

European Cooperation in the field of Scientific and Technical Research - COST - Brussels, 22 November 2013

COST 081/13

MEMORANDUM OF UNDERSTANDING

Subject:

Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TD1308: Origins and evolution of life on Earth and in the Universe (ORIGINS)

Delegations will find attached the Memorandum of Understanding for COST Action TD1308 as approved by the COST Committee of Senior Officials (CSO) at its 188th meeting on 14 November 2013.

COST 081/13

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MEMORANDUM OF UNDERSTANDING For the implementation of a European Concerted Research Action designated as

COST Action TD1308 Origins and evolution of life on Earth and in the Universe (ORIGINS)

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

- The Action will be carried out in accordance with the provisions of document COST 4114/13
 "COST Action Management" and document COST 4112/13 "Rules for Participation in and
 Implementation of COST Activities", or in any new document amending or replacing them,
 the contents of which the Parties are fully aware of.
- 2. The main objective of the Action is to address, using an interdisciplinary approach, three great questions about the origin, evolution and distribution of life: a) where, when and how did life emerge and evolve on Earth? b) what are the conditions under which life can exist? c) does life exist elsewhere in the Universe and, *if it does*, how can it be detected and identified?
- 3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 72 million in 2013 prices.
- 4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.
- 5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of section 2. *Changes to a COST Action* in the document COST 4114/13.

GENERAL FEATURES

Initial Idea:

Where, when and how did life appear on Earth? Has life developed elsewhere in the Universe? These fundamental questions have fascinated humanity since antiquity.

However, it is only now that results from recent solar system and exoplanets space missions (e.g. Mars Science Laboratory, Cassini-Huygens, Curiosity, CoRot, Kepler, Rosetta, etc.) have provided the opportunity for an integrated research programme that can answer, at least partly, these crucial questions.

Such a programme necessitates a transdisciplinary approach involving:

- *Astronomers* investigating the formation and evolution of stellar systems hosting potentially habitable planets,
- *Astrochemists* studying the formation of complex molecules of prebiotic interest in extraterrestrial environments,
- *Planetologists* investigating the habitability of planets and their moons,
- *Space scientists and engineers* preparing missions to solar system planets and developing technology for remote sensing of biomarkers on exoplanets,
- Geologists studying how the early Earth formed and evolved into a habitable planet,
- *Chemists* studying the transition from abiotic organic chemistry to biochemistry,
- *Paleontologists* investigating the first traces of life,
- *Biologists* investigating the extent and limits of biological diversity on Earth and how life emerged, evolved and diversified in early times,
- *Philosophers and historians of science* exploring the origins of life to answer the central question: «what is life»?

Such a transdisciplinary approach requires a framework within which to develop the research, training and outreach necessary for such a scientific programme and a COST TD Action is certainly the best (unique) structure for launching such a European programme.

Keywords: early Earth environment, traces of life, origin of life, early life evolution, limits of life, space exploration, habitable planets

STRATEGY

Objective 1 (A.5) - Type: Development of knowledge needing international coordination: new or improved theory / model / scenario / projection / simulation / narrative / methodology / technology / technique

- 1. Unpublished Aspects of Knowledge Creation, Including Experimentation and Testing, scientific experiment or test.
- 2. Achievement of Specific Network Features in terms of Working Group (WG) Composition, expertise.
- 3. Joint peer-reviewed publication, behind pay wall.
- 4. Scientific Publication (including Science and Technology study and excluding handbooks, guidelines and best practices. Excluding Joint Peer-Reviewed Publication), behind pay wall.
- 5. Science and Technology Coordination, Short-Term Scientific Missions (STSM).

Objective 2 (B.13) - Type: Bridging separate fields of science/disciplines to achieve breakthroughs that require an interdisciplinary approach

- 1. Science and Technology Event or Meeting, Action Conference.
- 2. Science and Technology Coordination, Application for Funding to Intergovernmental Programs or Agencies.
- 3. Achievement of Specific Network Features in terms of WG Composition, expertise.
- 4. Internal and External Communication, Participation to Activities of Other Networks.
- 5. Science and Technology Coordination, Short-Term Scientific Missions (STSM).

Objective 3 (A.3) - Type: Coordination of experimentation or testing

- 1. Database, Open access.
- 2. Achievement of Specific Network Features in terms of WG Composition, expertise.
- 3. Science and Technology Output, Development of software.
- 4. Internal and External Communication, Virtual Network: any web-based resource needed for work coordination among Action Members.

5. Unpublished Aspects of Knowledge Creation, Including Experimentation and Testing, other.

Objective 4 (A.9) - Type: Dissemination of research results to the general public

- 1. Internal and External Communication, Participation to Activities of Other Networks.
- 2. Science and Technology Output, Education and/or Training Material.
- 3. Internal and External Communication, Production of dissemination material for distribution.
- 4. Internal and External Communication, Conference Attendance for Action Dissemination Purposes.
- 5. Internal and External Communication, Website.

A. CHALLENGE

This COST Action addresses three basic questions that fascinate and intrigue scientists, and the general public alike, questions that are pivotal to our understanding and appreciation of our place in the Universe:

- Where, when and how did life emerge and evolve on Earth?
- What are the conditions under which life can exist?
- Does life exist elsewhere in the Universe and, if it does, how can it be detected and identified?

One of the greatest challenges for science in the 21st century is to provide answers to these questions. Indeed the discovery of life on a planet other than Earth (even in its simplest form) will be a defining moment in human history.

