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Theoretical and empirical issues of the Mediocrity Principle

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Abstract

The following article is an analysis of the epistemological validity of the Mediocrity Principle, according to which Earth-like planets and life are widely spread throughout the Universe. Through theoretical arguments, probabilistic reasoning, Cosmology and to recent developments in the field of Astrobiology we will show that this reasoning cannot be justified *a priori*. However, the new scenarios offered by the icy moons of the Solar System could induce a new non-geocentric paradigm regarding the existence of extraterrestrial life.

1. Introduction

> Oh my God, look at that picture over there! There's the Earth coming up. Wow is that pretty[1].

On December 24, 1968, aboard Apollo 8, astronaut Bill Anders took a snapshot from the lunar horizon of an Earth sunrise, giving us a never-before-seen image of our planet. For the first time oceans, landmasses and all living beings were included in a single image. This event was only one of the milestones of the so-called conquest of space. Meanwhile, on our planet, humans were working to create telescopes and probes to search for other worlds and extraterrestrial life. The 1960s were pivotal in scientific investigations about hypothetical living beings beyond the Solar System. However, the lack of empirical data has limited these debates to a theoretical

[1] NASA's Scientific Visualization Studio (2018).

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field. In this context, the first optimistic inferences regarding the presence of extraterrestrial civilizations emerged, often incorporating the so-called Mediocrity Principle as a methodological approach for SETI (*Search for Extraterrestrial Intelligence*) research programs.

This assumption establishes that the formation of an Earth-like planet and the evolution of life are typical events in the Universe. Thus, our world could be one of many scenarios for the emergence of living beings in the cosmos. In this work we evaluate this hypothesis through three perspectives:

- *Theoretical Context*: we read the Mediocrity Principle as an analogical argument and question whether this assumption can be justified *a priori*.

- *Cosmology and Astrochemistry fields*: we try to understand whether this inference can be justified *a posteriori*.

- *Astrophysics field*: we compare this argument with data about exoplanets discovered in our Galaxy.

Moreover, we don't talk about "extraterrestrial civilizations", that is the possibility that there exist living beings on other planets that can develop a technological civilization. Instead, we consider a weakened version of the Mediocrity Principle, which postulates the existence of less complex forms of life. Indeed, the hypothesis of the universality of the evolutionary path of Earth-like life, in which humanity is one of many outcomes, is not currently justified. There are many speculations aimed to demonstrate the convergence of adaptations of different species in similar environments[2]. At present, the debate is still open and there is no way to repeat the Earth-like life experiment to understand whether the known evolutionary storyline is universal. Therefore, we consider a concept of life that does not necessarily allude to intelligent life.

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[2] Cfr. Powell (2020).

2. From Reid's Argument to Mediocrity Principle

The Mediocrity Principle is an assumption based on a simple idea: if life exists on Earth, then it could also exist on other similar planets. This hypothesis fits into the larger and older debate regarding the pluralism of worlds[3]. In 1785 Thomas Reid advanced an argument to support the hypothesis of the existence of extraterrestrial life:

> We may observe a very great similitude between this earth which we inhabit, and the other planets, Saturn, Jupiter, Mars, Venus, and Mercury. They all revolve round the Sun, as the earth does, although at different distances, and in different periods. They borrow all their light from the sun, as the earth does. Several of them are known to revolve round their axis like the earth, and, by that means, must have a like succession of day and night. Some of them have moons, that serve to give them light in the absence of the sun, as our moon does to us. They are all, in their motions, subject to the same law of gravitation, as the earth is. From all this similitude, it is not unreasonable to think, that those planets may, like our earth, be the habitation of various orders of living creatures[4].

The philosopher identified a few similarities between Earth and planets in the Solar System. Consequently, Reid concluded that, by virtue of some known similarities, these worlds could also be inhabited by living beings. In this reasoning, the key condition supporting the conclusion is the intrinsic connection between some properties of the Earth and the emergence of life on a planet (the so-called abiogenesis[5]). By assuming the availability of these features as the basic prerequisite for the origin of life, then planets with similar features are also plausibly worlds inhabited by living beings. Clearly, we could claim that not all similarities are relevant. Indeed, analogies identified by Reid are too general. Planets in our planetary system are very different from Earth. However, Reid's reasoning shows a basic and widely methodological approach in the field of Astrobiology. It is based on analogies that exist between two sets: the Earth and the other planets of the Solar System. This kind of reasoning is called an analogical argument[6].

Nevertheless, a problem arises: Is an analogical argument able to support a conclusion? Generally, analogical reasoning shows issues about the criteria for evaluating arguments. Thus, they could be considered weaker tools than other types of arguments. However, in the framework of hypotheses about extraterrestrial life, the picture is different. Indeed, today we only know a

[3] Cfr. Crowe (1999) and Dick (1998).
[4] Reid (2002, 52).
[5] Which is the process that describes the origin of life from inanimate matter.
[6] Bartha (2019).

single planet that shows clear evidence of the existence of life. Furthermore, there are several hypotheses regarding abiogenesis, but the debate about the origins of life is still open.

Finally, although living things show heterogeneity of forms and adaptations, they possess a single common ancestor, LUCA (*Last Universal Common Ancestor*)[7]. They are nothing more than the surviving branches of a single phylogenetic tree (also called as the tree of life), which establishes the degrees of relatedness among all existing or extinct living things. Consequently, our background knowledge about life is limited to a single model, which, as far as we know today, evolved exclusively on Earth. This issue is also known as the *N=1 problem* and justifies the appeal to analogical arguments to make assumptions about extraterrestrial life. Therefore, although these arguments show anthropocentric and geocentric assumptions, they represent the only way to formulate hypotheses regarding life on other celestial bodies.

