POLARBEAR-2 Cryogenic Half-Wave Plate

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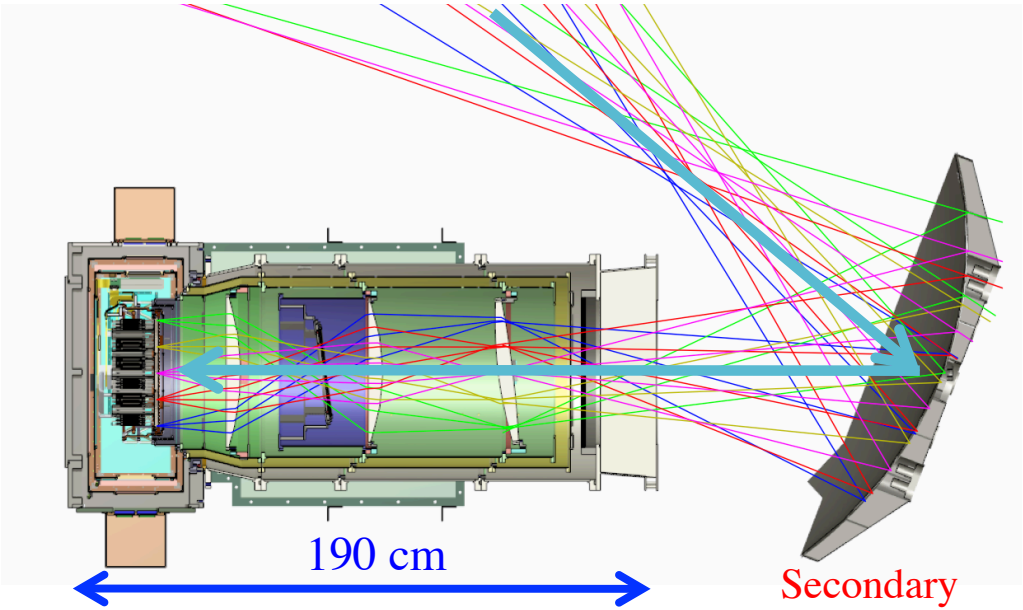
B-modes in Space
2017-12-05

POLARBEAR-2 optical system

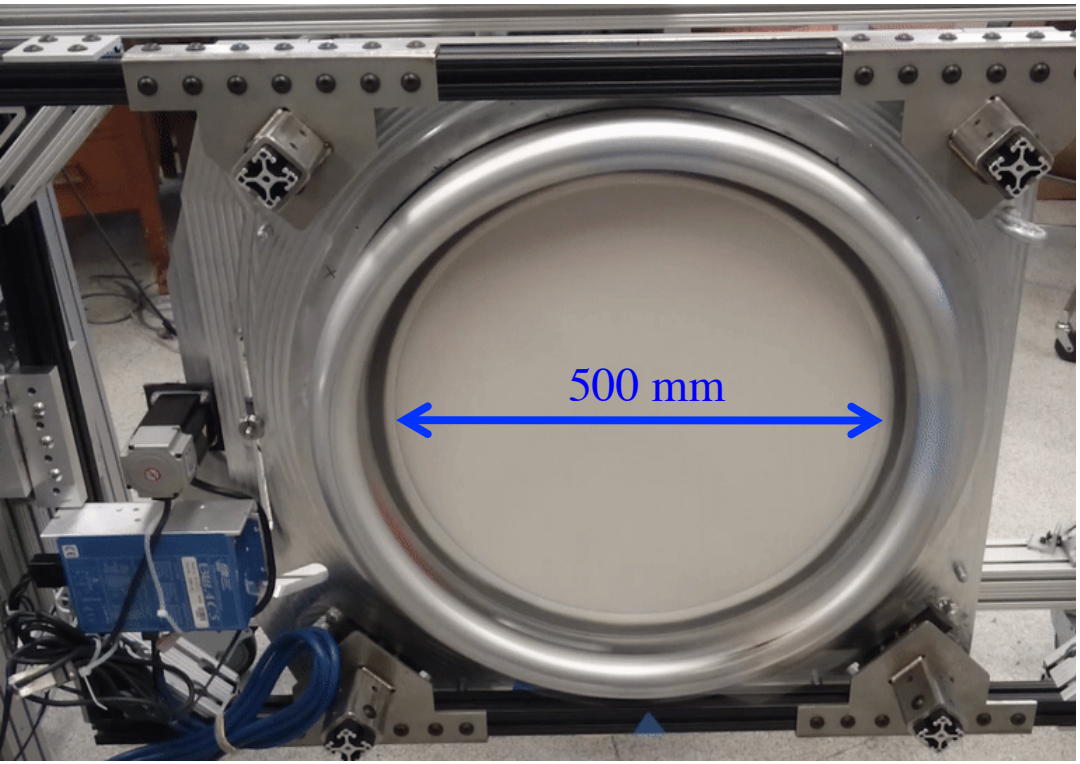
PB2 camera



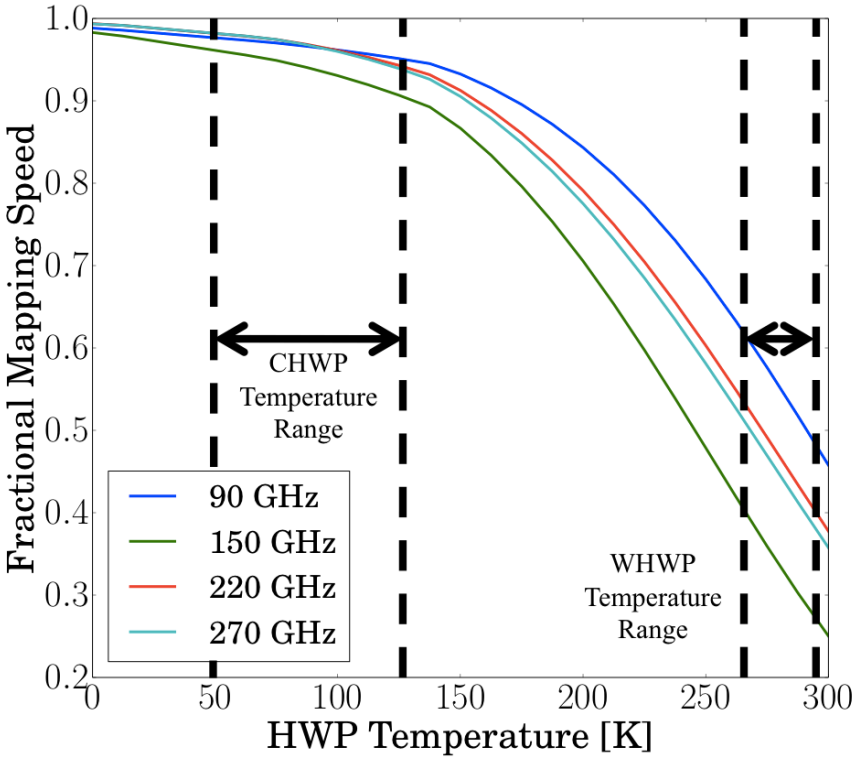
- Off-axis Gregorian telescope
- 95/150 GHz dichroic detectors
- Three alumina reimaging lenses
- 365-mm-diameter focal plane
- 4 deg field of view