Today, for the first time it is possible to develop a robust scientific programme to explore these fundamental questions. This requires a transdisciplinary alliance drawing on researchers from astronomy, biology, chemistry, engineering, geosciences, physics and philosophy. For example, physicists and chemists can simulate the prebiotic conditions existing on interstellar ices or on the early Earth but can only do so if provided with data from astronomical observations and models or, in case of early Earth, ancient geological records provided by geologists. Hence, to develop the transdisciplinary research programmes necessary to explore the above three fundamental questions it is vital to assemble interdisciplinary teams that will provide a forum for effective exchange of information and this is best done on a European scale, pooling national resources. The TDP COST

Action "ORIGINS" intends to provide the roadmap and framework to answer these questions.

This endeavour is extremely timely since in the last decade the European Research Area (ERA), with the European Space Agency (ESA) has established itself as a competitor to the larger (and, until now, better funded) National Aeronautics and Space Administration (NASA) space research programme thanks to successful missions such as the Mars Express (the first purely European mission to another planet), the launch of Rosetta to study and land on a comet, the ongoing success of the European Instrument packages on the joint ESA/NASA Cassini-Huygens mission to the Saturnian system and the European Union's (EU's) major commitment to the European Southern Observatory (ESO) through the use of the Very Large Telescope (VLT) and Atacama Large Millimeter Array (ALMA). Together with the development of the European Aurora programme to explore the solar system and ultimately send humans to Mars, the ERA will have the opportunity to establish itself as a leader in exploration of the solar system and the Universe. In this context, the Action will also play its part in stimulating younger Europeans and to produce not only a scientifically skilled workforce but also a scientifically literate public capable of appreciating and supporting its industry and encouraging their children to study the sciences. Indeed few scientific topics provide the opportunity for developing public engagement in the importance and appeal of science as the exploration of our origins and searching for life beyond Earth.

The "Challenge" is divided into four themes corresponding to the four Working Groups (WGs) set out in the "Action Structure". The wider interdisciplinary questions related to the history of science (how did this new interdisciplinary research field emerge and develop itself?), and philosophy (what are the ethical issues concerning research in astrobiology?) are an integral part of each theme whereas the very important aspects of "training and education" and "dissemination and outreach" (which are common to all WGs) are presented here in a fifth paragraph (as shown in the "Action Structure" two special teams will be in charge of these activities).

Each theme, and the challenges the Action will face, will now be discussed:

1. Understanding the formation and evolution of planetary systems and habitable planets

Planet formation is intrinsically connected to the physical and chemical properties of the host star and its circumstellar material. In particular gaining an understanding of processes such as the

evolution of the host star's luminosity versus its mass and its main sequence progress, the distribution of elements in the protostellar disk and its chemical structure, the dynamics of grains and volatiles in the presence of a gas cloud, and the chemical composition of the star are all central to understanding of planetary formation and evolution and developing state-of-the-art stellar models. These models should also include very specific magneto-hydrodynamical processes (e.g., magnetic interaction between the star and its accretion disk, angular momentum redistribution, chemical mixing, tidal forces, etc.) that are not yet fully understood but are known to be crucial to explain key observational features of proto-stars and young stars.

The commonality of Sun-like stars in the Milky Way strongly suggests that many stars in our galaxy hosts planetary bodies, some of which might be habitable, indeed around nine hundreds exoplanetary bodies and more than three thousands planetary candidates have now been discovered with the prospect of many more being revealed as the data from the Kepler mission is analysed. The presence of several low-mass planets orbiting their host stars in their Habitable Zones (HZ) suggests that many Earth-like habitable planets exist. Upcoming space missions and ground-based telescopes (e.g., Extreme Large Telescope, ELT) are expected to identify many more of these bodies and will provide the opportunity for characterizing their atmospheres and hence exploring their potential for supporting life.

It is therefore timely to study the origin as well as the physical and dynamical characteristics of these objects. Such studies require a detailed theoretical approach to develop comprehensive models for the formation and evolution of planetary bodies, and particularly the habitable ones. It is then necessary to develop a deeper understanding of i) the formation of giant planets, superearths, and smaller bodies, ii) the processes of their dynamical evolution such as planetary migration, planet-planet scattering, and their long-term stability, and within the context of habitability, iii) their atmospheric characteristics and their interior properties.

Within this context, the Action will address the challenge of gaining a fuller understanding of planetary systems and habitable planets by:

- Developing custom-made stellar models that include specific magneto-hydrodynamical processes.
- Investigating accretion processes in the range of submillimeter to centimeter (fluffy aggregates and grains), meter to kilometer (planetesimals) and several kilometers (planetary embryos).

- Simulating the evolution of protoplanets in the protoplanetary disc, including dynamical processes affecting their inward and outward migration.
- Studying the evolution of planetary systems and investigating in particular the processes determining the final state (rotational speed, orbit eccentricity). To what extent are these processes stochastic (chance collisions) or predictable (interaction with neighbouring giant planets)?
- Model the final architecture of planetary systems, particularly those with low mass planets orbiting in the habitable zones of their host stars.
- Developing new and sophisticated numerical techniques to study and model exoplanetary atmospheres to identify biosignatures.
- Developing sophisticated models of the interior of Earth-sized and super-Earth extrasolar planets, and determine the connection between their interior dynamics and atmospheric structure.
- Investigating whether or not our solar system is typical or similar to other exoplanetary systems.

These tasks require combined expertise from astrophysics, geosciences, atmospheric science, chemistry and also history of science which will deal with the history of planetary sciences and the emergence of a new interdisciplinary field called "astrobiology".

2. Searching for the origins of the building blocks of life

Once a habitable planet is formed, how are the building blocks of life formed? Did they form *in situ* on the planet or were they delivered from space, or both? The space telescope HERSCHEL has detected several new interstellar molecules in space while the new ALMA interferometer array will enable the identification of even larger chemical species in star-forming regions, hot cores and protoplanetary discs. The major scientific challenge is to find out how and where these molecules are formed and how they can be delivered onto habitable planets including Earth.

