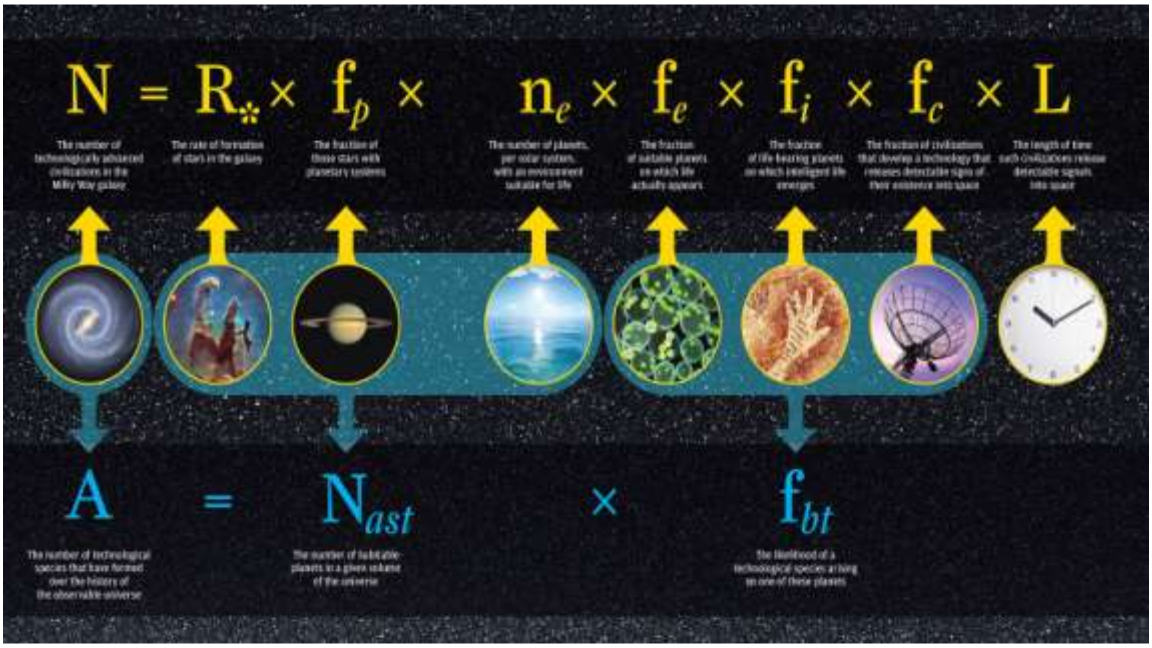
Drake Equation & Rare Earth Hypothesis

Drake equation



The drake equation was proposed by Frank Drake in 1961 to estimate the number of advanced civilizations likely to exist in the Milky Way galaxy.

The prospect of intelligent life anywhere in the Universe has been puzzling astronomers and recently Astro-biologists, and there have been some attempts to estimate probabilities. This led Drake to construct an equation that collects the ideas together i.e. the Drake equation. It is a mathematical representation of factors relating the probability of finding life and, in particular, an intelligent civilisation elsewhere in the Universe. The Drake Equation is composed of seven terms. The first six are used to compute the rate at which intelligent civilizations are being created and the final term identifies how long each lasts on average as a broadcasting civilization. Drake Equation applies only to intelligent civilizations in the Milky Way galaxy. It does not apply to civilizations in other galaxies because they are too distant to be able to detect their radio signals. This is an extreme example of ‘hypothesis multiplication’ and should be treated with caution. The equation is written:

$$N = R^{*} \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

where N is the number of intelligent civilisations in the Universe with whom we might communicate, R* is the rate of formation of stars in the galaxy, f_p is the fraction of stars that have planetary systems, n_e is the average number of habitable planets within a star’s planetary system, f_l is the fraction of habitable planets upon which life arises, f_l is the fraction of habitable planets upon which there is intelligent life, f_c is the fraction of civilisations interested in communicating and L is the average lifetime of a civilisation.

The problem comes with assessing the values of the factors to place within the equation and this leads to some very optimistic or pessimistic estimates.

R* : A simple estimate just takes the total number of stars in our galaxy, and divides by our galaxy’s age.There are approximately 10^{11} stars in our galaxy and given that the age of the galaxy is some 10 Gyr. So the rate of star formation is then approximately 10 stars per year.

f_p: This could be as large as 0.5 but may be complicated by binary stars and other local factors: pessimistically it is 0.01 and optimistically 0.3–0.5.

n: Our solar system may have had as many as three habitable planets (Earth, Mars and maybe Venus, at least for a while), however giant planet formation may have removed inner terrestrial-type planets by collision during the formation process: optimistically it is 3, pessimistically 0.01.

f_l: Is life the product of a collection of simple chemical processes, in which case it should be everywhere, or is it more of a fluke: optimistically it is 1, pessimistically 10^{-6}.

f_i: Intelligence on Earth took 4.5 Gyr to evolve and many stars do not live this long (dependent on their mass) so they choose some extremes: optimistically it is 0.5 and pessimistically 10^{-6}.

f_c: If they are like human beings then everybody wants to talk so, about to 1.0.