Motivation for a cryogenic half-wave plate

Warm HWP for PB2a



Impact of HWP temp on MS



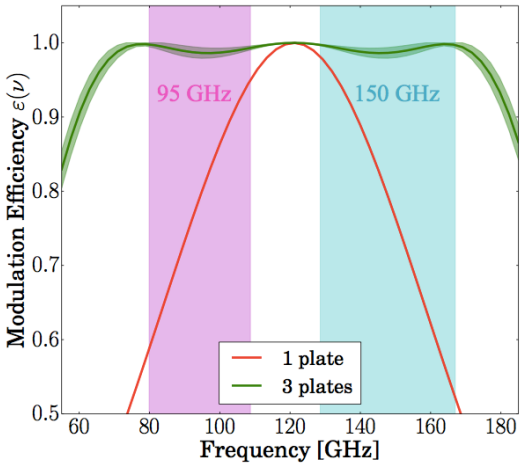
- An ambient-temperature half-wave plate (HWP) has been constructed for PB2a
- A cryogenic HWP (CHWP) improves PB2 mapping speed by ~2x compared to a warm HWP

PB2 CHWP optical stack

D = 510 mm sapphire

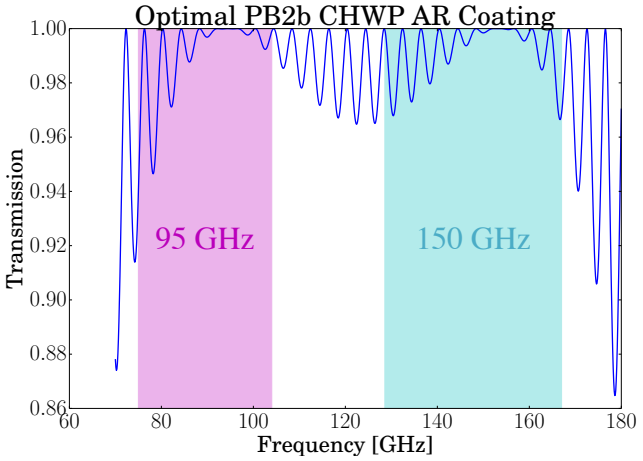
Parameter	Value
A-plane	± 1 deg
Parallelism	< 0.050 mm
Bow	< 0.010 mm

Achromatic 3-stack HWP



Band	Mod Eff
95 GHz	98.9 %
150 GHz	99.1 %

2-layer thermal spray AR

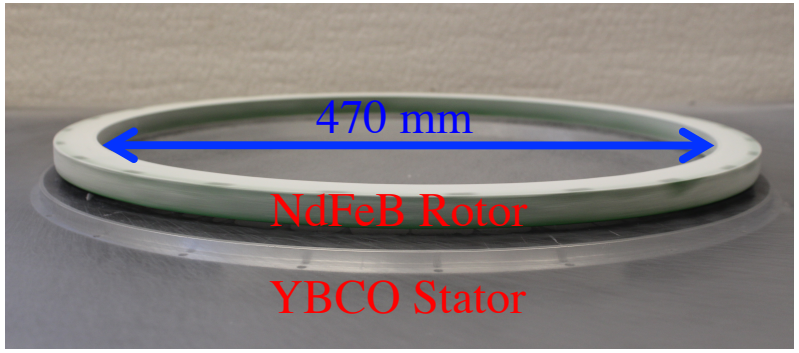


Band	Refl	Abs
95 GHz	0.5 %	< 1.4 %
150 GHz	0.6 %	< 0.8 %

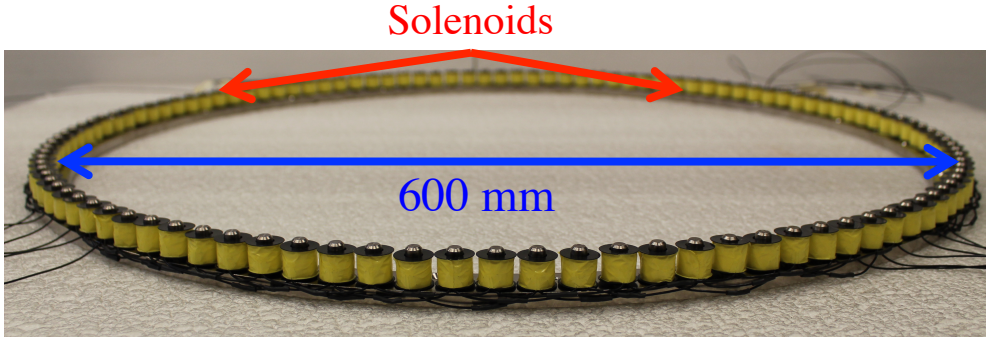
Stack Element	Thickness [mm]	Index of Refraction	Loss Tangent [10^{-4}]
Top AR Layer: SiO_2 TS	0.435 ± 0.025	1.39	< 10
Bottom AR Layer: Al_2O_3 TS	0.265 ± 0.025	2.30	< 10
Sapphire Ordinary Axis	3.90 ± 0.2	3.37	< 0.5
Sapphire Extraordinary Axis		3.05	

