Second-generation VLTI Instruments: a First Step is Made

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As the VLTI continues its successful science operations with the first scientific instruments, MIDI and AMBER, plans are already under way for the horizon beyond 2010. To maintain the VLTI at the top of the international competition, a next generation of instruments is being evaluated: more versatile, more complete, but also more complex and technically challenging. Phase A studies for three candidates have just started, and we provide here a brief summary of their characteristics.

It took the work of dozens of engineers and astronomers, a decade of planning, design and testing, hundreds of thousands of lines of code, the (occasionally unorthodox) use of telescopes from 40 cm to 8.2 m in diameter, and a lot of sweat in the dry Paranal air. But the goals set back in the nineties, to make interferometry a standard technique at ESO and make the VLTI the most powerful facility of its kind in the world, have been achieved. To be sure, some problems remain, mainly in the form of unwanted vibrations: a lot of work has been devoted to this, particularly by the so-called Interferometric Task Force, and several solutions are being considered. But it is undeniable that the VLTI constitutes today the term of reference for interferometry, in terms of sensitivity, angular resolution and accuracy. The 8.2-m Unit Telescopes and the movable 1.8-m Auxiliary Telescopes represent a unique combination of large collecting areas and long, flexible baselines which remains unmatched not just in performance but also in ease of operation. The two facility instruments, MIDI and AMBER, are offered to the community and carry out routine observations both in visitor and in service mode. Altogether, about 80 interferometric proposals are received at ESO in each semester, totalling approximately 10 % of the Paranal scientific requests. MIDI is a unique mid-infrared beam combiner, and it can be fairly said that each observation with this instrument is the first of its kind for any given astronomical target. AMBER is unique in its ability to combine beams from three 8-m telescopes at a time, providing so-called closure phases which are a key to measure not just the size of a target but also its asymmetries and rough geometrical appearance. Both instruments are equipped with the possibility of generous spectroscopic dispersion. Counting in also the very prolific production from the previous VINCI test instrument, the VLTI has generated already in its commissioning period and early scientific operation many dozens of refereed papers, dominating the relatively restricted field of interferometric results world-wide.

One might think that all this is reason enough to lay back for a moment and enjoy the fruits of a long effort: nothing could be further from the truth. In its resolution on scientific strategy of December 2004, with the first scientific results from the VLTI in hand, the ESO Council sanctioned that it was a priority to exploit the unique capabilities of this facility. Faithful to this directive, a Workshop was organised in Garching in April 2005, among other things to identify the ideas and visions in the community about the development of interferometry at Paranal. At this venue, nine technical and instrumental concepts were presented. These were evaluated by the ESO STC, which recommended to study a subset of them. Four instruments were subsequently investigated, and at their meeting of October 2005 the ESO STC praised their scientific potential but recommended further optimisation of synergies as well as a formal call for proposals. This was done, and finally in April 2006 three second-generation instrumental concepts for the VLTI were formally introduced: MATISSE, VSI and GRAVITY. ESO STC recommended to go ahead with Phase A studies, and these started in June 2006 with an expected duration of about 15 months.

MATISSE is the natural successor to MIDI. It will cover the 10 micron spectral window as does the latter, but additionally extend coverage to the *L*-, *M*-bands (3 to 5 microns) and possibly the *Q*-band at 20 microns. Especially the shorter wavelengths are an interesting addition, since they are not covered by the first-generation instruments and in fact by almost any other interferometer. MATISSE will combine four beams, which represents an enormous jump from MIDI with two baselines only: this will yield six baselines simultaneously (MIDI only one) and provide three closure phases, providing the first-ever possibility of interferometric imaging in the mid-infrared. Of course, caution has to be taken, as with all optical interferometers, that here imaging means the simple combination of a limited number of visibilities and phases in Fourier space, and would not be at the level of quality we are used to from radio interferometers. Nevertheless, this represents a quantum step in optical interferometry observations. Scientific objectives are a natural continuation of those of MIDI, with a focus on cool dusty environments in many classes of stars and including the challenging goals of AGNs and exoplanets. With MATISSE, it would be possible to add substantially more information on the geometry and spatial distribution of the dust.

