Cometss - a Vehicle for Panspermia[1,2]

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[1]*In* C. Ponttampengtna (ed.), Comets and the Origin of Life, pp 227-239,
D. Reidel Publishing Company, 1981; originally issued in the Cardiff Astrophysics Preprint Series
[2]First explicit exposition of our cometary panspermia theory.

Abstract: Arguments are given for life being a cosmic phenomenon. The physical and chemical conditions associated with comets favour the hypothesis that comets carry, amplify and disperse life throughout the universe.

The earliest beginnings of panspermia are buried in the mists of antiquity. Anaxagoras, the Greek philosopher who lived around 500 BC, and who discovered the true nature of eclipses, is credited to have been the first person to state clearly the principle of panspermia - that the seeds of plant and animal life are inherent in the cosmos, and that they take root whenever the conditions become favourable. The great resurgence of this idea occurred a little more than a century ago. It is not generally remembered that this resurgence took place largely due to the work of Louis Pasteur. Panspermia was in fact a natural corollary of Pasteur's demonstration that life would seem always to be derived from life. Thus the physicist, Helmholtz, wrote in 1874 that:

"It appears to me to be a 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 ..."

If we look at the geological record there is no possible case for a denial of the principle that life can only be derived from life all the way back to 3.83 by before the present time. About 3.83 by ago the Isua sediments were deposited, and these sediments contain clear evidence for photosynthetic life (Pflug,1979). At an earlier epoch, however, the Earth was most probably sterile. From recent lunar data we know that both the Moon and the Earth received meteoritic bombardment, so there could not have been a stable crust or an atmosphere on the Earth until the cessation of impacts about 3.9 by ago. Thus the first 600 my of the Earth's history would have to be written off as regards life.

The situation before 3.83 by leads to two distinct logical possibilities:

(1) There is a requirement for a chemical evolution leading to the spontaneous generation of life on the Earth at about 3.83 by ago.

(2) There was no spontaneous generation on the Earth and the principle that life could only be derived from life was maintained throughout by means of panspermia. The seeds of life took root at the first moment the physical condition became favourable, which was

3.83 by ago.

The overwhelming majority of scientists have opted for (1), although there is of course no *a priori* reason for preferring (1) to (2). We shall argue here that (2) is indeed more probable and that the vehicle for the transference of panspermia was most likely to have been the comets.

In assessing the possibility of (1) referred to above much attention has been focussed on the formation of individual biological monomers. Many ingenious experiments, carried out over the years in a number of different laboratories, have shown that the formation of these monomers by inorganic processes may not be too difficult. Nor is it indeed difficult to form non-biological polymers such as, for instance, polypeptides and polynucleotides. But the big question that remains unanswered concerns the origin of the information content of life. The information content of living matter is highly specific in quality and astronomical in quantity. How was this information content acquired from a situation that was initially chaotic? In attempting to tackle this question we believe that there is a simple *reducto ad absurdum* argument that militates strongly against the possibility (1).

It is well known that there are some 1000-2000 enzymes that are crucial over a wide spectrum of life ranging from simple microorganisms all the way up to man. The variation of amino acid sequences in these enzymes from one species to another are, on the whole, rather minor. A number of key positions on these chains are occupied by almost invariable amino acids.

Let's consider now how these enzyme sequences could have been arrived at in a primordial soup on Earth. Consider a soup of twenty biologically important amino acids in equal concentrations. At a conservative estimate, say, ten sites per enzyme are crucial for proper biological function. The number of trial assemblies that are needed to produce a single working enzyme is in excess of $(20)^{10}$, and the probability finding N such enzymes by random assembly is $1:(20)^{10N}$. It is easily seen that we obtain a number of trials exceeding the number of all the atoms in all the stars in the whole universe even before we come to N = 100.

From this numerical difficulty there are *one of three* deductions possible:-

(a) Life is a cosmic phenomenon, *panspermia*.

(b) Life is terrestrial, but its information content contains enormous redundancy by a factor a $(20)^{2000}$ for the case of the enzymes.

(c) Life is terrestrial. It occurs with such a miniscule probability that it is unique to the Earth.

The consensus view at the moment is that (a) is impossible, and that either (b) or (c) has to be true. In our view there is no evidence for (b), (c) is distinctly pre-Copernican and so we are left with (a).

Let us now see how (a) stands up when compared with what we know from biology as well as astronomy. The beginnings of such a comparison are to be found in Svante Arrhenius' classic book “Worlds in the Making”, first published in Swedish in 1904 (Arrhenius, 1907).

