A Cryogenic Half Wave Plate Rotator for the Simons Observatory Small Aperture Telescopes

Peter Ashton
UC Berkeley / LBNL / Kavli IPMU
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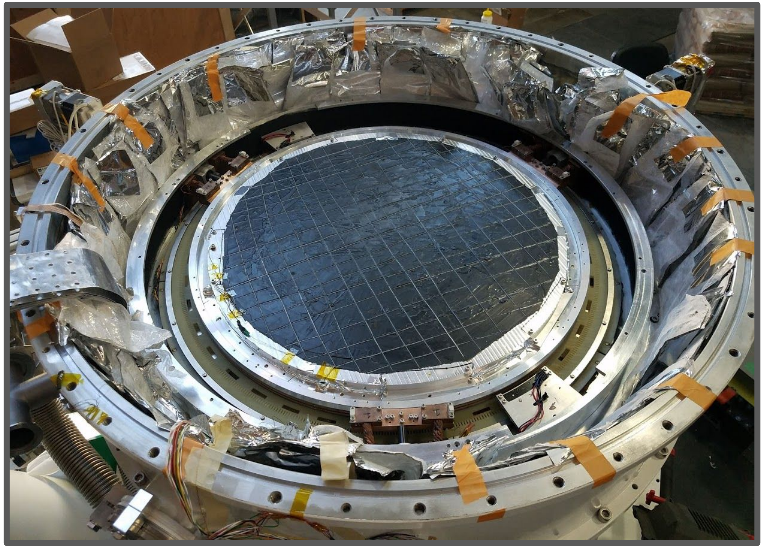
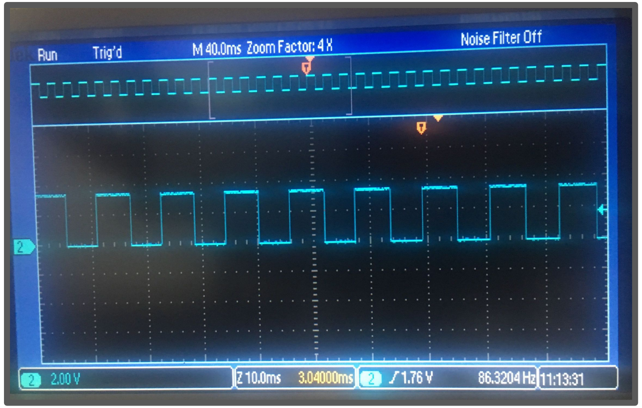
One-Minute Summary

- Simons Observatory Small Aperture Telescopes (SATs) will use a rapidly rotating cryogenic half wave plate rotator (CHWP) in order to control systematics and reduce 1/f noise.
- We use a superconducting magnetic levitation bearing, which is the largest diameter such bearing used in a telescope to date.
- Here we describe in detail the design of the CHWP and some initial characterization.
- We achieve 2 Hz rotation on the ~50 K stage with nominal power dissipation.
- CHWP will deploy with SAT-1 to Chile in 2021!

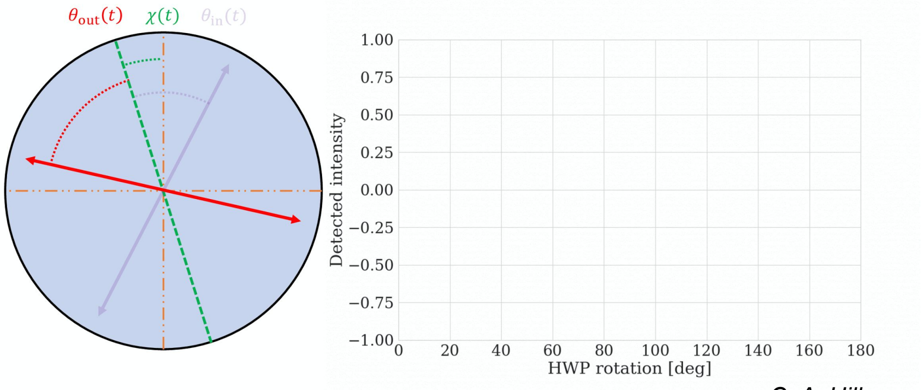




Overview

- Intro to half wave plates
- SO SAT Cryogenic half wave plate rotator (CHWP) design
- Initial testing
- Lessons learned
- Conclusions and future work

Intro to Half Wave Plates (HWPs)



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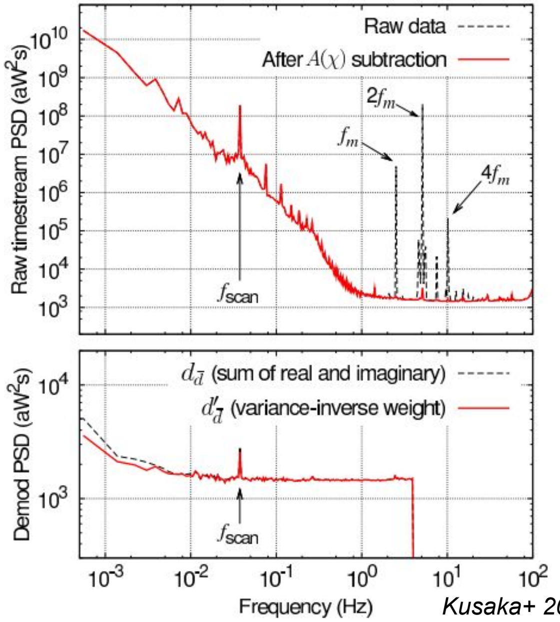
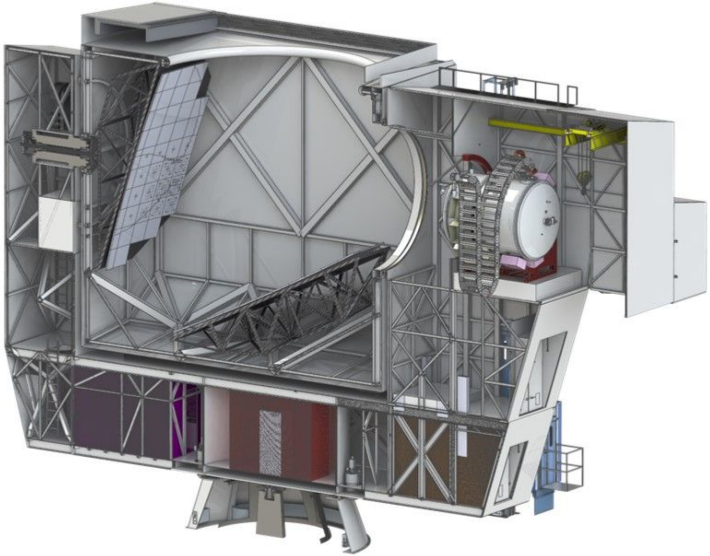


