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Panspermia in perspective

Abstract

Panspermia, an ancient theory implying the dispersal of life throughout the universe, was revived in its modern form by Fred Hoyle and the present author in a series of publications over the period 1977 to 2001. Although unpopular at first, it is now slowly gaining support and is coming to be discussed as a serious scientific possibility among theories of the origin of life. A summary will be given of the modern scientific case for panspermia, indicating that astronomical, geological and biological evidence is converging towards its support.

Keywords: Panspermia, comets, meteorites, microfossils, interstellar matter, origins of life

Introduction

In its modern form the concept of *in situ* generation of life was introduced in the early part of the twentieth century by Oparin and Haldane[1]. The first step involves the formation of prebiological molecules, the chemical building blocks of life, from inorganic chemicals. Such molecules were supposed to form in the Earth's primitive atmosphere through the action of electric discharges, as would occur in lightning, and from exposure to ultraviolet light from the sun, and then rain down into the oceans generating a dilute 'organic soup'. An undefined sequence of chemical transformations were next supposed to take place leading ultimately to the emergence of the first primitive living system from which all other life-forms subsequently evolve.

Attempts to justify such a scheme have concentrated mainly on the formation of the organic building blocks of living systems from inorganic molecules under laboratory conditions. The passage of high voltage electric discharges through a mixture of inorganic gases such as water, methane and ammonia can be shown to produce traces of organic chemicals including sugars, nucleotides and amino acids, as was done, for instance, in the classic experiments of Harold Urey and Stanley Miller[2,3,4] in the early 1950's. A basic requirement for all such experiments was that the starting mixture of gases had an overall reducing property, that is to say, an effective excess of available hydrogen over oxygen. Recently these ideas have suffered a major set-back because geochemists have discovered that the Earth's primordial atmosphere was of an *oxidising* rather than of a *reducing* nature[5,6]. In such an atmosphere organic molecules cannot form, and even if such molecules were brought from outside, as has now been recognized[7], they are all too easily oxidised and destroyed.

The most difficult problem to resolve in a purely terrestrial context concerns the origin of the information content of life. The information needed to put life together, even in its simplest and most primitive form, is specific in kind and superastronomical in quantity. How was this highly specific information acquired in the first place from a situation that was initially thoroughly chaotic? The minimal number of random trials needed to discover the crucial molecular arrangements needed for life, as for instance in the enzymes, through random shufflings of the constituent amino acids, far exceeds anything that could happen in all the oceans of the Earth, let alone in Darwin's "warm little pond". The number of shufflings that are needed is superastronomically vast[8]. Transferring the problem a presumed "RNA world" does not alleviate these difficulties. If one supposed that the super-astronomical quantity of information needed for the emergence of life is somehow broken up into an infinity of much smaller informational hurdles, then one could perhaps think that the problem could be solved. But this would be so *only* if the steps involved (evolutionary steps) follow each other with an inevitability that is somehow destined to discover life at the end. There is an assumption of an unproved principle of biological determinism. In other words the laws of physics a deep level – perhaps at the level of the wavefunctions of atoms – must somehow conceal the superastronomical information content of life. There is of course no empirical basis for such a proposition. If honesty prevails one has to admit that the ultimate origin of life is an event so improbable as to verge on the miraculous. So to constrain this event to our minuscule planet is not only unnecessarily restrictive; it is pre-Copernican in philosophy.

First steps to panspermia

A crucial development in the 19th century that led to a revival of panspermia followed from the work of Louis Pasteur. Pasteur showed by his classic experiments on the souring of milk and the fermentation of wine that *life is always derived from life*. This was demonstrated at the microbial level, but in its generalised form Pasteur's *life from life* dictum implied that each generation of every life-form is preceded by a generation of the same life-form. Several contemporary scientists of note, particularly physicists, were quick to take this dictum to its logical conclusion. Amongst them German physicist Hermann Von Helmholtz[9] wrote thus in 1974

"It appears to me to be fully correct scientific procedure, if all our attempts fail to cause the production of organisms from non-living matter, to raise the question whether life has ever arisen, whether it is not just as old as matter itself, and whether seeds have not been carried from one planet to another and have developed everywhere where they have fallen on fertile soil...."

