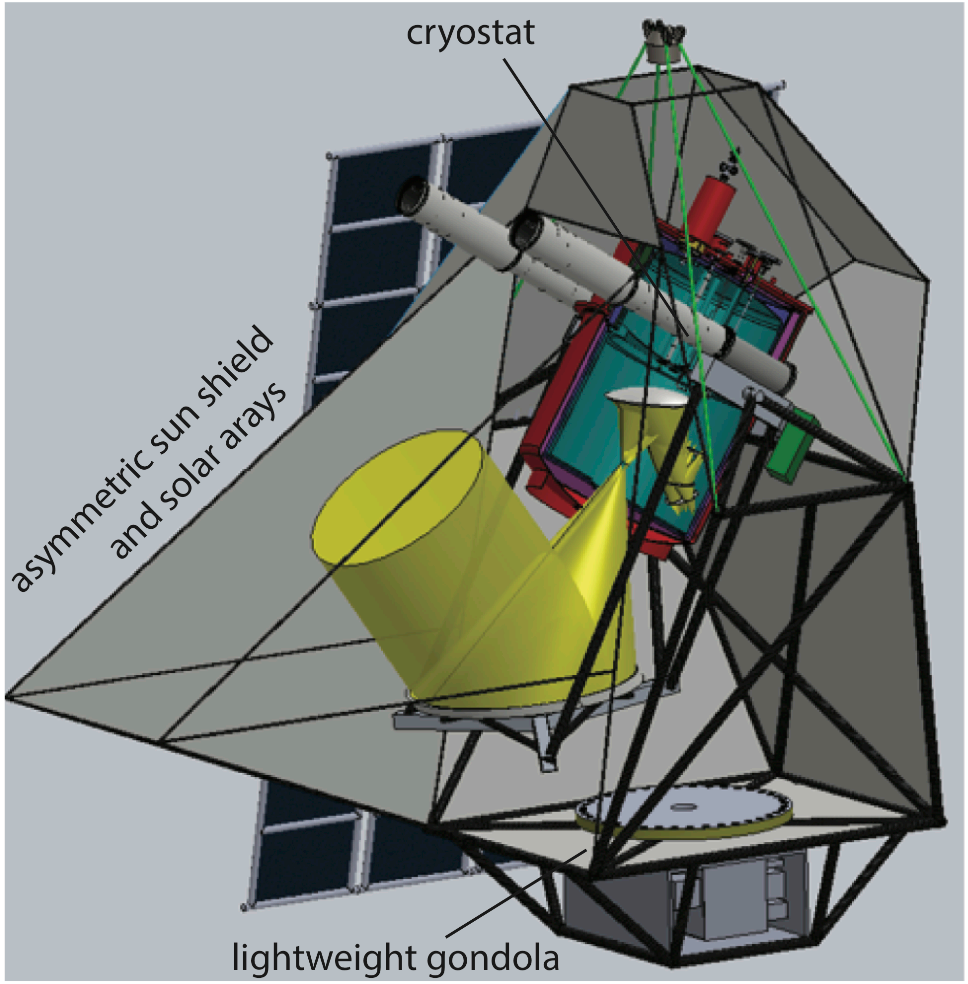
# Reionization, Neutrino Mass, and Inflation with the BFORE Balloon Mission

Sean Bryan
*Arizona State University*

# BFORE

Peter Ade, J. Richard Bond, Francois Boulanger, Sean Bryan, Mark Devlin, Simon Doyle, Jeffrey Filippini, Laura Fissel, Christopher Groppi, Gilbert Holder, Johannes Hubmayr, Philip Mauskopf, Jeffrey McMahon, Johanna Nagy, C. Barth Netterfield, Michael Niemack, Giles Novak, Enzo Pascale, Giampaolo Pisano, John Ruhl, Douglas Scott, Juan Soler, Carole Tucker, Joaquin Vieira

