Systematics: POLARBEAR/Simons Array perspective

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on behalf of the POLARBEAR/Simons Array Collaboration

Guiding Questions From Reijo

- How and when were systematics **discovered**?
- How are systematics **mitigated**?
- What should **CMB-S4 do differently**?
- Which systematics should we be **most concerned** about? Can they be translated into **technical requirements**?
- What to do about systematics that may be **mitigated in processing**? Should there be technical **requirements** on both pre and post mitigation levels? Can we simulate mitigation techniques that haven't been implemented?

We, POLARBEAR/Simons Array, have checked various systematics, e.g. pointing, beam systematics, detector none-linearity, cross-talk, I-to-P leakages, wafer fabrication (Q/U pixels, type-A/B), and so on.

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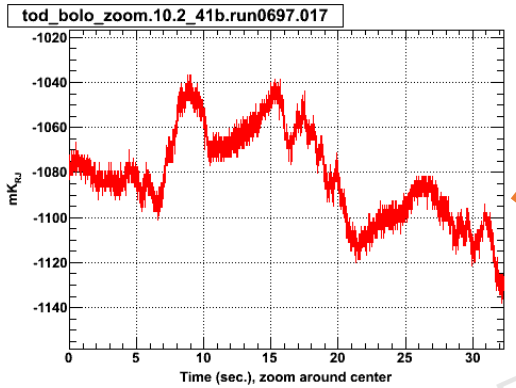
In the next 10 min, focus on POLARBEAR's
scan synchronous signal (and ground pickups)

because it's one of the largest systematics and there're many/useful stories

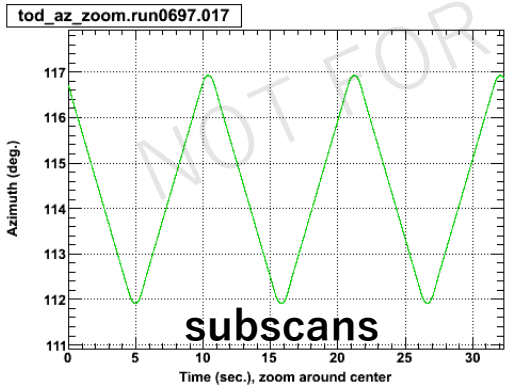
What's the scan synchronous signal (SSS)?

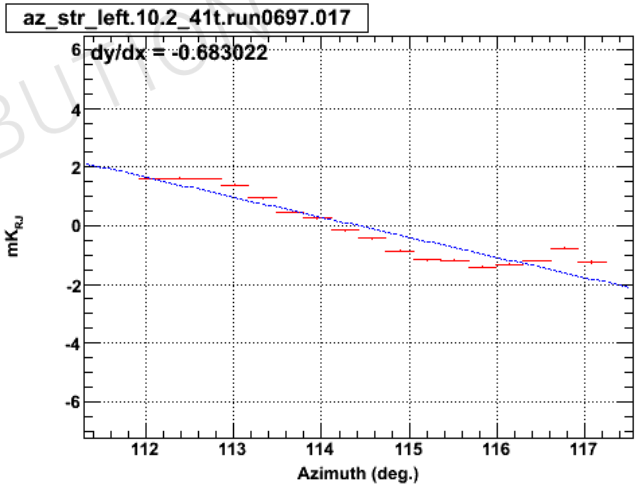
- Signals synchronized w/ azimuth subscans
  - it comes from **sidelobe pickups, ground pickups, magnetic pickups, telescope vibrations, atmosphere, (ice) clouds**, and so on
  - they could be repeated & polarized somehow

Bolo TOD



Az TOD



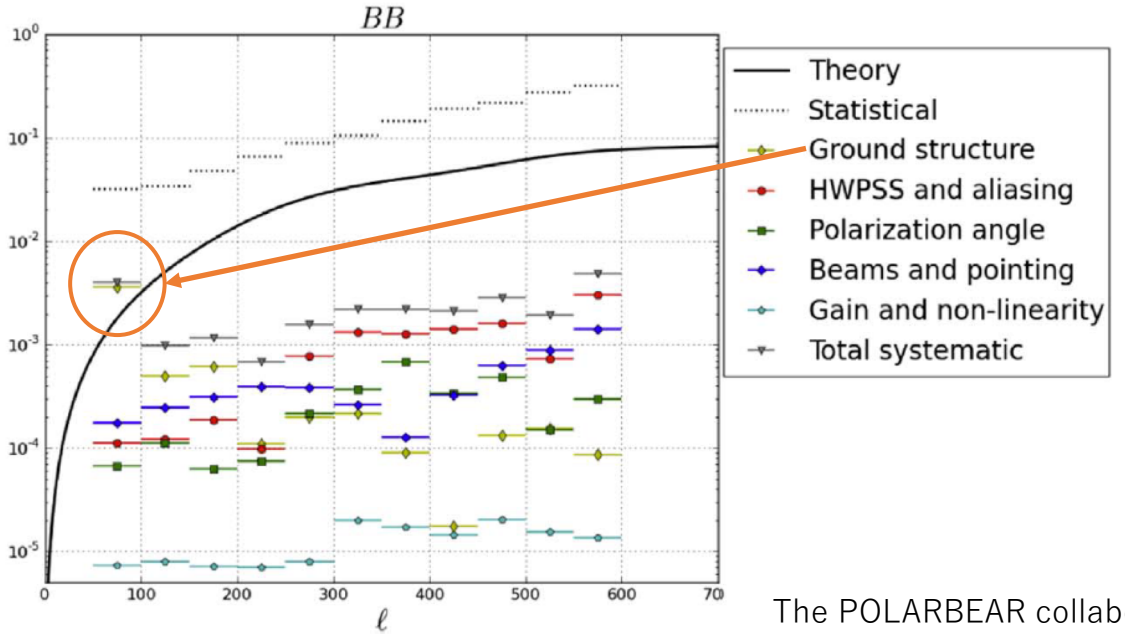


signal projected on the az coordinate

What's the scan synchronous signal (SSS)?

