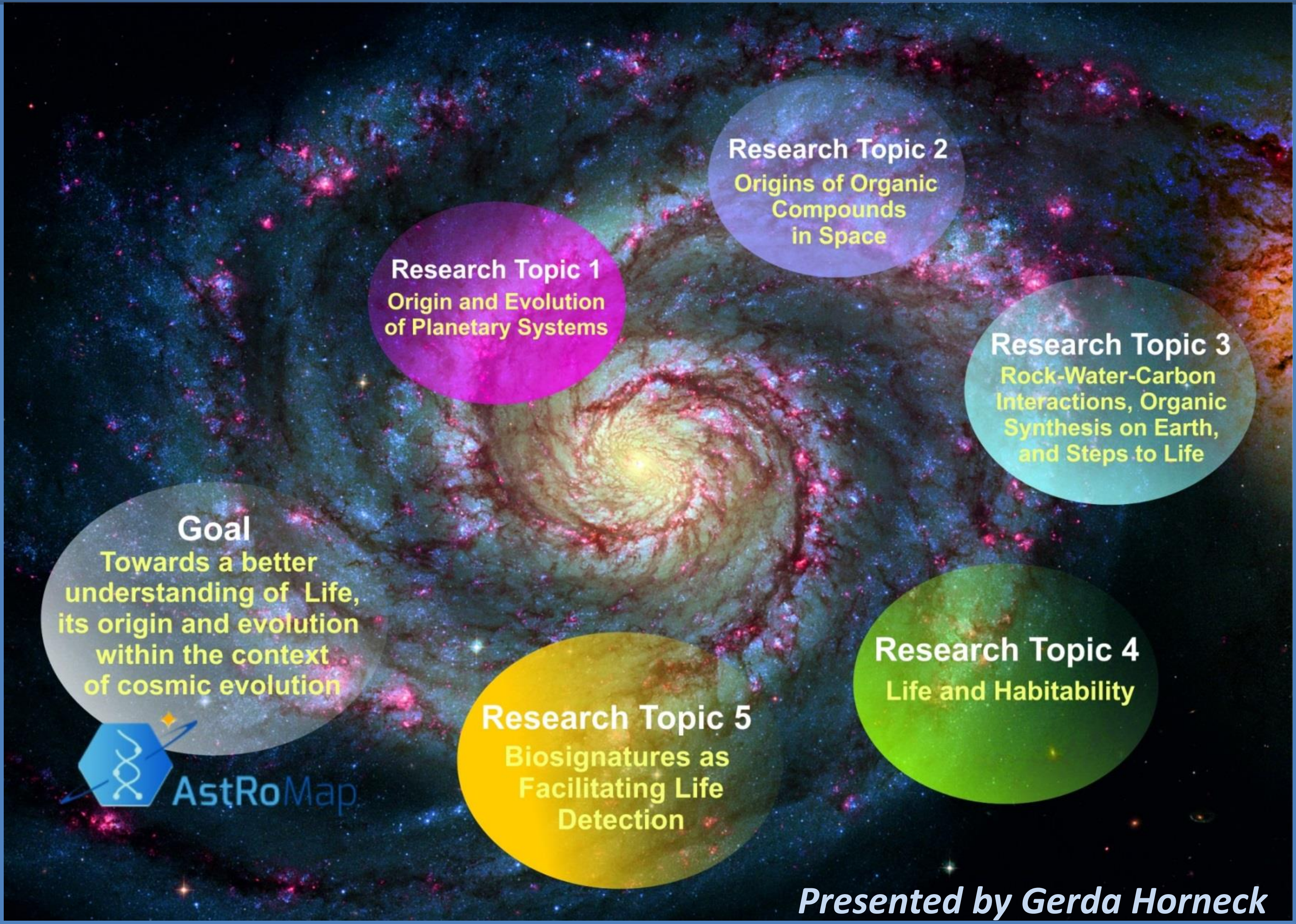
European Astrobiology Roadmap

www.astromap.eu



SPACE SCIENCE WEEK, March 29-31, 2016, Washington D.C.

SEVENTH FRAMEWORK PROGRAMME

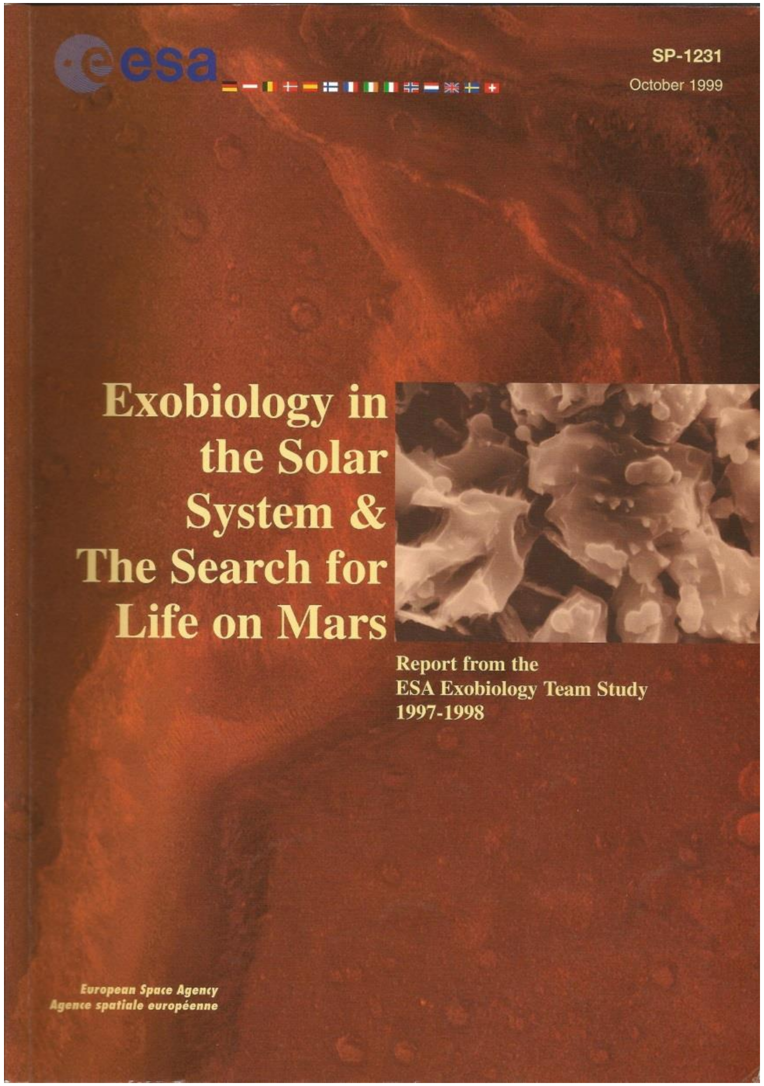
AstRoMap

Exobiology in the Solar System & The Search for Life on Mars, Report of the ESA Exobiology Team Study ESA SP 1231, 1999 (Team leader: André Brack)

Recommended research activities:

- Search for extant and extinct life (Mars, Europa, Titan, Martian meteorites)
- Study the precursors of life (comets, meteorites and micrometeorites)
- Organic chemistry processes and microorganisms in space (experiments on a space station)
- Laboratory-based studies (simulation of planetary environments, basic research)

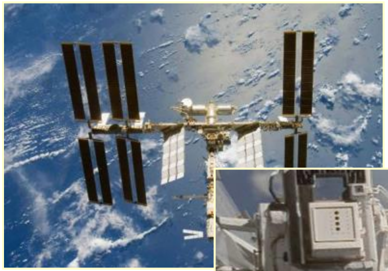
This study has essentially influenced the development of ESA's Aurora Program and the Flagship mission ExoMars, with launches in 2016 and 2018

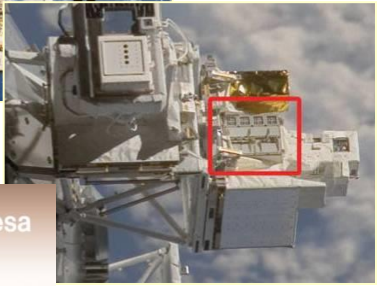


European Astrobiology Landscape
Astrobiology at ESA

SEVENTH FRAMEWORK PROGRAMME

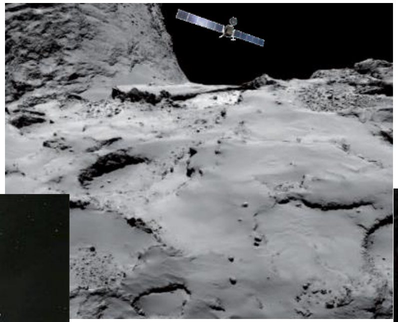
AstRoMap





1. **Directorate of Human Spaceflight and Operations (DHSO): EXPOSE-missions**
2. **Directorate of Space Sciences and Exploration (DSE): ExoMars (2016/2018)**

other science missions, not called "astrobiology":
Rosetta (2004)



JUICE (2028)

Herschel (2009)
Cheops (2017)

PLATO 2.0 (2024)

Instruments and data analyses are provided by national space agencies

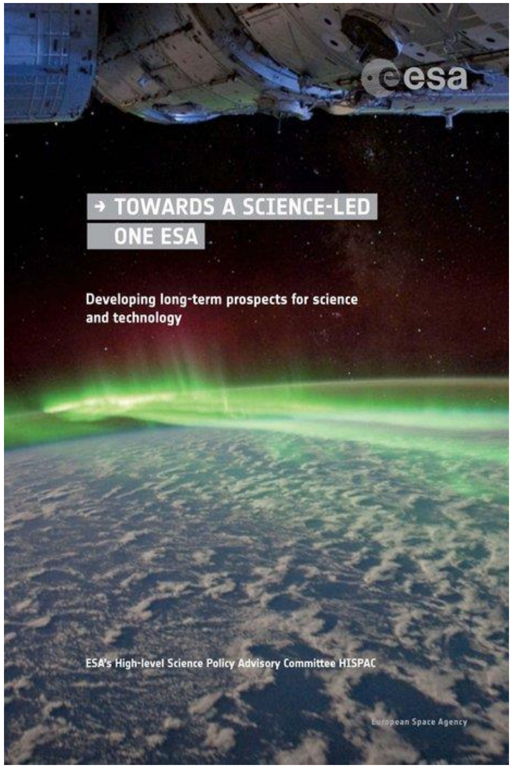
Cosmic Vision,
Space Science for Europe 2015-2025

Directorate of Human Spaceflight and Operations (DHSO)
Issued 2005

First theme is strongly related to astrobiology, although "astrobiology" is not mentioned:
"What are the conditions for planet formation and the emergence of life?" with the topics:

- From gas and dust to stars and planets.
- From exo-planets to biomarkers. Search for planets around stars other than the Sun, looking for biomarkers in their atmospheres, and image them.
- Life and habitability in the Solar System. Explore in situ the surface and subsurface of the solid bodies in the Solar System most likely to host – or have hosted – life. Explore the environmental conditions that make life possible.

ESA High-level Science Policy Committee (HISPAC)
set up by ESA Director General in 2007
to address the issue of
promoting and advising
on the creation of a Science-led One ESA.



