 06:01:31.7     5      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:01:47.5 - 06:03:52.7     6      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:04:08.9 - 06:06:13.8     7      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:06:29.9 - 06:08:34.9     8      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:08:50.5 - 06:10:55.9     9      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:11:11.9 - 06:13:16.8    10      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:13:32.2 - 06:15:37.4    11      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:15:53.6 - 06:17:58.8    12      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:18:14.7 - 06:20:13.9    13      0 1646-50                1440  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:20:35.0 - 06:22:40.3    14      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:22:56.6 - 06:25:01.7    15      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:25:17.7 - 06:27:22.8    16      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:27:38.3 - 06:29:43.2    17      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:29:59.1 - 06:32:04.2    18      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:32:20.5 - 06:34:19.7    19      0 1646-50                1440  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:34:41.1 - 06:36:46.0    20      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:37:01.4 - 06:39:06.8    21      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:39:23.2 - 06:41:22.5    22      1 G333.6-0.2             1440  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:41:43.6 - 06:43:48.7    23      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:44:04.9 - 06:46:10.1    24      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:46:26.0 - 06:48:30.8    25      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:48:46.9 - 06:50:51.8    26      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:51:07.5 - 06:53:12.6    27      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:53:28.5 - 06:55:33.7    28      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:55:49.6 - 06:57:54.6    29      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                06:58:10.7 - 07:00:15.8    30      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                07:00:31.6 - 07:02:36.9    31      0 1646-50                1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
Insert Message:                                    Lock scroll
```

Log Messages (:/Users/mur412/Documents/work/BIGCAT/ASDM...

```
Time                 Priority  Origin      Message
2025-07-29 01:20:30 INFO  ...summary+                15:19:04.4 - 15:21:09.6   242      1 G333.6-0.2             1560  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...summary+                15:21:25.7 - 15:22:53.5   243      0 1646-50                1080  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_PHASE
2025-07-29 01:20:30 INFO  ...:summary
2025-07-29 01:20:30 INFO  ...summary+     ObservationID = 1         ArrayID = 0
2025-07-29 01:20:30 INFO  ...summary+    Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)    ScanIntent
2025-07-29 01:20:30 INFO  ...summary+    27-Jul-2025/15:25:17.3 - 15:41:00.2   244      2 1934-638              11400  [0,1,2,3,4,5,6,7]  [9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94, 9.94] [CALIBRATE_BANDI
2025-07-29 01:20:30 INFO  ...:summary            (nRows = Total number of rows per scan)
2025-07-29 01:20:30 INFO  ...:summary  Fields: 3
2025-07-29 01:20:30 INFO  ...summary+    ID   Code Name                RA               Decl           Epoch   SrcId      nRows
2025-07-29 01:20:30 INFO  ...summary+    0    C    1646-50             16:50:16.635000 -50.44.48.37000 J2000   0          189120
2025-07-29 01:20:30 INFO  ...summary+    1    C    G333.6-0.2          16:22:11.100000 -50.06.11.00000 J2000   1          188040
2025-07-29 01:20:30 INFO  ...summary+    2    C    1934-638            19:39:25.026000 -63.42.45.63000 J2000   2           11400
2025-07-29 01:20:30 INFO  ...:summary  Spectral Windows:  (8 unique spectral windows and 1 unique polarization setups)
2025-07-29 01:20:30 INFO  ...summary+    SpwID  Name           #Chans   Frame   Ch0(MHz)  ChanWid(kHz)  TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
2025-07-29 01:20:30 INFO  ...summary+    0      continuum_8      128    TOPO    5436.500      1000.000    128000.0   5500.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    1      continuum_9      128    TOPO    5564.500      1000.000    128000.0   5628.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    2      continuum_10     128    TOPO    5692.500      1000.000    128000.0   5756.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    3      continuum_11     128    TOPO    5820.500      1000.000    128000.0   5884.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    4      continuum_12     128    TOPO    5948.500      1000.000    128000.0   6012.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    5      continuum_13     128    TOPO    6076.500      1000.000    128000.0   6140.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    6      continuum_14     128    TOPO    6204.500      1000.000    128000.0   6268.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...summary+    7      continuum_15     128    TOPO    6332.500      1000.000    128000.0   6396.0000         1  XX  XY  YX  YY
2025-07-29 01:20:30 INFO  ...:summary  Sources: 24
2025-07-29 01:20:30 INFO  ...summary+    ID   Name                SpwId RestFreq(MHz)  SysVel(km/s)
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             0     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             1     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             2     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             3     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             4     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             5     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             6     -              -
2025-07-29 01:20:30 INFO  ...summary+    0    1646-50             7     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          0     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          1     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          2     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          3     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          4     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          5     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          6     -              -
2025-07-29 01:20:30 INFO  ...summary+    1    G333.6-0.2          7     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            0     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            1     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            2     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            3     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            4     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            5     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            6     -              -
2025-07-29 01:20:30 INFO  ...summary+    2    1934-638            7     -              -
2025-07-29 01:20:30 INFO  ...:summary  Antennas: 6:
Insert Message:                                    Lock scroll
```



