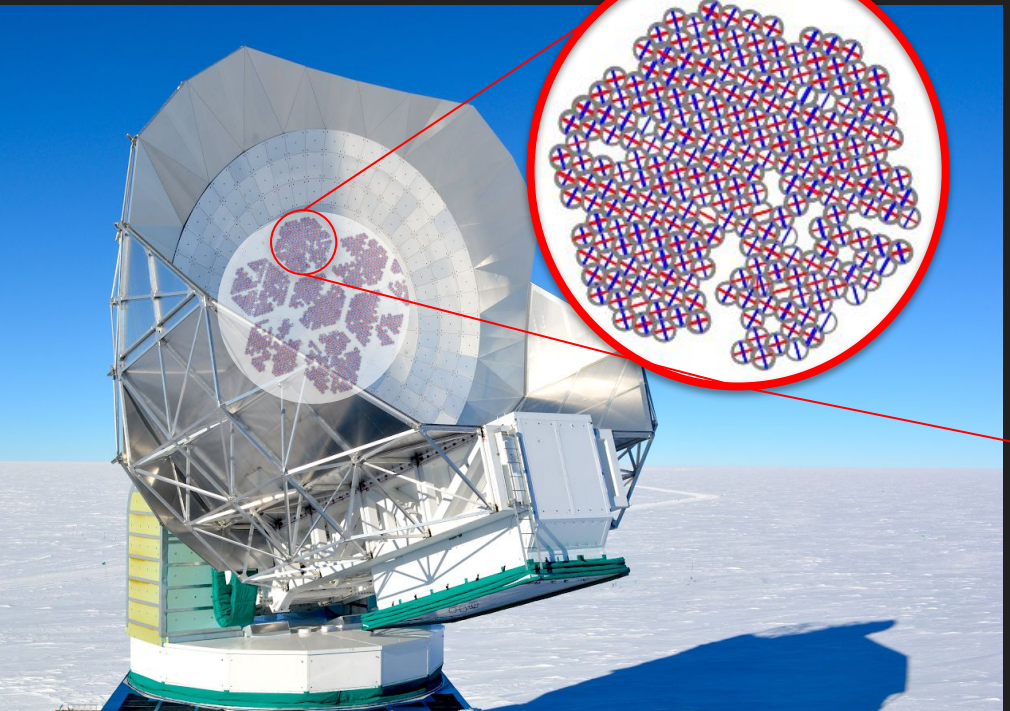
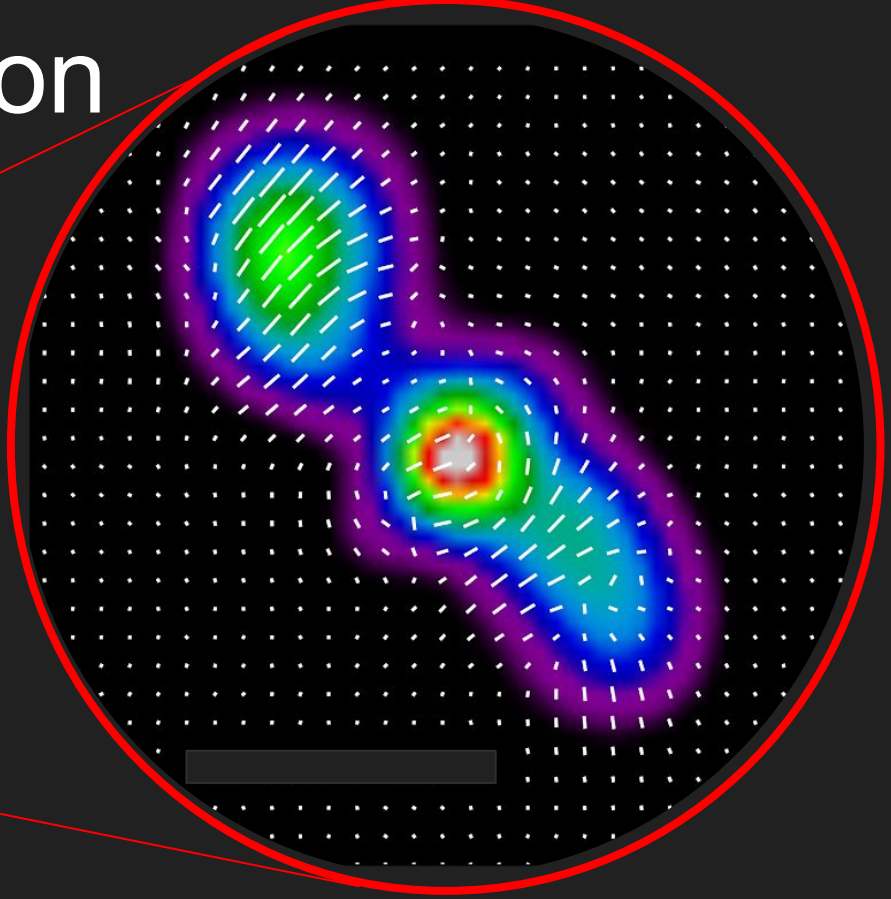
Polarization Calibration Using Cen A





Allen Foster, CMB-Cal
November 2024

1) Polarization Angle Calibration

2) Why CenA?

3) Polarization (self-*) calibration using CenA.

4) Results + Future Outlook

1) Polarization Angle Calibration

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4) Results + Future Outlook

5) Satellites?!

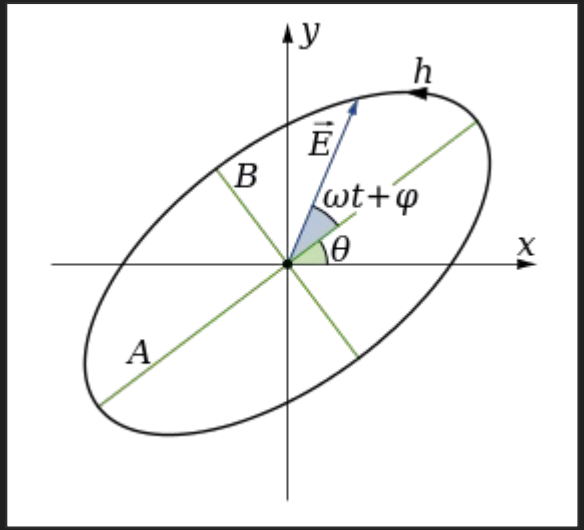
Measuring Polarization

We don’t ‘measure’ E-modes or B-modes...

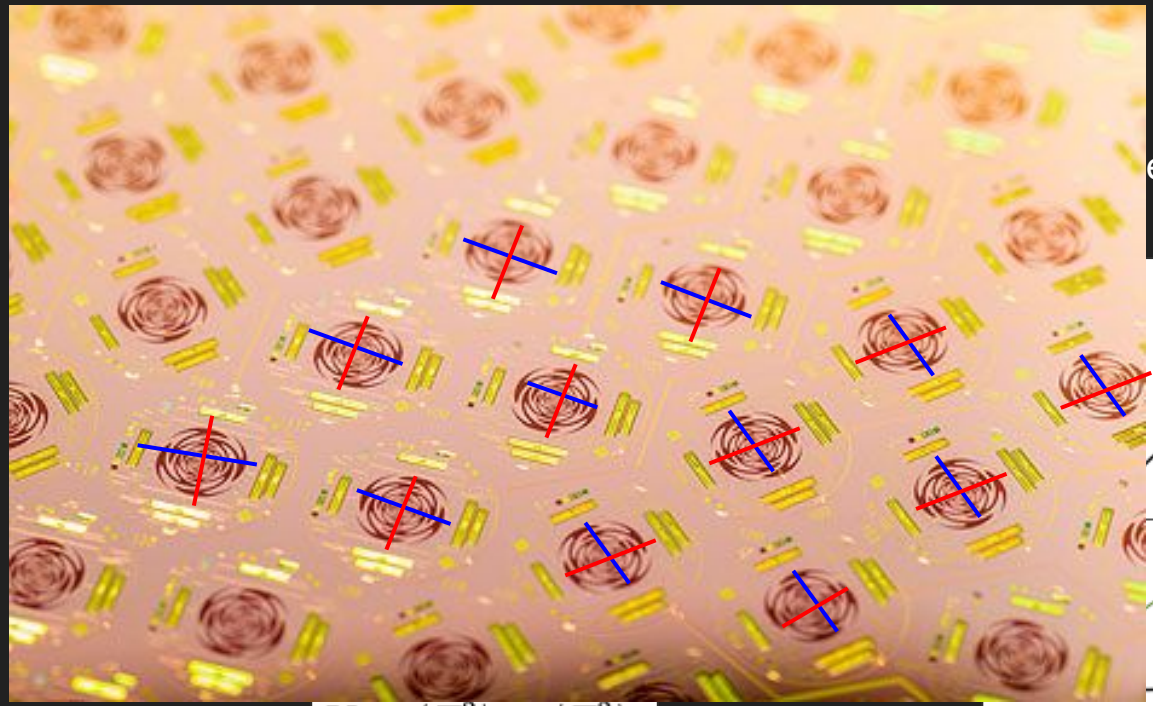
Measurable quantities are power (i.e. the time-averaged intensity in some linear polarization)

We can measure Stokes’ Parameters:

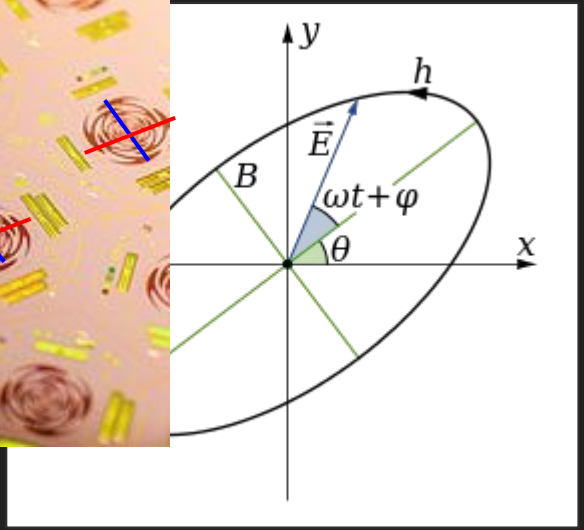
$$
\begin{aligned}
I &\equiv \langle E_x^2 \rangle + \langle E_y^2 \rangle \\
&= \langle E_a^2 \rangle + \langle E_b^2 \rangle \\
&= \langle E_l^2 \rangle + \langle E_r^2 \rangle, \\
Q &\equiv \langle E_x^2 \rangle - \langle E_y^2 \rangle, \\
U &\equiv \langle E_a^2 \rangle - \langle E_b^2 \rangle, \\
V &\equiv \langle E_l^2 \rangle - \langle E_r^2 \rangle.
\end{aligned}
$$



Measuring Polarization



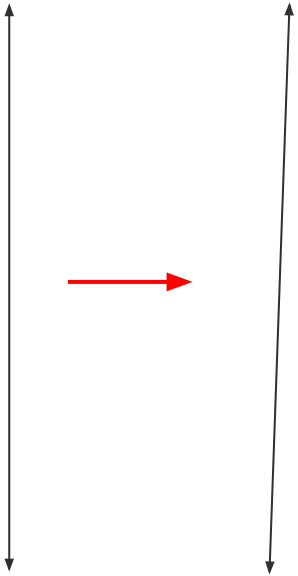
ensity in some linear



$$V \equiv \langle E_l^2 \rangle - \langle E_r^2 \rangle.$$

Measuring Polarization

What if our angle is slightly off?



