Tau“Я”Us

Sho Gibbs (UIUC)
For the Taurus Collaboration

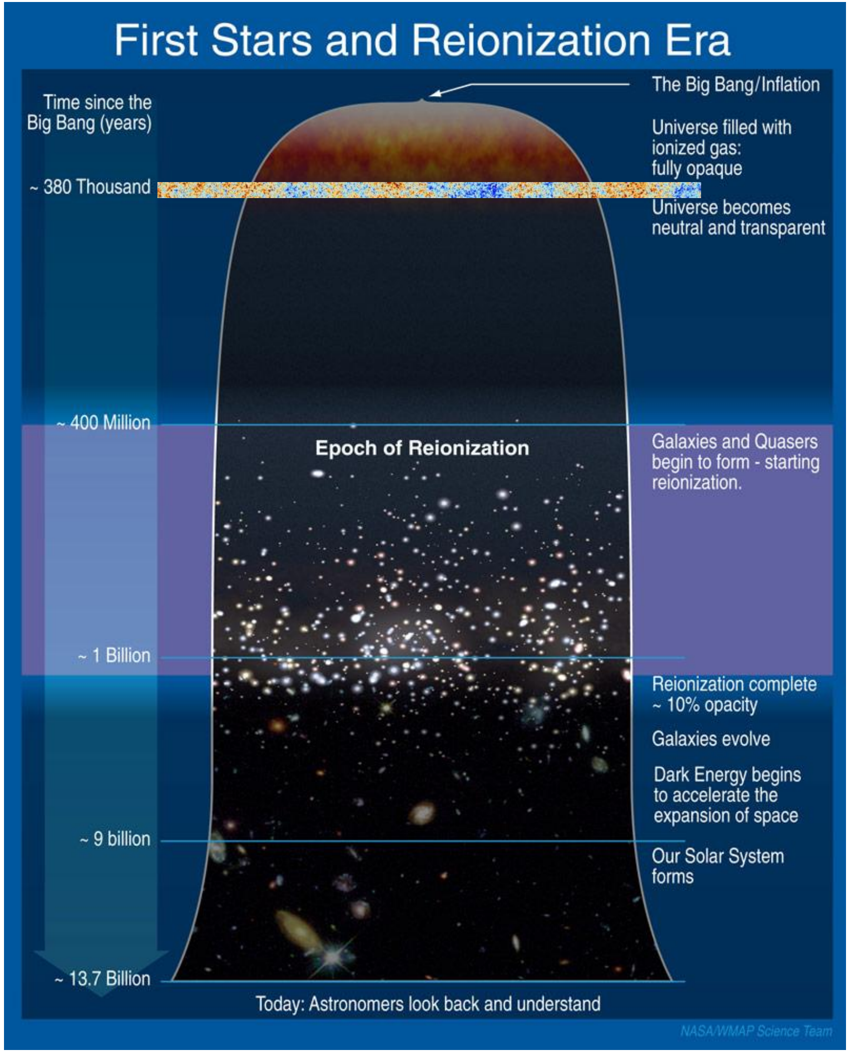
The Collaboration: tauruscmb.com

The CMB and Reionization:

Cosmic Microwave Background:
baby picture of the universe

Epoch of Reionization:
When the universe turns on

τ: Optical Depth to Reionization
0.054±0.007 (Planck 2018)
0.059±0.006 (Pagano et al. 2020)

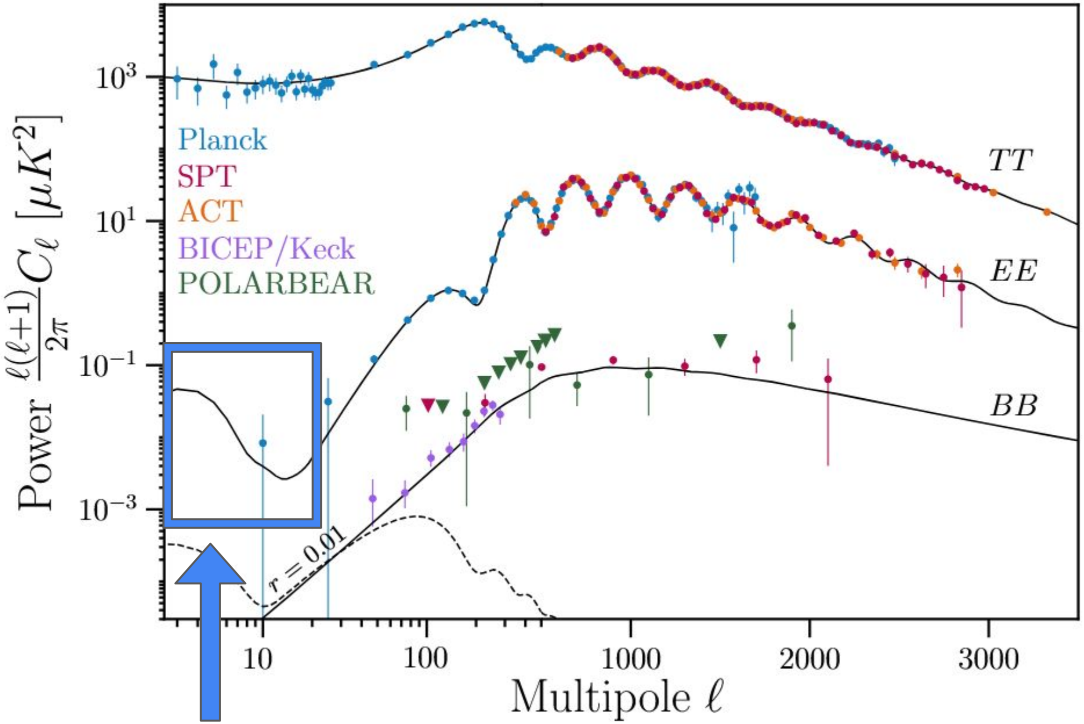


The Science Case

CMB:

- Large Scale
  - Low multipole
- Polarization
  - Reionization Bump

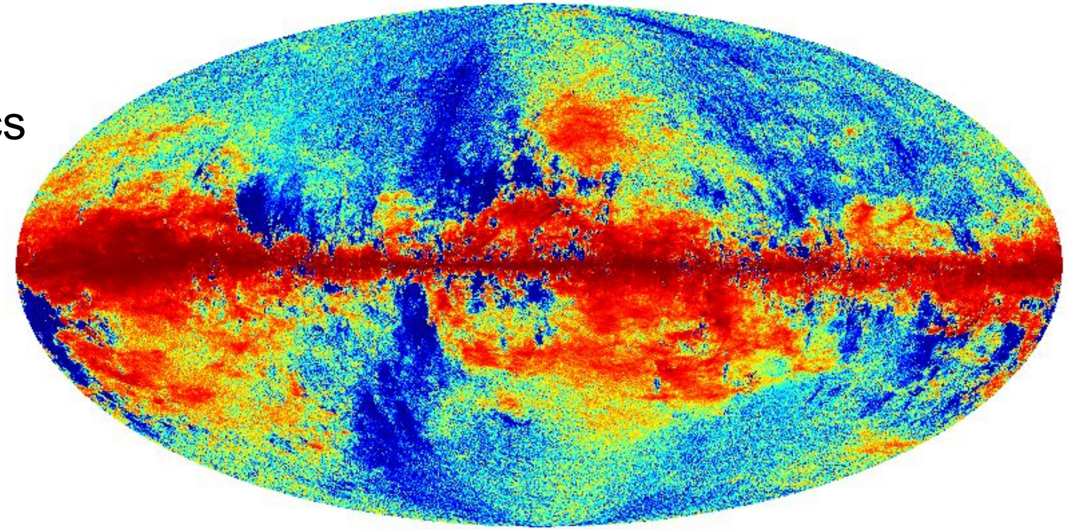
Map of Galactic Foregrounds



Snowmass 2021, 2203.07638

Some Challenges

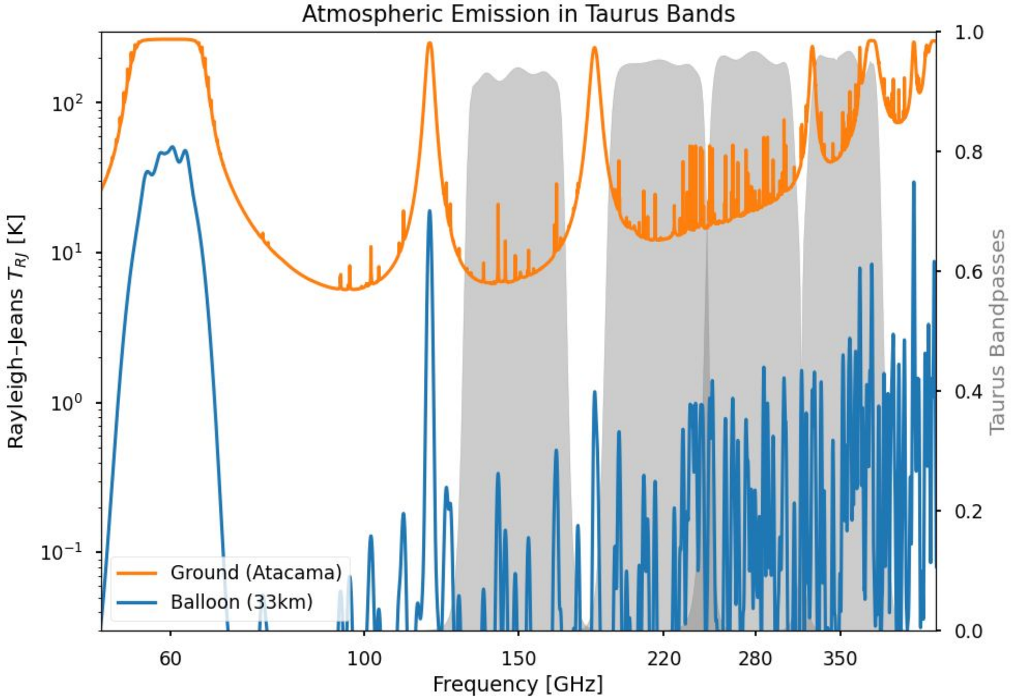
- Understanding Systematics
- Large Sky Fraction
- Foregrounds
  - Polarized Galactic Emission →
  - The Atmosphere



Thermal Dust, Stokes Q and U, Planck 2018

Some Challenges

- Understanding Systematics
- Large Sky Fraction
- Foregrounds
  - Polarized Galactic Emission
  - The Atmosphere →

