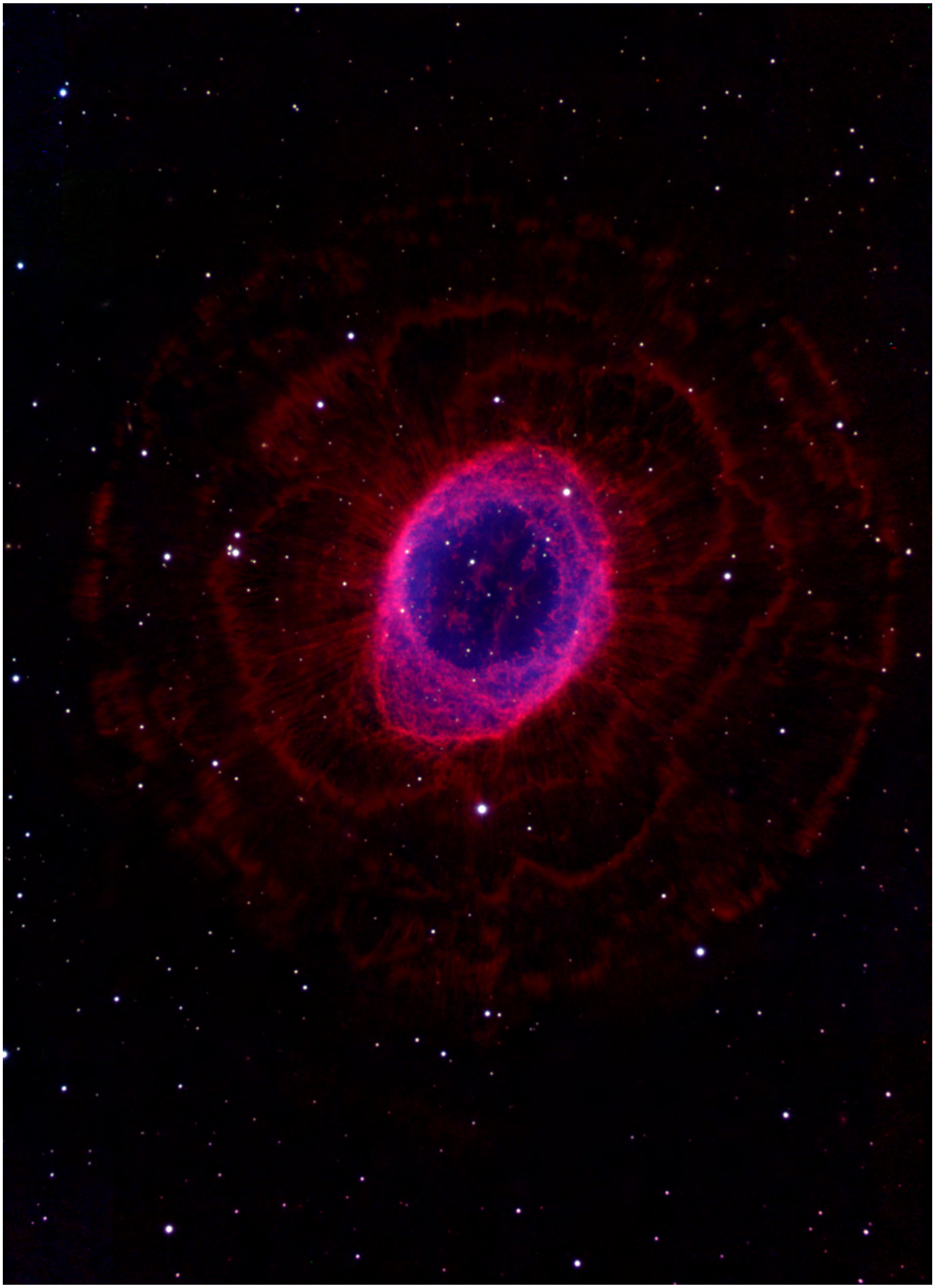
Large Binocular Telescope Observatory

Annual Report 2022



LUCI Image of the Planetary Nebula M57 (Blue: Paβ 1.28 μm, Green: [FeII] 1.64 μm, Red: H_2 2.12 μm)

Large Binocular Telescope Observatory Annual Report – 2022

Contents

The Large Binocular Telescope Observatory

The Large Binocular Telescope is a pair of 8m class telescopes installed on a common mounting. This configuration delivers the equivalent collecting area of an 11.8m telescope and, most crucially, the spatial resolution of a single 22.8m telescope. By virtue of these unique features, LBT is a scientific and technological pathfinder of the future generation of Extremely Large Telescopes.

LBTO has a mission of advancing astronomical research with the efficiency and versatility of modern 8- to 10-m telescopes, while demonstrating innovations that open a new landscape of discovery embodied in the emerging generation of larger facilities leveraging multi-mirror technologies.

The Observatory members represent an international collaboration with a wide diversity of scientific interests, including solar system planets and exoplanets, stars and stellar explosions, galaxies and quasars, and galaxy clusters and cosmic structure. Their scientific goals are enabled by a versatile suite of instruments spanning the optical through mid-infrared bandpasses, supported by sophisticated adaptive optics technologies correcting for distortions introduced by the earth's atmosphere.

The Observatory is expanding its adoption of forefront instruments and technologies to address the most compelling questions of our times on the nature of the cosmos.

The LBTO will thereby continue its mission of *discovery driven by innovation.*

Introduction from the Board

I am delighted to introduce this first public LBT Annual Report, commencing with 2022 as the entire world emerged from the pandemic. The last several years were challenging for the LBT, just as for all scientific institutes and facilities in the world. We used these challenges as opportunities to change and improve, and LBT emerges from the pandemic years stronger and better organized. This Annual Report testifies to the hard work accomplished in 2022 and the ambitious plans for the following years, along with the examples of some of the outstanding scientific results from 2022.

The telescope continued to operate and carry out observations throughout this period despite limited on-site staffing and scientists observing remotely from their home institutions if not their actual homes. Despite these difficult conditions, the staff was able to keep the facility fully operational and we learned a great deal about supporting scientific operations with leaner resources. These lessons will have a long-term impact on how our scientists use the telescope and how we manage the facility.

As planned, Christian Veillet, who led the Observatory for nearly ten years, decided to step down from the role of Director in 2022. Christian very effectively led the transition of the Observatory from the construction phase into the regime of routine scientific operations. LBT now operates at high efficiency and has a well-developed culture focused on science as the first priority in large part because of his leadership. We welcome the new Director, Joseph C. Shields, who will fully realize the scientific capabilities of the LBT's most advanced instrumentation, especially the new generation of adaptive-optics instruments that are being commissioned.

A major accomplishment in 2022, was the upgrade of the entire LBT Adaptive Optics infrastructure. Thanks to the effort of the Adaptive Optics Tiger Team, an external team of world-class experts, both the AO hardware and the staff organization were closely reviewed and significantly improved. The technical readiness of the instruments and the staff ownership of the system greatly benefitted from these efforts, and they will be the basis of future major upgrades of the AO system.

These achievements are based on two pillars. One is the incredibly talented and committed staff that operates, maintains, and improves the facility both in Tucson and on the mountain. The Members are grateful for their dedication and hard work. The other pillar consists of the scientists and institutions that develop, support and utilize the observatory. They form a diverse and vibrant community with the expertise and interests that make the organization a lively and attractive environment. In my years as Chair of the Board of Directors I have been very pleased to see that all the stakeholders are working towards shared goals for the LBT, despite their tremendous diversity of interests and priorities.

Astronomy has a brilliant and exciting future: fundamental mysteries concerning the nature and fate of the Universe remain unsolved and will require the use of the best facilities to be addressed. With its unique suite of instruments, LBT has a clear role in leading the exploration of the Universe over the next decade and we look forward to the exciting discoveries that are ahead.

Adriano Fontana, Chair

Message from the Director

The year 2022 was a period of continued progress and change at the Large Binocular Telescope Observatory, reflected in personnel, instrumentation, and operations. I am honored to report on the activities of the past year in my new status as LBTO Director. I was motivated to take on this role based on the observatory's achievements to date and its distinctive potential for future scientific discovery.

Christian Veillet, who began his service as LBTO Director in February 2013, retired from that position in June 2022, transitioning to the role of Senior Astronomer at the Observatory. Christian deserves great credit for his leadership through this period, particularly in overseeing the transition of the Observatory's first generation facility instruments to consistent operational status, while minimizing facility downtime. I have appreciated his assistance and wisdom throughout the leadership transition.

The LBT has a record of accomplishment in implementing new innovations in adaptive optics, and significant progress was made over the past year in advancing AO performance after some challenges affecting hardware and new system implementation. Under the leadership of the AO Tiger Team, both adaptive secondaries are now in routine use. The SOUL upgrade for single-conjugate AO observations was formally accepted for the SX focal stations, with acceptance reviews for DX planned for 2023. Further efforts to improve system robustness are in progress.

The last year also saw significant progress with new instrumentation, including the arrival and precommissioning activity for the SHARK-NIR instrument, which is designed to leverage the AO systems to deliver high angular resolution, high contrast imaging and spectroscopy. Its optical companion, SHARK-VIS, is projected to arrive in 2023. Similarly, preparations are in an advanced state for installation of the iLocater near-infrared spectrograph, which is optimized for extremely high precision radial velocity studies. iLocater is also expected to arrive in 2023.

