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Neopanspermia – Evidence That Life Continuously Arrives at the Earth from Space

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Abstract. The theory of panspermia in a variety of forms remains an important theory to account for the origin of life on Earth and possibly also on other planetary bodies orbiting the "habitable zones" of stars. A form of panspermia we review here, that can be called *neopanspermia,* encapsulates the concept that a continuing infall of microbiota from space contributes both to the inception of life on Earth and its subsequent evolution. We discuss the development of the theory of panspermia and show how, over the past decade, we have used balloon-borne samplers (lofted to heights approaching 30km) to isolate unusual Biological Entities (BEs) which, we maintain, are continuously arriving at the Earth from space. These BEs are carbon-based, show bilateral symmetry, contain DNA and are in the range 10-40 micrometres in dimension. Their sizes are an order of magnitude higher than particles (including bacteria and viruses) of terrestrial origin that are normally recovered in the stratosphere. The fact that Earth-organisms (e.g. pollen grains, grass-shards and fungal spores) have not been found in our samples provides additional evidence that the isolated BEs originate from space and are of extraterrestrial provenance. We propose that such incoming microorganisms led to the emergence of life on the primitive Earth between 3.83 and 4 billion years ago and thereafter have continuously contributed to its evolution.

Keywords: Panspermia, astrobiology, comets, stratospheric microbiota

1 Introduction

The theory of panspermia, life everywhere, was first proposed by the Greek philosopher Anaxoragas (500-428BCE) in the 5th century BCE. Scarcely a century later, however, this concept was challenged by Aristotle (384-322BCE), who advocated instead the idea of the spontaneous generation of life, famously proposing that insects emerge spontaneously from a mixture of warm earth and morning dew. It is still widely believed that life arose on Earth when a variety of chemicals came together to form the basic building blocks of life, such as amino acids, followed by their incorporation into biomolecules including nucleic acids and proteins, leading to the formation of cell membranes and other organelles which ultimately led to the emergence of the first viable terrestrial organisms. Although Darwin's "warm little pond" is often cited as the origin of this idea, somewhat earlier in 1844, Robert Chambers speculated, in his *Vestiges of the Natural History of Creation* (p.144), that:

> "The first steps in the creation of life on this planet was a chemo-electrical operation by which simple germinal vesicles were produced."

This, so-called "chemical theory" of the origin of life or *abiogenesis* has become the default explanation of how life on Earth began. However, this idea still faces almost unsurmountable challenges, not least of which is the super-astronomical informational hurdle that has to be overcome before the first primitive *evolvable* living system comes into existence (Hoyle and Wickramasinghe, 1982).

Of course, all theories concerning life's origins necessarily assume a starting point, i.e. life must have a definite point of origin in time and space. Philosophically and within some cosmological models it is possible to maintain that life "always was". However, since the finite human mind is programmed to think in terms of beginnings and endings most scientists would relegate such considerations to the realms of religion, despite *life always* being a concept no stranger than say infinity in mathematics or multiverses in cosmology. Thomas Paine expressed this point succinctly (Paine, 1854):

> “It is common for mankind to regard everything as having a beginning and an end. Every human production does have, and hence the impossibility of the mind’s conceiving aught that does not have….”

Assuming that life did indeed begin at some point it would seem unlikely, considering the vastness of the Universe and our increasing awareness of the presence of billions of rocky planets, that it occurred only once, and on the Earth. Of course, that is not to imply logically that life could not have originated here, even though the probability of such an event appears, in our estimation, infinitesimal. We contend that is far more probable that life exists everywhere in the cosmos and is therefore to be regarded a “cosmic imperative” (Hoyle and Wickramasinghe, 1982). Some scientists and philosophers have even argued the case for the proposition that the Universe was *meant for life.*

If life is indeed common in the Universe, then it stands to common sense to assert that it is widely distributed, thus leading to an alternative theory concerning the beginnings of life on Earth, namely *panspermia* - the view that life arrived to this planet from the external universe.

2 Early Ideas on Panspermia

The scientific case for panspermia followed from Louis Pasteur’s classic experiments of the 1860’s where he showed that microbial life is always derived from pre-existing microbes and declared *“Omne vivum ex vivo”* – all life from life. Pasteur’s declaration was later taken up by Svante Arrhenius (1908) who correctly argued that microorganisms are the *right* size to be driven through the near vacuum of space by radiation pressure due to starlight reaching terminal speeds that would transport them from one-star system to the next. This idea was later termed *Radiopanspermia.*

Radiopanspermia came to be challenged, however, when some early laboratory experiments seemed to “prove” that microorganisms cannot survive the extreme conditions that persist in space (Becquerel, 1924). This criticism was subsequently shown to be false, and certainly after the dawn of the space age, the space-hardiness of bacteria (notably extremophiles) came to be generally recognised. In addition, it was realised that the survival of microorganisms traversing interstellar and interplanetary space will be enhanced by encapsulation within meteorites or when shielded within clumps of cosmic dust.

The suggestion that much larger bolides carrying bacteria, bacterial spores and even seeds could have been transported through the galaxy was first discussed by Lord Kelvin (William Thomson,1881). At the 1881 presidential address to the British Association in Edinburgh he stated thus:

> “...Hence, and because we all confidently believe that there are at present, and have been from time immemorial, many worlds of life besides our own, we must regard it as probable in the highest degree that there are countless seed-bearing meteoritic stones moving about through space. If at the present instant no life existed upon the Earth, one such stone falling upon it might, by what we blindly call natural causes, lead to its becoming covered with vegetation….”

