An Introduction to Interferometry with the ESO Very Large Telescope

Oskar von der Lühe

European Southern Observatory
Karl-Schwarzschild-Str. 2, D – 85748 Garching

1 Introduction

The interferometric mode of the ESO Very Large Telescope (VLT) permits coherent combination of stellar light beams collected by four Unit Telescopes (UTs) with 8m diameter and by several Auxiliary Telescopes (ATs) of the 2m class. While the position of the UTs is fixed, ATs can be moved on rails and can operate from 30 stations distributed on the top of the observatory site for efficient UV coverage. Coherent beam combination can be achieved with the UTs alone, with the ATs alone, or with any combination of up to eight telescopes. A distinct feature of the interferometric mode is the high sensitivity due to the 8m pupil of the UTs with the potential for adaptive optics compensation in the near-infrared spectral regime.

The VLT Interferometer is conceived as an evolutionary programme where a significant fraction of the interferometer’s functionality is initially funded, and more capability may be added later while experience is gained and further funding becomes available. The scientific program is now defined by a team which consists of a VLTI Scientist at ESO and fifteen astronomers from the VLT community. ESO has recently decided to resume the construction of the VLTI which was delayed in December 1993, in order to achieve first interferometric fringes with two of the 8m telescopes around the year 2000, and routine operation with ATs from 2003 onwards.

This paper presents an overview of the history of the VLT Interferometer and its basic capabilities. The synthesis capability and the sensitivity of VLTI are addressed in more detail. An extensive bibliography on VLTI-relates papers is also provided.

2 History of VLTI

A coherent combined mode has been part of the Very Large Telescope program since its beginning in the early 80’s (Enard, 1984, Merkle, 1986, 1988a and 1988b, Lena, 1987 and 1988). Combining the collecting power of 8m diameter telescopes with the resolution of a baseline of about 100m seemed to be an opportunity too good to miss. The main driver for including the interferometric mode were making images of celestial sources at a resolution of the milli-as. At
that time, interferometry at radio wavelengths was becoming recognized as a very powerful tool, which could provide much of the data analysis techniques needed for the optical spectral ranges. Speckle interferometry and related techniques were intensely researched and well on the way to their current “toolbox” state. Exploiting the diffraction limit with adaptive optics appeared as a more distant possibility. There was only little experience with distributed interferometers at optical wavelength, essentially concentrated in Europe.

The main thrust for interferometry with large aperture telescopes was for observations in the near infrared domain (Roddier and Léna, 1984). It was recognised early on that a fixed configuration of large telescopes would prove too inflexible to make faithful images of sources with even moderate complexity. Therefore, the VLT includes several smaller Auxiliary Telescopes of the 2m class which can be relocated to easily change baselines which complement those of the fixed large telescopes. Also, more baselines could be provided at a given time which would result in a better and faster covered UV plane. It was not until later that the power of the small telescopes for providing an independent interferometric array which could be used all of the time was recognised.

The early definition of conceptual choices for the VLTI was performed by an ESO Working Group (VLT Report No. 49, 1986). The development of a detailed technical concept commenced, after the ESO Council approved the VLT Programme in 1987, in 1988 with a team led by Jacques Beckers for more than three years (Beckers et al., 1990a, Beckers, 1990b, Beckers, 1990c, Beckers, 1990d, Beckers, 1991a, Beckers, 1991b). An Interferometry Panel set up from experts in high angular resolution observations and related science fields made many contributions until end of 1992. As a result of the work of this body, the first implementation plan for VLTI was published in 1989 (Beckers et al., VLT Report 59 1989). In hindsight, it is interesting to see how many of the current science targets were already addressed in this report. However, astrometric capability was not considered feasible, as the potential of narrow-angle astrometry was not yet recognised. A second report (Beckers et al., VLT Report 65 1992) addressed the concepts for instrumentation for combined focus (Claret et al., 1991, Reinheimer et al., 1991), and still serves as a reference for the variety of possible techniques to combine beams.

