# ALMA Manual Calibration

Dominic Ludovici | 21st Synthesis Imaging Workshop| May 28th, 2026

# Learning Objectives

At the end of this tutorial, participants should be able to…

1. Summarize the basic steps for calibrating ALMA data.
2. Use CASA to calibrate an ALMA observation.
3. Interpret graphs of ALMA data and calibration solutions

# Tutorial Guide

- I will use Active Learning techniques to keep you engaged.
  - We will often stop for discussion and questions.
  - Please sit near someone else.  Help each other and check your work against your neighbors.

- Your understanding is important to us!
  - I will be walking around the room to help while you work.
  - We have many others here to help as well.

- Ask us questions!  Raise your hand and someone will come to help!

# Your CASA tutorial team

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# Your CASA tutorial team

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# Overview

1. Data and Project Description
2. Getting Started in CASA
3. Initial Calibration and Data Preparation
4. Data Inspection
5. Calibration

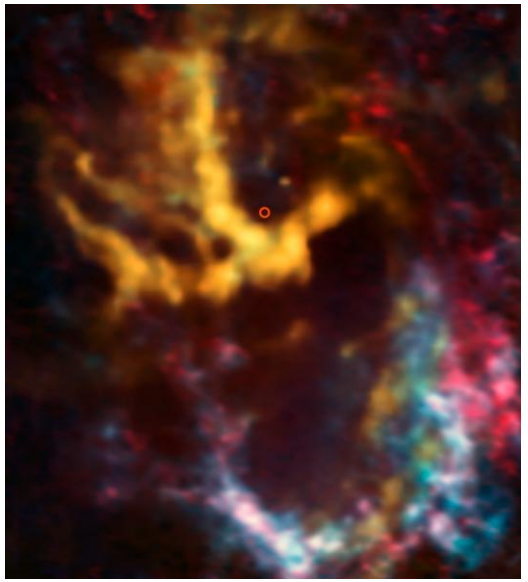
# Data Description

Today's data is from the ALMA Atacama Compact Array (ACA) filler projects observed during cycle 6.

# Data Description

We will examine the heart of our own galaxy: SGR A*!

- Sgr A* is a variable source of radiation from the Radio up to gamma rays.
- During the observing campaign, ALMA cooperated with Spitzer, Chandra, and NuStar to observer our central black hole.
- The data contain both continuum and spectral line observations, allowing us to examine the emission from Sgr A* as well as the Circumnuclear Disk!



Sgr A* as seen by ALMA in multiple bands.

# Data Description

We will image the  continuum emission and CO line emission observed at Band 6.

- Link to paper:
- https://iopscience.iop.org/article/10.3847/1538-4357/ac2d2c/pdf and
- https://iopscience.iop.org/article/10.3847/1538-4357/ac6104/pdf

# Getting Started

**Navigating to Your Data**

Starting CASA

Task Help

Running Tasks

In your directory there should be two sub-directories labeled /Calibration and /Imaging.

In **ALMA_manual_calibration_tutorial.tar** you should have:

- **uid___A002_Xdf0444_X10bd** (the raw ASDM data file containing uncalibrated data)
- **calibration.py** (the script we will work through together to calibrate the data)
- analysis_scripts

# Getting Started

Navigating to Your Data

**Starting CASA**

Task Help

Running Tasks

CASA (Common Astronomy Software Applications)

- CASA is the offline data reduction package for ALMA and the VLA (data from other telescopes usually work too, but not primary goal of CASA)
- Code is C++ (fast) bound to Python which provides ease of use and scripting
- Provides data import/export, inspection, editing, calibration, imageing, viewing, and analysis
- Also supports single dish data reduction
- We have a lot of documentation (CASA docs), reduction tutorials (CASA guides), and a helpdesk.

# Getting Started



Start CASA.

Lets make sure everyone can start CASA!

If you put CASA in your path, you should be able to start it by typing "`casa`" on the command line.

If not, give the full path:
</path/to/casa/install>/bin/casa

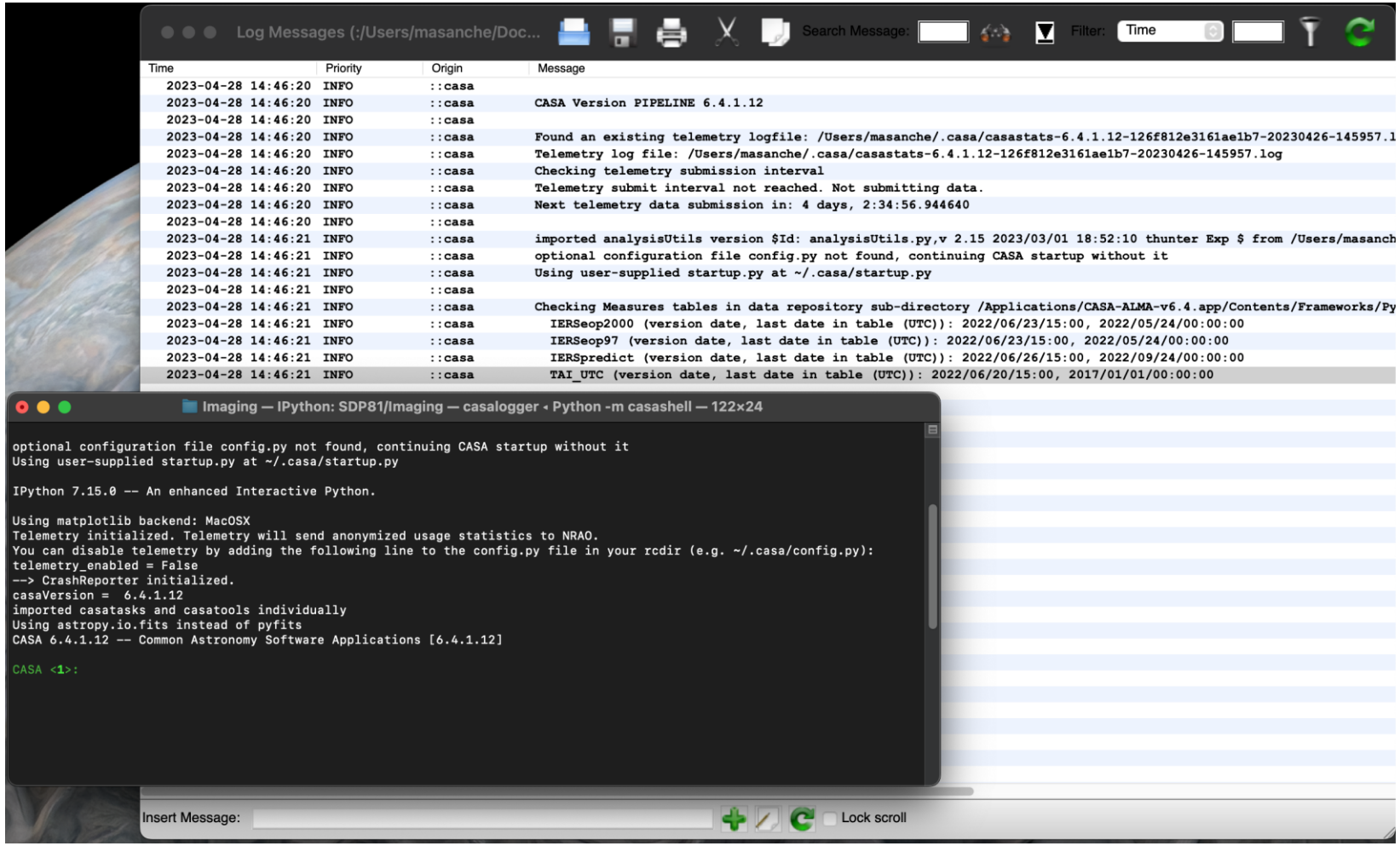
# Getting Started

Navigating to Your Data

**Starting CASA**

Task Help

Running Tasks






National Radio Astronomy Observatory

# Getting Started

Navigating to Your Data

**Starting CASA**

Task Help

Running Tasks

CASA runs within pythons scripts or through the interactive *IPython* (ipython.org) interface

- IPython Features:
  - shell access
  - auto-parenthesis (autocall)
  - Tab auto-completion
  - command history (arrow up and “hist [-n]”)
  - session logging
  - casaTIME.log – casa logger messages
  - numbered input/output
  - history/searching

# Getting Started

Navigating to Your Data

Starting CASA

**Task Help**

Running Tasks

Tasks - high-level functionality

- function call or parameter handling interface
- these are what you should use in tutorials

Tools - complete functionality

- **tool.method()** calls
- they are internally used by tasks or can be used on their own sometimes shown in tutorial scripts and CASAGuides

Applications – some tasks/tools invoke standalone apps

- e.g. **casaviewer, mpicasa**

Shell commands can be run with a leading exclamation mark

- **!du –ls** or inside **os.system("shell command")**
- (some key shell commands like "ls" work without the exclamation mark
- We will use **os.system()** exclusively within this tutorial.)

# Getting Started

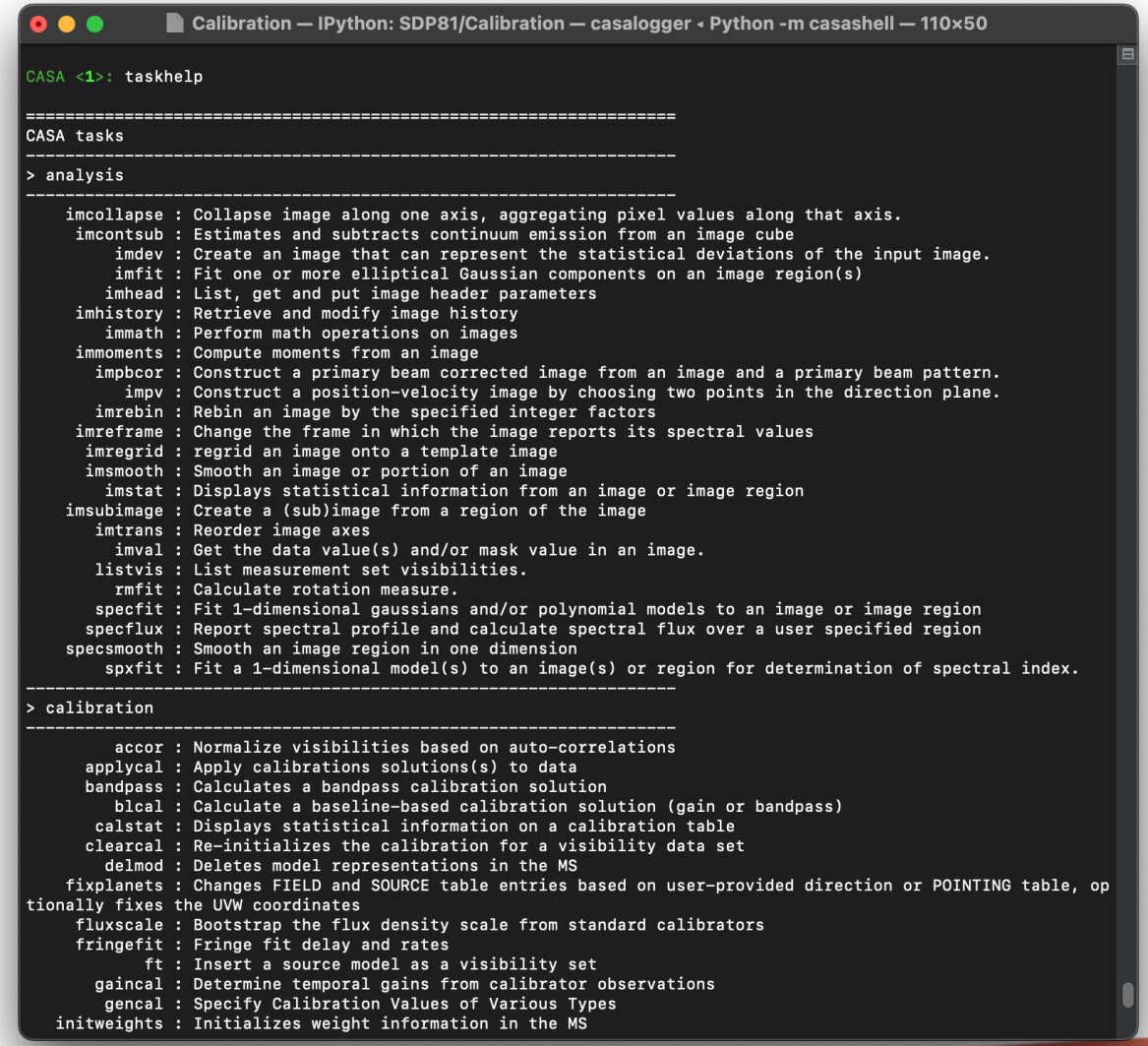
Navigating to Your Data

Starting CASA

**Task Help**

Running Tasks

## taskhelp



# Getting Started

Navigating to Your Data

Starting CASA

Task Help

**Running Tasks**

## Task Execution:

Write the full parameter set in a line:

- taskname( arg1=val1, arg2=val2, ... )
- e.g. tclean(vis='input.ms',imagename='galaxy', robust=0.5, imsize=[200,200])

unspecified parameters will be set to their default values (globals not used; i.e. not to previously set variables)

Useful in scripts, but also in 'pseudo-scripts':

- To keep a record, it is frequently a good idea to write down the full line as above in an editor, then cut and paste into CASA.
- When changes are needed, change in editor and cut and paste again. That is good practice to keep a record of the exact input.
- But note that the logger is also repeating the full task command

# Getting Started

Navigating to Your Data

Starting CASA

Task Help

**Running Tasks**

Scripts can be run with the following:

execfile('<yourscript.py>')

Python 3 removed the execfile built-in function. CASA provides a convenience function that attempts to reproduce the behavior of the Python 2.7 built-in execfile function.

# Getting Started

Navigating to Your Data

Starting CASA

Task Help

**Running Tasks**

CASA also has an asking interface, similar to AIPS, MIRIAD, etc.

- parameter manipulation commands
  - inp, default, saveinputs, tget, tput
- use parameters set as global Python variables
  - <param> = <value>
  - (e.g. vis = 'ngc5921.demo.ms' )
- execute
  - <taskname> or go ( e.g. tclean() )

- return values (except when using "go")
  - some tasks return Python dictionaries, assign a variable name to get them, e.g. myval=imval()
  - Very useful for scripting based on task outputs

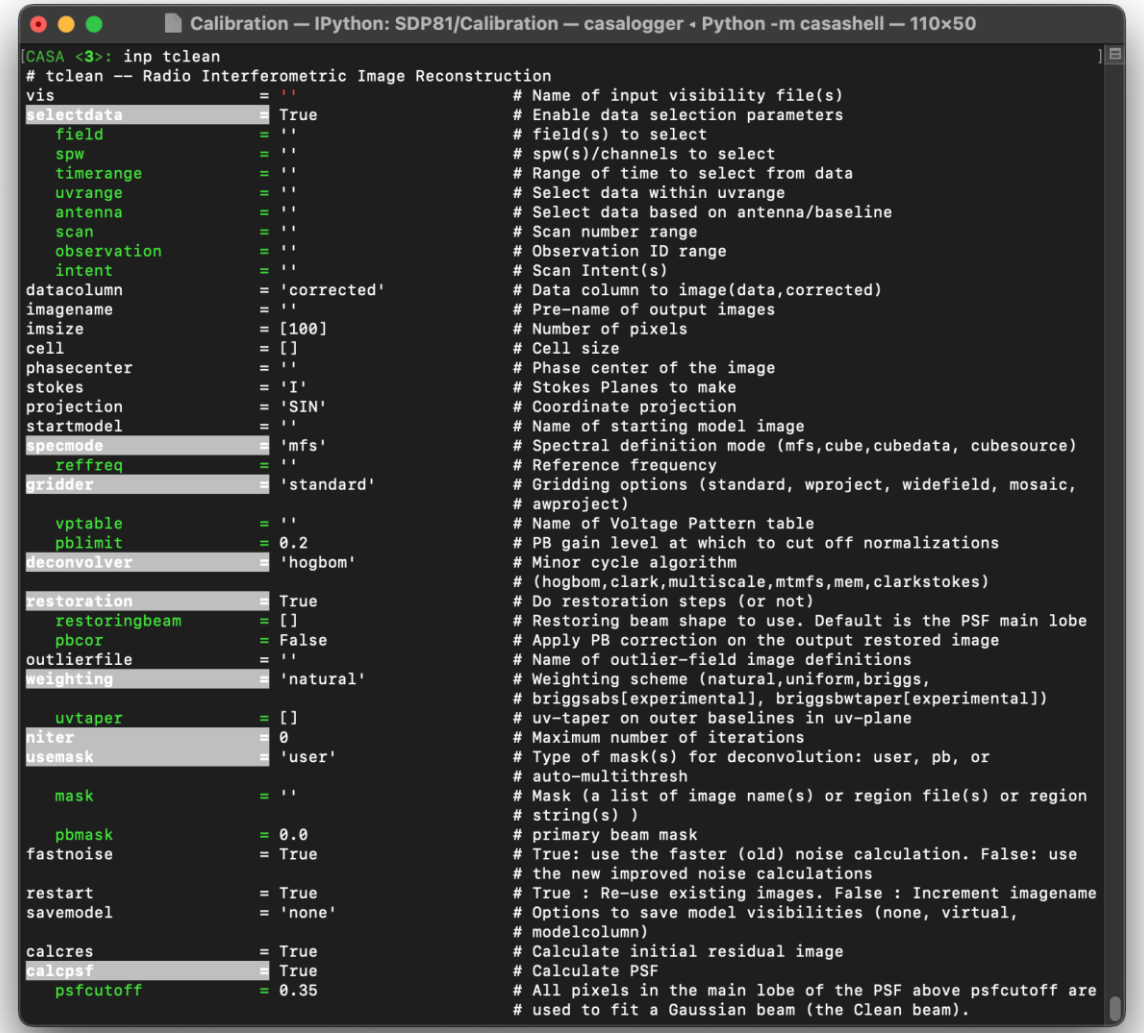
# Getting Started

Navigating to Your Data

Starting CASA

Task Help

**Running Tasks**



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# Getting Started

Navigating to Your Data

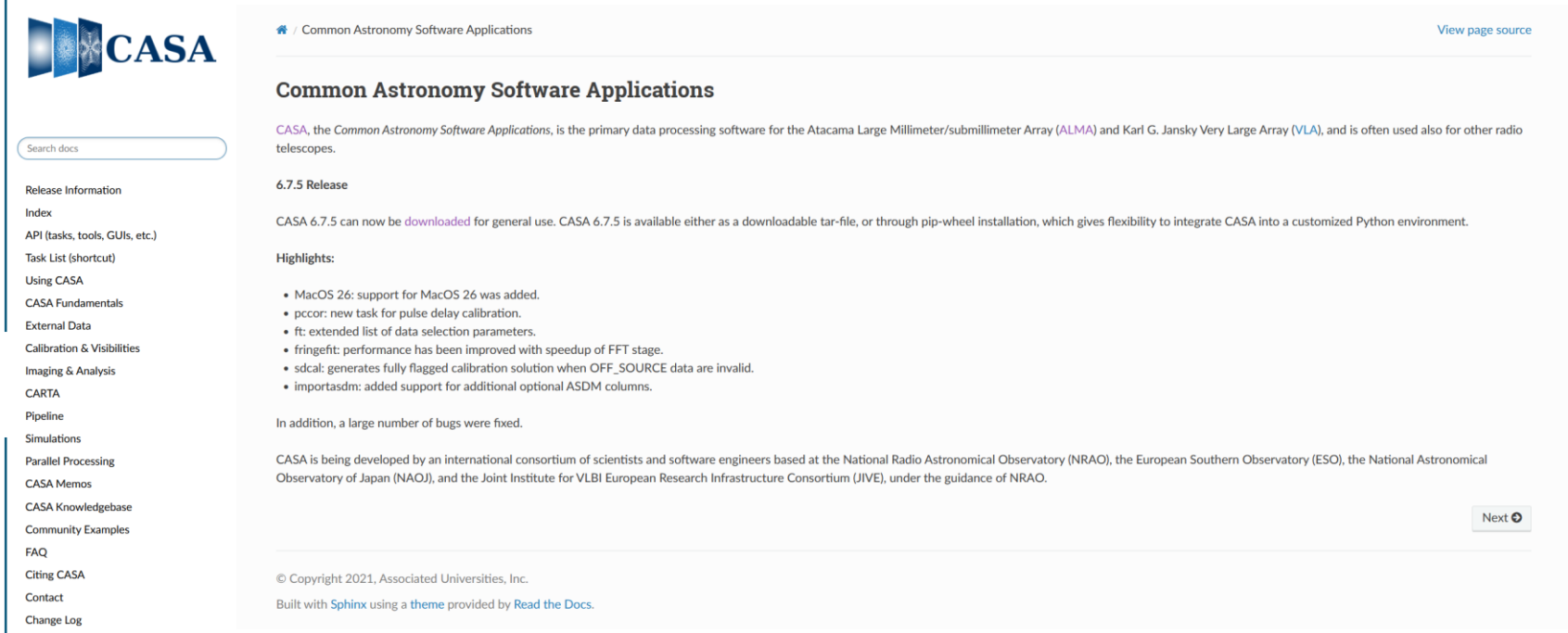
Starting CASA

Task Help

**Running Tasks**

# Getting Help:

https://casadocs.readthedocs.io/en/stable/



# Initial Calibration

# Data Preparation

**Importing your ASDM**

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

Downloading data from the ALMA archive will return raw data along with the scripts necessary for calibrating the data.

In this section, we will explain the steps taken to prepare the data for full calibration. This is an initial calibration that applies online corrections to the data.

- Import the raw data into a casa measurement set.
- Occasionally a dataset will require a fix to some of the metadata (i.e. the header). In this case, no table corrections are needed.
- Data that is known to be irrelevant to calibration or to be problematic (even without inspection of the data) is flagged. Examples: data taken when the telescope was not on source yet, when the system temperature load was too close to the beam, when the receivers were not yet tuned)
- Create 3 correction tables (WVR, Tsys, antenna positions) and apply them.
- The output of this initial calibration will be uid___A002_Xdf0444_X10bd.ms.split

# Data Preparation

**Importing your ASDM**

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

When downloading data from the ALMA archive, the data arrive in .asdm.sdm format. These data must be imported before processing. You may need to remove the .asdm.sdm file extension as well. The import will take a few minutes.

From calibration.py:

```
importasdm('uid___A002_Xdf0444_X10bd',
  asis='Antenna Station Receiver Source
  CalAtmosphere CalWVR CorrelatorMode SBSummary',
  bdfflags=True,  lazy=False,
  process_caldevice=False)
```

# Data Preparation

Importing your ASDM

**Table Corrections**

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

A dataset may require a fix to some of the metadata (i.e. the header). In this case, some coordinates in the metadata are adjusted.