An analogical argument arises from the comparison between two sets or domains. In the case of Reid's argument, the first domain consists of a set of objects and statements that describe the Earth. This set is the *source domain*. Instead, the second set is the *target domain*. It includes all the objects and statements that describe planets in the Solar System. Identifying similarities between these two domains consists of a one-to-one mapping between the elements of the source and target domains. Thus, the philosopher identifies some similarities between the characteristics of Earth and that of the other planets. Positive analogies that can support the hypothesis of the existence of extraterrestrial life. Therefore, it is possible to put Reid's reasoning as follows:

Reid's Argument: It is plausible that life exists on other planets in the Solar System by virtue of some known similarities with Earth.

In this reasoning, the common properties between the two domains are:

[7] Cfr. Woese (1998).

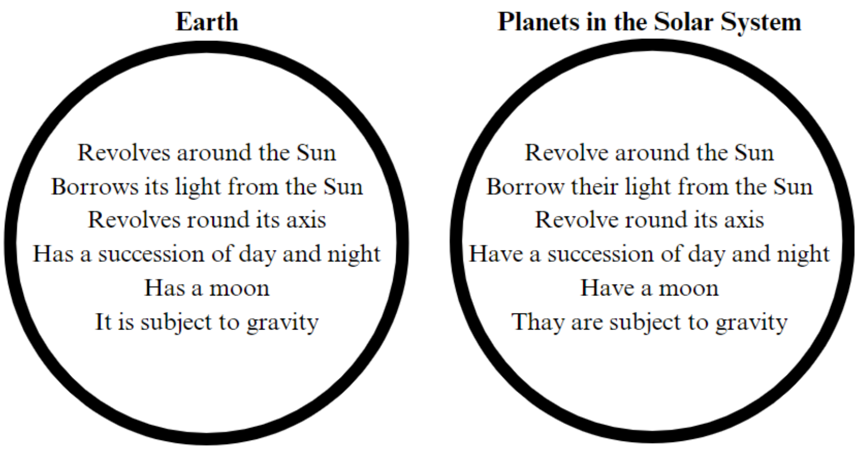

Fig. 2.1 Graphical representation of analogies between the source domain, which includes the known properties of Earth, and the target domain, the set of known properties of the Solar System planets common with our planet

This analogical argument is based on the fundamental assumption that the existence of life is causally related to the availability of certain features found on Earth and, in Reid's perspective, also on the other planets in our planetary system. Thus, it is possible to formalize this analogical reasoning from single evidence:

$$P(T) \wedge Q(T) \qquad (2.1)$$

where T is the source domain, which includes all the objects, properties and thus statements that define the Earth. Instead, P represents positive analogies (in this case, the set that includes known properties of life), while Q is the hypothetical analogy, the existence of life. In Reid's argument, $P\ (T)$ is the set of Earth features, while $Q(T)$ is the evidence of life on Earth. The latter element is a feature found in the source domain that could also exist in the target domain. However, this is possible by inductively assuming the following generalization:

$$\forall x(P(x) \Rightarrow Q(x)) \qquad (2.2)$$

This universal proposition implicitly assumes that it is possible to suppose the existence of life on any planet from the presence of certain features or properties. It is a generalization based on a single case, life on Earth (2.1). However, from the assumption of this proposition, the second part of the argument takes the form of a deductive argument:

$$\frac{P(E) \qquad P(E) \Rightarrow Q(E)}{Q(E)} \qquad (2.3)$$

where E is the target domain, that is the set of planets in the Solar System that show some analogies with the Earth $P(E)$. Consequently, $Q(E)$ is the conclusion of the analogical argument, "It is plausible that life exists on other planets in the Solar System." The argument is based on a universal proposition, $\forall x(P(x) \Rightarrow Q(x))$, an inference from a single case: $P(T) \wedge Q(T)$, namely the existence of life on Earth, a planet with certain known properties. Therefore, it can be inferred that the same relationship $P(E) \wedge Q(E)$ is also valid on the other planets. Finally, the existence of similar characteristics in the target domain (in this case, P(E)) leads to the plausible conclusion that planets in the target domain E also harbours life forms like those known $(Q(E))$.

This kind of analogical argument was described by Aristotle and is known as a *paradeigma* (arguments from examples)[8]. These arguments begin with an inductive inference from one or more similar cases (in our case, the evidence is unique). From these cases, a universal proposition is established. Then one can argue deductively and arrive at the conclusion $Q(E)$.

From an empirical point of view, Reid's argument shows several weaknesses. Indeed, we know that the other planets in the Solar System are very different from Earth. The set of negative analogies (or differences), which we can call A, includes many more elements than the set of positive analogies P. Thus, the similarities identified by Reid are not sufficient to justify the conclusion that life exists on these worlds. However, there are many other worlds beyond our planetary system. Some of these may resemble our planet's features and harbour life. Consequently, by changing the target domain, another analogical argument about extraterrestrial life can be proposed.

3. The Mediocrity Principle: the best methodological approach?

According to the Mediocrity Principle, the emergence and evolution of life are widespread phenomena in the Universe. This argument is based on a fundamental assumption, which according to physicist David Bates is

[8] Cfr. Aristotle (1989).

attributable to Sebastian van Hoerner[9]. He applied it to the issue of the existence of extraterrestrial civilizations in 1961[10]:

> The basic hypothesis in the present article is that our planetary system and our civilization are about average, and that life and intelligence will develop by the same rules of natural selection, wherever the proper surroundings and the needed time are given[11].

This assumption was not the subject of his work. Rather, it was a methodological approach aimed to search for signs of extraterrestrial life in the Milky Way, a scientific investigation that must presuppose a certain model of technological civilization (that is explicitly inspired by our own). As stated earlier, adopting this principle means justifying one's inferences from a particular interpretation of a single evidence, proposing reasoning like this: «Anything seemingly unique and peculiar to us is actually one out of many and is probably average»[12]. According to van Hoerner, it is an excellent method aimed to create the best possible working hypothesis in epistemic situations where knowledge is insufficient to create scientifically testable hypotheses:

> All that is needed in this approach is the right classification and one absolute value from to start with [...] The resulting estimate can be, of course, completely wrong, but the probability that it will be is very small, and the probability that the result will be right is high. This is the best we can demand[13].