The astronomical community's current focus on planning and construction of Extremely Large Telescopes (ELTs) is a reminder that the LBT can rightfully be considered the first of this new generation of discovery machines. While the James Webb Space Telescope has, with good reason, dominated the headlines for astronomical discoveries in the past year, it is worth remembering that the LBT, with its 23m baseline, exceeds JWST in resolving power. The LBT Interferometer has continued to demonstrate increased capabilities over the past year, with further upgrades planned.

LBTO maintained a high level of performance throughout 2022, despite the vicissitudes of the evolving pandemic. C-19 service observing was available through both semesters and remained the primary mode of operation. Many of our staff continue to work remotely or in a hybrid modality. Scientists from some of our member institutes are expressing interest in returning to in-person observing, and we anticipate that a hybrid mode will be the norm for observations conducted in the coming year.

With its existing and emerging capabilities, the LBT is producing cutting-edge science across a wide swath of fields – including exoplanets, gamma-ray bursts, galaxy evolution, high-redshift quasars, and more. The Observatory is well-positioned to continue growing its reach and impact in the coming years.

Joseph C. Shields

Governance of the Observatory

The LBTC Corporation and its members

The Observatory is funded, owned, and governed by the **Large Binocular Telescope Corporation** (LBTC), a nonprofit entity established in 1992. The Corporation's current members, constituent institutions, and ownership interests are shown in the table.

Arizona Board of Regents, United States • Arizona State University • Northern Arizona University • University of Arizona	26.25%
Istituto Nazionale di Astrofisica (INAF), Italy	25%
LBT Beteiligungsgesellschaft, Germany • Landessternwarte Heidelberg • Leibniz-Institut für Astrophysik Potsdam • Max-Planck-Institut für Astronomie • Max-Planck-Institut für Extraterrestr. Physik • Max-Planck-Institut für Radioastronomie	25%
The Ohio State University, United States • Ohio State University • University of Notre Dame • University of Minnesota • University of Virginia	23.75%

The LBTC contracts with the University of Arizona for the operation of the facility, with the **Large Binocular Telescope Observatory** unit functioning administratively and budgetarily as a department within the UA College of Science. The LBTO staff are University of Arizona employees, and the Tucson offices are housed on the UA campus.

The Board of Directors

The LBTC is governed by a **Board of Directors** representing the members. The Board approves the annual program plan and budget for the Observatory, and provides direction on strategic priorities, new instrumentation, and policies related to time allocation and other matters. The Board meets in person twice annually and conducts business at other times as needed via teleconference.

Board Members during 2022 were

- Adriano Fontana, INAF (Chair and President)
- Chris Kochanek, OSU (Vice Chair)
- Danny Gasch, Research Corp (Hon. Director)
- Buell Jannuzi, AZ
- Evan Kirby, OSU (UND)
- Andreas Quirrenbach, LBTB
- Roberto Ragazzoni, INAF
- Matthias Steinmetz, LBTB
- Dennis Zaritsky, AZ

Unanimous approval of four **Member Representatives** is required for matters such as the program plan, LBTC budget, the financial contributions of the Members, and the designation of the Observatory Director.

Member Representatives during 2022 were

- Buell Januzzi, AZ
- Thomas Henning, LBTB
- Susan Olesik, OSU
- Filippo Zerbi, INAF

Advisory Committees

The LBT **Finance Committee** (FC) advises the Board and the Observatory Director on financial issues, including the annual LBTC budget, financial performance, policies, and audit process and outcomes. The Finance Committee meets face-to-face annually. Marco Lezzi (INAF) concluded his service on the Finance Committee in September 2022.

FC voting members at the end of 2022 were

- Matthias Voss, LBTB (Chair)
- Nicole Cochran, OSU (Vice Chair)
- Mark Buglewicz, AZ
- Ugo Di Giammatteo, INAF

Additional FC at-large members were

- Danny Gasch, Research Corp (Vice Chair)
- Leonie Heming, LBTB
- David Pappone, UMinn

The LBT **Science Advisory Committee** (SAC) provides the LBTC Board with high-level scientific and organizational advice. The SAC addresses specific questions concerning the competitiveness and timeliness of major upgrades of the existing instrumentation or new instrumental developments, as well as general advice on scientific priorities or organizational matters.

SAC voting members during 2022 were

- Eduardo Bañados, LBTB (Chair)
- Serena Benatti, INAF
- Josh Eisner, AZ
- Rick Pogge, OSU (Vice Chair)

Additional SAC at-large members were

- Sally Oey, U. Michigan
- Chick Woodward, UMinn

The LBT **User Committee** (UC) is an advisory committee for the LBTO Director. The UC assists the Director in all technical and operational matters of the LBT collaboration, providing feedback on operational areas that affect current users of the facility.

UC members during 2022 were

- David Sand, AZ (Chair)
- Justin Crepp, UND
- Felice Cusano, INAF
- Eichi Egami, AZ
- Adriana Gargiulo, INAF
- Peter Garnavich, UND
- Roland Gredel, MPIA
- Tom Herbst, MPIA
- Rick Pogge, OSU
- Mike Skrutskie, UVa
- Roberto Speziali, INAF
- Kris Stanek, OSU
- Klaus Strassmeier, AIP
- Mark Whittle, UVa
- Chick Woodward, UMinn

LBT Science Highlights

The Peculiar Gamma-ray Burst 200826A

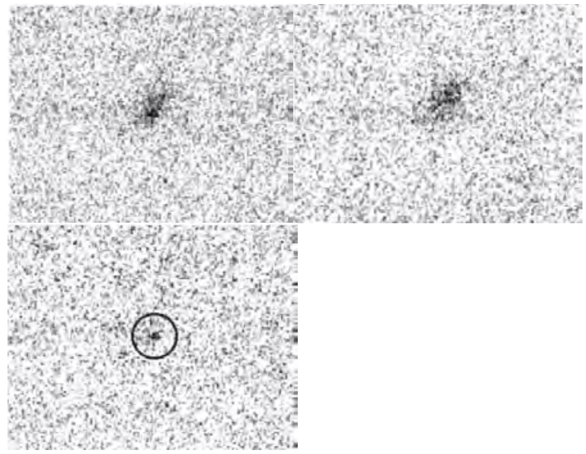
The phenomenology of gamma ray bursts (GRBs) is an important tool for understanding the endpoints of stellar evolution. GRBs are routinely classified as long and short events based on the duration of the gamma-ray emission. Long GRBs (LGRBs) with durations exceeding 2s constitute the majority of observed sources, while short GRBs (SGRBs) usually have a subsecond duration.

Optical observations reveal that LGRBs are typically associated with highly energetic broad-lined Type Ic supernovae, and thus identified with the explosion of a massive star undergoing core collapse. By contrast, SGRBs arise from the merger of compact objects, illustrated by SRGB 170817A and its link to the detected gravitational wave signature of a binary neutron star merger.

This simple picture has now been complicated by the discovery of SGRBs with an associated supernova signaling the explosion of a massive star. Clearly burst duration is not sufficient to reveal the nature of the GRB progenitor.

An interesting case study in this regard was published by Rossi et al. (2022) who used MODS to obtain optical spectra and images, and LUCI to obtain infrared images, for the GRB 200826A. This event, associated with a galaxy at a redshift z=0.748 determined from the MODS spectra, showed a short gamma-ray duration. Late epoch optical images of the host galaxy were obtained with the LBC.

The LUCI images were acquired using the Single conjugate adaptive Optics Upgrade for LBT (SOUL), the telescope's second-generation adaptive optics system. The SOUL system, leveraging the LBT's adaptive secondary mirrors, produced H-band images 37 days post-explosion with point source FWHM $\leq 0.13''$.



LUCI-1 AO H-band images of GRB 200826A taken 37 days post-explosion (top left) and four months later (top right), with resulting difference image (bottom left). The field of view of each image is 2.6"x2.0".

The afterglow was detected with MODS in the g' and r' bandpasses in the first few days post-explosion, and the LUCI measurement a month later produced a detection with H~27.4 mag. These results supplemented with other measurements reveal a light curve consistent with a late-time bump arising from a supernova. This finding points to GRB 200826A as a typical core-collapse-driven event in the low tail of the duration distribution of LGRBs.

More work is needed to define the processes that underlie the different elements of GRB phenomenology. The AO-supported near-IR follow-up observations in this study are the first to detect and pinpoint the location of a SN associated with a GRB, track the SN evolution, and determine the properties of the host galaxy.