L: This has been a few tens of years in the case of our civilisation and we may yet destroy ourselves within 10,000 years; optimistically it is 1 billion years and pessimistically 100 years.

Performing the optimistic sum gives $N_c = 5 \times 10^9$ and the pessimistic sum gives $N_c = 10^{-13}$.

The Drake equation is a just a mathematical way of saying ‘who knows’ but it does allow the factors that might control the origins of life to be identified. The Drake equation has proven to be a durable framework for research, and space technology has advanced scientists' knowledge of several variables. But it is impossible to do anything more than guess at variables such as *L*, the probably longevity of other advanced civilizations.

Rare Earth Hypothesis:

Rare Earth, a science book written by two University of Washington professors, geologist Peter Ward and astronomer Don Brownlee (W&B) depicts our galaxy as a lonely place dotted with hostile lifeless planets orbiting stars that are mostly too hot, too cold, too unstable, or too short-lived to sustain the development of complex life. Basically the ideas of W&B are summarizes as ***rare earth hypothesis.***

Rare Earth Hypothesis

- Astronomical events
  - Within galactic habitable zone
  - Supernovae to seed our system
  - Sun the "right" size
  - Within solar system's habitable zone
  - Large gas giants
  - Large satellite (Moon)
  - Occasional bolide strikes
- Geologic events
  - ze of Earth
  - amo Earth forms magnetic poles
    - Magnetosphere
  - Plate tectonics
  - Atmosphere
  - Lithosphere
  - Oceans (water terrestrial or extraterrestrial?)
  - Glaciations

The Rare Earth hypothesis argues that the emergence of complex multicellular life on Earth (and, subsequently, intelligence) required an improbable combination of astrophysical and geological events and circumstances. This hypothesis suggests that Earth like planets containing complex (animal) life as we know it are likely quite rare in the universe. The hypothesis argues that complex extraterrestrial life is a very improbable phenomenon and likely to be extremely rare.

Rare earth equation gives N, the number of earth like planets having complex life forms as:

$$N= N^* \times f_p \times f_{pm} \times n_e \times n_g \times f_i \times f_e \times f_l \times f_m \times f_j \times f_{me}$$

N^* is the number of stars in the Milky Way galaxy, **f_p** is the fraction of stars with planets, **f_{pm}** is the fraction of planets that are metal-rich, **n_e** is the average number of planets in the star's habitable zone, **n_g** is the number of stars in the galactic habitable zone, **f_i** is the fraction of habitable planets where life does arise, **f_c** is the fraction of planets where complex metazoans arise, **f_l** is the fraction of the total lifetime of the planet that is marked by the presence of complex metazoans, **f_m** is the fraction of planets with a large moon, **f_j** is the fraction of solar systems with Jupiter-size planets, and **f_{me}** is the fraction of planets with a critically low number of extinction events.

N*(stars) - Estimating the number of stars in the Milky Way galaxy is tricky, because we don't know our galaxy's mass very well, and there is little information about the population of very small stars. **N*** is roughly 500 billion stars of all classes.

f_p (planets) - In 1995 astronomers discovered the first planets orbiting other stars. Since then more and more planets have been discovered. However, it is not clear what fraction of the stars in the galaxy actually have sizable planets.

f_{pm} (metal) - One interesting correlation stands out among the existing observations of extra-solar planets. All of the observed planets orbit metal-rich stars. This suggests that planets, or at least planets large enough to have been observed so far, may not be all that common and may be peculiar to the subset of stars that are rich in metals.

n_e (habitable zone) - The orbit of Earth happens to be "just right", falling in a narrow habitable zone of orbit distances in which a planet not only has liquid water now, but also had liquid water several billion years ago when the Sun was cooler and life first formed. W&B mention a 1993 estimate indicating that if Earth's orbit was 5% smaller or 15% larger it would not be in this habitable zone. This zone shrinks for more massive stars because of their more rapid evolution and for less massive stars because the zone of liquid water itself in narrower. Thus the average number of planets in habitable zones, averaged over all stars in the galaxy may be very small indeed.

n_g (galactic zone) - The Solar System is about 25,000 light years from the galactic center, roughly a third of the distance from the centre to the outside edge. This position is fortunate. Stars too close in have too may close neighbours that disturb the system's orbits, too much fireworks from neighbour supernovas, and too much radiation that comes from the galactic centre. Stars too far out are too deficient in the heavy elements cooked up in supernovas near the galactic centre.

