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Philosophy and data in astrobiology

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Abstract: Creating a unified model of life in the universe – history, extent and future – requires both scientific and humanities research. One way that humanities can contribute is by investigating the relationship between philosophical commitments and data. Making those commitments transparent allows scientists to use the data more fully. Insights in four areas – history, ethics, religion and probability – demonstrate the value of careful, astrobiology-specific humanities research for improving how we talk and think about astrobiology as a whole. First, astrobiology has a long and influential history. Second, astrobiology does not decentre humanity, either physically or ethically. Third, astrobiology is broadly compatible with major world religions. Finally, claims about the probability of life arising or existing elsewhere rest heavily on philosophical priors. In all four cases, identifying philosophical commitments clarifies the ways in which data can tell us about life.

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Introduction

Astrobiology is synthetic. It brings together diverse fields to create a comprehensive picture of life in the universe. While a publication in geochemistry suffices when it gets the geochemistry right, an astrobiology publication aims to get the geochemistry right in context. Astrobiologists aspire to research and communication that is cognizant of, and accountable to, research in related fields. This synthesis warrants journals and conferences; it makes astrobiology a common endeavour rather than a random assortment of specialists. It also requires careful attention to how ideas are generated, communicated and integrated. The standards differ between disciplines, even within the natural sciences, and important information can be lost. Thus, humanities research will be important, even essential, to astrobiology when it reveals the relationship between individual research and the comprehensive picture. It can inspire more productive research – targeted at improving the picture – and help to keep the picture accountable to the data. Insights in four areas – history, ethics, religion and probability – demonstrate the value of careful, astrobiology-specific humanities research for improving how we talk and think about astrobiology as a whole.

The argument

In science, all conclusions require data to support them. The data, however, are rarely sufficient. Some philosophical assumptions will be required as well. While these philosophical assumptions cannot be removed, they can be accounted for. When Viking 1 sent its first colour image to Earth, scientists mistakenly rejoiced over the light blue sky and gray-green tinge to the land. Due to public excitement and some distraction, these images were released to the public within 8 hours using a process which, inadvertently, deepened the blue colour. Good data and experimental design soon won out. A test chart had been placed on the lander so that pictures could be colour-calibrated. That, along with some reflection about the composition of the atmosphere and the effect of dust in the air, revealed the now familiar pink-white sky and gray to orange landscape. Data overcame intuition that skies should be blue and that equipment should work exactly as anticipated. The moral is not that data are unimportant or that scientists are incautious. Precisely the opposite. Close attention to assumptions allows scientists to be cautious and apply the necessary data. They can only do this when they carefully differentiate data from intuition and prior philosophical commitments.

Other examples include the Viking labelled-release experiment and the Martian meteorite ALH84001. Both raised important questions about the standards used to make a convincing argument. In both cases, evidence thought sufficient before an experiment was found to be insufficient after. Astrobiologists are familiar with the challenges of defending a contentious claim – in other words critical epistemology.

Some readers may feel that the claims in this paper lie beyond astrobiology as science. That position, in and of itself, requires a certain level of philosophical commitment about the bounds of science. Hopefully this paper will help identify where the boundary is. Significantly, though, once the boundary has been drawn, no conclusions can be reached on the other side – whether for or against a given claim. If astrobiology is not allowed to argue (as science) that humans are significant, it is also not allowed to argue (as science) that they are insignificant. The cases presented here were chosen because an argument has been made in one direction, while the humanities evidence suggests it should be made in another. Astrobiologists need not comment on history, significance and broader questions of worldview. (It may be impossible to avoid probability.) If they do, they can draw on a growing literature that critically assesses the questions and supports some claims over others.

Philosophical priors – that is foundations for arguments other than data – should be identified and reported on. They impact interpretation. Whether communicating with the public or with other astrobiologists, they shape our common understanding of life in the universe. They can affect funding levels, avenues of research and data interpretation. They are necessary and may be justified, but the audience cannot determine this without knowing what they are.

An outline

Four humanities insights will be covered. Each insight relates to the relationship of natural science findings to larger narratives about the role of life in the universe. Each highlights an area where the epistemology of science approaches potential boundaries. First, astrobiology has a long and influential history. Proposed answers to fundamental questions have always drawn on empirical observations and they continue to require philosophical sophistication. Knowledge about this history reveals both past and present philosophical commitments. Second, astrobiology does not decentre humanity, either physically or ethically. Humans have rarely occupied the physical centre of our cosmologies and empirical data are ill-equipped to speak to our metaphysical centrality. Third, surveys show that astrobiology is broadly compatible with major world religions. While some religions and their attendant theories of knowledge conflict with science; many do not. When conflicts are proposed, communicators should be explicit, identifying both the religious tradition and the epistemology in question. Finally, data are currently very limited with regard to the existence of extra-terrestrial life; therefore, claims about the probability of life arising or existing elsewhere rest heavily on philosophical priors.

Astrobiology works because it involves multiple experts in a discussion about the history, extent and future of life in the universe. That discussion requires common language and understandings about how claims are defended. These insights and the related astrobiology humanities research, contributes to that common core.

Insight 1: Astrobiology draws on centuries of observation.

Astrobiology as it developed in the 1990s shows a remarkable spirit of humility, trans-disciplinary inquiry and willingness to think broadly. It also takes advantage of new technologies. These innovations can be lauded without making parallel and inaccurate claims that new questions are being addressed or that old questions are suddenly amenable to scientific investigation. Astrobiologists frequently cite the newness of astrobiology (e.g., Chela-Flores 2001; Ward & Brownlee 2004; Cranford 2011). The last 20 years have witnessed a rapid increase in technology as well as trans-disciplinary scientific research. Perhaps the most dramatic advances have been in astronomy – with new telescopes revealing thousands of planets – and biology – with new molecular techniques and phylogenetics revealing thousands of species. Known potential habitats and known ways of living have grown exponentially. Both of these sciences build on centuries of experiments and exist in dialogue with millennia of commentary in philosophy, often drawing on the precursors of modern science. Questions about the extent of life in the universe and scientific/empirical methodologies have a long pedigree.

