The CLASS 150/220 GHz Polarimeter Array: Design, Assembly, and Characterization

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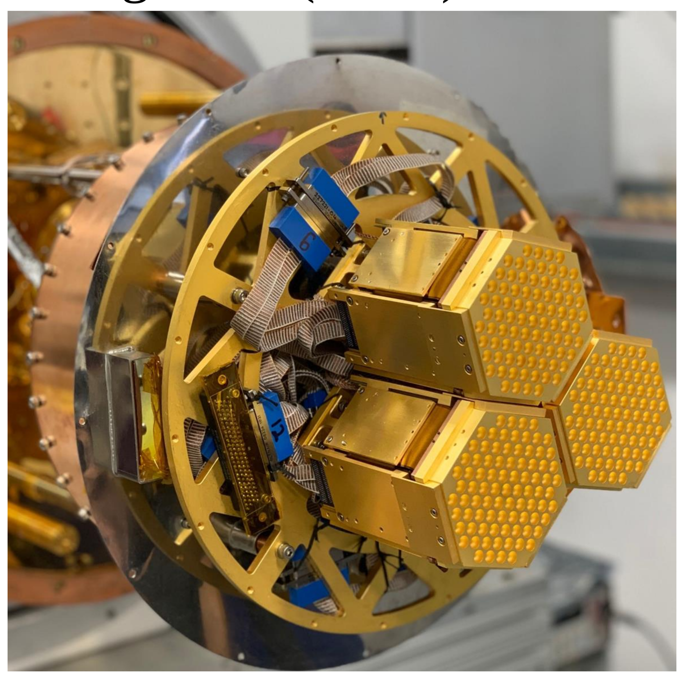
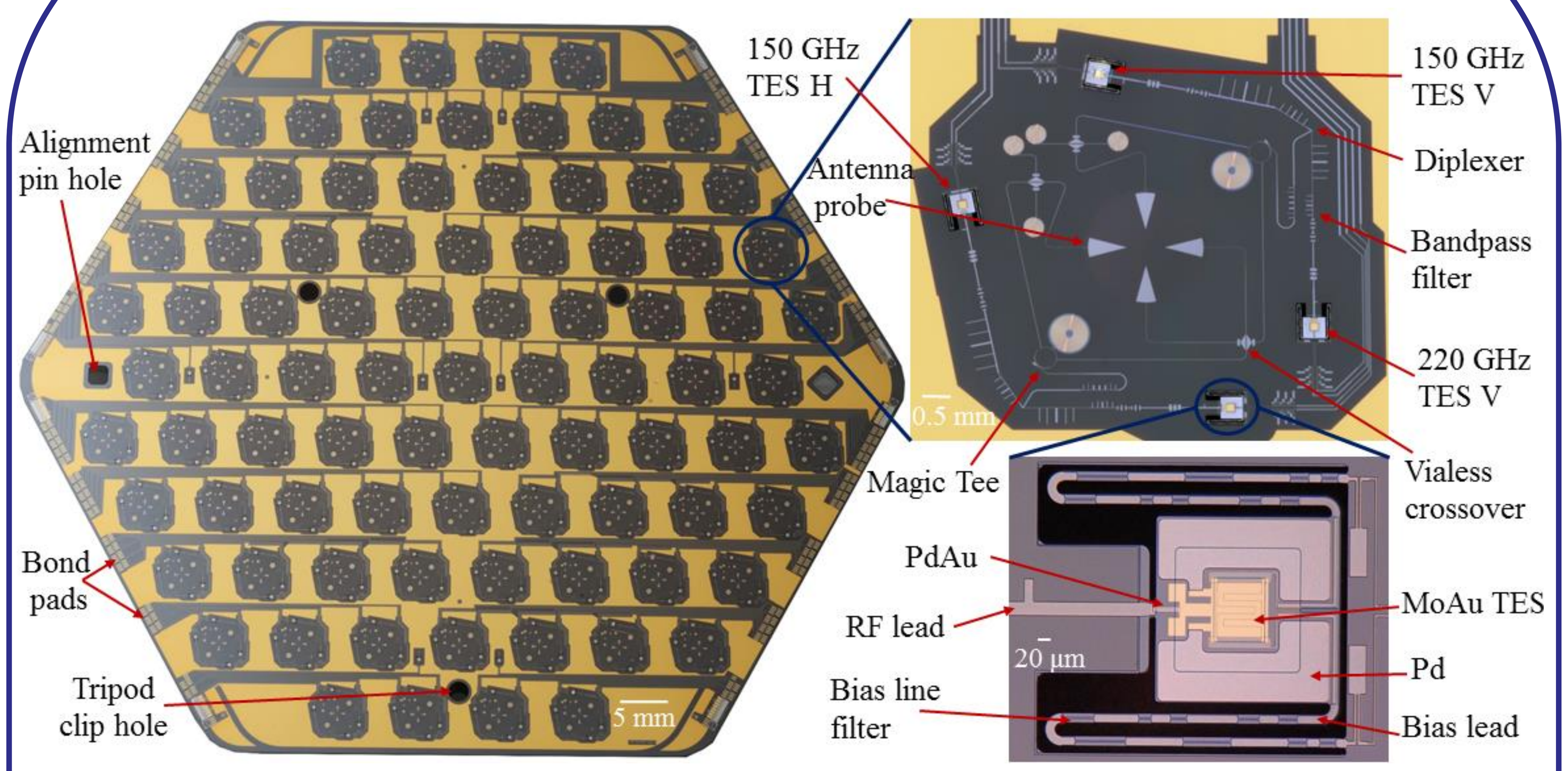
INTRODUCTION

