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Extremely Large Synthesis Array: Science and Technology

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Abstract: An Extremely Large Synthesis Array (ELSA) with 27 ten-meter telescopes and baseline lengths up to 10 km could provide completely new insight into many astrophysics phenomena. It could be used to obtain resolved images of nearby brown dwarfs which would reveal weather phenomena in their atmospheres, to give detailed pictures of stellar surfaces, interacting binaries, and circumstellar material, to study general-relativistic effects on the orbits of stars near the center of our Galaxy, to obtain "movies" of expanding supernovae, to image the broad-line regions of active galaxies, and to measure the geometry of the fireballs producing the afterglow of gamma-ray bursts.

Observations of faint objects will be possible by using an external reference star (within the isoplanatic angle) to co-phase the array. Telescopes with large diameters are essential to provide good sky coverage in this observing mode. The use of optical fibers for beam transport and delay compensation is highly desirable, as this eliminates the need for an expensive beam train with meter-sized optical elements, and a very large vacuum system. The most challenging aspect of fiber-coupled interferometry is dispersion in the fibers, which has to be eliminated or compensated precisely.

Advances in telescope technology and fiber optics expected for the next decade may bring the cost of a facility similar to the ELSA concept discussed here into a range that would be affordable as an international project.

1 Introduction

The first scientific results from the Keck Interferometer and the Very Large Telescope Interferometer (VLTI) have ushered in a new era of high-resolution astronomy: the use of 10 m class apertures for observations with milliarcsecond resolution. The present interferometers with baselines of up to a few hundred meters are complementary to filled-aperture telescopes; they provide ten to one hundred times better angular resolution albeit at much poorer sensitivity. The development of phase-referencing techniques at optical and infrared wavelengths will make much fainter objects accessible for interferometric observations (e.g., Quirrenbach 2003). It is evident, however, that a filled-aperture telescope with 100 m diameter such as envisioned by ESO's OWL study (e.g., Dierickx et al. 2002, Brunetto et al. 2004) would outperform an interferometer of the dimensions of the VLTI in almost every respect.

In the present article I will attempt to address the question of the role of interferometry in the era of Extremely Large Telescopes (ELTs). I will start from the premiss that an imaging interferometer is only attractive if it provides much better angular resolution than the largest telescope operational at the same time[1], and sketch the science case for the strawman concept an Extremely Large Synthesis Array (ELSA) with 27 telescopes and baselines of up to 10 km. I will then discuss the strategy to phase this array, critical technologies needed for its realization, the array layout, and criteria for the site selection.

It appears that an ELSA facility could be built today with existing technologies, but the cost would probably be prohibitively high. A technology roadmap for ELSA must therefore provide solutions that are not only *technically feasible*, but also *affordable*. In this context it will be interesting to explore to which extent cost-reduction approaches that are being investigated for the design and construction of large monolithic telescopes – such as the OWL concept – can also be applied to ELSA.

2 SCIENCE WITH ELSA

With baselines up to $B = 10\,\mathrm{km}$ in length and operating at wavelengths down to $\lambda = 0.5\,\mu\mathrm{m}$, ELSA would deliver images with $10\,\mu$as resolution, two orders of magnitude better than any other telescope contemplated at the moment. Combined with a sensitivity (for compact objects) that equals or surpasses present-day large monolithic telescopes, this spectacular angular resolution enables a wealth of completely new observing programs in many different areas of astrophysics. For orientation, Fig. 1 shows the linear resolution as a function of distance in the local Universe, together with the distances and sizes of a few benchmark objects. In Fig. 2, the linear resolution at a wavelength of $0.5\,\mu$m is plotted versus redshift z for cosmological distances, adopting a world model with $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$, and $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

Based on the resolution-distance relation displayed in these figures, one can compile a list of "showcase applications", including:

- *Imaging of brown dwarfs.* ELSA will provide images with 16 resolution elements across the disk of the brown dwarf GJ 229 B. It will thus be possible to study weather phenomena in Jupiter-size objects at distances of $\sim 10\,\mathrm{pc}$.

- *High-quality images of stellar surfaces.* ELSA will obtain images with 90 resolution elements across the disk of Solar-type stars at 10 pc. This allows detailed observations of spots, flares, convection, differential rotation, and other phenomena in stellar atmospheres. Spatially resolved observations of stellar oscillations will provide new constraints on stellar structure models. Superb images can also be obtained of giant stars at much larger distances.

- *Detailed imaging of pre-main-sequence disks.* ELSA observations in the near-infrared will provide detailed information on disks of pre-main-sequence stars. Determining the global structure of these disks (temperature and density laws, vertical structure, flaring, connection with the stellar magnetosphere, formation of jets and outflows) is a key piece in the puzzle of understanding star and planetary system formation. Nascent planets are predicted to clear gaps in the disks, which can easily be observed at the resolution of ELSA, giving us a direct view of the processes governing planet formation and migration.