Following this line, the only evidence for life (Earth-life) is enough to justify the hypothesis that the emergence of living beings as we know is universal and widespread in the Universe. This is a working hypothesis and, according to van Hoerner, it is the best possible approach. Starting from this way of reasoning, the Mediocrity Principle has been the main argument of scientists with an optimistic view about the existence of extraterrestrial

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[9] Cfr. Bates (1972).

[10] After the publication of the work, which showed a pessimistic perspective on the probability of contact with extraterrestrial civilizations, van Hoerner moved from Germany to Green Bank, USA. There he would work on the technical optimization of the radio telescope at the National Radio Astronomy Observatory (NRAO) together with Francis Drake, one of the pioneers of modern Astrobiology.

[11] van Hoerner (1961, 1839-1843).

[12] van Hoerner (1961, 1839-1843).

[13] van Hoerner (1961, 1839-1843).

civilizations, including Carl Sagan, I.S. Shklovskii and many other researchers in the SETI[14] (Search for Extraterrestrial Intelligence) program.

However, the Mediocrity Principle shows similarities with Reid's argument. Indeed, the inference is again based on a single instance. The existence of extraterrestrial civilizations is supported by analogies between Earth, considered as a typical object, and other planets in the universe. It is an extension of Reid's argument. The source domain remains Earth, the only known planet on which living things exist. In contrast, the target domain includes all planets in the universe. Consequently, the Mediocrity Principle is an analogical argument that establishes:

Mediocrity Principle: It is plausible that life exists on other planets in the universe by virtue of certain known similarities to Earth.

This reasoning is very similar to the Reid's argument. The only difference involves the target domain, which in the Scottish philosopher's perspective was the set of planets in the Solar System, excluding Earth. Despite this difference, the Mediocrity Principle can be formalized by starting from the same premises as Reid's argument:

$$P(T) \land Q(T) \qquad (3.1)$$

Accordingly, the following universal proposition can be stated:

$$\forall x (P(x) \Rightarrow Q(x)) \qquad (3.2)$$

Consequently, it is possible to support the plausibility of the existence of extraterrestrial life deductively:

$$\frac{P(U) \qquad P(U) \Rightarrow Q(U)}{Q(U)} \qquad (3.3)$$

where the target domain U includes the set of planets in the universe. As can be seen, both the Mediocrity Principle and Reid's argument share an identical logical form, a *paradeigma* that underlies other scientific investigations regarding extraterrestrial life as well.

However, during the 1960s even the existence of other planetary systems was still an open question. There was no empirical basis that could offer a test

[14] Shklovskii and Sagan (1966).

case for the Mediocrity Principle. Then, at the end of the last century, the right methodologies and technologies were developed. Therefore, humans began to observe such distant bodies in search of Earth-like worlds[15]. The 1990s was a golden decade for Astrobiology, the result of years of hypotheses, failed attempts, poor telescope availability and false positives[16]. Sixty-three years after the publication of van Hoerner's paper, scientific knowledge is still insufficient to answer with certainty the problem of the existence of other life forms in the Galaxy. However, the increasing number of exoplanets discovered, renewed knowledge of the evolution of the early Earth and of life itself could provide a coherent framework for testing the strength or limitations of analogical argument about extraterrestrial life.

4. If billions of planets exist, how is it possible that extraterrestrial life does not exist?

Regarding the philosophical critique of the Mediocrity Principle, it is interesting to consider the arguments by Roy Mash. In *Big Number and Induction in the Case for Extraterrestrial Life*[17], the philosopher questions the validity of this methodological assumption through criticism of theoretical reasoning that should support it. For instances, Mash introduces a possible reply to the following question: Given the huge number of stars in the Universe[18], around which at least a planet might orbit, how is it possible that favourable initial conditions have emerged only once in the history of the Universe?[19]

The issue is related to a common reasoning that does not necessarily pertain in scientific thinking. The core of the argument consists in the assumption that even an improbable event, by increasing the set of events and thus the base population, can become relatively probable. Life could be an improbable phenomenon by considering, for example, 1.000 planetary systems. However, if our set of planets consists of billions, or even hundreds of billions of planetary systems, the probability of the existence of an Earth-

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[15] The average brightness of a planet relative to a star is about a million times smaller. As a result, most modern observational methodologies can detect an exoplanet indirectly, considering the gravitational effects of planets on the star. Indeed, direct exoplanet observation methods can only detect planetary systems close to the Solar System and are therefore limited.
[16] Cfr. Covone (2023).
[17] Cfr. Mash (1993, 204-222).
[18] $1 \cdot 10^{22}$ stars in about 100 billion galaxies.
[19] The estimated age of the Universe is 13.8 billion years.

like planet increases. According to Mash, the mistake in this position consists in the oversimplification of the problem, which is placed in a purely theoretical context carrying with it a basic ambiguity. Indeed, it is not clear which of the many properties of our planet should be typical. Thus, *in what sense is it possible to say that there are other Earth-like planets? What characteristics of our planet are we referring to?*[20] Perhaps, it is possible to consider the distance from the star, the chemical composition of the atmosphere or the presence of liquid water. However, our planet has many other peculiarities: a satellite like the Moon, the presence of human beings, or even the existence of intelligent beings posing the problem of extraterrestrial life. By including more elements of our only model (the Earth) finding another similar planet could be a very difficult task.

This argument is not exhaustive or conclusive. First, in Astrobiology, an Earth-like planet is not necessarily a twin celestial body, reiterating the complexity of our world beyond the physical and chemical features considered. Thus, this is an inconclusive attempt, as Mash argues. However, it shows the weakness of some attempts to theoretically support the Mediocrity Principle.

5. Theoretical Fallacy of the Mediocrity Principle

Is the Mediocrity Principle really the best possible approach? The arguments proposed by Mash raised some doubts in this regard. However, these are not sufficient to support the opposite hypothesis. *Are there other theoretical arguments that can refute (or confirm) the Mediocrity Principle?* According to André Kukla, the implicit assumptions in this perspective could show definitively the inconsistency of this argument[21].

