

THE MOON AND SETI†

JEROME PEARSON

Wright Laboratory, WL/FIBG, WPAFB, OH 45433-6553, U.S.A.

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Abstract—Many studies lead to the expectation that millions of planets in the galaxy are suitable for life. Studies of interstellar travel and migration show that the entire galaxy could be colonized in a few million years. Our 4-billion-year old solar system should have been colonized by other civilizations by now. This leads to Fermi's Paradox: where are the extraterrestrials? To answer that question, this paper focuses on the obvious but often overlooked observation that the Earth and the Moon constitute a unique "double planet." Some evidence suggests that the moon was captured early in the history of the solar nebula and profoundly affected Earth's evolution. The Earth may have ended as a frozen, one-plate Mars or a runaway-greenhouse Venus if it had not enjoyed the presence of the Moon. Because of the expected rarity of double planets, we may be alone in our galaxy, and the search for extraterrestrial intelligence (SETI) may be more successful in nearby galaxies than in the Milky Way.

1. INTRODUCTION

Drake's equation for the estimated number of civilizations in the galaxy results in perhaps 1 to 10 million [1], depending on the choice of probabilities for suitable stars, planets, the origin of life, and the rise of civilizations. Studies of interstellar travel and migration indicate the possibility of colonizing the entire galaxy in a time period of millions of years. Since the planets of the solar system have been in existence for more than 4 thousand million years, they should have been colonized by other civilizations by now. This leads to Fermi's Paradox [2]: where are the extraterrestrials?

In SETI, the search for extraterrestrial intelligence, several possible answers to this paradox have been proposed. Among these are (1) that there are no extraterrestrials, and humanity is unique [3]; (2) that the process of interstellar colonization and diffusion of civilizations is so slow that all species are kept busy in their own stellar neighborhoods [4-7]; or (3) that we have been discovered and are living in a "zoo" under observation [8]. This paper proposes a modification of the first and second answers; we are not necessarily unique, but the probability of duplicating the Earth's environment is lower than has been assumed in previous studies.

In recent years, it has been common to assume that the Earth is average, and that similar planets must be common in the galaxy. This ignores the obvious observation that the Earth and the Moon are unique in the solar system. No other major planet has a satellite so large in comparison with its primary, one that causes such phenomena as the tides in the oceans

and body of the Earth. No trace of life was discovered on Mars by the Viking spacecrafts, or on Venus by the Venera spacecrafts. Earth's position should be re-examined to shed new light on why life in the solar system is limited to the Earth, and on the likelihood of there being other Earth-like planets in the galaxy.

2. HABITABLE SOLAR SYSTEMS

When the galaxy formed some 10 billion years ago, it consisted of pure hydrogen and helium. The first stars condensed from gaseous nebulas that contained no dust, and they had no planets. As the supergiant stars ended their short lives and became supernovas, they created heavier elements and spewed them out into the galaxy. Each generation of stars ended in supernova explosions that created higher proportions of heavier elements. Several generations after the initial formation of the galaxy, nebulas had high enough concentrations of heavy elements that rocky planets were formed during the nebular collapse [9]. Thus several generations of supernovas must be formed before a solar system like ours can arise. The Sun is made up of material from many generations of previous stars.

The planetesimal hypothesis holds that the collapse of the pre-solar nebula resulted in a central star that contracted and began hydrogen burning to place it on the main sequence, while the planets accreted from a combination of dust and gas. The giant planets formed first, in the denser portions of the nebula; they consisted of rocky cores surrounded by extensive mantles of hydrogen and helium [10]. The terrestrial planets formed in less dense portions of the nebula and closer to the Sun, where most of the gas was heated and expelled by the forming Sun.

