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The Hercules Mount: Shouldering the Weight of the Argus Array Technology Demonstrator

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ABSTRACT

As technological improvements continue to lower manufacturing costs, astrographic telescopes and cameras are becoming cheaper and more accessible to a wider community. The Argus Optical Array (AOA) capitalizes on these advances to create an all-sky, high-cadence telescope array with arcsecond-resolution and a cost in the $20M range. The completed array will have a 5-m class collecting area consisting of over 900 individual telescopes observing the entire Northern sky simultaneously at a 1-minute cadence (and capable of observing at second-timescales). The Argus Array Technology Demonstrator (A2TD) enables the investigation of the performance of telescopes, cameras, climate control, precision tracking and pointing systems for inclusion in the completed AOA. It consists of nine 8-inch telescopes under a hemispherical enclosure mounted onto the Hercules Mount, a semi-fixed, equatorial mount. The mount adjusts its polar axis alignment via two high-precision linear actuators while supporting a load of over 180 kg including counterweights. The dome is decoupled from the platform containing the telescopes to minimize the effect of windshake during observations. Sidereal tracking is performed by two linear actuators which connect to the outer dome and the telescope platform separately and track synchronously at arcsecond precision. The Hercules mount was constructed from a combination of low-cost commodity materials, with only three key components requiring precision CNC machining. Systems tested on the Hercules Mount will scale or transfer directly to the next instrument in the Argus series of prototypes: Argus Pathfinder. Here we present on-sky results of the Hercules Mount and our plans for the next generation of Argus prototypes.

Keywords: Argus Optical Array, Argus Prototype Series, Argus Pathfinder, mount

1. INTRODUCTION: THE ARGUS OPTICAL ARRAY – SUCCESSOR TO THE EVRYSCOPES

The Argus Optical Array (AOA) builds on the success of the Evryscopes, the first high-cadence, full-sky, gigapixel scale telescopes to observe the entire night-sky simultaneously.[1] The AOA improves upon the performance of its predecessor with a total collecting area of over 200 times that of an Evryscope and an increase in pixel scale from 13.2 arcsec/pixel to 1.4 arcsec/pixel with the use of scientific-grade CMOS detectors. This results in an increased observation depth from m_g=16 to m_g=20, and with the use of scientific-grade CMOS detectors, the AOA can operate at a 1-second cadence.[2]

The Argus Array Technology Demonstrator (A2TD) is the first telescope in the Argus Prototype series. Its purpose is to prototype and test the instruments and technologies that will be deployed in Argus Pathfinder – the second telescope in the Prototype series. This includes validating which cameras and telescopes[3] will be selected for the deployment, testing the polar alignment and sidereal tracking drives,[4] and developing the environment control system which will be installed in Pathfinder.[5] These systems will then transfer directly or scale up to