- One of the worst systematics in **POLARBEAR's low-ell result**
  - ➢ we can prevent it w/ dedicated visor, baffle (and ground screen)
  - ➢ we can mitigate it by poly filtering, Az-fixed template subtraction, but
    - ✓ resulting in **decreasing efficiency at low-ell ranges**
    - ✓ **systematic budget due to SSS itself (and its reduction) could matter** even though the mitigation processing is applied

In PB, the residual depends on time-variation of the ground



The POLARBEAR collaboration et. al., ApJ (2020)

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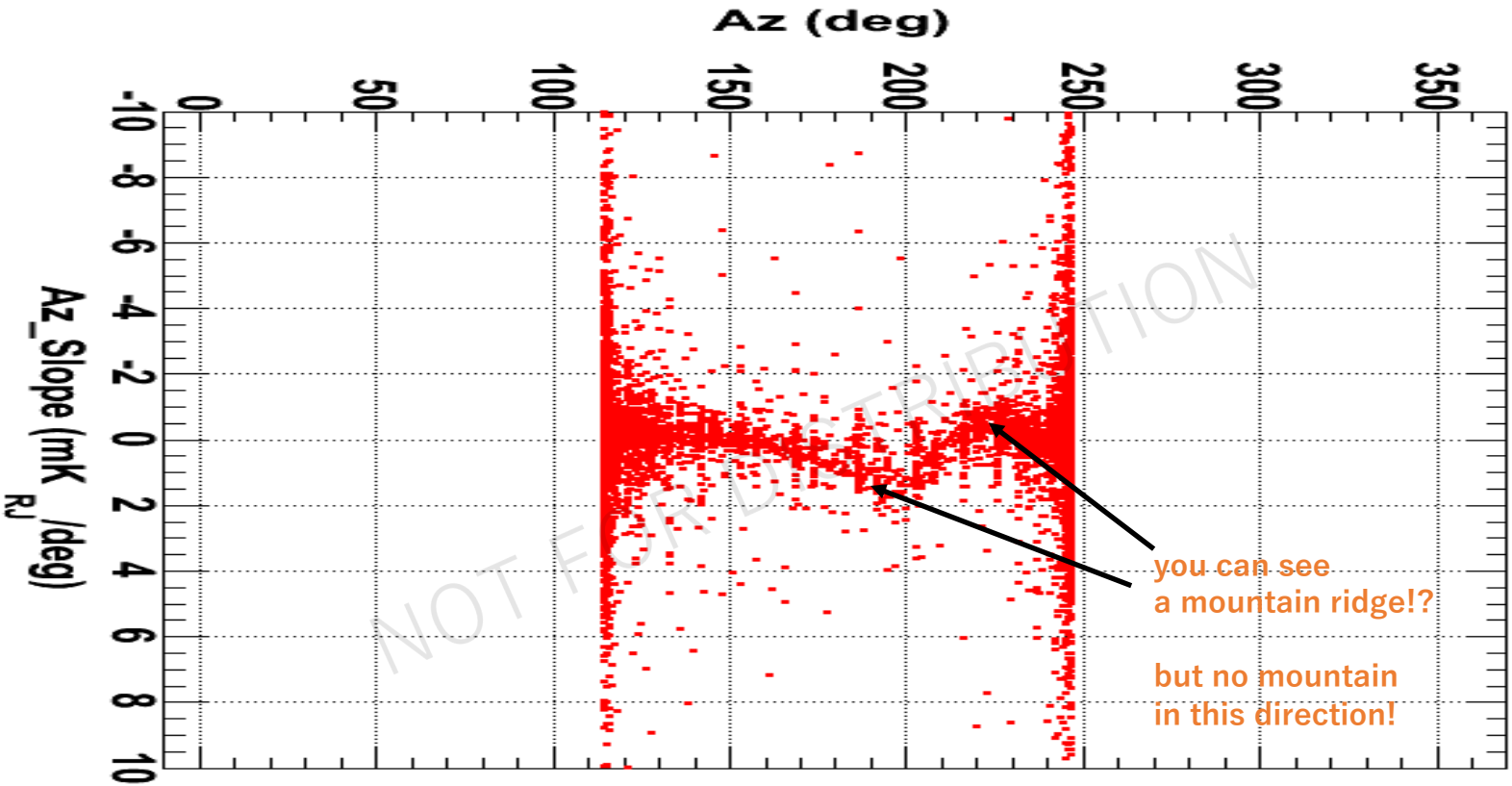
    - ✓ resulting in decreasing efficiency at low-ell ranges
    - ✓ systematic budget due to SSS itself (and its reduction) could matter even though the mitigation processing is applied
- Seems almost all the experiments were not able to avoid applying this kind of processing?
  - ➢ Just DC subtraction for every subscan does not seem enough?
    - ✓ because sources of SSS are so complicated
      - ◆ wondering any possibility to improved it?

