LARGE BINOCULAR TELESCOPE OBSERVATORY

Annual Report 2023

Contents

Left: *LBC image of NGC 5907*

Cover photo: The Eagle Nebula
Large Binocular Camera (LBC) gri image -

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

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.

Introduction from the Board

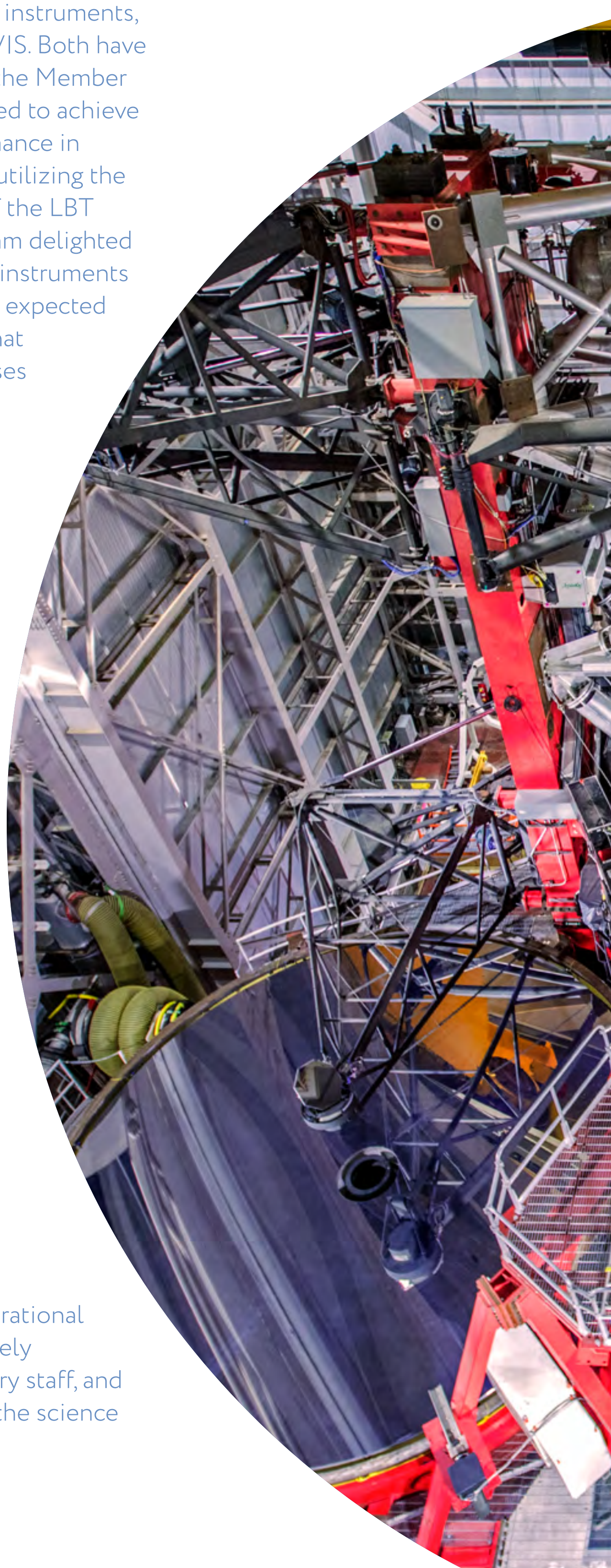
I am delighted to introduce this second edition of the LBT Annual Report, which presents the accomplishments and prospects of LBT for the year 2023. The reader will notice that this edition comes with a completely revised design, introducing a new logo and graphic signature for the Observatory. A redesigned website also welcomes users with revised content and easier navigation.

These changes exemplify the constant drive of LBT toward innovation and progress. In this respect, the year 2023 fulfilled expectations by introducing important changes in the organization and capabilities of the Observatory, which have been immediately appreciated by users from all the institutional Members.

To begin with, the Observatory has emerged from the pandemic era with a stronger and more capable support service for observers – both local and remote. It is now becoming increasingly common for national and international LBT users to perform observations remotely and/or rely on the support and execution by the LBTO staff. This is important for increasing flexibility and scientific efficiency, as well as reducing the running costs of the partners. This experience is paving the way to a full reanalysis of observing modes, which is underway by the Science Advisory Committee (SAC) and the Director, with the ultimate goal of implementing new observing strategies to maximize the LBT's scientific return and to accelerate the completion of high priority observing programs. Following the Board's directives, the SAC and the Director are already working in this direction. We look forward to seeing the outcome of this exercise by the end of the year.

The year 2023 also saw the start of the commissioning of two new instruments, SHARK-NIR and SHARK-VIS. Both have been built by consortia of the Member institutions and are designed to achieve diffraction-limited performance in imaging and spectroscopy utilizing the superlative performance of the LBT Adaptive Optics system. I am delighted to report not only that the instruments have perfectly attained the expected performance criteria, but that the commissioning processes went extremely smoothly and professionally. Both instrument teams praised the level of participation and support from the Observatory staff, and the well-organized managerial structure which coordinated the efforts of all the teams. We look forward to seeing a similar experience when the new high-precision AO-fed spectrograph, iLocater, begins commissioning later this year.

All three new instruments benefit from the full functionality of the AO system, which constitutes the core of LBT's exceptional performance. It is extremely rewarding to see that this system has reached a high level of operational stability, can now be routinely operated by the Observatory staff, and offers an easy interface to the science

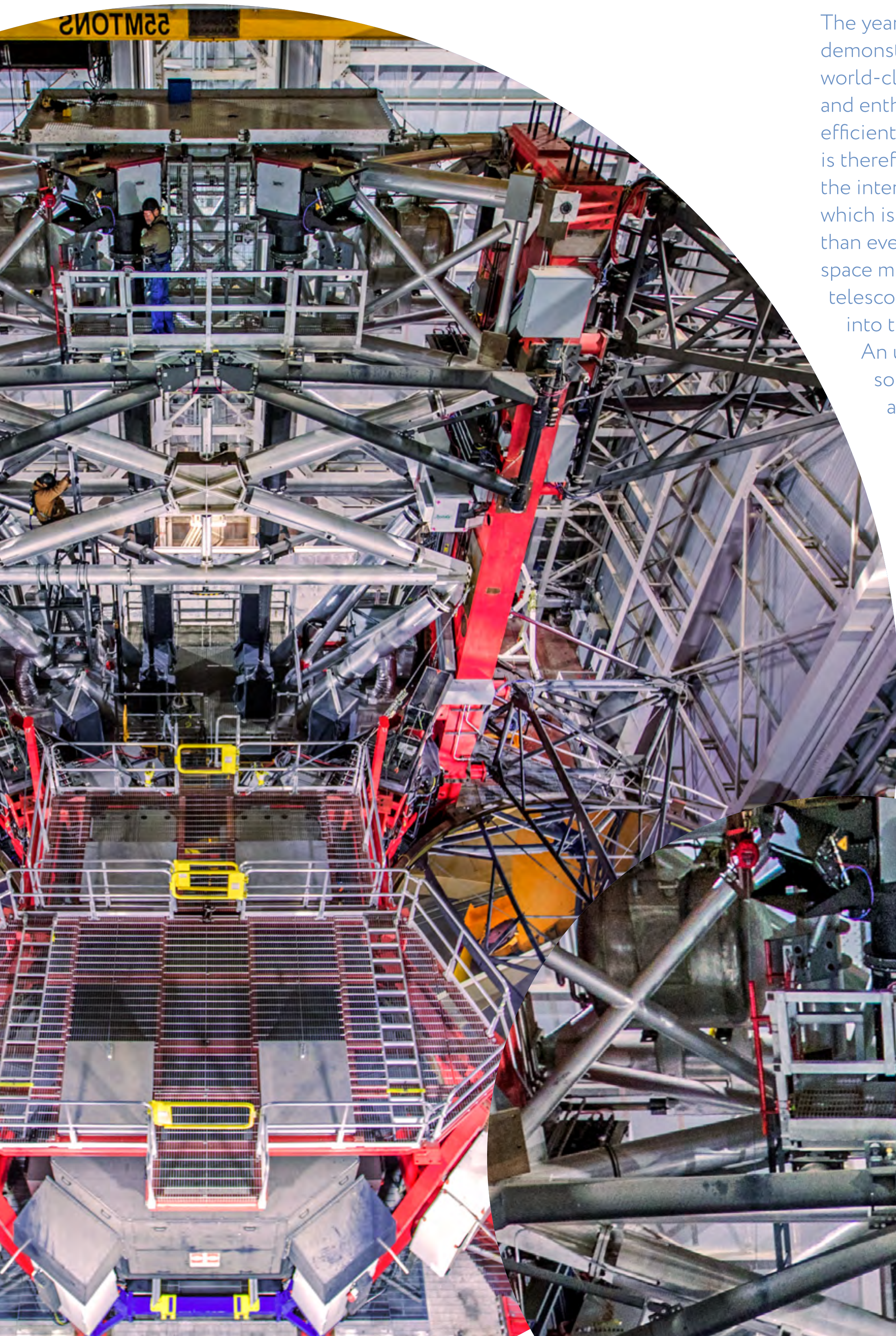


instruments. These achievements are the result of hard work and strengthened management over the last few years. Under the leadership of the new AO lead, Sam Ragland, who joined the LBT family in 2023, this will be the starting point for the deployment of more advanced capabilities and the exploration of new approaches to effective AO.

