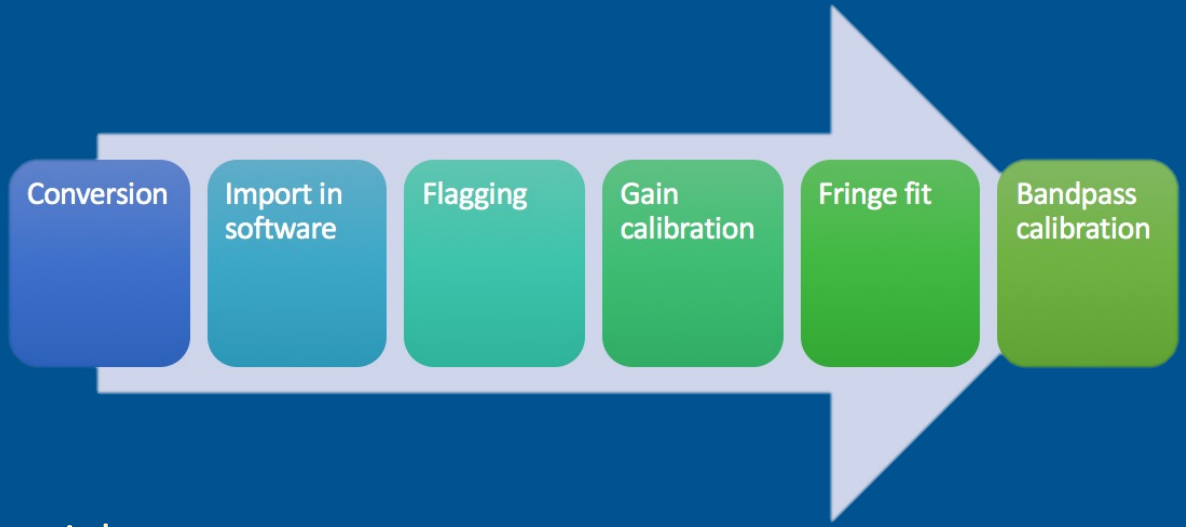
VLBI continuum calibration

Getting your hands dirty

All calibration steps (tomorrow!)

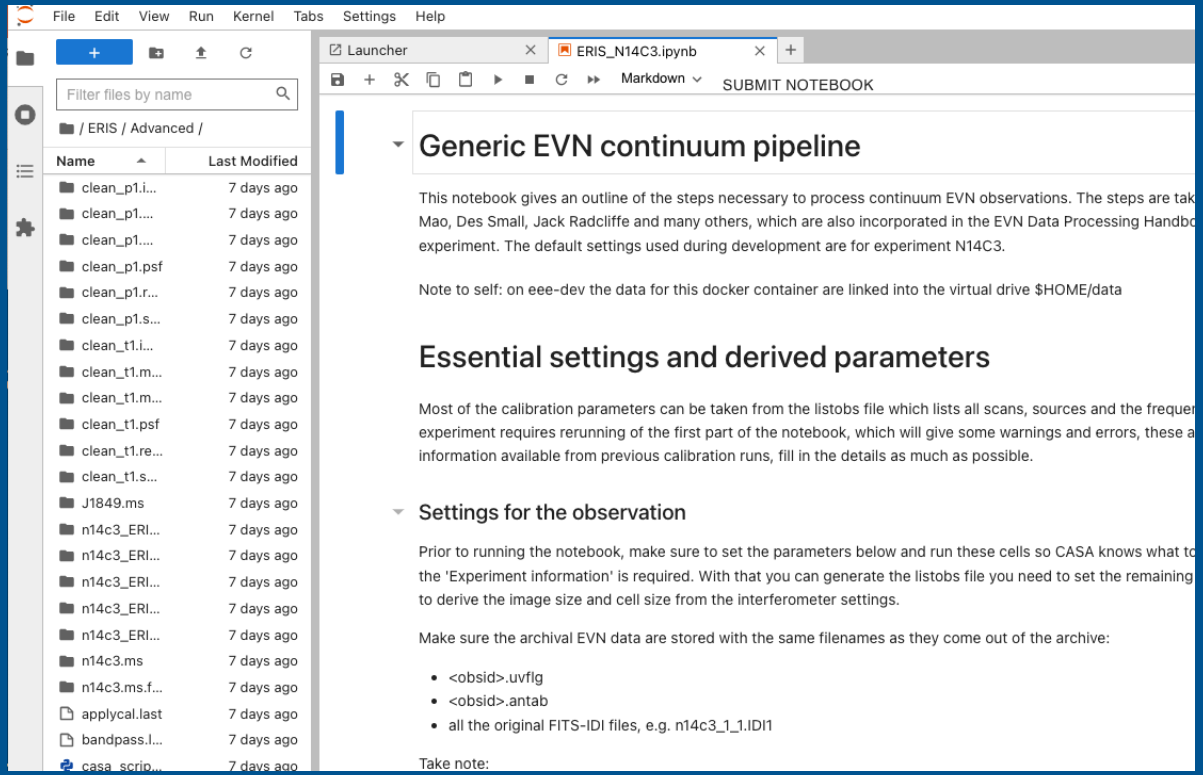


Online materials:

