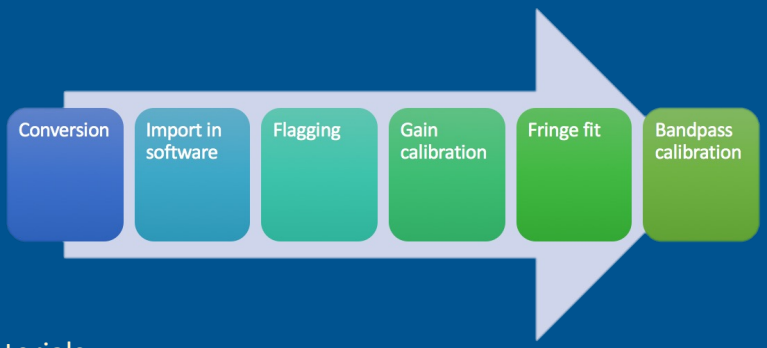
VLBI continuum calibration

Getting your hands dirty

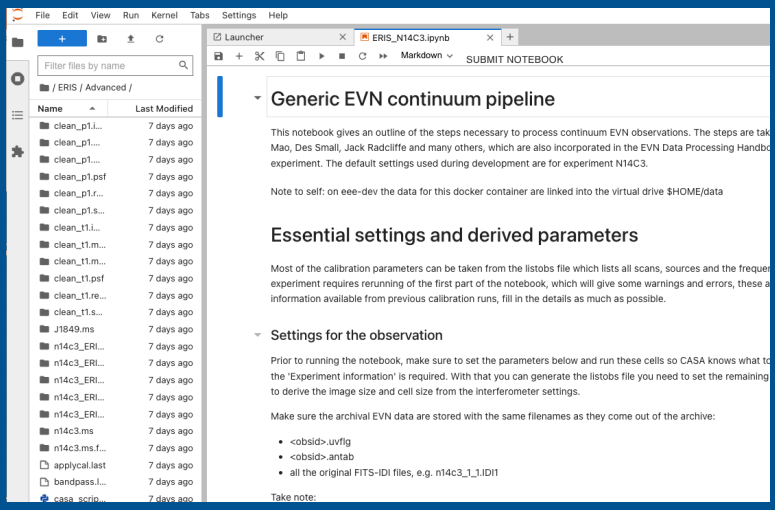
All calibration steps (tomorrow!)

