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The VLTI Program: a status report

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ABSTRACT

The VLTI (Very Large Telescope Interferometer) is one of the operating modes of the VLT, presently being built on Cerro Paranal, Chile. It aims at providing access to an observing mode at very high angular resolution and very high sensitivity (with respect to the currently operating astronomical interferometers).

After a long period of conceptual, then detailed, studies, ESO is starting to build and to procure the main components of the interferometer in order to open this unpaired observing facility by the turn of the century.

Keywords: Interferometry, Very Large Telescopes, Astrophysics at very high angular resolution

1. INTRODUCTION AND BACKGROUND

The introduction of an interferometric mode inside the VLT program has been decided at the beginning of the VLT project. The idea was to take the opportunity of the existence of four large 8 meters Unit Telescopes (UTs) to provide a 'coherent beam-combination' facility, opening access to astrophysical observations at very high angular resolution (typically 1 to 10 milli-arcsec, depending on the wavelength). The concept of movable Auxiliary Telescopes (ATs) was also introduced soon, in order both to optimally use the interferometric infrastructure (the ATs are fully devoted to interferometric observations), and to access a larger coverage in the spatial frequencies plane, hence improving the quality of the reconstructed image of the source.

Since the decision by the ESO Council in December 1993 to postpone the implementation of the VLTI, ESO has pursued a program with the aim to develop all necessary designs to assure a fast implementation as soon as funds would become available. As a part of this program the Interferometry Science Advisory Committee (ISAC), a committee of astronomers who have a background in high angular resolution astrophysics and interferometry, was established. One of its first charges was to review the development of, to define a key science program for, and to recommend necessary conceptual changes to, the VLTI. The ISAC found a wealth of scientific topics which could be addressed favorably or uniquely with the VLTI. Some of them have been described in more detail (see Ref. 1 and 2). The top level technical requirements which result from the ISAC scientific requirements are:

- The VLTI should acquire first fringes around the turn of the century in order to ensure competitiveness with other interferometry programs.
- There should be a phased approach to the implementation of the VLTI. The first phase shall include the 8m Unit Telescopes from the start, and shall focus on spectral regimes where telescopes can perform near the diffraction limit with a minimum of adaptive control.
- Auxiliary Telescopes should have a diameter of order 1.8 m as a compromise between cost and sensitivity.
- A field of view for the science target of 2 arc seconds ("primary beam") is sufficient. In order to enable phase referencing as well as narrow-angle astrometry, the capability to do interferometry at a second field position ("secondary beam") within 1 arc minute radius from the science beam shall be included.
- VLTI shall have the capability to simultaneously combine four telescopes, out of at least two 8m Unit Telescopes and up to three Auxiliary Telescopes.

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- Beam combination instruments shall operate in "single mode" (fringe detection on fields of the size of the Airy disk) in the red, near-infrared, and in the mid-infrared.
- VLTI should have narrow-angle astrometric capability with a precision comparable to the atmospheric limit.

In view of the progress made in the scientific definition as well as of the growing competition, ESO decided in December 1995 that the time was right to reintroduce the implementation of the VLTI into the VLT program, within funds available at ESO as well as in the community. A "New Plan" has been introduced, with a technical scope which is adapted to a limited budget, and a significantly modified technical concept which meets better the scientific needs. The main goal of the New Plan is to introduce the original VLTI capability, but in several phases. However, there will be several changes to the earlier concept.[3]

2. VLTI DEVELOPMENTS

2.1. Main VLTI components

The major components of the VLTI include:

- The VLT Unit Telescopes (UTs): the 8 m telescopes have been specified, from the beginning of the VLT project, in order to meet the very stringent requirements of the coherent combination of their light beams, down to the visible domain of the spectrum. Recent measurements performed on the erected UT1 structure on Paranal give confidence that these requirements will be met: a report of these measurements is given in these Proceedings[4] .

  Figure 1 illustrates the lay-out of the Paranal site and the disposition of the four UTs. The maximum baseline, between UT1 and UT4, is 130 meters.

- The Auxiliary Telescopes (ATs): these telescopes will be entirely dedicated to interferometry: they have been specified accordingly. A specific feature of the ATs is that they can be relocated on 30 different stations (see Fig. 1), providing a large flexibility in the choice of the baselines for a specific target. The maximum baseline for ATs is 202 meters.

  ESO is in the process of choosing an industrial contractor for the procurement of two ATs. The contract signature is expected for the summer 98. The first two ATs will be later complemented by a third one.

- The Delay Lines (DLs): ESO has recently signed a contract with Fokker Space for the delivery of two DLs. The initial design of Fokker foresees a two-stage system for the whole 60 meters stroke with very low power dissipation in the tunnel. Further details can be found in these Proceedings.[5]

The general optical lay-out of the VLTI is illustrated in Figure 2.

