Field Manual of Fine-Tuning
Chapter Notes: Hierarchy of Fine Structure Constants

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Physics Covered
Fine Structure Constants, Galaxy Size, Nucleosynthesis, Stars

Previous Chapter:
This is chapter 1

Following Chapter:
Standard Model

Types of Fine-Tuning:
Multiple variations of fine structure constants: $\alpha_S^3 \sim \alpha_e^m$ for processes. Relationships between dimensionless constants.

Directly explored Fine-Tuned Parameters:

- $\alpha_e$: The Electric fine structure constant
- $\alpha_G$: Gravitational fine structure constant
- $\alpha_w$: Weak fine structure constant
- $\alpha_S$: Strong fine structure constant
- $S$: Photon-baryon ratio
- $m_p/m_e$: proton to electron mass ratio

Indirectly explored Fine-Tuned Parameters:

- $M_{star}/M_g$: Star mass over total galactic mass
- $t_{now}$: The current time
- $V_H$: The Higgs vacuum expectation value

Assumed Background:

- Stellar physics (supernovae, nucleosynthesis)
- Baryogenesis
- Bayesian/Frequentist probability
Outline of Chapter:

Statement of the question: What ranges of fine structure constants are allowed?

- What are fine-structure constants, and why are they important?
- Scales and fine-structure constants: how are they related.
- Relationships between fine-structure constants.
- What are the fundamental constants? Are fine-structure constants fundamental?
- Can the observed coincidences be explained by fundamental physics?

Types of Fine-Tuning:

- Coincidences and dependences on $\alpha_i$ ($i = e, s, g, w$).
- Selection effects and the weak anthropic principle.
- How many fine-tunings are there and which are the ones required for life.
- “Higgs mass is fine-tuned but not for anthropic reasons”.

Anthropic Constraints:

- Convective stars ($\alpha_g \sim \alpha_{e}^{20}$)
- Supernovae, $\alpha_g \sim \alpha_{w}^{4}$.
- Triple alpha coincide.
- Constraints on $\alpha_s$ and $\alpha_e$ from chemistry.
- Photon-to-baryon ratio ($S$): constraints at different times (before BBN, during radiation era, GUT epoch, ...).
- Is the photon-to-baryon ratio really fine-tuned? There seems to be a relatively large anthropic parameter space.
- The actual value of $S$ is $10^9$, which is very close to the saturation value ($\sim 10^{10}$).
- Matter density: for $\Omega \ll 1$ fluctuations freeze before structure formation, $\Omega \gg 1$ universe collapses.
- Amplitude of primordial fluctuations: $Q$ too small does not allow structures to form, $Q$ too large implies black holes instead of stars.
- Cosmological constant: if small galaxies cannot form, if too large fast cooling.
- “Clearly $\alpha_s$ is constrained”.

Coincidences:

- Proton to electron mass ratio.
- Dicke’s argument for the “golden age” of the universe.
- Number of stars in the universe as $\alpha_{g}^{-1/2}$.
- The mass of a typical MW-like galaxy is the same as the mass of the universe by a factor $\alpha_{g}^{2}$.
- $\alpha_{g}^{-1/4}$ roughly of the order of Peccci-Quinn scale. Is this a condition for axionic dark matter?
- $\alpha_{g}^{5/4}$ is the typical distance between stars (upper limit solar system size).
- $10^{-3}$ cm is an interesting scale: scale of $\Lambda$; scale of higher dimensions (??).
- Interesting link between Planck mass BHs and cosmological BHs.
- “Why is inflation so fine-tuned?”

Number of Dimensions:

- (Refer to Tegmark’s dimension diagram)
- In which sense is the number of dimensions fine-tuned?
- Is this a “normal” fine-tuning?
- Constraints do not apply to compactified dimensions.
- Time dimension appears to be constrained differently from space dimensions.
- Compactified time dimensions violates causality.
- Space dimensions may be closed in scales of $10^{100}$.

Parameter Space and Fine-Tuning:

- Vary multiple constants at a time may be problematic.
• We can’t have too many constraints or we wouldn’t have life at all.
• We could be (in the parameter space) in an island of life.
• We can only explore close to this island, but there may be other islands.
• Baby universe idea (Smolin) turns this around.

Philosophical Digression:

• “The key is the head of the snake” → higher dimensions at that scale?
• Carter’s argument on the rarity of life: $T$ much smaller than age of the universe implies life is abundant (Fermi paradox); $T$ much larger than age of the universe implies that we are just lucky.
• Would it be anthropically bad if life were abundant?
• Fine-tuning as a condition for complexity.