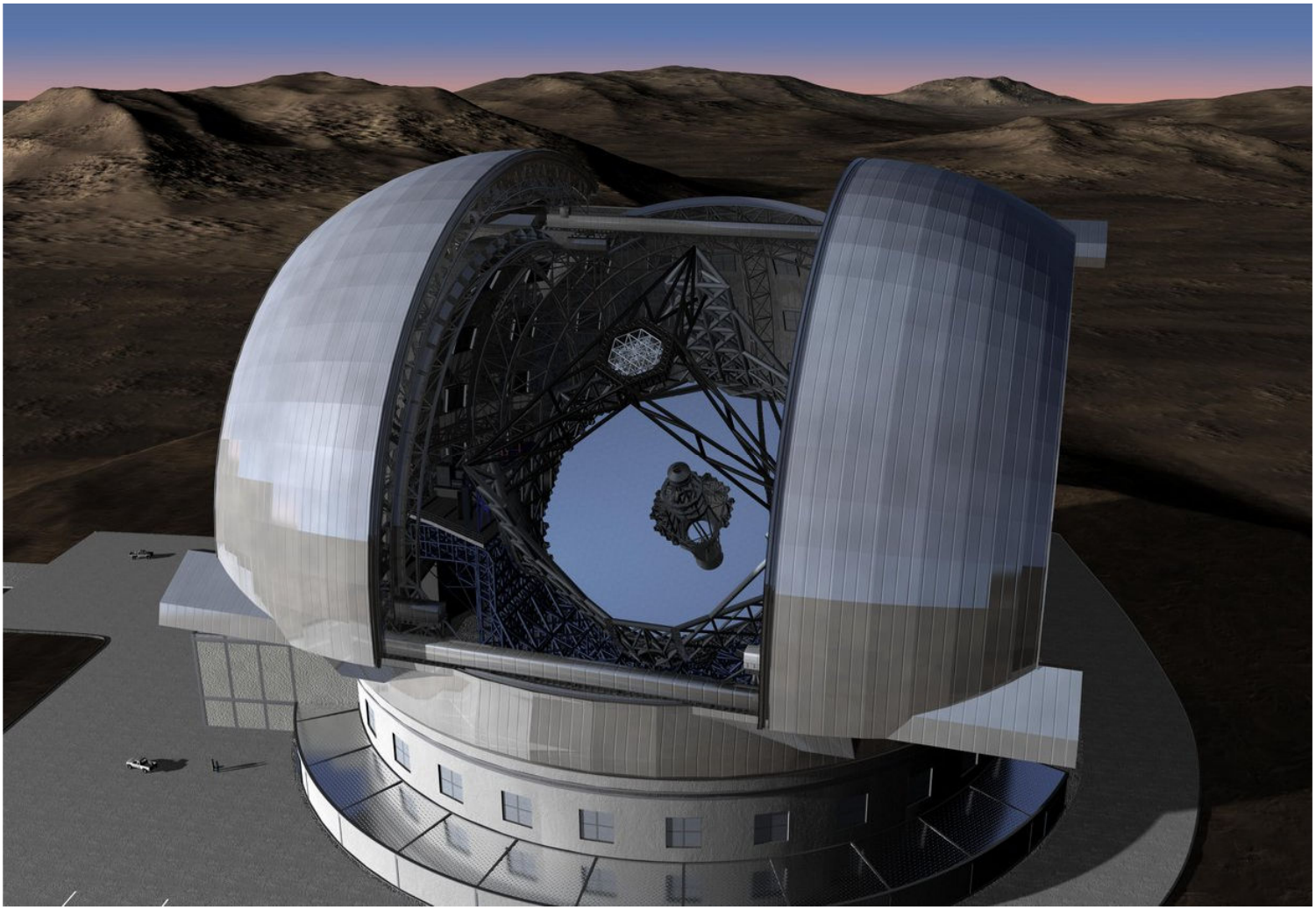
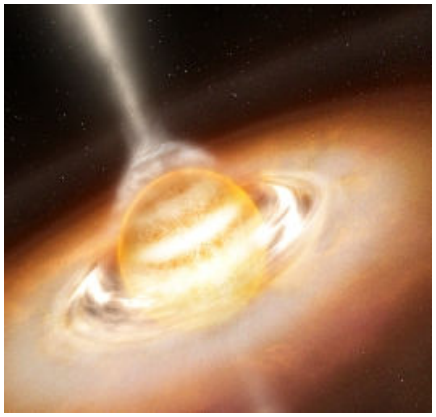
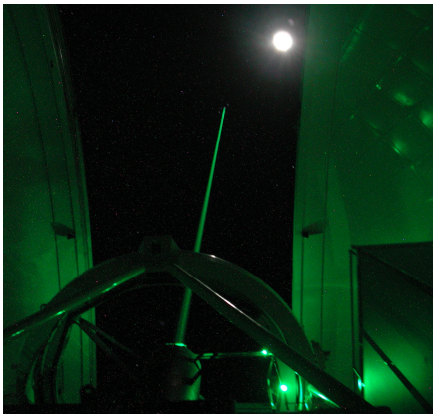