2.2. Related VLTI activities

Several other critical components of the VLTI are also being procured:

- Variable Curvature Mirrors (VCMs): these deformable mirrors will be integrated in the Delay Lines. They will allow to re-image the output pupil of each beam at a fixed location in the interferometric recombination laboratory. The VCMs are described in greater detail in these Proceedings.[6,7]
- Test siderostats: according to the "New Plan", the first interferometric connection of two VLT telescopes will be performed with two UTs. It is of course not reasonable to commission the VLTI, including the VLTI instruments, with the UTs. This is why, ESO will procure two small test siderostats in order to achieve the initial phase of commissioning of the VLTI components and optimize their performances.
- UT Coudé trains: a new design for the UT Coudé trains has recently been completed. It is based on a combination of spherical and cylindrical mirrors and features a flat mirror for M8 (see Fig. 2). This will allow, at a later stage the introduction of the deformable mirror of an adaptive optics system at this location.

Figure 1. VLTI site lay-out.

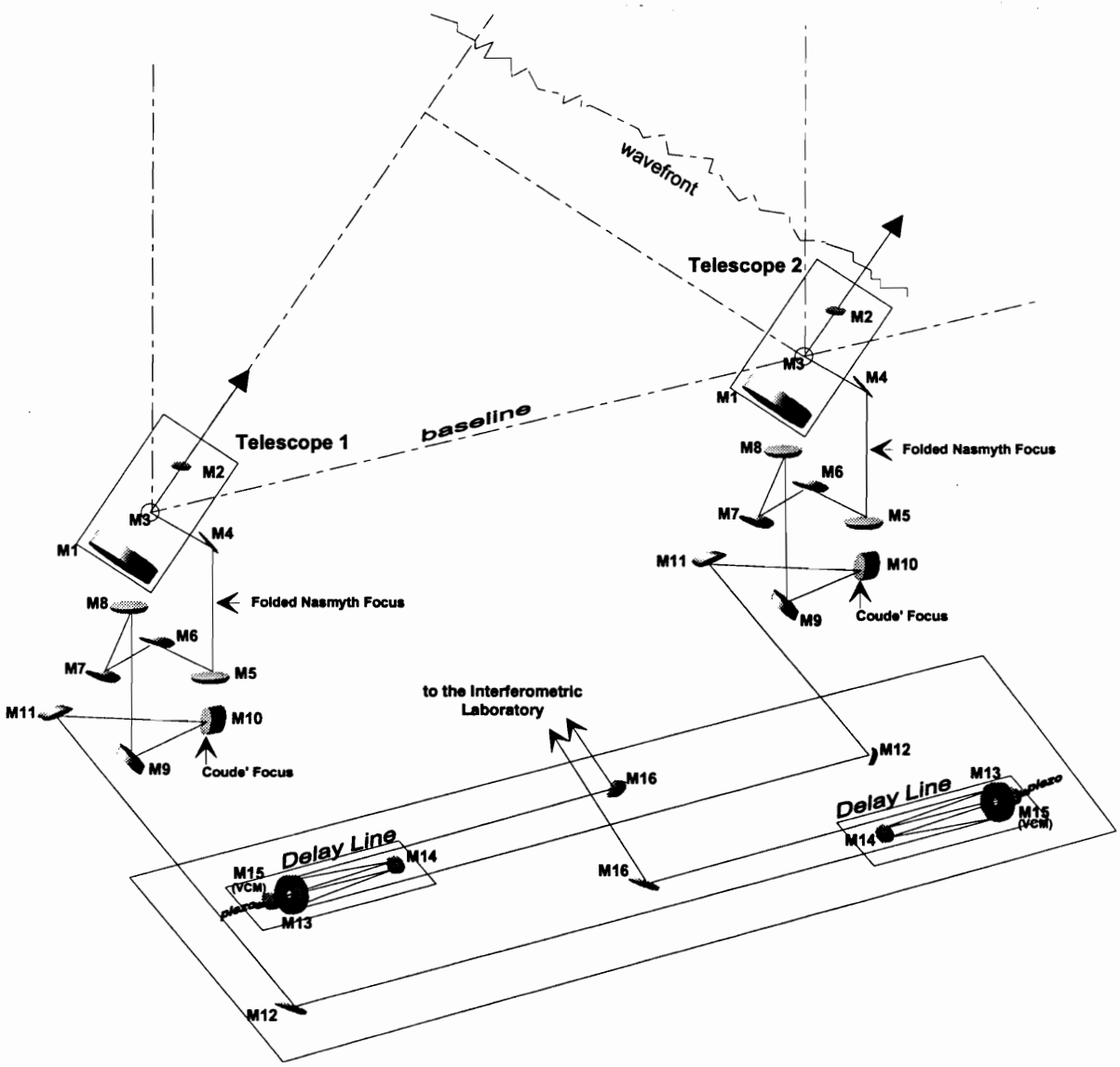

Figure 2. Optical lay-out for one VLTI baseline.

