3D Printing and Sidelobe Interpretation

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My work consists of 3D printed parts that are being assembled into smaller scale size models of The Cerro Chajnantor Atacama Telescope-prime [1], or CCAT-p for short. I'm printing these models so that the various features and functions of the CCAT-p telescope can be shown. A few models are being printed; one version that is to be motorized so it can move in azimuth and elevation. Another version is being printed with attachments so the internal components can be seen. I have also been running simulations through an optical design program called Zemax, which emits rays from a source within the telescope; they are not only reflected on the primary and secondary mirrors but throughout the internal components of the telescope. We are interpreting how/which parts of the internal structure create interferences (sidelobes) on the CMB map, and the intensity of them.

The CCAT-p is aimed to be a telescope that will be making observations at millimeter and submillimeter wavelengths. This telescope will map the Cosmic Microwave Background (CMB) roughly 10 times faster than current telescopes [2]. To be able to map the CMB more precisely, we have to minimize the intensity of the sidelobes created by the internal structure. With CCAT-prime, scientists will be able to make direct measurements of galaxy cluster motions under influence of dark matter and dark energy; study how galaxies and galaxy clusters first evolved; and study the properties of neutrinos, some of the lightest known fundamental particles [3]. When the CCAT-p telescope aims at and reads a certain part of the sky, light focuses down on the mirrors and then into the camera. Superconducting Transition Edge Sensors then detect the signals. There are a lot of other signals (thermal radiation) from the sun, moon and other parts of the galaxy that influence CMB readings depending on the geometry of the telescope. The aim of my project is to analyze the effects of sidelobes from running ray simulations in the internal structure of the CCAT-p model and determine which components of the CAD model are producing the largest amounts of interference so we can work with the vendor to redefine the structure. To simulate sidelobes we must calculate them in a time reverse sense; placing a source where the camera is located to emit $\sim 10^7$ rays onto the secondary mirror and then placing a detector around the CAD model to illustrate at what angle the rays are exiting.

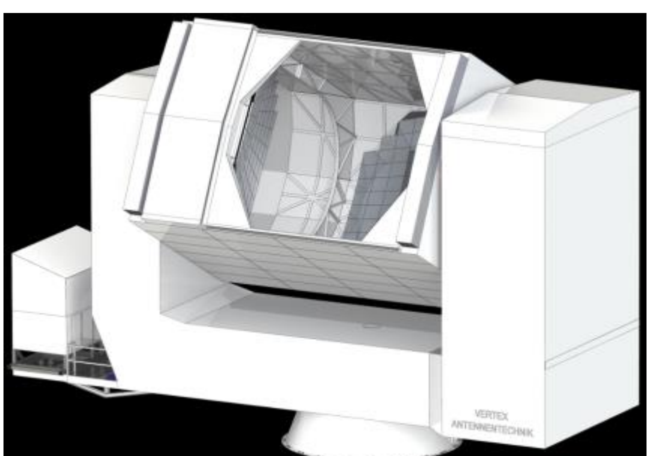

Figure 1: CCAT-prime Telescope

Ideally we want all of the rays to interact with only the primary and secondary mirrors and leave the model perfectly vertical to be able to map the CMB more precisely (Figure 2). Figure 3 shows the rays that had not hit the mirrors but in fact collided with certain parts of the internal structure and offset the ray to be shot into the sky at various angles creating sidelobes on our detector (Figure 5). Of the $\sim 10^7$ rays emitted from the camera 4 percent create sidelobes. Figures 4 and 5 show at which angles the rays escaped the telescope relevant to the boresight (location of the sky the telescope is aimed towards) +/- 100 degrees in all directions. Figure 4 shows all the rays that go directly from the camera to the sky; this represents 21% of all the rays that create sidelobes. Furthermore, 27% of the rays that created sidelobes interact with the support and back wall of the secondary mirror. Installing large sheets of absorbing material will reduce sidelobes at the expense of increasing camera noise and the mapping of the CMB could increase by years. Future work includes studying different elevations and different baffling strategies.

