The Primordial Inflation Polarization ExploreR (PIPER): Characterization of the Receiver and Detector Arrays

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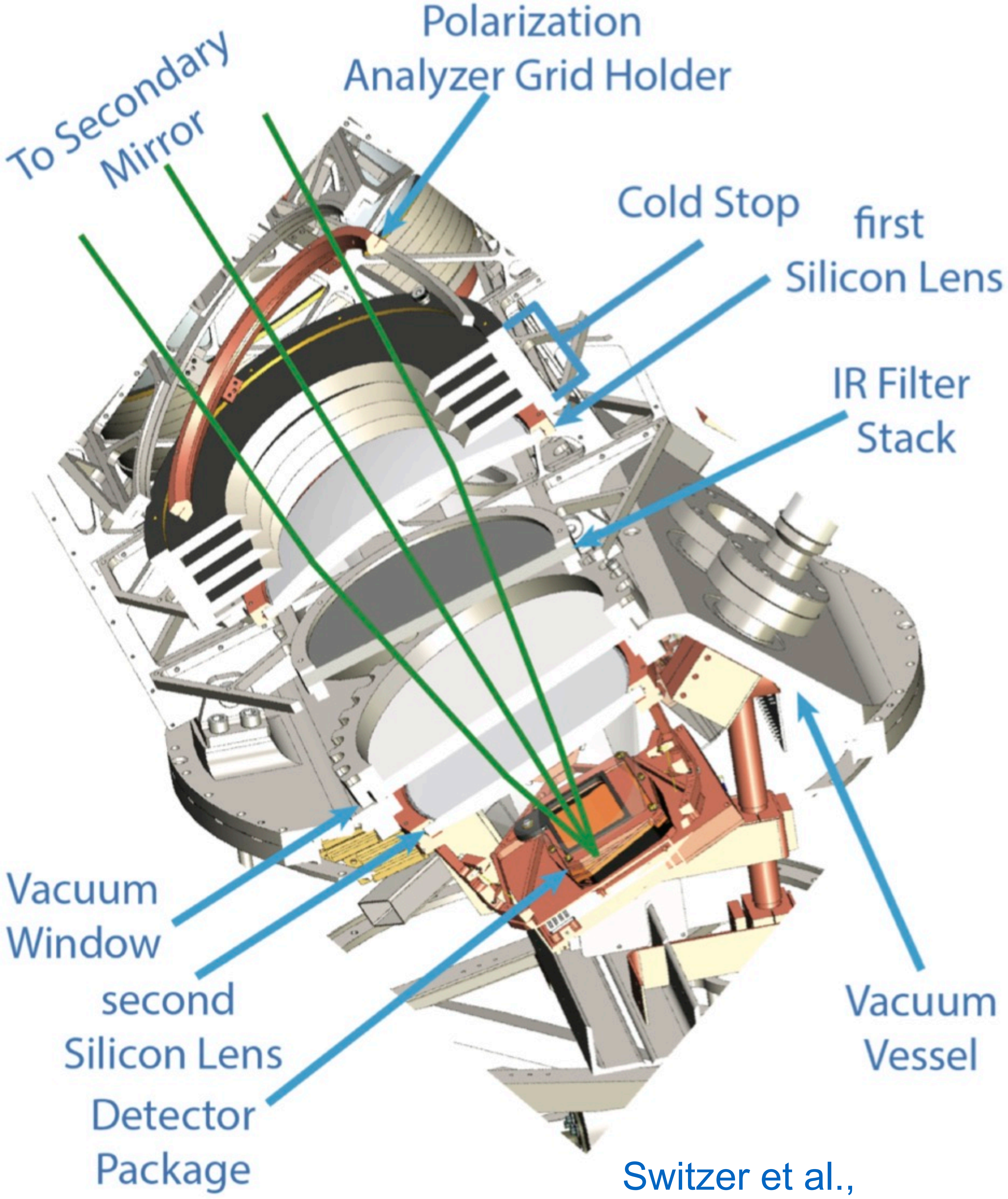
PIPER Receiver

- PIPER uses two 32 x 40 arrays of Backshort-Under-Grid (BUG) Transition-Edge Sensors (TES) with a pixel-to-pixel spacing of 1.135 mm developed at GSFC (Jhabvala et al., *SPIE Proc. Vol. 9153, 91533C, 2014*).

- Each TES measures total incident power integrated over a band defined by bandpass filters in front of the array.

- Polarization sensitivity is provided by the upstream Variable-delay Polarization Modulator (VPM) and analyzer grid.

