

THE SPREAD OF LIFE THROUGHOUT THE COSMOS

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Summary

There is growing evidence for the widespread distribution of microbial material in the Universe. A minuscule ($< 10^{-21}$) survival rate of freeze-dried bacteria in space ensures the continual re-cycling of cosmic microbial life in the galaxy. Recycling and amplification occurs within comets during the early phases of the formation of a new planetary system. Evidence that terrestrial life may have come from comets has accumulated over the past decade. The implications of this point of view, which was developed in conjunction with Fred Hoyle since the 1970's, are now becoming amenable to direct empirical test by studies of cometary material collected in the stratosphere.

1. Introduction

The standard theory for the origin of life begins with a primordial atmosphere on the Earth in which the synthesis of the chemical building blocks of life (e.g. amino acids) from inorganic gases occurs through the action of solar ultraviolet radiation and electric discharges. Organic molecules so formed are then supposed to rain down into the primitive oceans producing a dilute soup. In such an exceedingly dilute solution reaction rates would be minimal and biochemistry hard put to produce all the complex chemical transformations needed for an origin of life. It is therefore proposed that evaporation of water from shallow lakes and ponds, and at the margins of the sea led to sufficient concentrations of organics for prebiotic chemistry to proceed, and after millions of years a self-replicating living cell is postulated to arise. This was essentially the model proposed by Oparin and Haldane¹, which was at least partly vindicated by the work of S. L. Miller² over 50 years ago. The formation of the relatively simple chemical building blocks of life was demonstrated, but the further steps leading to life remained elusive.

The highly specific and exceedingly intricate complexity of living organisms at a molecular level is self-evident, and it is clear that no significant progress has been made in 50 years towards understanding how the information gap between a non-living mixture of organic molecules and life could be achieved. For instance Margulis³ has stated that to proceed "...from a bacterium to people is less of a step than to go from a mixture of amino acids to that bacterium". Moreover we have no definite knowledge by which we can assert that this step ever happened on the Earth – namely that a *de novo* origin was localised to a tiny speck of 'cosmic dust' that is the Earth. The superastronomical information gap between non-life and life provides, in the view of the author, the main justification for considering theories of origin that involve the universe as the whole. The final information content of life could have been arrived at by a cumulative addition of truly minuscule probabilities in self-replicable partial stages that are repeatedly and serially impressed on a vast cosmic system. This

process must be envisaged to take place over cosmological timescales, and to involve the resources of all the stars in all the galaxies in the entire universe.

2. Rationale for panspermia theories

There is no logic that demands an origin of life on the Earth. The fact that life is found on the Earth does not mean that life necessarily started here. The Earth is not disconnected from the wider Universe, or sealed away from cosmic contaminants. Even today cometary organic molecules arrive here plentifully, at an average rate of tens of tones per day. Thus a chain of connection:

Earth→Comets → Presolar nebula → Interstellar clouds → stars → Galaxy → Universe can be envisaged.

Living material contains about twenty different types of atoms, the most important being carbon, nitrogen, oxygen and phosphorus. The ultimate source of origin of these chemical elements is stellar nucleosynthesis – the process by which the primordial element H is converted first to He and thence to C, N, O and heavier elements in the deep interiors of stars. Thus at the level of the constituent atoms we are indisputably creatures derived from the cosmos.

From the 1970's onwards, astronomers discovered a host of organic molecules in interstellar clouds, and since 1986 similar molecules were also found in comets. These discoveries prompted Fred Hoyle and the present author^{4,5} to re-examine the ancient theory of panspermia, which posits that life is a cosmic phenomenon, and that life on Earth is derived from a vast cosmic system.

Louis Pasteur's classic experiments^{6,7} in the 1850's and 1860's, in which he showed that microorganisms are always derived from pre-existing microorganisms, provided perhaps the most important experimental basis for panspermia. Indeed this was a conclusion that was reached quite early in 1874 by the German physicist Hermann Von Helmholtz⁸:

"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...."

The next noteworthy proponent of panspermia at the dawn of the 20th century was the Swedish Chemist Svante Arrhenius¹⁰. In 1908 Arrhenius' noted that microorganisms possess unearthly properties, properties that cannot be explained by natural selection against a terrestrial environment. The example for which Arrhenius himself was responsible for taking seeds down to temperatures close to zero Kelvin, and of then demonstrating their viability when reheated with sufficient care. Arrhenius conceived of microorganisms travelling individually through the galaxy from star system to star system. He noticed that organisms with critical dimensions of 1 micron or less are related in their sizes to the typical radiation

wavelengths from dwarf (sun-like) stars in such a way that radiation (light) pressure can have the effect of dispersing these particles throughout the galaxy.

3. The survival problem

Space-travelling individual bacteria would be susceptible to deactivation and damage from the ultraviolet light of stars, and this was already known in the first decades of the twentieth century. Becquerel¹¹ criticised panspermia on the basis of possible ultraviolet damage of space-travelling microbes, and similar criticisms were repeated ever since, even in modern times¹². These arguments are either flawed or highly insecure, however. Even under normal laboratory conditions microorganisms are not readily killed by ultraviolet, they are mostly deactivated due to the dimerization of pyrimidine bases. No genetic information is lost in the process and in many instances the damage can be repaired by the operation of specialised enzymic systems. Dimerization of bases distorts the DNA configuration and has the effect of impeding transcription. Exposure of UV irradiated bacteria to visible sunlight is known to promote repair. So also does the holding of ultraviolet-irradiated cells in the dark in non-nutrient buffers, the repair in this case being mediated by the operation of a 'dark repair' mechanism.

