Part I:
PHILOSOPHY OF THE COSMOS

Intelligent Characteristics of Potential Microbial Life During the LHB

Ian von Hegner

A research scientist, Future Foundation Assoc. (Karlslunde, Denmark)
E-mail: tellus@live.dk
https//orcid.org/0000-0002-8401-0171

von Hegner, Ian (2024) Intelligent Characteristics of Potential Microbial Life During the LHB. *Philosophy and Cosmology*, Volume 32, 4-26. https://doi.org/10.29202/phil-cosm/32/1

The 'disparitas conjecture' states that unicellular life is common in the galaxy but that multicellular life is rare in comparison. A variation of this conjecture is that unicellular life may be common in the galaxy but that intelligent life is rare. However, microbial life can and does indeed display characteristics of intelligence. Thus, in this work, how life could have potentially endured through the Late Heavy Bombardment (LHB) through intelligent strategies such as decision-making, association and anticipation, communication and self-awareness was investigated. At the LHB, there would have been, for microbial life, an unpredictable environmental fluctuation regarding pools of amino acids, lipids and fluids available when impacts and reimpacts launched organisms into new habitats. Thus, evolutionary strategies must have been favoured that could stretch the available external and internal resources as long and as efficiently as possible. Thus, inclusive fitness or kin altruism could have emerged, where organisms adapt to acquire energy and nutrients from siblings who voluntarily autolysed to replenish the amino acid pool for their kin. A further strategy could also evolve where members of the same species can recognize each other and actively isolate themselves from other species, which allows them to better utilize the amino acid pool. Thus, the organisms will potentially be able to survive for a long time in this manner until new impacts launch them to new spots with amino acid pools. There has thus been an alternating increase and decrease in the number of organisms during this localized planetary reseeding, and life may have endured this way until the bombardments were over. Thus, if a world inhabited only by analogous bacteria, archaea and protists is located elsewhere in the galaxy, the existence of intelligent life there cannot be excluded.

Keywords: astrobiology, bacterial altruism, localized planetary reseeding, the Hadean.

Received: 2 January 2024 / Accepted: 14 January 2024 / Published: 5 February 2024

1. Introduction

Whether there is life elsewhere in the galaxy and beyond is a much-discussed topic, marked according to how probable the emergence of life and its subsequent evolution is considered to be. However, an ongoing search for exoplanets and exomoons with conditions suitable for life as we know it and a search for worlds actually having life are occurring.

In the search for life elsewhere, the informal middle position has emerged, which states that unicellular life is common in the galaxy but that multicellular life is rare in comparison. This 'disparitas conjecture' or 'disparitas hypothesis' may explain the reason for the silence we observe when we search the galaxy for traces of technosignatures such as radio transmissions. After all, in the majority of the Earth's history, life has existed in the form of unicellular life and is, in fact, still the dominant form. In terms of reproductive fitness, it is also the most successful lifeform known, existing in virtually all terrestrial habitats.

A natural extension of the discussion about life elsewhere is the discussion about intelligent life elsewhere. Thus, an occasionally heard variation of this middle position is the view that unicellular life may be common in the galaxy but that intelligent life is rare. This seemingly trivial variation is important to address, as it follows that if during a search for intelligent life one locates a world where only microbial life exists, the possibility of the presence of intelligent life on that world is excluded. This has nontrivial implications, as the notions that microbial life is common but that intelligent life is rare are self-contradictory.

Thus, in microbiology, the convergent attitude is that microbial life can and indeed does display characteristics of intelligence. While a single microbial organism can be said to be an automaton (which may itself be debatable), macromolecular networks can confer intelligent characteristics in microbial organisms. Thus, microbial organisms do indeed display characteristics of intelligence such as decision-making, association and anticipation, self-awareness, robust adaptation, and problem-solving capabilities (Westerhoff et al., 2014). If a world exists where only microbial life thrives, the probability of intelligent characteristics associated with this life is also high. Therefore, the conceptual distinction between microbial life and intelligent life is a misnomer in the debate that should be moved away from, and a more precise terminology regarding the search for life elsewhere is needed.

Life can display intelligent characteristics in many different situations. As an illustration, a scenario relevant to astrobiology can be considered. The Earth has been impacted ever since its formation approximately 4.5 billion years ago, although the frequency and size of these impactors have declined since the Late Heavy Bombardment (LHB) (Reyes-Ruiza et al., 2012). This event, which may have been due to discrete early, postaccretion and later planetary instability-driven populations of impactors (Bottke and Norman, 2017), began approximately 4 billion years ago and is estimated to have ended 3.8 billion years ago, although some evidence indicates that terrestrial impacts did not cease but rather waned gradually until approximately 3.0 billion years ago (Lowe et al., 2014).

While much remains to be elucidated regarding the details, an autonomous cell with a high degree of certainty existed on the Earth 3.5 billion years ago, in the Archean Eon (Schopf et al., 2007), dated to span between 3.8 and 2.5 billion years ago (Coenraads & Koivula, 2007). However, the chemical evolution leading to this life was probably not a single event; instead, the transition from chemistry to biology was a gradual series of thresholds of increasing complexity over time (von Hegner, 2021). Thus, some lines of evidence point to the emergence of life occurring earlier, between 4.1 to 3.5 billion years ago (Bell et al., 2015), in the Hadean Eon, dated from the end of the Earth's accretion until 3.8 billion years ago (Coenraads & Koivula, 2007).

The Hadean and early Archean world was in many ways an alien world compared with the current Phanerozoic world. Thus, the presence and composition of primitive continents at that time have been under intense debate. A study estimates that the few very large impactors that impacted the Earth would have resurfaced less than 25% of the planet's surface, meaning that most of the crust was not melted or thermally metamorphosed to a significant degree (Abramov & Mojzsis, 2009). Another study suggested that a large landmass existed in the Hadean world, with an environment that could have included nearly all geochemical conditions that favour the chemical evolution of life (Maruyama et al., 2013).

Several hypotheses regarding where and how life could have arisen have been posited over time. Life may, for example, have started at hydrothermal vents at the ocean floor, but it could also have started at shallow ponds in what has been called Deamer's 'hot little puddle' (Damer, 2019), a modern version of Darwin's 'warm little pond'.

If life indeed existed in the period when the LHB took place, the LHB must have had an influence on life, and life must have faced scenarios differently from those in later times. One such scenario is that at the LHB, the incoming impactors would have meant that there was an unpredictable fluctuation of available building material for the organisms, or in other words, that there would be a depletion of a pool of amino acids, lipids and fluids available for a cell. Thus, it is puzzling to understand how life survived through this period.

There are many variables to consider, and many microbial strategies may have been at play and tested through the LHB. However, the LHB has provided an environmental pressure different from anything else life has experienced on this planet. However, the evolutionary responses and impact dynamics can be described and predicted. Their interaction during this period may have yielded strategies different from anything else life has experienced, which could have pushed life through a unique survival strategy that has not been seen since at the same scale. Thus, the following text will examine how life could potentially have managed to survive through this period through strategies that demonstrated intelligent characteristics.

2. Discussion

In this article, Section 3 introduces the LHB and impact rate. Section 4 introduces the effect of the LHB from life's perspective. Section 5 introduces the course of action that life must have taken due to the restraints of the bombardment. Section 5.1 highlights the selection of organisms that can endure the longest. Section 5.2 highlights the evolution of altruism, a characteristic of intelligence. Section 5.3 highlights the evolution of cooperation, a characteristic of intelligence. Section 6 clarifies how evolutionary strategies have enabled life to make it through the LHB. Finally, Section 7 summarizes the results of this investigation as well as its limitations and strengths and its significance for the search for intelligent life on other worlds.

3. The Late Heavy Bombardement

Estimating how many impacts the Earth endured during the LHB is associated with considerable uncertainty, as the Earth has erased much of its own early history. A modern estimate, based on lunar cratering, radiometric data and a record of the late Archaean (3.5-2.5 billion years) impact flux provided by terrestrial impact spherule layers, yields an upper limit on the number of impacts in the time span of 4.5–2.5 billion years of 60000 impactors with bodies ≥10 km in diameter. This estimate is based on a smoothly declining flux (no

LHB), while a model with an LHB at 4.0 billion years would yield approximately a factor of 100 fewer impacts in the same time frame (Marchi et al., 2014; 2021).

