Bandpass Calibration: Hands-on

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What is Bandpass Calibration?

In general, the goal of calibration is to find the relationship between the observed visibilities, V_{obs}, and the true visibilities, V :

$$V_{ij}(t,\nu)_{obs} = V_{ij}(t,\nu)G_{ij}(t)B_{ij}(t,\nu)$$

where t is time, ν is frequency, *i* and *j* refer to a pair of antennas *(i,j)* (i.e., one baseline), *G* is the complex "continuum" gain, and *B* is the complex frequency-dependent gain (the "bandpass").

Bandpass calibration is the process of measuring and correcting the *frequency-dependent* part of the gains, $B_{ij}(t,\nu)$.

B_{ij} may be constant over the length of an observation, or it may have a slow time dependence.

Why is BP Calibration important?

Good bandpass calibration is a key to detection and accurate measurement of spectral features, especially weak, broad features.

Bandpass calibration can also be the limiting factor in dynamic range of continuum observations.

- Bandpass amplitude errors may mimic changes in line structure with ν
- ν-dependent phase errors may lead to spurious positional offsets of spectral features as a function of frequency, mimicking doppler motions
- ν-dependent amplitude errors limit ability to detect/measure weak line emission superposed on a continuum source. Consider trying to measure a weak line on a strong continuum with ~ 10% gain variation across the band.

Bandpass Calibration

- Determine the variations of phase and amplitude with frequency
- Account for slow time-dependency of the bandpass response
- We will arrive at antenna-based solutions against a reference antenna
  - In principle, could use autocorrelation data to measure antenna-based amplitude variations, but not phase
  - Most bandpass corruption is antenna-based, yet we are measuring N(N-1)/2 baseline-based solutions
  - Amounts to channel-by-channel self-cal

Bandpass Calibration: What makes good calibrators?

- Best targets are bright, flat-spectrum sources with featureless spectra
  - Although point-source not absolutely required, beware frequency dependence of resolved sources
  - If necessary, can specify a spectral index using *setjy*