No data exists at the present time relating directly to the effects of ultraviolet irradiation on bacteria under cryogenic conditions and in the absence of air and water, conditions such as would apply in interplanetary or interstellar space. It should also be pointed out that microorganisms are easily shielded against ultraviolet light. Indeed molecular clouds in the galaxy are highly effective in this respect, both in cutting out the glare of ultraviolet radiation and permitting the growth of protective mantles around bacterial particles. Thin skins of carbonised material around individual bacteria, only 0.02 μm thick, would also effectively block the damaging ultraviolet light¹³.

On the whole microbiological research of the past 10 years has shown that microorganisms are remarkably space-hardy. Thermophiles are present at temperatures above boiling point in oceanic thermal vents, and as we have already pointed out entire ecologies of psychrophilic and psychrotrophic microorganisms are present in the frozen wastes of Antarctica. A formidable total mass of microbes also exists at great depths in the Earth's crust, some 8 kilometres below the surface, greater than the biomass at the surface¹⁴. A species of phototrophic sulfur bacterium has been recently recovered from the Black Sea that can perform photosynthesis at exceedingly low light levels, approaching near total darkness¹⁵. There are bacteria (e.g. *Deinococcus radiodurans*) that thrive within the cores of nuclear reactors¹⁶. Such bacteria perform the amazing feat of using an enzyme system to repair DNA damage, in cases where it is estimated that the DNA experienced as many as a million breaks in its helical structure.

Most modern objections to panspermia have been based on arguments relating to cosmic ray survival¹² – it being claimed that cosmic ray exposures in space over hundreds of thousands of years would prove fatal for microorganisms. These criticisms are again highly dubious and, moreover, fails to take account of the fact that the replicative power of bacteria is so

great that only a minute ($\sim 10^{-21}$) survival is required at each regeneration site between periods of freeze-dried dormancy in the interstellar medium.

Ionising radiation limits viability by dislodging electrons, causing bond breaks in the DNA and by forming reactive free radicals. The radiation doses that seriously compromise viability in cultures depend critically on the particular bacterial species, and as mentioned earlier some species such as *B. subtilis* and *D. radiodurans* are more resistant than others. In vegetative cultures, under laboratory conditions, doses equivalent to 2 megarads (2Mr) have been found to limit residual viability of *Streptococcus faecium* by a factor of 10^{-6} (Christensen¹⁷), whereas similar doses have little or no effect on cultures of *D. radiodurans* or *M. radiophilus* (Lewis¹⁸).

The doses of ionising radiation received by a bacterium in interplanetary space within the solar system depends on distance from the sun and the phase of solar activity, being highest at times near the peak of the solar sunspot cycle. In a recent NASA/LDEF (Long Duration Exposure Facility) experiment, direct exposure of spores of *B. subtilis* to unshielded solar radiation for 2107 days was found to lead to significant rates of survival (Hornek et al¹⁹). The survival of common species of bacteria near the Earth's orbit for about a decade therefore seems well-attested.

The dose of cosmic rays received by a naked bacterium in a typical location in interstellar space, over a timescale of a fraction of a million years, can at present be only very poorly estimated. It is possibly in the range 10-45 Megarad per million years. Doses of this order are of course higher than the doses that have been delivered to laboratory cultures where survival is well-attested. Yet the exposure conditions in space, where two successive cosmic ray ionising events are separated by about 100 years, would be dramatically different from those pertaining to the laboratory experiments.

A low flux of ionising radiation in space delivered over astronomical timescales to dormant freeze-dried bacteria (in the absence of H₂O and air) would perhaps bear no comparison with equivalent doses on vegetative cultures in the laboratory. The nearest terrestrial analogue might be for microbial spores that have been exposed to the natural radio activity of rocks for geological timescales. Indeed viable cultures of bacteria have been recovered from ice drills going back 500,000 years, from isolates in amber over 25-40 million years^{20,21} and from 120 million year old material²². Similarly bacteria have been recovered in salt crystals from a New Mexico salt mine dated at 250 Myr (Vreeland et al²³). The present day dose rate of ionising radiation on the Earth arising from natural radioactivity is in the range 0.1-1 r yr⁻¹. These well-attested recoveries of dormant bacteria/spores after 10⁸ yr must therefore imply tolerance to ionising radiation with total doses in the range ~ 10 -100Mr.

4. Interstellar organic molecules and dust

Notwithstanding the remarks of the previous sections some fraction of cosmic bacteria which have no protective coatings and which are exposed remorselessly to cosmic rays and to the background of starlight in unshielded regions of interstellar space would be subject to degradation and eventual destruction. The polyaromatic hydrocarbons that are so abundant in the cosmos could have a similar origin to the organic pollutants that choke us in our cities -

products of the degradation of biology, biologically generated fossil fuels in the this case, cosmic microbiology in the interstellar clouds. The theory of cosmic panspermia that we propose leads us to argue that interstellar space serves both as a graveyard of cosmic life as well as its cradle. Only the minutest fraction (less than one part in a trillion) of the interstellar bacteria needs to retain viability, in dense shielded cloudlets for instance, for panspermia to hold sway.

