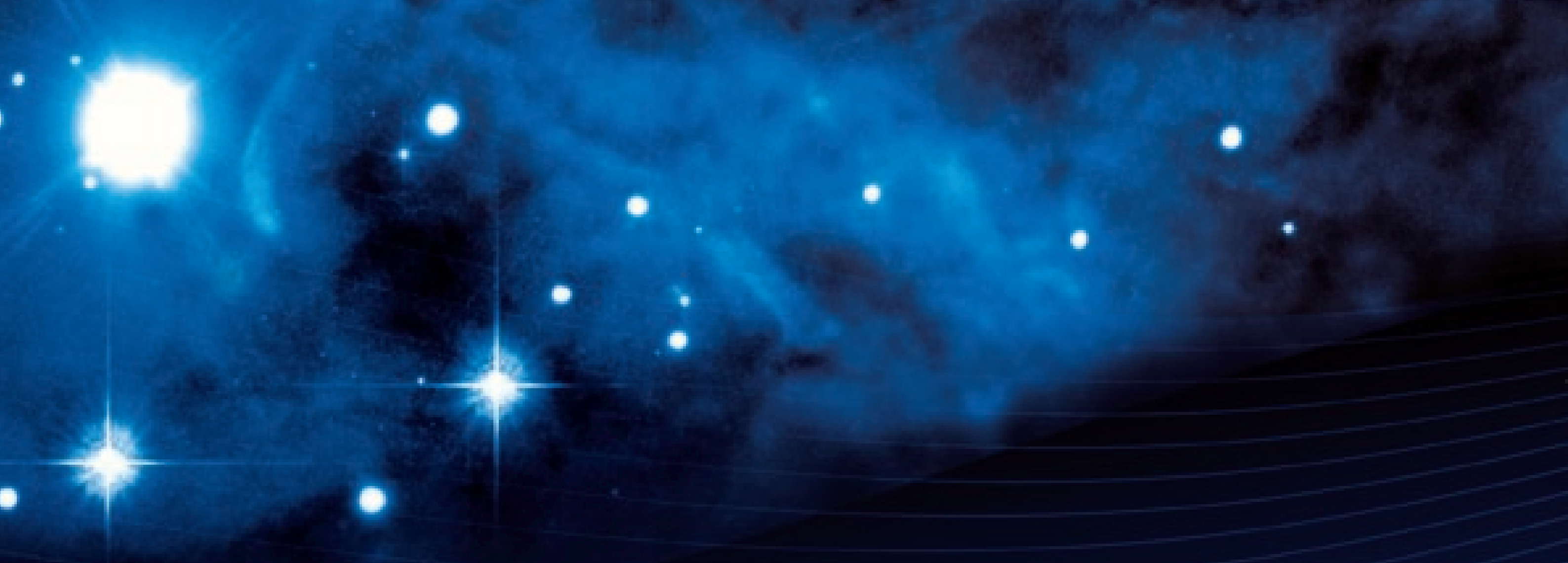
TOWARDS A STRATEGIC PLAN FOR EUROPEAN ASTRONOMY

ASTRONET
www.astronet-eu.org

The ASTRONET Roadmap: Strategic Planning for European Astronomy

Pre-release version – confidential

EXECUTIVE SUMMARY



Background: The Global Scientific Context

This is a golden era for astronomy. The past few years have brought a number of epochal discoveries, from the detection of the first planets orbiting other stars, to the accelerating Universe dominated by enigmatic dark energy. Europe is at the forefront in all areas of contemporary astronomy and the challenge now is to consolidate and strengthen this position for the future.

In a world of ever-fiercer global competition, European astronomy has reached its current position by learning to cooperate on both a bi- and a multilateral basis, and especially through the European Southern Observatory (ESO) and the European Space Agency (ESA). However, the scientists and research programmes in universities and research organisations at the national level remain the backbone of European astronomy. The scientific challenges of the future will require a comprehensive long-term strategy and the coordination of financial and human resources, underpinned by vibrant, national scientific and technological communities across the whole of Europe. This approach is also needed if Europe is to be a strong and effective partner in the largest, global projects.

ASTRONET, supported as an ERA-Net by the European Commission, was created by the major European funding agencies and research organisations to prepare long-term scientific and investment plans for European astronomy for the next 10–20 years. The present *Infrastructure Roadmap* represents the core of this effort and is unique in the history of European astronomy. Firstly, it considers the whole of astronomy: from gamma-ray to radio wavelengths as well as particles, from the ground and in space, and from the distant borders of the Universe to *in situ* exploration of Solar System bodies, and includes theory, computing and laboratory studies. Secondly, it involves all of Europe, including the new EU member states, and explicitly includes the human resources that are crucial to the delivery of the scientific outcome.

We know that astronomy interests people of all ages; as well as expanding their horizons, it can encourage younger people to consider careers in science or technology. Astronomy also drives high technology in areas such as optics and informatics. These are all powerful reasons to support European astronomy. As this report shows, astronomy is also a fully international science whose communities welcome the establishment of the European Research Area.

Hubble and Chandra composite of the galaxy cluster MACS J0025.4-1222, showing the hot, diffuse gas trapped in the cluster's powerful gravitational field.