PB2 CHWP rotation mechanism

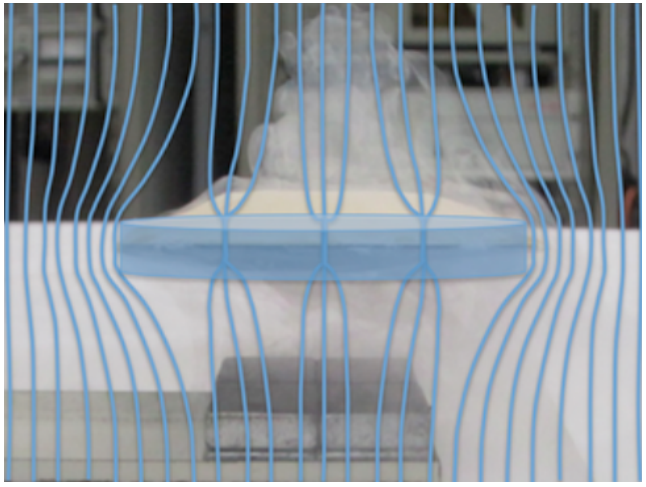
Magnetic levitation bearing



Magnetic motor

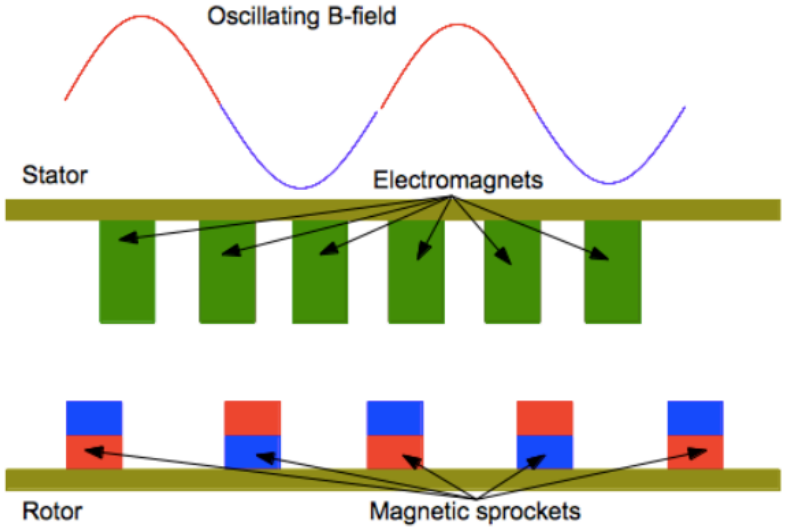


Flux pinning concept



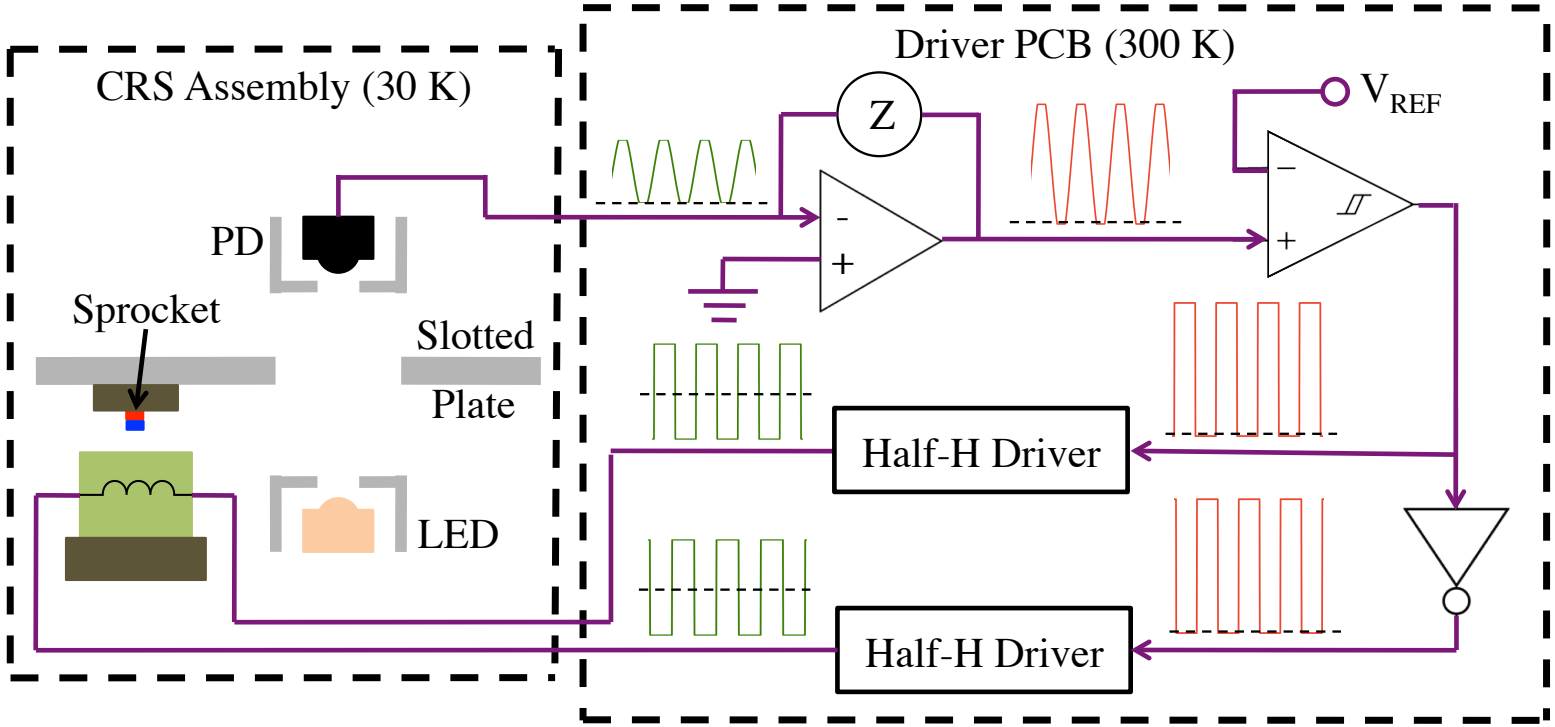
- ~100 N/mm spring constant at 5 mm separation and 77 K
- < 10 mW dissipation at 2 Hz and 77 K