Life in the Universe and Astrobiology
were laid down as one of the
four grand Science Themes for ESA
in the 2013 HISPAC report
***Towards a Science-led One ESA* (ESA BR-315)**

European Commission

HORIZON 2020

The EU Framework Programme for Research and Innovation

European Commission > Horizon 2020

- **Horizon 2020 addresses all aspects of space science and technology development for the period 2014-2020**
- Horizon 2020 is structured around bi-annual work programs and annual calls
- Most Horizon 2020 space-related call topics are targeted towards developing appropriate space technologies and services, and fostering European industry competitiveness
- Total budget: 1.4 B€ , of which 5 % targets "space sciences"
- First call for space sciences in 2014 (4 M€): Mars data evaluation and the definition of a European sample curation facility (http://www.euro-cares.com/)
- Second call for space sciences in 2015: (1.5 M€) Scientific exploitation of astrophysics, comets, and planetary data; (1 M€) addressing international cooperation in the context of planetary protection

European Astrobiology Landscape
European Astrobiology Network Association

19 European countries, ~200 individual members. Plus association/affiliation with organizations in Brazil, China, Japan, Mexico, USA

Highlight activities:

- Annual Workshops
- Publications
- On-line teaching
- Road-mapping

http://eana-net.eu

European Astrobiology Landscape
European Astrobiology Network Association

AstRoMap

Astrobiology Road Mapping for Europe

AstRoMap Team:
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P. Rettberg, DLR, Köln, Germany

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AstRoMap

Astrobiology Road Mapping for Europe

In the context of **AstRoMap**
astrobiology is understood as
'the study of the origin, evolution, and distribution of life in the context of cosmic evolution; including habitability in the Solar System and beyond'

www.astromap.eu

Main objectives

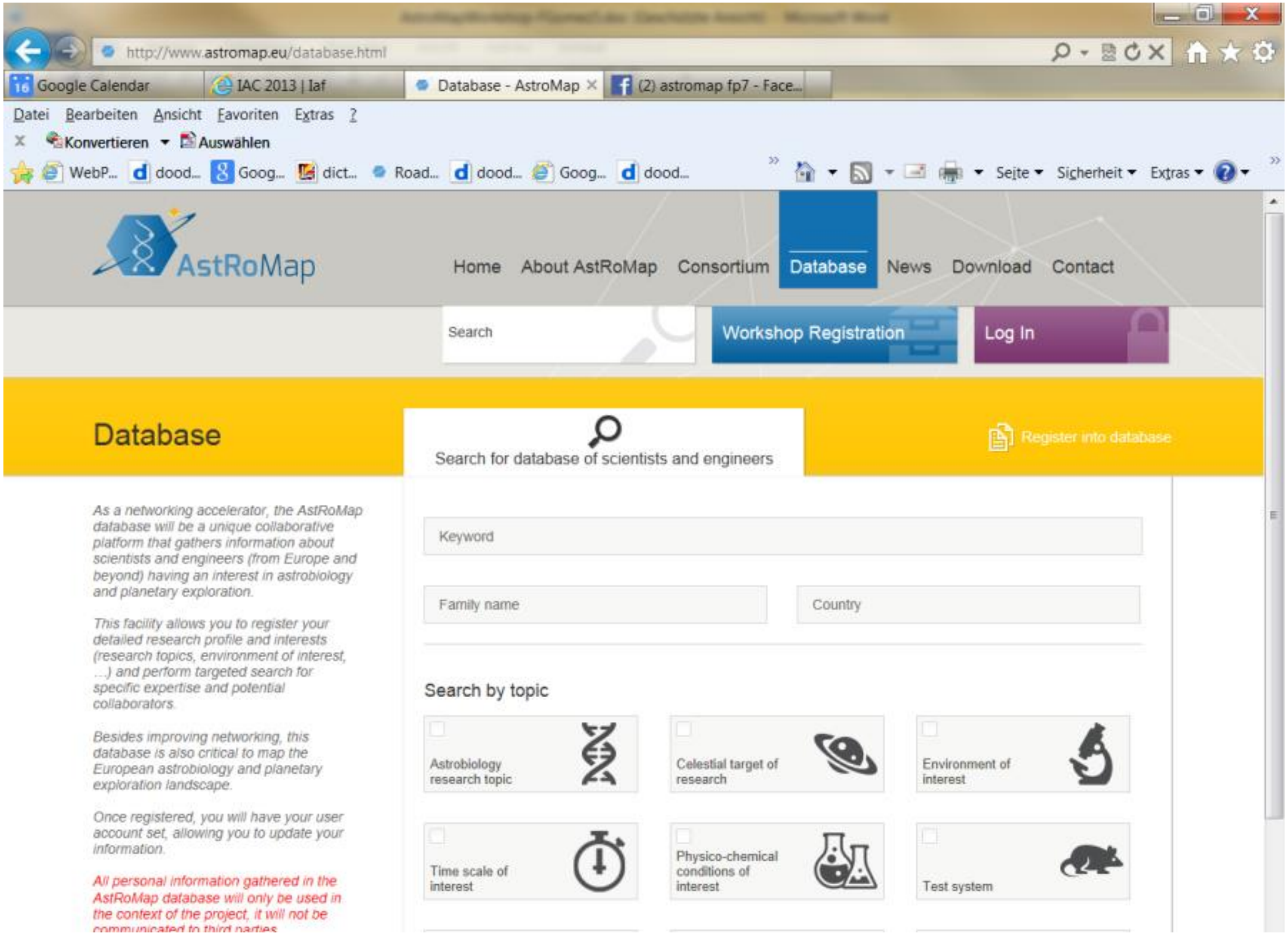
- **Map** scientific knowledge related to astrobiology in Europe
- **Identify the main astrobiology issues** to be addressed by Europe in the next decades in relation with space exploration
- Identify **potential mission concepts** that would allow addressing these issues
- Identify the **technology developments** required to enable these missions
- **Provide a prioritised roadmap** integrating science and technology activities as well as ground based approach

SEVENTH FRAMEWORK PROGRAMME

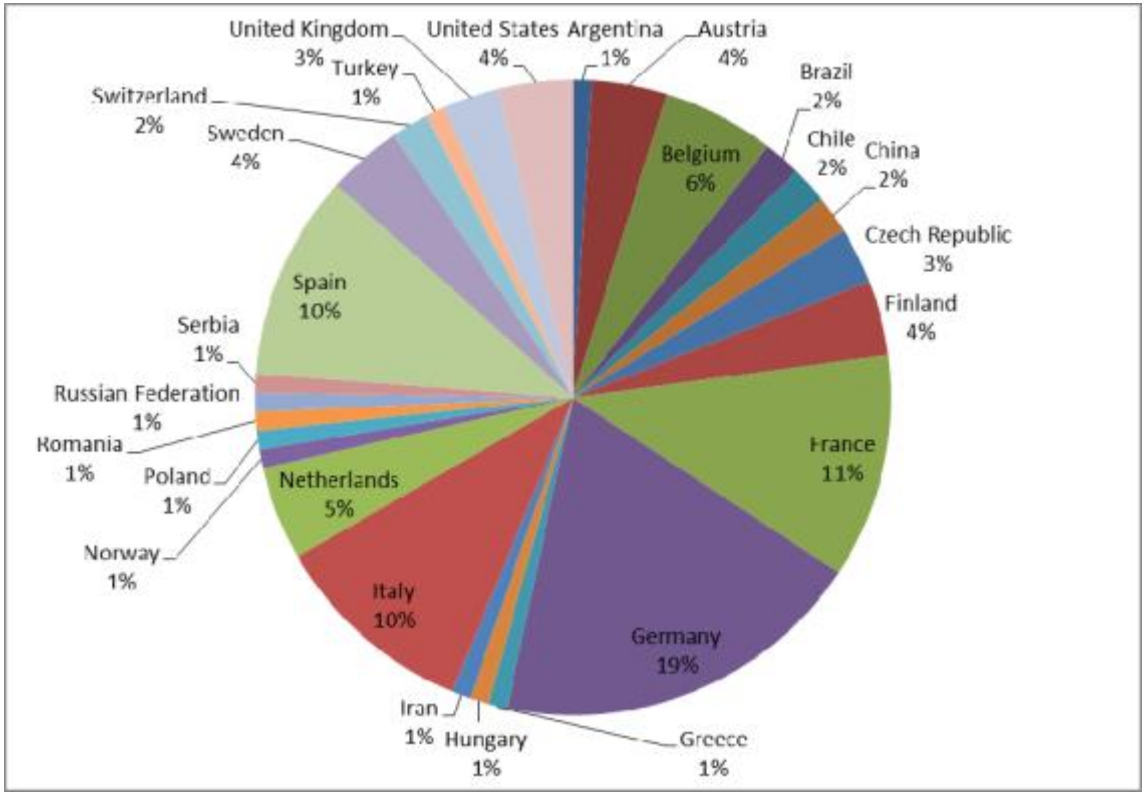
AstRoMap
European Astrobiology Roadmap

AstRoMap

Map scientific knowledge related to astrobiology in Europe

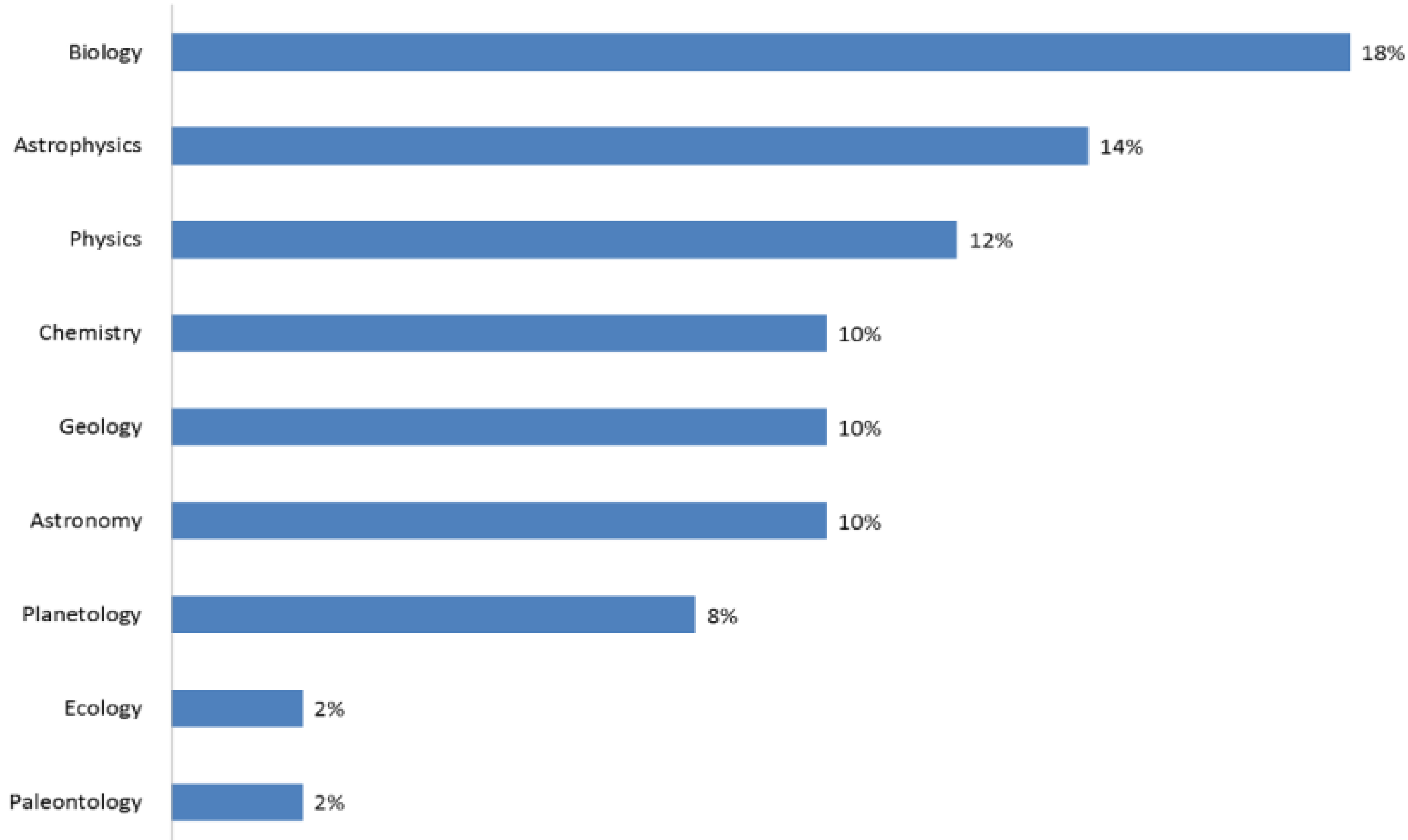


Geographical distribution



As of November 22, 2013, the AstRoMap database included the profiles of 105 European and international scientists

Scientific background



AstRoMap
European Astrobiology Roadmap

Résumé

- The astrobiology community in Europe is widely spread over all nations of the European Union and beyond
- The astrobiology community in Europe is multidisciplinary with a wide spectrum of scientific backgrounds.
- This multidisciplinary field of astrobiology is not sufficiently supported – if at all – by national or European governmental organizations.

