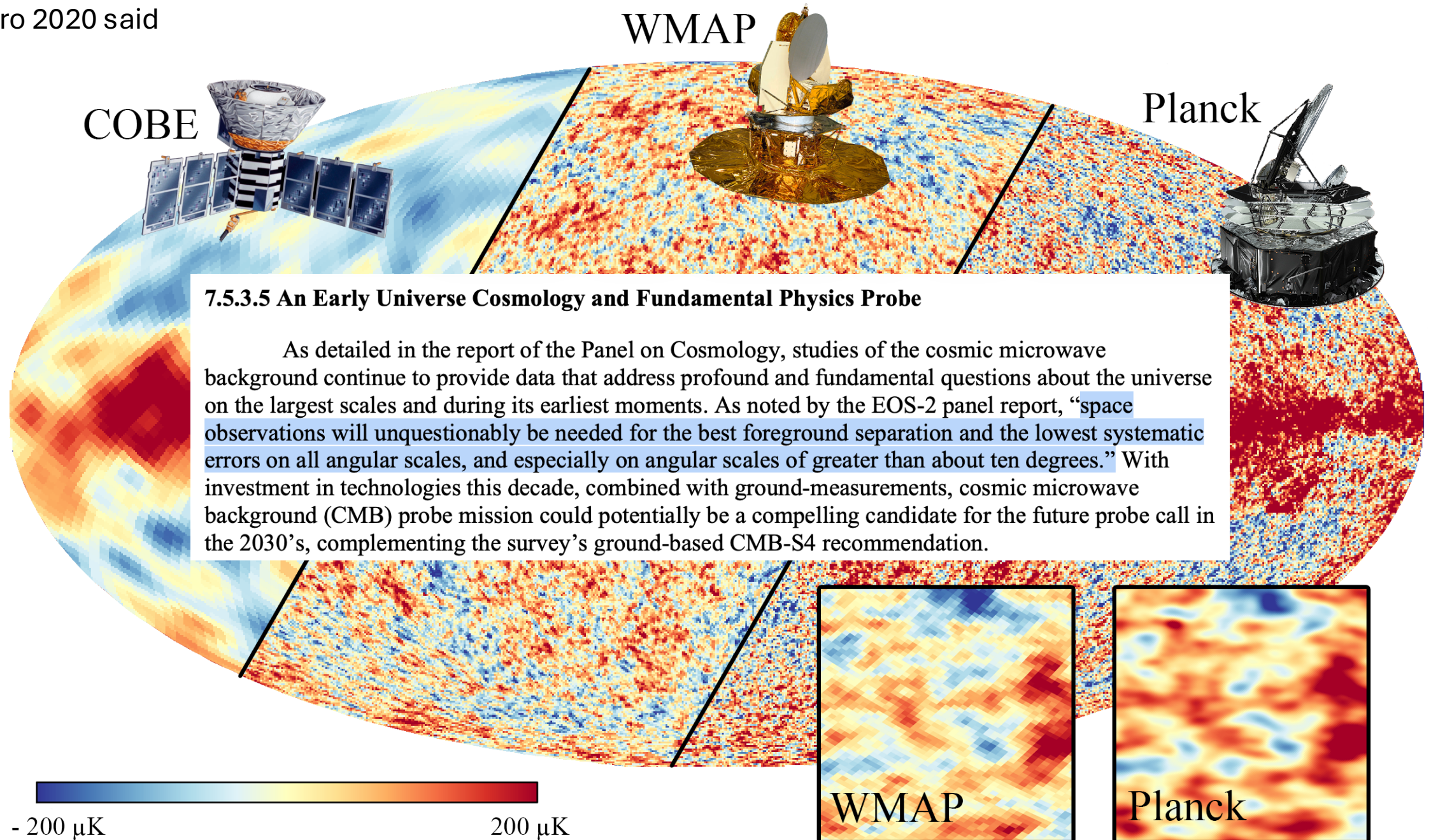


Telescope Architectures for a CMB Probe+

Brendan Crill

(Jet Propulsion Laboratory, California Institute of Technology)

