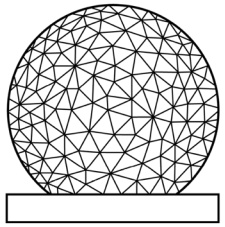
Linear and Circular Polarizations

Dan Hoak (for the Haystack correlation team)

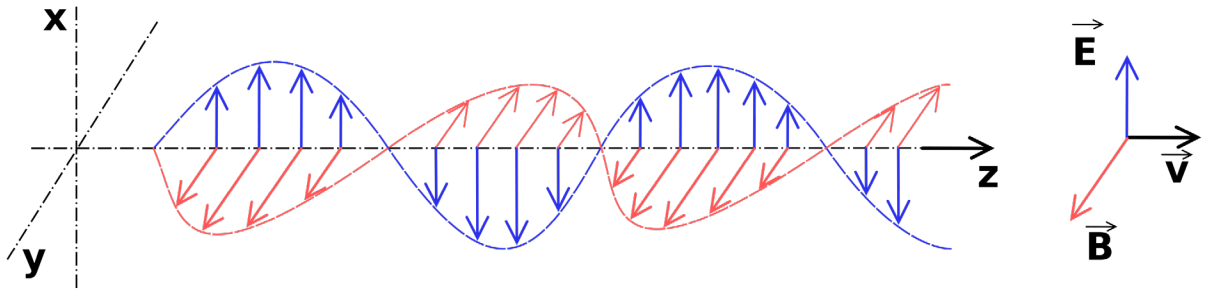
TOW Correlator Workshop May 4-5 2023



MIT
HAYSTACK
OBSERVATORY

VGOS – Linear vs Circular Polarization

Electromagnetic waves are transverse and polarized!



The polarization of an EM wave refers to the direction of the electric field, and how it changes as the wave propagates. We can describe EM waves as either linear or circularly polarized.

Making an antenna that is sensitive to linear polarization is straightforward.

For circular polarization, use four separate antennas, and sum the signals with quarter-wave-plates.

Quarter-wave-plates will phase shift the signals by 90 degrees each, but only in a narrow range of frequencies.

VGOS – Linear vs Circular Polarization

So it's hard to make broadband antennas that are sensitive to circular polarization.

VGOS bandwidth is 2-14 (7x), very wide-band. This motivated linear pol receivers.

But, circular polarization has a lot of benefits!

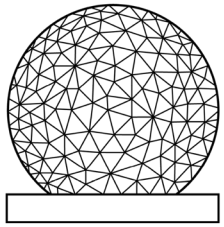
- No longer necessary to account for parallactic angle differences along baselines
- Much easier to form the Stokes basis of I,Q,U,V
  - …which makes polarimetry easy! We can do some real astrophysics.
- Full-Stokes compared to pseudo-Stokes (eg, accounting for X/Y amplitude as well as phase & delay) should improve Stokes-I SNR.

In the era of wideband receivers, we need to be able to convert from linear to circular polarization! If we do this in software, we need to measure the Y-X cross-band filter properties.

ER2201: Comparison of PolConvert with pseudo-Stokes

Dan Hoak (for the Haystack correlation team)

TOW Correlator Workshop May 4-5 2023



MIT
HAYSTACK
OBSERVATORY

ER2201 – Comparison of PolConvert and pseudo-Stokes Results

Experiment to test 4C39.25 as a VGOS calibrator source

Data collected on Sep 8 2022

- Six stations: M E S T V Y
- Six hours of data
- 37 scans (1x NRAO150, 1x OJ287, 35x 4C39.25)
- Wf cable wrap problem affecting scan 251-1403
- Mg missing data after 251-1332; only a few seconds per scan
- Yj missing Band D

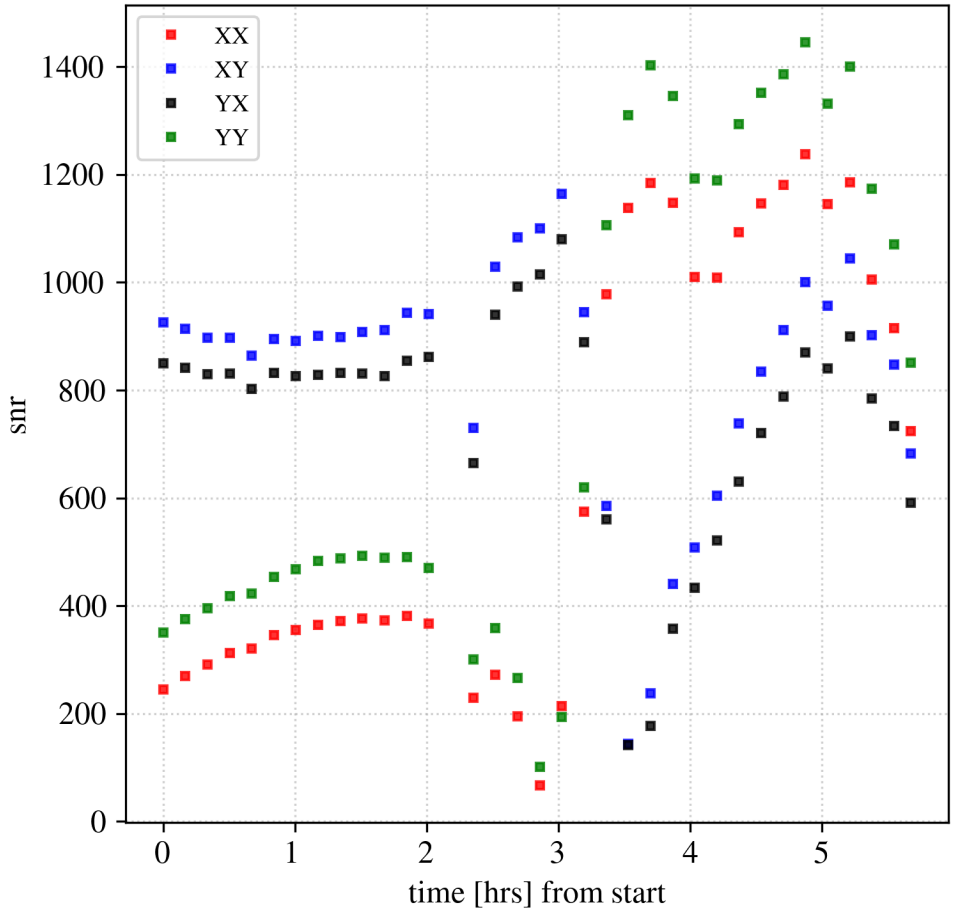
pseudo-Stokes results: correlation, post-processing, `fourfit` as usual

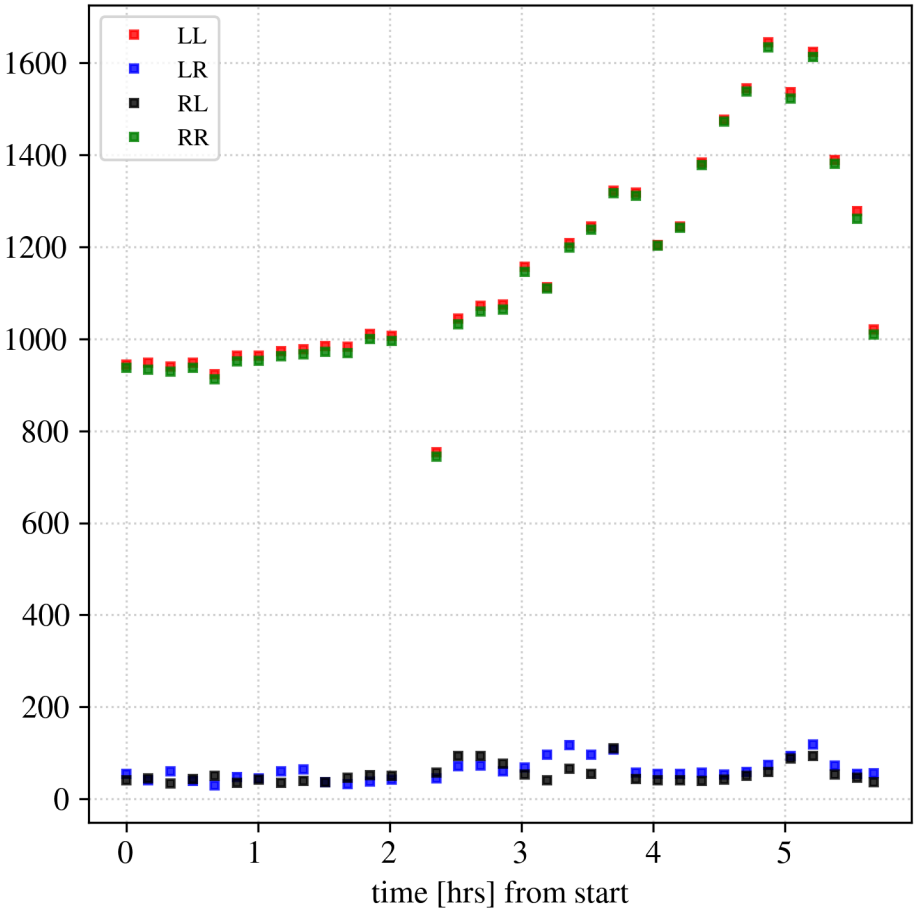
PolConvert results:

- APPLY_AMP = True; CHAVG = 8; 160 spectral points per IF
- MG as reference station (and subsequent tests with OE)
- Polconverted all DiFX files; reference scan was 251-1152
- Sampler delays from Mike's correlation (same as recent VGOS sessions)
- Calculated pcphases cor circ pol "by hand" starting from blank control file
- `fourfit` to get Stokes I (LL+RR)