Horneck, G., Rettberg, P., Walter, N., Gomez, F. (2015) European Landscape in Astrobiology, Results of the AstRoMap Consultation. Acta Astronaut. 110, 145-154, doi:10.1016/j.actaastro.2015.01.015

Provide a prioritised roadmap integrating science and technology activities as well as ground based approach

- **Four topical workshops organized in 2013-2014**

  (More than 50 participants)

  - **Origin of Solar System, the astrobiology point of view**
  - **Origin of organic compounds, steps to life**
  - **What are the physico-chemical boundary conditions for habitability?**
  - **What bio-signatures facilitate life detection?**
- **Each expert workshops was supported by a community consultation**
- **Two integrating workshops organized in 2014-2015 to substantiate and finalize the AstRoMap roadmap**

  (12 experts in the roadmap panel)

AstRoMap Report

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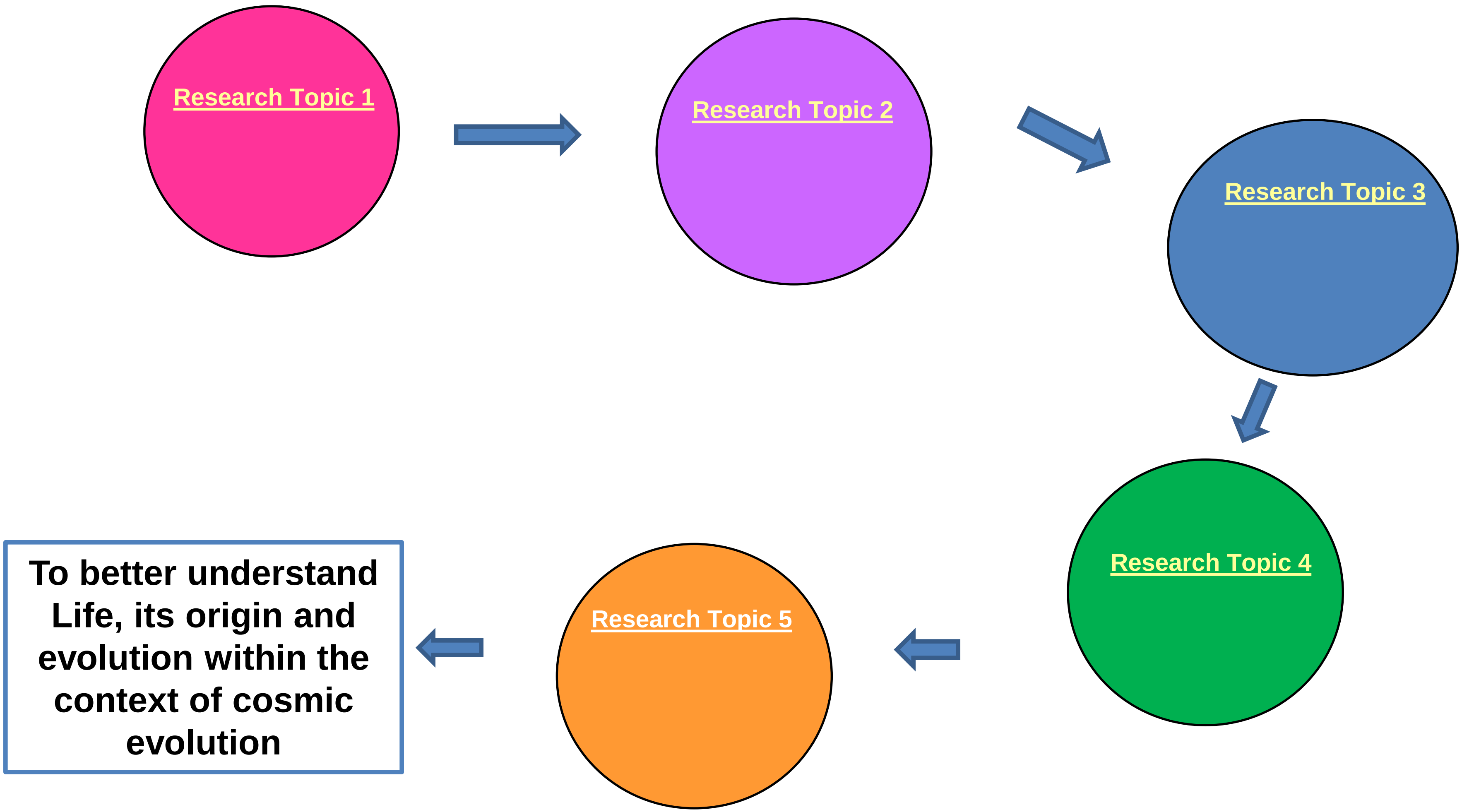
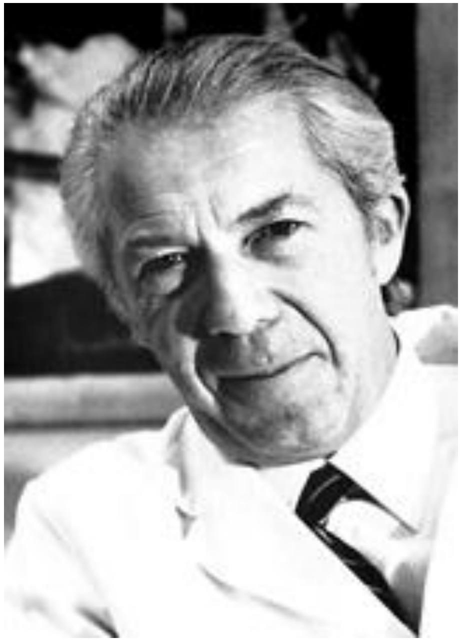
AstRoMap Roadmap



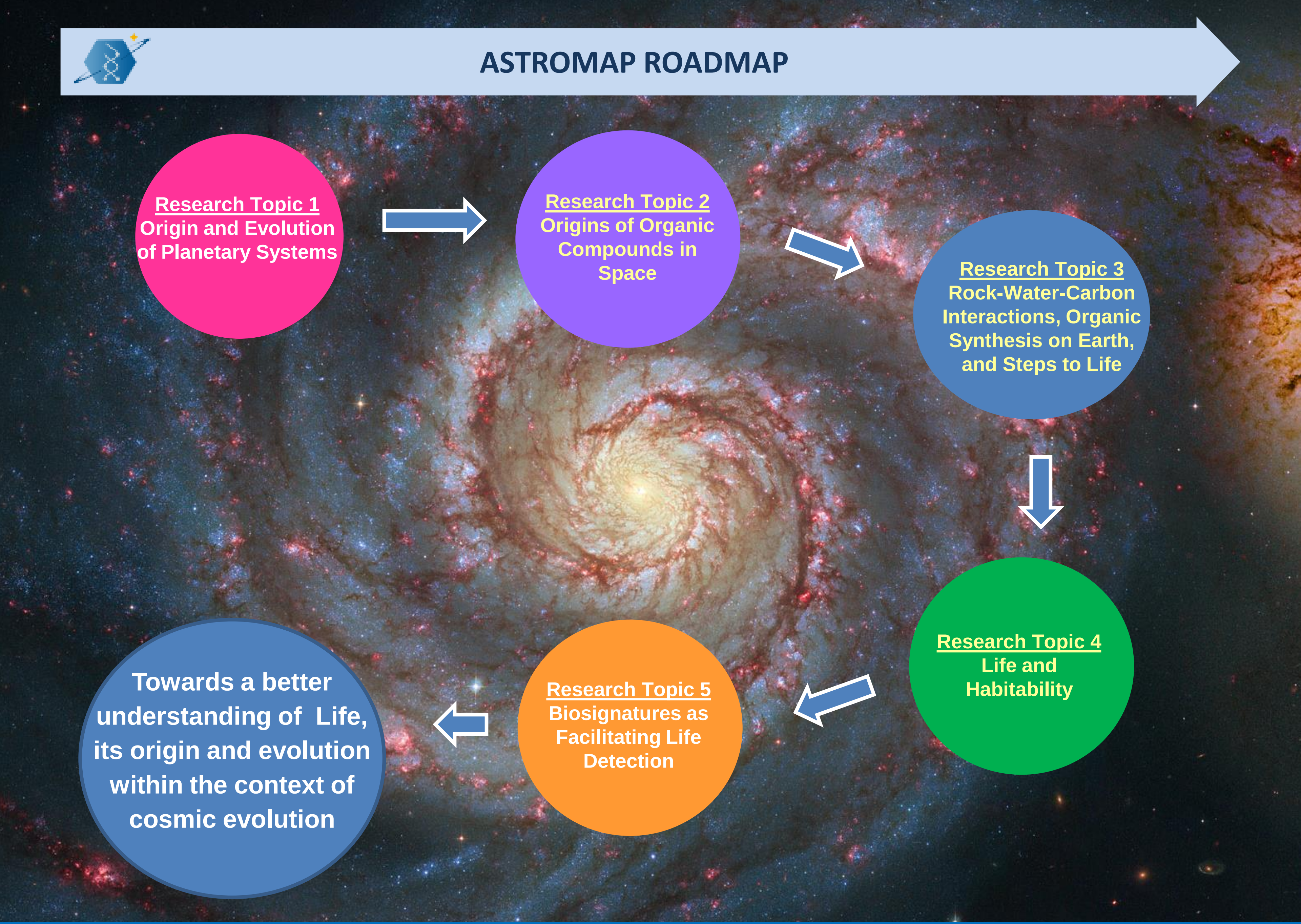
Life as a cosmic imperative

" Life emerges at a certain stage of
either cosmic or planetary evolution,
if the right environmental physical and
chemical requirements are provided "

Christian De Duve, 1996



*Christian De Duve (1917-2013)
Nobel Price (1974) for his work
on the structure and function of
organelles in biological cells*



Background picture Credit: S. Beckwith (STScI), Hubble Heritage Team, (STScI/AURA), ESA, NASA, Additional Processing: Robert Gendler
http://apod.nasa.gov/apod/ap080614.html

AstRoMap Roadmap

Key Objective 1
To assess the elemental and chemical picture of protoplanetary stellar disks

Key Objective 2
To better understand our Solar System: Planet formation, dynamical evolution and water/organics delivery to the Earth and to the other planets/satellites

Research Topic 1

Origin and Evolution of Planetary Systems

Key Objective 3
To better understand the diversity of exoplanetary systems and the development of habitable environments

AstRoMap

AstRoMap Roadmap

Research Topic 1
Origin and Evolution of Planetary Systems

Key Objective 1 To assess the elemental and chemical picture of protoplanetary stellar disks

Subobjective 1. To understand the metallicity of stars

Subobjective 2. To improve chemical models of protoplanetary disc formation and evolution

Sub-objective 3. To improve our understanding of the evolution of circumstellar discs, in relation to their host stars

Sub-objective 4. To determine the chemical history of key molecules (such as water, oxygen) in the evolution from molecular clouds to star-planet(s) system

Sub-objective 5. To interconnect chemistry with disc hydrodynamics and structure

AstRoMap Roadmap

Research Topic 1
Origin and Evolution of Planetary Systems

Key Objective 2 To better understand our Solar System: Planet formation, dynamical evolution and water/organics delivery to the Earth and to the other planets/satellites

Sub-objective 1. *To better understand the transition from planetesimals to planets and satellites (end to end)*

Sub-objective 2. *To better understand the dynamical evolution of the "young" Solar System*

Sub-objective 3. *To improve models on conditions for survival and/or generation of essential molecules during impacts*

