CCAT-prime: a novel telescope for submillimeter astronomy.

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INTRODUCTION

CCAT-prime is designed to operate in the millimeter to submillimeter (100 GHz to 1.5 THz) range with a 6-meter aperture, 7.8° diameter field of view (FoV) at λ = 3 mm. The telescope supports multiple instruments to cover the different science cases. The requirements include a one half wavefront error (HWFE) of less than 11 μm, a pointing error (PE) of less than 1.4 arcsec, and an emissivity of less than 2.8% for wavelengths longer than 850 μm (350 GHz).

TELESCOPE OVERVIEW

The overall mechanical design is shown below. It is similar to a fork-structure (which we designate the yoke) elevation-over-azimuth mount without a reflector. Instead, the offset optics are contained inside what would normally be the secondary focus cabin, called the elevation housing, which shelters the reflecting surfaces from wind and solar illumination. A shutter closes the opening during periods of inclement weather. Rough overall size is 23 x 8 x 16 meters (L x W x H), with the elevation axis ~11 m above ground. Total weight is over 220 metric tons with ~200 tons moving in AZ and ~60 tons moving in EL.

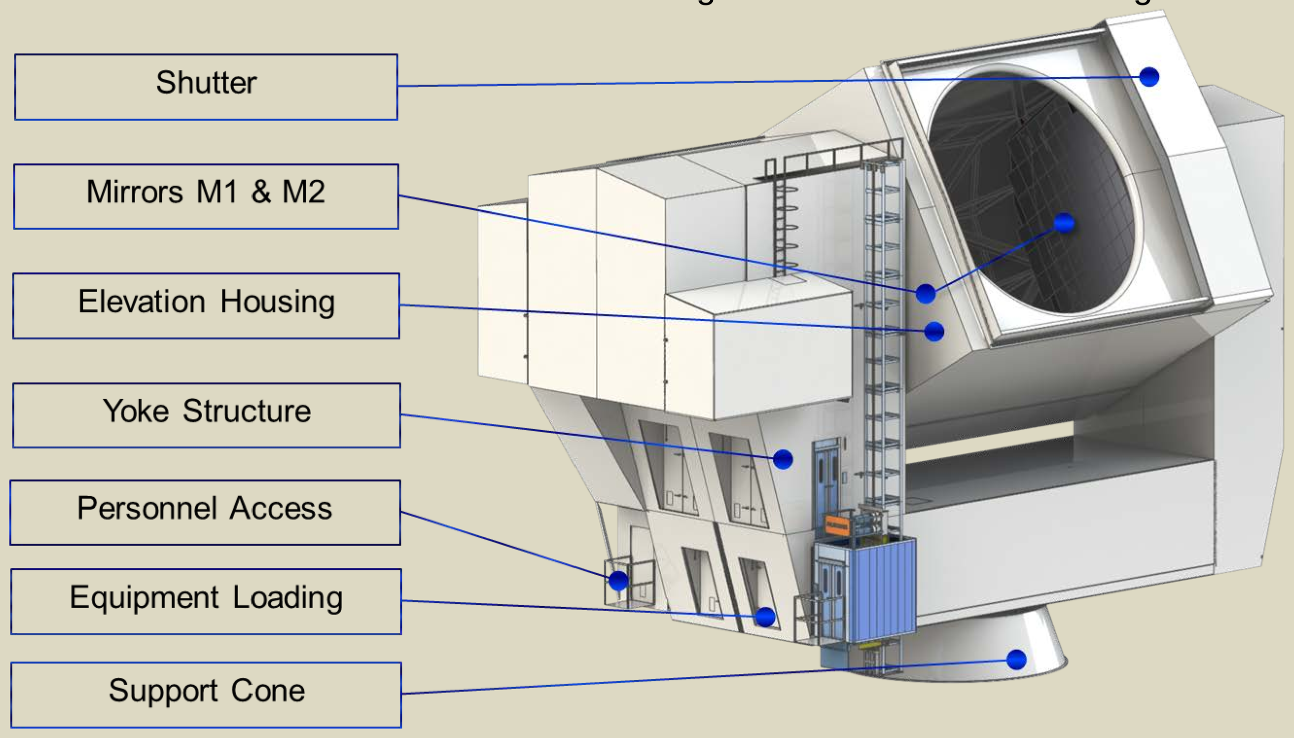


Figure 1. CCAT-prime telescope mechanical design model with major elements labeled. For reference, the opening in the elevation housing is approximately 7 m.