This will require the detection of prebiotic organic molecules in space and elucidation of their formation mechanisms by a combined experimental, theoretical and modeling effort. It is then necessary to determine chemical origin of biomolecules and how those can self-organize into the structured dynamic reaction networks that constitute a living entity. This will require a laboratory reconstruction of life's essential building blocks under simulated primitive Earth conditions which can only be achieved through a systemic and transdisciplinary perspective that includes astrochemistry, geology and atmospheric chemistry to define the proper "boundary conditions" for

prebiotic chemistry.

The availability of biologically relevant building blocks is necessary but is still not sufficient for the emergence of life. Only the conversion of such compounds into biopolymers and the subsequent organization of these products into interconnected networks/systems (i.e. primeval cell structures) will allow the emergence of those multi-molecular processes that distinguish inanimate and animate matter. In the context of astrobiology, mineral or ice matrices may have played a fundamental role in the initial biopolymerization events, as they can selectively adsorb and protect molecules, assisting prebiotic synthesis and, perhaps, the organization of reaction networks. Coordination of research undertaken in this Action will focus on defining the minimal chemical systems that can be considered as potential candidates towards the development of the early cellular architecture. This effort will be supported by evolutionary studies using comparative genomic, phylogenomic and phylogenetic approaches.

Thus, the requirement of a dynamic, spatial and hierarchical organization requires a new approach to our understanding of prebiotic chemistry. Within this Action coordination of both theoretical and experimental studies will be performed in order to:

- Provide a novel conceptual systemic view to traditional prebiotic chemistry, by linking it to geochemistry and astrochemistry.
- Understand the continuity between chemical, prebiological, and early biological evolution.
- Advance the current knowledge of the formation of biomolecular precursors in space, heterogeneous and enantioselective catalysis, supramolecular self-assembled or selforganized chemical reaction networks, surface chemistry and synthetic cells.
- Provide the chemical understanding needed to define biosignatures on other planets/moons.

This task of following the biomolecular evolution from atoms in the interstellar medium through biopolymers to cells requires a broad cooperation between scientists from diverse fields: astrophysics, chemistry, geology, biochemistry as well as the history of science and philosophy that deals with questions about the level of complexity of life and asks: "Is life a gradually emerging phenomena or does it have some necessary and/or sufficient characteristics?"

3. Tracing the origin and evolution of life on Earth and finding its limits

To date terrestrial life is the only unambiguous example of life in our universe. Understanding how life evolved on Earth and diversified to colonize all available habitats will help to build a reference to look for potential forms of extraterrestrial life. The Action will take a bidirectional approach by i) studying the oldest traces of life on Earth and establishing realistic environmental constraints for the earliest life forms and ii) studying extant diversity to try to infer information about early biological diversification and the limits of life.

a) Early traces of life.

When, where, and how life emerged on Earth remains controversial and these three questions are the most challenging ones this theme will have to face. Learning more about earliest microbial ecosystems is crucial to understand how life shaped and intertwined with abiotic processes on Earth. Interdisciplinary expertise will be used to study traces of life in past environments at different temporal and spatial scales by:

- Investigating the nature, dynamics and diversity of Archean environments, to unravel realistic physico-chemical constraints imposed on the evolution of early life. This will involve geological mapping, geochemical-geophysical-petrographic characterization of target environments, dating, studies of sedimentary basins to constrain ecological gradients (pH, redox, temperature, nutrients), and investigations of hydrothermal circulation driven by magmatic and possibly meteorite impact heating. Target environments will include shorelines, shallow-marine sediments, cherts, banded-iron formations, carbonates, interbedded volcanic strata, and marine and continental hydrothermal environments.
- Developing new microscopic and microchemical tools and criteria to test candidate textural, geochemical, biomineral traces in the rock record, and microbial fossilization mechanisms through analysis of morphology, ultrastructure, chemical, elemental and isotopic composition.
- Modeling Archean biotic and abiotic processes in order to discriminate them.

b) The extent and limits of life.

Substantial progress has been made in the exploration of microbial diversity using molecular tools that document i) the greater genetic diversity of microorganisms compared to eukaryotic animals and plants, and ii) that a substantial fraction of that microbial diversity thrives in extreme

environments thought to be previously inhospitable to life. Amazing adaptations characterize microorganisms from very hot to very cold habitats, from hypersaline to highly acidic or alkaline environments and from the deep, cold sea to the subsurface environments in the oceanic and continental crusts.

Despite significant methodological molecular and metagenomic advances, scientists are however still far from understanding the extent of biological diversity and its limits. The most challenging part for this theme will be to:

- Extend and better define the physico-chemical limits within which life is expected to occur. This may help to orient the search for extraterrestrial life and to redefine habitable zones.
- Infer, via comparative phylogenomics, common features present in the last common ancestor of terrestrial organisms. This should help to impose biological constraints on the nature of even earlier living organisms and primordial entities before subsequent diversification of life in three domains (Archaea, Bacteria and Eucarya).

Interdisciplinary collaborations between biologists, geologists, chemists, astrophysicists and philosophers fostered by the Action, should provide a coherent and critical set of boundaries for the distribution of life across the broad spectrum of terrestrial ecosystems and possibly on other planetary systems.

4. Detecting life on other planets and satellites

An obvious target for search for life on another celestial body is our neighbour Mars. Observations indicate that Mars' Noachian period (4.1 to 3.7 Ga ago) was relatively life-friendly and although the average conditions were probably cold, the potential for liquid water and associated ice melting existed (volcanism, hydrothermal, impact-driven). Present-day Mars is also cold, but strong UV irradiation and hostile chemical conditions inhibit life's survival, at least on the Martian surface. The goal of the forthcoming EU ExoMars rover mission is to explore an ancient wet environment down to 2 m depth.

