The Primordial Inflation Polarization ExploreR (PIPER)

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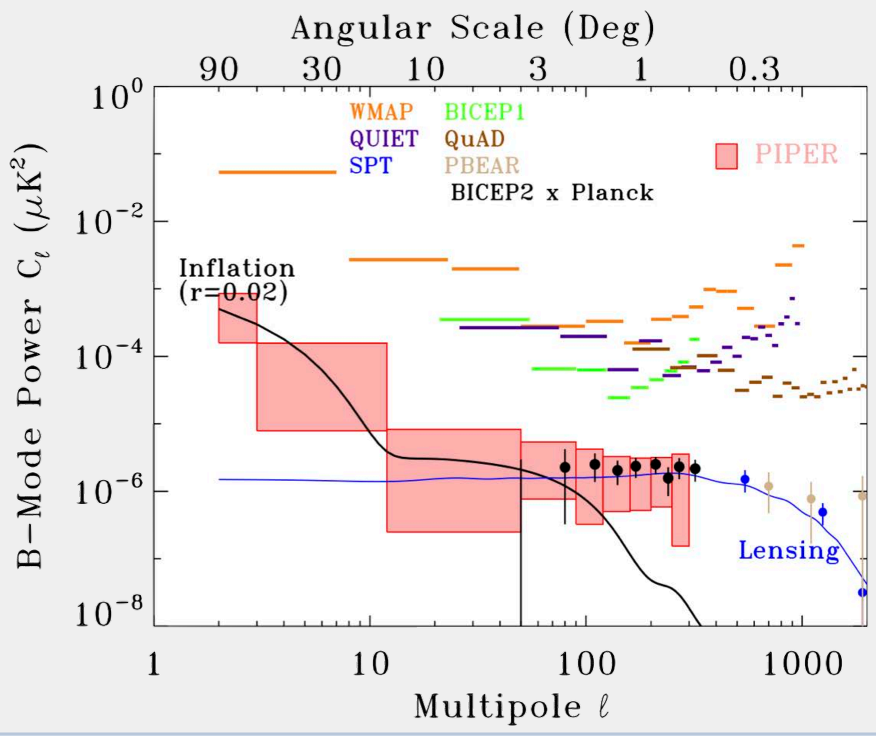
Science Goals

B-mode CMB polarization induced by inflationary gravitational waves

- PIPER will map the large scale polarization of the Cosmic Microwave Background (CMB) in order to look for the B-mode polarization pattern caused by gravitational waves from inflation.
- PIPER will measure the shape of the B-mode power spectrum over a range of angular scales corresponding to multipole ℓ of upto 300, encompassing both the reionization bump and the recombination peak, in four frequency bands centered at 200, 270, 350, and 600 GHz.
- After 8 flights, PIPER will constrain the level of the B-mode signal (parameterized by the tensor-to-scalar ratio r) to $r < 0.007$.

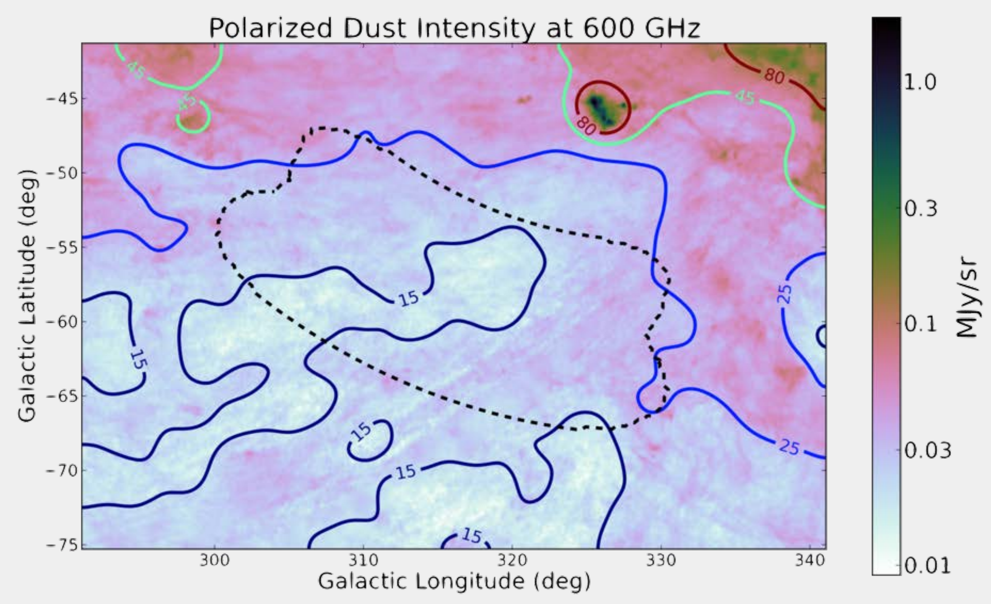
(Below) B-mode spectrum assuming a tensor-to-scalar ratio $r = 0.02$ from inflationary gravitational waves (black) and gravitational lensing (blue).