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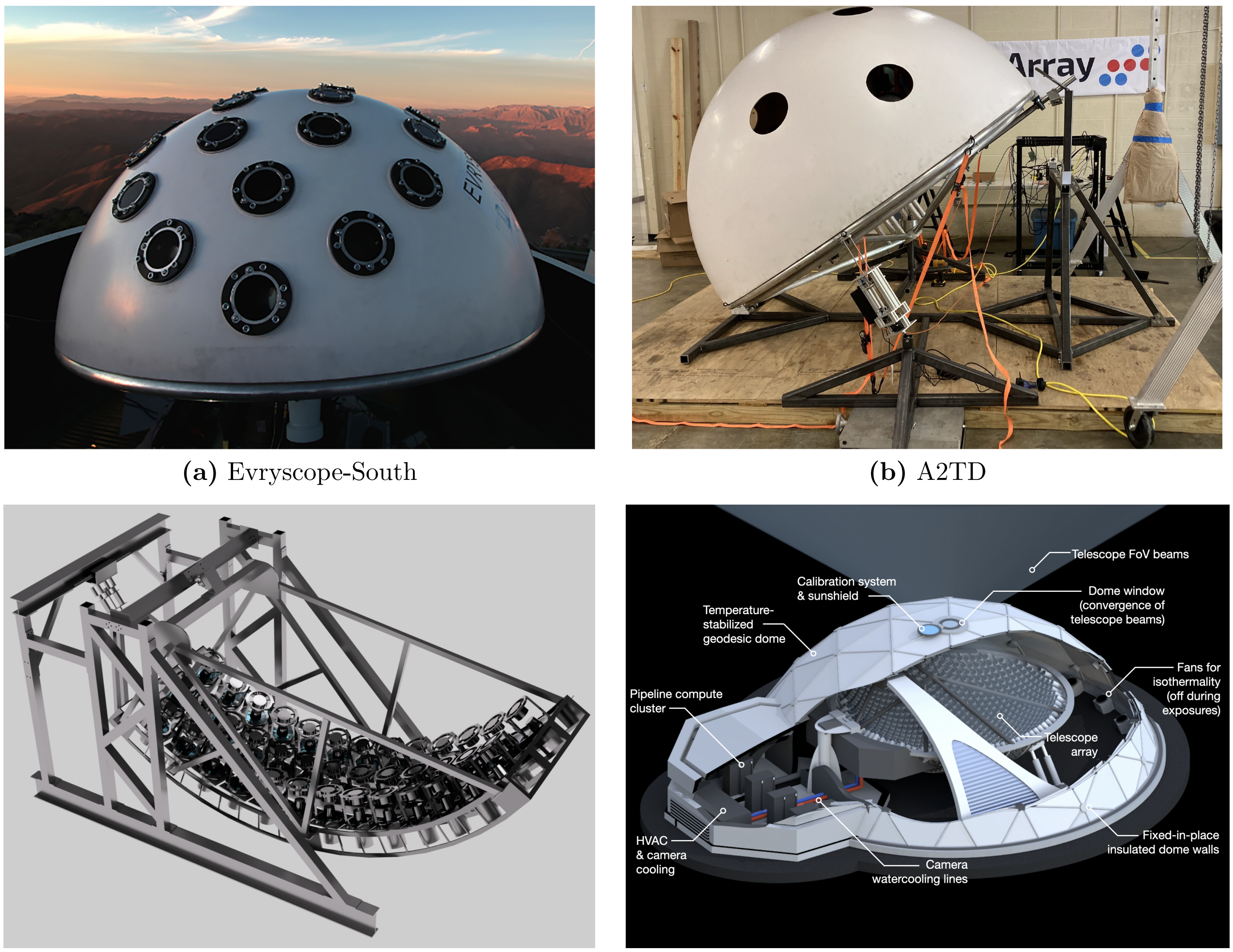
the full Argus Optical Array. Further details on these projects can be found elsewhere in the Proceedings and are included in the References.

In this paper, we present our work designing, building, and testing the Hercules Mount for the A2TD instrument. In Section 2 we outline the structural and performance requirements for the Hercules Mount as dictated by its various subsystems. Section 3 describes how the mount components were designed and built to meet their requirements. In Section 4 we present the results of mount's stability and the first on-sky test. Section 5 provides a brief summary of the Argus Prototype series and the transferable designs to Argus Pathfinder.



(a) Evryscope-South

(b) A2TD

(c) Argus Pathfinder

(d) The Argus Optical Array

Figure 1: **(a)** The Evryscope-South is a 27-telescope array deployed in May 2015 at CTIO, Chile. Its sister telescope, Evryscope-North was deployed in October 2018 at MLO, California. **(b)** The A2TD is a 9-telescope array with a climate-controlled enclosure whose purpose is to prototype Argus Optical Array technologies and control systems. **(c)** The Argus Pathfinder is a 38-telescope array and the second Argus Prototype telescope. It inherits the systems tested by the A2TD and scales them up. **(d)** The Argus Optical Array is a 900-telescope, 55Gpix. array with the same collecting area as a 5-meter class telescope.

2. THE ARGUS ARRAY TECHNOLOGY DEMONSTRATOR (A2TD) – STRUCTURAL AND PERFORMANCE REQUIREMENTS

In order to test the multiple systems and hardware combinations, the A2TD was designed to meet a wide range of structural requirements. This includes validating camera and telescope performance (Ref. 3), developing control and analysis pipelines (Ref. 6), testing environmental control systems (Ref. 5), and evaluating polar alignment and sidereal tracking drive performance (Ref. 4). This section presents a detailed description of these constraints.

2.1 Durability

The A2TD was designed to be operated remotely after a planned deployment at the Pisgah Astronomical Research Institute (PARI) in Rosman, North Carolina. Since the telescope would not be sheltered by an outer enclosure, the Hercules Mount (and the instruments contained within) had to be capable of withstanding the site's weather conditions. We planned to deploy it for a six-month period, so the mount had to resist exposure to a wide range of temperature and climate conditions. This includes rain, snow, strong winds, and a continuous sun exposure.