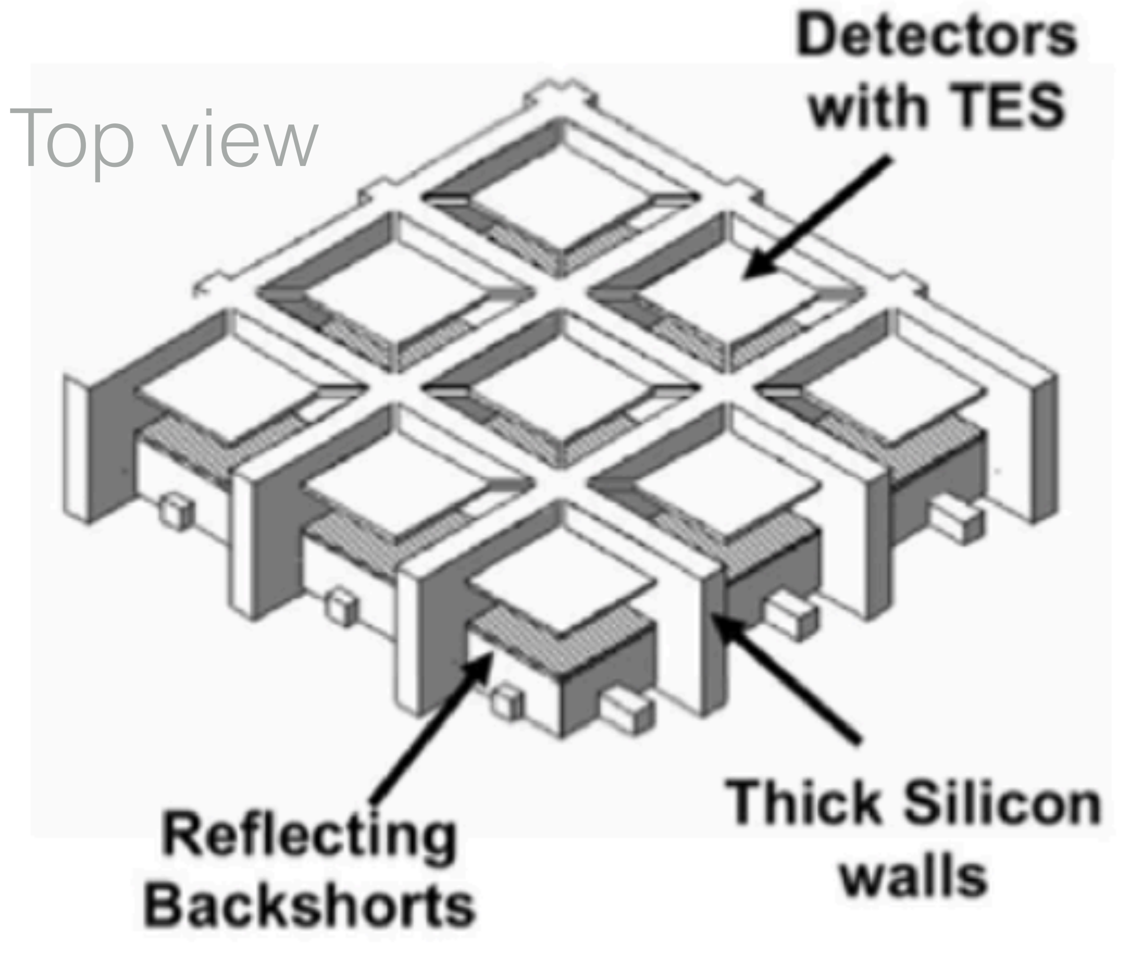
- 4-stage Continuous Adiabatic Demagnetization Refrigerator (CADR) cools detectors to 100 mK, cascades heat up to LHe bath.

