LCOGT Sites and Facilities

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ABSTRACT

LCOGT is currently building and deploying a world-wide network of at least twelve 1-meter and twenty-four 0.4-meter telescopes to as many as 4 sites in the Southern hemisphere (Chile, South Africa, Eastern Australia) and 4 in the Northern hemisphere (Hawaii, West Texas, Canary Islands). Our deployment and operations model emphasizes modularity and interchangeability of major components, maintenance and troubleshooting personnel who are local to the site, and autonomy of operation. We plan to ship, install, and spare large units (in many cases entire telescopes), with minimal assembly on site.

Keywords: Network, world-wide, modularity, autonomous, interchangeability

1. INTRODUCTION

Building and deploying a globally distributed network of astronomical observatories is a daunting engineering and logistical challenge. Adding to this complexity is the fact that each of our sites will consist of multiple enclosures, telescopes, and support facilities. Among the many concerns that need to be addressed are: existing site infrastructure, varying site characteristics (topography, soils, utility/electrical grid standards, etc.), managing within a limited available footprint, and producing reliable facilities and equipment that have the long mean-time-between-failures required for a truly robotic and autonomous network of observatories.

To efficiently manage these concerns, LCOGT developed a “standard model” of facility design and site layout that enables us to fabricate most components at our company headquarters located in Southern California, where strict engineering and manufacturing control is more easily applied. Our telescope and observatory enclosure designs use a modular approach which allows minimal disassembly into manageable subassemblies for shipping, but also facilitate rapid reassembly on site with minimal decision making during the deployment process. This approach minimizes reliance on differing contractors for construction and deployment, allowing for a greater degree of “as-built” uniformity across all network sites.

Fabrication of telescopes, instrumentation, and electronic control panels all follow the same standard model approach, allowing for easy interchangeability of standard components that are identified as more likely to fail. This in turn reduces maintenance to a relatively simple matter of swapping out a failed module with an on-site stocked spare part, ensuring that the “up time” of that particular network node, as well as the continuity of the global network, is maximized.

2. THE GLOBAL NETWORK

2.1 LCOGT mission

The general mission of the Las Cumbres Observatory Global Telescope network (LCOGT) is to establish a durable scientific institution dedicated to time-domain astrophysics. LCOGT has primarily a scientific directive, but an educational component as well. The more specific scientific focus is discovery/characterization of extra-solar planets, active galactic nuclei, and stellar oscillations/variable stars. The educational component is directed at inspiring critical thinking and technical understanding in young people through collaborations with professional astronomers.

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2.2 Site selection criteria

Achieving our scientific mission requires the development of specialized facilities and equipment, along with deployment to selected locations around the globe. By carefully selecting site locations distributed longitudinally, one or more nodes of the global network will always be in dark skies, allowing for continuous data collection of transient events.

There are several other factors besides longitude that drive our site selections. 1) Astronomical considerations: Obviously atmospheric seeing conditions must be generally arc-second or better, and the fraction of available clear Moonless nights must be high. The sites should be of relatively high altitude to be above local marine layers and/or inversion layers. Also, the separation of the North and South network rings from the equator should be sufficient to allow excellent declination coverage of the sky with generous overlap, especially of the Milky Way bulge. 2) Pre-existing infrastructure: Because of our need to keep costs down and timelines reasonable, establishing infrastructure from scratch at multiple remote locations is impractical. Therefore the only sites under consideration are those that have, at a minimum, power, communications, and reasonable transportation access already in place. 3) Political stability: Although our facilities are generally considered to be autonomous, we do realize that personnel will need to visit each network node several times throughout its life cycle, and personal safety is a serious matter. Therefore countries undergoing severe political unrest or otherwise represent a dangerous environment are not considered, regardless of their other qualifications.

2.3 Chosen network node distribution

Six sites have so far been identified as prospective network nodes. Two of the sites (Hawaii and Eastern Australia) already have 2.0-meter telescopes operational (Faulkes Telescope North and South, respectively), and 2 sites (Chile and South Africa) have all civil work completed and are awaiting the start of our standard facility installation to accommodate a cluster of 1.0-meter and 0.4-meter telescopes. Other sites are in various stages of negotiation, site planning, or groundbreaking.

Table 1. The six known LCOGT northern and southern ring network node locations, listed west and east of Greenwich, respectively.

Site Designation	Latitude, Longitude, Altitude	Location
TFN	28.133650^o N, 16.511619^o W, 2390m	TO, Tenerife, Canary Islands, Spain
ELP	30.680072^o N, 104.014883^o W, 2029m	McDonald Obs., UT, Texas, USA
OOG	20.707058^o N, 156.257375^o W, 3034m	HO, IFA, UH, Maui, HI Islands, USA
LSC	30.167500^o S, 70.805000^o W, 2153m	CTIO, La Serena, Chile
CPT	32.380694^o S, 20.809797^o E, 1759m	SAAO, Sutherland, South Africa
COJ	31.271767^o S, 149.061692^o E, 1144m	SSO, ANU, Siding Spring, Australia

The average network node latitude is approximately +/- 31 degrees of the equator, with a maximum of 32 degrees and a minimum of 21 degrees. In addition to these six, we are investigating possible sites in Asia and Western Australia.

