

# LINC-NIRVANA: the Fizeau Interferometer for the Large Binocular Telescope

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## ABSTRACT

LINC-NIRVANA is an innovative imaging interferometer fed by dedicated multi-conjugated adaptive optics systems. The instrument combines the light of the two, 8.4-meter primary mirrors of the Large Binocular Telescope (LBT) on a single focal plane, providing panoramic imagery with 23-meter spatial resolution. LINC-NIRVANA is entering its final integration phase, with the large adaptive-optics and imaging subsystems coming together in the clean room in Heidelberg. Here, we report on progress, including insights gained on instrument assembly and vibration control.

**Keywords:** near-infrared, imaging, interferometry, Fizeau, LBT

## 1. INTRODUCTION

LINC-NIRVANA (LN) is a near-infrared (1-2.5  $\mu\text{m}$ ) Fizeau beam combiner, which will occupy one of the shared focal stations on the central platform of the Large Binocular Telescope (LBT). At this location, LN receives light from both of the 8.4-meter telescopes. By combining the radiation in the focal plane in Fizeau mode, LINC-NIRVANA will synthesize a telescope of 12 meter collecting area and 22.8 meter spatial resolution.

LINC-NIRVANA is being built by a consortium of four institutes: the Max Planck Institute for Astronomy (MPIA) in Heidelberg, INAF (including the observatories of Padova, Bologna, Arcetri, and Rome), the University of Köln, and the Max Planck Institute for Radioastronomy (MPIfR) in Bonn.

## 2. FIZEAU INTERFEROMETRY ON LBT

Figure 1 shows LINC-NIRVANA mounted on the LBT. Herbst *et al.*<sup>1</sup> describe the optical path and major subsystems. Using a set of ambient temperature fore-optics, LN creates a scaled-down image of the telescope entrance pupil at the mid-line of the instrument. This satisfies the so-called “sine condition” or homotheticity requirement for Fizeau interferometry. After subsequent recombination on the focal plane, the field of view of such an interferometer is limited only by the size of the delivered, diffraction-limited field. LINC-NIRVANA employs dual-layer multi-conjugated adaptive optics (MCAO), in which a pair of wavefront sensors and two deformable mirrors per telescope correct turbulence induced in the ground and upper layers of the atmosphere. The LN MCAO system delivers a diffraction limited field two arcminutes in diameter. This is considerably larger than the 10 arcsecond science field of view, but the additional area ensures good sky coverage to search for essential fringe-tracking stars.

Figure 2 shows a simulation of LINC-NIRVANA imagery. The individual point spread function (PSF) can be understood as a single, 8-meter Airy pattern crossed by fringes due to the presence of both apertures – essentially a Young’s two-slit experiment. The key to LINC-NIRVANA’s unique capability is the fact that all objects in the field display this PSF, and hence we can gain high angular resolution information across a field of view thousands of times larger than in a conventional, coaxial interferometer, whose field is usually limited to a fraction of a single PSF.

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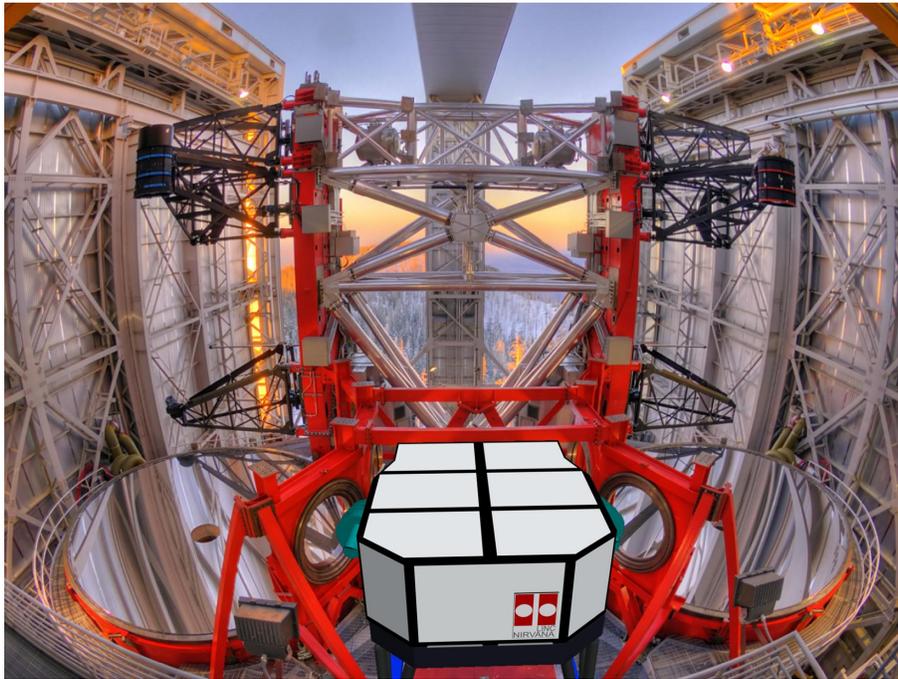


