European Astronomy — reviewing national and international planning

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Summary

This report describes the efforts of Astronet, which assembles the important players of European astronomy, namely the European Intergovernmental Research Organisations ESA and ESO as well as astronomy-related national and regional funding organisations. Following extensive discussions among its partners, Astronet formulated and published a 'Science Vision' in 2007. A Roadmap was then developed and published in 2008. This Roadmap is, to some extent, an equivalent of the US Decadal Surveys, yet it is distinct from its American model: it has a time horizon of 20 to 25 years, rather than a decade only, it covers all fields of astronomy at once, and from the outset takes the global context into account. We note that the Astronet Roadmap was not developed in isolation: interrelationships existed with other relevant major fora, such as the European Strategy Forum on Research Infrastructures (ESFRI), and with Integrated Infrastructure Initiatives such as ASPERA, a European Research Area network coordinating and funding national research efforts in particle astrophysics (Appendix A). The second phase of Astronet has started in 2011, and deals with the implementation of the Roadmap. We also take a look at selected projects in Asia (Appendix B) and at plans for large ground-based telescopes in the USA (Appendix C). Some debating points for the EAS form part of the conclusions.

Preamble

«The European Astro-political Landscape and the Role of the European Astronomical Society» was the topic of an article by Thierry J-L Courvoisier in the European Astronomical Society's Newsletter No. 35 (June 2008, pp. 2–7). The paper summarised discussions held in January 2008 in Leiden, where EAS Council met for the first time with representatives of the Affiliated Societies of EAS.[1] In the course of these discussions it was noted that many organisations in Europe were making plans, had produced roadmaps and funding recommendations. Some of these studies, it was stated, explicitly used inputs from the community, others less so. Council then proposed to review the planning material generated by that time, be it of national or international origin, and to write a synthetic view of the findings.

Shortly after this meeting a five-year study project funded with 2.5 M€ by the 6th EU Framework Programme published its final report. Astronet had gone into more depth than the task defined by the January 2008 meeting mentioned above; nevertheless this indicated that the report initiated by EAS Council could have turned into a rather extensive exercise. The EU Framework Project in question, Astronet, has been directed by a Board composed of representatives of 29 European astronomy-related national and regional organisations and of ESA and ESO, two astronomy-related European inter-governmental Research Organisations (EIROs).[2]

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[1] In contrast to many other European learned societies, the EAS is not a federation of national astronomical societies: EAS has only Individual (and Organisational) Members. However, in order to establish a link to the European national astronomical societies, EAS invited them to become Affiliated Societies. The 24 Affiliated Societies of the EAS are listed on the web site http://eas.unige.ch/affiliates.jsp.

[2] The organisations behind this project were subdivided into contractors, associates and forum members (see Appendix D for explanations of acronyms):

- 9 Contractors: BMBF/DESY (DE), CNRS (FR, Coordinator), INAF (IT), NWO (NL), ESO, NOTSA (Nordic), NCBiR (PL), MICINN (ES), STFC (UK) and
- 19 Associates: ESA, FWF (AT), FWO+FRS (BE), BAS (BG), MSES (HR), IA-CAS (CZ), MPG, DFG (DE), ESF (EE), GNCA (GR), HAS (H), LAS (LT), FCT (PT), ROSA (RO), IA SAS (SK), ARRS (SI), SRC (SE), SER (CH), UAS (UA), as well as
- 6 Forum members: DK, FIN, IS, ISR, NO, LV

With these organisations Astronet covered an astronomy community associated with a total population of over 550 million people in 20 countries.

At the end of this report we suggest that EAS critically evaluate the premises and conclusions of the Astronet study and discuss any consequences for EAS policies. This is advisable also in view of the fact that, following the completion of Astronet of FP6, Astronet 2 has started in 2011 under FP7.

Where does European astronomy planning stand today?

The initial result of the Astronet project had been a «Science Vision», discussed at a symposium in Poitiers in January 2007, and published as a 150-page book in September 2007. Based on this vision, a Roadmap was developed, then presented and discussed in June 2008 at a symposium in Liverpool with over 300 participants. The final outcome of this groundwork was published in November 2008 as the

«Astronet Roadmap Report — a Strategic Plan for European Astronomy».[3]

In the 'pan-European' sense this report is comprehensive beyond anything achieved before. Moreover, it goes beyond traditional ground-based and space astronomy: the report covers scientific fields, methods and activities that are basic for astronomical research, such as laboratory data of astrophysical interest. Before, such activities were viewed as belonging to, and therefore also to be funded by other disciplines.

Specifically, both the Astronet «Science Vision» and «Roadmap» comprise the following topics:

i. High energy astrophysics, particle astrophysics, gravitational waves
ii. Ultraviolet, optical & infrared (OIR) and radio/mm astronomy (ground & space)
iii. Solar telescopes, solar system missions, laboratory studies
iv. Theory, computing facilities and networks, virtual observatory
v. Education, recruitment and training, public outreach.

It is true, of course, — and in accord with the EAS discussion in Leiden — that the «Astronet Roadmap Report» had been initiated by, and elaborated through a collaboration between astronomy-related national and regional funding organisations and the two European Inter-governmental Research Organisations ESA and ESO. Overall, the report nevertheless bears the imprint of the community. As a rule, the Astronet Board Members were astronomers — albeit employed by research funding or research performing organisations — who *ex-officio* had to be in close contact with the community. Moreover we observe that the projects of both ESA and ESO are community-driven.

