An Overview of Instrumentation for the Large Binocular Telescope

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ABSTRACT
An overview of instrumentation for the Large Binocular Telescope is presented. Optical instrumentation includes the Large Binocular Camera (LBC), a pair of wide-field (27’ × 27’) UB/VRI optimized mosaic CCD imagers at the prime focus, and the Multi-Object Double Spectrograph (MODS), a pair of dual-beam blue-red optimized long-slit spectrographs mounted at the straight-through F/15 Gregorian focus incorporating multiple slit masks for multi-object spectroscopy over a 6’ field and spectral resolutions of up to 8000. Infrared instrumentation includes the LBT Near-IR Spectroscopic Utility with Camera and Integral Field Unit for Extragalactic Research (LUCIFER), a modular near-infrared (0.9-2.5 μm) imager and spectrograph pair mounted at a bent interior focal station and designed for seeing-limited (FOV: 4’ × 4’) imaging, long-slit spectroscopy, and multi-object spectroscopy utilizing cooled slit masks and diffraction limited (FOV: 0.5 × 0.5) imaging and long-slit spectroscopy. Strategic instruments under development for the remaining two combined focal stations include an interferometric cryogenic beam combiner with near-infrared and thermal-infrared instruments for Fizeau imaging and nulling interferometry (LBTI) and an optical bench beam combiner with visible and near-infrared imagers utilizing multi-conjugate adaptive optics for high angular resolution and sensitivity (LINC/NIRVANA). In addition, a fiber-fed bench spectrograph (PEPSI) capable of ultra high resolution spectroscopy and spectropolarimetry (R = 40,000–300,000) will be available as a principal investigator instrument. The availability of all these instruments mounted simultaneously on the LBT permits unique science, flexible scheduling, and improved operational support.

Keywords: Optical and infrared instruments, imaging cameras, spectrographs, interferometers, Large Binocular Telescope

1. INTRODUCTION
When completed in 2005, the Large Binocular Telescope (LBT) will be the largest single-mount telescope in the world. The LBT is located in the Coronado National Forest on Emerald Peak at an altitude of 3191 m (10470 feet) in the Pinaleno Mountains of southeastern Arizona near Safford. The binocular design of the LBT has two identical 8.4 m telescopes mounted side-by-side on a common altitude-azimuth mounting for a combined collecting area of a single 11.8 m 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 14.4 m center-to-center and provide an interferometric baseline of 22.7 m 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. The LBT is an international collaboration of the University of Arizona, Italy (INAF: Istituto Nazionale di Astrofisica), Germany (LBTB: LBT Beteiligungsgesellschaft), The Ohio State University, and the Tucson-based Research Corporation. The current status of the LBT is summarized by Hill and Salinari (2003) and in these proceedings (Hill and Salinari 2004).

In this contribution, we provide a general description of the various instruments under construction for the LBT, their capabilities, and current status. The LBT instrumentation program and suite was previously reviewed by Wagner (2003). The reader is referred to the contribution by Herbst and Hinz (2004) in these proceedings.
summarizing in more detail the status of LBT interferometric instrumentation. In addition, one large principal investigator instrument (PEPSI) is also under construction for the LBT as well and has been described previously by Strassmeier et al. (2003).

2. SITE CHARACTERISTICS

Taylor, Jansen, and Windhorst (2004) recently completed a study of observing conditions on Mount Graham based on measurements at the 1.8 m Vatican Advanced Technology Telescope (VATT) between 1999 and 2003. They find an average low-airsnow (1.2) sky surface brightness in U, B, V, and R of 22.0, 22.5, 21.5, and 20.9 mag arcsec\(^{-2}\) respectively. The night sky surface brightness for the darkest runs were 0.3-0.4 mag arcsec\(^{-2}\) fainter on average. These results indicate that under the best conditions Mount Graham can compete with the darkest sites in Chile and Hawaii. Seeing measurements were inconclusive because they were dominated by the image quality of the VATT itself which is an optically fast telescope but without active optics. We are planning more aggressive seeing measurements beginning in the 3rd quarter of 2004 as part of telescope integration and commissioning.

