The Half Wave Plate Rotator for the BLAST-TNG Balloon-borne Telescope

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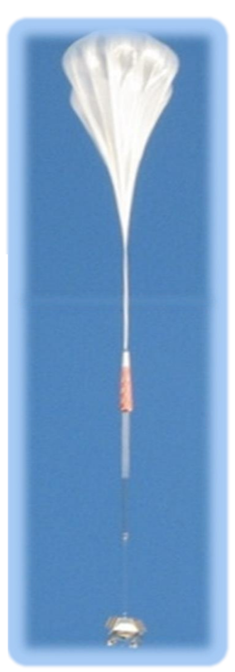
BLAST Collaboration and the BLAST-TNG Telescope[1]

- BLAST (**B**alloon-borne **L**arge **A**perture **S**ubmillimeter **T**elescope) is an international collaboration studying the roles of magnetic fields in star formation processes by observing polarized light from molecular clouds.
- The group has successfully launched two telescopes from Antarctica: *BLAST* (2005, 2006) and *BLAST-Pol* (2010, 2012).
- **BLAST-TNG ("The Next Generation")** is currently in-development and testing in preparation for a 2016 launch.


BLAST-Pol in flight
Image by: BLAST Group

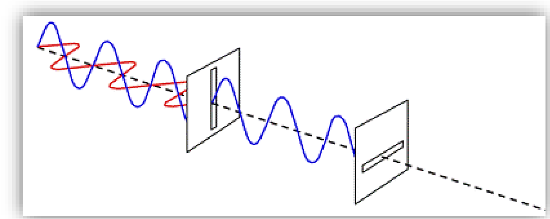
- The telescope will capture **light with submillimeter wavelengths** (250, 350, and 500 µm).
- The telescope has **polarization capability**, using a rotating Half Wave Plate (HWP) and polarization-sensitive detectors.
- The light we are seeking to observe is **blocked by Earth's atmospheric water vapor**. The telescope's *float altitude is above 99.5% of the Earth's atmosphere.*

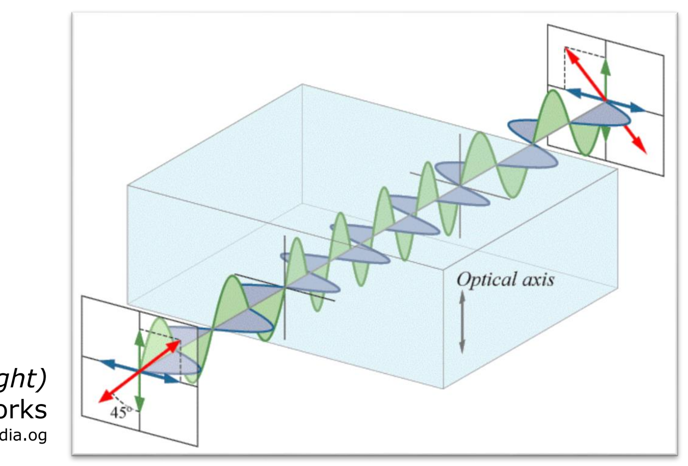
BALLOON-BORNE LARGE APERTURE SUBMILLIMETER TELESCOPE · THE NEXT GENERATION · BLAST-TNG


(left)
The BLAST-TNG
Image by: BLAST Group

Polarimetry Method and the Half Wave Plate Rotator (HWPr)

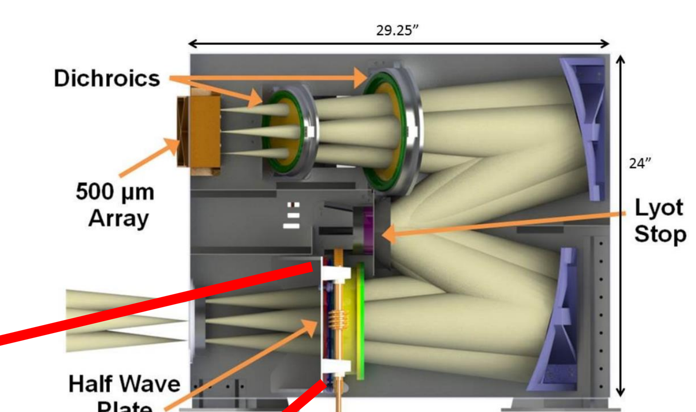
- Polarization states of the incoming light waves will be measured. The detectors at the end of the path have 4 different configurations: $\oplus\otimes$. HWP will be rotated in four 22.5^0 steps using a HWP rotator (HWPr).