= Slightly smaller Q + some U

Measuring Polarization

What if our angle is slightly off?

$$
\begin{aligned}
C_\ell^{TE} &= \cos(2\Delta\psi)\tilde{C}_\ell^{TE} \\
C_\ell^{EE} &= \sin^2(2\Delta\psi)\tilde{C}_\ell^{BB} + \cos^2(2\Delta\psi)\tilde{C}_\ell^{EE} \\
C_\ell^{EB} &= \frac{1}{2}\sin(4\Delta\psi)\left(\tilde{C}_\ell^{BB} - \tilde{C}_\ell^{EE}\right) \\
C_\ell^{TB} &= -\sin(2\Delta\psi)\tilde{C}_\ell^{TE} \\
C_\ell^{BB} &= \cos^2(2\Delta\psi)\tilde{C}_\ell^{BB} + \sin^2(2\Delta\psi)\tilde{C}_\ell^{EE}\,.
\end{aligned}
\tag{5}
$$

Brian G. Keating *et al* 2013 *ApJL* **762** L23

Why do we use an astrophysical source?

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Far field for a large aperture CMB telescope is many kilometers…

Drones require special permits by the NSF to be used in Antarctica
(plus it's very cold, -30C on average during warmest parts of summer)
((to get a drone to ~far field would be difficult))

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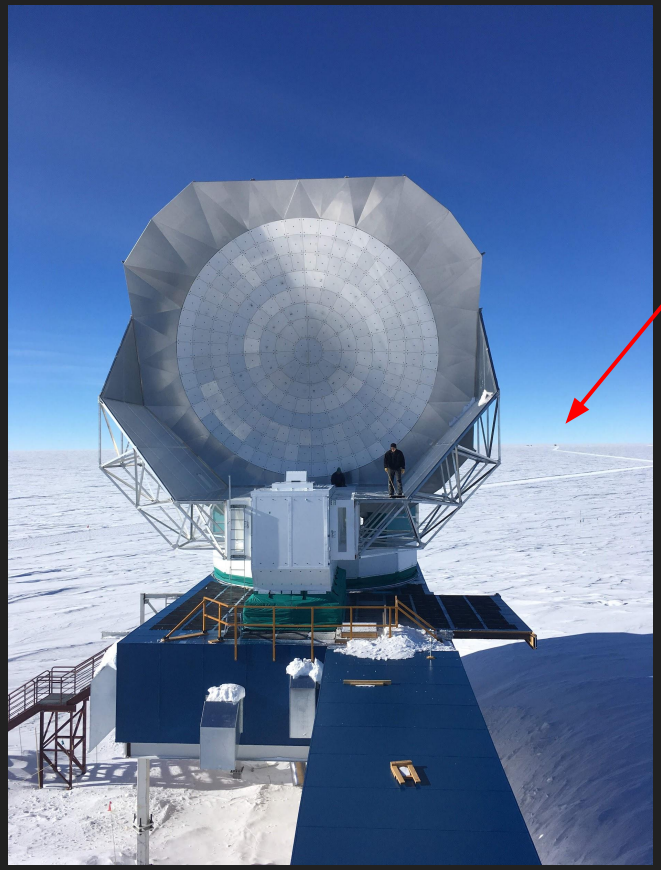
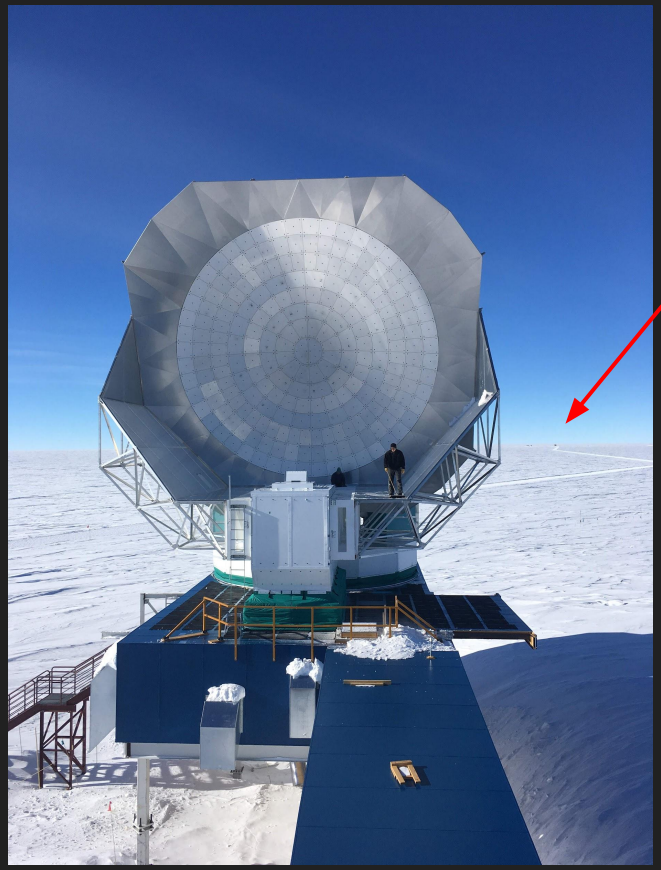
The CMB EB nulling characterizes the instrument, but computationally intensive to make single detector maps!
(and we want to know individual detector properties for time-domain)

SPTpol attempted polarization calibration in pseudo far-field



The source was 3km away… but near the ground.

SPT3G saturates when looking this low in elevation…



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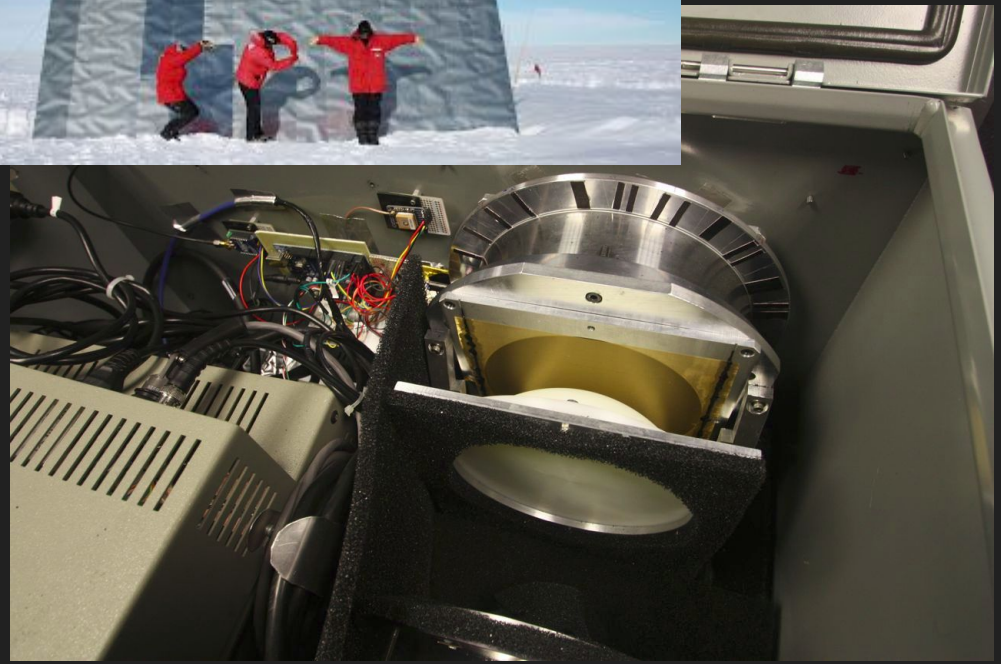
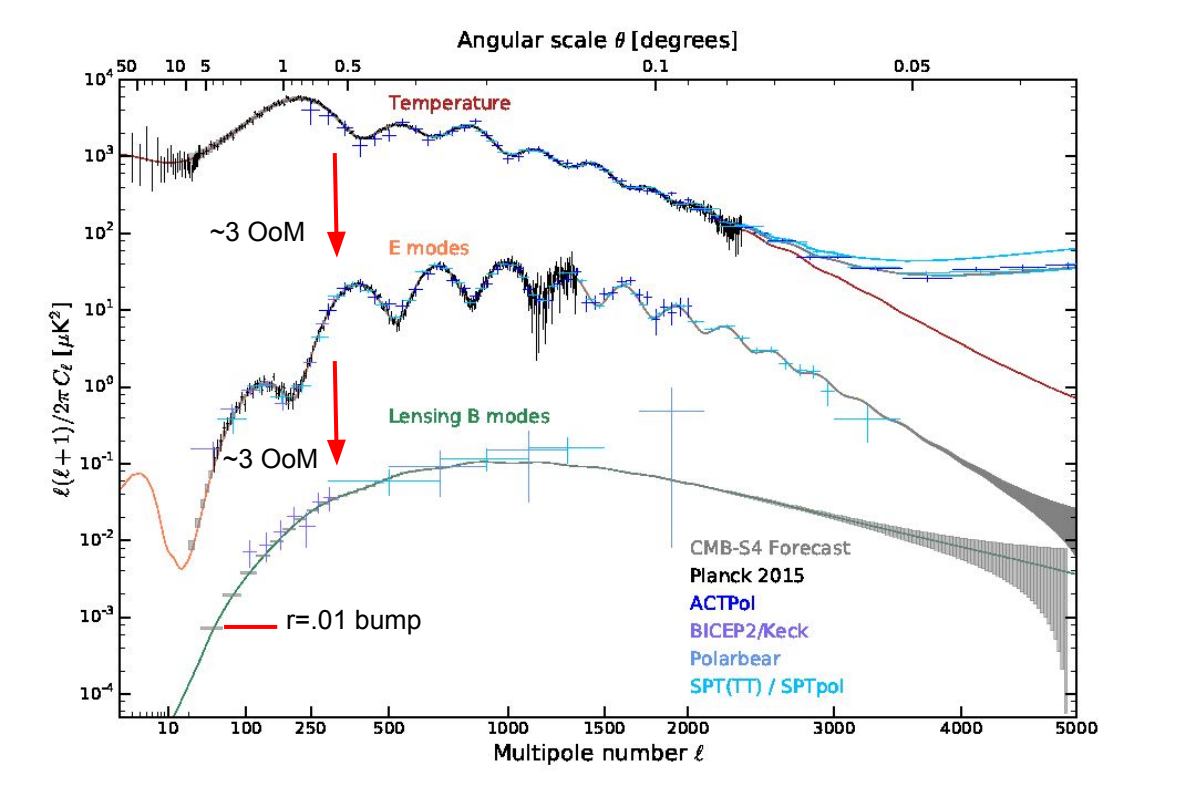


The hard part.



