Life in the Universe

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Introduction

1. Trying to predict the future or make hypothesises about advanced alien civilizations is a lot like reading tea leaves.
2. As of right now we don't know any life forms other than the terrestrial ones.
3. An example of poor judgement of computer development's future: John von Neumann claimed that in the future computers will be getting larger and larger and they will be capable of accurate weather forecasting.

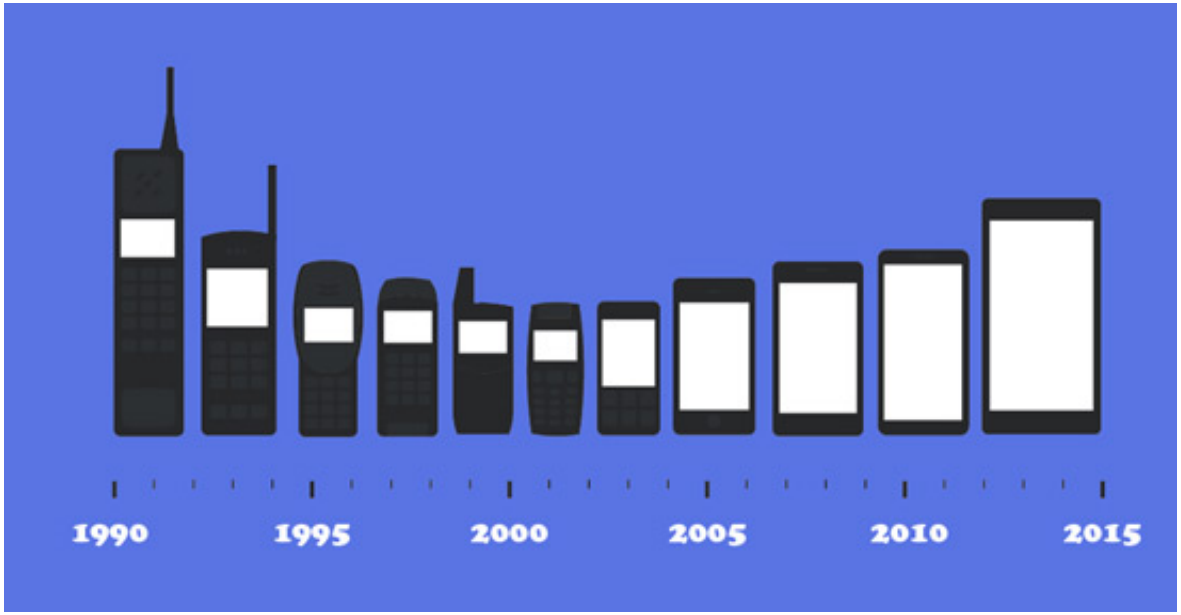
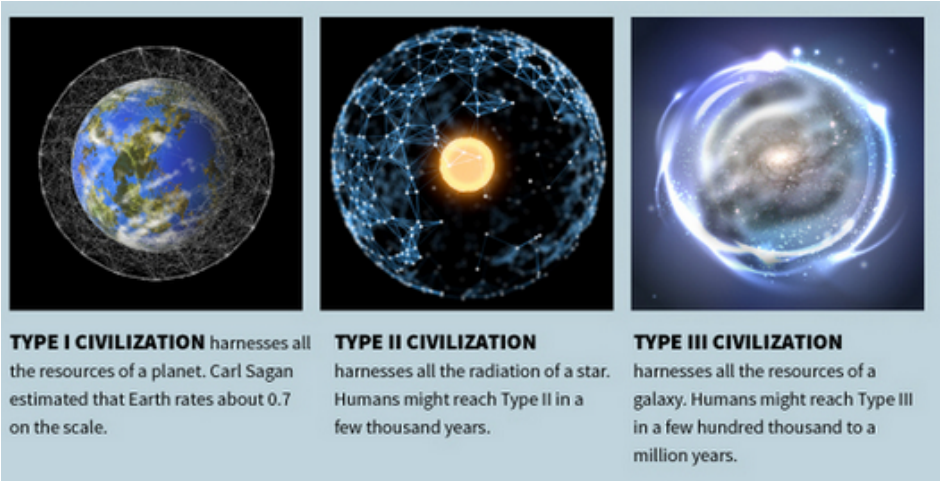


Figure: Until the year 2000 telephones were getting increasingly smaller, but the use of touchscreens made their evolution take a completely different path. Source: https://easytechnow.com/learn-technology/the-evolution-of-mobile-phones/

Kardashev scale

We are able to extrapolate over short periods of time to determine the level of technological advancement. It is impossible over longer periods (technological advancement is often dependent on qualitative breakthroughs, e.g. the invention of transistor). The Kardashev scale is an attempt to foresee in what way could technological civilizations develop in space without foreseeing those breakthroughs.

1. *Type I civilization* – can harness all of it's planet's energetic resources.
2. *Type II civilization* – can control and use it's star's energy.
3. *Type III civilization* – controls the whole galaxy and get's energy from the stars in their galaxy.



Source: https://www.quora.com

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The Solar System

The Solar System consists of:

1. 1 star (Sun).
2. 8 planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune).
3. Dwarf planets (including: Pluto, Ceres, Haumea, Makemake and Eris).
4. Planets' moons (there are hundreds of them, e.g. Jupiter has 60 discovered).
5. Billions of planetoids and probably trillions of comets.

The Sun constitutes 99,8% of all of Solar System's mass.