This idea that has come to be designated *Lithopanspermia* has been revived and extended in recent decades (eg. Wallis and Wickramasinghe, 2004). The great advantage of *Lithopanspermia* is that it is relatively free from the criticism that ionizing radiation, particularly galactic cosmic rays, could limit the viability of free-floating bacteria in space.

3 Revival of Panspermia in the Space Age

Over the past four decades the resurgence of all forms of panspermia as a valid process for the origin of life as well as its later evolution has become more or less inevitable (Hoyle and Wickramasinghe, 2000, Steele *et al.*, 2018, 2019). Before 1980, the earliest evidence for microbial life in the geological record was in the form of cyanobacteria-like fossils dating back to 3.5 Ga ago, and this left open a “comfortable” interval of geological time for abiogenesis to have possibly occurred. From the moment of the formation of a stable crust 4.3 Ga ago, following an episode of violent impacts with comets and asteroids (the Hadean Epoch), there seemed to be available an 800 million-year timespan during which the canonical Haldane-Oparin primordial soup may conceivably have developed.

Very recent discoveries, however, have shown that this time interval for abiogenesis may have to be greatly reduced. Detrital zircons older than 4.1Gy, discovered in rocks belonging to a geological outcrop in the Jack Hills region of Western Australia, have been found to contain micron-sized graphite spheres with an isotopic signature of biogenic carbon (Bell *et al.*, 2015). Although other arguments have been subsequently advanced to suggest that these graphite spheres are unconnected to biology, the situation at present is not fully resolved (Mennekan *et al.*, 2017). Perhaps more securely the moment of the first appearance of microbial life on the Earth is now considered to be *at least* as far back as is indicated by traces of biogenic carbon in 3.95 Ga sedimentary rocks in Labrador, Canada (Tashiro *et al.*, 2017), as well as in the Isua sedimentary rocks of West Greenland that go back to 3.84 Ga (Ohtomo *et al.*, 2014).

The first moment of life's origin on the Earth, from all the available evidence, could now be placed at a time earlier than 3.9 Ga, which is possibly the first geological epoch during which microbial life could have survived. It is thus noteworthy in our view that life's first emergence on Earth actually coincides with a period of intense cometary bombardment. This supports the view that life was most plausibly introduced to Earth by comets, pointing to panspermia as the mode of its origin. This version of panspermia has been termed "Cometary Panspermia".

3.1 Cometary Panspermia

In the book *Space Travellers –The Bringers of Life* – in which Hoyle and Wickramasinghe first launched the concept of cometary panspermia the following prescient comment was made:

> "The potential of bacteria to increase vastly in their number is enormous. It should occasion no surprise, therefore, that bacteria are widespread throughout astronomy. Rather it would be astonishing if biological evolution has been achieved on the Earth alone, without the explosive consequences of such a miracle ever being permitted to emerge into the Universe at large. How could the Universe ever be protected from such a devastating development? This indeed would be a double miracle, first of origin and second of terrestrial containment.
>
> Some biologists have probably found themselves in opposition to our arguments for the proprietary reason that it seemed as if an attempt were being made to swallow up biology into astronomy. Their ranks may now be joined by those astronomers who see from these last developments that a more realistic threat is to swallow up astronomy into biology……"
> (Hoyle and Wickramasinghe, 1981)

The emergence of the new discipline of astrobiology thereafter became inevitable (Wickramasinghe, 2002). The role of comets as the main amplifying sites of cosmic microbiology as well as its distributors continued to be developed in a long series of publications by Hoyle and Wickramasinghe, first summarised by these authors in the book *Living Comets* (Hoyle and Wickramasinghe, 1985). Here they discussed the dynamics of comets in the solar system, the perturbations of the Oort Cloud of comets by passing stars, and most importantly a model for the internal structure of comets that included liquid water domains maintained by radioactive heat sources. The predictions of a biological comet, as contained in this book, was later verified with the arrival of Comet Halley at its last perihelion in 1986 (Hoyle and Wickramasinghe, 1986, Wickramasinghe, *et al.* 1986). A decade later the mechanisms they had proposed for eruptions of comets due to sub-surface biological activity were also amply verified with eruptions observed in comet Hale-Bopp at 6.5AU (Wickramasinghe, *et al.* 1996). Unerring consistency with the theory of cometary panspermia continued to be established through to the recent explorations of comet 67P/C-G in the Rosetta Mission (Smith *et al*, 2015).

Most of the debris shed by comets is as fine dust - the form in which biologically relevant material is delivered to Earth. However, transport of biomaterial to Earth could also be imagined via carbonaceous meteorites, or on rare occasions when larger cometary objects impact the Earth (Chyba and Sagan, 1992). The existence of microscopic structures identified as microfossils in carbonaceous chondrites has been a subject of discussion for several decades (Wickramasinghe, et al, 2010). A major concern for neocriticists has been the lack of evidence for the parent bodies of these meteorites to have been in contact with liquid water for timescales in excess of several billion years. This data has recently been reviewed and earlier arguments for lack of recent water has come to be seriously challenged (Turner et al, 2021). From a new analysis of short-lived uranium isotopes in carbonaceous chondrites that yielded excesses of 234-uranium over 238-uranium, and 238-uranium over 230-thorium, it has been concluded that a fluid condition must have persisted in the parent bodies of these meteorites as recently as over the past few 100,000 years. These new results give strong support to the idea that viable microbes and Biological Entities (to be discussed later) could indeed be carried within fragments of carbonaceous comets.

