A visible MCAO channel for NIRVANA at the LBT

R. Ragazzoni[a,b], T.M. Herbst[b], W. Gaessler[b], D. Andersen[b]
C. Arcidiacono[c], A. Baruffolo[d], H. Baumeister[b], P. Bizenberger[b]
E. Diolaiti[e], S. Esposito[a], J. Farinato[a], H.W. Rix[b]
R-R. Rohloff[b], A. Riccardi[a], P.Salinari[a], R. Soci[b]
E. Vernet-Viard[a], W. Xu[b]

[a]Astronomical Observatory of Arcetri, Firenze – Italy
[b]Max Planck Institut für Astronomie, Heidelberg – Germany
[c]Dipartimento di Fisica, Universitá degli Studi di Firenze – Italy
[d]Astronomical Observatory of Padova – Italy
[e]Dipartimento di Astroomia, Universitá degli Studi di Padova – Italy

ABSTRACT

In order to achieve moderate Field of View (2 arcmin in diameter) and nearly diffraction limited capabilities, at the reddest portion of the visible spectrum in the interferometric mode of LBT, two sophisticated MCAO channels are required. These are being designed to perform a detailed correction of the atmospheric turbulence through three deformable mirrors per telescope arm: the secondary adaptive mirror and two commercial piezostack mirrors, leading to an overall number of degree of freedom totaling ~ 3000. A combination of numerical and optical coaddition of light collected from natural reference stars located inside the scientific Field of View and in an annular region, partially vignetted, and extending up to ≈ 6 arcmin in diameter, allows for such a performance with individual loops characterized by a much smaller number of degree of freedom, making the real-time computation, although still challenging, to more reasonable levels. We implement in the MCAO channel the dual Field of View layer-oriented approach using natural guide stars, only allowing for limited, but significant, sky coverage.

Keywords: Adaptive Optics, multi–conjugation, interferometry

1. INTRODUCTION

The Large Binocular Telescope (LBT)[1] is a unique telescope. With having two 8.4m mirrors on the same mounting, implementing interferometry is in principle easier, since much shorter delay lines would be required. Moreover, the baseline is not dramatically larger than the apertures; hence, on–sky measurements are expected to be performed with deconvolution techniques[2] of a three–fringe PSF, rather than by measuring fringe visibility. Of course, the LBT has a smaller final resolution than the other interferometers in its class of apertures, such as Keck and VLTI. The interested reader should refer to the paper by Herbst et al. (Ref.3) for details specific to the attainable science and the interferometric mode. We here focus on the Multi Conjugated Adaptive Optics channels (MCAO) for this telescope. Contrary to what one could think, most of the MCAO channel, and specifically a large fraction of its wavefront sensor, being in the combined beam, is strictly equivalent (and for several aspects, more difficult) than the one required for a single dish telescope with an equivalent maximum size of 22.4m in diameter. The design, from this point of view, represents an interesting enginering exercise for the wavefront sensing part of a next generation Extremely Large Telescope[4,5,6] (ELT) whose aperture, in the range 30 to 100 m in diameter, is not so much larger than the scales considered here.

Send correspondence to R. Ragazzoni – E-mail: ragazzoni@arcetri.astro.it

Adaptive Optical System Technologies II, Peter L. Wizinowich, Domenico Bonaccini, Editors, Proceedings of SPIE Vol. 4839 (2003) © 2003 SPIE · 0277-786X/03/$15.00

2. THE OVERALL LAYOUT

The NIRVANA MCAO incorporates the layer–oriented approach[7,8,9] in its multiple Field of View[10,11] variation. Actually a dual FoV is used. The layer–oriented approach is described elsewhere, but it is useful to recall that it essentially build up a three dimensional anamorphic copy of the atmosphere where detectors and DMs can be placed in order to compensate the turbulence for specific and limited volume of the atmosphere. In NIRVANA aboard LBT, the reimaging volumes are different for the ground, mid and high altitude DMs and they are, moreover, in a different region of the instrument for the wavefront sensing of the two highest layers. Ground layer three dimensional reconstruction is, on the other hand, performed in a virtual way inside a real–time reconstructor. The multiple FoV variant, allows us to sense the wavefront by using sources located in different regions of the sky, thereby enables a much larger set of natural references. This increases the sky coverage. The latter depends ultimately on the degree of achieved correction and on atmospheric seeing conditions.

