A New Limit on CMB Circular Polarization from SPIDER

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for the SPIDER collaboration

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TeVPA 2017

Stokes Parameters

Plane wave traveling in the z direction

$$E = \left(E_x e^{i\phi_x}\hat{x} + E_y e^{i\phi_y}\hat{y}\right) e^{i\omega t}$$

$$I = \left\langle E_x^2 \right\rangle + \left\langle E_y^2 \right\rangle \qquad U = \left\langle 2E_xE_y \cos\left(\phi_x - \phi_y\right)\right\rangle$$

$$Q = \left\langle E_x^2 \right\rangle - \left\langle E_y^2 \right\rangle \qquad V = \left\langle 2E_xE_y \sin\left(\phi_x - \phi_y\right)\right\rangle$$

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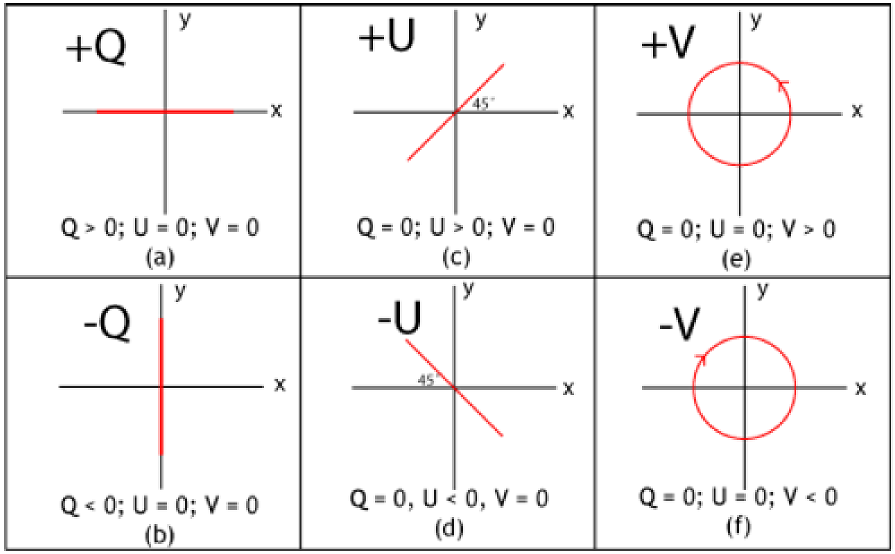
Polarization



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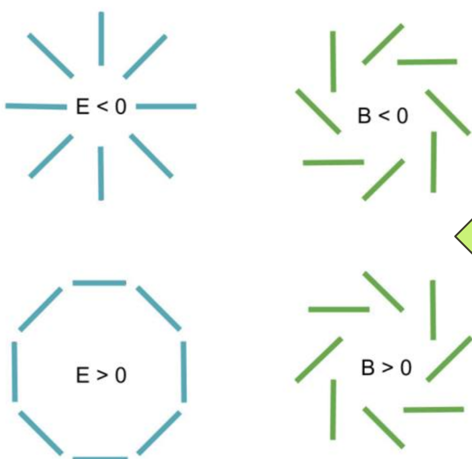

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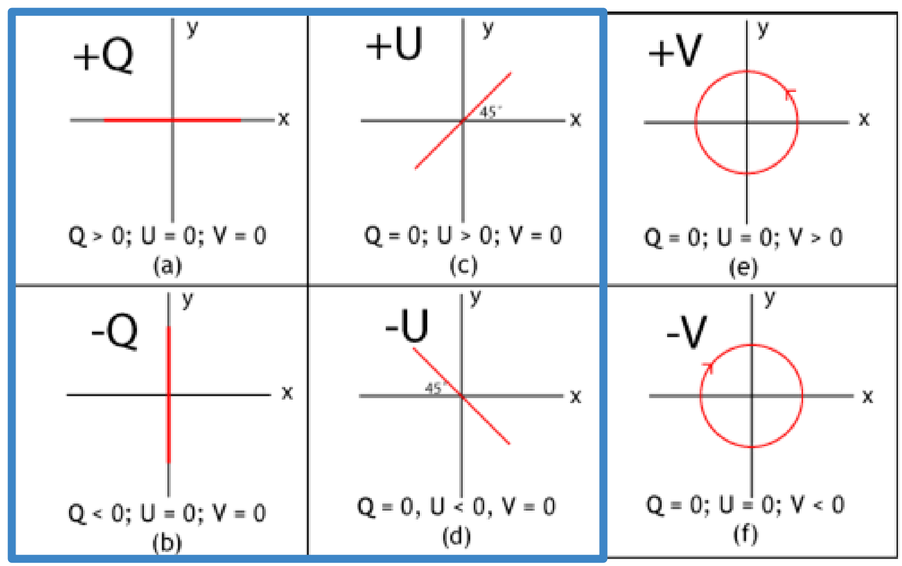
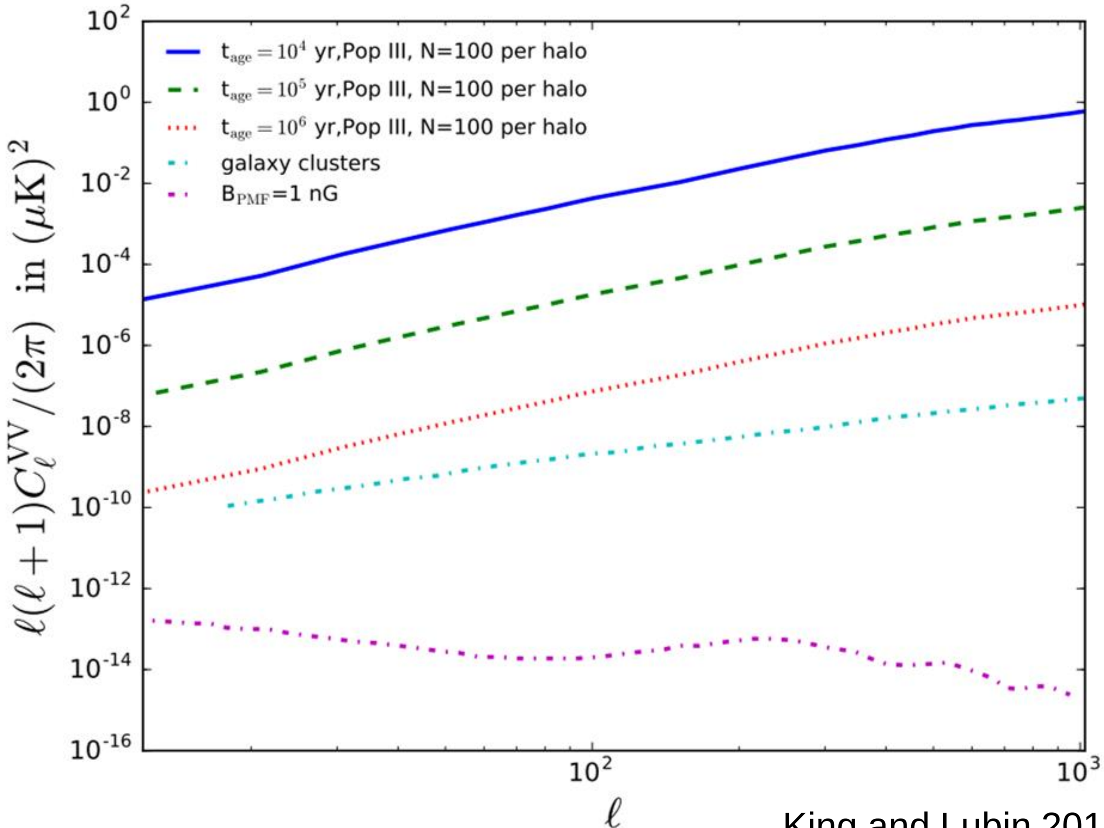


