The ASTRONET Infrastructure Roadmap: A Twenty Year Strategy for European Astronomy

Michael Bode[1]
Guy Monnet[2]
on behalf of the ASTRONET Roadmap Working Group

[1] Liverpool John Moores University, UK
[2] ESO

The process followed by ASTRONET to build a long-term strategy for European astronomy is presented. The main conclusions and priorities given in the recently unveiled report on the Infrastructure Roadmap for the next 20 years, following the establishment of a Science Vision last year, are summarised. These reports together hopefully represent a blueprint for a bright future for European astronomy.

Astronomy is experiencing a golden era, with recent epochal discoveries from the identification of the first exoplanets to the hunt for the still-unidentified dark matter and the enigmatic dark energy. Europe is presently at the forefront of astronomy in essentially all areas, a quite recent achievement that has been largely gained by learning to cooperate on a multilateral basis, especially through ESA and ESO, although the backbone of European astronomy remains the scientists and research programmes at the national level. Addressing the scientific challenges of the future now requires a much higher cooperation level, based on a long-term strategy underpinned by vibrant national communities; in short a true European Research Area in astronomy. In view of fierce, worldwide competition, it is also a must for Europe to be a strong international partner in large global projects.

To meet this challenge, a group of European funding agencies created ASTRONET *(http://www.astronet-eu.org)*, a 2005–2009 programme funded by the European Commission to create a comprehensive long-term plan for European astronomy. The now much-enlarged consortium comprises 29 agencies, representing most of the astronomical resources across Europe. The ASTRONET playing field is equally broad, covering both ground- and space-based facilities and the whole astronomical domain from the Sun, and Sun–Earth connection, to the primordial Universe, with every conceivable observational means (photons, astroparticles and gravitational waves).

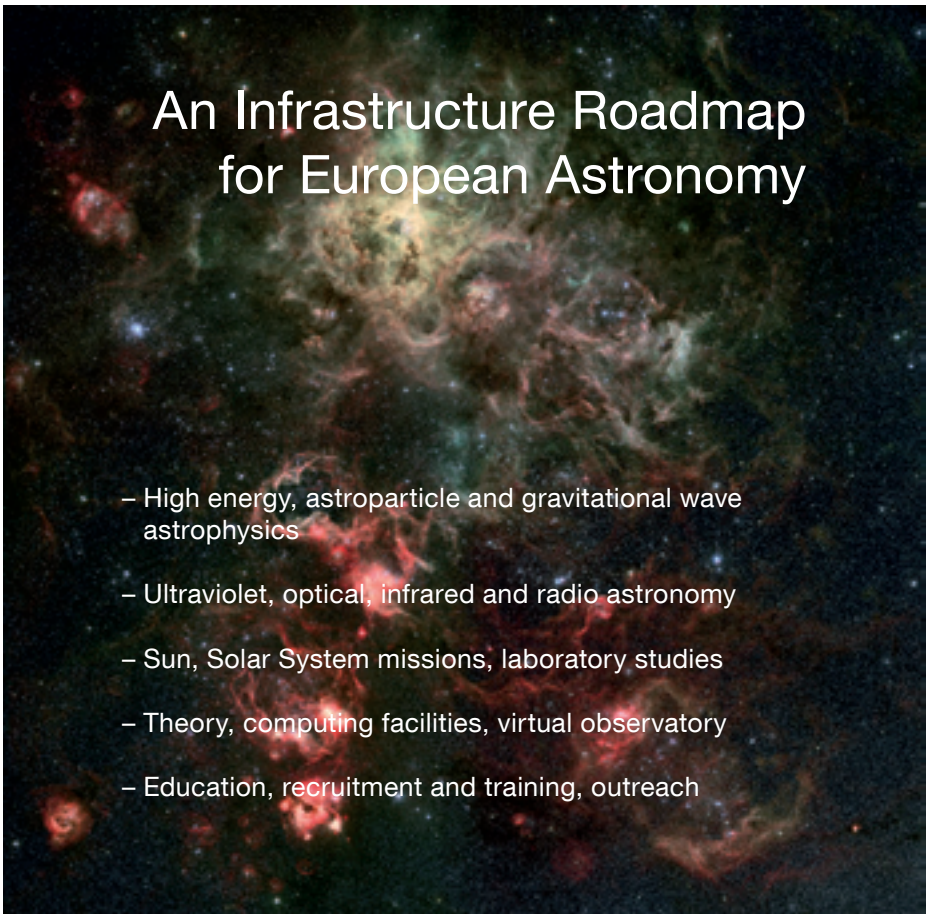

Figure 1. The broad coverage of the ASTRONET Infrastructure Roadmap.