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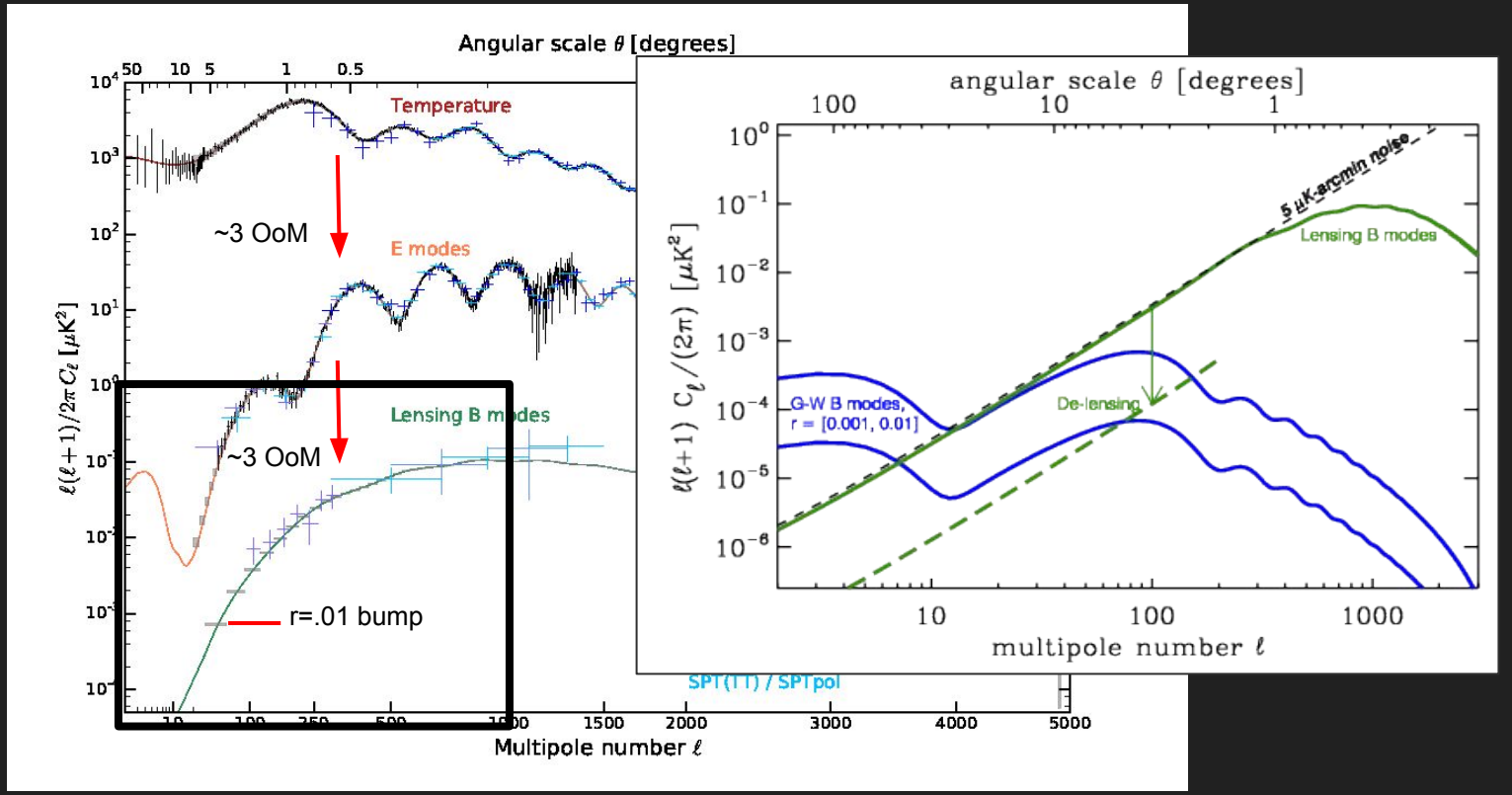

Why CenA?

X-ray: NASA/CXC/CfA/R.Kraft et al.; Submillimeter: MPIfR/ESO/APEX/A.Weiss et al.; Optical: ESO/WFI

Why CenA?

It’s the brightest AGN in the SPT observable sky*

Nearest AGN (3.4Mpc)!

Large radio lobes that are polarized!

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Calibration

Use Centaurus A. with it's beam-filling polarized lobes.

T,Q,U coadd maps

$$d = \frac{1}{2} G \left[(2-\rho) T + \rho \cos(2\alpha) Q + \rho \sin(2\alpha) U \right]$$

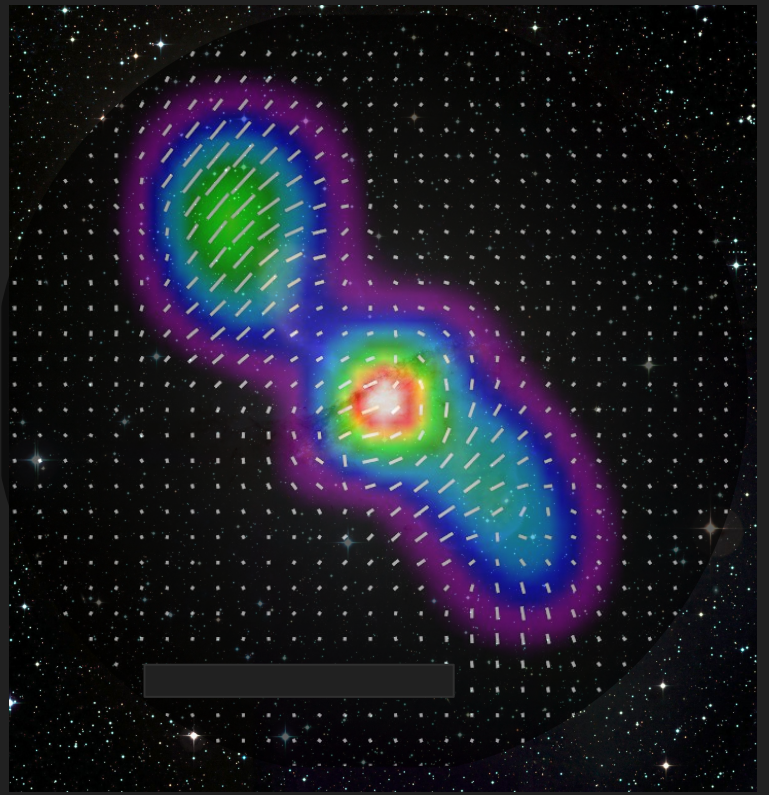
Detector polarization angle

Detector gain

Detector polarization efficiency

Individual Detector map

… Pulling ourselves up by our bootstraps



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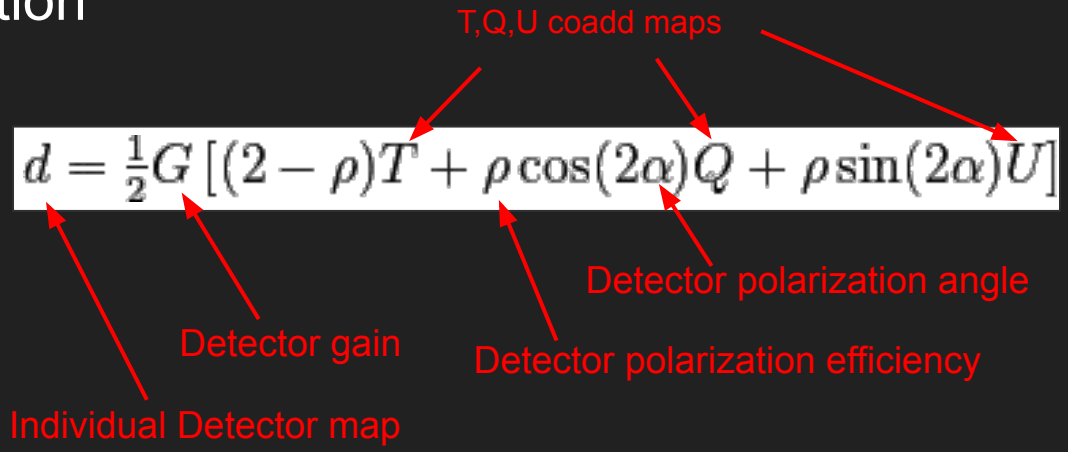
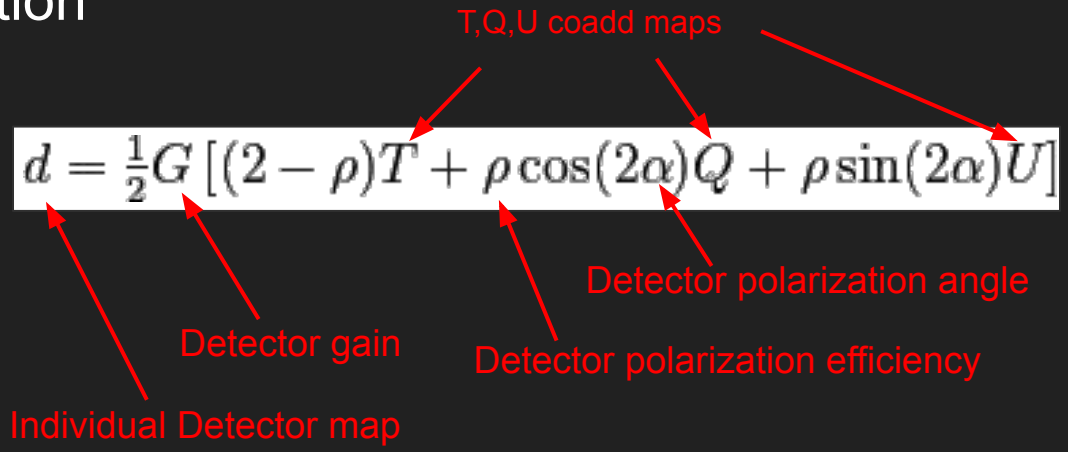


We don’t know the true fractional polarization* (Q/T, and U/T), so G and ρ are degenerate.

