Report on the JENAM 2008 Meeting Symposium Science with the E-ELT

Guy Monnet
ESO

The symposium "Science with the E-ELT" was held at the Joint European and National Astronomy Meeting (JENAM) 2008 meeting. It featured presentations on the development of a comprehensive E-ELT science case and how it is driving the detailed design of the facility, followed by talks addressing topical observational domains in which the E-ELT should have a major scientific impact. All presentations can be accessed at *http://www.eso.org/sci/facilities/eelt/science/meeting/jenam08/EELT_JENAM08_Programme.pdf*.

The European Extremely Large Telescope (E-ELT) project is presently in the midst of its three-year (2007–2009) detailed Phase B design phase. This effort covers the whole observing facility (infrastructure, enclosure, telescope) including feasibility studies within the ESO community for focal instruments and adaptive optics modules (see Spyromilio et al., 2008, for details). This phase will be concluded with a number of internal and external reviews in the first semester of 2010. The proposal for a decision on the subsequent construction phase is planned to be presented to the ESO Council in June 2010.

By mid-2008, the time was just ripe for this Symposium to discuss and assess the main science goals for this major observing facility. JENAM 2008, as a gathering of a significant fraction of European astronomers, was a fitting location for such an event and we are grateful to its organisers for their offer and continuous support in organising the meeting. Our prime goals were to inform the community of the scientific perspectives opened up by such a facility and to elicit its feedback on the science goals and requirements, with the aim of making the E-ELT a powerful scientific tool for European astronomy in the coming decades.

The event

The 2008 JENAM was held on 8–12 September 2008 at the University of Vienna, Austria. The unifying theme of this year's

Figure 1. Poster for the Science with the E-ELT Symposium.

meeting was to explore "New Challenges to European Astronomy". Quite naturally within this framework, ESO and Opticon jointly organised one of the nine JENAM 2008 symposia, namely Symposium #1 on "Science with the E-ELT". The Symposium was conducted in three sessions, on the afternoons of 8 and 9 September, and in the morning of 10 September. Despite heavy competition from other topical Symposia being held in parallel, attendance was good, with close to a hundred participants.

A total of 22 presentations were delivered at the Symposium. Six addressed the project status, and the remaining 16 its scientific potential, either covering a science domain and the potential impact of the E-ELT when equipped with suitable instrumentation, or alternatively focusing on one instrument presently under study and covering its most important scientific uses. In that way, most scientific aspects relevant to the E-ELT were covered in depth. All presentations can be accessed on the web (*http://www.eso.org/sci/facilities/eelt/science/meeting/jenam08/EELT_JENAM08_Programme.pdf*). Here follows a short summary in session number order covering the scope and main conclusions of the presentations.

Session #1: E-ELT programme

Roberto Gilmozzi (ESO), the E-ELT Principal Investigator, presented the status of the present detailed design (Phase B) of the facility. He first addressed all ELT projects worldwide in the global context of planned space- and ground-based large facilities. This was followed with a summary status of the main aspects of the present project (site characterisation, infrastructure, enclosure, telescope mount, optics, control, maintenance and operations). He then discussed the most critical science drivers for the E-ELT (exoplanets, stellar archaeology, cosmology and the unknown) and the corresponding technical challenges, in particular how to achieve superb image quality, down to the diffraction-limit of the 42 m aperture of the telescope, through wind and atmospheric turbulence correction, based on adaptive optics (AO), over the full working field of the facility.

The status of the Design Reference Mission (DRM) was presented by Isobel Hook (Oxford University), who is responsible for the DRM. This development is driven by the Opticon–ESO Science Working Group (SWG) with the help of the community. The goal is to produce a set of science proposals, with accompanying simulations of the observing results taking into account the whole facility, including adaptive optics systems and instrumentation, leading to a quantitative assessment of the expected science output. This significant effort, covering nine prominent science cases, involves a total of 17 proposals to be analysed in depth and four cases are well advanced at this time. Preliminary conclusions point to a broad E-ELT science case with such highlights as direct detection of super-Earths, watching galaxies form, real-time observation of the accelerating Universe, plus a strong discovery potential for new science. Details on the DRM can be found at *http://www.eso.org/sci/facilities/eelt/science/*.

