The Large Binocular Telescope


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ABSTRACT

The Large Binocular Telescope (LBT) Observatory is a collaboration between institutions in Arizona, Germany, Italy, Indiana, Minnesota, Ohio and Virginia. The telescope on Mt. Graham in Southeastern Arizona uses two 8.4-meter diameter primary mirrors mounted side-by-side to produce a collecting area equivalent to an 11.8-meter circular aperture. A unique feature of LBT is that the light from the two primary mirrors can be combined to produce phased array imaging of an extended field. This coherent imaging along with adaptive optics gives the telescope the diffraction-limited resolution of a 22.65-meter telescope. We will describe the scientific results and technical challenges of monocular prime focus imaging starting in Fall 2006. Binocular imaging with two co-pointed prime focus cameras began in Fall 2007. Installation of a rigid (non-adaptive) secondary mirror occurred in Spring 2008 in time for the arrival of the first Gregorian spectrometer. The telescope will use two F/15 adaptive secondaries to correct atmospheric turbulence. The first of these adaptive mirrors is now being tested in Italy, and is planned to be at the telescope by Summer 2009.

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

1. INTRODUCTION

The Large Binocular Telescope (LBT) uses two 8.4-meter diameter honeycomb primary mirrors mounted side-by-side to produce a collecting area (110 square meters) equivalent to an 11.8-meter circular aperture. A unique feature of LBT is that the light from the two primary mirrors can be combined optically in the center of the telescope to produce phased array imaging of an extended field. In practice this extended phased field can be of order 1-arcminute in diameter. Active and adaptive optics have been designed into the telescope from the beginning to augment the telescope performance from visible to mid-infrared wavelengths. The main wavefront correctors are the F/15 Gregorian adaptive secondary mirrors. 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. Several of the instruments will implement an additional wavefront corrector at a higher conjugate after the initial Gregorian focus. This coherent imaging gives the telescope the diffraction-limited resolution of a 22.65-meter telescope. We will be able to produce images with a resolution of 5-milliarcseconds in visible light and 20-milliarcseconds in the near-infrared. The binocular configuration leads to a compact and stiff mechanical structure. The short focal ratio primary mirrors help minimize the size of the co-rotating enclosure. The telescope is located at Mount Graham International Observatory in the Pinaleno Mountains of Southeastern Arizona at an elevation of 3192 meters. Development of the project through First Light has been previously described by Hill, Green and Slagle (2006) and references therein. The two primary mirrors can also be used independently to obtain seeing-limited images over a wide field-of-view. Monocular prime focus science imaging started in Fall 2006, with regularly scheduled science observations using both primary mirrors starting in January 2007.

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Figure 1. Photo of the Large Binocular Telescope with two 8.4-meter diameter primary mirrors open and ready for observing at sunset with the two prime focus cameras. The telescope enclosure with two 10-meter wide shutter openings co-rotates with the azimuth axis of the telescope at speeds up to 1.5 degrees per second. The forest around the telescope is composed of spruce, fir and aspen trees.
2. BINOCULAR PRIME FOCUS

2.1 Second Light and Scheduled Science Observing

The first scientific instruments to be installed and commissioned on the LBT were the blue-optimized and red-optimized prime focus cameras known as the “Large Binocular Camera” (LBC). Each camera has four CCD (charge-coupled devices) chips in the focal plane - each with dimensions of 2048x4608 pixels - for a total of 36 megapixels per camera. After on-sky commissioning of the blue-optimized prime focus camera in Fall 2006, a period of consortium-wide science observations with the single 8.4-meter mirror was carried out in the Spring of 2007. Giallongo et al. (2008) describe the technical results of the on-sky commissioning of the blue-optimized prime focus camera. The second prime focus corrector assembly was installed on the right side of the telescope in Winter 2006-2007. This corrector assembly is a set of six BK7 corrector lenses that correct the comatic aberration of the fast primary mirror to make an extended field-of-view in front of the CCD array. Each camera contains eight broad-band or SDSS filters for making deep scientific images. The prime focus cameras are described in further detail by Ragazzoni et al. (2006) and by Speziali et al. (2008). The CCD cryostat for the red-optimized camera arrived on Mt. Graham in Fall 2007. Binocular imaging with two co-pointed prime focus cameras began in late-Fall 2007. Second Light with two functioning prime focus cameras was announced in January 2008. The dark of the moon has been dedicated to imaging science with both cameras since January 2008. Green et al. (2008) discuss observing and telescope operations in additional detail.