In the meantime, the location for the observatory on Cerro Paranal was decided and the work on the site progressed. The layout of the VLTI – a subject of debates since years – was completed after some fulminant weeks early 1992 and remained unchanged ever since (von der Lühe et al., 1991). The four 8m Unit Telescopes (UTs) are placed in some sort of a semi-circle. A more accentuated circle would have been more desirable but was not possible for reasons of wind obstruction and the quality of the rock in certain locations. The locations of the delay line tunnel and 30 stations for the ATs telescopes were identified and are now cast in concrete. The goal was to optimise the array layout for imaging and to leave the door open for a variety of phase recovery methods.

At this time, VLTI consisted of the coude optical trains on all UTs, two movable ATs (Plathner et al., 1991), two delay lines with a 60m stroke each
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(Jörck et al., 1991), and a beam combination telescope in the interferometry laboratory with an 8 as continuous field (Beckers et al., 1990a, Beckers et al., 1991c). The large field requirement came from the desire to use sources in the field for phase referencing (the equivalent to adaptive optics with a reference star) but resulted in very large dimensions for the delay lines and the transfer optics. An extra budget was foreseen for the development of the fringe detection instrumentation within the community.

The development of VLTI had its all time high when the French Centre National de la Recherche Scientifique (CNRS), the Max-Planck Society (MPG) and ESO signed an agreement on the enhancement of the interferometric mode of the VLT in December 1992 (The Messenger, 1993a). Under this agreement, a third AT and a third delay line could be developed together with the first two, thereby substantially enhancing the synthesis capability of the array by adding phase closure capability. VLTI could be used all of the time with the ATs in phase closure modes, removing much of the pressure from the UTs.

An all time low was reached just a year later, when the ESO Council determined in December 1993 that the development of VLTI should be put on hold for reasons of cash flow levelling (The Messenger, 1993b). The development continued in the form of a “research and development programme” while means to overcome the budgetary situation were sought (von der Lühe et al., 1994 and 1995a, Köehler et al., 1994, Ferrari et al., 1994a and 1994b, Gay et al., 1994a and 1994b). Also, a fresh look at the concept and its scientific justification were taken when the successor to the Interferometry Panel, the Interferometry Science Advisory Committee (ISAC) was assembled in 1995. A summary of a science programme and the resulting conceptual consequences is described in the ESO Messenger (Paresce et al., 1996). One proposal was to limit the operational wavelength for the early phases with Auxiliary telescopes to the near infra-red and with UTs to the thermal infra-red spectral ranges. The VLTI would then not require higher order adaptive optics systems which considerably reduces system complexity and cost. Atmospheric and instrumental control can be limited to tip-tilt compensation only.

Although the efforts to acquire additional funding were not successful, ESO decided in December 1995 to go ahead with the development of a reduced VLTI. A “new plan” which accounts for the recommendations of the ISAC was developed during the first half of 1996 (von der Lühe et al., 1996) in coordination with the partners of the VLTI agreement, in order to secure their continued support. Further details of this plan are described in this paper. The detailed definition of the VLTI is continuing (Köehler et al., 1996, Léveque et al., 1995a, 1995b and 1996). This ESO workshop is another milestone on the way towards a new and improved VLTI.

The implementation of the VLTI is now distributed over two phases. The first phase (Phase A) includes the coude optical trains on two UTs, two delay lines, two auxiliary telescopes and the beam combination instrumentation for the near-infrared (ATs) and the thermal infrared (UTs). This phase is funded and will carry the program through the year 2003. A second phase (Phase B)
includes a third AT, the remaining two coudé trains on the UTs and two more delay lines will require additional funding. Phase B can be concluded by 2005 if funding is possible from 2000 onwards.

3 General Capabilities

3.1 Layout of the VLT Interferometer

Fig. 1 shows the layout of the VLTI on Paranal. The North direction is approximately 20 degrees clockwise from topwards. The four UTs are seen on the upper half of the picture. The delay line tunnel transverses the mountain in the middle. The lower part of the mountain is filled with Auxiliary telescope stations and the tracks on which they will be transported. Two tracks extend across the tunnel to the northern part of the site, the western one passes close by the central facilities where a station is located which will be used for servicing the coudé inlets.