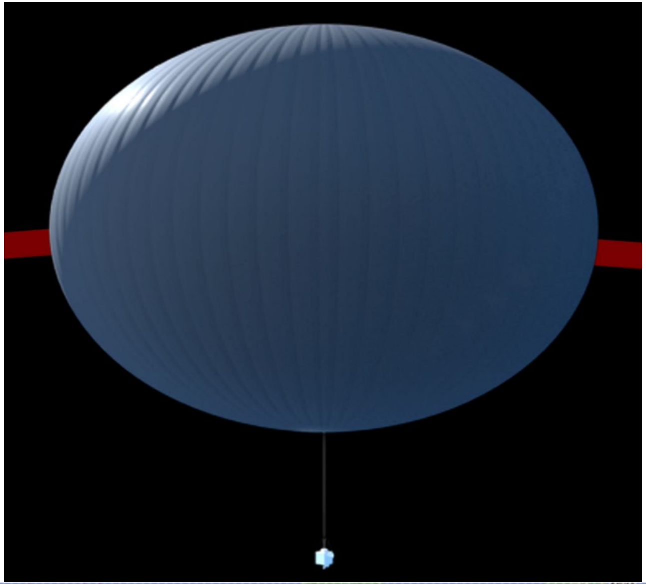


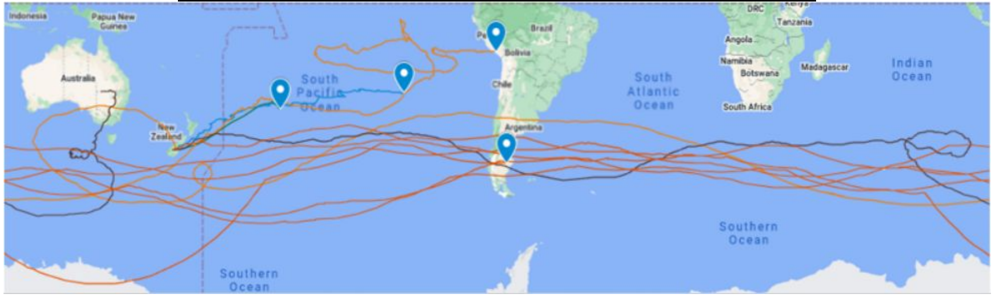
Steve Benton, Taurus

Balloon time!

NASA Super Pressure Balloon

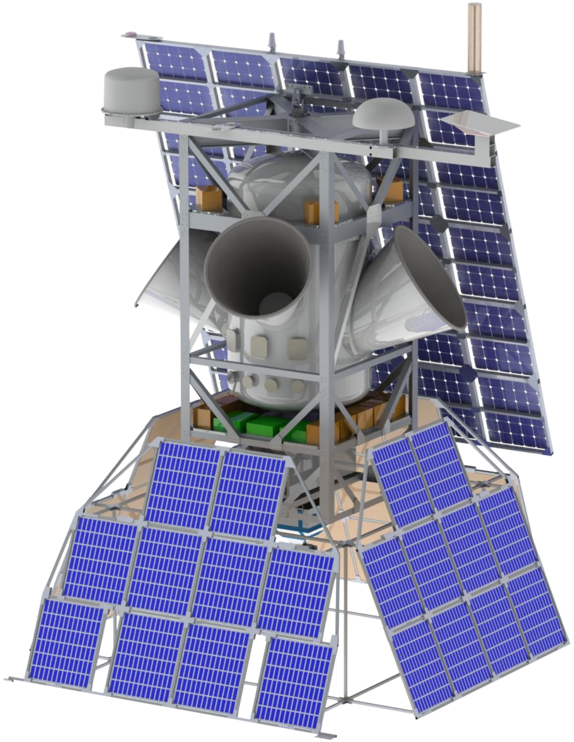
- From Wanaka, NZ
- Reach ~ 33 km altitude
- Target mission length >30 days
- Can see ~ 70% of the sky