Methods of Generating Circular Polarization

1. Magnetic Fields
    - Primordial magnetic fields
    - Galaxy clusters
    - Pop III supernova remnants
2. Interactions with Known Particles
    - Scattering from neutral H
    - Cosmic neutrino background
3. Extensions to QED
    - Quantum vacuum corrections
    - Lorentz invariance violating operators
    - Axion fields

More complete list and references in King and Lubin 2016 (1606.04112)

Predicted V Signals are Small

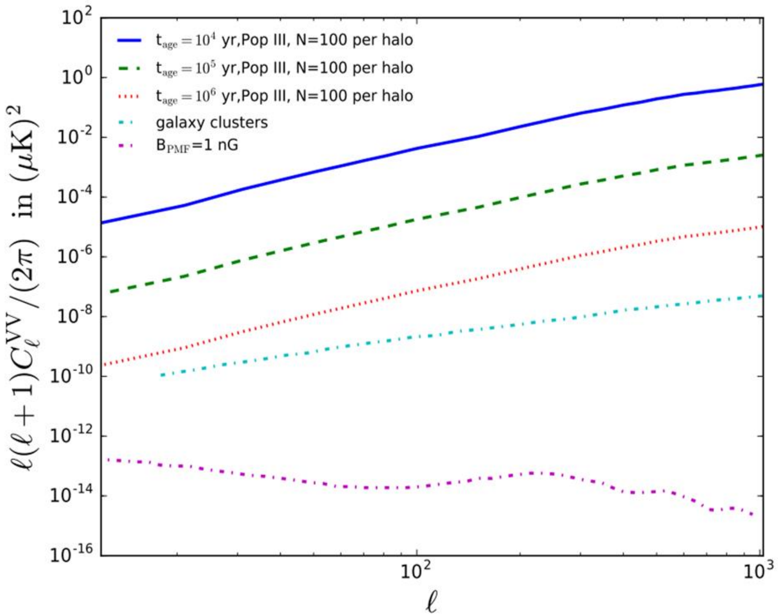


King and Lubin 2016
1606.04112

Signal predictions rely on many assumptions
(some poorly constrained)