My own interest in panspermia began with attempts to understand the nature of cosmic dust²⁴. Interstellar dust grains populate the vast open spaces between stars of the Milky Way, showing up as a cosmic fog, dense enough in many directions to blot out the light of distant stars. Remarkably these dust grains can be shown to be of a size that would be typical for a bacterium, a micrometre or less.

A fact that impressed me from the outset was that the total mass of interstellar dust in the galaxy is as large as it possibly can be if all (or nearly all) the available carbon, nitrogen and oxygen in interstellar space is condensed in the grains. The amount is about three times too large for the grains to be mainly made up of the next commonest elements, magnesium and silicon, although magnesium and silicon could of course be a component of the particles, as would hydrogen, and also many less common elements in comparatively trace quantities.

If one now asks the question: what precisely are the dust grains made of, a number of inorganic molecules composed of C,N,O in combination with hydrogen present themselves as possible candidates. These include water ice, carbon dioxide, methane, ammonia, all such materials being easily condensable into solids at temperatures typically of about 20-50 degrees Kelvin, which is the average temperature of the dust grains in space. During the decade starting from the early 1960's Fred Hoyle and I studied the properties of a wide range of inorganic grain models, comparing their electromagnetic properties 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 interstellar panspermia when I 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 type²⁵. Of course there are a vast number of organic compositions that are possible, making for a great number of further investigations that could be done. 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 interstellar dust grains had by now to satisfy a very large number of observational constraints.

In 1979 Fred Hoyle and I stumbled on a result that led to many further discoveries, all of which pointed in the direction of panspermia. As already noted bacterial grains in interstellar space would be freeze-dried. Freeze drying of a bacterium would ensure that free water in the cell diffuses out of the porous cell wall leading to the development of a vacuum cavity.

The volume of the vacuum cavity for a typical bacillus amounts to about 60% of the total, and the resulting average refractive index of the entire structure is readily calculated as $n=1.16$. Next we require a distribution of sizes for the bacteria, which was available in the literature for spore-forming microorganisms (see Figure 1).

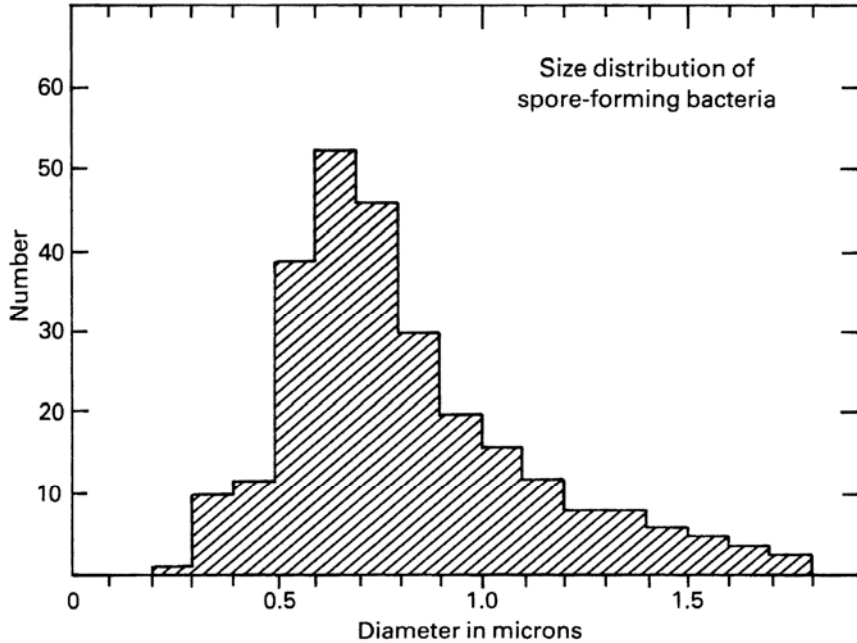


Fig. 1: Histogram of diameters of spore forming bacteria

When the extinction behaviour of this ensemble of freeze-dried bacteria was calculated, the result compared with the astronomical data on the dimming of starlight is shown in Fig. 2.

I was indeed dumbfounded to find a result so good after so many years of failure to obtain a satisfactory fit using highly contrived inorganic models. Once the proposition is made that “interstellar grains are bacteria” there is no further room for maneuver – the model is completely defined. But for the astronomical data further in the ultraviolet another refinement was required. Added to the bacterial population we need two further components derived from biology: non-hollow viruses and/or nanobacteria contributing 29% to the total mass, and free biological aromatic molecules, which would be the most stable subunits and molecules to result from the degradation of unshielded bacteria in space. The combination of these components leads to the curves depicted in Fig. 3

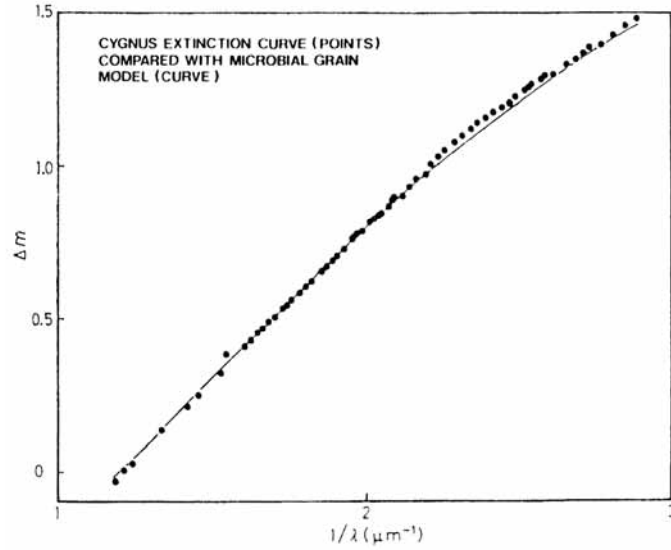


Fig. 2: Bacterial extinction over the visible spectrum compared with interstellar extinction data.