Markus Kissler-Patig (ESO), E-ELT Project Scientist, showed how the science requirements are driving the project. This started as a generic process, with the publication of the 2005 Opticon–ELT science cases (Hook, 2005), and the Opticon–ESO SWG then focused on the

E-ELT. The resulting report on the science case and requirements released in May 2006 established, in particular, the need for a multi-purpose facility with a large field-of-view and a built-in adaptive optics capability. The SWG is now leading the project Design Reference Mission (see previous presentation description). The ESO E-ELT Science Office is in charge of injecting the science requirements assembled by the SWG and the ten instrument science teams into the design phase. To enlarge the E-ELT scientific base, the community is presently being asked to help build a Design Reference Science Plan (DRSP) by providing additional science cases through a web interface at *http://www.eso.org/sci/facilities/eelt/science/drsp*.

Mark Casali, on behalf of Sandro D'Odorico, who is responsible for the ESO E-ELT instrumentation, covered the status of the current instrumentation feasibility studies. Eight instruments and two post-focal adaptive optics modules are presently being studied by 36 research institutes across Europe with the goal of delivering full science cases, detailed instrument requirements (including telescope/observatory interfaces), consistent and feasible concepts, costs and construction schedules. The complete list of studies is given in Table 1 of Spyromilio et al., 2008. This huge community effort is on track to provide, by the first quarter of 2010, thoroughly studied, scientifically powerful and technically feasible options for the E-ELT first generation instrumentation, which form an essential input for the mid-2010 evaluation process and anticipated decision to build the facility.

Finally, Florian Kerber (ESO), E-ELT Calibration Scientist, described the objectives and methods pursued by ESO, with the help of external partners, to ensure that all E-ELT instrument observational data will be properly calibrated and that adequate pipelines will be available to transform raw data into measurable and accurate quantities expressed in physical units. He stressed the importance of physical modelling of the instruments to minimise the statistical and systematic uncertainties associated with the measuring process. It is equally important to build a set of calibration reference data such as accurately known wavelength calibrators and faint spectrophotometric standards, especially for the near-infrared (near-IR).

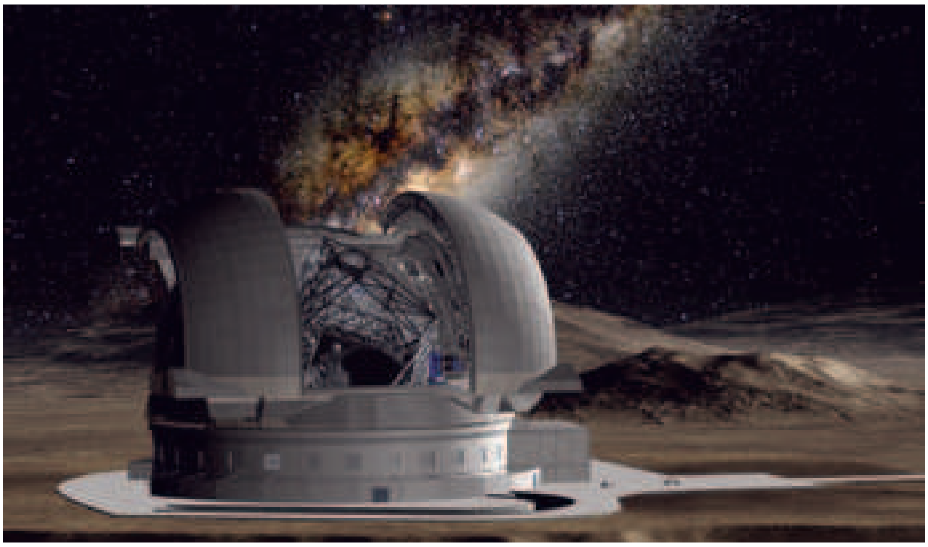
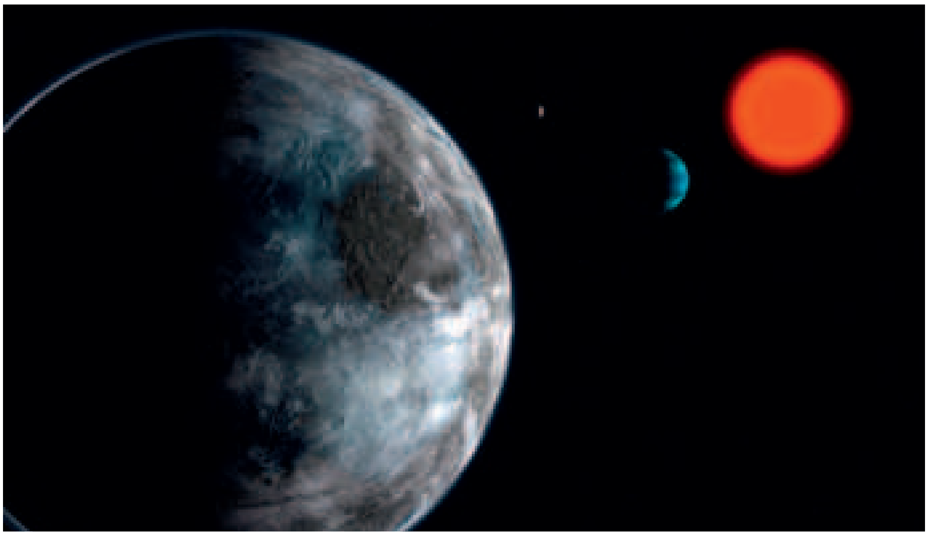


