LINC-NIRVANA - first attempt of an instrument for a 23m class telescope

Wolfgang Gaessler[a], T. M. Herbst[a], R. Ragazzoni[a,b], D. Andersen[a], C. Arcidiacono[b], H. Baumeister[a], U. Beckmann[d], T. Bertram[c], P. Bizenberger[a], H. Boehnhardt[a], E. Diolaiti[b], A. Eckart[c], J. Farinato[b], S. Ligori[a], H.-W. Rix[a], R-R. Rohloff[a], P. Salinari[b], R. Soci[a], C. Straubmeier[c], E. Vernet-Viard[b], G. Weigelt[d], R. Weiss[a], W. Xu[a]

[a]Max-Planck-Institut für Astronomie, Heidelberg - Germany
[b]Astronomical Observatory of Arcetri, Firenze - Italy
[c]1. Physikalisches Instiut, Universität Köln - Germany
[d]Max-Planck-Institut für Radioastronomie, Bonn - Germany

ABSTRACT

LINC-NIRVANA is a Fizeau interferometer which will be built for the Large Binocular Telescope (LBT). The LBT exists of two 8.4m mirrors on one mounting with a distance of 22.8m between the outer edges of the two mirrors. The interferometric technique used in LINC-NIRVANA provides direct imaging with the resolution of a 23m telescope in one direction and 8.4m in the other. The instrument uses multi-conjugated adaptive optics (MCAO) to increase the sky coverage and achieve the diffraction limit in J, H, K over a moderate Field of View (2 arcmin in diameter). During the preliminary design phase the team faced several problems similar to those for an instrument at a 23m telescope. We will give an overview of the current design, explain problems related to 20m class telescopes and present solutions.

Keywords: Imager, interferometer, adaptive optics, multi-conjugation

1. INTRODUCTION

An intermediate step from the current 8-10m Telescopes to the next generation of 20, 30 or even 100m Telescopes will be the Large Binocular Telescope (LBT)[1] at Mt Graham in Arizona. The LBT can be looked at as an aperture-masked 22.8m telescope with two 8.4m sub-apertures. Currently, we are building for the LBT a near infrared instrument with the name LINC-NIRVANA[2,3] (L-N) which will take advantage of the spatial resolution provided by a 22.8.m telescope. L-N is a Fizeau interferometer, which will be placed in the front bent Gregorian Focus of the LBT, combining the incoming beams from the two 8.4m mirrors (see Figure 1). The diffraction limited images will show the spatial resolution of an 8.4m telescope in one direction and of a 23m telescope in the other (see Figure 2). With observations of the same target at different parallactic angles, we can restore an image which shows the spatial resolution as if obtained with a 23m telescope[4]. Diffraction limited imaging will be achieved with the help of
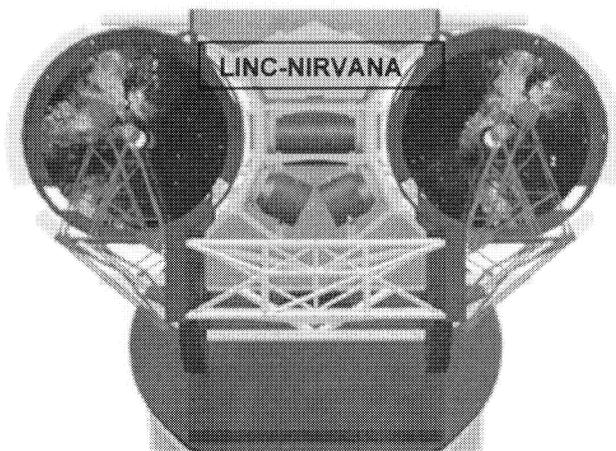

Figure 1. The Large Binocular Telescope as seen from above. LINC-NIRVANA is placed at the front bent Gregorian focal station

Adaptive Optics (AO) using Natural Guide Stars (NGS). The AO system is a Multi-Conjugated Adaptive Optics (MCAO) system using novel techniques also proposed for AO at Extremely Large Telescopes (ELT).
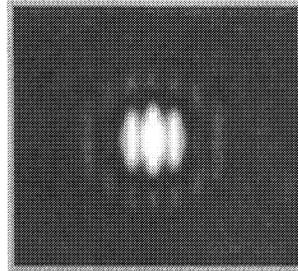

Figure 2. PSF of a point source as L-N will obtain, with the spatial resolution of an 8.4m telescope in the vertical direction and of a 22.8m telescope in the horizontal