Sub-objective 4. *To identify dynamical processes that can redistribute essential material throughout a system*

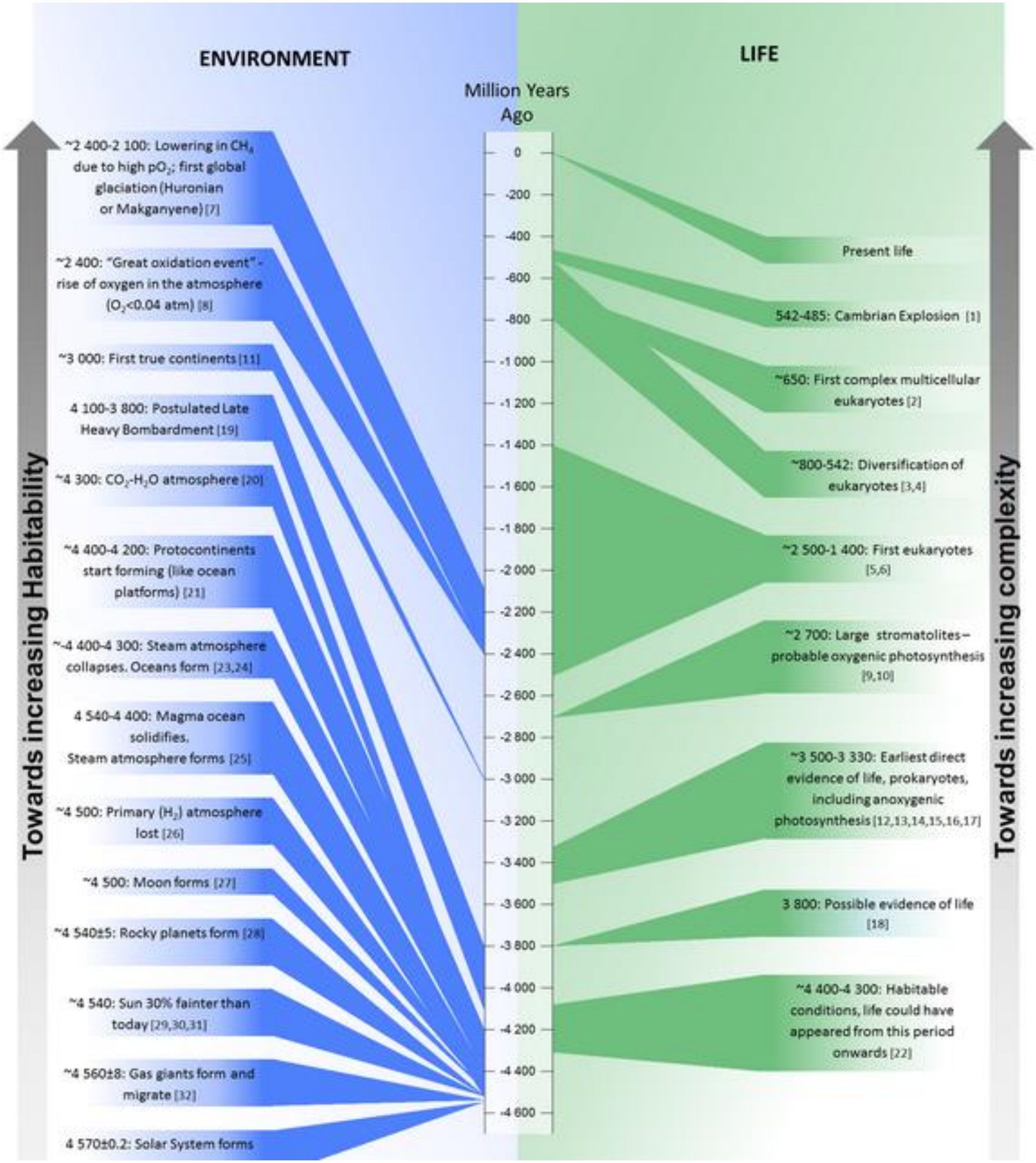
Sub-objective 5. *To better understand the effects of post-formation bombardment episodes on Earth and other planetary bodies generally assumed to have been important for the development of life*

Sub-objective 6. *To better define the timeline of the formation of the Solar System and water/organic delivery on Earth*

Sub-objective 7. *To interpret the temporal link between Solar System evolution and the rise of life on Earth*

AstRoMap

Research Topic 1
Origin and Evolution of Planetary Systems



To interpret the temporal link between Solar System evolution and the rise of life on Earth

Key Objective 3 To better understand the diversity of exoplanetary systems and the development of habitable environments

Sub-objective 1. *To better understand the dynamical mechanisms that lead to the observed diversity of exoplanet architecture, and assess how they affect habitability*

Sub-objective 2. *To identify biomarkers and promising methods of detection*

Sub-objective 3. *To find out how the study of exoplanets can help to fill the gaps in our understanding of the formation of our own Solar System*

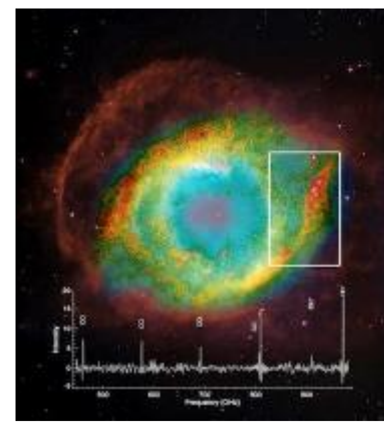
AstRoMap Roadmap

Research Topic 1
Origin and Evolution of Planetary Systems

Observations with telescopes

From ground: ALMA (ESO)
(Atacama Large Millimeter/submillimeter Array)
since 2011

From space:
Herschel (ESA)am L2 piont
(Infrared-Telescope:
from far-IR to submillimeter
wavelengths) Launch 2009



Detection of OH+ as precursor of water in dying stars

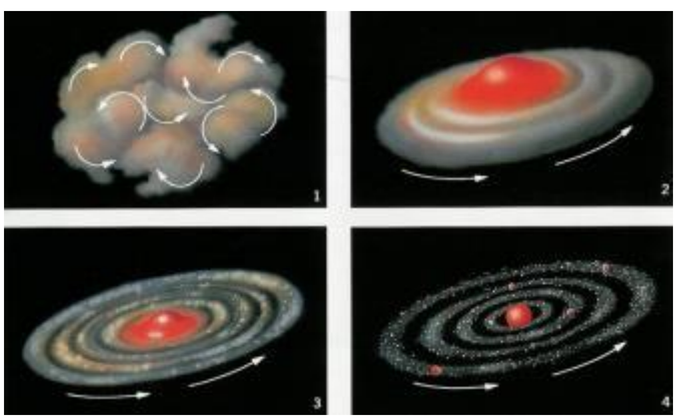
AstRoMap Roadmap

Research Topic 1
Origin and Evolution of Planetary Systems

Laboratory experiments

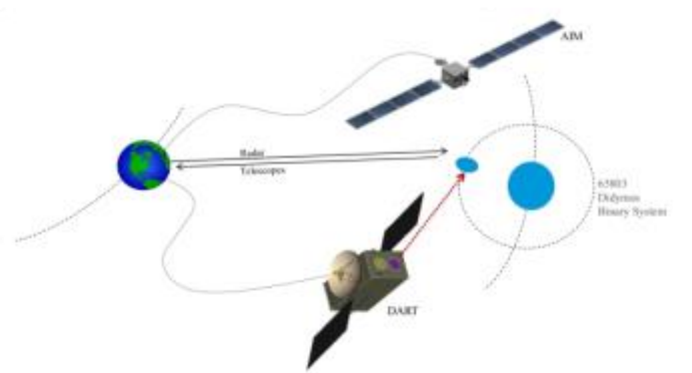
Hypervelocity -Impacts
(light gas gun (LGG) University Kent (UK)

Modelling



Credit: Monica Grady

Exploring the beginning of our Solar System



Asteroid Impact Mission (AIM) (ESA)
Launch 2020

AstRoMap Roadmap

Research Topic 1
Origin and Evolution of Planetary Systems

KO 1: To assess the elemental &chemical picture of protoplanetary stellar discs

Observations from ground
- ALMA, NOEMA, E-ELT
- PSN, complex molecules | PSN, complex molecules

Observations from space
- Herschel — Spectra, Model validation
- JWST, PLATO2.0 — PSN

Modelling
- 3D disc modelling

KO 2: To better understand our Solar System: Planet formation, dynamical evolution and water/organics delivery to the Earth and to the other planets/satellites

Laboratory studies
- Impact research facility (e.g. EMI, U Kent)
- Impact studies: Generation/survival of organics

Space missions
- AIM/AIDA — Asteroid impact
- Sample return & sample curation facility — Asteroid, comet, main belt transition objects

Modelling
- Robust theory of Solar System formation, Advanced formation models
- Timeline, Origin of water/organics on Earth

KO3: To better understand diversity of exoplanetary systems & habitable environments development

Space missions
- JWST, CHEOPS, PLATO 2.0,
- Specification of exoplanets, Candidate list of habitable exoplanets

Modelling
- Planet formation in diverse stellar environments
- Diversity of exosystems

Year: 2015 — 2025 — 2035

AstRoMap Roadmap

Key Objective 1
To promote our understanding of the diversity and the complexity of abiotic organics

Key Objective 2
To better understand the molecular evolution of abiotic organics present in Solar System objects, including the early Earth, under the combined role of several physical agents

Research Topic 2

Origins of Organic Compounds in Space

Key Objective 3
To understand the role of spontaneous inorganic (organic) self-organisation processes in molecular evolution

AstRoMap Roadmap

Research Topic 2
Origins of Organic Compounds in Space

Key Objective 1 . To promote our understanding of the diversity and the complexity of abiotic organics

Subobjective 1. To study the mechanisms for the formation of organics and their evolution under space conditions

Subobjective 2. To better understand the role of catalysts in the formation processes of organics

Key Objective 2. To better understand the molecular evolution of abiotic organics present in Solar System objects, including early Earth, under the combined role of physical agents such as thermal variations, high energy particles, photons, and solar wind irradiation

Key Objective 3. To understand the role of spontaneous inorganic (organic) self-organization processes in molecular evolution

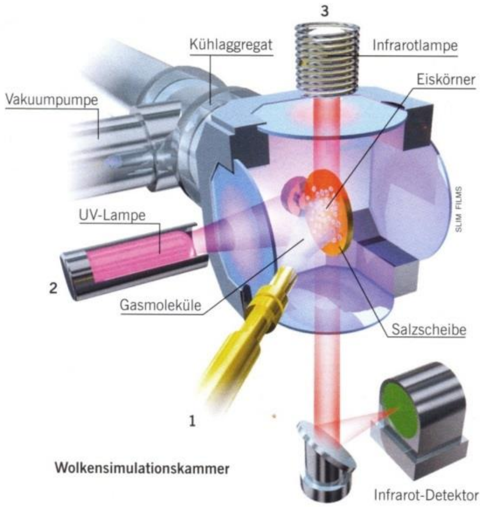
Sub-objective 1. To identify and structurally characterize novel spontaneous self-organized inorganic and organic systems

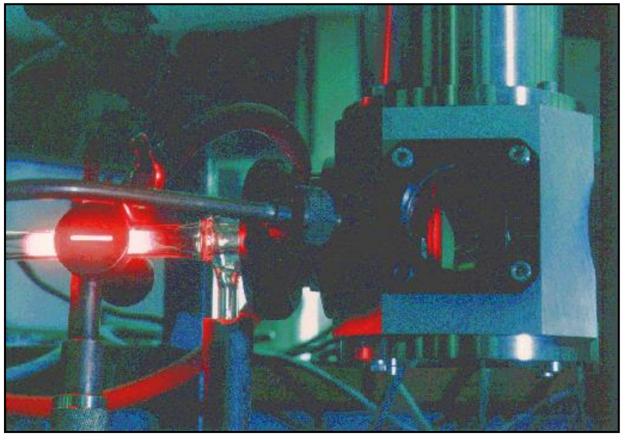
Sub-objective 2. To determine the mechanism of spontaneous self-organized systems and their role in the prebiotic synthesis of biomolecules