Gitea repository

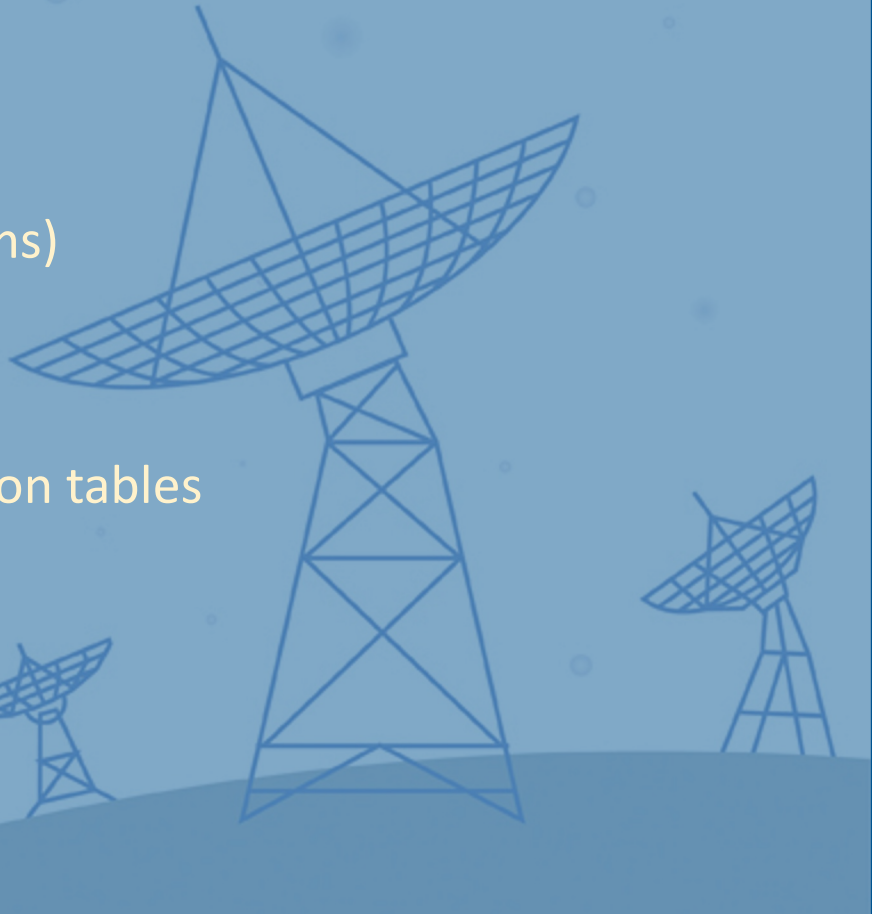
DARA EVN continuum tutorial

Jupyter-CASA interface



This tutorial

1. Inspect a VLBI dataset (listobs, plotms)
2. Find a good scan
3. Fringefit
4. If time: inspect & apply the calibration tables



This tutorial

Preparations:

- Have the materials downloaded from Gitea
- Make sure you type `git pull` before starting
- Go into the Plenary folder
- Launch CASA

You can execute every command in a WHITE BOX

(beware of plotms!)

1. Inspecting your data

CASA task `listobs`

```
# listobs -- List the summary of a data set in the logger or i
vis             = ''                    # Name of input visib
selectdata      = True                  # Data selection para
   spw          = ''                    # Selection based on
   field        = ''                    # Selection based on
   antenna      = ''                    # Selection based on
   uvrange      = ''                    # Selection based on
   timerange    = ''                    # Selection based on
   correlation  = ''                    # Selection based on
   scan         = ''                    # Selection based on
   intent       = ''                    # Selection based on
   feed         = ''                    # Selection based on
   array        = ''                    # Selection based on
   observation  = ''                    # Selection based on
verbose         = True                  # Controls level of i
listfile        = ''                    # Name of disk file t
listunfl        = False                 # List unflagged row
cachesize       = 50.0                  # EXPERIMENTAL. Maxim
```

```
listobs(vis='n14c3_TY_GC_flags.ms/')
```

```
================================================================================
           MeasurementSet Name:  /Users/bemmel/Science/EVN_CASA/ERIS/Plenary/n14c3_TY_GC_flags.ms      MS Version 2
================================================================================
   Observer: N14C3     Project: N14C3
Observation: EVN
Data records: 1846080       Total elapsed time = 10800 seconds
   Observed from   22-Oct-2014/12:00:00.0   to   22-Oct-2014/15:00:00.0 (UTC)

   ObservationID = 0         ArrayID = 0
  Date        Timerange (UTC)          Scan  FldId FieldName             nRows     SpwIds   Average Interval(s)     ScanIntent
  22-Oct-2014/12:00:00.0 - 12:04:00.0     1      1 3C345                 52800  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:06:00.0 - 12:10:00.0     2      1 3C345                 63360  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:12:00.0 - 12:13:00.0     3      1 3C345                 15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:13:40.0 - 12:14:40.0     4      1 3C345                 15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:15:20.0 - 12:16:20.0     5      0 J1640+3946            15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:17:00.0 - 12:18:00.0     6      1 3C345                 13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:18:40.0 - 12:19:40.0     7      0 J1640+3946            13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:20:20.0 - 12:21:20.0     8      1 3C345                 15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:22:00.0 - 12:23:00.0     9      0 J1640+3946            15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:23:40.0 - 12:24:40.0    10      1 3C345                 13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:25:20.0 - 12:26:20.0    11      0 J1640+3946            13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:27:00.0 - 12:28:00.0    12      1 3C345                 15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:28:40.0 - 12:29:40.0    13      0 J1640+3946            15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:30:20.0 - 12:31:20.0    14      1 3C345                 13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:32:00.0 - 12:33:00.0    15      0 J1640+3946            13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:33:40.0 - 12:34:40.0    16      1 3C345                 15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:35:20.0 - 12:36:20.0    17      0 J1640+3946            15840  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:37:00.0 - 12:38:00.0    18      1 3C345                 13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
              12:38:40.0 - 12:39:40.0    19      0 J1640+3946            13200  [0,1,2,3,4,5,6,7]  [2, 2, 2, 2, 2, 2, 2, 2]
```