Figure 2. An artist's impression of the E-ELT during observations.

Session #2: Planetary systems and stellar formation

The science case for EPICS, the E-ELT planet finder, was put forward by Markus Kasper (ESO) and Rafaele Gratton (INAF–OAP, Italy) on behalf of the consortium. The fundamental characteristics of the instrument were briefly discussed as well as the hardware, software and observational strategies envisioned to achieve the extreme contrast required to make large scientific inroads into the highly competitive field of exoplanet direct detection. EPICS is a near-IR, extreme contrast, spectral and polarimetric imager with the potential to detect a substantial number of self-luminous exoplanets, especially around hundreds of young stars, and including nearby giant planets down to the mass of Neptune, as well as dozens of nearby rocky planets. The present feasibility study, including the instrument development plan, should be concluded by early 2010.

Figure 3. An artist's rendering of the three-planet system around Gliese 581, as found from highly precise radial velocity measurements with the ESO 3.6 m HARPS spectrograph.



Hans Zinnecker (AIP–Potsdam, Germany) with Fernando Comeron (ESO) and Mark McCaughrean (Exeter University, UK) covered infrared investigations of massive star formation with the E-ELT through diffraction-limited imaging and three-dimensional (3-D) spectroscopy. Observing in the *K*-band and beyond up to 12 μm is essential to observe the early stages of cluster formation, penetrating as much as 200 magnitudes of visual extinction. A combination of high definition imaging, astrometry and spatially resolved radial velocities is required to probe these extremely active dynamical phases. As a complement to observations from the Atacama Large Millimeter/submillimeter Array (ALMA), the E-ELT has the potential to provide clear scientific breakthroughs in the field of massive star formation in dense environments.

Session 3: The stellar component

Rafael Rebolo (IAC, Tenerife, Spain) showed the "unique and fascinating" impact of the E-ELT on the understanding of the origin and evolution of stars and planets. The main research thrust aims at: determining the initial stellar mass function, including multiplicity; studying protoplanetary systems; establishing exoplanet demography and characterising their global physical properties. The E-ELT will also be a powerful tool for investigating a large variety of objects (planets, moons and comets) in our Solar System. All these programmes will require: (a) ultra-stable high resolution spectroscopy in the optical (the CODEX instrument) and near-IR (SIMPLE instrument) wavelength domains for indirect detection of companions and planets; and (b) a fully AO-equipped ELT providing 1–20 μm imaging and spectroscopy at high angular resolution and high contrast (to be provided by the EPICS, HARMONI and METIS instruments) for direct planet detection and physical assessment.

Ernesto Oliva (INAF–Arcetri, Italy) presented the status of the study of the E-ELT high spectral resolution, near-IR diffraction-limited spectrograph (SIMPLE) on behalf of a recently assembled consortium. The project features a wide wavelength coverage (0.8–2.5 μm), high efficiency and radial velocity accuracy, with a minimum 10^5 spectral resolution. He emphasised the unique science within reach with such an instrument, including kinematics and metal content of Lyman-α absorbers, early chemical nucleo-synthesis and chemical enrichment in the inner Galaxy, spectro-astrometry of inner stellar discs within ~ 1 AU, and detection of atmospheric absorption features of Earth-like planets around low mass stars from transit observations.