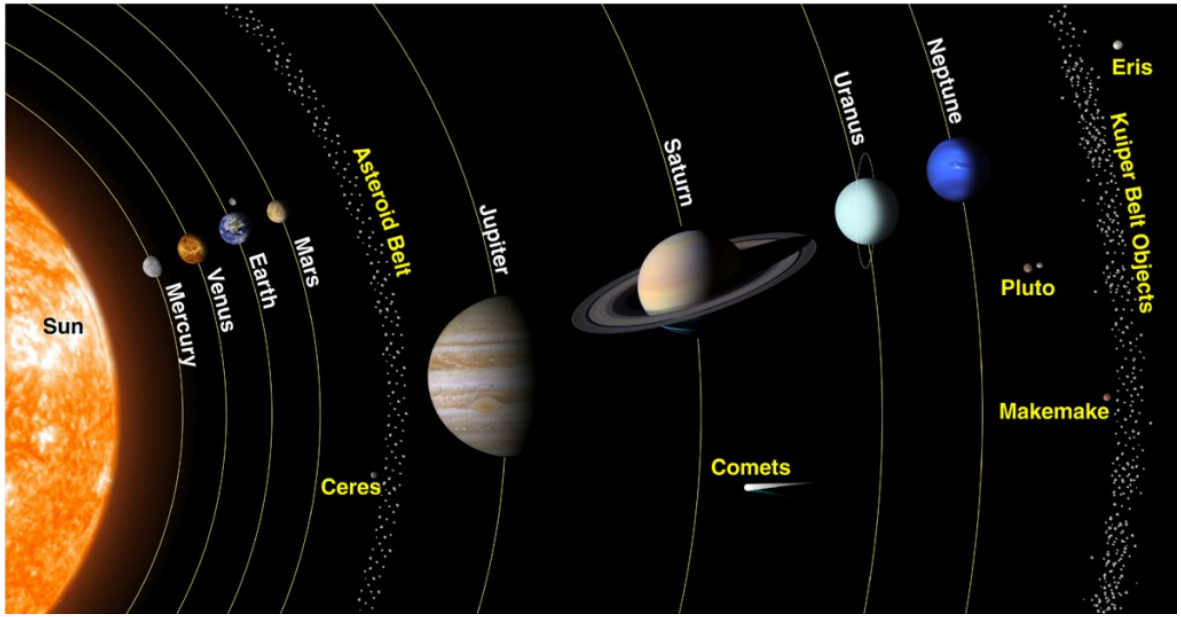

Figure: Diagram of the Solar System. Source: https://theplanets.org/solar-system/

The Solar System

Places where life could potentially exist:

1. The object's surface temperature comes within -70° and +80°.
2. The object has a dense atmosphere with biosignatures in it (O_2, O_3, CH_4, H_2O (also liquid)).
3. There are liquid water reservoirs underneath the object's surface.
4. There is a specific collection of isotopes of different elements such as C, H, N, which couldn't be created without living organisms' contribution.

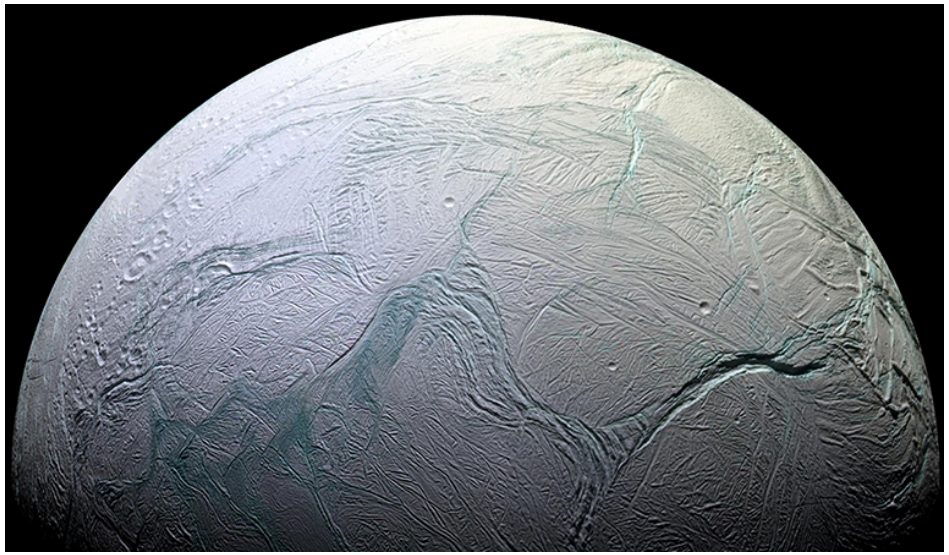

Figure: The Saturn moon Enceladus probably has an undersurface ocean of liquid water. Source: NASA.

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Extremophiles

Those are living organisms tolerating or requiring extreme environmental conditions to live and to breed (e.g. high temperature, high pressure, acidic environment etc.). In most cases extremophiles are unicellular organisms (of the Archaea domain), but also exist among other groups.

Figure: An example of some of the extremophiles' habitat can be a gazer in the Yellowstone National Park, USA.

Extremophiles

We distinguish a few types of extremophiles:

1. **Thermophiles** – live in temperatures between 60°C and 80°C (hyperthermophiles – above 80°C). An example of them are bacteria Archaea Strain 121 living in the hot streams of Yellowstone National Park.
2. **Acidophiles** – live in environments in which the pH is lower than 3. Example: Sulpholobus found in Lechuguilla Cave, New Mexico.
3. **Radioresistant** – organisms resistant to heavy ionising radiation, example: Deinococcus radiodurans found in radioactive garbage holding sites of USA.
4. **Xerophiles** – exist in environments with restricted access to water, e.g. deserts.
5. **Piezophiles** – exist only in places with extremely high pressure (¿40 MPa) like ocean depths.

And many other types. Some organisms, like tardigrades, can be apart of several groups.

Examples of extremophiles not being unicellular organisms

Tardigrades:

1. They are common invertebrates sized between 0,01 and 1,2 mm.
2. In the state of suspended animation they can withstand extreme temperatures (ranging from close to absolute zero to over 100°C).
3. They are also highly resistant to lack of water, high pressure or high salt concentration.

Source: youtube.com

Hesiocaeca methanicola (methane ice worms)

1. Can grow up to a few cm and live under the surface of seabed in environments rich in methane clathrate.
2. Their source of nourishment are methanotrophic bacteria (those capable of metabolising methane).

Source: public domain.

