



## Increased sky coverage for the 23-meter LBT

Albert Conrad, Jordan Stone, Steve Ertel

### ► To cite this version:

Albert Conrad, Jordan Stone, Steve Ertel. Increased sky coverage for the 23-meter LBT. Adaptive Optics for Extremely Large Telescopes 7th Edition, ONERA, Jun 2023, Avignon, France. <10.13009/AO4ELT7-2023-039>. <hal-04419769>

**HAL Id: hal-04419769**

**<https://hal.science/hal-04419769v1>**

Submitted on 26 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



# Increased sky coverage for the 23-meter LBT

Al Conrad<sup>a</sup>, Jordan Stone<sup>b</sup>, and Steve Ertel<sup>c</sup>

<sup>a</sup>LBT

<sup>b</sup>USN NRL

<sup>c</sup>Steward Observatory

## ABSTRACT

Twin adaptive secondaries at the Large Binocular Telescope (LBT) enable powerful observing modes. Two of these, imaging (Fizeau) interferometry and nulling interferometry, make the LBT in many respects the first Extremely Large Telescope (ELT) [1]. Science programs that have been conducted using LBT as a 23-meter telescope include measuring habitable-zone dust around nearby stars and imaging planets during early stages of formation [2, 3]. To allow LBT to function as a 23-meter telescope, the light from its two 8.4-meter segments must be combined coherently. To this end, the Large Binocular Telescope Interferometer (LBTI) co-phases the two incoming beams via a piezo-electric path length corrector. This device is controlled by a fringe-tracking system that measures optical path difference in real time. Here we describe an upgrade to this system: the Fizeau Fringe Tracking Camera (FFTCam) [4]. New science will be enabled. For example, the number of exosolar systems in Taurus-Auriga that can be probed down to 3.5 AU\* that can be studied with LBTI will increase by nearly two orders of magnitude.

**Keywords:** LBT, LBTI, Saphira, Interferometry

## 1. OVERVIEW OF LBT AS A 23-METER TELESCOPE

LBT can be operated as either:

- A 12-meter<sup>†</sup> telescope: Two independent instruments.
- A 14.4 meter telescope: Nulling interferometry.
- A 23-meter telescope: Fizeau imaging.

In 12-meter mode we use the 110 square meters of primary mirror to:

- Observe faint objects,

---

Further author information: aconrad@lbto.org

\*The approximate location of the snow line in many disks.

<sup>†</sup> $2 \times \pi(4.2)^2 \sim \pi(5.94)^2$

- Observe brighter objects more efficiently, and
- Pair complimentary instruments<sup>‡</sup>

In 12-meter mode, observations can be seeing-limited, AO-corrected, or a mix of both. In this report we focus on the second two modes, in which LBT operates as either a 14.4 meter telescope or as a 23-meter telescope. This is an AO-only mode in which light from the two 8.4 meter mirrors must be combined coherently.<sup>§</sup> To this end, the Large Binocular Telescope Interferometer (LBTI) co-phases light from the two incoming beams [9, 10].

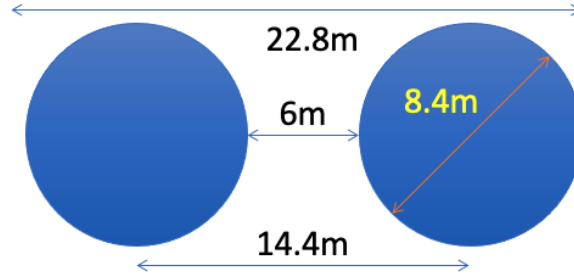


Figure 1. To allow LBT to function as a either a 14.4-meter or 23-meter telescope, the light from its two 8.4-meter segments must be combined coherently.

## 2. SCIENCE PROGRAMS CONDUCTED WITH LBT AS A 23-METER TELESCOPE

In this section we highlight three selected science programs conducted with LBT as a 23-meter telescope: measuring dust within the habitable zone of nearby stars, imaging the complex disk structure around MWC 297, and imaging volcanoes on Jupiter’s volcanic moon Io.

### 2.1 NASA HOSTS Survey

The Hunt for Observable Signatures of Terrestrial Systems (HOSTS) program was conducted between 2014 and 2018 to measure emission from dust within the habitable zone of nearby stars [11, 12, 2, 13]. As seen in figure 2, with the angular resolution provided by a 23-meter baseline, and the application of nulling to block the light from the parent star, LBTI improved sensitivity over previous surveys by an order of magnitude.<sup>¶</sup> We are now conducting detailed follow-up observations of detected systems to characterize their dust distribution and properties more closely [14].

