Design and development of a cryogenic continuously-rotating achromatic half-wave plate for CMB polarization modulation on POLARBEAR-2

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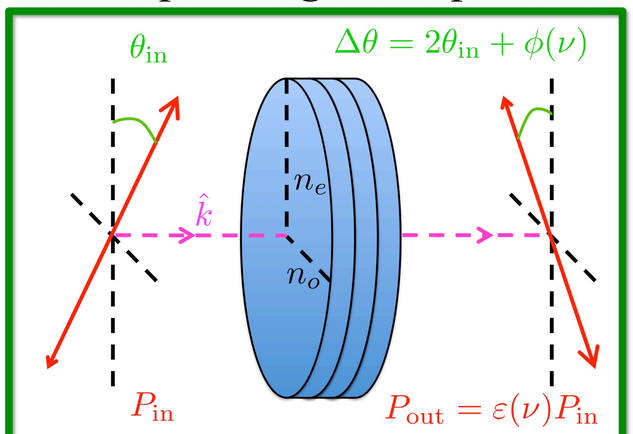
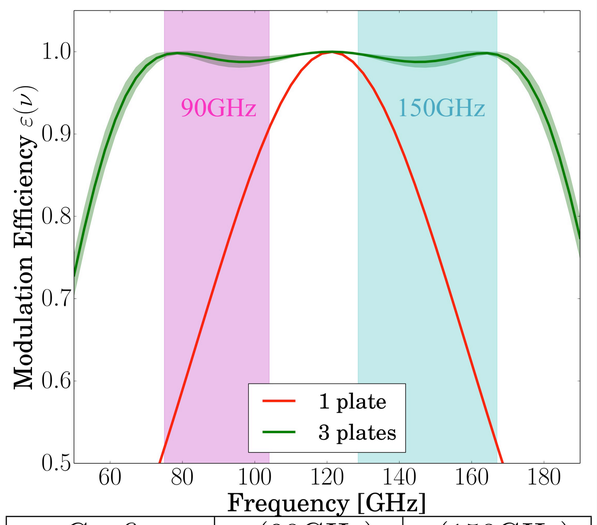
POLARBEAR-2 (PB2) Cryogenic Half-wave Plate (CHWP) Design

Operating Principle



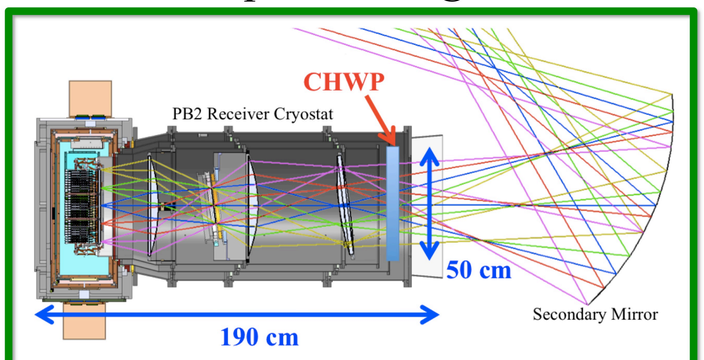
- A HWP rotates linear polarization while preserving input polarization fraction
- The HWP is made broadband by stacking multiple birefringent plates in an optimized orientation

Polarization Efficiency



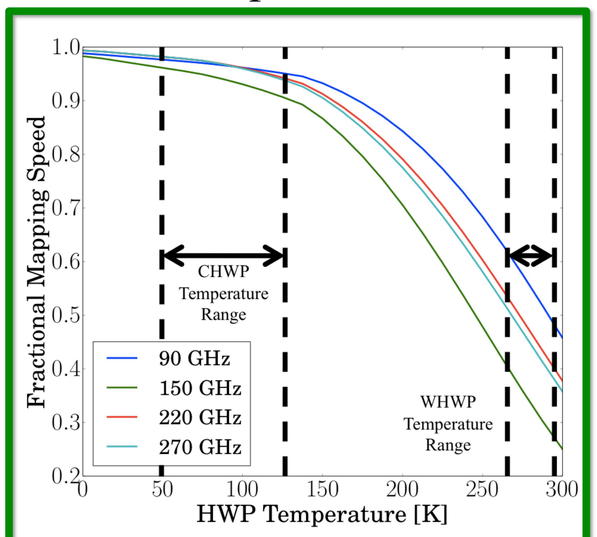
Config	ε(90GHz)	ε(150GHz)
Single HWP	0.721	0.780
AHWP	0.99 ± 0.01	0.99 ± 0.01

PB2 Optical Integration



- The CHWP has a 460 mm clear aperture and modulates all 1,897 detector pixels simultaneously from near the telescope focus
- The CHWP modulates Q/U at $4f_{\rm HWP} = 8$ Hz to suppress 1/f noise and sits sky-side of all lenses to mitigate refractive beam systematics