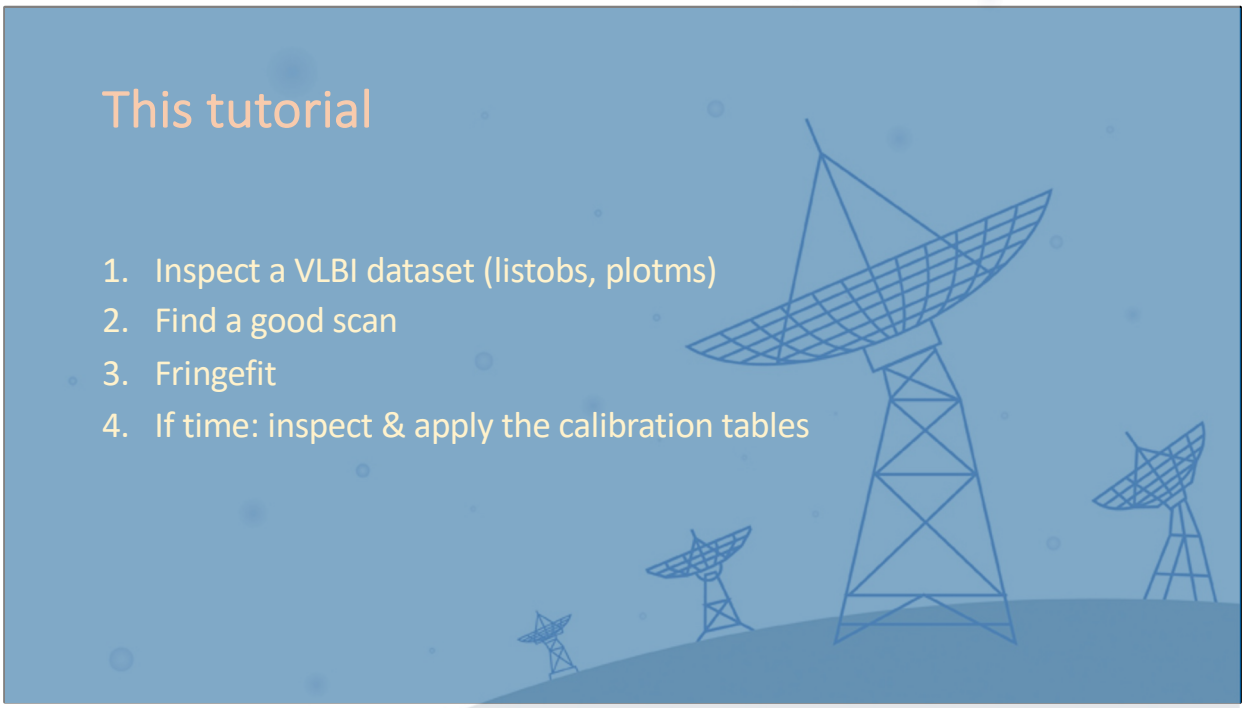


Online materials:
Gitea repository
DARA EVN continuum tutorial

This tutorial is a summary. It is strongly recommended to use the original DARA EVN tutorial in the link.

Jupyter-CASA interface





This is what you normally would download from the EVN archive. The naming N14 means this is a Network Monitoring Experiment taking in 2014. The C means it is C-band (or 5GHz).
The file format is FITS-IDI, the standard for VLBI though we are moving to MS. The ANTAB file contains information about Tsys and Gain Curves for each individual antenna in these observations. The flag file is more extended than what you would usually get, to save you the trouble of intensive data inspection at this time. Go through the actual tutorial to learn more about that.

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]
```

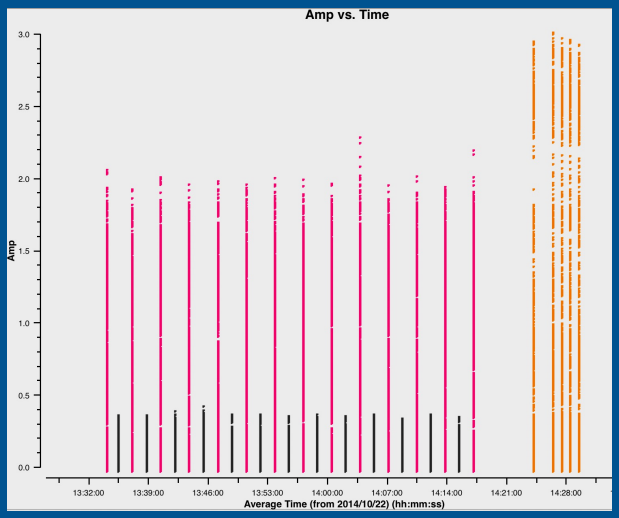
Can you tell if this is a phase referencing experiment or not?
How many sources are there?
What is the frequency setup?
How many antennas participated?