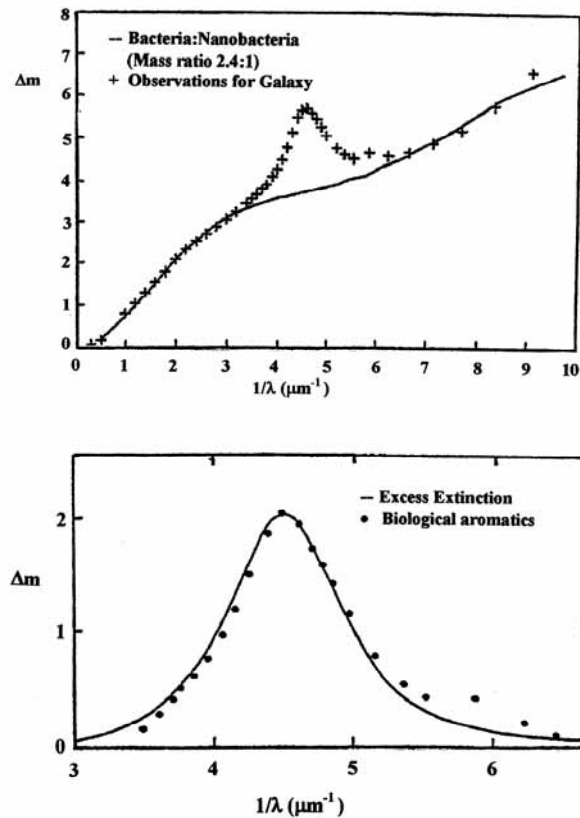


Fig. 3: Top: Interstellar extinction data over the 0.2-10 μm waveband compared with scattering by freeze-dried bacteria and nanobacteria.
Bottom: Excess extinction over the mid UV band compared with absorption by an ensemble of biologically derived aromatic molecules.

Perhaps the most startling confirmation of the bacterial model followed the observations²⁶ of a source of infrared radiation, GC-IRS7, located near the centre of our galaxy. 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. A laboratory spectrum of the desiccated bacterium *E. Coli*, together with a simple modeling procedure provided an exceedingly close point by point match to the astronomical data over the entire 2-4 micron waveband (Fig. 4).

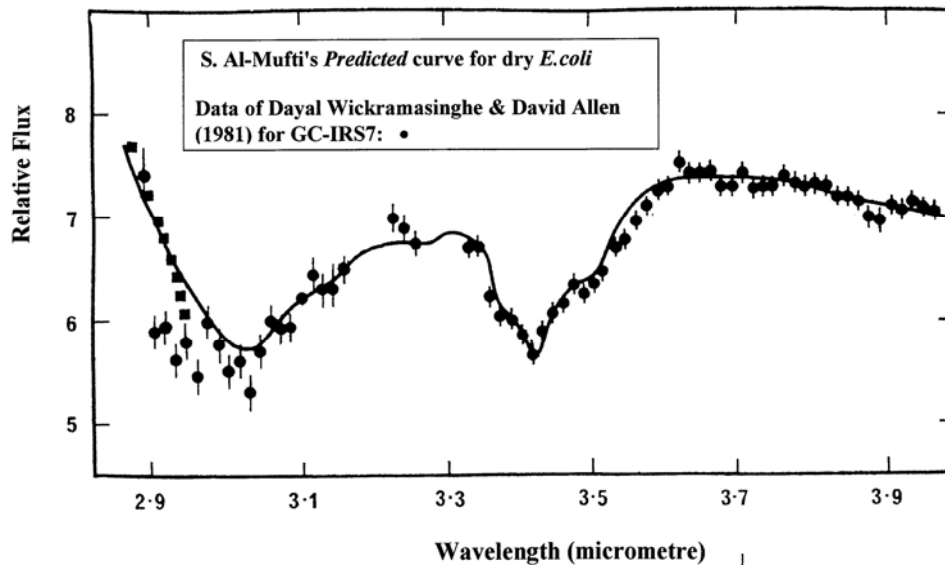


Fig. 4. Infrared spectrum of GC-IRS7 compared with bacterial model

At this stage we found there was no alternative but to face up squarely to the conclusion that a large fraction of the interstellar dust were not merely hollow and organic, but they *must* spectroscopically be indistinguishable from freeze-dried bacterial material. In our galaxy alone the total mass of this bacterial type material had to be truly enormous, weighing a formidable 10^{33} tonnes.

5. Replication in Comets

By far the simplest way to produce such a vast quantity 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. A continued cascade of doublings with unlimited access to nutrients would lead to a culture that enveloped the interior of a 10km radius comet in less than a week. 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.