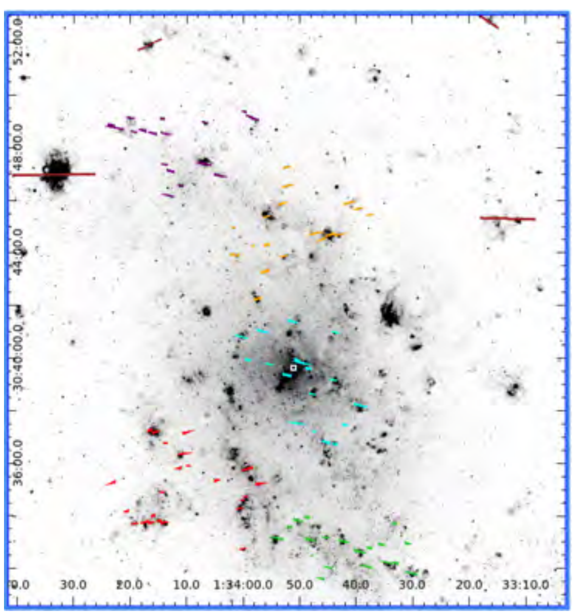
Reference:

The Peculiar Short-duration GRB 200826A and Its Supernova, Rossi et al. 2022, ApJ, 932, 1.

Large-Scale Abundance Structure in M33

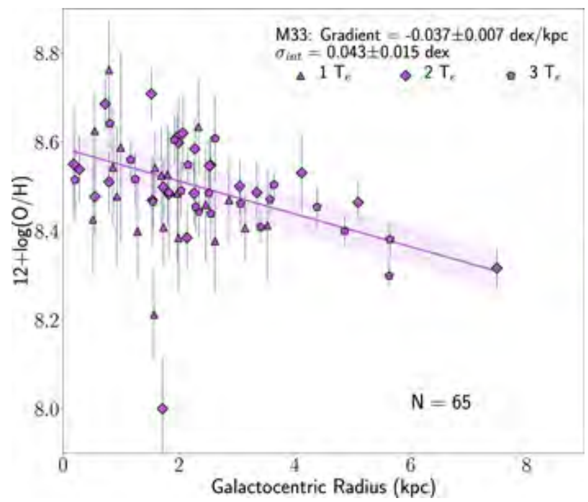
Spiral galaxies are known to display gas-phase abundances of heavy elements that typically decrease with increasing radius, and the abundance gradient and scatter at a given radius contain important information on the chemical evolution and mixing processes in the overall system. The scatter in particular is a potentially important indicator of the degree to which local enrichment is important in driving chemical evolution, as opposed to large-scale mixing processes resulting, for example, from supernovae and stellar winds.

A team led by University of Minnesota doctoral student Noah Rogers recently published new results based on new LBT measurements that constitute the authoritative study of nebular abundances in the Local Group spiral M33.



Continuum-subtracted Hα image of M33 from Massey et al. (2006) reproduced in Rogers et al. (2022), with MODS multi-object and long-slit locations indicated and color-coded by field or pointing.

The ability to derive such abundances and their dispersion as a function of radius for M33 and other galaxies has been limited in past studies by sparse spatial sampling, inhomogeneous data and data quality, and sensitivity to poorly determined nebular temperatures, among other factors.



Oxygen abundance gradient in M33, with symbol type indicating the number of directly measured temperatures used in calculating the abundance, derived from MODS spectra.

The new study utilizes spectra of ~100 HII regions to derive abundances of multiple elements from emission-line measurements. The high sensitivity, coverage of the full optical bandpass, and data homogeneity allowed direct determination of temperatures from multiple temperature-sensitive line ratios.

The findings indicate a small intrinsic dispersion in abundances at a given radius, implying that the interstellar medium in M33 is chemically well-mixed and homogeneously enriched from inside out. The results underscore the importance of using direct temperature measurements across multiple ionization zones to reduce sources of systematic error.

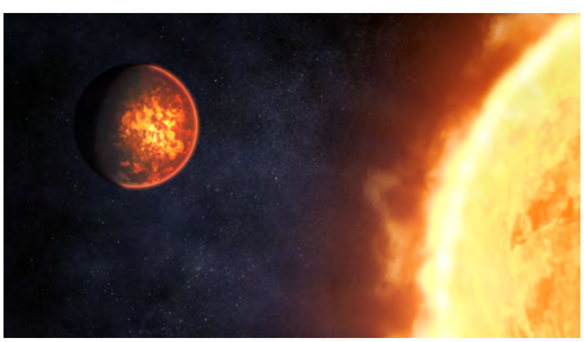
Reference:
CHAOS. VII. A Large-scale Direct Abundance Study in M33, Rogers et al. 2022, ApJ, 939, 44

PETS: the PEPSI Exoplanet Transit Survey

An important advance in our ability to directly probe the atmospheric properties of planets outside the Solar System has been by studying spectroscopic features imprinted by the transmissive atmosphere of a planet as it transits across the face of its host star as seen from Earth.

The PEPSI Exoplanet Transit Survey (PETS) takes advantage of the high-resolution, high-precision capabilities of the *Potsdam Echelle Polarimetric and Spectroscopic Instrument* (PEPSI) to carry out transmission spectroscopy of exoplanet atmospheres for a large sample of transiting systems. PETS is distinctive in representing a collaboration of scientists drawn from all of the LBT members and their associated allocations of observing time. The survey, conducted over the four semesters of 2021-2022, recently concluded with 28 targets successfully observed and an additional 11 sources with partial data.

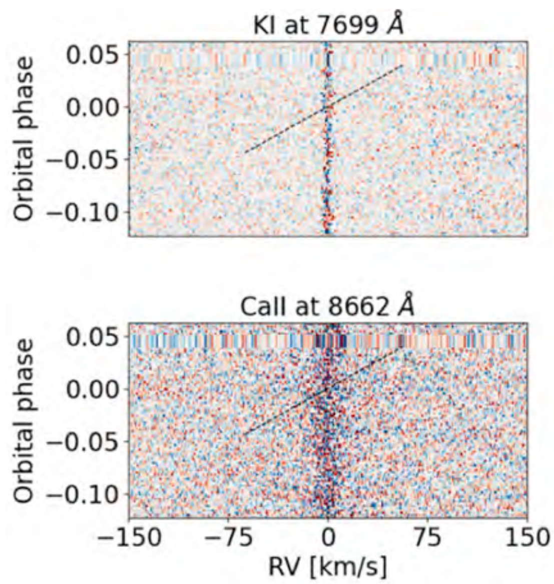
Initial science results from PETS are now appearing, with a study of the super-earth 55 Cancri e published by Keles et al. in March 2022. Models for the exoplant, with mass of ~8.0 M_e, radius ~2 R_e, and orbital period of 0.66d, have suggested several alternatives for a potential atmospheric composition. A primordial gaseous envelope dominated by hydrogen-helium is expected to evaporate on short timescales and is therefore unlikely.



55 Cnc e's close orbit results in a frontside temperature in excess of 2000 K (STScI/NASA visualization).

Proposed alternatives depend on the interior composition of the planet. A rocky interior may be associated with an envelope of silicate species, while less rocky material may implicate envelopes rich in water, or carbon dioxide and molecular nitrogen.

The PETS data were used to place sensitive limits on the presence of various atmospheric silicate species (tracing elements including Fe, Ca, Mg, K). A silicate-vapor atmosphere might be expected from sputtering of an Earth-like crust by stellar irradiation, or outgassing processes from molten magma. The PETS results imply, however, that a widely extended silicate envelope around this super-Earth can be excluded.



Example 2D maps of the Cnc e residual spectra at different orbital phases for KI and CaII lines, with the expected absorption trace shown by the dashed black line.

Additional results from PETS are currently submitted for publication and in preparation. The PETS collaboration was organized by Klaus Strassmeier at AIP-Potsdam.

Reference:

The PEPSI Exoplanet Transit Survey (PETS) I: Investigating the Presence of a Silicate Atmosphere on the Super-Earth 55 Cnc e, Keles et al. 2022, MNRAS, 513, 1544

An Ongoing Galaxy Cluster Merger

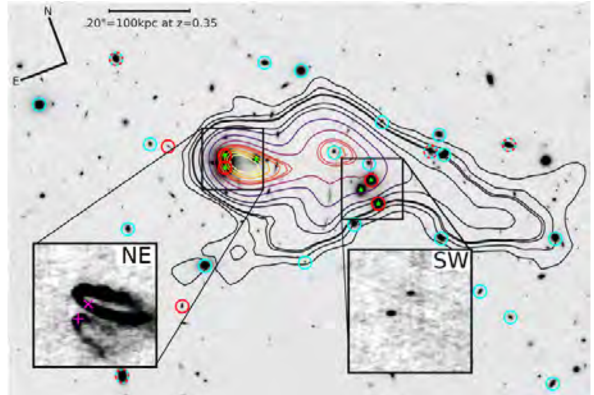
Gravitational lensing is a powerful tool for tracing the underlying structure of galaxy clusters. Pascale et al. (2022) have recently published a detailed study using LBC and LUCI measurements in combination with other data to elucidate the structure of the binary cluster PLCK G176.7+67.0 (G165).

G165 was discovered based on its far-infrared properties in Planck and Herschel data. Follow-up observations with the Hubble Space Telescope yielded 11 cases of single galaxies imaged into multiple locations. These multiply-imaged galaxies were used to construct a lens model, and from it to estimate a cluster mass of 10^{14} $M_{\odot}$. The large mass contrasts with a low X-ray luminosity, suggesting an unusual recent history such as a major cluster disturbance.

