Transfer of Life-Bearing Meteorites from Earth to Other Planets

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ABSTRACT

The probability is investigated that the meteorites originating on Earth are transferred to other planets in our Solar System and to extra solar planets. We take the collisional Chicxulub crater event, and the material that was ejected as an example of Earth-origin meteors. If we assume the approximate size of the meteorites as 1cm in diameter, the number of meteorites to reach the exoplanet system (further than 20 ly) would be much greater than one. We have followed the ejection and capture rates estimated by Melosh (2003. If we consider the possibility that the fragmented ejecta (smaller than 1cm) are accreted to comets and other icy bodies, then buried fertile material could make the interstellar journey throughout the Galaxy. If life forms inside remain viable, this would be evidence of life from Earth seeding other planets. We also estimate the transfer velocity of the micro-organisms in the interstellar space. In some assumptions, it could be estimated that, if life has originated 10^{10} years ago anywhere in our Galaxy as theorized by Joseph and Schild (2010a,b), it will have since propagated throughout our galaxy and could have arrived on Earth by 4.6 billion years ago.

Key Words: Organisms disperse, Panspermia, meteorites, ejection, Chicxulub, Gl 581

1. Introduction

A number of scientists now believe that micro-organisms can be transferred to and from various planets and moons, including from Earth to other worlds such as Mars (Joseph and Schild 2010a,b; Joseph, Dass, Rizzo, et al. 2019; Wainwright et al., 2010). To determine the probability of the transfer of viable organisms between planets, we've used Earth as the origin of life-bearing rocks and have determined the likelihood that viable life could be deposited on those stellar objects in this solar system which are believed capable of sustain life, i.e. Enceladus, Europa, Ceres and dwarf planet Eris. Recently it has been reported that the detection of the super-Earth planets in the Gl 581 system which reside at the warming edge of the habitable zone of the star (Udry et. al. 2007). Therefore, we also investigate the probability of successful transfer to extra solar planets, such as Gl 581. The propagation distances of life-bearing rocks are also estimated, and we have determined that under some circumstances, life originating in one stellar system could propagate throughout Galaxy.

2. Seeding Other Planets With Life

Super-Earth planets have been recently detected, including in the Gl 581 system and which orbits at the warming edge of the habitable zone of the star (Udry et. al. 2007). If this planet or other super-Earth's may harbor life is completely unknown. On the other hand, if microbial life were to be deposited on a super-Earth through mechanisms of panspermia (Joseph and Schild 2010a,b, Napier and Wickramasinghe 2010), then it could be predicted that these microbes might flourish and reproduce.

The only planet which we know has life, is Earth. Therefore, Earth would be a likely source to seed other planets with life. This could take place following solar storms which eject microbes from the outer atmosphere into space, or from bolide impacts which eject bounders, rocks, and oceans of water into space (Joseph and Schild 2010a,b; Napier and Wickramasinghe 2010). Naturally, those meteors, asteroids or comets which strike with the most force, would eject the most material into space. Thus it could be predicted that the asteroid or meteor which struck this planet 65 million years ago, and which created the Chicxulub crater (Alvarez, et al 1979) would have ejected substantial amounts of rock, soil, and water into space, some of which would have fallen onto other planets and moons, including stellar bodies outside our solar system, including Kuiper belt objects, Oort Cloud objects, and possibly exosolar planets.That meteorite was estimated to be about 10 km in diameter (Alvarez, et al 1979).

Here, we investigate the transfer probability of Earth origin rocks to our Solar System. We put parameters as following that N_0 rocks are ejected from Earth, s (cm) is the distance to the object, and the cross section of the rock captured by the object is σ (cm^2). Then the impact rock number is estimated that N_0 times σ over the surface of sphere of radius s as

$N_{impact} = N_0 \sigma/(4\pi s^2)$.

When the Chicxulub meteorite collided to Earth, it could be estimated that almost the same amount mass could be ejected from Earth , where we have taken the optimistic value (Wallis & Wickramasinghe, 2004). Then it is assumed that the ejected mass from Earth is f_1 times M_0, where M_0 is the mass of the Chicxulub meteorite and the factor f_1 (~ 0.3) denotes the fraction of the mass ejected from Earth. Taking that the mean diameter of rocks is r_1 (cm) and the estimated diameter of the Chicxulub meteorite is R_1(cm), the number N_0 of ejected rocks from Earth is estimated as f_1 times of the cubic of (R_1/r_1). If we take R_1 and r_1 as 10(km) and 1(cm), the number N_0 of ejected rocks is the order of

$$N_0 \sim 3\times10^{17} (f_1/0.3)(R_1/10\mathrm{km})^3(r_1/1\mathrm{cm})^{-3}.$$

This is a rather crude approximation. To be precise, we have to include the size distributions of rock fragments. Here we only tentatively want to estimate the number of rocks. If we take $r_1 \sim 1$mm, the above value has increased factor ~ 10^3. However the cosmic radiation in space will damage the micro-organism within the fragments of size ~ 1mm, unless it is covered by molecules such as ice or other elements.