Starlight from telescopes is directed underground towards the tunnel in the form of collimated beams. Mirrors direct the light beams along the tunnel towards the opposite sides where the cat’s eyes optics of the delay line retro-reflect the beams. Another set of mirrors redirects the light near the center of the tunnel towards the beam combination equipment in the laboratory. Beam combination and detection of interferometric fringes occur in the laboratory.

3.2 Availability

Whenever the UTs will be used for the interferometric mode, their time allocation will go through ESO’s ordinary review process, which means competition with single telescope programs. Only observations which require high sensitivity and/or high spectral resolution will usually require UTs. We expect that the use of them will be limited to a small percentage of the observing time initially, and will evolve with experience.

In contrast, the Auxiliary telescopes will be available all of the time for interferometry, as these specialised telescopes will not support any other observing mode. They will therefore support observing programs which need a lot of observing time, but less sensitivity, and for synoptic programs.

3.3 Sky coverage and access

The sky coverage is limited by the sky coverage of the telescopes and the optical delay that the delay lines can produce. All telescopes support a coverage of 60 deg from Zenith with full performance. The delay lines support a coverage of 60 deg from Zenith for baselines up to 130m (i.e., all UT baselines). For AT configurations with baselines larger than 120m, the coverage is reduced and depends on the exact configuration. A good value to use here is 30 deg. Ultimately, the sky coverage can be increased to 60 deg on all baselines.
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two (four) Unit Telescopes equipped with coude trains

UT1

UT2

UT3

UT4

Fig. 1. Configuration of the VLT on Cerro Paranal.

VLTI supports rapid slewing between sources to enable efficient observation of multiple sources and calibrator sources. This is essential for maximizing on-source time. The target time for acquiring fringes on nearby sources (within 1 degree) is of the order of 30 sec. The telescopes can acquire a source anywhere in the sky within 3 min.

3.4 Field of View and Dual Feed

The desire for including narrow-angle 1992 astrometric capability into VLTI with Auxiliary telescopes became apparent in 1994 (Léger et al., 1995, Quirrenbach 1995). The original idea to accommodate this capability was to augment the optics for the Auxiliary telescopes (von der Lühe et al. 1995b). In view of the current changes in the concept we intend to pursue a different approach.

The coude foci of Unit and Auxiliary telescopes will be equipped with dual feeds which support two field angles, one of which is on the axis, to be selected and fed into the interferometer. There will be a 2 as field centered at each of the two field positions. One field position will be used to transfer the light from the source under investigation, the other will be used for phase referencing (UTs...
and ATs) or astrometric referencing (ATs only). The range of the selection will be 5··.60 as from the axis, this accommodates the complete field at the coudé foci. The two beamlines share the delay lines optics.

The concept behind the phase reference is similar to a reference star for adaptive optics; it will serve for image and fringe tracking should the science target be too faint. Atmospheric effects introduce differential phase errors between the two field positions of the dual feed which result in fringe contrast loss. For typical conditions at Paranal, a reduction of fringe contrast by a factor 0.7 occurs for field separations of 10 as at a 2.2 μm wavelength, and of 40 as at 10 μm.

The requirements and engineering implications of narrow angle astrometry are, on the other hand, very severe and need thorough studies. The atmospheric limits to astrometric precision depend linearly on field angle and amount to about 10 μas with a 100 m baseline and 30 min of integration. Achieving this precision in practice requires the knowledge of the vector baselines to 50 μm accuracy and of the instrumental differential delay between the primary and secondary beam to 5 nm accuracy. At this time, the technical limits to determine the differential delay are not known.

The concept for the dual feed is still under development. Although designs for dual feeds exist elsewhere, the requirements for VLTI are not trivial. For example, the requirement for spectral coverage and astrometric precision essentially exclude the use of transmissive optics.

3.5 Fringe-tracked and blind operation

The term fringe-tracked operation refers to the generation of a fringe position error signal near the point of beam combination with a suitable sensor. The Observatoire de Côte d’Azur currently develops a fringe sensor prototype under contract with ESO (Gay et al., 1994b). The sensor operates independently from any other beam combination instrument in the H band (1.6 μm) on the science source or a reference source. The error signal is fed to the control system of the delay lines to adjust their position. The high frequency part of the fringe position error operates on a piezoelectric element which controls the piston of the cat’s eye field mirror.

