VLA Data Reduction Techniques

Emmanuel Momjian
NRAO

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Outline

- The archive tool.
- Loading the data set.
- CASA
- Examining/Flagging the data set.
- Calibration
  - Including high and low frequency considerations.
- Imaging
  - Including spectral line, continuum, wide band, and wide field.
- Image analysis

I

II

Assumptions

This presentation assumes that you are familiar with **the basics of**:

- radio interferometry.
- flux density calibration, *antenna-based* calibration (complex gain, bandpass) and self-calibration.
- imaging and deconvolution.

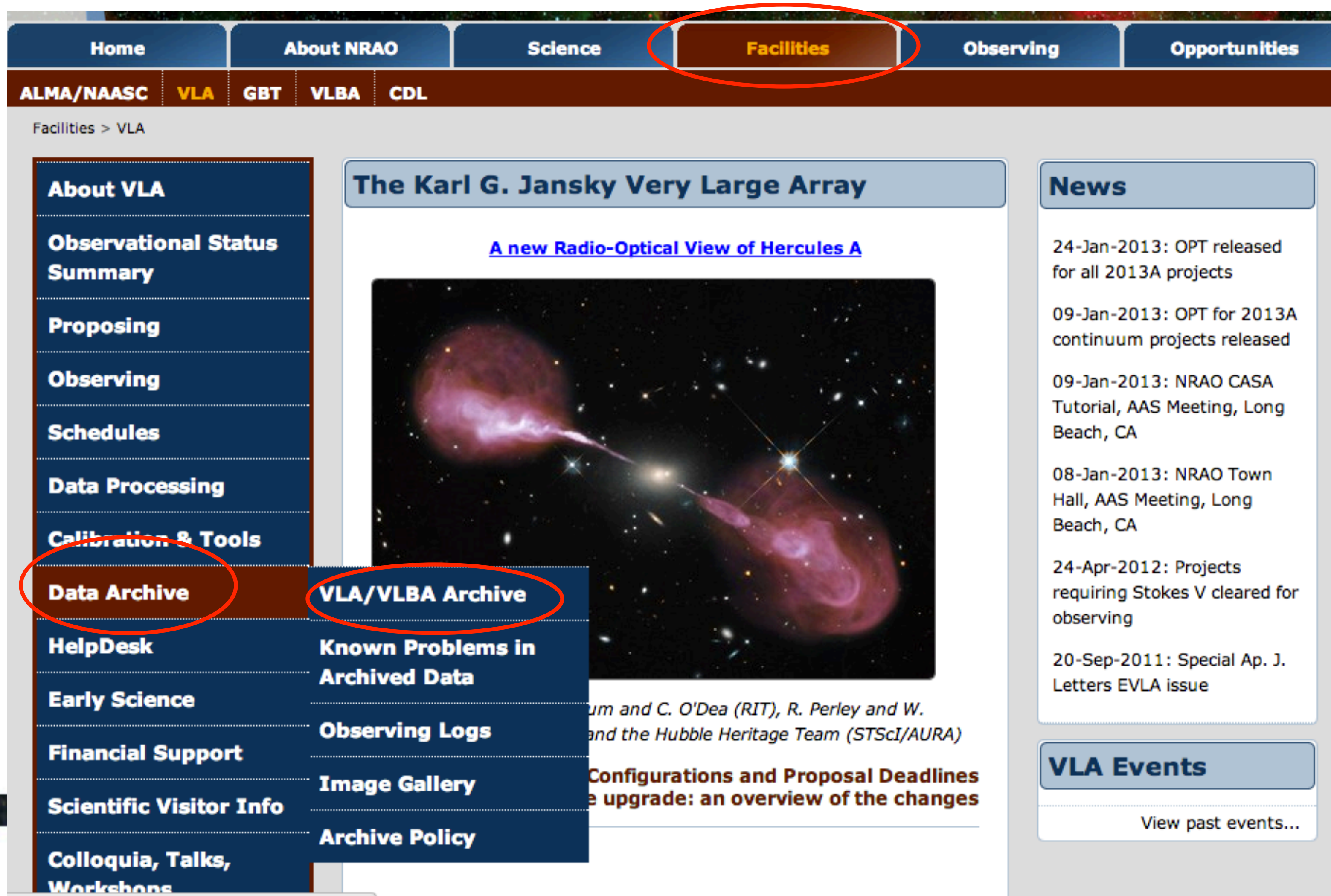
For references on the above, please check:

- The lectures of the synthesis imaging workshop http://www.aoc.nrao.edu/events/synthesis/2012/
- Synthesis Imaging for Radio Astronomy II (eds. Taylor, Carilli, and Perley).
- Interferometry and Synthesis in Radio Astronomy (by Thompson, Moran, and Swenson).

The archive tool

https://science.nrao.edu/

→ Facilities → VLA, Data Archive (left menu), VLA/VLBA Archive



The archive tool

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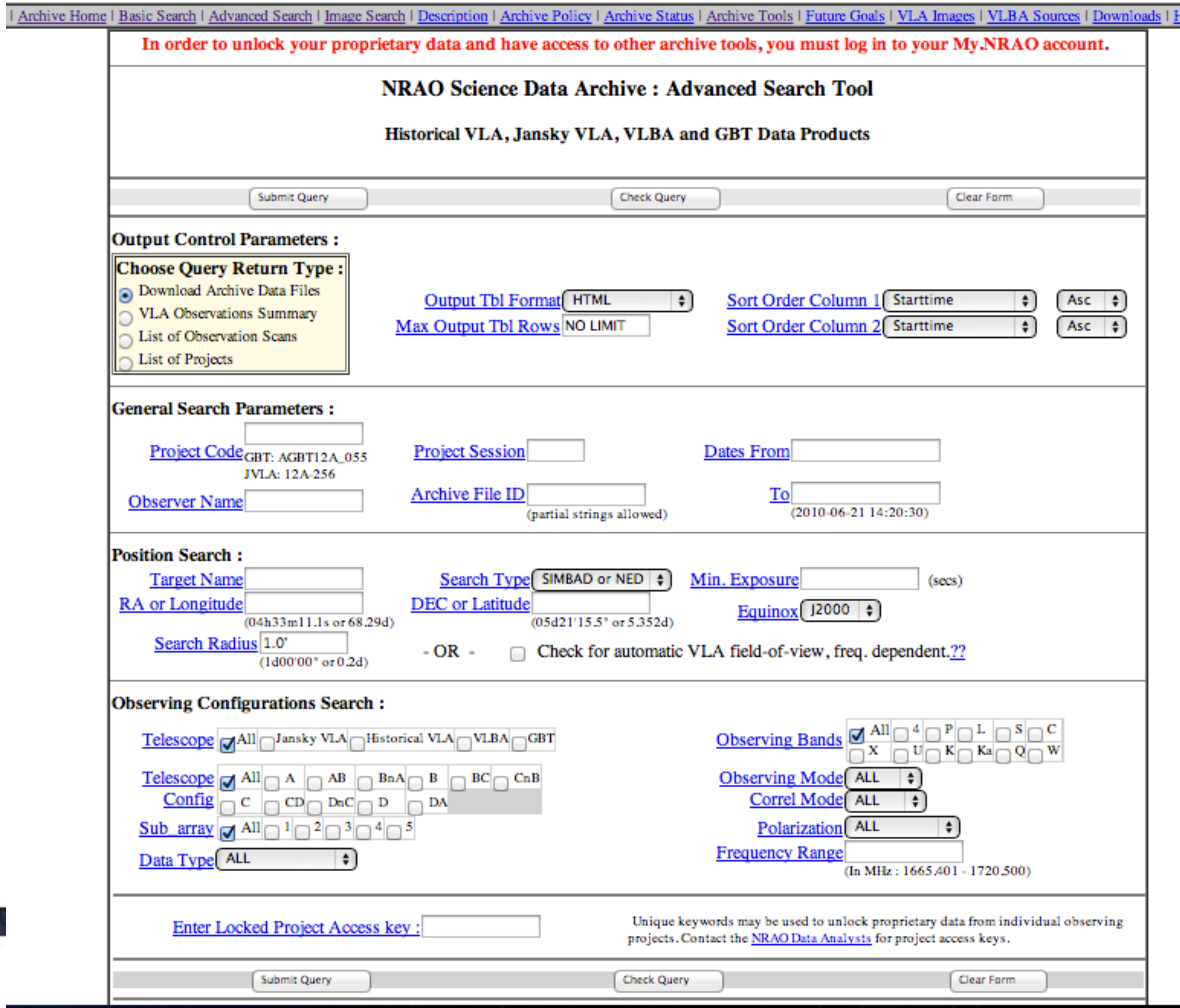

| Archive Home | Basic Search | Advanced Search | Image Search | Description | Archive Policy | Archive Status | Archive Tools | Future Goals | VLA Images | VLBA Sources | Downloads |

In order to unlock your proprietary data and have access to other archive tools, you must log in to your My.NRAO account.

NRAO Science Data Archive : Advanced Search Tool

Historical VLA, Jansky VLA, VLBA and GBT Data Products

Submit Query | Check Query | Clear Form

Output Control Parameters :

Choose Query Return Type :
- Download Archive Data Files
- VLA Observations Summary
- List of Observation Scans
- List of Projects

Output Tbl Format: HTML
Max Output Tbl Rows: NO LIMIT
Sort Order Column 1: Starttime, Asc
Sort Order Column 2: Starttime, Asc

General Search Parameters :

Project Code (GBT: AGBT12A_055, JVLA: 12A-256)
Project Session
Dates From
Observer Name
Archive File ID (partial strings allowed)
To (2010-06-21 14:20:30)

Position Search :

Target Name
Search Type: SIMBAD or NED
Min. Exposure (secs)
RA or Longitude (04h33m11.1s or 68.29d)
DEC or Latitude (05d21'15.5" or 5.352d)
Equinox: J2000
Search Radius: 1.0' (1d00'00" or 0.2d)
- OR - Check for automatic VLA field-of-view, freq. dependent. ??

Observing Configurations Search :

Telescope: All, Jansky VLA, Historical VLA, VLBA, GBT
Telescope Config: All, A, AB, BnA, B, BC, CnB, C, CD, DnC, D, DA
Sub_array: All, 1, 2, 3, 4, 5
Data Type: ALL
Observing Bands: All, 4, P, L, S, C, X, U, K, Ka, Q, W
Observing Mode: ALL
Correl Mode: ALL
Polarization: ALL
Frequency Range (In MHz : 1665.401 - 1720.500)

Enter Locked Project Access key :

Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.

Submit Query | Check Query | Clear Form

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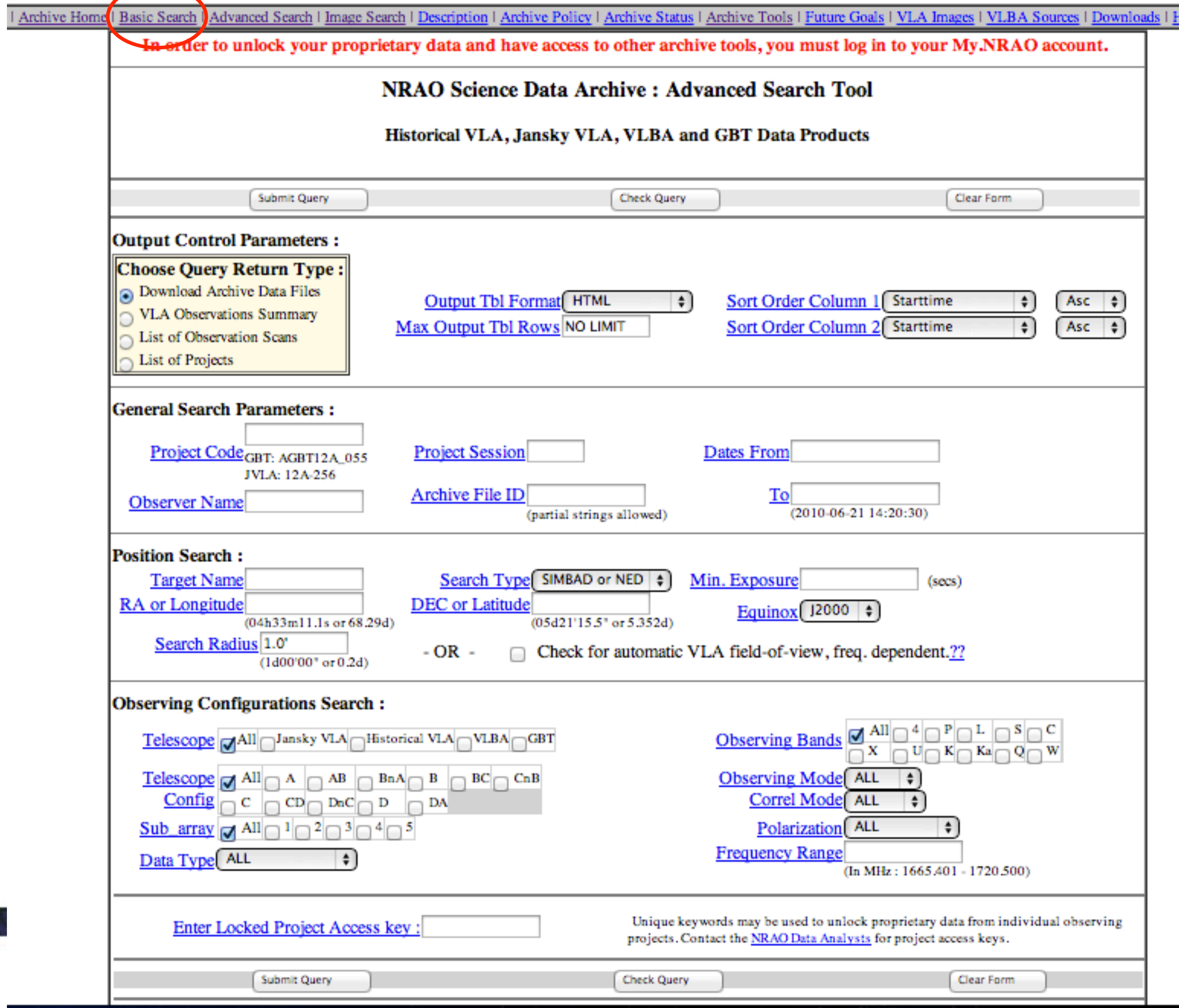
The archive tool

https://archive.nrao.edu/



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Project Session
Dates From
Observer Name
Archive File ID (partial strings allowed)
To (2010-06-21 14:20:30)

Position Search :

Target Name
Search Type: SIMBAD or NED
Min. Exposure (secs)
RA or Longitude (04h33m11.1s or 68.29d)
DEC or Latitude (05d21'15.5" or 5.352d)
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- OR - Check for automatic VLA field-of-view, freq. dependent. ??

Observing Configurations Search :

Telescope: All, Jansky VLA, Historical VLA, VLBA, GBT
Telescope Config: All, A, AB, BnA, B, BC, CnB, C, CD, DnC, D, DA
Sub_array: All, 1, 2, 3, 4, 5
Data Type: ALL
Observing Bands: All, 4, P, L, S, C, X, U, K, Ka, Q, W
Observing Mode: ALL
Correl Mode: ALL
Polarization: ALL
Frequency Range (In MHz : 1665.401 - 1720.500)

Enter Locked Project Access key :

Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.

Submit Query | Check Query | Clear Form

Basic Search: A Simple data retrieval tool

| Archive Home | Basic Search | Advanced Search | Image Search | Description | Archive Policy | Archive Status | Archive Tools | Future Goals | VLBA Sources | Downloads |

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NRAO Science Data Archive : Basic Search Tool

Historical VLA, Jansky VLA, VLBA and GBT Data Products

Instructions on how to download your data : click here

Project (Proposal) Code		The NRAO proposal or observing project id.
Observer :		The observer's name. Case sensitive, partial string searchs best.
Telescope	ALL	You may restrict the search to a single telescope.
Observe Start Date :		Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss
Observe Stop Date :		Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss

Query Control Parameters :

Enter Locked Project Access Key :		Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.
Query Returns :	Download Archive Files	Select 'Download Archive Files' to proceed to the download page, the other options are for browsing.

Submit Query   Clear Form

Please direct feedback and/or questions concerning this page and its associated search engine to NRAO DAS contact.

Version 5.9.3

Basic Search: A Simple data retrieval tool

| Archive Home | Basic Search | Advanced Search | Image Search | Description | Archive Policy | Archive Status | Archive Tools | Future Goals | VLBA Sources | Downloads |

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NRAO Science Data Archive : Basic Search Tool

Historical VLA, Jansky VLA, VLBA and GBT Data Products

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Observer :		The observer's name. Case sensitive, partial string searchs best.
Telescope	ALL	You may restrict the search to a single telescope.
Observe Start Date :		Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss
Observe Stop Date :		Format : yyyy-MMM-dd or yyyy-MMM-dd hh:mm:ss

Query Control Parameters :

Enter Locked Project Access Key :		Unique keywords may be used to unlock proprietary data from individual observing projects. Contact the NRAO Data Analysts for project access keys.
Query Returns :	Download Archive Files	Select 'Download Archive Files' to proceed to the download page, the other options are for browsing.

Submit Query   Clear Form

Please direct feedback and/or questions concerning this page and its associated search engine to NRAO DAS contact.

Version 5.9.3

The archive tool

- For each observing session, the archive tool allows the observer to view:
  - The logs
  - The scans
  - The SDM-BDF set (listing of the sdm and bdf files)
  - Any data quality issues.

Archive File	Status	Project	Seg	Project Data Starts	Project Data Stops	File Size	Telescope: config:sub"	Bands	Format	Type	DQ	View Scans	Logs etc.
☐ 11A-291.sb4911125.eb4924302.55782.00136674769	locked	11A-291	x	11-Aug-09 00:02:01	11-Aug-09 01:01:45	42.46GB	EVLA:A:0	L	SDMset	raw	OK	Scans	Logs
☐ 11A-291.sb4911125.eb4944094.55784.99251239583	locked	11A-291	x	11-Aug-11 23:50:07	11-Aug-13 02:14:44	30.29GB	EVLA:A:0	L	SDMset	raw	OK	Scans	Logs
☐ 11A-291.sb4910900.eb4947827.55787.6933925	locked	11A-291	x	11-Aug-14 16:39:27	11-Aug-14 18:39:07	78.96GB	EVLA:A:0	L	SDMset	raw	info	Scans	Logs

Checking the data in the archive tool

The scan listing:

Project	Scan :sub	Source	Cal Code	Start Time	Stop Time	Sys	TOS (sec)	Intrvl (sec)	Scan Intent	Spect Win	Obs_Freq (MHz)	Bandw (MHz)	Polar	Spect chans	Corr Mode	Tele:config :sub:nants	RA(J2000)	DEC(J2000)	Archive File
11A-291	1:1	J1120+1420		11-Aug-09 00:02:01	11-Aug-09 00:02:54	UTC	53.5	1	OBS	CD_0:SW_0	998.000000	64.000	RR,LL	128	WIDR	EVLA:A:1:27	11h20m27.807s	+14d20'54.99"	11A-291.sb4911125.eb4924302.55782.00136674769 uid____evla_bdf_1312848123251.bdf
										CD_0:SW_1	1062.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_2	1126.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_3	1190.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_4	1254.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_5	1318.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_6	1382.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_7	1446.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_8	1506.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_9	1570.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_10	1634.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_11	1698.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_12	1762.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_13	1826.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_14	1890.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_15	1954.000000	64.000	RR,LL	128	WIDR				
11A-291	2:1	J1120+1420		11-Aug-09 00:02:54	11-Aug-09 00:03:54	UTC	59.8	1	CAL	CD_0:SW_0	998.000000	64.000	RR,LL	128	WIDR	EVLA:A:1:27	11h20m27.807s	+14d20'54.99"	11A-291.sb4911125.eb4924302.55782.00136674769 uid____evla_bdf_1312848123257.bdf
										CD_0:SW_1	1062.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_2	1126.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_3	1190.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_4	1254.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_5	1318.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_6	1382.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_7	1446.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_8	1506.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_9	1570.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_10	1634.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_11	1698.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_12	1762.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_13	1826.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_14	1890.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_15	1954.000000	64.000	RR,LL	128	WIDR				
11A-291	3:1	J1120+1420		11-Aug-09 00:03:54	11-Aug-09 00:05:24	UTC	89.8	1	CAL	CD_0:SW_0	998.000000	64.000	RR,LL	128	WIDR	EVLA:A:1:27	11h20m27.807s	+14d20'54.99"	11A-291.sb4911125.eb4924302.55782.00136674769 uid____evla_bdf_1312848174961.bdf
										CD_0:SW_1	1062.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_2	1126.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_3	1190.000000	64.000	RR,LL	128	WIDR				
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										CD_0:SW_9	1570.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_10	1634.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_11	1698.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_12	1762.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_13	1826.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_14	1890.000000	64.000	RR,LL	128	WIDR				
										CD_0:SW_15	1954.000000	64.000	RR,LL	128	WIDR				

Checking the data in the archive tool

The scan listing (reference pointing):

11A-258	42:1	0542+498=3C147		11-Jun-01 01:26:47	11-Jun-01 01:27:07	UTC	19.4	1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891607524.bdf
11A-258	42:2	0542+498=3C147		11-Jun-01 01:27:07	11-Jun-01 01:27:27	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891608043.bdf
11A-258	42:3	0542+498=3C147		11-Jun-01 01:27:27	11-Jun-01 01:27:47	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891627503.bdf
11A-258	42:4	0542+498=3C147		11-Jun-01 01:27:47	11-Jun-01 01:28:07	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891647507.bdf
11A-258	42:5	0542+498=3C147		11-Jun-01 01:28:07	11-Jun-01 01:28:27	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891667503.bdf
11A-258	42:6	0542+498=3C147		11-Jun-01 01:28:27	11-Jun-01 01:28:47	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891687511.bdf
11A-258	42:7	0542+498=3C147		11-Jun-01 01:28:47	11-Jun-01 01:29:07	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891707505.bdf
11A-258	42:8	0542+498=3C147		11-Jun-01 01:29:07	11-Jun-01 01:29:27	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891727505.bdf
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11A-258	42:10	0542+498=3C147		11-Jun-01 01:29:47	11-Jun-01 01:30:07	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891767505.bdf
11A-258	42:11	0542+498=3C147		11-Jun-01 01:30:07	11-Jun-01 01:30:27	UTC	20	1.1	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891787507.bdf
11A-258	42:12	0542+498=3C147		11-Jun-01 01:30:27	11-Jun-01 01:30:42	UTC	15.4	1.2	POINT	CD_1:SW_16 CD_1:SW_17	8332.000000 8460.000000	128.000 128.000	RR,RL,LR,LL RR,RL,LR,LL	64 64	WIDR WIDR	EVLA:BnA->A:1:25	05h42m36.138s	+49d51'07.23"	11A-258.sb4139176.eb4258095.55713.0339549537 uid___evla_bdf_1306891807506.bdf

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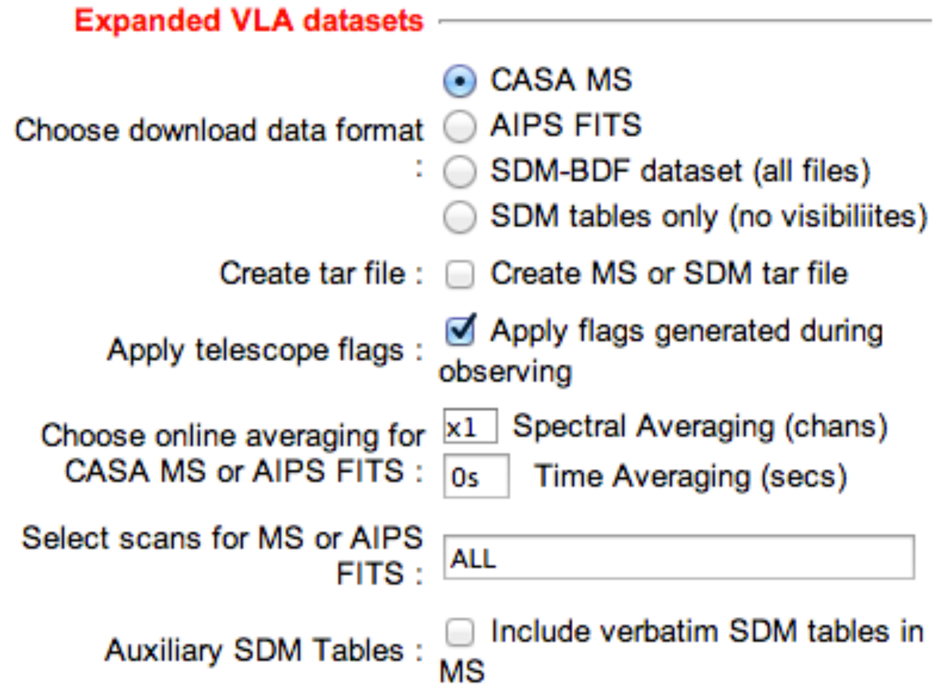
Loading The Data: The archive tool

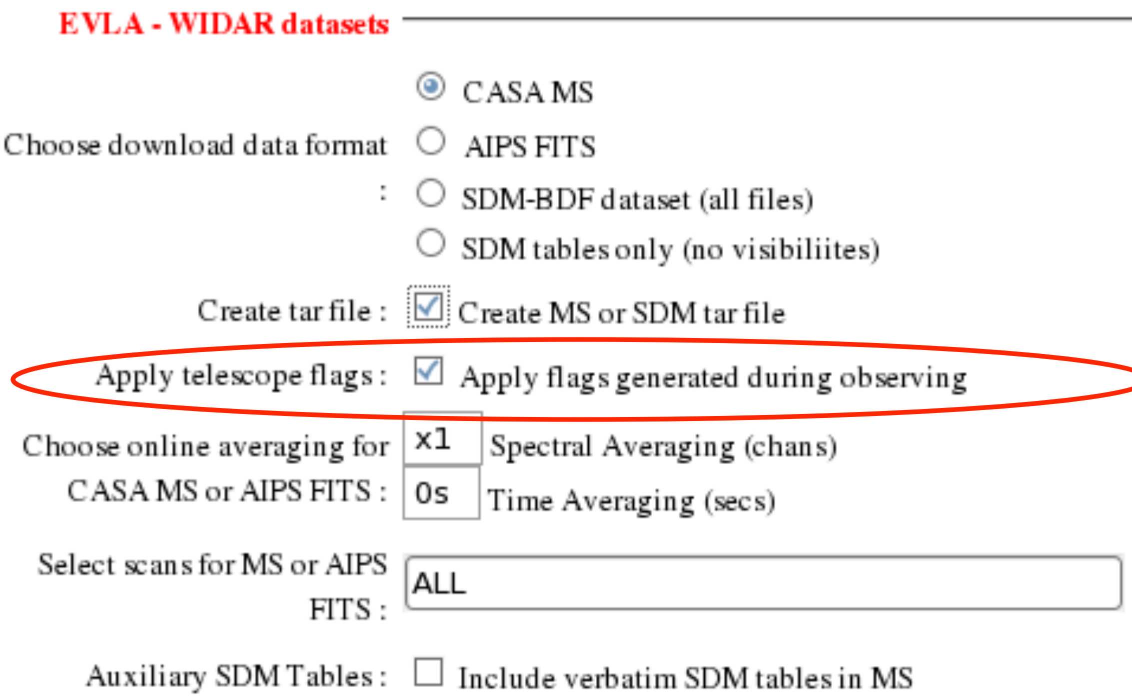
- Data formats:
  - SDM-BDF (native format; desirable for the pipeline)
  - CASA MS (default)
  - AIPS FITS



- If CASA MS is requested, the SDM-BDF is loaded to a staging area and converted to MS using CASA's *importevla* task.
- If AIPS FITS is requested, then the MS made above will be exported as a FITS file using CASA's *exportuvfits* task.

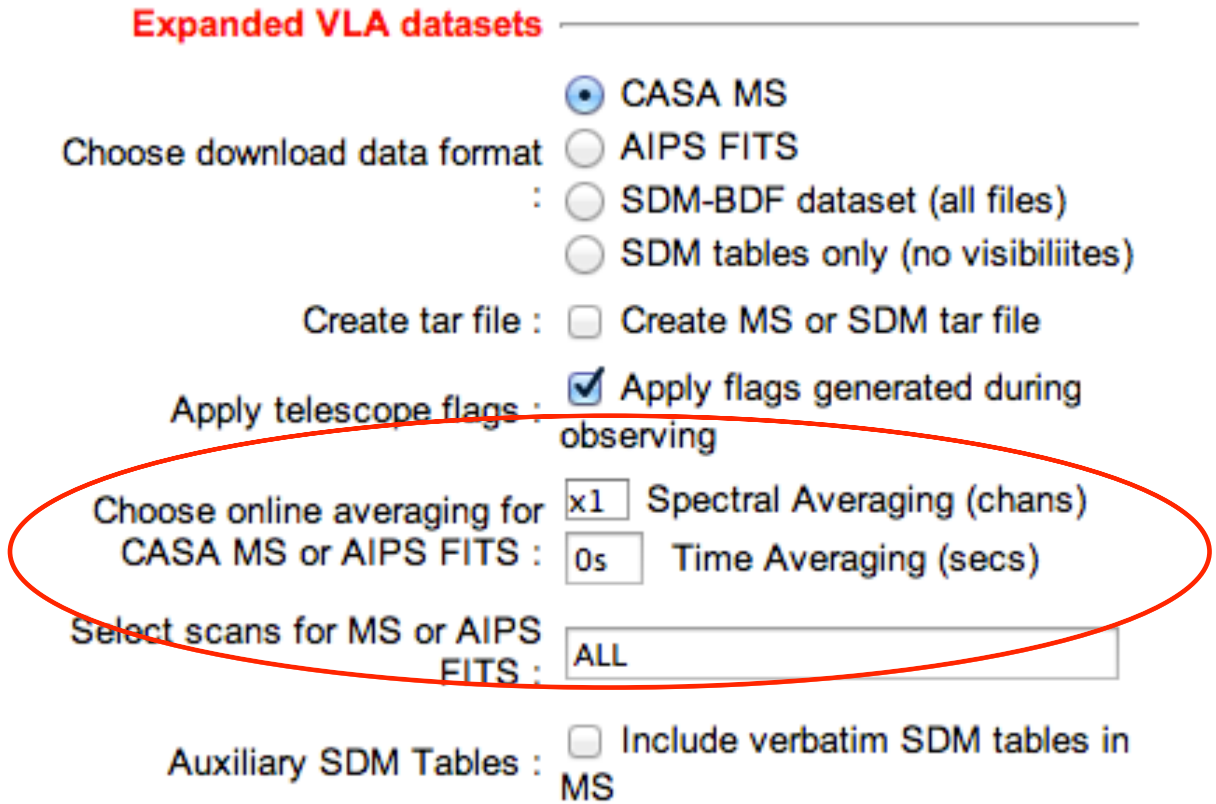
Loading The Data: The archive tool

- If the apply flags option is not checked, the flags are written to a FLAG_CMD MS table. They can later be applied by using the CASA task *flagcmd.*
- If checked, the flags are applied on the data.



- For UVFITS, the flags need to be applied, as there will not be a FG table in the resulting file.

