Scientific Strategy Planning at ESO

Introduction by Ralf Bender, Chair of the Scientific Strategy Working Group

At its 100th meeting in June 2003, the ESO Council decided to install a Working Group to discuss ESO's scientific strategy until 2020. The time appeared ripe to discuss the future, as the VLT was now largely completed, ALMA had just been approved, and the ESO community had been significantly strengthened by the recent accession of the United Kingdom. Furthermore, the discussions and concept studies for the next large facilities (notably the Extremely Large Telescopes) were underway world-wide. Evidently, it was important to develop a strategy for ESO's future now.

The Scientific Strategy Working Group was composed of members of Council: Ralf Bender (Chair), Tim de Zeeuw, Claes Fransson, Gerry Gilmore and Franco Pacini; Bruno Marano and members of the STC, the VLTI Implementation Committee and the European ALMA Board: Jean-Loup Puget, Thomas Henning, and Simon Lilly. ESO was represented by Bruno Leibundgut, Guy Monnet and Peter Quinn. The Director General and the Head of Administration attended all meetings as well.

The charge to the Working Group was defined by Council as follows: "Prepare and assess the options for ESO's long term programme, taking a broad view of ESO's role in world astronomy [...]. In doing so, the Group shall consider ESO's long term scientific goals and objectives. To this end, current and future developments and the possible implications of further external collaboration and enlarged membership may also be considered."

The Working Group met three times and prepared a report accompanied by a set of recommendations. After minor revisions, the ESO Council adopted the recommendations as a formal "Council Resolution on Scientific Strategy" in its last meeting in December 2004. Both documents are printed below.

I take this opportunity to thank all Working Group members for very good and open discussions, constructive contributions and pleasant and efficient meetings.

Report from the Working Group on Scientific Strategy Planning

Introduction

1. ESO's mission was stated in the Convention as to "*establish and operate an astronomical observatory in the southern hemisphere, equipped with powerful instruments, with the aim of furthering and organising collaboration in astronomy*". In the current world and in view of Europe's and ESO's achievements in astronomy in the last decade, ESO's mission could be stated more ambitiously: ESO should provide European astronomers world-class facilities to pursue the most fundamental astronomical questions.

2. ESO cannot do this alone. A close partnership between ESO and the astronomical institutions in its member countries is crucial to the development and preservation of the scientific and technical excellence of European Astronomy. This implies that the success of European Astronomy relies equally on a world-class ESO and on strong and active research institutions throughout Europe.

3. The granting of access to ESO facilities, participation in ESO programmes, and even membership of ESO are based primarily on scientific excellence. ESO will continue to be open to new members and collaborations, following the principles of furthering excellence and scientific cooperation.

The Astronomical Framework

4. Over the past two decades, Astronomy has entered its golden age. A few examples of what has been achieved are: We have now direct evidence for the evolution of galaxies and stars throughout 90 % of the age of the universe. We have found supermassive black holes in most galaxy centres and have probed their evolution to high redshifts. We have seen the seeds of galaxies and their large-scale distribution in the cosmic microwave background. We have determined the cosmic parameters with an order of magnitude better accuracy. We have confirmed the existence of dark matter which is 5 times more abundant than ordinary matter, and we have found that the universe is filled to 70 % with the so-called 'dark energy', a new state of energy of hitherto unknown nature. And last, not least, we have, for the first time, found planets around other stars.

5. It is evident that progress in astronomy is driven by both unexpected discoveries (e.g. dark matter, dark energy) as much as by particular experiments designed to test specific theories (like ongoing microwave background experiments). Astronomical discoveries are often made by pushing the limits of observation with the most powerful telescopes on the ground and the most advanced satellites in space (e.g. high redshift galaxies, black holes, gamma ray bursts etc), but smaller workhorse telescopes and instruments used in a new mode of operation can also produce very exciting discoveries (e.g. MACHOS, planets etc.).

6. Key scientific questions in astronomy and astrophysics over the next 20 years will include (i) the nature of dark matter, (ii) the nature of dark energy, (iii) the formation of the very first stars and galaxies and following their evolution from the highest redshifts until today, (iv) extreme conditions of matter and energy (e.g. black holes), (v) the formation of stars and planetary systems, and (vi) the characterization of extra-solar planets including the search for extraterrestrial life.