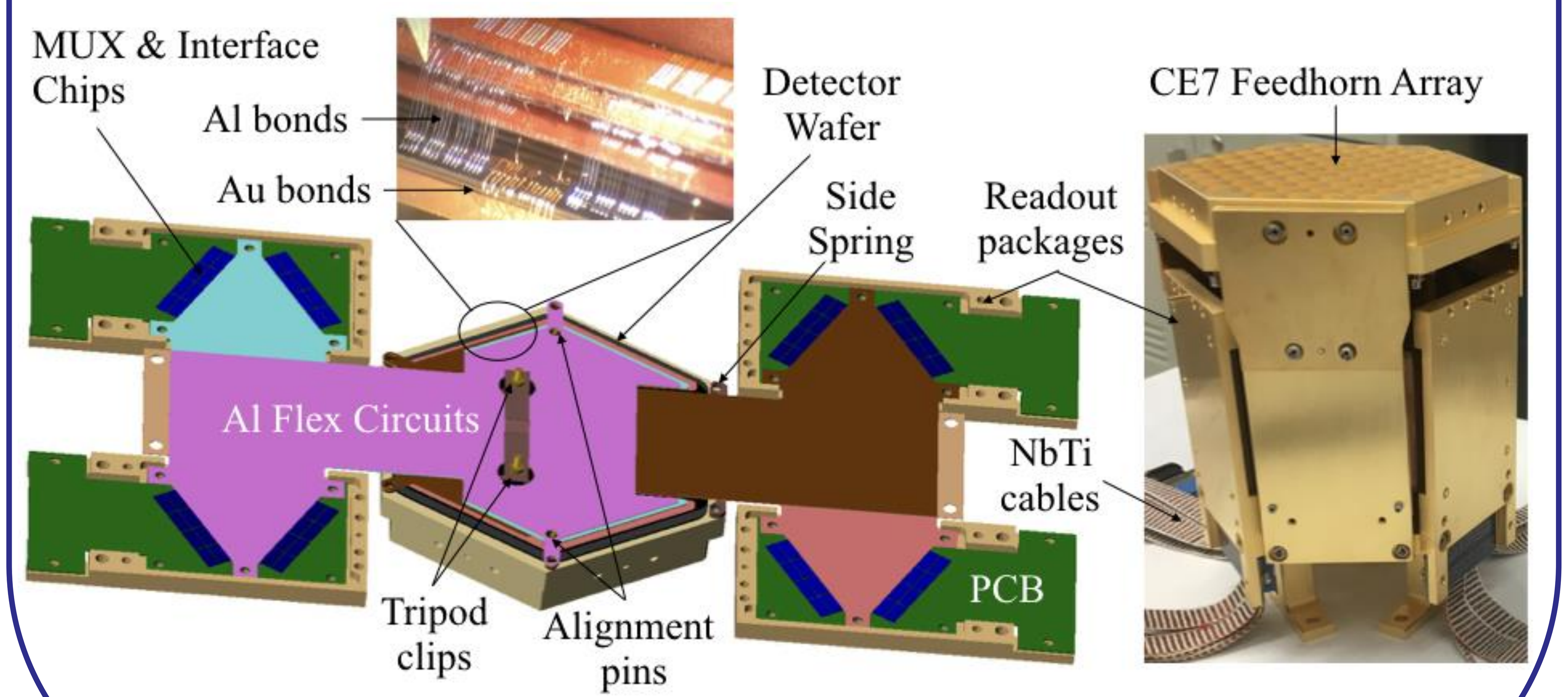
The Cosmology Large Angular Scale Surveyor (CLASS) is a multi-frequency polarimeter array that maps the comic microwave background (CMB) polarization at large angular scales. A dichroic (150/220 GHz) detector array was delivered to the CLASS site in the Atacama Desert, Chile in June, 2019. This high frequency (HF) instrument will provide additional sensitivity to CLASS's CMB observations and help characterize the dust foregrounds. The HF focal plane consists of three identical hexagonal modules with 255 dichroic dual-polarization pixels in total, and is maintained at ~ 80 mK bath temperature by a pulse-tube cooled dilution refrigerator. Each module contains 85 smooth-walled feedhorns made from Au-plated aluminum-silicon (CE7) alloy [1].