Fields: 5

ID	Code	Name	RA	Decl	Epoch	nRows
0		J1640+3946	16:40:29.632770	+39.46.46.02836	J2000	254400
1		3C345	16:42:58.809965	+39.48.36.99402	J2000	383520
2		J1849+3024	18:49:20.103406	+30.24.14.23712	J2000	276480
3		1848+283	18:50:27.589825	+28.25.13.15523	J2000	388800
4		2023+336	20:25:10.842114	+33.43.00.21435	J2000	542880

Spectral Windows: (8 unique spectral windows and 1 unique polarization setups)

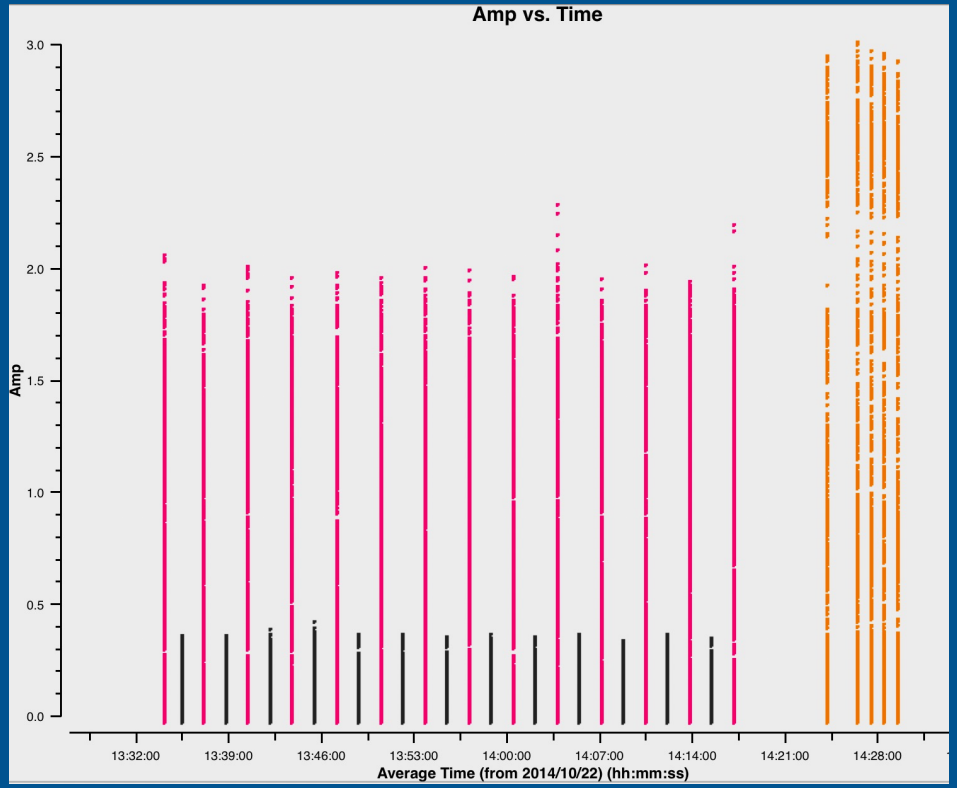
SpwID	Name	#Chans	Frame	Ch0(MHz)	ChanWid(kHz)	TotBW(kHz)	CtrFreq(MHz)	Corrs			
0	none	32	GEO	4926.990	500.000	16000.0	4934.7400	RR	RL	LR	LL
1	none	32	GEO	4942.490	500.000	16000.0	4950.2400	RR	RL	LR	LL
2	none	32	GEO	4958.990	500.000	16000.0	4966.7400	RR	RL	LR	LL
3	none	32	GEO	4974.490	500.000	16000.0	4982.2400	RR	RL	LR	LL
4	none	32	GEO	4990.990	500.000	16000.0	4998.7400	RR	RL	LR	LL
5	none	32	GEO	5006.490	500.000	16000.0	5014.2400	RR	RL	LR	LL
6	none	32	GEO	5022.990	500.000	16000.0	5030.7400	RR	RL	LR	LL
7	none	32	GEO	5038.490	500.000	16000.0	5046.2400	RR	RL	LR	LL

Antennas: 12:

ID	Name	Station	Diam.		Long.	Lat.
0	EF	EF	0.0	m	+006.53.01.0	+50.20.09.1
1	WB	WB	0.0	m	+006.38.00.0	+52.43.48.0
2	JB	JB	0.0	m	-002.18.30.9	+53.03.06.6
3	ON	ON	0.0	m	+011.55.04.0	+57.13.05.3
4	NT	NT	0.0	m	+014.59.20.6	+36.41.29.4
5	TR	TR	0.0	m	+018.33.50.6	+52.54.37.8
6	SV	SV	0.0	m	+029.46.55.0	+60.22.02.0
7	ZC	ZC	0.0	m	+041.33.54.6	+43.35.44.2
8	BD	BD	0.0	m	+102.14.02.1	+51.34.59.0
9	SH	SH	0.0	m	+121.11.58.8	+30.55.45.2
10	HH	HH	0.0	m	+027.41.07.4	-25.44.20.1
11	YS	YS	0.0	m	-003.05.12.7	+40.20.05.0