3. LBT INSTRUMENTATION SUITE

The LBT instrumentation program was summarized previously by Wagner (2003). LBT instrumentation is distributed in three broad categories. Facility instruments are available for use by anyone in the partnership and are supported and maintained by the LBTO. Visitor or principal investigator instruments are private instruments and are supported and maintained solely by the builders. Strategic instruments are technically challenging developmental instruments which are considered crucial to the long term scientific success of the LBT. Strategic instruments may be unique and are expected to have a major impact on astronomy as a whole. It is expected that these instruments will be available to the general LBT community on a shared-risk basis during their development and may become facility instruments in the future at the discretion of the LBT Corporation (LBTC).

Three facility and two strategic instruments as well as one major principal investigator instrument are under construction for the LBT. The instruments are as follows:

1. Large Binocular Camera (LBC),
2. MultiObject Double Spectrograph (MDS),
3. LBT NIR-Spectroscopic Utility with Camera and Integral-Field Unit for Extragalactic Research (LUCIFER),
4. LBT Interferometer (LBTI),
5. LBT Interferometric Camera (LINC) and the Near-IR/Visible Adaptive Interferometer for Astronomy (NIRVANA),
6. Potsdam Echelle and Polarimetric Spectroscopic Instrument (PEPSI)

The LBC, MDS, and LUCIFER are facility instruments. The LBC is a pair of blue-red optimized prime focus imagers with a field of view of almost 0.5. MDS is a pair of dual-beam blue-red optimized optical spectrographs supporting long-slit, multi-slit, and direct imaging modes. LUCIFER is a pair of near-infrared (NIR) imagers and spectrographs that can be used in both seeing- and diffraction-limited modes by virtue of interchangeable cameras for direct imaging, long-slit spectroscopy, and multi-slit spectroscopy. In addition, both visible-NIR (LINC/NIRVANA) and thermal-infrared (LBTI) interferometers are under development and construction with preliminary installation planned for mid-2006. PEPSI is a fiber-fed echelle spectrograph for ultra high resolution spectroscopy and spectropolarimetry. The basic parameters of LBT instruments are summarized in Table 1 and shown graphically in Figure 1.

The locations of these instruments on the LBT at the various foci are shown in Figure 2. The LBC is mounted at the prime focus. MDS is attached at the straight-through F/15 Gregorian focus. LUCIFER, LBTI, and
**Figure 1.** Left: Spatial resolution versus wavelength of LBT infrared instruments. The diffraction limit of an 8.4 m and 22.8 m telescope is shown. Right: Spectral resolution versus wavelength for LBT instruments.

**Figure 2.** LBT focal station allocation. Ten focal stations are available. The locations of the LBC, MODS, LUCIFER, LBTI, and LINC/NIRVANA are shown. Fiber bundles for the Potsdam Echelle Polarimetric and Spectroscopic Instrument (PEPSI) are shown schematically as well.
Table 1. LBT Instrument Parameters