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

CASA Tasks for Bandpass Calibration

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

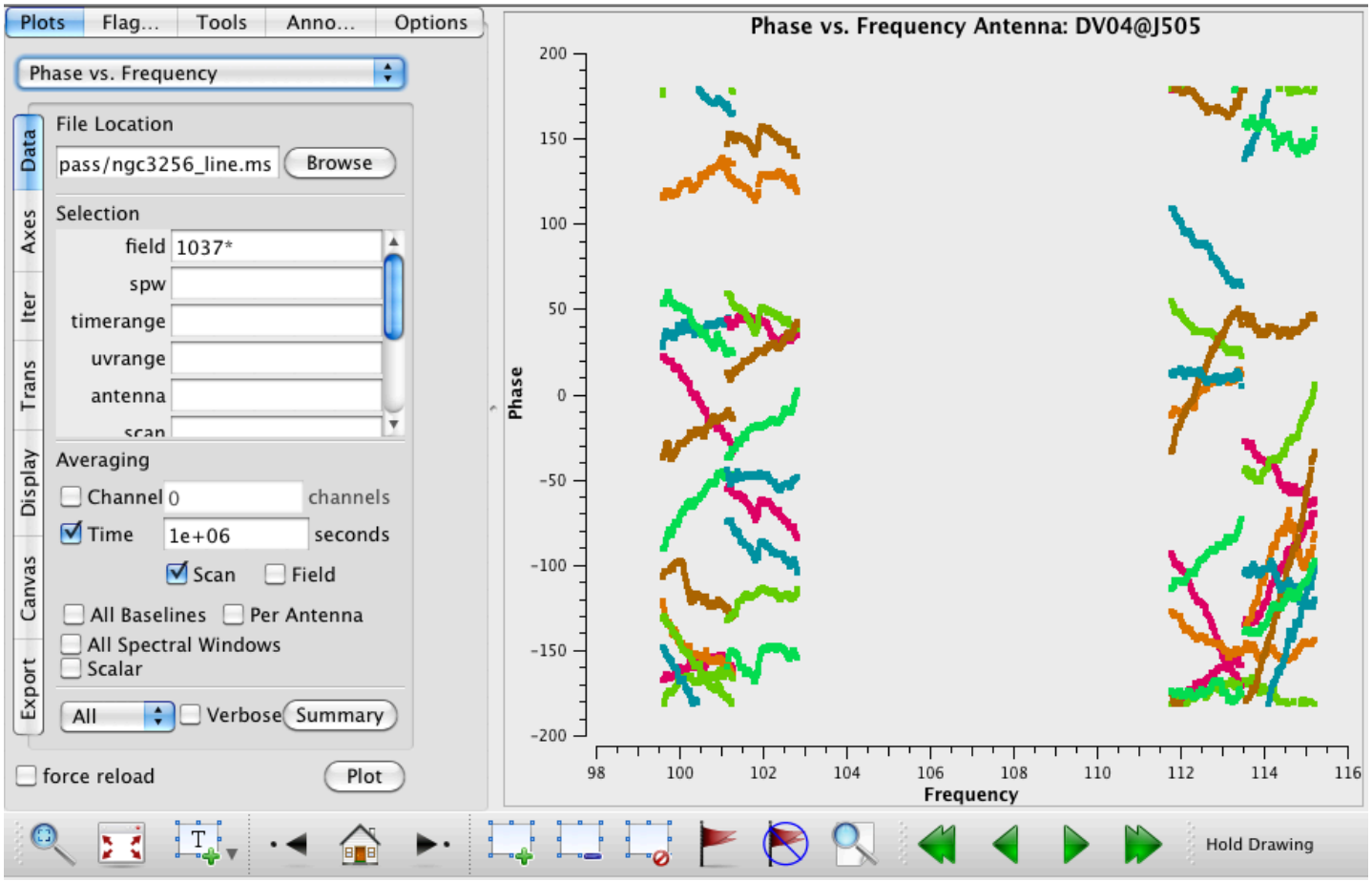
Bandpass Calibration

From here we will follow the commands in the script:

