CHARA Technical Report

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CHARA Michelson Array Pathfinder: Transport and Enclosure Design

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ABSTRACT: An initial design for the trailer-mounted 1-meter Planewave telescope and enclosure is presented. CAD models of the major components are shown, pre-structural analysis. Procedures for telescope transport and observing installation are outlined.

1. INTRODUCTION

The CHARA Array has recently begun work on a project to expand the current array by adding a 7th telescope to the existing 6. The CHARA Michelson Array Pathfinder (CMAP) will utilize a mobile telescope design to both expand the available CHARA long baselines and to fill *uv*-coverage for short baselines. This is a path finder, technology demonstrator, and a science project. It will demonstrate the potential of extremely long baselines, reconfigurable mobile optical arrays, and fiber-fed interferometric arrays. The extra short baselines will improve imagining of large stars and circumstellar environments. At the distant extension, the angular resolution of the Array will reach < 0.2 milli-arcseconds in the H-band, resolving the diameters of small stars. The addition of the CMAP telescope brings the number of available baselines from 15 to 21; if one includes asynchronous observation then the addition of 3 sites for the telescope brings the total number of possible baselines to 36.

This new telescope, made by PlaneWave, will have a one meter aperture and a focal ratio of 2.5. It will be equipped with an adaptive optics system and will launch light into an optical fiber. H-band light from this fiber will be combined in the CHARA Array Beam Combining Lab (BCL) alongside beams from the current array telescopes that are being equipped with optical fibers. We are building upon the experience of the OHANA project and with input from the ALOHA teams, who are experienced in recombining light via optical fiber transport.

Critical to this project is a system for transporting the telescope to the various prepared sites around Mount Wilson. All but one of these sites are on observatory grounds and none require highway travel. The roads are narrow and uneven and include some steep inclines. At each site a concrete pad will be poured with an isolated inner pier and channels for cabling. Once at the site the transport trailer will become the telescope enclosure and will be mechanically isolated from the telescope, the concrete pier, and the steel telescope support pier.

A video tour of the CAD model and animation of the operation can be viewed here: `https://www.youtube.com/watch?v=T5hPlE_MIzo`.

2. DESIGN CONSIDERATIONS

Due to the winding nature of the observatory private roads, we need a transport system:

- $<$ 8.5 feet wide at the road level
- as short in length as possible
- with a relatively low trailer tongue weight

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- with high ground clearance
- that can be maneuvered around the narrow observatory roads
- that can accurately position the telescope repeatedly within a few millimeters ideally or ≈ 1 cm at least
- that can keep the telescope pointed close to zenith during transport
- that can support the weight of the telescope/enclosure/pier and has a means for raising/lowering the telescope
- that doubles as the telescope enclosure and protects from the elements with a roof or dome
- that is capable of being isolated so vibration from wind doesn't affect observations
- allows the telescope to observe down to an elevation of $\approx 30°$
- that allows the sites, when not in use, to have minimal obstructions or extensions above ground.

Our plan is to use a Bobcat or telehandler vehicle to move a modified heavy equipment trailer. Towing the telescope trailer using the hydraulic front forks of these vehicles will allow CMAP to be kept relatively level across the uneven roads. Alternatively, a hydraulically actuated levelling hitch could be used. The trailer we have is rated for $> 30{,}000$ lbs, more than enough for our estimated 10,000 lb load.

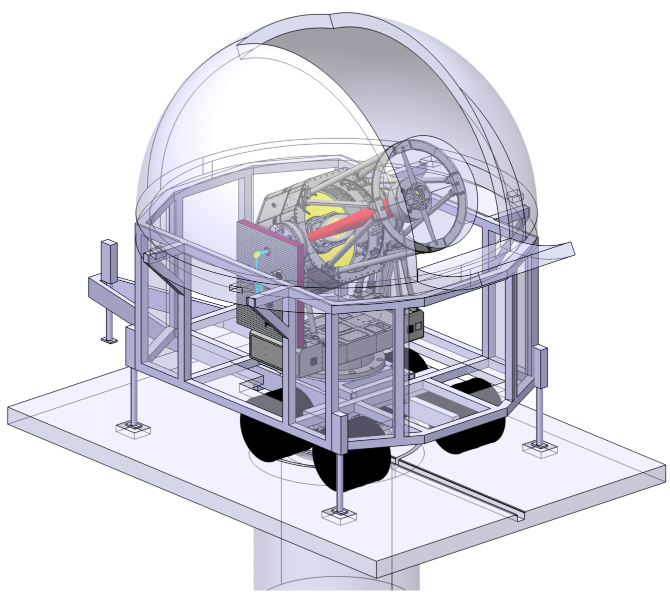


FIGURE 1.: Complete view of the telescope, pad, transport, and dome.

Key for this design (Figure 1) is that this trailer does not have through axles for the two pairs of 4 wheels. This leaves a 31 in square hole in front of the single cross support. Through this hole a support pier can be placed. A cradle structure can support this pier so that the telescope is secured to the frame of the trailer during transport. Once at the concrete pad, the telescope is unlocked from the trailer and can be raised by either chain falls or electric winches a few inches and secured in place. This provides clearance for a lower receiving pier installed on the concrete pad. Once over the lower pier the telescope is unlocked from its raised position and lowered onto kinematic mounts. In this way the telescope is isolated from vibration of the enclosure (See Figure 2).