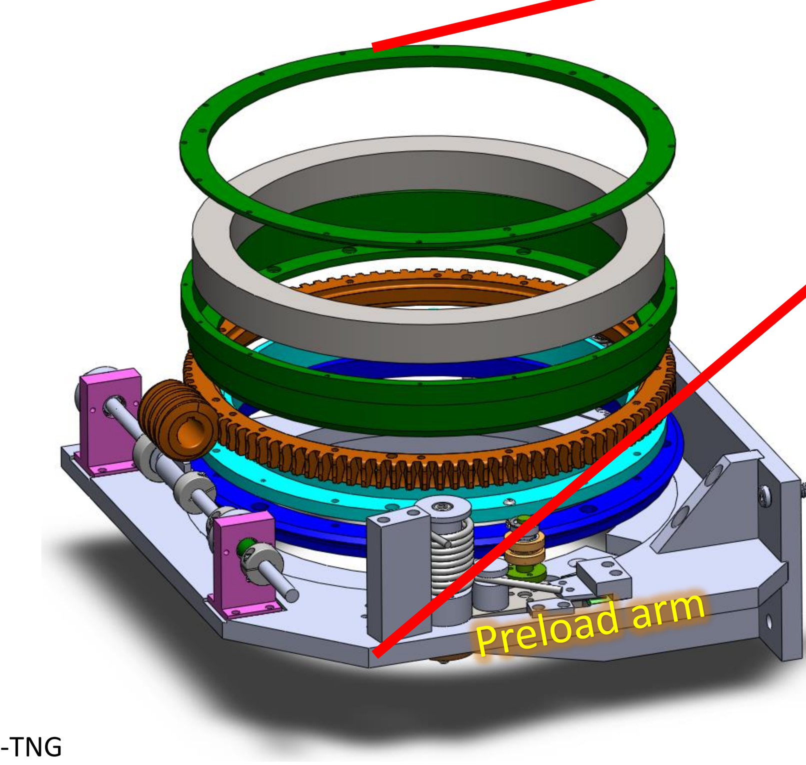

(above)
Illustration of how polarization filter works
Image by: resourcefulphysics.org

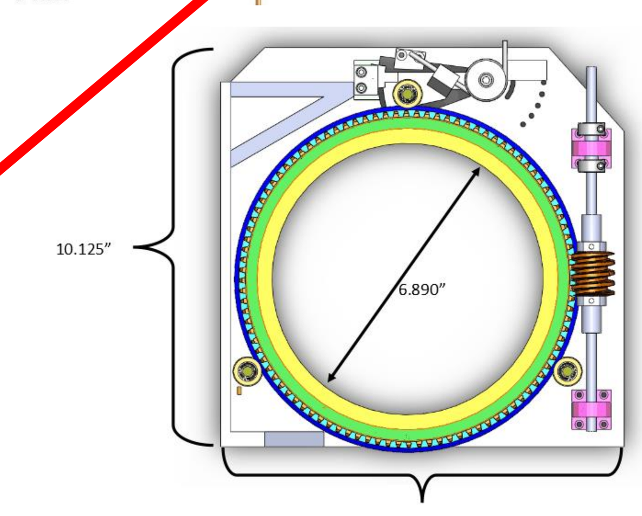


(right)
Illustration of how HWP works
Image by: Wikipedia.og

- The **differences in signal power** in different detectors will *determine* the polarization angle. Data from different HWPr angles will be compared to *minimize systematic errors.*
- The HWPr will be *mounted inside* BLAST-TNG **optic box.**
- The HWPr consists of several parts and mechanisms, as shown in this **exploded view**:





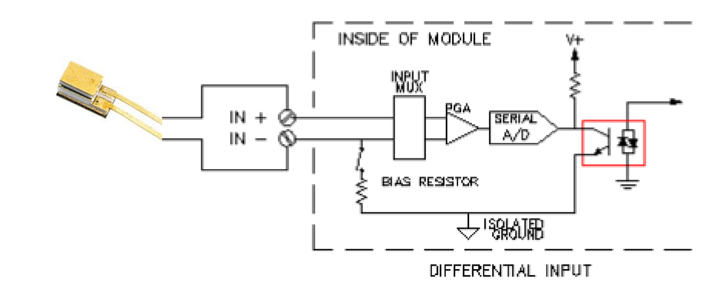


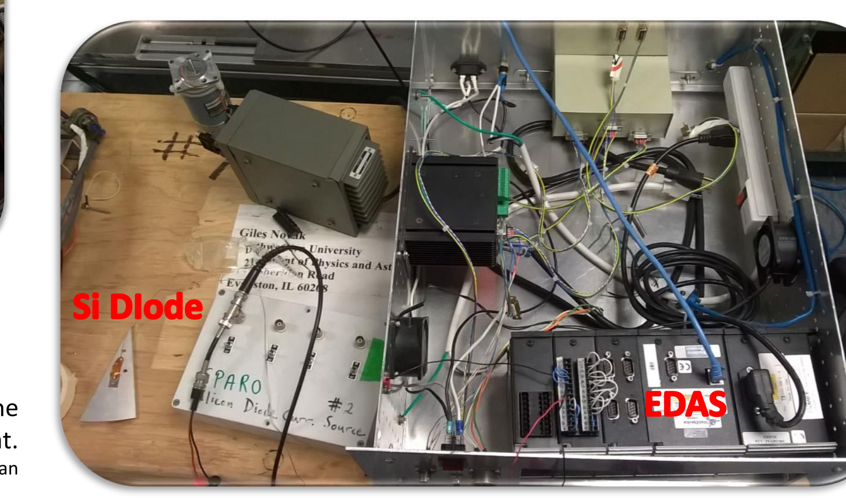
(left)
The exploded view of the current design of the Half Wave Plate rotator (HWPr).
(above)
The Optics box of BLAST-TNG and HWPr dimension
Images by: BLAST group [1]

HWPr Cold Testing

- To reduce noise in data, HWPr will **operate at 4 K** to **avoid internal thermal radiation.**
- Thus, a **cold-test is necessary** to make sure that *thermal contraction*, due to the low temperature, will **not** affect the functionality of HWPr.
- We used **liquid Nitrogen and Helium** to reduce the temperature.


BLAST-TNG Cryostat
Image by: BLAST Group

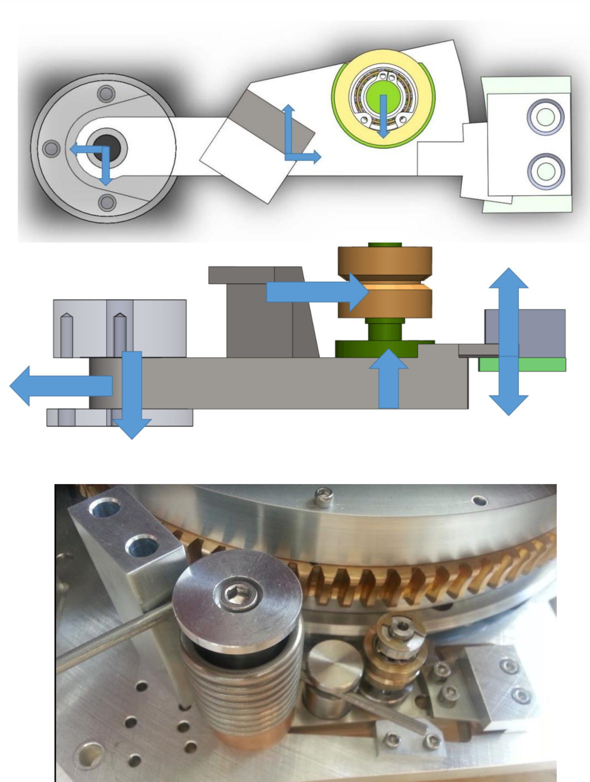




Electronics set-up to test the temperature inside cryostat.
Image by: H. Setiawan

- We designed a system to test the HWPR independently, adapting the SPARO cryostat and reading out thermometry with the EDAS-CE.
- The EDAS-CE **reads** in analog voltage signal, **digitizes** it, **calculates** the temperature associated with the voltage, and allows user to **access** the data remotely.
- The test results were **positive**: As it reaches 77 K and 4 K, the HWPr still turns and functions properly.

HWPr Torque and Friction Calculations

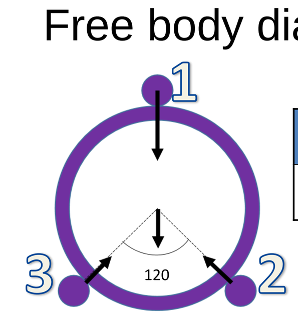

Preload arm of HWPr. *Images by: BLAST Group*

Preload Arm friction

- One ball bearing is attached to a *spring loaded* pivoting 'preload arm' to account for thermal contraction.
- The friction between the ball bearing and the geared rotor changes as the position of the spring is changed.
- The friction is accommodated by having sufficient input torque applied (next calculations).