4 Variants of the Theory of Panspermia

In addition to the theory of cometary panspermia variants of panspermia have included, among other possibilities, the transference of partially inactivated viruses or bacteria across the universe. Thus Wesson (2010) introduced the concept of Necropanspermia, implying that essentially all bacteria or viruses expelled from a source will be "killed" during interstellar transits, and whatever life system that reaches a virgin planet might be initially non-viable. In such a model all that can be rescued will be in the form of bacterial and viral gene fragments, and these must somehow be "repaired" in order to be utilised by an already flourishing biology on the destination planet. In this context we should mention that viruses, presenting much smaller target areas for potentially damaging cosmic rays, would be the survivors of choice in interstellar transits.

The emerging picture is of an initial injection to Earth of a viable cellular life-form which takes root and begins to evolve that subsequently could be genetically augmented and diversified by viruses carrying suites of new genes – even partially inactivated genes (Steele et al, 2018). This grand ensemble of cosmic viral genes coding for every contingency of biological evolution would have been delivered in comet dust over the past 4.2 billion years. What we find on Earth therefore is the combined result of this cosmic influx of genes selected through processes of Lamarckian and Darwinian evolution.

From the beginning the Earth would have been subject to injections of cosmic life in the form of viable comet-borne microorganisms as well as viral DNA suitably protected from the harsh conditions of space. It is likely that the fraction of these incoming life-forms that survives the rigours of entry, such as atmospheric heating and impact heating, would arrive as a mixed population of space-derived heterotrophs and autotrophs that begin to compete with each other. Due to the law of doubling (already discussed) and because of the lack of any competing organisms on the primitive Earth, the first incoming microorganism(s) would be expected rapidly colonise the entire planet. Both autotrophs and oligotrophs (i.e. those heterotrophs which can live on a trace of nutrients) would initially be at an advantage, but the continued input of organic matter from space would also serve to support heterotrophs.

Incoming viruses would exist independent of such nutrients but would need the development of a host or host cells to replicate; an incoming virus would therefore need to arrive already associated with a host cell, or need to acquire one on short order. The establishment and development of these individual life forms with multiple interdependencies would depend on the prevailing conditions on the host planet.

The sequence of events discussed in this section might be considered to be either unsustainable or would be severely curtailed without the presence of an atmosphere. This is not just to sustain any organism requiring gases such as oxygen or carbon dioxide, but because an atmosphere might be needed to slow down incoming life-delivery systems and thus prevent their destruction on impacting the Earth's surface. As a result, panspermia-derived life would have difficulty in establishing itself or evolving before the formation of an early atmosphere.

We conclude this section by noting that in 2021 the theory of panspermia is becoming increasingly more sophisticated and diverse as new "variants" of the theory are being developed and discussed. We have already referred to variants including Lithopanspermia, Radiopanspermia and Necropanspermia. Another variant Neopanspermia, the main subject of this article, refers to the view (to which the authors subscribe), that life not only arrived at Earth from space as a one-off event but continues inevitably to do so. A further variant that is perhaps less discussed at the present moment might be termed Pathospermia, referring to the idea that diseases of plants and animals occurring on Earth, such as influenza originate from space (Hoyle and Wickramasinghe, 1979). Another more exotic possibility could include the bizarre prospect that viable microbes and spores brought to Earth within meteorites might lie dormant an buried near the surface and that such life-laden cosmic rocks may one day be ejected from terrestrial building material and thrown back into space by future impact events – leading to a variant called Archeapanpsermia (Alharbi *et al.*, 2011).

In the following sections of this article we shall restrict the use of the term Panspermia to the most general view that life on Earth had a cosmic origin.

5 Searching for Incoming Biology

While the theory that microorganisms are continuously arriving at the Earth from space is viable and self-consistent it remains difficult to prove unambiguously. One way to achieve such proof is to send samplers high above the Earth's surface and directly intercept any incoming space-derived biology, a process best achieved above the Earth's atmosphere, perhaps using the ISS (the International Space Station) orbiting at 400 km above the surface. Our present work however, is limited to use of helium-balloon-launched samplers which achieve a maximum altitude of around 41km, more commonly 25-30km.

In the following studies air/aerosol samples were recovered from the stratosphere using a balloon-launched sampler. Six successful stratospheric sampling balloon launches were conducted, four from the UK (sampling heights of 22-27 km), one from Reykjavik, Iceland (sampling height, 22-25km) and one from Death Valley National Park, USA (sampling height,24-28km).

A Styrofoam sampler box contained a CD-drawer-box which could be opened and closed by remote command whilst in the stratosphere. The base of the drawer contained wells in which were inserted new, sterilized SEM stubs (Leit tabs, Fig.1). The sampling apparatus was shielded from the possible contamination of particulate matter from the balloon itself by means of a cover. The sampler box also included a video camera used to monitor the correct opening and closing of the sampling drawer, in addition to recording the view of the Earth from the stratosphere.