Loading The Data: The archive tool

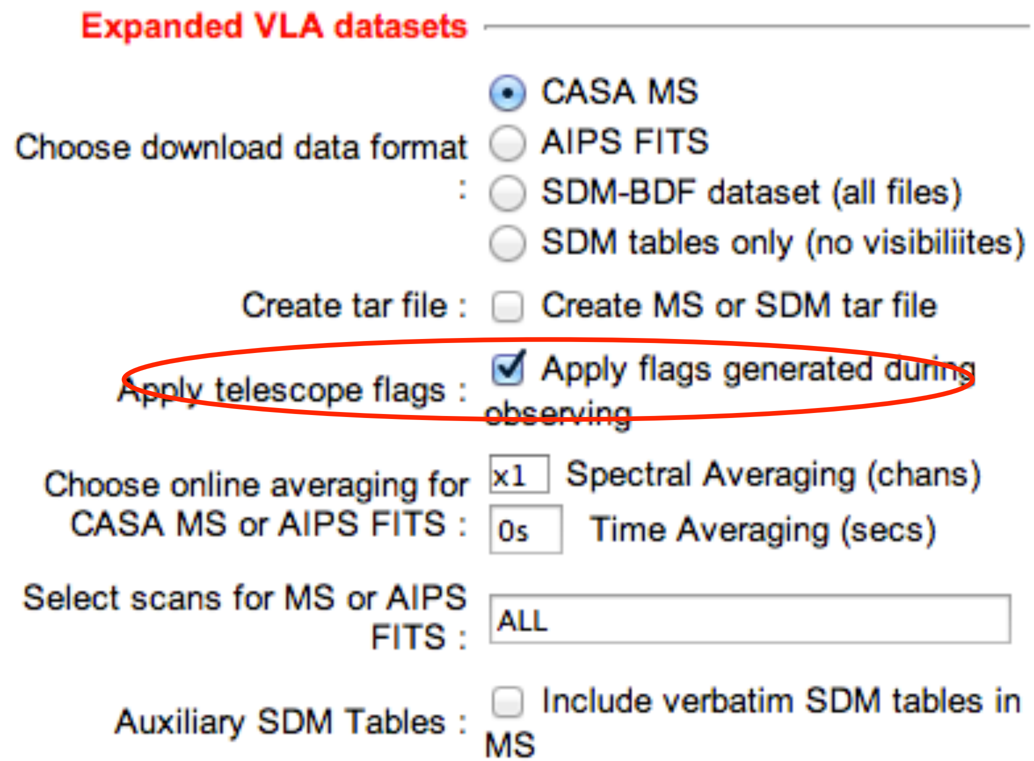


- The tool allows the observer to average the data in time and/or in frequency.
- It also allows the selection of scans.
- For these, the archive tool uses the CASA task *split*.

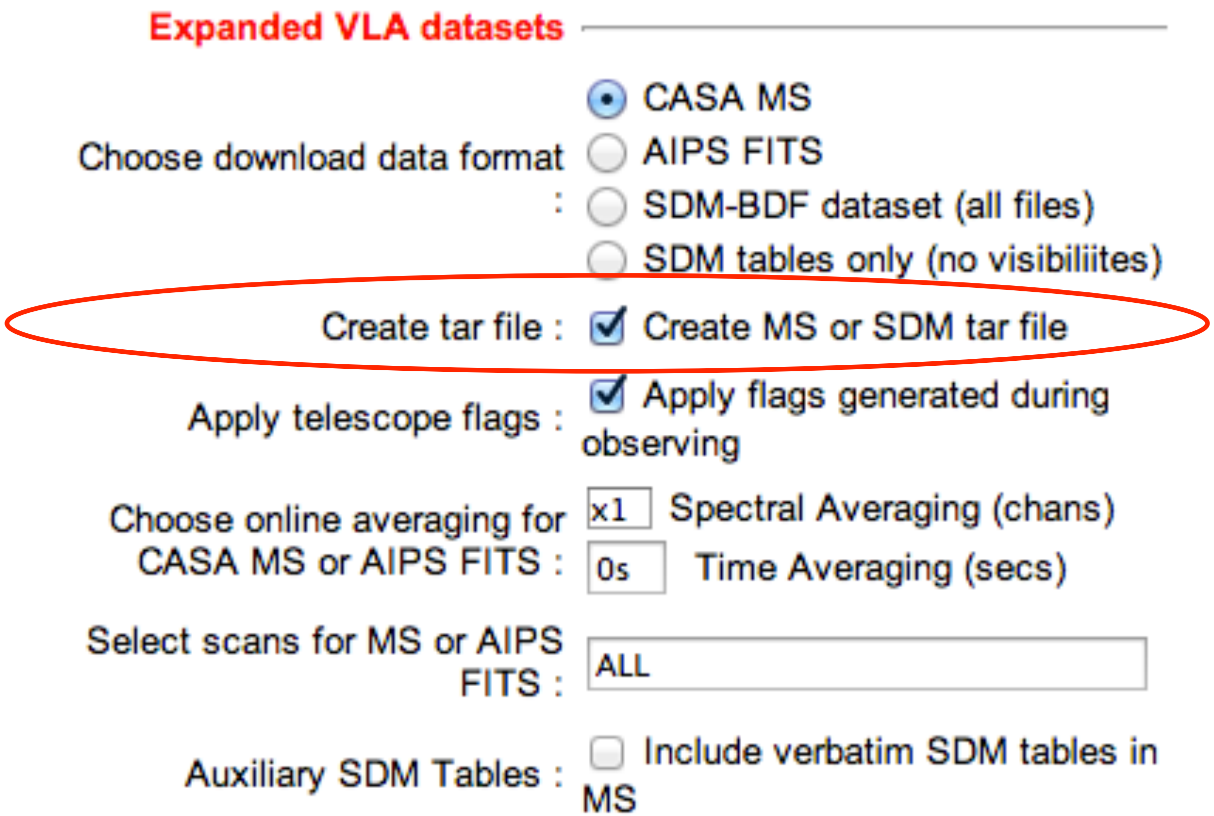
Loading The Data: The archive tool

If applying online averaging:

1. Make sure to apply the flags.
2. Averaging in frequency is discouraged as delays can cause coherence loss. We recommend reviewing the data before frequency averaging.
3. Averaging in time should take into account the type of science you would like to do. See the VLA Observational Status Summary for amplitude loss due to time averaging.



Loading The Data: The archive tool



- The SDM-BDF and MS are directories. For downloading through the net, make sure to ask for a tar file.

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Loading The Data: The archive tool
Requesting the data on a hard disk

- NRAO offers a data shipping service using hard disks:
  - when the size of the data is large, or
  - when the user does not have fast enough internet connection.
- This disk-ordering process is done through the archive tool.
- The data will be saved on 1.8 TB disks and shipped to the observer.
- Cost $125.00 USD.
- Disk shipment information and policies are posted at
  - https://archive.nrao.edu/archive/hdshipInfo.html
  - https://science.nrao.edu/facilities/evla/data-shipment

CASA

- Web site: http://casa.nrao.edu/
- Available for both Linux and Mac OS.

- Make sure to subscribe to the CASA mailing lists:
  - casa-announce: For announcements of new releases, workshops, etc…
  - casa-users: For critical bugs and code updates.

  http://casa.nrao.edu/ → Getting Help → Mailing lists

CASA

- Documentation is available at http://casa.nrao.edu/ → 'Using CASA'
- Training material is available at http://casaguides.nrao.edu
- For help, use the NRAO help desk at: http://help.nrao.edu

CASA 4.1.0 (stable revision 22971) will be used at this workshop

CASA

- All CASA tasks can be listed by *tasklist*.
- The tasks are grouped as:
  - Import/export
  - Information
  - Editing
  - Manipulation
  - Calibration
  - Modeling
  - Imaging
  - Analysis
  - Visualization
  - Simulation
  - Single dish
  - Utility
- AIPS – CASA dictionary, and (historic) MIRIAD-CASA and CLIC-CASA dictionaries are available in the CASA cookbook.

  http://casa.nrao.edu/ → 'Using CASA' → 'User Reference and Cookbook'.

Loading The Data: *importevla*

If one chooses to download the SDM-BDF

- The task *importevla* converts the SDM-BDF to MS.
- *importevla* is an enhanced version of *importasdm* that allows the use of the VLA online flags.
- It converts the data into a MS, and carries out various types of flagging (online flags, pure zeros, shadowing).

```
asdm          =      'archive_sdm_directory'
vis           =      'output MS name'
ocorr_mode    =      'co'    (or load ca, ao)
scans         =       ''
```

Loading The Data: *importevla*

Flags:

```
online              =        True
    tbuff           =        0.0
flagzero            =        True
    flagpol         =        True
shadow              =        True
    tolerance       =        0.0
applyflags          =        False
```

- If `applyflags = False` (default) => the flags are written to a FLAG_CMD MS table. They can be examined (listed, plotted) and applied by using the task *flagcmd* [recommended].

- If `applyflags = True` => the flags are applied on the data.

Examining Your Data

- Observing summary (sources, scans, spectral windows, antennas, etc…): *listobs*

- Plotting the antennas: *plotants*

- Plotting/displaying data: *plotms* (unix command line *casaplotms*), and *msview*

Examine your data carefully before flagging

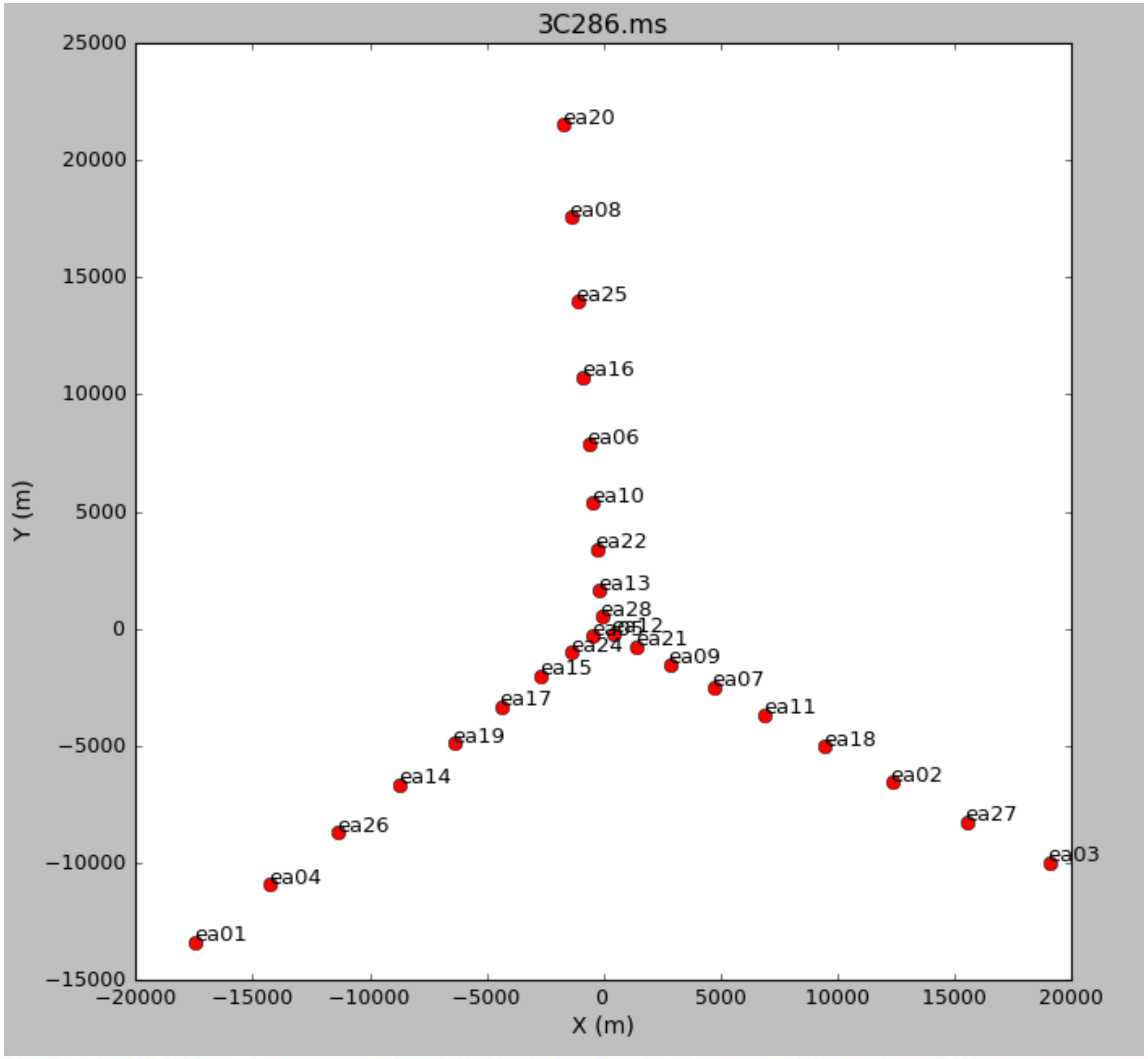
Observing Summary: *listobs*

```
vis          = 'MS file name'
verbose      =      True      (or False)
selectdata   =      True      (or False)
```

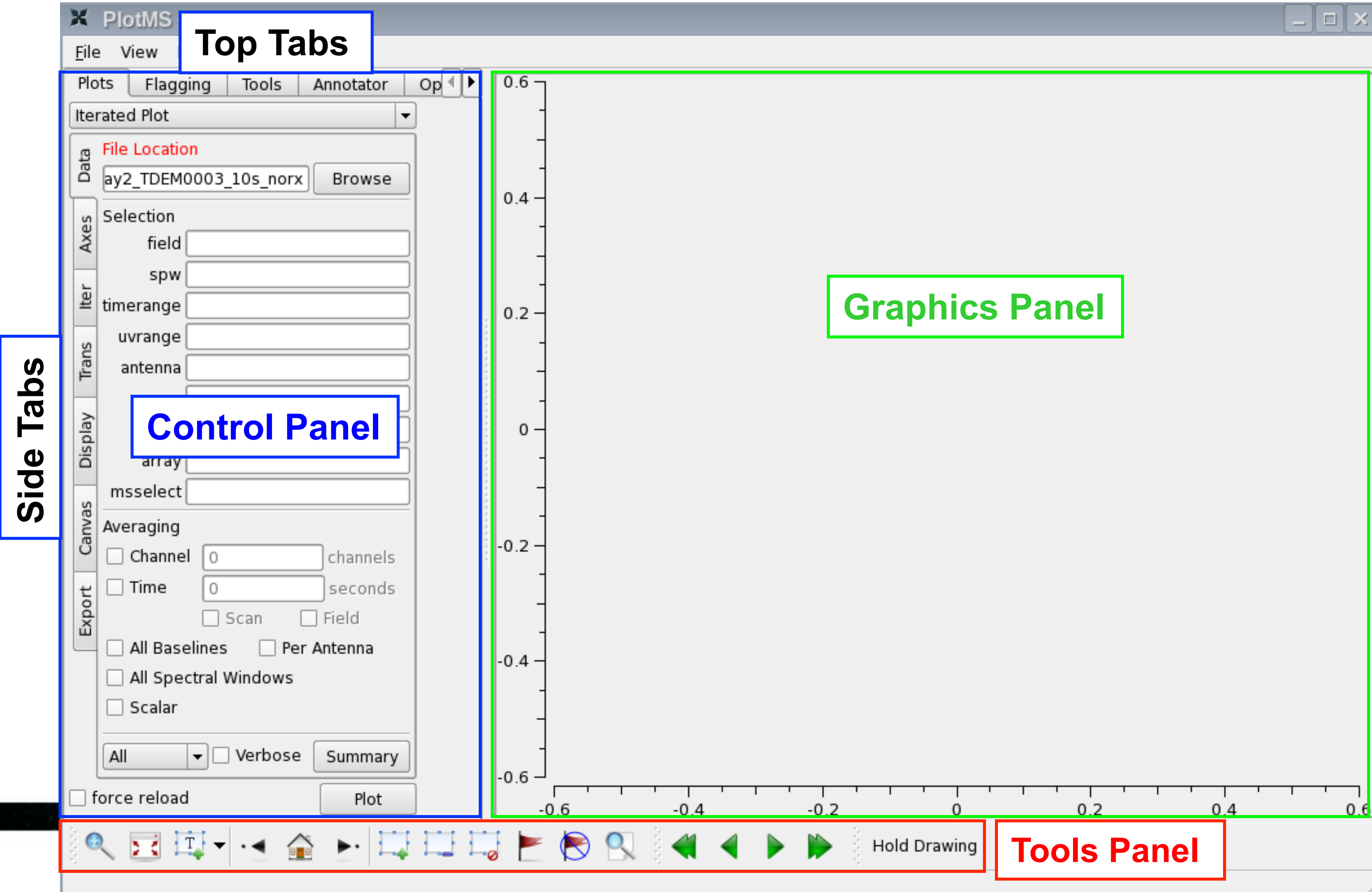
```
listobs:… ===========================================================================
listobs:…             MeasurementSet Name:  /lustre/aoc/users/emomjian/zeeman/StokesV_50Hz_
listobs:… ===========================================================================
listobs:…    Observer: Dr. Emmanuel Momjian     Project: T.B.D.
listobs:… Observation: EVLA(27 antennas)
listobs:… Data records: 1249911       Total integration time = 3586.94 seconds
listobs:…    Observed from   12-Jul-2011/10:22:38.6   to   12-Jul-2011/11:22:25.5 (UTC)
listobs:… Fields: 3
listobs:…   ID   Code Name         RA             Decl            Epoch   SrcId
listobs:…   0    D    J1851+0035   18:51:46.7217 +00.35.32.4140 J2000   0
listobs:…   1    NONE G37.40+1.52* 18:54:14.2627 +04.41.41.4167 J2000   1
listobs:…   2    E    0137+331=3C* 01:37:41.2994 +33.09.35.1330 J2000   2
listobs:…    (nVis = Total number of time/baseline visibilities per field)
listobs:… Spectral Windows:  (1 unique spectral windows and 1 unique polarization setups)
listobs:…   SpwID  #Chans Frame Ch1(MHz)    ChanWid(kHz)TotBW(kHz)  Ref(MHz)    Corrs
listobs:…   0         256 TOPO  6667.85673  0.9765625   250         6667.85673  RR  LL
listobs:… Sources: 3
listobs:…   ID   Name         SpwId RestFreq(MHz)  SysVel(km/s)
listobs:…   0    J1851+0035   0     6668.518       41
listobs:…   1    G37.40+1.52* 0     6668.518       41
listobs:…   2    0137+331=3C* 0     6668.518       41
listobs:… Antennas: 27 'name'='station'
listobs:…    ID=   0-3: 'ea01'='W72', 'ea02'='E56', 'ea03'='E72', 'ea04'='W64',
listobs:…    ID=   4-7: 'ea05'='W08', 'ea06'='N40', 'ea07'='E32', 'ea08'='N64',
listobs:…    ID=  8-11: 'ea09'='E24', 'ea10'='N32', 'ea11'='E40', 'ea12'='E08',
listobs:…    ID= 12-15: 'ea13'='N16', 'ea14'='W48', 'ea15'='W24', 'ea16'='N48',
listobs:…    ID= 16-19: 'ea17'='W32', 'ea18'='E48', 'ea19'='W40', 'ea20'='N72',
listobs:…    ID= 20-23: 'ea22'='N24', 'ea23'='E16', 'ea24'='W16', 'ea25'='N56',
listobs:…    ID= 24-26: 'ea26'='W56', 'ea27'='E64', 'ea28'='N08'
```

Plotting the antennas: *plotants*

```
vis   = 'MS file name'
```



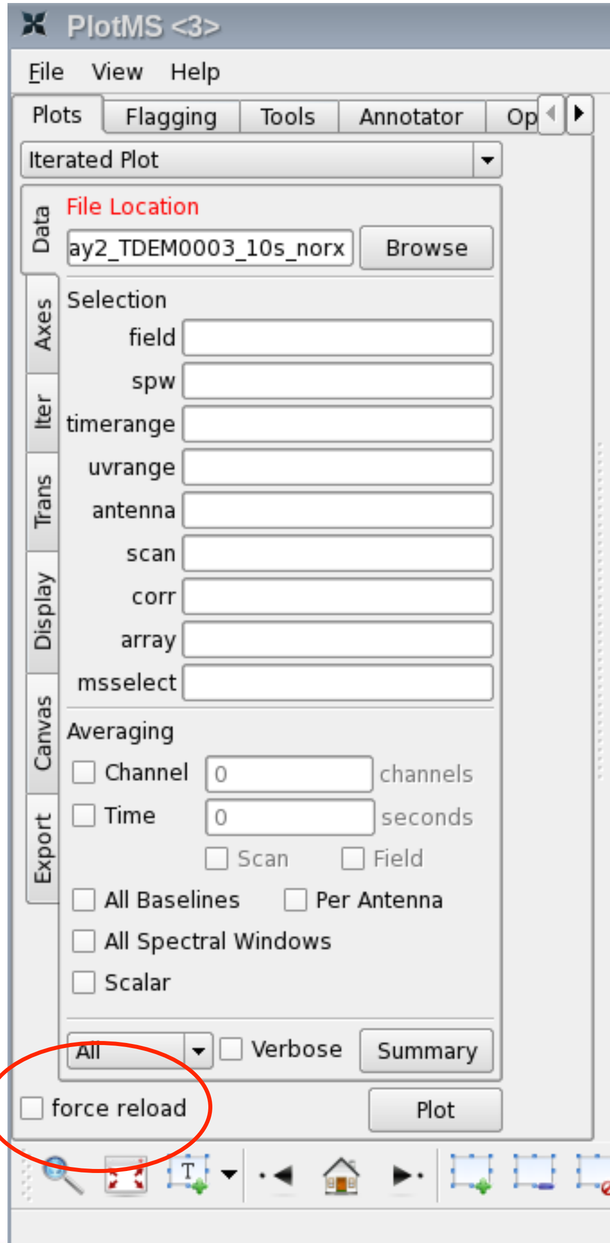
Data Review: *plotms* (unix command line *casaplotms*)



Data Review: *plotms*

Control Panel: Data

Use the ‘force reload’ if the MS has been modified through another task.



Data Review: *plotms*

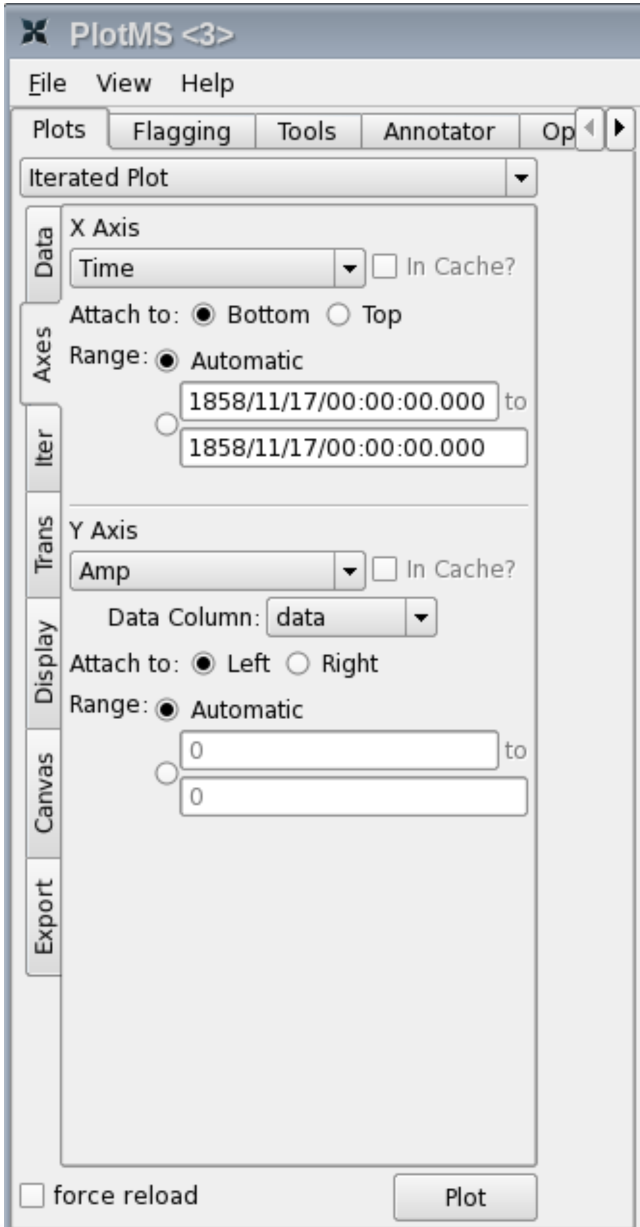
Axes

MS Ids and other meta info:

- 'scan' (number)
- 'field' (index)
- 'time',
- 'interval'='timeint'='timeinterval'='time_interval'
- 'spw' (index)
- 'chan'='channel' (index)
- 'freq'='frequency' (GHz)
- 'vel'='velocity' (km/s)
- 'corr'='correlation' (index)
- 'ant1'='antenna1' (index)
- 'ant2'='antenna2' (index)
- 'baseline' (a baseline index)
- 'row' (absoute row Id from the MS)

Visibility values, flags:

- 'amp'='amplitude'
- 'phase' (deg)
- 'real'
- 'imag'='imaginary'
- 'wt'='weight'
- 'flag'
- 'flagrow'



Data Review: *plotms*

Axes

Observational geometry:

'uvdist' (meters)

'uvwave'='uvdistl'='uvdist_l' (wavelengths, per channel)

'u' (meters)

'v' (meters)

'w' (meters)

'azimuth' (at array reference; degrees)

'elevation' (at array reference; degrees)

'hourang'='hourangle' (at array reference; hours)

'parang'='parangle'='parallacticangle' (at array reference; degrees)

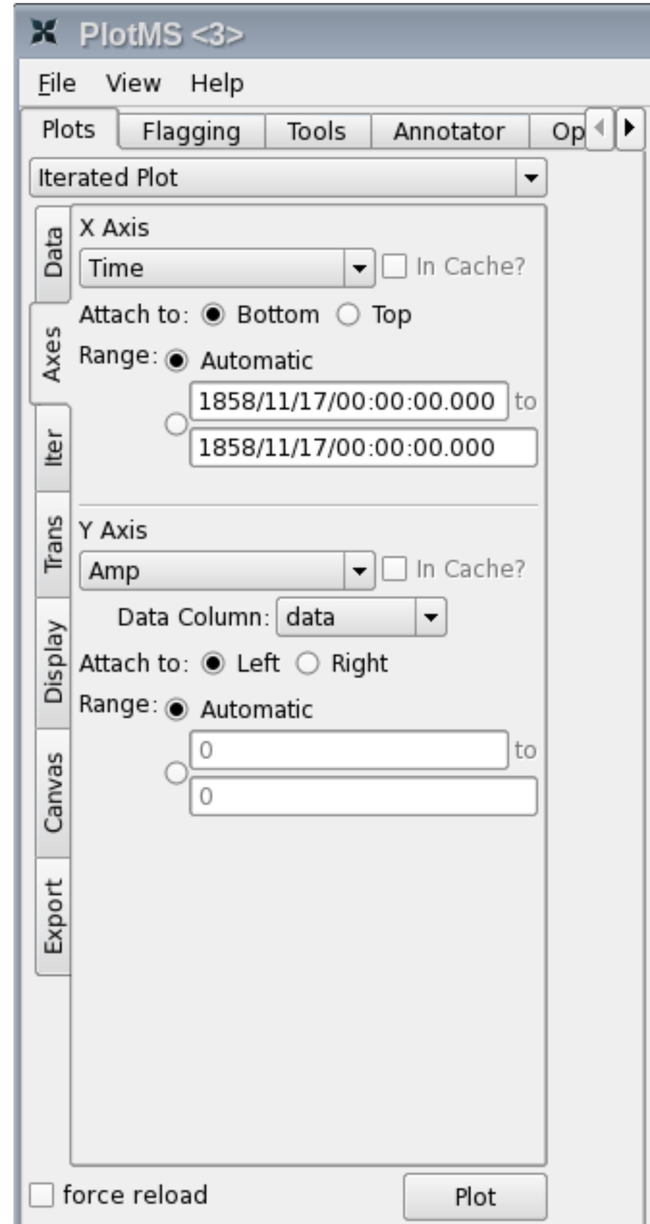
Antenna-based (only works vs. data Ids):

'ant'='antenna'

'ant-azimuth'

'ant-elevation'

'ant-parang'='ant-parangle'

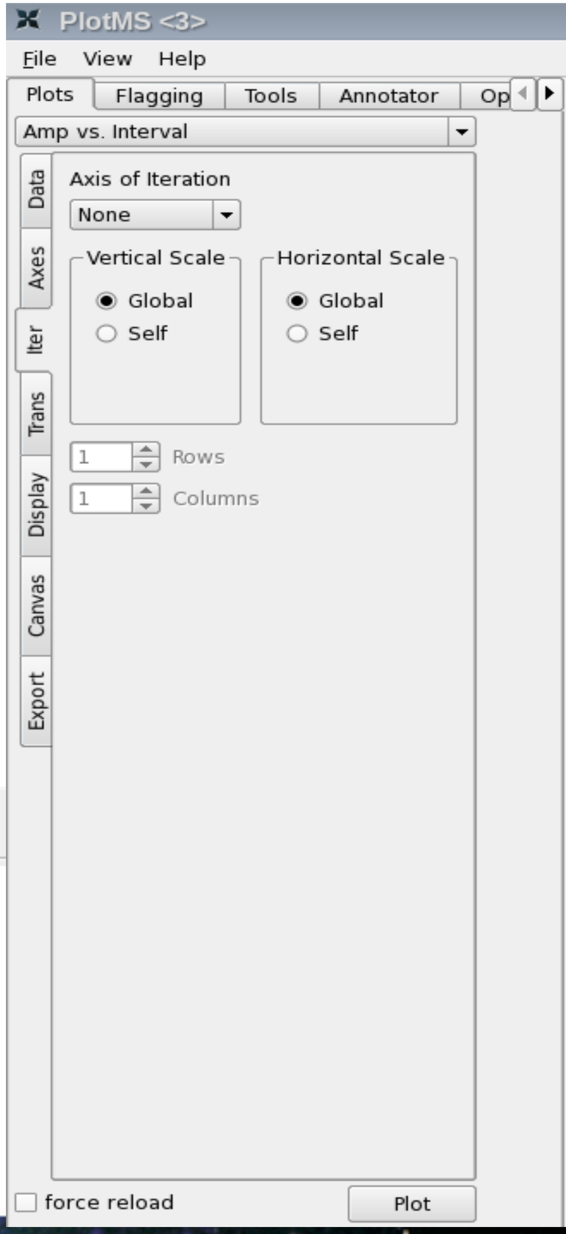


Data Review: *plotms*

Iteration

- Scan
- Field
- Spw
- Baseline
- antenna

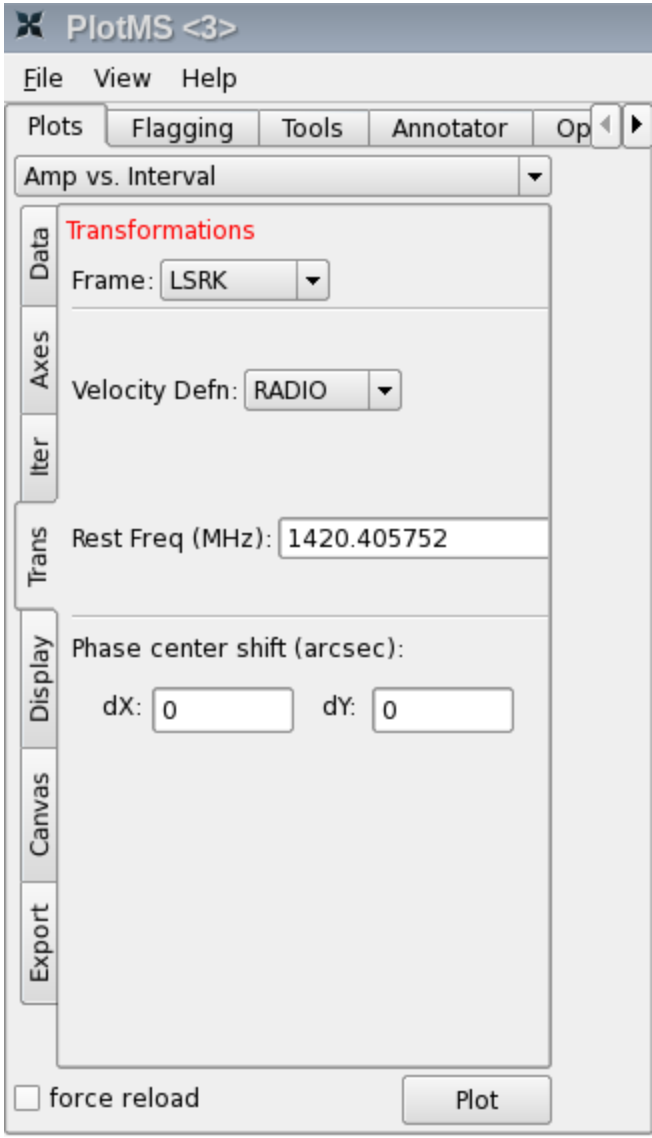
Tool panel



Data Review: *plotms*

Transformations

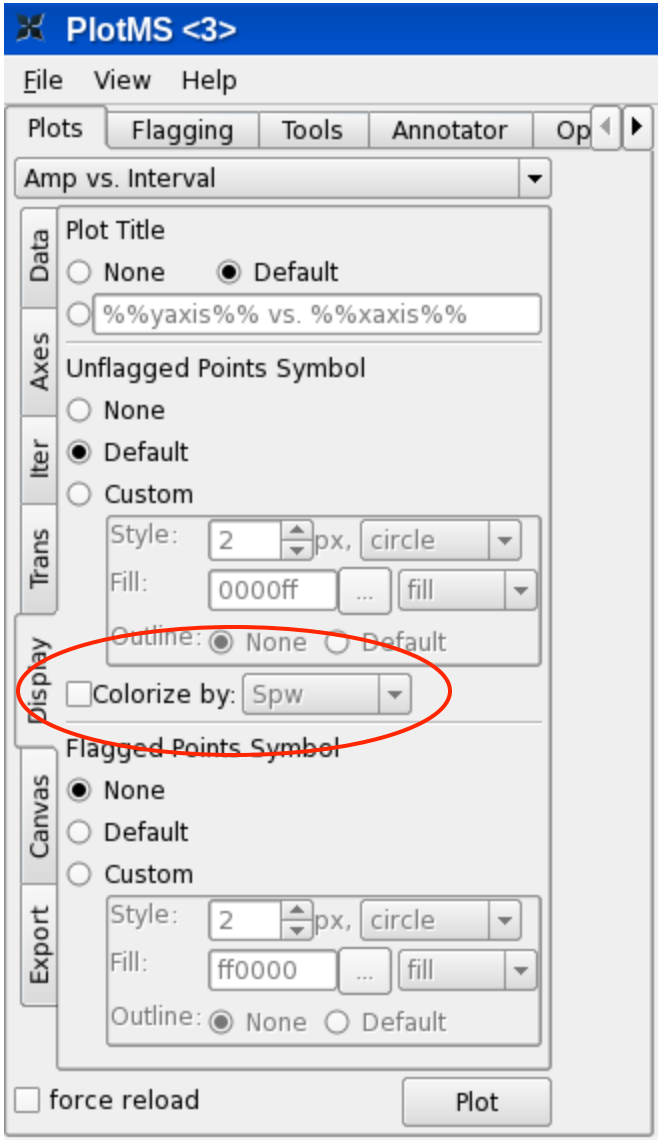
Frame: TOPO, GEO, BARY, LSRK, LSRD, etc..



