4. The Next Steps

The next major milestone in 2001 will be First Fringes with UT1 and UT3 in November. The installation of the coudé optical trains and of the relay optics in the Unit Telescopes is progressing – the coudé focus of UT3 had its First Light in May – as well as of the beam compressors in the VLTI Beam Combination Laboratory. The beam compressors are required to convert the 80 mm collimated beam from the UTs into a 18-mm input beam for the instruments and to improve the sensitivity when observing with the siderostats. In addition, tip-tilt sensor units (STRAP) will be installed in the coudé foci of the UTs improving the beam feeding into the optical fibres of VINCI.

This wraps up the VLTI activities for this year. A complete summary of the subsystems and of the instruments of the VLTI can be found in the proceedings of the SPIE conference on Interferometry in Optical Astronomy [3].

In 2002, the science instruments MIDI and AMBER and the fringe sensor unit FINITO will arrive, and the integration of the Auxiliary Telescopes will start. Figure 7 shows the erected mechanical structure of AT1 at AMOS in Liège, Belgium. Once the ATs and the science instruments are functional, regular science operations can start. The following article by Francesco Paresce [2] gives a taste of the science programmes that are planned with the VLTI.

5. Acknowledgements

In addition to the authors of this article, about twice as many ESO staff have contributed to the VLTI. Unfortunately, there is not enough room to name them all. Fortunately, we did have the support of such a large and experienced team, and we would like to thank all of them for their enthusiasm and their hard work.

The results presented in this article were produced with the software provided by the Observatoire de Paris for the Jean-Marie-Mariotti Centre for Interferometry in Grenoble.

References

[1] Glindemann, A., et al. 1999 *The Messenger* **98**, 2–7.
[2] Paresce, F., et al. 2001, *The Messenger* – This volume.
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Scientific Objectives of the VLT Interferometer

F. PARESCE, ESO

Astronomers have long sought to improve the sensitivity and spatial resolution of their observations in order to see as far back in time and as sharply as possible. As the photon-collecting power scales as the telescope diameter D^2 and spatial resolution as D^{-1}, the solution of the problem has always been in the form of ever larger collecting-aperture telescopes. Unfortunately, although this solution did indeed increase dramatically the sensitivity of astronomical observations, it still was far from ideal in terms of spatial resolution owing to the negative effects of the earth's atmosphere. On the ground, the improvements were mainly due to finding the proper location where the seeing was best (California, Hawaii and Chile) and, more recently, to the technique of adaptive optics as shown schematically in Figure 1.

Apart from the development of a ~100-m-diameter telescope, the foreseeable breakthroughs in optical/IR resolution in the near future are essentially only two: operating in space (HST and, in the future, NGST) and aperture synthesis interferometry. In essence, even going to space with a simple filled aperture telescope of 6 m diameter (NGST) still does not approach the potential of the latter technique even on the ground. This is especially true in the infrared at 2.2 μ where very high sensitivity can be coupled to very high angular resolution of ~1 milliarcseconds (mas).

Because of these considerations, interferometry has begun to play a central role in ground-based high-resolution astronomy, and numerous instruments have been completed or are in the process of construction (see Table 1 for a summary of the present situation in this regard). Several large-aperture interferometers will come on-line in the next few years. The impending presence of these new instruments represents an important incentive both for clarifying the scientific cases for various VLTI implementation plans and for ensuring VLTI's competitiveness in the international context over the next 10–20 years.

It has always been ESO's aim to operate the VLT in an interferometric mode which allows the coherent combination of stellar light beams collected by the four 8-m-diameter telescopes (UT) and by several smaller 1.8-m-diameter auxiliary telescopes (AT). Thus, the VLTI has the unique advantage of being the only large telescope facility together with the LBT designed from the very start as an interferometer. This means that it will have three main characteristics that are unprecedented for this type of array:

• very high precision visibilities (up to $\Delta V/V=10^{-4}$) for moderately bright sources,