2.1. The ground–layer loops

An outer, annular FoV ranging from 2 arcmin to 6 arcmin is used to sense and compensate for the ground layer turbulence, using the secondary adaptive mirror[12,13] in the telescope. Each of the two mirrors is equipped with an independent loop for this purpose and whenever the density of stars is large enough, these should cancel or at least strongly attenuate, the ground layer turbulence, where most of the degradation of image quality usually occurs.

The ground layer correction is accomplished by a numerical layer–oriented approach using up to 16 individual pyramid wavefront sensors[14,15,16,17] equipped with the very low noise L^3CCD[18,19], then coadded in a layer–oriented fashion. Because the aim is correction of the ground layer only, such coaddition is simply the average of the whole set of independent wavefront measurements. We adopted the numerical co–addition instead of the optical one for the following reasons:

- Individual stars are, enough bright on average to make irrelevant the small (but non–zero) noise coming from the detectors;
- The relatively large FoV would require, for reasonable pupil size, very fast optics;
- The optomechanical design can be made more compact in a part of the instrument where the available space is particulary small;

Since making a numerical layer–oriented coaddition, star brightness variations will have no impact on the quality of the ground layer correction, and, although the effectiveness of this is questionable on an 8m–class telescope, it could, in principle, provide high resolution data for any layer by superposition (after shifting the pupil images by the proper amount) as requested by the multiple–resolution approach.

In a certain sense, one can conceive the real instrument as starting from the nominal focal plane of the telescope, just after the ground layer–correction. This is, in principle, a favourable condition, because it is expected that most of the turbulence has already been rejected, and the MCAO and interferometric parts of the instrument face an easier task. One should not ignore, however, that including wavefront deterioration, sky coverage, reliability and hence effective attainability of operations on sky, the first ground layer removal, already involves an unprecedently–complex optomechanical system.

2.2. The mid–and high–altitude layer loops

The mid and high–altitude corrections are performed by a couple of commercially available Xinetics deformable mirrors (DM), 349 actuators each, one per telescope arm (i.e. 4 DMs in total). The useful FoV here is limited to the central 2 arcmin. We have choosen an optical configuration with a *quasi*–collimator giving a constant metapupil over the physical size of the controllable portion of the DMs, followed by a *parallelizer* to combine the beams in a single focus. The *quasi*–collimator, in fact, provides slightly diverging beams. Combination of the light coming from the two telescope is impossible within a FoV of any significance, because the star appears to come from two distinct virtual points. The *quasi*–collimator, the DMs and the *parallelizer* have to perform