The first step is to recall the starting problem: Are there other planets suitable for the emergence of life? The possible answers to that question are "they exist" or "they do not exist", which we call solution A and solution B, respectively. In a *situation of indifference* regarding the real answer to the issue, one possible approach is to consider A and B as two equiprobable options (with a value of $\frac{1}{2}$). In the perspective adopted by van Hoerner, the evidence for life on Earth would tip the balance in favor of alternative A, making the Mediocrity Principle the best possible approach. Hence the conclusion that, assuming there are many other Earth-like planets, it is

[20] Cfr. Mash (1993, 204-222).
[21] Cfr. Kukla (2010).

reasonable that life is widely distributed. According to Kukla, the equiprobability of A and B is one of the fundamental implicit assumptions of the Mediocrity Principle. An argument that is based on the so-called *principle of indifference*, which states:

> The advocate of logical probability says that when there is no evidence favoring one of *n* mutually exclusive and jointly exhaustive hypotheses, then one should assign them each probability 1/n. This is called the principle of insufficient reason, or the principle of indifference[22].

However, this principle leads toward contradictory scenarios. The problem of reasoning is quite clear: *How is it possible that, through the appeal to a theoretical assumption, we were able to transform our situation of indifference or ignorance into a very precise probabilistic information?* How reliable and accurate is this kind of belief? The argument is not convincing. Indeed, the principle of indifference has a fallacy. Recalling the values attributed earlier to alternatives A and B ($\frac{1}{2}$), let us imagine another situation. According to the principle of indifference, if we are in a situation of indifference about the real values of options P and Q, we are also indifferent about the P_1, P_2...P_n decompositions of P. Thus, by following Kukla's reasoning and applying this rule to the issue of extraterrestrial life, one of the implicit contradictions emerges.

Suppose we have a set of 3 planets among those already detected: O, R and Earth. We want to estimate the probability of finding life on at least one between O and R. The only evidence we have is the existence of life on our planet. Since we are indifferent to the question "Are there other planets suitable for the emergence of life?", we are in the same position as previously described. Consequently, we can decide to assign equiprobable values to all possible alternatives. This time, however, the number of answers is greater than in the initial problem[23]:

1. *Life exists only on Earth*.

2. *Life exists on Earth and planet O, but not on R*.

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[22] Hacking (2009, 143)
[23] Cfr. Kukla (2010).

3. *Life exists on Earth and planet R, but not on O.*

4. *Life exists on all three planets in the set.*

According to the principle of indifference, all solutions have the probabilistic value of $\frac{1}{4}$. In this new perspective, the probability of extraterrestrial life existing on at least one other planet besides Earth is $\frac{3}{4}$. A result that provides a higher value for the probability of the existence of life beyond the Earth.

However, a problem emerges. Indeed, by considering the same question in two different but related situations, *the results do not coincide*. According to Kukla, this is precisely the fallacy of the principle of indifference. Therefore, it cannot transform the lack of knowledge into beliefs able to support the Mediocrity Principle. Indeed, by inserting the only certain instance "there is life on Earth" into different reasoning, we obtained a contradiction. So, it is possible to say that this evidence is insufficient. Any inference derived from this instance can only be weak, although this does not imply that such evidence is completely uninformative[24]. By reasoning in a theoretical way, we found that the Mediocrity Principle is not the best of the approaches, as van Hoerner argued. It is not possible to turn a situation of ignorance into certainty, or indifference to objective probabilistic values. Thus, the evidence "there is life on Earth" is not enough to take a position on the issue of extraterrestrial life. Nevertheless, for the same reason it is still not possible to refute the idea that there are other planets suitable for life. So, the contradictions implicit in the theoretical foundations of the Mediocrity Principle cannot justify hypotheses about the absence of life outside the Solar System.

6. The Copernican perspective of the cosmos and the Mediocrity Principle

The reasoning proposed above has shown how the Mediocrity Principle is based on weak or contradictory assumptions. However, these inferences can be updated in relation to an empirical background knowledge which includes different fields of research.

[24] Cfr. Whitmire (2022).

During the 1900s, General Relativity and the subsequent development of modern Cosmology and Astrophysics greatly increased our knowledge of the Universe on a large scale. In addition, the ability to observe large distances in space and time has enabled us to better understand the history of the cosmos and the position of our astronomical context in an expanding, centreless Universe. However, according to Einsteinian relativity, we are not able to observe the whole Universe: most events in the cosmos are not causally connected to observers on our planet or telescopes in space. In addition, observational difficulties also arise: our point of observation is within the Universe itself. Moreover, the *surface of last scattering* represents the observational limit beyond which it is impossible to observe the past of the cosmos. It is the set of points in spacetime where the decoupling event is thought to have occurred 400,000 years after the Big Bang, with the Universe beginning to become transparent. Thus, our telescopes are only able to receive signals from a little portion of spacetime known as the *observable universe*, a hypersurface surrounding us with a diameter of about 93 billion light-years. Therefore, the following analysis considers only what we can observe, without any claim to extend inferences to what is beyond the *cosmological horizon*, the measure of the maximum distance from which information can be received.

Earth is a rocky planet that orbits with 7 other planets and other celestial bodies around the Sun, a G-class star. Our star is only one of 200-400 billion stars orbiting the centre of the Milky Way, our galaxy. Then, the Milky Way is only one of the galaxies included in the so-called Local Group, located in the central zone of the Virgo Supercluster, a flattened disk with a diameter of 100 million light-years that includes about 100 clusters or groups of galaxies. Finally, this portion of the cosmos is included in one of the even more extensive systems, the Laniakea Supercluster.

On cosmological scales, superclusters appear as filaments of matter distributed in the cosmic void in an approximately homogeneous structure. In this perspective, matter takes the form of a *cosmic web*. In the observable universe considered on these scales, the Earth occupies a space-time position indistinguishable from other points in the cosmos. According to this perspective, there is nothing special about our *cosmic address*; it is a typical point in a centreless cosmos, as established by the Cosmological Principle:

Cosmological Principle: Taking the Universe on sufficiently large scales, its properties will be the same from any observation point[25].