LBC images were obtained in the *g* and *i* bandpasses, and K-band images were obtained with LUCI in conjunction with the Advanced Rayleigh Ground layer adaptive Optics System (ARGOS). The resulting images have point source FWHM of 1.37″, 1.07″, and 0.29″ respectively.

The LBT data were combined with HST and Spitzer data to estimate photometric redshifts, supported by Gemini and MMT spectra for the cluster galaxies. In addition, radio continuum measurements at 6GHz (VLA) and 120-168 MHz (LOFAR) were acquired as a means to trace nonthermal emission structures in the cluster.

In total, 21 cluster galaxies were spectroscopically confirmed in the central cluster region. This galaxy catalog and the 11 lensed galaxies with multiple images were used to construct a 2D projected mass map for the lens. The improved lens model recovers two distinct components in the mass distribution separated by ~200 kpc in projection.



LUCI-ARGOS K-band image with spectroscopically and photometrically confirmed cluster members (red and blue circles, respectively) and six dominant galaxy members indicated by green stars. LOFAR radio data is shown as contours, and insets depict VLA 6 Hz images in 15″ × 15″ regions. The LBT observations enabled the estimation of photometric redshifts which constrained the lens model.

A bimodality is also seen in the LOFAR low-frequency radio emission, along with structures that may implicate interaction between the two components. The LOFAR emission is elongated along the major axis of the system; the NE peak has a comet-like morphology with a tail pointing to the SW.

The VLA images reveal two head-tail sources associated with the NE component, representing radio jets from active galactic nuclei that are swept back by the passage of the host galaxy through the cluster medium. The radio galaxies are aligned with each other and the larger cluster extension, suggesting a scenario in which the two cluster components have already traversed each other, as part of an ongoing merger event.

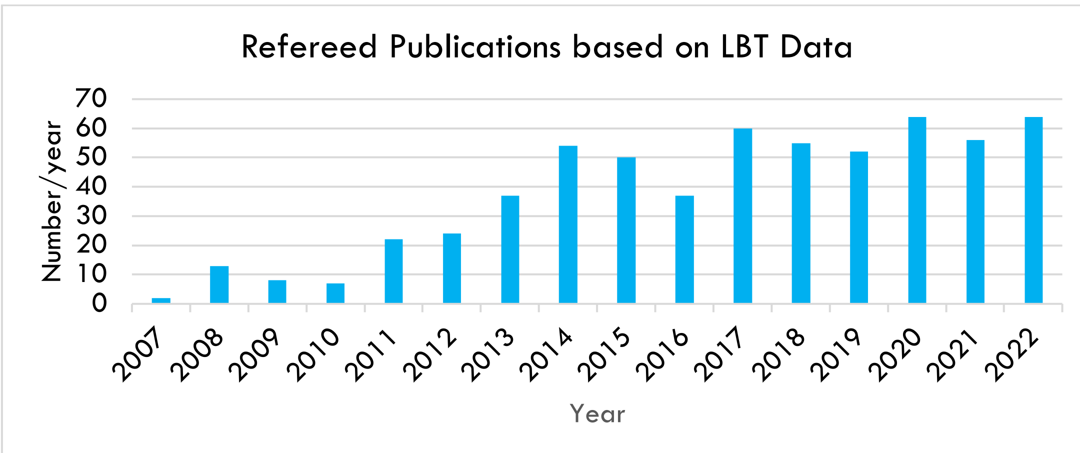
It is in part thanks to the successful results of the LBT image analyses that G165 will be observed using JWST/NIRCam in Cycle 1 (program 1176).

Reference:

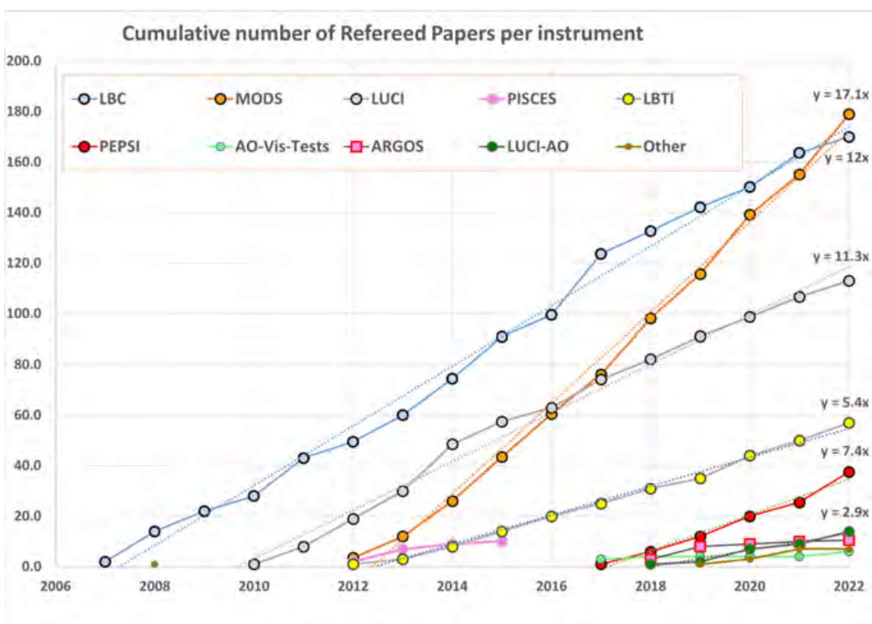
Possible Ongoing Merger Discovered by Photometry and Spectroscopy in the Field of the Galaxy Cluster PLCK G175.7+67.0, Pascale et al. 2022, ApJ, 932, 85.

LBTO Publications

Publication of new findings is a primary indicator of an observatory's contributions to advancing knowledge. The number of peer-reviewed publications based on LBTO data in 2022 tied with the record set in 2020, at 64 papers. The long-term trend since the Observatory's inception is shown in the figure.



The cumulative growth in publications for data from individual instruments is illustrated in the second figure. The different starting points reflect the span of commissioning dates for the LBT's instruments. The growth in published results is broadly supported by the Observatory's suite of instruments, with the strongest rate of increase resulting from MODS data.



Observatory Budget

Funding for the LBT is provided by member contributions assessed based on percentage interests in the Corporation. The Observatory fiscal year starts on January 1st, with budget recommendations reviewed for approval during the prior fall Board of Directors meeting.

Regular activities are included in the Operation Fund, which represents activity funded under contract with the University of Arizona, and in the Corporation Fund that represents activity funded directly by the LBTC. Budget and actual expenditures for both components are shown in the table. Overall expenditures in 2022 were within 1.4% of the budgeted total.

The largest single budget item is payroll, with University of Arizona and Mt Graham International Observatory (MGIO) services representing additional major components. MGIO provides mountaintop site support, including transportation of potable and waste water, road maintenance, custodial services, and operation and maintenance of power and communication systems, for the three telescopes at this location.

The Corporation Fund supports administrative expenses for the LBTC and outreach activity, the latter consisting of partial funding for the MGIO Summer Youth Program and a college scholarship program.

Operation Fund	*Budget 2022*	*Actual*	*Variance*	*Budget 2023*
	$k	$k	%	$k
Payroll	6,850	6,633	-3.2%	6,953
Travel	70	67	-4.3%	74
Utilities	1,180	1,211	2.6%	1,239
Supplies & Services	1,430	1,473	3.0%	1,502
Other Labor	90	120	33.3%	95
Total	9,620	9,504	-1.2%	9,861
UA Services	1,950	1,853	-5.0%	2,068
MGIO	1,240	1,339	8.0%	1,475
Total Operations	12,810	12,696	-0.9%	13,404
Corporation Fund				
Payroll	50	60.7	21.4%	50
Travel	10	3.3	-67.0%	20
Gen. & Admin Exp	10	9.8	-2.0%	15
Outreach	35	2.8	-92.0%	55
Consulting	75	34.9	-53.5%	20
UA Services	10	9.3	-7.0%	10
Total	190	120.8	-36.4%	170
Summary				
Operation Fund	12,810	12,696	-0.9%	13,404
Corporation Fund	190	121	-36.4%	170
Total	13,000	12,817	-1.4%	13,574

Both outreach components are intended to benefit the San Carlos Apache community in proximity to Mt Graham. The Summer Youth Program provides summer site maintenance jobs for a dozen Apache students from the San Carlos and Fort Thomas High Schools, with transportation provided by the Observatory. The scholarship supports San Carlos Apache tribal members pursuing degrees at a two-year or four-year college in Arizona. Both outreach programs were adversely affected by the pandemic, resulting in a significant underspend in 2022.

The budget for 2023 reflects broadly incremental changes across all categories of expenses. Personnel and utility costs are increased by 5% in response to inflation. To achieve a more realistic alignment with actual expenses, the budgeted payroll cost has been reduced, starting in 2023, assuming 2 staff positions will be vacant at any given time (using an average individual salary and benefits).

Instrument and Development Funding

To date LBTO has relied on its members for development of major instruments. The cost of producing new facility instruments is acknowledged by the collaboration through an equalization process, in which the contributed investment is equated to an increased allocation of observing nights on a formulaic basis.