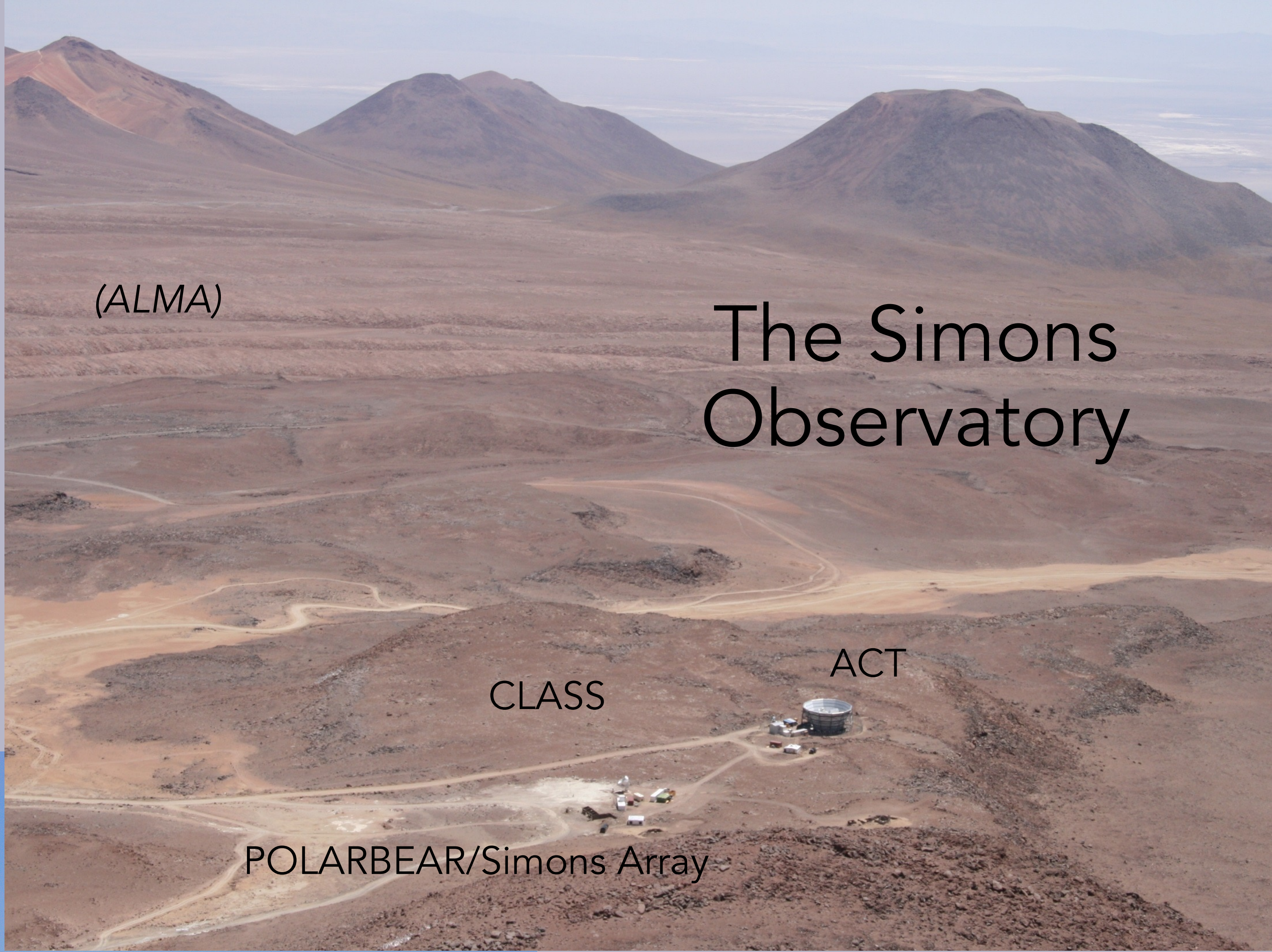



Mission Overview at LTD17: astro-ph/1707.01488

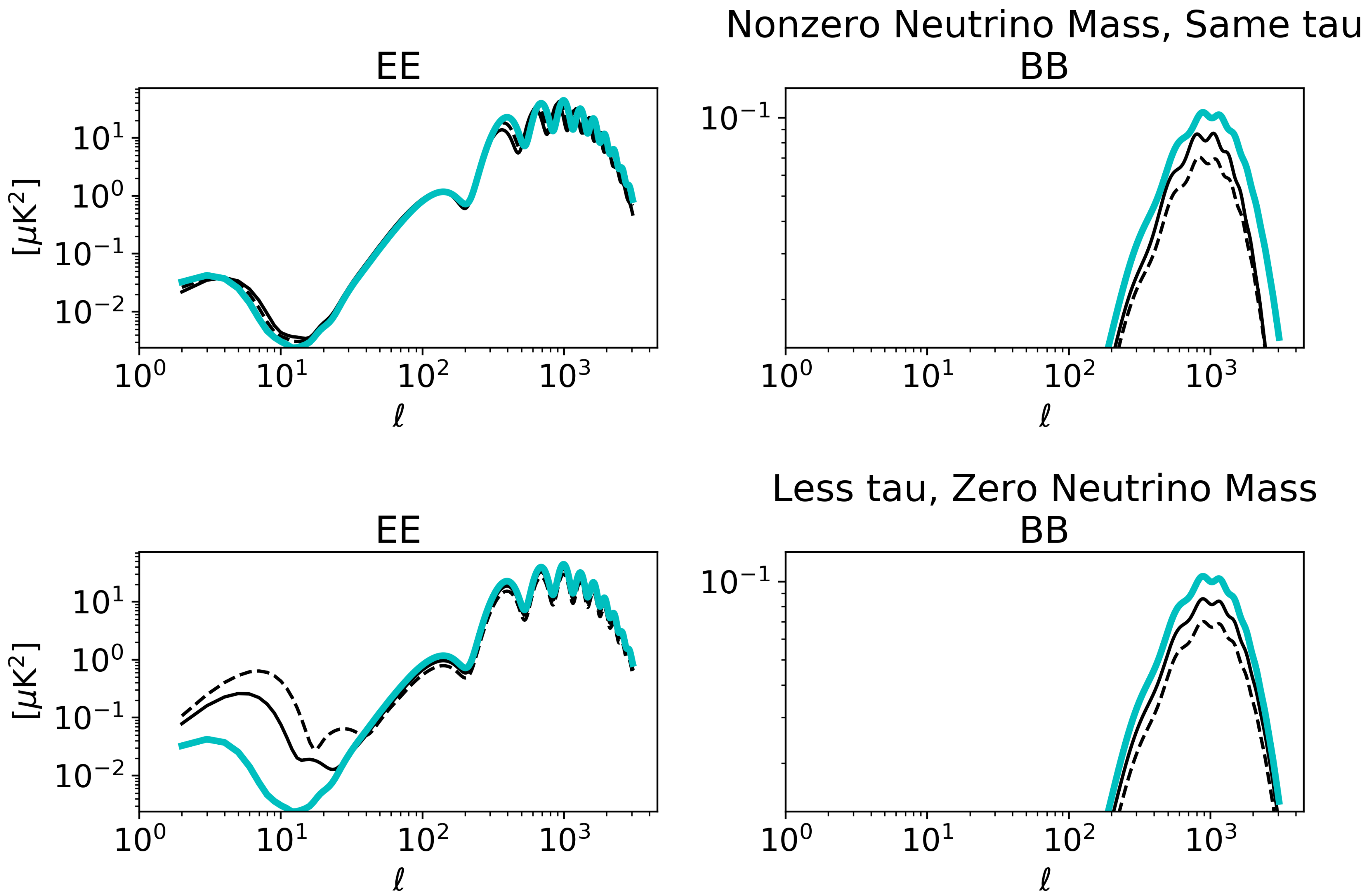
# Key Current/Future CMB Science Goals

- Gravitational waves from inflation
- Lensing induced by z~2 large scale structure
  - Neutrino Mass
  - Dark Energy
- Reionization by the first stars
  - Need improved data to detect neutrino mass
  - Astrophysical interest too of course!
- Galaxy Clusters (tSZ tracing mass, kSZ tracing velocity)
  - Additional tracer of structure growth
  - Astrophysical interest too of course!