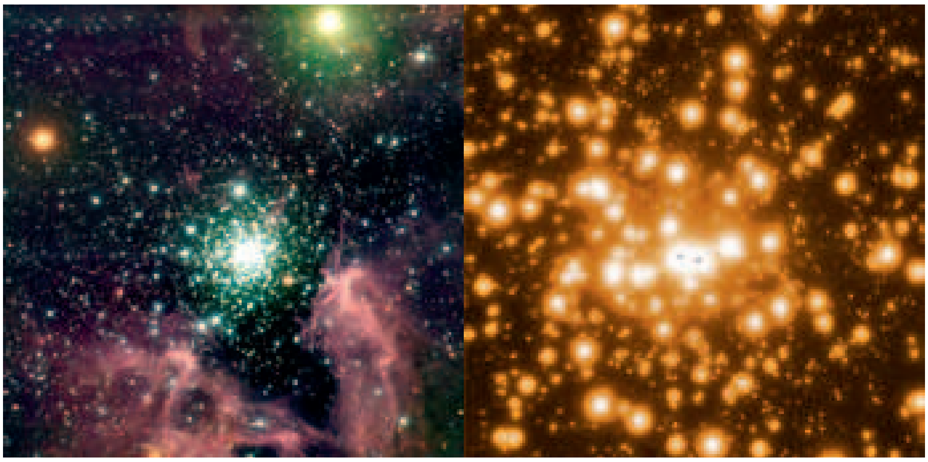


Figure 4. Near-IR images of the Galactic starburst region NGC 3603 at the VLT. Left: 0.4" seeing-limited *J, H,* K_s composite image taken with ISAAC. Right: Diffraction-limited *K*-band image obtained with the MAD adaptive optics demonstrator.

Norbert Przybilla (Sternwarte Bamberg, Germany) addressed the role of blue supergiants (BSGs) as tracers for the cosmic cycle of matter. BSGs emerge as powerful tools for studying: (a) stellar atmosphere physics; (b) metallicity effects on stellar evolution; (c) abundance gradients in field, group and cluster galaxies; and (d) the cosmic distance scale. Quantitative studies of extragalactic BSGs with an ELT require diffraction-limited, near-IR spectra at intermediate resolution. The role of the VLT's Cryogenic high-Resolution Infrared Echelle Spectrograph (CRIRES) as a preparatory tool for ELT science, through observations of Galactic BSGs in order to test stellar atmosphere models and analysis methodology, was strongly emphasised.

Maria Fernanda Nieva (MPA, Garching, Germany) and collaborators made the case for near-IR high resolution spectroscopy of OB stars with CRIRES at the VLT as a pilot study for an ELT science case. Their aim is to determine accurate atmospheric parameters and chemical abundances of Galactic OB stars from identification of metal lines with CRIRES to compare with optical data. Beyond obtaining more accurate models, a very useful by-product of these observations will be the establishment of a set of telluric line standards. Direct application to an ELT includes high precision determination of the chemical composition of massive stars in the Local Group in diverse environments (star formation regions, field stars, the Galactic Centre, etc.).

Chris Evans (UKATC, UK) presented the case for spectroscopy of stellar populations with EAGLE, a near-IR spectrograph with deployable integral field units, currently under phase A study for the E-ELT. The stellar science case spans spectroscopic studies of obscured stellar clusters and resolved stellar populations in and beyond the Local Group (galaxy archaeology), including the central regions of our Galaxy. The primary instrument requirements imposed by the stellar cases are the inclusion of a high (R ~ 10000) spectral-resolving-power mode, and the extension of the wavelength coverage bluewards of 1 μm to include the calcium triplet region. The unprecedented primary aperture of the E-ELT, combined with a large patrol field, modest multiplexing and excellent AO correction, will yield huge gains in sensitivity and efficiency over current facilities, leading to unique advances in studies of stellar populations.

Giuseppe Bono (INAF–OAR, Italy) and collaborators presented recent results on crowded stellar photometry in Galactic globular clusters with the VLT's Multi-conjugate Adaptive optics (MCAO) Demonstrator (MAD). Deep J and K_s images of NGC 3201 were obtained over the 2' x 2' field with a spatial resolution (full width at half maximum) of 70–100 milliarcseconds. Simultaneous reduction of these near-IR images and Hubble Space Telescope (HST) optical images were performed with "classical" reduction packages. This gave a precise Colour Magnitude Diagram (CMD) down to 2 magnitudes below the main sequence turnoff. Stars down to 0.1 $M_\odot$ have been detected in the Galactic starbust NGC 3603 from K_s-band images. The discovery space with an E-ELT looks wide open, provided extensive J-H-K calibrations down to ~ 19 magnitude are obtained (see report on presentation by Kerber, above) together with a vigorous effort to improve theoretical models and stellar diagnostics.