A second instrument inside the sampler recorded the GPS position and altitude, the internal and external temperature, humidity, air pressure, acceleration - all of which were analysed and interpreted following the sampler's retrieval. A locator (SIM-based positioning system) was also included to enable the box to be located and recovered after its parachute descent to Earth.

Upon collection of the sampler a preliminary examination was performed on the box to make sure it was undamaged. If this was the case, it was delivered to the laboratory for analysis. The box was opened under sterile conditions in a clean room. Prior to launch the sampling drawer had been scrupulously cleaned, air-blasted, and swabbed with 70% alcohol to ensure the absence of contaminants.

The stratosphere-exposed scanning electron microscope (SEM) stubs were removed in a clean room and maintained in a covered, ultraclean, sterile box. The stubs were next transferred to an electron

Figure 1. Scanning electron microscope stubs (black discs, contained in the sampling drawer box) onto which stratospheric particles were directly deposited when exposed in the stratosphere.

microscope under scrupulously clean conditions and the stratosphere-exposed surface was examined. EDAX was used to determine the elemental composition of any observed stratosphere-isolated features.

Separate control flights were also launched before each of the sampling flights in which the stratospheric sampling drawer containing E/M stubs remained closed. All other analysis techniques were followed as in case of the exposure flights. No particulate matter whatsoever was seen on the unexposed control stubs, proving that the sampling drawer was airtight when closed and also that the processing of the stubs, after removal in the laboratory, was achieved without being contaminated.

The problem of microbial contamination from the Earth's surface has been a constant constraint in all such stratosphere-biology experiments. All earlier studies conducted from the mid-1960's onwards have indicated that an upper size limit might exist for particles of a few micrometres in radius reaching heights above 20km (Rosen, 1969; Malinina *et al.*, 2018). This is largely due to the falling (terminal) speed of aerosols through the atmosphere which for particles of radius 3 microns is about 0.3cm/s at a height of 30km, thus giving a settling time of the order of a few months. However, some recent studies have shown that smaller particles, including bacteria, fungal-hyphal fragments and viruses, can occasionally reach the stratosphere. Events such as volcanic eruptions or freak atmospheric phenomena might be involved in such a transport process but their residence time will be limited and consequently their densities very low (Wickramasinghe *et al.* 2018a).

During the past two decades samplers were launched by us as well as others to the stratosphere to heights above 25km in the expectation that terrestrial lifeforms (above micrometre sizes) cannot normally reach such heights, and that any larger biological structures and composites recovered must therefore have originated from space. Occam's razor might arguably be used to contend that since the Earth's surface and the oceans are replete with microorganisms, the most likely source of bacteria isolated in the stratosphere is terrestrial. This conclusion does not *a priori* show that microorganisms could not be both arriving at the Earth from space whilst also being elevated from the surface to the stratosphere.

6 Biological Entities in the Stratosphere

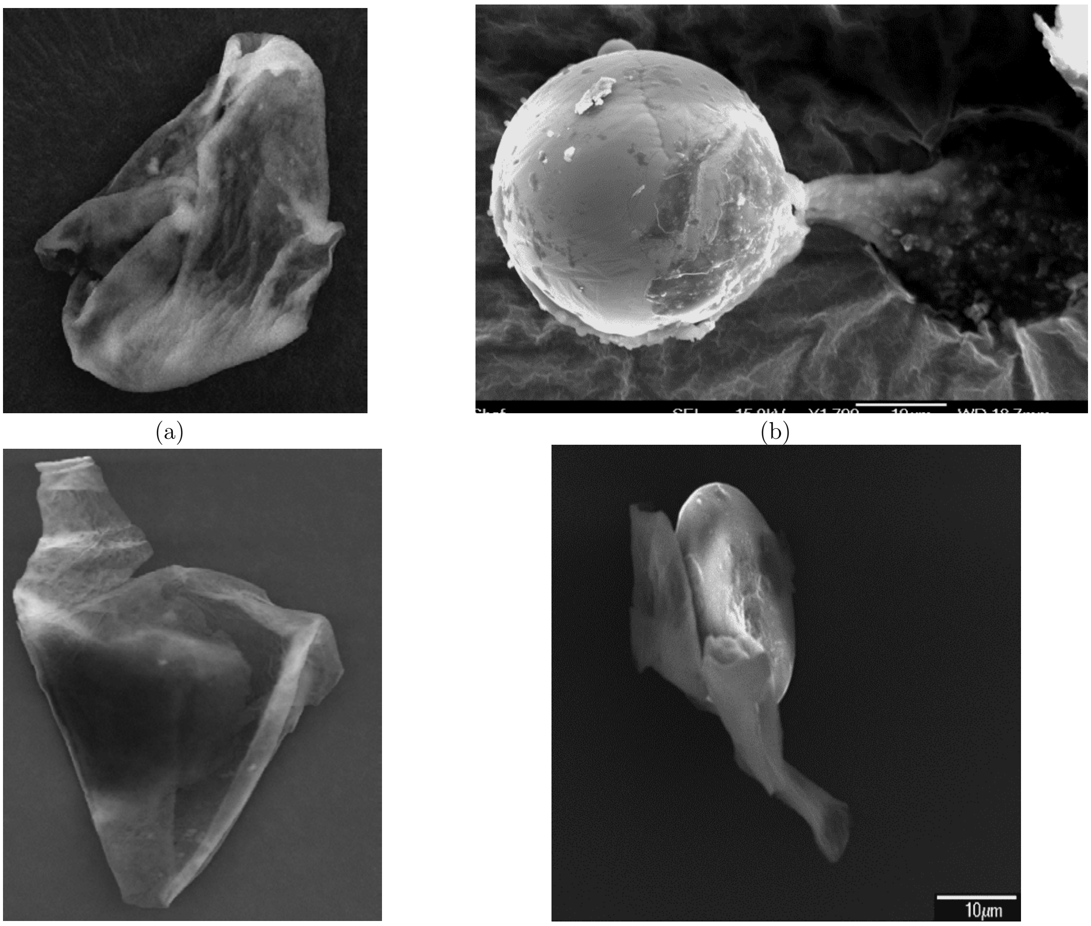
Using the balloon-launched sampler described earlier we have isolated what we term "biological entities" (BEs) providing more convincing examples of *incoming* microscopic lifeforms (Wainwright, 2015, 2016; Wainwright *et al.*, 2015a, b, c). We use this term to describe putative organisms which we cannot identify as being "types" that are easily recognisable within terrestrial biology. The BEs range in dimension from ~10-40 micrometres (Fig. 2, a-d) and therefore clearly exceed the sizes that might readily be elevated from Earth's surface to space.