An increasingly important avenue for expanding LBT's capability is through development of Principal Investigator (PI) Instruments. PI Instruments are funded entirely through resources generated by one or more of the Members; their use is limited to the instrument developers and their collaborators utilizing time within their corresponding Member allocations. The second-generation instruments SHARK-NIR, SHARK-VIS, and iLocater slated for commissioning in 2023-2024 all fall in this category.

Upgrades to instruments and the larger facility are supported through designated allocations by the Board that are tracked as part of a Development Fund outside of the annual budget, since these projects frequently cross fiscal years.

At the conclusion of 2022, the unexpended balance in the Development Fund totaled $790k, with over half of this amount committed for upgrades to the MODS CCD controllers anticipated in 2023/2024. Other major projects designated for support include maintenance for the telescope enclosure, projects to improve monitoring of dome seeing, and recoating of a thin shell for the adaptive secondary mirrors. The Board approved allocation of an additional $200k in 2023 designated for renovation of the primary mirror aluminization control system.

Contingency and Reserve Fund

The Observatory maintains a balance outside of its operating budget to cover unanticipated expenses and mitigate financial risk. This Contingency and Reserve Fund has fluctuated over time and contracted during the pandemic when the Members elected to reduce contributions in response to their own financial constraints.

The Contingency and Reserve Fund had a balance of $742k at the conclusion of 2022. On the recommendation of the FC, the Board has established a goal of maintaining a balance of 5% of the combined Operation and Corporation Fund budgets going forward. Member contributions have been adjusted for 2023 to achieve this target.

Staff

Staff Transitions During 2022

Arrivals:

Michelle Aros	Business Affairs Mgr
Peter DeMars	Principal Engineer
Lyann Lau	Accounting Associate
Sam Neff	Junior Staff Technician
Joseph Shields	Director
Jose Trujillo	Junior Staff Technician

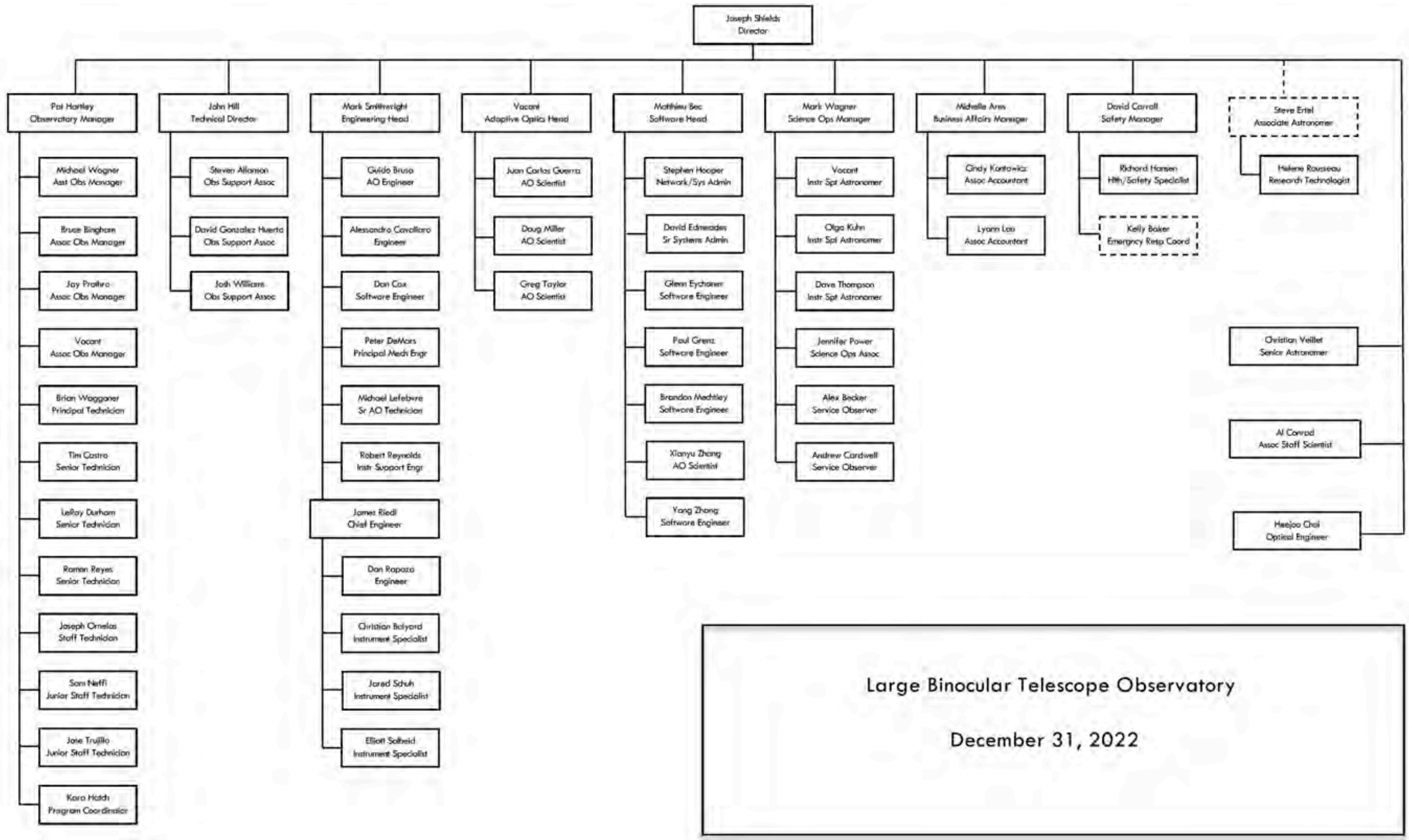
Departures:

Gene Bechetti	Technician
Michael Gardiner	Engineer
Juan Pablo Haddad F.	Engineer
Louise McDermott	Accounting Associate
Gustavo Rahmer	Engineer
Barry Rothberg	Instr Spt Astronomer
James Wiese	Engineer