These are the most prominent examples of numerous positive changes that have been implemented at LBT. The Members deeply thank the Director and the entire staff for their passionate and effective work. We also appreciate the continuing guidance of the Finance Committee and their constant attention to controlling costs in these difficult times.

The year 2023 ends with LBTO demonstrating multiple successes with world-class instrumentation, a competent and enthusiastic staff, and a lean and efficient organization. The Observatory is therefore extremely well-positioned in the international astronomical landscape, which is more exciting and promising than ever. In the next few years, upcoming space missions and ground-based survey telescopes will open new windows into the exploration of the Universe. An unprecedented wealth of new sources will require follow-up and characterization, including newly discovered exoplanets, a multitude of transient objects, and exciting high redshift galaxies and AGNs: all ideal targets for LBT's unique suite of instruments.

– Adriano Fontana, Chair



LUCI Image of the Planetary Nebula M57 (Blue: Brγ 2.16 μm, Green: K_s, Red: H_2 2.12 μm)

Message from the Director

The Large Binocular Telescope Observatory saw significant progress during 2023 in its mission of advancing scientific discovery driven by innovation. This progress is reflected in scientific results, instrumentation, personnel, and connection to the community.

Important advances occurred in the Observatory's adaptive optics (AO) systems. LBTO welcomed a new AO Head, Dr. Sam Ragland, who arrived in June from the W. M. Keck Observatory where he was Senior Adaptive Optics Scientist. Sam brings very extensive experience in astronomical instrumentation, particularly related to adaptive optics and interferometry. At LBTO he is leading efforts to enhance AO performance and automation, while also laying the groundwork for new development initiatives.

The SOUL upgrade for single-conjugate AO observations successfully passed its acceptance reviews in 2023, with completion of formal handover planned for early 2024. SOUL utilizes the LBT's adaptive secondary mirrors, which continued in routine operation. The thin shell for the SX adaptive secondary mirror received a new reflective coating, resulting in significant improvement in throughput.

The LBT's AO system is a key enabler for the Observatory's second-generation instruments, all of which rely on AO correction. The SHARK-VIS instrument arrived in 2023, joining its companion SHARK-NIR which arrived the previous year. The two instruments are designed for high angular resolution, high contrast imaging, with SHARK-NIR also providing spectroscopic capability. Both instruments achieved rapid progress in commissioning, with first science results expected for release in 2024. A further second-generation instrument, the iLocater near-infrared spectrograph, will provide extremely high precision radial velocity capability following installation in 2024.

The cumulative impact of the LBT's scientific contributions continues to grow. While the rate of publication, measured by paper count, is modest in comparison with some other leading observatories, citation metrics indicate that the impact of LBT publications compares favorably to that for other large-aperture optical telescopes.

The Observatory has correspondingly placed new emphasis on telling the LBT story to increase awareness of its significance and impact. In addition to this annual report, released for the first time last year for calendar year 2022, the past twelve months have seen the launch of a quarterly newsletter, renovation of the www.lbto.org website, and engagement of an international design firm for creation of a contemporary logo.

LBTO has also restarted public tours of the facility, and taken other steps to engage and support the local community. The return of the public reflects a new normal in the post-pandemic era, with observers also returning to Mt. Graham to collect their data, while many colleagues continue to benefit from service observing support. The interaction between community members, astronomers, and our outstanding staff is a reminder that our mission to further the understanding of the cosmos is a distinctly human endeavor.

– Joseph C. Shields

Governance of the Observatory

The LBT 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.

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.

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 Extraterrestriche 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%

LUCI image of the young star cluster and nebula NGC 1931 (Blue: B rγ 2.16 μm, Green: K_s, Red: H_2 2.12 μm)

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. Danny Gasch (Research Corp) concluded his service on the Board in September 2023.

Board Members at the end of 2023 were
- Adriano Fontana, INAF (Chair and President)
- Chris Kochanek, OSU (Vice Chair)
- 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 2023 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. Danny Gasch (Research Corp) concluded his service on the Finance Committee in September 2023.

FC voting members at the end of 2023 were
- Matthias Voss, LBTB (Chair)
- Nicole Cochran, OSU (Vice Chair)
- Mark Buglewicz, AZ
- Ugo Di Giammatteo, INAF

Additional FC at-large members were
- 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 2023 were
- Eduardo Bañados, LBTB (Chair)
- Serena Benatti, INAF
- Josh Eisner, AZ
- Rick Pogge, OSU (Vice Chair)

Additional SAC at-large members were
- Sarah Tuttle, U. Washington
- Chick Woodward, UMinn

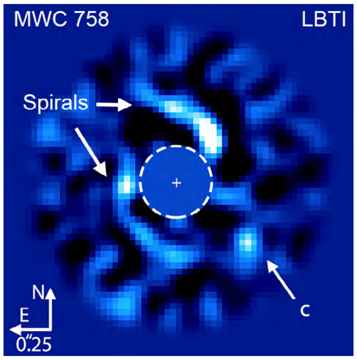
The LBT **User Committee** (UC) is an advisory committee for the LBTO Director. The UC assists the Director in all technical and operational matters of the LBT collaboration, providing feedback on operational areas that affect current users of the facility.

UC members during 2023 were
- Silvia Belladitta, MPIA
- Sanchayeeta Borthakur, ASU
- Eichi Egami, AZ
- Adriana Gargiulo, INAF
- Peter Garnavich, UND
- Roland Gredel, MPIA
- Jochen Heidt, LSW
- Ester Marini, INAF
- Nathan Smith, AZ
- Roberto Speziali, INAF
- Kris Stanek, OSU
- Ji Wang, OSU
- Mark Whittle, UVa
- Chick Woodward, UMinn

LBT Science Highlights

A Giant Protoplanet Driving Spiral Arms in a Circumstellar Disk

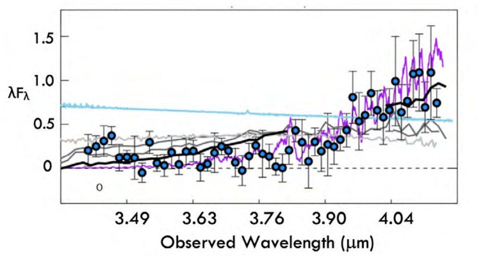
Giant protoplanets emerging from circumstellar disks may interact gravitationally with their natal environment, with resulting consequences for subsequent planet formation. Wagner et al. have recently published results providing new insight into the behavior of young giant planets and their interaction with protoplanetary disks. The study utilized LBTI with the integral field unit ALES for infrared (IR) observations of MWC 758, a young A-type star and associated circumstellar disk.



LBTI/ALES image in the 3.4-4.1 μm bandpass, with the newly detected source MWC 758c indicated.

The MWC 758 disk is notable for displaying a two-armed spiral pattern. Such morphologies are predicted from models for a disk interacting gravitationally with a stellar or planetary companion. Several systems consistent with this picture are known, but MWC 758 is representative of others where no stellar or brown dwarf companion is evident. The lack of a second compact source is surprising in this case since the detailed disk structure is consistent with a companion-driven morphology.

The new observations provide an answer to this puzzle through detection of a compact source, labeled MWC 758c, in the 3.4-4.1 μm bandpass. The source exhibits a very red spectral energy distribution (SED), which explains the lack of previous detections in shorter wavelength bandpasses.



LBTI/ALES spectrum of MWC 758c (blue points), compared with brown dwarf spectral standards (grey to black), a 500 K exoplanet model atmosphere (purple), and scaled spectrum of the parent star+inner disk (blue).

Model comparisons with the SED coupled with other theoretical considerations point to a source with a very low temperature $T_{eff} \leqslant 600K$, or a warmer source subject to substantial reddening by dust corresponding to $A_V \geqslant 8$. If the actual extinction is small, MWC 758c would be the coldest currently known directly imaged exoplanet. The alternative of substantial reddening would implicate the likely presence of a circumplanetary disk or envelope, in which case accretion may be ongoing. The LBTI/ALES result demonstrates that mid-IR measurements may be essential in many cases to reveal the presence of young protoplanets, and their relationship to circumstellar disks.

