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Provisional Title of Book: Habitable Worlds and Planetary Sustainability
or Habitable Worlds and Sustainable Life on Earth and Beyond

Book Editor: Amy J. V. Riches

VISION FOR THE BOOK

Constraining the conditions under which life arises and may then be sustained is a matter of importance and concern for a range of disciplines. This subject, commonly considered as 'blue sky science', is of particular interest to broad-based planetary scientists targeted by the envisioned advanced-level text. The results from work such as that encapsulated in this book bring useful lessons and beneficial technologies to our management of Earth. This original outlook could have a long-lasting influence and is a priority to advocate for among the broader geoscience, sustainability, and other Earth-oriented applied science communities.

Goals:

1. This book seeks to provide a high-level overview of our current understanding of the origin(s), and key influences on habitability largely from the perspective of inorganic and organic chemical information derived from asteroids, Mars, key bodies among Saturn's moons (e.g., Titan and Enceladus), selected Galilean moons of Jupiter, the Moon and early-Earth. The integration of key perspectives from other disciplines, including the results from astronomical studies of exoplanets and legal frameworks concerning space policy development, are also vital aspects of this book.
2. The potentially transient and / or oligotrophic nature of life and the means by which planetary ecosystems - including our own - can be sustained is examined via ground-based experimental approaches involving BIOSPHERE 2, linked to lessons learned and the benefits to human practices gained through technologies initially developed for space exploration, and appraised in the context of international space exploration / planetary protection policies. The latter points inherently overlap with how we conduct and plan for the curation of extraterrestrial materials.
3. The philosophical motivation for this book, and aligned international meeting planned for 2021 (link), is driven by a passion to bring together members of sometimes disparate fields of study so as to promote the useful exchange of ideas. This objective will help us advance and promote how we understand not only the rise of early life and its evolution, but how it is sustained and protected in extraterrestrial settings. Crucially, this book's approach, largely rooted in space and planetary sciences (including meteoritics and astrobiology), will explore how such knowledge and related technologies can and do help us improve the sustainability of our own practices on Earth during the present day and the climate / ecological / resource crises that we currently face.

Topic Coverage:

The proposed standalone advance-level reference text provides for a transdisciplinary approach to explore two interwoven themes of critical importance to science and society. The motivation for this book is thereby reflected in the chosen provisional title "Habitable Worlds and Planetary Sustainability". This contribution will also serve as a reference to help inform space mission targeting and scientific priorities (e.g., choice of asteroids / moons / planets to study, surface regions of interest, and important and specific research questions to target).

The book leverages information from what others may regard as distinct fields of study and in doing so will help to advance and promote the exchange of ideas across disciplines to realise shared goals. Though the proposed text includes contributions from organic chemists who are considered as astrobiologists / microbiologists, a significant portion of this book will explore findings from the inorganic chemistry of meteorites, models of the mode(s) of creation and thermal histories of asteroids, moons, and planets, as well as understanding of the possible atmospheres and surface water / ices of such bodies. Taken together, this information informs us of the conditions that may either support or thwart life. Crucially, the possibly transient and/or oligotrophic nature of life will be examined in relation to our understanding of the sustainability of ecosystems on other worlds as well as on Earth via works concerning BIOSPHERE 2, the means by which we regulate our practices during space exploration so as to protect life (a matter closely linked to what we learn through extraterrestrial sample curation), and the benefits of technologies that support planetary exploration and the search for life elsewhere . In relation to the latter point, concluding chapters will address the benefits not only of the primary applications of space exploration technologies, but will purposefully emphasise the importance of developments in this field of study for our understanding and abilities to better manage the present-day needs of our species and its current and forecast demands on the Earth and, perhaps, elsewhere. These pressing considerations are in addition to the needs of numerous new space missions and major long-term projects in support of wider exploration; for which the Giant Magellan Telescope, European Space Agency's CHEOPS and ARIEL missions, the NASA-led James Webb Space Telescope, and the proposed Lunar Gateway (an orbital platform) are key examples.