Figure 1: LINC-NIRVANA (light gray box in foreground) installed courtesy of Photoshop at the rear, bent shared focus of the Large Binocular Telescope. At this location, LN receives light from both 8.4 meter primary mirrors.

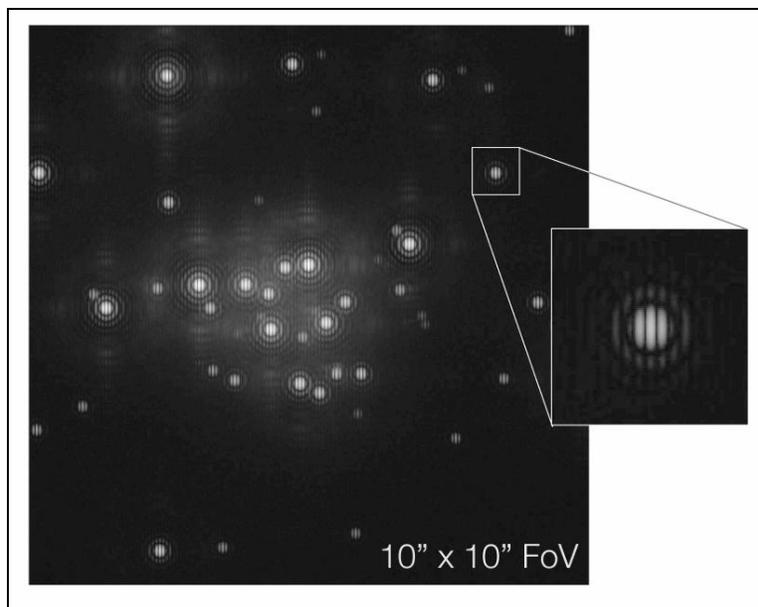


Figure 2: Simulated LINC-NIRVANA image of a dense stellar cluster. All objects in the field show the characteristic PSF.

Given that diffraction-limited 8-meter class telescopes have been in operation for approximately a decade now, the key to LINC-NIRVANA's scientific success lies in exploiting both the enhanced sensitivity and, particularly, the higher spatial resolution. Stated in interferometric terms, the latter imperative for the design and operation of LINC-NIRVANA

corresponds to preserving maximum information at spatial frequencies associated with baselines between 8 and 23 meters.

The modulation transfer function (MTF) provides a convenient visualization of this aim. Figure 3 shows LINC-NIRVANA's MTF under ideal conditions – that is, 100% Strehl ratio and essentially perfect fringe tracking. The structure of the MTF is readily understood as the sum of a single dish MTF and a pair of “ears” at high spatial frequencies arising from the second aperture. Fizeau or image-plane interferometry differs from conventional coaxial mode in allowing each part of one telescope pupil to interfere with all regions in the other. In coaxial interferometry, the pupils are superposed, and there is only a single baseline and (u,v) point associated with each observation.