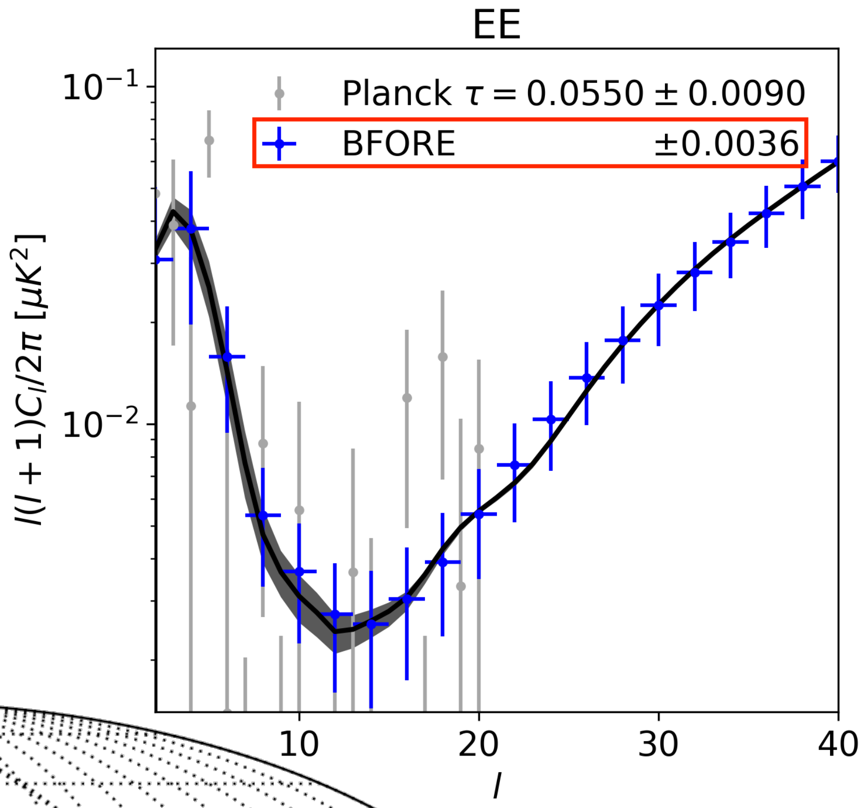
# CMB-S4

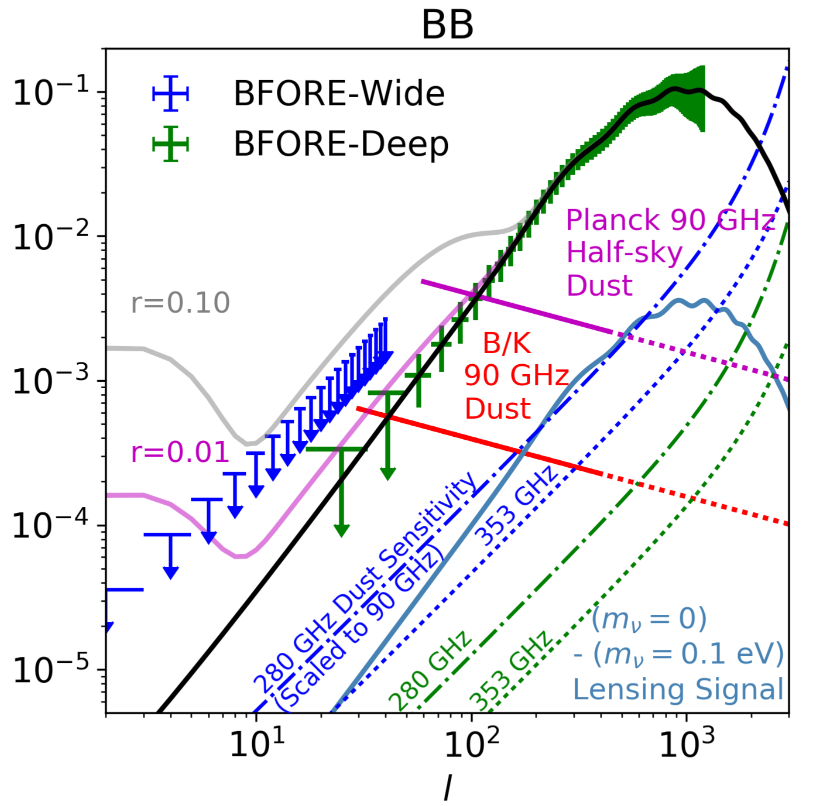

(ALMA)
The Simons Observatory
ACT
CLASS
POLARBEAR/Simons Array

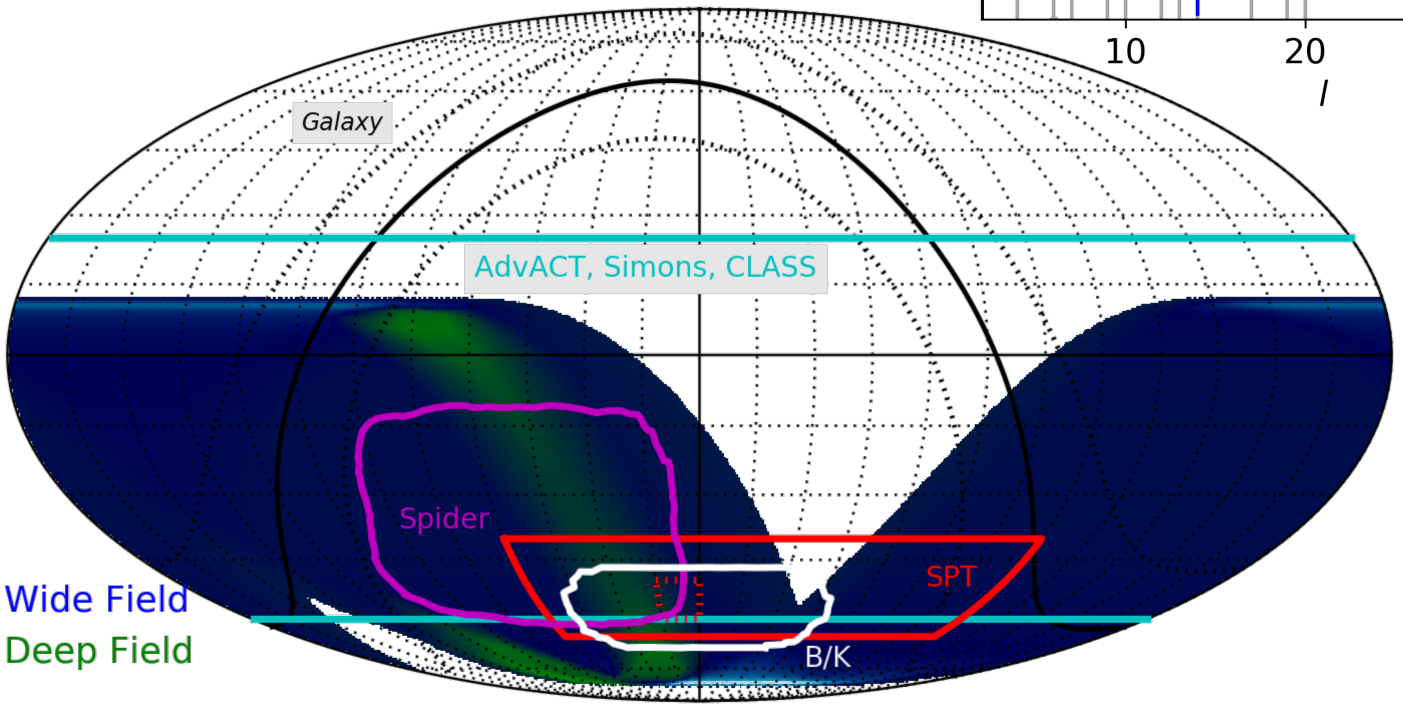

SPT
BICEP
Keck


Nonzero Neutrino Mass, Same tau
EE
BB
$[\mu K^2]$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{0}$
$10^{1}$
$10^{2}$
$10^{3}$
$\ell$
Less tau, Zero Neutrino Mass
EE
BB

- 150 GHz large-angular scale E-mode data for tau
- 220, 280, 353 GHz for dust overlapping many existing and upcoming experiments

