Journal of the British Interplanetary Society, Vol. 32, Pp. 419-423. 1979

DIRECTED PANSPERMIA: A TECHNICAL AND ETHICAL EVALUATION OF SEEDING NEARBY SOLAR SYSTEMS

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Abstract

Advanced solar sail, deployed at appropriate locations in heliocentric space will be capable of ejecting small (payloads of moderately radiation protected biological material from the Solar System at 0.0001-0.001c. For deceleration at the target a low technology device can be provided by silvering both sides of the interstellar sail and aiming directly at a solar-type star. The probability of capture by target planets will be enhanced by the dispersion of pansperms in a circular orbit intersecting with the ecliptic plane in the target ecosphere. Biological criteria for interstellar panspermia selection include radiation resistance, and the microorganisms' nutritional requirements. Interstellar panspermia is proposed on the basis of the following ethical considerations: the moral obligation to insure the survival of the fundamental genetic heritage common to all living organisms; the desire to promote the evolutionary trend of the conquest of novel and more extensive habitats by living matter; and the pursuit of an intuitive drive to affect natural history on a universal scale. An ethical objection is the possibility of interference with indigenous biota. The chances for a destructive interference may be minimized by the proper selection of pansperms.

1. Introduction

The concept of interplanetary or interstellar migration of simple life forms, as a theory for the origin of terrestrial life, can be traced to antiquity. A scientific evaluation of radiopanspermis, or the propagation of microorganisms by stellar radiation pressure, was first given by Arrnheis [1], but later rejected in the grounds that unprotected microoganisms would be destroyed by U.V. radiation [2]. The hypothesis of lithopanspermia, the interstellar transportation of microorganisms entrapped and protected in meteorites [3] was rejected because of the low probability for the capture of meteorites originating in other solar systems [3]. Nevertheless, the panspermia hypothesis was revived by Crick and Orgel [5] who suggested that microbial life may have been spread to new planetary habitats by design, by an early civilization extant in the galaxy at the time of the origin of life on Earth; and that the abundance of trace elements in contemporary organisms could serve as a test for the origin of life in an extraterrestrial environment. Crick and Orgel [5] did not evaluate in detail the technological requirements for engineered interstellar panspermia, though they suggested that a study of the required propulsion system would be of value. Indeed, such an evaluation is necessary if we desire to evaluate the level of sophistication that intelligent civilizations in general must achieve before panspermia by design becomes possible. This question is of general interest since engineered panspermia may constitute one mechanism for the spread of organic life in the Universe.

In this report we shall point out that a planned panspermia program designed to seed nearby solar systems with terrestrial life could be accomplished by a civilization on our contemporary level of technical sophistication. Specifically, we shall outline a strategy for engineered panspermia using current or near future technology. The design incorporates the essential elements of the radiopanspermia and lithopanspermia mechanisms; propulsion of the microbial payload will be achieved by radiation pressure using a solar sail device, and the microorganisms will be encapsulated to provide protection against U.V. radiation. An important feature of the proposed strategy is that capture of pansperms at the target solar system is not predicated on the use, and requisite interstellar survival, of complex automated navigational devices. Rather, the solar sail itself is used as a primitive deceleration device, and dispersion of pansperms in the target ecosphere serves to enhance the probability of capture.

Evidently the implementation of a panspermia project by any civilization can have no utilitarian objectives, and it will have to be motivated by philosophical considerations. The elements of motivation are not less vital for the eventual implementation of engineered panspermia than are the technical aspects. This fact was also recognized by Crick and Orgel [5], but again they did not examine this subject in detail. Because of the importance of the motivation factor, we shall survey in some detail the ethical implications of spreading, by intelligent design, terrestrial life in the universe.