2.2 Climate Controlled

In order to maintain the telescopes in their focus position over the course of the planned deployment, the upper part of the mount which would contain them had to be insulated. However, this requirement did not extend to the entirety of mount structure, only the upper part that would support and house the telescopes.

2.3 Sidereal Tracking

Instead of attaching the telescopes to individual mounts for motion, we required that all nine telescopes be mounted to a single tracking platform. The platform had to be capable of moving all of the telescopes while tracking the sidereal motion of the stars simultaneously with the dome during the exposure period. This approach decreases the total number of components with the benefits of lower development and maintenance costs, as well as fewer points of failure in the telescope.

2.4 Low-Deformation

To constrain the pixel-drift in our images to the sub-pixel level, we calculated that the telescope platform could not deform more than 0.1 mm during a 15-minute observation period. We determined that, at minimum, the platform should be capable of supporting a load of 135 kg without deforming past the 0.1-mm limit. Considering that each telescope weighs 7 kg, this means we would be able to support an additional 72-kg of hardware and components.

2.5 Minimal Windshake

To avoid image blurring caused by windshake of the instrument, the A2TD's dome was required not to touch the platform containing the telescopes. In this configuration, the dome would receive the blow from a gust of wind, rather than the instruments. The impact force would then be broken and distributed across the dome's surface due to its spherical shape thus minimizing the effect of windshake.

2.6 Adjustable Polar Alignment

Since the A2TD was designed to be deployed at various sites and operated remotely, it was imperative that the polar axis of the telescope be adjustable. The axis had to accommodate an inclination range of $35°$ to $36°$ in order for it to be operable in both Chapel Hill, North Carolina (for rapid systems testing) as well as at PARI.

2.7 Portable

For the Hercules Mount to be portable, it had to be designed so that it could be assembled and disassembled easily on-site without the use of specialty equipment or machinery. The individual parts must all be able to fit in a standard 12-foot trailer for transportation.

3. CAD MODELING AND HARDWARE MANUFACTURING

All of the mount components were designed and modeled using Autodesk's Fusion 360 software.* During this process, we also tested the structural stability and resilience of the mount using the finite element analysis (FEA) function in Fusion 360. The finalized models were constructed from low-cost, commercially available materials. This includes the 5052 aluminum tubing, hot rolled square steel tubing, and 6060 aluminum blocks. The swivel joints and pillow block bearings are available for purchasing from McMaster-Carr † and the plywood was purchased from a local lumber supplier. All of the mount's custom components were manufactured at our on-campus Instrument Shop.

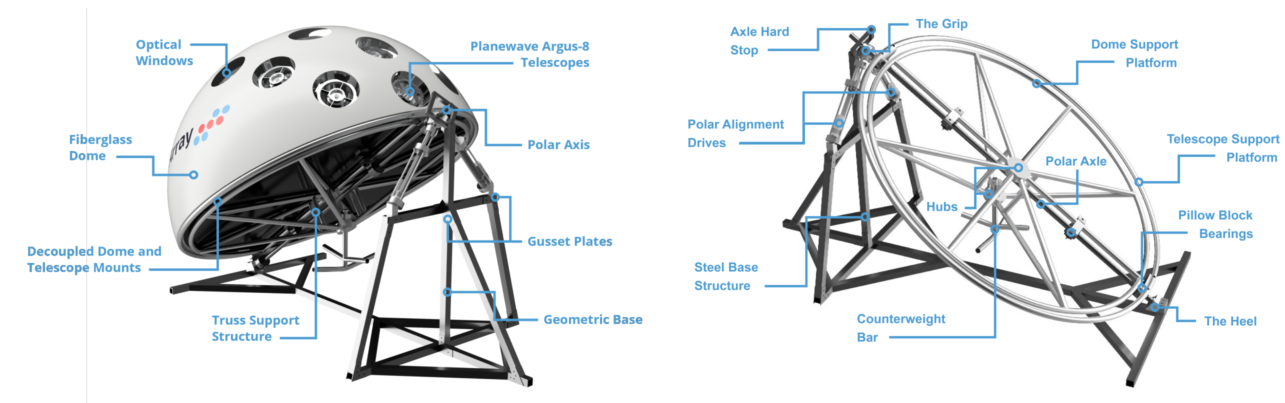


Figure 2: A CAD model depicting the complete A2TD telescope with the fiberglass dome installed (left) as well as with the dome removed (right).

