# THE VLT INTERFEROMETER

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**Abstract.** One of the observing modes available with the ESO Very Large Telescope will be coherent combination of the light received by up to four 8 m unit telescopes and several 1.8 m auxiliary telescopes. The location of the main telescopes is fixed, while auxiliary telescopes can be moved among some 30 observing stations. The locations of these stations were chosen to augment the $(u, v)$ coverage of the unit telescopes as well as to function as an independent interferometric array.

The 8 m telescopes will be equipped with adaptive optics to correct for seeing-induced wavefront aberrations. This wavefront correction will be complete at near-infrared wavelengths, giving the interferometer very high sensitivity in this spectral regime. This paper gives a brief description of the VLT Interferometer and an update on its status.

**Key words:** Instrumentation: interferometers – Telescopes

## 1. Introduction

The Very Large Telescope (VLT) is currently being built in Chile by the European Southern Observatory. It is located on Cerro Paranal in the Atacama Desert, 130 km south of the town of Antofagasta. The site is distinguished by excellent seeing and a very high percentage of clear nights.

The VLT Interferometer (VLTI) is an observing mode that will allow coherent combination of light from two arrays of telescopes:

**VIMA** (the VLTI Main Array)—four fixed 8 m unit telescopes
**VISA** (the VLTI Sub-Array)—several movable 1.8 m auxiliary telescopes.

Most of the commissioning of the system will be done using VISA, which is dedicated to interferometry. Funding is now secure for three auxiliary telescopes and three delay lines, giving VISA imaging capabilities in its own right. After this commissioning period, observations will begin with the array of unit telescopes (VIMA) and also using both arrays together in a hybrid configuration. A stationary cat's eye in addition to the three movable delay lines would allow four telescopes to be used at a time.

Basic to the design concept of the VLTI is the requirement for a wide interferometric field of view: 8 arcsec with VIMA and at least 3.5 arcsec for VISA. This demands large delay-line optics, as well as the ability to re-map the input pupil homothetically onto the output pupil at the image beamcombiner. That is, the configuration of the telescopes as seen from the observed source should be mapped onto the beamcombining telescope in such a way that the relative lengths and orientations of all baselines are preserved.

Initially the VLTI will operate in the near-infrared, with subsequent extension to visible wavelengths and the addition of the homothetic remapper at the imaging beamcombiner. Other future expansion of the instrument may include adding more auxiliary telescopes and delay lines (up to a maximum of eight), the capability to rapidly reconfigure VISA, the ability to do "blind" observations on faint sources

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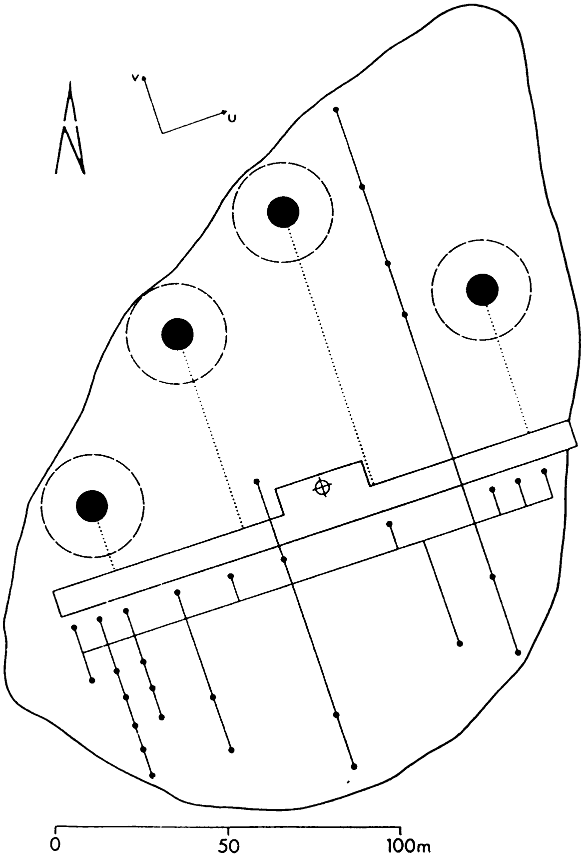

Fig. 1. Layout of the VLT Observatory on Paranal.

and the use of adaptive optics with laser guide stars. This paper summarizes the main features of the VLTI; more details can be found elsewhere (Beckers 1991; Beckers *et al.* 1990, 1992; von der Lühe *et al.* 1992a; Faucherre *et al.* 1992).