No fringe sensor is used when operating “blindly”. The delay lines track the expected geometric delay, which is calculated using a model for the instrumental delays and telescope positions, similar to a telescope pointing model. Short exposure interferograms which “freeze” the disturbance effects of the atmosphere are taken. Those will show fringes only if the deviation from zero path difference is small (within ≈ 3 μm in the V band, 10 μm in the K band, and 50 μm in the N band). Atmospheric piston will produce path differences of 10··30 μm rms. This mode requires accurate knowledge of the instrumental characteristics of VLTI.
3.6 Beam combination and Instruments

The beam combination laboratory area will accommodate instruments, at least for the near and thermal IR, along with a number of other subsystems. Figure 2 shows an overview of the layout. Stellar light beams enter the laboratory from below. A switchyard which consists of dichroic and fully reflective mirrors direct the light towards the instruments and to the fringe and image sensors. A calibration unit which provides various sources also feeds both instruments and sensors and assures intercalibration. Laser metrology beams feed the fringe sensor, as well as the instruments, for internal calibration. Other metrology beams travel back to the telescopes and determine the delay line zero position for the internal path. Primary and secondary beams emerging from the delay line carriages (hatched boxes in the tunnel) are directed towards the laboratory in the upper half. The switchyard is near the center of the layout. Instruments are on the top and right. Fringe and image sensors are to the left. The structure to the lower right is the metrology beam launching system.

![Diagram of the beam combination laboratory](image)

**Fig. 2.** Layout of the beamcombination Laboratory.

The initial operation of VLTI will concentrate on the near IR with ATs and on the thermal IR with the UTs. Top-level capabilities of beam combination instruments as recommended by the Science Advisory Committee are given below.

- ISAC recommendations for the Near-IR
  - support four beam lines
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- spectral range 0.7...4 μm with a spectral resolution up to 10,000
- calibration through single mode operation ("spatial filter")
- internal fringe tracking capability
- support dual feed
- ISAC recommendations for Mid-IR
  - support two to four beam lines
  - spectral range N+Q bands (extension to M), resolution up to 1,000
  - calibration through single mode operation
  - internal fringe tracking capability
  - fringe detection by temporal modulation
  - may not deliver "zero spacings"

3.7 Operational Capabilities

The development of VLTI’s capabilities in Phases A and B is shown in table 3.7. The concept of VLTI is prepared for evolution beyond the capabilities of phases A and B, an indication for this evolution is given in the last column.

<table>
<thead>
<tr>
<th></th>
<th>Phase A</th>
<th>Phase B</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of UTs</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Number of ATs</td>
<td>2</td>
<td>3</td>
<td>3+</td>
</tr>
<tr>
<td>Number of delay lines</td>
<td>2 (3 fixed cat’s eye and reduced sky coverage)</td>
<td>4 (5 fixed cat’s eye and reduced sky coverage)</td>
<td>8</td>
</tr>
<tr>
<td>Adaptive Optics</td>
<td>tip-tilt only</td>
<td>tip-tilt only</td>
<td>NIR AO with UT</td>
</tr>
<tr>
<td>Diff.-limited wavelength range</td>
<td>5 - 20 μm with UTs, 1 - 20 μm with ATs</td>
<td>1 - 20 μm</td>
<td></td>
</tr>
<tr>
<td>Relocation of ATs</td>
<td>during the day</td>
<td>during the day</td>
<td>within 1 h</td>
</tr>
</tbody>
</table>

Table 1. Growth of VLTI capabilities with time.

