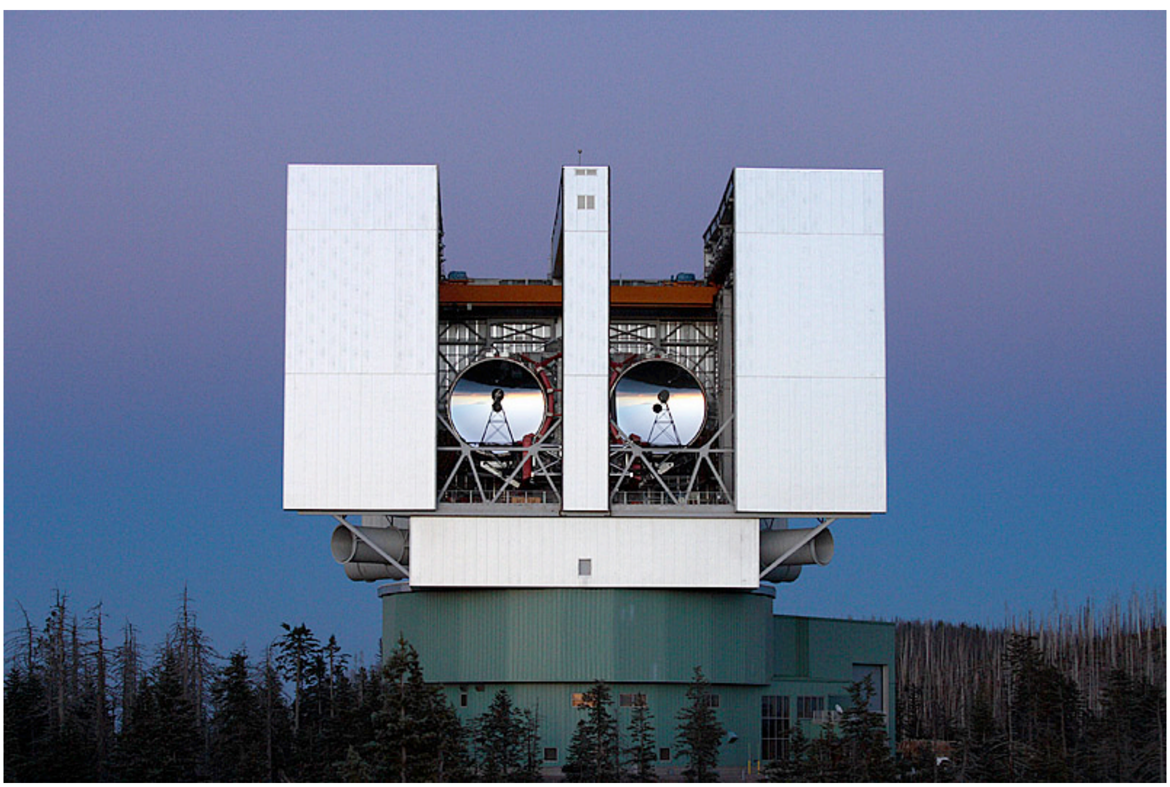
Status of the Large Binocular Telescope

R. F. Green and J. M. Hill
Large Binocular Telescope Observatory

ABSTRACT

The Large Binocular Telescope (LBT) Observatory is a collaboration among 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. Monocular prime focus imaging started 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 in September 2008. 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 the beginning of 2010. When its two beam-combining interferometers are in routine use, LBT will be the pathfinder for science with the next generation of 20-meter class telescopes.



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. In this sense, LBT is the first of the 20-meter telescopes.

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. A more detailed technical description of the telescope can be found in Hill et al. (2008), and references therein. The two primary mirrors can also be used independently to obtain seeing-limited images over a wide field-of-view. Additional information can be found on the LBTO web site: http://www.lbto.org

INSTRUMENTS

The binocular telescope facility will provide general observational utility to its partner astronomers through instrument pairs used in parallel. The facility instruments to be handed over to and operated by LBTO staff are paired to use the two telescope beams simultaneously. The two optics trains must co-point to within tight tolerances, so the instruments will observe a common field of view. Wagner (2008) describes the instruments in detail. There is a pair of wide-field prime focus cameras, and there will be a pair of optical long-slit / multi-slit spectrographs, and a pair of near-IR long-slit / multi-slit spectrographs. Two additional instruments will take advantage of the diffraction-limit of the combined focus and the adaptive secondaries.