AstRoMap Roadmap

Research Topic 2
Origins of Organic Compounds in Space

Laboratory experiments

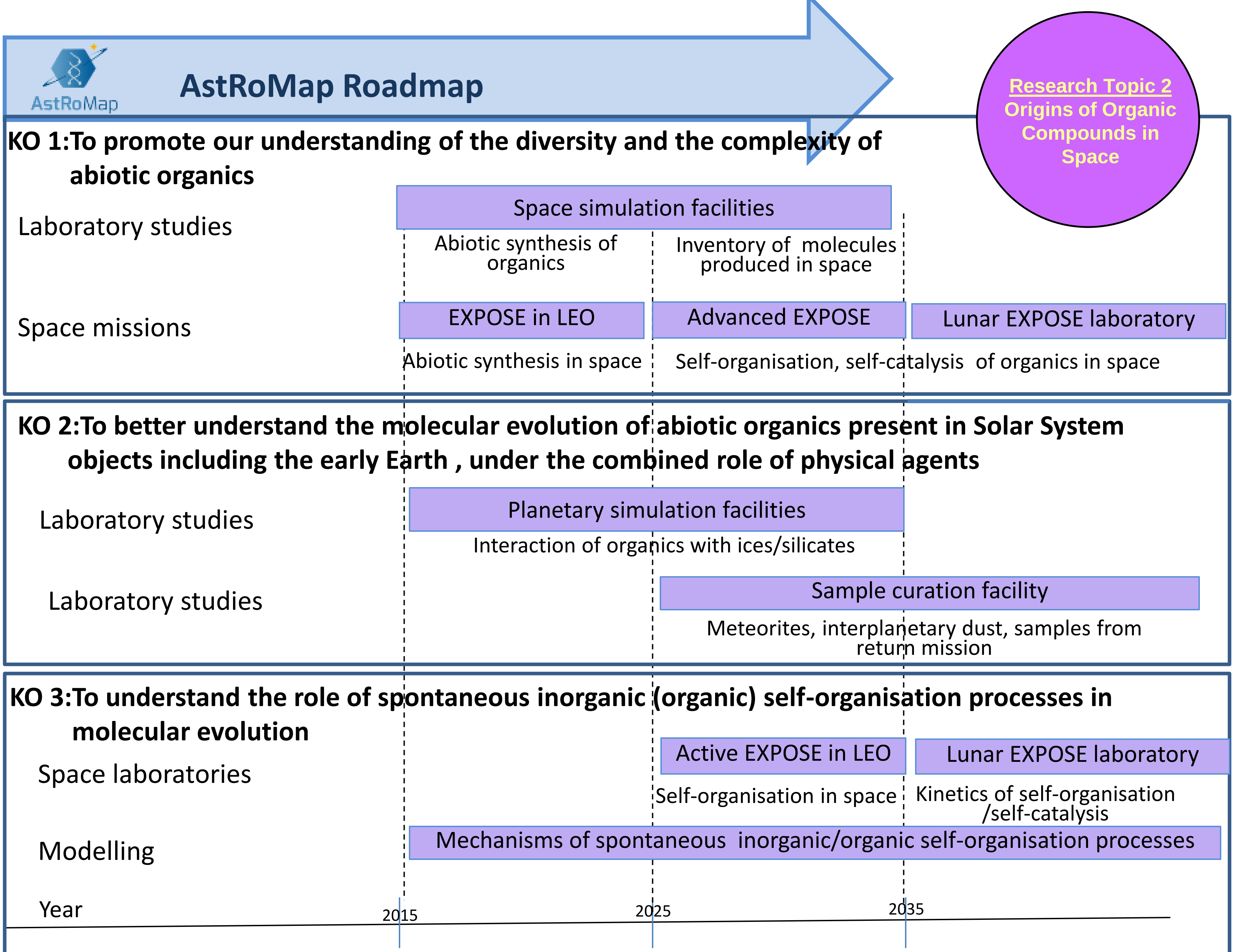


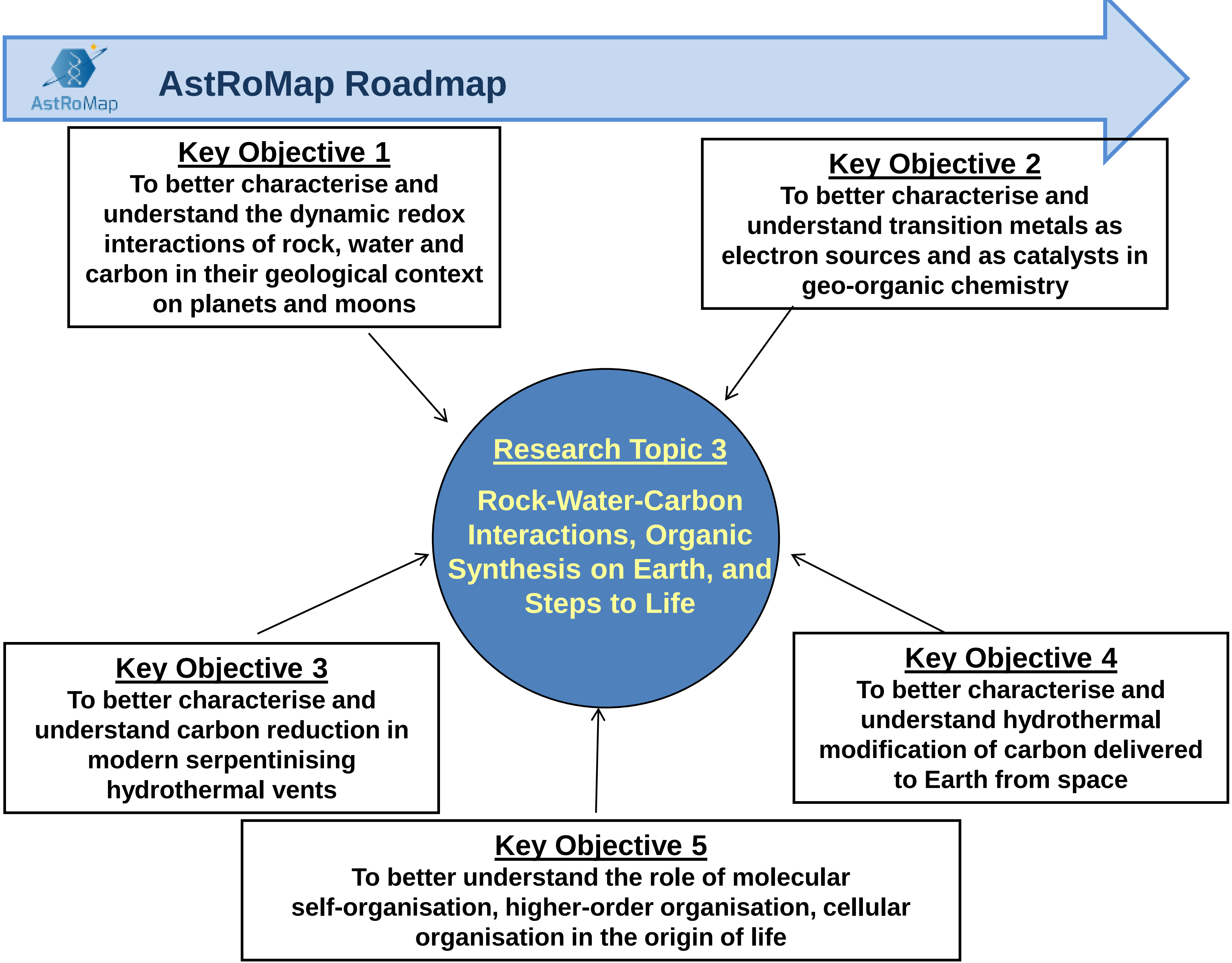


Space simulation chamber (Leiden Observatory, NL)

Space experiments

Exposure- and experimentation facility in Earth orbit (EXPOSE-E of ESA on ISS)


AstRoMap
AstRoMap Roadmap
Research Topic 2
Origins of Organic Compounds in Space
KO 1:To promote our understanding of the diversity and the complexity of abiotic organics
Laboratory studies
Space simulation facilities
Abiotic synthesis of organics
Inventory of molecules produced in space
Space missions
EXPOSE in LEO
Advanced EXPOSE
Lunar EXPOSE laboratory
Abiotic synthesis in space
Self-organisation, self-catalysis of organics in space
KO 2:To better understand the molecular evolution of abiotic organics present in Solar System objects including the early Earth , under the combined role of physical agents
Laboratory studies
Planetary simulation facilities
Interaction of organics with ices/silicates
Laboratory studies
Sample curation facility
Meteorites, interplanetary dust, samples from return mission
KO 3:To understand the role of spontaneous inorganic (organic) self-organisation processes in molecular evolution
Space laboratories
Active EXPOSE in LEO
Lunar EXPOSE laboratory
Self-organisation in space
Kinetics of self-organisation /self-catalysis
Modelling
Mechanisms of spontaneous inorganic/organic self-organisation processes
Year
2015
2025
2035


AstRoMap
AstRoMap Roadmap
Key Objective 1
To better characterise and understand the dynamic redox interactions of rock, water and carbon in their geological context on planets and moons
Key Objective 2
To better characterise and understand transition metals as electron sources and as catalysts in geo-organic chemistry
Research Topic 3
Rock-Water-Carbon Interactions, Organic Synthesis on Earth, and Steps to Life
Key Objective 3
To better characterise and understand carbon reduction in modern serpentinising hydrothermal vents
Key Objective 4
To better characterise and understand hydrothermal modification of carbon delivered to Earth from space
Key Objective 5
To better understand the role of molecular self-organisation, higher-order organisation, cellular organisation in the origin of life

AstRoMap Roadmap

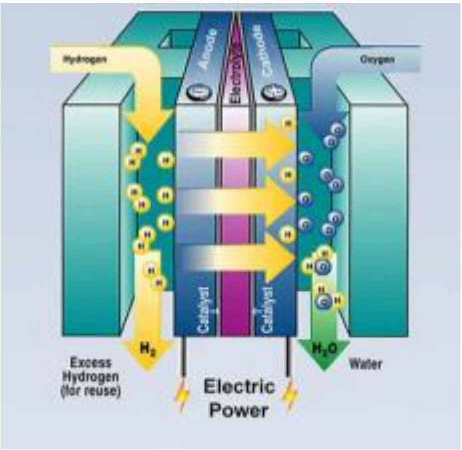
Research Topic 3
Rock-Water-Carbon Interactions, Organic Synthesis on Earth, and Steps to Life

Excursions

Black smoker
Water temperature up to 350°C

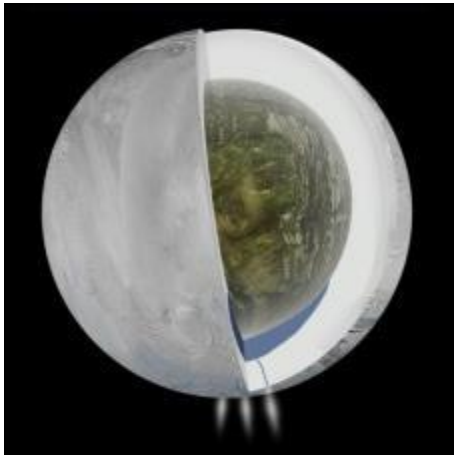
Lost city in Atlantik
Water temperature ~70°C

Laboratory experiments



Flow reactor

Space missions



Saturn‘s Moon Enceladus

AstRoMap Roadmap

Research Topic 3
Rock-Water-Carbon Interactions, Organic Synthesis on Earth, and Steps to Life

KO 1: To better characterise and understand the dynamic redox – interactions of rock, water and carbon in their geological context