This dataset does not require any of these corrections, and we are making efforts to fix data that required these fixes so that they are not necessary anymore. However, you may see something like the example below in some older scripts:

Unrelated Example:

```
es.fixForCSV2555('SDP81_B4_uncalibrated.ms')
fixsyscaltimes(vis = 'SDP81_B4_uncalibrated.ms')
```

# Data Preparation

Importing your ASDM

Table Corrections

**Initial Flaging**

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

We proceed by flagging the data which will not use for the calibration: pointing measurements and tsys measurements, as well as autocorrelations (correlations within a given antenna). Note that the information on tsys is still contained in the measurement step, as a table (which we extract later).

From data_prep.py:

```
flagdata(vis = 'uid___A002_Xdf0444_X10bd.ms',
  mode = 'manual',
  spw = '4~11,16~23',
  autocorr = True,
  flagbackup = False)

flagdata(vis = 'uid___A002_Xdf0444_X10bd.ms',
  mode = 'manual',
  intent = '*POINTING*,*ATMOSPHERE*',
  flagbackup = False)

flagcmd(vis = 'uid___A002_Xdf0444_X10bd.ms',
  inpmode = 'table',
  useapplied = True,
  action = 'plot',
  plotfile = 'uid___A002_Xdf0444_X10bd.ms.flagcmd.png')

flagcmd(vis = 'uid___A002_Xdf0444_X10bd.ms',
  inpmode = 'table',
  useapplied = True,
  action = 'apply')
```

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

**Online Correction: WVR**

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

The Water Vapor Radiometers (WVR) provide corrections to the phase delay due to the atmosphere.

- Key to correcting short-timescale phase variations
- Time variable phase calibration

12m antennas have WVRs.  However 7m datasets do not.

Do we need to apply WVR corrections to our data today?

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

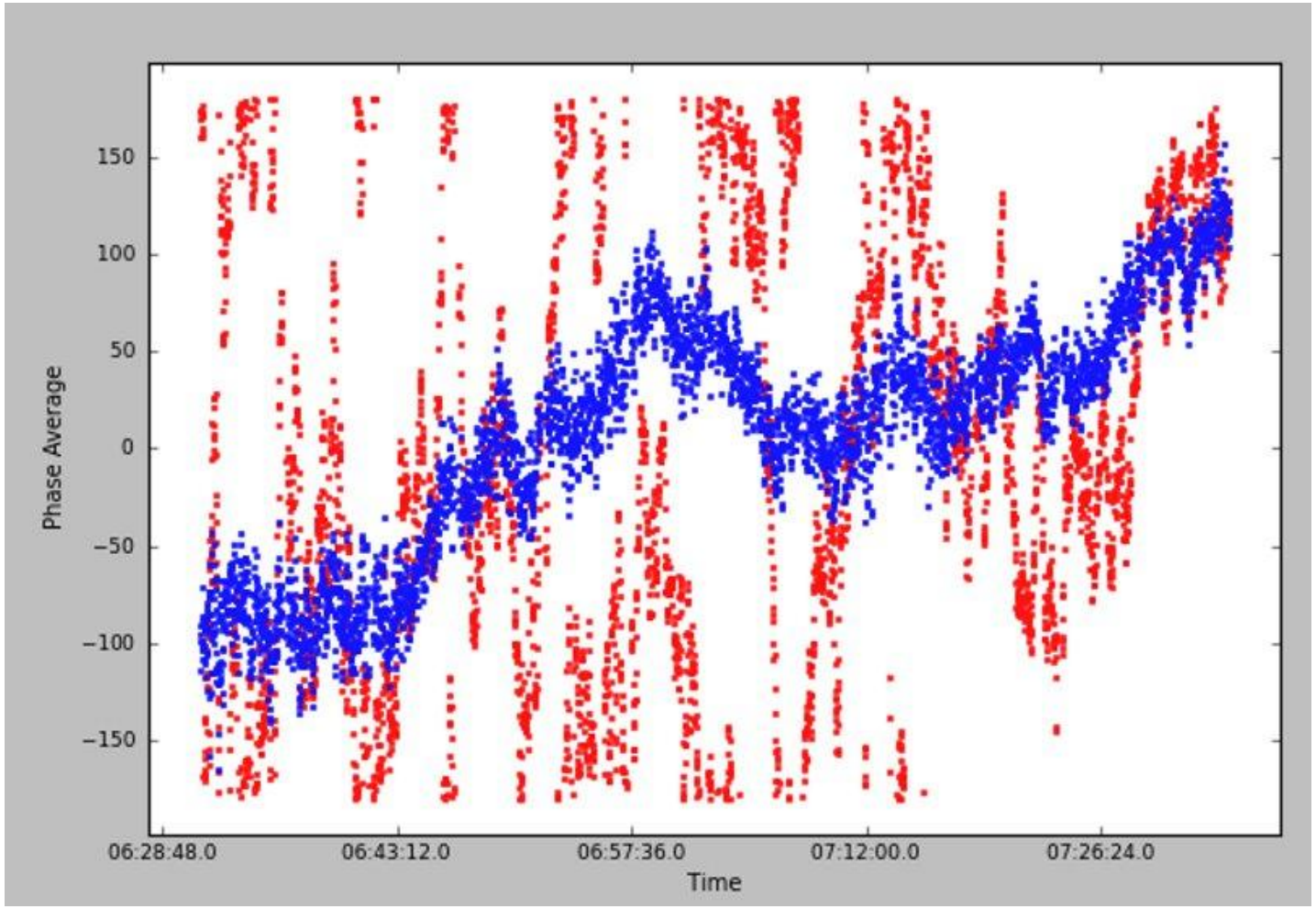
**Online Correction: WVR**

Online Correction: Tsys

Online Correction: Antenna Position

Applying Corrections and split

High Frequency data from TW Hydra to illustrate what WVR does.



# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

**Online Correction: Tsys**

Online Correction: Antenna Position

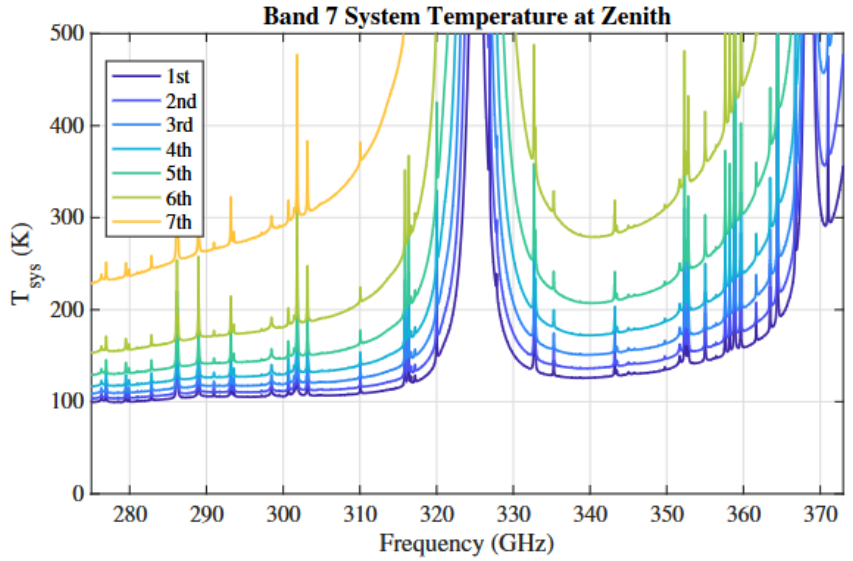
Applying Corrections and split

System Temperature (Tsys) corrections allow for the correction of atmospheric emission and opacity.

System Temperatures are important for

- Gain transfer across elevation
- Frequency dependent amplitude calibration

Tsys can vary from from ~50 K in Band 1 to ~1500 K in Band 10.



# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

**Online Correction: Tsys**

Online Correction: Antenna Position

Applying Corrections and split

## Tsys calibration table application:

From data_prep.py:

```
gencal(vis = 'uid___A002_Xdf0444_X10bd.ms',
    caltable = 'uid___A002_Xdf0444_X10bd.ms.tsys',
    caltype = 'tsys')
```

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

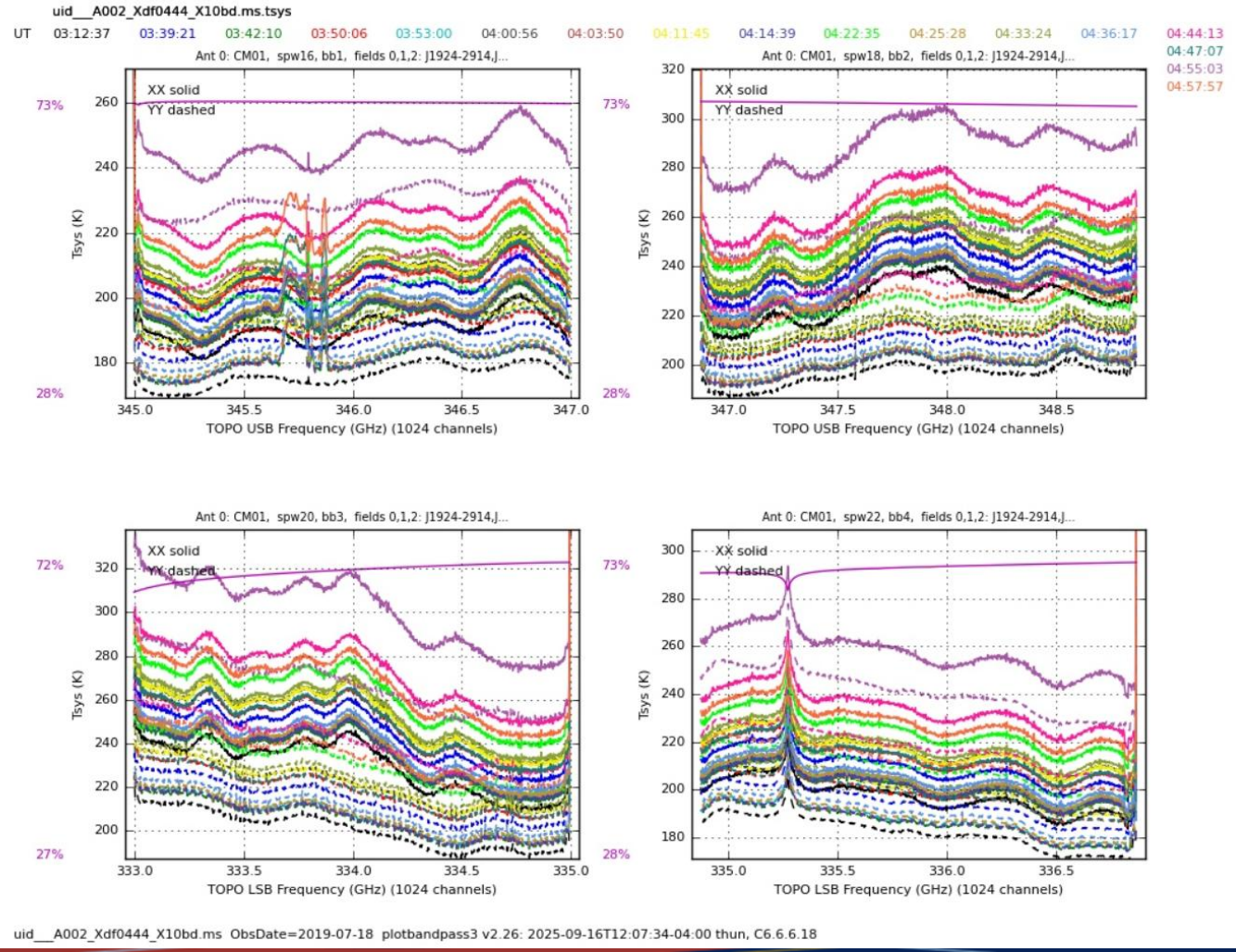
Online Correction: WVR

**Online Correction: Tsys**

Online Correction: Antenna Position

Applying Corrections and split

When looking at Tsys plots, look for very high spikes and discontinuities. These look okay, but some problems are there.



# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

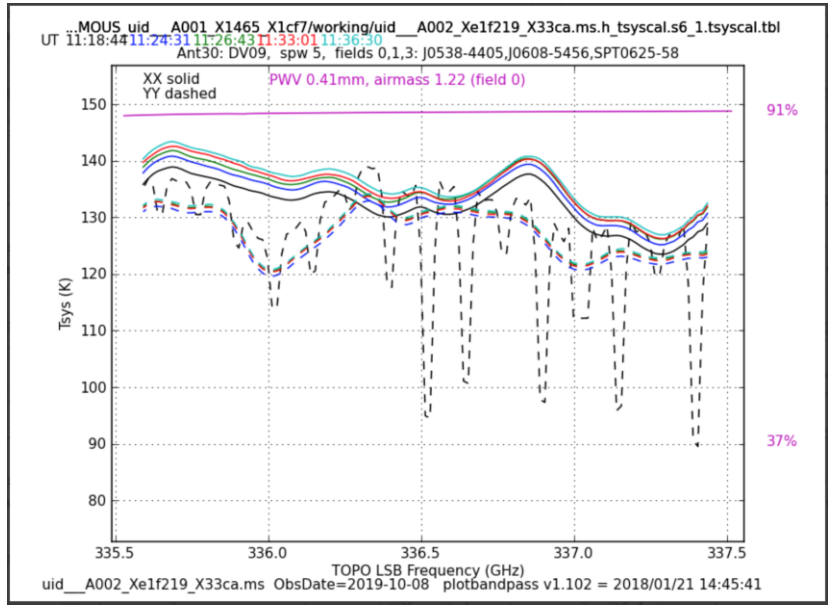
**Online Correction: Tsys**

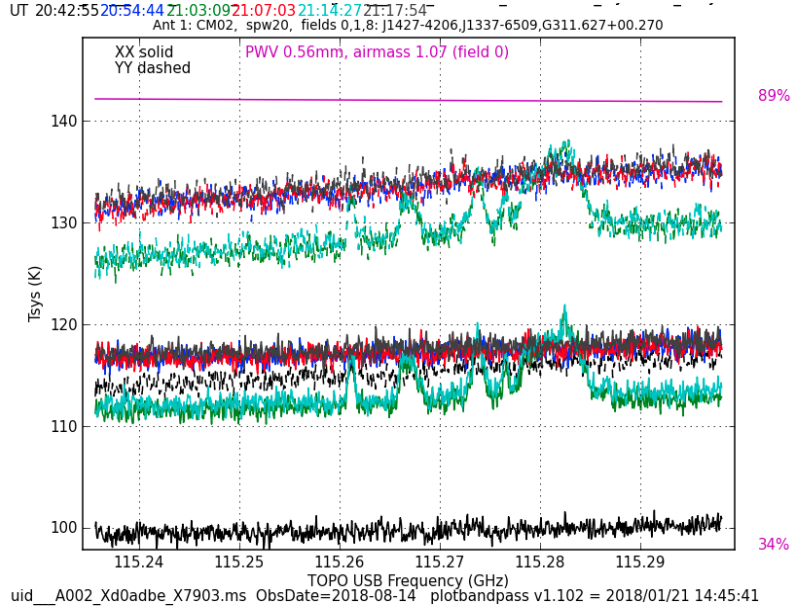
Online Correction: Antenna Position

Applying Corrections and split

When looking at Tsys plots, look for very high spikes and discontinuities.

On the right is an example of Tsys contamination from an astronomical source. The channels involved would need flagged so we can interpolate across the contamination.



# Data Inspection

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

**Online Correction: Tsys**

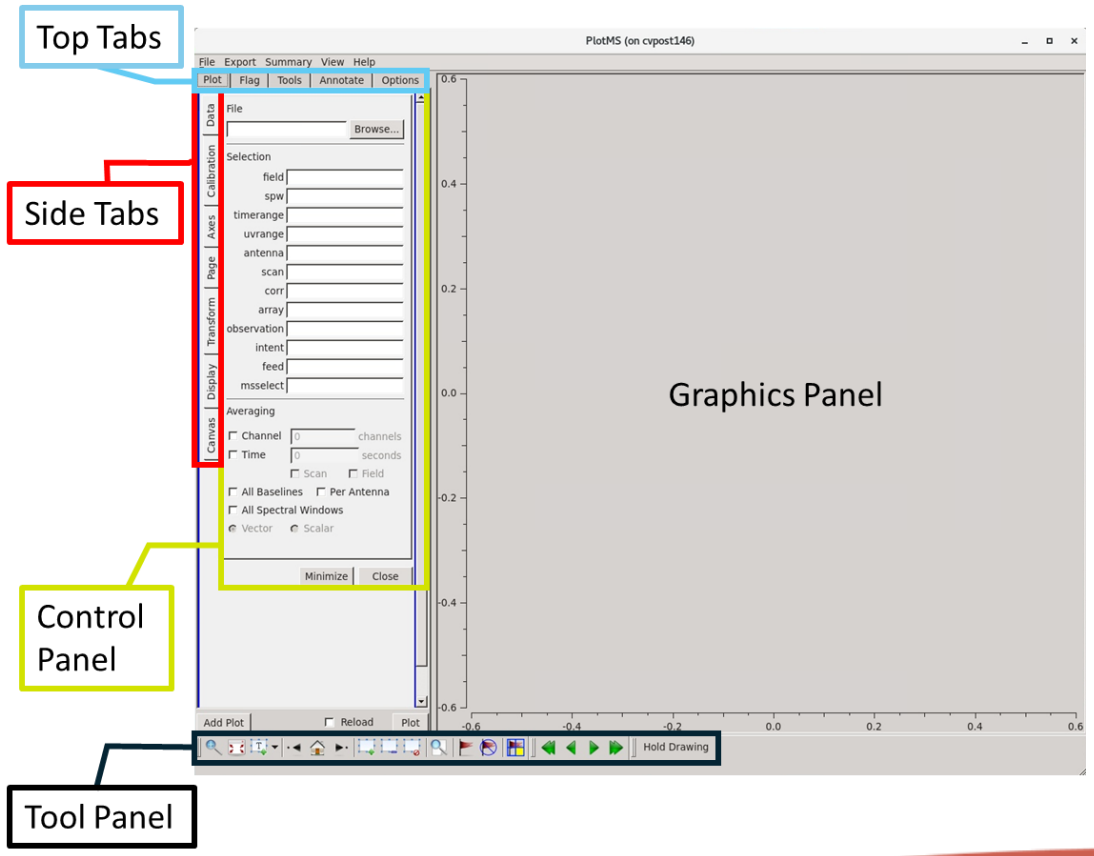
Online Correction: Antenna Position

Applying Corrections and split

Plotms is a general purpose graphical interface for plotting and flagging UV data and calibration tables.

You can start plotms from the CASA interface:

```
Plotms()
```



# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

**Online Correction: Tsys**

Online Correction: Antenna Position

Applying Corrections and split

## Sgr A* shows tsys contamination

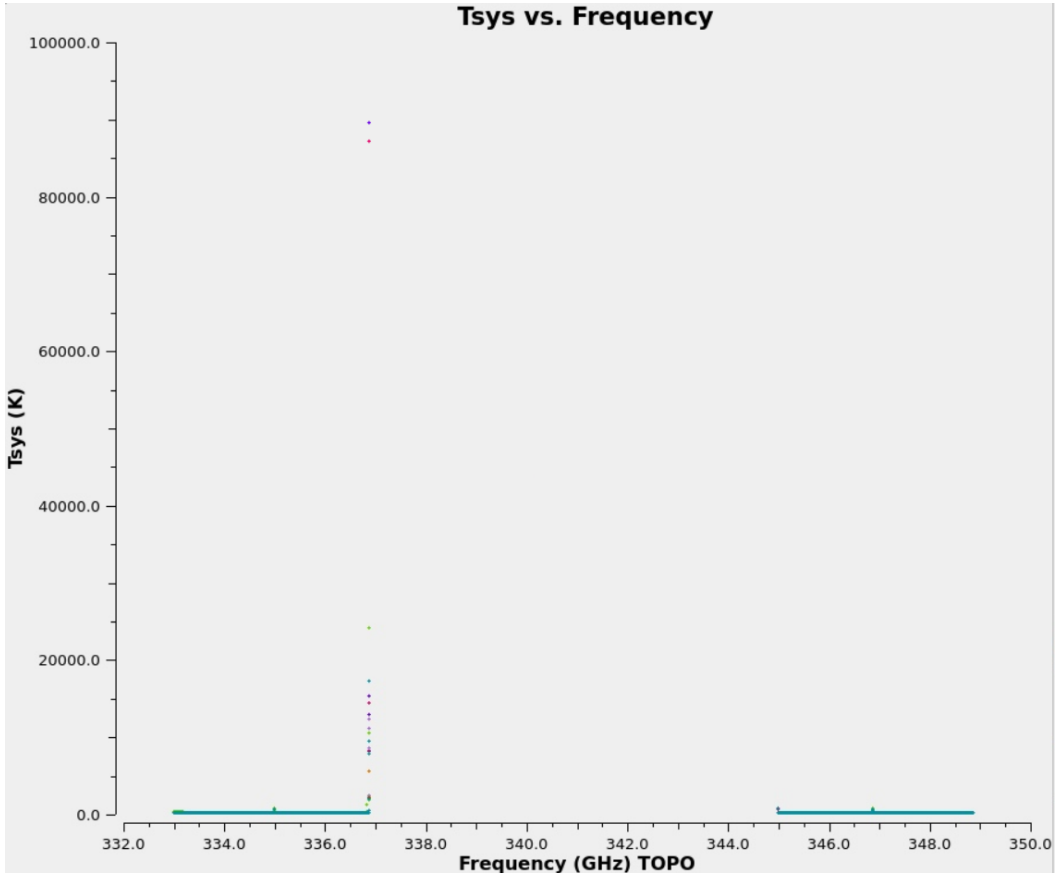
Start plotms(). We are going to make a plot!

We want to look at our tsys calibration table, plotting tsys vs frequency. We are going to average the data over all baselines, and color the points by scan.

1. In the side tab labeled “Data”, click on browse and select the file for the tsys table.
2. In the side tab labeled “Data”, check the box for all baselines.
3. In the side tab labeled “Axis”, select the axis to be Tsys vs frequency. Make sure the data column is “data”.
4. In the side tab labeled “Display” select “Colorize” and choose to colorize by scan.

# Question: Plotms

- From the graph, can you tell what spectral window is which?
- What features stand out to you?




