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# Directed Panspermia. 3. Strategies and Motivations for Seeding Star-Forming Clouds

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# DIRECTED PANSPERMIA. 3. STRATEGIES AND MOTIVATION FOR SEEDING STAR-FORMING CLOUDS

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## ABSTRACT

Microbial swarms aimed at star-forming regions of interstellar clouds can seed stellar associations of 10 - 100 young planetary systems. Swarms of millimeter size, milligram packets can be launched by 35 cm solar sails at 5E-4 c, to penetrate interstellar clouds. Selective capture in high-density planetary accretion zones of densities > 1E-17 kg $m^{-3}$ is achieved by viscous drag. Strategies are evaluated to seed dense cloud cores, or individual protostellar condensations, accretion disks or young planets therein. Targeting the Ophiuchus cloud is described as a model system. The biological content, dispersed in 30 μm, 1E-10 kg capsules of 1E6 freeze-dried microorganisms each, may be captured by new planets or delivered to planets after incorporation first into carbonaceous asteroids and comets. These objects, as modeled by meteorite materials, contain biologically available organic and mineral nutrients that are shown to sustain microbial growth. The program may be driven by panbiotic ethics, predicated on:

1. The unique position of complex organic life amongst the structures of Nature;
2. Self-propagation as the basic propensity of the living pattern;
3. The biophysical unity humans with of the organic, DNA/protein family of life; and
4. Consequently, the primary human purpose to safeguard and propagate our organic life form.

To promote this purpose, panspermia missions with diverse biological payloads will maximize survival at the targets and induce evolutionary pressures. In particular, eukaryotes and simple multicellular organisms in the payload will accelerate higher evolution. Based on the geometries and masses of star-forming regions, the 1E24 kg carbon resources of one solar system, applied during its 5E9 yr lifespan, can seed all newly forming planetary systems in the galaxy.

## 1. INTRODUCTION

Panspermia, natural or directed, is a possible mechanism for the spread of life through interstellar space [1-7]. In fact, we may be already capable to use solar sail technology for seeding nearby new planetary systems with our DNA/protein form of life [4-6]. The program can become realistic in decades, due to rapid advances in high-precision astrometry, advanced propulsion, discovery of extrasolar planetary systems, and microbial genetic engineering [5]. An essential component for realizing directed panspermia is the ethical motivation. Seeding distant planets with life is the ultimate altruism, bearing results long after the generations that implement it. The ethical motivation for such a program must recognize:

(1) the unique position of complex, self-propagating organic Life in Nature;

(2) the unity of all organic, cellular DNA/protein life, from microbes to humans and post-humans;

(3) and, consequently, the primary human purpose, to safeguard and propagate our life-form [4,5].

Prime targets for biological expansion can be regions of interstellar clouds where newly forming stars and planetary systems are concentrated. The discussion below will consider the physical environments of such regions, and the implications for the microbial missions. The article will survey both the technological and ethical aspects of seeding with life star-forming interstellar clouds.

## 2. THE TARGET ENVIRONMENTS: STAR-FORMING CLOUDS, DENSE CORES AND PLANETARY ACCRETION DISKS

The mission will be illustrated by choosing a representative candidate, Rho Ophiuchus (distance = 520 ly), a cloud that forms long-lived low and medium mass stars. As described by Mezger [8] (figure 1), the overall cloud extends to about 50 ly as low density gas (hydrogen atom density $n_H$ < 1E3 $cm^{-3}$, (i.e., < 1.7E-18 kg $m^{-3}$)) of total mass ≈ 3,000 M¤ (solar mass M¤ = 2E30 kg), and contains a 6x6 ly dense fragment with a density of 1E4 $cm^{-3}$ and mass ≈ 500 M¤ , containing 78 young stellar objects of low-mass dust-embedded or early accretion stage T Tauri stars. Within this cloud are four cores with diameters of ≈ 1 ly and densities of 1E6 $cm^{-3}$ (1.7E-15 kg $m^{-3}$) and masses of 1 - 15 M¤ .One of these cores shows four protostellar condensations with radii of ≈ 3E14 m, densities of 1E7 $cm^{-3}$ (1.7E-14 kg $m^3$) and masses of 0.4 to 3 times the mass of the sun. Dust temperatures in this region are 15 - 20 K.

Small panspermia capsules captured in a protostellar condensation or about a young star in an accreting planetary system will become part of the dust in the system. The protostellar condensation free-falls in ≈ 4E4 yr to cores with radii of 100 au and densities of 1E11 - 1E12 $cm^{-3}$ (1.7E-10 - 1.7E-9 kg $m^{-3}$), which collapses further during 1E5 - 1E6 yr into a 1E6 m thick, 100 au (about 1E13 m) radius dust ring [9], that comprises 0.01 M¤ (2E28 kg) (possibly up to 0.1 M¤ (2E29 kg)) mass about a 1 M¤ young T-Tari star, and has a temperature of T = 50 - 400 K at 1 au (consider 250 K) (with possible periodic heating over 1,000 K), and $T = 250a^{-0.58}$ at other distances a (in au = 1.5E11 m units) [10]. In the ring, the dust accretes rapidly (in 1E3 - 1E4 periods of revolution) from micron-size grains to 1 - 10 km planetisimals; then, in about 1E5 years, to 1E3km radius, 1E21 kg runaway planetary seeds that develop into 1E23 kg planetoids; and in the next 1E8 years, to planets [10]. Most of the gas is ejected from the disk in 1E6 - 1E7 yr by bipolar outflow and stellar UV radiation [10]. A fraction of the residual materials accrete in a zone of several tens of au from the star to become 10 km diameter, 1E14 - 5E14 kg nuclei of 1E13 comets, most of which are expelled to interstellar space [11], except 1E11 - 1E12 comets with a total mass of 1E25 - 1E26 kg that are retained in the Oort cloud at 1.7E4 - 1E5 au. [12] Another about 1E23 kg materials form the Kuiper belt comets [13], and 1E22 form the main-belt asteroids [14].

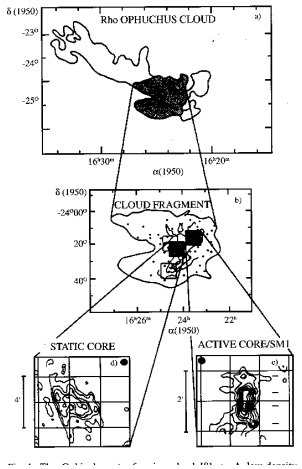


**Figure 1. The Rho Ophiuchus cloud [8], a potential target for directed panspermia. See enlarged picture in Chapter 3 "Seeding the Universe".**

a. Low-density envelope or mass 3000 $M_{SUN}$ is shown shaded.
b. The dense region, showing the positions of 78 young stellar objects.
c. Active star-forming core of mass 15 $M_{SUN}$. d. Static, non star-forming core. (From P.G. Mezger, "The Search for Protostars Using Millimeter/Submillimeter Dust Emission as a Tracer", in "Planetary Systems: Formation, Evolution and Detection", B.F. Burke, J.H. Rahe and E. E. Roettger, eds., Fig 6, p. 208. Reproduced with kind permission from Kluwer Academic Publishers).

