The Large Binocular Telescope Project

John M. Hill\textsuperscript{a} and Piero Salinari\textsuperscript{b}

\textsuperscript{a}University of Arizona, Large Binocular Telescope Observatory, Tucson AZ 85721, USA
\textsuperscript{b}INAF - Osservatorio Astrofisico di Arcetri, 50125 Firenze, Italy

ABSTRACT

The Large Binocular Telescope (LBT) Project is a collaboration between institutions in Arizona, Germany, Italy, and Ohio. The first of two 8.4-meter borosilicate honeycomb primary mirrors for LBT is being polished at the Steward Observatory Mirror Lab this year. The second of the two 8.4-meter mirror blanks waits its turn in the polishing queue. The baseline optical configuration of LBT includes adaptive infrared secondaries of a Gregorian design. The F/15 secondaries are undersized to provide a low thermal background focal plane which is unvignetted over a 4-arcminute diameter field-of-view. These adaptive secondary mirrors with 672 voice-coil actuators are now in the early stages of fabrication. The interferometric focus combining the light from the two 8.4-meter primaries will reimage the two folded Gregorian focal planes to three central locations for phased array imaging. The telescope elevation structure accommodates swing arm spiders which allow rapid interchange of the various secondary and tertiary mirrors as well as prime focus cameras. The telescope structure accommodates installation of a vacuum bell jar for aluminizing the primary mirrors in situ on the telescope. The telescope structure was fabricated and pre-assembled in Italy by Ansaldo-Camozzi in Milan. The structure was disassembled, packed and shipped to Arizona. The enclosure was built on Mt. Graham and is ready for telescope installation.

Keywords: binocular telescope, honeycomb mirror, telescope enclosure, adaptive optics, phased array imaging

1. INTRODUCTION

1.1. Project Overview

The Large Binocular Telescope (LBT) is now being installed in its enclosure on top of Mt. Graham. The binocular design of LBT has two 8.4-meter telescopes mounted side-by-side on a common altitude-azimuth mounting. This provides LBT with a collecting area of 110 square meters — equivalent to an 11.8-meter circular aperture. The two mirrors on a common mounting with a 14.4-meter center-center distance provide an interferometric baseline of 22.8 meters for diffraction-limited observations. By using fast focal ratio primary mirrors, the entire telescope and enclosure can be relatively compact. The LBT Project has previously been described by Hill & Salinari (2000) and references therein.

1.2. Partners

The international partners in the Large Binocular Telescope Corporation include Arizona (25%), Germany (25%), Italy (25%), Ohio State (12.5%) and Research Corporation (12.5%). The Arizona portion of the project includes astronomers from the University of Arizona, Arizona State University and Northern Arizona University. The German portion is represented by the LBT Beteiligungsgesellschaft which is composed of Max-Planck-Institut für Astronomie in Heidelberg, Max-Planck-Institut für Radioastronomie in Bonn, Max-Planck-Institut für Extraterrestrische Physik in Munich and Astrophysikalisches Institut Potsdam. National participation in Italy is organized by the Istituto Nazionale di Astrofisica. Partners at individual institutions include The Ohio State University in Columbus, Research Corporation in Tucson and The University of Notre Dame.

Further author information: \(\text{Send correspondence to J.M.H.}\)
J.M.H.: E-mail: jhill@as.arizona.edu, Telephone: +1 520 6213940 Fax: +1 520 6269333
P.S.: E-mail: salinari@arcetri.astro.it, Telephone: +39 055 2752290 Fax: +39 055 223319

1
Figure 1. The first 8.4-meter honeycomb mirror for the left aperture of LBT is being polished at the Steward Observatory Mirror Lab. The stressed lap actively adjusts its shape as it is stroked across the mirror to fit the portion of the F/1.142 paraboloid where it is in contact.

2. PRIMARY MIRRORS

The primary mirrors for LBT are being fabricated by the Steward Observatory Mirror Lab at the University of Arizona. Each 8.4-meter diameter mirror is a spincast borosilicate honeycomb structure weighing 16 metric tons. Each primary mirror has a clear aperture of 8.408 meters and has a paraboloidal surface with a focal length of 9.600 meters (F/1.142). The honeycomb structures provide light weight and good stiffness against wind forces. They also provide a short thermal time constant (45 minutes with ventilation) to be sure that the telescope images are not blurred by local mirror seeing.