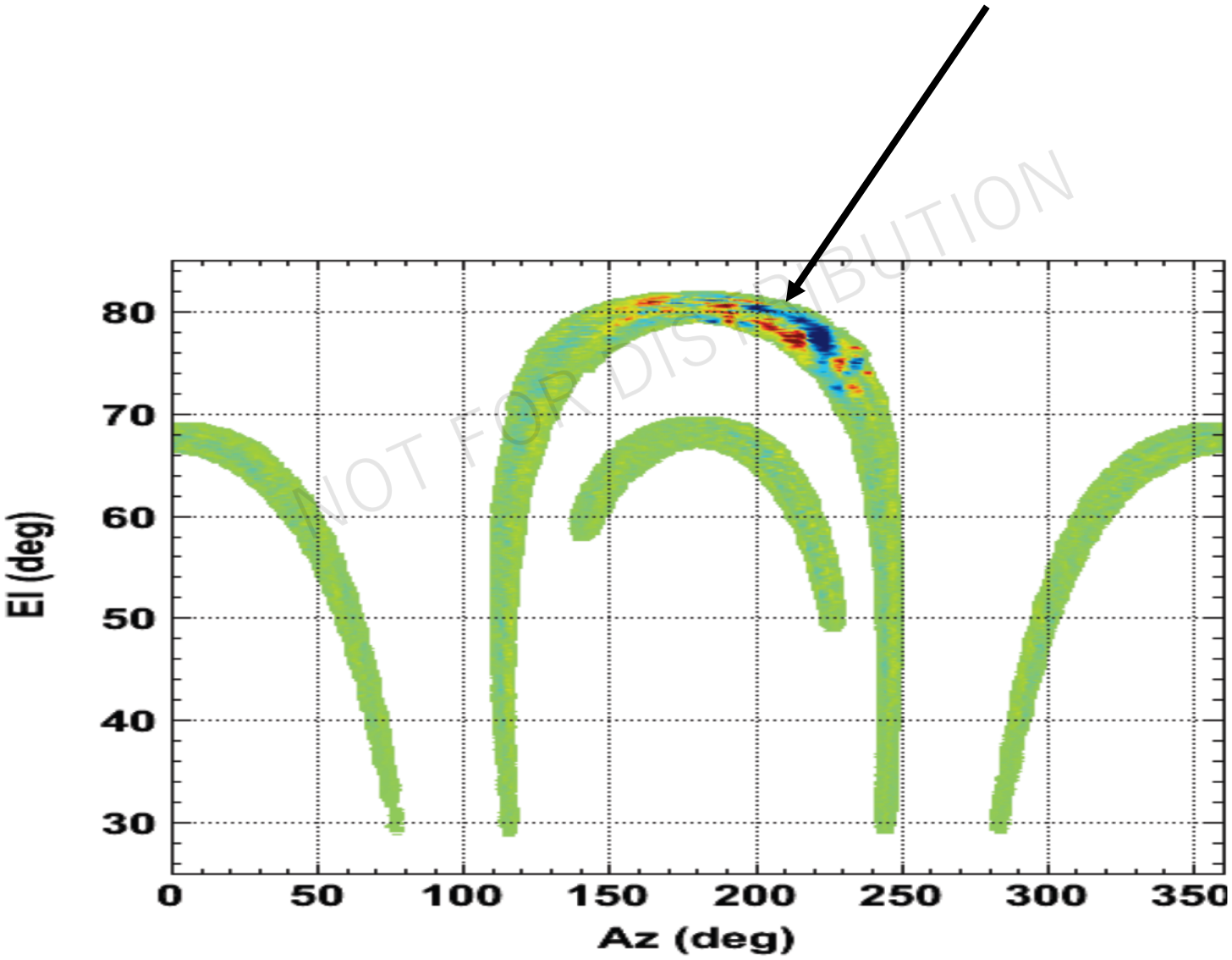
How and when were systematics discovered?

- Have processed TOD w/ **Az-fixed template subtraction**
- Had a coefficient of d(bolo)/dAz for various Az ranges
- Plotted it w/ Az!



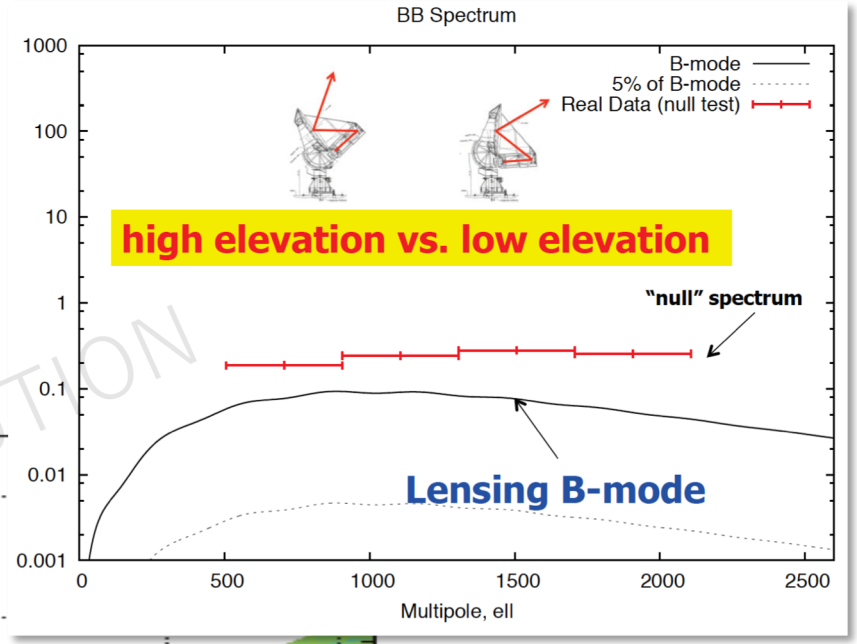
How and when were systematics discovered?

