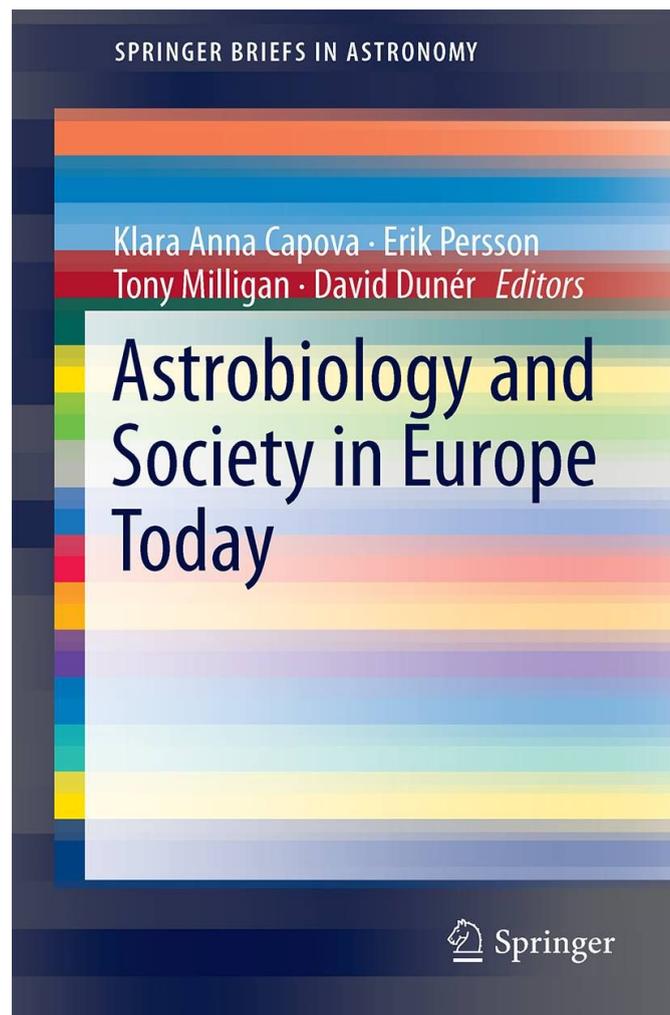


The White Paper “Astrobiology and Society in Europe Today”, edited by K.A. Capova, E. Persson, T. Milligan, D. Dunér, is published through the SpringerBriefs in Astronomy book series, Springer, Cham (2018).

The final authenticated version is available online at:

<http://dx.doi.org/10.1007/978-3-319-96265-8>





# Astrobiology and Society in Europe Today

The White Paper on the societal implications of astrobiology research  
in Europe and the need for a European Astrobiology Institute

TD1308 Origins and Evolution of Life on Earth and in the Universe,  
Working Group 5: History and Philosophy of Astrobiology



**Co-Lead Editors:** K. A. Čáková<sup>4\*</sup>, E. Persson<sup>24\*</sup>, T. Milligan<sup>20</sup>, D. Dunér<sup>7</sup>

### **Chapter Editors**

J. Arnould<sup>2</sup>, K. A. Čáková<sup>4</sup>, H. Χατζηθεοδωρίδης (E. Chatzitheodoridis)<sup>5</sup>, D. Dunér<sup>7</sup>, M. Gargaud<sup>8</sup>, W. Geppert<sup>9</sup>, N. Mason<sup>18</sup>, E. Persson<sup>24</sup>

### **Section Editors**

J. Arnould<sup>2</sup>, K. A. Čáková<sup>4</sup>, H. Χατζηθεοδωρίδης (E. Chatzitheodoridis)<sup>5</sup>, L. Dartnell<sup>6</sup>, D. Dunér<sup>7</sup>, M. Gargaud<sup>8</sup>, W. Geppert<sup>9</sup>, A. Kereszturi<sup>12</sup>, P. Laine<sup>14</sup>, J. Martínez-Frías<sup>16</sup>, N. Mason<sup>18</sup>, T. Milligan<sup>20</sup>, E. Persson<sup>24</sup>, K. Smith<sup>26</sup>, S. Tirard<sup>27</sup>, M. Waltemathe<sup>28</sup>

### **Authors**

A. Anglés<sup>1</sup>, J. Arnould<sup>2</sup>, L. Billings<sup>3</sup>, K. A. Čáková<sup>4</sup>, H. Χατζηθεοδωρίδης (E. Chatzitheodoridis)<sup>5</sup>, L. Dartnell<sup>6</sup>, D. Dunér<sup>7</sup>, M. Gargaud<sup>8</sup>, W. Geppert<sup>9</sup>, E. Hemminger<sup>10</sup>, Z. Kaňuchová<sup>11</sup>, A. Kereszturi<sup>12</sup>, G. Kminek<sup>13</sup>, P. Laine<sup>14</sup>, A. Losiak<sup>15</sup>, J. Martínez-Frías<sup>16</sup>, Z. Martins<sup>17</sup>, N. Mason<sup>18</sup>, A. Melin<sup>19</sup>, T. Milligan<sup>20</sup>, P. T. Mitrikeski<sup>21</sup>, E. Nabulya<sup>22</sup>, L. Noack<sup>23</sup>, E. Persson<sup>24</sup>, S. Ramos<sup>25</sup>, K. Smith<sup>26</sup>, S. Tirard<sup>27</sup>, M. Waltemathe<sup>28</sup>

### **Advisory Board**

O. Chon-Torres<sup>29</sup>, K. Denning<sup>30</sup>, S. Dick<sup>31</sup>, A. Gupta<sup>32</sup>, S. Kwok<sup>33</sup>, L. Mix<sup>34</sup>, A. Pross<sup>35</sup>, K-U. Schroggl<sup>36</sup>

## **Affiliations**

1. University of Hong Kong, Hong Kong.
2. Centre national d'études spatiales (National Centre for Space Studies), France.
3. Consultant to NASA's Astrobiology Program, USA.
- 4\*. Durham University, United Kingdom, \*k.a.capova@durham.ac.uk.
5. Εθνικό Μετσόβιο Πολυτεχνείο (National Technical University of Athens), Ελλάδα (Greece).
6. University of Westminster, United Kingdom.
7. Lunds universitet, Sweden.
8. Laboratoire d'Astrophysique de Bordeaux, France.
9. Physics Department (Fysikum), Stockholm University (Stockholms universitet), Sweden.
10. Evangelische Hochschule Rheinland-Westfalen-Lippe, Germany.
11. Astronomický ústav SAV (Astronomical Institute SAS), Slovakia.
12. Csillagászati és Földtudományi Kutatóközpont (Research Centre for Astronomy and Earth Sciences), Hungary.
13. European Space Agency, Noordwijk, The Netherlands.
14. Jyväskylän yliopisto, Finland.
15. Polska Akademia Nauk (Polish Academy of Sciences), Poland.
16. Instituto de Geociencias, IGEO (CSIC-UCM), Madrid, Spain.
17. Instituto Superior Técnico, Universidade de Lisboa, Portugal.
18. School of Physical Sciences, The Open University, United Kingdom.
19. Malmö universitet, Sweden.
20. Department of Theology and Religious Studies, King's College London, United Kingdom.
21. Institut za istraživanje i razvoj održivih ekosustava (Institute for Research and Development of Sustainable Ecosystems), Croatia.
22. Makerere University, Uganda.
23. Freie Universität Berlin (Free University Berlin), Germany.
- 24\*. Lunds universitet, Sweden, \*erik.persson@fil.lu.se
25. Universidad Nacional Autónoma de México, Mexico.
26. Clemson University, USA.
27. Université de Nantes, France.
28. Ruhr-Universität Bochum, Germany.
29. Universidad de Lima, Peru.
30. York University, Canada.
31. 2013-2014 Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology, USA.
32. Assam University, India.
33. Faculty of Science, The University of Hong Kong, Hong Kong.
34. Harvard University/CTI Princeton, USA.
35. Ben Gurion University of the Negev, Israel.
36. Director General's Cabinet of the European Space Agency, France.

## **Version Information**

Version: V8 June, 2018

## Table of Contents

Executive Summary	7
Acknowledgements	8
Abbreviations	9
<b>1. Astrobiology and Society in Europe (D. Dunér)</b>	<b>10</b>
1.1 The Contribution of Humanities and Social Sciences to EU Astrobiology (K. A. Čáková, E. Persson)	10
1.2 What is Astrobiology? (A. Kereszturi, M. Gargaud)	11
1.3 Organising EU Astrobiology Research (M. Gargaud, W. Geppert)	12
Background	12
Challenges	12
Suggestions	12
<b>2. The International Context of Astrobiology (E. Persson, J. Arould)</b>	<b>14</b>
2.1 European Astrobiology Research to Date (S. Tirard)	15
Background	15
Challenges	16
Suggestions	16
2.2 International Outlook (E. Persson)	17
Africa (E. Nabulya, E. Persson)	17
Asia (E. Persson, A. Anglés)	17
North America (L. Billings, K. Smith)	18
Latin America (S. Ramos)	19
2.3 Current Regulations and Planetary Protection (J. Arould, G. Kminek)	19
Background	19
Challenges	20
Suggestions	21
<b>3. Society, Worldview and Outreach (K. A. Čáková)</b>	<b>22</b>
3.1 The Public Understanding of Astrobiology (K. A. Čáková)	22
Background	22
Challenges	23
Suggestions	23
3.2 Popularisation, Dissemination and Outreach (L. Dartnell)	23
Background	23
Challenges	24
Suggestions	25

3.3 Rethinking Humanity’s Place in the Universe (D. Dunér)	25
Background	25
Challenges	26
Suggestions	26
3.4 Astrobiology and Religion (A. Melin, P. T. Mitrikeski)	26
Background	26
Challenges	27
Suggestions	27
<b>4. Environment and Sustainability (E. Persson)</b>	<b>28</b>
4.1 Environmental Protection and Sustainability (T. Milligan)	28
Background	28
Challenges	29
Suggestions	29
4.2 Earth Sites of Importance for Astrobiology (J. Martínez-Frías)	29
Background	29
Challenges	30
Suggestions	30
4.3 Environmental Ethics in Space (T. Milligan, E. Persson)	31
Background	31
Challenges	31
Suggestions	32
<b>5. Education, Training and Scholarship (W. Geppert)</b>	<b>33</b>
5.1 Astrobiology Training and Education (W. Geppert)	33
5.2 Astrobiology and Society in European Scholarship (D. Dunér, Z. Kaňuchová)	34
5.3 Science and Technology Awareness among Students (M. Waltemathe, E. Hemminger)	36
Background	36
Challenges	37
Suggestions	37
<b>6. Technological Innovation and Commerce (E. Chatzitheodoridis)</b>	<b>38</b>
6.1 Technological Innovations Driven by Astrobiology (E. Chatzitheodoridis)	38
Background	38
Challenges	39
Suggestions	39
6.2 Potential Conflicts of Interest (E. Persson, K. A. Čápová)	39
Background	39
Challenges	40
Suggestions	40

<b>7. Science and Research (N. Mason)</b>	<b>41</b>
7.1 Advancing Astrobiology Research in Europe (N. Mason)	41
Background	41
Challenges	42
Suggestions	42
7.2 Careers in Astrobiology (P. Laine, A. Losiak, Z. Martins, L. Noack)	43
Background	43
Challenges	44
Suggestions	44
7.3 The Social Study of Astrobiology as a Science (K. Smith, K. A. Čápková)	46
Background	46
Challenges	46
Suggestions	46
<b>8. Leading the Future of Astrobiology in Europe (M. Gargaud, W. Geppert)</b>	<b>48</b>
8.1 Challenges Facing the EU Astrobiology Community	48
8.2 The Role of the European Astrobiology Institute	49
8.2.1 Principal Tasks	50
8.2.2 Research Areas	51
8.2.3 Funding and Mentorship	52
8.2.4 Suggested Activities of the EAI	53
8.2.5 Multidisciplinarity and Networking	54
<b>9. Appendices</b>	<b>55</b>
9.1 Definitions (drawing upon the Encyclopedia of Astrobiology)	55
9.2 Presentation of the Group	56
9.3 COST Action Memorandum	57
9.4 The American Experience (L. Billings, K. Smith)	58
9.5 Suggested Literature	60

## **Executive Summary**

This White Paper describes the state of Astrobiology in Europe today and its relation to European society at large. With contributions from authors in twenty countries and over thirty scientific institutions worldwide, the document illustrates the societal implications of astrobiology and the positive contribution that astrobiology can make to European society.

The White Paper has two main objectives: 1. It recommends the establishment of a European Astrobiology Institute (EAI) as an answer to a series of challenges relating to astrobiology and also to European research, education and society at large. 2. It acknowledges the societal implications of astrobiology, and thus the role of the social sciences and humanities in optimizing the positive contribution that astrobiology can make to the lives of the people of Europe and the challenges they face.

Astrobiology enjoys a great deal of interest among the public, probably more than most other fields of research. It also has implications for human life outside the laboratories and lecture halls. It has the potential of being a flagship of European cooperation in science. It provides an ideal ground for collaborative European projects which support the ethos of cooperating countries. Astrobiology is inherently interdisciplinary and based on collaboration between disciplines, universities and countries. For Europe to take a leading role in this research, it is very important to have a stable structure that can coordinate research, research infrastructure, funding and relations to the surrounding society in an efficient way. The establishment of a EAI, as a consortium of institutions, will provide the perfect forum for such collaborative efforts and should be a key priority for European research institutions as well as the European astrobiology community and the EU. To have an active astrobiology research programme, coordinated and fostered by such an institute, will enhance the international standards of European space research, and of European science in general.

The EAI will be able to promote astrobiology research, assist in the decision-making processes of relevant European institutions, be involved in mission planning, engage in science dissemination, education and communication, as well as outreach and media work in a much more efficient way than individual research institutions. The EAI will act as a strong voice for the astrobiology community in dialogue with decision makers, funding agencies, the media, other stakeholders and the general public. It will be proactive in the debate on important legal and ethical issues in astrobiology and space research.