And Lord Kelvin (W. Thomson)[10] pronounced in a similar vein as follows: "Dead matter cannot become living without coming under the influence of matter previously alive. This seems to me as sure a teaching of science as the law of gravitation..."

If life had preceded the Earth, one could ask how had it arrived here and where had it come from? This question was to be addressed some years later by the Swedish chemist Svante Arrhenius[11]. Arrhenius suggested that life came from space, and he proposed an explicit mechanism by which bacterial spores could be transferred from one star system to another, carried along by the pressure exerted on them by starlight. Arrhenius' ideas came to be known by the term *panspermia* – a word coined from the Greek roots *pans* (meaning all) and *spermia* (seed) – to mean all-seeding, or life everywhere. It is fair to say that from the very outset panspermia did not have many friends. It was perceived as a threat to Earth-centred religious dogmas, and to the burgeoning doctrine of Darwinism at the same time, thus attracting enemies, as it were, from both camps.

An attack on Arrhenius' views was mounted in 1924 by P. Becquerel[12] on the basis that ultraviolet radiation in space would not permit bacterial survival and propagation. The same criticism was widely accepted at the time and it has been repeated many times since. We now know that a carbonaceous coating of only a few microns thick, which would inevitably occur in interstellar space, provides essentially total shielding against ultraviolet light, and there are several modern experiments that have demonstrated precisely that[13]. However, the unremitting propaganda of journals such as *Nature* throughout most of the 20th century was so successful that theories of panspermia were discounted for close upon three-quarters of a century, for reasons that turned out to be spurious.

Whilst it is true that the conditions of interstellar space are potentially hazardous for long-term survival of microorganisms, there are many routes to survivability over billions of years. A point that is consistently and stubbornly ignored by critics is that the wholesale destruction of microbiota through any of the processes that might operate in space is utterly impossible. A planetwide or solar or stellar-system wide ecology of microbial life would be effectively immortal. For instance the last vestiges of life threatened with extinction in a hostile environment could survive within tiny clumps of dust, shielded from the ultraviolet radiation of stars, inside the cosy interiors of rocks or within the deep freeze of comets. And such objects harbouring life could be hurtling through space, travelling from one star system to another. The point to be stressed is that there would *always* be survivors, and even the minutest rate of survival would ensure the propagation of microbial life across cosmic distances. Collectively, microbial life once established in the cosmos is immortal and indomitable.

A hundred years ago survival of microbes in space may indeed have seemed a dicey business, but not so any more. Recent developments in microbiology have shown that many types of bacteria are endowed with properties that make them ideally suited to space travel. Thermophyllic, heat-loving bacteria can replicate in superheated water at temperatures above 100C in deep sea thermal vents. Entire ecologies of psychrophyllic or cold-loving microorganisms are found to thrive in Antarctic permafrost. And viable bacteria have also been recovered from deep ice drills in the Antarctic that have lain dormant for nearly half a million years. A viable strain of the bacterium *Streptococcus Mitis* was recovered within a TV camera placed on the Moon after two years of exposure to unshielded radiation from the sun. Some types of bacterial species are found to survive and even replicate in the intense radiation environment within a working nuclear reactor. Bacteria have been found at depths of some seven kilometres below the Earth's crust. Most recently, a quarter of a billion year old dormant bacterium in a salt crystal was shown to be viable. In an experiment specially designed to test the space hardiness of microbes, colonies of the bacterium known as *Bacillus subtlis* were exposed for 6 years to the unshielded radiation from the sun in NASA's Long Duration Exposure Facility, and again the cells were found to be fully viable and culturable. It is thus reasonable to proceed on the basis that the old polemic of non-survivability in space is no longer valid. On the contrary, once life has got established in any large enough cosmic niche it would surely take a miracle to destroy its last vestiges.

Evidence supporting panspermia is also to be found in the recently discovered antiquity of microbial life on the Earth. The earliest evidence for terrestrial life has now been pushed back beyond 3.83 billion years BP, well into an epoch when we know for certain that the Earth was severely pumelled by comet and meteorite impacts[14]. This evidence comes in the form of a slight enhancement of the lighter isotope of carbon ^{12}C relative to ^{13}C in the oldest metamorphic rocks. The argument is that life has a slight preference for the lighter isotope of carbon and this is reflected in the carbon extracted from rocks that could date back to about 4 billion years. The primordial soup, if there was one, is now required to operate under the harshest of conditions in circumstances where the survival of organic molecules, let alone life is in doubt.