Motor operation concept



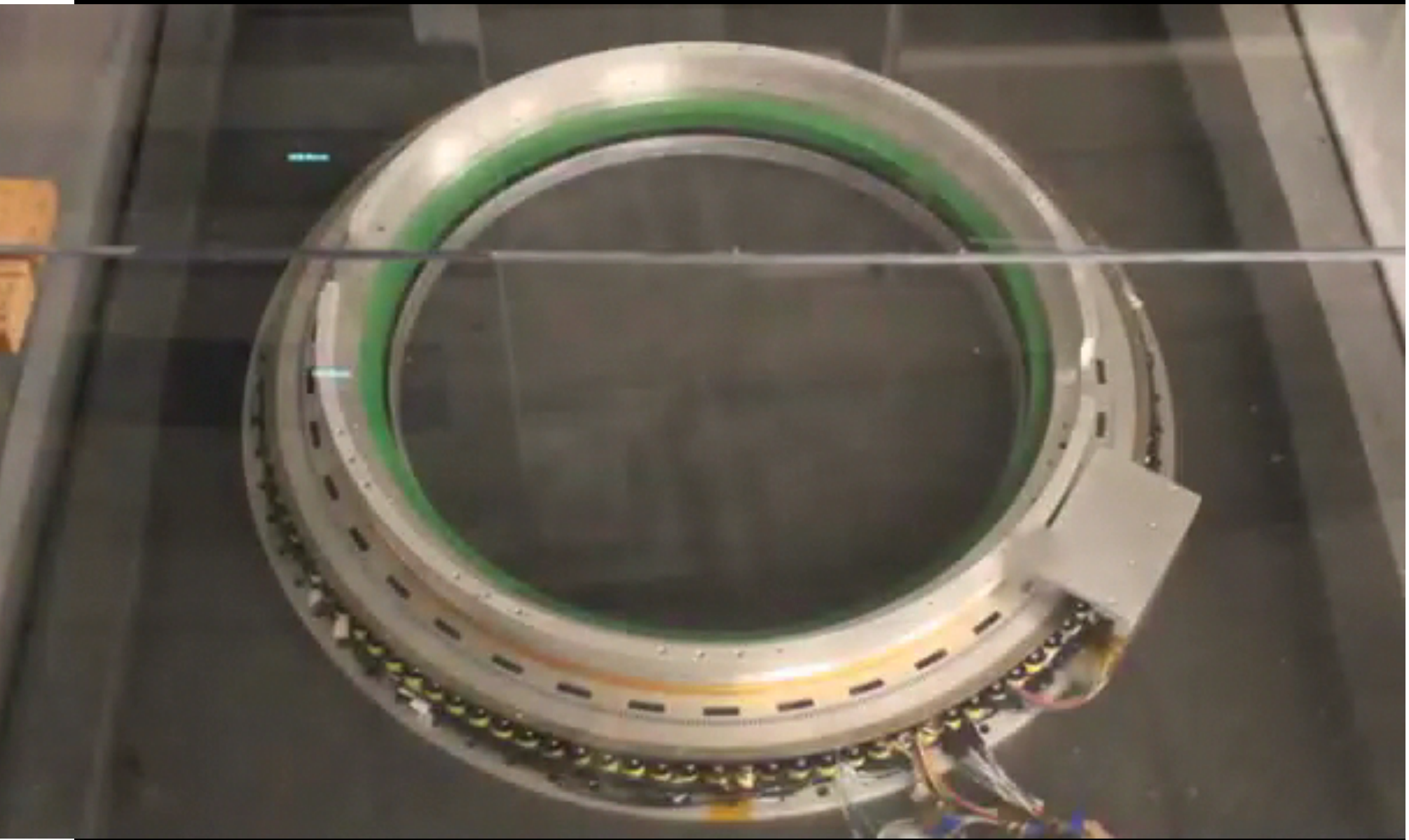
- Three-phase operation
- < 100 mW motor power dissipation during 2 Hz continuous rotation