2. Interstellar Launch of the Panspermia Payload

As an example of a panspermia mission we shall consider the use of a flat solar sail to launch a payload of 10kg to an interstellar trajectory. The acceleration imparted to the sail and payload by solar radiation pressure is calculated from Eq. 1

$$a = \frac{(1+P)\, A\, S\, R_e^2}{c\,(\sigma A + m_P) R^2} - \frac{G\, M_S}{R^2} \qquad (1)$$

The first term on the right hand side is derived from the formula of Tsu [6] and represents the acceleration imparted by solar radiation pressure; the second term represents the solar gravitational acceleration. Here P is the reflectivity of the sail, taken as 0.9; A and σ the sail area and thickness, respectively, the latter in units of g cm^{-2}. R_e is the mean Sun-Earth distance and R is the instantaneous distance of the sail from the Sun; G the gravitational constant; M_s the solar mass; S the solar constant. The payload mass m_p will be selected so that $m_p = 0.1\,(\sigma A) = 0.1\, m_s$, where m_s is the sail mass. Fig 1 represents the trajectories and final velocities computed for sails of thicknesses of 10^{-5}, 10^{-4}, and 1.3x10-^{4} gcm^{-2}, launched from an orbit at 1 au.

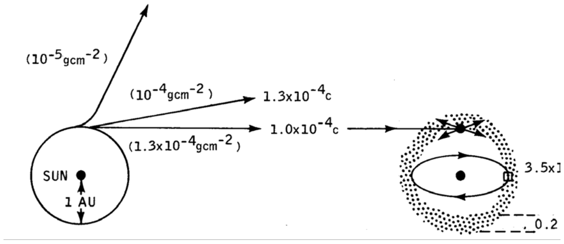

Fig. 1. Schematic illustration of the launching and capture of a solar sail device and the dispersion of the encapsulated microbial payload, for a mission whose physical parameters are discussed in the text.

Initial trajectories and final cruise velocities of vehicles, for sail thickness as indicated in parenthesis, are indicated on the left hand side diagram.

We note that films of 10^{-4} gcm^{-2} are currently available commercially. Thinner sails will be feasible to manufactory by vapour deposition techniques under micro-gravity high vacuum space conditions. A planar sail with m^s = 100kg and $\sigma = 10^{-4}$ gcm^{-2} will require a radius of 178 m, a size of feasible dimensions.

Launching of the solar sail device from a solar orbit can be achieved by prompt exposure to solar radiation, for example, by ejection of a massive shield or the closing of a "venetian blind" structure. In this article we shall consider the example of a sail of 1.3x 10^{-4} gcm^{-2}. For a sail of this thickness the two terms in the right hand side of Eq. 1 cancel, i.e., radiation pressure exactly balances gravity at any distance from the sun. Exposure to solar radiation will therefore cause the spacecraft to move in a linear outbound trajectory at the orbital velocity of 10^{-4}c. Higher speeds may be obtained by thinner sails as noted above, or by positioning the spacecraft in an orbit with a radius smaller than 1 au prior to launch. To obtain small starting orbits, the device may be maneuvered prior to the interstellar launch by orienting the sail such as to increase the orbital velocity. Trajectories aimed at targets out of the plane of the ecliptic may also be achieved by maneuvering the sail in cranking orbits prior to interstellar launch [7].

3. Navigation, Drag sand Erosion of the Interstellar Sail

To assure arrival of the spacecraft within the ecosphere of the target solar system, satisfactory navigational accuracy must be achieved. Currently, spacecraft attitudes can be monitored to 10^{-2} arc sec by interferometric star tracking [8]. Launching from 1 au, this precision allows a launch window of 0.2 sec. For a target at a distance of 10 light years, whose movement is defined exactly, this accuracy will assure entry into an orbit defined within ±0.024 au. However, the limiting factor at present time is the resolution of the measurement of stellar motion. Relative proper motions of starts at low galactic latitudes were determined recently with an average standard error of ± 0.11 arcsec/century [9]. This will result in an error of ± 120 au for a flight time of 10^5 years. The resolution of star motion may be improved by orders of magnitude in the near future by long-base-line interferometry using the forthcoming space telescope and its descendants. If the motion of the target star can not be defined more accurately, an increased number of missions can be used to assure that at least a few vehicles will be captured near the desired orbit at 1 au.

As the sail moves through interstellar medium, it will constantly strike interstellar particles, mostly hydrogen atoms and ions, at the rage of $Av\rho$ particles sec^{-1}, where A is the sail area, v is sail velocity and ρ the average interstellar hydrogen density.

