Habitable Zone

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Overview

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Definition der HZ

Dole (1964):
- 10 % of the surface had a mean temperature of between 0 and 30 °C
- extremes not to exceed -10 or 40 °C

Fogg (1992):
- “biocompatible” ⇒ describe planets possessing liquid water
- “habitable” ⇒ planets suitable for humans

Kasting et al. (1993):
- region around a star in which a planet with an Earth-like atmosphere could support liquid water on its surface

Pollack et al. 1996; Ikoma et al. 2001; Lissauer et al. 2009:
- maximum mass from 0.1 to 16 Earth masses
Different types of HZ

Tidal habitable zone (THZ):
• Tidal heating that on Io and produce similar surface conditions ⇒ life seems unlikely
• tidal heating is too less (not minimum to initiate plate tectonics)
• ⇒ CO₂ may not be recycled through subduction
• runaway greenhouse ⇒ sterilizes the planet

Insolation habitable zone (IHZ):
• Close to the star ⇒ too hot for liquid water
• Far from the star ⇒ too cold for liquid water
• between is a range of orbits for which liquid water is stable on the surface
• habitable orbits lie closer (∼0.1 AU) to low-mass stars than to Sun-like stars ⇒ are less luminous
Different types of HZ

Continuously habitable zone (CHZ):

• Sun increases in luminosity as it ages

• The width of the CHZ $\Rightarrow$ length of time that a planet is required to remain habitable

• Orbital distances for the 1st condensation, maximum greenhouse, and “early Mars” limits are 1.15, 1.39 and 1.49 AU

• Runaway greenhouse formed inside 0.95 AU

• Runaway glaciations formed outside 1.01 AU
Habitable Zone in the Solar System

Fig. 1: Extrasolar Planets, R. Dvorak et al., 2008
• Conservative case: 0.95 AU to 1.37 AU
• Optimistic case: 0.75 AU to 1.90 AU
• Immediate case: 0.84 AU to 1.77 AU
Limits for the outer edge

Three possible limits:

• 1) distance at which CO₂ clouds formed and have a fixed surface temperature of 273 K
⇒ “1st condensation”

• 2) maximum distance at which a cloud-free CO₂ atmosphere can maintain a surface temperature of 273 K
⇒ “maximum greenhouse”

• 3) early Mars have liquid water
Limits for the inner edge

• the mean surface temperature exceeding the critical temperature for water 647K

• Two critical values:
  • 1) the stratosphere becomes wet
  • 2) the oceans evaporate entirely
Habitable Zone around main sequence stars

Fig. 2: Habitable Zone around main sequence stars, Kasting et. al., 1993
Habitable Zone around solar-type stars

• 40 K increase ⇒ water loss limit from 0.95 AU to 1 AU

• CO$_2$ condensation (near the outer edge of the HZ) depends strongly on stratospheric temperatures
  – 20 K decrease ⇒ the 1$^{\text{st}}$ condensation limit move from 1.37 AU to 1.27 AU
  – 20 K increase ⇒ the 1$^{\text{st}}$ condensation limit move out to 1.47 AU

• Two different types of clouds:
  – H$_2$O clouds ⇒ most important near the inner edge
  – CO$_2$ clouds ⇒ only important near the outer edge
Non-earth-like planets

Large planets:

• better to hold their atmospheres over time
• stronger gravitation
• more difficult for molecules to escape
• have higher internal heat flows
• maintain tectonic activity

• Earth: H and He escape
• Mars also loses C, N and O
Circumstellar habitable zones and mass loss (solar-type)

- Mass loss model $\Rightarrow$ increase in the early solar flux
- Early Sun $\Rightarrow$ more massive and luminous than today
- Explain the existence of water on early Mars
- Lithium $\Rightarrow$ photosphere of the Sun
- Significant mass loss is associated with rapid rotation
Circumstellar habitable zones and mass loss (solar-type)

Other 4 models are:

• accretion from an interstellar cloud
• dynamical perturbation
• solar luminosity variations
• ecliptic flux focusing

• eccentricity of Mars varies from 0.093 to about 0.14
• luminosity of a young solar-type star increase due to the sudden disappearance of star spots
• are expected to be heavily spotted
Tidal limits to planetary habitability