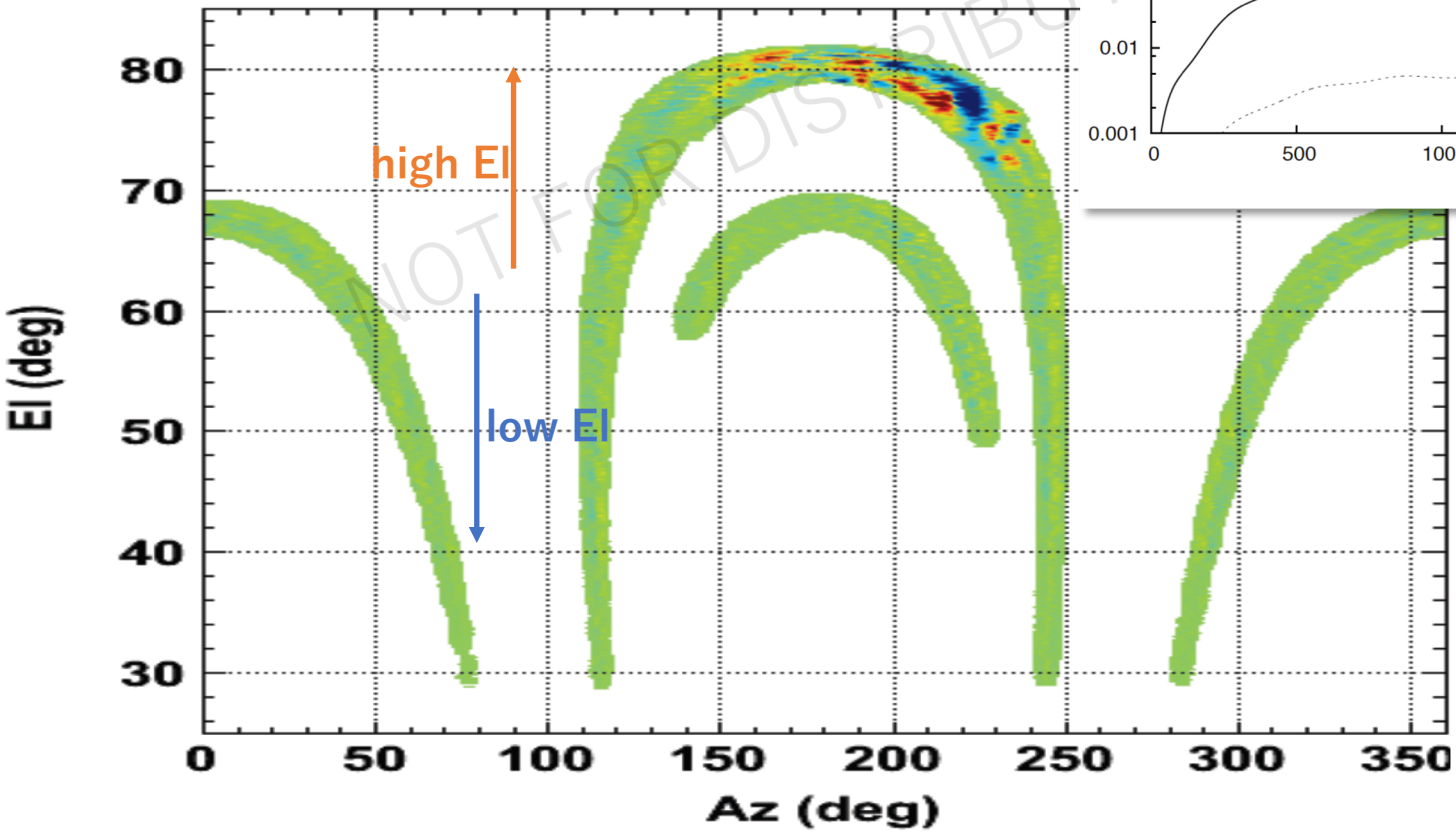
- Projected data into Az coordinates to map a ground
  - Huge contaminations are found at the same Az range



How and when were systematics discovered?