History is essential to astrobiology because it identifies the framework in which questions are asked and the range of solutions that are considered acceptable. Astronomers attempted to account for planetary motion using circular motion for 2000 years before Kepler proposed elliptical orbits. More recently, models of solar system formation and planetary abundance were heavily influenced by the technologies used to find planets and the biases built into those technologies. Dwarf stars were overlooked in early searches for planets, perhaps due to assumptions about available mass or energy output. The discovery of seven rocky planets in orbit around TRAPPIST-1 demonstrates the value of identifying and investigating assumptions about planetary abundance. Emphasizing the role of historical theories about astrobiology gives modern researchers another tool for identifying their own predispositions.

To draw an example from biology, the endosymbiotic theory was popularized by Lynn Margulis (Sagan 1967). The idea, however, was first proposed – with clear observational data – over 50 years earlier by Minchin (1916) and Merechowsky (1910). The concept of an obligate intracellular symbiote could not catch on without the conceptual framework of population genetics and phylogenetics. History gave Margulis the idea and contemporary theoretical biology gave her the context.

'*Astrobiology is new*'

A common but problematic claim asserts that we are now starting to apply science to fundamental questions for the first time in human history. Speaking of Carl Sagan's optimism about finding extra-terrestrial life, David Weintraub (2014, p. 5) says this. 'Sagan wrote at a time when the theological philosophical doctrine of plenitude had been replaced with the probabilistic, mathematical certitude of statistics. Sagan based his statistical arguments on numbers gleaned from data obtained with telescopes, in laboratory physics experiments and via space exploration.' This scientific supersessionism appears repeatedly, sometimes more, sometimes less visible. Carl Pilcher, then Director of the NASA Astrobiology Institute, spoke to an interviewer in 2009. 'We are living at essentially the first time in human experience when we can bring the tools of science to bear on questions that were the province of philosophers and theologians and science fiction writers before this.' It also appears in the description of the Baruch S. Blumberg NASA/ Library of Congress Chair in Astrobiology, a position created to explore 'astrobiology's role in culture and society' (Library of Congress 2016). 'Before the advent of modern science, these questions were largely in the realm of philosophy, theology and ethics. Today, the tools of science are increasingly being brought to bear to address these questions' (ibid.). David Grinspoon (2003, p. 69–70) admits of a broader timescale, but still speaks of science over the last 400 years providing answers (presumably the first real answers) to ancient questions and providing an alternative story of creation.

I date modern astrobiology from the mid-1990s, with the rise of exoplanet research and debates around the Allen Hills Meteorite. The NASA Astrobiology Institute was founded in 1998. The International Astronomical Union's working group on biastronomy arose 16 years earlier. This has been an exciting time for life and space science, but it is not new. There was a previous wave of excitement in the 1960s and 1970s with US and Soviet spacecraft travelling between planets for the first time. This wave of exploration fed the optimism of Sagan and many others. Before that, there was a surge of interest in biochemistry and the origins of life in the early 20th century fuelled by research from Haldane, Muller, Oparin, Schrödinger, Trolland and von Neumann into self-replicating and self-regulating systems (Mix 2014). There was even a flurry at the turn of the last century as radioactivity was considered a possible missing link to provide a theory of 'cosmic life' (Burke 1906; Campos 2015). A half century before that, Thomas Henry Huxley (1869) was touting our new, scientific appreciation that biology was – through theories of protoplasm – consistent with mechanical explanation. Each provoked a wave of popular interest in science, claiming that recent empirical discoveries gave them insight into the place of life in the cosmos.

Reaching further back in time, we can look to Immanuel Kant. Drawing on Thomas Wright's astronomical observations, Kant argued that the Milky Way is a disc of stars and proposed that many astronomical objects are really 'galaxies' of stars (*Universal Natural History and Theory of the Heavens*, 1755). He speaks of infinite inhabited worlds and speculates on the character of their inhabitants based on astronomical conditions. William Derham's book *Astro-Theology* (1714) reasons from astronomy to theology, suggesting every star is a sun with its own inhabited planets. The famous astronomer Christian Huygens concluded life must exist beyond Earth in a book devoted to the topic, *Cosmotheoros* (1698). Still further back in time, we see a long line of commentaries on the 'plurality of worlds' reaching back into antiquity.

Though the data available were scarce by modern standards, the commentators were eager to use the best observations available. None of these authors failed to speculate on how their theories impacted our understanding of ourselves and our place in the cosmos. Theories about the 'plurality of worlds' went in and out of favour throughout the 2400 years from Aristotle to today. Brief summaries of this long history can be found (Sullivan & Carney 2007; Dick 2009; Hewlett 2013) as well as more extensive treatments (Dick 2001; Crowe 2008; Impey *et al.* 2013; Rubenstein 2014; Vakoch 2013, parts I and II).

Writers hoping to provide a new take on astrobiology and its impact on society – from science to sociology, ethics and theology – can draw on an extensive literature. We find ourselves on a wave of public and scholarly interest, but it is not the first such wave. If we wish to assert the superiority of modern approaches – as I believe we do – it will be important to articulate why and how they are different.

Modern astrobiology makes some questions tractable by focusing our attention on the data. Prior philosophical commitments, through which we interpret the data, can be minimized. When they are necessary, researchers can be aware of them, assess them with philosophical rigor and communicate them clearly. The remaining insights address specific philosophical commitments common in astrobiology, but not always critically assessed.

Insight 2: Astrobiology does not decentre humanity; it confirms our physical mediocrity.

Philosophical commitments about the significance or insignificance of humanity have been common throughout history, but an oversimplified narrative about them can detract from both current research and historical understanding. Copernicus, Galileo and Newton changed science dramatically by asserting that the same laws of physics applied to local and celestial bodies. As previous researchers considered heavenly motion more perfect than terrestrial motion, this was a demotion of the heavens and a promotion of earth. The Copernican Principle has become integral to astrobiology as we think about the rules for life elsewhere. It will be 'life, not as we know it,' yet we feel confident that it will be constrained by the same physical and chemical regularities we find on Earth. Conversely, knowledge of extremophiles has broadened our ideas about the range of environments in which life might thrive. It is important to recognize the ways in which we expect alien life (not yet observed) to be like Earth life. This appears most dramatically in our discussions of human significance, though in many ways it applies to all Earth life.