September 2, 2026



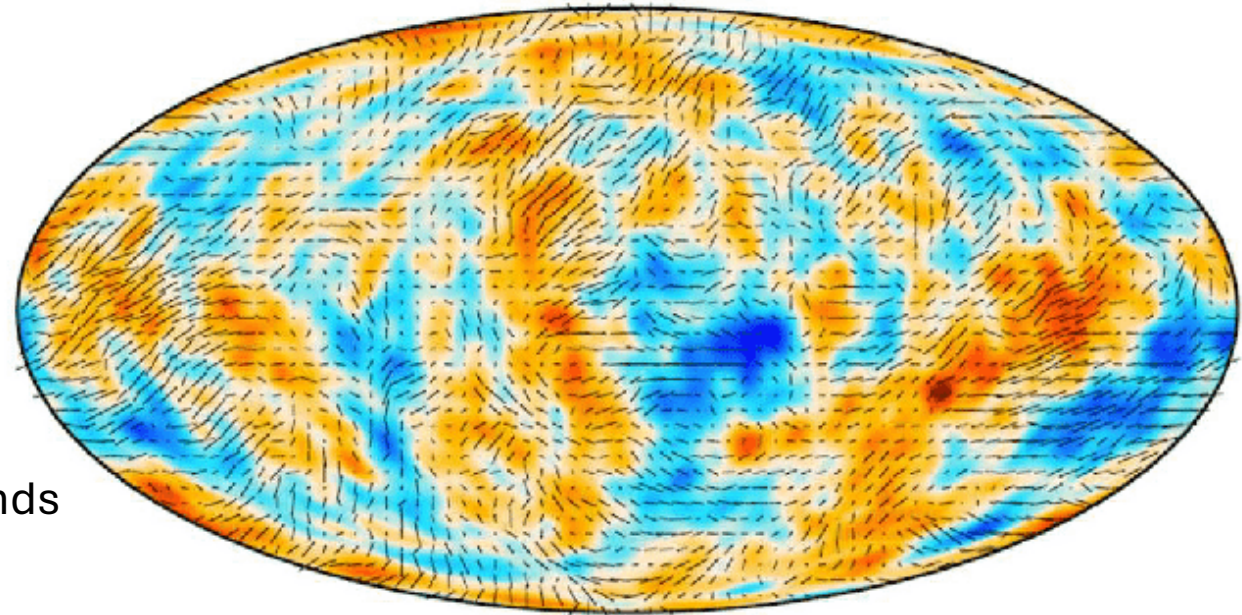
Observatory architectures for a CMB Probe+

Telescope feeds polarized detectors
sensitive to wide bands and/or a spectrometer
covering roughly 10-1000 GHz (3cm - 300 microns)

Drift scan + orbit around sun -> polarization
reconstruction over the full sky

Defining observatory and mission parameters are
critical for science return in the presence of foregrounds
(Galactic, lensing) and controlling systematic errors

For inflation science, looking to detect ~ 1 nK RMS B-mode polarization signal on 2.7K background
-> map depth equivalent to 10,000 Planck missions enables broad groundbreaking science

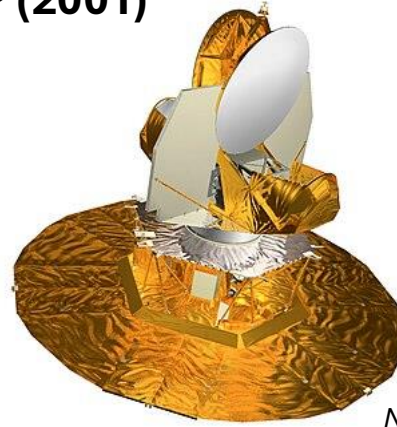


COBE (1989)



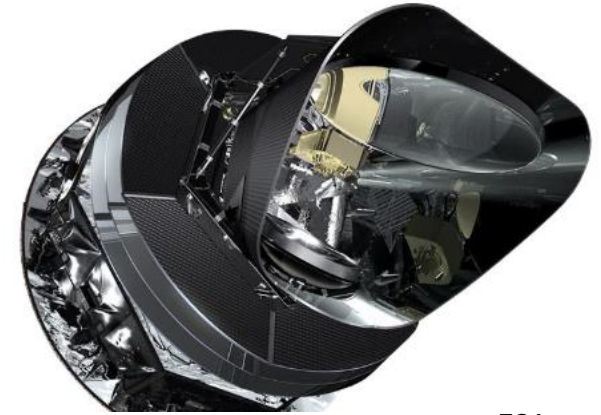
NASA

WMAP (2001)



NASA

Planck (2009)



ESA

LiteBIRD (target 2036)