Reference:

Direct images and spectroscopy of a giant protoplanet driving spiral arms in MWC 758, Wagner et al. 2023, Nature Astronomy, 7, 1208

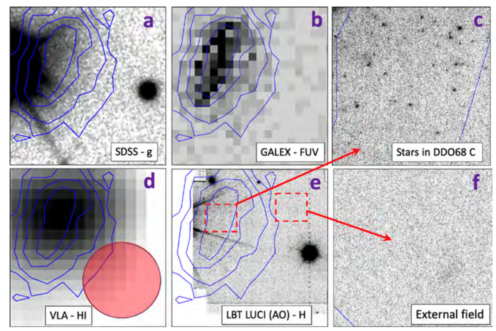
AO Imaging of a Satellite Dwarf Galaxy

Nearby dwarf galaxies with low metallicity and active star formation are of distinct interest for the similarity they provide to primordial galaxies in the early universe. The gas-rich galaxy DDO68 is one such source, with HII regions displaying oxygen abundance only ~3% of the solar value. Understanding this object has been challenging, however, because the low gas metallicity is well below expectations based on the galaxy's stellar mass of $\sim 10^8$ $M_\odot$. Similar disparities are seen in some other extremely metal poor galaxies. A possible solution may be that the galaxy's interstellar matter has been modified via accretion of low-metallicity gas from the intergalactic medium or a low-mass companion source. Detailed studies are needed to validate this explanation.

Previous work has revealed two smaller satellite galaxies that may be interacting with DDO68. One of these, DDO68 B, is known to be gas-rich from HI 21 cm observations, with morphological indications that it is tidally interacting with the primary galaxy. However, detailed analyses conclude that the two companion objects are unlikely to provide sufficient material to explain DDO68's low metallicity.

An additional candidate gas donor has been identified in the form of another gas-rich companion at larger projected distance, DDO68 C, that appears connected to the main source via a low surface brightness HI bridge. A direct measurement of DDO68 C's distance would be important to confirm a physical association with DDO68. However, studies of DDO68 C have been hindered by a foreground bright star TYC 1967-1114-1 (K=8.5 mag) close to the galaxy line of sight.

Annibali et al. have recently published an analysis of DDO68 C using LBT observations that provide new insight into this important object. The new study incorporates near-infrared LUCI imaging that takes advantage of the bright foreground source by using it as a reference for the SOUL adaptive optics system. Measurements thus obtained in the J and H bandpasses yielded data with point source FWHM ⩽ 0.15". Comparison of the LUCI infrared results in relation to other bandpasses is shown in the figure.



DDO68 C in different bands: (a) SDSS g, (b) GALEX FUV, (d) VLA HI (with beam shown in red), (e) LUCI AO H-band, with FUV contours in blue. The field of view is 30"× 30", with zoomed 6"× 6" views centered on (c) the stellar emission from DDO68 C and (f) a nearby background field.

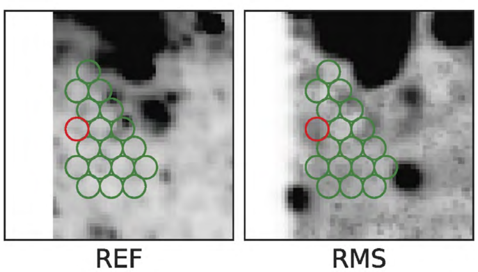
While outshone in the SDSS optical bandpass by the foreground star, DDO68 C is revealed in VLA HI 21 cm and GALEX far-UV images. The LUCI images enable measurement of individual stars in this source for the first time (panel c). The new data do not allow for a direct distance measurement from the tip of the red giant branch, but analysis of the resulting color-magnitude diagram in conjunction with the existing far-UV and Hα data are consistent with an interpretation that places this source and DDO68 at a common distance of ~13 Mpc. DDO68 and its companions are thus of great interest as a dwarf galaxy likely interacting with three satellites, with the bulk of the low-metallicity gas contributed by DDO68 C.

Reference:
DDO68 C: The Actual Appearance of a Ghost Satellite Dwarf through Adaptive Optics at the Large Binocular Telescope, Annibali et al. 2023, ApJ, 942, L23

Observations of SN 2023ixf in M101

An exploding star discovered in May in the galaxy M101 (d~6 Mpc) provided opportunities to study the brightest Type II supernova in nearly a decade. Results on this source utilizing LBT data are now starting to appear in the literature.

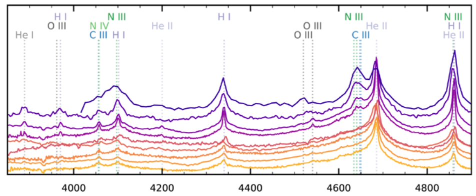
The behavior of massive stars in the years leading up to core collapse is of interest, due to predicted rapid evolution and potential for outbursts and associated mass loss. To address this issue, Neustadt et al. utilized LBC UBVR images of M101 acquired as part of a monitoring program spanning 2007 – 2022 to look for variability of the supernova progenitor. No variability is detected, with an RMS limit < 10^3 $L_\odot$ in R band, roughly 3 times the predicted luminosity of the progenitor, which was likely highly dust-obscured.



R-band reference (left) and RMS (right) images of the environs of SN 2023ixf with the location of the supernova indicated in red and background regions used for the analysis shown in green (Neustadt et al.). The circles are 1.3" in diameter.

Circumstellar material ejected by the progenitor of a core-collapse supernova can be revealed in the early-time emission spectra post-explosion. Bostroem et al. published a time series of optical spectra obtained with facilities including MODS at LBT, spanning 1.2 – 14 days from explosion.

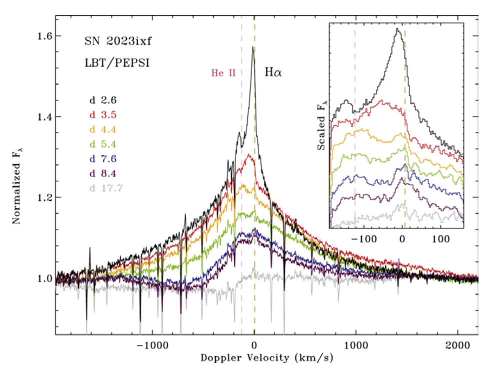
The early data reveal strong narrow emission lines with broad wings, with early growth in high-ionization features. The line emission subsequently fades until the spectrum presents a nearly featureless continuum after ~7 days.



Spectra of SN 2023ixf from day 1.18 to day 3 (top to bottom; Bostroem et al.)

The emission is interpreted as arising from circumstellar gas at small radii that is photoionized by the supernova shock, with emission decaying as this matter is swept up by the expanding ejecta. The emission and the timescale of its duration allows estimation of the mass of radiating gas and its radial extent, which translates into a high mass loss rate of 10^{-3} – 10^{-2} $M_\odot$ yr^{-1} as this star approached the end of its life.

Additional analysis of the circumstellar material in SN 2023ixf was reported by Smith et al. using PEPSI spectra obtained 2 – 18 days post-explosion. The high-resolution spectra provide detailed information on the narrow emission line profiles and kinematics.



Sequence of PEPSI spectra of SN2023ixf showing the evolution of the Hα emission line (Smith et al.)

The data reveal that the pre-shock material was expanding away from the star with a velocity of 115 km s^{-1}, indicative of eruptive mass loss from the progenitor or radiative acceleration of this gas. A lack of narrow blueshifted absorption by matter along our line of sight indicates that the circumstellar material is asymmetric.

