

ESD Ideas: Exoplanet, origins of life and biosphere researchers offer a perspective fundamental to ensuring humanity's future

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Introduction. We are at a crucial moment in human history. Earth's natural systems are in extreme flux and threaten the health of civilisation (Romanello et al., 2022). Continued human-induced climate and ecosystem disruption (IPCC, 2023) demonstrate that human power structures are built to function as though they are distinct from Nature. No one would set their house on fire unless they believed themselves immune to the flames; and yet we are setting our house on fire. The collective response by the political, economic and social powers that have precipitated these crises over the next 10-15 years will determine humanity's future over the next millennium. Acknowledging the deep resilience and interdependence of the Earth-life system is a necessary step to mapping a sustainable future. Scientists exploring the histories of planets and life are uniquely positioned to communicate a perspective that is fundamental to our survival: *humanity is wholly embedded in the Earth and its biosphere. There is no escaping our planet and its history.* Only policies that build on this perspective will contribute to a flourishing future for humanity. Here, we offer a few brief glimpses of this cosmic perspective, and call on our colleagues to acknowledge the powerful stories emanating from their work.

Life is deeply embedded in Earth history

How life began remains one of the biggest unanswered questions in science. There is no fossil record of life's emergence on Earth: weathering, plate tectonics, and the carbon cycle collude to obliterate the imprints of biology as time passes.

25 Nevertheless, we know more about our planetary history than even a few decades ago. We are learning more about other planets both in the solar system and beyond, and this allows us to contextualize Earth and its history. For example, we can now consider the prevalence of terrestrial, temperate planets, the relationship between how planetary systems form and evolve and how likely they are to be hospitable to life, and the influence of the host star on planetary habitability (e.g. Kopparapu et al., 2018; Meadows et al., 2020; Bryson et al., 2021). We also have the example of a rich and thriving biology on our planet. A 30 great achievement of modern biology is the insight that all living things are essentially the same at the molecular level, having evolved from common primordial ancestors. The Last Universal Common Ancestor (LUCA) would have possessed the fundamental properties we associate with living cells (Koonin, 2003). Our primary strategy for experimentally studying the

origin of life in the laboratory is the understanding that however life started, its earliest features allowed for a pathway that lead to LUCA. Research into the origin of life thus points to an ancient event, not long after the birth of our planet (Pearce et al., 2018), that transformed a chemical system into that of a durable biology.

Acknowledging our place in the biosphere and in the Earth system

Everything we know in our daily lives, and all the biology teeming around us, has spread from the emergence of life on our planet billions of years ago. Our relatedness is profound: life is one family sharing one home. Biology has covered the planet very thoroughly: from rock deep beneath the ocean floor to the high reaches of the atmosphere (and even on space probes!), every niche that can support life—and even some that would seem inhospitable—is inhabited (Rothschild, 2001). The biosphere as a whole has shown striking resilience throughout Earth's history, adjusting to cataclysmic changes in its planetary environment over time (Corsetti, Olcott, & Bakermans, 2006). Humans are latecomers to this story. Our very existence is enabled by the expansive diversity of life that preceded us and that is actively maintaining the niche we occupy. We are inextricably embedded in something much bigger than our senses can register. If we want to ensure a sustainable future for humanity, then we must first acknowledge our place in the biosphere's planetary playground and epic history. *We do not argue that this acknowledgement will lead to a sustainable future, but rather that a sustainable future is impossible without it.* Life has become integrated into Earth's planetary-scale workings over billions of years. Biology, oceans, atmosphere, and land interact with one another through massive feedback mechanisms. The result is a robust homeostasis: the Earth system is stable and resilient to small, slow perturbations (Lovelock & Margulis, 1974; Lovelock, 2016). For example, the carbon cycle functions as our planet's thermostat and stabilizes Earth's climate over millions of years (Isso et al., 2020). Life, as a whole, further increases resilience to climate perturbations and thus actively contributes to maintaining habitable temperatures on Earth's surface (Schwartzman & Volk, 1989; Vicca et al., 2022). Our planet and biology are interlaced. All the living things that make up the biosphere right now are products of an equally long stretch of evolution: from bacteria to conscious beings, each species has evolved to fit a particular environment. Humans evolved to fit a narrow niche, but, in the grand scheme of things, we are a part of the planet in the same way as every other organism. Planet and Life co-evolve together (Schwartzman, Jorgensen, & Fath, 2008): we are not apart from or above this system we call Nature. *Humans will not survive without a robust and resilient biosphere: it is our life support system.*

