VLA Data Reduction Tutorial

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Introduction

- We will use CASA 4.0
- This tutorial is based on the VLA high frequency spectral line tutorial targeting the AGB star IRC+10216.
- The array was in D-configuration.
- The frequency band was Ka (26.5 - 40 GHz)
- There are two spectral windows in this data set. One is centered on the HC3N line and the other on the SiS line.
- The full tutorial can be found at:

  http://casaguides.nrao.edu

  (Under CASA Tutorials, go to Karl G. Jansky VLA Tutorials → IRC+10216 Tutorial).

The data set

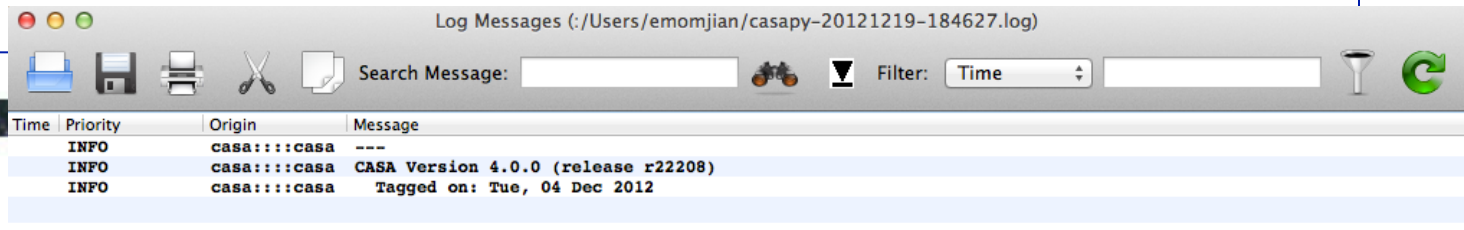
- You were asked to download a file from
  - ftp ftp.aoc.nrao.edu
  - login as anonymous, enter your email address for the password.
  - cd /staff/emomjian/Mexico
  - get data.tar.gz
- Un-compress the file, e.g., tar –zxvf *data*.tar.gz
- The result will be four files:
  - day2_TDEM0003_20s_full
  - IRC10216_spls.ms
  - IRC10216_HC3N.image
  - IRC10216_SiS.image

The data set

- 'day2_TDEM0003_20s_full' is a measurement set
- This data set is different than the one in the original tutorial:
  - Time averaging of 20 seconds have been applied (to make the size of the file more manageable).
  - The antenna position corrections have been applied.
  - Opacity corrections have been applied.

CASA Startup

```
> casapy

CASA Version 4.0.0 (r22208)
  Compiled on:Wed 2012/12/05 00:58:44 UTC

---------------------------------------------------------------------
    For help use the following commands:
    tasklist              - Task list organized by category
    taskhelp              - One line summary of available tasks
    help taskname         - Full help for task
    toolhelp              - One line summary of available tools
    help par.parametername - Full help for parameter name
---------------------------------------------------------------------
Activating auto-logging. Current session state plus future input saved.
Filename       : ipython-20121219-184629.log
Mode           : backup
Output logging : False
Raw input log  : False
Timestamping   : False
State          : active
*** Loading ATNF ASAP Package...
*** ...ASAP (trunk rev#21811) import complete ***

CASA <2>:
```



Initial examination and flagging

- List the summary of the data set: `listobs`
- Make a graphical plot of the antenna positions: `plotants`
- Plot the data: `plotms`
- Flag some bad data: `flagdata`

CASA: listobs

1

- List the summary of the data set: `listobs`
  - type `default listobs` in casa, hit enter
  - type `inp`
  - set

```
vis                         = 'day2_TDEM0003_20s_full'
```

  - type `go`
  - Check the casa logger

Data set Summary

Fields: 4

ID	Code	Name	RA	Decl	Epoch	SrcId	nRows
2	D	J0954+1743	09:54:56.82363	+17.43.31.2224	J2000	2	32726
3	NONE	IRC+10216	09:47:57.38200	+13.16.40.6600	J2000	3	99540
5	F	J1229+0203	12:29:06.69973	+02.03.08.5982	J2000	5	5436
7	E	J1331+3030	13:31:08.28798	+30.30.32.9589	J2000	7	2736

Spectral Windows: (2 unique spectral windows and 1 unique polarization setups)

SpwID	#Chans	Frame	Ch1(MHz)	ChanWid(kHz)	TotBW(kHz)	Corrs
0	64	TOPO	36387.2295	125	8000	RR RL LR LL
1	64	TOPO	36304.542	125	8000	RR RL LR LL

Sources: 10

ID	Name	SpwId	RestFreq(MHz)	SysVel(km/s)
0	J1008+0730	0	0.03639232	-0.026
0	J1008+0730	1	0.03639232	-0.026
2	J0954+1743	0	0.03639232	-0.026
2	J0954+1743	1	0.03639232	-0.026
3	IRC+10216	0	0.03639232	-0.026
3	IRC+10216	1	0.03639232	-0.026
5	J1229+0203	0	0.03639232	-0.026
5	J1229+0203	1	0.03639232	-0.026
7	J1331+3030	0	0.03639232	-0.026
7	J1331+3030	1	0.03639232	-0.026

Antennas: 19:

ID	Name	Station	Diam.	Long.	Lat.
0	ea01	W09	25.0 m	-107.37.25.2	+33.53.51.0
1	ea02	E02	25.0 m	-107.37.04.4	+33.54.01.1
2	ea03	E09	25.0 m	-107.36.45.1	+33.53.53.6
3	ea04	W01	25.0 m	-107.37.05.9	+33.54.00.5
4	ea05	W08	25.0 m	-107.37.21.6	+33.53.53.0
5	ea07	N06	25.0 m	-107.37.06.9	+33.54.10.3
6	ea08	N01	25.0 m	-107.37.06.0	+33.54.01.8
7	ea09	E06	25.0 m	-107.36.55.6	+33.53.57.7
8	ea12	E08	25.0 m	-107.36.48.9	+33.53.55.1
9	ea15	W06	25.0 m	-107.37.15.6	+33.53.56.4
10	ea19	W04	25.0 m	-107.37.10.8	+33.53.59.1
11	ea20	N05	25.0 m	-107.37.06.7	+33.54.08.0
12	ea21	E01	25.0 m	-107.37.05.7	+33.53.59.2
13	ea22	N04	25.0 m	-107.37.06.5	+33.54.06.1
14	ea23	E07	25.0 m	-107.36.52.4	+33.53.56.5
15	ea24	W05	25.0 m	-107.37.13.0	+33.53.57.8
16	ea25	N02	25.0 m	-107.37.06.2	+33.54.03.5
17	ea27	E03	25.0 m	-107.37.02.8	+33.54.00.5
18	ea28	N08	25.0 m	-107.37.07.5	+33.54.15.8

Summary of Observing Strategy

Complex gain calibrator	J0954+1743; field id=2
Bandpass calibrator	J1229+0203; field id=5
Flux calibrator	J1331+3030 (3C286); field id=7
Science target	IRC+10216; field id=3

Ka-band spws = 0, 1

CASA: plotants

2

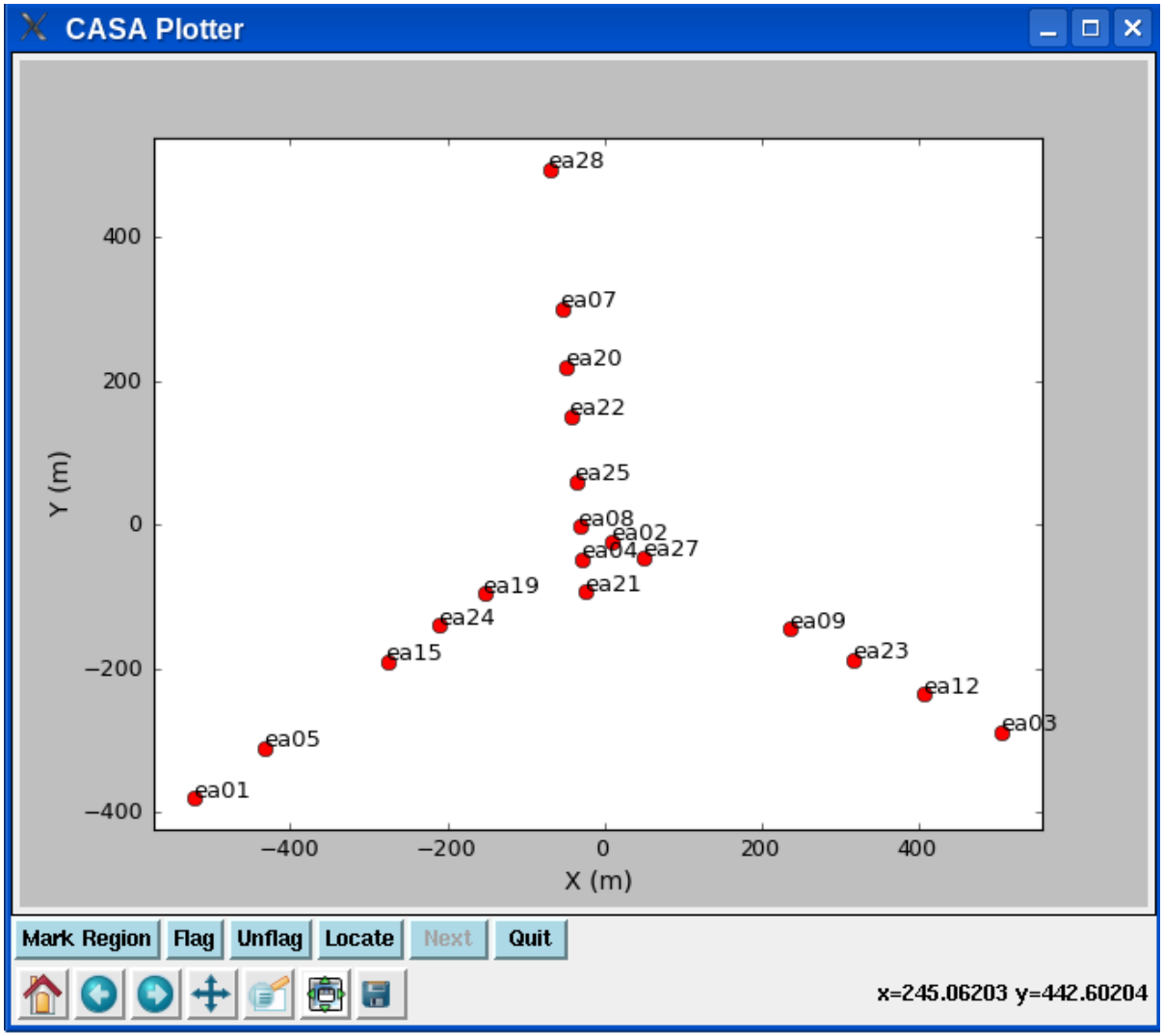
- To make a graphical plot of the antenna positions: `plotants`
  - type `default plotants` in casa, hit enter
  - type `inp`
  - populate the relevant adverbs, e.g.,

```
vis                 = 'day2_TDEM0003_20s_full'
figfile             =          ''
```

