An Interferometric Mode for the VLT
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1. The Emergence of Optical Interferometry

The heart of the VLT concept is the choice of an 8-m thin mirror. As early as 1963 (at the Cargèse Workshop), it was thought that an array of several telescopes, with its great flexibility, might be preferable to a giant Multi-Mirror Telescope. An array concept was presented at IAU Colloquium 79 in April 1984. It immediately appeared obvious that one had to investigate whether a coherent combination of the array telescopes would work. On the one hand, formidable difficulties were expected, on the other it presented an exceptional possibility to greatly increase the scientific potential of the VLT and to give it a unique and long lasting capability among planned instruments. This evaluation became the task of the Interferometry Working Group.¹

The main questions to be answered were: Which gain can the use of large telescopes in optical interferometry bring? Do acceptable compromises exist between the interferometry requirements and the more conventional use of the VLT, as required by a large fraction of today’s European astronomical community? Is interferometry technically feasible with large telescopes, given the limited experience in this field available today? Can the associated costs be identified and accepted?

Fortunately, during the investigation by the Working Group (1984–1986), the interest for diffraction-limited imaging at optical wavelengths rapidly grew within the community. The maturation of speckle techniques led to several discoveries: separation of Pluto and its moon, Charon, resolution of the hypothetical supermassive star R 136a, of T Tauri, of the nucleus of NGC 1068. Shells (IRC +10216, OH-IR stars) and pothetical supermassive star R 136 a, of T Tauri, of the nucleus of NGC 1068. Shells (IRC +10216, OH-IR stars) and

² The growing interest is shown by several successive meetings: ESO Conference on High Angular Resolution (Garching 1981); joint ESO-NOAO Workshop (Onsala 1987); ESA Workshops (Garching 1984, Granada 1987) and their copious Proceedings, as well as the increasing literature on the subject. A recent review (P. Roddier, Physics Reports, 1987, in press) gives over 1,000 references on "Interferometric Imaging in Optical Astronomy."
of magnitude gain in sensitivity and/or integration time over smaller interferometers, and limited but appreciable imaging capabilities comparable to the ones of VLBI.

3. A Scientific Programme for Interferometry

On the basis of the above conservative performances, and when a factor of 20 in angular resolution is obtained over almost two decades of wavelength, a wide field of new observations and programmes will open. It is probably within the fields of star formation and galactic nuclei that the new contributions will become most important, at least during the first phase of infrared observations and programmes.

Only VLA centimetric observations give today access to the innermost part of the core of an object like L 1551, considered a prototype of a very young object. The high dust opacity of the disk and its temperature make infrared interferometry one of the most powerful tools to investigate the environment of proto- and young stars. Recent indications on the existence of accretion disks around T Tauri stars lead to the same conclusion. Presently, the sample of very young objects embedded in dense molecular clouds is limited to a few dozens, rapidly increasing as IRAS survey data are analysed and followed up by ground-based studies. Although none of these can yet be proven to be a protostar stricto sensu, spectroscopy indicates that the regions of accretion or ejection of matter will only be accessible to interferometry. About five disks have been identified with reasonable certainty and more than ten are suspected in nearby associations, all are a few hundred A.U. in size. The relations between disks and large scale mass outflows, local magnetic fields, locally collimated flow and rotation axis all need to be investigated on the 10–100 milliarcsecond scale.

Galactic nuclei at infrared and visible wavelengths offer another field of investigation. The structure of the Broad Line Region appears to be close to the available resolution. The small (<1 milliarcsec) and bright, visible nucleus of a Seyfert galaxy is suitable as point-reference source for infrared interferometry which allows phase control, similar to self-calibration in radio astronomy, and long time integration.

When interferometry progresses towards visible wavelengths, the mapping of the star surfaces will open a new field in stellar physics: convection cells, surface magnetic fields, shock waves in red evolved variables, mass exchanges between close binaries are problems which all fall in the range of resolution and sensitivity discussed above.