Calibration



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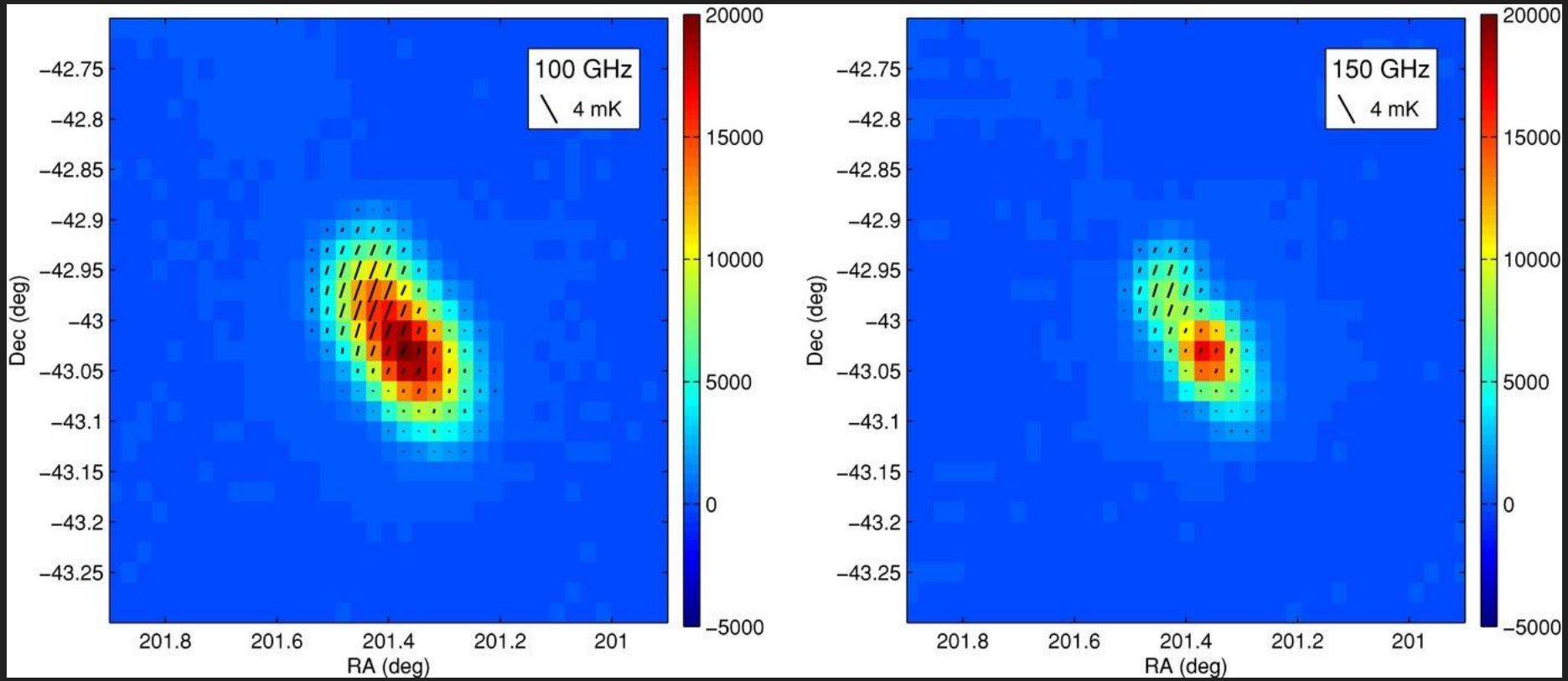
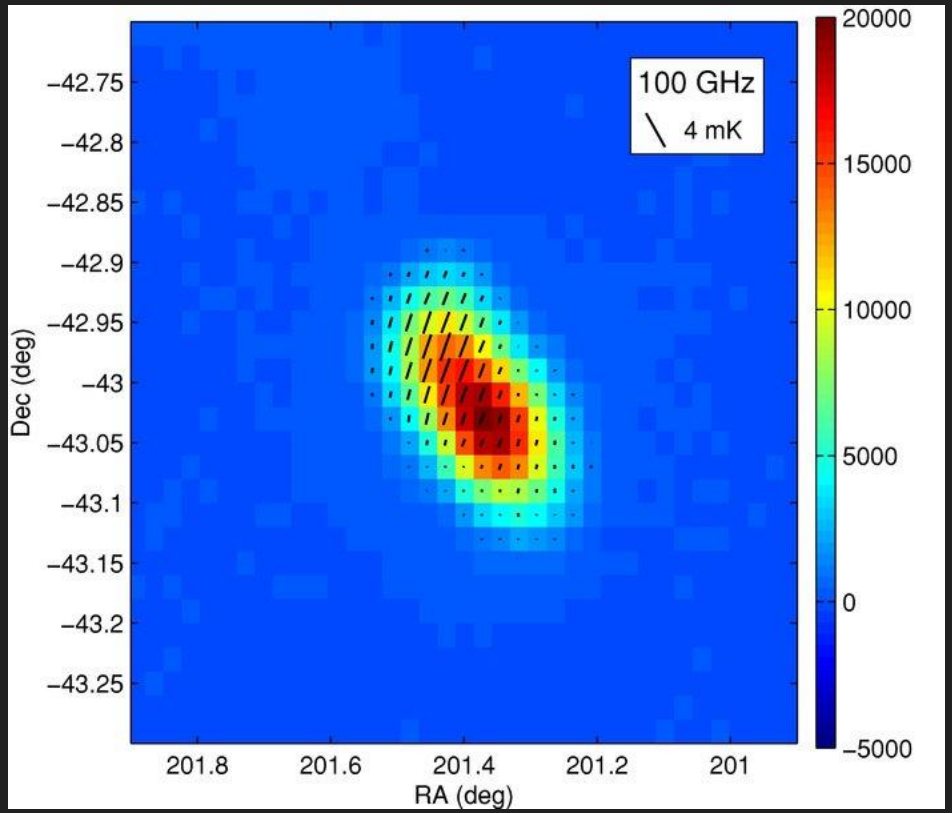
*QUAD did measure the polarization angle of CenA (with 0.5deg accuracy)

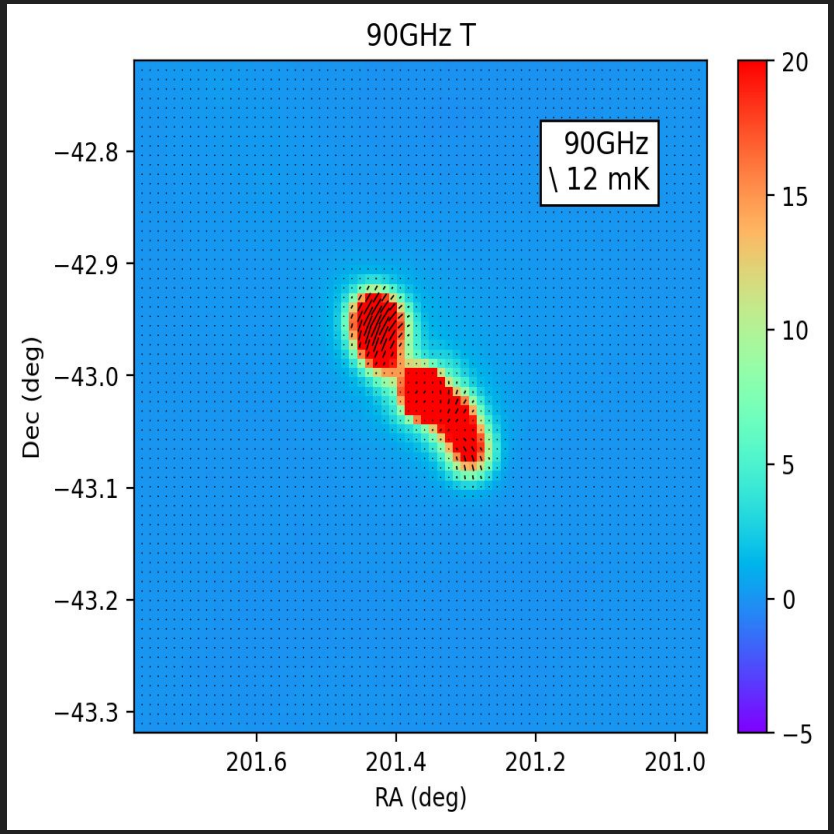
M. Zemcov *et al* 2010 *ApJ* **710** 1541

QUAD measurement of polarization



QUAD measurement of polarization consistent in Northern Lobe





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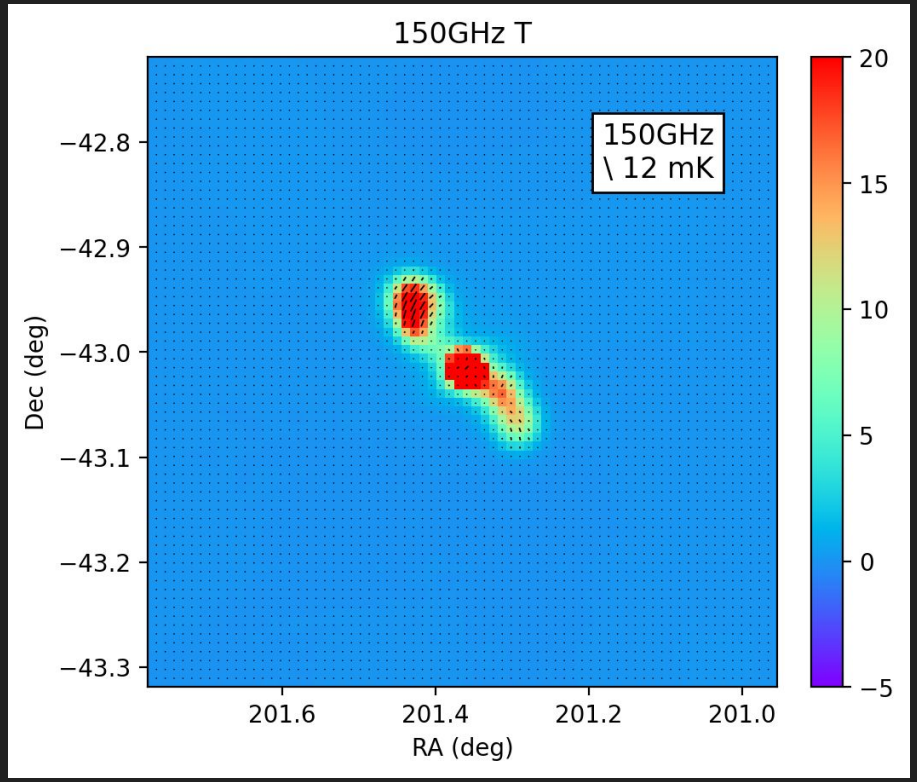