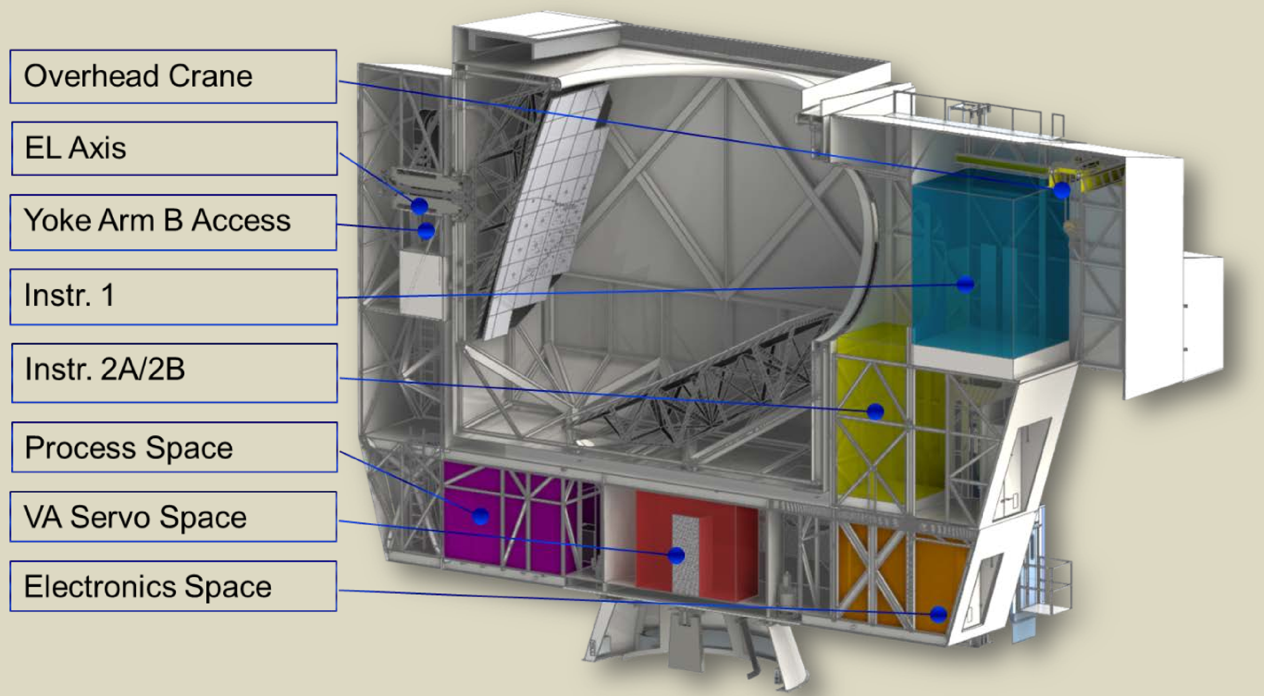


Figure 2. Cross section through the CCAT-prime telescope highlighting science equipment spaces and access.