  - type `go`

Antenna locations from running plotants

We choose ea02 as the reference antenna



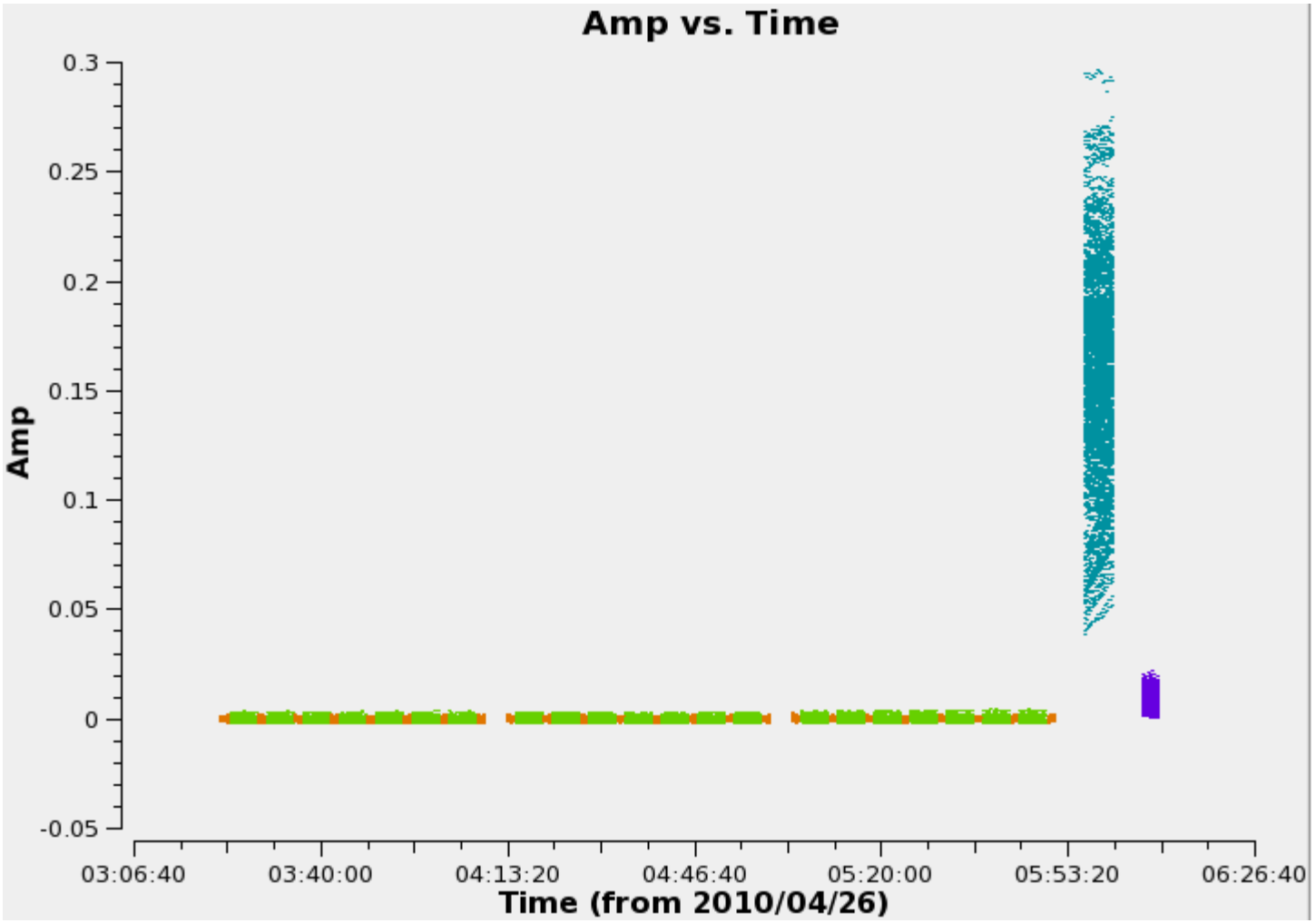
CASA: plotms

- To plots the data using various types of axes: `plotms`
  - Plot amp vs. time
  - type `default plotms` in casa, then type `inp`

```
vis                 = 'day2_TDEM0003_20s_full'
xaxis               = 'time'
yaxis               = 'amp'
selectdata          =  true
 spw                = '0:4~60'
 correlation        = 'RR,LL'
averagedata         =  true
 avgchannel         = '64'
coloraxis           = 'field'
```

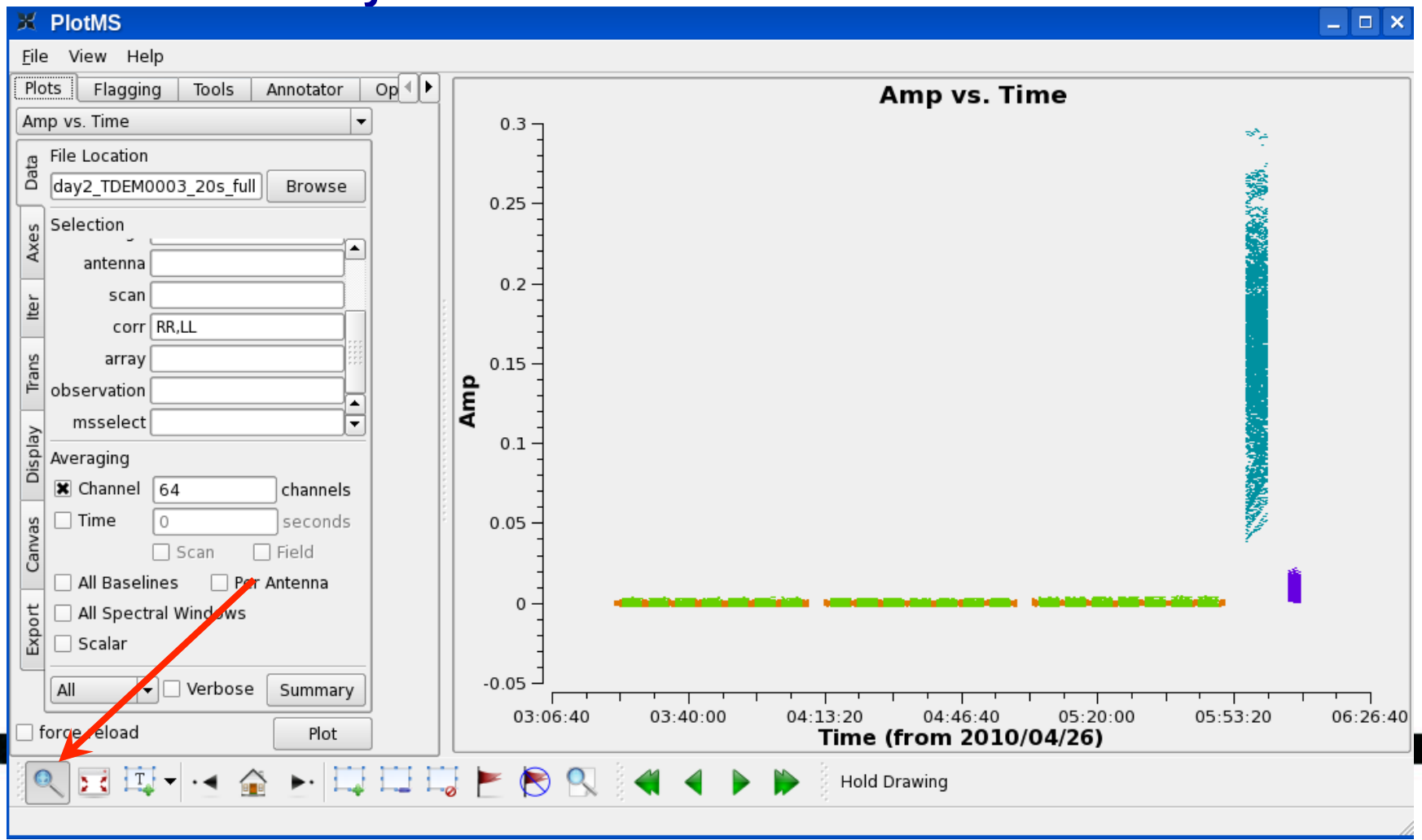
  - go

CASA: plotms


Amp vs. Time
Amp
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
03:06:40
03:40:00
04:13:20
04:46:40
05:20:00
05:53:20
06:26:40
Time (from 2010/04/26)