~/distrib/ngc3256/bandpass/bandpass.py

Bandpass Calibration

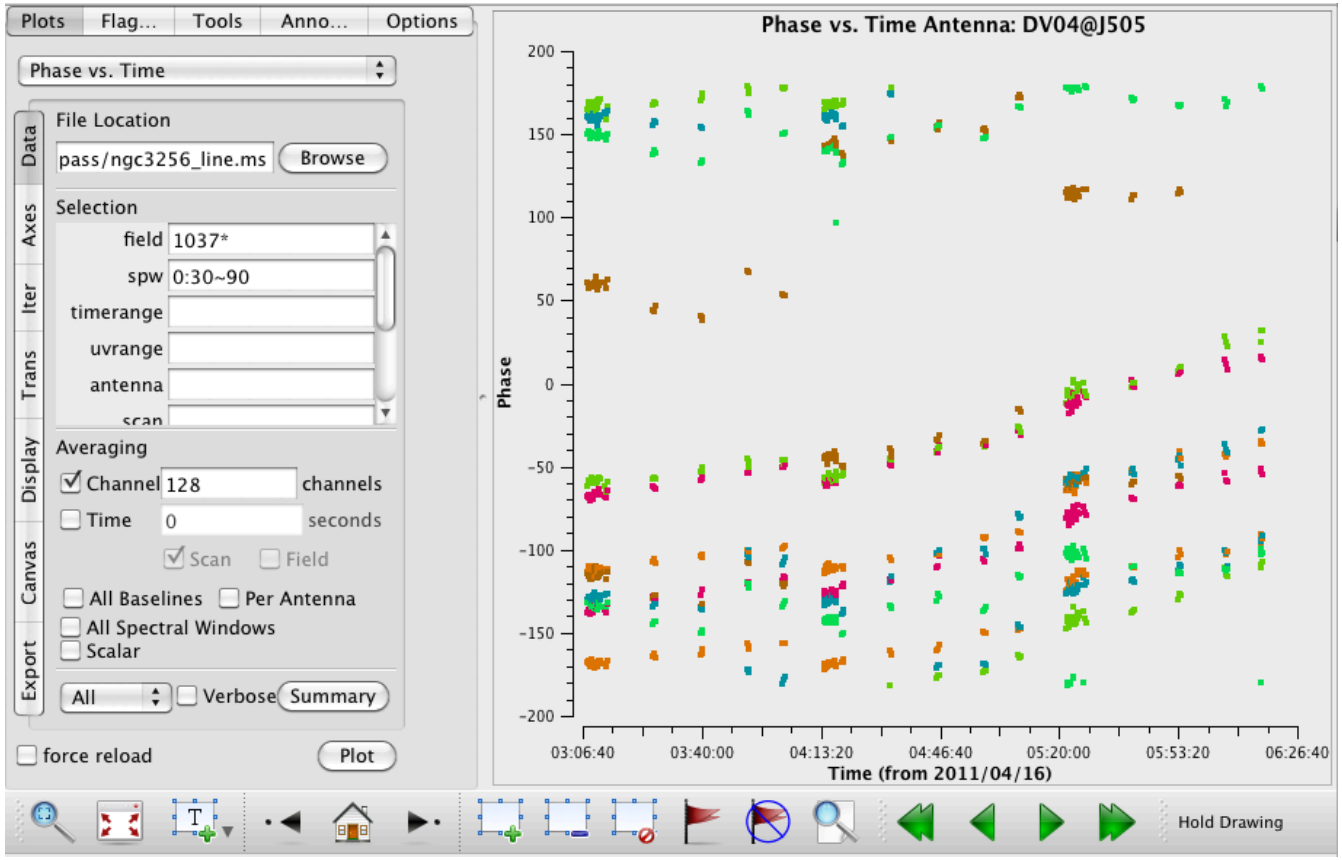
```
plotms(vis='ngc3256_line.ms', xaxis='freq', yaxis='phase', selectdata=True,
       field='1037*', avgtime='1E6', avgscan=T, coloraxis='baseline', iteraxis='antenna')
```