DESIGN & ASSEMBLY

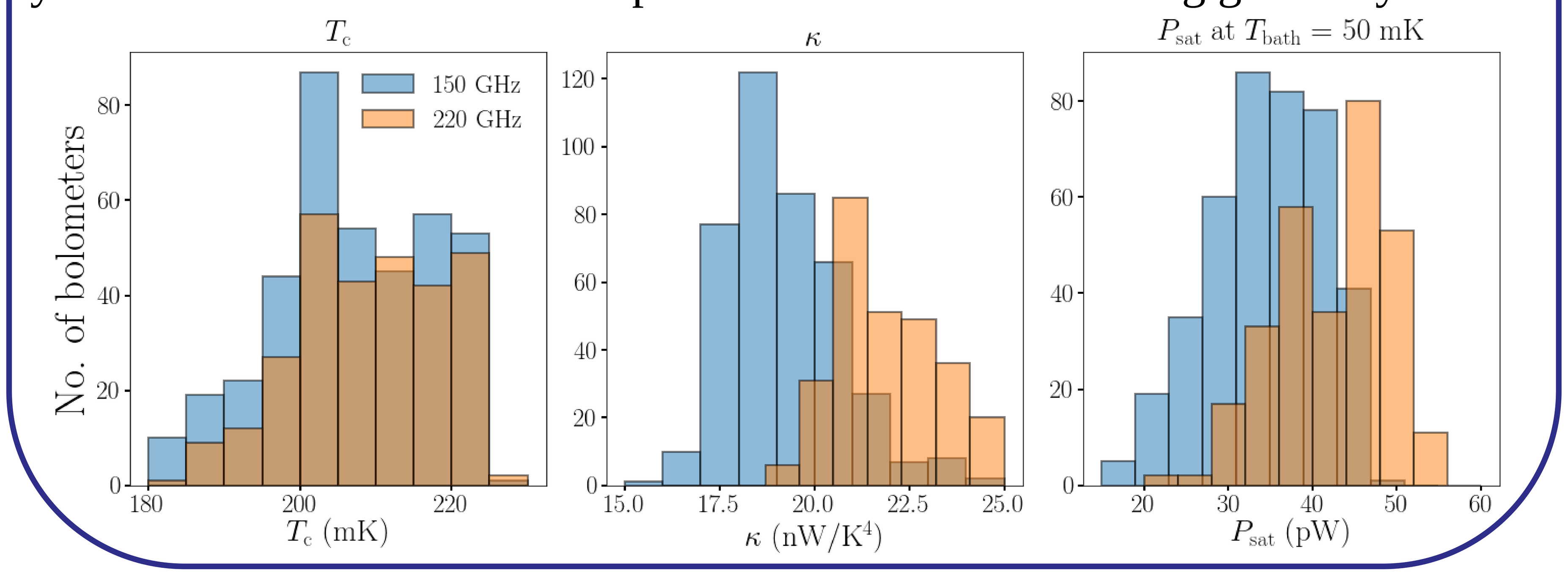


CLASS HF detectors are fabricated on single-crystal silicon for its excellent microwave and thermal properties [2]. Each feedhorn couples light to a planar orthomode transducer (OMT). A diplexer followed by on-chip filters separates the signal into two frequency bands. The signal is eventually terminated at a PdAu resistor on the transition-edge sensor (TES) membrane. The detector wafer is hybridized with a photonic choke wafer and a backshort assembly [3] and mounted onto a CE7 feedhorn array as a single assembly. Four Al flex circuit layers are stacked on top, and wire bonded to the detector wafer. The detector signal is routed to four separate readout packages with eight time-division multiplexer chips and eight interface chips each. The interface chips have 200 µΩ shunt resistors and 310 nH Nyquist inductors. After assembly, the readout packages are folded up and bolted to the CE7 and support structures.