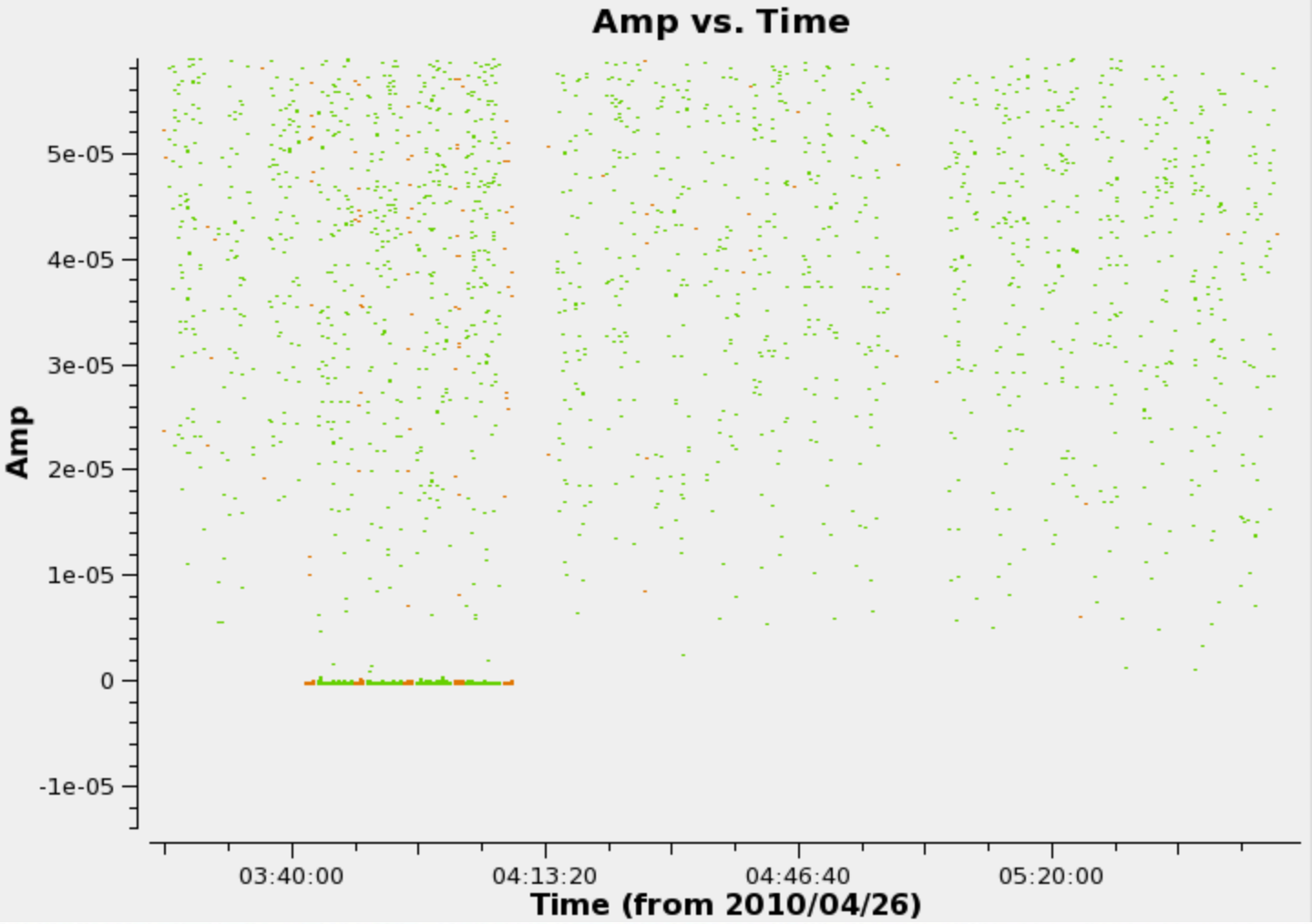
CASA: plotms

- In plotms, zoom in on the region very near zero amplitude for sources J0954+1743 and IRC+10216.



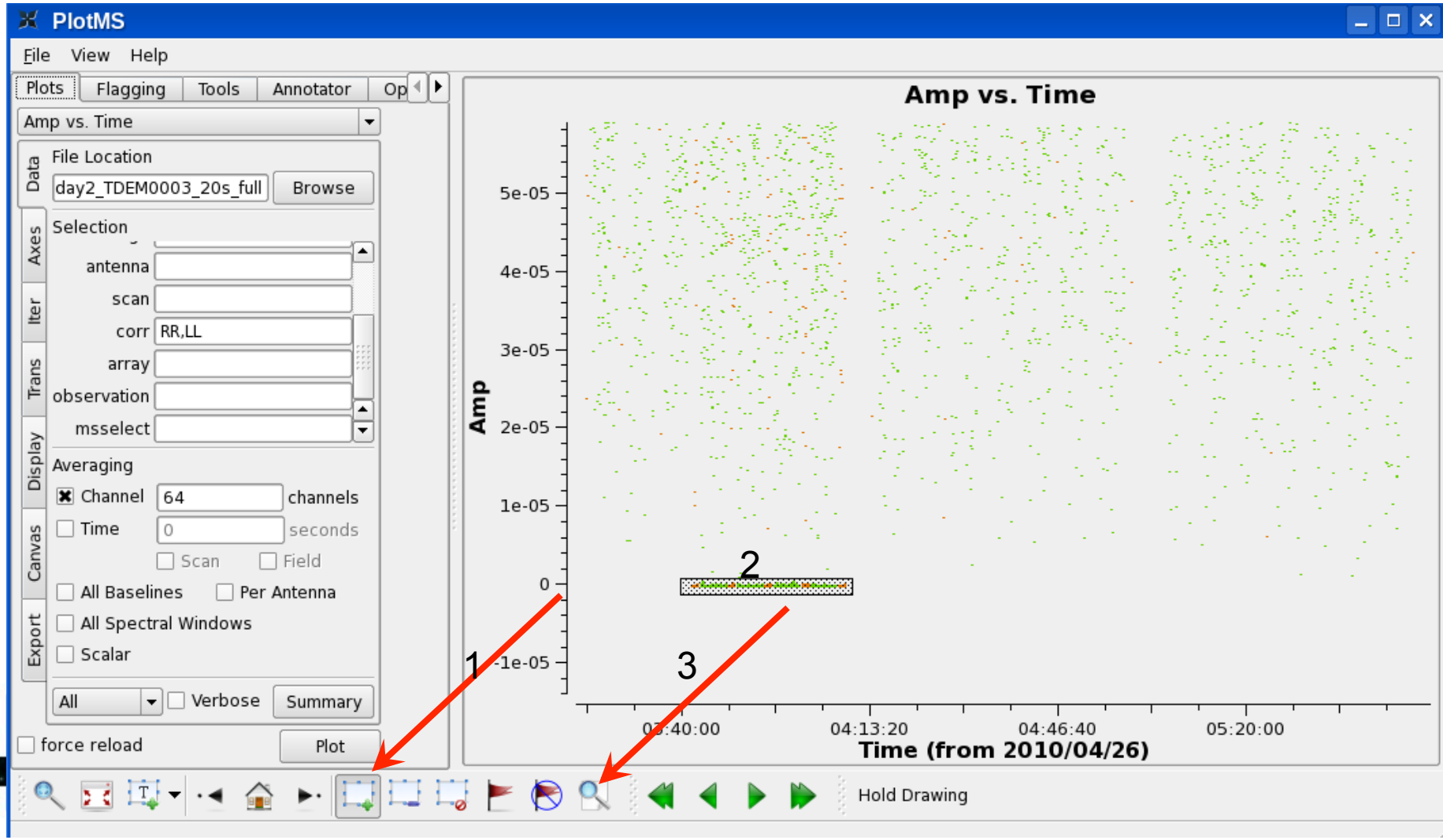
CASA: plotms

- May need to zoom-in several times to get to this.