While the record is likely incomplete and uncertainties remain, it is also the case that these estimates apply only to large impactors. Thus, it seems reasonable to hypothesize that many smaller impactors also hit the ground but failed to leave a trace. Thus, e.g., the current-day flux of extraterrestrial material in terms of meteorites falling to the Earth's surface, where it has been estimated that the global fall flux is 17,600 objects each year for masses >50 g, can be mentioned (Evatt et al., 2020).

Most of these meteorites do not cause significant damage to the Earth's surface; however, it is reasonable to assume that a scenario between these two extremes also existed during the LHB, where impactors large or dense enough to impact the Earth's surface, but not necessarily capable of leaving traces in the present, existed. Their number and frequency may have been greater than those of the large impactors, such that rather than the Earth being hit only by impactors ≥10 km in diameter every few million or thousand years, the Earth was also hit in different places every year by impactors able to reach the surface and affect the potential habitats for life there. Thus, it is assumed here for the sake of discussion that an impact shower situation with 1000 impactors per year on average can be expected, i.e., one impactor can be expected each:

$$\text{Impactor}_{\text{Rate}} = \left(\frac{525948.766 \text{ minutes}}{1000 \text{ impactors}}\right) \quad (1)$$

$$= 525.94 \text{ minutes},$$

i.e., one every 8.76 hours somewhere on Earth. From these values, the rate parameter for the impactor shower situation is obtained:

$$\left(\frac{1 \text{ impactor}}{525.9 \text{ minutes}}\right) \times 525948.8 \text{ minutes} = 1000 \text{ impactors expected}, \quad (2)$$

the most likely number of impactors that will be observed in a year.

At the LHB, there would thus be an almost continuous incoming of impactors on the Earth. Although this was a global influx of impactors, for microbial life, these would be experienced as locally infrequent impactors spread over time and place, i.e., there would be an unpredictable environmental fluctuation in that new impacts would hit a habitat and send some organisms off to new environments.

During impacts, a ring system is formed, and a model for this ring system has been made by von Hegner (2022), consisting of two central rings, namely, the primary ring (containing 5 rings) and the secondary ring (containing 5 rings), which will be used in the following. Thus, the first stage of the redistribution of life as a result of impact dynamics is the landing of the impactor. It will be assumed here that each ring initially contains $N = 1 \times 10^6$ organisms evenly distributed throughout. This quantitative assessment may be considered a low number today and perhaps too large a number then; however, for the sake of calculation, this will be assumed here.

Thus, in ring 1, the centre of impact, 100% of the 1 x 10^6 organisms perished.

In ring 2, 80% of the 1 x 10^6 organisms perished; thus, 200,000 organisms survived the impact blast.

For the next rings, 3, 4 and 5, the survival rate decreased correspondingly by 60%, 40% and 20%, respectively.

Thus, n = 2 × 10^6 organisms out of N = 5 × 10^6 organisms survived the impact blast T_1.

In this model, the impactor could be considered invariant, as although the incoming impacters will vary in their diameters, densities and velocities, it is still the case that the organisms in the centre of the impact blast will perish, while some organisms in the adjacent rings will survive. The quantitative assessment that 100%, 80%, 60%, 40%, and 20% of the organisms perished for each ring outward is an assumption, based on the notion that the effect of the impact blast decreased for each ring outward.

Only local impactors are taken into account, the minimum impact velocity a small body has with the Earth is 11.2 km/s (Cordero-Tercero et al., 2016), capable of reaching down through the atmospheric shield and making an impact. Global planet sterilizing impactors are not considered here, although this rain of local small impactors may have given life tools to be better equipped against large global impactors.

In the second phase of the redistribution of life as a result of impact dynamics, some organisms are ejected into rings 6, 7, 8 and 9 as a result of the impact blast.

Thus, in ring 1 of the primary ring, 100% of the organisms will perish, i.e., no living organisms will be launched into the secondary ring.

In ring 2, 80% of the 2 × 10^5 organisms, i.e., a total of 160,000 organisms, are launched into the secondary ring.

For the next rings, 3, 4 and 5, the organisms are similarly launched over 60%, 40% and 20%, respectively.

Therefore, n = 1.2 × 10^6 organisms remain in the primary ring, while n = 8 × 10^5 organisms are launched into the secondary ring. A more simplified model than this will be sufficient and will be used from here on, where survivors deposited in 4 of the 5 outer rings in the secondary ring are considered to be in a ring.

Such a continuous impacting and relaunching environment can be expected to lead to the emergence of the bet hedging strategy, which was discussed by von Hegner (2022), as it was an unpredictably fluctuating environment in which it was not possible for life to obtain cues because the impactors did not hit the same place with the same frequency. Bet hedging can be characterized as a form of decision-making, a characteristic of intelligence, in that a population can maintain two variants, $V_{Robustus}$ and $V_{Intervallum,}$ even when there is a uniform environment. However, other strategies may also have arisen, as there was a demand to not only survive the pressure from impacts but also to survive in changed conditions regarding the availability of a pool of amino acids, lipids and fluids.

4. The LHB from the perspective of life

At the LHB, the incoming impactors would mean that for microbial life, there was an unpredictable environmental fluctuation in terms of available building material, or in other words, that there would be an alternating depletion of a pool of amino acids, lipids and fluids available for a cell, as the organisms may be cut off from such an external pool when sent to a new location.

Energy would indeed be available for life in the form of energy derived from light from the sun or chemical processes; however, such available energy is not sufficient, a pool of amino acids, lipids and fluids must also be present. Thus, phototrophs, organisms that can use visible light as an energy source to manufacture organic compounds, require more than light, namely, an amino acid pool and water. Even chemotrophs, organisms that obtain energy by the oxidation of reduced compounds, either organic or inorganic, are no better off, as the abrupt change in the environment is the issue here. They are sent abruptly to new environments, so there is no time for gradual adaptations. Thus, even if they can harvest the amino acids they need somewhere, they can again be sent to a place where they cannot immediately harvest it.

In today's Phanerozoic Eon, amino acid pools can be found in most places; however, in the Hadean Eon, it could be very different. There is much discussion regarding the presence of amino acids during the early Earth (McCollom, 2013), which will not be the goal of this work. It will be assumed here that amino acids existed, either as a result of terrestrial chemical processes, as a result of extraterrestrial delivery through impactors (Chyba & Sagan, 1992; Takeuchi et al., 2020), or both, and that some organisms had evolved metabolic pathways for amino acid biosynthesis. What matters is that they existed.

What is debatable is how widely spread and available they were at the time. There may have been two scenarios when the bombardment increased.

In one scenario, there may initially have been spots with amino acid pools scattered around the planet.

In the second scenario, there may initially have been an even distribution of amino acid pools on the planet, which the bombardment has gradually transformed into a lane with spots with amino acid pools on it. In the second scenario, the organisms initially had good conditions for life, though these environments gradually narrowed as the frequency of the bombardment increased, while the organisms in the first scenario already had narrow conditions for life.

However, in both scenarios, for life, when the bombardment comes to an end, it will have become the same scenario. Thus, for simplicity, the discussion will be based on the scenario in which there was not an even distribution of amino acid pools but that they were spread unevenly around, like spots on a lane.

Life faces two potential issues when launched, as the organisms can in principle land in 2 places, an area that is sterile and one that is not. As time goes on and increasingly more impacts have occurred, this will mean that the organisms can land in areas that have and have not been sterilized by a previous impact. The environment that has not been sterilized can itself be divided into two situations.

The environment can be so different that even if there is an amino acid pool there, the microbial life is initially unable to take advantage of it.

The environment can be virtually identical to the native environment of an organism, making it easy to absorb the amino acid pool there. Thus, the first of these environments may initially have the same lack of utility as the environment that has been sterilized by the impact.

It must be said that the organisms will never arrive at an ideal environment due to the very nature of the bombardment. Thus, the arriving matter will land with the same velocity as that

when they were sent up by the impact (Melosh, 1989). Thus, the incoming matter will land at a sufficiently high velocity to wreak havoc where it lands. It will not be destruction to the same extent as with an impact launch. There it was an entire impactor that landed, while here it will be fragments of material that land. Here, there will be scattered areas with the possibility of an amino acid pool.