Above the enclosure we have decided on utilizing a customized 14'6" telescope dome from Ash-Dome. This is similar to our existing 16' Ash domes used on the other Array telescopes. The extra width of the dome is high enough above road level that there is no impediment in moving between sites. The profile of the enclosure and dome can be seen in Figure 3

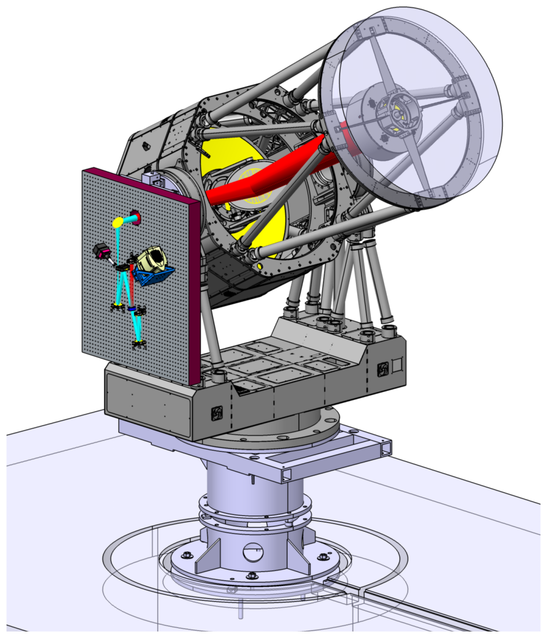


FIGURE 2.: This shows just the mechanically isolated parts of the system: the telescope, upper pier/lifting frame, and lower pier. Here the telescope is installed on the pad with the trailer transport and enclosure is hidden for illustrative purposes. In practice, the trailer/enclosure envelopes but is mechanically isolated from the telescope-pier system.

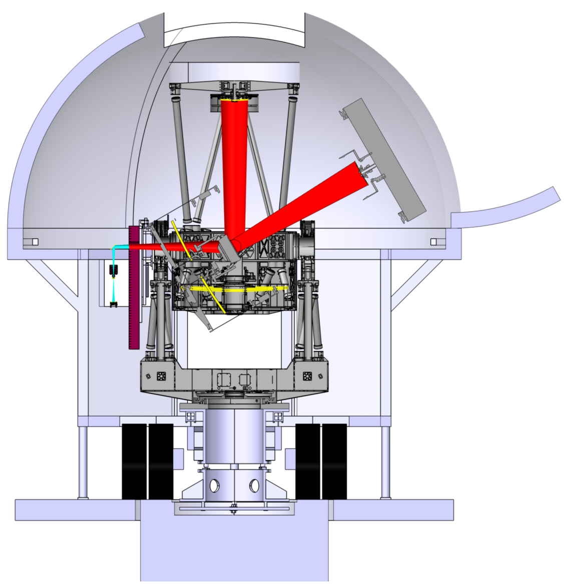


FIGURE 3.: A section view showing the telescope at zenith and at its lower limit of 25° elevation.

3. THE TELESCOPE TRANSPORT AND ENCLOSURE SYSTEM

For this concept, the telescope, its pier and support system, the transport system, and the protective enclosure are a unified design. During transport, the entire system is connected. When stationary, the telescope and its pier are isolated from the transport and enclosure.

3.1. The Pad, Preparation, and Pier

In common with a traditional fixed telescope, the site will host a substantial concrete pier and a pad. The pier will be a concrete cylinder poured below ground level to the depth required to provide stability. The exact depth may vary with the location, soil and subterranean conditions of the decomposed granite substrate. This concrete pier will support the steel pier of the telescope. The surrounding, but isolated, pad will support the trailer and enclosure (See Figure 4).

There will be vibration reducing fill material in the gap between the concrete pier and the pad and at the locations for the trailer support jacks. The pad and pier will have a

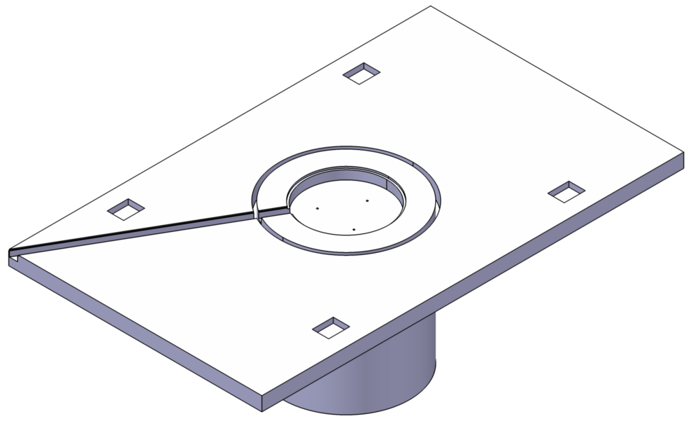


FIGURE 4.: At each CMAP location there will be constructed a 20 foot long rectangular concrete pad. The widths of the pads will vary depending on the specific site, but will nominally be 14 feet wide. In the center will be a gap in the concrete to isolate the telescope pier. A covered channel for optical fibers, internet, and power will be run in the pad concrete. The center pier will be both mechanically isolated and sunken below the outer pad surface by 6 inches. Embedded within this center concrete pier will be sockets for 3 long threaded rods. This position will normally be covered by a metal plate that can be removed and replaced with the lower pier of the telescope mount. The four rectangular depressions in the pad are the contact points for the trailer's stabilizing jacks and may be filled with a dampening material to reduce the transfer of vibration from the enclosure to the center pier.

covered channel for fiber, data, and power cable routing. This channel will go from the concrete pier to the edge of the pad. Further details about the pads and their specific requirements will be discussed in a future TR.