4 Array configuration and UV coverage

Table 2 shows the coordinates of the UTs and the Auxiliary telescope stations. The notation of the array configuration is also indicated in fig. 1. Both latitude and longitude, as determined by a GPS measurement of the location of UT4, and the north and east relative coordinates in meters, relative to the position of UT1, are shown. The nominal height above sea level of the intersection of altitude and azimuth axes is 2676 m for UTs and 2669 m for Auxiliary telescopes. The delay constant is the distance along the optical path from the coude area at each telescope or station to the center of the delay line tunnel, this distance must be taken into account when the position of the cat’s eyes is determined.
The information presented here can be used to calculate the UV response of any configuration of telescopes in the VLTI and the corresponding positions of the delay line carriages.

Baselines between UTs range from some 30m (UT2 and UT3) to some 130m (UT1 and UT4). Baselines are shorter (and the UV coverage is thinner) in the NW–SE direction. Baselines between ATs range from 8m in the SW corner to 200m in the NS direction. The station layout is very flexible, virtually any desired configuration of three or four ATs can be obtained. Some stations have been placed in such a way that the limited UV coverage of the UTs can be...
complemented with baselines between a UT and an AT ("hybrid mode"), to result in an even and circular coverage. The centers of all telescopes and stations are located on an 8m by 8m grid.

Figure 3 shows the UV coverage of the array which consists of only the four UTs. This array is referred to as the "VLT Interferometer Main Array" (VIMA). The source declinations cover the range which is accessible with the VLT. It is evident that the UV coverage of the four main telescopes is less than perfect. There are substantial holes and the NW-SE corner is not well covered.

Some locations of AT stations were selected such as to optimally complement the VIMA array in terms of UV coverage with baselines between a UT and an AT. Figure 4 presents the UV coverage of the array which consists of all four UTs and three ATs located at the stations long track 4 and long track 7 and cross track 2, as an example. This configuration closes many of the holes which are left in the VIMA coverage, but there is still some reduced coverage in the NW direction. This can be improved by including an AT station near the south-eastern end of the site, e.g., cross track 6.

In all cases, a substantial lack of UV coverage will occur for relatively short baselines. This "central hole" is a common problem which is due to the mutual obstruction of UTs by their enclosures, so it cannot be solved with UTs. Only baselines between ATs can be made short enough (less than 8m) to fill the central 25m of baseline space. The cluster of short spacings south of UT1 has been specifically laid out to provide these short spacings.

5 Sensitivity and Limiting Magnitudes

The sensitivity of an interferometer depends critically on the context of the measurement and cannot be comprehensively covered here. We will however give some guidelines which can be used to assess the feasibility of most experiments. An important sensitivity measure is the signal-to-noise ratio of the fringe's contrast magnitude, which is relevant to measurements of visibility magnitude and of referenced phases. Closure phase measurements involve triple product statistics which are significantly less sensitive than visibility magnitude measurements. The visibility magnitude signal-to-noise ratio (SNR) depends mostly on the following factors.

1. Detected source flux: the detected source flux determines directly the strength of the measured signal. Depending on source magnitude, spectral bandwidth and integration time the detected source flux may vary enormously. The associated photon noise grows with the square root of the signal strength. There are two regimes which are distinguished by the significance of the photon noise due to the source. In the photon rich regime, the photon noise of the source dominates all other noise sources, and the signal-to-noise ratio grows with the square root of the flux (one decade of SNR per 5 magnitudes). In the photon starved regime, the photon noise of the source flux is less significant that the noise from other sources. The SNR is now directly proportional to the flux (one decade of SNR per 2.5 magnitudes).
2. Optical quality: any differential aberration of the wavefronts brought to interference results in a loss of fringe signal. The optical quality can be expressed in terms of the Strehl ratio (the ratio of the peak intensities of an point source image with aberrations and an aberration-free point source image), a number which is practically always less than unity. For many methods of beam combination, the Strehl ratio determines directly the fraction of source flux which contributes to the fringe signal. Some beam combination techniques...
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Fig. 4. UV coverages of the VLT Main Array. Declinations: top left $+15^\circ$, top right $0^\circ$, middle left $-15^\circ$, middle right $-30^\circ$, bottom left $-45^\circ$, bottom right $-65^\circ$. Units are meters.

are able to reject the excess flux which does not contribute to the fringe signal. Those have better photon noise characteristics. A common source of aberrations is atmospheric seeing which is incompletely compensated by an adaptive optics system, or not compensated at all.