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Focal Station</th>
<th>Modes</th>
<th>Spectral Coverage (µm)</th>
<th>Spectral Resolution</th>
<th>Field of view</th>
<th>Pixel scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBC-Blue</td>
<td>Prime</td>
<td>Direct CCD</td>
<td>U, B</td>
<td>4-50</td>
<td>27&quot; x 27&quot;</td>
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<tr>
<td>LBC-Red</td>
<td>Prime</td>
<td>Direct CCD</td>
<td>V, R, I</td>
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<td>MODS-Blue</td>
<td>Direct F/15</td>
<td>Imager, Longslit, MOS</td>
<td>0.32-0.60</td>
<td>10²&quot;⁻¹</td>
<td>6&quot; x 6&quot;</td>
<td>0.15</td>
</tr>
<tr>
<td>MODS-Red</td>
<td></td>
<td></td>
<td>0.60-1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUCIFER</td>
<td>Front-Bent</td>
<td>Imager, Longslit, MOS AO</td>
<td>z, J, H, K</td>
<td>4&quot; x 4&quot;</td>
<td>0.12-0.25</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>J, H, K</td>
<td>30'' x 30''</td>
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<td></td>
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<tr>
<td>LBTI</td>
<td>Center-Bent</td>
<td>Nulling Interferometer</td>
<td>8-13</td>
<td>2-30</td>
<td>25''</td>
<td>0.1</td>
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<tr>
<td>LINC/NIRVANA</td>
<td>Rear-Bent</td>
<td>Fizeau Interferometer</td>
<td>J, H, K'</td>
<td>5-20</td>
<td>10-20''</td>
<td>0.006</td>
</tr>
<tr>
<td>PEPSI</td>
<td>Rear-Bent</td>
<td>Spectroscopy</td>
<td>0.39-1.1</td>
<td>4000 to 30000</td>
<td>0.5-1.4</td>
<td>0.165</td>
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<tr>
<td></td>
<td>Direct F/15</td>
<td>Spectropolarimetry</td>
<td></td>
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</table>

LINC/NIRVANA are mounted at the front, center, and back interior F/15 focal stations respectively. The PEPSI spectrograph is located in the base of the LBT pier in a temperature controlled environment and is connected to the LBT focal plane by optical fibers. These instruments will be mounted on the telescope simultaneously to take advantage of exquisite but rare observing conditions, flexible scheduling, mixed-mode observing programs, targets of opportunity, and remote observing. We summarize the capabilities and status of the LBT facility and strategic instruments below. The reader is referred to the article by Strassmeier et al. (2003) for further information regarding PEPSI.

4. FACILITY INSTRUMENTS

4.1. The Large Binocular Camera (LBC)

The LBC consists of a pair of wide-field mosaic optical CCD imagers at the F/1.14 prime focus of each 8.4 m primary mirror. Each camera is mounted on a swing-arm spider attached to the elevation structure of the telescope. Thus, the cameras can be swung into and out of the telescope beam at any time and be ready for observations with minimal effort. Given the binocular telescope, two cameras were designed. The blue camera is optimized for the UB bands while the red camera is optimized for the VRIz bands. Assuming 0.6 seeing, the LBC should achieve limiting magnitudes as faint as U ≃ 26.4; B ≃ 28; V ≃ 27.8; and I ≃ 26.5 at a signal-to-noise ratio of 5 for a total integration time of 1 hour. The LBC principal investigators are E. Gallongo (Rome) and R. Ragazzoni (Arcetri). The LBC was described by Ragazzoni et al. (2000), Diolaiti et al. (2003), Pedichini et al. (2003), and by Ragazzoni et al. (2004) in these proceedings.

The extremely fast LBT primary mirrors require significant optical corrections at the prime focus in order to produce superb images over such a large field of view. This is achieved by a camera consisting of six lenses, the first of which has a diameter of ~80 cm. The blue camera design results in images with 80% encircled energy within 1 pixel (0.128) both at the field center and at 15" off-axis in the U- and B-bands and 2 pixels in the V-band. The red channel corrector is similar to the design of the blue channel corrector but is made of BK7. No atmospheric dispersion corrector has been included in the design of either camera.

Each science array consists of 4 E2V 42-90 three-side buttable CCDs (2048 x 4608, 13.5µm square pixels) which cover about 75% of the corrected field (Figure 3). These CCDs offer low read noise, good quantum efficiency, and can be read out in about 20 seconds using a 1 MHz SkyTech controller. The cryostat is composed of a spherical bi-metallic dewar 300 mm in diameter containing 8 liters of LN₂.

