Meeting of the Aristotelian Society, held at Senate House, University of London, on 11 *November* 2024 *at* 6:00 *p.m.*

IV—Optimism in the Search for Extraterrestrial Life? A Philosophical Perspective

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The large number of planets in our galaxy is often appealed to as the basis for optimism that life exists beyond earth in sufficiently large quantities that we might reasonably hope to detect or otherwise encounter it. In an article published over thirty years ago, Roy Mash argued against this inference on broadly philosophical grounds. It is argued that, despite scientific advances in recent decades, the spirit of Mash's case stands and optimism remains under-supported.

There is confidence within much of the scientific community—certainly the nascent 'astrobiology' community, as well as among astronomers and those in cognate fields—that life exists in non-negligible quantities in the galaxy at large. This is evidenced directly in quotations (below) and in recent survey data (for example, Vickers et al. forthcoming). It is also evidenced indirectly by the large sums of money being poured into the search itself. The James Webb Space Telescope is presently being used to study the atmospheric composition of distant planets, the hope being that it will stumble upon evidence of life (see, for example, Tsai et al. 2024). Such a strategy would make little sense in the absence of reasonable confidence that life exists beyond earth. For without reasonable confidence that one might find something, a very large investment in looking for it is prima facie irrational.

It would also make little sense were the *quantity* of life beyond earth only negligible. Suppose, for example, that life existed on only one or two other planets in the galaxy. Looking for it would be a case of searching for a needle in a haystack. There are, after all, billions of planets in the galaxy, and successfully identifying life given present technology—even on those planets on which it does in fact exist—is widely acknowledged to be very difficult (for example,

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Vickers 2022; Foote et al. 2023). So, given the search, there must be confidence that life is somewhat—I'll say non-negligibly—common, sufficiently so that we have a chance of finding it given the size of the galaxy. I use the term *Optimism* to refer to this confidence. The question is whether it is warranted.

Optimism is typically supported by an argument that I shall refer to as the *Big Numbers Argument*; an argument premised on the *sheer number* of possible sites: planets, moons, and so on. This argument is frequently appealed to by the mainstream scientific community. Consider, for example, recent expressions by two British astronauts, Helen Sharman:

> Aliens exist, there no two ways about it. There are so many billions of stars out there in the universe that there must be all sorts of different forms of life …[1]

And Tim Peake:

> I think the universe is teeming with life. If you're in any doubt as to the vastness and the scale of the universe, just go and Google some of these James Webb Space Telescope shots that we're getting now … I mean, hundreds of billions of stars in our own Milky Way galaxy, which is very average.[2]

What should we make of this argument?

I

Sharman and Peake are referring to the search for *biosignatures*: signs of biological life. This will be our concern too. But an appeal to 'big numbers' was also prominent several decades ago in a slightly different context: the search for extraterrestrial *intelligence* (Mash 1993, pp. 205–7; Sagan 1995; Drake 2011). This is a helpful starting point. The idea was that because there are so many possible sites, we can be confident in the existence of extraterrestrial intelligence, and so warranted in conducting the kind of radio searches undertaken by early SETI. In a far-sighted article published in *Philosophy of Science*

[1] https://www.theguardian.com/lifeandstyle/2020/jan/05/astronaut-helen-sharman-this-much-i-know.

[2] https://thetraveldiariespodcast.com/episodes/tim-peake-astronaut/.

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in 1993, the philosopher Roy Mash took aim at this (Mash 1993). Clearly, he argued, the inference from lots of sites to non-negligible quantities of intelligent life—indeed to *any* intelligent life—isn't strictly valid. Interim premisses would be required. And when Mash examined the existing attempts to provide those premisses, what he found was underwhelming. The conclusion was a tempered scepticism about Optimism in the context of the search for extraterrestrial intelligence specifically.

Let's call the claim that there are many planets in the galaxy *Big Number*. How is the inference from here to Optimism (about ETI) meant to go? Mash focuses on one route that can be found in the literature: via the *Principle of Mediocrity*, or as it is sometimes known, the *Copernican Principle* (Mash 1993, p. 213; Ćirković 2018, ch. 3). This principle states that we should assume the earth to be a fairly typical planet. One of this fairly typical planet's properties is that it hosts life. So if there are enough other planets—and Big Number says there are—we should assume that some of them host life too. Hence Optimism (about ETI).