Thus, the Universe is spatially isotropic and homogeneous on a large scale, and there are no privileged directions or points. However, we have never observed the Universe from a sufficiently distant point of the cosmos to assert this claim with absolute certainty. Consequently, the extension of the spatial isotropy we observe to the entire Universe is connected to the following philosophical assumption:

Copernican Principle: Earth is not in a special, privileged, or central position in the Universe[26].

The *Cosmological Principle* is partially confirmed by experimental data. Indeed, by observing the cosmos from Earth, it is possible to see that cosmic background radiation permeates the observable universe with an approximate isotropy[27]. However, there are no empirical reasons to believe that, from another observation point, the observable universe relative to that *specific light cone* shows the same homogeneous and isotropic structure. In addition, the *Copernican Principle* is not empirically demonstrated and there are local fluctuations that break this perspective from the scale of galactic clusters. Isotropy and homogeneity are features we observe within our light cone, one of many possible observation points of the cosmos. What reasons do we have for claiming that this scenario is typical? What would happen if we observed the Universe from a point 20,000 light-years away from Earth? In a sense, to claim that the Universe has the same structure as the observable universe would imply the assumption that the portion of the cosmos observable from Earth is typical. An argument that takes the same logical form as the Mediocrity Principle, and so runs up against similar theoretical problems, with the addition of insuperable physical limits. Therefore, the Cosmological Principle represents an excellent approximation of the structure of matter in the visible cosmos, considered on the level of the cosmic web and connected to our special point of observation. It is a qualitative (and approximate) description of the distribution of matter in the portion of the universe that we can observe. Thus, it is impossible to make testable inferences about the spread of atoms and molecules beyond the cosmological horizon. Additionally, recent studies revealed further limits to the validity of the

[25] Cfr. Keel (2007).
[26] Cfr. Bondi (1952).
[27] CDM has fluctuations of 1/100000.

Copernican perspective of the cosmos. Indeed, the expansion rate of the universe, measured in our supercluster of galaxies Laniakea, differs slightly from the outside. This phenomenon is caused by the different distribution of dark matter, a finding that shows that our cosmic address is not typical at this scale[28]. Moreover, this reasoning does not consider the peculiar structure of what we call life, or the diversity of astronomical objects placed below the threshold of galactic superclusters. *So why should life not make our typical cosmic address special?*

The approximate validity of the Cosmological Principle does not extend to the set of phenomena such as the emergence of life, the *abiogenesis*. Thus, the attempt to justify the hypothetical typicality of our planet and life by referring to the cosmological perspective cannot produce adequate reasoning. However, a further attempt can be made by abandoning cosmic objects and considering the atoms and molecules that constitute all known life and that, potentially, could represent the basis for extraterrestrial life in other places in the observable universe.

7. The infinite repetition of histories in a spatially infinite Universe

As stated in section 4, the Mash's argument is not sufficient to refute the reasoning based on the large number of planets in the Universe. Consequently, this answer is weaker when compared with assumptions based on a spatially infinite Universe. Indeed, in this context the question might become: *In a spatially infinite Universe*, *how is it possible that the birth and evolution of life did not occur more than once*?

This question has been the subject of much speculation, providing reasoning such as *Ellis-Brundrit argument*, which is underlined by the assumption that Universe is spatially infinite and, by implication, by the cosmological principle. It can be summarized as follows[29]:

- The number of galaxies and planets in a spatially infinite and homogeneous Universe is infinite.
- Thus, the number of possible history lines in the space of configurations in this Universe is infinite.
- Some of these story lines are compatible with the formation and evolution of DNA-based life forms, with the number of history lines having to be at least 1 considering our existence.

[28] Cfr. Giani *et al.* (2024).
[29] Cfr. Ellis and Brundrit (1979, 37-41).

- If the probability of life based on DNA is greater than 0, then in an infinite Universe it contains an infinite number of such living beings, whose history lines could differ negligibly such that they would arrive at the same result.
- The number of possible configurations for life based on DNA is finite, as DNA cannot be an arbitrarily long molecule.
- Thus, an infinite Universe will include an infinite number of copies of the possible DNA-based configurations of life that can evolve on infinite Earth-like planets.

Thus, given an infinite repetition of histories lines compatible with the evolution of DNA-based life, the Mediocrity Principle could be considered valid. However, the conclusions of this argument can be criticized in different ways. Indeed, in *About the infinite repetitions of histories in space* F.J Soler Gil and M. Alfonseca have proposed some arguments aimed at refuting the Ellis-Brundrit argument· One of that is called "*Chaotic argument*" and it states that the existence of almost-equal history lines is impossible:

> a) The uncertainty principle sets a minimum difference for the initial conditions of two different history lines.
> b) The equations of classical relativistic physics (those used by E-B) – i.e., Ellis and Brundrit – are of the kind that give rise to chaotic behaviour.
> c) Therefore two different history lines, which at the beginning will differ at least in the limits set by the uncertainty principle, must separate arbitrarily along their history, according to the definition of chaotic functions. This is even more true because the universe expands. And though the expansion of the universe seems to be un-chaotic (at least in the current state of our knowledge), it is well-known that the behaviour of galaxies and stars is chaotic. Since every history line of a living being must go through a galaxy, a star and a planet, it would be automatically affected by their chaotic behaviour[30].

The core of this criticism is based on the *Chaos Theory*, concerning the underlying models and deterministic laws of dynamical systems that are highly sensitive to initial conditions. Therefore, they can be defined as *nonlinear dynamical systems*. In Soler Gil and Alfonseca's perspective, history lines compatible with DNA-based life can be considered in this way. Moreover, the uncertainty principle implies that there is little difference in the conditions of two history lines, however similar they may be in the sense expressed in the Ellis-Brundrit argument. The susceptibility to change in the initial conditions of nonlinear dynamical systems implies that it is impossible

[30] Cfr. Francisco J. Soler-Manuel Alfonseca (2014, 361-373).

to make assumptions about the long-term development of the system, that is, the evolution of DNA-based life forms elsewhere in the Universe. In addition, as the authors argue, it is not possible to put forward arguments that clarify how, in an infinite set of possible histories, those compatible with the evolution of life should repeat more than one time.

