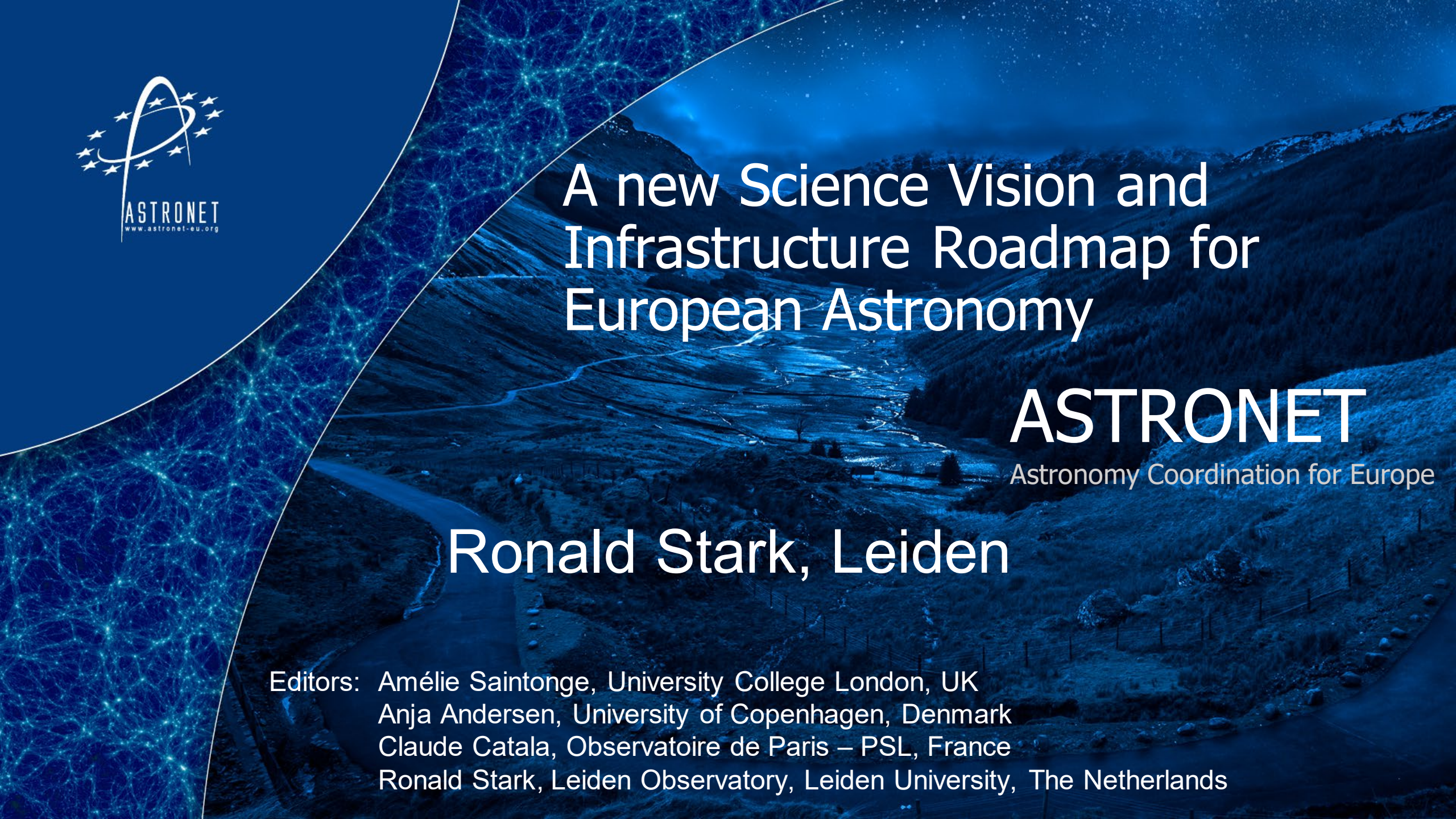

A new Science Vision and Infrastructure Roadmap for European Astronomy

ASTRONET

Astronomy Coordination for Europe

Ronald Stark, Leiden

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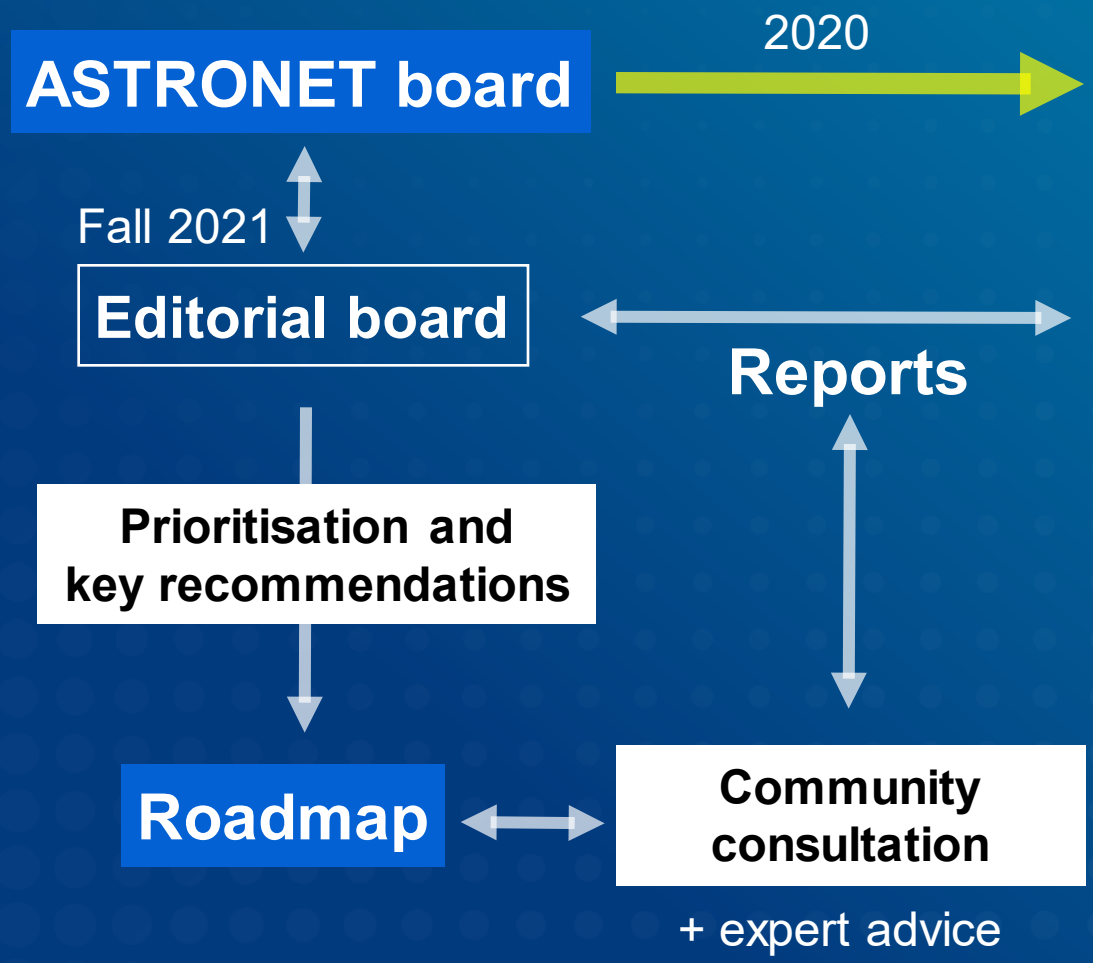
What is ASTRONET?

- A consortium of European funding agencies, national societies, infrastructures and academies providing a forum to coordinate scientific direction and new capabilities for all of Astronomy
- Originally supported by EC, but independent for last few years
- 20 members – a mix of full members and observers
- Has been focussed on Science Vision and Infrastructure Roadmap for European Astronomy and now upon acting on recommendations from it
- Strong links to EAS, APPEC, Europlanet, and EC programmes
- Effort entirely based on in-kind contributions
- Chaired by UK, who also commissioned the Science Vision

Roadmap organisation



Science panels (~100 scientists involved)

A- Computing; big data, HPC and data infrastructure (chair: E. Emsellem, ESO / U. Lyon)

B- Origin and evolution of the Universe (chair: L. Koopmans, U. Groningen)

C- Formation and evolution of galaxies (chairs: P. Dayal, U. Groningen / M. Hayes, Stockholm U.)