f_i (life) - W&B suggest that the fraction of habitable planets where life does arise, at least in the form of bacteria, may be large. Geological evidence suggests that bacteria were present on the Earth as early as planetary conditions made it possible for them to exist. This view is also supported by observation of living bacteria from rock extracted from very deep wells and mines. The controversial claim that bacteria fossils may have been observed in meteorites of Martian origin found in the Antarctic, if true, also supports this idea.

f_c (complex metazoans) - W&B argue that the fraction of planets with bacterial life where complex metazoans arise may be very small. They base this view on the observation that for four fifths of the time since life first appeared on the Earth, some 2.5 billion years ago, there was only bacterial life. They also point out that the Cambrian Explosion, when complex metazoans first appeared, was preceded by some extraordinary climactic and geological events that may have triggered it.

f_l (planet lifetime) - Even if complex metazoans arise, their development, as indicated above, may take a long time. Finding complex life on another planet depends on the size of this time window.

f_m (large moon) - Except for the Earth's moon, the satellites of the Solar System have only a tiny fraction of the mass of their primary. Mercury and Venus have no satellites at all. The moons of Mars, Phobos and Demios, are small rocks with masses of only 27 and 5 billionths of the mass of Mars. Even the rather large moons of Jupiter and Saturn have masses of only a few parts in 10^5 of their planet's mass. Our Moon, on the other hand, has 1.2% of Earth's mass. This raises the question of how Earth could have acquired such a large satellite. The prevailing explanation is that a random collision occurred between the just-forming Earth and a Mars-size object, with Earth capturing most of the mass from that collision while about 1% of the debris coalesced into our Moon. Such an event is very unlikely, which suggests that most Earth-size planets will not have moons with anything approaching 1% of the planet's mass.

An important consequence of our giant Moon is that it stabilizes the 23° tilt of the Earth's rotational axis with respect to its orbital plane. Geological evidence indicates that over many millions of years the tilt of the Earth's axis has stayed within a few degrees of its present value. Recent calculations have shown that without the Moon, the gravitational effects of Jupiter and the Sun would have caused the Earth's tilt to wander chaotically over a wide range, producing enormous changes in climate and a hostile environment for the development of complex life.

f_j (Jupiter) - W&B argue that if Jupiter (300 times more massive that Earth) were removed from the Solar System, the frequency of comet and asteroid impacts on the Earth would increase by a factor of about 10,000. A major asteroid strike capable of significant extinction of species is estimated to occur in an average time interval of about 100 million years. If Jupiter were not present or was in a significantly different orbit, this interval might increase to one strike every 10,000 years, impeding the development of complex life.

f_{me} (extinctions) - Since the evolution of bacterial life on Earth some 2.5 billion years ago, there have been no extinction events large enough to sterilize the planet. W&B argue that this critically low number of extinction events may be unusual. The fossil record shows that there have been some very severe events, the most recent of which was the asteroid strike 65 million years ago that killed the dinosaurs as well as much of the life in the oceans. W&B argue that a very stable planetary system is required, which nearly circular orbits for all of the outer planets, for this condition to exist. An accident such as the gravitational perturbation of a passing star could easily destroy this delicate stability.

The Rare Earth Hypothesis provides an opportunity to examine the conditions that have resulted in the only example of intelligent life discovered in the universe. i.e., WE. The Rare Earth Hypothesis is actually the summation of two hypotheses. The **first is that simple** life (like bacteria, for instance) is very widespread in the universe. The **second hypothesis states that complex life** (and therefore intelligent life) is extremely rare. In defending the two hypotheses, the Rare Earth examines a set of variables that contribute to the likelihood that complex life develops elsewhere in the universe.

The conclusion of W&B theory or rare earth hypothesis is that, a rare place where many random factors have conspired to create a nearly ideal site for the evolution of complex life. Putting plausible numerical estimates into the Rare Earth equation suggests that there are only a few planets with complex life per galaxy. Thus, it's possible that Earth is the only planet in our galaxy with intelligent life.

Reference Books:

1. **Amino Acids and the Asymmetry of Life by Uwe Meierhenrich**
   file:///C:/Users/sony/Downloads/ebooksclub.org__Amino_Acids_and_the_Asymmetry_of_Life__Caught_in_the_Act_of_Formation__Advances_in_Astrobiology_and_Biogeophysics_.pdf

2. **Complete Course in Astrobiology by Gerda Horneck and Petra Rettberg**
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3. **Astrochemistry from Astronomy to Astrobiology by Andrew M. Shaw**
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