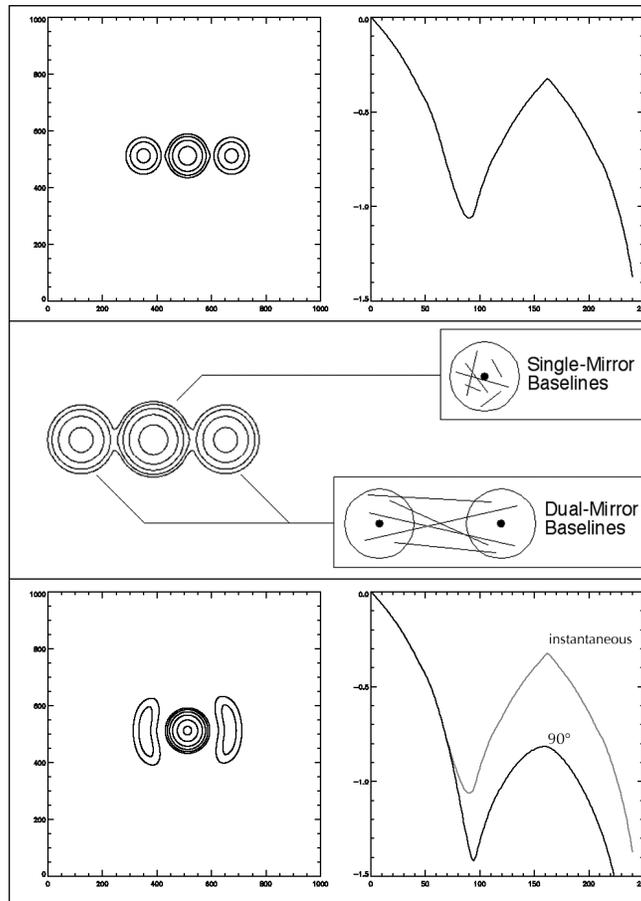


Figure 3: Modulation Transfer Function of LINC-NIRVANA. (top) Instantaneous MTF, log scaled with a cut showing that the ratio of mirror diameter to separation in the LBT produces no nulls between 0 and 23 meter spatial resolution. (center) Fizeau interferometry allows all parts of the pupils to interfere with each other, providing complete (u,v) coverage. (bottom) MTF after 90° of sky rotation. Note the reduction in relative sensitivity at high spatial resolution.

The LBT has an alt-azimuth mount and LINC-NIRVANA, as an interferometer, must remain pupil fixed. As a result, the field of view rotates, allowing us to exploit Earth rotation synthesis to fill in the (u,v) plane and thereby produce high fidelity images of complex sources (figure 3). Note, however, that the relative exposure depth at the high spatial frequencies will be lower. This is because every on-sky integration produces complete information on 8-meter and smaller baselines, whereas the 8-23 meter range will only be sampled at the appropriate parallactic angle. This reinforces the importance of preserving the 8-23 meter baseline performance of LINC-NIRVANA.

To address this goal, the LINC-NIRVANA team has developed a merit function, called R23, which represents the ratio of the area under the high frequency lobe of the actual delivered MTF to that of the MTF under ideal conditions (figure 4). Egner *et al.*<sup>2</sup> describe this merit function further and demonstrate its use in the evaluation of the LN error budget.