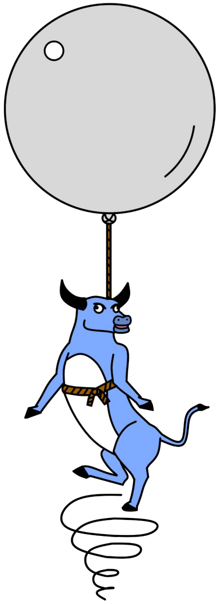




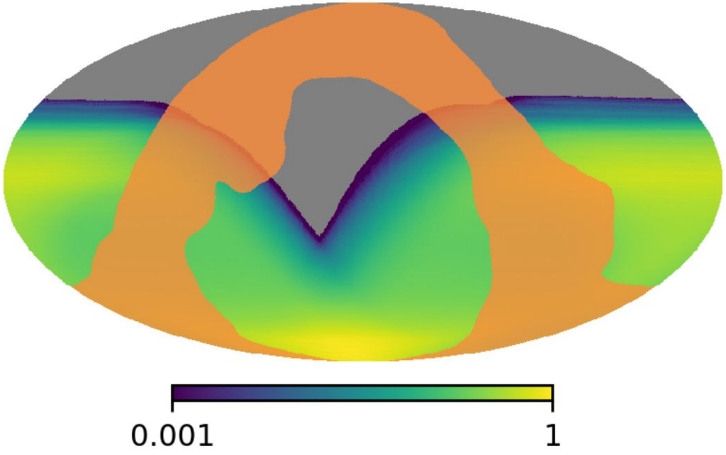
NASA

Gondola and Scan Strategy





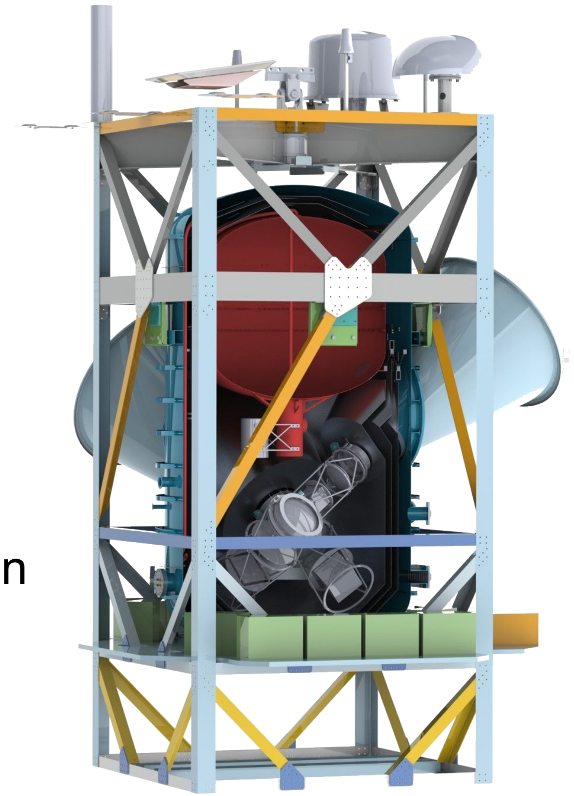
Taurus Normalized Hits Map:



Assumes a late March flight

Cryogenics

- Cryostat hold time of ~50 days at float
- Liquid Helium tank and vapor-cooled shields
    - 70K, 35K equilibrium for the shields
    - 4K main tank of 660 L
- Superfluid tank maintained by capillaries
- Closed cycle dilution units (3uW @ 100 mK)
    - ~100 mK for detectors during observation

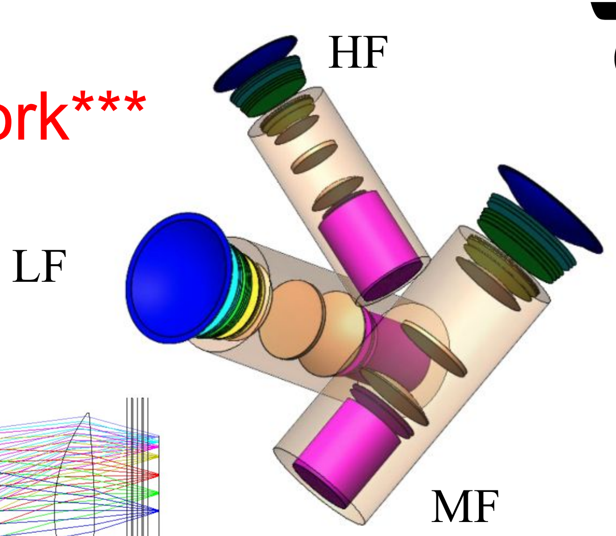


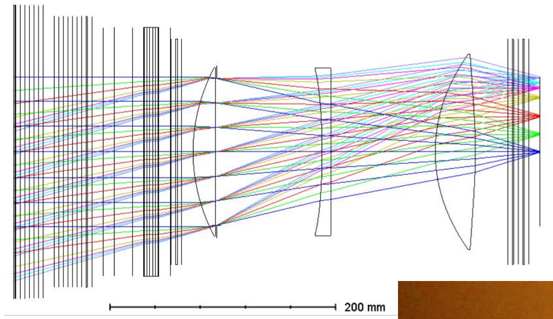
Also, custom Housekeeping:

- See: Tartakovsky, 2505.07986

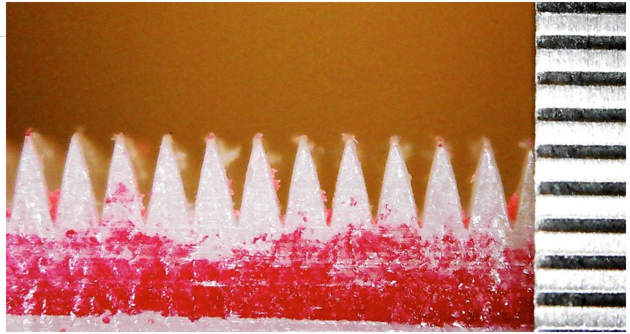
Receivers & Optics ***Ongoing Work***

- Three de-pointed receivers held at fixed 35 degree elevation
    - LF: 150 and 220 GHz
    - MF: 220 and 280 GHz
    - HF: 280 and 350 GHz
- Three lens refracting:
    - Grooved plastic lenses
    - 30 degree FOV
    - f-number f/1.7
- Stepped Half-Wave Plate at 4K
    - 5-layer sapphire