References:

Constraints on pre-SN outbursts from the progenitor of SN 2023ixf using the Large Binocular Telescope, Neustadt et al. 2024, MNRAS, 527, 5366

Early Spectroscopy and Dense Circumstellar Medium Interaction in SN 2023ixf, Bostroem et al. 2023, ApJ, 956, L5

High-resolution Spectroscopy of SN 2023ixf's First Week: Engulfing the Asymmetric Circumstellar Material, Smith et al. 2023, ApJ, 956, 46

Abundance Dispersion in Low-metallicity Stars

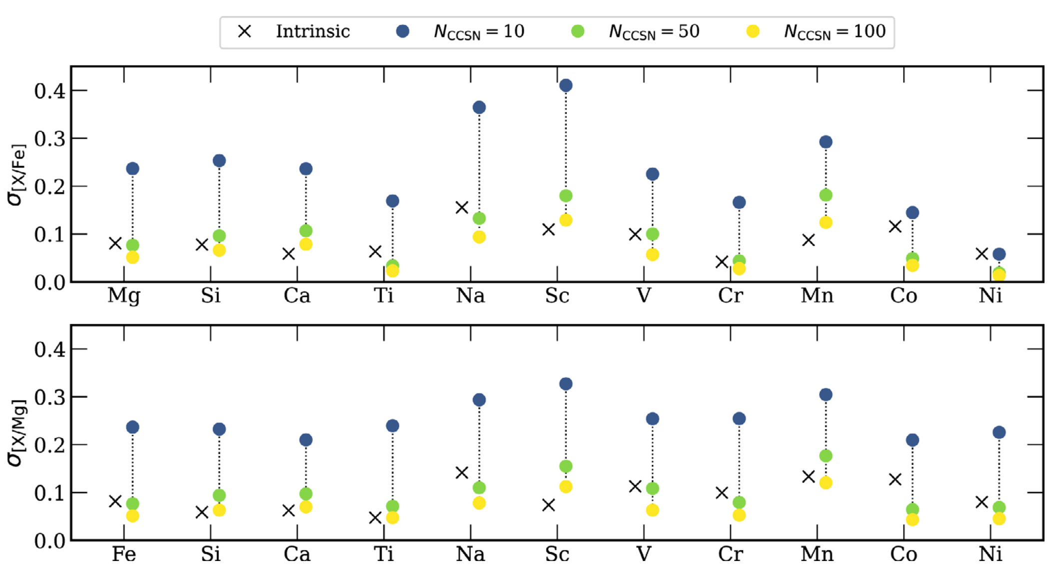
The abundances of heavy elements in stars trace the history of nucleosynthesis by earlier stellar generations. At low metallicity, a small number of supernovae or other sources may be responsible for most of the element enrichment beyond Big Bang nucleosynthesis. The relative abundances of different elements reflect the nucleosynthetic yields of those earlier enrichment events, which can vary markedly depending on the mass of the exploding star.

In a recent paper, Griffith et al. used PEPSI data to study abundances for 12 elements in a sample of 86 metal-poor subgiant stars ($-2 \lesssim [Fe/H] \lesssim -1$) in the solar neighborhood and used the dispersion in abundances to infer the properties of their nucleosynthetic forebears. Their analysis included detailed modeling of photon noise in order to extract the intrinsic signal.

The measured values were compared with predictions of variable enrichment by core-collapse supernovae resulting from a stochastic sampling of the initial mass function, with corresponding variation in yields. The authors find that the measured dispersions can be plausibly explained by such a model, with ~50 supernovae contributing to the enrichment of a typical sample star. At the median metallicity for the sample, this result implies that the supernova ejecta are mixed over a gas mass of $\sim 6 \times 10^4\ M_\odot$ before forming the current generation of stars.

Reference:

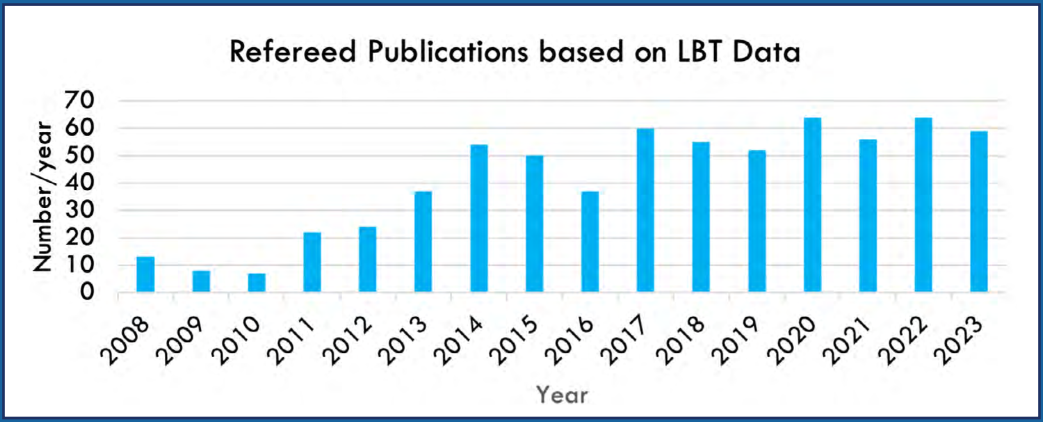
Untangling the Sources of Abundance Dispersion in Low-metallicity stars, Griffith et al. 2023, ApJ, 944, 47



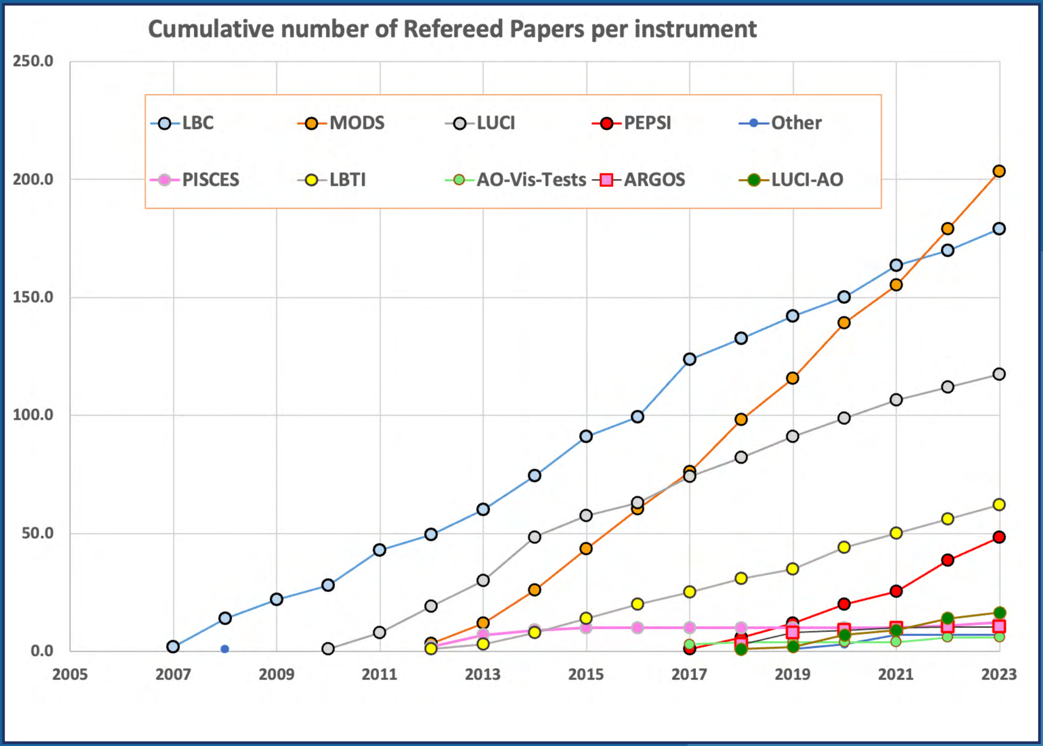
Dispersion in abundance relative to Fe and Mg for elements indicated on the horizontal axis. The x symbols represent measured values, while blue, green, and yellow dots represent predictions for enrichment from a random sampling of 10, 50, and 100 core collapse supernovae.

LBTO Publications

Publication of new findings is a primary indicator of an observatory's contributions to advancing knowledge. A total of 59 publications based on LBTO data appeared in the peer-reviewed literature in 2023, similar to the total seen in recent years. 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.

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.

	Budget 2023 ($k)	Actual ($k)	Variance %	Budget 2024 ($k)
Operation Fund				
Payroll	6,953	6,843	-2%	7,092
Travel	74	111	50%	112
Utilities	1,239	1,406	13%	1,532
Supplies & Services	1,502	1,707	14%	1,500
Other Labor	95	138	45%	135
SubTotal	**9,861**	**10,205**	**3%**	**10,371**
UA Services	2,068	1,945	-6%	2,148
MGIO	1,475	1,536	4%	1,579
Total Operations	**13,404**	**13,686**	**2%**	**14,098**
Corporation Fund				
Payroll	50	61.1	22%	54
Travel	20	4.7	-77%	3
Gen. & Admin Exp	15	8.6	-43%	21
Outreach	55	51.8	-6%	52
Consulting	20	62.2	211%	39
UA Services	10	11.1	11%	9.8
Total	**170**	**199.5**	**17%**	**178.8**
Summary				
Operation Fund	13,404	13,686	2%	14,098
Corporation Fund	170	200	17%	179
Total	**13,574**	**13,886**	**2%**	**14,276**

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.

Overall expenditures in 2023 exceeded the budgeted total by 2%, with the overage covered by the Observatory's Contingency and Reserve Fund. The overspend was driven by unanticipated increases in utility costs, infrastructure repair costs, and targeted investments to mitigate future risk.