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Our galaxy

1. Diameter: about 100 000 light years, thickness – about 1000 light years.
2. Number of stars: 100-400 billions.
3. Number of known exoplanets: a few thousand (including terrestrial ones and those revolving in the ecosphere[1].

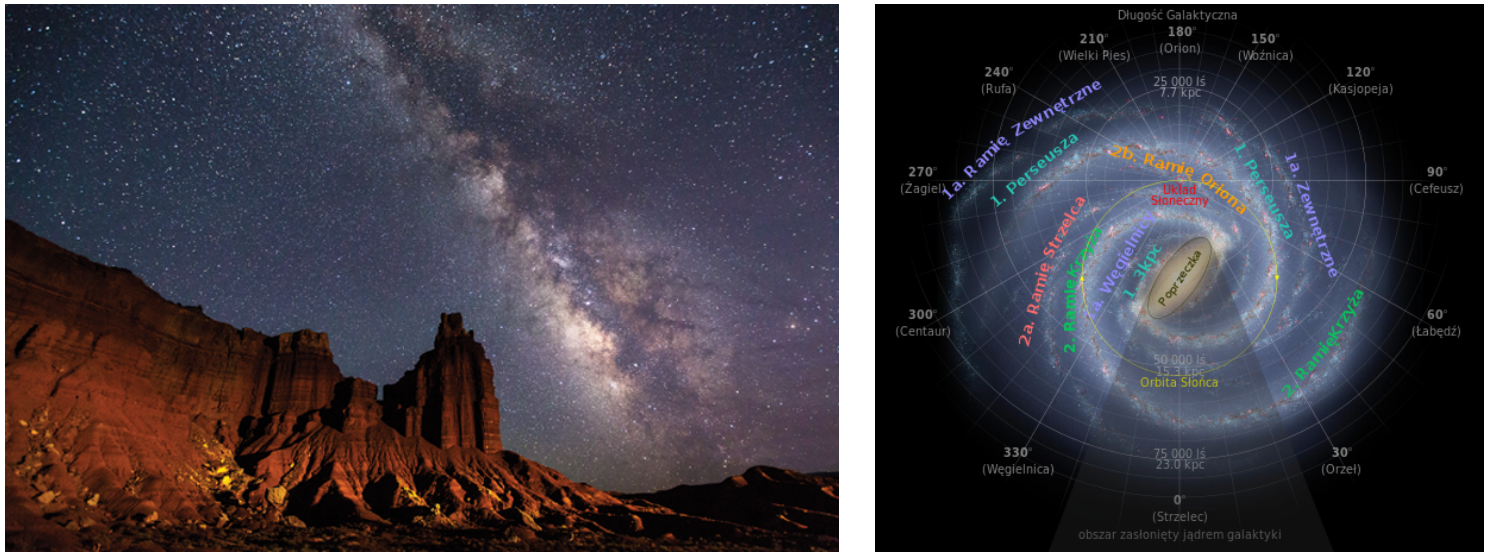

Figure: Picture: left: a photo presenting a part of the Milky Way. Right: presumed structure of our galaxy. Source: public domain.

[1] It's a place around a star, where liquid water and life sustaining conditions can exist. More specifically the temperature there should be at about -70 to 80°C. In our Solar System the ecosphere is at the distance of around 1 au from the Sun.

What about that life in Galaxy?

Let's estimate the number of extraterrestrial civilizations in the Galaxy. Let's make following assumptions[2]:

1. Number of stars in the Galaxy: 200 billions
2. Percentage of Sun-like stars: 10%
3. Percentage of Sun-like stars having planets: 10%
4. Percentage of Earth-like planets: 10%
5. Percentage of Earth-like planets with conditions suitable for existence of life (atmosphere, temperature, etc.): 10%
6. Percentage of planets listed above where life developed: 10%
7. Percentage of planets listed above where intelligent life developed: 10%

Based on the assumptions made above we can state that planets on which we could expect intelligent life to exist revolve around $200000000000 \cdot 0{,}1 \cdot 0{,}1 \cdot 0{,}1 \cdot 0{,}1 \cdot 0{,}1 \cdot 0{,}1 = 200000$ stars.

[2] Note that all of those parameters (apart from the amount of stars in the Galaxy) are practically unknown, which makes it easy to achieve vastly different results by making different assumptions.

Fermi paradox – where are They?

Enrico Fermi noticed that if the Galaxy contains such an amount of technologically developed civilizations, how come we can't observe any traces of their existence, e.g. signals they send, probes, spaceships, or representants of those civilizations. This is the so called Fermi paradox.

Figure: Where are They? Source: https://www.123rf.com

Figure: Enrico Fermi (born September 29th 1901 in Rome, Italy, died November 28th 1954 in Chicago, USA). An Italian physicist (in the USA since 1938) associated with nuclear physics. He was one of the cocreators of the first nuclear reactor and the first atom bomb. In 1938 he received the Nobel Prize. Source: public domain.

Fermi paradox – where are They?

If we haven't observed any tracks of the aliens yet, this means that either:

1. The assumptions concerning extraterrestrial civilizations are wrong and life is far more scarce.
2. Alien civilizations send different signals to space, however our civilization is not developed enough to detect them.

Source: http://datanews.levif.be

Attempts to solve the Fermi paradox

1. Annihilation of civilizations.
2. The distances between stars.
3. The ZOO hypothesis.
4. The planetarium hypothesis.
5. Other hypothesises.

Source: http://fermisparadox.com/

Attempts to solve the Fermi paradox: annihilation of civilizations

Civilizations' destruction due to global conflicts.

1. Sources of conflicts on planets: shrinking resources of food, water, valuable minerals.
2. Nuclear, thermonuclear, biological, or chemical weapons as potential sources of destruction of a civilization.