JAXA; Aizawa et al 2026

**2018 PICO concept
(early 2040's?)**

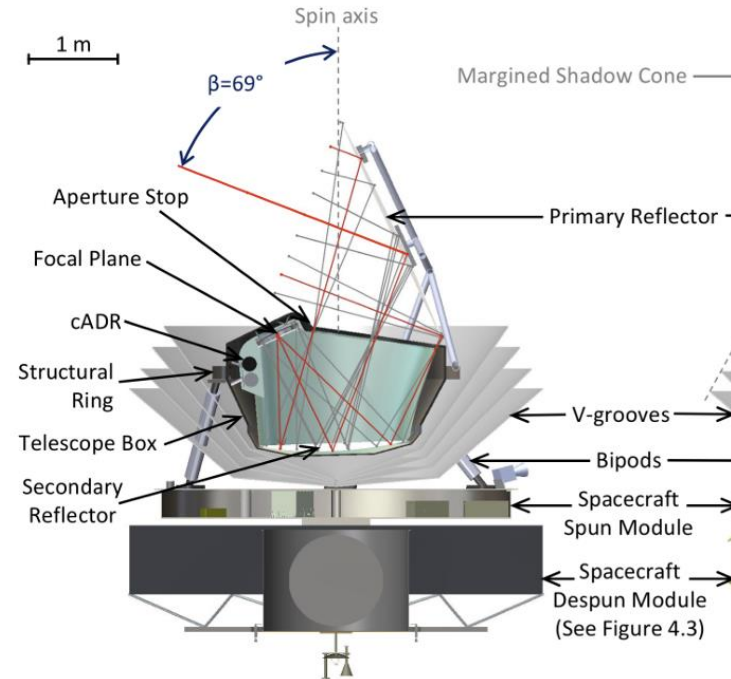


NASA

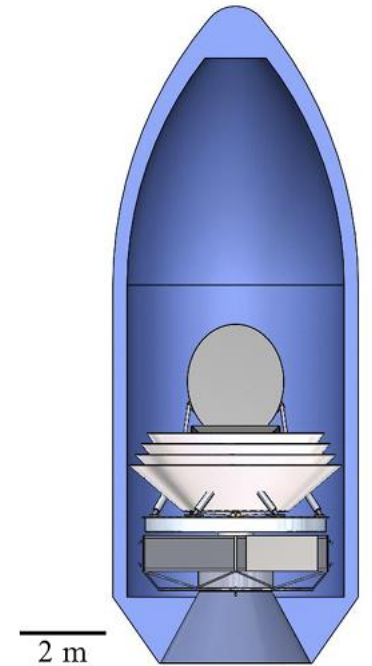
CMB Probe+

CMB space observatory considerations

- Likely to need a focal plane with roughly 10^4 cryogenic ($<0.1\text{K}$) detectors
 - Multi-chroic vs. single-band feeds and implications for focal plane area impacts telescope design
- Higher angular resolution (i.e. a larger telescope) -> more science
 - May also be necessary to handling non-Gaussian foregrounds
- Constrained by rocket fairing
- Passive cooling and stability
 - V-Groove architecture Each V-groove shades the ones interior to it.
- Scan strategy is also key