## 2. Layout and Imaging Characteristics

The layout of the VLT Observatory is shown in Fig. 1. About 32 m of soil has been removed from the top of Cerro Paranal, providing a platform with an area of about 25 000 $m^2$. The locations of the four unit telescopes are marked by large filled circles, with dashed circles showing the telescope enclosures. Also shown are the stations for the auxiliary telescopes (ATs) and the transportation tracks that allow them to move between stations.

The long rectangular structure in Fig. 1 is a 160 m by 8 m underground tunnel that houses the delay lines and beam redirection optics. At the centre is an underground laboratory which contains the beamcombiner and instrumentation, together with support infrastructure (a control room, several offices, an integration room and computer equipment).

Light from the telescopes enters the tunnel through pipes 1.25 m below ground, shown in the figure as dotted lines. The orientation of the tunnel is rotated anticlockwise degrees from the EW direction by 20°; this is to balance the fixed optical path between the unit telescopes and the beamcombiner laboratory.

### 2.1. THE VLTI MAIN ARRAY

The configuration of the four unit telescopes is a compromise between the desire for good $(u, v)$ coverage and other competing factors. These include meteorological considerations (the predominant wind direction is NNW, while the best seeing is correlated with winds from the NW), the characteristics of the rock on which the telescopes are anchored, and the need for clearance between the telescope enclosures. The $(u, v)$ coverage of VIMA for several source declinations is shown in Fig. 2.

### 2.2. THE VLTI SUB-ARRAY

Several considerations went into choosing the locations of the 30 auxiliary telescope stations (von der Lühe *et al.* 1992b). Some of the stations are designed to complement VIMA when hybrid modes are used, generating baselines between UTs and ATs that substantially improve the $(u, v)$ coverage. An example is shown in Fig. 2.

Another consideration in the definition of the AT stations was the desire for coverage of short baselines which are not accessible to VIMA. This is the purpose of the dense cluster of stations at the SW corner of the site, an area where wind-shadowing effects from the unit telescopes should be small. Baselines within this cluster help to fill the central hole in the VIMA coverage.

Auxiliary telescope stations also contribute the longest baselines available in the VLT interferometer. Stations at the extreme northern and southern edges of the platform provide baselines of up to 200 m. At visible wavelengths, this corresponds to an angular resolution of 0.5 mas.

All the telescope stations are located on a common square grid with a spacing of 8 m. This was done to support the technique of "redundant spacings calibration," in which information from redundant baselines is used determine the object phases uniquely, without the need to model the object (see reviews by Greenaway 1991 and Wieringa 1992). For instance, the linear array of ten AT stations lying parallel to the delay-line tunnel allows measurement of the object phase on baselines of all integer multiples of the grid spacing, up to 18 times 8 m.

## 3. Major Subsystems of the VLTI

### 3.1. UNIT TELESCOPES

The primary mirror of each unit telescope is an 8 m monolithic glass-ceramic meniscus with a focal ratio of 1.8. The primaries will have active supports to compensate

