Bulletin de la Socié Royale des Sciences de Liège - Vol. 74, 1-2-3, 2005, pp. 17-22

More Waves to Come: the VLTI, la OLA and beyond

F. Delplancke [1*]

[1]European Southern Observatory, VLTI, Garching bei Muenchen, Germany

Abstract: The current status of the Very Large Telescope Interferometer is presented as well as planned enhancements and possible second-generation instrumentation. Then two personal ideas of future interferometric projects, using the European Southern Observatory expertise, are outlined.

1 Introduction

The Very Large Telescope Interferometer (VLTI), developed by the European Southern Observatory (ESO), is reaching its mature stage: most of the infrastructure has been installed, one instrument, MIDI (the MID-infrared Instrument for the VLTI) is under scientific operation and the second instrument, AMBER (a near-infrared spectroscopic instrument), is being commissioned and will soon be offered to the astronomical community. However, a lot of work still needs to be done: more Auxiliary Telescopes (AT, 1.8 meter in diameter) are coming, the Phase-Referenced Imaging and Micro-arcsecond Astrometry facility (PRIMA) is being developed and will arrive in Paranal in 2006. Several second generation instrument projects are being discussed. And, last but not least, the VLTI has to be brought to the same level of efficiency for routine operations as the current Unit Telescopes (UT) and single-telescope instruments of the VLT.

So it is important, in the framework of discussion of next-generation interferometers, to review the current status, successes, failures and difficulties encountered during the development of the VLTI. This is the main aim of the first section of this paper. Then some personal ideas of interferometric projects using the ESO expertise and assets will be offered for discussion.

2 VLTI Status

2.1 Infrastructure

A large part of the VLTI infrastructure has now been completed, or will be completed in the course of 2005:

- all four Unit Telescopes will be equipped with the adaptive optics system MACAO-VLTI and can feed the VLTI simultaneously with their on-axis beam;

*fdelplan@eso.org

- two Auxiliary Telescopes are now in Paranal, one fully tested and the other to be integrated at the beginning of 2005 for first fringes in February;
- six Delay Lines are operational in the tunnel, allowing the use of all AT stations and any combination of up to four UTs;
- the Variable Curvature Mirrors, to be placed at the focus of the Delay Lines to relay the pupil, have been delivered and will be installed as soon as a critical alignment problem of the Delay Line rails is resolved;
- the relay optics, infra-red tip-tilt sensor (IRIS), alignment and calibration sources (ARAL) in the VLTI laboratory can currently feed three beams simultaneously and will soon be upgraded to four beams for PRIMA;
- the Interferometric Supervisor Software and all its related electronics, hardware and software is fully integrated and up to VLT standards, and the VLTI can be run as a fifth telescope from the main control room;
- several diagnostic tools (temperature, humidity, seismic sensors etc) have been installed to give continuous feedback on the VLTI environment;
- pipeline software, as well as observation preparation and data reduction tools, are available to the community in parallel with the instruments, and are continuously being improved and updated.

Most of the infrastructure remaining to be installed is related to PRIMA.

Since 1999, the VLTI has been operated mainly on two siderostats and also on two UTs with its test instrument VINCI. In shared risk observations, it has already provided several interesting scientific results, including the oblateness of the rapid rotating star Achernar (de Souza et al. 2003), the 5 milli-arcsec elongation of the Eta Carinae inner core (Van Boekel et al. 2003), and the distance of nearby Cepheids with unprecedented accuracy (Kervella et al. 2004).

Experience has shown that the items most critical to an efficient operation of the interferometer are in the telescope tracking system; in the tip-tilt sensing and compensation; in the alignment of the Delay Line metrology system; and in the stability of the interferometer environment (internal wind and turbulence). In the near future, fringe tracking (with FINITO and PRIMA Fringe Sensor Unit) will be the next challenge.

2.2 MIDI

MIDI is the mid-infrared instrument of the VLTI (http://www.eso.org/instruments/midi/), working with 2 telescopes in co-axial beam combination between 8 and 13 μm with spectroscopic resolution. It was installed in 2002, and has been offered to the scientific community since June 2003 (Science Demonstration Time).