**Expected plotms output**

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

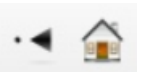
Online Correction: WVR

**Online Correction: Tsys**

Online Correction: Antenna Position

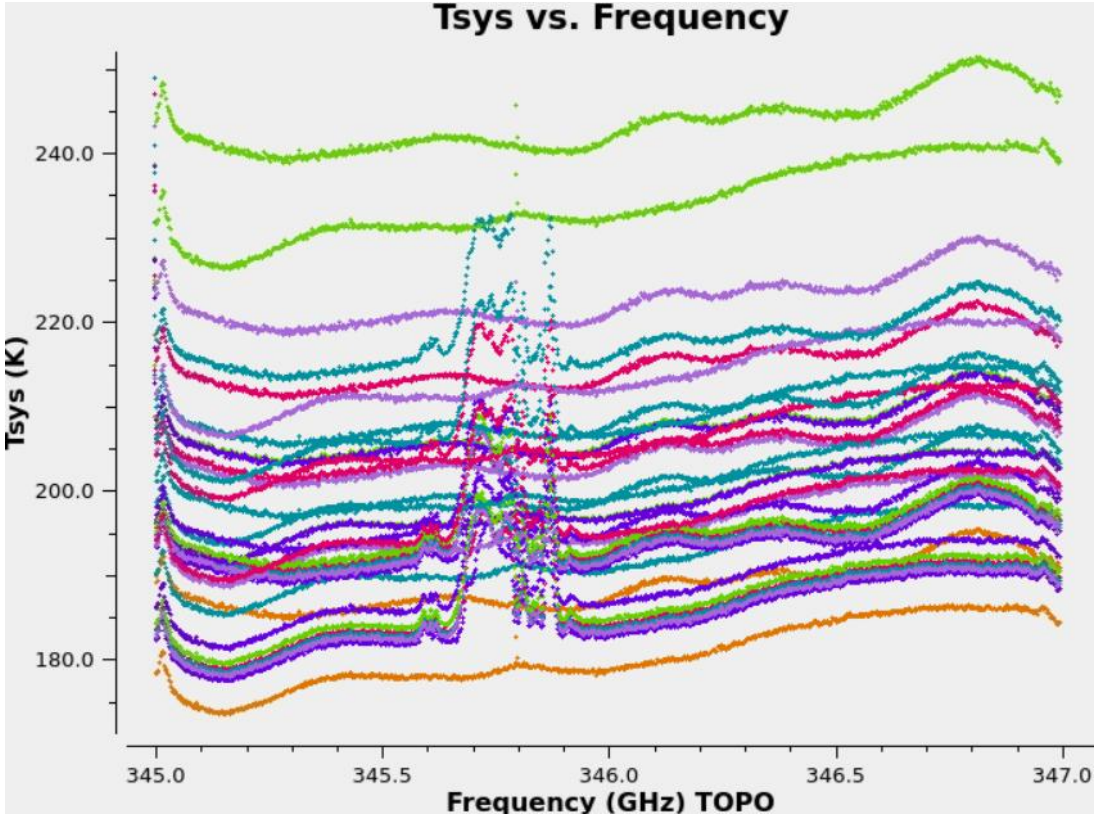
Applying Corrections and split

Sgr A* shows tsys contamination

- Highlight points with  and click locate (  ).
- Zoom in using 
- Zoom back out using 

# Question: Tsys

- Can you find the channels affected by the Tsys contamination?




**SPW 16 Tsys plot**

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

**Online Correction: Antenna Position**

Applying Corrections and split

Antenna position corrections update the accuracy of the antenna positions.

The positions are in meters with respect to the International Terrestrial Reference Frame (IRTF) [Earth center of mass] and normally look like this:

```
antposdict = {'data': {
'CM05': [2225063.546167333, -5440128.205156475, -2481550.0793227106],
'CM04': [2225074.0678211474, -5440115.249666032, -2481568.943718657],
'CM03': [2225076.734637714, -5440122.932431717, -2481549.8241761364],
'CM02': [2225070.958073706, -5440127.671532504, -2481544.654997596],
'CM01': [2225080.355326109, -5440132.95741112, -2481524.789694901],
'CM12': [2225089.4383623223, -5440119.773868732, -2481545.3989717225],
'CM11': [2225065.4337490173, -5440120.432743067, -2481565.3131666067],
'CM10': [2225078.929314356, -5440126.085415632, -2481541.021137885],
'CM08': [2225063.532861316, -5440134.134661704, -2481537.2018038123],
'CM07': [2225090.999713028, -5440126.601164743, -2481529.1336666625],
'CM06': [2225084.240627651, -5440114.9985198965, -2481560.411347928]},
'metadata': {'caltype': 'ALMA antenna positions', 'description': 'ALMA ITRF antenna
positions in meters', 'product_code': 'antposalma', 'outfile': 'tmp_antennapos.json',
'hosts': ['https://asa.alma.cl/uncertainties-
service/uncertainties/versions/last/measurements/casa/'], 'asdm':
'uid://A002/Xdf0444/X10bd', 'search': 'auto', 'successful_url':
'https://asa.alma.cl/uncertainties-
service/uncertainties/versions/last/measurements/casa//?asdm=uid%3A%2F%2FA002%2FXdf0444%2FX
10bd&search=auto', 'timestamp': '2026-01-21 14:17:38.984734'}}
```

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

**Online Correction: Antenna Position**

Applying Corrections and split

Our dataset did require antenna position corrections. (How did I know?)

However, we should still follow this step to make sure that the positions are correct even if not all datasets require the update. Write the dictionary to a .json file and then generate the calibration table.

From calibration.py:

```
with open('antennapos.json', 'w') as f:
  json.dump(antposdict, f)


gencal(vis='uid___A002_Xdf0444_X10bd.ms',
  caltype='antpos',
  infile='antennapos.json',
  caltable='uid___A002_Xdf0444_X10bd.ms.antpos')
```

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

**Applying Corrections and split**

Finally, we apply our corrections and split out the data.

Tsysmap is a list mapping each SPW to the tsys SPW it uses for calibration.

From calibration.py:

```
tsysmap = tsysspwmap(vis = 'uid___A002_Xdf0444_X10bd.ms', tsystable
= 'uid___A002_Xdf0444_X10bd.ms.tsys', tsysChanTol = 1)


applycal(vis = 'uid___A002_Xdf0444_X10bd.ms',
  field = '0',
  spw = '16,18,20,22',
  gaintable = ['uid___A002_Xdf0444_X10bd.ms.tsys',
'uid___A002_Xdf0444_X10bd.ms.antpos'],
  gainfield = ['0', ''],
  interp = 'linear,linear',
  spwmap = [tsysmap,[]],
  calwt = True,
  flagbackup = False)
```

# Data Preparation

Importing your ASDM

Table Corrections

Initial Flaging

Online Correction: WVR

Online Correction: Tsys

Online Correction: Antenna Position

**Applying Corrections and split**

Repeat this step for field 1 and field 2. We will then split out the data.

```
mstransform(vis = 'uid___A002_Xdf0444_X10bd.ms',
  outputvis = 'uid___A002_Xdf0444_X10bd.ms.split',
  datacolumn = 'corrected',
  spw = '16,18,20,22',
  reindex = False,
  keepflags = True)
```

This will complete the data preparation!

# Discussion

- Before we move on, what are your questions, comments, and concerns?

**ALMA PM Antenna at Night**

# Data Inspection

# Data Inspection

**Viewing Observation Information**

Plotting Antenna Distribution

Viewing Uncalibrated Data

We are going to inspect our data to learn about the observation and check for problems.

We are still following the calibration.py script if you want to copy the commands and follow along.

Jim Torson analyzes data from the Very Large Array in its computer room in 1983. (Image Credit: NRAO)

# Data Inspection

**Viewing Observation Information**

Plotting Antenna Distribution

Viewing Uncalibrated Data

Lets start by looking at a summary of the measurement set.

Use the task `listobs()`

**From calibration.py:**

```
listobs("uid___A002_Xdf0444_X10bd.ms.split")
```

# Question: Listobs

After taking a look at the listobs output in the logger window, what information do you see that you think may be useful during processing?

You can write your listobs to a file using:

```
listobs(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
 listfile = 'uid___A002_Xdf0444_X10bd.ms.split.listobs')
```

# Data Inspection

**Viewing Observation Information**

Plotting Antenna Distribution

Viewing Uncalibrated Data

Lets start by looking at a summary of the measurement set.

Use the task `listobs()`

```
listobs("uid___A002_Xdf0444_X10bd.ms.split")
```

```
MeasurementSet Name:  uid___A002_Xdf0444_X10bd.ms.split
MS Version Fields: 4
Fields: 3  ID   Code Name                RA               Decl           Epoch   SrcId      nRows
0   none J1924-2914          19:24:51.055956 -29.14.30.12106 ICRS    0          33000
1   none J1700-2610          17:00:53.154063 -26.10.51.72542 ICRS    1          39072
2   none SgrAstar            17:45:40.038000 -29.00.28.06900 ICRS    2          88968

Spectral Windows:  (4 unique spectral windows and 1 unique polarization setups)  SpwID  Name #Chans   Frame   Ch0(MHz)  ChanWid
TotBW(kHz) CtrFreq(MHz) BBC Num  Corrs
16  X67236705#ALMA_RB_07#BB_1#SW-01#FULL_RES   1024   TOPO  344996.785      1953.125   2000000.0 345995.8086        1  XX  YY
18  X67236705#ALMA_RB_07#BB_2#SW-01#FULL_RES   1024   TOPO  346871.763      1953.125   2000000.0 347870.7859        2  XX  YY
20  X67236705#ALMA_RB_07#BB_3#SW-01#FULL_RES   1024   TOPO  334994.897     -1953.125   2000000.0 333995.8738        3  XX  YY
22  X67236705#ALMA_RB_07#BB_4#SW-01#FULL_RES   1024   TOPO  336869.897     -1953.125   2000000.0 335870.8738        4  XX  YY
```

# Data Inspection

Viewing Observation Information

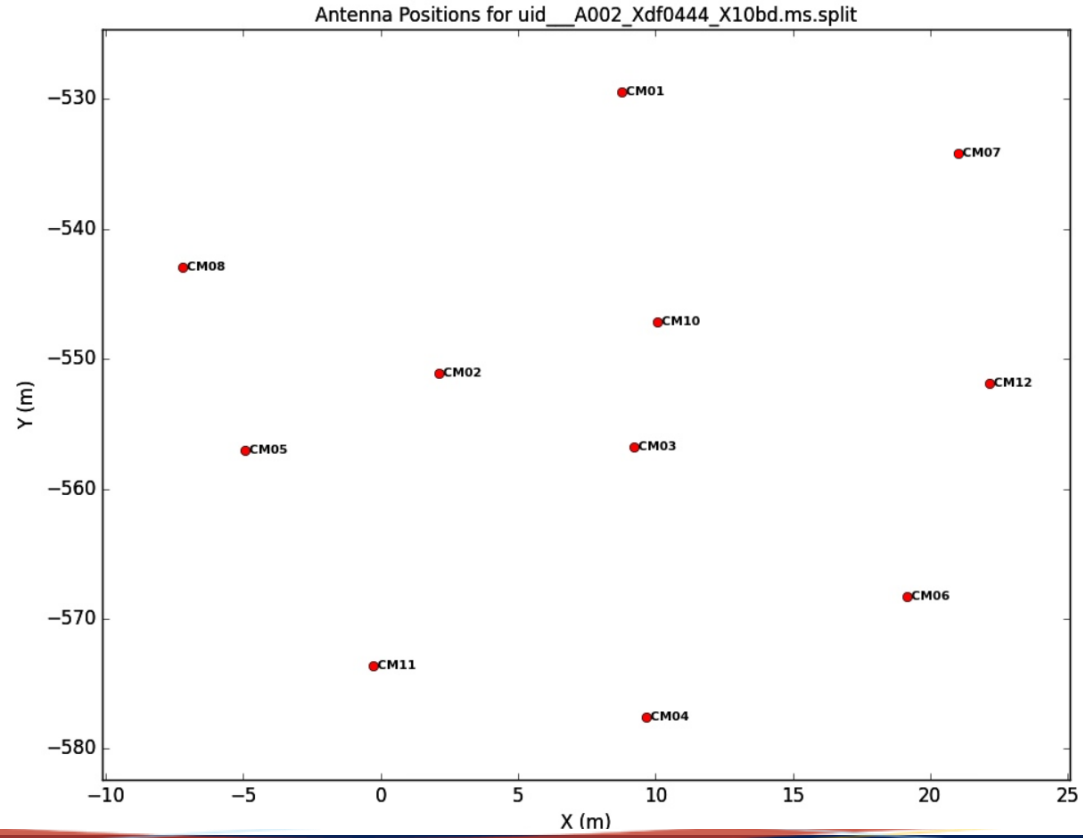
**Plotting Antenna Distribution**

Viewing Uncalibrated Data

Now, we will plot the antenna distribution using listobs()

From calibration.py:

```
plotants("uid___A002_Xdf0444_X10bd.ms.split",
    figfile="plotants.png")
```



# Question: Reference Antenna

- When calibrating, we typically want a reference antenna that is well behaved and towards the center of the array.

- What antennas do you think would work out well?

# Data Inspection

Viewing Observation Information

**Plotting Antenna Distribution**

Viewing Uncalibrated Data

We are going to choose CM12 as our reference antenna.  This will be used in all commands going forward.

WAIT?!?

I just said we wanted to use an  antenna in the center of the array?

Well, I didn't notice before I sent out the script…  Also, the 7m array is small enough that it is not a big deal.

# Data Inspection

Viewing Observation Information

Plotting Antenna Distribution

**Viewing Uncalibrated Data**

Plotms is a general purpose graphical interface for plotting and flagging UV data and calibration tables.

You can start plotms from the CASA interface:

```
Plotms()
```

You can also fully specify the plotms command from the command line. For example:

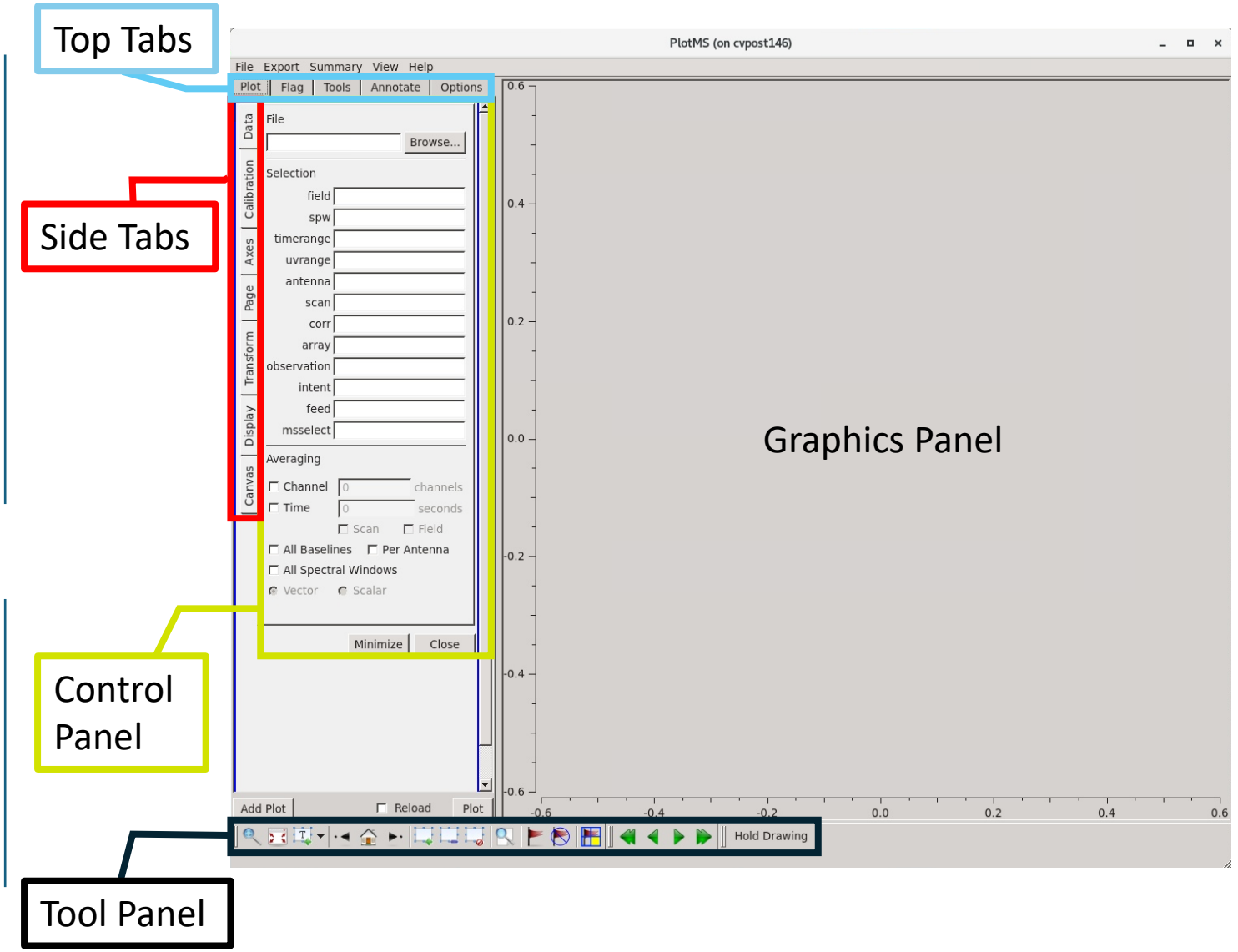
```
plotms(vis="uid___A002_Xdf0444_X10bd.ms.split",
 xaxis="time", yaxis="amp",
 averagedata=True,
 avgchannel="1e3",
 coloraxis="field")
```

# Data Inspection

Viewing Observation Information

Plotting Antenna Distribution

**Viewing Uncalibrated Data**



# Data Inspection

Viewing Observation Information

Plotting Antenna Distribution

**Viewing Uncalibrated Data**

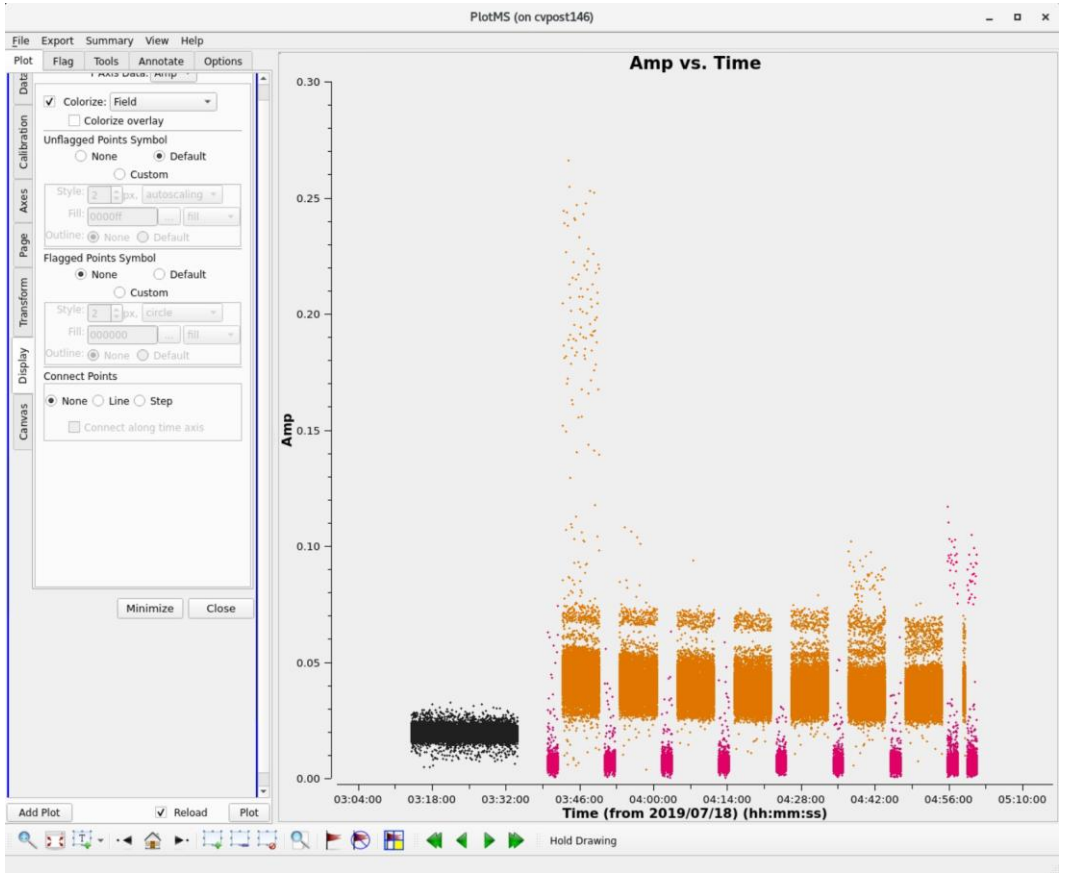
Start plotms(). We are going to make more plots!

We want to look at uid___A002_Xdf0444_X10bd.ms.split, plotting amplitude vs time. We are going to average the data by channel, and color the points by field.

1. In the side tab labeled “Data”, click on browse and select the file measurement set.
2. In the side tab labeled “Data”, check the box for Channel averaging. Then enter a number that averages all the channels (in an spw) together. (Look at your listobs output!)
3. In the side tab labeled “Axis”, select the axis to be Amplitude vs Time. Make sure the data column is “data”.
4. In the side tab labeled “Display” select “Colorize” and choose to colorize by field.

# Question: Plotms

- From the graph, can you tell what source is the science target?
- Did you look at some of the options?  What were some?
  - Axis options?
  - Colorize options?

