67th International Astronautical Congress (IAC), Guadalajara, Mexico, 26-30 September 2016.

IAC-16,A1,5,1,x33891

The European Astrobiology Roadmap – AstRoMap – Report from the project team

Gerda Horneck[a,f], Nicolas Walter[b]*, Felipe Gomez[c], Christian Muller[d], Stefan Leuko[a], Ernesto Palomba[e], Maria Teresa Capria[e], Petra Rettberg[a]

[a]DLR Institute of Aerospace Medicine, Deutsches Zentrum fur Luft- und Raumfahrt e.V. (DLR), Germany
[b]European Science Foundation, France, nwalter@esf.org
[c]Centro de Astrobiologia (INTA-CSIC), Spain
[d]Belgian User Support and Operation Centre, Belgium
[e]INAF-Institute for Space Astrophysics and Planetology (IAPS), Italy
[f]European Astrobiology Network Association (EANA), France
* Corresponding Author

Abstract

AstRoMap was supported by the European Commission Seventh Framework Programme (FP7) from 2012 to 2015. The main outcome of the AstRoMap project is its roadmap for European astrobiology, astrobiology being understood as the study of the origin, evolution and distribution of life in the context of cosmic evolution; this includes habitability in the Solar System and beyond. The AstRoMap roadmap was compiled by an interdisciplinary group of 18 authors, coordinated by the six AstRoMap partners and published in March 2016. The AstRoMap roadmap puts forward five core research topics that represent interrelated roadmap building blocks. Each research topic is broken down into several key objectives (and sub objectives) that put forward more detailed priority areas to be addressed in the future.

1. Introduction

Astrobiology is a broad research domain that encompasses wide areas of the scientific landscape. This maturing field cuts across many disciplines ranging from prebiotic chemistry to geomicrobiology, atmospheric sciences and astronomy, it also traverses a very wide spectrum of spatial and temporal scales. By nature, astrobiology touches on some of the more fundamental societal questions: What is life? How did it start? Is it present beyond the Earth? It is also relevant to more earthbound concerns such as the evolution of ecosystems under growing environmental pressure or the development of new and innovative (bio)technologies.

Between 2012 and 2015, the AstRoMap project, supported by the European Commission Seventh Framework Programme (FP7) addressed many facets of the European Astrobiology landscape, including the scientific community and programmatic aspects. Through workshops and consultations of the AstRoMap project resulted in the compilation of the first European roadmap for astrobiology. This contribution summarises the content of the AstRoMap roadmap [1].

2. The European Astrobiology Environment and Landscape in Europe

2.1 The European Space Agency and the European Union

Astrobiology (originally termed ‘exobiology’) was recognised by ESA as a future research area as early as 1996. Issued in 2005, the first theme of ESA’s Cosmic Vision programme (2015-2025) is strongly related to astrobiology: What are the conditions for planet formation and the emergence of life? As of mid-2015 six missions have been selected as part of the Cosmic vision programme and are in various stages of development. Half of those missions have relevance to astrobiology: two missions, CHEOPS (launch planned in 2017) and PLATO 2.0 (launch planned in 2024), are dedicated to the detection of exoplanets and one large mission, JUICE (launch planned in 2028), will explore the Jovian system flying by three of its icy moons (Callisto, Europa and Ganymede) before orbiting Jupiter. Astrobiology is also at the core of the ExoMars mission, the 2018 element will carry the ExoMars Rover with its suite of astrobiology experiments. Finally astrobiology is fully integrated in ESA’s optional European Life and Physical Sciences in Space programme (ELIPS). This programme allowed the development and use of the EXPOSE facility mounted on the outside of the ISS. This facility was deployed on three occasions and allowed the implementation of 20 experiments.

One of the main research and technology development programmes of the European Union is Horizon 2020 (2014-2020); it is expected that Horizon 2020 will dedicate approximately 1.4 B€ to space activities, 5% of which will target space sciences (most space-related call topics are targeted towards developing appropriate space technologies and services, and fostering European industry competitiveness).

2.2 The European Astrobiology Community

In addition to the programmatic arena, the European astrobiology community benefits from networking and interaction platforms at national, European and international levels. European networks include: the European Astrobiology Network Association (EANA), the COST Action ORIGINS (TD1308), EUROPLANET. At the core of these networks, the European astrobiology community is mostly composed of planetologists interested in habitability and life detection as well as of biologists interested in extremophiles on Earth but it also involves astrophysicists, physicists, chemists, geologists and astronomers.