```
2025-07-29 01:20:30 INFO     ...summary+   2    1934-638         7     -             -
2025-07-29 01:20:30 INFO     ...:summary  Antennas: 6:
2025-07-29 01:20:30 INFO     ...summary+   ID   Name  Station   Diam.    Long.        Lat.              Offset from array center (m)                ITRF Geocentric coordinates (m)
2025-07-29 01:20:30 INFO     ...summary+                                                                   East         North     Elevation              x                  y                  z
2025-07-29 01:20:30 INFO     ...summary+   0    CA01  W64       22.0 m   +149.34.16.1 -30.08.43.7        2020.3485        1.1228        1.8415 -4751941.257644  2791165.398599 -3200483.700799
2025-07-29 01:20:30 INFO     ...summary+   1    CA02  W84       22.0 m   +149.34.04.7 -30.08.43.7        1714.2141        0.9291        1.5237 -4751785.882095  2791429.173019 -3200483.708797
2025-07-29 01:20:30 INFO     ...summary+   2    CA03  W100      22.0 m   +149.33.55.5 -30.08.43.7        1469.3249        0.7902        1.2757 -4751661.592063  2791640.177319 -3200483.704381
2025-07-29 01:20:30 INFO     ...summary+   3    CA04  W110      22.0 m   +149.33.49.8 -30.08.43.7        1316.2715        0.6956        1.1258 -4751583.907674  2791772.050400 -3200483.710853
2025-07-29 01:20:30 INFO     ...summary+   4    CA05  W113      22.0 m   +149.33.48.0 -30.08.43.7        1270.3512        0.6651        1.0867 -4751560.602838  2791811.617628 -3200483.717551
2025-07-29 01:20:30 INFO     ...summary+   5    CA06  W392      22.0 m   +149.31.08.2 -30.08.43.8       -2999.9953       -0.8778       -1.6171 -4749393.198000  2795491.050000 -3200483.694000
2025-07-29 01:20:31 INFO     ...::::casa  Task listobs complete. Start time: 2025-07-29 11:20:28.326015 End time: 2025-07-29 11:20:30.565881
2025-07-29 01:20:31 INFO     ...::::casa  ##### End Task: listobs             #####
2025-07-29 01:20:31 INFO     ...::::casa  ##########################################
2025-07-29 01:23:49 INFO     ...::::casa  ##########################################
```



*Figure 2 Output from listobs. It lists the various fields, scans, spectral windows, sources as well as antenna locations*

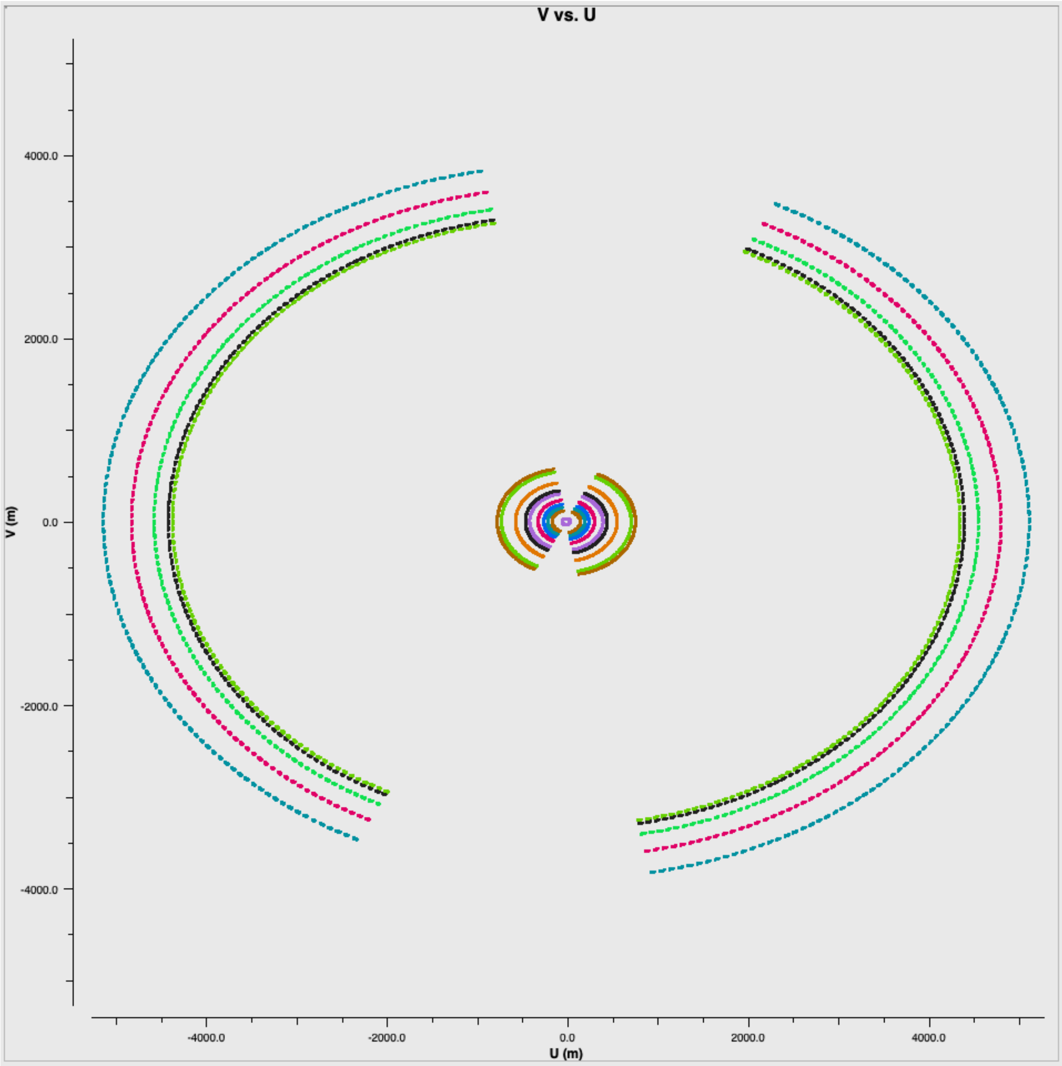



*Figure 3 UV coverage of the target. The different colours are the various baselines*

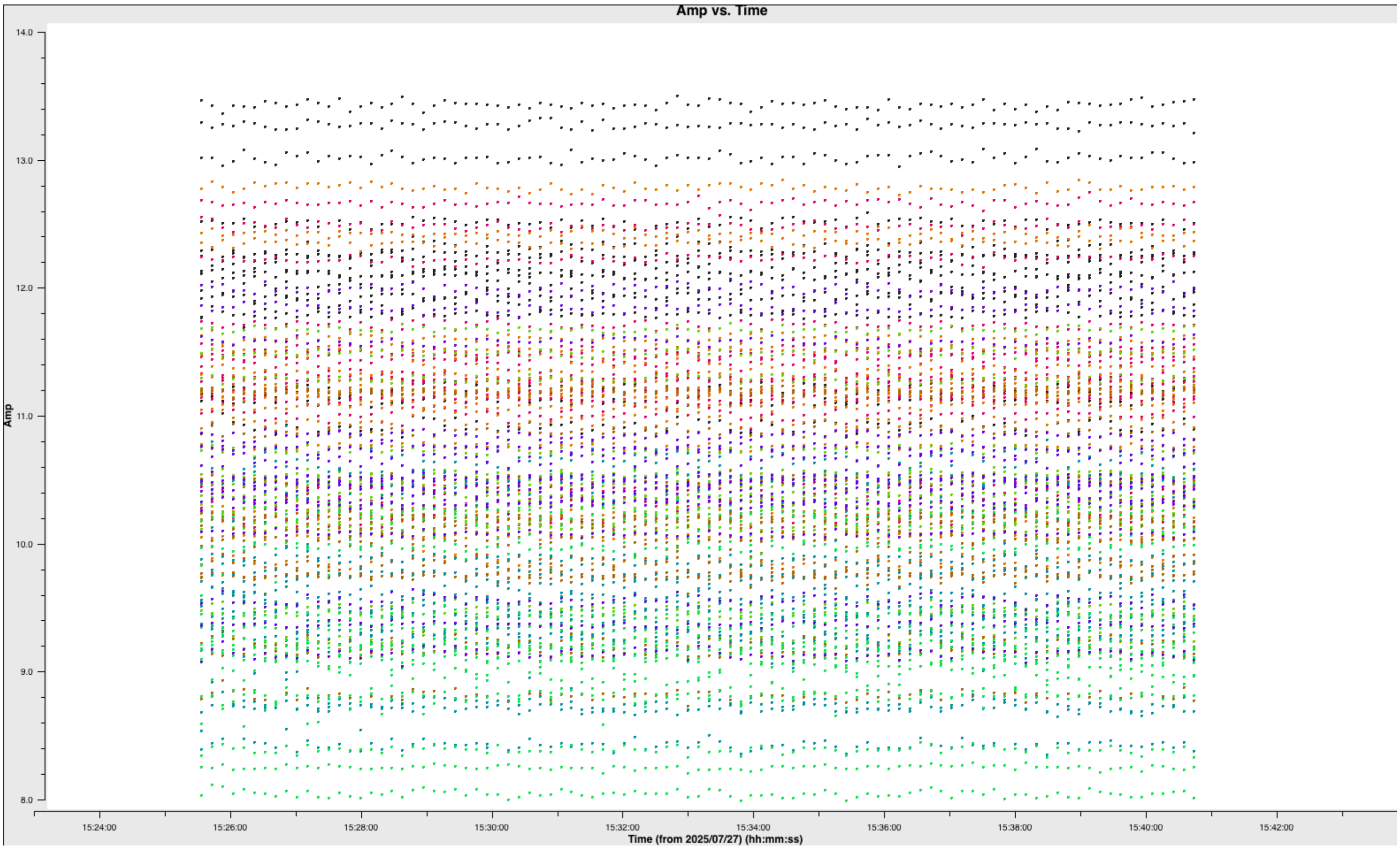



*Figure 4 Amplitude Vs Time, all SPWs, channel averaged.*

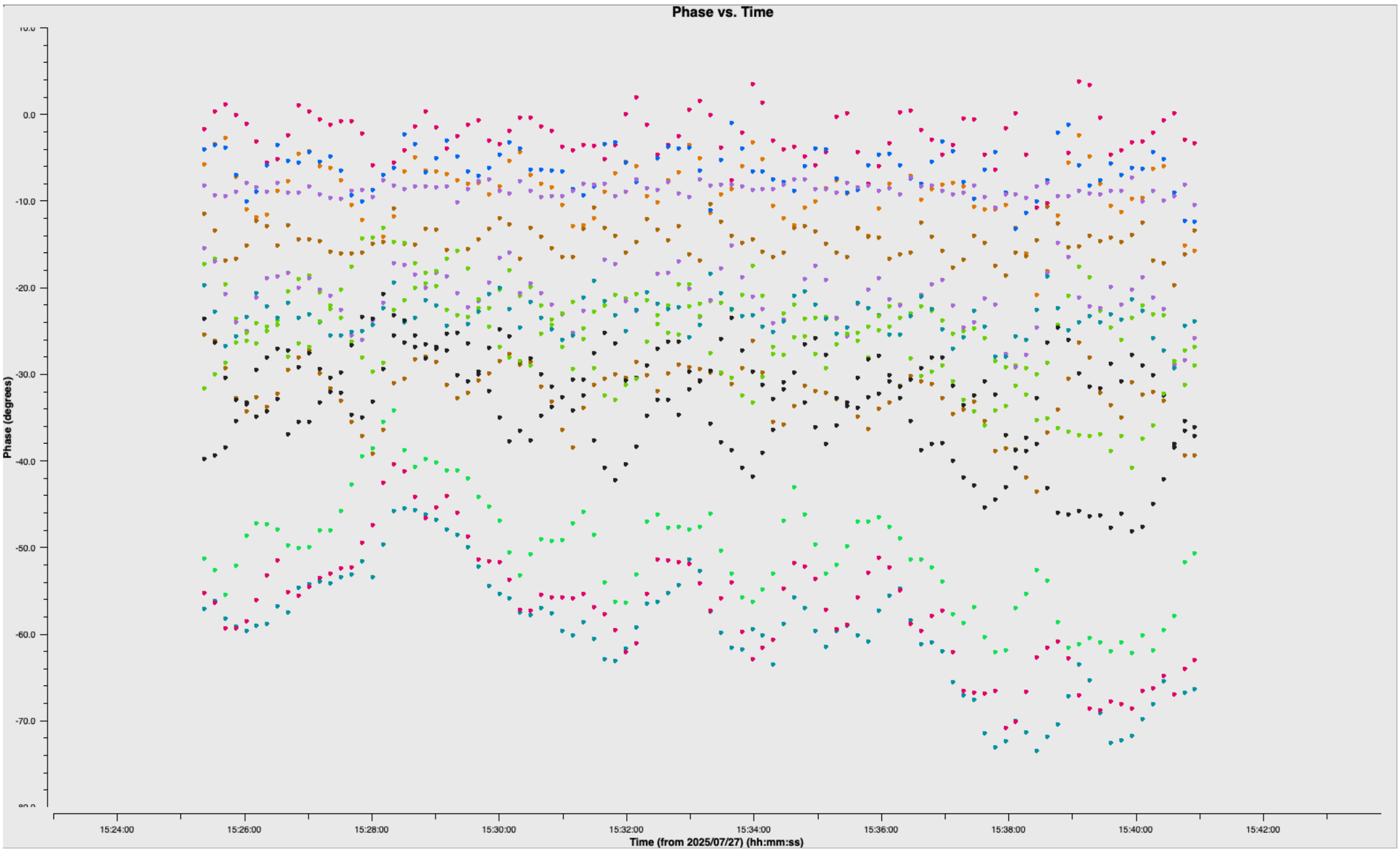



*Figure 5 Phase Vs time, all SPWs averaged together. Plotting cross-correlated data products in single XX polarisation only. Different colors are different baselines*

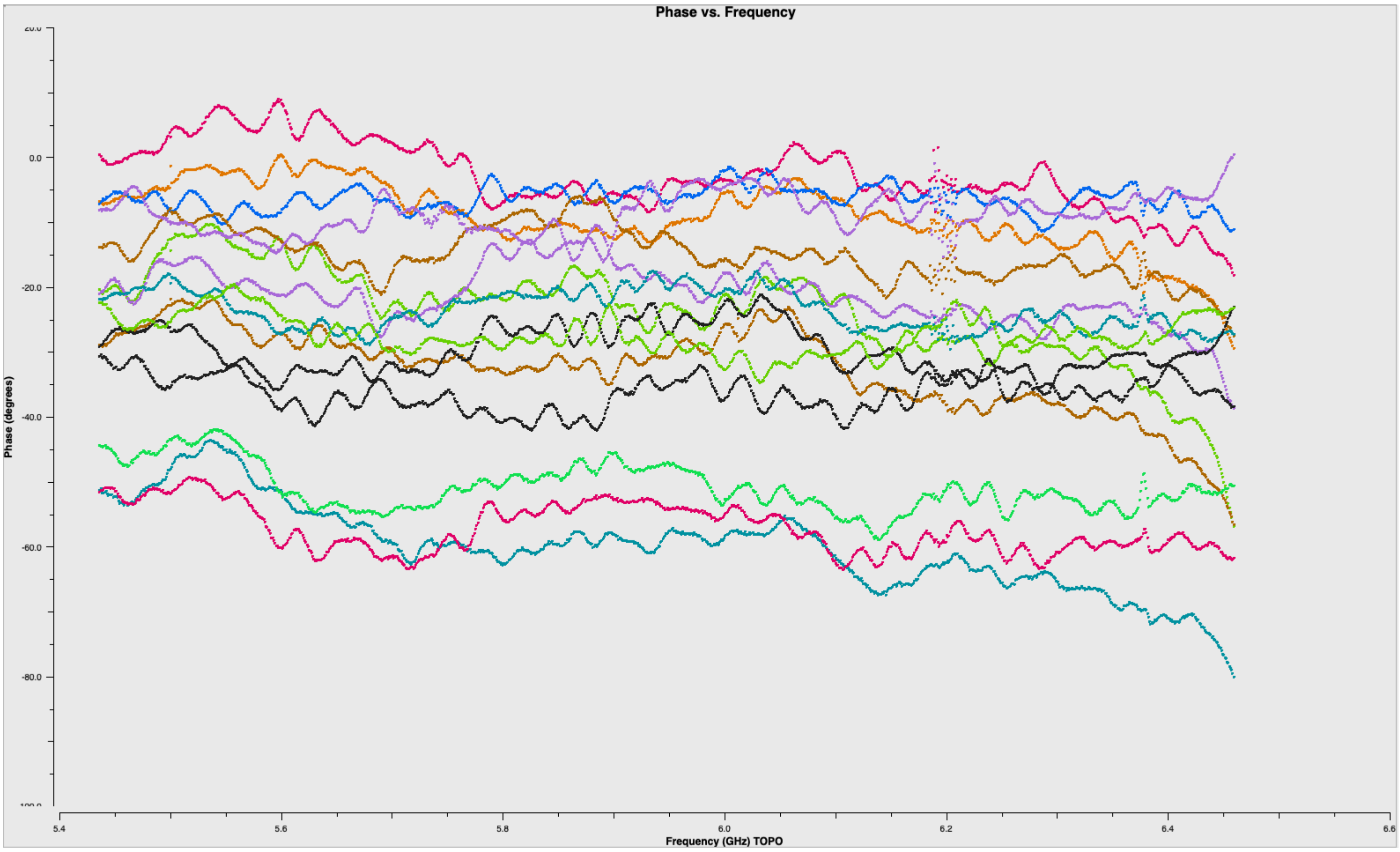



*Figure 6 Phase Vs frequency after averaging all scans and all integrations together. The various colours are different baselines.*

**Set some parameter values**

`visname = 'combined.ms'.` # you can set this to be your unflagged/uncalibrated MS data set
`pri = '2'` # the number denotes the field ID of the primary calibrator. NOTE, this can vary based on your observations. Set the correct field ID for the primary (you can get this from the output printed by *listobs*)
`sec = '0'` # field ID of secondary calibrator. NOTE, again, set this correctly as this number might vary depending on your observations.
`tar = '1'` # field ID of the target.
`ref = 'CA03'` # name or ID of the reference antenna. Choose a stable antenna.

# Flagging:

Flagging in CASA is typically done using the task '*flagdata*'. Before we start flagging it is a good idea to save the current flag state so that we can restore the data back to the original state in case we end-up being not happy with the flagging etc at a later stage. This can be done using the '*flagmanager'* task in CASA.

`> flagmanager(vis = visname, mode = 'save', versionname = 'flag_v1')` # save any initial flags before starting the flagging process

`> flagdata(vis = visname, mode = 'clip', clipzeros = True, flagbackup = False)` #flag any zeros and NaN values in the data.

`> flagdata(vis = visname, mode = 'shadow', tolerance = 0.0, flagbackup = False)` # flag any antenna shadowing