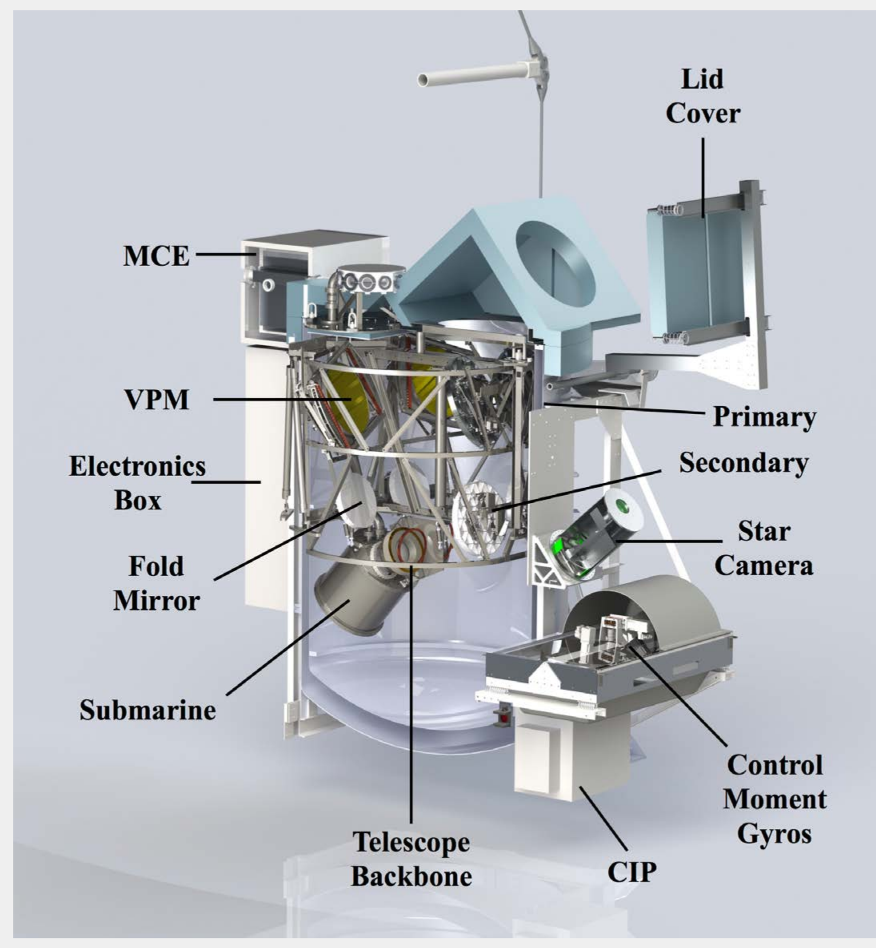
Polarized Galactic Foreground Contamination

- Understanding dust polarization is crucial as it is the dominant foreground for any CMB polarization experiment.
- PIPER will measure the polarized emission from galactic dust to a signal-to-noise ratio greater than 10 for regions of low dust intensity.
- The PIPER dataset will provide a high fidelity template at 21′ resolution that CMB experiments can use to remove the foreground contamination from the measurements.