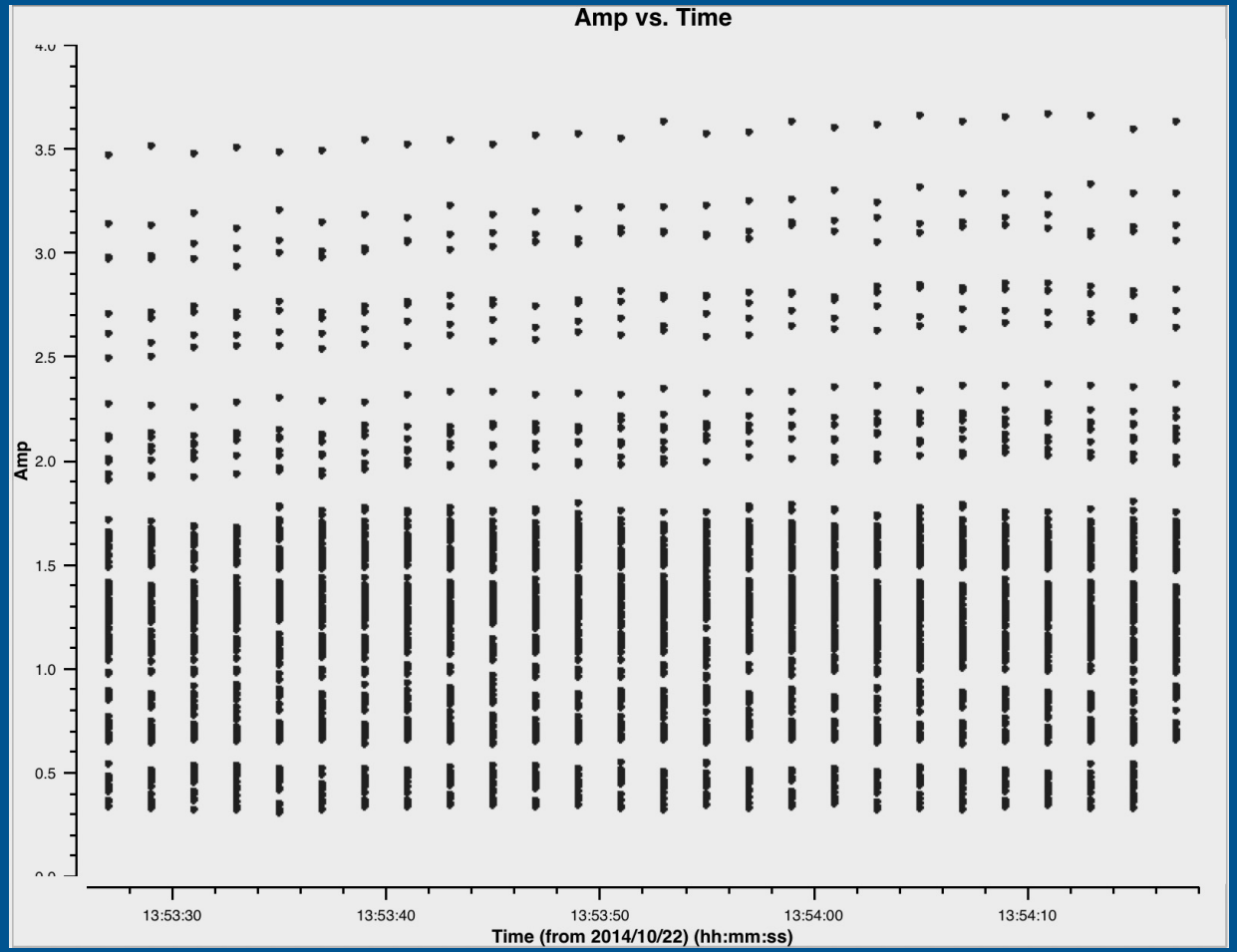
~
~

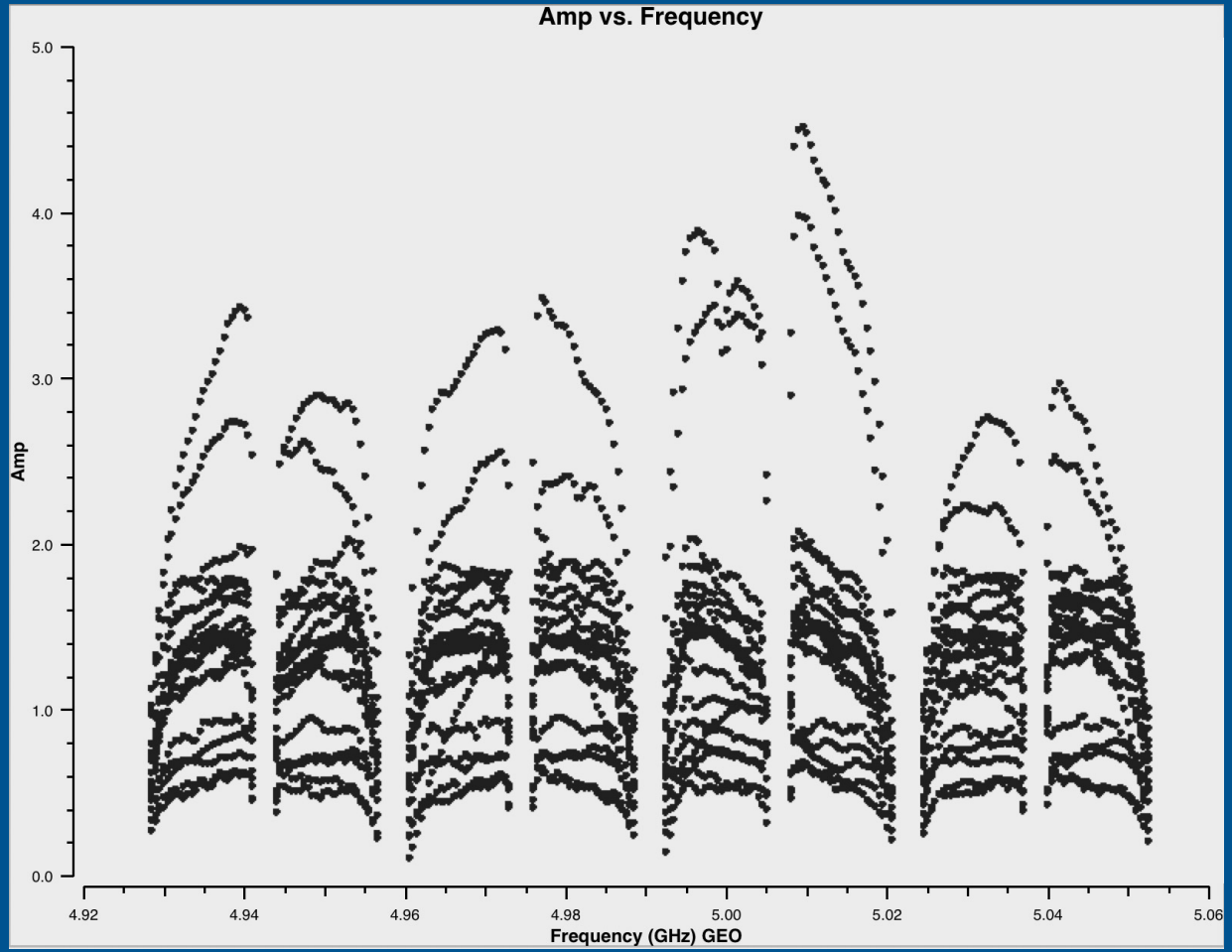
```
plotms(vis='n14c3_TY_GC_flags.ms/', <…>, …)
```