Data Review: *plotms*

Display

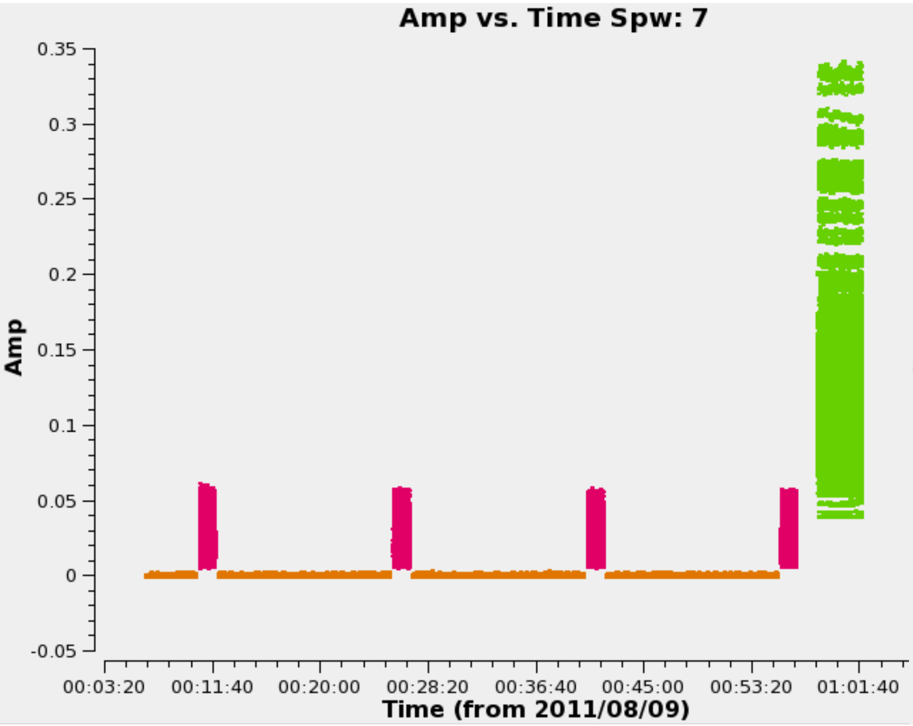
Colorize by:
- Scan
- Field
- Spw
- Antenna1
- Antenna2
- Baseline
- Channel
- Correlation

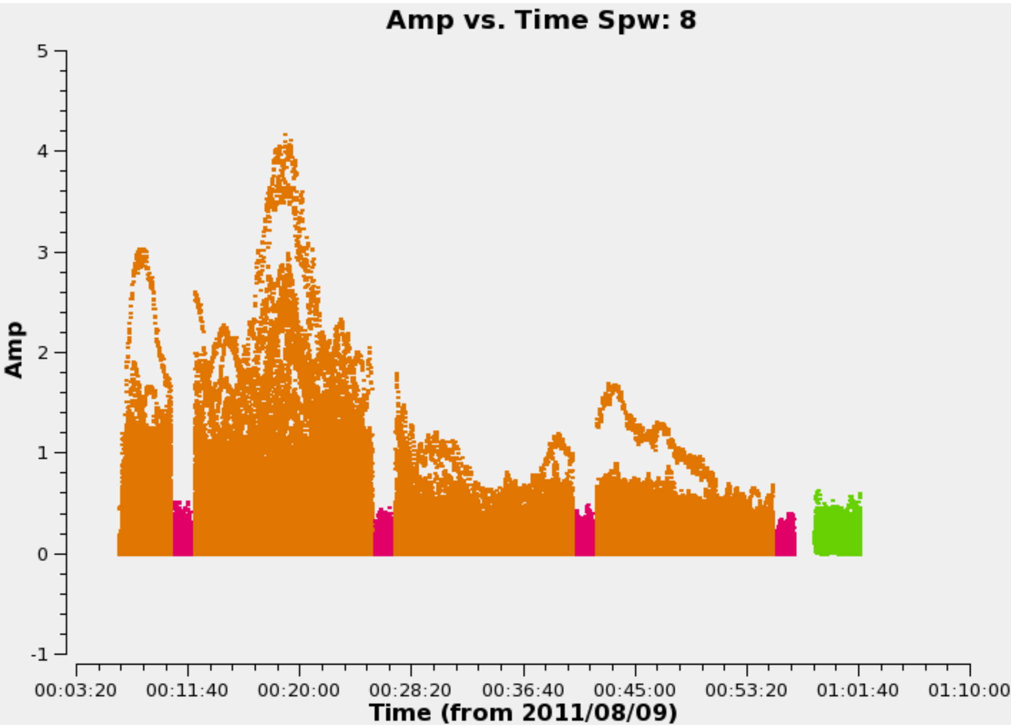


Data Review: *plotms*

Example: x-axis: time, y-axis: amp

iter: spw (with all channels averaged)

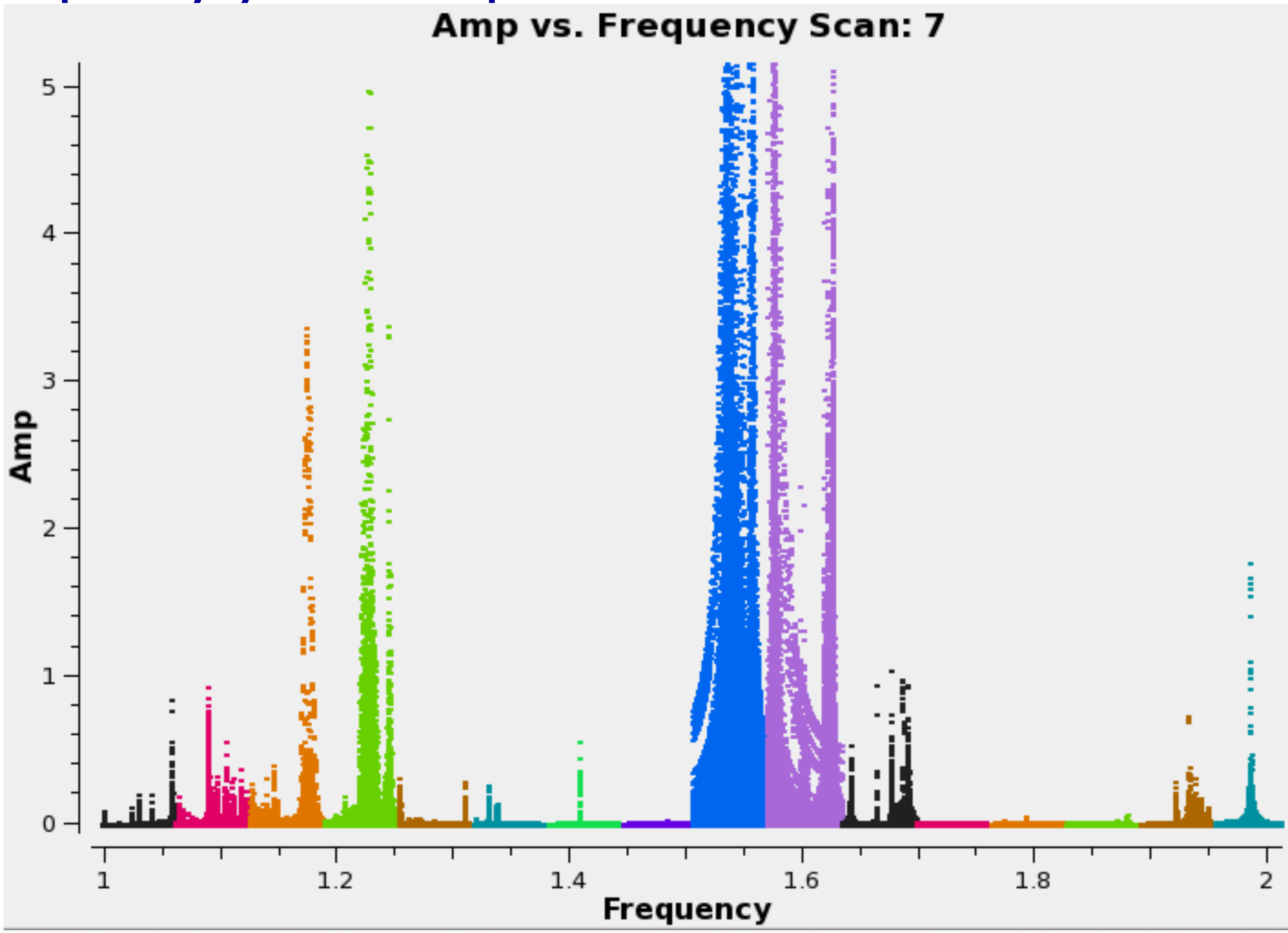




Data Review: *plotms*

Example: x-axis: frequency, y-axis: amp

iteration: scan



Flagging (or unflagging) Data

1. *flagdata:* All purpose flagging task based on selection.
   - Includes RFI flagging capabilities (RFLAG, TFCROP).
2. *flagcmd:* All purpose flagging task based on commands (alternative to *flagdata* for certain types of flagging).
3. *plotms:* Interactive flagging
4. *msview:* Interactive flagging

Review the VLA operator's log carefully.
Certain issues (e.g., antennas without receivers), do not end up in the online flags, and need to be flagged manually.

Flagging (or unflagging) Data
A few important notes

1. Data in CASA are either flagged or not flagged.
   - Every MS has a flag column.
   - Every bit of data has its own flag (set either to true or false).
   - Applying flags means setting the flag column entries of the selected bits of data to true.
2. *Most* flagging tasks have the option of creating a flag backup.
3. A flag backup is a MS that contains the state of the flags before running a flagging task.
4. Using *flagmanager*, backed-up flags can be restored (or a flag backup can be made).

Flagging Data: *flagdata* - Modes

- *list* = apply a list of flagging commands
- *manual* = flagging based on specific selection parameters
- *clip* = clip data according to values
- *quack* = remove/keep specific time range at scan beginning/end
- *shadow* = remove antenna-shadowed data
- *elevation* = remove data below/above given elevations
- *tfcrop* = auto identification of outliers on the time-freq plane
- *rflag* = auto detection of outliers based on sliding-window RMS filters
- *extend* = extend and/or grow flags
- Also *summary* (per antenna, correlation, field, scan, total), and unflag.
- Can also flag calibration tables.

Flagging Data: *flagcmd*

- It allows listing, plotting, saving, applying, or un-applying flags.
- Flagging modes (`inpmode`) are:
  - table: uses the FLAG_CMD MS table (initially created by *importevla*)
  - list: uses an ASCII file that contains a set of flagging commands.
  - xml: uses the online flags from Flag.xml in the MS.
- It allows the user to save the flag records in the FLAG_CMD MS table or a file.

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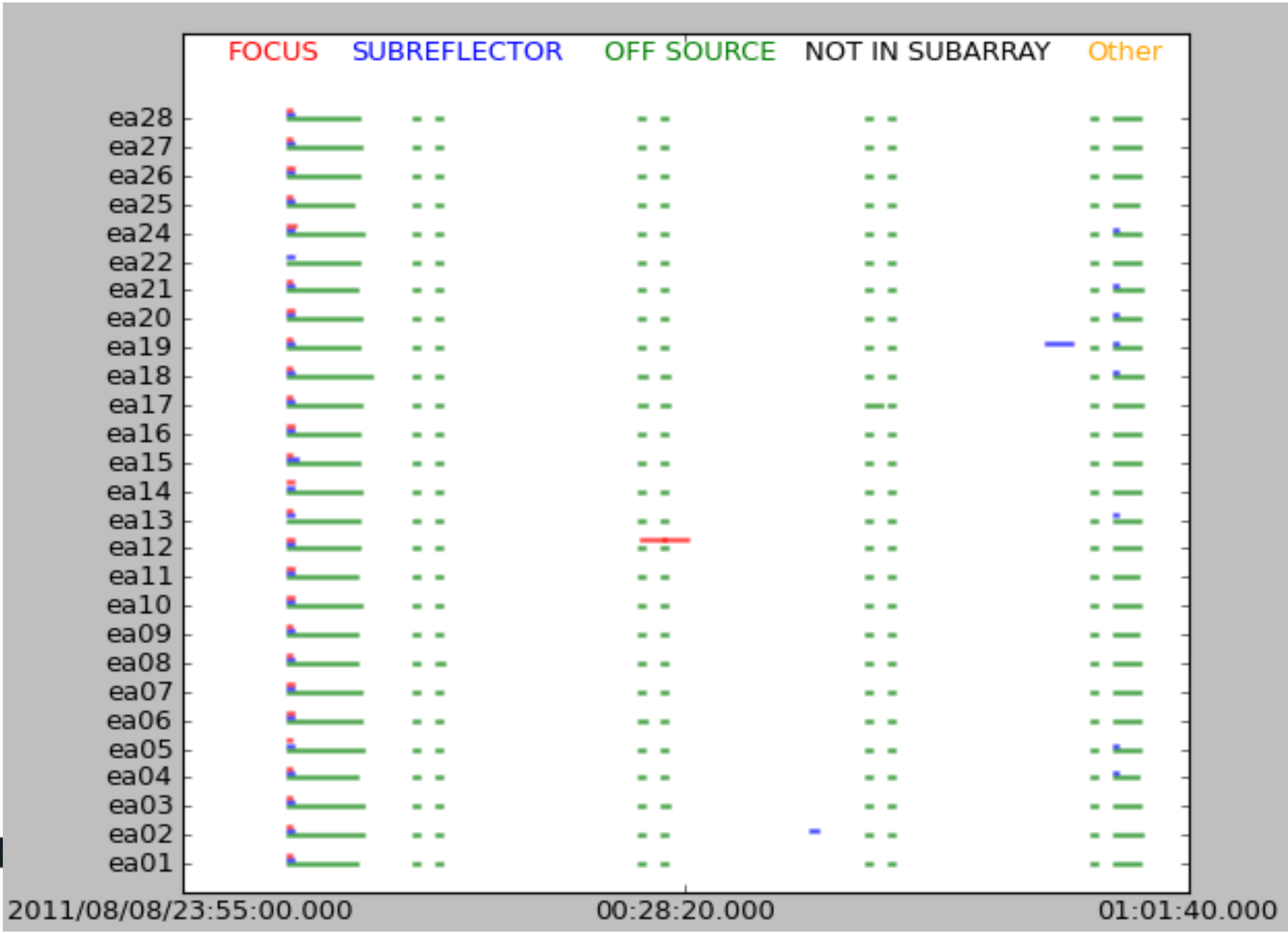
Examining the flags with *flagcmd*

list

Key	FlagID	Antenna	Reason	Timerange
0	0	ea28	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.401~2011/08/09/00:02:15.300
1	1	ea26	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.435~2011/08/09/00:02:15.274
2	2	ea21	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.478~2011/08/09/00:02:15.093
3	3	ea08	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.478~2011/08/09/00:02:15.300
4	4	ea22	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.487~2011/08/09/00:02:14.946
5	5	ea27	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.487~2011/08/09/00:02:15.594
6	6	ea20	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.522~2011/08/09/00:02:15.343
7	7	ea03	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.548~2011/08/09/00:06:58.537
8	8	ea03	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.548~2011/08/09/00:02:15.551
9	9	ea18	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.573~2011/08/09/00:07:31.533
10	10	ea18	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.573~2011/08/09/00:02:15.084
11	11	ea04	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.573~2011/08/09/00:06:30.586
12	12	ea04	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.573~2011/08/09/00:02:15.179
13	13	ea19	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.591~2011/08/09/00:06:42.907
14	14	ea19	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.591~2011/08/09/00:02:16.069
15	15	ea28	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.599~2011/08/09/00:06:42.397
16	16	ea07	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.608~2011/08/09/00:06:46.907
17	17	ea16	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.591~2011/08/09/00:06:39.658
18	18	ea07	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.608~2011/08/09/00:02:15.663
19	19	ea16	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.591~2011/08/09/00:02:15.706
20	20	ea10	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.608~2011/08/09/00:06:45.810
21	21	ea01	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.591~2011/08/09/00:06:30.301
22	22	ea10	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.617~2011/08/09/00:02:15.706
23	23	ea01	SUBREFLECTOR_ERROR	2011/08/09/00:02:00.591~2011/08/09/00:02:15.430
24	24	ea02	ANTENNA_NOT_ON_SOURCE	2011/08/09/00:02:00.625~2011/08/09/00:06:59.098

Examining the flags with *flagcmd*

plot



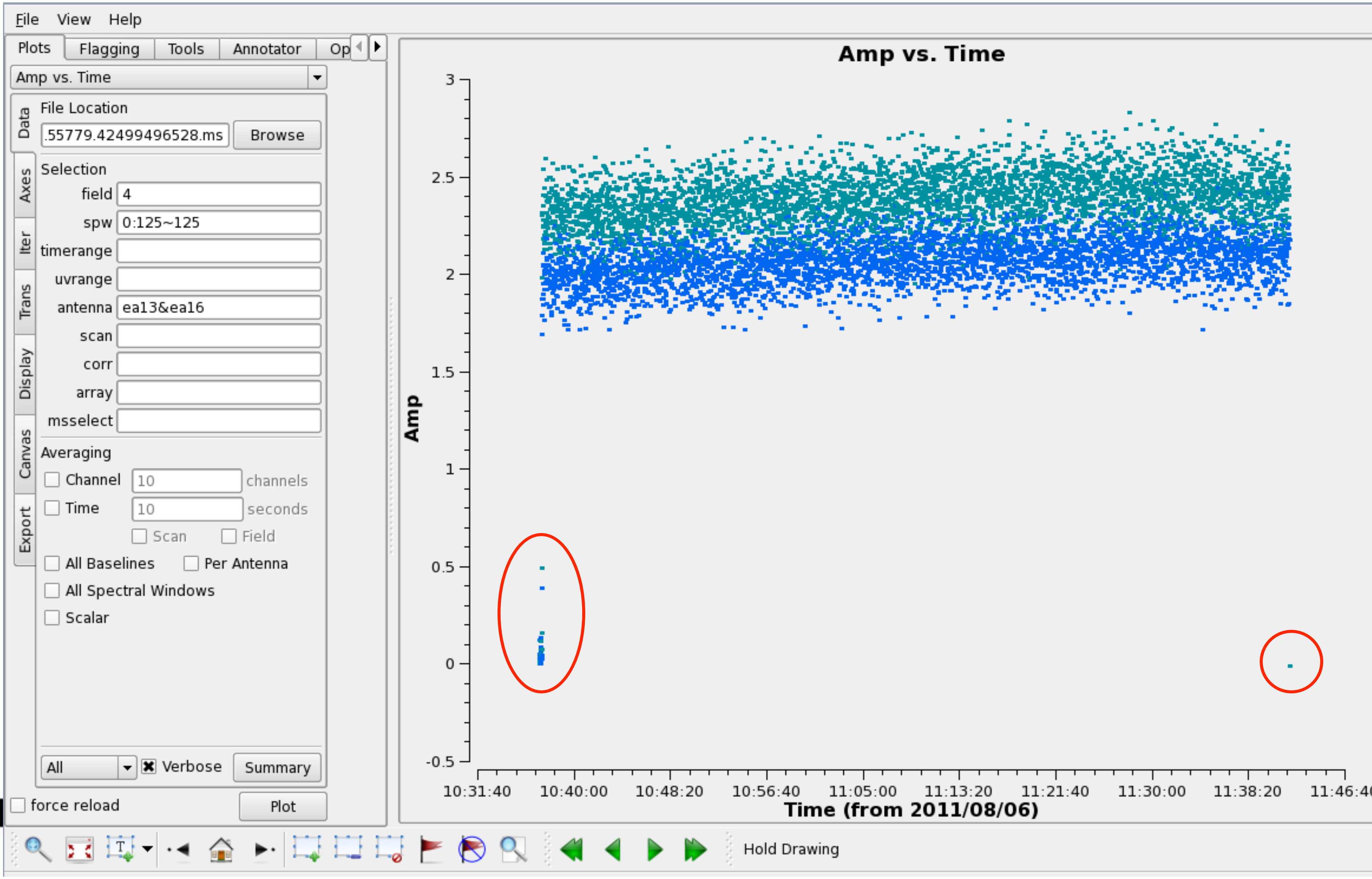
Flagging Data: *flagdata vs. flagcmd*

- Complementary flagging tasks.
- Have several common features.
- Some of the important differences:

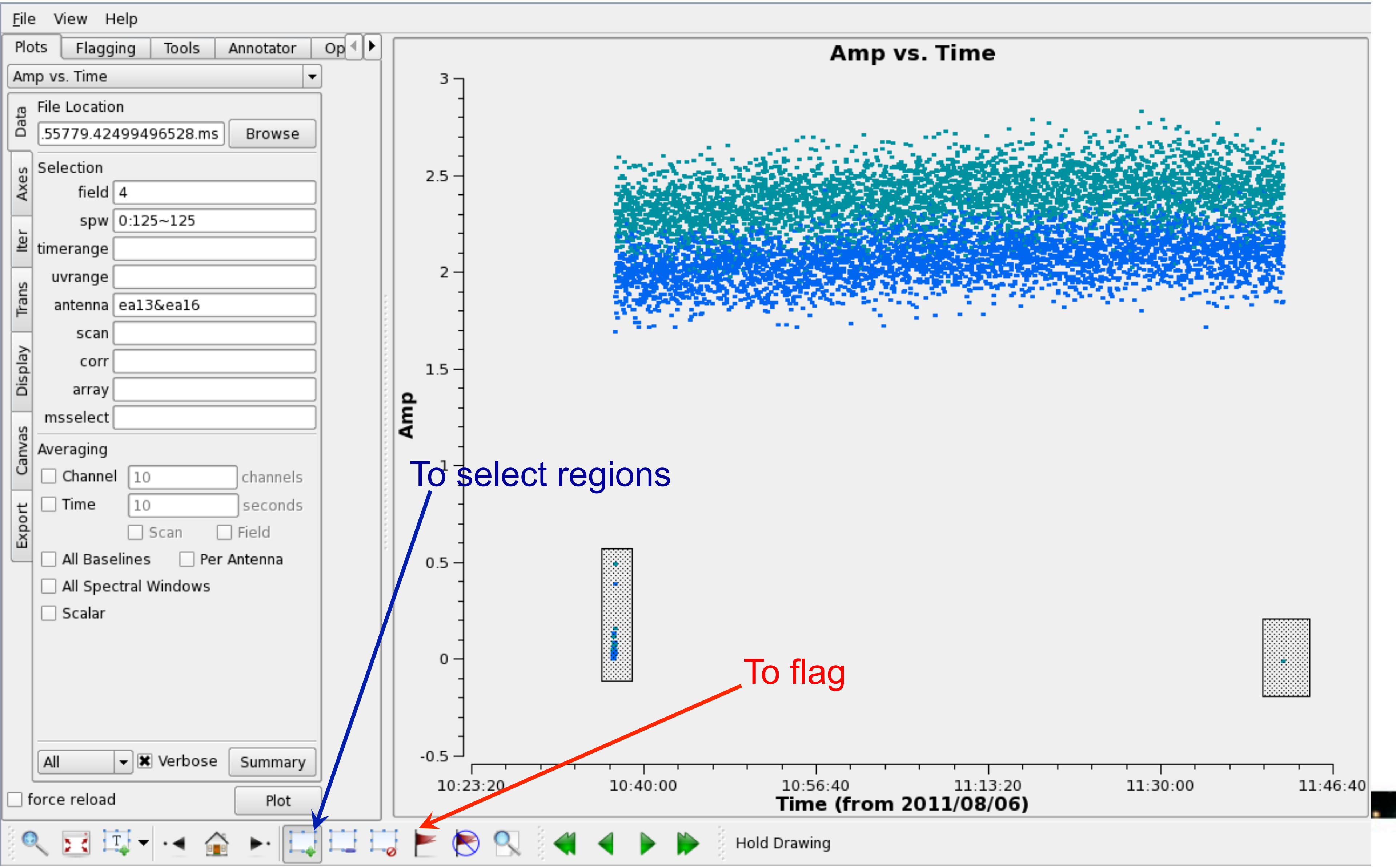
Flagdata	Flagcmd
RFI flagging (tfcrop, rflag)*	Access to the Flag.xml
Runtime displays* (before and after flagging)	Apply the online (and other) flags in FLAG_CMD MS table
	Plot Flags