Thus, there are 3 situations to consider.

In the first situation, the organisms are placed in an environment where there is no amino acid pool because this pool has been destroyed or was not initially present. It is possible for a world to be habitable yet uninhabited. It is also possible under certain circumstances for a region to be uninhabitable yet to be inhabited for a time. Being transported to such a spot would be similar to the transport of a person to the Atacama Desert; the person can immediately live there for a while but cannot obtain external native resources to live there indefinitely.

Thus, even if the organisms can pragmatically survive the initial arrival and placement there and the environment does not destroy them, there will not be a life-sustaining amino acid pool available for the organisms. Initially, these sterilized areas belonged to the minority, but as the bombings have hit an increasing number of areas, their number has increased, and the scale of environmental severity has increased.

In the next situation, it applies that there is an inverse proportionality between life and environments. Even if an amino acid pool were present where the organisms land, the fact is that it may be in a form they are not adapted to use. Thus, microbial life can adapt quickly to new environments, but this applies when they spread by themselves, where reproduction, variation and selection, the key mechanisms of Darwinian evolution, are at stake. However, here, the organisms are sent off abruptly to new environments without their own influence and may encounter a completely different environment. Thus, in the new environment, there may be an amino acid pool they are initially unable to utilize. This will be the issue for photostrophs and even for chemostrophs.

In the next situation, there is also an inverse proportionality between life and the environment. However, here, the environment is virtually the same as the organisms' own environment, which means that the organisms can absorb the amino acid pool.

In all 3 situations, it applies that new impacts can occur, where some organisms will again be thrown away from the impact site in all directions in the form of an expanding impact circle and land in a new place. Since this will be one of those places with no, different, or usable resources, the situations discussed will again be relevant.

5. Evolutionary strategies

Continuous but infrequent bombardment is a parameter that distinguishes this period of the Hadean from the present. In this situation, there have been two types of pressures for life. The first has been to survive the bombings in the highest possible numbers. The second has been to economize with the amino acid pool as much as possible, i.e., to evolve strategies that make the most of the available resources. Here, the specific circumstances have been able to push the evolutionary strategies in certain directions. Thus, since the external environment under these circumstances has not been reliable in terms of an available amino acid pool, selection favouring survival mechanisms through utilization of the only reliable amino acid pools available, namely, the limited amino acid pools available at the new site, must evolve and/or those existing in the various organisms themselves, have evolved. Thus, during the LHB, evolutionary strategies would have been developed to economize on the internal resources.

5.1. The first and second rounds

The third stage of the redistribution of life as a result of impact dynamics is the landing of the $n = 8 \times 10^5$ organisms in a new environment. It is assumed here that the first scenario described in Section 4 applies, i.e., that the organisms land in a place where no amino acid pool exists.

As discussed in Section 3, the organisms in each ring as a result of the impact blast perished at a percentage of 100%, 80%, 60%, 40%, and 20% for each ring outward from the blast. The material ejected from an impact crater follows a nearly parabolic trajectory, and when it begins to fall back to the surface, it will strike with the same velocity as when it was launched from the blast (Melosh, 1989). Thus, in the secondary ring, some of the organisms will perish in a reverse sequence like the one in the primary ring.

Thus, matter from ring 1 will land, although with no live organisms, as they were eliminated by impact.

Matter with 160,000 organisms from ring 2 will land, and 80% of the arrived organisms will not survive the landing. Thus, 32,000 surviving organisms will be deposited there.

For the next rings, 3, 4 and 5, the survival percentages will be 60%, 40% and 20%, respectively.

Thus, in total, $n = 4 \times 10^5$ surviving organisms will be deposited there. In the first round, there may have been different species that arrived with the deposited material. These can compete against each other for access and utilization of the external amino acid pool that became available to them (see Figure 1). They will also compete against each other to evolve the best fit for the environment in which they arrived. However, such a strategy is costly overall, as an arms race will arise in which both parties mutually evolve mechanisms against each other.

The special circumstances of the situation are that there is only a limited external amino acid pool available, so the different species cannot continue to compete for fitness as they otherwise could in today's more ideal conditions. Therefore, even if it is assumed that half of the arriving organisms perished and released their amino acid pool, there will not be enough for all the survivors to undergo reproduction. However, there may be enough for some strains to go through several reproductive cycles where adaptations can occur.

Evolution is a short-term tinkerer, not a long-term planner. Thus, the various species may eventually run out of the external amino acid pool before the next impact potentially sends them to a place where there is an amino acid pool.

The second round begins when the amino acid pool runs out. Here, a competition to stretch the internal resources as long as possible will then occur, where the organisms will have to stretch their metabolism as long as possible to survive.

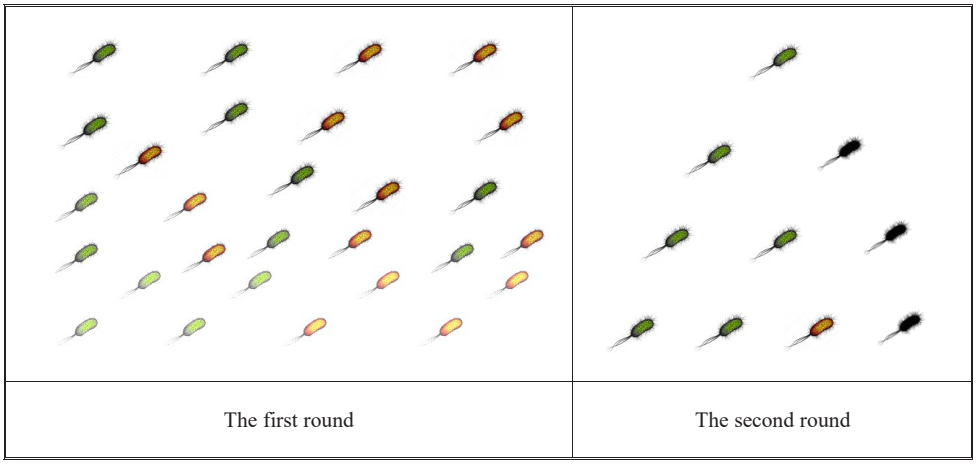

Figure 1. The initial situation in the first and second rounds. In the first round, there are external resources such that new adaptations (shown with changing colours) in two different species (green and yellow) can occur. In the second round with internal resources, organisms are seen that gradually die in a stochastic manner (shown in dark), although due to differences in constitution, one species has more survivors. When one organism in a row dies, the others in the row have enough amino acids to survive to the next row. For simplicity, the organisms' reproduction is not depicted here. Credits: bacterial images adapted from Mirumur, 2011, 2014.

Thus, in the second round, they will not compete with regard to fitness but focus on enduring, as there are only internal resources (see Figure 1). When the second round begins, two things may have occurred in the first round.

There may be only one variant from one species left that has outcompeted the others, or there may still be several variants from different species left that have managed to survive this far. However, whether there was one or more species that made it through the first round is irrelevant with regard to the second round, as under these circumstances, there will inevitably be one organism left that will survive longer than the others.

The second round is different from the first round. In the first round, there was an external amino acid pool, whereas there was only an internal amino acid pool in the second round. It exists in every single organism and can be accessed in two ways.

The first way is by one organism consuming another to obtain its amino acid pool. Thus, if there were two species that survived through the first round, they could initially continue in the second round by devouring each other. This may in other circumstances lead to an arm's race, but there are insufficient resources to continue this for long, even among those who manage to survive by devouring others.

Therefore, under these conditions, another way can arise. Regardless of how long they can stretch their metabolism, there are those that will perish before the others, which means their amino acid pool becomes available to the others without them taking it in a hostile way.

Thus, the organisms will be able to survive longer by peacefully absorbing the necromass pool from those who cannot survive as long as themselves. This means that it is possible for members of different species to also survive, not by hostilely devouring others but by peacefully obtaining energy and nutrients from the detritus of organisms that perish by themselves. However, there will still inevitably be one individual left through the first and second rounds, as one must perish before the other.

Strictly speaking, there could be one surviving member of each species left before the last ultimate survivor is unveiled, giving this scenario a 50% probability. However, it is more likely that the organism survived so long because of its physiological constitution, an advantage shared by the clonal colony. Thus, one species possessed an advantage that made it survive longer than the other. Thus, it is not entirely stochastic factors that come into play here. Therefore, the last two survivors are likely to be from the same species, after which one devours the other and only one individual remains.