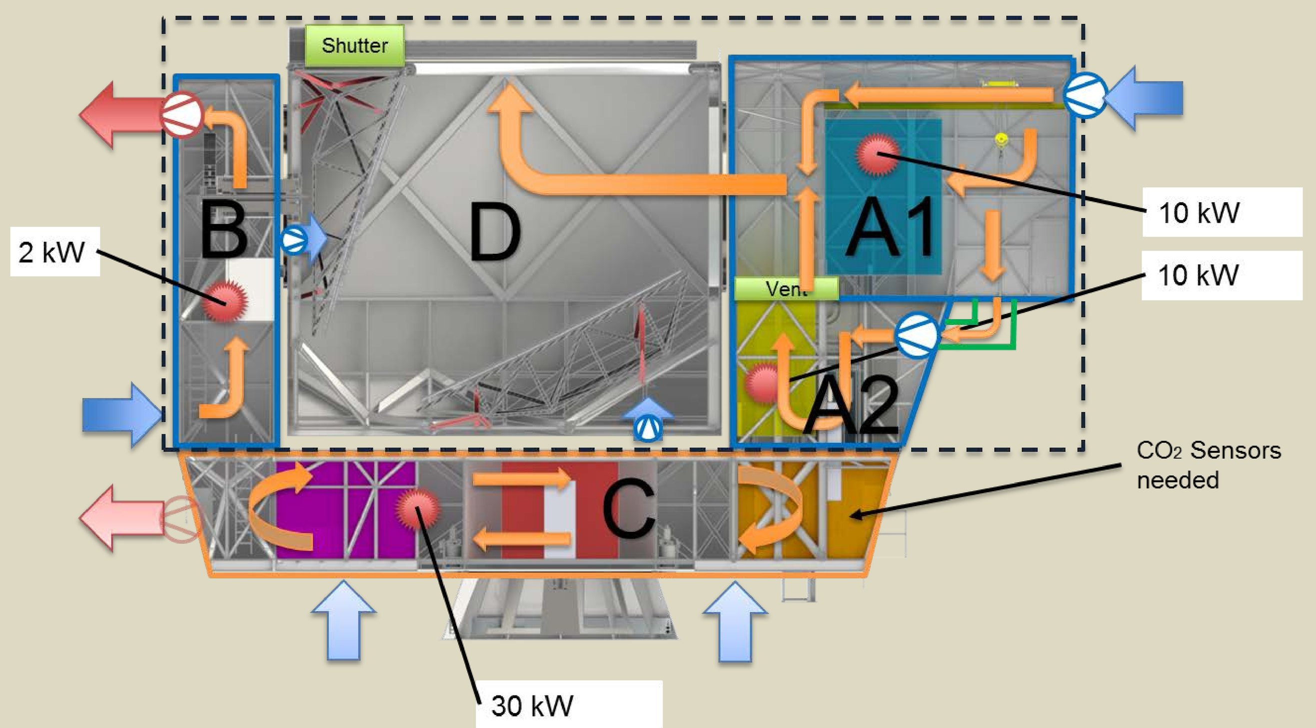
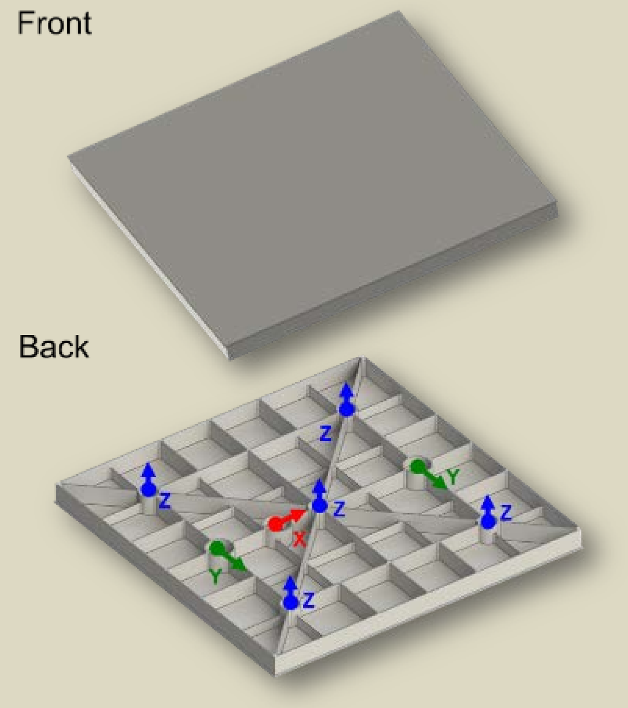


Figure 3. Ventilation concept for CCAT-prime. The yoke traverse is insulated and maintained between 10-20° C while the yoke arms and elevation housing are ventilated to improve temperature uniformity within the structure.

SUBASSEMBLIES AND COMPONENTS

This section details the major components critical to the mechanical structure, starting at the reflecting surfaces and ending at the ground. Each component is optimized individually before being combined into the full telescope model for further total optimization which allows for parallel path development and leads to a good understanding of the sensitivity of the system to design changes.