After covering the origin of the claim that humans were 'decentred' by science, this section assesses the evidence. Humans were not physically decentred by modern astronomy. 'Metaphysical' decentring is more problematic. Aspects of human significance as animal, rational and uniquely important are discussed below. The decentring of humans as transcendent minds did occur in the 19th century, but it was the product of changes in philosophy, not changes in biology.

The role of modern science in decentring humanity has become a trope in Western culture. Emil du Bois-Reymond (1883), eulogizing Darwin, compared him with Copernicus. Both had struck great blows to anthropocentrism, the latter removing us from the centre of the universe, the former placing us among the animals. Sigmund Freud, somewhat egocentrically, added himself to the list, claiming that psychoanalysis had decentred the ego in human decisions and behaviour (1920, p. 246–247). Stephen Jay Gould re-popularized this narrative as science fighting human self-importance in 1994. Combined with Sagan's supersessionism and Lynn White's (1967) association of Christianity with anthropocentrism, a strong popular narrative emerged. Christianity placed humans at the centre of creation and science – through Copernicus, Darwin and Freud – had knocked us off our pedestal.

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Carl Sagan phrases this quite poetically (1995, p. 12). 'If we long to believe that the stars rise and set for us, that we are the reason there is a Universe, does science do us a disservice in deflating our conceits?' Caleb Scharf looks closely at our specificity and significance in his book, *The Copernicus Complex*, but even he starts with the assertion that Copernicus 'demoted' Earth and 'decentred' humanity (2014, p. 8, 230). David Dunér, addressing the history of astrobiology and theology, speaks much less cautiously (2016, p. 451). 'The theological and existential implications of the new astronomical worldview are well-known. When Nicolaus Copernicus showed … that Earth did not need to be considered the center of the universe any longer, the human being … lost the central position in the divine creation.' A careful look at historical astrobiology shows a long tug-of-war between the advocates for a plurality of worlds and the advocates for anthropocentrism (Dick 2009, p. 177). Let us look more closely at the claim that the most recent shift decentred humanity and that science was the cause of that shift.

Physical decentring

Confusion arises over our treatment of Earth as a planet. The true revolution of Copernicus – carried through by Kepler, Galileo and Newton – was to apply one physics both locally and celestially. The Copernican Principle (or the principle of mediocrity) is a philosophical tenet, consistent with, but not determined by, the data. It holds that the same rules apply everywhere. This perspective suggested new observations and was one of the most important steps towards modern science. It also changed our picture of the universe from one in which earth was an element and a location, to one in which Earth was a planet.

In the Aristotelian/Ptolemaic picture of the cosmos, popular throughout the Middle Ages, the cosmos formed a sphere, with the 'bottom' at the centre. The element earth (lower case 'e') settles downward. Change occurs due to the movement of elements to their proper place: with earth below water, below air, below fire, below aether. Elements undergo change and must re-equilibrate. This layered model gives us an onion-like cosmos. Humans are not at the centre, but somewhere in the realms of water and air, above earth and below the fiery and/or aetherial heavens. Scholars thought of us as intermediate or mediocre. We were poised between the heights and depths, though their calculations were more likely to place us in the low-rent neighbourhood, just above earth. In *The Timaeus*, Plato never identifies the centre, but he places Tartarus, the realm of unforgiven and unredeemable souls, closer than anything else. Tartarus is below Hades as Hades is below the earth under our feet. Aristotle and Ptolemy did not speculate, but Medieval Christians provide commentary. In the early 14th century, Dante spelled out the most famous Medieval cosmology in *The Divine Comedy*. God cast Satan to the bottom of the trash-heap, where he rests at the core of the spherical earth. With physics friendly sensibilities, there is no farther he could fall. C.S. Lewis (1964) points out that this reflects an inversion from the proper perspective with God in the centre and Hell at the outside. Humans after the Fall fail to understand the centrality of God (in the realm *above* the stars) and the peripheral quality of earth; humans get cosmology backwards. Whether or not we accept Lewis' account, before Copernicus, humans occupied an *undignified* and intermediate place, neither at the bottom of the heap with mud and Hell, nor at the top with the air and stars.

Copernicus gave earth the dignity of a proper noun, a capital letter and the attribution of 'planet' or wanderer. Earth moves and, thus, has a location, either here or there. Humans no longer occupy an undistinguished middle layer of the onion cosmos. Instead, we are located on a rock moving through the heavens. In some ways, this was a promotion from mud-creatures to star-farers.

I do not wish to de-emphasize the importance of the Copernican Principle to science and modern knowledge. The application of terrestrial physics to celestial mechanics was a huge step forward. It was not, however, a demotion for humanity. We could not lose a physical centrality we never had. Nor was the centre/bottom of earth a privileged place in the cosmologies of Greek antiquity and Medieval Christendom (Lovejoy 1936, p. 99–106). Quite the opposite.

As a side note, it is worth mentioning that the word 'world' also shifted meaning. In Old English 'world' suggested the 'age' or experiences of humanity. This human realm covered less than half of the earthly sphere in Dante – the remainder was ocean and the mountain of Purgatory. Earth can only become equated with world when the Earth becomes a specific place and humans see themselves as particular to and covering it. Prior to this equation of Earth, world and planet, a plurality of worlds could as easily refer to parallel universes, distant countries, or diverse perspectives as to a number of rocks in space. Copernicus did not decentre humanity. He decentred earth, changing it into 'the Earth' and changing our perspective on the meaning of 'world' and 'planet'.