EDAX analysis shows that BEs are composed of carbon with trace of nitrogen and lack elements such as silicon, calcium and heavy metals typically found in cosmic dust. We consider that these stratosphere-derived organisms are highly unusual and cannot be assigned to known terrestrial taxonomic groups. (Wainwright, 2015, Wainwright and Omairi, 2016)). Biological Entities exhibit bilateral, symmetry, show varied morphology and do not, we maintain, result from *pareidolia* – the tendency to associate visual patterns with expected or familiar objects!

Based on their regular appearance, showing apparent biological characteristics, they can be readily differentiated from inorganic particles and cosmic dust such as those shown in Fig.3a. It is worth pointing out that the unknown BE's shown in Fig.2 are relatively complex organisms, compared to bacteria, and may be Eukaryotes. It is also worth noting that entities of the sizes of BEs will be slowed down by the atmosphere high above Earth and as a result will only be mildly heated and therefore are likely to survive entry, especially when protected by coatings of cosmic dust and ice.

A potential criticism of our findings could be that they are the result of contamination. It is important to note at the outset that we checked for any any signs of damage to the sampler on its return from the stratosphere and only proceeded with laboratory analysis if it was found to be intact. All of the laboratory work was done under strict sterile conditions using clean rooms. Control flights showed that nothing was found on the discs if they were not opened and exposed to air in the stratosphere.

Analysis of the outside of the box showed, furthermore, the expected presence of Earth-derived particles, such as fungal spores, pollen and grass-shards; none of this material was ever found on the sampling stubs (see background to all stub-sample images). We are confident therefore that the BE's we discovered were sampled from the stratosphere. Clearly no sieve is present in the lower stratosphere



(a) (b)

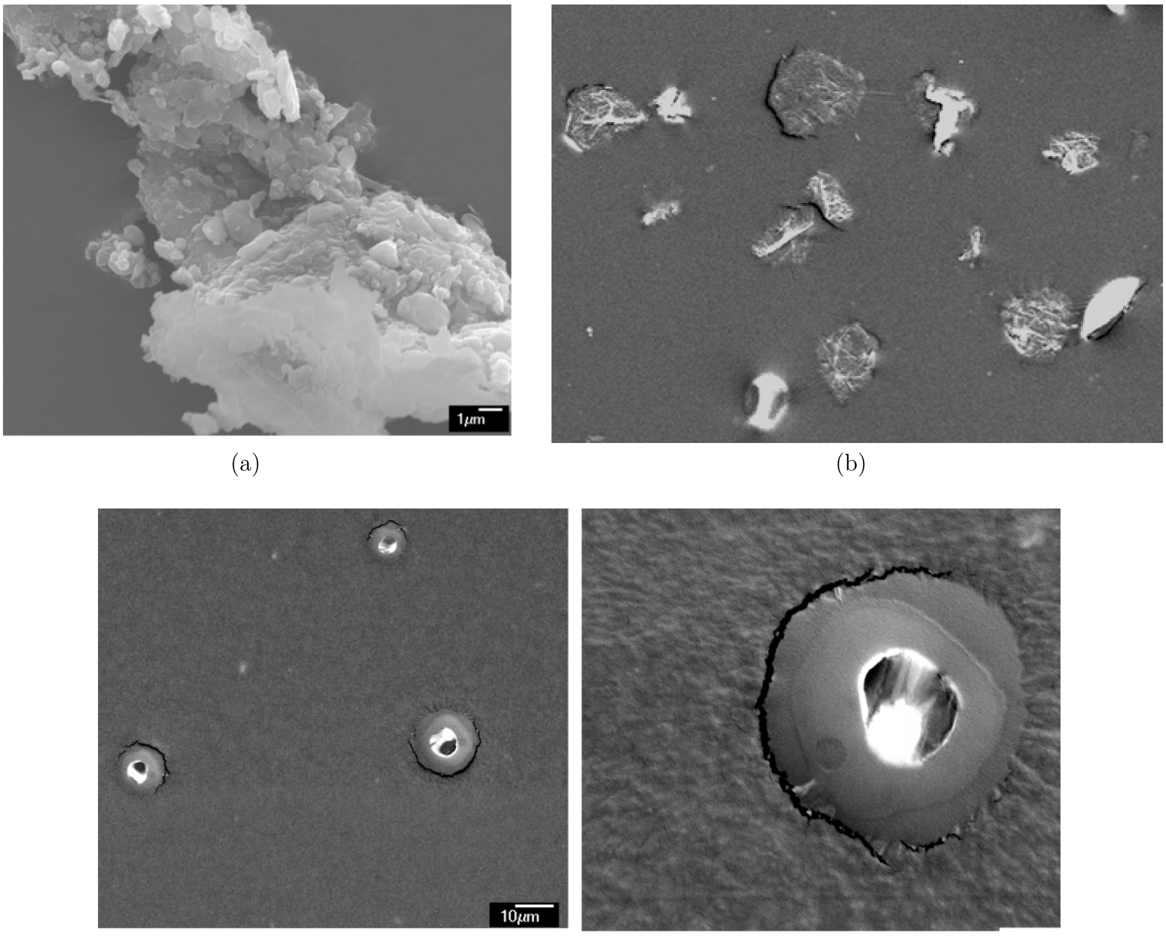
(c) (d)