Interstellar grains to panspermia

When Fred Hoyle and the present author approached the subject of panspermia, we did so not from a biological standpoint, but from an attempt to understand the nature of interstellar dust[15] (See also ref. 22). The cosmic dust grains populate the vast stretches of the Milky Way, showing up as a cosmic fog, dense enough in many directions to blot out the light of distant stars. The first thing to note was that these grains appear to be much the same in all directions, as we look outwards from the Earth. They are of a size that would be typical for bacteria, a micrometre or less.

Another fact that is of crucial importance is that the total mass of interstellar dust in the galaxy is as large as it possibly can be if all the available carbon, nitrogen and oxygen in interstellar space is condensed in the grains. If one now asks the question: what precisely are the dust grains made of, a number of inorganic molecules composed of H,C,N,O present themselves as possible candidates. These would include water-ice, carbon dioxide, methane, ammonia, all these materials being easily condensible into solids at temperatures typically of about 20-50 degrees Kelvin, which is the usual temperature of the grains. During the decade starting from the early 1960's the properties of a wide range of inorganic grain models were studied, comparing their electromagnetic behaviour against the formidable number of observations that were beginning to emerge. Such models stubbornly refused to fit the available data to anything like the precision that was required. The correspondences between predictions for assemblies of inorganic particles and the observations could be lifted to a certain moderate level of precision but never beyond that, no matter how hard one tried.

It was a milestone in our progress towards panspermia when the present author realised that there is another very different class of materials that can be made from the same four commonest elements - C,N,O,H, namely organic materials, possibly of a polymeric type[16]. Of course there are a vast number of possible organic compositions, making for a great number of further investigations that could be made. By the mid-1970's, the astronomical observations were spanning a large range in wavelength, from 30 microns in the infrared, through the near infrared, into the visible spectrum, and further into the ultraviolet. So a satisfactory theory of the nature of grains had by now to satisfy a very large number of observational constraints.

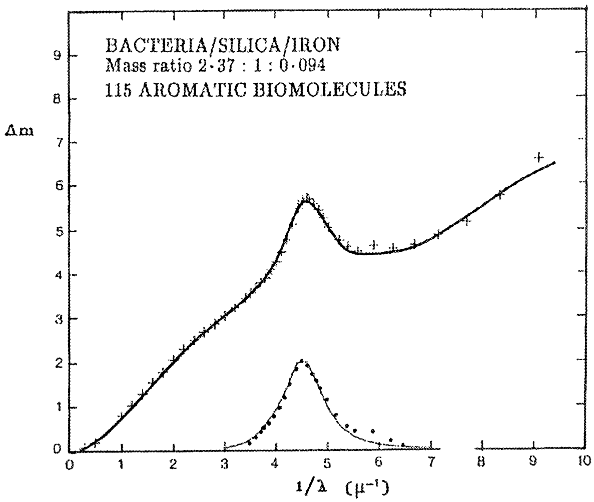

Figure 1. The filled circles (points) are excess interstellar absorption values over and above a scattering curve for hollow bacteria. Crosses are the mean interstellar extinction data. The heavy curve is calculated for hollow bacteria with and admixture of bioaromatic molecules and trace quantities of silica and iron in the form of submicron sized grains. The thin line is the absorption profile for an ensemble of bioaromatic molecules. (Full references and credits in Refs 15)