A main consequence of this set-up was that the Roadmap quite naturally became the agreed plan of the funding agencies themselves: it reflected their consensus on what they considered to be the most effective way of spending their own astronomy budgets.

Involving the funding organisations from the start also had the beneficial effect that financial realities were kept in mind throughout, particularly as the funding organisations themselves participated dealing with their own projects. This is clearly an advantage of the structure of Astronet, and may hopefully help in maintaining a European virtue — a virtue that could be observed in some previous major European projects and long-term plans, where the cost and time of completed projects and accomplished long-term plans corresponded rather closely to the original estimates. This contrasts with some projects led by organisations overseas.[4] We also recall that ideas were presented in 1977 for 'next-generation' optical telescopes of the 25-m class at an ESO conference on ‚Optical Telescopes of the Future'; none of these are in operation today, 35 years later.[5]

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[3] The final report (178 pp) as well as an Executive Summary (12 pp.) can be downloaded from the web site http://www.astronet-eu.org/FP6/astronet/www.astronet-eu.org/.

[4] See, for example, L Billings (2010) The telescope that ate astronomy, *Nature* 467:1028-1030. Similar, albeit less pronounced excesses might, of course, also be found among European science projects.

[5] Two US-led international partnerships are currently engaged in pursuing projects for Giant Segmented Mirror Telescopes (GSMT), which are expected to become operational in the early 2020s: the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT); both described in Appendix C.

Conversely – after having assured that the member states would be prepared to fund such a project – the Director General of ESO introduced at the same conference the more modest idea of a 16-m aperture-equivalent telescope. This became the project for the Very Large Telescope that was approved at the end of 1987, and put into operation with all four 8-m telescopes in 2000.[6] ESA's 'Horizon 2000' program is another example: it was completed within the foreseen financial limits and within two years of its predicted 20-year timeframe.[7] Similarly, ESO's recent decision to restrict the diameter of the primary mirror of its European Extremely Large Telescope (E-ELT) to 39.3 metres combined with a faster f-ratio[8] reflects a considered approach to financially responsible planning, which European policy makers would be well advised to continue pursuing.

Appendix A — «Interrelationships of the Astronet Roadmap» —, which is taken verbatim from the Astronet Roadmap Report, considers and examines Astronet's many connections to other planning exercises: "…there are several EU initiatives that seek to enhance the planning and implementation of different aspects of our subject. The ASTRONET Roadmap team sought to foster cooperation and coordination between our project and all the other relevant organisations and initiatives." As mentioned above, ESA and ESO were directly involved in the elaboration of Astronet's Roadmap Report. Astronet also had regular interchanges with ASPERA, OPTICON, RadioNet, EuroPlanNet and the European Virtual Observatory. Moreover, the direct link of many founding agencies of Astronet with the work of the European Strategy Forum on Research Infrastructures (ESFRI) turned out to be very helpful.

The Astronet Roadmap Report presented at JENAM 2010 — a Counterpart to the US Decadal Reports

At the JENAM 2010 in Lisbon the conclusions of the «Astronet Roadmap Report» have been reported by members of the Astronet team. The report was introduced as a „pilot project in coordinated strategic planning." The «Astronomy Roadmap Report» is, in fact, modelled on, but not merely a European copy of the US Decadal Surveys.

With science advisory and science funding structures being different in Europe, the Roadmap had to be established through a procedure at variance with that employed for the 'Decadal Reports.' In Europe, agencies in the individual countries fund both the inter-governmental organisations ESA and ESO as well as their national facilities, and we lack a European equivalent of the US National Research Council (which is operated by the US National Academies, and generates the US Decadal Surveys). A solution then was to have funding agencies initiate a report that was supported by the European Commission as a European Research Area (ERA-NET) project.

Notably, the «Astronet Roadmap Report» diverges from US Decadal Surveys in several respects:

- it covers a 20- to 25-year time span (while, as their name says, Decadal Surveys cover a decade only),
- it presents a coherent picture, as it covers astronomy as a whole in one report (while Decadal Surveys on Astronomy, Planetary Science, Solar Physics etc. appear sequentially as separate Surveys), and
- it is adapted to European as well as global political realities (while Decadal Reports only recently began to take developments outside the US into account).[9]

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[6] Woltjer L (1978) The case for large optical telescopes in *Proc ESO Conf ,Optical Telescopes of the Future'* (Geneva, Dec 1977, eds F Pacini, W Richter & RN Wilson) pp 5-12; Woltjer L (2006) *Europe's Quest for the Universe*, pp 43-85 (Les Ulis, EDP Sciences).

[7] Bonnet R-M & JAM Bleeker (2011) A Dark Age for Space Astronomy? *Science* **333**:161-162.

[8] cf. http://www.eso.org/public/announcements/ann11034/

[9] The 2010 Decadal Report on astronomy «New Worlds, New Horizons in Astronomy and Astrophysics» actually recommended a joint strategic planning process for the future. A free PDF copy of the report can be downloaded from the web site http://www.nap.edu/catalog.php?record_id=12982.

Astronet aims to establish such an activity permanently in Europe, and considers itself a European initiative that is developing into an irreversible global process. This would tie in with the 'joint strategic planning' recommended in the 2010 Decadal Report on astronomy.