Predicted V Signals are Small

V Predictions



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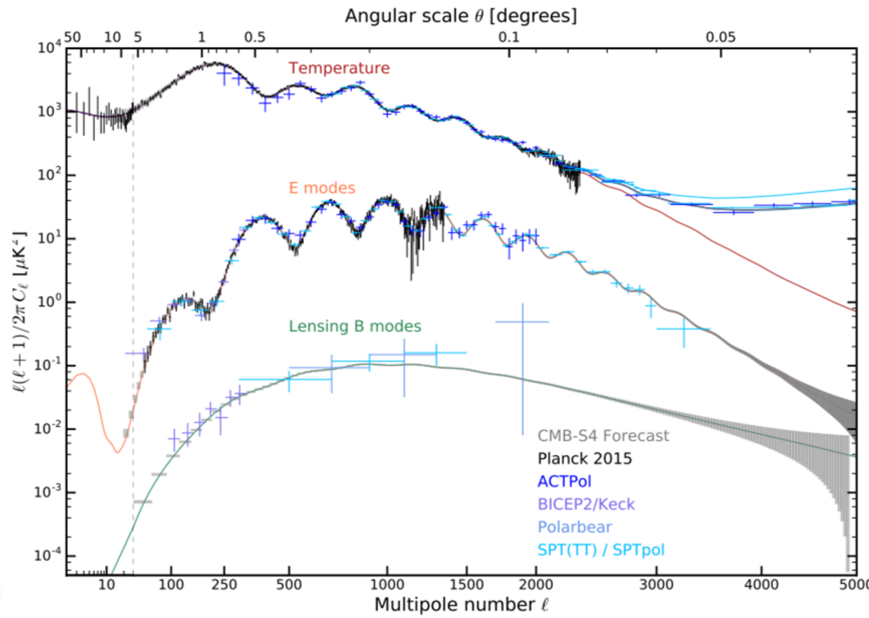
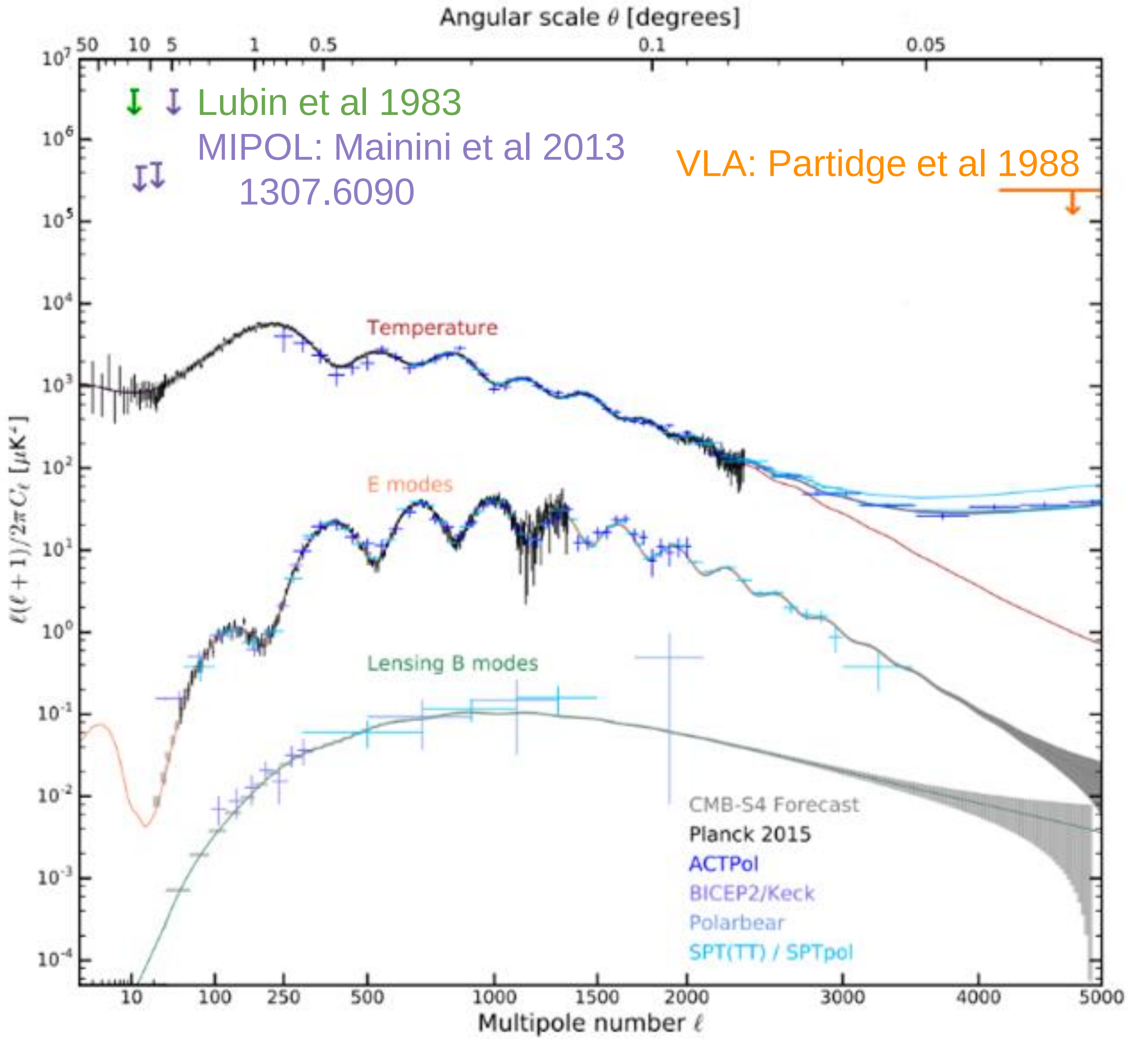
I, Q, and U Measurements



CMB-S4 Science Book
1610.02743

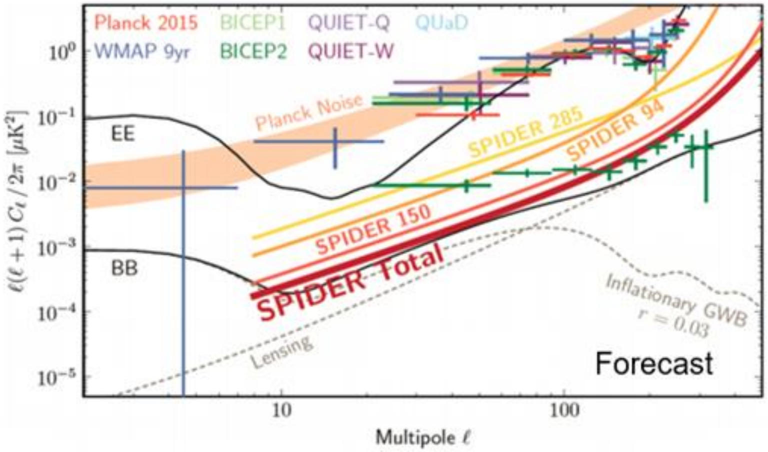
V predictions are much smaller than linear polarization measurements

CMB Circular Polarization Measurements



SPIDER Overview

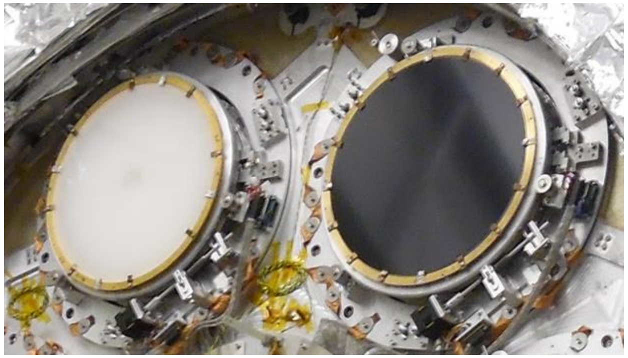
- 16 day flight in Jan 2015
- 95 and 150 GHz
- ~0.5 degree beams
- 2nd flight with 285 GHz receivers planned for Dec 2018