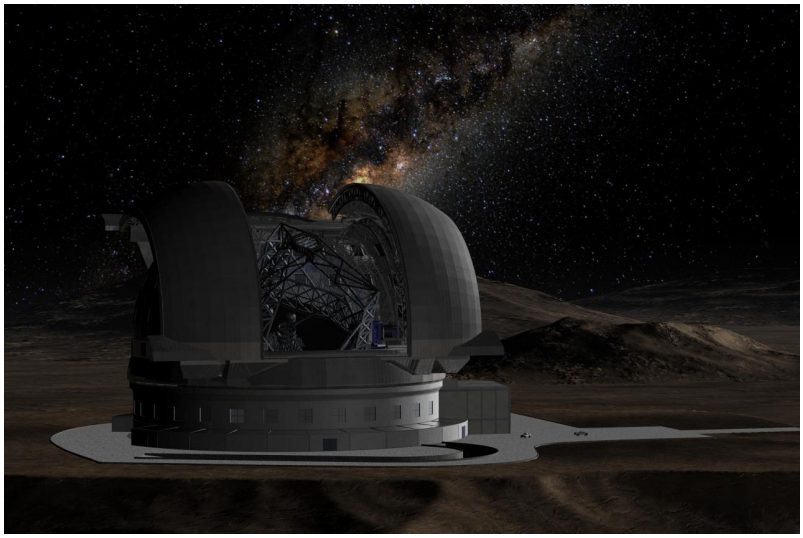
Building the UK Leadership Role in the European Extremely Large Telescope





Ground-based Facilities Review Statement
July 2009

The European Extremely Large Telescope (E-ELT)



The E-ELT is the flagship European optical-infrared telescope project, which will revolutionise our understanding of the space around us, from our own Solar system to the nature of the expanding Universe itself. The design includes adaptive optics (AO) as an integral part of the telescope to correct for turbulence in the Earth's atmosphere, providing observations five times sharper than those from the James Webb Space Telescope. When coupled with a collecting area some 25 times that of current 8-m class telescopes, this will provide a dramatic increase in discovery power. This statement to the Ground-Based Facilities Review (GBFR) summarises the UK role in the E-ELT project, which ranges from leadership of the science case development, leading design studies for first-generation instrumentation and research and development in key technologies with industrial impact.

Submitted by Prof. Colin Cunningham
on behalf of the UK-ELT Collaboration

1 Overview

The E-ELT will be the world's leading optical/IR facility for decades to come, delivering scientific discoveries that will surpass our imagination and will tackle some of the biggest problems in physics. The huge gain in telescope collecting area, combined with exquisite image quality, will deliver imaging and spectroscopy to address a broad range of science topics, from direct imaging of exo-planets, to studies of the first galaxies in the Universe.

The next 18 months are pivotal in the development of the E-ELT. The output from the Phase B design of the telescope and eight Phase A instrumentation studies will be combined into a full construction proposal in 2010, including a plan for the first-generation instrumentation suite and an announcement of the site. Subject to approval and funding, construction could commence in 2011, with first light in 2018. The capital and running costs of the E-ELT are documented in the ground-based review consultation document, but note that the UK's existing ESO subscription (excluding the residual costs of entry) would cover ~75% of the UK share of the capital and running costs of the project, in addition to continued access to Paranal/La Silla/ALMA. ESO are actively seeking new members/participants in the E-ELT and are also discussing modest increases in subscriptions with existing partners – together these would give a fully-funded project.

A major motivation for joining ESO was to implement ALMA and to ensure the UK had a leading role in the next large telescope facility. Indeed, the recent ASTRONET Infrastructure Roadmap identified the E-ELT as the first to be implemented of the two top-priority facilities for European astronomy. If the UK commits fully to the E-ELT now we can expect our leadership role in science and instrumentation to continue, with expanding UK influence and scientific and industrial return. Conversely, half-hearted UK support would damage this critical international partnership, and lose the very strong position we currently hold in the project. Given finite resources and mid-term financial uncertainty, it is vital that the UK position itself to take a leading role in Europe's foremost project to be developed over the time-frame of this review.

