

Directed Panspermia

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It now seems unlikely that extraterrestrial living organisms could have reached the earth either as spores driven by the radiation pressure from another star or as living organisms imbedded in a meteorite. As an alternative to these nineteenth-century mechanisms, we have considered Directed Panspermia, the theory that organisms were deliberately transmitted to the earth by intelligent beings on another planet. We conclude that it is possible that life reached the earth in this way, but that the scientific evidence is inadequate at the present time to say anything about the probability. We draw attention to the kinds of evidence that might throw additional light on the topic.

INTRODUCTION

It was not until the middle of the nineteenth century that Pasteur and Tyndall completed the demonstration that spontaneous generation is not occurring on the Earth nowadays. Darwin and a number of other biologists concluded that life must have evolved here long ago when conditions were more favourable. A number of scientists, however, drew a quite different conclusion. They supposed that if life does not evolve from terrestrial nonliving matter nowadays, it may never have done so. Hence, they argued, life reached the earth as an "infection" from another planet (Oparin, 1957).

Arrhenius (1908) proposed that spores had been driven here by the pressure of the light from the central star of another planetary system. His theory is known as Panspermia. Kelvin suggested that the first organisms reached the Earth in a meteorite. Neither of these theories is absurd, but both can be subjected to severe criticism. Sagan (Shklovski and Sagan, 1966; Sagan and Whitehall, 1973) has shown that any known type of radiation-

resistant spore would receive so large a dose of radiation during its journey to the Earth from another Solar System that it would be extremely unlikely to remain viable. The probability that sufficiently massive objects escape from a Solar System and arrive on the planet of another one is considered to be so small that it is unlikely that a single meteorite of extrasolar origin has ever reached the surface of the Earth (Sagan, private communication). These arguments may not be conclusive, but they argue against the "infective" theories of the origins of life that were proposed in the nineteenth century.

It has also been argued that "infective" theories of the origins of terrestrial life should be rejected because they do no more than transfer the problem of origins to another planet. This view is mistaken; the historical facts are important in their own right. For all we know there may be other types of planet on which the origin of life *ab initio* is greatly more probable than on our own. For example, such a planet may possess a mineral, or compound, of crucial catalytic importance, which is rare on

Earth. It is thus important to know whether primitive organisms evolved here or whether they arrived here from somewhere else. Here we reexamine this problem in the light of more recent biological and astronomical information.

OUR PRESENT KNOWLEDGE OF THE GALAXY

The local galactic system is estimated to be about 13×10^9 yr old (See Metz, 1972). The first generation of stars, because they were formed from light elements, are unlikely to have been accompanied by planets. However, some second generation stars not unlike the Sun must have formed within 2×10^9 yr of the origin of the galaxy (Blaauw and Schmidt, 1965). Thus it is quite probable that planets not unlike the Earth existed as much as 6.5×10^9 yr before the formation of our own Solar System.

We know that not much more than 4×10^9 yr elapsed between the appearance of life on the Earth (wherever it came from) and the development of our own technological society. The time available makes it possible, therefore, that technological societies existed elsewhere in the galaxy *even before the formation of the Earth*. We should, therefore, consider a new "infective" theory, namely that a

primitive form of life was deliberately planted on the Earth by a technologically advanced society on another planet.

Are there many planets which could be infected with some chance of success? It is believed, though the evidence is weak and indirect, that in the galaxy many stars, of a size not dissimilar to our Sun, have planets, on a fair fraction of which temperatures are suitable for a form of life based on carbon chemistry and liquid water, as ours is. Experimental studies of the production of organic chemicals under prebiotic conditions make it seem likely that a rich prebiotic soup accumulates on a high proportion of such Earthlike planets. Unfortunately, we know next to nothing about the probability that life evolves within a few billion years in such a soup, either on our own special Earth, or still less on other Earthlike planets.