Fraisse et al 2013, 1106.3087
Rahlin et al 2014, 1407.2906

HWP Polarization Modulators

95 GHz 150 GHz

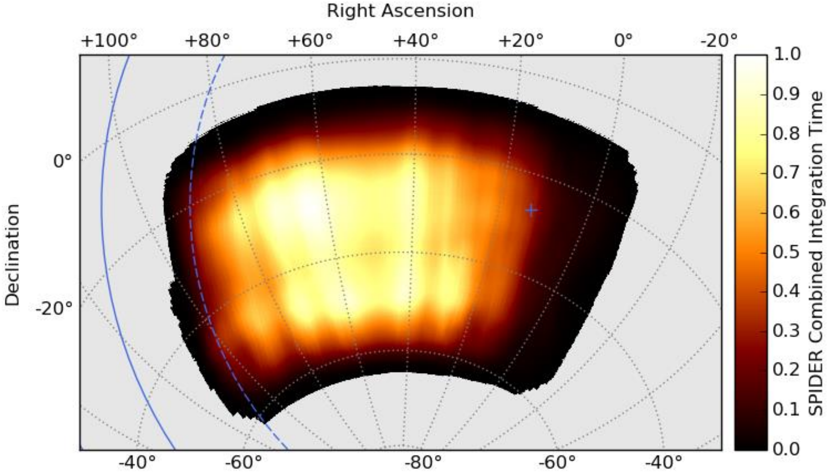


- Modulate instrument polarization sensitivity
- Birefringent single-crystal sapphires
- 4 K operation
- Rotated in discrete steps

Flight Operation

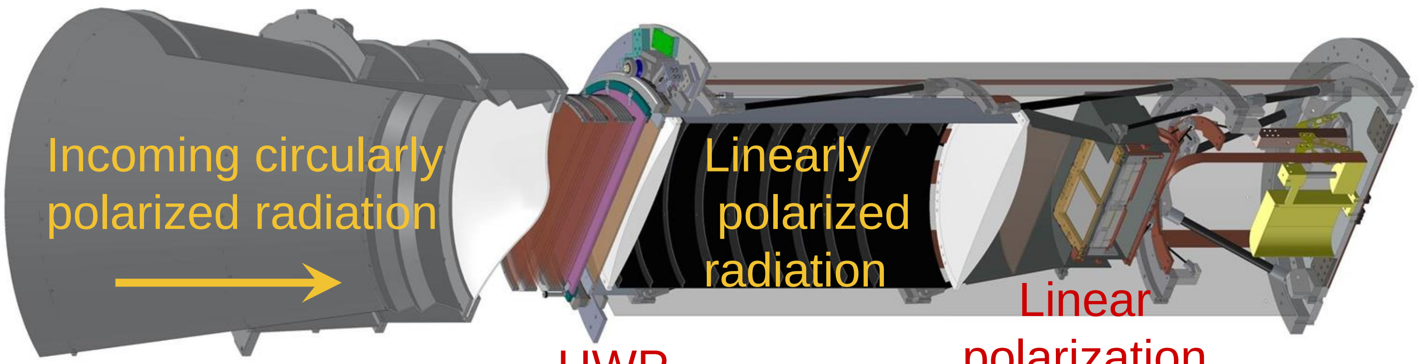
- Step in integer multiples of 22.5° every half day
- Use complementary angles for good Q/U coverage at each frequency
- 8 distinct HWP positions

2015 Flight Sky Coverage



HWPs and Circular Polarization

A non-ideal HWP partially transforms circular polarization to linear



Power detected

$$d_V \sim \boxed{s} \gamma \sin(2\theta_{HWP} - 2\xi_{det})$$

HWP *V*-coupling

Calculating SPIDER's V-Coupling

Theoretical procedure can be found in Bryan et al 2010 and Savini et al 2006

Calculate *s* for each HWP based on

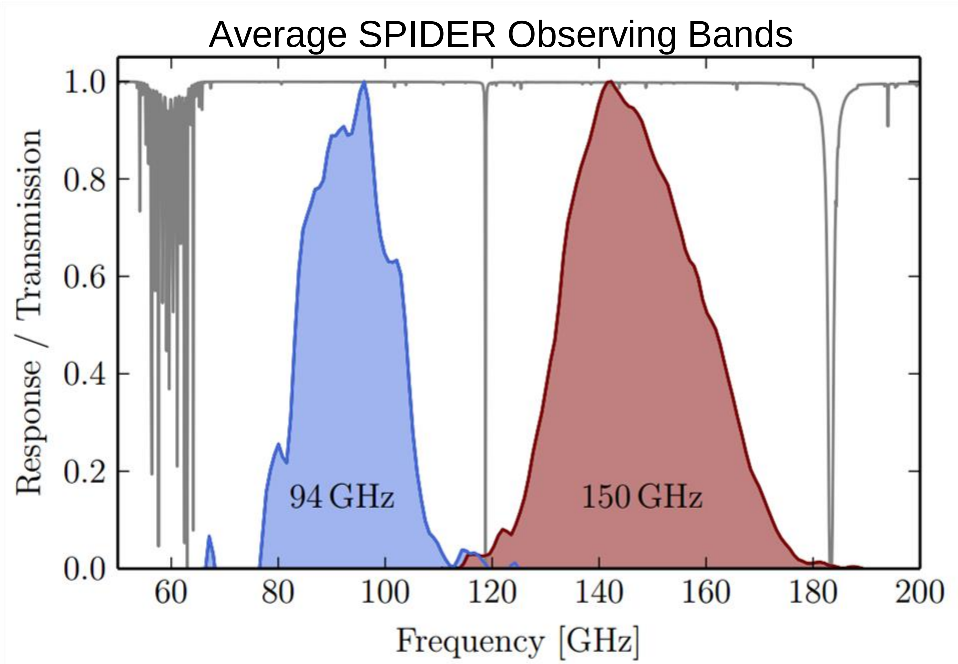
1. Measured physical HWP properties
2. Measured observing bands (for each receiver)
3. Source spectrum (CMB blackbody)