### 2.2 MWC 297

During 2018, LBTI was used as a 23-meter telescope to image the circumstellar disk around MWC 297 [3]. By applying non-redundant masking (NRM) observers were able to achieve  $\sim 17$  milliarcsecond spatial resolution. The data taken for this study revealed a complex disk structure and a candidate companion (see figure 3).

### 2.3 Volcanoes on Io

LBTI was used as a 23-meter telescope during 2013 and 2015 to study the structure and evolution of the lava lake at Loki Patera on Jupiter’s volcanic moon Io [15, 16]. The latter study took advantage of an occultation of Io by Europa. That data set was later mined to study three other volcanoes visible during the Europa occultation: Pillan Patera, Kurdalagon Patera, and the vicinity of Ulgen Patera/PV59/N Lerna Regio [17].

<sup>‡</sup>For simultaneous observations over different band-passes or to combine imaging with spectroscopy, for example.

<sup>§</sup>In addition to phasing, several other technical challenges must be overcome to realize 23-meter Fizeau science (e.g., increased automation, avoiding phase jumps, and the removal of non-common-path differential aberrations). To enable Fizeau imaging as a routine science mode, considerable work has been done to address these challenges [5, 6, 7, 8]

<sup>¶</sup>And two orders of magnitude over existing capabilities, since KIN has been decommissioned.

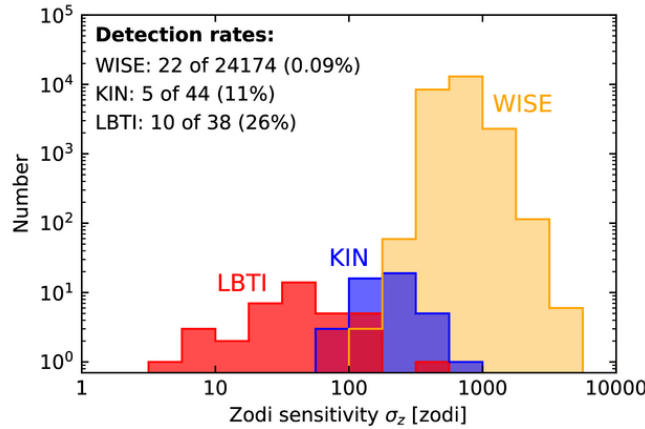


Figure 2. The detection rates for three exozodiacal dust studies are shown. In its observation of 10 targets, LBTI demonstrated sensitivity down to a few Zodis. One Zodi corresponds to the surface density of habitable-zone dust in the Solar system. Figure from [2].

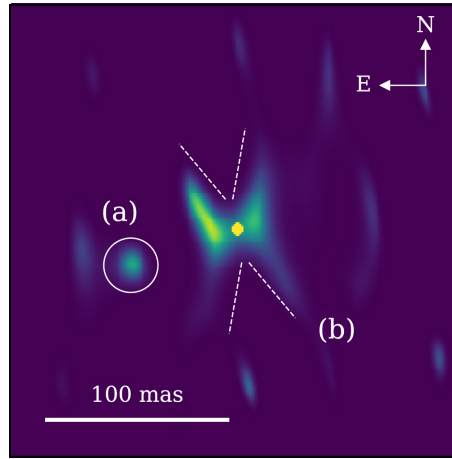


Figure 3. Reconstructed image of MWC 297, annotated to highlight: (a) a companion candidate, and (b) a possible outflow cavity (see also dashed lines). The image is shown north up, east left. Figure and caption from [3].

### 3. AN UPGRADE TO THE SYSTEM FOR PHASING

#### 3.1 PhaseCam

The LBTI fringe tracker combines light from the two LBT mirrors coherently. The sensor in the system, PhaseCam, is an imager. H- and K-band light from LBTI's optical path is sensed by PhaseCam's detector, a Rockwell PICNIC array. The corrector in the system is a three-axis piezo-driven device. These components of the fringe tracker are shown together with the other LBTI subsystems in figure 5.

The optical path delay (OPD) is measured by overlapping the pupil images of the two incoming beams. A tilt difference is maintained between the left and right-side telescope pupils, resulting in a circular image striped with fringes. With a Fourier transform, both phase and tip-tilt can be measured (see figure 6).

#### 3.2 FFTCam

The existing Rockwell PICNIC detector in PhaseCam has enabled impactful science, but is over 20 years old. PhaseCam sensitivity, and hence sky coverage, is largely determined by the quality of the detector. The quantum efficiency (QE) and noise numbers for the PICNIC are poor by today's standards.