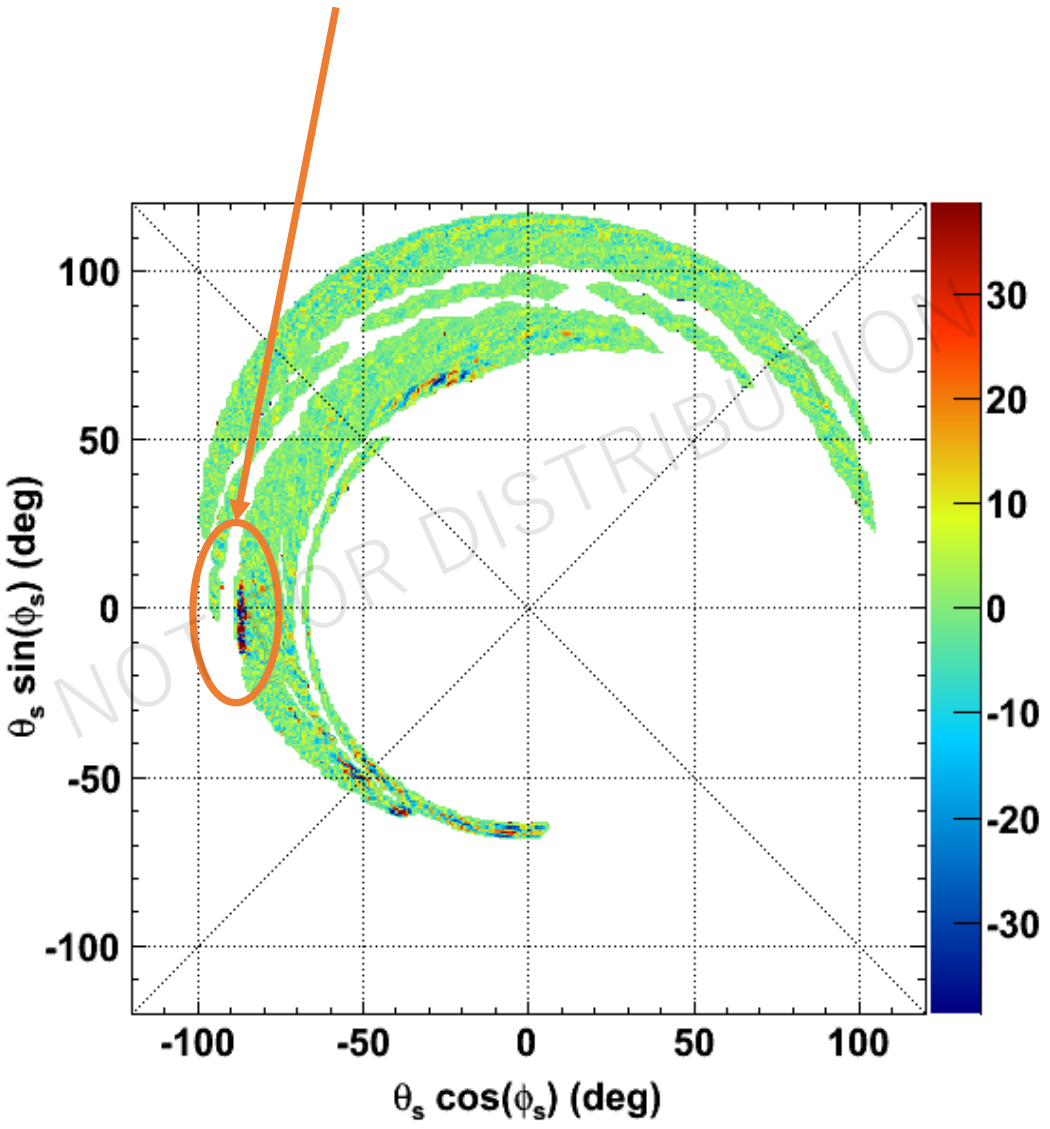
- A null test btw high El vs. low El had failed





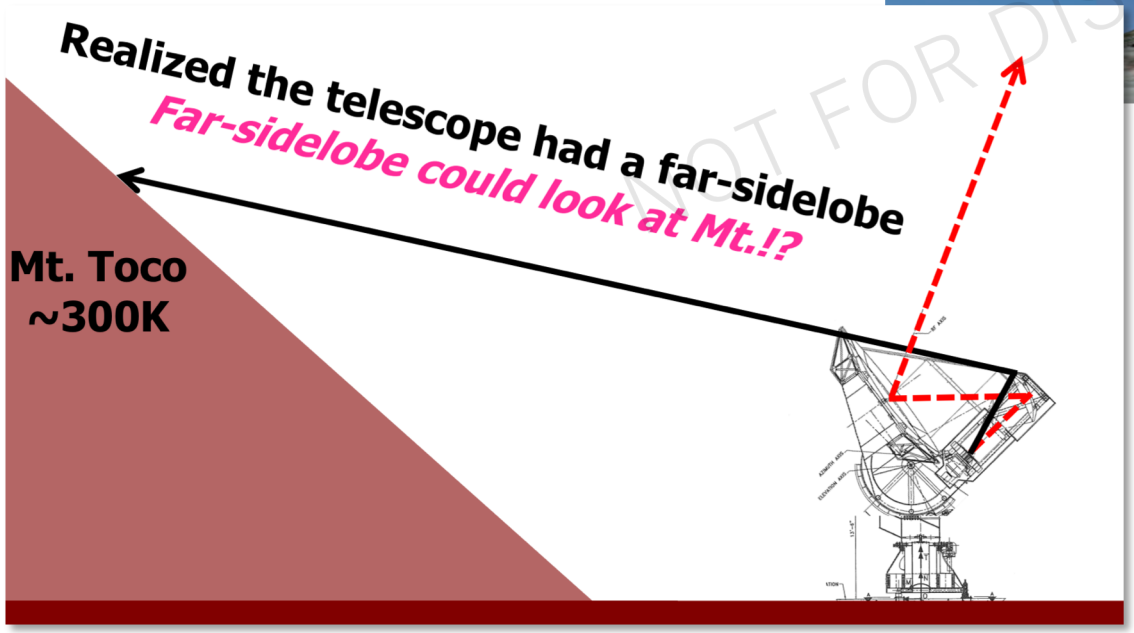
How and when were systematics discovered?