3.1 The Tracking Platforms

The Hercules Mount includes two tracking platforms (shown in Figure 2), whose design was tightly constrained by the performance requirements listed above in Sections 2.2, 2.3, and 2.4. To accommodate the dome, we designed the platform in a circular shape with an 87-inch diameter so that there is 1-inch gap between the two parts, allowing them to move independently without interfering with each other. This clearance also makes it easier to install or remove the fiberglass dome without hitting the mount. The final design of the telescope platform frame (shown in Figure 2) consists of an 8-spoke aluminum wheel and an inverted 3-truss assembly to add extra strength and rigidity. The frame spokes, ring, and struts were fabricated from 1.5-inch diameter aluminum tubing. The eight spokes are joined in the center by an aluminum hub which was added to reduce the complexity of the fabrication process and facilitate its assembly. Similarly, the struts of the truss system were welded to the same hoop at their outer ends and a second aluminum hub was added at the point where the three trusses connect in the center point directly under the spoke hub. A hole was added to the truss hub for a removable bar to enable the use of counterweights. To better withstand the load of the counterweights, the counterweight bar was made from cold-rolled steel tubing with a 1.5-inch diameter and MIG welded into a shape resembling a ship anchor as shown in Figure 2.

The dome is a hemispherical shell made from marine-grade fiberglass with a 1/4-inch thickness and a 94-inch diameter, the largest size that our supplier could manufacture. Nine holes were later cut into the dome to fit 9-inch optical windows through which the telescopes would observe the night sky. The location of these windows was calculated using sky-coverage optimization algorithm described elsewhere in the Proceedings.[7] The bottom edge of the dome has a 6-inch-wide lip that folds inward and provides a surface for mounting it to the dome platform.

The dome platform has a much simpler design. It consists of a 94-inch diameter hoop made out of 1.5-inch diameter aluminum tubing. To make the hoop portable, it was split into two pieces of equal length and fabricated

*https://www.autodesk.com/fusion360
†https://www.mcmaster.com/

by bending the straight metal pipes into arcs with a radius of 47 inches. They are joined together by two metal inserts at either end of the arcs that lock into place with set screws.

The final part of the telescope platform is the plywood floor, which is made out of two semi-circles with a 43.5-inch radius cut from two 3/4-inch, 4' x 8' sheets of marine-grade plywood. The two semicircles sit on top of the platform frame and join together along their diameter. We chose plywood for this part since it would provide the telescopes with a firm foundation for mounting, and because of its relatively low thermal conductivity. Its thermal conductivity could also be readily improved with off-the-shelf products if it did not provide enough insulation to the inside of the dome. Additionally, it can easily be painted black to minimize reflections.