Two E2V 42-10 CCDs (512 x 2048, 13.5µm square pixels) are located inside the corrected field on each side of the science array. One of these devices coincides with the science focal plane and is used for guiding and focus adjustments. The other CCD is located 880 µm below the science focal plane and incorporates a series of glass
wedges cemented to the CCD to provide intra- and extra-focal images suitable for the measurement of both low and high order optical corrections (Figure 3). All of these corrections are achieved by bending the active primary mirrors of the LBT. Models suggest that at least one guide star with \( V = 19 \) or \( B = 20 \) will be found at high galactic latitudes. An image quality pipeline is under development which utilizes information from the guiding, image analysis, and science detectors to maintain exceptional image quality.

The blue channel of the LBC passed laboratory acceptance tests in April 2004 (Speziali et al. 2004). It was subsequently disassembled and shipped to the LBT one month later and installed on the telescope in June 2004 (Figure 4) in preparation for telescope commissioning and first light currently planned for October 2004. Commissioning of the instrument is planned for March-April 2005. The laboratory tests suggest that the LBC blue channel imager will achieve its scientific performance goals. It is anticipated that the red channel imager will be delivered to the LBT in September 2005.

4.2. The MultiObject Double Spectrograph (MODS)

MODS consists of a pair of identical double-beam blue-red optimized optical spectrographs attached to the straight-through F/15 Gregorian focus of each 8.4 m primary mirror. The optical layout of MODS (Figure 5) incorporates a dichroic beamsplitter behind the slit assembly and reflects red light to the red channel through a fold mirror. MODS may be used in three basic modes: (1) red+blue dual channel using the dichroic beamsplitter for simultaneous broad wavelength coverage; (2) red-channel only using a silvered flat mirror; and (3) blue-channel only using an open position for optimal red and blue only observations respectively. For acquisition, guiding, and wavefront sensing, a modified version of the standard LBT Potsdam AGW system is being constructed since the red channel protrudes into the volume normally occupied by these units. The spectrographs are being designed and constructed by The Ohio State University Imaging Sciences Laboratory. The MODS principal investigator is P. Osmer. MODS was previously summarized by Osmer et al. (2000) and by DePoy et al. (2004) in these proceedings.

MODS offers spectral resolutions of \( 10^5-4 \) and a useable field of about \( 6' \times 6' \). A variety of slit widths will be available but a \( 0''6 \) wide slit will take advantage of the typical median seeing at the LBT and project to four pixels at the detector. A low resolution mode (\( R \approx \text{few hundred} \)) is under investigation. The optical train (Byard and O'Brien 2000) provides broad spectral coverage and high throughput by incorporating a de-centered and unvignetted Maksutov-Schmidt camera and optimized coatings on the optics and detectors (Figure 6). MODS can accommodate an \( 8K \times 4K, 15 \mu \text{m} \) square pixel CCD without any vignetting. The procurement of these or similar devices is being considered. The baseline plan calls for the installation of one or two buttable \( 4K \times 4K \) pixel CCDs by the University of Arizona Imaging Technologies Laboratory. In addition, MODS incorporates a close-loop image motion compensation system (IMCS; Marshall et al. 2002; Marshall et al. 2004) to compensate for flexure due to gravity, temperature fluctuations, and mechanical effects. Without active compensation, image motion deflections could be \( \sim 100 \mu \text{m} \) in the focal plane. Recent tests of an IMCS prototype suggest that the deflections can be reduced to \( \sim 1 \mu \text{m} \) rms (Marshall et al. 2004).

MODS has three observing modes: long-slit, multi-slit, and direct imaging. In long-slit mode, a 5' long slit provides spatial coverage across a slice of the MODS field of view and can be oriented at any angle by the instrument rotator assembly. In multi-slit mode, a slit mask will be used to precisely locate a series of small “slitlets” centered on targets within the MODS field of view. As many as 48, 5'' long slitlets can be accommodated in the design across a 4' field. Each MODS spectrograph can have up to 25 slit masks stored on the telescope in the cassette mechanism. Finally, a direct imaging mode of the spectrograph can be implemented by removing the slit mask from the focal plane and replacing the grating by a plane mirror. The direct imaging mode will allow MODS to perform precise target acquisition on single and multi-slit focal plane masks as well as for science programs that require simple direct imaging observations. The grating turret mechanism holds up to 3 gratings plus the imaging flat mirror.

