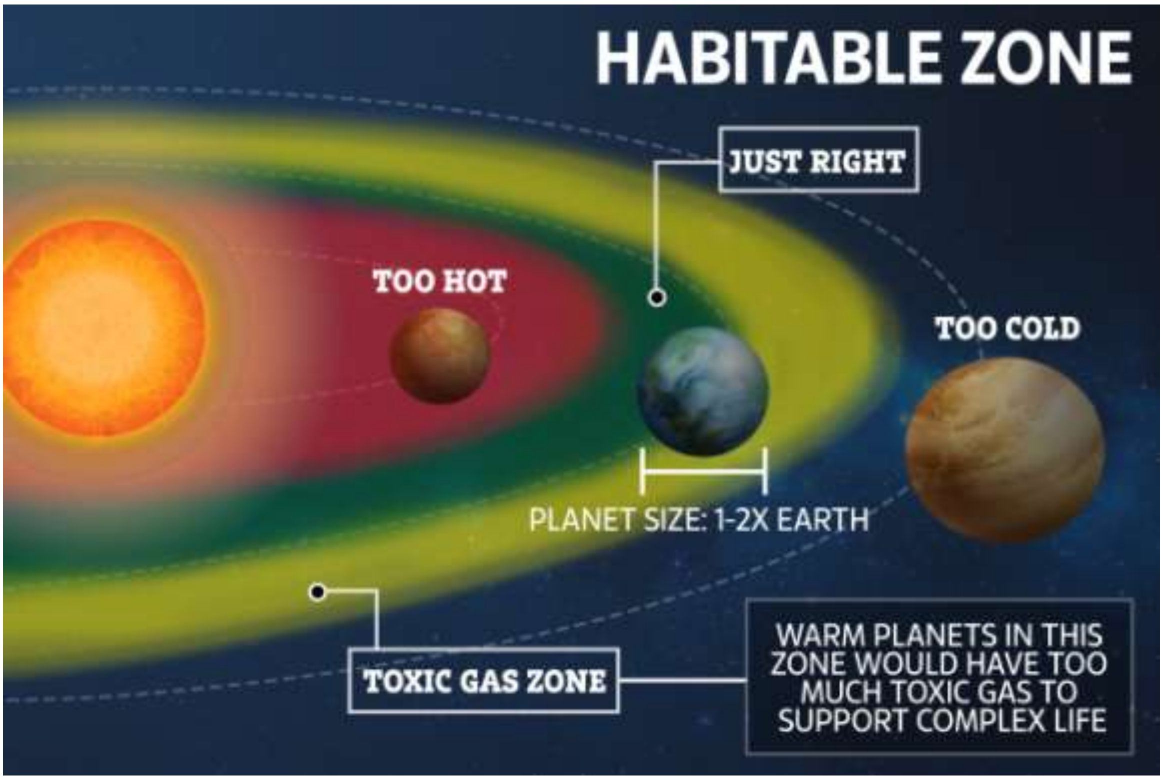
Habitable Zone



In astronomy and astrobiology, the circumstellar **habitable zone** (CHZ), or simply the **habitable zone**, is the range of orbits around a star within which a planetary surface can support liquid water given sufficient atmospheric pressure.