Phase Before Bandpass Calibration

Bandpass Calibration

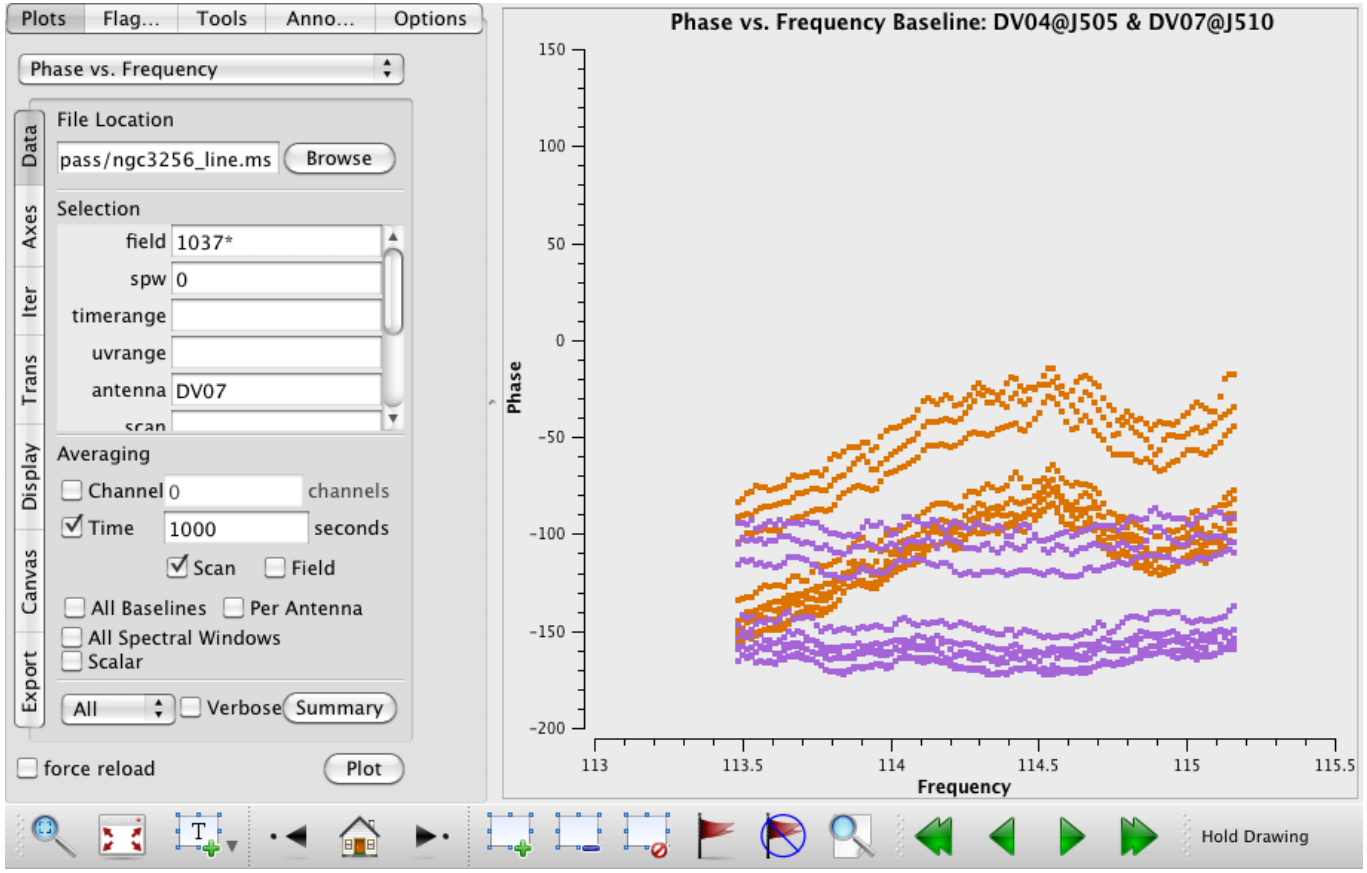
```
plotms(vis='ngc3256_line.ms', xaxis='time', yaxis='phase', selectdata=True, field='1037*',
       spw='0:30~90', avgchannel='128', avgscan=T, coloraxis='baseline', iteraxis='antenna')
```



Phase variation with time for the BP calibrator before calibration.

Bandpass Calibration

```
plotms(vis='ngc3256_line.ms', xaxis='freq', yaxis= 'phase', selectdata=True, field='1037*',
       avgtime='1E3', avgscan=T, spw='0', coloraxis='corr', antenna='DV07', iteraxis='baseline')
```

