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: $\alpha_S^n \sim \alpha_e^m$ for processes. Relationships between dimensionless constants.

Directly explored Fine-Tuned Parameters:

- α_e: The Electric fine structure constant
- α_G: Gravitational fine structure constant
- α_w: Weak fine structure constant
- α_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 α_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 α_s and α_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 α_s is constrained".

Conicidences:

- 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 α_e^5.
- $\alpha_g^{-1/4}$ roughly of the order of Peccei-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 Λ; 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" $\rightarrow$ 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.