Bulletin de la Société Royale des Sciences de Liège, Vol. 74, 5-6, 2005

Synergies between a Future Generation Interferometer and Extremely Large Telescopes

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Abstract: The potential synergies between Extremely Large Telescopes (ELT) and New Generation Optical and Infra-red Interferometers (NGOI) are investigated both on the scientific field and on the technical point of view. ELTs would provide full u-v coverage and imaging capabilities up to *baselines* of several tens of meters on very faint objects but would be limited mainly by the performance and artifacts left over from the segmented technology and adaptive optics. NGOIs with very long baselines (up to several kilometers) would give access to even smaller details with much better mastered and easier to calibrate artifacts but only on relatively bright objects. So ELTs and NGOIs are more complementary than concurrent.
Synergies on the technologies to be developed for both projects as well as the different requirements and constraints in terms of site choice are also highlighted.

1 Introduction

In the frame of the current feasibility study phase of Extremely Large Telescopes (ELT) taking place on both sides of the Atlantic (Sanders 2004, Gilmozzi 2004, Andersen 2004), it is important to analyze if all scientific fields targeted by ELTs are best fulfilled with such filled aperture of several tens of meter diameter or if some fields are not better suited to very long baseline interferometers. In section 2, these scientific complementarities are studied based on the parameter space. It can then be envisaged to start building New Generation Optical and Infrared Interferometers (NGOI) at the same time as an ELT, following (or not) the way the Very Large Telescope Interferometer (VLTI) used the impulse of the VLT construction to produce one of the most efficient interferometric facility available today in optical / infrared astronomy. Indeed some technologies to be developed for each field could be common and know-how could be shared, as for example in the structure and mirror production, in co-phasing and in detector technology (see section 3). However, it is not certain that, as for the VLT-VLTI, both an ELT and an NGOI could be developed at the same site, with the same kind of telescopes, as some constraints on the environmental parameters could be different (section 4). On the opposite, if both projects can share enough development, the cost and schedule could remain in an affordable range.

In this paper, the following assumptions are being made:

- for the ELT, the concept of OWL (OverWhelming Large Telescope) as presented in the

OWL Blue Book of October 2005 (OWL team 2005) is taken: fully steerable 100 meter diameter telescope with segmented spherical primary, equipped with adaptive optics;

- for the NGOI, the conclusions of the 2004 Liège's workshop on future generation of optical / infrared interferometers are used (Quirrenbach 2004): spare array of 10 to 20 10-meter-class telescopes, each equipped with adaptive optics, on baselines of up to 10 km.
- all technological challenges posed by both projects (like adaptive optics for the ELTs or the beam transport for the NGOIs) have been solved successfully and within the current hopes.

Space telescopes and interferometers as well as LBT-like interferometers (LBT stands for Large Binocular Telescope) are being excluded from the current discussion as they are specifically addressed by other authors in these proceedings (Coude 2006, Herbst 2006).

2 Scientific synergies

The main scientific objectives of ELTS are linked to imaging and spectroscopy with a very high sensitivity. The limiting magnitude goal of OWL stands at higher than 30 in the visible. These very high limiting magnitudes are necessary to study the galaxies in the early universe, the dark matter and dark energy, and the early stars (to study the stellar populations across the universe, at various stages of its expansion). An example of the resolution and sensitivity of an ELT compared to the current telescopes is given in figure 1. Thanks to the high resolution that such telescopes provide, the problem of field crowding is not as critical as it is for seeing limited telescopes: many stars are dug out of the background but can be distinguished from each other. However the presence of bright stars close to the field of view combined with the complex structure of the Point Spread Function (PFS) of a multi-segmented telescope (see figure 2) could cause some problems.

In this field of cosmology and faint targets, ELTs have almost no concurrence from NGOIs. Indeed, NGOIs have a very low limiting magnitude compared to ELTs: around K-magnitude 13 for self-fringe tracking up to maximum 20, if a suitable bright star can be found nearby to stabilize the fringes. Moreover, the field of view of an interferometric spare array is very small (one PSF or seeing-limited spot), except if complex wide-field or compositing techniques are used. In any case, a typical interferometric field of view will never grow up to more than some arcseconds. In interferometry field crowding is not a big issue as long as all telescopes point at the same point in the sky (within the PSF).