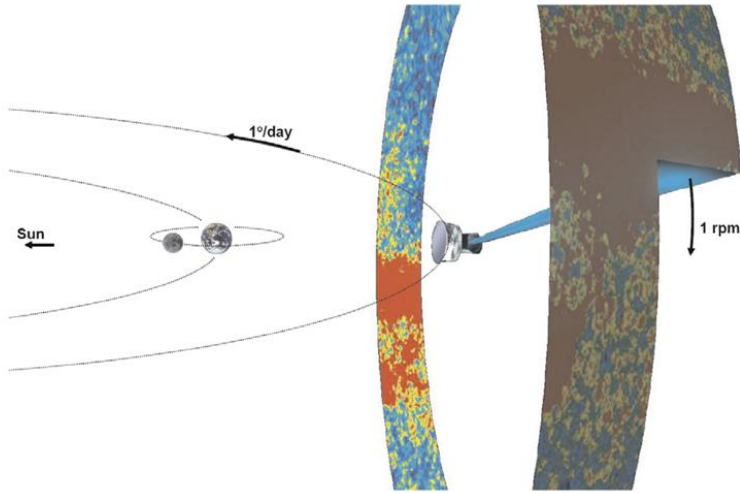
PICO report fig 3.1



PICO report fig 4.1

Scan strategy

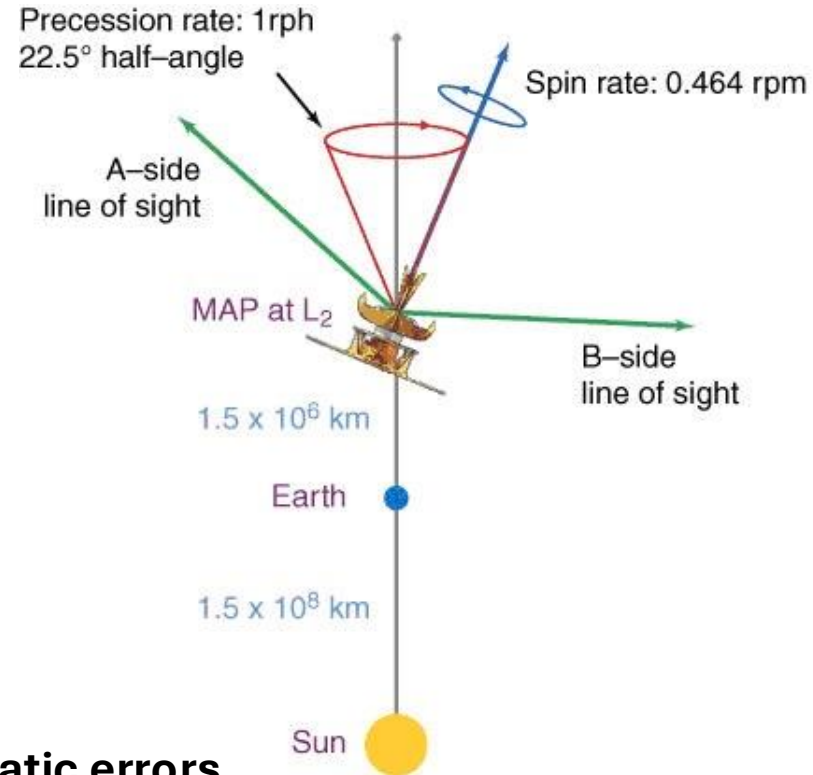
Planck



Tauber et al (2010)

Better cross linking reduces systematic errors associated with polarization reconstruction

WMAP



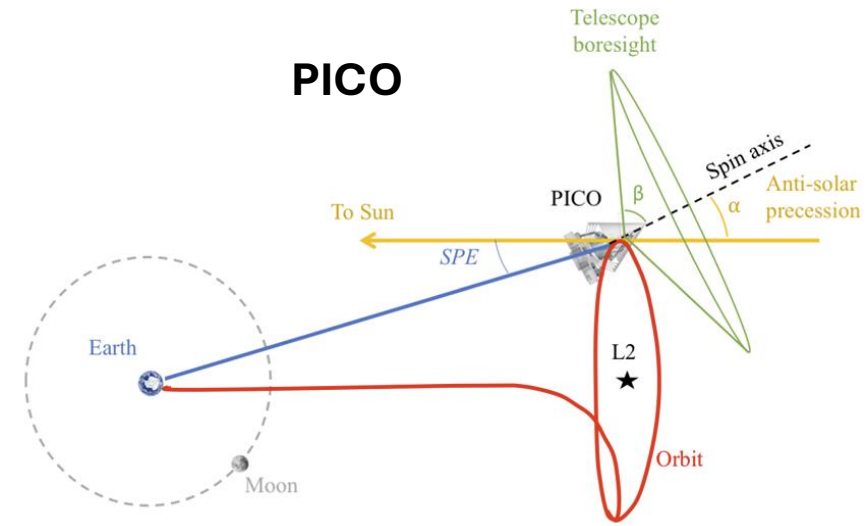
Bennett (2007)

CMB Probe+

A key CMB Probe+ trade:

**for fixed V-groove size,
increasing precession angle means smaller telescope**

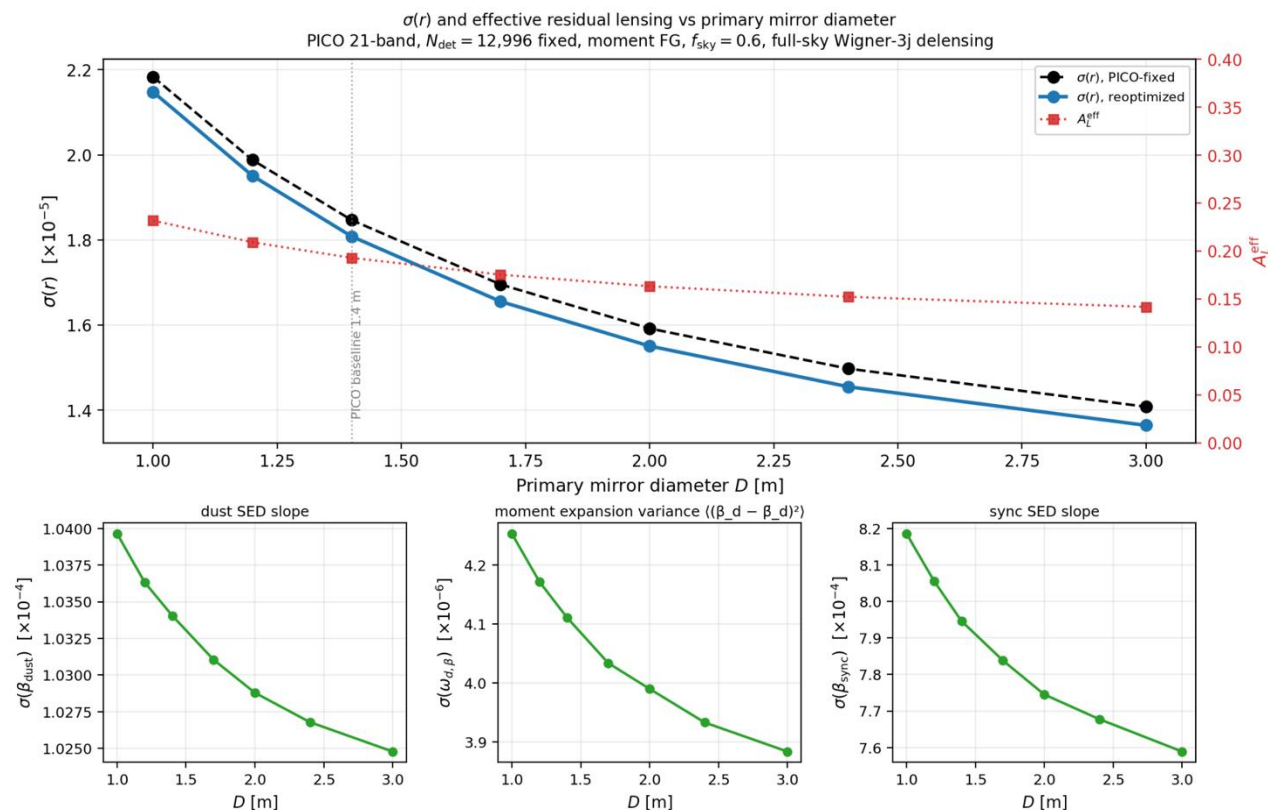
PICO



PICO report fig 4.2

Augr

- A fast fully differentiable CMB mission science performance forward-modeling toolbox
- Optimize any mission parameter: frequency band arrangement, focal plane layout, telescope size, etc.
- Delensing and foreground separation
- Validated against PICO and BICEP/Keck
- **See poster by J. Cheshire**