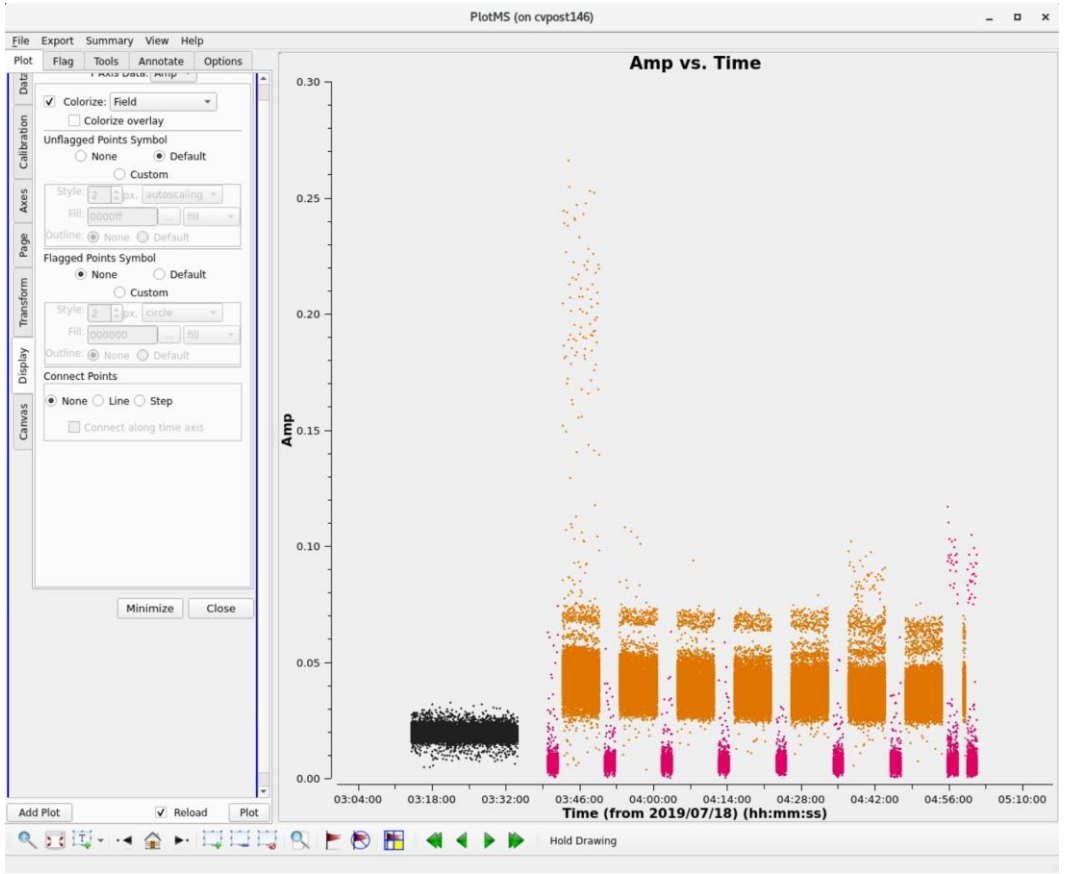



**Expected plotms output**

# Your Turn:

- Make a plot using plotms of the uncalibrated data using a different combination of axis. Ask an assistant if you need assistance!

- What combo did you use?  Did you run into any difficulties.



# Calibration

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

Renormalization Correction

Applying the Calibration

Checking the Calibration

We are finally ready to discuss calibration!

Derive Calibration Tables

- setjy: set “model” (correct) visibilities using known model for a calibrator
- bandpass: calculate bandpass calibration table (amp/phase vs frequency)
- gaincal: calculate temporal gain calibration table (amp/phase vs time)
- fluxscale: apply absolute flux scaling to calibration table from known source

Manipulate Your Measurement Set

- flagdata/flagcmd/flagmanager: flag (remove) bad data
- applycal: apply calibration table(s) from previous steps
- split: split off calibrated data from your ms

Inspect Your Data and Results

- plotms: inspect your data and calibration tables interactively

# Calibration



Before proceeding, we want to save the flagging of our data. This is good practice in case a mistake is made later.

Only run this once. The if statement before this in **calibration.py** will ensure it is not run twice.

```
flagmanager(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
    mode = 'save',
    versionname = 'Original')
```

Later, if you want to restore to the original flagging state, we can restore the flags to this original state using:

From **calibration.py**

```
flagmanager(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
    mode = 'restore',
    versionname = 'Original')
```

# Calibration



Initial Flagging includes data we know to be problematic even without visual inspection:

**Shadowing**

- Issue at low elevations
- Issue for compact arrays

In CASA:

```
flagdata(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  mode = 'shadow’,
  flagbackup = False)
```

**Observing Log**

- Many observatories will note weather or hardware problems that affect the data.

**Other obvious errors**

- Edge Channels

In CASA

```
flagdata(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  mode = 'manual',
  spw =
  '16:0~6;1019~1023,18:0~6;1019~1023,20:0~6;1019~1023,22:
  0~6;1019~1023',
  flagbackup = False)
```

# Calibration

Saving Flagging State

**Flagging Known Bad Data**

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

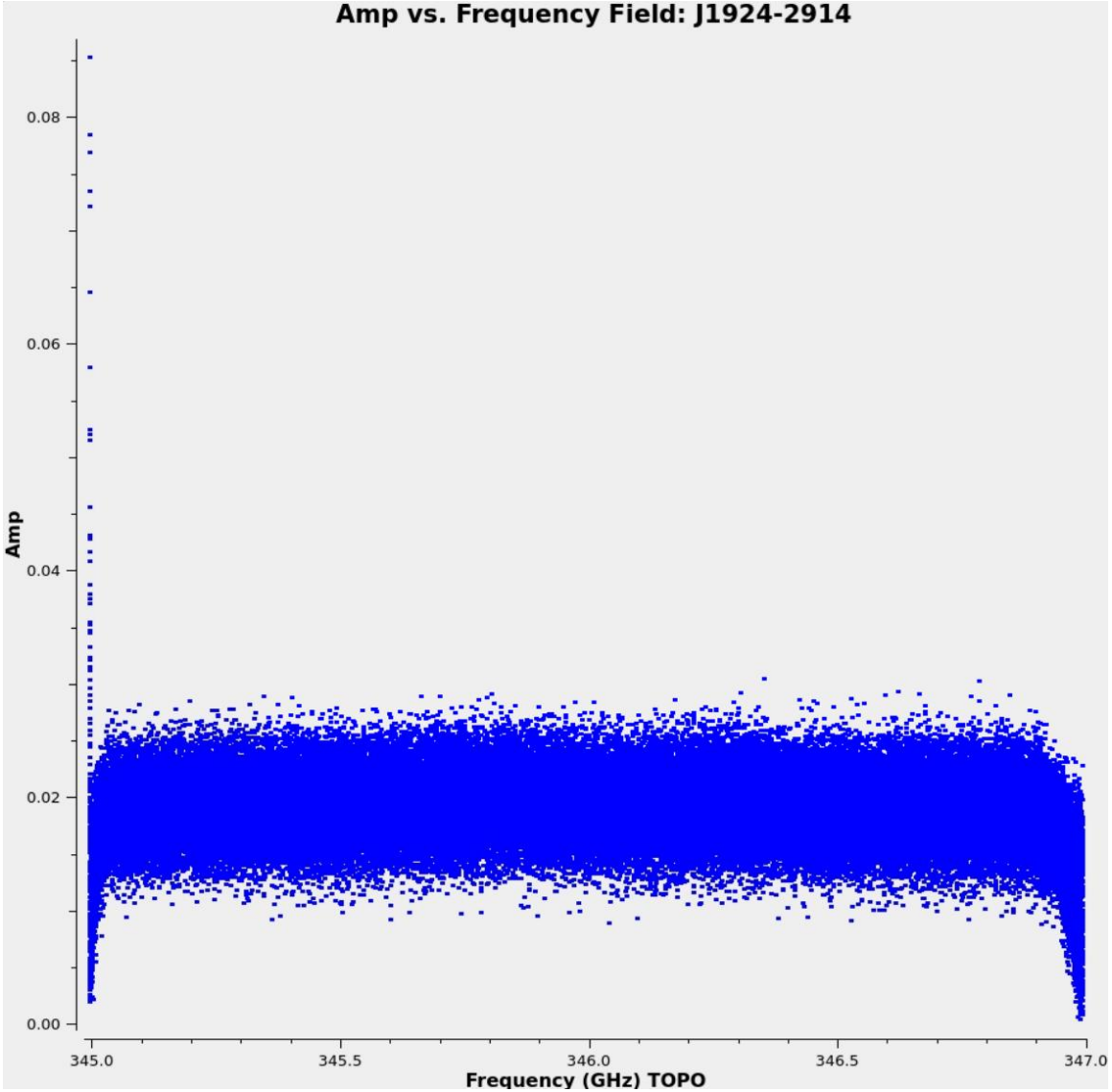
Gain Calibration

Setting the Flux Scale

Renormalization Correction

Applying the Calibration

Checking the Calibration



# Calibration

Saving Flagging State

Flagging Known Bad Data

**Other Flags**

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

Renormalization Correction

Applying the Calibration

Checking the Calibration

Your first time though the data, no other flags are applied.

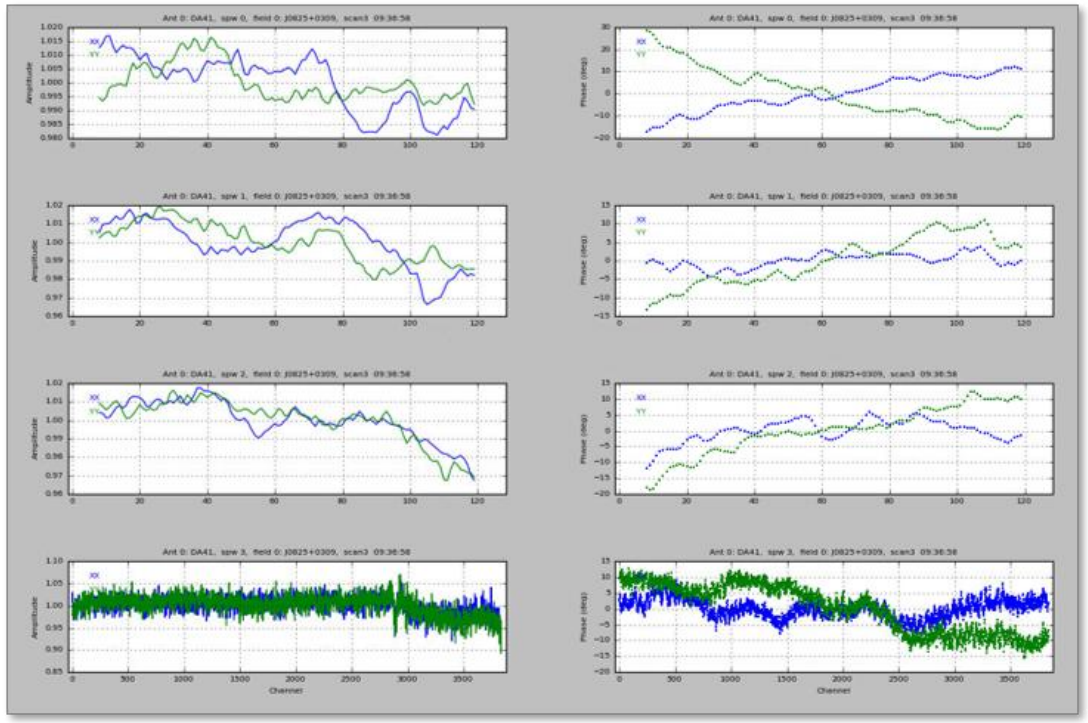
After the rest of the calibration, if you identify any bad data, flags are placed in this part of the script.

As you can see, most of the bad data are from edge channels. These will be flagged anyway.

So we will skip this for now.

# Question: Bandpass

Why is bandpass calibration important?



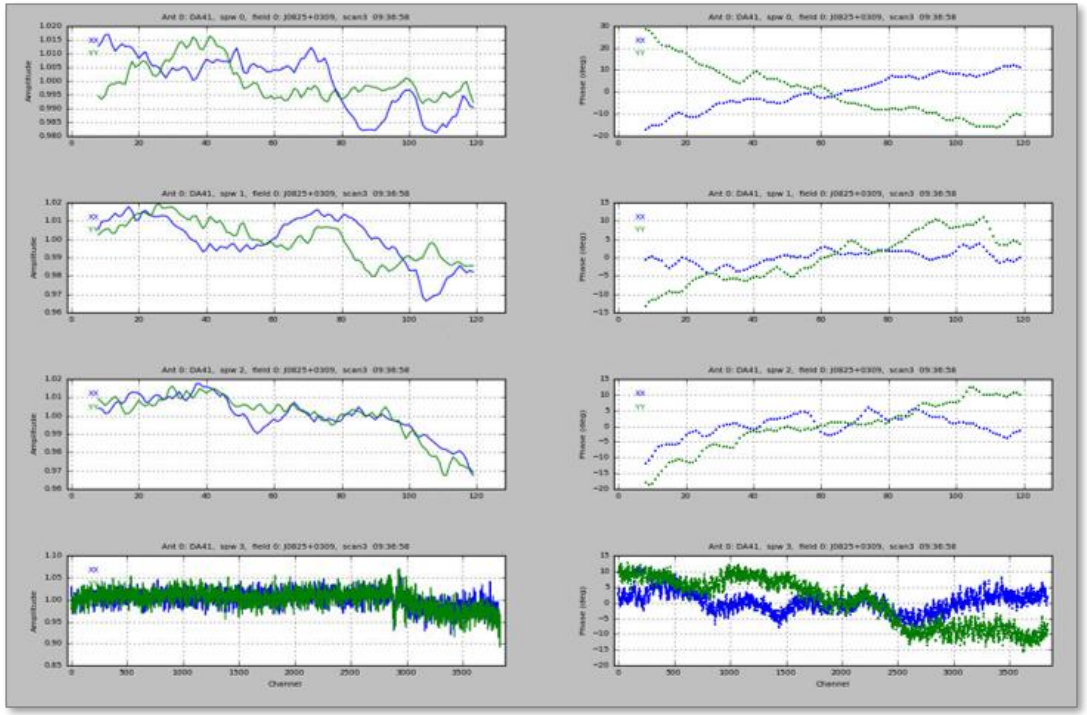
**A sample of bandpass solutions.**

# Question: Bandpass

Why is bandpass calibration important?

Bandpass Calibration allows us to correct for the frequency dependent part of the gains $\left(B_{ij}(t,\nu)\right)$.

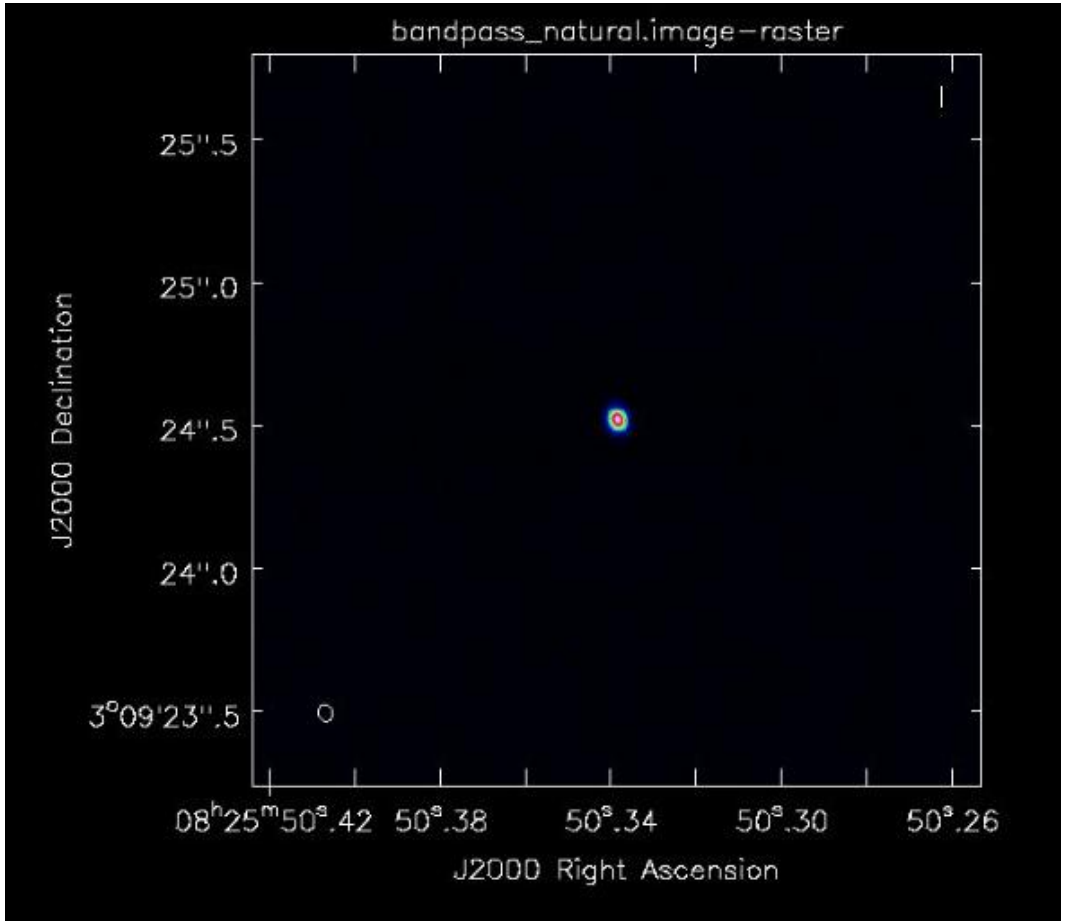
$B_{ij}$ is usually treated as constant over the length of an observation but may have a slow time dependence.



**A sample of bandpass solutions.**

# Question: Bandpass

What makes a good bandpass calibrator?




**Bandpass Calibrator J0825+0309**

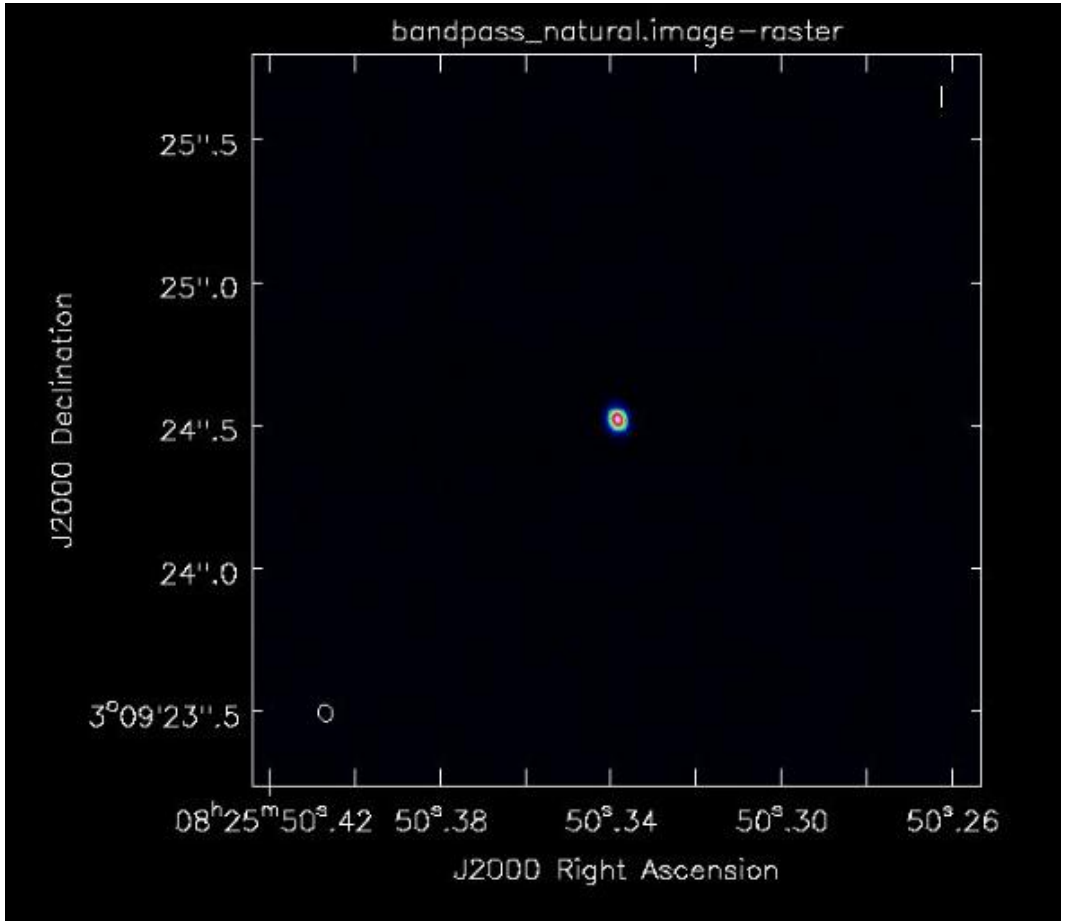
# Question: Bandpass

## What makes a good bandpass calibrator?

Best targets are bright, flat-spectrum sources with featureless spectra

- Although point-source not absolutely required, beware frequency dependence of resolved sources
- If necessary, can specify a spectral index using *setjy*

Don’t necessarily need to be near science target on the sky




**Bandpass Calibrator J0825+0309**

# Question: Bandpass

Bandpass corruption is typically antenna-based.

Does this give us any advantages compared to a baseline-based calibration?

# Question: Bandpass

Bandpass corruption is typically antenna-based.

Does this give us any advantages compared to a baseline-based calibration?

Yes, this means we have N-1 baselines to consider. The problem is over-determined.

# Calibration



- We will use *gaincal* to measure time variation of phase
- Then use *bandpass* task
  - We will calibrate channel-to-channel variation (preferred method)
  - Alternatively, could fit a smooth function
  - Pay close attention to solutions; e.g. bright calibrators are rare, esp. at Bands 8, 9, and 10
- Use *applycal* to apply the bandpass solution to other sources

# Calibration



Using the Listobs output, determine which source is the bandpass.

- This is J0825+0309 (identified as field 0).

Run the following command:

```
gaincal(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.ap_pre_bandpass',
  field = '0', # J1924-2914
  spw = '16:0~1023,18:0~1023,20:0~1023,22:0~1023',
  scan = '3',
  solint = 'int',
  refant = 'CM12',
  calmode = 'p')
```

# Calibration



While gaincal runs:

Gaincal is the general purpose task to solve for time-dependent amplitude and phase variations for each antenna.

Here we carry out a short-timescale phase (“p”) solution ("int") on the bandpass calibrator. This is saved as a calibration table "phase_int_bpass.cal".

We only fit the phase to the central channels to avoid edge channel effects.

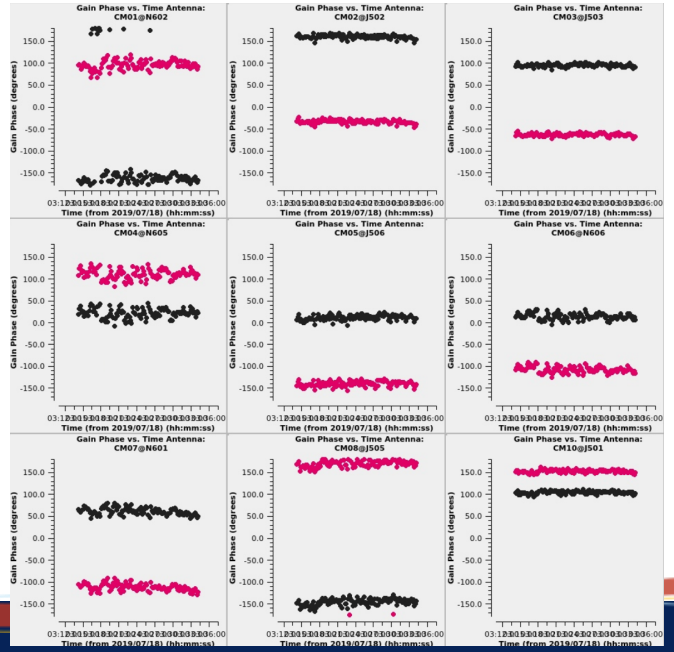
The Field and scan designations are redundant, but good to make sure the correct data for the solve.