Thus, selection between taking the amino acid pool hostilely and between taking it peacefully from randomly succumbed organisms will be able to occur.

Thus, the organisms that can stretch the available external and internal resources as long as possible and use them as efficiently as possible are also those that have the greatest opportunity to survive the longest in some spot in the first and second rounds until a new impact sends them to a place with an external amino acid pool. Since they are also the organisms with the greatest opportunity to exist in the greatest numbers, they are also the most likely to send off more members of their species, or only their species.

5.2. The third round I: altruism

The environmental pressures discussed in the previous section could potentially lead to the emergence of a remarkable strategy, namely, inclusive fitness or kin altruism. This was described by Hamilton (1963; 1964) in social insects, where one organism helps another to increase its reproductive fitness at the expense of decreasing its own. This strategy has since been shown to also exist in microbial life such as *E. coli* (Akaizin et al., 1990), where autolysis of part of a starving population occurs, thereby replenishing the amino acid pool for the surviving organisms and, thus, promoting the survival of the rest of their kin.

This is a form of microbial self-awareness, a characteristic of intelligence. For this strategy to occur, a third round is required, where the surviving organisms are selected by being sent back and forth in spots over several rounds.

In new impacts, organisms will be flung away from the impact site in all directions in the form of an expanding circle, and some of the organisms will be able to end up in a new place with an amino acid pool. If the new site possesses a suitable amino acid pool, the organisms that survive being placed there will also be able to build up their numbers strongly again. It has thus been a population that has repeatedly disappeared upon impact and landing and then grew again. Reproduction occurs by binary fission, where the number of microbial life forms increases exponentially, which can be expressed as follows:

$$N_n = N_0 2^n \tag{3}$$

where N_n represents the number of organisms at the end of a time interval, N_0 represents the initial number of organisms at the beginning of a time interval, and n represents the number of generations. Thus, if there are sufficient amino acids in the new spot, it will only take a single arriving organism 20 reproductive rounds to reach ~1×10^6 organisms.

In the first and second rounds, events proceeded fairly mechanical. While evolutionary adaptations could occur in the first round and acquired or existing preadaptations could play a role in the second round, the prevailing conditions still made the events proceed in a predictable manner.

While the evolutionary adaptations in the arms race in the first round were not entirely predictable, as they could take many different directions, this is irrelevant as the organisms

would run out of external resources anyway, and the second round would be decisive as it would take its point of departure in the adaptations that were when resources ran out, and individual members surviving on internal resources would ultimately be left.

The third round occurs fairly mechanically as well. The organisms are mechanically sent back and forth between spots. Only in a few places will a new impact send them off in time for survivors to come along. Those who may remain may be infused with a necromass amino acid pool, as the impact released it from those that perished on impact.

This repeated situation can lead to cooperation between the organisms, where it is important to economize with the resources as much and as efficiently as possible. Thus, rather than organisms in the second round starting a competition against each other, they can also initiate cooperation to give cues by voluntary autolysis (see Figure 2). A cooperation will in the situation be safer, as randomly obtaining the amino acid pool from those who perish will take time and will be very uncertain, as it cannot be determined when and where it occurs.

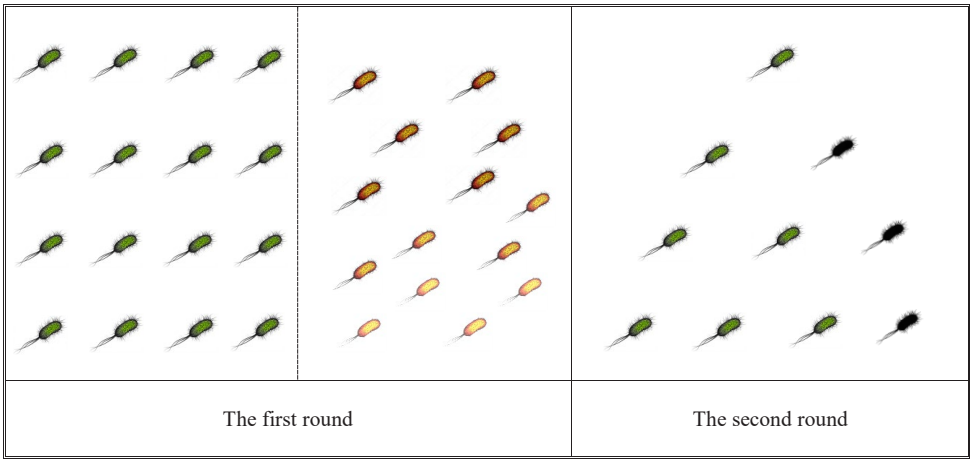

Figure 2. The subsequent situation in the first and second rounds. In the first round, there are external resources that one species (green) makes better use of by having evolved the strategy of isolating itself from the other species. Next to it is the species (changing colours in yellow) found irregularly in an arm's race. In the second round, organisms undergoing autolysis are seen in a row such that the others in the row have enough amino acids to survive to the next row. Although this scenario resembles the one in Figure 1, the latter shows stochastic events, while this scenario shows altruistic sacrifice. In reality, there will not be equal absorption of amino acids, and some will be lost each time. When reproduction is included, uptake will follow an arithmetic sequence of 11, 9, 7, 5, 3, 1. Credits: bacterial images were adapted from Mirumur, 2011, 2014.

However, when the organisms communicate with each other about when there is a need to renew the amino acid pool, this will reduce the randomness that prevails in these circumstances, and the chance of survival will increase as a result of communication, again a characteristic of intelligence.

Thus, a selection will gradually occur such that it will not be a random forced act that an organism dies and gives its amino acid pool to a sibling, but a selection will actually be able to occur, whereby the colony will evolve such that a part of them voluntarily sacrifices themselves as food for their siblings, and the colony can even communicate when it happens or when it is best for this to occur (Figure 2).

This scenario has indeed been observed. Thus, an *E. coli* population experiencing starvation would gradually split into two subpopulations. One subpopulation eventually perished through autolysis, whereas the other subpopulation utilized the released cellular detritus and continued growing and reproducing (Akaizin et al., 1990). The interesting point here is that in other situations when a population of organisms reproduces, there will be a doubling in number. However, in this situation, the population will both reproduce and yet decrease in number. If this happened over several rounds of being sent back and forth, there could now be adaptations in an arm's race to stretch the metabolism further, as there is now a selection for this in the renewed first round, and cues that this will be needed in the renewed second and third rounds will occur. Thus, association and anticipation, characteristics of intelligence, can now be evolved.

The following calculation can illustrate the value of this. It is assumed that there are initially $N = 8 \times 10^5$ organisms in the same clonal population in the spot. Of those, 4×10^5 will be destroyed or autolyse voluntarily, leaving 4×10^5 organisms. For example, 15% of cellular detritus is used for metabolism, reproduction and growth.

Of course, it is not a reproductive *perpetuum mobile.* Thus, even if it is half of the population that sacrifices themselves, there will not be a doubling in reproduction of the other half of the population, as the amino acid pool will diminish over time both because the energy released by an autolysed organism is less than the amount of energy required to build a new organism and because some of the cellular detritus is lost, which, for the sake of the example, is set to 5% for each round.

Therefore, 20% of the detritus is collectively used or lost up to the first round and again after each new round, while 80% of the detritus is reintroduced into the remaining population each time. Thus, the first generational cycle is given by:

$$G_{cycle} = P \times (1 - r\,\%)^n \qquad (4)$$

$$= 8 \times 10^5 \times (1–0.20\%)^n$$

$$= 8 \times 10^5 \times (0.80\%)^1$$

$$= 6.4 \times 10^5 \text{ organisms,}$$

i.e., after the first round of reproduction, the surviving population has increased to 6.4×10^5 organisms.

When the next subpopulation among them has autolyzed, resulting in 3.2×10^5 surviving organisms, these reproduce. With a 20% loss of the original amino acid pool, they will have increased in number to 5.12×10^5 organisms after the second round and so on. Thus, it will take $n = 60$ reproductive rounds before ~ 1.23 organisms of the 8×10^5 are left, meaning that the population will be able to last 60 generations solely by the reintroduction of internal resources into the population. The situation is simplified in terms of both the biochemistry involved as well as the physical circumstances, but it is appropriate here.

