SECOND GENERATION INSTRUMENTATION FOR THE VLTI: THE FRENCH VLTI CONNECTION

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Abstract. We describe the current French ideas for the instrumentation of the second generation of the VLTI. Instruments concepts addressed include: integrated optics beam combiner, extension of MIDI to a four beam facility, extension of AMBER to the visible and a densified pupil direct imaging beam combiner.

Keywords: VLTI, instrumentation

1. Introduction

After more than ten years of development, the European optical long baseline interferometer (the VLTI) is gradually reaching its full performances with the scheduled commissioning in 2003 of a large number of main subsystems: focal instrument MIDI for the 10 μm band, focal instrument AMBER for the near infrared and the three telescopes mode, adaptive optic devices MACAO for the UTs, fringe sensor unit FINITO.

As such, the VLTI will become one of the very first interferometric facility in the world. A very high quality and quantity of astrophysical results could be certainly expected in the coming years. New extensions are soon foreseen like a dual field facility (PRIMA) that would allow astrometric measurements with a spatial resolution of the order of a few tens of micro arcseconds. This will also allow to increase the limiting magnitude of the first generation focal instruments by the use of the technique of the phase reference imaging. Also, a demonstrator of nulling interferometry (GENIE) is under study in the framework of a collaboration with the European Space Agency concerning the preparation of the Darwin mission.

During the June 2001 workshop about the second generation of instruments for the VLT/VLTI, ESO has concluded about two main priorities for the development of the VLTI: an imaging mode with 6 to 8 beams and an extension to the shortest wavelengths (visible band). In both cases, the French community has brought some original ideas that should be discussed in the European astronomical community. Among these, we will describe in more details the following actions: **IONIC-**

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VLTI (integrated optics beam combiner) **APRES-MIDI** (extension of MIDI to a four beams facility) **VINI** (extension of AMBER to the visible band) **VIDA** (densified pupil direct imaging beam combiner). Other actions have been started during the last two years in the context of the 'Action Spécifique Haute Résolution Angulaire' from INSU/CNRS and of the 'Jean-Marie Mariotti Center'. Different working groups have started to work on systems or software aspects especially in the domain of interferometric imaging.

2. IONIC-VLTI

With milli-arcsecond spatial resolution, many scientific topics like dust torus around AGN, disks around young stars, envelopes around AGBs, require imaging. The current VLTI instruments (AMBER and MIDI) give access to information at high angular resolution, yet without actual imaging. Since as a rule of thumb, the image quality accessible with an optical interferometer is roughly proportional to the number of telescopes used simultaneously, the more the apertures, the better the reconstructed image. We propose (Malbet et al., 2002) the interferometric beam combination of N telescopes (N between 4 and 8) thanks to the integrated optics technology: four 8-m telescopes in the short term and/or eight 1.8-m telescopes in the long term. The goal is to have access to an instrument whose image quality is equivalent to the one achieved with millimeter radio interferometers with a spatial resolution better than the one foreseen with ALMA, in the visible and/or in the near infrared. This instrument would be able to acquire routinely images with 1 mas resolution with a 13- to 20-mag sensitivity in the NIR with a spectral range from 0.5 to 2.5 microns. The high accuracy achievable with integrated optics on visibility amplitude and phase measurements allows to reach high dynamic range even on faint objects.

Components able to recombine up to 4 beams have been tested on the sky, first at the IOTA interferometer and recently on the VINCI test instrument on the VLTI. The main competitors of the VLTI are the Keck interferometer with two 10-m telescopes and four 1.8-m outriggers and CHARA with six 1-m telescopes. We could also cite the experimental program OHANA that will combine the large telescopes at the Mauna Kea summit. However only the VLTI will be able to combine 4 telescopes of 8-m class placed in the best configuration for imaging to achieve accurate investigation of extra-galactic objects, if a imaging instrument is developed soon. Following our experience in interferometry and the VLTI already existing infrastructure, we propose a strategy in two stages.

In the short term, an imaging instrument for the main array (4 UTs) working from 0.8 to 2.5 μm. The required infrastructure is limited: 4 adaptive optics already funded, 4 delay lines among the six that will be installed, 1 additional fringe sensor.

In the long term, an imaging instrument for the extended array with possibly 8 telescopes (additional ATs or combination of ATs with some UTs) working from

0.6 to 5 μm. The required infrastructure is bigger: additional telescopes with a total of 6 to 8 ATs, a total of 8 delay lines, adaptive optics for the ATs if extension to the visible domain, and a cophasing instrument (IO technology?). A full system study is needed to determine the best development strategy including the fringe tracking.

3. APRES-MIDI

This proposition is not really a second generation instrument. It could be developed as an upgrade of the MIDI beam combiner in order to extend its astrophysical and imaging capabilities. A group in France is currently studying an optical concept aiming at recombining 4 telescopes beams (Lopez et al., 2002). Interference fringes are sampled in the pupil plane. Such a principle is perfectly adapted for reconstructing images by aperture synthesis at 10 μm with the VLTI. This principle could be used for building a new generation 10 μm instrument, but instead of doing a totally new instrument, we propose the design of an optical module that can supply the current MIDI-VLTI instrument with 4 beams.

One of the major interest of the mid infrared band like the 10 μm domain concerns the study of the dusty environments in a wavelength domain where warm dust grains radiate efficiently. The research in several currently relevant astrophysical program will strongly benefit of interferometers operating in the mid infrared and aiming at producing images. These programs concern: the study of the geometry of dust torii in active galactic nuclei, the study of dust disc characteristics surrounding the young stellar objects, the study of the morphology of the circumstellar environments embedding late type stars. The 10 μm window being very well adapted to the mapping of the aerial surrounding various type of astrophysical sources and being not much employed by astronomers up to now due to a lack of facilities, many new results could be expected in the fundamental programs mentioned above. Aside from the study of dusty media, the observation of gaseous envelopes like those surrounding hot Be stars, as well as the observation of stellar atmospheres and the study of low mass companions in binary system are astrophysical topics that will strongly benefit also from 10 μm interferometric observations.