* More details on Tuesday by U. Rau

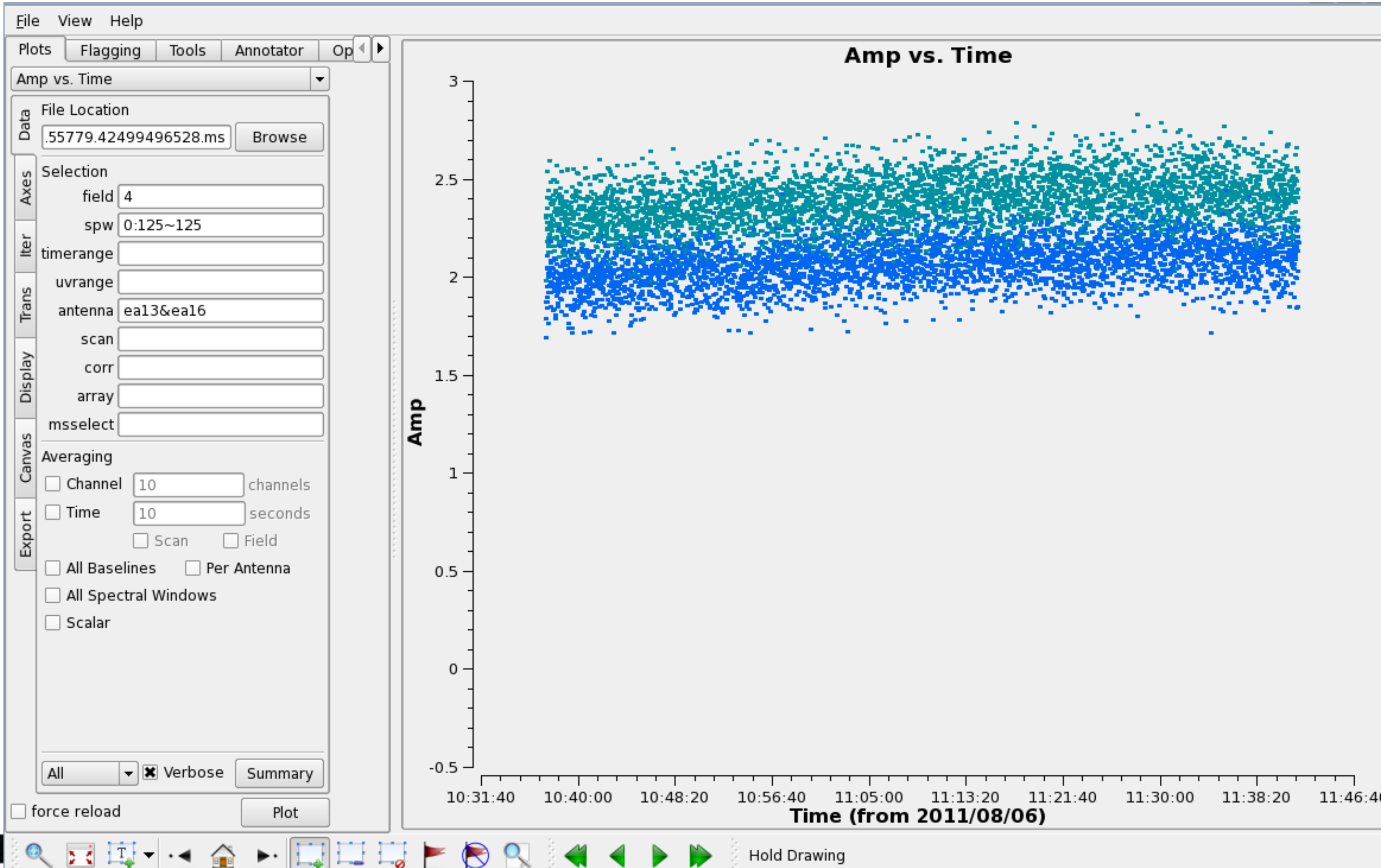
Flagging Data: *plotms*



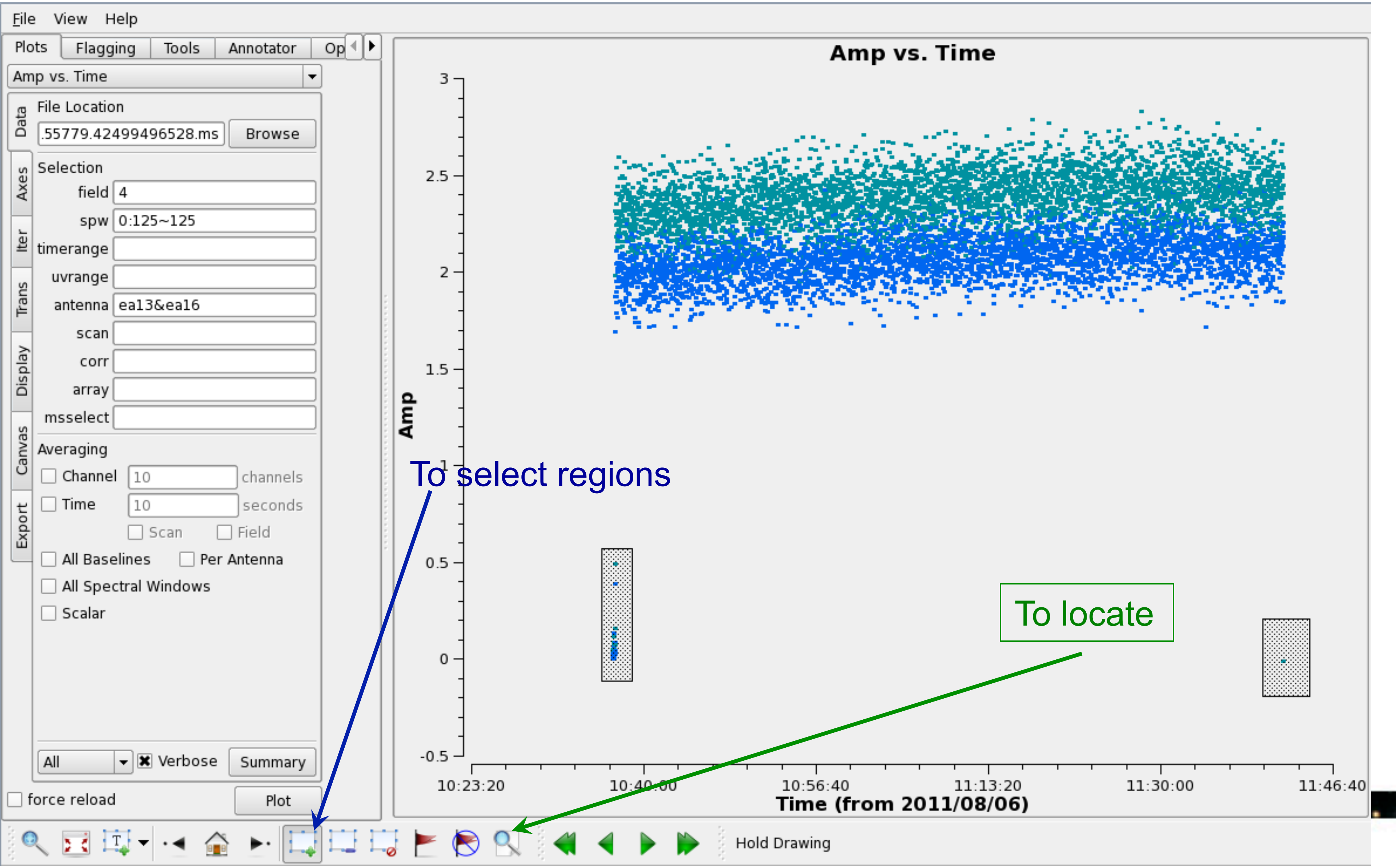
Flagging Data: *plotms*



Flagging Data: *plotms*



Flagging Data: *plotms*



Flagging Data: *plotms*

The output of locate in the casalog

```
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:57.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:57.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:58.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:58.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:59.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:36:59.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:00.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:00.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:01.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:01.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:02.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:02.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:03.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:03.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:04.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:04.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:05.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:05.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=LL
Scan=9 Field=W3IRS5[4] Time=2011/08/06/10:37:06.3 BL=ea13&ea16[11&14] Spw=0 Chan=125 Freq=22.2398 Corr=RR
```

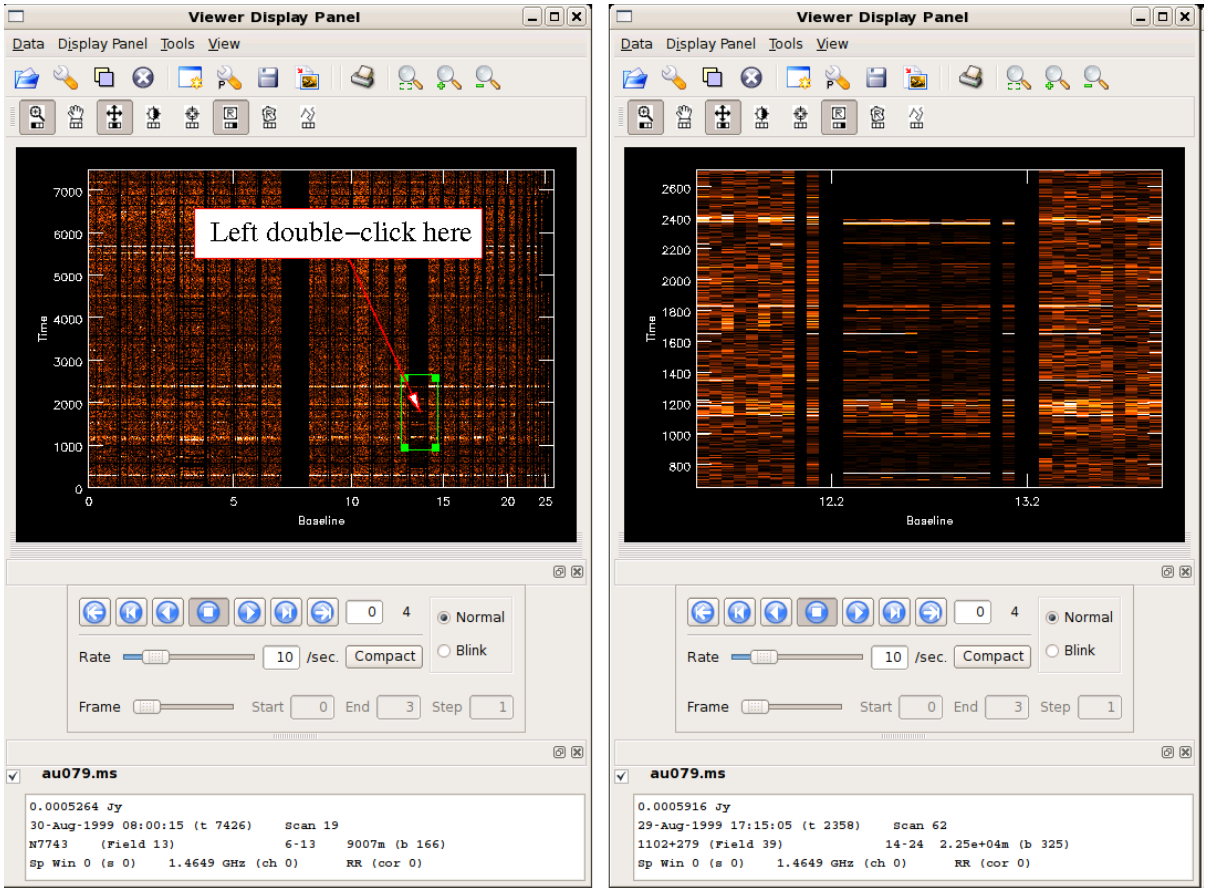
Flagging Data: *plotms*
A few important notes

- Use *plotms* carefully for flagging data.
- Keep in mind that flagging data with *plotms* often requires extending the flags (through the Flagging tab).
- *plotms* does not produce a flag backup (*flagmanager* has to be used).
- Use *plotms* to identify bad data (through the locate option). Then flag the bad data using *flagcmd* or *flagdata*.

Flagging Data: *msview*

- Shows gray scale (or colored) waterfall, plots.
- Plots Time vs. Baseline, or Time vs. Channel for
  - Amplitude (or amplitude diff or amplitude rms)
  - Phase (or phase diff or phase rms)
  - Real
  - Imaginary
- Provides interactive flagging tools (comparable to TVFLG and SPFLG in AIPS).

Flagging Data: *msview*



http://casaguides.nrao.edu/ → Data flagging with viewer

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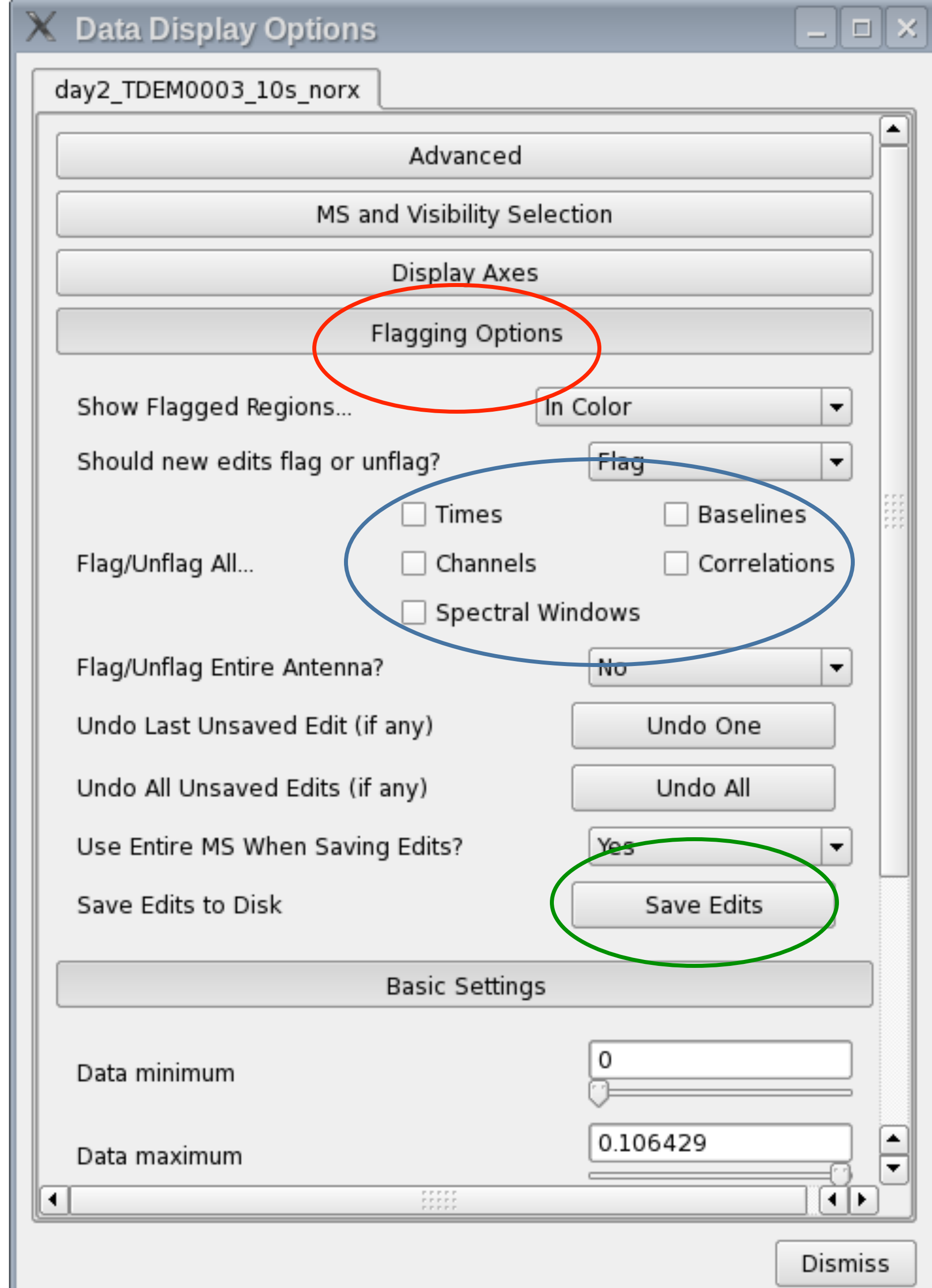
Flagging Data: *msview*

Use the Flagging Options

- to expand the flags.
- **to apply the flags.**



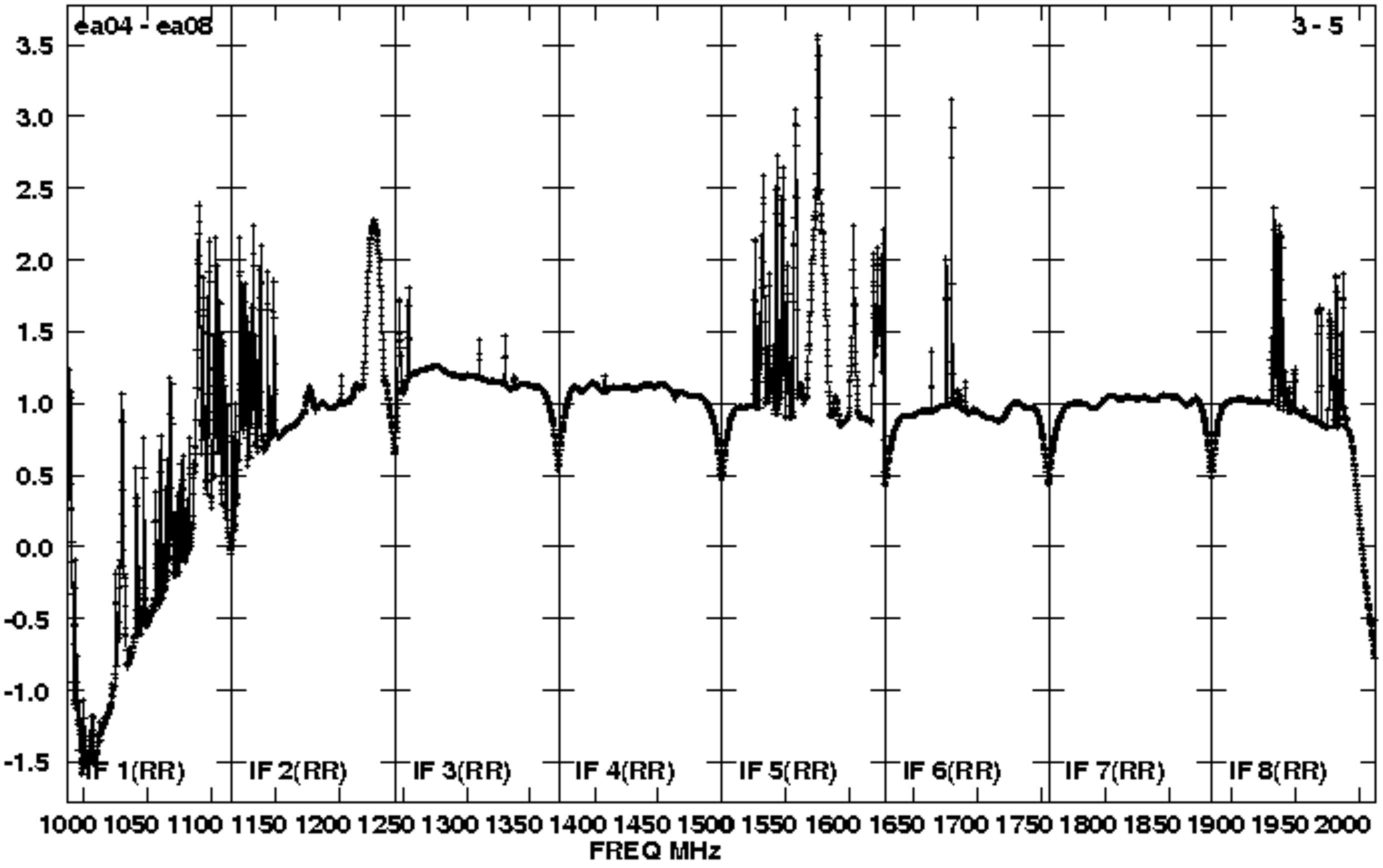
Radio Frequency Interference (RFI)

1. VLA observations, particularly at the lower frequency bands, will be severely affected by RFI.
2. VLA RFI information is available at:

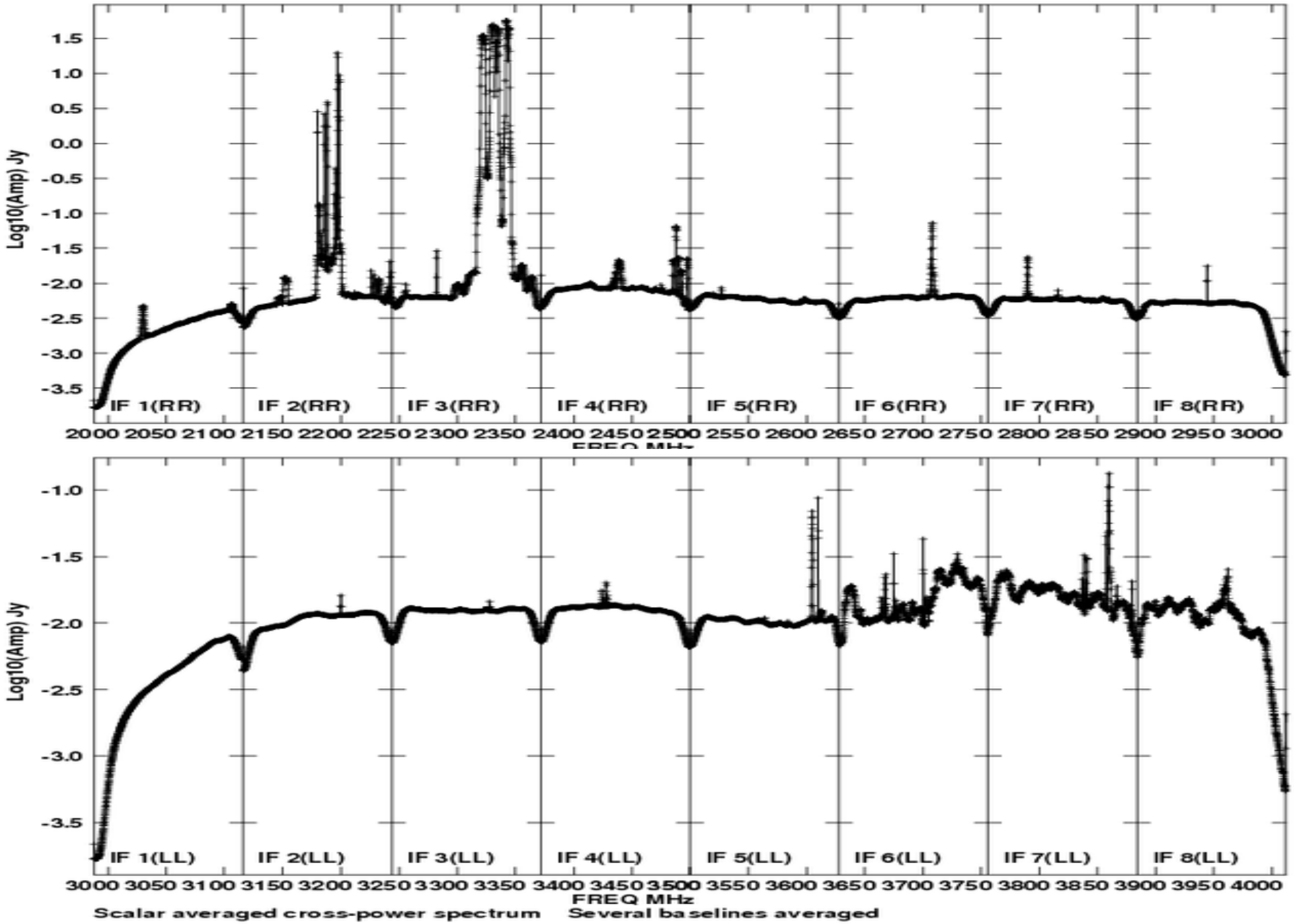
   https://science.nrao.edu/ → VLA → Observing → Guide to VLA Observing → Radio Frequency Interference

   - RFI listings per frequency Band.
   - Spectra of various RFI sweeps between 1-50 GHz.

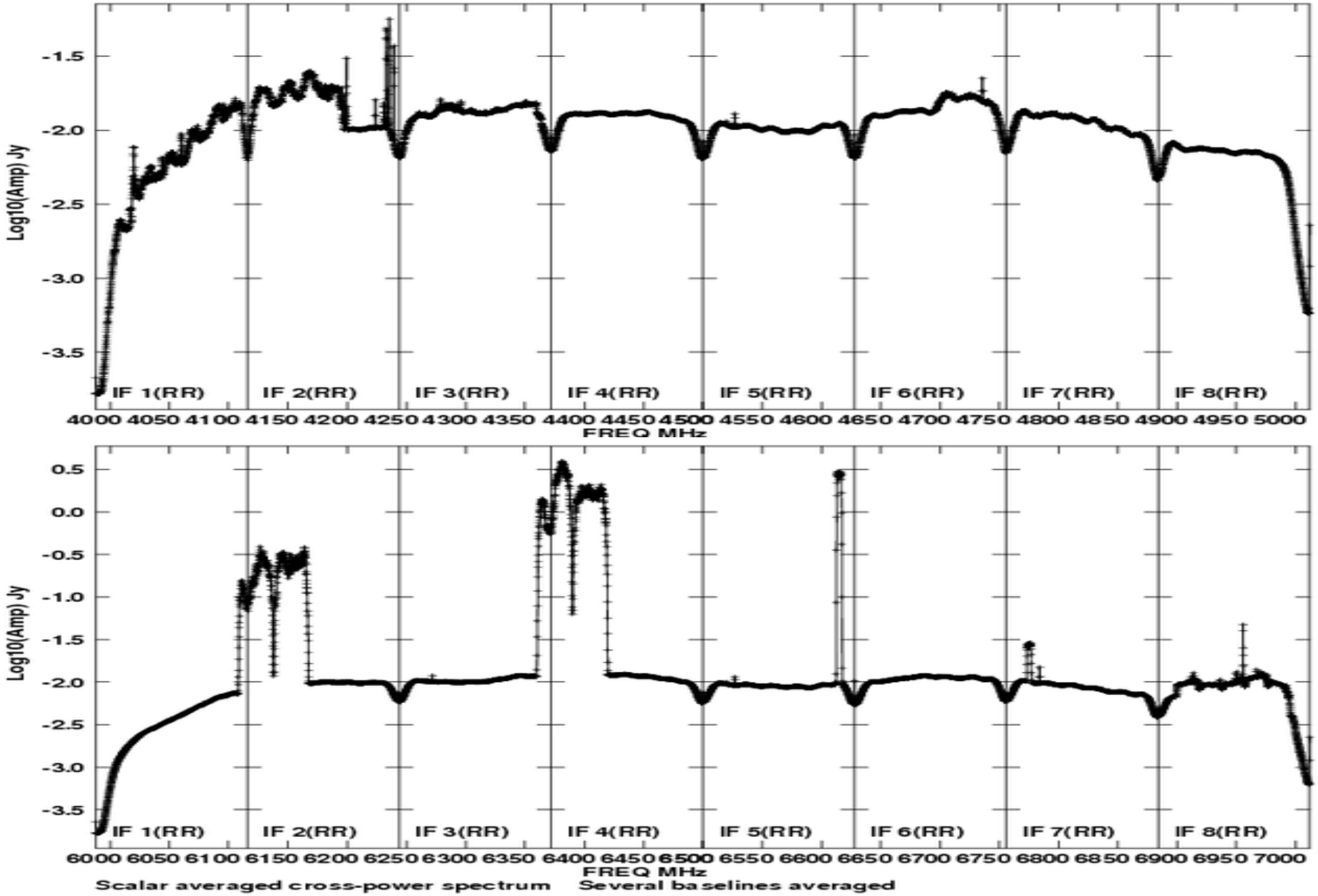
RFI: L-band


ea04 - ea08
3 - 5
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000
FREQ MHz

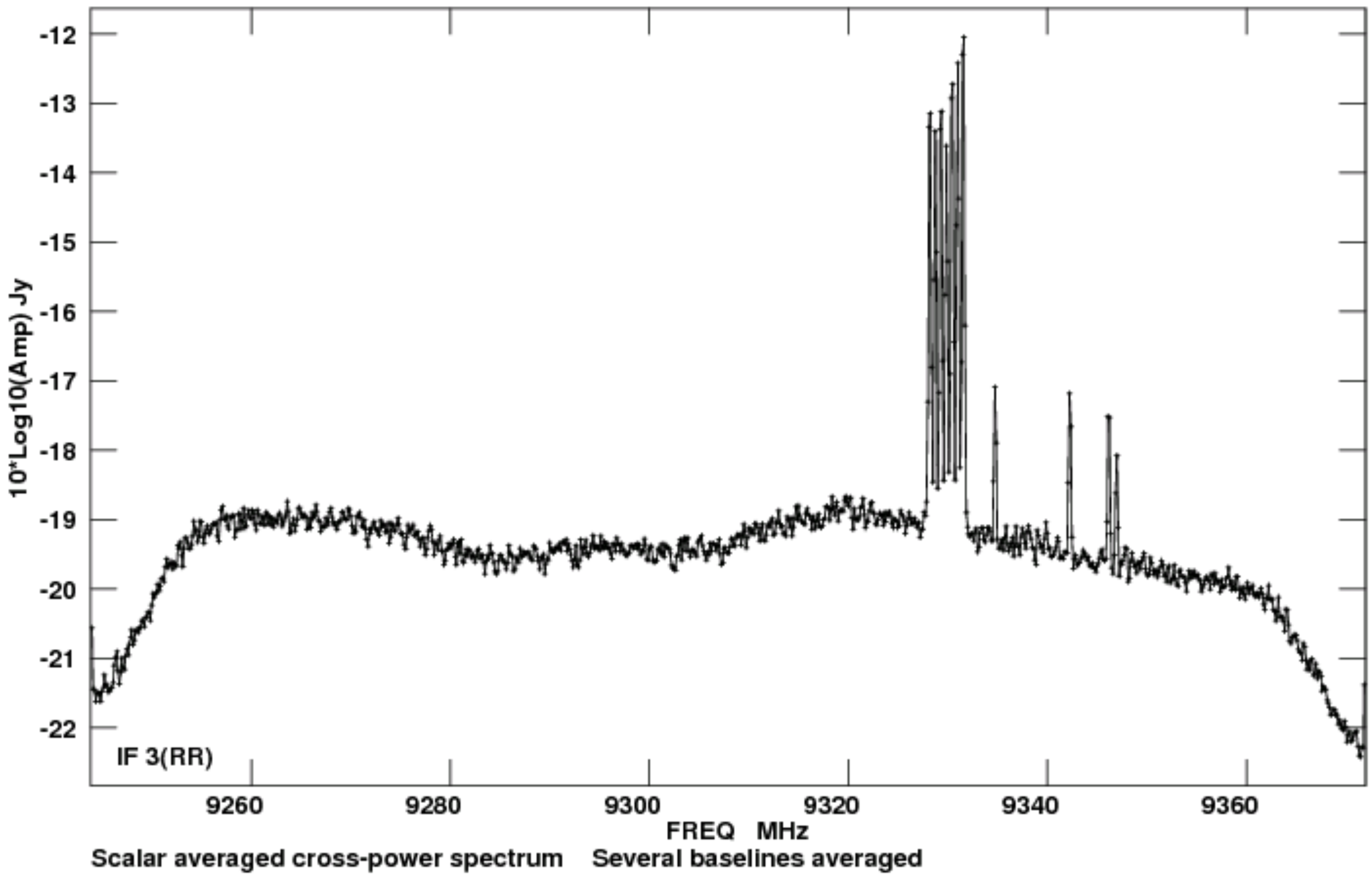
RFI: S-band


Log10(Amp) Jy
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
2000 2050 2100 2150 2200 2250 2300 2350 2400 2450 2500 2550 2600 2650 2700 2750 2800 2850 2900 2950 3000
IF 1(LL)
IF 2(LL)
IF 3(LL)
IF 4(LL)
IF 5(LL)
IF 6(LL)
IF 7(LL)
IF 8(LL)
3000 3050 3100 3150 3200 3250 3300 3350 3400 3450 3500 3550 3600 3650 3700 3750 3800 3850 3900 3950 4000
FREQ MHz
Scalar averaged cross-power spectrum
Several baselines averaged