```
> flagdata(vis = visname, mode = 'quack', quackinterval = 10.0, quackmode = 'beg', flagbackup = False) # this is optional, but often good to do. This omits the first 10 seconds of the observations. You can choose this to be longer if necessary
```

```
> flagdata(vis = visname, mode =  'clip', clipminmax = [0,100], flagbackup = False) # clip amplitudes over 100. NOTE, you may need to look at the response of your data before setting the appropriate max value to clip.
```

```
> flagmanager(vis = visname, mode = 'save', versionname = 'flag_v2') #save flags
```

Check the amplitude Vs frequency response using '*plotms*' and look for any obvious RFI in the data. You can choose to cycle through various correlations xx, yy, xy, yx. You can choose to flag data within *plotms* using the flagging option at the bottom of the GUI (see Fig. 8 below), or we can use the flagging options within '*flagdata*' to do this (recommended). It is a lot faster and more efficient to use the automated flagging routines to flag the data than to manually flag them in the *plotms* GUI. Below we will run some basic flagging routines to flag the data.

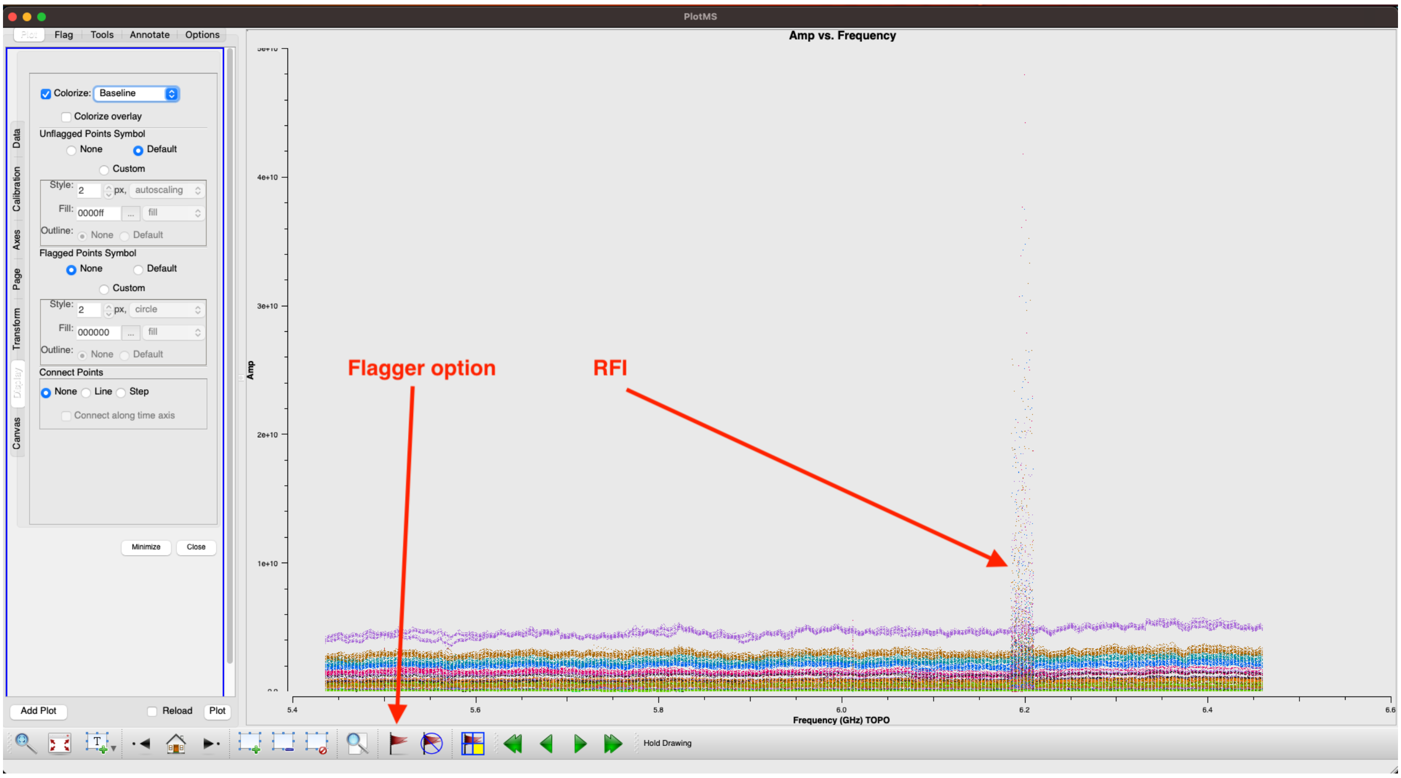



*Figure 7 Amplitude as a function of frequency for multiple baselines. plotms has the option to flag data on the go using the GUI.*