ER2201 – SNRs of linear and circular polarization products

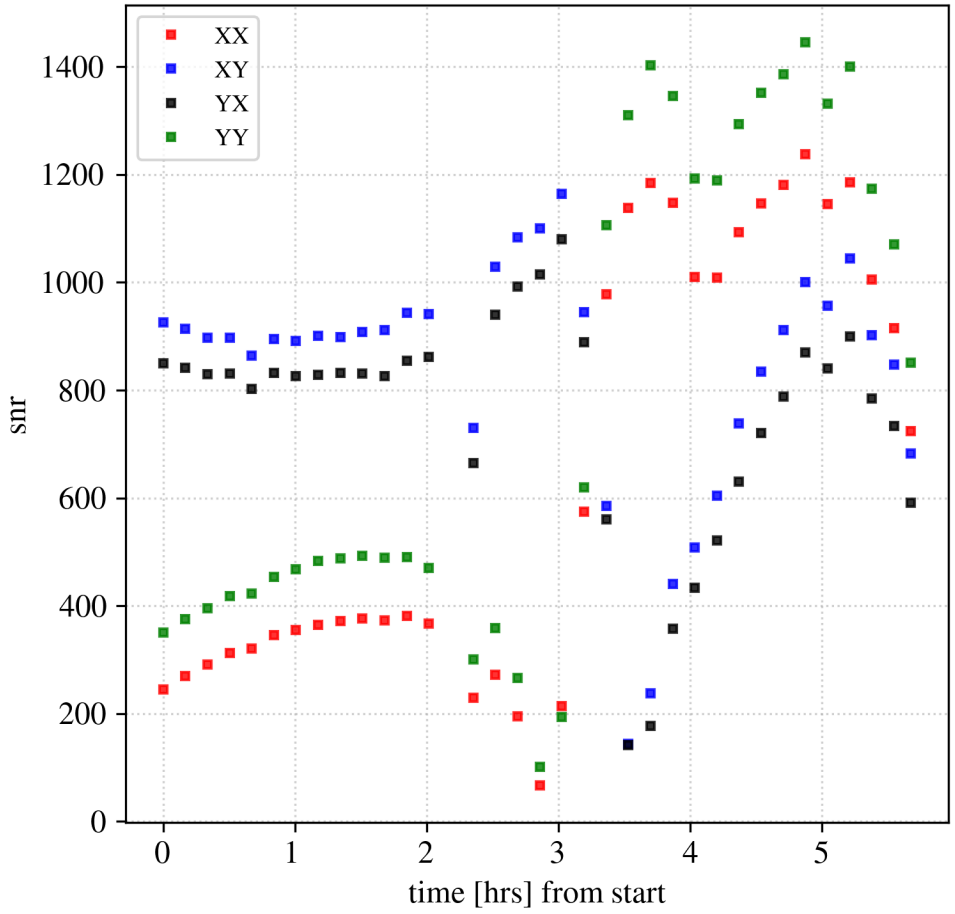
The cross-hand polarization products in the linear basis have high SNR. In the polconverted data, the cross-hands are weak.

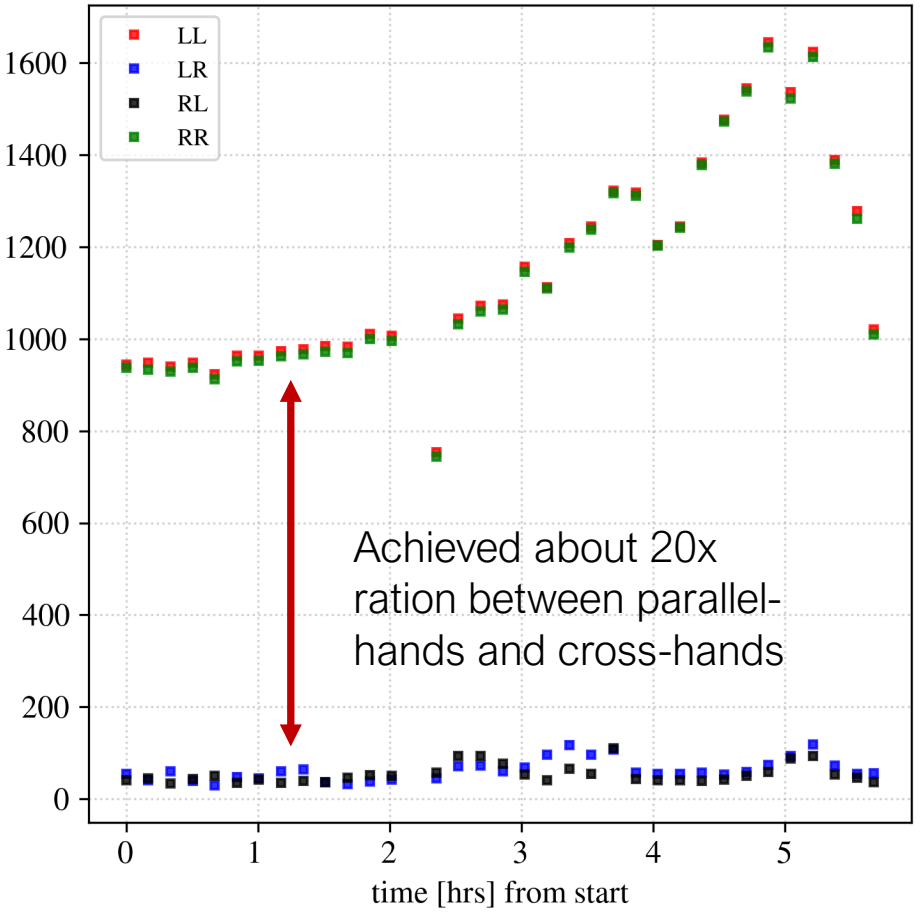




ER2201 – SNRs of linear and circular polarization products

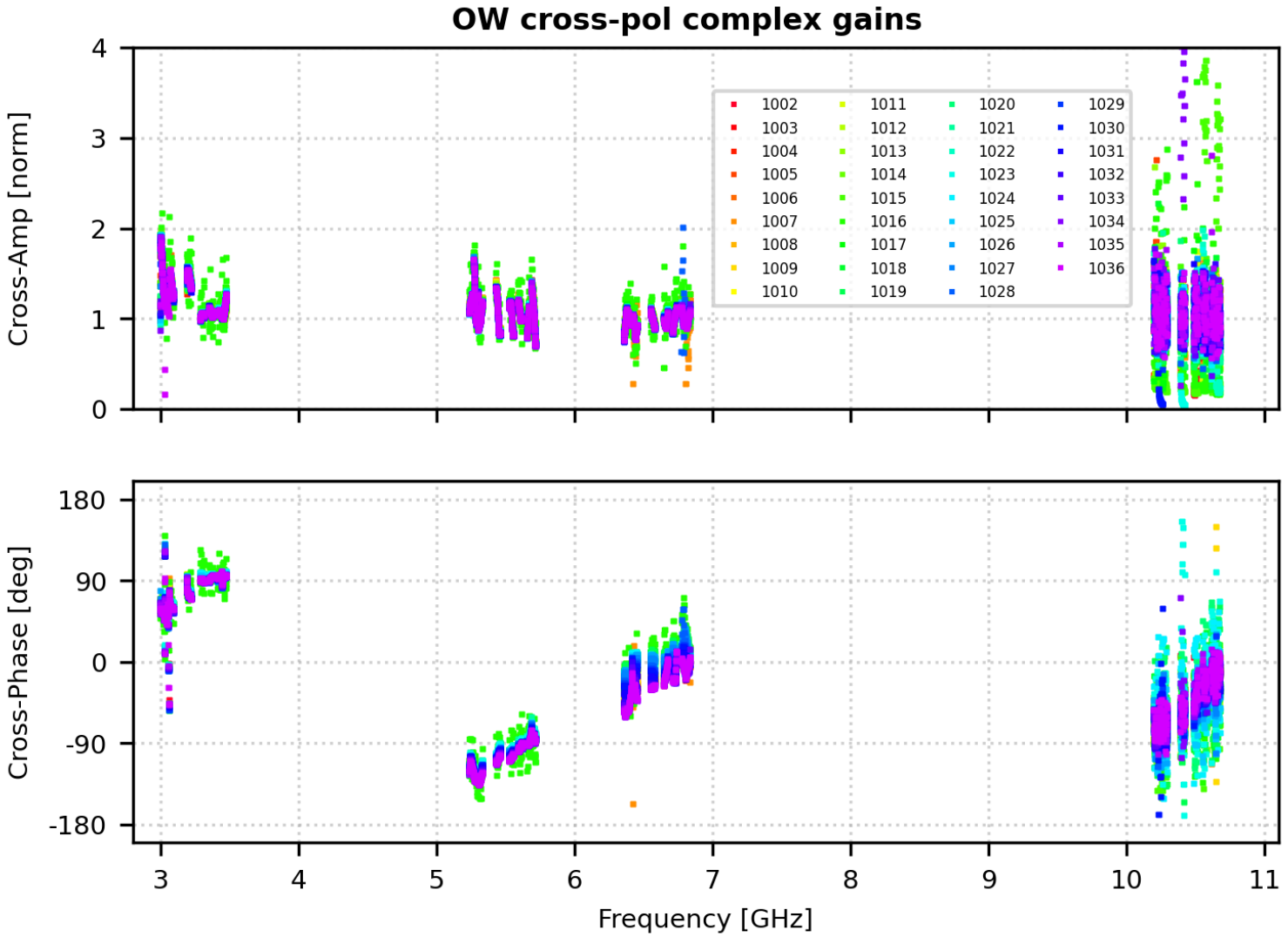
The cross-hand polarization products in the linear basis have high SNR. In the polconverted data, the cross-hands are weak.





