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THE ASTRONET INFRASTRUCTURE ROADMAP: A STRATEGIC PLAN FOR ASTRONOMY IN EUROPE

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Abstract. The ASTRONET Infrastructure Roadmap represents a pioneering venture for Europe in long-term planning of astronomical endeavour. It aims thereby to maintain and strengthen Europe's rôle in astronomy internationally over the next 10-20 years. In this review, I first describe the background to ASTRONET. This is followed by an outline of the development of a Science Vision, and then the Roadmap itself. Details are given of the working methods used and the conclusions reached, which include not only those regarding future facilities but also areas such as theory, computing, laboratory studies, human resources, industrial impact and public engagement. Gaps and opportunities in our proposed provision are outlined before addressing the next steps for the ASTRONET programme as a whole.

1. What is ASTRONET?

ASTRONET was founded by the major European funding agencies and initially funded from the European Commission Framework 6 programme at the level of 2.5M Euros over five years from September 2005 (we shall refer to this as ASTRONET-1 below). The success of the programme has led to its continuation under Framework 7 at 1.6M Euros for a further four years from January 2011 ('ASTRONET-2'). ASTRONET is an ERA-Net coming under the initiative 'Integrating and Strengthening the European Research Area' (ERA). It is coordinated by CNRS/INSU, with Jean-Marie Hameury as project manager, and the ASTRONET-1 Board was chaired by Johannes Andersen of NOTSA during the phase of the project that included the development of both the Science Vision and Roadmap, and is now chaired by Ronald Stark of NWO. At the time of writing, it comprises 11 primary Contractors (mainly national funding agencies, plus ESO) together with 21 Associate member organisations (again, mainly national funding agencies, plus ESA) and a further two nations represented as Forum members. Further information, publications and updates on progress of the initiative can be found on the project's website[1].

The funding agencies decided to form ASTRONET for the following over-riding reason: large projects proposed for the next 10-20 years in astronomy and astro-particle physics require investments of several billion Euros. The EU only provides for a few percent at most of this cost – the funding agencies and other government organisations would be expected to meet the rest. ASTRONET was thus established to help national funding agencies to take science-based, rational, coordinated decisions for the long term benefit of European astronomy – and, at a higher level, to help unlock further necessary resource for our science in Europe. We are therefore effectively prototyping a counterpart of the US Decadal Surveys for Europe, but with a wider remit and in a rather more complex environment. Hence this is a very ambitious undertaking. The ASTRONET Roadmap also complements that of the European Strategy Forum on Research Infrastructures (ESFRI) in that (i) it is a valuable input for the ESFRI committee, (ii) it has a much broader scope across astronomy (although of course focussed on that field), and (iii) it contains a prioritised list of projects.

Activities within ASTRONET-1 from 2005 were organised under five main headings:

- Preparation of a common Science Vision for the next 20 years (published in September 2007[2]).
- Establishment of a Roadmap of infrastructures to address the Science Vision (published in November 2008[3]).
- Networking, including the integration of new participants (ongoing) and the production of a Report on the Management of European Astronomy (published by ASTRONET in July 2007).
- Coordinated Actions, which required work towards launching a common call for proposals with a common or joint budget (launched, and successful proposals are underway under the title 'Common Tools for Future Large Sub-mm Facilities').
- Implementation, including specific actions arising (see the last section of this article for the development of this under ASTRONET-2).

[1] http://www.astronet-eu.org/
[2] See de Zeeuw & Molster (2007).
[3] See Bode et al. (2008).