If each particle striking the sail is elastically reflected, the fractional lost in sail momentum per unit time is given by

$$\Delta P_S / P_S = 2 M_H \sigma v / \sigma \qquad (2)$$

where M_H is the hydrogen mass. Taking $\rho = 1/\mathrm{cm}^{-3}$, $v = 10^{-4}c$, $\sigma = 1.3\mathrm{x}\ 10^{-4}$ggm cm^{-2} we obtain $\Delta P_S / P_{S\ =\ 7.8\ \mathrm{x}\ 10}{}^{-4\prime}$ sec^{-1} for a voyage of 10^5 years, the original velocity will be reduced by 12% at the target due to interstellar drag.

Erosion is a potential problem since we desire to protect the side of the sail facing the target star so that it can be utilized during deceleration. Powell [10] has calculated that erosion will only become a problem at moderate relativistic speeds. A potential solution to both the drag and erosion problems is a sail of venetian-blind structure that will open during interstellar transit.

4. Capture of Pansperm Capsules in the Target Ecosphere

By symmetry, the trajectory of the solar sail upon approach to a sun-like target star (T_t) will be the inverse of the motion following launch. At a desired distance from S_t, e.g., 1 au, a thermally or photoactivated device can be utilized to eject the sail. The payload, moving at the orbital velocity at this point, will be captured to an orbit about S_t. This orbit will be included at a random angle to the plane of the target ecliptic, since the latter cannot be determined in advance. To ensure an acceptable probability of capture, the microbial payload will be distributed therefore in a ring which intersects the local ecliptic. For example, a payload of 1 kg containing 10^{15} microorganisms,)(each of an average mass of 10^{-12}g), will be distributed into 10^{12} capsules, each containing 10^3 microorganisms. Each of these capsules will weigh 10^{-9} g, and will be shielded by a protective film against uv radiation. A reflective coating can also be used to keep the encapsulated microorganisms at a low temperature.

A chemical propellant may be used to impart to the capsules a distribution of velocities of $\pm$ 5 x 10^{-6}c about the mean orbital velocity of 10^{-4}c. Using the standard equations of propulsion we find that the required mass of an efficient propellant (specific impulse = 400 sec) is 0.46kg; the required propellant may thus easily be accommodated in the payload mass.

The capsules distributed in this manner will disperse in 20 years into a ring with a density of 3.5 x 10^{-15} capsules/cm^2. The pansperm ring will be spread in width from 0.90 to 1.1 au. A planet with a gravitational radius of 10^4km, whose orbit in the target intersects the microbial ring, will thus capture 1.1x10^4 capsules, or 3.3 x 10^7 microorganisms per passage through the ring, as illustrated in Fig.1.

Capsules consisting of 10^3microorganisms will have a radius of about 7 microns. Their orbit will not be affected substantially by solar radiation pressure (Arrhenius, quoted by Tobias and Todd [11]) and they will stay in their orbit indefinitely. Multiple passage of the target planet through the microbial ring will thus be possible.

With proper adjustment of capsule size and reflectivity, a predetermined portion of the capsules may be designed to be swept outwards gradually by radiation pressure, transit the cross-section of the target ecosphere and seed all the planets therein. An interesting further elaboration may be implemented if the reflectivity of the capsule coating material is rendered inversely variable with incident radiation. I this case the capsule parameters may be so adjusted that they will oscillate between orbits of preset minimum and maximum radii, corresponding to the limits of the ecosphere. In this case, all the microbial capsules will be swept up by planetary or asteroid objects I this volume.

Since the relative orientations of the capsule and target planetary orbits are random, high relative velocities (up to twice the orbital velocity) may lead to the burnup of the capsules in a substantial fraction of the missions. At the other extreme, however, when the orbital orientations of the capsules and the target accidentally coincide, small relative orbital velocities of the capsules should assure safe entry to the target atmosphere. Once landed, the thin metal or organic foil coating of the capsules should corrode with ease in the planetary atmosphere or hydrosphere, and free distribution of the microorganisms into the planetary environment will be permitted.

5. Biological Considerations

The basic biological criterion is that the pansperm payload is required to satisfy survival during transport and landing, and growth in the target environment. The question of the survival of microorganisms in space and under various planetary conditions have been the subject of a great volume of investigation in relation to planetary quarantine [12] and we shall address briefly only a few related points.