This work includes eight to eleven chapters across the two following themes:

- Theme 1: What conditions lead to worlds that support life?
  (Six chapters)
- Theme 2: How can we protect and sustain life on Earth and across the wider Universe?
  (Five chapters)

The number of chapters for each theme will help to ensure thematic balance within the book. The subject matter of each chapter is outlined overleaf, where the selected focus of each is designed to result in a coherent and well-integrated book, and for which details are not repeated here. However, this thematic volume will bring together a set of works that addresses and develops a number of key questions including:

- How can we constrain the favourable conditions and initial stages of the rise of life via astrobiology studies? What role do studies of Earth's extremophile organisms play in this?
- How can we trace and model the birth and life-histories of Earth, planets that were potentially habitable long-ago, and habitable bodies elsewhere? What information do Mars and the Earth's Moon provide to inform us of how, why, and when life arose on our habitable planet?
- Why has life survived and evolved here, perhaps elsewhere, and why might it have been stifled on other bodies in the Solar System?
- Where have we found other potentially habitable worlds and where should we continue to look for more?
- What is the underlying motivation for, and current status of, planetary protection policies in an age of increasing private sector interest in space exploration and *in situ* resource utilisation (e.g., the collection of water or ice, and mining of metals) that could enable space colonisation?
- How are we to colonise other worlds?
- What ('greening') technological developments derived from international space missions have arisen with the potential to enhance and sustain life on Earth (in both developed and developing nations) and across the wider universe?
- What lessons can we take from Earth to benefit the search for life and its sustainability on other worlds?
- Are we living unsustainably on our home world? As custodians for future generations, what approaches can and should we take / develop to better protect diverse life and precious resources on Earth?

BOOK'S CONTENTS

The envisaged advanced-level reference book will comprise an introduction of approximately four to six pages, eight to eleven technical chapters, and a conclusion of roughly 10 pages. This book will total approximately 375 to 470 pages in length. Chapters will each be approximately 20,000 words in length (equating to c.45 pages of printed text) and will include roughly seven diagrams / images and up to two data tables. Chapters of 15,000 words will be acceptable. Authors will be encouraged to cross-reference other chapters where appropriate so as to produce a coherent book. Information on the benefits to authors and reviewers can be obtained from Amy upon request. A list of the planned contents is outlined here:

INTRODUCTION

Dr. **Amy Riches** will author a short introductory chapter that sets out the context and purpose of this book while emphasising the links among its content. This section will also provide a general but concise introduction to concepts of planetary habitability / what makes a planet habitable and life on it sustainable. A dedicated chapter on Venus is omitted from this book because we lack samples and its thick atmosphere - though of great interest in itself - posed significant challenges to the scientific goals of prior Venusian space missions. As such, the comparative atmospheric / planetary evolution of Venus relative to that of Earth will be addressed here. Emerging recognition of the potential importance of ices among Kuiper Belt objects for Solar System habitability will be included. The key current and future space missions of relevance to the book's themes and what signs of life these missions are designed to look for will be outlined here too.

Theme 1: What conditions lead to worlds that support life?

CHAPTER 1. What have we learnt about the origins of life from the organics present in chondritic meteorites?

The opening chapter to the proposed book will be led by *Dr.* **Queenie Chan**, former NASA Postdoctoral Fellow and current Postdoctoral Research Associate at the Open University, UK. *Assoc. Prof..*, **Yoko Kebukawa,** Yokohama National University, Japan, and *Asst. Prof.,* **Maitrayee Bose,** Arizona State University, USA, bring their respective sets of expertise as co-authors.

Queenie will work with a co-author team of her choosing to produce a chapter that examines the nature of organics present in chondritic meteorites and 'stardust' samples. Organic materials present in some of the earliest formed materials of the Solar System are key to understanding the origins of life, and critical to assessing possible extraterrestrial links to the virtually ubiquitous 'left handed' homochirality of life observed on Earth. This contribution will assess how organic materials in chondritic meteorites respond to exposure to heat and fluids, how such events could be linked to impact processes, and how organics might survive planetary processing and be transferred to icy or even thoroughly melted rocky worlds like our own.

CHAPTER 2. The infancy of habitable worlds as constrained by achondrite meteorites.

Dr. **Amy Riches** will play a key role in the authorship of this chapter, and where I shall assemble a transdisciplinary team of co-authors, including those of astrophysical backgrounds who specialise in models of celestial mechanics / dynamical modelling of the Solar System.