Temperature

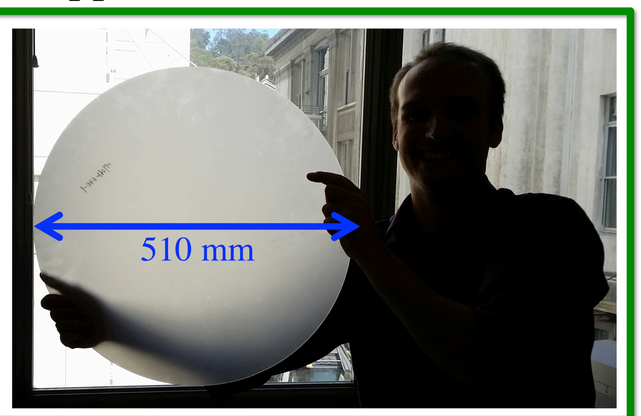


- The CHWP target temperature range is 50 – 125 K where its impact on PB2 mapping speed is < 10%

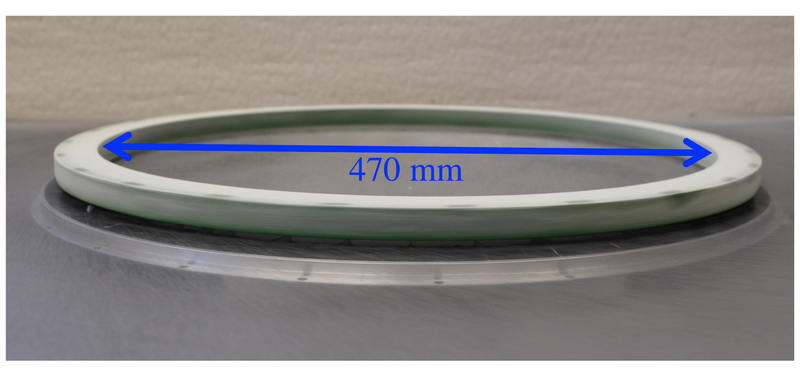
PB2 CHWP Hardware

Sapphire

Three 510 mm diameter, 3.7 mm thick sapphire windows from GHTOT rotate polarization with tanδ ~ 10^{-4} at 300 K and polarization modulation efficiency ε ≈ 99%



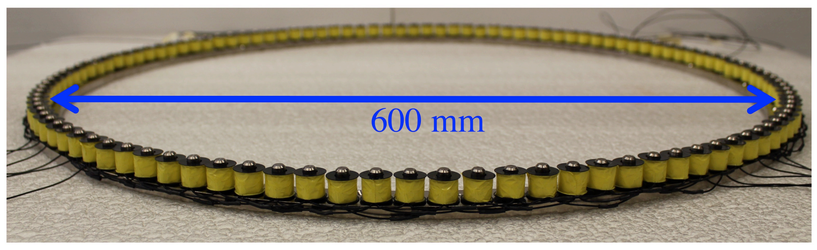
Superconducting Magnetic Bearing



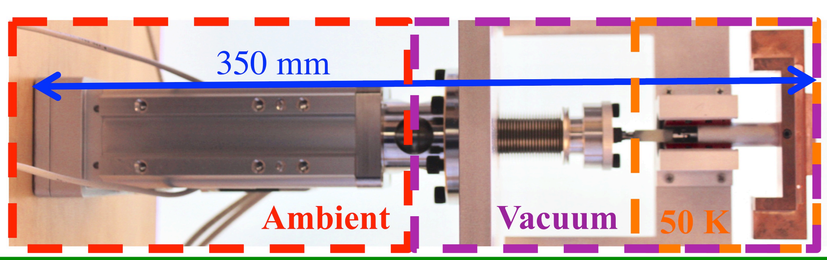
A superconducting magnetic levitating thin-section bearing from ATZ GmbH operates with a friction coefficient $\mu_k < 10^{-7}$ at 77 K and dissipates < 10 mW at 2 Hz rotation

Magnetic Motor

An open-loop-feedback, three-phase, non-contact magnetic motor dissipates < 100 mW at $f_{\rm HWP} = 2$ Hz



Gripping Mechanism

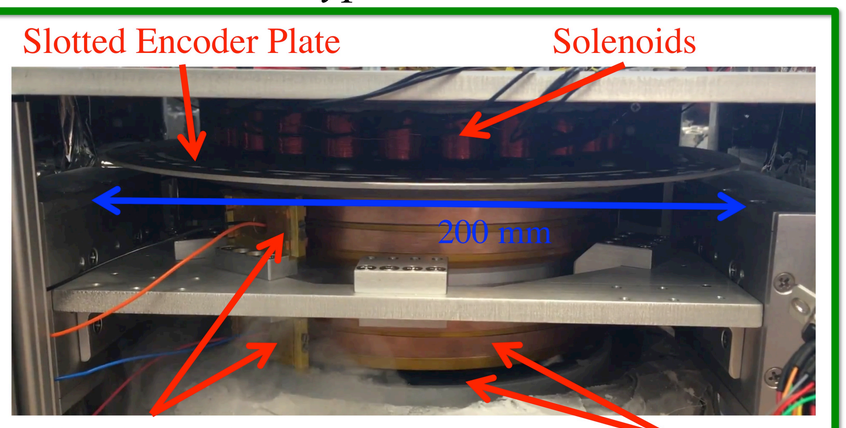


Three gripper arms hold the CHWP rotor when warm, cool it via conduction, and release it when cold