## **Acknowledgements**

The editors would like to acknowledge the continuous support of COST Action TD1308 ORIGINS, namely through the Short Term Scientific Mission (STSM) fundings: STSM-TD1308-010216-070847, STSM-TD1308-121216-081651, STSM-TD1308-1604180-40883 and STSM-TD1308-150418-040842. Further, the support of the Pufendorf Institute for Advanced Studies at Lund University, Sweden, through the ‘A Plurality of Lives’ research theme.

The editors would also like to thank all of the authors and researchers and members of advisory board who contributed to the Astrobiology and Society White Paper. For their comments on the text, we extend our thanks to Julie Nováková (Charles University in Prague, Czech Republic), Caroline Dorn (University of Zurich, Switzerland), Vladimir Bozhilov (Sofia University, Bulgaria), and John Robert Brucato (Astrophysical Observatory of Arcetri, Italy).

## Abbreviations

AbGrade	Astrobiology Graduates in Europe	n/a
ASB	Astrobiology Society of Britain	<a href="http://astrobiologysociety.org">http://astrobiologysociety.org</a>
ASSA	Astronomical Society of Southern Africa	<a href="http://assa.sao.ac.za">http://assa.sao.ac.za</a>
COSPAR	Committee on Space Research	<a href="https://cosparhq.cnes.fr">https://cosparhq.cnes.fr</a>
COST	Cooperation in Science and Technology	<a href="http://www.cost.eu">http://www.cost.eu</a>
DAbG	German Astrobiology Society	<a href="https://www.astrobiologie.de">https://www.astrobiologie.de</a>
EAC	European Astrobiology Campus	<a href="http://astrobiology-campus.eu">http://astrobiology-campus.eu</a>
EAI	European Astrobiology Institute	n/a
EANA	European Astrobiology Network Association	<a href="http://www.eana-net.eu">http://www.eana-net.eu</a>
EC	European Commission	<a href="https://ec.europa.eu">https://ec.europa.eu</a>
ELSI	Earth Life Science Institute	<a href="http://www.elsi.jp/en">http://www.elsi.jp/en</a>
ESA	European Space Agency	<a href="http://www.esa.int">http://www.esa.int</a>
ESO	European Southern Observatory	<a href="http://www.eso.org">http://www.eso.org</a>
EU	European Union	<a href="http://europa.eu">http://europa.eu</a>
FAST	Five Hundred Meter Aperture Spherical Telescope	<a href="http://fast.bao.ac.cn/en">http://fast.bao.ac.cn/en</a>
IAGETH	International Association for Geoethics	<a href="http://www.icog.es/iageth">http://www.icog.es/iageth</a>
IAU	International Astronomical Union	<a href="https://www.iau.org">https://www.iau.org</a>
ICSU	International Council for Science	<a href="https://www.icsu.org">https://www.icsu.org</a>
ISSI	International Space Science Institute	<a href="http://www.issibern.ch">http://www.issibern.ch</a>
ISU	International Space University	<a href="http://www.isunet.edu">http://www.isunet.edu</a>
JAXA	Japan Aerospace Exploration Agency	<a href="http://global.jaxa.jp">http://global.jaxa.jp</a>
NAI	NASA Astrobiology Institute	<a href="https://nai.nasa.gov">https://nai.nasa.gov</a>
NASA	National Aeronautics and Space Administration	<a href="https://www.nasa.gov">https://www.nasa.gov</a>
NNA	Nordic Network of Astrobiology	<a href="http://www.nordicastrobiology.net">http://www.nordicastrobiology.net</a>
OST	Outer Space Treaty	n/a
SIA	Italian Society of Astrobiology	<a href="https://astrobiologia.weebly.com">https://astrobiologia.weebly.com</a>
SFE	The French Astrobiology Society	<a href="http://www.exobiologie.fr">http://www.exobiologie.fr</a>
STEM	Science, Technology, Engineering, Mathematics	n/a
STS	Science and Technology Studies	n/a
STSM	Short Term Scientific Mission	n/a
SOMA	Mexican Society of Astrobiology	<a href="http://web.soma.org.mx">http://web.soma.org.mx</a>
TD	Trans Domain	n/a
UN	United Nations	<a href="http://www.un.org">http://www.un.org</a>
UNAM	National Autonomous University of Mexico	<a href="https://www.unam.mx">https://www.unam.mx</a>
UNESCO	UN Educational, Scientific and Cultural Organization	<a href="http://en.unesco.org">http://en.unesco.org</a>
UNOOSA	United Nations Office for Outer Space Affairs	<a href="http://www.unoosa.org">http://www.unoosa.org</a>
WG5	Working Group 5	

[www.life-origins.com/content/wg5-history-and-philosophy-sciences](http://www.life-origins.com/content/wg5-history-and-philosophy-sciences)

# 1. Astrobiology and Society in Europe (D. Dunér)

There is only, as we know it, one planet with life – our own Earth. However, current research in astrobiology searches for a second sample of a living world. Astrobiology, which concerns the origin, evolution, and future of life here on Earth and beyond, has become a rapidly expanding research field during the last two decades. European researchers are playing a leading role. Thousands of planets in other solar systems have been discovered. Knowledge about life’s evolutionary origin, and its requirements and environmental conditions have expanded considerably. It is not unlikely that one day – some say that this could happen within the next few decades – we will discover evidence of the existence of another living planet. Living or fossilized microbes could be found within our Solar System, or we could find signs of biological processes on planets in other solar systems. But even if this never happens, astrobiological research will still give us a new understanding of how life emerged on our planet, how it evolved, and what environmental conditions it needs in order to survive. In all, current and future research in astrobiology will change the view of how humans look at themselves, what it means to be a human, to be alive, to survive, where we come from, and where we are heading. Astrobiology has clear existential implications, but beyond these, it also has concrete cultural, ethical, societal, educational, political, economic, and legal consequences. How will the general public react if we discover life on another planet? What pedagogic role can astrobiology play in elementary and higher education? To what extent should we utilize space for commercial and industrial purposes? How should this be politically managed and how should it be legally regulated? This White Paper on the societal implications of astrobiology research in Europe, which is a joint interdisciplinary effort of Working Group 5 within the COST Action TD1308 “Origins and Evolution of Life on Earth and in the Universe”, aims to gather together these challenges and implications, and in so doing lay the ground for a European Astrobiology Institute.

## **1.1 The Contribution of Humanities and Social Sciences to EU Astrobiology (K. A. Čápková, E. Persson)**

The aim of this document is to lay the ground for a coordinated multidisciplinary European Astrobiology Institute (EAI) and to establish the contribution of the social sciences and

humanities to astrobiology research in Europe. It is envisioned that the humanities and social sciences will make the following contributions to EU Astrobiology:

- Assist in the shaping and modification of foundational scientific concepts such as ‘life’, and provide useful social and historical frameworks for these concepts.
- Support the foundation of the European Astrobiology Institute and assist in shaping the future of European astrobiology research.
- Anticipate and prepare for novel ethical challenges related to the conduct of science; and assist in making informed decisions on astrobiology research.
- Provide insights into popular understandings of astrobiology and support astrobiology communication, dissemination, education and training.
- Initiate and conduct relevant social science and humanities research activities in a European context; conduct research into societal perceptions of astrobiology and into the immediate effects of the advancement of science on society.
- Explore the existential implications of scientific findings.
- Disseminate research results to the public and produce materials for dissemination; increase astrobiology awareness and literacy.
- Take part in educational activities such as summer schools, outreach events, and engagement with mass media.
- Assist in the production of educational materials as well as school curriculum development, training programmes and teacher training.

## **1.2 What is Astrobiology? (A. Kereszturi, M. Gargaud)**

Astrobiology, the study of the origin, evolution, distribution, and future of life, is a multidisciplinary activity that involves natural sciences such as biology, astronomy, chemistry and geology. Astrobiology encompasses the search for life elsewhere in the universe and in terrestrial environments which are analogous to those of outer space. The study of extreme life forms, extremophiles, is of great importance to astrobiologists in these efforts to expand our view of the potential for life elsewhere. The scope of astrobiology research is framed by the following set of questions:

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

## **1.3 Organising EU Astrobiology Research (M. Gargaud, W. Geppert)**

### **Background**

Astrobiology has the potential to be a flagship of European cooperation in science. It provides an ideal ground for collaborative European projects which support the ethos of cooperating countries. Making astrobiology a visible part of European science should therefore be a priority for the EU.

### **Challenges**

The establishment of a European Astrobiology Institute will provide the perfect forum for such collaborative efforts and should be a key priority for European research institutions as well as the European astrobiology community. To have an active astrobiology research programme, coordinated and fostered by such an institute, will enhance the international standards of European space research, and of European science in general.

This White Paper recognises the establishment of the EAI as such a priority and is designed to be one of its founding documents. It also acknowledges the societal implications of astrobiology, and thus the role of the social sciences and humanities in optimizing the positive contribution that astrobiology can make to the lives of the people of Europe and the challenges they face.

### **Suggestions**

A dedicated European Astrobiology Institute should coordinate astrobiology activities across Europe and benefit from interdisciplinary and multidisciplinary engagement. The EAI will be well placed to promote astrobiology research, assist in the decision-making process of relevant European institutions, be involved in mission planning, engage in science dissemination, education and communication, as well as outreach and media work. The following would be appropriate tasks:

- Perform cooperative cutting edge research in Europe, focussing on a set of agreed central themes.
- Coordinate astrobiology research and related scientific activities in Europe.
- Support interdisciplinary networking and interactions between researchers from different fields.

- Coordinate European training, education and outreach activities in astrobiology.
- Act as an external advisor for ESA and other European research bodies.

The EAI will thus function as a distinct entity to coordinate, promote and further develop EU research in astrobiology. It will cover all aspects of astrobiology research on a European level and strive to sustain the European Research Area's role as a world leader in this comparatively new but established and rapidly developing field.

## 2. The International Context of Astrobiology (E. Persson, J. Arnould)

Astrobiology is an internationally established field with research taking place on all continents, including Antarctica, by research teams from all over the world. The International Astronomical Union (IAU) established a commission for what was then called ‘Bioastronomy’ in 1982. Its successor, the Astrobiology Commission of the IAU was established in 2015.

The USA is currently the main leading nation within astrobiology with the largest number of researchers as well as the highest level of research output. This is at least partly an effect of the establishment of the NASA Astrobiology Institute (NAI) in 1998 to promote cooperation and provide meeting grounds and funding for the research community. European research teams are, however, already playing an important role and have provided several major breakthroughs in the field. In order for the European research community to become an even more highly regarded actor and valued cooperation partner in the field, we believe that it is important to draw lessons from other countries and adapt them to a European setting. The establishment of the NAI was an important research infrastructure initiative. However, in order to work in a European setting, and draw out our areas of strength, the idea of an institute needs to be adapted. Europe has essential and unique strengths in astrobiology: a network of national and international scientific institutions, with high-level skills proven by several space missions and programs; a community of lawyers and a distinctive legal tradition involved in the elaboration and evolution of space law; an extensive academic network, already committed to reflection on the scientific and social dimensions of astrobiology.

An important strength is the European tradition of bridging the ‘two cultures’ of science and the humanities, and integrating the practice of science with social responsibility. Although there are crossovers between the two in other parts of the world, such a distinctive *ethos* of interdisciplinarity and multidisciplinary is less visible elsewhere. Below, it is recognised as a limitation of the, otherwise strong, US experience.

## **2.1 European Astrobiology Research to Date (S. Tirard)**

### **Background**

The European Space Agency (ESA) was founded in 1975 and its missions and projects have helped to promote the emergence of a dynamic research on space in Europe. The International Space University (ISU) was founded in 1987 in Strasbourg, dedicated to the research and development of outer space exploration for peaceful purposes, through international and multidisciplinary education and research programs.

Astrobiology has its place in most ESA programs, and is therefore supported by substantial financial and technological investments from its member states. The Rosetta mission's confirmation, in 2016, of a connection between comets and the life-supporting atmosphere of the Earth illustrates the point. So too does the ongoing ExoMars Program, a joint astrobiology project of ESA and the Russian space agency Roscosmos with a focus upon biosignatures and habitability.

To help coordinate work in the field, the European Astrobiology Network (EANA) was created in 2001 and has organised a yearly European workshop on astrobiology as well as an online training course. Other permanent networks involved in astrobiology have emerged. For example, the Astrobiology Society of Britain (ASB) was created in 2003; the Italian Astrobiology Society (SIA) in 2006; the Nordic Network of Astrobiology (NNA) was established in 2007; the French Astrobiology Society (SFE) in 2009; the German Astrobiology Society (DAbG) in 2016, and since 2014 the COST Action "Origins and evolution of life on Earth and in the Universe" (Origins) has brought together scientists from 30 European countries. At several European research institutions (e.g. the universities of Edinburgh, Szczecin, Stockholm) astrobiology centres have been launched. Furthermore, an association of students and early career scientists (AbgradE) has been founded. These networks help to organize conferences, grant bids, summer schools and outreach events. They are characterized by interdisciplinarity. As a result, the community of European scientists interested in astrobiology is building a European identity for work in this field.

A number of new initiatives have also recently emerged. The Action ORIGINS has been a welcome boost to the European astrobiology community, organizing a series of well attended meetings and providing funding for research visits by European scientists and students as well as training events. Also, the Action has funded short-term scientific missions for scientists and

held yearly conferences and specialised workshops. The different working groups of the Action have been active in discussing and pursuing new research avenues and organizing focused workshops. For example, the working group on historical, ethical and philosophical questions in astrobiology has been instrumental in bringing researchers from science and the humanities together through the organization of a workshop and an associated summer school in Southern Sweden and through follow-up engagement. Last, but not least, the present White Paper is one of the outcomes of this Action.