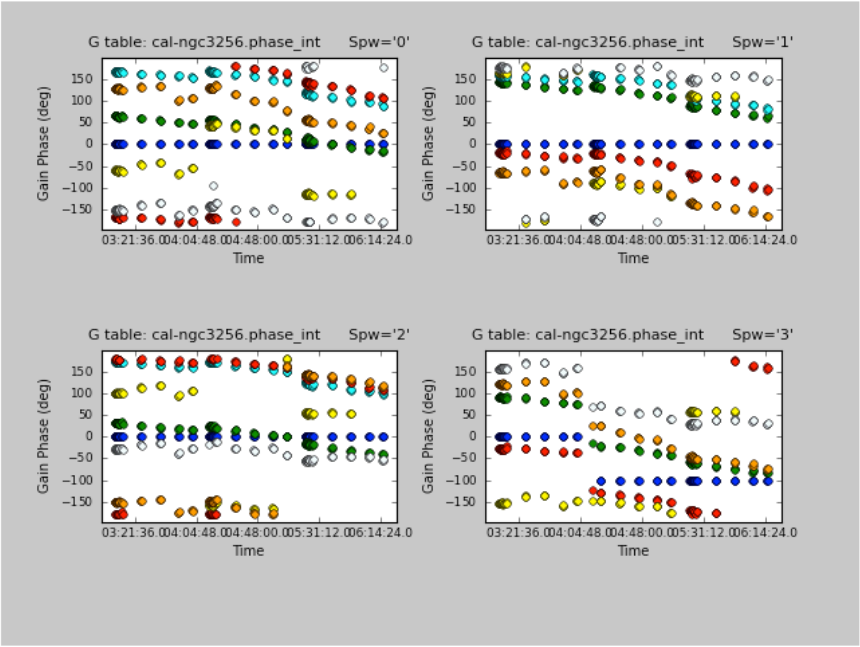


BP shape can change with time, but here it is stable over a few hours, apart from a phase offset

Bandpass Calibration

Calculate the time-dependent phase variation:

```
os.system("rm -rf cal-ngc3256.phase_int")
gaincal(vis='ngc3256_line.ms',
        caltable='cal-ngc3256.phase_int',
        spw='*:40~80',
        field='1037*',
        selectdata=T,
        solint='int',
        refant='DV04',
        calmode='p')
```