- **Mapped the far-sidelobes w/ Sun** & we successfully confirmed its origin: over-primary sidelobe



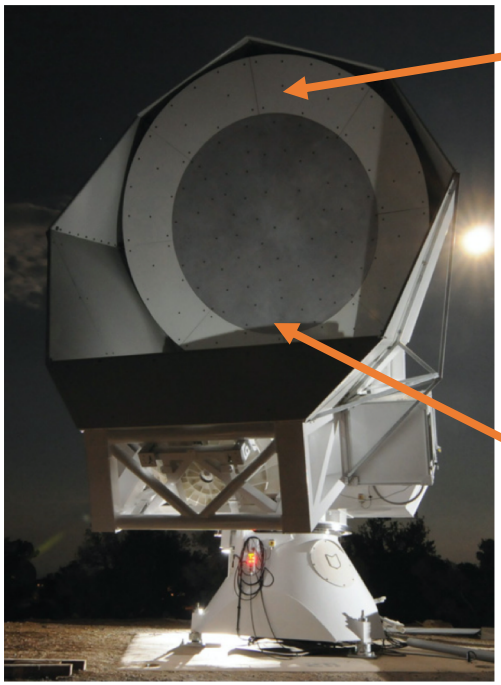
How and when were systematics discovered?

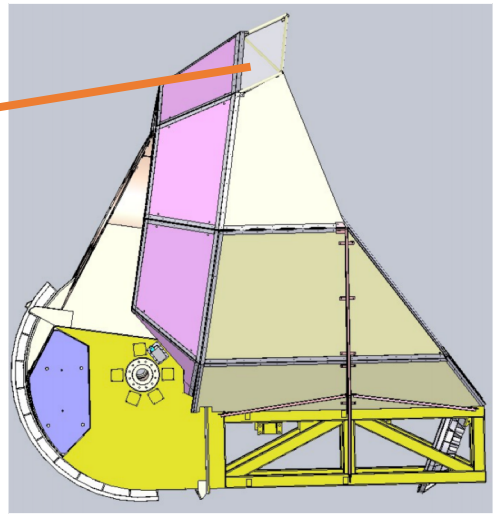
- Have realized that the **over-primary sidelobe** could look at Mt. Toco when the telescope scans **behind the mountain**!

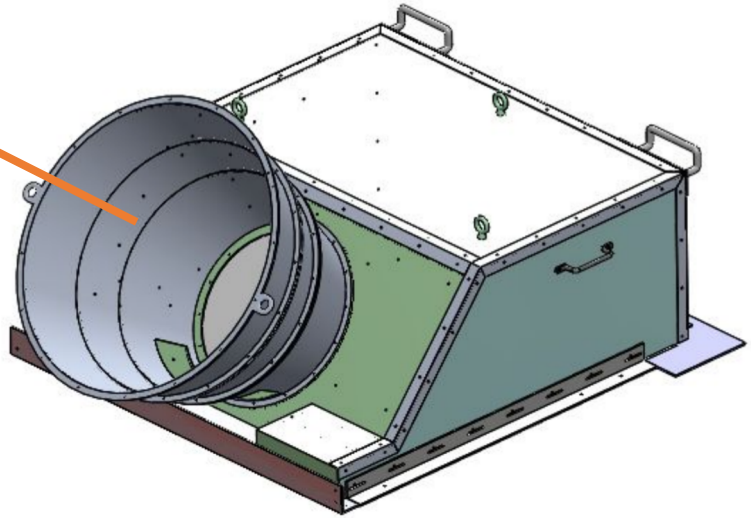


How are systematics mitigated?

- **Instruments:** Designed and installed a visor and baffle to block sidelobes out **during** observation seasons







deployed w/o visor & (good) baffle and started observation even we knew the possibility.

How are systematics mitigated?

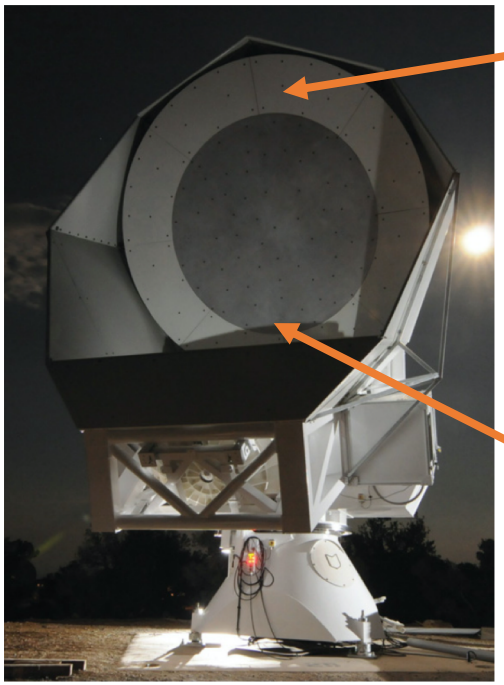
- **Instruments:** Design and install a visor and baffle to block sidelobes out **before** science observation starts
- **Observation:** Modify observing strategy so that sidelobes could not see any mountain at the site, and Sun/Moon on the sky
- **Analysis:**
  - Implement the **Az-fixed template subtraction** as well as **low-order poly-filter subtraction** for each subscan
    - ✓ but resulting in sensitivity loss at low-ell ranges
  - Drop data that sidelobes could look at Sun or Moon
    - ✓ but resulting in overall sensitivity loss
  - (if deck can rotate) **Take the cross-spectra in the Az-deck space because the deck rotation could modulate the systematics, c.f. QUIET**

