The CASA calibration model

(and how it differs from AIPS)

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Measurement Equation
(RIME)

- Formulated by: Hamaker, Bregman & Sault, 1996, A&AS, **117**, 137
- Reformulated in: Smirnov, 2011, A&AS, **527**, A106
- Mathematical basis for calibration of a radio interferometer
- Fully incorporates polarization

Electric field at the source: $\mathbf{e} = \begin{pmatrix} e_r \\ e_l \end{pmatrix}$

Recorded voltages of feeds at telescope: $\mathbf{v} = \mathbf{J}\mathbf{e}$ with (2x2) Jones matrix $\mathbf{J}$

Visibility matrix produced by the correlator: $\mathrm{V}_{pq} = 2\langle \mathbf{v}_p \mathbf{v}_q^H \rangle$

Measurement equation: $\mathrm{V}_{pq} = 2\langle \mathbf{J}_p (\mathbf{e}_p \mathbf{e}_q^H) \mathbf{J}_q^H \rangle = \mathbf{J}_p \mathbf{B} \mathrm{J}_q^H$ with brightness matrix B $= \begin{pmatrix} I+Q & U+iV \\ U-iV & I-Q \end{pmatrix}$

Goal is to determine $\mathbf{J}_p$ for all antennas p.

Measurement Equation
continued

$\mathbf{J}_p = \mathbf{B}_p \mathbf{G}_p \mathbf{D}_p \mathbf{E}_p \mathbf{P}_p \mathbf{K}_p \mathbf{T}_p$

- $\mathbf{T}_p$ Polarization-independent multiplicative effects introduced by the troposphere, such as opacity and path-length variation.
- $\mathbf{K}_p$ Delay (this is VLBI!)
- $\mathbf{P}_p$ Parallactic angle, which describes the orientation of the polarization coordinates on the plane of the sky. This term varies according to the type of the antenna mount.
- $\mathbf{E}_p$ Effects introduced by properties of the optical components of the telescopes, such as the collecting area's dependence on elevation.
- $\mathbf{D}_p$ Instrumental polarization response. "D-terms" describe the polarization leakage between feeds.
- $\mathbf{G}_p$ Electronic gain response due to components in the signal path between the feed and the correlator.
- $\mathbf{B}_p$ Bandpass (frequency-dependent) response, such as that introduced by spectral filters in the electronic transmission system.

CASA always applies these in the same (physically correct) order!

CASA calibration

SN table

- CASA calibration tables represent Jones matrices
  - Have an identity
  - Contain real or complex parameters that are used to calculate elements

    Complex gain: $\mathbf{G} = \begin{pmatrix} g_r & 0 \\ 0 & g_l \end{pmatrix}$ is described by tow complex paramaters.
  - Can be given arbitrary (meaningful) names
- **Always explicitly specify calibration tables to be applied!**
  - There is no equivalent of an AIPS CL table

CASA calibration
continued

- Calibration tables are specified with task parameters:
    - `gaintable = [caltable1, caltable2]`
    - `gainfield = [field1, field2]` e.g. `'3C84', 'J1023+43'`
      (*field1* applies to *caltable1*, *field2* to *caltable2*)
    - `interp = [interp1, interp2]` e.g. `'linear', 'nearest'`
      (*interp1* applies to *caltable1*, *interp2* to *caltable2*)
    - `parangle = True` or `False` (default)
- Data without calibration solutions is automatically flagged!
    - Can be bypassed when applying the final calibration
- Data is aggressively flagged if it is partly flagged:
    - `corrdepflags = True` or `False` (default); `True` prevents flagging both pols if one is flagged

New in 5.7/6.1

Data Formats

- MeasurementSet (v2)
  Native data format of CASA
- UV-FITS
  What AIPS writes
- FITS-IDI
  Produced by the SFXC (EVN) and DiFX (VLBA, LBA, …) correlators