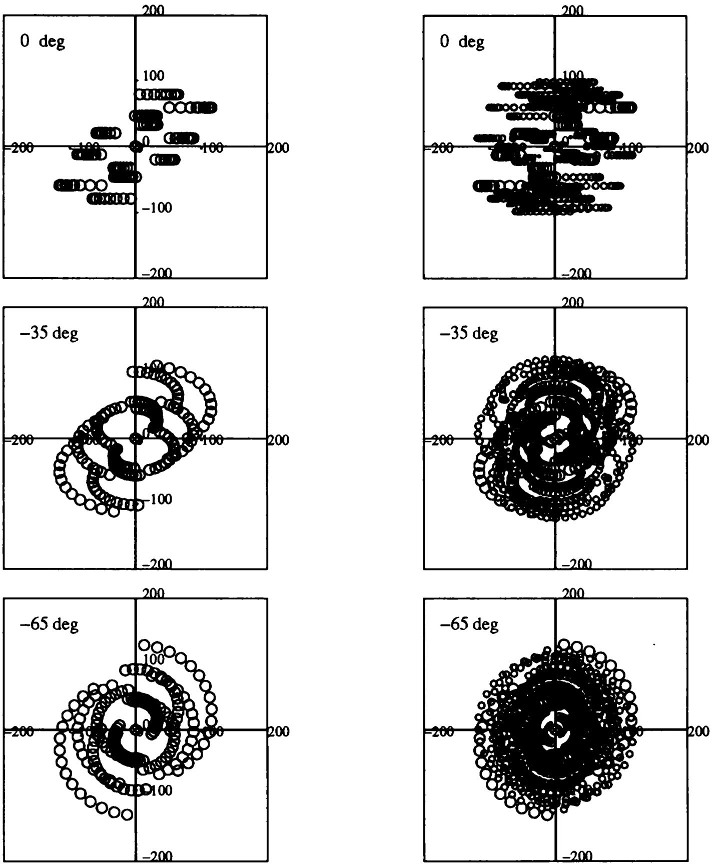

Fig. 2. Left: the $(u, v)$ coverage of VIMA for three source declinations (axes in metres). The calculations assume the source to be observable down to a zenith distance of 60°. Right: improved $(u, v)$ coverage when VIMA is augmented by telescopes at five AT stations.

for static and slowly-varying deformations of the telescope optics (Merkle *et al.* 1989; Enard 1992). The VLT Interferometer will use the coudé light paths. As shown in Fig. 3, there are two symmetric coudé optics trains: one is coated for visible wavelengths and the other for the red and infrared.

The unit telescopes will be equipped with adaptive optics to correct for seeing-induced wavefront aberrations. Each system will have about 250 actuators, providing full correction for wavelengths longer than 2.2 $\mu$m (Merkle and Hubin 1991).

## 3.2. AUXILIARY TELESCOPES

An extended feasibility study of the auxiliary telescopes has been performed by IRAM under ESO contract (Plathner and Beckers 1992). Detailed analyses have confirmed the feasibility of all our critical requirements, including the requirement for stable optical path lengths, something essential for interferometry. The optical

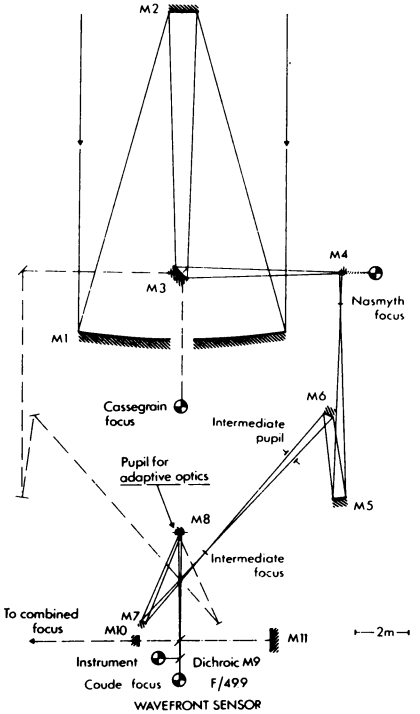

Fig. 3. Unit telescope optics.