This self-sacrificial behaviour is, as described by Hamilton, not entirely altruistic because it is aimed at transmitting the individual organisms' own genes. Thus, organisms with a binary mode of reproduction represent virtually ideal clones, and the genes of such microbial organisms are indeed transmitted to the next generation via an alternative carrier in the form of the sibling, not the individual organism *per se.* Thus, whether an organism reproduces or whether it is its kin that reproduces is not important.

The continuation of the same genes continues in both cases. Thus, a strategy of cooperation and communication, a characteristic of intelligence, will lead to a safer use of the collective internal amino acid pool, thus ensuring a longer collective survival than if the organisms compete against each other (arms race), devouring each other in a hostile manner (arms race), devouring those who perish (chance).

This cooperation does not occur by conscious choice but by natural selection. There will simply be a selection to absorb nourishment from those who randomly die, which implies randomness and a potentially long time between each time the organism autolyses, and for an organism to autolyse at an expected time and place, i.e., other organisms have cues to where and when an amino acid pool is available. There is an intricate connection between the amino acid pool and the gene pool, as an organism ensures that the offspring of its sibling can potentially achieve one more reproductive round in the future by providing its amino acid pool.

In addition, the passage of time has not been taken into account. Thus, how quickly they reproduce and how quickly they metabolize can occur at different rates. Thus, if organisms reproduce slowly and/or metabolize slowly to economize on resources, it applies that even if it were 60 generations, the duration could vary considerably from one scenario to another.

This collaboration can also evolve to further increase the effectiveness of inclusive fitness, since it is important to stretch the available resources as long as possible, while also using them as efficiently as possible. Therefore, saving resources only by lowering the metabolism and reusing the amino acid pool may not be sufficient due to the different situations.

Thus, a collaborative strategy can eventually make stretching the metabolism and reusing the amino acid pool even more effective. Metabolism is the sum of all reactions that occur within the cell and that provide the energy needed for growth and reproduction but also to maintain internal repair after damage. In fact, sublethal injuries may under these conditions have had a higher frequency.[1]

Thus, selection must initially have ensured that maintenance of the organisms can occur but also that the resources can be used efficiently for as long as possible. The organisms in a clonal population maintain repair of damage, but there comes a point where it is not worthwhile to invest further in repair due to the extent of damage. Thus, rather than invest further in repairing extensive damage, an organism sacrifices itself, saving collective resources, and at the same time releases the amino acid pool for its kin. In this manner, inclusive fitness can be made more efficient.

In addition, as mentioned, the organisms will eventually be able to evolve to communicate with each other about when it is best to initiate this response. This can gradually lead to an extensive coordinated altruistic response in situations not only specifically with injuries but also generally with limited resources affecting the entire population, to which they react in an intelligent communicative manner by many in the population sacrificing themselves for their siblings. Thus, organisms individually increase the amino acid pool to continue the collective gene pool.

Although the self-sacrificial behaviour in the interests of direct kin seems incredible and contradicting classical Darwinian evolution, this altruistic behaviour does not imply conscious self-sacrifice. What changes in evolution are changes in gene frequencies in gene pools over generations. Even fitness is in accordance with this genetic view of evolution,

[1] It is also known that bacteria can survive extremely long by entering a dormant state. However, the special circumstances the LHB offered must be kept in mind. Thus, there could be an increased frequency of injuries in these circumstances, and a reproductive lifestyle may have been the better option.

whereby the genes programming autolysis for the sake of survival of the kin spread as a result of natural selection, provided that it contributes to the survival of the microbial population. Here, natural selection occurs due to the circumstances described thus far in the LHB.

5.3. The third round II: cooperation

The environmental pressures discussed in the previous section could lead to inclusive fitness potentially arising in the form of organisms adapting to acquire energy and nutrients from cellular detritus from those that voluntarily autolysed. As reviewed, there will be pressure to stretch the available resources as long as possible, but there will also be pressure to evolve adaptations to use the available resources as efficiently as possible.

Thus, it applies that voluntarily giving one's amino acid pool to one's siblings only has maximum benefit when it is one's siblings, and not unrelated members from the competing species, who benefit from this sacrifice. This is the essence of Hamilton's rule (Hamilton, 1964). In the calculation example reviewed in the previous section, 5% of the necromass amino acid pool was wasted. While part of this is due to an unavoidable waste resulting from the circumstances, this could also be partly because, although it is organisms from the same colony here, there is a possibility that the chunk of material that landed with them also contained members from other species or that there were other species where they landed. Thus, members of other species had the opportunity to take some of the available cellular detritus and thus contribute to the 5% disappearing from the population.

As a response to this, the cooperative strategy will evolve further to ensure the most effective recycling of the necromass pool. Through the cooperative strategy in the form of taking up the amino acid pool from its siblings and developing it to give and perceive cues for when this happened, there was already a pressure to evolve. Thus, this could evolve further such that members of the same species can recognize each other and gather together, thus actively isolating themselves from other species, which again is a characteristic of self-awareness (see Figure 2). This isolation strategy evolves from both their collaboration on the internal amino acid pool as well as the external amino acid pool. The rounds will occur repeatedly when new impacts send them to a new spot.

First, when organisms land in a new spot with an external amino acid pool, reproduction will again occur. Organisms are already automatically collected as a necessary side consequence of other features. Thus, in clonal organisms such as bacteria and archaea, the organism will divide into two, and the two into four etc. Thus, a colony of siblings always begins at one point due to reproductive constraints and spreads from that one point.

Second, it applies that a selection of organisms had occurred, which could eventually yield cues as to when autolysis occurs, could read cues as to when it happened, could initiate autolysis at 'agreed' times, and could be ready when this happened.

Thus, after having gone through the third round several times and evolving an altruism strategy, the scenario in the first round will eventually play out differently. When the organisms in the clonal colony are launched again, they may land in a place where there is another species, but rather than the organisms mixing arbitrarily and competing against each other, making adaptations in an arm's race, the organisms in the arriving colony will bring the adaptations for cues that remove the randomness that prevailed in random scattered autolysis regarding where and when they can take up the amino acid pool. The members therefore do not have to move far to gain access to the amino acid pool when there are cues about autolysis in progress. There will thus be a shorter time between release and uptake of the amino acid pool, and as much as possible can be harvested from the necromass pool.

Thus, the scenario in the first round as it occurred the first time will not happen again. Not only have the organisms evolved a strategy to perform better and more efficiently in the second round, but that strategy also leads to a strategy to perform better in the renewed first round. If this is the first time for one particular species, the arriving organisms will have an advantage over them. They are adapted to handle the situation that will inevitably occur in the next round, while the other species is in a race to be fit at the present time; they are essentially gluttonous with the resources. Thus, the isolationist species may be the only ones to reach the second round; they are naturally selected in that manner.

However, as time goes by with many repeated impacts, both species will have evolved these strategies, and both species will isolate themselves from each other, focusing on utilizing the external and internal resources most efficiently to get through the rounds. Even if there are no other organisms where they land, the isolation strategy will still evolve, as the members do not have to move far to gain access to the amino acid pool when there are cues about autolysis in progress.

Thus, gradually, the first round will transition from being a short-term and costly arms race to a long-term isolationist scenario, just as the second round gradually transitioned from being stochastic events to being an evolved strategy. Thus, the impacting dynamics are still the same; in fact, the situation with suitable spots may eventually worsen, but the evolutionary strategy improves and ensures that the organisms can cope for a longer time.

Cooperation among microbial organisms can arise for several different reasons and occur in several forms, for example, swarming motility, collective repairing of holes in biofilm, collective capture of food, collective aggression etc. (Westerhoff et al., 2014). Their cooperation on the internal amino acid pool can also eventually affect their cooperation on the external amino acid pool. Since a new impact can send them to a place with an external amino acid pool available, the cooperative strategy can further evolve to also cooperating in utilizing these resources as best as possible rather than a new competition arising between them.

Thus, a collaboration to find an external amino acid pool could occur.

A cooperative effort to isolate themselves will also maximize the use of the internal amino acid pool, as they physically avoid the presence of other species among them and thus prevent others from gaining access to their collective amino acid pool.