A mandatory progress review of the MODS project was held in April 2004. The discussion included status reports describing management, optics, mechanics, software, IMCS, detectors, and schedule. It is anticipated that a complete dual-channel MODS1 spectrograph will be delivered to the LBT in the first quarter of 2006.
Figure 3. Left: LBC blue channel focal plane science CCD array with adjacent guiding and image analysis CCDs. Right: Enlargement of the image analysis CCD showing the glass wedges cemented to the detector for low and high order analysis of intra- and extra-focal images.

Figure 4. The LBC blue channel prime focus imager mounted on the LBT for the first time on June 2, 2004.
Figure 5. MODS Optical Layout. A dichroic beamsplitter behind the slit reflects red light to the red channel through a fold mirror. The slit mask exchange mechanism, grating turrets, and blue and red cameras are shown.

Figure 6. Left: MODS de-centered Maksutov-Schmidt camera design. Right: Estimated MODS low-resolution mode throughput based on the spectrograph and detector only. Telescope and slit losses are not included.

4.3. The Near-Infrared Imager and Spectrograph (LUCIFER)

The NIR Imager and Spectrograph (LUCIFER: LBT NIR-Spectroscopic Utility with Camera and Integral-Field Unit for Extragalactic Research) consists of a pair of cryogenic NIR imagers and spectrographs mounted at the front-center bent F/15 Gregorian foci of each LBT primary mirror. It is anticipated that one LUCIFER will be delivered to the LBT by the end of 2005 with the second instrument to follow 18 months later. LUCIFER is a joint project of the Landessternwarte Heidelberg (LSW), Max Planck Institut für Astronomie Heidelberg (MPIA), Max Planck Institut für Extraterrestrische Physik Garching (MPE), Astronomisches Institut der Ruhr-Universität Bochum (AIRUB), and Fachhochschule Mannheim, Hochschule für Technik und Gestaltung (FHTG). The LUCIFER principal investigators are Immo Appenzeller and Holger Mandel. A description of LUCIFER was presented by Mandel et al. (2000) and Seifert et al. (2003), and by Mandel et al. (2004) and Seifert et al.
LUCIFER will have excellent sensitivity across the entire 0.9-2.5 μm spectral range. The instrument is capable of the following observing modes: (1) seeing-limited imaging over a 4′ field of view; (2) seeing-limited long-slit spectroscopy across a 4′ long slit and a resolution ≥ 5,000 for OH suppression; (3) seeing-limited multi-slit spectroscopy for up to ~24 targets (Hofmann et al. 2004); (4) diffraction-limited imaging over a 30′ × 30′ field of view; and (5) diffraction-limited long-slit spectroscopy in J, H, and K with spectral resolutions up to ~40,000. An integral field unit can be implemented at a future date. These modes can be selected by the choice of three different cameras.

Figure 7. Left: Schematic layout of the optical path and components of LUCIFER. The entrance window is at the bottom in this illustration. Four fold mirrors are present to bring the light to the grating or imaging flat. Right: Overview of the LUCIFER cryostat showing the location of two closed cycle coolers, electronic boxes on the backside, and the circular port for the cryogenic mask exchange unit.

The optical layout of LUCIFER is shown in Figure 7. The design of the cryostat and its components is complicated by the small volume (1.5 × 2 m) available for the instrument at the front-center focal station and four fold mirrors have been implemented to bring the light to the grating assembly (Figure 7). LUCIFER has been optimized for use in the K-band, but will work equally as well in the J- and H-bands. Light from the telescope first enters a tilted CaF entrance window located just above the focal plane. The tilted window transmits infrared photons but reflects visible wavelength photons back up into the on-axis wavefront and tip-tilt assembly in the AGW box where a total field of 4′ × 6′ will be available for the wavefront sensor.