```
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/', <…>, …)
```



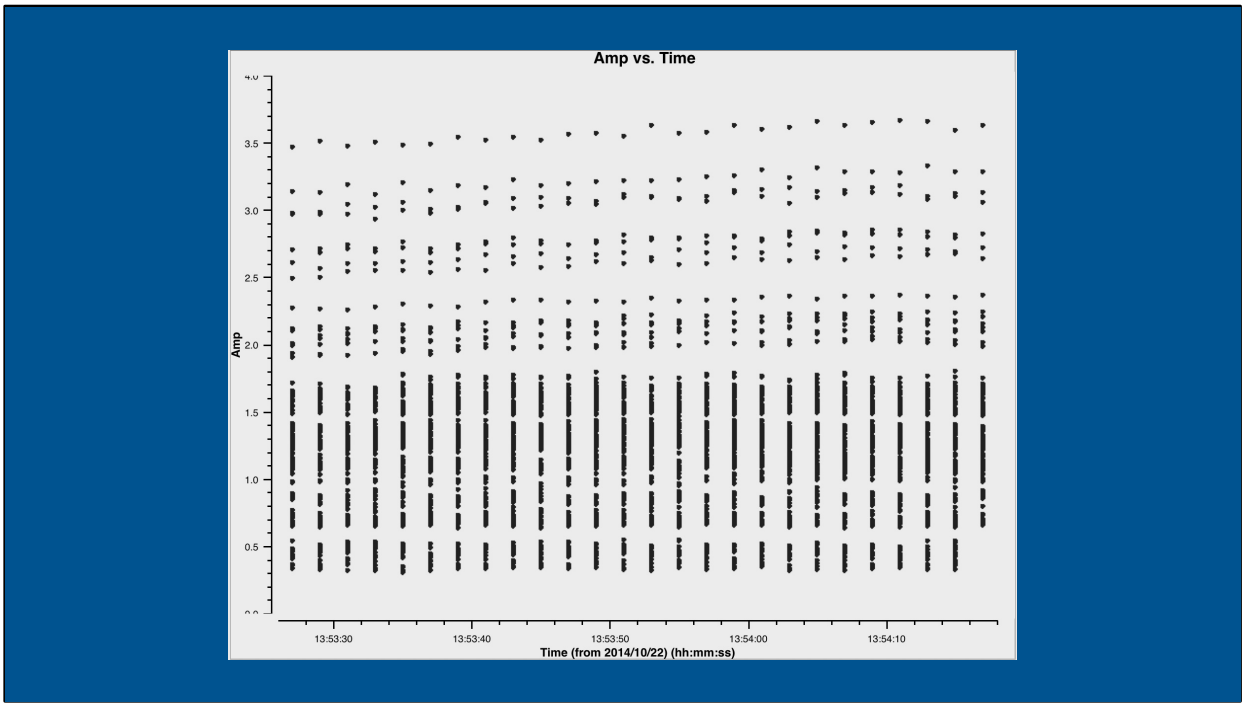
The plot clearly shows this is a phase referencing experiment, as shown in the lecture. In this case the phase calibrator is also bright enough to correct for the instrumental delay.

This experiment has two pairs of target-phasecal, in principle one instrumental delay correction is enough for the entire experiment, but you can also split the experiment into two and handle each separately.