3. **Thermal background:** measurements in the near and thermal infrared are mostly limited by the emission of the atmosphere and the optics. The thermal background can be modelled by the spectrum of a blackbody at a observa-
tory temperature. It creates signal independent photon noise which increases with the square root of the exposure. The detected background flux is given by the product of the emission coefficient of the atmosphere and the optics, the optical etendue of the detection system, and the integral of the Planck function weighted by the spectral response of the detection system. For an interferometer which has lots of optics, the emission coefficient can be assumed as \((1 - T_{opt})\) where \(T_{opt}\) is the overall transmission of the optics. A beamcombiner which limits the detected field to the Airy disk of an array element has an etendue of \(\lambda^2\) where \(\lambda\) is the mean detected wavelength.

4. **Detector noise**: many detectors generate thermal or readout noise which degrades the signal and needs to be taken into account. This type of noise may have different characteristics with respect to integration time. Thermal noise can be reduced by increasing integration time while readout noise occurs for every readout of a detector, irrespective of how long an integration takes.

5. **Intrinsic visibility**: the proper (“intrinsic”) visibility of the source at the observed baseline determines directly the strength of the fringe signal. Most interesting sources have low intrinsic visibility, a useful range is values from \(10^{-3}\) to \(10^0\).

6. **Coherent and incoherent integration times**: the term “coherent” integration time refers to a single detector readout of a stabilised fringe. Depending on the experiment, the coherent integration time may be milli-seconds (for a measurement limited by the atmospheric correlation time) to minutes (for a measurement with fringe stabilisation which is only limited by the time dependence of the baseline). Several coherent integrations of the fringe signal may be combined to an “incoherent” integration by, e.g., averaging the squared moduli of the fringe amplitude measurements. This kind of integration is relevant when, e.g., each coherent integration would be too noisy to reliably detect the position of a fringe. The SNR of one incoherent integration increases with the square root of the number of accumulated coherent integrations.

7. **Number of elements**: the number of array elements which are simultaneously detected may influence the measured signal on a given baseline. The fringe signal of a non-redundant baseline is given by the intrinsic visibility of the source divided by the number of array elements which contribute to the detection. For example, with beam combination in the image plane where the light of all array elements is superimposed to a fringed source image, all array elements contribute to the detection. Another option is to split the light of each element several ways and to beamcombine pair-wise, then the number of contributing elements is two, but the loss of flux due to the multi-way beamcombination needs to be accounted for.

For a measurement where the detected flux is limited to the fraction of energy corresponding to the Strehl ratio, the signal-to-noise ratio for a measurement of visibility magnitude is given with
SNR\textsubscript{V} = \frac{SN_p}{\sqrt{1 + N_b + SN_p + N_d^2 N_{Tel}}} \frac{V}{\sqrt{K}} . \quad (1)

For a measurement where all of the flux is detected, the signal-to-noise ratio is given with

\[ \text{SNR}_V = \frac{SN_p}{\sqrt{1 + N_b + SN_p + N_d^2 N_{Tel}}} \frac{V}{\sqrt{K}} . \quad (2)\]

\( S \) is the Strehl ratio, \( N_p \) is the number of detected photons of the source, \( N_b \) is the number of detected photons of the background, \( N_d \) is the \textit{rms} detector noise expressed in photon counts, \( V \) is the intrinsic visibility of the source (i.e., the quantity of interest), \( N_{Tel} \) is the number of array elements which contribute to the fringe measurement, and \( K \) is the number of coherent integrations averaged to form the (incoherent) measurement.

Figures 5 to 5 show the dependence of the signal-to-noise ratio with source magnitude under a variety of conditions which apply to the combination of two elements of the VLT Interferometer. Each figure refers to a different photometric band and shows two sets of four panels. The four upper panels refer to combination of two CTs, the lower four refer to combination of two ATs. Each panel has four plots which represent, from top to bottom, intrinsic source visibilities of \( 10^0, 10^{-1}, 10^{-2}, \) and \( 10^{-3} \).