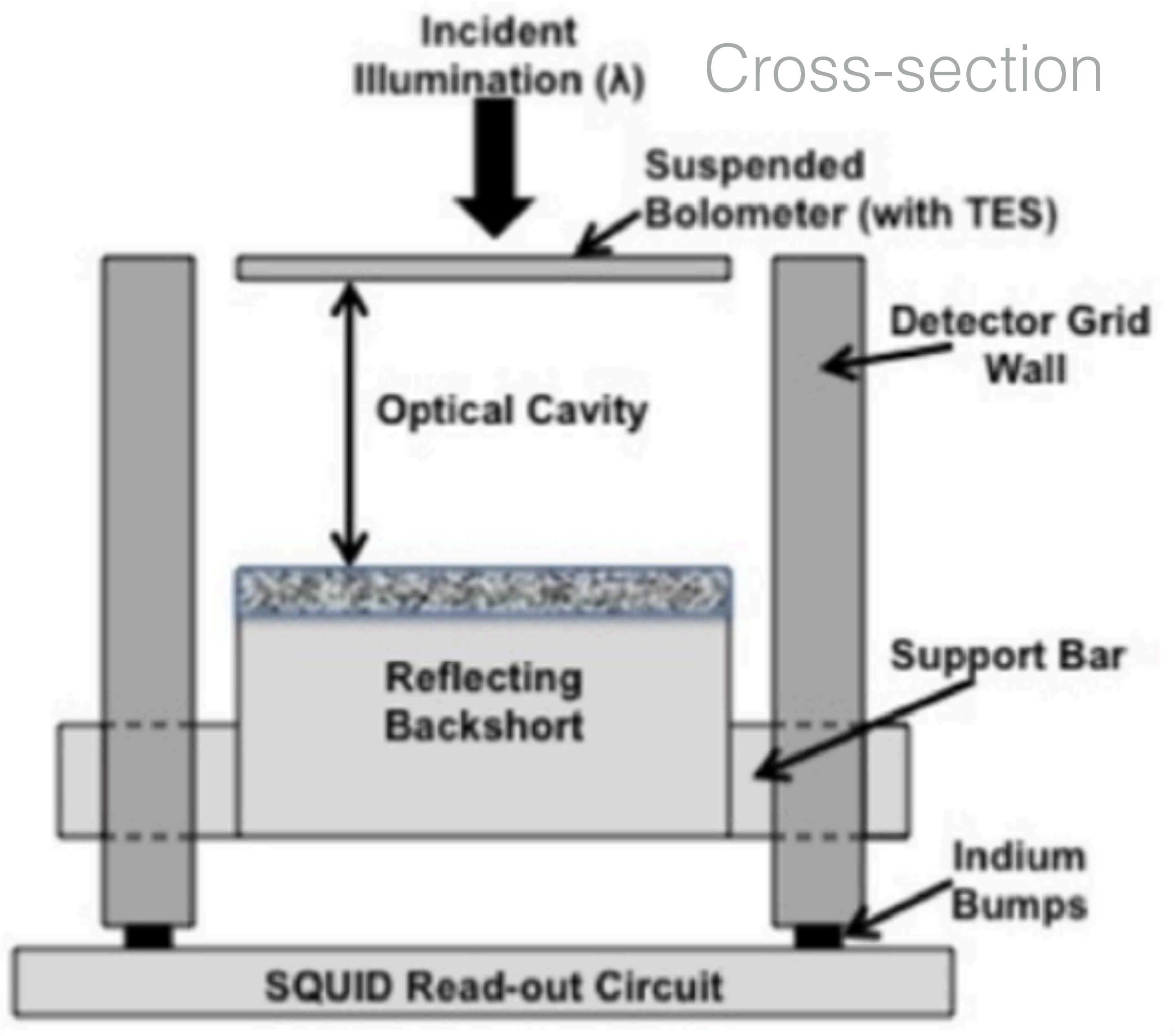


Switzer et al., *Rev. Sci. Instr. Vol. 90 Issue 9 (2019)*

BUG Detector Architecture

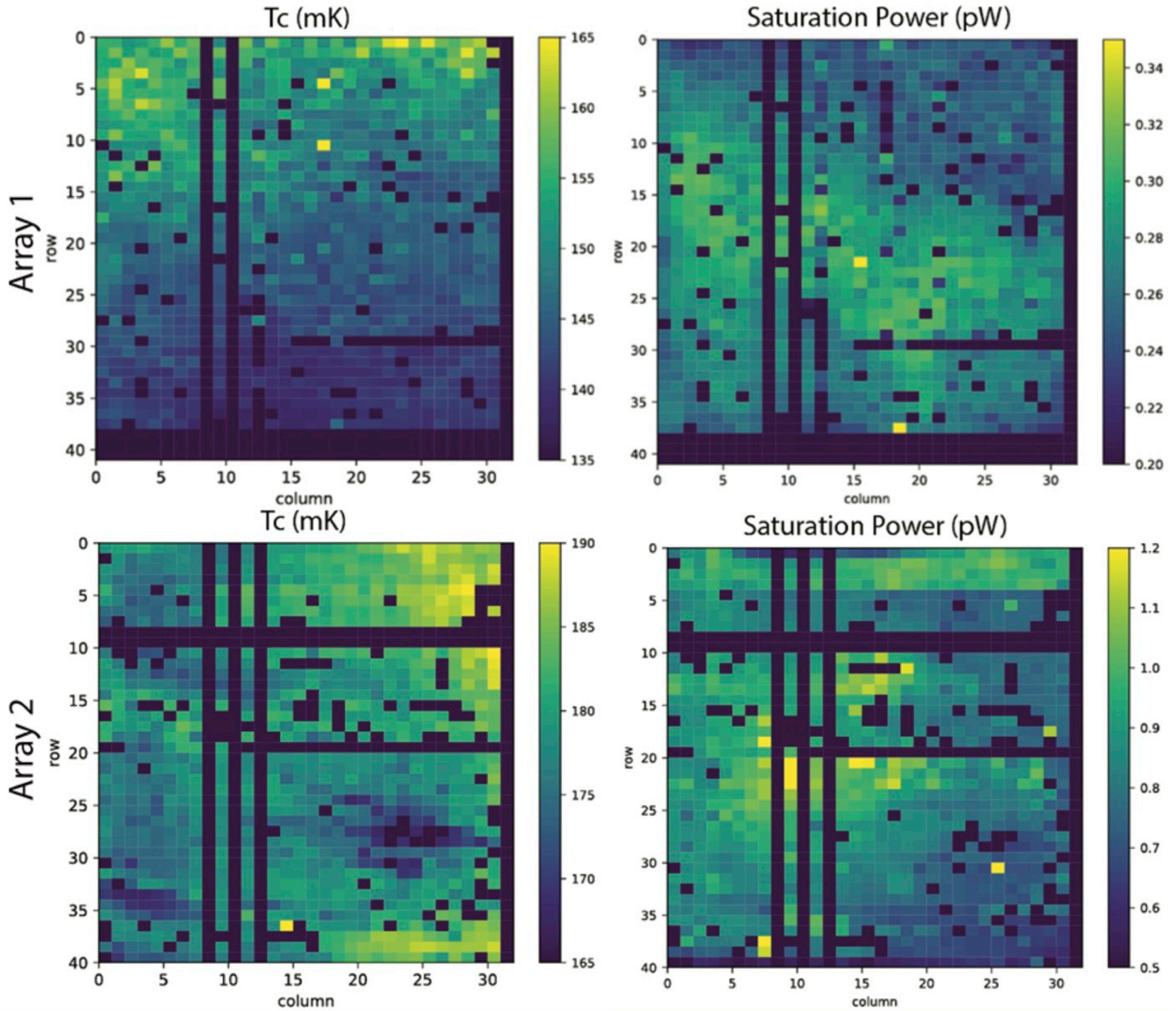
- The TESs are on leg-isolated, absorber-coated, silicon membranes and designed to have a superconducting transition (Tc) at ~140 mK.
- Each pixel has its own reflective backshort placed at a fixed spacing designed to optimize detector performance in the four PIPER frequency bands.
- Each 32 x 40 array is indium bump-bonded to a 2D SQUID based time-domain multiplexer (2D MUX) chip developed by NIST.
- Superconducting connection from TESs to back side of the array, where indium bump bonding occurs, is achieved by means of Through-Wafer-Vias (Jhabvala et al., *JLTP Vol. 184 pp. 615–620, 2016*).





Detector Dark Parameters from Lab Measurements

- Tc and saturation power (Psat) at 100 mK bath for the two 32 x 40 pixel PIPER arrays.
- Array 2 is measured to have a somewhat higher Tc than the design target, while the saturation power for Array 1 is lower than the design target.
- The dark detector Noise Equivalent Power (NEPs) are consistent with expectations and the detector arrays demonstrate uniformly low NEP performance.



* blue pixels are either bad pixels or represent dead row/column in the readout chain

Detector Dark Parameters from Lab Measurements

Mean and standard deviation of measured detector dark parameters and array pixel yield

Array	T_c(mK)	G (pW/K)	P_{sat}(pW)	NEP_G(aW$\sqrt{s}$)	Yield
1	147.9±5.7	8.3±0.8	0.26±0.04	2.37±0.14	75%
2	179.9±3.7	18.9±3.3	0.8±0.14	4.45±0.32	80%