Between the entrance window and focal plane an atmospheric dispersion corrector (ADC) and small field (10′ × 10′) slit viewer will be incorporated. The ADC is required for diffraction limited imaging and spectroscopy in the J- and H-bands at certain zenith angles. An IR tip-tilt sensor covering the isokinetic patch is incorporated directly behind the entrance window. The refractive collimator is fixed and provides a beam size of 102 mm. Three fold mirrors direct the light to the grating and mirror assembly which is used to select spectroscopic or imaging mode respectively. A fourth fold mirror directs the light to one of three cameras giving image scales of 0″.25, 0″.12, and 0″.015 per pixel. The cameras have been designed for seeing-limited spectroscopy covering the full wavelength range of each filter band, seeing-limited imaging and spectroscopy covering half of the JHK-bands at higher spectral resolution, and for diffraction-limited imaging and spectroscopy respectively. The sampling in the diffraction-limited mode was selected to optimally sample (2 pixels) the Airy disk in the J-band (FWHM = 0″.031).

The detector of each LUCIFER instrument will be a Rockwell HAWAII-2 2K × 2K HgCdTe chip with 18 μm square pixels and quantum efficiencies approaching ~60% in the K-band. Filters will be mounted in two filter
Figure 8. LUCIFER opto-mechanical assemblies and optics. Top: Filter wheel and z-band filter. Bottom: Grating holder and 210 gpm grating.

wheels located in the converging beam just in front of the camera field lens. A set of 27 broadband \( z \)JHK \( K \)s, narrow-band atomic line and molecular band, and other filters will be available. In addition to a plane mirror used to select direct imaging mode, the grating turret will have two low-dispersion gratings (64 gpm and 48 gpm) covering the range 0.9-1.8 \( \mu m \) and 1.2-2.5 \( \mu m \) at a resolution of 500 and one 210 gpm high dispersion grating used in 2-5th order covering the KHIJ \( z \) bands respectively. Various LUCIFER optical components are shown in Figure 8.

5. STRATEGIC INSTRUMENTS

Two strategic instruments have been approved by the LBTC. The LBT Interferometer (LBTI) is based on earlier nulling and Fizeau interferometers developed at the 6-mirror Multiple Mirror Telescope (Hinz et al. 2000; Lloyd-Hart et al. 1993), but with the addition of an optimized cryogenic beam combiner (McCarthy et al. 2000) to combine the light of the two LBT primaries. Important goals for LBTI include a nulling survey of nearby solar-type stars in a search for possible exo-planetary systems, the development of nulling interferometry techniques, provide a test-bed for multi-pair nulling techniques as a prelude to TPF and Darwin, and provide a combined-beam focal station for thermal-IR Fizeau interferometry.

The second strategic instrument is LINC/NIRVANA (LN), a joint German and Italian project. LINC (LBT INterferometric Camera) is a visible-NIR beam combiner operating in the \( \sim1.0 \)-2.4 \( \mu m \) spectral region including single, on-axis adaptive optics. NIRVANA (Near-IR/Visible Adaptive iNterferometer for Astronomy) is the LINC concept but with the future incorporation of multi-conjugate adaptive optics to yield a wider field of view. Science drivers for LN include a wide variety of astrophysical problems including supernova cosmology, star formation, the structure of circumstellar disks, imaging of planetary surfaces and atmospheres, and the search for exo-solar planets.
We briefly summarize both instruments in more detail below. The reader is referred to the summaries of both instruments by Herbst and Hinz (2004) in these proceedings.