In some cases compromise was necessary in order to fill longitudinal gaps in the network ring. For example, a conceivable Asian site would be Urumqi, China which is not optimal because of its more northerly latitude and lower clear fraction of observing nights. This is a case in which longitudinal coverage is deemed more important for maintaining continuity of the network.

A map representation of the entire LCOGT global network can be seen in Figure 1.

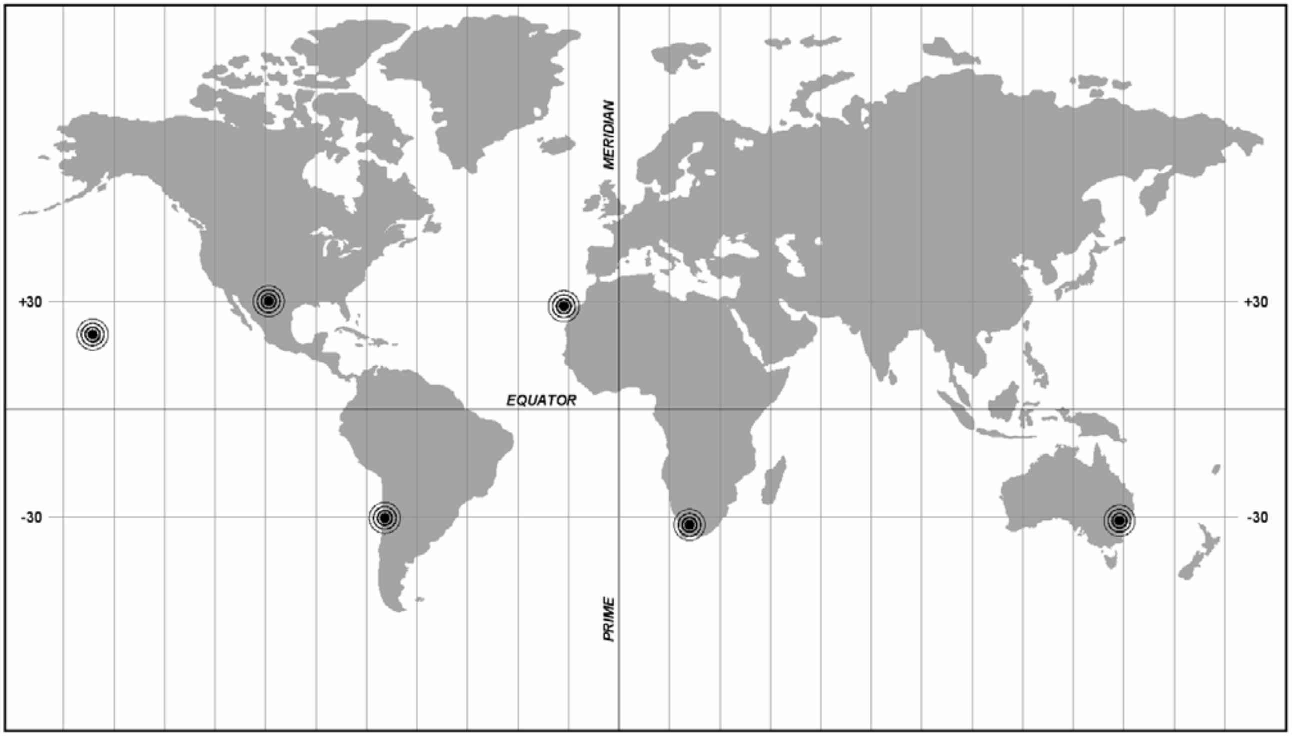

Figure 1. A world map showing all the known LCOGT network nodes in various latitude and longitude positions.

3. SITE DESIGN AND CIVIL WORK

3.1 Site layout considerations

All of our sites are designed to be relatively compact and efficient arrangement to accommodate three 1.0m telescope enclosures, three 0.4m telescope clamshell enclosures called Aqawans (Chumash for “to keep dry”), a site services building (SSB), a weather station tower and a storage building.

The minimum footprint of the site is determined by zenith-angle (Z-angle) analysis. Our requirement is that the maximum zenith angle clearance required for all telescopes on site is 75 degrees, or the equivalent of about 4 air masses. To accomplish this requirement while covering the smallest practical footprint, an equilateral triangle arrangement was adopted. Each side of the triangle measures about 14 meters, which provides just enough space to position the SSB and weather station tower near the center of the layout without interfering with the observatories. The triangle’s orientation varies somewhat from site to site depending on local landscape, but if possible is arranged to take best advantage of prevailing weather patterns and laminar air flow.

The Aqawan cluster must be placed at least 20 meters from the 1.0m cluster to honor our Z-angle restriction, because the 1.0m telescope enclosures are nearly 2.5 times taller than the Aqawans. Likewise, our weather station tower is limited to a height of 5 meters so that it remains invisible to the 1.0m telescopes that surround it. The tower is attached to the SSB so that cumbersome guy wires can be eliminated from the site. The generous spacing between the 1.0m telescope cluster and the 0.4m telescope cluster permit easy ingress and egress by site vehicles, including forklifts, cranes, and other equipment that may be needed for installation and assembly, or maintenance/replacement of larger components.