2.2 Sample Science Programs

Of course, every three astronomers you meet will have five observing programs that they want to carry out with a large telescope like the LBT. The science programs carried out by the LBT partner institutions range from searching for asteroids in the outer regions of our own solar system, to surveying the sky for high redshift quasars at the limits of the observable universe. Wide-field cameras like LBC were built to carry out deep broad-band imaging surveys, so it comes as no surprise that the majority of the prime focus observing time goes to such surveys. Most of the time is spent collecting parallel near-ultraviolet (U-BESSEL or U-special) and near-infrared (Y or z’) data to complement existing surveys already done with other smaller telescopes.

Another typical observation carried out with the LBT prime focus cameras is deep photometry of stars in faint dwarf spheroidal galaxies which are orbitting our own Milky Way galaxy. Figure 2 shows a deep image of the Hercules dwarf galaxy taken by Coleman et al. (2007). The striking thing about this image is that even in a deep exposure with an 8.4 meter aperture, you can hardly notice the faint giant stars belonging to this faint galaxy. The 1-sigma magnitude limit for 30-minutes of integration time is an AB-magnitude of 27-28 depending on which broad-band filter is used.

Another class of science observations with the LBC cameras are variable or transient objects where the sensitivity of LBT increases the available parameter space for observing such objects by allowing shorter exposures. Observations of the faint optical afterglows following Gamma Ray Bursts (GRBs) are one example of this type of observation. Optical observations of the afterglows demonstrate that the bursts are likely beamed toward us greatly reducing the required energy output. Even the reduced total gamma-ray energy output turns out to be similar to the energy produced in a core-collapse supernova. Numerous small telescopes are used to observe these afterglows within minutes of when the bursts are detected by gamma-ray satellites. LBT has the sensitivity advantage that it can collect deep photometry of a typical afterglow and its host galaxy up to a month after the burst when the afterglow has decayed to a feeble r’ magnitude of 26. These observations have typical integration times of 20-30 minutes. Sampling of the late-time light curves allows us to measure jet breaks and other emission components of the optical light curves. See Dai et al. 2008 for details on six GRBs observed by LBT in 2007. Figure 3 shows an image of one of these GRB afterglows observed by Garnavich et al. (2007).

Of course, not all science images are of stars in low-luminosity galaxies or incredibly distant galaxies. A number of astronomers are using LBT/LBC to study details (sometimes individual stars) in nearby bright galaxies. Figure 4 shows an example of a deep image of the spiral galaxy, NGC 3184, taken during Science Demonstration Time in Spring 2007.
Figure 2. Image of the Hercules dwarf spheroidal galaxy by Coleman et al.\textsuperscript{6} This image is a composite of five 300-second exposures in $r'$, four 300-second exposures in V, and six 300-second exposures in B. The photometric completeness level for 50\% detection of individual stars is $V=25.7$ magnitude. Even if you can’t see them in this stretch of the image, observing in three filters allows photometric selection of stars in the dwarf spheroidal galaxy against the foreground stars from the Milky Way. With an elongation of 3:1, this dwarf is among the most elongated of such systems.