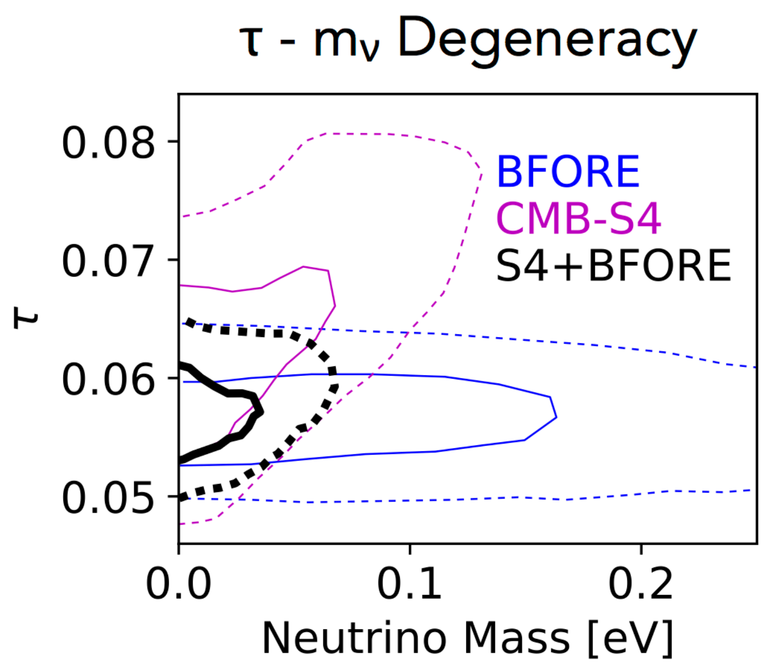


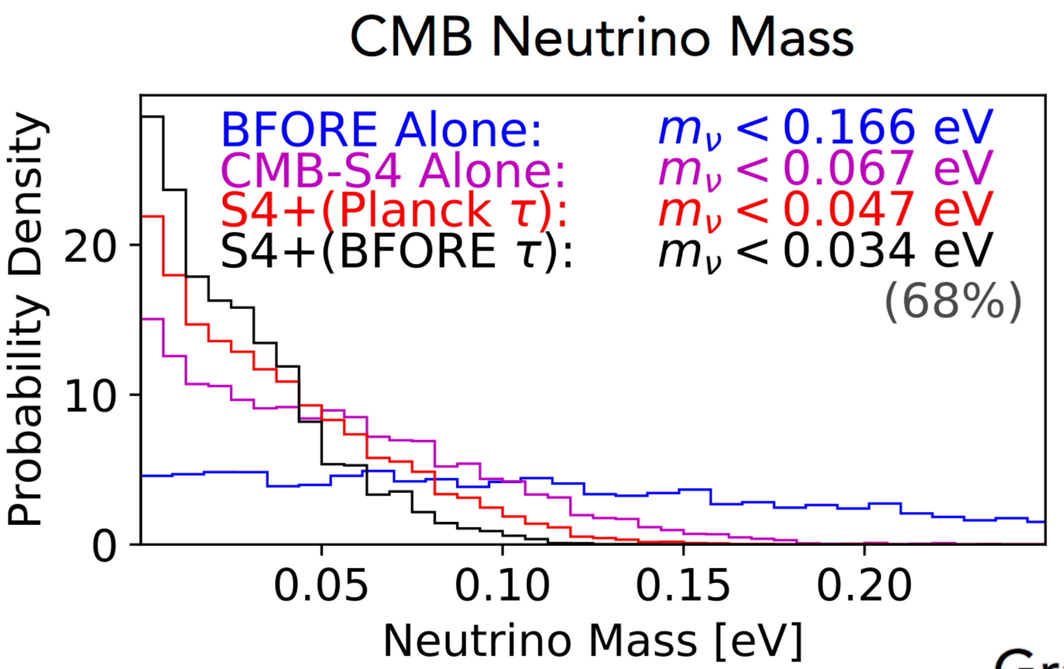



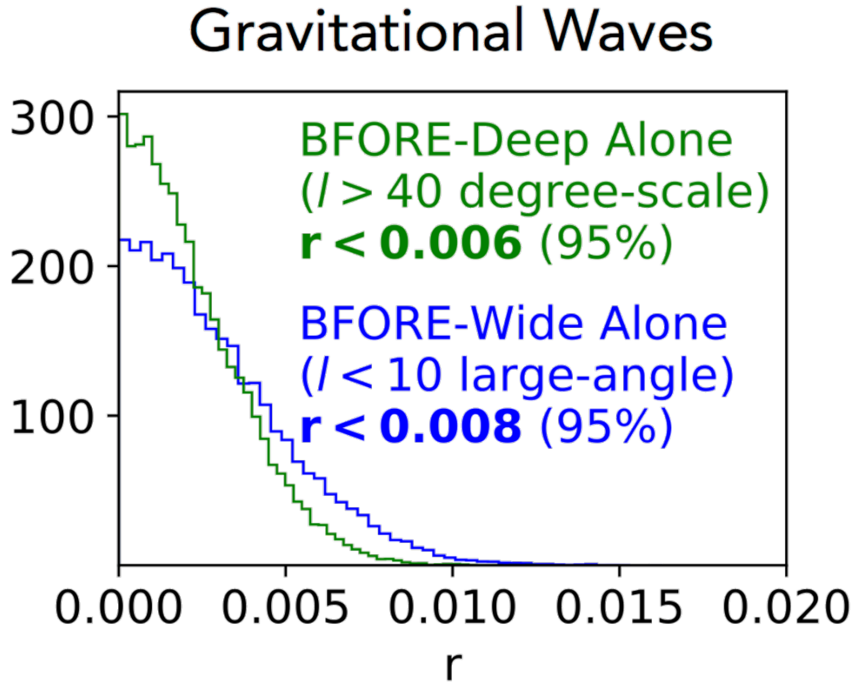




NASA/CSBF Ultra Long Duration Flight from New Zealand at midlatitudes

-> 50% sky coverage by spinning at night



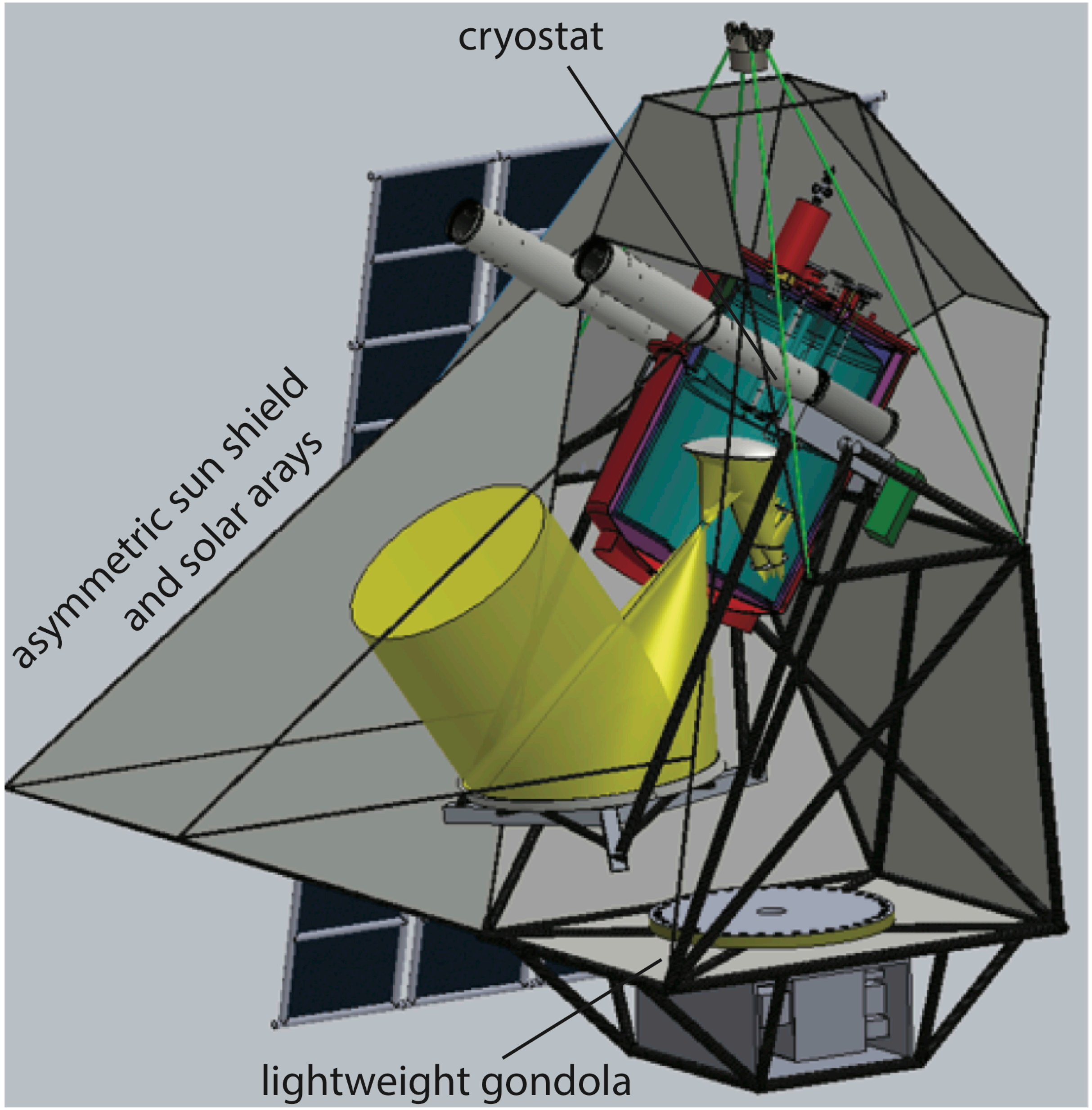




- Breaking the degeneracy between neutrino mass and tau significantly improves the reach of ground-based CMB on neutrino mass
- Measuring tau with a balloon for this science goal is discussed in the CMB-S4 CDT report