Figure 2. Biological Entities isolated from around 30km. Note the absence around the structures of common contaminating material from Earth (e.g. spores, pollen and grass shards). Compare with the anamorphous mass of cosmic dust particle seen in Fig.3a. The entities are composed of carbon and oxygen and lack the inorganic elements typically found in cosmic dust.

that would remove such common terrestrial organisms and prevent them from appearing on interior sampling discs, a fact which is critical to our assertion that the BEs we sample must come from space. It is also of interest to note that on some of the sampling discs the BE's present were associated with impact crater-images caused by impact from micrometeorites and cosmic dust (Fig.3c).

For safety reasons, we did not attempt to culture any of the stratosphere-derived BEs. We are frequently asked if these organisms present a danger to life on Earth. This is a possibility that is impossible to exclude, but since they have been arriving from space to Earth for billions of years we can argue that they are a "natural", and likely to be a largely non-pathogenic component of the Earth's biology. It is, however conceivable that some of the stratosphere-derived BEs could pose a health risk, as indeed could incoming bacteria and viruses. The possibility that pathogenic viruses could have a space origin comes under the remit of the theory of pathospermia, which was originally emphasized by the work of Hoyle and Wickramasinghe (1979) and more recently by Wickramasinghe and co-workers in relation to the COVID-19 virus (Steele et al., 2020). Since viruses are obviously of sub-micron sizes there is no theoretical reason why they could not be readily transferred from Earth to the stratosphere and in the reverse; this fact is in itself may be highly relevant to the epidemiology of these infectious diseases.

Recent studies discussed in a recent PhD Thesis by Omairi (2017) show that a vast array of bacterial DNA is present at around 30 km in the stratosphere. Omairi additionally isolated human DNA. Although the obvious possibility is that such DNA is a contaminant, this finding opens up the intriguing



(a) (b)

(c) (d)

Figure 3. (a), typical inorganic material (cosmic dust) found on the exposed sampling stubs. Note the lack of organism-like structure. The mass was shown to consist on inorganic elements, notable silicon, iron and aluminium, but no carbon, (b), examples of Earth-biology found on the outside of the sampler box, but never on the stratosphere-exposed E/M stubs, (c) and (d) impact craters often found close to BEs on the sampling discs; note the presence of a presumed inorganic particle in the enlarged image.

possibility that small particles of human material such as sub-micron skin-fragments are being continually elevated from Earth to the stratosphere.

A most intriguing finding in relation to this work is a report by Russian workers of bacteria (including species of *Delftia* and *Mycobacterium*) on the outside windows of the International Space Station. Although these organisms are found on Earth, there is no plausible way by which they could have been carried to the orbiting height of the ISS. Nor indeed is there any mechanism available for lofting rare extremophiles from the surface of the Earth to a height of 400km not once but 6 times over a period of a decade (Grebennikova *et al.*, 2018, Wickramasinghe and Rycroft, 2018). The Russian workers did not report the presence of BEs on the ISS, which is not surprising since they used molecular identification methods appropriate to bacteria and not, as we did, scanning electron microscope (SEM) studies aimed at observing larger, unknown organisms. How bacteria reached the ISS and how they survived the rigours of the environment at this height continues to remains a mystery, but a space origin appears to be the most reasonable possibility.

It is noteworthy that the presence of DNA has been demonstrated in some of the stratosphere-derived biological entities (Fig.4a) (Wainwright *et al.,*2015a). If microscopic life forms have been arriving at the Earth from space for billions of years, as it is suggested by our findings, then it is entirely possible that terrestrial organisms would have received exogenous DNA, a process which would have played a major role in the evolution of terrestrial life by the well-attested process of horizontal gene transfer (Hoyle and Wickramasinghe, 1982, Wickramasinghe, 2013, Wickramasinghe *et al.*,2018b).

7 Arrival of Microbiota and BEs on Other Planetary Bodies

If life forms impact Earth from cometary sources they will also arrive at the surfaces of other astronomical bodies in the solar system, including for instance Enceladus, Europa and the Moon (Wickramasinghe, Wickramasinghe and Steele, 2018b). Indeed it is likely that comet-borne microbiota are widespread throughout the solar system.