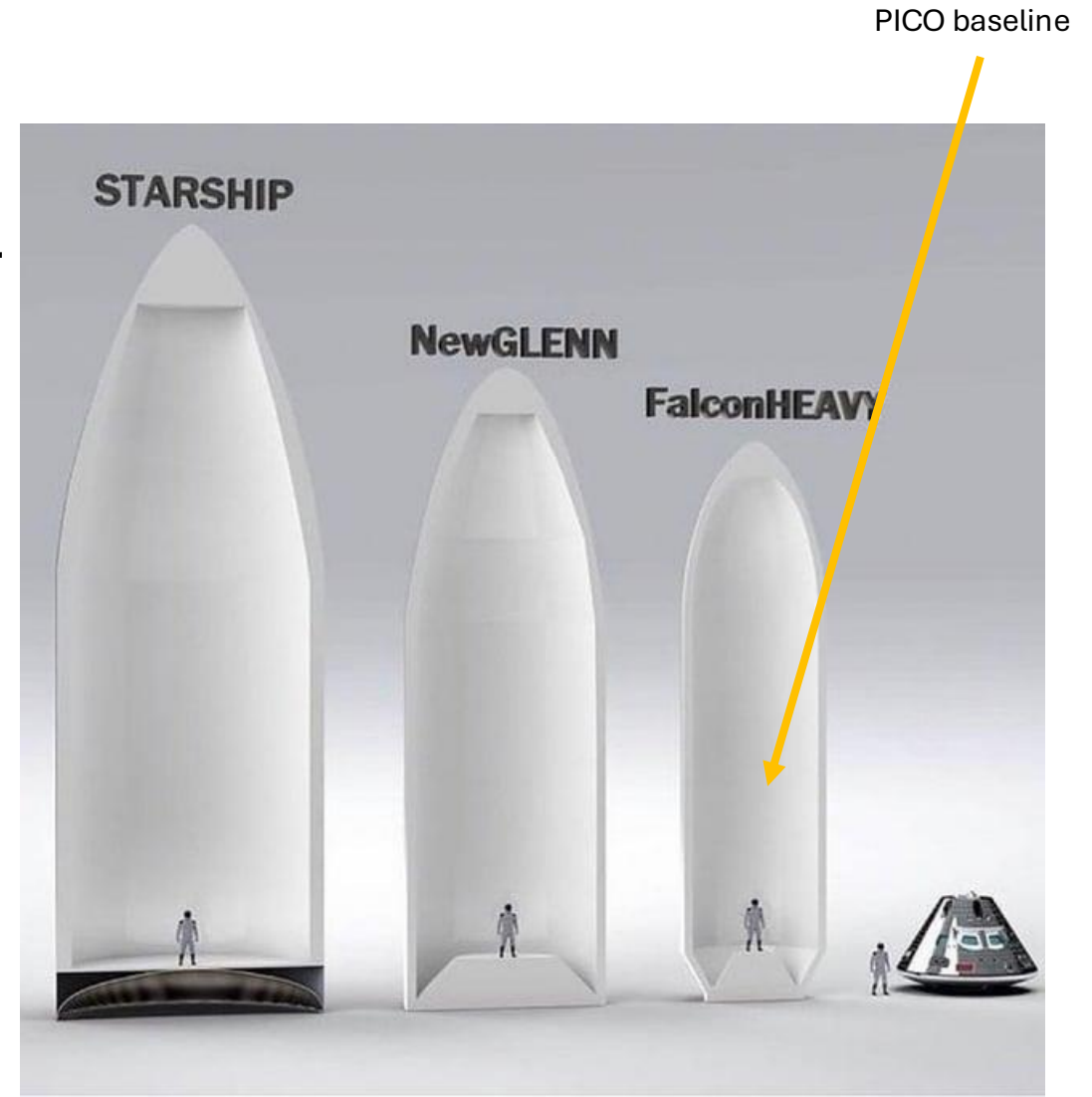
<https://github.com/jrcheshire/cmb-augr>
`pip install cmb-augr`
(still early alpha version; $\sigma(r)$ numbers preliminary)

Likely characteristics of a CMB Probe+ to be studied

- sensitivity to 10-1000 GHz: what frequency range is enabling vs. enhancing?
- Angular resolution requirements: ~ 1 -3m primary mirror
- Cryogenic temperatures: Sub-K detectors; optics, primary mirror (passive or actively cooled?)
- Thermal stability is critical: Earth-Sun-L2 orbit: stability, large field of regard
- Continuous scan the sky: rotation ~ 1 rpm; slower nutation for high degree of cross-linked scans
- $\sim 10^4$ focal plane detectors
- Noise stability in detectors, including common-mode noise (use amplifiers w/ differential polarimetry?)
- Low polarization systematics
- Low pickup of far sidelobes

Other options to explore

- Spectrometer + Imaging Polarimeter
- Telescope design: Dragone, three-mirror anastigmat
- Multiple telescopes?
- Larger launch fairings
 - New launch vehicles will be available with 8-9m fairings (vs 5m Falcon 9)



Going forward:

The time is right for a CML-3 study of a CMB mission ahead of Astro 2030

- Architecture trades along many axes will explore science return for possible mission configurations, available launch vehicles, cost, etc.
 - We have software tools to quickly evaluate trades
 - New space economy presents important opportunities (i.e. new launch vehicles)
- Need large-scale simulations addressing systematic error and Galactic foreground challenges
- Key technology needs are maturing well: need space-environment performance demonstrations
 - Detectors (see next talk by J. Hubmayr)
 - Leverage ongoing ground-based work
 - Cryogenics (see parallel talks by W. Chen and P. Shirron)
 - Leverage work done for PRIMA, X-ray missions

CMB Probe+: A full sky millimeter/submillimeter-wave polarimetric imager and spectrometer