- Forecasting in the CMB-S4 Science Book shows that (BFORE CMB tau) + (SO and/or S4 CMB lensing) + (DESI BAO) would yield 3-sigma or greater on the minimal 0.058 eV $m_\nu$

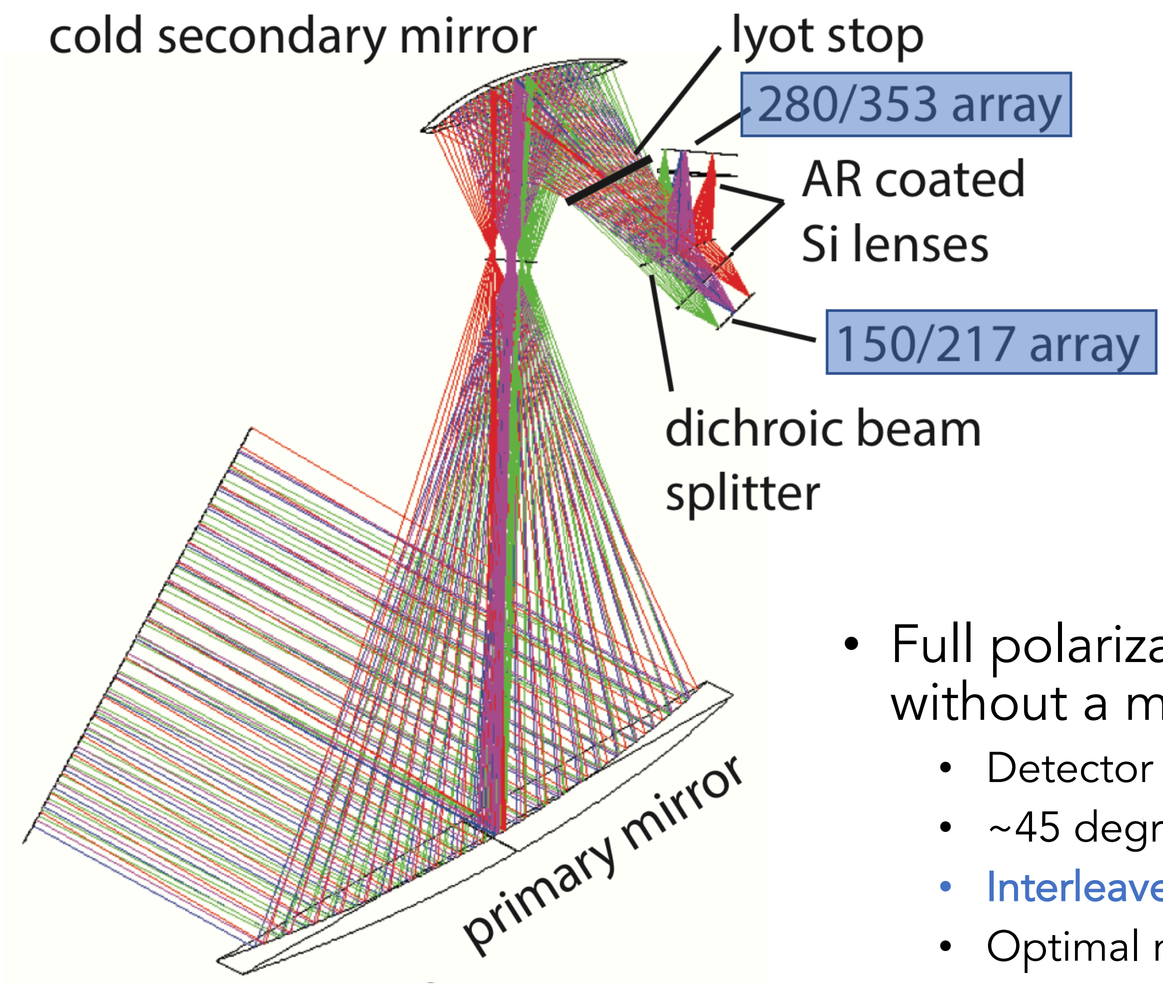
# Balloon Payload

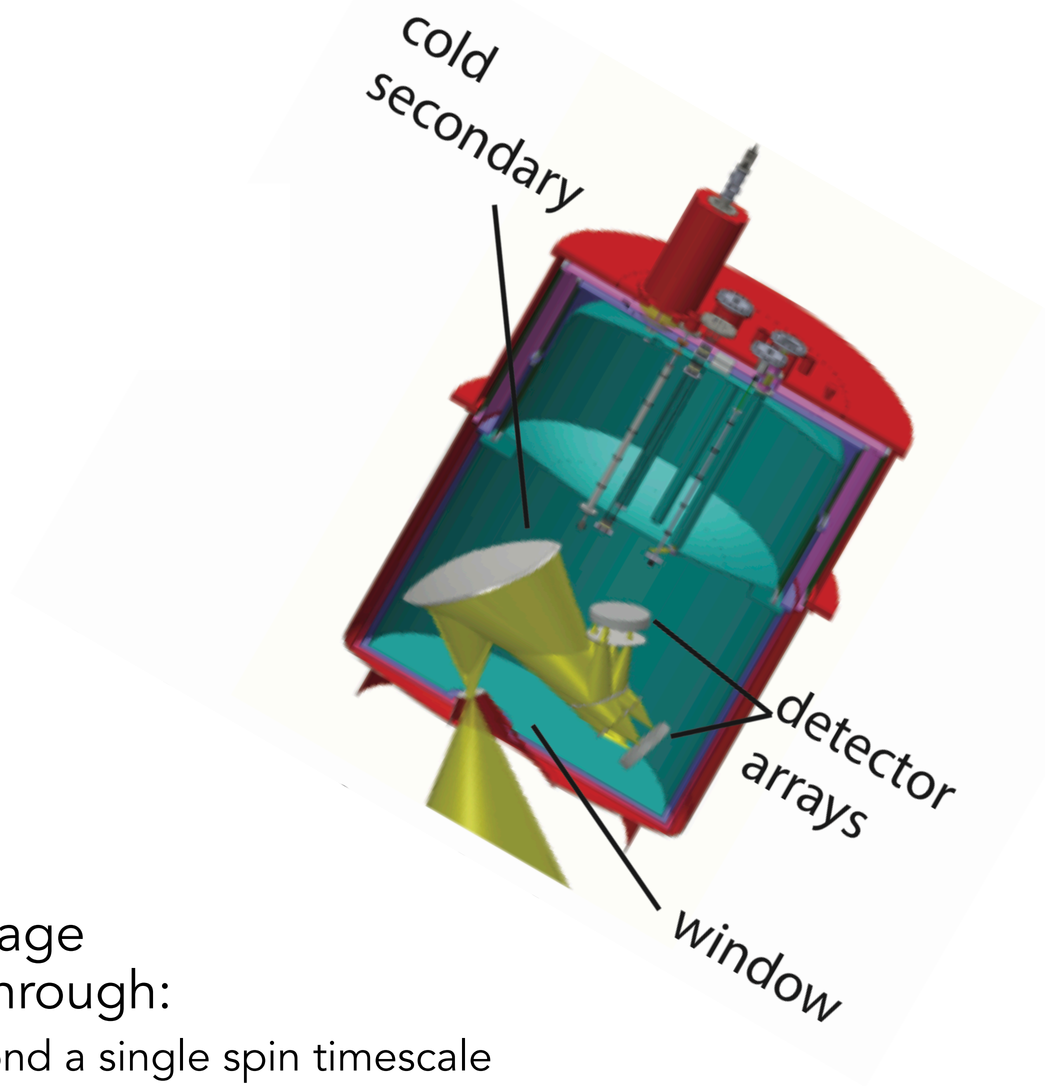
- "Lightweight" payload to meet the ULDB mass budget
- Carbon fiber gondola similar to the one flown in Spider
- High heritage pointing system similar to systems flown in Spider and BLAST



