Optical design of the Simons Observatory large telescope and its cold optics

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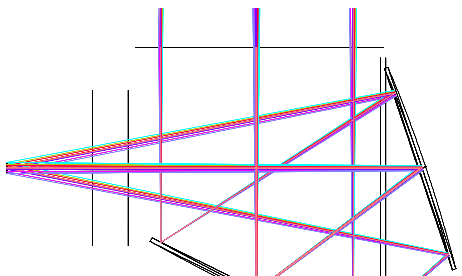
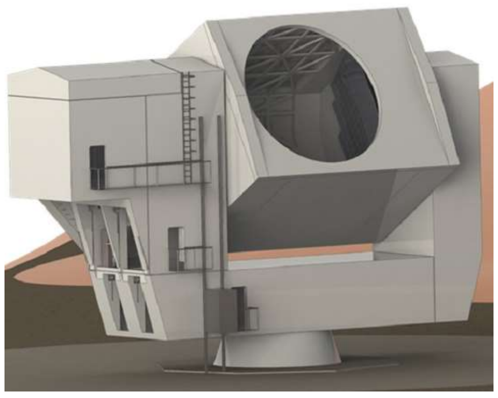
The Simons' Observatory (SO) will consist of one large 6m telescope and three or more smaller telescopes working together with a goal of measuring the polarization in the Cosmic Microwave Background on angular scales from ~1' to larger than 1° at a sensitivity far greater than has ever been reached before. We will place stringent limits on primordial gravitational waves and many other astrophysical phenomena. To reach these sensitivities over 90000 background limited TES detectors on the large telescope are required - hence a large field-of-view is needed. The telescope design we have selected is a copy of the CCAT-prime telescope, a Crossed Dragone with an extra aspheric term to increase the diffraction limited field-of-view. This poster outlines some details of our warm and cold optics.

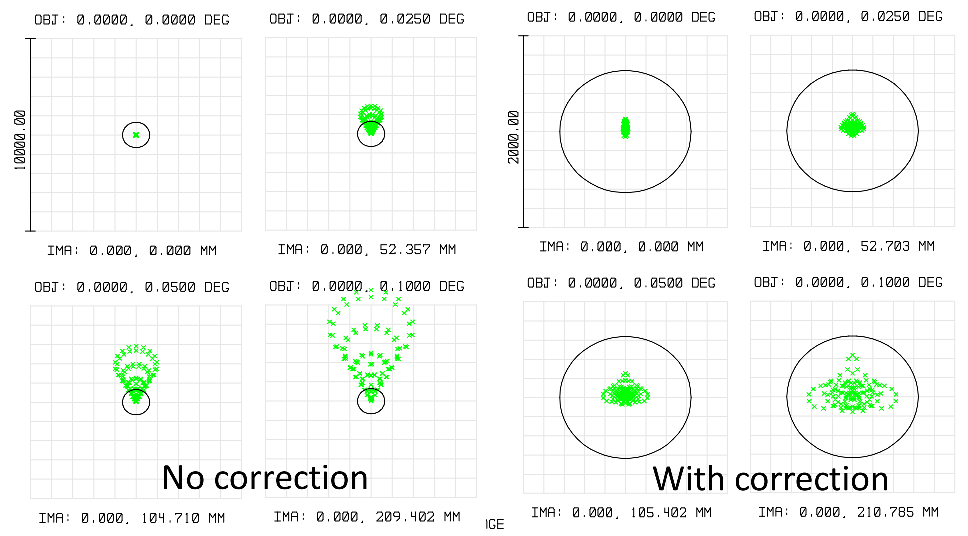
Simons Observatory Large Telescope





- To be located at 5200m elevation on Cerro Toco, Chile.
- Based off a Crossed Dragone telescope design.
- Cancelling x^2 terms are added to the primary and secondary mirrors greatly increasing the field of view by cancelling out coma (similar concept to the on-axis Ritchey–Chrétien telescope)
- Slightly modified copy of CCAT-prime (http://www.ccatobservatory.org and a talk by Dominik Reicher)
- Clear aperture 6m (5.5m used) ; f2.6 at secondary focus; 7.9deg field-of-view.
- 30 GHz to 300 GHz operation.
- Both telescopes are being built be Vertex (http://www.vertexant.com).
- Pro
  - Unblocked aperture – important to lower loading and sidelobes.
  - Compact
  - Easily accessible focal plane, lots of room for instrumentation.
- Con
  - Every mirror panel is different - the mirrors are no longer rotationally symmetric about any axis.