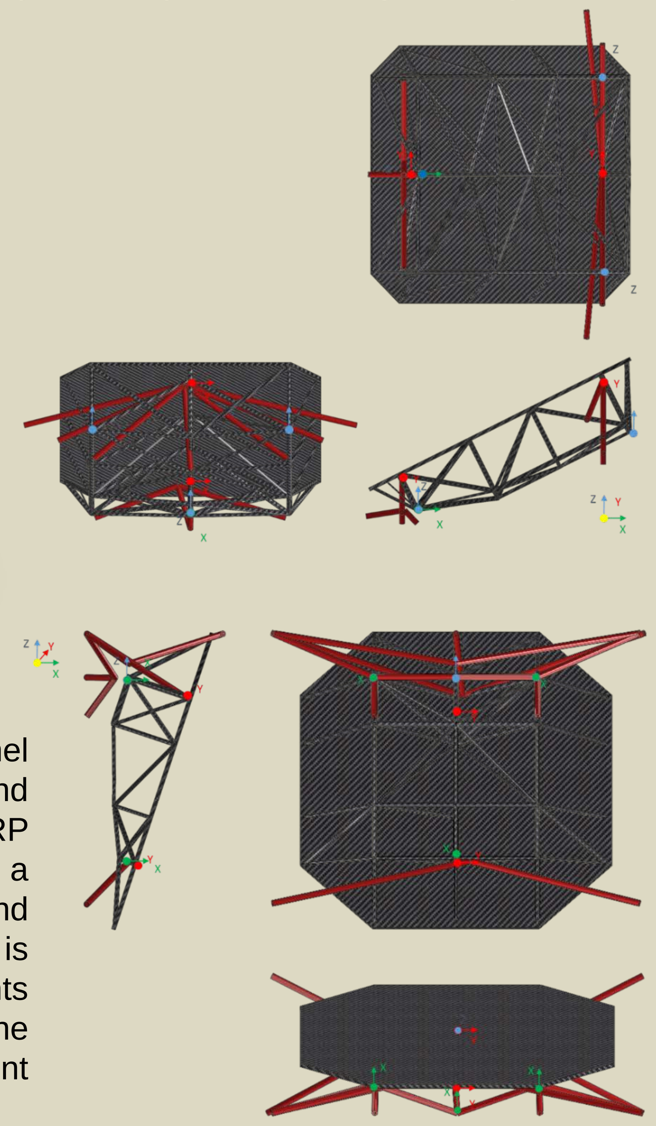


Figure 4. Above – aluminum mirror panel showing backside light weighting and adjuster mounting points. Right – CFRP mirror backup structures consisting of a CFRP-AL-CFRP sandwich top plate and supporting CFRP truss. The primary is above, secondary below. The red elements are tuned CTE beams that minimize the HWFE due to imperfect mirror alignment from thermal effects.