CASA: plotms

- Identify what's the cause of the bad points:



CASA: plotms

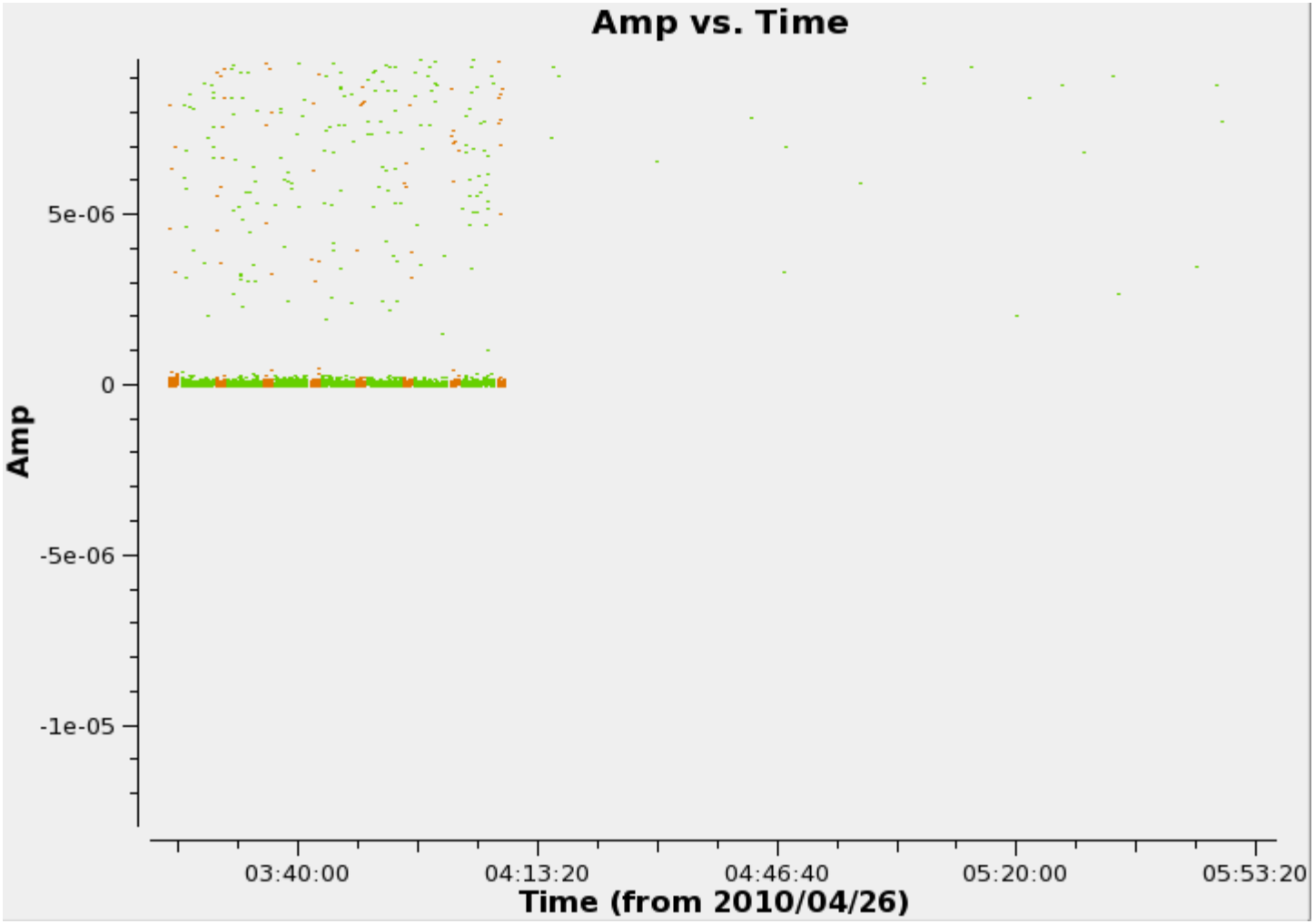
- Check the casa logger.
- Notice that all the baselines of these data points include antenna ea12.
- Note the time range 03:40:00 to 04:10:00
- We could flag interactively/graphically, but we rather flag globally addressing the root cause of the problem.

- In plotms, click on 'Clear Regions'

CASA: plotms

- Now check spectral window 1:
  - change '**0**:4~60' to '**1**:4~60' in the spw window on the side menu of plotms, and hit plot.
  - Zoom in again (several times).

CASA: plotms


Amp vs. Time
5e-06
0
-5e-06
-1e-05
Amp
03:40:00
04:13:20
04:46:40
05:20:00
05:53:20
Time (from 2010/04/26)

CASA: plotms

- Identify what's the cause of the bad points:
  - Make a region, and locate.

CASA: plotms

- The problem in spw 1 is due to ea07.
- Time range 03:21:40 to 04:10:00
- Hit the 'Clear Region' to remove the box.
- In the antenna field of plotsms, type !ea07 (this excludes all data points with antenna ea07). Zoom in several times to note that the bad points are no longer displayed.

CASA: flagdata

4

- We have identified two problematic antennas.
- To flag, use the task `flagdata`
- `Default flagdata,` then `inp`

```
vis                 = 'day2_TDEM0003_20s_full'
mode                = 'manual'
spw                 = '0'
field               = '2,3'
selectdata          =       True
 antenna     = 'ea12'
 timerange   = '03:41:00~04:10:00'
```

- Type `go`, and check the casa logger.

CASA: flagdata

- `tget flagdata`

```
spw         = '1'
antenna     = 'ea07'
timerange   = '03:21:40~04:10:00'
```

- Type `go`, and check the casa logger.

Calibration Strategy

- Setting the flux density scale: `setjy`
- Making a calibration table for antenna gain curves and efficiencies: `gencal`
- To properly calibrate the bandpass in high frequency observations:
  1. Phase only calibration (short solint) on the bandpass calibrator: `gaincal`
  2. Bandpass calibration applying (1) : `bandpass`
- The calibration table (1) is ignored in consequent steps. The bandpass table (2) is applied on the fly in consequent steps.

CASA: setjy

- Flux density calibration using 3C286.
- This source requires a model.
- Use the task `setjy`
- To find out if a model is available (`default setjy`)

```
vis                 = 'day2_TDEM0003_20s_full'
listmodels          =       True
```

- Type `go`
- The Ka-band models have '_A' in the names.
- For our data set, we will use 3C286_A.im

CASA: setjy

Now set

```
listmodels          =       False
field               =         '7'
modimage            = '3C286_A.im'
```

Type `go`

The logger will report:

J1331+3030 (fld ind 7) spw 0 [I=1.7764, Q=0, U=0,V=0] Jy, (Perley-Butler 2010)

J1331+3030 (fld ind 7) spw 1 [I=1.7795, Q=0, U=0,V=0] Jy, (Perley-Butler 2010)

CASA: gencal

- The task `gencal` allows for making various types of calibration tables for opacity, gain curve, tsys, etc..
- We will use this task to make a calibration table for the gain curves.
- The gaincurve describes how each antenna behaves as a function of elevation, for each receiver band.

CASA: gencal

- Default gencal, then inp

```
vis                 = 'day2_TDEM0003_20s_full'
caltable            = 'gaincurve.cal'
caltype             = 'gceff'

go
```

'gceff' will write both antenna gain curves and antenna efficiencies in the output table.

CASA: gaincal

- Phase only calibration (short solint) on the bandpass calibrator: `gaincal`.
- This is to correct the phase variations with time before solving for the bandpass to prevent decorrelation.

CASA: gaincal

- default gaincal, then inp

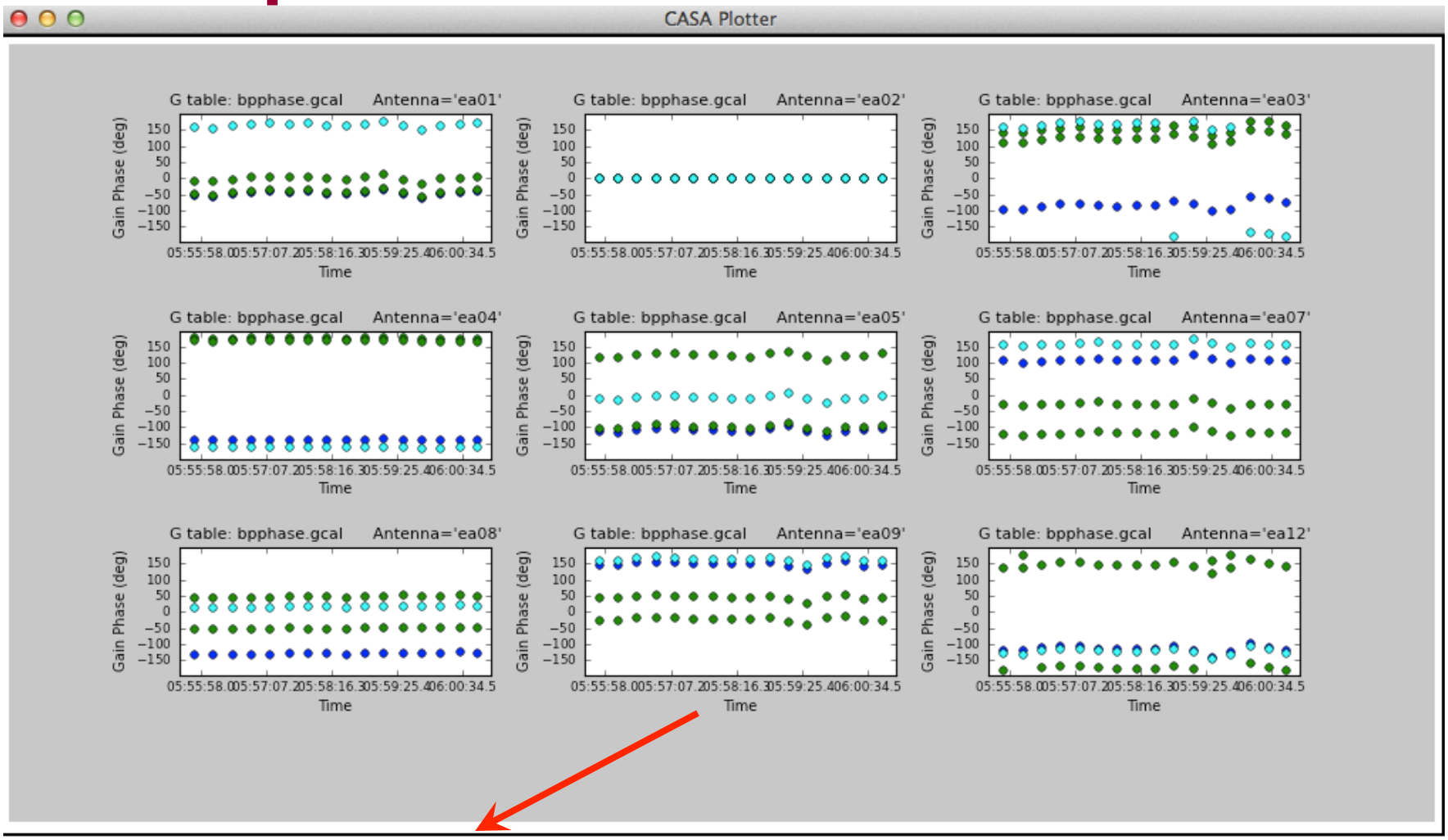
```
vis                 = 'day2_TDEM0003_20s_full'
caltable            = 'bpphase.gcal'
field               =        '5'
spw                 = '0~1:20~40'
solint              =      'int'
refant              =     'ea02'
gaintype            =        'G'
calmode             =        'p'
gaintable           =  'gaincurve.cal'

go
```