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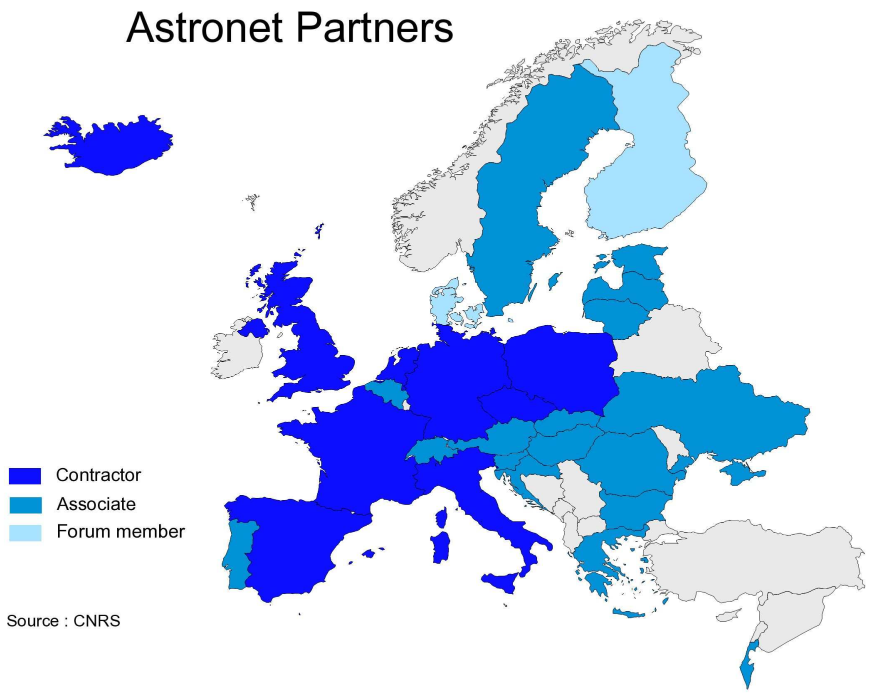

Figure 1. Map showing the current extent of the ASTRONET partnership. (© CNRS)

2. Developing the Science Vision

The brief here was to look broadly at key science questions in all of astronomy for the next two decades, with NWO of the Netherlands as the lead agency. It was recognised very early in the process that a great deal of material already existed and thus it was that maximum use was made of available documents (e.g. national strategic plans, ESA's Cosmic Vision report, joint ESO-ESA reports, scientific cases for new facilities). It was also vital to involve a broad, knowledgeable and well respected cross-section of the science community. In the end around 50 people were direct members of the Science Vision Working Group and its four thematic panels. The working group chair was Tim de Zeeuw (now Director General of ESO). Wider community input was solicited via a web-based discussion forum and an open symposium. The latter event was held in Poitiers in January 2007 and was attended by over 200 astronomers from all over Europe and

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beyond.

The Science Vision exercise was divided into four key questions, each addressed by a specialist panel, these being:

A. Do we understand the extremes of the Universe?
B. How do galaxies form and evolve?
C. What is the origin and evolution of stars and planetary systems?
D. How do we fit in?

Within each key question were developed a number of specific goals, with up to seven under each heading. Overall, the Science Vision was developed in sufficient detail to allow the identification of generic capabilities of the facilities needed to deliver the Vision[4]. This was then to be the basic starting point of the Infrastructure Roadmap, as we will now describe.

3. Developing the Roadmap

Here, the brief was to assemble a plan for the infrastructures that will enable European astronomy to deliver the Science Vision, with the STFC of the UK as the lead agency and the current author as the Roadmap Task Leader. We therefore naturally took the Science Vision as the point of departure. Our remit was very broad, covering both ground and space-based facilities, plus the Virtual Observatory, (super)computing, theory, human resource issues, outreach, education and training and industrial links. We were to incorporate existing plans (of ESO, ESA etc.) as far as possible, and have a global perspective. Overall, we were to attempt to fit this within reasonable budgetary envelopes and schedules. The process of developing the Roadmap got underway in earnest in the Autumn of 2006. The motivations and modes of operation are described in detail in Chapters 1 and 2 of the final report (Bode et al. 2008), which, together with an Executive Summary, is available from the ASTRONET website.

As with the Science Vision, the task of developing the Roadmap was undertaken by specialist panels, reporting to a working group. The panels were organised under the following headings (with the relevant chapters of the final report indicated in each case):

A. High energy astrophysics, astro-particle astrophysics, gravitational waves (Chapter 3)
B. UVOIR and radio/mm astronomy (Chapter 4)
C. Solar telescopes, solar system missions, laboratory studies (Chapter 5)
D. Theory, computing facilities and networks, virtual observatory (Chapter 6)

[4]pdf versions of both the Science Vision and Infrastructure Roadmap can be downloaded from `http://www.astronet-eu.org/`

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E. Education, rcruitment and training, public outreach, industrial links (Chapter 7)