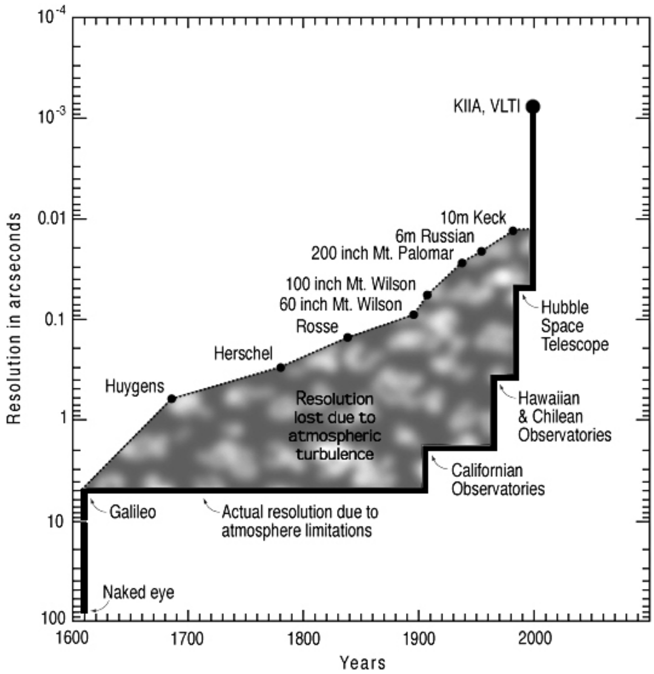

Figure 1. Spatial resolution as a function of historical time since Galileo. Adapted from P. Bely (ESA SCI(96)7, 1996).

Table 1. Current ground-based optical long-baseline interferometer projects

Programme (Nation)	No. of simultaneous baselines (ultimate)	Maximum baseline [m]	Telescope diameter [m]	Status or year of first fringes
GI2T (F)	1	65	1.52	Operational
ISI (USA)[3]	1	35	1.65	Operational
COAST (GB)	3 (6)	100	0.40	Operational
SUSI (AUS)	1	640	0.14	Operational
IOTA (USA)	1 (3)	45	0.45	Operational
NPOI (USA)	3 (6,15)	250	0.35	Operational
ASEPS (USA)	1	100	0.45	Operational
CHARA (USA)	10	350	1.00	2000
KIIA (USA)	1/6/15[1]	75/180[2]	10/1.8	2001
VLTI (EUR)	6/3/21[1]	128/200[2]	8 /1.8	2001
LBT(USA/I/D)[4]	1	20	8.4	2005
MAGELLAN (USA)	1	20	6.5	>2005

Notes: [1]Beam combination: main / auxiliary / hybrid. [2]Between main / auxiliary telescopes. [3]Heterodyne, to be changed into a homodyne interferometer. [4]Monolithic array.

• excellent (u,v) coverage (a synthesised beam of 1–2 mas FWHM at 2 μ),
• very high sensitivity to faint sources (down to K ~ 20 with a brighter reference).

Of course, it has to be realised that, in practice, these capabilities will be acquired over a period of time in various phases starting with the easiest to implement and progressing to ever more demanding capabilities. The dates listed in Table 1 represent the start of operations in the various facilities with the most basic of capabilities. In general, these phases can be broken down into the following periods:

Phase 1: two-beam combination to measure fringe visibility leading to the amplitude of the object's Fourier transform. This phase usually includes the gradual development of additional capabilities leading to a significant improvement in sensitivity like on-source fringe tracking and wave-front reconstruction using adaptive optics (AO) techniques. In this phase, earth rotation and relocation of telescopes over a grid of different positions ensure a reasonable coverage of the (u,v) plane in order to obtain a well behaved point spread function for moderately bright objects (K~14). These capabilities allow one to reconstruct several components of the object's Fourier transform and, by fitting to a few-parameter model, to invert the transform and extract useful astronomical information at resolutions of several mas for simple objects with the main arrays and moderate spectral resolutions in the 1–20 μ range.

Phase 2: maintaining equal optical paths in the two beams to within a fraction of a wavelength or co-phasing the interferometer. Fringes can be tracked on a bright reference star, allowing long integrations on the fainter target source located an atmospheric coherence length away (~ 1′ at K). This allows phase-referenced imaging of sources of brightness up to K ~ 20 with the UT (main array, VIMA) and very accurate astrometry with precisions up to 10 microarcseconds (μas) with a dual beam instrument such as PRIMA for the VLTI with the AT (auxiliary array, VISA). This phase will follow the first by a few years for the VLTI.