RFI: C-band

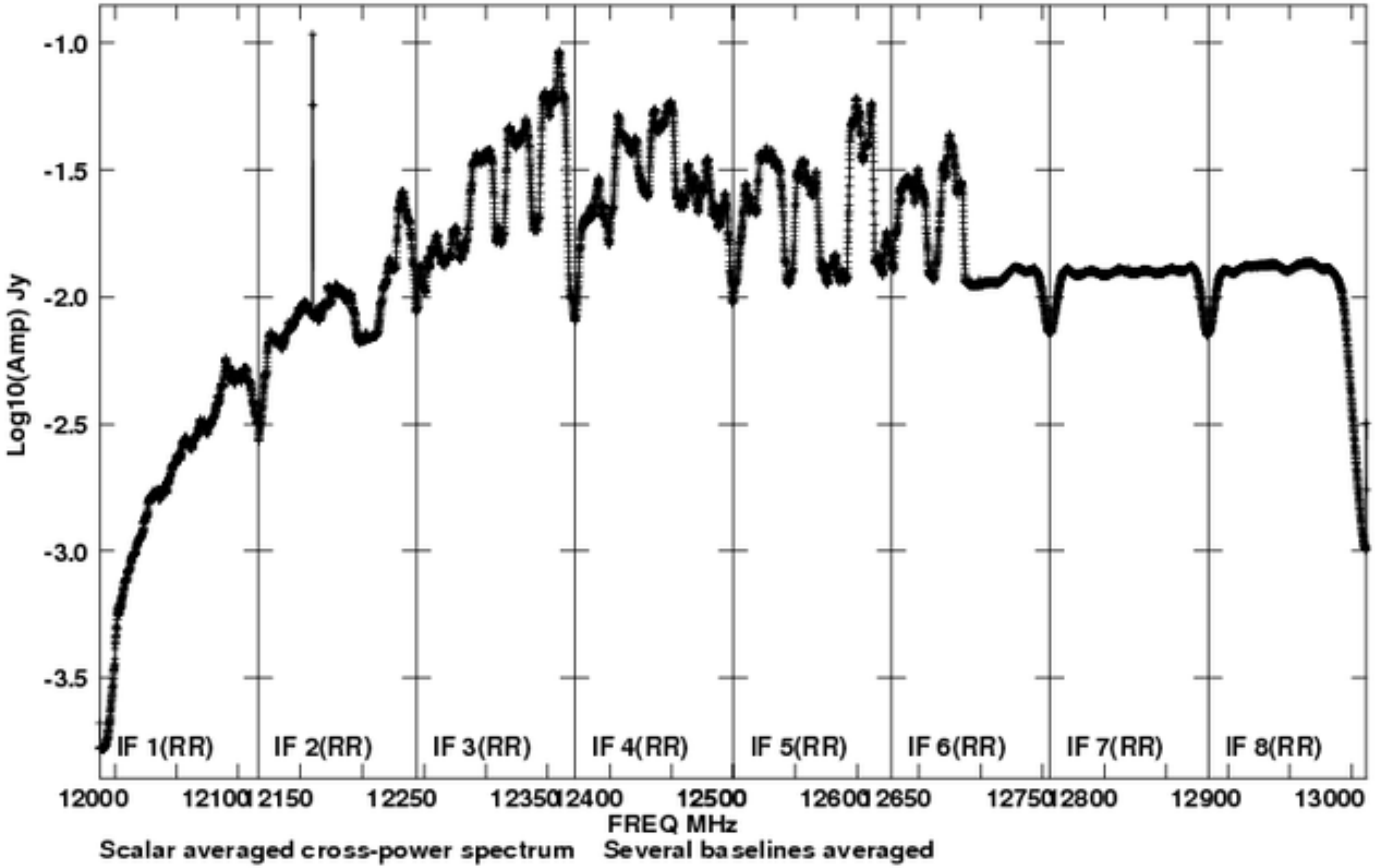

Log10(Amp) Jy
-1.5
-2.0
-2.5
-3.0
-3.5
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
4000 4050 4100 4150 4200 4250 4300 4350 4400 4450 4500 4550 4600 4650 4700 4750 4800 4850 4900 4950 5000
FREQ MHz
Log10(Amp) Jy
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
6000 6050 6100 6150 6200 6250 6300 6350 6400 6450 6500 6550 6600 6650 6700 6750 6800 6850 6900 6950 7000
FREQ MHz
Scalar averaged cross-power spectrum
Several baselines averaged

RFI: X-band



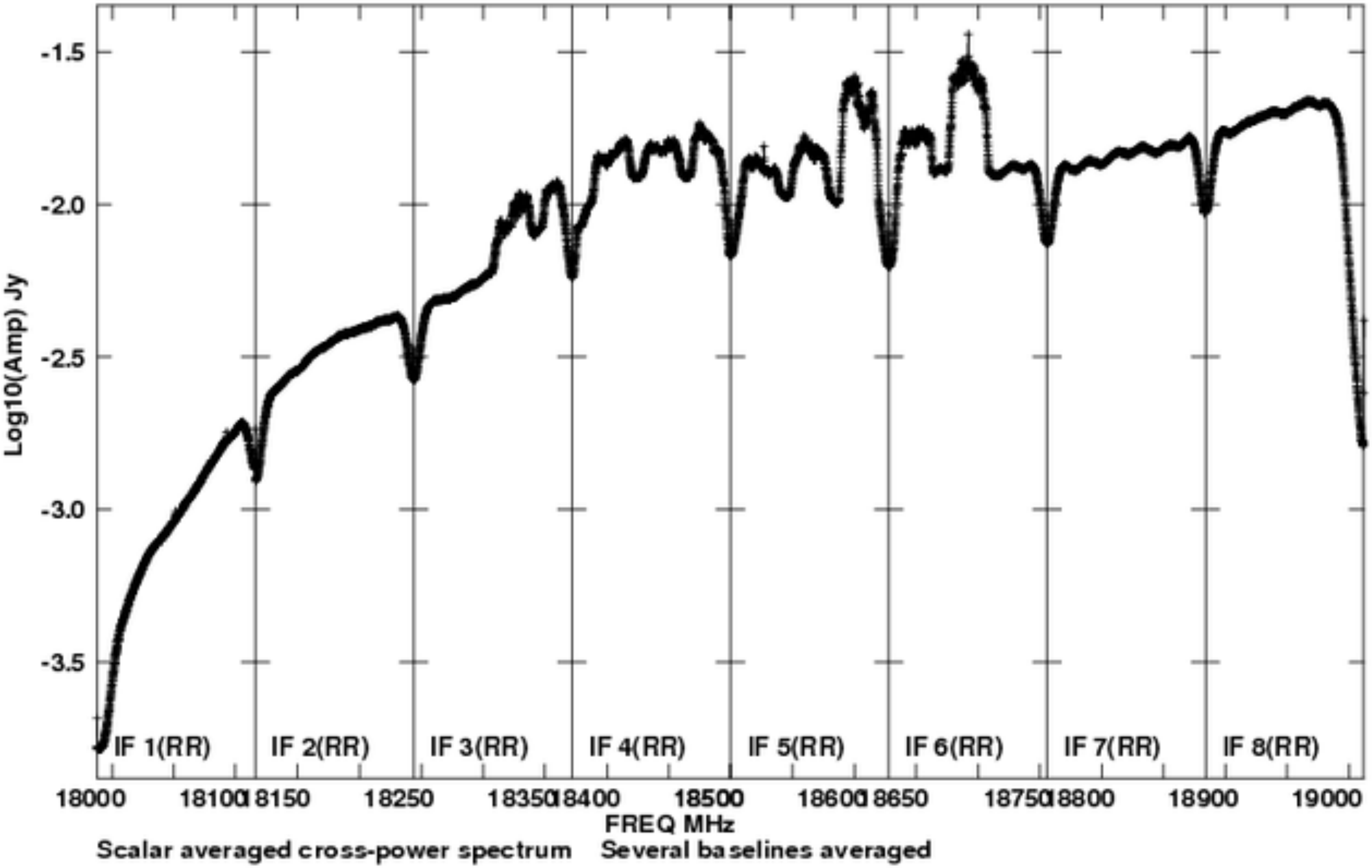
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
10*Log10(Amp) Jy
IF 3(RR)
9260
9280
9300
9320
9340
9360
FREQ MHz
Scalar averaged cross-power spectrum Several baselines averaged

RFI: Ku-band

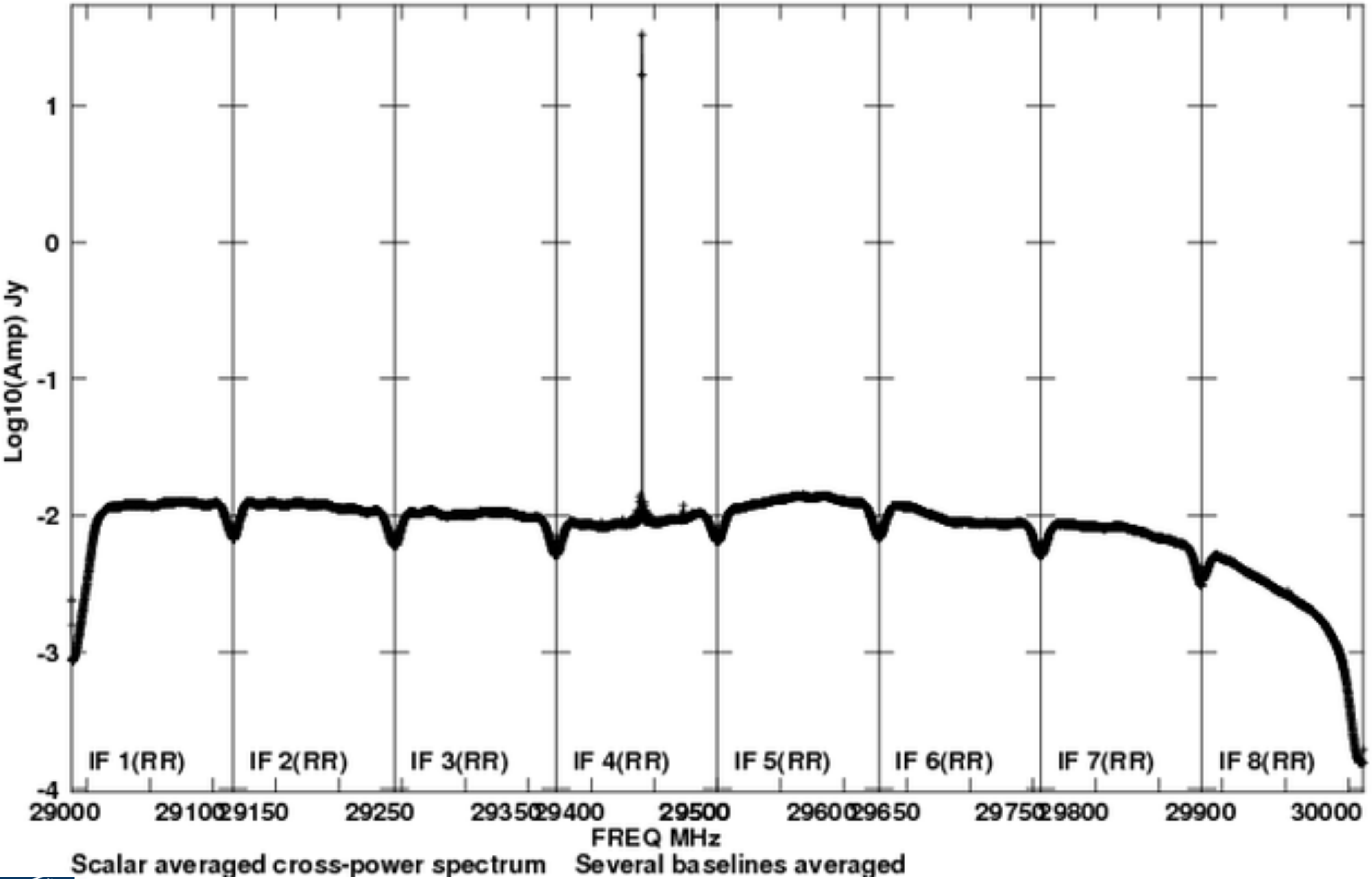


-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
Log10(Amp) Jy
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
12000
12100
12150
12250
12350
12400
12500
12600
12650
12750
12800
12900
13000
FREQ MHz
Scalar averaged cross-power spectrum Several baselines averaged

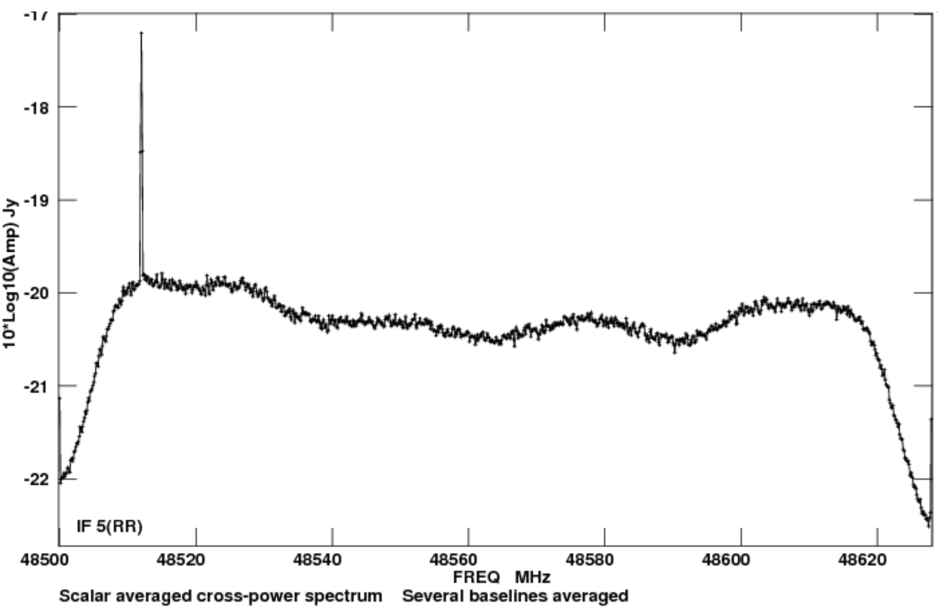
RFI: K-band


Log10(Amp) Jy
-1.5
-2.0
-2.5
-3.0
-3.5
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
18000
18100
18150
18250
18350
18400
18500
18600
18650
18750
18800
18900
19000
FREQ MHz
Scalar averaged cross-power spectrum
Several baselines averaged

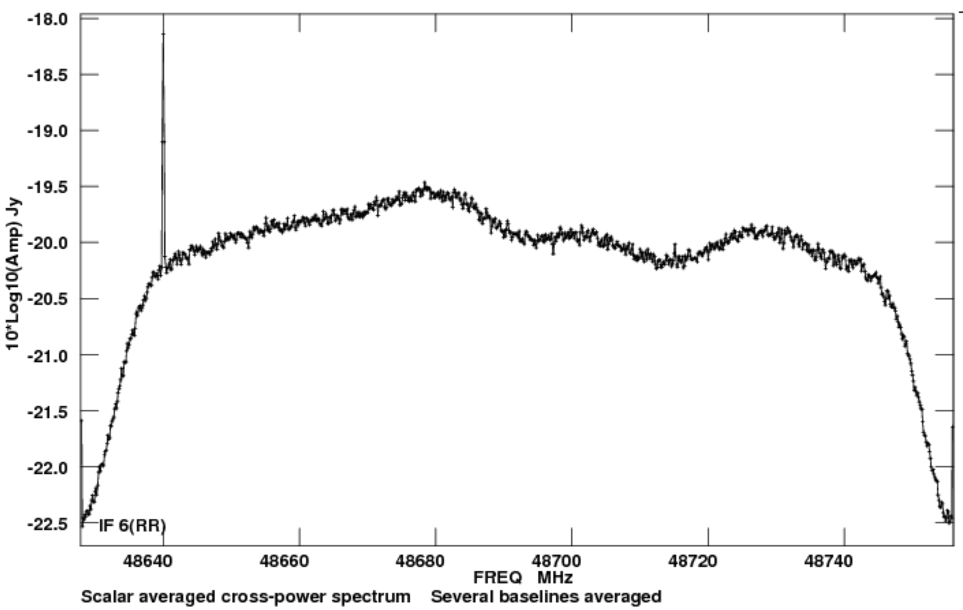
RFI: Ka-band


Log10(Amp) Jy
1
0
-1
-2
-3
-4
IF 1(RR)
IF 2(RR)
IF 3(RR)
IF 4(RR)
IF 5(RR)
IF 6(RR)
IF 7(RR)
IF 8(RR)
29000
29100
29150
29250
29350
29400
29500
29600
29650
29750
29800
29900
30000
FREQ MHz
Scalar averaged cross-power spectrum
Several baselines averaged

RFI: Q-band



-17
-18
-19
-20
-21
-22
10*Log10(Amp) Jy
IF 5(RR)
48500
48520
48540
48560
48580
48600
48620
FREQ MHz
Scalar averaged cross-power spectrum Several baselines averaged



-18.0
-18.5
-19.0
-19.5
-20.0
-20.5
-21.0
-21.5
-22.0
-22.5
10*Log10(Amp) Jy
IF 6(RR)
48640
48660
48680
48700
48720
48740
FREQ MHz
Scalar averaged cross-power spectrum Several baselines averaged

RFI: feedback from observers

- The VLA has opened the full 1 to 50 GHz frequency range.
  - Also the 230-470 MHz range [shared risk].
- This exposed us to all types of RFI.
- RFI is direction dependent.
- User feedback is critical for our ongoing RFI identification and monitoring efforts.
- Observers are asked to email nrao-rfi@nrao.edu and provide:
  – Observation/project code
  – Frequency and Time of the observations
  – The characteristics of the RFI signal (e.g., continuous, intermittent)
  – A spectrum

RFI: spectral (Gibbs) ringing

- Strong RFI will introduce disturbing spectral ringing.
- Hanning-smoothing should be applied on such data sets before attempting any spectral flagging, or calibration.
- In CASA, the task to use is *hanningsmooth*.

VLA Data Reduction Techniques: II

Emmanuel Momjian
NRAO

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

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Outline

- The archive tool.
- Loading the data set.
- CASA
- Examining/Flagging the data set.
- Calibration
  - Including high and low frequency considerations.
- Imaging
  - Including spectral line, continuum, wide band, and wide field.
- Image analysis

I

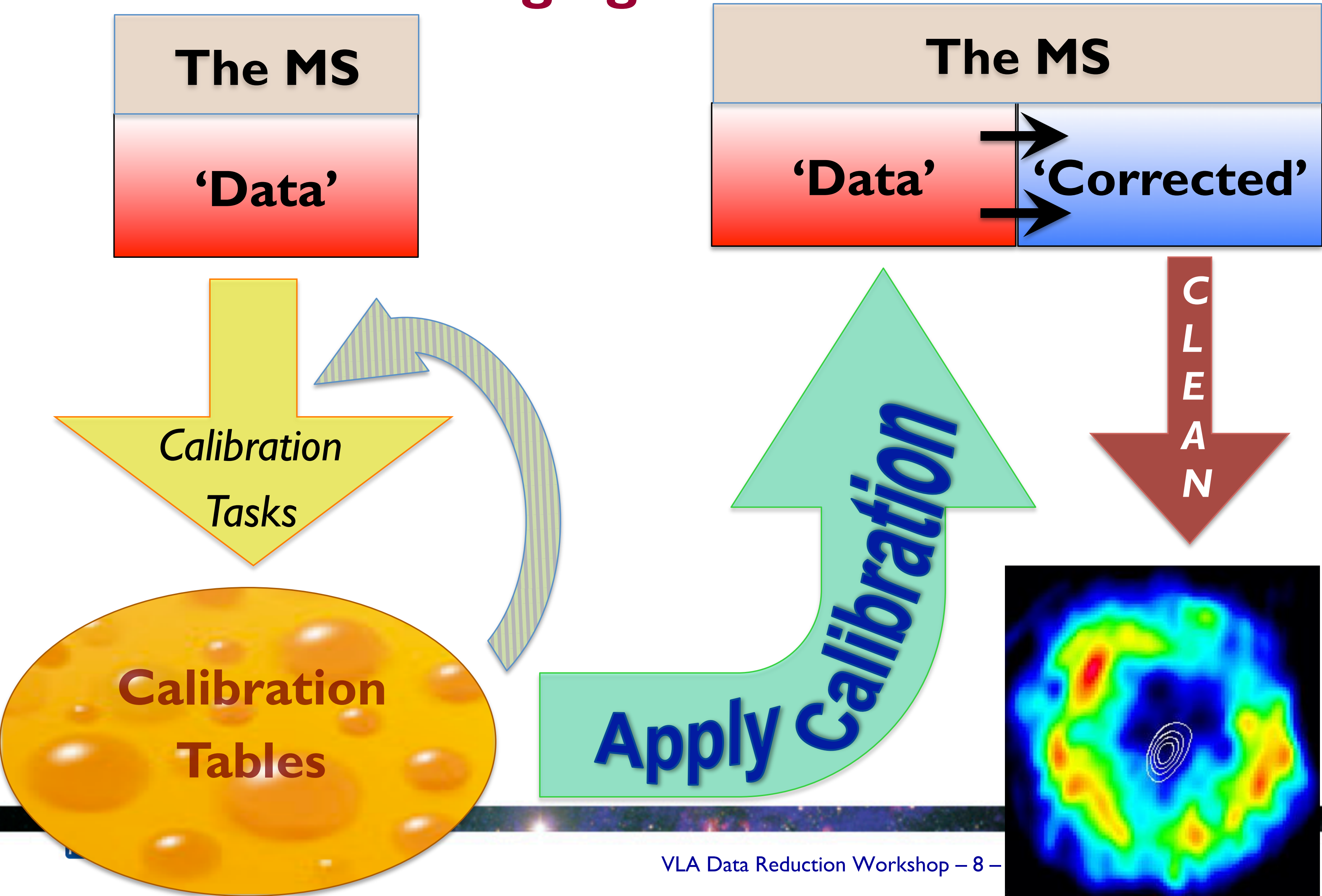
II

The MS structure

'Data' column	'Corrected' Column	'Model' Column (optional)
Raw Data	Calibrated Data	FT of source model

- When you load your data from the archive, your MS will only have the 'Data' column.
- The other two columns can be created by various means.
- The creation of the other two columns → MS tripling in size.
- The 'Model' Column is optional.
  - If not created → MS doubling in size.
  - Models can be "attached" to the MS, FT-ed and used when needed (replacing the need for the 'Model' column).

Calibration & Imaging Flow



Calibration

- Correcting antenna positions
- Gain Curves
- Opacity (HF) and Ionospheric (LF) corrections
- Requantizer gain calibration (for 3-bit)
- Setting the flux density scale
- Delay calibration
- Initial Phase only calibration (HF)
- Bandpass calibration
- Complex gain calibration
- Polarization Calibration
- Setting the flux scales of the secondary calibrators

} Prior Calibration (first five items)

gencal

- *gencal* is a task for various types of corrections:

```
'amp'= amplitude correction
'ph' = phase correction
'sbd'= single-band delay
'mbd'= multi-band delay
'antpos' = ITRF antenna position corrections
'antposvla' = VLA-centric antenna pos. corrections
'tsys' = Tsys from the SYSCAL table (ALMA)
'swpow' = EVLA switched-power gains (experimental)
'rq' = EVLA requantizer gains
'opac' = Tropospheric opacity
'gc' = Gain curve (zenith-angle-dependent gain)
'eff' = Antenna efficiency (sqrt(K/Jy))
'gceff' = Gain curve and efficiency
```

Antenna Positions: *gencal*

- Check the operator's log to see if any antennas were recently moved.
- Use the task *gencal* to produce a calibration table that includes the antenna position corrections

```
caltype  = 'antpos'
caltable = 'antpos.cal'
```

- Baseline correction related information is at:

  http://www.vla.nrao.edu/astro/archive/baselines/

Gain Curves: *gencal*

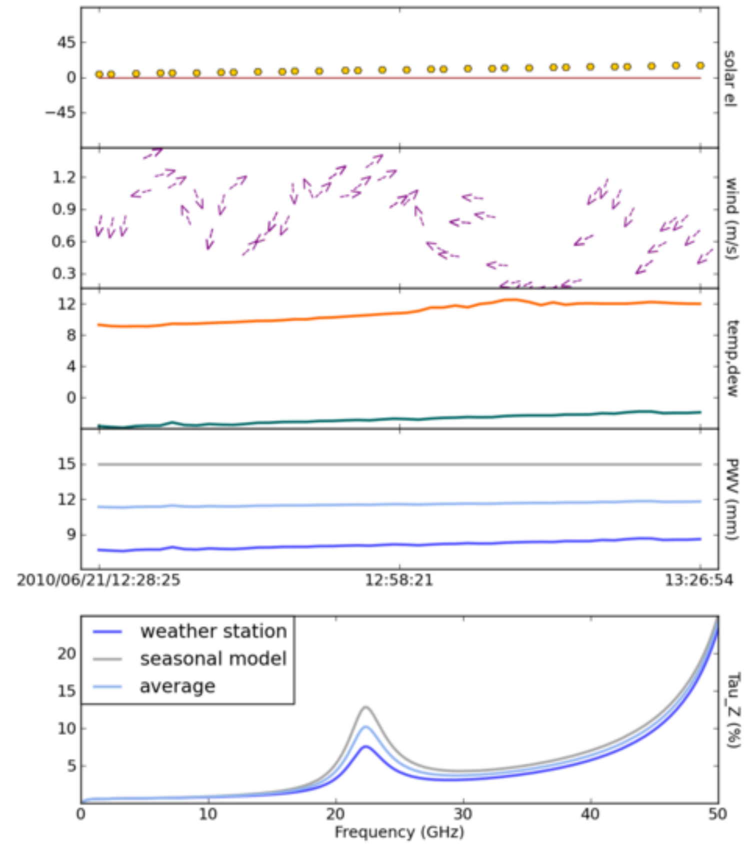
- Large antennas have a forward gain that changes with elevation.
- Gain curves describe how each antenna behaves as a function of elevation, for each receiver band.
- The polynomial coefficients for the VLA are available directly from the CASA data repository.
- Especially important for higher frequencies.
- In *gencal*, set

```
caltype  = 'gc'
caltable = 'gaincurve.cal'
```

Opacity Corrections (HF): *plotweather, gencal*

- Atmospheric optical depth corrections.
- Important for high frequency observations (>15 GHz).
- Use *plotweather* to estimate opacities.
  - Uses weather statistics and/or seasonal models.
  - Plots weather statistics.
- Use *gencal* to make a calibration table using the derived opacities.

```
caltype  = 'opac'
caltable = 'opacity.cal'
```



Ionosphere Correction

- Needed for lower frequency observations (< 1 GHz).
- Available in AIPS (task *TECOR*; derives corrections for ionospheric Faraday rotation and dispersive delay).
- An improved version will be implemented in CASA in the future.

Requantizer gains (3-bit): *gencal*

- Required for 3-bit data.
  - During the observations, the setting of the requantizer gains introduces 5-10% gain changes.

- In *gencal*, set

```
caltype  = 'rq'
caltable = 'requant_gains.cal'
```

- Need to use CASA version 4.1

Setting the flux density scale: *setjy*

- Calculates the absolute flux density
  - as a function of frequency for standard flux calibrators
  - also time for Solar System objects.
- If provided, attaches a model record to the MS

```
vis           =    'MS file name'
field         =      '?'
spw           =      ''
modimage      =      '?'
listmodels    =     False
scalebychan   =     True
fluxdensity   =      -1
standard      =    'Perley-Butler 2013'
usescratch    =     False
```

Calibration: *setjy*

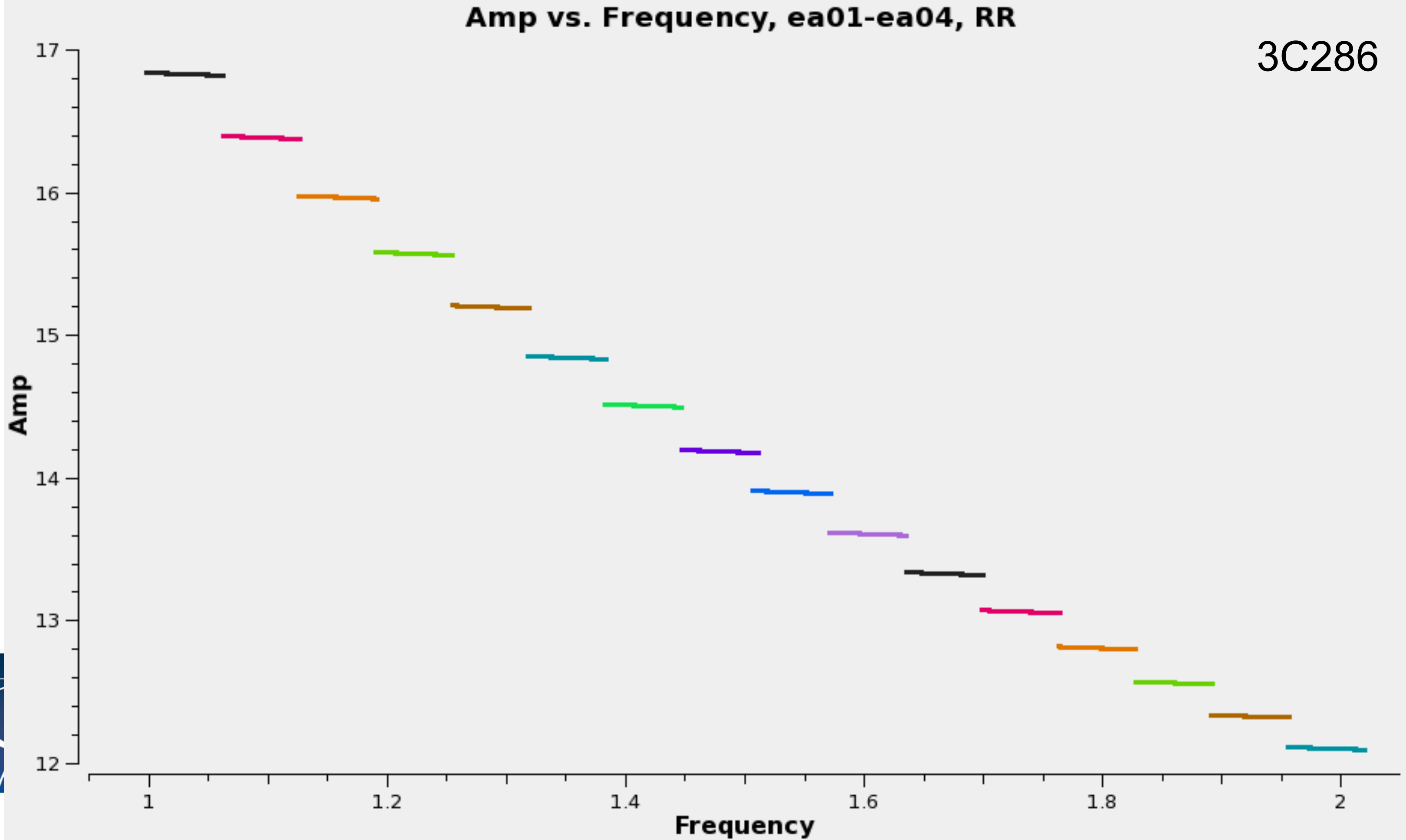
- `listmodels`
  - If `True`, the task will only list the available primary calibrator models (3C138, 3C147, 3C286, 3C48; at L, S, C, X, U, K, A, Q bands).
  - If `False`, the task will calculate the flux density.

- `usescratch`
  - If `True`, the 'Model' column will be created. This will increase the size of the MS.
  - If `False`, the model is simply attached to the MS. When needed, it will be FT-ed and used.