We can flesh this reasoning out (see Garriga and Vilenkin 2008 and Vilenkin 2011). Consider the following principle:

> *Likely Draw*: When drawing elements from a set, one is more likely to draw an element from a larger subset than from any smaller subset.

To see this, consider a bag of ten marbles: six red, two yellow, two blue. You make a single draw. It is more likely to be red than any other colour. Likely Draw explains this. Now imagine a different bag that contains only coloured marbles, but whose distribution you don't know. You draw one. It is red. From Likely Draw you can conclude that it is more likely to have been from the larger subset than from any other. So it is more likely that more marbles are red than any other colour. Now think about the planets. The same structure applies. But rather than drawing marbles from a bag, we have—so to speak—drawn earth from the set of all of the planets. It has various properties. One is that it is inhabited by intelligent life. So we should conclude that, from the set of all planets, the subset of planets inhabited by intelligent life is likely larger than its complement. Add this to Big Number and the result is Optimism (about ETI).

This is a bad argument. There are two main problems.

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The first problem is that it over-generalizes. If the argument were sound, it would entail that for any property the earth has, we should be fairly confident about finding that property in non-negligible quantities elsewhere. Consider, for example, the fact that there are precisely *z* gallons of water on planet earth. Or that there are shoelaces on planet earth. We should be confident that these too are widespread in the galaxy at large. This over-generalization is a symptom of the fact that the Principle of Mediocrity, as outlined above, is an instance of induction from a single case. Consider some event, E, with some properties p_1—p_n. If one can draw a pure inductive inference from E's having some specific property p_i to some further events, E_1–E_n, having p_j, then one can draw the same inference with respect to *any* property, p_k, of E.

The second problem is that, unlike a marble drawn from a bag, the earth is not drawn randomly from the set of planets. It is drawn in a way that generates a bias toward us drawing a planet that hosts intelligent life. For if the earth hadn't hosted intelligent life, then we wouldn't be here, and if we weren't here we wouldn't have drawn it. Consider as an analogy a case where whichever marble you draw from a bag will, in virtue of touching your hand and prior to your observing it, turn red. You make a random draw. You get a red marble. Suppose you were to infer that because you have drawn a red marble, the bag probably contains more red marbles than non-red. This would be a bad inference. The process is non-random in a way that biases toward you drawing a red marble. Similarly, our having drawn the planet that we did (earth) is non-random in a way that biases toward its hosting intelligent life, and so blocks the inference to the conclusion that planets that host intelligent life are typical.

Given these problems, Mash concludes that the inference from Big Number to Optimism about ETI—via Mediocrity—fails. We would need a much more restricted inferential rule. The same structure of objection applies to the Big Number Argument in the context of simple biosignatures. Consider again the quotations from Sharman and Peake. They state a version of Big Number as their major premiss. We need an inferential rule to take us from here to Optimism. That rule *can't* be the Principle of Mediocrity. Firstly, it over-generalizes. If it allows us to infer that life is typical elsewhere, then it allows us to infer that every property found on earth is typical elsewhere. Secondly, the fact that we couldn't have drawn planet earth unless it

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hosted life means that the draw of earth isn't relevantly random; and so inferences that assume it *is* fail.

II

Mash was, however, writing over thirty years ago. Much has changed since then. So perhaps we are now better placed to fill in the inferential steps without illegitimate over-generalization. Consider four specific advancements. Firstly, we now *know* that there are many billions of planets in the galaxy; the detection of the first exoplanet was not until 1992—the year in which Mash submitted his article (Wolszczan and Frail 1992). Secondly, we now know that many of these planets exist within what is commonly termed 'the habitable zone' of their host stars: neither too hot nor too cold (Cockell et al. 2016). Thirdly, we now know of the existence of liquid water oceans within our own solar system: on Mars approximately one billion years ago, and today on the moons of the gas giants (Khurana et al. 1998; Vincent 2022; Wright et al. 2024). It is highly likely that there are many billions of such sites across the galaxy. Fourthly, we now know that the basic elements from which life is built—carbon, hydrogen, nitrogen, oxygen, potassium and sodium (CHNOPS)—exist in large quantities beyond earth (for example, Cockell 2020, ch. 3). Indeed, we can be reasonably confident in the existence of simple molecules built from these basic elements—including amino acids—on many sites beyond earth (see, for example, Lorenz 2018 and Altwegg et al. 2016).