Credit: NASA, ESA, CXC, M. Bradac (University of California, Santa Barbara, USA), and S. Allen (Stanford University, USA)

Science-Driven Prioritisation

Scientific planning must be based on scientific goals. Accordingly, this process began with the development of a *Science Vision for European Astronomy*, published in October 2007. It reviewed and prioritised the main scientific questions that European astronomy should address over the next 10–20 years under four broad headings:

- Do we understand the extremes of the Universe?
- How do galaxies form and evolve?
- What is the origin and evolution of stars and planets?
- How do we fit in?

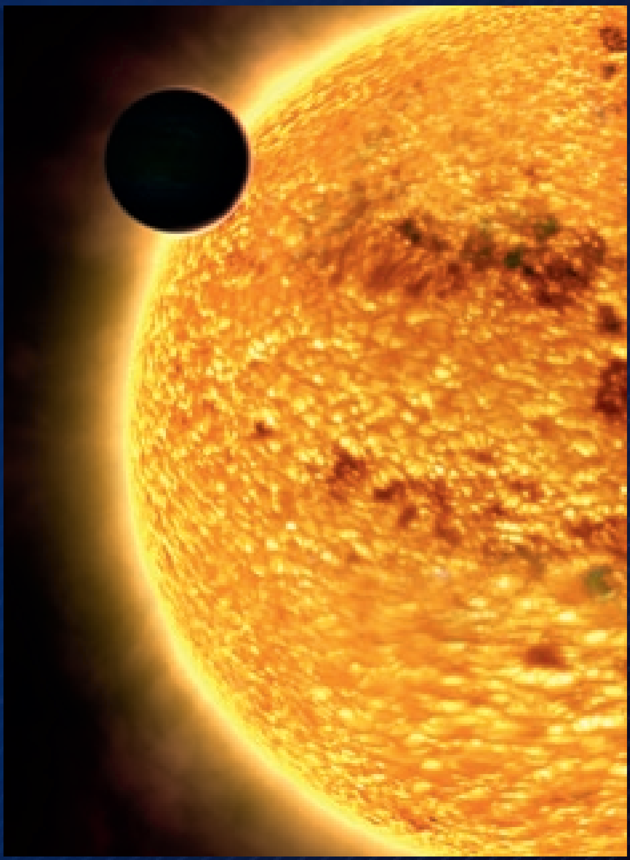
In doing so, the *Science Vision* identified the types of research infrastructure that would be needed to answer the key questions under each heading, but did not address specific projects. The present *Infrastructure Roadmap* builds on the *Science Vision*. It aims to develop a matching set of priorities for the material and human resources needed to reach these goals, and a plan for phasing the corresponding investments so that the bulk of the *Science Vision* goals can be reached within realistic budgets. It extends the *ESFRI Roadmap* by analysing and comparing the flagship projects in all areas of astronomy in technical and financial detail, and by addressing directly the hard facts of the implementation phase.

The ASTRONET *Roadmap* was developed primarily on scientific grounds by a Working Group appointed by the ASTRONET Board. Existing and proposed infrastructure projects across astronomy — well over 100 in all — were reviewed by three specialist panels of top-ranking European scientists. Two other panels considered the concomitant needs for theory, computing and data archiving, and human resources including education, recruitment, public outreach and industrial involvement. Overall, over 60 European scientists were directly involved in this effort. Feedback from the community was invited through both a web-based forum and a large symposium held in June 2008.

The panels worked by assessing projects requiring new funds of €10 million or more from European sources and on which spending decisions are required after 2008. They examined each project for its potential scientific impact, its uniqueness, its level of European input, the size of the astronomical community that would benefit from it, and its relevance to advancing European high-technology industry.