Paolo Ciliegi (INAF–OAB, Italy) presented the Multi-conjugate Adaptive Optics RelaY (MAORY) for the E-ELT on behalf of the consortium. High system performance, in particular in terms of differential photometric precision and relative astrometric accuracy, is required to enable prominent E-ELT science cases, such as deep CMDs of resolved stellar populations (see report on previous presentation), in conjunction with the near-IR MICADO imager (see next reported presentation), to be achieved. These two critical performance requirements are being evaluated by the MAORY consortium with simulated, field-variable point spread functions and simulated globular cluster images. Final conclusions are expected by the end of 2009.

The science case for the E-ELT MCAO Imaging Camera for Deep Observations (MICADO), was presented by Renato Falomo (INAF–OAP, Italy) on behalf of the consortium. An advanced exposure time calculator produces realistic simulated sky images on which data analysis algorithms are tested. Science cases cover a rather wide range, from stellar dynamics around the Galactic Centre, through 100 microarcseconds astrometry, to photometric evidence for supermassive black holes in the centres of galaxies and the physical structure of high redshift galaxies. Two cases were presented in detail in the talk, namely resolved stellar populations in galaxies up to the Virgo cluster distance and QSO hosts and environments at high redshift. A report with a comprehensive scientific analysis is expected soon.

Session #4: The Universe fabric

Klaus Strassmeier (AIP, Potsdam, Germany) presented the ubiquitous role of magnetic fields with examples of the Sun–Earth magnetic connection and its exoplanet version, stellar magnetic fields during core collapse, main sequence and planetary nebula phases, and the still open case of an Intergalactic Magnetic Field (IGMF) as a possible primordial seed. For the last example, the proposed breakthrough with the E-ELT would be to obtain high spectral resolution optical and near-IR linear spectropolarimetry of background quasars in order to measure the Faraday rotation due to the IGMF. This observation requires polarimetric modulation at the E-ELT intermediate focus, comparable to the upcoming PEPSI instrument at the Large Binocular Telescope (LBT). Feeding an optical and a near-IR spectrograph simultaneously would permit access to a wealth of objects from Solar System and extra-Solar System bodies to bright quasars. More discussion of this topic will take place at the IAU Symposium 259 (Cosmic Magnetic Fields: from Planets, to Stars and Galaxies) in November 2008.

One prominent E-ELT science case in the DRM is the determination of the physics and mass assembly of galaxies up to z ~ 6 from a survey of ~ 1000 galaxies with a multi-object integral field spectrograph (see report on the presentation by Evans above). Mathieu Puech (ESO) presented in detail the simulation pipeline developed to assess quantitatively the potential of the E-ELT for this case. This pipeline includes distant galaxy modelling and evaluation of the effects of the point spread function, thermal background and noise sources. From these detailed simulations, the impact of telescope size, site (thermal background and seeing) and instrument characteristics (AO correction, pixel scale and spectral resolution) are being assessed. Finally, a provisional strategy for an optimal survey able to succeed in this science case was unveiled.

Malcolm Bremer (Bristol University, UK) presented the state-of-the-art observations and the impact of the future astronomical large facilities on the exploration of the early Universe during its first gigayear. The James Webb Space Telescope (JWST) will probably be the first to identify the sources of reionisation, but full spectroscopic confirmation will probably require an ELT equipped with an efficient spectrometer working at a spectral resolution of ~ 10^4 to explore the z ~ 6 intergalactic medium (IGM) seen against

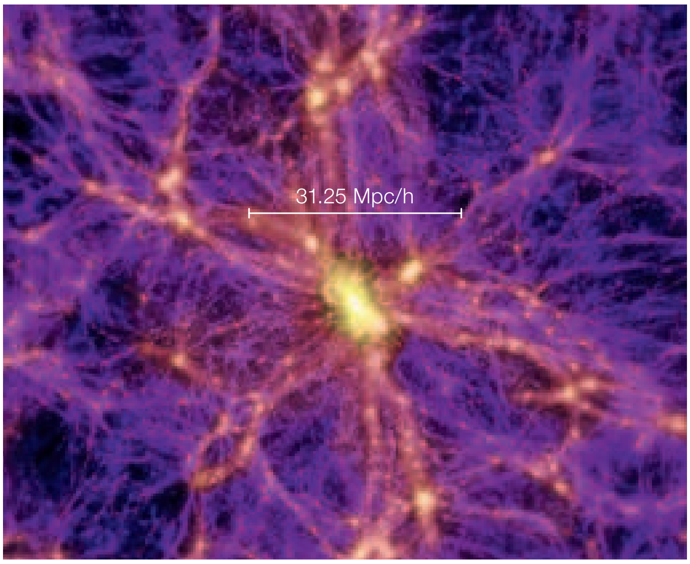


Figure 5. The cosmic tapestry at z = 0 (from the Millennium Simulation).