PB2 CHWP encoding and driving

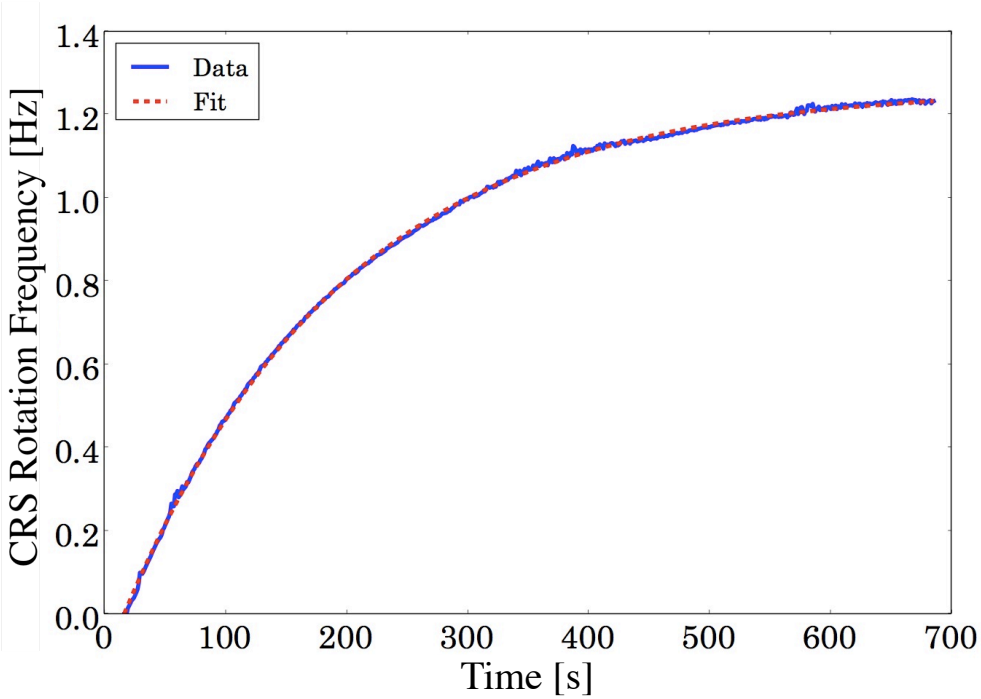


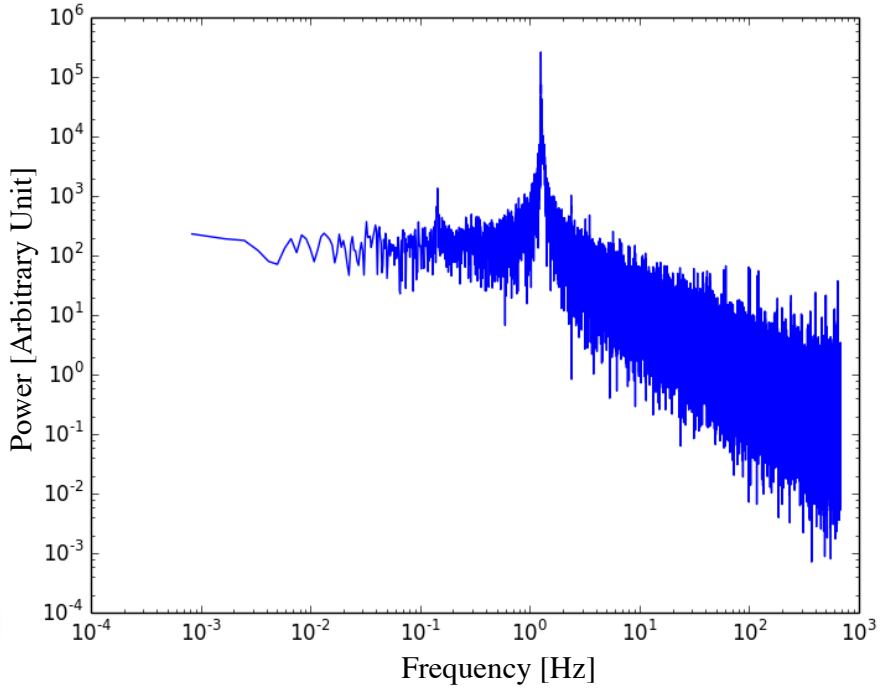
- Motor (and angle) encoding done using photodiode-LED pairs and a slotted plate
  - IR LED emitters (SPIDER)
  - Silicon photodiodes (SPIDER)
  - Quadrature readout
  - 1 reference pulse per cycle (for absolute angle)
  - 0.3 deg angular resolution (540 slits in slotted plate)
  - < 1 us timestamp jitter (leading to 10 uRad angle jitter using interpolation)
  - PD amplified warm and signal fed to dual Half-H drivers to excite coils

Table-top motor test



Motor performance

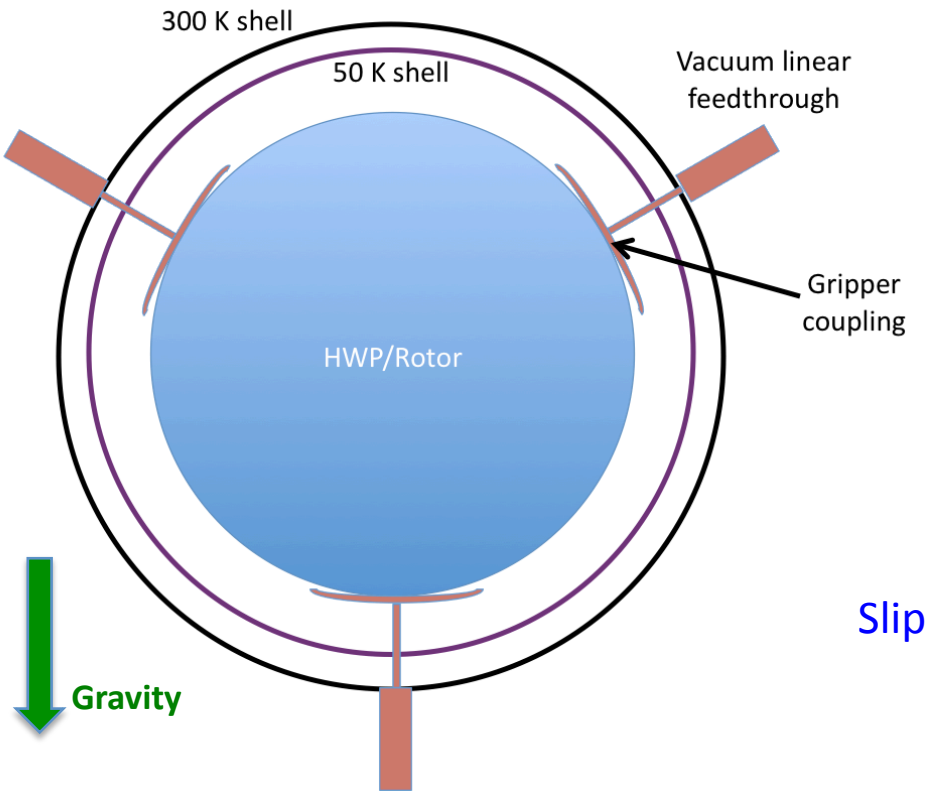




- Table-top testing results
  - 1/f knee at < 1 mHz → very stable rotation
  - Measured frictional dissipation < 50 mW
  - No pathologies in power spectrum indicates functional DAQ