The Action will seek to develop an understanding of the geological and chemical contexts, including aqueous processes, for EXOMARS. Specifically it will develop a multi-faceted approach integrating studies of early Earth rocks (ancient weathering, biosignature preservation) and Mars analogue

environments (Iceland) with Mars observations, and modelling of the early solar system evolution in order to define an optimal landing site on Mars.

Other potentially habitable bodies in our solar system are the icy moons of Jupiter. The JUICE (JUpiter ICy moons Explorer) mission will investigate Jupiter and the interior plus surface of its largest moons Ganymede, Callisto, and Europa, all of which likely harbour subsurface oceans. JUICE will study their interior and surface features. The results are important for the whole solar system, as Jupiter played a role in the formation of the terrestrial planets and their volatile budget. Jupiter is also a proxy for giant exoplanets (and their moons).

The Action will bring together different disciplines, to provide new insights which will be invaluable in the planning of future European space missions to other planets. The most challenging tasks will be to:

- Understand the geological history of water and ice on Mars as well as environmental conditions (temperature, geochemistry) at key sites to evaluate past habitability.
- Utilise the above information to identify candidate landing sites for the ExoMars rover.
- Coordinate tests with ExoMars rover's instruments using analogue materials, collaborate with the instrument teams and prepare cross-instrument comparisons in European laboratories
- Exploit Mars analogue environments on Earth (e.g Iceland) with a focus on habitability.
- Prepare a database of possible chemical and compositional geological targets that may be encountered on the Jovian moons to support the interpretation of mission results.

These tasks require a combination of expertise from astronomy, geophysics, biology, chemistry and engineering as well as the history of science and philosophy. Indeed, when searching for extraterrestrial life, the scientific community will have to establish concrete international ethical guidelines for planetary protection and terraforming. Moreover, and in order to plan successful manned space missions, one needs to know how the human mind reacts in interpreting and encounter unfamiliar extraterrestrial environments.

5) Education, training, dissemination and outreach

Astrobiology has expanded immensely during the last two decades, with its own well-established scientific journals, conferences, research groups, university courses, PhD programs, etc. However,

astrobiology also involves society, politics, economy, religion, and public communication. The main reason why astrobiology is so intriguing and so popular for the general public is that it raises existential questions, challenging our everyday conception of ourselves as human beings in the Universe. This, however, also means that it is necessary to inform the general public both about the newest scientific results in astrobiology and the ethical issues concerning research in astrobiology.

A multidisciplinary subject such as astrobiology also requires a new generation of scientists that are capable of working across boundaries between scientific subjects. However, to date, most research is conducted by groups isolated within their own narrow disciplines (e.g. astronomy, microbiology, geology). This has been a major obstacle to overcoming current challenges associated with the themes described above. This Action gives the opportunity to develop a multidisciplinary training programme that aims to provide, in collaboration with EANA (European Astrobiology Network association), an exemplar for the European astrobiology community.

Therefore, the Action has to be and will be heavily engaged in education, training, dissemination and outreach and will therefore develop an active programme of education, training, dissemination and outreach.

B. ADDED VALUE OF NETWORKING

It is common knowledge that the major questions in Science (e. g. 'How did life emerge and evolve on Earth?') cannot be solved by one scientific discipline alone, but requires an interdisciplinary cooperative effort by scholars from sometimes even seemingly unrelated disciplines like astronomy, biology, geology, chemistry, engineering and philosophy. It is also unlikely that the immense expertise necessary for tackling these questions can be found in any one institution and even within one single country alone. Therefore, a coordinated approach on a higher (European) level is necessary.

Several countries have already responded to this challenge. In the US, a NASA Astrobiology Institute (NAI) exists since 1998 and a networking activity on the origin of life recently started at Harvard University, while another one on the search for life on Mars has been initiated at the Carnegie Institute. In Australia, the Australian Centre of Astrobiology has a long-standing tradition of excellent scientific work in the field and in Brazil, an astrobiology centre (Núcleode Pesquisa em

Astrobiologia) has recently been established. In Europe, the European Astrobiology Network Association (EANA) exists, but does not have any major funding for scientific missions and training schools. National and regional initiatives include the UK Centre of Astrobiology, the Centro de Astrobiología in Spain, the Societé Française d'Exobiologie, the Nordic Network of Astrobiology and the Società Italiana di Astrobiologia, but many of these organisations lack funding for large-scale cooperative efforts in research, training and outreach. Therefore a COST Action in the field of astrobiology is therefore crucial to allow scientists from all fields to make significant progress in the understanding of the origins of life on Earth and in the preparation of new spatial missions. Moreover, it is essential to educate the next generation of scientists involved in astrobiology field, to organise European training events and to increase outreach activities in the field of astrobiology.

The inherent breadth of astrobiology implies that many of its scientific projects involve cooperation between institutions in different countries. New projects such as large-scale space missions require cooperation between scientists of different disciplines that may not have collaborated previously, e. g. in order to plan new missions, develop payload instruments and to perform post mission data evaluation.

As a general rule, the collaborations between the members of ORIGINS COST Action will ensure an effective use of data and techniques, leading to better-constrained theoretical models and improved understanding of the multiple processes leading to the origin and evolution of life on Earth and possibly on other habitable planets. Short-time scientific missions (STMS) and working group (WG) meetings provided by an open flexible structure like this COST Action are ideal means for fostering such collaborations.

The added-value for each WG and for the special themes of history of science and philosophy, training and education, dissemination and outreach, which are part of all WGs, are now presented.

1) Understanding the formation and evolution of planetary systems and habitable planets

One of the fastest growing fields in astrobiology (and astrophysics) is that of exoplanets and this vast subject will hugely benefit from a European interdisciplinary synergic effort. Chemical sciences will provide rate constants of photochemical reactions and their dependence on physical parameters, e.g., temperature, which are key inputs for chemical network models of exoplanetary atmospheres.