The distance to the interesting objects within our Solar System is the order of astronomical unit. So we take the representative value as $s \sim 1\mathrm{AU} \sim 1.5\times10^8$ km. The problem is the cross section σ. So we consider the following two models.

Model A : The cross section σ for the direct collision to the object is the order $\sigma \sim \pi R_0^2$ where R_0 is the radius of the object. Then the number of impact rocks is estimated for the case $R_0 \sim 10^3$ km and $s \sim 1$AU as

$$N_A \sim N_0\sigma/(4\pi s^2) \sim 3\times10^6 (f_1/0.3)(R_1/10^3\,\mathrm{km})^3(r_1/1\mathrm{cm})^{-3}(R_0/10^3\,\mathrm{km})^2 \times(s/1\mathrm{AU})^{-2}.$$

This model corresponds to the high velocity case of ejected rocks.

3. Model B.

After rocks are ejected from Earth, they are orbiting around Earth and then ejected to orbits around Sun through swing-by. If rocks could be deaccelerated by gravitational interaction, rocks are captured to objects. After a few My, some fraction of rocks could fall into objects. The gravitational infall to the object could be inferred by the gravitational accretion radius $R_g \sim G m_0/v_0^2$ where m_0 is the mass of the object. Then the cross section σ is estimated as $\sigma \sim \pi R_g^2$ which is proportional to the mass square m_0^2. As the dominant planet is Jupiter, the infalling rate is roughly proportional to $(m_0/M_J)^2$ where M_J is Jupiter's mass. Then the number of falling rocks is estimated for the case of $m_0 \sim 10^{20}$ kg as

$$N_B \sim N_0 (m_0/M_J)^2 \sim 10^3 (f_1/0.3)(R_1/10\mathrm{km})^3 (r_1/1\mathrm{cm})^{-3} (m_0/10^{20}\mathrm{kg})^2 \times (M_J/2\times 10^{27}\mathrm{kg})^{-2}.$$

This model corresponds to the low velocity case of ejected rocks. The values for Enceladus, Europa, Ceres, Eris, Moon and Mars are presented in the Table.

Table. The values of s, R_0, m_0, N_A, N_B for Enceladus, Europa, Ceres, Eris, Moon and Mars

For every object, the number N_A and N_B are much greater than one. Although it is uncertain how rocks enter the presumed sea under the surface, for example, of Enceladus and Europa, the probability may be high that micro-organisms transferred from Earth would be adapted and growing there. The orbital calculations of meteorite transfer among planets within our Solar System are estimated by Melosh (2003).

Probability of reaching Gl 581 and extra solar planets

To extend the above consideration to the extra solar planets is almost straightforward. We introduce the factor f_2 (~ 0.3) which denote the fraction of rocks ejected from our Solar System.

As the distance to Gl 581 is 20 light years, we take the representative value for s as $s \sim 10^{19}$ (cm). The problem is the cross section σ. So we consider the following model A and C, where model A is the almost the same in section 2.

4. Model A

The cross section σ for the direct collision to the planet in the Gl 581 system is of the order $\sigma \sim \pi r^2 \sim \pi(m/m_\oplus)^{2/3} r_\oplus^2$ where m and $m_\oplus$ are the mass of the planet and Earth, respectively. Then the cross section factor becomes $\sigma/(4\pi s^2) \sim (m/m_\oplus)^{2/3}(r_\oplus/s)^2/4 \sim 3\times10^{-21}(m/5m_\oplus)^{2/3}(s/10^{19}\mathrm{cm})^{-2}$,

and the impact number becomes as

$$N_{impact} \sim N_0\sigma/(4\pi s^2) \sim 3\times10^{-4}(f_1 f_2/0.1)(R_1/10\mathrm{km})^3(r_1/1\mathrm{cm})^{-3}(m/5m_\oplus)^{2/3} \times(s/10^{19}\mathrm{cm})^{-2}.$$

The probability for the direct collision is small.