| | | | | | | |
|---|---|---|---|---|---|---|
| Telescope: | Temperature | 250 K (Primary), 4.2 K (Secondary) | | | | |
| | Primary diameter | 1.35 m, emissivity $\leq 0.005$ | | | | |
| Detectors: | Central frequencies | **150** | **217** | **280** | **353** | **GHz** |
| | Number of TESs | 2400 | 2400 | 2880 | 2880 | |
| | Detector NEP | 0.6 | 0.8 | 1.0 | 1.2 | $\times 10^{-17}$ W/$\sqrt{\mathrm{Hz}}$ |
| | Background power | 1.0 | 1.5 | 2.0 | 2.5 | pW |
| | Background NEP | 1.7 | 2.3 | 3.1 | 3.7 | $\times 10^{-17}$ W/$\sqrt{\mathrm{Hz}}$ |
| Half-sky map: | $\Delta Q/U$ (RJ) | 13 | 11 | 18 | 12 | $\mu$K-arcmin |
| (28 nights | $\Delta Q/U$ (CMB) | 22 | 34 | 101 | 158 | $\mu$K-arcmin |
| w/ 90% obs. eff.) | $\Delta Q/U$ (Dust scaled to 150 GHz) | 22 | 10 | 13 | 9 | $\mu$K-arcmin |
| Deep map: | $\Delta Q/U$ (RJ) | 4.1 | 3.6 | 5.7 | 3.8 | $\mu$K-arcmin |
| (28 days : | $\Delta Q/U$ (CMB) | 7.1 | 11 | 32 | 54 | $\mu$K-arcmin |
| w/ 90% obs. eff.) | $\Delta Q/U$ (Dust scaled to 150 GHz) | 7.1 | 3.2 | 4.2 | 3.2 | $\mu$K-arcmin |
| Beam: | FWHM | 6.1 | 4.2 | 3.3 | 2.6 | arc-minutes |
| | Bandwidth | 38 | 60 | 50 | 90 | GHz |
| | Field of view | 3.4 degree diameter | | | | |
| | Overall instrument transmission | 40% | | | | |