Earth and planetary sciences will contribute on how planetary interior dynamics critically affect volatile outgassing and cycling, and hence the mass and composition of planetary atmospheres. Stellar physicists will investigate how key input parameters, like luminosity, activity and effective temperature, modeling the atmospheric evolution of planets affect the planetary energy budget and the atmospheric escape processes. Planetary scientists will study how planet formation influences initial volatile reservoirs and the proto- atmospheres of planets and will determine atmospheric mass and composition. Finally, engineers will plan future instrumentation for space telescopes to study the atmospheres of rocky exoplanets. These collaborations cannot be organised at a national level and the COST networking structure provides an ideal scheme for securing a leading role for European exoplanet research.

2) Searching for the origins of the building blocks of life

Understanding of the chemical evolution of biomolecules and, subsequently, the first cells, is a vast task exceeding the capabilities of single institutions and national research communities. To understand how the building blocks of life originated from simple molecules, a systemic and transdisciplinary perspective, including astrochemistry, prebiotic chemistry, geology, atmospheric chemistry and engineering is needed. The explicit adoption of this general perspective through intensive, multi-disciplinary collective work and reciprocal exchange of knowledge is a major goal of the Action.

To investigate the formation of biomolecule precursors in space and on planetary surfaces, the Action will create, possibly in association with the Europlanet project, a European Astrobiology Laboratory Network. This Network will focus primarily on astrochemistry and atmospheric chemistry but will subsequently encompass others fields. It will not only share the competences of leading European Research Laboratories, but will also make maximum use of large instruments for astrochemistry, atmospheric chemistry, extraterrestrial sample analyses and laboratory simulations.

The research community working on prebiotic chemistry and related subjects is large, but the importance of cross- disciplinary and trans-domain activities is still not sufficiently recognized. The Action will build a platform to initiate collaboration between experts from different research fields in order to advance our understanding of how life can emerge and develop. In this respect,

the international platform provided by this COST trans-domain initiative will help considerably to trigger joint projects that would be otherwise improbable. The duration of the COST Actions provides a sufficiently long timeframe for setting up real collaborations between groups of prebiotic chemists and specialists of other disciplines like geology, planetology, geochemistry and biology.

3) Tracing the origin and evolution of life on Earth and finding its limits

The benefit of a pan-European structure provided by a COST Action is particularly evident in the study of the astrophysical, geological and biological contexts of the early Earth and life in extreme environments. Across the European community, expertise on this theme is diverse and developed at a very high level although there is not much interaction between the individual researchers. In this field, substantial progress can only be expected from a profound and long-lasting collaboration between astrophysicists, biologists, chemists, and geologists. This Action will create a network that will bring these different research groups and disciplines together, to facilitate the exchange of information and learn to "speak one another's language", so as to develop new strategies for investigating the first traces of life. This will also result in designing new ways of investigating the early record of life on Earth and elsewhere and sensitize scientists to the particular challenges of the Archaean rock record. Participation of European scientists with different expertise in the study of a set of common extreme biotopes will enable an in-depth understanding of the resilience of life processes that would not be possible in national settings. The open structure of COST will facilitate this effort.

4) Detecting life on other planets and satellites

The detection of life on other planets and satellites is linked to several important sub-questions such as "What is life?", "How can one detect it?" and "Which evidence can be thought conclusive?". Inputs from both humanities and life sciences are needed to define "what is life", whereas biologists and geologists collaborate to detect life in (possibly extreme) environments. These scientists, together with physicists, chemists, engineers and astronomers, can then identify biomarkers for remote detection of life and subsequently develop strategies to detect them on other celestial bodies including exoplanets. The interaction among these diverse and complementary disciplines requires networking. That this networking occurs across different European countries

as supported by COST can only help to integrate various thinking traditions into, hopefully, an even greater critical syncretism.

At this particular moment in time, a COST Action would also permit to promote the various programmes on Mars and Jupiter already initiated in several European institutes, thereby contributing to a better return on investment. Such an interdisciplinary programme has been running in the US under the auspices of the NASA-supported NAI-Astrobiology programme for more than a decade and Europe would also benefit from this type of networking.

The only way to obtain the broad, interdisciplinary effort necessary to take advantage of the already existing excellence of European science for answering the above-mentioned fundamental research questions and to place European excellence in the field in the forefront of international science is to create a network, such as a COST Action.

5) History of science and Philosophy, Education and Training, Dissemination and Outreach

As discussed in Part A, experts on the history of science and philosophy, as well as education and dissemination will participate in each WG. They will benefit from networking as follows:

a) History of science and Philosophy

An adequate integration of the different fields and lines of research involved will require the elaboration of a global perspective of an encompassing theoretical framework. This is a task for which historical and philosophical approaches are particularly well suited. Thus scientists from humanities will be integrated in each WG.

b) Education and Training

Space missions and other astrobiology science projects are usually long-term efforts. Thus, today's young scientists will be the people who guide these missions in the not too distant future. Therefore, a strong focus of the Action will be on the training and involvement of students and early career scientists in those projects. For this task, a single institution is not able to provide the expertise and experience to organise top-level multidisciplinary courses for students and early career scientists.

Therefore, the Action will organise high-level interdisciplinary courses, covering both astrobiology in a general sense, but also more specialized subjects. Furthermore, courses on generic and transversal skills such as proposal writing, presentations at scientific meetings, job interviews, etc. will be offered.

A special inter-group team inside the COST Action, gathering members of all WGs, will take care of the Education and Training.