- Since Array 1 has low saturation power, a Neutral Density Filter (NDF) was installed in front of both arrays to block a significant fraction (~70%) of the incident power in the observing band.
- Given the total power loading on the detectors in the 200 GHz observing band at float altitude is expected to be well below 1 pW, this choice of NDF is a conservative but safe choice for the first science flight of PIPER.
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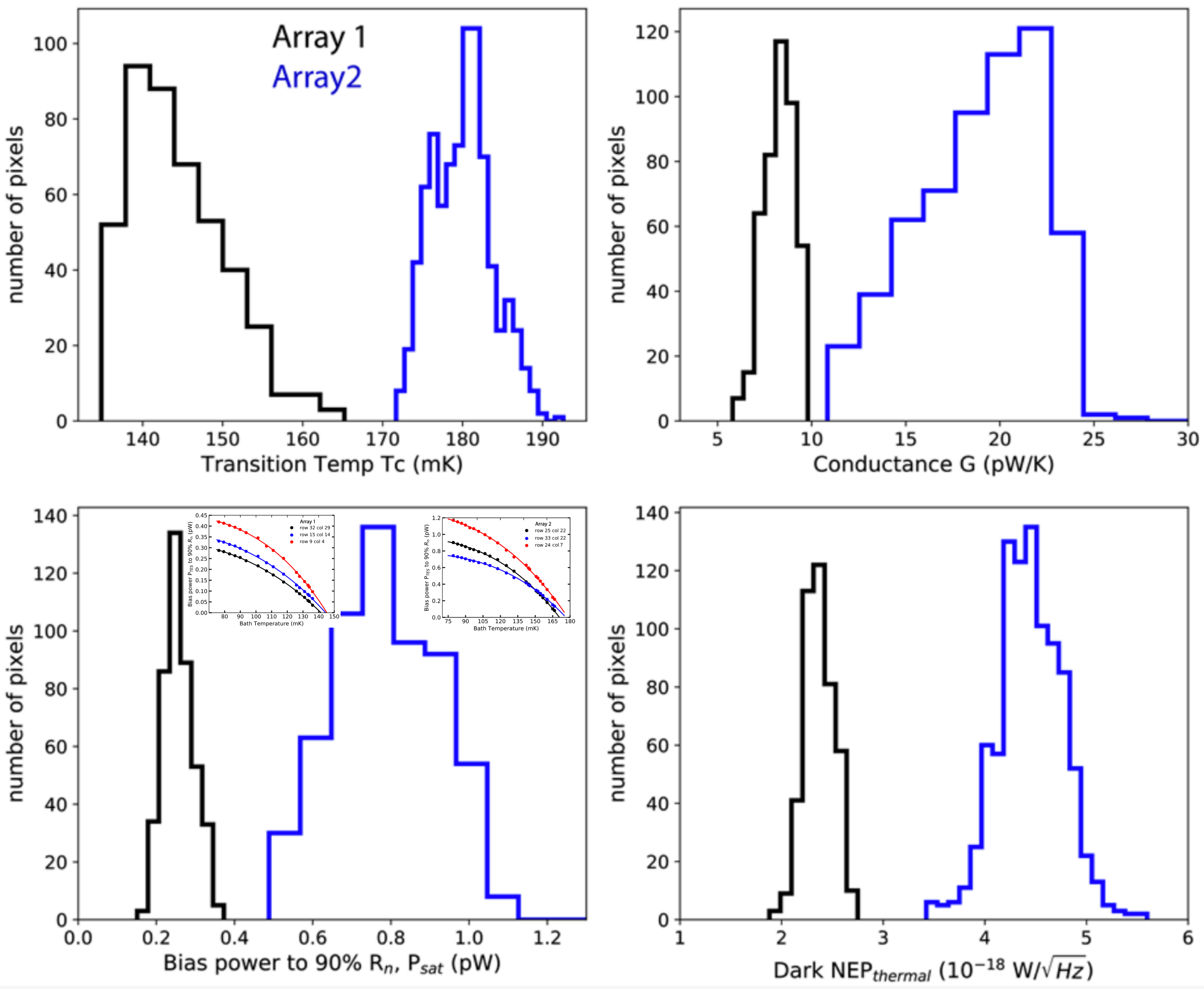
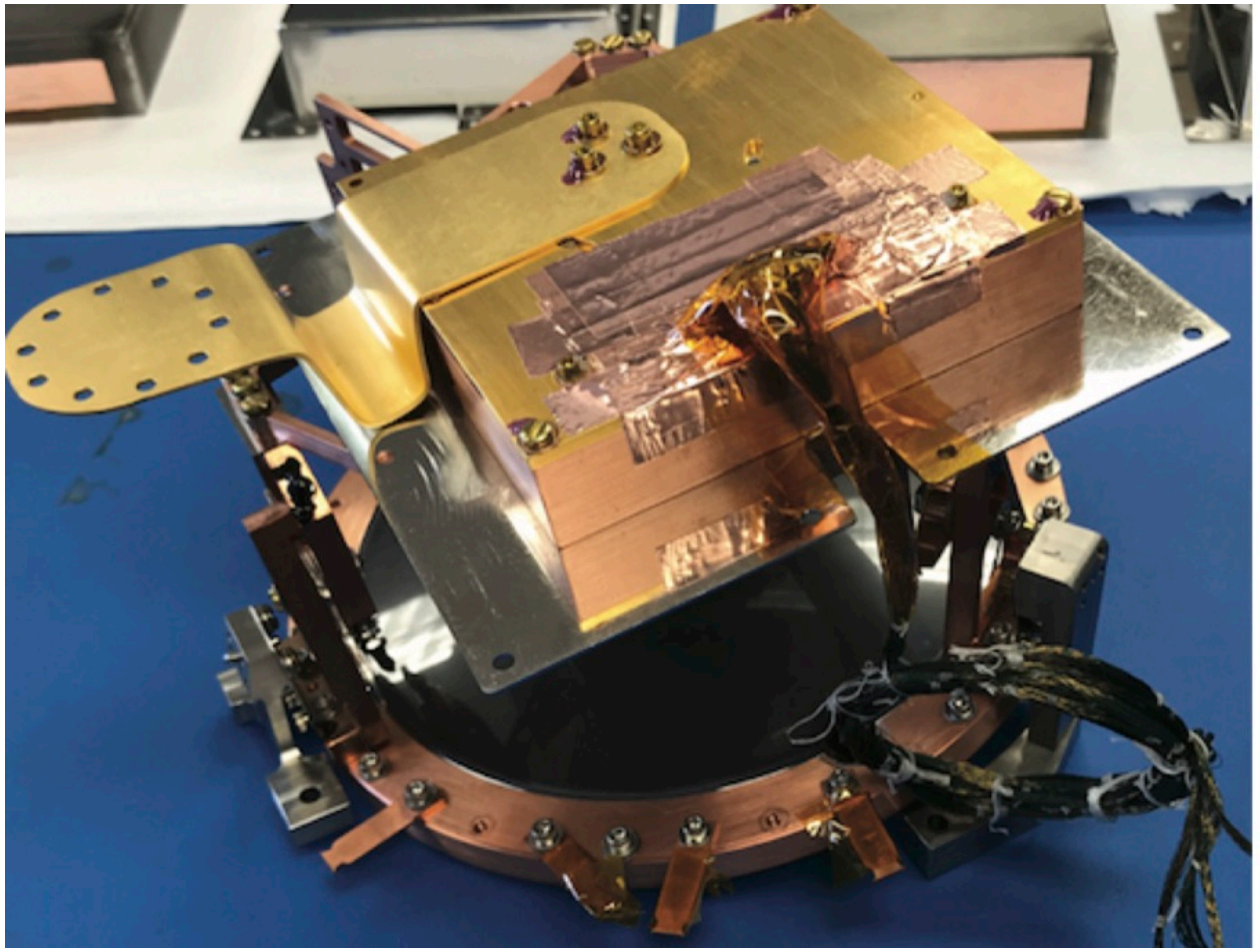
Histograms of measured detector dark parameters for the PIPER detector arrays