- ESO has contracted to a consortium of laboratories led by Observatoire de la Côte d'Azur the study and realization of a Prototype Fringe Sensor Unit (PFSU). The aim of this prototype equipment is to study the performance of a coherencing and cophasing device for the VLTI. This prototype could form the basis of the final VLTI fringe sensing unit. A description of the PFSU can be found in Ref. 8.

On the other hand, ESO is developing the tools allowing the integration of these components into an integrated observing facility. The main axis of these developments are:

- The VLTI end-to-end model: ESO is developing a simulation tool allowing to produce a dynamic representation of the main output of the interferometer (i.e., the interferometric signal). Presently, this technical model includes the optical propagation inside the interferometer and several sources of mechanical disturbances, including wind-load on the telescopes and seismic perturbations. It will be further enhanced in order to take into account the atmospheric turbulence, as well as more subtle effects, such as the polarization mismatch or the Fresnel diffraction effects*.

  One of the main goal of this 'technical' model is to provide realistically simulated data to the 'scientific' end-to-end model. This model aims at simulating all the aspects of a typical interferometric observation with the VLTI, including the source characteristics and the practical limitation encountered during an observing sequence. The development of this model is described in these Proceedings[9] .

- The VLTI group is also developing the VLTI control tools: these include the modelization and bread-boarding of the main control loops, e.g. the OPD control model, and the VLTI Control Hardware and Software. This latter topic is addressed in the contribution of these Proceedings[10] .

Several studies aiming at further improving the performances of the VLTI after completion of the New Plan are pursued at ESO. This includes a proposal to equip the UT Coudé trains with an adaptive optics system based on the components of the ESO MACAO system. The main goals of this study are described in Ref. 11. Also, a study aiming at achieving the calibration of systematic optical path differences is described in Ref. 12.

Finally, the VLTI group is starting the conceptual design of the dual-feed mode for the VLTI: this includes the definition of the star separator, of the differential delay line, of the specific beam-combination unit and of the metrology system tying all these components.

3. INSTRUMENTATION FOR THE VLTI

The VLTI will be complemented by a set of one technical and three scientific instruments:

- VINCI (VLT INterferometer Commissioning Instrument): this instrument will allow to perform the technical commissioning of the interferometer, to optimize the operation of its critical components and to test the basic VLTI operation modes. It will operate at $2.2\,\mu$m.

- MIDI (Mid-InfrareD Instrument) is essentially a $10\,\mu$m camera with limited spectroscopic capabilities. Extension of the wavelength range toward the $20\,\mu$m window is foreseen. More details are given in Ref. 13.

- AMBER (Astronomical Multi-BEam Recombiner) is a $2.2\,\mu$m instrument exploiting both a phase closure imaging mode and a high spectral resolution mode. The introduction of an Adaptive Optics module will allow AMBER to use efficiently the beams from the UTs in the near-IR, and to extend its operating wavelength range down to the visible domain with the ATs.

- PRIMA (Phase Referenced Instrument for Micro-arcsec Astrometry): this instrument will exploit the possibilities provided by the introduction of a dual-feed in the VLTI. Basically, it will be able to perform phase referenced imaging on very faint sources with the UTs. The introduction of an accurate metrology will also allow the instrument to perform differential astrometry in a 2 arcminute field-of-view with an accuracy of a few tens of micro-arcsec (see Ref. 14).

The main characteristics of the VLTI scientific instruments are summarized in Table 1

*More details can be found at http://huey.jpl.nasa.gov/ice/imos_presentations/bkoehler.pdf

Table 1. Main characteristics of the VLTI instruments: λ is the wavelength range, $\mathcal{R}_\lambda$ is the maximum spectral resolution. Note that budget estimates are only preliminary: also, they do not include manpower.

	MIDI	AMBER	PRIMA
Main targets	YSOs Disks	Imaging of stellar surfaces and environment	*Imaging* Extragalactic Science
	Circumstellar environments	'Hot Jupiters'	*Astrometry* Extra-solar planetary Systems Galactic Center
$\lambda(\mu m)$	10 (20)	$0.6 \rightarrow 2.5$	2.2
$\mathcal{R}_\lambda$	400	$10 \rightarrow 10000$	10 (?)
Budget (MDM)	1.5 – 2.0	1.8 – 2.2	7.5 (?)
1st light	01/2001	04/2001	~2001 for first phase

4. CONCLUSIONS

The decision to allow interferometric coupling of the various telescopes of the VLT has been taken at the starting point of the VLT project. After a long phase of conceptual, then detailed, studies, the implementation of the VLTI has started. This phase includes the near completion of the civil engineering work on the Paranal site (ATs station foundations, delay line tunnel and light ducts, interferometric recombination laboratory), as well as the signature of industrial contracts for the procurement of the main VLTI components (ATs and DLs). By the end of this year, most of the budget of the program will be committed.

At the same time, ESO is preparing the integration of these components into an optimized observing facility. This task is supported by the European astronomical community, through the participation of several Institutes in the definition and construction of the VLTI instruments. Also, the community has been largely involved in the re-definition of the scientific priorities of the VLTI.

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