Fig. 1 shows the so-called extinction curve of starlight, the way that starlight is dimmed as it travelled through clouds of interstellar dust. A puzzle here relates to how the visual part of this curve (over the 1 - 3 inverse micrometre range) could be reproduced almost exactly in all directions of the sky. For inorganic condensation models one requires a rather precise definition of particle sizes, and that is difficult to justify. The puzzle remained unresolved until we began to consider organic particles, particularly organic particles that were hollow. Particles that have about 70 percent hollow space gave very good results. This is what bacteria become when they are fully dried out. So now, a decade and a half after starting on this problem, Hoyle and the present author decided in 1979 to test the hypothesis that the interstellar dust particles might really represent a graveyard of bacteria. The big attraction was that such tests could be carried out quite easily. One didn't have to draw up a catalogue of assumptions in making the calculations. One didn't need for example to *assume* a size distribution for our supposed bacterial particles. One could use a known bacterial size distribution, making the investigation without assumption on this and on a number of other issues as well. The result is shown as the solid curve in Fig. 1. This curve (heavy line) combines the effects of hollow bacterial particles with clusters of aromatic molecules that result naturally from the inevitable degradation of bacteria, along with a small admixture of silica-iron particles of submicron sizes that could explain the rise in the extinction into the far ultraviolet. Here at last was a good correspondence of the observational data points to the calculated expectation of a model, and it so happened that the model was of a bacterial nature.

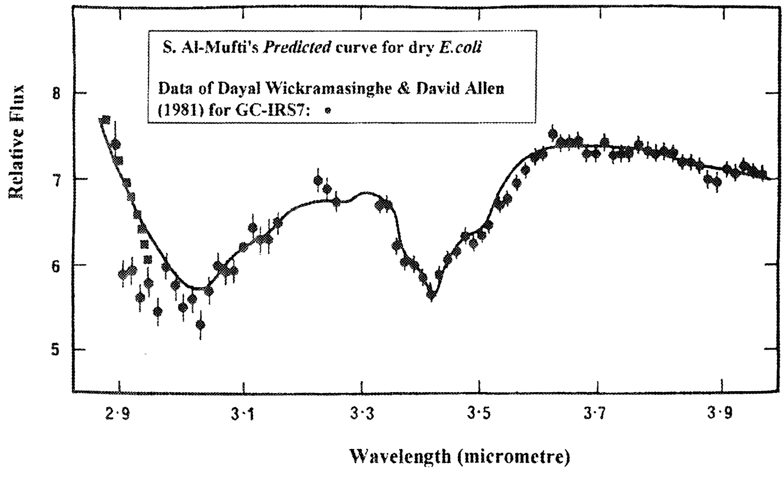

Figure 2. The agreement between an *E Coil* model (curve) and the flux data for the Galactic Center infrared source GC-IRS7. (Ref. 17).

Perhaps the most dramatic confirmation of the bacterial model followed the pioneering observations by D.T. Wickramasinghe and D.A. Allen[17] of the infrared source GC-IRS7. The spectrum of this source revealed a highly detailed absorption profile extending over the 2.9-3.8 micrometre wavelength region, indicative of combined CH, OH and NH stretching modes as seen in Fig.2. A laboratory spectrum of the desiccated bacterium *E. Coli*, obtained some months *earlier* by S. Al-Mufti, together with a simple modelling procedure provided a close point by point match to the astronomical data over the entire 2-4 micron waveband, as seen here. At this stage there was no alternative but to face up to the somewhat startling conclusion that a large fraction of the interstellar dust *must* spectroscopically at least be indistinguishable from freeze-dried bacterial material.

It has often been claimed that a curve like the one in Fig. 2 could be obtained from non-biologically derived organic materials in many ways. Such a possibility cannot be denied, although to this day a competing fit using a *clearly defined and easily reproducible* organic mixture has not been found. Some elaborate laboratory procedures, involving carefully controlled irradiation of inorganic mixtures, have yielded undefined "organic residues" that possess some of the desired properties (see ref. 15), but the relevance of these experiments and experimental conditions to an astronomical situation could be questioned with some justification.

Another remarkable development in recent years has been the discovery of vast quantities of aromatic molecules; molecules based on hexagonal carbon-ring structures, such as are responsible for the hump in the interstellar extinction curve at 2175A (Fig. 1). These molecular structures appear to be distributed quite extensively on a galactic as well as an extragalactic scale, and once again a large fraction of the available interstellar carbon seems to be tied up in this form. Needless to say, such molecules are part and parcel of biology, and their occurrence in interstellar space is readily understood as arising from the break-up of bacterial cells.

