Adjustment of the Earth orbit

Life is a very fragile phenomenon which can only exist in a benign environment. Such an environment is described as the habitable zone. It must meet the basic requirements necessary for life such as liquid water, the right temperature and low radiation. However, these conditions are essential but not sufficient to support life. A planet which is going to harbor life must meet many other conditions.

The selection of a planet with the potential for a benign environment must start with an analysis of the conditions in our galaxy and the identification of a suitable zone where life could exist. The next step would be the search for an appropriate sun which would provide a stable energy supply over many billions of years. The position of the planet within the solar system is vital and must also be in the habitable zone.

The selection of a sun in our galaxy

We are living in the Milky Way which is a spiral galaxy. Spiral galaxies, when viewed from above, look like a disc with branching arms. Our galaxy has a diameter of approximately 100,000 light-years[1] and is about 2,000 light-years thick. The Milky Way has about 400 billion stars, but it is not known how many of them might be suitable to support life.

The central zone of our galaxy is a very active region which has a high density of stars. New stars are born, old stars explode and there are many collisions between stars in this region. In this region there are many neutron stars and supernovae which are the source of dangerous radiation. The level of high energy ionizing particles, gamma rays and X-rays is very high there making life in this region impossible. The protection of life from this high energy radiation can only be secured by separation because the intensity of radiation falls with the square of the distance from the source. Therefore a planet which could shelter life must be as far away as possible from this zone.

However, at the outer regions of the galaxy the concentration of heavy elements necessary for the formation of solid planets is low. To form an Earth-like planet, large quantities of metals, silicon and oxygen are needed which are very rare in the outer regions. Many more elements heavier than helium such as nitrogen, carbon, etc. are

[1] A light year is the distance travelled by light during one year.1 light year = 9.4607×10^{12} km.

also necessary to create life. It appears that the selection of a zone close to the position of our Sun, about 27,000 light-years from the centre of the galaxy, is optimum for offering good safety from radiation and an abundance of planet and life building materials.

There are many stars in this zone but only one of a particular size would be suitable to support life. A suitable star must have strong enough electromagnetic radiation to provide enough energy for an extended habitable zone and must also have a long enough life span to support life for many billions of years.

In the Milky Way the most common stars are red dwarfs which are smaller and cooler than the Sun. But such small stars are not suitable for harboring life. For example, a star having mass equal to about half of that of the Sun would have luminosity of only 3.5 percent of that of the Sun.

A slightly larger star, say having a mass of 1.3 of our Sun, would have a large habitable zone starting beyond Mars' orbit. However its life span would be less than 4 billion years which would be too short to develop the right planetary conditions to sustain intelligent life for a long period of time.

It appears that our Sun perfectly meets all the criteria required of size, position, habitable zone and its lifetime. Our Sun's lifespan is about 10 billion years which should be sufficient to develop and sustain intelligent life.

Position of the planet in the solar system

One of the most important conditions to sustain intelligent life is the right temperature of the environment. Since the chemistry of life is based on water, the average surface temperature of the planet should be above the freezing point. Life would find it very difficult to survive over long periods of time in temperatures below freezing. Since cold blooded animals can be killed by temperatures above 40°C, the average temperature should be well below this upper limit. Warm blooded animals can cope much better with extreme temperatures but preferably not much outside the range of -40°C to +50°C. Taking into account the above limitations the average temperature of a habitable planet should be between 5°C and 25°C with extreme temperatures between -40°C and +50°C.

The planet's temperature depends on several factors. The most important factor is how much energy is delivered from the Sun and this in turn depends on the level of the Sun's radiation and on the distance between the Sun and the planet. To receive enough energy the planet must be placed in the right orbit around the Sun. Too close and the temperature would rise above the boiling point of water. Too far and temperatures would drop below zero preventing the growth of life.

The second factor is how much energy is absorbed by the planet and this depends on the planet's albedo, or reflectivity coefficient, which determines how much energy is reflected back into space. The planet's albedo depends on the condition of its surface, for example ice, snow and clouds reflect a large proportion of energy making the planet cooler. On the other hand plants and water absorb a large amount of incident energy. Water vapors forming clouds in the lower atmosphere reflect the Sun's visible radiation increasing the planet's albedo but also prevent the loss of heat by stopping infrared energy radiating into space.