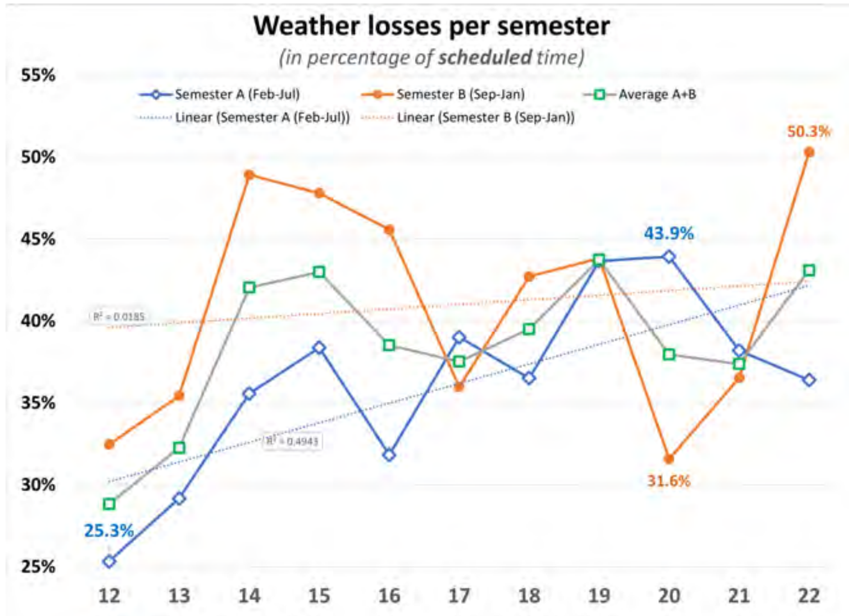
Current Staff

as of December 31, 2022

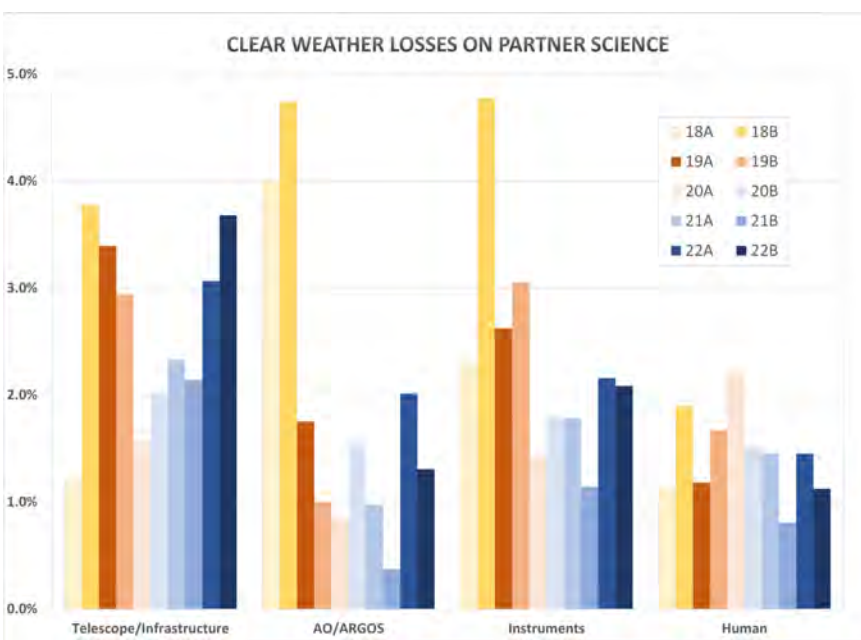
Allanson, Steven	Obs Support Assoc
Aros, Michelle	Business Affairs Mgr
Bec, Matthieu	Software Head
Becker, Alexander	Service Observer
Bingham, Bruce	Assoc Obs Manager
Bolyard, Christian	Instrument Specialist
Brusa Z., Guido	AO Engineer
Cardwell, Andrew	Service Observer
Carroll, David	Safety Manager
Castro, Tim	Sr Staff Technician
Cavallaro, Alessandro	Engineer
Choi, Heejoo	Optical Engineer
Conrad, Al	Assoc Staff Scientist
Cox, Dan	Software Engineer
DeMars, Peter	Principal Engineer
Durham, LeRoy	Sr Staff Technician
Edmeades, David	Sr Systems Admin
Ertel, Steve	Assoc Astronomer
Eychaner, Glenn	Software Engineer
Gardner, Gene	Business Affairs Mgr
Gonzalez H., David	Obs Support Assoc
Grenz, Paul	Software Engineer
Guerra, Juan Carlos	AO Scientist
Hansen, Richard	Hlth/Safety Specialist
Hartley, Patrick	Observatory Mgr
Hatch, Kara	Program Coordinator
Hill, John	Technical Director
Hooper, Stephen	Network/Sys Admin
Kontowicz, Cindy	Accounting Associate
Kuhn, Olga	Instr Spt Astronomer
Lau, Lyann	Accounting Associate
Lefebvre, Michael	Sr AO Technician
Mechtley, Brandon	Software Engineer
Miller, Douglas	AO Scientist
Neff, Sam	Jr Staff Technician
Ornelas, Joseph	Staff Technician
Power, Jennifer	Science Ops Associate
Prothro, John	Assoc Obs Manager
Rapoza, Daniel	Engineer
Reyes, Ramon	Sr Staff Technician
Reynolds, Robert	Instr Support Engineer
Riedl, James	Chief Engineer
Rousseau, Helene	Research Technologist
Schuh, Jared	Instrument Specialist
Shields, Joseph	Director
Smithwright, Mark	Engineering Head
Solheid, Elliott	Instrument Specialist
Taylor, Greg	AO Scientist
Thompson, Dave	Instr Spt Astronomer
Trujillo, Jose	Jr Staff Technician
Veillet, Christian	Senior Astronomer
Waggoner, Brian	Principal Technician
Wagner, Michael	Assist Obs Manager
Wagner, Mark	Science Ops Manager
Williams, Josh	Obs Support Assoc
Zhang, Xianyu	AO Scientist
Zhang, Yang	Software Engineer


Joseph Shields
Director
Pat Hartley
Observatory Manager
Michael Wagner
Asst Obs Manager
Bruce Bingham
Assoc Obs Manager
Jay Prothro
Assoc Obs Manager
Vacant
Assoc Obs Manager
Brian Waggoner
Principal Technician
Tim Castro
Senior Technician
LeRoy Durham
Senior Technician
Ramon Reyes
Senior Technician
Joseph Ornelas
Staff Technician
Sam Neff
Junior Staff Technician
Jose Trujillo
Junior Staff Technician
Kara Hatch
Program Coordinator
John Hill
Technical Director
Steven Allanson
Obs Support Assoc
David Gonzalez Huerta
Obs Support Assoc
Josh Williams
Obs Support Assoc
Mark Smithwright
Engineering Head
Guido Brusa
AO Engineer
Alessandro Cavallaro
Engineer
Dan Cox
Software Engineer
Peter DeMars
Principal Mech Engr
Michael Lefebvre
Sr AO Technician
Robert Reynolds
Instr Support Engr
James Riedl
Chief Engineer
Dan Rapozo
Engineer
Christian Bolyard
Instrument Specialist
Jared Schuh
Instrument Specialist
Elliott Solheid
Instrument Specialist
Vacant
Adaptive Optics Head
Juan Carlos Guerra
AO Scientist
Doug Miller
AO Scientist
Greg Taylor
AO Scientist
Matthieu Bec
Software Head
Stephen Hooper
Network/Sys Admin
David Edmeades
Sr Systems Admin
Glenn Eychaner
Software Engineer
Paul Grenz
Software Engineer
Brandon Mechtley
Software Engineer
Xianyu Zhang
AO Scientist
Yang Zhang
Software Engineer
Mark Wagner
Science Ops Manager
Vacant
Instr Spt Astronomer
Olga Kuhn
Instr Spt Astronomer
Dave Thompson
Instr Spt Astronomer
Jennifer Power
Science Ops Assoc
Alex Becker
Service Observer
Andrew Cardwell
Service Observer
Michelle Ares
Business Affairs Manager
Cindy Kontowicz
Assoc Accountant
Lyann Lao
Assoc Accountant
David Carroll
Safety Manager
Richard Hansen
Hlth/Safety Specialist
Kelly Baker
Emergency Resp Coord
Steve Ertel
Associate Astronomer
Helene Rousseau
Research Technologist
Christian Veillet
Senior Astronomer
Al Conrad
Assoc Staff Scientist
Heejoo Choi
Optical Engineer
Large Binocular Telescope Observatory
December 31, 2022

Observing Performance – Weather and other Losses



The fraction of observing time lost due to weather is shown in the figure, covering years 2012-2022. Curves are shown separately for the A and B semesters as well as their average. Seasonal losses are dominated by a winter rainy season and summer monsoons. Weather losses were unusually high in 2022B, in contrast with 2022A.



Causes of clear-weather losses of observing time from 2018-2022. Losses have generally decreased over this interval, although power disruptions and a change in the mix of observing modes produced an increase in telescope and infrastructure losses during 2022.

The Large Binocular Telescope

The Telescope

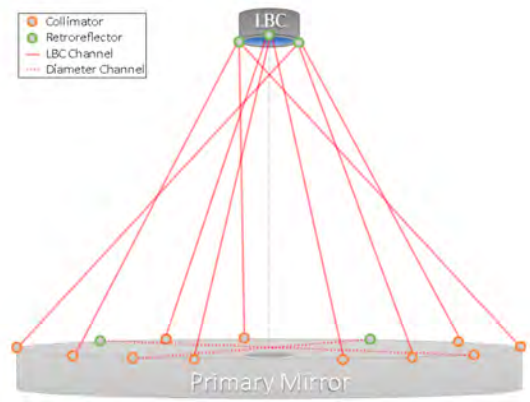
The Large Binocular Telescope Observatory is located in southeastern Arizona near Safford in the Pinaleno Mountains on Emerald Peak at an altitude of 3200m.

The binocular design of the LBT has two identical 8.4m mirrors mounted side-by-side on a common altitude-azimuth mounting for a combined collecting area of a single 11.8m telescope. The entire telescope and enclosure are very compact by virtue of the fast focal ratio (F/1.14) of the primary mirrors.

The two primary mirrors are separated by 14.4m center-to-center and provide an interferometric baseline of 22.8m edge-to-edge. The binocular design, combined with integrated adaptive optics utilizing adaptive Gregorian secondary mirrors to compensate for atmospheric phase errors, provides a large effective aperture, high angular resolution, low thermal background, and exceptional sensitivity for the detection of faint objects.

Several initiatives contributed to performance enhancements for the telescope in 2022.

Collimation has benefitted from the Telescope Metrology System (TMS), which is a laser-truss-based metrology system. The TMS maintains the relative position and orientation of each primary mirror and its respective Large Binocular Camera (LBC) to within a few microns over slews and over time. TMS has been installed and commissioned for use with the LBCs through a collaborative effort between the Giant Magellan Telescope Observatory, the U. Arizona Wyant College of Optical Sciences, and the LBTO, with the dual goal of prototyping a TMS for use at the GMT and improving the image quality and efficiency when observing with the LBCs.



Cartoon representation of a laser truss for one primary mirror – prime focus corrector pair, from Rakich et al. (2022).

The TMS system consists of a network of collimators, mounted along the edge of the primary mirror, and retroreflectors, mounted on the LBC hub, enabling laser-interferometric absolute distance measurements every ~30 seconds that are used to adjust the M1 position. The TMS has substantially reduced the need to re-collimate after every slew or every ~30-40 minutes while tracking.

A major update to the telescope's supporting infrastructure in 2022 was the installation of a new chiller. The new Budzar system is providing improved performance and reliability for cooling systems in the telescope and instruments. The new chiller was also selected for its very low vibration levels, representing a substantial improvement over the previous system. The new unit has also been installed with a new type of coupling to further reduce the transmission of the remaining vibration to the other chiller components and the telescope.

AO System

The LBT was the first telescope to implement adaptive secondary mirrors (ASMs) in routine operation. The system today utilizes two 0.9m AO secondaries, with reflecting thin shells driven by 672 actuators each at rates up to 1700 Hz. Pyramid wavefront sensors are employed for single conjugate AO correction.

The Observatory has benefitted over the last 1.5 years from the guidance of an AO Tiger Team (ATT) consisting of Simone Esposito (INAF-Arcetri, Chair), Laird Close (U. Arizona), Sebastian Rabien (MPE), and William Rambold (Gemini Observatory). The ATT worked with LBTO personnel to define priorities for improving AO performance, and to establish a structure for follow-through. The ATT concluded their work at the end of 2022, with a transition of project management to Observatory staff.