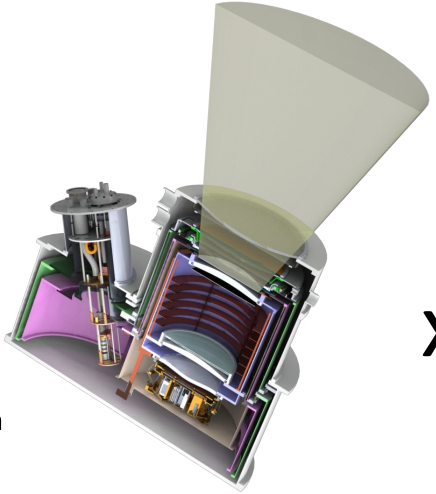
Kusaka+ 2014

- A HWP has different indices of refraction along perpendicular axes, so that the polarization angle of transmitted light is rotated.
- Rotating a HWP at frequency f produces a modulated polarization signal at 4f.

- Experience from ABS (and others) shows how polarization signal can be demodulated to mitigate 1/f noise.
- For ground-based telescopes like SO, 1/f is primarily due to unpolarized atmospheric fluctuations.

The Simons Observatory





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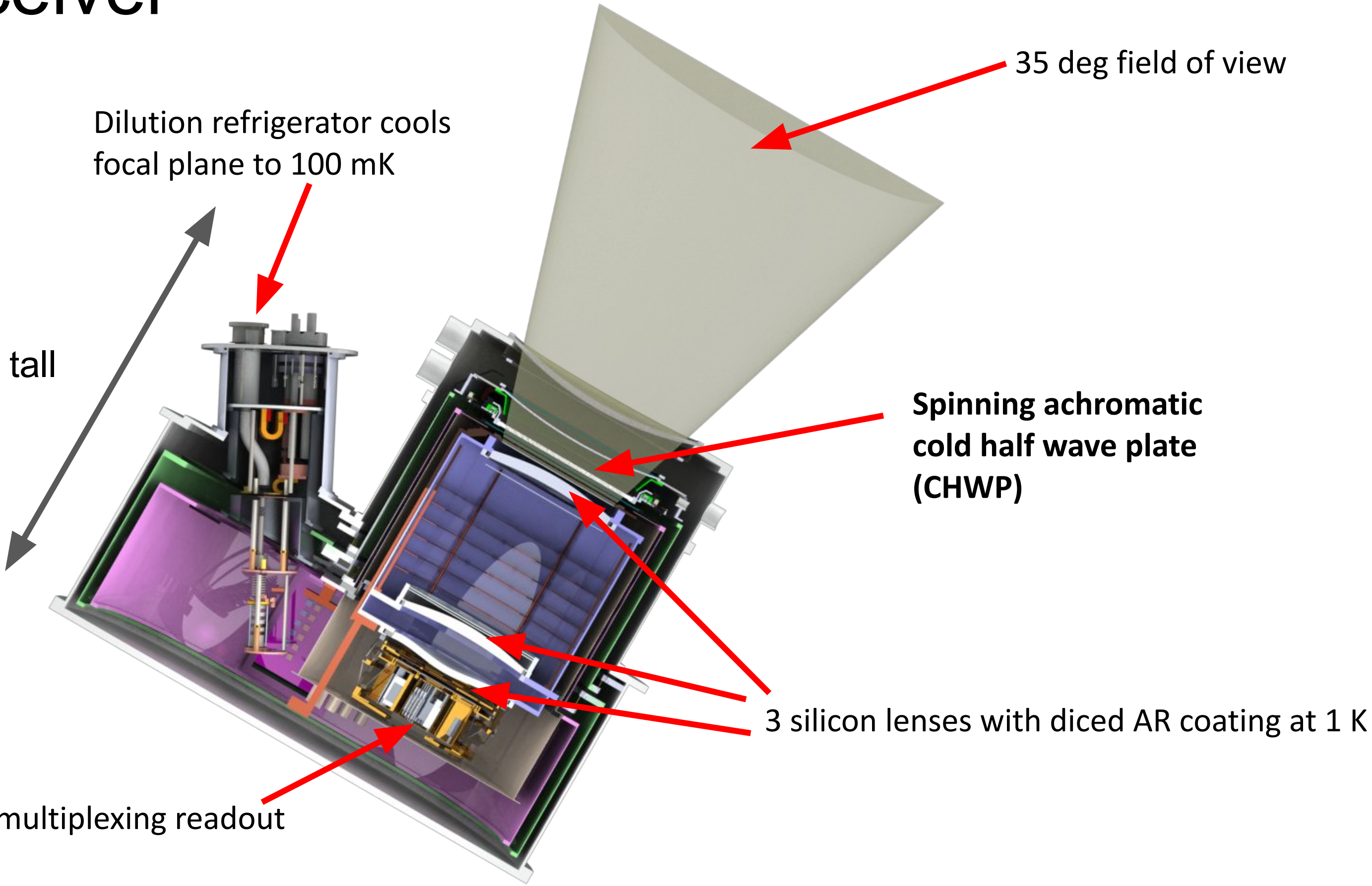
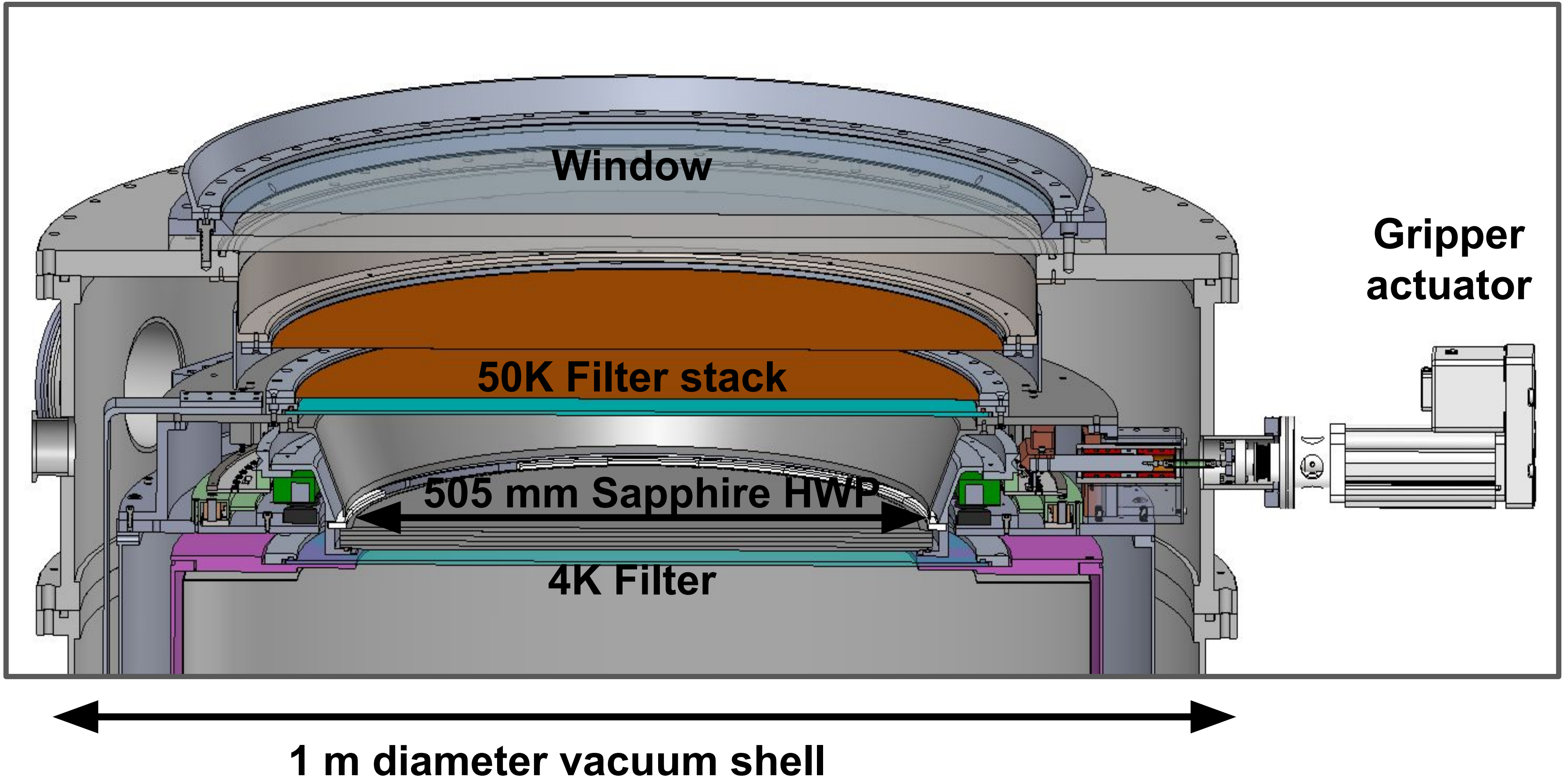
- 5200 m elevation site in the Atacama Desert, near ACT, CLASS, and Simons Array.
- 1 large aperture telescope (6 m primary) + 3 small aperture telescopes (42 cm stop)
- SAT has 0.5° resolution at 90 GHz, especially targeting primordial B-mode polarization