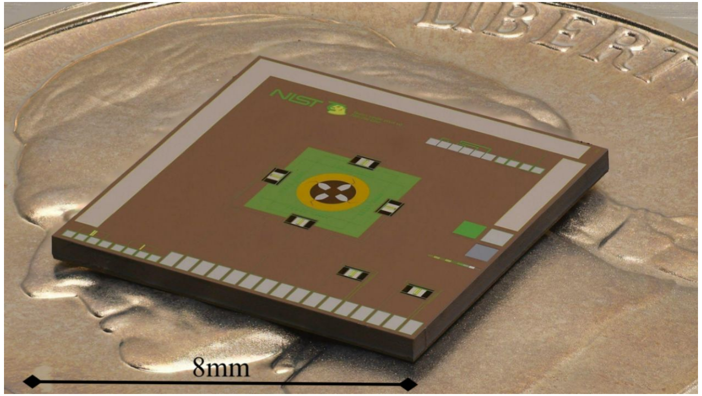
Johanna Nagy



Detectors

*** Ongoing Work ***

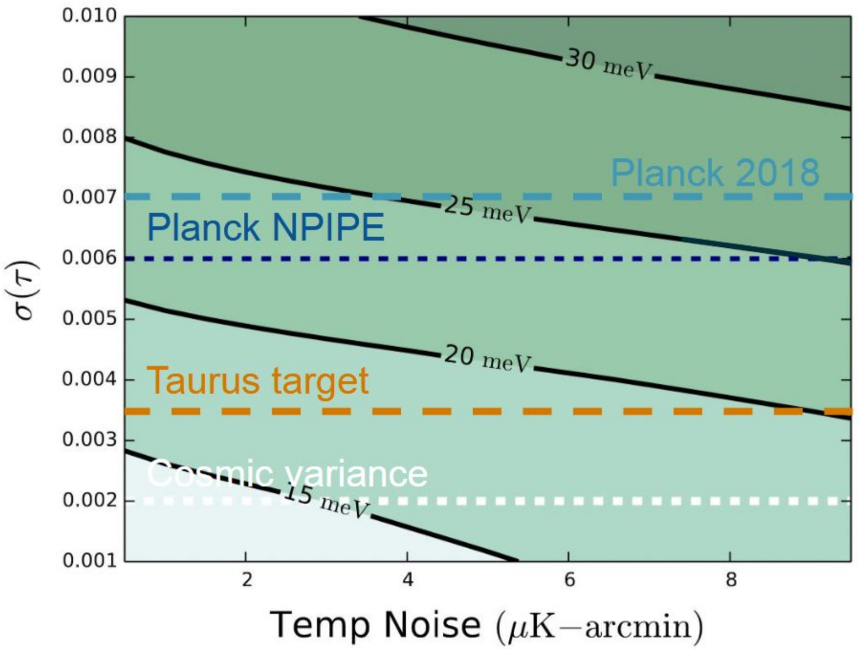
- Dichroic transition edge sensor (TES) bolometers made by NIST
- Operate at 100 mK
- Advanced TDM readout based off of CMB-S4 development (SLAC)



Receiver	Band Centers [GHz]	Pixels (TESs)	FWHM [arcmin]	NETs [uK √s]
LF	150/ 220	832 (3328)	30 / 22	76 / 123
MF	220/ 280	1024 (4096)	30 / 22	123 / 220
HF	280/ 350	492 (1968)	26 / 22	220 / 550

Conclusion

- Taurus is a NASA funded balloon-borne telescope designed to observe large scale CMB polarization and dust foregrounds
- Targeting a factor of ~2 reduction of Planck 2018 constraint on τ
- Target flight date of Spring 2027**



CMB-S4 Science Book 1st Edition

Thank You!

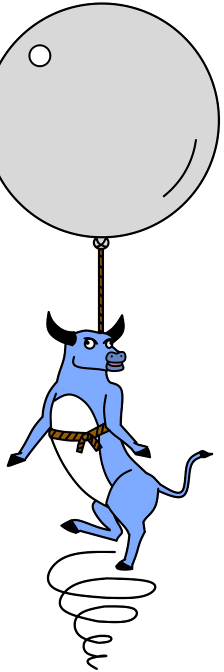
Any Questions?
taurusCMB.com

Instrument Overview:
May et al. 2024
2407.01438

Cryogenics Design:
Tartakovsky et al. 2024
2410.18150

Optical Systematics:
Adler et al. 2024
2406.11992

Bonus Slides!



Low ell impact of different taus, from Alex's Taurus Paper! Adler, 2406.11992 :

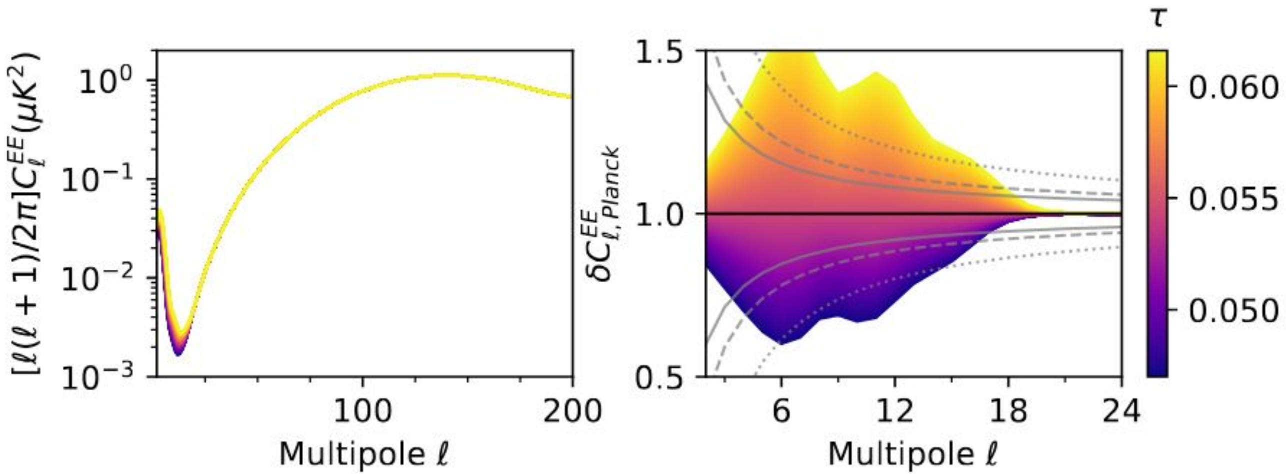
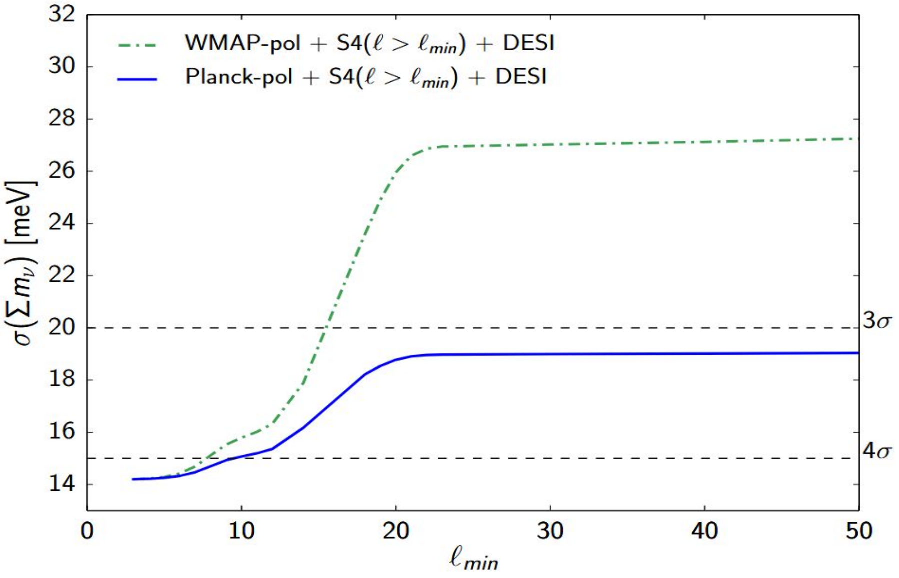