8. Astrochemistry: the ubiquity of chemical reactions of carbon compounds

As anticipated above (section 2), we know a unique model of life. First, one of the universal features of living forms is the genetic code, which shows that the origins of all living things are connected to a single common ancestor (Last Universal Common Ancestor, LUCA)[31]. Like any natural object, informational molecules such as DNA and all other molecules essential for life are made of atoms. In this sense, the choice of basic elements to build a cell or any other living organism is common. Indeed, all living beings are composed of the same atoms, the so-called elements CHNOPS (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur)[32]. These corpuscles are formed in stars during the stages of nuclear fusion. Thus, they are distributed in the interstellar medium through events such as supernovae, the final act in the history of stars with a mass at least 9 times that of the Sun. Therefore, all known living forms, regardless of the complexity of the organism or cell, are composed of *stardust*.

However, by themselves these atoms are not enough to trigger the phenomenon of abiogenesis, that is, the emergence of life from inorganic inanimate material. Thus, more complex molecules (i.e., potential precursors to life) and suitable environments for the emergence of certain chemical reactions are necessary. For most of the last century it was difficult to imagine that these phenomena could occur in places different from planets. However, the development of telescopes capable of detecting infrared radiation and the discovery of interesting environments in the cosmos has increased chemists' interest in space[33]:

- *Interstellar clouds*: areas where the interstellar medium is found to have a higher density, implying a greater presence of atoms and molecules ($2 \cdot 10^{25}$ under standard conditions), and may be one of the

[31] Cfr. Woese (1998).
[32] Cfr. Cockell (2020).
[33] Cfr. Cockell (2020).

scenarios for the formation of carbon compounds by UV irradiation, albeit with products of lower complexity.

- *Molecular clouds*: these are interstellar clouds composed of a higher quantity of molecules, as well as the place where stars form. There are more than 100 molecules detected in these portions of the cosmos, demonstrating that even before the formation of a star (and a planetary system), some chemical reactions are already present.

- *Protoplanetary disk*: as we will see in the next section, this is the physical system from which planets form. This object has very different environmental conditions: temperatures between 100 K and 1000K in the inner zone and around 10 K for the outer zone. These differences amplify the possibilities of synthesizing different organic compounds that can chemically enrich planets during the chaotic planetary formation phase.

- *Interstellar grains*: very small celestial bodies composed of silicate or carbon-rich compounds enclosed by a layer of water ice. These bodies may offer a surface where carbon compounds can concentrate. Subsequently, irradiation of these molecules by cosmic rays and UV rays from stars could trigger a series of chemical reactions[34].

- *Comets*: celestial bodies composed of water, methane, ammonia and carbon dioxide that, when orbiting near a star, are recognizable by the double tail of plasma and dust formed by the evaporation of matter due to rising temperatures. Comets are the scenario for numerous chemical reactions involving carbon compounds, producing a fair diversity of organic molecules[35]. Some of the *cometary dust* can reach the upper atmosphere of a planet in the form of *interplanetary dust particles* (IDPs).

Enviroments described above have very different conditions that induce complex chemical reactions. Thanks to the increasing number of observations, we know that environments such as comets are capable of

[34] To be precise, the chemical reactions that could occur on interstellar grains are: 1) Eley-Rideal reactions; Langmuir-Hinshelwood reactions; Hot atom reaction. Cfr. Cockell (2020).
[35] For example, spectrometric analysis of comet 67P/Churymov-Gerasimenko showed the presence of 16 organic compounds, some of which include nitrogen compounds that could provide a good basis for the distribution on planets of the basic elements of life. Cfr Cockell (2020).

hosting chemical reactions from which possible precursors of molecules of life, such as formaldehyde, emerge. In addition, the discovery of a good variety of organic compounds and amino acids such as glycine in meteorites is a demonstration that complex chemistry is also possible in space. These celestial bodies are in a sense the waste material of planet formation, once present in the protoplanetary disk. Therefore, the *ubiquity of chemical reactions* in the cosmos capable of producing organic molecules could provide an argument for the Mediocrity Principle. However, the spread of organic molecules and life precursors does not necessarily entail the existence of life beyond the Earth. It is not yet clear whether the role of each mentioned environment may play a role in an event such as abiogenesis. Therefore, it is not possible to include these data in a larger scenario, a single coherent path that starts with the formation of organic compounds in space and clarifies their role in the formation of early life. Using these arguments to support a Mediocrity Principle entails including it in the *space-time invariance framework of the Universe*, a sort of uniformity of nature, which is valid only on large scales (and within the theoretical limits set out in the previous section). Therefore, the hypothetical uniformity of the cosmos remains a very weak hypothesis that cannot empirically support the Mediocrity Principle.

9. The formation of the Solar System and the assumption of mediocrity

The search for exoplanets represents one of the most fertile areas of the new millennium. The amount of data from these scientific investigations is growing and has profoundly changed our assumptions about the origins of planetary systems, presenting scenarios and histories very different from our cosmic context.