# Cryogenic Optics

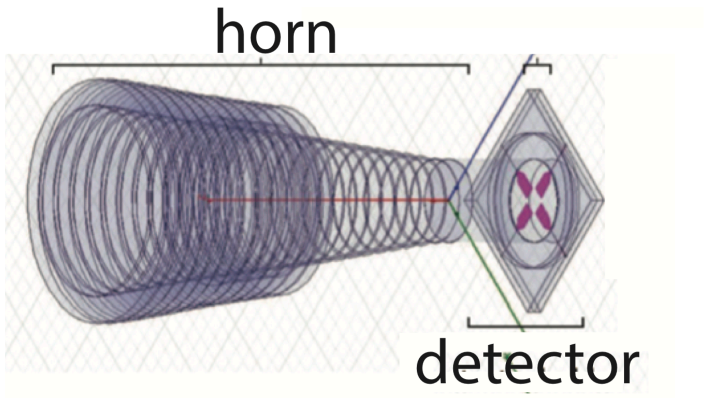


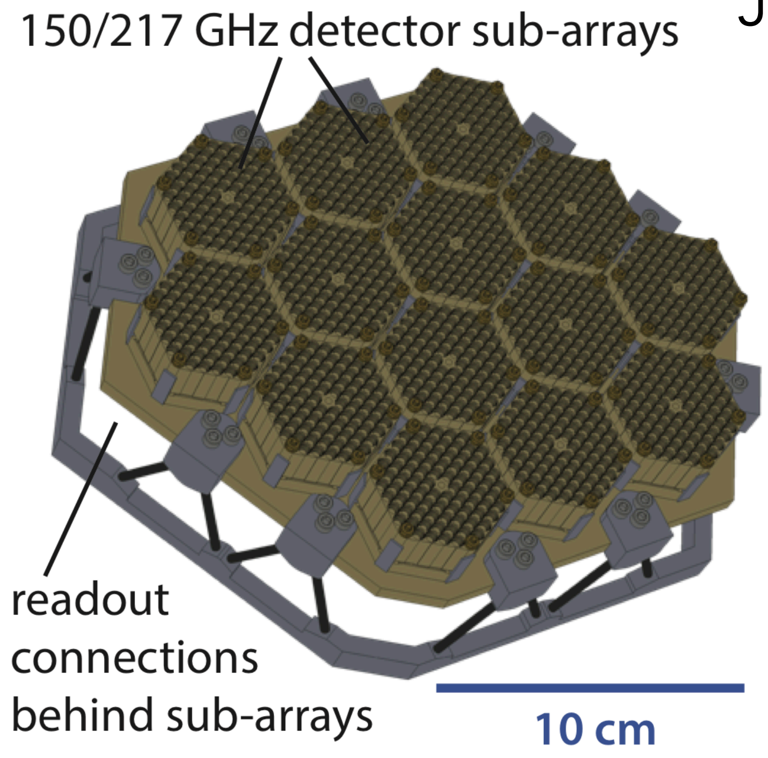



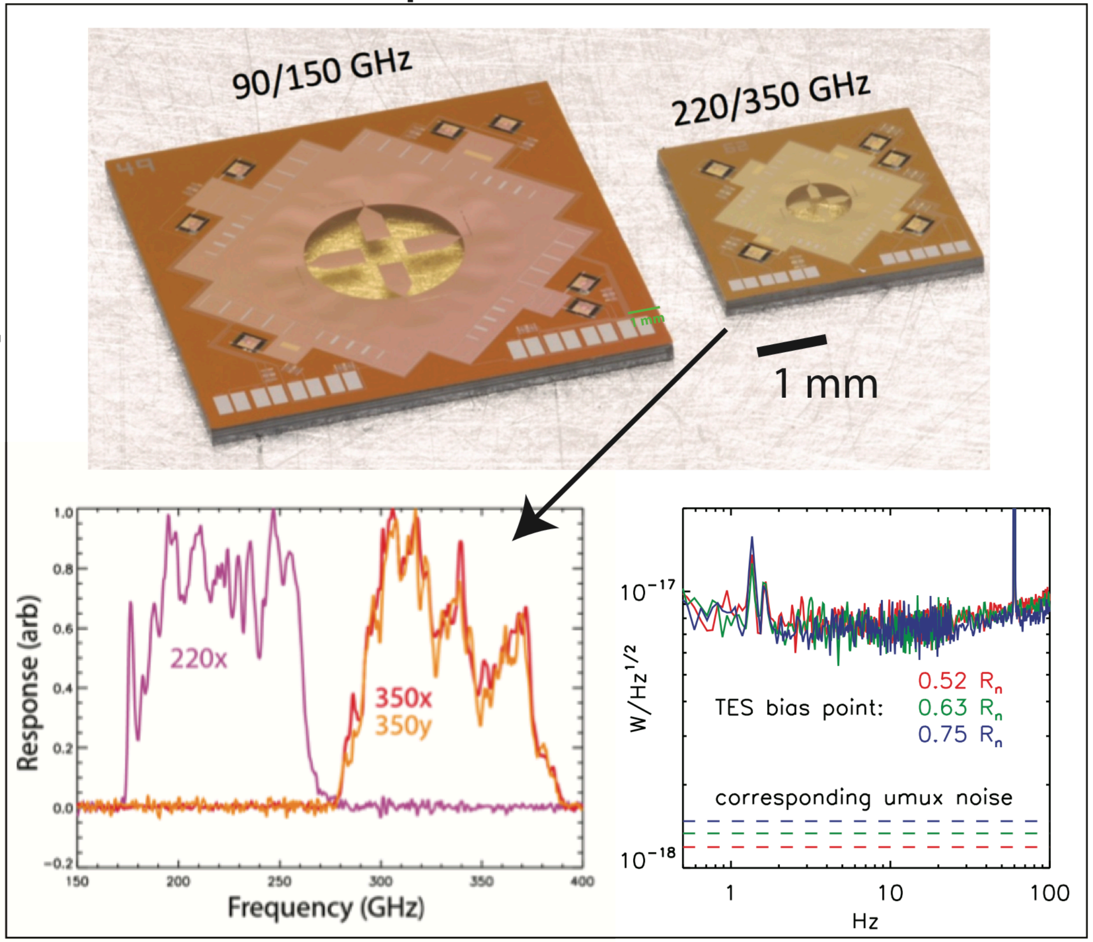

- Full polarization coverage without a modulator through:
  - Detector stability beyond a single spin timescale
  - ~45 degree mid-latitude sky rotation to completely modulate Q to U
  - Interleaved pixels ( +Q / +U / -Q / -U ) like SPTpol and others
  - Optimal mapmaker and/or beam deprojection as used in ACT and BICEP
  - Lower impact on tau science due to small primary beam

# TES Detectors

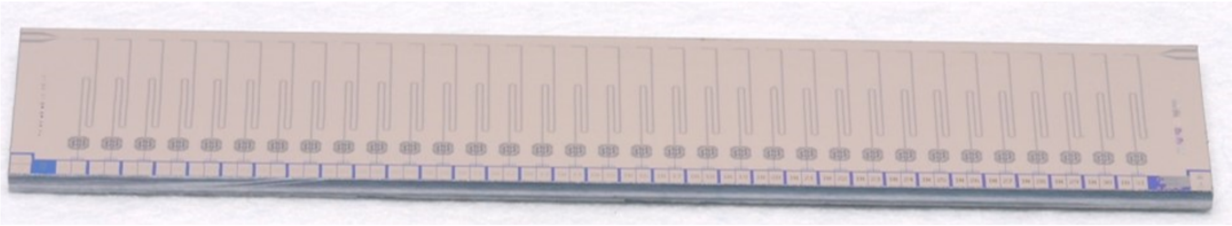
- Dichroic horn-coupled TES pixels
  - Two bands, two polarizations
- Similar ones deployed in ACT as reviewed by Jay Austerman