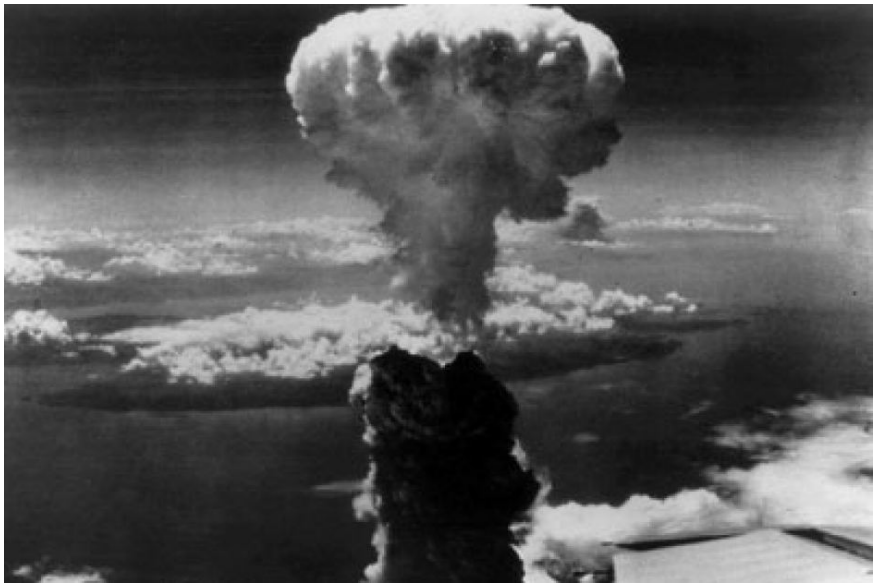

Figure: Atomic mushroom cloud created as an effect of dropping an atom bomb on Hiroshima in 1945. Source: public domain.

Attempts to solve the Fermi paradox: ecological crisis

Global ecological crisis.

1. Consequences of polluting the environment: lack of drinkable water, sterilization of soil, emission of glasshouse gasses, destruction of the layer of atmosphere protecting against radiation.
2. Environmental pollution as one of the reasons for blocking (or utterly destroying) a civilization's development.

Figure: A factory in Tangshan, China being the key element of the Kailuan coalfield. Source: https://www.bloomberg.com

Attempts to solve the Fermi paradox: ice age

Ice age.

1. Causes: changes in the orbit position's parameters, change in the inclination between the equator and the ecliptic, others?
2. Ice ages have caused massive changes in the amount of species inhabiting Earth.
3. An ice age could bring destruction to a space civilization.

Figure: An artistic vision of a city devastated by a potential future glaciation. Source: https://ethicsalarms.com

Attempts to solve the Fermi paradox: distances between stars

1. There are less than 20 stars in the 10 light years radius from the Sun.
2. The closest star (right after Sun) to Earth is Alfa Centauri located at 4,22 light years away from Earth.
3. The Sun – 8 light minutes from Earth.

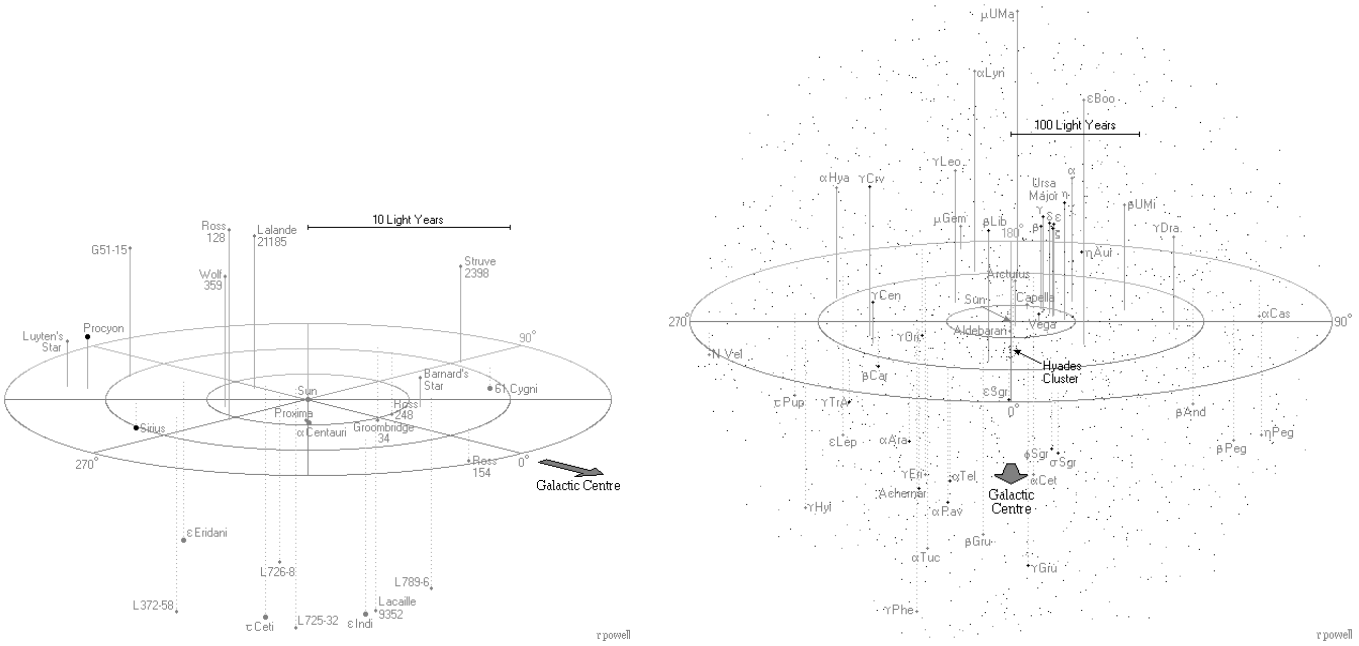

Figure: The closest surroundings of the Solar System, in the size of 10 light years – left, and 100 light years – right. Source: http://www.atlasoftheuniverse.com

Attempts to solve the Fermi paradox: distances between stars

1. Size of the Galaxy: Diameter - about 100 000 light years, thickness – about 1000 light years.
2. The Voyager 1 probe is the human-made object furthest from the Earth.
3. Its velocity is 13 km/s. It's around 140 astronomical units away from Earth (19 light hours).
4. In about 40 000 years the probe will reach the Gliese 445 star located around 17,5 light years away from Sun.
5. The distances between two stars around which life exists can reach hundreds, thousands, or even more light years. The two civilizations might fall before they can contact one another.

