The Simons Observatory: the Large Aperture Telescope (LAT)

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The Simons Observatory (SO) is a Cosmic Microwave Background (CMB) experiment to observe the microwave sky in six frequency bands from 30 GHz to 290 GHz. The Observatory—at ~5200 m altitude—comprises three Small Aperture Telescopes (SATs) and one Large Aperture Telescope (LAT) at the Atacama Desert, Chile. This research note describes the design and current status of the LAT along with its future timeline.

**Keywords:** Observational cosmology (1146), Early universe (435), Cosmic inflation (319), Cosmic microwave background radiation (322), Astronomical instrumentation (799), Time domain astronomy (2109)

1. INTRODUCTION

The Simons Observatory (SO) (Galitzki et al. 2018; Ade et al. 2019) is a cosmic microwave background experiment being built at the Chilean Atacama Desert. SO will have one large-aperture 6-m telescope (LAT) (Parshley et al. 2018) and three small-aperture 0.5-m telescopes (SATs) (Ali et al. 2020), with a total of 60,000 polarization-sensitive transition-edge sensors (TESes) (Healy et al. 2020) in the initial configuration.

The SATs target large angular scales, mapping ~10% of the sky to a noise level of 2 µK-arcmin in combined 90 and 150 GHz bands. The primary science goal of the SATs is to measure the primordial perturbation tensor-to-scalar ratio ($r$), at a target level of $\sigma(r) = 0.003$.

The LAT will map ~40% of the sky at a noise level of 2 µK-arcmin in combined 90 and 150 GHz bands to measure the integrated mass distribution in the universe, constrain the effective number of relativistic species, measure the sum of the neutrino masses, and improve our understanding of galaxy evolution and cosmic reionization. The LAT will also conduct a wide-field microwave survey for time-domain astronomy. The 40% sky coverage overlaps with future astronomical surveys, including DESI² (DESI Collaboration 2016) and LSST³ (Ivezić et al. 2019).

2. THE LAT DESIGN AND CURRENT STATUS

The SO LAT adopts a coma-corrected, 6-m aperture, crossed-Dragone optical design (Niemack 2016). The telescope design delivers a 1.9-m diameter focal plane at 100 GHz (3 mm wavelength). Both the 6-m mirrors are formed by rectangular panels (Woody et al. 2008): 77 panels for the primary mirror and 69 panels for the secondary mirror. The panels are supported by carbon fiber backup structures, and can be individually adjusted for alignment. As shown in Figure 1, the elevation structure rotates to change observation elevation. The entire telescope structure rotates, around the support cone, to change azimuth.

Light entering the telescope elevation structure is reflected twice before entering the telescope camera: the Large Aperture Telescope Receiver (LATR) (Xu et al. 2020; Zhu et al. 2021). The LATR is mounted on a support cradle that co-rotates along the elevation structure. The co-rotation maintains constant secondary mirror illumination for maximal optical stability. The LATR, which measures 2.3 m in diameter and 2.6 m in length, contains cold optics to re-image the telescope focal plane. The LATR contains five cryogenic temperature stages (80 K, 40 K, 4 K, 1 K, 100 mK). The 80 K, 40 K, and 4 K stages are cooled by pulse tube refrigerators; the 1 K and 100 mK stages are cooled by a dilution refrigerator. The LATR is capable of cooling up to 70,000 detectors (along with their support structures) to <100 mK on a 1.9-m diameter focal plane.

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¹ Although two frequency bands are mentioned here, maps will be available for all six frequency bands at 30, 40, 90, 150, 230, and 290 GHz.
² DESI website: https://www.desi.lbl.gov/
³ LSST website: https://www.lsst.org/
The LAT is currently being manufactured and tested at Vertex Antennentechnik GmbH\(^4\) in Germany. The SO collaboration is working closely with Vertex in the testing and validation procedure before the LAT shipment to Chile.

For the LATR, after our design was finalized, we collaborated with a vendor\(^5\) for manufacturing. The LATR vacuum and cryogenic shells were delivered to the University of Pennsylvania in 2019. Since then, the LATR has gone through extensive testing and integration. Currently, the LATR is fully equipped with the vacuum system, the thermometry system, and the cryogenic system. The cold optics performance and the detector/readout functionality have been validated. Three OTs are installed in the LATR for initial testing without focal-plane modules or cold optics. Four more OTs are scheduled to be added soon.

In addition, the LATR has passed mechanical and cryogenic tests. The mechanical test verifies that the structure holds its $\sim$5,000 kg weight and supports atmospheric pressure on its $\sim$27 m\(^2\) exterior surface. The cryogenic test demonstrates that each temperature stage cools below the required base temperatures within expected time (Coppi et al. 2018). Specifically, based on the 3-OT test, the fully-equipped 13-OT 100 mK stage is projected to reach $<100$ mK base temperature in $<18$ days. Thermal loading on the fully-equipped 100 mK stage is expected to be $<70\,\mu$W (Xu et al. 2020; Zhu et al. 2021).

The scale and complexity of implementing the microwave-multiplexing technology in the LATR is unprecedented; preliminary detector/readout testing results show no signs of additional systematics compared to results from test cryostats (Xu et al. 2020). The detector/readout system (along with the cryogenic system) is currently being tested for susceptibility to mechanical vibration, environmental temperature, external magnetic field, radio-frequency interference. A subset of the OTs are being optically tested in a test cryostat at the University of Chicago (Harrington et al. 2020). These tests aims to validate the optical design of the LATR in each of the frequency bands, including system efficiency, beam shape (including far side-lobes), polarization beam, detector polarization angle, and bandpass measurement.

3. FUTURE TIMELINE

The LAT acceptance at Vertex is expected in 2021. Then the telescope will be shipped to the Chilean ob-

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\(^4\) Vertex website: [https://www.vertexant.com/](https://www.vertexant.com/)

\(^5\) Dynavac website: [https://dynavac.com/](https://dynavac.com/)
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...production site, where the final assembly at the site will be conducted. After the site assembly, final verification will be performed before Vertex hands the telescope over to the SO Collaboration.

The LATR will have all the initial seven OTs constructed and tested in 2021, making it ready to support focal-plane modules and readout components as they become available. The LATR will be shipped to Chile in 2022 to begin commissioning.

We expect the LAT, in the 7-OT initial configuration, to begin full scientific observation in 2023.

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