When a site is not in use, it is required that the surface is flat and does not obstruct use of the area and does not create a hazard. For this purpose, the concrete pier is sunken below the road grade and a steel cover plate can be fixed above the pier (See Figure 5). Embedded in the concrete pier, steel sleeves with 1 inch female threaded holes serve as attachment points for threaded rods or bolts that hold the cover plate in place. The cover weighs 500 lbs and will be moved with a crane or Bobcat. The pad and concrete pier will need to have planning for adequate drainage.

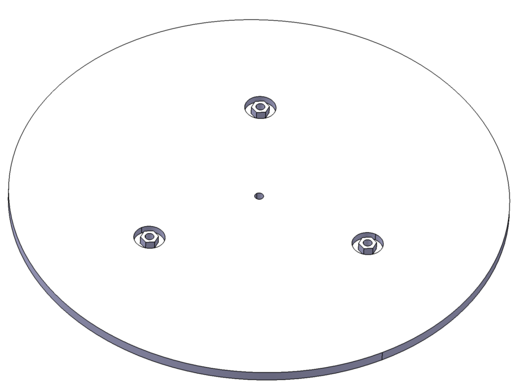


FIGURE 5.: This is a detail of the concrete pad cover plate. It can be bolted to the three threaded rods coming from the concrete pier. To aid removal there is a center 1 inch threaded hole to mount an eyebolt.

Atop the concrete pier, there is an acceptor plate (Figure 6). This plate mounts to the concrete pier via 1 inch threaded steel rods and rests on corresponding washers and nuts.

Slotted holes in the plate allows the plate to be adjusted in rotation and leveled during the initial install. Once installed, the acceptor plate can remain in position indefinitely and is protected by the pad cover plate when not in use. Having the plate raised off of the concrete protects against corrosion and provides space for drainage. The plate has three 2 inch kinematic mount points of the plate, vee, socket type. These accept the lower pier (discussed below). There are also holes for capture bolts to secure the pier.

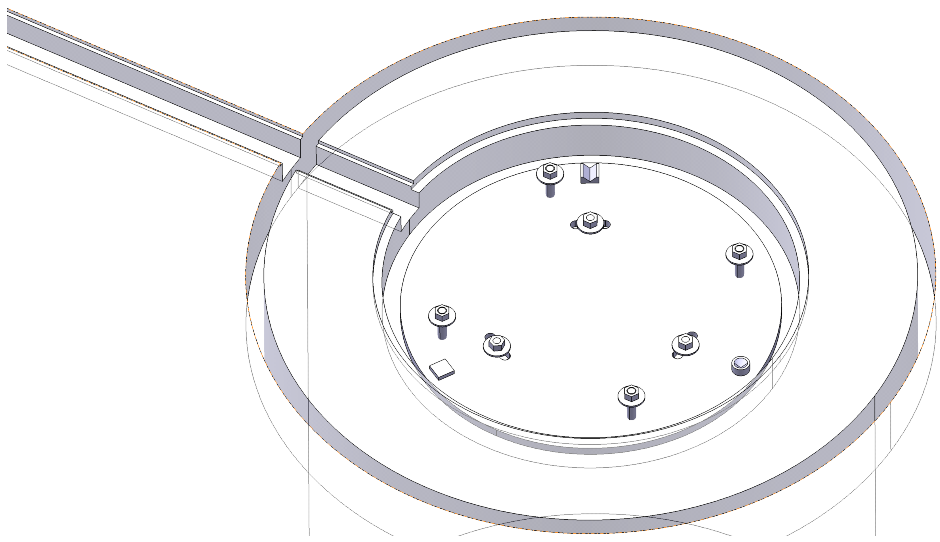


FIGURE 6.: Underneath the pad cover plate an acceptor plate is installed. This 1 inch metal disk is supported to the concrete pier by three 1 inch threaded bolts. The washer, nuts, and slotted holes allow this plate to be adjusted. Rising up from this plate are 4 locator pins/telescope safety points used to guide the telescope lower pier onto the plate and lock it to the acceptor plate. Three kinematic points are mounted on the plate.

To facilitate the transport of the telescope system while keeping an unobstructed pad, it was necessary to separate the steel pier commonly seen in telescopes into two sections. The lower section (Figure 7) is moved into place after the cover is removed and before the telescope is moved over the concrete pier. At this stage of development, we have assumed a 24 inch diameter, 1 inch thick steel pier core with added gussets to increase rigidity. This pier core has end caps that have a larger diameter to better match the base of the telescope mount. The final design may have a different diameter, thickness, and gusset layout after optimizing for reducing vibration.