Bandpass Calibration

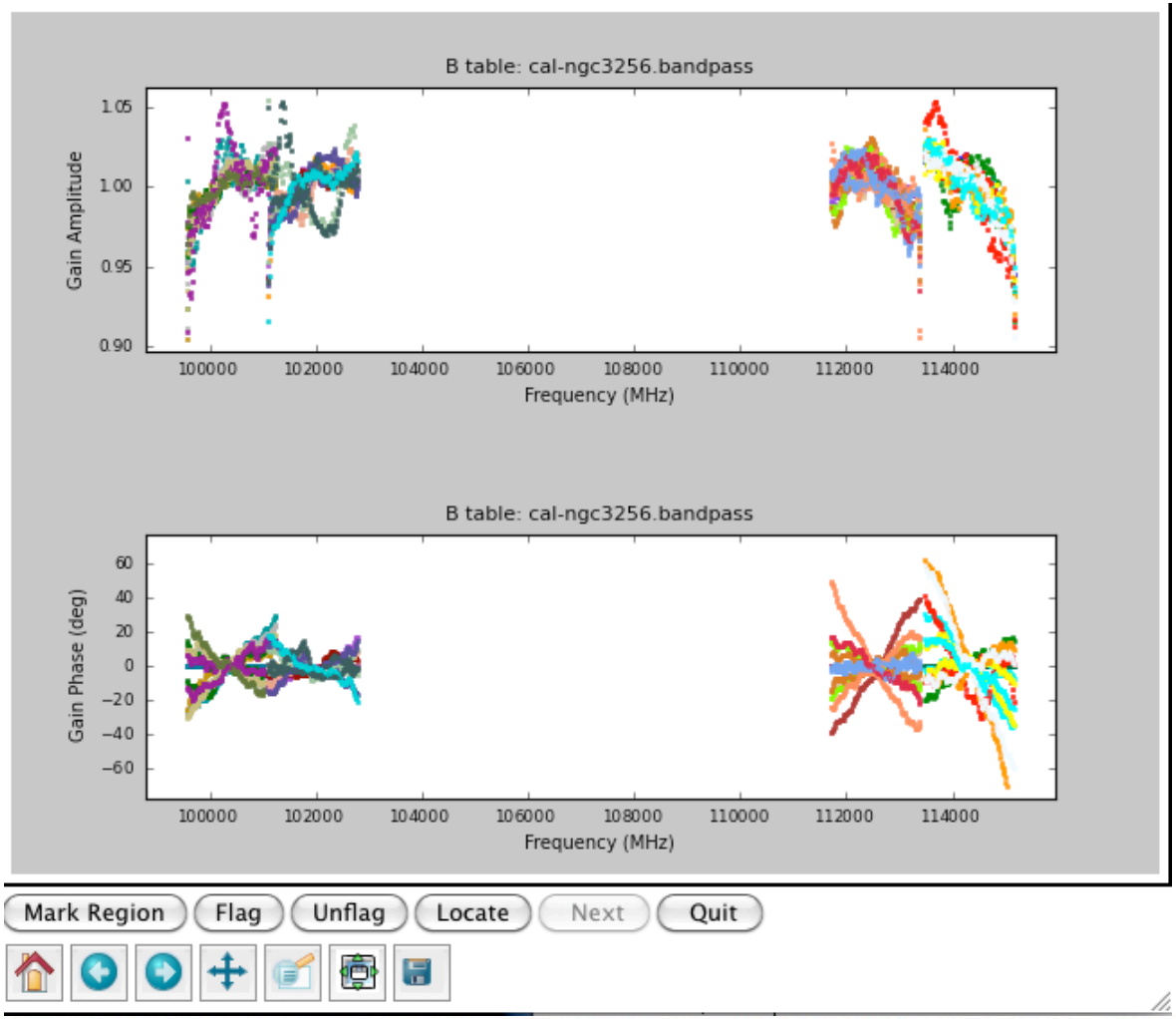
```
CASA <8>: inp bandpass
--------> inp(bandpass)
#  bandpass :: Calculates a bandpass calibration solution
vis                 =         ''            #  Name of input visibility file
caltable            =         ''            #  Name of output gain calibration table
field               =         ''            #  Select field using field id(s) or field name(s)
spw                 =         ''            #  Select spectral window/channels
intent              =         ''            #  Select observing intent
selectdata          =      False            #  Other data selection parameters
solint              =      'inf'            #  Solution interval in time[,freq]
combine             =         ''            #  Data axes which to combine for solve (scan, spw, and/or field)
refant              =         ''            #  Reference antenna name(s)
minblperant         =          4            #  Minimum baselines _per antenna_ required for solve
minsnr              =        3.0            #  Reject solutions below this SNR (only applies for bandtype = B)
solnorm             =      False            #  Normalize average solution amplitudes to 1.0
bandtype            =        'B'            #  Type of bandpass solution (B or BPOLY)
     fillgaps       =          0            #  Fill flagged solution channels by interpolation

smodel              =         []            #  Point source Stokes parameters for source model.
append              =      False            #  Append solutions to the (existing) table
gaintable           =       ['']            #  Gain calibration table(s) to apply on the fly
gainfield           =       ['']            #  Select a subset of calibrators from gaintable(s)
interp              =       ['']            #  Interpolation mode (in time) to use for each gaintable
spwmap              =         []            #  Spectral windows combinations to form for gaintables(s)
gaincurve           =      False            #  Apply internal VLA antenna gain curve correction
opacity             =         []            #  Opacity correction to apply (nepers), per spw
parang              =      False            #  Apply parallactic angle correction
async               =      False            #  If true the taskname must be started using bandpass(...)
```

Bandpass Calibration

```
bandpass(vis = 'ngc3256_line.ms',
         caltable = 'cal-ngc3256.bandpass',
         gaintable = 'cal-ngc3256.phase_int',
         field = '1037*',
         minblperant=3,
         minsnr=2,
         solint='inf',
         combine='scan',
         bandtype='B',
         fillgaps=1,
         refant = 'DV04',
         solnorm = T)
```