Calibration: *setjy*

The `scalebychan` parameter

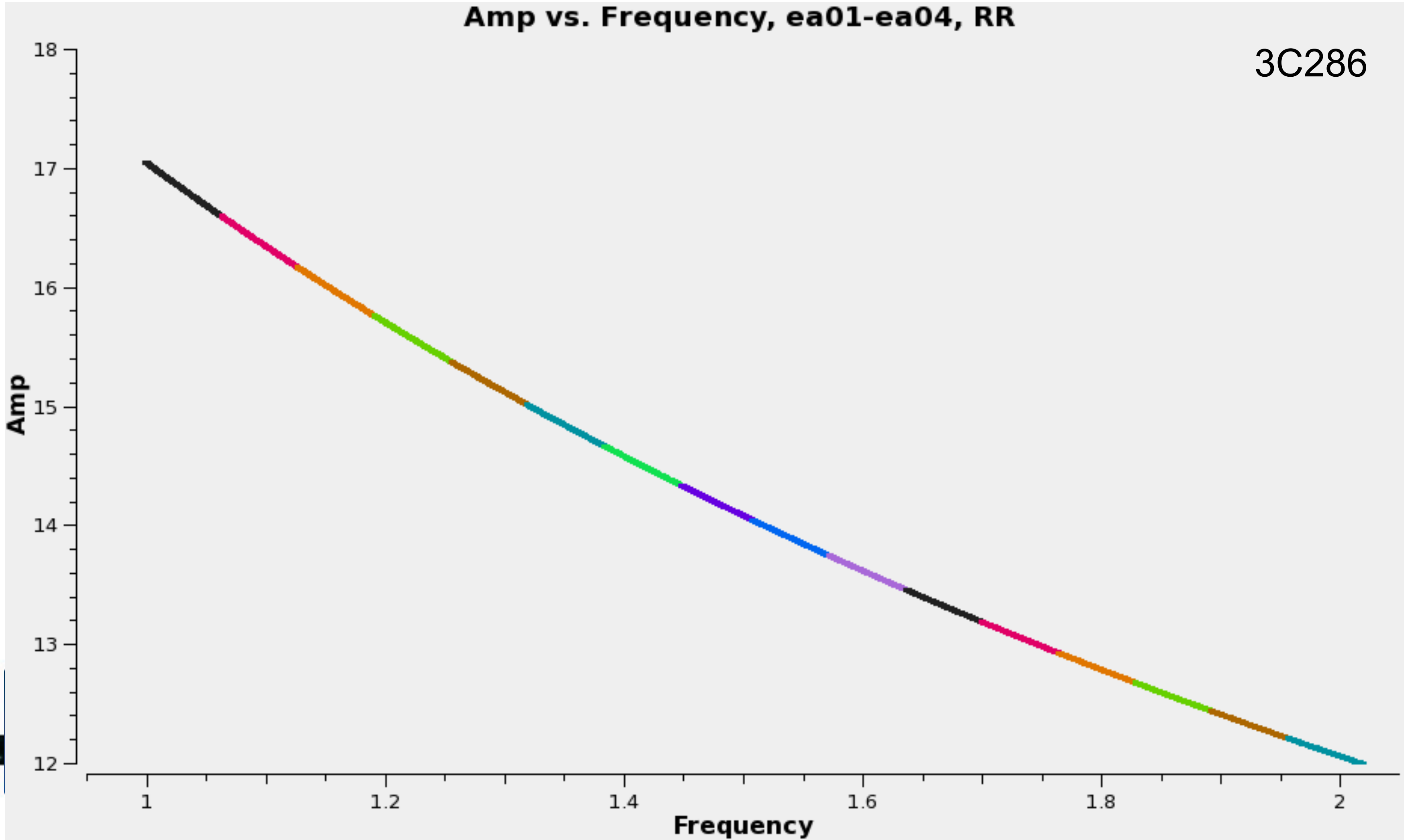
- If **`False`**: The values will be per spectral window.
- **Do not set it to False!**



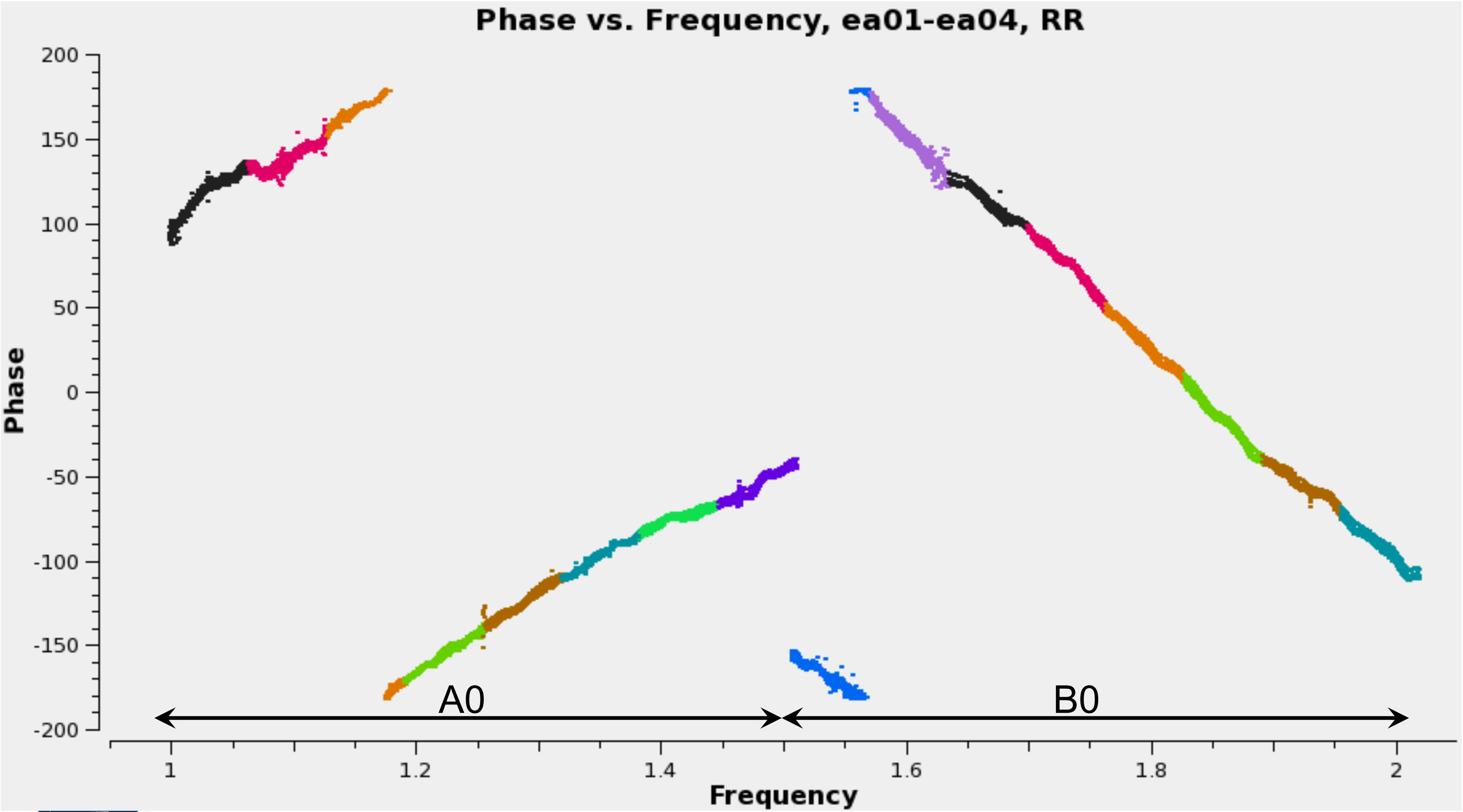
Calibration: *setjy*

The `scalebychan` parameter

- If **`True`**: The values will be per spectral channel

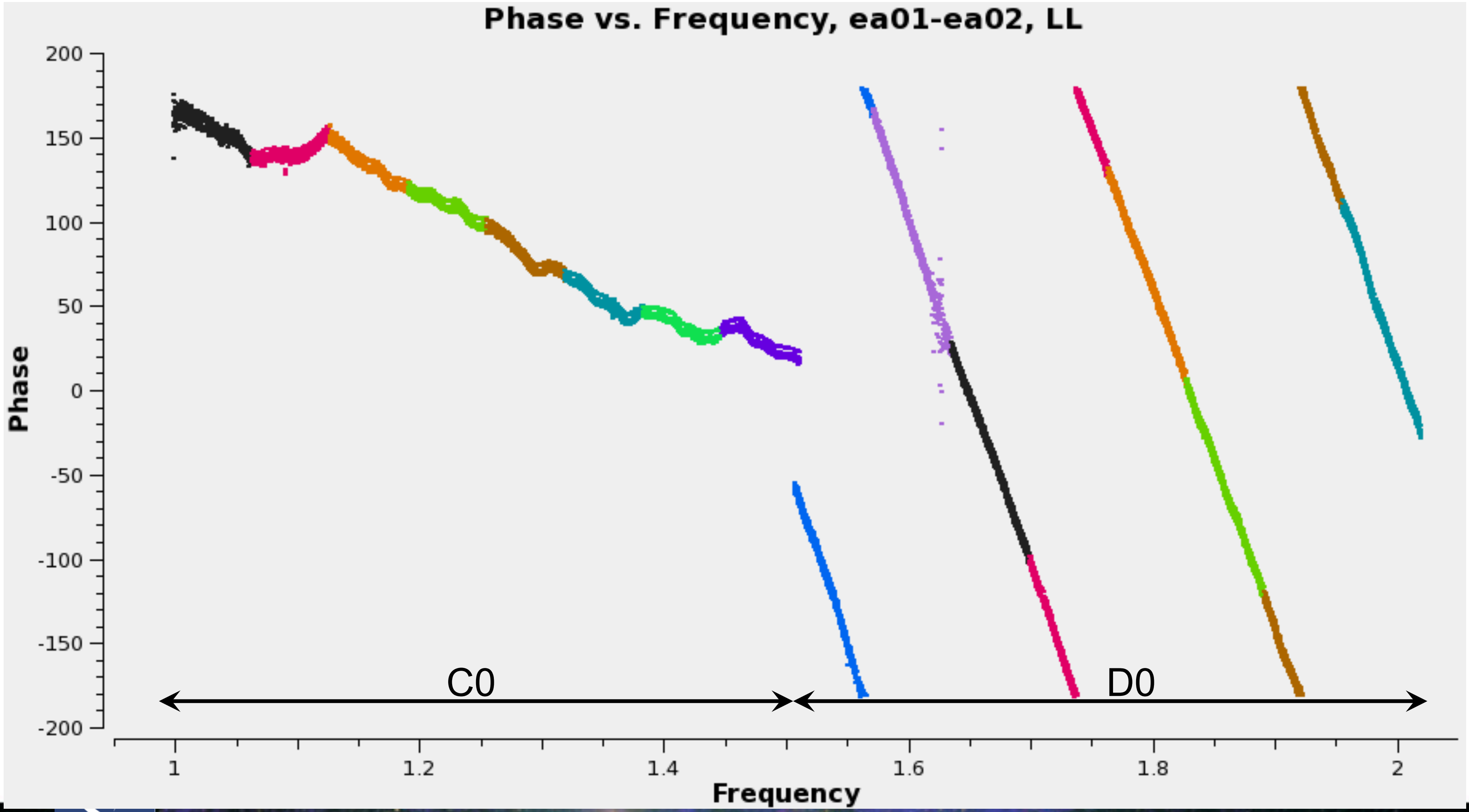


Delays



Phase vs. Frequency, ea01-ea04, RR
Phase
Frequency
200
150
100
50
0
-50
-100
-150
-200
1
1.2
1.4
1.6
1.8
2
A0
B0

Delays


Phase vs. Frequency, ea01-ea02, LL
Phase
Frequency
200
150
100
50
0
-50
-100
-150
-200
1
1.2
1.4
1.6
1.8
2
C0
D0

Delay Calibration: *gaincal*

```
vis          =    'MS file name'
caltable     =    'delays.cal'
field        =    '? '
solint       =    '60s'
refant       =    'ea??'
gaintype     =    'K'
gaintable    =    'previous cal tables'
```

- Choose 1 min of data on a strong source (through `selectdata` → `timerange`).
- Make sure the `refant` has baselines to all the antennas in the selected time range.
- This is not a Global Fringe Fitting; it solves for antenna based single-band delays.

Before Bandpass Calibration

- Bandpass calibration is not only needed for spectral-line observations, but also for continuum.
- Before calibrating the bandpass, do phase-only calibration on the bandpass calibrator (to be applied when calibrating the bandpass).
    - Prevents decorrelation when vector averaging.
    - Critical for high frequency observations.
    - Can also be used in low frequency observations.

Initial Phase only calibration: *gaincal*

- Run *gaincal* on the bandpass calibrator using:
  - a short solution interval, and
  - a few channels per spw (free of RFI).
- This table should only be used while calibrating the bandpass.
- In *gaincal*, set

```
– caltable  =‘bpphase.gcal’
– calmode   = ‘p’
– gaintype  = ‘G’
– gaintable = ‘various calibration tables’
– solint    = ‘a short time interval’
```

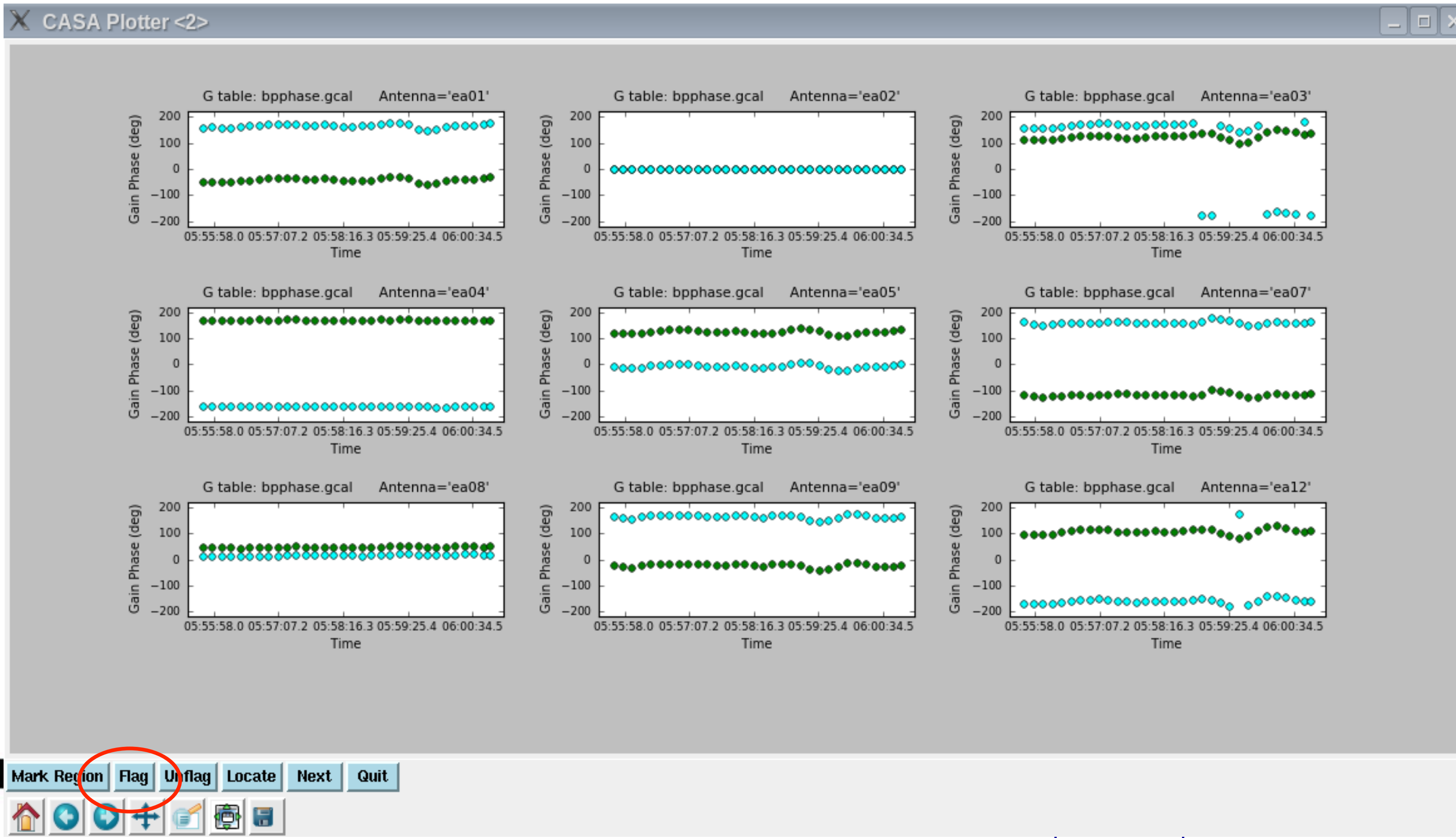
Initial Phase only calibration
Plotting the solutions: *plotcal*

- *plotcal* is a multi-purpose plotter (editor) for calibration results
- To plot the phase calibration results:

```
caltable    = 'bpphase.gcal'
xaxis       =     'time'
yaxis       =    'phase'
spw         =        '1'
subplot     =        331
iteration   =  'antenna'
plotrange   = [0, 0, -200, 200]
```

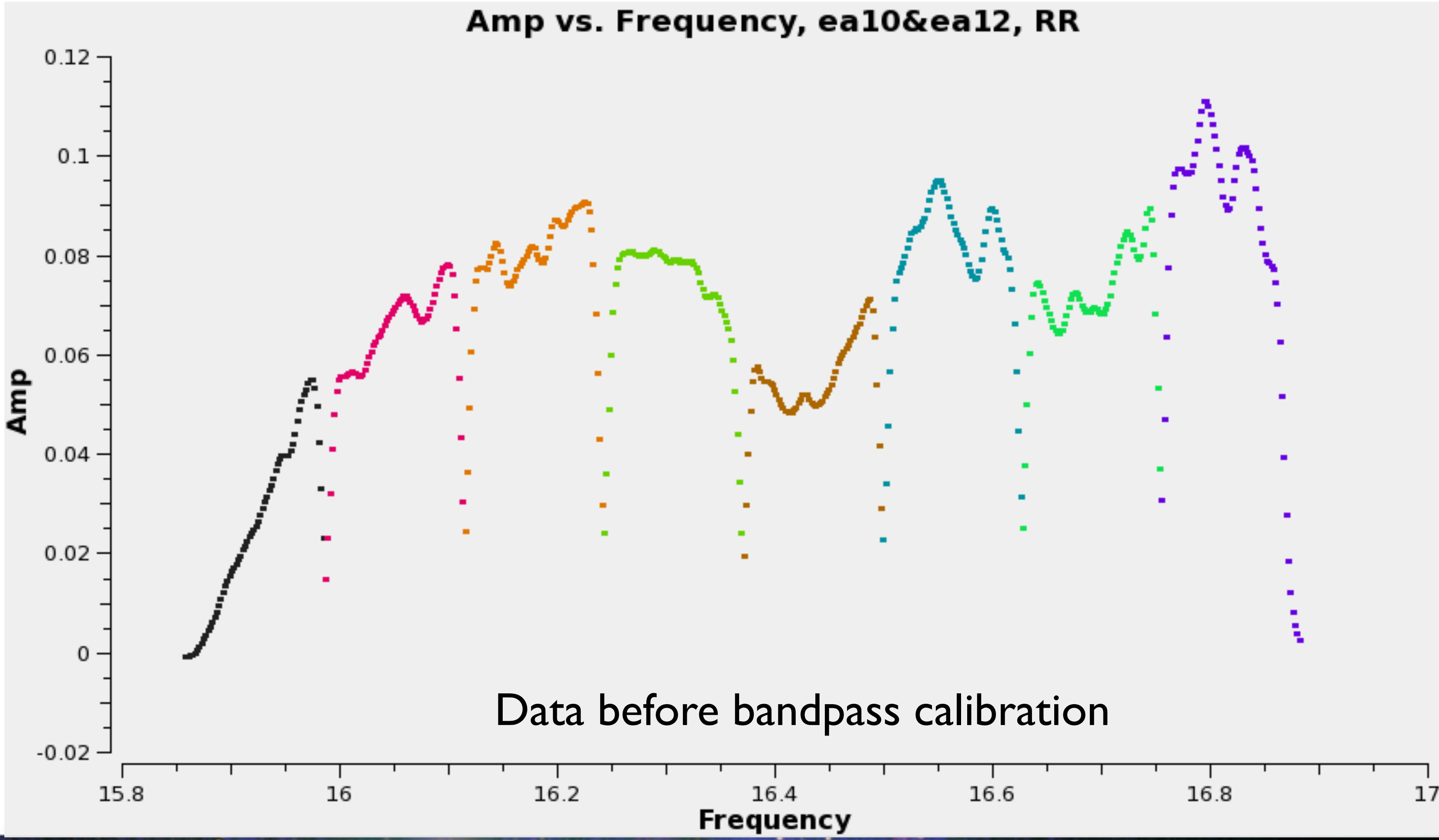
Initial Phase only calibration

Plotting the solutions: *plotcal*



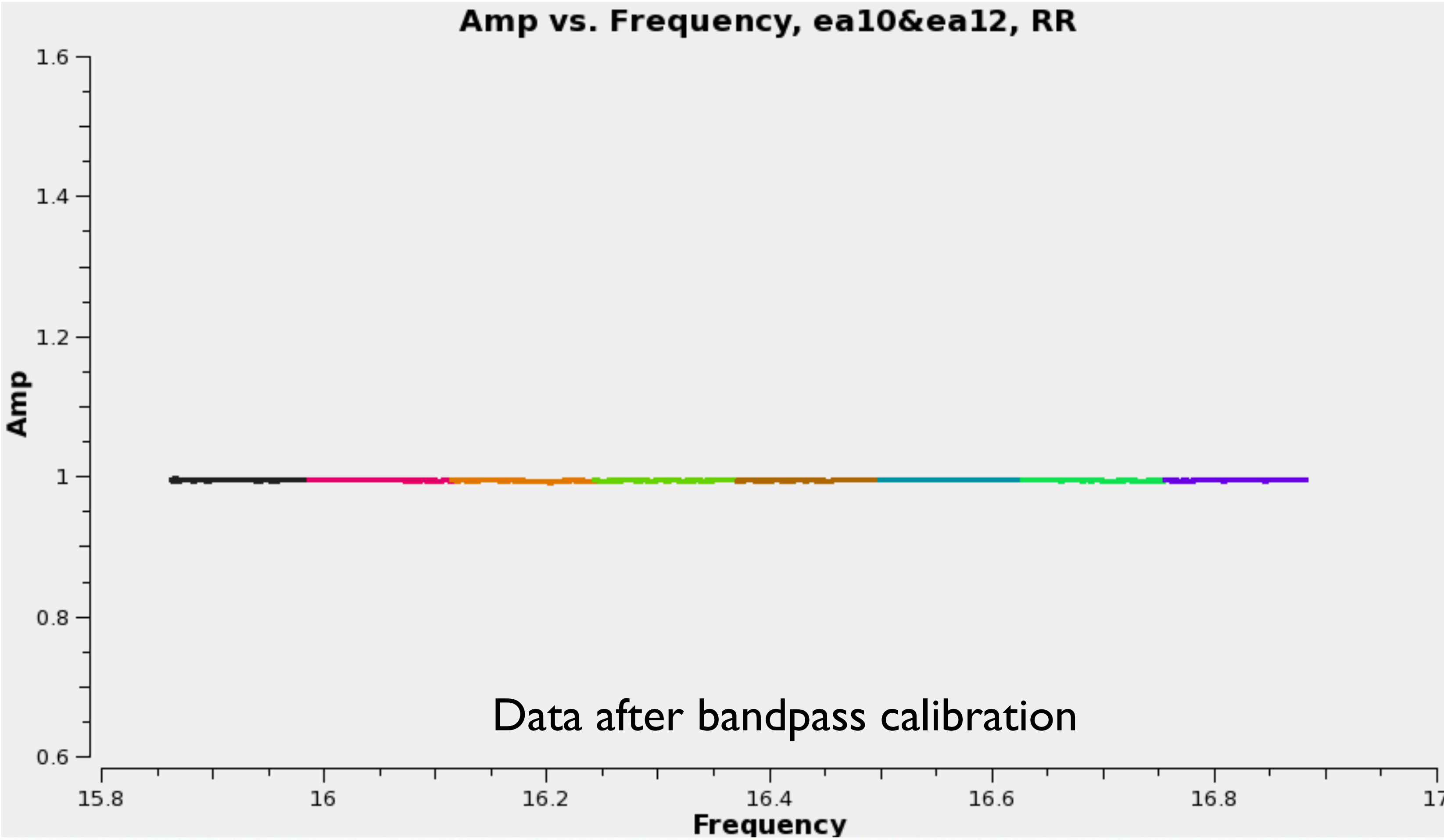
Bandpass Calibration: *bandpass*

- Needed for continuum observations too.



Bandpass Calibration: *bandpass*

- Needed for continuum observations too.



Bandpass Calibration: *bandpass*

```
caltable        =   'bandpass.bcal'
field           =   '?'
solint          =   ' '
refant          =   'ea??'
solnorm         =   False
bandtype        =   B    or   BPOLY
    fillgaps    =   3    (for B bandtype)
gaintable       = various calibration tables
```

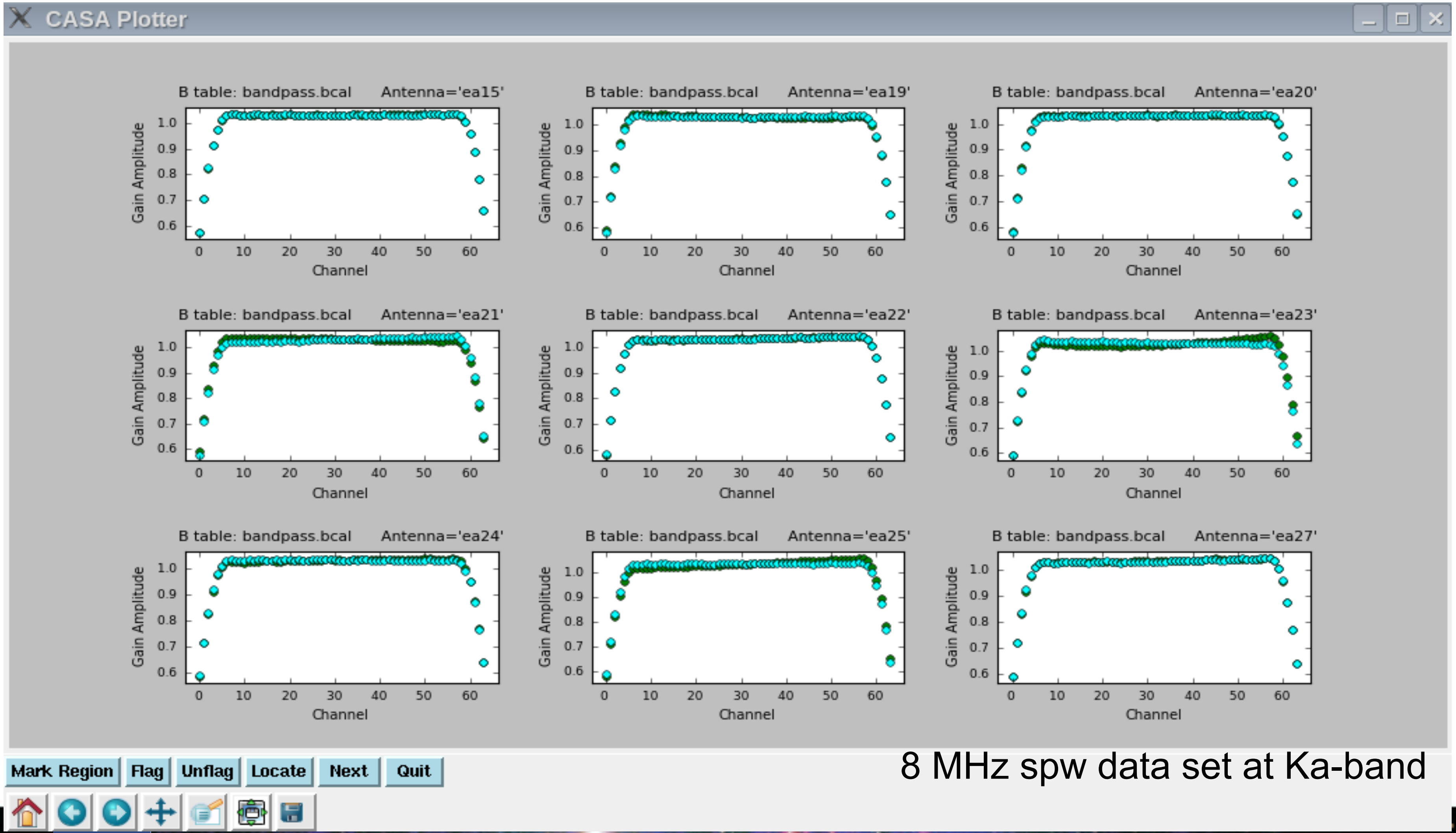
- If using a source other than the flux calibrator, the spectral index (and the spectral curvature) should be accounted for.
- CASA will report these while bootstrapping the flux densities.
  - Use *setjy* to insert these values.