The budget for 2024 reflects broadly incremental changes across several categories of expenses. Utility costs are increased by 24% to reflect the current level. 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, 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 $718k, committed for ongoing projects including upgrades to the MODS CCD controllers and aluminization control system. The Board approved allocation of an additional $517k in 2024 designated for refurbishment of an adaptive secondary mirror currently located at the Magellan Observatory, to be relocated to LBTO as a spare; recoating of a corresponding thin shell; and an upgrade to the M2/M3 controllers.

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 $680k at the conclusion of 2023. 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 2024 to achieve this target.

Staff

Staff Transitions During 2023

Arrivals:

Riccardo Ansaldi	Staff Technician
Jason Chu	Instr Spt Astronomer
Steven Harmon	Staff Technician
Sam Ragland	Adaptive Optics Head
Adam Ray	Junior Staff Technician
Justin Rupert	Service Observer

Departures:

David Edmeades	Senior Systems Admin
Lyann Lou	Accounting Associate

R. Mark Wagner, 1955 – 2023

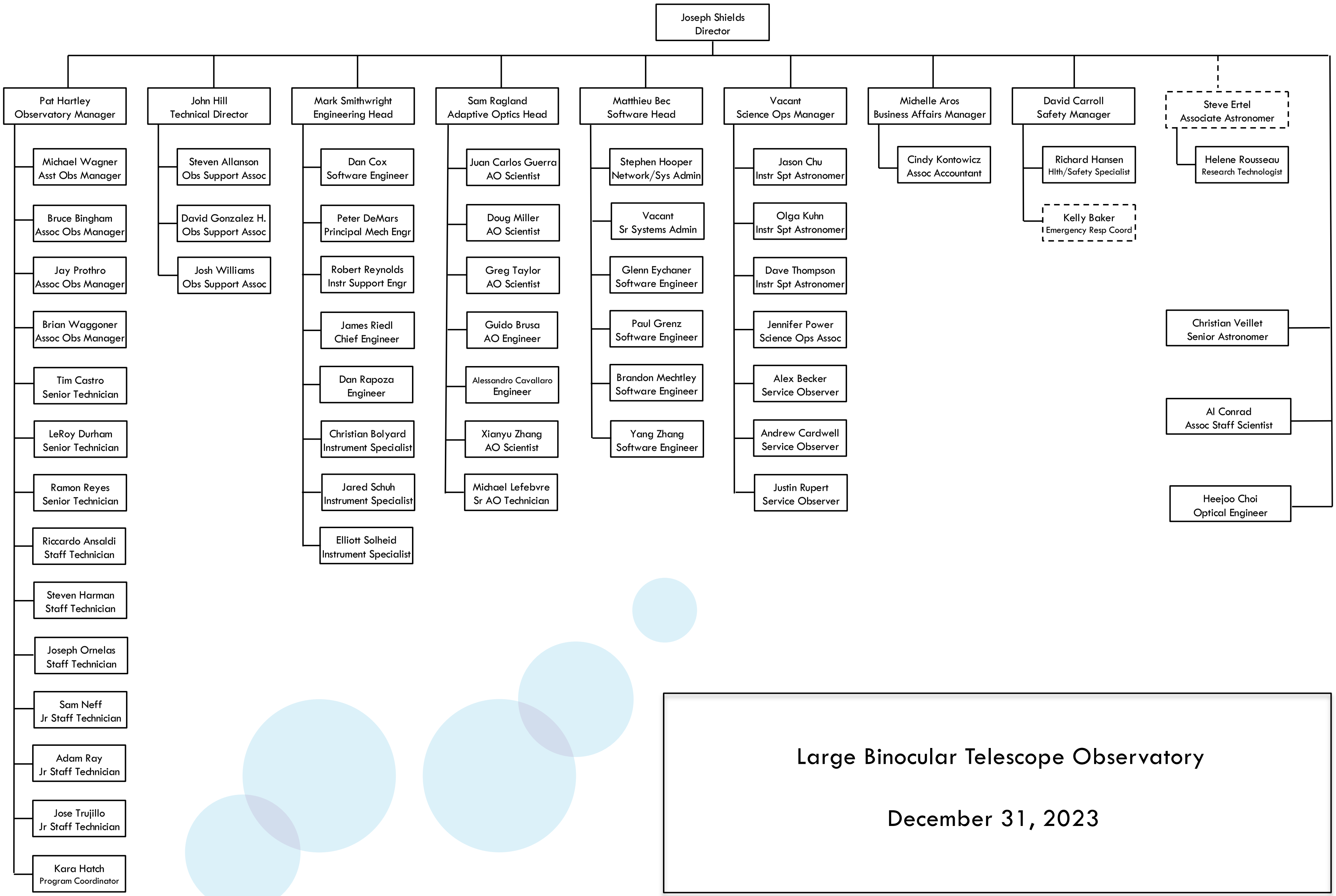
The LBTO community was saddened by the loss of Science Operations Manager R. Mark Wagner, who died on September 02 after a brief illness. Mark was a member of the LBTO staff for 25 years and made major contributions to the early development of the observatory, as well as its successful transition from construction to operations with a growing suite of instruments.

Mark was an accomplished scientist who maintained an active research program to the end of his life, and in addition he had a remarkable breadth of knowledge related to instrumentation and detectors. Mark was highly regarded as a colleague and as someone who was deeply committed to making the Observatory successful. The impact of his many contributions will be felt at LBTO for years to come.

Current Staff

as of December 31, 2023

Allanson, Steven	Obs Support Assoc
Ansaldi, Riccardo	Staff Technician
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
Chu, Jason	Instr Spt Astronomer
Conrad, Al	Assoc Staff Scientist
Cox, Dan	Software Engineer
DeMars, Peter	Principal Engineer
Durham, LeRoy	Sr Staff Technician
Ertel, Steve	Assoc Astronomer
Eychaner, Glenn	Software Engineer
Gonzalez H., David	Obs Support Assoc
Grenz, Paul	Software Engineer
Guerra, Juan Carlos	AO Scientist
Hansen, Richard	Hlth/Safety Specialist
Harmon, Steven	Staff Technician
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
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
Ragland, Sam	AO Head
Rapoza, Daniel	Engineer
Ray, Adam	Jr Staff Technician
Reyes, Ramon	Sr Staff Technician
Reynolds, Robert	Instr Support Engineer
Riedl, James	Chief Engineer
Rupert, Justin	Service Observer
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
Williams, Josh	Obs Support Assoc
Zhang, Xianyu	AO Scientist
Zhang, Yang	Software Engineer