At those magnitudes and field of view, only the central core of the closest extra-galactic objects can be studied with interferometers. This contribution of interferometry is essential, as has been proven by the first observations on NGC1068 (Jaffe 2004) and NGC4151 (Swain 2003), but cannot be compared to the broad breakthrough that ELTs would bring in the cosmological field.

Other important targets for ELTs are located close to very bright objects: environment of close-by stars, dust disks, extra-solar planets, imaging of planet atmospheres in our solar system... All these objectives require extreme adaptive optics (with Strehl ratios of the order of 99%) and/or coronographic techniques. Indeed the diffracted light from the bright star would wash out the faint signals that astronomers are looking for. As shown in figure 2, the PSF of a segmented telescope with large support structures for M2 presents several strong artifacts expanding far from the central peak.

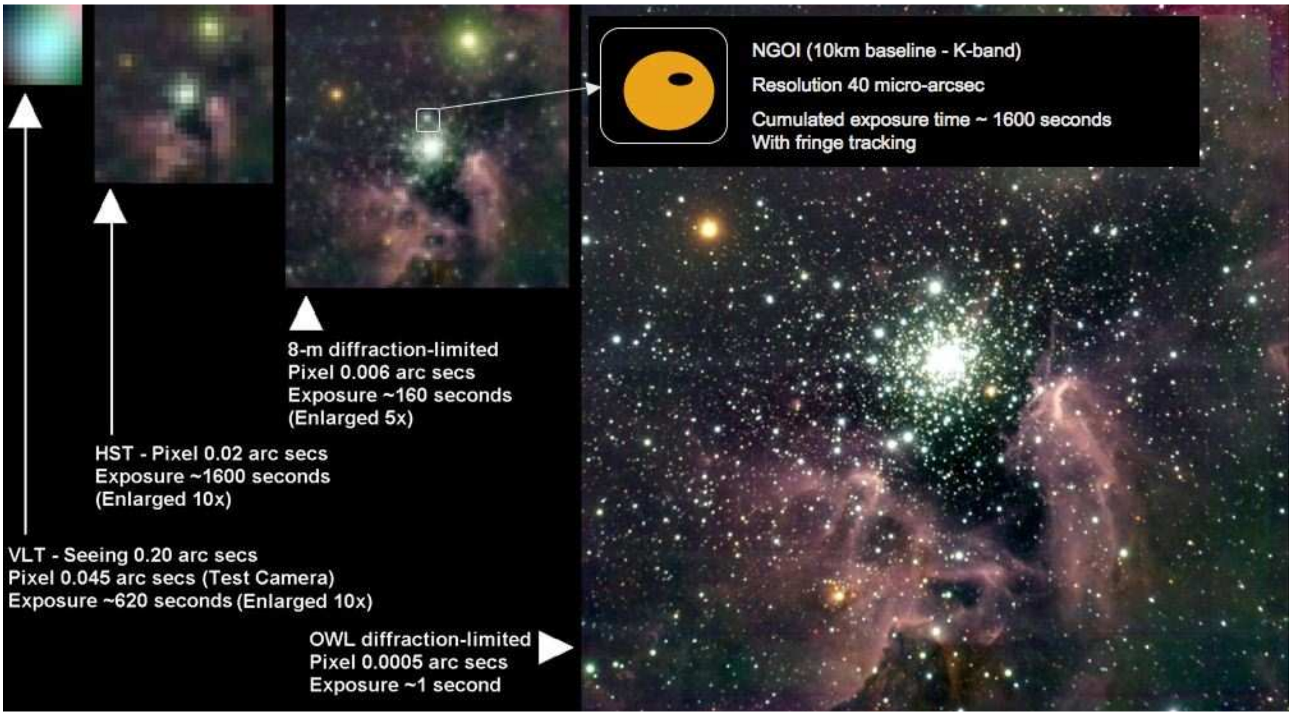

Figure 1: Resolution and sensitivity of different type of telescope: 8-meter-class ground-based seeing-limited telescope, 2-meter-class space telescope, 8-meter-class diffraction limited telescope and 100-meter-class diffraction limited telescope (courtesy ESO OWL team). The resolution and field of view of an NGOI is superimposed as a resolved elongated star with a spot.