These are major advances. They license the following updated version of Big Number:

> *Big Number**: There is an enormous number of sites at which an important prerequisite for life (liquid water) and the basic constituent elements of life (CHNOPS) are present.

Suppose this is true. Does it warrant Optimism? Not without additional premisses. One candidate premiss would be:

> (A) If both an important prerequisite for *X* and the basic constituents of *X* exist at some site, then there is a non-negligible likelihood that *X* exists at that site.

If (A) were true, we could conjoin it with Big Number* to get Optimism. But (A) is not true. We can see this by noting that, like the

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Principle of Mediocrity, it over-generalizes. Water and CHNOPS are important prerequisites and constituents for spaghetti bolognese. So if Big Number* and (A) warrant Optimism, then they also warrant an equivalent optimism about the prevalence of spaghetti bolognese in the galaxy at large. This is over-generalization. The source of the over-generalization is confusion of necessary conditions with sufficient. (A) effectively tells us that we can take some necessary conditions for *X* to warrant non-negligible credence in *X*. If that's right, then we can infer that *any X* for which these necessary conditions obtain is non-negligibly likely. This includes (for example) spaghetti bolognese.

Perhaps this is too quick. There are some special cases in which confirming the existence of a necessary condition for some *X does* in fact warrant belief in *X*'s existence. These are cases in which the necessary condition is the last of a set of individually necessary and jointly sufficient conditions. Suppose that I find some playing cards at the bottom of my bag. I wonder whether it is a complete pack. I immediately identify full suits of hearts, clubs and spades. I now know that if there is a full suit of diamonds, there will be a full pack. Here, identifying a necessary condition for a full pack (the existence of a suit of diamonds) will suffice to confirm the existence of the complete pack. Might an analogue of this be true of the relationship between life, water and CHNOPS, and so support Optimism?

No. The existence of water and the constituent elements is not the last necessary condition in a set of necessary and jointly sufficient conditions for (non-negligible confidence in) life. There is much more that we do not know but would need to. Compared to its basic constituents, even the simplest life is fabulously complex, so much so that estimates of the likelihood of its spontaneous emergence from random combinations of the relevant constituents give mind-bogglingly tiny values: values of ten to the minus hundreds, even thousands (see, for example, De Duve 1991; Hoyle 1999). These are numbers so small that, even given Big Number* and the vastness of the galaxy, we could not be confident that life exists in non-negligible quantities without a reason to think that the odds of its emergence are substantially shorter than randomness. Consider an analogy. Suppose that you enter a lottery that consists of a long list of integers from which a single winning number will be drawn. Even if you have one hundred billion tickets, if the list of numbers

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goes all the way from one to ten to the power one thousand, your confidence in winning should be next to nothing.

If Optimism is to be warranted, Big Number* is not enough. We must also have grounds for confidence that the odds of life's emergence are not *too* short. One route to this would be via *frequency sampling*. We could look at a sufficiently large and representative set of sites beyond earth at which life's constituent elements are present, count the number at which life is also present, and take the ratio of the latter to the former as a measure of likelihood. Clearly, this is not an option that is open to us at present. We do not know of *any* sites at which life is present beyond earth. A second route would be to identify a *model or mechanism*: an explanation of *how* life emerges from non-life that would allow us to assign a probability to the former given the latter. In the origins of life literature this kind of model or mechanism is known as a *pathway*: a pathway from non-life to life. The problem for Optimists is that we do not at present know what that pathway is. The search for it is the central, *ongoing* task of origins of life research. This is, I think, uncontentious (for example, Cockell 2020, ch. 12; Lingam and Loeb 2021, ch. 2). So neither frequency sampling nor inference via a model or mechanism yields Optimism from Big Number*.

This is perhaps too quick. While we do not at present know the pathway(s) to life, perhaps we do not need to in order to know enough *about* it to warrant Optimism. Suppose, for example, that there were lots of plausible theories of the pathway from non-life to life in the present literature. And suppose that while none were *known* to be true, all independently *pointed towards* life's emergence being non-negligibly likely given the presence of liquid water and CHNOPS. Then Optimism would be warranted even though we didn't know what the pathway was.