However, eventually, two groups that isolate themselves from each other can also start an arms race against each other to gain access to each other's resources, even if the cost may be higher than the benefit. They can mount a common defence against other species that either seek to devour individuals from their colony or gain access to resources they have collected themselves. Such a common defence against other species can arise quickly, as they obtain not only the amino acid pool but also occasionally the gene pool from those who sacrifice themselves. Thus, if a variant obtains a defence against the other species, this trait can be taken up and distributed by its kin, and a selection in which they quickly manage an arms race occurs. Here, there is also an arms race, not between members of the same species but between species, where one species gradually achieves less cost through their cooperation on a common defence and can thus be selected for further survival.

Among these cooperation strategies, a further strategy could potentially arise. As reviewed, it has been observed that bacteria have their own version of inclusive fitness, where some sacrifice their amino acid pool so that the gene pool of their siblings can continue. However, a hypothesis could be made that it could also be possible under certain circumstances for microbial organisms to display the classic inclusive fitness seen in social insects, where they

actually refrain from reproducing themselves and instead dedicate themselves to assisting their siblings with survival and reproduction.

In the second round, there comes a point where the last organism will not obtain enough from the amino acid pool from the second last organism to be able to reproduce. Here, there is an intermediate stage between many organisms and only one organism. While cues will eventually arise regarding organisms voluntarily autolyzing when it is best to do so, obtaining as much of the amino acid pool as it can, this intermediate stage may be significant enough for a selection with cues for a more profound cooperation to occur.

Thus, a strategy may evolve where, rather than the second last organism voluntarily autolyzing, it may refrain from giving its amino acid pool to the last organism, even though this may be critical under these circumstances.

Of course, in this situation, it is not meaningful to say who is the second last and who is the last, as they both coexist here and one of them will eventually automatically perish sooner or later in the second round and give its amino acid pool to the last organism. However, here, it is said that a strategy could evolve after several rounds in the third round. If this intermediate stage is reached, the organisms can either continue with the first evolved strategy of providing their amino acid pool, or the stage can be so significant that a transition is made, and an assistance strategy is initiated.

Here, either in the renewed first round or the renewed second round, or both, there can actually be a short period during which an organism actively assists its kin if there is a higher chance of survival for the gene pool this way until a new impact sends them to another location. Here, organisms known for their fast, ruthless and complete reproduction by dividing into two organisms will instead decrease their own fitness to increase that of others and, thus, ensure that their genes will live on in their kin. This could potentially take several forms.

If this is in the renewed first round, they can cooperate to destroy the last member of a competing species, and one organism refrains from taking up the achieved amino acid pool in favour of the needy kin.

If this is in the second round, it may provide a synergetic effect that will allow them to survive longer than otherwise expected under these circumstances.

The opposite of cooperating organisms are ‘microbe-cheaters’, meaning that while the colony can gradually evolve cooperation, where they share the internal amino acid pool among themselves, there can be organisms among them that instead acquire a disproportionate share of group-generated resources while making minor contributions themselves. Such ‘microbe cheaters’ can disrupt cooperative systems (Westerhoff et al., 2014).

Such organisms correspond in that way to the organisms in the initial first round and the second round, where each organism fights for itself and for its own survival. Such an organism can, in the same way as the organisms in the cooperative strategy, be expected to be able to endure until the next impact comes and transport them to a new amino acid pool. The fact that new impacts will occur is clear, but the timing is not possible to know, thus, the organisms in the two strategies are on equal footing in this regard.

However, in the subsequent first and second rounds, where the organisms have repeatedly been through third rounds, it will apply that the organisms with the cooperative strategy will not only utilize the amino acid pool more efficiently than the free exchange strategy; it will also mean that a species isolates itself and keeps other species at a distance. It must be remembered that such organisms will disrupt cooperative systems. Thus, as the advantage of the system breaks down, nothing will be able to protect them from potentially being eaten by another species, thereby losing both their amino acid pool and their gene pool.

Thus, there will be an initial modest difference between the two strategies, which over time can slowly win out in favour of the collaborative strategy. However, the difference in how long each strategy has contributed to the survival of organisms may not initially have been that large. This means that life's overall survival through the LHB could have been even harder in that way, as some populations in some spots invariably collapsed in that way, while others managed to keep the free loathers away from them.

Thus, under these circumstances, a selection will essentially occur between Darwinian evolution and Hamiltonian evolution (although Hamiltonian evolution is of course derived from Darwinian evolution).

As the length of the LHB has progressed, the cooperative strategy will have had an edge that led to more survivors and more members being sent off on impact, resulting in a selective advantage.

6. Localized planetary reseeding

It is clear that even these displays of intelligence in the form of association and anticipation, communication and self-awareness will invariably lead to the downfall of the organisms as the number of organisms for each new generation decreases as the necromass recycling that sustains the biological system is used up. Thus, living isolated in a spot is a time-limited way to survive, unless a new impact sends the organisms to an environment with a new amino acid pool.

When an impact occurs, an impact ring will appear, where matter is sent away from the impact site in all directions in the form of an expanding circle. If it is assumed that the impact ring will send matter in ten different directions in a subsequent impact, and one direction is toward an amino acid pool, then this event can be viewed in two ways.

The first way is that if there are ≥10 organisms and they are sent in different directions, at least one organism will arrive.

The other way is that if there was only one organism left and it can be sent in ten different directions, the probability of it arriving at an amino acid pool is:

$$P(E) = \left(\frac{1}{10}\right) \qquad (5)$$

$$= 0.1 = 10\%$$

If the organism reaches the amino acid pool, it belongs, so to speak, to the statistically 'lucky' part, where an impact does not actually mean the organisms' (total) destruction, but rather their rescue from staying in a spot. Well placed in the new external amino acid pool, the organism can build up the number of organisms again.

Thus, the impact ring is both a destroyer, an initiator of adaptations, and the renewer of the organisms' possibility of survival by moving them to a new place.

However, even in that manner, overall, there will be a continuous decrease in the possibilities of survival. Because although this organism will quickly be able to build up the number of organisms again, life has only partially been able to rely on being sent to where there were spots with amino acid pools, as there was only a 10% probability of landing somewhere with an amino acid pool. As mentioned, this also includes the fact that some organisms will also perish both when the impact hits and when they land in a new place.

There has thus been an alternating increase and decrease in the number of organisms during this localized planetary reseeding, and although there are many variables, the tendency must have been leading toward an overall decrease in the number of organisms.

In addition, life in many such spots has probably not survived, as the time before a new impact sends one or more of them off can be longer than their resources and the number of generations can be stretched.[2] As mentioned, it could be expected that an impactor hits a location on Earth every 525.94 minutes, i.e., every 8.76 hours. There are several studies on how long a colony of microbial organisms can survive without the addition of nutrients. A study showed that *E. coli* can be maintained in batch culture at densities of ~10^6 CFU per ml for more than 5 years, although it was necessary to regularly provide sterile distilled water to maintain the volume and osmolarity (Finkel et al., 2000). However, even with these values in mind, it is uncertain whether an impact would occur before the last organism had disappeared.

In addition, at the impact centre, all material is destroyed, including the cellular detritus, while in the adjacent rings, part of the materials and organisms will be destroyed.

Initially, many areas were untouched by the impacting, and these sterilized impact centres belonged to the minority; however, as the impactors hit an increasing number of areas, their number gradually increased and affected most locations on the planet. Therefore, the number of such spots with amino acid pools has gradually decreased. Thus, the scale of environmental severity has increased and may eventually pose an issue even for life that survives by reuse of the collective amino acid pool.

However, evolutionary strategies occur in an ecological setting. Thus, if the organisms can endure long enough on the internal resources, further ecological scenarios will also come into play, resulting in the possible occurrence of one of the following 3 situations briefly described in Section 4.

In the first situation, it applies that even if the organisms have been placed in an environment where there is no amino acid pool, they may survive long enough on internal resources that individual organisms gradually move out of that environment to potentially fertile marginal areas with amino acid pools.

If such marginal areas exist, life can gradually move to them, as this is how life in well-known ecological settings can spread. Evolution is adaptation to changing local environments, where organisms gradually adapt to changed environments in peripheral areas. This occurs through reproduction, variation and selection, the key mechanisms of Darwinian evolution. However, the situation is initially different from the well-known gradual adaptation in peripheral areas today, as the organisms cannot draw on external resources but must draw on internal ones, at least until they have moved out of the centre.