Metaphysical decentring

Scharf (2014, p. 230) ends his book with a fascinating quote. 'We are, I think, still unlikely to be central to the universe, either astrophysically or metaphysically.' He also speaks throughout of the 'significance' of humanity. What does it mean to be cosmologically significant, and is it possible that Copernicus and Darwin decentred us in a less literal fashion? The location of our bodies shifted from a-surface-among-spheres to a-sphere-in-space, but both are mediocre, middling, non-central. So, perhaps the key decentring had to do with human uniqueness or value, the metaphysical component.

My first response would be to say that this clearly takes us beyond the realm of science. Empirical data do not give us confidence about value statements. They can tell us that one thing is different from another, but not that it is better, more significant or dignified. Were the decentring of humanity not such a popular trope, I would avoid the topic altogether. It has been raised by Sagan and Scharf in the context of astrobiology. It contributes to philosophical commitments with regard to religion, covered below. And, in my experience, it is one of the more popular hooks used in astrobiology outreach. Readers willing to concede that neither the importance nor

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unimportance of humanity falls within the purview of astrobiology as natural science may safely skip ahead to Insight 3. Those interested in defending the claim one way or the other are encouraged to continue with arguments about what constitutes 'metaphysical significance.'

The significance of human as animal

Throughout Western history, humans have been conceived as an awkward hybrid – having both physical and psychological traits. I will treat them one at a time, as the physical aspects, more clearly amenable to biological interpretation, are also more clearly mediocre historically. Human bodies have, almost without exception, been treated as animal bodies in the West. Though they are distinct from the rest of the universe with regard to nutrition, reproduction, sensation and locomotion, they are not distinct from fish, coral and countless other Earth species. In this respect, human significance did not change with Copernicus, Darwin, or Freud.

From Plato through the Middle Ages, humans were classified as rational animals with physical, mortal, animal bodies. Debates raged over the relationship between body and mind, but a biological Copernican Principle applied. Human physiology was animal physiology. If the mind was distinct, it was so because of some addition to the physical processes, not a contravention or removal of them. Speculation was rampant and popular that our bodily processes inhibited, compromised, or even determined our mental states.[1] Not until Descartes (17th century) was cognition removed from human bodies and placed in an immaterial *res cogitans* while all other animals were relegated to senseless mechanical motion. Thus, Darwin's theory of common descent – and subsequent reservations about human rationality unimpaired by animal physiology – at most overturned two centuries of philosophy, not 20. Humans remained animals, they did not suddenly become them. Any theory of our animality that resulted from the discovery of extra-terrestrial animals would only strengthen this position. In calling humans animals, biology does not decentre the human body, but affirms the philosophical priors of philosophy and theology. Theories of our rationality may prove more problematic.

The significance of human as rational

Trust in the human intellect was shaken by Darwin and Freud. Thomas Aquinas and Rene Descartes held a belief that humans might have complete certainty about some propositions because of our transcendent minds (Osler 2004; Robinson 2015, p. 3–16). Anthropocentrism was not a doctrine of the Christians *per se*, but of the Humanists (Dick 1996, p. 37). Darwin led us to believe that this confidence – based on the uniqueness and transcendence of our minds – was compromised by our relationship with animals. Freud led us to believe it was compromised by our irrational unconscious. Doctrines that elevate the human mind above physical causality – and therefore above doubt – were at stake in the 'decentring.' Transcendent minds could be accommodated with Darwin by a claim that transcendent reason was miraculously imposed upon an evolutionary lineage. Darwin's contemporaries, Cambridge historian Charles Kingsley and Harvard biologist Asa Gray had no difficulty taking such a position, though Darwin himself had doubts. A.H. Strong argues that, 'The wine in the miracle was not water because water had been used in the making of it, nor is man a brute because the brute has made some contributions to its creation.' (Strong 1907, p. 472) While I have reservations about these positions theologically, they demonstrate that both interventionist and theistic evolution interpretations were readily available within Darwin's lifetime.

The real problem arose when transcendent minds could not be accommodated to the new materialism of the 18th and 19th centuries. This philosophical shift simultaneously elevated and demoted the human mind (Schrödinger 1992, p. 117–127; Foucault 1994; Brooke 1998). It elevated the mind as the locus of reason and observation, capable of discovering the order in the world. It demoted the mind from Platonic certainty to situated awareness. Huxley, in particular, leaned on Descartes rather than Darwin, in his famous claim that the human mind is an epiphenomenon of the body (Huxley 1874). Darwin and Freud did not decentre human bodies with science; Descartes and Huxley centred and decentred human minds with rationalism.

Dignity and anthropocentrism

This leaves us with questions of value. Do humans lose some dignity or intrinsic value when moved from earth to the Earth or when related to other animals? According to the old saw, the Bishop of Worcester's wife, when hearing about the relation of humans to chimpanzees remarked, 'Let us hope it is not true, but if it is true, let us hope it does not become widely known.' I have no doubt that the mediocrity of humans, demonstrated in the work of Copernicus and Darwin, can undermine beliefs that humans are special, privileged and of more worth than their non-human neighbours. I simply see no reason to think that this high view of humanity was more popular before Copernicus and Darwin. (See Lovejoy 1936, p. 99–143 and Peters 2013 for concurrent opinions.)

Anthropocentrism is only equivocally present in Christianity. Biblical narratives both elevate and suppress human self-importance (Brown 2010; Mix 2016). Numerous theologians have highlighted the idolatry of anthropocentrism (Gustafson 1981; Kelsey 2009). In the context of astrobiology, C.S. Lewis (1955) goes out of his way to say that human depravity is a reason alien life should be protected from us. He speculates freely on alien intelligence and alien theology in his Space Trilogy. Ted Peters (2016) and others argue that Jesus' incarnation here on the Earth and in human flesh reflects positively on us as a planet and as a species. This, however, seems inconsistent with scriptures that make a point of Jesus being born to poor parents in Nazareth, a country disreputable in both Rome and Israel. Many of Jesus' attributes are not seen as limiting the extent of his redemption: gender, country of

1 See Plato's *Republic*, books III and IV and antique discussion of irrational souls. See also Aquinas' *Summa Theologica* II.1.6 and Medieval discussion of irrational appetites.

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origin, hair colour… Though arguments persist, it does not follow of necessity that species and planet of origin should be any more limiting. More specific arguments would be required.