DX adaptive secondary mirror on the telescope in December 2022.

The DX ASM was restored to service in 2022 after being offline for an extended period due to hardware issues and pandemic delays. Substantial work was completed on the unit during Summer Shutdown, including regluing of magnets on the thin shell, and replacement of vibration isolators in the electronics crate on both DX and SX.

The Advanced Rayleigh Ground layer adaptive Optics System (ARGOS) was formally accepted as a facility instrument by LBTO in 2022. Operation of ARGOS is currently suspended for reasons including optical limitations and degradation of the laser launch mirrors. An assessment of options for remediation, along with costs in relation to scientific benefit, is in progress.

Significant advances were realized in 2022 with implementation of the telescope's second-generation AO system, the Single conjugate adaptive Optics Upgrade for LBT (SOUL). Relative to the initial AO installation, SOUL enables faster loop frame rates, more correction modes, and the ability to use fainter AO reference stars. SOUL supports wavefront sensor cameras at four focal stations; the two SX elements were formally accepted in 2022, with acceptance reviews for the DX stations planned for 2023.

AO observation planning has benefitted from predictions of seeing and atmospheric conditions provided on a nightly basis by the ALTA Center at INAF-Osservatorio Astrofisico di Arcetri. ALTA uses the Meso-Nh mesoscale atmospheric model developed by the Centre National de Recherches Météorologiques (CNRM) and Laboratoire d'Aérologie (LA) in Toulouse, France, for forecasting atmospheric parameters including temperature, relative humidity, wind speed, and wind direction, with predictions also generated for optical turbulence and seeing.

Current Instruments

LBT instruments fall into three classes:

- Facility instruments funded by the LBT consortium as a whole, and supported by the observatory for general use by Member astronomers.

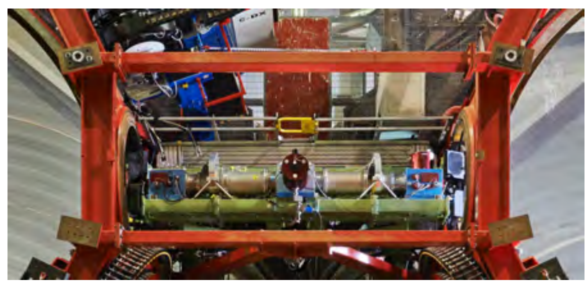
- Strategic instruments, which are interferometric instruments funded by a subset of Members and utilizing significant support from Member personnel in operations.
- Principal Investigator (PI) instruments, which are developed and funded by one or more Members, who retain authority over instrument access.

Current Facility Instruments are

- Large Binocular Cameras (LBCs). The LBCs consist of two prime focus optical cameras, one optimized for the red and one optimized for the blue. Each camera consists of four 4k x 2k CCDs with a pixel scale of 0.224 arcsec for a total field of view of approximately 23 x 23 arcmin.
- Multiple Object Double Spectrographs (MODS). The two units are optical imaging spectrographs, covering 230-1100nm with a 6 x 6 arcmin field of view at a typical spectral resolution of R~2000; a low-resolution prism mode (R~150-500) is also available. The spectrographs can hold 24 slit masks, including standard long slits. The two units each have separate blue and red cameras with a dichroic split at 565 nm.
- LBT Utility Cameras in the Infrared (LUCIs). The two LUCI instruments provide imaging, and longslit and multi-object spectroscopy over a bandpass of 0.95 – 2.4 μm. The units provide a field of view of 4 arcmin in seeing-limited mode, and 30 arcsec in AO mode. The cryogenic mask cassettes can hold 33 masks.
- Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI). PEPSI is a high resolution spectrograph fed by a fiber pair (target + sky) from each primary mirror. The four fibers transmit to a single bench-mounted spectrograph with maximum resolution of R~250,000, and wavelength coverage spanning 383-912 nm. A separate polarimetry mode is available.
- L- and M-band Infrared camera (LMIRcam). LMIRcam operates behind the Large Binocular Telescope Interferometer at 3-5 μm. The instrument can be used in several imaging modes, and also has an integral field spectrograph with 50x50 spaxels and a spectral resolution of R~100.

Current Strategic Instruments are

- LBT Interferometer (LBTI). LBTI is an interferometric beam combiner designed to feed other instruments. The instrument combines the beams from the two primary mirrors incoherently, or coherently with either Fizeau imaging or a nulling mode. LBTI feeds the LMIRcam and NOMIC instruments.



LBT Interferometer, located between the two primary mirrors.

- LINC/NIRVANA is a multiconjugate AO system providing diffraction-limited near-IR imaging across a field of view of up to 2 x 2 arcmin. The instrument is currently in a commissioning phase. The LINC/NIRVANA platform provides an optical bench with the potential for future interferometric or other uses.

Through 2022 the only available PI instrument has been the Nulling Optimized Mid-Infrared Camera (NOMIC). NOMIC is fed by LBTI, providing imaging capability at 8-13 μm. The instrument has a field of view of ~9 x 9 arcsec and spatial resolution at 10μm of 0.27 arcsec for a single 8.4m LBT aperture, and 0.1 arcsec for Fizeau interferometry with the dual apertures.

New Instruments

Three new PI instruments are in an advanced stage of development.

- SHARK-NIR. SHARK is the *System for coronography with High order Adaptive optics from R to K band*, implemented in two channels, with the near-infrared (NIR) and visible (VIS) instruments installed at the central bent Gregorian focal station on the SX and DX sides, respectively. SHARK-NIR was built by a consortium led by INAF-Padova, and is designed with coronagraphic and other capabilities to carry out high-angular-resolution, high contrast imaging and spectroscopy in the 0.96-1.7 micron bandpass.

  SHARK-NIR passed its Preliminary Acceptance Europe (PAE) review in April 2022 and shipped to LBTO in June 2022. Installation on the telescope and daytime pre-commissioning activities were carried out during several runs during the 2022B semester, with a first night-time run scheduled for January 2022. Additional commissioning runs are scheduled during the 2023A semester.

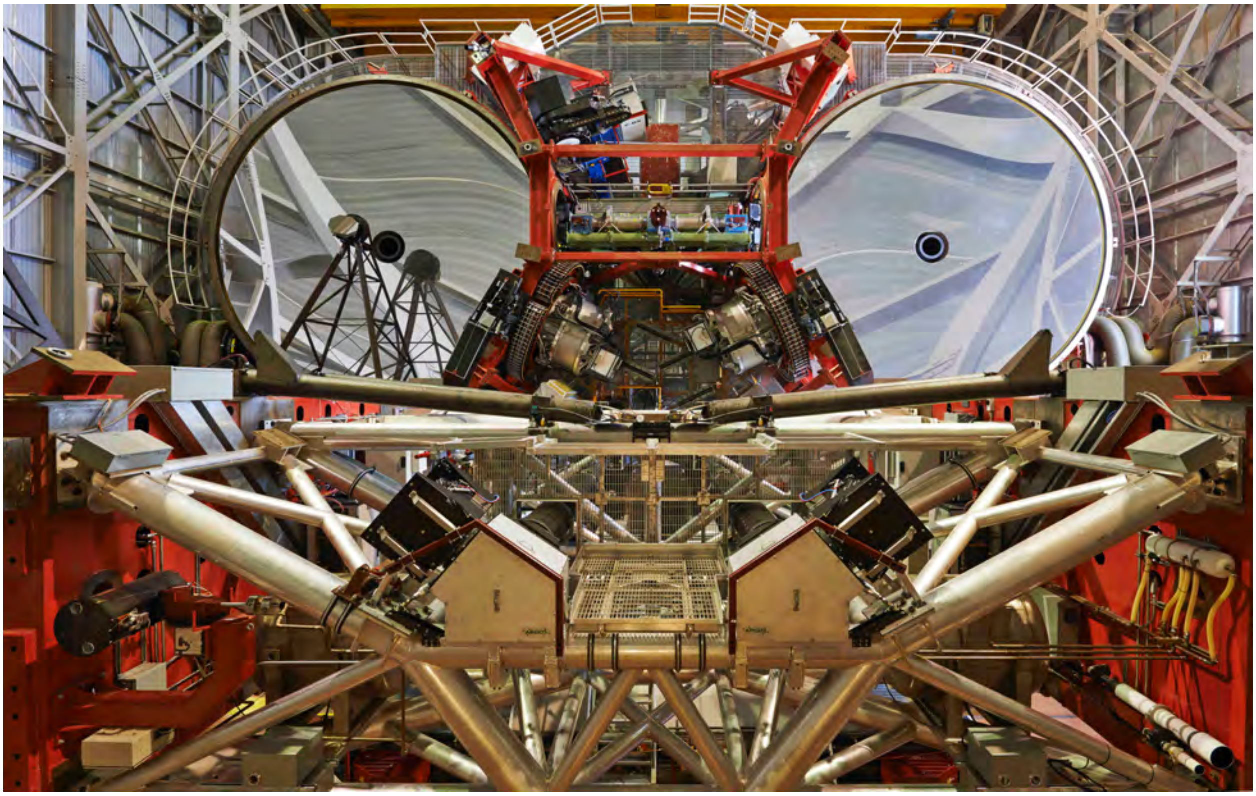
Members of the SHARK-NIR team with the instrument soon after its arrival at LBTO: left to right, Simone Di Filippo, Luca Marafatto, Jacopo Farinato, Maria Bergomi.