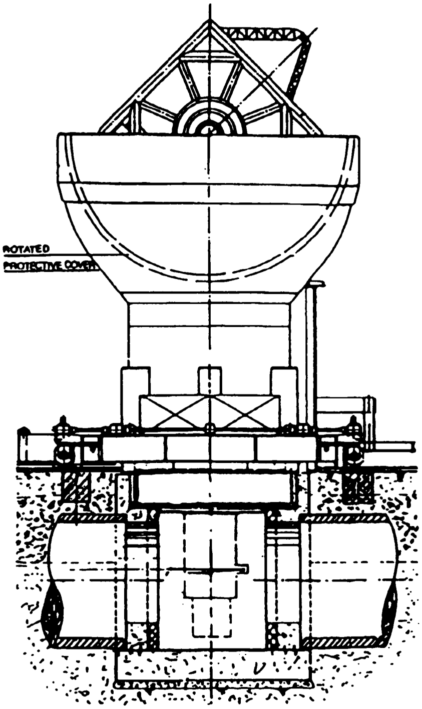

Fig. 4. Auxiliary telescope design.

layout is very similar to that of the unit telescopes; this is to make polarization and field rotation properties identical for all elements of the VLTI.

A view of an auxiliary telescope is shown in Fig. 4. The design includes a built-in cover for protection against the weather. This cover is stowed during observations, exposing the telescope tube to the wind so as to minimize the effects of dome seeing. Each AT is equipped with a transporter, allowing the array to be reconfigured in less than one hour. At present there is no allocation in the budget for adaptive optics for the ATs. However, tip-tilt correction will be provided and the design allows for a full adaptive optics system to be implemented at a later stage.

### 3.3. RELAY OPTICS AND DELAY LINES

An overview of the optical design of the interferometer is presented in Fig. 5. Light from the individual telescopes is relayed to the delay lines via underground pipes. The delay lines have a stroke of 60 m, thus providing a total variation in optical path of 120 m.

Fig. 6 shows a delay-line carriage. This is a carbon-fibre structure containing a paraboloidal primary mirror and a variable-curvature secondary. The curvature of the secondary in each delay-line carriage will be adjusted as the carriage moves,

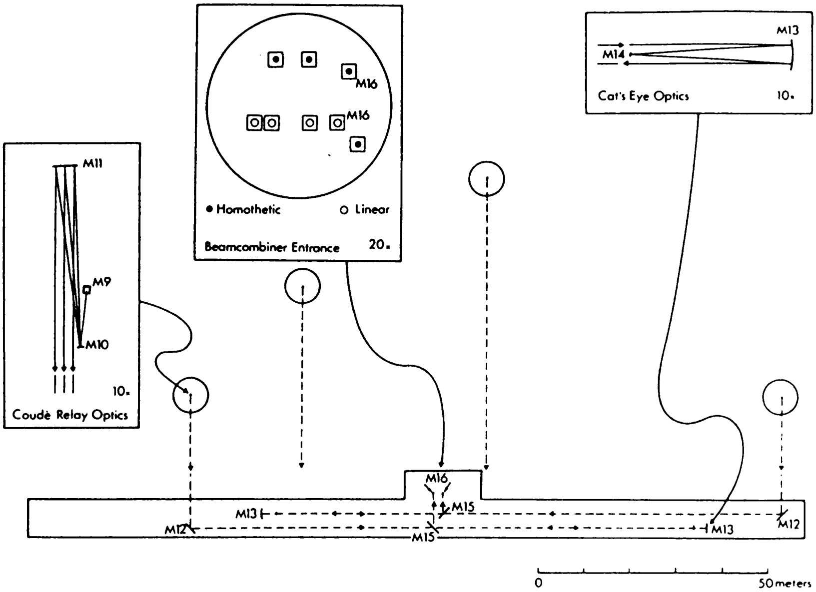

Fig. 5. Optical layout of the VLTI. Here, only the unit telescopes are shown. The insets provide magnified details of the coudé relay optics, cat's eye optics, and the beamcombiner entrance configuration.

so as to re-image the pupil of the corresponding telescope onto the beamcombiner. This is to ensure that the field of view is not reduced by vignetting. A prototype for the variable-curvature mirror is being built at the Observatoire de Marseille.