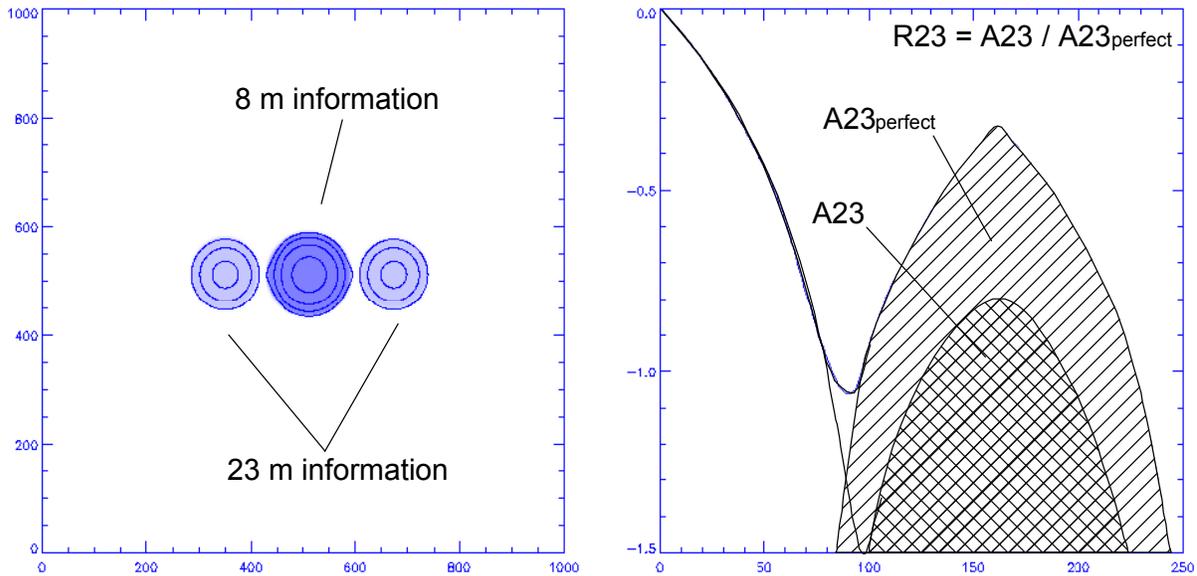


Figure 4: The R23 parameter measures the fraction of high spatial frequency information preserved in the instrumental PSF.

### 3. LINC-NIRVANA CONSTRUCTION STATUS

LINC-NIRVANA is entering the final integration and test phase in the MPIA clean room in Heidelberg. Coordinating this activity is a challenge, since the instrument consists of multiple components and subsystems, and working several meters off the ground on the large optical bench is inconvenient and potentially dangerous. As a result, we have adopted a hierarchical approach to integration, which involves tests of the individual components at the suppliers, then assembly and verification of these components into subsystems in a conventional laboratory environment. Finally, the subsystems come together for final integration, flexure tests, etc. on the large bench in the clean room. Figure 5 shows some of the hardware undergoing this process.

### 4. CHARACTERIZING VIBRATIONS AT THE LARGE BINOCULAR TELESCOPE

Experience at other large ground-based interferometers has highlighted the importance of understanding and controlling vibrations in the observatory environment. Although LINC-NIRVANA is more compact and self-contained than other interferometric systems, vibrations will undoubtedly be an issue at the LBT as well.

In order to pre-empt these difficulties as much as possible, we have undertaken a series of measurement campaigns to characterize vibrations at the telescope under realistic observing conditions. This involves wiring a network of accelerometers to key telescope components and performing synchronous data acquisition. Proper combination of the signals gives accelerations and displacements of the telescope opto-mechanics along the LINC-NIRVANA optical path, and hence the anticipated optical path difference (OPD). For example, we synchronously combine the up-down motion of the primary and secondary mirrors, the up-down and lateral motions of the tertiary, and the lateral motion of the instrument platform (figure 6). The most recent campaign in October-November of 2007 indicated prominent resonant features at 12 and 20 Hz, very likely associated with the secondary and tertiary mirror supports, respectively. Brix *et al.*<sup>3</sup> describe the vibration measurement campaign in detail.