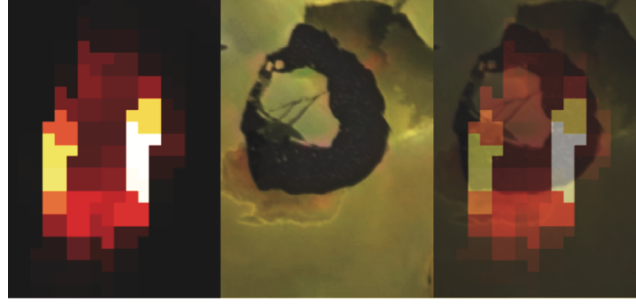


Figure 4. Three views of the lava lake at Loki Patera: the deconvolution result from the 2013 M-band observation, a Voyager image of the same location, then the two overlaid with one another in the final image on the right. Figure from [15].

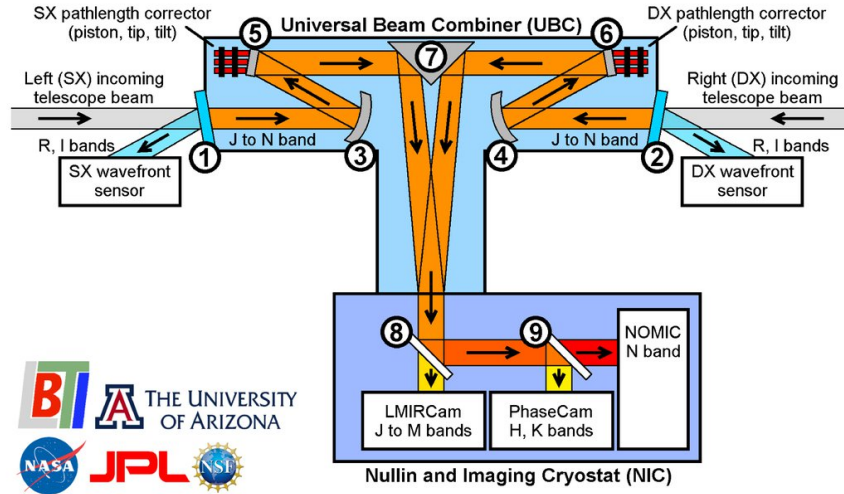


Figure 5. The components used for fringe tracking, PhaseCam and the pathlength correctors (5, 6, 9), are shown along with the other subsystems comprising LBTI. A complete description for the figure is given in [2].

The evolution from p-i-n technology to avalanche photodiode (APD) has yielded detectors with orders of magnitude improved noise and QE performance over the PICNIC device (see table 1). The Fizeau Fringe Tracking Camera (FFTCam) will replace the PICNIC detector with a modern avalanche photodiode detector, the Saphira array from Leonardo.

FFTCam will also gain sensitivity through improvements to the control loop. With the current system, pathlength correction includes measurements from accelerometers (see figure 7) which are combined with the pathlength error measured by PhaseCam. With the upgrade, capacitive sensors have been integrated into each pathlength corrector. With this improvement, the kHz disturbances from telescope vibrations (measured by the vibration monitoring system) and pathlength corrector imprecision (measured by the capacitive sensors) can be corrected by a separate, fast control loop. The 10-100Hz disturbances caused by the atmosphere, and measured using the method described in section 3.1, can then be corrected in a slower loop. This will allow for longer integration times and therefore greater sensitivity.

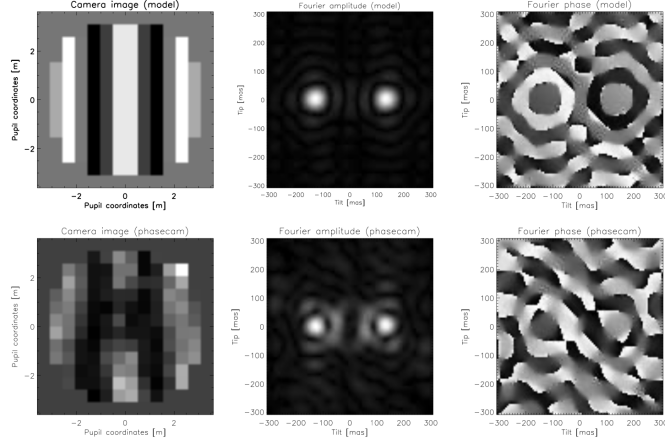


Figure 6. LBTI’s phase sensing approach (noise-free model on top and on-sky data from March 17th 2014 on the bottom). Pupil images are shown on the left. From these the the Fourier transform is computed to sense both tip/tilt and phase. The peak position in the amplitude of the Fourier image (middle images) provides the tip/tilt error signal while the argument of the Fourier image (right images) at the peak position provides the phase. Figure and caption from [10].