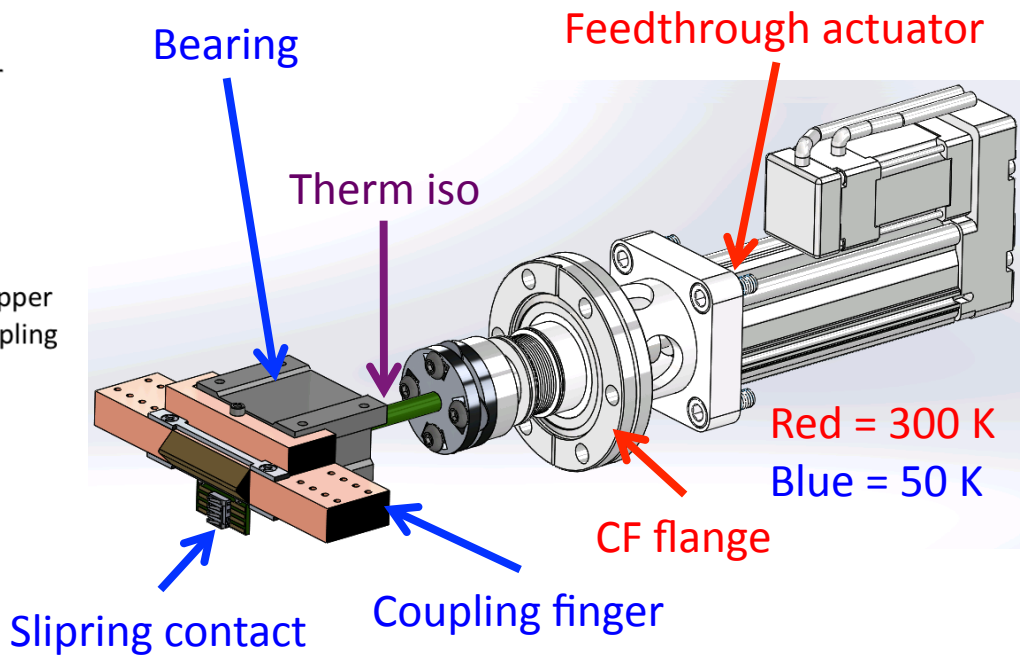
PB2 CHWP gripper

Conceptual cartoon



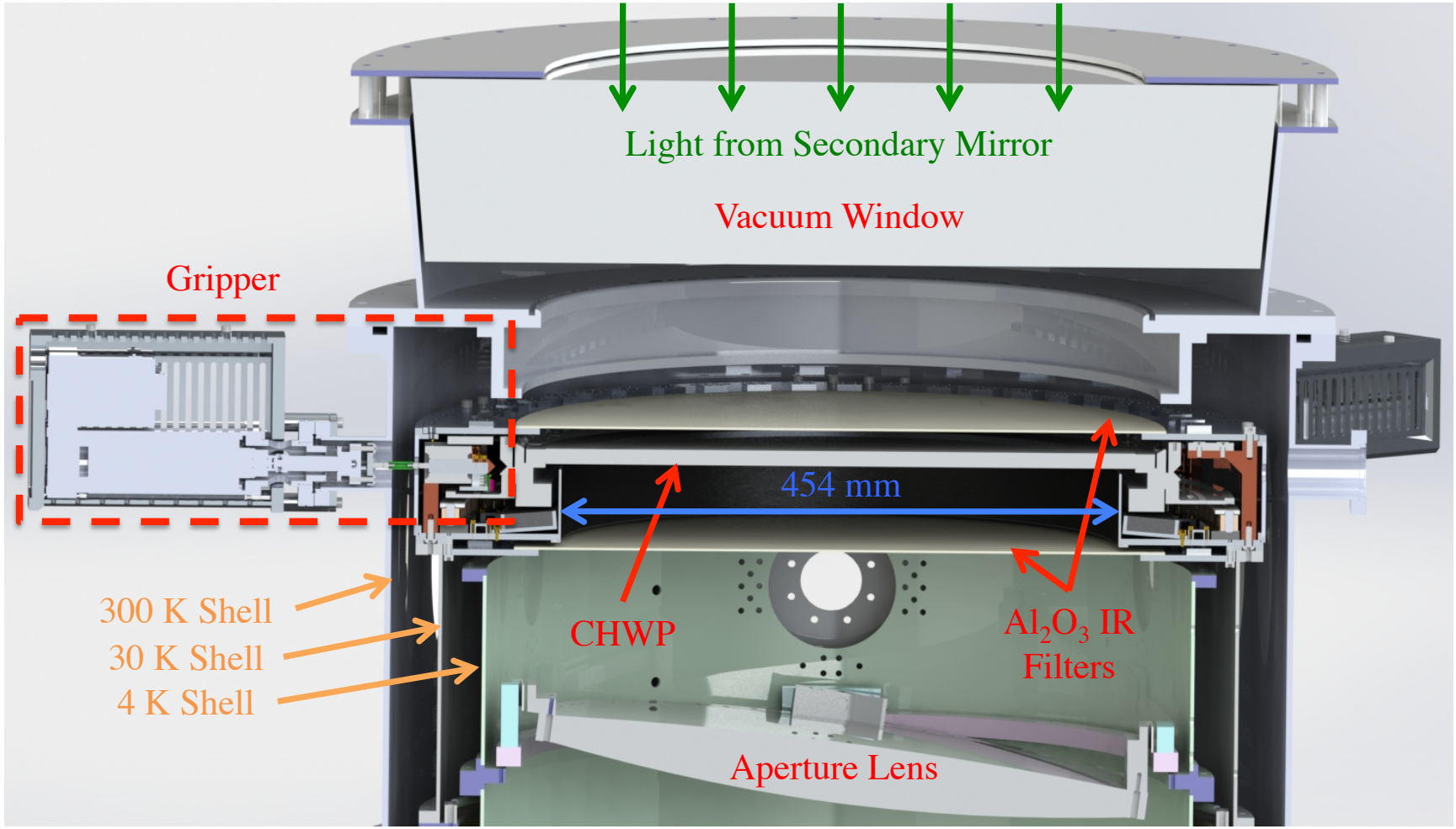
- "Grip" to align the HWP
- "Ungrip" to spin the HWP
- Three gripper modules to constrain HWP position

