Thoughts on Systematic Errors for a CMB Polarization space mission

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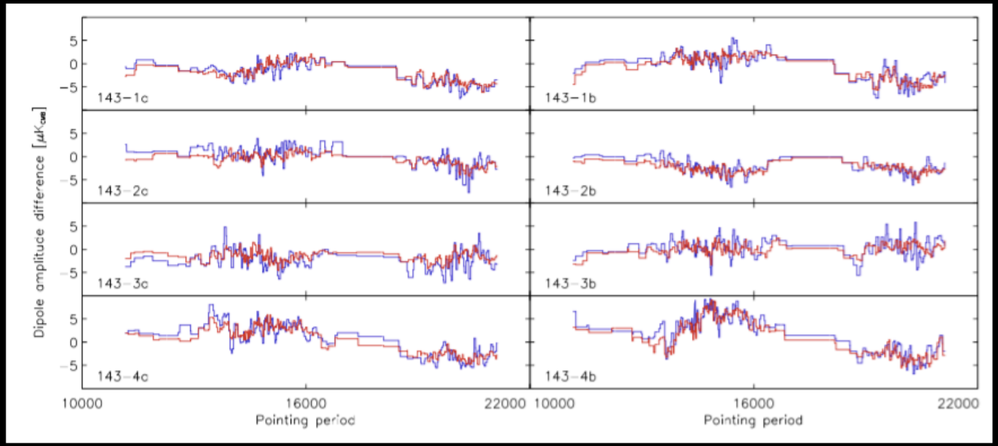
PICO study

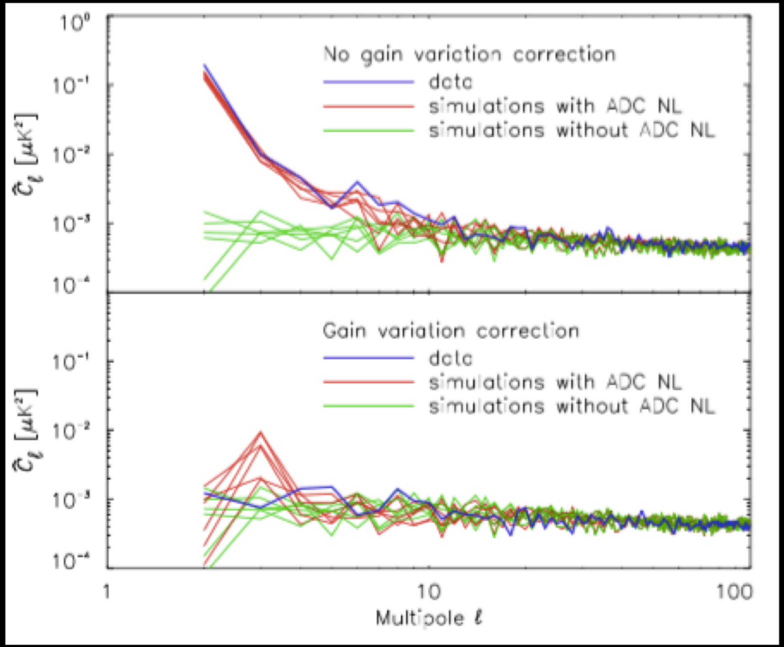
- PICO is a NASA-chartered "probe study" (PI Shaul Hanany) : one of ~1 dozen selected for study ahead of 2020 Decadal Survey
- Major boundary conditions:
  - cost constrained to be < $1B: does not include fast modulator like a half-wave plate
  - Mission assumed to consist of imaging focal plane with polarization sensitive detectors
  - Polarization reconstructed using combination of an array of O(10^3 to 10^4) detectors with individual polarization sensitivity

- PICO Systematics Working Group gathered list of known systematic errors https://zzz.physics.umn.edu/ipsig/preliminary_list_of_systematic_effects_to_consider
- The group also prioritized the list:
  - "Systematics Risk Factor" was defined: includes impact on science results, difficulty in mitigating through instrument/mission design or analysis, and whether the particular systematic is well understood.
  - Highest SRF systematics are ones that are design-driving and/or not well understood
  - Each identified systematic error was assigned an SRF
  - Many of these systematics could be reduced with a fast modulator, though with possible introduction of additional modulator-synchronous systematics
- Top three priority systematics are now under more detailed study through detailed simulation
  - Detector Gain mismatch
  - Far Sidelobes
  - Polarization Angle Calibration

Detector gain mismatch/stability

Planck HFI





No correction for Variable gains

After correction

A&A 596, A107 (2016)

- Drifts in time in relative gain of detectors leaks temperature signal to polarization
- Planck (both LFI and HFI) gained experience correcting time-variable gain
    - A relevant note: HFI "gain variation" was never actually detector response variation, it was always something else (in particular, ADC nonlinearity)
- Simulations underway given PICO scan strategy, will measure S/N of gain reconstruction (mainly using CMB dipole) using Planck code.
    - What is the level to which the gain can be measured on ~1 day time scales?
    - set limits in B-mode spectra on how well we can hope to correct any gain drifts in a PICO mission
- NOTE: fast modulation helps with relative gain mismatch and most of individual detector level; only remaining gain fluctuations are those on timescales shorter than a waveplate rotation.