Though a good strategy in principle, this is not obviously applicable in the present case. Existing work does not point in this direction. If anything, it points away. It is arguably the most basic and challenging sociological fact about origins of life research that models of life's emergence must work with extremely finely tuned—and so, all-else-equal unlikely—initial conditions concerning, for example, temperature, pressure, pH, salinity, radioactivity and available elements, minerals, surfaces and containers, if pathways are to become viable (for example, Conway Morris 2003; Barrow et al. 2007; Behe 2008; Koonin 2011; Cleaves et al. 2012; Kitadai and Maruyama 2018).

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And pathways themselves must contend with low probability events as 'hurdles' along the way. For example, the much-discussed RNA world hypothesis must explain how the complex proto-RNA molecule could have existed in stable condition for a long enough period of time given its extreme susceptibility to hydrolysis (Bernhardt 2012).

There is, of course, a great deal of scientific literature on the subject of life's origins. One may dispute my reading of it. Rather than entering into this in more detail, however, I shall in what follows assume—I think warrantedly—that neither an appeal to frequency sampling nor appeal to a model or mechanism are sufficient to support a premiss of the strength needed to get from Big Number* to Optimism. (Note also that the quoted defences of Optimism do not rely on any such claim.) I shall, rather, present and assess a different reason for thinking that life's emergence is sufficiently likely that the inference from Big Number* to Optimism is warranted.

III

Life emerged very early in earth's 4.5 billion-year history. It is sometimes claimed that this is evidence that life's emergence on earth was fairly likely (for example, Lineweaver and Davis 2002; Powell 2020; and see the works cited in Spiegel and Turner 2012, nn. 10–17). To see why, suppose I have a ticket for a lottery. I know that there is a fixed number of entrants, each of whom has one ticket. I also know that a draw will be made each week. I do not, however, know how many entrants there are, so I do not know the likelihood that I will win on any given week. Now suppose I win in the first week. This should skew my confidence toward smaller estimates of the numbers of entrants. This is because the chance of my ticket having come up in week one is greater if the number of entrants is smaller than if it is larger. Here's the general thought: if an outcome occurs early within a series of draws, this is evidence that the likelihood of that outcome skews higher rather than lower for any given draw. Call this the *Earlier Means Likelier* principle. Now apply this to the emergence of life on earth. We can think of the natural history of the earth as a series of draws in which the laws of nature operate on the conditions of the earth. On one occasion the outcome of the draw was life. Furthermore, this outcome occurred very early on in the sequence of draws, a mere couple of hundred million years into the process.

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Add to this Big Number*, which—generously interpreted—allows us to assume that there are many sites with earth-like conditions. The result is support for Optimism.

Consider three preliminary objections to this argument.

The first concerns over-generalization. Suppose the above argument is sound. Then, just as we should be confident in the existence of life—in non-negligible quantities—beyond earth, so to exactly the same extent we should be confident in finding everything else that existed on the early earth in non-negligible quantities beyond earth too. But this seems implausible. Suppose that at the same time that life emerged on the early earth, a cataclysmic geological event occurred that caused an ocean to form with a volume of 186.21 quintillion gallons of water. Optimists about extraterrestrial life should also be optimistic about the widespread existence beyond earth of cataclysmically formed oceans with this volume. Yet it is not clear that they would—or should—want to be committed to this. The problem is simply a consequence, once again, of generalization from the single case.

I only classify this as a *preliminary* objection. This is because there is a somewhat plausible response to it. Optimism about the widespread existence of cataclysmically caused oceans with a volume of 186.21 quintillion gallons of water is indeed unattractive. But arguably this should not be thought of as an objection to Earlier Means Likelier. It is, rather, a consequence of specifying the outcomes whose likelihood we are assessing very precisely. That is why optimism about the widespread existence of cataclysmically caused oceans with a volume of 186.21 quintillion gallons of water is unattractive. In order to generate a problem for Earlier Means Likelier, we would need (a) an event early in earth's history, that (b) it would be unattractive to be optimistic exists throughout the galaxy, but where (c) this is not the result of condition (b) being very precisely specified. And it is actually more difficult to identify events of this kind. Consider events from the history of the early earth that are specified at a higher level of abstraction, for example, that it experienced collisions with other bodies, that its magma layer cooled to form a crust, that an ocean formed. It is not obvious that optimism about the repetition of these events across the galaxy is so unattractive.

