

# Fine-tuning of the Universe

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- ① What is Fine-tuning?
- ② Key Fine-tuned Constants
- ③ Physical Analysis

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# What is Fine-tuning?

- Fine-tuning describes the extreme sensitivity of the universes largescale behaviour to tiny changes in its fundamental parameters.
- "Life as we know it" could not exist if the constants of nature were even slightly different  $\implies$  the universe must be tuned specifically for life.



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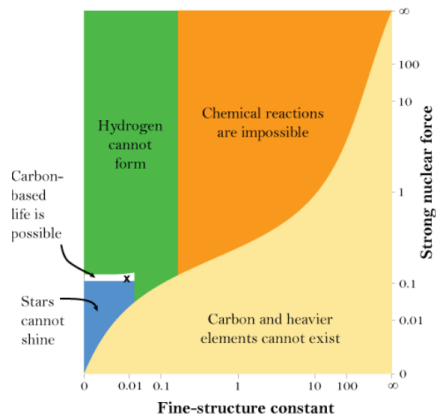
# Key Fine-tuned Constants

**Gravity / EM:**  $N = \frac{e^2}{4\pi\epsilon_0 G m_p^2} \sim 10^{36}$

- **Slightly weaker:** Stars like the Sun would be too cool; no supernovae, no heavy elements.
- **Slightly stronger:** Stars would have formed from smaller amounts of material, much smaller and more short-lived.

**Strong nuclear force / EM:**

- **Stronger:** H would have been burned in the very early universe.
- **Weaker:** inefficient heavy element production.



# Key Fin-tuned Constants

## UpDown Quark Mass Split:

- **Slightly different:** Protons and neutrons become unstable, much simpler and less complex universe.

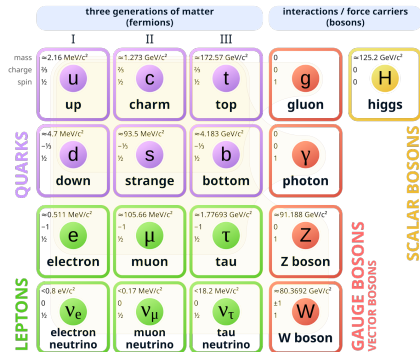
## Weak Force Strength:

- **Slightly weaker:** Too many neutrons in the early universe quickly forming  ${}^2_1\text{H}$ ,  ${}^3_1\text{H}$ , and  ${}^4_2\text{He}$ . Very little H would remain, no hydrogen-burning stars like the Sun.

**Cosmological Constant:**  $\Lambda \approx 10^{-122} \ell_P^{-2}$

- **Stronger:** Expansion fast enough to prevent stars from forming.

## Standard Model of Elementary Particles



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# Why is the Universe Fine-tuned?

## Main Explanatory Paths:

- **1. Multiverse (Anthropic Reasoning)** Billions of universes exist with random constants; we live in a rare one compatible with life. *"We observe this universe because we couldn't exist in any other."*
- **2. Physical Necessity** A deeper unified theory will fix all constants by necessity. No other values are possible.
- **3. Chance Fact** Constants simply have the values they have, with no deeper reason. Just luck.
- **4. Design Hypothesis (Philosophical)** The universe appears finely adjusted as if by intent - though this enters philosophical territory beyond empirical science.

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**Thank you**  
for your attention!