The first three panels effectively covered facilities in the main, and the latter two some additional critical underpinning infrastructure in its widest sense, and the broader impact of our work on society in general. The panels comprised up to twelve members each, with selection being based primarily on relevant expertise, but bearing in mind a reasonable spread of nationality and gender. Each panel reported to the Working Group whose membership comprised the chair and co-chair of each panel together with ten members at large who assisted the panels with their work. Overall however, the task of the working group was to synthesise the recommendations of the panels into the final Roadmap, ably aided and abetted by the Assistant Scientists (Maria Cruz of Liverpool JMU and Frank Molster of NWO) and chaired by the current author. Altogether, over 60 scientists, plus educators and journalists on Panel E, were members of the panels and working group.

4. Working Methods

From March 2007 until October 2008 around 40 meetings of the panels and working group were held. Most of these were face-to-face, but Panel D in particular, rather fittingly, held several virtual meetings via teleconference. Panels A to C identified well over 100 facilities which might be evaluated in the roadmapping exercise. As part of this, a questionnaire was sent to all of them, generating an almost complete return by early July 2007 (the full list of facilities surveyed can be found in Appendix IV of the final report). An evaluation template was formulated and then completed by each assigned panel rapporteur for each facility. Evaluation criteria were developed to give first-pass rankings, then each facility was further discussed, further information gathered as appropriate, and initial judgements refined (for example in the light of the ESA Cosmic Vision first call results which were available to the panels in October 2007). In parallel with this, the ASTRONET Science Vision was launched in September 2007.

The main focus of the Roadmap is of course on future facilities (but well-defined major upgrades and significant operational prolongations were also included). Only facilities with a significant European content (in terms of a likely funding requirement) and well enough developed to be able to be judged adequately were included. We had to set some lower bound to the ‘scale’ of projects to be scrutinised, and decided upon a European funding requirement of greater than 10M Euros capital cost and/or greater than 10M Euros operational cost over five years (unless there were a special reason to lower this limit in a particular case). Finally, only those facilities where a major European funding decision was expected to be required from

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2009 onwards were included.

Broad categories of prioritisation were used for initial ranking of facilities: High, Medium and Low, with only High priority projects normally discussed in detail in the final report; other facilities were included for 'context' and some smaller scale current facilities have been grouped. It was recognised that a large facility may on average address more Science Vision questions than a smaller-scale example, but the smaller one may very cost-effectively address a sub-set of important science questions. Therefore projects were sub-divided into cost categories: Small (10M-50M Euros); Medium (50M-400M Euros), and Large (greater than 400M Euros). These mapped to some extent onto the previous US Decadal Survey for ground-based projects (the latest Decadal Survey for Astronomy and Astrophysics[5] being published in August 2010) and the original ESA Cosmic Vision 'M-class' and 'Flagship (L-class)' designations for space-based missions, including instruments. We also utilised a timescale division (to full operation) as follows: Short-term (<2015); Medium-term (2016-2020); Long-term (>2020) and assigned each project a current Technology Readiness Level. The evaluation criteria we used (in decreasing weight) were Scientific Impact (particularly in relation to delivering the Science Vision), Competition/Uniqueness, European Involvement, User Base and Industrial Relevance. This evaluation gave us a first-pass ranked list of projects in each of Panels A-C.

The terms of reference for Panels D and E were naturally somewhat different from Panels A, B and C. Specific questions from these panels were included in the questionnaire sent to facilities, but D and E also undertook considerable additional information gathering as detailed in Chapters 6 and 7 of the final report. Panel D then gave members responsibility for specific areas within their remit and Panel E sub-divided into several task groups. Information exchange with other panels took place throughout the process, both directly and through the working group.