HWP Properties

Refractive index and thickness of

-sapphire
-both AR coats
-bonding layers

for each HWP



Rahlin et al 2014, 1407.2906

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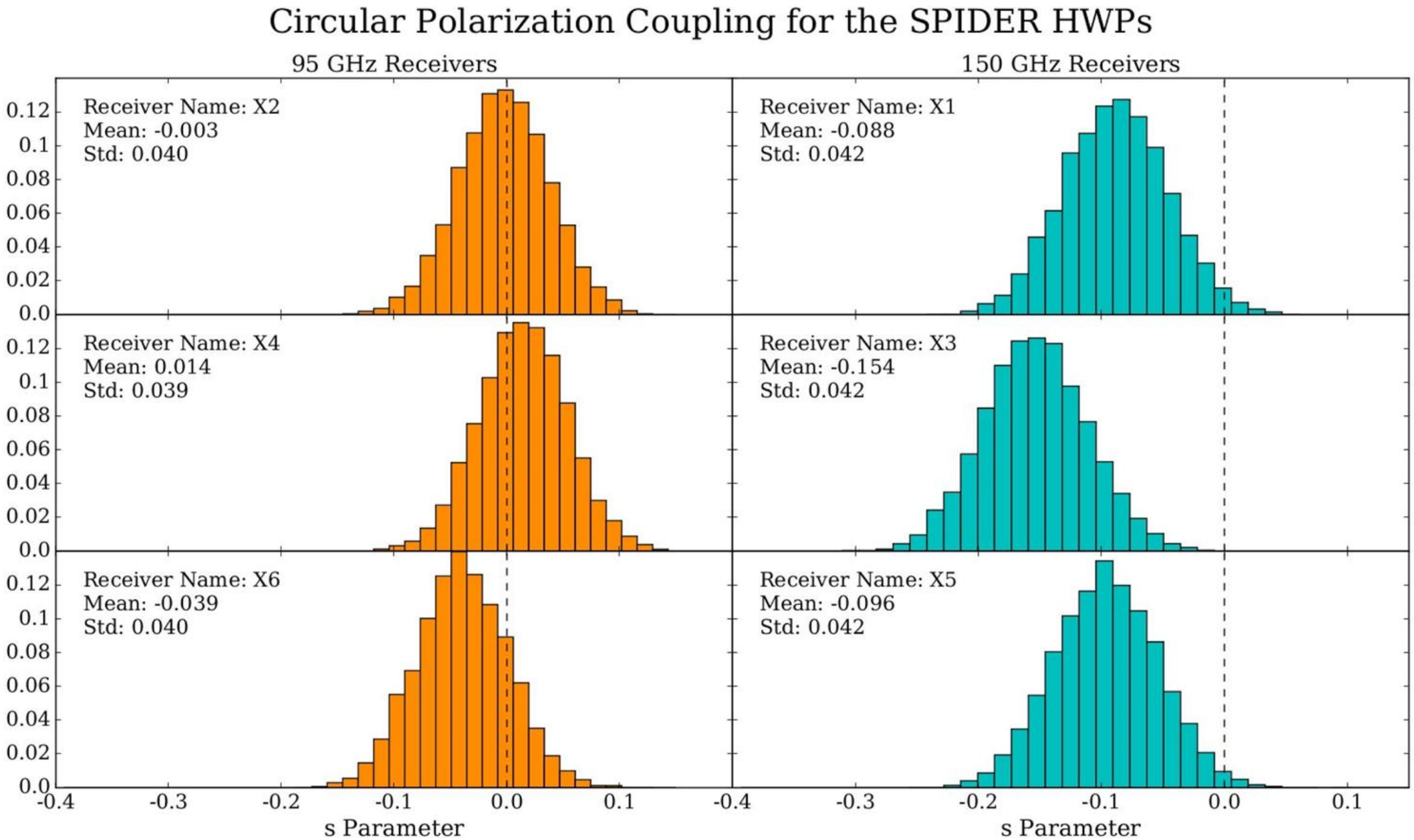
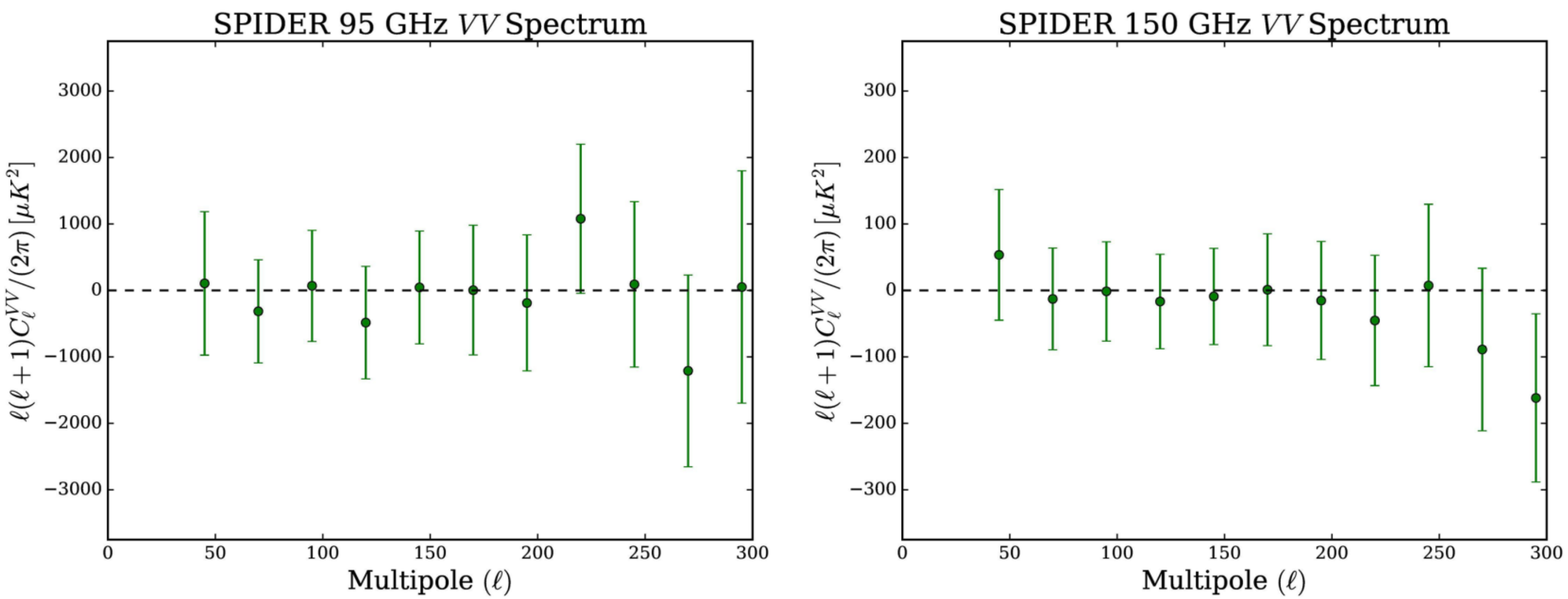