There is a small "habitable zone" about the star in which the equilibrium temperature of a planet allows

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the existence of liquid water on the surface [11]. The habitable temperature zone around main-sequence stars may be very narrow, with a range of only one to three percent of the orbital radius. Cooler stars have smaller habitable zones, and those cooler than spectral class K5 have no habitable zones at all [12]. Temperate planets about these stars would be so close that their rotation periods would be locked into their orbital periods by tidal friction, resulting in extreme temperature ranges and no liquid water on their surfaces. On the other hand, stars hotter than spectral class F5 show higher rotation rates that indicate that they have retained all of their initial angular momentum, losing none of it in the formation of planetary systems. They also have shorter lives. Therefore, only a small range of spectral types can support planets within a habitable temperature zone for billions of years. Many of these stars are further excluded from having habitable planets because they are members of multiple star systems, preventing the formation of stable, temperate planetary orbits [13].

3. HABITABLE PLANETS

Dole [11] recognized several characteristics of a planet that determines its habitability, including a stable, nearly circular orbit within the habitable zone of the parent star, a moderate mass, and a reasonable rotation rate and an inclination of the axis to produce equable days and seasons.

One of the key elements in creating habitable planets not addressed by Dole is a molten core and a magnetic field to protect life forms from the deleterious effects of ionizing radiation. Though this point has not been demonstrated we think that life on the Earth is sensitive to magnetic fields, and that many species disappeared during those times when the Earth's core changed polarity and the magnetic field disappeared temporarily. In the Sun, this polarity change takes place regularly with a cyclic time of 22 years; in the giant planets, typical reversals have periods on the order of hundreds of years, and in Earth the field reverses several times in a million years. The recorded instances on the Earth of field reversal and temporary disappearance show how dependent life is upon the magnetic field [14]. The magnetic field of a planet depends on the size, composition, and temperature of the core, and the rotation rate of the planet.

On a magnetic version of Bode's Law plotting magnetic field moment vs angular momentum, most of the planets lie on a straight line [15]. This relationship is shown in Fig. 1 which plots updated values for Venus and Mars [16], and uses the Voyager II 1986 flyby data for Uranus [17]. However, Mercury and Earth have higher fields than this relationship would indicate. Because Mercury is so close to the Sun, its core is heated tidally more than the theory allows, giving it a high magnetic field for its size and rotation speed. Earth also has an anomalously high magnetic

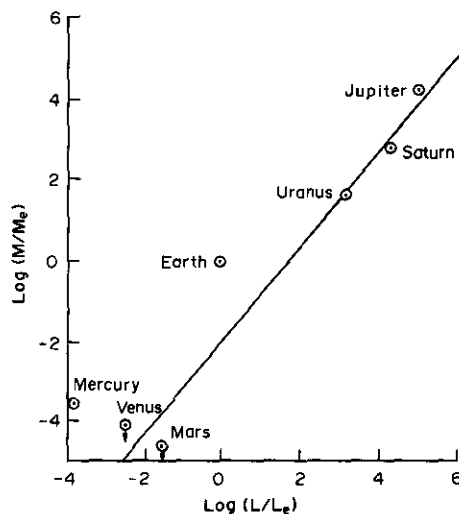


Fig. 1. Bode's Law of planetary magnetism.

field [14]. The Earth's magnetic field moment is about 100 times as strong as expected from the nominal line plotted in Fig. 1. This high magnetic field may be crucial for life.

A further requirement for maintaining a habitable planet may be the presence of life itself. If life arises on a planet in the habitable zone, it creates a negative feedback on the environment conditions—an oxidizing atmosphere that allows the evolution of land animals and intelligence, an ozone layer that blocks out ionizing radiation harmful to surface creatures, and a layer of carbon dioxide to act as a moderate greenhouse [18].