The roadmapping process was not without cognizance of, and inputs from, other organisations and initiatives with an important role in the future shape of astronomy in Europe. For example, the working group included representatives of ESO and ESA, plus the EC-funded Integrated Infrastructures Initiatives (I3s) OPTICON and RadioNet. In addition, the EuroPlaNet initiative had representation on Panel C (and on the working group in the initial phases)[6]. Information exchange with the astro-particle

[5]See `http://sites.nationalacademies.org/bpa/BPA_049810`

[6]On those intitiatives, see contributions in the earlier *Organizations and Strategies in Astronomy (OSA)* series (Ed. A. Heck, Springer, Dordrecht): for OPTICON, the chapter by G. Gilmore in OSA 2 (2001), pp. 83-102; for RadioNet, the chapter by A.G. Gunn in OSA 7 (2006), pp. 171-180; for EuroPlaNet, the chapter by M. Blanc and the EuroPlaNet

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ERA-Net, ASPERA, included round-table meetings with ASTRONET. Finally, links with ESFRI were gradually strengthened as the ASTRONET initiative progressed.

In order to meet the deadlines set at the start of the project, activity was intense between the constitution of the working group and panels in early 2007 and the delivery of the final report in November 2008. An important milestone was then a meeting with the agencies in London in February 2008 where our initial findings were presented for a 'sanity check' in terms of, for example, funding envelopes and competing national aspirations. Further work ensued on the draft, which was then released for public consultation in early May 2008, at which point a web-based forum was also made available to the community to post their comments. As with the Science Vision, the centrepiece of the consultation was an open symposium, held over four days in June 2008 in Liverpool, which was attended by around 300 participants. The consultation period then ended in July 2008. The final panel and working group meetings were subsequently held to amend their conclusions in light of the consultation. Responses to all comments made were posted on the web forum following the launch.

5. Priorities and Recommendations

5.1. GROUND-BASED PROJECTS

Among the *large scale* ground-based infrastructure projects, two emerged as clear and equal 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 40m-class optical-infrared telescope being developed by ESO as a European-led project. The E-ELT passed its Phase B final design review in September 2010 with a decision on construction planned for December 2011.
- The Square Kilometre Array (SKA), which is to be the world's most capable radio telescope. Led from the international Project Office at Jodrell Bank, the SKA is being developed by a global consortium with an intended European share of up to 40%. It will be built in phases of increasing size, area, and scientific power, with final site selection between Australia and South Africa in 2012, detailed design envisaged to start in 2013 and construction of Phase 1 from 2016.

It was concluded that although the E-ELT and SKA are very ambitious projects requiring large human and financial resources, they can both be

Coordinating Team in OSA 7 (2006), pp. 155-170. (Ed. Note)

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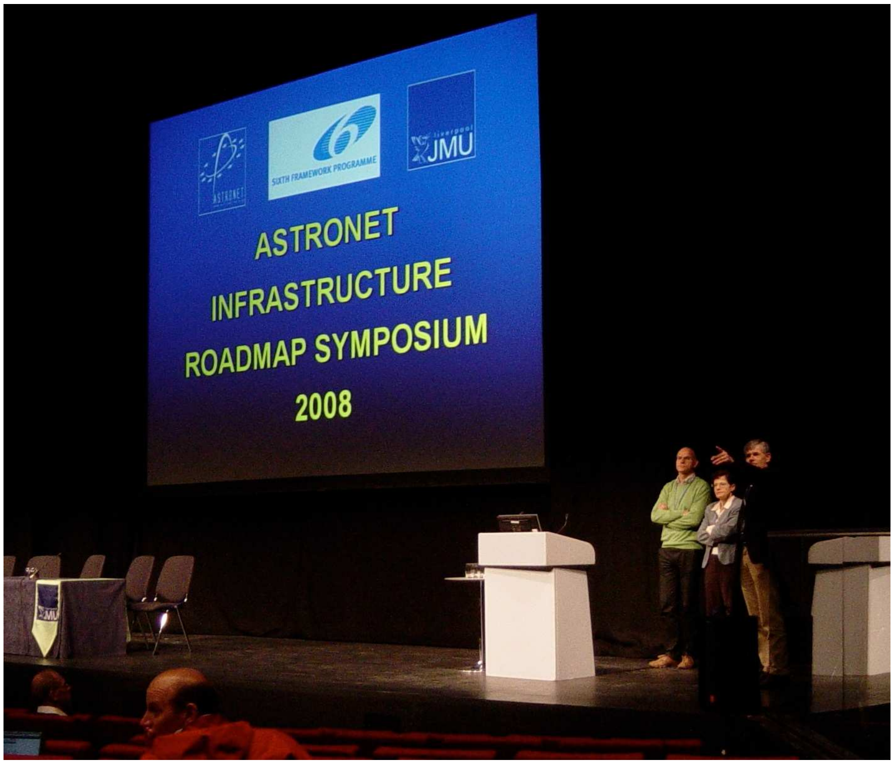