3 independent measurements at each frequency improves V sensitivity

Making V Spectra

Compute cross-spectra for pairs of $s = 1$ maps at each frequency

Use Monte Carlo sims to combine with s distributions

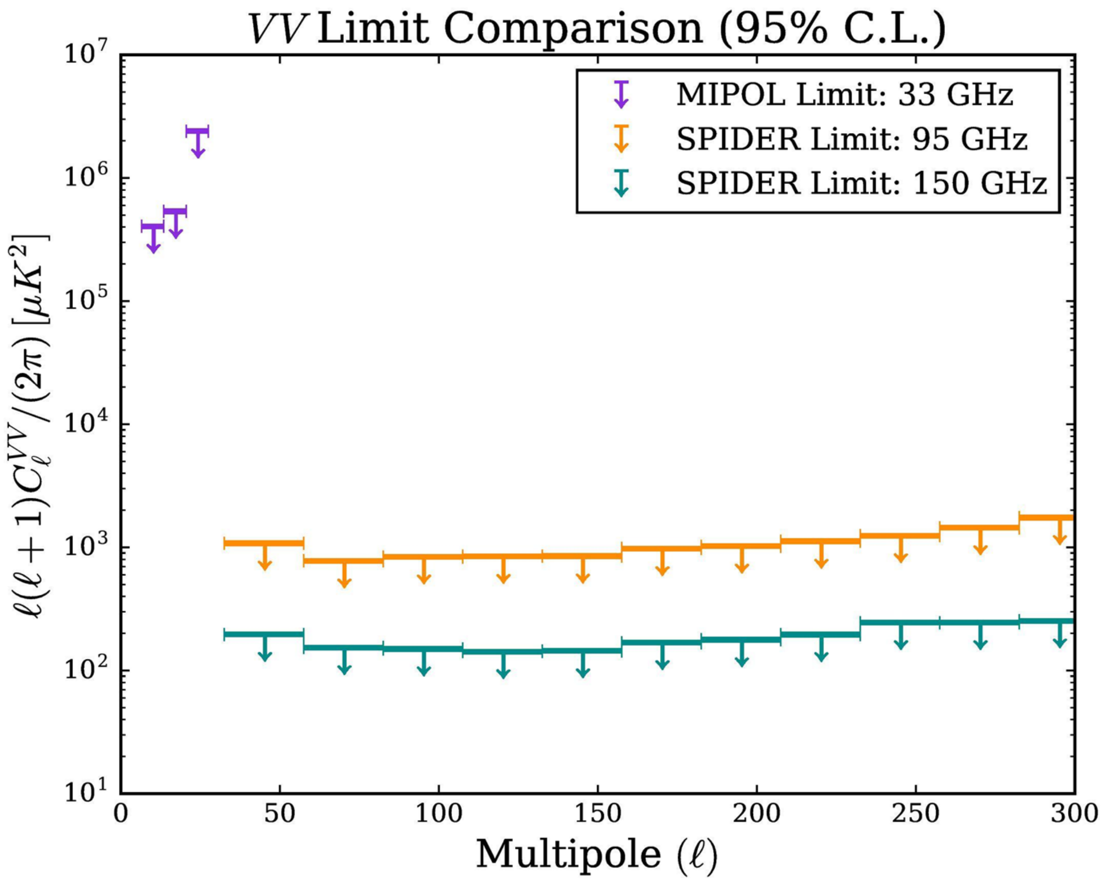


No detection of circular polarization

Error in s is highly correlated between bins

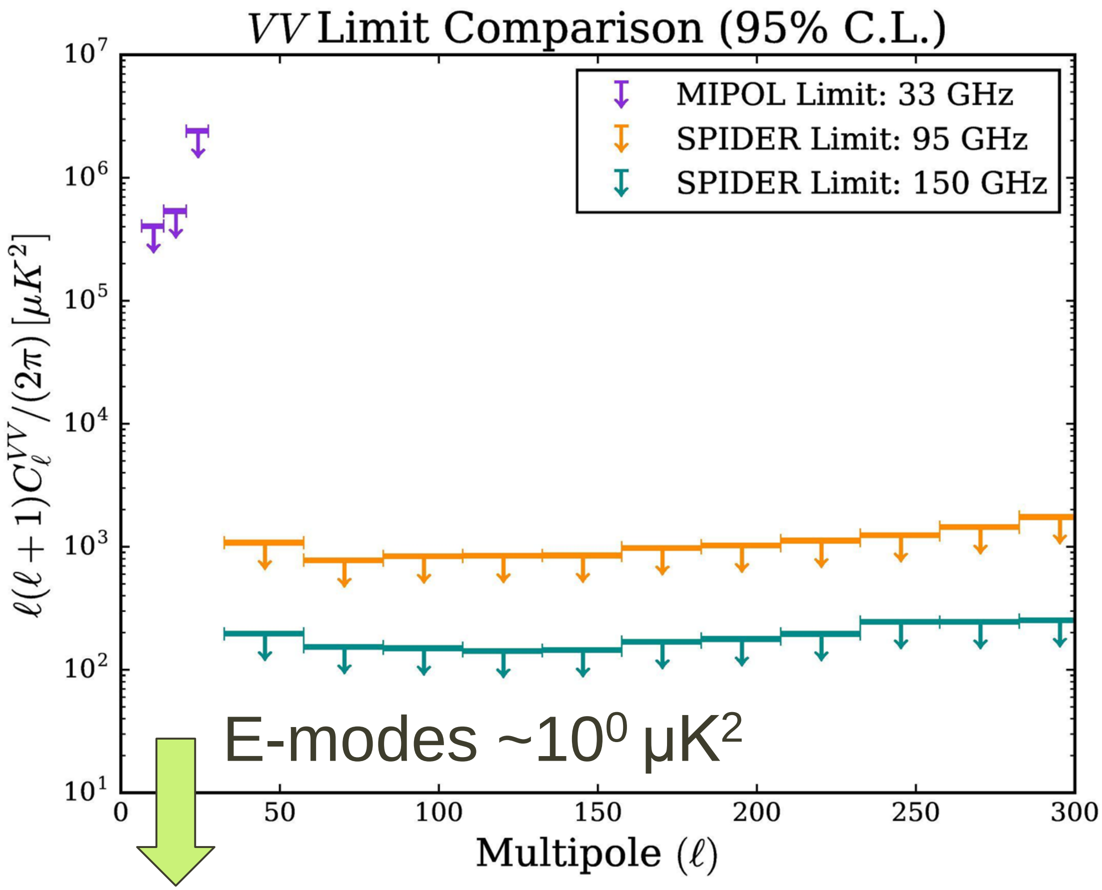
SPIDER's CMB V Limit

Convert spectra to 2σ upper limits and compare to other measurements



SPIDER's CMB V Limit

Can be extended to a limit on foregrounds and other source spectra



Conclusions

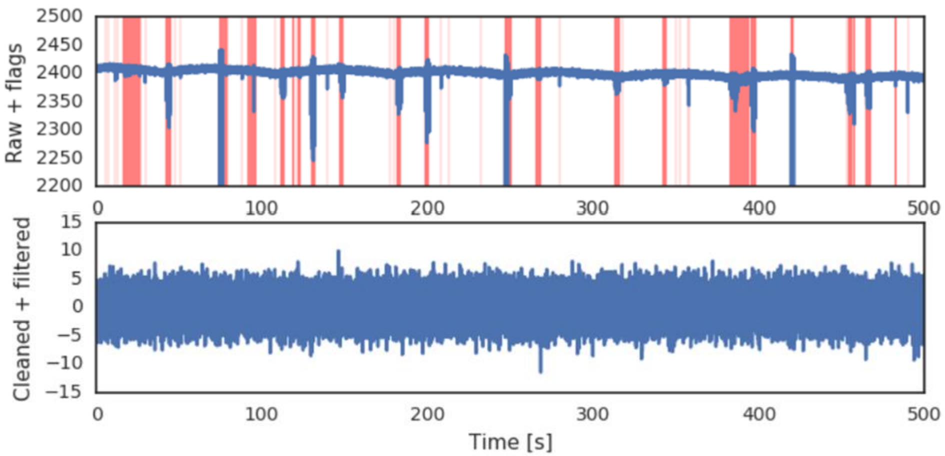
- SPIDER is primarily a linear polarization experiment, but can measure V through HWP non-idealities.
- New upper limit on CMB VV spectrum of 141 to 255 μK^2 from $33 < \ell < 307$ at 150 GHz.
- No proposed generation mechanisms predict signals at this level, but this is a free sanity check on the universe.
- Other CMB experiments may be able to apply this technique to their data to improve this limit (including SPIDER2).