The strategic planning activity was conducted in two successive steps. The first was the development with the community of an integrated Science Vision, which identifies the key astronomical questions that may be answered in the next 20 years or so by a combination of observations, simulations, laboratory experiments, interpretation and theory. This step was concluded in September 2007 with the public release of the Science Vision *(http://www.astronet-eu.org/-Science-Vision-)*, as reported in Monnet et al. (The Messenger, 130, 2, 2007). The next step was to construct a Roadmap that defines the required infrastructures and technological developments, leading to a long-term implementation plan. This is now being concluded with the public release of the final Infrastructure Roadmap at the end of November 2008 *(http://www.astronet-eu.org/-Infrastructure-Roadmap-)*. This article presents the process leading to the release of the Roadmap and its main results and concludes with a rough sketch of the implementation steps ahead.

The Infrastructure Roadmap process

The process started in late 2006, led by Michael Bode, with the help of Maria Cruz (then at Liverpool John Moores University) and Frank Molster (Leiden University). It built on the Science Vision input, an analysis of the main scientific questions, addressed under four broad headings: (1) Do we understand the extremes of the Universe?; (2) How do

galaxies form and evolve? (3) What is the origin and evolution of stars? (4) How do we fit in? In doing so, the Science Vision identified generic types of research infrastructures required to answer key questions under each heading. The aim of the Infrastructure Roadmap was to define and prioritise the specific developments needed to get the required observing capabilities and to set up a realistic plan to reach these goals, taking into account the expected human and material resources. The ASTRONET Roadmap thus complements the European Strategy Forum on Research Infrastructures (ESFRI) selection of a number of infrastructure flagships over all sciences, but goes one step further by tracing the future astronomical landscape — adding smaller-scale, but still much-needed, facilities, identifying promising research and development (R&D) areas and addressing the hard facts of implementation.

In a rather similar way to the Science Vision, the Roadmap was developed primarily on scientific grounds by five specialist panels, supervised by a working group appointed by the ASTRONET board. The first three Panels covered observational domains: high energy astrophysics, astroparticle astrophysics, and gravitational waves (Panel A); ultraviolet, optical, infrared and radio/mm astronomy (Panel B); solar telescopes, Solar System missions and laboratory studies (Panel C). Two other Panels considered respectively the parallel needs regarding theory, computing facilities, networks and virtual observatories (Panel D); and the human resources including education, recruitment and training, public outreach and industrial impact (Panel E). Overall, over 60 European scientists were directly involved in this effort.

The Working Group and Panels took into account existing national and international European strategic plans, including those of ESFRI, ESA and ESO. They also considered the worldwide context and, in particular, the plans of our major intercontinental partners. Close contacts were maintained with the astrophysical FP6 infrastructure networks (OPTICON, RadioNet, EuroPlanet, and ILIAS) and with our astroparticle "sister-net", the AStroParticle ERAnet, ASPERA.

Feedback from the community

In preparation for the Infrastructure Roadmap symposium in June 2008, a first draft of the Roadmap document was put online at the beginning of May 2008, shortly followed by the opening of a web-based discussion forum to get grass-roots community feedback. By the time the forum had closed on 4 July 2008, around 50 astronomers had contributed, often with extensive and multiple comments, to the building of the Roadmap. Their input has been taken into account by the Panels and the Working Group, first in preparation for the symposium, then in the writing of the final document.

The symposium was held on 16–19 June in Liverpool, United Kingdom. About 300 participants from 34 countries (22 EU member states, eight other European states, four non-European states) came for this crucial steering process. General presentations on the status of European Infrastructure analyses by ESFRI, ASTRONET and ASPERA, and on the similar US decadal process, were presented on the Monday afternoon. After the Tuesday morning presentation of preliminary conclusions from the five panels, each participant enrolled in one of the panels for parallel intense discussions during the following day and a half. This essential feedback ended with a 90 minute plenary discussion on Wednesday afternoon. Revised Panel conclusions were presented on Thursday morning, followed by concluding remarks from Johannes Andersen, the ASTRONET chair. For more information, please look at the symposium pages *(http://www.astro.ljmu.ac.uk/~airs2008/Process.html)*, which, in particular, feature the detailed programme and all presentations.

The Roadmap: ground-based projects

Among 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 planetary systems (including our own) to cosmology:

– The European Extremely Large Telescope (E-ELT), a 42 m optical–infrared telescope being developed by ESO as a European-led project, with a decision on construction planned for 2010.

– The Square Kilometre Array (SKA), a low frequency radio telescope being developed by a global consortium with an intended European share of up to 40 %, to be built starting in 2012 in phases of increasing size, area and scientific power.