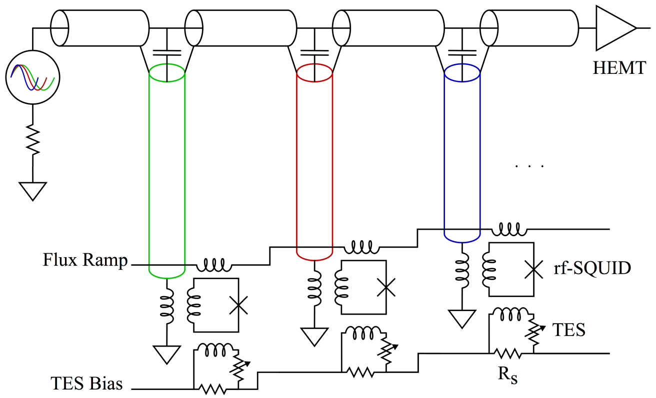


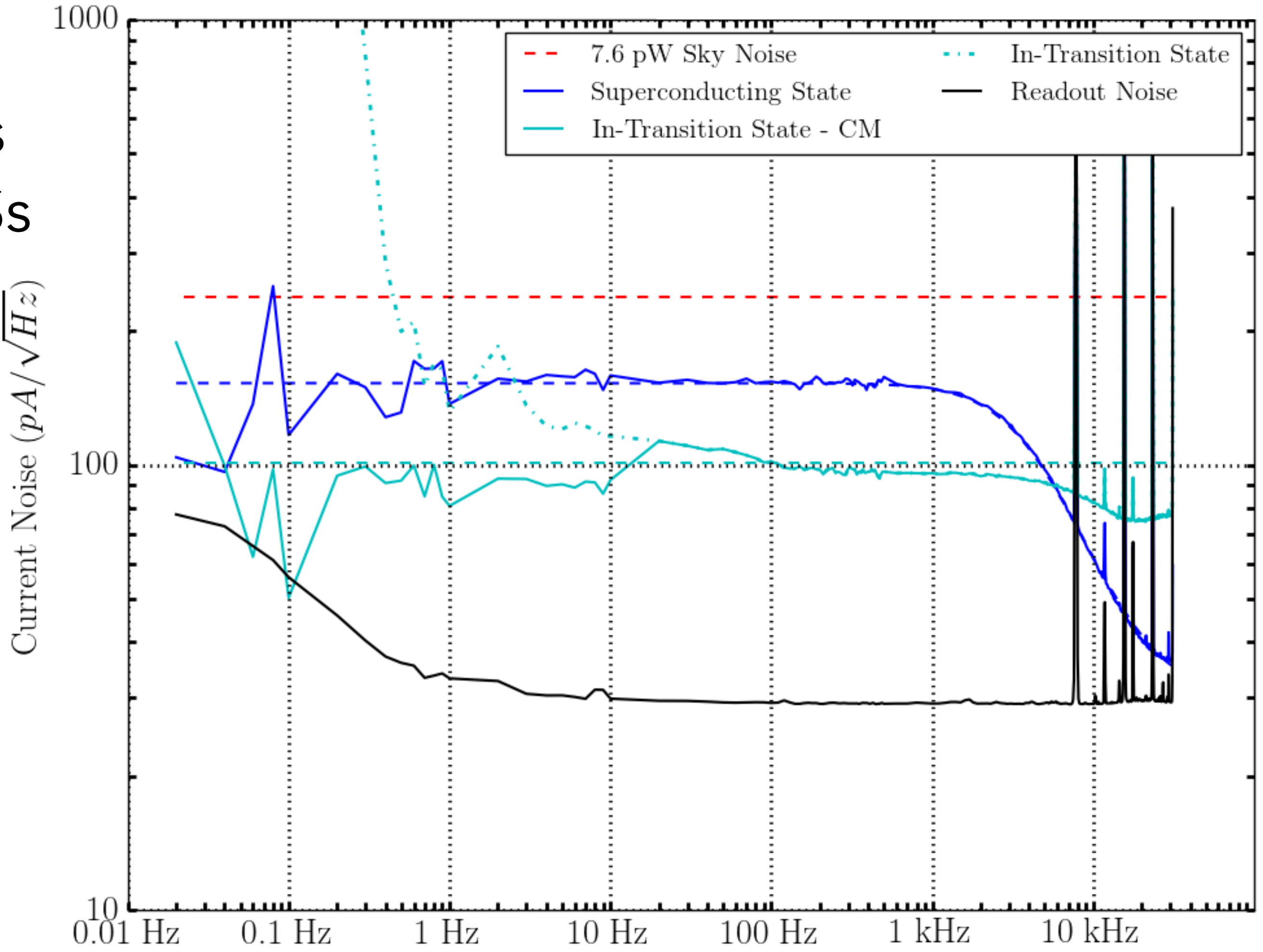



# mSQUID Readout






- "Best of both"
  - High multiplexing factor of LEKIDs
  - High CMB science heritage of TESs
- 1/f and white noise properties are already demonstrated
  - Lab demo had 64x MUX
  - Higher MUX being developed in the context of Simons Observatory and CMB-S4

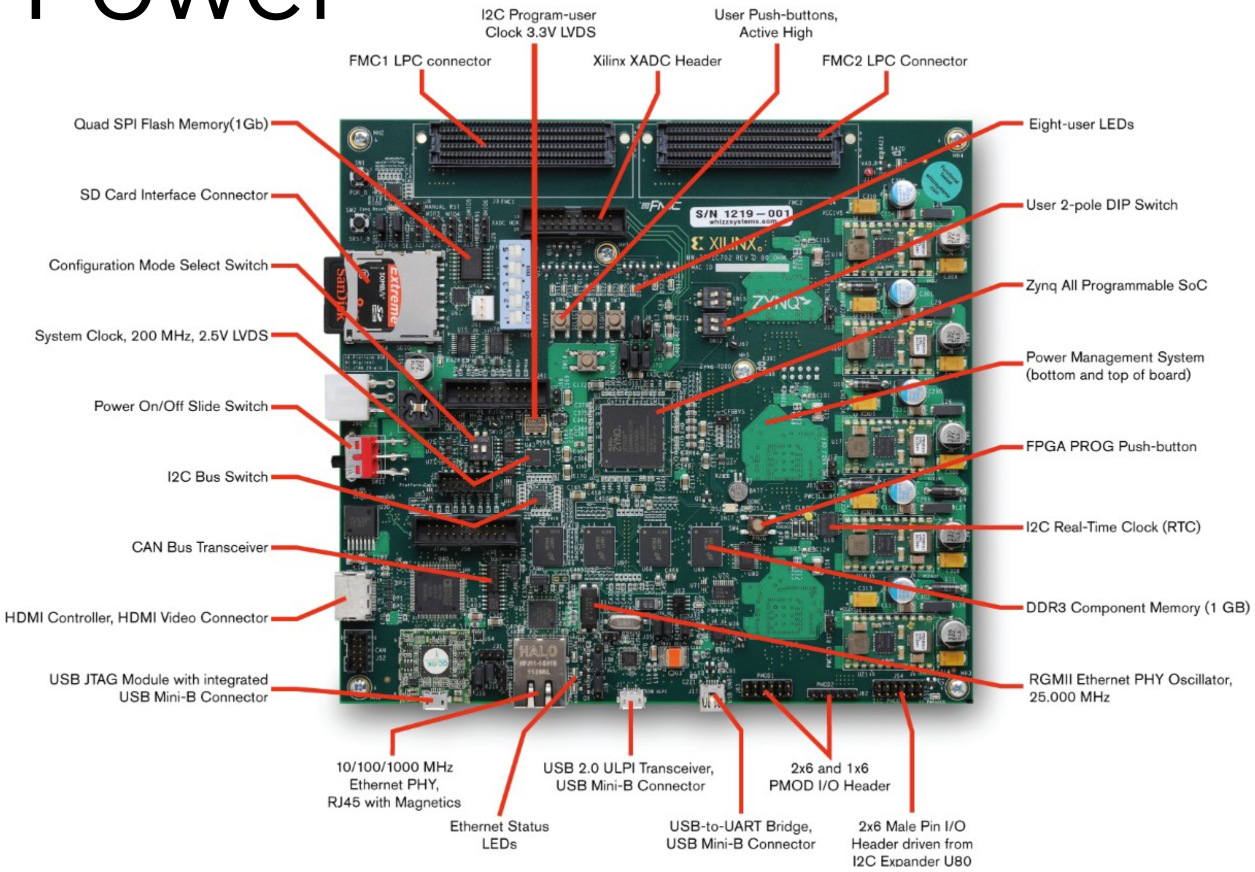



Dober et al. astro-ph/1710.04326

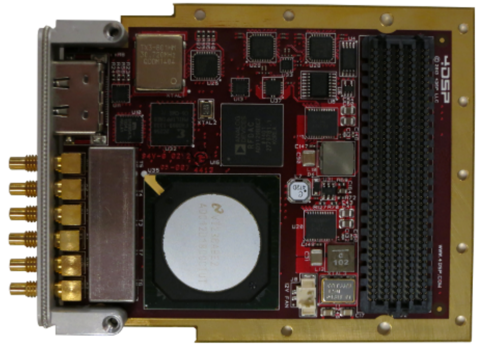
# Commercial/New Low Power Warm Electronics

- Commercial FPGA boards are lower power than the ROACH1 and 2 boards, with similar or better FPGA resources
- Commercial A/D boards are available
- New low-level firmware would need to be written, but the ASU group has experience doing that
- The radio astronomy community broadly is evaluating these, and they are already standard in electrical engineering
- Goal is ~40 W of power per readout line

Xilinx Zynq-7000 FPGA(+CPU)




FMC163 12/14-bit 4/5.7 gigasample ADC/DAC



# Conclusions

- A ULDB flight from mid latitudes is great for large angular scales and high frequencies
- This dataset will yield:
  - Significantly improved tau constraints which will enable a detection of neutrino mass
  - Large angular scale B-mode data, and degree-scale data, both at the r~0.01 level
  - Foreground maps at 280 GHz and 353 GHz with legacy value
- BFORE has been selected for further study by NASA
  - Supporting further mission development, further warm readout and mSQUID development