All thee formats can contain metadata such as gain curves and T_sys

Preparing your data

ANTAB

scripts at https://github.com/jive-vlbi/casa-vlbi

- Extract gain curves
  - Use gc.py script to import gaincurves from ANTAB files (EVN & Co)

    `casa -c gc.py` *`antabfile gcfile`*

  - Use gc2.py script to import gain curves from FITS-IDI files (VLBA)

    `casa -c gc2.py` *`fitsfile gcfile`*

- Attach T_sys measurements (EVN & Co)

  `casa -c append_tsys.py` *`antabfile fitsfiles…`*

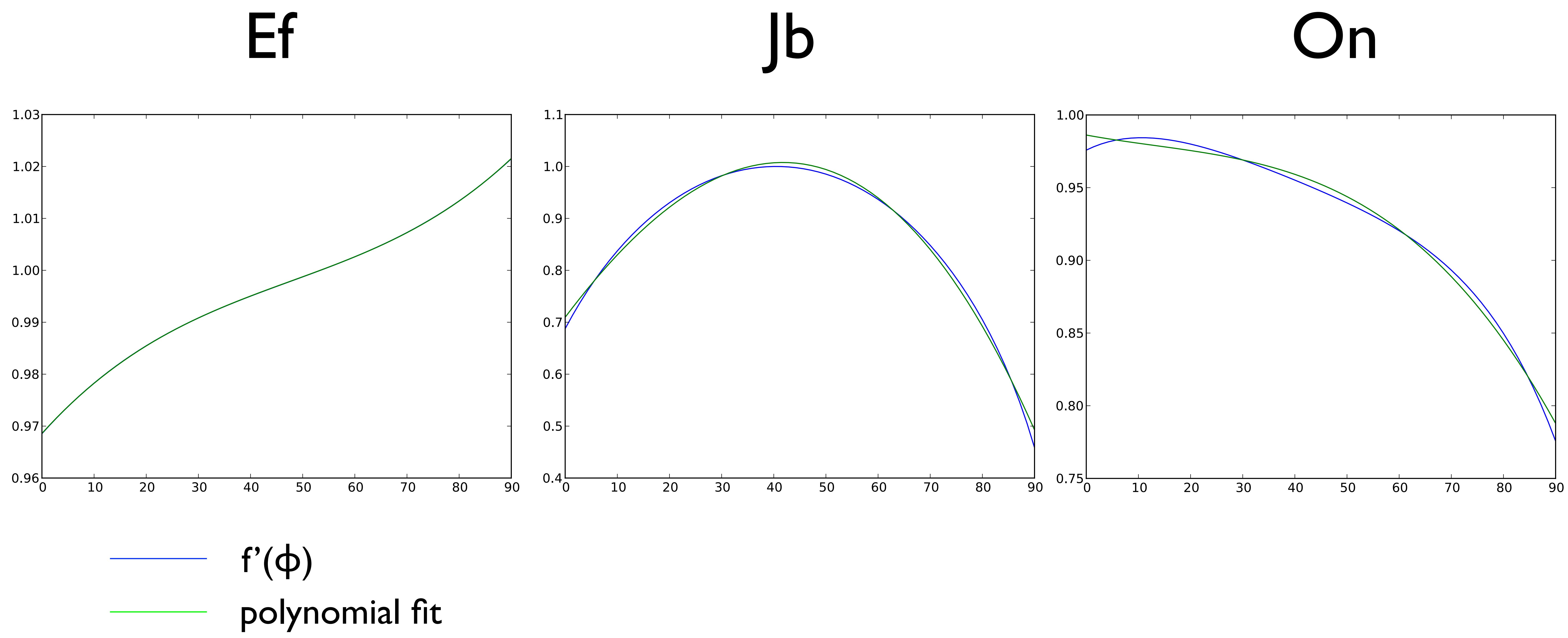
Gain curves

- Different ways to express gain curves
  - voltage vs. power
  - parametrization (function of zenith angle vs. elevation)
- CASA 5.7/6.1 only supports voltage as function of zenith angle
  - `gc.py` and `gc2.py` scripts convert by sample and refit
  - gain curves are not always well-behaved
    use `—min-elevation` and `—max-elevation options`