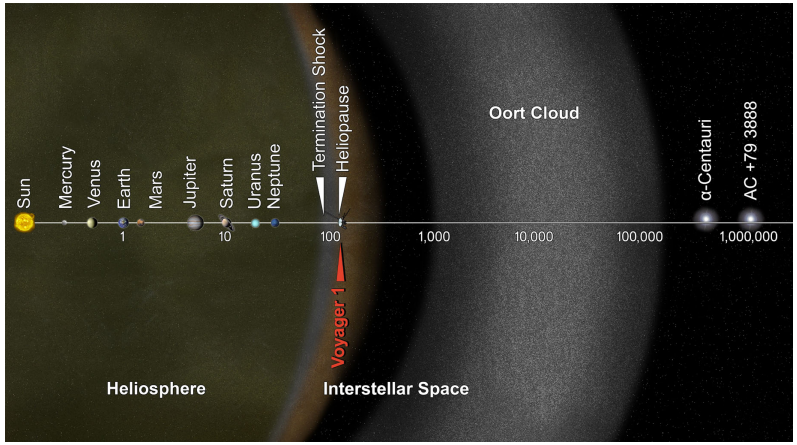

Figure: Comparison of the Voyager 1 distance to other objects in the Solar System and the closest stars. Source: NASA

Attempts to solve the Fermi paradox: the ZOO hypothesis

1. The aliens instead of contacting us would rather just observe us while remaining undetected.
2. Exemplary reasons: they don't want to interfere with our civilization, or it is too primitive for them.
3. The ant analogy: we prefer to watch ants thus researching their behaviours, rather than trying to "talk" with them.
4. Weak point of this hypothesis: if the amount of developed civilizations is high, then some of them might intend to meet us instead of just observing.

Source: Space Studies Institute.

Attempts to solve the Fermi paradox: the planetarium hypothesis

1. The hypothesis assumes, that we don't really exist, that we are merely rendered in a virtual reality by alien life forms (kind of like in the movie "Matrix").
2. The life form that created the simulation has to be technologically advanced (Type III on the Kardashev scale).
3. The virtual reality generates only life on Earth.

Source: https://listverse.com

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The search of exoplanets in ecospheres

Exoplanet – a planet circling around a different star (or stars) than the Sun.

1. The first exoplanet was discovered in 1992.
2. Currently (the beginning of 2018) we know over 3000 exoplanets.
3. Most of them have been discovered in the radius of about 1000 light years from the Sun.
4. Exoplanets can potentially be places where life has developed.
5. Exoplanets are not discovered directly (they reflect a negligible amount of light in comparison to the stream emitted by their star).

Figure: An artistic vision of a world in a triple solar system. Source: http://www.boulder.swri.edu/~terrell/dtart.htm

The search of life on exoplanets

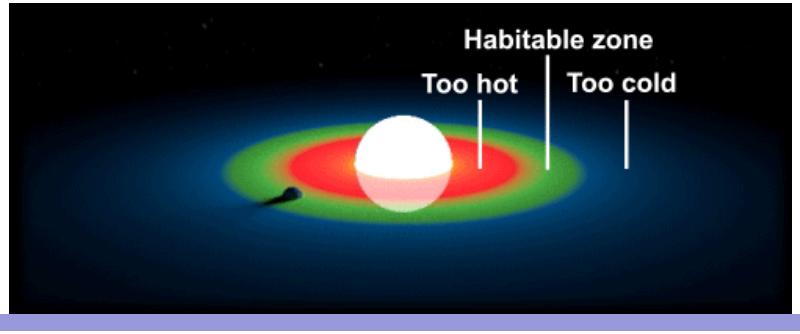
1. Searching for radio signals to receive (programs like SETI).
2. Contents of exoplanets' atmospheres (looking for biosignatures).
3. The size and density of exoplanet (based on it we can judge if it's made of rocks or gasses, or does it e.g. contain water).
4. Inclination of rotation axis to the plane of planet's movement, length of day.
5. Picking exoplanets with conditions suitable to sustain life (those in the ecosphere).

Figure: An artistic vision of the surface of a planet in a double system. Source: https://exoplanets.nasa.gov

The search for exoplanets in ecospheres

Ecosphere (also known as habitable zone) is an area in a spherical shape located around a star where physical and chemical conditions necessary to sustain life can be present (especially liquid water and temperatures ranging from -70°C to +80 °C).