Cometary mass ablating in transits maintains a Zodiacal dust cloud of 2.5E16 kg and mean lifetime of 1E5 yr by injecting at present, about 2E4 kg $s^{-1}$ dust near the perihelion passes at <3.5 au [15]. Of this, 0.15 kg $s^{-1}$, i.e., a fraction of 1E-5, is collected by the Earth [16a]. At higher densities in the prebiotic period between 3 and 4 Gyr (1Gyr = 1E9 yr) ago, 1E17 kg of the cometary dust accreted onto the Earth in the form of 0.6 to 60 μm radius particles in which organic material can be preserved during atmospheric transit [2]. Similar to the Zodiacal dust collection efficiency, 1E-5 of the asteroid fragments produced by collisions eventually impacts on the Earth as meteorites [16b]. Both data suggest that 1E-5 of the objects in orbit within several au of a habitable planet are eventually collected.

Altogether, the 1E17 kg material of cometary origin that was collected by the Earth in the early biotic period between 3 - 4 Gyr ago, constitutes about 1E-13 of the total 1 M¤ (2E30 kg) protostellar condensation, 1E-11 of the mass of the original accretion dust ring, and 1E-9 of the total present Oort cloud cometary mass.

These data from our solar systems are used as models. These data are current, model-dependent estimates with uncertainties up to an order of magnitude, and respective figures may be of course different in other solar systems.

## 3. AN OVERVIEW OF THE SWARM STRATEGY

In the previous papers [4-6], we considered solar sail missions of a few vehicles targeted at specific nearby planetary systems that possess protoplanetary dust rings, such as Vega, beta Pictoris, and Fomalhout. For such missions, suitable targets should be within <100 ly for targeting accuracy, and have observable accretion disks or planets, preferably about young F, G or K type stars that will stay on the main sequence for >1E9 years to allow higher evolution. Only a few suitable objects are known.

It may be more efficient therefore to aim for nearby star-forming regions with large concentrations of accreting planetary systems. Such regions are found in collapsing dense molecular clouds that fragment to form stellar associations, some with up to 100 new 0.5 – 5 M¤, long-lived stars.

The nearest suitable star-forming zones are dense regions (>$10^6$ $cm^{-3}$), that are >100 ly away. It is not possible to target a few vehicles accurately at individual stars at such distances, and even if targeted, the vehicles may be scattered by the high density medium. For such environments, a statistical swarm strategy may be preferred.

The swarm strategy uses solar sails to launch large numbers of small, milligram weigth, microbial packets. The size of the packets is designed so that they transit the thinner cloud regions and are captured in high-density protostellar condensations, where they will fragment into small, e.g., 30 μm radius capsules. Some capsules will land on already accreted planets, while other capsules that arrive in actively accreting protoplanetary systems, will be captured in asteroids and comets. Subsequently, when host comets warm up near perihelion passages, the microbial payload in them may multiply [17]. Eventually, microbes or capsules will be ejected with the cometary dust particles and like them, a fraction will be captured by planets. Alternatively, the capsules can be transported to planets when the host asteroids and comets, or their meteorite fragments, impact. Using nutrients provided in the capsule, supplemented by the rich nutrients in the host carbonaceous meteorite or cometary matrix [18,19], and subject to wet and warm planetary conditions, the microbial payload can then start to multiply. Materials from the planet will mix with the capsule and meteorite microenvironments, and the microorganisms can adapt gradually to the planetary chemistry. Finally, the microorganisms will break free to multiply and evolve in the environment of the new planet.

This sequence will be evaluated below quantitatively, to estimate the probability of success and the required amounts of panspermia material.

### 3.1 Propulsion and Launch

Our previous papers considered technologies for sending large microbial payloads on the order of 10 kg to nearby solar systems [4-6]. We considered relatively simple technology, using solar sail vehicles with areal densities 1E-4 $kg/m^2$ with thin sails of thickness 1E-7 m (0.1 microns), and of sizes on the order of 1E6 $m^2$, which can reach velocities of 5E-4 c when launched from 1 au. The sails must remain stable during transit times of 2E5 years to targets up to 100 ly away, so that they can provide braking by radiation pressure after arrival.

In comparison with the 10 kg payloads of directed missions, the swarm approach launches large numbers of small payloads. The considerations below suggest launching 1 mm radius, 4.2E-6 kg microbial packets. Therefore, the swarm method miniaturizes the mass of each launched payload by about a factor 2E6, which further reduces the technological requirements and may allow new propulsion approaches. Once in the target region, the packets can further decompose into 4E4 capsules of 30 μm radius containing 1.14E-10 kg microbial mass, that is appropriate for eventual non-destructive atmospheric entry. The large numbers can also increase the probability of capture.

Even for the milligram payloads, the most imminent technology appears to be solar sailing. For effective devices, the sail/payload ratio should be about 10:1, requiring sails of 4.2E-5 kg. With an areal density of 1E-4 kg $m^{-2}$, this will require sails of 0.42 $m^2$, i.e., sails with a radius of 0.35 m. Such small sails can be mass manufactured easily, which is important since very large numbers are required. For planetary targets in the dilute medium within 100 ly, the 30 μm, 1.1E-10 kg capsules can be launched individually, using 1E-9 kg sails of 0.18 cm radius. These miniature objects can be mass manufactured and launched even more easily.

The thin sail devices with $\sigma_a$ = 1E-4 kg $m^{-3}$ could transit the local low-density medium about the Sun with little drag. However, the sail devices cannot penetrate even a diffuse interstellar cloud with desity of 1E-19 kg $m^{-3}$, where they will stop rapidly, for example, slow down to 15 m $s^{-1}$ in the first 0.4 ly. For this reason, and to minimize scattering during transit, a useful strategy would be for the sails to eject the capsules once they obtained the final velocity of 1.5E5 $ms^{-1}$, possibly with an impulsive ejection using the sail as countermass, to impart the payload further acceleration. Alternatively, the sails may be manufactured of biopolymers that would fold over the payload after exit from the solar

system. They can then provide additional shielding in transit, and be used as a nutrient shell once the capsules land on the host planet.

The transit time for a sail-launched capsule to a cloud 100 ly away is 2E5 years, during which the payload will be subject to 2E6 rad of ionizing radiation. This can be lethal, or at least strongly damaging to most microorganisms. It may be desirable therefore to use alternative propulsion methods to achieve greater velocities and shorter transit times. However, at high speeds, ablation and heating of the capsules can be significant, especially in the dense cloud area, requiring velocities <0.01 c. At such high entry velocities, even sub-millimeter size, sub-milligram capsules may penetrate the clouds sufficiently, so further miniaturization of the microbial packets down to microgram levels may be possible.

