The VLTI and its instrumentation

Andrea Richichi, Andreas Glindemann, and Markus Schöller

European Southern Observatory, Karl-Schwarzschildstr. 2,
85748 Garching b.M., Germany

Abstract. High angular resolution is one of the key factors needed to detect and investigate young stars, their circumstellar environment and the possible presence of exoplanets. In this respect, the VLTI represents one of the most powerful tools available in the short term. We describe the phased implementation of the VLTI, from the basic configuration which has recently achieved first fringes, to the full array with all subsystems and complete instrumentation that will be operational in the next years. We provide examples of techniques for the study of young stars and exoplanets.

1 Concept and current status of the VLTI

The ESO Very Large Telescope Interferometer (VLTI) is located on Cerro Paranal, in northern Chile. This facility consists of the four fixed 8.2 m Unit Telescopes (UT), and of a number of 1.8 m Auxiliary Telescopes (AT) which can be moved over an array of 30 stations (Glindemann et al. 2000b). A scheme of the VLTI is shown in Fig. 1.

All the AT stations, as well as the UTs, are connected by a network of underground light ducts. Central to the facility is the delay line tunnel, where optical path differences are continually adjusted to correct for both long-range effects (such as those due to sidereal motion) and fast, short-range variations such as those due to differential atmospheric piston. A number of relay mirrors feed the light from the telescopes into the tunnel, and from there to a central underground laboratory, where the beams from two or more chosen telescopes are brought together and coherently combined.

At present, only test telescopes (40cm siderostats) are being used, mainly for commissioning purposes. Recently, the major milestones of first fringes has been achieved, using the siderostat telescopes placed on the same stations on which the ATs will be used (ESO PR 06/01 2001). Details on further phases of the project are given in Sect. 3.

In the following, we will concentrate on the instrumentation which is available or is currently under construction, and we provide an overview of the developments that will take place in the course of the next few years.

2 VLTI instrumentation

A number of first-generation instruments have been planned for the VLTI. The first one is VINCI, a K-band, 2-beam combiner which has been developed by

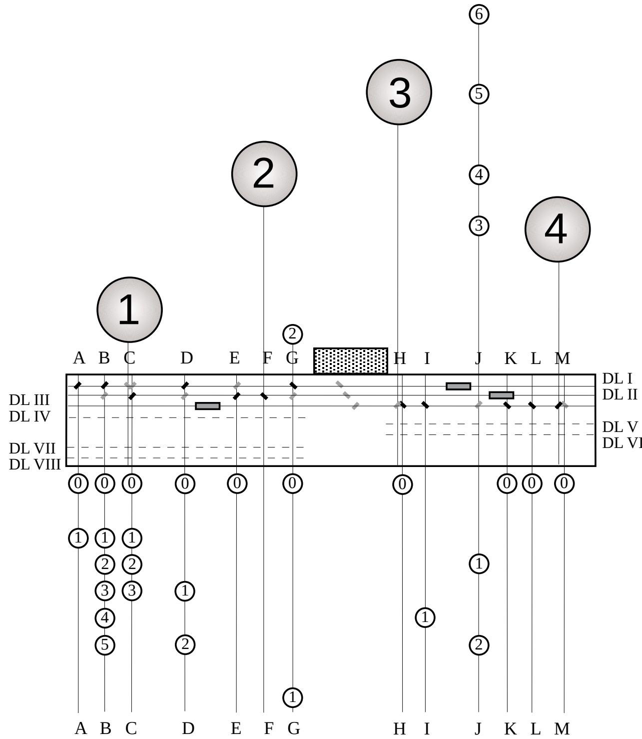

Fig. 1. General lay-out of the VLT Interferometer. Marked are the positions of the 4 UTs, the 30 AT stations, the systems of light ducts (vertical lines in the figure), the delay line tunnel, and the interferometric laboratory.

the Observatoire de Paris (France) in collaboraton with ESO. Strictly speaking VINCI was designed to be used as a test instrument only. It achieved first fringe detection in March 2001 (see ESO PR 06/01, 2001). VINCI is currently being used to characterize the AT stations, as well as the optical, mechanical and software subsystems of the interferometer. It will also be used to commission new subsystems as they come on-line, such as for instance the fringe tracker and the adaptive optics system. Perhaps the main characteristic of VINCI is the fact that it uses optical fibers to combine the two beams, using a scheme successfully implemented at the IOTA interferometer (Coudé du Foresto et al. 1998). The fibers act also as spatial filters, selecting only the light within the Airy disk of each telescope, where the coherence information is higher, and they output a gaussian-shaped wavefront with only tip-tilt as a major distortion. This has the cost of sacrificing some sensitivity, but results in excellent stability and precision of the instrumental visibility, with accuracies which are expected to be at the 10^{-4} level. It should be stressed that for such performance, the main limitation will actually be imposed by the quality of the calibrators. A program to establish a database of VLTI calibrators has been started and is expected to last for some years.