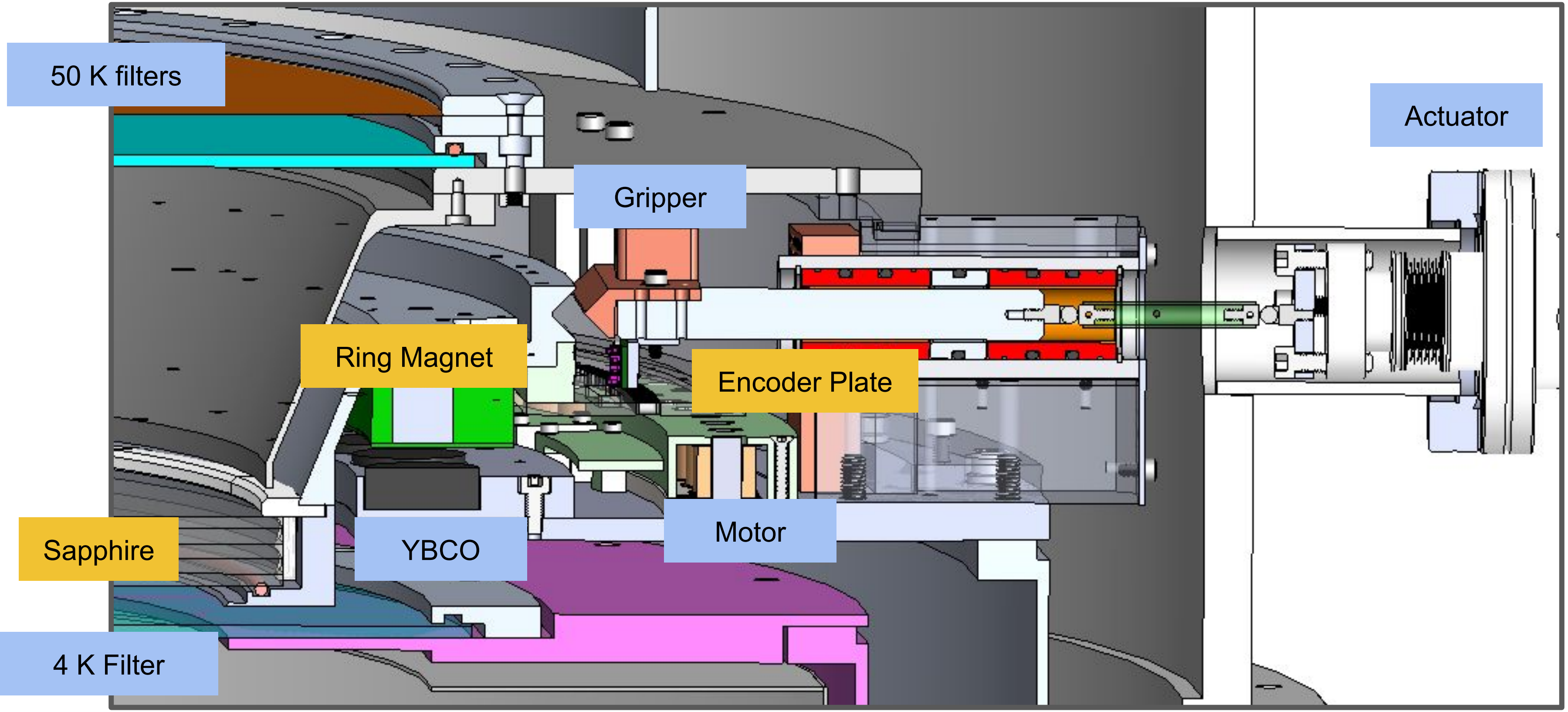
The SAT Receiver



The SAT Receiver Front End



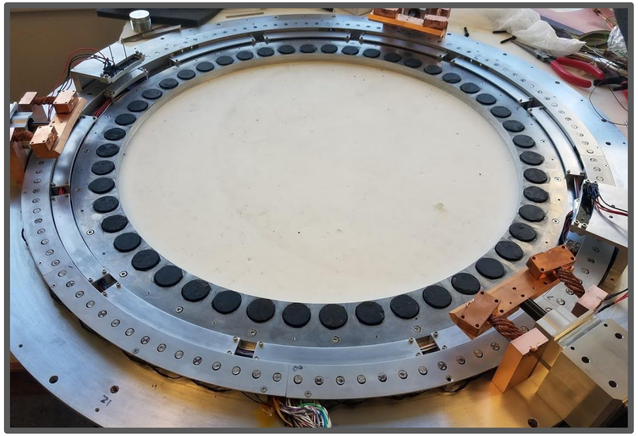
CHWP Assembly



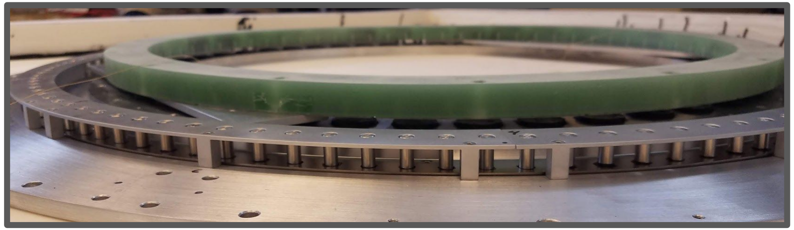
Rotor and Stator parts. In normal operating mode, the CHWP spins continuously at ~2 Hz on a high-T_c maglev bearing, carrying 3 slabs of 505 mm diameter sapphire to modulate sky polarization at 90 &150 GHz.

Detail: Magnetic Levitation Bearing

- Ring magnet on rotor is azimuthally symmetric NdFeB.
- Series of yttrium barium copper oxide (YBCO) tiles on stator has transition temperature ~90 K.
- Below this temperature, magnetic flux is trapped in vortices, and rotor is free to rotate but locked in other degrees of freedom.
- Effective bearing spring constant measured to be > 10^3 N/mm
- Largest diameter (550 mm) maglev bearing used in a telescope to date!