Figure 1. Left: the CMB *EE* power spectrum for $2 \leq \ell \leq 200$ for a variety of values of τ within Planck's 1σ uncertainty [2] (color bar), with the product $A_s e^{-2\tau}$ kept constant. Right: the relative variation from the *Planck* nominal value for $2 \leq \ell \leq 24$. The grey lines represent the sample variance associated with the *EE* spectrum for different observed sky fractions: the dotted line is for $f_{\mathrm{sky}} = 0.4$, the dashed line for $f_{\mathrm{sky}} = 0.7$ and the full line is the cosmic variance limit on $\sigma(\tau)$. In our simulations, we estimate the power spectrum on roughly 40 % of the sky.

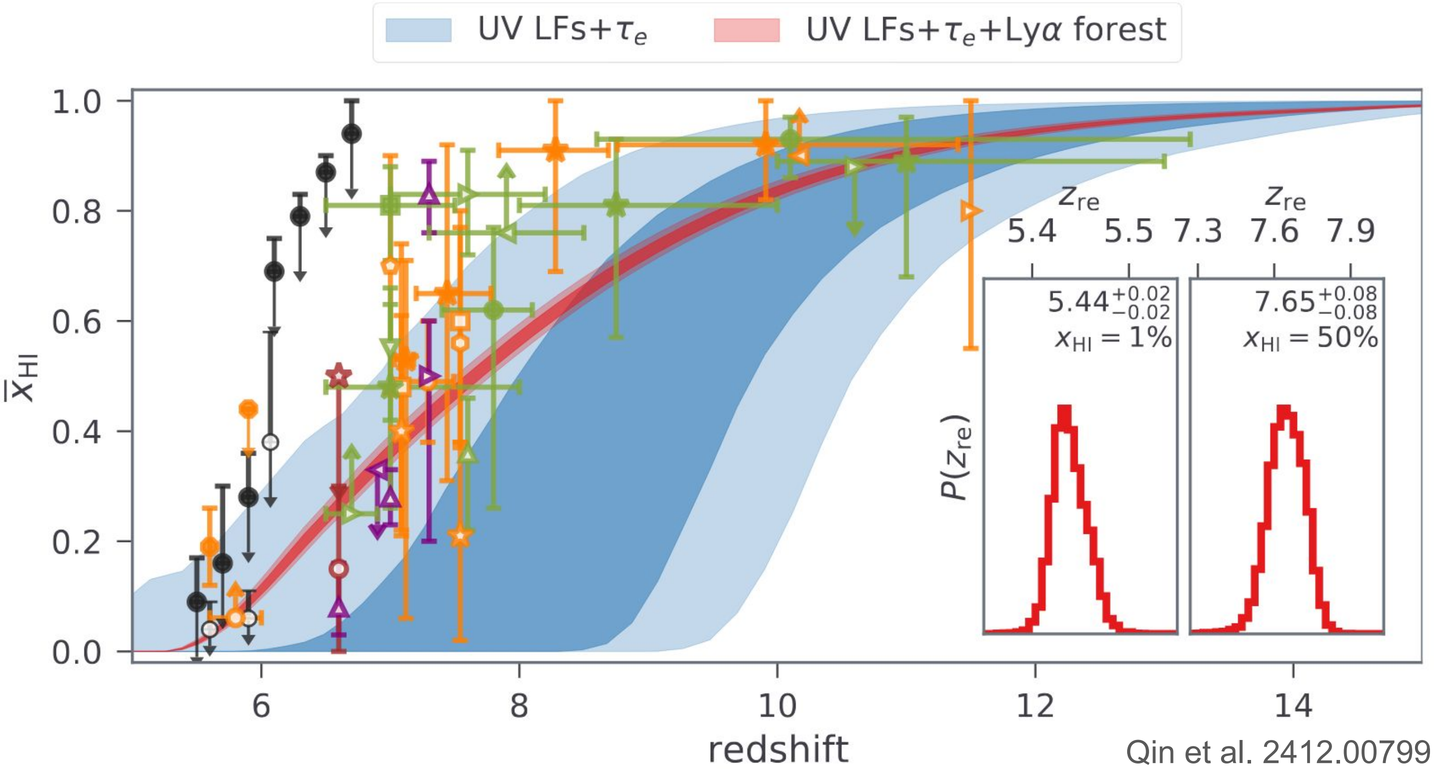
Ell min vs Neutrino Mass Constraints

CMB low multipole data really tightens the neutrino mass constraint



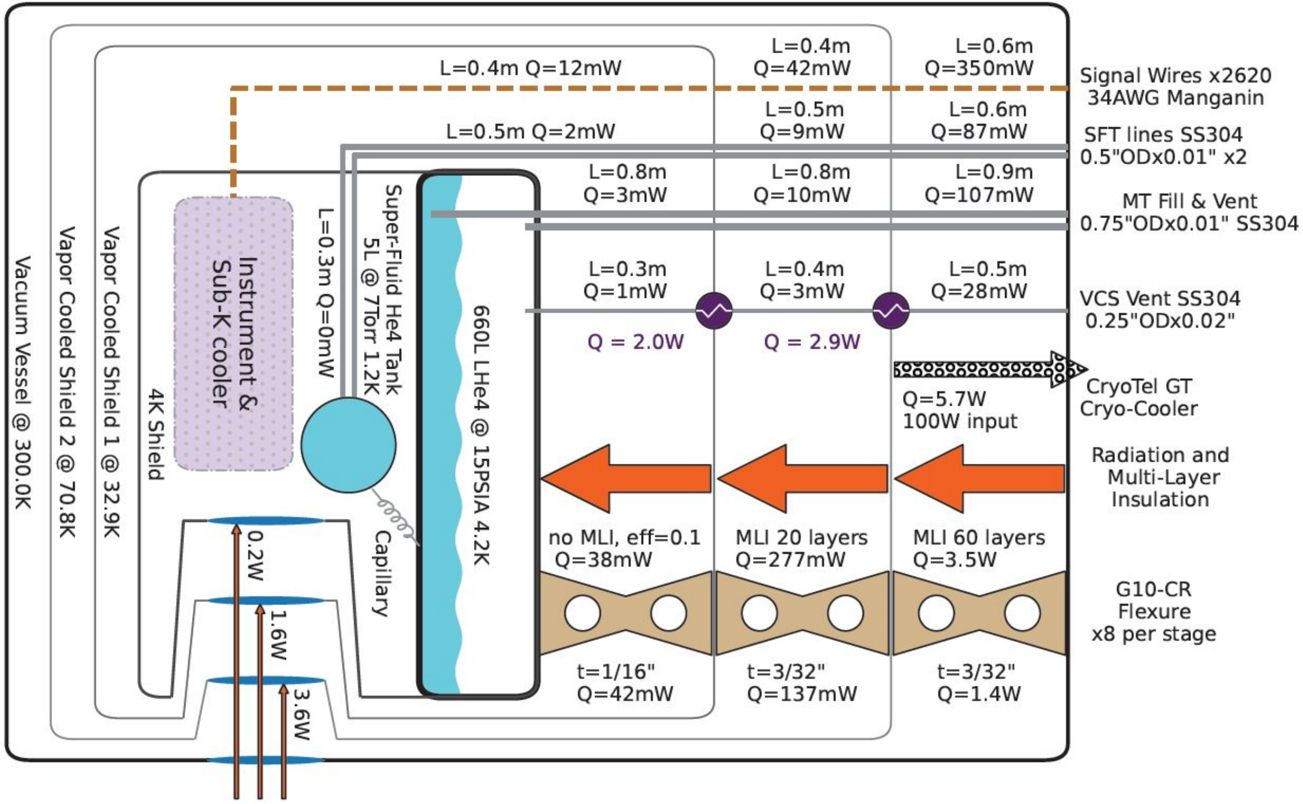
Phys. Rev. D 92, 123535 (2015). 1509.07471

Reionization History as a Precision Science



Qin et al. 2412.00799

Cryostat thermal model



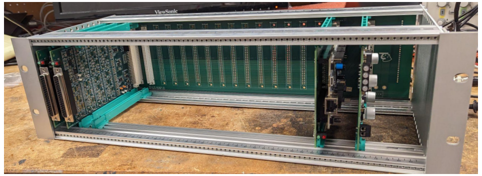
Ways to extend hold time/ stirling cooler's appeal

Table 2: Comparison of explored schemes which can be used to increase the hold time of the Taurus flight cryostat. Added mass is computed by adjusting the solid models to get an accurate estimate. The cryo-cooler case will be adopted by the Taurus cryostat due to its small mass penalty and ability to be descoped as described in section 3.3.

Case	**Vapor Cooled Shield Temperature (K)**	**Hold Time (days)**	**Added Mass (estimated, lbs)**
Base	42.0 – 112.3	48.4	+0
Stirling-Cooler (100 W input)	**34.5 – 69.8**	**59.8**	**+55 (battery & solar)**
Larger MT	42.1 – 112.0	59.7	+60 (scale cryostat)
Extra VCS	35.0 – 72.0 – 154.3	59.7	+75 (larger VV & shield)

Housekeeping Overview

- Modular all-in-one solution for HK and experiment control
  - Functionality expanded with daughter cards such as: **RTD readout, diode readout, cryogenic heaters**, power distribution, ambient heaters, motor controllers and more!
  - Eurocard standard size - fits in commercial subracks (with EMI shields).
  - Daughter cards are swappable in the field.
  - Maximum 16 daughter cards per crate



- Based on ARM-Cortex M7 microcontroller (STM32H723).
- Commanding and streaming using UDP/IP over Ethernet with *Protocol Buffer* serialization format.
  - *Agent* software acts as a bridge between the microcontroller and flight system.
  - *Protocol Buffers* are well supported in many languages and *Agent* software can easily bypassed.
- Mutual flight code development with the Taurus experiment.