MIDI is the VLTI instrument designed to operate in the mid-IR. It is being developed jointly by a consortium of German, Dutch and French partners led by the Max-Planck-Institut für Astronomie in Heidelberg (Leinert et al. 2000). It will work at 10 and 20μm, with some spectroscopic capabilities. Most of the MIDI subsystems have already been manifactured, and integration is to begin by summer 2001. It is expected that the instrument will be completed and tested by spring 2002, and transported to Paranal shortly thereafter. MIDI will have an initial test period with the siderostats. However, due to the intrinsic characteristics of the thermal IR background and detectors, it will need large apertures to perform observations of scientific significance, and it is expected to be operated mostly with the UTs (already from summer 2002), and with the ATs for a limited number of programs which target expecially bright sources. One of the challenges imposed by MIDI is the very high data rate, given that individual exposures will have to be limited to few tens of milliseconds by the background brightness. Continuous rates of about 2Mb/s are expected, and will require special care to be dealt with by the pipeline and archive facilities of ESO. It will also be one of the first interferometric beam-combiners to operate in the thermal IR in a classical way, as opposed to instruments based on heterodyne detection (the only approach used until now), such as the ISI interferometer (Monnier et al. 2000).

In the near-IR, the facility instrument which will be offered by the VLTI is AMBER, which is being built by a consortium of French, German and Italian institutes based mainly, but not only, in Nice, Grenoble, Bonn and Florence (Petrov et al. 2000). AMBER will cover the 1 to 2.4μm range, with a range of medium and relatively high spectroscopic dispersions, up to $R = 10^4$. It is noteworthy that this instrument is designed to combine 2 or 3 telescopes. In this latter case, closure phases can be measured, which are fundamental if one wishes to attempt actual imaging (as opposed to the mere measurement of visibilities which is the classical product of standard interferometers).

For what concerns sensitivities, the performance of AMBER and MIDI will be strongly dependent on the quality of atmospheric seeing and coherence time, as well as on the availability and operation of subsystems such as the fringe tracker, the AO and PRIMA (see Sect. 3). Limiting magnitudes in long (cumulative) integrations for MIDI are close to N=8 (with fringe tracker on the UTs), and close to K=13 for AMBER (AO on the UTs). These limits are for self-tracking on the scientific source. The dual feed facility PRIMA would allow to push these limits significantly.

The instruments will be installed in an underground laboratory, expecially designed to be clean (class 30,000) and with a constant temperature (to within 0.1^{o}C). For this, all instruments are designed to be operated remotely from the control room, and will not need human intervention during the night. The same applies of course to the delay line tunnel. A layout of the interferometric laboratory is given in Fig. 2. Also a coherent reference light source (LEONARDO)

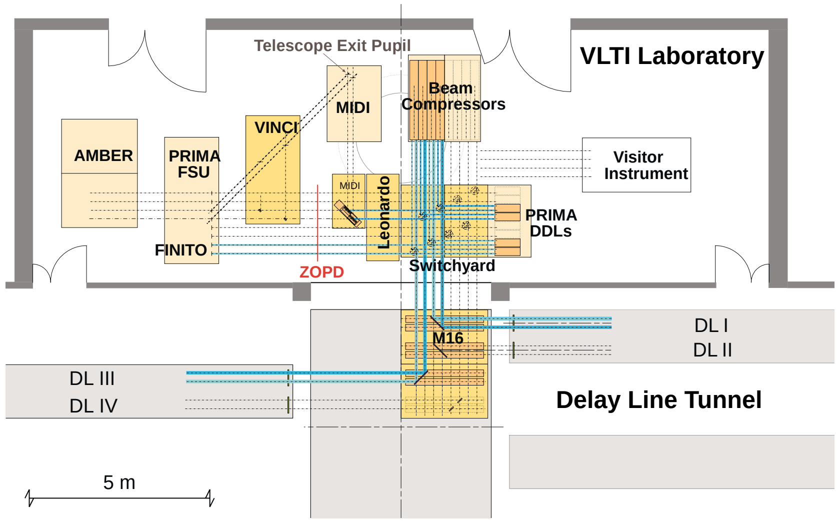

Fig. 2. Lay-out of the underground interferometric laboratory. The beams from the Delay Line tunnel (bottom) are propagated to the switchyard (center), and from there they are sent to the various optical tables by motorized mirrors.

is present. It should be noted that space has been reserved (to the right of the laboratory in Fig. 2) for the possibility of visitor instruments. One first such instrument could be the GENIE nulling instrument, which is currently being studied by the European Space Agency and that should serve as a technology demonstration for the Darwin space interferometer (Fridlund 2000).

3 Future developments

The VLTI is following an implementation plan that is characterized by the progressive introduction of several subsystems. The main milestones in this plan are summarized in Fig. 3, and are briefly discussed in the following.