It is also well known that PSF characterization of adaptive optics corrected telescopes is a very difficult task. The feasibility of high contrast coronography and of the observation of faint objects very close (a couple of PSF diameter) to bright star with adaptive optics, especially on corrected segmented telescope, is still to be proven. The construction of Planet Finder for the VLT is a step in this direction.

Contrarily to ELTs, interferometers are particularly (if only) adapted to bright targets. As shown by the masked aperture technique (Tuthill 2005) on the Keck telescope, the PSF equivalent for this interferometric technique is very well controlled and calibrated. This allows a better deconvolution of the image and the extraction of fainter details close to the central bright image core. Moreover, NGOI, with their larger baseline than ELTs diameters, can access details even closer to the star. Having access to several baseline lengths as in a spare array allows the adjustment of the interferometer resolution to the target under study so that the researched details can pop out in particularly cleaned up portions of the reconstructed PSF. The use of monomode optical fibers in interferometry also helps cleaning the field of view and eliminating any artifacts resulting from the individual telescope optical design.

It would thus be particularly interesting to compare quantitatively the performance of the following techniques on the search of extra-solar planets:

- extreme adaptive optics on ELTs,
- masked aperture technique on ELTs,
- nulling interferometry on ground and space interferometers,
- interferometric imaging with NGOIs,