```
> flagdata(vis = visname, mode = 'tfcrop', datacolumn = 'data', chanbin = 1, ntime = 'scan', combinescans = False, timecutoff = 4.0, freqcutoff = 3.0, timefit = 'line', freqfit = 'poly', maxnpieces = 7, flagdimension = 'freqtime', usewindowstats = 'none', halfwin = 1, extendflags = False, action = 'apply', display = 'report', flagbackup = True, savepars = False,  writeflags = True)
```

Reload the data in '*plotms*', examine the data and make sure to remove any remaining RFI by running the above command again. You can also use the manual flagging option in '*plotms*' to flag any remaining outliers etc. Once satisfied we can extend the flags to all correlations and then save the flags.

```
flagdata(vis = visname, mode = 'extend', ntime = 'scan', combinescans = False,
extendpols = True, growtime = 80.0, growfreq = 80.0, growaround = False,
flagneartime = False, flagnearfreq = False, action = 'apply', display =
'report', flagbackup = True, savepars = False, writeflags = True)
```

```
> flagmanager(vis = visname, mode = 'save', versionname = 'flag_before_cal')
```
#save the flags version

## Calibration:

Set the flux level for the primary calibrator. Note that the calibrator PKS 1934-638 is not available in the 'Perley-Butler 2017' database (which is the default in CASA 6.6), so you may have to set 'standard = Perley-Butler 2010'.

```
> setjy(vis = visname, field=pri, scalebychan = True, standard = 'Perley-Butler
2010', usescratch = True)
```

Running this should produce an output like this, with the model flux value for each spectral window.

```
{'2': {'0': {'fluxd': array([5.03409809, 0.        , 0.        , 0.        ])},
  '1': {'fluxd': array([4.89560895, 0.        , 0.        , 0.        ])},
  '2': {'fluxd': array([4.76331005, 0.        , 0.        , 0.        ])},
  '3': {'fluxd': array([4.63685037, 0.        , 0.        , 0.        ])},
  '4': {'fluxd': array([4.51590169, 0.        , 0.        , 0.        ])},
  '5': {'fluxd': array([4.40015705, 0.        , 0.        , 0.        ])},
  '6': {'fluxd': array([4.28932936, 0.        , 0.        , 0.        ])},
  '7': {'fluxd': array([4.18314998, 0.        , 0.        , 0.        ])},
  'fieldName': '1934-638'},
 'format': "{field Id: {spw Id: {fluxd: [I,Q,U,V] in Jy}, 'fieldName':field name }}"}
```

You can examine this visually by plotting the model amplitude as a function of frequency for 1934-638 (or your specific primary calibrator). You can do this by setting "field=1934-638", "corr=XX,YY" in the *plotms* GUI. In the 'Axes' tab (on the left), select 'model' under the Y-axis 'Data' tab. This should plot the calculated model amplitude for 1934-638 as a function of frequency. In the 'Display' tab to the left, set 'Colorize=spw' to show the response across all spectral windows.

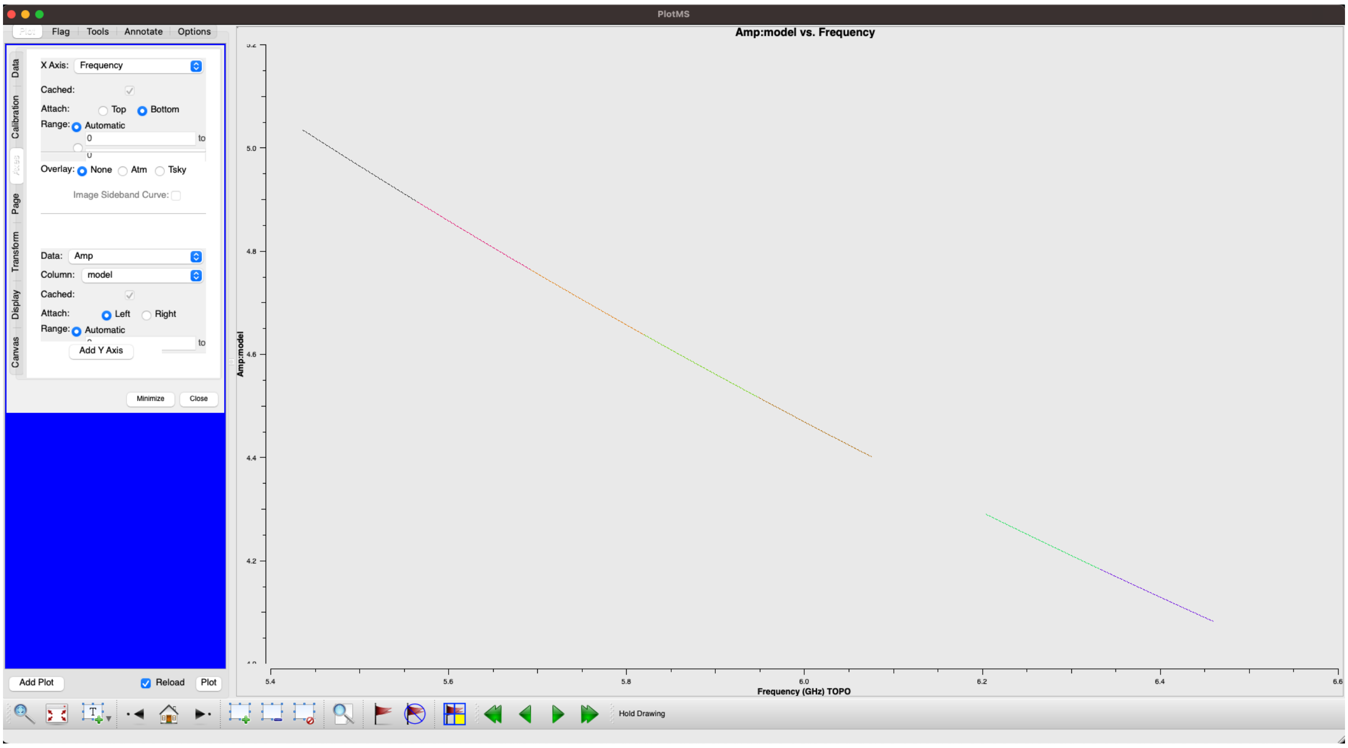



*Figure 8 Using plotms to show the model amplitude Vs frequency plot for 1934-638*

Next use '***gaincal***' to perform phase calibration for the primary calibrator. Run ***gaincal*** as shown below.

```
>  gaincal(vis = visname, caltable = 'cal.G0', field = pri, refant = ref, gaintype = 'G', calmode = 'p', parang = True, solint = '60s')
```
# you can also set solint to shorter durations (e.g., '30s' or 'int') if you want to track phase changes at shorter time intervals. 'int' is the integration period of the observations (typically ~10s for most observations, but can vary based on the experiment)

```
> bandpass(vis = visname, caltable = 'cal.B0', field = pri, spw='', refant = ref, solnorm = True, solint = 'inf', bandtype = 'B', gaintable = ['cal.G0'], parang = True)
```
# solve for the bandpass response

```
> gaincal(vis = visname, caltable = 'cal.G1', field = pri+','+sec, refant = ref, spw = '*', gaintype = 'G', calmode = 'ap', parang = True, solint = '60s', gaintable = ['cal.B0'])
```
# solve the gains using the secondary this time.

```
> polcal(vis = visname, caltable = 'cal.D0', field =  pri, refant = ref, gaintable = ['cal.B0','cal.G1'],  poltype = 'Df', solint = 'inf')
```
# solve for the polarisation leakage

Now we can attempt to derive better solutions using the previous gains tables. So re-do the above steps, but this time use the previously solved gains tables.