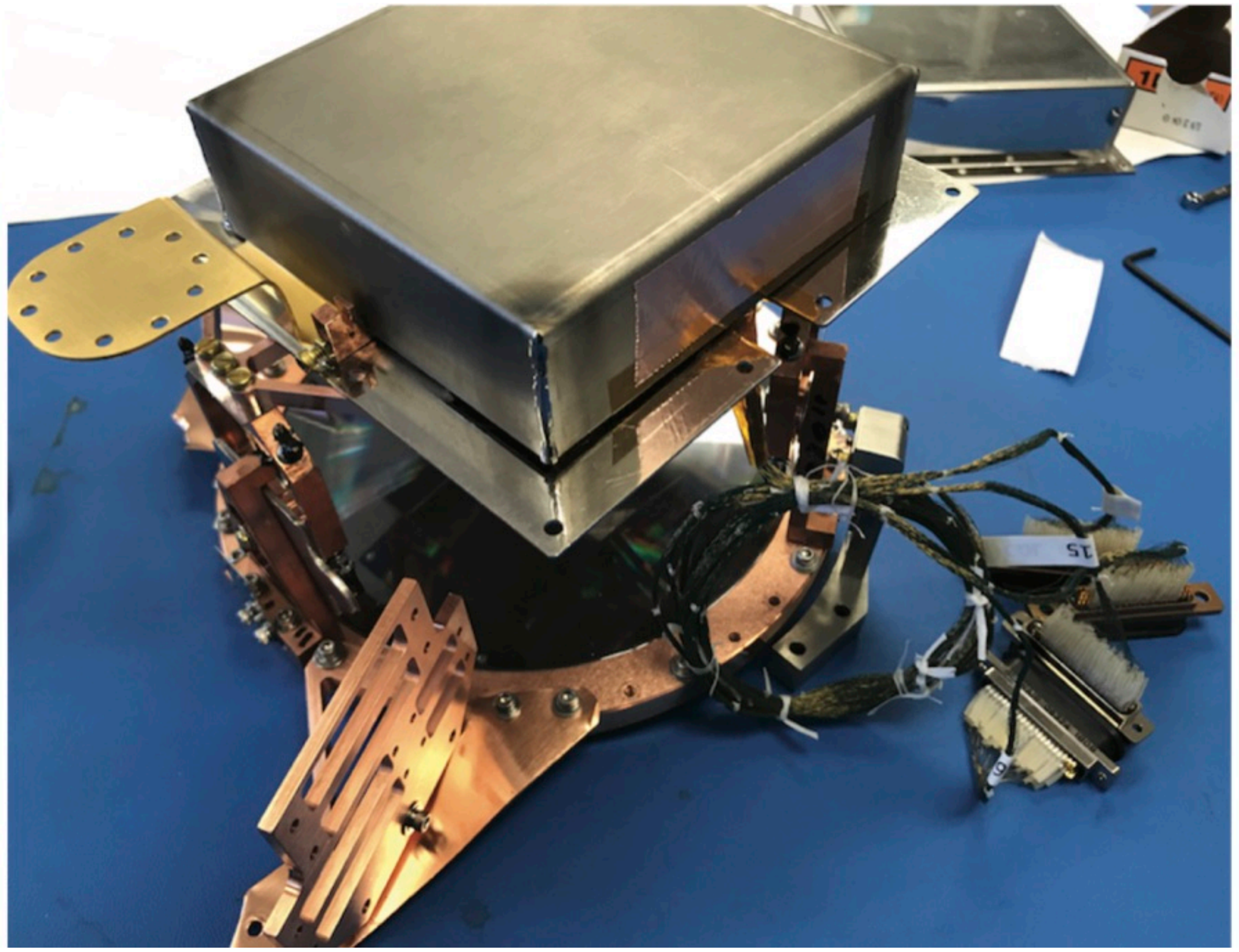
Receiver Integration

Detector Package and Lens Assembly

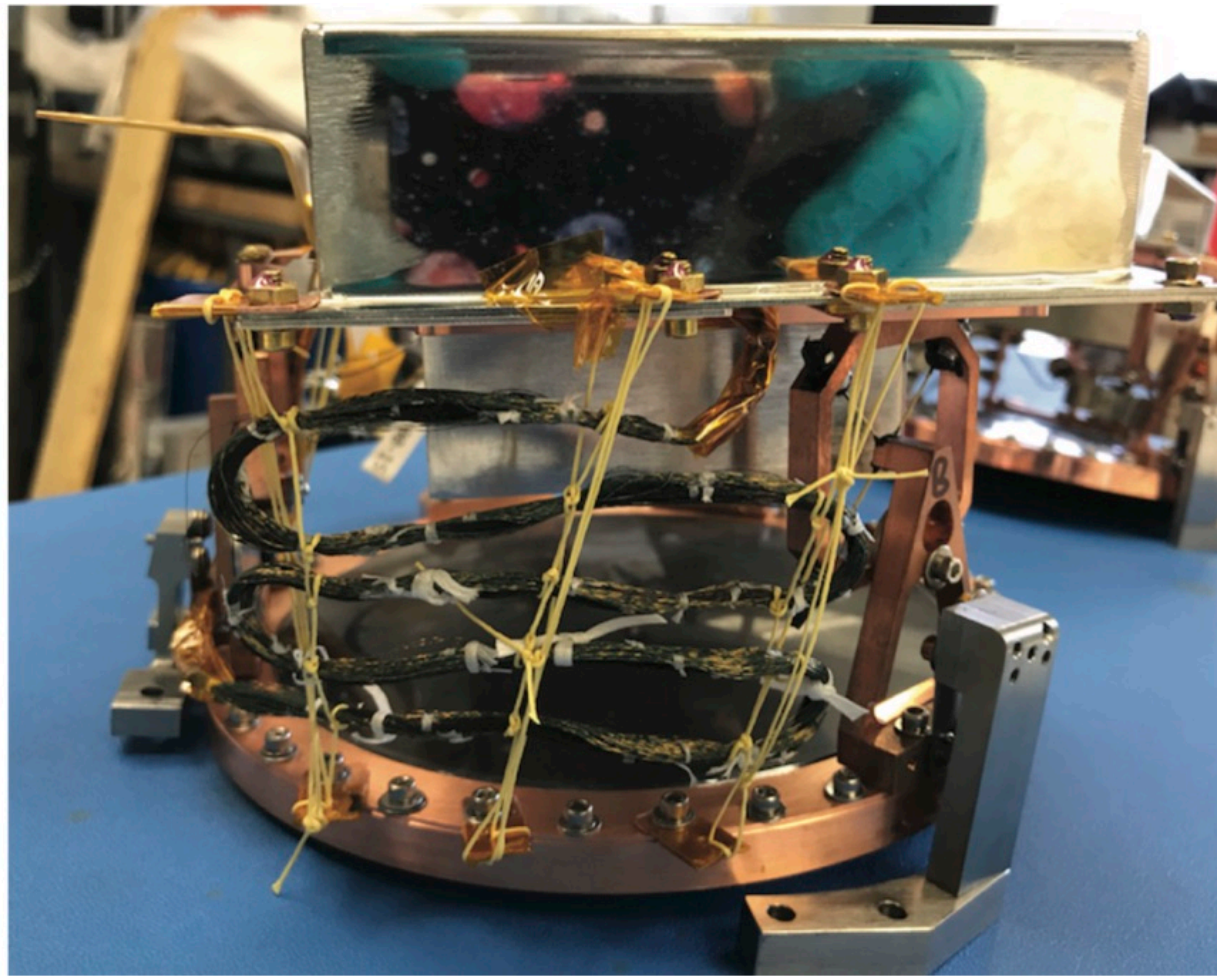
Detector package and thermal strap



Niobium shield installed



Outer magnetic shield installed

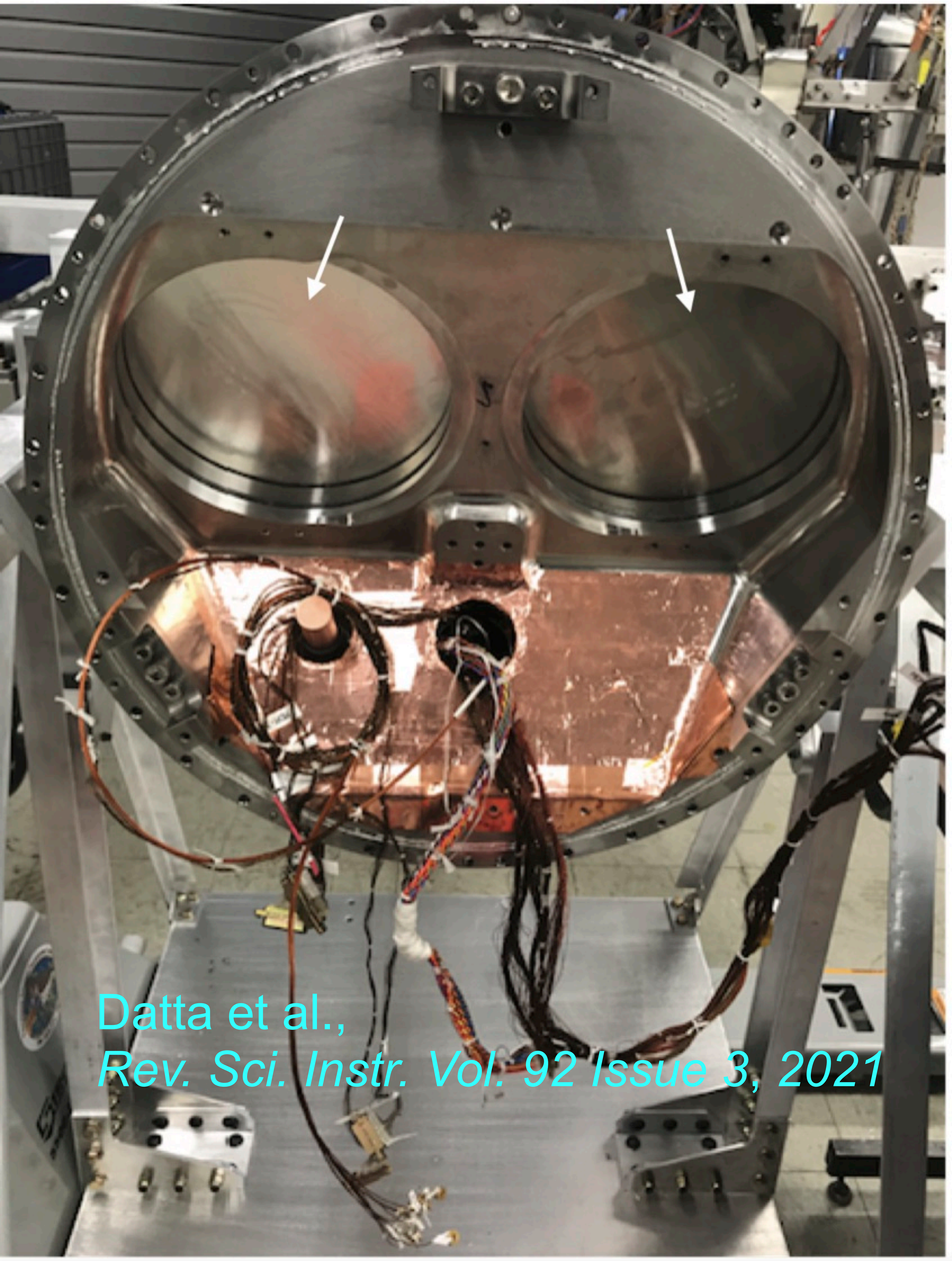


- Each detector package is cooled through a thermal strap that connects to the main 100 mK bus.
- The package assembly is capped from behind with an Nb box and enclosed in an Amuneal A4K shroud.
- The wiring harness is routed by meandering across a Kevlar suspension.