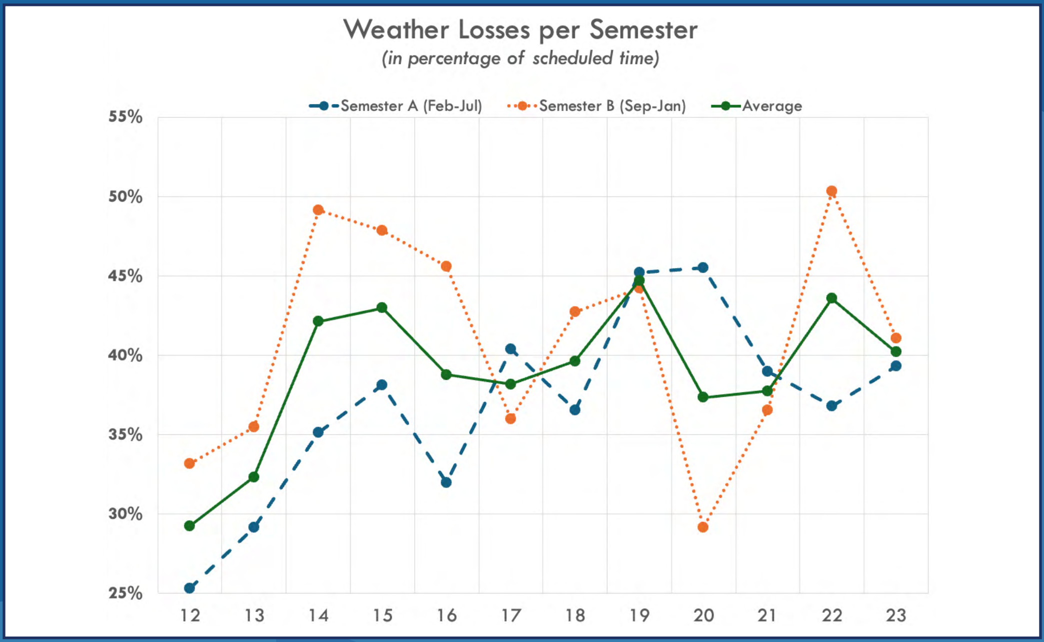


Large Binocular Telescope Observatory

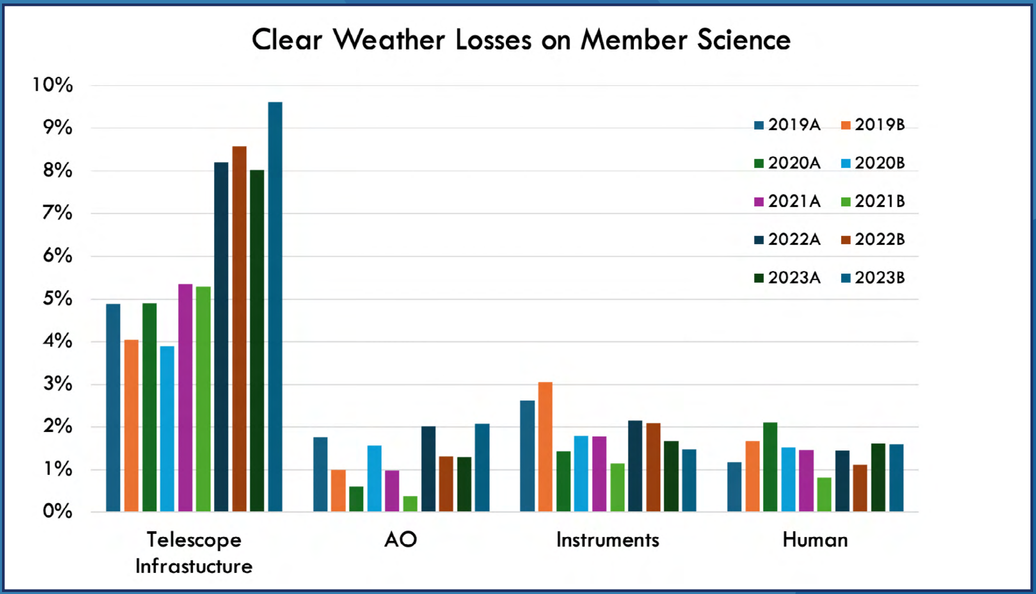
December 31, 2023

Observing Performance – Weather and Other Losses

The fraction of observing time lost due to weather is shown in the figure, covering years 2012-2023. 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 in 2023 were similar to the long-term average.



Causes of clear-weather losses of observing time are shown for 2019-2023. Losses have generally remained stable over this interval, although power disruptions and a change in the mix of observing modes produced an increase in telescope and infrastructure losses in recent semesters, exacerbated by a failure of GPS timekeeping hardware in 2023.



The Large Binocular Telescope

The Telescope

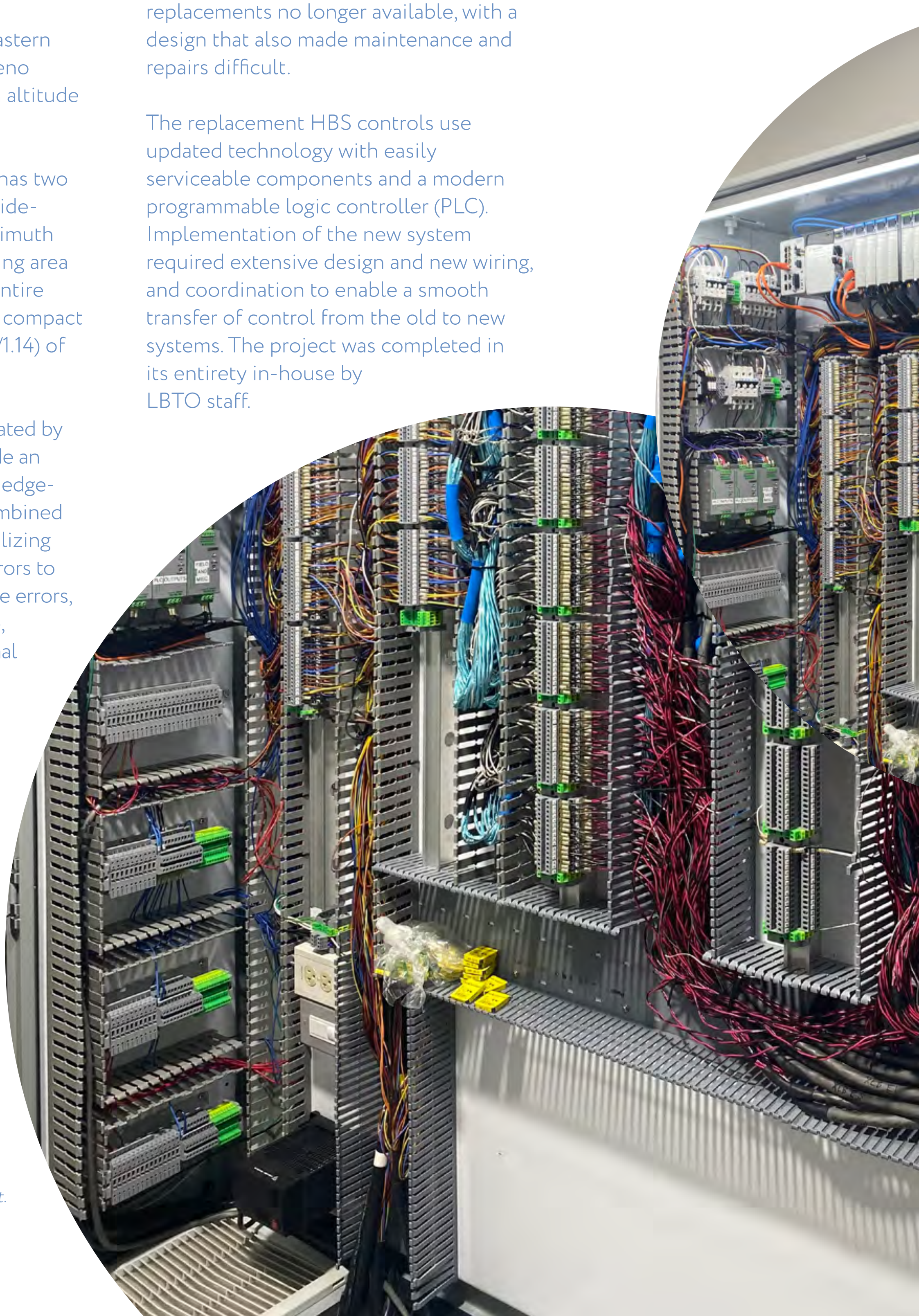
The Large Binocular Telescope Observatory is located in southeastern Arizona near Safford in the Pinaleno Mountains on Emerald Peak at an altitude of 3200m.

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.

A major initiative completed in 2023 was an upgrade to the hydrostatic bearing system (HBS) providing support for the telescope. The HBS utilizes multiple pumps, cooling elements, and sensors, monitored by telemetry to maintain stable operation. The original control system relied on parts that were reaching their anticipated lifetime and with replacements no longer available, with a design that also made maintenance and repairs difficult.

The replacement HBS controls use updated technology with easily serviceable components and a modern programmable logic controller (PLC). Implementation of the new system required extensive design and new wiring, and coordination to enable a smooth transfer of control from the old to new systems. The project was completed in its entirety in-house by LBTO staff.



Right: New HBS controls cabinet.

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 SX ASM thin shell (TS5) was successfully recoated during the 2023 summer shutdown. This step was undertaken in response to serious degradation in the TS5 reflective coating in the 13 years since it was previously applied, with resulting loss of throughput.

TS5 was shipped roundtrip to Italy, where the recoating process was completed by A.D.S. International. Measurements indicate that the TS5 reflectivity has been restored to a level close to the theoretical prediction.

The telescope's second-generation AO system, the Single conjugate adaptive Optics Upgrade for LBT (SOUL), successfully completed its remaining acceptance reviews in 2023 and is now in routine operation. Relative to the First Light AO (FLAO) 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. Formal handover of the system is planned for early 2024.

SX adaptive secondary mirror with recoated thin shell, on the telescope in September 2023.

AO observation continues to benefit 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.