'bright' background sources. ELTs will be a key component in elucidating the detailed properties of the earliest galaxies, in particular when used along with complementary facilities such as ALMA and the extended Very Large Array (EVLA). The ELT requirement is for spatially resolved, diffraction-limited spectroscopy to achieve ~ 100 pc spatial resolution, a capability that should, in principle, be offered by the current planned instrumentation.

Andreas Kelz (AIP, Potsdam, Germany) discussed the need for ELT optical spectroscopic follow-up of space- and ground-based imaging surveys. He presented the highly promising observing potential of seeing-limited, modular, high-multiplex spectrometers as the most cost-effective and currently feasible approach. Astrophysical examples from the PMAS instrument at the 3.5 m Calar Alto telescope. and from the VLT MUSE and the Hobby–Eberly Telescope (HET) VIRUS 3-D spectrometers under construction, were given. For the E-ELT, the proposed concept features a modular design built from seeing-matched, deployable, fibre integral field units and multiple, replicable, small-size spectrometers. Optionally, photonic components such as fibre Bragg OH suppressors, integrated photonic spectrographs, etc. (see Bland Hawthorn et al., 2006) can be incorporated. Such advanced photonic technologies are amongst the concepts for the proposed ERASMUS instrument study for the E-ELT.

Joe Liske (ESO) presented the E-ELT COsmological Dynamics EXperiment (CODEX) on behalf of the team. The aim of the instrument is to probe the acceleration of the expansion of the Universe directly, one of the most fundamental problems in cutting-edge physics, not only astrophysics. This requires a high resolution optical spectrograph with exceptional radial velocity (*viz.* wavelength) stability of the order of 1 cm/s to detect the so-called redshift drift in the Lyman-α forest spectra of ~ eighteen $2 < z < 5$ QSOs over a 15–20 year period (Liske et al., 2008). The availability of key instrument subsystems, in particular a laser frequency comb to provide the required ultra-stable wavelength calibration, was assessed. A successful detection of the redshift drift on the 42 m E-ELT requires a total of about 4 000 hours of observing time spread over two decades.

Figure 6. The ever-growing progress of the ELT science case under the Opticon aegis, from Marseille in 2003, to Florence in 2004 and back to Marseille in 2006.

Wolfram Freudling (ESO), with Eric Emsellem (CRAL–Lyon, France) and A. Küpcü Yoldaş (MPE, Garching, Germany) investigated the potential E-ELT scientific impact on dynamical mass estimates of supermassive black holes (SMBH). Present day knowledge of these objects was summarised, followed by detailed simulations of potential observations with the E-ELT. Advances in this scientific field require a diffraction-limited 3-D spectrometer at a spectral resolution of ~ 1 000–3 000. Preliminary results show that detection of relatively low mass SMBHs in Virgo should require only ~ 15 minutes integration with 5–10 hours required for the most massive SMBHs to z ~ 0.3. ELTs clearly have the potential to open a new era for SMBH research, and in particular to understand the processes of their formation and evolution better.

Session #4: Conclusions

Gerry Gilmore (IoA, Cambridge, UK), Opticon chairman, summarised the history of European involvement in ELTs and delineated the role played by Opticon since 2002 in bringing out a united pan-European effort, first towards the design-independent FP6 ELT Design Study, then rallying around the E-ELT Project. Opticon has played a major role in developing, in close collaboration with the community, a comprehensive science case for the E-ELT, including its first top level science requirements. The importance of the three "big questions" — the physical meaning of dark energy, the nature of dark matter and the ubiquity of life — and the potential E-ELT role in attacking these problems were emphasised in the talk. He concluded: "The E-ELT is an excellent and realistic project, enjoying a strong and wide community support that the ESO design team must retain. The community must continue active involvement and work for national agency support, to raise the funds and approval by mid-2010."

References

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