The second preliminary objection concerns a corollary of Earlier Means Likelier. In arguing for this principle we considered a lottery case. The claim was that the earlier one's ticket is drawn, the

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likelier one should conclude its draw to have been. But now consider this corollary. Suppose that, having won early and believing Earlier Means Likelier, one concludes that one's ticket *is* likely to be drawn (because the lottery is small). Now suppose that one continues to play this lottery each week for the next four billion years. One should expect one's number to come up *again*. If it does not, this is evidence that the lottery was *not* small—and the draw likely—in the first place. Now transpose this to the case of life on earth. We have no evidence that life has emerged more than once. The chemical profile of all life on earth—of which we are presently aware—strongly suggests that it comes from a single source (Moody et al. 2024). So it would seem that we have not won again in four billion years of playing. So our early win was just luck. Again, this is only a preliminary objection. This is because the prior presence of life on earth may present a barrier to the emergence of any novel life: the former may already occupy the niches that the latter would require to prosper in. So the fact that we have no evidence that life has emerged more than once is consistent with its early emergence rendering it likely.

The third preliminary objection concerns an anthropic-type selection bias that underlies the argument from Earlier Means Likelier. Suppose a surveyor is conducting a study into how easy it is to win the lottery. She goes door-to-door with a questionnaire, asking each homeowner whether they have won the lottery. She begins at an enormous house on Millionaire's Row. The owner says that she has won the lottery. She now surveys the other one hundred houses on this street. It is found that they are all lottery winners too. The surveyor concludes that the lottery is easy to win. Otherwise, she reasons, it is incredibly unlikely that all of the first hundred people surveyed should be winners. There is a problem with her reasoning. No one would be able to afford a house on Millionaire's Row unless they had won the lottery! Now consider the case of life's early emergence on earth. Plausibly, none of us would be here now unless life had emerged early. So the fact that life emerged earlier rather than later (on earth) is only evidence for its being likely in the same sense that our surveyor's questionnaire is evidence that the lottery is easy to win. That is to say, it is evidence that provides only very limited support for the thesis.

The key premiss is that we would not be here now unless life had emerged early. Why think this? There are both shallow and deep reasons. The shallow reason is that if life had emerged later, it would

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not be *us* (that is, you and me), but rather some other individuals, who would be here now. This is a consequence of 'non-identity' reasoning: even minor variations in the causal chain leading to our birth would have resulted in the birth of a different individual (Parfit 1984, Pt. IV). The time at which life emerged is one such variation. I say that this is a *shallow* reason because it focuses on the wrong thing. Optimists are interested in whether the early emergence of life on earth is evidence for its likelihood. They are not interested in whether the early emergence of life on earth is evidence for the likelihood that the *specific individuals* who presently exist do so.

The deeper reason—which is a variant on an argument from Brandon Carter (1983)—poses more of a problem. We are presently inquiring into the likelihood of life's emergence on earth. This requires a certain kind of cognitive capacity. It has taken almost four billion years for this capacity to emerge via natural selection. Suppose this is fairly standard; suppose that intelligent life is unlikely to evolve much more quickly. This means that life is likely to emerge early on planets on which the relevant cognitive capacities evolve. This is because if life were to emerge later—say after five billion years—there would be insufficient time for intelligent life to evolve before the host planet's star deteriorated to a point at which it became uninhabitable (the relevant stable period of a star like ours being roughly ten billion years). So on any planet on which someone is in a position to enquire into the nature of life and its emergence, life probably emerged early. But this is consistent with life's early emergence being very rare indeed.

Although more troubling, I shall also only classify this as a preliminary objection. This is because it relies on two insufficiently supported assumptions. The first assumption is that life's emergence and subsequent existence typically occurs on stars with a sequence roughly like that of our own sun. This may not be true. The most common stars in the galaxy are red dwarfs. These burn for many billions of years longer than yellow dwarfs like our own sun. So, if life could emerge and evolve on red dwarf systems, it could in principle do so after many billions of years have *already* elapsed. The second assumption is that the emergence of cognitive capacities sufficient to inquire into the nature of life takes approximately four billion years. This assumption is dubious. It is possible that the process took much longer on earth than is standard. To assume that the period for intelligence's evolution on earth is equal to the period elsewhere

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is to make the same kind of problematic inductive inference from a single case that we criticized earlier in the context of the Principle of Mediocrity.