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

Three other outstanding projects, but with narrower fields and lower budgets, were grouped together on a separate list and are, in descending order of priority: (1) the 4 m European Solar Telescope (EST) to be built in the Canary Islands; (2) the Cherenkov Telescope Array (CTA), a "true" high energy gamma-ray observatory; and (3) the proposed underwater neutrino detector, KM3NeT. In addition, a working group is being set up to study the case for a wide-field spectrograph for massive surveys with an 8 m-class optical telescope. Finally the report stresses the need to enhance support for laboratory astrophysics — including curation of Solar System material returned by space missions.

The Roadmap: space missions

The Working Group and Panels independently agreed with ESA's initial selection of Cosmic Vision missions, all recognised to be of high scientific value. The final choice of missions by the standard ESA procedure, which tracks 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, Roadmap priorities, including some non-ESA missions, are as follows:

– Among the large-scale missions, the gravitational-wave observatory, the Laser Interferometer Space Antenna (LISA) and the International X-ray Observatory (XEUS/IXO) were ranked together at the top. Next were the proposed Titan and Enceladus Mission (TandEM) and LAPLACE missions to

the planets Saturn and Jupiter and their satellites. One of these will likely be selected in early 2009; it will then compete with IXO or LISA for the next L-mission slot. ExoMars was ranked highly as well, just below TandEM/LAPLACE, but does not compete directly with the other science missions as it belongs to a different programme (Aurora). The longer-term missions, Darwin (search for life on "other Earths"), the Far InfraRed Interferometer (FIRI; formation and evolution of planets, stars and galaxies), and the Probing Heliospheric Origins with an Inner Boundary Observing Spacecraft (PHOIBOS; a close-up study of the solar surface) were also deemed very important. However, they still require lengthy technological development, so it was regarded as premature to assign detailed rankings to them at this stage.

– Among medium-scale investments, science analysis and exploitation for the approved Horizon 2000 Plus astrometric mission GAIA was judged most important. Among proposed new projects in this category, the dark energy mission EUCLID and the Solar Orbiter were ranked highest. Next, with equal rank but different maturity, are Cross-Scale (magnetosphere), Simbol-X (a non-ESA X-ray project), the PLAnetary Transits and Oscillations of Stars mission (PLATO; exoplanet transits) and SPICA (far-infrared observatory). Below these is Marco Polo (near-Earth asteroid sample return).

The Roadmap: role of existing facilities

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, however, 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-user instruments, equipped and operated without overall coordination. This is inefficient in the era of 8–10 m telescopes and ASTRONET has therefore 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, and to report by September 2009. Reviews of Europe's existing mm–sub-mm 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 class optical telescopes as we enter the era of the E-ELT. These reviews will help Europe to establish a coherent, cost-effective complement of medium-size facilities.

The Roadmap: 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 this precious information obtained with public funds for future use by other researchers, creating a Virtual Observatory. The Virtual Observatory will enable new kinds of multi-wavelength science and present new challenges to the way that results of theoretical models are presented and compared with real data. Along with other initiatives, the Roadmap proposes that a "virtual" European Astrophysical Software Laboratory, (a centre without walls), be created to accelerate developments in this entire area on a broad front.

The Roadmap: education, recruitment and outreach

Ultimately, the deployment of skilled people determines what scientific facilities can be built and operated as well as the scientific returns that are derived from them. Recruiting and training the future generation of Europeans with advanced scientific and technological skills is therefore a key aspect of any realistic roadmap for the future.

Astronomy is a proven and effective vehicle for attracting young people into scientific and technical careers, with benefits for society as a whole, far beyond astronomy itself. The Roadmap identifies several initiatives to stimulate European scientific literacy and provide European science with the human resources it needs for a healthy future, drawing on the full 500-million-strong population of the new Europe.

The Roadmap: technology development

Technological readiness, along with funding, is a significant limiting factor for many of the proposed projects, in space or on the ground, and key areas for development are identified in each case. However, astronomy also drives high technology in areas such as optics and informatics. Maintaining and strengthening a vigorous and well-coordinated technological R&D programme centred on promising future facilities and in concert with industry is therefore an important priority across all areas of the Roadmap.

Conclusions and perspective for the future

The Roadmap's aim is to represent a community-based comprehensive plan that addresses the great majority of the Science Vision goals. Its implementation will maintain and strengthen the role of Europe in global astronomy, as well as providing a much-needed tool in negotiating international partnerships for the largest projects. In order to achieve this in a timely manner, given the stiff international competition, a budget increase of order 20 % over the next decade will be required, a somewhat tall order, but also a very cost-effective investment for Europe.

The context of the Roadmap has 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. Finally, 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.