VSI is the natural successor to AMBER, from which it adopts many design aspects including the use of monomode fibres as spatial filters to clean the wavefronts from high-order perturbations before achieving interference. VSI represents an evolution of AMBER in the number of beams, which would be boosted from the current three to four or even six (this being the maximum number allowed by the VLTI delay lines). Remembering that the number of baselines and closure phases increases approximately with the square of the number of beams, the advantage is obvious especially concerning the imaging possibilities of this instrument. With six beams, VSI would provide simultaneously 15 baselines and 10 closure phases, compared with 3 and 1 respectively for AMBER. Another innovative aspect, currently under evaluation, could be the use of integrated optics for beam combination, i.e. replacing large bulk optics with a single stamp-sized optical chip. This has an obvious advantage for the alignment and the stability of the instrument, as well as opening up the possibility of adding beams in a quasi-modular fashion. As in the previous parallel between MATISSE and MIDI, the science goals of VSI would also follow closely in the footsteps of AMBER, with the additional important goal of increasing dramatically the amount of information on the geometry and the spatial distribution of the sources.

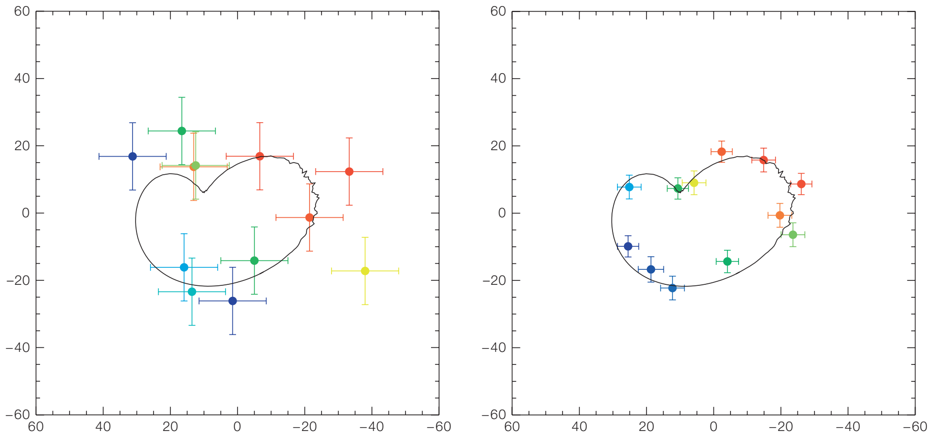

Figure 1: Simulated GRAVITY observations (axes in μas) of a hot spot orbiting the Galactic Centre black hole at a few Schwarzschild radii (RS ~ 9 μas). **Left:** Already a single observation of a flare will allow us to trace the overall motion at high significance. **Right:** Combining the data from several flares will reveal general relativistic effects (e.g., multiple images from lensing), probing the space-time around the supermassive black hole (Eisenhauer et al. 2005, Paumard et al. 2005).