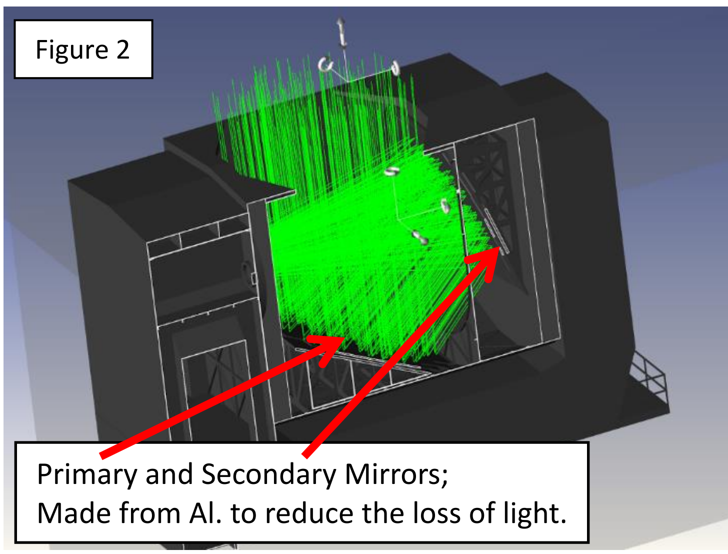

Figure 2

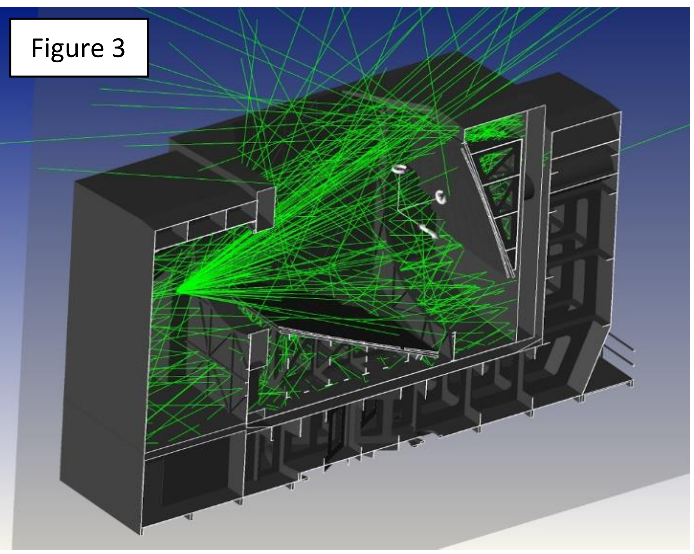

Figure 3

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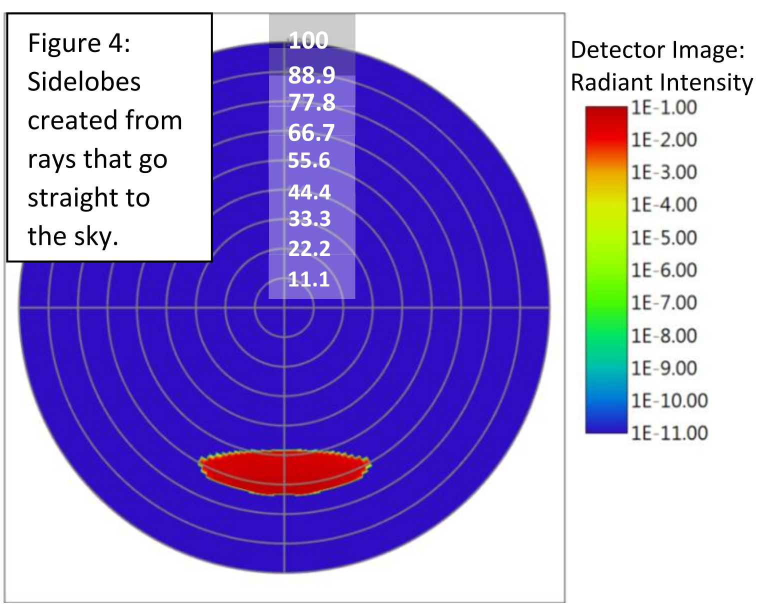


Figure 4: Sidelobes created from rays that go straight to the sky.