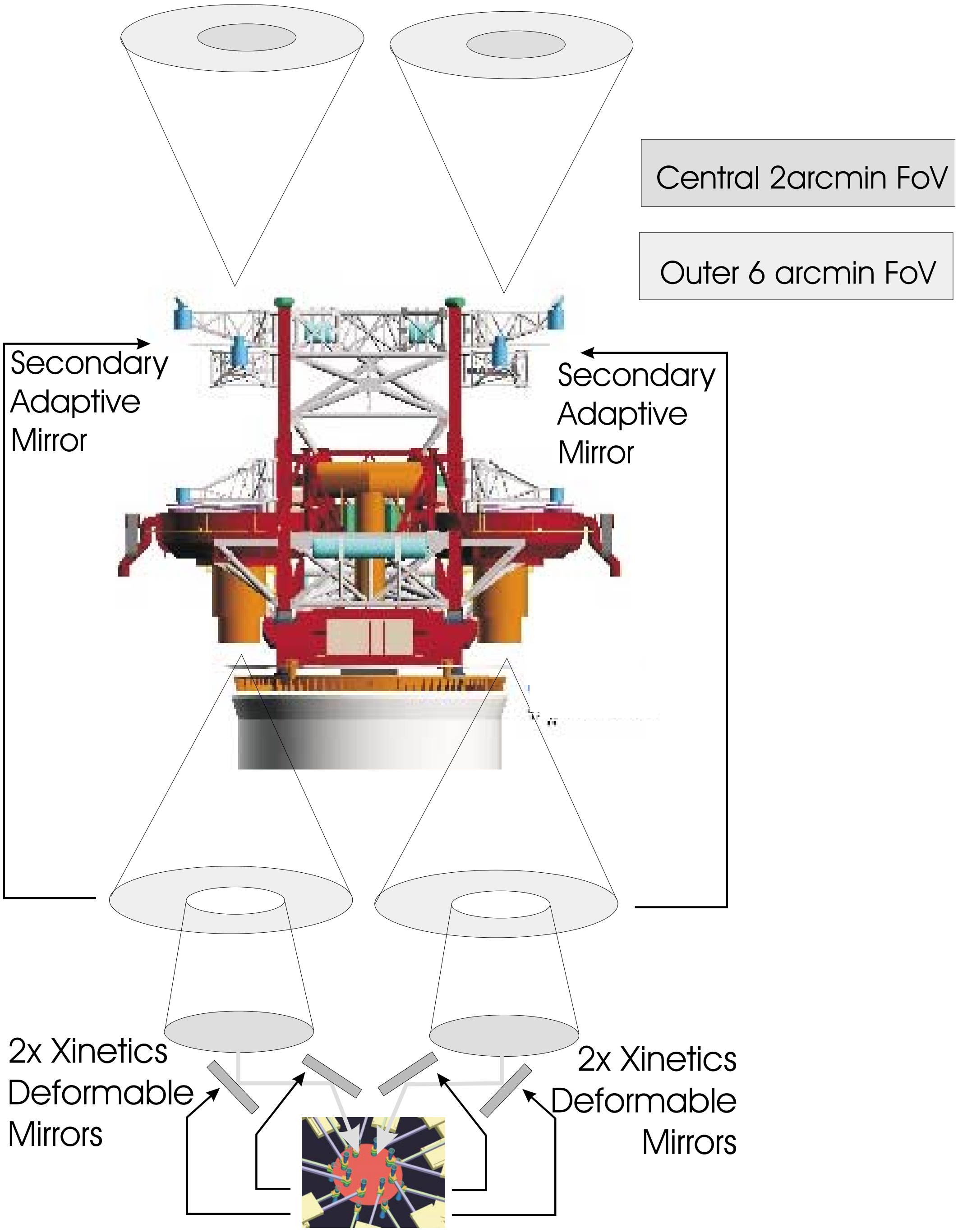

Figure 1. NIRVANA aboard LBT, using the Dual Field of View and Layer–Oriented approach. In this sense, six independent loops are running in the MCAO system, three independently per each mirror; one uses stars lying in an annular FoV whose inner and outer diameters are 2 and 6 arcmin, respectively, and drives the secondary adaptive mirror, conjugated to the ground. The other two loops drive two commercial DMs conjugated to mid– and high–altitude layers; it is noteworthy that, although most of the wavefront sensing part is done in the combined beam, the final wavefront sensing is accomplished by independent detectors, leading to really three independent loops.