(Below) Projected polarized dust intensity at 600 GHz assuming a 10% polarization fraction. The dotted line shows the BICEP2 observing region. S/N contours are shown for $\ell \sim 80$ after a single 600 GHz PIPER flight.



PIPER Payload



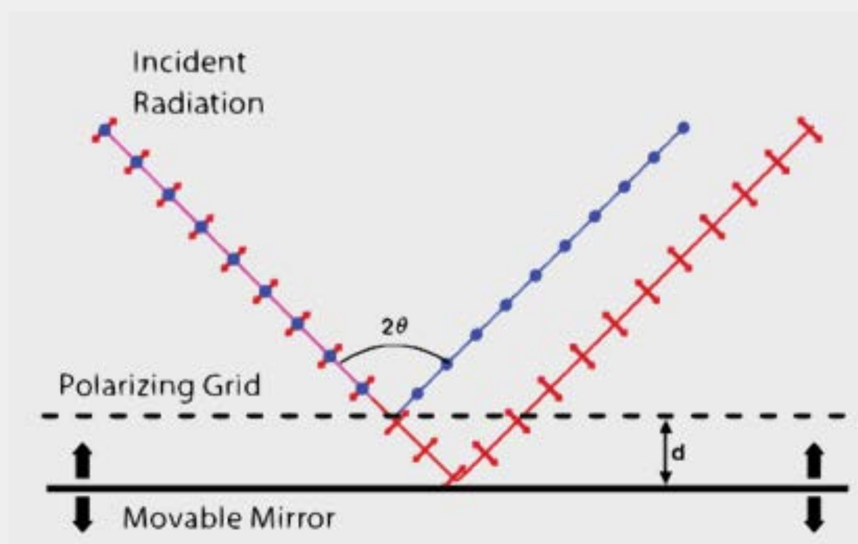
Model of the PIPER payload.

- An open-aperture LHe dewar keeps the optics at 1.5 K.
- Twin telescopes simultaneously measure Stokes Q and U in the same position on the sky.
- A 3 Hz Variable-delay Polarization Modulator (VPM) modulates the polarization of incoming light between U and V.
- The optical elements comprise aluminum mirrors and monocrystalline high-resistivity silicon lenses with metamaterial anti-reflection coated surfaces.
- Anti-reflection coated quartz windows let light into the vacuum vessel that houses the detectors, filters, lenses, and the CADR inside the LHe bucket dewar.
- The instrument has background-limited sensitivity provided by fully cryogenic (1.5 K) optics focusing the sky signal onto kilo-pixel arrays of time-domain multiplexed Transition-Edge Sensor (TES) bolometers held at 100 mK using a Continuous Adiabatic Demagnetization Refrigerator (CADR).
- The payload moves in azimuth using a pair of control moment gyros. A star camera provides absolute pointing information.

Enabling Technologies

Variable-delay Polarization Modulator (VPM)

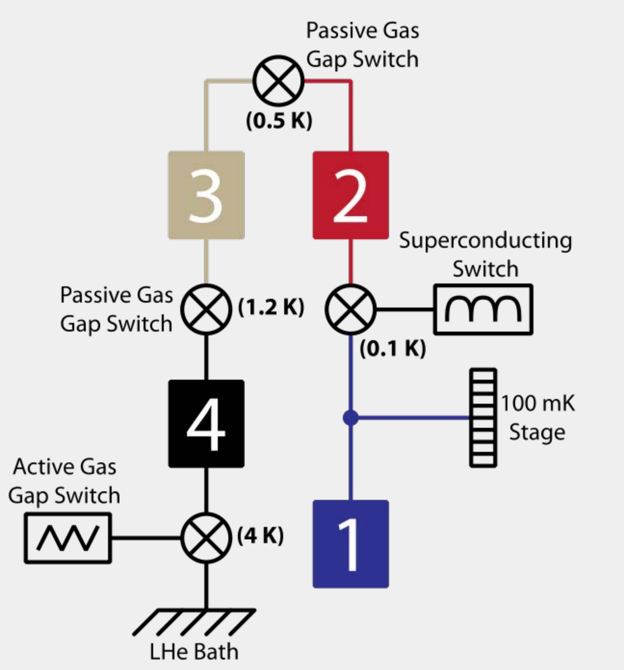
- The first optical element of each telescope is a Variable-delay Polarization Modulator (VPM), ensuring instrumental polarization cannot be modulated and thus controlling systematics.
- The VPM consists of a grid of 36 µm wires spaced 115 µm apart, placed in front of a moveable mirror. The mirror-grid distance, d, determines the phase difference between orthogonal polarizations, leading to modulation of local Stokes U and V, leaving Q unchanged.