William Stoeger (2013, p. 57), for example, argues that astrobiology reveals relationships and that ethics 'is about recognizing and respecting relationships.' If relationships, rather than species, are the key element in redemption and if astrobiology tells us about those relationships, it strengthens Christianity. In this way, astrobiology reveals some – though not all – foundations for reasoning about human dignity and obligations. Not all audiences will view astronomy, astrobiology, or biology as decentring in a metaphysical sense. Nor will the divide be based on having a Christian, Atheist, or scientific worldview alone. Other commitments must be identified, which make these new discoveries threatening to human significance.

Steven J. Dick (1996, p. 36–58) presents a thorough treatment of anthropocentrism and astrobiology in recent history. Over the last few hundred years we have moved away from a Humanist anthropocentrism to a picture of human mediocrity. He concludes that 'in its broadest aspect, this is precisely the core of the twentieth-century extraterrestrial life debate: to demonstrate through science the uniqueness or mediocrity of humanity' (p. 58). Such a 'scientific' demonstration may or may not be possible depending upon one's concept of science and how it relates to other ways of knowing, which brings us to questions of astrobiology and religion.

Insight 3: Astrobiology fits into a larger picture of the universe, including ethics and epistemology

What is beyond the scope of the origin, extent and future of life in the universe? Having already attempted a synthesis of natural sciences, questions of worldview, ethics and epistemology frequently get drawn in, especially in talks for the public, rendering astrobiology as the study of 'life, the universe, and everything.' Perhaps this is unavoidable; it motivates public interest in the field. At the same time, it begins to push the limits of what it means to be an expert in astrobiology. Multiple astrobiologists have made claims about the compatibility of astrobiology with religion.

'A large fraction of the public believes … that a discovery of life elsewhere – particularly intelligent life – that is not generally related to terrestrial life would have major, and devastating, implications for most modern religions' (Jakosky 2006, p. 106–107). Paul Davies suggests that 'the discovery of any sign that we are not alone in the universe could prove deeply problematic for the main organized religions, which were founded in the pre-scientific era and are based on a view of the cosmos that belongs to a bygone age' (Davies 2010, p. 188). This antagonism appears as a common misconception, often related to the decentring discussed in the last section. 'Religion' itself is a contentious term, accepting a variety of definitions. The four most populous religions – Christianity, Islam, Hinduism and Buddhism – have so many adherents (Buddhism, the smallest, has roughly 500 million) that a huge variety appears in each. So, it is trivially true that, within each, some adherents will be troubled by astrobiology. Some will not. The more substantive question will be whether any core principles or findings of astrobiology conflict with the core principles of a particular religion.

If a generic statement must be made based on data, we should say that astrobiology does not threaten religion. Weintraub (2014) opens with a quip of Einstein's. When asked if extraterrestrial life led to conflict between science and religion, he said no, 'though it depends, of course, on your religious views.' This default compatibilism seems to be the consensus. The issue has arisen repeatedly in the history of Christian theology and recent surveys suggest that Christians do not find their own beliefs threatened – though they think the beliefs of others should be (Dick 1996, p. 517; Peters 2011, 2013). Weintraub (2014, p. 5) cites a survey in which 37% of American respondents believed that extraterrestrial life exists. Atheists tended to be more positive (55%) as did Muslims (44%) while Baptists were less (29%). Roman Catholics, Methodists, Hindus and Jews were close to the overall average.

Staying focused on the social science data, religion is broadly compatible with astrobiology, the discovery of extra-terrestrial life and the discovery of extra-terrestrial intelligence. More specific claims about subsets of the major world religions should be qualified appropriately. Readers satisfied that this is the state of the art and that astrobiologists – as scientists – have no need to talk about religious issues, positively or negatively, are invited to skip ahead to Insight 4. The remainder of this section is devoted to more specific questions arising in areas of potential conflict. Is there a narrative conflict; do religion and astrobiology tell competing stories? Is there an ethical conflict; do religion and astrobiology lead to competing value systems? Is there an epistemological conflict; what may be known of God, humanity and reality through science? I can only survey these questions briefly, but extensive commentaries are available with detailed analysis of Christian theology as well as surveys of astrobiology in other religions (Bertka 2009; Impey *et al.* 2013; Vakoch 2013; Wilkinson 2013; Weintraub 2014).

Religious and astrobiological narratives

Astrobiologists frequently frame their science in terms of a grand narrative about the universe that can take on religious overtones, or at least compete with other grand narratives. In this context, the narrative aspects of greatest interest will be creation – how things came to be as they are – significance – what role we play in the continuing story – and destiny – where we are going. Note that these fit surprisingly well with the three basic questions of the astrobiology roadmap: 'how does life begin and evolve, does life exist elsewhere in the universe, and what is the future of life on Earth and beyond?' (Morrison & Schmidt 1999; Des Merais *et al.* 2003, p. 219, Des Merais *et al.* 2008, p. 715). It is essential to ask whether these narratives are intended to replace, modify, or compliment the narratives of creation, significance and destiny present in religious traditions. Some sociologists consider 'worldview construction' central to religious identity and function

(Berger 1967). If we construct our ideas of religion and astrobiology on exactly those terms, conflicts must arise.

Ann Druyan, in her introduction to *Cosmic Connection*, makes it clear that she believes Sagan has produced a new religion based on science, including creation story, anthropology and ethics (Sagan 2000, p. xvii–xxvii). Quoting Carl Guthke, Steven Dick (1996, p. 554) argues that cosmic evolution and biophysical cosmology may be the central myth of our age. Grinspoon (2003), along with many modern atheists, present scientific origin theories (Big Bang and origin of life) as 'creation' stories without interrogating the role of creation stories in scripture, where they do normative, evaluative and relational work in addition to (or even in place of) historical work. One should attend to which aspects of creation are being replaced. Grinspoon (2003, p. 70) says, 'our knowledge of Cosmic Evolution is not in conflict with the core belief of most of the religions, and it certainly isn't necessary to discard or discredit older origin stories to embrace this new one.' He has no intention of going beyond a historical clarification, which may or may not work with particular religious histories. Nonetheless, his willingness to frame his presentation as 'the greatest story ever told,' 'origin tale,' and 'living myth' (p. 69) invites comparison with the Bible. He even discusses it in relation to interpretations of Genesis. Any such application will raise questions of whether and to what extent the normative, evaluative and relational content of creation stories depends on historical content. Authors unwilling to venture into this territory should avoid using words like 'creation' and 'genesis' which inevitably carry philosophical and religious baggage for members of the audience.