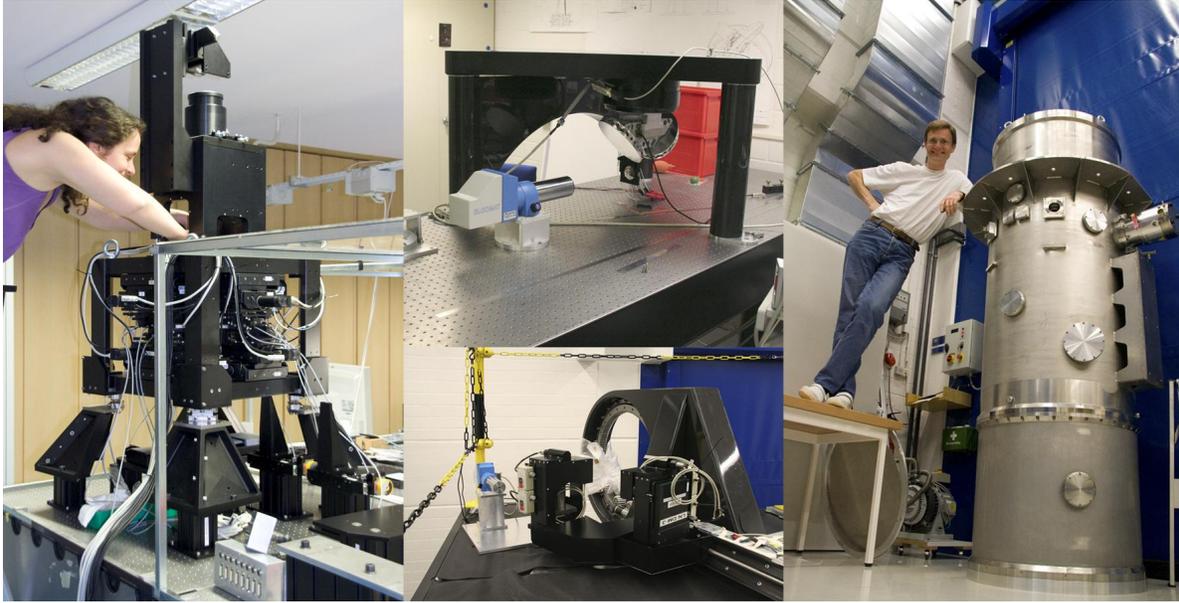


Figure 5: Component and subsystem integration. Clockwise from left: the first Mid-High Layer Wavefront sensor, characterizing the dynamic performance of the LINC-NIRVANA fast delay line or “piston mirror,” the large vacuum cryostat for the science channel, and verifying flexure performance of warm fore-optics assembly. See Herbst *et al.*<sup>1</sup> for further information on the opto-mechanical components of LINC-NIRVANA.

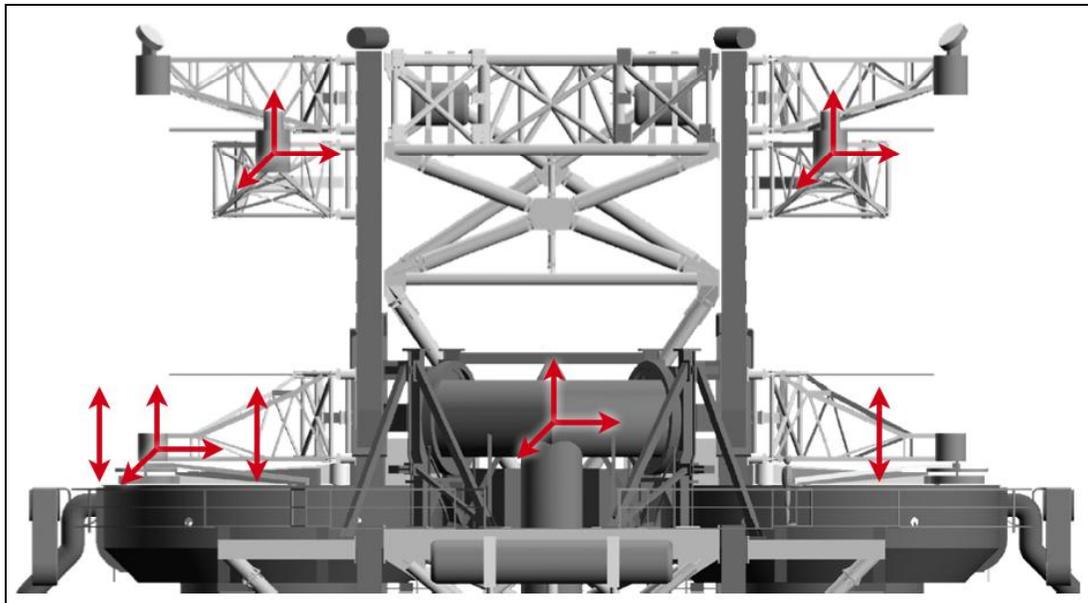


Figure 6: Location of the accelerometers for characterizing vibrations and OPD. The groups of three arrows represent 3-axis accelerometers, while the double-headed arrows correspond to linear accelerometers. Proper synchronous combination of the appropriate signals leads to an assessment of the mechanical OPD produced by telescope vibrations. See Brix *et al.*<sup>3</sup> for details.