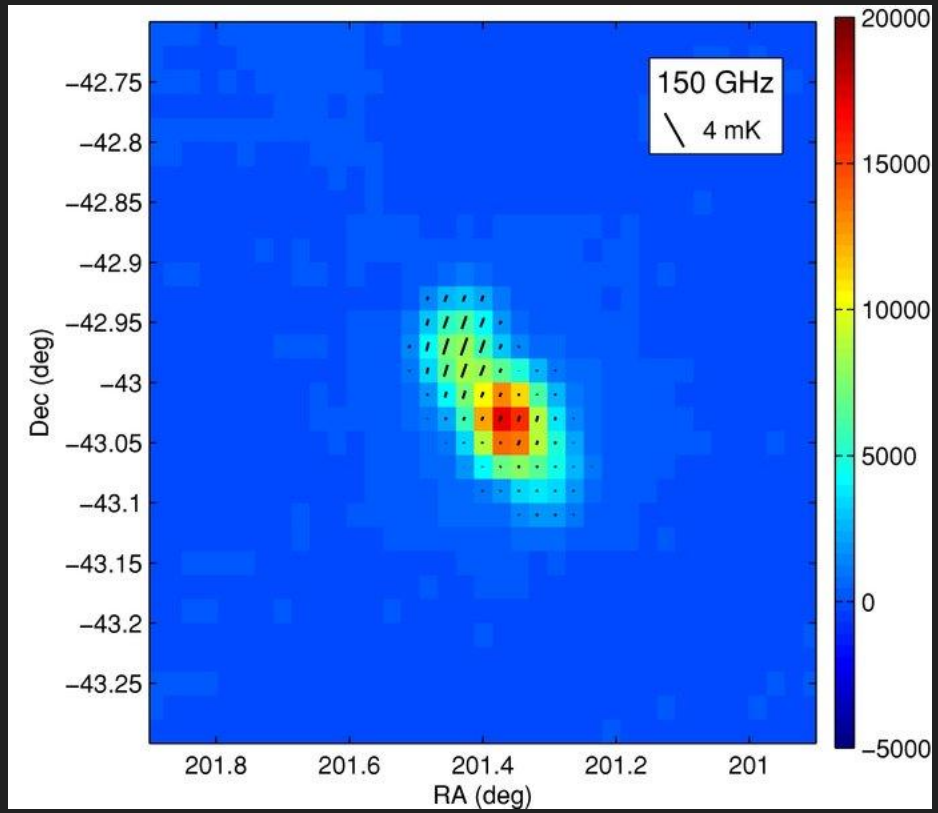

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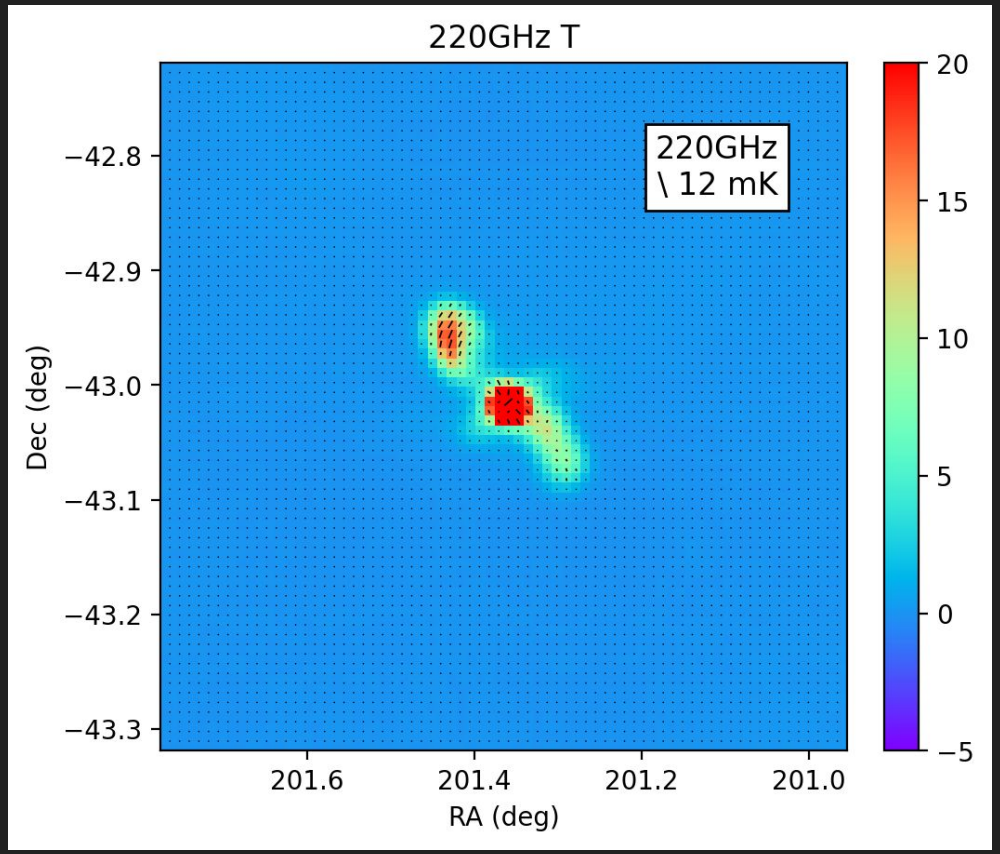

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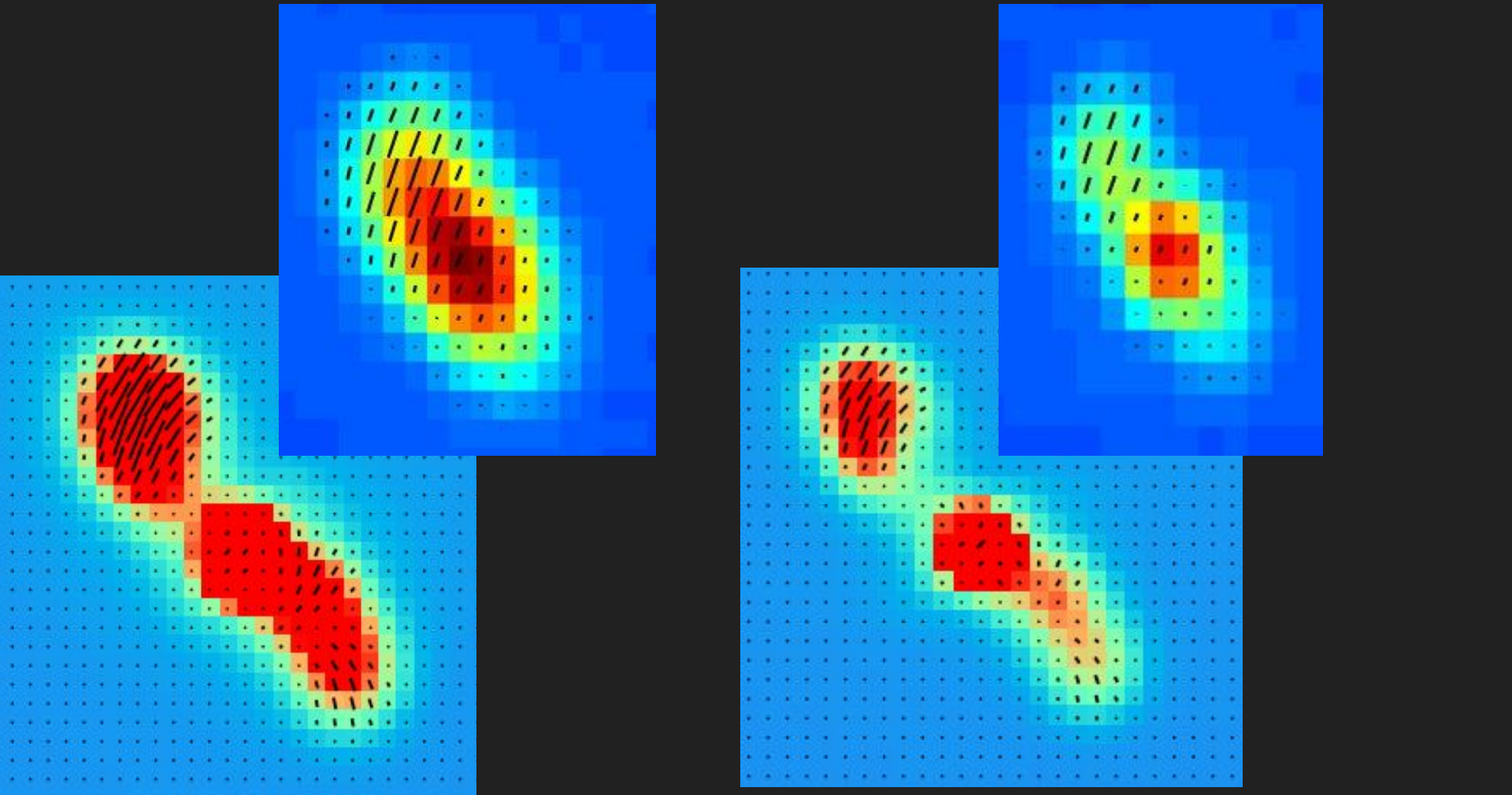