The European Astrobiology Campus, launched as a Strategic Partnership under the Erasmus+ programme has provided a coherent and comprehensive training programme in astrobiology. One of its main activities has been to continue and extend the successful series of summer schools organized by the Nordic Network of Astrobiology and the French Society for Exobiology. These events have offered training for future European research leaders in astrobiology, by world renowned scientists, at astrobiologically interesting sites in the field. They have also enabled the attendees to find future cooperation partners and to start their own research projects based on the practical exercises carried out in the summer schools. In a multidisciplinary field it is also important to train the trainers and to foster the development and exchange of innovative teaching methods. To this end, the European Astrobiology Campus and the IAU Commission on Education co-organised a conference on Education in Astronomy and Astrobiology in Utrecht in July 2017. Furthermore, workshops on outreach have been organised and the leading reference work, the *Encyclopedia of Astrobiology*, was co-sponsored by the initiative. The funding for the COST Action and the European Astrobiology Campus are now at an end, officially ending in spring 2018 and autumn 2017, respectively.

## **Challenges**

These initiatives demonstrate the need for greater overall structure and coordination for astrobiology research in Europe. More specifically, the research dynamic is characterized by:

- The need for a more structured interdisciplinary network covering a large spectrum of scientific disciplines and including both the humanities and social sciences (e.g. sociology, anthropology, law, political science, theology, history, and philosophy).
- The need for a sustained coordination of international projects.

## **Suggestions**

These developments and challenges help to provide reasons for establishing a European Astrobiology Institute. The institute will emerge out of the current networks and will be the

best tool to achieve the more ambitious goals of European-wide scientific cooperation. Whereas the EAI will be a consortium of institutions, EANA is (and will remain) a society of individuals. The president of EANA and the four other EANA Executive Council members are also members of the Interim board of the EAI. The discussions on the establishment of the EAI have been held at several EANA workshops.

As a stronger involvement of astrobiology is expected within science in general, societal impact should also be considered seriously, in its own right, and as part of the ongoing dialogue about social responsibility and the broader impact of science and technology. The Institute will have to deal with these issues.

## **2.2 International Outlook (E. Persson)**

### **Africa (E. Nabulya, E. Persson)**

Astrobiology has not, to date, been a major research area in Africa. There are, however, local exceptions. One is the Palaeontological Society of Southern Africa which spearheads research on fossils, for instance the Barberton fossils in the Mpumalanga region. This allows them to consider ideas on the origin of life. Another is the Ibn Battuta Centre for Exploration and Field Activity in Marrakech, Morocco, which is operated by the European research network Europlanet and is used mainly as an analogue environment for testing equipment and strategies for Mars missions. ‘Astrobiology’ is mentioned on the website for the Working Group on Space Sciences in Africa but without any details, and is not mentioned in the Mombasa Declaration on Space and Africa’s Development, an important statement on the future of research in Eastern Africa. Nor is it among the areas of interest listed by the Astronomical Society of Southern Africa (ASSA). Notwithstanding, there is a detectable interest throughout Africa in issues concerning extraterrestrial life in cultural products such as films, fiction and fine art.

### **Asia (E. Persson, A. Anglés)**

China and Japan are both active in astrobiology research. Both are fairly well represented at international astrobiology conferences, and both are involved in international cooperation with European research groups and individual European researchers. Important international astronomy conferences have been held in Japan, Vietnam and India, and the International Conference on Astronomy and Astrobiology in 2018 will take place in Osaka, Japan. The Astronomical Research Institute of Thailand (NARIT) is cooperating with its Asian partners,

such as the Astrobiology Centre (Japan), Beijing Planetarium (mainland China) and KASI (South Korea) to organise outreach events related to astronomy and astrobiology for high school and university students, teachers and the general public. The Thai-Asian Astronomy Forum also receives support from other organizations to organise talks and events about Astrobiology and Life in the Universe. The Earth Life Science Institute (ELSI) at the Tokyo Institute of Technology is already one of the most active research institutes in the field and continues to invest substantially in active research, research facilities and in recruiting top researchers from Japan as well as Europe and elsewhere. Since 2015, the Japanese Space Agency (JAXA) and a number of Japanese universities have run an experiment at the International Space Station (ISS) investigating the potential for interplanetary transfer of organic material. One of the missions for China's new Five Hundred Meter Aperture Spherical Telescope (FAST) will be to search for radio signals from Extraterrestrial Intelligent Life, partly backed by the Breakthrough Initiative (a body involving Mark Zuckerberg and the late Stephen Hawking). There is also a newly initiated cooperation between Europe and China, the ISSI Astrobiology Team, aiming at accelerating the growth of astrobiology in China. The University of Hong Kong, one of the members of the International Space Science Institute (ISSI) Astrobiology Team, is a top-level research institution where researchers are focused in the detection of life beyond Earth and the origin of life on Earth. India and South Korea also have active research groups and research centres as well as some ongoing educational work in astrobiology. In 2016, the International Centre for Interdisciplinary Science Education in Vietnam organised an international astrobiology conference in cooperation with European researchers.

### **North America (L. Billings, K. Smith)**

North America, traditionally the leader in space exploration programmes, also plays a leading role in astrobiology research worldwide. The establishment of the NAI in 1998 was an innovative way to develop the field of astrobiology and to provide a scientific framework for flight missions. Recently, NASA has undertaken new initiatives designed to broaden the community of scholars working on the societal aspects of astrobiology research.

Since 2012, in collaboration with the Kluge Center of the US Library of Congress, the NAI has funded a Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology. The Blumberg Chair makes it possible for a senior researcher to be in residence at the Kluge Center, to make use of the Library of Congress collections, and to convene programs that ensure the subject of astrobiology's role in culture and society receives considered treatment.

The Chair has resulted in a series of congressional hearings on astrobiology held by the House Science, Technology, and Space Committee as well as a number of books, interdisciplinary dialogues, and several public symposia. (For fuller information, see Appendix 9.3)

### **Latin America (S. Ramos)**

Astrobiology research in Brazil dates back to 1958 with Brazilian astrobiology focusing on extremophiles and biosignatures on exoplanets. NAP-AstroBio is an online discussion forum based at the University of São Paulo, covering these and related topics, spanning extremophiles, extraterrestrial environment modeling, and habitability. The Mexican Society of Astrobiology (SOMA) is also pursuing multiple lines of astrobiology research and organises the Mexican School of Astrobiology. The majority of Mexican astrobiology researchers are associated with the National Autonomous University of Mexico (UNAM). Researchers at the National University of Colombia are also addressing astrobiological issues from both scientific and philosophical perspectives.

Chile is the host country for the European Southern Observatory, with the latter playing an important role in exoplanet research. Researchers in Atacama Biotech Astrobiology and Biotechnology are working on projects in the Atacama Desert, which is considered a good analog model for Mars. As a result of its profile in the field, Chile was also the host country for the 2017 IAU astrobiology conference. Peru has several astrobiology oriented organisations and has hosted meetings on astrobiological issues. The La Joya desert, located in the Arequipa region of Peru, is a Mars analogue. The University of Lima gives classes and workshops discussing links between astrobiology and philosophy. The Scientific Society in Peru is also aiming to develop an Institute of Astrobiology in Latin America. Argentina is already home to two research groups in astrobiology with both groups working on simulation of interplanetary conditions. They have developed a device for use with future space missions that can probe for evidence of life in other parts of the Solar System.

## **2.3 Current Regulations and Planetary Protection (J. Arnould, G. Kminek)**

### **Background**

The first concerns about contamination that could jeopardize future scientific exploration have been raised already in 1958 and the first code of conduct to avoid such problems was used by the US Ranger missions to the Moon in 1961. Since then, various mission beyond Earth orbit

had to implement planetary protection measures at different degrees – ranging from simple documentation to terminal sterilization of entire flight systems.

The basic goals for planetary protection regulations are to:

- Ensure that scientific investigations of possible extraterrestrial life forms, precursors, and remnants are not compromised (forward planetary protection)
- Protect the Earth from potential harmful extraterrestrial biological contamination (backward planetary protection)

The forward planetary protection regulations provide the right boundary conditions to allow astrobiological science missions to other moons and planets. The legal basis for planetary protection was subsequently established in Article IX of the 1967 United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies (Outer Space Treaty). The Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) maintains the planetary protection regulations as a reference for spacefaring nations and to guide compliance with Article IX of the Outer Space Treaty.

### **Challenges**

The methodological and legal principles, which have shaped planetary protection regulations and measures currently seem sufficiently reasonable and consistent with the science of astrobiology. There are, however, two aspects that require more attention and action by some stakeholders:

- The increased interest of non-governmental entities in space exploration and utilization has shed some light on a regulatory aspect not properly covered by some States that are signatories of the Outer Space Treaty. Article VI of the Treaty clearly states that the States Parties to the Treaty bear international responsibility for their national space activities and are also required to authorize and continuously supervise the activities carried out by non-governmental actors.
- Understanding the origin, evolution and distribution of life in the universe is a clearly stated objective in the recommendations of various scientific organizations and is reflected in the different space agencies programs. In addition to the basic scientific interest, the presence of extraterrestrial life could also present a threat to human explorers, equipment they use, in-situ resource utilization, and the terrestrial biosphere after their return. In this context planetary protection has to be understood as an

enabling capability to avoid compromising scientific investigations and to support the preparation of subsequent human exploration and use of outer space.

### **Suggestions**

To address the first issue a number of State Parties to the Treaty - some of them are new or prospective spacefaring nations, but some of them pioneers in space - still need to establish or extend their national regulatory regime to be in line with the full scope of their responsibilities identified in the Treaty.

To address the second issue it is necessary to ensure that the relevant investments to further develop the planetary protection capability are in place, and are harmonized with the overall exploration roadmaps at national, European and international level.

Acting on both of these issues is considered essential and time critical in order to ensure that planetary protection measures continue to protect our investment in space science, exploration and utilization of space, for all humankind.

### 3. Society, Worldview and Outreach (K. A. Čáková)

As well as impinging upon issues of law and governance, astrobiology is also bound up with questions concerning who we are and where we come from, worldview questions of a more existential and philosophical sort. The questions that it seeks to tackle have, for centuries, been central to the humanities and to social science disciplines.

The social significance of astrobiology stands out in its impact on forms of social life such as religious beliefs, spiritual commitments and the worldviews of contemporary Europeans. The question ‘where do we come from?’ is a common theme in theoretical cosmogonies of origin that explain the creation of the world (creation myths) and origin of the humankind globally. They are a central component of human self-understanding and a cultural frame of reference in worldview formation.

Given the social and cultural significance of these questions, their public appeal and attractiveness to mass media, astrobiology carries the potential for academic and social impact. However, the far broader social implications of these questions and the role they play in contemporary debates, are reflected in numerous literary works, in films, plays, gaming industry, music, and fine arts. They are integral to contemporary (Western) society and popular culture.

#### 3.1 The Public Understanding of Astrobiology (K. A. Čáková)

##### **Background**

The role of the social sciences and the humanities in relation to astrobiological research and its public reception can be divided into four broad areas: clarifying key scientific concepts and providing them with background narratives; understanding, and anticipating, the social impact of science; astrobiology outreach and popularisation; and science education and training. Astrobiology as a science and as the production of new knowledge may change the ways in which we situate ourselves in the world, but it is likely to do so at least in part through rapidly evolving communication channels and digital media. As examples, the worldwide reporting of discoveries of liquid water on Mars, and of new extrasolar planets, have occurred in real time and have been subject to all of the kinds of scrutiny, modification and reinterpretation that our developing technologies allow.

## **Challenges**

Astrobiology as a newly formed multi-disciplinary field of scientific enquiry plays an important role in the study of knowledge production and science as a practice. The history and philosophy of science contribute to an understanding of the dynamic processes of science development. New fields of social research, such as Science, Technology and Society (STS) and the anthropology of science, explore how society (on the one hand) and science, research, and technology (on the other) affect one another.

With the power of social media on the rise, it can provide what may seem almost the opposite to the academic peer review process. Social media make science easily distributable yet they may also affect its credibility and the reliability of the information that is shared, modified and often reproduced in altered contexts. Making sure that information is distributed in a reliable way to the interested public, as well as to classrooms, will be a challenge. There is a need for scientists, as well as decision makers and planners, to understand how the public responds to science and how it understands new discoveries in basic research. There is also a need to address at least some popular beliefs that mimic certain aspects of science, especially beliefs that tend to compromise the practice of actual science and the reliable dissemination of its results.

## **Suggestions**

The social sciences and humanities play a key role in understanding, anticipating, and handling misconceptions about scientific research. Their more qualitative approach may provide understandings of social processes and help to provide insights into how the workings of astrobiology may be communicated to a broader audience than that of practicing scientists.

## **3.2 Popularisation, Dissemination and Outreach (L.Dartnell)**

### **Background**

Science engagement with the general public is a crucial component of academic research. Much research is publically funded, and thus ultimately paid for by taxpayers. Outreach and dissemination are part of the reasonable transparency and openness of science that the public are financing. A public that is engaged with science may also be better placed to appreciate it, better placed to recognise the value of conducting diverse research, and better placed to comment on the practice of science from an informed viewpoint. The importance of this has

been highlighted in recent years through unwarranted but widespread suspicion of genetic engineering and nanotechnologies.

Outreach can provide school students with captivating events and role models to inspire them to continue Science, Technology, Engineering, Mathematics (STEM) subjects through to secondary education and university. This is vital for the information and technology economy as well as for training the next generation of research scientists. The potential for astrobiology outreach will differ from that for medical or healthcare research, and may have a different appeal. But this diverse interdisciplinary research field is intrinsically interesting to the general public and to school students. It also has a large potential for attracting positive attention to science.

### **Challenges**

Given the appeal of speculation on our origins, and the search for life beyond Earth, astrobiology has a large potential to contribute to producing not only a scientifically skilled workforce but also a scientifically literate public, with the further benefit of orienting young people toward technology-related domains alongside science. However, this interest in the subject-matter of astrobiology means that the field is also vulnerable to misinterpretation, or even mistaken association with pseudo-scientific theories. A special challenge is presented by mass media which tends to favour fascinating stories about life elsewhere. A common misconception is the conflation of astrobiology and the search for life with UFOs and abduction stories. Fascination and interestingness can take the place of concern for reliable evidence and truth, with basic levels of scientific accuracy being compromised.

