Bulletin de la Société Royale des Sciences de Liège, Vol. 74, 5-6, 2005

VIDA: a direct imager for the VLTI and a first step toward hypertelescopes

O. Lardière[1], F. Patru[2], F. Martinache[3], V. Borkowski[1] and D. Mourard[2]

[1] LISE - Collège de France, Observatoire de Haute-Provence, France
[2] Département GEMINI, Observatoire de la Côte d'Azur, France
[3] Department of Astrophysics, Cornell University, USA

Abstract: The next step in stellar interferometry will be the transition from "pairwise interferometry" providing visibility measurements to direct imaging with large cophased multi-aperture interferometers. If the VLTI telescopes are cophased, Cerro Paranal becomes a unique site where direct imaging could be tested and validated, before the construction of larger cophased arrays as hypertelescopes or ELTs. For these reasons, a direct imager has been proposed for the next generation of VLTI instruments.

1 Introduction

The next step of stellar interferometry will be the transition from current small coherent arrays to large cophased arrays. Direct snapshot imaging with an all-to-one beam combiner seems to be the natural and the simplest way to observe with large cophased arrays (Martinache & Lardière, 2005) (fig. 1).

A *densified pupil* or *hypertelescope* imaging mode can concentrate more light into the high-resolution Airy peak than the Fizeau mode, providing more luminous images without field loss (fig 2). This technique has been validated on the sky at small scales (Pedretti *et al.* 2000, Gillet *et al.* 2003), but a new demonstrator working on an existing interferometer seems necessary. For this reason, a direct imager (VIDA) has been proposed for the VLTI second generation instrumentation (Lardière *et al.* 2005a) in order to:

- exploit the unique full VLTI infrastructure (8 telescopes, AO, FSUs...),
- validate the pupil densification on sky at a larger scale,
- propose long-exposure direct imaging in JHK bands with snapshot capability, high sensitivity (K=20) and high dynamic-range (for coronagraphy),
- open new scientific fields for interferometry, as faint extragalactic sources and exoplanet direct detection and analysis,

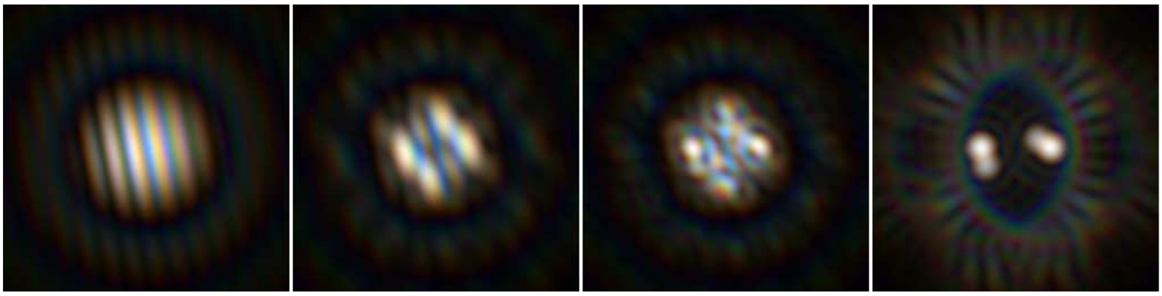

Figure 1: VIDA: a transition from fringe visibilities to direct imaging. From 3 decades, two-aperture interferometers provide fringes helping to constrain the object model (1^{st} image), but the VLTI could now deliver direct images of the object if its 4 or 8 telescopes are cophased simultaneously (2^{nd} and 3^{rd} images respectively). Future larger arrays, such as a hypertelescope involving 39 telescopes, will provide very high quality images (last image). The object considered is a quadruple star system.

- prepare science and technology of future large cophased arrays as Carlina-like (Borkowski *et al.* 2005b) or OVLA-like hypertelescopes (Lardière *et al.* 2005b) or even Extremely Large Telescopes (ELTs).

Finally, the VIDA proposal is a return to a more conventional imaging telescope. Actually, VIDA will work as an ELT, but with a field limited to N^2 resels (resolution elements) due to the gaps of the u-v coverage (Martinache & Lardière, 2005).