Table 1. Quantum efficiency and noise performance comparison between the existing PICNIC array and the Saphira detector planned for the upgrade.

	PICNIC	Saphira
QE	50%	> 80%
Noise (electrons)	96	0.1

## 4. NEW SCIENCE ENABLED BY THE UPGRADE

### 4.1 Sky Coverage

The current fringe-tracking system (PhaseCam) has been effective, but is limited to very bright reference stars ( $K_{\text{mag}} 4.7$ ). The upgrade will increase the limiting magnitude to approximately  $K=10$ , taking the number of potential reference stars from approximately 50 thousand to 10 million

### 4.2 Exoplanets in Taurus

Young planets orbiting protostars in Taurus are bright at 3-5 microns. They can be detected if spatial resolution is high enough to go below 5 AU at the Taurus distance of 140 parsecs [19]. Imaging interferometry with FFTCam will increase the spatial resolution for these types of studies by a factor of three.

With the FFTCam upgrade, the number of systems that can be studied at this resolution increases from one to 94 (see figure 8).

## 5. STATUS AND PLANS FOR THE PROJECT

All hardware, including the Saphira array and the readout electronics, have been procured and are in hand. Hardware implementation in the lab is under way. Software changes to accommodate the new input stream are planned to begin this year. Deployment on the telescope is planned for summer 2024 with first light in the fall.

## 6. CONCLUSIONS

LBT operates as a 23-meter telescope when light from the two mirrors is combined coherently by LBTI. Operation in this mode currently requires a nearby reference star that is brighter than 4.7 magnitude at K. The FFTcam upgrade will raise the limiting magnitude to 10 at K, yielding a dramatic increase in sky coverage and new

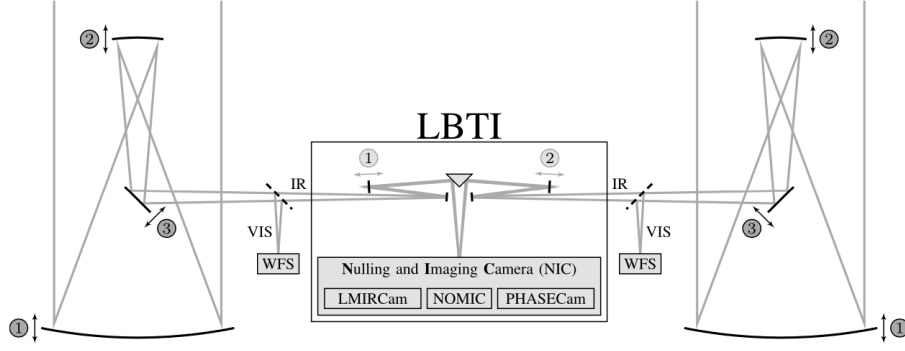


Figure 7. The optical layout of LBT with LBTI. The mirror motion of M1, M2, and M3 on both sides due to wind loads is measured using three accelerometers along the optical axis of each mirror. Figure from [18].

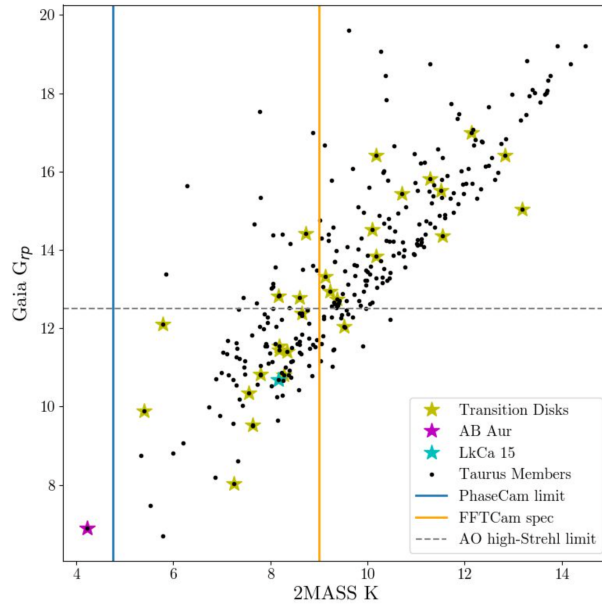


Figure 8. Taurus objects from Luhman et al. (2010) plotted in a plane of 2MASS K vs Gaia Grp. The Gaia Grp band closely resembles our AO wavefront sensor band, and 2MASS K represents the band where our fringe tracking camera operates. Systems with known evidence for a gap in their circumstellar dust disks —transition disks— are indicated with a star. The gray horizontal line represents the limiting magnitude for high-Strehl AO performance necessary for imaging interferometry. The blue vertical line indicates the current fringe tracking sensitivity limit with PhaseCam, indicating only 1 young system targetable with current means. The Orange vertical line indicates our specified minimum sensitivity limit for FFTCam. With the new fringe tracker, at least 94 Taurus objects are targetable with interferometry, including 13 known transition disk sources. Figure and caption from [4].

possibilities for science. For example, the upgrade will increase the number of protostars in Taurus that can be searched for young planets orbiting within 5 AU from 1 to 94. The upgrade is scheduled for installation on the telescope during summer 2024 with first light in the fall.