### 3.2 Astrometry and Targeting

The large size of star-forming regions, compared with individual planetary systems, is a major advantage. Compared with astrometry requirements for targeting a habitable zone about a specific star, on the order of several au (1E11 - 1E12 m), the size of the model star-forming Ophiuchus cloud fragment is larger by a factor of 10,000 i.e., about 6 ly (6E16 m). In terms of angular resolution, a 1 au planetary target zone at 50 ly distends 1.8E-5 degrees, whereas the 6 ly Ophiuchus fragment at 520 ly distends 0.68 degrees as seen from Earth.

Given the substantial space velocities of interstellar clouds, on the order of 1E4 m $s^1$, the vehicles must be aimed at the expected positions of the targets at the time of arrival. The uncertainty in calculating this position arises from the limits of the resolution of the proper motion of the cloud when the vehicles are launched. The positional uncertainty at the time of arrival, $\delta y$, is expressed by equation (1), where $\alpha_p$ is the resolution of proper motion, d is the distance from Earth, and v the velocity of the vehicle ($\alpha_p$ in arcsecs/yr, other units in SIU).

$$\delta y = 1.5E\text{-}13\ \alpha_p\ (d^2/v) \qquad (1)$$

Angular proper motion resolutions of 1E-5 arcsec/yr can be anticipated. The positional uncertainties of the various targets considered upon the arrival of fast (v = 0.01 c) or solar sail based (v = 5E-4 c) missions, i.e., the $\delta y$ values, are listed in Table 1. Note that for the large cloud core, and even for individual protostellar condensations, the uncertainty is smaller than the radius of these objects.

Given the uncertainty $\delta y$ in the position of the target when the vehicles arrive, the panspermia objects should be launched with a scatter, to arrive in a circle with radius $\delta y$ about the calculated position (scatter with a Gaussian distribution may be more effective). The probability that the vehicle will actually arrive in the target region, $P_{target}$, is then estimated from the ratio of cross-sectional areas of the target region to that of the area of the targeting scatter. Equation (6) in reference [5] was derived on this basis, and similarly we obtain equation (2) for a spherical target with a radius $r_{cloud}$ with cross-sectional area $A_{target} = \pi r^2$. For planetary targets within a habitable zone of radius $R_{hz}$ and width $w_{hz} = 0.4_{hz}$, the area of the target habitable zone is equal to that of a circle with radius $r = 0.89\ r_{hz}$.

$$P_{(target)} = A_{(target)} / \pi\ (\delta y)^2 = 4.4E25\ (r_{target}{}^2\ v^2)/(\alpha_p{}^2\ d^4) \qquad (2)$$

For cases where the area of the target is larger than of the positional uncertainty, we obtain $P_{target} > 1$, which may be interpreted as approximately unit probability. Equation (2) yields the $P_{target}$ values as shown in Table 1. Note that most of the microbial packets will arrive in the targeted star-forming cloud region, and even the smaller specific protostellar condensations can be targeted accurately. In fact, even with a reduced resolution of 1E-4 arcsec/yr, the dense core can be targeted reliably. However, even with $\alpha_p$ of 1E-5 arcsec/yr, $P_{target}$ for a 100 au radius dust sphere about a dust-embedded star or accretion disk (perpendicular to the Earth-star axis) is 3.9E-3, and for 1 au habitable zone about a star at the

same distance of 520 ly is only 3.9E-7. Targeting these smaller specific objects at these distances is inaccurate because of the $d^{-4}$ dependence of the $P_{target}$ function.

### 3.3 Capture at the Target Zone, and Considerations of Capsule Size

In the target interstellar clouds, the density increases gradually from the diffuse cloud to a dark cloud fragment, dense cores, protostellar condensations and accretion disks. This allows designing the capsule geometry (size) for selective capture in the desired zone, based on drag by the medium as given by equation (3) for elastic collisions with gas molecules [6].

$$dv/dt = -2(\rho_m v^2 A_c/m_c) \qquad (3)$$

Here $\rho_m$ is the density of the medium; v is the velocity, $A_c$ the area and $m_c$ the mass of the capsule. Note that $A_c/m_c = 1/\sigma_a$, where $\sigma_a$ is the areal density of the object. For a spherical object, $\sigma_a = (4/3)\rho_c r_c$, where $\rho_c$ is the density of the capsule material, assumed to be 1E3 kg $m^{-3}$ for a biological payload, and $r_c$ is radius of the capsule. Using these relations we can substitute for $A_c/m_c$ in equation (3) to give the radius directly as a variable in equation (4), which was used for numerical integration.

$$dv/dt = -(3v^2/2\rho_c)\, \rho_m/r_c \qquad (4)$$

In these calculations we consider spherical capsules entering the cloud with a velocity of 1.5E5 m $s^{-1}$, and consider that their velocity becomes homogenized with the medium when they are decelerated to 2E3 m $s^{-1}$, a typical internal velocity of grains in a cloud. Since most of the distance is covered during the high velocity entry period, continuing travel under further deceleration has little effect on the depth of penetration. Calculations also show that acceleration due to the gravity of the cloud adds only an insignificant velocity increment of about 1E4 m $s^{-1}$ before entry to the cloud. Other effects such as the complex gravitational and magnetic fields in the clouds require further study. Note that in equation (4) the critical variable is $\rho_m/r_c$, i.e., for a given desired penetration depth, the capsule radius has to vary proportionally with the density of the medium.

To reach the dense protostellar regions or accretion disks, the microbial packets need to penetrate first through the less dense, but larger zones in the diffuse cloud, the dark cloud fragment and the dense core. Figure 2 shows the deceleration of spherical objects with radii of 35 μm and 1 mm, injected into these clouds with an initial velocity of 5E-4 c (1.5E5 m $s^{-1}$), in terms of velocity vs. penetration distance as computed using equation (4), along with the radii of the various zones. The 35 μm object penetrates the Ophiuchus cloud fragment with a density of 1.7E-17 kg/$m^3$ to about 1 ly, while the 1 mm object penetrates it fully and passes through its 3 ly radius. The 35 μm object is stopped at about 0.01 ly in the active dense core of a density of 1.7E-15 kg/$m^3$ but the 1 mm object passes through its 0.04 ly radius and penetrates to the even denser protostellar condensations with density of 1.7E-14 kg/$m^3$ where both objects are stopped well before full penetration through its 0.03 ly radius. In this region, the 1 mm object penetrates only to about half of the radius. This is adequate so that the capsule will be incorporated into the dust cloud. In fact, larger objects with r > 1mm would transit the protostellar region and would not be captured. These calculations illustrate the use of microbial capsule size for selective capture in desired regions.