To advance understanding of how life arose and was sustained in environments that provide them with the requisite conditions and nutrition, we must understand the means by which habitable worlds form and grow. This chapter thereby builds on chapter 1 by exploring not only what habitable conditions exist, or existed in the past, but what processes account for their creation and how both simple and complex life forms did - or could have - taken advantage of this. In recent years, much exciting new evidence from the mineralogies and chemistries of achondrite type meteorites, experiments to 'recreate' processes pf melting and core formation, as well as space-mission based studies of planetary cratering histories has arisen and continues to be published concerning the conditions and processes operating in the early Solar System. This information is critical to our understanding of how planets such as Earth and Mars came to be. This is an important topic to review at this juncture because an up-to-date work of this nature is a much needed reference for this field of study. This contribution will permit readers to grasp firmly the current state of knowledge of the past histories of habitable and potentially habitable worlds (whether life was transient or persists in present-day subsurface environs); thereby serving to advise on the priorities of future research directions and space mission targets. Thus, this chapter will provide a useful and essential read for those working in these disciplines.

CHAPTER 3. The importance of the Moon in understanding the past, and future, of life on Earth.

Prof. **Ian Crawford**, Professor of Planetary Science and Astrobiology, Birkbeck University of London, UK, is confirmed as the lead author for this chapter. Ian brings expertise in both lunar science and astrobiology. *Prof.* **Nicolle Zellner**, Albion College, USA, brings her lunar science / LHB expertise to this chapter as a co-author. As does *Prof.* **Dave Waltham**, Royal Holloway, University of London, UK.

Any model for the rise of life on the Solar System's habitable planets such as Earth must be in accord with- and utilise knowledge for our nearby partner, our orbiting Moon. This is an active and rapidly advancing area of research that deserves a chapter of its own in this thematic text. The question central to this chapter is: Does Earth's Moon provide unrivalled evidence to inform us of how, why, and when life arose on our habitable planet? It also addresses the possible role of lunar resources in reference to emerging space economies that could support wider space exploration as well as potentially alleviating some of the environmental pressures on Earth. This chapter will provide an up-to-date and authoritative exposition of pertinent aspects of:

1) The influence of the Moon on Earth's habitability such as the consequences of the Moon-forming giant impact, the stabilisation of Earth's obliquity, etc.
2) The role of the Lunar geological record in aiding our understanding of Earth's past habitability. This will include a critical examination of the rates of impact, the theorised late heavy bombardment, and the history of galactic cosmic ray flux over Lunar history.
3) The potentially useful resources available on the Moon and the means by which these could be accessed as space economies develop.

CHAPTER 4. The early co-evolution of complex life and environments.
This contribution will be led by a prominent scientist who specialises in this area and who will assemble a transdisciplinary authoring team. *Dist. Prof.* **Ariel Anbar**, Professor and Distinguished Sustainability Scientist, Arizona State University, USA, may contribute to this chapter.

This book then flows into a chapter that offers readers the opportunity to comprehend more fully the rise of early life and the impacts that this has upon the evolution of planetary atmospheres, hydrospheres and possible weathering processes, with implications for the longer term sustainability of life on a given planet. In this case, Earth is the chosen example. This chapter will provide a much needed new contribution that brings together important new knowledge and understanding to explore the lessons from the Earth regarding the relationships between sustained habitability, environmental evolution as a driver and consequence of life, and key processes at the solid-liquid Earth interface as far back as c. 3.5 to billion years ago. This chapter will include a section that succinctly reviews extremophile life forms and their importance in this context.

CHAPTER 5. Habitability conditions in our Solar System – the case for Mars and the icy moons.
The fifth chapter to this thematic volume will be led by *Assoc. Prof.* **Zita Martins**, Instituto Superior Técnico, Portugal. Zita has engaged a number of co-authors with astrobiological expertise complementary to her own.

We know that Earth is inhabited by complex interconnected ecologies, and the previous chapters serve to prime readers in understanding how this might have occurred and the impacts that this has on chemical cycles and planetary conditions. Critically, there are signs that life could have existed and that organic molecules are currently present elsewhere in the Solar System, relatively convincingly on Mars and some icy moons. In the latter case, these icy moons are outside the classical habitable zone with the consequence that life may exist in environments not traditionally considered feasible for life and its adaptation / evolution. What is this life like, did it arise in ways similar to what we understand for Earth, and is it even possible that such life could have occurred first and "seeded" the early Earth? This contribution will be an authoritative new work that presents a critical and timely overview of the evidence that astrobiology studies, as well as findings arising from collaborative international space missions such as Cassini-Huygens, provide for prebiotic materials and the origins of life as we do and don't know it. The planetary surface, space probe, and meteoritic findings that can testify to planetary environs, fluid activity, and impact events with the potential to create niche environs will be examined so as to constrain the pathways by which precursors and life itself may arise and persist, or be extinguished. This chapter will also highlight the importance of this work to current and future space missions at a time when the international exploration of the cosmos is rapidly accelerating.