Gripper module

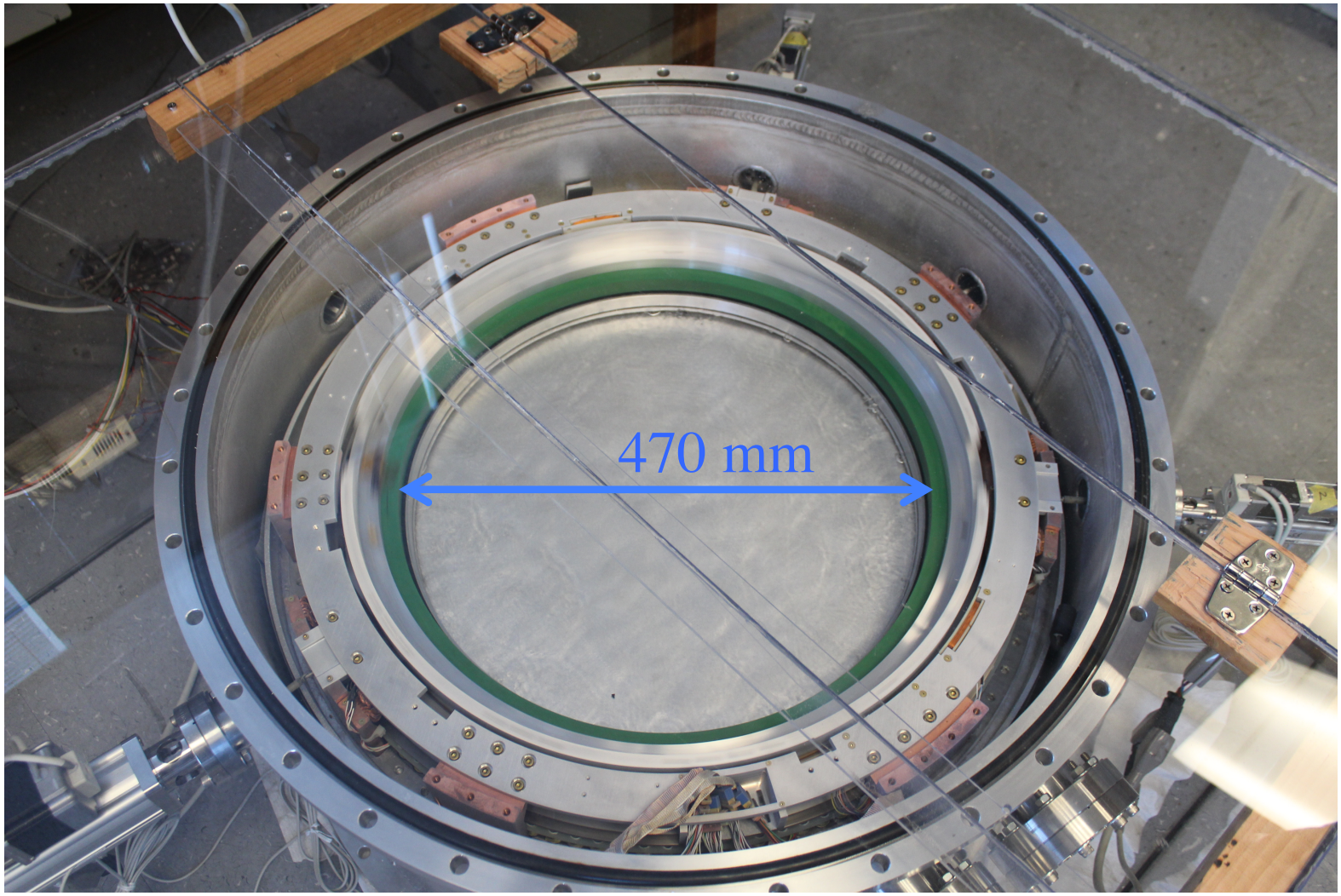


- Vacuum feedthrough actuator
- G10 isolation
- 50 K Frelon bearing
- Copper contact finger with slip-ring contact for stationary thermometry

PB2 CHWP implementation



PB2 CHWP implementation



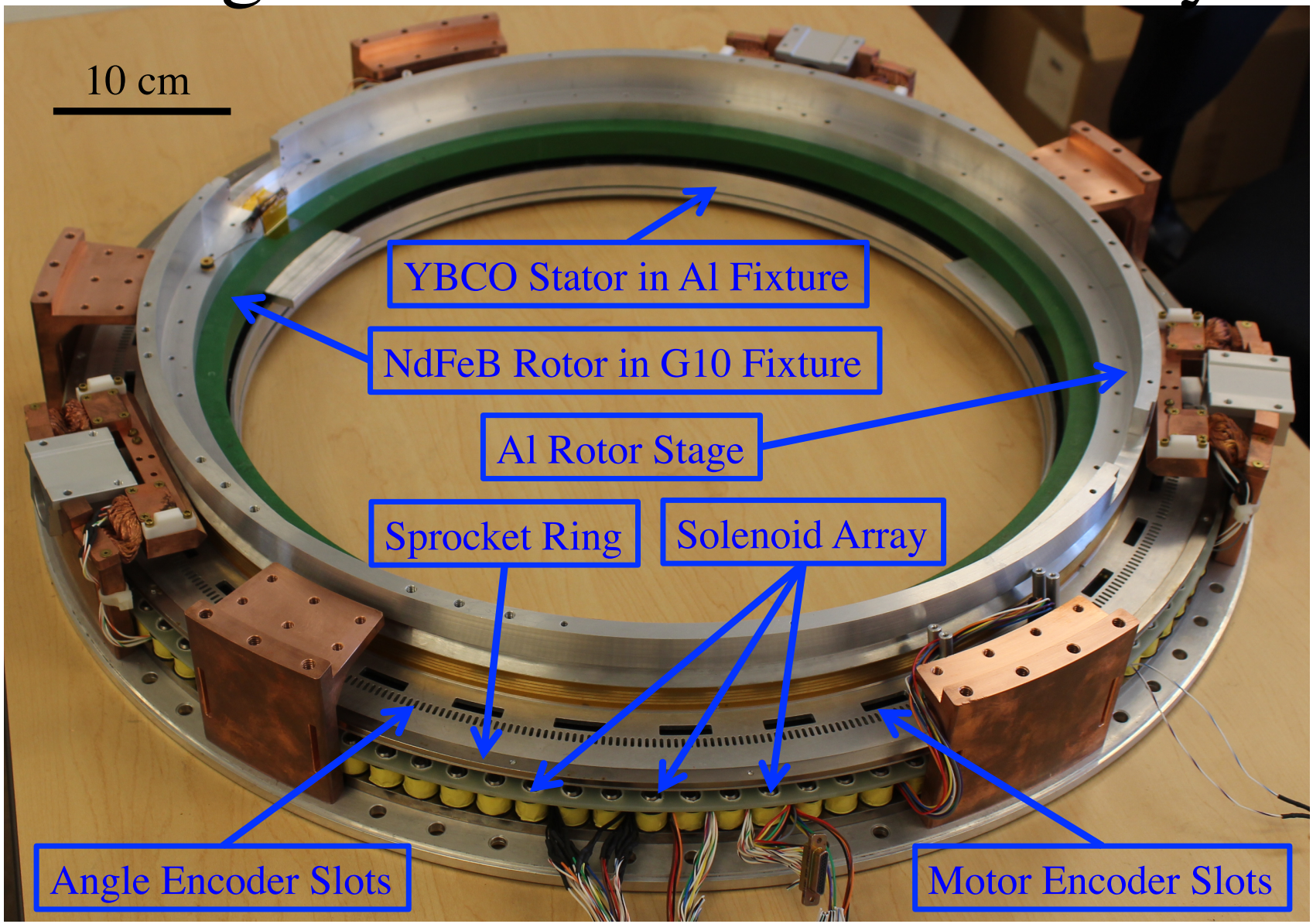
- CHWP system currently under evaluation at LBNL