The net effect of the advent of life on a planet is to moderate and maintain an environment conducive to its survival, in spite of the increasing radiation of the evolving central star, which gradually moves the habitable zone farther outward. Without the feedback to maintain moderate surface temperatures in the presence of the hotter sun, a runaway greenhouse would produce a world like Venus. The advent of life can be viewed as creating a living planet that maintains its own environment—the Gaia hypothesis. This situation is represented in Fig. 2, which shows planetary temperature vs time. After the initial accretion

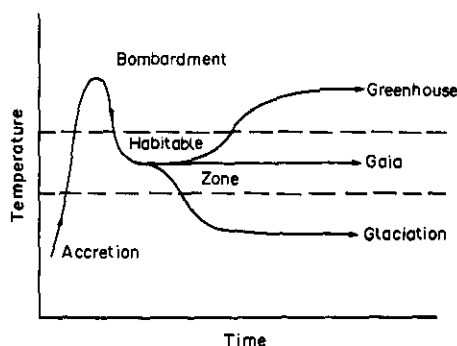


Fig. 2. The temperature history of a planet.

and meteoroid bombardment, planets in the habitable zones achieve an equable climate. However, unless life arises soon, the climate becomes unstable and the temperature leaves the habitable range via a runaway greenhouse or a runaway glaciation. If this outline is correct, then the emergence of life is necessary for a planet to maintain a habitable environment.

4. DOUBLE PLANETS

In the normal process of planetesimal accretion, bodies at the preferred Bode locations grow at the expense of smaller planetoids [10]. Eventually, all the smaller bodies are swept up in the cataclysmic bombardment whose scars are still visible on the faces of the Moon and the satellites of Jupiter and Saturn. The giant planets are able to capture their own retinues of moons as miniature solar systems, but the terrestrial planets are not. The giant planets may even prevent nearby planetoids from accreting, which could account for the small mass of Mars [20]. Mercury and Venus are moonless, as expected.

Then there is Earth: how did our planet alone acquire such an enormous Moon? Did Earth capture the Moon [21,22] or split into two bodies [23]? The origin of our Moon is not known for certain, even in the light of the Apollo voyages. One attractive theory suggests that as the planetoids accreted, the largest planetoid in each zone gradually acquired and destroyed the smaller ones in that zone; there had to be a second-largest planetoid, and its collision and destruction was the largest event in the planet's history [21]. In the case of the Earth and Moon, this final impact may have been only a grazing collision, speeding up the Earth's rotation, sweeping away its primordial atmosphere of hydrogen and helium, and breaking up the Moon before it reformed in orbit about the Earth [9]. Later, sweeping of debris and tidal interaction resulted in the present inclined but nearly circular orbit. The Moon thus represents the capture of the second-largest planetoid, and it may be a rare case indeed.

This unusual, almost unique event may have been necessary for the Earth to become habitable. During the creation of the Moon, the Earth's core was heated above normal and enhanced the Earth's magnetic field. The Moon's well-known tidal effects on the Earth produce a higher core temperature than normal; the Moon was apparently much closer to the Earth in the past, heightening this effect. This means that the Moon may have produced the magnetic field and radiation shielding that allowed life to survive on Earth long enough to create a Gaian environment. If the only way to create a high magnetic field is by proximity to the Sun or the presence of a large satellite, only double planets may be habitable.

Let us examine the solar system for clues to the probability of occurrence of double planets. Among the major planets from Mercury to Neptune, only the

Earth-Moon system is double. This double planet is unique in the solar system, in total mass and relative masses of the two bodies. Pluto and Charon have similar masses, but their total mass is only 1% of the Earth-Moon mass, and their solar orbit is so eccentric that the pair may be considered a double asteroid rather than a double planet; they may be escaped moons of Neptune. In the Jovian system, 1 of 14 satellites is either locked in a Lagrangian orbit with a twin or is intricately bound as a "shepherd" to a ring of debris [24]. In the Saturnian system, 3 of 13 satellite show such a connection [25], and in the Uranian system 1 of 14 is affected [16]. There are no interacting satellites known in orbit about Neptune, but Voyager II may change that status in its 1989 flyby.