With its large scope, COST Actions are an ideal vehicle to endorse high quality training for future scientists involved in astrobiology, which cannot be accomplished by single countries. Special care will be taken to involve female scientists in these training events.

c) Dissemination and Outreach

The size of the COST Action will enable us to coordinate outreach activities in astrobiology on a European level. A special inter-group team inside the COST Action, gathering members of all WGs, will take care of the dissemination and outreach. Their tasks are listed in Part D (structure).

Several Network members are senior editors of the "Encyclopedia of Astrobiology", which is an ideal tool for disseminating knowledge about astrobiology in and beyond the scientific community. The COST Action will facilitate up to date maintenance of the Encyclopedia by facilitating the necessary editorial meetings.

6) Impact of the Action beyond its duration

Referring to the Horizon 2020 programme, the Action will cover several key priorities of this programme, indeed several of the topics listed in the draft Space and Research Infrastructures calls (for 2014-15) are relevant to the aims and objectives of this Action, the Action may act as a forum and focal point for the community's reponse to such calls. It will make Europe an attractive location for the world's best researchers in an interdisciplinary field that traditionally attracts (as previous events organised in the field have shown) very bright, motivated and excellent students and thus lead to excellent European science. It is particularly suitable for meeting the social challenges in science and bringing together resources and knowledge across different fields. It is noted here that

Horizon 2020 envisages removal of the barriers preventing women from pursuing successful scientific careers. Since Astrobiology has a long tradition of attracting female scientists (more than 30% of the Proposers are female scientists), the Action will strongly contribute to this policy.

Finally, the COST Action will create a permanent structure after its conclusion, i.e. a **European Astrobiology Institute** (EAI), that will continue beyond the lifetime of the Action. This EAI, equivalent of the NAI at the European level, will consist of a European association of universities and other research institutes engaged in astrobiology. The tasks of this institute include:

- to conduct interdisciplinary research projects in astrobiology that are too large to be performed at the national level.
- to plan space missions with an astrobiologicaly focus.
- to provide high-level interdisciplinary courses for students and early career scientists.
- to carry out outreach projects on an European scale.

In pursuit of these efforts, the EAI will cooperate with other international institutes pursuing synergistic goals. Thus, the COST Action will have an impact far beyond its lifetime.

C. MILESTONES AND DELIVERABLES: CONTENTS AND TIME FRAMES

The Action Members will meet the challenges listed in Part A through a cooperative research effort including seeking funds from national, international and European bodies. The Action will strongly promote STSMs to be carried out every year. Priority will be given to early career scientists and students without easy access to funding from other sources. Many common projects, described in detail below, will be carried out.

I. Deliverables

- 1) Development of knowledge needing international coordination (A5 objective)
- a) Understanding the formation and evolution of planetary systems and habitable planets

The Action will produce peer-reviewed papers on:

- The correlation between physical and chemical conditions in star forming regions, the properties of protostars and stars at various stages of their evolution, and the occurrence of planetary systems.
- The hypotheses on the origin and evolution of the early solar system, focusing on cometary and asteroidal samples, meteorites and micrometeorites and analogues mineral surfaces.
- Exoplanets models with self-consistent treatment of major processes which affect the habitability of planets.

b) Searching for the origins of the building blocks of life

The Action will produce peer-reviewed papers on:

- The formation of biomolecule precursors in the interstellar medium and planetary atmospheres and their abundance distributions in star-forming regions and protoplanetary disks.
- The physical and chemical characteristics of comets and asteroids and their role as carriers of volatile molecules, biomolecular precursors and other species that could be important in probiotic chemistry
- Experimental and theoretical approaches to investigate the routes that increase the complexity
 from small prebiotic molecules to oligomers or polymers, to supramolecular aggregates, to
 dynamic chemical networks, to spatially-defined microreactors.
- Specific cases of auto- and cross-catalysis, enantioselective reactions, self-replication and self-reproduction, the origin of selection/competition/cooperation dynamics, and the origin of evolvability.

c) Tracing the origin and evolution of life on Earth and finding its limits

The Action will produce peer-reviewed papers on:

- The nature, dynamics and diversity of Archean physico-chemical environments, constraining early life's habitats and evolution.
- The preservation and characteristics of biosignatures and pseudo-biosignatures, from modern extreme environments to the early Earth geological record.
- The early metabolic pathways and their consequences for the co-evolution of biosphere and the geosphere.
- The diversity and adaptations of life in diverse and extreme environments.
- The nature of LUCA (Last Universal Common Ancestor)

d) Detecting life on other planets and satellites

The Action will produce peer-reviewed papers on:

- Water related past environmental parameters on Mars derived from Earth analogues and laboratory data.
- Landing site selection for the ExoMars rover mission.
- Galilean moons' surface environments and the fate of organics.

2) Coordination of experimentation or testing (A3 objective)

a) Astrochemical database

The Action will develop a database (using funding other than COST) to correlate the elemental composition and physical-chemical properties of non-terrestrial materials with specific prebiotic processes. This database will be made available to the general scientific community. It will also contribute to update existing critical databases of astrobiological and astrochemical interest, like the KIDA (Kinetics Database for Astrochemistry) one.

b) Mars paleoenvironment reconstruction database

The challenge of ExoMars mission is to find a Martian geological environment that might have preserved biosignatures, if life (as it is known) ever appeared. Therefore it is necessary to understand the past geologic history of water on Mars and identify suitable candidate landing locations. The Action will develop a database (using funding other than COST), based on Earth analogues and laboratory data (water volume, temperature, pH, duration of existence, rock/water ratio), to help the reconstruction of Mars past aquatic environments.

c) Biosignatures and pseudo-signatures database

Biogeological studies of traces of life and their preservation in past and modern extreme environments, as well as investigations of abiotic processes mimicking life and producing pseudobiosignatures, and the improvement of analytical approaches, will provide crucial data for

the unambiguous detection of life on early Earth and beyond Earth in space missions. This work will be summarized in a peer-refereed review.