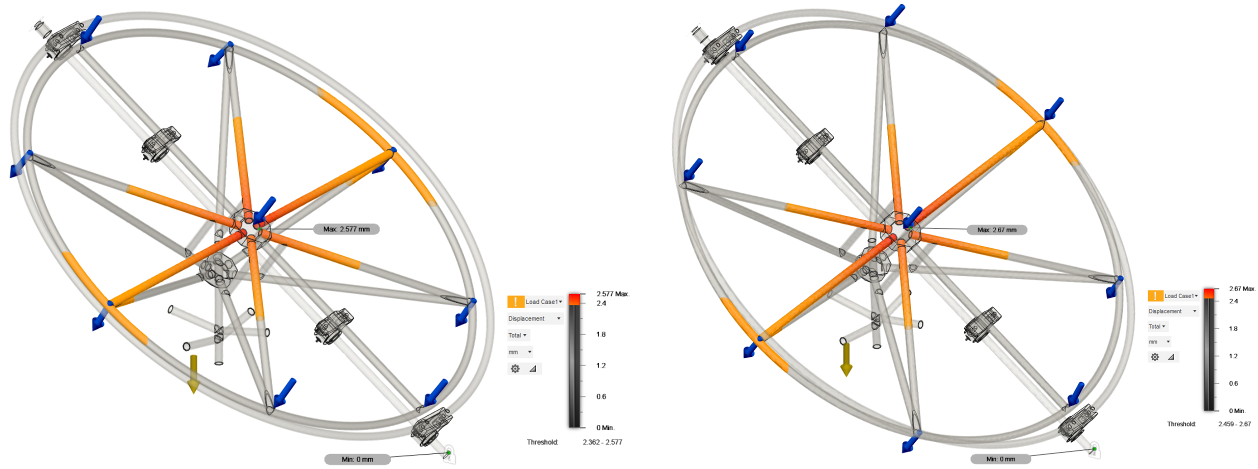


Figure 3: FEA simulations showing the deformation of the A2TD telescope platform at the beginning and end of a ratchet. The yellow arrow represents the force of gravity. **Left:** A static load of 155 kg (depicted as blue arrows) is applied symmetrically on the telescope platform to simulate the weight of the hardware that it will support. **Right:** The same static load is applied after rotating the platform by 5° about the polar axle, its final position at the end of a ratchet. The dome platform remains fixed for visual reference.

3.2 FEA Simulations

One of the features of Fusion 360 is the ability to conduct finite element analysis (FEA) for the materials that we used to build the A2TD. This is how we calculated the load rating for the telescope platform to ensure that it performed within the constraints described in Section 2.4.

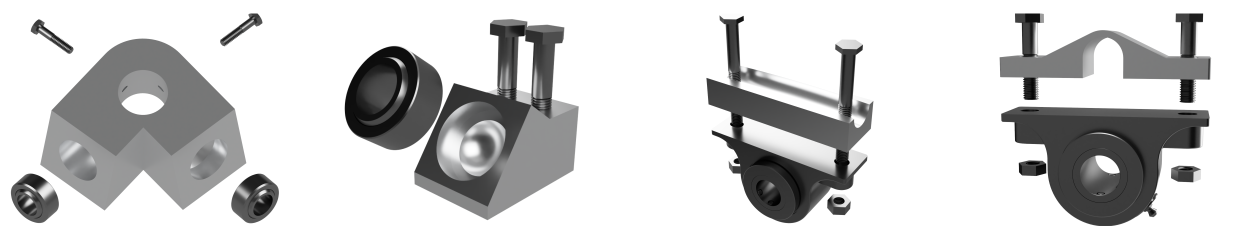
Our concern with the telescope platform (Sec. 3.1) was that the telescope's field of view would drift over the course of an exposure on the scale of one pixel or greater, consequently reducing the quality of our data. In order to avoid this scenario, we used FEA simulations to model the deformation of the telescope platform with an applied load to simulate the weight of the equipment it would have to support, including telescopes, cameras, and cabling. To calculate the maximum load capacity for the platform, we ran multiple deformation simulations while varying the load mass from 135 kg to 180 kg. We then repeated those simulations with the telescope platform rotated by 5 degrees about the polar axle to replicate the maximum inclination it would experience at the end of a "ratchet". We define a ratchet as the sidereal tracking motion of the instrument platforms as they tilt from $0° - 5°$ with respect to the meridian. By taking the difference of these deformations we concluded that 180 kg is the maximum weight that the platform could support while restricting image drift to sub-pixel scale as shown in Figure 3. Under normal operations, the total weight supported by the platform is approximately 150 kg in total.

3.3 Adjustable Polar Axle

To ensure that we could deploy the A2TD at multiple locations, the polar axis of the mount was designed to be adjustable. To accomplish this task, we designed the Hercules Mount so that a steel rod would function as the polar axis; we call it the polar axle. The axle measures 1.5 inches in diameter, has a length of 105 inches, and is made from turn-ground-polished steel. A 1.5-inch diameter swivel joint (with a 17° swivel range) slips on the lower end of the axle and couples it to a custom CNC manufactured part dubbed the "Heel" of Hercules as shown in Figure 4a. The Heel is cut from an aluminum block and acts as a backstop for the polar axle as well as the pivot point about which moves.

At the opposite end of the rod is another custom-made part cut from aluminum and dubbed the "Grip" of Hercules as shown in Figure 4b. Similar to the swivel joint, the Grip slips onto the polar axle and is locked into place via two set screws to prevent it from slipping. The lower half of the Grip splits at a 40° angle and the two ends link the polar axle to the polar actuator drives described in detail elsewhere in Proceedings.[4] This configuration enables the Hercules mount to adjust the pointing of the polar axle by several degrees in altitude and azimuth. For safety reasons, this range of motion is restricted by the axle hard stop (shown in Fig. 2) which is located at the upper end of the axle. The hard stop limits the pointing of the axle to a range of $34.5° - 37.5°$ in altitude and $\pm$ 1.5° from the pole in azimuth. This prevents the mount from moving into an unstable and unsafe position while still having the necessary mobility required in Sec 2.6. This adjustability enabled us to deploy at multiple locations without needing to perfectly aligned with the pole by manually.