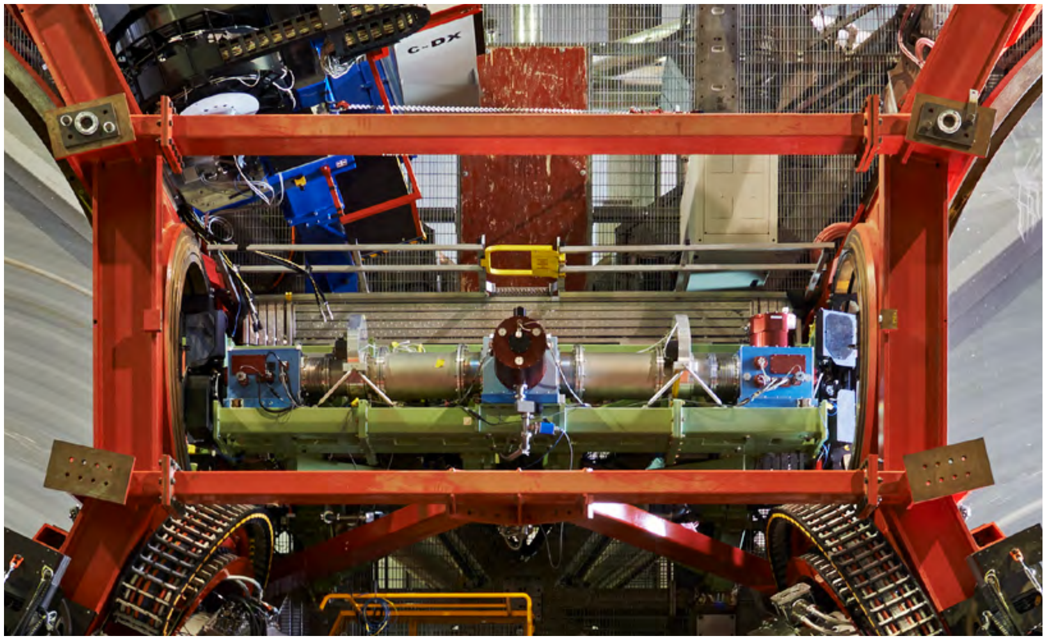
Current Facility Instruments are:

- **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 0.225 arcsec for a total field of view of approximately 23 x 25 arcmin.
- **Multiple Object Double Spectrographs (MODS).** The two units are optical imaging spectrographs, covering 320-1100nm 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) and imaging through Sloan filters are 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 383-907 nm. A separate polarimetry mode is available.

  A significant amount of work was completed on PEPSI during the 2023 summer shutdown, led by the AIP-Potsdam team. The original instrument CCDs were replaced with new Semiconductor Technology Associates (STA) CCDs, which show significant improvement in noise characteristics relative to the original detectors. Both the Blue and Red cross-disperser lifts were also replaced, and a spare delivered. The Blue lift became inoperable in early 2023, and with the replacement all allowed cross disperser combinations are available again.
- **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 utilizes the beams from the two primary mirrors non-coherently, or combined coherently with either Fizeau imaging or a nulling mode. LBTI feeds the LMIRcam and NOMIC instruments.

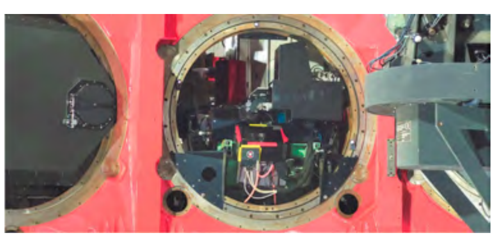


LBT Interferometer, located between the two primary mirrors.

- **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.

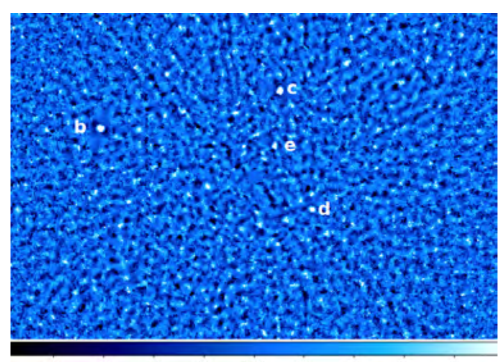
Current PI Instruments are:

- **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.
- **SHARK.** 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.



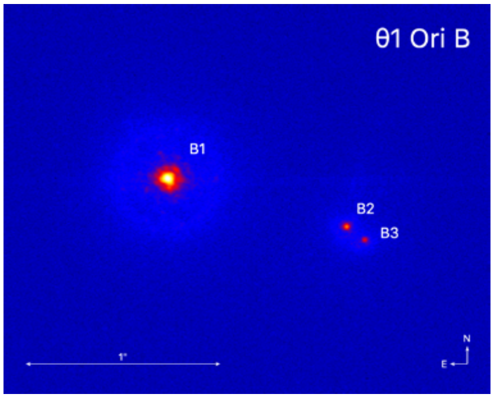
SHARK-VIS mounted at the LBTI bent Gregorian focal station – the instrument is in the black L-shaped enclosure in the upper right quadrant.

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 μm bandpass. SHARK-NIR shipped to LBTO in June 2022 and most commissioning activity was completed in 2023. Initial testing of coronographic modes has yielded contrasts of $\sim 10^{-4} - 10^{-5}$ at separations of 0.″1 – 0.″3.



SHARK-NIR coronographic image of HR 8799 showing the four known planets for this system. The two outer planets b and c were detected with signal-to-noise ratio (SNR) > 20, and inner planets d and e were detected with SNR ~ 6. Planets b and e are respectively ~1.″5 and ~0.″4 from the star's position at the center of the image.

SHARK-VIS is an optical (400-900 nm) instrument for high-contrast and coronographic imaging, built at INAF-Rome. Used in conjunction with the SOUL AO system, with fast imaging and frame selection post-processing, the instrument is designed to deliver angular resolution down to 15 millarcsec. On-sky commissioning activity began in October, with good progress and promising early results.

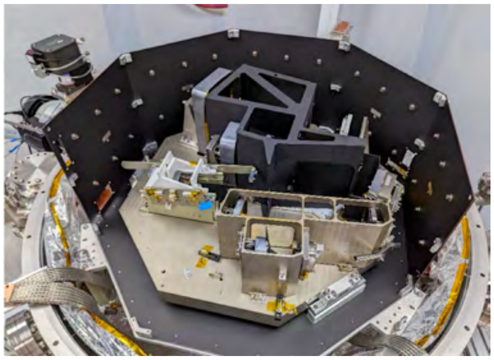


SHARK-VIS image of the stellar multiple Θ1 Ori B in the Hα bandpass. The field of view is ~2."5 x 2" and separation between stars B2 and B3 is 0." 11. Θ1 Ori B is one of the components of the Trapezium cluster in the Orion Nebula.

The SHARK instruments share focal stations with LBTI on their respective sides of the telescope. The configuration allows simultaneous observation with both SHARKs and with LMIRCam on LBTI, providing wavelength coverage from optical through mid-infrared wavelengths.

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, with contributions also from The Ohio State University. The instrument is in an advanced state of progress, with completion pending delivery of gratings from NASA-JPL and detector on loan from NASA-GSFC. Shipment to LBT is anticipated in fall 2024.



The iLocater spectrograph undergoing integration and testing at The Ohio State University.

Upgrade Plans for 2024

Several projects are planned to enhance performance for the overall facility, telescope, and existing instruments.

- **AO system.** Continued work is planned to enhance the robustness of the AO system. A major initiative is also planned for 2024 to increase the degree of AO system automation, enabling reliable operation with less human oversight and intervention.
- **MODS detectors.** The original MODS CCD controllers are obsolete and no longer supported, and lack spares. New STA Archon controllers to serve as replacements were purchased in 2023, and development is underway at Ohio State University for new Head Electronics Boxes that will support the Archon units and associated control electronics. Installation of the new controllers is planned for the 2024 Summer Shutdown.
- **Aluminizing plant control system.** The current control system utilizes obsolete hardware and software, with inadequate spares. Development of a replacement system was initiated in 2023 with continuation planned for 2024.

- **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 was initiated in 2023 to secure loose panels, tape seams, and replace seals and gaskets.

This work was facilitated by rental of a telescoping boom lift allowing access by staff to all parts of the rotating building walls. Completion of the enclosure work is planned for 2024.

Several projects are planned to enhance performance for the overall facility, telescope, and existing instruments.

Boom lift in action.

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 employees' 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 2023 the Observatory conducted numerous in-person training sessions and drills in alignment with its annual goals and in support of the LBTO HSE Management System.

Training completed in 2023 included emergency medical responder (EMR) training, emergency evacuation vehicle operations, drive-on snow track vehicle operations, fall rescue training for the large boom lift, scenario-based training with MGIO, SMT, and VATT telescope staff, hazardous materials ("hazmat") transportation training, machine shop equipment training, and crane inspector training.

LBTO vehicle with drive-on snow tracks for emergency transportation.

Observatory personnel participating in medical evacuation drill.

Additionally, new employee safety training was completed for seven new LBTO staff members. While the topics are diverse, the training aims to prepare staff to identify, evaluate, and control risks while developing skills and confidence in responding to likely emergency situations at the Observatory's remote site.