# Calibration



Plot the solutions using plotms!

- Plot the phase_int_bpass.cal table in  phase vs time.  Spw 0 only.  Color by correlation.
- Under the side tab labeled Axis, set the range on phase to be -180 to +180 degrees.
- New this time: iteration axis! Under the page tab, select axis => antenna
- Under the top tab labeled “Options”, set rows and columns both to three.
- Use the tool panel buttons  to navigate the plots.



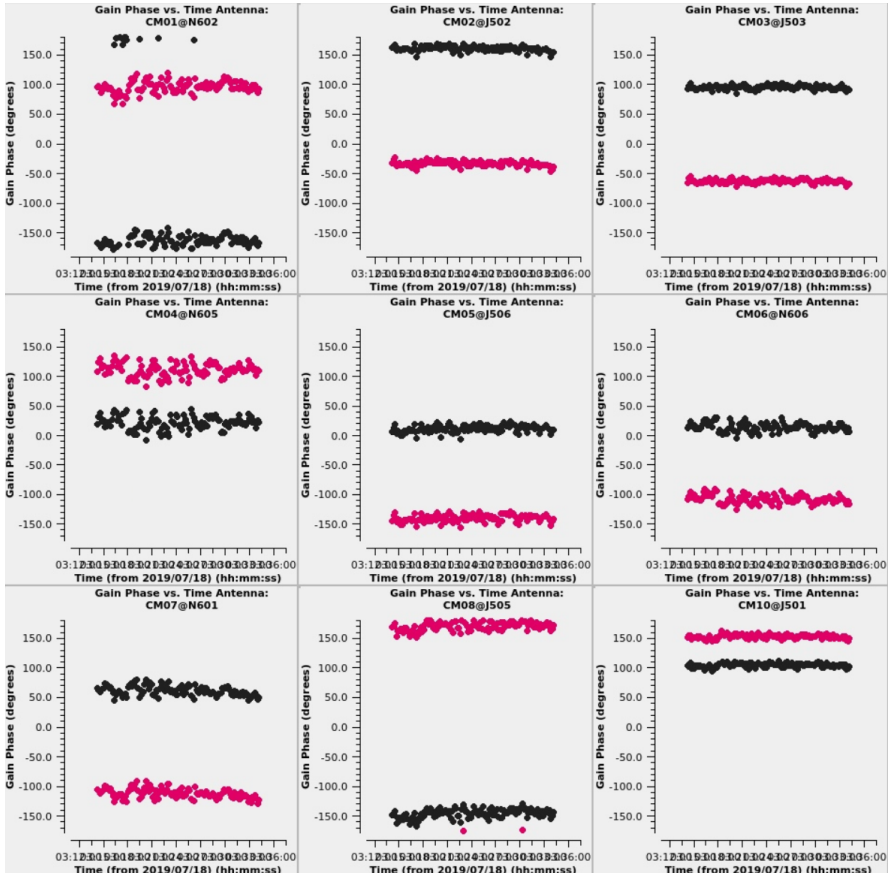



National Radio Astronomy Observatory

# Question: Phases

A few plots stand out in our phase solutions.

- Why does the phase plot for CM12 have the shape it has?
- What is the cause of the discontinuities for CM01?




**Good phase plots for the bandpass.**

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

**Bandpass Calibration**

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

Renormalization Correction

Applying the Calibration

Checking the Calibration

Now we will carry out a bandpass solution. This will solve for the amplitude and phase corrections needed for each channel on a per-antenna basis.

Lets run the bandpass task:

```
bandpass(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.bandpass’,
  field = '0', # J1924-2914
  scan = '3’,
  solint = 'inf’,
  combine = 'scan’,
  refant = 'CM12’,
  solnorm = True,
  bandtype = 'B’,
  gaintable = 'uid___A002_Xdf0444_X10bd.ms.split.ap_pre_bandpass')
```

# Calibration



While that is running:

- We use gaintable to feed the short-timescale phase solution to the task.
  - This table will be applied before the bandpass solution is carried out.
- We have not flux calibrated yet, so we are determining a normalized solution with solnorm=True.
- Solint=inf and combine=scan combines all data.
- Bandtype = B is the standard

# Question: Bandpass

Why is it okay to combine all the bandpass data together?


**ALMA CM and PM antennas**

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

**Bandpass Calibration**

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

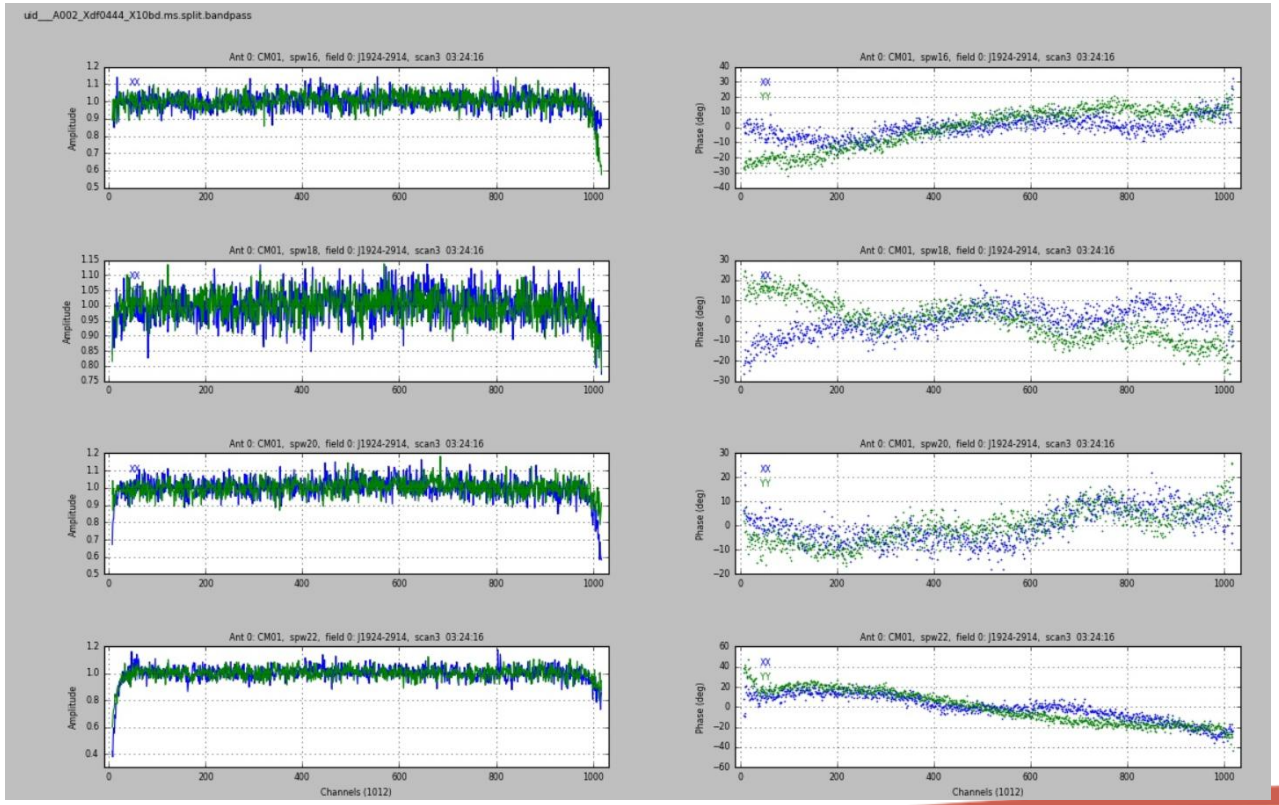
Renormalization Correction

Applying the Calibration

Checking the Calibration

We are going to use the plotbandpass() task to plot the bandpass solutions.

```
plotbandpass(
caltable="uid___A002_Xdf0444_X10bd.ms.split.bandpass",
     xaxis="chan",
     yaxis="both",
     subplot=42)
```



# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

**Checking Bandpass Calibration**

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

Renormalization Correction

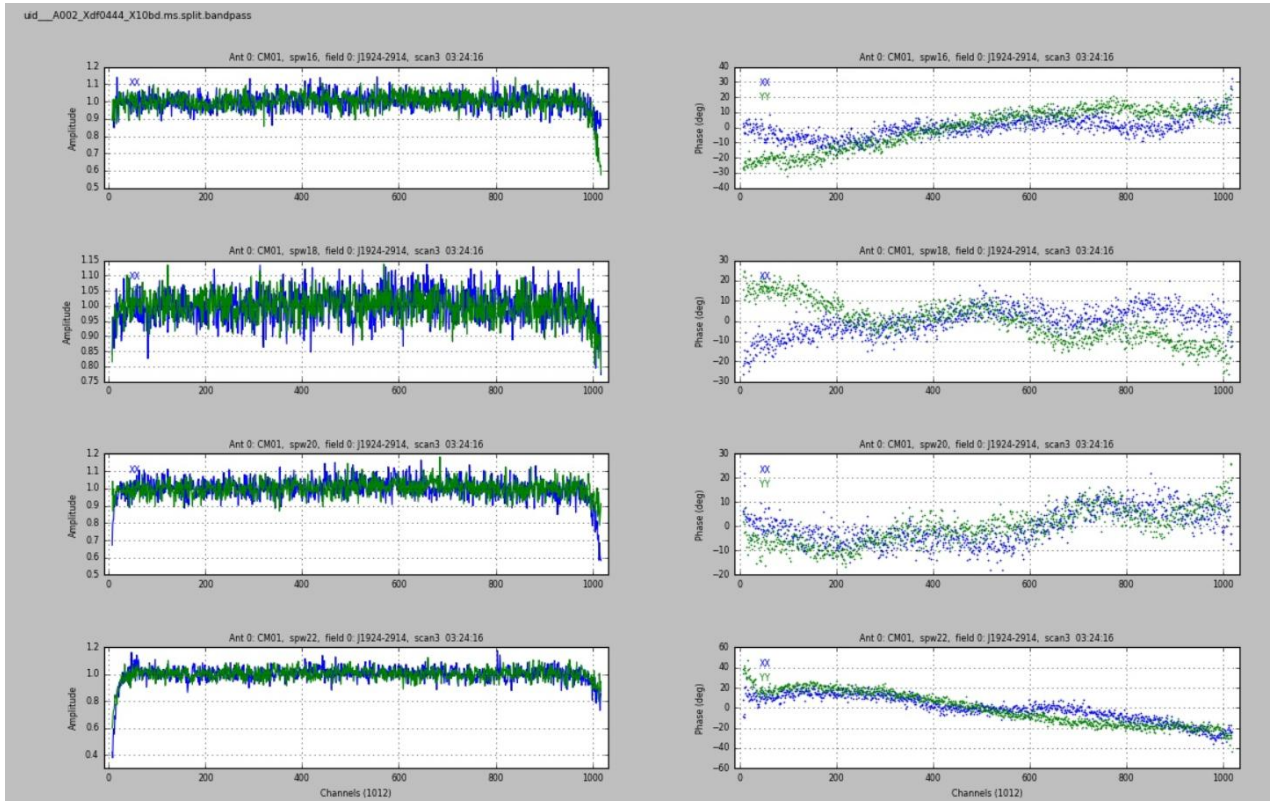
Applying the Calibration

Checking the Calibration

What are we looking for in a bandpass solution?

The bandpass solution should be smooth. Some features at the location of atmospheric lines are expected.

Keep an eye out for discontinuities.. Standard practice is to flag whole antenna if you find something wrong.



# Calibration



All of these SPWs have a lot of noise.  This is because of the increased spectral resolution.  (line windows, not continuum windows)

Let's redo the bandpass calibration, with smoothing.

# Redoing Bandpass Calibration

```
bandpass(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.bandpass’,
  field = '0', # J1924-2914
  scan = '3’,
  solint = 'inf’,
  combine = 'scan’,
  refant = 'CM12’,
  solnorm = True,
  bandtype = 'B’,
  gaintable = 'uid___A002_Xdf0444_X10bd.ms.split.ap_pre_bandpass')
```

# Mistake in the script!!!

```
plotbandpass(
  caltable="uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch",
  xaxis="chan",
  yaxis="both",
  subplot=42)
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

**Bandpass Calibration**

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

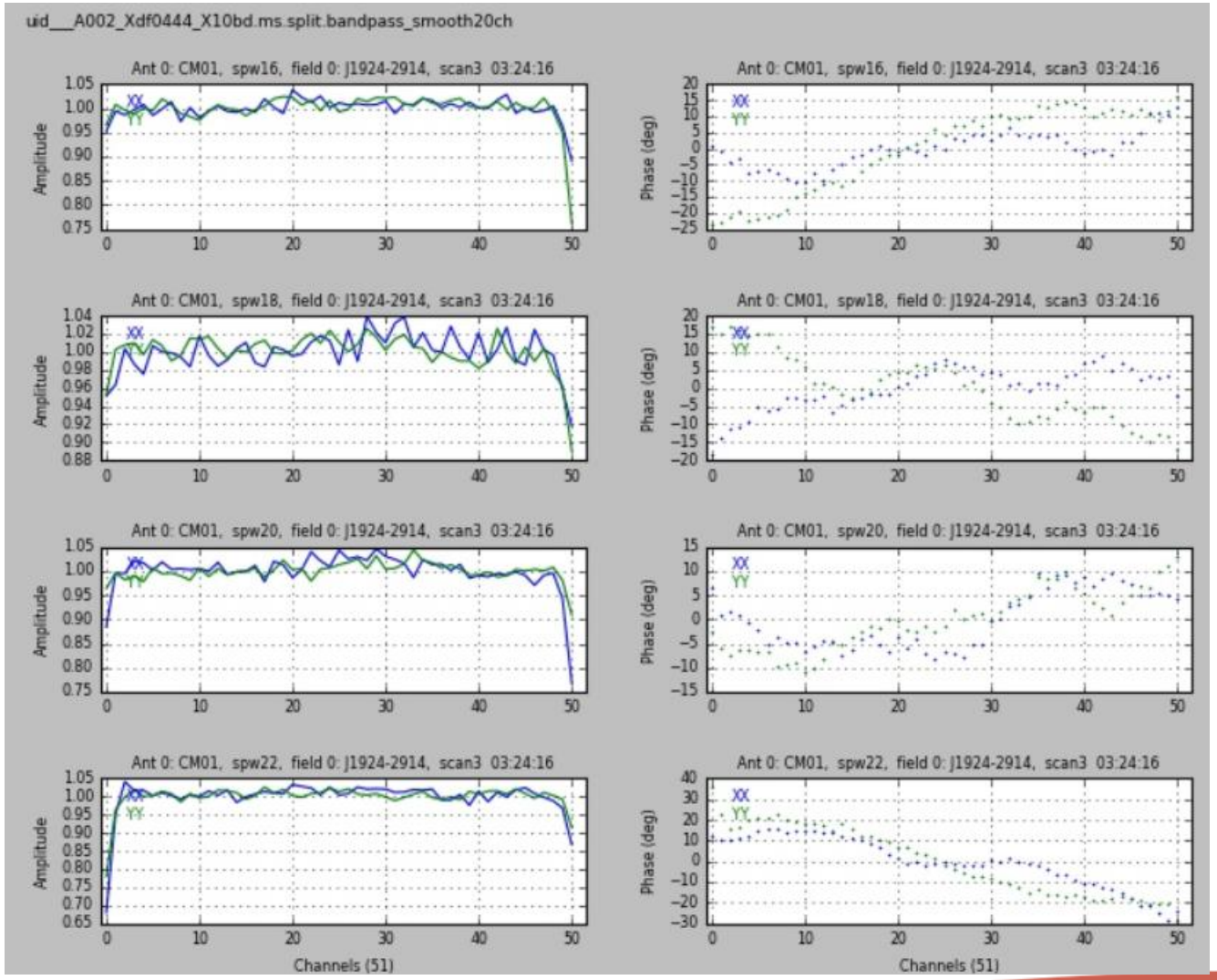
Setting the Flux Scale

Renormalization Correction

Applying the Calibration

Checking the Calibration

Use plotbandpass to plot the new table.



# Calibration



To check the bandpass solution, we need to apply the corrections.

```
applycal(vis="uid___A002_Xdf0444_X10bd.ms.split",
  field="0",
  gaintable=["uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch",
  "uid___A002_Xdf0444_X10bd.ms.split.ap_pre_bandpass"],
  interp=["linear","linear"],
  gainfield=["0","0"],
  applymode='calonly')
```

We will talk about this command while it runs!

# Calibration



To check the bandpass solution, we need to apply the corrections.

```
applycal(vis="uid___A002_Xdf0444_X10bd.ms.split",
  field="0",
  gaintable=["uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch",
  "uid___A002_Xdf0444_X10bd.ms.split.ap_pre_bandpass"],
  interp=["linear","linear"],
  gainfield=["0","0"],
  applymode='calonly')
```

We will talk about this command while it runs!

Field is telling applycal to only apply to the bandpass calibrator.
Gaintable is the list of calibration tables we want to use.
Interp is telling what type of interpolation we use for each table.
Gainfield tells what source solution we will apply.

# Calibration



Open plotms.

- Select "uid___A002_Xdf0444_X10bd.ms.split,
- Plot phase on the Y axis and use the data column for phase.
- Plot channel on the X axis.
- Select the bandpass calibrator (field = 0), spw=16, and Average over the whole scan.
- Color by correlation.

Make some notes about what you see. Then switch the phase column from data to corrected. Remake the plot, and check the results.

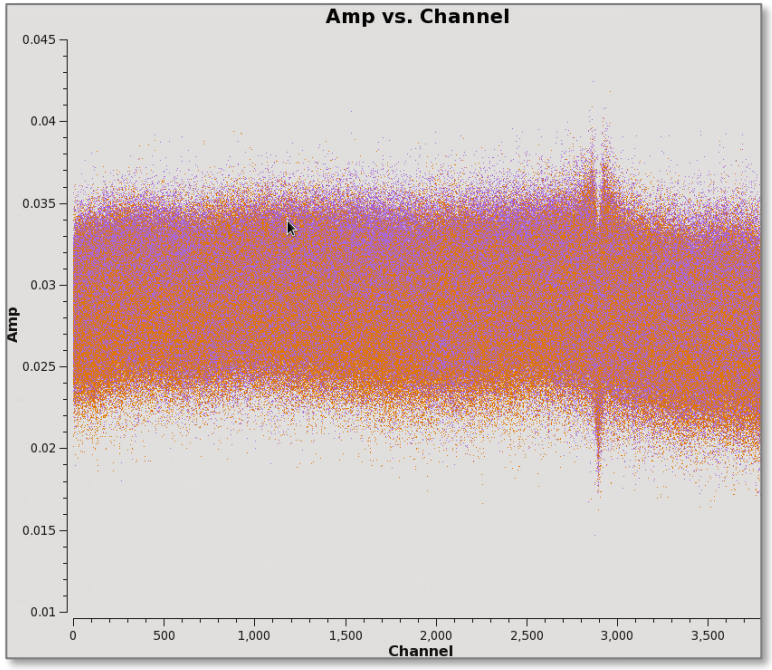
Remake the plot again using amplitude instead of phase. Compare the data column to the corrected column data.

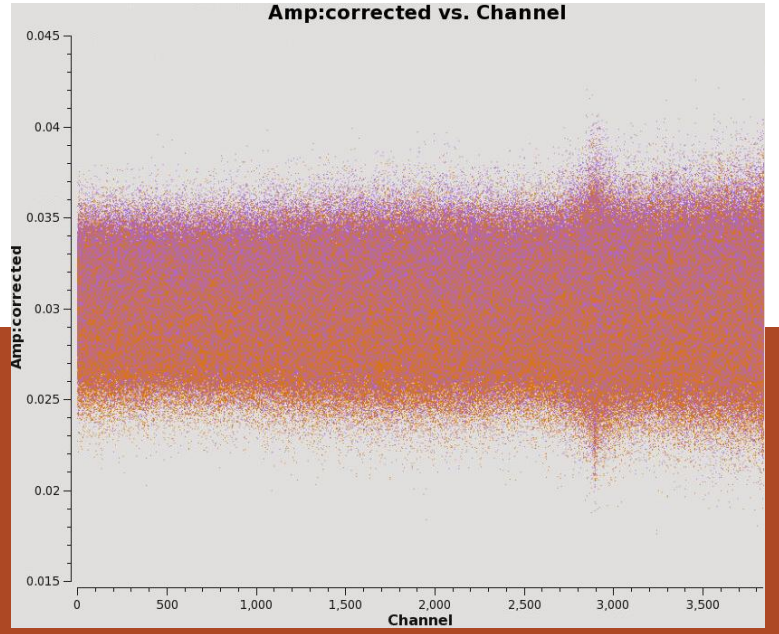
# Question: Bandpass

- What did the bandpass calibration do to the data?
- Are there any features you are concerned about?

# Question: Bandpass

- What about this bandpass?
- If you saw this, would you be concerned?



# Calibration



There is a small mistake in the script comments.

```
“##### Our flux reference source is J0854+2006 (field 1). So we use the results of aU.getALMAFluxForMS for field 1 in the following setjy command.”
```

Should read

```
“##### Our flux reference source is J1924-2914 (field 0). So we use the results of aU.getALMAFluxForMS for field 0 in the following setjy command.”
```

# Calibration



After successfully determining the bandpass solutions, we want to set the model for our flux calibrator. Our flux reference source is a quasar J1924-2914 (field 0).

We use a routine to parse the ALMA calibrator database, interpolate the expected flux for the calibrator reference,  and put in the 'model' column of the data using setjy.

```
aU.getALMAFluxForMS('uid___A002_Xdf0444_X10bd.ms.split')
```

# Calibration



Now run setjy to set the model.

```
setjy(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
      standard = 'manual',
      field = 'J1924-2914',
      usescratch = True,
      fluxdensity = [2.2942105694549557, 0, 0, 0],
      spix = -0.5846359878009907,
      reffreq = '340.9333355239418GHz')
```

# Calibration



## Gain Calibration: Long-term phase solutions

First, we calibrate the phase for each antenna for each scan. This is the right cadence to transfer to the science target, which is visited only on a every-other-scan timescale.