2.1. First Primary Mirror

The first 8.4-meter primary mirror is now in the final phases of polishing with the stressed lap on the Large Optical Generator at the Mirror Lab. The figuring of the mirror is expected to be complete by the end of 2002. The mirror on the polishing machine is shown in Figure 1. More details of the optical fabrication process are provided by Martin et al. (2002). After polishing, the mirror will be integrated onto the support system in the telescope cell before being transported to the mountain.

The 8.4-meter mirrors are supported in the telescope cell by active adjustable pneumatic supports. The mirrors are supported at 158 axial support locations and with lateral supports at 104 of these locations. The
lateral forces are applied to loadspreads on the backplate of the mirror with the overturning moment compensated by the axial supports. The mirrors are positioned in the cells by rigid hardpoints which kinematically position the mirror. The entire weight of the mirror cannot be safely supported on the hardpoints, so they must be engineered to collapse above a certain load. The pneumatic support system is being built by Steward Observatory. The hardpoints are being built by Max-Planck-Institut für Extraterrestrische Physik. The mirrors will be shipped to the mountain in a double-frame vibration-isolated box.

2.2. Second Primary Mirror

The second 8.4-meter primary mirror was cast at Steward Observatory Mirror Lab during summer 2000. After waiting for the handling fixture to become available, it was removed from the furnace deck in August 2001. Since then the honeycomb mold material has been removed. The E6 glass blank seen in Figure 2 now waits its turn on the generating and polishing machines.
3. ADAPTIVE OPTICS

The baseline optical configuration of LBT includes adaptive infrared secondaries of a Gregorian design. The F/15 secondaries are undersized to provide a low thermal background focal plane which is unvignetted over a 4-arcminute field-of-view. By integrating the adaptive secondaries into the telescope design, we achieve adaptive correction without any penalty in throughput or emissivity. Each adaptive secondary mirror is a 911-mm diameter Zerodur shell which is 1.6 mm thick. These aspheric (-0.7328) shells are being fabricated by Steward Observatory Mirror Lab. The shell is supported by 672 voice-coil actuators which act on magnets glued to the shell. The position of the shell is measured relative to a thicker Zerodur reference body using capacitive sensors. Custom DSP cards control the currents in the voice-coil force actuators and read the capacitive sensors to stabilize the shell position. The LBT672 adaptive secondaries can respond to wavefront correction commands at a rate of 1 kHz or can be operated as passive secondaries when wavefront information is not available. More information on the LBT adaptive secondaries is provided by Riccardi et al. (2002). The mechanical supports and voice-coil actuators are described by Gallieni et al. (2002). The DSP control system is described by Biasi et al. (2002). The DSP cards of the secondary also handle the job of wavefront reconstruction. The adaptive secondary units are supported in the telescope by swing-arm “spiders” fabricated by Carpeniteria Fratelli Colombo of Monte Marenzo, Italy. Hexapod actuators designed and built by ADS International align the secondaries in focus and collimation. Control software for the adaptive secondaries is being developed at Osservatorio Astrofisico di Arcetri. Esposito et al. (2002) describe the overall LBT adaptive optics system for first light. Adaptive wavefront sensing is done with pyramid sensors.

Additional swing-arms on the telescope support prime focus instruments and tertiary mirrors. In addition to a pair of direct Gregorian F/15 foci, the steerable tertiary mirrors provide three pairs of bent Gregorian foci in the center of the telescope. These central focal stations can be used for pairs of conventional instruments and for interferometric observations which reimage the Gregorian focal planes to a combined focus. The combined focus will be used for phased array imaging taking advantage of the 22.8-meter diffraction-limited baseline of the binocular telescope. All the focal stations have instrument rotator bearings. The central pair of focal stations has additional derotator bearings which can support a gravity-invariant instrument. Off-axis guide probes carry Shack-Hartmann wavefront sensors for active correction and collimation of the telescope. The suite of LBT facility instruments is described by Wagner (2002).