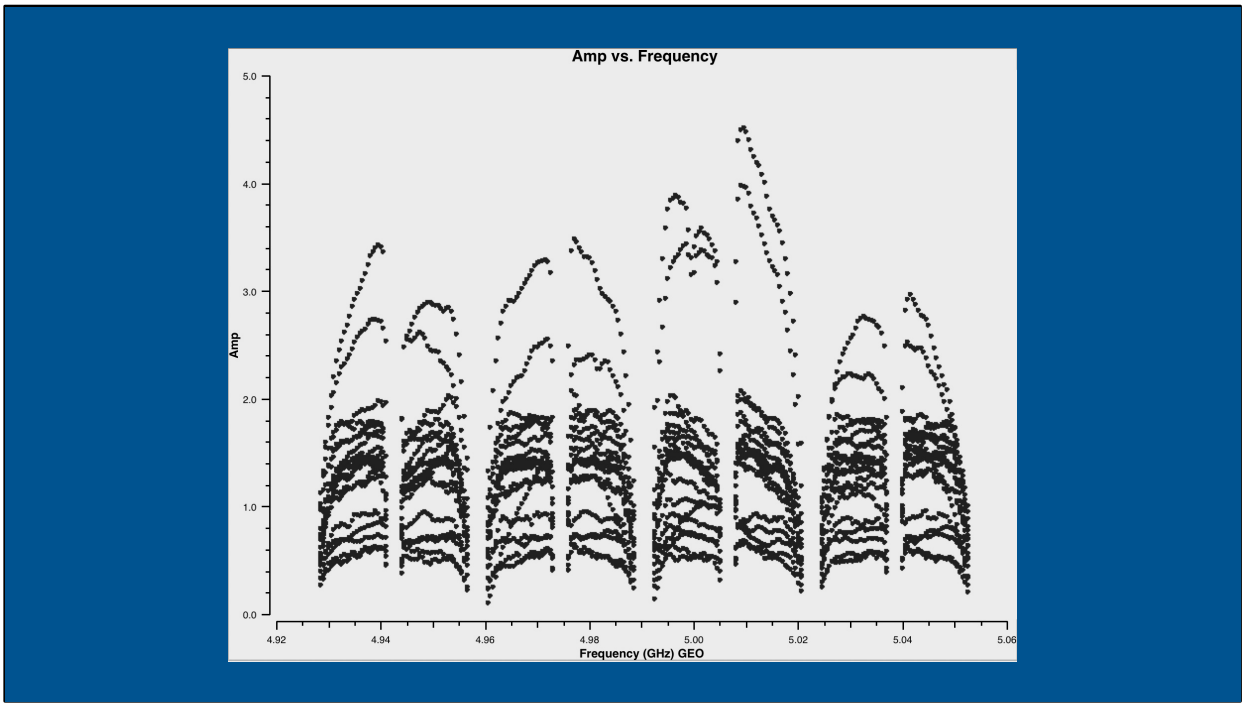
2. Selecting a calibration scan

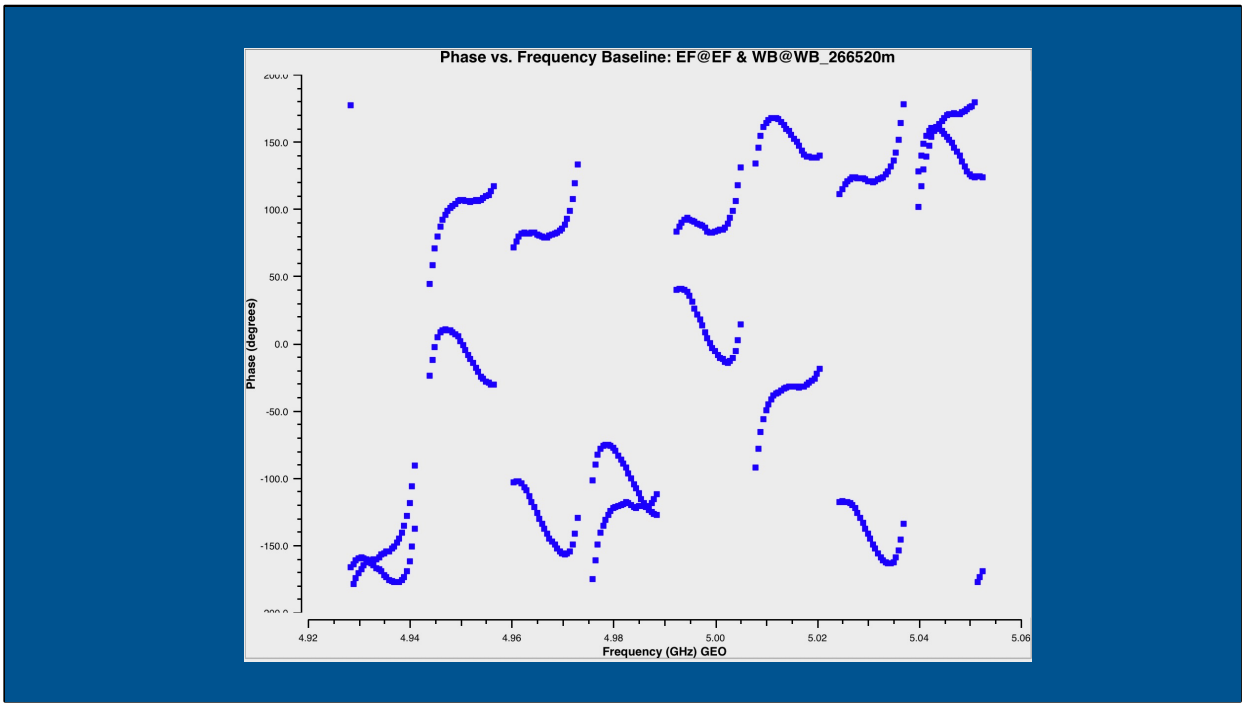
- Bright source
- Middle of the observation
- Single scan for the instrumental delay correction
- Verify:
  - All antennas present
  - Stable phases in time/freq
  - No weird stuff in amplitudes

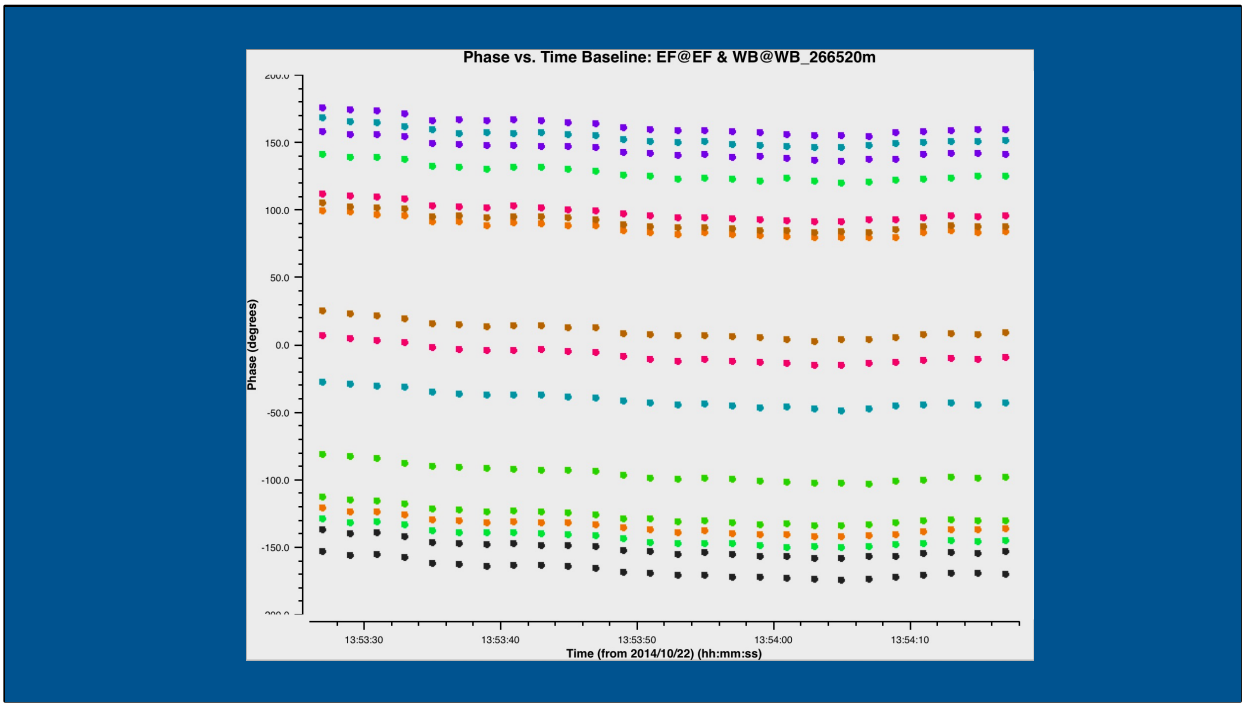
For the instrumental delay calibration we need a bright point source.