Simon Tartakovsky, 2505.07986

Plastic Metamaterial AR Coats

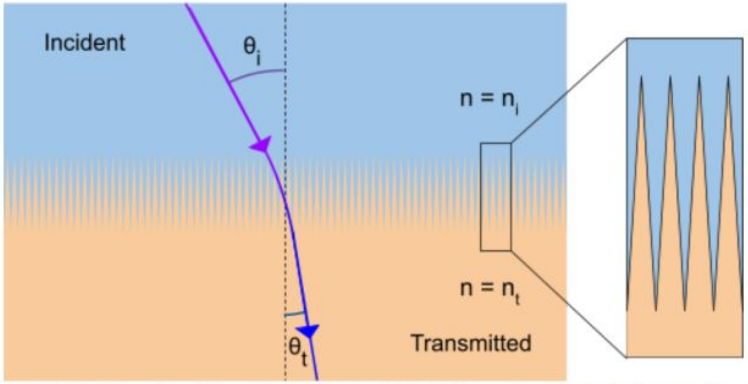


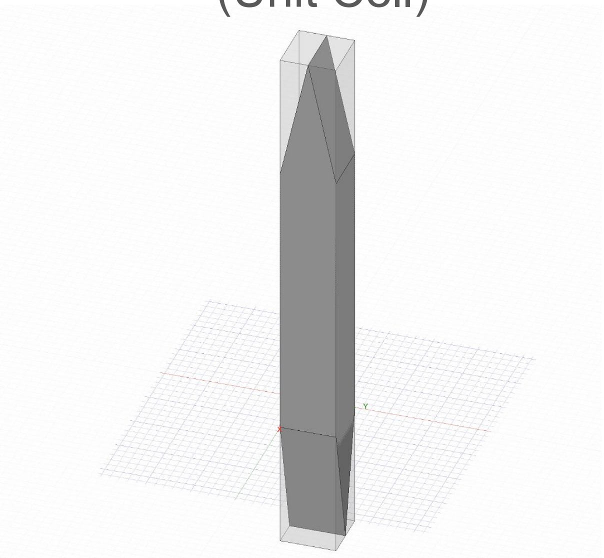
Diagram not to scale

- Good broadband performance
- No cryogenic delamination
- Simple mass production
- Heritage from 3G and ALMA windows

Prototype Groove Target Params:
Spacing = 0.625 mm
Depth = 1.421 mm
Angle = 24.8°

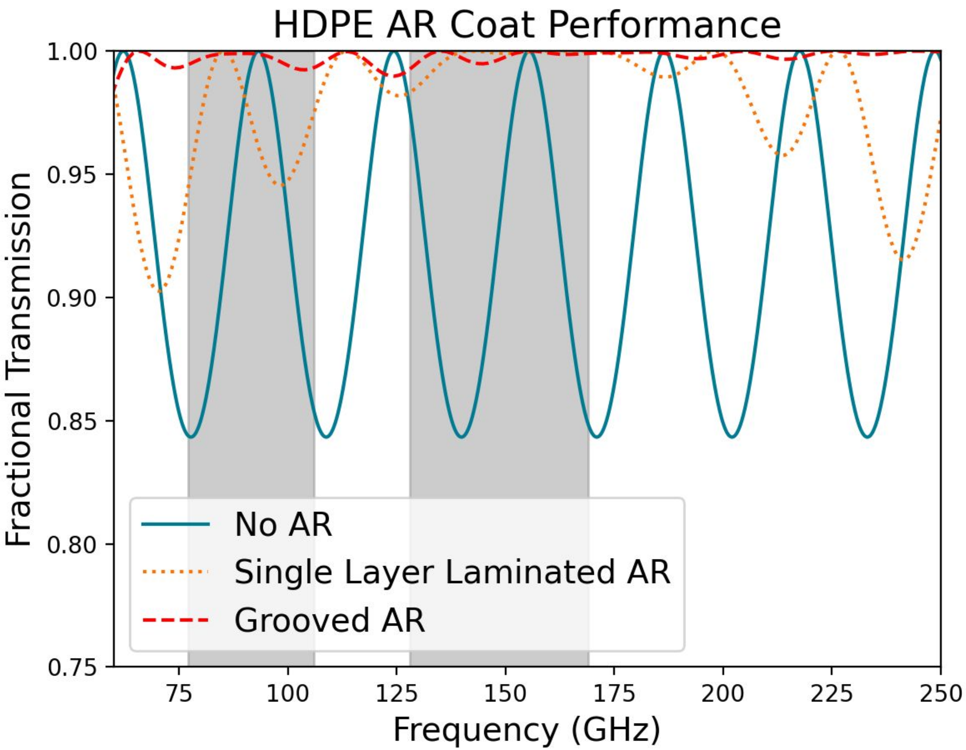
Custom Saw Blade

HFSS Model
(Unit Cell)



Johanna Nagy

Expected Performance - HDPE



Band-averaged Transmission

No AR
90 GHz: 92.3%
150 GHz: 91.5%

Single-Layer AR
90 GHz: 97.0%
150 GHz: 99.8%

Grooved AR
90 GHz: 99.7%
150 GHz: 99.8%

Johanna Nagy