In 2023, a change in the University of Arizona's interpretation of applicability to the hazardous materials regulation necessitated the development of a hazardous materials ("hazmat") program. The LBTO conducted a regulatory review and developed the written program, the first of its kind at the University, in partnership with the University of Arizona Risk Management. This resulted in changes to training requirements, vehicle placarding, the use of shipping papers, and the need for commercial driver's licenses (CDL) for drivers when transporting larger tanks of liquid nitrogen to the summit. The Observatory achieved compliance with the regulation, and has benefitted from partnership with MGIO CDL-licensed staff for continued delivery of liquid nitrogen to the site while options to license LBTO staff are further evaluated.

Investments in safety-motivated projects are now being integrated into the Observatory's long-term budget planning in a more structured way. This includes major infrastructure requiring multi-year planning, such as a fire alarm system upgrade, elevator renewal, and MGIO radio system upgrade. Smaller projects were ranked by risk and evaluated for cost, yielding a list of safety projects that are in development for shorter-term completion.

Examples of projects from this list that were completed during 2023 with minimal cost include installation of fall protection over the upper treehouses on the telescope and PEPSI Polarimeter storage area, installation of personal protective equipment (PPE) cabinets throughout the observatory, and acquisition of a safe lifting fixture for plastic drum handling. Projects planned for 2024 include improvements to the liquid nitrogen instrument fill systems, fall protection for the LUCI platform, redesign of the primary mirror vent boxes, and redesign of Meissner traps used on the telescope in the primary mirror aluminization process.

LBTO staff practice CPR on a patient simulator.

Observatory Outreach

LBTO is committed to advancing science in the public interest. Results from LBT observations are disseminated to the professional community through the peer-reviewed literature, as documented elsewhere in this report.

The observatory supports other programs to advance the public understanding of its mission, and promote positive relationships with the local and extended community.

Observatory Tours

Public tours of the LBT and other telescopes at the Mount Graham International Observatory (MGIO) are offered via an agreement with Eastern Arizona College (EAC) Discovery Park Campus. Following a hiatus caused by the COVID-19 pandemic, EAC Discovery Park resumed tours in 2023 on weekends through the summer months. Transportation to the summit is provided via vans with professional drivers, with tours hosted by volunteer guides. Advance reservation is required with a charge to cover participant costs. The tours are very popular, with all slots booked well in advance.

Apache Summer Youth Program

MGIO, with support from the LBTC and the University of Arizona Office of Research Innovation & Impact, provides a summer work opportunity for Apache students from high schools on and adjacent to the San Carlos Apache Reservation. After shutting down during the pandemic, in 2023 a dozen students were employed as part of an eight-week program, contributing to MGIO maintenance needs.

MGIO provides transportation to the worksite and supervision by a crew leader from the local educational community. The program gives participants experience in seeing their labors benefit the facility, while working as part of a team and earning a paycheck. Feedback from participating youth and their families has been very positive.

Joe Shields with 2023 scholarship recipients Mikayla Kindelay and Jada Cheney, and Mikayla's mother Jessica Kindelay.

LBTO Scholarship Program

The LBTC has for many years sponsored a scholarship for students from the San Carlos and White Mountain Apache Tribes as an expression of its interest in supporting these communities, which are nearby and historically connected with Mount Graham.

In 2023 the scholarship was restructured to remove obstacles to participation and encourage use by Apache students.

Going forward the scholarship is offered in partnership with Eastern Arizona College, which serves as a local college for the San Carlos and White Mountain reservations, via its location in Thatcher, Arizona (adjacent to Safford). Students who are enrolled members of the San Carlos or White Mountain Tribes who apply for admission to EAC will be automatically considered for the scholarship, with no need to complete an additional application. The scholarship supports tuition and other expenses, with preference based on financial need.

Refereed Publications – 2023

Agüí Fernández J. F., Thöne C. C., et al.
GRB 160410A: The first chemical study of the interstellar medium of a short GRB
MNRAS, 520, 613

Annibali F., Pinna E., Hunt L. K, et al.
DD068 C: The Actual Appearance of a Ghost Satellite Dwarf through Adaptive Optics at the Large Binocular Telescope
ApJL, 941, L23

Ashcraft T. A., McCabe T., Redshaw C., et al.
Deep Large Binocular Camera r-band Observations of the GOODS-N Field
PASP, 135, 24101

Bañados E., Schindler J.-T., et al.
The Pan-STARRS1 $z>5.6$ Quasar Survey. II. Discovery of 55 Quasars at $5.6<z<6.5$
ApJS, 265, 29

Belladitta S., Moretti A., Caccianiga A., et al.
A powerful (and likely young) radio-loud quasar at $z=5.3$
A&A, 669, A134

Berg M. A., Lehner N., Howk J. C., et al.
The Bimodal Absorption System Imaging Campaign (BASIC). I. A Dual Population of Low-metallicity Absorbers at $z<1$
ApJ, 944, 101

Bostroem K. A., Dessart L., Hillier D. J., et al.
SN 2022acko: The First Early Far-ultraviolet Spectra of a Type IIP Supernova
ApJL, 953, L18

Bostroem K. A., Pearson J., Shrestha M, et al.
Early Spectroscopy and Dense Circumstellar Medium Interaction in SN 2023ixf
ApJL, 956, L5

Brogan R., Krumpe M., Homan D., et al.
Still alive and kicking: A significant outburst in changing-look AGN Mrk 1018
A&A, 677, A116

Casey K. J., Greco J. P., Peter A. H. G., et al.
Discovery of a red backsplash galaxy candidate near M81
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The sharpest view on the high-mass star-forming region S255IR. Near infrared adaptive optics imaging of the outbursting source NIRS3
A&A, 676, A107

Fernández-Ontiveros J. A., López-López, X. et al.
Compact jets dominate the continuum emission in low-luminosity active galactic nuclei
A&A, 670, A22

Fitzmaurice E., Martin D. V., et al.
Spectroscopy of TOI-1259B – an unpolluted white dwarf companion to an inflated warm Saturn
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Glikman E., Rusu C. E., Chen G. C.-F., et al.
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Griffith E. J., Johnson J. A., et al.
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ApJ, 944, 47

Holoien T. W.-S., Berger V. L., Hinkle J. T., et al.
Examining the Properties of Low-luminosity Hosts of Type Ia Supernovae from ASAS-SN
ApJ, 950, 108

Hubrig S., Järvinen S. P., et al.
Searching for magnetic fields in pulsating A-type stars: the discovery of a strong field in the probable δ Sct star HD 340577 and a null result for the γ Dor star HR 8799
MNRAS, 526, L83

Jin X., Yang J., Fan X., et al.
(Nearly) Model-independent Constraints on the Neutral Hydrogen Fraction in the Intergalactic Medium at $z\sim5$-7 Using Dark Pixel Fractions in Lyα and Lyβ Forests
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RAA, 23, 25018

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Convective blueshift strengths for 242 evolved stars
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Littlefield C., Hoard D. W., Garnavich P., et al.
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A&A, 674, A115

Mainali R., Stark D. P., Jones T., et al.
Spectroscopy of CASSOWARY gravitationally lensed galaxies in SDSS: characterization of an extremely bright reionization-era analogue at z = 1.42
MNRAS, 520, 4037

Mannucci F., Scialpi M., Ciurlo Al, et al.
GMP-selected dual and lensed AGNs: Selection function and classification based on near-IR colors and resolved spectra from VLT/ERIS, Keck/OSIRIS, and LBT/LUCI
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The SOUL view of IRAS20126+4104. Kinematics and variability of the H_2 jet from a massive protostar
A&A, 672, A113

McCabe T., Redshaw C., Otteson L., et al.
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Melo A., Motta V., Mejía-Restrepo J., et al.
Black hole masses for 14 gravitationally lensed quasars
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Astroseismology and Spectropolarimetry of the Exoplanet Host Star λ Serpentis
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Nestor Shachar A., Price S. H., et al.
RC100: Rotation Curves of 100 Massive Star-forming Galaxies at z = 0.6-2.5 Reveal Little Dark Matter on Galactic Scales
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Neustadt J. M. M., Hinkle J. T., et al.
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Onorato S., Cadelano M., Dalessandro E., et al.
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Acronyms and Abbreviations

AIP	Leibniz-Institut für Astrophysik Potsdam
AO	Adaptive Optics
ASM	Adaptive Secondary Mirror
DX	Dexter - The right side of the telescope
FC	Finance Committee
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
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
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
PEPSI	Potsdam Echelle Polarimetric and Spectrographic Instrument
PETS	PEPSI Exoplanet Transit Survey
PI	Principal Investigator
SAC	Science Advisory Committee
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
TS	Thin Shell (deformable mirror)
UC	User Committee
UMinn	University of Minnesota
UND	University of Notre Dame
UVa	University of Virginia

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Large Binocular Telescope Observatory
933 N Cherry Ave
Tucson, AZ 85721 USA
www.lbto.org