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 organic 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 organic 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. An independent analysis of dust impacting on mass spectrometers aboard the spacecraft Giotto also led to a complex organic composition that was fully consistent with the biological hypothesis²⁷. Broadly similar conclusions have been shown to be valid for other comets as well, in particular Comet Hyakutake and Comet Hale-Bopp. Thus one could conclude from the astronomical data that cometary particles, just like the interstellar particles, are *spectroscopically* identical to bacteria.

In summary, the logical scheme for the operation of cometary panspermia is as follows: The dust in interstellar clouds must always contain the minutest fraction of viable bacteria (less than one in 10^{21}) that retain viability despite the harsh radiation environment of space. When a new star system (eg. a solar system) forms from interstellar matter, comets condense in the cooler outer periphery as a prelude to planet formation. Each such comet incorporates, at the very least, a few billion viable bacteria, and these bacteria are quickly reactivated and begin to replicate in the warm interior regions of the comets, thus producing vast numbers of progeny. As a fully-fledged stellar or planetary system develops, comets that plunge into the inner regions of the system release vast quantities of bacteria. Some of the evaporated bacterial material is returned into the interstellar medium. New stars and star systems form and whole cycle continues with a positive feedback of biologically processed material.

6 Oldest Life on Earth

Along with the accumulation of astronomical evidence supporting panspermia in one form or another there has also been evidence from geology. 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 pummeled by comet and meteorite impacts³³. 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. Whilst the early epoch of heavy bombardment would not have been conducive to prebiotic chemistry, it would nevertheless have offered ample scope and many occasions for the transfer of cometary life to Earth. It is interesting to note that this mechanism for transferring life from comets to Earth would permit some types of microbial life adapted to high pressures and subsurface conditions to become trapped in a stable way. As the impacts of comets and asteroids continued to add material to the Earth's crust in the last stages of the "late accretion epoch" a deep hot biosphere¹⁴, such as

we now have, would easily have been generated. So also could microbial life in deep sea thermal vents be explained as representing a primordial habitat that accommodated the most heat resistant of the microbes that arrived from space.

7. More evidence of microbiology outside the Earth

We have discussed earlier how modern microbiology has yielded a wealth of new discoveries relating to ‘unearthly properties’ of microorganisms. Furthermore, from recent explorations of the solar system we know that other planetary bodies besides Earth might have conditions appropriate to serve as habitats for microbial life. For instance, the Jovian satellite Europa, with growing evidence of its subsurface oceans beneath a frozen crust, provides many opportunities for a highly developed microbiota. Life may even be present in the clouds of Venus. Whilst the surface of Venus is too hot to sustain life, there is an intriguing possibility of an aerobiology thriving in the Venusian clouds. Dirk Schulze-Makuch and his colleagues have recently pointed out that 30 miles above the surface there are droplets of water and chemical tell-tale signs of life. They had expected to find high levels of carbon monoxide, but instead found hydrogen sulphide and sulphur dioxide, gases normally not found together and also carbonyl sulphide, a gas so difficult to produce by inorganic chemistry that it is generally considered to be a marker for living organisms. Likewise with new evidence of liquid water on Mars, there could be plenty of scope for microbial life in secluded subsurface niches.

According to theory described in this paper life on Earth began with the introduction of microorganisms from comets. It is clear, however, that this process could not have stopped at some distant time in the past. Comets have been with us throughout, and the Earth has continued to plough through interplanetary and cometary dust. In our view the evolution of terrestrial life is controlled and directed by the continuing input of cometary debris in the form of bacteria, fragments of bacteria, nanobacteria and smaller particles such as viruses and viroids. It is well known that viral genes sometimes come to be included in the genomes of cellular lifeforms, and that such genes could serve as potential for further evolution. Without this input of cometary genes life on Earth could not have evolved beyond the stage of a simple ancestral microbe.

There are several recent reports of genes that appear to be older, when dated by the rate of sequence variation, than the composite systems or species, in whose genomes they are included^{34,35}. Other reports show that genes required by more highly evolved species may reside without evident function in the genomes of prokaryotes³⁶ or viruses³⁷. One cannot help but notice that these findings corroborate the concept of cosmic bacteria and cosmic genes.

7. Present-day tests

A direct way to test the theory of cometary panspermia is to examine a sample of cometary material under the microscope and search for signs of microbial life. Comets are literally at our doorstep and the technology to carry out the relevant microbiological experiments has been available for at least a decade. The basic procedure would involve collection of cometary material as it enters the stratosphere, with suitable precautions being taken to eliminate spurious contamination from terrestrial sources, and then examine the samples for

extraterrestrial microorganisms. With a daily input of cometary debris averaging some 100 tonnes, the possibility of detecting infalling microbes must surely exist.

The earliest experiments to search the upper atmosphere for microorganisms were carried out using high altitude balloons in the early to mid-1960's. Although microbiological techniques available at the time were primitive compared to the present, there were already some intriguing indications of the presence of extraterrestrial microbes in air samples collected at heights of 30 km and above³⁸. Positive detection of microorganisms at 39 km and a population density that increased with height pointed to a possible extraterrestrial source. Not surprisingly these early results were not taken seriously, nor were they followed up at a later date by NASA with more refined experiments as the relevant microbiological techniques evolved.