```
gaincal(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.phase_inf',
  field = '0~1', # J1924-2914,J1700-2610
  solint = 'inf',
  refant = 'CM12',
  gaintype = 'G',
  calmode = 'p',
  gaintable = 'uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch')
```

# Question: Gain Calibrators

- What makes a good gain (phase) calibrator?

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

**Gain Calibration**

Setting the Flux Scale

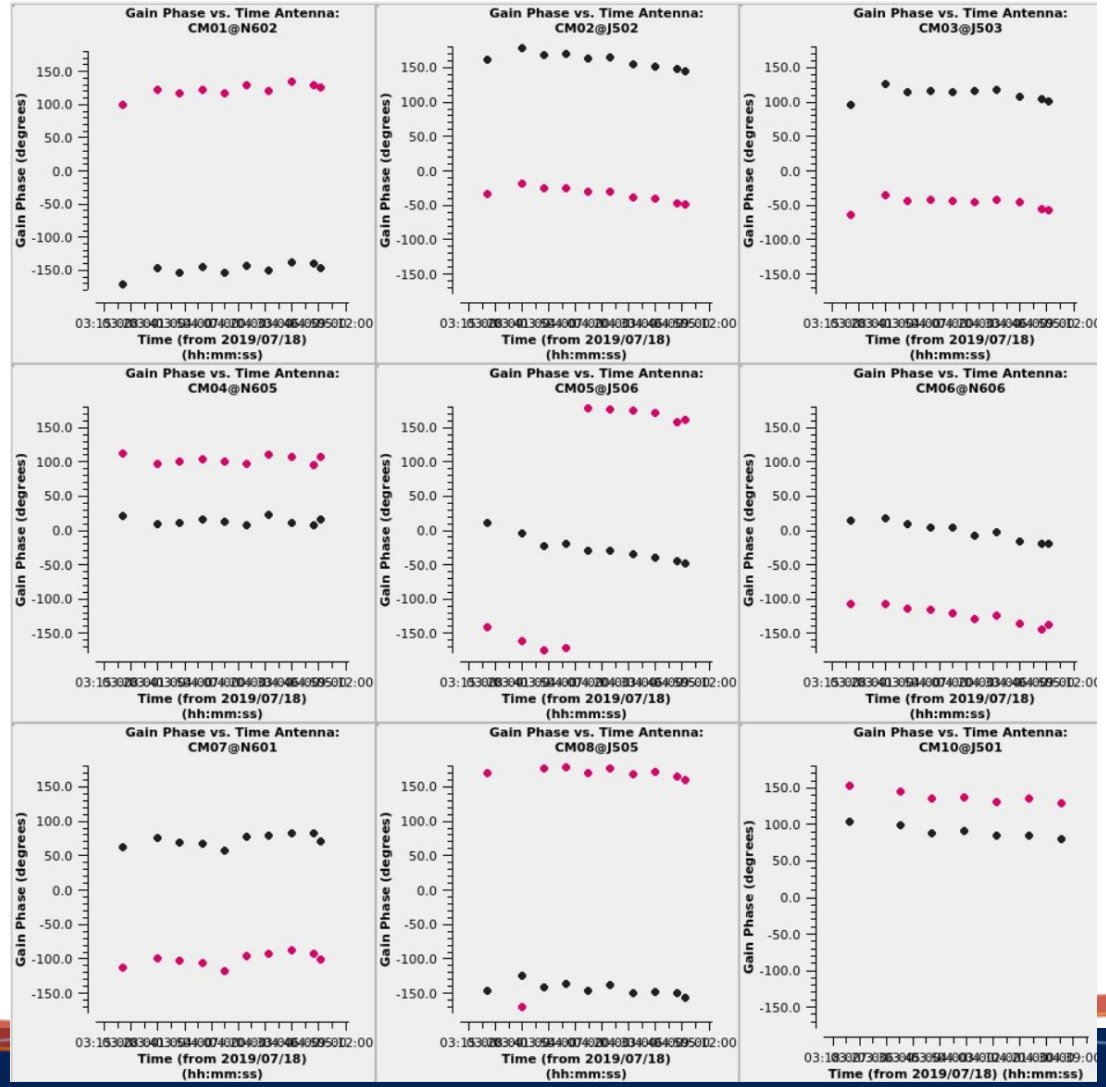
Renormalization Correction

Applying the Calibration

Checking the Calibration

Plot the resulting phase calibration

Use the plotms commands in calibration.py



# Calibration



## Gain Calibration: Short-term Phase Solutions

Now we want to remove any short timescale phase variation from the sources involved in the bandpass and flux calibration. We do so using gaincal.

```
gaincal(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  caltable ='uid___A002_Xdf0444_X10bd.ms.split.phase_int’,
  field = '0~1', # J1924-2914,J1700-2610
  solint = 'int’,
  refant = 'CM12’,
  gaintype = 'G’,
  calmode = 'p’,
  gaintable = 'uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch')
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

**Gain Calibration**

Setting the Flux Scale

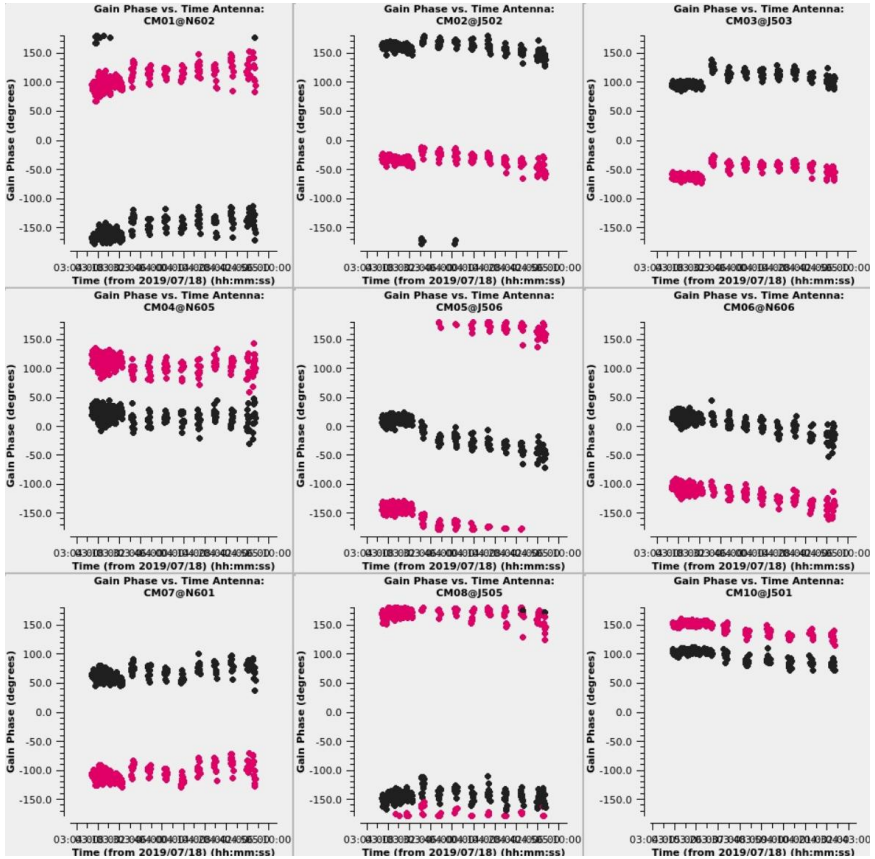
Renormalization Correction

Applying the Calibration

Checking the Calibration

Plot the resulting short timescale phase calibration.

Just like before, you need to run the four plotms commands from your calibration.py script.



# Calibration



## Gain Calibration: Amplitude Solutions

To create long term amplitude corrections, we will use the calmode = ‘a’ option in gaincal.

```
gaincal(vis = 'uid___A002_Xdf0444_X10bd.ms.split’,
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.ampli_inf’,
  field = '0~1', # J1924-2914,J1700-2610
  solint = 'inf’,
  refant = 'CM12’,
  gaintype = 'T’,
  calmode = 'a’,
  gaintable =
    ['uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch',
    'uid___A002_Xdf0444_X10bd.ms.split.phase_int'])
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

**Setting the Flux Scale**

Renormalization Correction

Applying the Calibration

Checking the Calibration

The gaincal solved for the amplitude scaling to make the data match the current model.

For the quasar J1924-2914, we have taken care to set the correct model using setjy.

For the other two calibrators, however, we don't a priori know the flux.

Those have been calibrated using the default model, which is a point source of amplitude 1 Jy at the middle of the field.

We now use fluxscale to bootstrap from the (correct) flux of the quasar through the amplitude calibration table to estimates of the true flux of the other two calibrators.

This will output both a new table and the flux estimates themselves.

Run the first four lines of the “Setting the flux scale” section in calibration.py

# Calibration



```
fluxscaleDict = fluxscale(
  vis = 'uid___A002_Xdf0444_X10bd.ms.split',
  caltable = 'uid___A002_Xdf0444_X10bd.ms.split.ampli_inf',
  fluxtable = 'uid___A002_Xdf0444_X10bd.ms.split.flux_inf',
  reference = '0') # J1924-2914

##### Set the log back to the CASA logger.
casalog.setlogfile(mylogfile)
```

Afterwards, plot the solutions with plotms.

```
plotms(vis="uid___A002_Xdf0444_X10bd.ms.split.flux_inf",
 xaxis="time",
 yaxis="amp",
 gridcols=3,
 gridrows=3,
 iteraxis="antenna",
 symbolsize=10,
 plotfile="ss20_flux_scan.png")
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

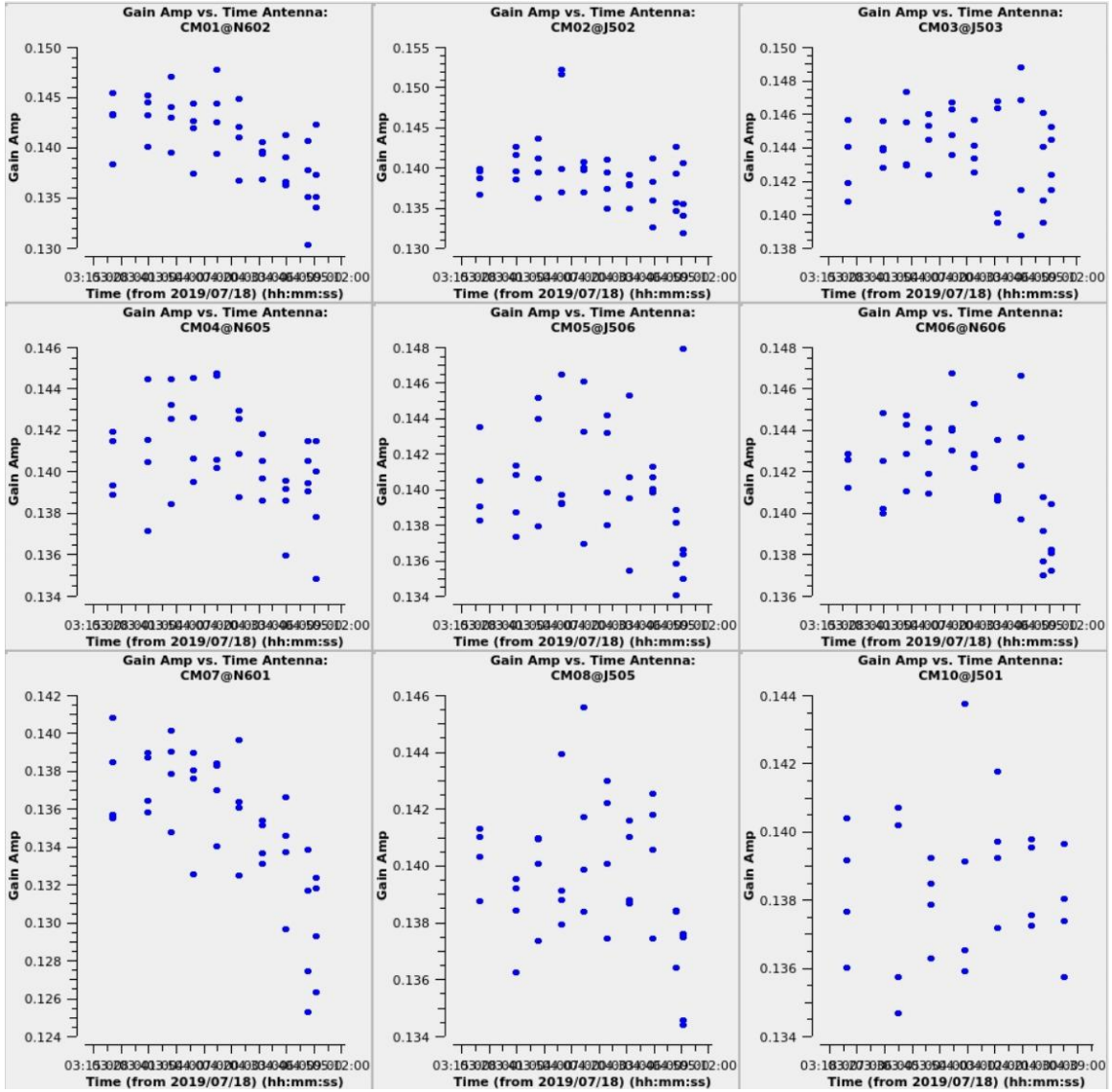
Gain Calibration

**Setting the Flux Scale**

Renormalization Correction

Applying the Calibration

Checking the Calibration



# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration

Change applyRenorm = False and run.

```
                    ##########################################################################################
                    ################################### Applying Renorm ######################################
                    ##########################################################################################


### This dataset needs renorm. A detailed description about renormalization
#and how this process is carried out can be found at the following link:
#https://help.almascience.org/kb/articles/what-are-the-amplitude-calibration-issues-caused-by-alma-s-normalization-strategy.


os.system('rm -rf uid___A002_Xdf0444_X10bd.ms.split.renorm.tbl')

from pipeline.extern.almarenorm import ACreNorm

# QA2 analyst: First run this step individually with the following variable *applyRenorm* set to False
#              in order to determine the max. renormalization scaling factor.
#              If the factor is <= 1.02, don't change anything and proceed with the remaining steps.
#              If the max. renormalization scaling factor is > 1.02, then edit the following line in this script
#              and set applyRenorm=True, and then re-run this step.
#              In any case, note here the max. renorm factor you determined:  <max. renorm factor determined in this step>
applyRenorm = True
applyonly=False

if applyRenorm or applyonly!=True:

  if not applyRenorm: os.system('rm -rf RN_plots')

  rn=ACreNorm('uid___A002_Xdf0444_X10bd.ms.split')

  if applyRenorm or applyonly==True:
    diagSpectra=False
  else:
    diagSpectra=True

  rn.renormalize(createCalTable=applyRenorm, diagSpectra=diagSpectra, antHeuristicsSpectra=False, atmAutoExclude=True, fillTable=True)

  if applyRenorm or applyonly==True:
    pass  # no plotting
  else:
    rn.plotSpectra()

  if os.path.exists('RN_plots') and applyRenorm:
    os.system('rm -f RN_plots/*.pdf RN_plots/*_scan*_field*.png')
    os.system('mv RN_plots uid___A002_Xdf0444_X10bd.ms.split.renorm.plots')

  if not applyRenorm:
    mystats = rn.rnpipestats
    casalog.post('Maximum Renormalization scaling factors:\n'+str(mystats))

    rnfactors = []
    for field in mystats.keys():
      print(' ************************')
      print(field, ': max. renorm. scaling for each SPW')
      for spw in mystats[field].keys():
        print(spw,': ', mystats[field][spw])
        rnfactors.append(mystats[field][spw]['max_rn'])
    maxScaling = max(rnfactors)
    print(' ************************')
    print(' The maximum Renormalization scaling is '+str(maxScaling))
    if maxScaling>1.02:
      casalog.post('Renormalization caltable should be created before proceeding.','WARN')
      rn.close()
      sys.exit('Please edit the renorm step to set applyRenorm=True and rerun the step!')
    else:
      print(' No Renormalization needed.')
    print(' ************************')

  rn.close()
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration

Renormalization:

A visibility amplitude calibration error that affects fields containing strong line emission

Corrected in affected datasets that have >10% flux offset since Cycle 7.

Knowledgebase Article:

https://help.almascience.org/kb/articles/what-are-the-amplitude-calibration-issues-caused-by-alma-s-normalization-strategy

New pipeline stage for pipeline-calibrated datasets

Manually calibrated datasets are checked and corrected before delivery. This dataset does not require renorm correction. However, the script includes a demonstration using the pipeline renorm module

# Calibration



Traditional scheme

$$c_{ij}(f)\ [\mathrm{V}^2] \xrightarrow{\text{norm}} \frac{c_{ij}(f)}{\sqrt{\langle c_{ii}\rangle_f \langle c_{jj}\rangle_f}}\ [\mathrm{V}^2] \xrightarrow{\text{cal}} c_{ij}(f)\ [\mathrm{V}^2]\ \frac{\sqrt{\langle T_i\rangle_f[K] \cdot \langle T_j\rangle_f[K]}}{\sqrt{\langle c_{ii}\rangle_f \cdot \langle c_{jj}\rangle_f}\ [V^2]} \longrightarrow c_{ij}(f)[\mathrm{K}]$$

Averaged

ALMA scheme

$$c_{ij}(f)\ [\mathrm{V}^2] \xrightarrow{\text{norm}} \frac{c_{ij}(f)}{\sqrt{c_{ii}(f)c_{jj}(f)}}\ [\mathrm{V}^2] \xrightarrow{\text{cal}} c_{ij}(f)\ [\mathrm{V}^2]\ \frac{\sqrt{T_i(f)[K] \cdot T_j(f)[K]}}{\sqrt{c_{ii}(f) \cdot c_{jj}(f)}\ [V^2]} \longrightarrow c_{ij}(f)[\mathrm{K}]$$

Not spectrally averaged

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration

$$c_{ij}(f)[V^2] \rightarrow c_{ij}(f)[V^2] \frac{\sqrt{T_i(f)[K] \cdot T_j(f)[K]}}{\sqrt{c_{ii}(f) \cdot c_{jj}(f)}[V^2]} \rightarrow c_{ij}(f)[K]$$

- Both the autocorrelations and the system temperature measurements are a total power-like measurement of the sky.
- If the target source is highly extended and bright, then the source can be picked up in these total power measurements which then impacts this normalization scheme in any channels where the emission was picked up!
- Dividing by the autocorrelations will under-scale the cross-correlations in any affected channels.
- Multiplying by $T_{sys}$ measurement will over-scale the cross-correlations in any affected channels.
- These effects perfectly cancel each other ONLY if they are of the same field.

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

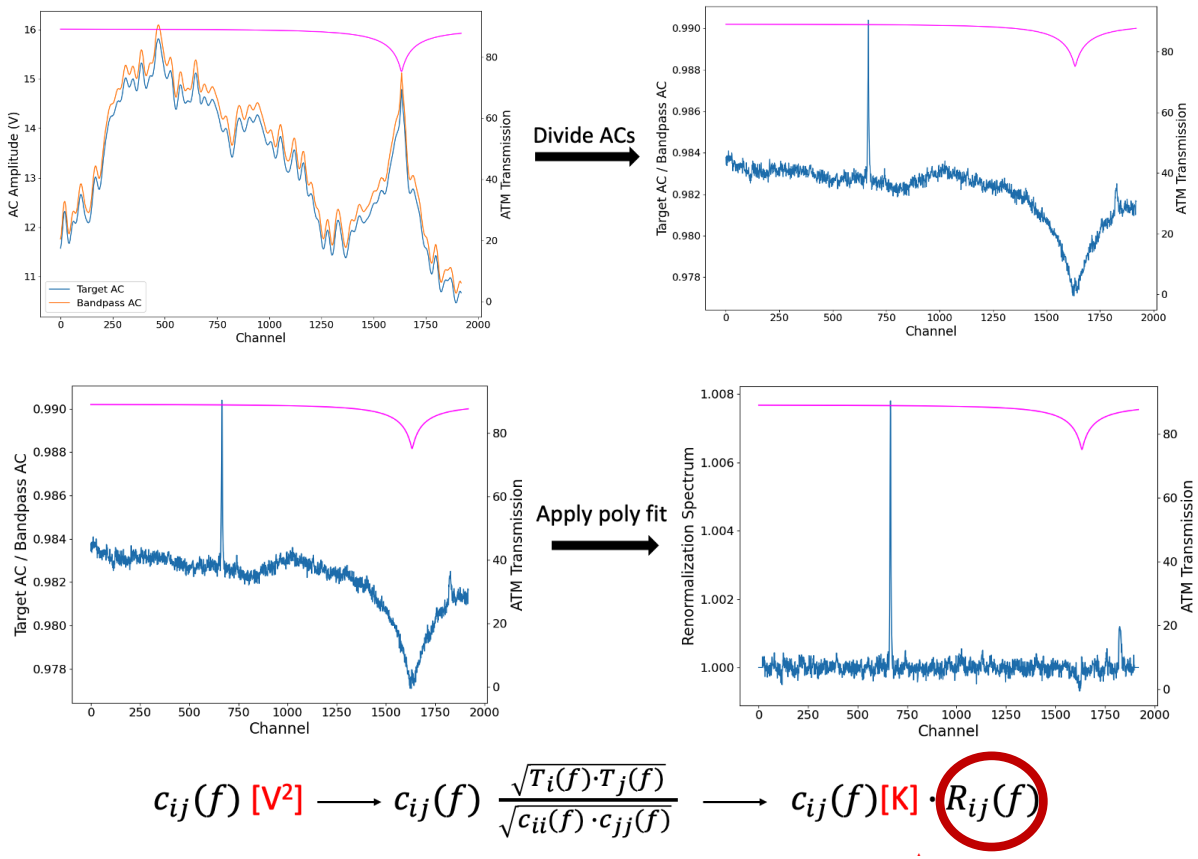
Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration




$$c_{ij}(f)\ [\mathrm{V}^2] \longrightarrow c_{ij}(f)\ \frac{\sqrt{T_i(f)\cdot T_j(f)}}{\sqrt{c_{ii}(f)\cdot c_{jj}(f)}} \longrightarrow c_{ij}(f)[\mathrm{K}]\cdot R_{ij}(f)$$

# Calibration



What can change?

os.system('rm -rf uid___A002_Xdf0444_X10bd.ms.split.renorm.tbl')

- Clearing name of renorm table

applyRenorm = True

- Do you want to create the table? Only makes plots if False.

rn=ACreNorm('uid___A002_Xdf0444_X10bd.ms.split')

- Name of measurement set

os.system('mv RN_plots uid___A002_Xdf0444_X10bd.ms.split.renorm.plots')

- Moving plot to MS name folder

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

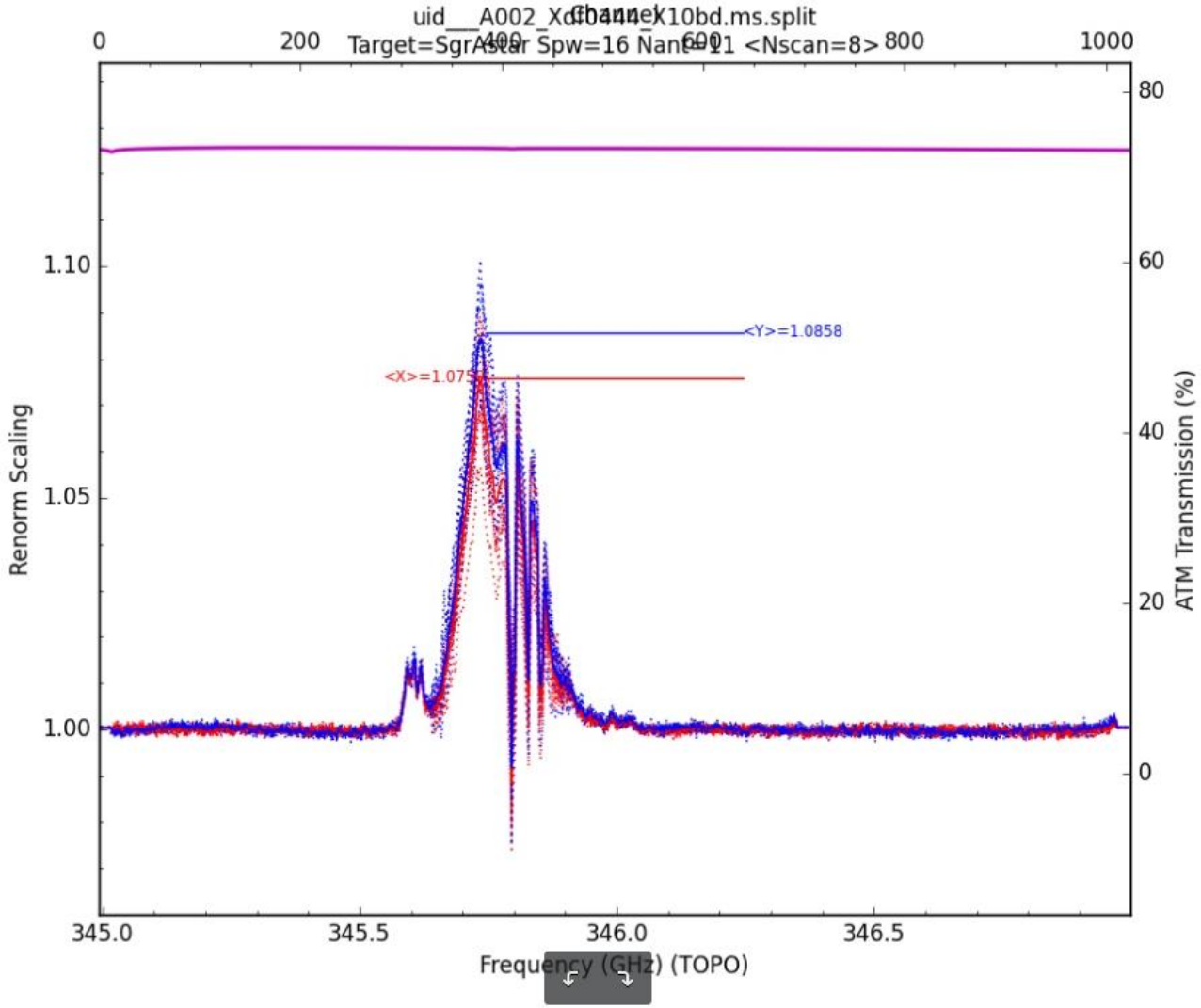
Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration



# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

**Renormalization Correction**

Applying the Calibration

Checking the Calibration

We do need the table!

Run with applyRenorm = True and this will let you create the table.

# Calibration is finished!

- We have now created all the calibration tables.
- All we need to do now is apply the calibration.

# Calibration



For our bandpass and flux calibrator (fields 0), we apply our bandpass calibration and our gain calibration (short term phase + flux).

For our phase calibrator and science target (fields 1 & 2), we apply our bandpass calibration and our gain calibration (long term phase + flux).

Before applying the calibration, we want to save the flags.