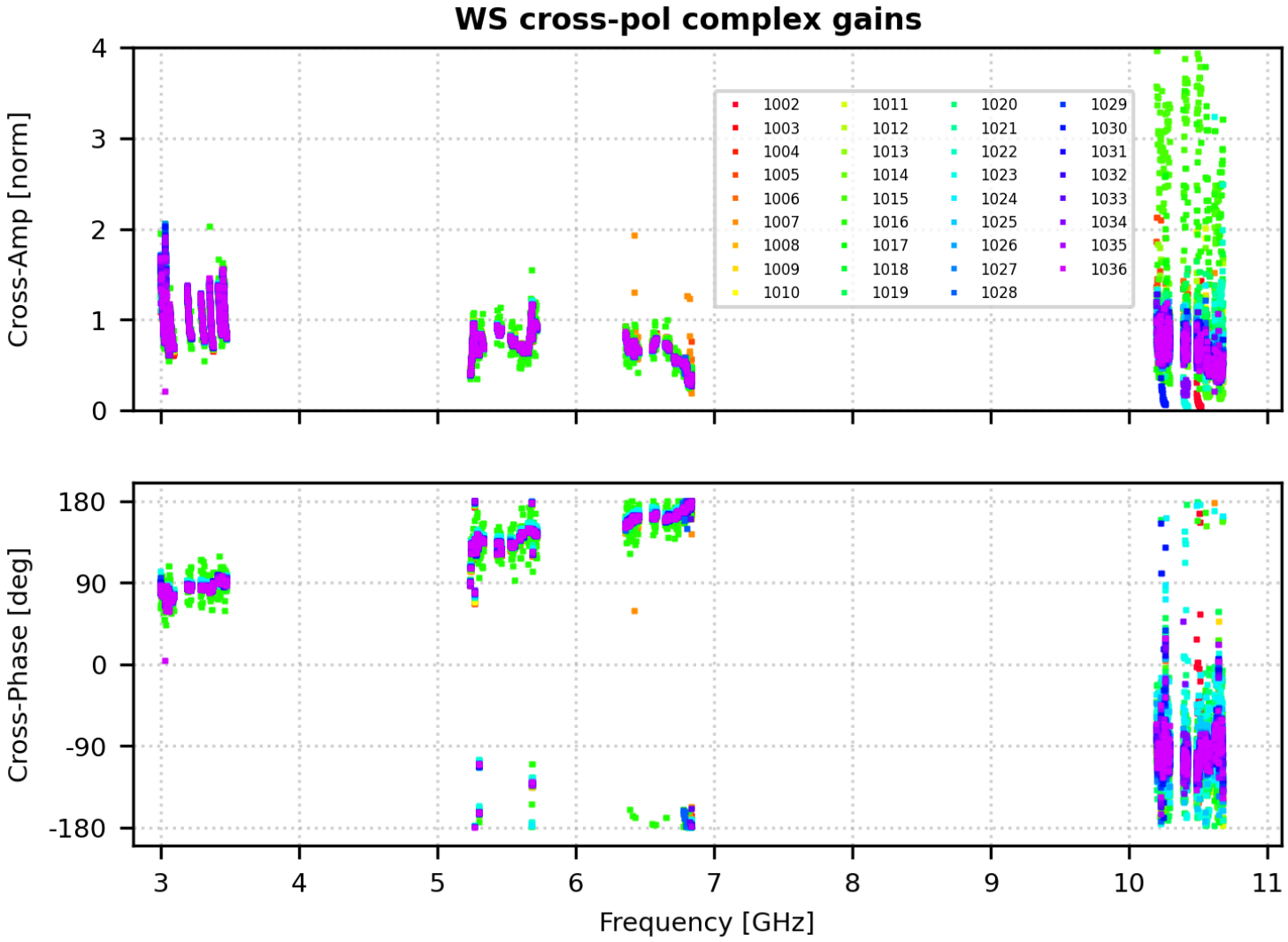
ER2201 – cross-polarization complex gains

We used the full 10-min scans to estimate the cross-bandpass filter. The complex gains are fairly stable across the experiment. Band D estimation worse because missing at Yebes.



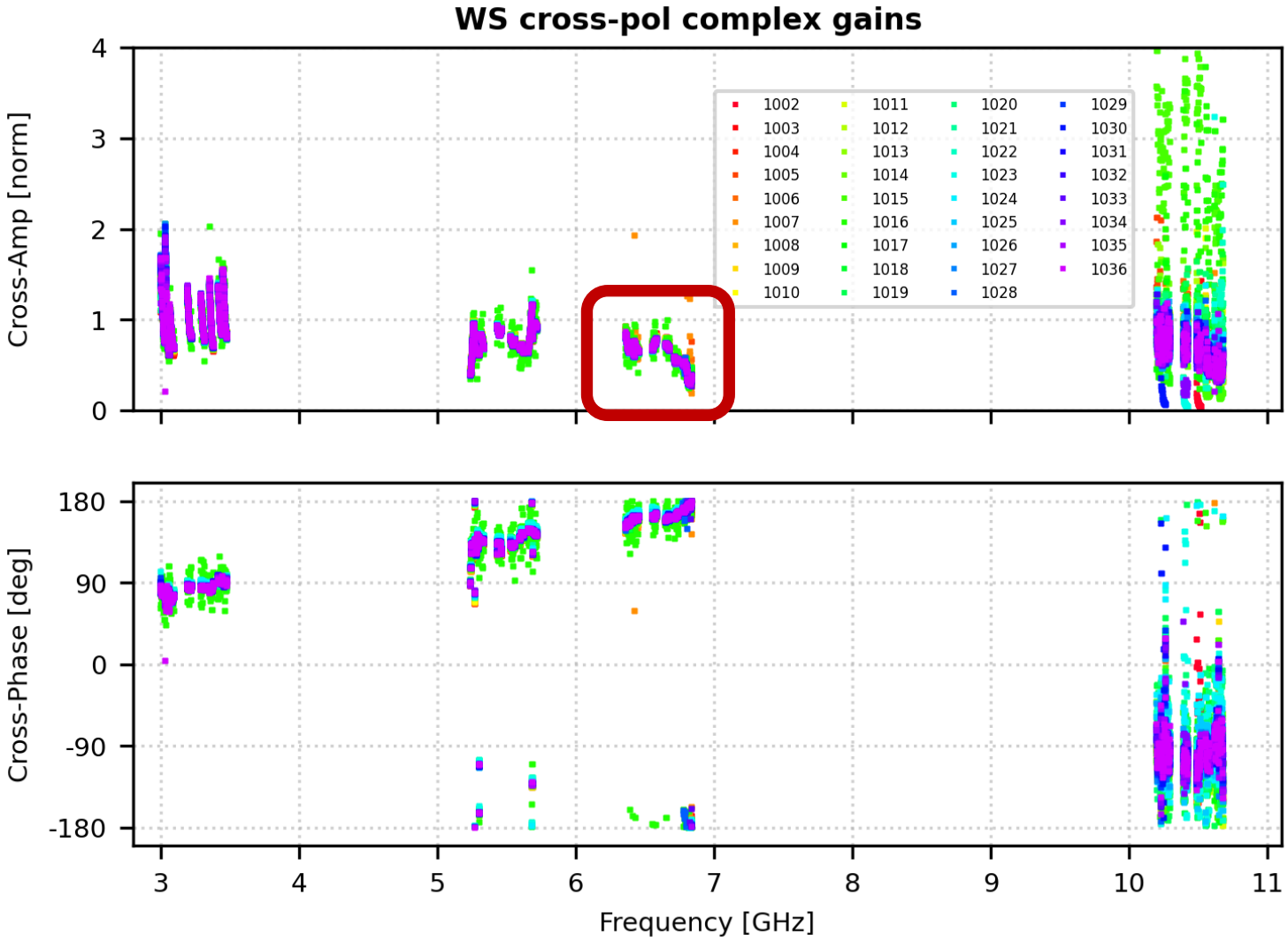
ER2201 – cross-polarization complex gains

We can see some features of the Wettzell cross-bp filter in the channel amplitudes…



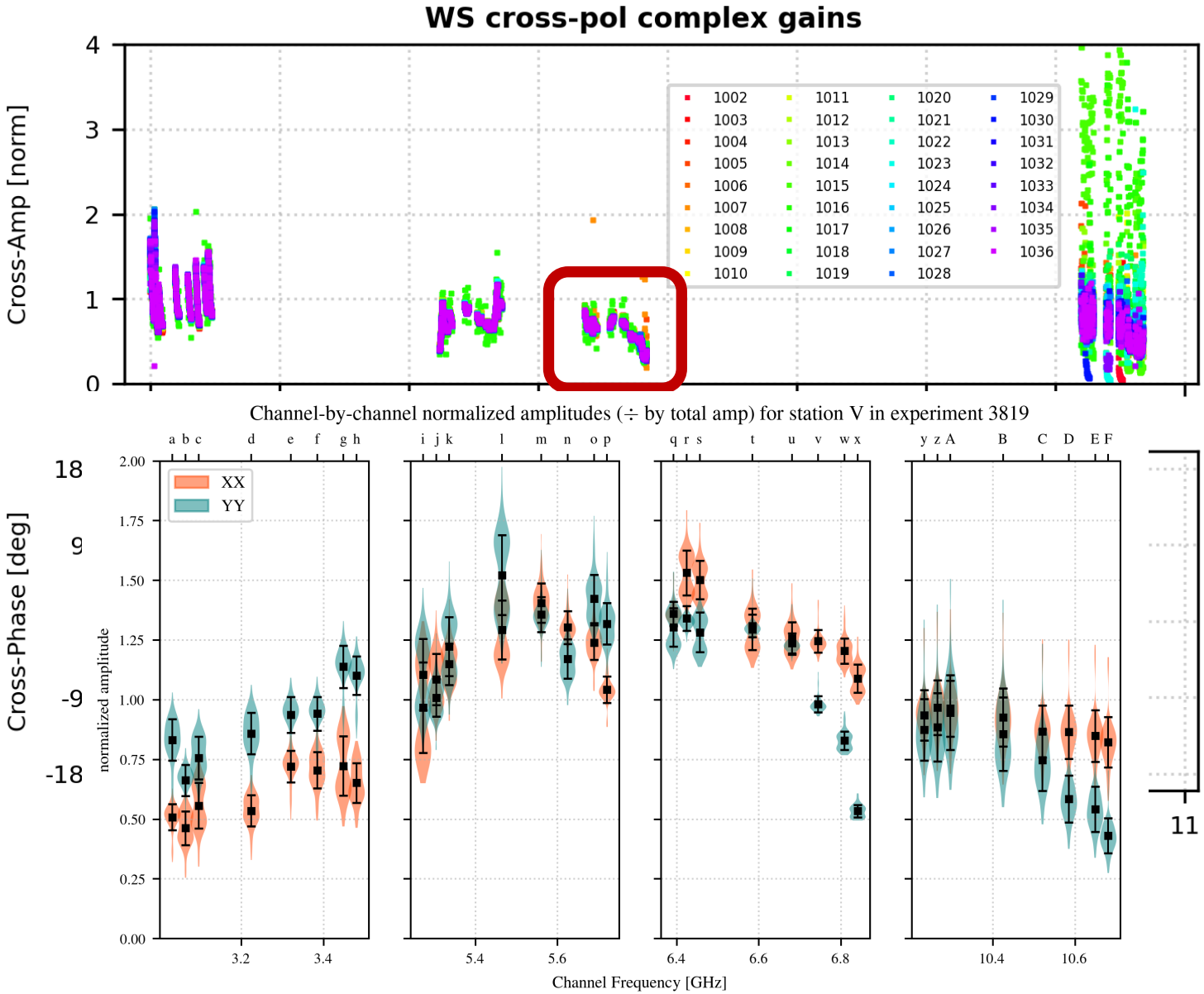
ER2201 – cross-polarization complex gains