The longitudinal positions of the delay-line secondaries will be adjusted to equalize the optical paths to within the coherence length. The signal for this correction is provided by a fringe sensor, currently under development by OCA in Nice. For sufficiently bright objects, it will be possible to co-phase the array, i.e., to match optical paths to within a fraction of a wavelength.

### 3.4. BEAMCOMBINER

Initially, the beams will be combined in a pupil plane. This method presents advantages for infrared observations and is also relatively simple to implement. Wide field-of-view operation, however, requires combining the beams in the image plane. We propose to use an imaging beamcombiner telescope, the current design of which is shown in Fig. 7. It consists of a 2 m diameter, $f/25$ Gregorian looking upwards from a deep pit. The final plate scale will be 41.3 mas/mm and the full unvignetted field is about 200 mm. The back focal distance of the Gregorian is large enough to allow room underneath the primary for image-position sensors, wavefront sensors and the like. The second $f/25$ focus, out to the side, will be used for the instruments and for the fringe sensor.

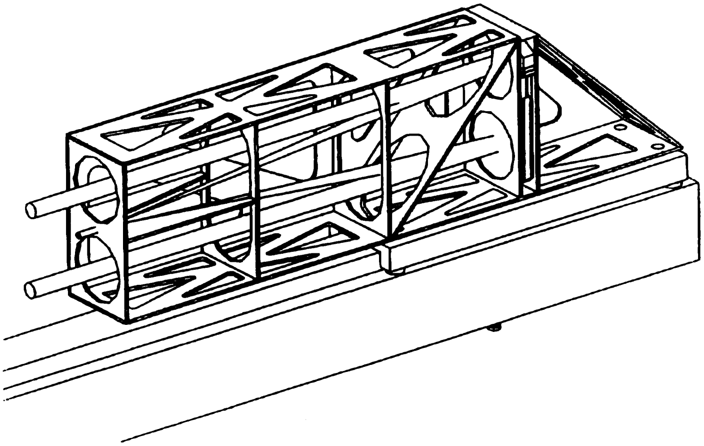

Fig. 6. Delay line carriage structure.

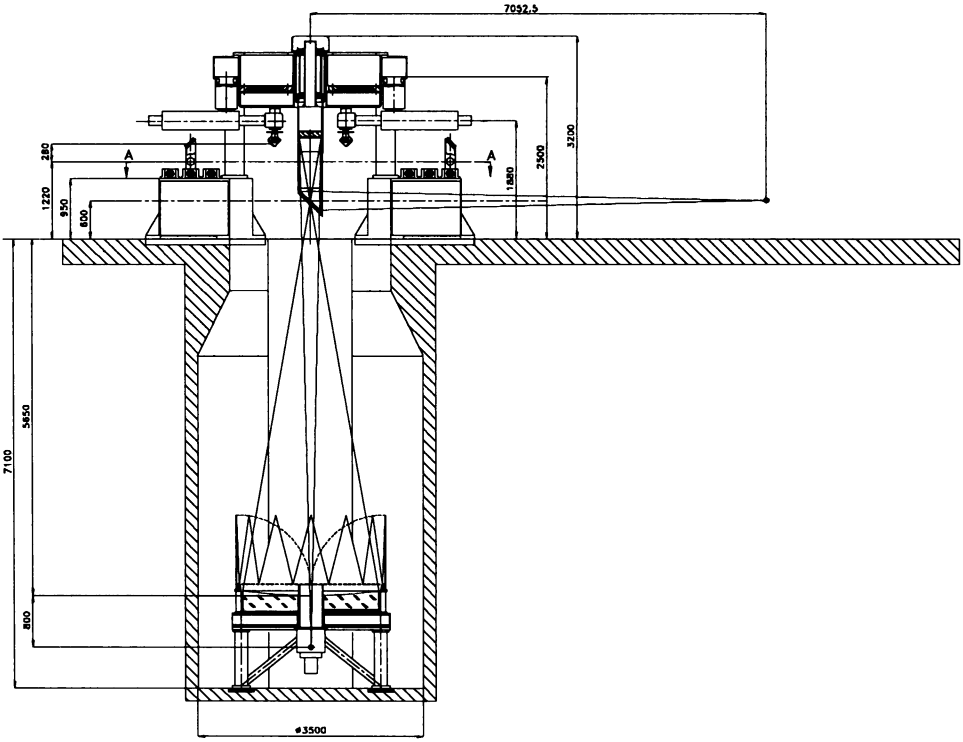

Fig. 7. Side view of the imaging beamcombiner telescope.