Astronet is largely compatible with previous planning — not the least because of the care exercised by Astronet to consider the interrelationships with other fields (cf. Appendix A on «Interrelationships of the Astronet Roadmap»). In particular:

- the top-priority ground-based Astronet projects are those in the ESFRI list,
- the top-priority Astronet astroparticle projects are the same as those in the ASPERA Roadmap (although the ranking sometimes differs), and
- the larger top-priority space projects in the Astronet Roadmap Report are the same as those in the ESA Cosmic Vision initial list.[10]

It was important to prioritise large projects and to place them in scientific and financial context of the entire field, with proposed schedules. This applies especially to agreed European strategy and to priorities now defined for global-scale projects, such as the Square Kilometer Array (SKA). That Europe was considered a serious partner in the US Decadal Survey is a positive aspect resulting also from the timeliness of the Roadmap Report.

Astronet 2 has started

The extension of Astronet, Astronet 2, has started in 2011 as an activity within the 7th EU Framework Programme. Astronet 2 is funded for a 4-year period with 1.6 M€, and its aim is the implementation of the Roadmap. The Astronet 2 Board has met twice: on 28 September 2011 and on 23 May 2012. At the last meeting a strengthening of relations with EAS was discussed.

Membership and Priorities at the Start of Astronet 2

Astronet 2[11] started with a membership that differed somewhat from the original one,[12] and with a list of Work Packages that reformulated the original list of topics.[13] Priorities for infrastructure projects in categories (i) 'High energy astrophysics, particle astrophysics, gravitational waves', (ii) 'Ultraviolet, optical & infrared (OIR) and radio/mm astronomy (ground & space)' and (iii) 'Solar telescopes, solar system missions, laboratory studies' of the original list of topics (see p. 2 of this report) are as follows:

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[10] This initial list has changed, as ESA developed descoped ESA-only missions in response to NASA's withdrawal from their planned participation in ESA's Large Missions: EJSM-Laplace, IXO and LISA became, respectively, JUICE, ATHENA and NGO.

[11] cf. the web site www.astronet-eu.org/

[12] it now consists of:

- 1 Coordinator: CNRS/INSU (FR),
- 10 Contractors: BMBF (DE), ESO, INAF (IT), STCF (UK), NOTSA (Nordic), MINECO (ES), NOW (NL), PT-DESY (DE), NCBiR (PL), CAS (CZ),
- 21 Associates: ESA, MPG (DE), DFG (DE), LAS (LT), SRC (SE), GNCA (GR), HAS (HU), ESF (EE), SER (CH), AI SAS (SK), FWF (AT), ROSA (RO), NASU (UA), ARRS (SI), BAS (BG), LU AI (LV), ISA (IL), FCT (PT), MZOS (HR), FRS-FNRS (BE), FWO (BE), and
- 2 Forum Members: FNU (DK), AF (FI)

[13] Six Work packages have been defined for Astronet 2:

- WP1 Networking
- WP2 Coordination of European astronomy
- WP3 Integration of new members
- WP4 Coordination action
- WP5 Common actions
- WP6 Consortium management

For ground-based astronomy:

- Large Scale
    1. E-ELT and SKA (where it is realised that phasing is very important)
- Medium Scale
    1. European Solar Telescope
    2. Cherenkov Telescope Array
    3. Multi-km^3 sized Neutrino Telescope (KM3NeT)
- Small scale
    1. Wide Field, Multiplexed Spectrograph (for existing 8-m to 10-m telescopes)

  Plus, as a general goal, optimisation of access to existing telescopes: Solar, 2-m to 4-m, and 8-m to 10-m for optical/IR, radio and millimetre to sub-millimetre astronomy)

For space astronomy:

- Large scale
    1. XEUS/IXO and LISA[14]
    2. Tandem/Laplace[15]
    3. Exomars

  and Darwin, FIRI, Phoibos, which are foreseen for post-2020
- Medium scale
    1. GAIA: data analysis
    2. Euclid
    3. Solar Orbiter
    4. Cross-scale, Simbol-X, Plato, Spica
    5. Marco Polo

  Plus continued European contribution to the operation of XMM-Newton, Integral, HST, Cluster, SOHO, STEREO, and Hinode over specified terms.

For categories (iv) 'Theory, computing facilities and networks, virtual observatory' and (v) 'Education, recruitment and training, public outreach' in the original list of topics, Astronet 2 starts with these priorities:

- Laboratory Astrophysics; Computing[16]; Theory; Virtual Observatory
    - Enhanced laboratory astrophysics[17]
    - Pan-European (Virtual) Astrophysical Software Lab
    - Further development of the Astrophysical Virtual Observatory
- Wider impact
    - Improvement in communications to the public
    - Greater interactions with European industry
    - Provision of adequate numbers of highly skilled people
    - Measures to enhance science and technology education
    - Enhanced exploitation of results

Looking beyond Europe to Asia

For the sake of completeness we recall the longstanding relations between Europe and Asia regarding space astronomy in Appendix B. In addition, we describe there two innovative Chinese astronomical facilities: LAMOST, currently the largest Schmidt telescope, and Dome A on the Antarctic plateau, a project in rapid evolution and with particularly exciting prospects.

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[14] now replaced by ATHENA and NGO

[15] now replaced by JUICE, which subsequently was selected on 2 May 2012 by ESA's Science Programme Committee as project for the next Large Mission.