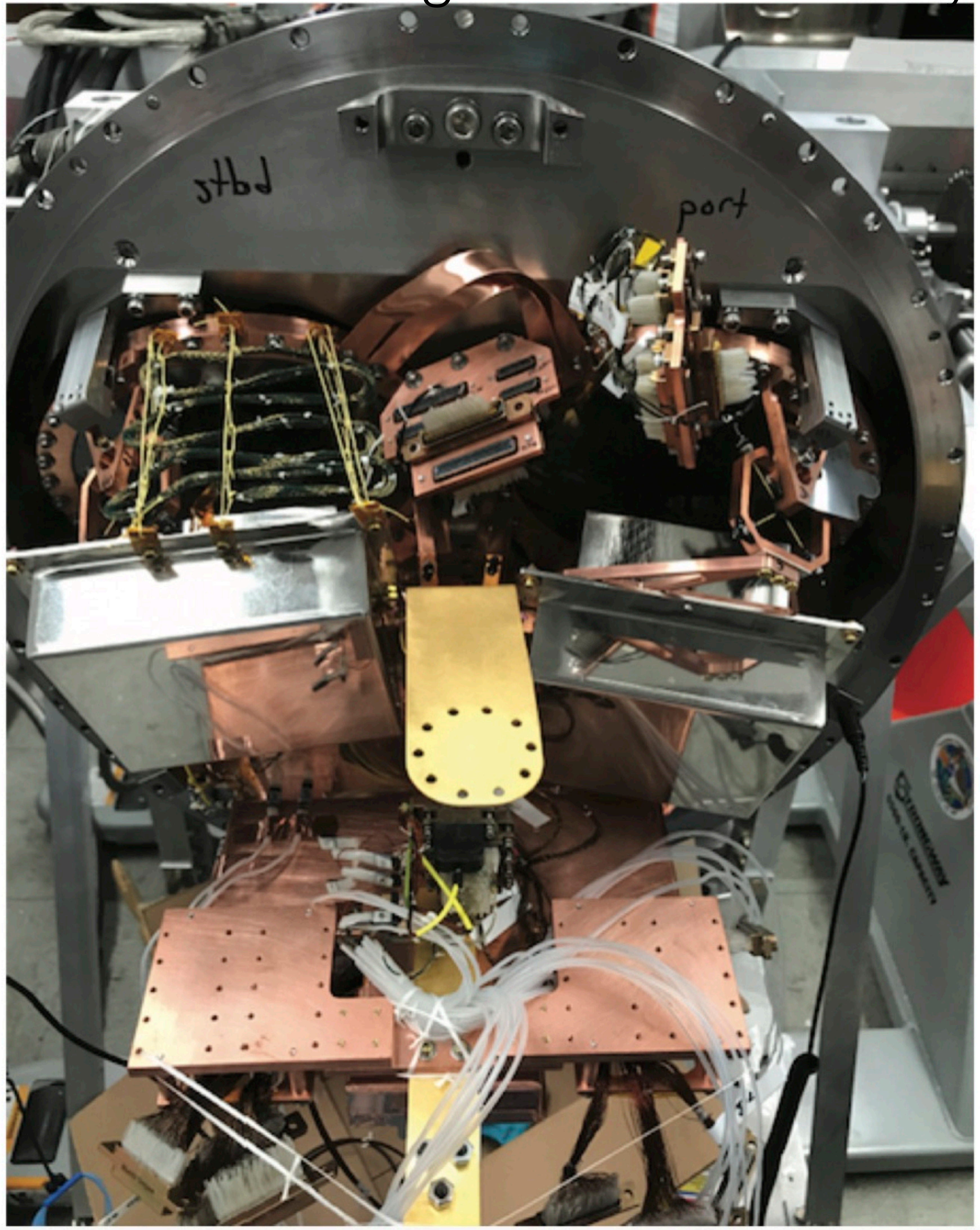
Switzer et al., *Rev. Sci. Instr. Vol. 90 Issue 9, 2019*

Receiver Integration (Contd.)