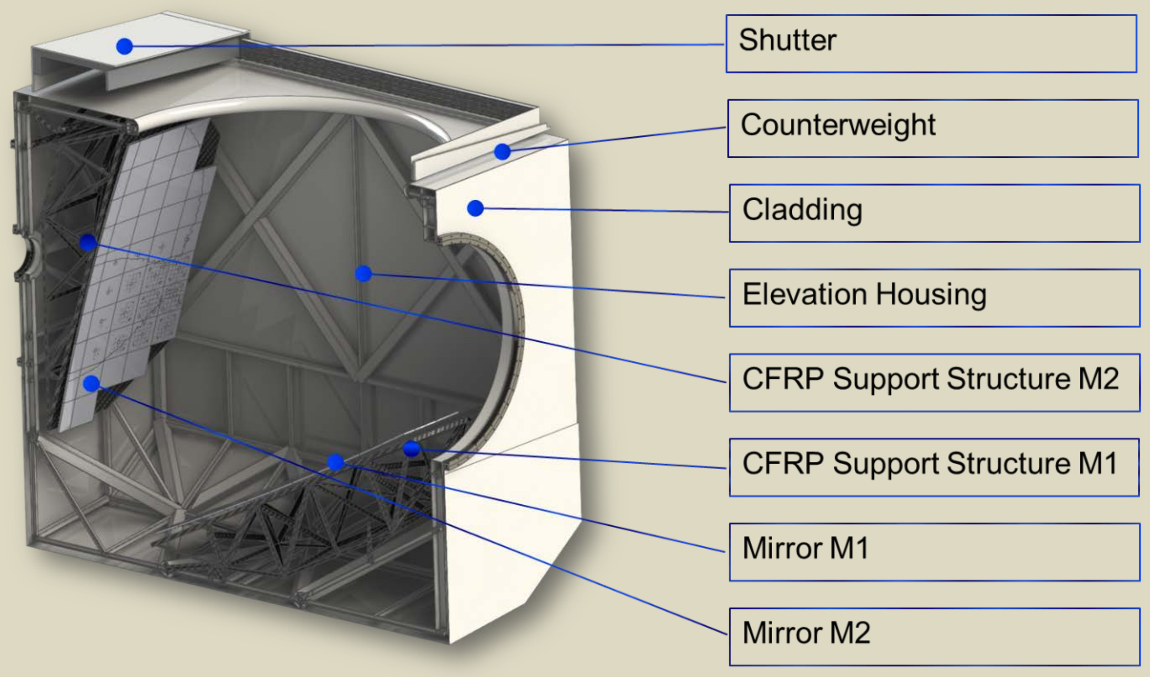


Figure 5. Elevation housing in cross-section through the telescope mid-plane with mirrors installed. The EL housing is an Invar beam structure with insulating cladding.