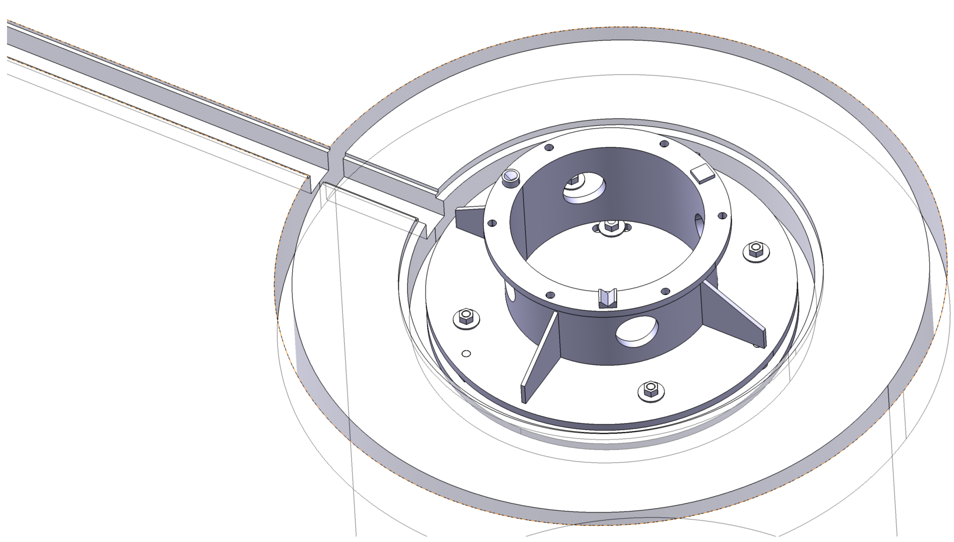


FIGURE 7.: This is the telescope lower pier. Underneath it has the three counterparts to the acceptor plate kinematic mounts. The pier is lowered onto the plate using the guide pins and settled onto the kinematic points. Once in place the four threaded guide pins can be used to lock the lower pier using washers and four nuts. These are not tightened but left with only light contact to protect the telescope from tipping in the event of misfortune, for instance a seismic event.

Underneath the lower pier are the three 2 inch spheres for the kinematic mount receptors on the acceptor plate. It is installed on these and then the safety capture bolts are secured, loosely or with springs so as to not over-constrain the system (See Figure 8). On top of the lower pier is another set of kinematic mounts. Both the lower and upper piers are gusseted for added strength.

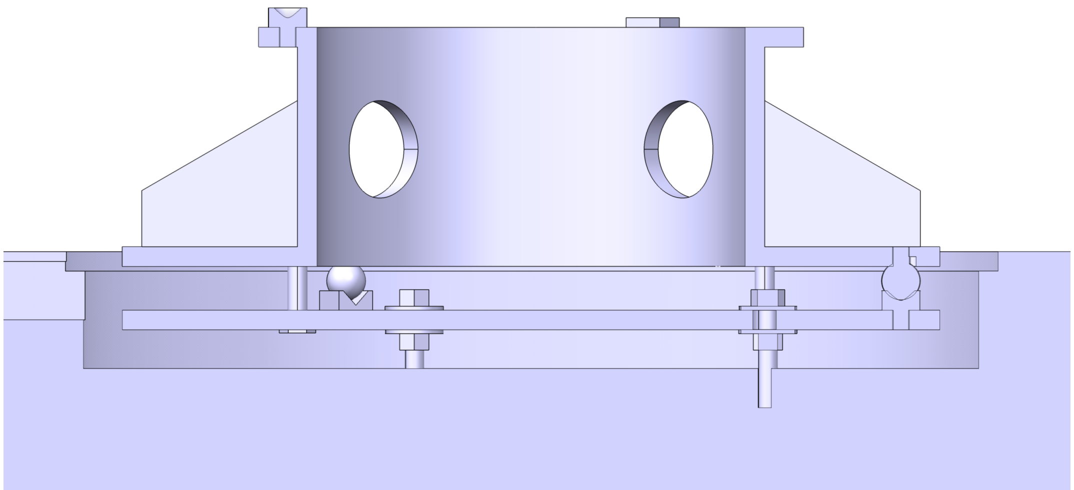


FIGURE 8.: A section view of the lower pier/acceptor plate/concrete pier assembly. The holes in the walls of the lower pier allow for cables to pass through the telescope and upper pier and out through the lower pier.

3.2. The Telescope Transport and Operations

There are options available for transporting telescopes, but to suit our needs we chose to develop a custom trailer system. This trailer will safely and reliably convey the CMAP telescope across the sites on Mount Wilson. The requirements for the 1-meter Planewave telescope and the attached Adaptive Optics Board (AOB) and our site requirements for transport across Mt. Wilson Observatory drive the design for the CMAP Telescope enclosure and transport.

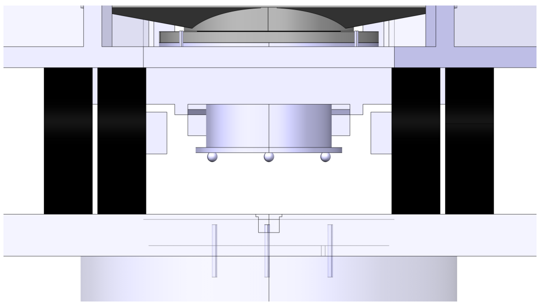
The dome is a custom 14 foot 6 inch model from Ash-Dome. This dome has an added lower skirt to raise the horizon and allow clearance for the dome AZ motor and to allow the telescope access to a lower elevation limit of 25°.

The telescope rests on a steel upper pier that is captured within the frame of the trailer. As mentioned previously, a requirement of the sites is that when not in use there is only a flat pad. So this upper captured pier remains attached to the telescope at all times and mates with the removable lower pier on site. This also provides adequate ground clearance for the trailer during transport (Figure 9a). The steel pier also serves to lower the center of gravity of the telescope for the lifting process.