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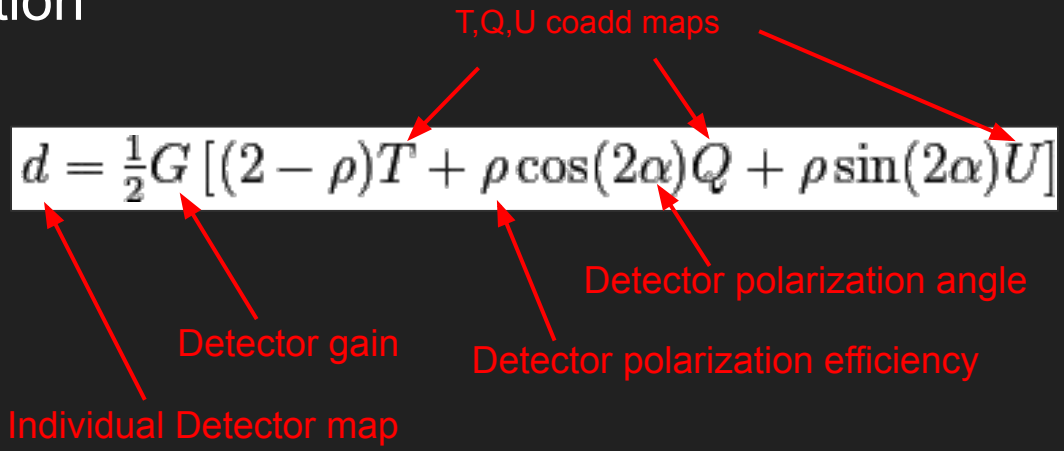
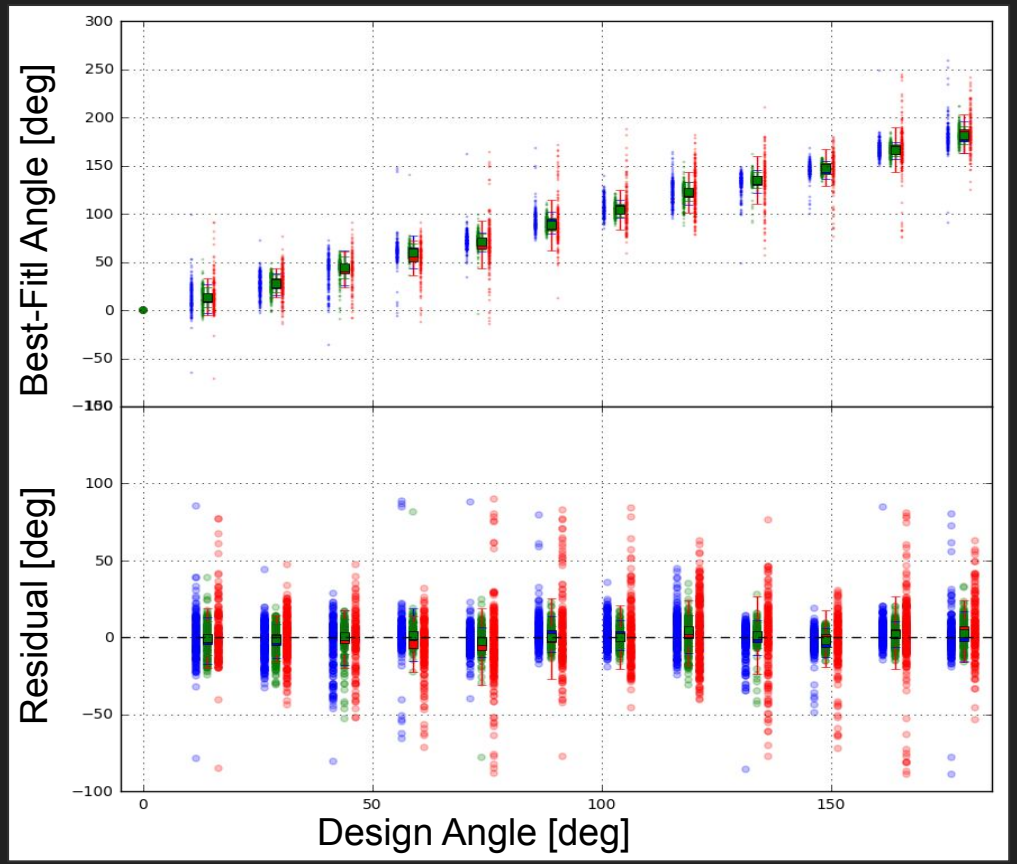
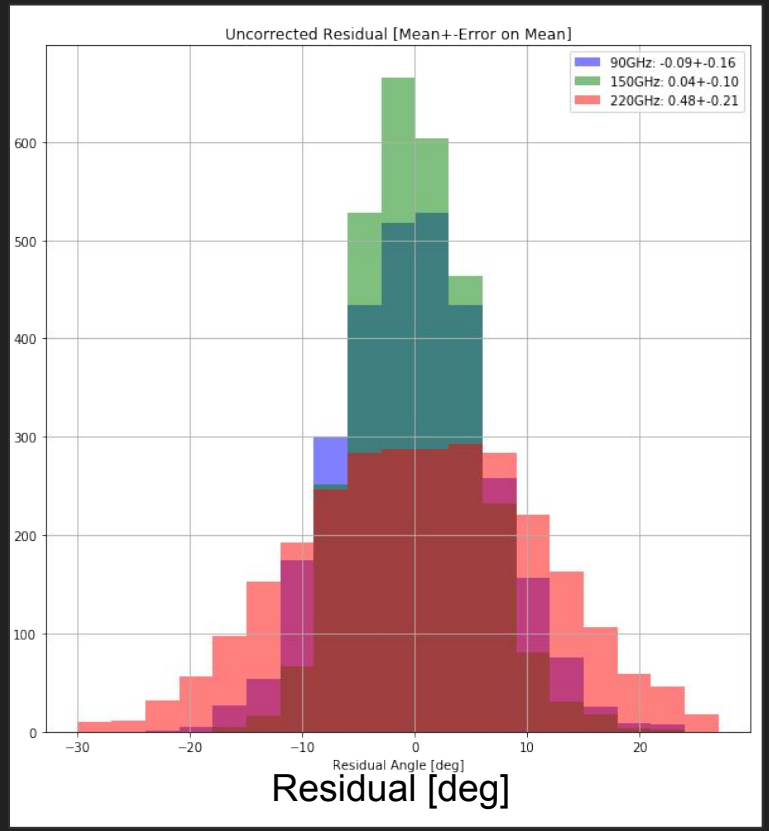


We don’t know the true fractional polarization* (Q/T, and U/T), so G and ρ are degenerate.

Fix ρ=1 and fit for G, and angle.

Internal Calibration O(10,000) bolometers





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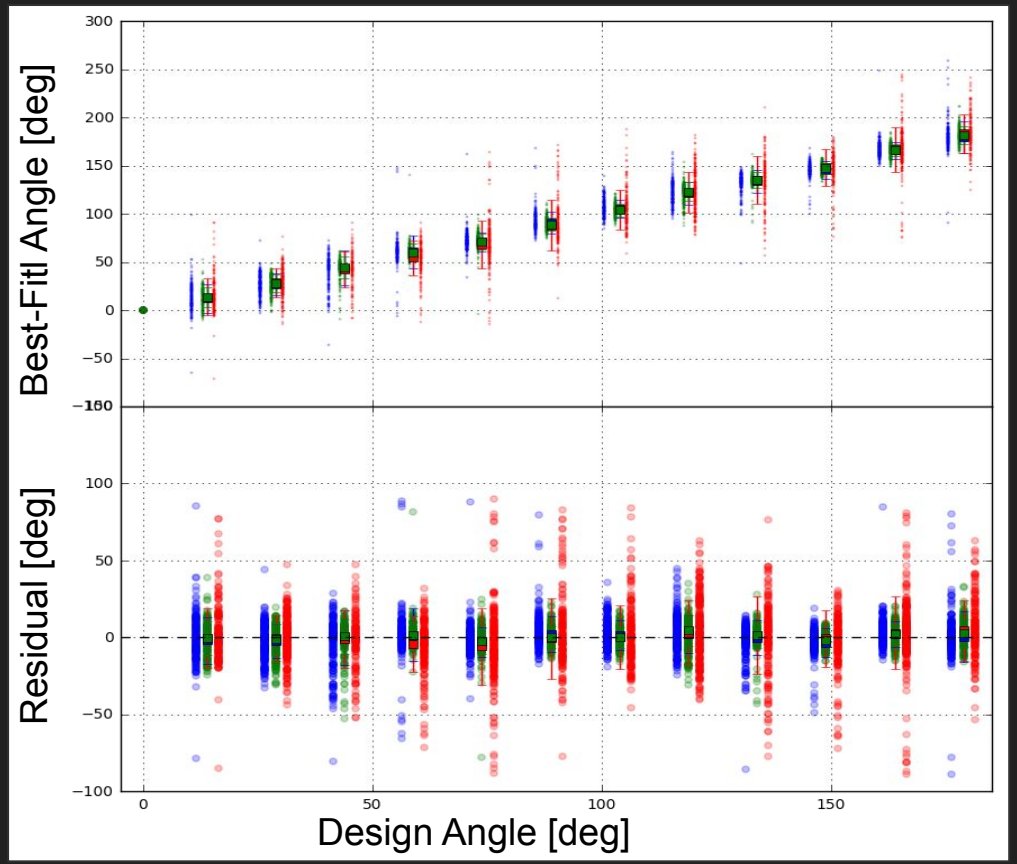
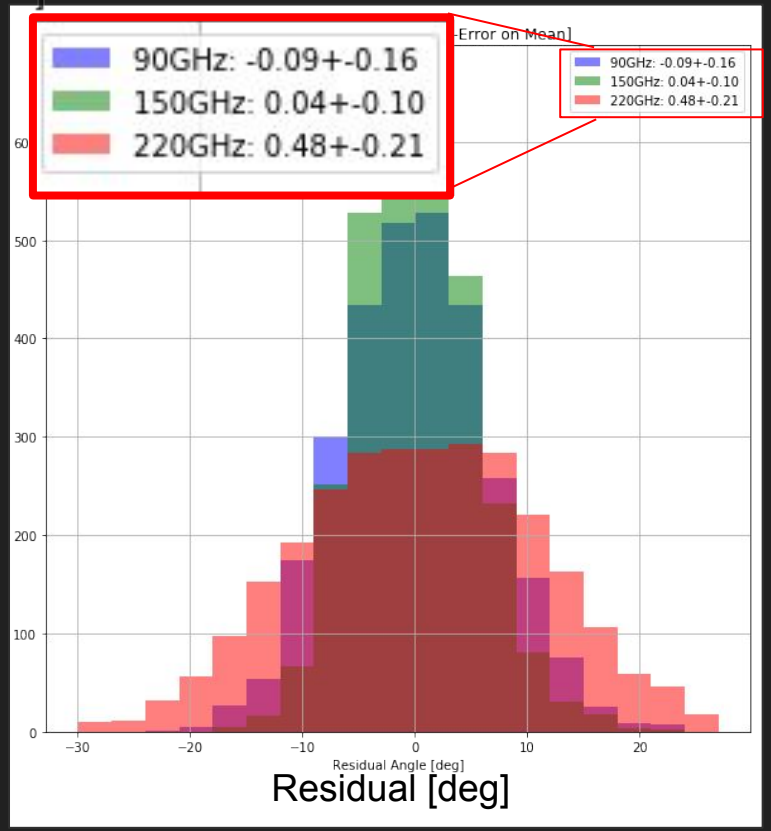
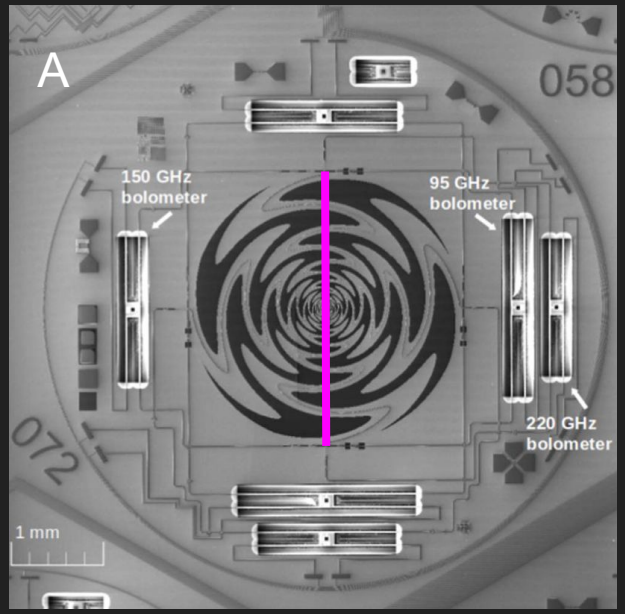
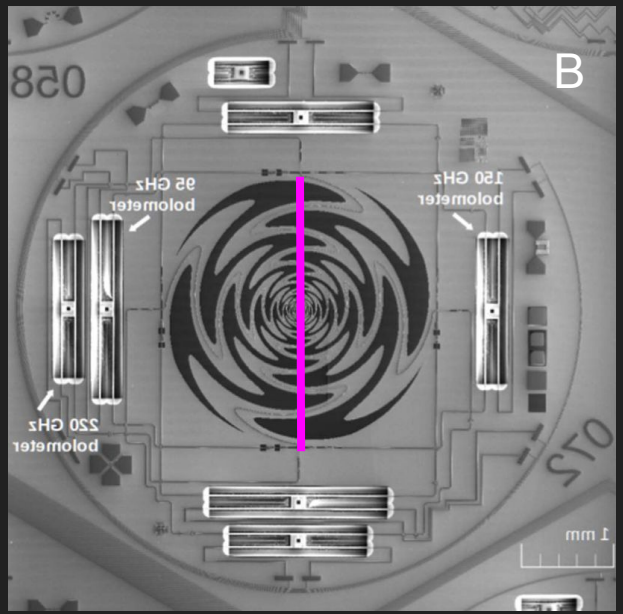