Nagy et al, 1704.00215

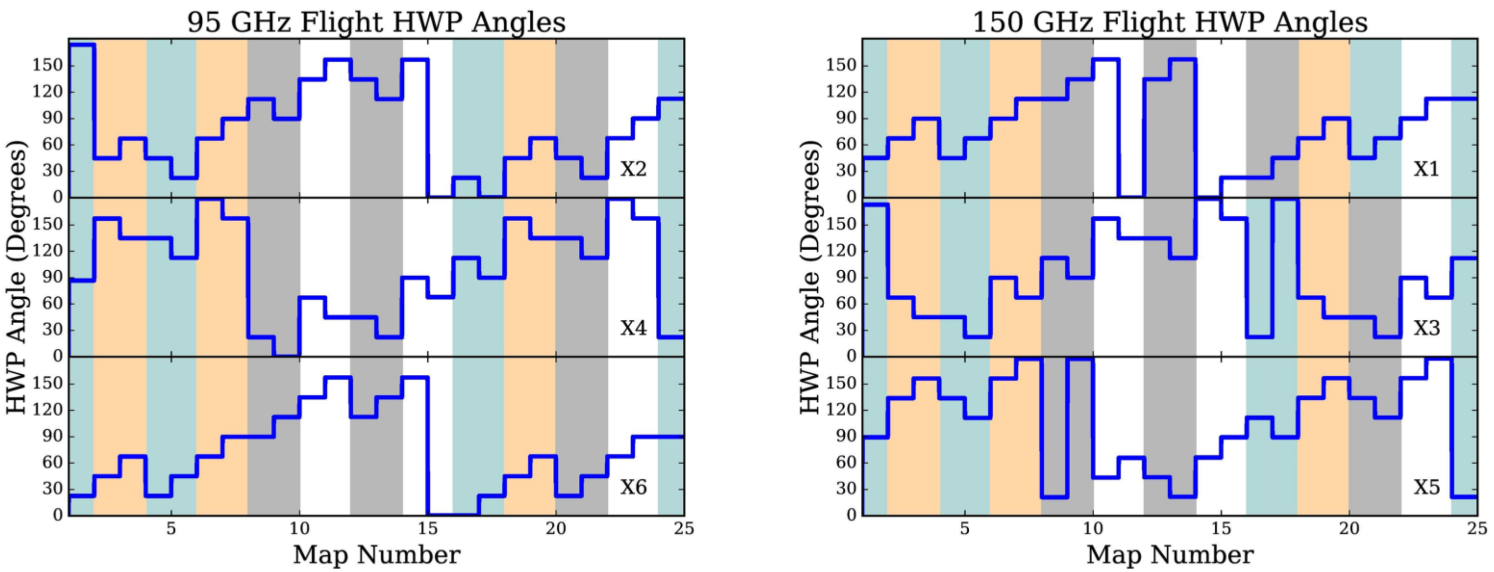
Bonus Slides

Making V Maps

Deglitch and filter the raw data



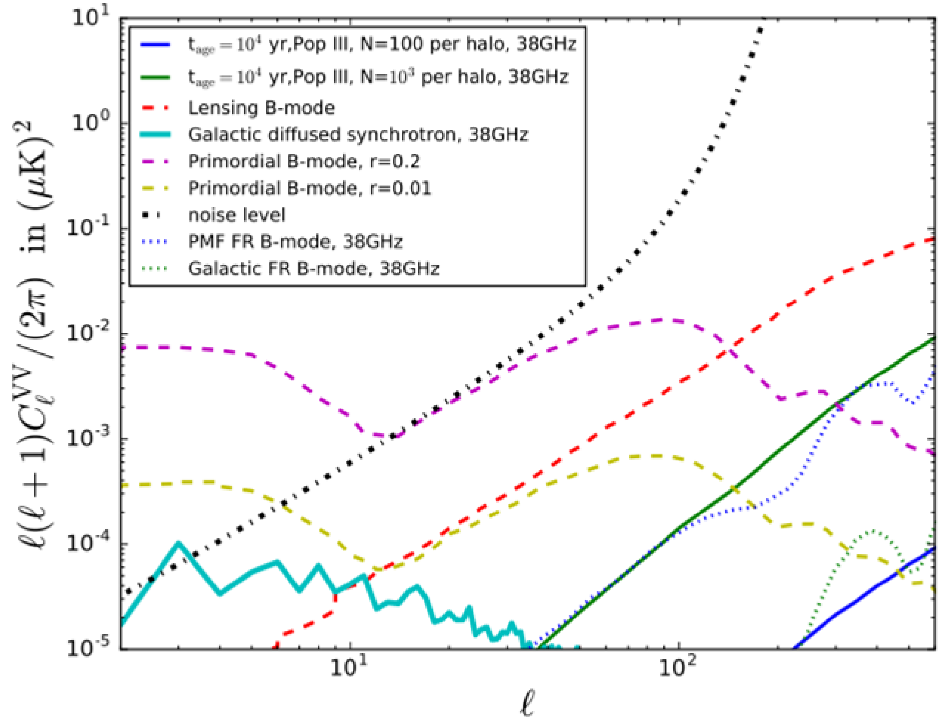
Split data into 4 independent maps for each receiver



Circularly Polarized Foregrounds

- Galactic foregrounds are the primary concern
- Dominated by synchrotron at the low frequencies of interest
- Can extend SPIDER's limit to foregrounds, but expected signals are small (though typically larger than expected cosmological signals)