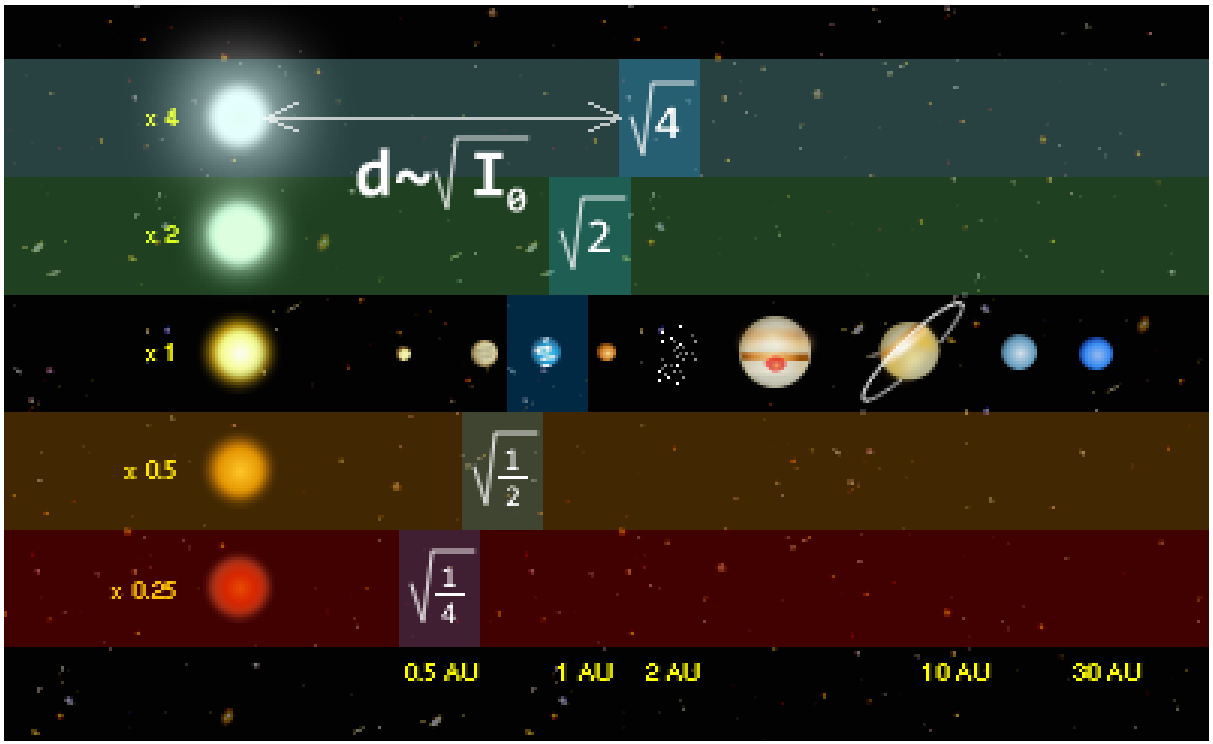
1. In the Solar System it is in the distance from 0,72 to 1,52 au from the Sun (definitions may vary).
2. The location of the ecosphere depends on the star's parameters, e.g. its brightness.
3. The location of the ecosphere depends on many factors such as composition of the atmosphere (clouds, glasshouse gasses, etc.) or planet's albedo.
4. Liquid water can exist on an exoplanet (exomoon) due to the heat caused by existence of tidal forces.
5. Ecospheres of exoplanets which life is e.g. ammonia based can be located in completely different places (other temperature of ammonia's melting).



Source: http://earth-chronicles.com/space/the-habitable-zone.html

The search for exoplanets in ecospheres

Because in most cases we don't know an exoplanet atmosphere's composition and its other parameters we can assume (in a certain approximation), that an exoplanet's position is determined by formula $d \sim \sqrt{I}$, where d is the distance from a star, and I is the star's brightness.



Source: public domain.

Exoplanet detection methods: radial velocity method

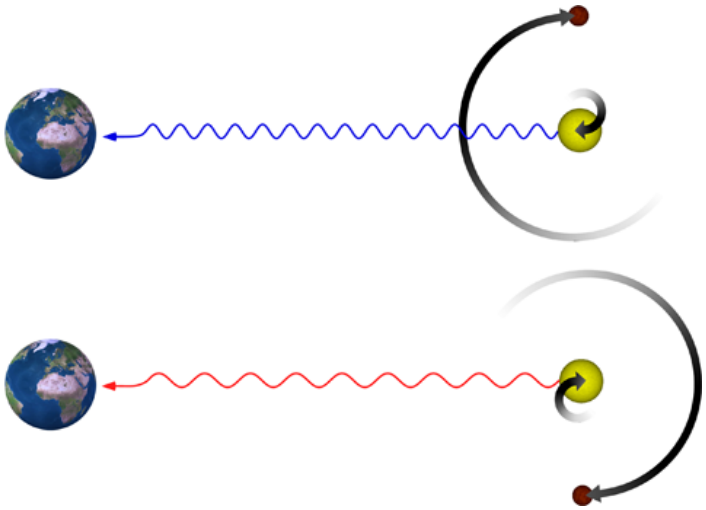


Figure: When a star gets away from the observer, the length of the observed wave decreases (red line), and when the star gets closer, the wavelength increases (blue line). Source: https://phys.org

Exoplanet detection methods: transit method

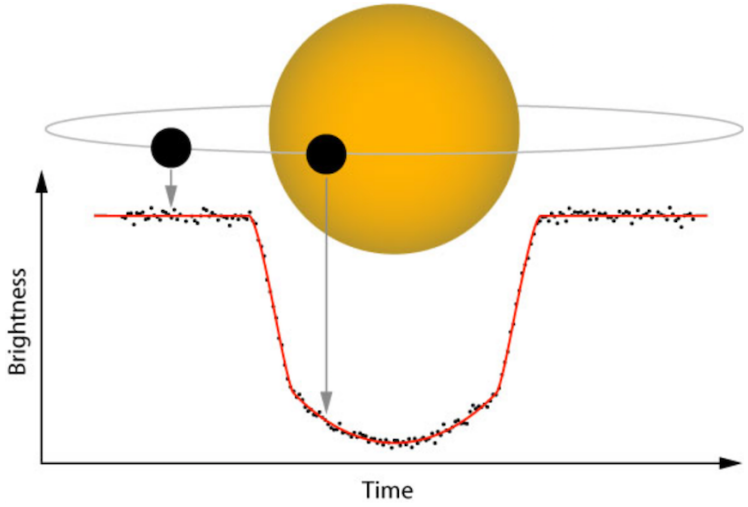


Figure: Planet's transit in front of a star and observed change in star's brightness caused by the transit. Source: NASA.

Exoplanet detection methods: astrometry method

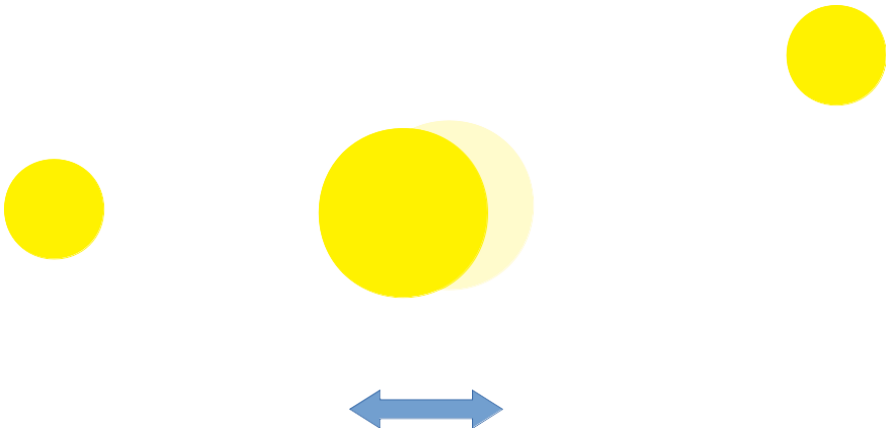


Figure: A stars motion in front of other stars can mean that the star has a (few) planet(s) revolving around it.