We can now set these three preliminary objections to one side. Suppose we accept Earlier Means Likelier. This means accepting that life's early emergence is evidence for its likelihood. But how much evidence is it, and for what degree of likelihood? In other words, how does the evidence determinately effect the resulting probability distribution? This is a question of statistics. It is one most naturally approached in the Bayesian idiom, as this allows us to assign a value to the likelihood of life's emergence on earth *updated on* the fact that its emergence was early. More precisely, we say that the likelihood that life should emerge on earth given that that it emerged early, $p(A|B)$, is equal to the likelihood that it should emerge early given that it emerges at all, $p(B|A)$, over the likelihood that it should emerge at all, $p(B)$, multiplied by the likelihood that it emerged early $p(A)$.

A small number of studies exist to this end (for example, Lineweaver and Davis 2002; Spiegel and Turner 2012; Kipping 2020; Snyder-Beattie et al. 2021). While there is some variation, the following picture is clear. The *posterior* likelihood of life's emergence on earth given its early appearance, $p(A|B)$, is almost entirely determined by the choice of one's *prior* likelihood assignment; that is, the prior likelihood that life should emerge on earth at all, $p(B)$. Low priors produce low posteriors. Higher priors produce high posteriors. The prior assignment *dominates* the assignment of the posterior value. The effect of the new evidence (namely, that life emerged early) on the posterior is small. This should be unsurprising. We have only a single data point; namely, that life emerged several hundred million years into earth's history. One should, in this kind of case, *expect* the prior to dominate, as it does in other, similar cases (for example, Lineweaver 2022).

This is not good news for Optimists. It means that for life's early emergence on earth to significantly support Optimism, Optimists must provide us with some independent reason to assign a reasonably high prior value to life's emergence on earth. But this is not something that they can warrantedly do. For how would they do it? One route would be to appeal to frequency sampling. Optimists could look at a sample of relevantly earth-like planets, count the number on which life is present, and determine a ratio. They could

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then use this ratio to determine the prior for life's emergence on earth. But, as we noted earlier, this route is not available. We do not know of any planets beyond earth on which life is present. The second obvious route would be via appeal to a mechanism or model; an account of the pathway of life's development from initial earth-like conditions that allows one to assign a probability to its emergence from those conditions. But again, as noted earlier, this is something that we do not at present have. So the obvious ways for Optimists to justify the high prior assignment that they would need are blocked off.[3]

Suppose, however, that Optimists *were* able to assign a relevantly high prior—and so a high posterior—to life's emergence on earth given that it was early. It would at most follow that life has a high likelihood of emerging *on earth*. However, Optimism requires more than this. It requires that life's likely emergence on earth supports confidence that it emerges with non-negligible likelihood at sites *other than* earth. We cannot make this inference unless we assume that the conditions under which life emerged on earth are, to a relevant degree of similarity, repeated at a non-negligible number of sites other than earth. In setting up the argument (for Optimism, from life's early emergence) I said that we could, if 'generously interpreted', use Big Number* to license this assumption of repetition. After all, Big Number* tells us that there is an enormous number of sites that possess conditions that resemble those on earth in important respects. But in truth this is *over*-generous. In the absence of an account of the conditions from—and pathway through which—life emerged on the earth, we do not know what the 'degree of similarity' other sites would need to stand in to earth must be in order for the likelihood of life's emerging on the former to warrant a significant increase in the likelihood of its emerging on any instance of the latter. We could safely draw this inference—even in the absence of the relevant information about life's emergence—if we assumed:

> *Big Number***: There is a large number of sites of a near arbitrary degree of similarity to earth.

[3] Optimists may perhaps appeal to *generic* considerations with respect to the assignment of prior probabilities to domains in which the priors are unknown. There are some studies to this effect. Some are more supportive of Optimism than others, but the range is wide. See Kipping (2020).