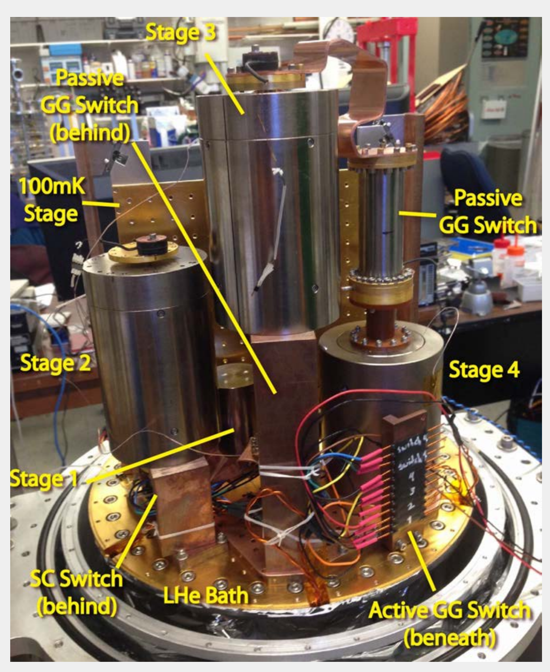
Schematic of the VPM

Continuous Adiabatic Demagnetization Refrigerator (CADR)

- PIPER's detectors are cooled to 100 mK using a Continuous Adiabatic Demagnetization Refrigerator (CADR). The CADR consists of independent stages connected by gas gap (GG) and superconducting (SC) heat switches.
- The CADR provides 15 µW of cooling power to the 100 mK detector stage by decoupling and cycling the four stages, cascading heat up to the LHe bath.