Less transparent, but far more common narrative elements involve referring to the universe as 'vast, dark cold, empty, and dead' (Hanson 2014) as well as purposeless (e.g., Gleiser 2015). These may seem innocuous, but they hold rhetorical weight because they invite comparison with some alternative story about the cosmos. No one makes these points about a diamond, despite the fact that it is, relative to other carbon chemistry, sterile, cold and inert. Writers and speakers who emphasize these traits are constructing a narrative in opposition to other, more familiar narratives. With only one universe available empirically, we have no way to be objective about such comparisons. Cozy and well-provisioned describes the universe just as well as vast and empty (Chesterton 1908, p. 113). Value-laden words are useful, but when using them, it pays to attend to where the values come from, what work they are intended to do and whether the audience will be sympathetic.

Communicators wishing to frame astrobiology as 'deep history,' 'cosmic drama,' and 'creation story' should consider the work they intend this language to do. Religious accounts of creation (and existence) have strong ethical elements. If the language only serves to frame empirical data, the data would be better framed less poetically, making it accessible to more audiences without inviting religious commentary. If the language really does mark an intent to change minds about religion, it should do so transparently and with the same scholarly attention to sources as one would give to the scientific data.

Religious and astrobiological ethics

Popularizers of astrobiology often use science to justify evaluative and normative claims. The perspective gained from seeing 'Earthrise' or the 'pale blue dot' and the awareness of our own power gained from recognizing the 'Anthropocene' have been used in attempts to move from astrobiological insight to ethical insight (Mix 2016). Older tropes include 'Gaia,' 'Spaceship Earth,' and 'Star-stuff.' In each case, we are asked to update our ethics in light of scientific advances. We must ask how one makes this move logically or rhetorically.

Hume and Kant suggest an is/ought gap. Hume argues that the two are epistemologically distinct in *A Treatise of Human Nature*. One cannot reason deductively (with logical necessity) from a statement of what is to a statement about what we ought to do. Kant provides a skeptical argument. Because empirical reasoning only provides conditional knowledge, 'all reference to empirical conditions – even to the most established facts of human nature – must be excluded from the grounds of morality' (Scruton 2001, p. 85). More recent philosophers have argued for and against this 'naturalistic fallacy' of reasoning from is to ought (Richardson 2013). Conflicts with religion may arise over incompatible models of moral reasoning. Stoeger (2013) and Cleland & Wilson (2013) specifically raise this caution in relation to astrobiology and ethics. On the other hand, Sagan (2000, p. xxx) and Kauffman (1995, p. 4–5) do not hesitate in drawing normative conclusions from scientific facts.

Astrobiologists can provide important insights about the place of humans within a broader picture of the cosmos. Even when the scientific community agrees on particular factual conclusions, however, no consensus exists on how such a conclusion would be translated to an ethical position. Thus, ethical positions should not be presented as the product of 'astrobiology' *per se*. Nor are they self-evident. Rather, they arise as a product of astrobiology plus some external factors. Grinspoon's moral of Cosmic Evolution (2003, p. 86) and Tyson's cosmic perspective (2015) draw on Sagan's ethical cosmology. Crysdale's (2009) ethic of risk and Walker & Wickramasinghe's (2015) ethic of gratitude draw on Alfred North Whitehead's process philosophy. Meanwhile Conway Morris (2003) and O'Meara (2012) are clearly drawing on natural theology in light of Thomas Aquinas. McKay (2013, p. 159) obscurely claims that 'Life is not the only source of value, but it is perhaps the most important source,' without any defence at all. Presumably he follows the environmental ethics of Aldo Leopold as in McKay (2009) and Sullivan (2013), but unless this is stated, the reader may be confused. Thinking along parallel lines, the Committee on Space Research (Rummel *et al.* 2012, p. 1021) recommends work 'to further explore the ethical values (e.g., intrinsic and instrumental) that apply to life, non-life and environments as well as to the different classes of target objects in our solar system to provide guidance for balancing the different interests.' Future discussions about the intrinsic value of life, planetary

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protection and the significance of humanity would benefit from more explicit statements about ethical sources.

How far can astrobiology go?

Threaded throughout the discussion so far has been the question of when we have left astrobiology as science and entered the territory of astrobiology as humanities, or perhaps left astrobiology altogether. Every discipline must decide as a community what the boundaries of its own expertise are. Astrobiology is no different. In some ways, the problem is intensified by interdisciplinary research teams and strong public interest. Only astrobiologists can set the bounds for good astrobiology. Only peer-review can distinguish well-supported claims from speculation, opinion and digression. Conversational knowledge of epistemology, then, should be part of the core knowledge for all astrobiologists. Similarly, the astrobiology community benefits from a few academics in the humanities with a deep knowledge of epistemology (and history, ethics, sociology, etc.) who can be consulted when such issues arise.

In tackling questions of cosmic history and human significance, astrobiologists run the risk of overreaching the data. The Copernican Principle is indeed useful, but we must also think carefully about sample bias. In seeking 'life as we do not know it' we run the risk of overconfidence (Lupisella 2009). A careful approach will attend to two questions. What constitutes valid scientific reasoning? And, are there other ways of knowing? Debate persists, often under the heading of the 'demarcation problem' (Hansson 2015).