A further challenge for astrobiology communication concerns the response to an actual discovery of clear evidence for life beyond our planet. Answers to key questions concerning the responsibilities of the media, the scientific community and government authorities are unclear. Particularly so over key questions of how best to respect a public entitlement to know, how to inform the general public about a successful detection of extraterrestrial life, and when to do so. Press conferences before peer review have often turned out to be premature and can harm confidence in astrobiology and commitment to the funding of viable forms of research. A delay in making a discovery of life public, until the result has been through the peer review process, could on the other hand result in rumours and feed conspiracy theories. A set of guidelines or protocols stating how to proceed could prove useful.

Another challenge, but also an opportunity, is to engage the citizen science community even more in the process of searching for habitable planets and to further engage the public in the co-creation and open use of research data by exoplanetary surveys. Commitment to doing so is a core value of the Open Science, Open data and Open to the World policy, as stated by the European Commission.

### **Suggestions**

The internet is a very powerful tool for research and for the dissemination of results. It has also increased the rapidity with which views can spread in a ‘viral’ or ‘meme-like’ way. It is, therefore, important for astrobiology researchers to engage with the public through such media in order to present the discipline as it truly is, the scientific methods that are used, and the genuinely exciting discoveries being made. To effectively manage situations of major discovery and instances of viral misreporting would require, at least, a statement by a reputable astrobiology community body in response to the dissemination of any inaccurate information, especially where the latter carries the potential to affect future funding decisions and the conduct of science. Overall, a unified strategy for astrobiology communication is needed alongside active engagement in astrobiology outreach and the dissemination of research results at the international level. Such a strategy would involve, firstly, the development of a dissemination plan to raise awareness of the EAI and the work of the astrobiology community within the EU in, and among, target audiences and stakeholders. This would help to maximise the impact of communication efforts. Secondly, such a communication strategy would raise awareness of work on astrobiology within the broader science community and help to develop models for outreach and the dissemination of astrobiology to schools, the general public, and private companies, using available communication channels known to be favoured by the relevant audiences.

## **3.3 Rethinking Humanity’s Place in the Universe (D. Dunér)**

### **Background**

Astrobiology can help to answer longstanding questions about whether or not we are alone in the universe and about where we have come from, where we are going, and how life first emerged. As indicated above, it responds to questions of a more philosophical and existential sort. We might even say that, although it is a scientific discipline, it responds to the deep longings of humans as social beings. The separation of disciplines that is an unavoidable feature of a classic system of education, specialization and academic training, leads many of

us to set aside questions of this kind at some point. These fundamental questions can, however, keep people motivated in searching for answers, and keep people open minded and oriented towards scientific and technical fields that promise some kind of reliable answer as well as supporting economic development by innovation.

### **Challenges**

Astrobiology challenges our understanding of ourselves as human beings in the Universe. The search for life elsewhere touches on fundamental hopes and fears, on what it means to formulate a theory, grasp a concept, and develop our imagination. Contemporary astrobiology is, however, more than the result of discoveries and theories. It is the product of multiple and complex social and cultural processes. These include collaborations and technological changes which have made the current goals of astrobiology ambitious but realisable. The future success of astrobiology rests on how well the astrobiological community can perform efficient collaborations, build up supporting institutions, and integrate new technologies into research and into the spread of new knowledge. The challenges are socio-cultural as well as scientific.

### **Suggestions**

As astrobiology is a human endeavour to answer profound existential questions about humanity, the consolidation and further success of astrobiological research would benefit from a recognition of the societal, and cultural factors involved in science. Among other things, it would benefit from closer consideration of the ethics of space exploration, questions about the nature of knowledge, and about the historical emergence of astrobiology as a scientific enterprise. Research in the humanities and research in the social sciences are therefore necessary contributions to astrobiology and complement the relevant ongoing work within biology, chemistry, geology, and astronomy.

## **3.4 Astrobiology and Religion (A. Melin, P. T. Mitrikeski)**

### **Background**

Religion is an important influence upon beliefs, behaviours and sense of belonging. It can influence people's perception of astrobiology and the prospects for a discovery of life elsewhere. The latter could have an unsettling effect on particular faith groups, although perhaps less so for Buddhists (who often believe in many worlds), and Muslims (given the apparent commitment to such life in the Qur'an). Based on an interpretation of the ancient

Biblical poem, The Song of Deborah, several well-known Jewish rabbis have argued that intelligent extraterrestrials exist. According to Judaism, salvation is also open to all creatures with moral choice, and it is not dependent on the existence of one unique savior. Some (not all) Christian denominations face a larger challenge.

### **Challenges**

For Christians, the possibility of microbial life outside of the earth raises the theological question of whether there might also be intelligent life elsewhere, and beings also in need of redemption. For evangelical Christians, committed to some notion of a divine plan, the existence of microbial life on its own, playing no further role, could be difficult to accommodate. However, the possibility of more advanced life elsewhere gives rise to the theological problem that there could also be more than one savior. Historically, many mainstream theologians within Western Christianity have denied the existence of extraterrestrial life for precisely this reason: the uniqueness of Christ's redemptive mission seems to rule out the possibility of intelligent life forms on other planets. However, some Christian traditions in Europe, such as the Orthodox Christianity of the East, might place greater emphasis upon love and divine glory, and may more readily accommodate discovery since it can change little in the traditional beliefs of the Eastern Church. However, the split here may not be East/West, but rather along the lines of Protestant evangelical (where skepticism about life elsewhere has been most concentrated) and other forms of Christianity. Yet, even this is a simplification of complex patterns of religious attitudes, with many Protestant evangelicals perfectly open to the prospect of extraterrestrial life, and ready to accommodate its possible theological implications.

### **Suggestions**

Research about religious views of extraterrestrial life (however microbial) has tended to be primarily historical and focused on canonical texts. Thus, there is a need to extend and incorporate more sociologically oriented empirical research about religious believers' views about such life. The results of such research should be communicated to religious bodies and to the public.

## 4. Environment and Sustainability (E. Persson)

There are strong links between astrobiology and environmental concern. Astrobiology is the study of the origin, evolution and distribution of life in the universe – including Earth. Understanding life, and in particular the basic conditions for life, is important for our ability to create a sustainable future on Earth. The connection goes both ways, however. The preservation of biodiversity and of pristine environments on Earth is of the greatest importance for our ability to study life, its origin, distribution and future. Of special interest from an astrobiology perspective is the preservation of areas with conditions that can serve as analogues to extraterrestrial environments, areas with conditions similar to those under which life originated on Earth, and in general environments where extreme adaptations can be studied. Astrobiology also presents some direct environmental challenges that need to be considered, namely in the form of forward and back contamination (discussed above in 2.3). Both issues need to be approached from a technical perspective, but also from a societal perspective. And both must be understood within a broader context of ensuring the sustainability of practices, both scientific and commercial.

### 4.1 Environmental Protection and Sustainability (T. Milligan)

#### **Background**

While the prospects for commercial mining in space may be good, and while space may seem to offer inexhaustible resources for scientific investigation and commercial use, the resources which are actually available at any given time are likely to remain limited and unevenly distributed. Without direct access to the asteroid belt, there are only a small number of metallic asteroids whose trajectories might allow them to be mined. Similarly, there are only a limited number of actual planetary surfaces within the Solar System where in situ scientific investigation by humans is ever likely to occur. The gravity wells of the outer planets may simply be too deep for return missions from the gas giants to be practical. Nearer to Earth, there are only a limited number of sites where special target resources such as helium 3 (for possible energy generation) can be found in the kind of density that might make an extraction industry viable. And there are only a limited numbers of sites where strategically valuable resources (such as water ice and the most favourable conditions for solar arrays) can be found in combination. While, overall, the opportunities are immense, the resources which will be

available at any given time are exhaustible. In some modified form, familiar terrestrial concerns about ensuring that the use of resources remains sustainable, will continue to apply.

### **Challenges**

The idea of a ‘colonisation’ of space is deeply embedded in popular culture, yet it may not be the only or best way to make sense of exploration (and possibly settlement). This is not simply a matter of the problematic historic associations of the concept. Rather, it may also suggest that human activity in space is about one single project, rather than a cluster of different projects and activities, involving multiple interests and stakeholders. When the latter are faced with a limited resource, or with limited opportunities, some way of building a reasonable consensus about how to proceed will be required. Such a consensus will have to factor-in (i) the importance of not rapidly exhausting what lies nearest; (ii) considerations about terrestrial impact (e.g. how an emerging space economy with comparatively rapid growth rates will impact upon economic development on the Earth); (iii) the importance of sustaining continuous access to suitable opportunities for scientific research. For example, on some occasions the window of opportunity to conduct an assessment of the potential astrobiological importance of a site may be restricted, in which case advance preparation (e.g. through work at analogue sites) will be of key importance.

### **Suggestions**

While sites of special scientific or cultural significance (e.g. first-landing sites) may need comprehensive protection from commercial use, many locations will be candidates for both scientific examination and commercial activity. Protocols for site evaluation will need to be developed, and ways of assessing impact devised. As part of a broader overview, there is also a need for new methods to help classify site types and to quantify overall human activity (of various sorts) in order to avoid the problems associated with exponential growth.

## **4.2 Earth Sites of Importance for Astrobiology (J. Martínez-Frías)**

### **Background**

On Earth, three types of environment are especially important sites for astrobiology: habitats for extremophiles; areas that can be used as analogues for environments (and paleoenvironments) on other worlds; and areas that are dark, have a large number of cloud-free nights and a stable atmosphere and are therefore suitable for space observation.

These areas match up with three of the deep questions about life introduced in previous sections: How does life begin and evolve? Does life exist elsewhere in the universe? What is the future of life on Earth and beyond? Analogues are of particular importance. Space exploration and research confirms that the Earth is a system, but also a model. New discoveries on other moons and planets (e.g. Mars) are largely supported and guided by knowledge obtained from the study of particular analogue sites on Earth. These planetary analogues have distinctive geological and environmental features which approximate, in specific ways, those we may encounter on other celestial bodies in their present condition, or which may have prevailed during their earlier geological histories. Such analogues are especially important for preparing missions to these worlds through the gathering of general knowledge, the testing of equipment and (in the case of manned missions) the training of the crews. For example the ESA-Pangaea course (Planetary ANalogue Geological and Astrobiological Exercise for Astronauts in Lanzarote) is designed to provide European astronauts with the practical knowledge required to work as effective partners for planetary scientists and engineers.

### **Challenges**

Astrobiology can reshape our understanding of which resources are scarce, or more scarce than we might imagine. With regard to the third type of site that is of importance to astrobiology, it is significant to note that darkness is a resource that is becoming rare and needs special protection. Some areas that are important for one or more of these three reasons are already protected as world heritage sites, national parks, or UNESCO Global Geoparks. However, in order to be able to continue European astrobiological research, much more has to be done in this respect. It is important to note that new planetary discoveries enrich, through a feedback process, our appreciation of the relevant features of such terrestrial sites. However, at present, some of the sites that are most important for European astrobiological research are located outside of Europe and this poses an associated set of challenges. (See section 2.2, above, for one such site.)

### **Suggestions**

It is important to deal with the protection and preservation of all three types of sites on a societal and ethical level in order to handle potential conflicts between astrobiological research and other uses. As some of the most important sites for European research are located outside Europe, the process can require complex methodological protocols and multidisciplinary input from Political Science, Applied Ethics and Law.

## **4.3 Environmental Ethics in Space (T. Milligan, E. Persson)**

### **Background**

One of the dominant ethical issues in contemporary astrobiology is the avoidance of contamination. Such avoidance is partly dealt with by the planetary protection guidelines (described above in 2.3). Planetary protection has been an important aspect of astrobiology since its emergence in the 1950s, and a key part of the legislative framework for exploration set out in the Outer Space Treaty (OST). As noted previously, the Treaty does not cover all aspects of contamination since it centers upon worries about forward contamination (preventing damage to sites in order to protect opportunities for science) and back contamination (ensuring that dangerous materials are not returned to Earth). This is the legally underpinned framework within which COSPAR currently makes its recommendations. In recent years there has been a good deal of discussion, inside and outside of COSPAR, about how the OST can be read in the ‘best light’ and about whether or not planetary protection should now be thought of in broader terms than those of Article IX which deals with contamination avoidance. Also, there has been a good deal of discussion about whether the ethical principles underlying concern about back contamination should also carry implications for forward contamination. (In which case, they may have to be understood in some broader way.)

### **Challenges**

It is not obvious that the original focus on protection for scientific examination, and for the avoidance of returning contaminants, is sufficiently broad to match up with a more contemporary understanding of environmental ethics. Within the latter, other considerations are regularly brought into play:

- Recognition of the possible value and moral status of extraterrestrial life and of extraterrestrial environments beyond their value as study objects.
- Recognition of the special cultural standing of particular places.
- Sustainability over multiple generations, e.g. protection of places for future generations of humans to experience and to use.
- Wilderness zoning.
- Memorialization of historic sites (e.g. Apollo landing sites).
- Balancing out economic development, scientific interest and ethically driven protection.

- The identification of potentially scarce resources (such as water ice) and how access to, and the use of, such resources are best approached.
- Engaging with ethical and religious discussions about the importance of ‘place’ and the ‘integrity’ of locations, as well as discussions about notions of ‘inherent value’ (beyond human use) that places might have.

### **Suggestions**

To begin to meet these challenges, there is a need for more research in the astrobiological humanities and especially into the crossovers between discussions of space exploration within disciplines such as ethics, law, policy and anthropology. There is also a need for a framework to promote greater engagement between those working within such disciplines and stakeholders within the emerging space economy.

## 5. Education, Training and Scholarship (W. Geppert)

Astrobiology deals with research questions which are at the core of our human existence. This means that such questions are well suited to attract attention by scholars and students of all age groups, as well as the general public. As it is an interdisciplinary research field, astrobiology can be included as a subject in different STEM disciplines, and in different branches of the humanities and social sciences, at almost all levels of education. In studies involving the use of the Internet, primary school students have already shown an increasing interest in astrobiology-related topics. These include topics such as the identification of habitable exoplanets, icy satellites and minor bodies inside the Solar System. Other topics which have been particularly of interest include planetary missions to look for organic molecules and liquid water on Mars. At secondary school level, astrobiology could provide an integrative framework for forging connections between different subjects and encouraging cooperation between teachers. It could also form the basis for a more project and problem oriented education in science subjects.