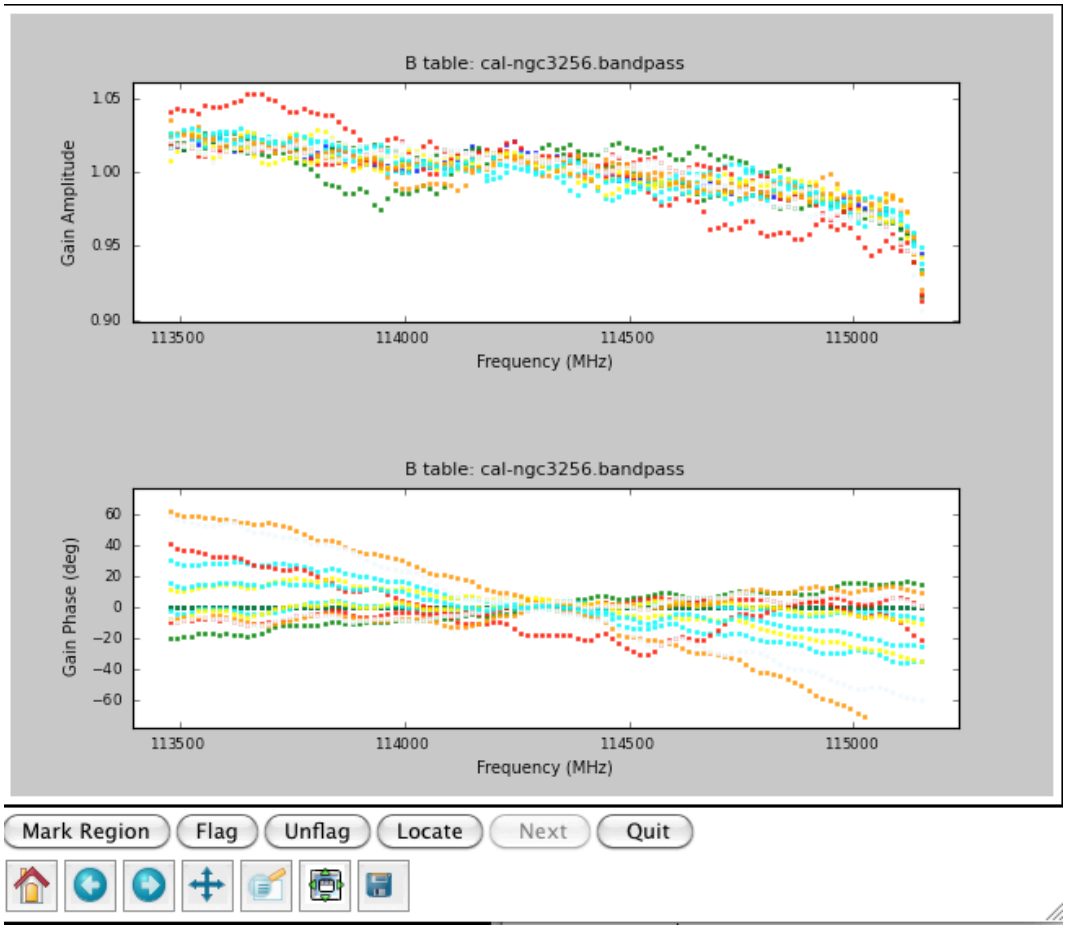
Bandpass Calibration

We determine solutions …



Bandpass Calibration

Looking at only spw 0 …



Bandpass Calibration

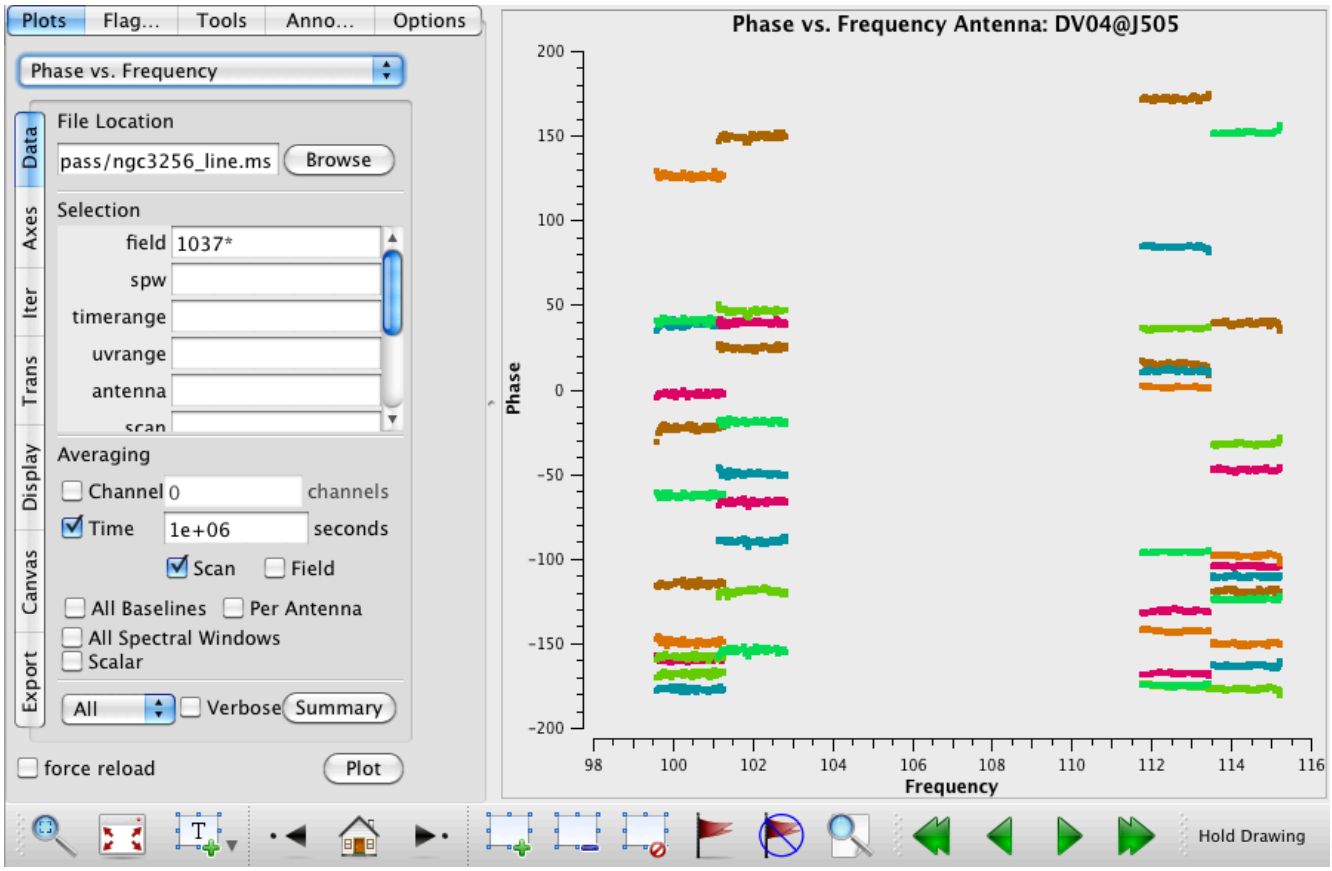
Apply the calibration …

```
applycal(vis="ngc3256_line.ms",
         field="",
         spw="",
         gaintable="cal-ngc3256.bandpass",
         gainfield="1037*",
         interp="nearest,nearest")
```

Bandpass Calibration

Apply the bandpass calibration and then examine the phase of BP calibrator with solutions applied

```
plotms(vis='ngc3256_line.ms', xaxis='freq', yaxis='phase', selectdata=True, field='1037*',
       avgtime='1E6', avgscan=T, coloraxis='baseline', iteraxis='antenna', ydatacolumn="corrected")
```



Bandpass Calibration

… and amplitude of bandpass calibrator with solutions applied