- *Binary stars.* Many classes of binary stars can be imaged with ELSA. Phenomena such as Roche lobe overflow, mass transfer, and accretion can thus be studied directly.

[1]There is a separate science case for astrometric interferometry, upon which the present article touches only briefly. It has been suggested that sites in Antarctica offer superb conditions for such instruments (e.g., Lloyd et al. 2002).

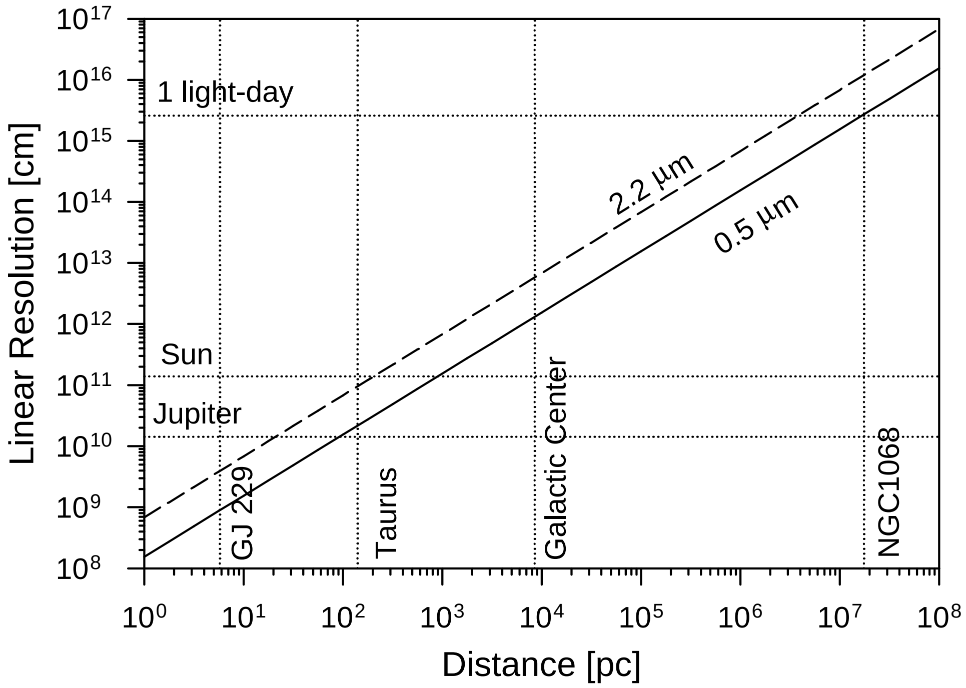

Figure 1: Linear resolution of an array with 10 km baseline length for objects in the local Universe. The solid line is for a wavelength of 0.5 μm, the dashed line for 2.2 μm. The vertical dotted lines are the distances of the star GJ 229, which has a brown dwarf companion, of the Taurus-Auriga star formation region, of the Galactic Center, and of the Seyfert Galaxy NGC 1068. The horizontal lines correspond to the diameters of Jupiter and the Sun, and the scale of one light-day.

- *Globular clusters.* Equipped with a high-resolution spectrograph for measurements of "dispersed fringes", ELSA will be an ideal tool for following the three-dimensional motions of stars in dense environments such as the cores of globular clusters. At a distance of 10 kpc, a transverse motion of 1 km s^{-1} corresponds to a proper motion of 20 μas yr^{-1}, which should be easily observable. The radial velocities can be derived with equal precision from the spectra of the stars.

- *Mapping the orbits of stars near the Galactic Center.* Observations of individual stars in the cluster surrounding the center of our Galaxy have established the existence of a massive black hole. With ELSA it will be possible to determine the general-relativistic precession of these orbits, as well as the precession due to an extended mass distribution (Rubilar & Eckart 2001, Eckart et al. 2002). ELSA observations of the Galactic Center will also help to monitor the physical properties of Sgr A*, the source associated with the black hole itself.