### 5.1 Astrobiology Training and Education (W. Geppert)

#### Background

The effectiveness of this interdisciplinary approach has been shown by several examples of curricula development in the US. Similar initiatives have also emerged in Europe. The astrobiology research community can contribute to education in Europe by providing training for teachers, visits to schools, organising trips to top level laboratories, and by contributing to textbooks and online information resources. Because of the continuously changing content of scientific knowledge, teaching in astrobiology can also support the development of a flexible and open minded, problem oriented approach towards science. Furthermore (as noted in section 3.2), the high profile of astrobiology-related questions makes astrobiology teaching a useful tool for attracting young people to careers in science and technology.

#### Challenges

Training in astrobiology at the university level is of particular importance because astrobiology provides fundamental and intriguing research questions for students and early stage researchers, questions that cannot be tackled by any one discipline alone. Multidisciplinary and interdisciplinary training is therefore important to educate researchers capable of working on these issues. The expertise to provide this training is not usually found

in single institutions or even in one country. The Nordic Network of Astrobiology and the COST Action “Life-ORIGINS” have already demonstrated the effectiveness of interdisciplinary astrobiology training for future researchers in Europe through the holding of a number of international summer schools for PhD students and early stage researchers. The training has included practical field work at relevant sites. Nevertheless, a coherent and comprehensive European training structure in astrobiology is required. The above mentioned organisations have therefore created the “European Astrobiology Campus”.

### **Suggestions**

A continuation of the activities on the European level is necessary to provide state of the art training in astrobiology at all levels. The main tasks should be thought of as:

- Providing interdisciplinary training for students and multidisciplinary courses, held at astrobiologically interesting places, involving practical research work.
- Encouraging participants in summer schools to plan and perform follow-up research work, and training them in the transferable skills that they will require in order to become future research leaders.
- Creating a forum for lecturers to exchange ideas, concepts, and lecture materials as well as holding meetings on astrobiology training (i.e. training the trainers).
- Providing materials for school teachers in astrobiology.
- Coordinating outreach activities in astrobiology at a European level in collaboration with museums and other stakeholders.
- Creating reference works in astrobiology for the scientific community, for students and for the general public (comparable to the *Encyclopedia of Astrobiology*).
- Holding summer camps for undergraduate students in astrobiology.
- The organisation of meetings for students and early career scientists.

## **5.2 Astrobiology and Society in European Scholarship (D. Dunér, Z. Kaňuchová)**

### **Background**

While a considerable body of scholarship on space policy has already been produced, academic research on the societal aspects of astrobiology (with the exception of Space Law) is still in its infancy. As the relevant societal issues are of general interest, they often receive passing mention in more scientific publications. However, sustained analysis is comparatively rare in spite of a longstanding recognition of their significance. The very first serious

treatment of societal issues in Europe seems to have been in 1974, when the Royal Society of London sponsored a meeting on “the recognition of alien life”. Since then, the field has gradually begun to attract serious scholarly and worldwide attention among academic researchers in the social sciences and humanities. European researchers are clearly in the forefront of these efforts, with European research groups tending to take a broader interpretation of “interdisciplinary research” than their US counterparts. A European Astrobiology Institute with a mission of disciplinary inclusiveness would thus take advantage of an important opportunity.

European researchers have been especially active in the last decade. In 2009, the Vatican hosted a week-long conference on extraterrestrial life which brought together scientists and theologians to address social, ethical, and religious issues in astrobiology. The following year, an explicitly multidisciplinary research project began at Lund University on “Astrobiology – Past, Present, and Future”. This project involved several humanities researchers and resulted, among other things, in the first international conference on the History and Philosophy of Astrobiology, as well as a special issue of the journal *Astrobiology*, and an anthology published by Cambridge Scholars on the same theme.

Then, in 2011, The Royal Society hosted a conference on “The detection of extraterrestrial life and the consequences for science and society”, which resulted in a conference volume. In 2012 The Center for Space and Habitability was founded at Bern University with the explicit mission of fostering dialogue and interactions between the various disciplines interested in broader astrobiological issues. In 2014, the Vatican Observatory cosponsored a conference with the University of Arizona’s Steward Observatory on the search for life. In 2015, the Second International conference on History and Philosophy of Astrobiology was organized by the Nordic Network of Astrobiology in 2015, and in 2016, COST sponsored the “From Star and Planet Formation to Early Life” conference, which explored various social and ethical themes. There is a solid foundation of collaborative work to build upon.

### **Challenges**

One of the major challenges for research concerning astrobiology and society is interdisciplinarity, finding opportunities for interdisciplinary/multidisciplinary collaboration both between science and the humanities/social sciences and between disciplines within the humanities/social sciences. A further challenge is integrating relevant research within the humanities/social sciences that can contribute towards research concerning the societal implication of astrobiology research.

## **Suggestions**

A future European Astrobiology Institute should take an important role in interdisciplinary and multidisciplinary collaborations for developing an understanding of the societal implication of astrobiology research. It will give a platform for mutually beneficial collaborations across disciplines, and take advantage of contemporary research within the humanities and social sciences which has special relevance for the understanding of astrobiology and society in Europe today.

## **5.3 Science and Technology Awareness among Students (M. Waltemathe, E. Hemminger)**

### **Background**

Research data on the attitudes toward science and technology held by students enrolled in teacher-training programs in the humanities and social sciences shows a dichotomy between attitude and knowledge. The students have only basic knowledge about key concepts of science and technology. At the same time, these same students feel it necessary to ethically and morally evaluate science and technology and their place in our modern society. Also, in spite of a widespread interest in science and technology among university students from the humanities and social sciences, they will often lack key competencies that would enable them to make useful connections between their own disciplines and science and technology research. The reasons for this are complex but include discipline specialization and differing research cultures, as well as the depiction of science and technology in humanities and social science courses.

As a result, social science students may find it hard to justify attempts to address social, philosophical and ethical issues in science and technology. Astrobiology as a discipline would greatly benefit from bridging the gap between the two. Astrobiology uses existing knowledge about life in order to extrapolate into unknown realms. It teaches us how to approach the unknown in an exemplary fashion while at the same time including broader, and sometimes traditional, philosophical, religious and social questions about knowledge and how it is produced. The social sciences and humanities can bring a methodological sophistication to these issues and to the analysis of data, structures and processes, as well as a deepened understanding of the production of knowledge, its social impact, and its place within a larger

pattern of historical social development. To do that, social scientists and academics from the humanities need to rely on a thorough understanding of science and technology.

### **Challenges**

The main challenges in this area are those of promoting greater familiarity with current science and technology on the part of students and researchers from the humanities and social sciences, but also to educate scientists about the methodology of the humanities and social sciences. It is also necessary to develop analyses of underlying assumptions about scientific practices and scientific reasoning within astrobiology. Such analyses will have connections to non-STEM fields and will motivate students and researchers to acquire the competences required to participate, in an informed way, in ongoing discussions about astrobiological knowledge.

### **Suggestions**

There is a need for a closer identification of the role of the social sciences and humanities within an interdisciplinary practice of astrobiology as well as a need for communicating non-STEM methodology and practices to scientists in order to foster a true interdisciplinary dialogue on a level that is acceptable for academic research. Astrobiology lends itself to this task, as it is already a discipline working across the boundaries of traditional academic fields. Care must be taken, however, to ensure that work across boundaries of disciplines is equal in quality on both sides.

## 6. Technological Innovation and Commerce (E. Chatzitheodoridis)

Technological innovation is partly a result of high-end research. Such research is the outcome of merged efforts between scientists coming from theoretical, experimental, and engineering disciplines when they aim to answer significant open questions. Sometimes, the direct goal is the provision of new services or products, very often with a commercial value. This bringing together of disciplines requires the development of new tools, practices and protocols for scientific research, in order to promote technological development and increase knowledge. The merging of efforts brings together industry, universities, governmental institutions and private organisations. A recent example is provided by the field of nanotechnology, where technological research at universities and institutions has resulted in entrepreneurial ventures and partnerships with existing companies and has produced a wealth of commercial products. We expect that the interdisciplinary and cross-sectoral aspect of astrobiology can also trigger new types of technological innovation. New knowledge in astrobiology will help to generate new problems to be solved, creating a demand for innovative techniques and tools to carry out space research and planetary exploration.

### 6.1 Technological Innovations Driven by Astrobiology (E. Chatzitheodoridis)

#### Background

The field of astrobiology provides an excellent example of a mix of a large number of disciplines and sectors. Disciplines such as biology, chemistry, astronomy, geology, planetary science, ecology, physics, material sciences, computer sciences, and medical sciences, join together with ethics and the philosophical, humanistic, and historical sciences to understand the origins of life and how best to search for it. At the same time, engineering fields such as robotics, computer and data engineering, microelectronics, telecommunications, photonics, analytical instruments and laboratory automation, propulsion, and spaceflight engineering, assist in the above endeavour. Multi-analytical techniques gain attention and innovative instruments are produced and tested in terrestrial-analogue environments. Some of these instruments are then employed in astrobiology exploration missions, *i.e.*, missions such as the 2020 mission to Mars, while the same instruments or some others find their way to the market.

## **Challenges**

Different sectors and stakeholder communities (e.g. research institutions, space agencies, countries, and industries) must cooperate to make space and planetary research missions possible. They jointly expand our reach to greater distances into the cosmos. They advance research methodologies and broaden our knowledge. From this expansion, new ethical guidelines, legislation and regulations emerge, such as those concerning planetary protection. The development of astrobiology, as we know it today, is a dynamic process which is expected to flourish as space missions which involve humans increase in number, and discussions about ways to establish a stable and continuous presence on other planetary bodies become mature dialogues. There is a huge potential for significant economic growth for all communities which have a proactive role in this endeavour.

## **Suggestions**

Focusing on the core of astrobiology, the novel research approach to study the origins, evolution and distribution of life requires new, state-of-the-art, highly miniaturised and hyper-sensitive instrumentation, as well as new analytical protocols. It also requires special ways for processing the new data, and suitable ways for archiving and consolidating this data into knowledge structures that both humans and non-human systems can work with. There is, finally, a demand for more experimental work in the lab, and for field work in extreme environments and within terrestrial analogues. These are some of the challenges that astrobiology has brought forward and already new techniques for high-precision detection and microanalysis, identification of contamination, data reduction, delicate sample handling and storing procedures are being designed.

## **6.2 Potential Conflicts of Interest (E. Persson, K. A. Čápková)**

### **Background**

The potential conflicts of interest between astrobiology and the commercial use of space, as well as the need for legal protection of habitable extraterrestrial environments, have become timely topics. In December 2015, President Obama signed the U.S. Commercial Space Launch Competitiveness Act into U.S. law, encouraging commercial exploration and resource utilization activities such as the mining of asteroids.

In Europe, Luxembourg has taken the lead in this area through its initiative to put together a legal framework for the commercial use of space resources. Several commercial companies already have ambitious plans to utilize outer space, most notably through asteroid mining and space tourism ventures. A number of companies, such as Deep Space Industries and Planetary Resources, have also been formed with the express purpose of mining asteroids. The first ‘space ports’ for commercial spaceflight are also beginning to emerge across the world, for example in the U.S., Sweden, and Abu Dhabi, and there has been a sustained discussion about the possibility of establishing a spaceport in the UK.

### **Challenges**

Both mining and tourism in space are things of the non-distant future. In their early stages, mining operations will only target asteroids, which are of limited interest for astrobiology, and space tourism will initially be restricted to Low Earth Orbit. There are, however, plans to go further, with opportunities then emerging for cooperation, and the potential for conflicts of interest. One key challenge is to make sure that astrobiology and commercial initiatives can manage to coexist peacefully, and cooperate for mutual benefit.

### **Suggestions**

This is a challenge that needs to be handled through open minded discussion and negotiations that will be better facilitated if there is an established body such as a European Astrobiology Institute with the overview, personnel and trust to represent the consensus among researchers. It will need a large input from ethics, law, political science and other social sciences over issues such as data sharing and the co-ordination of priorities driven by research and by commerce.

## 7. Science and Research (N. Mason)

In the coming decades, astrobiology-focused research is likely to provide some of the most significant paradigm-changing scientific advances in our understanding of our origins and of our place in the Universe.

### 7.1 Advancing Astrobiology Research in Europe (N. Mason)

#### Background

Several advances are set to transform our understanding of the universe and of how the Earth fits into its rich diversity: studies of the chemical structure of exoplanet atmospheres; data from next generation large telescopes revealing the chemical complexity of the interstellar medium, as well as shifts in our knowledge of the chemical nature of planet formation. Similarly, studies of extremophiles (which, by mass, may exceed ‘normal’ life), and more sensitive analytical tools to determine when life first emerged on Earth, will reveal more about how our planet evolved into the rich and diverse habitat that it is today.

On these matters, European research has an important, and distinctive, role to play. The well-earned reputation of the USA and the NASA Astrobiology Institute can sometimes draw attention away from the fact that European science has already played a major role in the emergence of astrobiology research. Astrobiology was not created in the 1950s with the Urey and Miller experiments to simulate the Earth’s early atmosphere. Rather, as a field of scientific enquiry, astrobiology began in Europe in the 1920s, with the theories of Oparin and Haldane (and possibly earlier with Darwin’s conjecture that life began in a warm little pond of shallow water). Studies of the origins of life, as astrobiology research was broadly entitled before the 1990s, were conducted within mainstream European science departments from 1950 to 1990 with European leaders such as Andre Brack playing a key role. Such research predates the idea of a cohesive discipline of ‘Astrobiology’. However, the simultaneous discovery of the Allan Hills Martian Meteorite with its putative fossilised bacteria, and the detection of the first exoplanets in the 1990s, helped to reframe and relaunch the field and so ‘Astrobiology’, in a more official and recognized sense, was born.

## **Challenges**

The European scientific research community has, perhaps, been slower than its US counterpart to embrace the term and to recognise the opportunities to reinvigorate and develop astrobiology as a multidisciplinary research field. The first European ‘Astrobiology’ entitled entity, the European Astrobiology Network Association (EANA) was only created in the new century with the first annual EANA meeting held in Frascati in 2001. These early years did, however, coincide with global austerity and with a reduction in the available research funding that has been particularly difficult for new and multidisciplinary fields.