[16] To underline this point: note that the data flow and concomitant resource requirements of the SKA (to be built 2016-2024) is 20 PB/20 s, >20 MW power for Computing and Data Management (according to ASTRON)

[17] Working Group web site: http://home.strw.leidenuniv.nl/~linnartz/ETFLA/

Conclusions and Debating Points for EAS

Astronet, tried to integrate the many somewhat parallel planning endeavours that transcend the classical discipline 'Astronomy'. The outcome is as follows:

- the Astronet Roadmap is a kind of European equivalent of the US Decadal Reports
  - and has been taken note of by US policy makers,
- yet it is distinct from its American equivalents,
  - it does not have the stamp of approval of an Academy, but is supported by European Inter-governmental Research Organisations as well as by regional and national funding organisations,
  - it has a time horizon of 20 to 25 years, rather than a decade only,
  - covers all fields at once,
  - and clearly takes into account the global context.[18]

European astronomy projects — in particular those led by ESA and ESO — are recognised as being competitive by the US policy makers. This is manifested in the latest Decadal Report on Astronomy, which recommends a joint strategic planning process for the future (cf. footnote 9).

The comprehensive «Astronet Roadmap Report» goes well beyond traditional astronomical activities; it spells out solar physics and solar-system exploration as components of the enterprise, and also formally includes activities such as laboratory astrophysics, the maintenance of a virtual observatory, science and technology education, outreach etc.

The activities of Astronet and a recent workshop on "Lessons Learned in Decadal Planning in Space Science"[19] show that astronomy planning now takes financial aspects more seriously into account — actually on both sides of the Atlantic.

Nevertheless, the economic downturn of the past four years[20] and what in retrospect appears as an over-achieving attitude in planning as well as a redundancy in projects,[21] have slowed down progress both in implementing missions and further planning.

With growing project size one observes a trend towards intercontinental collaborations. The ground-based Atacama Large Microwave Array (ALMA) located in Chile, for example, is a joint undertaking of ESO, the US National Radio Astronomy Observatory (NRAO) and the National Astronomical Observatory of Japan (NAOJ). And ESO counts on Brazil ratifying its status as Member Country, so that it can realise the E-ELT. And the US projects for a 25-m or 30-m telescope, finally, are based on associations with Canada, Japan, China and India, or Australia and South Korea, respectively (cf. Appendix C).

We also discern a tendency of some learned societies to reach beyond their own continent. The Optical Society of America (OSA) is a prime example, they hold conferences in South America with increasing frequency and it has even been suggested that OSA, which anyway has had a large part of its membership working outside of America, may eventually drop the 'of America' in its name. Given the number of South-American students in Europe — and also the fact that cultural values in South America are rather close to the European ones — EAS might also think of establishing links with that part of the World.[22]

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[18] Decadal Surveys took the global context into account in the more recent past only.

[19] http://sites.nationalacademies.org/ssb/CurrentProjects/SSB_070954.htm

[20] A specific consequence is the withdrawal of NASA's planned support during ESA's three Large Mission studies (EJSM-Laplace, LISA and IXO), cf. footnote 10.

[21] Some over-achieving may be inherent in the joint NASA/ESA JWST, while ESA's 'BepiColombo' mission may better fit the label of redundancy.

[22] The European Physical Society (EPS), an EAS sister society, for example, regularly receives reports on the activities of the Federation of Ibero-American Physical Societies (FEIASOFI), and is represented at FEIASOFI general meetings. Similarly, the European Research Council (ERC) decided 'to go global', i.e., to award grants also to scientists residing outside Europe.

Similarly, one might even consider whether the EAS should try to emulate its sister society EPS, which has organised two Asia-Europe Physics Summits (ASEPS) so far.

The EAS now intends to follow the development of Astronet more closely, for example as an observer. This might perhaps also entail a discussion on whether the coverage of astronomy by EAS — as it has been practiced up to now — is adequate, or whether it should be broadened to more closely match that of Astronet's definition of 'Astronomy'.

One might think that the many European astronomers who are members of the American Astronomical Society (AAS) would provide a good link to the US community in planning matters. However, European members of the AAS are implicitly supporting the policies of AAS.

It is in turn a task for the European Astronomical Society to push from the European side for enhanced collaboration in planning between Europe and the US.

The European Science Foundation's (ESF) European Space Sciences Committee (ESSC), which follows all space sciences, and thus reaches well beyond astronomy, has been advocating repeatedly a better coordination of efforts concerning surveys conducted by different agencies, especially in Europe and the US. The EAS might raise its international profile, for example, by supporting this recommendation.

Before concluding, we want to emphasise again the importance of realism in planning and cost projections. Following the decision to have a two-continent version of SKA, this issue was recently put into focus again at a conference. Several examples are cited in a paper presented there[23] that have led to devastating defeats for projects; even more seriously, such defeats sometimes lead to a loss of prestige of an entire field of science. As mentioned above, realism and financial prudence have been European virtues; we better strive to maintain them!

In conclusion we might recall again that science has become a multi-disciplinary enterprise, i.e., an endeavour that cannot any more be cleanly subdivided to be dealt with in disciplinary compartments. It may be appropriate therefore to evaluate, whether some of the methods that had been foreign to astronomers, but which have taken on growing importance in measuring, exploring and explaining the Cosmos, should be better taken into account by a learned society such as EAS.[24]

References to the 'Science Vision' and the 'Infrastructure Roadmap' of Astronet

Bode, MF, MJ Cruz & FJ Molster, eds 2008, *The Astronet Infrastructure Roadmap: a Strategic Plan for European Astronomy*, A document created by the Infrastructure Roadmap Working Group and Panels under the auspices of ASTRONET, ISBN: 978-3-923524-63-1 (can be downloaded via the URL <http://www.astronet-eu.org/FP6/astronet/www.astronet-eu.org/spipb52c.html?rubrique28>)

de Zeeuw, PT & FJ Molster, eds 2007, *A Science Vision for Europe — What is the origin and evolution of stars and planets? How do galaxies form and evolve? Do we understand the extremes of the Universe? How do we fit in?* A document created by the Science Vision Working Group under the auspices of ASTRONET, ISBN 978-3-923524-62-4 (http://www.astronet-eu.org/spip.php?article115&lang=en).