- *Baade-Wesselink distances.* Many types of stars are variable with time scales of hours or days; an array with 27 elements will provide good snapshot capability which will enable making "movies" of the dynamic phenomena. Combining them with spectral information will make it possible to derive Baade-Wesselink distances to objects such as pulsating

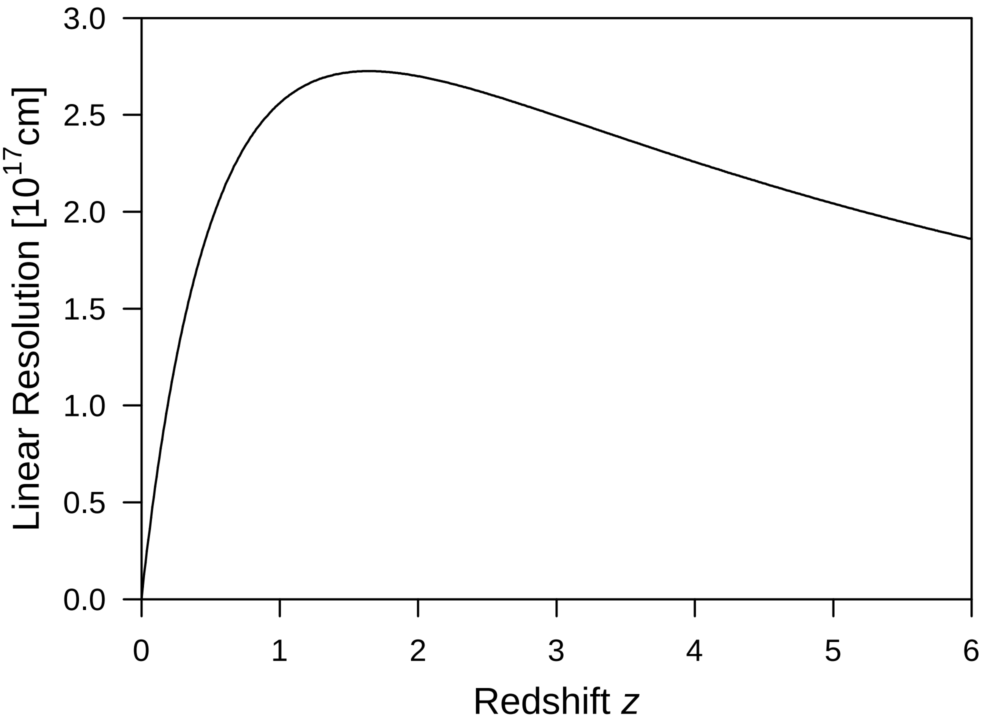

Figure 2: Linear resolution of a 10 km array at a wavelength of 0.5 μm for objects at a cosmological distance. A world model with $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$, and $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ has been adopted.

stars, novae, and supernovae (out to the Virgo cluster and beyond); this technique has already been successfully applied to Nova Cygni 1992 (Quirrenbach et al. 1993).

- *Extragalactic stellar populations.* Stellar populations in external galaxies could be resolved even in those cases where an OWL-sized telescope remains confusion limited, as in star-forming regions and galactic nuclei.

- *Detailed images of broad-line regions in active galaxies.* The broad-line regions of active galaxies have typical sizes of a few light-days, well resolvable with ELSA. Images in different spectral lines will thus reveal their global structures; observations with higher spectral resolution will enable studies of the gas dynamics and measurements of the black-hole masses. The distances of quasars can be derived directly by combining interferometric determinations of the angular size with reverberation mapping, which gives the linear size (Elvis & Karovska 2002). ELSA could perform such measurements to cosmological distances and thus contribute to the determination of the geometry of the Universe.

- *Resolving the afterglow of gamma-ray bursts.* The fireballs created by gamma-ray bursts have typical sizes of $10^{16} \ldots 10^{17}$ cm (e.g., Mészáros & Rees 1997). Considering that one can measure sizes and shapes of objects as small as a tenth of the interferometer resolution with well-calibrated visibilities, ELSA will be well-suited to determine the apparent geometry of gamma-ray afterglows, to constrain their Lorentz factors, and to follow their temporal evolution.

Many other projects can be added to this somewhat subjective "top ten" list, but these examples should demonstrate that ELSA will impact almost all fields of astrophysics.

Precise narrow-angle astrometry would be another interesting application of ELSA. The astrometric error for very long baselines scales with $\theta L_0^{1/3}/B$, where θ is the angle between the target and an astrometric reference star on the sky, L_0 the outer scale of atmospheric turbulence, and B the baseline length (Shao & Colavita 1992). L_0 is generally believed to be of order 100 m (e.g., Quirrenbach 2002), which means that it should be possible to achieve an accuracy considerably better than 1 μas, which would allow the detection of terrestrial planets through the reflex motion of their parent stars, and to measure their masses dynamically.

3 INTERFEROMETER CO-PHASING STRATEGY

The most important technical consideration for the design of an interferometer (but one that is sometimes woefully neglected) is the question: how will the array be co-phased? The co-phasing strategy drives many design parameters, from telescope size and array geometry to the choice of the best site, and should therefore be discussed before any other technical issue.

