Lecture 34: Habitable Zones around Stars

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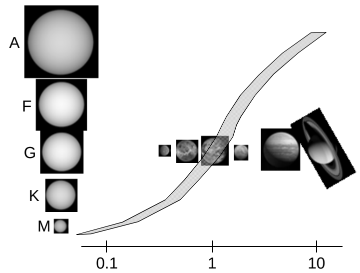
Habitable Zones around Stars



Astronomy 141 – Winter 2012

This lecture examines the factors affecting the habitability of stars.

A likely place to look for life is on rocky planets in the Habitable Zones of low-mass Main Sequence stars.

Brighter stars have wider Habitable Zones further away from the star.

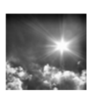
Planets in Habitable Zones close to their parent stars can become tidally locked.

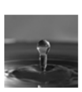
Low-mass M stars experience violent super-flares that could have a negative impact on habitability.

Stars that emit a lot of UV radiation would possibly sterilize the surfaces of their planets.

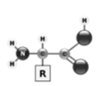
Basic Requirements for Life in a Planetary Context

Stable, Long-lived Source of Energy
Energy to fuel chemical reactions
Warmth to permit liquid water

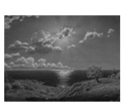




Complex Chemistry
Elements heavier than H and He
Carbon, liquid water, inorganics



Location for life to emerge
Oceans, land masses (place to swim/stand)



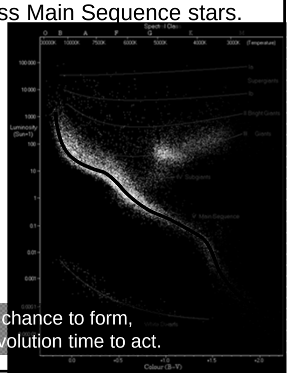
Benign Environmental Conditions
Stable, well-regulated climate
Protection from harmful UV radiation

These conditions should occur on rocky planets in the Habitable Zones of low-mass Main Sequence stars.

Main Sequence stars stably generate energy by core Hydrogen fusion

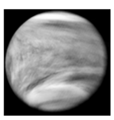
Low-mass stars (<3–4M_{sun}) have M-S lifetimes of >1 Gyr

Provide a stable source of heat for a long time.

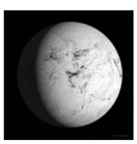


Long enough to give planets a chance to form, life a chance to emerge, and evolution time to act.

The Habitable Zone is the region around a star where liquid water is stable on a planet's surface



Planet too close:
Runaway greenhouse effect superheats the atmosphere and vaporizes all the water.

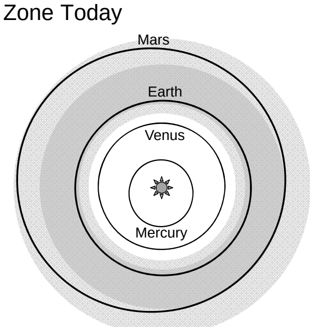


Planet too far:
Water freezes out and won't be liquid on the surface.

The Sun's Habitable Zone Today

Conservative:
0.95 – 1.4 AU

Optimistic:
0.84 – 1.7 AU



Region around the Sun where liquid water is stable on the surface of a planet at a pressure of 1 atmosphere.

The location of a star's Habitable Zone depends on its luminosity.

Inner edge of Habitable Zone:

$$d_{inner} = 0.95\,AU\sqrt{\frac{L}{L_{sun}}}$$

Outer edge of Habitable Zone:

$$d_{outer} = 1.4\,AU\sqrt{\frac{L}{L_{sun}}}$$

Brighter stars have more distant Habitable Zones.