Figure 2. The culmination of the community consultation on the Roadmap was the Symposium held in Liverpool in June 2008. Here Thijs van der Hulst (Univ. Groningen) of the main Working Group chairs a discussion on the development of software, computing and the Virtual Observatory following a presentation by Francoise Combes (Obs. Paris) and Paolo Padovani (ESO), chair and co-chair of Panel E respectively. (© M. Bode)

delivered via an appropriately phased plan, as detailed in Chapter 4 of the report.

Three outstanding projects were identified in the *medium scale* category. In descending order of priority these comprise:

– The 4m European Solar Telescope (EST) to be built in the Canary Islands.
– The Cerenkov Telescope Array (CTA), a high-energy gamma-ray 'true' observatory.
– The proposed underwater neutrino detector, KM3NeT.

In addition, in terms of the highest priority *small scale* project, a working group has been established to study the options for the provision of a Wide-Field Multiplexed Spectrograph for massive surveys on a 4-10m-class optical telescope. This group is expected to provide its report imminently,

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with important input from that of the ETSRC (see below), but it has already sparked several initiatives internationally to deliver such an instrument.

5.2. SPACE-BASED PROJECTS

The working group and panels independently agreed with the 2007 round of selection of Cosmic Vision missions for the initial study phase made through the ESA Advisory Structure. 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, was therefore broadly supported. Within this framework, the roadmap priorities, including some non-ESA missions, are set out below.

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 proposed TandEM and Laplace missions to the planets Saturn and Jupiter and their satellites. Of these, Laplace became the joint Europa Jupiter System Mission (EJSM-Laplace – with NASA and JAXA) and was selected to proceed to the next stage by the ESA process in early 2009 to compete with IXO or LISA for the next L-mission slot.
  However, the US National Research Council (NRC) subsequently released Decadal Surveys for both astronomy and planetary science[7]. While both surveys recommended continued cooperation with ESA, and ranked highly all three L-class mission concepts, none of them was ranked as top priority in the corresponding survey. The US budget outlook also became known in February 2011, and in ESA's recent discussions with NASA it became clear that it is quite unlikely that any of the L-class mission candidates can be implemented as a joint Europe-US mission in the planned timeframe of the early 2020's. Instead, ESA has begun a rapid definition effort to identify new science goals and mission concepts in the fields of gravitational wave astronomy, X-ray astronomy, and exploration of the Jupiter system. These should be implemented as part of an ESA-only or ESA-led mission to be launched in the early 2020's for a cost to ESA of about 850M Euros, with additional national contributions from ESA member states. The ESA Science Programme Committee will be considering the path forward for the new-style L-missions at their February 2012 meeting, after

[7] See `http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412` for the latter

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the ongoing rapid study phase. Overall, this illustrates the fact that the very largest scale projects often inevitably rely on global co-operation to come to full fruition, but it also emphasises the strength of Europe's capability when those co-operative endeavours don't go strictly to plan.

– 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 within ESA (Aurora).

The longer-term missions Darwin (search for life on 'other Earths'), FIRI (formation and evolution of planets, stars and galaxies), and PHOIBOS (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 these three missions at this stage.

Among *medium scale* investments:

– GAIA science analysis and exploitation (an approved Horizon 2000 Plus astrometric mission) was judged most important.
– Within the proposed new projects in this category, the dark energy/dark matter mission Euclid was ranked highest, followed by Solar Orbiter (a joint project with NASA). At the ESA Space Science Advisory Committee (SSAC) in January 2010, both were selected for further study towards the selection of the first two missions that will proceed to launches expected in 2017-18.
– Next in the ASTRONET rankings, with equal rank but different maturity, are Cross-Scale (magnetosphere), Simbol-X (a non-ESA X-ray project), PLATO (exoplanet transits) and SPICA (a far-infrared observatory – led by JAXA). Of these, PLATO has been selected for further study by ESA in the M-class missions and SPICA has also been endorsed to proceed to the definition study phase, but as ESA is a minor partner to JAXA, it is being treated separately from the other approved Cosmic Vision missions. However Cross-Scale was not selected and funding for future development of Simbol-X was not secured by its international partners.
– Below these in the ASTRONET rankings was Marco Polo (a near-Earth asteroid sample return), which was also not selected by the ESA process to go forward to the next stage of the Cosmic Vision programme for 2017-18 launches. However, the revised mission, Marco Polo-R, is now one of the 4 M-class missions selected in the 2011 round of submissions to proceed to the next stage of assessment for a launch in 2020-22.