After merely a year-and-an-half of operation for a couple of days per month on the UTs, the harvest of scientific results is already impressive:

- the first mid-infrared interferometric observation of an extra-galactic object, NGC 1068, a 30 milli-arcsecond warm dust torus structure and a central hot component (Jaffe et al. 2004);

- infrared spectra of the innermost regions of proto-planetary discs around young stars showing the proper elemental distribution to start formation of rocky planets (Van Boeckel et al. 2004);
- several additional scientific papers are currently being published and will be presented at the ESO-EII workshop in April 2005.

So far, data analysis and diagnostics have been found to be critical items. These are very difficult to develop for such a novel instrument, but are essential to the production of high quality scientific results.

2.3 AMBER

AMBER is a 3-telescope near-infrared instrument working in the J, H and K-bands, able to provide phase closure together with high resolution spectroscopy (R = 10 000). It uses focal plane beam combination and optical fibers for beam filtering (http://www.obs-nice.fr/amber/). AMBER had its first light with 2 telescopes in March 2004 and with 3 telescopes in May 2004. It is currently under commissioning and ESO hopes to offer AMBER to the scientific community by the end of 2005.

In this case, the crucial point to have an operational instrument is to maintain very accurate alignment of the instrument optics, especially the optical fibers, which is challenging in an open environment like the VLTI laboratory where temperature is varying (however slightly).

2.4 PRIMA

PRIMA, the Phase-Referenced Imaging and Micro-arcsecond Astrometry facility, is a complex system distributed throughout the VLTI infrastructure (see http://www.eso.org/projects/vlti/instru/prima/index_prima.html). Its aims are three-fold: to increase the VLTI limiting magnitude by off-axis fringe tracking, to provide imaging at interferometric resolutions for the AMBER and MIDI instruments, and to perform narrow-angle differential astrometry with 10 micro-arcsecond resolution. Its main scientific objectives are extra-galactic targets, extra-solar planet characterization, galactic center dynamics, young stellar objects and stellar surface imaging. PRIMA includes:

- two Fringe Sensor Units (one used for fringe tracking, the other used as an astrometric camera),
- Star Separators at the focus of the telescopes (to pick up, collimate and stabilize the light of two stars in a 2 arcmin field-of-view),
- Differential Delay Lines (to introduce a differential OPD between optical paths in order to get fringes on both Fringe Sensors),
- an incremental internal Metrology system (to measure the differential OPD within 5 nm),
- Supervisor Software (to coordinate all PRIMA related activities and perform all calibrations necessary to reach the 10-microarcsecond accuracy level).
- As PRIMA will be sensitive to many minute environmental changes (temperature and humidity of the air in the tunnels, micrometric movements of the telescopes with respect to each other, etc), a complex global data analysis software has to be developed to analyze

and reduce the long term trends in the collected data. This is especially critical for the astrometric goal of PRIMA, but will be useful as well for PRIMA imaging mode operation.

The Differential Delay Lines and data analysis software are under development, while all other sub-systems are already at the manufacturing stage. PRIMA will be subjected to an in-depth testing phase in Europe before this complex system is sent to Paranal in 2006 for integration and commissioning.

After FINITO experience, we suspect that the most difficult aspect of PRIMA operation will be fringe tracking, followed by the PRIMA metrology. In order to reach the ultimate accuracy, the data and long term trend analysis tools will also be critical.

2.5 Second-generation instrumentation for the VLTI

Several concepts for second generation instruments are currently on the drawing board. Candidates will be presented in April 2005 at the ESO-EII Workshop (see http://www.eso.org/vltiws05) and a selection will be made. Several concepts deal with the combination of four or more telescopes in phase-closure imaging mode, and different methods are proposed for different wavelengths. Other proposals include GENIE, a nulling interferometer experiment for the ESA mission DARWIN; an OHANA like combination of the telescope VISTA with the VLTI through monomode fibers giving a kilometric baseline; heterodyne interferometry at mid-infrared wavelengths; and visible interferometry with high resolution spectroscopy. These second generation instruments will use the existing VLTI infrastructure, possibly enhanced with a multi-way fringe tracker. Their development will benefit from the lessons learned from the first generation instrumentation.