If the probability that life evolves in a suitable environment is low we may be able to prove that we are likely to be alone in the galaxy (Universe). If it is high the galaxy may be pullulating with life of many different forms. At the moment we have no means at all of knowing which of these alternatives is correct. We are thus free to postulate that there have been (and still are) many places in the galaxy where life could exist but that, in at least a fraction of them, after several billion years the chemical systems had not evolved to the point of self-replication and natural selection. Such planets, if they do exist, would form an excellent breeding ground for external microorganisms. Note that because many if not all such planets would have a reducing atmosphere they would not be very hospitable to the higher forms of life as we know them on Earth.

OUR PROPOSAL

The possibility that terrestrial life derives from the deliberate activity of an extraterrestrial society has often been considered in science fiction and more or less light-heartedly in a number of scientific papers. For example, Gold (1960) has suggested that we might have evolved from the microorganisms inadvertently

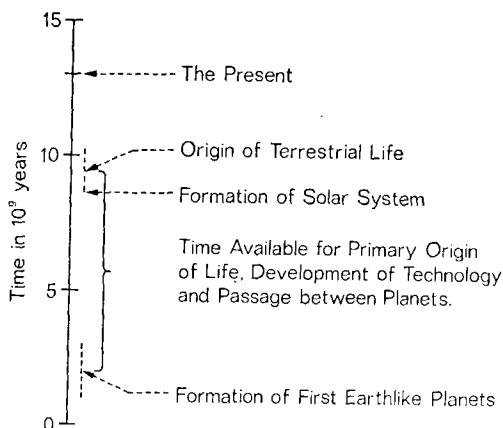


FIG. 1. An approximate time-scale for the events discussed in the paper. To simplify illustration the age of the galaxy has been somewhat arbitrarily taken as 13×10^9 yr.

left behind by some previous visitors from another planet (for example, in their garbage). Here we wish to examine a very specific form of Directed Panspermia. Could life have started on Earth as a result of infection by microorganisms sent here deliberately by a technological society on another planet, by means of a special long-range unmanned spaceship? To show that this is not totally implausible we shall use the theorem of detailed cosmic reversibility; if we are capable of infecting an as yet lifeless extrasolar planet, then, given that the time was available, another technological society might well have infected our planet when it was still lifeless.

THE PROPOSED SPACESHIP

The spaceship would carry large samples of a number of microorganisms, each having different but simple nutritional requirements, for example blue-green algae, which could grow on CO_2 and water in "sunlight." A payload of 1000 kg might be made up of 10 samples each containing 10^{16} microorganisms, or 100 samples each of 10^{15} microorganisms.

It would not be necessary to accelerate the spaceship to extremely high velocities, since its time of arrival would not be important. The radius of our galaxy is about 10^5 light years, so we could infect most planets in the galaxy within 10^8 yr by means of a spaceship traveling at only one-thousandth of the velocity of light. Several thousand stars are within a hundred light years of the Earth and could be reached within as little as a million years by a spaceship travelling at only 60,000 mph, or within 10,000 yr if a speed of one-hundredth of that of light were possible.

The technology required to carry out such an act of interstellar pollution is not available at the present time. However, it seems likely that the improvements in astronomical techniques will permit the location of extrasolar planets within the next few decades. Similarly, the problem of sending spaceships to other stars, at velocities low compared with that of light, should not prove insoluble once workable

nuclear engines are available. This again is likely to be within a few decades. The most difficult problem would be presented by the long flight times; it is not clear how long it will be before we can build components that would survive in space for periods of thousands or millions of years.

Although there are some technological problems associated with the distribution of the microorganisms in viable form after a long journey through space, none of them seems insuperable. Some radiation protection could be provided during the journey. Suitable packaging should guarantee that small samples, including some viable organisms, would be widely distributed. The question of how long microorganisms, and in particular bacterial spores, could survive in a spaceship has been considered in a preliminary way by Sneath (1962). He concludes "that life could probably be preserved for periods of more than a million years if suitably protected and maintained at temperatures close to absolute zero." Sagan (1960) has given a comparable estimate of the effects of radiation damage. We conclude that within the foreseeable future we could, if we wished, infect another planet, and hence that it is not out of the question that our planet was infected.