Arrhenius followed the logic of Pasteur right through. He considered the possibility that bacterial cells (spores on particular) are lifted out of the gravitational wells of their planets by electromagnetic effects, and then dispersed through space by the action of radiation pressure from stars. For particles of bacterial size (radii of a few tenths of a micron) the force of radiation pressure due to a star like the Sun exceeds gravity. Particles that are freed from planetary gravity are then expelled out from the entire planetary system. In very tenuous gas, such as exists between interstellar gas clouds, such grains can attain speeds ~ 100 km/s and could thus cross the distance between interstellar clouds in less than ~100,000 years.

A difficult bottle-neck in the Arrhenius picture was the requirement for expelled grains to gain re-entry into another stellar planetary system. Just the same force of radiation pressure that expelled grains from one system would also serve to repel grains as they approached a new system. Arrhenius got over this problem by arguing that the entry speed of a grain would be checked at some distance from the star, and if a planet just happened to be at the same point at the same time then a transfer of living cells may occur. But it had to be admitted that this was a rare event, and Arrhenius guessed at a number of cells entering the Earth at the present time as being no more than a few dozen every year.

We ourselves have argued for a process that is far more efficient than this for amplifying life and for dispersing it on a cosmic scale (Hoyle and Wickramasinghe, 1981). We first note that the overall atomic composition of comets appears to agree well with the composition of living material, as pointed out by Delsemme (1981). Next we note that organic matter and water are present in comets so there is potentially an excellent culture medium for some types of microorganisms.

We have argued for comets having liquid interiors due to the slow release of chemical and radioactive heat sources (e.g. ^{26}Al) that were present in the material that formed the comets (Hoyle and Wickramasinghe, 1978). Once melted the interior remains melted for timeshares of a geological order, but a great deal of biology could happen even in years. The conditions in melted cometary interiors are well suited to the amplification of autotrophic anaerobic bacteria. And the frozen condition generally prevailing in comets is appropriate for the indefinite preservation of almost all forms of microorganisms known to exist on the Earth today.

Next we turn to the cosmogony of the solar system in relation to some of the ideas we have considered. Suppose that some population of bacterial cells were present in the parent aloud from which the Sun and planets condensed. In our view the bulk of the material of the inner planets accumulated at relatively high temperatures during the early superluminous phase of the Sun, so any biology present in this material would have been destroyed. The outer planets Uranus and Neptune accreted from cooler cometary bodies. The final stages of the accumulation of these comet-type bodies involved the mopping up of hard-frozen bacterial cells that were present in the original parent cloud. On the road to forming Uranus and Neptune, liquid water would have been retained in abundance for considerable periods of time on a multitude of planetary-sized objects. In such watery objects on the outer regions of the solar system living cells could have been explosively amplified in number. A fraction of these cells would have been ejected out of the entire solar system by the effect of radiation pressure, and a fraction retained to be mopped up by comets which we think might have originated at about the orbital distances of the outermost planets. Such cells would have an almost indefinite persistence within comets.

Cells are now spewed off along with volatile gases when comets become deflected into the inner regions of the solar system. Some of these cells could find their way onto planets within the solar system, but the majority would be expelled away into interstellar space.

Cells expelled from the solar system, either now or in the past, are not easily injected directly onto planets of another distant stellar system. They are very efficiently slowed down and stopped in the first dense gas cloud that is encountered. Bacterial cells are amplified on a cosmic scale by the feed back loop shown in Fig. 1.

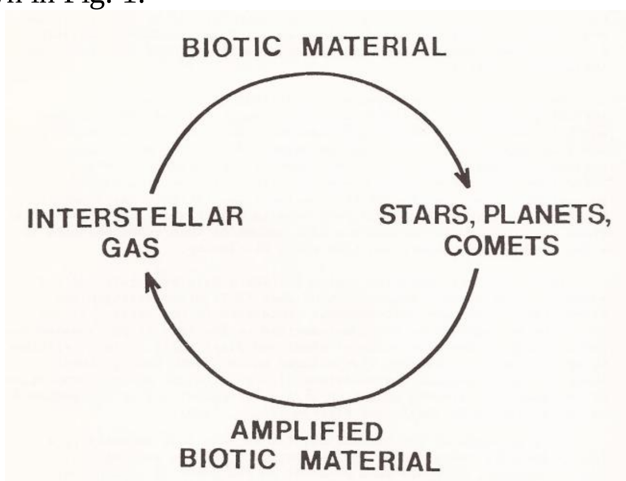


Fig. 1 Cosmic amplification cycle for biology

For the solar system an estimated 1-10% of the mass of the Sun was returned to the interstellar gas. The bulk of this returned material was of course H and He, but in our view about 1% could be in the form of biological material processed in comets. Each star that is formed in the galaxy is a potential circuit in the feedback loop of Fig.1. With 10^{11} such circuits , 10^{7}-10^{8} M_{SUN} of biotic material is produced in the galaxy. This is indeed the entire mass of dust grains that is known to exist in the spiral arms of the galaxy.