CASA: plotcal

- `gaincal` made the table `bpphase.gcal`
- Plot the derived solutions: `plotcal`

```
default plotcal
 caltable                = 'bpphase.gcal'
 xaxis                   =     'time'
 yaxis                   =    'phase'
 subplot                 =        331
 iteration               =     'antenna'
 plotrange               = [0,0,-180,180]
go
```

CASA: plotcal



CASA: bandpass

- **Bandpass calibration:** `bandpass`

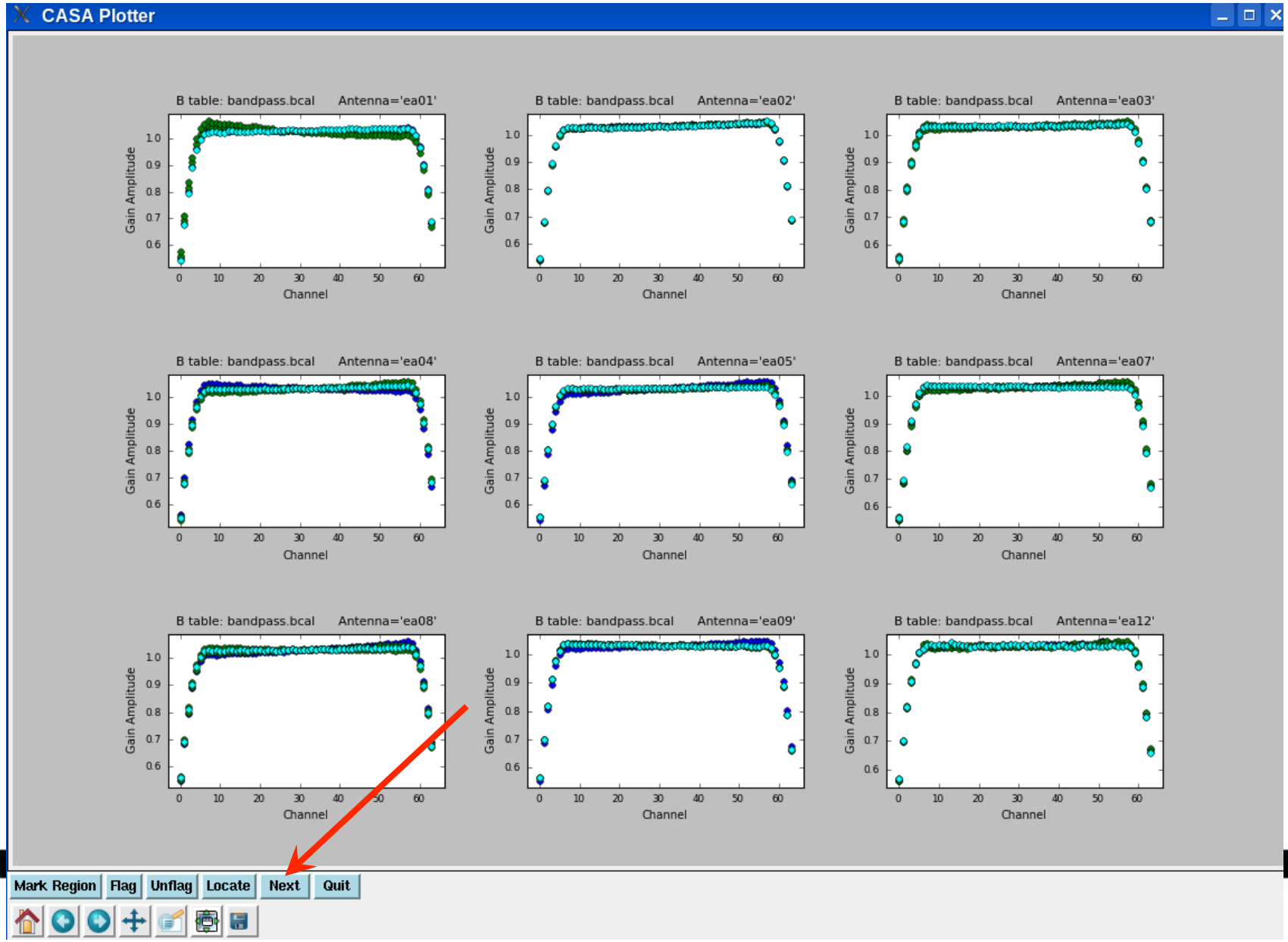
```
default bandpass
vis          = 'day2_TDEM0003_20s_full'
caltable     = 'bandpass.bcal'
field        =          '5'
solint       =       'inf'
refant       =      'ea02'
solnorm      =        True
gaintable    = ['gaincurve.cal','bpphase.gcal']

go
```

CASA: plotcal

- `bandpass` **made the table** `bandpass.bcal`
- **Plot the derived amplitude solutions:** `plotcal`

```
default plotcal
caltable              = 'bandpass.bcal'
xaxis                 =     'chan'
yaxis                 =    'amp'
subplot               =        331
iteration             =     'antenna'
go
```

CASA: plotcal

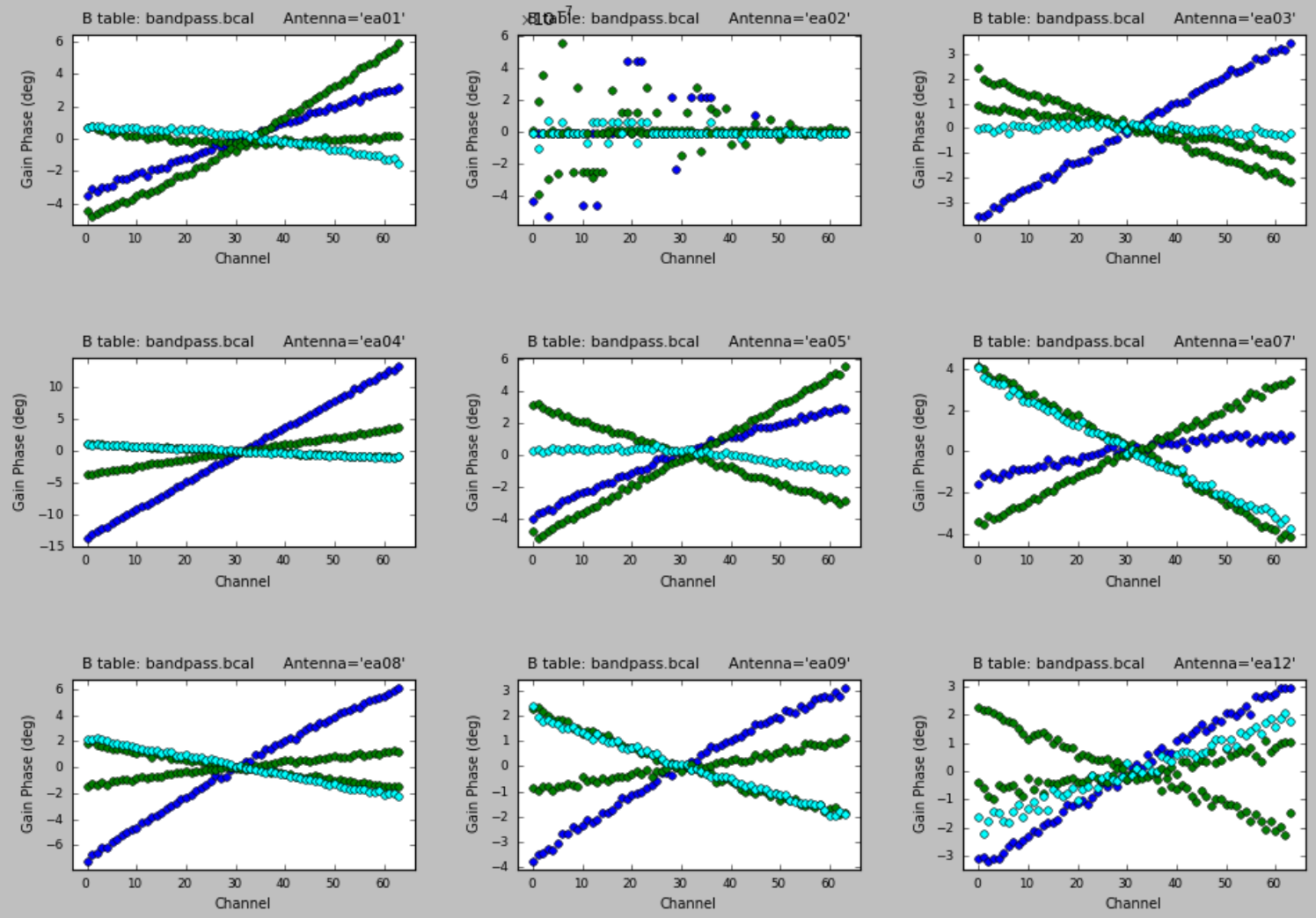


CASA: plotcal

- Plot the derived amplitude solutions: `plotcal`

```
tget plotcal
yaxis                    =       'phase'
go
```