The Large Binocular Cameras (LBC) are situated at the f/1.14 prime focus, and were developed by an Italian collaboration centered in Rome, Padova and Firenze. They are two 36-Mpixel Mosaic CCD array cameras, one of which is highly optimized for the near-UV and blue; the other for red and near-IR, with cross-over in the yellow. The field-of-view is approximately 24 x 24 arcminutes with 0.23 arcsec pixels. They are fitted with broad-band and SDSS filters, as well as a y filter and custom broad U filter. This instrument has already made LBT a relatively unique facility in terms of its superior etendu and ability to take deep near-UV images.

The Multi-Object Double Spectrographs (MODS) being produced by Ohio State University will be mounted at the direct Gregorian foci. Each of the two spectrographs have red and blue channels, and accommodate both long-slit and multi-slit masks. MODS will provide low-medium resolution grating spectroscopy (R=2000-8000) over the entire 330 - 1100 nm band with a 6 x 6 arcminute field-of-view.

The LUCIFER instruments are being produced in Germany by a collaboration centered at the Landessternwarte of the University of Heidelberg and MPIA. They are wide-field near-IR imager/spectrographs, with cold custom-cut slit masks. The masks are deployed in cassettes of 24; a transfer dewar facilitates the removal of the cassette in the instrument, followed by the insertion of the pre-cooled cassette with the next set of masks. LUCIFER will accommodate both seeing-limited observations over a 4 x 4 arcminute field and diffraction-limited observations over a 0.5 x 0.5 arcminute field.

The two interferometers are currently classified as strategic, meaning that their development teams and collaborators will have initial use, but the intention is to make them facility instruments once their capability has proven to be reliable. The University of Arizona with support from NASA is producing a mid-IR interferometer, LBTI, with nulling and imaging modes, as well as a 3-5 micron camera. MPIA Heidelberg is leading a collaboration to produce a near-IR Fizeau imager, LINC-NIRVANA, with three levels of adaptive correction.

In addition, there is a facility-scale, high-resolution, high-stability, fiber-fed spectrograph, that currently has PI status for its development group led by AIP, Potsdam. The intention again is to make this PEPSI instrument more widely available to partner astronomers.