7. Addressing all of these questions requires a co-ordinated observational and experimental approach, spanning all wavelengths of the electromagnetic spectrum with facilities on the ground and in space but also exploring new observing windows to the universe, like underground neutrino detectors, or space interferometers for gravitational wave detection. Ground-based astronomy with large aperture telescopes plays a pivotal role in the overall concept because (a) most sources we want to study emit a large fraction of their radiation between optical and radio wavelengths, (b) this wavelength range provides crucial and detailed information about the physical nature of the sources, and (c) the sources we want to study are generally very faint. In addition, large telescopes like Keck and VLT have not only made important discoveries by themselves but also have provided crucial complementary information to discoveries made with satellites (e.g. the Hubble Space Telescope, ISO, Chandra etc.) which otherwise could often not be interpreted comprehensively and would remain inconclusive. And finally, beyond their large light collecting power, the additional strengths of ground-based telescopes are their high versatility and the possibility to explore new technologies rapidly.

8. Astronomy has from its very beginning been a technology-enabled science and is

View of La Silla from the 3.6 m telescope.

now progressing more rapidly than ever before, with its technology feedback benefiting industry. In ground-based astronomy, improving the performance of existing telescopes and the construction of the next generation of telescopes and instruments will require investment in several critical technologies. Important over the next 10+ years will be, e.g., the development of multi-conjugate adaptive optics, laser guide stars, the mastering of increasingly complex telescope/instrument systems and the handling and exploration of Petabytes of data.

ESO's Facilities

9. ESO and its collaborating institutes have a highly skilled and very motivated staff specialized in the design, construction and operation of large optical/IR telescopes and their instruments. Another major strength of ESO is the efficient management of large projects which is one reason why the VLT is the best ground-based astronomical facility today. It took decades to build this expertise and this asset must be preserved if Europe is to stay competitive in the future. ESO has also managed its facilities effectively, opening a new site for the VLT because it was scientifically advantageous to do so, and closing facilities on La Silla when no longer scientifically cost effective.

10. **La Silla** is still one of the most successful observatories world-wide. Survey and monitoring projects with dedicated instruments (e.g. HARPS for planets) have become increasingly important and produce impressing scientific results. La Silla has also been needed to provide targets for the VLT. However, with the installation of VST/OmegaCAM and VISTA, preparatory observations and target finding for the VLT will not have to rely on La Silla beyond 2006.

11. The **VLT** is the most powerful and versatile 8 m telescope system to date. It is now fully operational. Further upgrades and the development of second generation instruments should ensure European leadership in most areas of optical/IR astronomy for at least 10 more years. Once a 30 m+ telescope and the James-Webb-Space-Telescope go into operation, the role of the VLT needs to be reconsidered and more specialization may be required.

12. The **VLTI** is acknowledged to be the most advanced interferometer in the world in almost all aspects (except nulling interferometry with Keck). It will be the best system to enable faint science (e.g. structure of Active Galactic Nuclei) and ground-based astrometry, because it is the only system that can potentially combine four 8 m telescopes interferometrically. The VLTI is still being constructed, with new instruments to be added and four Auxiliary Telescopes to be completed.

13. **ALMA** will open a new window to the universe and provide unprecedented access to the gaseous medium and the star formation processes both in our Galaxy and in the most distant galaxies in the universe. ALMA will discover vast numbers of faint sources that require complementary observations at other wavelengths.

14. These facilities, and many others around the world, produce an enormous amount of archived data which is available to the astronomical community. ESO is working with European institutions in a global effort to establish an International **Virtual Observatory**. This project addresses critical requirements for handling the steadily increasing data rates from ESO telescopes and for connecting them with data sets obtained by other facilities and at other wavelengths. Data handling and processing is one of the key new challenges in astronomy.