2.3 Image Quality at Prime Focus
Image quality delivered by the prime focus cameras has run the full gamut from 0.4 arcsec FWHM images that are undersampled by the 0.225 arcsec pixels, to really remarkably bad seeing behind a winter cold front of 4 arcsec FWHM. Already in November 2006 we had some 90-second U-band exposures that were 0.5 arcsec FWHM without guiding. Then in spring 2007, through some history that we have never recovered, the blue corrector assembly got tilted by several arcminutes to give varying astigmatism across the field. For a few months, this astigmatism was limiting the best images to about 0.7 arcsec FWHM. Rakich et al. (2008)\textsuperscript{9} describe the optically interesting recovery from that misalignment. We also had some focus problems related to spherochromatism in the extrafocal pupils which are discussed by Hill et al. (2008)\textsuperscript{10} along with the LBT/LBC Active Optics system. The prime focus cameras are focussed and collimated by making a geometrical analysis of extrafocal pupils. Since December 2007, the image quality in both cameras has nearly always been limited by seeing.

3. BENT GREGORIAN FOCUS
3.1 Rigid Secondary Mirror
In 2006, the several LBT partners decided to purchase a single rigid (non-adaptive) secondary mirror to be sure that telescope commissioning and initial commissioning of Gregorian instruments would proceed promptly even
if there were schedule slips with the technically complex adaptive secondary units. The borosilicate honeycomb mirror blank for this secondary mirror came from HexTech in Tucson. It was polished by SESO in France. The support system was built by Ohio State University. The hexapod used to position the mirror was designed and built by ADS International in Italy. The secondary mirror was coated by EMF Corporation in Ithaca. This unit was mounted on the left side of the telescope in April 2008 and is performing optically as expected. Figure 5 shows the Gregorian secondary mirror mounted on the telescope. After the second adaptive secondary unit arrives in 2010, this rigid secondary will serve as a spare. In the meantime, it is serving its expected purpose on the telescope.

3.2 Tertiary Mirrors

The borosilicate honeycomb tertiary mirror blanks which are 54 x 64 cm octagonal shapes (unvignetted for a 4 x 8 arcminute field) were fabricated by HexTech in Tucson several years ago. They have been polished to optical flats by Zygo Corporation. The tertiary mirrors were also coated by EMF Corporation in Ithaca. The tip-tilt and rotation mounts have been designed and built by ADS International in Italy. The first tertiary mirror was installed on the telescope in Spring 2008 in preparation for observing at the first Bent Gregorian Focal Station. This tertiary mirror on its deployable swing arm can be seen in Figure 6. The second tertiary mirror is waiting

Figure 3. This is a red image (SDSS r') of gamma-ray burst GRB 070518 taken with LBC-Blue on 19-May-2007 when the burst was 17-hours old. This image is composed of a stack of five 200-second exposures taken during LBT Science Demonstration Time. The r’ magnitude of the object indicated by the arrow is 23.0. The field shown in this image is 3 arcminutes across (only a fraction of the total LBC field). Image courtesy of P. Garnavich (Notre Dame).
Figure 4. This image is a section of a U-BESSEL (near-ultraviolet) mosaic image of the spiral galaxy NGC 3184. The mosaic is composed of eight 164-second exposures for a total integration time of 1312 seconds in the regions of maximum overlap. This galaxy was observed by R. Pogge and E. Egami in 0.8 arcsec seeing during LBT Science Demonstration Time in March 2007. This mosaic reaches a depth of U=24.5 (3σ) in non-photometric conditions. Image courtesy of D. Zaritsky and S. Herbert-Fort (University of Arizona). Similar U and V data on a number of disk galaxies are being used to study massive star formation and stellar populations.

in the lab to be installed later in 2008.

3.3 Gregorian Rotator

A major technical effort by the LBTO engineering and software groups during 2007 and 2008 has been the design, fabrication, and installation of the instrument rotator systems at four focal stations. The rotator bearings were delivered with the telescope structure. Now we are finishing the job of turning each of the bearings into a rotator system by adding motors, brakes, encoders, controls, limit switches and software. The first 1.8m diameter Bent Gregorian rotator went operational on the left side of the telescope in February 2008. The rotator routinely tracks open-loop with an accuracy of 10 arcsec rms. This is the rotator which will hold the first near-infrared spectrometer, LUCIFER. The cable chain for this rotator was delayed by procurement issues and is being installed in June-July 2008. The right side Bent Gregorian rotator is planned to be installed during the 2008 summer shutdown. The first 3.5 meter diameter instrument rotator for the direct Gregorian instruments will be
installed in Winter 2008. Note that while these rotators appear small on the scale of LBT, they are comparable in size to many telescopes.