```
> bandpass(vis = visname, caltable = 'cal.B1', field = pri, spw='', refant = ref, solnorm = True, solint = 'inf', bandtype = 'B', gaintable = ['cal.G1','cal.D0'], parang = True)
```

```
> gaincal(vis = visname,  caltable = 'cal.G2', field = pri+ ',' +sec, refant =
ref, spw = '*', gaintype = 'G', calmode = 'ap', parang = True, solint = '60s',
gaintable = ['cal.B1','cal.D0'])
```

**> polcal(vis = msname, caltable = ‘cal.D1’, field = pri, refant  = ref, gaintable = ['cal.B1','cal.G2'], poltype = 'Df',  solint= 'inf')**

We can look at the bandpass and gains solutions using plotms

```
> plotms(vis = 'cal.B1', xaxis = 'freq', yaxis = 'amp', coloraxis = 'spw') #
plot the bandpass solutions
```

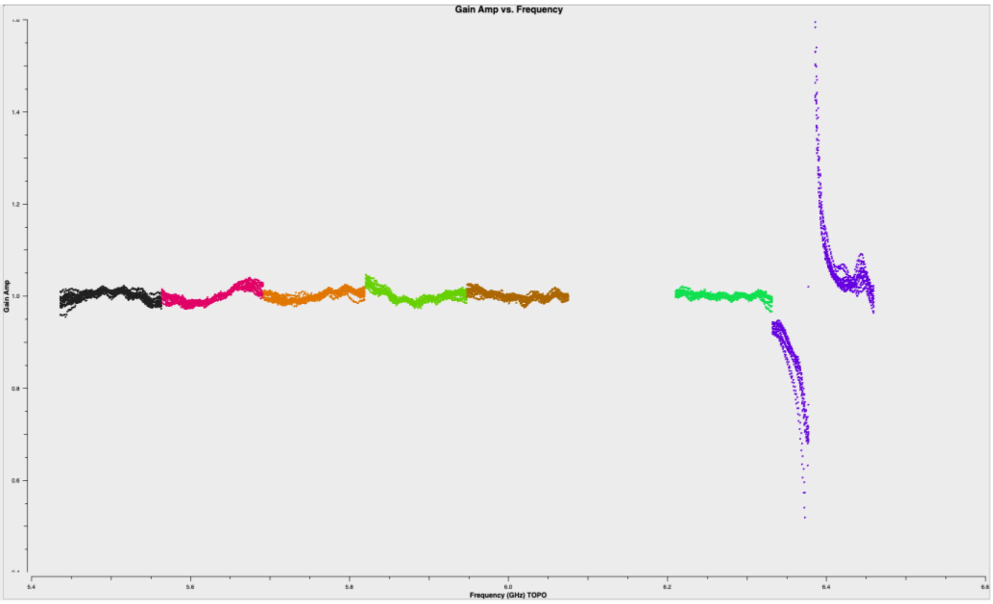



*Figure 9 Bandpass solutions. Note that in this case one of the sub-bands is missing as it was completely flagged due to bad RFI. The solutions in the last sub-band do not seem to converge. One should be cautious and perhaps re-do the flagging/calibrations steps or choose to omit that specific sub-band during the imaging step.*

Examine the (amplitude and phase) gain solutions for the primary calibrator

```
> plotms(vis = 'cal.G2', xaxis = 'freq', yaxis = 'amp', field = pri, iteraxis =
'antenna', coloraxis = 'spw')
```

```
> plotms(vis = 'cal.G2', xaxis = 'time', yaxis = 'phase', field = pri, iteraxis =
'antenna', plotrange = [0,0,-180.,180.] ,coloraxis = 'spw')
```

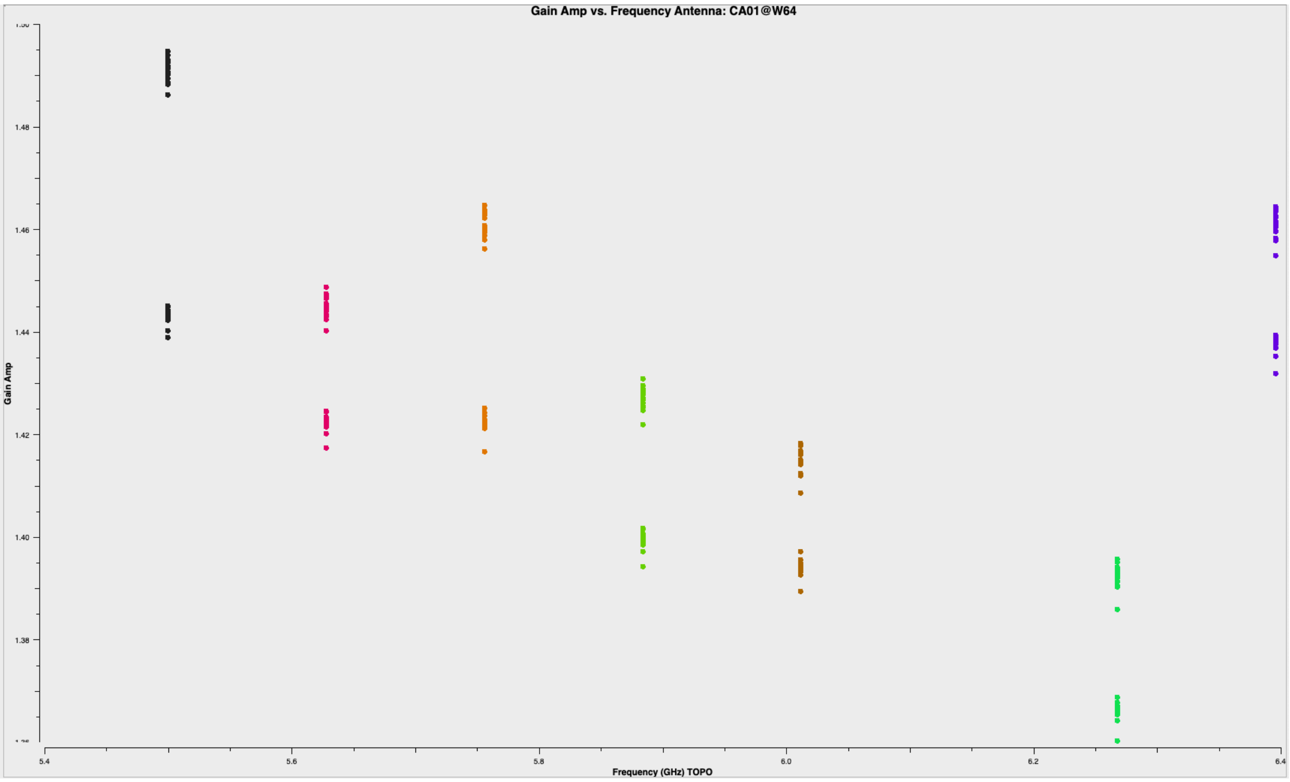



*Figure 10 Amplitude gains for the primary calibrator*

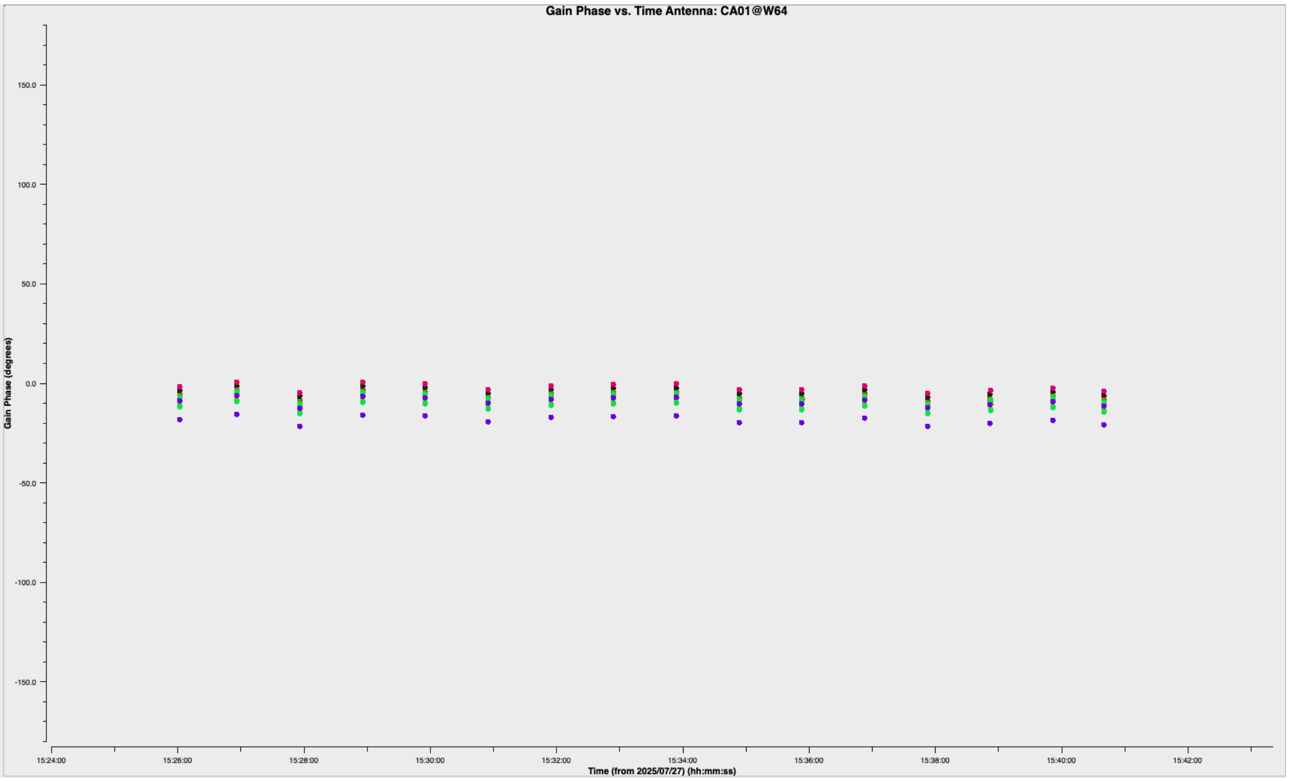



*Figure 11 Phase gains solutions for the primary calibrator*

Examine the (amplitude and phase) gain solutions for the secondary calibrator