```
flagmanager(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
    mode = 'save',
    versionname = 'BeforeApplycal')
```

# Calibration



Now we can apply the calibration to the bandpass / flux calibrator:

```
applycal(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
  field = str(0),
  gaintable =
        ['uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch',
        'uid___A002_Xdf0444_X10bd.ms.split.phase_int',
        'uid___A002_Xdf0444_X10bd.ms.split.flux_inf'],
  gainfield = ['', '0', '0'],
  interp = 'linear,linear',
  calwt = True,
  flagbackup = False)
```

Note, that renorm is not applied to the calibrators, only the target.

# Calibration



The script has some if statements to make it work with renorm, just in case you did not need it. Lets apply the data to the phase calibrator

```
applycal(vis ='uid___A002_Xdf0444_X10bd.ms.split',
        field = '1', # phasecal
        gaintable =
        ['uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch',
        'uid___A002_Xdf0444_X10bd.ms.split.phase_inf',
        'uid___A002_Xdf0444_X10bd.ms.split.flux_inf'],
        gainfield = ['', '1', '1'], # J1700-2610
        interp = ['linear','linear','linear'],
        calwt = True,
        flagbackup = False)
```

We are interpolating linearly across the solutions from the phase calibrator and applying them to the science field.

# Calibration



The script has some if statements to make it work with renorm, just in case you did not need it. Lets apply the data to the phase calibrator

```
applycal(vis = 'uid___A002_Xdf0444_X10bd.ms.split',
        field = '2', # SgrAstar
        gaintable =
        ['uid___A002_Xdf0444_X10bd.ms.split.bandpass_smooth20ch',
        'uid___A002_Xdf0444_X10bd.ms.split.phase_inf',
        'uid___A002_Xdf0444_X10bd.ms.split.flux_inf',
        'uid___A002_Xdf0444_X10bd.ms.split.renorm.tbl'],
        gainfield = ['', '1', '1', ''], # J1700-2610
        interp = ['linear','linear','linear','linear'],
        calwt = True,
        flagbackup = False)
```

We are interpolating linearly across the solutions from the phase calibrator and applying them to the science field.

# Calibration



- Next, we will review the basics of data inspection and flagging.
- We will now use plotms to make a series of diagnostic plots. These plots have been picked because we have a good expectation of what the calibrators (fields 0, and 1) should look like in each space.
- Typical plots for calibrated data inspection are the following:
  - Amplitude vs time
  - Phase vs time
  - Amplitude vs frequency
  - Phase vs frequency
  - Amplitude vs UV distance
  - Phase vs UV distance
- Iterate over Antenna, Spectral Window, or source
- Typically, start by plotting the calibrators.
  - Be careful flagging the target, as you could be flagging out real structure on the target.

We will go through the plots in the order they are listed in calibration.py

# Calibration



## Flagging with plotms

It is possible to flag within the GUI with plotms. This is done by boxing the data with the  button, and then flagging with the  button.

Unflagging can be performed by plotting flagged points and using the  button.

**<u>FLAGGING USING PLOTMS IS NOT ENCOURAGED!!!</u>**

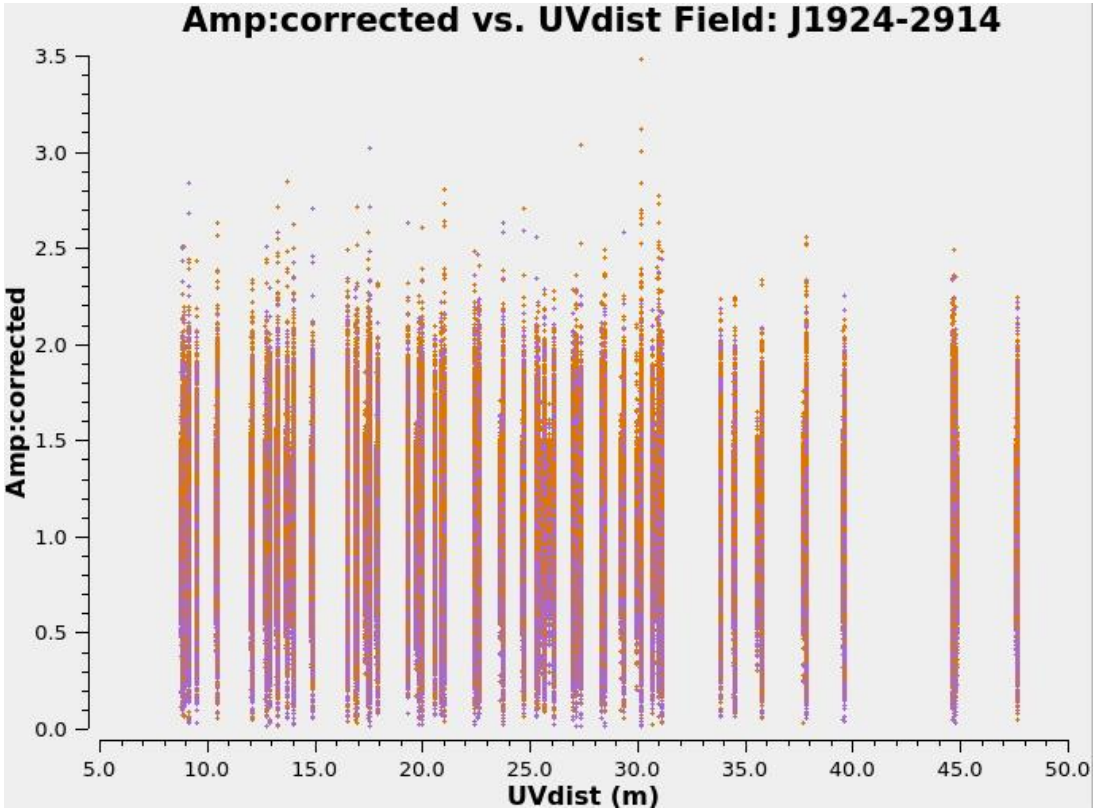
Flagging with plotms is not considered reproduceable. Due to the nature of drawing boxes in plotms, it is difficult to tell what points were flagged.

It is best to use plotms to identify bad data, and then flag using flagdata.

# Question: Amp vs UVdist

Look for individual baselines or antennas not following the other baselines.

What do we expect a point source at the phase center to look like in terms of Amplitude vs UV distance?




**UV distance vs amplitude for Calibrator J1924-2914**

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

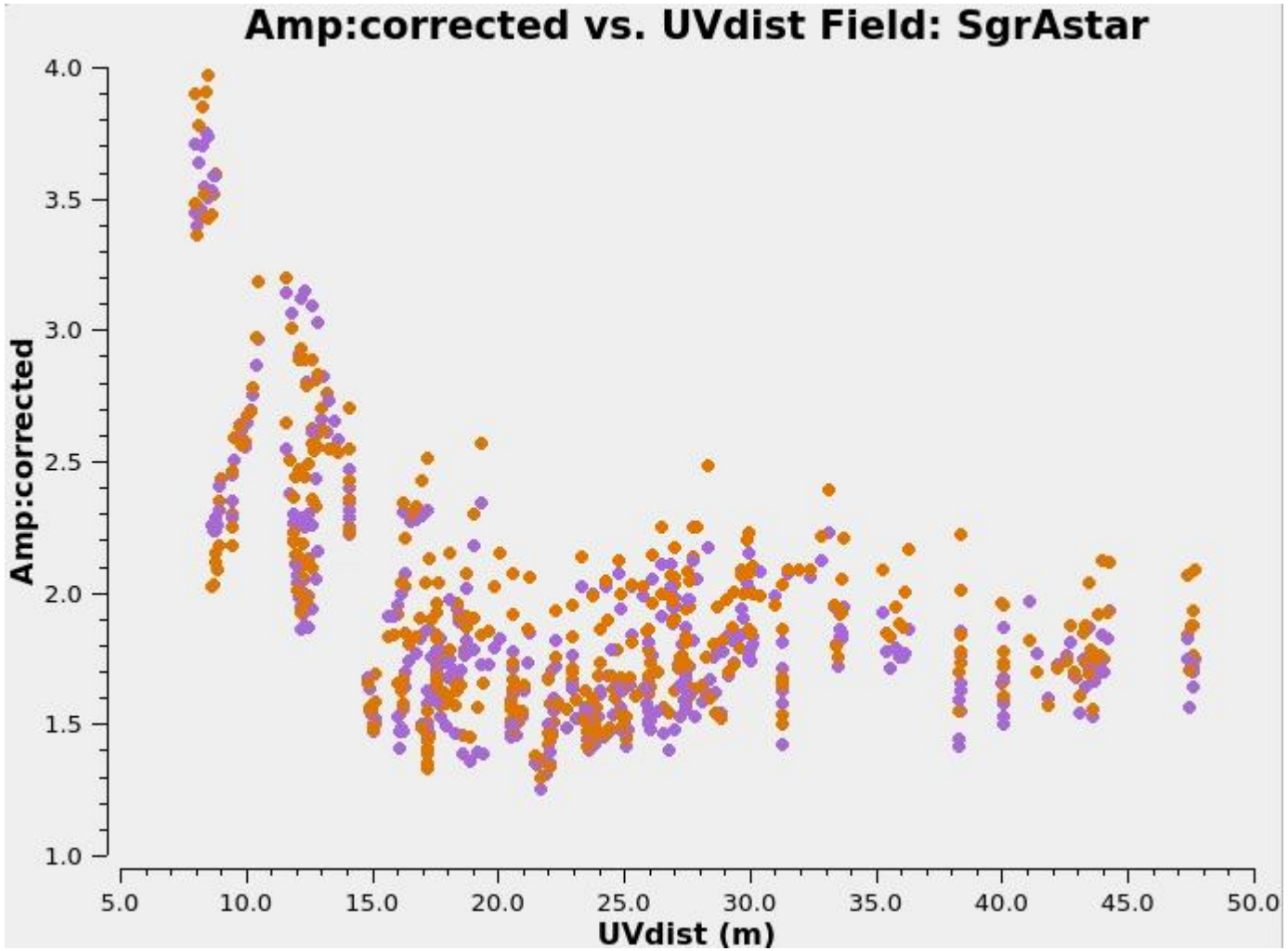
Setting the Flux Scale

Renormalization Correction

Applying the Calibration

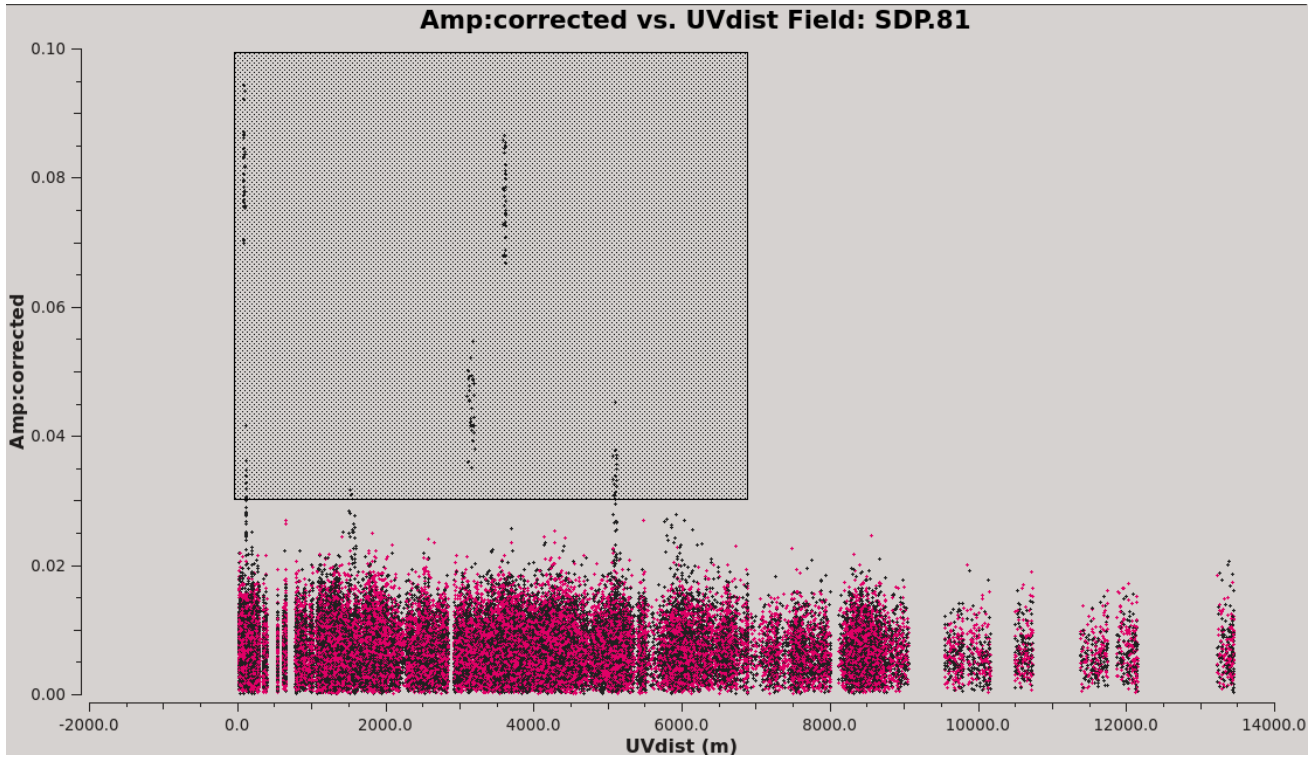
**Checking the Calibration**

Look at all three sources. Do you notice any points that stand out?



# Calibration

- Highlight points with  and click locate (  ).
- What is in common?




```
Scan=59 Field=SDP.81 [3] Time=2014/11/03/10:19:48.1440 BL=DA50@W204 & PM04@T703 [1&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=5119.21 Y=0.0364852 (
Scan=59 Field=SDP.81 [3] Time=2014/11/03/10:19:48.1440 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3608.39 Y=0.0727789 (
Scan=59 Field=SDP.81 [3] Time=2014/11/03/10:19:48.1440 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.0455 Y=0.0777865
Scan=61 Field=SDP.81 [3] Time=2014/11/03/10:21:05.8080 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3135.01 Y=0.0470909 (
Scan=61 Field=SDP.81 [3] Time=2014/11/03/10:21:05.8080 BL=DA50@W204 & PM04@T703 [1&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=5119.11 Y=0.0355896 (
Scan=61 Field=SDP.81 [3] Time=2014/11/03/10:21:05.8080 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3606.49 Y=0.0845674 (
Scan=61 Field=SDP.81 [3] Time=2014/11/03/10:21:05.8080 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.1765 Y=0.0752248
Scan=61 Field=SDP.81 [3] Time=2014/11/03/10:21:05.8080 BL=DV21@A004 & PM04@T703 [22&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=119.004 Y=0.0361741
Scan=63 Field=SDP.81 [3] Time=2014/11/03/10:22:23.4720 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3131.89 Y=0.0453449 (
Scan=63 Field=SDP.81 [3] Time=2014/11/03/10:22:23.4720 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3604.52 Y=0.0779968 (
Scan=63 Field=SDP.81 [3] Time=2014/11/03/10:22:23.4720 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.309 Y=0.0817332 (
Scan=65 Field=SDP.81 [3] Time=2014/11/03/10:23:41.1360 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3128.73 Y=0.0477873 (
Scan=65 Field=SDP.81 [3] Time=2014/11/03/10:23:41.1360 BL=DA50@W204 & PM04@T703 [1&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=5118.47 Y=0.0371042 (
Scan=65 Field=SDP.81 [3] Time=2014/11/03/10:23:41.1360 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3602.45 Y=0.0681095 (
Scan=65 Field=SDP.81 [3] Time=2014/11/03/10:23:41.1360 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.4368 Y=0.0755574
Scan=67 Field=SDP.81 [3] Time=2014/11/03/10:24:58.8000 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3125.55 Y=0.0501428 (
Scan=67 Field=SDP.81 [3] Time=2014/11/03/10:24:58.8000 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3600.29 Y=0.0858272 (
Scan=67 Field=SDP.81 [3] Time=2014/11/03/10:24:58.8000 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.5662 Y=0.0753881
Scan=67 Field=SDP.81 [3] Time=2014/11/03/10:24:58.8000 BL=DV21@A004 & PM04@T703 [22&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=118.901 Y=0.0346102
Scan=69 Field=SDP.81 [3] Time=2014/11/03/10:26:16.4640 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3122.34 Y=0.0359895 (
Scan=69 Field=SDP.81 [3] Time=2014/11/03/10:26:16.4640 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3598.06 Y=0.0727033 (
Scan=69 Field=SDP.81 [3] Time=2014/11/03/10:26:16.4640 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.6965 Y=0.0839206
Scan=73 Field=SDP.81 [3] Time=2014/11/03/10:29:08.7360 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3115.13 Y=0.0487719 (
Scan=73 Field=SDP.81 [3] Time=2014/11/03/10:29:08.7360 BL=DA62@W206 & PM04@T703 [9&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3592.79 Y=0.0783596 (
Scan=73 Field=SDP.81 [3] Time=2014/11/03/10:29:08.7360 BL=DV10@A024 & PM04@T703 [15&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=99.9755 Y=0.0934339
Scan=75 Field=SDP.81 [3] Time=2014/11/03/10:30:26.4000 BL=DA41@S301 & PM04@T703 [0&24] Spw=2 Chan=<0~63> Avg Freq=156.444 Corr=XX X=3111.84 Y=0.0460959 (
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

Gain Calibration

Setting the Flux Scale

Renormalization Correction

Applying the Calibration

**Checking the Calibration**

Example flagging command (Not specific to our current dataset)

```
## Outlier antenna in spw2
flagdata(vis = 'ms.split',
  mode = 'manual',
  spw = '2',
  antenna= 'PM04',
  flagbackup = False)
```