What to do if your phasecal is resolved?



Data for EF baselines only


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

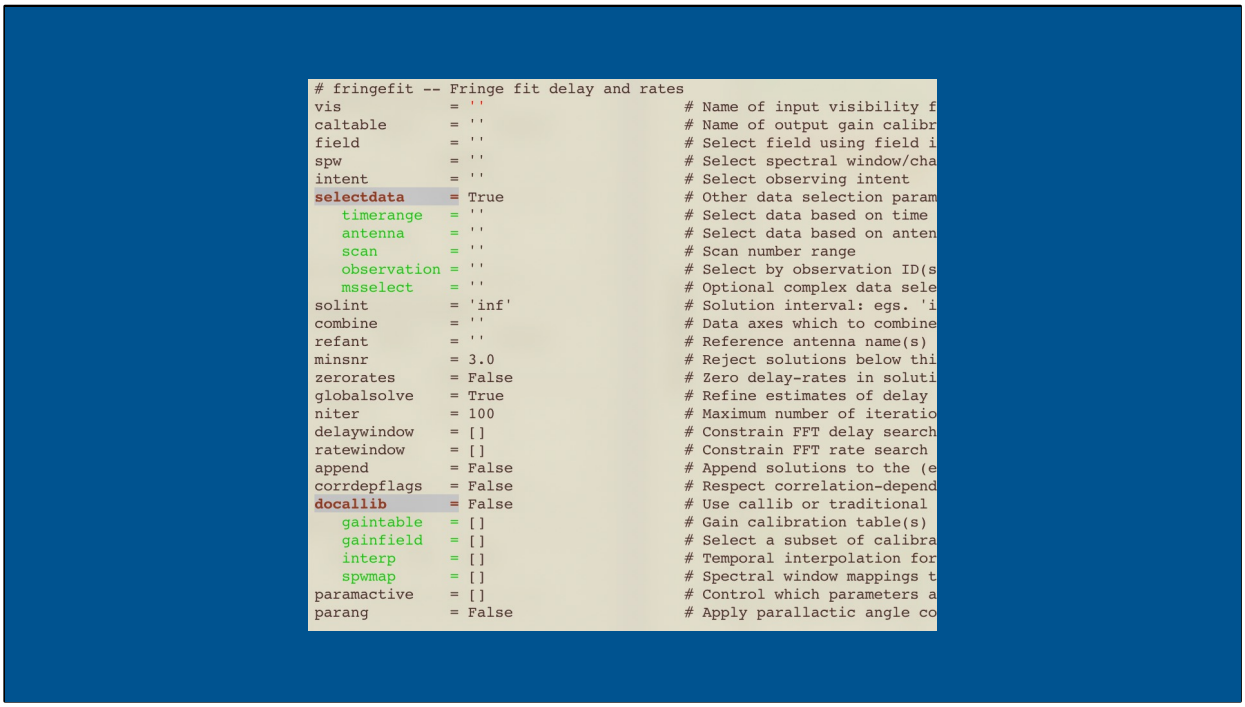

Phase vs. Time Baseline: EF@EF & WB@WB_266520m
Phase (degrees)
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
13:53:30
13:53:40
13:53:50
13:54:00
13:54:10
Time (from 2014/10/22) (hh:mm:ss)

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

Fringe fitting is done to calculate the instrumental delay