Even much earlier, in 1962, the presence of aromatic molecules in space might have been inferred from the so-called diffuse interstellar absorption bands. It has been known for over half a century that some 20 or more diffuse absorption bands appear in the spectra of stars, the strongest being centred on the wavelength 4430A. Despite a sustained effort by scientists over many years no satisfactory inorganic explanation for these bands has emerged. In the early 1960's F.M. Johnson[18] showed that a molecule related to chlorophyll - magnesium tetrabenzo porphyrin - has many of the required spectral properties. Chlorophyll of course is an all important component of terrestrial biology - it is the green colouring substance of plants, the molecule responsible for photosynthesis, the process that lies at the very base of our entire ecosystem on the Earth.

There is yet another property of biological pigments such as chorophylls that persistently shows up in astronomy. Many biological pigments are known to fluoresce, in the fashion of pigments in glowworms. They absorb blue and ultraviolet radiation and fluoresce over a characteristic band in the red part of the spectrum. For some years astronomers have been detecting a broad emission feature of interstellar dust over the waveband 6000-7500 Angstroms. Chloroplasts containing chlorophyll, when they are cooled to temperatures appropriate to interstellar space fluoresce precisely over the same waveband[19].

In this section we have discussed only a small subset of the astronomical data that since the 1980's have appeared to point consistently to in the direction of panspermia. At the most conservative the astronomical data show decisively the overwhelming dominance of highly complex organic molecules in a condensed state. On this there is no longer any disagreement. Also isotropy of visual extinction curve of starlight shows that these organic grains must be substantially the same in one direction from the Earth as in another. By far the simplest way to produce a vast quantity (10^{40} grams) of small organic particles everywhere of the sizes of bacteria is from a bacterial template.

The power of bacterial replication is immense. Given appropriate conditions for replication, a typical doubling time for bacteria would be two to three hours. With a continuing supply of nutrients, a single initial bacterium would generate some 2^{40} offspring in 4 days, yielding a culture with the size of a cube of sugar. Continuing for a further 4 days and the culture, now containing 2^{80} bacteria would have the size of a village pond. Another 4 days and the resulting 2^{120} would have the scale of the Pacific Ocean. Yet another 4 days and the 2^{160} bacteria would be comparable in mass to a molecular cloud like the Orion Nebula. And 4 days more still for a total since the beginning of 20 days, and the bacterial mass would be that of a million galaxies. No abiotic process remotely matches this replication power of a biological template. Once the immense quantity of organic material in the interstellar material is appreciated, a biological origin for it becomes an almost inevitable conclusion.

Comets and life

The next question to be addressed is: where did the interstellar organic particles or bacterial grains come from? How did they get where we now observe them to be? And this in turn leads us to another important step along the path towards panspermia, to the comets.

An individual comet is a rather insubstantial object. But our solar system possesses so many of them, perhaps more than a hundred billion of them, that in total mass they equal the combined masses of the outer planets Uranus and Neptune, about 10^{29} grams. If all the dwarf stars in our galaxy are similarly endowed with comets, then the total mass of all the comets in our galaxy, with its 10^{11} dwarf stars, turns out to be some 10^{40} grams, which is just the amount of all the interstellar particles.

How would microorganisms be generated within comets, and then how could they get out of comets? We know as a matter of fact that comets do eject particles, typically at a rate of a million or more tons a day. This was what Comet Halley was observed to do on March 30-31, 1986. And Comet Halley went on doing just that, expelling organic particles in great bursts, for almost as long as it remained within observational range. The particles that were ejected in March 1986 were well placed to be observed in some detail. No direct tests for a biological connection had been planned, but infrared observations pointed unexpectedly in this direction. Fig. 3 shows the infrared emission spectrum of dust from Comet Haley obtained by D.T. Wickramasinghe and D.A. Allen compared with bacterial and abiotic organic models[20]. We note that a bacterial model gives a significantly better fit. The analysis of dust impacting on mass spectrometers aboard the spacecraft Giotto also leads to composition of the dust that are exceeding complex and organic and fully consistent with the biological hypothesis. (See ref. 21,22 for full list of references and more details). Largely similar conclusions have been shown to be valid for other comets as well including Hyakutake and Hale-Bopp. Thus one could conclude that cometary particles, just like the interstellar particles, are *spectroscopically* identical to bacteria.