2. MCAO CONCEPTS

L-N uses MCAO mainly to increase the sky coverage and currently takes advantage of the AO correction in an extended Field of View only for the Fringe and Flexure Tracker, but not for the science camera. Several novel AO concepts are used and will partly be tested for the first time with the instrument:

- Pyramid wave front sensor[5]
- Layer oriented MCAO[6]
- Optical co-adding of NGS[6]
- Multiple field of view[7]

The pyramid sensor is a pupil plane sensor which measures the first derivative of the incoming wavefront. An optical element in the form of a pyramid is used to accomplish a knife edge test in two directions at once. The sensor is supposed to exhibit higher sensitivity in closed loop, when correction is applied in the sensing wavelength.

The layer oriented MCAO approach corrects local layers at different altitudes in the atmosphere with separate control loops. This lowers the complexity of the control system and allows building such systems with off the shelf components.

Optical co-adding of NGS increases the signal to noise ratio of the sensor using several guide stars simultaneously. This technique is possible with any kind of pupil plane sensor. In the part of the meta-pupil where the stars overlap, a higher signal is received.

Multiple fields of view increase the sky coverage by use of a larger field with the ground layer sensor than the high layer sensors. At lower altitude the separation of the re-imaged stars get smaller, down to full overlap at the ground. Therefore, guide stars with larger angular separation show no effects on the size of the re-imaged meta-pupil for the ground layer.

3. INSTRUMENT OVERVIEW

An overview of the instrument appears in Figure 3. The main components of the instrument are:

- Ground Layer Wavefront Sensor (GWS)
- Constant envelope collimator with mid and high layer deformable mirrors
- Piston mirror (PM)
- Dichroic
- FP20 camera
- Mid and High Layer Wavefront sensor (MHWS)
- Cryostat with science detector and Fringe and Flexure tracker system (FFTS)

The wavefront sensing is done at 3 different altitudes separately for the left and right telescope beams. The GWSs control the Adaptive Secondary[8,9], while the MHWSs control the deformable mirrors (DM) in the collimator, these DMs can be adjusted to different altitudes by moving a linear stage. The beam combination follows after the PM and the dichroic inside the Cryostat. A part of the infrared light is used by the FFTS to control with the PM the optical path difference between the two beams.

Since the beam of each telescope arm reaches the instrument bench with a certain angle, it is impossible to do a common field de-rotation for the complete instrument. Therefore each wavefront sensor, the science detector and the FFTS must do the field de-rotation separately.

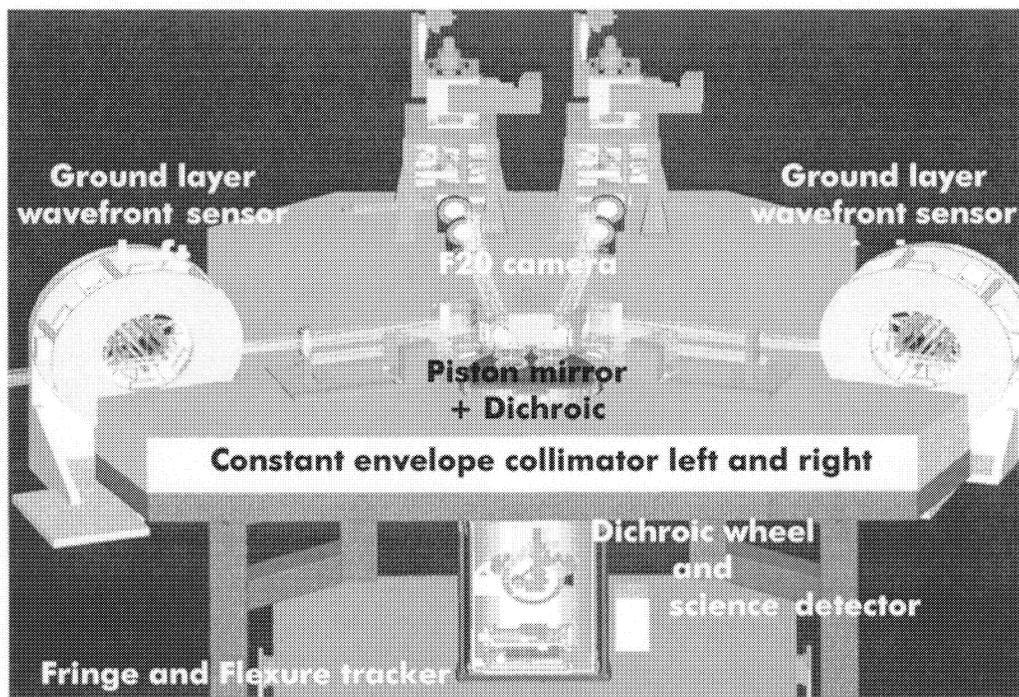## Mid –High-Layer wavefront sensors arm left and right

Figure 3. Overview of LINC-NIRVANA.