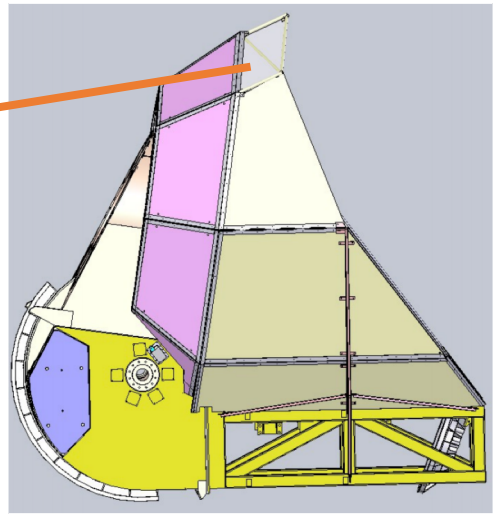
What should CMB-S4 do differently?

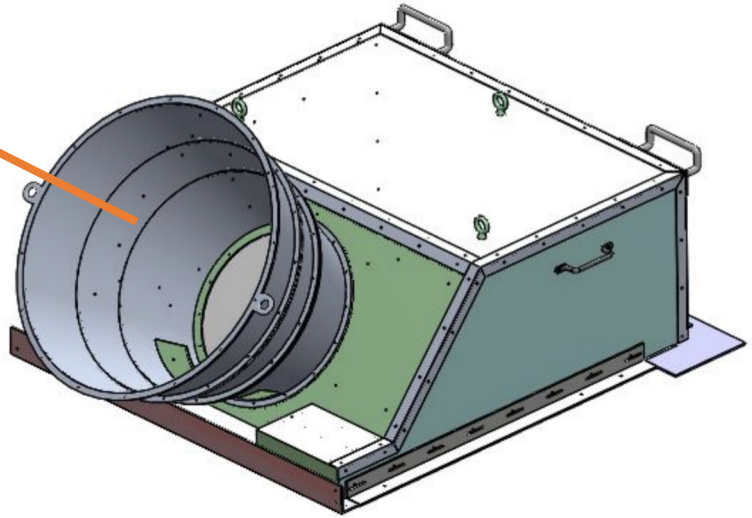
w/ raytracing simulation

- Should design instruments that could prevent any possible sidelobes & deploy/install them **before science observation**

e.g. POLARBEAR







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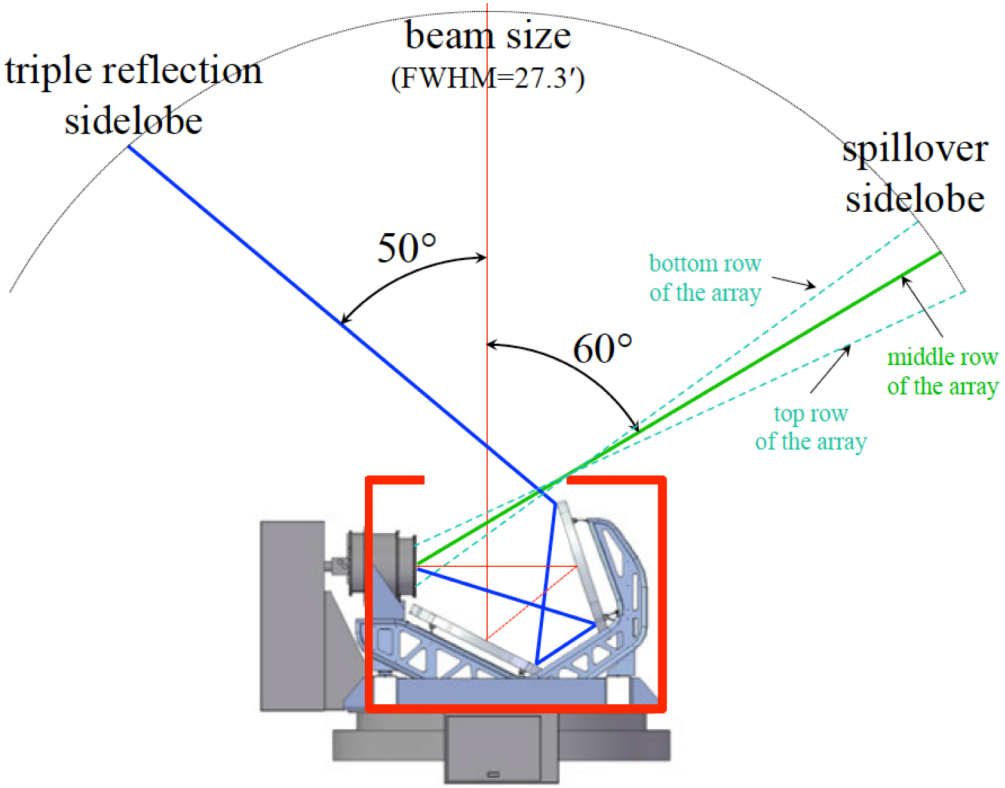
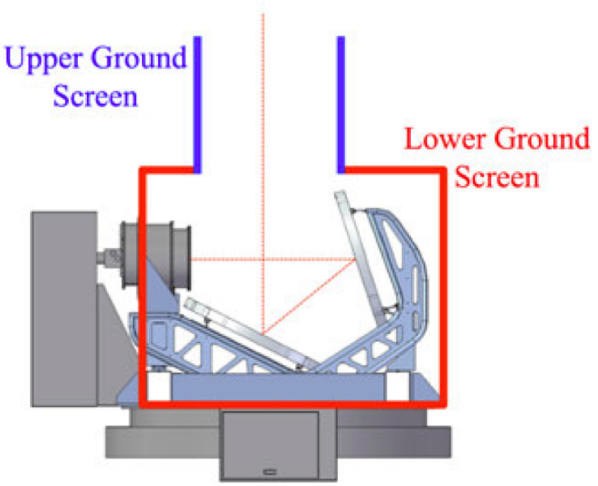
e.g. QUIET