Gain curves

Fitted gain curves

Third order polynomial fit of $f'(\phi) = \sqrt{f(90-\phi)}$



Preparing your data

The future

Expected in CASA 5.8/6.2

- Attach gain curves (EVN & Co)

  `append_gc.py` *`antabfile fitsfiles..`*

- Attach T_sys measurements (EVN & Co)

  `append_tsys.py` *`antabfile fitsfiles…`*

No preparation needed for VLBA data!

Importing your data

FITLD

- FITS-IDI data can be imported using the importfitsidi
  - A single FITS-IDI file:

```
importfitsidi(vis=ms, fitsidifiles=[fitsfile],
              scanreindexgap_s=seconds)
```

15 seconds is good (matches FITLD)

  - Multiple FITS-IDI files for a single observation:

```
importfitsidi(vis=ms, fitsidifiles=[fitsfile1, fitsfile2],
              constobsid=True, scanreindexgap_s=seconds)
```

Use Python glob module for EVN data

  - Applies digital corrections for DiFX correlator (VLBA & Co)

```
import glob
fitsfiles =  sorted(glob.glob(”N20C2_1_1.IDI*”)
```

- UVFITS data can be imported using importuvfits

```
importuvfits(vis=ms, fitsfile=[fitsfile])
```

This does not import most of the VLBI metadata correctly!

Normalizing your data

ACCOR

- Fix correlation amplitudes based on autocorrelations (VLBA & Co)

```
accor(vis=ms, caltable=caltable)
```

- Generates G-type calibration table

- CASA data selection provides AIPS `ACSCL` functionality

Flagging your data

UVFLG

- Apply a-priori flagging (EVN & Co)

```
$ flag.py uvflgfile fitsfile > flagfile
```

```
flagcmd(vis=ms, inpmode='list',inpfile=flagfile)
```

- Additional flagging is don using `plotms`

Amplitude calibration

ANTAB

- Generate caltables for gain curves:

  ```
  gencal(vis=ms, type=’gc’, infile=gcfile, caltable=gctable)
  ```

- Generate caltables for T_sys:

  ```
  gencal(vis=ms, type=’tsys’, caltable=tsystable)
  ```

- Generates G-type calibration tables
- To apply use:

  ```
  gaintable=[gctable, tsystable]
  ```

  In subsequent calibration tables.

Bandpass calibration

BPASS

- Generate caltables for gain curves:

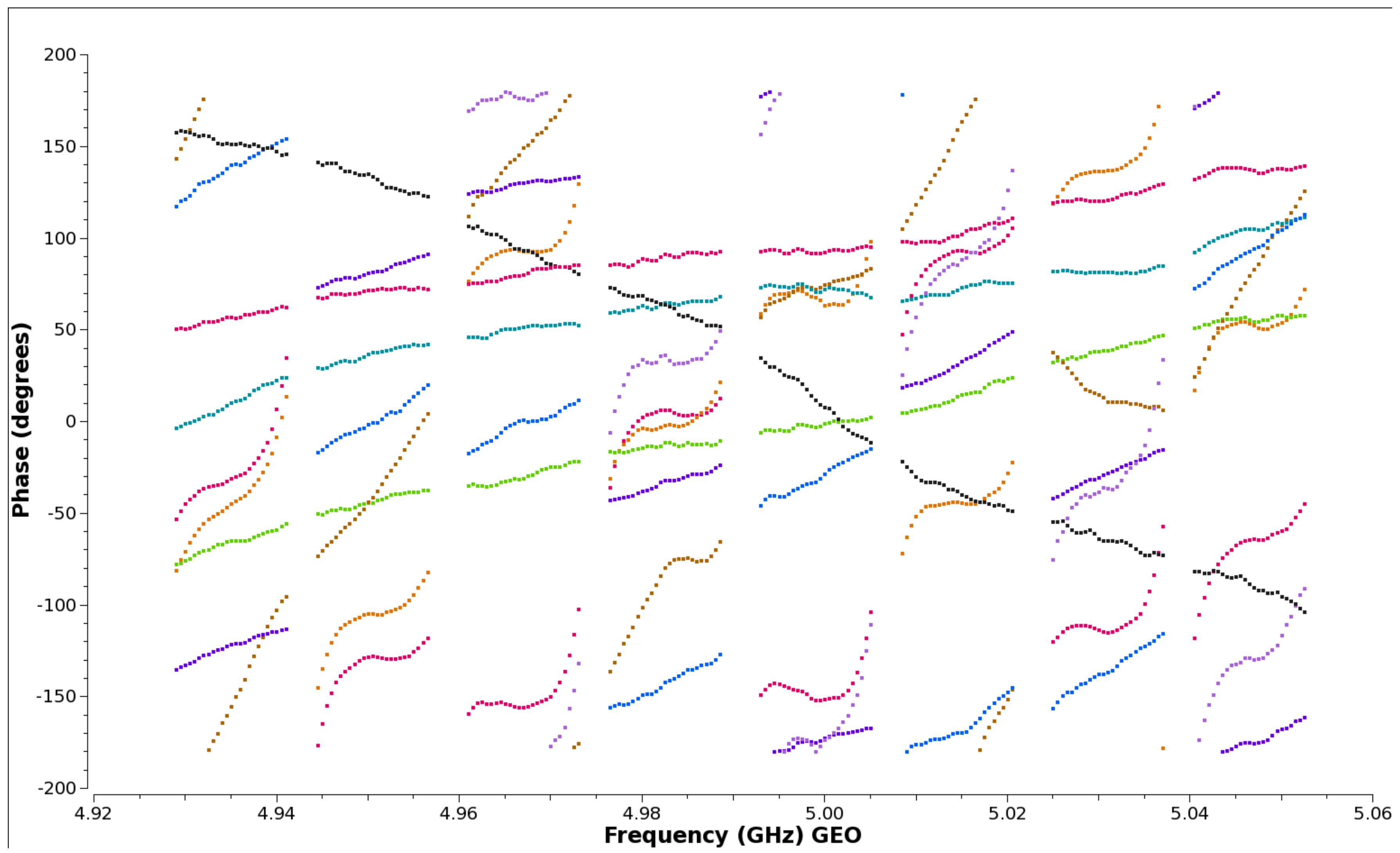
```
bandpass(vis=ms, field=field, refatnd=refant,
    gaintable=[…], solnorm=True, caltable=bptable)
```