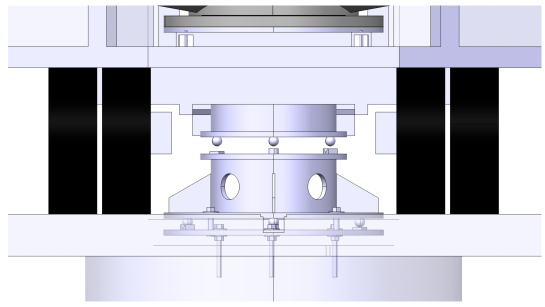
To ensure the safety of the telescope during transport this structure may be bolted to the trailer frame, and two crossbeams are installed in the walls of the enclosure on load bearing points. Upon reaching the observing pad, the telescope is unbolted from the trailer. Using 4 chain falls or electric winches attached to the crossbeams the telescope can then be lifted up off of the frame along 4 guide pins. Once raised the telescope may be locked in place approximately 3 inches higher than the frame. The locking mechanism remains to be designed but could be a set of blocks that interlock with the frame and bolt in place. The trailer is then parked over a removable lower pier (Figure 9b). The telescope is then lowered 1 inch so it can be bolted to the lower pier while remaining above the trailer frame (Figure 9c). This serves to isolate the telescope mechanically from the trailer, enclosure, and dome.

The upper pier is welded to two hollow square steel beams that make up part of a cradle to lift the telescope into place for observing (See Figure 10).

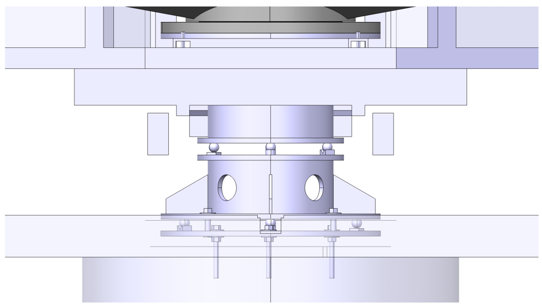
The support structure (Figure 11) within the walls of the enclosure must support the weight of the dome and, during lifting, the telescope and upper pier. For the current model 4 inch square steel tubes are used. Exact design and the required thickness of the walls of the tubes is TBD upon analysis by a mechanical engineer. For the lift procedure, removable cross-beams are added. These stiffen the side walls of the support structure and serve as attachment points so the winches are above the lift points of the cradle. A requirement for these crossbeams is that they can be installed by two people without aid of equipment.



(a) Transport



(b) Raised



(c) Observe

FIGURE 9.: A section view showing (from bottom to top) the concrete pad, the adapter plate that connects the lower steel pier via kinematic mounts, the mating of the lower pier to the upper pier also via kinematic mounts, and the telescope and trailer above. (*a*) The telescope in the transport position with the lift plate and the trailer frame locked in contact; in this configuration the trailer can be moved across the observatory grounds. (*b*) The telescope in the raised position with 3 inches between the lift plate and the trailer frame and moved over the lower pier. (*c*) The telescope in the observe position, connected to the lower pier.

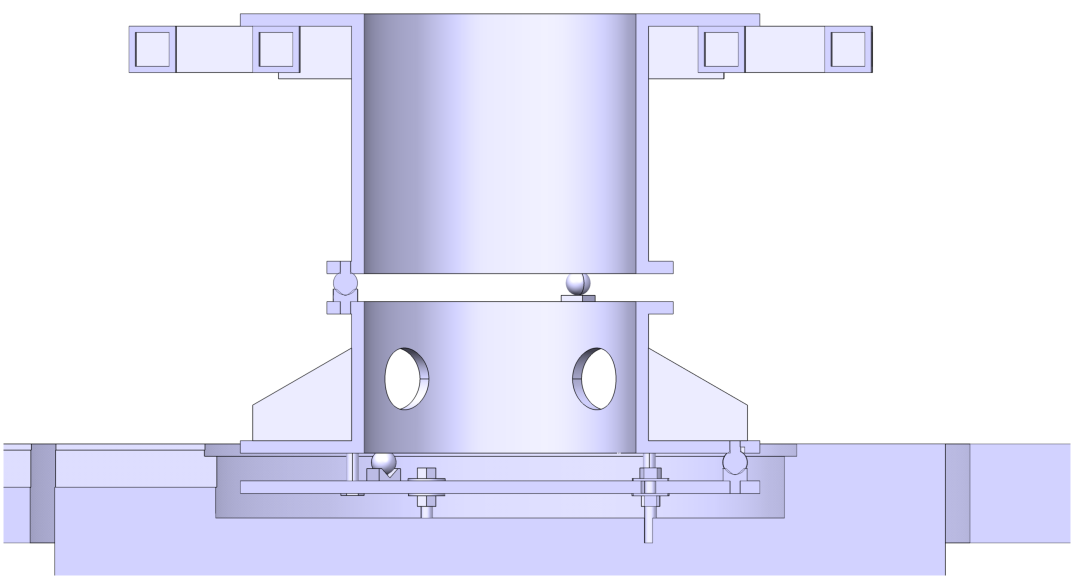


FIGURE 10.: A section view of the lift plate/upper pier/lower pier/acceptor plate/concrete pier assembly in the kinematic contact position for observing. At this angle the gusseting of the upper pier is not visible

There are several commercially available rigging trusses that have adequate strength to support the weight of the telescope and pier.