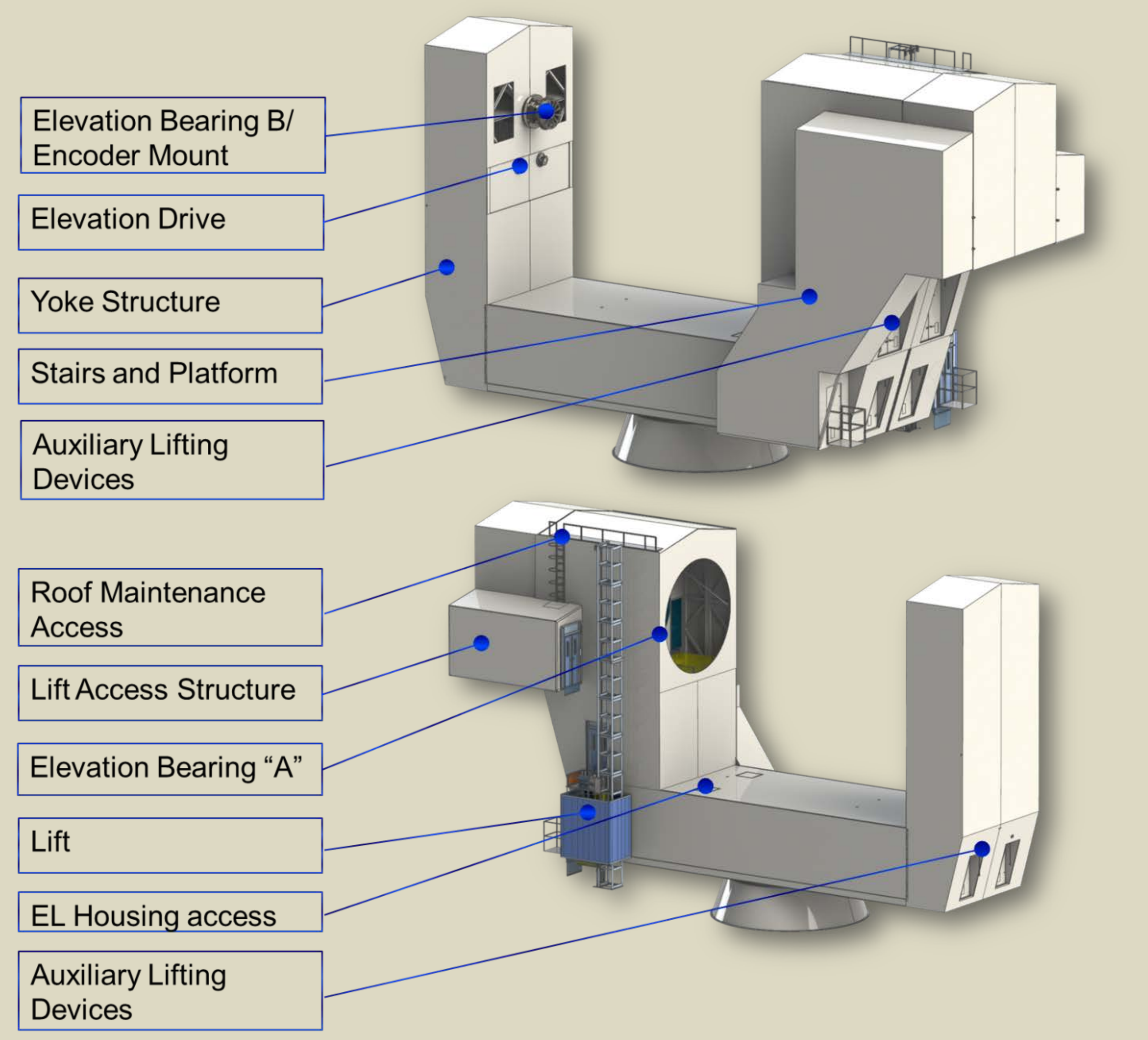


Figure 6. Two views of the yoke structure and support cone, both insulated steel framework assemblies. Elevation drives are opposite the focal panel. A lift is provided to move personnel and small equipment between floors.

SIMULATED PERFORMANCE

The overall performance of the telescope is simulated under various load cases. The steady-state effects of gravity, thermal gradients, uniform temperature changes, and wind are applied to the model. Wind loads are computed by CFD / FSI analysis. Relative deformations are calculated from the results and converted into one half wavefront error (HWFE) and pointing error (PE). Resonant frequencies are also calculated for the entire structure.

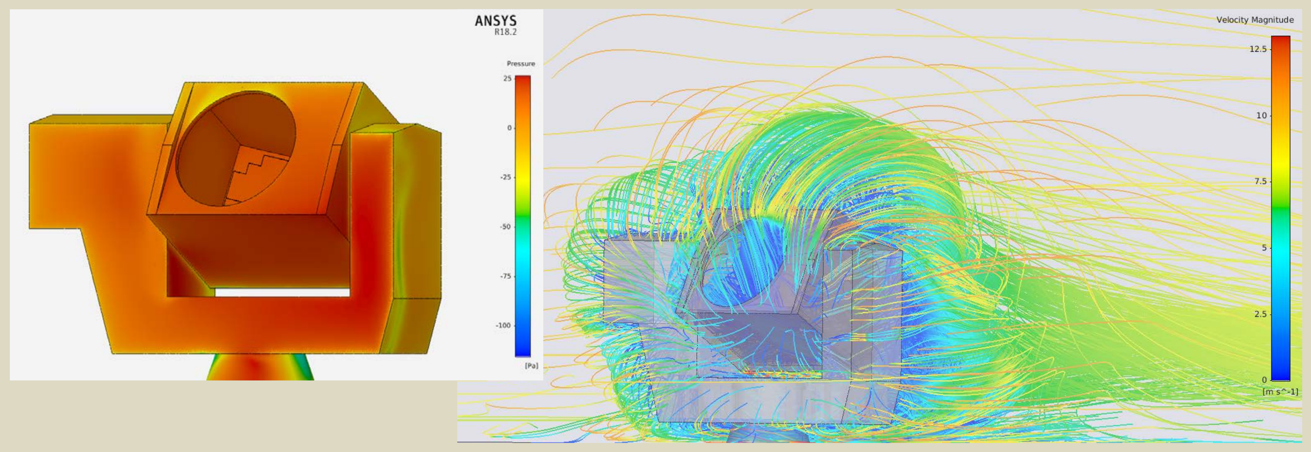


Figure 7. Right – wind visualized by a streamline plot, wind speed 9 m/s, telescope oriented at -30° AZ & 30° EL, ρ_{air} = 0.646 kg/m^3. Left – resulting pressure distribution.

Table 1. HWFE by component and error type, all in μm rms.

Component \ Error Type	Grav.	T, grad	T, soak	Wind	Align.	Mfg.	Margin	Comp. Total
Mirror config.	4.2	0.3	3.5	0.0	2.0	0.0	1.0	5.9
M2 BUS	2.3	1.0	0.1	0.2	2.0	0.0	1.0	3.4
M1 BUS	5.1	1.0	0.1	0.4	2.0	0.0	1.0	5.7
M2 panel	0.8	2.2	0.9	0.2	0.0	3.0	1.0	4.0
M1 panel	0.8	2.2	0.9	0.2	0.0	3.0	1.0	4.0
Error Type Total	7.1	3.4	3.7	0.5	3.5	4.2	2.2	Telescope Total: 10.5

Table 2. PE, all errors are in arcsec rms.