The major source of lethal damage to microorganisms in space is uv radiation. However, protection against uv damage may be provided by very thin shielding. For example, a chromium film of 800 angstrom is sufficient to protect microorganisms against solar uv [13]. A shielding metal film of this thickness for a capsule of 10^3 microorganisms, weighing 10^{-9}g, will weigh only 7.3 x 10^{-11} g. Thus, uv shielding will not add substantially to the payload mass.

On the other hand, shielding against ionizing radiation requires a thickness which is prohibitive in the present context, although the explosive propellant used for capsule dispersion and other structural elements may provide some protection during interstellar transit. Microorganisms that survive doses in the range of 10^6 rad are known [11]. Less resistant strains can adapt to radiation; low-temperature, frozen and dehydrated conditions, which may be achieved under interstellar transit, can also increase resistance up to an order of magnitude. We thus consider 10^6 rad as the limiting permissible does of ionizing radiation. Given an average flux of galactic ionizing radiation of 10 rad/year [14], a voyage of 10^5 year is permissible. Minimum shielding and low temperatures may allow an interstellar transit time of 10^6 years. This time scale is adequate to reach targets at distances of 1-=100 light years by solar sail propulsion.

To grow at the target planet, the selected pansperms will almost certainly have to be anaerobic. It is also desired that the pansperms will be photosynthetic, autotrophic and/or spore forming. The first two traits will facilitate independence in terms of energy and nutrition. The use of spores will enhance the probability of survival under extreme conditions.

Averner and co-workers [15] recently studied the habitability of Mars, and concluded that blue-green algae, or probably a strain combining desired characteristics of several species of algae, may well be able to grow under Martian conditions. This also appears a suitable choice for panspermia candidates. Other species adapted to survive in reducing environments may also be included in the payload. For example, the autotrophic, anaerobic, photosynthetic species Thiospirillum and Chromatium may be suitable for early terrestrial type environments where CO_2 and H_2S both may be available. The large number of microorganisms in a mission will allow combining in each capsule species suited to grow under diverse conditions.

6. Ethical Motivation

The ethical arguments that may induce us to implement panspermia missions or to refrain from doing so are necessarily subjective and qualitative. The ethical arguments that we shall survey are based on notions prevalent in contemporary natural philosophy.

a. *Promoting the evolutionary trend to the conquest of new habitats.*

The primary rationale for engineered panspermia, in our view, is to *promote and perpetuate the genetic heritage common to all terrestrial life.* This proposition is predicated on the notion that qualities universal to all terrestrial life do exist. In the framework of contemporary biochemistry, these unifying qualities may be identified as those patterns of the hereditary and metabolic mechanisms which are shared by all cellular organisms from prokaryotes to man. These fundamental universals of terrestrial life were preserved throughout evolution, and adapted to function in diverse external environments, including extreme conditions of pH, temperature, pressure and water activity. Indeed, the trend to conquer all accessible habitats may be seen as a characteristic manifestation of biological evolution.

In this framework, we may propose that the unique human capacities of cognition and manipulation imply a moral obligation on the part of our species towards the totality of terrestrial life. This obligation suggests that technology should be used to promote the conquest of new habitats by living matter, as extensively as our technology permits. Evidently, engineered panspermia will serve this object.

b. *Interference with indigenous biota*

The possibility that pansperms will disrupt or destroy an indigenous biosystem presents the most severe argument against engineered panspermia. The possibility of destructive interference with indigenous organisms could be eliminated only by the close range survey of the target; this is far beyond the level of technology considered here. However, we wish to present some arguments which may mitigate this problem.

The most tragic outcome of a panspermia mission would be to harm intelligent organisms endowed with self-awareness. This would happen only if these inhabitants have not yet developed the means to eliminate primitive biological invaders. It is likely, however, that the evolution from the inception of consciousness to a complete biological control of the environment should be in general rapid, occupying at most a few million years, as seems to be likely in our case. To encounter a civilization at this brief phase of its evolution, in the near vicinity of our solar systems, must be highly improbably by any estimate.