The sample return mission "Stardust", which was launched on 7 February 1999 heading to Comet Wildt-2 (rendezvous date, 2 January 2004; return 2006) was conceived and planned before a change of attitude to panspermia took place. In the event no microbiological experiments as such were catered for. The comet dust is to be captured in a "particle catcher" filled with aerogel, a material of extremely low density. The hope is that the aerogel would act as a soft landing cushion to show down particles from an initial relative speed of 6.1 km/s to rest fairly gently, without significantly modifying original chemical structures. The thinking behind the experiment was to bring back prebiotic organic molecules. No provisions were made for the possibility that living cells might be present, so the best one might hope for when we get samples back in 2006 is the intervention of serendipity. Perhaps one might find evidence of "dead bacteria" or other clues for life in the molecules that are recovered.

The stratospheric collection experiments of the 1960's have also been resumed by the Indian Space Research Organisation (ISRO) in collaboration with groups at Cardiff and Sheffield. The aim was to collect stratospheric air aseptically, and to examine it in the laboratory for signs of life³⁹. The sample collection was done using a number of specially manufactured sterilized stainless steel cylinders that were evacuated to almost zero pressures and fitted with valves that could be open and shut at different heights in the atmosphere. An assembly of such cylinders was suspended in a liquid Ne environment to keep them at cryogenic temperatures, and the entire payload launched from the TATA Institute Balloon launching facility in Hyderabad, India on 20 January, 2001. As the valves of the cylinders are opened upon ground telecommand at predetermined heights, ambient air rushes in to fill the vacuum, building up high pressures within the cylinders. The valves are shut after a prescribed length of time, the cylinders hermetically sealed and 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. In the first phase of this investigation evidence for the presence of clumps of viable cells were discovered in air samples collected from as high as 41 kilometres, well above the local tropopause (16 km), above which no aerosols from lower down would normally be transported^{40,41}. The detection was made using a fluorescent dyes which are only taken up by the membranes of living cells. When the isolate treated with the dye is examined under an

epifluorescence microscope the picture on the left of Fig. 5 is obtained. The picture on the right is an image from an electron microscope which shows a similar structure comprised of cocci and rods. The variation with height of the distribution of such cells indicates strongly that the clumps of bacterial cells are falling from space. Dr. Milton Wainwright of the University of Sheffield was further able to isolate an culture two organisms: one micococcus and one microfungus closely related to known species which must therefore have fallen from the skies. The daily input of such biological material is provisionally estimated to be in the range one third to one tonne over the entire planet.

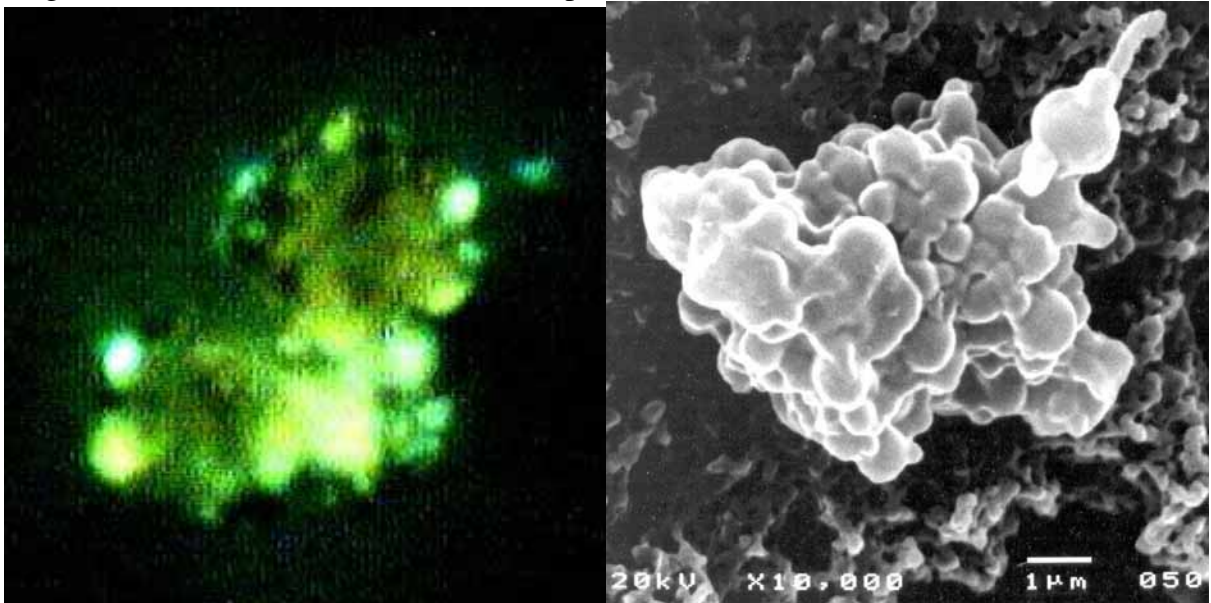


Fig. 5: Left: Clump of viable bacteria fluorescing in cyanine dye
Right: Scanning Electron Microscope picture of similar structure showing clump of cocci and a rod

Work to verify these results are in progress, with ISRO launching a new balloon-borne cryosampler in April 2005. If these findings are confirmed panspermia would cease to be a theory, it would have become a fact.

8. Distribution of life beyond the galaxy

The transfer of life across extragalactic distances requires the pre-existence of the elements C,N,O and other metals in adequate quantity, which implies access to regions where star-formation is under way. Spectroscopic studies of nearby galaxies have also shown evidence of advanced stages of nucleosynthesis and chemical evolution involving large quantities of carbonaceous material suitable as a feedstock for life, often including evidence of CO and H₂CO and other organic molecules in the gas phase.