Astronomical context is essential for building a sustainable future

Although we occupy a privileged and exciting moment in our understanding of the universe, *we will not find another haven to escape our planetary and humanitarian crises.* There is no planet B (Nicholson & Haywood, 2023). The search for exoplanets and life is about gaining knowledge and perspective about the planet we live on. For example, we are using observations of planets in our solar system and beyond to test and validate climate models (e.g. Pierrehumbert, 2011; see further works in the review by Shields, 2019). Observations of exoplanets and the planets of the solar system (e.g. Meadows et al., 2020) show us what different possible planetary histories and futures may look like (e.g. Nicholson et al., 2018). Although Venus is Earth's

65 sister, it has taken a very different path, to a runaway greenhouse. Examining other planets informs models of planetary evolution with direct observations (e.g. Raymond, Izidoro & Morbidelli, 2020). Building a statistical sample of planetary snapshots will provide insights into the mechanisms that determine stable climate states (Scharf, 2014). Our models of the Earth system, informed by the data of new frontiers in astronomy, could and should help guide policy decisions, serving as civilization's compass for navigating rapid planetary changes.

70 **Calling our fellow scientists to inspire and lead**

We are explorers of the origin and fate of life and planets. Our research community offers a unique and powerful perspective on humanity's most acute intergenerational challenges: humans are a part of the biosphere, embedded in the Earth system, one among billions of planets in the galaxy (e.g. Grinspoon, 2016; Frank, 2019). This perspective confers immense responsibility. Today's urgent planetary crises demand that we scientists acknowledge and communicate the broader implications of our 75 research (Green, 2020). Our academic freedom gives us unique agency and flexibility to pursue research avenues that align with our values. We exhort our colleagues to move beyond the myth that scientific research is value-free. Social sciences provide clear evidence that science is not value-neutral (e.g. Oreskes, 2019; Sinatra & Hofer, 2021). Engaging in advocacy does not diminish public trust in scientists (Kotcher et al., 2017); on the contrary, the public expects climate advocacy from us (Cologna et al., 2021). Scientists are the most trusted professionals alongside doctors (Ipsos, 2022). The COVID-19 pandemic 80 boosted people's confidence in scientists (Wellcome, 2020), suggesting that society may increasingly turn to us as planetary crises worsen. Here, we have sketched some expansive and immediately relevant perspectives offered by our fields of research, without being prescriptive. Our goal is to encourage our colleagues to be innovative and creative in connecting their research with global crises, while leveraging the trust, credibility, and privilege of the scientific enterprise. We have a duty to not only highlight the cosmic perspective, but to ensure that it serves as a basis for action. Let us educate and inspire, inform and act.

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References

Bryson S., Kunimoto M., Kopparapu R. K. et al.: The Occurrence of Rocky Habitable-zone Planets around Solar-like Stars from Kepler Data. *AJ*, **161**, 36, 2021.

90 Cologna, C., Knutti, R., Oreskes, N., and Siegrist, M.: Majority of German citizens, US citizens and climate scientists support policy advocacy by climate researchers and expect greater political engagement. *Environ. Res. Lett.*, **16**, 024011, 2021.

Corsetti, F. A., Olcott A. N., and Bakermans, C.: The biotic response to Neoproterozoic snowball Earth. *Palaeogeography, Palaeoclimatology, Palaeoecology* 232.2-4, 114-130, 2006.

Frank, A.: *Light of the stars: Alien worlds and the fate of the Earth*. W.W. Norton & Company, 2019.

95 Green, J. F.: Less Talk, More Walk: Why Climate Change Demands Activism in the Academy. *Daedalus*, 149 (4), 151-162, 2020.

Grinspoon, D.: *Earth in human hands: shaping our planet's future*, Grand Central Publishing, 2016.