5. Model C

The cross section σ could be enlarged including the effect of the gravitational interaction such as swing-by. If rocks could be deaccelerated by gravitational interaction, rocks are captured to the stellar system. Although the velocity dependence of the cross section is pointed out by Melosh (2003), it is difficult to include this effect here. Then we simply assume the cross section as $\sigma \sim f_3 \pi R^2$, where R is the orbit radius of the planet and the uncertainty factor f_3 is included. The number of impacted rocks, N_{impact}, becomes

$$N_{impact} \sim N_0 f_2 f_3 (R/s)^2/4 \sim 10^4(N_0 f_2/10^{17})(f_3/0.1)(R/1\mathrm{AU})^2/(s/10^{19}\mathrm{cm})^2.$$

Due to the estimation of numerical simulations by Melosh (2003), the factor

f_1, and f_2 are roughly 0.3. We take f_3 tentatively as ~ 0.1. Even though there are many uncertainty factors, the probability could increase by considering the small rocks which are smaller than 1cm.
If we consider the possibility that the fragmented ejecta (smaller than 1cm) are accreted to comets and other icy bodies in the 'Edgeworth-Kuiper Belt', the securely buried fertile material could make the interstellar journey through Galaxy (Wallis & Wickramasinghe, 2004).

The above estimated number N_{impact} is the captured number of rocks in the Gl 581 system. If we consider the falling probability f_4 to the appropriate planet and the landing probability f_5 to the appropriate circumstances of the planet, the probability for the proliferation of the life must be decreased. Then the numbers of rocks for the proliferation becomes

$$N_{proli} \sim 10^2 (N_0 f_2 f_3 /10^{16})(f_4 f_5 /0.01)(R_1/10\text{km})^3 (r_1/1\text{cm})^{-3} (R/1\text{AU})^2 \times (s/10^{19}\text{cm})^{-2}.$$

If we take the mean velocity of meteorites in the interstellar space as 10 km/s, the elapsed time to travel to GI 581 system is

$$T \sim s/v \sim 10^6 (s/20\text{ ly})(10\text{ km/s}/v) \text{ years.}$$

Then the time to be ejected from our Solar System through swing-by (several Million years) and the orbiting time to fall in the planet through swing-by after captured to Gl 581 system (several Million years) are longer than the travel time to Gl 581 system.

6. Transfer Distance and Velocity of rocks with Micro-Organisms

In this section, we estimate the distance and velocity of rocks with micro-organism through the interstellar space.

Model I: The number of ejected rocks from our Solar System is

$$N_{ej} \sim 10^{17} (f_1 f_2 /0.1)(R_1/10\text{km})^3 (r_1/1\text{cm})^{-3}.$$

To apply the estimate to general stellar systems, we change the size of the system from ~ 1AU to ~ 10AU where the orbits of Jupiter and/or Saturn like planets are considered. If the radius of the planet orbit is taken as R , the cross section σ is given by $\sigma \sim \pi R^2$. The number of accumulated rocks to the system is

$$N_{impact} \sim N_{ej}\, \sigma /(4\pi L^2),$$

where L is the distance between the origin and the system. For the propagation of the micro-organism, N_{impact} must be greater than N_{crit} (~ 1). From the criterion ($N_{impact} \geq N_{crit}$), the distance L is limited as

$$L \leq L_{crit} \sim (N_{ej}/N_{crit})^{1/2} R/2 \sim 3\times10^4 (N_{ej}/10^{17})^{1/2} (1/N_{crit})^{1/2} (R/10AU) \text{ly}.$$

The propagation time T to the L_{crit} is given by

$$T \sim L_{crit}/v_{mean} \sim 10^9 (L_{crit}/3\times10^4 \text{ ly})(10 \text{ km s}^{-1}/v_{mean}) \text{ years},$$

where we take the mean velocity of rocks as 10 km s^{-1}. Then, by 10^9 years, rocks could reach each stellar system within the distance 3×10^4 light years. The above estimate is rather optimistic. We must consider the uncertainty factor such as f_3, f_4 and f_5. If we include these factors, the value of N_{crit} must be greater than 10^3. Then the above critical length decreased to

$$L_{crit} \sim (N_{ej}/N_{crit})^{1/2} R/2 \sim 10^3 (N_{ej}/10^{17})^{1/2} (10^3/N_{crit})^{-1/2} \text{ ly}.$$

The propagation time T to L_{crit} is given by

$$T \sim L_{crit}/v \sim 3 \times 10^7 (L_{crit}/10^3 \text{ly})(10 \text{ km s}^{-1}/v) \text{ years}.$$

Then, by 3×10^7 years, the many rocks (~10^3) could reach each stellar system within the distance 10^3 light years.
To estimate the longer distance then L_{crit}, we consider the following model.