The first task is to phase the individual array elements, which are much larger than the Fried parameter r_0, except at the longest wavelengths considered here ($\lambda \gtrsim 10\,\mu$m). For the purpose of this paper it is assumed that each array element will be phased with an adaptive optics system providing a Strehl ratio of $\gtrsim 50\%$ in any desired direction on the sky, and in a second direction which may be offset from the first by up to $60''$. The design of such a telescope phasing system is a challenging task by itself (potentially requiring multi-conjugate adaptive optics with multiple laser guide stars), but one can certainly hope that it will have been solved in a decade from now.

For a single-baseline interferometer consisting of two elements that are phased with adaptive optics, the limiting magnitude for fringe tracking can be calculated from

$$m_{\rm lim} = -2.5 \log \frac{2 N_0 f_g}{\pi \mathcal{F}_0 \eta \Delta\nu D^2} \quad ; \tag{1}$$

here $\mathcal{F}_0$ is the zero point of the magnitude scale in phot $\mathrm{s}^{-1}\,\mathrm{m}^{-2}\,\mathrm{Hz}^{-1}$, η the end-to-end efficiency (including Strehl losses due to incomplete adaptive optics correction), $\Delta\nu$ the bandwidth, D the telescope diameter, f_g the Greenwood frequency of the atmospheric turbulence, and N_0 the number of detected photons required per time interval $1/f_g$ for the fringe tracking servo to run reliably. Figure 3 shows $m_{\rm lim}$ as a function of D for the R band under the assumptions $\eta = 25\%$, $\Delta\nu = 1.5 \cdot 10^{14}$ Hz, $f_g = 40$ Hz, and $N_0 = 100$. It is evident from this figure that fringe tracking is possible on fairly faint objects, provided that the efficiency is high, and the telescope diameter large. Still, many of the targets for ELSA are too faint (or too resolved) to use them for fringe-tracking; it is therefore necessary to phase the array externally on a reference star located nearby (in projection) on the sky.

The search radius for off-axis reference stars is limited by anisoplanatism. It depends on the wavelength ($\propto \lambda^{6/5}$) and on the vertical distribution of the atmospheric turbulence. The chance of finding at least one suitable reference star within that search radius depends on the local (projected) star density; it decreases strongly from the Galactic plane to the Galactic poles. Figure 4 shows the sky coverage near the North Galactic Pole, calculated from Eqn. 1 and star counts from the Digital Palomar Observatory Sky Survey (Odewahn 2003). From this figure it is evident that the ability to co-phase the array is a major driver for the telescope size; at an excellent site the search radius for the R band should be of order $15''$, giving a sky coverage of

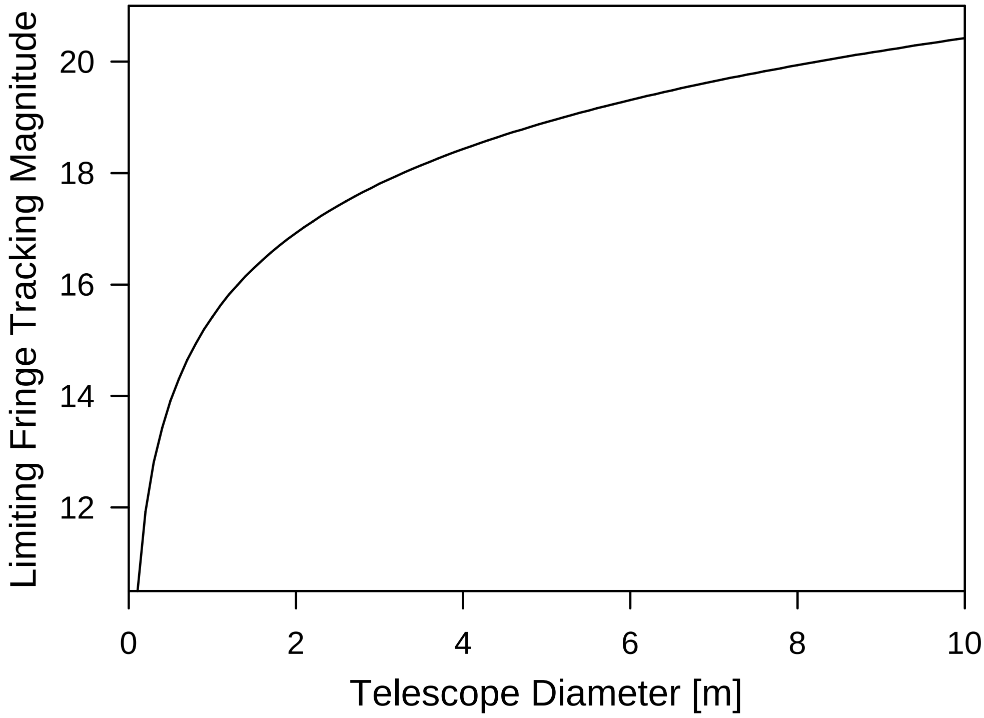

Figure 3: Limiting sensitivity for fringe tracking in the R band as a function of telescope diameter. This estimate is based on an assumed efficiency of 25%, a Greenwood frequency $f_g = 40\,\mathrm{Hz}$, and the assumption that 100 detected photons are required per time interval $1/f_g$ for the fringe tracking servo to work reliably.

nearly 10% if the array elements have 10 m diameter. The sky coverage will be almost complete near the Galactic plane, of course.