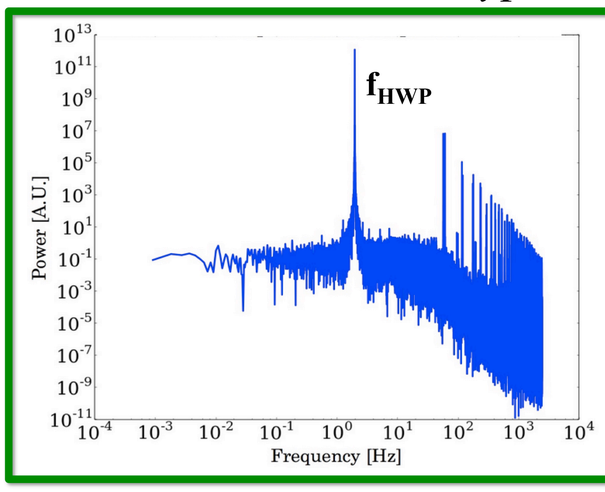
CHWP Prototyping

CHWP Prototype

A 6” non-optical CHWP prototype was built to evaluate novel hardware components and inform the design of a deployable modulator for PB2 and Simons Array



CHWP Prototype Performance



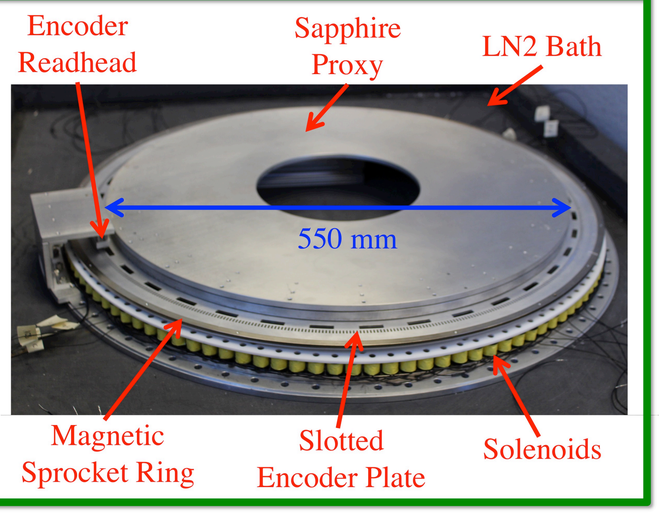
The prototype rotational power spectrum shows good encoder signal-to-noise, rotational stability, and low-frequency performance, validating the magnetic motor + bearing design

Ongoing Development: Deployment-ready CHWP

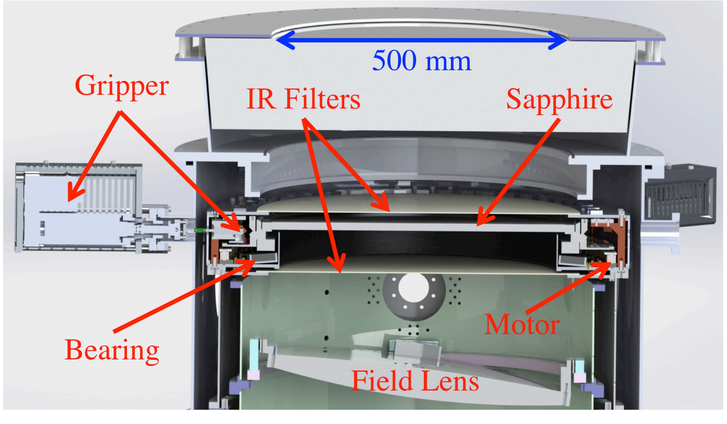
Full-scale CHWP

Initial LN2 testing of the full-scale motor + bearing + encoder system shows low friction, smooth rotation, and nominal motor operation.

Upcoming measurements include magnetic fields at the focal plane, motor-induced RF noise, startup and braking time, and encoder jitter



CHWP on PB2b



A full-scale CHWP will be deployed on PB2b in 2018 and is under evaluation in a test cryostat at LBNL

Looking forward, effort is ongoing to compactify the CHWP mechanical footprint for easier implementation on future experiments, such as Simons Observatory