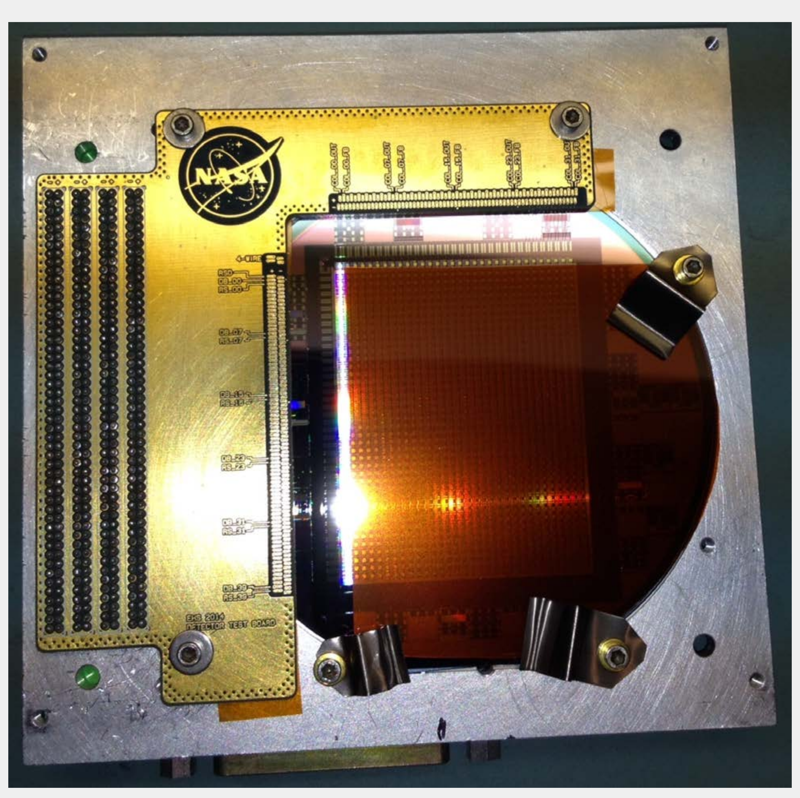
Schematic of the 4-stage CADR



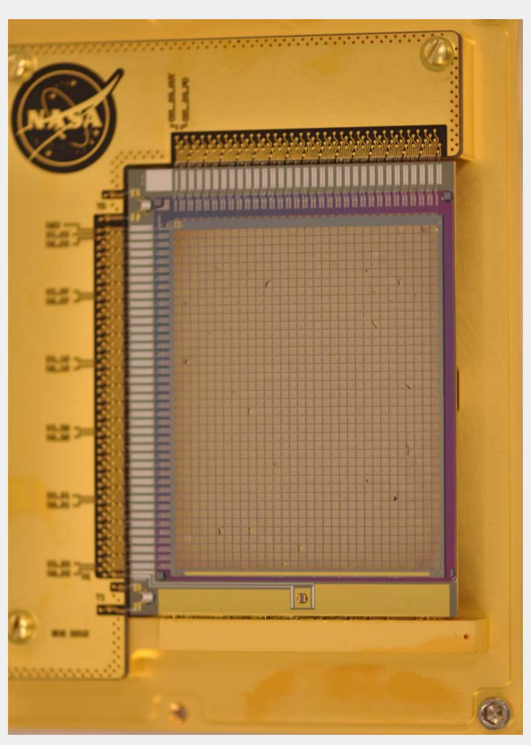
CADR in the lab

Kilo-pixel Backshort-Under-Grid (BUG) Transition Edge Sensor (TES) Detector Arrays

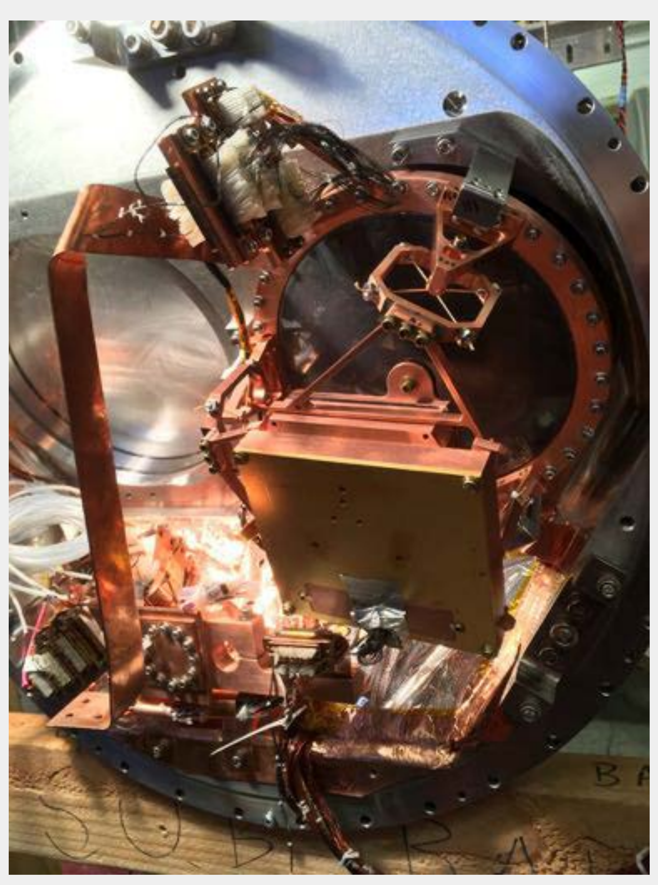
- PIPER uses two 32 x 40 pixel arrays of backshort-under-grid (BUG) transition-edge sensors, developed at NASA's Goddard Space Flight Center. Each array receives light in a single linear polarization.
- Each detector array is indium bump-bonded to a 2D superconducting quantum interference device (SQUID) based time-domain multiplexer (MUX) chip designed and fabricated by NIST and read out by warm Multi-Channel Electronics (MCE) developed by the University of British Columbia.
- Each pixel measures total incident power over a frequency band defined by bandpass filters from Cardiff University placed in front of the array.