3) Bridging separate fields of science/disciplines to achieve breakthroughs that require an interdisciplinary approach (B13 objective)

a) European Laboratory Network

In the first year of the Action, a European Laboratory Network will be created. Its objective will be to share the competences from each community, to pool the instrumental resources available and, as a first step, to bring together three different scientific communities (astrochemists, chemists and climatologists). These communities have individually been networking quite successfully in the past (also through launching of COST Actions) but haven't, to date, had the opportunity to combine their efforts. The European Laboratory Network will work towards a comprehensive understanding of the complex processes involved in the molecular evolution of life on Earth, but also of the formation and evolution of atmospheres of habitable planets and their relevance on other solar system objects. Furthermore, Action Members will engage in observational projects that will determine the abundance and distribution of complex organic molecules in star-forming regions, protoplanetary disks and circumstellar envelopes using state-of-the-art telescopes like the ALMA interferometric array.

b) European Astrobiology Institute

The COST Action members will create, after its conclusion, a European Astrobiology Institute (EAI) that will continue beyond the lifetime of the Action. This EAI, equivalent of the NASA Astrobiology Institute at the European level, will consist of a European association of universities and other research institutes engaged in astrobiology. The Action will prepare the launch of this EAI during the last year of the Action.

c) Working Group and Project Planning Meeting (WGPP Meeting)

The Action will organise a yearly forward-looking workshop (named "Working Group and Planning Project Meeting") in which WGs members will discuss their field intensively and where

new projects (and short-time scientific missions) will be planned.

This workshop will consist of

• plenary sessions on 1 or 2 hot topics (chosen to alert members of the Action to new important and fast developing new fields whilst introducing new people into the Action),

• parallel workshops of the WGs,

planning of new projects in smaller groups,

 the annual MC meeting (to allow the MC to be updated on the new developments of the COST Action)

Particular attention will be paid to coordination with other European astrobiology projects such as the European Community's 7th Framework Program (EU FP7) Astromap, and other COST Actions linked to the origins and evolution of life field. (e.g CM1304: Emergence and Evolution of Complex Chemical Systems)

d) White paper on ethical, epistemological and societal problems of astrobiology

The Action will also deal with cognitive, linguistic, epistemological, ethical, cultural, societal and historical perspectives on the development of astrobiology as a research field in order to answer the following questions:

• What is meant by "life" and other concepts involved in astrobiological research?

 How do humans deal with the integration of different types of knowledge, research programs, technologies?

• What ethical, epistemological and societal problems are involved in space exploration?

A white paper on these issues will be published during the Action.

The Action will also organise the second international conference on "The History and Philosophy of Astrobiology".

4) Dissemination of research results to graduate/PhD students and to the general public (A9 objective)

a) Training schools

Many members of the Action have considerable experience in organising schools in astrobiology for students and early career scientists. This guaranties efficient and successful organization by the members of the Action of two courses of 1-2 weeks per year in different COST countries. The sites and length of the courses will allow field trips and practical science projects to be carried out by the students. These should ideally not be mere "training exercises", but real research projects leading to publishable data. Courses on generic skills (proposal writing, presentation at scientific meetings, job interviews) will, however, also be offered as part of these schools.

Co-funding from other bodies (e.g. NAI, national research bodies) will be sought for these schools. The Action will therefore cooperate with other institutions and networks in organizing the summer school "Water, Ice and the Origin of life in the Universe" which will take place at the 3rd year at the latest. In addition, the Action will encourage graduate students and early career scientists to host the international "Astrobiology Graduate Conference (AbGradCon)", a meeting designed for and organised by young researchers, in a COST Country and to provide some funding for the event.

b) Dissemination and outreach

Several members of the Action are senior editors of the Encyclopaedia of Astrobiology, first published in 2011. This encyclopedia of 2500 entries, written by more than 350 authors, under the responsibility of 25 editors, serves as the key to understand technical terms from the different areas of astrobiology. It is addressed at both new and experienced researchers and graduate students in adjacent fields of astrobiology and intends to accelerate the interdisciplinary advance of astrobiology. The COST Action structure will organize a one-day encyclopedia meeting, just before or after the WGPP meeting to update the entries and discuss new advances. Funds will be sought from the publisher.

The size of the COST Action will also enable us to coordinate the outreach activities on a European level. A special team inside the COST Action will take care of the production of teaching materials for schools, moveable exhibitions, documentations on astrobiological subjects, participation of the scientists to outreach activities like the European 'Night of the Researcher' etc. On the international level, the COST Action will provide input for the Formulation of Framework Programmes and other scientific policy documents.

II.Milestones

1) First Year of the Action

- 30 STSM and 2 astrobiology schools successfully carried out
- First WGPP Meeting (at all workshops a book of abstracts will be produced)
- European Laboratory Network created

2) Second Year of the Action

- 60 STSM and 4 astrobiology schools successfully carried out in total (cumulative result)
- Second WGPP Meeting held
- Database on past environmental parameters on Mars installed
- 2nd Conference on History and philosophy of Astrobiology carried out
- Field trip to Mars-like landscapes carried out.

3) Third Year of the Action

- 90 STSM and 6 astrobiology schools successfully carried out in total (cumulative result)
- 10 peer-reviewed papers published
- Third WGPP Meeting held

4) Fourth Year of the Action

- 120 STSM and 8 astrobiology schools successfully carried out in total (cumulative result)
- 20 peer-reviewed papers published in total
- Fourth WGPP Meeting held
- Database on elemental composition and physical-chemical properties of non-terrestrial materials launched
- Database of biosignatures and pseudo-biosignatures launched
- Third edition of the Encyclopedia of Astrobiology launched
- Document regarding the selection of the landing site on Mars published
- White paper on ethical, epistemological and societal problems of astrobiology composed
- Final "COST Origins Conference" carried out
- Launch of the "European Astrobiology Institute" prepared

D. ACTION STRUCTURE AND PARTICIPATION – WORKING GROUPS, MANAGEMENT, INTERNAL PROCEDURES

The Action will be supervised and coordinated by a Management Committee (MC).