In each set of four panels, the top left panel refers to the sensitivity of a fringe tracker with a coherent integration time adapted to the atmospheric correlation time and using the full width of the photometric band. The top right panel refers to coherent integration of 900 sec with the exception of the N band where an incoherent integration of 50 msec exposures, covering 900 sec, is shown. The spectral bandwidth is 200 mA and represents a high spectral resolution mode. The bottom two panels show the SNR for incoherent averages of many short exposures with a spectral bandwidth of 100 \( \text{mA} \), totalling 900 sec integration time. All panels except for the bottom right ones assume the operation of an adaptive optics compensation system which improves the Strehl ratio. The adaptive optics is optimised for the near-infrared (4.5 degrees of freedom per \( \text{m}^2 \) area in the entrance aperture and a closed loop bandwidth of 50 Hz) and the improvement in the V band is marginal. The bottom right panel represents the “blind tracking” mode without the use of adaptive optics and fringe control loops. All cases assume a single pixel detector which is photon counting for the V band (no detector noise). The assumed overall optical throughput including detector sensitivity is 0.1.

These plots are intended to provide an indication of the sensitivity of the VLTI, and require some comments to avoid misunderstandings.

1. All initial observations with the VLTI will be done with a single baseline, so the SNR shown was calculated for \( N_{Tel} = 2 \). Adding more baselines either reduces the source flux by a factor \( N_{Tel} - 1 \) if an \( N_{Tel} \)-way pairwise beamcombiner is used, or \( N_{Tel} \) in eqns. 1 and 2 needs to be adjusted.
Fig. 5. SNR of the visibility magnitude for the V band.
Fig. 6. SNR of the visibility magnitude for the J band.
Fig. 7. SNR of the visibility magnitude for the K band.
Fig. 8. SNR of the visibility magnitude for the N band.
2. The fringe tracking case appears to be less sensitive than the long integration case which presupposes fringe tracking. With the VLTI, fringe tracking will be performed in the H band, so one should take the J band curves which are similar to the H band performance. The plots are representative for the ATs where "adaptive optics" will be realized in terms of fast tip-tilt guiding, rendering the ATs diffraction-limited in the near-infrared. The plots are representative for the UTs only with an adaptive optics system, which is currently not part of Phases A or B. Therefore the sensitivity for fringe tracking with UTs without AO systems will be somewhat lower than indicated here, about at the level of the sensitivity of ATs.

3. In case that more than two telescopes are used, fringe tracking may be performed on shorter baselines which tend to sample higher intrinsic visibilities, while long term integration is performed on the longer baselines with lower visibility. This potential may unveil the real power of the fringe tracking mode.

4. The long exposure cases all assume a spectral bandpass of 200 mÅ which is relevant to shorter wavelengths, but definitely too narrow for the K and N bands. The curves shown are therefore rather conservative. Also, the SNR per spectral channel is shown. A beamcombiner with a dispersive element may permit many channels to be detected, where the signal could be combined to increase the SNR even further.

6 Conclusions

We have described the current status of the interferometric mode of the ESO Very Large Telescope. The development plan for the VLTI has been adapted to the difficult financial situation by substantial modification of the concept and by implementing capability gradually in two phases. We feel that the modifications simplify the project in many areas while even strengthening the scientific potential. However, introducing the astrometric capability is a new requirement which will certainly be difficult. When Phases A and B are completed, a large subset of the initial goals for VLTI will have been put into existence. At this time, the VLTI will be far from complete, and one should prepare for further upgrades.

An important capability will be the near infrared capability of Unit telescopes through adaptive optics. Those can be systems which are optimised for interferometric use and therefore may be simpler than standalone adaptive optics systems developed for other instruments. Introducing adaptive optics will tremendously increase the sensitivity with the UTs, as indicated by the SNR plots. Another important capability would be extending the spectral regime towards the visible, opening a wide range of spectral diagnostics and even higher resolution. Similarly important would be adding a fourth Auxiliary telescope and more delay lines to bring the number of beamlines up to a number of eight. VLTI will then unveil its full potential as an optical aperture synthesis array.
References