The tubing platforms were connected to the polar axle via two pillow blocks placed along their diameter in parallel to the polar axis as shown in Figure 3, allowing the platforms to rotate about the axle. The dome platform and the telescope platform are each connected to an independent linear actuator drive that will track the night-sky synchronously at arcsecond precision (Ref. 4). The two bearings at the bottom of the mount have a dynamic radial capacity of 3560 kg and a dynamic thrust load capacity of 1155 kg. These limits are well above what the Hercules Mount would experience, but they were the only option with a thrust load rating that could fit on our polar axle. To stay on budget, we used two more cost-effective pillow blocks to connect the upper part of the platforms since the mount did not require additional thrust load capacity.



(a) The Grip (b) The Heel (c) Outer Bearing (d) Inner Bearing

Figure 4: A closer view of CAD models depicting the Grip (a) and the Heel (b) with their swivel joints, as well as the bearings and clamps that attach the dome platform (c) and telescope platform (d) to the polar axle.

3.4 Steel Base Structure

The base structure is what supports the weight of the entire A2TD and provides the Hercules Mount with structural support and rigidity. It was designed using basic triangular shapes to optimize strength and cost-efficiency as shown in Figure 2. It was made using hot rolled, 2-inch, steel square tubing that was cut and MIG welded into four separate components making it easier to transport. The parts can be assembled together using gusset plates cut to shape from 1/8-inch thick cold rolled steel plates. This keeps the Hercules Mount structurally sound and easily portable as stated in Section 2.7.

4. STABILITY AND ON-SKY TESTING

We tested the stability of the Hercules Mount by assembling the base (as shown in Figure 5), checking for deformations, and seeing if it held its position over the course of several days without moving. During this process, we discovered that the telescope platform was slipping downwards through the clamps that secured it to the pillow blocks shown in Figure 4d. Upon closer inspection, we determined that this was due to the platform not making full contact with the clamps' surface. We fixed this by returning the platform to its original position, adding spacers to increase surface contact, and increasing clamping pressure by tightening the clamps further. After a week, we inspected the A2TD and confirmed that the platform had remained in place and had not slipped.

Figure 5: **Left:** The fully constructed Hercules Mount with the dome installed. **Right:** The A2TD with the dome removed showing the telescope mounting configuration on top of the telescope platform. (*Image credit: Johnny Andrews/UNC-Chapel Hill*)

The second problem we discovered was that the Grip would rotate the axle after the telescope had been polar aligned. This was caused by the heel having an extra degree of freedom granted by the two swivel joints which attach it to the polar drives. Consequently, the polar alignment would shift during operation and on-sky testing. To correct this drift, we replaced one of the swivel joints connecting the Grip to the linear actuators with a rigid sleeve to limit that extra degree of freedom. After re-aligning the polar axle, we monitored the Grip over the course of a week and confirmed that it would no longer drift from its aligned position. With those two problems resolved, on November 23, 2021, the A2TD took its first astronomical image shown in Figure 6.

Figure 6: **Left:** Testing the A2TD at our local build faciltiy at Chapel Hill, NC. (*Image credit: Johnny Andrews/UNC-Chapel Hill*) **Right:** A cutout showing the central million pixels of the first image taken with the A2TD.

5. SUMMARY

The first instrument of the Argus Prototype series is the Argus Array Technology Demonstrator (A2TD). This telescope tests the performance of the structure, technologies, and essential subsystems which will scale or transfer directly to the full-sized Argus Array. To enable these investigations, we designed, built, and tested the Hercules Mount, a low-cost, high-durability, and portable mount for the A2TD. The mount is a constrained equatorial mount capable of supporting the weight of the instrument while allowing for sidereal tracking with arc-second precision. Argus Pathfinder is a 38-telescope, 2.3 Gpix array that inherits the structural support and polar alignment systems from the A2TD. It is currently under construction and on track to deploy in Q3 of 2022. The final Argus Optical Array will be a 900-telescope, 55Gpix array capable of observing the entire night sky simultaneously at high-cadence (≤ 1 minute), arc-second resolution.

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