We can see some features of the Wettzell cross-bp filter in the channel amplitudes…



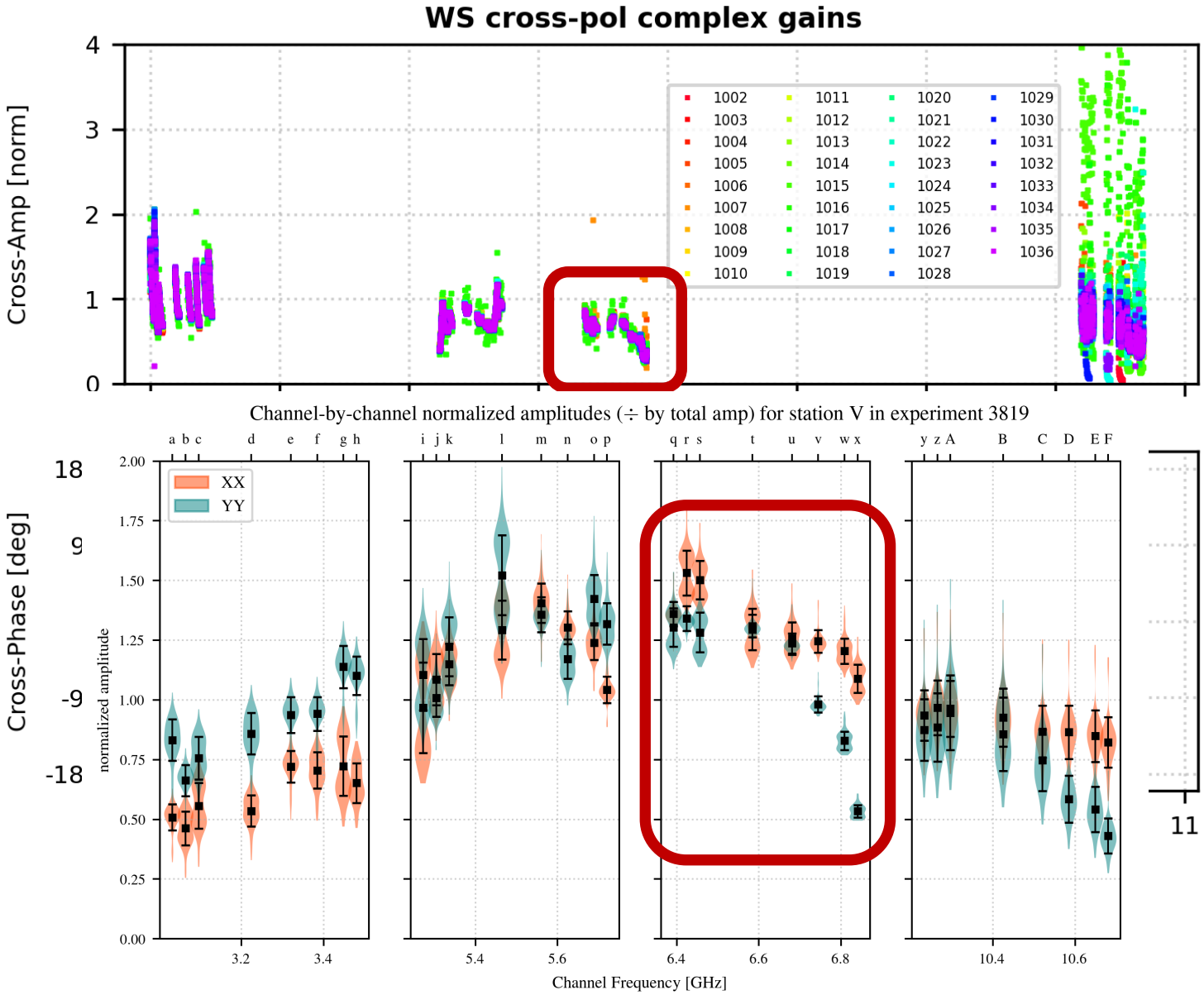
ER2201 – cross-polarization complex gains

We can see some features of the Wettzell cross-bp filter in the channel amplitudes…



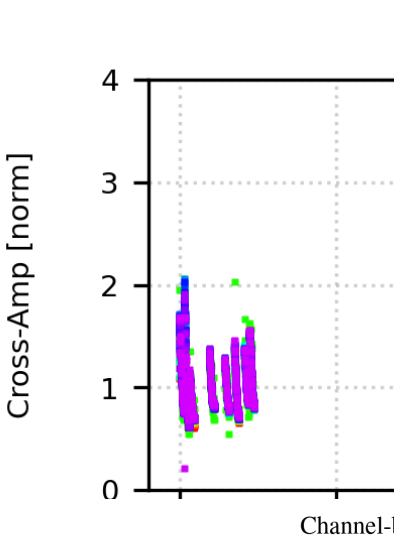
ER2201 – cross-polarization complex gains

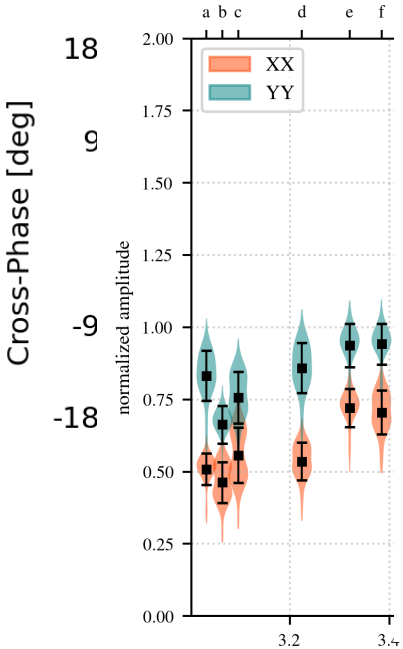
We can see some features of the Wettzell cross-bp filter in the channel amplitudes…

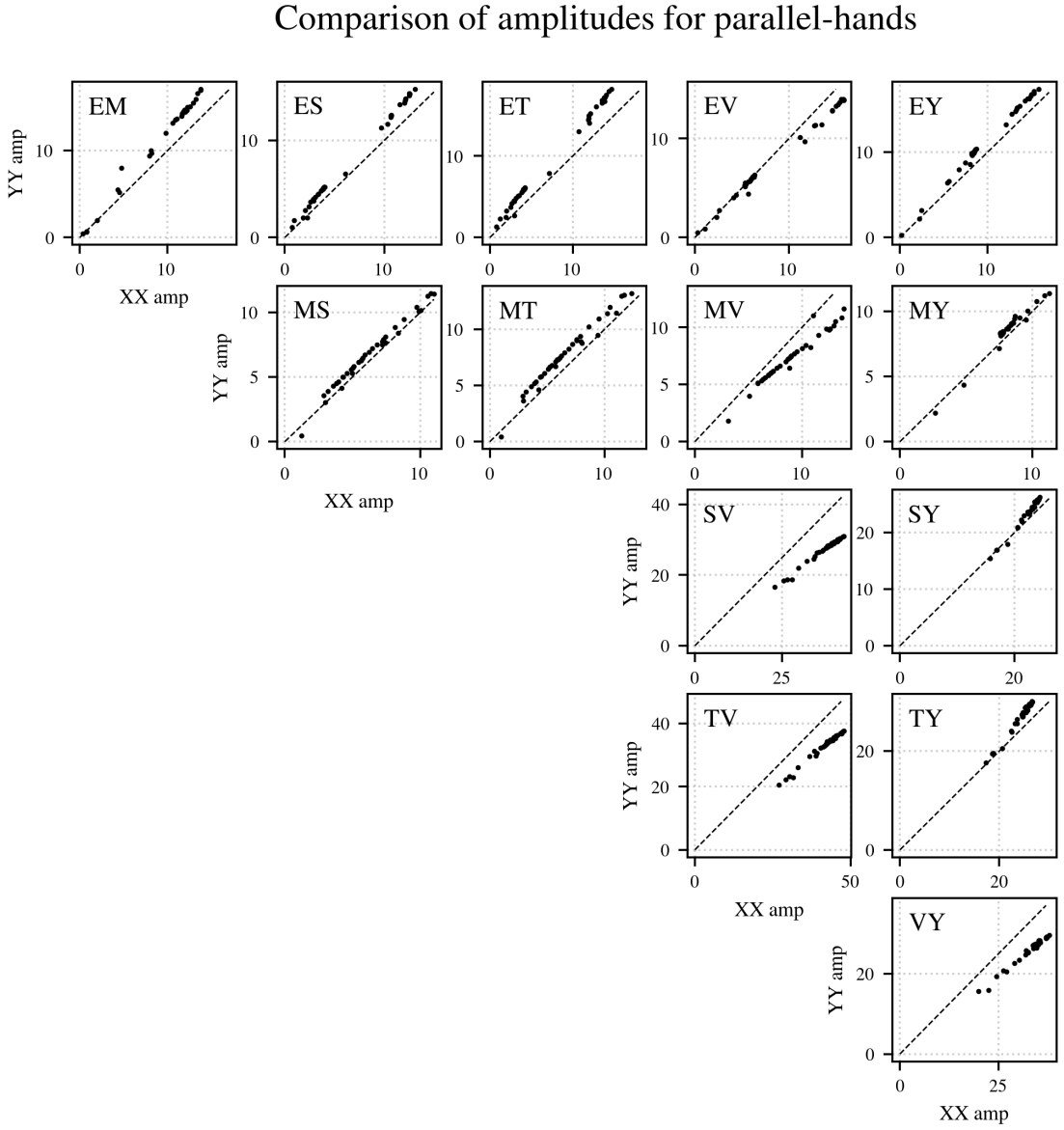


ER2201 – cross-polarization complex gains

We can see some features of the Wettzell cross-bp filter in the channel amplitudes…