**Table 1. Parameters for advanced (v = 0.01 c) and solar-sail (v = 5E-4 c) microbial swarm missions to nearby stars and to the Rho Ophiuchus cloud.**

| | d (ly)[a] | r (m)[b] | Dy (m)[c] v (c) 0.01 | 5E-4 |
|---|---|---|---|---|
| **Nearby Stars** | | | | |
| **Alpha PsA** | 22.6 | 5.0E11 | 2.3E10 | 4.6E11 |
| **Beta Pic** | 52.8 | 1.3E12 | 1.3E11 | 2.5E12 |
| **Rho Ophiuchus Cloud** | | | | |
| **Dense Fragment** | 520 | 3E16 | 1.2E13 | 2.4E14 |
| **Protostellar** | 520 | 3E14 | " | " |
| **Early Accretion Disk** | 520 | 1.5E13 | " | " |
| **Late Accretion Disk** | 520 | 2.6E12 | " | " |
| **Young Stellar Object** | 520 | 5.3E11 | " | " |

**Table 1 (continued)**

| | $P_{target}$[d] v (c) 0.01 | 5E-4 | $P_{planet}$[e] v (c) 0.01 | 5E-4 | m (kg)[f] v (c) 0.01 | 5E-4 |
|---|---|---|---|---|---|---|
| **Nearby Stars** | | | | | | |
| **Alpha PsA** | (4.7E2) | (1.2E0) | 1E-5 | 1.1E-5 | 1.1E-3 | 1.1E-3 |
| **Beta Pic** | (1.0E2) | 2.7E-1 | 1E-5 | 2.5E-6 | 1.1E-3 | 4.5E-3 |
| **Rho Ophiuchus Cloud** | | | | | | |
| **Dense Core** | (6.3E6) | (1.6E4) | 1E-16 | 1E-16 | 1.1E8[g] | 1.1E8[g] |
| **Protostellar** | (6.3E2) | (1.6E0) | 1E-13 | 1E-13 | 1.1E5 | 1.1E5 |
| **Early** | (1.6E0) | 3.9E-3 | 1E-11 | 3.9E-14 | 1.1E3 | 2.8E5 |
| **Late Accretion** | 4.7E-2 | 1.2E-4 | 1.5E-11 | 3.8E-14 | 7.5E2 | 2.9E5 |
| **Young Stellar** | 1.9E-3 | 4.9E-6 | 1.9E-8 | 4.9E-11 | 5.8E-1 | 2.2E2 |

**a.** Distance to the target.

**b.** Radius of the target objects. For planets, the radius of a circle with an area equal to that of the habitable zone i.e., $r = 0.89r_{hz}$. alpha PsA and Beta Pic, $r_{hz}$ from ref. 5, for 1 solar mass young stellar object, $r_{hz} = 1$ au. For the late accretion disk, radius of a circle with an area equal to a disk from 10 to 20 au.

**c.** Uncertainty in target position at arrival, from equation (1).

**d** Probability of arrival within the target zone, from $r^2/(dy)^2$. For values of P > 1, shown in parentheses, the arrival probability is approximately unity.

**e**. Probability of capture by a planet in the habitable zone, obtained from $P_{target}$ x $P_{capture}$. For targeted planets, $P_{capture}$ = 1E-5; for other targeted objects, see text.

**f**. Launched biomass necessary for the capture of 100 capsules of 1.1E-10 kg at the target planet, calculated from $1.1E\text{-}8/P_{planet}$.

**g**. Mass requirements per planetary system. Note this mission requires launching 100 times the given masses, for distribution through the cloud.

Capture in accretion disks requires special considerations. Statistically, most objects will encounter the 1E6 m thick, 1E13 m radius disks on the disk face (rather than the edge). An early accretion disk containing the original 100:1 gas/dust ratio can be considered as a homogenous gas medium with a density (from the mass/volume ratio) of 2.8E-5 kg $m^{-3}$. The 1E-3 m capsule entering with v = 1.5E5 $ms^{-1}$ will be captured at a depth of 1E5 m, about 1/10th of the thickness. At later stages of accretion, the disk becomes thinner, and dominated by increasingly large solid aggregates. Also, because of the close approach of 1E6 meter to the central plane of the disk before drag braking starts, the approaching objects may be significantly accelerated by the disk's gravity. Once the disk is gas-free, the capsules will be captured into the disk by collisions with solids, or will be captured gravitationally into circumstellar orbits. In fact, capture at the later stages of cometary accretion, into the outer cometary crust is desirable as this facilitates the subsequent release and delivery to planets.

Finally, for planetary targets, for objects placed in orbits near the planet at <3.5 au, a fraction of 1E-5 will be captured by the planet as noted above (note that this factor was not considered in reference [5]).

For maximizing the probability of success, it is desirable to maximize the number of survivable units for a given total payload mass and therefore to minimize the capsule size. From the drag considerations, the optimal size for penetrating the cloud is 1 mm. However, once in the target region, sufficient drag is in fact necessary for capture, and the capsule size can be reduced further. In fact, it is estimated that only dust particles in the range r = 0.6 - 60 μm can survive atmospheric entry and still remain cold enough to preserve organic matter [20]. A median size in this range, r = 30 μm and mass of 1.1E-10 kg is considered below. This requires that the millimeter size capsules will be designed to disintegrate into smaller capsules once within the target protostellar or accretion regions. For example, the 1 mm capsule may be made as a looser aggregate that will disintegrate by collisions with dust particles, or by evaporation of the binding matrix in the relatively warmer target zone, into 30μm capsules. This particle size is comparable to the <1E-10 kg particles that constitute about 10% of the zodiacal cloud. Significantly, this particle size will not be ejected from the solar system by radiation pressure [14].

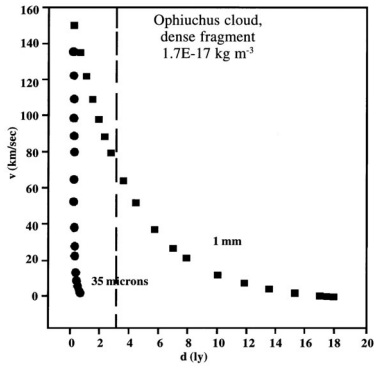


**Fig. 2**. The deceleration of 35μm and 1 mm radius objects inserted at a velocity of 1.5E5 m $s^{-1}$ into representative regions of the Ophiuchus cloud. The objects are considered stopped at v = 2000 m $s^{-1}$.

## 4. TARGETING STRATEGIES AND PROBABILITY OF SUCCESS

The fraction of launched panspermia swarm that will reach the target zone (the interstellar cloud, protostellar condensation etc.,) $P_{target}$, was calculated above. We consider here the further term $P_{capture}$, the probability that once in the target zone, the payload be eventually captured into the habitable zone of a planet. The overall probability for capture in the target planet is then obtained from equation (5).

$$P_{planet} = P_{target} \times P_{capture} \qquad (5)$$

As noted above, for calculated values of $P_{target} > 1$, we use $P_{target} = 1$. The following sections summarize the considerations to estimate $P_{capture}$, and from it, $P_{planet}$. The results are summarized in Table 1. The following discussion applies to solar sail missions (v = 5E-4 c), but results for advanced missions (v = 0.01 c) are also shown in Table 1.