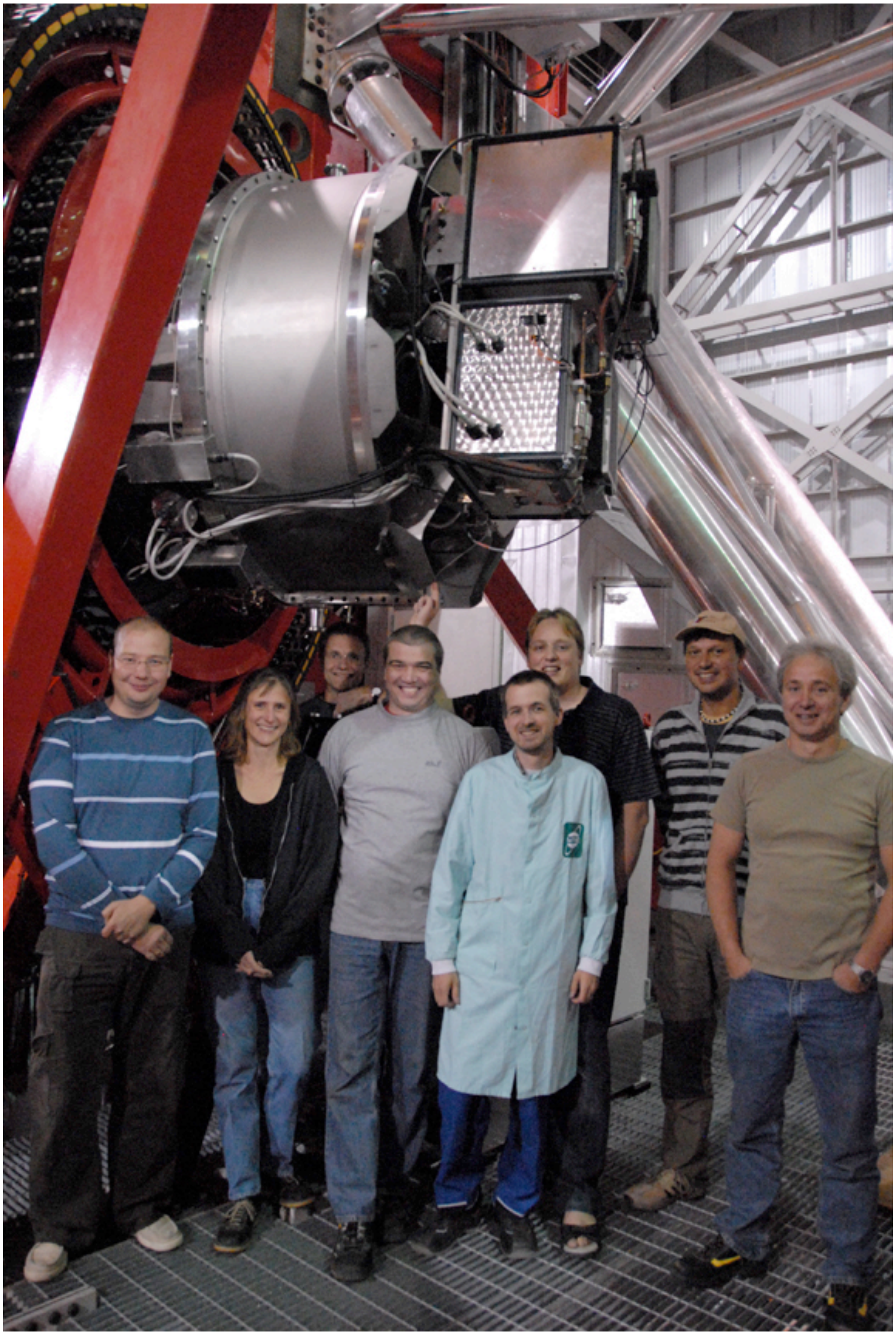
The LBT Project was established very much as a partnership enterprise. LBTO management therefore does not control the development and delivery of instruments. The instrument teams have agreed to progress reviews and acceptance testing as their projects proceed. The projected instrument commissioning schedule is based on planned progress with telescope operations and close exchange of information with the instrument teams.

OBSERVING STATUS

LBT is now almost completely assembled, and is in commissioning along with its complement of science instruments. First light was achieved with one primary mirror and one prime focus camera (LBC-Blue) in October, 2005, with a widely publicized picture of the edge-on spiral galaxy, NGC 891. Just after first light, the telescope was shut down for installation of the second primary mirror. That task was successfully completed; the second primary mirror was aluminized in-situ in January 2006. Monocular prime focus science imaging started in Fall 2006. The LBC-Red prime focus cryostat was delivered in late-Fall 2007. Binocular imaging with two co-pointed prime focus cameras began in December 2007. Regularly scheduled science observations using both primary mirrors and both prime focus cameras during the dark of the moon started in January 2008. Image quality delivered by the prime focus cameras has run the full gamut from 0.4 arcsec FWHM images that are undersampled by the 0.23 arcsec pixels, to really remarkably bad seeing behind a winter cold front of 4 arcsec FWHM.

As of January 2009, the Large Binocular Telescope Observatory has supported three full semesters of observing with prime focus imaging. Interspersed were optical alignment and initiation of binocular mode for the prime focus, as well as installation and initial commissioning of the first bent Gregorian focal station. Green et al., (2008) summarize the initial operating plans and statistics.