As this text is being written, the beam compressors are being installed, which will permit to make full use of the aperture of the siderostats (from first fringes until now, only about 10 cm could be used). By the end of 2001, first fringes will be attempted on the 8.2 m telescopes. It must be noted however that by this time the UTs will not have a Coudé AO system yet; therefore this milestone will have only demonstration purposes, and almost no scientific use is foreseen.

The FINITO fringe sensing unit will permit to stabilize the fringes, using light at a different wavelength than that used for the scientific observation. This will permit to use longer integration times on all instruments, thereby extending their sensitivity. It is foreseen to be completed and installed by mid-2002. By that time, also MIDI should be delivered on Paranal. By end of 2002, it will be joined by AMBER, which however will not be able to access the UTs until an

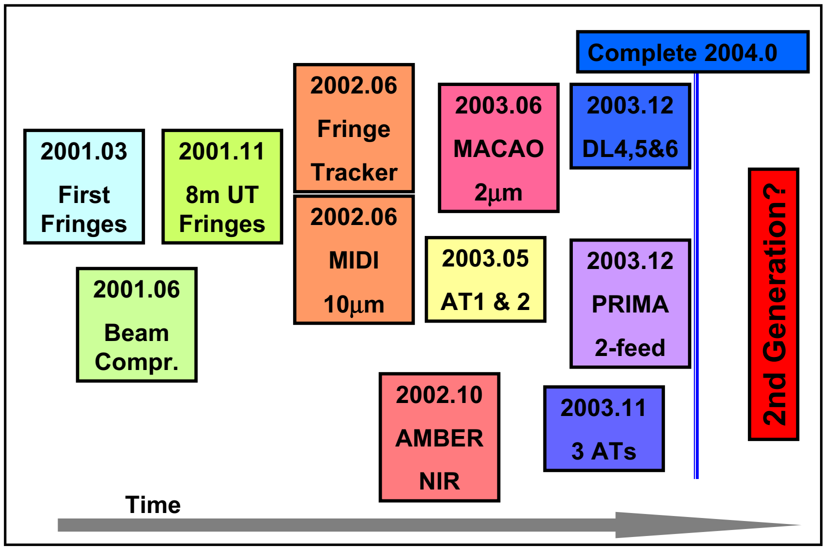

Fig. 3. Timeline of the progressive implementation of the VLTI subsystems. Concepts for second generation instrumentation are currently being examined.

AO system will be available. On the contrary, since it is expected that the good seeing of Paranal and fringe tracking will deliver a good image quality in the thermal IR, MIDI could use the UTs almost from the beginning.

The next step will be the delivery of the first two 1.8 m AT telescopes, which will enable AMBER to increase significantly the range of its scientific observations. A major milestone will then be represented by the introduction of the MACAO-VLTI AO system (Donaldson et al. 2000), which will provide image quality sufficient for the interferometric use of the UTs (initially UT2&4, subsequently UT1&3) also in the near-IR.

Subsequently, it is foreseen that the VLTI will be completed with the delivery of the third AT (enabling AMBER to combine three beams), the installation of additional delay lines (which will permit to extend the range of AT stations that can be combined), and finally with the completion of PRIMA. This is the VLTI dual feed facility, which will permit to select a nearby (typically $\lesssim$30 arcsecs) bright source for fringe tracking in one beam, and use a second beam to feed a fainter source to the scientific instruments. In this way, the limiting sensitivity will be pushed by several magnitudes. It is expected to reach K$\approx$20 under favorable conditions.

By the end of 2003, the VLTI should be completed in all its subsystems and operate to the full extent permitted by AMBER and MIDI. Beyond that, concepts for future extensions of the instrumentation and/or of the interferometer itself are being considered.

4 Studying young stars and exoplanets with the VLTI

With its wide range of baselines, its set of instrumentation and their predicted performance, the VLTI will be a key tool for studies of young stars and exoplanets. Reviews have been given by Glindemann et al. (2000a) and Richichi (2001).

Here we only mention that one of the main areas of research in which interferometers are going to be used, is the detection and study of orbital motions in star-star and star-planet systems. Such motions are of course a proof of the existence of the companion (in the case of exoplanets, this constitutes a fundamental counterpart to the detections by radial velocities), but they also represent the only way to determine the masses of the system. Masses of young stars are until now very poorly known.

In order to detect orbital motions with some accuracy also over relatively short periods of time, a quick computation shows that it is necessary to achieve angular resolutions much smaller than the pure diffraction limit of hectometric baselines provided today by the largest interferometers.

The VLTI can achieve this, in at least two different ways. On one hand, it is possible to detect small changes in the visibility of a binary system, when high accuracy and stability is achieved. On the other hand, given a bright reference star nearby, the VLTI equipped with PRIMA will perform micro-arcsecond astrometry and detect the reflex motion of the primary in a binary system. Both methods have been outlined by Richichi (2001).

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