Delivery of water to Earth

Water is essential for the existence of life and any quest for intelligence in the Universe is based on the search for water. Its properties are so unusual that one could almost imagine that water was specially invented for this purpose. Why does water exist on Earth? Where did it come from? These are fundamental questions that we will try to answer.

The origins of water on Earth

While hydrogen is the primordial, most abundant element in the Universe, oxygen was produced later, inside the first generation of stars. These stars, at the end of their life, exploded spreading heavy elements into space forming solar nebulas. It was proposed that in such a solar nebula, which was the precursor to our solar system, these two elements were widely present and possibly in the form of water. It is believed that when the solar system was formed, water was present on the giant gas planets such as Jupiter, Uranus, Neptune and Saturn situated in the cold part of the solar system. However, very little water has been discovered on these planets. In fact, more water is present on the moons circling these planets. It is probable that water is more abundant beyond Neptune, in the regions of the Kuiper belt, 20 AU away and Oort Cloud stretching from 2000AU.

The terrestrial planets closer to the Sun such as Mars, Earth, Venus and Mercury, being in the hot zone, were practically dry and are still dry with the exception of Earth. Only Earth has a huge reservoir of water, more than one billion cubic kilometers. How this happened is still a mystery. What is more interesting is that water arrived on Earth immediately after the right conditions on Earth were established.

Academic hypotheses of the origin of water

There is general agreement that water on Earth had to come from outside the Solar System and was not present on Earth when the planet was formed. There are several hypotheses on how water originated on Earth but there is no consensus on the source of water. Most scientists believe that water came from outside the Solar System in the form of ice-bearing comets, or large asteroids migrating from the asteroid belt. A few researchers think that water is ‘home grown’ and came from the proto-planetary nebular disk which provided material for our solar system.

Comets have long been considered the leading candidate for the origin of water on the terrestrial planets. This hypothesis was accepted for two reasons. Firstly, it is widely assumed that the inner solar system was too hot for water to be present. Thus an external source of water was needed. Secondly, Earth and other terrestrial planets underwent one or more magma ocean events[1] that some authors believed would effectively remove any existing water.

The solar system formed as a result of the collapse of a large, cold, slowly rotating cloud of gas and dust into a disk that defined the plane of the solar system. The terrestrial planets grew in this accretion disk in which hydrogen, helium and oxygen were the dominating elements. Some of that hydrogen and oxygen combined to make primordial water.

The region of the solar system inside 3 AU was too warm for volatile molecules like water to condense, so the planets that formed there could only form from compounds with high melting points, such as metals (iron, nickel, and aluminium) and rocky silicates. These rocky bodies would then become the terrestrial planets.

Many scientists believe that when Earth was formed it was very hot and dry. They therefore suggest that millions of water-rich asteroids bombarded our planet around 4 billion years ago. Asteroids could come from the asteroid belt which is located roughly between the orbits of Mars and Jupiter, around 2.2 to 3.2 AU from the Sun. It is occupied by numerous irregularly shaped bodies most of which are quite small. At present the total mass of the asteroid belt is approximately 4 percent of that of the Moon, therefore it does not contain much water.

The main drawback of this hypothesis is that a few billion asteroids would be needed, assuming that each one brought about one cubic kilometer of water. The problem remains how such a large quantity of asteroids could have arrived on Earth and at the same time missed Mars and Venus.

The ratio of hydrogen isotopes

One parameter used to help identify the source of water on Earth is the ratio of

[1] Magma ocean event is the stage of a planet's development when high temperature liquid magma is present on the planet's surface.

deuterium[2] to hydrogen, D/H. The ratio for terrestrial water is 1.49×10^{-4}. When this ratio was measured for comets such as Halley and Hale-Bopp, it transpired that it was twice that for the ratio of water on Earth, convincing many scientists that comets could not have significantly contributed to the supply of water on Earth. However the recent data for comet 103P/Hartley 2 shows a D/H ratio that matched terrestrial water's perfectly opening the possibility of comets being a source of water. It is interesting that the D/H ratios in the water of Martian meteorites agree with the values for comets, showing that water on Earth came from a different source than water on Mars.

A team from the University of Michigan's Astronomy department found that the D/H ratio for primordial water is 2.1×10^{-5} which is almost seven times smaller than the ratio for the water on Earth, thus excluding the proto-planetary nebular disk as the source of water.

Based on the D/H ratio measurements the majority of researches agree that water had to come from an external source. It is possible that the water could have originated from asteroids because the D/H ratio in our sea water matches the value found in water-rich asteroids.

Delivery of water

It is becoming more accepted by the academic world that water was delivered to Earth by several huge asteroids or small planets situated in the outer solar system. If we assume that several asteroids were used to deliver water, we have to consider that the collisions of the last asteroids with Earth would cause the ejection of water which had already been delivered during previous impacts. Water carrying asteroids would have to have a diameter of around a thousand kilometers.
Considering several of the most common hypothesis I came to the conclusion that it was most likely only one body which delivered water to Earth. This body could have originated from the Oort Cloud which is a region of frozen objects more than 2,000 AU from the Sun.

To check the feasibility of this hypothesis let's do a few calculations. The body would

[2] Deuterium is a heavy isotope of hydrogen which contains a neutron in addition to a proton.

have to deliver at least 1.4 billion cubic kilometers of water. Assuming that about 20 percent of its weight was water and its density was 2.6 g/cm^3, the diameter of the body would need to be about 1,720 km and the mass of this body would be about one thousandth of the mass of Earth (Appendix 1).