The Solar System appears today as a relatively peaceful place. However, our cosmic context was very different. The history of our planetary system began 4.56 Ga ago and can be described through the *solar nebula hypothesis*. The first formulation of this theory can be attributed to Emanuel Swedenborg in 1734[36]. Later, the hypothesis was independently readjusted by Kant and Laplace (indeed the hypothesis is also known as the *Kant-Laplace model*)[37]. Then, in 1969, this model was further revised by Russian astronomer Viktor Sergeevič Safronov, who advanced the *planetesimal hypothesis* for the formation of planets[38]. According to this theory, *planet formation is a*

[36] Cfr. Swedenborg (1734)
[37] Cfr. Laplace (1802).
[38] Safronov (1972).

byproduct of star birth. A chaotic consequence caused by the gravitational collapse of a molecular cloud related to external perturbations generating the necessary local conditions[39]. By the law of conservation of angular momentum, the collapse of the cloud induces matter to orbit around the centre of gravity of the system in the same direction as the star's motion. The motion caused the matter to flatten out, taking the shape of a disk or, to be precise, a *protoplanetary disk*. Meanwhile, near the centre of gravity of the system, gravitational collapse continued leading to the formation of a protostar that, through the solar wind, pushed lighter elements such as hydrogen outward from the system. According to this model, protoplanets formed in a relatively short time (around 5 million years). Through electrostatic and gravitational interactions and special pressure conditions, interstellar dust and gas became increasingly massive grains called *chondrules*. Then, the accumulated material formed objects with higher mass, increasing the gravitational force and attracting the lighter bodies they encountered along their orbit. Through this *accretion process*, grains of dust and gas became *planetesimals*. This process is chaotic and included not only the celestial bodies found in the Solar System today[40]. Planetesimals that emerged in the outer zone of the Solar System were formed earlier and attracted light gasses such as hydrogen, to form Gas Giant or Neptune-like planets. While the inner planetesimals were formed using heavier elements such as iron or silicates, which were a tiny portion of the original disk. As a result, the size, and the mass of the planets in that area is smaller. The primordial Earth and other rocky planets formed in this way. Through the solar nebula hypothesis, it is possible to justify the present configuration of the Solar System, the orbits and direction of motion of the planets, and the existence of the other celestial bodies. A story that begins with chaos and ends with a planetary system that has *three peculiar symmetries*[41]:

1. *The orbits of the planets are almost circular*.

2. *The orbits of the planets are almost all in the same plane*.

[39] The trigger that started the history of the Solar System is thought to be due to the explosion of a supernova located in the same galactic zone as our Sun, previously closer to the galactic centre. Cfr. Cockell (2020).
[40] Models predict that there were at least 50 to 100 such celestial bodies during the planetesimal epoch, some of which would have been incorporated into the more massive bodies giving rise to the planets, while others were ejected outside the solar system. Probably now they are lone planets. Cfr. Cockell (2020).
[41] Cfr. Covone (2023).

3. *The gas giants and Neptune-like planets are all located beyond the "snow line" (2.7 AU)*[42].

Moreover, almost all planets show a motion of revolution around the Sun in the same direction, and they also show the same rotational direction around their own axis. However, Venus has a retrograde rotational motion, in the opposite direction from the other planets, which breaks this symmetry. Finally, all planets have an axis of rotation perpendicular to the axis of their orbit, except that of Uranus, which is nearly parallel. As can be seen, even a planetary system like ours, seemingly calm and harmonious, has local asymmetries probably due to asteroid impacts during the Solar System's chaotic past.

Until the 1990s, the model just described was based on the only known planetary system structure. As often happens in science, scientific investigations are based on what is known, on the available empirical evidence. Therefore, early astrophysicists interested in the search for extrasolar planetary systems hypothesized that they would find similar structures. In a sense, this is an application of mediocrity from the evidence offered by our planetary system. However, there are no physical laws that, from these initial conditions, prevent planetary systems to assume a different structure. Thus, hypotheses about the extrasolar planetary systems were based on similarities between the Sun and other stars. Indeed, if the formation of the Sun triggered the genesis of our planetary system, why should this phenomenon not be repeated elsewhere? This is a very similar reasoning to Reid's argument and the Mediocrity Principle. Therefore, this hypothesis is also based on an analogical argument in which, this time, the main actors are stars. Therefore, the following argument can be made: it is plausible that planets exist around all the star in the universe by virtue of some known similarities with the Sun.

To which corresponds a logical form identical to Reid's argument and the Mediocrity Principle, although both the source and target domains are different (the Sun and the set of stars in the universe, respectively). However, the major difference between this argument and the others concerns background knowledge. Indeed, at the time of their formulation, there was insufficient empirical evidence to evaluate the strength of these arguments. In contrast, in the case of the existence of exoplanets, the solar nebula hypothesis represented a valid theory at least for the Solar System. Consequently, the

[42] The distance of the ice line changes in function to the type of star considered. The value introduced refers to the Sun, and thus to G-class stars that are not in a binary system.

related analogical argument regarding exoplanets possessed greater force. During the 1990s'the existence of exoplanets was demonstrated, providing empirical support for this analogical argument. But as is often the case when analogy is used, the observed worlds showed important differences from our astronomical environment from the earliest cases.

10. The heterogeneity of the planetary contexts beyond the Solar System

Since the 1990s, the existence of planets outside the Solar System has been demonstrated. Today, more than 5500 exoplanets have been detected, with more than thousands of candidates to be confirmed. The set of known exoplanets is much larger than in the last century, proposing a first concrete test case for theories about extraterrestrial life. However, the scenarios observed by planet hunters showed many surprises that have strongly discredited the Mediocrity Principle. The astronomical context of exoplanets tended to be very different from our own, which has the three symmetries introduced earlier. In particular, the classes of exoplanets identified in the Milky Way can be seen below:

Class	**Mass**	**Radius**	**Methodologies applied before the JWST**	**Number of confirmed exoplanets**[43]	**Example in the Solar System**
Mini-Earth	$\mathbf{0.00001 - 0.1\ M_\oplus}$	$\mathbf{0.03 - 0.4\ R_\oplus}$	**Radial Velocity, Photometric Transit and Timing**	**8**	**Mercury**

[43] Data about confirmed exoplanets, dated March 2024, are extrapolated from the NASA catalogue: https://exoplanets.nasa.gov/exoplanet-catalog/.