This situation can also apply to the impact dynamics itself. Thus, the arriving impactors could have different sizes, densities and velocities, meaning that the rings could have different distances, and the impact ring could, e.g., launch the organisms back in the direction they came from, but not the entire distance. If they land at the edge of an amino acid pool, they must move there.

In the second situation with an inverse proportionality between life and environment, it was true that even if an amino acid pool was present where the organisms landed, it could be in a form they are not adapted to use, and they may not have evolved a metabolic pathway to

[2] Although there may have been many spots where the organisms did not survive long enough to be sent off, fractional genetic transfer may be important (von Hegner, 2020). Even if the last organism did not survive, its components can in principle still have been sent to a place where there are organisms. These organisms may incorporate some of its genes into their own; thus, genes that have previously been selected for altruism and cooperation may give some advantage to the new organisms.

it. However, microbial life can adapt relatively quickly to the use of new amino acid pools. However, the issue is that they change environments abruptly and have no influence over where they land. This is the issue faced by chemostrophs.

They can adapt relatively quickly, however, and the organisms could have adapted to be able to use the amino acid pool present before reaching the last generation and running out of the amino acid pool they reuses. Then, as in the first situation, they will gradually be able to move out into the peripheral areas, gradually adapting to the new conditions here, still drawing on what they are adapted to, but adapting to new conditions. Such an adaptation can be spread in a clonal colony by the fact that when some of the organisms have adapted and some of these organisms subsequently autolyse, their kin, rather than letting their DNA be used up and reused, can incorporate part of it into their own DNA. This ability is quickly spread and fixed in the gene pool. This can be considered decision-making, a characteristic of intelligence.

In the third situation, organisms that land in an environment with virtually the same amino acid pool as the one they came from will of cource survive. There are 3 subtle but important subscenarios in this latter scenario.

The first subscenario is that they can land in a completely new place with a new suitable amino acid pool.

The second subscenario is that an impact ring, as mentioned, will send matter away from the impact site in all directions in the form of an expanding circle, which was assumed to be in ten different directions. One direction must be back to where the progenitor of the organisms came from. As mentioned in Section 3, some organisms will remain in the primary ring, while some organisms are launched into the secondary ring. Thus, there could potentially still be an adequate amino acid pool that the organisms can live of.

The third subscenario is that, in retrospect, life must have arisen where there was plenty of the amino acid pool. Thus, if an organism is sent back to the starting point, back to where life originated, a suitable amino acid pool is present there.

Thus, the organisms will potentially be able to survive for a very long time in these 3 scenarios, longer than by relying on internal resources. However, even if the organisms can endure in the 3 situations and thus go beyond the evolutionary strategies described, it applies that the organisms will still be in the same situation as before they were sent away. Thus, under the conditions the LHB offered, sooner or later, the organisms will be sent off again by a new impact. In this manner, the organisms in all 3 situations are in the same overall situation over time. The 3 scenarios therefore do not provide a long-term solution for the organisms.

Thus, there has been an alternating increase and decrease in the number of organisms during this localized planetary reseeding, leading toward an overall decrease in number.

However, life has endured by drawing on internal resources and locally increasing its numbers again and again after landing in places where there were external resources. However, it has also potentially been able to live a long time and be distributed widely according to the 3 scenarios described. Thus, even as there are fewer spots, and the infrequent impact has sent them from place to place, these two general scenarios combined make it possible for life to have survived until the bombardments were over. Thus, bombardment is a double-edged sword. Although it has wreaked havoc by bombarding the planet and the environments in which life exists, it may have also preserved life by moving the organisms around in a localized planetary reseeding. It may actually have contributed to spreading life around the planet from the point where life must have necessarily arisen.

7. Conclusions

In this work, it has been described how intelligent characteristics can make a difference in a world, some of which have been concretely reviewed to show how life could have survived through the LHB, meaning that the LHB did not delay the emergence of intelligent life on the Earth, as intelligent life may have been there all along during this period.

There are other intelligent characteristics than these, and other scenarios could probably also have been used as an illustration. However, it has been sufficient here to demonstrate that the view that microbial life can be common in the galaxy, but that intelligent life is rare, is a misnomer in that macromolecular networks can confer intelligent characteristics.

If a world inhabited by analogous bacteria, archaea and protists is located elsewhere in the galaxy, this does not exclude the existence of intelligent life there; when life on Earth reverts back to consisting solely of bacterial life (due to the sun's changes toward the red giant stage), this does not exclude that intelligent life will still be on the planet. Thus, the conceptual distinction between microbial life and intelligent life should be abandoned, as the very statement hampers the search for intelligent life elsewhere.

While the conceptual distinction between microbial life and intelligent life is not valid, the distinction between intelligent life *per se* and intelligent life able to harness the insight and power of science and philosophy, expressed as, e.g., the ability to send out interstellar communication through technology (which is a premise at institutions such as SETI), seems to be sound.

It is interesting to note here that the presence of technology indicates the existence of intelligence, while the absence of technology does not indicate the absence of intelligence, just as, in light of the discussed scenarios, it is interesting to note that consciousness requires intelligence, while intelligence does not require consciousness, as microbial life do not appear to possess consciousness. However, this is a complex subject that falls outside the scope of the present work. It is sufficient to note that a more precise terminology regarding talking about intelligent life in the search for life elsewhere is needed.

It is debatable whether the LHB was severe enough to drive the evolutionary responses discussed, even with the assumption of impacts occurring at intervals of hours. However, the discussed impact dynamics and the evolutionary strategy are still relevant, as similar scenarios could potentially also occur on other worlds in the galaxy and beyond; for example, LHB-like conditions around Eta Corvi, an F-type main-sequence star, may be present (Lisse et al. 2011).

The emergence of life and the appearance of the LHB appeared to have been unrelated events in this solar system, and it is debatable whether life actually existed during the period when the impacting took place. However, the presented scenario is still relevant for astrobiology, as LHB-like scenarios can not only exist in other solar systems but can also potentially occur later in a world's history than it did for Earth, giving a greater possibility for life to exist when the bombardment starts.

It also applies that although the impact dynamics will mechanically occur in the same way in every world with the same conditions, altruism is only one intelligent response among several. Although environmental pressures push evolution down a certain path in this scenario, contingency still plays a role. Thus, other intelligent responses could potentially be selected for on a world. In fact, there could be competition between strategies of different populations that met, meaning that the very strategies evolve.

The strategies discussed may also be relevant in other situations applicable to space science. The ecological setting has been suggested to be taken into account in the unintentional but potential transport of organisms by spacecraft (von Hegner, 2021). Thus, the inclusive fitness

strategy could also potentially arise from spaceship-mediated transport; here, the external amino acid pool is cut off, but the internal amino acid pool can be used for a long time and thus contribute to the organisms reaching another world in the solar system.

Did these strategies occur? It is not certain that life has survived through this period in that way, and it may not be possible to show that this was the case due to the Earth having had much of its early history erased. Science proceeds in two ways: one is, as in the physical sciences, to test predictions despite issues with potential auxiliary assumptions, and the other is, as in the historical sciences, to look for a smoking gun that distinguishes between two or more hypotheses, albeit there is overlap between both of these paths (Cleland, 2001; 2013). The Earth has had much of its early history erased, making it difficult to find clues regarding whether these responses have occurred; however, it can be shown to be theoretically plausible, as has been done here.

Thus, it is fruitful to bring together fields that are otherwise so different, i.e., evolutionary theory and physical dynamics, in a common framework to understand what could have been going on at a time in the history of the Earth, and possibly life, in which little was known. This is obviously more of a retrodiction than it is a prediction.

However, evolutionary responses can be described and predicted, as can impact dynamics. Natural selection is the differential survival of genes in gene pools. It acts on the available variants and is driven in certain directions both by selective pressure between organisms and pressure from the environment. There were certain environmental conditions here in the form of impacts and reimpacts and between spots with limited amino acid pools. The impacting dynamics themselves act as selectors of organisms.

Evolution is fundamentally variation. It starts as a lump of variation that spreads outward in all directions. There is no specific direction and no measure for the spread of the variation, and most of the variants disappear again in competition with each other and against the pressure of the environment. However, a few survive, and become a point from which variation spreads outward in all directions. In that sense, the LHB is an extension of this. The impactors act as initiators for certain evolutionary strategies that can allow life to react even to such celestial onslaughts.