The most efficient intergalactic transport of biological information can be achieved with microbes attached onto iron whiskers, such as are important for explaining aspects of the cosmic microwave background. Such metallic whiskers have diameters typically 0.02µm and lengths about a millimetre and they condense naturally in expanding envelopes of supernovae, as metallic vapours cool⁴². These whiskers, along with their microbial hitch-

hikers, are very strongly repelled by the infrared radiation from parent galaxies, reaching typical speeds of $\sim 10^4$ km/s in intergalactic space. Even with the minutest fraction of surviving biological “messages” attached to fast moving whiskers in this way, biology could diffuse through a radius of ~ 50 Mpc of intergalactic space, a volume occupied by $\sim 10^6$ galaxies, in a mere Earth age, $\sim 4.7 \times 10^9$ years.

From an observational point of view the clearest signal that may be indicative of biology is perhaps the $\lambda 2175\text{\AA}$ ultraviolet feature of interstellar dust. The $\lambda 2175\text{\AA}$ feature has been found in dust associated with both the SMC, LMC and a few nearby galaxies including M31, where observation of this band was feasible^{43,44}.

The most dramatic recent discovery is the presence of the 2175Å band in the lens galaxy of the gravitational lens SBS0909+532 which has a redshift of $z=0.83$ (Motta et al⁴⁵). The extinction curve for this galaxy is reproduced in Fig. 6, with the dashed curve representing a scattering background attributed to hollow bacterial grains.

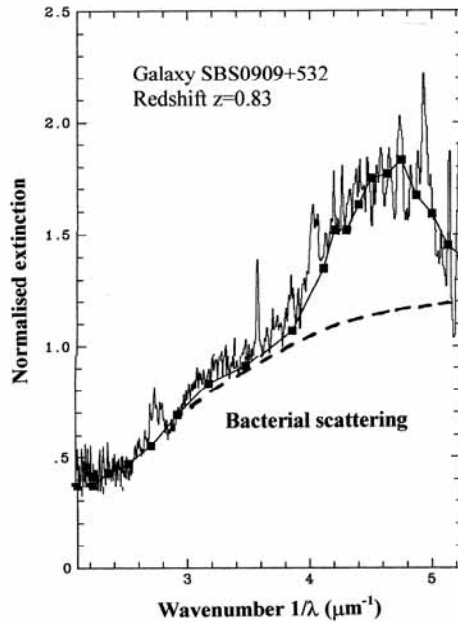


Fig. 6. The continuous line is the extinction curve for the gravitational lens galaxy SBS0909+532 excluding well-defined spectral lines due to MgII, CIII and CIV (Motta et al⁴⁵). The dashed curve is the scattering background attributed to bacterial particles.

The excess absorption over and above this scattering background, normalised to unity at the peak, is plotted as the points with error bars in Fig.7. The curve in this figure shows the absorption of biological aromatic molecules similarly normalised⁴⁶.

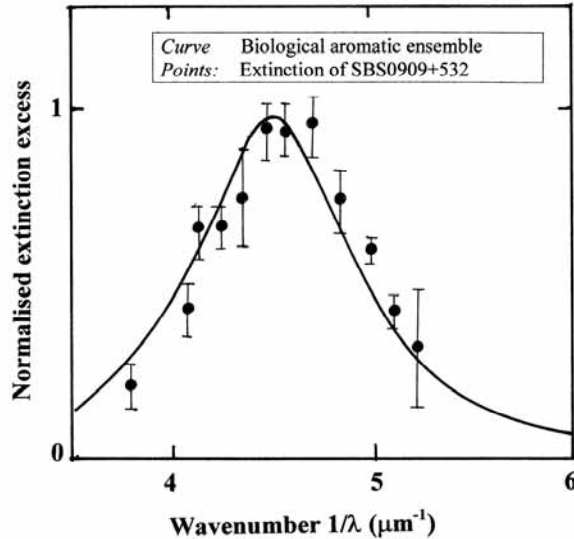


Figure 7. The curve is the normalised absorption coefficient of an ensemble of 115 biological aromatic molecules. The points are the observations of the galaxy SBS0909-532 due to Motta et al⁴⁵).

The correspondence between the astronomical data and the model in Fig. 7 can be interpreted as strong evidence for biology prevailing at redshifts $z \approx 0.83$, that is to a distance $D \approx cz/H \sim 2.5\text{Gpc}$, assuming a Hubble constant of 100 km/s per Mpc. The $3.3\mu\text{m}$ infrared emission band and other indications of biological-type organics have also been observed in extragalactic sources (including the galaxy Antennae referred to above), and particularly starburst galaxies upto redshifts $z \sim 0.2$. All such data are consistent with the spread of microbial life encompassing a significant fraction of the radius of the observable universe.