At first sight it might appear that microbiota arriving at planetary bodies devoid of atmospheres would not survive. Whilst this is true for particles impacting at normal or near normal incidence, individual biological entities or meteoroids carrying such entities would survive if they are captured at glancing angles in overtaking encounters with the planetary body. Such encounters will inevitably happen on the Moon, and we might expect BE's and comet-borne microbes to find a route to survival in some locations on our nearest celestial neighbour. Although microbial life has not yet been discovered on the Moon the possibility that it exists in the Moon's polar ice or deep in the lunar surface remains a distinct possibility (Wickramasinghe, *et al.,* 2017).

Why then do we not find evidence of deposits of dead BEs on the Moon's surface? The answer could be simple, the Moon has no atmosphere, so *most* of the incoming BEs would be smashed to smithereens and any surviving fragile, biological structures entering in overtaking encounters would be destroyed by unattenuated UV light incident on the Moon's surface. On the other hand, it remains the case the surface of the Moon has only been barely scratched in our attempts to unravel its history and composition.

The consequences of comet and asteroid impacts on a life-laden planet like the Earth have already been discussed by Wallis and Wickramasinghe (2004). The possibility arises for viable life forms including BE's to be expelled from the entire solar system and transported to distant planetary systems in the Galaxy in albeit relatively rare events. Conversely our solar system in the course of its 240 billion-year orbit around the centre of the Galaxy can occasionally encounter exosolar cometary bolides in hyperbolic orbits that might deliver fertile ejecta from other inhabited exoplanets. The entire galaxy in such a model will become a single connected biosphere. According to our theory, the origin, development and evolution of life on Earth could only have occurred following the development of an atmosphere sufficient to slow down incoming BEs and other life forms. Life will therefore be spread throughout the cosmos via the processes of panspermia, but will only become established on those planets that have atmospheres capable of slowing their descent. On the other hand, watery planetary domains such as are likely present in Enceladus could be replete with microbes that were transported by much larger cometary bolides the interiors of which may have survived the heat released on impact (Wickramasinghe, *et al.*,2018b).

8 Reverse Panspermia and Directed Panspermia

Ginsburg, *et al.* (2018) have further developed this concept estimating the rates at which life-bearing rocky ejecta from one planetary system are captured by another. Recently, Siraj and Loeb (2020) have proposed that sub-metre sized rocky bolides grazing the Earth in hyperbolic orbits through the stratosphere could pick up microbial colonies and transport them to distant exoplanets. The process involves the grazing object laden with Earth-life being thrown first into a Jupiter-family comet orbit, and thence by a gravitational encounter with Jupiter to be ejected from the entire solar system. Their speculation is based on a recent report by Shober *et al.* (2020) the detection of such a 30-cm object that skimmed the stratosphere at 58.5km and thereafter entered a Jupiter family comet orbit. Assuming that colonies of Earth-bacteria were indeed present at this height the possibility of their galactic spread is one that merits attention.

Another variant of panspermia is the concept of Directed Panspermia. Here the suggestion is that a highly advanced civilization with advanced biotech capabilities combined with advanced space technology deliberately infected the Earth. Extrapolating from currently available human technologies it is entirely reasonable to speculate that a century from now we would have the capability to produce vast quantities of bacteria/viruses at will and to expel such a biological cargo from the entire solar system.

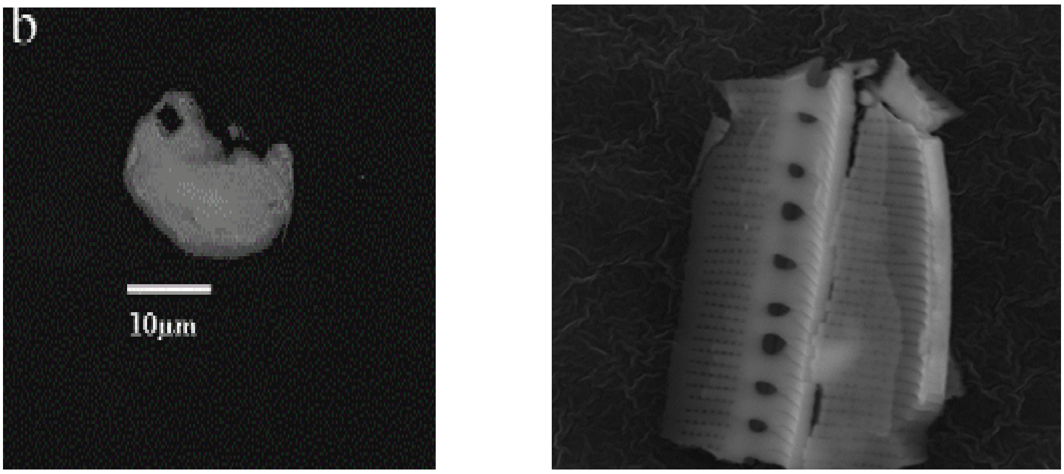
So, is this how life got started on the Earth? Directed panspermia posits precisely that - life was deliberately sent to Earth by an external cosmic civilisation (Shklovskii and Sagan, 1966, Crick, 1973, Crick and Orguel, 1973). Crick and Orguel argued this case from the standpoint of the grotesque improbabilities involved in the transformation of organic chemicals to life and in particular to the arrangement of nucleotides in DNA, an issue which was also discussed by Hoyle and Wickramasinghe (1982). According to Directed Panspermia, life was presumably sent by and alien advanced civilisation in some kind of craft or vehicle (e.g. a rocket); since we are unlikely to discover such a delivery vehicle, the idea to some at least might appear unscientific. By way of extending this concept we are tempted to suggest that the titanium microsphere recovered from the stratosphere seen in Fig. 2b could conceivably serve as such a vehicle, its use being far more efficient than rockets or spacecraft for interstellar transportation of life.