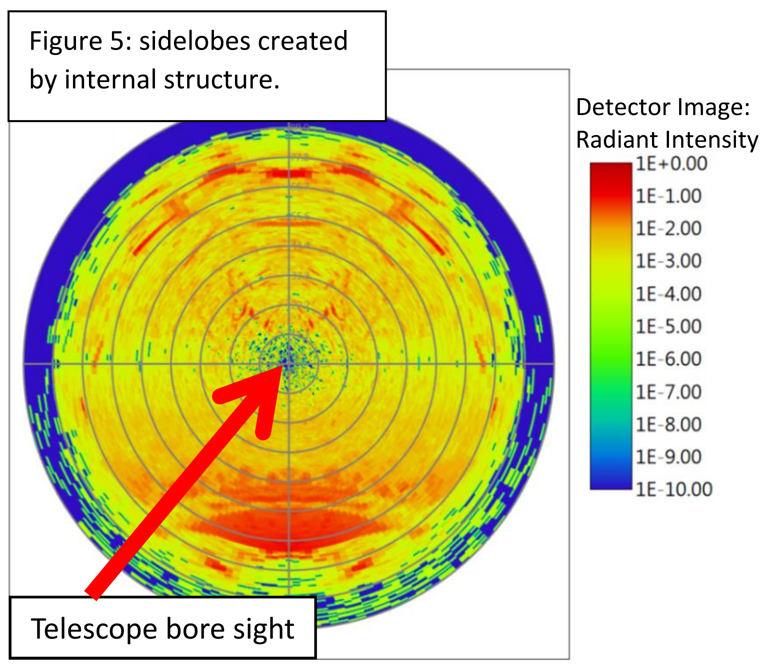


Figure 5: sidelobes created by internal structure.

Figure 6: Another visual representation of a single ray offset at a certain angle

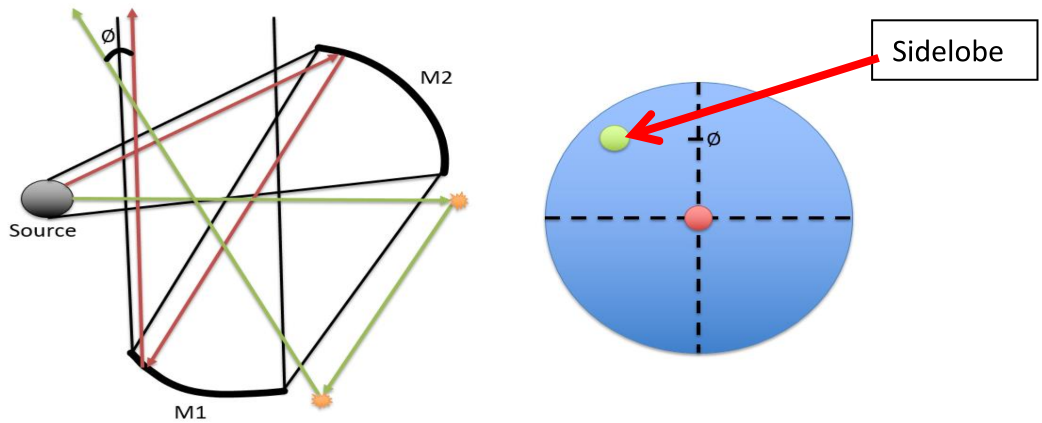


Figure 7: Ultimaker 2+ in action [4]