### 4.1 Targeting the Dark Cloud Fragment

Equation (2) yields $P_{target} > 1$ for the dense Rho Ophiuchus cloud fragment. In other words, because of the large size of the target cloud, virtually all of the microbial capsules launched at it will arrive to the 3E16 m radius, 1E33 kg target. The cloud contains four dense cores with a total mass of about 1E31 kg, one of which has already formed protostellar condensations, and the others with the potential to form such condensations [8]. In addition, capsules may be also captured into the already formed 78 young stellar objects, which would have 100 au (1E13 m) radius dust shells or disks. Assuming that the cloud will eventually form 100 stars of 1E30 kg, from the mass ratio of each star to the overall dense cloud fragment, 1E-3 of the launched mass will be captured into each accreting solar system, i.e., for each star, $P_{target}$ = 1E-3. By the mass ratios of 1E17 kg dust captured by a planet during the suitable 1E9 yr prebiotic period to 2E30 kg mass of the protostellar condensation, about 1E-13 of the capsules will be captured, giving $P_{capture}$ = 1E-13. Altogether, therefore, $P_{planet}$ = 1E-16 for each accreting solar system, i.e., 1E-16 of the mass launched at the cloud will be captured by a terrestrial planet in each accreting system. In total, 1E-14 of the launched mass will be captured in terrestrial type planets in the 100 accreting stars in this cloud. Note that with this strategy, individual stars are not targeted, and the mass that is launched must provide for seeding the entire cloud.

### 4.2 Targeting Individual Protostellar Condensations

The calculations above yielded $P_{target} > 1$ also for specific protostellar condensations, and therefore such regions can be targeted individually and we can use $P_{target} = 1$. From the mass balance ratios as above, $P_{capture}$ = 1E-13, giving also $P_{planet}$ = 1E-13.

The advantage of targeting individual protostellar condensations, rather than the overall cloud, is the greater chance for reaching a known, already established star-forming zone. This strategy also decreases the exposure time and radiation dose received when the payload would be diffusing through the cloud. A disadvantage is that, although the calculations yielded $P_{target} > 1$ for both the cloud and the individual protostellar condensations within it, the value was 1.4E4 for the cloud and only 1.4 for the condensation region, and realistically, the chances of capture are much greater in the larger cloud. Another disadvantage of targeting existing protostellar condensations is that the missions will miss many new star-forming condensations that form after the launching of the capsule swarm.

### 4.3 Targeting Early Accretion Disks

The 78 young stellar objects observed in Rho Ophiuchus are dust embedded or are in the T Tauri stage, with 100 au radius accretion disks. Because of their small size, $P_{target}$ = 3.9E-3 for

these objects. On the other hand, the capsules will be distributed only in the circumstellar dust but not in the star mass, avoiding a major source of loss. Assuming that the majority of the dust is accreted into the original 1E13 comets with a total mass of 1E28 kg, of which 1E17 kg is eventually captured by a planet, gives $P_{capture}$ = 1E-11, and $P_{planet}$ = 3.9E-14.

### 4.4 Targeting Late Accretion Disks

Targeting accretion disks at the late stages of comet formation is advantageous because the capsules will be accreted into the outer cometary shell, which is most readily released subsequently. The theory of cometary accretion is uncertain, and a zone of some tens of au, say 10 - 20 au about the star may be considered for initial comet formation. For this area we obtain $P_{target}$ = 1.2E-4. It will be assumed that the entire payload reaching the zone will be captured into orbit and eventually accreted into cometary shells. Assuming capture into the 100 m outer shell in 1E13 initial comets of 5,000 m radius, the microbial payload will be embedded in 3.1E26 kg dust, of which 1E17 kg will be delivered eventually to the planet, yielding P(capture) = 3.2E-10, and P(planet) = 3.8E-14.

### 4.5 Targeting Planets

The most direct approach is to target planets in already accreted planetary systems. As noted above, this may be better applied to planets at least 0.5 Gyr after accretion, as the initial conditions may be sterilizing. Targeting planets directly may be appropriate if older accreted planets are identified, or if further research suggests that young planets are survivable.

We consider capture of the payload within <3.5 au from the star, which yields $P_{target}$ = 4.9E-6. From the Zodiacal dust and meteorite capture statistics, $P_{capture}$ =1E-5, and therefore $P_{planet}$ = 4.9E-11.

### 4.6 Biomass Requirements

The amount of material that needs to be launched is calculated from the $P_{planet}$ values, allowing for the delivery of 100 capsules. The factor of 100 also corrects for other uncertainties in the mission. The mass required for the delivery of 100 capsules of 1.1E-10 kg each is then given by m = 1.1E-8/$P_{planet}$. The results are shown in Table 1.

For targeting the entire dense star-forming region, a very massive program of 1E8 kg per accreting star in the cloud is required, which can be only accomplished using space resources. If targeted at individual protostellar condensations or accretion shells or disks, requirements on the order of 1E5 kg for a sail mission, and especially 1E3 kg for an advanced mission, are realizable. Finally, if already accreted planetary systems in the cloud or closer are identified and targeted, the mass requirements on the <1 kg to 100 kg scale are easily met. Such panspermia programs should be affordable to small motivated groups or even individuals, which increases that likelihood that the program will be actually enacted.

### 4.7 Swarm Missions to Nearby Stars

It is of interest to evaluate the swarm method also for closer planetary systems. For alpha PsA (Fomalhout), d = 22.6 ly, $P_{target}$ was found as 1.2, and for beta Pictoris, 0.27, for capture into orbit in the habitable zone. For $P_{capture}$ we use 1E-5, although of course it may be different in different solar systems. With this assumption, $P_{planet}$ = 1E-5 and 2.7E-6, respectively, is obtained for the two targets. These stars are in the local low-density interstellar medium, and the sail method described in the previous papers [4 - 6] may be used, miniaturized for launching 30 μm radius, 1E-10 kg capsules by small, 1.8 mm radius sails. These sails may be, for example, envelopes of thin reflective film that enclose the payload, mass-produced using industrial microencapsulation technologies. As few as 1E7 or 5E7 capsules, i.e., 1 or 5 g of microbial payload launched toward these stars in a swarm, respectively, could then deliver 100 capsules to a planet. Remarkably, with current launch costs of $10,000/kg, a panspermia

swarm with a reasonable probability of success can then be launched to these stars, nominally, at the cost of $10. Of course, it should be easy to scale up such missions by a factor of 1,000 to kilogram quantities for increasing the probability of success or for allowing much less accurate, easier methods to launch the capsules, still within a very low-cost program of $10,000. Therefore, directed panspermia swarms to nearby planetary systems can be easy and inexpensive.