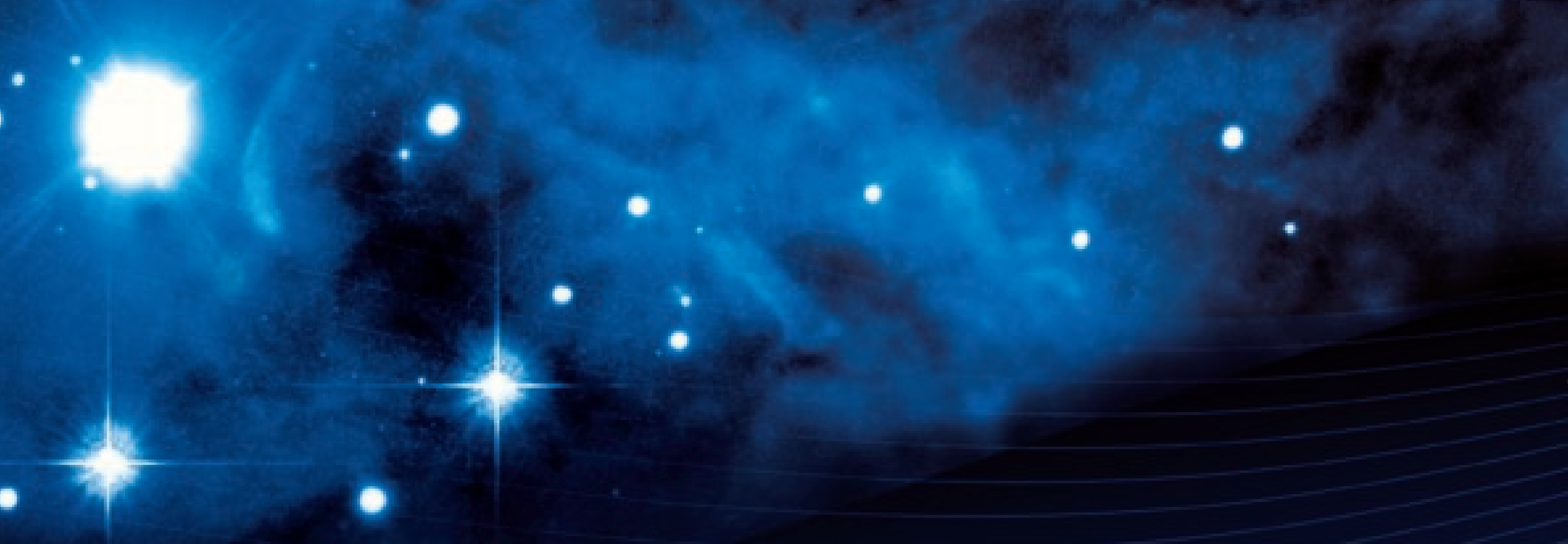
The Working Group and Panels were mindful of existing national and international strategic plans, including those of ESFRI, ESO and ESA. They also considered the global context, including the plans of our major international partners. Close contact was maintained with the infrastructure networks OPTICON, RadioNet, EuroPlaNet and ILIAS and the ERA-Net ASPERA. The Working Group has sole responsibility for the final report.

Three aspects of the *Roadmap* are notable. Firstly, it emphasises the need to include the entire electromagnetic spectrum — and beyond — in the study of most cosmic phenomena, from young stars and planets to supermassive black holes in the distant Universe. Secondly, the priorities of proposed new space missions were reviewed independently by the ASTRONET and ESA Cosmic Vision panels. Although they were prepared by different groups of scientists, the conclusions were very similar. Thirdly, the *Roadmap* identifies a number of gaps, for which technological solutions are needed, as well as inconsistencies in current policies. It points to the lack of consistency between the resources devoted to major projects and their scientific exploitation, and to the need to coordinate space projects with the matching ground-based efforts that are needed to secure the full scientific returns from the investment.



Artist's impression of the the extrasolar planet HD 189733b.

Credit: ESA/Hubble/M. Kornmesser



Financial and Human Resources

A useful roadmap must include realistic estimates of costs, technological readiness and available resources. Independent advice as well as information provided by the projects have been used to assess their cost and maturity, but the reliability of these data varies from project to project. For future space missions in particular, projects have been changing and merging either internally or with other projects internationally while this report was being prepared. Resource estimates, and also scientific capabilities given here should be regarded as a snapshot of the current situation, based on the best information available to date. Known or estimated costs for operations are included throughout.

More surprisingly, the available information on present financial and human resources for European astronomy is itself fragmentary and inconsistent, especially when national universities, projects, and bi- or multilateral collaborations are to be included in addition to ESO, ESA and national funding agencies. The demarcation between astronomy and other natural sciences such as physics, chemistry or biology is another source of uncertainty. A breakdown of resources into astronomical disciplines such as cosmology or exoplanet research is not possible, and substantial effort will be required to achieve it. This report can give only approximate totals, but they do represent the best pan-European information available today.

In the following, ground-based and space-based projects are considered separately, as the funding sources and project selection procedures for them are often separate. The recommendations are, however, based on the overall scientific perspectives described in the *Science Vision*.

Artist's impression of the European Extremely Large Telescope (E-ELT) during observations. In the background the centre of the Milky Way is just rising above the enclosure of the telescope.

Credit: ESO/H. Zodet

Ground-Based Projects

Among the ground-based infrastructure projects, two emerged as clear top priorities due to their potential for fundamental breakthroughs in a very wide range of scientific fields, from the Solar and other planetary systems to cosmology:

- The *European Extremely Large Telescope* (E-ELT), a 40-m-class optical-infrared telescope being developed by ESO as a European or European-led project. A decision on construction, based on a detailed design and cost estimate, is planned for 2010.
- The *Square Kilometre Array* (SKA), a huge radio telescope being developed by a global consortium with an intended European share of 33-40 per cent. The SKA will be developed in three phases of increasing size, scientific power, and cost. Construction of Phase 1 could be decided in 2012, followed by first science and a decision on Phase 2 around 2016, and with Phase 3 envisaged after 2020.