D- Formation and evolution of stars (chair: C. Evans, STFC / STScI)

E- Formation and evolution of planetary systems (chairs: I. Snellen, Leiden / A. Sozzetti, INAF Torino)

F- Solar system and the conditions for life (chairs: L.M. Lara, IAA-CSIC Granada / N. Vilmer, Obs. Paris)

G- Extreme Astrophysics (chairs: J. Hessels, U. Amsterdam / A. Levan, Radboud U. / N. Rea, ICE Barcelona)

H- Astronomy and society (chair: P. Russo, Leiden)

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Science vision & infrastructure roadmap 2022 – 2035 : contents

ELT in construction
at Cerro Armazones, Chile.

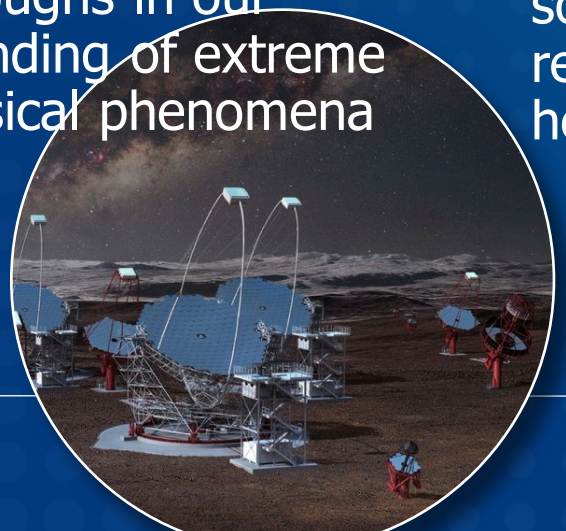
Credit:
ESO/ S. Lowery

Summary of the roadmap recommendations

New ground-based facilities

→ Reminder: completion and commissioning of
ELT + 1st generation instruments
SKA-1 + SKA regional centres → Major importance for European astronomy

Completion of the **Cherenkov Telescope Array** (CTA). As the first true large-scale observatory dedicated to the study of high energy gamma rays, CTA will lead to breakthroughs in our understanding of extreme astrophysical phenomena



Completion of the **European Solar Telescope** (EST), and synergetic operations with the US-based DKIST. EST will significantly increase our understanding of the solar magnetic field and its relations with the heliosphere and the Earth

European involvement in a **wide-field, high multiplex optical spectroscopic facility**, behind a 8-10m class telescope. Such a facility will enable a broad range of science investigations and provide follow-up capabilities for facilities such as JWST, LSST, and Euclid

Ground-based facility upgrades and new instruments

- An upgrade of the Atacama Large Millimeter Array (**ALMA**), as explored for example in the ALMA 2030 Vision, and including extending the frequency coverage with Band 1 and 2 receivers, longer baselines, wider bandwidths, and improved VLBI capabilities

- Even in the era of ELTs, the Very Large Telescope (VLT) will remain the workhorse of European ground-based optical/IR astronomy, and should be supported and developed. Particular priorities for the community are the **BlueMUSE** integral field spectrograph, as well as **high-contrast, high angular resolution instrumentation**, e.g. for exoplanetary systems

- While the European Large Telescope (ELT) and its first generation of instruments will see first light by the end of this decade, the immediate funding and development of second-generation instruments **ANDES** and **MOSAIC** is recommended

Space-based facilities

➢ Secure launch and operation of missions already selected, but facing various kinds of difficulties
➢ Current exercise has shown their major importance in several scientific areas

- **Athena:** L-class X-ray mission in ESA's Cosmic Vision 2015–25 → groups and clusters of galaxies, role of the earliest supermassive black holes
- **LISA**: L-class mission, 1st space-based gravitational wave detector → low frequency GW and their sources in the whole universe, including galactic compact binaries, supermassive black hole mergers, as well as stochastic GW background from the inflation phase

→ Both are of prime importance for a wide range of areas. Currently undergoing studies aimed at ensuring a cost cap of 1.3 G€ for each mission. Recommendation is to have both missions fully adopted and developed in the best timeframe, preserving their initially planned scientific return

- **Mars exploration:** Europe's participation rests on two main pillars

(1) with NASA → MSL/Curiosity + Mars2020/Perseverance → Mars Sample Return (late 2020s)
(2) **ExoMars** strongly impacted by the geopolitical situation → rescued but with severe delay
→ Proceed with new solution + re-examine and adapt European strategy for Mars exploration