### 3.4 Acquisition, Guiding and Wavefront Sensing

The third Acquisition, Guiding and Wavefront (AGw) unit was delivered from Potsdam at the end of 2007 and installed on the telescope in March 2008. This particular unit contains only the off-axis guide probe, acquisition camera, and S-H wavefront sensor (small “w”). It is being used to commission the left Bent Gregorian focal station on-sky. This unit does conventional off-axis guiding with a probe that patrols outside the 4 arcminute field of the science instrument. A dichroic splits off light to a Shack-Hartmann wavefront sensor so the telescope focus and collimation can be updated continuously. The details of the AGw units are described by Storm et al. (2004). The first AGW unit is in the test tower at Arcetri Observatory for the system testing of the first adaptive secondary with the fast on-axis pyramid wavefront sensor (big “W”). The second AGW unit is also at Arcetri to be integrated with the second on-axis wavefront sensor unit which occupies the second half of the AGw unit housing.

### 3.5 Fast Infrared Test Camera

LBT has procured two fast-readout near-infrared test cameras to use for commissioning and testing active and adaptive optics at the F/15 Gregorian focal stations. The first of these is mounted with the adaptive optics test
setup at Arcetri Observatory, while the second is mounted on the telescope. These camera systems are described by Foppiani et al. (2008).\textsuperscript{13} The detector in these cameras is an InGaAs array in a commercial camera built by XenICs. The camera is operating in either J-band or H-band with a Peltier cooler. Fore-optics allow a selectable field-of-view between 30x30 and 3x3 arcsec. Exposure times are selectable between 1 microsecond and 5 minutes, although the H-band sky plus dark saturates in 4-5 seconds when using the wide field-of-view.

### 3.6 Gregorian Commissioning Activities

We are presently spending the bright phases of the moon doing engineering observations to commission the first Bent Gregorian focus on-sky. This work has included the testing of the infrared test camera, verification of the instrument rotator, creating preliminary collimation models and pointing models, verification of the secondary hexapod motions, testing and calibration of the acquisition guiding and wavefront unit, and testing of the guiding and wavefront sensing software. By the second week of June 2008, we have images as good as 0.4 arcsec FWHM; we are able to guide the telescope; we have closed the active optics loop using the Shack-Hartmann wavefront sensor. Still to be completed are: some tasks related to offsetting the telescope and re-acquiring off-axis guiding automatically, a few remaining tasks in the commissioning of the AGw units, refinements of the collimation and pointing models, and alignment of the secondary mirror to eliminate field tilt and binodal astigmatism. Rakich et al. (2008)\textsuperscript{9} provide additional details on the field alignment at the Gregorian focus.

### 4. INSTRUMENTS

In addition to the pair of prime focus cameras described above, the following instruments are planned for LBT in the next few years. A pair of facility near-infrared spectrographs optimized for wide-field multiobject work
and for diffraction-limited observations will be mounted at one pair of the bent Gregorian focal stations in the center of the telescope. The first of these LUCIFER spectrographs\cite{11} is undergoing its laboratory acceptance test in Heidelberg after this conference and is scheduled to arrive on Mt. Graham in Fall 2008. Below the primary mirrors, two large optical-UV spectrographs are mounted at the direct Gregorian focal stations. The first of these MODS facility spectrographs is expected to arrive at LBT in Spring 2009. The second instance of both spectrographs should go on the telescope in 2010. Much more detail on the LBT instruments is provided by Wagner (2008)\cite{14} and other instrument papers referenced therein.