In view of what has been said we shall now explore the radical hypothesis that interstellar grains (or a large fraction of them) are bacteria. If by “bacteria” one means the well-studied terrestrial bacteria, this hypothesis is quite precise. Under interstellar conditions a bacillus loses free water as indicated in Fig. 2.

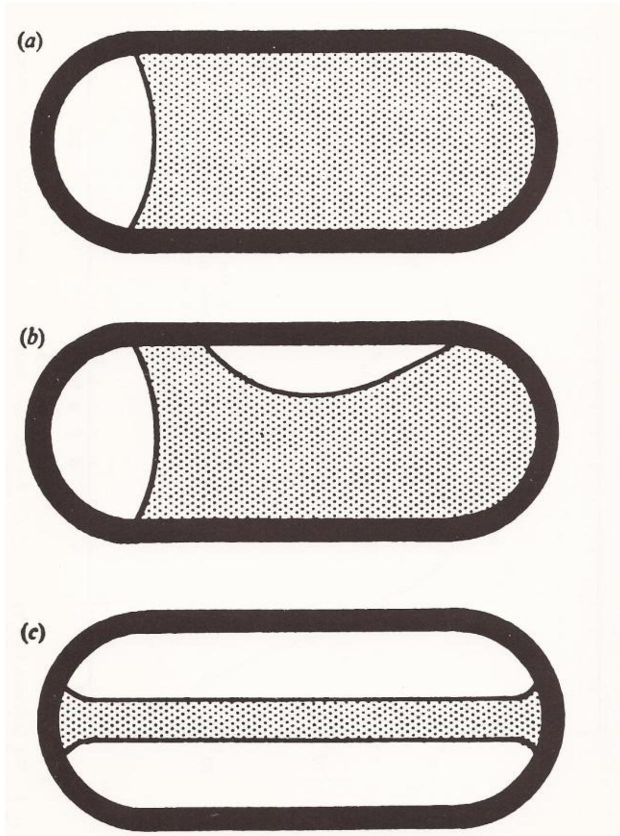


Fig.2. Several stages of dehydration of a bacillus

Now, if we take the known size-distribution function for terrestrial bacteria, and with *no other* assumptions we obtain a good match to the observed wavelength dependence of extinction in the visual spectral region (Hoyle and Wickramasinghe, 1979). The well-known constancy or near constancy of this part of the extinction curve is now understood in terms of the reproducible properties of microbiology. For an inorganic grain model with free surfaces and variable gas densities a constancy of size has always been hard to understand. For a particular grain type one had to postulate a size parameter that remained fixed to a few percent everywhere, and this was a difficulty.

In the infrared spectral region too there have been quite definite pointers to an organic composition of dust (D.T. Wickramasinghe and Allen, 1980). The two most abundant molecules in the galaxy, H_2 and CO, could be regarded as being polymerized (via H_2CO) in the form of a polysaccharide, particularly in the cell walls of plant and algal cells. Since cellulose (a polysaccharide) is by far the most abundant biosubstance on the Earth the agreement shown in Fig. 3 between the behaviour of dry cellulose and the properties of the galactic infrared source OH 26.5+0.6 cannot easily be dismissed as being fortuitous (Hoyle and W|ckramasinghe, 1980).