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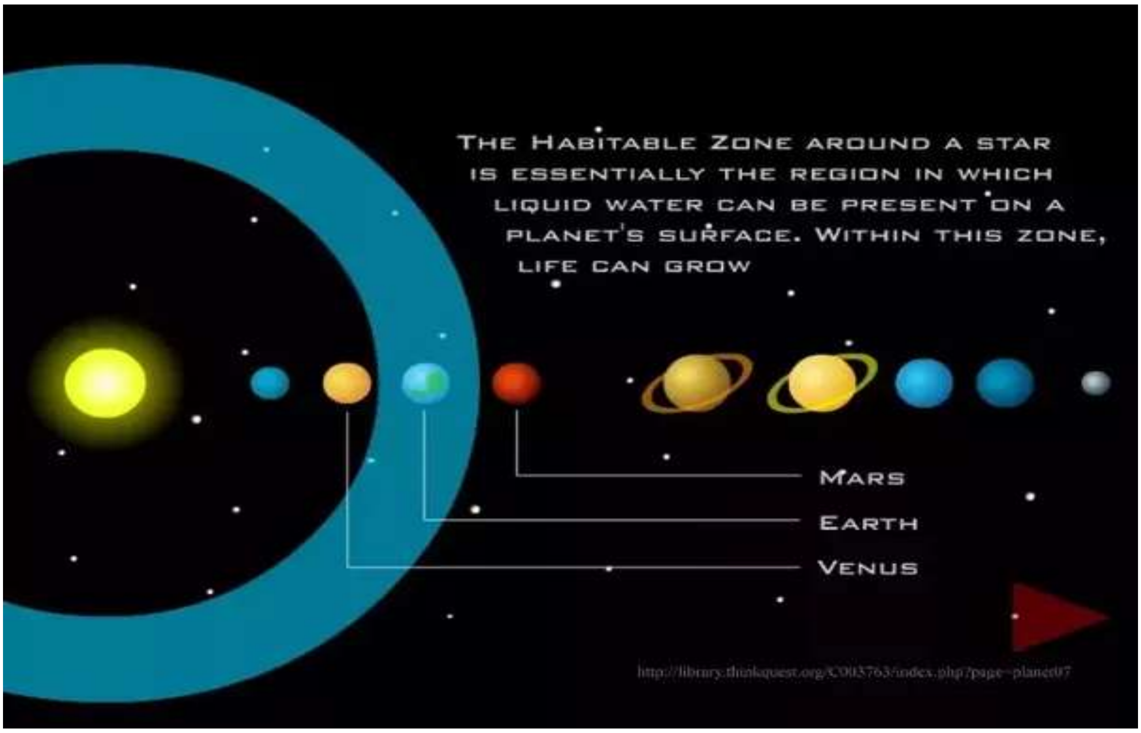
Habitable Zone

As the liquid water is important for life on Earth, then there is a distance from the local star that would receive sufficient radiation from the star to maintain the effective surface temperature of the planet above the melting point of water, 273 K. This condition defines a habitable zone around a star and is the range of distances from which an orbiting planet will have liquid water on its surface. So the region in which water can exist in the liquid form (273-373 K) is known as **habitable zone**. For earth this region lies between Mars and Venus.



As for the Earth, the habitable zone is determined by two factors: the effective surface temperature of a planet as determined by the flux arriving from the local star; and the radiation-trapping efficiency of the atmosphere around the planet. Inner and outer boundaries have been calculated for the

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habitable zone around the Sun based on the arriving solar energy and H_2O–CO_2 content of the atmosphere over geological time. A thick H_2O–CO_2 atmosphere would allow the Earth to maintain a habitable zone extending about 1.7 AU from the Sun, just outside the orbit of Mars, whereas the inner boundary is determined by the runaway-greenhouse effect as observed on Venus. If the surface temperature were too hot, above 373 K, this would vaporise all water on the surface of the planet. The inner boundary is around 0.85 AU so the habitable zone spans 0.85–1.7 AU for our Sun but the current habitable zone spans 0.85 – 1.3 AU. The habitable zone was much larger when the Sun's luminosity was greater and narrower when the luminosity was smaller. And the continually habitable zone lays in the region 0.95–1.2 AU – a remarkably small region.

Some physical and chemical factors important for defining whether an environment is habitable and the ranges tolerated by microorganisms and humans

Parameter	Microorganisms	Humans
Temperature	< 0–121℃	0–30℃
Pressure	<50 hPa–>10 000 hPa	700 hPa–5 000 hPa
Radiation	4000 Gy	1–3 Gy
pH	0–13	Near Neutral
Oxygen	0–~100%	15–25%
Carbon dioxide	0–100%	<1%

Planets are in equilibrium with their surroundings, they are neither getting hotter nor colder. All planets absorb radiation from Sun but they must radiate away the same amount of energy to maintain equilibrium. The temperature of a planet can be approximated by considering it as black body.