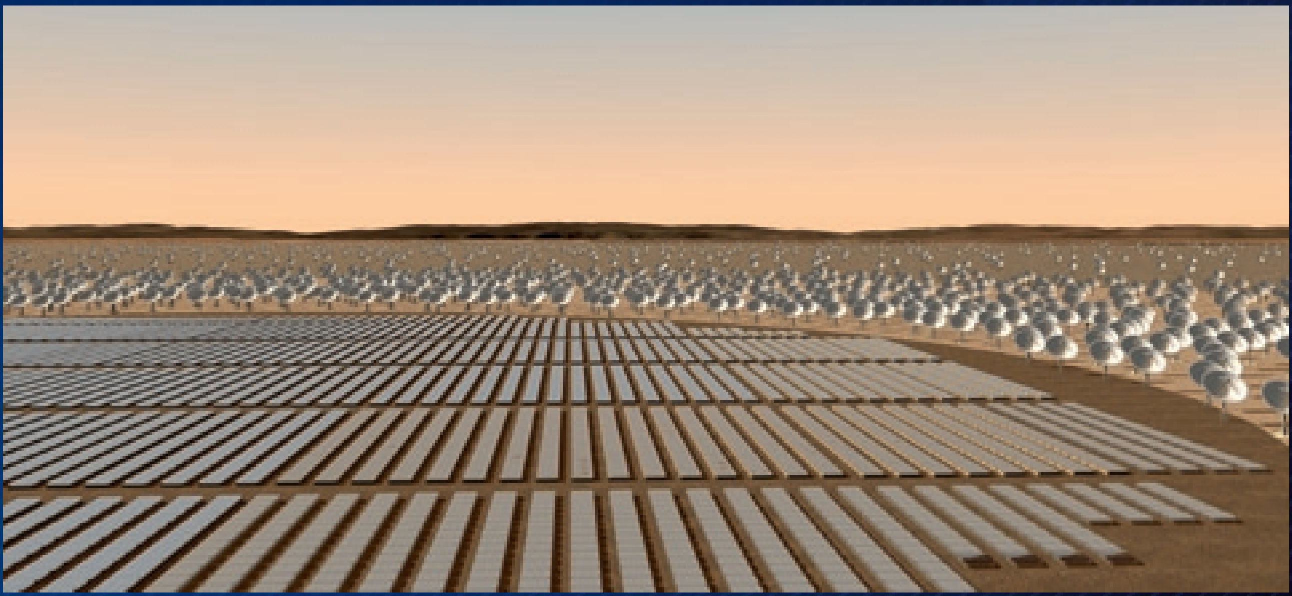
It was concluded that although the E-ELT and SKA are very ambitious projects requiring large human and financial resources, they can both be delivered via an appropriately phased plan.

Three other projects were considered scientifically outstanding in areas with European leadership, but in narrower fields and with lower budgets than the E-ELT and SKA. These have been grouped together in a separate list which comprises, in descending order of priority:

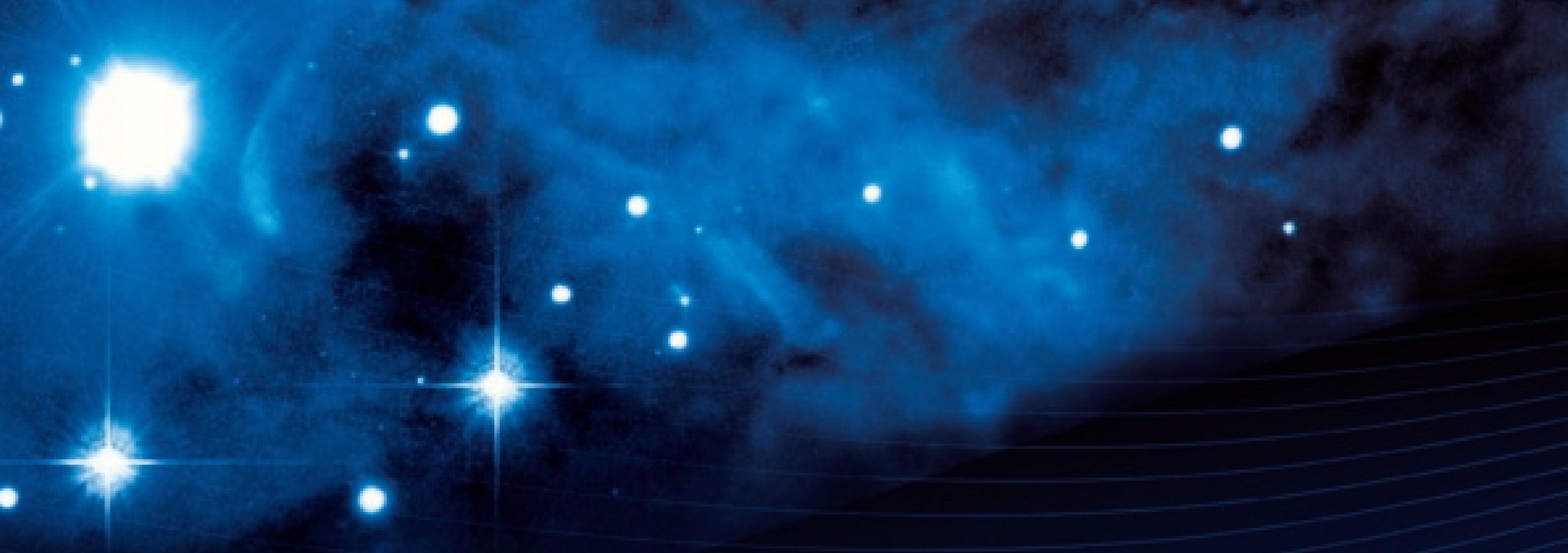
- The *European Solar Telescope* (EST), an advanced 4-m solar telescope to be built in the Canary Islands. The EST will enable breakthroughs in our understanding of the solar magnetic field and its relations with the heliosphere and the Earth; when ready, it will replace the existing national solar telescopes in the Canary Islands.
- The *Cerenkov Telescope Array* (CTA), an array of optical telescopes to detect high energy gamma rays from black holes and other extreme phenomena in the Universe. Building on existing successful European experiments, the CTA — the first true observatory at such energies — is expected to bring about a breakthrough in our understanding of the origin and production of high energy gamma rays.
- The proposed underwater neutrino detector, *KM3NeT*, was also considered of great scientific potential, but ranked lower than the CTA because of the more proven astrophysical discovery capability of the latter.