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[23] Woltjer L (2012), A Bridge Too Far ? in 'From Antikythera to the Square Kilometre Array: Lessons from the Ancients', *Proc. of Science* (http://pos.sissa.it).

[24] In recent testimony to a congressional subcommittee on budgetary issues for „astronomy and astro-physics", the President of the American Astronomical Society, DM Elmegreen included research "on the Sun, Solar System, and the rest of the Universe" in her remarks, but surprisingly avoided any reference to techniques other than the traditional ground-based and space-borne telescope observations and planetary exploration by rovers. No mention was made even of X-rays, and none of gravitational waves, although these are predominant themes in «New Worlds, New Horizons in Astronomy and Astrophysics», i.e., the 2010 Decadal Report (cf. https://aas.org/files/AAS_Testimony_to_CJS_2012.pdf)

Appendices

A. Interrelationships of the Astronet Roadmap

To explain the Interrelationships of the Astronet Roadmap, we reproduce here Section 2.2 of this report (entitled ‚Interrelationships'):

The Roadmap cannot be developed or implemented in isolation. As well as the national funding agencies themselves, and large pan-European organisations that are responsible for the development of facilities of particular relevance to ASTRONET, there are several EU initiatives that seek to enhance the planning and implementation of different aspects of our subject. The ASTRONET Roadmap team sought to foster cooperation and coordination between our project and all the other relevant organisations and initiatives.

Both the European Southern Observatory and the European Space Agency are formal founding partners on the ASTRONET project, ESO as a Contractor and ESA as an Associate. Both are represented at ASTRONET Board level and have participated in the formulation of the Science Vision and now the Roadmap. ESA's representation was especially valuable on the Roadmap Working Group (see below), particularly through the period in 2007 when ESA was considering submissions for missions to fulfil its Cosmic Vision[25] ambitions. ASTRONET was not privy to the ESA selection process, but performed its own independent evaluation of the proposed projects. The outcomes of the two parallel exercises are discussed in the Panel reports in the subsequent chapters. Good working relations were established to ensure mutual understanding of any differences in outlook and perspective.

The ASPERA[26] initiative is another ERA-NET comprising national agencies and funded by the EU under the Framework Programme for Research and Technological Development (FP6). Its primary objective is to provide coordinated planning for the future of astroparticle astrophysics in Europe. Its remit overlaps with Astronet's Roadmap Panel A, and to a lesser extent with Panel B. The work of both Panels has benefited from a regular interchange of information on progress. This has included the participation of ASTRONET in ASPERA open meetings as the ASPERA Roadmap was being developed, and taking part in both videoconference and face-to-face meetings. In this way, excellent working relations have been established with ASPERA.

ESFRI[27] brings together representatives of EU Member and Associated States, appointed by the Ministers in charge of Research, plus one representative of the European Commission. The role of ESFRI is to support a coherent approach to policy-making on research infrastructures in Europe, and to act as an incubator for international negotiations about well- specified initiatives. Several of the largest infrastructures considered by ASTRONET are on the ESFRI roadmap and several of the founding agencies of ASTRONET are central to the work of ESFRI.

The OPTical Infrared COordination Network for astronomy (OPTICON)[28] is an Integrated Infrastructure Initiative (I3), initially funded under FP6, which brings together all the international and national organisations that fund, operate and develop Europe's major optical and infrared astronomical infrastructure, together with several world-class facilities for solar astronomy located in the Canarian Observatories. OPTICON incorporates networking, transnational access (TNA) and Joint Research Activities (JRA) to foster collaboration and development of facilities within its remit. RadioNet[29] is another I3 funded under FP6. It has pulled together all of Europe's leading radio astronomy facilities to produce a focused, coherent and integrated project whose goal is to enhance the quality and quantity of science performed by European astronomers significantly. Both OPTICON and RadioNet are represented on the

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[25] http://esa.int/esaSC/SEMA7J2IU7E_index_0.html
[26] http://www.aspera-eu.org
[27] http://cordis.europa.eu/esfri
[28] http://www.astro-opticon.org
[29] http://www.radionet-eu.org

ASTRONET Infrastructure Roadmap Working Group and links between the three initiatives are very strong.

Finally, EuroPlaNet[30] is an I3 network linking planetary scientists from across Europe, again funded under FP6. The aim of EuroPlaNet is to promote collaboration and communication between partner institutions and to support missions to explore the Solar System. The EuroPlaNet coordinator was a member of the ASTRONET Roadmap Panel C. Similarly Euro-VO[31] aims to deploy an operational Virtual Observatory in Europe. ASTRONET Panel D included a leading member of this initiative.

B. Notes about Japanese and Chinese telescope projects in space and on the ground

Before turning to Appendix C, where we summarise the projects for large ground-based telescopes planned by the US, we must recall, for completeness sake, the successful cooperation in space astronomy between Europe and Japan, or more exactly between ESA and JAXA/ISAS.

It is important, too, to sketch some of the outstanding projects of China to round off the report. We have selected two examples, namely the currently largest Schmidt telescope and the work on Dome A, the highest point of Antarctica, where China is exploring, together with international partners, a site that albeit being on the surface of the Earth, may exhibit conditions close to those prevailing in space.