The first of the pair of (LUCIFER) near-IR imager and spectrometer instruments arrived at the telescope in August 2008. Fall 2008 and early 2009 was spent commissioning this instrument along with some aspects of the telescope itself during the bright of the moon. The first scheduled science observations with LUCIFER at the bent Gregorian focal station are expected in May 2009. The first of the optical-UV (MODS) spectrometers is expected to arrive at the telescope in late 2009. The second LUCIFER is now expected late summer of 2010, and the second MODS a year after delivery of the first.

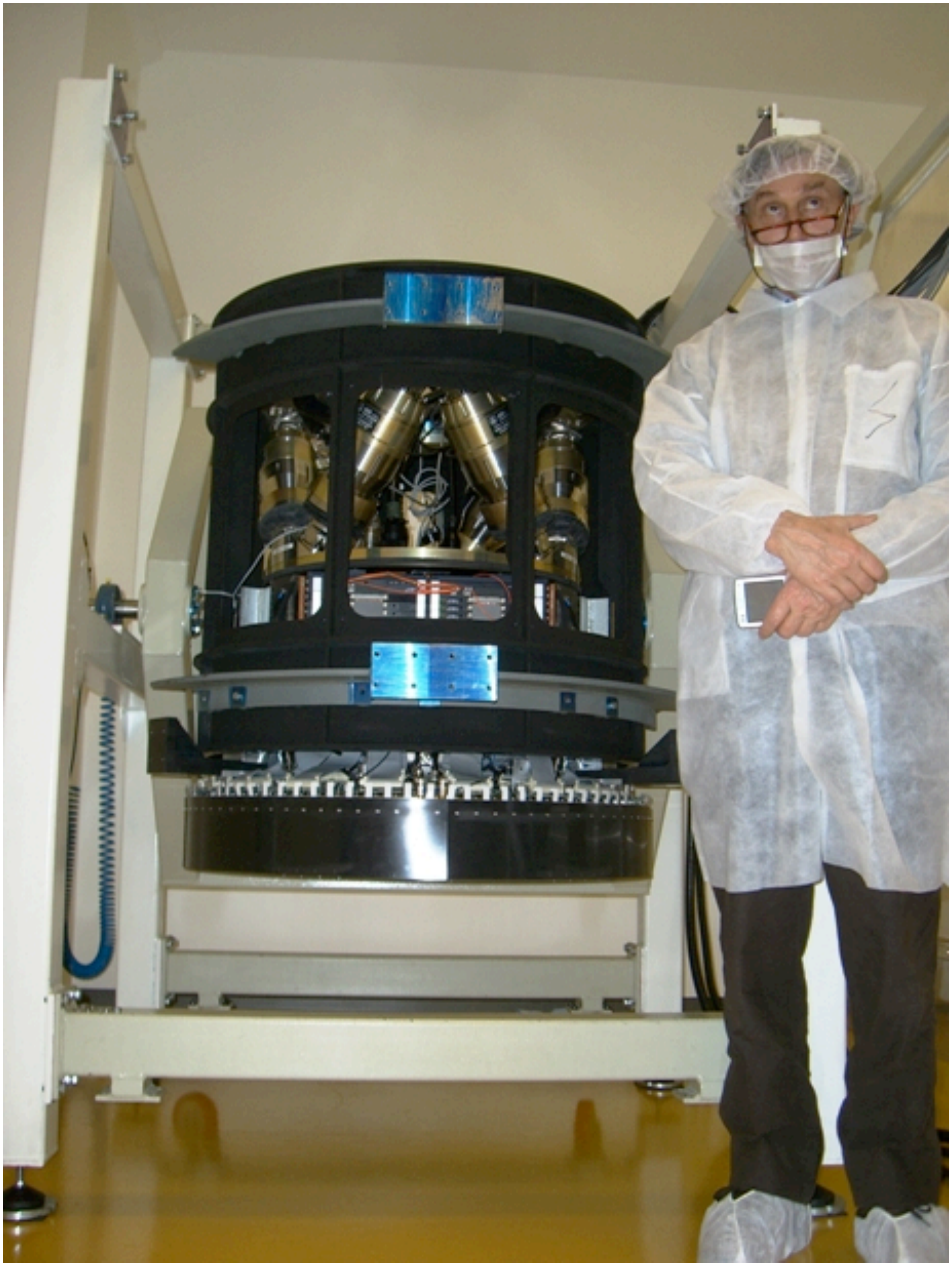


The LUCIFER team having just installed their instrument.