The expected sensitivity of APreS-MIDI is equivalent to the one of the MIDI instrument (Lopez et al., 2002). MIDI is presently under commissioning at ESO at its effective sensitivity will be known after the full operability of the VLTI and of MIDI will be achieved. The theoretical sensitivity of MIDI corresponds to a coherent flux of N = 4 (about 1 mJy – 10 sigma detection above noise) using UTs and without the assistance of the external fringe tracker (Leinert et al., 2002).

4. VINI

AMBER is the near infrared instrument installed in the VLTI focal laboratory. There, it benefits from the general interferometric infrastructure on Paranal. Three telescopes are selected among the 4 UTs and the 3 ATs available. For each telescope the wavefront errors are partially corrected by the MACAO Adaptive optics on the UTs and to tip-tilt correction on the ATs. The beams are transported through delay lines used to equalize the optical path difference, which is stabilized by a fringe tracker. A star separator and differential delay lines allow to use an off axis reference star, up to 1 arc minute away from the science source, for wavefront and fringe sensing . Originally, one of the (lower priority) design criteria for AMBER was an easy extension to the red wavelength, at least around the Hα line. The key idea was that Adaptive Optics and a focal instrument efficient in the K band with 8 m telescopes ($D/r0 = 11$) would be well adapted to observations in the red with 1.8 m telescopes ($D/r0 = 12$). The original proposal included adaptive optics system in the focal laboratory usable in the infrared with the UTs and in the red with the ATs. After the Concept Design Revue, the work was concentrated on the infrared instrument, but at least at a preliminary analysis level, the extension to the R band remains possible.

In general terms the interest of a visible instrument compared to an infrared one is that (Stee et al., 2002) visible and near-IR interferometry are complementarity. For example, both infrared and optical interferometry are often required for detailed radiative transfer modelling. Also the spatial resolution is 2 times better than in J and 4 times better than in K, which is decisive for many sources. Then the astrophysical signal produced by many processes is substantially stronger in the visible. For exempla, the optical emission lines of Be star envelopes and of the AGN BLR are much stronger than the corresponding IR lines. It is also much easier to have a higher spectral resolution in the visible. If one accepts the same size constraints than for the infrared AMBER spectrograph, the limiting spectral resolution in the visible is of the order of 40000, which is the kind of resolution needed for real progress in stellar activity studies. And last, the detectors in the visible remain substantially more efficient. In particular, photon-counting detectors with fair quantum efficiency now exist and further progress is expected.

The main scientific cases for a visible extension of the VLTI concern the following programs: distance scale in the Universe with the Cepheids stars, Active Galactic Nuclei, Stellar activity, Stellar rotation and orientation axes, Binary and binary formation and evolution, Circumstellar material, Miras stars.

Originally the idea was an extension of the AMBER focal instrument but discussions are currently in progress in order to merge the different propositions and to design a full capabilities imaging second generation instrument working from the visible to the near infrared wavelengths.

5. VIDA

Only in the recent years did it has been realized that multi-aperture interferometric arrays could provide direct snapshot images and coronagraphic images in a non-Fizeau mode. Whereas homothetic mapping of entrance pupil to exit pupil is useless when the aperture is highly diluted, a 'densified-pupil' or 'hypertelescope' imaging mode can concentrate most light into a high-resolution Airy peak. In addition to the luminosity gain, there is a contrast gain particularly valuable for stellar coronagraphy and exoplanets finding. The current VLTI is able to combine light from two telescopes coherently. In subsequent phases, a combiner is planned for applying closure phase with up to eight telescopes (UT and AT). The small number of apertures currently considered at the VLTI, does not take full advantage of hypertelescope imaging, but still performs significantly better than other observing modes (+3.8mag gain in comparison with Fizeau mode (Lardière et al., 2002)). We propose some possible optical scheme for a densified-pupil combiner for the VLTI (Lardière et al., 2002). Beyond its science value, the proposed instrument can serve as a precursor for many-element post-VLTI hypertelescopes.

The pupil densification consists in enlarging each sub-aperture by the same factor, their centers pattern being kept invariant. This densification factor is defined as $\gamma_d = (do/Do)/(di/Di)$, where di and do are the diameter of each aperture element before and after the pupil densification respectively and Di and Do are the array size before and after the pupil densification respectively. After pupil densification, the central interference peak of the focal image is intensified by a factor ${\gamma_d}^2$, whereas the FOV diameter is divided by γ_d. Indeed, the usable field of the hypertelescope, called 'Zero Order Field' (ZOF), has an angular radius of $\lambda/((\gamma_d - 1).di)$ on the sky, where λ is the wavelength.

The optimal amount of pupil densification is thus a trade-off between the image intensity and the FOV and this trade-off should be considered with respect to the scientific cases that could be covered by such a direct imaging instrument.

It appears also possible to increase the accessible field of view by using an array of pupil densifiers spaced by λ/di. The use of integrated optics systems and/or optical fibers should simplify a lot the design and fabrication of such complex beam combiner.

6. Conclusion

There is a strong interest of the French community for an imaging second generation instrument for the VLTI. The development of such an ambitious project is conditioned by a certain number of steps. The problematic of interferometric imaging could progressed a lot with short terms studies like IONIC-4T and APRES-MIDI.

We are now starting the definition phase of the second generation instrument taking into account the scientific potential of the current instruments, the unique potential of the VLTI infrastructure and of course the most promising scientific cases as well as new conceptual ideas in the field of long baseline interferometry.

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