A Chair and Vice-Chair will be elected by the MC during the kick-off meeting.

Four Working Groups (WGs) will be established and each will be lead by a Chair and Deputy Chair. The WG leaders, appointed by the MC, will:

- Coordinate the activities within their WG to meet the objectives defined in the scientific program.
- Stimulate and foster the set-up of joint research, funded by members' own institutions and grant awards (e.g. through use of short-term scientific missions, (STSM).
- Plan appropriate scientific meetings.
- Promote the co-authoring of scientific publications.
- Ensure the reporting of WG progress to the Action MC and Chair.
- Participate in MC meetings

To improve communications between MC and WGs as well as to prepare annual MC meetings and reportings, a Steering Group (SG), consisting of the Chair and Vice-Chair of the MC and the leaders of the WGs, will be established. The SG will also act as a STSM Evaluation Committee.

Researcher training (students and early career scientists), education and dissemination are essential tasks for all WGs. Therefore, two interdisciplinary teams will be formed to coordinate the activities of the Action in these areas.

At the kick-off meeting of the MC, the grant holder, the secretary and the Web coordinator, will be elected and the Action will establish the following four WGs and two teams.

WG 1. Understanding the formation and evolution of planetary systems and habitable planets

Exploring the

- Formation and evolution of planets and their host stars.
- Planetary architectures and their stability.
- Internal structure and atmospheres of solar system planets and exoplanets.

- Habitability of exoplanets and of the Earth in the young solar system and now.
- History of planetary science and of astrobiology.

WG 2. Searching for the origins of the building blocks of life

Exploring the

- Emergence of life on Earth: role of extraterrestrial material received on Earth, prebiotic chemistry in the geochemical and astrochemical framework (young sun, atmosphere composition, ocean temperature, etc.).
- Extraterrestrial samples: physical and chemical properties analysis, interactions with biomolecules.
- Chemical pathways to biologically relevant compounds and to progressively complex systems:
 laboratory experiments, computer simulations, search for similar processes in exoplanetary systems.
- Biotic systems versus prebiotic systems: from which stage of assembly and complexity?
- Origin of self-organization processes, metabolisms, genetic codes and cells.
- Continuity between chemical, prebiological and biological evolution.
- Definition of possible hallmarks for life detection on other planets/moons.
- Philosophy of science: from which level of complexity can one talk about life?

WG 3. Tracing the origin and evolution of life on Earth and finding its limits

Exploring the

- Interplay between physico-chemical processes and biological evolution.
- Nature, dynamics and diversity of Archean environments and their impacts on life origin and evolution.
- Modelling of biotic and abiotic processes.
- Preservation mechanisms of fossil microorganisms Biosignatures on the early Earth and beyond Earth.
- Last Universal Common Ancestor (LUCA): research into comparative phylogenomics, structural and functional properties.
- Physico-chemical limits of life.
- Extreme environments analogous of past ecosystems.

- New compounds discovered in extremophiles.
- Geochemical traces of life in the rock record: developments of new tools and criteria.
- History and philosophy of science: what are the motors of evolution (from stars to living systems)?
- Definition of life and characteristic features of life.

WG 4. Detecting life on other planets and satellites

Investigating

- Biomarker versus biosignature.
- Type of biosignatures left by living organisms and their activities, developments of state-of-theart tools to detect life on exoplanets.
- Biomolecules in space environment: stability and degradation processes.
- Use of Earth analogue observations to interpret ExoMars rover mission's data.
- Past geologic history of water on Mars.
- Ethics of exploration of other planets, planetary protection and terraforming.

The four WGs therefore cover the fundamental questions of contemporary astrobiology in a comprehensive way. They are very interdisciplinary in nature and therefore need to bring together scientists and students from different fields. Some overlaps between the WGs exist, indeed these are are desirable, Thanks to the open structure of the COST Action, the general interest in the subjects of the WGs will encourage newcomers into the field.

WGs will meet once at least a year, preferably during the "Yearly Working Group and Planning meeting" described in Section C. Common tasks of all WGs will be to prepare and carry out STSMs and to participate equally in all activities of the Action, including education/training and outreach/dissemination for which the Action will form 2 inter- working teams. These teams will be led by a MC member who (like the WG leaders) will report to the MC regularly about their activities and plans. Their tasks are listed below:

Team A: EDUCATION AND TRAINING

Responsabilities include:

• Organisation of a biannual winter/summer school and evaluation of lectures.

- Networking (or Lobbying) for the integration of astrobiology training into universities curricula.
- Publication of astrobiological on-line training material.
- Cooperation with national, regional and international networks and bodies in astrobiology training.
- Design and publication of material for school teachers.

Team B: DISSEMINATION AND OUTREACH

Responsabilities include:

- Coordination of dissemination efforts of the Action.
- Organisation of exhibitions for the general public.
- Participation to European initiatives like 'Researchers Night'.
- Networking with science journalist interested in astrobiology.
- Update of the Encyclopedia of Astrobiology.
- Networking with national and European bodies for funding of these activities.

In summary the Action possesses a clear coherent, meaningful and powerful structure, ensuring cooperation between the different WGs, as well as developing teaching activities from public to university level. Such a set-up will ensure that the Action can carry out its wide-ranging ambitious tasks in a novel manner.