Current pan-European Astrobiology initiatives are new and innovative. They support this community in a coherent manner at various career stages, and provide visibility and stability to its researchers. This demonstrates that the European astrobiology community has reached a level of maturity that enables both on-going projects to be built up as well as data from past projects to be exploited, and to engage in a better coordination and consolidation of astrobiological projects.

3. The AstRoMap European Astrobiology Roadmap

The AstRoMap European Astrobiology Roadmap is structured around five core research topics that represent interrelated roadmap building blocks. Each research topic is broken down into several key objectives (and sub-objectives) that put forward more detailed priority areas to be addressed in the future.

3.1 Research Topic 1: Origin and Evolution of Planetary Systems

Our Solar System is the planetary system that is best-known to us and so far it is the only sys-tem known to host life. A wealth of data, collected over many decades by observations, space missions, field and laboratory studies, has been used to formulate our ever-evolving theories of how the Earth, the other planets and their satellites formed and how the system has dynamically evolved towards its current state. In the context of astrobiology, understanding the origin of water and other material, essential for life, on Earth and other, possibly habitable environments in the Solar System, is of profound importance.

European astronomers take a leading role in development of dynamical models to simulate the evolution of planetary systems and Europe has been a leader in numerous fields of exoplanet research and many world-renowned experts on observations and theory of planetary science work for European institutes, performing high-quality research.

The AstRoMap roadmap identifies for this research topic three key scientific objectives

- Key Objective 1.1. To assess the elemental and chemical picture of protoplanetary stellar discs
- Key Objective 1.2. To better understand our Solar System: planet formation, dynamical evolution and water/organics delivery to the Earth and to the other planets/satellites
- Key Objective 1.3. To better understand the diversity of exoplanetary systems and the development of habitable environments

3.2 Research Topic 2: Origins of Organic Compounds in Space

Almost two hundred organic molecules have been detected as gaseous species in space. They are formed in cold molecular clouds and in the early phases of star formation. Gas phase chemistry cannot explain the abundances observed for most of them. It is therefore thought that most of them form on cold dust grains on which atoms and molecules accrete to form icy mantles. As demonstrated by a large number of laboratory studies (e.g. [2]), surface reactions and/or energetic processing (by UV-photons, electrons, atoms and ions) induce the formation of a solid complex organic refractory material (often referred to as ‘organic residue’) and of a plethora of molecules that, once released by thermal (e.g., around a forming star) or non-thermal (e.g., by sputtering in shocks) processes, are observed in the gas phase.

Europe plays a leading role in many relevant sub-fields. This is due to the coordinated efforts of many groups across Europe. As an example it is relevant to outline the role played by the European COST actions that have been and are very important to promote collaborations between European groups with different backgrounds

The AstRoMap roadmap identifies for this research topic three key scientific objectives and four sub-objectives related to this research topic.

- Key Objective 2.1. To promote our understanding of the diversity and the complexity of abiotic organics
- Key Objective 2.2. 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 such as thermal variations, high energy particles, photons and solar wind irradiation

- Key Objective 2.3. To understand the role of spontaneous inorganic (organic) self-organisation processes in molecular evolution

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

Geology and geochemistry provide the boundary conditions for our understanding of life on Earth — the best studied planet so far and an example for more distant systems, central to this understanding are rock-water-carbon interactions between carbon and the environment. Rock-water-carbon interactions dissipate energy at a planetary level. At a microscopic level, the energy produced by these interactions is dissipated by microbial metabolisms. Thus, the ‘rocks’ in microbial cells are represented by catalytic Fe-Ni-S clusters in enzymes of the core carbon and energy metabolism [3,4]. On the planetary scale, on metal-rich planets such as the Earth, the main process of energy dissipation is serpentinisation during which water circulates through hydrothermal systems and chemically reacts with rocks [5].

One of Europe's greatest strengths in this general field has been plurality of views and the close interactions between biologists and geologists. It also has a high concentration of expertise in the following areas, which are of pivotal importance for achieving progress on these objectives: Early Earth geological and geochemical settings; the nature and habitat of early life; redox disequilibria; serpentinising systems in nature and in the laboratory simulations; anaerobic autotrophs and how they generate reduced iron from H2 (electron bifurcation); autotrophic origins, hydrothermal vents, bioenergetics of anaerobic microbes; theory and principles of higher order self-organisation.