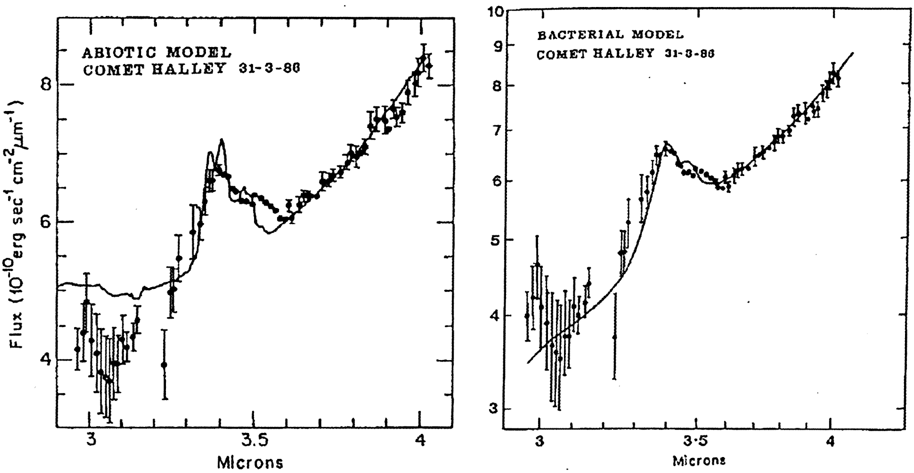

Figure 3. Observational data for dust released from Comet Halley (points) compared with predictions for abiotic and bacterial dust models.

The radiation pressure from sunlight drives small particles expelled from comets rapidly outwards in the solar system, and ultimately out into interstellar space. This is exactly what is happening when we observe the tails of comets. The dust tails consist of small organic particles, expelled rapidly outwards by sunlight. So this is how the organic particles get out from comets into interstellar space. They are sprayed out from a great multiplicity of events like that which occurred to Comet Halley in March 1986, like all the cometary explosions that supply the materials of the comas and tails of comets.

Comets are believed to have formed already in the early stages of the condensation of the sun. Here we reach a delicate point in our argument. We require some small fraction of microorganisms present in the parent solar nebula to have retained their viability. Or to be capable of being reactivated after becoming incorporated in comets. The fraction could be exceedingly small, however. For one percent of the mass of the initial comet cloud being made up of interstellar dust the total number of "graveyard bacteria" included within a single comet would be some 10^{28}. A viable fraction as small as one part in 10^{17}, would still yield a hundred billion bacteria for each comet to start life with. That is of course vastly more than enough for panspermia to operate. Once replication starts inside a newly-formed comet, all previous losses become irrelevant, because of the enormous capacity of even a single viable cell to multiply, as we have already seen.

But replication requires heating so as to produce liquid water. The cloud in which the solar system formed would be expected to have harboured one or more massive stars of the types that produce the unstable isotope ^{26}Al with a half-life of three-quarters of a million years. This gives long enough time for the solar nebula to form, and to condense before all the ^{26}Al is effectively gone. Because ^{26}Al is a major source of the stable isotope of magnesium, ^{26}Mg, which was a common element in the solar nebula, the original amount of ^{26}Al must then have been substantial. In primitive cometary condensations, ^{26}Al would be expected to make up a mass fraction of about one tenth of a percent, or less, according to the time which elapsed since its stellar synthesis.

It can be easily shown that the energy released in the radioactive decay of ^{26}Al is more than enough to maintain a warm liquid interior in comets for a million years or more. There is good reason to believe therefore that the early comets were indeed liquid.