The other two pairs of bent Gregorian focal stations will be mainly used for phased array imaging. Two "strategic instruments" are being built to combine the light from both primaries and take advantage of the diffraction-limit from the full 22.65-meter baseline. An instrument emphasizing nulling interferometry in the mid-infrared is being built in Arizona with an additional 3-5 micron camera being built by Virginia and Minnesota. An instrument emphasizing phased-array imaging in the near-infrared with multi-conjugate adaptive optics is being built by a collaboration centered in Heidelberg and Padova. The fiber cables for feeding light to the PEPSI bench-mounted echelle spectrograph have already been installed on the telescope. The actual PEPSI spectrograph and its sealed enclosure should be installed in the LBT pier in 2009. An instrumentation laboratory has been completed on the mountain to provide a clean environment for working on these large and complex instruments.

5. TELESCOPE PERFORMANCE

5.1 Primary Mirror Cells and Coatings

Some of our technical challenges\cite{1} related to mirror cell actuators oscillating in the cold are happily behind us. The primary mirror cells and the mirror support systems now operate happily down to temperatures of -15 degC on the coldest winter nights. Ashby et al. (2008a)\cite{15} describe the technical performance of the repaired mirror cell actuators and the overall mirror support system. The mirror support system can respond to external forces such as wind with a bandwidth of 5 Hz. The one remaining technical issue related to the mirror cells is that we seem to have about 10 microns of lost motion whenever the primary mirrors are repositioned by the hardpoints. This has been difficult motion to track down since the LVDT transducers in the primary mirror hardpoints apparently report the correct position reading within 1 micron. This lost motion results in a small focus shift, and 1-2 arcsec of pointing jitter on the sky. This problem is presently being investigated. Other aspects of the primary mirror system including the mirror ventilation system seem to be working as planned.

We are on a regular cycle of in-situ coating one of the two 8.4m primary mirrors each summer when the telescope is closed for maintenance during the monsoon thunderstorm season. The alternate mirror is pressure washed with chemical degreaser and soap at the same time. The technical challenge of the coating process is getting the 350 nm reflectivity up the last 3 - 5% that we expect. The problem is likely related to pressure during coating or the deposition rate. We had some issues with leakage from the inflatable seal around the edge of the mirror during the 2007 coating.

5.2 Telescope Tracking and Pointing

The LBT telescope mount is tracking and pointing reliably. The Farrand Inductosyn strip encoders which are mounted directly to the azimuth and elevation axes went into regular service at the end of 2007. Previously the mount had been tracking with the Heidenhain rotary encoders on the motor shafts, which left us with occasional 2 arcsec jumps when crossing the gaps between the rim gear sectors. With the strip encoders gear tooth errors are servoed out, and the mount tracks in both axes to 10 milli-arcseconds rms over intervals of minutes. This is good enough that we can’t measure any short-term tracking error in the images which are limited by the atmospheric image motion. More technical details of the LBT main-axis encoders and servo system are provided by Ashby et al. (2008b)\cite{16}. We’ve constructed pointing models so that the pointing over the sky is 5 arcsec rms with 7 terms in the pointing model. The open-loop tracking is presently limited by the quality of the pointing and collimation models near zenith. Of course, the challenge here is that we have to get both optical trains on both sides of the telescope pointing at the same location that the mount is tracking. Typically we collimate the right side prime focus, and then we adjust the pointing model so that the right prime focus points well around the sky. Then, we iteratively adjust the collimation of the left prime focus so that it is pointing at the same
place in the sky as the right side. The tolerance is about an arcsec for co-pointing near zenith, but it relaxes when you are at lower elevation. The challenging part of adjusting the collimation models to get the two sides co-pointing is to avoid running out of the available range of travel of either or both primary mirrors. To improve the all-sky pointing beyond 5 arcsec rms, we need to improve our modelling of thermal gradients in the telescope structure, and to fix the 2 arcsec pointing jitter in the primary mirror cells.