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There are some factors which are important for habitable zone or habitable planet: They are as follows-

1. **Albedo**: *Fraction of solar energy reflected from the planet into space.* Planets do not absorb total incident light. Some fraction is reflected and some gets absorbed. The albedo of earth is 0.37 and of Venus is 0.65. More reflection leads to a colder planet. This factor is very important to maintain the temperature of a planet to make it habitable. This extends the inner edge of the habitable zone inwards (Solar irradiation X albedo).

2. **Greenhouse Effect:** If radiation is trapped then the planet heats up beyond the temperature it would normally acquire. An obvious example is that of Venus. Planets are not ideal black bodies. Carbon dioxide, water vapour, and other atmospheric gases are opaque in the near-IR. A less-than-ideal radiator must be hotter than a black body to radiate the same amount of luminosity. This extends the outer edge of the habitable zone outwards.

3. The stars evolve in the main sequence and become brighter and hotter. This makes the habitable zone move out with time. The Sun is now some 30% brighter than it was 4 billion years ago, and will eventually double that brightness before evolving off the main sequence. In the figure, the habitable zone moves outward between times t_0 and t_1. The region labelled CHZ is the continuously habitable zone. About 4 billion years ago, Venus was located near the inner edge of the habitable zone; today it lies closer to the Sun than the inner edge of the habitable zone.

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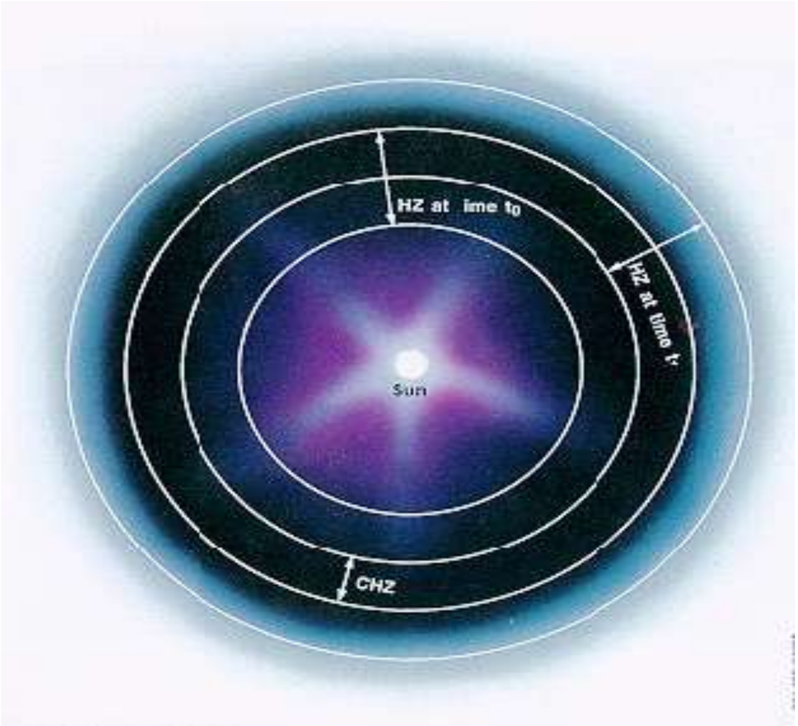

The temperature can be determined through total energy flux and solar luminosity via following derivation:

$$F = \sigma_{SB} T^4 \qquad (1)$$

where F is total energy flux, T is effective temperature and σ_{SB} is Stefan-Boltzmann constant.

$$F = L/4\pi r^2 \qquad (2)$$

Where L is the luminosity of the star and r is the distance at which flux is calculated.