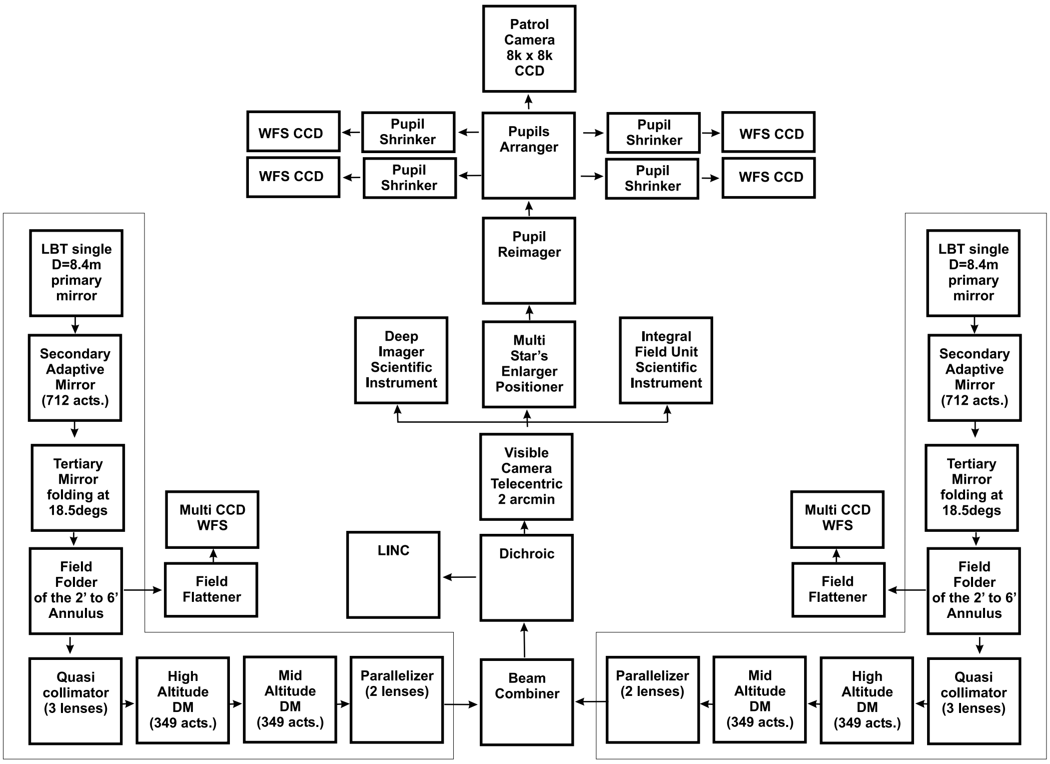

Figure 2. This block–diagram shows the components and optical flow through the NIRVANA instrument and MCAO system.

well over the whole wavelength range used for both technical (i.e. wavefront sensing) and scientific purposes. For practical reasons, we limit ourself to 550nm $\ldots 2.4\mu$m.

Shortly after these components, the beams from the two telescopes are combined and then split into Near Infrared and Visible channels. At the level of the exit pupil the NIR channel is fed into a cryostat to an efficient, background rejecting infrared camera.

From this point on both the NIR and visible optics can be seperately specified in terms of optical quality and aperture. Although optical elements close to the pupil plane will be only partially used, and hence the effective optical quality can be marginally relaxed with respect to the full aperture, all the optics are circular and in ratio to a telescope aperture of full 22.4m diameter.

In the visible channel, a camera will bring the light onto a flat, highly non–telecentric focal plane with focal ratio 60. This focal plane, in fact, will be characterized by the F ratio typical of the single telescope beam, and by the combined one. Conventionally we decided to mantain the notation related to the single beam F ratio. The corresponding focal plane will be denoted FP60. The FP60 plane is the place where some pick–up mirrors could convey some light to scientific cameras exploiting the interferometric capabilities at the visible wavelength.

