The Large Binocular Telescope Interferometer

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ABSTRACT

The Large Binocular Telescope (LBT), with dual 8.4 m optics on a common mount, is unique among the large-aperture interferometers. Deformable secondaries on the telescope capable of adaptive atmospheric correction allow beam combination after only three warm reflections. The design allows the implementation of two powerful uses of interferometry: suppression of starlight (or nulling interferometry) and wide-field imaging (or Fizeau interferometry). Nulling will allow detection of extrasolar planetary systems (from either zodiacal emission or giant planets) down to solar system-equivalent levels for nearby stars. This will dramatically increase our knowledge of the prevalence and make-up of extrasolar planetary systems. Fizeau interferometry will allow imaging of even complex structure at the resolution of a 22.8 m telescope. To implement these two powerful techniques the University of Arizona and NASA are collaborating to build the Large Binocular Telescope Interferometer (LBTI) a cryogenic instrument capable of sensitive interferometric observations in the infrared.

1. INTRODUCTION

Optical interferometry has long been realized as a useful technique for increasing the resolution of astronomical observations since Michelson’s first observations of Jupiter’s moons and measurement of the diameter of Betelgeuse. However, since the astronomical targets have typically been single or double objects, the field has gradually gravitated toward ever increasing baselines focused on single objects, with the notable exception of the Multiple Mirror Telescope (now upgraded to a single 6.5 m mirror) and the Large Binocular Telescope, currently under construction. These optical interferometers are quite different in concept from the long baseline concepts such as the Keck and Very Large Telescope Interferometers. The Large Binocular Telescope is an interferometer on a single elevation-azimuth, allowing both simple beam combination and true image formation of a field on the sky, rather than interference of a single object.

The design and implementation of an instrument for such an interferometer is quite different than for long baseline systems, requiring care in beam combination that preserves the imaging properties of the system and does not degrade the inherent infrared sensitivity of the fixed-pupil interferometer.

2. FIXED-PUPIL AND LONG-BASELINE INTERFEROMETRY

Long-baseline interferometers are typically implemented with individual mounts that are fixed on the ground. As a consequence of this the entrance pupil of the optical system, as well as the path-length difference is continually changing as the system tracks the object across the sky. In order to track the path-length variations delay lines and many beam transfer optics are needed before beam combination. For infrared observations, especially, this results in reduced sensitivity due to the emissivity of the optical system. Implementing interferometry over a field-of-view would require a significant increase in complexity in order to arrange the final beam-combination to not only track phase variations, but also changes in the entrance aperture. The difficulty of this task for long baseline interferometers is attested to by the fact that no one has implemented this plan to carry out multiple object observations.

In contrast to this, fixed pupil interferometers maintain their entrance pupil geometry (as well as path-length differences) as they track objects across the sky, obviating the need for long delay lines, and...
implicitly allowing interference to be possible over a field-of-view limited only by the isoplanatic patch of the adaptive optics system. This allows simple beam-combination which is inherently capable of multiple-object observations.

Although fixed pupil interferometers have up to now been planned as common-mount structures, creating a fixed, modest scale baseline, it is possible to have a fixed-pupil geometry interferometer that also has separate mounts for each telescope and a variable baseline, as proposed by Roger Angel\textsuperscript{1} for a next 30 m class observatory.

**Figure 1.** Optical design for the LBT. The incoming beams are adaptively corrected by the deformable secondary mirrors for each telescope, providing diffraction-limited images at the f/15 focal plane for the beamcombiner.

### 3. THE LARGE BINOCULAR TELESCOPE

The Large Binocular Telescope consists of two 8.4 m primaries separated by 14.4 m on a common telescope mount. The secondary mirrors of the telescopes are deformable by 670 voice coil actuators to provide correction for atmospheric turbulence. Tertiary mirrors fold the light to an instrument platform between the mirrors, where the f/15 beams form two image planes separated by 3.8 m, as shown in Figure 1.

The telescopes, as well as the instruments, are mounted on a single structure mounted on a rotatable azimuth ring, and capable of tilting via two large C-ring surfaces near the base of the structure. The LBT Interferometer occupies the central instrument platform of the telescope, as shown in Figure 2.