Sinuous Antenna Wobble!



Frequency-dependant response which effectively rotates the measured polarization w freq.



Residual [deg]

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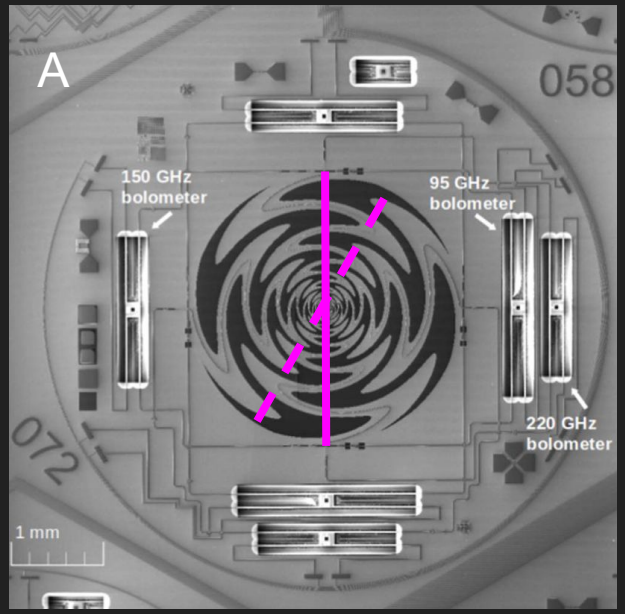

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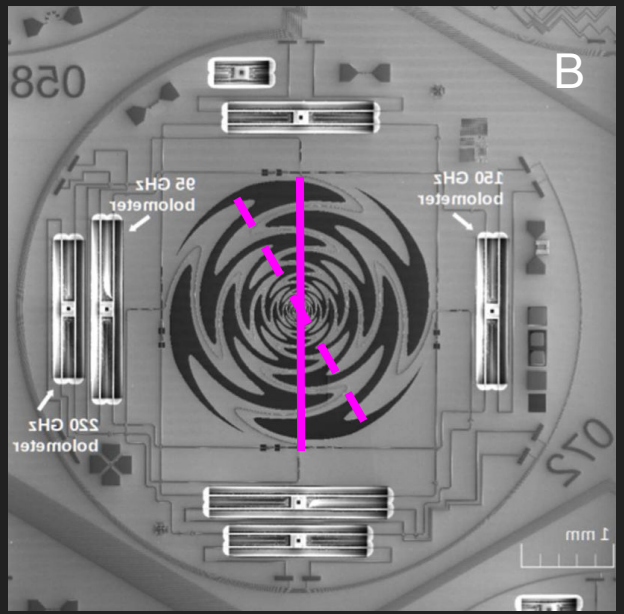

Residual [deg]

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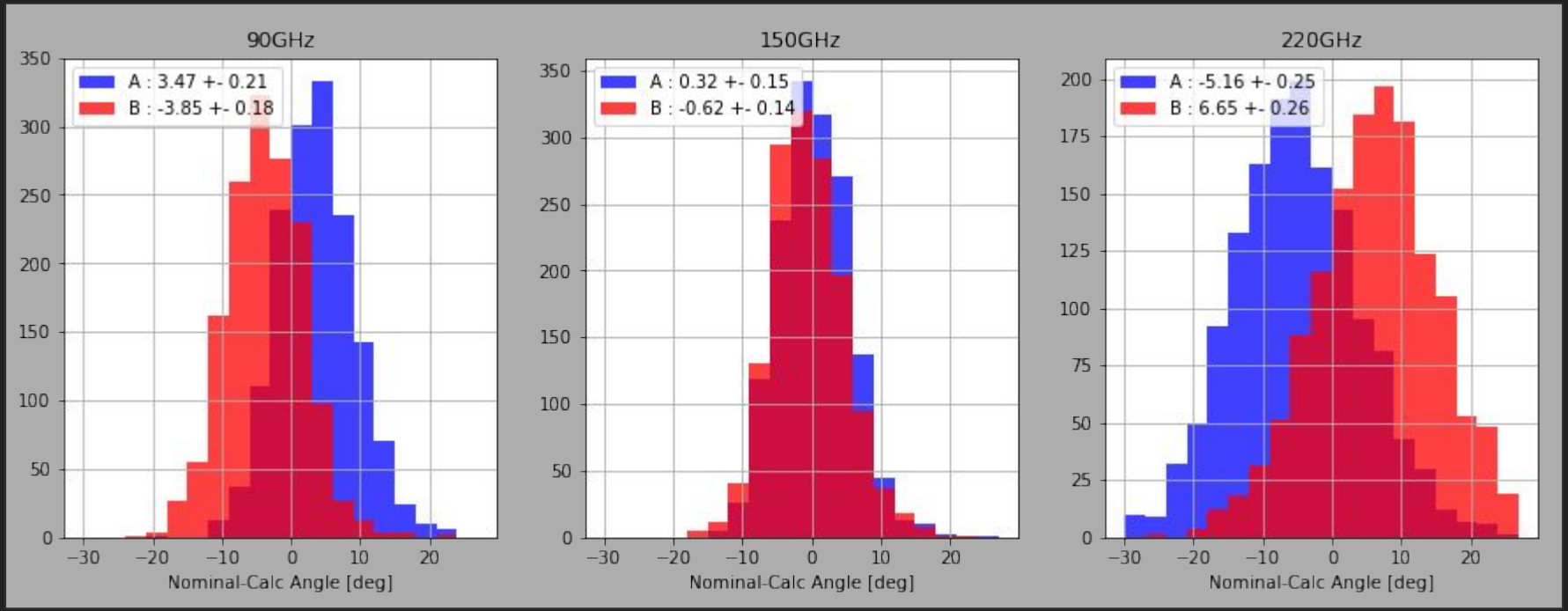

Residual [deg]

What’s next?

Simons Observatory will have absolute polarization calibration pinned via SATs.

Use SO LAT to measure CenA, calibrated w SAT
Make high SN maps with calibrated SO LAT → bootstrap SPT measurement

Use satellites??

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No pol cal, but we have detected thermal emission from LEO satellites at high S/N


Detection of Thermal Emission at Millimeter Wavelengths from Low-Earth Orbit Satellites

A. Foster,[1] A. Chokshi,[2] P. A. R. Ade,[3] A. J. Anderson,[4,5,6] B. Ansarinejad,[2] M. Archipley,[5,6] L. Balkenhol,[7]

Paper coming very soon to an Arxiv near you!

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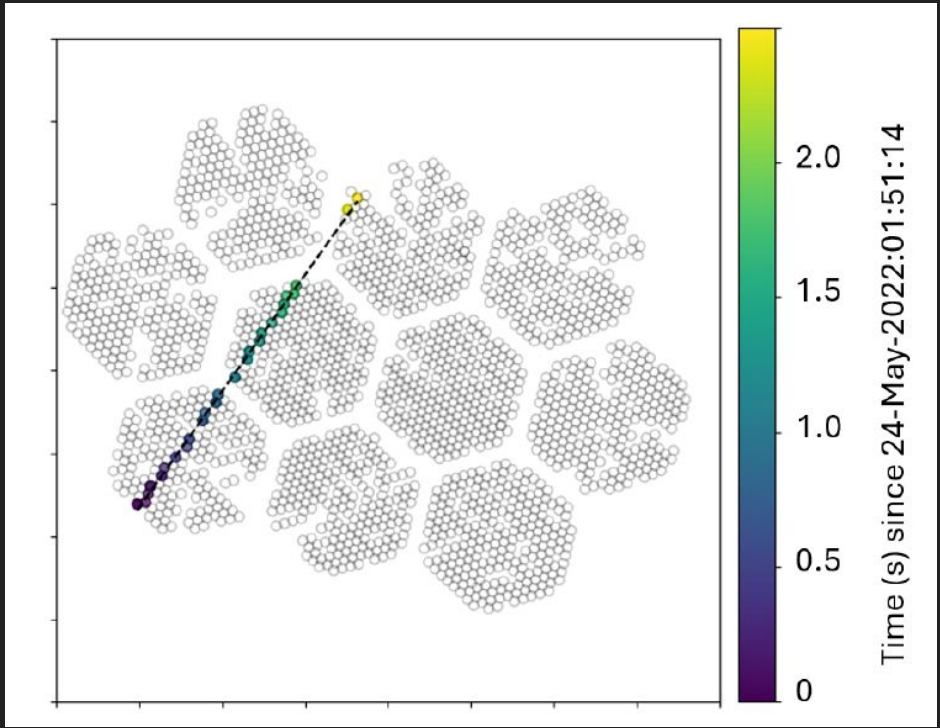
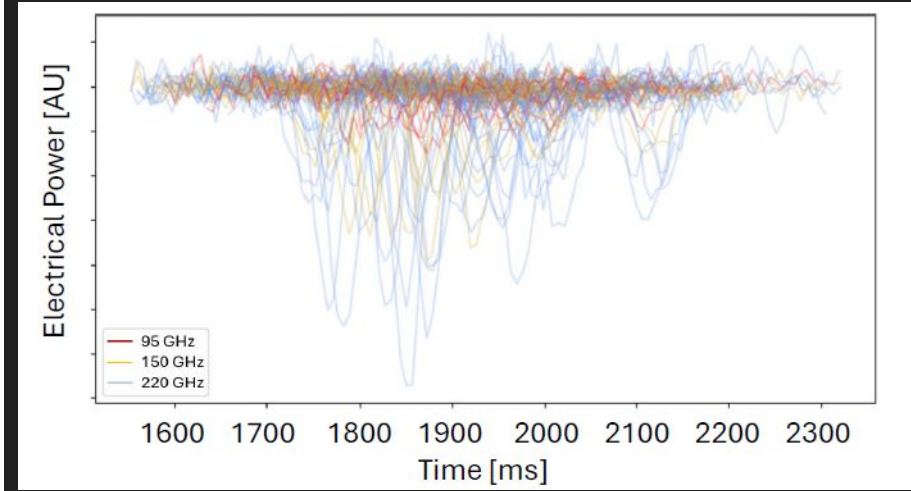