CHAPTER 6. Understanding habitability potential through modelling the atmospheric evolution of other worlds
The authoring team for this chapter is under development, and the lead author has been personally invited.

This chapter builds on the knowledge embedded in those that precede it. Given the new abilities to resolve the composition of distant atmospheres via some emerging new ground-based telescopes and astronomically oriented space missions, this contribution may potentially focus on the TRAPPIST-1 system and provides a logical transition into chapter 7. Using numerical models and -where available - space mission data to constrain the composition and evolution of atmospheres on sub-Neptune planets, moons, and other bodies provides information of fundamental import to our knowledge and prediction of both simple and complex life in our Solar System and beyond.

CHAPTER 7. Over fifty potentially habitable exoplanets, how many billions more could there be?
This chapter will be led by *Assoc. Prof* **Charley Lineweaver**, Senior Fellow and Convener of the Planetary Science Institute, Associate Professor in both the Research School of Astronomy and Astrophysics and the Research School of Earth Sciences**,** Australia National University.

Given our understanding of organic molecules, planetary histories, and the rise of life in our own Solar System – and considering the metallicity of our Sun and our Solar System's position on the Galactic Habitable Zone of the Milky Way Spiral Galaxy - where else might life exist and what clues and conditions should we continue to look for beyond our immediate planetary neighbourhood? Exoplanets include a wide variety of worlds, many of which do not closely resemble the present day Earth but are where habitable environments and extraterrestrial life could yet exist. After all, the Drake Equation has long provided us with a probabilistic means of calculating the number of existing and communicative extraterrestrial civilisation in the Milky Way Galaxy and such theory can be applied to the wider universe.

DRAKE EQUATION

$$N = R \times f_s \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- R average rate of star formation
- f_s fraction of good stars that have planetary systems
- n_e number of planets aound these stars within an "ecoshell"
- f_l fraction of those planets where life develops
- f_i fraction of living species that develop intelligence
- f_c fraction of intelligent species with communications technology
- L lifetime of the "communicative phase"

This chapter will evaluate present-day knowledge of habitable exoplanets. This is an important interdisciplinary chapter to include in this volume and is expected to stimulate invigorating and important new discussions between astronomers, planetary thermodynamic / astrophysical modellers, and meteoritical scientists during its production. This chapter will include a section on exomoons because we have found lots of large gas giants that are not habitable. Yet they can support similar potentially habitable icy moons to those examined in Chapter 5, which is positioned in the book to immediately precede this contribution. Although research in this area is not presently extensive it does suggest that, if we consider moons around large exoplanets, the range of potential habitable worlds could significantly increase. Taken together, this chapter will synthesise the latest available information to produce a profound new work that addresses the following question: where have we found other potentially habitable worlds, what are they made of, and where should we continue to look for more? This will thereby be an important reference for the community and will help shape the direction of future space exploration. As such, this chapter will identify future directions for research, concludes theme one, and provides for an elegant transition to theme two.

Theme 2: How can we protect and sustain life on Earth and across the wider Universe?

CHAPTER 8. Provisional Title: Catastrophes for life due to solar system hazards.
This chapter will be led by Research Professor **Sean P.S. Gulick**, University of Texas at Austin, USA, https://ig.utexas.edu/staff/sean-p-s-gulick/. He is presently assembling co-authors.

This subject will draw readers into theme 2 as to understand how we can protect and sustain life as we know it (and perhaps as we don't know it), we must have knowledge of what threatens it. The chapter shall utilise dramatic examples of periods of extinction (+ subsequent diversification) of life on Earth to examine the implications of processes associated with, for example, impact events and asteroid break-up in inhibiting life and bringing about change in evolutionary paths. Case studies include the Chicxulub impact crater that is subject to current drill core studies, associated fossil beds such as those in North Dakota, as well as the hypothesised dimming of the Sun during the Ordovician due to the break-up of the L-chondrite parent body and 'dusting' of the inner Solar System. This section will also highlight ongoing efforts by astronomers to monitor potential hazardous objects (PHOs), including some relatively fast-moving Trojan asteroids and comets.