We also have one permanent storage container (8’ x 20’) on site for storing tools and spare parts, rigging, CO_2 bottles for cleaning optics, and other miscellaneous items.

Figure 2 illustrates the main elements and arrangement of various facilities at a typical observatory site, including the equilateral dome layout. The outer dashed circle represents the open swing radius of the lower shutter door on the 1.0m telescope domes, and the dashed rectangle represents the extent of the opened clamshell roof of the Aqawans. Note that each Aqawan enclosure houses 2 of the 0.4m telescopes (represented by the light gray circles in this schematic).

The SSB serves as central services for the site, distributing UPS power, utility power, and fiber communication to all telescope enclosures and to the weather station, via underground conduit.

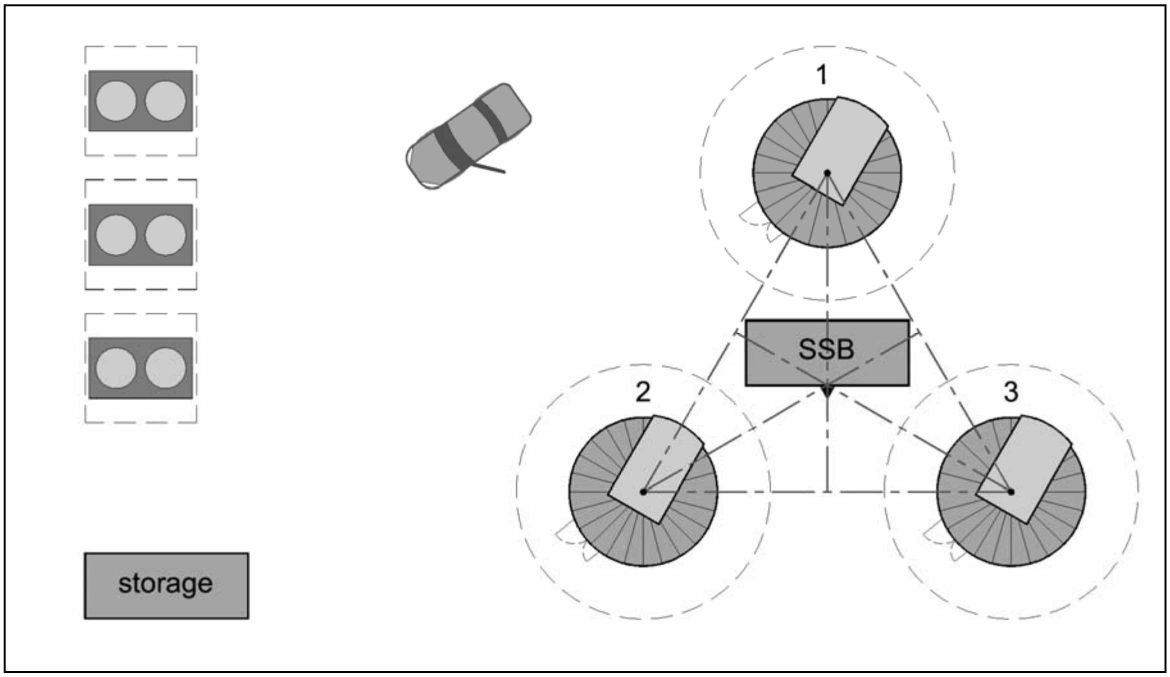

Figure 2. A typical site layout. Automobile shown for scale.

An added advantage of the standard model method of site design and layout is that, barring unusual site constraints, it allows development of relatively predictable costs and timelines for site readiness.

3.2 Site preparations

Most sites require a bit of earthwork before construction can begin. In general we require that soils beneath our foundations are compactable to at least 95%, and that the building pads be reasonably flat. At some sites drastic measures are required to properly prepare the site. In the case of CTIO, for example, our site location is on a rocky slope, requiring that hundreds of cubic meters of prepared fill be built up into a level pad. Once the soil pads are properly prepared, a true north-south line is established, and laying the foundations can begin.

3.3 Foundation requirements

All concrete foundation designs are certified by a civil/structural engineer to ensure that safety and longevity requirements are met, as well as international building codes. Our requirement is that all buildings/foundations be rated to endure earthquake shaking likely encountered in seismic zone IV, and wind loading from 150kph storms. For our 1.0m telescope, the concrete pier is extended down to, and keyed into, bedrock. The piers are engineered to have high resonant frequencies so that they will not excite from wind loading or the fast slew motions of the telescope mounting. Telescope piers are isolated from building foundations by a 25mm foam gap to reduce dome motion vibrations and building wind loading forces transmitted to the telescope, and aligned north-south to within one degree of the pole.

Concrete slabs for the smaller Aqawan enclosures are monolithic and do not contain separate isolated piers for the two 0.4m telescopes. Since the clamshell design of the Aqawan requires that the roof open only once and not move during the night, separate pier isolation was deemed unnecessary.