The overall dimensions and approximate weights of the components that need to be moved or lifted are given in Table 1. The total weight of the telescope, Adaptive Optics Bench (AOB), lifting plate, and upper pier that need to be lifted as a unit to position the telescope on the lower pier is 4200 lb.

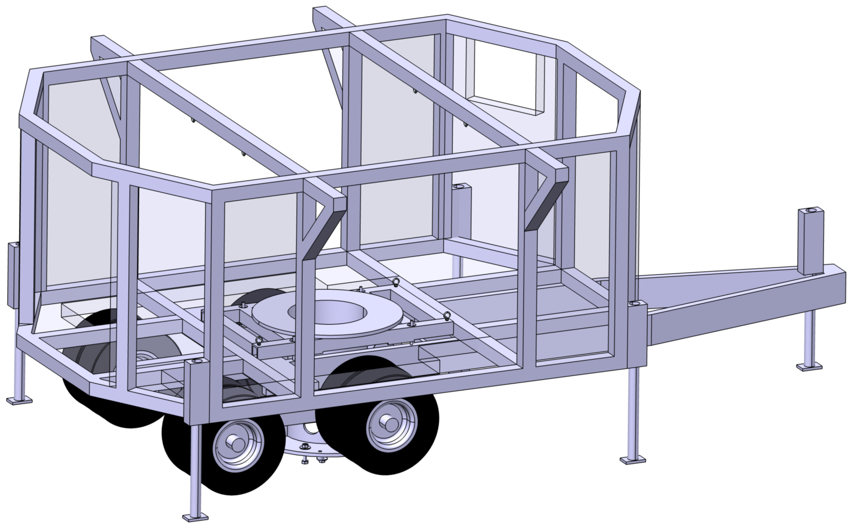


FIGURE 11.: Detail of the support frame and lifting frame. Here the two crossbeams are installed across the top of the support frame for lifting the telescope.

Part	Dimensions (X x Y x Z or R x Z, in)	Weight (lb)
Pad Cover	23.875 x 1	500
Lower pier	21 x 12.25	675
Upper pier	21 x 21	760
Lifting Plate	60 x 37.25 x 3.75	440
Telescope	36 x 133	2600
AOB	47 x 40 x 2	400
Dome	87 x 87	2400

TABLE 1.: Dimensions and approximate weights of components. The assumption is A36 steel for all parts other than the telescope, AOB, and dome. The widest dimensions of the upper and lower piers are given, the cores of the piers have a 12 inch radius.

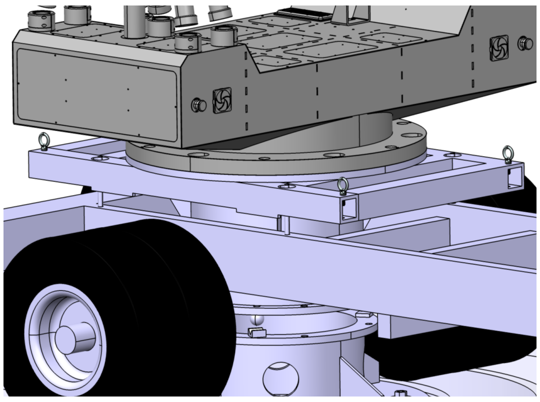
3.3. Observing Operation Procedure

To reiterate, here is the process step-by-step to install the CMAP on a observing station:

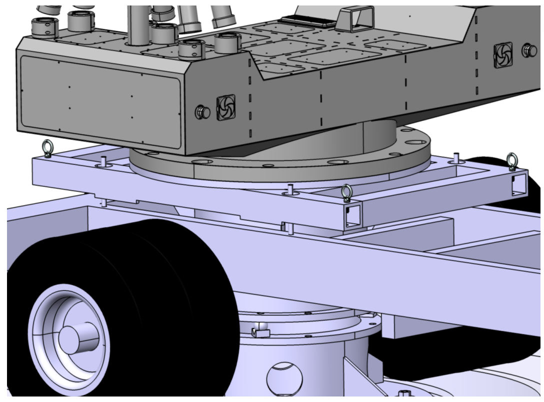
1. The steel pad cover is removed with a crane or Bobcat. This exposes the pier adapter plate that receives the telescope lower pier. The position of this plate can be adjusted at initial install but otherwise one remains fixed in place at each site.
2. The lower pier is lowered onto the kinematic points using a crane or Bobcat. Safety bolts are secured to hold in an emergency but not over-constrain the mount.
3. The telescope is raised from its transport position and locked into its raised position (Figure 12a) using chainfalls or winches mounted on the crossbeams.
4. The trailer is slowly moved over the lower pier.
5. Once in position, the telescope is lowered so the upper pier mates onto the kinematic points of the lower pier (Figure 12b). Safety bolts are added here as well.
6. Corner jacks are lowered to stabilize the enclosure.
7. The crossbeams and winches are removed and (optionally) the wheels are removed for further isolation.

Once installed on the pad, the telescope and its pier are isolated from the trailer/enclosure by ≈ 1 inch. The trailer corner jacks can come down to support and stabilize the enclosure. Optionally the trailer wheels can also be removed in the case of long term positioning at a site.

As with all other CHARA Array telescopes, once in place the CMAP telescope will be remotely operable from the CHARA control room.