A smaller project, but again of high priority, is a wide-field spectrograph for massive surveys with 8–10-m telescopes. A Working Group is to be appointed by ASTRONET to study this in detail. Finally, the report identifies a need to incorporate and support laboratory astrophysics — including the curation of Solar System material returned by space missions — more systematically than now.

Artist's view of the central element of the Square Kilometre Array. The phased elements will be able to observe the whole sky and study multiple objects simultaneously with independent beams. Surrounding the central elements is a widely distributed array of antenna dishes providing added sensitivity and resolution.



Credit: SKA

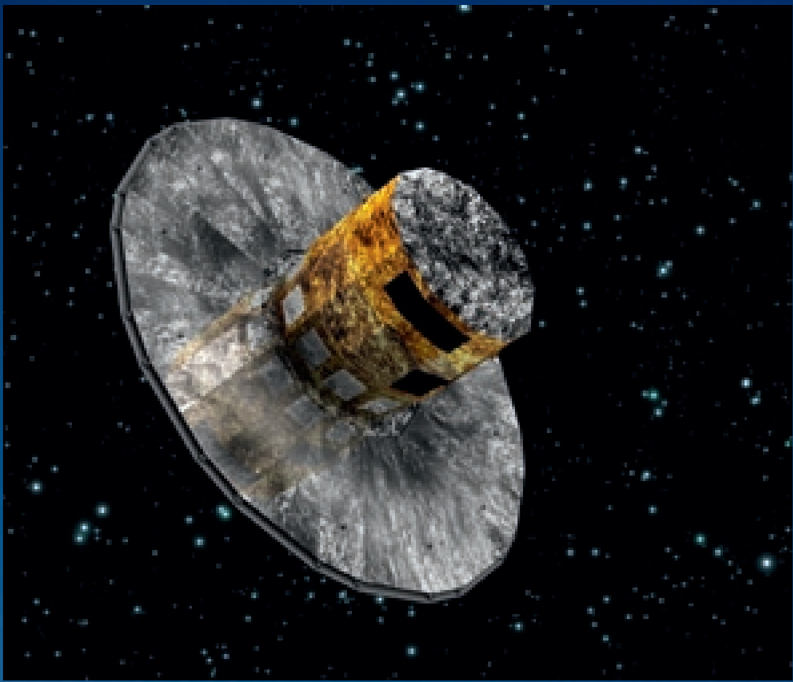


Space Missions

Although important national and multinational space projects are being developed outside the ESA structure and the *Roadmap* also encourages the continued development of fast-track smaller missions, ESA's strategic planning, most recently the *Cosmic Vision* exercise, dominates the development of major scientific space missions in Europe. Regardless of scientific merit, only a couple of new L-class (Large scale) and a very few M-class (Medium scale) missions are likely to be selected or implemented in the next decade within the *Cosmic Vision* plan; mission proposals are currently undergoing major changes and transformations before the final selection is made. Their overall impact depends on maintaining a strong science programme at ESA.

The *Roadmap* Working Group and Panels independently agreed with ESA's initial selection of *Cosmic Vision* missions. All the proposed missions were judged to be of high scientific value. The final choice of missions by the standard ESA review and down-selection procedures, which track changes in mission scope and cost and possible mergers with, or replacement by, other European or international projects, is therefore broadly supported. Within this framework, our priorities, including some non-ESA missions, are as follows:

- Among the large-scale missions, the gravitational-wave observatory LISA and the X-ray observatory XEUS/IXO were ranked together at the top. Next were the TANDEM and LAPLACE missions to the planets Saturn and Jupiter and their satellites. One is likely to be selected late in 2008 and will then compete with IXO or LISA for the next L-slot. ExoMars was ranked highly as well, but below TANDEM/LAPLACE and does not compete with the others as it belongs to a different programme (*Aurora*). The longer-term missions Darwin (search for life on "other Earths"), FIRI (formation and evolution of planets, stars and galaxies), and PHOIBOS (very close-up study of the solar atmosphere) were also deemed very important but still require lengthy technological development. It was regarded as premature to assign a detailed priority ranking to these three missions at this stage.