To ensure that concrete slabs are not compromised in any way, all concrete foundations contain NO penetrations for conduit. All services are brought into the telescope enclosures from trenches that terminate at the foundation edge, then rise up and penetrate directly into the side wall of each facility. Also, since our enclosure walls are engineered to a standard model configuration in advance of site work, no anchor bolts are installed into wet concrete at site. Wet laid anchors invariably get placed at inconvenient or even inappropriate locations, and/or are not plumb. Therefore all concrete anchors for securing walls are drilled and epoxied in place after wall erection, ensuring that their placement perfectly matches what is needed by our pre-fabricated wall modules.

Finally, after the foundations have cured for at least 2 weeks, they are coated with an anti-static paint.

3.4 Electrical distribution, grounding, and lightning protection

Distributing UPS power, utility power, communication fiber, and grounding protection from the SSB to 6 different telescopes on site is no trivial matter. To accomplish this we use an organized system of half-meter deep trenches containing PVC conduit that carries all services connecting all facilities.

To minimize quantity and complexity, we use just one large conduit between the SSB and each building, and this conduit carries all services. Buried at the bottom of each trench is a 15mm stranded copper wire that connects all foundations, buildings, domes, and control panels back to the SSB main grounding bus bar. This bar is solid copper, 100mm wide by 6mm thick, by 3 meters long, and tin plated for corrosion protection. All the SSB's internal control panels ground to this bar, and the bar itself is grounded to the trench-buried stranded copper "ring" running throughout the site by the two copper grounding wires (shown in Figure 3) extending downward at either end of the bus bar. This system should provide adequate protection from transients and lightning strikes.

The SSB wire trough, essentially a weather tight galvanized box measuring 25cm x 25cm x 3m, provides the gateway between the site services building control systems and the various facilities scattered throughout the site. All services, whether power, fiber, grounding, or even compressed air, pass through this trough. Figure 3 below illustrates the various arrangements of components into and out of the SSB wire trough. The five holes indicate penetration into the outside wall of the SSB.

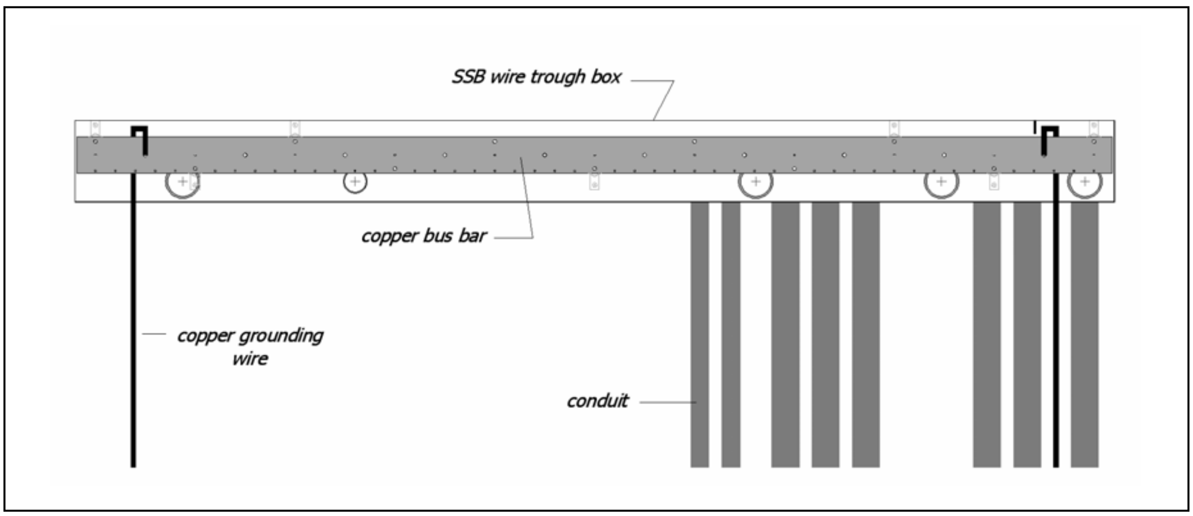

Figure 3. A typical SSB wire trough "standard model" layout. Cross-section with major components labeled.

All distribution from within the SSB to the outside world occurs through the five hole penetrations shown. Holes from left to right are: communication fiber out; spectrograph fiber in (from telescope); UPS power out; utility power out; and utility (site) power incoming. A single disconnect breaker switch is positioned near the incoming utility power, and tripping this switch powers down the entire observatory complex.

Conduit drops from left to right are: compressed air in; services out to weather station tower; services out to Aqawan cluster; services out to dome A; services out to dome B; services out to dome C; services out to dome D; and site utility services (power and fiber) incoming. There is also room for an extra 75mm conduit for uses that we have not yet thought about. We're confident those uses will be forthcoming!