In 2016 the European community, supported by the European Commission-funded AstRoMap project, published the first authoritative and inclusive European Astrobiology Roadmap providing a European view of astrobiology research. It outlined five key research topics:

Topic 1: Origin and Evolution of Planetary Systems;

Topic 2: Origins of Organic Compounds in Space;

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

Topic 4: Life and Habitability;

Topic 5: Biosignatures as Facilitating Life Detection.

There are clear similarities between these research topics and the research themes of the NAI. There is also a distinctly European dimension based on an evaluation of European skills, facilities and expertise.

## **Suggestions**

European astrobiology needs to establish the structures and secure the financial support that will allow it to develop as a mature and active multidisciplinary research field. The AstRoMap proposed the creation of a European Astrobiology Institute (EAI) “to streamline and optimize the scientific return by using a coordinated infrastructure and funding system” and this should be rapidly established. The EAI should target the European Commission’s H2020 programme to secure funding that will allow a Europe-wide coordination of astrobiology research, for example through a Research Infrastructure opening European field sites and laboratories to the wider European astrobiology research community. The EAI should also build upon the success of education initiatives, such as the European Astrobiology Campus, to promote multidisciplinary astrobiology teaching and to train a new generation of researchers who are designated astrobiologists. The astrobiology community needs to engage with Marie Curie Schemes for Innovative Training Networks, and to support the development

of Early Career Researchers through Marie Curie Fellowships and European Research Council grants. The EAI should act as a forum for the whole European astrobiology research community and ensure that this new discipline is appropriately recognised and supported by the existing fields from which it has developed, and with which it will collaborate (e.g. astrochemistry, earth sciences, and biochemistry).

## **7.2 Careers in Astrobiology (P. Laine, A. Losiak, Z. Martins, L. Noack)**

### **Background**

Astrobiology is an interdisciplinary subject, with scientists being specialists in diverse areas. A career in astrobiology often starts by taking an undergraduate degree in a specific subject related to astrobiology, e.g. biology, chemistry, physics, geology, astronomy, etc. In contrast to the US and Canada, there is, as yet, no dedicated undergraduate degree offered in astrobiology in Europe. Several European countries, however, provide specific courses or modules at Universities on astrobiology or astrobiology-related topics. Online courses are also becoming increasingly popular. The next step is to do a PhD, with a project that is related to astrobiology and/or in a group that performs research in astrobiology. At this point in the career, it may be better to go to one of the universities with research groups focused on astrobiology as this can result in greater experience in the research field, better networking and participation in publications related to the topic.

Careers can be in academia (i.e. University, Museums, Research Institutes), and also in non-academic/science sectors, e.g. industry and space agencies. Most positions in academic institutes are short-term offers. Contracts at space agencies and industry partners, in particular with involvement in space missions, will last as long as a project or mission continues, and therefore there is no long-term perspective, or career progression. Furthermore, research fellowships from ESA to work in astrobiology are included in the Planetary Science topic. National and international funding agencies are more and more open to the topic of astrobiology. This is due in part to the fact that research proposals nowadays often have to be interdisciplinary, and astrobiology fits in this category by definition. To reinforce this, there are increasing numbers of astrobiology-relevant networks which have been funded in recent years in Europe, as well as European-wide COST networks. ESA has formed different astrobiology-relevant topical teams, leading to several publications on the future of astrobiology in Europe. This has been reinforced by the European Astrobiology Roadmap,

AstRoMap, which was supported by the European Commission Seventh Framework Programme.

### **Challenges**

One of the main challenges of a career in astrobiology is how to attract future astrobiologists. Interested students cannot just study Astrobiology. They need to focus first on a different discipline, and only later transfer to a challenging multidisciplinary field. Furthermore, students do not automatically know which books related to astrobiology to read, both at an undergraduate level and graduate level. Students also do not always know which degrees to apply for later to have a career in astrobiology. Online platforms would be a possible solution and a great way to advise students. However, this has been done so far only at national level in a couple of countries, and a Europe-wide platform is still missing.

Another challenge is the fact that astrobiology is sometimes considered to be too broad and lacking a specific focus, which can have implications in terms of funding and/or securing a tenured job. Specifically, when a project is funded for a specific topic, it might have nothing to do with astrobiology. Also, funding is often for only a short period of time (i.e. a couple of years at most after finishing a PhD) unless it is tied to a long-term project.

Finally, astrobiology conferences are often not selective enough regarding dubious abstracts that can harm the way astrobiology is seen by the broader public.

### **Suggestions**

In order to attract new students and researchers to the field, and enhance chances for securing funding, it is necessary to increase awareness of astrobiology as a scientific discipline. This should be done through a broad involvement of all current Astrobiologists in the popularization of astrobiological science. Actions should be focused on two main target groups. The first target group is the general public; basic astrobiological information should be spread through public lectures, articles in magazines/newspapers, and TV and radio appearances. Reaching this group is part of a long-term (i.e. decades-long) strategy of “raising” future students and increasing public willingness to fund astrobiological research. The second target group is current students and researchers of relevant subjects (biology, geology, chemistry, astronomy and physics). Information about astrobiology should be disseminated through seminars and short courses, and by including astrobiological topics within the curriculum or in relevant classes. This is a short term (months to years) strategy to attract new students to the field, and to enhance cooperation between Astrobiologists and representatives of the more established fields such as biology and geology.

Astrobiologists are trained in a specific scientific field, but then need to apply their knowledge in the interdisciplinary field of astrobiology. To smoothen the way it would be advantageous to have more astrobiology overview courses or astrobiology relevant courses at national universities. These courses can also be coordinated internationally.

Additional training might be needed for early career scientists to be able to understand the interdisciplinary context of astrobiology, and to avoid misunderstandings by “not speaking the same language” as the other disciplines. For example, training schools including a hands-on section in which people from different disciplines work together on a common research project can help to build bridges between the disciplines. The goal can also be achieved by national and international training and networking symposia, for example the biennial symposium Astrobiology Graduates in Europe (AbGradE) or the Exobiologie Jeunes Chercheurs meeting (EJC) in France, which bring together students and early career scientists from all astrobiology-related fields. However, contributions that are not based on scientific facts or data should ordinarily be rejected, and we need to clearly present this approach to the general scientific community backing the field of astrobiology.

More online tools and initiatives could be developed at an international level, to compare different career paths in astrobiology, summarize web training possibilities, and give an overview of astrobiology-relevant projects at national and international level. This should be a task of a future European Astrobiology Institute. Such an astrobiology forum could also help to foster joint networks and to establish new astrobiology related research programs. Free web-based astrobiology courses (similar to the Coursera program from the University of Edinburgh) could be developed with a focus on bridging between disciplines (for example, including courses such as biology for geologists or geology for physicists).

Training the next generation of astrobiologists in the skills required for writing larger proposals is also important, as it can lead to both establishing a larger, well-linked astrobiology community, and to more joint efforts for project proposals. Coordination of cooperation between different labs and research institutes (for example via a research infrastructure) can contribute to better linking of the different astrobiology disciplines with each other, and to the building of a strong community, which will in turn help to make astrobiology a well-respected field in science. In astrobiology, we need to think bottom-up, as well as institutionally, and start new initiatives for the future. The next generation of

astrobiologists needs to be well equipped for that process, to ensure more successful careers in astrobiology.

### **7.3 The Social Study of Astrobiology as a Science (K. Smith, K. A. Čápková)**

#### **Background**

Astrobiology presents new directions for social study. For example, epistemological issues emerge concerning the status of astrobiology as a science, the problematic nature of inference from fragmentary and non-representative evidence, and the limits of scientific enquiry. Perhaps the most important (and engaging) aspect of astrobiology is the study of life's origins and the possibility of life beyond Earth. We need to know where we came from and who might inhabit the universe with us to better understand the cosmos and humankind's place within it.

#### **Challenges**

Topics of enquiry in the social and conceptual areas include the grand metaphysical and scientific issues, such as how best to define "life", "mind", "intelligence", and "culture". Of course, each of these terms has been extensively debated, but almost entirely in a terrestrial, human-centered context. Additionally, the role of contingency and necessity in the origin of these fundamental phenomena require investigation if we are to understand whether or not life, and in particular intelligent life, is likely to be a regular product of natural processes, a unique exception, or something in between. Social sciences and humanities need to recognise the importance of astrobiology in forming these questions as well as in shaping the answers. One challenge is the development of methodology for conducting ongoing and dynamic social research to advance our understanding of the impact of astrobiology on society at a European level. Anthropology of science, that focuses on science as situated in its social contexts and takes into account everyday dimensions of knowledge production, would provide useful assistance in future studies of social aspects of astrobiology.

#### **Suggestions**

It is proposed that the social study of astrobiology follow three initial directions. Firstly, a focus upon societal issues such as the likely theological, ethical, and worldview impact of the discovery of microbial or intelligent life; along with an examination of whether the search for extraterrestrial life should be pursued at all, and with what precautions. Secondly, a focus on issues related to the sociology of scientific knowledge, including the diverse attitudes and

assumptions of different scientific communities and different cultures towards the problem of life beyond Earth. This includes areas of science and technology studies and social studies of astrobiology. And thirdly, a study of the impact of astrobiology upon society and upon popular beliefs about life beyond Earth, the meaning of life and humanities place in the universe. The large scale study of public understanding of, and engagement with, science and technology on the European level is a challenging task yet would prove relevant to our understanding of the broader impact of science upon contemporary society and public attitudes to astrobiology alike.

## 8. Leading the Future of Astrobiology in Europe (M. Gargaud, W. Geppert)

The advent of the Space Age has put humankind in a position to be able to tackle long established questions about life, its origin and distribution, in a scientific manner. Exciting new discoveries about extrasolar planets, life under extreme conditions, and the existence of hydrothermal systems on the Saturnian satellite Enceladus have fuelled speculations about extraterrestrial life. The detection of complex organic molecules in the interstellar medium, star-forming regions and protoplanetary disks also raises the question of a possible extraterrestrial origin of the basic molecular building blocks of life.

It is clear that we are increasingly well placed to answer a number of major questions concerning not only the possibility of extraterrestrial life and the origin of the building blocks of life on Earth. Other questions are also moving within reach, questions concerning the co-evolution of the biosphere and the geosphere on our planet, and the influence of cosmic events upon it (e.g. changes of solar luminosity, as well as meteorite, comet and asteroid impacts). However, these questions cannot be tackled by one branch of science alone. They require intensive cooperation from scientists across disciplines that might otherwise seem unrelated. And the opportunity to answer such questions is emerging at a time when the European science landscape is undergoing a fundamental transition from a discipline-centered, to a more research-question centered, form of organization. New fields have emerged around burning issues of early evolution of life, exoplanet research and astrobiology. These fields areas are inherently multidisciplinary and carry the potential for new forms of interdisciplinary cooperation and thinking across boundaries of scientific subjects.

### **8.1 Challenges Facing the EU Astrobiology Community**

Multidisciplinarity and interdisciplinarity also entail challenges and even risks. Firstly, scientists have to “learn” the language of other disciplines, which might result in some initial misunderstandings and misconceptions. Secondly, interdisciplinary fields require the training of a new generation of scientists who are able to work across science branches and successfully interact and collaborate with colleagues from other and seemingly remote science branches. This is a task that the European higher education system is still only weakly

prepared for. The associated difficulties are sometimes increased because it takes time for new research fields to feed into the often very traditional curricula of universities.

Thirdly, there is an inherent risk that pseudoscience may enter interdisciplinary fields, especially when the subject is vast, few researchers can claim full expertise on even parts of it, and the subject enjoys a great deal of public interest. There is even a danger that such fields may attract some individuals whose talent for publicity greatly exceeds their commitment to the reliable norms of science. Without proper accreditation, procedures and regulation, incidents of this sort may not only endanger the public standing of astrobiology, but also the broader reputation of the entire scientific community. It is therefore important to create structures in order to ensure impeccable scrutiny and thus the high quality of astrobiology-related research in Europe. A European Astrobiology Institute functioning as a consortium of prestigious research institutions across Europe would be an ideal structure to help accomplish this task. It would also have the intellectual strength to be able to shield science from the encroachment of pseudoscience.

The strength of any scientific community is, in the long run, determined by its ability to encourage the development of the best scientists and to curtail the influence of persuasive imitations of science. Excellence attracts other excellence and, by establishing contacts with eminent researchers and scholars outside their own field, scientists can extend their own scope of research. This, however, depends upon the existence of efficient fora and structures to foster the required kinds of interaction. The NASA Astrobiology Institute (NAI) is a textbook example of an entity that has succeeded in nurturing such a lively research community. The main conference in the field in the US (AbSciCon) now attracts around one thousand researchers. Internationally, leading research groups at leading institutions based in the United States are competing to obtain the status of an NAI team with quality standards set high enough for several research consortia in Ivy League universities to have been turned down. European astrobiology has been lagging behind these institutional developments, but the various networks mentioned above kindle well-founded hopes about its future.

## **8.2 The Role of the European Astrobiology Institute**

The European Astrobiology Institute will act as a strong voice for the astrobiology community in dialogue with decision makers, funding agencies, the media, other stakeholders and the general public. It will be proactive in the debate on important legal and ethical issues in astrobiology and space research.

## 8.2.1 Principal Tasks

The principal tasks of the EAI should be as follows:

- To promote and implement multidisciplinary European research projects in all fields of astrobiology.
- To foster international collaboration in astrobiology inside Europe as well as together with other astrobiology communities.
- To act as a forum to discuss new findings in astrobiology through the organisation of conferences, meetings, and online seminars, and to disseminate new research highlights among the scientific community and the general interested public in an apt way after thorough scrutinisation.
- To form the kernel of a network for institutions and institutes, as well as for researchers, to plan cooperative astrobiology projects.
- To perform training, education, outreach and result dissemination in astrobiology in Europe in a comprehensive, synergistic and collaborative way.
- To collect and disseminate astrobiology-related scientific and programmatic information.
- To initiate proposals for grants in order to obtain external financial support (e.g. EU projects).
- To engender debates on important legal and ethical issues in astrobiology and space research.
- To interact with European transnational organisations (e.g. ESA) and European Research agencies on programmatic issues, and to ensure awareness of astrobiology research with decision makers by
  - acting as a strong voice for the European astrobiology community;
  - approaching and informing decision makers in governmental and non-governmental organisations at a national, regional and European level in a coordinated manner in order to promote astrobiology research in Europe as transdisciplinary research activity;
  - contributing to the development of a common European Research Area and research policy in the field of astrobiology.
- To formulate and continuously update a long-term astrobiology research strategy for the European Research Area.
- To collaborate with astrobiology networks and institutes inside Europe and beyond.