The third factor affecting temperature is the greenhouse effect. The greenhouse effect works by trapping the Sun's energy in the atmosphere. The atmosphere is transparent to the Sun's visible radiation which is converted into heat on the planet's surface. This hot surface radiates back infrared energy. However the infrared radiation is captured by the atmosphere and is sent back to the surface warming the planet. So the system operates in a similar way to a glass greenhouse. Water, carbon dioxide and methane are the three most important greenhouse gases. Recent research shows that water vapor in high atmosphere acts as a strong greenhouse gas by absorbing infrared radiation more effectively than carbon dioxide. Greenhouse gases are eventually broken down by the Sun's radiation and should be replenished to prevent cooling of the planet.

Placing Earth in the right orbit

Finding a planet meeting so many criteria and requirements was not an easy task. When Earth was eventually selected as the most suitable planet in our galaxy for the development of intelligent life, it would have been a miracle if the Earth's distance from the Sun, right from the very beginning, was correct. It is most likely that it was necessary to nudge Earth into its required orbit. As already discussed, the habitable zone around the Sun is determined by the Sun's radiated energy and also depends on tectonic plates, the planet's atmosphere and other factors. All these parameters would have to be considered in the calculation of the new orbit. At the time of adjustment some of these factors such as the atmosphere were not present, therefore to calculate the correct orbit their future effects would have to be predicted.

It is known that when the Earth's distance from the Sun is changed by about 10 million kilometers or by about 7 percent, the Earth's average temperature alters by about 8°C (Appendix 2). Presently, the Earth's average temperature is about 16°C and is optimized for supporting life on Earth. It has been evaluated that the habitable zone in which water remains liquid around the Sun extends from 0.95 AU[2] to 1.69 AU, but the optimum zone for supporting advanced life is much narrower, between 0.95 AU and 1.15 AU giving the average temperature range between 22°C and minus 1°C.

The most important parameter which affects the position of the habitable zone is the Sun's radiation. This radiation is not constant and increases with time as the Sun ages. It is estimated that 4.5 billion years ago, when Earth was formed, the Sun's radiation was about 30 percent weaker than it is now. Therefore selecting the Earth's orbit to secure the position of the planet in the habitable zone, even after several billion years, would have to take into account any future variation of the Sun's energy. As estimated by some scientists Earth is now lying close to the hot limit of the habitable zone, but during the period of Earth formation it was positioned in a much cooler region. There is some geological evidence suggesting that even a few billion years ago whole Earth was covered in snow and ice and the oceans were frozen. Therefore it was necessary to push Earth closer to the Sun.

Adjusting the Earth's orbit could be possible by ramming Earth with another body. A technique suitable for changing the Earth's orbit is presented in Appendix 1. Calculations show that using a small body with a mass less than one hundredth that of Earth would be sufficient to decrease the distance of Earth from the Sun by 10 million kilometers. This in turn could increase the Earth's average temperature by about 8°C which is a very significant amount.

To decrease the Earth's distance from the Sun it is proposed that a projectile was needed to come from the outer solar region, such as the Kuiper belt, which is about 50 AU from the Sun. A head-on collision slowed Earth by about 480 km/sec and then

[2] AU - the astronomical unit of length, roughly the distance from Earth to the Sun equal to 149.6 million kilometers

the Sun’s gravity pulled Earth onto its new, closer orbit. A second collision was needed to stabilize the Earth’s new orbit.

Although at present we are worried about the greenhouse effect caused by carbon dioxide, the real problem would be if Earth was too far from the Sun and the Earth’s temperature was too low. At sub-zero temperatures water in the form of ice and snow would significantly increase the Earth’s albedo causing most of the Sun’s energy to be reflected resulting in the runaway freezing of the planet. However, increased Sun energy would generate more dense clouds increasing the albedo and as a result decreasing the Earth’s temperature working as a temperature regulator.

Let us look into the origins of the collision. Could it be possible that this collision just happened by chance? First, there were not very many large bodies present in the solar system. How would it have been possible for such a body to leave its orbit and come to Earth? This event was very well timed because it happened soon after Earth was accreted but not completely formed.

The more difficult problem was the collision itself. Nowadays the catastrophic danger of asteroids hitting Earth is widely publicized by some fame seeking scientists. But if we look into the history of asteroid collisions it is an extremely rare event. The last impact of an asteroid as small as 10 km in diameter happened about 66 million years ago. The fact is that even when an asteroid is close to Earth there is no guarantee that it is going to hit it. We know that the escape velocity from Earth is about 11.2 km/sec. This means that a body having a relative speed higher than the escape velocity when passing even very close to the Earth’s surface would miss the planet because the Earth’s gravity is not strong enough to pull it in.

It has been observed that a typical speed of asteroids hitting Earth is about 17 - 20 km/sec although much higher speeds have been recorded. Since the Earth’s gravity would not be able to pull a body travelling with such a speed, the asteroid would have to be aimed directly at the Earth’s surface.