5.1. LBTI

The LBTI consists of a cryogenic, all-reflective, beam combiner (UBC: Universal Beam Combiner) located at the center Gregorian focal station and an instrument port that can accommodate multiple cameras for both nulling and Fizeau interferometry (Figure 9). The UBC combines the light from the two individual 8.4-m telescopes into a single focal plane with an F/15 envelope. The UBC is designed to provide high throughput, a wide-field of view, and excellent on-axis image quality over the 0.5-20 μm spectral region. The UBC design includes a PZT-mounted mirror for fast tip-tilt and phase compensation adjustments as well as a simple adjustable mirror for tip, tilt, and path-length adjustments. A cold pupil spot is incorporated for optimum infrared sensitivity. The calculated optical performance of the UBC shows that the design delivers >80% Strehl over a 40'' diameter field of view in the K-band and >99% at a wavelength of 10 μm. The LBTI principal investigator is Philip Hinz. A description of the LBTI has been presented by Hinz (2002) and Hinz (2004) in these proceedings.

The precise overlapping and phasing of the beams takes place in a second instrument and dewar designed and optimized for nulling interferometry (NIL: Nulling Interferometry for the LBT). The design is based on the existing nulling cryostat (BLINC) now in operation at the 6.5 m MMT in which the two beams from the UBC are folded to overlap at a semi-transparent mirror. NIL provides broad suppression of a central point source so that thermal emission from circumstellar shells, zodiacal dust clouds, or giant planets can be observed. Detection takes place in the Nulling-Optimized Mid-Infrared Camera (NOMIC) which provides high throughput detection of excess thermal infrared emission simultaneously in both the 8.0-9.5 μm and 10.0-12.4 μm bands allowing low resolution spectral analysis. The detector in NOMIC will be a 256 × 256 Si:As BIB array which has 80% quantum efficiency at 10 μm.

LBTI is in the final design phase and has proceeded with procurement and fabrication of some components. The UBC has completed a final design review and many components are on order. It is expected that the complete UBC will be delivered to the laboratory in late 2004. A preliminary design for NIL has been completed based on the previous BLINC design in use at the MMT. It is expected to be available for laboratory testing in mid-2005. The detector for NOMIC has been purchased and fabrication of the camera should begin starting in early 2005 with integration to follow in late 2005.
Figure 10. LINC/NIRVANA optical path including the collimator lenses, cold pupil stop, wavefront sensors, fringe tracker, and cryogenic camera. The additional optical folds will accommodate the future implementation of deformable mirrors to achieve a wider field of view.

5.2. LINC/NIRVANA

LINC is a 1.0-2.4 μm beamcombiner and Fizeau interferometer for the LBT and will be mounted in the centerback focal station (Figure 10). LINC will initially use the single, on-axis, adaptive optics system of the LBT to produce interferometric images with the sensitivity of an 11.8 m telescope but with the spatial resolution of a 22.7 m telescope (10 mas at J and 20 mas at K) over a science field of view of 10". LINC will require several observations of targets to fill in the (u,v) plane in the same manner as LBTI to produce images free of the LBT PSF. The performance of LINC suggests that reconstructed point sources as faint as ~26 mag with a S/N ratio of 5 can be detected in one hour at K. The LINC principal investigator is Tom Herbst. LINC/NIRVANA has been summarized by Herbst et al. (2004) in these proceedings.

The optical design of LINC includes additional folding mirrors at conjugates of significant atmospheric turbulence layers. Initially these are simple flat mirrors. However future plans call for the flat mirrors to be replaced by deformable mirrors driven by a sophisticated sensor system and wavefront computer. This will allow simultaneous correction of multiple atmospheric layers resulting in a larger field and of course correspondingly larger detector arrays. The optical design of LINC already accommodates these larger fields. NIRVANA is the extension of LINC with the inclusion of multi-conjugate adaptive optics.
6. FURTHER INFORMATION

Further information regarding the LBT and its instruments can be found at the following web addresses:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Website</th>
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<tbody>
<tr>
<td>LBT</td>
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<td><a href="http://lbc.mporzio.astro.it">http://lbc.mporzio.astro.it</a></td>
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REFERENCES