However, most of the visible channel is actually devoted to wavefront sensing. A set of 16 *star enlargers* are used to magnify the F ration from F/60 to F/400. Each pice is picking up the light of a single star over a limited FoV, in the range of 1 to 2 arcsec, to convey it through a corresponding pyramid to the same pupil image, where the light of several faint stars can be efficiently piled up. The seperation of the stars on the new F/400 focal plane remains the same of the F/60 since the focal ratio is only locally so large. Therefore the new focal plane is characterized by two plate–scales: one for the relative positions of the reference stars, and one

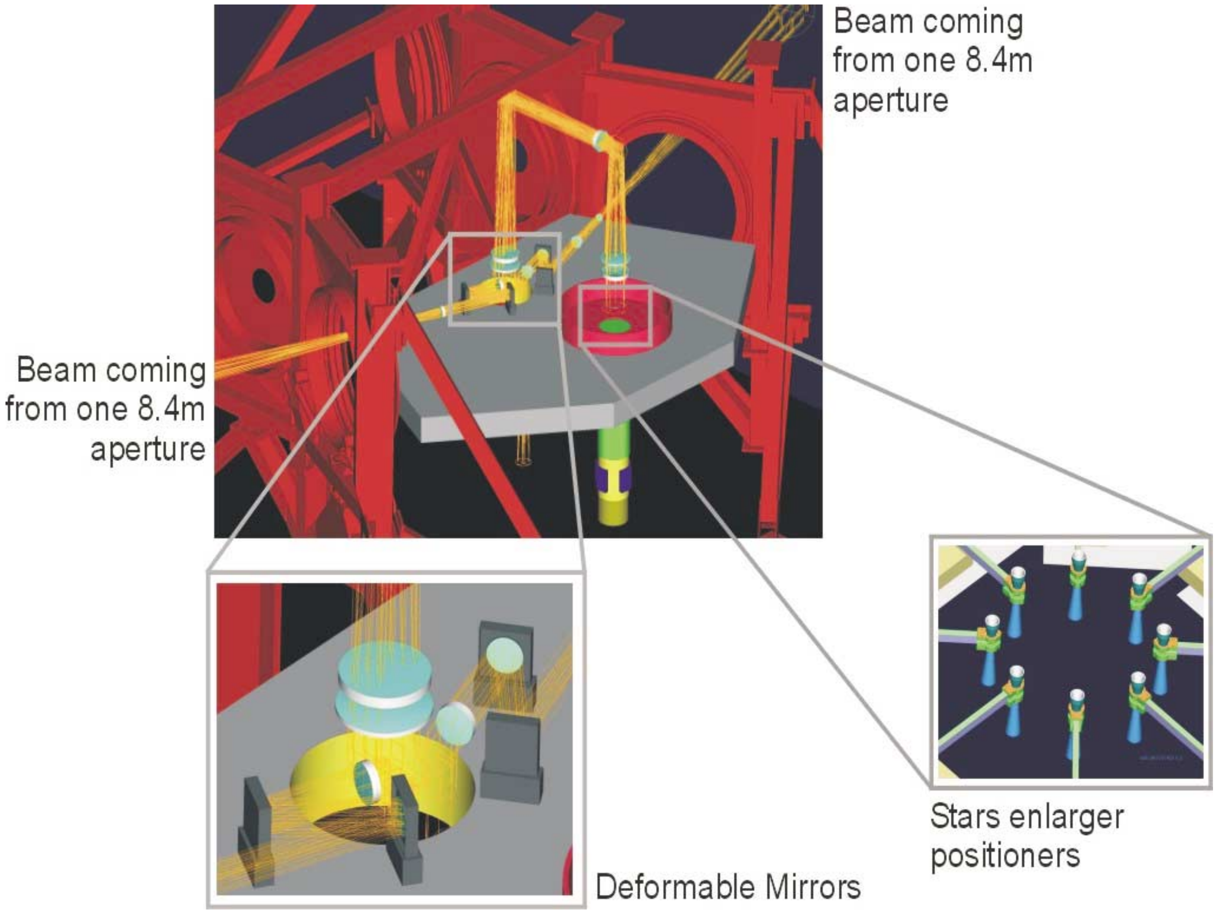

Figure 3. Two enlarged versions of the MCAO part of NIRVANA are visible in this picture.

for the PSF of the single stars themselves (F/400). The pyramids placed in the FP400 split the light into four pupil images containing the first derivative information of the observed wavefront.