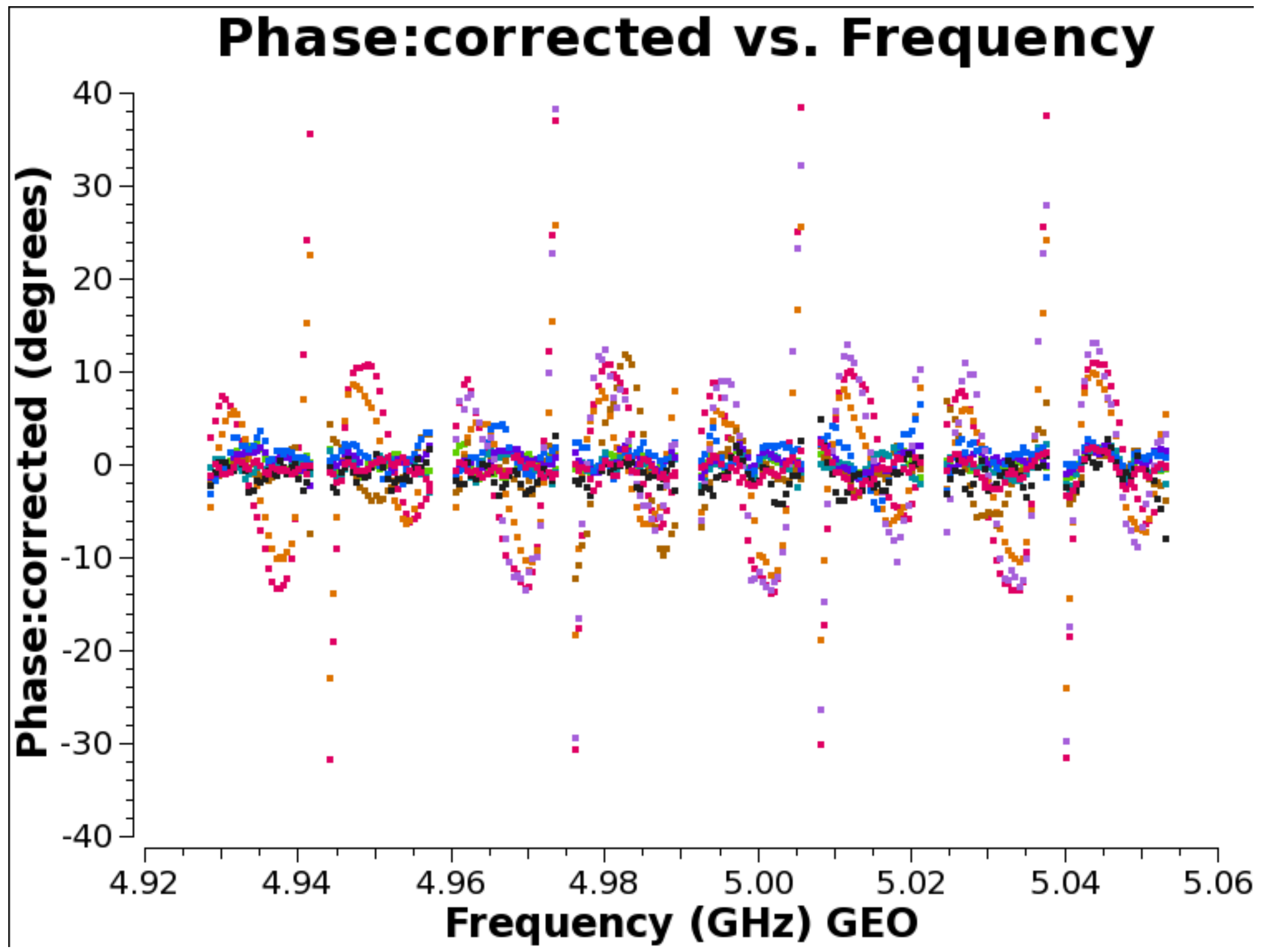
- Generates B-type calibration tables

Fringe Fitting

FRING

- See lecture by Des Small on tuesday





Apply calibration

SPLIT

- Applying calibration to the whole MeasurementSet:

  ```
  applycal(vis=ms, gaintable=[…], interp=[…], …)
  ```

  - Adds a CORRECTED_DATA colum; full copy of the data
- Split the MeasurementSet:

  ```
  split(vis=ms, outputvis=splitms, field=field, …)
  ```

  - Supports averaging (time & frequency)
  - Needs to be run for each field you want to image
  - The `mstransform` task can also be used.
    - Ends up running the same code.

CASA5 vs CASA6

Python 2 or Python 3

- CASA 5.x uses Python 2.7
  - Python 2 is no longer supported
  - Python scripts need to be invoked using `casa -c`
  - Still includes `plotcal`
  - Will go away in the future
- CASA 6.x uses Python 3.6
  - The world is moving to Python 3
  - No longer includes `plotcal`
  - Proper Python modules, can be easily included in Python

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