2 The concept of VIDA

VIDA is a direct imager for the near-IR using an all-to-one beam combiner involving single-mode fibers. Fibers offer a convenient solution for the beam combination as well as for the pupil remapping and densification (Patru *et al.*, 2005).

The most constraining requirement is the beam cophasing: a $\lambda/10\,rms$ accuracy is enough for standard imaging, but $\lambda/120\,rms$ or better are required for coronagraphy. To meet this last requirement, an internal accurate Fringe Sensor Unit (FSU) is planned to aid the VLTI FSUs (FINITO, PRIMA). A focal-plane FSU seems more interesting for multi-aperture interferometer than a conventional pairwise FSU. Two approaches are under study: the *Dispersed Speckle* FSU (Borkowski *et al.* 2005a) and the *Phase retrieval* FSU (Cassaing et al. 2005).

The optical layout of the VIDA instrument is shown on figure 3 and consists in six main subsystems:

- injection modules,
- fiber beam combiner and densifier,
- internal accurate FSU for coronagraphy,
- coronagraph (removable),
- differential static delay lines for dual-feed imaging,
- focal instrumentation (spectro-imager).

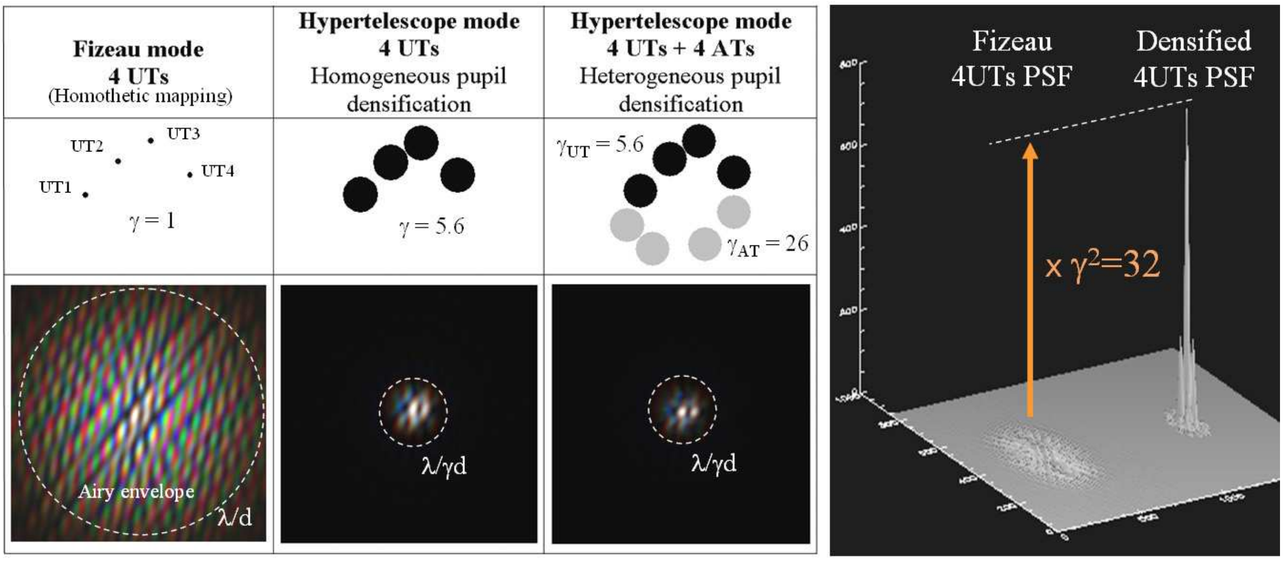

Figure 2: Direct images of a binary star obtained with the VLTI in the Fizeau case and in the Densified-Pupil case. The Fizeau PSF is spread over λ/d in numerous speckles. A complete pupil densification (the densification factor γ is 5.6 with UTs) concentrates all the flux into the field accessible by the baselines in one observation ($\approx 4 \times 4$ resels), providing an intensity gain of the central peak equal to $\gamma^2 = 32$ with 4 UTs. ATs can be advantageously coupled to UTs thanks to a heterogeneous pupil densification.

