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_\odot) 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:
\[ d_{\text{inner}} = 0.95 \text{AU} \sqrt{\frac{L}{L_{\odot}}} \]

Outer edge of Habitable Zone:
\[ d_{\text{outer}} = 1.4 \text{AU} \sqrt{\frac{L}{L_{\odot}}} \]

Brighter stars have more distant Habitable Zones.

Examples:
- Sun (G Star): \( L = L_{\odot} \), \( d_{\text{HZ}} = 0.95 – 1.4 \text{ AU} \)
- A Star: \( L = 80 L_{\odot} \), \( d_{\text{HZ}} = 8.5 – 12.5 \text{ AU} \)
- M Star: \( L = 0.008 L_{\odot} \), \( d_{\text{HZ}} = 0.08 – 0.12 \text{ AU} \)

Brighter stars have broader Habitable Zones.
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’s 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

\[
\text{Tidal Locking Timescale} = 10^7 \text{years} \times \left( \frac{a}{\text{AU}} \right)^6 \left( \frac{M}{M_{\odot}} \right)^{1/2}
\]

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

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

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. M star G star A star

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 Habitible Zones