4. TELESCOPE CONSTRUCTION IN MILAN

The LBT telescope mount is a dual-ring altitude over azimuth design. The two primary mirrors are mounted side-by-side on a common elevation structure. Two large rolling sectors or C-rings form the 7 meter radius elevation bearings of the structure. A direct load path from the primary mirror cells to the C-rings to the azimuth frame to the azimuth ring gives the structure a high resonant frequency of about 8 Hz. The 10 x 14 meter azimuth frame is equivalent to a yoke structure with very short yoke arms. The azimuth frame carries the hydrostatic bearing pads for both the azimuth and elevation bearings, and also carries the telescope drive motors. The moving mass of the telescope structure is approximately 600 metric tons. Each axis is driven by four DC motors which drive 60:1 pinions against rim gears at a 7-meter radius from the axis. The large diameter rim gears are made of pre-machined gear sectors which are 1.5 meters (11.25 degrees) long. The telescope elevation structure accommodates swing arm spiders which allow rapid interchange of the various secondary and tertiary mirrors as well as prime focus cameras. The detailed design of the telescope structure was carried out by European Industrial Engineering of Venice, Italy and ADS International of Lecco, Italy in cooperation with Osservatorio Astrofisico di Arcetri and Steward Observatory.

The main steel structure of the LBT telescope was fabricated and machined by Ansaldo-Camozzi Special Energy Products S.p.A. in Milan, Italy. The structure was pre-erected in the factory in Milan during 2001 to verify the mechanical tolerances before shipping the telescope to the top of Mt. Graham in Arizona. The assembled telescope structure is shown in Figure 3. Specific sub-systems were fabricated by other companies. The hydrostatic bearing system and the rim gears for the drives were designed and built by Tomelleri S.r.l. of Verona, Italy. The hydrostatic bearing pads, drive motors and rim gears can be seen in Figure 4. The swing arm spiders which support the secondary mirrors and tertiary mirrors were built by Carpeniteria Fratelli Colombo.
Figure 3. This photo shows the steel structure of the telescope assembled in Milan in June 2001 prior to shipping to Arizona. This view is from the rear side of the telescope so the elevation bearings face primarily the opposite side. The swing arm spiders and the central bent Gregorian focal station are not mounted. The level of the observing chamber floor will be about 2 meters higher than the factory floor.
Figure 4. This photo shows one of the elevation hydrostatic bearing pads and one of the elevation drive motors mounted on the corner of the azimuth frame. The elevation bearing with rim gear is being lowered into position as this photo was taken. (photo by Luciano Miglietta)
Figure 5. During September 2001, the drive systems of the assembled telescope were tested in the Ansaldo-Camozzi factory in Milan. This view shows the telescope tilted toward the horizon. The primary mirror cell on the right is the dummy cell which does not have all the machined interfaces for the primary mirror supports.

S.r.l. in Monte Marenzo, Italy. The drive motor housings for the Kollmorgen DC brushed motors were built by Castellini Officine Mechaniche S.p.A. near Brescia, Italy. The azimuth frame was machined by Fravit S.r.l. of Lecco, Italy.

We closed preliminary servo control loops on both axes of the telescope during acceptance testing in September 2001. These tests used the pinion encoders and not the main position encoders on each axis. This activity is seen in Figure 5. Disassembly of the telescope structure for shipping started in October 2001. Additional details of the telescope pre-erection process may be found in Miglietta et al. (2002).

The telescope structure accommodates installation of a vacuum bell jar for aluminizing the primary mirrors in-situ on the telescope. The pumping and aluminizing system of the bell jar is being implemented by The Ohio State University. The bell jar and the dummy cell, which also serves as the temporary base for the bell jar, are shown in Figure 6.

5. ENCLOSURE ON MT. GRAHAM
The telescope enclosure was completed in 2002. The LBT site is at the Mt. Graham International Observatory (MGIO) in southeastern Arizona. Construction on 3192-meter Emerald Peak in the Pinaleno Mountains began
Figure 6. During April 2001, the vacuum bell jar (right) was mated with the dummy primary mirror cell (left) to test the vacuum integrity of the weldments. For testing, the two components are mounted on carriages that move on rails. When aluminizing the mirror, the two components are mounted in the same horizon-pointing configuration on the telescope. The roughing pump and Roots blower are mounted on the lower portion of the bell jar.
Figure 7. This photo shows the open enclosure on Mt. Graham in June 2002. In addition to the two shutter doors on the front and top of the building, there are four ventilation doors on the sides and rear of the building. A 55-ton bridge crane traverses the top of the rotating enclosure for telescope assembly and mirror installation. Spruce fir trees on the horizon are dying as a result of an insect infestation.
in 1996. The telescope enclosure is a co-rotating box that tracks with the telescope in azimuth. The box is supported by four bogies with a total of 20 wheels that carry 100 tons each. The enclosure has two 10 meter wide shutter doors that cover the front and top of the enclosure cube. Each of these two L-shaped shutter doors rolls to the side when open. The shutter doors can be seen in Figure 7 and the shutter openings can be seen from the inside in Figure 8. In addition to the shutter doors, there are four ventilation doors in the sides and rear of the enclosure to promote ventilation and equilibration with ambient air. In the rotating floor just below the observing chamber, there are exhaust fans to pull residual heat from the telescope. This equipment level also contains the oil system for the telescope hydrostatic bearings, the air conditioning system for ventilating the honeycomb mirrors and the air compressors for the mirror support system. A cable chain on top of the telescope pier supplies AC power and chilled water/glycol to the rotating portion of the building. A 55-ton bridge crane in the rotating enclosure is used for all the telescope assembly and mirror installation operations. Construction occurred under the auspices of Hart Construction Management Services of Safford, Arizona. The enclosure design was executed by M3 Engineering & Technology of Tucson, Arizona. Additional details of the enclosure construction can be found in Teran et al. (2002).