CASA: plotcal



Calibration Strategy

- To bootstrap the flux densities of the secondary calibrators:
  a) Phase only calibration (short solint) on all calibrators: `gaincal`
  b) Amplitude only calibration (scan based) on all calibrators: `gaincal`, apply (a) on the fly
  c) Derive the flux densities of the secondary calibrators: `fluxscale`, use (b) as input. This will also correct the amplitude solutions of (b) and write a new table.
- To calibrate the target source:
  – Phase only calibration (scan based) on the phase calibrator: `gaincal`
  – The amplitude will be calibrated using the table from (c).

Calibration Strategy

- Apply the calibration tables on the target
  - The task to use is `applycal`
  - The various calibration tables relevant to the target source gets applied on the target. For instance:
    - The bandpass table.
    - The scan based phase calibration table.
    - The amplitude calibration table (written by `fluxscale`).
  - The calibrated data is written in the 'corrected column' of the ms.

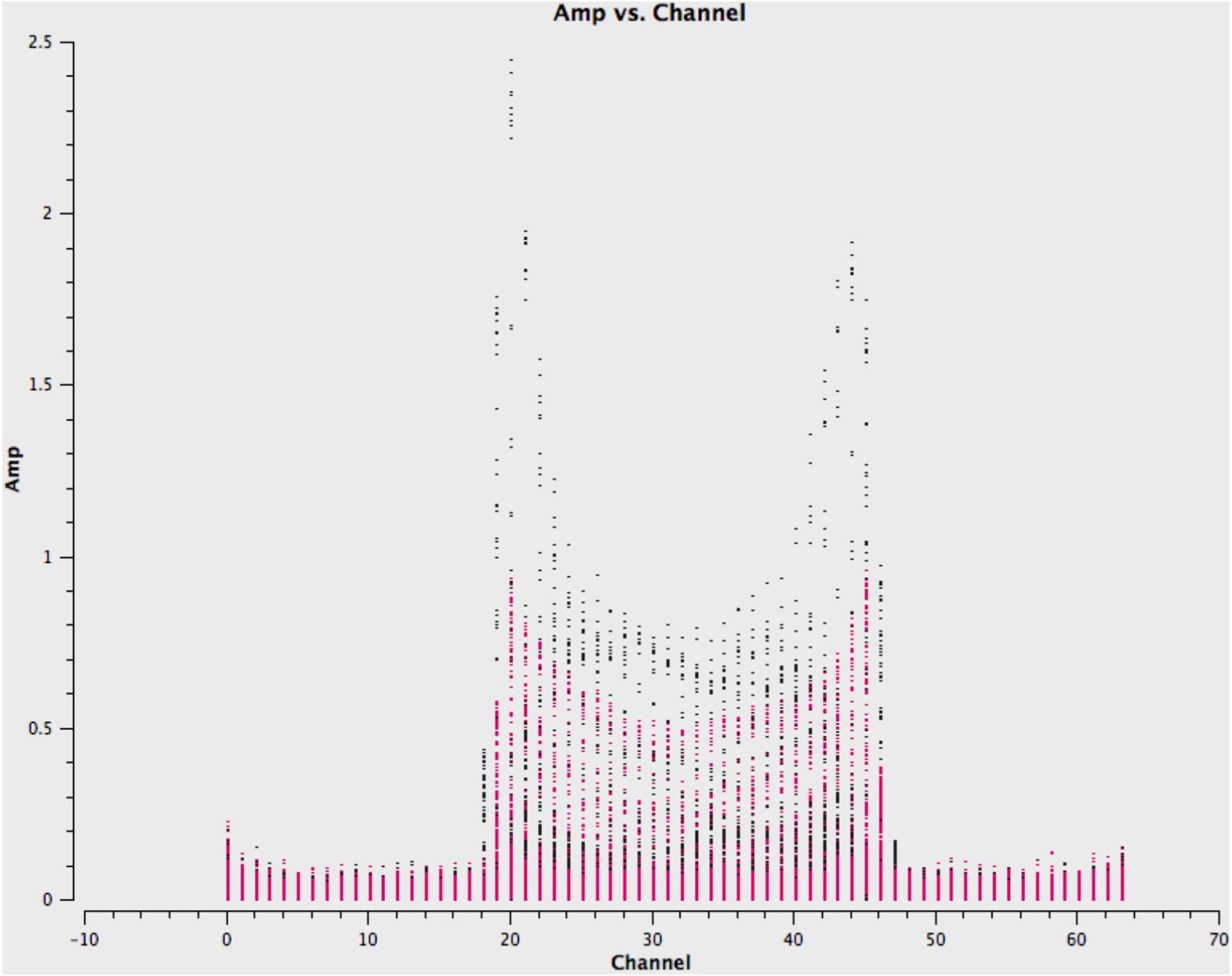
Calibration Strategy

- Examine the calibrated data with plotms.
- Identify bad data and/or antennas, flag, and redo all the calibration.
- Redo `applycal` and re-examine.
- If all look good, then
  - `split` the target source into a new ms (for convenience).
  - Subtract the continuum using `uvcontsub`
  - Doppler correct the data using `CVEL` (or let clean do the Doppler corrections on the fly) .

The spectral line data set

- The continuum-subtracted spectral-line data set is IRC10216_spls.ms. Plot the lines

```
default plotms
vis                 = 'IRC10216_spls.ms'
xaxis               =  'channel'
yaxis               =      'amp'
averagedata         =       True
   avgtime          =      '1e8'
   avgscan          =       True
coloraxis           =      'spw'
go
```


Amp vs. Channel
Amp
Channel
2.5
2
1.5
1
0.5
0
-10
0
10
20
30
40
50
60
70

CASA: Clean

- For illustration: image/clean channel 22 of the SiS line.

```
default clean
vis                 = 'IRC10216_spls.ms'
imagename           =     'ch22'
spw                 =  '1:22~22'
mode                =  'channel'
nchan               =            1
start               =           ''
width               =            1
niter               =       100000
gain                =          0.1
threshold           =    '3.0mJy'
```