## 5. SURVIVAL AND GROWTH IN COMETS AND ASTEROIDS

The missions to star-forming regions can arrive into solar systems at stars in various stages of star formation, that may coexist in a target cloud. Stars that are at the dust-embedded or T Tauri stages when the missions are launched will last in these stages 1E5 - 1E6 years, similar to the transit time. When the missions arrive, these stars will have formed accretion rings. The subsequent planetary accretion lasts for 1E8 years, and high temperatures, intense solar UV flux, and frequent major impacts may make the new planets habitable only after 5E8 yr. However, capsules arriving at this stage can be preserved frozen if captured in asteroids and comets at $r > 2.3$ au at temperatures of $T < 150$ K, as calculated from the temperature function $T = 250r^{-0.6}$ (r distance in au). Furthermore, capsules accreted into a depth of several hundred g $cm^{-2}$ in the comet will receive a radiation dose reduced by a factor of 100 from those on the cometary surface, which can assure survival on the Gyr time-scale.

Optimally, a fraction of the capsules may be embedded into the protected layers of the outer cometary crusts. These loose porous icy aggregates and embedded dust evaporate losing several hundred gm $cm^{-2}$ in the first perihelion passage [11], and further inner layers evaporate gradually during further transits, releasing dust that is later captured into planets from the zodiacal cloud.

Capsules that are more deeply embedded in cometary nuclei or asteroids may also arrive on planets with impacts [21], and within the meteorite rock can survive atmospheric transit.

Of the original 1E13 comets formed, 99% are ejected to interstellar space [12], but where Jupiter-sized planets fail to form, the cometary populations that remain bound to the solar system are greater, and barriers to penetration to crossing Earth-like planetary orbits are smaller. Jupiter-family comets can then remain in these orbits for 1E7 - 1E8 yr, instead of the present 1E5 yr, and the frequency of major cometary impacts increases from 1E-8 $yr^{-1}$ to 1E-5 $yr^{-1}$ [22]. In such planetary systems, the amount of cometary material and embedded microbial capsules that is delivered to the planets can increase by a factor of 1,000.

In addition to comets, microorganism capsules may also become embedded in asteroids, and in the meteorites fragmented from them. Compared with the 1E26 kg total cometary mass, the total asteroid mass of 1E21 - 1E22 kg is much smaller, but it can provide a favorable nutrient microenvironment, (see below).

## 6. SOME BIOLOGICAL CONSIDERATIONS

The biological requirements were considered in relation to missions to nearby solar systems [4,5]. Some key points are as follows.

The microbial design must allow survival during transit, and subsequently in diverse planetary and possibly cometary environments, and facilitate evolutionary pressures that will lead to higher evolution.

These criteria suggest a diverse microbial assembly. The anaerobic environment will require at least facultative anaerobes. Blue-green algae, and possibly eukaryotic algae may be the best colonizing organism, the latter may lead to higher plant evolution. The photosynthetic organisms may survive first and establish an oxygen-containing atmosphere. Higher aerobes, including predatory heterotrophs can grow from the capsules that are meanwhile stored in comets and asteroids, and are delivered to the planet later. The ensuing predator/pray selection pressures will lead to higher evolution. This may require aerobic conditions, although conceivably, higher, including intelligent anaerobes may be possible.

The inclusion of simple multicellular eukaryotes is crucial, as this development may be a major evolutionary bottleneck. This development required billions of years on Earth, but then led rapidly to higher life-forms. Such a low probability event may not occur at all in other evolving ecosystems.

Even the most primitive single-cell organism must include the complex DNA and protein structures for replication, as well as complex energy mechanisms and membrane transport systems. The origin of such a complex system would seem to have a low probability. Panspermia helps to overcome this probability barrier. Possible findings of Martian micro-organisms do not prove a large probabiliy of independent origins, because much material, over 1E8 kg, including microorgansims, would have been exchanged beween early Earth and Mars [26]. In any event, overcoming the second probability barrier to multicellular eukaryoteson the taget planets may in itself justify the panspermia program.

For interstellar transit, the microbial payload may be freeze-dried, as is the current practice for preserving microbial cultures. For UV survival, the capsules must be shielded appropriately, at least with UV resistant films. It may be also desirable to include a nutrient medium in the capsule, and to enclose it in a selective membrane that will allow the supplied nutrient to slowly absorb and mix with the local planetary nutrients, so that the microorganisms can gradually adjust to the planetary chemistry (pH, redox potential, toxic components, specific local nutrients). For aerobic eukaryotes, it may be desirable to enclose them in separate capsules with shells that will dissolve only in oxygen-containing environments. This will preserve the aerobic eukaryotes until photosynthetic organisms create a suitable oxygen-containing atmosphere.

It may be possible to provide some of this shielding and nutrient using the solar sail that launches the capsule. The sail must constitute about 90% of the total mass of the small vehicles. The sail could be possibly made of proteinaceous or other biodegradable organics. It may be designed to fold over the microbial packets after propelling them from the solar system, and provide shielding during transit and capture, and eventually to provide nutrient materials on the host planet.

For successful missions, the microorganisms must find adequate nutrients, which may be carbonaceous materials accumulated from dust particles, comets and asteroids, with organic content resembling carbonaceous chondrites. As a model, soil nutrient analysis of the Murchison C2 meteorite showed biologically available nutrient content (in mg/g) of: C and N in hydrothermally (121 $^{o}$C, 15 minutes) extractable organics, 1.8 and 0.1; S as soluble $SO_4^{-2}$, 4.5; P as $PO_4^{-3}$, 6.4E-3; and extractable cations by 1 M $CH_3COONH_4$ solution at pH 7, Ca, 4.0; Mg, 1.7; Na, 0.57; K, 0.65 mg/g; and cation exchange capacity of 5.8 milliequivalents/100 g. All of these are values are comparable or higher than in average terrestrial agricultural soil. Use of the organic meteorite nutrients as sole carbon source was demonstrated by light emission from *Pseudomonas fluorescence* modified with a lux gene when challenged with the meteorite extract, and preliminary observations of growth of the thermophile eubacteria *Thermus* and *Thermotoga* in the extract. The soil microorganisms *Flavobacterium oryzihabitans* and *Nocardia asteroides* grew in materials extracted from 100 mg meteorite powder into 1 ml water, as illustrated in fig. 3, to populations up to 5E7 colony forming units/ml in 4-8 days, similar to growth in extracts from agricultural soils, and retained stable populations in the meteorite extract for several months. Biological effect on higher plants was demonstrated by *Asparagus officinalis* and *Solanum tuberosis* (potato) tissue cultures. When the above meteorite extract was added to partial 10 mM $NH_4H_2PO_4$ nutrient solution, the average fresh weight of asparagus plants grew from 1.5±0.3 to 2.1±0.8 g, and of potato from 3.0±1.2 to 3.9±1.2 g, and both showed enhanced green coloration. Correspondingly, the elemental S content of asparagus dry mass increased from 0.07 to 0.49%, of Ca from 0.02 to 0.26, of Mg from 0.03 to 0.41, of K from 0.18 to 0.32, of Fe from 0.02 to 0.03% [18,19].