4. FACILITY DESIGN AND CONSTRUCTION

4.1 1.0m telescope enclosure requirements

Required maximum tolerances for telescope enclosures:

- Wind speeds of 150kph in the closed condition. Must close safely in 60kph winds.
- Light-tight, to allow daytime calibrations.
- Telescope can move to all operating angles inside closed enclosure, and enclosure can completely close regardless of telescope position.
- Watertight against driving rain during winds mentioned above and during fog.
- Dust-tight against winds mentioned above down to sand-sized grains (0.0625 in).
- Thermal insulation to maintain daytime internal temps as close as possible to night-time operating temps.
- Telescope and all mirrors/parts should equilibrate to night-time operating temperature within 45 minutes of first opening enclosure (open e.g. 30 minutes before sunset).
- Enclosure opening/closing time to be less than 90 seconds.
- Enclosure opening mechanism to be maintained ice-free and protected from dust accumulation.
- Withstand direct lightning strike up to 120ka.
- Battery power (UPS) to close enclosure during sustained power-failure.
- All electrical services are wall surface-mounted for easy access, troubleshooting, and maintenance.

4.2 1.0m telescope enclosure design

As mentioned above, our building structural requirements are stringent and numerous. In addition, our "standard model" approach of pre-fabrication at our plant rather than on site requires that the observatory's circular wall be modular, with the ability to break down into 6 arcs that can be easily packed, shipped, and reassembled on site with a high degree of precision in a short period of time. To accomplish this, we developed a wall framing design built entirely from 16 gauge galvanized metal components, including 2x6 studs, top and bottom plates, and connector strapping.

Central to the design is specially fabricated curved metal 2x6 "track" that serves as the top and bottom plates of the wall, within which the metal 2x6 studs fit. This track is bent into the proper wall radius by crimping the inside edge every 75mm which creates "cells", and 171 of these cells combine to form a complete circle. These cell positions are then used to precisely define the locations of wall studs, fans, electrical penetrations and connections, external and internal siding attachment points, and the break points where the wall is divided into six arcs or modules.

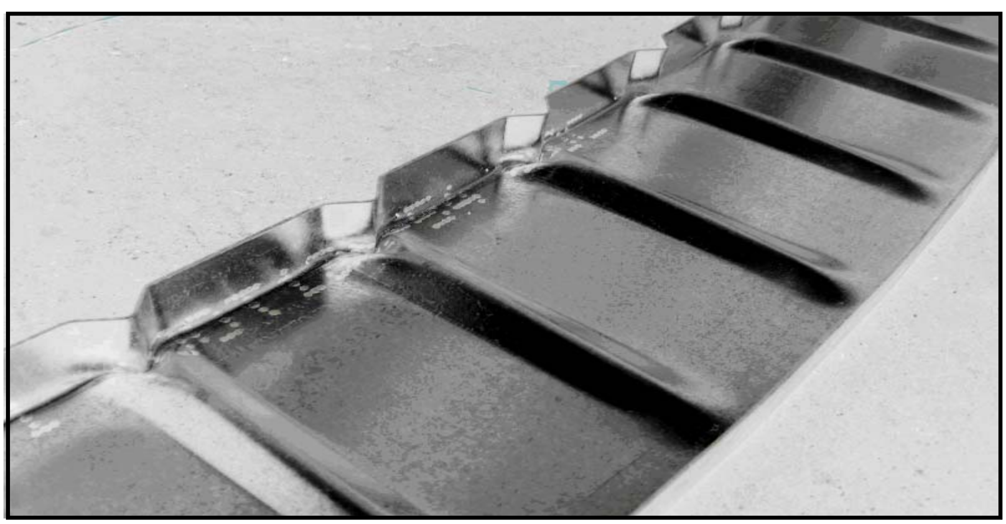

Figure 4. Photo of a section of the crimped bottom wall plate, showing "cells".

This ability to precisely define positions of every component of the wall system is key to enabling the manufacture of good replicas. With perhaps two dozen of these telescope enclosures eventually shipping to remote sites, having a consistent and known as-built condition is invaluable during deployment and maintenance operations.