Exoplanet detection methods: gravity microlensing method

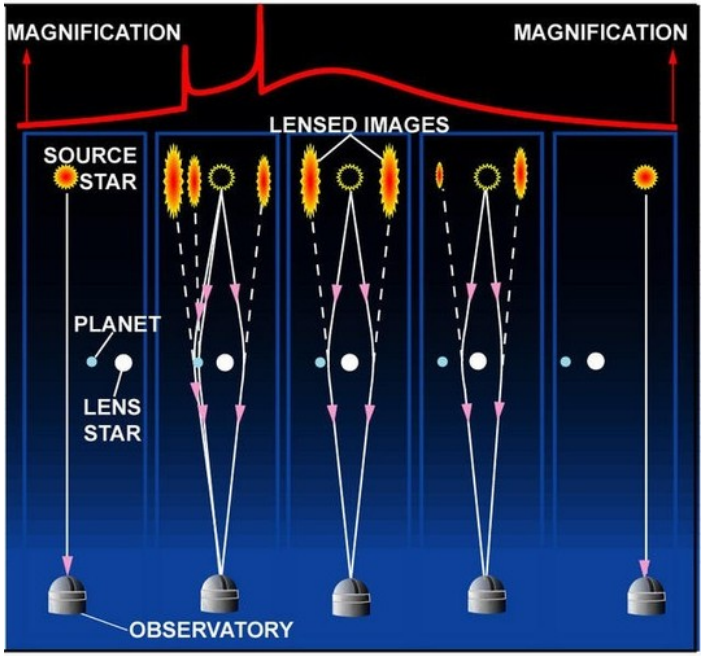


Figure: An illustration explaining how this method works. Source: http://www.planetary.org/explore/spacetopics/

Exoplanet detection methods: direct detection and imaging method

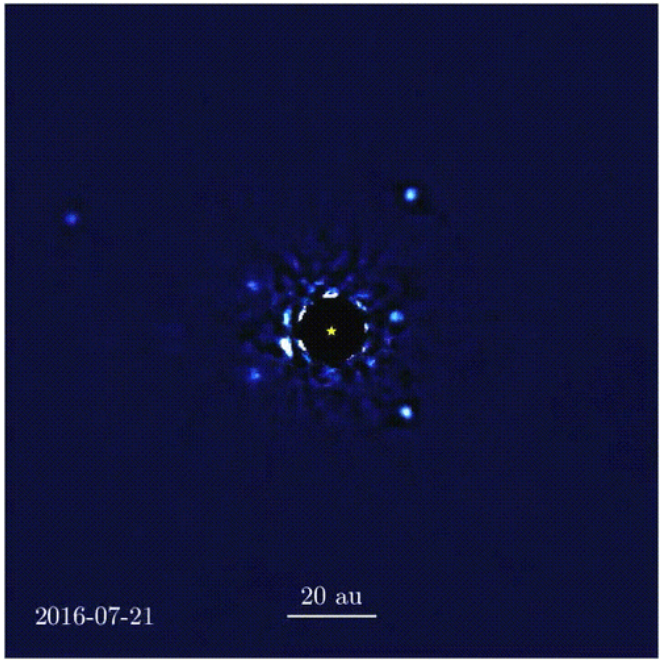


Figure: HR 87799 star accompanied by its planets. Source: Keck's observatory.

Some exoplanetary statistics

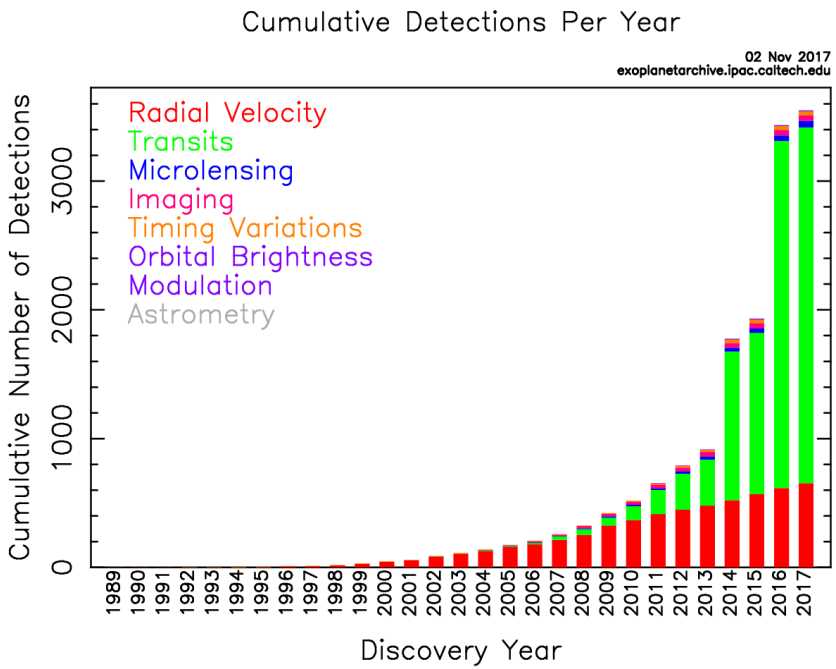


Figure: Cumulated chart of exoplanet detection with method division. Source: https://exoplanetarchive.ipac.caltech.edu