By their nature, there were no small scale space projects under consideration for inclusion in the Roadmap.

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5.3. THE RÔLE 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. Recommendations on mission prolongations are summarised in Chapter 8 of the final report.

On the ground, the existing set of small to medium-size night-time 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 8-10m telescopes and ASTRONET therefore appointed a committee (the European Telescope Strategy Review Committee – ETSRC) to review the future rôle, organisation, and funding of the European 2-4m optical telescopes within the context of the Roadmap. The final ETSRC report is available via the ASTRONET website. As mentioned above, a working group has been established to investigate the provision of a Wide Field Multiplexed Spectrograph on a 4-10m class optical telescope, building on some of the work of the ETSRC, and due to report imminently. A review of Europe's existing radio telescopes is also now underway as SKA development gathers pace and is due to report on a similar timescale. That for mm/sub-mm facilities will be undertaken shortly after, followed later by a review focusing on the optimum exploitation of our access to 8-10m class optical telescopes as we enter the era of the E-ELT, and the rationalisation of ground-based solar telescopes as we move into the EST era. These reviews will help Europe to establish a coherent, cost-effective complement of medium-size facilities required to augment the major new facilities.

5.4. THEORY, COMPUTING AND DATA ARCHIVING

It is acknowledged that 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. The Roadmap therefore proposes continued development of the Virtual Observatory, including recommending planning for the provision of a public, VO-compliant archive with any new facility.

The Roadmap also proposes that a 'virtual' European Astrophysical

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Software Laboratory (ASL – a centre without walls) be created to accelerate developments in this entire area on a broad front. The ASL would coordinate and raise funds for software development and support, user training, postdoctoral positions within a programme of pan-European networks, and set standards. It is proposed that the ASL would select a few highly competitive astrophysics projects per year to send proposals to the top-tier, pan-European high performance computing centres to help ensure a significant share of CPU hours at the petascale level for astronomy. The report also makes recommendations on the development of novel data grids by exploiting the popular appeal of astronomy in order to get CPU owners to donate spare CPU cycles, or by initiating a classical market in such cycles. The ASL could have a rôle in coordinating this activity. An ASL Committee has now been established, chaired by Matthias Steinmetz of Potsdam, to coordinate the implementation of this initiative.

5.5. LABORATORY ASTROPHYSICS

The report stresses the need to enhance support for laboratory astrophysics – including the curation of solar-system material returned by space missions in a proposed European Analysis and Curation Facility. The report also proposes the establishment of a Technical Fellowship Programme and of new European networks stimulated by Joint Calls between the agencies, as pioneered by the call undertaken in the current ASTRONET project. To take these initiatives forward, a European Task Force for Laboratory Astrophysics has been formed, chaired by Louis d'Hendecourt (Univ. Paris-Sud) and Jonathan Tennyson (UCL). The Task Force is cognizant of the international dimension, and in particular conclusions drawn in this area in the latest US Decadal Survey, and will report in 2012.

5.6. EDUCATION, RECRUITMENT, OUTREACH AND INDUSTRIAL LINKS

Ultimately, 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. 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. Conversely, 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 plus population

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of the new Europe. The proposed initiatives include among others:

- Enhanced training of teachers in astronomy – this has now been taken up for implementation by IAU Commission 46 under the auspices of the Network for Astronomy School Education (NASE), chaired by Rosa Maria Ros of the Technical University of Catalunya.
- Inclusion of astronomy more widely in national curricula – this is an action likely to be followed up in ASTRONET-2 (see below).
- New or enhanced educational portals – these are being created in several languages and are to be hosted on the website of Universe Awareness (UNAWE, an organisation also associated with the IAU).
- Establishment of a standardised European communication portal for media, educators, interested people and others – this has now been implemented[8].
- Appropriate funding and recognition of outreach activities – again something that should be followed up in ASTRONET-2.
- Creation of an international network of experts in technology transfer – there has been some subsequent progress on the national scale, but the international initiative still needs pursuing.
- Enhanced scientific exploitation of facilities – the issue has been taken up with the European Research Council, but also requires the attention of the various national funding agencies to ensure that Europe maximises the scientific output of its facilities.