The telescope is currently under construction with first light with both telescopes expected late in 2005. The enclosure is complete on Mt. Graham in Arizona, the telescope structure has been completed and is
4. THE LARGE BINOCULAR TELESCOPE INTERFEROMETER

The Large Binocular Telescope Interferometer (LBTI) is the interferometer being built to take advantage of this unique telescope by the University of Arizona, as part of NASA’s Navigator Program to develop techniques for extrasolar planet detection. The instrument is both a general purpose, high-resolution imager, and a precision nulling interferometer capable of extrasolar zodiacal dust and giant planet detection.

The first-stage of the LBTI is a general purpose re-imager, called the Universal Beam-Combiner (UBC) which re-images the individual focal planes of the telescopes to a common image plane, while preserving the sine condition of the interferometer. This allows interference to take place for an object over the field-of-view of the beam-combiner, limited by the isoplanatic patch of the adaptive optics correction.

In order to keep the UBC general-purpose, it is a reflective design which has an unvignetted field-of-view of 40 arcsec. Several design were studied, and a simple off-axis ellipse was found to have appropriate imaging properties for the beam-combiner. The optical design is shown in Figure 3. The beam-combiner will be cooled to liquid nitrogen temperature to minimize the system’s contribution to the background in the infrared. However, mechanical stability will be provided by an external structure, keeping difficulties with deformations due to cold optics to a minimum.

The second-stage of the LBTI is the three instrument ports that are fed by the UBC. Currently the main one under design is a nulling interferometer (NIL) and its associated Nulling Optimized Mid-Infrared Camera (NOMIC). This instrument is being optimized for sensitive observations of nearby stars to determine
whether they have faint zodiacal dust disks, lie our own solar system, indicative of extrasolar planetary systems. The remaining two ports will be used for cameras suitable for high-resolution imaging in the near and mid-infrared.

![Diagram](image.png)

**Figure 3.** The Universal Beam-Combiner. The combiner reimages the telescope beams to a common focal plane, providing a magnification of approximately three and an unvignetted field of 40 arcsec. The optics will be enclosed in an evacuated structure, as shown in Figure 2, and cooled to liquid nitrogen temperature for observations.

### 5. HIGH-RESOLUTION IMAGING PERFORMANCE

In order to provide true high-resolution imaging over the designed field-of-view for the instrument, the UBC must preserve image overlap (due to different plate scales or differential distortion), path-length differences (due to the wrong plate scale or absolute distortion), as well as image quality in the individual beams. These criteria were, in fact how we evaluated different designs for suitability, as described in McCarthy et al. In order to explicitly determine the resulting point-spread functions from these design we also developed custom code, based on ZEMAZ ray traces fro each arm of the interferometer, which calculated the expected interference pattern. Figure 4 shows the expected imaging properties for the UBC, demonstrating that we expect good interference from the system over the full field of the beam-combiner.

### 6. NULLING PERFORMANCE

The nulling performance of the system is constrained by two independent parameters: the photometric sensitivity of the system and the expected level of suppression of the point source. The photometric sensitivity for the system is determined by the background emission of the sky and optics. The LBTI provides a uniquely sensitive platform in this regard, by having only three warm mirrors to contribute to the infrared background.
Figure 4. Calculated point-spread functions for the LBTI UBC. The image quality and resulting interference is sufficient for a greater than 80% Strehl ratio over the full 40 arcsec field-of-view.

The suppression level is also expected to be quite good with the LBT. Fundamentally a good null can be achieved because of the relatively modest baseline of the instrument, which allows the stellar disk to remain unresolved by the system. For a good null, however, we also require a well-corrected wavefront. This will be possible with the LBT due to the high-order AO system built into the telescope. The 670 actuators for each pupil should correspond to a final image which has greater than 98% Strehl at 10 microns, suitable for a suppression level of one part in $10^4$. The combination of these two capabilities in the LBT will make it sensitive to dust disks approaching the faintness of the sun’s own zodiacal dust disk around nearby stars. In addition giant planets, especially if young, may be detectable in the same observations for zodiacal dust. Thus the LBTI is planned as an important tool for future studies of extrasolar systems.

7. REFERENCES