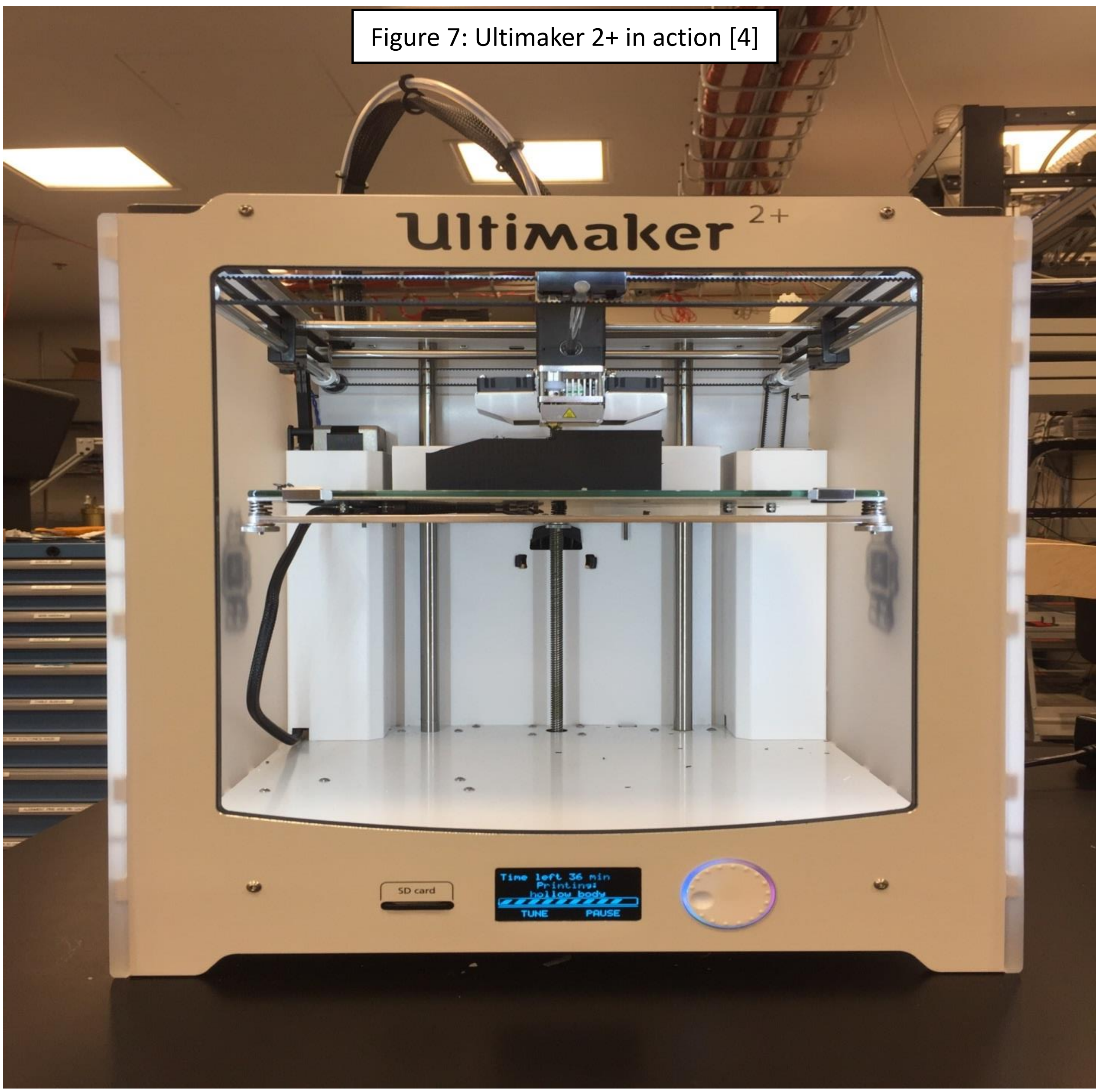


Figure 8: 1:100 scale size motorized replica to display elevation and azimuth movements.