```
> plotms(vis = 'cal.G2', xaxis = 'freq', yaxis = 'amp', field = sec, iteraxis =
'antenna', coloraxis = 'spw')
```

```
> plotms(vis = 'cal.G2', xaxis = 'time', yaxis = 'phase', field = sec, iteraxis =
'antenna', plotrange = [0,0,-180.,180.],coloraxis = 'spw')
```

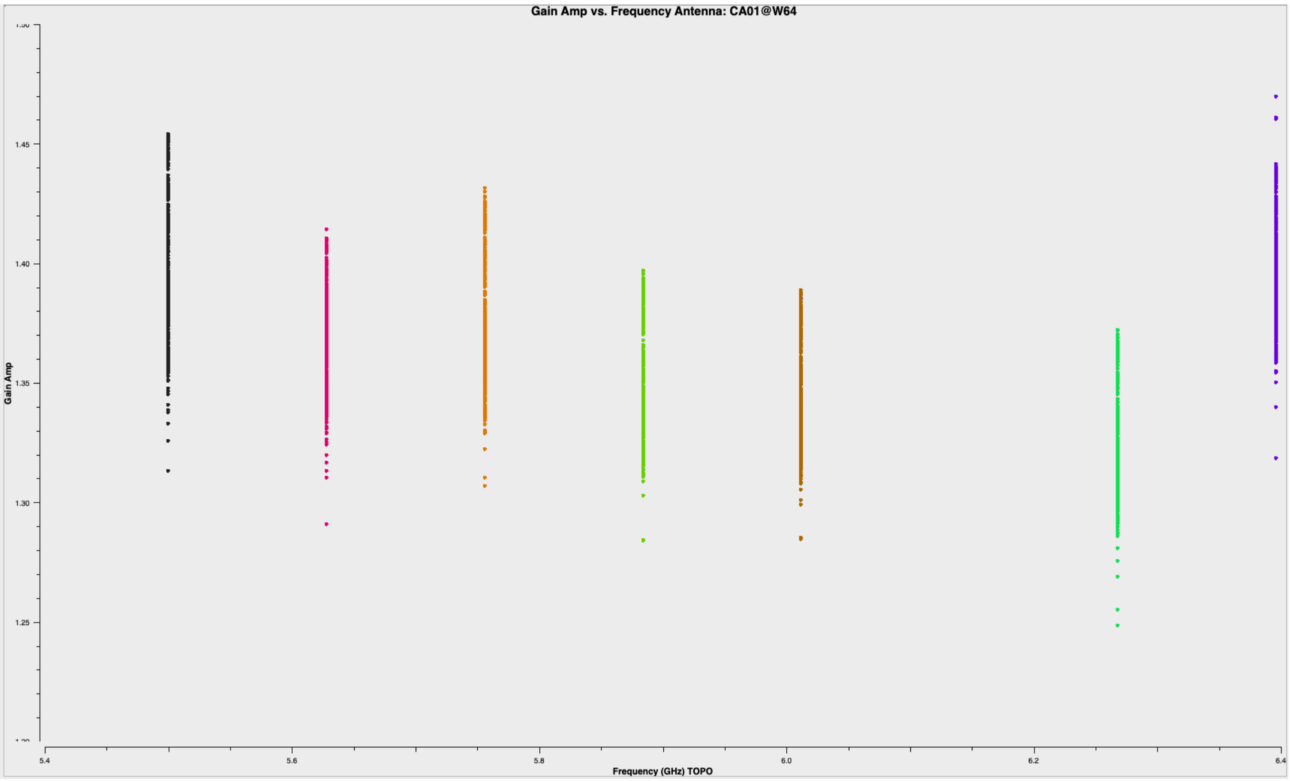



*Figure 12 Amplitude gains as a function of frequency for the secondary calibrator*

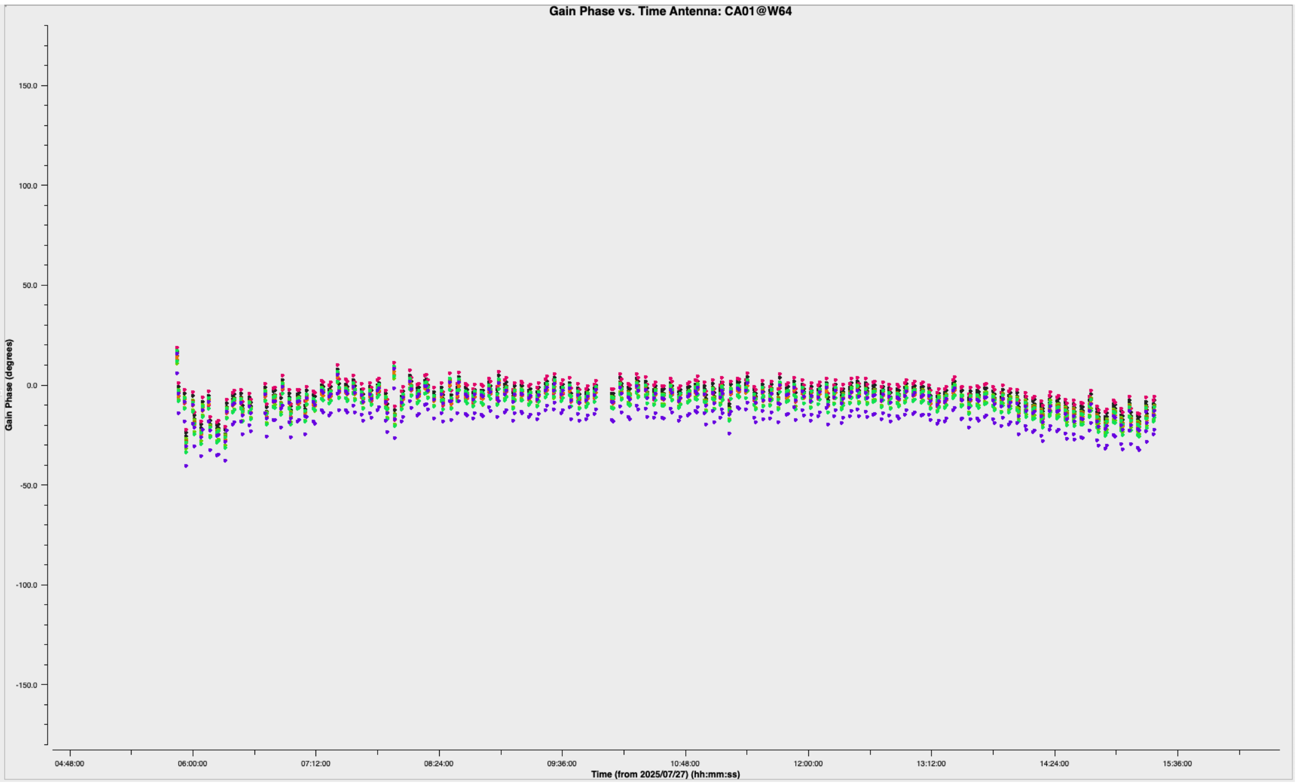



*Figure 13 Phase gains as a function of time for the secondary calibrator*

We see that the phase gain solutions over time are quite stable.

We first scale the flux appropriately.

```
> fluxscale(vis = visname, caltable = 'cal.G2', fluxtable = 'cal.F0', reference = pri)
```

Then go ahead and apply the calibrations to the target field

```
> applycal(vis = visname, gaintable = ['cal.B1','cal.D1','cal.F0'], gainfield =
[pri,pri,pri],field = pri, parang = True, flagbackup = False)

> applycal(vis = visname, gaintable = ['cal.B1','cal.D1','cal.F0'], gainfield =
[pri,pri,sec], field = sec+','+tar, parang = True, flagbackup = False)
```

Next, we run the final set of flagging routines to make sure any outliers are properly flagged. We use flagdata for this purpose again, but this time use the mode set to 'rflag'.