5.3 Hydrostatic Bearing System
The hydrostatic bearing system for the telescope main axes has been operating fairly reliably. Like any system with pumps and filters it requires attention to regular maintenance to keep it operating. The biggest operational challenge has been keeping the oil in the tank near the nighttime ambient temperature. This has been solved by moving the temperature sensors and by increasing the circulation inside the tank. As soon as we started observing on-sky we discovered that wind (10 m/sec) was quite effective at spreading drops of oil around the dome floor. Drops of oil were dripping off of the rim gears and other surfaces up to 6 meters above the floor and were easily redistributed by the wind. This lead to a year-long campaign of oil mitigation as we designed various scrapers and shields and brushes to keep the oil contained near the bearing pads. We also rerouted some plumbing to keep the oil return path away from the wind. We’ve added a special sheet metal screen above the azimuth bearing to minimize the quantity of dirt and debris that can fall on the track surface and the azimuth encoder. We are in the middle of a program to improve the stiffness of the hydrostatic bearings by moving the capillaries that regulate the pocket pressures closer to the bearing pads.

5.4 Swing Arms for Optical Configuration
The LBT telescope design uses swing arm “spiders” to deploy and retract various optical elements into and out of the telescope optical beams. Individual swing arms which support each of two prime focus cameras, each of two secondary mirrors, and each of two tertiary mirrors have now been installed and commissioned on the telescope. These swing arms are of a rather unconventional design since they only attach to the telescope structure on one side of the optical beam. The swing arms have been a design success in the sense that they have met their basic performance goals with only a few engineering fixes. The arms reposition in the beam (on a short timescale, hours) with a repeatability of better than 50 microns. On longer timescales (days) the position repeats only at the level of 500 microns because of thermal gradients in the steel structure and some as yet unidentified mechanical hysteresis. The resonant frequencies are not as high as we were expecting - not because of any fault with the swing arms - but because the instrument payloads are coming in with 50% more mass than originally expected. We have also experienced problems with vibrations in the secondary swing arms excited by a not-well-isolated set of fans elsewhere on the telescope structure. The swing arms are fully welded structures and thus quite high-Q structures. It appears that we will need to add some damping to them to keep the vibrations down. (We’ve already fixed the fans.) Swing arms for the secondary mirror and the prime focus camera can be seen in Figure 7, and the full complement of six swing arms can be seen in Figure 8.

5.5 Other Telescope Systems
During 2007-2008, we have also completed the on-telescope instrument cooling system to deliver near-ambient-temperature water/glycol to cool the instruments and the optics packages on the telescope. We have also completed the dynamic balancing system which uses 6-tons of water/glycol to adjust the balance of the telescope when we use the swing arms to change optical configurations during the night. We have verified that the 6-tons of water in several tanks does not cause any sloshing problems for the servos of the main axis drives.

5.6 Telescope Control System
About 80% of the LBT Telescope Control System (TCS) software is now deployed and operating on the mountain for observing. The TCS is divided into a number of high-level sub-systems that control various aspects of the observatory operation. These sub-systems which are already operating include the primary mirror cell (PMC) controls, the enclosure controls (ECS), optical supports (OSS), the point spread function (PSF) controls and the pointing control system (PCS). These software sub-systems run on Linux servers in the control room and most of them have corresponding hardware interface machines distributed around the telescope and enclosure.
For example, a real-time VxWorks machine controls each of the primary mirror cells, and Allen-Bradley PLCs control the enclosure, enclosure rotation and some of the telescope safety logic. A Siemens PLC controls the oil delivery for the hydrostatic bearing system. Each sub-system has ethernet connections for command and control, for reflective memory, and for telemetry and logging. The guiding control system (GCS) is now being tested on-sky. Sub-systems which will soon be deployed to the mountain include the adaptive optics system (AOS) and telemetry (TEL). During the coming year we will be upgrading the function of PCS to be a fully binocular pointing and guiding system. Until now, the second prime focus camera has been operating in a master-slave mode with the red camera guiding with the mount, and the blue camera guiding with the primary mirror tip-tilt.