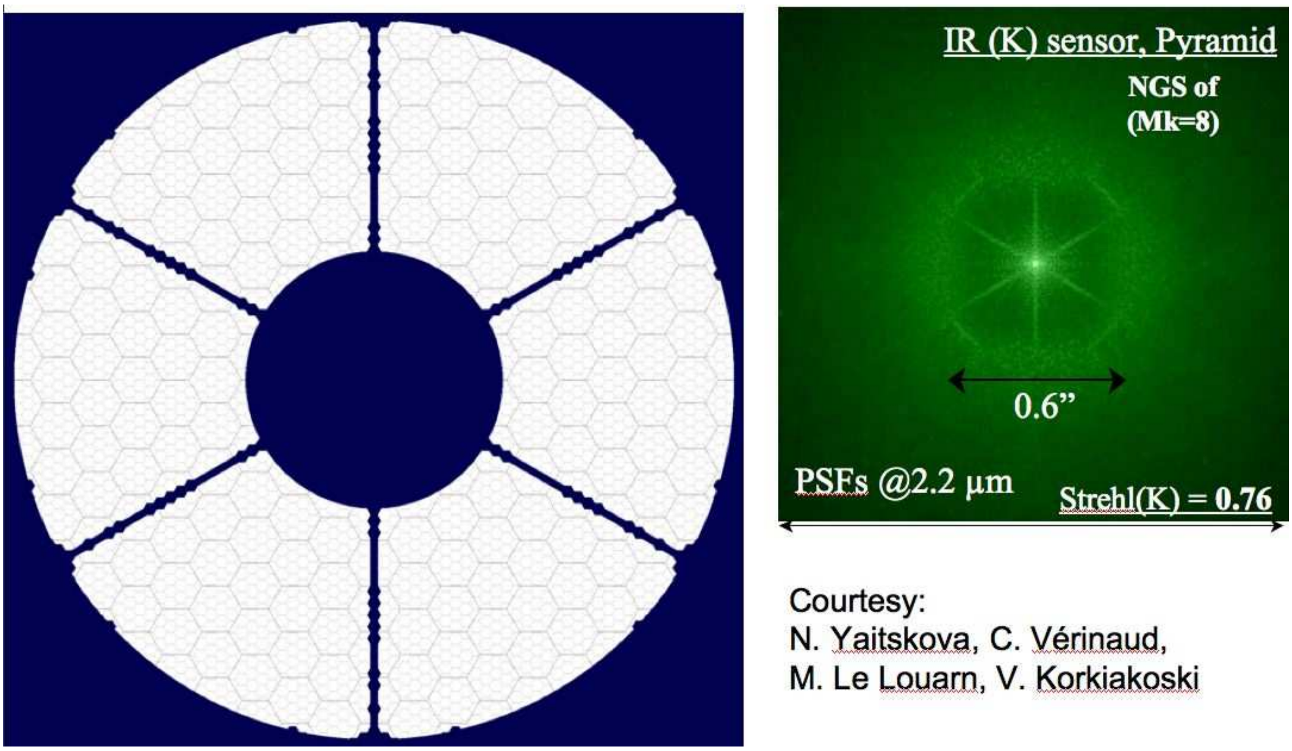

Figure 2: Typical simulated PSF (right) of an adaptive corrected OWL segmented pupil (left). The main PSF structure arise from the so-called *missing segments* (segments behind the mechanical support structure of the secondary mirror, in six-fold symmetry), from the secondary and primary mirror segmentation. The PSF is displayed in logarithmic scale.

- differential phase with NGOIs.

The NGOI scientific niche is linked to medium sensitivity imaging and medium spectral resolution spectroscopy at very high angular resolution. It is particularly adapted to the study of stars and their close environment. Fundamental astronomical questions as star radius, surface structure, activity, presence of spots, binarity and masses are pet subjects of NGOIs that cannot be addressed properly by ELTs. Indeed, the ELTs are too sensitive for such targets and diameters smaller than 100 meter do not provide enough resolution to bring new information compared to the current generation of interferometers. Interferometry is the best way to provide an extensive study of stars and their environment.

Finally, looking at the u-v coverage, it is clear that a filled-aperture telescope is better suited to imaging than an interferometer with less than 50 telescopes (typically the number of antennas for the Atacama Large Millimeter Array, ALMA). However, in the fields where model-fitting imaging can be applied, interferometers with more than 10 telescopes (or access to an equivalent number of baselines) are still competitive and can reach a good dynamic range. NGOI is also the only way to reach sub-milli-arcsecond spatial resolution, so accessing a parameter space not within reach of ELTs.

3 Technical synergies

Building a giant interferometer with current technologies would be as expensive as building an ELT despite the much smaller collecting area. Indeed, an NGOI cannot benefit from the

ELT scale factor as too few telescopes are built. If synergies between the ELT and NGOI technologies can be found, it could help reduce the cost of an NGOI.

One field of synergy is the telescope design and structure. For NGOIs, one has the choice, for the individual telescopes, between a segmented spherical primary design à la Hobby-Heberly Telescope or a meniscus primary mirror à la VLT. In the first case, the chain production of 1 or 2-meter class segments that can be developed for the ELTs could be used for the NGOI primaries production. The segment radius of curvature should be adapted and proper spherical aberration correctors should be developed. Lightweigthing of the mirror segments developed for ELTs will also be beneficial to the construction of any other telescope. In case of meniscus primaries, a scale factor gain is more difficult to obtain.

Similarly, the fractal structure envisaged for OWL mount could be scaled down to a 10-meter class telescope and applied to the NGOI units. Using the same kind of structure and elements would reduce the individual cost of the units.

The second field of synergy is adaptive optics: each telescope in the interferometric array requires an adaptive optics system to reach diffraction limited performance. Here the know-how and systems developed either for the 2nd generation instrumentation of the VLT (*e.g.* FALCON) or for the ELTs could be used. This strategy has already been used successfully (but on a smaller scale) with MACAO (Multi-Application Curvature Adaptive Optics): replicas of the same basic concept equip the Coude foci of the 4 VLT telescopes feeding the VLTI, as well as a Cassegrain and a Nasmyth foci feeding two VLT imaging instruments (SINFONI and CRIRES respectively). However, one has to pay attention to the slightly diverging requirements on an adaptive optics system for imaging and for interferometry: imaging requires a very high long exposure Strehl ratio but does not care about very short term PSF explosions while interferometry requires a good and very stable Strehl also at very short timescale. The optimization of the adaptive optics system could be different in both cases.