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But this is a *much* stronger claim than Big Number*, and one that we are not at present entitled to. Indeed this point is to the fore in those Bayesian studies that assign the *highest* prior—and so posterior—probabilities to life's emergence on earth, studies that otherwise *support* Optimism. They quite explicitly resist the inference from (what they see as) life's *likely* emergence on earth given its *early* emergence to its likely emergence elsewhere. Consider, for example, Lineweaver and Davis:

> Although we can make reasonable estimates of what the crusts and atmospheres are made of, without detailed knowledge of the steps of chemical evolution, we cannot be sure that astronomical planets have the same [probability of biogenesis] as earth. (Lineweaver and Davis 2002, p. 302)

And Kipping:

> It is tempting to apply these numbers to potentially habitable exoplanets being discovered. However, we caution that our analysis purely concerns the Earth, treating abiogenesis as a stochastic process against a backdrop of events and conditions which might plausibly be unique to earth. (Kipping 2020, p. 12002)

So in *neither* case in which the prior assignments to life's emergence on earth are high is the high resulting posterior value taken as evidence of a high posterior value for planets beyond earth, as would be needed for Optimism. So the early emergence of life on earth does not allow the Optimist to get around the basic problem posed by the lack of either a sample of non-earth worlds on which life is present or an account of the pathway to life.

There are few options left for the Optimist. One intriguing route is appeal to broadly a priori considerations. Consider the following argument (see White 2007; and, for example, De Duve 1991, p. 217). Some unlikely events occur simply by *fluke*. Suppose, for example, that I toss a coin and it lands heads ten times in a row. It is possible that this is the result of a biased coin. But suppose the coin is not biased. Then the run of heads was just a fluke. There need be—indeed there is—no deeper explanation of why it happened. Clearly though, some events cannot plausibly be explained as flukes. Suppose I throw a pack of cards in the air and walk out of the room. When I return, I find that the cards are in a pattern that

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very precisely spells my name. This couldn't be a fluke. Someone must have deliberately arranged them. Perhaps I did it myself and suffer from amnesia. The emergence of life from non-life is like this. One does not *by fluke* get from basic constituent elements to self-sustaining, self-replicating entities at a probability of ten to the power of hundreds or thousands. Suppose this is true. Also assume the falsity of Creationism. It follows that there must be a causal pathway from non-life to life that renders its emergence somewhat likely. Because if there were not, then it would be a fluke. And it's not. So we can conclude that there is indeed a pathway from non-life to life that yields a non-negligible probability of the latter given the former. So Optimism is warranted.

It is a premiss in this argument that we should rule out that life's emergence was a fluke. This is questionable. A fluke may in fact be the best explanation available. Suppose, to return to the previous example, that we *can* rule out the hypothesis that the cards that spell my name were deliberately arranged. There are now two options. One is that it was a fluke. The other is that there is some systematic bias in the laws (of physics) acting on the cards that systematically and without fluke explains why they landed as they did. This would be a very peculiar inference to draw indeed. The 'fluke' explanation seems at least as good. Similar considerations can be used to support the 'fluke' explanation of life's emergence. Assume Creationism's falsity. The question is now whether it is more plausible that life's emergence was a fluke or that there is reason, independently of life's existence, to think that the laws of nature are systematically biased toward producing objects with the properties of life. It is not obvious what the answer to this is (see White 2007; Knab 2016; Weidemann 2017). Fortunately, we do not need to answer this question. For suppose that we simply *assume* that life's emergence was not a fluke. Still this would not be enough for Optimism. Optimism, as earlier characterized, is not merely the view that life exists on some site beyond earth (a view that we perhaps *could* warrantedly reject if life was merely a fluke). It is rather the view that life exists in *sufficient quantities* beyond earth; for without this, the possibility of *finding* it would remain vanishingly small. And the mere fact that life is not a fluke does not establish this. Indeed it falls a long way short. This is because life's emergence not being a *fluke* is perfectly consistent with the pathway to it having very low probability indeed. To think otherwise would require ruling out a priori any very low probability

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but non-flukey events. This, like the earlier appeal to the Principle of Mediocrity, would clearly over-generalize.

IV

It is not obvious that Optimism is presently warranted. This is the case despite the advances in recent scientific understanding. The sceptical conclusion drawn by Mash almost thirty years ago remains reasonable today.

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