A 32 x 40 pixel 2D Multiplexer chip in a test package. The 2D MUX chips are screened in the lab prior to hybridization with the detector array



32 x 40 pixel BUG detector array for the PIPER engineering flight in a test package for lab characterization

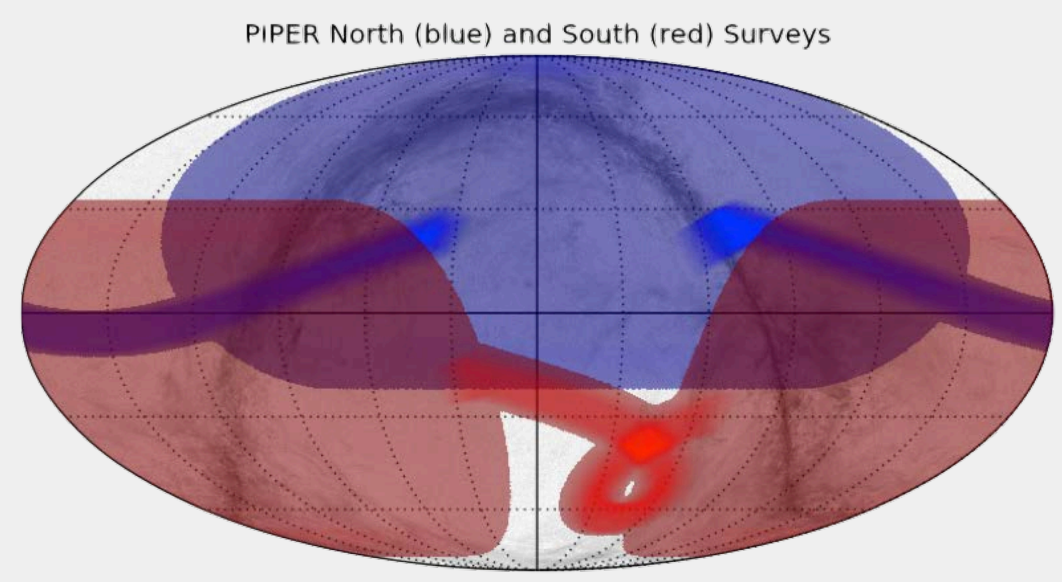


A detector array and silicon lens assembly installed in the camera for the engineering flight.

Observing Strategy

- PIPER observes at an altitude of 120000 feet on a stratospheric balloon platform provided by NASA's Columbia Scientific Balloon Facility (CSBF).
- Cold optics and the lack of a warm window permit PIPER to achieve sensitivity at the sky-background limit. This gives a 10x improvement in mapping speed, allowing 50% of the sky to be mapped in a single conventional overnight flight.
- PIPER will fly from CSBF launch sites in both the Northern and Southern hemispheres, covering over 85% of the sky over the course of 8 conventional balloon flights.

(Below) During the night PIPER spins in azimuth, covering the large oval regions. During the day PIPER scans back and forth avoiding the sun, covering the dark narrow strips.



2017 Flight Campaign and Future plans

The payload was fully integrated at Goddard, then shipped to CSBF in Fort Sumner, NM. There, PIPER was integrated with a support package provided by the balloon facility for issuing commands and receiving data during the flight. It had its first flight in October 2017. This was an engineering flight with a single telescope to test various systems and telemetry. Overall, the flight was successful and analysis of the data is underway.

(Above) The PIPER payload on the launch vehicle prior to its first flight in Fort Sumner, NM.

In the summer of 2018, the plan is to fly PIPER in its full twin telescope configuration with two science grade detector arrays from Palestine, TX.

This will be followed by a second science flight in the fall of 2018 from Fort Sumner, NM.

(Below) View from a camera on the PIPER payload at float.