Y. Chinone PhD thesis (2011)





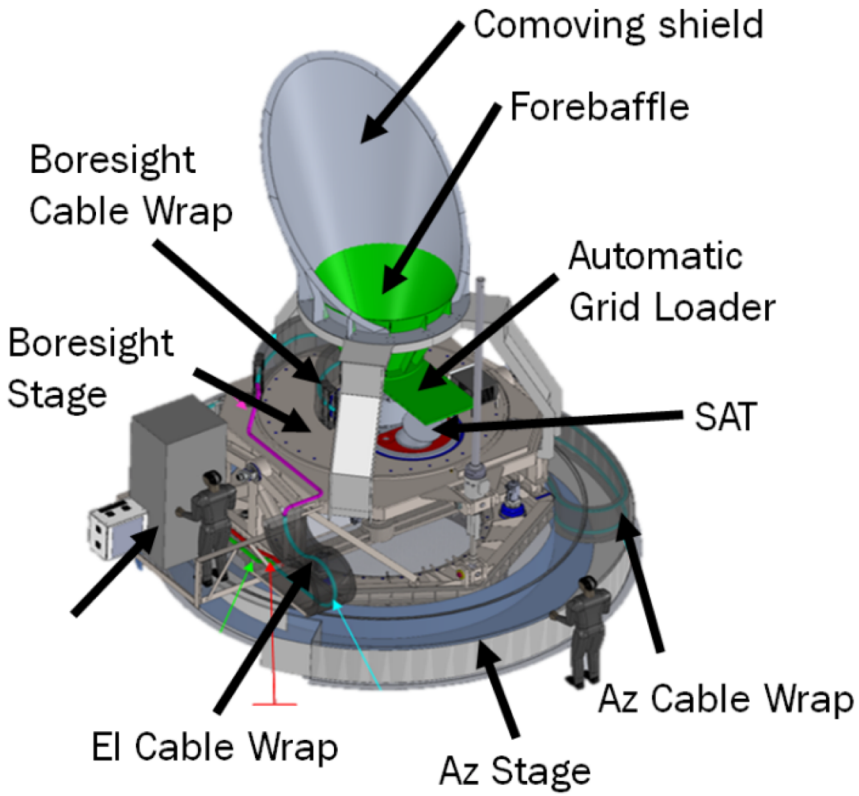
With simulation and measurement, we knew the upper-ground screen is important to prevent SSS. But deployment of the upper-ground screen was delayed. We started observation w/o it.

What should CMB-S4 do differently?

w/ raytracing simulation

- Should design instruments that could prevent any possible sidelobes & deploy/install them before science observation

e.g. feedback to Simons Observatory small aperture telescopes



For SO SAT, a forebaffle and comoving shield (and ground screen) have been designed and will be deployed before observation.

Which systematics should we be most concerned about? Can they be translated into technical requirements?

- SSS and ground pickups should be concerned about
- **We know how to avoid/mitigate them (by design & analysis)**
  - Don't know all of sources but know sources mostly concerned about
    - ✓ Could be difficult to separate SSS not coming from ground pickups, e.g. thermal & magnetic pickups, (ice) clouds, etc.
  - Make thermal and magnetic environment as stable as possible
    - ✓ I know BICEP/Keck has already reported SSS by magnetic field is r<1e-8
- It's already translated into forecast if we have already assumed the **observed N_{ell} spectrum w/ the 1/f component**
  - e.g. S4 r forecast (w/ BICEP2/Keck map) and SO SAT forecast (w/ QUIET/ABS/POLARBEAR knowledge)
    - ✓ of course, we should worry about SSS which can not be mitigated by Az-fixed template subtraction & poly-filter subtraction. But it's not SSS anymore…

- If we can prevent all SSS by instruments, no processing is best
- But most people think some processing are necessary
  - even pair-diff can be done well?
  - even demodulation w/ HWP can be done well?
- Impact by the processing on overall sensitivity of r is **5-10%**
  - this could be small enough for current experiments, however, it might matter to a $500M project like S4!?
  - w/ more stable instruments, could try to reduce any data processing which could decrease the sensitivity @ low-ell ranges
    - ✓ magnetic pickup seems small enough by BICEP/Keck
    - ✓ need to improve stability of readout/thermal environment (c.f. Satoru T. et. al., (2017))
  - **more study w/ on-going experiments is useful**