Examples:

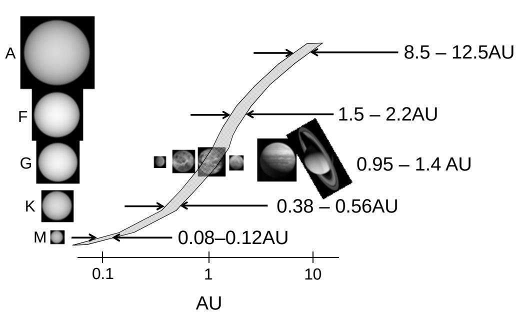

Sun (G Star): $L = L_{sun}$, d_{HZ} = 0.95 – 1.4 AU


A Star: $L = 80\ L_{sun}$, d_{HZ} = 8.5 – 12.5 AU

M Star: $L = 0.008\ L_{sun}$, d_{HZ} = 0.08 – 0.12 AU

Brighter stars have *broader* Habitable Zones.

Habitable Zones for low-mass Main Sequence Stars



It is not enough for a planet to just be in the Habitable Zone of its star…

Other factors can influence habitability:

Planets in Habitable Zones close to their parent stars risk becoming tidally locked.

Low-mass M stars are subject to stellar flares that could have a potentially negative impact on life.

Excess ultraviolet radiation could produce environments hazardous to life (likelihood of dangerous mutations)

If a small body orbits too close to its parent body, its rotation will become tidally locked.

Examples:

The Moon's rotation period is synchronized with its orbital period around the Earth.

Always keeps the same face towards the Earth

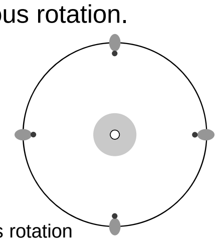
Galilean Moons of Jupiter are tidally locked in synchronous rotation with their orbits.

Always keep the same face towards Jupiter.

It takes time for a small body to become tidally locked into synchronous rotation.

Example: The Moon

The Earth raises body tides on the Moon.



Constant squeezing & stretching of a rapidly rotating Moon generates heat

Energy gets taken from the Moon's rotation

The Moon' rotation slows down until its rotation & orbit periods are the *same*, stopping the squeezing.

The Tidal Locking Timescale depends on the size of the orbit and the mass of the parent star

$$\text{Tidal Locking Timescale} = 10^{12}\ \text{years}\ \times \left(\frac{a}{\text{AU}}\right)^{6} \left(\frac{M}{M_{Sun}}\right)^{-2}$$

How far can a planet be from its parent star such that it becomes tidally locked after 4 Gyr?

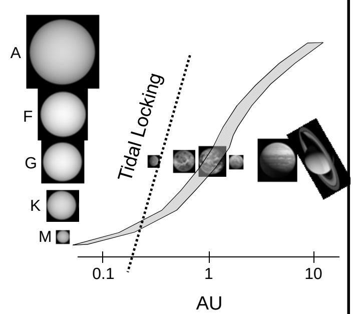
$$\text{Tidal Locking Radius} \sim 0.4\ \text{AU} \left(\frac{M}{M_{Sun}}\right)^{1/3}$$

Planets in the habitable zones of M main-sequence stars may be tidally locked.

One side of the planet gets all the starlight

Near-side gets too Hot

Far-side gets too Cold



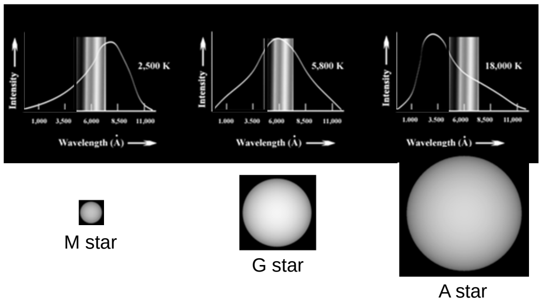
M stars are magnetically active and can produce powerful stellar flares.

Flares are enormous outbursts of high-energy (X-ray and UV) radiation.

Could potentially be sterilizing.

But it could also stimulate evolution by increasing the mutation rate.

Hot stars produce a great deal of UV radiation that can be damaging to life.



Could potentially sterilize the surfaces of their planets

In our search for stars that might harbor habitable planets…

Exclude Giants and White Dwarfs without a stable source of energy.

Exclude short-lived O & B stars and UV-bright stars

Maybe exclude low-mass stars with strong flaring and tidal-locking in their Habitable Zones