A single pupil reimager (essentially a doublet lens) re–form the pupil images with an F/5 focal ratio, as measured in the pupil plane. These pupils are still too large to fit onto the high speed CCDs so, after a re–arrangement by some folding and beamsplitting, they are further shrunk by a factor up to 5 with some very compact optical relays. Note that the pupil re–arrangement is made in such a way that the pupils for a single mirror are conveyed to a single detector, so that each detector–DM pair (altogether 4 pairs) is fully independent.

The pupil images allow, by the introduction of a camera, a relatively fast imager acting on the whole 2 arcmin FoV. We call this the *patrol camera* since it can be used for getting accurate position measurements of the reference stars, as well as for observation of objects in the full interferometric mode. Such a camera, will likely be strongly undersampled, in order to keep the overall number of pixels manageable and affordable.

The reasons why we have chosen for the central FoV sensing in the combined beam an optical co–addition of the light (at least as baseline design) are the following:

- The average brightness of each individual star is significantly less than that for the annular FoV, and, even with the use of L^3CCDs, unless the equivalent readout noise is extremely low, the gain in using the optical coaddition is over the numerical one.
- The optical relay components are affordable, both in size and speed (realistic focal ratio);

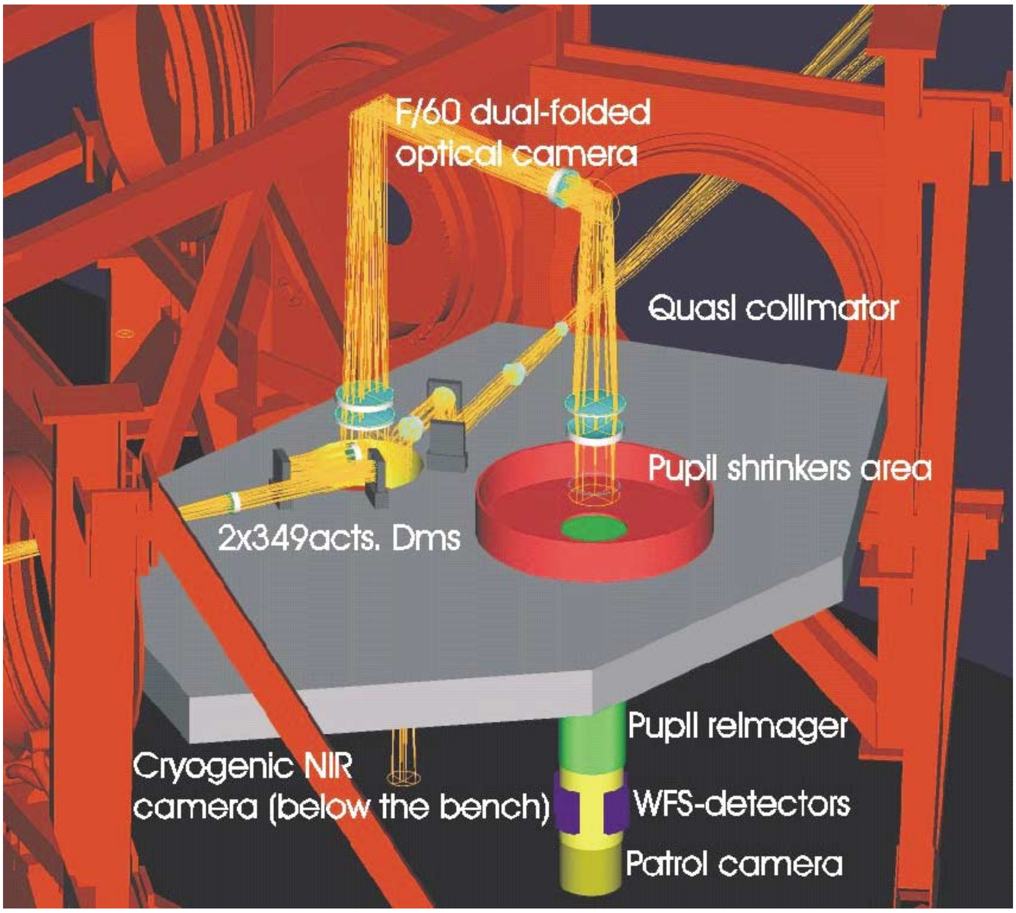

Figure 4. Arrangement of the various optical elements of the MCAO channel in the NIRVANA volume.

Deformable Mirror	Conjugation range	Actuators on pupil	Actuators on meta–pupil
Secondary Mirror	≈ 100m	$\approx 24 \times 24$	$\approx 24 \times 24$
DM2	4...10km	$\approx 12 \times 12 \ldots 16 \times 16$	$\approx 21 \times 21$
DM3	8...15km	$\approx 10 \times 10 \ldots 13 \times 13$	$\approx 21 \times 21$