PB2 vs LiteBIRD CHWP

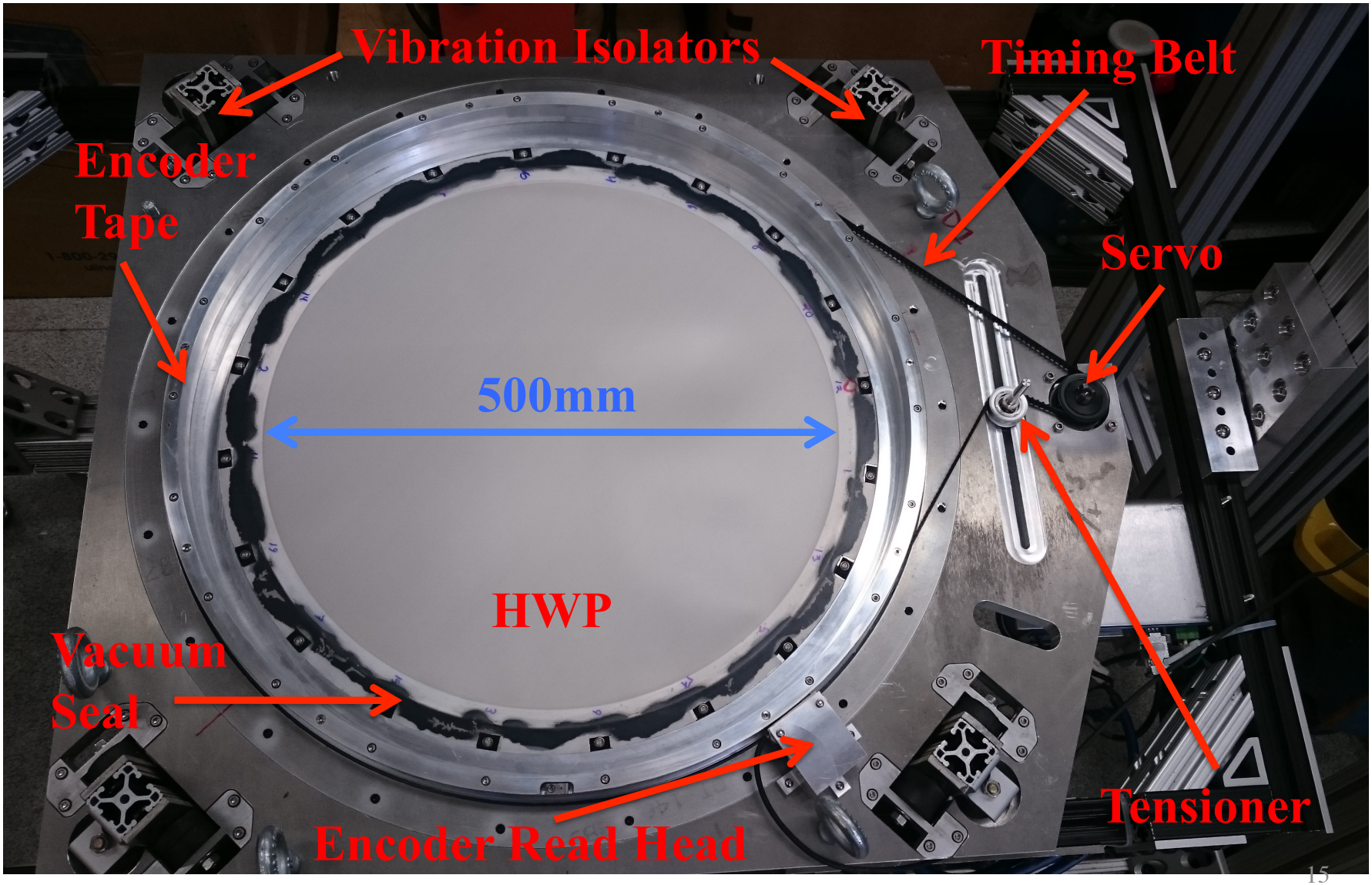
PB2	LiteBIRD
Gripper: Linear Actuator	
300 K (ATM ambient)	4 K (L2 ambient)
1e3 Torr (ATM ambient)	1e-10 Torr (L2 ambient)
~3 mm throw (bearing sag at 100 K)	~2 mm throw (bearing sag at 4 K)
50 lb holding force (HWP weight)	> 250 lbs (15g launch RMS, 4~5σ peak force)
Gripper: Compactness	
~12” gripper footprint in radius	~< 6” gripper footprint in radius
Gripper: Robustness	
~10 gripper motions during operation	Many gripper motions possibly needed for periodic cooling
HWP Cooling	
Strapped alumina filter on both sides of the HWP for good radiative cooling	Exposed to environment beyond entry aperture, no controlled radiative coupling
Bandwidth	
2:1 (2 bands, 75 – 165 GHz)	8:1 (12 bands, 35 – 270 GHz)

Backup Slides

Integrated rotor/stator assembly



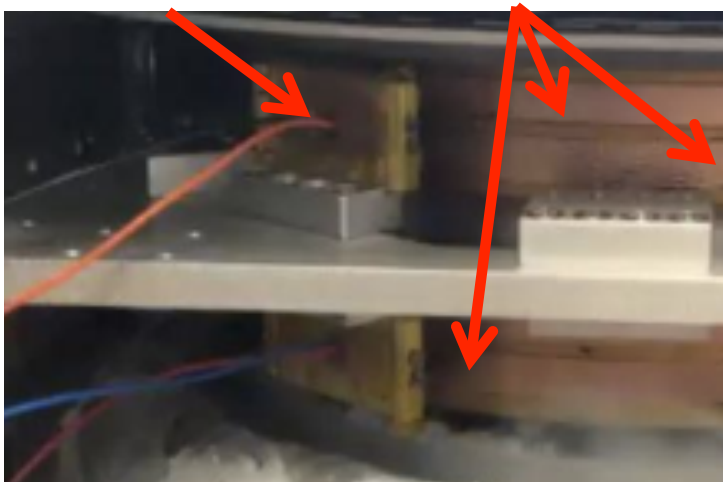
PB2a WHWP


Vibration Isolators
Timing Belt
Encoder Tape
Servo
500mm
HWP
Vacuum Seal
Encoder Read Head
Tensioner

Slip-ring thermometer

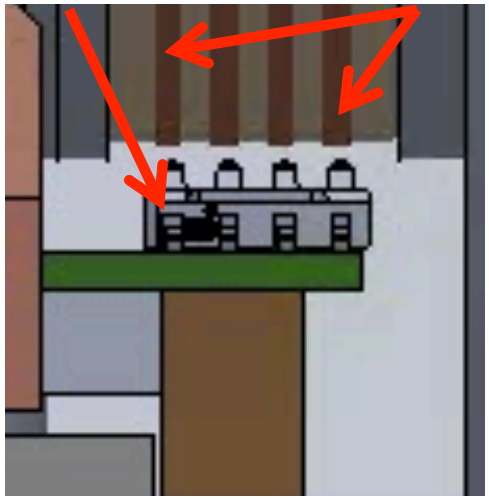
Prototype system

Slip-ring contact Slip-ring traces



Full-scale system

Slip-ring contact Slip-ring traces



- Prototype
  - Measured the temperature of stationary rotor
  - Acted as a switch for the “gripped” mode
  - Designed to lightly touch while rotating
- Full-scale
  - Only designed to measure stationary
  - Will rely on remote thermometry for floating measurement