Europe-Japan cooperation: exchanging observing time on space telescopes
In a tradition of cooperation spanning two decades ESA and the Japanese space agency JAXA/ISAS have given access to observing time on space telescopes, such as on ESA's ISO, or on Akari, Suzaku and now Astro-H of ISAS, to astronomers related to the other agency. The offer of a slice of observing time by one agency is compensated by the other agency through support of operations and users, and in some cases also by contributing hardware components. The share of observing time made available by the agency owning the telescope then goes to the best proposers of the other agency, following an open Announcement of Opportunity.[32]

Two of the past missions, ISO and Akari, have carried infrared telescopes; Suzaku and the telescope Astro-H foreseen for the future exchange of observing time give insight into the high-energy Universe. Astro-H is scheduled for launch in 2014, and will perform high-throughput spectroscopy with high spectral but moderate spatial resolution over the energy range 0.3-600 keV.[33]

LAMOST, the Large sky Area Multi-Object fiber Spectroscopic Telescope — currently the largest Schmidt telescope
LAMOST, also called Guoshoujing Telescope[34], is one of the 'National Major Scientific Projects' undertaken by the Chinese Academy of Science. A large spectroscopic survey with LAMOST has started in September 2012; it will provide data for the study both of the structure and evolution of the Galaxy and of the large-scale structure of the Universe.

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[30] http://www.europlanet-eu.org
[31] http://www.euro-vo.org/pub
[32] Similar cooperations between ESA and JAXA/ISAS exist for BepiColombo in the field of planetary exploration, as well as for Earth observations and for telecommunications satellites.
[33] A description of the Astro-H mission, i.e. its aims, instruments, participants etc. can be found on http://astro-h.isas.jaxa.jp/; http://www.esa.int/esaSC/SEM61VEWF0H_index_0.html reports on the signing of the cooperation agreement between ESA and JAXA/ISAS.
[34] Guo Shoujing was a Chinese astronomer, engineer and mathematician who lived from 1231 to 1316. Johann Adam Schall von Bell (1591–1666), a Jesuit priest, who had been sent to Beijing to reform the Chinese calendar and who later also became Director of the Imperial Observatory, is said to have been so impressed with the preserved astronomical instruments of Guo that he called him the Tycho Brahe of China (cf., http://en.wikipedia.org/wiki/Guo_Shoujing).

LAMOST, whose site lies 170 km northeast of Beijing at 960 m above sea level, is a special, quasi-meridian reflecting Schmidt telescope with a field of view of 5° and an effective aperture ranging between 3.6 m - 4.9 m, depending on the source position. The telescope employs active optics, i.e., the shape of the surface of the Schmidt mirror changes continuously during the observation.[35] The 1.75-m diameter focal surface can accommodate 4000 optical fibres, whose positions can be individually controlled. The fibres feed 16 spectrographs, each with 32 CCD cameras; thus the telescope's rate of spectral acquisition is without precedent.

Developments at Dome A in Antarctica — the site of three Antarctic Survey Telescopes, AST3

Grand developments are taking place at the highest elevation of the Antarctic plateau, at Dome A: three second-generation Chinese telescopes — the Antarctic Survey Telescopes AST3[36] — are being erected. AST3-1, the first unit of three wide-field optical imaging telescopes to be installed, has been deployed early in 2012. It has an entrance pupil with a diameter of 0.5 m, an *f*-ratio of 3.73 and a field of view with a diameter of 4°.14. The three optically identical telescopes that will make up the final configuration of AST3 will observe in the *G*-, *R*- and *I*-bands, and will cover the sky down to 70° from zenith.

The AST3 telescopes will carry out time-domain astronomy to time scales of around a minute, i.e. they will be used to detect microlensing caused by exoplanets, with a sensitivity reaching Earth-mass planets, as well as to detect Type-Ia supernovae and to follow them with daily high-quality multi-colour photometry.

Developing the site at Dome A is exceptionally interesting, because it may turn out to be the best observing site on the surface of the Earth. Most of the turbulence in the air is restricted to the first tens of metres above ground.[37] The high transparency and low water vapour content of the atmosphere[38], the low wind speed, as well as three months of continuous observing time each year are further advantages.

On the other hand, the same extreme environmental conditions at the high-altitude site of Dome A just mentioned — temperatures down to -80 °C, low atmospheric pressure and low water-vapour content — currently still preclude the presence of personnel during the austral winter. Remote operation of the telescopes is therefore mandatory. PLATO fulfils this requirement: it is a remotely controlled laboratory that includes power supplies and control computers not only for the telescopes but also for instrumentation that monitors site-quality.[39] A multi-national team, including the Chinese Center for Antarctic Astronomy, the University of New South Wales (UNSW) and the Texas A&M University supports both the infrastructure and the building of the telescopes; further contributions come from the UK. The UNWS team monitors and operates the power and computing systems from Sydney; the ATS3-1 telescope is operated from China.[40]

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[35] Cui X et al 2012, The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), *Research in Astron Astrophys* 12:1197–1242. For the method of active optics through controlled deformation of surfaces on elastic substrates, see also Lemaitre GR 2009, Astronomical Optics and Elasticity Theory: Active Optics Methods, *Astronomy and Astrophysics Library* (Berlin: Springer).

[36] Yuan X and Su D 2012, Optical system of the Three Antarctic Survey Telescopes, *Mon Not R Astron Soc* 424: 23–30.