Laboratory studies
- Vent simulation
- Cont. flow reactor

Serpentinisation-dependent CO_2 reduction

Space missions
- Enceladus fly-by
- Enceladus *in situ* study

Study of extraterrestrial hydrothermal systems

KO 2: To better characterise and understand transition metals as electron sources and as catalysts in geo-organic chemistry

Laboratory studies
- Vent simulation
- Cont. flow reactor

Electron sources and catalysts on early Earth

KO 3: To better understand carbon reduction in modern serpentinising hydrothermal vents

Field studies
- Serpentinisation sites (e.g Chimera, Lost city)

Serpentinisation-dependent CO_2 reduction

KO 4: To better understand hydrothermal modification of carbon delivered to Earth from space

Laboratory studies
- Vent simulation / cont. Flow reactor

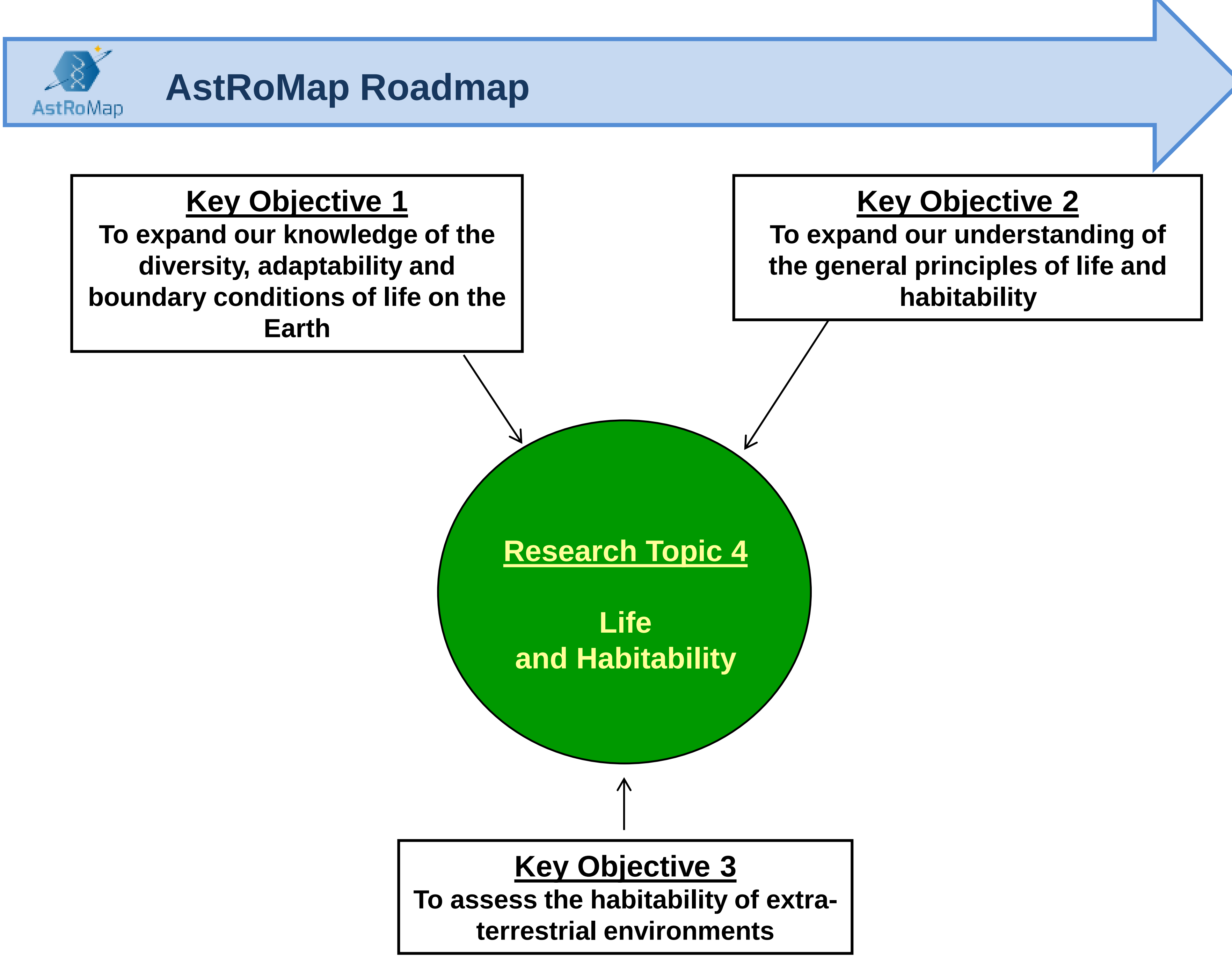
Processing of meteoritic carbon

KO 5: To better understand the role of molecular self-organisation, higher-order organisation, cellular organisation in the origin of life

Modelling
- Autocatalytic networks / stochastic replicators

Bridging the gap between complex organic molecules and replicating cells

Year: 2015 – 2025 – 2035


AstRoMap
AstRoMap Roadmap
Key Objective 1
To expand our knowledge of the diversity, adaptability and boundary conditions of life on the Earth
Key Objective 2
To expand our understanding of the general principles of life and habitability
Research Topic 4
Life and Habitability
Key Objective 3
To assess the habitability of extra-terrestrial environments

AstRoMap Roadmap

Research Topic 4
Life
and Habitability

Key Objective 1 . To expand our knowledge of the diversity, adaptability, and boundary conditions of life on Earth

Subobjective 1. To explore the diversity of life on the Earth

Subobjective 2. To explore biological interactions and systems ecology

Key Objective 2. To expand our understanding of the general principles of life and habitability

Key Objective 3. To assess the habitability of extra-terrestrial environments

Sub-objective 1. To determine and investigate terrestrial analogues for putative extra-terrestrial habitats

Sub-objective 2. To determine the limits for growth and survival of life under simulated planetary conditions, in the laboratory and in space

Sub-objective 3. To explore the potential of synthetic biology for future exploratory mission