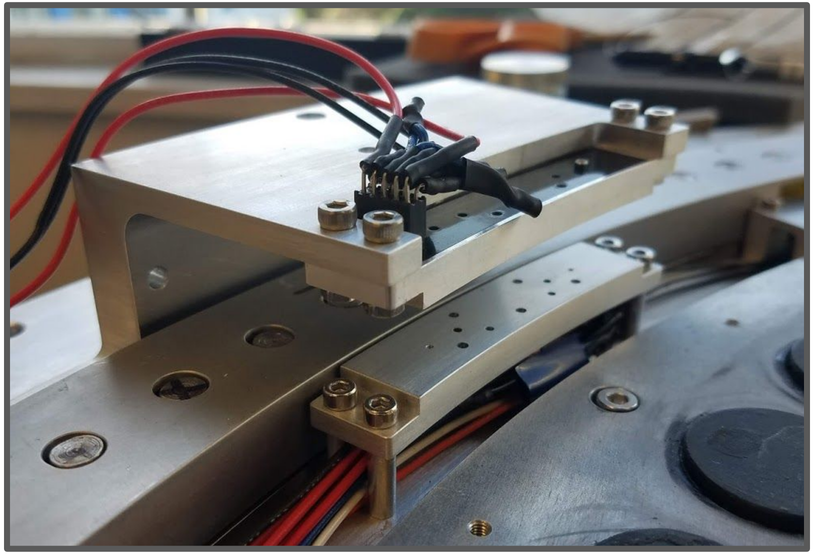


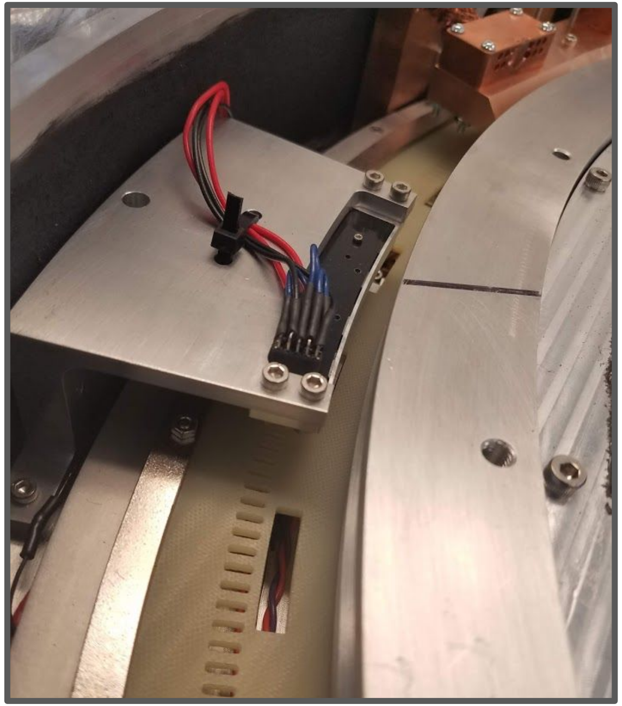
YBCO tiles



Ring magnet

Detail: Encoder

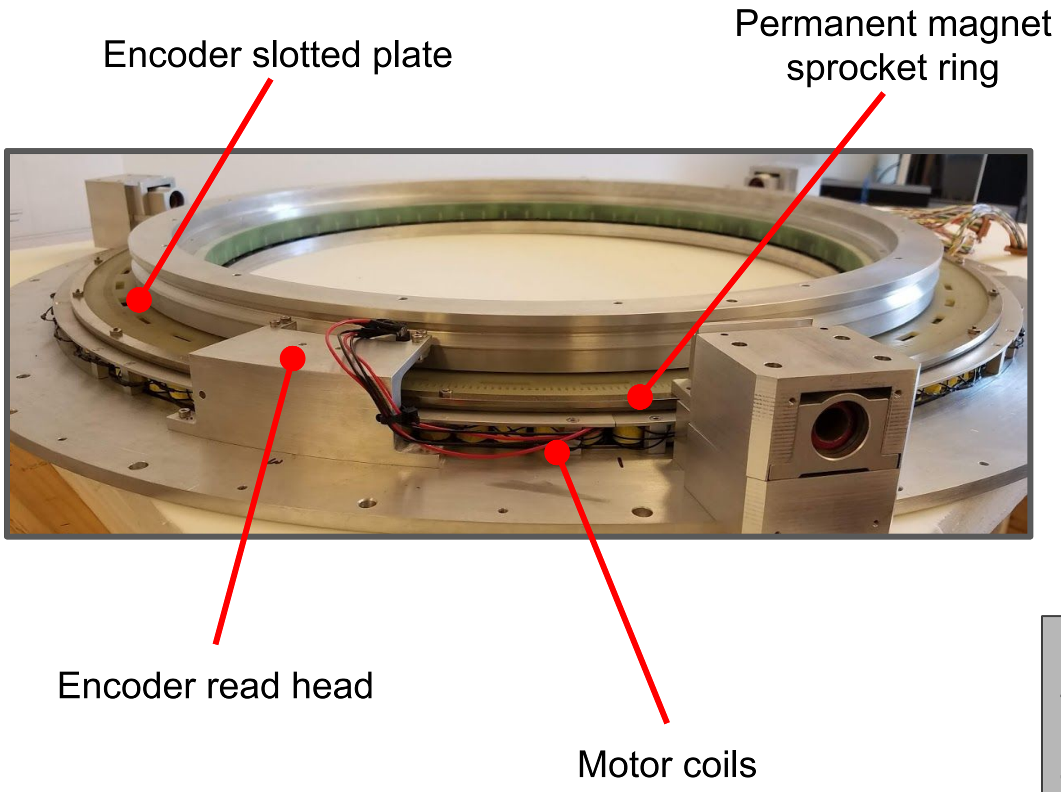


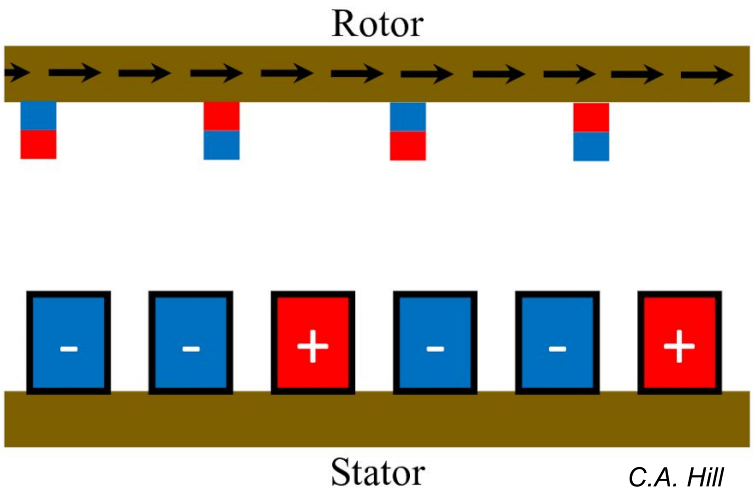


5 LED/photodiode pairs per read head with 2 redundant read heads:

- 2 pairs on “fine” slits provide quadrature encoder angle readout for demodulation
- 3 pairs on “coarse” slits aligned with motor coils generate synchronous motor signal.