These observations suggest that microorganisms entering young planetary environments, and even higher organisms, can grow on the large amounts of accreted interplanetary dust, meteorite and cometary [23] materials. Implanted microorganisms may multiply as well in carbonaceous asteroid parent bodies during the warm hydrothermal

alteration phase, and in dust-sealed comets if they contain sub-surface water when warmed to 280-380 K during perihelion transits [27]. After landing, microorganisms can use the meteorite matrix materials. In fact, water in fissures in carbonaceous meteorites can create concentrated organic and mineral nutrient solutions conducive to prebiotic synthesis, and provide early nutrients after life arose in these meteorite microenvironments [19].

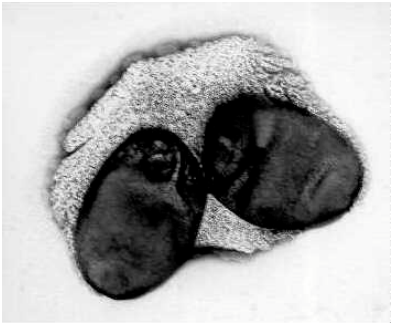

**Fig. 3 Microorganisms identified tentatively as *Flavobacterium oryzihabitans* grown in extraterrestrial nutrient extracted from the Murchison meteorite, with a meteorite fragment in the background.**

Reprinted from M. N. Mautner, R. R. Leonard and D.W. Deamer, "Meteorite Organics in Planetary Environments: Hydrothermal Extraction, Surface Activity and Microbial Utilization", Planetary and Space Science 43, 139-147 (1995), Fig. 4, p.144. (Reproduced with kind permission from Elsevier Publishers)

## 7. ADVANCED MISSIONS AND DEVELOPMENT NEEDS

Advanced technologies can increase substantially the probability of success, and reduce the required swarm mass.

(1) Preparation of Biological Payload. Genetically engineer microorganisms, including multicellular eukaryotes that combine extremophile traits for survival in unpredictable, diverse environments and that can efficiently metabolise extraterrestrial nutrients. It may be necessary to devise missions where the microbial payload can defrost and multiply/recycle periodically, say every 1E5 yr, for renewal against radiation-induced genetic degradation.

(2) Propulsion. Develop new methods to accelerate sub-milligram objects to 0.01 c. For example, antimatter - matter recombination has the potential to reach velocities close to c. Interestingly, the energy for a capsule of 1E-6 kg travelling at 0.01 c, i.e., 4.5E6 J, which can be provided by mass-to-energy conversion of 5E-11 kg of antiparticles. Launching smaller, microgram capsules at 0.01 c requires the production of 5E-14 kg of antiparticles, which brings even this exotic technology within the capabilities of current technology [24].

(3) Navigation. Apply on-board intelligent robots for in-course navigation, and for identifying suitable accretion systems and habitable planets; for landing on these targets; and to control the initial incubation.

(4) Accretion into comets and asteroids. Use self-replicating robots to multiply on those bodies and to turn them into biological hatcheries. Use comets and asteroids in this solar system to grow large panspermia biomasses for interstellar and galactic panspermia, and as growth and storage media in the target systems.

At the highest technological level, human interstellar travel can promote life. For example, Oort-belt cometary nuclei can be converted to habitats with resources to sustain

each up to 1E13 kg biomass (1E12 human population), and their large-aphelion orbit readily perturbed to leave the solar system. Human interstellar travel may require centuries of far-reaching developments, including the bioengineering of space-adapted, science-based "homo spasciense". Space adaptation may also need man/machine cyborgs and the risk of robot takeover. In this case, strong measures must ensure that control stays vested in organic intelligent brains with self-interest in perpetuating their (and our) genetic heritage as DNA/protein life-forms.

Such problems illustrate that human interstellar travel is tenuous. The longevity of intelligent civilizations is unknown, and the long-term ability of organic intelligent Life to propagate itself in space is unpredictable. It is therefore prudent to enact a panspermia program early using available technology, and advanced technologies can be incorporated as they develop.

## 8. RESOURCE EQUIREMENTS FOR SEEDING THE GALAXY

Although aimed at specific targets, the microbial payloads may carry life further in space and time.

First, much of the microbial swarm will miss or transit the target. Secondly, of the initial 1E13 comets that capture capsules in the accreting system, up to 99% will be ejected into interstellar space [11], carrying the microbial content. These embedded capsules, shielded from radiation and preserved at 3 K, may survive in the comets for many Gyr, until eventually captured in accreting systems in other regions of the galaxy. Of the perhaps 1E11 comets remaining in the accreting system, most will remain in the cold <10 K Oort cloud which will be eventually ejected into interstellar space. Therefore the majority of the launched biomass will eventually carry the microbial payload further into the galaxy. The spread of microbial life by comets is similar to the proposals of Hoyle and Wickramasinghe [17], but we postulate here a directed origin.

Future programs may aim intentionally to seed the entire galaxy. It is interesting to assess the feasibility of such a program.

Once launched randomly into the galactic plane at v = 0.01 c, the microbial packets will traverse the galaxy (r = 7E4 ly [25]) in 7E6 yr. The packets are gravitationally bound to the galaxy and will eventually perform random paths. At these speeds, mm size capsules will transit all thin regions and will be captured only in protostellar condensations or denser accretion zones. The mass ratios above showed that 1E-13 of the captured biomass in these areas will be delivered to planets. With 100 capsules of 1E-10 kg, i.e., a biomass of 1E-8 kg required to seed a planet, and with star-formation rate of 1 $yr^{-1}$ in the galaxy, biomass needs to be launched at the rate of 1E5 kg/yr for 5E9 yr to seed all new stars during the lifetime of the solar system. For example, the biomass can be dispersed in pulses of 1E12 kg to seed the population of star-forming clouds as it is renewed every 1E7 yr. The total required biomass is 5E14 kg, compared for example with the 1E19 kg organic carbon (1%) in the 1E21 kg total asteroid mass. This resource allows increasing the launched biomass up to a factor of 2E6 to account for losses.

As a more conservative estimate, assume a 5 au capture zone, with a volume of 2E36 $m^3$, with the total capture volume of 2E47 $m^3$ about 1E11 stars. With a capture probability of 1E-5 and for delivering 100 captured capsules of 1E-10 kg each, 1E-3 kg needs to be placed about each star. This corresponds to a density of 5E-40 kg biomass $m^{-3}$ in these circumstellar volumes. Assuming that this is achieved by establishing a similar biomass density through the 5E61 $m^3$ volume of the galaxy, then the total biomass needed in the galaxy is 2.5E22 kg. Renewing this density each 1E9 yr for the 5E9 yr lifetime of the solar system, to seed every new planetary system during the first Gyr after its formation, gives a material requirement of about 1E23 kg, about 10% of the 1% C content in 1E26 kg of the total cometary mass.

The material requirements can be reduced by many orders of magnitude if the missions are directed to star-forming regions rather than distributing biomass through the galaxy at random. Of course, the microbial population may be subject to substantial losses,

but may be enhanced in the target zones by gravitational attraction. The fate of biological objects traversing the galaxy requires detailed analysis.