The delivery of water could only be organized and carried out by extraterrestrial beings who selected and moved a suitable body from its orbit and directed it towards Earth. The main problem faced was how to ensure the body would hit Earth. To achieve this it would have been necessary to predict the position of both Earth and the body, and also their speeds at the time of impact. It would be very easy for the body to miss Earth, even passing as close as a couple of hundred kilometers from its surface. So this was a very precise operation.

Appendix 1 shows the calculations of how to bring a body 10,000 AU away, from the Oort Cloud, to Earth. A body moving on a circular orbit around the Sun with speed of 297.4 m/sec was slowed down by 293.2 m/sec to change its orbit to the elliptical transfer orbit. Once on the transfer orbit the Sun's gravity would bring it close to Earth's orbit.

A body was nudged from its stable orbit using a propulsion system. To change the orbit of such a large body would have required very powerful engines operating over a very long period of time. It is possible that such a propulsion engine could use energy generated by hydrogen fusion. Since hydrogen would have been abundant on the body it was sufficient to have a suitable reactor which over a period of many thousands of years slowly changed the planet's trajectory and controlled its passage. Calculations show that to change the orbit during 30,000 years of operation a power of 300TW would be needed (Appendix 1). Another possible solution would be to arrange a suitable collision with another body in the same region which could slow down the water carrying body.

During the journey it would be necessary to implement several corrections of the trajectory and speed. Once the body was moving in the right direction, it is possible that gravitational fields of other solar planets were utilized as means of propulsion. We used planetary gravitational fields when sending out exploration spacecrafts such as New Horizons and Cassini Huygens.

The speed of the body when approaching the Earth's orbit was about 42 km/sec, therefore the impact speed with Earth was about 12.2 km/sec. The energy released during the impact would increase the Earth's temperature by a maximum of 159°C if all the kinetic energy was changed into heat. In reality this rise in temperature would be much lower as some energy would be used to eject large amounts of material from Earth. Also at that time the Earth's surface temperature was much lower than at present due to lower Sun radiation and the absence of the greenhouse effect.

Earth holds exactly the right quantity of water to have huge oceans and tectonic plates, but not too much to make Earth waterlogged[3]. Such a precise quantity indicates that water was delivered by a planned action. Calculations provided in Appendix 1 illustrate the feasibility of such solutions, but in reality the mechanism for the delivery of water could be very different. It is impossible to prove how water was delivered to Earth and where it came from. However, it is certain that water came from elsewhere as a result of a precisely planned operation, and Earth was chosen as its final destination.

Appendix 1. Calculations for the delivery of water to Earth

1. Energy needed to deliver water to Earth

Volume of water to be delivered to Earth:

1.4 billion cubic kilometers = 1.4×10^{18} m^3 = 1.4×10^{21} liters.

Let's assume that water was delivered by an asteroid with a density of 2.6 g/cm^3 and made up of 20% water.

Total mass of asteroid: $m = 7 \times 10^{21}$ kg = 7×10^{18} tons

The asteroid's mass is about 0.0012% of Earth's mass.

Volume of asteroid: $V = 2.7 \times 10^{9}$ km^3.

Diameter of asteroid: D = 1,720 km

Let us assume that this asteroid originated from the Oort Cloud and its distance from the Sun was R_2 = 10,000 AU.

The orbital speed of the asteroid was:

$$V_{orb} = (GM/R_2)^{½} = 297.4 \text{ m/sec} \qquad \text{...... (1)}$$

[3] The volume of water is about five times larger than the volume of dry land above the sea level.

where the Sun's standard gravitational parameter GM = 1.327×10^{20} m^3/sec.
The asteroid could have been brought to Earth using, for example, Hohmann[1] transfer.
During this process a body travelling on its original circular orbit is slowed down and put onto a transfer orbit. This transfer orbit is calculated in such a way that its trajectory would cross the Earth's orbit.
The semi-major axis of the transfer orbit is
$a = (R_1+R_2)/2 =$ 5,000 AU
where R_1 = 1 AU is the distance of Earth from the Sun
The period of the transfer orbit is calculated as
$P_T = 2\pi\times(a^3/ GM)^{½} = 1.12\times10^{13}$ sec = 3.3×10^5 years .... (2)
For an asteroid to change its circular orbit onto the transfer orbit its speed must be reduced to the aphelion speed, V_{aph} of the transfer orbit.
The change of speed ΔV_2 = 293.2 m/sec.
The asteroid's kinetic energy must be changed by
$K_E = m(V_{orb}^2 - V_{aph}^2)/2 = 3.1 \times 10^{26}$ J ... (3)
where V_{aph} = 4.2 m/sec.
To reduce the asteroid's speed over 10^{12} seconds, or 30,000 years, about 300 TW of power would have been needed.
However, if the whole process was spread over a much longer period of time or the gravitational forces of other planets were used, much less power would have been needed.
When the asteroid reached the Earth's orbit it would have been travelling with a perihelion speed of V_{ph} = 42 km/sec. Since Earth was moving with a speed of about 29.8 km/sec, the relative speed of impact would have been about 12.2 km/sec. The final speed after the collision would have been 29.813 km/sec.