This returns us to the question of supersessionism. If science is the only or ultimate arbiter of truth, then the expansion of science to the scale of the universe relegates all other ways of knowing to historical curiosities. Such a position will conflict with any philosophy that admits of other types of reasoning. If, on the other hand, we see science having a very particular scope (e.g., 'depictions' in Jakosky 2006, p. 56 and 'mutual observables' in Mix 2009, p. 12), then no such problem arises. Astrobiology is well served by taking on the narrower view, with a discrete epistemology. Astrobiologists can confidently assert many things about life in the universe without making any exclusive claims about metaphysics or epistemology.

Stephen Hawking and others have attempted exactly this type of epistemological showdown in speaking about the history of the cosmos, claiming that physical causation is sufficient to explain everything. Neither God nor will nor design are needed – a position frequently called 'nothing buttery' (Midgley 1983, p. 16). Nothing but chance and physics are necessary to explain evolution. Nothing but chance and evolution are necessary to explain consciousness. Nothing but chance and consciousness are necessary to explain intelligence. And so on. I am not a materialist, myself, but I agree with Richard Lewontin's (1997) statement about scientific reasoning.

> 'It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on the contrary, that we are forced by our *a priori* adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated.'

The issue has arisen repeatedly in evolutionary biology around questions of the sufficiency of natural selection to explain human behaviour, experience and reason. Science functions well with a methodological commitment to materialism. Astrobiologists can label that commitment and move on without wading into questions of ultimate reality, significance and purpose, which are not material questions. Those who wish – as philosophers – to tackle those questions certainly may, but they should not present their conclusions as astrobiology science.

One should be very careful making claims about the sufficiency of an explanation, precisely because these have been topics of hot debate among philosophers (Plantinga 2011; Nagel 2012), biologists (Mayr 1982; Gould 1990, 2011; Conway Morris 2003) and the general public. Ian Barbour (2000) provides a quick, authoritative introduction to the possible relationships of science and religion with specific examples and citations. Those interested in how thoughts about chance and probability shape scientific reasoning in biology can find detailed philosophical (Sober 2008) and historical (Ruse 2009) treatment.

Insight 4: Astrobiologists have limited data on extraterrestrial life; current probability calculations rely on axioms

Returning more concretely to astrobiology science, issues of probability arise regularly. While questions of biological convergence, chance and contingency may seem distant from questions of ethics and religion, they also require careful attention to philosophical priors. Good research disentangles prior commitments and data, so that both can be improved. The philosophy of probability has been discussed extensively in the field of evolutionary biology, in large part due to the way that biology interacts with broader social questions of human significance, ethics and religion.

Astrobiologists cannot avoid speculation on the probability of finding life beyond the Earth. If nothing else, careful experimental design requires us to judge the likelihood of particular outcomes. Speculation need not be incautious. The philosophy of probability has a long history, with much pioneering work done within biology. Astrobiologists can benefit from knowing the basic outlines of this work, particularly when it comes to experimental design, confidence and the effect of *a priori* commitments. Limits on the data make our estimates unusually susceptible to philosophical bias. Clarity and transparency about our priors can lead to better communication about the data available and the predictive power of specific theories.

Astrobiologists have always had a close relationship with probabilities. This may be most evident in the Drake Equation, which labels the relative contributions to estimates on finding extra-terrestrial intelligence. More recently, we can see how the frequency of observed planets shapes models of solar system formation and mission development. High frequencies can be self-reinforcing – why not continue with a proven method (i.e., astrometry finds super-Jupiters). They can also hide sample bias (i.e., astrometry finds super-Jupiters). Attending to the bias produced by philosophical commitments and instrumental limitations can suggest new research and better quantify confidence.

When it comes to finding life in the universe, life-positive and life-negative estimates have been very popular in the recent literature. On the one hand, there is a Sagan-esque optimism often associated with the Drake Equation. Recent data demonstrate an unexpected size of the universe and number of planets. One might also consider arguments that life is inevitable along the lines of Simon Conway Morris (2003). Here the *a priori* commitment is to discernable universal laws. Some authors, meanwhile, display skepticism, refusing to argue from one instance of life to a general rule (Scharf 2014) or suggesting that known general rules make life rare. This contrarian position has been popularized recently by Brownlee & Ward (2003) and Davies (2010). Life positive, life-negative and skeptical positions all stem from *a priori* commitments.

The claims relate to a much older disagreement about the role of chance and necessity in biology. Claims about the probability of life in the universe – based on science – are dangerous precisely because they hitchhike on this older discussion. Fred Hoyle was a famous defender of the steady-state universe theory, which was displaced by Big Bang cosmologies. Hoyle also became famous for arguing from the specificity of nucleosynthetic reactions in stars to a strong anthropic principle. The universe must be fine-tuned for life (Walker & Wickramasinghe 2015, p. 11–20). Hoyle frames the famous '747 in a junkyard argument,' stating that the probability of life arising from random processes is like the probability of a 747 being assembled by a tornado passing through a junkyard and throwing the pieces together (Hoyle 1981). It became very popular with anti-evolutionist creationists in the late 20th century. This argument has been thoroughly defeated with regard to the development of complexity within Darwinian evolution. Biased probabilistic processes can do the necessary work (Sober 2008, p. 122–128). With regard to the origin of life it is problematic only if we grant that life arose from a previously complex system. That simply reiterates our original problem: how did complexity arise?

An infelicity of language can be traced to popular – and academic – confusion over how to use the words 'random' and 'chance' (Mix & Masel 2014). The words may mean without purpose, or probabilistically, or probabilistically with a uniform distribution (all outcomes are equally likely). The first is an *a priori* commitment of modern science. The second is the general state of evolutionary biology explanations, theory laden but well supported by observation. The third is clearly implausible with respect to the origin-of-life and the development-of-complexity. Evolutionary trends exist, though we argue about how strong they are and what they trend toward. One cannot infer the presence of a designer (or an inherent teleology) from the improbability of an event. Very unlikely events do occur probabilistically – even with very small sample sizes. Nor can one infer a designer from evolutionary trends, which can arise due to systemic constraints (Gould 2011). Astrobiologists should be careful, whether arguing the life-positive or life-negative position, not to undo the work done by evolutionary biologists in informing the public about probabilistic processes. The frequency of life in the universe is 100%; it occurs at least once in 1/1 observed universes. Though we have more biological data, it may not be data that reduces the bias of our sample; thus, subjective probabilities of finding life elsewhere are still chiefly driven by philosophical commitments.