Bandpass Calibration

Plotting the solutions: *plotcal*

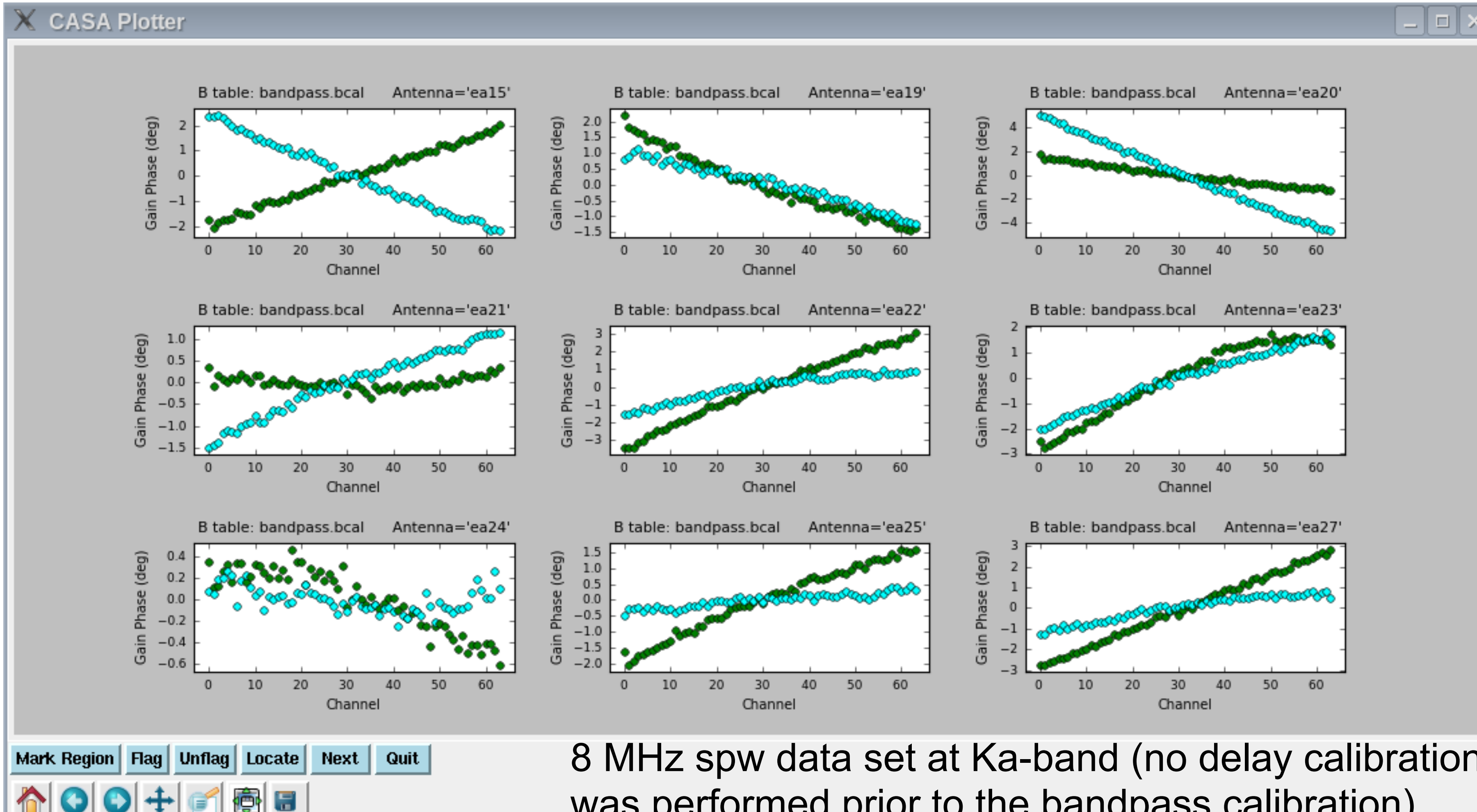
```
caltable        = 'bandpass.bcal'
xaxis           =     'chan'
yaxis           =     'amp'   or  'phase'
spw             =        '1'
subplot         =        331
iteration       =  'antenna'
```

Bandpass Calibration
Plotting the solutions: *plotcal*



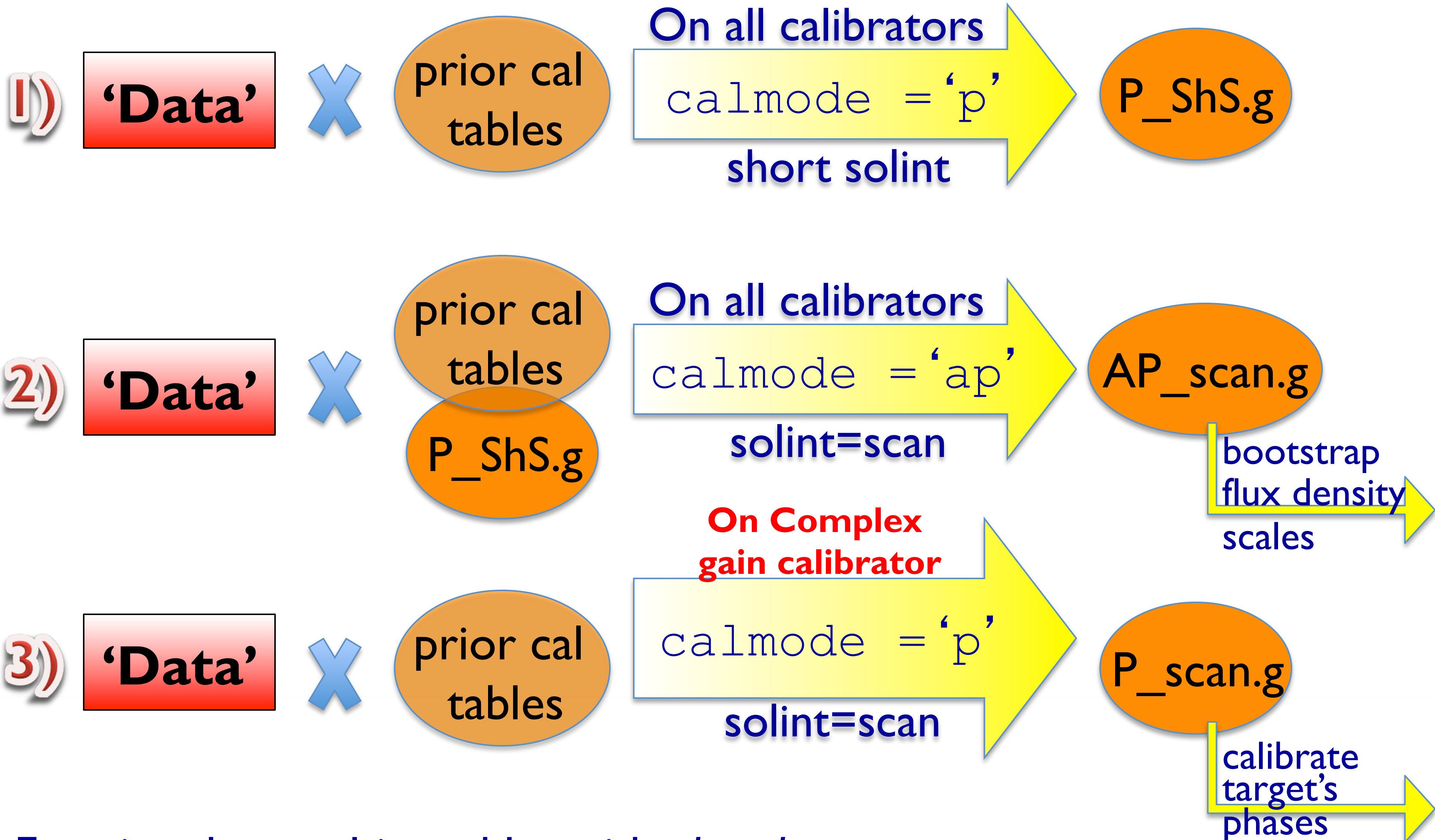
8 MHz spw data set at Ka-band

Bandpass Calibration
Plotting the solutions: *plotcal*



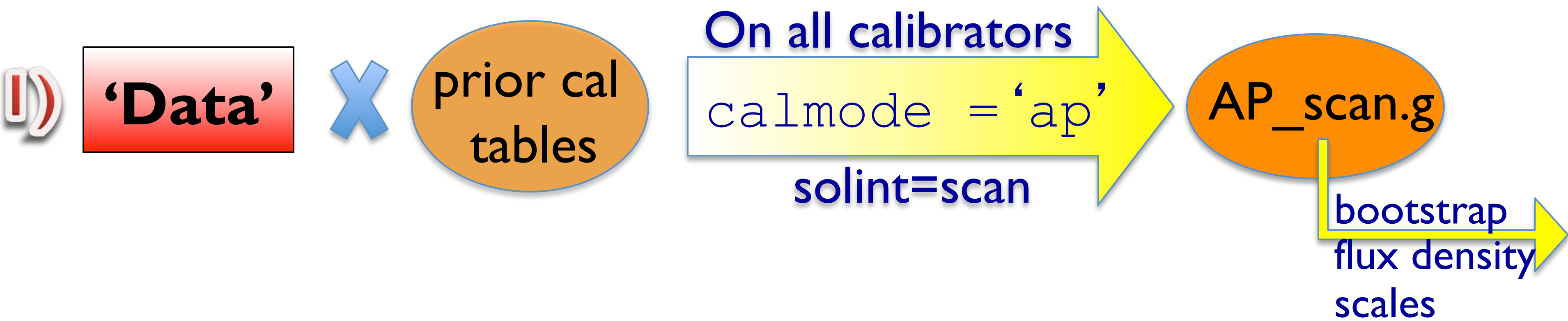
8 MHz spw data set at Ka-band (no delay calibration was performed prior to the bandpass calibration).

Complex Gain Calibration: *gaincal*, High Freq



Examine the resulting tables with *plotcal*

Complex Gain Calibration: *gaincal*, Low Freq



- Examine the resulting table with *plotcal.*
- If the phases show rapid variations (e.g., due to ionosphere), use the method outlined for high frequencies.
- The calibration pipeline uses the HF approach.

Polarization Calibration

- *Gaincal*
  - solving for the cross-hand delays
- *Polcal*
  1. solving for the leakage terms
  2. solving for the R-L polarization position angle

➢ For VLA observations, and particularly for wide bandwidth observations: have channel based solutions for the leakage terms and for the R-L polarization position angle.

➢ Both CASA and AIPS allow solving for these per spectral channel.

Polarization Calibration: *gaincal*

- For polarization calibration, you will typically observe
  - A source to calibrate the leakage terms (this can be a polarized or an unpolarized source), and
  - A source with very well known polarization characteristics to calibrate the polarization position angle.
- Before running *polcal*, we recommend calibrating the cross hand delays:
  - Use one of the polarized sources.
  - Run *gaincal* with `gaintype = 'KCROSS'`.
  - Examine the resulting table with *plotcal*.
  - Apply the resulting table in subsequent steps.

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Polarization Calibration: *polcal*
1. Solving for the leakage (D) terms (instrumental pol.)

- For an unpolarized calibrator (*Q=U=0*):
  - Use `poltype = 'Df'` to solve for the leakage terms (D) on per channel (f) basis.
- For a polarized calibrator with unknown polarization:
  - Use `poltype = 'Df+QU'` to solve for channel base leakage terms & apparent source polarization.
    - This requires several scans (at least 3), and
    - good parallactic angle coverage (60° of parallactic angle range is recommended).

Examine the resulting tables with *plotcal*.

Polarization Calibration: *polcal*
2. Solving for the R-L polarization position angle

- To obtain an accurate polarization position angle, the R-L phase needs to be calibrated.
- In *polcal*, use `poltype = 'Xf'` for a frequency dependent polarization position angle calibration.
- Requires the use of a source with known polarization angle (use *setjy* to set its Q and U values).
- Examine the resulting table with *plotcal*.
- VLA/VLBA polarization monitoring databases:
  - http://www.vla.nrao.edu/astro/calib/polar/ (up to 2009)
  - http://www.aoc.nrao.edu/~smyers/evlapolcal/polcal_master.html

Scale flux density: *fluxscale*

- Bootstraps the flux density scale of the secondary calibrators.
- Uses the scan based `'ap'` gain table   AP_scan.g

```
vis            =   'MS file name'
caltable       =   'input ap table'
reference      =   'field # of the flux cal'
fluxtable      =   'output table'
incremental    =   True or False
```

- Reports the flux density values per calibrator per spw.
- Fits across the spw's of each calibrator to report a spectral index and curvature (can be supplied through *setjy* if needed).

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Scale flux density: *fluxscale*

```
fluxtable        =   'output table'
incremental      =      T or F
```

- If `incremental = F`

  The `output table` replaces the input `'ap'` table.

- If `incremental = T`

  The `output table` contains only the scaling factors, and should be used alongside the input `'ap'` table.

Apply Calibration: *applycal*

```
field       =          '?'
interp      = nearest or linear
gaintable   = various calibration tables
gainfield   = fields corresponding to the
                      above tables
parang      = False   (True if polcal was run)
calwt       =       False
```

- One field at a time, but targets with the same calibrators can be grouped together.
- Use the appropriate tables for each source.
- Make sure to match the gainfield entries with the gaintables.

Examine the calibrated data (the corrected column) with *plotms*.

Flag, if needed, and re-calibrate.

The VLA Calibration Pipeline

- Performs basic flagging and calibration using CASA.
- It has been run on all data sets since the start of the current D-configuration (semester 2013A).
- Primarily designed for Stokes *I* continuum data.
- To run successfully, the scan intents in the scheduling block must be set correctly.
- Information and scripts are at:

https://science.nrao.edu/facilities/vla/data-processing/pipeline

- Many more details on Wednesday by C. Chandler.

Split the target(s): *split*

- Split the target source(s) using the corrected column.
- Optionally:
  - apply time averaging
  - apply frequency averaging
  - choose spectral windows/channels
  - choose certain antennas
  - choose a certain UV range
  - choose particular scans
  - choose polarization
- The *split*-ed data will occupy the 'data column' in the resulting MS.
- Self-calibration can be performed if the target is strong enough.
- Self-calibrated data will be placed in the corrected column (upon running applycal).

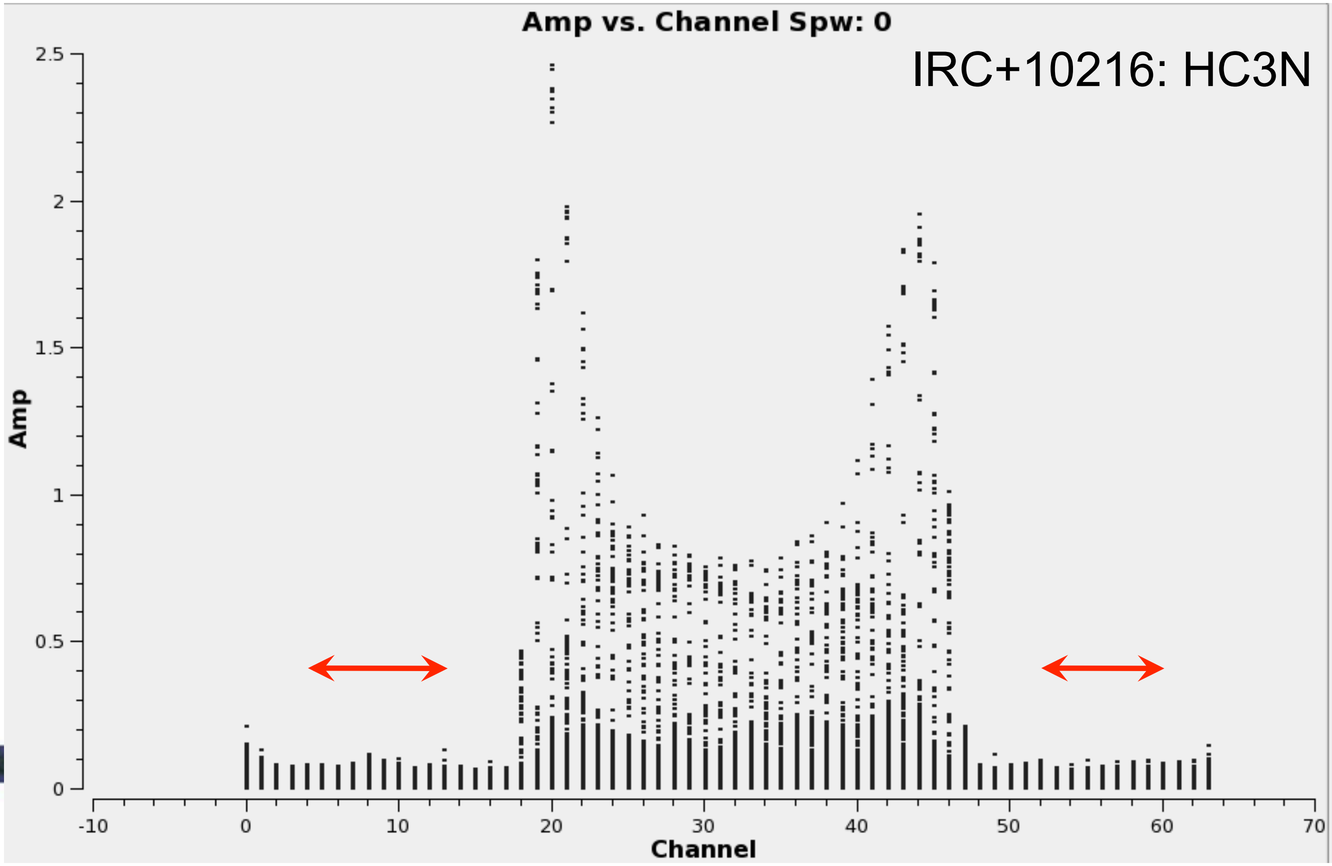
(Re)Weighting visibilities: *statwt*

- VLA data currently have their weights set to 1.
- *statwt* reweights the visibilities according to their scatter.
- Needed to down-weight underperforming antennas, or spw's affected by RFI.
- How/when to use it:
  - The data should be fully calibrated.
  - Highly recommended to *split* the data (source) of interest first (some time averaging might be helpful).
  - While *split*-ing, avoid applying any frequency averaging.
  - Run *statwt*, and then average the data as needed/desired.

Continuum Subtraction: *uvcontsub*

```
vis        = 'MS file name'
fitspw     = '0:4~13;52~60'
want_cont  =     False
```

can choose multiple spw's



Doppler Correction: *cvel*

- The VLA does not offer Doppler Tracking, but only Doppler setting.
- The line of interest may shift over one or more channels during the observations.
- If adding different observing blocks, one can choose to first Doppler correct (*cvel*) each block, concatenate (*concat*) and then image (*clean*). However, stay tuned for the alternative…
- *cvel* should be run if one needs/wants to do self-calibration using a (narrow) strong spectral line.
- *cvel* could also be used if several spw's need to be combined (to make a single spw).

Imaging: *clean*

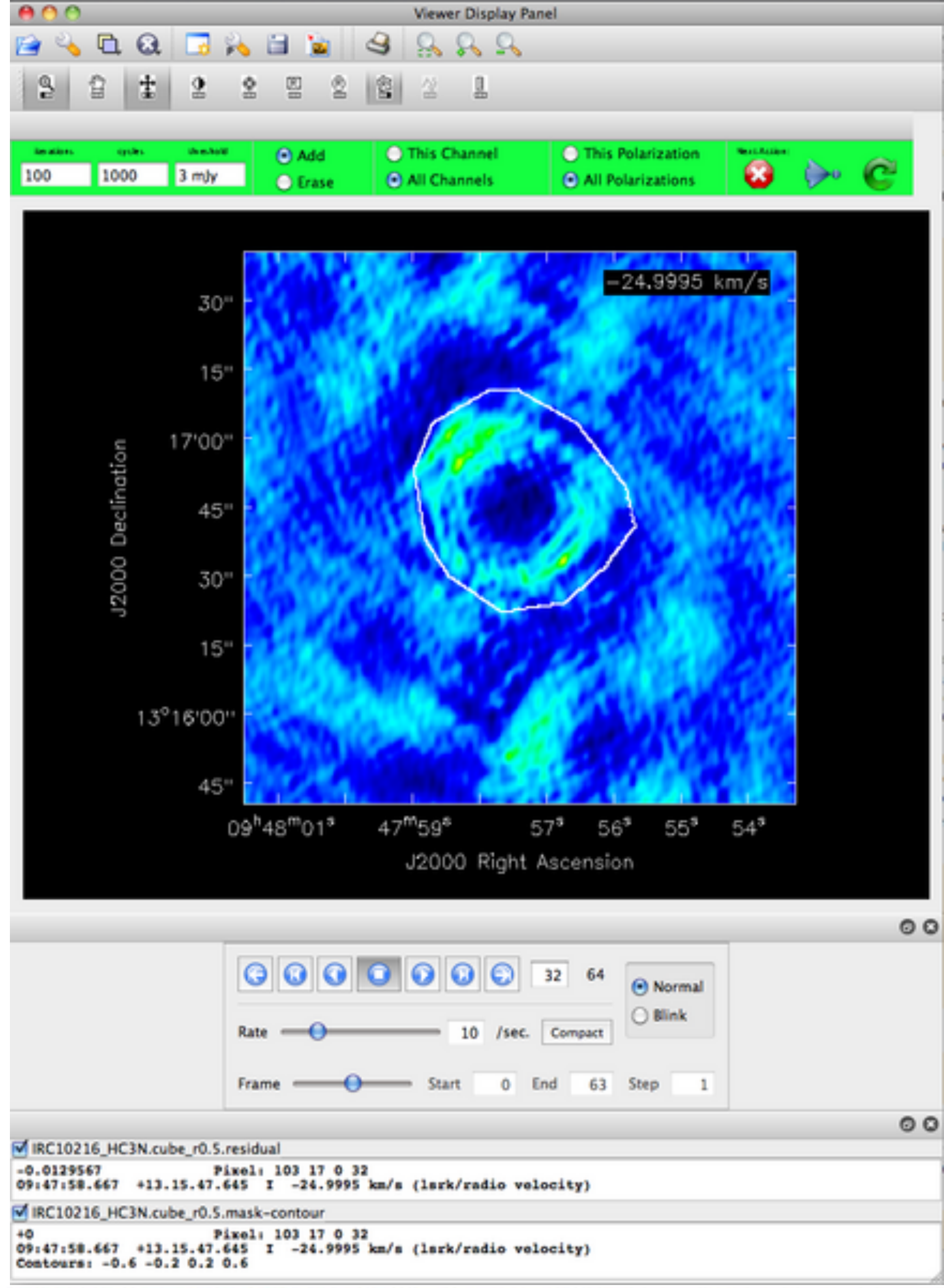
The imaging/cleaning task in CASA provides various options:

- Make 'dirty' image and 'dirty' beam (psf).
- Multi-frequency-continuum images or spectral channel imaging
- Full Stokes imaging
- Mosaicking
- Multi-scale cleaning
- Widefield cleaning
- Interactive clean boxing
- Use starting model (e.g., from single dish)
- Imaging outlier fields

Imaging: *clean*

Interactive cleaning:

- Invokes the viewer.
- Cleaning regions (masks) can be made for each spectral channel if needed.
- If no mask is specified, cleaning is not performed (only in interactive mode).



Channel 28 of the HC3N cube of IRC+10216.

The white contour is showing the mask that has been drawn with the polygon tool.

Rectangular or ellipsoidal masks can also be made.

NRAO

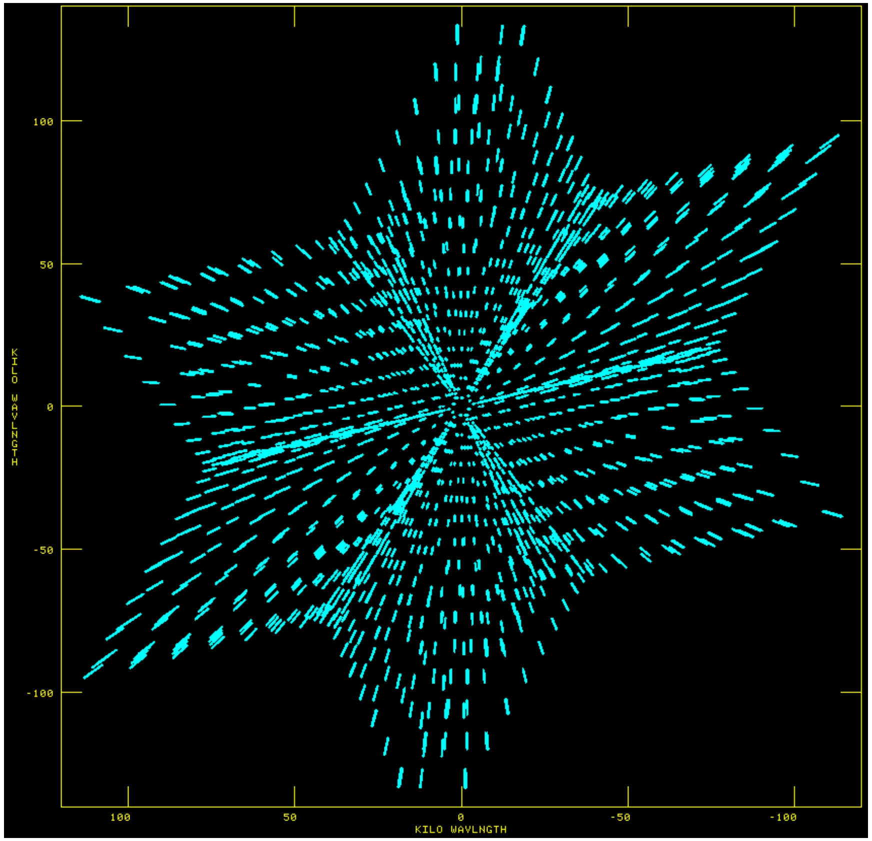
Imaging: *clean*

- If redoing, rename the output (`imagename`).
- Always check the CASA log while imaging.
- Avoid ^c while imaging → it might disturb your UV data.
- Can use mask files from previous clean iterations.
- If dirty image is desired, set `niter = 0`.
- By default, a model record gets attached to the MS (e.g., for self-calibration). If `usescratch = T`, it generates the Model column.

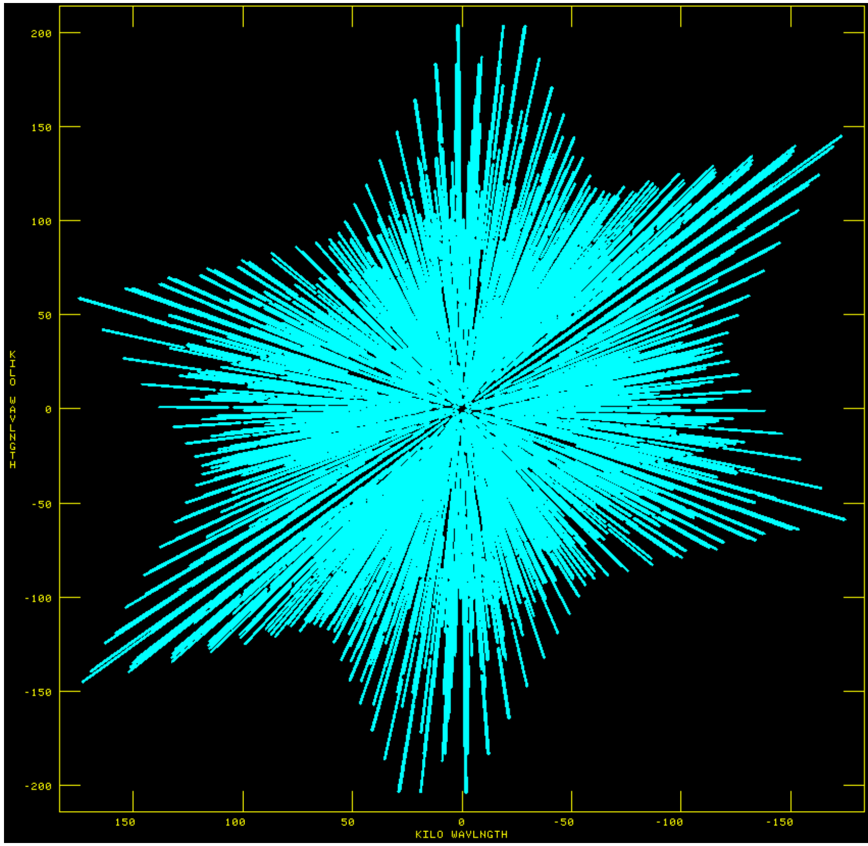
Spectral Line Imaging: *clean*

- Allows for imaging in the following `modes`:
  - Channel
  - Frequency
  - Velocity
- If the data are not Doppler corrected (*cvel*-ed), *clean* can perform the correction on the fly with the velocity (or frequency) mode.
- *clean* can also image multiple MS files, Doppler-correcting them on-the fly. This results in a single (concatenated) image cube.

Continuum Imaging: clean
Wide-band narrow-field imaging



1 x 64 MHz spw



16 x 64 MHz spw

Continuum Imaging: clean
Wide-band narrow-field imaging

- Wide bandwidths:
  - Better UV coverage → cleaner dirty beam → better image fidelity.
  - More data → better SNR.
- In *clean*, `mode = 'mfs'` ; multi-frequency synthesis.
  - Combines all channels during imaging.
  - With `nterms=2`, get both average intensity and spectral slope image (intensity x spectral index). It also gives a spectral index image.
- If imaging sources that have complicated spatial structure, also use the parameter `multiscale` in *clean* => MS-MFS.
- This subject will be covered in detail on Tuesday by U. Rau.

Continuum Imaging: *clean*

Wide-band wide-field imaging

- Wide field imaging is required because:
  - The VLA provides wide bandwidths, which in turn
    - greatly improves the continuum sensitivity, and
    - makes it sensitive for emission from a larger area.