CHAPTER 9. Sustaining Life on Earth and Beyond – lessons from BIOSPHERE 2
This chapter will be led by *Dean and Prof.* **Joaquin Ruiz**, University of Arizona, alongside the team that he may choose to assemble for this purpose. This contribution will, in particular, utilise knowledge that has arisen from the BIOSPHERE 2 Project - https://biosphere2.org/research/our-mission, https://en.wikipedia.org/wiki/Biosphere_2. In so doing, this section of the thematic volume will critically examine approaches to sustaining life on other worlds, most notably our present capabilities and known challenges to supporting human life beyond Earth. A priority in an age where the possibility of habitation on other worlds is of increasing interest, and may be needed for the survival of our kind.

CHAPTER 10. Provisional Title: Space Technologies improving life here and perhaps everywhere? A case study.
The authoring team for this chapter is under development, and the lead author has been personally invited.

To build on the preceding chapters and to prime readers for the topics of chapters 11 and 12, this contribution asks what are we presently able to achieve to protect and sustain extraterrestrial life and how do we accomplish this? This will be a key chapter that addresses the important and urgent topic of space science technologies and their wider applications to support sustainability on Earth. This work will emphasise new technologies spun-off from Solar System exploration and further developed for the purpose of improving our efficiencies and capabilities in sustaining life.

The established legacy of successfully translated and more widely beneficial technologies in relation to exploration of the Moon, as well as a body of literature on potential lunar in situ resource utilisation will be utilised in this section. This chapter will allow for an engineering focus, but with the idea of the content being engaging to research students and more established scientists working in other areas of planetary science. This will thereby help to cross-pollinate ideas and perhaps seed interest among research students who may diversify their contributions during their subsequent careers. Such a work could prove pertinent in relation to the planned lunar gateway, as well as in relation to the Moon's potential to support exploration to more distant worlds also (including its surface volatiles that might be 'harvested' as fuel). Any potential overlap with chapters 9, 11, and 12 will be carefully managed at the point of the editor's review of section/subsection headings and before chapters are drafted in full.

CHAPTER 11. Protecting life during space exploration, sample return, and future colonisation.
This chapter is confirmed to be led by *Prof.* **Michelle L. D. Hanlon**, Lawyer and Professor of Space Law, School of Law and Center for Air and Space Law, University of Mississippi, USA. *Dr.* **Samantha Rolfe**, Lecturer and Principle Technical Officer, Bayfordbury Observatory, School of Physics, Astronomy and Maths, University of Hertfordshire, UK will contribute to this chapter as co-author. Likewise, **Yo-Ann Velez,** JACOBS / NASA Marshall Space Flight Center, USA, a microbiologist who specialises in Planetary Protection and Biofilms in Space (Europa and the International Space Station), will also serve as co-author.

This chapter logically follows chapter nine, and shall drive an important element of interdisciplinary dialogue concerning space governance. This section will examine the motivation for, and current status of, planetary protection policies (e.g., the United Nations Moon Treaty of 1979, the Outer Space Treaty of 1967) in an age of increasing private sector interest in interstellar and solar system exploration, as well as *in situ* resource utilisation that could, potentially, enable human habitation of the Moon (or near-Moon space), non-Earth planets, and asteroids. In examining and advocating for the advancement of activities currently addressed through biannual meetings of The Committee on Space Research (COSPAR, which gathers together ~2,000 to 3,000 scientists) this will be an important and accessible contribution for the community. It shall also incorporate a critical appraisal of advances in the curation of space rocks / minerals returned from international space missions to laboratories on Earth for the benefit of science, and where we seek to avoid biocontamination of or by extraterrestrial bodies and life forms.

CHAPTER 12. Improving practices to enhance the sustainability of life on Earth
The authors of this concluding chapter will be led by *Prof.* **Holly Stein**, Founding Director, AIRIE Program, Colorado State University, and the University of Oslo, Norway. Holly will involve approximately three other scholars in this effort, potentially including specialists in environmental science / marine ecology. *Dist. Prof.* **Ariel Anbar**, Professor and Distinguished Sustainability Scientist, Arizona State University, USA, is confirmed as a co-author.