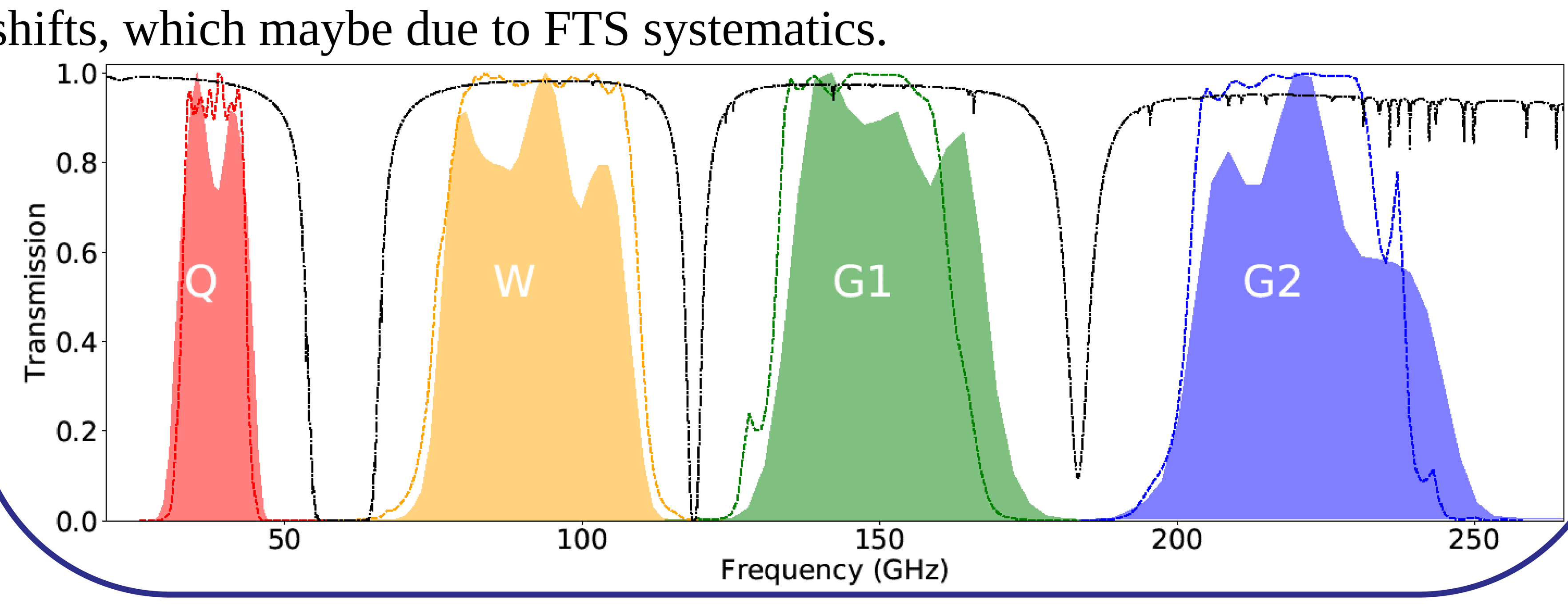
PARAMETERS

We characterize electro-thermal properties of the detectors in the dark through I-V curves. TES saturation power (P_{sat}) is calculated for multiple bath temperatures (T_{bath}) from 70 to 250 mK and fit to $P_{sat} = \kappa\,(T_c^4 - T_{bath}^4)$. The small spread in the parameters fit seen below is a result of uniform and controlled fabrication processes, and ballistic thermal transport to the bath in all the TESs. The current array yield is 80% for 150 GHz and 57% for 220 GHz. The lower yield in 220 GHz is due to complications in the wire bonding geometry.