(a) Raised



(b) Observe

FIGURE 12.: (*a*) The telescope is raised at least 3 inches and locked. The trailer is then positioned over the lower pier. The telescope is unlocked and the upper pier aligned with the lower pier. There are four guide pins that correspond to oversized holes in the lifting frame. This keeps the telescope always safe from unexpected or dangerous movement and also allows for some lateral and angular adjustments when connecting the two piers. The telescope is then lowered 1 inch and the upper and lower piers are connected. The telescope is then 1 inch above the trailer frame and only in physical contact with the pier. (*b*) The telescope connected to the lower pier and ready for observing. Note the clearance between the lifting frame and the trailer frame.

4. SUMMARY

The addition of the CMAP 7th telescope for the CHARA Array is truly a pathfinder. Expanding the number of available baselines for the array, filling in *uv* coverage at short baselines, and extending our long baselines to reach unprecedented angular resolutions will be a significant achievement. The mobile enclosure solution we have envisioned opens up possibilities for reaching this goal.

At this stage:

- the Planewave 1m telescope is expected to arrive Fall 2023.
- the Ash Dome is ordered and expected to arrive in Spring 2023.
- We have the base trailer for the preliminary design we have shown here and are in the process of structural and vibration analysis.
- Modifications to the trailer, including the addition of fail-safe redundant braking systems are underway.
- Design work remains to be done related to routing of fiber optics and electrical wiring.
- Fabrication of the enclosure should begin in Spring of 2023 as well.
- During Spring/Summer of 2023 the sites will be prepared and concrete pads poured.

The design presented here meets the basic requirements stated earlier in this document but will likely evolve after input from mechanical analysis. The dimensions of structural elements have many free parameters and still need to be optimized for vibration, weight, ease of construction, and stability. Lessons learned from the construction of the CMAP will likely feed forward and inform the design of future telescopes to be added to the CHARA Array.

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A. DIMENSIONS OF COMPONENTS

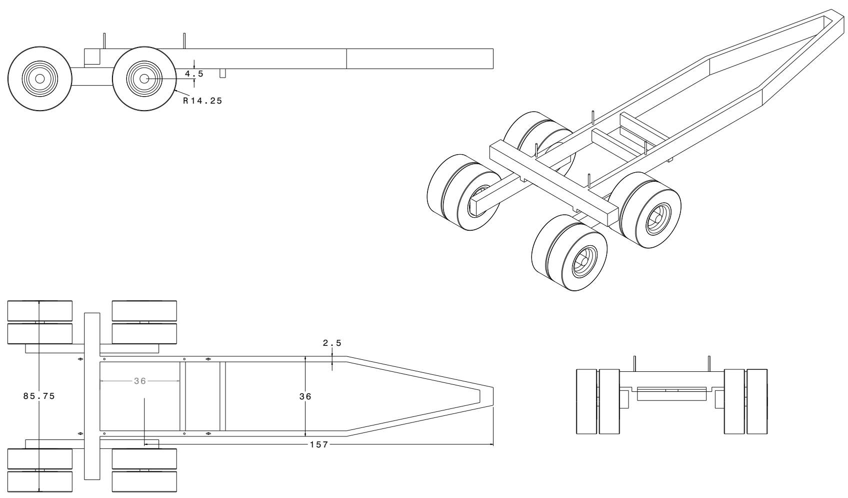

FIGURE 13.: The telescope trailer with dimensions. All measurements are in inches.

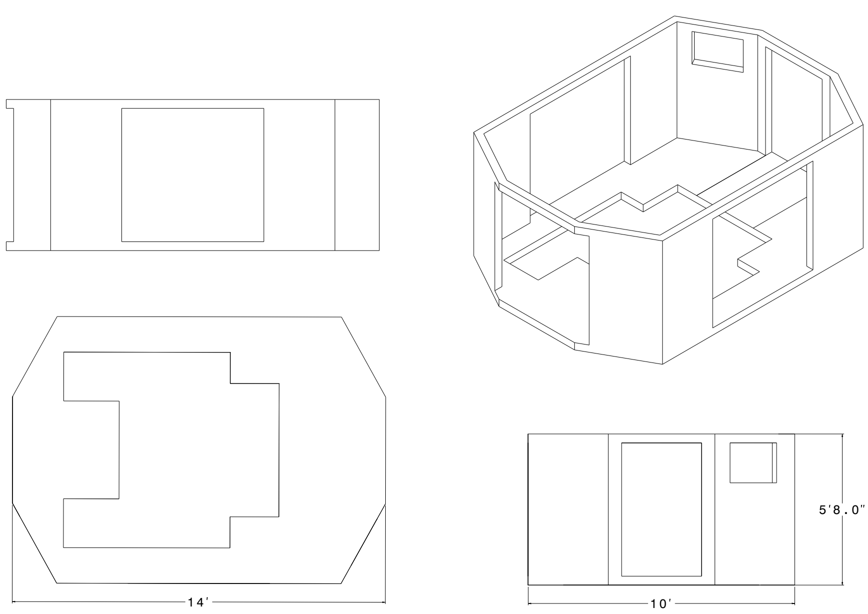

FIGURE 14.: The enclosure room itself with dimensions and cut-outs for roll-up doors, normal doors at each end, and cut-outs for an AC unit. Clockwise from top left: long dimension side view, above perspective view, narrow dimension side view, and plan of the floor. There is a large floor cut-out that can be covered that provides access to the telescope lifting frame and trailer frame.