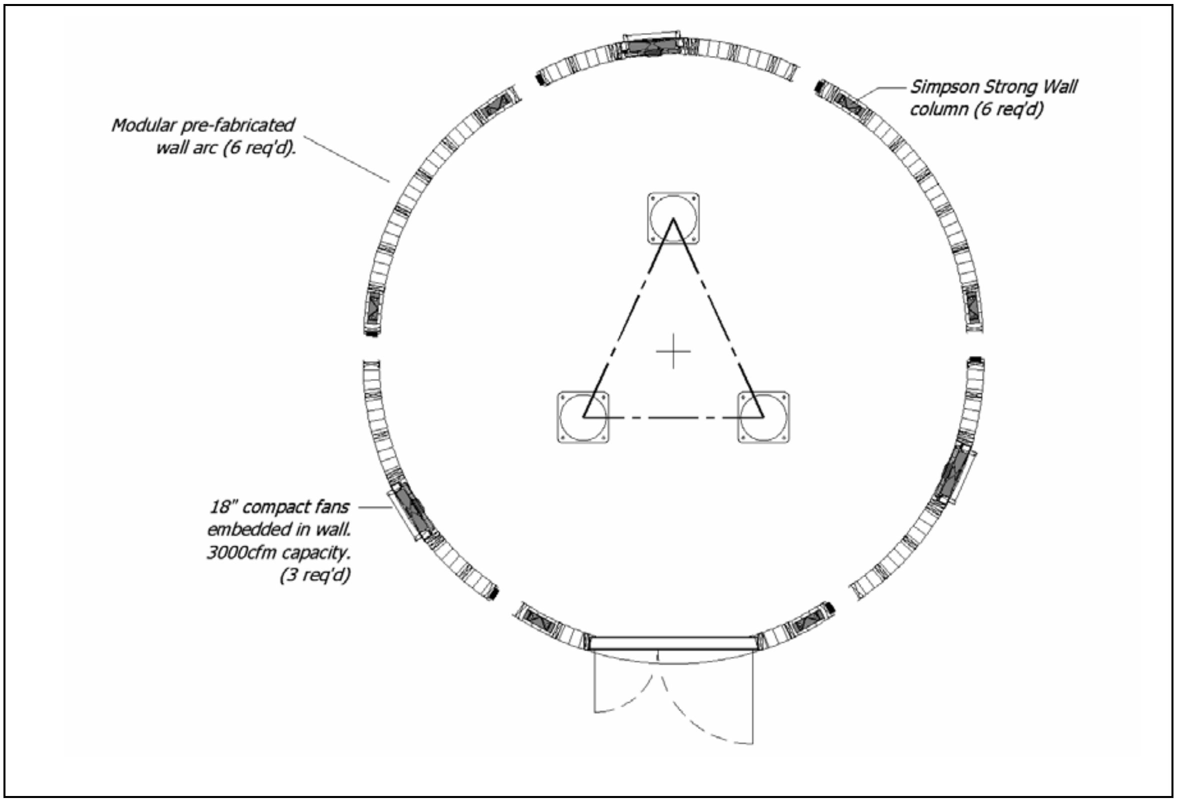

Figure 5. Exploded top view of 1.0m telescope enclosure's six wall modules, with major components labeled.

We use domes made by Ash Manufacturing Company, in Plainfield, Illinois, USA. Our domes are approximately six meters in diameter with an extra wide 2.1m shutter aperture (the wide aperture allows craning the telescope mounting into the enclosure in one piece). With our current 1.0m telescope configuration inside, we have a viewing angle range of seven degrees above the horizon to three degrees past the zenith. It would seem that a 1.0m aperture telescope with an f/2.5 primary is just about the largest instrument that can be housed within a dome of this size. Our swing clearance inside the dome is only a few inches.

The Ash dome was ordered equipped with four contactor bars on the dome ring for power transfer, and with the hydraulic lower shutter option. In addition, several modifications to the dome are deemed necessary to fully meet our needs. These modifications are implemented by us and not by Ash:

- We increased the clear swing radius by modifying some components of the dome interior.
- Added a robust labyrinth around the azimuth ring to create better light & dust tightness.
- Added extra/improved limit switches and proximity sensors to both shutter doors.
- Improved neoprene seals around shutter doors.
- Designed an azimuth drive mesh adjustment mechanism to eliminate spur gear thumping.
- Upgraded azimuth drive motors and gearboxes to allow triple speed and better performance.
- Improved and added tie-down points between dome and walls for better structural integrity.

The domes are grounded to our site grounding system with two stranded copper wires attached to dome wheel mounts separated by 180 degrees in azimuth. All our domes and other buildings on site are painted with titanium dioxide white paint. This paint contains a high (38%) solids content that has good broad-spectrum reflectivity (92%) that lowers building internal temperatures by several degrees Celsius vs. the unpainted condition. Figure 7 below illustrates pointing range as well as the scaled size of the telescope relative to the dome internal clearances.

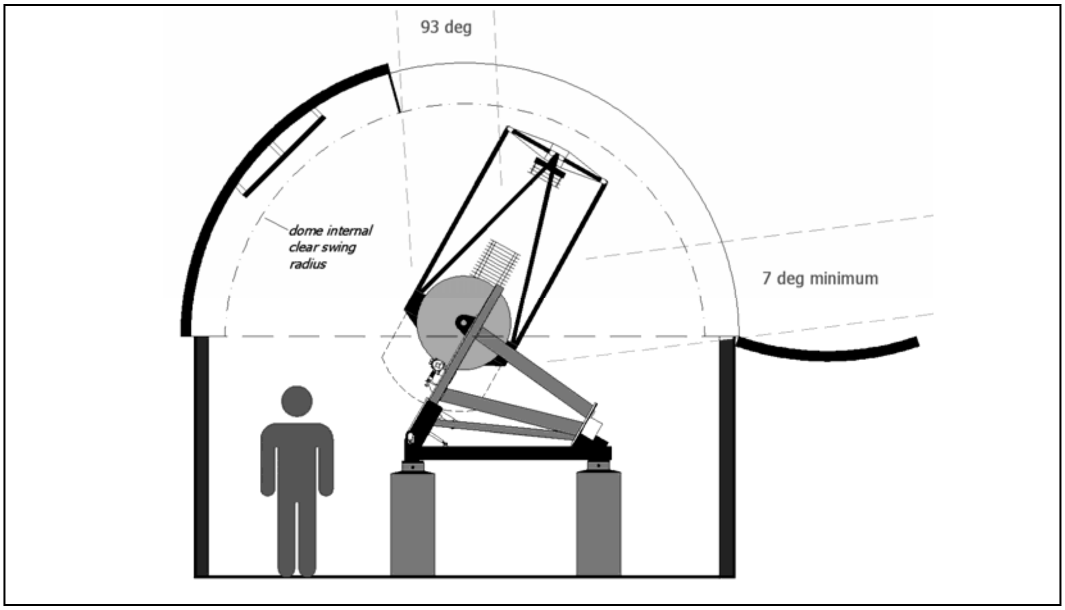

Figure 6. A typical 1.0m telescope enclosure cross-section. Person shown for scale.