5.7. TECHNOLOGY DEVELOPMENT AND INDUSTRIAL SPIN-OFF

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 the Roadmap 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. The required technology development and industrial applications are summarised in Chapter 8 of the final report.

6. Perceived Gaps and Opportunities in Europe's Future Observational Capability

Inevitably, the roadmap process revealed several gaps in future provision where some of the questions posed in the Science Vision may not be fully addressed. We briefly outline these here:

[8] http://www.portaltotheuniverse.org/

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- Small-scale and fast-track space missions – while our prioritisation of facilities naturally focussed on the medium to large scale space missions, we recognise the opportunities afforded by smaller projects as a crucial part of a balanced future programme.
- High Energy Astrophysics – Panel A identified various areas of instrumentation that are strongly called for in the Science Vision but are not yet programmatically ready, and/or do not yet provide large improvements over existing experiments at affordable cost. One such area is 0.1-10 MeV imaging and spectroscopy and another is all-sky monitoring in both X-rays and γ-rays.
- UV Astronomy – there is a pressing need for a successor to IUE in terms of a dedicated FUV/EUV astronomy mission. Panel C also identified the need for an (E)UV Solar mission with X-ray capabilities.
- Optical/IR ground-based interferometry over kilometric baselines – this is a natural successor to VLTI.
- mm-submm Astronomy – European access is required here to a large aperture single dish with array detectors on an extremely high site. There is also a requirement for further CMB polarisation studies post-Planck.
- Radio spectral imaging of the Sun – such imaging at centimetre to metre wavelengths is essential in particular in furthering our understanding of physical processes in the solar corona.
- Arctic and Antarctic sites – these offer special opportunities for the development of astronomy and their further exploration and development are encouraged.

7. Next Steps and Concluding Remarks

It was very pleasing to see the ASTRONET project continue into its next phase through the provision of Framework 7 funding. The main objectives here are to:

- Establish a permanent mechanism for planning and coordination in European astronomy.
- Follow-up and implement the Roadmap, thus ensuring the construction of the new facilities that are needed to keep Europe at the forefront of scientific knowledge and at the same time optimise existing programmes in scientific as well as financial terms.
- Narrow the scientific and – in particular – technological gaps between the European countries.
- Establish a regularly updated data base with key information on the financial and human resources available to astronomy in all European

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countries, as well as the structure and governance of astronomical research in each country.

This will allow several of the initiatives mentioned above to come to full fruition, with ASTRONET acting as a facilitator and champion, and also enable the updating of the Science Vision and the Roadmap. Towards the end of this period, preparations will start for a full revision of the Roadmap itself.

The Roadmap is a pioneering venture for Europe, and a complex and challenging task. Its implementation will however help to maintain and enhance Europe's leading rôle in addressing what are foreseen as the major questions in our area of science. It will also enhance the scientific and technical capability of Europe at all levels and aid collaborations with our wider international partners on some of the largest-scale, global projects over the next two decades. We have a job to do to persuade our political masters to provide adequate funding to realise our goals, but having brought our own house in order, we have some powerful and compelling arguments in our favour to help them to decide to do so.

Acknowledgments

I would like to thank the many individuals, including scientists, educators, administrators and journalists, who gave their time so willingly and worked so hard and impartially to deliver the ASTRONET Infrastructure Roadmap. I am grateful to Mark McCaughrean of ESA, Johannes Andersen of NOTSA and Jean-Marie Hameury of CNRS for valuable comments on the draft of this article. Sincere gratitude is also due to the wider astronomical community, both individuals and organisations, and other persons across Europe, who provided valuable comments and suggestions along the way. Finally, thanks must go to the European Commission for funding the whole ASTRONET endeavour.

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