REFERENCES

1. Oparin, A.I., *The Origin of Life*, transl by S. Margulis, Dover. 1953; J.B.S. Haldane, *The Origin of Life*, Chatto and Windys. 1929
2. Miller, S.L., *Science* 117, 528. 1953
3. Margulis, L., As quoted by Horgan, J., in *End of Science*, Ch.5 (Addison Wesley, Publ), 1996
4. Hoyle, F. and Wickramasinghe, N.C., In *Comets and the Origin of Life* (ed. C. Ponnamperna), D. Reidel, p. 227, 1981
5. Hoyle, F. and Wickramasinghe, N.C., *Astronomical Origins of Life: Steps towards Panspermia* (Kluwer Academic Publ), 1999
6. Pasteur, L., *C.R.Acad.Sci.*, 45, 913-916, 1857
7. Pasteur, L., *C.R.Acad.Sci.*, 45, 1032-1036, 1857
8. von Helmholtz, H., In W. Thomson & P.G. Tait (eds) *Handbuch de Theortetische Physik*, Vol.1. Pt.2. Brancscheig. 1874
9. Thomson, W., *British Association for the Advancement of Science, Presidential Address*, London. 1871
10. Arrhenius, S., *Worlds in the Making*, Harper, Lond. 1908

11. Becquerel, P., *Bull.Soc.Astron.*, 38, 393. 1924
12. Mileikowsky, C., et al, *Icarus*, 145, 391, 2000
13. Wickramasinghe, N.C. and Wickramasinghe, J.T., *Astrophys.Sp.Sci*, in press, 2003
14. Gold, T., *Proc.Natl.Acad.Sci.*,89, 6045-6049, 1992
15. Overmann, J., Cypionka, H. and Pfennig, N., *Limnol.Oceanogr.*, 37 (1), 150-155, 1992
16. Secker, J., Wesson, P.S. and Lepock, J.R., *Astrophys.Sp.Sci.* 329, 1, 1994
17. Christensen, E.A., *Acta Path. et Microbiol. Scandinavia*, 61, 483, 1964
18. Lewis, N.F., *J. Gen. Microbiol*, 66, 29, 1971
19. Hornek, G. et al., *Adv.Space Res.*, 14, 41, 1994
20. Cano, R.J. and Borucki, M., *Science*, 268, 1060, 1995
21. Lambert, L.H.. et al, *Int. J. Syst. Bact.*, 48, 511, 1998
22. Greenblatt, C.L., et al, *Microbial Ecology*, 38, 58, 1999
23. Vreeland, R.H., Rosenzweig, W.D. and Powers, D., *Nature*, 407, 897-900, 2000
24. Hoyle, F. and Wickramasinghe, N.C., *The Theory of Cosmic Grains*, Kluwer. 1990
25. Wickramasinghe, N.C., *Nature* 252, 462. 1974
26. Allen, D.A. and Wickramasinghe, D.T., *Nature*, 294, 239. 1981
27. Wickramasinghe, N.C., In *Infrared Astronomy*, p.303, ed. By A. Mampaso et al,
28. Claus, G., Nagy, B. and Europa, D.L., *Ann. NY Acad. Sci.*, 108, 580.1963
29. Pflug, H.D., In *Fundamental Studies and the Future of Science*, ed. C. Wickramasinghe, Univ. College Cardiff Press. 1984
30. Hoover, R.B., *Proc. SPIE Conference on Instruments, Methods, and Missions for the Investigation of Extraterrestrial Microorganisms*, 3111, 115-136, 1997Cambridge University Press. 1993
31. Hoover, R.B., Rozanoz. A.Y., Jerman, G.A., 2003, *Proc. SPIE*, Vol 5163, in press, 2003
32. McKay, D.S., et al., *Science*, 273, 924. 1996
33. Mojzsis, S.J. et al, *Nature* 384, 55. 1996
34. Kumar, S. and Blair Hedges, S., *Nature*, 392, 917. 1998
35. Cooper, A. and Penny, D., *Science*, 275, 1109. 1997
36. Bult, C.J., et al., *Science*, 273, 1058. 1996
37. Smith, M.C., et al., *Science*, 279, 1834. 1998
38. Bruch, C.W., in *Airborne Microbes Symposium of the Society of Microbiology* (eds P.H. Gregory and J.L.Monteith) p.345, Cambridge University Press, 1967
39. Narlikar, J.V., Ramadurai, S., Bhargava, P., Damle, S.V., Wickramasinghe, N.C., Lloyd, D., Hoyle, F. and Wallis, D.H., *Proc. SPIE Conference on Instruments, Methods, and Missions for Astrobiology*, Vol.3441, 301-305, 1998
40. Harris, M. J., et al, *Proc. SPIE Conf.*, 4495, 192, 2002
41. Wainwright, M., Wickramasinghe, N.C., Narlikar, J.V., P. Rajaratnam and Perkins, J. *Proc SPIE*, Vol 5163, in press 2003
42. Hoyle, F. and Wickramasinghe, N.C., 1988. *Astrophys.Sp.Sci.*, 147, 245
43. Fitzpatrick, E.L., 1986. *Astron. J.*, 92, 1068
44. Biachi, L., Clayton, G.C., Bohlin, R.C., Hutchings, J.B. and Massey, P., 1996. *Astrophys.J.*, 471, 203
45. Motta, V., Mediavilla, E., Munoz, J.A., Falco, E., Kochanek, C.S., Arribas, S., Garcia-Lorenzo, B., Osoz, A., and Serra-Ricart, M., 2002. *Astrophys. J.*, in press (arXiv:astro-ph/0204130 v1 8 April)
46. Wickramasinghe, N.C., Hoyle, F., and Al-Jabori, T., 1989. *Astrophys.Sp.Sci.*, 158, 135