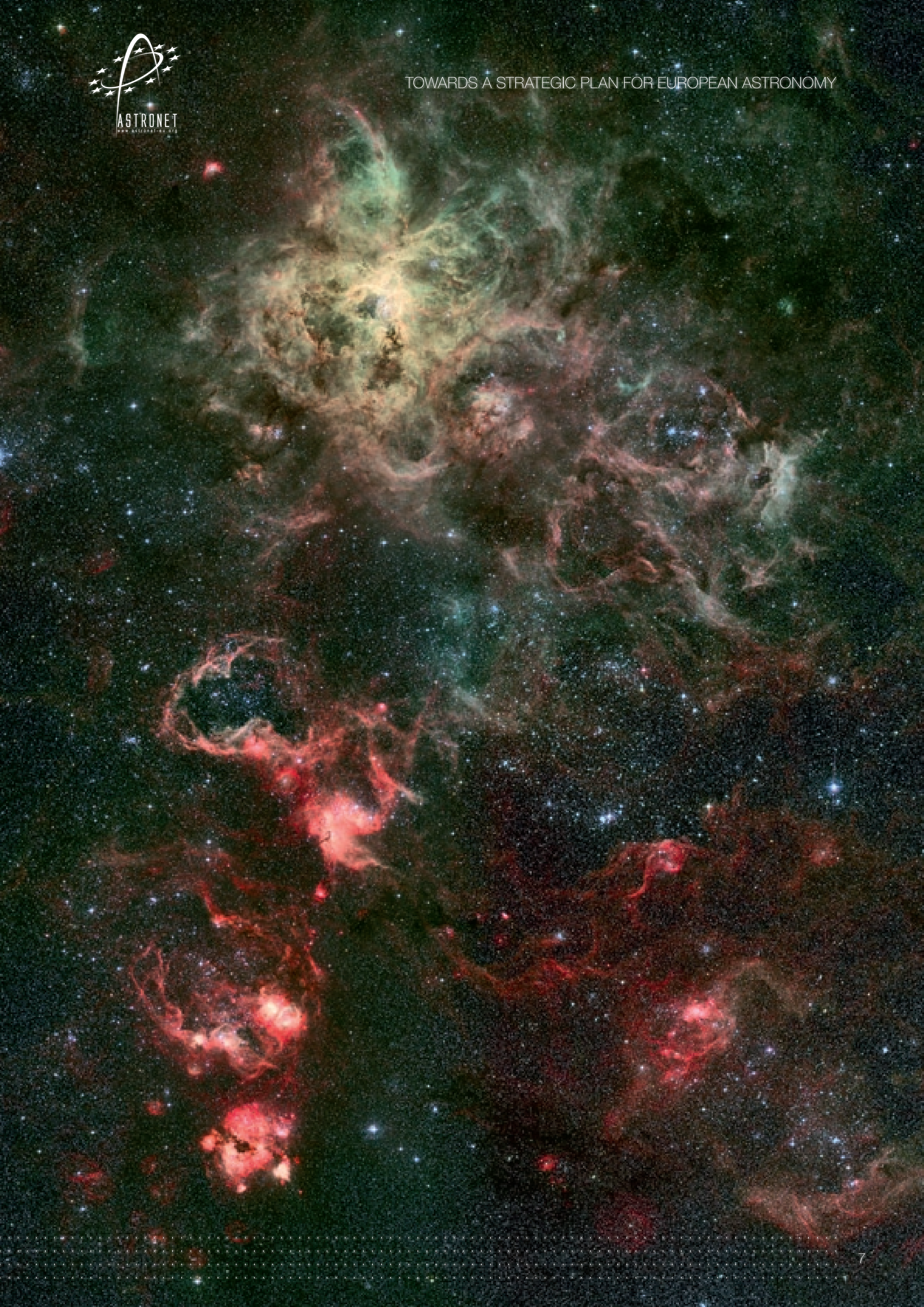
Credit: ESA

- Among the medium-scale missions, science analysis and exploitation for the astrometric mission Gaia was ranked highest, followed by the dark energy mission EUCLID and then Solar Orbiter. Next, with equal rank but different maturity, are Cross-Scale (magnetosphere), Simbol-X (a non-ESA X-ray project), PLATO (exoplanet transits) and SPICA (far-infrared observatory). Below these in priority is Marco Polo (near-Earth asteroid sample return).

Left: ESA's Gaia spacecraft: artist's impression.

Right: The young, star-forming Tarantula Nebula in the Large Magellanic Cloud. The colours show the locations of the many massive, hot young stars and the heated and ionised regions they have carved out of their natal gas cloud.

Credit: ESO/ J. Alves, B. Vandame, Y. Bialetski, R. Fosbury



The Role of Existing Facilities

The role of existing and approved facilities is also considered in the *Roadmap*. In space, several current missions are so successful that an extension of their operational lifetimes beyond those already approved is richly justified on scientific grounds. In a constrained environment, the selection of the missions that can be extended within available funds should be based on the scientific productivity of the mission and, for ESA-supported missions, the overall balance in the ESA programme.

On the ground, the existing set of small to medium-size optical telescopes is a heterogeneous mix of national and common instruments, equipped and operated without overall coordination. This is inefficient and is an impediment to effective ground-based support for space missions. ASTRONET has appointed a committee to review the future role, organisation and funding of the European 2–4-m optical telescopes within the context of the *Roadmap*, to report by September 2009. Reviews of Europe's existing mm-submm and radio telescopes will be undertaken shortly after, followed later by a review focusing on the optimum exploitation of our access to 8–10-m optical telescopes as we enter the era of the E-ELT. Together, these reviews will enable Europe to establish a coherent, cost-effective complement of mid-size facilities.