Table 1. Deformable mirrors and their features, as aboard LBT and NIRVANA.

- The overall number of detectors and related electronics is kept to a minimum, increasing substantially the reliability of an already very complex system;
- Differential tilts, plate–scales, field rotation and distortion are detected directly by sensing in the combined beam, and actions can be pursued to keep these quantities under control;
- The use of conventional CCDs is possible, so the design does not depend upon the development of novel technologies.

On the other hand we note that in the NIRVANA baseline, we are essentially designing both the numerical and optical co–addition modes for the layer–oriented schemes so that, eventually, a configuration switch from one of the two approaches to the other would be relatively easy.

3. CONCLUSIONS

The NIRVANA instrument is now in its conceptual design phase and we cannot exclude significant variation to the baseline design described here. Performance of the instrument[20], is system dependent and relates to the expected median seeing conditions, and are therefore the subject of current study and refinement. The instrument, with both MCAO with NGSs and a visible interferometric mode, incorporates a number of risky features. Care is being taken in order to reduce single point failures and to avoid compromises for the more basic observational modes, which are nevertheless at the leading edge of what one can achieve today. Budget and timeline management clearly depend on the discussed considerations, although the goal is to ship the instrument to the telescope shortly after implementation of the second primary mirror in LBT in late 2005. Finally, we wish to point out that a few precursor projects, including MAD on VLT[21,22], asince they adopt similar technologies, will provide extremely useful experience in order to adjust and finalize the design and implementation of the most novel features on the NIRVANA instrument.