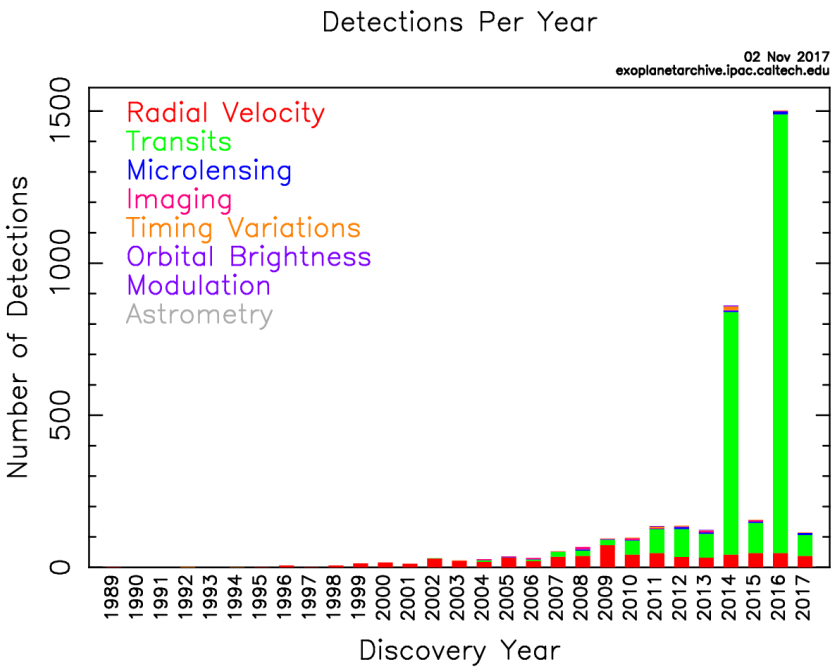


Figure: Yearly exoplanet detections with the detection method division. Source: https://exoplanetarchive.ipac.caltech.edu

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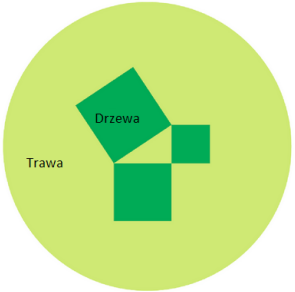
First communication attempts

1. First attempts to communicate with Moon and Mars (C. F. Gauss).



2. Another Gauss' idea: sending reflected sunlight beams towards the Moon.
3. N. Tesla suggests to use electromagnetic waves to communicate with Mars (early XX century).

The New York World October 12, 1919

Signals to Mars Based on Hope of Life on Planet

Written Specially for the Herald
By NIKOLA TESLA.

Light Ray Project.

The Miracle Performed.

Source: http://www.theteslasociety.com

Present times: Arecibo message

1. The Arecibo message was sent on November 16th 1974 towards the M13 Great Globular Cluster in Hercules, at a distance of about 25 000 light years from the Sun.
2. The message consists of 1679 bits sent consecutively.
3. The message included information on the DNA structure, human appearance, amount of people on Earth, Earth's position in the Solar System, and the Arecibo radio telescope, all coded in the binary code.

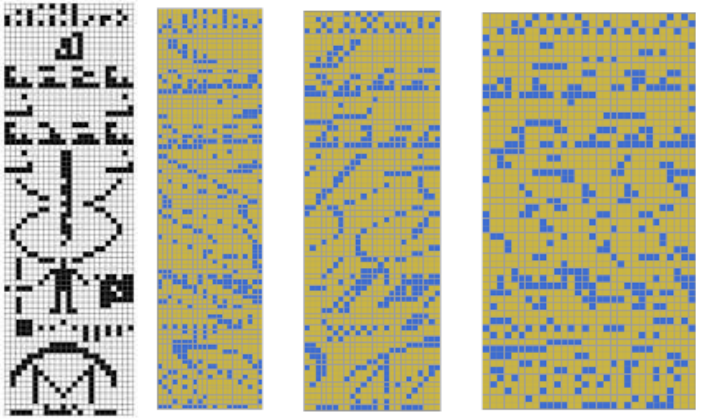
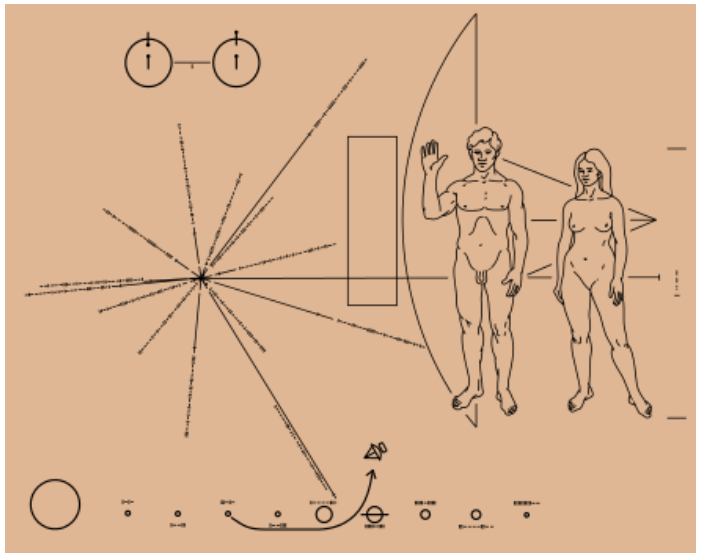


Figure: Left picture: Correctly decoded Arecibo message (23 columns and 73 verses). Other pictures: incorrectly decoded message (from left: 22, 24 and 30 columns). Source: public domain.

Present times: Pioneer plaque

1. Pioneer plaque are two metal plaques placed on space probes Pioneer 10 (mission started on March 3rd 1972) and Pioneer 11 (April 5th 1973).
2. They are made of aluminium covered in a thin layer of gold (15 cm x 23 cm).
3. They contain drawings of a woman, a man, the probe and its journey through the Solar System, and the Solar System's planets also marking the Earth.
4. The plaque also contains information of solar System's position in the Galaxy.



Source: public domain.