[37] Bonner CS et al 2010, Thickness of the Atmospheric Boundary Layer Above Dome A, Antarctica, during 2009, *Pub Astron Soc Pacific* 122:1122–1131.

[38] Sims G et al 2012, Precipitable Water Vapor above Dome A, Antarctica, Determined from Diffuse Optical Sky Spectra, *Publ Astron Soc Pacific* 124:74–83.

[39] Yang H et al 2009, The PLATO Dome A Site-Testing Observatory: Instrumentation and First Results, *Publ Astron Soc Pacific* 121:174–184.

[40] Updated information about the projects at Dome A can be found at the web site of the Chinese-Australian Workshop on Wide-field Optical Astronomy from Antarctica, held at the Sydney Institute for Astronomy (SIfA) on 13th August 2012 (http://astronomyaustralia.org.au/AChAntarctica.html).

C. Notes about US Projects for large ground-based telescopes (25-m & 30-m class)

The 2010 Decadal Report describes on pp. 1-11 three projects for future ground-based telescopes:

1. The Large Synoptic Survey Telescope (LSST)
   - an 8.4-meter optical telescope to be sited in Chile, which will image the entire available sky every 3 nights.
   - with a 10-year lifetime this shall result in a publicly accessible database of 100 billion megabyte.
   - its design is relatively mature with an appraised construction cost of $465 million, of which it is recommended that the NSF and DOE contribute one third each, with the remaining third coming from international and private partners.
   - its annual operations costs are estimated at $42 million, of which $28 million is recommended to be split between NSF and DOE.
   - first light is foreseen in 2022
2. Giant Segmented Mirror Telescopes (GSMT)
   - The committee recommended that a choice between the following two projects be made as soon as possible for a federal partnership at a level of about a 25 % investment in one of them. A schedule and budget plan should then be developed. The survey appraises a total GSMT construction cost in the range of $1.1 billion (GMT appraisal) to $1.4 billion (TMT appraisal) and assumes that the federal share of the capital cost will be borne by Major Research Equipment and Facilities Construction funding, while recognizing that the total share may be secured through whatever combination of capital cost, operating funds, and instrumentation support is most favourable. The federal share of the operations cost is expected to be carried by the NSF Division of Astronomical Sciences (NSF-AST).
     a. 30 m Telescope (TMT)
        - A non-profit TMT Observatory Corporation was founded in June 2003,
          with Partner Institutions
          - Association of Canadian Universities for Research in Astronomy (ACURA)
          - California Institute of Technology (Caltech)
          - University of California (UC)

          with Collaborating Institution
          - National Astronomical Observatory of Japan

          and with Observers
          - National Astronomical Observatories of the Chinese Academy of Sciences
          - Department of Science and Technology of India
        - Schedule:
          - June 2003: TMT Observatory Corporation founded as a non-profit corporation by:
            - the Association of Canadian Universities for Research in Astronomy (ACURA),
            - the University of California (UC), and
            - the California Institute of Technology (Caltech)
          - March/April 2009:
            - TMT five-year Design Development Phase (DDP) completed
            - TMT commenced its Early Construction Phase
          - 2021
            - TMT is scheduled to begin scientific operations in 2021 on Mauna Kea, Hawaii as a next-generation astronomical observatory.

b. Giant Magellan Telescope (GMT: seven 8.4 m segments, 24.5 m equivalent collecting area)

- The GMT Corporation, an international consortium was founded in 2009 *with seven partners from USA:*
  - Carnegie Institution for Science
  - Harvard University
  - Smithsonian Institution
  - University of Texas at Austin
  - Texas A&M University
  - The University of Arizona
  - University of Chicago

  with two partners from Australia:
  - Astronomy Australia Ltd.
  - The Australian National University

  and one partner from South Korea:
  - Korea Astronomy and Space Science Institute
- Schedule:
  - January 2012:
    - casting of second mirror blank
  - March 2012,
    - rock blasting on Las Campanas to prepare the site
  - 2020
    - first light predicted

An interesting aspect of GMTO concerning budget aspects is that it has a Finance and Audit Committee, consisting of members from Australia, South Korea and four US Universities.

D. Acronyms and Mission Names

AAS	American Astronomical Society
ACURA	Association of Canadian Universities for Research in Astronomy
ALMA	Atacama Large Microwave Array, a joint undertaking of ESO, the US National Radio Astronomy Observatory (NRAO) and the National Astronomical Observatory of Japan (NAOJ)
ARRS	Slovenian Research Agency
ASEPS	Asia-Europe Physics Summits
ASPERA	AstroParticle ERAnet, a network of national government agencies responsible for coordinating and funding national research efforts in Astroparticle Physics
ASTRON	Netherlands Institute for Radio Astronomy
ATHENA	Advanced Telescope for High-ENergy Astrophysics, descoped, ESA-alone IXO
BAS	Bulgarian Academy of Sciences
BMBF	Bundesministerium für Bildung und Forschung
Caltech	California Institute of Technology
Cassini	Mission to Saturn, with NASA providing the launch and the interplanetary spacecraft and with ESA supplying the Titan lander Huygens
CNRS	Centre National de la Recherche Scientifique, represented in Astronet by the Institut National des Sciences de l'Univers
Cosmic Vision	Long-term science programme of ESA, follow-on programme after Horizon 2000 and Horizon 2000+
CRAF	Committee on Radio Astronomy Frequencies (an Expert Committee of the ESF)
Cross-Scale	a mission concept to study the nonlinear coupling of electron, ion and fluid scale processes which control the key plasma phenomena of shocks, reconnection and turbulence. Study stopped in 2010
DARWIN	Study of a mission designed for finding Earth-like planets that was ended in 2007