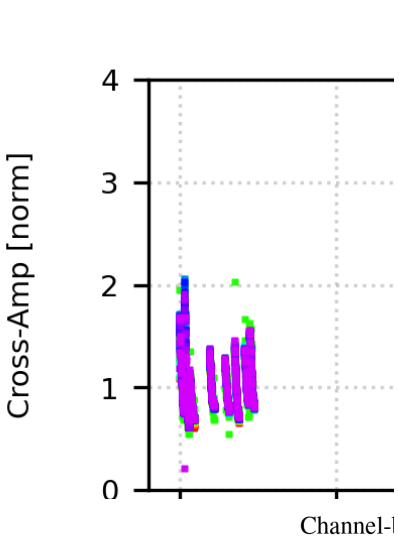


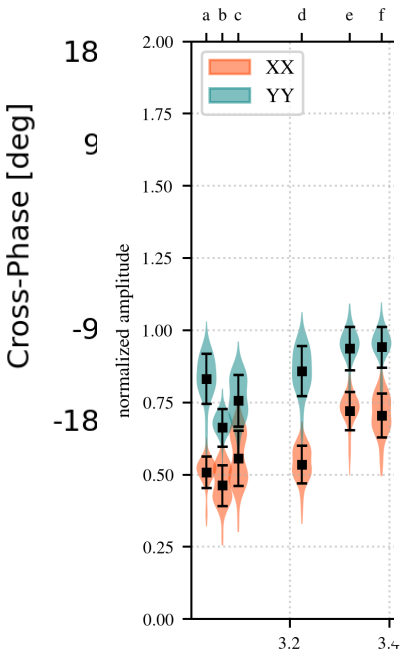


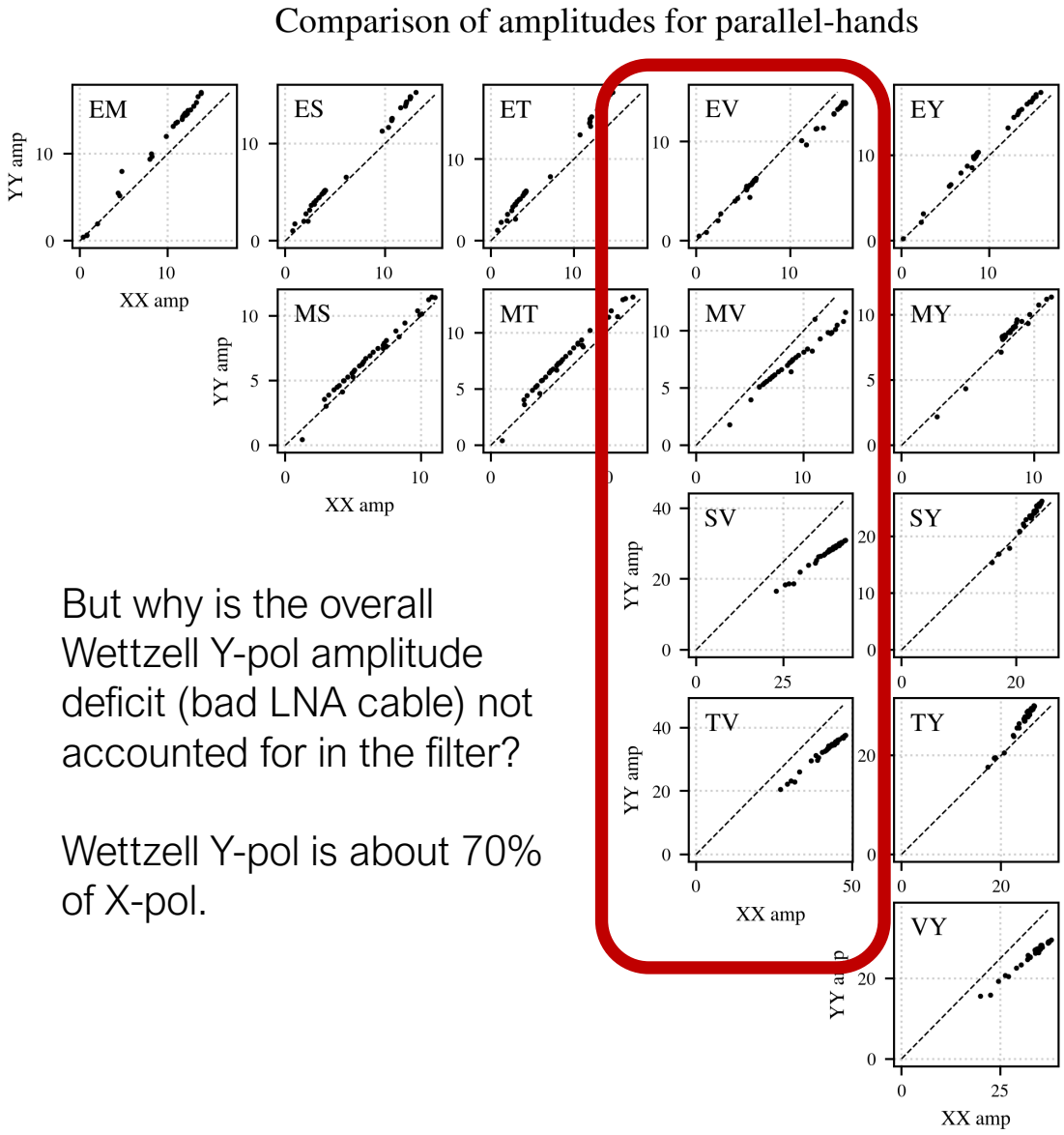


ER2201 – cross-polarization complex gains

We can see some features of the Wettzell cross-bp filter in the channel amplitudes…





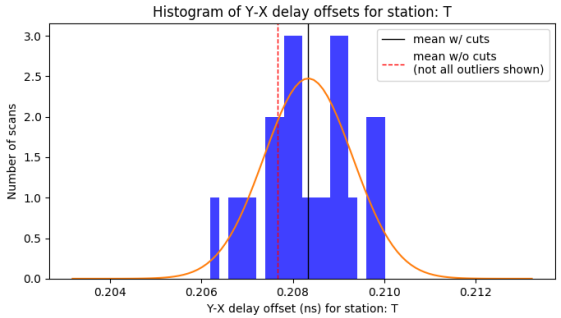


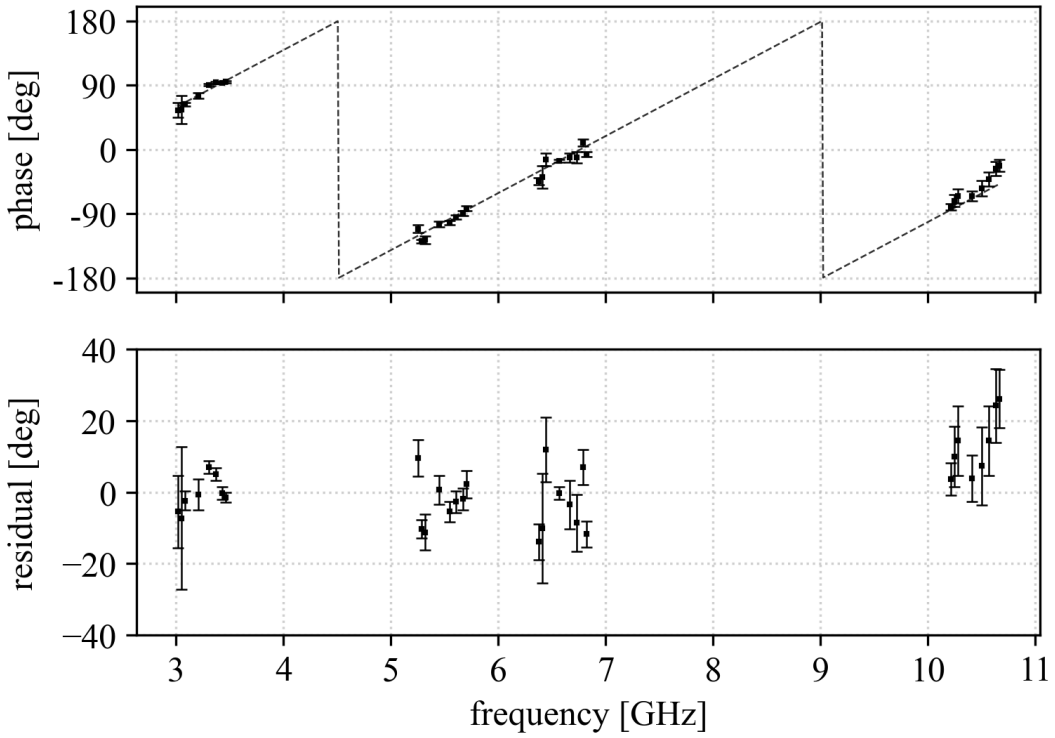
But why is the overall Wettzell Y-pol amplitude deficit (bad LNA cable) not accounted for in the filter?

Wettzell Y-pol is about 70% of X-pol.

ER2201 – cross-polarization complex gains

For stations with a significant group delay in the cross-bandpass filter, the group delays agree fairly well with the y-x delays that we estimate in the standard VGOS post-processing for pseudo-Stokes I.