Together this team will take account of the chapters and subject matter preceding this contribution and will frame the chapter about - Diverse life and its implications in the modern world: What does the geologic record predict for our future? What can we expect from biogeochemical cycles operating on land, oceans, icy-regions and atmosphere through which planetary conditions are regulated? This chapter has the primary purpose of evaluating Earth in its present-day context and highlights the impacts on climate and biodiversity emanating from the Earth's natural inhale-exhale and the adverse effect of global societies operating unsustainably on our home world. This contribution explores – As custodians for future generations, what approaches can and should we take / develop to better preserve diversity of life and to manage the precious and limited resources on Earth? It thereby synthesizes current knowledge, trends and trajectories going forward, and the lessons laid out in Earth's geologic record. Will humanity survive the Anthropogene, and what will it take?

CONCLUSION

Dr. **Amy Riches** will author a short concluding chapter that summarises the key findings of each contribution to this book. This section will emphasise the importance of the chapters and their inter-related subject matter for the directions that future interdisciplinary research will or should take. This text will also explore how these findings and identified goals will shape the priorities of international space missions and the ongoing development of space protection policies.

The proposed authors engaged at this stage to each lead a chapter are all well-respected experts, decorated (nationally and internationally), currently active in these areas of research, and very experienced and accomplished in their fields. The primary research interests and career summaries of agreed authors can be accessed at the webpage links provided below, and for reasons of brevity are not repeated here. These authorship commitments at the proposal stage, as well as my own contributions, provide for original, up-to-date, and accurate works for 85 % of the envisaged chapters. Suitable leadership of the remaining 15 % of the envisaged chapters has been invited.

All engaged authors were contacted with a mailing in mid-October, the purpose of which was to communicate a deadline of on or close to December 9th 2019 for the completion of headings and sub-headings for each chapter along with identified full co-author teams.

Firmly agreed authors include but are not limited to:

Holly Stein
Professor and Founding Director of the AIRIE Program, Colorado State University, United States of America and Senior Research Scientist, University of Oslo, Norway.
Webpage: http://www.airieprogram.org/hstein.html

Joaquin Ruiz
VP for Innovation and Strategy, Executive Dean, Colleges of Letters, Arts and Science, and Dean of the College of Science University of Arizona, United States of America
Webpage: https://biosphere2.org/research/directory/joaquin-ruiz

Zita Martins
Associate Professor
Instituto Superior Técnico, Portugal
Webpage: https://fenix.tecnico.ulisboa.pt/homepage/ist31684

Queenie Chan
Currently Postdoctoral Research Associate
Planetary and Space Science Discipline, The Open University, UK.
On a discretionary basis, Queenie has advised me that she is currently settling the terms of her next appointment. Her CV is appended to this file.
ORCID: https://orcid.org/0000-0001-7205-8699

Yoko Kebukawa
Associate Professor
Faculty of Engineering
Yokohama National University, Japan
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Ian Crawford
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Nicolle Zellner
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Dave Waltham
Professor
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Ariel Anbar
Professor, Distinguished Sustainbility Scientist, and Director of the anbarlab
Arizona State University, USA
Webpage: https://sustainability.asu.edu/person/ariel-anbar/

Charley Lineweaver
Senior Fellow and Convener of the Planetary Science Institute
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Michelle L. D. Hanlon
Lawyer and Professor of Space Law
Co-founder of For All Moonkind
School of Law and Center for Air and Space Law
University of Mississippi, USA.
Webpage: https://law.olemiss.edu/faculty-directory/michelle-hanlon/ and https://www.forallmoonkind.org/

Crucially, Michelle brings a useful dimension to this book in that she has conducted a lot of research and analysis regarding planetary protection and has worked with many of the individuals at COSPAR. She is an Observer to the UNCOPUOS and to the Hague International Space Resource Working Group, and has contributed to efforts to address the utilisation of space resources by private entities in both of these forums. Michelle is also the co-head of the Cultural Working Group of the Moon Village Association where she addresses a lot of "deeper" questions regarding our responsibilities not just with respect to biocontamination, but also concerning the export of our own human culture.

Samantha Rolfe
Lecturer in Astrobiology and Principal Technical Officer at the Bayfordbury Observatory
University of Hertfordshire, UK

Yo-Ann Velez
Planetary Protection and Biofilms in Space Microbiologist
Advanced Exploration Systems LSS
Environmental Control and Life Support Systems l ES62
JACOBS/ NASA Marshall Space Flight Center

Sean P.S. Gulick
Research Professor
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