Model II: The Chicxulub crater event is 65 My ago and such event is happened roughly per every 100 My, which is consistent of the accretion rate of crater

forming bodies (10^{11} g /y, Sephton (2003)). Then the mean number of ejected rocks per year N_{mean} is estimated as $N_{mean} \sim N_{ej}/(10^8 y) \sim 10^9/y$.
The number $N_{acc}(t)$ of accumulated rocks in the system of the distance L after t year is

$$N_{acc}(t) \sim N_{mean} \times t \times \pi R^2/(4\pi L^2).$$

Then the distance ($L_{crit}(t)$) which satisfies the criterion that $N_{acc}(t)$ is greater than N_{crit} ($\sim 10^3$) is given by

$$L_{crit}(t) \sim (N_{mean} \times t \times R^2/(4 N_{crit}))^{1/2}$$
$$\sim 10^3 (N_{mean}/10^9)^{1/2} (t/10^8 y)^{1/2} (10^3/N_{crit})^{1/2} (R/10\ AU)\ ly.$$

As the radius of Galaxy (R_G) is about 5×10^4 ly, it takes 3×10^{11} years for $L_{crit}(t) \geq R_G$, which is much greater than the age of our Galaxy.

Model III: If we assume that the propagated system becomes the place where the micro-organisms adapt, multiply and proliferate, the system becomes the source of the rocks with micro-organisms. If it takes t_0 time to propagate to such a system with distance L and t_1 time to proliferate there enough, the propagation velocity v_{prop} is

$$v_{prop} \sim L/(t_0 + t_1) \sim 10^3\ ly/(10^8\ y),$$

where we take $L \sim L_{crit} \sim 10^3$ ly , $t_0 \sim 3 \times 10^7$ years and $t_1 \sim 10^8$ years, respectively.
1) If the multiplication factor m of such descendents for each generation is high ($m \gg 1$) , the propagated distance L_{prop} would be proportional to the time as

$$L_{prop} \sim v_{prop} \times t .$$

It takes 5×10^{9} years for $L_{prop} \geq R_G$, which means that if origin of life has begun within our Galaxy 10^{10} years ago, it has propagated through Galaxy, as our Galaxy age is almost 1.3×10^{10} years. The problem may be that many types of life which evolved differently from the same origin are falling to Earth nowadays.

2) If the multiplication factor m of such descendents for each generation is not high ($m \cong 1$) and they eject rocks with micro-organism only one time after t_1, the propagated distance L_{prop} would be proportional to the square root of time for its random walk property, as

$$L_{prop} \sim L_{crit} \times (t/10^{8}\,y)^{1/2}.$$

If we take $L_{crit} \sim 10^{3}$ ly, it takes 2.5×10 years for $L_{prop} \geq R_G$. It means that, if origin of life has begun within our Galaxy 10^{10} years ago, it has propagated only $10L_{crit} \sim 10^{4}$ ly. If there are $X \sim 25$ sites where the life began 10^{10} years ago in our Galaxy, the propagated surface is about the same of our Galaxy by the equation

$$\pi(10L_{crit})^{2} X \sim \pi R_G^{2}.$$

Then the probability is almost one that our solar system is visited by the micro-organisms originated in extra solar system.

7. Conclusions and Discussion

Although there are many uncertain factors, the probability of rocks originated from Earth to reach nearby star system is not so small. The rough estimation is

$$N_{impact} \sim 10^{4}(N_0 f_2/10^{17})(f_3/0.1)(R/1AU)^{2}(s/10^{19}cm)^{-2}.$$

Although it is not certain that the micro-organisms within the size ($\leq$ 1cm) of meteorites are still viable for several My under cosmic radiation in space, there is the possibility that the fragmented ejecta are covered by accreted molecules such as ice or other elements. It is pointed out the possibility that fragments are accreted by comets and other ice objects where the buried fertile material could endure the cosmic radiation (Wallis & Wickramasinghe, 2004). Under these circumstances fragments could continue the interstellar journey and Earth origin meteorites could be transferred to Gl 581 system. If we take it is viable, we should consider the panspermia theories more seriously.

We estimate the transfer velocity of the micro-organisms among the stellar systems. Under some assumptions, it could be estimated that if origin of life has begun 10^{10} years ago in our galaxy as estimated by Joseph and Schild (2010a,b), it could propagate throughout our Galaxy by 10^{10} years, and could certainly have reached Earth by 4.6 billion years ago (Joseph 2009), thereby explaining the origin of life on Earth.

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