The Copernican and Darwinian revolutions belong to the great thresholds in history that adjusted humanity's understanding of the cosmos.

The Copernican revolution removed the Earth from the centre of the universe, indeed, the entire solar system from the centre of the universe, opening up the possibility of the existence of other worlds and, ultimately, for life on other worlds.

The Darwinian revolution removed any particular species from the centre of nature; indeed, it removed any inherent direction from the centre of nature, ultimately revealing that special characteristics are not monopolized by single species on any world.

That macromolecular networks in microbial life confer intelligent characteristics and may even be a precursor to the intelligence seen in many multicellular organisms, simultaneously their descendants and cousins, should not be surprising. Thus, perhaps it is time to embrace both revolutions equally fully and not view intelligence as seen from the human perspective, or even view intelligence as flowing from a particular organ.

🕮 References

Abramov, Oleg and Mojzsis, Stephen J. (2009) Microbial habitability of the Hadean Earth during the late heavy bombardment, *Nature*, May 21;459(7245): 419-22.

Akaizin, E.O., Voskun, S.E., Panova, L.A., and Smirnov, S.G. (1990) Heterogeneity of Escherichia coli Populations during Induced Autolysis. In *Mikrobiologiya*, vol. 59, pp. 283-88.

Bell, Elizabeth A., Boehnike, Patrick, Harrison, T. Mark and Mao, Wendy L. (2015). Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon. *Proc. Natl. Acad. Sci. U.S.A*. 112 (47): 14518-14521.

Bottke, William F. and Norman, Marc D. (2017) The Late Heavy Bombardment. *Annual Review of Earth and Planetary Sciences*. 45 (1): 619-647.

Chyba, Christopher, and Sagan, Carl. (1992) Endogenous production, exogenous delivery and impact-shock synthesis of organic molecules: an inventory for the origins of life. *Nature*, Volume 355, 125-132.

Cleland, Carol E. (2001) Historical science, experimental science, and the scientific method, *Geology* 29 (11): 987-990.

Cleland, Carol E. (2013) Common cause explanation and the search for a smoking gun. In Baker, V.R., ed., *Rethinking the Fabric of Geology: Geological Society of America* Special Paper 502, p.: 1-9.

Coenraads, Robert R. and Koivula, John I. (2007) *Geologica: Earth's dynamic forces, Elanora Heights*. NSW: Millennium House.

Cordero-Tercero, Guadalupe, Velázquez-Villegas, Fernando, Vázquez-Hernández, Carlos Francisco, Ramírez-Cruz, José Luis, Arévalo-Vieyra, Alejandro, Mendoza-San-Agustín, Asahel, Camacho-Martínez, Fernando (2016) *The Mexican Meteor Network: A Preliminary Proposal: Geofis. Intl*. Vol.55 no.1 Ciudad de México ene./mar. 2016.

Damer, Bruce (2019) David Deamer: Five Decades of Research on the Question of How Life Can Begin. *Life* (Basel). Jun; 9(2): 36.

Evatt, G.W., Smedley, A.R.D., Joy, K.H., Hunter, L., Tey, W.H., Abrahams, I.D. and Gerrish, L. (2020) The spatial flux of Earth's meteorite falls found via Antarctic data. *Geology,* 48 (7): 683-687.

Finkel, S. E., Zinser, E. and Kolter, R. (2020) *Bacterial Stress Responses*, Eds. Storz, G. & Hengge-Aronis, R. 231–238. ASM Press, Washington DC.

Hamilton, W. D. (1963). The evolution of altruistic behaviour. *American Naturalist*. 97 (896): 354-6.

Hamilton, W.D. (1964a) The genetical evolution of social behaviour. I. *J. Theor. Biol*., 7 *(1): 1-16.*

Hamilton, W.D. (1964b) The genetical evolution of social behaviour. II. *J. Theor. Biol.*, 7 *(1): 17-52.*

Lisse, C.M., Chen, C.H., Wyatt, M.C., Morlok, A., Thebault, P., Bryden, G., Watson, D.M., Manoj, P., Sheehan, P., Sloan, G. and Currie, T.M. (2011) *Linar and Planetary Institute Science Conference Abstracts* 42, p.: 2438, Spitzer Observations of η Corvi : Evidence at ~1 Gyr for an LHB-Like Delifeery of Organics & Water-Rich Material to the THZ of a Sun-Like Star."

Lowe, Donald R., Byerly; Gary R. Kyte and Frank, T. (2014) Recently discovered 3.42-3.23 Ga impact layers, Barberton Belt, South Africa: 3.8 Ga detrital zircons, Archean impact history, and tectonic implications. *Geology* 42 (9): 747–750.

Marchi S., Bottke W.F., Elkins-Tanton L.T., Bierhaus M., Wuennemann K., Morbidelli A. and Kring D.A. (2014) Widespread mixing and burial of Earth's Hadean crust by asteroid impacts. *Nature* 511: 578-582.

Marchi, S., Drabon, N., Schulz, T., Schaefer, L., Nesvorny, D., Bottke, W.F., Koeberl C. and Lyons. T. (2021) *Delayed and variable late Archean atmospheric oxidation due to high collision rates on Earth*. Nature Geoscience.

Maruyama, S., Ikoma, M., Genda, H., Hirose, K., Yokoyama, T. and Santosh, M. (2013) The naked planet Earth: most essential pre-requisite for the origin and evolution of life. *Geoscience Frontiers,* 4, 141e165.

McCollom, Thomas M. (2013) Miller-Urey and Beyond: What Have We Learned About Prebiotic Organic Synthesis Reactions in the Past 60 Years? *Annual Review of Earth and Planetary Sciences*, Vol. 41: 207-229.

Melosh, H. J. (1989) *Impact Cratering: A Geologic Process*, Oxford University Press, New York.

Mirumur (2011) Available online: https://depositphotos.com/vector-images/bacterium.html

Mirumur (2014) Available online: https://depositphotos.com/49770579/stock-illustration-e-coli-bacteria-isolated-red.html

Reyes-Ruiza, M., Chaveza, C.E., Acevesa, H., Hernandezb, M.S., Vazqueza, R., Nunezc, P.G. (2012) *Dynamics of escaping Earth ejecta and their collision probability with different Solar System bodies*, Icarus.

Schopf, J. William, Kudryavtsev, Anatoliy B., Czaja, Andrew D., and Tripathi, Abhishek B. (2007) *Evidence of Archean life: Stromatolites and microfossils Precambrian Research*. Volume 158, 5 October 2007, Pages 141-155.

Takeuchi, Yuto, Furukawa, Yoshihiro, Kobayashi, Takamichi, Sekine, Toshimori, Terada, Naoki and Kakegawa, Takeshi (2020) Impact-induced amino acid formation on Hadean Earth and Noachian Mars, *Scientific Reports,* Volume **10**, Article number: 9220.

von Hegner, Ian (2020) Interplanetary transmissions of life in an evolutionary context. *International Journal of Astrobiology*, 19 (4): 335-348. https://doi.org/10.1017/S1473550420000099

von Hegner, Ian (2022) The indeterminacy bottleneck: Implications for habitable worlds. *Acta Biotheoretica,* Volume 70, Issue 1: 1. https://doi.org/10.1007/s10441-021-09432-0.

von Hegner, Ian (2021) Evolutionary processes transpiring in the stages of lithopanspermia. *Acta Biotheoretica,* 10 April 2021; preprint published online in HAL archives-ouvertes.fr | CCSD, 21 April 2020.

von Hegner, Ian (2023) A potential survival strategy during the Late Heavy Bombardment. *Serbian Astronomical Journal*, Vol. 206, Iss. 1: 9-27. https://doi.org/10.2298/SAJ2306009H

Westerhoff, Hans V. Brooks, Aaron N. Simeonidis, Evangelos. Garcia-Contreas, Rodolfo. He, Fei. Boogerd, Fred C. Jackson, Victoria J. Goncharuk, Valeri and Kolodkin, Alexey (2014) Macromolecular networks and intelligence in microorganisms. *Front. Microbiol. 22(5): 379. https://doi.org/10.3389/fmicb.2014.00379*.