- SHARK-VIS is an optical (400-900 nm) instrument for high-contrast and coronographic imaging, built at INAF-Rome. SHARK-VIS passed its PAE review in June 2022. Shipment to the LBT remains contingent on formal acceptance of the SOUL-DX-LBTI AO system which is anticipated in the first half of 2023. Shipment of the instrument is consequently anticipated later in the year, with installation and commissioning activities to follow.
- iLocater is a high-resolution (R=190,500 median) near-infrared spectrograph designed to deliver extremely precise radial velocity measurements for exoplanet studies. The spectrograph will operate in a diffraction-limited regime with single-mode-fiber injection of light. The instrument is being built by the University of Notre Dame, and as of late 2022 is moving through key integration steps, with final delivery and integration with the cryostat system continuing through spring 2023. Shipment to LBT is anticipated in fall 2023.

Upgrade Plans for 2023

In additional to commissioning activity for the new instruments, several projects are planned to enhance performance for the overall facility, telescope, and existing instruments.

- Telescope Enclosure. The LBT enclosure is showing wear in several respects, with one consequence being an increase in water leaks following rain or snow episodes. Maintenance is planned to secure loose panels, tape seams, and replace seals and gaskets during Spring.
- Hydraulic Bearing System (HBS) Control System. The HBS control system is aging and critical to operation of the telescope. A major upgrade with a modern programmable logic controller was



initiated in 2022 but delayed due to supply chain issues affecting availability of parts. Completion of the system upgrade is planned for 2023.

- Aluminizing plant control system. The current control system utilizes obsolete hardware and software, with inadequate spares. Development of a replacement system will be initiated in 2023.
- Vibration mitigation. Efforts are planned to further reduce sources of vibration and their impact on instrument performance. The current rigid mounts for electronics cooling fan units on the telescope structure will be replaced by steel cage and spring modules in 2023, to reduce transmitted vibration. In addition, an active damping system for the LUCI crycoolers has been prototyped and testing is planned to determine its potential benefit.
- ASMs. The reflectivity of the SX ASM has shown a significant decline over time. Planning is underway to realuminize the mirror during the 2023 Summer Shutdown. Upgrades are planned for the ASM anemometers on both sides to improve reliability.
- SOUL system. Continued testing and evaluation is planned for the DX units in anticipation of acceptance reviews during 2023. Additional diagnostic activities are planned with the goal of increasing system robustness.
- MODS detectors. The original MODS CCD controllers are obsolete and no longer supported, and lack spares. Procurement of new STA Archon controllers is planned for 2023, with installation scheduled during the 2024 Summer Shutdown.
- PEPSI detectors. New STA1600 CCDs have been ordered and will be installed during summer 2023. The new detectors are expected to lead to significant improvements in performance by reducing read noise and amplifier glow relative to the current hardware.

Observatory Safety

In carrying out its mission of enabling forefront research, the Large Binocular Telescope Observatory is committed to operating in a manner that safeguards its employee's health and well-being, the safety of its equipment, and the environment. Over time the Observatory has developed a strong culture of safety, and its staff play a key role in identifying safety hazards as well as solutions, embodied in a set of standards and practices defined in the LBTO Health, Safety and Environmental (HSE) Manual and Management System.

The LBTO sets annual objectives and targets in HSE and strives to meet those goals in an effort to continually improve the HSE function. Over time this approach has eliminated or mitigated many hazards through engineering and administrative controls, such as installing safe access and fall protection equipment, implementing an online HSE training system and enhanced in-person training, utilizing digitally verified standard operating procedures for high-risk operations, developing emergency action and forest fire plans, partnering with Banner Medical Center in Tucson for emergency management and on-call physician services, and developing the policies, procedures, standards and forms that comprise the HSE Manual and Management System.

In 2022, the LBTO made a number of important advancements in HSE. Of particular note are the hiring of an Emergency Response Coordinator/Trainer at MGIO, Kelly Baker, and an HSE Specialist at the LBTO, Rick Hansen. Both staff join the Mt. Graham team in the HSE Group, working in partnership with the HSE Manager/Engineer, David Carroll. This partnership allows for improved coverage and an enhancement in capacity to further advance the safety culture, infrastructure, and systems at the Observatory. Further, it positions the LBTO to mature the safety functions into the next 2 decades and beyond.

Kelly Baker, a certified helicopter flight paramedic with education in emergency management, brings over twenty years of experience in emergency medical services and management to the observatory. In her role, she has already increased hands-on trainings, drills, and use of standardized equipment, and she aims to form a more fluid and experienced Emergency Response Team (ERT) on Mt. Graham. The ERT members are first responders at LBT's remote mountain site, and their role in an emergency is critical to linking up with off-site emergency services. Similarly, Rick Hansen brings 15 years' experience at the LBTO as a principal technician and many more in the mining and logistics industries. In his new role, he will be instrumental in ongoing efforts to reduce risk at the observatory with a focus on additional hazard mitigation infrastructure improvements, improving procedures, and promoting safety through training and direct communication with mountain staff.

In 2022, the Observatory's HSE incident and near-miss data highlighted three areas of focus: winter driving safety, altitude health, and minor musculoskeletal sprains/strains. While the total injury count remains low (1 for 2022), employee participation in safety is demonstrated by their submittal of 12 near-miss reports. These reports led to the mitigation of slip hazards, improvements to the medical oxygen protocol, the introduction of a snow track egress vehicle, and several training and safety committee presentations delivered by the HSE group on altitude health and emergency response, slip, trip, fall awareness, and winter and mountain driving.

The Observatory's goals in 2023 and beyond are to continue improving the readiness of the ERT through increased hands-on training and drills, review and revise emergency plans, continue to further reduce fall hazard risks, and ensure the safe integration of a new generation of new-hire mountain staff technicians and next-generation instruments into the Observatory. Additionally, emergency preparedness will be enhanced by erecting a winter shelter at the summit for the emergency evacuation and snow track vehicles. A distributed antenna and radio system upgrade is also planned, to provide seamless radio coverage within, between, and outside all buildings on site, including lone-worker man-down alarm functionality.

The LBTO is increasingly seen as a leader in growing a safety culture and implementing EHS best practice in an observatory setting. One outcome is that the LBTO's HSE personnel are increasingly called upon to share their expertise with other astronomical facilities at multiple sites in Arizona. A robust HSE program dedicated to continuous improvement is a fundamental priority for the Observatory, benefitting our personnel and members in their pursuit of discovery.

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Acronyms and Abbreviations

AIP	Leibniz-Institut für Astrophysik Potsdam
AO	Adaptive Optics
ARGOS	Advanced Rayleigh Ground layer adaptive Optics System
ASM	Adaptive Secondary Mirror
ATT	AO Tiger Team
DX	Dexter - The right side of the telescope
ERT	Emergency Response Team
FC	Finance Committee
GMT	Giant Magellan Telescope
GRB	Gamma-ray Burst
HBS	Hydrostatic Bearing System
HSE	Health, Safety, and Environment
INAF	Istito Nazionale di Astrofisica
IR	Infrared
LBC	Large Binocular Camera
LBT	Large Binocular Telescope
LBTB	LBT Beteiligungsgesellschaft (LBTC member representing institutions in Germany)
LBTC	Large Binocular Telescope Corporation
LBTI	LBT Interferometer - A nulling and Fizeau interferometry instrument.
LBTO	Large Binocular Telescope Observatory
LGRB	Long Gamma-ray Burst
LINC/NIRVANA	LBT Interferometric Camera/Near-IR Visible Adaptive Interferometer for Astronomy
LMIRcam	L- and M-band Infrared camera
LUCI	LBT Utility Camera in the Infrared
M1	Primary Mirror
MGIO	Mt Graham International Observatory
MODS	Multi-Object Double Spectrograph
MPE	Max-Planck-Institut für Extraterrestriche Physik
MPIA	Max-Planck-Institut für Astronomie
NIR	Near InfraRed
NOMIC	Nulling Optimized Mid-Infrared Camera
OSU	Ohio State University
PAE	Preliminary Acceptance Europe
PEPSI	Potsdam Echelle Polarimetric and Spectrographic Instrument
PETS	PEPSI Exoplanet Transit Survey
PI	Principal Investigator
SAC	Science Advisory Committee
SGRB	Short Gamma-ray Burst
SHARK	System for coronography with High order Adaptive optics from R to K band
SN	Supernova
SOUL	Single conjugated adaptive Optics Upgrade for LBT
SSD	Summer Shutdown
STA	Semiconductor Technology Associates Inc.
SX	Sinister - The left side of the telescope
TMS	Telescope Metrology System
TS	Thin Shell (deformable mirror)
UC	User Committee
UMinn	University of Minnesota
UND	University of Notre Dame
UVa	University of Virginia


LBT Observatory
The Eagle Nebula
Large Binocular Camera (LBC) gri image - © 2018 LBTO

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