## 4. Status

The VLT Interferometer will be managed by a project team within ESO's VLT program, with substantial support from Europe's interferometric community. The team at ESO is making feasibility studies and generating detailed concepts for the various subsystems of the interferometer. Major subsystems, like the auxiliary telescopes and the delay lines, have been studied by external contractors. Those studies are completed and the results are being reviewed by our team in preparation for calls for tenders. Instruments for the VLTI will be developed and built outside ESO by European consortia. We plan to install the interferometer on Paranal, equipped with several of these instruments, in 1996–7. "First fringes" should be detected in 1998.

## References

Beckers, J. M. *et al.,* 1990, The VLT Interferometer: I. Proposed Implementation, in *SPIE Proc. 1236,* p. 108, and several other papers in the same Proceedings.

Beckers, J. M., Faucherre, M., Koehler, B., and von der Lühe, O., 1992, A progress report on the implementation of the VLT Interferometer, in *Proceedings of the ESO Conference on High-Resolution Imaging by Interferometry II,* edited by J. M. Beckers and F. Merkle, p. 775, Garching bei München, F.R.G., October 1991.

Beckers, J. M., 1991, Interferometric imaging with the Very Large Telescope, *J. Opt. (Paris),* **22**, 73.

Enard, D., 1992, ESO VLT: A status report on telescopes and enclosures, in *Progress in Telescope and Instrumentation Technologies,* edited by M.-H. Ulrich, p. 25, Garching bei München, F.R.G., April, 1992.

Faucherre, M., Koehler, B., von der Lühe, O., Merkle, F., and Zhu, N., 1992, The VLT Interferometer: Current status and expectations for the next 20 years, in *Targets for Space-Based Interferometry, ESA SP-354,* p. 91, Beaulieu, France, December 1992.

Greenaway, A. H., 1991, Optical aperture synthesis, *Meas. Sci. Technol.,* **2**, 1.

Merkle, F. and Hubin, N., 1991, Adaptive optics for the European Very Large Telescope, in *Active and Adaptive Optical Systems,* edited by M. A. Ealey, Vol. 1542 of *SPIE Proc. Ser.,* p. 283, San Diego, California, July 1991.

Merkle, F. *et al.,* 1989, *VLT Optics: Design of the Telescope Optics,* VLT Report 58, European Southern Observatory, December 1989.

Plathner, D. and Beckers, J. M., 1992, The design of the Auxiliary Telescopes for the VLT Interferometer, in *Proceedings of the ESO Conference on High-Resolution Imaging by Interferometry II,* edited by J. M. Beckers and F. Merkle, p. 939, Garching bei München, F.R.G., October 1991.

von der Lühe, O., Beckers, J. M., Faucherre, M., Koehler, B., Merkle, F., and Zhu, N., 1992a, Interferometry with the Very Large Telescope, in *Solar Physics and Astrophysics at Interferometric Resolution, ESA SP-344,* edited by L. Damé and T.-D. Guyenne, p. 247, Paris, France, February 1992.

von der Lühe, O., Beckers, J. M., and Braun, R., 1992b, The configuration of the VLT Interferometer on the Paranal site, in *Proceedings of the ESO Conference on High-Resolution Imaging by Interferometry II,* edited by J. M. Beckers and F. Merkle, p. 959, Garching bei München, F.R.G., October 1991.

Wieringa, M. H., 1992, An investigation of the telescope based calibration methods 'redundancy' and 'self-cal', *Exp. Astron.,* **2**, 203.