Detail: Motor Drive





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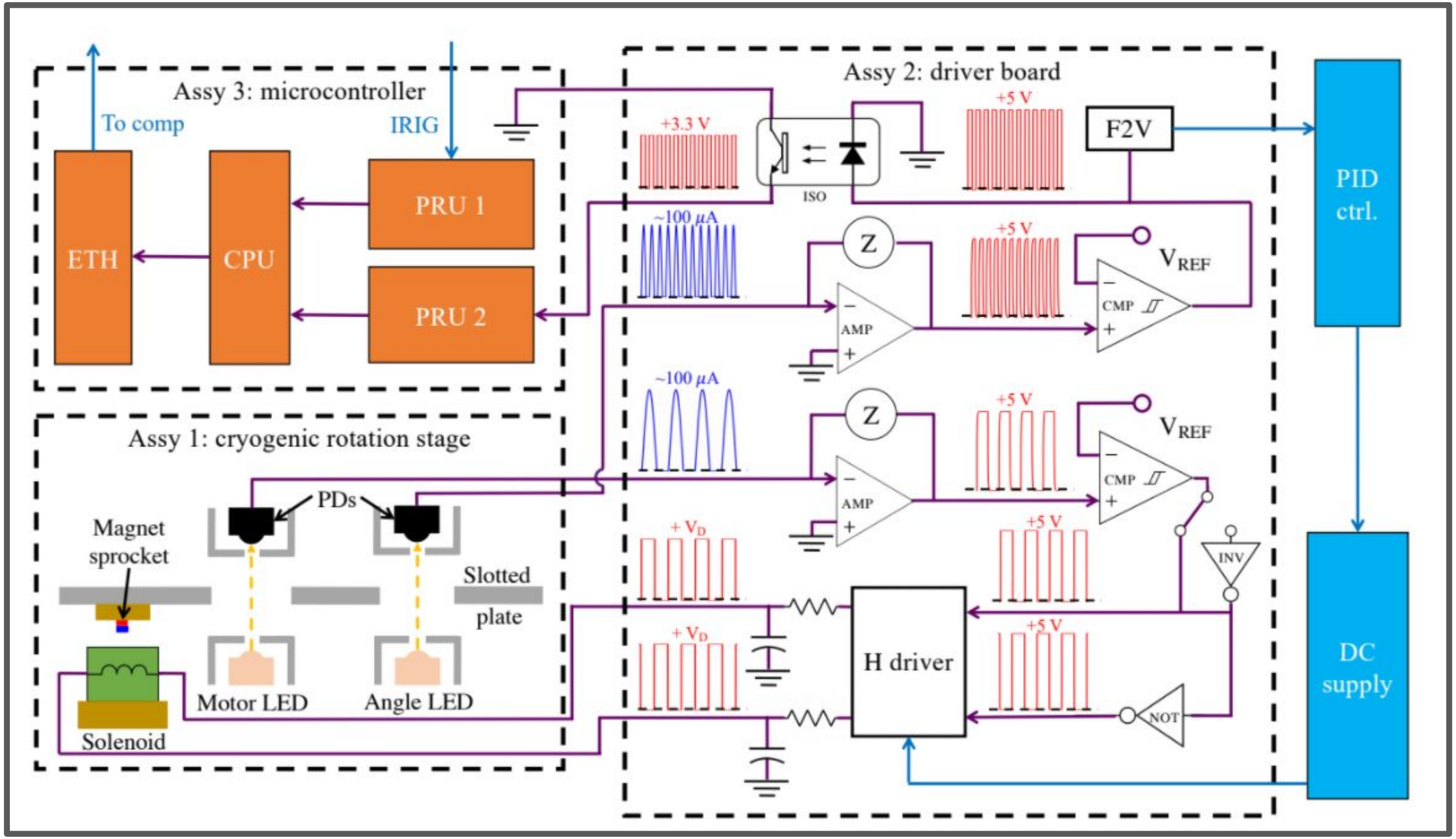
120 coils total, arranged in 3 phases, apply torque to permanent magnets on rotor rim.

Terminal speed is determined by varying the coil bias voltage.