Torque and Gear friction

Free body diagram of the gear ring (pointing horizon):

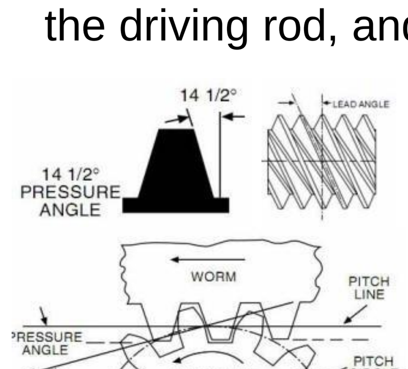


Bearing 1 [N]	Bearing 2 [N]	Bearing 3 [N]	Total Friction [N]
40	71.1	71.1	3.64

$$F_f = \mu \sum F_n = 3.64\ N$$

Calculation assumes rolling friction of 0.02 (manufacturer value)

The relationship between input torque (M_1), applied to the driving rod, and output torque (M_2) in a worm gear:



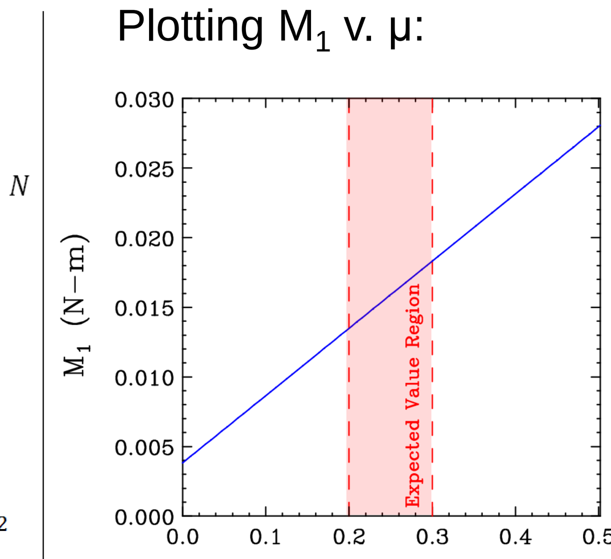
$$f(\mu) = \left[\left(\frac{d_2}{d_1}\right)\left(\frac{\cos(\alpha)\cos(\gamma) - \mu\sin(\gamma)}{\cos(\alpha)\cos(\gamma) + \mu\cos(\gamma)}\right)\right]^{-1} \qquad M_1 = f(\mu)M_2$$

$$M_2 = F_f\frac{d_2}{2} = 3.64\ N * \left(\frac{0.2117}{2}\right)m = 54.6\ N.m$$

Where:

- d_1 = worm pitch diameter = 0.0254 m
- d_2 = worm gear pitch diameter = 0.2117 m
- α = pressure angle = 14.5^0
- γ = lead angle = 4.77^0
- µ = friction coefficient between worm and gear

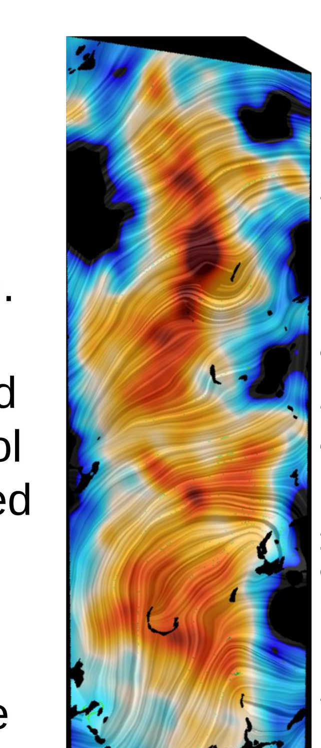
Plotting M_1 v. µ:



- M_1 increases linearly as µ increases, which is expected.
- Friction coefficient may change with temperature, causing uncertainty in the exact values. It also depends on the material (Phosphor Bronze).
- Based on some preliminary tests and references, the expected and realistic value is about 0.25 ± 0.05.
- Test results have been positive. The HWPr still functions properly at low temperature.

Next Steps

- The HWP from Cardiff University (UK) will be installed in HWPr at UPenn.
- The HWPr will be integrated with the BLAST-TNG control system and will be employed for detector tests in coming months.
- BLAST-TNG is on-schedule to launch December 2016.


Inferred magnetic field map of Vela C from BLASTPol 2012
Image by: Dr. Laura Fissel, et al. (2015-submitted to ApJ)

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REFERENCES:

[1] Galitzki, N., et al. [2006] "The next generation BLAST experiment," *Journal of Astronomical Instrumentation* **Vol. 3, Issue 2**, id. 1440001

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