3.1 COLLIMATOR AND DEFORMABLE MIRRORS

Deformable mirrors (DM) of an MCAO system are placed in image planes conjugated to certain altitudes. The design of a collimator for such a system as well as the decision on the DM parameters needs special consideration:

- Number of actuators (This is depending on the correction one want to achieve.)
- Pitch size of actuators (Not all kind of pitch sizes are easily available!)
- Overall diameters of optics (Lenses are only available up to a certain size!)
- Selection of altitude and adjustment of DM with different elevation (Fixed or moving DM)

L-N has a constant envelope collimator which allows the use of the same kind of DM over the full range of selectable altitudes. The Figures 4a,b show the difference and advantages of the constant envelope collimator compared to an conventional collimator design.
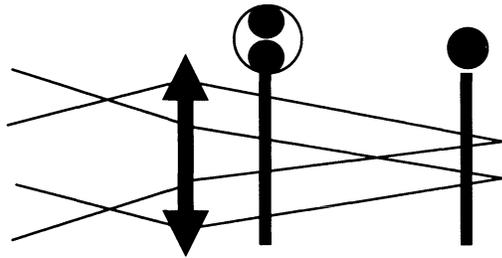
Figure 4a. A conventional collimator design is shown. The image size of the star is constant while the size of the meta-pupil changes. Different pitch size, different mirror size is needed or actuators have to be extrapolated.
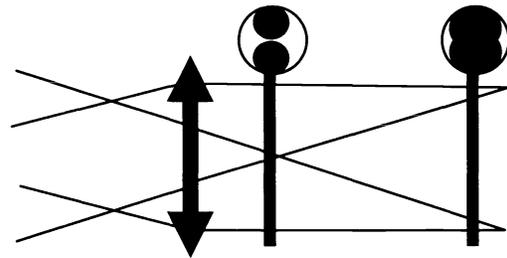
Figure 4b. A constant envelop design is shown. DMs with same pitch and size can be used and moved to different altitudes without loss.

3.2. THE WAVEFRONT SENSORS

Figures 5a and 5b show the GWS and MHWS. The most important parameters of the sensors appear in table 1. The current design of the wavefront sensors is not in the combined beam and uses optical co-addition. We are also studying other solutions, i.e. in the combined beams of the full 23m aperture or with a numerical co-adding. The approach for a
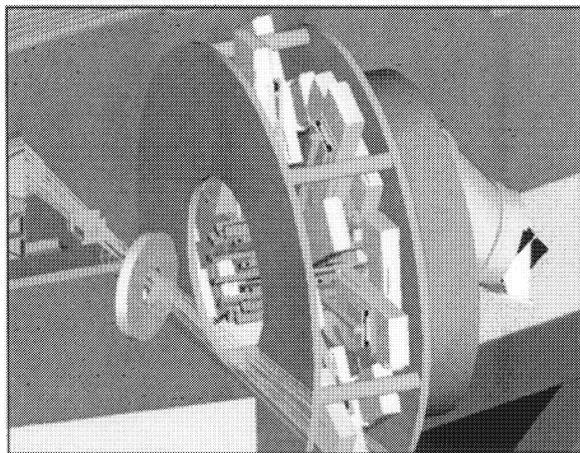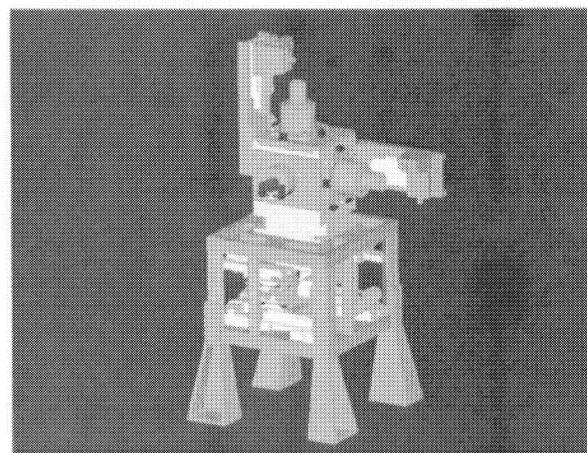

Figure 5a. Ground Layer Wavefront Sensor (GWS).