Now equating equation 1 & 2, we get

$$\sigma_{SB} T^4 = F = L/4\pi r^2 \qquad (3)$$

When we consider a single solar system, then not only σ_{SB} and 4π but also the luminosity L are constants with distance, hence

$$T^4 \alpha\ 1/r^2$$

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Therefore this proportionality can be used to calculate a distance for a given temperature or vice-versa. For example if temperature is 300K at 1 AU then four times farther away the temperature is $4^{-1/2}$ = ½ times as great or 150K. Similarly the distance where the temperature is 600K would be given by $(600/300)^{-2}$ x 1 AU = 0.25 AU

Through above proportionality the **<u>inner and outer limit</u>** of habitable zone can also be determined:

The average temperature of Earth is about 15°C or 288K. Water freezes at 0°C=273K and boils at 100°C=373K;

so the scaling indicates that the habitable zone could extend from $(373/288)^{-2}$ X 1 AU=0.6 AU to $(273/288)^{-2}$ X 1 AU=1.1 AU

So habitable zone ranges from 0.6 AU to 1.1 AU around the sun. It includes Venus but not mars. It is a principle value which can be modified according to the factors affecting the luminosity of the star. In some cases or a optimistic value of range this value ranges from **0.95 AU to 1.5 AU** also.

The Circumstellar Habitable Zone:

The range around a star in which any planet or planets may contain the liquid water (with sufficient mass and atmospheric pressure) to support the existence of life is known as circumstellar habitable zone. It is a concept that was given before the detection of exoplanets, to quantify the properties of a star-planet system that were amenable to supporting life. It is also sometimes referred to as the “Goldilocks zone”. For the permanent existence of life planet must be in the continuously habitable zone. The continuously habitable zone is the range that is favourable for liquid water

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for many billions of years of a star’s existence. The bounds of the circumstellar habitable zone are calculated using the known requirements of Earth’s biosphere, its position in the Solar System and the amount of radiant energy it receives from the Sun. The circumstellar habitable zone depends on the properties of the host star as well as the planet, and that the CHZ varies with time as the host star evolves, and as the planet's properties change.

Water is believed to have been vital in the formation of life on Earth due to its function as a solvent in biochemistry. Although the region is a spherical shell that surrounds a star. Realize that the CHZ is closely related to the inverse square law – how energy falls off with distance from a star. Thus, the size and location of the CHZ change over time as a star evolves. For the Sun at present the CHZ ranges from 0.97 AU to 1.37 AU. Principally, the inner and outer edges of the CHZ are straightforward to define:

- The inner edge of the CHZ (closest to the host star) is determined by the breakup of water into its constituents due to intense radiation.
- The outer edge of the CHZ (farthest from the host star) is affected by the condensation of carbon dioxide out of the atmosphere, which affects the reflection (scattering) of light, and therefore the energy balance (and therefore the temperature).

Galactic Habitable Zone:

A galactic habitable zone is the putative region inside a galaxy with physical conditions compatible with the origin, development, and long-term existence of life-as-we-know-it. Minimum requirements are the existence of enough heavy chemical elements to form Earth-like planets

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and a low occurrence of catastrophic events (e.g., supernovae, close stellar encounters) in order to allow the evolution of complex life forms. The galactic habitable zone is currently beleved to be an annulus with the outer space of about 10Kpc and an inner radius close to galactic center.

A number of physical processes that may either favour or hinder the developement of extraterrestrial life, depend strongly upon location in the Milky Way.

Metallicity

Metals are very important in the formation of any planet. There is evidence suggesting that Terrestrial planets and Jovian planets both cannot form without metals. That stars which have extrasolar planets have high metallicities whereas the stars without extrasolar planets have low metallicities. There is a threshold value of metallicity necessary for terrestrial planet formation.The amount of metals in the interstellar medium varies with location in the Milky Way. These elements are produced in nuclear reactions in the cores of massive stars and distributed through supernovae explosions into the interstellar medium. Two metallicity trends are apparent in the Milky Way disk

1. metallicity has been generally increasing over time
2. metallicity is larger near the center where star formation is more substantial than toward the disk's edge.