2 UK E-ELT Programme

The UK has been a key partner in the E-ELT project to date, playing a leading role in development of the science case, instrumentation design and industrial studies for the telescope. Support of current UK involvement in the project has been highly-rated and recommended for funding by PPRP/STFC, with specific objectives to:

- Maintain leadership of the E-ELT science case development, ensuring that the UK community is well connected to the process and will be prepared to exploit the E-ELT.
- Ensure that UK teams have leading roles in building the first and subsequent generations of E-ELT instrumentation.
- Capitalise on this investment to deliver early breakthroughs to UK astronomers, via guaranteed time observations and detailed knowledge of the instruments we develop.
- Enable UK industry to secure contracts in the telescope and instrument build phase.

The UK programme includes:

- A technology plan comprising on-sky demonstrators and prototyping of key components.
- A UK Project Office to coordinate/manage the programme and to liaise with industry.
- A steering committee to provide oversight that is independent of the project office.
- A comprehensive outreach plan, in support of STFC's public engagement priorities, to take advantage of the iconic scale and accessibility of the project.

2.1 Science

Future upgrades to the current generation of 8-10m ground-based telescopes include ingenious new instrumentation and AO retro-fits. Although these will have considerable impact, the fundamental limits set by collecting area and diameter (thus spatial resolution) have already been reached in a large number of science areas. VLT-Interferometry will be capable of providing higher spatial-resolution observations for bright sources in specialised observing regimes, but lacks the sensitivity of a filled-aperture ELT.

Over the past six years the E-ELT Science Case has been developed by a substantial segment of the European astronomical community. The E-ELT will make a unique contribution to our understanding of the Universe over all scales, directly addressing many of the fundamental questions listed as scientific goals by the GBFR document, which echo those posed by the ASTRONET Science Vision, such as:

- **What is the diversity of planetary systems in the Galaxy, and is there evidence for life on them?** The E-ELT will provide unprecedented high-contrast imaging and spectroscopy of exoplanets, probing planets in the habitable zone around their parent stars, and offering the chance to look for tracers of life in their atmospheres.
- **How do galaxies form and evolve?** Why do local galaxies appear as they do today? Using observations of resolved stars in the Local Volume and spatially-resolved observations of high-redshift galaxies, the E-ELT will study the formation, growth and evolution of galaxies over the whole of cosmic time.
- **How did the Universe emerge from its Dark Ages?** E-ELT spectroscopy will characterise the properties of "first light" galaxies at the greatest redshifts, providing essential insight into the first stars, formation of the first galaxies and growth of supermassive black holes, identifying the sources responsible for re-ionisation of the Universe.

In parallel to the telescope and instrument design, a "Design Reference Mission" (DRM) has produced detailed observing proposals (available from the ESO web-pages) and simulated data for nine prominent science cases, to inform design trade-offs and to investigate performance across the full parameter space of the observatory. Once the E-ELT is operational its use will be decided on scientific merit, but the DRM proposals alone demonstrate 10 years of potential observations. These are just examples of the high-impact science we can imagine doing now – in practice the E-ELT will certainly surpass these with discoveries that we cannot conceive of at present, as proved to be the case when moving from the 4m to 8-10m class telescopes.

2.1.1 Performance

In many regimes the E-ELT will yield observations 5 magnitudes deeper than the VLT, at unprecedented spatial resolution. The exceptional point-source sensitivities of the E-ELT are shown in Table 2, together with the diffraction limit (λ/D) of a 42-m telescope at each band. The ground-layer correction (GLAO) delivered by the telescope as its basic operating mode will yield enhanced image quality compared to seeing, with even better sensitivity yielded by high-performance, laser-tomography AO (LTAO). For comparison, the equivalent point-source sensitivity with VLT-ISAAC is K = 21.5.

Table 1: E-ELT Point-source Sensitivities (>5σ in 1 hr, Vega mags)

Band	λ (μm)	λ/D (mas)	E-ELT - LTAO	E-ELT - GLAO
V	0.55	2.7	27.5	29.0
R	0.64	3.1	28.5	29.0
I	0.79	3.9	29.5	28.5
J	1.25	6.1	28.5	26.0
H	1.65	8.1	28.0	25.0
K	2.16	10.6	27.5	24.5

Calculated using the ESO E-ELT Exposure Time Calculator, with the S/N reference area and pixel scale chosen to best match the simulated PSFs (magnitudes rounded to nearest 0.5).

2.2 Instrument Studies

The UK has a leading role in E-ELT instrumentation, and it is vital that we maintain this edge for the benefit of our technical and scientific communities, via support in the short as well as longer term. Proponents and builders of the first-generation instruments will be best placed, through their expert knowledge and involvement in commissioning and guaranteed-time observations, to reap the early discoveries.