IPCC, 2023: *Climate Change 2023: Synthesis Report*. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, (in press)

00 Ipsos: Veracity Index 2022: Trust in professions survey. Version 1, 2022.

Isson, T. T., et al.: Evolution of the global carbon cycle and climate regulation on Earth. *Global Biogeochemical Cycles* 34.2, e2018GB006061, 2020.

Koonin, E.: Comparative genomics, minimal gene-sets and the last universal common ancestor. *Nat. Rev. Microbiol.* 1, 127–136, doi.org/10.1038/nrmicro751, 2003.

05 Kopparapu, R. K., et al.: Exoplanet Classification and Yield Estimates for Direct Imaging Missions. *ApJ*, 856, 122, 2018.

Kotcher, J. E., Myers, T. A., Vraga, E. K., Stenhouse, N., and Maibach, E. W.: Does Engagement in Advocacy Hurt the Credibility of Scientists? Results from a Randomized National Survey Experiment. *Environmental Communication*, 11:3, 415-429, DOI: [10.1080/17524032.2016.1275736](https://doi.org/10.1080/17524032.2016.1275736), 2017.

10 Lovelock, J. E., and Margulis, L.: Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis. *Tellus* 26.1-2, 2-10, 1974.

Lovelock, J.: *Gaia: A new look at life on Earth*. Oxford University Press, 2016.

Meadows, V. S., et al.: *Planetary Astrobiology*. The University of Arizona Press, 2020.

Nicholson, A. E., Wilkinson, D. M., Williams, H. T. P., and Lenton, T. M.: Gaian bottlenecks and planetary habitability maintained by evolving model biospheres: the ExoGaia model. *MNRAS*, 477, 727-740, 2018.

15 Nicholson, A. E., and Haywood, R. D.: There's no planet B. *Aeon*, <https://aeon.co/essays/we-will-never-be-able-to-live-on-another-planet-heres-why>, 2023.

Oreskes, N.: *Why Trust Science?*. Princeton University Press, reprint edition (April 6, 2021), originally published 2019.

Pearce, B. K. D., et al.: Constraining the Time Interval for the Origin of Life on Earth. *Astrobiology*, 343-364, doi.org/10.1089/ast.2017.1674, 2018.

20 Pierrehumbert, R. T.: A Palette of Climates for Gliese 581g. *The Astrophysical Journal Letters*, Volume 726, Issue 1, article id. L8, 5 pp., 2011.

Raymond, S. N., Izidoro, A., and Morbidelli, A.: Solar system formation in the context of extrasolar planets. Chapter in Meadows, V. S., et al., *Planetary Astrobiology*, The University of Arizona Press, 2020.

25 Romanello M, et al.: The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *Lancet*, 400(10363):1619-1654. doi: 10.1016/S0140-6736(22)01540-9. Epub 2022 Oct 25. Erratum in: *Lancet*. 2022 Nov 3;; Erratum in: *Lancet*. 2022 Nov 19;400(10365):1766. PMID: 36306815, 2022.

Rothschild, L. J., and Mancinelli R. L.: Life in extreme environments. *Nature* 409.6823, 1092-1101, 2001.

Scharf, C.: Our Cosmic Context. Project Syndicate, <https://www.project-syndicate.org/commentary/caleb-scharf-explains-how-investigations-into-life-on-other-planets-help-us-to-understand-earth-s-challenges>, 2014.

30 Schwartzman, D. W., and Volk, T.: Biotic enhancement of weathering and the habitability of Earth. *Nature* 340.6233, 457-460, 1989.

Schwartzman, D. W., Jorgensen S. E., and Fath, B. D.: Coevolution of the Biosphere and Climate. *Global Ecology*, 648-658, 2008.

Shields, A. L.: The Climates of Other Worlds: A Review of the Emerging Field of Exoplanet Climatology. *The Astrophysical Journal Supplement Series*, Volume 243, Issue 2, article id. 30, 11 pp., 2019.

35 Sinatra, G. M., and Hofer, B. K.: *Science Denial: Why it happens and what to do about it*. Oxford University Press, 2021.

Vicca, S., et al.: Is the climate change mitigation effect of enhanced silicate weathering governed by biological processes?. *Global change biology* 28.3, 711-726, 2022.

Wellcome: Wellcome Global Monitor: How Covid-19 affected people's lives and their views about science. Wellcome Trust, 40 2020.

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