3 La OLA

When 50 to 100-meter class telescopes become operational, interferometry will have to take another step in scale: kilometer baselines. This would give imaging angular resolution a factor 10 better than OWL, the Overwhelming Large Telescope, i.e. around 100 micro-arcsecond. If the limiting magnitude of such interferometers can reach 20 in K-band, this would open up the scientific fields of the observation of AGN cores and the origin of stellar jets. The concept of la OLA, Overwhelming Large Array, builds on ESO expertise in telescope development: it will be composed of about 20 8-meter class telescopes on kilometric baselines. Telescope like the VLT UTs, equipped with adaptive optics and dual-feed (for off axis fringe tracking), could be used. The problem of diffraction along kilometric Delay Lines could be solved with integrated optics for fast beam switching and shorter Delay Lines (some tens of meters) for tracking. The wavelength range could go from 1 to 20 m. A first rough estimate of the cost of the civil work, telescopes, adaptive optics, delay lines, fringe trackers and instruments ranges between 600 and 900 M and 600 Full Time Equivalents.

The choice of a proper installation site and of the most appropriate array configuration will be critical as so-called baseline bootstrapping for fringe tracking will be necessary: bright stars will be resolved by the long baselines and very good fringe tracking performance will be necessary.

4 An interferometric instrument for ELTs

An interferometric instrument could also have its place at the focus of Extremely Large Telescopes like OWL. Indeed, such telescopes will be made of a large number of individual mirrors (equivalent to 1 or 2 meter class telescopes) placed on a common mount. This property will remove the need of large-stroke delay lines. Then an instrument using a smaller or large number of the individual mirrors, with very small stroke (millimetric) OPD compensators, could provide for co-phasing of these mirrors and imaging with a dispersed aperture.

This kind of OWLish interferometric instrument has four advantages or complements compared to classical filled-pupil imaging instruments :

- it can be installed on ELTs during their construction phase, when the pupil is not yet filled, using the full resolution of the telescope at an early stage;
- it can work without adaptive optics without degraded resolution, and could possibly avoid the necessity of segment cophasing (as long as mirrors are aligned within the mini-delay line range);
- the out-of-field contamination properties of interferometric images are radically different from those of a full-aperture adaptive optics system and is complementary to it;
- interferometry is primarily dedicated to bright objects that will be more difficult to observe with ELTs and adaptive optics, which are designed for faint objects.

Several concepts of OWLish interferometric instruments could be used:

- Labeyrie-type densified pupil interferometry
- Keck-like bispectrum speckle interferometry or aperture masking,
- Fizeau interferometry.

Bispectrum speckle interferometry on the Keck telescope has shown high-resolution images of bright objects as good or better than adaptive optics (Tuthill at al. 2002). It seems that the artifacts and ghosts around the bright object are better behaved with the interferometric technique. However, it does work only with bright objects as more than 90% of the light collected by the telescope is rejected.

Simulations of densified-pupil interferometers have shown that this type of instrument is well suited for the imaging of faint companions close to bright stars. It has a relatively narrow field (of the order of the arcesecond) but uses the collected light optimally.

5 Conclusion

The VLTI is just reaching its maturity stage, producing regularly good quality scientific results. Part of the infrastructure, mainly related to the dual-feed, has still to be installed and the VLTI operations have to be optimized to get the best efficiency possible for an interferometer. With second generation instruments ready to be developed, the VLTI will probably produce a lot of cutting edge scientific results in the next 15 to 20 years. Then with the arrival of Extremely Large Telescopes a new generation of interferometers needs to be built with new challenges. An example of them is la OLA, the Overwhelming Large Array. An intermediate *niche* however exist between OWL and OLA: the large focus of ELTs could host interferometric instruments and provide fully resolved images of bright objects at very early stages of the telescope construction.

References

Domiciano de Souza A. et al, 2003, A&A 407, L47
Jaffe W. et al., 2004, Nature 429 (issue 6987), 47
Kervella P. et al., 2004, A&A 416, 941
Tuthill R. et al., 2002, A&A 389, 889
Van Boekel R.et al., 2003, A&A 410, L37
Van Boekel R. et al., 2004, Nature 432 (issue 7016), pp. 479