REFERENCES

1. Hill J.M., Salinari P. "Large Binocular Telescope project" SPIE proc. **4004**, 482 (2000)
2. Carbillet M., Correia S., Boccacci P., Bertero M. "Restoration of interferometric images. II. The case-study of the Large Binocular Telescope" A&A **387**, 744 (2002)
3. Herbst T.M., Andersen D., Bizenberger P., Eckart A., Ragazzoni R., Rix H.–W., Rohloff R.–R., Salinari P., Straubmeier C. "LINC/NIRVANA: a Fizeau imaging interferometer for the Large Binocular Telescope" SPIE Proc.**4838**, (*in press*)
4. Gilmozzi R. "Science with 100-m telescopes" SPIE proc.**4005**, 2 (2000)
5. Nelson J.E. "Design concepts for the California Extremely Large Telescope (CELT)" SPIE Proc.**4004**, 282 (2000)
6. Ardeberg A., Torben A., Espinosa J.–M."Euro50: Proposal for a 50 m Optical and Infrared Telescope" Astronomische Gesellschaft Abstract Series, Vol. 18 (2001)
7. Ragazzoni R. "Adaptive Optics for Giant Telescopes: NGS vs LGS" in ESO Proc. vol.57, p.175 (1999) Backascog conf. on Extremely Large Telescopes
8. Ragazzoni R., Farinato J., Marchetti E. SPIE proc. 4007, 1076 (2000) "Adaptive optics for 100-m class telescopes: new challenges requires new solutions"
9. Diolaiti E., Ragazzoni R., Tordi M. "Closed loop performance of a layer-oriented multi-conjugate adaptive optics system" A&A **372**, 710 (2001)
10. Ragazzoni R., Diolaiti E., Farinato J., Fedrigo E., Marchetti E., Tordi M., Kirkman D. "Multiple Field of View Layer Oriented" ESO Conference in Venice on "Beyond conventional Adaptive Optics" (*in press*)
11. Ragazzoni R., Diolaiti E., Farinato J., Fedrigo E., Marchetti E., Tordi M., Kirkman D. "Multiple Field of View Layer Oriented Adaptive Optics" A&A (*in press*)
12. Brusa G., del Vecchio C. "Design of an Adaptive Secondary Mirror: A Global Approach" Applied Optics **37**, 4656 (1998)
13. Riccardi A., Brusa G., del Vecchio C., Salinari P., Biasi R., Andrighettoni M., Gallieni D., Zocchi F., Lloyd-Hart M., Wildi F., Martin H.M. "The adaptive secondary mirror for the 6.5 conversion of the Multiple Mirror Telescope" Beyond Conventional Adaptive Optics ESO COnference (*in press*)
14. Ragazzoni R. "Pupil plane wavefront sensing with an oscillating prism" J. of Mod. Opt. **43**, 289 (1996)
15. Ragazzoni R., Farinato J. "Sensitivity of a pyramidic Wave Front sensor in closed loop Adaptive Optics" A&A **350**, L23 (1999)
16. Eposito S., Feeney O., Riccardi A. "Laboratory test of a Pyramid Wavefront Sensor" SPIE proc.**4007**, 416 (2000)
17. Ghedina A., Cecconi M., Ragazzoni R., Farinato J., Baruffolo A., Crimi G., Diolaiti E., Esposito S., Fini L., Ghigo M., Marchetti E., Niero T., Puglisi A. "On sky test of the Pyramid Wavefront Sensor" SPIE Proc. (*this conference*)
18. Mackay C.D., Tubbs R., Bell R., Burt D., Jerram P., Moody I. "Subelectron read noise at MHz pixel rates" SPIE Proc.**4306**, 289 (2001)

19. Tubbs R.N., Baldwin J.E., Mackay C.D., Cox G.C. "Diffraction-limited CCD imaging with faint reference stars" A&A **387**, L21 (2002)
20. Ragazzoni R., Diolaiti E., Farinato I., Fedrigo E., Marchetti E., Tordi M., Kirkman D. "Sky coverage in layer–oriented adaptive optics" SPIE Proc.**4494**, 52
21. Marchetti E., Hubin N., Fedrigo E., Brunnel J., Delabre B., Donaldson R., Franza F., Conan R., Le Louarn M., Cavadore C., Balestra A., Baade D., Lizon J.–L., Gilmozzi R., Monnet G., Ragazzoni R., Arcidiacono C., Baruffolo A., Diolaiti E., Farinato J., Viard E., Butler D., Hippler S., Amorim A. "MAD the ESO multi-conjugate adaptive optics demonstrator" SPIE Proc. (*this conference*)
22. Vernet–Viard E., Ragazzoni R., Arcidiacono C., Baruffolo A., Diolaiti E., Farinato J., Fedrigo E., Marchetti E., Falomo R., Esposito S., Carbillet M., Verinaud C. "Layer–oriented Wavefront Sensor for MAD: Status and Progress"