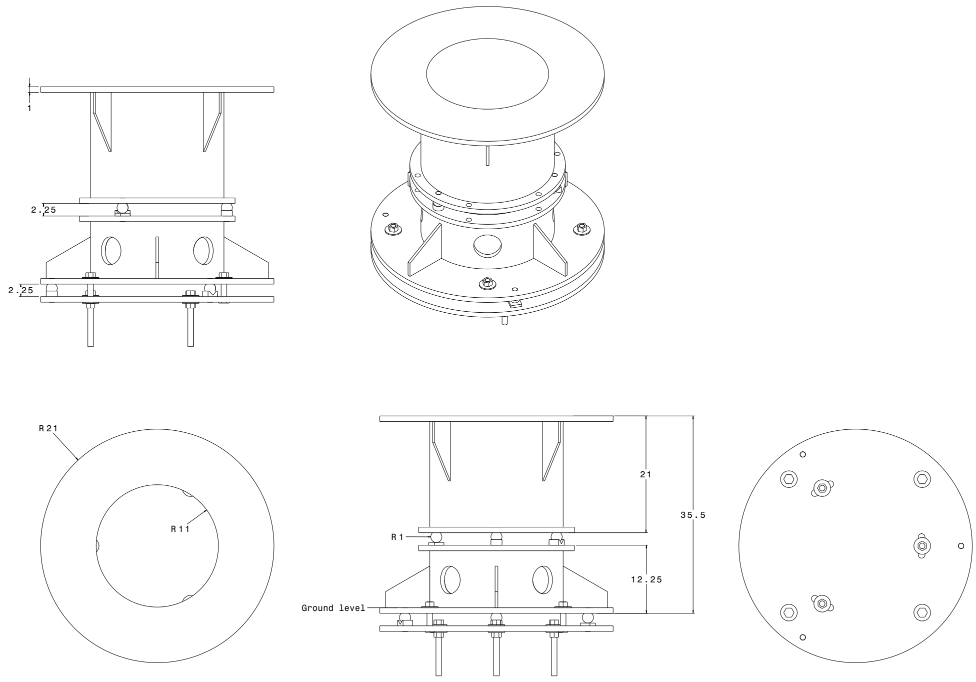

FIGURE 15.: Dimensions of the combined pier. The upper and lower sections are connected by 2 inch kinematic mounts. The lower pier has holes in the sidewall to allow access for cable pass-throughs from the azimuth axis of the telescope. The bottom of the lower pier also has kinematic mounts to connect to the acceptor plate (lower right) which lies below ground level and connects to the concrete pier. All dimensions are in inches.

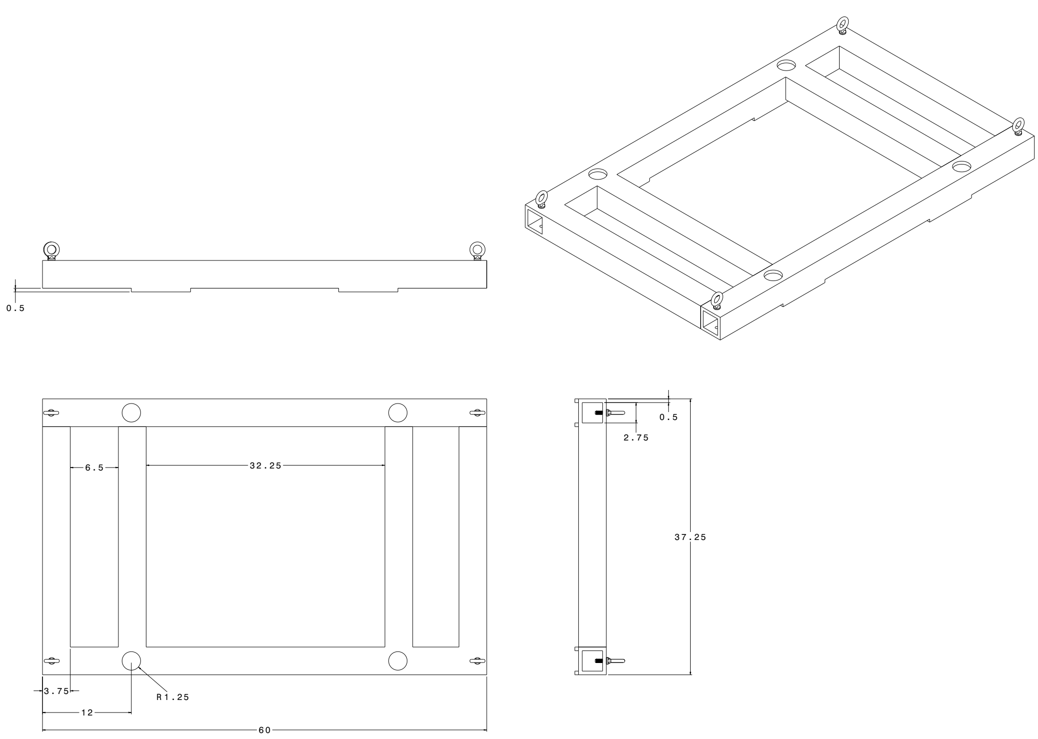

FIGURE 16.: Dimensions of the lifting plate that is attached to the upper pier and telescope adapter. This is permanently attached below the telescope, welded to the adapter plate and upper pier, and is used as the lifting point for the chain falls or winches that are attached to the crossbeams above. The oversized holes allow for movement of the telescope when mating the two piers while keeping the telescope secured. There are also welded tabs on the bottom of each that help guide the lifting frame onto the trailer frame and secure it for transport along with bolts. All dimensions are in inches.