9 Parsimony in Relation to Our Theory – Apparently Anomalous Diatom

Critics often use Occam's razor (or parsimony) to dismiss our contention that the BEs we isolated in the stratosphere are arriving at the Earth from space, the argument being that other more conservative explanations have not been identified and excluded. However, as Francis Crick (Crick, 1988) noted:

> "While Occam's razor is a useful tool in the physical sciences it can be a very dangerous implement in biology. It is thus very rash to use simplicity and elegance as a guide to biological research."

Similar arguments are used in relation to the recovery of microorganisms from the exterior of the International Space Station at 400 km above the Earth (Grebennikova *et al.* (2018). The argument being that since the Earth is home to a vast amount of biology it is far more likely that any organism found in the stratosphere or higher, originates from Earth rather than space. Such a reaction does not, however, tally with theoretical objections that have been discussed for the transport of microbial life from Earth to the stratosphere and beyond (Wickramasinghe and Rycroft, 2018).



(a) (b)

Figure 4. (a) a stratosphere-isolated BE's (from 41km) showing positive fluorescence after staining with the DNA stain DAPI, (b) a naked, empty diatom frustule isolated around 30km.Note the lack of associated Earth biology on the sampling disc.

One of the first indications that biology resides in the stratosphere came with our isolation of an empty diatom frustule from this region (Fig.4a.). Since vast numbers of diatoms exist in the world's oceans critics argued that this frustule *must* have been carried up from Earth to the stratosphere and then isolated by our sampler. This would appear to make sense, except that, because of its mass, such an empty diatom frustule would be very difficult to uplift from Earth to heights around 30km. Critics could avoid this argument by suggesting that there must exist an unknown mechanism by which a particle of the size and mass of a diatom frustule could *somehow* be elevated to these heights. However, such an assertion yet again begs the question - if this is the case, why are the insides of our samplers not be replete with Earth-derived organisms of similar size and lower mass, such as grass-shards, fungal spores and pollen grains?

In fact, the isolation of an empty diatom frustule in the stratosphere adds rather than detracts from our theory. Watery planets are common in the Galaxy and these could arguably provide a home for photosynthetic, oxygen-producing diatoms, as could comets (Wickramasinghe *et al.*, 2013). Additionally, diatom frustules could act as an ideal physically protective panspermic vehicle for the algal cell itself as well as for any oxygen-requiring associated microorganisms, such as aerobic bacteria; frustules might also serve to protect against ionizing radiation.

In addition, diatoms are known to be resistant to UV, although possibly not UVC; protection against UVC would however, be provided by the finest coating of organic material or inorganic salt originating from an original watery habitat. The input of a large quantity of oxygen-producing photosynthetic organisms would obviously be highly advantageous to an anoxic early Earth. Finally, we note that Hoover *et al*, (1986) reported that there exists a close relationship between the measured infrared properties of diatoms and the infrared properties of in interstellar dust present in parts of the galaxy, and that many diatoms are of the right size and shape for entry into the Earth's atmosphere, even at diameters up to 100 microns. All these results point to the possible panspermic origin of the Earth's diatoms, and presumably of the stratosphere-isolated diatom frustule (BE) seen in Fig.4b.

A recent claim that may be potentially damaging to our argument is provided by Della Corte *et al.* (2014) who claimed to isolate a complex, unknown biology-like particle at ~30km in the stratosphere, described as being non-mineral and comprising mainly carbon and nitrogen and by our definition a Biological Entity). However, they also reported isolating a chain of fungal spores from the same height. At first sight this latter claim might be seen to be fatally damaging to our argument that terrestrial spores do not, because of their size, reach the stratosphere. However, closer examination of the spore chain provided by Della Corte *et al.* (2014) shows that it is pristine and therefore unlikely to have survived as a chain in the stratosphere, an environment of high winds and turbulence.

It is noteworthy that Dell Corte *et al.* (2014) suggest that the relatively benign effect of the SEM beam detached one of the fungal spores from the parent chain. The suggestion that such a spore-chain is of terrestrial origin and survived the rigours of residence in the stratosphere is therefore untenable and it must therefore be a terrestrial/laboratory contaminant. As a result the findings of Della Corte et al do not fundamentally damage our claim the that BEs we isolated in the stratosphere originated from space.

In conclusion, we reiterate that we are confident that we have isolated a range of unique Biological Entities from the stratosphere at heights around 30 and 41km and that such organisms are continually arriving from space to Earth, thereby providing evidence for panspermia and in particular, *neopanspermia*. It is to be hoped that other groups, including NASA, JAXA, ISRO and other international space agencies, would engage with these studies in order to extend our findings as well as to confirm their veracity.

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