Cosmic Threats

There are several kind of cosmic threats occurring in the space but the most dangerous threat to the development of complex life is supernovae explosion. Because it produce high-energy photons and protons which can obliterate the ozone, and make the planet like Earth open for sun’s UV

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radiations. The supernovae explosion occurs when the Sun passes through a spiral arm. The frequency of supernovae explosion is much higher in the inner regions of the Milky Way than the outer regions (supernovae at the Sun's location occur with a frequency on the order of 1 Gyr^{-1}).

The massive black hole at the center of the Milky Way is another threat to development of life. At present time it is inactive. But large amounts of matter will spiral into the black hole periodically and be consumed. As matter falls into the black hole it is heated to extremely high temperatures and will release very energetic photons and charged particles. This radiation would threaten life in the inner regions of the Milky Way.

Another possible problem is that our solar system is surrounded by a vast swarm of comet nuclei known as the Oort Cloud. When it is passes through the inner solar system it is said to be as a long period comet. However, if our solar system passes close enough to another star so that its gravity greatly disturbs the Oort Cloud, which may assault the inner solar system. This type of perturbation would occur mostly in the inner regions of the Milky Way than the outer regions.

Summation

The galactic habitable zone depends on the balance of two opposing trends. Metallicity decreases as one moves outward in the Milky Way, decreasing the number of potential planets. On the other hand, most of the cosmic threats occur in the inner region of the galaxy Milky way.

<u>Relation between the distance between earth and sun and their temperatures:</u>

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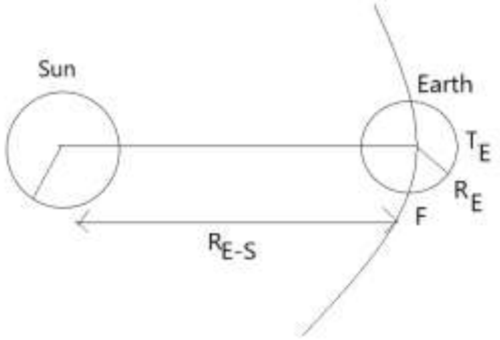

Ps=Power radiated by sun= $\sigma {T_s}^4 A = \sigma {T_s}^4\, 4\pi {R_s}^2$

F(flux at earth)=$\frac{P_s}{4\pi {R_{E-S}}^2} = \frac{\sigma {T_s}^4\, 4\pi {R_s}^2}{4\pi {R_{E-S}}^2} = \frac{\sigma {T_s}^4 {R_s}^2}{{R_{E-S}}^2}$

P_{ABS}=Power absorbed by earth=F($\pi {R_E}^2$) (1-Albedo)

= (1-Albedo) $\frac{\sigma {T_s}^4 {R_s}^2}{{R_{E-S}}^2} . \pi {R_E}^2$

PRAD= Power radiated by earth= $\sigma {T_E}^4 A = \sigma {T_E}^4\, 4\pi {R_E}^2$

For temperature maintenance, the minimum requirement is;

$P_{ABS}=P_{RAD}$

Hence, (1-Albedo) $\frac{\sigma {T_s}^4 {R_s}^2}{{R_{E-S}}^2} . \pi {R_E}^2 = \sigma {T_E}^4\, 4\pi {R_E}^2$

It implies, $4{T_E}^4$ = (1-Albedo) $\frac{{T_s}^4 {R_s}^2}{{R_{E-S}}^2}$

This implies, $T_E = \left[\frac{(1-\text{Albedo})\frac{{R_s}^2}{{R_{E-S}}^2}}{4}\right]^{1/4} . T_s$

i.e., **$R_{E-S} = \frac{(1-Albedo)^{1/2}}{2}\left(\frac{T_s}{T_E}\right)^2 R_s$**

Put the temperatures to get the range of distance (Habitable Zone).

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