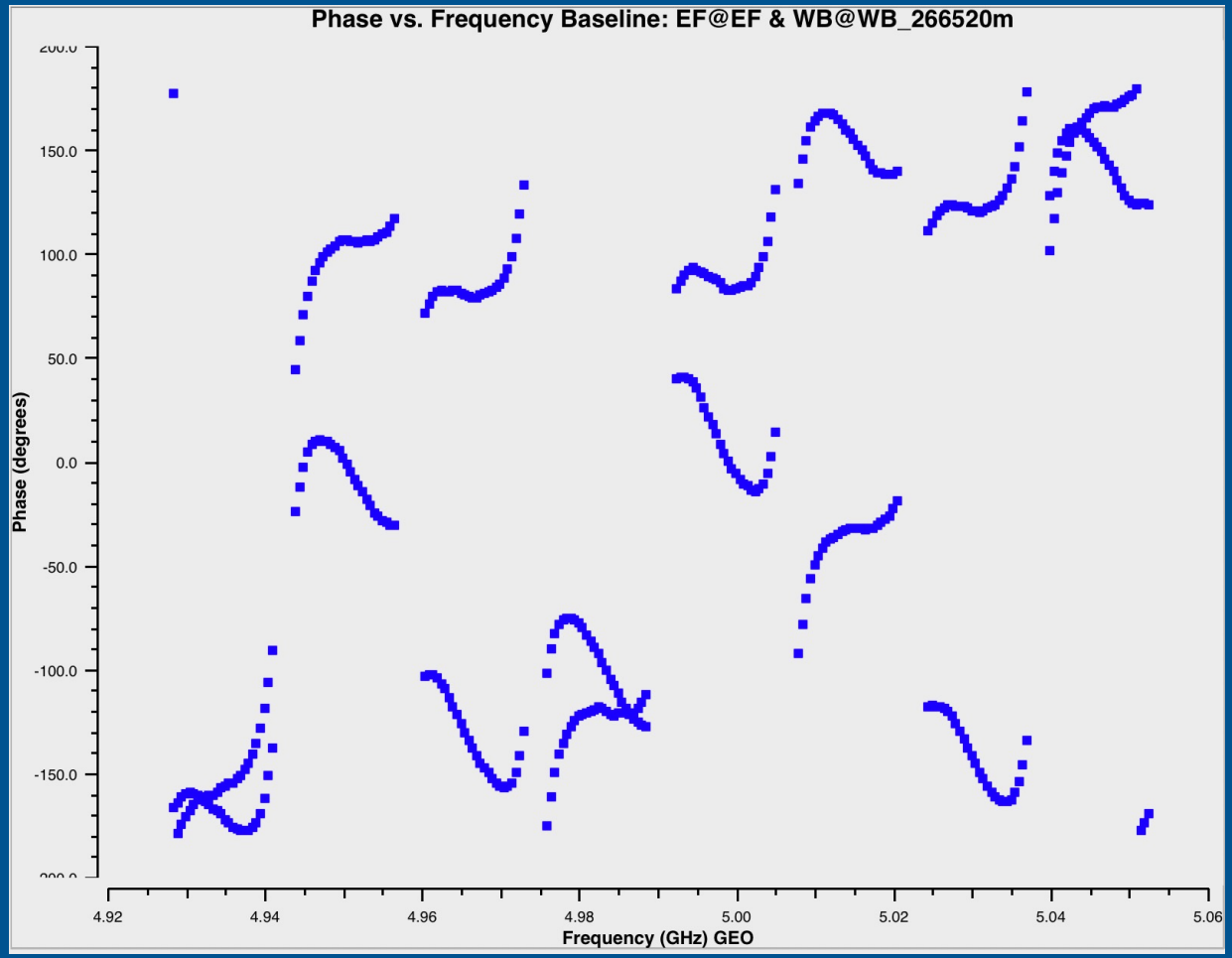


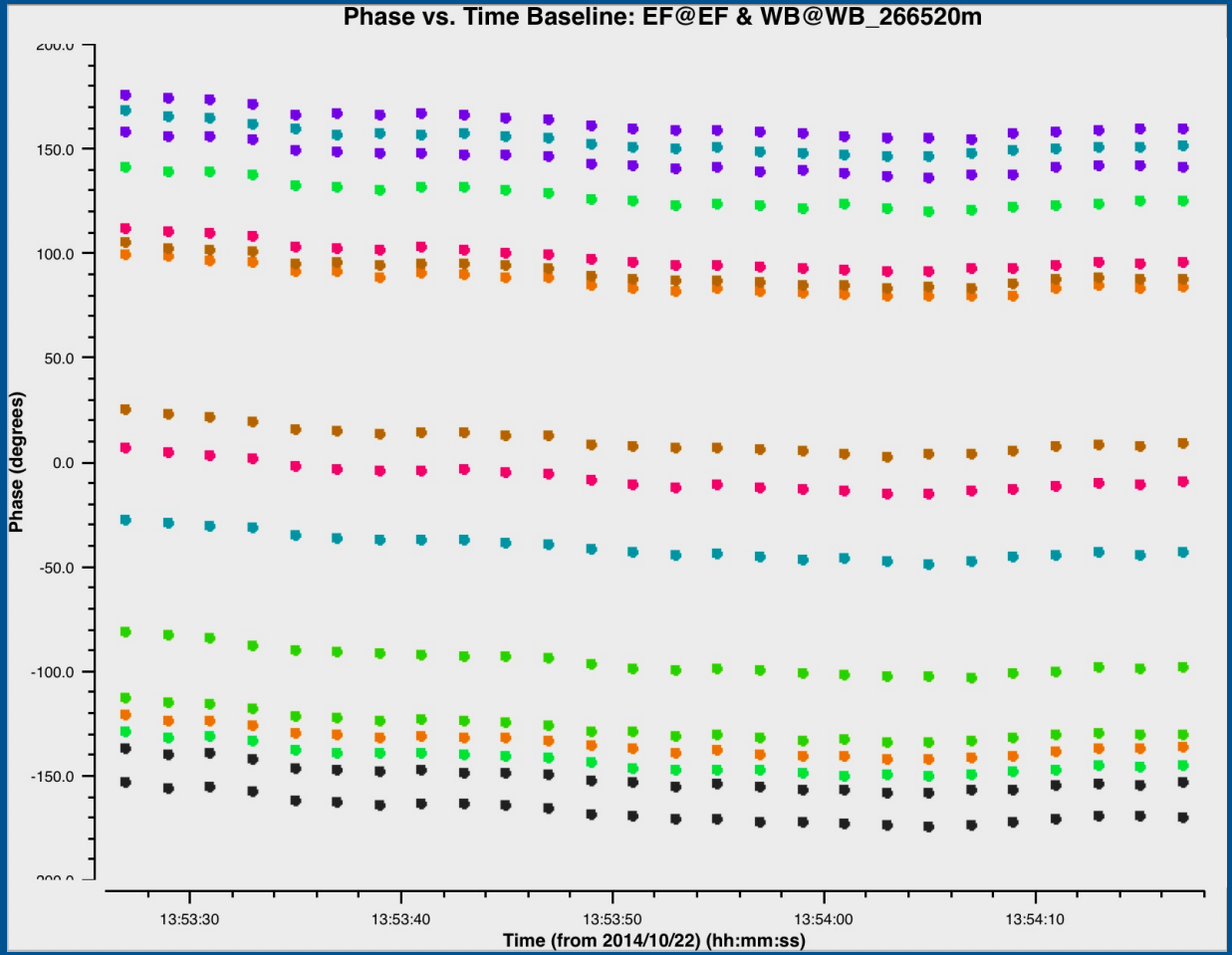
2. Selecting a calibration scan

- Bright source
- Middle of the observation
- Single scan for the instrumental delay correction
- Verify:
  - All antennas present
  - Stable phases in time/freq
  - No weird stuff in amplitudes


Amp vs. Time
Amp
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
13:53:30
13:53:40
13:53:50
13:54:00
13:54:10
Time (from 2014/10/22) (hh:mm:ss)