Phase 3: combining beams from more than three telescopes, ideally up to eight for a measurement of visibilities on 28 baselines simultaneously yielding a closure phase for 21 triangles. This would determine the exact fringe position as a measure of the phase of the Fourier transform of the object's brightness distribution. Combined with the visibility measurements, this allows, in principle, model-independent reconstruction of an image of the object. This phase requires developing a complex 8-way beam combiner and using many delay lines implying an advanced sophistication in the management of many highly complex and extremely sensitive components working simultaneously. The final outcome is an instrument capable of generating images on suitable sources of a few tens to a few hundred non-zero intensity mas spatial resolution elements or as many as the number of independent measurements in the (u,v) plane. This phase might also include more sophisticated AO techniques to allow expansion into the visible range and higher spatial and spectral resolutions.

Phase 4: enlarging the instantaneous field of view of the array from a single telescope Airy disk (~ 0.1–1″) to several arcseconds as required for imaging of complex extended sources such as a dense cluster of stars. This can be accomplished with a Fizeau-type interferometer with homothetic mapping over a large field. Attaining this capability, in essence, would place the VLTI at the pinnacle of human achievement in its attempt to resolve or distinguish very faint and distant astronomical objects as shown in Figure 1.

ESO is defining and prioritising the key science drivers for each phase of the programme and the technical specifications that flow from them. This article briefly presents these science goals as they currently stand. The list is not meant to be frozen or complete, but rather is intended to stimulate community reflection and comment. As already evident from the position of VLTI in Figure 1 with respect to all other facilities currently available, the kind of data which interferometry will access is so far beyond our current experience that it is inherently difficult to specify a definitive science justification. Indeed, much of the prospects are more in the nature of the unexpected. Although optical interferometry carries within it the potential to revolutionise whole areas of astronomy, it suffers currently from the difficulty to exactly foresee the details of the revolution. No one yet has peered into the very core of an AGN, for example, as the VLTI surely will and one can only speculate by engaging in risky extrapolations as to what one might find there. This is especially true since interferometric performance is still not well understood for a large class of sources which are extended on the scale of a few Airy disks.

In any case, it is still relatively straightforward to foresee, at least in general terms and on the basis of the expected VLTI performance parameters just described, the areas of research where VLTI is most suited to providing the kind of potential breakthroughs that we currently require in order to better understand our universe. Although the VLTI targets are mainly located in our relatively local universe due to the limitations in sensitivity inherent in high spectral and spatial resolution interferometry even with large telescopes, the impact of these breakthroughs on our knowledge of the furthest reaches of the observable universe cannot be underestimated. This is especially true when one considers that much of the universe consists of stars and fundamental information on stellar formation, the IMF, binarity, ages and distances are crucial in unravelling the mysteries of galaxy and structure formation, the reionisation of the IGM by the first stars, etc.

These research areas are the following:

• The structure and composition of the outer solar system.

• The mass function of-low mass stars, brown dwarfs (BD) and planets.

• The direct detection and imaging of extra-solar planets.

• The formation mechanism of stars and planetary systems.

• The formation of star clusters and their evolution.

• The surface structure of stars.

• The accurate distance to galactic Cepheids, the Large Magellanic Cloud and globular clusters.

• The baryonic composition of the galaxy's spheroid.

• The physical mechanisms responsible for stellar pulsation, mass loss and dust formation in stellar envelopes and evolution to the Planetary Nebula and White Dwarf stages.

• The structure and evolution of stellar and galactic nuclear accretion disks and associated features (jets, dust tori, Narrow-line Regions, Broad-line Regions, etc).

• The nature of the Milky Way nucleus surrounding the central black hole (BH).

• Interacting binary evolution and mass transfer mechanisms.

• The structure of the circumstellar environment of stellar BH and neutron stars.

• The evolution of the expanding shells of novae and supernovae and their interaction with the interstellar medium and its chemical enrichment.

• The mass distribution of the galaxy beyond the solar circle.

• The internal dynamics of star clusters and tidal interactions with the galactic potential.

Naturally, as the VLTI evolves in this time interval through the four development phases briefly outlined above, the quality and volume of information to be garnered in most areas will grow allowing fainter, more distant and/or more complex objects to be studied with greater accuracy.