```
# 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
```

The solutions calculated by the task will be written to a calibration table
Important parameters here are the gaintable, gainfield, zerorates and parang.
To get the highest quality data, take a short interval in the middle of a scan (1 minute or so)
As interferometry does not have an absolute zero point for phase, we need a reference antenna too

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.
```

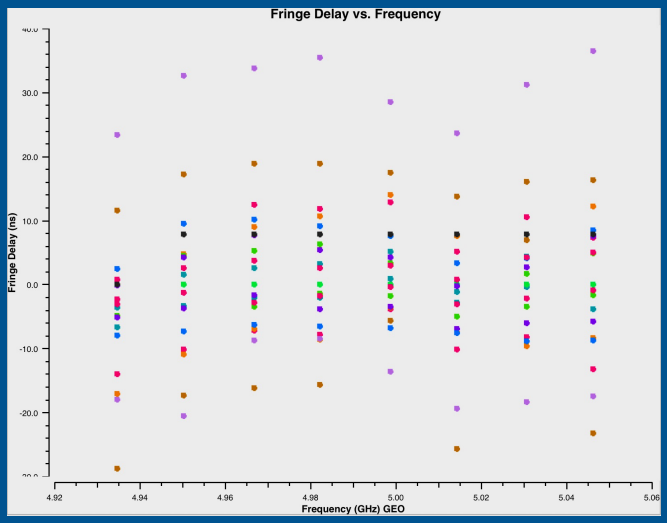
4. Inspect the results

```
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`



First inspect the CASA logger output, then plot the solutions.

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`

As a final check, apply the solutions to the data and verify that the calibrated phases for the selected timerange are corrected: they should be flat and around zero degrees for all baselines.

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'
)
```