## 5. SUMMARY AND FURTHER INFORMATION

Fizeau interferometry on the LBT offers the promise of sensitive, panoramic imagery of complex astrophysical sources. The LINC-NIRVANA instrument will exploit this unique capability via a combination of adaptive optics, fringe tracking, and Earth rotation synthesis. Final integration of the instrument has begun, and a parallel effort to characterize vibrations at the Large Binocular Telescope is well underway.

A single short paper cannot adequately capture progress over the last two years on an instrument as complex as LINC-NIRVANA. Interested readers are encouraged to consult the additional 2008 SPIE publications listed in Table 1. For the latest developments on the instrument, point your web browser to:

<http://www.mpia.de/LINC>

## REFERENCES

- [1] Herbst, T. M., Ragazzoni, R., Eckart, A., and Weigelt, G. Paper 7014-44, This conference.
- [2] Egner, S. E., Herbst, T. M., and Arcidiacono, C. Paper 7013-122 This conference.
- [3] Brix, M., Naranjo, V., Beckmann, U., Bertram, R., Bertram, T., Brynnel, J., Egner, S., Gässler, W., Herbst, T. M., Kuerster, M., Rohloff, R.-R., Rost, S., and Schmidt, J. Paper 7012-92 This Conference.

Table 1: LINC-NIRVANA publications at this conference, organized by discipline

Discipline	Paper	Authors	Title
Science	7013-169	Eckart <i>et al.</i>	The Potential of Interferometric Observations of the Galactic Center: Combining LBT in the Near-Infrared with ALMA/CARMA in the mm/submm Wavelength Domain
	7013-115	Cileigi <i>et al.</i>	Analysis of LINC-NIRVANA Simulated Images in Two Specific Scientific Cases
	7013-147	Desidera <i>et al.</i>	AIRY-LN: An ad-hoc Numerical Tool for Deconvolution of Images from the LBT Instrument LINC-NIRVANA
Fringe Tracking	7013-117	Lindhorst <i>et al.</i>	The LINC-NIRVANA Fringe and Flexure Tracking System: the Testbed Interferometer
	7013-78	Bertram <i>et al.</i>	The LINC-NIRVANA Fringe and Flexure Tracking System
	7013-118	Rost <i>et al.</i>	The LINC-NIRVANA Fringe and Flexure Tracker: Testing Piston Control Performance
Adaptive Optics	7015-202	Farinato <i>et al.</i>	The Multiple Field-of-View Layer-Oriented Wavefront Sensing System of LINC-NIRVANA: Two Arcminutes of Corrected Field using Solely Natural Guide Stars
	7015-192	Schreiber <i>et al.</i>	Integration of the Mid-High Wavefront Sensor to the LINC-NIRVANA Post-Focal Relay
Calibration & Control	7013-114	Labadie <i>et al.</i>	Calibration Procedures for Wide-Field Fizeau Interferometry on the LBT
	7012-92	Brix <i>et al.</i> (Reference 3)	Vibration Measurements at the Large Binocular Telescope
Software	7019-71	Briegel <i>et al.</i>	A Component-Based Astronomical Visualization Tool for Instrument Control
	7013-116	Pavlov <i>et al.</i>	LINC-NIRVANA Observation Preparation Software: a Flexible Approach
	7019-56	Kittmann <i>et al.</i>	Design and Implementation of a Service-Oriented Driver Architecture for LINC-NIRVANA
	7019-70	Berwein <i>et al.</i>	A SOA Developer Framework for Astronomical Instrument Control Software
General	7013-122	Egner <i>et al.</i> (Reference 2)	General Performance Analysis of a Fizeau Interferometer
	7014-8	Wagner <i>et al.</i>	An Overview of Instrumentation for the Large Binocular Telescope
	7013-77	Herbst <i>et al.</i> (Reference 1)	LINC-NIRVANA, Achieving 10 mas Imagery on the Large Binocular Telescope
Upgrades	7014-161	Müller-Sanchez <i>et al.</i>	Coupling LBT's Double Pupil into Optical Fibers
	7014-74	Müller-Sanchez <i>et al.</i>	SERPIL: A Design Study for Interferometric Imaging Spectroscopy at LBT
	7014-273	Gal <i>et al.</i>	LIINUS: A Design Study for Interferometric Imaging Spectroscopy at LBT