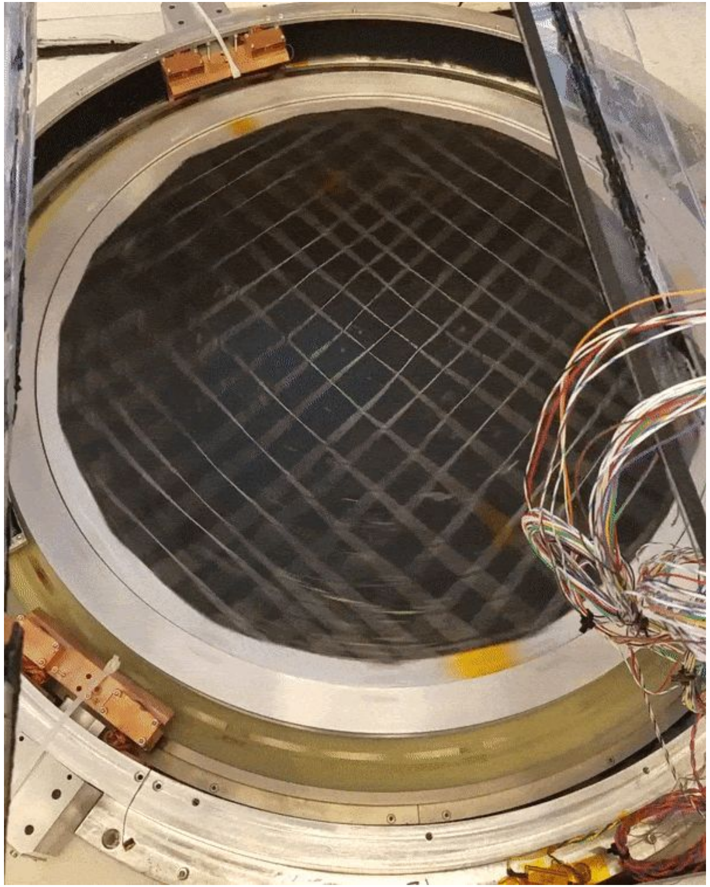
Custom Drive Electronics



Hill+, 2020

CHWP Benchtop Test in Liquid Nitrogen

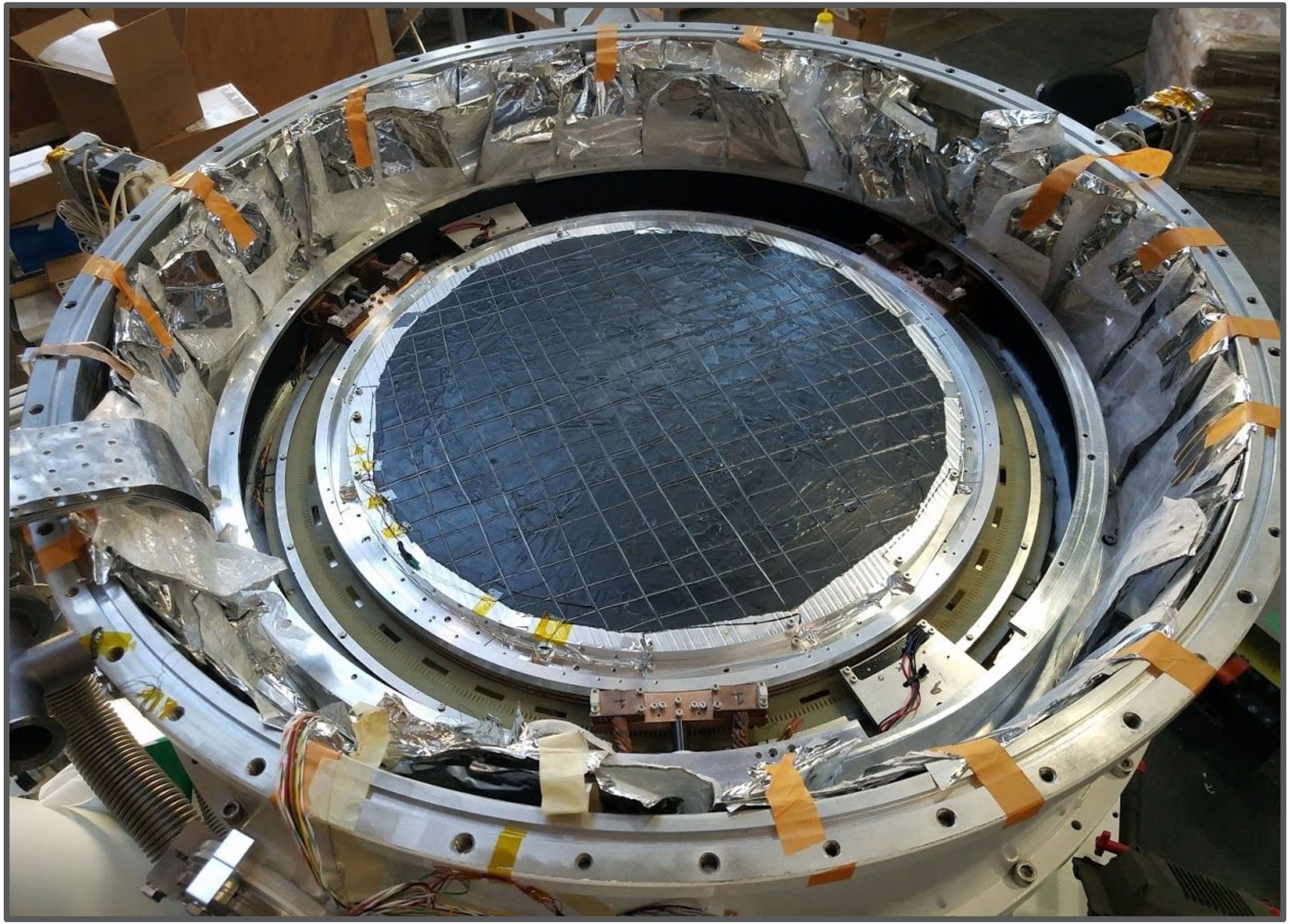
Encoder output is high SNR, square waveforms



Spin at ~1 Hz, limited by atmosphere in benchtop test.

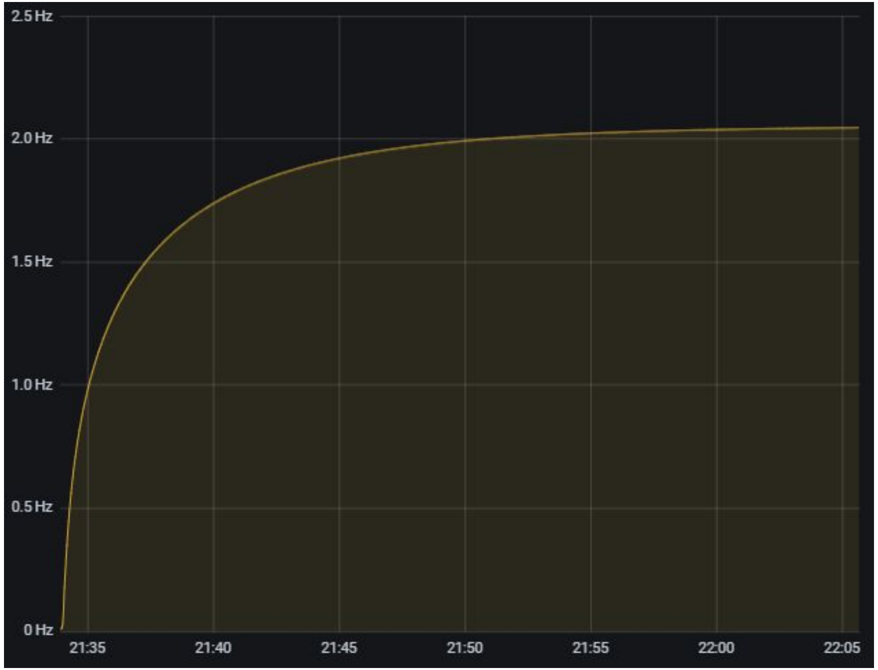
Nominal spin in cryostat is >2x faster.