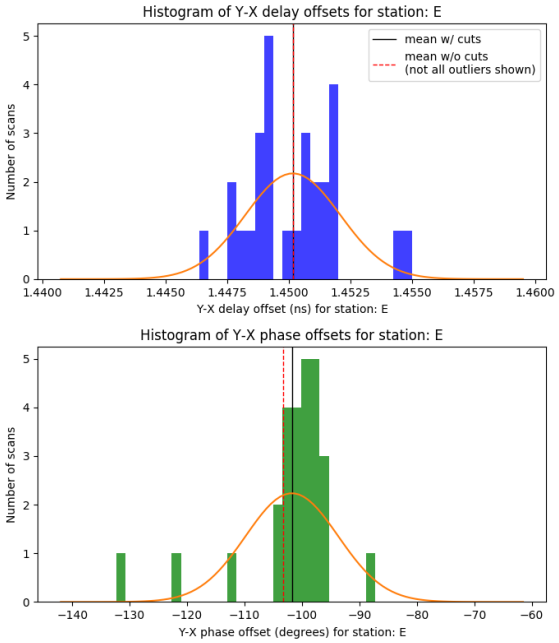
Onsala-West:

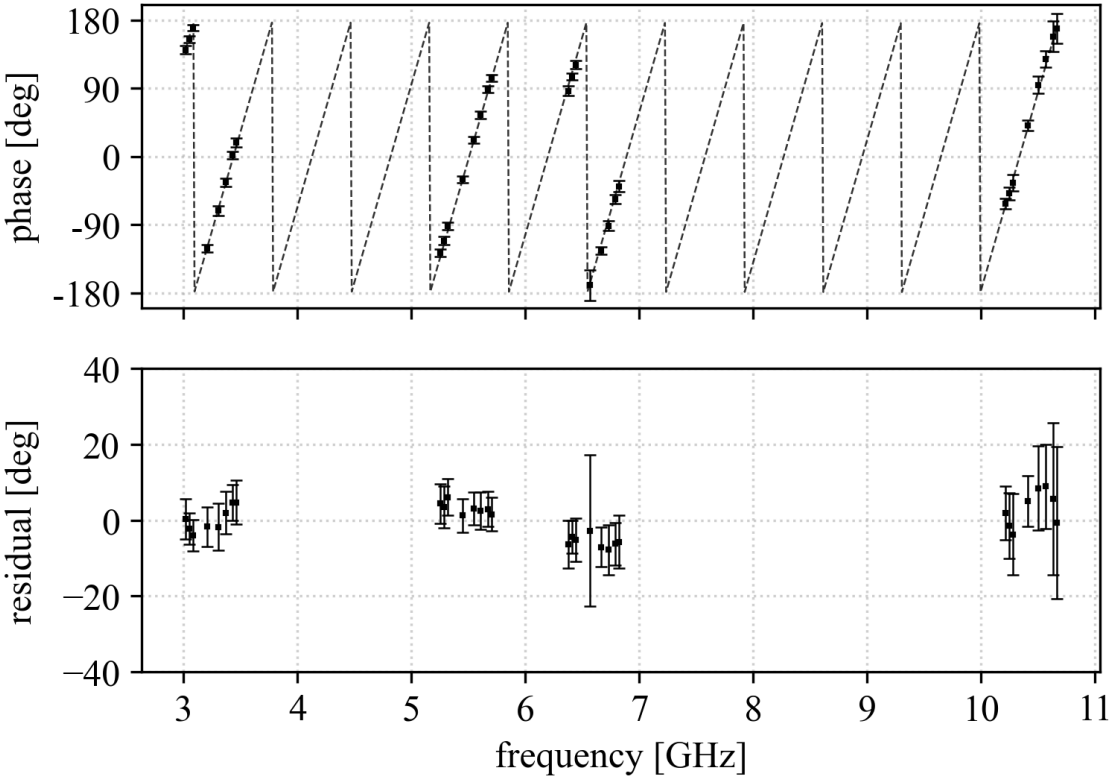
```
Results from fourphase.py:
pc_delay_y 0.208 * (ns) estimated error is +/- 0.001
pc_phase_offset_y -64.4 * (deg) estimated error is +/- 9.8

Group delay fit to Polconvert cross-bandpass filter:
delay [psec]: 221.8+/- 1.6                    (Frederic gets 230psec)
phase [deg]: 180.5 +/- 3.0
```

ER2201 – cross-polarization complex gains

For stations with a significant group delay in the cross-bandpass filter, the group delays agree fairly well with the y-x delays that we estimate in the standard VGOS post-processing for pseudo-Stokes I.





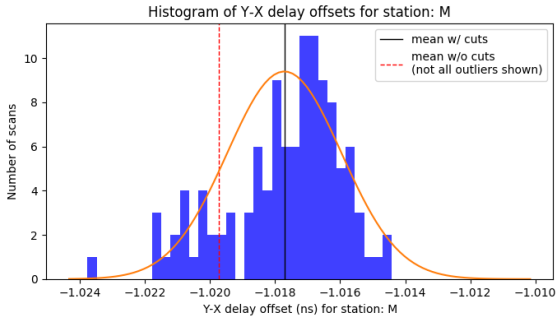
Westford:

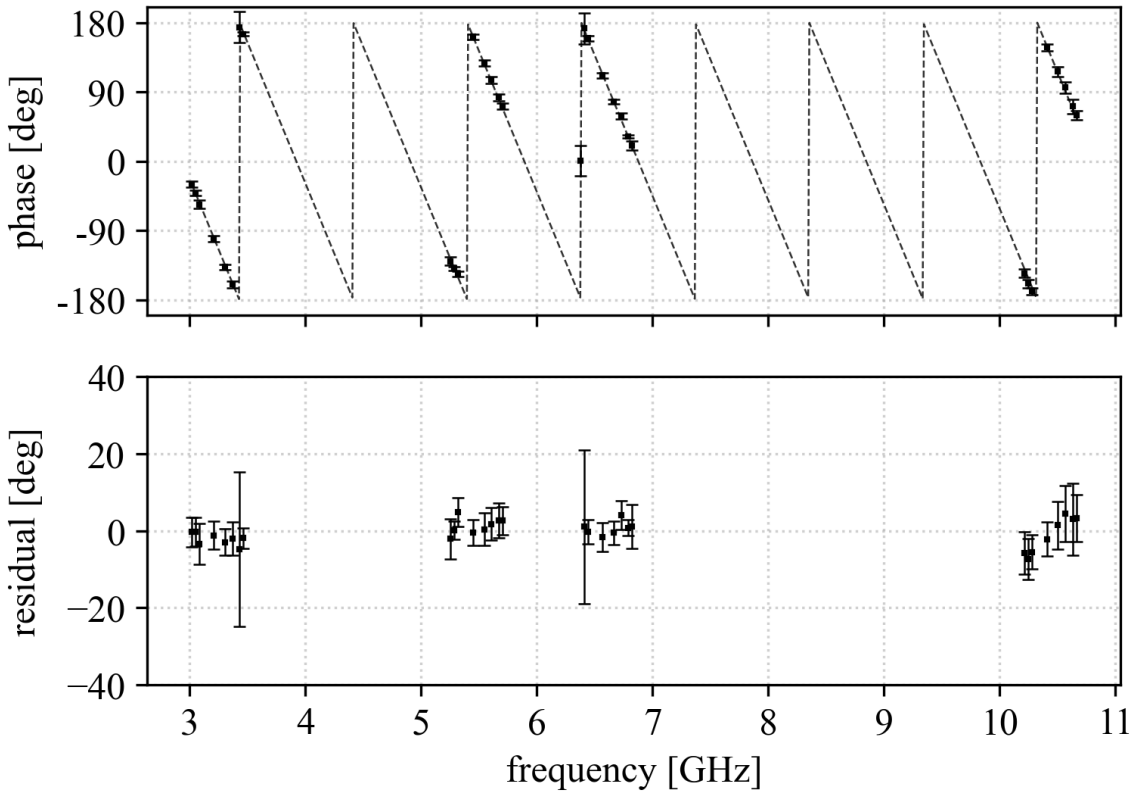
```
Results from fourphase.py:
pc_delay_y 1.45 * (ns) estimated error is +/- 0.002
pc_phase_offset_y -101.8 * (deg) estimated error is +/- 8.0

Group delay fit to Polconvert cross-bandpass filter:
delay [psec]: 1448.2 +/- 1.1
phase [deg]: -8.0 +/- 2.4
```

ER2201 – cross-polarization complex gains

For stations with a significant group delay in the cross-bandpass filter, the group delays agree fairly well with the y-x delays that we estimate in the standard VGOS post-processing for pseudo-Stokes I.





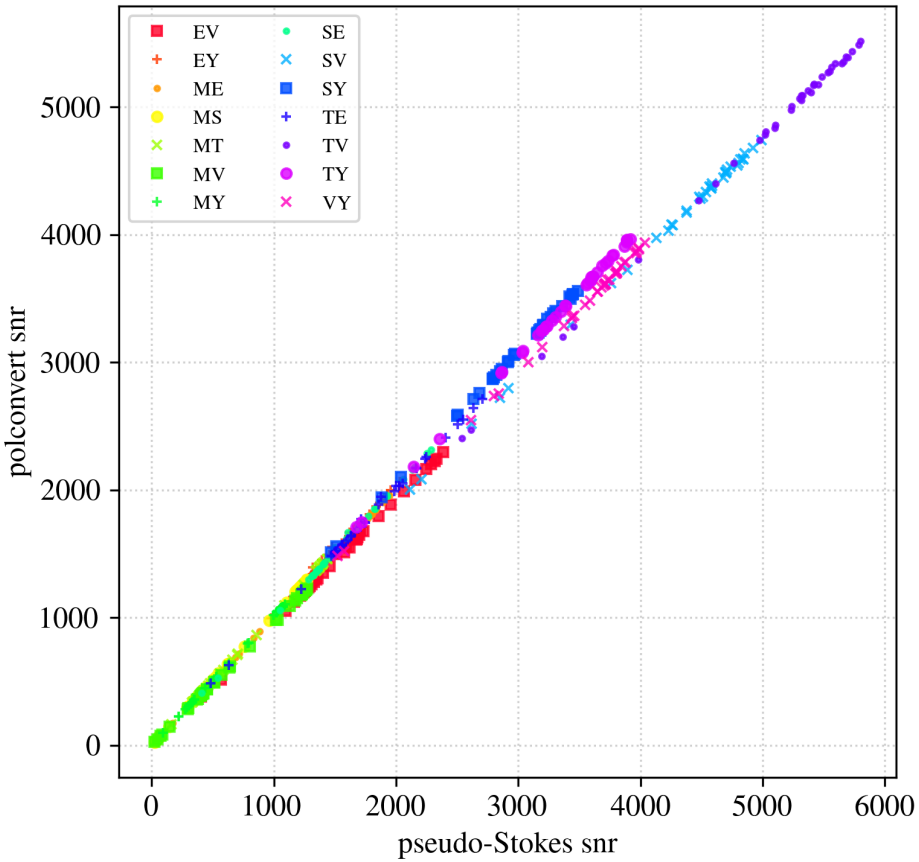
MGO:

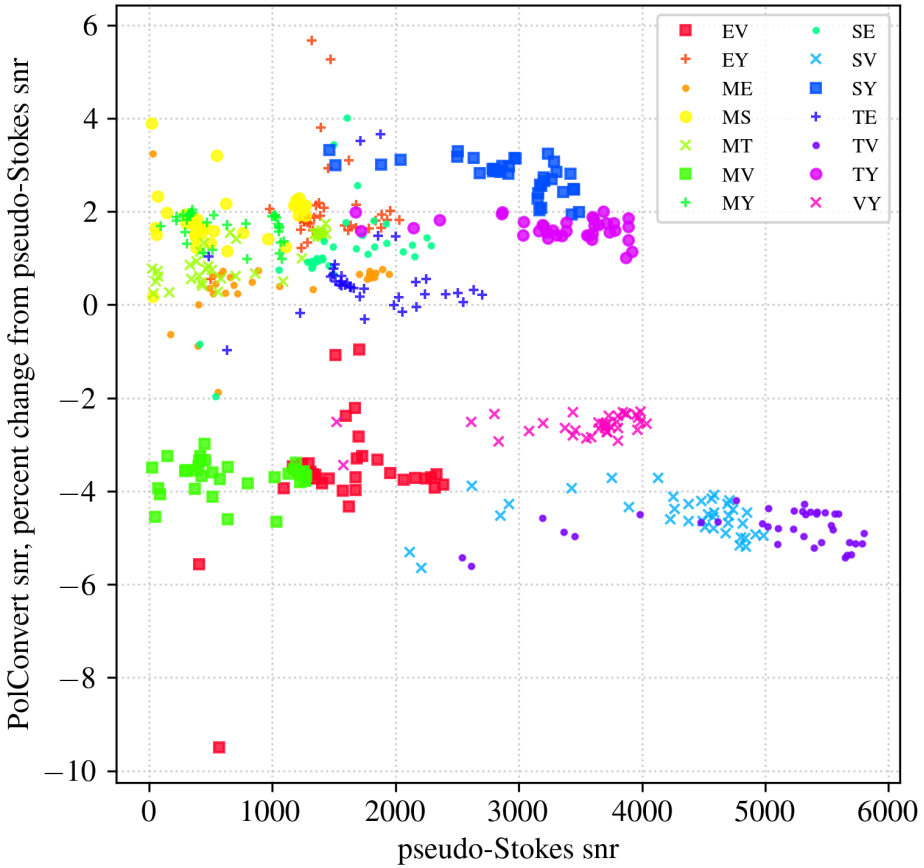
```
Results from fourphase.py:
pc_delay_y -1.018 * (ns) estimated error is +/- 0.002
pc_phase_offset_y -39.1 * (deg) estimated error is +/- 13.3

Group delay fit to Polconvert cross-bandpass filter:
delay [psec]: -1015.0 +/- 1.6
phase [deg]: -7.1 +/- 3.6
```

ER2201 – Results: SNR

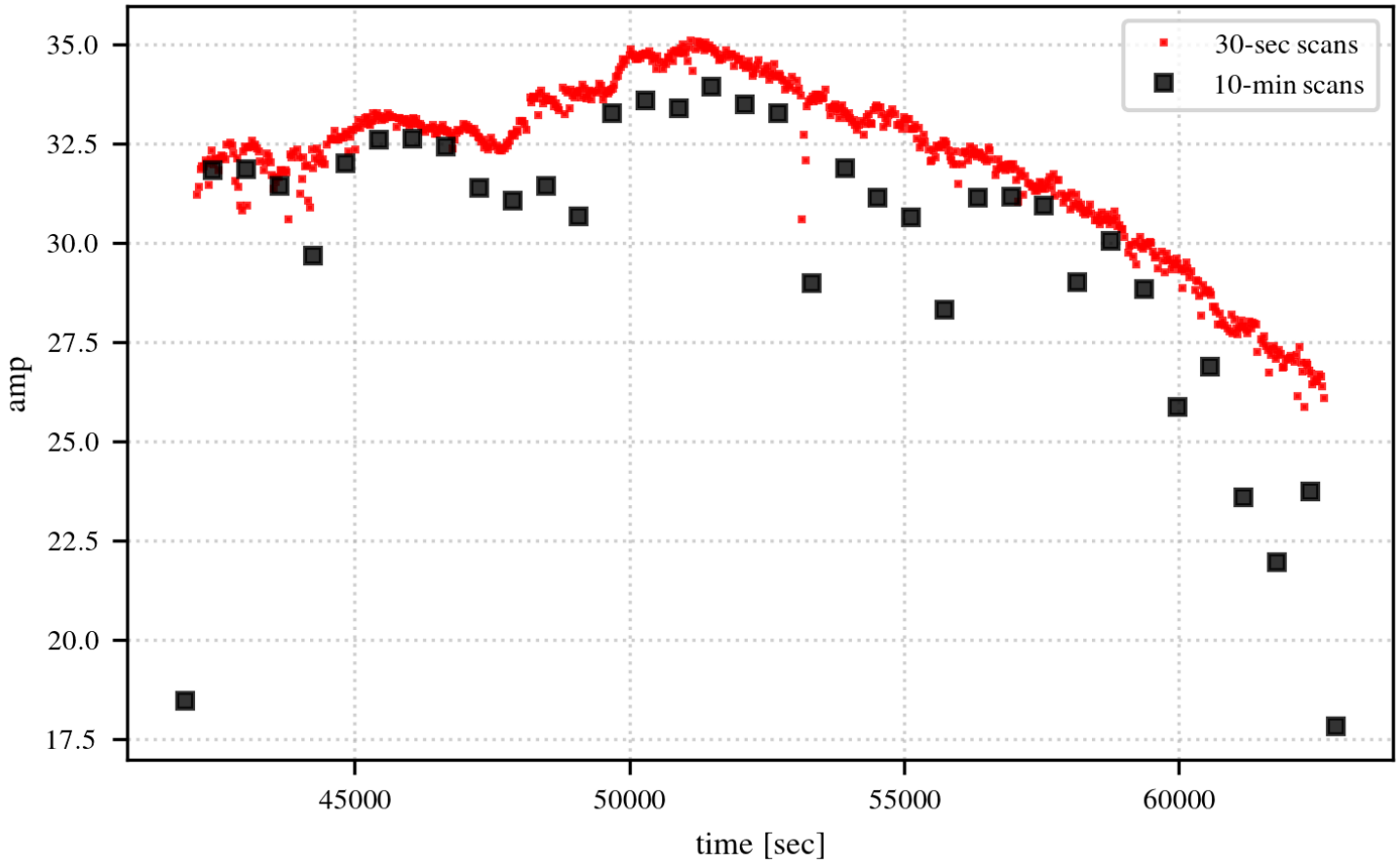
The PolConverted data improves on the pseudo-Stokes SNR by about 2%, but baselines to Wettzell are worse (-4%). Because of the large Y/X amplitude difference at Wettzel?





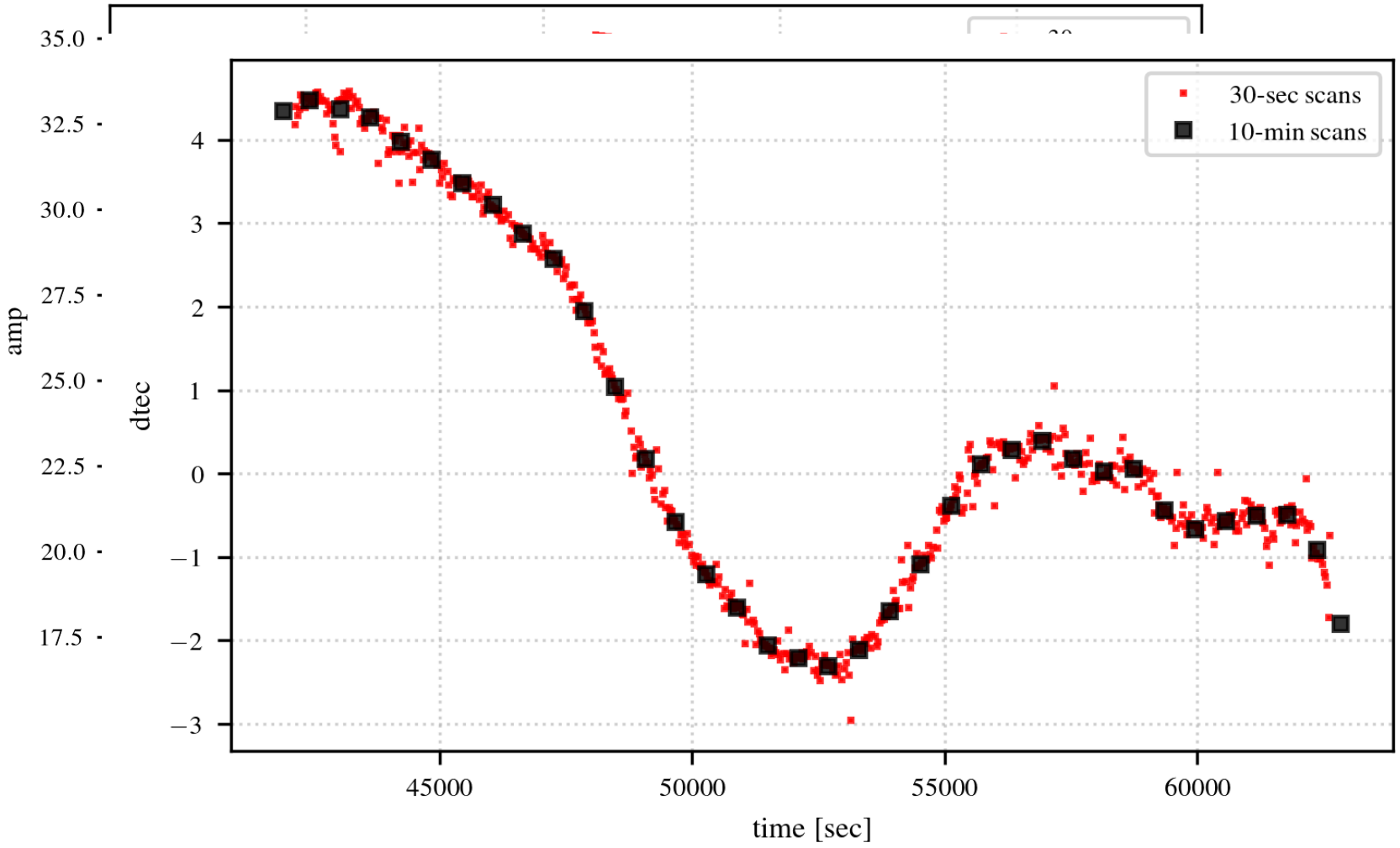
ER2201 – Results: Loss of phase coherence over 10-minute scans

VY baseline: amplitudes for 30-sec scans are higher than 10-min scans.