The AstRoMap roadmap identifies for this research topic five key scientific objectives related to this research topic.

- Key Objective 3.1. To better characterise and understand the dynamic redox interactions of rock, water and carbon in their geological context on planets and moons
- Key Objective 3.2. To better characterise and understand transition metals as electron sources and as catalysts in geo-organic chemistry
- Key Objective 3.3. To better characterise and understand carbon reduction in modern serpentinising hydrothermal vents
- Key Objective 3.4. To better characterise and understand hydrothermal modification of carbon delivered to Earth from space
- Key Objective 3.5. To better understand the role of molecular self-organisation, higher-order organisation, cellular organisation in the origin of life

3.4 Research Topic 4: Life and Habitability

Since their emergence, prokaryotic microorganisms continued to shape the Earth's biosphere during the first nearly 2 billion years of life’s history, before the first unicellular eukaryotes (cells with nuclei, flexible membranes and cytoskeletons) appeared [6]. Microbial evolution occurred and continues to take place under a vast variety of conditions that range from anoxic to oxic, hot to cold temperatures, low to high pH, free-living to symbiotic, etc. [7,8]. As a result of this supremacy of the microbial world, microorganisms defied natural catastrophes and never became extinct [9]. Parallel to research into (extreme) ecosystems on our planet, space exploration has paved the way for studying presumably habitable extraterrestrial environments [10]. However, efforts to characterise the habitability of these environments or even to search for indigenous life have encountered several challenges, including abiotic artefacts, technological and methodological limitations, and a lack of sufficient knowledge.

Europe has a large and diverse scientific community in astrobiology due to different cultures and countries. Experts in different fields are actively studying diverse aspects of extreme environments, spanning disciplines such as astronomy, biology, chemistry, geology, physics, medicine, space technology and biotechnology. There is strong expertise within several European laboratories in organising large scale expeditions, especially to places analogue to putative habitable extraterrestrial environments as well as in sampling, analysis and evaluation of probes from those extreme environments.

The AstRoMap roadmap identifies for this research topic three key scientific objectives and six sub-objectives related to this research topic.

- Key Objective 4.1. To expand our knowledge of the diversity, adaptability and boundary conditions of life on the Earth
- Key Objective 4.2. To expand our understanding of the general principles of life and habitability
- Key Objective 4.3. To assess the habitability of extra-terrestrial environments

3.5 Research Topic 5: Biosignatures as Facilitating Life Detection

The signatures of life (biosignatures) are extremely diverse and may be related either to living organisms or to the (fossilised) remains of extinct organisms. They comprise for example disequilibria (e.g. in redox conditions or in the thermodynamical state of the system), a pronounced chiral signature of the organic molecules used by life or characteristic spectral signatures. A challenging issue related to biosignatures is that they can occur over a wide range of spatial and timescales - with further modifications due to contextual conditions. On the microbial scale, there has been much study on biosignatures related to investigation of the traces of life on Earth through geological ages. On the planetary scale, the last ten years have seen an enormous expansion in modelling studies which focus on atmospheric biosignatures. Two central goals in biosignature research are (i) to distinguish true life signatures from abiotic ‘false friends’ which merely mimic life (‘false positives’); and (ii) to avoid situations where real biosignatures are overlooked (‘false negatives’) because their signals may be weak or masked, for instance, by a thick layer of cloud.

Europe already has the expertise in different disciplines (chemistry, geology, prebiotic chemistry, biology, etc.) and laboratories for the required studies to be carried out. Present and planned European missions in the Solar System have and will expand our knowledge of habitability in an astrobiological context. Europe also features state-of-the-art research centres for numerical modelling – both in an atmospheric and in a wet chemistry context. There also exist in Europe very well established teams working on the geological/geochemical context of energy for life. Further, Europe already has key expertise that can seed understanding of biosignature assemblages through geological time and during the evolution of life, as well as for experimentally testing biosignature preservation.

The AstRoMap roadmap identifies for this research topic four key scientific objectives and eight sub-objectives related to this research topic.