Predicted Foreground Signals

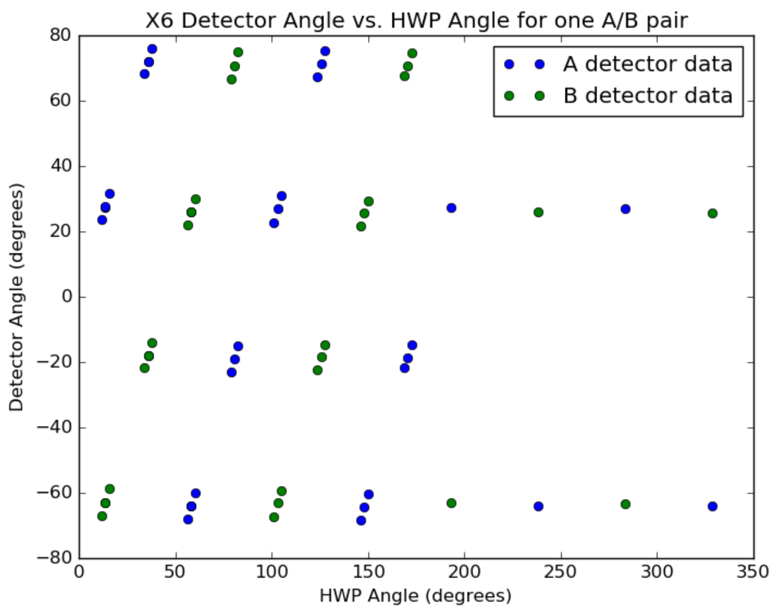


King and Lubin 2016
1606.04112

HWP Non-Idealities

- Arise due to wide band and imperfect AR coating
- See evidence from them in our angle calibration
- Create changes in linear polarization modulation

SPIDER Calibration Data



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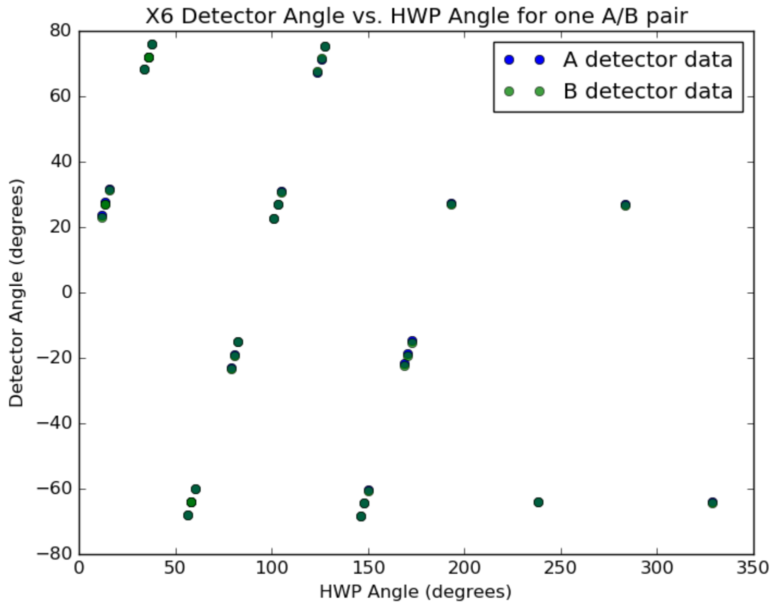

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