Far sidelobes

- Difficult to measure accurately on ground: may need to rely on models (i.e. GRASP or other physical optics code)
- Very low level compared to main beam (though large solid angle)
- Typically highly polarized
- Picks up bright far off-axis signals, i.e. galaxy in a scan-synchronous way
- PICO study using GRASP simulations to estimate FSLs of telescope, and use Planck simulation tools to compute sky signal pickup with PICO's scan, map making, etc.
- Room for improvement with design
- NOTE: fast modulation doesn't completely mitigate this effect. It helps with any differential FSLs

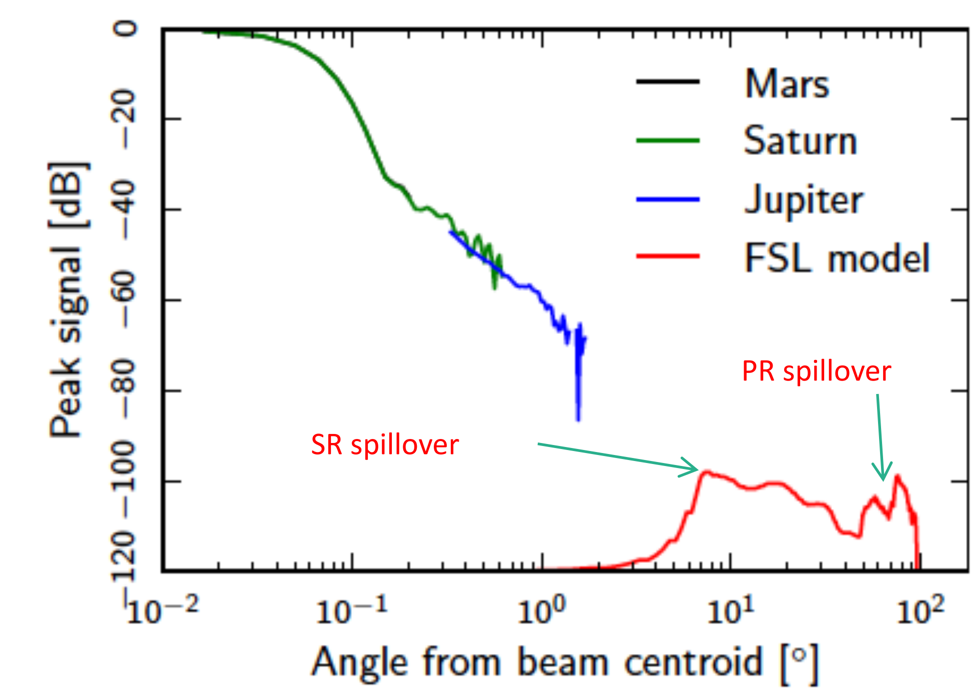
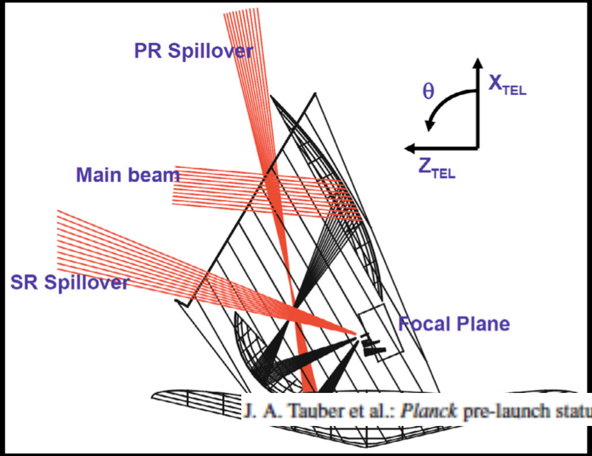


Fig. 14. Azimuthally averaged profiles of measured beams of channel 353-1 compared to the azimuthal average of the far sidelobe physical optics model.

Planck Collaboration: *Planck* 2013 results. VII.



J. A. Tauber et al.: *Planck* pre-launch status: The optical system

Polarization Angle Calibration

- Refers to knowledge of angle of sensitivity of detectors
- Relative angle between the different photometers can be calibrated to high precision in the limit that single photometers are independent, but absolute angle is not.
- With Planck, we were never successful at finding an astrophysical source for polarization angle calibration that is free from systematics. Great effort went into characterizing the Crab nebula (Tau A).
- HFI confirmed ground calibration results (Rosset et al 2010) to ~0.2 degrees by checking whether TB, EB are zero. (Planck Intermediate results XLVI 2016) No additional rotation needed.
    - Typical scheme for ground-based instruments as well
    - ***Of course… maybe cosmological TB and EB are not zero***
    - Spectral shape of angle error may not be completely degenerate with scientific signal in TB or EB
- NOTE: fast modulation doesn’t help with this: must calibrate absolute angle of modulator.
- Other ideas: external calibration satellite…?