It may be possible to grow the necessary large amounts of microorganisms directly in carbonaceous asteroids or comets. Carbonaceous C1 meteorites, and presumably asteroids, contain water in about the biological ratio of 5:1 $H_2O$/C, and N in the biological ratio of 10:1 C/N, as well as biologically usable forms of the other macronutrients S, P, Ca, Mg, Na and K in at least the biological C/X elemental ratios [19]. Once the nutrient components are extracted, the residual inorganic components may be used for shielding materials for the microbial capsules.

As a possible method for converting comets to biomass, the loose icy, cometary matrix may be fragmented and enclosed in membranes in 1 kg spheres. Warming and melting such a unit, from 10 to 300 K, requires 5.1E9 J, which can be provided by the solar energy flux of 325 W $m^{-2}$ at 2 au, incident on the 3.1 $m^2$ cross-section of a 1 m radius object during a two-months perihelion transit about 2 au. The microbial experiments show that in 6 - 8 days after inoculation, this organic solution will yield microbial densities of >1E8 CFU/ml which can survive for several months [18, 19]. Subsequently, the microbial solution can be converted to 1 mm "hailstones". These microbial ice capsules can be accelerated out of the solar system, for example, by first accelerating the comets sunward into parabolic orbits, and in this manner dispersing the Oort cloud at the rate of 20 comets $yr^{-1}$ during 5E9 yr. This rate is comparable to the natural rate of 3 new comets/yr plus up to 1E9 new comets per/year during cometary showers [16], and the task may be accomplished at the required rate by processing every new comet that arrives naturally from the Oort cloud.

An interesting experiment in this direction would be to inoculate the sub-crust zone of an inbound comet, and of enclosed samples of the cometary material embedded in the comet, the latter to allow melting near the perihelion without evaporation. Embedded sensors could monitor microbial growth during the perihelion passage, and in short-period comets during further passages, to verify microbial growth in cometary materials and environments. Laboratory microbiology experiments with returned cometary materials would be also of interest.

The above considerations suggest that a single technological civilization can seed the galaxy. Similarly, one past panbiotic civilization could have seeded the galaxy, accounting for the rapid emergence of life on Earth and possibly on Mars [2, 3, 26].

By extrapolation, the material resources of 1E11 solar systems in one galaxy may be sufficient to seed all the 1E11 galaxies.

## 9. MOTIVATION: THE PRINCIPLES OF PANBIOTIC ETHICS

Directed panspermia must rest entirely on enduring ethical motivation. Eventually, this non-material moral entity can have far-reaching consequences on the material future of the universe.

The insights of contemporary biology and cosmology can be synthesized into a Life-centered panbiotic ethics, as follows.

(1) Life is a process of the active self-propagation of organized molecular patterns.
(2) The patterns of organic terrestrial Life are embodied in biomolecular structures that actively reproduce through cycles of genetic code and protein action.
(3) But action that leads to a selected outcome is functionally equivalent to the pursuit of a purpose.
(4) Where there is Life there is therefore a purpose. The object inherent in Life in self-propagation.
(5) Humans share the self-propagating DNA/protein biophysics of all cellular organisms, and therefore share with the family of organic Life a common purpose.
(6) Assuming free will, the human purpose must be self-defined. From our identity with Life derives the human purpose to forever safeguard and propagate Life. In this pursuit human action will establish Life as a governing force in nature.

(7) The human purpose defines the axioms of ethics. Moral good is that which promotes Life, and evil is that which destroys Life.
(8) Life, in the complexity of its structures and processes, is unique amongst the hierarchy of structures in Nature. This unites the family of Life and raises it above the inanimate universe.
(9) Biology is possible only by a precise coincidence of the laws of physics. Thereby the physical universe itself also comes to a special point in the living process.
(10) New life-forms who are most fit survive and reproduce best. This tautology, judgement of fitness to survive by survival itself, is the logic of Life. The mechanisms of Life may forever change, but the logic of Life is forever permanent.
(11) Survival is best secured by expansion in space, and biological progress is best assured by adaptation to diverse multiple worlds. This process will foster biological and human/machine coevolution. In the latter, control must always remain with organic-based intelligences, who have vested interests to continue our organic life-form. When the future is subject to conscious control, the conscious will to continue Life must itself be forever propagated.
(12) The human purpose and the destiny of Life are intertwined. The results can light up the galaxy with life, and affect the future patterns of the universe. When the living pattern pervades nature, human existence will have attained a cosmic purpose.

Points 3-5 do not suggest teleology, i.e., it is not implied that the biological process recognizes an objective. Rather, these points are based on the principles of equivalence, that also underlie, for example, relativity and Turing's test of intelligence: if an entity is indistinguishable in all observables from another entity, then the two are identical. Applied here, if the biological process was seeking to propagate purposefully, it would function as it does actually. Therefore the behavior of the biological process is indistinguishable from, and equivalent to, action with purpose.

A serious panbiotic motivation in our young civilization is expressed by the Society for the Interstellar Propagation of Life [28]. Depending on the frequency of life in space, the panspermia program may have the following objectives.

(1) The complex mechanism of replication, transcription, energy production and membrane transport must be all present in even the simplest surviving cell. This crates a large probability barrier to the origin of life. If terrestrial life is alone, we have a special duty to safeguard and propagate this unique creation of nature.
(2) Eukaryotic and multicellular life emerged on Earth only after 3E9 yr. This shows a large probability barrier to higher evolution, which therefore may not occur at all in other primitive biosystems. Eukaryotes and simple multicellular organisms that could survive interstellar transport should be included in the panspermia payload to overcome this evolutionary barrier. A possible outcome of the resulting higher evolution, as our own panbiotic capabilities demonstrate, is the emergence of new intelligent species who will promote Life further in the galaxy.
(3) Extraterrestrial intelligent life is counter-indicated by a lack of scientific evidence and by Fermi's paradox. Should such civilizations exist, however, panspermia can serve as interstellar communication. The nature of our life form, that we cannot yet fully describe, is best communicated by samples. If our life form will have to compete with others, we shall have only extended this basic property of the living process. Our innate duty is first to our own organic life form.

The technical approaches to panspermia will evolve, but a permanent ethical foundation must prevail. The biocentric principles derive rationally from the scientific world-view, and are also consistent with the respect for life innate in healthy human emotions, civilizations and religions. The Life-centered panbiotic purpose to propagate Life can therefore serve as a lasting basis of human ethics.

The panbiotic enterprise will transform new solar systems through the galaxy into evolving biospheres. In this process, Life will achieve secure continuation, the diversification of species and even higher patterns of complexity. Eventually, all the material constituents of nature, as it extends in time and space, will become living substance and its sustaining resources. Once we plant life in space, the self-propagating nature of Life will assure that it will encompass all matter. In this sense, the physical universe itself will have become an interconnected living being.

When Life comes to the universe, the universe will come to life. In fulfilling the ultimate purpose of Life, our human existence will have assumed a cosmic meaning.

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