6. TELESCOPE TRANSPORTATION

During the spring of 2002, the telescope structural components were packed and shipped to Arizona for assembly on the mountain. The eight azimuth ring sectors were shipped in standard containers and arrived on Mt. Graham in May 2002. The remaining telescope parts were consolidated in a single shipment. The large components travelled by road from Milan to Cremona on the Po River. They were transported by barge down the Po to the ocean port at Mestre. The barge transportation is shown in Figure 9. The ship sailed from Mestre in July 2002, and arrived in Houston, Texas in August. From Houston, the telescope parts are being transported overland to the basecamp in Safford, Arizona. The oversized transportation included the boxes for the primary mirror cells which were 10 x 9 x 3 meters and weighed 50 tons. The unloading of one of the three azimuth frame sections can be seen in Figure 10. The Italy-Arizona transportation of the telescope parts is being done under contract to Fagioli S.p.A. Precision Heavy Haul of Phoenix, Arizona is a sub-contractor for the Houston-Safford transportation.

7. TELESCOPE INSTALLATION

The installation of the telescope into the enclosure on Mt. Graham began in June 2002 with the arrival of the eight sections of the azimuth ring. This work has proceeded through the summer while the other parts of the telescope are being transported to Arizona. Several of the azimuth ring sectors can be seen on the telescope pier in Figure 11. The schedule is to complete the mechanical installation of the telescope by Fall 2003.

8. CONCLUSION

The LBT telescope steel structure has been shipped from Milan to Arizona. The components of the aluminizing system have been shipped from Milan to Ohio for integration. The polishing of the primary mirrors is in progress at the Mirror Lab in Tucson. The adaptive optics system is under development in Tucson, Arcetri and Potsdam. The LBT enclosure is complete on top of Mt. Graham. First light with a prime focus camera and one primary mirror is expected in June 2004. Second light with both primary mirrors is expected in summer 2005.

Additional photos and other information can be found at the following web addresses:

Large Binocular Telescope http://medusa.as.arizona.edu/lbtwww/
Mt. Graham International Observatory http://mgpc3.as.arizona.edu/
Steward Observatory Mirror Lab http://medusa.as.arizona.edu/mlab/
Figure 8. This photo mosaic shows the view looking out from the inside of the LBT observing chamber. The telescope pier is shown at the bottom with the cable chain that feeds power and chilled water from the pier onto the rotating building. The obvious difference from a conventional dome is that the binocular telescope has two 10-meter wide shutter openings. The central portal between the two shutter openings is not retractable. The 4x10-meter hatch at the front of the observing chamber is used for lifting telescope components from the fixed building below.
Figure 9. This photo shows a C-ring (center) and two mirror cell boxes being transported down the Po river on the barge “Ticino” during June 2002. (photo by Enrico Brunetti)

REFERENCES

Figure 10. This photo shows one of the three sections of the azimuth frame being unloaded at the MGIO basecamp in Safford, Arizona during August 2002. Engineered lifting points are built into each of the large pieces. (photo by Jim Slagle)
**Figure 11.** The eight sections of the azimuth ring are being assembled on the telescope pier. The concrete pier is 14 meters in diameter. The bearing ring is anchored with 186 anchor bolts and adjusted with fixator jacks. Inside the azimuth ring on top of the pier are the enclosure cable chain and the telescope radial bearing (not mounted). The flat plates just inside the azimuth ring are jacking points to support the azimuth frame. The observing chamber floor is about 1 meter above the level of the azimuth bearing surface. Some sections of the floor have been removed to facilitate installation of the telescope.