Sub-objective 4. To provide basic data for planetary protection efforts

AstRoMap

AstRoMap Roadmap

Research Topic 4
Life and Habitability

Field campaigns

Southern-Viktoria Land, Antarctica

Mars-Analogue Sites: Rio Tinto, Spain

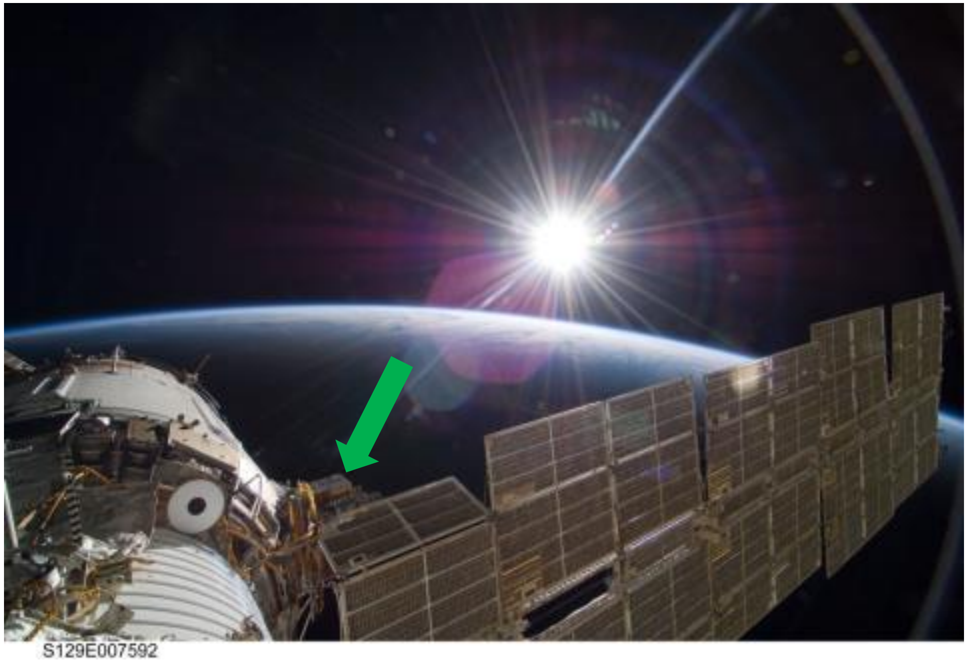
AstRoMap Roadmap

Research Topic 4
Life and Habitability

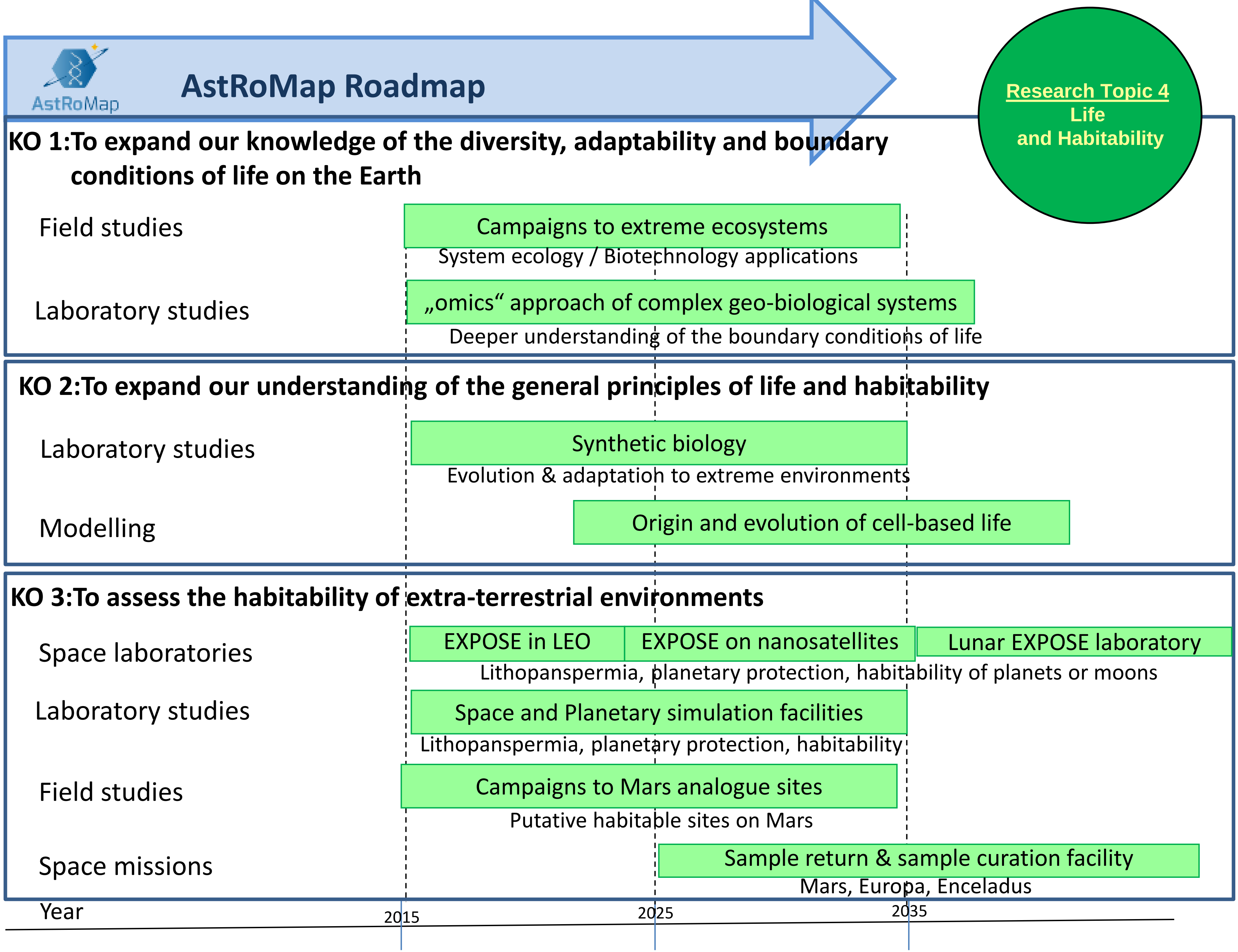
Laboratory experiments

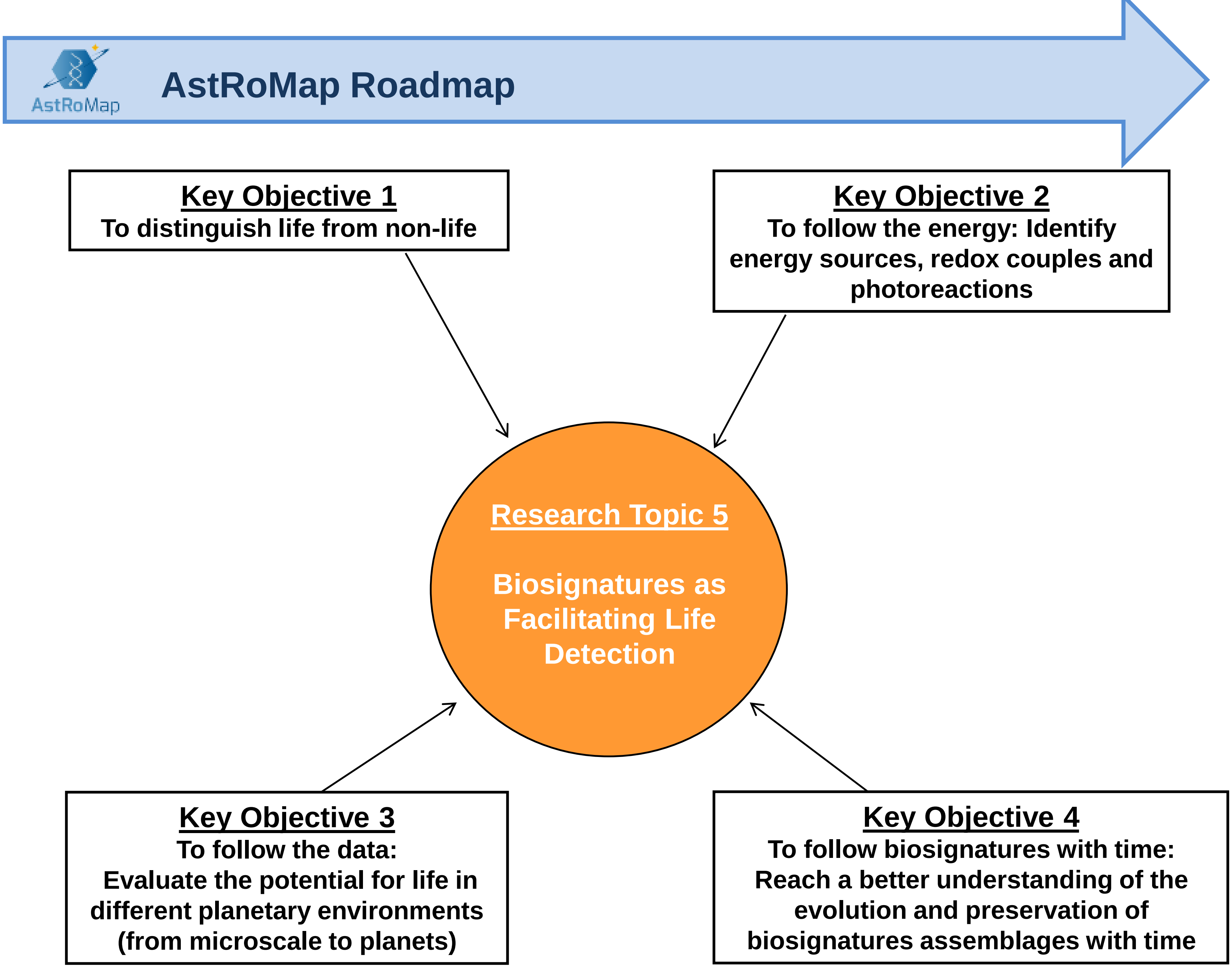
Simulation-chamber for the environmental conditions of space or planets (e.g. Mars) (PSI at DLR, Köln)

Space experiments



EXPOSE-R on ISS


AstRoMap
AstRoMap Roadmap
Research Topic 4
Life
and Habitability
KO 1:To expand our knowledge of the diversity, adaptability and boundary conditions of life on the Earth
Field studies
Campaigns to extreme ecosystems
System ecology / Biotechnology applications
Laboratory studies
„omics“ approach of complex geo-biological systems
Deeper understanding of the boundary conditions of life
KO 2:To expand our understanding of the general principles of life and habitability
Laboratory studies
Synthetic biology
Evolution & adaptation to extreme environments
Modelling
Origin and evolution of cell-based life
KO 3:To assess the habitability of extra-terrestrial environments
Space laboratories
EXPOSE in LEO
EXPOSE on nanosatellites
Lunar EXPOSE laboratory
Lithopanspermia, planetary protection, habitability of planets or moons
Laboratory studies
Space and Planetary simulation facilities
Lithopanspermia, planetary protection, habitability
Field studies
Campaigns to Mars analogue sites
Putative habitable sites on Mars
Space missions
Sample return & sample curation facility
Mars, Europa, Enceladus
Year
2015
2025
2035


AstRoMap
AstRoMap Roadmap
Key Objective 1
To distinguish life from non-life
Key Objective 2
To follow the energy: Identify energy sources, redox couples and photoreactions
Research Topic 5
Biosignatures as Facilitating Life Detection
Key Objective 3
To follow the data:
Evaluate the potential for life in different planetary environments (from microscale to planets)
Key Objective 4
To follow biosignatures with time:
Reach a better understanding of the evolution and preservation of biosignatures assemblages with time

AstRoMap Roadmap

Research Topic 5
Biosignatures as Facilitating Life Detection

Key Objective 1 To distinguish life from non-life

Subobjective 1. Biological context

Subobjective 2. Environmental context

Sub-objective 3. In situ *science*

Key Objective 2. To follow the energy: Identify energy sources, redox couples, and photoreactions

Sub-objective 1. Geological and mineralogical context

Sub-objective 2. Atmosphere context

Key Objective 3. To follow the data: Evaluate the potential for life in different planetary environments (from microscale to planets)

Sub-objective 1. Super-Earths – role of atmospheric composition

Sub-objective 2. Super-Earths orbiting cooler stars (M-dwarfs and K-dwarfs)

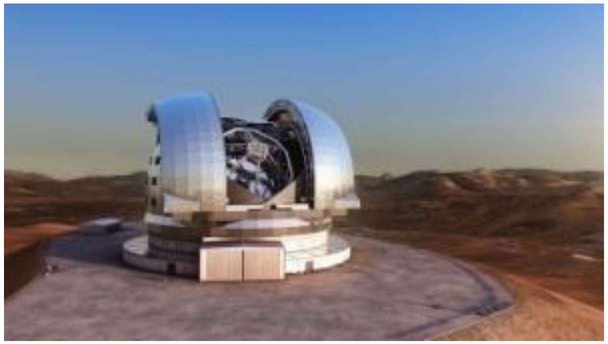
Sub-objective 3. Co-locate stratigraphy images with the spectral data

Key Objective 4. To follow biosignatures with time: Reach a better understanding of the evolution and preservation of biosignatures assemblages with time

AstRoMap Roadmap

Research Topic 5
Biosignatures as Facilitating Life Detection

Observations with telescopes



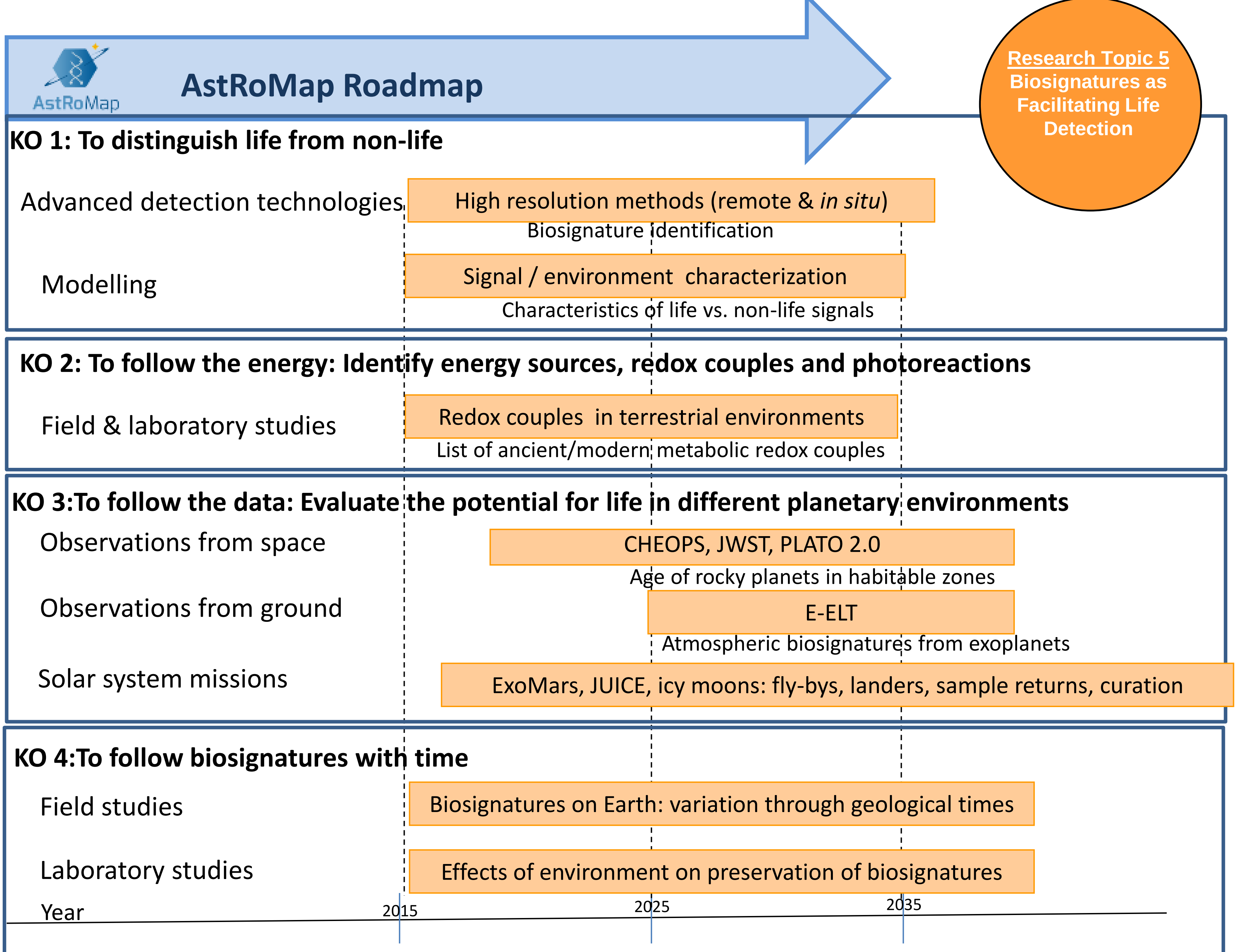
From ground:
E-ELT (ESO), Start 2024

From space:
PLATO 2.0 (ESA), Launch 2024

Space missions

ExoMars (ESA-Roscosmos)

JUICE (ESA)
Launch 2022



AstRoMap
AstRoMap Roadmap
Research Topic 5
Biosignatures as Facilitating Life Detection
KO 1: To distinguish life from non-life
Advanced detection technologies
High resolution methods (remote & in situ)
Biosignature identification
Modelling
Signal / environment characterization
Characteristics of life vs. non-life signals
KO 2: To follow the energy: Identify energy sources, redox couples and photoreactions
Field & laboratory studies
Redox couples in terrestrial environments
List of ancient/modern metabolic redox couples
KO 3:To follow the data: Evaluate the potential for life in different planetary environments
Observations from space
CHEOPS, JWST, PLATO 2.0
Age of rocky planets in habitable zones
Observations from ground
E-ELT
Atmospheric biosignatures from exoplanets
Solar system missions
ExoMars, JUICE, icy moons: fly-bys, landers, sample returns, curation
KO 4:To follow biosignatures with time
Field studies
Biosignatures on Earth: variation through geological times
Laboratory studies
Effects of environment on preservation of biosignatures
Year
2015
2025
2035