We can in fact go further than this. It may be possible in the future to send either mice or men or elaborate instruments to the planets of other Solar Systems (as so often described in science fiction) but a rocket carrying microorganisms will always have a much greater effective range and so be advantageous if the sole aim is to spread life. This is true for several reasons. The conditions on many planets are likely to favour microorganisms rather than higher organisms. Because of their extremely small size vast numbers of microorganisms can be carried, so much more wastage can be accepted. The ability of microorganisms to survive, without special equipment, both storage for very long periods at low temperatures and also an abrupt change back to room temperatures is also a great advantage. Whatever the potential range for infection by other organisms, microorganisms can almost

certainly be sent further and probably much further.

It should be noted that most of the earliest "fossils" so far recognized are somewhat similar to our present bacteria or blue-green algae. They occur in cherts of various kinds and are estimated to be up to 3×10^9 yr old. This makes it improbable that the Earth was ever infected merely by higher organisms.

MOTIVATION

Next we must ask what motive we might have for polluting other planets. Since we would not derive any direct advantage from such a programme, presumably it would be carried through either as a demonstration of technological capability or, more probably, through some form of missionary zeal.

It seems unlikely that we would deliberately send terrestrial organisms to planets that we believed might already be inhabited. However, in view of the precarious situation on Earth, we might well be tempted to infect other planets if we became convinced that we were alone in the galaxy (Universe).¹ As we have already explained we cannot at the moment estimate the probability of this. The hypothetical senders on another planet may have been able to prove that they were likely to be alone, and to remain so, or they may have reached this conclusion mistakenly. In either case, if they resembled us psychologically, their motivation for polluting the galaxy would be strong, if they believed that all or even the great majority of inhabitable planets could be given life by Directed Panspermia.

The psychology of extraterrestrial societies is no better understood than terrestrial psychology. It is entirely possible that extraterrestrial societies might infect other planets for quite different reasons than those we have suggested. Alternatively, they might be less tempted than we would be, even if they thought

¹ In a somewhat different context the seeding of Venus and other solar planets has been suggested by C. Sagan (1961), and T. Gold, private communication.

that they were alone. The arguments given above, together with the principle of cosmic reversibility, demonstrate the possibility that we have been infected, but do not enable us to estimate the probability.

POSSIBLE BIOLOGICAL EVIDENCE

Infective theories of the origins of terrestrial life could be taken more seriously if they explained aspects of biochemistry or biology that are otherwise difficult to understand. We do not have any strong arguments of this kind, but there are two weak facts that could be relevant.

The chemical composition of living organisms must reflect to some extent the composition of the environment in which they evolved. Thus the presence in living organisms of elements that are extremely rare on the Earth might indicate that life is extraterrestrial in origin. Molybdenum is an essential trace element that plays an important role in many enzymatic reactions, while chromium and nickel are relatively unimportant in biochemistry. The abundance of chromium, nickel, and molybdenum on the Earth are 0.20, 3.16, and 0.02%, respectively. We cannot conclude anything from this single example, since molybdenum may be irreplaceable in some essential reaction—nitrogen fixation, for example. However, if it could be shown that the elements represented in terrestrial living organisms correlate closely with those that are abundant in some class of star—molybdenum stars, for example—we might look more sympathetically at "infective" theories.

Our second example is the genetic code. Several orthodox explanations of the universality of the genetic code can be suggested, but none is generally accepted to be completely convincing. It is a little surprising that organisms with somewhat different codes do not coexist. The universality of the code follows naturally from an "infective" theory of the origins of life. Life on Earth would represent a clone derived from a single extraterrestrial organism. Even if many codes were represented at the primary site where life

began, only a single one might have operated in the organisms used to infect the Earth.

CONCLUSION

In summary, there is adequate time for technological society to have evolved twice in succession. The places in the galaxy where life could start, if seeded, are probably very numerous. We can foresee that we ourselves will be able to construct rockets with sufficient range, delivery ability, and surviving payload if microorganisms are used. Thus the idea of Directed Panspermia cannot at the moment be rejected by any simple argument. It is radically different from the idea that life started here *ab initio* without infection from elsewhere. We have thus two sharply different theories of the origin of life on Earth. Can we choose between them?