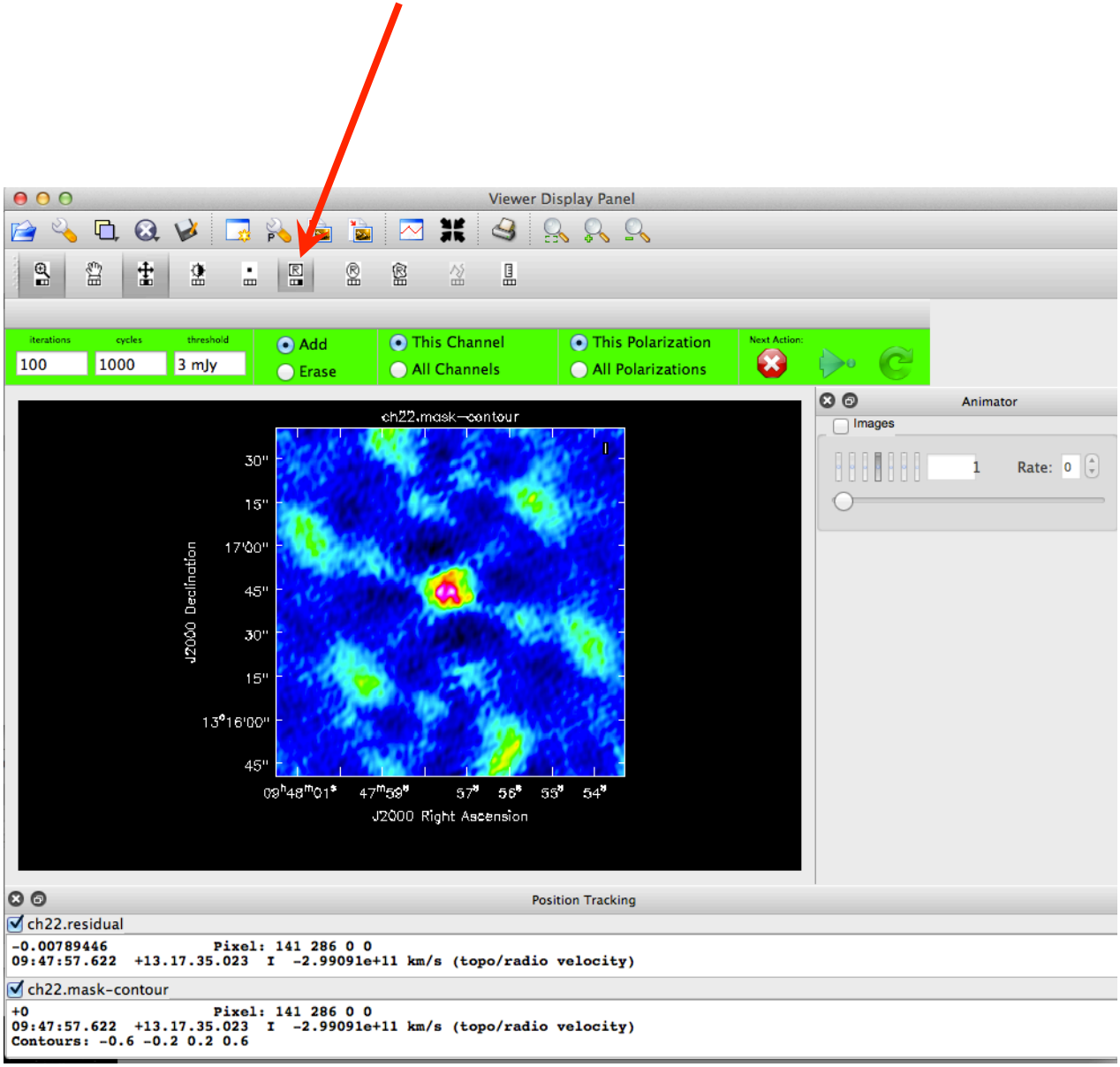
Don't type go yet

CASA: Clean


```
psfmode                =    'clark'
imagermode             =  'csclean'
interactive            =       True
npercycle              =        100
imsize                 =        300
cell                   = '0.4arcsec'
stokes                 =        'I'
weighting              =   'briggs'
robust                 =        0.5
go
```

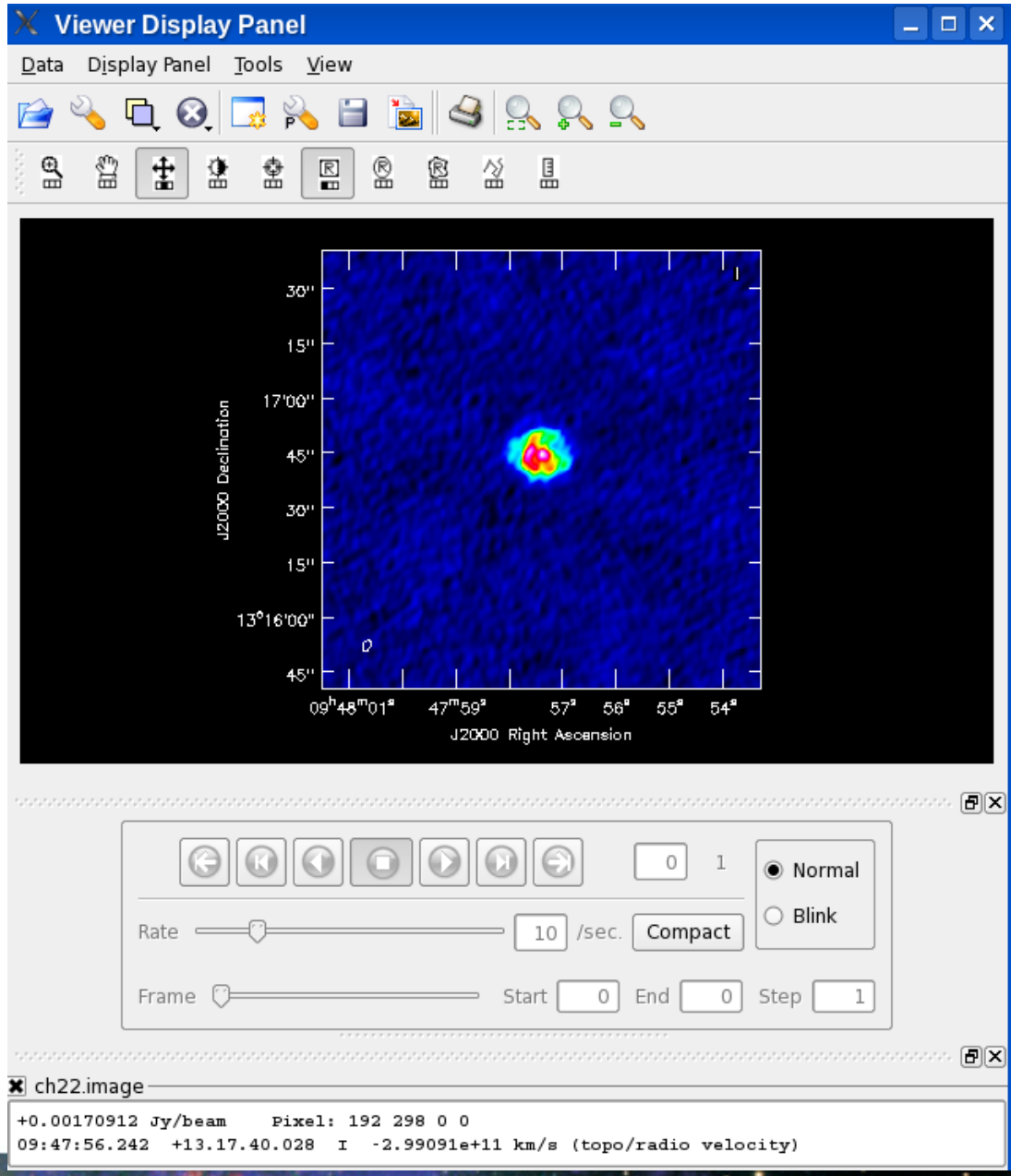
CASA: Clean

- Make a region.
- Double click inside the region (green outline turns white).
- Clean (click on the green circular arrow several times).



CASA: viewer

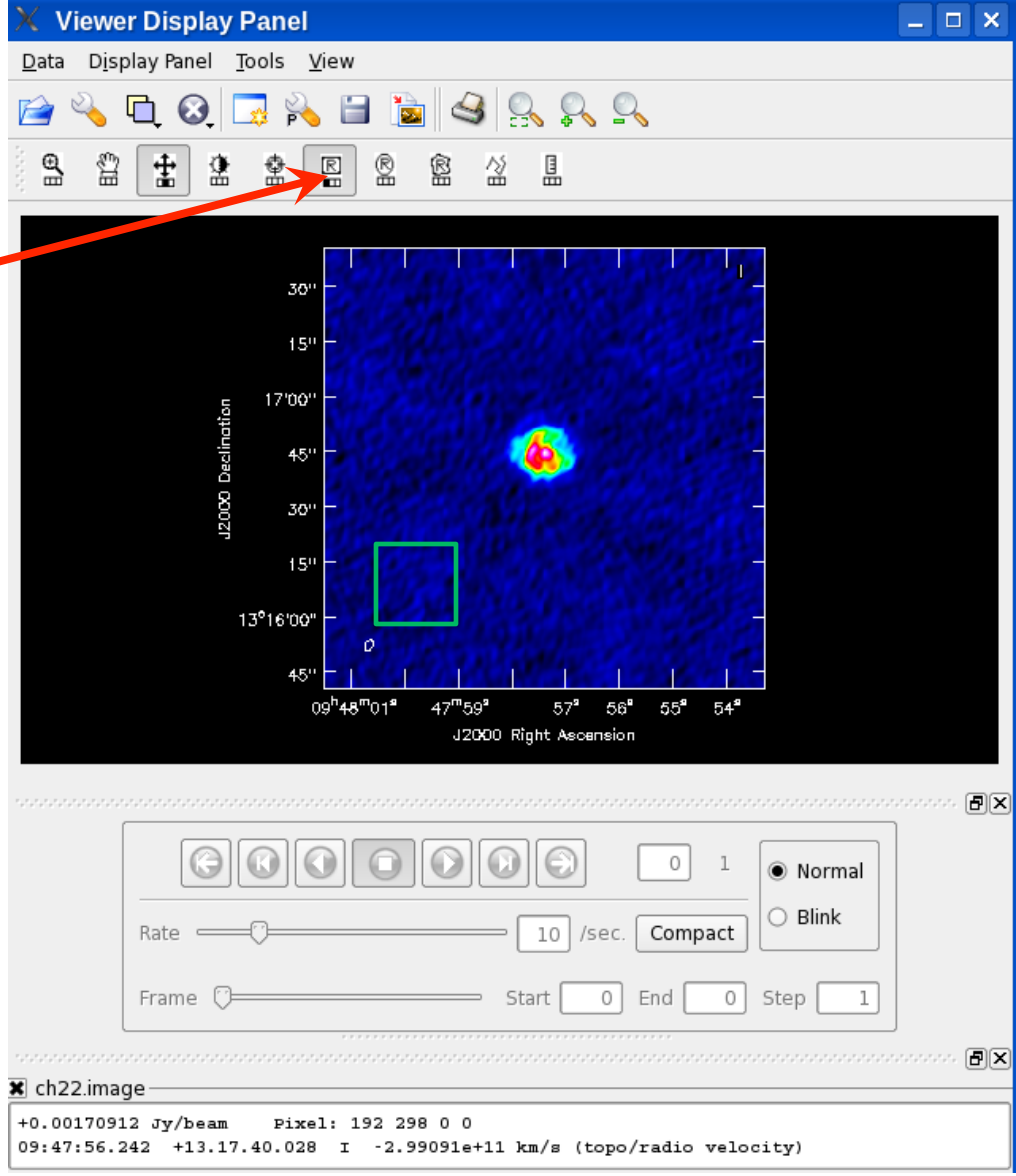
- Start the `viewer` (type `viewer` in CASA).
- Choose ch22.image.
- Load as 'raster image'.