Amp vs. Frequency
Amp
5.0
4.0
3.0
2.0
1.0
0.0
4.92
4.94
4.96
4.98
5.00
5.02
5.04
5.06
Frequency (GHz) GEO


Phase vs. Frequency Baseline: EF@EF & WB@WB_266520m
Phase (degrees)
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
4.92
4.94
4.96
4.98
5.00
5.02
5.04
5.06
Frequency (GHz) GEO


Phase vs. Time Baseline: EF@EF & WB@WB_266520m
Phase (degrees)
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
13:53:30
13:53:40
13:53:50
13:54:00
13:54:10
Time (from 2014/10/22) (hh:mm:ss)

3. Fringe fitting

CASA task: `fringefit`

- Requires:
  - Single scan on bright target
  - Select middle timerange of the scan, ~1-2 minutes
  - Select a reference antenna
  - Always set parang = True for VLBI
  - Instrumental delay: zerorates=true

```
# fringefit -- Fringe fit delay and rates
vis             = ''                        # Name of input visibility f
caltable        = ''                        # Name of output gain calibr
field           = ''                        # Select field using field i
spw             = ''                        # Select spectral window/cha
intent          = ''                        # Select observing intent
selectdata      = True                      # Other data selection param
   timerange    = ''                        # Select data based on time
   antenna      = ''                        # Select data based on anten
   scan         = ''                        # Scan number range
   observation  = ''                        # Select by observation ID(s
   msselect     = ''                        # Optional complex data sele
solint          = 'inf'                     # Solution interval: egs. 'i
combine         = ''                        # Data axes which to combine
refant          = ''                        # Reference antenna name(s)
minsnr          = 3.0                       # Reject solutions below thi
zerorates       = False                     # Zero delay-rates in soluti
globalsolve     = True                      # Refine estimates of delay
niter           = 100                       # Maximum number of iteratio
delaywindow     = []                        # Constrain FFT delay search
ratewindow      = []                        # Constrain FFT rate search
append          = False                     # Append solutions to the (e
corrdepflags    = False                     # Respect correlation-depend
docallib        = False                     # Use callib or traditional
   gaintable    = []                        # Gain calibration table(s)
   gainfield    = []                        # Select a subset of calibra
   interp       = []                        # Temporal interpolation for
   spwmap       = []                        # Spectral window mappings t
paramactive     = []                        # Control which parameters a
parang          = False                     # Apply parallactic angle co
```

Selecting a reference antenna

- For EVN: use Effelsberg (EF)
  - Biggest dish
  - Well behaved meta-data
  - Central in the array
- The parameter accepts a string, e.g.

```
refant = "EF,TR,ON"
```

- If not sure: use CASA task `plotants`

On-the-fly calibration

- `docallib = False`
- `gaintable=['n14c3_ERIS.tsys','n14c3_ERIS.gcal']`
- `interp=['nearest,nearest','nearest']`

All fringefit parameters

```
fringefit(vis='n14c3_TY_GC_flags.ms/',
     caltable='n14c3_ERIS.sbd',
     timerange='13:53:20.0~13:54:20.0',
     solint='inf',
     refant='EF',
     minsnr=50,
     zerorates=True,
     corrdepflags=True,
     gaintable=['n14c3_ERIS.gcal', n14c3_ERIS.tsys'],
     interp=['nearest','nearest,nearest'],
     parang=True
)
```

4. Inspect the results

```
2022-09-19 13:23:28  WARN            …ingefit::::  MS obs=0,fld=0,spw=0,ant=12 cannot be calibrated
2022-09-19 13:23:28  WARN            …ingefit::::  MS obs=0,fld=0,spw=1,ant=12 cannot be calibrated
2022-09-19 13:23:28  WARN            …ingefit::::  MS obs=0,fld=0,spw=2,ant=12 cannot be calibrated
2022-09-19 13:23:28  WARN            …ingefit::::  MS obs=0,fld=0,spw=3,ant=12 cannot be calibrated
2022-09-19 13:23:28  WARN            …ingefit::::  MS obs=0,fld=0,spw=4,ant=12 cannot be calibrated
2022-09-19 13:23:29  WARN            …ingefit::::  MS obs=0,fld=0,spw=5,ant=12 cannot be calibrated
2022-09-19 13:23:29  WARN            …ingefit::::  MS obs=0,fld=0,spw=6,ant=12 cannot be calibrated
2022-09-19 13:23:29  WARN            …ingefit::::  MS obs=0,fld=0,spw=7,ant=12 cannot be calibrated
```

This is normal, don’t worry!