- Key Objective 5.1. To distinguish life from non-life
- Key Objective 5.2. To follow the energy: Identify energy sources, redox couples and photoreactions
- Key Objective 5.3. To follow the data: Evaluate the potential for life in different planetary environments (from microscale to planets)
- Key Objective 5.4. To follow biosignatures with time: Reach a better understanding of the evolution and preservation of biosignatures assemblages with time

4. Towards a better coordination of astrobiology research in Europe – The need for a pan-European platform

Throughout the AstRoMap project, the need for a stable pan-European astrobiology programmatic platform (possibly virtual) was expressed without ambiguity by the community. Such a platform, would serve and allow progress to be made on all the scientific objectives presented in this roadmap and would definitely be a strong asset for the European astrobiology community. This platform should among other things, encourage and capitalise on multidisciplinary research and projects, crossing diverse space sciences and/or Earth sciences disciplines; allow a rational, possibly prioritised, access to relevant research infrastructures; allow the implementation of (and mobilise around) a prioritised research plan, taking into consideration the strengths and expertise available in different countries, and allowing them to be further improved and shared; and catalyse and facilitate undergraduate and graduate education, help with the development of PhD programmes and postdoctoral opportunities.

It seems critical that heads of main groups, laboratories and institutes are consulted, or organise themselves in order to define the baseline specifications and functions of a European platform for astrobiology. In this context, it is strongly recommended to look at the model applied by the NASA Astrobiology (virtual) Institute, as this efficient, flexible mechanism has been active since 1998 and has therefore capitalised a lot of experience.

There is no doubt that the establishment of a well-designed and managed European Astrobiology Platform (or Institute) would catalyse tremendous scientific achievements in the field while streamlining and optimising the use of funding and infrastructure. It is strongly recommended that steps are taken towards the definition and implementation of such a concept.

Acknowledgements

AstRoMap was supported by European Community’s Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n° 313102

References

[1] G. Horneck, N. Walter, Westall Frances, JL. Grenfell, W.F. Martin, F. Gomez, S. Leuko, N. Lee, S. Onofri, K. Tsiganis, R. Saladino, E. Pilat-Lohinger, E. Palomba, J. Harrison, F. Rull, C. Muller, G. Strazzulla, J.R. Brucato, P. Rettberg, M.T. Capria, AstRoMap European Astrobiology Roadmap, Astrobiology, 16(3) (2016) 201-243

[2] M.A Allodi, R.A Baragiola, G.A Baratta, M.A Barucci, G.A Blake, J.R. Brucato, C. Contreras, S.H Cuylle, P. Boduch, D. Fulvio, M.S Gudipati, S. Ioppolo, Z. Kaňuchová, A. Lignell, H. Linnartz, M.E. Palumbo, U. Raut, H. Rothard, F. Salama, E.V. Savchenko, E. Sciamma-O'Brien, G. Strazzulla, Complementary and Emerging Techniques for Astrophysical Ices Processed in the Laboratory. Space Sci. Rev. 180 (2013) 101-175.

[3] M.J. Russell, A.J. Hall, The emergence of life from iron monosulphide bubbles at a submarine

hydrothermal redox and pH front. J. Geol. Soc. Lond. 154 (1997) 377–402

[4] G. Wächtershäuser, From volcanic origins of chemoautotrophic life to Bacteria, Ar-chaea and Eukarya. Phil. Trans. R. Soc. Lond. B. 361 (2006) 1787–1806

[5] E.L. Shock, T.M. McCollom, M.D. Schulte, The emergence of metabolism from within hydrothermal systems. In: J. Wiegel, M.W.W. Adams (Eds), Thermophiles: The Keys to Molecular Evolution and the Origin of Life. London: Taylor & Francis. p 59–76 (1998)

[6] E.J. Javaux, The early eukaryotic fossil record. Adv Exp Med Biol 607 (2007) 1–19

[7] J.K. Kristjánsson, G.O. Hreggvidsson, Ecology and habitats of extremophiles. World J. Microb. Biot. 11 (1995) 17–25.

[8] C. v. Bakermans, (Ed.) Microbial Evolution under Extreme Conditions. Walter de Gruyter GmbH., Berlin (2015).

[9] C.S. Cockell, Impossible Extinction, Natural Catastrophes and the Supremacy of the Microbial World. Cambridge University Press, Cambridge, UK (2003).

[10] H. Lammer, J.H. Bredehöft, A. Coustenis, M.L. Khodachenko, L. Kaltenegger, O. Grasset, D. Prieur, F. Raulin, P. Ehrenfreund, M. Yamauchi, J.-E. Wahlund, J.-M. Grießmeier, G. Stangl, C.S. Cockell, Kulikov, N. Yu, J.L. Grenfell, H. Rauer, H., What makes a planet habitable? Astron. Astrophys. Rev. 17 (2009) 181–249