The Extremely Large Telescope

15. The unique capabilities of an Extremely Large Telescope (30 m and larger) are (i) its 16 to 160 times larger light collecting power than a VLT UT and (ii) its potentially 10 to 40 times higher spatial resolution than the Hubble Space Telescope. The combination of these two features will enable imaging and especially spectroscopy of sources up to a factor 50 fainter than currently possible. Considering the enormous progress the Hubble Space telescope brought with its factor 10 improvement in spatial resolution, and the 8 m class telescopes with their factor 5 in light collecting power, the discovery power and impact of an ELT can hardly be overestimated. With an appropriate choice of the site an ELT should also offer unique imaging capabilities in the sub-mm range complementing ALMA.

16. The case for an ELT alone is compelling; in the context of other facilities it is overwhelming. An ELT will be an important complement to ALMA, the James Webb Space Telescope (JWST), future space missions like DARWIN and XEUS, and to other space and ground observatories. It is important to realize that, because of their intrinsically different capabilities, ELTs on the one hand and space missions like DARWIN or JWST on the other hand, will not compete but rather support each other by providing complementary information about planets, stars and galaxies. In combination, these facilities will produce the next revolution in our understanding of the universe and its constituents.

17. The scientific reach of an ELT, and its potential for making new discoveries, are so great that there is a strong case for each of the world's regions having access to an ELT. Collaborative efforts should be encouraged, but should not be allowed to compromise European access to an ELT or to its associated technological benefits. It is therefore important that European astronomy builds on its current strength and aims for a leading role in the development and construction of an ELT. This is also vital in attracting the best young scientists and keeping them in Europe. North American institutions (CalTech, UC, AURA, Canada) are undertaking a detailed design

The VLT with stations of the VLTI (foreground).

study of a 30 m telescope, the TMT. Another group of institutions (led by Carnegie Observatories) has started constructing a 21 m telescope, the GMT. Their ambition is to have first light before 2016 for both projects. Europe must keep pace with this work.

18. ESO and European Institutions are jointly pursuing technology development and concept studies towards an ELT (in part through the FP6 framework). ESO has developed what appears to be the most innovative concept to date for an Extremely Large Telescope, namely the OWL[1]. The OWL concept studies have been carried out in close collaboration with industry and indicate that a fundamentally new approach to build large telescopes should allow the construction of a 60 m telescope for a cost comparable to that of a conventional 30 m telescope. The new paradigm is based on the adoption of serialised industrial production and a fully computer-controlled optical system to reduce cost without compromising performance. Below about 60 m, the OWL concept probably loses its high cost effectiveness. A detailed design study is essential to validate the OWL approach, including instrumentation, and establish the optimal balance between science, technology, and cost.

19. The total cost for a 100 m ELT based on the OWL concept is currently estimated to be about 1200 M Euros. A 60 m ELT would cost about half this amount, or roughly the cost of VLT or ALMA.

20. Three illustrative scenarios have been developed by ESO. They are not yet optimised for cash flow or resource usage, but are sufficient to illustrate the main points in the planning. While still including some allocation for technological development in crucial areas, Scenario I corresponds to the fastest schedule technology could plausibly allow. Scenario II-100 allows more extensive design and development periods before start of construction, and a relaxed integration schedule. Scenario II-60 corresponds to a 60 m instead of a 100 m telescope.

Scenario	Telescope diameter	Phase B starts	Phase C/D starts	Start of science (partially filled)	Full completion
I	100 m	2005	2007	2012 (50 m dia.)	2016
II-100	100 m	2006	2010	2017 (60 m dia.)	2021
II-60	60 m	2006	2010	2016 (40 m dia.)	2020

Conclusions

21. Over the last decade ESO has succeeded in becoming fully competitive and indeed world leading. However, the risk of falling back is real, even in the near future, especially with respect to ELTs. To maintain its position Europe has to adopt plans which keep its scientific and technical ambitions at the highest level to remain attractive for the best scientists and engineers. This means that Europe, and specifically ESO, must participate in the most important and challenging technical and scientific developments of the future and should set priorities accordingly. This is also important for European industries.

22. In the different scenarios for ESO's future until 2015, optimal support for the VLT and ALMA and the development of an ELT are unquestionable priorities. The operation of La Silla and the enhancement of VLTI can have different priorities.