The UK is involved in the scientific and technical aspects of five of the eight Phase A instrument studies, with scientific leadership of a sixth (Table 2). These are well matched to the areas in which UK astronomers excel, i.e. high-redshift galaxies and cosmology, resolved stellar populations, formation of protoplanetary disks and exoplanets. Each study is developing fully costed, advanced conceptual designs to enable ESO and the partner countries to plan and fund an effective instrument suite in the construction phase. The UK is also the major partner in the CANARY on-sky demonstrator which will test multi-object AO for EAGLE on the William Herschel Telescope.

Table 2: UK roles in Instrumentation Studies

Instrument	Description	Prime Goals	UK Role
EAGLE	Wide-field, AO corrected, multi-IFU, near-IR spectrometer	High-z galaxy evolution, first-light galaxies, resolved stellar populations	50% partner with France
EPICS	Imager and spectro-polarimeter for dedicated exoplanet studies	Direct imaging and characterisation of exoplanets and their atmospheres	Minor Partner
HARMONI	Diffraction-limited, near-IR & visible IFU spectrometer.	High-z galaxy evolution, first-light galaxies, resolved stellar populations	Lead
METIS	Thermal IR (5-30μm) imager and spectrometer	Formation and evolution of proto-planetary disks and planets	Minor Partner
OPTIMOS	Wide-field, high-multiplex, seeing-limited/GLAO, vis/nIR spectrograph	Galaxy evolution, IGM tomography, stellar populations.	Co-PI
CODEX	High resolution, seeing-limited, ultra-stable, optical spectrograph	Exoplanet detection, measurement of Universal acceleration.	Lead of sci. team

2.3 Impact of Optical/IR astronomy

The E-ELT will be a common-user facility contributing to all topical research issues, serving a broad base of users. Astronomy is inherently a multi-wavelength discipline, with dramatic advances often coming from synergy between facilities that have opened a new parameter space. For instance, ground-based studies complementing HST, high-energy satellites and discoveries from dedicated survey telescopes, have been the dominant source of the highest impact papers in recent years. Similarly, JWST and ALMA will provide abundant targets for E-ELT follow-up.

As demonstrated by the citation statistics included in the GBFR report, the impact of optical/IR facilities in which the UK is a major stakeholder is huge. It is impossible to assess the potential publications and scientific impact from the E-ELT, but the success of the VLTs in delivering high citation rates per paper are illustrative that European access to leading-quality facilities is indispensible for European scientific leadership. Indeed, the key requirement stated by the ESO Council of the E-ELT programme is to build a European facility `to retain European leadership' on a competitive timescale.

2.4 European and International Standing of the E-ELT

The European astronomy community is united in planning the E-ELT. In the coming decade ALMA will dominate ground-based, high-frequency radio astronomy and the JWST (with significant UK involvement through leadership of the Mid-Infrared Instrument, MIRI) will have an immense impact. Synergy with JWST is a strong driver on the schedule of the E-ELT. No optical/IR facilities are currently planned that will match or exceed the science performance of the E-ELT, and any such facility would necessarily be more than two decades in the future.

North America is leading two ELT projects at present, both of which are still seeking full funding: the Thirty Meter Telescope (TMT), a California/Canada partnership with Japanese involvement, and the Giant Magellan Telescope (GMT), a partnership of private US universities with Australian and Korean involvement. Both TMT and GMT are explicitly competing with the E-ELT for first-light but have smaller collecting areas (by factors of two and four, respectively) and smaller diameters, meaning that the E-ELT will be unmatched in terms of sensitivity and spatial resolution.

2.5 Industrial Benefit to the UK

A key strategic thrust of the UK E-ELT programme is to build opportunities for UK industry to participate in the construction phase of the telescope and associated sub-systems. The ground-work over the last few years has resulted in several UK companies venturing into what was a closed market-place for them during construction of the VLT. Industrial involvement is exemplified by Arup Ltd (enclosure study), by Observatory Sciences Ltd (common software systems) and by a consortium based at the OpTIC Technium in north Wales (prototyping of primary mirror segments). To date, the value of ESO and EU contracts to UK industry and institutes for the E-ELT programme is €8.5M.

The current UK E-ELT programme also supports five development projects (selected through open competition with ESO input) aimed at developing technologies such as deformable mirrors and detectors that are essential to the E-ELT objectives. Other areas to which UK industry could add significant value are being actively pursued, including potential commercialisation and spin-out opportunities (e.g. medical imaging, turbulence monitors).

Links

ASTRONET pages: http://www.astronet-eu.org

ESO E-ELT pages: http://www.eso.org/sci/facilities/eelt/

ESO E-ELT imaging exposure time calculator:
http://www.eso.org/observing/etc/bin/gen/form?VIEW.APPLIC.HTM=ins-elt.htm

UK E-ELT pages: http://www.roe.ac.uk/elt