6. ADAPTIVE OPTICS

6.1 Adaptive Secondary Mirrors and On-Axis Wavefront Sensors

The 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 secondaries will update their shape at kiloHertz rates to correct the distortions in the wavefront caused by atmospheric turbulence. We have made some design modifications to be sure that the shell is stable in the wind, even when the adaptive optics loop is turned off. The 1.6 mm thick, 911 mm diameter thin Zerodur shells for the adaptive secondaries have been polished by the Steward
Figure 8. This photo shows the Large Binocular Telescope with two 8.4m primary mirrors pointed at the horizon inside the observing chamber. The telescope is configured for observing with prime focus cameras on both sides. In the lower right of the picture, the rigid secondary mirror and the tertiary mirror can be seen on swing arms out of the optical beam. The first AGw unit for off-axis guiding and wavefront sensing can be seen mounted on the instrument rotator near the 8 o’clock position of the primary mirror on the right side of this photo. The central windbracing is wrapped with aluminum foil tape to minimize over-cooling by radiation to the sky. May 2008 photo by Ray Bertram.
Figure 9. First adaptive secondary mirror in the clean room with P. Salinari after its acceptance test in March 2008. The assembled unit includes the hexapod to position the secondary unit (top), the electronics package including the DSP cards (middle), the cooling plate, the Zerodur reference body, the 672 voice-coil actuators, and the 1.6 mm thin shell (bottom). Photo by D. Gallieni.

Observatory Mirror Lab at the University of Arizona. After breaking two thin shells in 2005, we have two thin shells ready for the two secondary units, and we have a spare shell in the final phases of polishing. The first adaptive secondary unit passed its factory acceptance tests in early 2008, and met all the specs on dynamic performance. Riccardi et al. (2008) provide technical details on the measured performance of the adaptive secondary unit with 672 voice-coil actuators supporting the thin shell. The assembled adaptive secondary unit is shown in the clean room at Microgate in Figure 9. The first of these adaptive secondary mirror units has now moved to the final stages of system testing at Arcetri Observatory. These tests conducted in the tower of a retired solar telescope will close the entire adaptive optics loop including the deformable secondary, the “W” on-axis wavefront sensor and the actual control software. The tower environment is pressure and temperature controlled so that we are able to simulate everything from the mountain environment except windshake. Details of the integration and system tests are reported by Esposito et al. (2008). The adaptive optics system for the telescope is a cooperative effort between ADS International of Lecco, Italy; Microgate of Bolzano, Italy; and the adaptive optics groups at Osservatorio Astrofisico di Arcetri in Firenze and at Steward Observatory and LBT.
Observatory in Tucson.

### 6.2 Laser Guide Star Development

The LBT consortium is planning to add a constellation of Rayleigh laser guide stars to enhance the adaptive optics performance of LBT. The initial deployment will be to provide ground-layer adaptive optics (GLAO) correction in front of the LUCIFER spectrographs. By averaging the wavefront from four low-altitude laser guide stars, the turbulence in the lower 1-2 km of the atmosphere can be corrected in order to improve the image concentration by a factor of 2-3 over the natural seeing. The system will also include upgrade paths to on-axis and multi-conjugate adaptive optics (MCAO) in the near future. Rabien et al. (2008)\(^{19}\) report on the detailed plans for this system.

### 7. OBSERVATORY 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, Zentrum für Astronomie der Universität 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 (INAF). Partners at individual institutions include the Ohio State University in Columbus, Research Corporation in Tucson, the University of Notre Dame, the University of Minnesota and the University of Virginia. Astronomers and engineers at all of these institutions are involved in building instruments and auxiliary equipment for the telescope.

### 8. SUMMARY

The Large Binocular Telescope has undertaken regularly-scheduled science observations with prime focus cameras mounted in front of both primary mirrors. The telescope is pointing and tracking well, while additional technical issues are being solved to improve performance and system reliability. On-sky commissioning of the first Bent Gregorian focal station is underway for the arrival of the first spectrometer in Fall 2008. The Bent Gregorian focal station includes a rigid secondary mirror, a tertiary flat mirror, an acquisition and guiding unit, and an infrared test camera. Adaptive secondary mirrors are being integrated and tested in Italy while the telescope makes seeing-limited observations. Recent photos and other news can be found on the LBTO web site: http://lbto.org

### REFERENCES