4. Technical Feasibility

Since the currently existing optical interferometers are modest in size and recent in completion, the practical experience in interferometry, although growing continuously, is not very extensive. There is nevertheless agreement about the critical issues: they are mainly the vibrational stability and the beam combination.

The vibrational stability set very strict tolerances, never before encountered in telescope design except what concerns the stability of the primary and the secondary mirrors themselves: the longitudinal (i.e., along the optical axis) displacement velocities must remain below 5 to 10 μm/s rms, or certainly smaller than what current mechanical design may achieve. This necessitates the use of active control to cophase internally the array, in the same way as each VLT primary mirror is cophased by active optics. Recent measurements carried out at La Silla (Fig. 1) show that existing large telescopes, although not especially designed for this purpose, have a stability which is not far from interferometric requirements: surprisingly, this stability appears fully adequate to allow coherent coupling between the 3.6-m and the CAT 1.4-m at a wavelength of 10 μm.

The strategy for beam combination, path compensations, and signal detection is an issue that has a number of solutions, depending on wavelength, relative size of the source and field-of-view. The extraction of coherent beams from each telescope has to be considered first. The VLT Proposal relies on classical mirror trains, common to the incoherent and the coherent modes, but the emergence of single mode optical fibers may make this approach obsolete and provide a convenient and economical coupling between each Nasmyth focus and the interferometric tunnel. For the beam combination itself, some common facilities have already been studied (Figs. 2, 3, 4). The progressive construction and operation of small interferometers will bring considerable experience in the next decade. New ideas are emerging, such as the Double Fourier Technique (Fig. 5), applicable at infrared wavelengths and potentially efficient in the use of observing time.

Since the main phase disturbing factors, atmospheric phase distortions, random time fluctuations and mechanical vibrations, all appear less detrimental and easier to correct when the wavelength increases, it has been proposed to begin the exploitation of the interferometric mode of the VLT with infrared wavelengths (λ > 3 μm) and to progressively extend it towards the visible. This step-by-step approach should minimize the technical risks.

5. Operating the VLT as an Interferometer

The availability of VLT observing time in the interferometric mode can only be considered for programmes of the highest scientific value, where the sensitivity and/or time gains provided by the large diameter are justified, when compared with the performances of smaller instruments. This situation is rather similar to the one of speckle programmes on existing large telescopes. Together with the need of frequency coverage discussed above, this led the Working Group to propose the inclusion in the VLT design of two additional, smaller and movable telescopes which are permanently available for interferometry and which can be coupled to the large ones, whenever requested. The design of these telescopes could be derived from the current interferometric programmes underway in France, Germany, the United Kingdom and the United States. For instance, a well engineered Phase A study is now under way at the Institut de Radioastronomie Millimétrique (IRAM, Grenoble), under contract by the French CNRS/INSU for the concept of interferometric telescopes of the 2-m class.

It has already been acknowledged that the VLT operation, even in incoherent mode, shall require more sophisticated, more decision aids and more artificial intelligence than is usual in optical astronomy. Interferometry, which gradually adds some complexity to the operations, will also make use of the overall basic flexibility of the VLT design.
6. Impact of the Site

The most critical factors for interferometric quality are the seeing and the infrared transparency; these two factors are indeed essential for all VLT purposes. The baseline choice comes next. A compact site like the main Paranal summit would force us to accept a redundant configuration, with a maximum East-West baseline of ~125 m. There would be some difficulties in the North-South baseline implementation but it would nevertheless be acceptable.

Some second-order parameters, specific to interferometry, like the microseismicity and the outer scale of atmospheric turbulence, will have to be investigated in the future.

7. Conclusions

In this short review we have summarized the main lines of thought which led to the inclusion of interferometry into the VLT Proposal. Subsequent cost estimates will have to be refined as the project progresses and several items deserve construction of laboratory models as well as research and development.

If the technical difficulties are solved, and it indeed appears that they are less formidable than initially thought, then the implementation of the interferometric mode will add a great and unique scientific capability to the VLT. It will represent long-term investment and put European optical astronomy in a leading position.