Sub-Earth	$\mathbf{0.1 - 0.5\ M_{\oplus}}$	$\mathbf{0.4 - 0.8\ R_{\oplus}}$	**Radial Velocity, Photometric Transit and Timing**	**77**	**Mars**
Earth-like	$\mathbf{0.5 - 5\ M_{\oplus}}$	$\mathbf{0.8 - 1.5\ R_{\oplus}}$	**Radial Velocity, Photometric Transit and Timing**	**113**	**Earth and Venus**
Super Earth	$\mathbf{5 - 10\ M_{\oplus}}$	$\mathbf{1.5 - 2.5\ R_{\oplus}}$	**All**	**1691**	**-**
Neptun-like	$\mathbf{10 - 50\ M_{\oplus}}$	$\mathbf{2.5 - 6\ R_{\oplus}}$	**All**	**1915**	**Uranus and Neptune**
Gas giants	$\mathbf{> 50\ M_{\oplus}}$	$\mathbf{> 6\ R_{\oplus}}$	**All**	**1783**	**Jupiter and Saturn**

Table 10.1 List of confirmed exoplanets

The distribution in the respective classes in Table 10.1 of confirmed exoplanets entails situations that discredits the typicality of the Earth. Firstly, there is a class that has no counterpart in our astronomical context: the Super Earth, planets with a mass between that of Earth and Neptune, heterogeneous chemical composition and therefore not necessarily rocky as the name would suggest. In addition, hidden in this list is an additional category unknown before these discoveries. These are Hot Jupiter, i.e., planets like Jupiter that orbit very close to their star (between 0.5 and 0.015 AU) due to a planetary migration phenomenon which prevents to rocky planets to be strictly Earth-like object from forming and discredits the typicality of the Earth.

The first discovery of an exoplanet orbiting a Sun-like star, Pegasi 51, occurred in 1995[44]. The result of the search showed just such a Hot Jupiter, Peg 51b. The scientific investigation conducted by astrophysicists Mayor and Queloz was aimed at finding another type of object, a brown dwarf[45]. The motivations driving the project in this direction were clear: a celestial body with a mass greater than that of Jupiter gravitationally affected the star and had to be a brown dwarf rather than a planet because, following the Solar System model, gas giants cannot orbit so close to their star[46]. Then, the awareness increased that this type of astronomical context, very different from our own, is on the contrary very widespread in our Galaxy. The symmetries shown by the Solar System are not compatible with the presence of this type of object, and no planetary system has been found to exhibit such characteristics. So, referring to empirical data from Astrophysics, *the Solar System and Earth-like planets are special*[47].

Conclusions: the limits of the Mediocrity Principle and our knowledge

Data produced by the search for exoplanets show a scenario in which Earth-like planets are not typical. Therefore, if life can only emerge and proliferate in this kind of environment, then the hypothesis of the existence of other life forms in the Galaxy can also be strongly challenged. It is therefore possible to show a list of reasons that can weaken the validity of a methodological approach such as the Mediocrity Principle:

- *The exoplanet data* show a set of planetary systems that lacks at least one of the symmetries shown by the Solar System, an astronomical context perhaps fundamental to the emergence of life on an Earth-like planet.

- *Planetary migration* is a discriminating factor in the formation of Earth-like planets and astronomical contexts such as the Solar System, and thus the permanence of gas and ice giants beyond the ice line may be a necessary factor.

[44] Cfr. Mayor and Queloz (1995, 355-359).
[45] Cfr. Mayor and Cenadelli (2018).
[46] In this case at about 0.0030 AU. Cfr. Mayor and Queloz (1995, 355-359).
[47] Cfr. Covone (2023).

- The typicality of each point in space-time breaks down, approximately, under the scale of the cosmic web, a kind of *threshold for the Copernican perspective*: from the typicality of each point in the observable universe it is not possible to infer nontrivially that the Earth and intelligent observers are not special.

- The *ubiquity of organic chemistry* in space is not yet clearly related to the phenomenon of life, and thus it is not yet clear how much of the matter produced in space provided the support of prebiotic material for the initiation of abiogenesis.

Together with the theoretical arguments refuting the *a priori* assumption of the Mediocrity Principle, the empirical scenario offered by these data only support the assumptions that our world is special. Moreover, even the Copernican perspective of the cosmos, defined through the homonymous principle, faces very strong validity limits. On the one hand, the impossibility of making demonstrable inferences beyond the observable universe, and on the other hand, the objects taken into consideration become more complex and unevenly distributed descending beyond the scale of the cosmic web. Galaxies, stars, and planets are not smoothly distributed, and the astronomical environments identified diverge from the structure of the Solar System, breaking at least one of the three symmetries typical of our planetary system. Therefore, by referring to data, *Earth is the result of a special history*, which allowed the formation of a non-typical rocky planet in the habitable zone around the Sun that, unlike most of other stars, is not included in a binary system of stars. In addition, the N=1 problem entails the impossibility of adopting non-geocentric models for concepts such as "habitable planet" or "life," limiting the search for extraterrestrial life to astronomical environments suitable for living beings from the known biosphere: a seemingly heterogeneous set of living things with a single common ancestor or, in short, a single model of life. Therefore, trying to definitively refute the Mediocrity Principle is a road that leads to the *limits of our knowledge*: Do biochemically diverse life forms exist? *Are Earth-like planets the only environment suitable for life?* Is abiogenesis a necessary phenomenon in the history of Earth-like planets or is it connected to other contingencies that might not happen?

These questions preclude proposing conclusive arguments against the hypothesis of the typicality of life, which might one day be justified *a* *posteriori* by new empirical knowledge. This crucial new information could come from the Cassini probe, which, in addition to studying Saturn, is looking for relevant data regarding the icy moons orbiting the planet. In particular, the latest studies concerning *Enceladus* have revealed the possibility that the moon's oceans under the icy layer could contain the CHNOPS elements[48]. Thus, it could be a possible environment for the emergence of extraterrestrial life. In a sense, finding life on Enceladus could challenge the geocentric model of environments for the emergence of life, entailing an eventual paradigm shift in the search for extraterrestrial life. According to this new paradigm, the Mediocrity Principle might be valid for life but not for Earth-like planets, which are generally special. Thus, in the coming years, the study of this new scenario, located beyond the habitable zone of the Solar System but potentially suitable for life, could offer a new and fundamental test case for the hypothesis of the typicality of living things. A crucial step in understanding whether life and humans are the only inhabitants of a Galaxy that seems silent and barren.

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