Combining the light from all telescopes is the most efficient fringe tracking strategy for faint point sources (le Poole & Quirrenbach 2002), and should thus be employed for external co-phasing of the array. For observations of bright resolved objects (e.g., for stellar surface imaging), forming a fringe-tracking chain by pairwise fringe tracking between neighboring telescopes is a better strategy (Armstrong et al. 1998). This principle is shown schematically in Fig. 5. The small black circles and crosses delineate two configuration with different resolutions. The large red circles mark a sub-set of telescopes belonging to the higher-resolution configuration, which have nearly equal spacings. Pairs of neighboring telescopes in this chain form short baselines, which are well-suited for fringe tracking. Fringes on the longer baselines have much lower contrast, but provide the astronomically interesting information.

4 ELSA REQUIREMENTS

The top-level requirements for ELSA must be derived from the science case and the array co-phasing approach. Some design parameters (such as number of telescopes, exact baseline length) are necessarily somewhat arbitrary, others (telescope size, efficiency) are derived from preliminary analyses and from guessing what might be technically feasible. Nevertheless, the strawman concept summarized in Tab. 1 should give a feeling for what would be required to

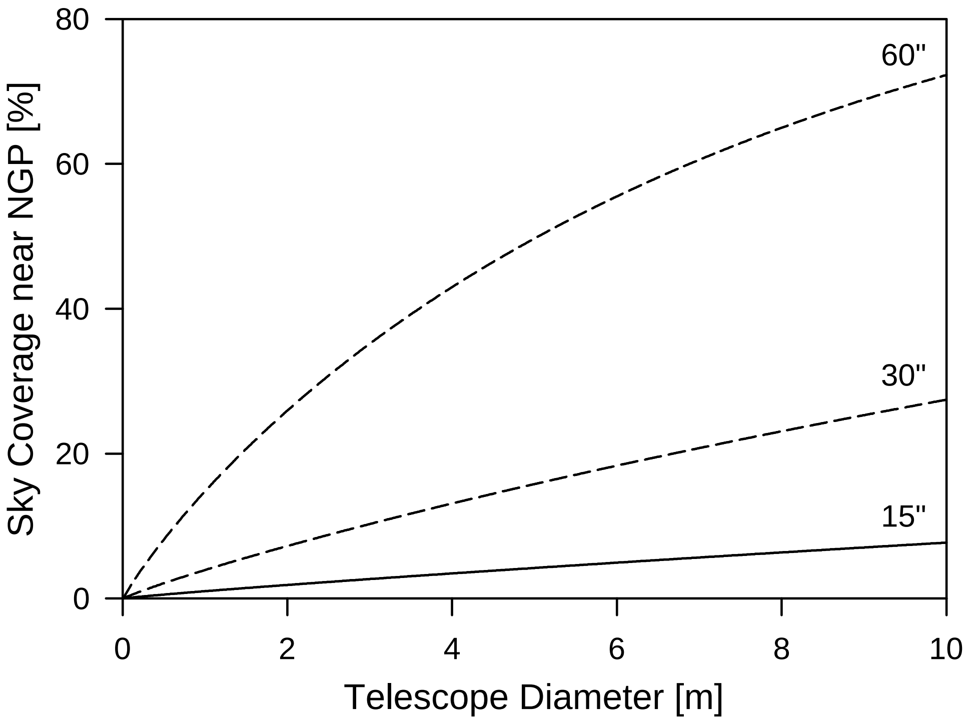

Figure 4: Sky coverage estimates for ELSA as a function of telescope diameter, based on star counts near the North Galactic Pole from the Digital Palomar Observatory Sky Survey. The three curves are for phase reference search radii of 15″, 30″, and 60″ around the science target.

make ELSA work; it could serve as a starting point for more detailed trade-off studies and for the development of a technology roadmap.