CASA: viewer

- Make a region off-source, double click in the region to get some statistics (in the CASA terminal).

- Close the viewer.



Stokes	Velocity	Frame	Doppler	Frequency
I	-2.99091e+11km/s	TOPO	RADIO	3.63073e+10
BrightnessUnit	BeamArea	Npts	Sum	Flux
Jy/beam	45.3306	5400	1.623533e+00	3.581542e-02
Mean	Rms	Std dev	Minimum	Maximum
3.006543e-04	2.030842e-03	2.008650e-03	-7.231708e-03	6.453225e-03

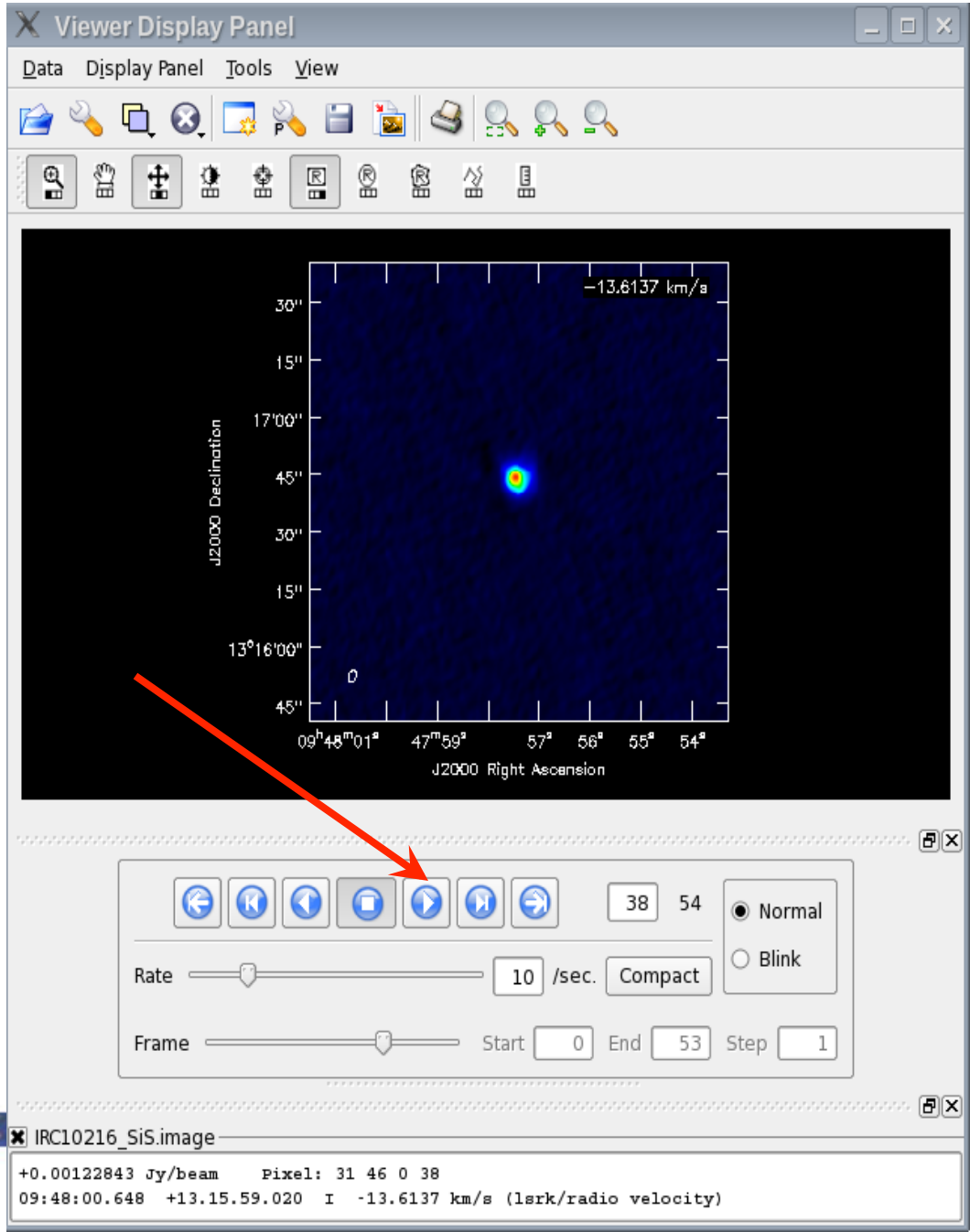
The Image cubes

- The data files we have provided included two image cubes
  - IRC10216_HC3N.image
  - IRC10216_SiS.image
- Using the `viewer`, display the image cubes

CASA: viewer

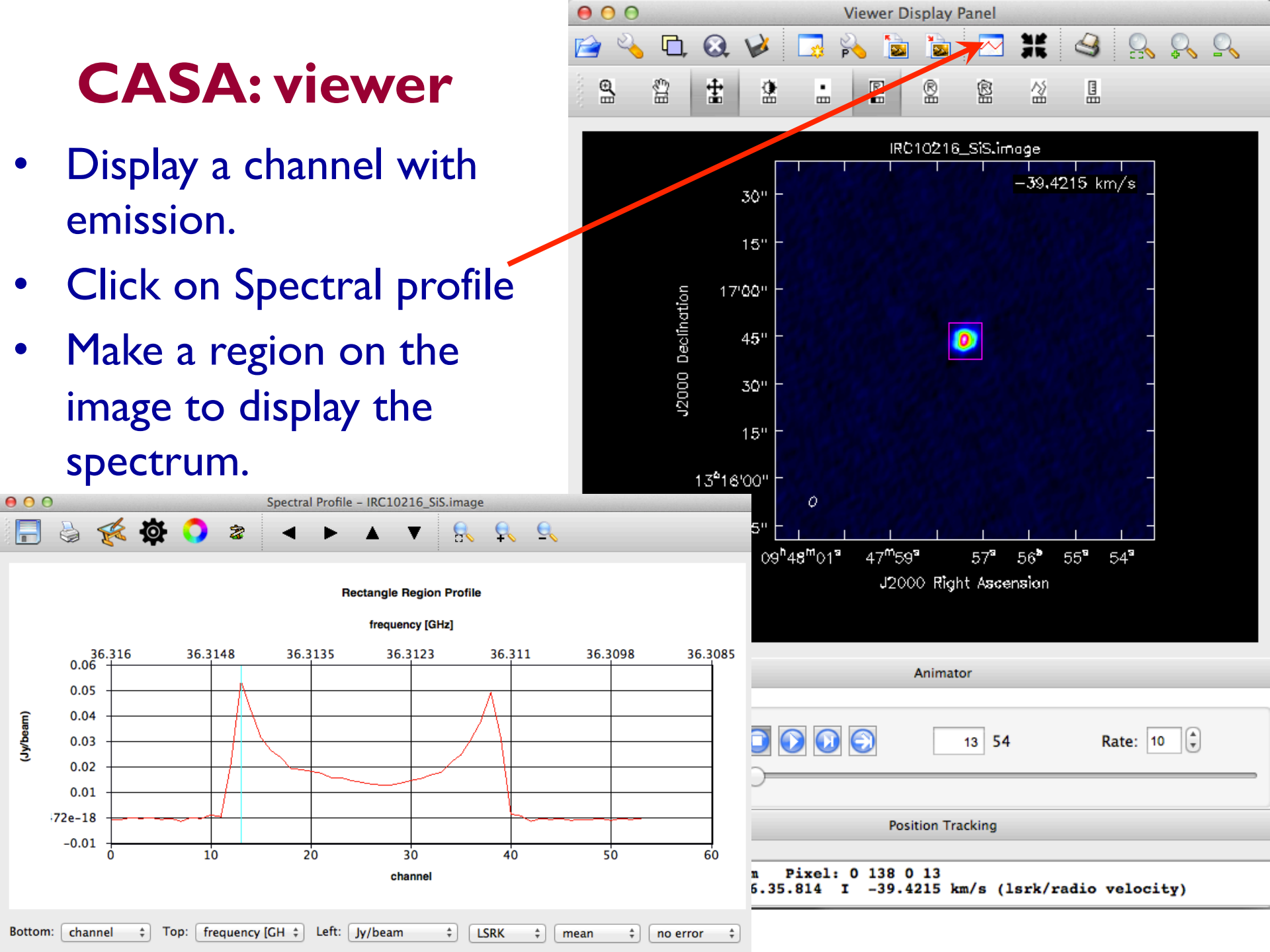
- Start the `viewer`
- Choose one of the image cubes.
- Load as 'raster image'.
- Play the movie.

- Load the other image cube and play the movie.



CASA: viewer

- Display a channel with emission.
- Click on Spectral profile
- Make a region on the image to display the spectrum.



CASA: immoments

- Determine the channels with emission in the SiS image cube.
- Make moment maps using the task `immoments`

```
default immoments
imagename                = 'IRC10216_SiS.image'
moments                  =         [0]
axis                     = 'spectral'
chans                    =    '12~40'
outfile                  = 'IRC10216_SiS.mom0'
go
```

- Specify appropriate pixel ranges if necessary (through includepix and/or excludepix parameters).

CASA: viewer

- Start the `viewer`
- Choose the moment 0 image.
- Load as ‘raster image’.
- Reload as ‘contour map’ to overlay contours.