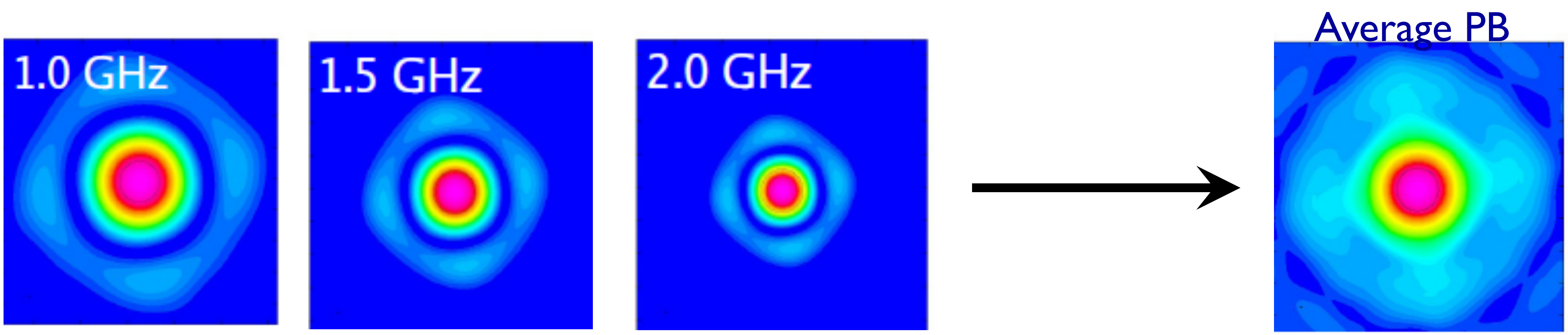


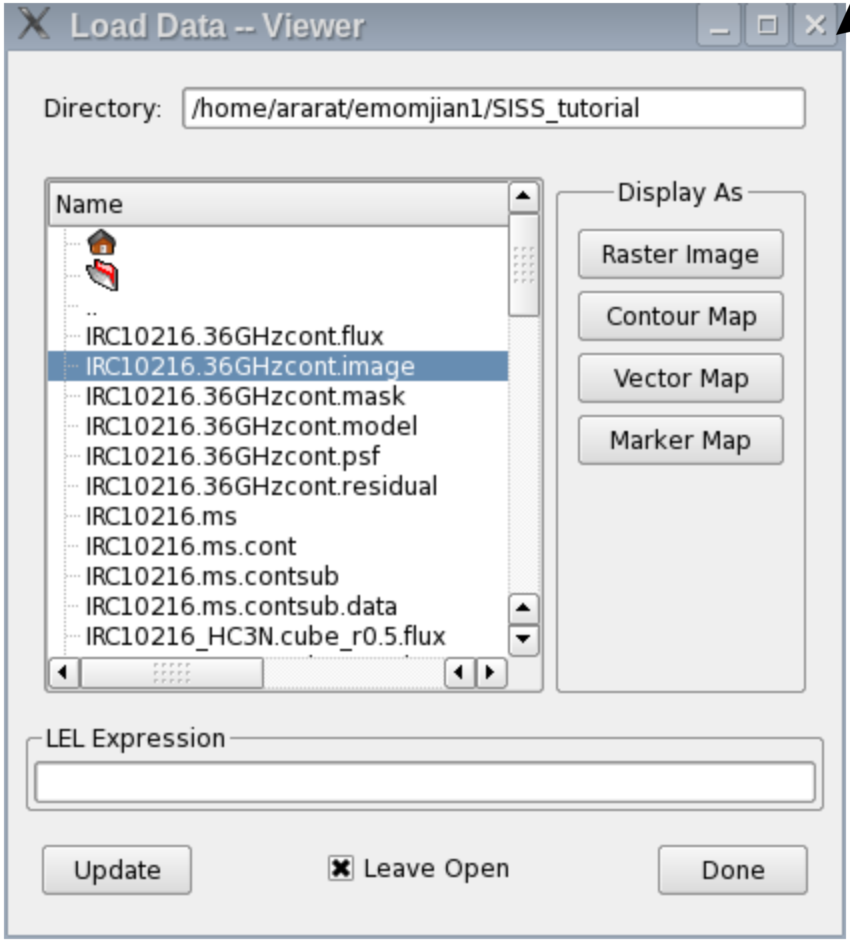
Image credit: U. Rau

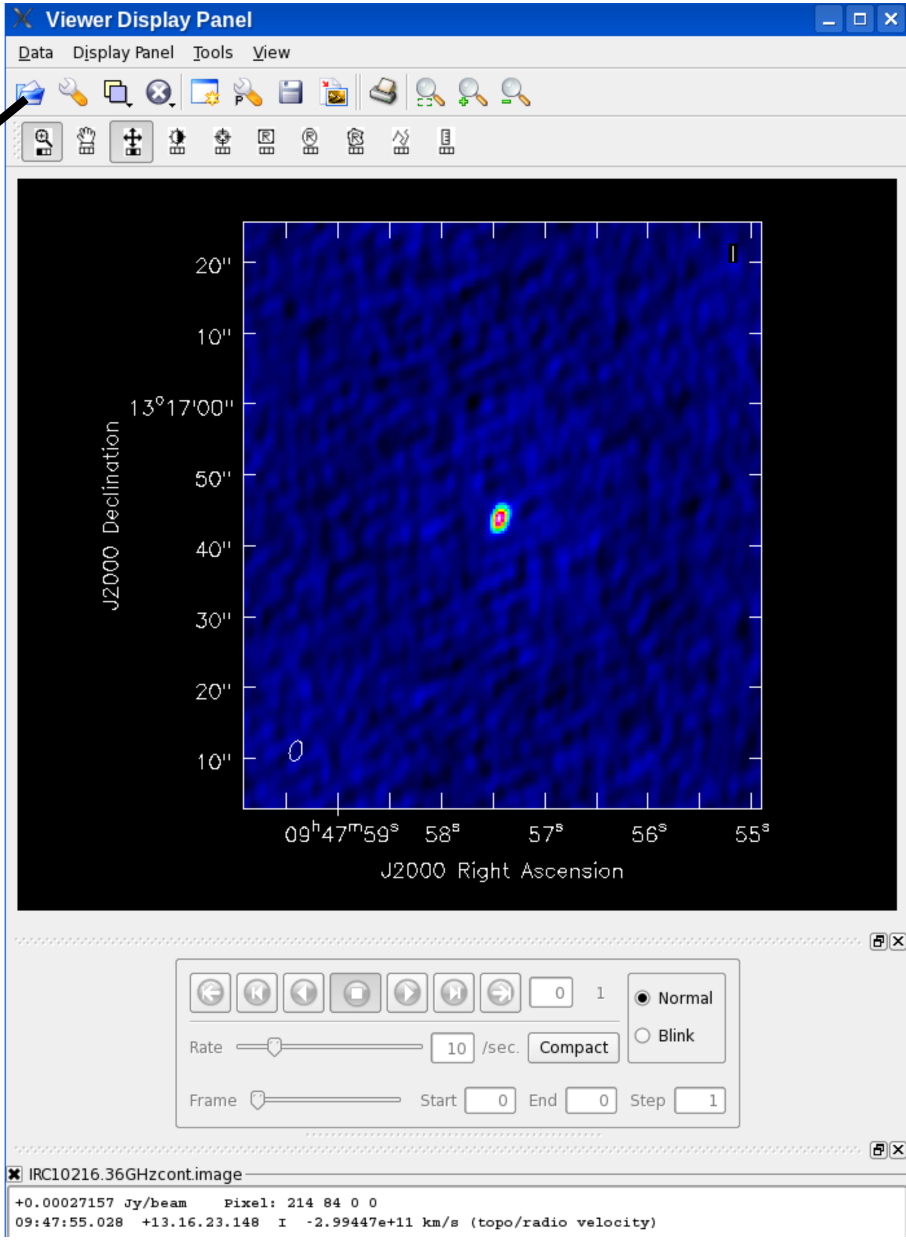
Continuum Imaging: *clean*
Wide-band wide-field imaging

- Set `gridmode = 'widefield'` in *clean*.
  - Applies corrections for non-coplanar effects during imaging by using:
    - The W-projection algorithm and/or Multi-faceting.
      - This can also be used for narrow-band wide-field imaging.
- This subject + more advanced topics will be covered in detail on Tuesday by S. Bhatnagar.

NRAO

Examine Images: *viewer*

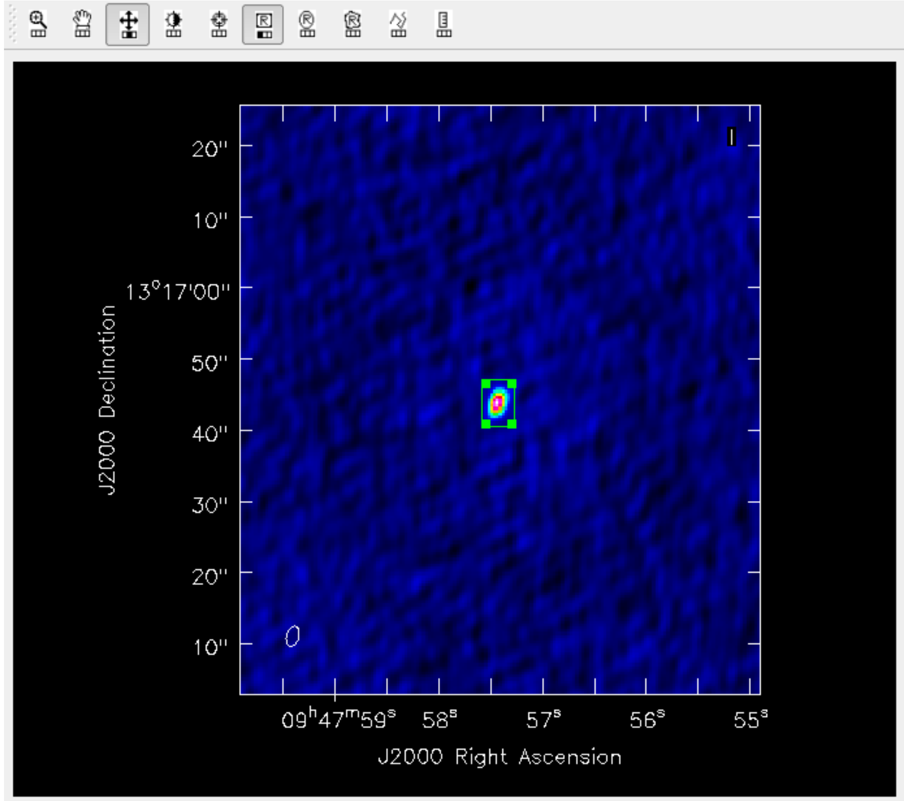




Examine Images: *viewer*

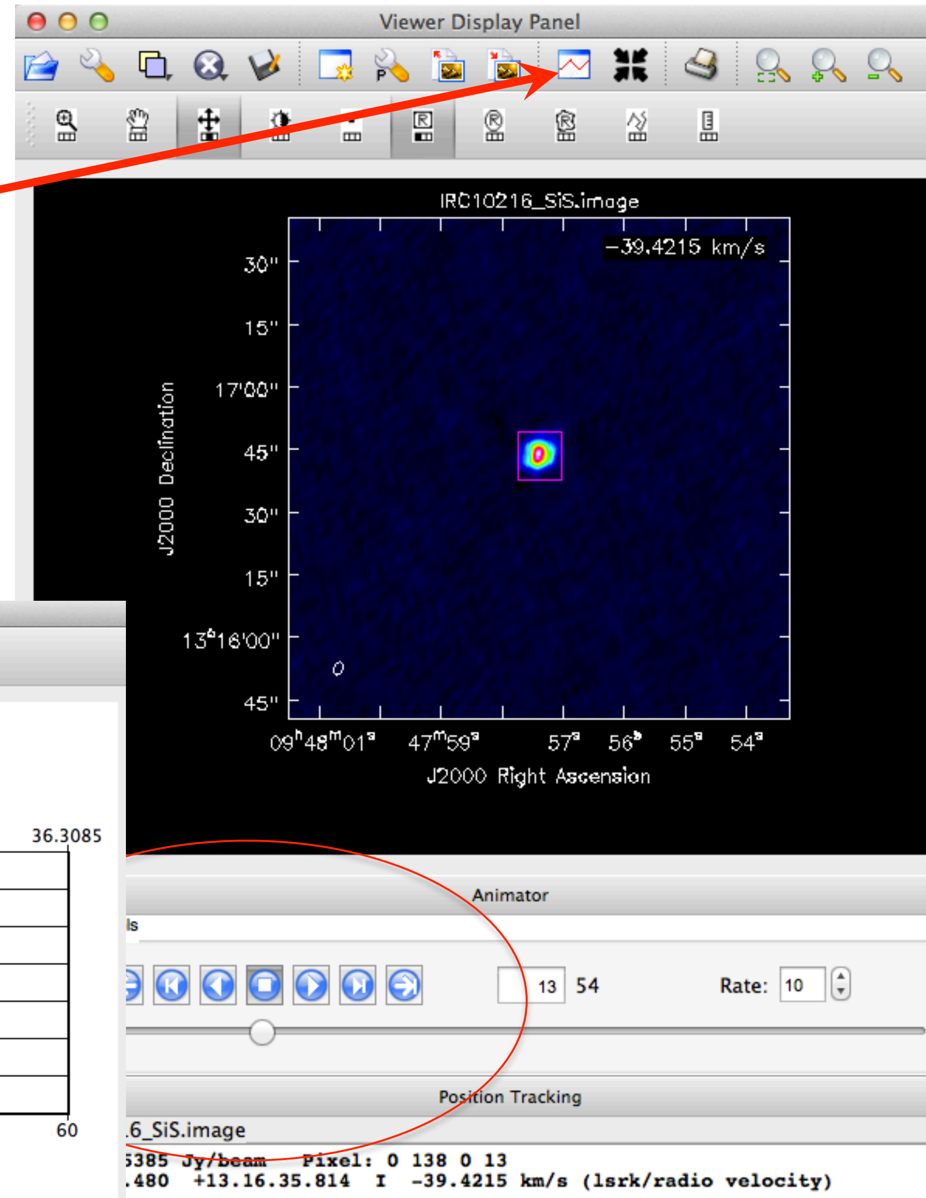
Obtain statistics by selecting a region and double-clicking:

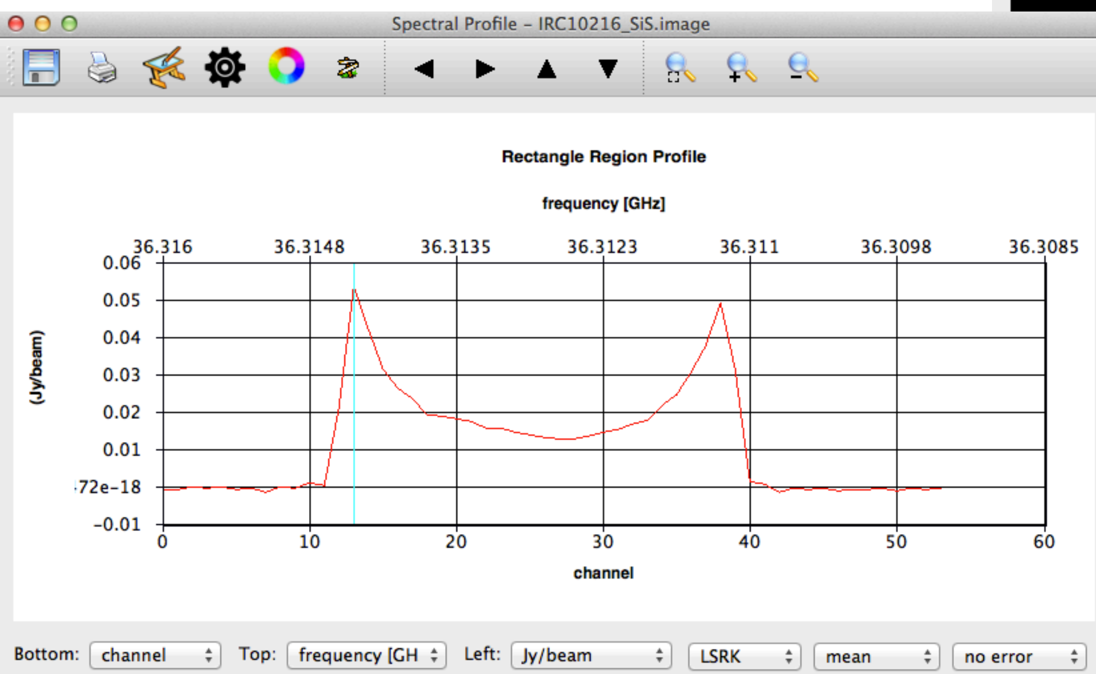
Npts	Sum	Flux (Jy)	Mean	Rms	Std dev	Minimum	Maximum
204	4.282397e-01	1.215614e-02	2.099214e-03	3.196456e-03	2.416455e-03	7.724831e-05	1.029828e-02



Examine Image cubes: *viewer*

- Click on Spectral profile
- Choose a point or make a region.





Continuum subtraction in the image plane: *imcontsub*

- Alternative to uvcontsub

```
imagename     =  'an image cube, line+continuum'
linefile      =          '?'
contfile      =          '?'
fitorder      =           0
region        =   'region file'      or use
box           =   'blc_x, blc_y, trc_x, trc_y'
chans         =         'x1~y1;x2~y2'
stokes        =         'I'
```

Moment Maps: *immoments*

```
imagename      =  'Input image-cube name'
moments        =        [0]   or  [0,1]  etc…
axis           = 'spectral'
region         =          ''
box            =          ''
chans          =        '11~40'
stokes         =         'I'
includepix     =  [x,y]
excludepix     =  [x,y]
```

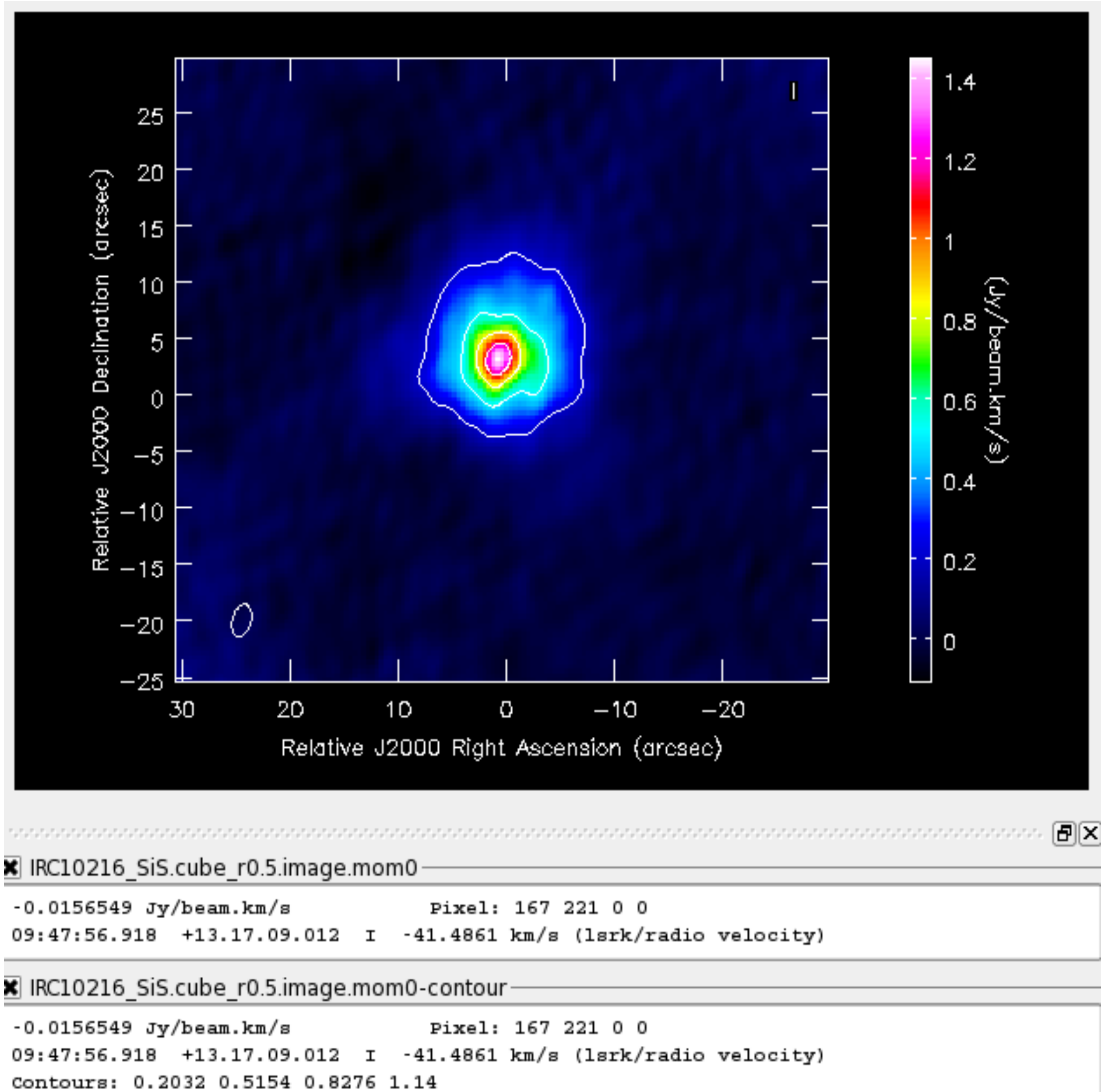
Moment Maps: *immoments*

moments=-1 - mean value of the spectrum
moments=0 - integrated value of the spectrum
moments=1 - intensity weighted coordinate; traditionally used to get 'velocity fields'
moments=2 - intensity weighted dispersion of the coordinate; traditionally used to get "velocity dispersion"
moments=3 - median of I
moments=4 - median coordinate
moments=5 - standard deviation about the mean of the spectrum
moments=6 - root mean square of the spectrum
moments=7 - absolute mean deviation of the spectrum
moments=8 - maximum value of the spectrum
moments=9 - coordinate of the maximum value of the spectrum
moments=10 - minimum value of the spectrum
moments=11 - coordinate of the minimum value of the spectrum

Moment Maps: *immoments*

IRC+10216 SiS

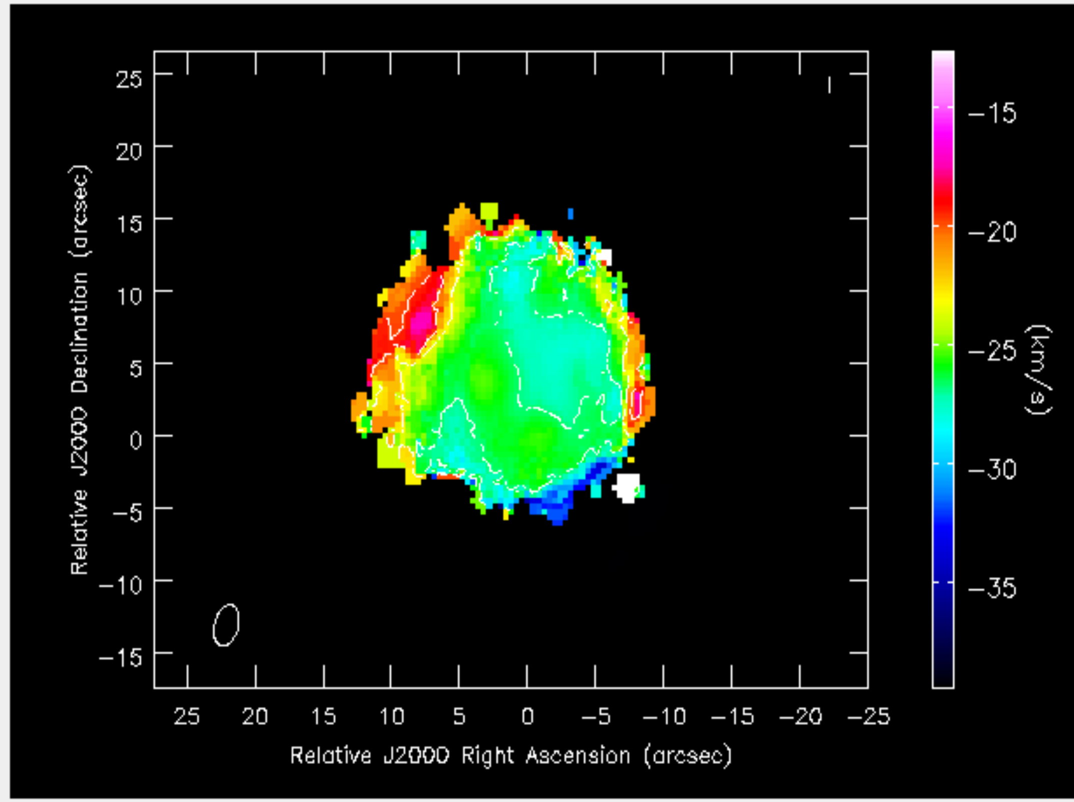
Total intensity:
Moment 0



Moment Maps: *immoments*

IRC+10216 SiS

Velocity field: Moment 1



IRC10216_SiS.cube_r0.5.image.mom1

```
masked                     Pixel: 191 203 0 0
09:47:56.259  +13.17.01.872  I  -41.4861 km/s (lsrk/radio velocity)
```

IRC10216_SiS.cube_r0.5.image.mom1-contour

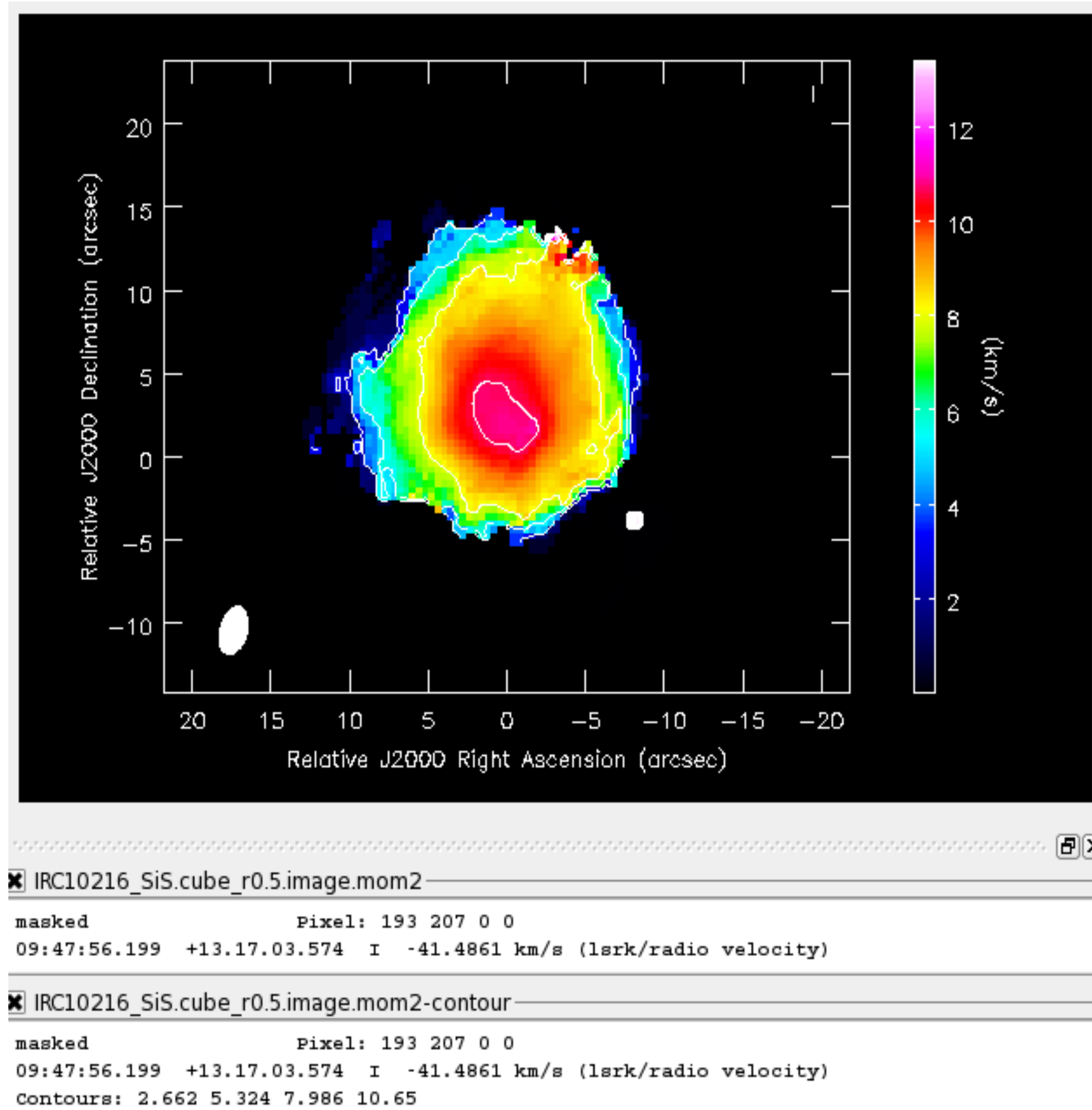
```
masked                     Pixel: 191 203 0 0
09:47:56.259  +13.17.01.872  I  -41.4861 km/s (lsrk/radio velocity)
Contours: -26.8 -23.2 -19.7 -16.1
```

NRAO

Moment Maps: *immoments*

IRC+10216 SiS

Velocity dispersion: Moment 2



viewer: moments

- Click on Moments tool
- Choose a point or make a region on the image

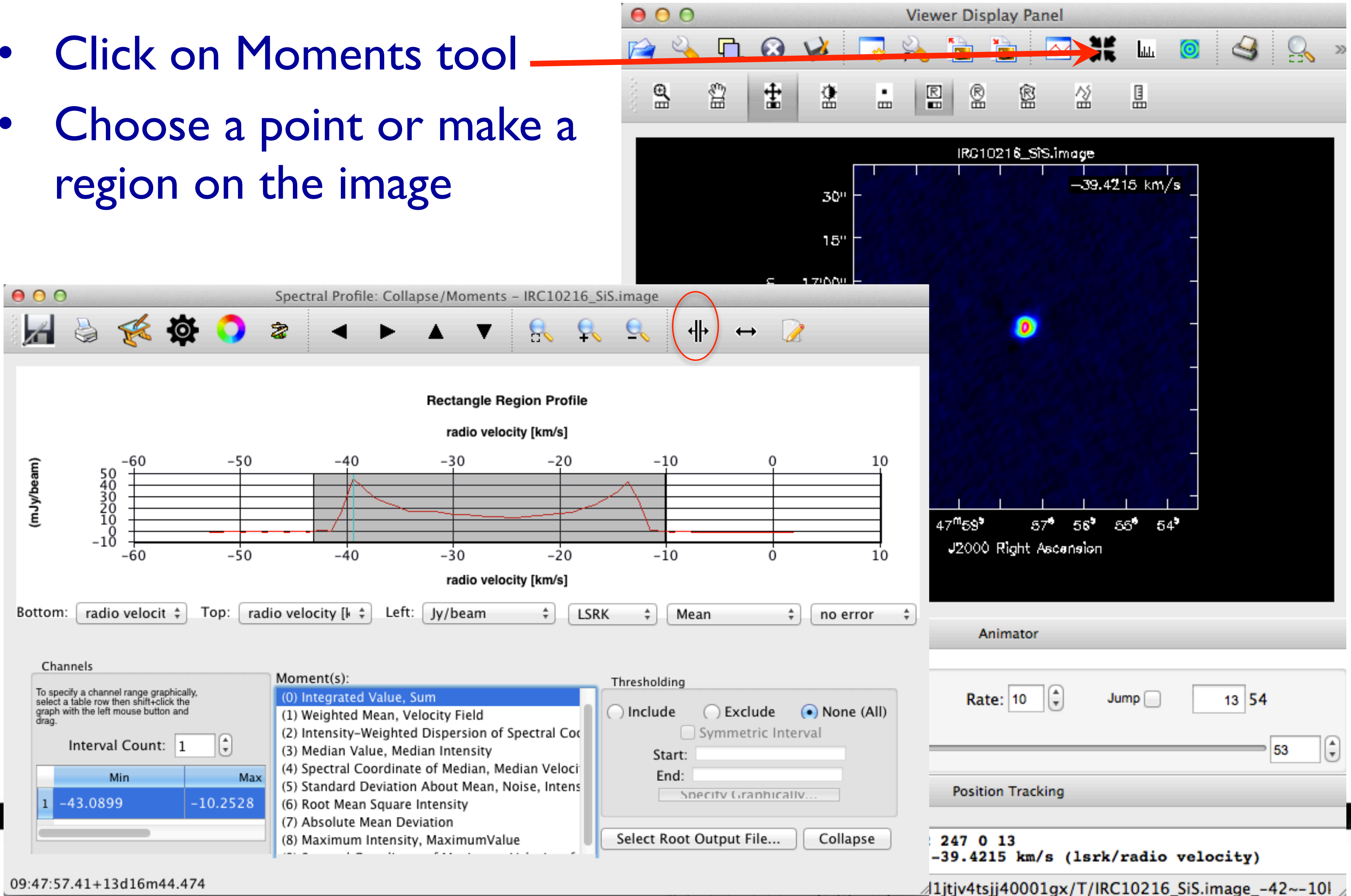
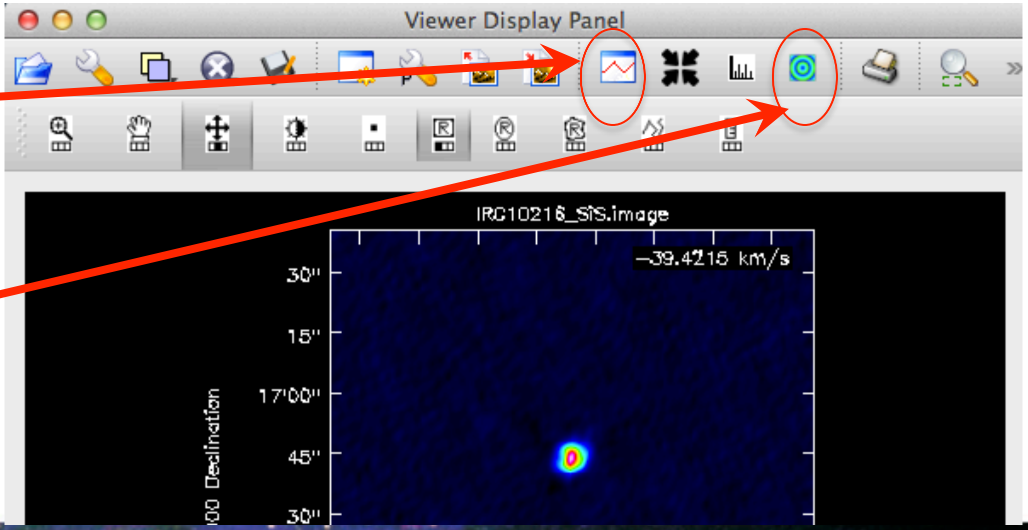


Image analysis:

- *specfit*: to fit 1D Gaussians and/or polynomial models to an image or image region.
- *imfit*: fit one or more elliptical Gaussian components on an image region(s).
- Interactively through the *viewer*

Spectral line fitting

2D fitting



The End