A synergy going from the interferometry field toward the ELTs can be found in cophasing. Indeed, hyper-telescopes (Borkowski 2005) require cophasing of several mirrors at the same precision level as ELTs. A common research field is thus developing.

Finally, interferometry and adaptive optics have similar requirements in the field of detectors as they are both aimed at measuring fast atmospheric phenomena: low number of pixels (compared to imaging), fast reading, very low read-out noise, sensitivity in the infrared and visible, potential slight spectroscopic resolution. High accuracy positioning systems (*e.g.* for optical fibers in interferometry and for pyramids in adaptive optics) are also needed to feed precisely these detectors with the maximum of light.

4 Site selection

ELTs and NGOIs have a lot of common requirements concerning the site selection: low (in amplitude and in altitude) and slow atmospheric turbulence, low humidity, low wind. However one aspect is very different: ELTs require a large (diameter larger than 100m) leveled plateau to place the telescope and its enclosure; the NGOIs require several smaller plateaus (30m diameter) or ridge in the same site but these can be physically separated from each other and possibly at different altitudes. ELTs have also much more stringent requirements on seismic stability, extreme wind conditions and weather variability (the time to close the dome being much longer with a 100m telescope).

Placing an NGOI close to an ELT would also have several advantages linked to the construction and maintenance as shown by the VLT-VLTI synergy. The same facilities can be used during the construction and operation phases: control building, laboratories, integration halls, coating chambers, living quarters... The operation scientific and technical teams can also be shared bringing a better efficiency, critical for interferometers. Indeed, 10-meter-class telescopes with adaptive optics have currently a 10% technical downtime. For an interferometer using 10 telescopes, it means that 30% of the time, one telescope has to be repaired. Thus the need of a large efficient engineering team.

Finally, NGOIs and ELTs should have access to similar portions of the sky. Indeed, interferometry needs a very good characterization of its targets and reference stars. This characterization has to be provided by classical astronomy (imaging, spectroscopy). To reinforce the complementarity between ELTs and NGOIs, both techniques should observe some common targets to provide information at all accessible spatial frequencies. It is the only way to provide a full picture of a complex object like an active galactic center. Thus, both projects should be installed in the same hemisphere, if not on the same site.

5 Conclusions

Giant interferometers with kilometer baselines are scientifically complementary to extremely large telescopes. Their astronomical niche, mainly the study of star structures and of their close environment but also of nearby galactic cores, is not part of the main scientific programme of ELTs. Indeed, these targets are too bright for such large telescopes and require spatial resolutions that can be reached only with baselines / diameters larger than 100 meters. Moreover, interferometers present some advantages compared to filled apertures corrected with adaptive optics in terms of PSF calibration and stability that can be used to get better images of bright objects.

Thus there is room for a parallel development of a New Generation Optical and Infrared Interferometer and of Extremely Large Telescopes. There are some possible technical synergies in the fields of mirror production and mechanical structure. But most fruitful collaborations can be found in the cophasing aspect of segmented aperture (filled like an ELT or sparse like an interferometer) and in the fast detectors needed for adaptive optics and fringe tracking.

The development of an NGOI would benefit from the geographic proximity of an ELT: the most important site requirements are similar, the facilities and operation costs would be shared and collaborative studies of common objects require a similar sky coverage for both devices.

Due to the very high and similar costs of NGOIs and ELTs, this kind of project cannot be undertaken by one institute alone but must be discussed in the frame of Europe-wide or worldwide collaborations and scientific initiatives like Astronet or Opticon.

Acknowledgements

The figures for OWL were provided by the OWL team at ESO, in particular by P. Dierickx, N. Yaitskova, C. Verinaud, M. Le Louarn and V. Korkiakoski.

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