These strawman requirements on telescope size, wavelength coverage, and baseline length are more ambitious than those contemplated previously for a next-generation interferometric array (Ridgway & Roddier 2000, Arnold et al. 2002, Coudé du Foresto et al. 2002). It appears that there are strong scientific motivations to aim for the resolution and sensitivity proposed here. Whether these goals turn out to be realistic will depend mainly on two factors: the price of "mass-produced" 10 m-class telescopes, and the availability of optical fibers for beam transport and delay compensation, which would make very long baselines possible.

5 THE TELESCOPES

The estimate of the sky coverage presented above (see Fig. 4) indicates that array elements with ~ 10 m diameter are required to meet the requirements of ELSA. At today's prices, 27 telescopes of that size would probably cost more than the notional total budget. Allocating half of the project cost to the telescopes would mean that each telescope should not cost more than about 7.5 M€, including enclosures and the adaptive optics system. It will therefore be necessary to capitalize on considerable advances in telescope technology to make ELSA affordable. Some of these advances are the same as those needed by OWL and ALMA: cheap mass production of primary mirror segments, standardized elements for the mechanical structure, and minimization of non-recurrent design and engineering effort through replication of identical elements. (An

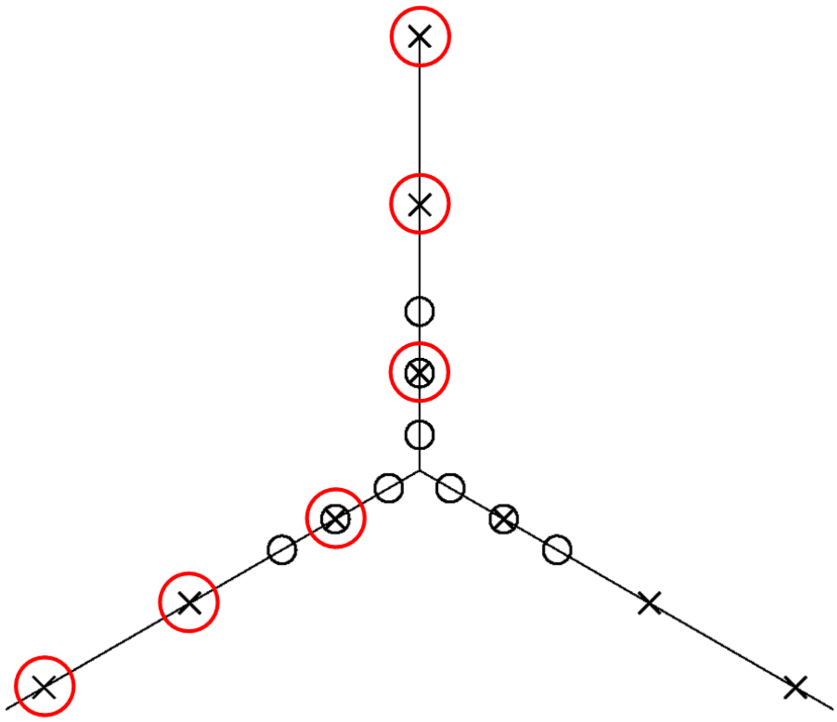

Figure 5: Y-shaped array layout for optical interferometry. Compact and wide configurations (small black circles and crosses) provide different resolutions. Quasi-uniform telescope spacings (large red circles) optimize fringe-tracking efficiency.

interferometer is the ideal case for the last item; we need 27 identical telescopes after all.) The interferometer elements will need only a rather small field-of-view (of order $1'$ for off-axis co-phasing), which should be easily achievable with a spherical primary mirror; this minimizes the cost of mirror segment fabrication. The adaptive optics system may have to be quite complicated, but the cost of AO systems is mostly in the design and non-recurrent engineering; 27-fold reproduction would therefore keep the price per system at a reasonable level.

How realistic, then, are the prospects of building 10 m telescopes for 7.5 M€ apiece? It is frequently stated that the cost of building telescopes of diameter D with a given technology scales $\propto D^{2.7}$ (e.g., Stepp et al. 2002). Applying this scaling law to the OWL concept (100 m for 1,000 M€, Dierickx et al. 2002) suggests a price of only 2 M€ for a 10 m telescope built with the same design and construction principles. This may sound overly optimistic, but a comparison of the cost of the Keck telescopes (10 m) with the elements of the CHARA array (1 m) shows that applying the same scaling relation to two current projects over one order of magnitude in diameter gives the correct answer to within a factor of two. A target of 7.5 M€ for the ELSA elements thus appears to be not totally unreasonable.

An important consideration concerns the question whether the telescopes should be moveable or not. The science case clearly calls for three or four scalable array configurations with different baseline lengths. This could be achieved either by building fixed telescopes at the stations of each configuration, or by moving a set of 27 telescopes to the desired locations. Experience from radio interferometry shows that the latter approach is clearly feasible even for fairly large telescopes, by moving them with a transport vehicle either on rails (as the VLA), or on tires (as ALMA). The logistics of moving telescopes at a windy high-altitude site have

Table 1: Summary of strawman ELSA parameters and characteristics.