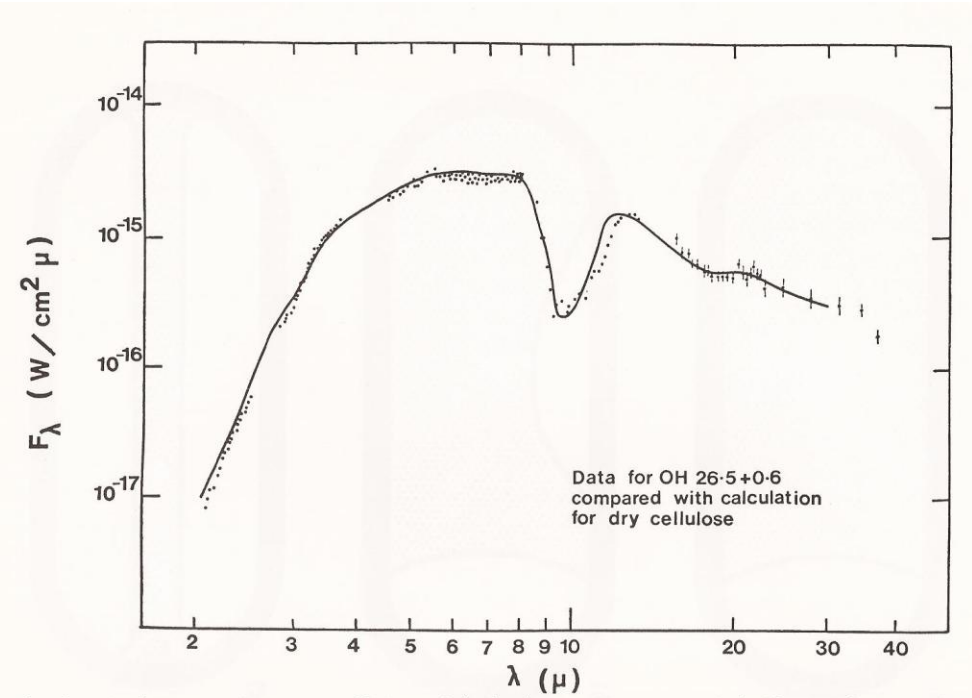
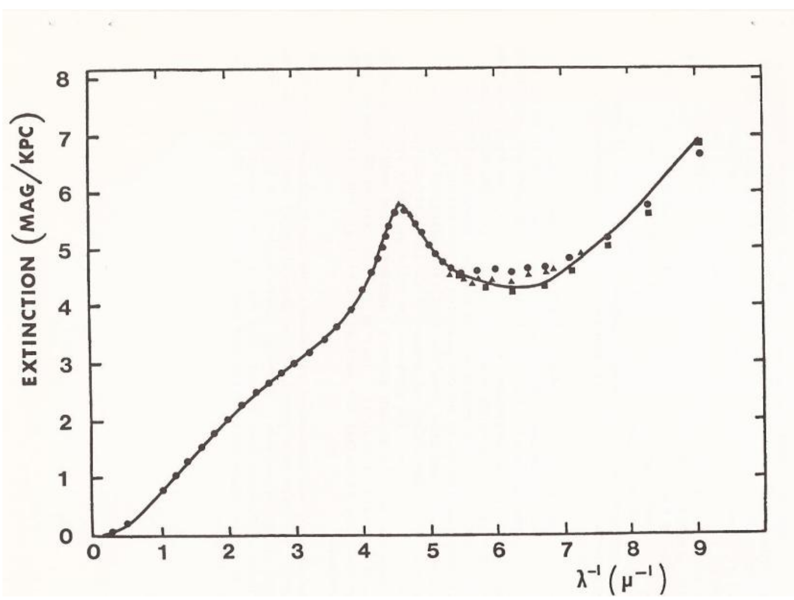


Fig. 3. The infrared flux from OH26.5+0.6 (points) matched to a model (solid curve) where the emitting material is comprised of dry cellulose.

Turning again to the extinction, let us note that essentially all the condensible resources of the interstellar gas are used up in the dust. Moreover, it would seem peculiar on the point of view of any inorganic theory that this matter has been used with the greatest possible quantum efficiency to block out optical and UV radiation experienced by any particular grain within an interstellar gas cloud.



Fig, 4. The best fit that can be achieved between the data points giving extinction per kiloparsec as a function of wavenumber and a model involving 65% by mass of bacilli, 25% by mases of micoplasmas and 10% by mass of graphite spheres.

The full range of available data on extinction (combining UV data from OAO2, ESA and TD1 as well as near infrared and optical data) is shown in Fig. 4. The solid curve, which gives an excellent fit to the data is for a three component mixture of particles. About 65% of the mass in this mixture comes from hollow dielectric cylinders with average refractive index m = 1.16-0.015i which are used to model the known size and composition distribution of terrestrial spore-forming bacteria. These grains which have an average radius of 1/3μm contribute mainly to visual extinction. A second component is comprised of presumed biological particles of radii 0.04 μm (refractive index, m = 1.5) making up nearly 25% of the grain mass. These grains contribute to the rising far UV part of the extinction. A third component making up a 10% of the mass is a population of graphite spheres of radii 0.02μm. We argue that these particles form from the anaerobic degradation of biological particles, analogous to the formation of coal and graphite ln biological deposits on the Earth. These grains contribute to the middle UV extinction including the peak of extinction at 2200A.