	9 m/s req.	9 m/s perf.	15 m/s perf.
Blind pointing	6.9	5.4	5.8
Offset pointing	2.7	1.6	2.7
Scan pointing, sector 1	1.4	1.4	2.5
Scan pointing, sector 2	1.9	1.5	2.6
Scan following	6.9	1.6	1.6
Pointing stability	1.4	1.7	1.9

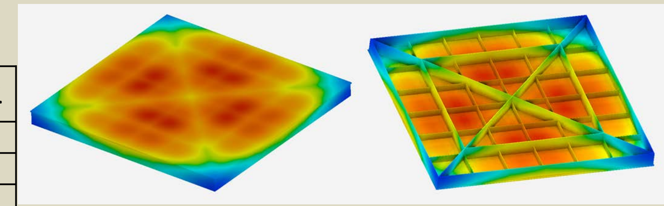


Figure 8. Thermal gradient for a single mirror panel computed by a transient analysis after 300 s, peak-to-peak ~0.3° C

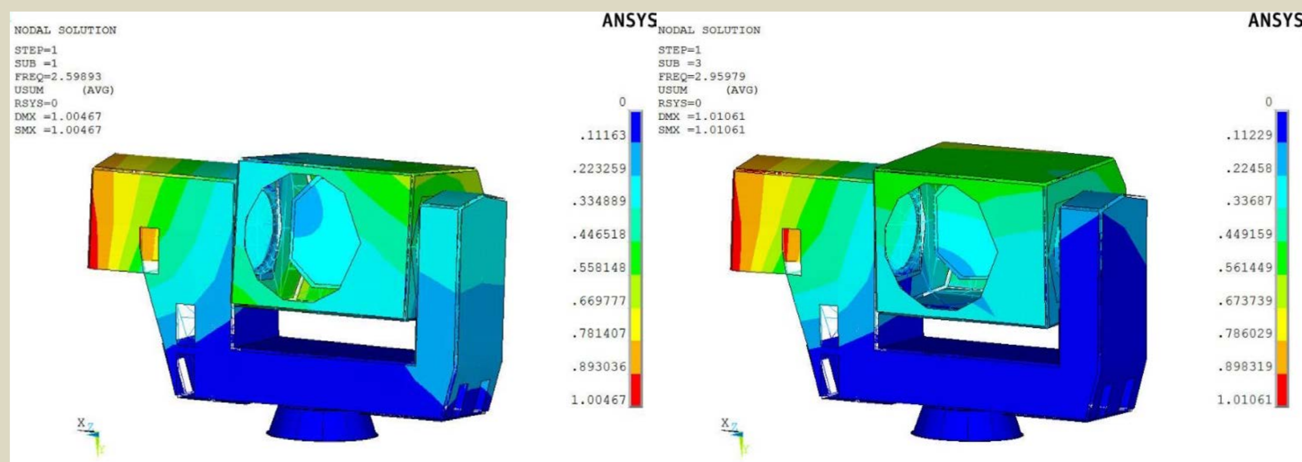


Figure 9. Left – 2.6 Hz locked rotor AZ, 1st mode. Right – 3.0 Hz locked rotor EL 3rd mode. Both for 0° elevation. Modes are not pure, stiffening yoke should improve this.

CONCLUSION

We have completed the preliminary detailed design and simulation for a 6 meter crossed-Dragone telescope with a primary to secondary mirror surface area ratio near unity. This design is capable of meeting or exceeding the performance requirements for HWFE, PE, blockage and dynamics.

There are clear advantages to this design configuration:
- optics "buried" inside the mount, lower wind loading on mirrors
- facilitates stray light control, reducing ground pickup
- integrated shutter provides protection from sun, rain, snow, and ice
- no tipping of instruments; improves stability, simplifies their design and mounting, easy to add co-rotator if desired
- elevation axis runs through secondary minimizing gravitational distortions
- symmetrical nature of mount allows for partial bore sight rotation by rotating beyond zenith and coming back around 180° in azimuth

The Simons Observatory has adopted the same telescope design for their Large Aperture Telescope, but with a steel EL housing instead of Invar for mm observations. The next phase will be a critical design review, followed by a final design review then construction and assembly. First light is anticipated in 2021.

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