3 Expected Performances

Thanks to the snapshot imaging capability, VIDA offers unprecedent performances to the VLTI, especially for the sensitivity and the dynamic-range.

3.1 Sensitivity

The following table shows the limiting magnitude per one square resel (*i.e.* $3.5mas^2$ in K) in imaging mode with 4 UTs or 4 ATs (SNR=10 in 10s). VIDA is significatively more sensitive than other current VLTI instruments ($K = 20.5$), simply because 70% of the flux falls in the central peak. These results are easily predictable by considering VIDA as a 130-m telescope for the angular resolution, and as a 16-m telescope with a 2% throughput for the collecting area.

	Imaging	Spectro-imaging		
		R=100	R=1500	R=30000
4 UTs	20.5	17.6	14.6	11.4
4 ATs	17.5	14.2	11.3	8.1

3.2 Coronagraphy and PSF contrast

If there are no phase errors and if the star is a point-like source, a phase mask coupled to a pupil remapping and apodization provide a total star extinction (fig. 4). The Lyot coronagraph is an alternative solution for partially resolved stars.

A PSF contrast of 10^{-3} is expected with a cophasing accuracy of $\lambda/120$ *rms* and photometric fluctuations between beams lower than 15% (MACAO and IRIS specifications). In such

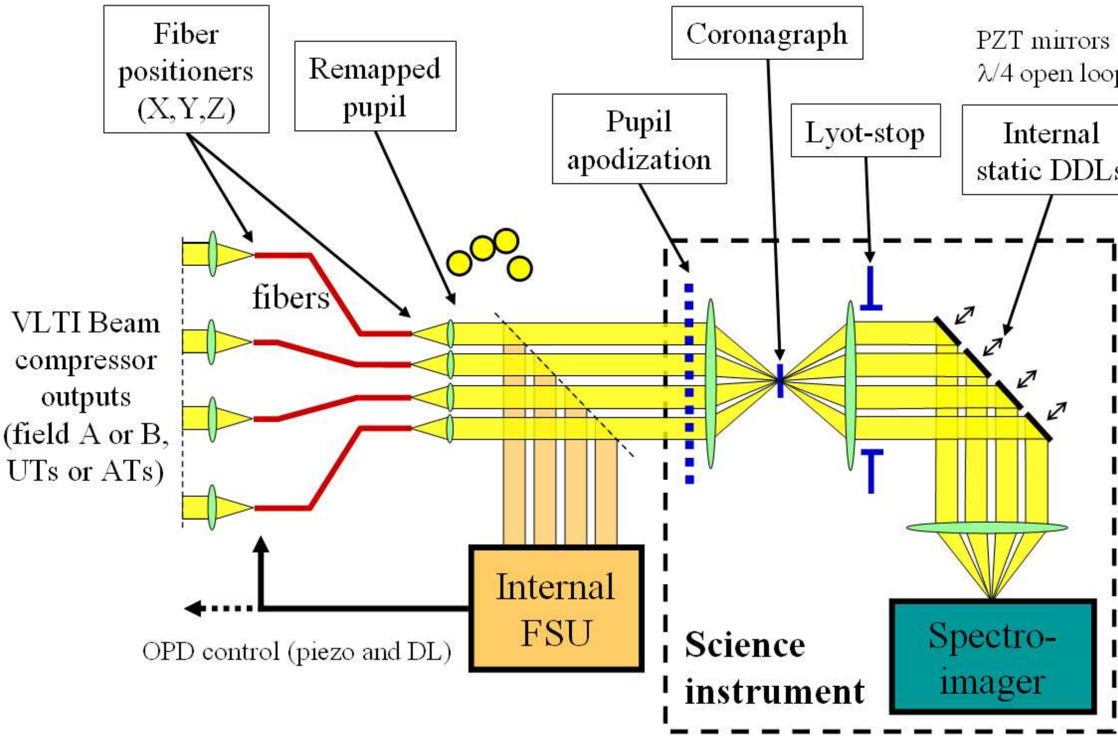

Figure 3: Schematic optical layout of the instrument VIDA.