```
> flagmanager(vis = visname, mode = 'save', versionname = 'before_rflag')

> flagdata(vis = visname, mode = 'rflag', field = pri, spw = '', datacolumn =
'corrected',  action = 'apply', display = 'report', correlation = 'ABS_ALL',
timedevscale = 3.0, freqdevscale = 3.0, winsize = 3, combinescans = True, ntime =
'9999999min', extendflags = False, flagbackup = False) # running the flagging routine on the
primary calibrator

> flagdata(vis = visname, mode = 'rflag', field = sec, spw = '', datacolumn =
'corrected',  action = 'apply', display = 'report', correlation = 'ABS_ALL',
timedevscale = 3.0, freqdevscale = 3.0, winsize = 3, combinescans = True, ntime =
'9999999min', extendflags = False, flagbackup = False) # running the flagging routine on the
secondary calibrator

> flagdata(vis = visname, mode = 'rflag', field = tar, spw = '', datacolumn =
'corrected',  action = 'apply', display = 'report', correlation = 'ABS_ALL',
timedevscale = 3.0, freqdevscale = 3.0, winsize = 3, combinescans = True, ntime =
'9999999min', extendflags = False, flagbackup = False) # running the flagging routine on the
target

> flagdata(vis = visname, mode = 'extend', field = pri+','+sec+','+tar, spw = '',
action = 'apply', display = 'report', flagbackup = False, extendpols = True,
correlation = '', growtime = 95.0, growfreq = 95.0, growaround = True, flagneartime =
False, flagnearfreq = False, combinescans = True, ntime = '9999999min') # extend the
flags to all correlations for the primary, secondary and the target
```

If we now look at the amplitude Vs freq. response for the primary we should see something like Fig. 15. You can examine this using the *plotms* task

```
> plotms(vis = msname, field = pri, xaxis = 'frequency', yaxis = 'amp', correlation =
'xx,yy' , ydatacolumn = 'corrected', coloraxis = 'spw')
```

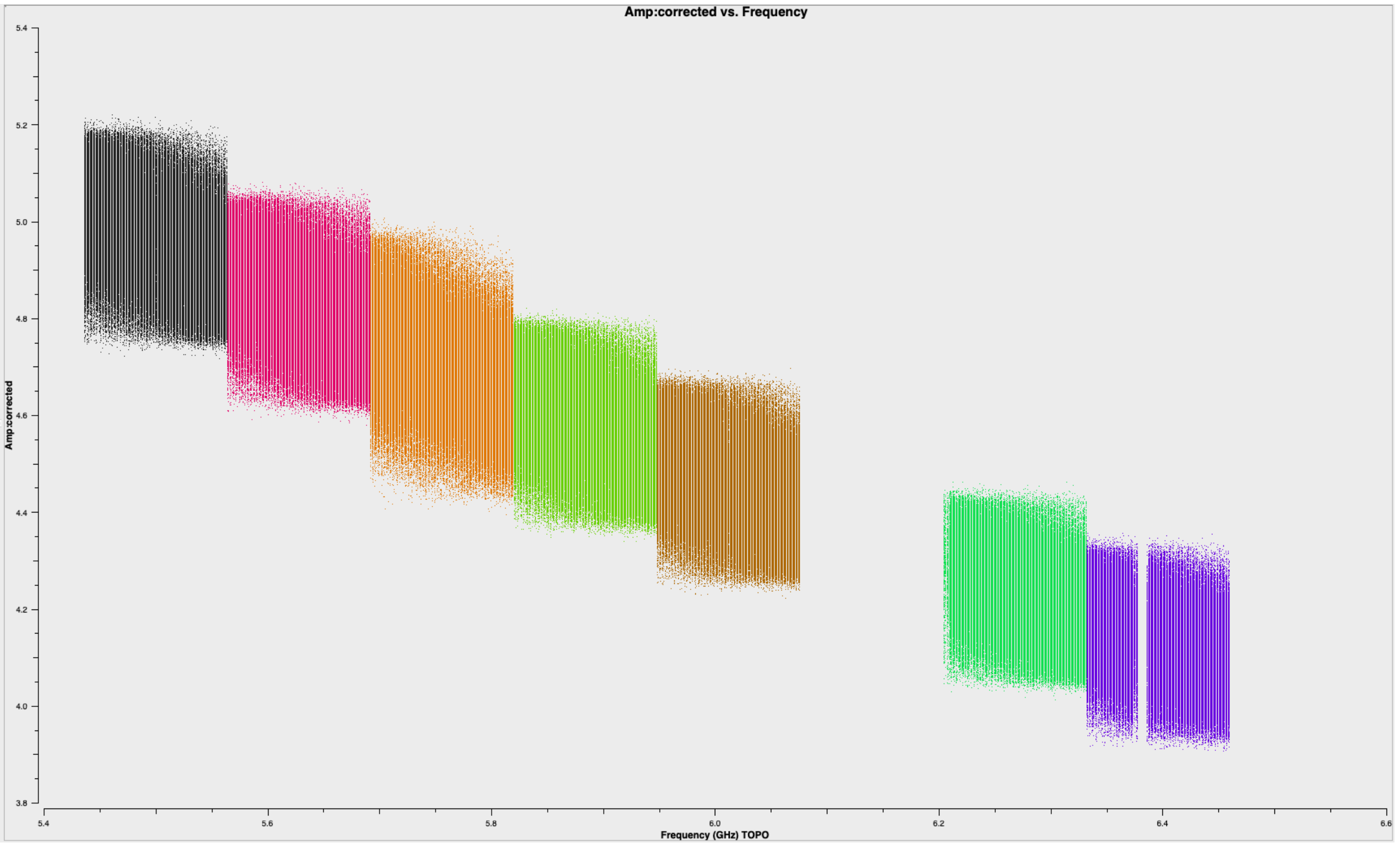



*Figure 14 Corrected amplitude Vs frequency for the primary calibrator.*

We can also look at the corrected amplitude vs freq. response for the secondary calibrator