Among these satellite systems, collisions and orbital interactions have been common [17]. However, most of these interactions have resulted in satellites occupying Lagrangian orbits with respect to each other and the primary planet [28,29], or satellites associated with and shepherding the ring-forming remains of a destroyed or stillborn satellite [30,31]. There are no known examples of double satellites in the solar system.

It appears that in the many interactions among giant planet satellites, the common outcome is not a double planet but co-orbiting separate bodies. Only about 1 in 10 of these satellites has been affected. If we assume that the facts of accretion of satellites parallel those of the major planets, then about one-tenth of all planets in other solar systems might show the result of a major orbital encounter. On the other hand, if the Earth-Moon system is the result of a rare grazing collision, and the Moon has been instrumental in the favorable evolution of the Earth, then planets suitable for human habitation may be very rare. This factor of double planet formation is an aspect that has been neglected in computer simulations of the formation of planets by accretion [32-34].

5. DOUBLE PLANETS AND SETI

The body tides in the Earth caused by the Moon may account for the large, molten core of the Earth, though this could be due also to its composition, and this may have resulted in the onset and the persistence of plate tectonics in the Earth, and the ozone layer and its protective shield against ionizing radiation [35]. The ocean tides may have profoundly affected the evolution of crustaceans and amphibians, leading to the emergence of land life. These effects lend credence to the speculation that the Earth may have ended as a frozen, one-plate Mars or a runaway-greenhouse Venus if it had not enjoyed the presence of the Moon [36]. The Moon might actually be necessary for the evolution of higher life. Without the widespread persistence of plate tectonics and the resulting large elevation changes and the uplifting of

continents, the Earth might have been covered with a global ocean [37–39], in which civilization could not arise.

When the rarity of double planet formation is applied to the Drake equation, the number of potential civilizations may be far fewer than the “conservative” estimate of Bond and Martin [40,41]. We may even be alone in our galaxy. In considering the “Gaia” hypotheses that life does its own terraforming of the planet upon which it arises, we may expect to find that very few potential planets will actually give rise to life, and the rest will be subject to runaway greenhouse effects or runaway glaciation and resemble Venus or Mars.

This implies that there may be two distinct types of terrestrial planets: the first type consists of double planets, with intensified magnetic fields, plate tectonics, tides, life, and Gaian-regulated climates; the second type consists of single planets, with deficient magnetic fields, aborted plate tectonics, and unstable climates that result in runaway greenhouses or runaway glaciation. This situation is somewhat similar to the differences between single and double stars. Only double stars give rise to the orbital interactions and mass transfers that result in such phenomena as recurrent novae and X-ray bursters; single stars are devoid of such complex and interesting behavior, as single planets may be devoid of life.

Potential interstellar colonizers may therefore face the problem that the only planets suitable for colonization will already have life upon them. This may cause ethical dilemmas, and it will certainly slow the rate of colonization. Our galaxy may therefore consist of just one civilization, or a very few that are kept busy terraforming the planets of nearby solar systems and have not yet ventured out into the galaxy at large.

6. CONCLUSIONS

The unique position of the Earth–Moon as a double planet has been overlooked in previous SETI investigations. The presence of the Moon may have had profound effects on the evolution of the Earth and of life upon it, and may even have been necessary for life to arise and survive. The possible rarity of double planets is cause for further study, as are the evolutionary effects of the presence of the Moon on the Earth. If double planets are necessary for life and they are comparatively rare, the probability of duplicating the Earth’s environment is lower than has been assumed in previous studies. We may be one of a very few civilizations, or perhaps the only civilization, in this galaxy. These conclusions, if substantiated, have serious implications for SETI. The nearest civilization to ours may be tens of thousands of light years away, and SETI may be more successful in contacting civilizations in nearby galaxies than in the Milky Way. Simulations attempting to derive the probability of solar systems and planets like our own

should be expanded to encompass the results of collisions and other orbital encounters, to find a more definitive estimate of the likelihood of double planets like the Earth–Moon system arising within the habitable zones of other suns.

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