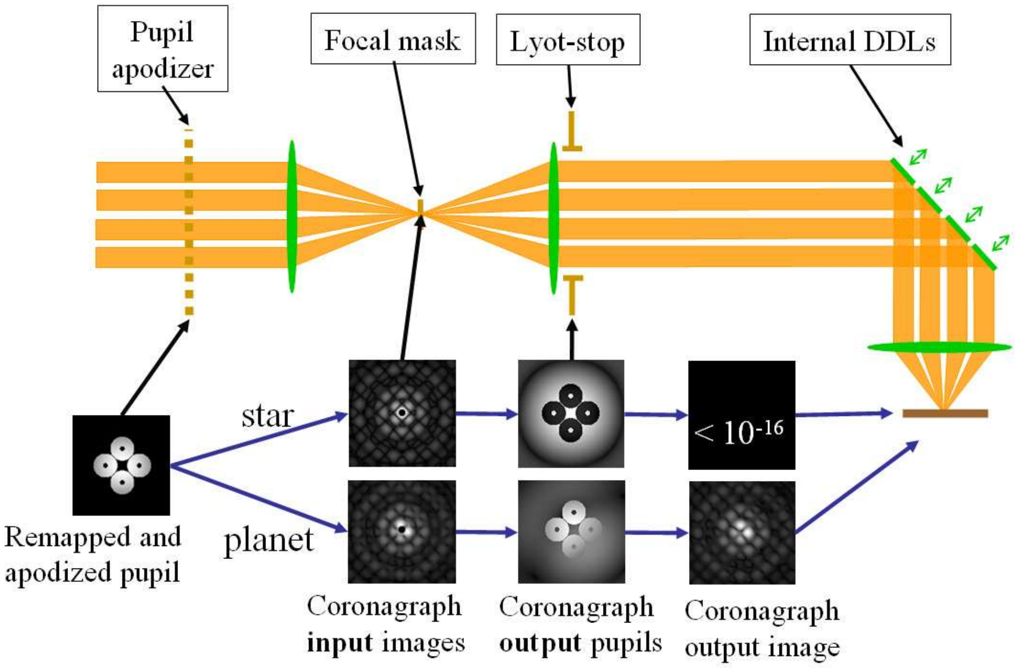

Figure 4: Coronagraphic channel of VIDA

conditions, direct detection of hot jupiters is then possible after 1-hour integration. This result assumes that the photon noise dominates the speckle noise as in differential imaging mode (Chelli 2005).

4 Conclusions

If the VLTI is cophased, direct imaging becomes natural and simpler than closure phase technique. For this reason, VIDA, a direct imager, is proposed for the VLTI next generation instrument. The performances of VIDA (field, limiting magnitudes, etc.) will be mainly limited by the VLTI itself, *i.e.* the small number of telescopes involved. However, VIDA seems to be a mandatory step to go from classical "pairwise interferometry" towards larger cophased arrays able to provide direct images of extended sources, as hypertelescopes and ELTs (fig. 1). The main objectives of VIDA are actually to :

- demonstrate the feasibility and the advantages of the direct imaging on an existing large interferometer.
- offer new capabilities on the VLTI as snapshot imaging, high sensitivity, high dynamic-range, differential astrometry, etc.,
- prepare the key-technologies of future arrays (multi-beam FSUs, all-to-one beam combiners),
- prepare the science of future interferometry (exoplanet detection and analysis, faint extragalactic sources...),
- try to demystify interferometry in the astronomical community (the interferometer is now presented as a more conventional telescope).

Acknowledgements

The authors are very grateful to the whole working group involved in the VIDA concept study made in the EII/OPTICON-JRA4 framework: J. Schneider, P. Antonelli, L. Arnold, D. Bonneau, Y. Bresson, M. Carbillet, F. Cassaing, O. Chesneau, J-M. Clausse, J. Dejonghe, L. Delage, A. Labeyrie, S. Lagarde, B. Lopez , L. Mugnier, F. Reynaud, G. Rousset, A. Schutz, Ph. Stee and A. Spang.

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