HABITABLE ZONE LIFETIMES AROUND MAIN SEQUENCE STARS

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What is a Habitable Zone (HZ)?

The Habitable Zone is a space near a star where it's not too hot or too cold, making it just right for water to stay liquid on a planet's surface—a key for life as we know it. This idea connects to big topics like how stars change over time, the way they give off energy, and what makes a planet's atmosphere just right for life.

What Properties of a Star Affect Its Habitable Zone?

- **Mass** influences a star's temperature and lifespan. Bigger stars are hotter and may have a wider but more short-lived habitable zone due to their shorter lifespans.
- **Luminosity** or how bright a star is, directly impacts how far the habitable zone stretches. A brighter star means a habitable zone that's further out, as more energy is emitted to warm distant planets to the right temperature for liquid water.

Why Do Habitable Zones Have Lifetimes?

Habitable Zones (HZs) change because stars evolve. At the start, when a star is in its Zero Age Main Sequence (ZAMS) phase, it begins stable hydrogen burning. Over time, as it moves towards its Terminal Main Sequence (TMS), it uses up hydrogen, grows brighter, and alters the HZ's position. This shift means a planet perfectly in the HZ initially might later become too hot or too cold for liquid water, marking the HZ's "lifetime."

Stellar Luminosity:

$$L = 4\pi R^2 \sigma T_{\mathrm{eff}}^4$$

A star's luminosity (L) represents the total energy it emits per unit of time. The luminosity depends on the star's radius (R) and its effective temperature (T). The Stefan-Boltzmann constant (σ) is a proportionality factor that relates the energy emitted by a black body to its temperature, emphasizing how both the size and the heat of a star determine its brightness and energy output.

HZ Boundaries:

$$\mathrm{HZ}_{\mathrm{inner/outer}} = \frac{L}{S_{\mathrm{inner/outer}}(T_{\mathrm{eff}})}$$

The distances to the inner and outer edges of the habitable zone (HZ) from the star, factoring in the star's luminosity (L) and the solar flux (S) necessary at these edges for water to remain liquid. The solar flux values are adjusted based on the star's effective temperature (Teff), highlighting the role of stellar energy output in defining where conditions may be right for life.

Transition Rate of HZ Boundaries:

$$\mu_{\mathrm{inner/outer}} = \frac{\mathrm{HZ}_{\mathrm{inner/outer}}^{\mathrm{TMS}} - \mathrm{HZ}_{\mathrm{inner/outer}}^{\mathrm{ZAMS}}}{\tau}$$

This key equation from the paper measures the rate at which the habitable zone's (HZ) boundaries transition over the star's main sequence (MS) lifetime (τ). By assessing the HZ's span from the Zero Age Main Sequence (ZAMS) to the Terminal Main Sequence (TMS), it quantifies how quickly a planet must adjust its orbit to remain within the HZ, thus maintaining conditions conducive to life.