At the moment it seems that the experimental evidence is too feeble to make this discrimination. It is difficult to avoid a personal prejudice, one way or the other, but such prejudices find no scientific support of any weight. It is thus important that both theories should be followed up. Work on the supposed terrestrial origin of life is in progress in many laboratories. As far as Directed Panspermia is concerned we can suggest several rather diverse lines of research.

The arguments we have employed here are, of necessity, somewhat sketchy. Thus the detailed design of a long-range spaceship would be worth a careful feasibility study. The spaceship must clearly be able to home on a star, for an object with any appreciable velocity, if dispatched in a random direction, would in almost all cases pass right through the galaxy and out the other side. It must probably have to decelerate as it approached the star, in order to allow the safe delivery of the payload. The packets of microorganisms must be made and dispersed in such a way that they can survive the entry at high velocity into the atmosphere of the planet, and yet be able to dissolve in the oceans. Many useful feasibility studies could be carried out on the engineering points involved.

On the biological side we lack precise

information concerning the life-time of microorganisms held at very low temperatures while traveling through space at relatively high velocities. The rocket would presumably be coasting most of the time so the convenient temperature might approximate to that of space. How serious is radiation damage, given a certain degree of shielding? How many distinct types of organism should be sent and which should they be? Should they collectively be capable of nitrogen fixation, oxidative phosphorylation and photosynthesis? Although many "soups" have been produced artificially in the laboratory, following the pioneer experiments of Miller, as far as we know no careful study has been made to determine which present-day organisms would grow well in them under primitive Earth conditions.

At the same time present-day organisms should be carefully scrutinized to see if they still bear any vestigial traces of extra-terrestrial origin. We have already mentioned the uniformity of the genetic code and the anomalous abundance of molybdenum. These facts amount to very little by themselves but as already stated there may be other as yet unsuspected features which, taken together, might point to a special type of planet as the home of our ancestors.

These enquiries are not trivial, for if successful they could lead to others which would touch us more closely. Are the senders or their descendants still alive? Or have the hazards of 4 billion years been too much for them? Has their star inexorably warmed up and frizzled them, or were they able to colonise a different Solar System with a short-range spaceship? Have they perhaps destroyed themselves, either by too much aggression or too little? The difficulties of placing any form of life on another planetary system are so great that we are unlikely to be their sole descendants. Presumably they would have made many attempts to infect the galaxy. If the range of their rockets were small this might suggest that we have cousins on planets which are not too distant. Perhaps the galaxy is lifeless except for a local village, of which we are one member.

One further point deserves emphasis. We feel strongly that under no circumstances should we risk infecting other planets at the present time. It would be wise to wait until we know far more about the probability of the development of life on extrasolar planets before causing terrestrial organisms to escape from the solar system.

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REFERENCES

- ARRHENIUS, S. (1908). "Worlds in the Making." Harper and Row, New York.
- BLAAUW, A., AND SCHMIDT, M. (1965). "Galactic Structure." University of Chicago Press, Chicago.
- GOLD, T. (May 1960). "Cosmic Garbage" "Air Force and Space Digest", p. 65.
- METZ, W. D. (1972). Reporting a speech by Allan Sandage. *Science* **178**, 600.
- OPARIN, A. I. (1957). "The Origins of Life on Earth." Academic Press, New York, New York (gives a general discussion on Panspermia).
- SAGAN, C. (1960). Biological contamination of the Moon. *Proc. Nat. Acad. Sci.* **46**, 396.
- SAGAN, C. (1961). The planet Venus. *Science* **133**, 849.
- SAGAN, C., AND WHITEHALL, L. (1973). To be submitted to *Icarus*.
- SHKLOVSKII, I. S., AND SAGAN, C. (1966 and 1967). "Intelligent Life in the Universe," p. 207. Holden-Day, San Francisco and Dell Publishing Co., New York.
- SNEATH, P. H. A. (1962). Longevity of microorganisms. *Nature (London)* **195**, 643.