The four 8-m telescopes of the ESO Very Large Telescope (VLT), on Cerro Paranal in Chile.

Credit: ESO/H. H. Heyer

Theory, Computing and Data Archiving

The development of theory and computing capacity must go hand-in-hand with that of observational facilities. Systematic archiving of properly calibrated observational data in standardised, internationally recognised formats will preserve precious information obtained with public funds for future use by other researchers. It will also create a Virtual Observatory that enables new kinds of multi-wavelength science and presents new challenges to the way that results of theoretical models are presented and compared with real data. The *Roadmap* proposes that a European Astrophysical Software Laboratory, a centre without walls, be created to promote and coordinate this development, along with a number of other initiatives.

Education, Recruitment and Outreach

In the end, the deployment of skilled humans determines what scientific facilities can be built and operated, as well as the scientific returns that are derived from them. Conversely, astronomy is a proven and effective vehicle for attracting young people into scientific and technical careers, for the benefit of society as a whole. The *Roadmap* identifies several initiatives to stimulate European scientific literacy and provide our science with the human resources it needs for a healthy future.

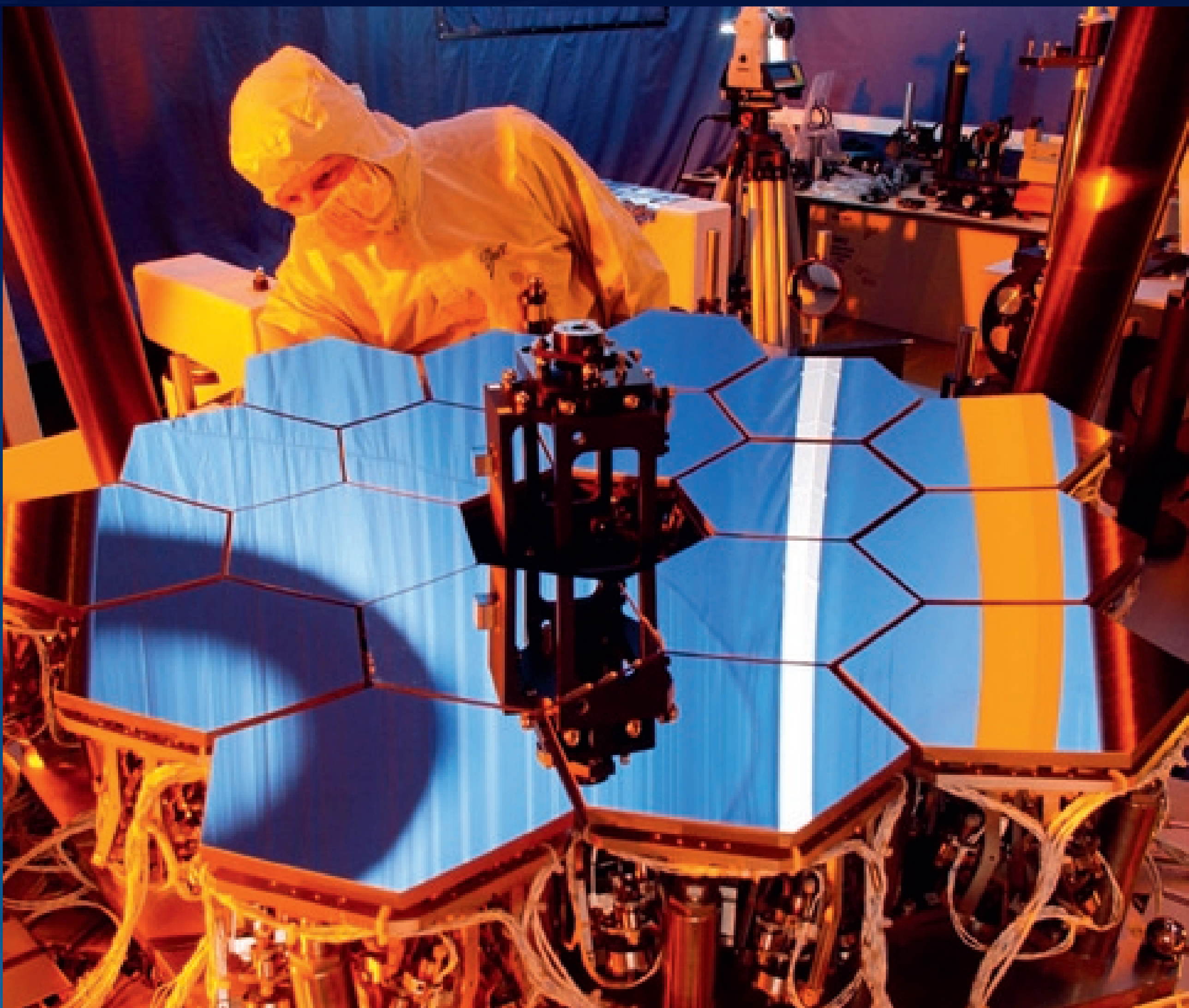
Schoolchildren observing the Sun

Credit: Kevin Govender

Technology Development

Technological readiness, along with funding, is a significant limiting factor for many of the proposed projects, in space or on the ground. Key areas for development are identified in each case. Maintaining a vigorous technological R&D programme to prepare for the future, in concert with industry to ensure technology transfer, is an important priority across all areas of the *Roadmap*.