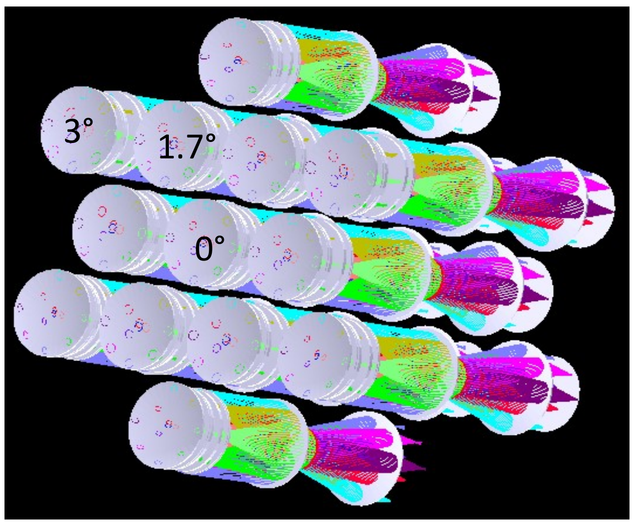
Simons telescope scaling to 50 meters



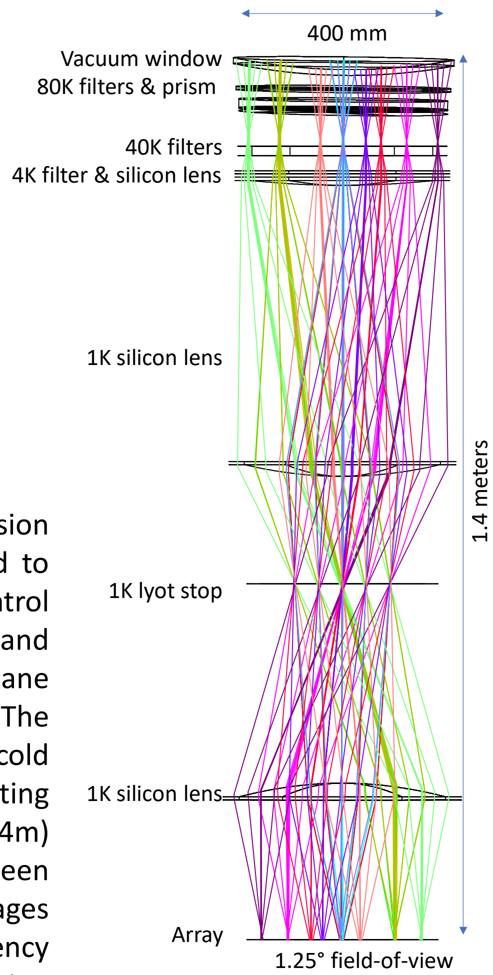
The power of adding the x^2 terms can be seen by comparing the spot diagrams from the classic Crossed Dragone design on the left to an equivalent design with the x^2 terms on the right. The black circles represent the airy disk diameter at 200µm. The table below shows the radius (in angles on the sky and radius on the focal plane) at which the Strehl ratios drop below 90%. The difference in throughput between the two designs is more than a factor of 30. The remaining dominant aberrations after the corrections are added are astigmatism and an increase in the field curvature.

Wavelength	100µm	200µm	1000µm
FOV without correction (half angle & radius)	0.013°	0.025°	0.125°
	26mm	52mm	261mm
FOV with correction (half angle & radius)	0.07°	0.14°	0.45°
	147mm	295mm	950mm

Simons Observatory Cold optical design



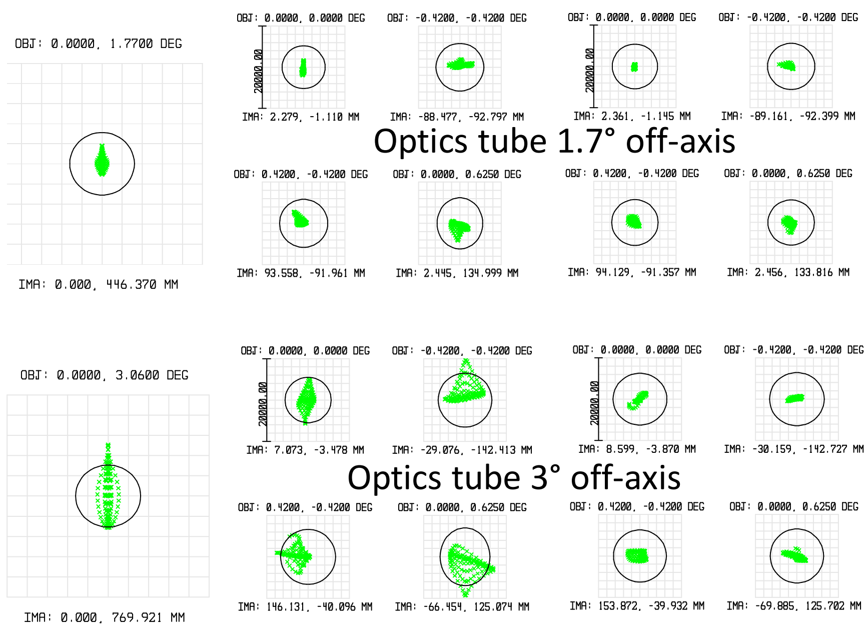
To take advantage of the low atmospheric emission at the SO site our detectors need to be cooled to 0.1K, great care needs to be taken to control scattered light, a cold (1K) Lyot stop is required, and to accommodate the detectors the final focal plane needs to be flat and the beams telecentric. The cryogenic volume required ruled out reflecting cold optics and the practicalities of making cold refracting optics the size of the telescope's focal plane (~2.4m) led us to populate the focal plane with thirteen ~400mm diameter optics tubes (above). Advantages to this modular design include greater frequency flexibility, better image quality (due to less variation in the beam shape at the secondary focus across each tube and the ability to deploy in stages.



The 1.7° off-axis tube

Biconic lenses

At angles over 3° off-axis astigmatism significantly degrades the 150 GHz image quality at the telescope focal plane (left). This is hard to correct using symmetrical lenses (center) but a single biconic surface improves image quality enough to make these tubes usable at 300 GHz (right). For optical tubes 1.7° off-axis biconic lenses are not required (even at 300GHz) however using them does offer some improvements in uniformity across the focal plane. Biconic lenses are harder to manufacture so in our initial deployment they will not be used but they remain a promising development path for the future.



Telescope focus   Final Focus no biconic   Final focus with biconic

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