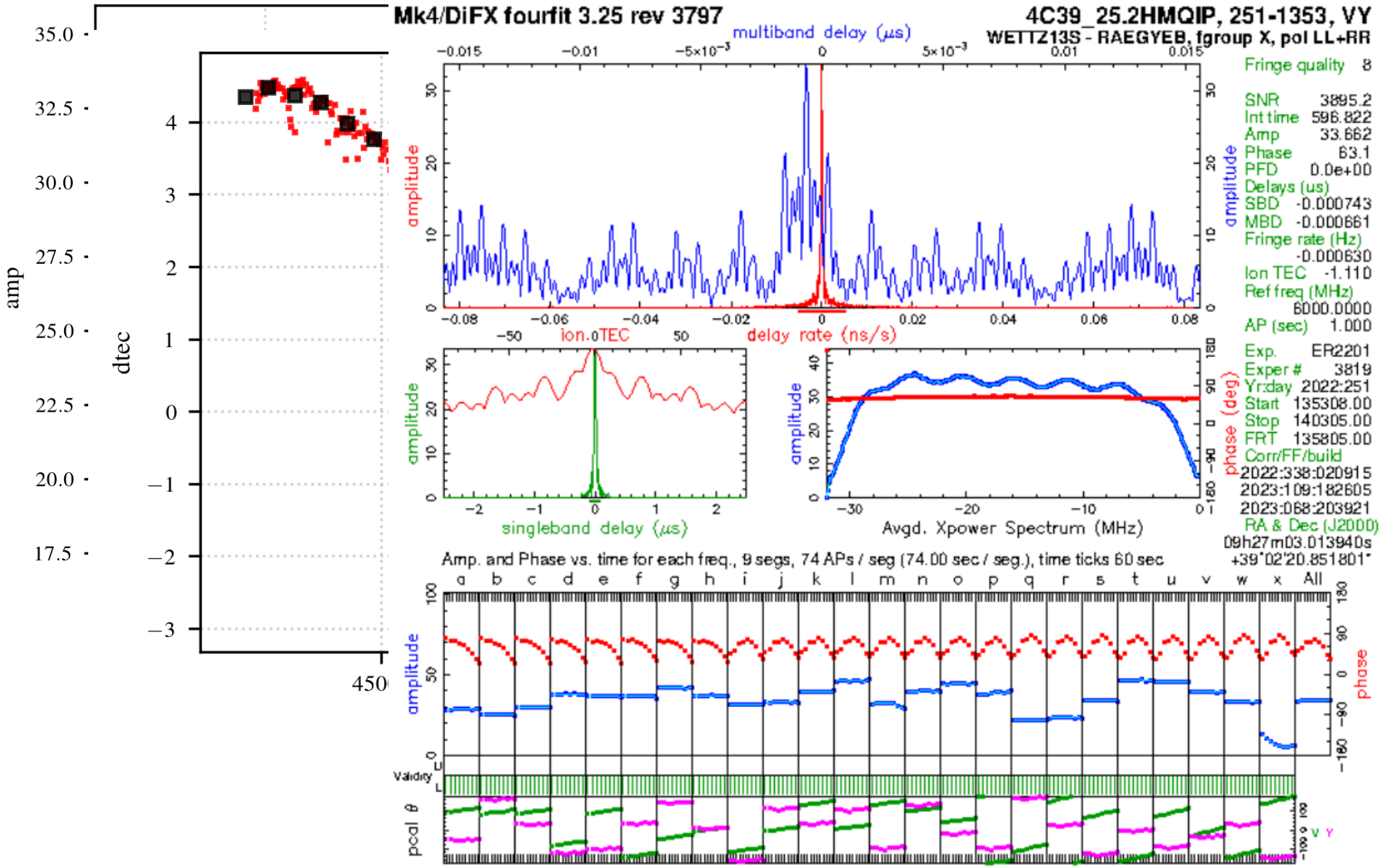
ER2201 – Results: Loss of phase coherence over 10-minute scans

VY baseline: dTEC is pretty stable, but there are other atmospheric effects…

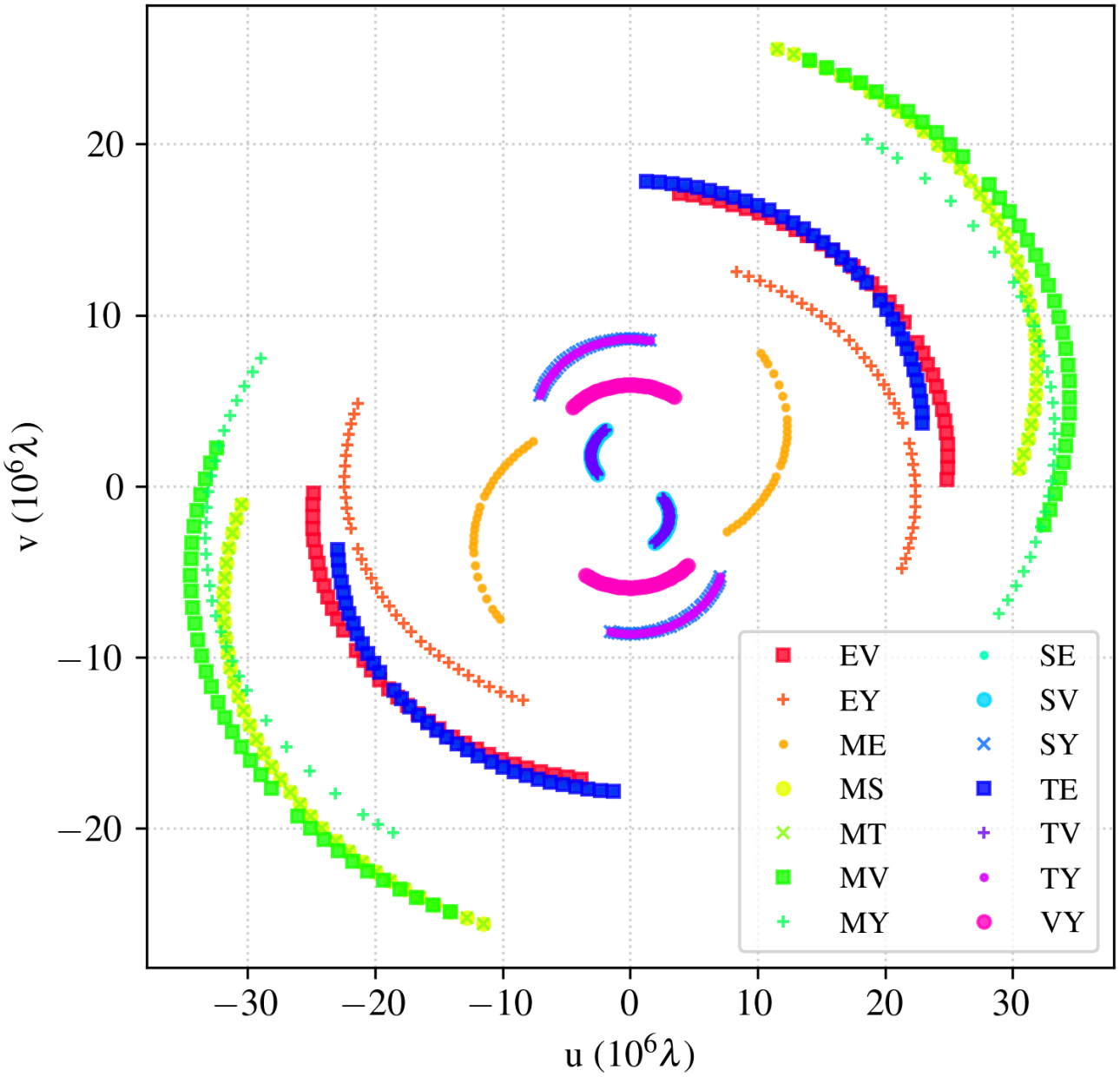


ER2201 – Results: Loss of phase coherence over 10-minute scans

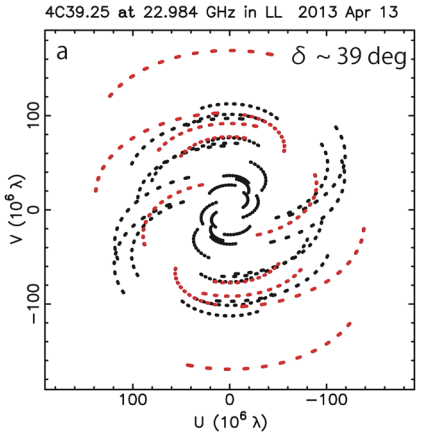
VY baseline: lots of phase evolution, sometimes 90deg or more!

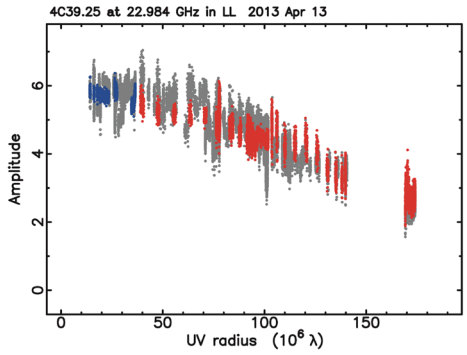


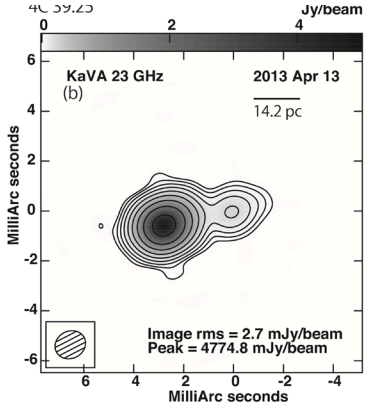
ER2201 – Results: (u,v) coverage



Some relevant figures from Niinuma et al. (2014):







ER2201 – Comparison of PolConvert and pseudo-Stokes Results

What have we learned?

PolConvert can recover the pseudo-Stokes-I SNR! And improve by a little bit.

- Measurements of Y-X group delay agree with pseudo-Stokes
- Cross-bandpass estimation depends on the size and quality of the network
- Is there any improvement in the geodetic observables?
- Using IONEX for dTEC in the fringe-fitting is probably not optimal…
- Is the amplitude information being used properly?
- Need to find more sources?

What should we try to optimize for the next experiment?

- More calibration with a larger network?
- Measure the geodetic observables?
- Motivate astronomy & polarimetry?