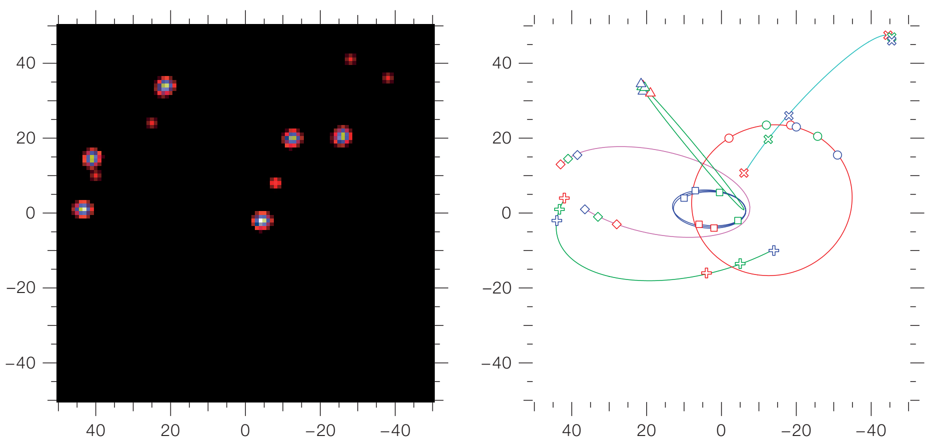

Figure 2: Simulated GRAVITY observations (axes in mas) of the stars in the central cusp of the Galactic Centre. **Left:** Image of the innermost 100 mas of the Galaxy as seen with GRAVITY in a nine-hour observation with the 4 UTs. Noise has been added to the visibilities and phases, and the image has been synthesised and deconvolved using the standard CLEAN algorithm. **Right:** 15 months of astrometry using the image synthesis technique allow tracing the orbits of the stars. Several stars have completed at least one orbit, exhibiting periastron shifts from relativistic effects and from the extended mass distribution in the Galactic Centre (Eisenhauer et al. 2005, Paumard et al. 2005).

GRAVITY is, in a sense, the new kid on the block. It is born out of the need to address a brand new observational mode, i.e. the ability to perform extremely accurate astrometric measurements on very faint sources. Interferometers can perform narrow-angle astrometry, by using a nearby reference source and measuring “the number of fringes” between the reference and the target. This concept is used for example in PRIMA, another VLTI development which is well underway and which will permit us to use a nearby bright star to either make observations of faint scientific targets, and/or to perform astrometry with a goal of 50–100 microarcseconds. However, the ultimate accuracy of the astrometric measurements depends, among other things, on the angular distance between target and reference. PRIMA is designed to cover distances up to one arcminute, and the beams pointing to the target and the reference are separated upstream in the optical train, close to the telescopes. GRAVITY proposes to separate them downstream instead, close to or inside the instrument. This will limit the possible angular distance to less than 2 arcseconds, but will in turn permit much higher astrometric accuracy, up to 10 micro-arcseconds. The main goal, though not the only one, is to investigate the motion of stars very close to the Sgr A* source in the Galactic Centre (see Figures 1 and 2), which is normally accepted to be a massive black hole based on evidence obtained at various wavelengths but without very high angular resolution. GRAVITY would go far beyond, by observing the relativistic effects in the orbits of the stars around the black hole and permitting the direct estimation of the BH mass as well as other parameters.

All these three instruments have exciting scientific goals, and represent significant improvements over the first-generation AMBER and MIDI. However, they also imply a number of technological challenges. Just to name one as an example, GRAVITY will need IR wavefront sensors in the lab (as opposed to the current MACAO visual adaptive optics systems at the UT telescopes) and a high-performace fringe-tracker for four beams, as well as internal metrology of accuracy comparable to that of PRIMA.

The three Phase A studies which have just started will have the task to investigate in detail these scientific challenges, identify potential showstoppers, prove feasibility and provide insight on actual costs and schedule of each instrument. ESO will not be just a spectator in this game. In addition to the usual role of supervision and involvment in the studies, a number of strategic choices need to be addressed internally. Will PRIMA need to be extended as well to meet the needs of the second generation? Will it be necessary to have a dedicated fringe tracker for each new instrument, or will a common one suffice? How many telescopes can be effectively combined for routine operations? Last but not least, what is the VLTI ultimate performance after the technical interventions currently in progress?

We hope to know the answers in a few Messengers from now.

References

Paumard T. et al. 2005, Proc. of the ESO Workshop on “The Power of Optical/IR Interferometry: Recent Scientific Results and Second-generation VLTI Instrumentation”
Eisenhauer F. et al. 2005, Proc. of the ESO Workshop on “The Power of Optical/IR Interferometry: Recent Scientific Results and Second-generation VLTI Instrumentation”