Parameter	Value	Comment
Number of telescopes	27	Needed for snapshot imaging
Telescope phasing	Autonomous	Adaptive optics
Array co-phasing	External	Dual-star operation
Sky coverage	$\gtrsim 10\%$	At R band, near Galactic pole
Telescope diameter	10 m	Needed to get sky coverage
Efficiency	25%	To limit telescope size
Wavelength range	$0.5 \ldots 20\,\mu$m	Could be reduced to $0.5 \ldots 2.2\,\mu$m
Cost	$\lesssim 400$ M€	Design-to-cost target figure

been studied in some detail and appear entirely manageable; a 27-element array with baselines up to 10 km could be completely reconfigured by three transporters in less than a week (Radford 1999). While it is possible that a detailed cost trade-off between stationary and moveable telescopes could lead to a surprise, it appears quite likely that transportable telescopes are the more cost-effective solution.

6 BEAM TRANSPORT AND DELAY COMPENSATION

The tasks of transporting the light from the individual telescopes to the central beam combination facility, and compensating for the delay difference between the different interferometer arms, become more arduous for longer baselines. Dispersion and "tube seeing" make air-filled beam pipes and delay lines poor choices for any interferometer; they are completely out of the question for kilometric baselines. The minimum diameter d of optical elements in a beam train of length L is

$$d = k \times \sqrt{\lambda L} + \theta L \quad , \tag{2}$$

where θ is the desired field-of-view, and $k > 1$ a constant that determines how severe diffraction effects will be. To ensure a visibility loss of less than 20%, one has to choose $k \gtrsim 2.5$ (Hrynevich 1994). For a propagation length of 10 km this means that meter-size optics are needed at $\lambda = 10\,\mu$m; for operation in the near-infrared a beam diameter of 50 cm is needed if a field of $2''$ is desired. While rather large and inexpensive vacuum systems have been developed for gravitational wave detectors such as GEO 600 (K. Danzmann, priv. comm.), the optics and vacuum tubes for the beam transport and delay lines are clearly a cost driver for a large interferometric array. Another problem is the notoriously low transmission of interferometers due to the many optical elements between the telescope primary and the beam combiner.

These difficulties could potentially be solved with optical fibers, which could be used for beam transport from the telescope to the central lab, for delay compensation, and for beam combination. Ideally, one would like to use fibers with the following characteristics:

- No significant light loss over 10 km;
- Extremely low dispersion;
- Polarization preserving;

- Available for wavelengths up to $20\,\mu$m.[2]

One could then couple the light from the target and the reference star into these fibers directly in the prime focus of the telescope, and relay the light to the central laboratory. Here the light would be coupled into a fiber delay compensator, which consists of fiber segments with lengths of 1 m, 2 m, 4 m, ...; selecting an appropriate chain of these segments can thus provide any desired delay in steps of 1 m. The remaining delay could be taken out in a fiber which is stretched mechanically to the desired length. The continuous variation of the delay due to the Earth's rotation has to be accommodated by changing the stress on the variable-length fiber. Once the end of the range of this fiber is reached, the chain of fixed-length segments is switched to the next step, and the variable-length fiber reset to the other end of its range.

The largest technological challenge for this concept is the development of fibers with extremely low dispersion, or of appropriate dispersion compensation schemes. These are needed because the length of fiber associated with each array element changes with time by amounts of several km. In addition, nearly lossless switches would be needed for selecting the sets of discrete fibers. If these requirements should turn out to be too demanding, one could consider as a fall-back a hybrid solution with constant balanced fiber lengths in the interferometer arms, and a classical bulk-optics delay compensation system; a similar concept is currently envisaged for the 'OHANA project (Perrin et al. 2002, Ridgway et al. 2002). In any case, multiplexing light from the target and phase reference star in the same fiber will be required to ensure phase coherence (Quirrenbach et al. 1998). The field-of-view limitation of fiber-coupled interferometers (essentially one Airy disk of the single array elements) could be overcome by re-imaging each telescope pupil onto a lenslet array attached to bundle of several fibers (Guyon 2002).