This is the executive summary of a report with the same title prepared by the author for ESO in February 2001. The complete text can be found at: http://www.eso.org/projects/vlti/science/VLTIscienceMarch2001.pdf

2p2 Team News

H. JONES, E. POMPEI and the 2p2 Team

Personnel Movements

Team member Patrick François returned to the Observatoire de Paris after several years with the team, his last of which was as Team Leader. We wish him continued success back in France. Patrick's responsibilities have been taken over by John Pritchard, who joined the 2p2 Team in April. Before joining ESO, John was a New Zealand Science and Technology Post-Doctoral Fellow, hosted by Copenhagen University Observatory. John has interests in Magellanic Cloud Eclipsing Binaries and was already a frequent visitor to La Silla before commencing work at the observatory.

In April we were also joined by Ivo Saviane and Rainer Madejsky. Ivo previously held a postdoctoral position at UCLA, studying stellar populations in dwarf galaxies, globular clusters, and the chemical evolution of galaxies. Rainer is a part-time team member and EIS Visitor, presently on leave from his university in Brazil, the Universidade Estadual de Feira de Santana. His scientific interests include interacting galaxies and the evolution of galaxies.

News from the 2.2-m

It has been a busy time at the 2.2-m telescope and there are three articles in this issue of *The Messenger* that cover recent activities at the 2.2-m in detail.

In March, Fernando Selman, Lutz Wisotzki and Alain Gilliotte commissioned two grisms (red and blue) for use with the Wide Field Imager (WFI). They offer a combined wavelength coverage of around 400 to 900 nm with dispersions of around 0.7 nm per pixel. For more details, see their special article about the new grisms and the possibilities they open for wide-field slitless spectroscopy with the WFI.

The 2.2-m telescope has been running under the VLT-style Observing Software for nearly half a year. This means that Observing Blocks are prepared and executed in a manner similar to that at the VLT, NTT and 3.6-m tel-

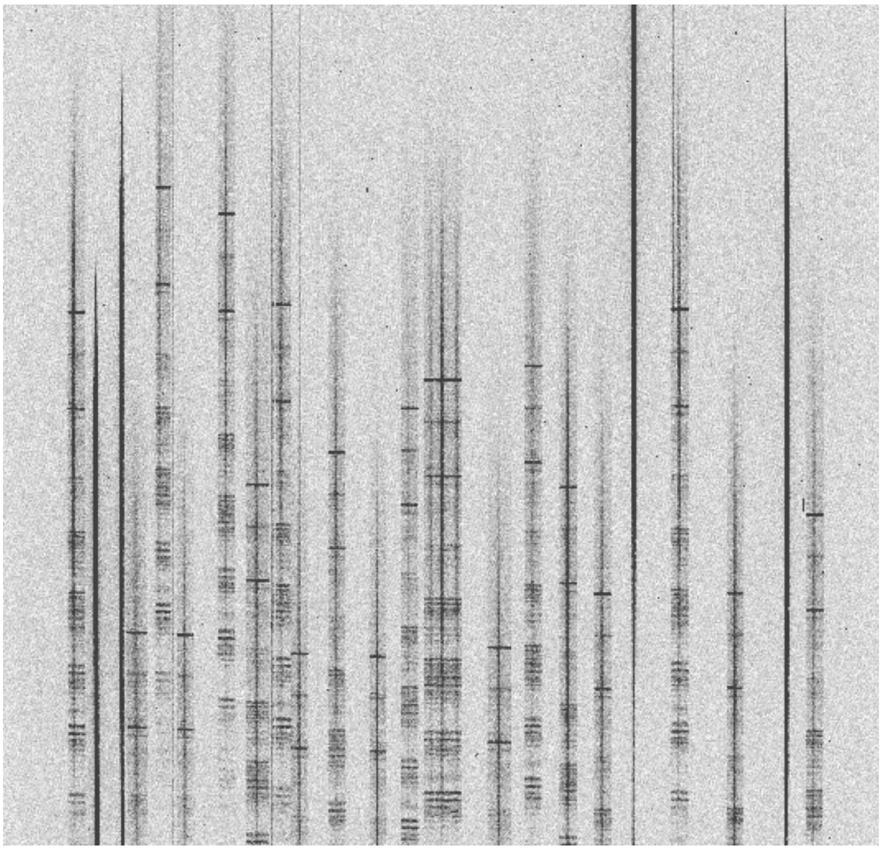

Figure 1. Twenty-minute exposure of galaxy spectra from the EIS 61 field, taken with the Danish 1.54-m in multi-object spectroscopic mode.