1/6 scale model of the main optical subsystem of the James Webb Space Telescope undergoing functional tests. Europe is making substantial contributions to this project, including important parts of the advanced instrumentation.



Credit: Ball Aerospace, NASA, ESA and CSA

Conclusion and Perspectives for the Future

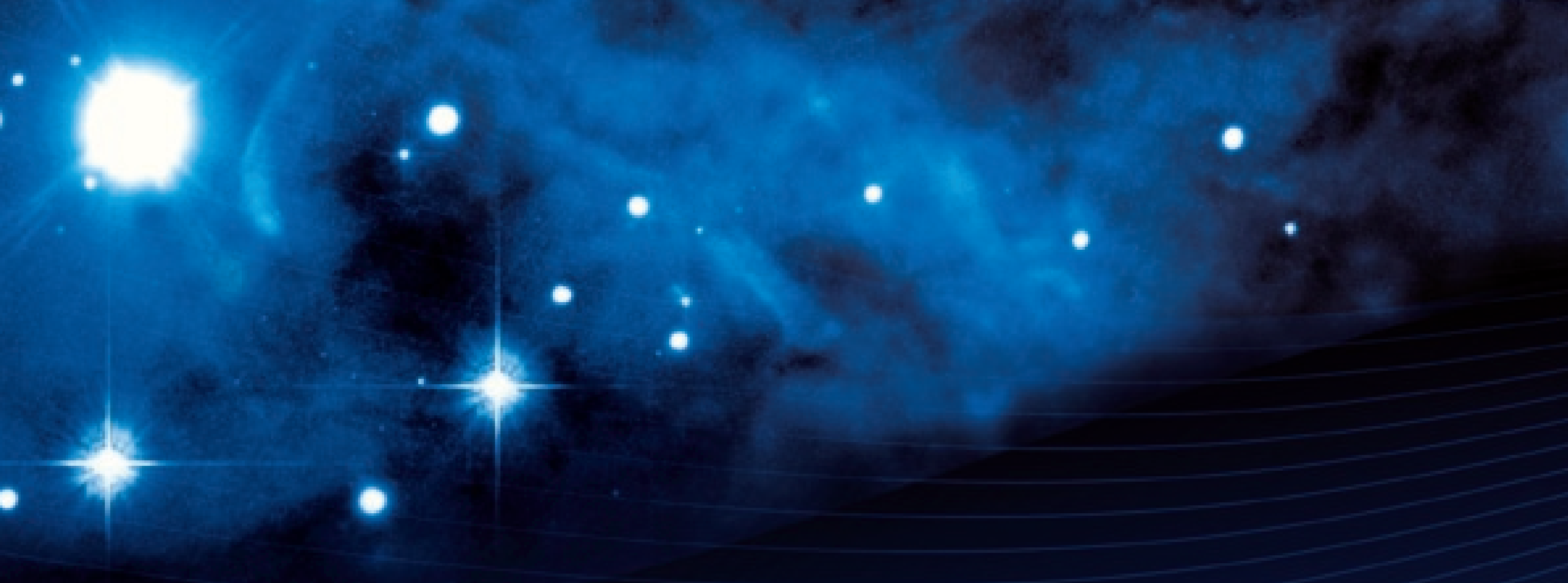
The *Roadmap* can be fairly represented as a community-based comprehensive plan that addresses the great majority of the *Science Vision* goals while maintaining and strengthening the role of Europe in global astronomy within realistic budget limitations. In order to implement it in a timely manner, given the stiff international competition, a modest budget increase over the next decade will be required. However, the coherent plan proposed here will make for a very cost-effective investment for Europe. Moreover, such a plan, with its overview and awareness of the global context, will also be a strong asset in negotiating international partnerships for the largest projects.

"Plans become useless, *but planning* is essential!" The context for the *Roadmap* kept evolving while it was being developed, and will continue to do so. ASTRONET, in concert with ESFRI, will monitor progress on implementing the proposals of the *Roadmap* over the next 2–3 years, whether small or large in financial terms. The entire European astronomical community awaits the outcome with keen anticipation. We foresee that a fully updated *Roadmap* will be needed on a timescale of 5–10 years. Whether the *Science Vision* then needs to be updated as well, will depend on scientific and financial developments on the international scene in the meantime.

The final version of the present *Roadmap* will become available at *http://www.astronet-eu.org*.

Artist's view of the brightest gamma-ray burst ever observed. The detailed observations obtained for this event have provided a wealth of information on how massive stars explode and interact with their environment.

Credit: ESO and Guido Chincarini, Stefano Covino, Cristiano Guidorzi, University of Miliano Bicocca and INAF-Brera, Italy. Illustration by Luis Calçada



SIXTH FRAMEWORK PROGRAMME

Designed and produced by ESO September 2008 www.astronet-eu.org