More generally, to cause damage to indigenous organisms by direct infection, their biology must be essentially similar to our own: for example, silicon-based organisms, or even ones using D-amino acids, will be probably unharmed. Interference by competition for food or energy resources is also possible. However, such competition may equally well arise from new species evolving by natural ways in the local biosphere. Moreover, harm to an ecosystem which have evolved photosynthesis may be avoided by selecting as pansperms strictly anaerobic organisms which will be destroyed by exposure to the oxygen atmosphere upon arrival. Thus the nature of the organisms which could be harmed by the pansperms may be confined into relatively narrow limits.

If competition between the pansperms and the local biota for vital resources should commence, it will but constitute an interstellar extension of the evolutionary struggle for the survival of the fittest. In this instance, panspermia will have served as a vehicle for the cosmic extension of organic evolution. This eventuality is not necessarily more evil than natural evolution on a local scale.

c. *Further Motivations: A Genetic "Noah's Ark"; Manipulation of Natural History; Cosmic Loneliness*

Engineered panspermia may become especially urgent if a catastrophic development threatening all life, or at last mankind of human civilization, appears imminent. A life system threatened with extinction, or one which perceives itself as such, may desire to perpetuate its genetic heritage by transplanting it to new habitats. Such motives were suggested by Crick and Orgel [5], Sagan and Shkloviskii [16] and others. A threat to the survival of our technological civilization may also suffice to motivate a panspermia project, since advanced technology will be required to escape the ultimate incineration of all terrestrial life by the Sun at its red giant phase.

It is generally recognized that current technology has the capacity to effect a global catastrophe; although it is impossible to estimate the actual probability that such a catastrophe will occur. However, the desirability of a panspermia project will be decided upon not on the basis of the actual, but the *perceived* probability that our civilization, human survival, or life on Earth in general is threatened. The survival time of the current civilization has been estimated in context of the search for extraterrestrial intelligence by several authors [17]. In general, the lifetime of this civilization is perceived as limited, estimates ranging from tens to thousands of years. For example, von Hoerner [18] estimates that an advanced civilization will destroy all higher life on its planet within 30 years with a probability of 60%, and that a catastrophic nuclear war will become more probable than peace after only 45.6 years even if the probability for war in every seven year period is only 10% [19]. Such expectations seem to be widespread; for example, an informal poll by Westman [20] showed that students estimate the longevity of our civilization as 100-200 years. We also conducted an informal survey of 32 young, mostly college-educated subjects. The average perceived probability for the destruction of all life within 500-1000 years through a man-made disaster was 22%, and for the destruction of civilization, 42%.

It is hard to assess the level of a perceived threat that would suffice to motivate our civilization to engage in directed panspermia; it would be even harder to assess the reactions of a past extraterrestrial civilization to a perceived threat. Nevertheless, it is interesting to note that in our own civilization the emergence of the technological level which makes panspermia possible generates, simultaneously, a threat that may also make directed panspermia desirable [21].

A further possible motivation for engineered panspermia may be provided by the expectation that it will afford a profound influencing of natural history by human design. Beyond transforming the history of the target ecosphere, the descendants of pansperm evolution - if not our own descendants - may in the long run further spread life in the universe. Via panspermia we may thus ultimately contribute to turning biological activity into a determinant force in the physical evolution of the universe.

Finally, the growing perception of the magnitude of the cosmos, and the absence of evidence for extraterrestrial life so far tend to induce a growing sense of our cosmic isolation. White the search for extraterrestrial life may lead to a passive solution, engineered panspermia will provide an active route of escape from the stark implications of cosmic loneliness.

7. Conclusion

We presented a scheme for engineered panspermia which relies only on propulsion by radiation pressure and other current or near future technologies. The point is made that in our own civilization these means were developed within decades after the advent of advanced technology. Also we noted that in a civilization with our level of general intelligence, ethical motivations for engineered panspermia arise concurrently with the advent of the required technology. All this indicates that there exist no significant barriers, technological or psychological, to the implementation of engineered panspermia by a civilization even at the earliest stages of its technological phase. Engineered panspermia could thus constitute a facile avenue for the spread of organic life in the galaxy.

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