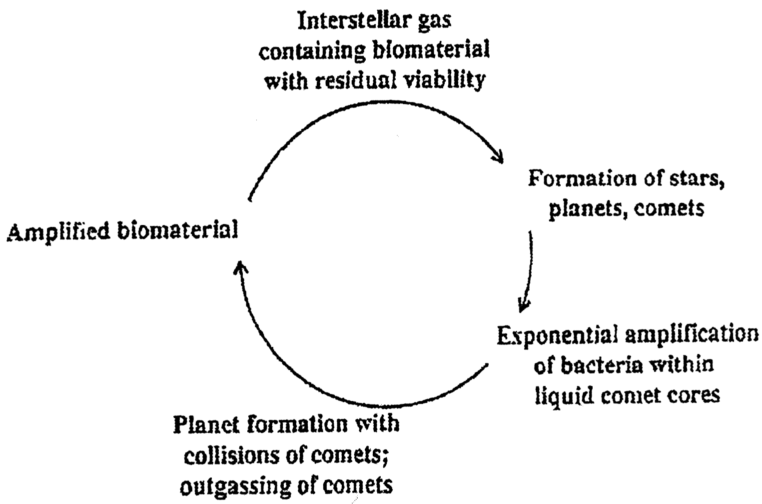

Figure 4. Cosmic amplification cycle

So it turns out that the comets are the viable places of replication of microorganisms - or more accurately they are among the more probable places of replication, leading to the cosmic amplification cycle of biology shown in Fig. 4.

The ALH 84001 saga

A major revival of interest in theories of panspermia came in August 1996 with studies of a 1.9kg meteorite (ALH 84001) which is believed to have originated from Mars[23]. ALH84001 is just one of a group of meteorites discovered in 1984 in Allan Hills, Antarctica, which is thought to have been blasted off the Martian surface due to an asteroid or comet impact some 15 million years ago. This ejecta orbited the sun until 13,000 years ago when it plunged into the Antarctic and remained buried in ice until it was discovered. The presumed Martian origin of these meteorites (also known as SNC meteorites) seems to have been confirmed by several independent criteria. One that is perhaps amongst the most cogent involves the extraction of gases trapped within the solid matrix which were found to resemble in relative abundances the gases that were discovered in the Martian atmosphere. Also the ratio of oxygen isotopes $^{17}O/^{18}O$ in the mineral component matches the value found on Mars so closely that there is no reason to doubt a Martian origin.

A team of investigators led by David S. McKay[23] have found that within the meteorite ALH 84001 there are sub-micron sized carbonate globules around which complex organic molecules are deposited. These molecules, including polyaromatic hydrocarbons, are characteristic products of the degradation of bacteria. McKay and his colleagues admit that their proposed identification involves a process of multi-factorial assessment. The totality of the available evidence, in their view, points to a microbial origin, although each single piece of evidence may be capable of more conservative interpretation. This conclusion has predictably been challenged by other groups, one particular issue that was raised relating to the temperature at which the carbonate globules condensed. Arguments have raged concerning the temperature at which the carbonate globules condensed, and whether any biological structures could survive such temperatures. With the best estimates for temperature now coming out to be less than 100C, McKay and his colleagues can still defend their original identification of microfossils and are advancing even stronger arguments and evidence. The debate seems destined to continue, however, perhaps until the day when Martian samples are returned to Earth. If the microbial explanation is eventually upheld, the deposition of the microfossils coincident with the condensation of carbonate globules can be dated at 3600 my BP. So one might conclude that microbial life existed on Mars some 3600 million years ago, probably concurrently with the earliest evidence of microbial fossils on the Earth. In accordance with the theory of cometary panspermia it would appear likely that both the Earth and Mars came to be seeded with bacterial life almost at the same time.

Direct detection of bacteria arriving from space

If comets seeded the Earth, Mars and perhaps other objects in the solar system with life 4 billion years ago, the same process would be expected to continue to the present day. It is known that about a hundred tonnes of cometary debris, much of which is organic, enters the Earth's atmosphere on a daily basis. The theory of panspermia discussed earlier must imply that a fraction of this debris contains viable microbes. The best prospect of testing this proposition that would be to collect samples of air in the very high stratosphere using sterile techniques. Above the tropopause, which is 18 km in the tropics and 10 km in temperatate latitudes, aerosols of 1-10 micrometres in size, including bacterial clumps, could not persist for more than a very short timescale, weeks or less. They would quickly fall under gravity. If small amounts of bacteria from the Earth's surface get lofted on rare occasions to great heights, for example after a volcanic eruption, they would quickly fall. Above 40 km you would not expect to find any terrestrial bacteria at all in normal times, so if significant quantities of stratospheric bacteria are discovered, this would provide *prima facie* evidence of panspermia.