IR-black mass proxy in place of sapphire stack



Integrated in SAT-1 Receiver 11 March 2020!

Sample Spin Data



30 minutes following a spinup to > 2 Hz rotation.

Spindown from 2 Hz over ~20 minutes.

Data shown is spinning in open-loop mode. Speed regulation with PID control will be implemented in next run.

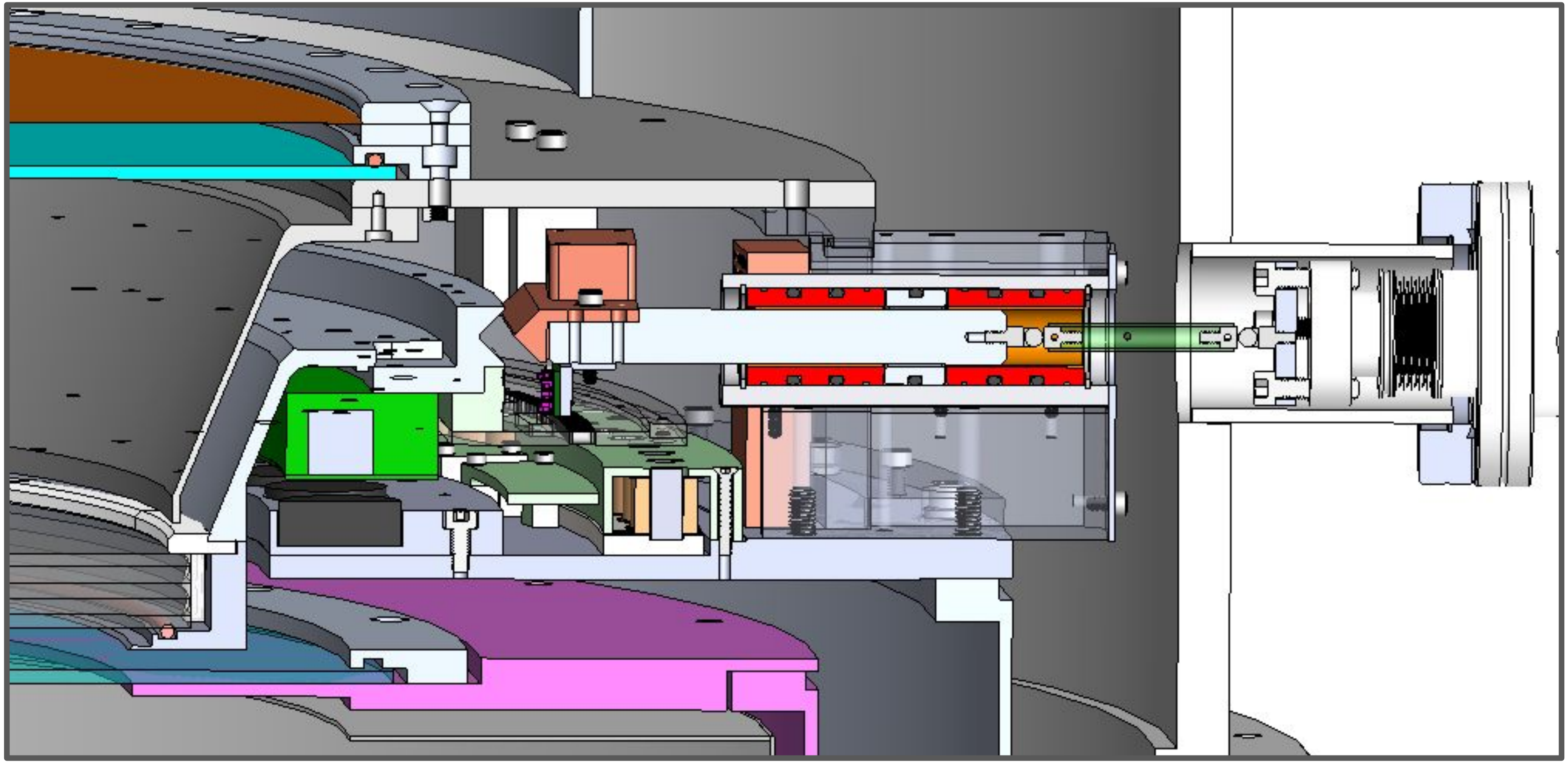
Lessons from CHWP Development

- Heat-sinking solenoids is important
  - With weakly-sunk coils, temperature drifts up with spin time => coil resistance drifts up with temperature => more power required to reach the same spin speed.
  - Easily fixed with a little stycast epoxy.
- Eddy current effects can be limiting.
  - Initially found higher friction than expected when compared with PB2b CHWP performance.
  - Replacing aluminum coil covers with lower electrical conductivity G10 improved performance significantly due to reduced eddy currents from sprocket magnets.
  - Investigating replacing more metal parts with low-conductivity materials for subsequent SATs.
- Rotor thermal time constant is extremely long.
  - Good news! Testing with a heater and thermometer tethered to the floating rotor show a time constant for temperature change O(30 hrs).
  - Expect a small temperature bump (~few K) but very stable overall.
  - Will have improved temperature monitoring for future runs and subsequent SATs.

Conclusions & Future Work

- We have developed a cryogenic half wave plate rotator for use in the Simons Observatory SATs, and here we present the details of that design.
- CHWP was integrated with SAT-1 receiver and testing is ongoing.
- So far performance is nominal, but we we will continue to characterize:
    - Thermal effects on all cryogenic stages
    - Any potential 4f pickup at focal plane
    - Polarization properties of sapphire stack in optical tests.
- Future development: contactless monitoring of rotor temperature and position (see work by Kyohei Yamada).
- A paper with full detail is forthcoming next year.

Credit to SO HWP Team!
Akito Kusaka
Bryce Bixler
Charlie Hill
Yuki Sakurai
Kyohei Yamada



Thank you!