23. The success and excellence of European astronomy requires ESO to maintain the **VLT** as a world-leading facility for at least 10 more years. The VLT needs constant upgrading, including MCAO and an adaptive secondary, and a vigorous 2nd generation instrument program because ESO must:

a. keep pace with the steadily improving capabilities of other 8 m telescopes (Keck, Gemini, Subaru, LBT …),
b. continue to utilise technological advances,
c. match the evolving European science requirements, and
d. maintain developments that are critical for an ELT.

24. The unique capabilities of the **VLTI** mean that the current generation of VLTI instruments and PRIMA for two telescopes should be completed with high priority. The case for the extension of PRIMA to four beam combination using either 4 ATs or 4 UTs needs to be demonstrated with simulations of realistic observing situations. If the demonstration is convincing, four beam combination should be implemented.

25. The role of **La Silla** beyond 2006 has been cogently presented. La Silla will still be useful and competitive in many respects, but it will not be as essential for the success of ESO as the VLT, VLTI, ALMA and an ELT which consequently must have higher priority than the continued operation of La Silla.

26. The European components of **ALMA** are being constructed in collaboration with institutes within the European astronomical community. This collaboration is also critical for the development of adequate data analysis tools which will help to educate European astronomers to make best use of ALMA and perform cutting-edge science projects. ESO should build up sufficient competences in the mm and sub-mm fields to coordinate and complement the expertise and support from outside institutions.

27. ESO must ensure that Europe preserves its current world-leading position into the **ELT** era, because ESO and European astronomers cannot afford to be left behind in the most important developments in ground-based optical/IR astronomy. This can be achieved through the construction of a 60 m OWL for a cost comparable to a US 30 m telescope. Thanks to its new concept based on serialised production, an OWL-type telescope can be realized at much lower cost than a 'conventional' 30 m telescope of Keck-design. However, the advantages of serialised production only become effective beyond about 60 m and are in fact being validated for a 100 m telescope.

28. One of the advantages of the ESO conceptual design is that the telescope is designed so that it can be 'staged' in diameter, becoming available for observations with only a partially completed primary mirror. An OWL-type telescope could have first-light as a 30 m telescope on a competitive timescale and then grow to a 60 m over several additional years (the ALMA project already adopts the same philosophy), and similarly a 100 m telescope could start operations as a 50 m or 60 m. Similarly, Europe can stay competitive in timescale by adopting this 'growing a telescope' concept and so having access to a world class 30 m telescope at the same time

Artist's image of the Atacama Large Millimeter Array (ALMA).

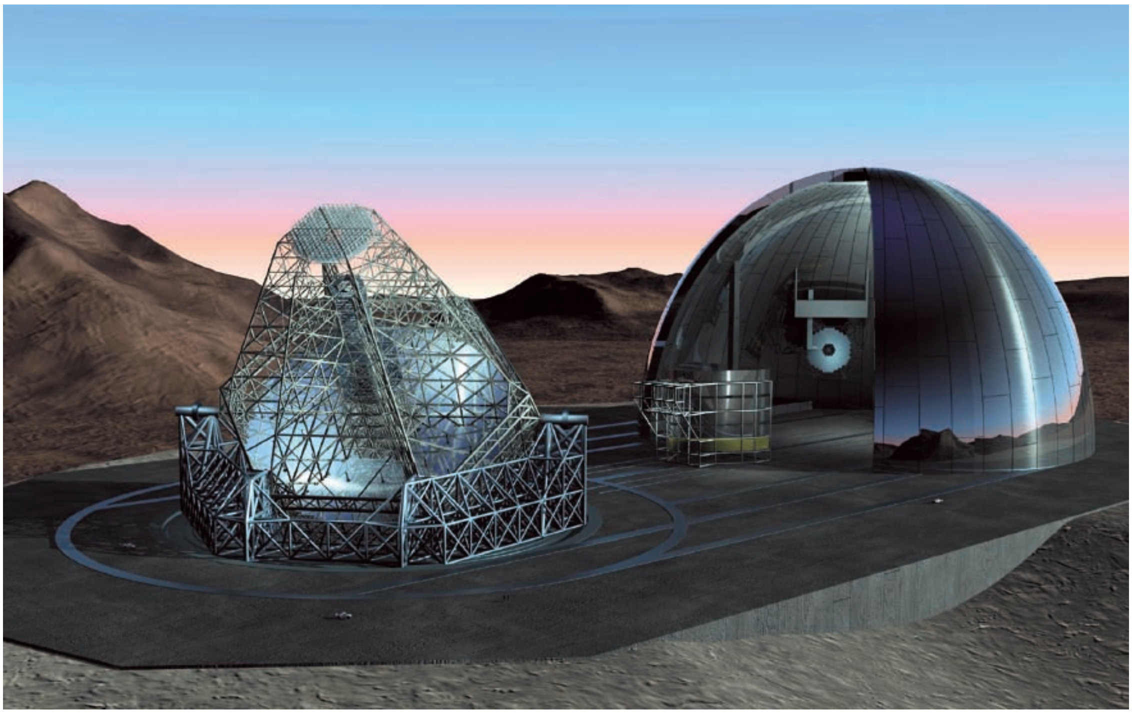
[1] In this document, the term ELT refers to all telescopes larger than 30 m, without reference to a specific design. Most technology development that has been carried out up to now (e.g. within EU-funded projects) is at the component level and is indeed design independent. The term OWL is used only when referring to the specific telescope concept that has been developed by ESO. All the statements related to OWL in this document should be revisited after the conceptual design review which is expected to take place at the end of 2005.