The earliest attempts to search for microorganisms in the upper atmosphere were made using balloons in the early 1960's. These experiments were conducted under the auspices of the US Space Agency NASA, presumably as a preparation for embarking on the Space Age and manned space flights. Although the techniques for conducting such experiments asceptically at the time were primitive some dramatic indications of extraterrestrially derived microorganisms were obtained[24,25]. Viable cultures were recovered from air samples at 39 km and higher with an indication that they were introduced from outside. However, such a claim was difficult to defend in view of primitive nature of the sterilization procedures that were used. The NASA atmospheric biosampling program seems to have been terminated and not taken up again until the present time.

A group of Indian scientists from several research institutions collaborated with a group of us at Cardiff to conduct an experiment that was long overdue[26]. The brief was in principle simple: to collect stratospheric air aseptically, and to examine it in the laboratory for signs of life. The collection part of the project was as follows. A number of specially manufactured sterilized stainless steel cylinders were evacuated to almost zero pressures and fitted with valves that could be open and shut on ground telecommand. An assembly of such cylinders was suspended in a liquid Ne environment to keep them at cryogenic temperatures, and the entire payload was launched from the TATA Institute Balloon launching facility in Hyderabad, India on 20 January, 2001. As the valves of the cylinders were opened at predetermined heights ambient air rushed in to fill the vacuum and built up very high pressures within the cylinders. The valves were shut after a prescribed length of time and the cylinders hermetically sealed to be parachuted back to the ground.

Back on the ground the cylinders were carefully opened and the collected air made to flow through sterile membrane filters in a contaminant free environment. Any bacteria or clumps of bacteria present in the stratosphere would then be collected on these filters. The analysis in Cardiff was conducted by a team at Cardiff University led by microbiologist Professor David Lloyd

Approximately 4 mm^2 squares were asceptically cut from the filters and treated with a fluorescent cationic cyanine dye sensitive to membrane potential. The details of this procedure for

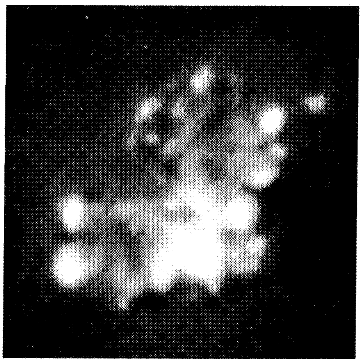

Figure 4. A cluster of fluorescing viable cells in an isolate from probe A detecting viable cells is described by Lloyd and Hayes[27] and Lopex-Amoros et al[28]. Any viable living cells present would be expected to give rise to fluorescent spots when illuminated with ultraviolet light and could be identified under an epifluorescence microscope. Each such spot would represent a single cell. Isolates from all probes studied so far showed fluorescent spots in the form of clumps of 0.1-0.3μm sized cells, the clumps themselves measuring a few micrometres across. An example of such a clump in a sample from 30 km height is shown in Figure 4. By counting the numbers of such clumps on the membrane filters and from the known quantities of air from which they were derived it is possible to estimate a

density profile of stratospheric bacteria from our investigation. Moreover, we can calculate the gravitational settling speed of the clumps and hence the infall rate of microorganisms from comets. Our provisional estimate is that approximately one third of a tonne of microbial material is incident globally on a daily basis.

Conclusion

According to the point of view that Fred Hoyle and the present author have developed over several decades nothing of great innovative significance in biology ever happened on the Earth. The Earth was simply a receiving station, a building site for the incomparably mangnificent edifice of cosmic life. It came in units - clumps of bacteria as we see in Fig. 4. Natural selection, according to the criterion of the survival of the fittest, selected those forms from the cosmically available master plan that were best suited to the local environment at all times. It is against this backdrop that the normal evolutionary processes discussed in conventional biology would operate, more in the manner of fine tuning than innovation.

On other planets around other stars these same processes would of course also operate. Life would inevitably develop on every habitable planet, descended from the same all pervasive cosmic genes. What then of intelligent life elsewhere?. The question of intelligent life outside the Earth continues to torment many geocentrically oriented critics. Having been forced to abandon their cherished doctrine of Earth-centred life, they now cling tenaciously to the idea that intelligence at least may be confined to the Earth. This idea will also in my view be proved wrong. One day we will make contact with an alien life form on a distant planet. And no matter how strange he or she may seem, we would know that we are related to that alien creature. We have our cousins out there in the big wide cosmos. We would know that our genetic ancestors still lurk amidst the stars.

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