7 BEAM COMBINATION

The beams from the individual array elements can be combined in many different ways; each beam combination technique has its own advantages and drawbacks (see e.g. Quirrenbach 2001). In its largest configuration, ELSA will be a very dilute array ($B/D \approx 1,000$), similar to long-baseline radio interferometers. For such arrays, image-plane beam combination is very inefficient, since the light from a point source is spread over a large number of pixels within the single-telescope point spread function; the peak intensity is reduced by a factor $\sim N(D/B)^2 \approx 27 \times 10^{-6}$ (Roddier & Ridgway 1999). One should thus combine the light in the pupil plane, in which case a small number of pixels per baseline and spectral resolution element is sufficient. The field-of-view is in this case limited to $\sim R$ spatial resolution elements across, where $R \equiv \lambda/\Delta\lambda$ denotes the spectral resolution of each wavelength channel, just as in a radio interferometer.

In the more compact configurations of ELSA (with maximum baseline of 300 m or 1 km), it would be desirable to image a larger field. This requires Fizeau beam combination in the image plane, an approach also known as homothetic mapping, i.e., the exit pupil of the interferometer must be a scaled replica of the input pupil. The construction of a homothetic beam combiner for a 27-element array will be a formidable challenge, because the input pupil changes continuously due to the Earth's rotation.

[2]The last of these properties seems to be hardest to achieve; one could therefore think about reducing the wavelength range of the fiber-coupled direct interferometry mode to $0.5 \ldots 2.2\,\mu$m, and to use a heterodyne system at longer wavelengths (Sonnabend et al. 2002).

8 ARRAY LAYOUT

The considerations determining the optimum array layout are somewhat different for optical arrays than for radio interferometers. Whereas in the radio optimization of the *uv* plane coverage and visibility calibration are the main drivers, the ability to co-phase is another important (or perhaps *the* most important) criterion for the layout of optical and infrared arrays, as discussed above. It is usually best to arrange the telescopes such that they form a long chain of elements with nearly equal spacings; this ensures that the array can be co-phased solely on short baselines, which give high visibilities.

Y-shaped configurations have been preferred for interferometers with bulk-optics beam transport, because this geometry facilitates the routing of beam lines and enables symmetric reflections for each beam, which is required to avoid visibility losses.[3] Fiber-coupled arrays offer more design choices, including circular arrangements, which have less redundancy than long linear chains of equally spaced telescopes. The final choice of layout will also have to take topographic and logistic (array reconfiguration) considerations into account.

9 SITE SELECTION CRITERIA

Finding a good site for an Extremely Large Synthesis Array is not a trivial task at all. It is obvious that one needs a reasonably flat plateau of considerable size, and such plateaus tend to have poorer seeing than the best mountain tops. One candidate site, for which data from a systematic site evaluation campaign are available, is Llano de Chajnantor, the location of the ALMA millimeter array at an altitude of 5000 m in the Chilean Andes. Typical values in the range $1'' \ldots 1.''5$ have been reported for the seeing at the Chajnantor plateau itself, with substantially better seeing at a location 100 m above the plateau (Giovanelli et al. 2001). This indicates that a rather large fraction of the turbulence occurs in the boundary layer just above the plateau, probably due to katabatic winds off the surrounding mountain slopes. The boundary-layer seeing is easier to correct with adaptive optics than high-altitude seeing, and it does not significantly contribute to anisoplanatism. This leads to the conclusion that Llano de Chajnantor should offer acceptable seeing conditions for ELSA.

It has also been suggested that Antarctica offers attractive sites for interferometry, in particular Dome C (Marks et al. 1998, Lloyd et al. 2002, Lawrence et al. 2004). During the winter, very little high-altitude turbulence is present above the Antarctic plateau; the isoplanatic angle is thus much larger than at mid-latitude sites. Since the diameter of the telescopes in ELSA is largely driven by the requirement to co-phase the array, there is a substantial advantage in going to a site with superb high-altitude seeing, as apparent from Fig. 4. One could thus trade off the cost of constructing and operating ELSA in the harsh Antarctic environment against the substantial savings in telescope size. It is very likely that the Antarctic option would only be attractive for a fiber-coupled interferometer, because otherwise the infrastructure cost would be dominated by the beam transport and delay line tubes.

[3] Note that the configuration for the Naval Prototype Optical Interferometer is a Y with equal telescope spacing to establish a fringe-tracking chain, whereas the antenna locations of the VLA follow a geometric progression to optimize *uv* coverage.

10 CONCLUSIONS

An Extremely Large Synthesis Array would be very complementary to an Extremely Large Telescope, by providing a hundred times better resolution at a sensitivity that is comparable to "deep" observations with today's large telescopes. A compelling science case can be made, addressing a wide range of topics in Galactic and extragalactic astronomy. From the technological point of view, ELSA will build on the experience gained with the VLTI and Keck Interferometer, benefit from ALMA, and capitalize on developments for OWL (telescopes) and for the telecommunications industry (fiber technology). Financial and intellectual contributions from a world-wide consortium could thus make an Extremely Large Synthesis Array reality in the next decade.

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