• geophysical processes (e.g., plate tectonics) that maintain long-term climate stability

• tidal heating can drive plate tectonics, including subduction

• heating inside the planet drive mantle convection
Climate stabilization by the carbonate-silicate cycle

Fig. 3: Extrasolar Planets, R. Dvorak et al., 2008
Planets with and without plate tectonics

- recycling of the crust through plate tectonics \(\Rightarrow\) keeps the crust thin
- If the crust is too thick:
  - lithospheric plate comprising the crust will be too buoyant to be subducted
  - on Earth the cratons never subducted anymore
- Plate tectonics \(\Rightarrow\) help to establish the right temperature conditions in the interior
- maintain the action strong magnetic dynamo
Earth-like worlds on eccentric orbits

• extrasolar giant planets on highly eccentric orbits ⇒ $e = 0.7$
• Systems with planets within or near the HZ will possibly harbour life on their moons
• spectral type from F7 to M5
• exact boundaries of circumstellar HZs vary slightly
• planets have different masses
• ⇒ inner edge: rate of atmospheric escape of water
• ⇒ outer edge: rate of global refrigeration
Earth-like worlds on eccentric orbits

Fig. 4: Earth-like worlds on eccentric orbits: excursions beyond the habitable zone, Williams et al., 2002
Earth-like worlds on eccentric orbits

• Planets around other stars other orbital eccentricity
• largest orbital eccentricity $\Rightarrow$ Pluto with $e = 0.25$
• approximately one-third of the newly discovered planets $\Rightarrow e = 0.4$
Earth-like worlds on eccentric orbits

- GENESIS 2 simulate how to respond a planet to extreme variations in stellar flux in an eccentric orbit.
- atmospheric general circulation model
- eccentricity from 0.0167 to 0.4:
  - temperature increase from 14.6 °C to 30.1 °C
  - within the HZ from 365 days to 180 days
Earth-like worlds on eccentric orbits

Fig.5: Earth-like worlds on eccentric orbits: excursions beyond the habitable zone, Williams et al., 2002
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Fig. 6: Earth-like worlds on eccentric orbits: excursions beyond the habitable zone, Williams et al., 2002
Classification of habitable planets

1) Class I habitats: earth-like planets
   • life forms as we only know it on Earth
   • G, K and F-type (close to G-stars)
   • water inventory can remain stable over geological time
   • important that environment can keep plate tectonics over billions of years

Classification of habitable planets

2) Class II habitats: Mars/Venus-type planets

- Planets orbiting within HZs of low mass M and K-type
- atmosphere + water end up after time \( \Rightarrow \) extreme radiation
- dry Venus-like or cold Martian-like planets (loss of water)
- possible that life started early \( \Rightarrow \) long enough for evolution

http://www.robinsonlibrary.com/science/astronomy/solarsystem/venus.htm

Classification of habitable planets

3) Class III habitats: subsurface oceans with silicate contact on the sea-floor

- Large satellites of Jupiter or Saturn ⇒ amount of water
- Europa ⇒ smaller icy layer (100 km)
- water-reservoirs ⇒ contact with heat sources by radioactive, volcanic, or hydrothermal activity
- large ocean can be in contact with the silicate layer
- assuming by impact of meteorites and comets
- problem: source of energy necessary to power an organism

http://de.wikipedia.org/wiki/Europa_%28Mond%29
Classification of habitable planets

4) Class IV habitats: subsurface-ice water worlds and “Ocean planets”
- have subsurface water oceans
- not interact with a typical silicate bearing sea floor like Europa
- life on such habitats could have evolved in the absence of black smokers
- Ganymede, Callisto, Enceladus, Titan
- problem: concentration of the necessary ingredients for life
Planetary Habitability

- Eccentricity
- Tidal heating
- Mass
- Stable orbit
- Rotation
- Habitable zone
- Liquid water on its surface
- Radius
- Stellar activity (x-ray, solar flares)
- Geophysical effects (plate tectonic)
- Long-term climate stability
- Age and internal structure of a planet
- Insolation-tidal HZ
Referenzen

- Papers:
  - Tidal Limits to planetary habitability, R. Barnes et al. 2009
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