DESY	Deutsches Elektron-Synchrotron
DFG	Deutsche Forschungsgemeinschaft
EC	European Commission
EIROs	European Intergovernmental Research Organisations
EJSM-Laplace	Europa Jupiter System Mission
EPS	European Physical Society
ERA	European Research Area
ERA-NET	the ERA-NET scheme helps to step up the cooperation and coordination of research activities carried out at national or regional level in the EC Member and Associated States through: • networking of research activities conducted at national or regional level, and • mutual opening of national and regional research programmes.
ERC	European Research Council
ESA	European Space Agency
ESF	European Science Foundation; the two European committees dealing with important aspects of astronomy — the European Space Sciences Committee (ESSC) and the Committee on Radio Astronomy Frequencies (CRAF) — which are part of the European Science Foundation were indirectly involved in the Astronet study.
ESFRI	European Strategy Forum on Research Infrastructures (ESFRI's delegates are nominated by the Research Ministers of the Member and Associate Countries, and include a representative of the Commission. ESFRI was formed in 2002 at the behest of the European Council, and has witnessed significant advances towards unity and international impact in the field of research infrastructures. ESFRI's Roadmap for pan-European research infrastructures, published in 2006, with an update in 2008, was a key contributing factor. Several projects are now entering the realization phase.)
ESO	European Organisation for Astronomical Research in the Southern Hemisphere
ESSC	European Space Sciences Committee (an Expert Committee of the ESF)
Euclid	Dark Universe mission, one of the first two medium-class missions of the Cosmic Vision 2015–25 plan, launch planned in 2019
EuroPlaNet	Coordination Action supported by the EU under FP6; it is now succeeded by Europlanet RI, the Europlanet Research Infrastructure.
Euro-VO	European Virtual Observatory
FCT	Fundação para Ciência e a Tecnologia
FEIASOFI	Federación Iberoamericana de Sociedades de Física
FIRI	Far Infrared Interferometer, an ESA technology study
FP6, FP7 etc.	6th, 7th etc. Framework Programme of the European Commission
FWF	Fonds zur Förderung der wissenschaftlichen Forschung
FWO and FRS	Fonds de la Recherche Scientifique and Fonds voor Wetenschappelijk Onderzoek
Gaia	a mission to be launched in 2013, will make a census of a thousand million stars (originally the acronym for 'Global Astrometric Interferometer for Astrophysics')
GNCA	Greek National Committee for Astronomy
GSMT	Giant Segmented Mirror Telescope
HAS	Hungarian Academy of Sciences
I3	Integrated Infrastructure Initiative
IA-CAS	Astronomical Institute, Czech Academy of Sciences
IA SAS	Astronomical Institute, Slovak Academy of Sciences
INAF	Istituto Nazionale di Astrofisica
ISA	Israel Space Agency
IXO	International X-ray Observatory
JUICE	JUpiter ICy moon Explorer, descoped ESA-only EJSM-Laplace
JWST	James Webb Space Telescope
LAS	Lithuanian Academy of Sciences
LISA	Large Interferometric Space Antenna

LSST	Large Synoptic Survey Telescope
Marco Polo	returning a pristine sample of a near-Earth asteroid to Earth; a first ESA study was stopped in 2010; a new ESA assessment study on the MarcoPolo-R Mission started in 2011.
MICINN	Ministry of Science and Innovation
MPG	Max-Planck-Gesellschaft
MSES	Ministry of Science, Education and Sports
NAOJ	National Astronomical Observatory of Japan
NASA	(US) National Aeronautics and Space Administration
NCBiR	(PL) National Centre for Research and Development
NGO	New Gravitational Observatory, descoped ESA-only LISA
NOTSA	Nordic Optical Telescope Scientific Association
NRAO	US National Radio Astronomy Observatory
NSF-AST	Division of Astronomical Sciences of the US National Science Foundation
NOW	Netherlands Organisation for Scientific Research
OPTICON	OPTical Infrared COordination Network for astronomy
OSA	Optical Society of America
PHOIBOS	a proposed mission ‚Probing Heliospheric Origins with an Inner Boundary Observing Spacecraft', kind of solar probe
PLATO	'PLAnetary Transits and Oscillations of stars' a mission to determine the frequency of planets around other stars, including so-called Earth-analogues. Study stopped in 2011
RadioNet	Integrated Infrastructure Initiative (I3) coordinating all of Europe's leading radio astronomy facilities. Now succeeded by RadioNet3
ROSA	Romanian Space Agency
SER	State Secretariat for Education and Recherché
Simbol-X	a proposed 20-m focal-length telescope for the hard X-ray (10–80 keV) region. Study stopped in 2009
SKA	Square-kilometre Array
SKADS	Square Kilometre Array Design Studies
Solar Orbiter	venturing closer to the Sun than any previous mission, one of the first two medium-class missions of the Cosmic Vision 2015–25 plan, launch planned in 2017
SPICA	an infrared (5 μm to 210 μm) imaging and spectroscopy mission to be led by JAXA. A decision on European participation will be taken, when JAXA takes SPICA from the current pre-project to project phase.
SRC	Swedish Research Council
STFC	Science and Technology Facilities Council
TMT	30-m Telescope
TNA	trans-national access
UAS	Academy of Sciences of Ukraine
UC	University of California