Experts disagree widely on the probability of life arising. Some say it is a rare occurrence, but still high enough that it must occur multiple times, given the number of planets in the universe. Others argue that it could be so improbable as to have happened only once. As the data are rarely in dispute, these differences must result from prior commitments inherent in the models being used. Spiegel & Turner (2012, p. 400), one of the few papers to explicitly calculate where their confidence is coming from, note that the models are 'almost completely insensitive to the data.' Scharf & Cronin (2016, p. 7) note that their own values are 'spectacularly approximate.'

Expert opinion draws, instead, on application of first principles, most often the Copernican principle or some form of parsimony. The Copernican or cosmological principle states that we are not in a privileged position in the cosmos (Mix 2009, p. 36–57). The Earth is not unique in circumstance or the application of the laws of nature. Yet, this is the only place where we know that life arose. Some argue that the simplest explanation calls for life as a common feature of the universe. It is simpler because it does not require extraordinary places or extremely improbable events. Others argue that the simplest explanation requires only one origin of life. Why assume there was more than one? Scharf (2014), despite rhetorical flourishes, does an excellent job of balancing what the data can and cannot tell us. It is not immediately obvious how to apply the Copernican principle, even when we agree to it in theory.

Another premise worth looking at has to do with biological convergence. To what extent will physical forces produce the same – or similar – biological phenomena in different locations. Simon Conway Morris (2003) argues that Earth-like outcomes are inevitable and will occur elsewhere. Stephen Jay Gould, famously, takes the opposite approach within biology. If the tape of history were replayed, an entirely different outcome would arise (1990). Gould was speaking of evolutionary trajectories, given life, but the argument can be applied to the question of physical trajectories and whether life would arise at all. In some cases, Sober (2008, p. 362–363) argues that we know neither the conditional probabilities (e.g., of life or intelligence arising) nor the dependence of those probabilities on initial conditions. As yet, we lack sufficient independent data to overcome those uncertainties.

A third premise has to do with our interpretations of chance and necessity. To what extent do we wish to invoke extraordinary, unlikely, or contingent events in our reconstruction of history? Is science amenable to 'it just happened that way' types of

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explanation, or is it necessary to provide a likely account? (Sober 2008, esp. p. 104–107).

Astrobiologists have long recognized the $n = 1$ problem. As the old saw goes, 'astrobiology is the only field with no subject matter.' That claim is clearly wrong; however, in defending the good work astrobiologists can do – and the commitments we can make to estimating the probability of life – it will be necessary to critically assess where our confidence comes from and what types of data will increase it. New data does not always increase confidence; therefore, when claiming that new data change our estimates (or our confidence) we must establish that it is independent in some significant way. We have growing confidence in estimates of star and planet formation; with regard to the origin of life, our sample size is still one. 'Yes, life *could* tend to arise quickly on Earth-type planets based on what happened here, but our prior ignorance is such that we cannot rule out the possibility that it doesn't' (Scharf 2014, p. 171, emphasis in the original).

By explicitly stating our models and attending to sources of confidence, we can make stronger arguments, craft better hypotheses and support public education about probability. Evolutionary biology provides a strong literature to draw on. Sophisticated treatments are available for the Drake Equation (Vakoch & Dowd 2015) and probability in evolutionary theory (Sober 2008).

The history of astrobiology is filled with examples of experiments that failed to provide compelling answers. The most famous include the radio-isotope experiments on the Viking lander, the detection of fossil-like features in the Allen Hills Meteorite and the appearance of arsenic based life. In all of these cases, the researchers failed to understand the breadth and likelihood of possible scenarios – the prior distribution – resulting in poor assessment of probabilities and, ultimately, uncompelling analysis. Whether or not the researchers were justified in their assumptions during experimental design, interpretation and publication, their results were compromised by a poor understanding of the probabilities involved. Critical assessment of priors can be just as important as critical assessment of data. Efficient communication makes priors transparent, distinguishes data-driven conclusions from prior-driven conclusions and avoids overstating confidence. Effective research can benefit from reflection on these issues as raised in the astrobiology and humanities literature.

Conclusions

'In spite of the fact that ET is now firmly in the domain of science, or at least science fiction, the religious dimension of SETI still lies just below the surface' (Davies 1995, p. 131). Astrobiology can be empirical and logically rigorous, but it will always be popular (and funded) because the public cares about the significance of life. The hope and challenge of astrobiology comes from its willingness to tackle fundamental questions about our place in the universe. Astrobiologists can make the most of this speculation by paying careful attention to the way science interacts with other fields. History, philosophy and theology all have contributions to offer to those conducting experiments and communicating with the public.

A deep history of astrobiology explains why we ask the questions we do. It also reveals how the questions we choose inform the answers we find. Astrobiology is neither new nor categorically different from earlier approaches to the grand questions. It does give us new insights when it incorporates new data or different *a priori* approaches to that data.

Philosophical and theological sophistication will help us to understand the way our prior commitments add normative content to the data. Many of our theories about what life is, how common life is and how we can find it rest on *a priori* commitments about our ability to reason and comprehend. The role of human minds in making sense of the universe has often been tied to human significance, importance and uniqueness. These commitments cannot be avoided and so must be tackled directly.

Academic study of astrobiology beyond the natural sciences is slowly picking up steam and the foundations of a literature are now available (Center for Space and Habitability 2016). A small, but significant kernel of this can be picked up by scientists in ways that improve both research and communication. It can add to the core knowledge expected for the common conversation. In some cases, the common wisdom has been refuted. Medieval Christians did not think the world revolved around humans. Contemporary Christians do not feel their faith would be threatened by extra-terrestrials. In other cases, conclusions rely on a specific ethical or epistemological framework that an audience may or may not share. How we move from specific data to general theory to universal narrative matters. Being transparent about the methodology can clarify the presenter's message while empowering the audience to reason along similar lines. Both will lead to better science and better communication.

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