European Astrobiology Roadmap
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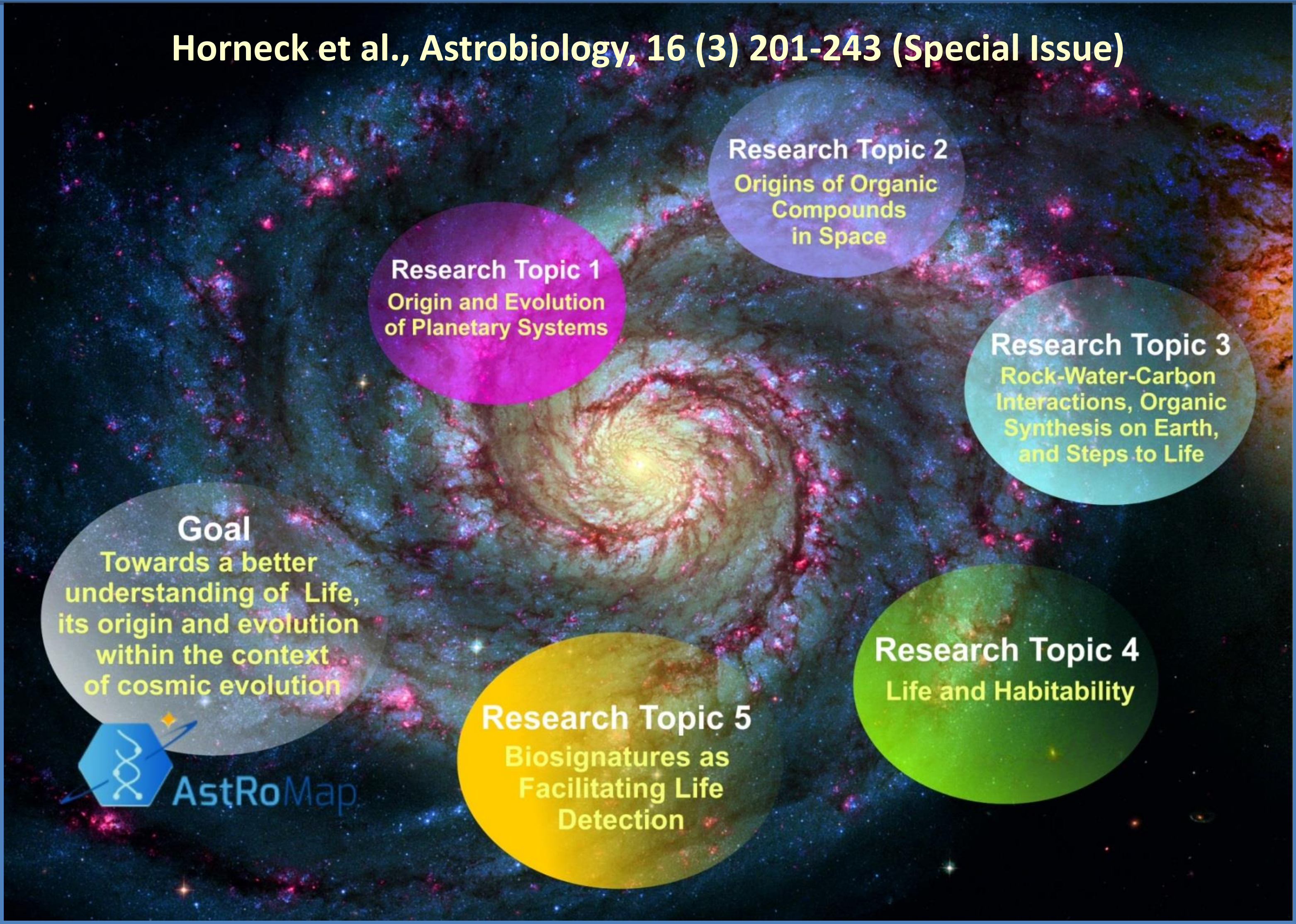

Background picture Credit: S. Beckwith (STScI), Hubble Heritage Team, (STScI/AURA), ESA, NASA, Additional Processing: Robert Gendler
http://apod.nasa.gov/apod/ap080614.html, Graphic design: Kerstin Kopp, DLR

AstRoMap Recommendations

- The AstRoMap Roadmap **should be adopted by the EU as challenge to enhance Europe's standing as an attractive partner** for international partnerships in space science and exploration.
- **The AstRoMap Roadmap should be realised** by supporting cross-disciplinary research groups along its five Research Topics
- This requires the **establishment of a pan-European astrobiology coordination platform or European virtual astrobiology institute** under the auspices of the EU, ESA or ESF.

AstRoMap Expectations

The AstRoMap Roadmap team is open for discussions with European and non-European organisations devoted to astrobiology

e.g. **NASA and its Astrobiology Strategy**

in order to foster international cooperation in this interdisciplinary field of astrobiology.

- Participants of the AstRoMap Topical Workshops – more than 50 experts:

Workshop on "Origin of organic compounds, steps to life "

- Cosmovici Cristiano (I); Danger Grégoire (F); Fox Stefan (D); Grenfell John-Lee (D); Guillemin Jean-Claude (F); Kee Terence P. (UK); Letho Harry (FIN); Letho Kirsi (FIN); Mason Nigel (UK); Ruiz-Mirazo Kepa (ES); Saladino Raffaele (I); Strasdeit Henry (D); Zaprudin Boris (FIN)

Workshop on “What are the physico-chemical boundary conditions for habitability?”

- Billi Daniela (I); Cockel Charles (UK); de Vera Jean-Pierre (D); Lee Natuschka M. (D); Leuko Stefan (D); Ori Gian Gabriele (I); Parro Victor (ES); Pearce David (UK); Prieto-Ballesteros Olga (ES); Tian Feng (CN)

Workshop on “What bio-signatures facilitate life detection?”

- Barbieri Roberto (I) ; FoucherFrédéric (F); Gómez-Elvira, Javier (ES); Grenfell Lee (D); Lepot Kevin (F); Leuko Stefan (D); Parro Victor (ES); Rodríguez Manfredi Jose Antonio (ES); Rull Fernando (ES); Tian Feng (CN)

Workshop on “Origin of the solar system, the astrobiology point of view”

- Billi Daniela (I); Famini Enrico (I); Macke Robert J. (I); Palomba Ernesto (I); Saladino Raffaele (I); Strazzulla Giovanni (I); Tsiganis Kleomenes (GR); Turrini Diego (I)

Participants of the AstRoMap integrating workshops – 12 experts with support from the AstRoMap Team:

- Grenfell Lee, DLR, Berlin (D), Harrison Jesse, Uni Edinburgh (UK), Lee Natuschka, Uni München (D), Leuko Stefan, DLR, Köln (D), Martin William, Uni Duesseldorf (D), Onofri Silvano, Uni Tuscia, Viterbo (I), Palumba Ernesto, INAF, Rom (I), Pilat-Lohningen Elke, Uni Wien (A), Rull Fernando, Uni Valladolid (ES), Saladino Raffaele, Uni Tuscia, Viterbo (I), Tsiganis Kleomenis, Uni Thessaloniki, (GR), Westall Frances, CNRS, Orleans (F)

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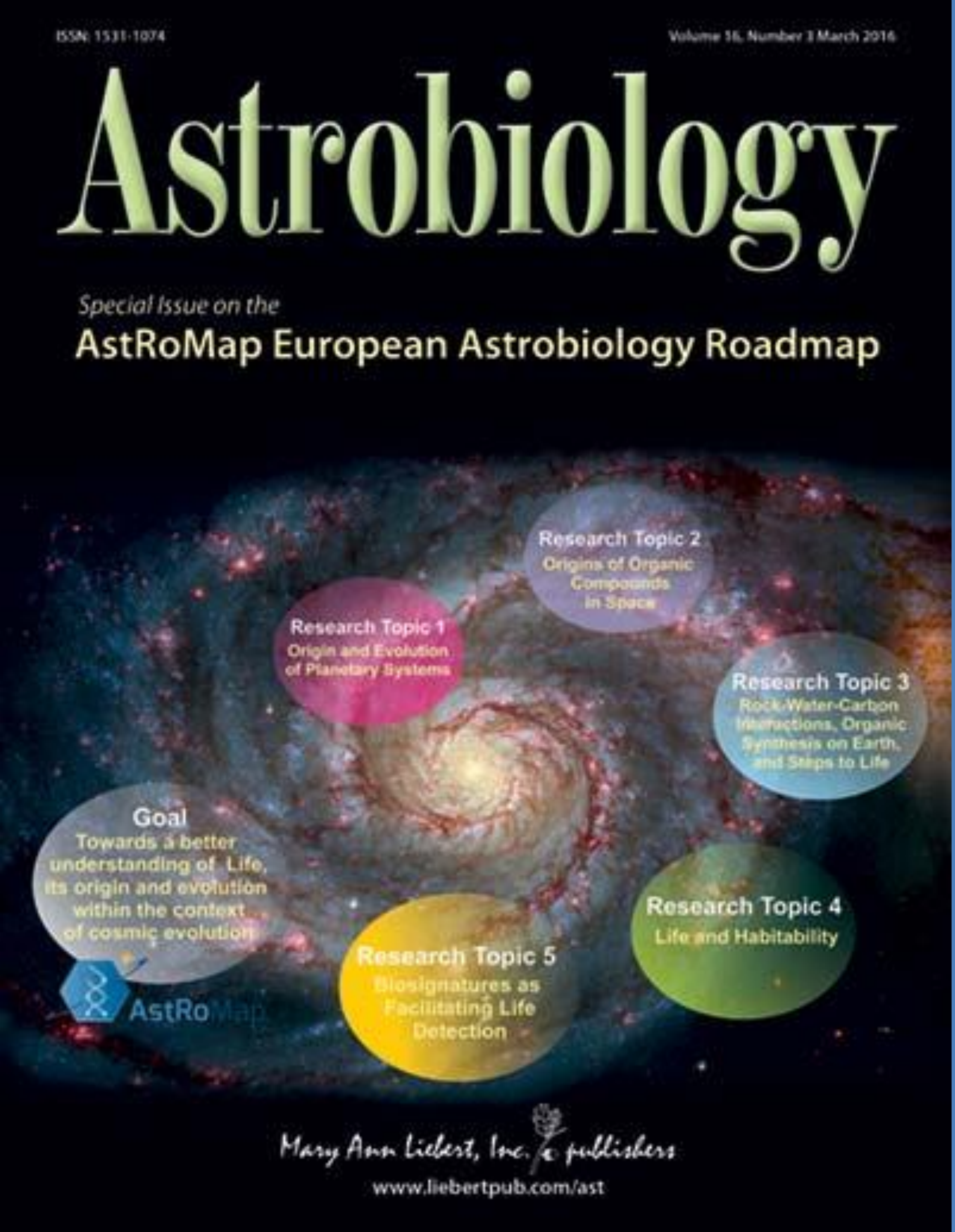

Horneck, G., Walter, N., Westall, F., Grenfell, J.L., Martin, W.F., Gomez, F., Leuko, S., Lee, N., Onofri, S., Tsiganis, K., Saladino, R., Pilat-Lohinger, E., Palomba, E., Harrison, J., Rull, F. Muller, C., Strazzulla, G., Brucato, J.R., Rettberg, P., Capria, M.T. (2016) AstRoMap European Astrobiology Roadmap. *Astrobiology,* 16, no 3 (Special Issue), 201-243 http://online.liebertpub.com/toc/ast/16/3