With Earth travelling at a speed of 30 km/sec it would only take her 7 minutes to cross a particular point on her orbit. This means that for a projectile to hit Earth, it must cross the Earth’s trajectory specific point within this time. To illustrate the accuracy required, let us consider a very simple example. Let’s assume that the body came from the region of the Kuiper belt, about 50 AU away. If the body travelled on an elliptical orbit it would have taken about 64.6 years (Appendix 3). Therefore the timing accuracy must have been about 0.2 parts per million.

The collision brought two important benefits. It not only adjusted the Earth's orbit but also resulted in the formation of the Moon.

Appendix 1. Change of the Earth's orbit

Let's assume that we want to change the Earth's orbit radius by 10 million kilometers and

$R_1 = 160\times10^6$ km was the initial distance between Earth and the Sun, and

$R_2 = 150\times10^6$ km is the current distance between Earth and the Sun.

Since Earth's present speed is 29.8 km/sec the speed on its initial orbit is given by:

$V_{160} = V_{150}\ (150/160)^{1/2} = 28.85$ km/sec

Earth's orbit could have been changed using Hohmann transfer.

The speed of Earth on the initial orbit was 28.85 km/sec. The aphelion speed of the elliptical transfer orbit is 28.37 km/sec therefore the Earth's speed must be reduced by 480 km/sec. The period of the Earth transfer orbit is 3.32×10^7 sec.

Earth's speed could be reduced by collision with a suitable body.

Since we can calculate that a body originating in the Kuiper belt would reach a speed of about 41.65 km/sec when crossing the Earth's orbit, we can calculate the mass of a body m_1 whose impact would reduce the Earth's speed to 28.37 km/sec from:

$$m_1 = m_E\ ((V_2 - V_F)/(V_1 + V_F) = 0.00685\ m_E = 4.11 \times 10^{22}\ \text{kg}$$

where m_E is the Earth's mass, $V_2 = 41.65$ km/sec, $V_F = 28.37$ km/sec and $V_1 = 28.85$ km/sec.

This means that a body with a mass of less than one hundredth that of Earth would be sufficient to move Earth to the transfer orbit.

When Earth reached the new transfer orbit its perihelion speed was 30.26 km/sec therefore its speed must have been reduced again by 480 km/sec to reach its final speed of 29.78 km/sec. The second speed reduction could have been achieved by a similar impact.

These calculations do not intend to prove that the change to the Earth's orbit occurred as presented. Rather they show that the shifting of Earth's orbit is feasible.

Appendix 2. Temperature change as a function of distance from the Sun.

To calculate Earth's temperature changes I use the following equation[2]

$T = 280\ [1- A]^{1/4} / a^{1/2}\ [°K]$ ....[4]

Where A is the Earth's albedo and **a** is the distance between the Sun and the Earth in AU (astronomical units).

This equation does not take into account the greenhouse effect.
For: $a = 1$, $A = 0.3$
$T = 256°K = -17°C$.
The greenhouse effect increases the Earth's surface temperature by 33°C.
If we increase the distance between the Sun and Earth by 10 million kilometers, from 150Mkm to 160Mkm we can calculate the Earth's temperature from equation [4]:

$a = 160/150 = 1.066$, $a^{1/2} = 1.033$, $T = 248°K$

$\Delta T = 248 - 256 = -8°K$

The Earth's surface temperature at a distance of 160 Mkm was 8°C lower than at a distance of 150 Mkm.
We could estimate that without the greenhouse effect, which should be constant for the same environmental conditions, the Earth's surface temperature changes by about 8°C when the distance from the Sun is changed by 10 million kilometers.

Appendix 3. Timing accuracy of the body to be able to hit Earth when travelling from the Kuiper Belt.

Let us assume that the asteroid came from the Kuiper Belt which is at a distance of 50 AU from Earth.

The period transfer orbit is calculated from equation

$P_T = 2\pi\times(a^3/ GM)^{½} = 4.08 \times 10^9$ sec = 129.3 years

Total travelling time of the asteroid to hit Earth is 64.6 years

Earth's orbital speed: 29.8 km/sec.

Earth's diameter: D = 12,756 km

Earth crosses a given point on its orbit in 425 seconds or about 7 minutes.

Therefore the accuracy of the timing is given by:

(Earth's crossing time)/(total travelling time) = $425/(2.04 \times 10^9) = 2.08 \times 10^{-7}$.

The timing accuracy must be better than 0.2 parts per million or 0.00002%