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

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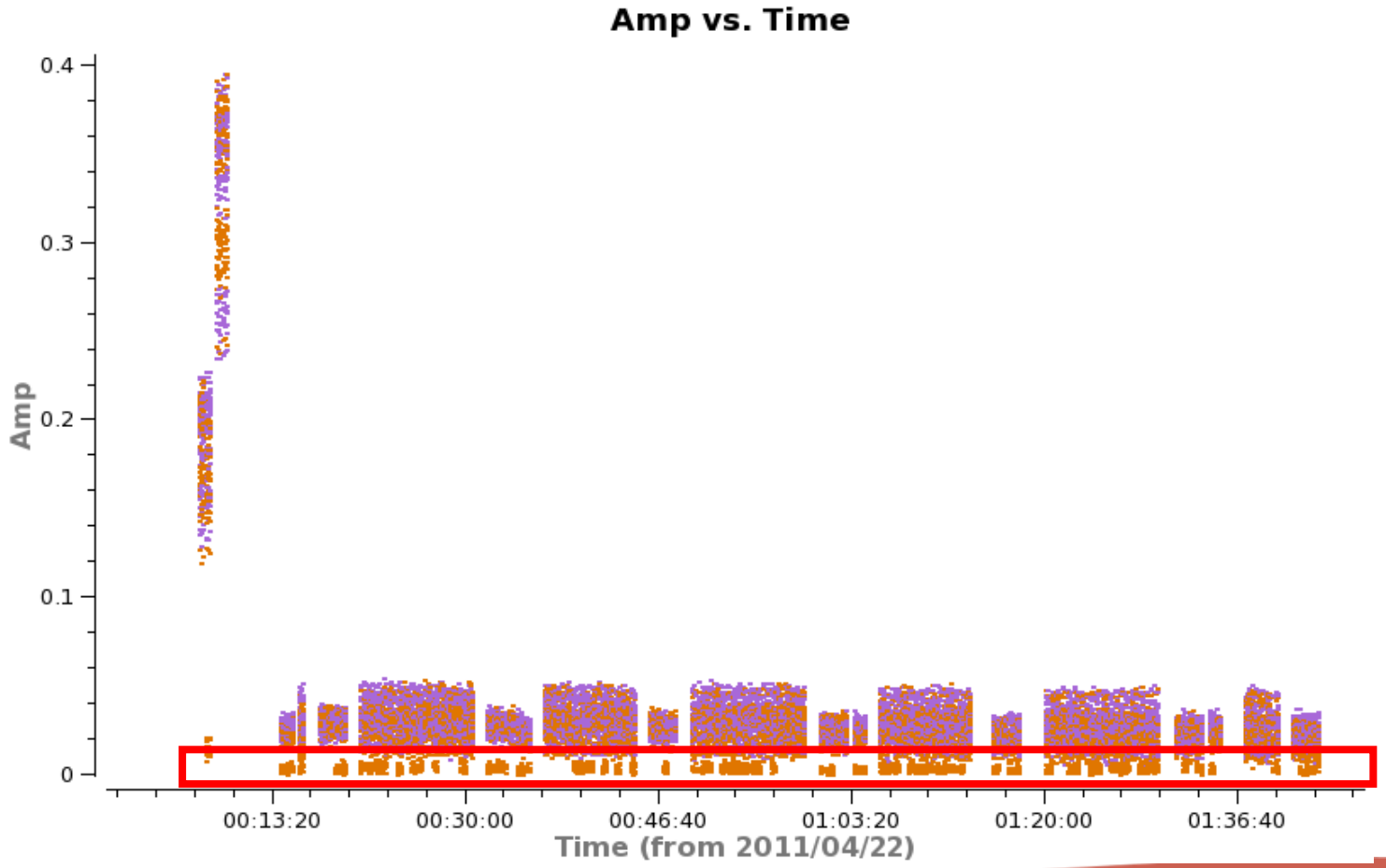
Applying the Calibration

**Checking the Calibration**

Amplitude vs time: Look for scans that are different than other scans of the same target.

Look for outliers (very low or very high antennas or baselines).



# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

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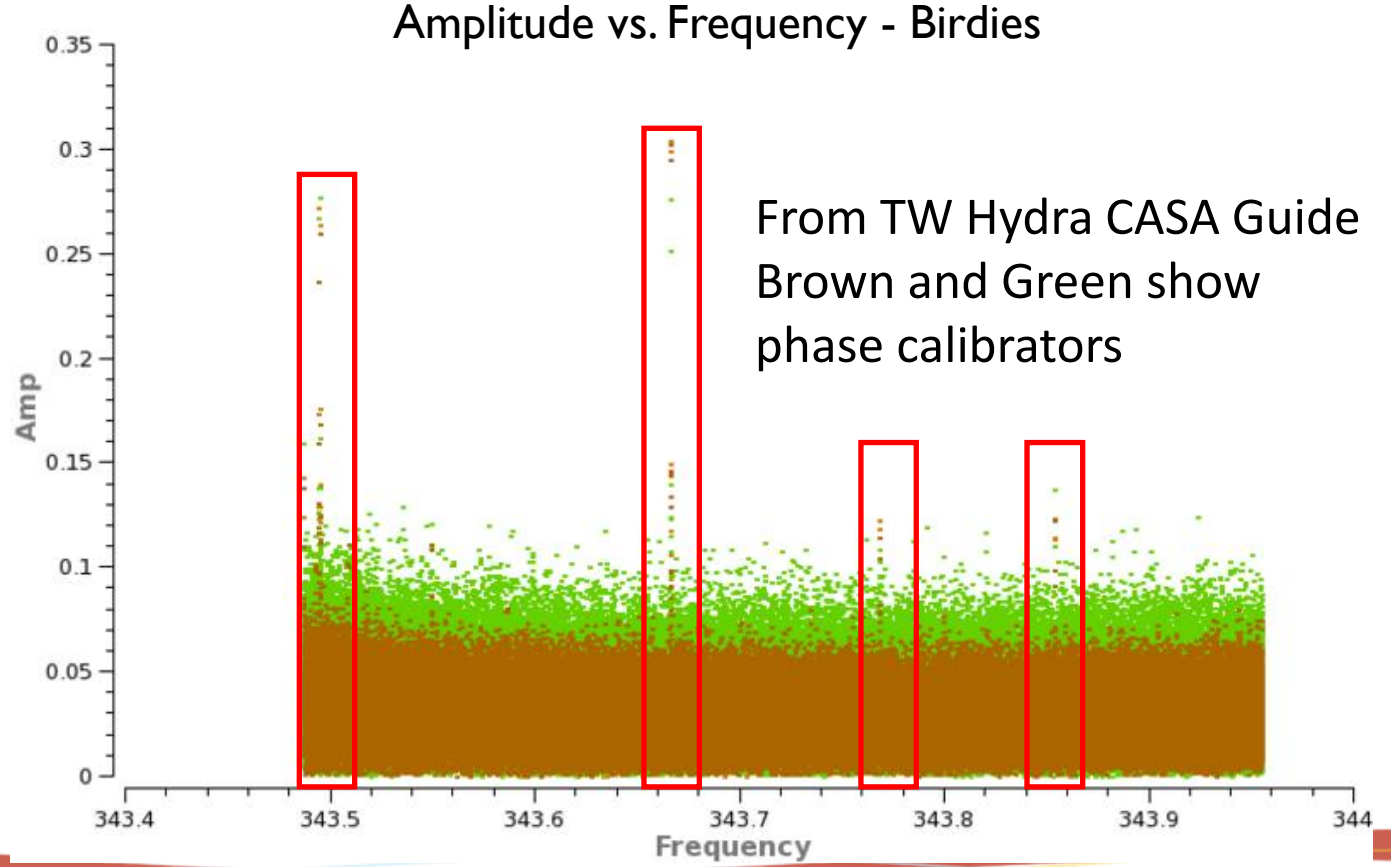
Checking the Calibration

For Amplitude vs frequency (or channel):

Look for bad edge channels, birdies, and other effects **IN THE CALIBRATORS!**

**The target may have spectral lines that can be real. Gain calibrators can also sometimes have native lines. Lines don't need to be flagged form the gain calibrator**.




From TW Hydra CASA Guide
Brown and Green show phase calibrators

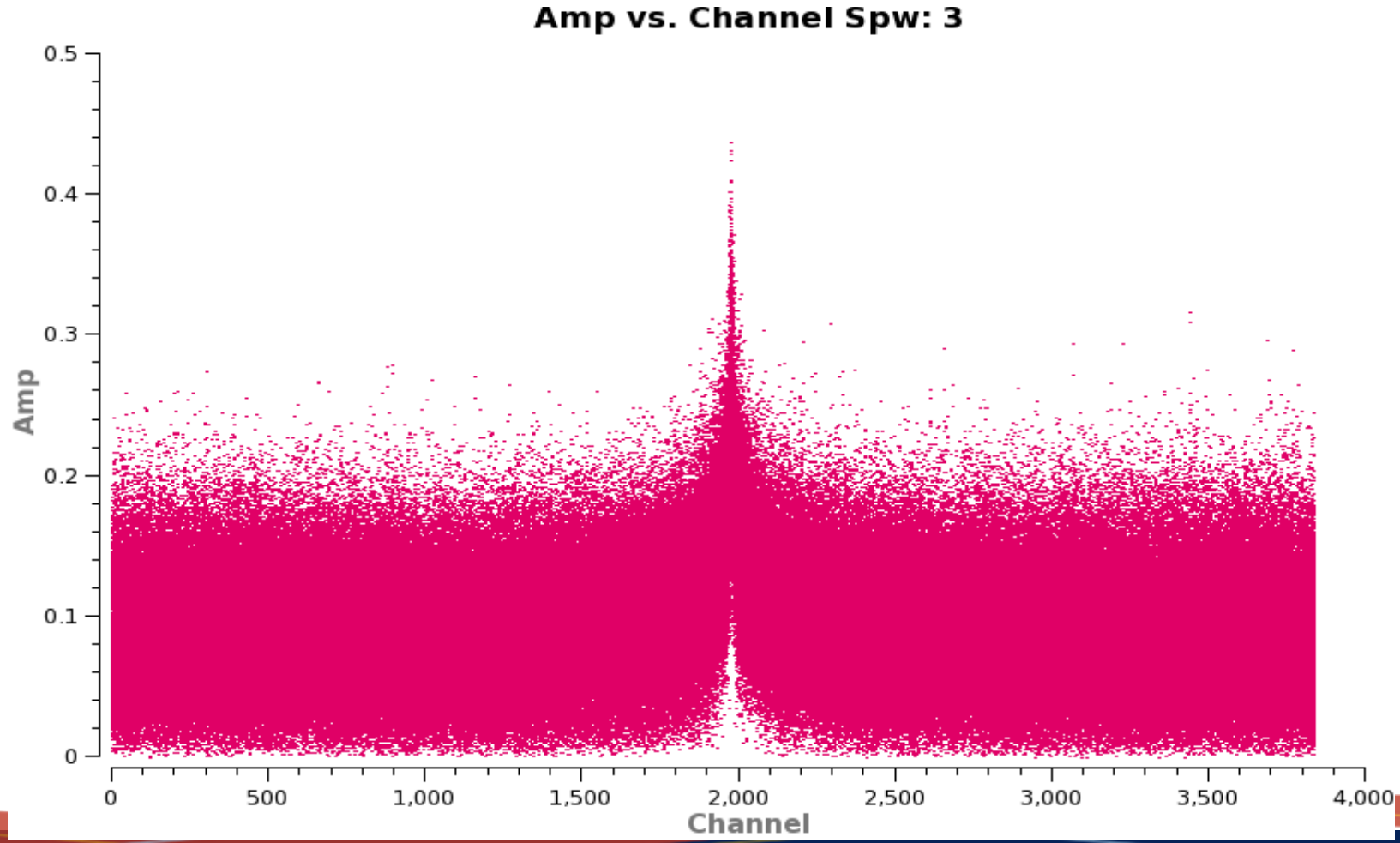
# Calibration

- Saving Flagging State
- Flagging Known Bad Data
- Other Flags
- Pre-Bandpass Phase Calibration
- Bandpass Calibration
- Checking Bandpass Calibration
- Apply Flux Calibrator Model to Data
- Gain Calibration
- Setting the Flux Scale
- Renormalization Correction
- Applying the Calibration
- **Checking the Calibration**

Spectral lines in flux calibrators should be flagged.

From TW Hydra Band 7 Guide

Spectral line in Titan (Flux Calibrator)

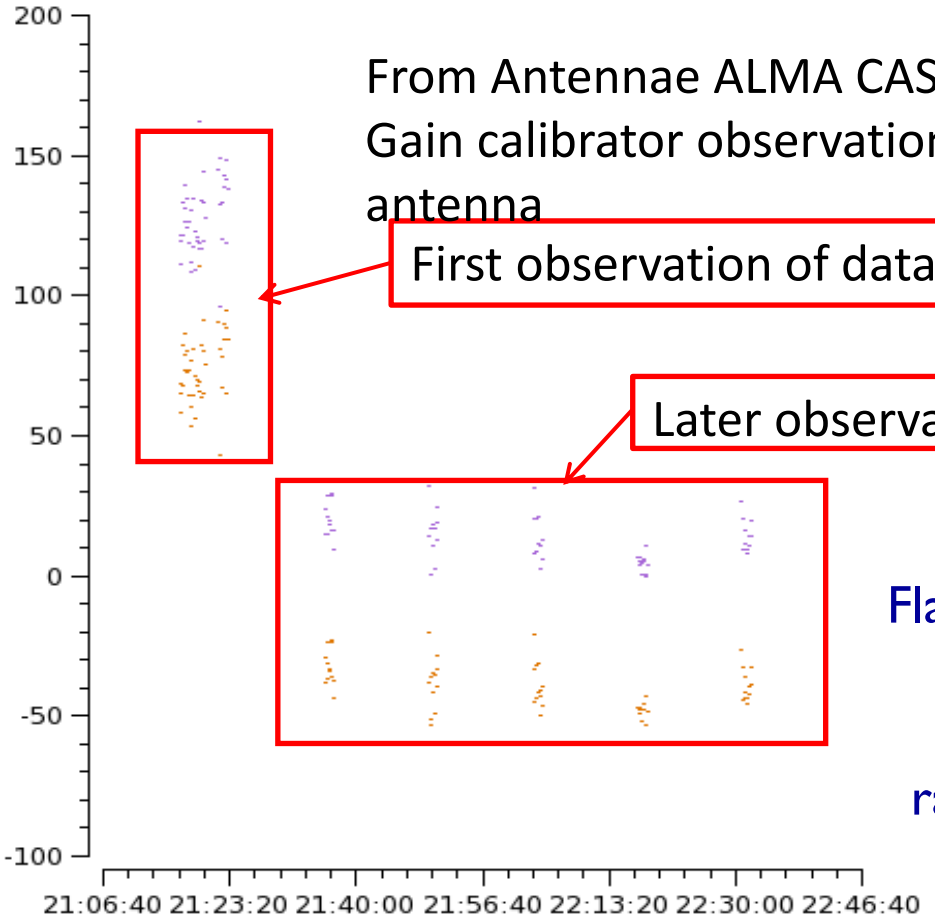


# Calibration



**Phase vs time and phase vs frequency:**

Look for discontinuities and where the phase changes rapidly. Increased phase noise is normal around atmospheric lines.




From Antennae ALMA CASA Guide
Gain calibrator observations on one antenna

First observation of data

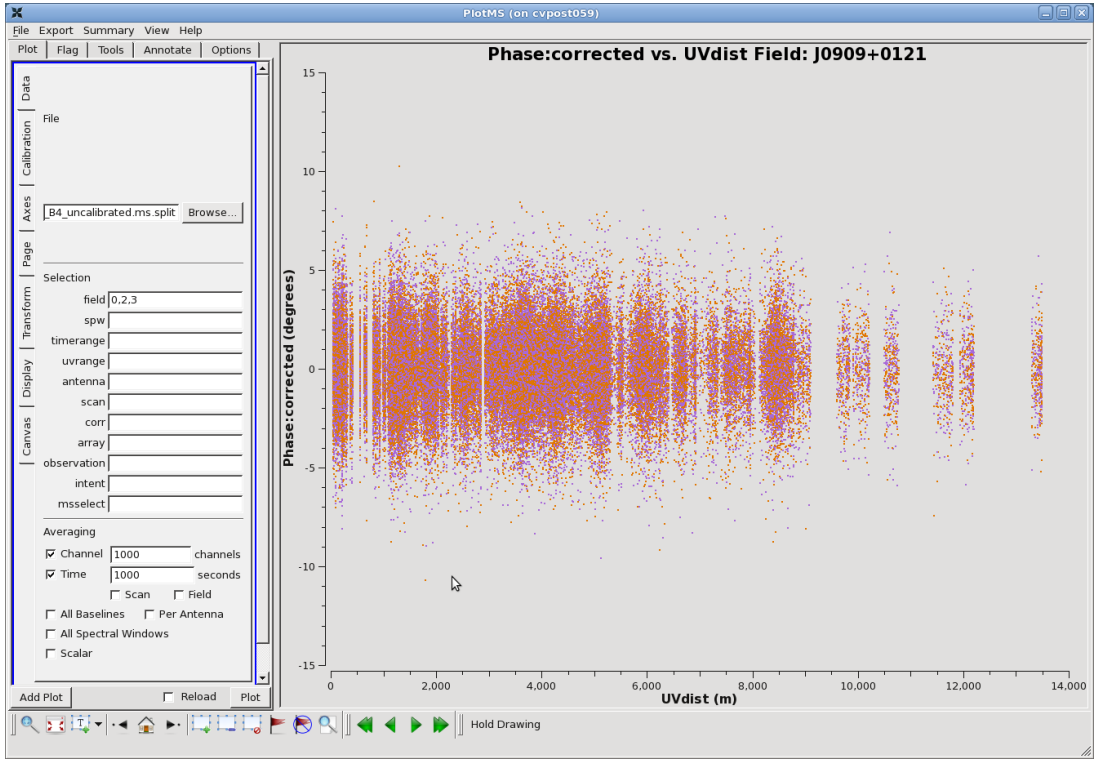
Later observations of data

Flag target data in the region where the solution is changing rapidly/discontinuously

# Your turn:

Look at the plots you did not look at yet:

- Amplitude vs time
- Phase vs time
- Amplitude vs frequency
- Phase vs frequency




**Phase vs UV distance for J0909+0121**

# Calibration

Saving Flagging State

Flagging Known Bad Data

Other Flags

Pre-Bandpass Phase Calibration

Bandpass Calibration

Checking Bandpass Calibration

Apply Flux Calibrator Model to Data

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Setting the Flux Scale

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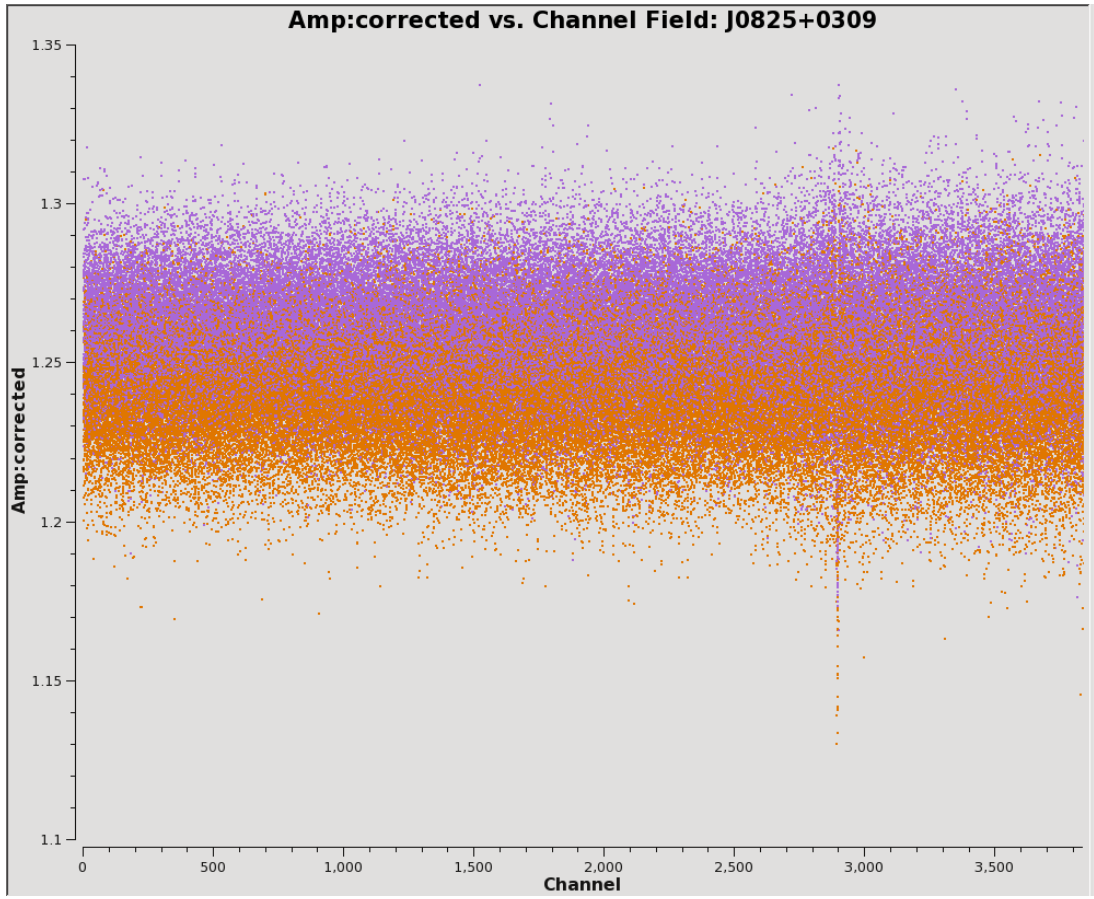
Applying the Calibration

**Checking the Calibration**

**Remember: We do not flag telluric lines in the data.**

After writing out all the flag commands, re-run the entire calibration!



# Calibration

Saving Flagging State

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**Checking the Calibration**

Final Steps:

After you finish

1. Calibrating the data
2. Inspecting the data
3. Adding flags
4. Repeat steps 1-3 as needed.

When finished, it is time to split the corrected columns to a new dataset.

# Calibration

Saving Flagging State

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Other Flags

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**Checking the Calibration**

Normally, we would now repeat this step for all other executions in the MOUS.

For Sgr A*, there were a total of 4 observations.

To save time, we have done the other 3 executions for you.

For imaging (next workshop or on your own) you can either image your single EB, or the full 4 EB MOUS.

# And we are finished!

- Thanks for sticking with me though that long workshop!
- If you have any further questions, feel free to ask!

- If you have problems or need to ask questions later, contact us at the ALMA help desk!  We are happy to help with your technical questions!

# Additional Resources:

- ALMA CASA Guides:
  - https://casaguides.nrao.edu/index.php?title=ALMAguides
- ALMA Documentation
  - https://almascience.nrao.edu/documents-and-tools
- ALMA Helpdesk:
  - https://help.almascience.org/

# Thank You!