While astrobiology, at first glance, does not appear to be a priority subject for industries, there are nonetheless areas of astrobiology that do also attract the interest of the private sector. These range from the study of enzymes used by extremophiles and employed in commercial detergents, through to genetic research and work on space technology. In order to efficiently exploit the possibilities for cooperation and synergies between research and industry, the European Astrobiology Institute should create a team for the liaison between research and industry, comprising representatives from both.

### 8.2.2 Research Areas

The main research areas of the EAI should be carefully defined but inclusive, in order to avoid leaving important (or newly emerging science areas) outside of the official reach of research support. A possible list of key areas might include the following:

- **Formation of planetary systems and detection of habitable planets and moons:** How are planetary systems formed? How do the conditions of the formation environments (e.g. at the level of galaxy or protoplanetary disk) influence the formation of habitable planets? Which factors define habitability? How can we detect extrasolar habitable planets and satellites?
- **Co-evolution of early Earth's geosphere, atmosphere and biosphere:** How did physical, chemical, geological and biological processes co-evolve on Earth? How did habitability evolve on early Earth? Which conclusions can we draw for other planets?
- **Early life and life under extreme conditions:** In which kind of environment did life first emerge (Darwin's little warm pool or some more extreme environment?) What boundary conditions exist for life and what can they tell us about early terrestrial and the possibility of extraterrestrial life?
- **The pathway to complexity: From simple molecules to first life:** Where and how did the complex organic molecules necessary for life originate (in space, in the atmosphere, or on the surface of the planet) and how were they delivered? How does the environment affect the production and stability of complex organic molecules? How did the formation of biopolymers and self-assembly of first cells proceed?
- **Search for life in early and extreme terrestrial environments and on other planets:** Which strategies should we employ for tracing early terrestrial, as well as extraterrestrial, life in environments? Which combination of individual biosignatures (chemical, geological, spectroscopic, other) and tracers of life present in these

environments would be seen conclusive? What novel methods and technologies can be developed to detect life

- **Historical, philosophical, societal and ethical issues in astrobiology:** How did our ideas about the origin of life develop? What views about extraterrestrial life exist in different cultures? What philosophical, societal, political, juridical and ethical issues are raised by the search for life on other planets and moons?

Research activities in these areas should be coordinated by working groups consisting of active researchers in the field. They can organize special meetings as well as training events, and launch collaborative research projects. The number, focus and themes of the different working groups should be responsive to new developments in astrobiology.

### **8.2.3 Funding and Mentorship**

As in all fields, research in astrobiology is dependent upon access to proper funding. For a thriving research community, it is indispensable to approach funding agencies in a concerted and organized manner to make the maximum use of available grants. The EAI will be well placed to ensure that all possible funding avenues are used by the community and that duplicate approaches are avoided. It will also be able to approach funding agencies in a proactive manner, in order to include grants for interdisciplinary research into funding programmes. Furthermore, the institute will work to introduce astrobiology questions into the scientific programme of space missions at an early stage of planning. The Institute can also work as an information hub to facilitate access to large research infrastructures and field sites. Access to both usually involves extensive red tape which can mean that important resources are still not utilised by the astrobiology community to a satisfactory extent. A centrally maintained and continuously updated information website run by the EAI would be invaluable as a means to encourage more scientists to use the available facilities and to perform field work at astrobiologically relevant sites. This holds especially for early career scientists. The summer schools organized by the Nordic Network of Astrobiology and the European Astrobiology Campus have been very successful in launching the scientific projects of students and young scientists, projects which have originated in field work performed during training events.

The EAI will also be well-placed to develop a mentorship programme for students and for early career scientists who are starting out on their own research projects. A comparable mentorship programme has been successfully initiated by the SAGANet astrobiology

grassroots organization in the US. Finally, the Institute can provide an ideal forum for scientists to meet and start new consortia to launch new research projects. Such efforts can range from smaller scale studies through to the proposal of actual space missions.

#### **8.2.4 Suggested Activities of the EAI**

Although it brings together many established disciplines, astrobiology itself is a comparatively new discipline and so it has to firmly establish itself within the scientific community. As part of this process, the following activities should be envisaged:

- the holding of high-level general conferences in astrobiology as well as smaller workshops on specific subjects in order to bring together scientists from different disciplines;
- the formulation and continuous updating of long-term planning for astrobiology research in the European Research Area;
- the provision of a forum for heads of labs/institutes to plan cooperative astrobiology projects;
- the production of high quality reference works;
- the holding of high-level training events and production of materials for training and education on all levels;
- the organisation of web-streamed seminars by leading scientists in astrobiology, and the provision of web based tools to collect and share existing astrobiology lectures of suitably high quality; see for example what has been done recently by the IAU working group on Education and Training in Astrobiology (led by M. Gargaud, France): <http://astrobiovideo.com/en/>;
- the facilitation of ongoing dialogue between researchers in the sciences, social sciences and humanities regarding conceptual, societal, ethical and existential questions in relation to astrobiology.

Activities of this sort will also serve to attract world leaders to the field – including those who do not yet define themselves as astrobiologists. It is also noteworthy that, as a new research field, astrobiology has already been able to attract a considerable number of female scientists from a variety of associated disciplines, thereby avoiding familiar problems of gender imbalance (and the detrimental impact upon research that this can produce).

### **8.2.5 Multidisciplinarity and Networking**

As the subject area of astrobiology is not yet on the radar screen of directors of studies and other training programmes designers, a European-wide effort is necessary. Given the success of the training programme provided by the European Astrobiology Campus in conjunction with the COST Action “Life-Origins”, it is suggested that the European Astrobiology Campus continue its work as the principal training entity of the European Astrobiology Institute and that it coordinates training and education activities through the following four key activities:

- Providing a comprehensive multidisciplinary European astrobiology training programme for students and early career scientists, offering both basic and specialised training events in the field as well as training in generic skills such as proposal writing and the planning of scientific projects.
- Creating a network for astrobiology education and providing training materials for basic, secondary and higher education in Europe.
- Providing a mentoring scheme for early career scientists in the field of astrobiology.
- Ensuring proper funding for these activities.

These measures will ensure proper training of the next generation of astrobiologists.

## 9. Appendices

### 9.1 Definitions (drawing upon the *Encyclopedia of Astrobiology*)

#### **astrobiology**

Astrobiology is the scientific study of the origins, evolution, and distribution of life, not only on Earth, but also at the scale of the Universe. Concepts such as astrobiology, exobiology, bioastronomy are associated with this scientific activity. They help to define the study of the origins of life on Earth, and elsewhere. They also help to define the search for the existence of life in the Universe. The idea of life itself is represented by ‘bio-’ or ‘biology’, and the universal field of study by ‘astro-’, ‘-astronomy’, or ‘exo-’. Beyond the terminological choices, these words suggest a great ambition for contemporary human knowledge, a need to exceed disciplinary divisions.

#### **extremophiles**

Extremophiles are organisms that thrive in ecosystems where at least one physical parameter is close to the known limits for life. While some organisms may temporarily survive harsh conditions by forming resistant stages (spores), or through specific mechanisms (heavy metal resistance), true extremophiles require these harsh conditions. For instance, hyperthermophiles successfully complete their life cycle at optimal temperatures above 80C, and commonly do not grow at all below 60–70C.

#### **exoplanets**

An exoplanet, or extrasolar planet, is a planet in orbit around another star. The first such object was discovered in 1992 and more than 3700 exoplanets had been identified by April 2018.

#### **habitability**

Habitability for the Solar System refers to suitability for carbon-based life. The presence of liquid water is the first potential indicator of the habitability of any Solar System body. The study of conditions on these bodies is basic to understand the difference between a habitable planet and one that is not suitable for such life.

#### **planetary protection**

Planetary protection is the process of preventing contamination of planetary environments by living protection of organisms from other planets, in accordance with Article IX of the 1967 Outer Space Treaty, and in accordance with policies maintained by COSPAR. Nations sending missions to other planets must ensure that Earth life does not contaminate these planets, and that any samples brought back to Earth do not release harmful organisms into our environment.

## 9.2 Presentation of the Group

Life-ORIGINS (TD1308) is a Trans Domain European COST Action dedicated to the scientific investigation of the origins and evolution of life on Earth and the habitability of other planets. Working Group 5: History and Philosophy of Science is led by D. Dunér (Sweden; 2014–2018), co-led by Ch. Malaterre (Canada; 2014–2016) and S. Tirard (France; 2016–2018).

The Group's Objectives: Life's nature is strongly dynamic and systemic, forming a collection of interacting parts. It now appears likely that its appearance on Earth is to be explained through the coupling of different types of molecular structures and of evolutionary processes in which these structures are involved. Within this broad scientific context, the overall objectives of this working group cover two main areas of investigation:

- An assessment, from a philosophical perspective, of how the boundaries between chemistry and biology are being transformed as a result of a shift towards increasingly systemic or holistic approaches in the quest for a naturalist explanation of the origin of life. The focus here will be on characterizing the new tools, models and conceptions that are being elaborated to tackle the problem of origins within this wider evolutionary scenario, and on how the latter will provide a completely new view of the chemistry-biology interface.
- An analysis, from a history of science perspective, of the debate concerning the origin of life and the chemistry/biology divide. This will involve study of changes in the definition of the life concept, in the classification and categorization of life, and in models for the evolution of life.

### **9.3 COST Action Memorandum**

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). 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:

1. 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

## 9.4 The American Experience (L. Billings, K. Smith)

While the US vision for astrobiology is very broad, in practice NASA focuses almost exclusively on natural science. The scope of NASA's mandate is specified by law and cannot include significant funding for research in the social sciences and humanities. It is thus difficult for NASA to provide more than occasional seed funding for these activities. In practice, this means that there is no broad infrastructure and interested scholars have to find other sources of support (funding, publication venues, networking opportunities, etc.) for their research. NASA's official astrobiology roadmap is similarly limited. On the one hand, the roadmap makes it clear that the community recognizes broad public interest in its work. On the other hand, it does not identify any specific goals, objectives, and questions relating to broader questions.

While NASA cannot provide the kind of support necessary to foster truly systematic investigation of these complex issues, it has sponsored some important US projects along these lines. However, they have been sparse, sporadic, and disconnected. The first formal investigation of these kinds of questions was a NASA-sponsored symposium held in 1972, which focused on "the social, philosophic, and humanistic impact" of the discovery of extraterrestrial life. However, the US did not capitalize on this promising beginning, focusing instead on the Shuttle and International Space Station programs. Only in 1996, following claims of fossil evidence of Martian life in a meteorite, did growing scientific, political, and public interest prompt NASA to attend to the societal implications of astrobiology.

NASA's Ames Research Center held a workshop on the "Societal Implications of Astrobiology" in 1999. In 2003-04, NASA's Astrobiology Program co-sponsored (with the American Association for the Advancement of Science (AAAS) Dialogue on Science, Ethics and Religion (DOSER) program) a series of workshops to address the "philosophical, ethical, and theological implications of astrobiology." Then in 2009, the Search for Extraterrestrial Intelligence (SETI) Institute in California held a workshop to develop a roadmap of societal issues relating to astrobiology. NASA's Astrobiology Institute approved the formation of a focus group on the social implications of astrobiology in 2012. However, this group foundered in 2015 and there are no plans to revive it.

Despite these challenges, in just the last few years, NASA Astrobiology (NAI) has undertaken three major new initiatives designed to broaden the community of scholars currently working on these issues. In collaboration with the Kluge Center of the US Library of Congress, NASA Astrobiology is funding the Baruch S. Blumberg NASA/Library of Congress Chair in Astrobiology. The Blumberg Chair makes it possible for a senior researcher to be in residence at the Kluge Center, to make use of the Library of Congress collections, and to convene programs that ensure the subject of astrobiology's role in culture and society receives considered treatment. The Chair has resulted in a series of congressional hearings on astrobiology held by the House Science, Technology, and Space Committee as well as two books, three interdisciplinary dialogues, and several public symposia.

From 2015-17, NASA also provided support for an exploration of the societal implications of astrobiology being conducted by the Center of Theological Inquiry (CTI) in Princeton, New Jersey. For this project, CTI gathered together a small group of researchers in theology and other disciplines, who spent an entire year in residence working on these kinds of questions.

Finally, the 2015-16 NASA Astrobiology Debates was a year-long academic project for university and secondary education students involving in-person and online debate tournaments, speech competitions, public exhibition debates, topic-expert panels for student audiences, and student-conducted topic interviews with a cross-disciplinary group of subject-matter experts. The debate topic for this project was: “Resolved: An overriding ethical obligation to protect and preserve extraterrestrial microbial life and ecosystems should be incorporated into international law.” The aim of the debates project was to stimulate student, teacher, and school research and dialogue on astrobiology in preparation for these events and at the events themselves.

Despite these promising recent developments, the number of researchers in the social sciences and humanities who have engaged in these activities is still relatively small. What is more, since NASA can make no long term commitment to funding this kind of activity and research, interested investigators are uncertain what, if any, support will be available in the future.

## 9.5 Suggested Literature

Balla, V.K., Roberson, L.B., O'Connor, G.W., Trigwell, S., Bose, S., Bandyopadhyay, A., 2013. First demonstration on direct laser fabrication of lunar regolith parts. *Rapid Prototyping Journal*, 18:451–457.

Barnett, M.J., Pawlett M., Wadham J.L., Jackson M., Cullen D.C., 2016. Demonstration of a multi-technique approach to assess glacial microbial populations in the field. *Journal of Glaciology*, 62:348–358.