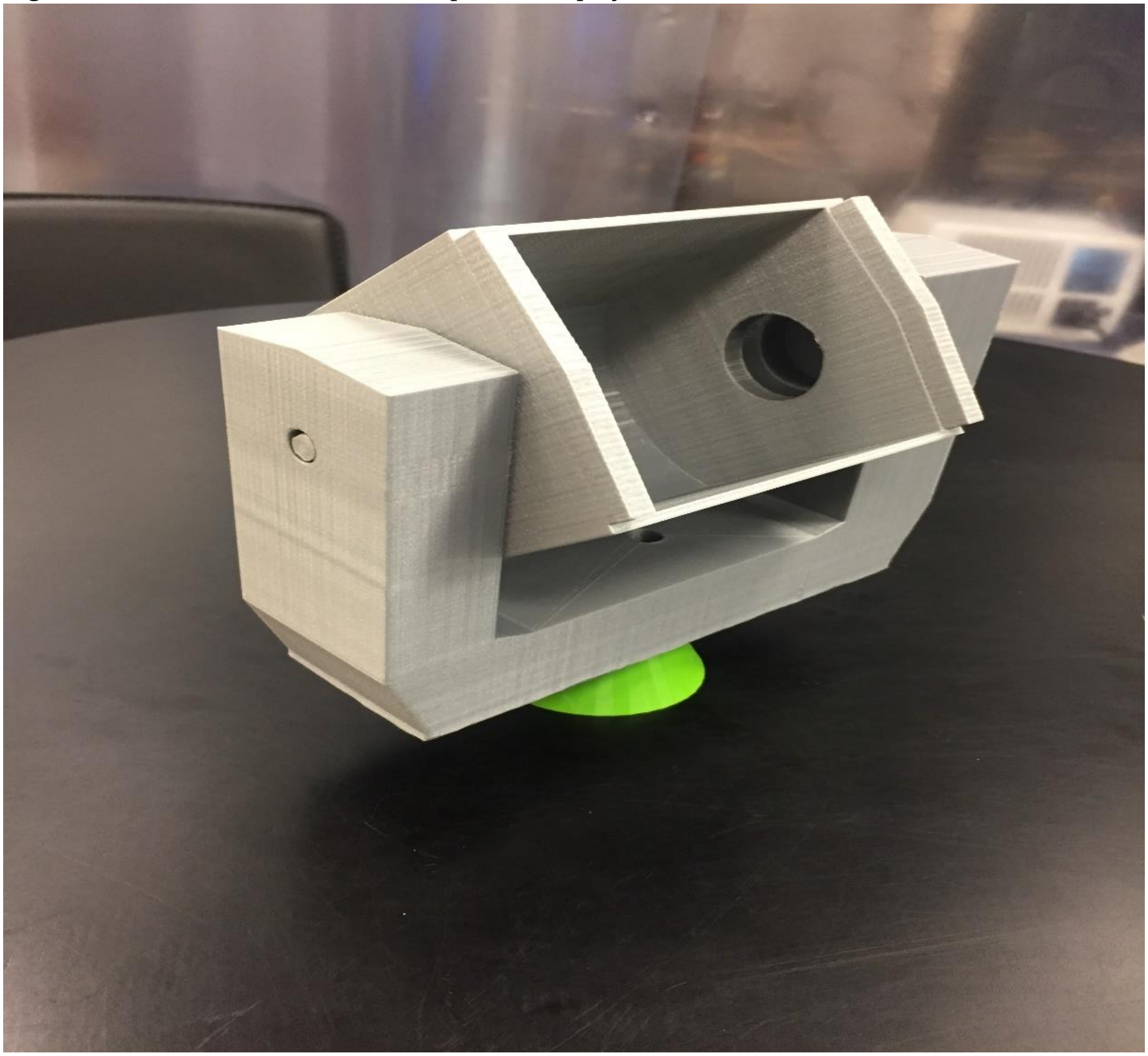
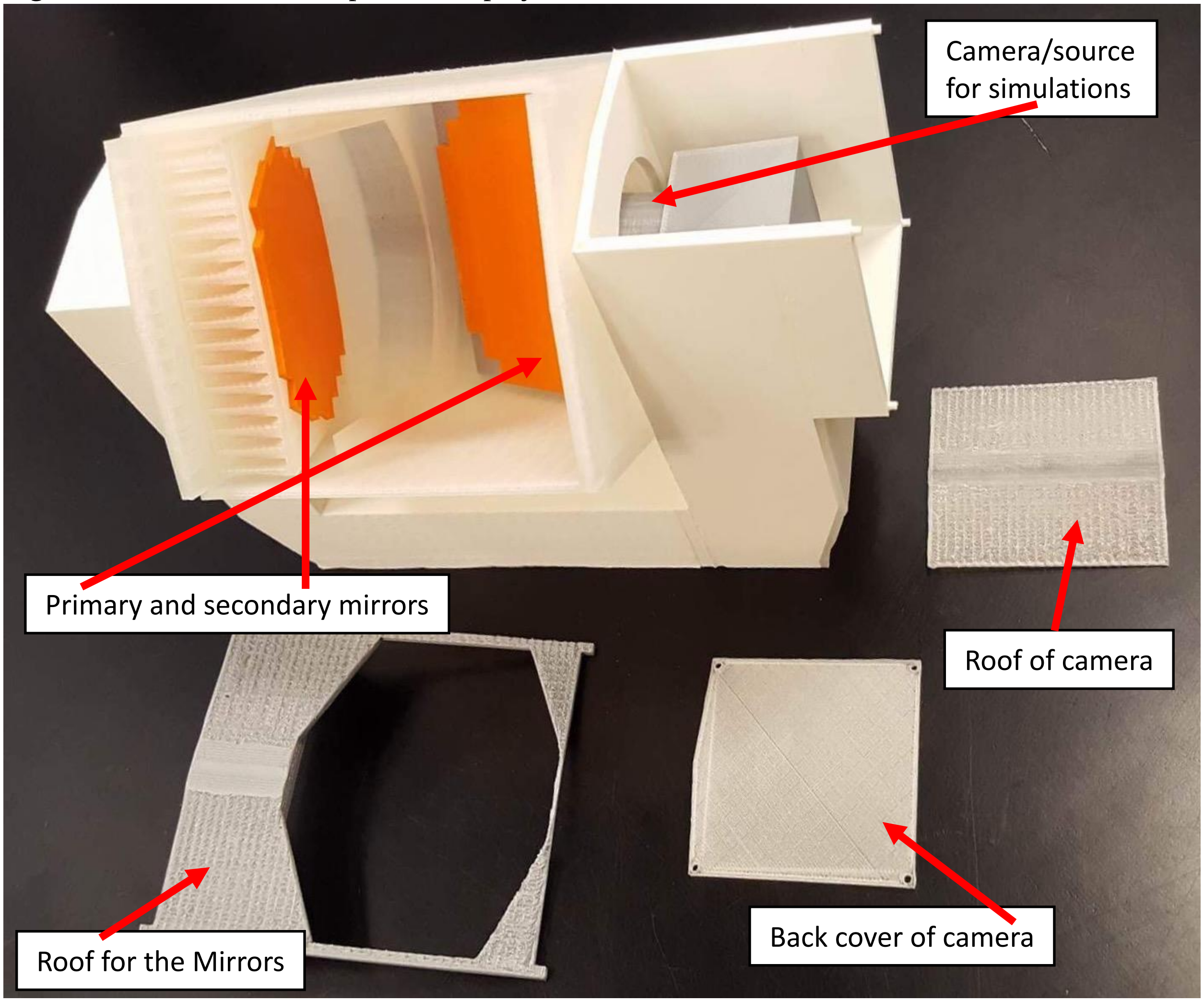


Figure 9: 1:100 scale size replica to display internal structure and instruments.



References:

[1] http://www.ccatobservatory.org/

[2] http://act.princeton.edu/overview

[3] http://news.cornell.edu/stories/2017/04/breakthrough-telescope-be-built-chile

[4] Ultimaker 2+ https://ultimaker.com/en/products/ultimaker-2-plus

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