4.3 0.4m telescope enclosure design

The 0.4m enclosure is a “clamshell” design similar to but much smaller than that used for the “Monet” telescope located at McDonald Observatory, Texas. However our enclosure employs many innovations that greatly improve operating reliability and weather tightness. For the most part, this design is a cost-driven solution to accommodate two telescopes within one enclosure, although reliability is also a factor. The footprint of the enclosure is about 2.5m by 4.5m.

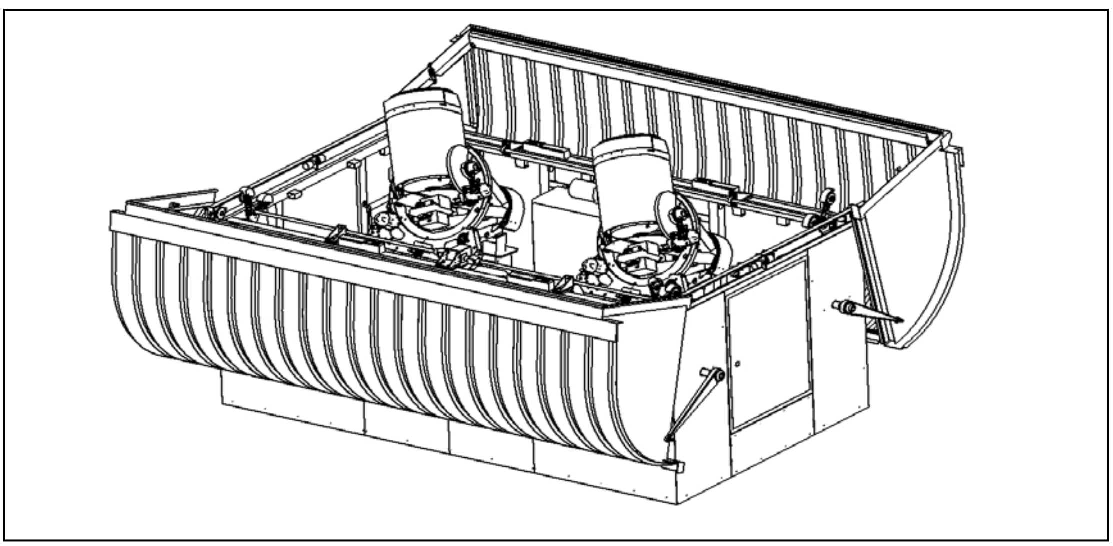

Figure 7. An isometric view of the dual 0.4m telescope enclosure called “Aqawan”, designed by Annie Hjelstrom.

4.4 Support facilities

Each site has three support facilities: the SSB mentioned earlier but to be discussed in more detail here; a weather station with full compliment of instrumentation, and a storage building.

The Site Services Building is a specially modified steel shipping container, ISO certified for international travel. The SSB is the central nervous system of the site, distributing all services to facilities as required. It houses:

- IT rack with computers for telescope control and data reduction.
- Uninterrupted power source
- Key access control box
- Spectrograph

The building is equipped with air conditioning sufficient for the removal of approximately 3000 watts of heat generated by various electronic components inside. The A/C unit will run during the day, but at night ventilation fans take over and use the cool night time air to dissipate this heat, which eliminated the concentrated heat plume of the centralized A/C unit. The fans are capable of flushing the entire volume of the SSB about once every 30 seconds.

Figure 8. A typical Site Services Building before outfitting with electronics, computers, and other components.

A weather station is also an integral part of all sites. We use a fiber fed Campbell Scientific station with tower mounted instruments as follows:

- Temperature/relative humidity probe
- High accuracy temperature/relative humidity sensor
- High accuracy temperature/relative humidity monitor
- Leaf wetness sensor
- Wetness sensing grid

- Rain gauge
- Barometer
- Pyranometer (solar radiation monitor)
- Electric field meter (lighting detector)
- Particulate monitor
- Boltwood cloud sensor
- Ultrasonic wind sensor

Because of the autonomous nature of our observatory sites, weather data generated by this system has the ability to cause the telescope enclosures to automatically close to ensure the safety of telescopes and equipment.

5. SHIPPING, DEPLOYMENT, AND MAINTENANCE OPERATIONS

5.1 Shipping considerations

Our modular component designs allow packing into shipping containers efficiently. Enclosure walls separate into six arcs that nest nicely into the container space (See Figure 9 below).