as the North American colleagues. Strong community involvement for system level development and provision of instrumentation will, as in the case of VLT and ALMA, be crucial for our success.

29. As with ALMA, a collaboration with North America and possibly others would enable an even more ambitious global ELT project to be undertaken.

30. ESO should continue to develop new data archiving, data access, and data mining technologies in collaboration with the European astronomical community and within the framework of the **International Virtual Observatory Alliance**. The availability of these technologies is an important factor for the future success of ESO and European Astronomy.

31. Because astronomy and astrophysics exploit leading edge technology, ESO should remain at the forefront of future mainstream and key technologies concerning telescopes, instruments, and data handling. To achieve this goal, ESO should continue its very successful partnership with European astronomical institutions and industries as in the past, also within the framework of EU funded projects.



Artist's impression of ESO's OWL concept.

ESO Council Resolution on Scientific Strategy

ESO Council, considering the report of its Working Group for Scientific Strategic Planning, ESO/Cou-990, and its recommendations in ESO/Cou-964 rev. 2, agrees that

- astronomy is in a golden age with new technologies and telescopes enabling an impressive series of fundamental discoveries in physics (e. g. dark matter, dark energy, supermassive blackholes, extrasolar planets),
- over the last decade, the continued investment of ESO and its community into the improvement of ground-based astronomical facilities has finally allowed Europe to reach international competitiveness and leadership in ground-based astronomical research,
- the prime goal of ESO is to secure this status by developing powerful facilities in order to enable important scientific discoveries in the future,
- only the continued investment in cutting edge technologies, telescopes, instruments and information technology will enable such scientific leadership and discoveries,
- ESO will continue to be open to new members and collaborations, following the principle of furthering scientific excellence,

and accordingly adopts the following principles for its scientific strategy:

- ESO's highest priority strategic goal must be the European retention of astronomical leadership and excellence into the era of Extremely Large Telescopes by carefully balancing its investment in its most important programmes and projects,
- the completion of ALMA is assured and conditions for an efficient exploitation of its superb scientific capabilities will be established,
- the VLT will continue to receive effective operational support, regular upgrading (especially to keep it at the forefront in image quality through novel adaptive optics concepts) and efficient 2nd generation instrumentation in order to maintain its world-leading position for at least ten more years,
- the unique capabilities of the VLTI will be exploited,
- the construction of an Extremely Large Telescope on a competitive time scale will be addressed by radical strategic planning, especially with respect to the development of enabling technologies and the exploration of all options, including seeking additional funds, for fast implementation,
- ESO and its community will continue their successful partnership and seek effective intercontinental collaborations in developing the most important and challenging technologies and facilities of the future.