LEO satellites zip through focal plane



High S/N in single-bolo TOD

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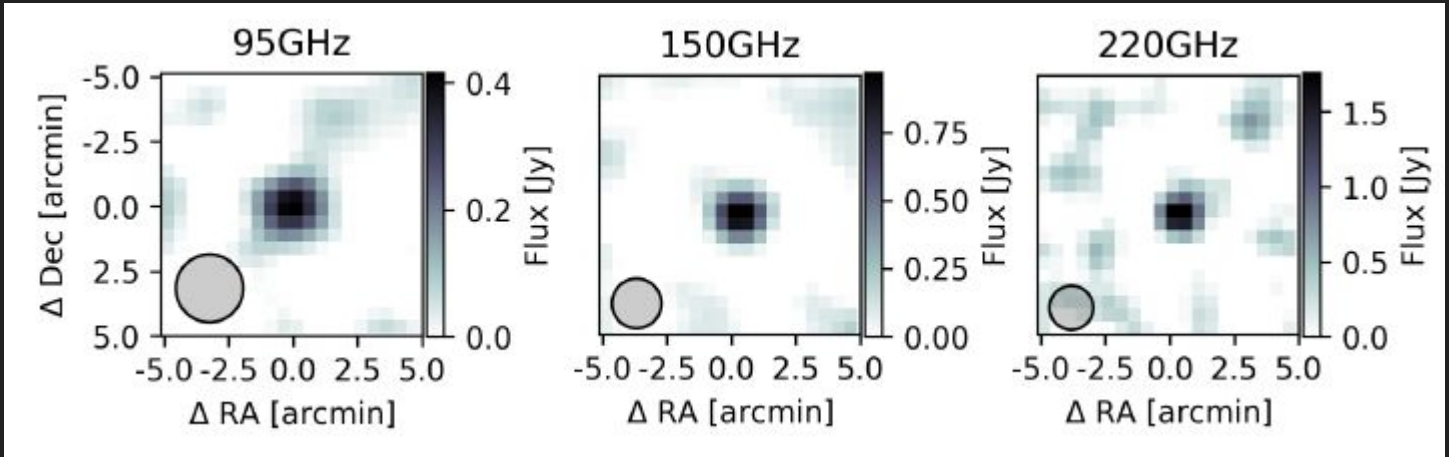

Make satellite-centered map using TLE-derived ephemeris…

Does this satellite look familiar??

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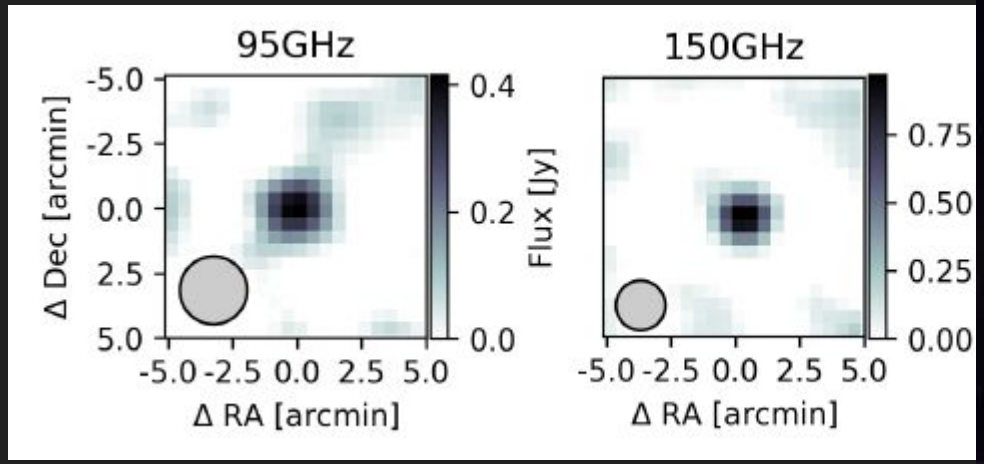

Make satellite-centered map using TLE-derived ephemeris… COBE!

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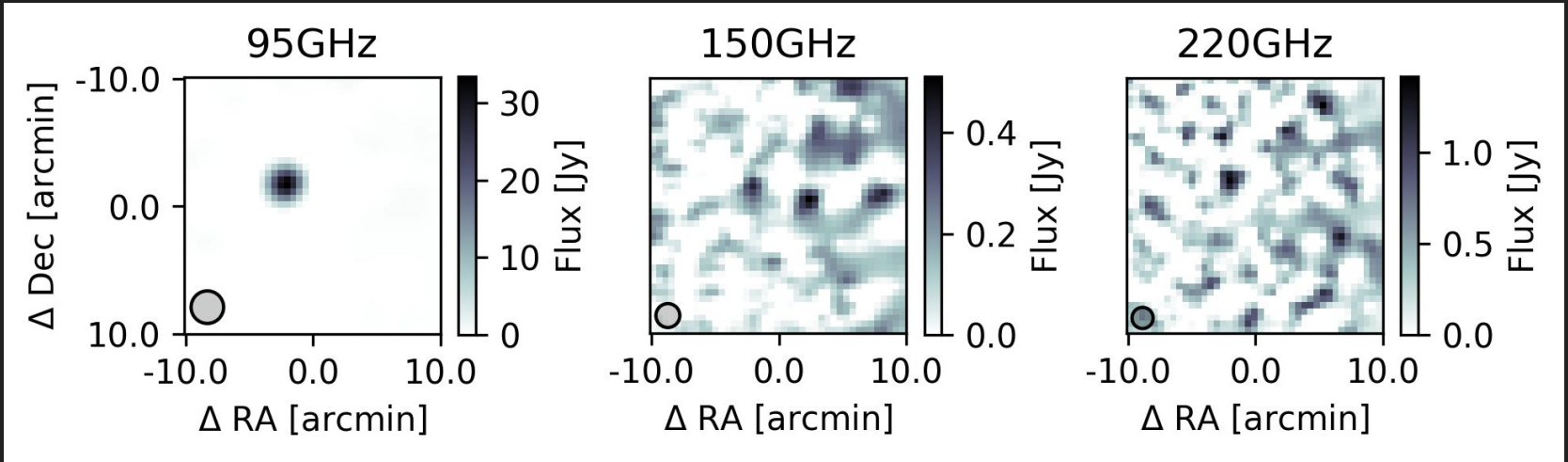
Beyond thermal emission: Cloudsat 94.05GHz radar (polarized!)



What’s next?

Need high accuracy polarization calibration sources for current sensitivity of SPT-3G.

South Pole is difficult, but perhaps we can get help from our SO friends soon.

Satellite calibration would be difficult if in LEO because of number of passes needed to cover focal plane.

GEO would be ideal… but $$$$

Thank you

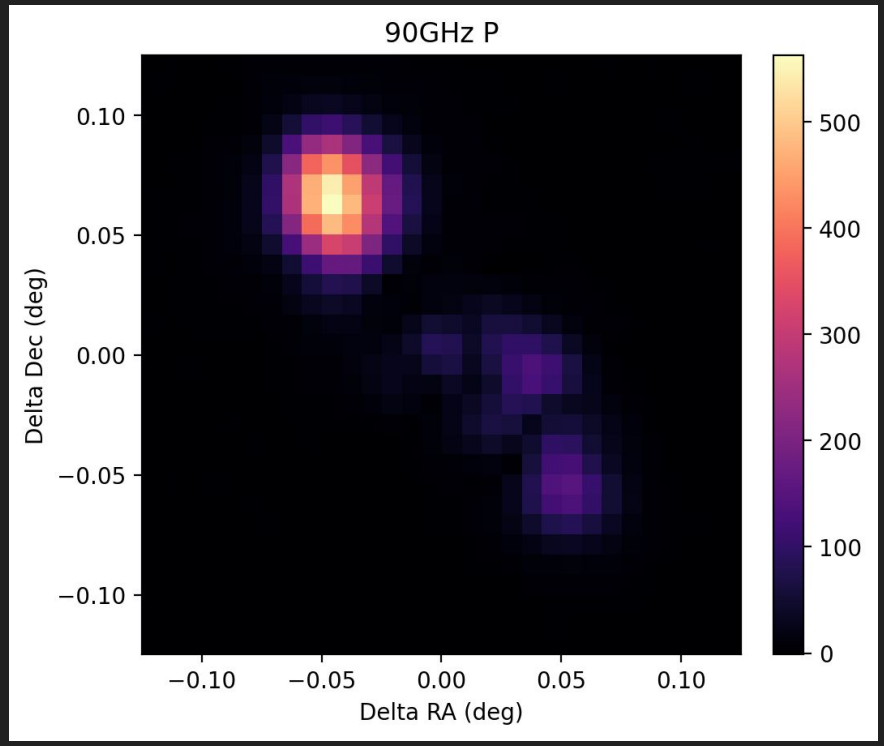
Optical image taken by my winterover partner, Geoff Chen, in 2020. SPT 220GHz overlay

Backup

Backup

Northern lobe ~ 500 mJy at 90GHz

in polarization, P!



Backup

Polarized fraction varies across jets.

Shock front in southern lobe visible