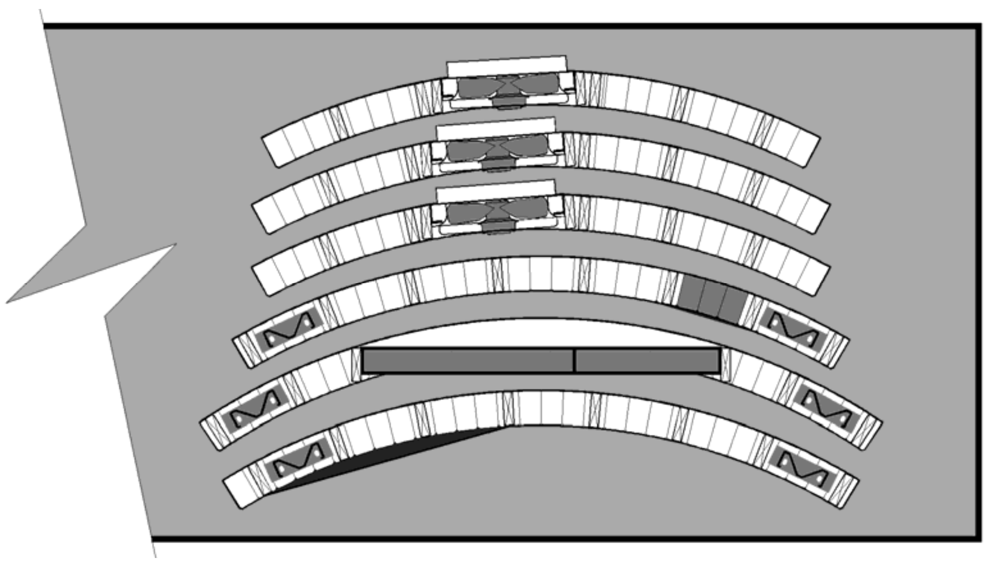

Figure 9. Enclosure walls separate into six arcs or modules that nest nicely into a standard shipping container.

Wall modules, spare parts, etc. are palletized inside the shipping container for ease of loading and unloading. The 1.0m telescopes will ship in two major assemblies: the OTA and the mounting. Optics are removed and packaged separately for their safety. Both M1 and M2 have specially designed containers to protect them during shipping. All components necessary for reassembling one 1.0m telescope are packaged and shipped inside one standard 8’x20’ shipping container.

5.2 Deployment of facilities

Once at site, all facility and telescope components can be rapidly deployed. Enclosure wall modules can be unpacked and assembled in only a few hours with no on-site construction other than drilling holes for anchor bolts, and with simple hand tools. Each wall module is designed to be handled and positioned into place by no more than 2-3 workers, and three sets of wall modules can be assembled on site in just one day. Domes are delivered to site directly from Ash Manufacturing and assembled weeks ahead of time by local observatory support personnel, so once our wall assembly is complete the domes are ready to be craned onto the wall units. This pre-planning and pre-assembly of components and modules should allow us to completely deploy three 1.0m telescope observatory facilities in just one week once our personnel arrive on site. Aqawans are likewise assembled from six smaller sub-assemblies in less than one day.

The SSB arrives on site at the same time as the enclosure wall modules, and is installed on its four concrete pads in a matter of hours. It arrives fully populated with all control systems, IT racks, computers, etc. The only work needing to be done inside the SSB is to install batteries into the UPS, and computers into the IT rack. At this point all wire pulls can be performed and connections and terminations made between the SSB and the telescope enclosures. Telescope shipment is timed for arrival after the site facilities are fully tested and operational. In this way the telescope deployment crew can concentrate solely on that task for best efficiency.

Because of pre-planning and pre-assembly of components and modules, it is expected that deployment of an entire site (facilities and telescopes) can be achieved in less than one month with a relatively small number of people.

5.3 Maintenance operations

All our facilities, telescopes, and instrumentation are engineered to have long MTBF. But we do realize that occasional component failures will occur and need to be rapidly addressed. In the case of facilities, these failure points are likely to be fans, batteries, computers, and control panel electronic components. Our telescope and facility control panels use highly modularized electronic components. Spare units of more-likely-to-fail items are stored on site (along with proper documentation) for easy replacement by local site personnel. In the case of telescopes, we will stock on site spare RA and DEC drive motors and controllers, sensors, limit switches, and BlackFin control boards, and instructions for their replacement. Even spare optics will be stored (in California) and be ready for shipment to site in the unlikely event of a breakage during re-aluminizing operations. In this regard, we specifically specified to our 1.0m optical fabricator that M1 and M2 be “unmatched” to each other, so that only the damaged optical component need be replaced rather than an entire set.

Manufacturer product lines tend to change over time or in some cases discontinued. To mitigate the risk of critical replacement parts becoming unavailable, our California warehouse will stock a 20 year supply of spare parts so that interchangeability and compatibility of components can be maintained over the entire observatory life cycle.

In the case of the smaller 0.4m telescopes, if there is a serious failure we are prepared to send an entire telescope to site for replacement, and the failed unit would be returned in the same crate to our home facility for repair.

6. CONCLUSION

Although daunting, the deployment and operation of a globally distributed network of astronomical observatories can be made more manageable by careful engineering of interchangeable components, prefabrication and modularization, and a high degree of as-build uniformity across all sites.