## ACKNOWLEDGMENTS

The LBT is an international collaboration among institutions in the United States, Italy and Germany. LBT Corporation partners are: The University of Arizona on behalf of the Arizona university system; Istituto Nazionale di Astrofisica, Italy; LBT Beteiligungsgesellschaft, Germany, representing the Max-Planck Society, the Astrophysical Institute Potsdam, and Heidelberg University; The Ohio State University, and The Research Corporation, on behalf of The University of Notre Dame, University of Minnesota and University of Virginia.

## References

- [1] Steve Ertel. “The LBTI as an ELT pathfinder”. In: *AO4ELT7 Proceedings* (2023).
- [2] S. Ertel, P. M. Hinz, and J. M. Stone et al. “Overview and prospects of the LBTI beyond the completed HOSTS survey”. In: *SPIE* (2020).
- [3] S. Sallum, J. S. Eisner, and J. M. Stone et al. “ELT Imaging of MWC 297 from the 23 m LBTI: Complex Disk Structure and a Companion Candidate”. In: *AJ* (2021).
- [4] J. M. Stone. “FFTCam: Enabling Imaging Interferometry with a 23 m telescope and LBTI to Directly Probe Planet Formation”. In: *Funding Proposal* (2018).
- [5] Eckhart et al Spalding. “Towards controlled Fizeau observations with the Large Binocular Telescope”. In: *SPIE* (2018).
- [6] Eckhart et al Spalding. “Status of commissioning stabilized infrared Fizeau interferometry with LBTI”. In: *SPIE* (2019).
- [7] E.R. Maier et al. “A two-band approach to  $n\lambda$  phase error corrections with LBTI’s PHASECam”. In: *SPIE* (2018).
- [8] E.R. Maier et al. “Implementing multiwavelength fringe tracking for the Large Binocular Telescope Interferometer’s phase sensor, PHASECam”. In: *SPIE* (2020).
- [9] P. M. Hinz, D. Defrere, and A. Skemer et al. “Overview of LBTI: a multipurpose facility for high spatial resolution observations”. In: *ApJ* (2016).
- [10] D. Defrere, P. M. Hinz, and E. Downey et al. “Co-phasing the Large Binocular Telescope: status and performance of LBTI/PHASECam”. In: *SPIE* (2014).
- [11] D. Defrere et al. “First-light LBT Nulling Interferometric Observations: Warm Exozodiacal Dust Resolved within a Few AU of  $\eta$  Crv”. In: *ApJ* (2015).
- [12] S. Ertel et al. “The HOSTS Survey—Exozodiacal Dust Measurements for 30 Stars”. In: *AJ* (2018).
- [13] D. Defrere et al. “The HOSTS Survey: Evidence for an Extended Dust Disk and Constraints on the Presence of Giant Planets in the Habitable Zone of  $\beta$  Leo”. In: *AJ* (2021).
- [14] S. Ertel et al. “The HOSTS survey for exo-zodiacal dust: preliminary results and future prospects”. In: *SPIE* (2018).
- [15] A. R. Conrad, K. de Kleer, and J. Leisenring et al. “Spatially resolved M-band emission from Io’s loki patera—fizeau imaging at the 22.8m LBT”. In: *AJ* (2015).
- [16] K. de Kleer, M. Skrutskie, and J. Leisenring et al. “Multi-phase volcanic resurfacing at Loki Patera on Io”. In: *Nature* (2017).
- [17] K. de Kleer et al. “Resolving Io’s Volcanoes from a Mutual Event Observation at the Large Binocular Telescope”. In: *PSJ* (2021).
- [18] M. Boehm, Jorg Uwe Pott, and Martin Kuerster et al. “Delay Compensation for Real Time Disturbance Estimation at Extremely Large Telescopes”. In: *IEEE Transactions on Control Systems Technology* (2017).
- [19] S. Sallum et al. “Accreting protoplanets in the LkCa 15 transition disk”. In: *Nature* (2015).