Figure 5b. Mid and High Layer Wavefront Sensor. (MHWS)

Ground Layer Wavefront Sensor	Mid and High Layer Wavfront sensor
Sensing wavelength 0.6-1 micron	
Pyramid sensor	
Optical co-adding	
12 NGS	8 NGS
Annular FoV 2'- 6'	Central 2' FoV
672 actuators (AO secondary)	349 actuators
CCD50 with 128x128 pixel used with 2x2 (1x1,4x4) binning	

Tabel 1. Parameters of L-N wavefront sensors.

wavefront sensor in the combined beams as shown in Figure 6a would need some camera optics of 6m length folded outside the bench with diameters up to 400mm. Tip-tilt specifications on linear stages are less than 15 microrad over the full travel range. With custom made components it is possible to build such a wavefront sensor.
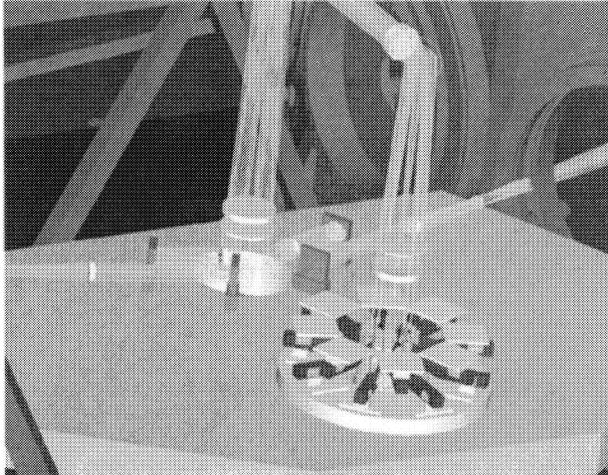

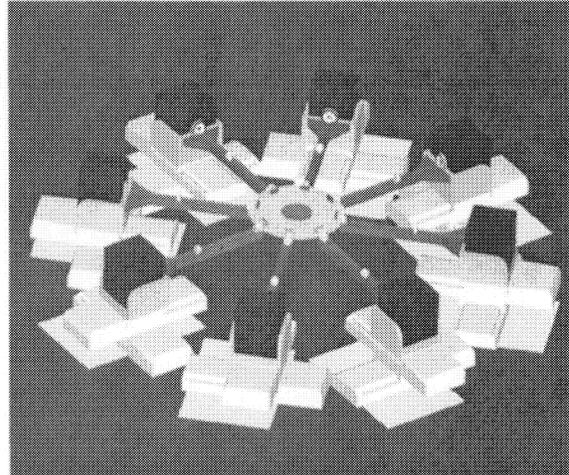**Figure 6a.** Study for a WFS in the combined beam.

Figure 6b. Study for a WFS with numerical co-addition.

The study for the WFS with numerical co-addition would make use of 8 L3CCD[10,11] cameras. L3CCDs are a new kind of CCD with sub-electron readout noise. Although L3CCD cameras are already commercially available, there are some problems still to be solved:

- Low dynamic range in high gain mode
- Statistical error in photon counting mode
- Limited readout speed
- The RON sums also to non negligible values with the number of co-added images.
- Need of more calculation power and electronics

3.3 THE CRYOSTAT

The science instrument is a conventional cryogenic near infrared camera. The most complex component is the FFTS in the lower part of the cryostat. The FFT detector will be able to select guide stars out of field of 1.5'x 1'. The FFTS recovers the optical path difference between the two telescope beams through deconvolution of the guide star PSF. The MCAO system will correct for a FoV of about 2'. To cover the full field there would require 94 HAWAII2 detectors.

Wavelenght range (science/FFT)	J, H, K
Detector (science)	HAWAII2 2048x2048 pixel
Detector (FFT)	HAWAII1 1024x1024 pixel
FoV (science)	11"x 11"
FoV (FFT)	1.5' x 1' (acquisition)
Pixel scale	~5.4"/pix

Table 2. Science detector and FFT parameters.

Figure 7. Cryostat with science camera and Fringe and Flexure tracker

4. CONCLUSION

We are building a Fizeau (= imaging) interferometer for the LBT, using MCAO with NGS. This allows us to test concepts of MCAO also proposed to be used at ELTs. Designing the instrument we are facing similar problems as for building an instrument for a full aperture 23m telescope. L-N will not only use the unique capabilities of LBT but will also be a test bench for instruments and techniques needed aboard ELTs.

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