Bedau, M.A., Cleland, C.E., 2010. *The Nature of Life: Classical and Contemporary Perspectives from Philosophy and Science*. Cambridge: Cambridge University Press.

Bertka, C.M., 2009. Exploring the origin, extent, and future of life: Philosophical, ethical, and theological perspectives. *Cambridge astrobiology 4*. Cambridge, UK, New York: Cambridge University Press.

Billings, L., 2007. Overview: Ideology, Advocacy, and Spaceflight. Evolution of a cultural narrative. In Steven J. Dick, Roger D. Launius Eds. *Societal impact of spaceflight*. Washington, DC: National Aeronautics and Space Administration Office of External Relations (The NASA history series, 4801), 483–499.

Billings, L., 2012. Astrobiology in culture: The search for extraterrestrial life as ‘Science.’ *Astrobiology*, 12(10):966–975.

Capova, K.A., 2016. The New Space Age in the making: Emergence of exo-mining, exo-burials and exo-marketing. *International Journal of Astrobiology*, 15(4):307-310.

Capova, K.A., 2013. The Detection of Extraterrestrial Life: Are We Ready? In: Vakoch D. (ed.), *Astrobiology, History, and Society*. Springer.

Cockell, C.S., 2001. ‘Astrobiology’ and the ethics of new science. *Interdisciplinary Science Reviews*, 2(2):90–96.

Cockell, C., Horneck, G., 2004. A Planetary Park system for Mars. *Space Policy*, 20(4):291–295.

Consolmagno, G., 2014. *Would you baptize an extraterrestrial? ...and other strange questions from the inbox at the Vatican Observatory*. First Edition. New York: Image.

COST Action TD1308, 2013. 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). Source: [https://e-services.cost.eu/files/domain\\_files/TDP/Action\\_TD1308/mou/TD1308-e.pdf](https://e-services.cost.eu/files/domain_files/TDP/Action_TD1308/mou/TD1308-e.pdf)

Cottin, H., Kotler, J.M., Bartik, K., Cleaves, H.J., Cockell, C.S., de Vera J.-P.P., Ehrenfreund, P., Leuko, S., Ten Kate, I.L., Martins, Z., Pascal, R., Quinn, R., Rettberg, P., Westall, F., 2017. Astrobiology and the Possibility of Life on Earth and Elsewhere.... *Space Science Reviews*, 209:1-42.

Cottin, H., Kotler, J.M., Billi, D., Cockell, C., Demets, R., Ehrenfreund, P., Elsaesser, A., d'Hendecourt, L., van Loon, J., Martins, Z., Onofri, S., Quinn, R.C., Rabbow, E., Rettberg, P., Ricco, A.J., Slenzka, K., de la Torre, R., de Vera, J.-P., Westall, F., Carrasco, N., Fresneau, A., Kawaguchi, Y., Kebukawa, Y., Nguyen, D., Poch, O., Saiagh, K., Stalport, F., Yamagishi, A., Yano, H., Klamm, B.A., 2017. Space as a Tool for Astrobiology: Review and Recommendations for Experimentations in Earth Orbit and Beyond. *Space Science Reviews*, 209:83–181.

Chon-Torres, O.A., 2018. Astrobioethics. *International Journal of Astrobiology*, 17(1):51-56.  
Cousins, C.R. and Cockell, C.S., 2015. An ESA roadmap for geobiology in space exploration. *Acta Astronautica*, 118:286–295.

Crowe, M.J., 1999. *The extraterrestrial life debate, 1750-1900*. Mineola, N.Y. Dover Publications.

Crowe, M.J., 2008. *The extraterrestrial life debate, Antiquity to 1915: a source book*. Notre Dame IN: University of Notre Dame.

Debus, A., 2004. COSPAR needs for Planetary Protection recommendations for sample preservation dedicated to exobiology. *Advances in Space Research*, 34(11):2320–2324.

Dick, S. J., 1996. *The biological universe: The twentieth-century extraterrestrial life debate and the limits of science*. Cambridge Univ. Press.

Dick, S. J. 2012. Critical issues in the history, philosophy, and sociology of astrobiology. *Astrobiology*, 12(10):906–927.

Dick, S. J., ed. 2015. *The impact of discovering life beyond earth*. Cambridge: Cambridge University Press.

Dick, S. J., 2018. *Astrobiology, Discovery, and Societal Impact*. Cambridge University Press.

Dominik, M., J.C. Zarnecki (eds.), 2011. The detection of extra-terrestrial life and the consequences for science and society, 369(1936):497-699. London: The Royal Society.

Dunér, D., Malaterre, Ch., Geppert, W., (eds.), 2016. *The History and Philosophy of the Origin of Life*. Special issue of *International Journal of Astrobiology* 2016.

Dunér, D., Persson, E., and Holmberg, G., ed. 2012. *The history and philosophy of astrobiology*. Special issue of *Astrobiology*, 12(10).

Dunér, D. Parthermore, J., Persson, E., Holmberg, G., (eds.), 2013. *The History and Philosophy of Astrobiology: Perspectives on Extraterrestrial Life and the Human Mind*. Cambridge Scholars.

European Cooperation for Space Standardization, ECSS-U-ST-20C Space Sustainability - Planetary Protection.

Garcia-Descalzoa, L., García-López, E., Morena, A-M., Alcazarb, A., Baqueroa, F., Cid, C., 2012. Mass spectrometry for direct identification of biosignatures and microorganisms in Earth analogs of Mars. *Planetary and Space Science*, 72:138–145.

Gargaud, M., William M. I., Amils, R., Cleaves, H. J., Pinti, D. L., Quintanilla, J. C., Rouan, D., Spohn, T., Viso, M., Tirard, S. (eds) 2015. Encyclopedia of astrobiology. Heidelberg: Springer.

Harrison P., 2016.: The Myth of a Perennial Battle between Science and Religion. Available online at <https://www.theologie-naturwissenschaften.de/startseite/leitartikelarchiv/conflict-myth.html>, checked on 2/16/2017.

Horneck, G., et al., 2016. AstRoMap European astrobiology roadmap. *Astrobiology*, 16(3):201–243.

Kereszturi, A., Bradak, B., Chatzitheodoridis, E., Ujvari, G., 2016. Indicators and Methods to Understand Past Environments from ExoMars Rover Drills. *Origins of Life and Evolution of Biospheres*.

Kissel, J., Altwegg, K., Clark, B.C., et al., 2007. Cosima – High Resolution Time-of-Flight Secondary Ion Mass Spectrometer for the Analysis of Cometary Dust Particles onboard Rosetta. *Space Science Reviews*, 128:823.

Kminek, G., 2015. Planetary protection - an enabling capability and contributor to sustainable space exploration. *Space Res. Today*, 194:5-6.

Kminek, G., Conley, C., Hipkin, V., Yano, H., 2017. COSPAR's Planetary Protection Policy. *Space Res. Today*, 200:12-25.

Magnani, P., Re, E., Senese, S., Rizzi, F., Gily, A., Baglioni P., 2010. The Drill and Sampling System for the ExoMars Rover. *i-SAIRAS Conference*, 044-2769.

Martins, Z., Cottin, H., Kotler, J.M., Carrasco, N., Cockell, C.S., de la Torre Noetzel, R., Demets, R., De Vera, J.P., d'Hendecourt, L., Ehrenfreund, P. and Elsaesser, A., 2017. Earth as a Tool for Astrobiology—A European Perspective. *Space Science Reviews*, 209(1-4):43-81.

McKay, C.P., 1987. Terraforming: making an Earth of Mars. *The Planetary Report* 7:26–27.

Musso, G., Lentini, G., Enrietti, L., Volpe, C., Ambrosio, E-P., Lorusso, M., Mascetti, G., Valentini, G., 2016. Portable on Orbit Printer 3D: 1st European Additive Manufacturing Machine on International Space Station. *Advances in Physical Ergonomics and Human Factors* 643–655.

NASA Technical Memorandum: Workshop on the Societal Implications of Astrobiology, Final Report, Ames Research Center, November 16-17, 1999.

Noack, L., Verseux, C., Serrano, P., Musilova, M., Nauny, P., Samuels, T., Schwendner, P., Simoncini, E. and Stevens, A., 2015. Astrobiology from early-career scientists' perspective. *International Journal of Astrobiology*, 14(4):533-535.

Noffke, N., 2005. Introduction: Geobiology – a holistic scientific discipline. In *Geobiology: Objectives, Concepts, Perspectives*, Edited by N. Noffke, Elsevier.

Parrish, C.F., 2003. Space colonization. *Aerospace America*, 41(12):94.

- Persson, E., Capova, K.A., Li, Y., (2018). Attitudes towards the scientific search for extra-terrestrial life among Swedish high school and university students. *International Journal of Astrobiology*, 1-9.
- Persson, E., 2013. Philosophical aspects of astrobiology in Dunér, D., Pathermore, J., Persson, E., Holmberg, G., (eds.): *The History and Philosophy of Astrobiology*. Cambridge Scholars pp.29-48
- Persson, E., 2014. What does it take to establish that a world is uninhabited prior to exploitation? A question of ethics as well as science. In *Challenges* (5), pp. 224–238.
- Persson, E., 2017. Ethics and the potential conflicts between astrobiology, planetary protection and commercial use of space. *Challenges*, 8(1):12
- Peters, T., 2011. The implications of the discovery of extra-terrestrial life for religion. In *Philosophical transactions A, Mathematical, physical, and engineering sciences* 369(1936):644-655.
- Peters, T., Froehling, F., 2008. The Peters ETI Religious Crisis Survey. Source: [www.counterbalance.net/etsurv/index-frame.html](http://www.counterbalance.net/etsurv/index-frame.html).
- Peters, T., 2009. Astrotheology and the ETI Myth. *Theology and Science*, 7(1):3–29.
- Race, M., et al. 2012. Astrobiology and society: Building an interdisciplinary research community. *Astrobiology*, 12(10):958–965.
- Rettberg, P. et al. 2016. Planetary Protection and Mars Special Regions - A Suggestion for Updating the Definition. *Astrobiology*, 16:119-125.
- Rochus, P., Plessier, J.Y., Van Elsen, M., Kruth, J.-P., Carrus, R., Dormal, T., 2007. New applications of rapid prototyping and rapid manufacturing (RP/RM) technologies for space instrumentation. *Acta Astronautica*, 61, 352–359.
- Romanides, J.S., 1965. All Planets the Same. *The Boston Globe*, April 8 edition, p. 18. Available online at <https://blogs.ancientfaith.com/onbehalfofall/an-orthodox-perspective-on-alien-life>, checked on 3/1/2017.
- Rummel, J.D., Billings, L., 2004. Issues in planetary protection: policy, protocol, and implementation. *Space Policy*, 20:49–54.
- Schulte, W., Hofera, S., Hofmann, P., Thiele, H., von Heise-Rotenburg, R., Toporski, J., Rettberg, P., 2007. Automated payload and instruments for astrobiology research developed and studied by German medium-sized space industry in cooperation with European academia. *Acta Astronautica*, 60:966–973.
- Sephton, M.A., 2014. Astrobiology can help space science, education, and the economy. *Space Policy*, 30(3):146–148.
- Siljeström, S., Lausmaa, J., Sjövall, P., Broman, C., Thiel, V., Hode T., 2009. Analysis of hopanes and steranes in single oil-bearing fluid inclusions using time-of-flight secondary ion mass spectrometry (ToF-SIMS). *Geobiology*, 8(1):37-44.

- Stephan, T., 2001. TOF-SIMS in cosmochemistry. *Planetary and Space Science*, 49:859–906.
- Sullivan, W. T., Baross, J. A., eds. 2007. *Planets and life: the emerging science of astrobiology*. Cambridge: Cambridge University Press.
- Traphagan, J., 2015. *Extraterrestrial intelligence and human imagination: SETI at the intersection of science, religion, and culture*. Cham: Springer.
- Traphagan, J., 2016. *Science, culture and the search for life on other worlds*. Cham: Springer.
- UNOOSA, The official Report on the United Nations/Austria Symposium on Space Science and the United Nations. Source: [www.unoosa.org/pdf/reports/ac105/AC105\\\_1082E.pdf](http://www.unoosa.org/pdf/reports/ac105/AC105\_1082E.pdf)
- UNOOSA, The Report on the United Nations/Austria/European Space Agency Symposium on Enhancing the Participation of Youth in Space Activities: Implementing the Recommendations of UNISPACE III. Source: [www.unoosa.org/pdf/reports/ac105/AC105\\\_774E.pdf](http://www.unoosa.org/pdf/reports/ac105/AC105\_774E.pdf) (Section III E)
- Vakoch, D. A., Harrison, A. A., eds., 2011. *Civilizations beyond earth: Extraterrestrial life and society*. New York: Berghahn Books.
- Vakoch, D. A., ed. 2013. *Astrobiology, history, and society: life beyond earth and the impact of discovery*. Berlin & Heidelberg: Springer.
- Vakoch, D. A., Dowd, M. F., eds. 2015. *The Drake equation: estimating the prevalence of extraterrestrial life through the ages*. Cambridge: Cambridge University Press.
- Waltemathe, M., 2017. A match made for heaven. *Astrosociological and astrotheological aspects of spaceflight and religion*. AIAA SPACE and Astronautics Forum and Exposition, AIAA SPACE Forum, AIAA 2017-5157.
- Weintraub, D.A., 2014. *Religions and Extraterrestrial Life. How Will We Deal With It*. Dordrecht: Springer Praxis Books.
- Wilkinson, D., 2013. *Science, religion, and the search for extraterrestrial intelligence*. First edition. Oxford, U.K. Oxford University Press.
- Willis, P.A., Greer, F., Fisher, A., Hodyss, R.P.; Grunthaner, F.; Jiao, H.; Mair, D.; Harrison, J., 2009. Lab-on-a-Chip Instrument Development for Titan Exploration. American Geophysical Union, Fall Meeting 2009.
- Workshop Report: Philosophical, Ethical and Theological Questions of Astrobiology, American Association for the Advancement of Science, Washington, D.C., 2007.