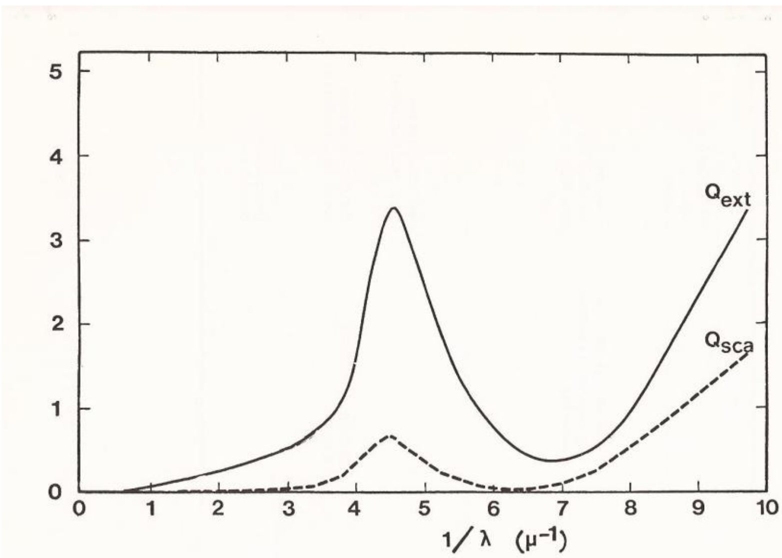


Fig. 5. The scattering and extinction efficiency factors for graphite spheres spheres of radii 0.02μm.

The absorption properties of graphite spheres of radii 0.02 μm are shown in Fig. 5. The broad absorption peak shown here would seem to have a profound relevance to panspermia. Ultraviolet radiation at wavelengths around 2600A is known to be deleterious to biology (although of course the occurrence of the well-known enzymic repair process in cells seeks under suitable growth conditions to unzip the pyrimidine dimers caused by UV radiation). A living cell within an interstellar cloud will largely be shielded from stellar ultraviolet radiation by the effect of graphite. The shielding could be due to separate graphite particles (wholly degenerate cells) in the general mix, or to graphitisation that occurs on the surfaces of individual cells. Indeed a bacterial cell with a 0.05 μm thick coating of any type of graphitic material would be rendered almost completely impervious to ultraviolet radiation in its interior. So it could be said that cosmic biology is preserved by the slow and inevitable degradation of itself - but only a minor fraction < 10% is degraded before the degradation process cuts off.

Table 1, adapted from Vallentyne (1963) shows the range of tolerance for microorganisms subject to various types of environmental stress. The temperature effects are well known. The survival properties of certain types of microorganisms after large doses of ionising radiation would be a mystery to any Earth bound theory of life. The atmosphere absorbs essentially all the x-rays at low energy, which are the main source of ionising radiation at the position of the Earth. And this situation must have been true from the earliest geological epoch when life was possible. The effect of x-rays is to cause strand breaks in the nuclear DNA of cells. The presence in cells af highly specific enzymes that can put the broken strands together is not easily understood in terms of terrestrial biology. Just as for the case of UV damage, the repair enzymes are redundant for terrestrial biology. but vital of course for panspermia.

According to our version of panspermia the Earth receives over 10^{18} viable cells per year as a result of the deposition of cometary particles at the top of the atmosphere. Although there would be a large fraction that perishes, of those that do not, the various environments on the Earth pick up the types best suited for replication under the conditions that locally prevail.

Table 1 (adapted from Vallentyne)

Environmental Limits for Growth and Reproduction of Microorganisms

Factor	Lower Limit	Upper Limit
Temperature	$-18^{\circ}C$ (Survival only down to $-270^{\circ}C$)	$104^{\circ}C$ (sulfate reducing bacteria at 1000 atmospheres hydrostatic pressure)
Eh	− 450 mv (at pH = 9.5 for sulfate reducing bacteria)	+ 850 mv (at pH = 3 for iron bacteria)
pH	0	>13
Water activity (a_w)	0.65	–
Hydrostatic pressure	~ 0	1400 atmospheres (deep sea bacteria)
Salinity	Double distilled water	Saturated brines (Dead Sea bacteria)
Ionising Radiation (recovery after)		$\sim 10^6$ rad (micrococcus Radiodurans)

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