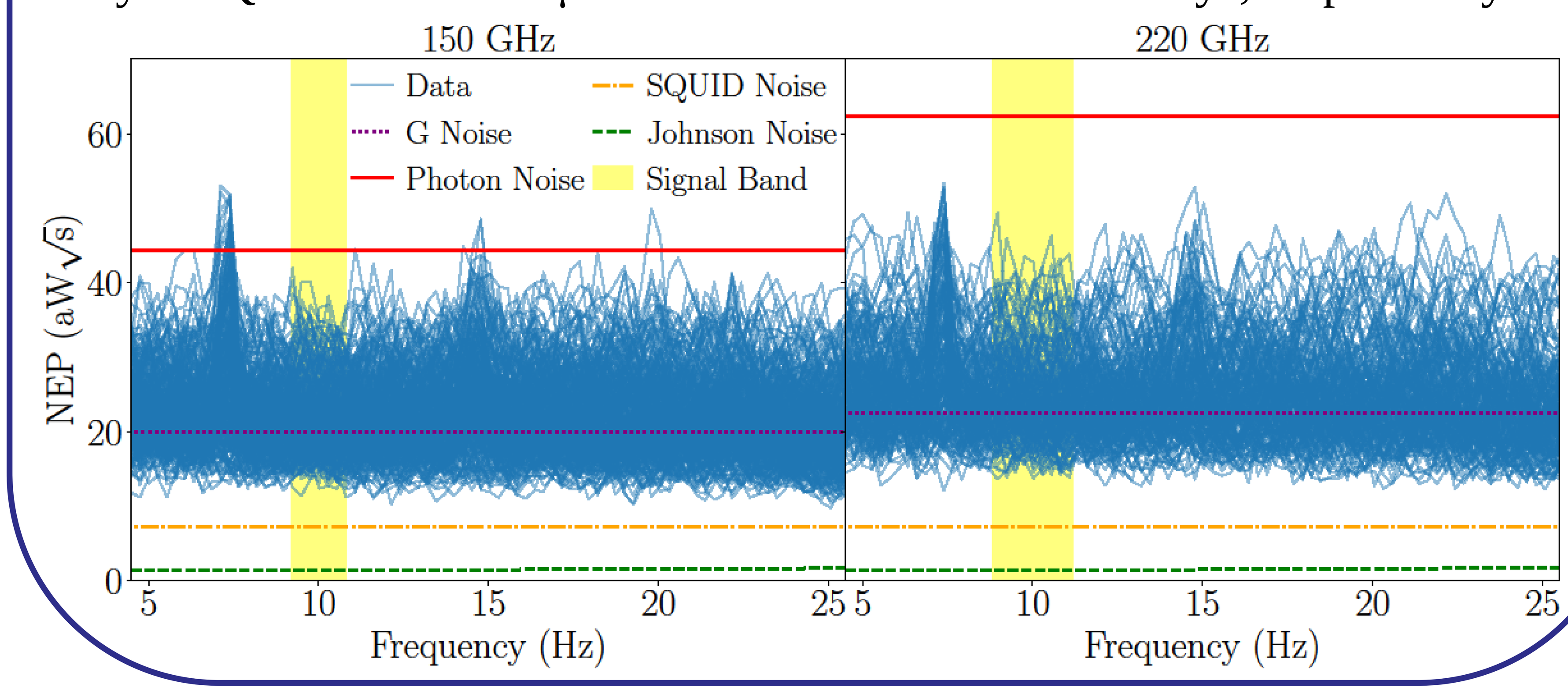
BANDPASS

We measured the bandpasses of the detectors in lab using a polarizing Martin-Puplett Fourier Transform Spectrometer (FTS). In the plot below, we compare the measured bandpasses (filled) with simulation (dashed) and atmospheric transmission model (dash-dot) at the CLASS site with precipitable water vapor of 1 mm. The bandpasses safely avoid strong atmospheric emission lines, as designed, and we see no evidence of high frequency out-of-band leakage. The HF bands are shifted by a few GHz towards higher frequencies compared to their simulations. We are currently investigating the source of these apparent shifts, which maybe due to FTS systematics.



NOISE

Noise spectra of the detectors in the dark is shown below. The average dark noise-equivalent power (NEP_{dark}) is 22 and 25 aW√s for 150 and 220 GHz, respectively. This is mostly explained by the expected phonon noise, as the SQUID readout and Johnson noise components are negligible when added in quadrature. Given the expected photon noise in the field, the HF detectors are photon-noise limited. With the current array yield and expected optical (50%) and modulation (150 GHz: 70% and 220 GHz: 50%) efficiencies, we estimate array NEQ of 24 and 101 µK√s for 150 and 220 GHz arrays, respectively.



SUMMARY

The CLASS HF detector array has been delivered to the telescope site and installed inside the cryostat receiver. This dichroic array sensitive to 150 and 220 GHz will provide additional sensitivity to CLASS's CMB observations and help characterize dust foregrounds. The detectors within each HF module show uniform parameter distributions, and their bandpasses safely avoid strong atmospheric emission lines with no evidence for high frequency out-of-band leakage. The HF detectors are photon-noise limited with average NEP_{dark} of 22 aW√s for 150 GHz and 25 aW√s for 220 GHz.

References: [1] A. M. Ali et al., Proc. SPIE 10708, 107082P, (2018)
[2] K. Rostem et al., Proc. SPIE 9914, 99140D, (2016)
[3] K. L. Denis et al., AIP Conference Proc. 1185, 371, (2009)

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