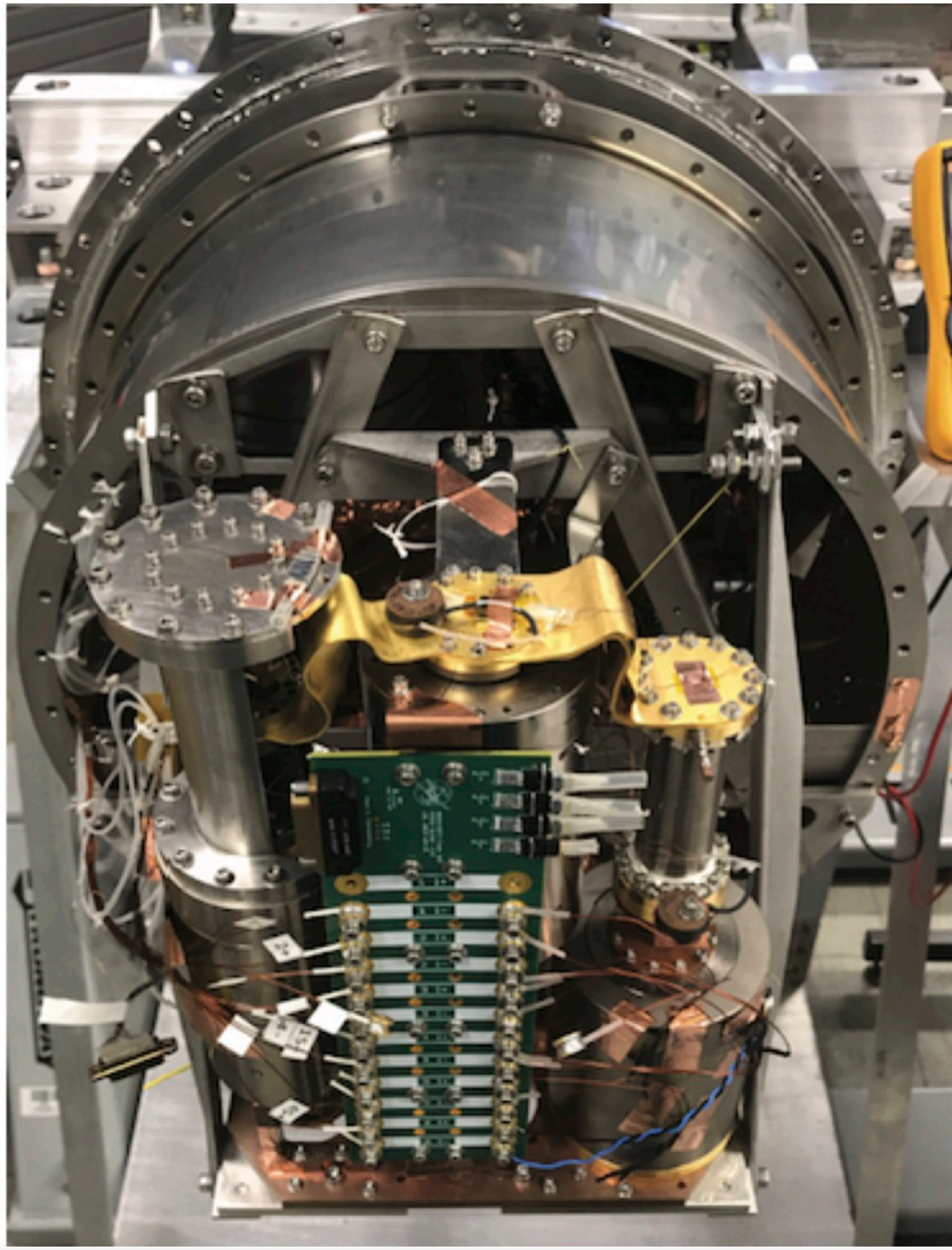
Vacuum windows installed



Detector Package + Lens Assembly

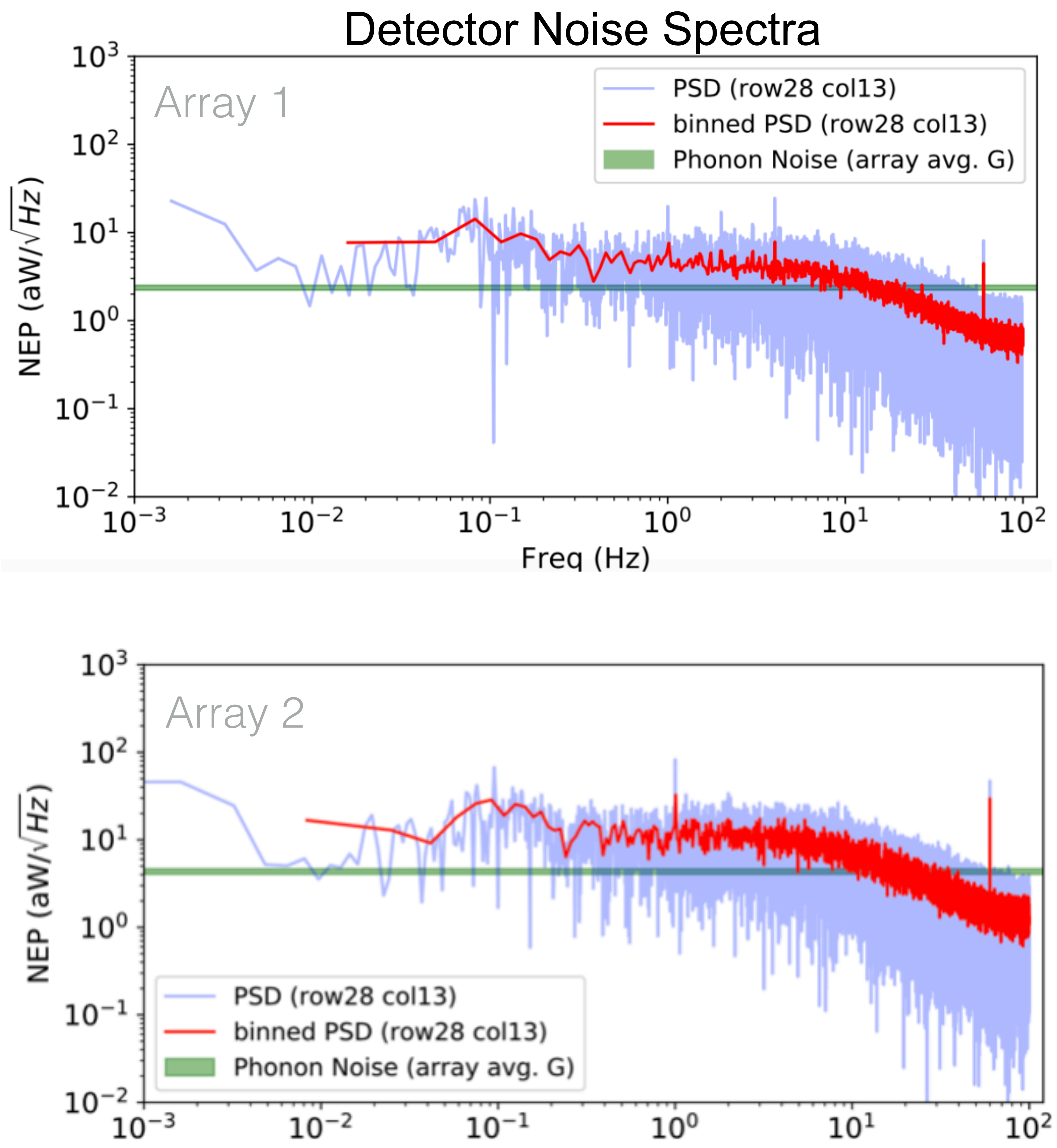


Readout + CADR



Pre-flight Testing

- The integrated receiver is tested in a smaller test dewar, which is partially filled with LHe and pumped out to simulate the ambient pressure at float.
- The receiver windows are capped with eccosorb sheets cooled with superfluid helium pumps to remain isothermal to the pumped LHe bath.
- TES IV curves are acquired in this configuration, and repeated at a few different eccosorb temperatures obtained by controlling the superfluid helium pumps.
- For the previous campaign, the pixel yields were significantly impacted by unreliable connections in the readout chain. For PIPER's upcoming flight, we are attempting to get back some of these detectors.
- Noise spectrum for a representative detector from each array, the array averaged dark NEP is shown for comparison.



Summary

- PIPER flies two 32 x 40 BUG TES arrays that have demonstrated uniformly low dark NEPs in the lab.
- The integrated receiver is tested in a LHe test dewar simulating the ambient pressure at float and basic detector, readout, and CADR performances are verified.
- Integration and testing is currently underway for PIPER's upcoming flight later this year.
- One of the two detector arrays was measured to have lower saturation power than the design target. Hence, for the upcoming flight, PIPER will adopt a conservative approach by installing Neutral Density Filters (NDF) in front of the arrays to limit the power incident on the detectors. Informed by the observed loading at float, the NDF option will be re-visited for subsequent flights.