Laboratory astrophysics

It is recommended that:

• Laboratories and archives are supported to effectively produce, archive, and provide fundamental data on atoms, molecules, and optical properties of solids (e.g. dust) for astrophysical and astrochemical purposes

• Individual laboratories are supported to tackle investigations of both meteoritic samples and space-mission sample return materials

Technology development

Anticipating on longer-term perspectives, key, cutting-edge technologies need to be developed in the next decade to enable major facilities for 2035+:

- Receiver technology, backend data handling and dish development for radio astronomy, in particular SKA-2
- Cryogenics and detector technology for a far-infrared space telescope, a strong priority of the research community
- High-contrast, high angular resolution instrumentation for exoplanetary systems, combining extreme adaptive optics, coronagraphy and high-resolution spectroscopy, en-route for ELT-PCS
- Space-qualified UV-optimised optical elements and detectors, to enable European participation to a large collecting area UV-to-IR space telescope
- New optical/IR interferometric technologies

Computing, data management, education, and society

The roadmap recommendations extend well beyond facilities and technology. Key areas include:

Computing / data

- integrate computing/data management plan with facility planning

- career pathways for software engineers, computation / statistics specialists, etc.

- collaborative and open framework for the astronomy-computing ecosystem

Sustainability / accessibility

- projects should include environmental footprint assessments and reduction plans

- diversity and inclusion to be central to funding strategies and project planning

- work with regulatory/policy bodies and with industry to ensure the protection of the dark and radio-quiet skies

Education / outreach

- improve training in transferable skills, in collaboration with industry

- educate (via national education curricula) on modern astronomy research, with emphasis on big science/data, AI and technology R&D

- recognition of education and public engagement for career progression

Summary of recommendations

New ground-based facilities: ELT + 1st gen instruments; SKA-1; CTA; EST; Wide-field/High multiplex spectrograph

Upgrades and new instruments: ALMA; VLT (BlueMuse, High contrast/High angular res); ELT 2nd gen instruments

Space-based facilities: Athena + LISA; Exomars (re-examine European strategy for Mars exploration)

Laboratory astrophysics: Data on atoms, molecules, solids + investigations of meteorites and space samples

Technology developments toward: radio-astronomy; space FIR space; ELT-PCS; UV-to-IR space telescope; optical/IR interferometry

Computing, data, theory: science-ready data products and analysis tools; data infrastructure; professional skills base; collaborative, open and synergistic view of the computing ecosystem

Sustainability, accessibility: carbon-neutrality, climate science, diversity/inclusion, dark and radio-quiet skies

Education, training, society: training programmes, transferable skills, career paths for instrumentation, computing and data science, public engagement, big science, big data, AI, R&D, equal/respectful engagement with communities

What's next?

- ASTRONET Board starting to consider the recommendations, but also to continue to promote awareness of the report in media, community and to policy-makers
- Already had links to APPEC, Europlanet, ORP, ESCAPE, AHEAD etc.
- Now working on improving links to ESFRI, EC: coordinated submissions to ESFRI Landscape Analysis with APPEC
- Engaged with process to develop ACME EC bid (including transnational access) across astroparticle and astrophysics, starting to engage with INFRA-Tech bids, ESCAPE2
- Highlighting recommendations not directly for ASTRONET to those more able to take them forward

What's next?

- Considering infrastructure recommendations
- For some, endorsement is sufficient – current ESA programme, ELT, Rubin etc.
- For others need to consider how best to encourage, facilitate and engage:
  - ESA /NASA future programmes – both science and exploration, and linkage with ground-based capabilities
  - Astroparticle facilities – CTA, ET etc. How best to work with APPEC to support these
  - Planetary capabilities – how to take discussion forward with community and representatives, how to ensure joined up approach to potential funders / policy makers

What's next?

Together with APPEC:

- Improving links to ESFRI, EC: coordinated submissions to ESFRI Landscape Analysis
- Engage with process to develop ACME EC bid across astroparticle and astrophysics, starting to engage with INFRA-Tech bids, ESCAPE2
- Astroparticle facilities: How best to work with APPEC to support CTA, ET, etc.
- Set-up working group for a European participation in CMB-S4
- Defining roadmap towards European CMB space mission