```
> plotms(vis = visname, field = sec, xaxis = 'frequency', yaxis = 'amp', correlation =
'xx,yy' , ydatacolumn = 'corrected', coloraxis = 'spw')
```

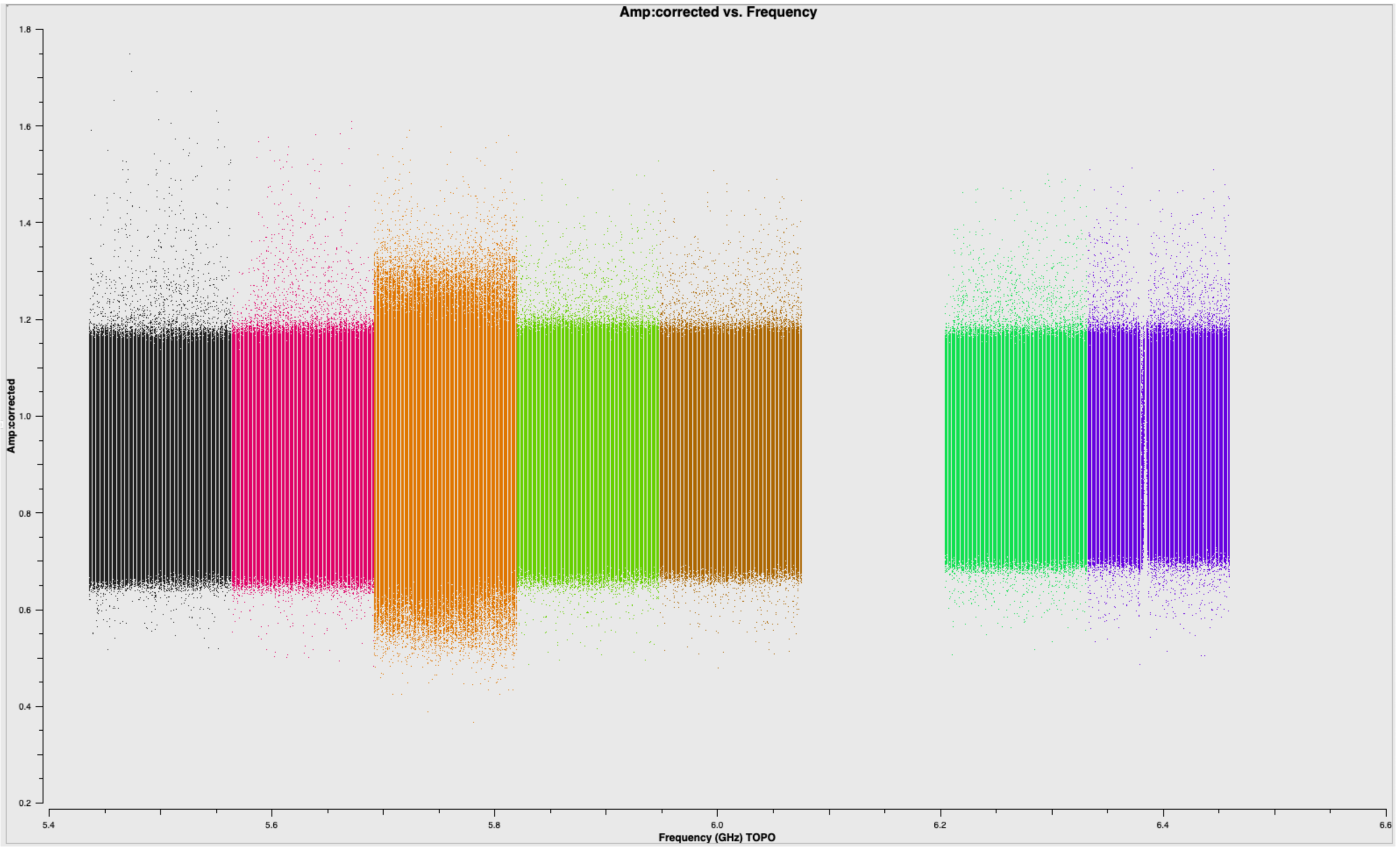



*Figure 15 Corrected amplitude Vs frequency for the secondary calibrator.*

We see that corrected amplitudes of both the primary and the secondary calibrators are well behaved.

At this point it might also be useful to have a look at the imaginary Vs real plot for the primary, secondary. Typically (but not always true), you want to see a nice, concentrated distribution of points centred on the flux of the calibrator in the real axis and 0 on the imaginary axis.

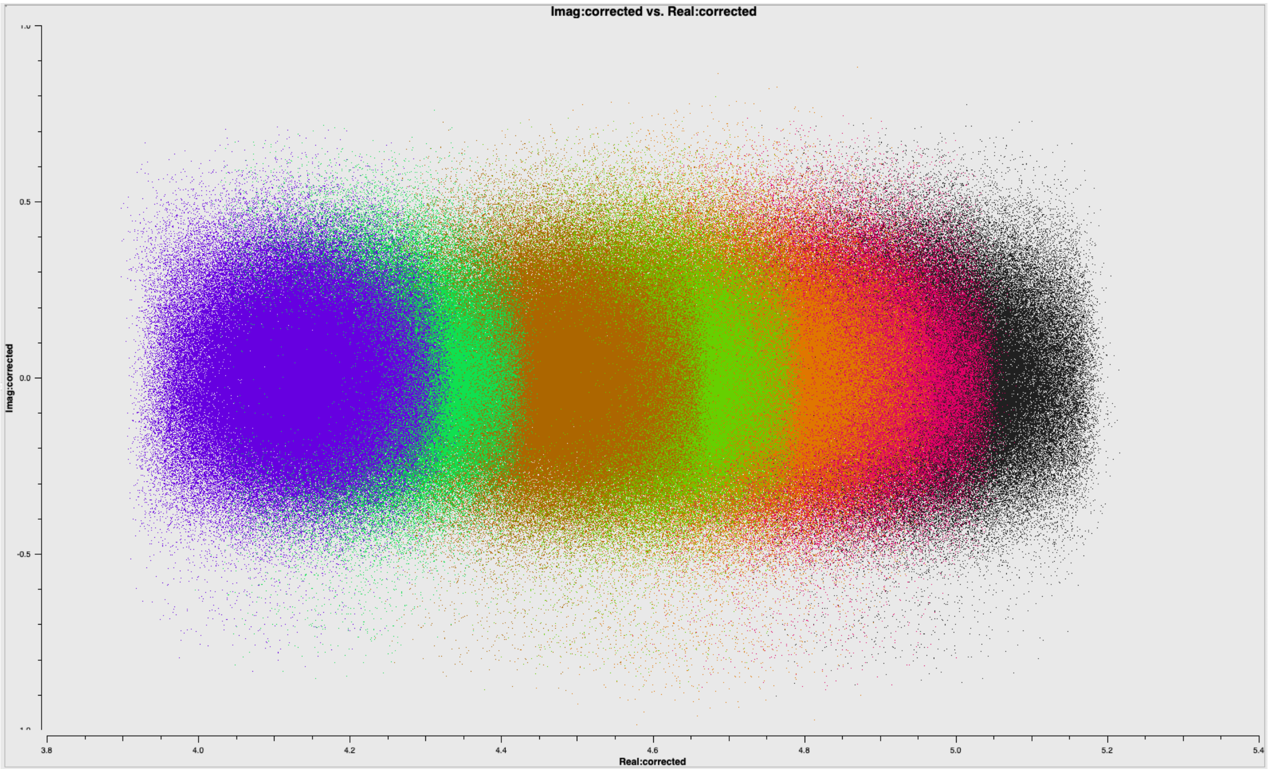



*Figure 16 Corrected imaginary Vs real plot for the primary calibrator.*

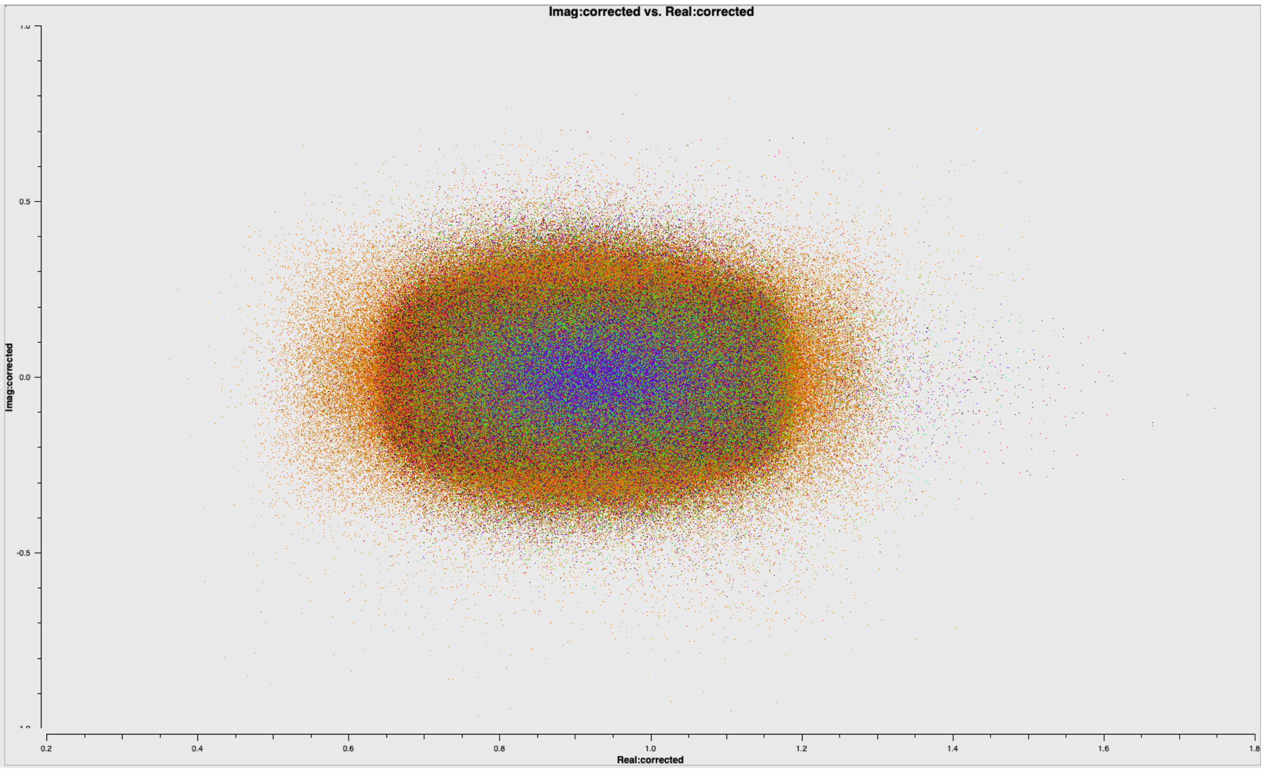



*Figure 17 Corrected imaginary Vs real plot for the secondary calibrator.*

## Imaging:

Once we are happy with the calibration we can finally proceed to the imaging step. This is done in CASA using the task ‘***tclean’***

```
> tclean(vis = visname, selectdata = True, field = tar, datacolumn = 'corrected', imagename = 'image_name', imsize = [1024, 1024], cell = '1.0arcsec', stokes = 'I', projection = 'SIN', specmode = 'mfs', gridder = 'standard', pblimit = 0.2, deconvolver = 'mtmfs', scales = [0, 5, 15, 50], nterms = 2, weighting = 'briggs', robust = 0.5, niter = 20000, threshold = '1e-4Jy', interactive = False)
```

# NOTE, you may have to change the image and cell size and other parameters such as the scales and the threshold for the minor clean cycles depending on your source and observations. We are using the 'mtmfs' routine to deconvolve as this is a good option to deal with wideband imaging (as is the case here). One can also try using 'multiscale'. If you intend to perform interactive cleaning set 'interactive = True'. This will open a GUI which will display the residuals after every major clean cycle, and the user may select specific regions to clean etc. For more details refer to the CASA user guide and/or other CASA imaging guides.

## Appendix: Optional and Advanced Steps

For improved results, consider adding:

1. Delay Calibration:
   `gaincal(vis=visname, caltable='cal.K0', gaintype='K', solint='inf', combine='spw,scan')`
   Removes instrumental delays across the wide bandwidth.
2. Statistical Weighting:
   statwt(vis=visname)
   Recomputes visibility weights after extensive flagging.
3. Self-Calibration: For bright targets, run iterative phase and amplitude self-calibration.
4. Continuum Subtraction (for spectral line studies):
   `uvcontsub(vis=visname, fitspw='0:5~100;200~400', fitorder=1)`
5. Imaging Options:
   - Use uvtaper for extended emission.
   - Use gridder='wproject' or gridder='mosaic' for wide-field imaging.
6. Exporting Products:
   `exportfits(imagename='image_name.image', fitsimage='image_name.fits')`
7. If you want to split the wideband into smaller chunks, you can consider using 'mstransform'. In the example below we are splitting-out the first 8 spectral windows/spws (or sub-bands) from 0 to 7 to create a new MS consisting of those spectral windows.
   ```
   > mstransform(vis = visname, outputvis = 'out_image.ms', spw ='0~7', datacolumn = 'data', regridms = True, mode = 'channel', nspw = 8, interpolation = 'linear')
   ```