ADAPTIVE OPTICS

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. The 1.6 mm thick, 911 mm diameter thin Zerodur shells for the adaptive secondaries have been polished by the Steward 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. 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 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. The current plan calls for commissioning of the first AO unit in early 2010, with the second unit to follow late in the year. 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.

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 spectrometers. By averaging the wavefront from three 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. This system is being developed by a group of LBT-partner astronomers and engineers centered in Garching. The (ARGOS) laser guide star system completed its Preliminary Design Review during February 2009.



The first adaptive secondary mirror unit near completion of electromechanical acceptance.

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, and the Research Corporation in Tucson, who have supported a partnership among the University of Notre Dame, the University of Minnesota, the University of Virginia, as well as OSU and Arizona.

The LBTO is a private observatory facility (as viewed from the U.S.) with a small fraction of national research funding through NSF and NASA. The sources of the funds for the construction and operation of the telescope vary considerably from partner to partner. In Italy, the funding to INAF is almost entirely derived from the national government. Most of the United States university partners derive their funding from a combination of state and private resources, with limited federal support for development of instrumentation. Astronomers and engineers at all of these institutions are involved in building instruments and auxiliary equipment for the telescope.

The construction and operation of the telescope is under the auspices of the Large Binocular Telescope Corporation, a 501(c)3 non-profit corporation in Arizona. The corporation is managed by a Board of Directors with representation in a "senate"-type model; i.e., a unanimous vote of all partners with 1/8 or great share is required for partner financial commitments. This corporation issues contracts with individual partners and with outside companies for the construction and operation of the telescope. The project is denominated in US dollars, although most of the European-based contracts get paid fully in Euros, regardless of the exchange rate. The corporation does not employ any staff directly. They do contract with the University of Arizona for the staff who are commissioning and operating the Observatory in Tucson and on Mt. Graham. The standing advisory structure consists of a Science and Technical Committee, who advise both the Board and the Director on matters of scientific priority including instrument development, and a Finance Committee, who advise the Board on issues of budget, auditing, and finance and LBTO management on reporting structures and coupling of budget to program.

The Board has worked collegially and effectively in bringing LBT through a protracted site approval and subsequent development phase to commissioning and operations as a working observatory. A challenging structural issue for the Board has been the means by which partners can bring their total contributions to match their intended fractional observing shares. This broad issue includes questions of assigning value to in-kind contributions such as major instruments, fixed vs. actual costs, implicit penalties to other partners for delayed deliveries of fixed-price items valued in constant dollars, timescale for equalization for a given complement of capabilities, and the treatment of strategic and next generation instruments. A fact of life with groups in Germany and Italy that develop technology and build optical/IR instruments is that their work for ESO comes with very stringent contract terms and schedules, and their countries are bound to their obligations by international treaty. A schedule for their LBTO commitments that explicitly takes into account those competing demands is vital for realistic estimates. The advantage of a broad international partnership is that each partner's wheel of fortune is in a different phase at any given moment. The Board is confronting the issue of how best to move development forward without reducing support to the level of the least advantaged partner of the moment. A successful approach has been flexibility on the short-term allocation of observing time fractions while maintaining inertia in the long-term fixed fraction of total investment. The U.S. partners would clearly benefit if NSF acts positively on the recommendation of the recent ALTAIR report to increase and stabilize the funding available for instrument development and operation of non-federal large-aperture telescopes, in exchange for some public access time.

The bottom line is that the LBT partnership is unified by the desire for a successful scientific facility. That success will result in a premier pair of tandem 10-meter class facilities and a pathfinder in the problems addressed by this first of the 20-meter class telescopes.

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