4. Inspect the results

```
Using reference antenna 0
sPok [8, 13]
Antenna 1 correlation 0 has (FFT) SNR of 1609.38.
Antenna 2 correlation 0 has (FFT) SNR of 1926.22.
Antenna 3 correlation 0 has (FFT) SNR of 5533.
Antenna 4 correlation 0 has (FFT) SNR of 3867.23.
Antenna 5 correlation 0 has (FFT) SNR of 5968.37.
Antenna 6 correlation 0 has (FFT) SNR of 0 below threshold (50).
Antenna 7 correlation 0 has (FFT) SNR of 7999.78.
Antenna 8 correlation 0 has (FFT) SNR of 6248.67.
Antenna 9 correlation 0 has (FFT) SNR of 885.085.
Antenna 10 correlation 0 has (FFT) SNR of 0 below threshold (50).
Antenna 11 correlation 0 has (FFT) SNR of 10894.2.
Antenna 1 correlation 1 has (FFT) SNR of 1596.69.
Antenna 2 correlation 1 has (FFT) SNR of 2517.05.
Antenna 3 correlation 1 has (FFT) SNR of 4479.48.
Antenna 4 correlation 1 has (FFT) SNR of 4135.53.
Antenna 5 correlation 1 has (FFT) SNR of 17669.6.
Antenna 6 correlation 1 has (FFT) SNR of 9734.02.
Antenna 7 correlation 1 has (FFT) SNR of 6020.06.
Antenna 8 correlation 1 has (FFT) SNR of 9241.53.
Antenna 9 correlation 1 has (FFT) SNR of 901.532.
Antenna 10 correlation 1 has (FFT) SNR of 1171.34.
Antenna 11 correlation 1 has (FFT) SNR of 8385.43.
Starting least squares optimization.
Least squares complete for correlation 0 after 3 iterations.
Least squares complete for correlation 1 after 3 iterations.
Zeroing delay rates in calibration table.
```

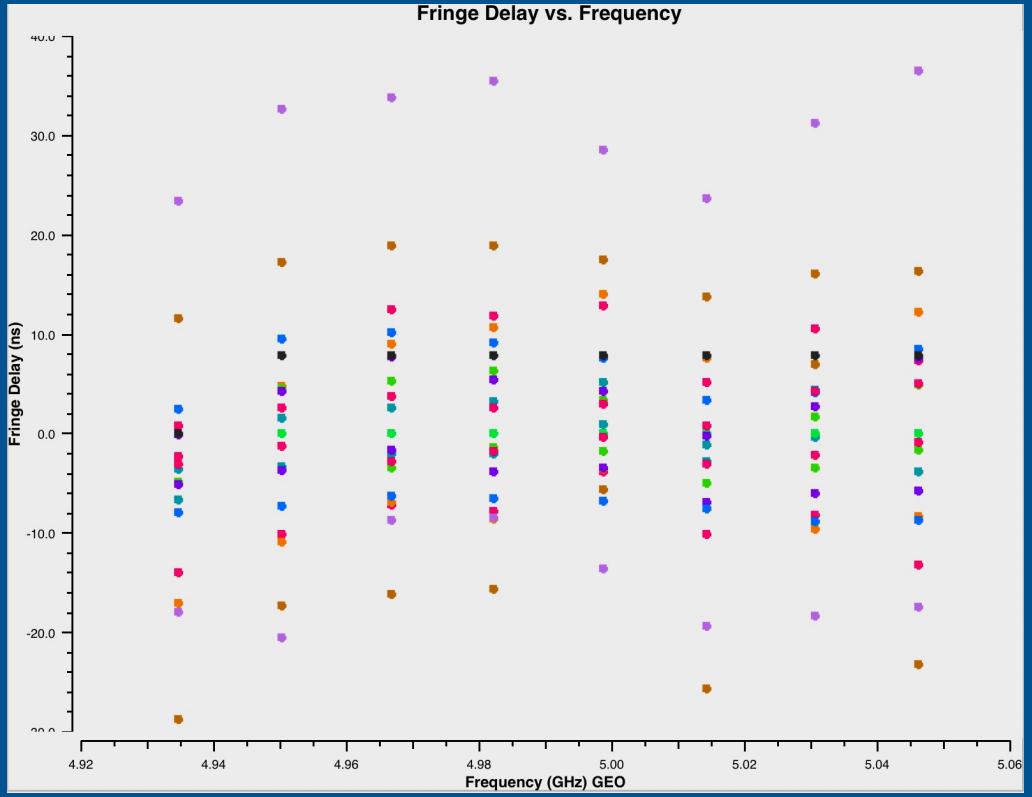
4. Inspect the results

```
Finished solving.
Calibration solve statistics per spw:  (expected/attempted/succeeded):
  Spw 0: 1/1/1
  Spw 1: 1/1/1
  Spw 2: 1/1/1
  Spw 3: 1/1/1
  Spw 4: 1/1/1
  Spw 5: 1/1/1
  Spw 6: 1/1/1
  Spw 7: 1/1/1
Task fringefit complete. Start time: 2022-09-19 15:23:25.938173 End tim
##### End Task: fringefit             #####
```

Plot the calibration table

CASA task `plotms`

Instead of MS, use calibration table as `vis`



Plot the calibration table

```
plotms(vis='n14c3_ERIS.sbd’,
     xaxis='freq’,
     yaxis='delay’,
     coloraxis='antenna1')
```

5. Apply the calibration

CASA task `applycal`

Creates CORRECTED_DATA column in your MS

- Add all available calibration tables
- Set the interpolation
- Set parang=True

- To clean-up a calibration: task `clearcal`

5. Apply the calibration

```
applycal(vis='n14c3_TY_GC_flags.ms/',
gaintable=['n14c3_ERIS.gcal','n14c3_ERIS.tsys',
'n14c3_ERIS.sbd'],
interp=['nearest', 'nearest,nearest', 'nearest'],
parang=True,
flagbackup=False
)
```

Plot the calibrated phases

```
plotms(vis='n14c3_TY_GC_flags.ms',
     xaxis='freq',
     yaxis='phase',
     ydatacolumn='corrected',
     timerange='13:53:20~13:54:20',
     antenna='EF',
     coloraxis='baseline',
     correlation='LL',
     averagedata=True,
     avgtime='120'
)
```