CENTER FOR SCIENCE & CULTURE | EVIDENCE OF DESIGN?

WHAT DOES IT MEAN THAT THE UNIVERSE IS FINE TUNED?

Guillermo Gonzalez
The Discovery Institute

Faith and Science
Krakow, Poland
June 1-3, 2023

Outline

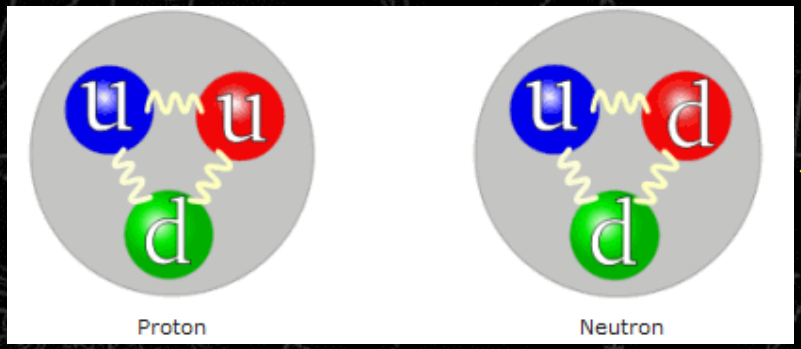
- What makes a universe life friendly?
- Physical laws, principles, and particles
- Fine tuning in physics and cosmology
- Examples of fine tuning
- What about the multiverse?
- Criticisms of the multiverse

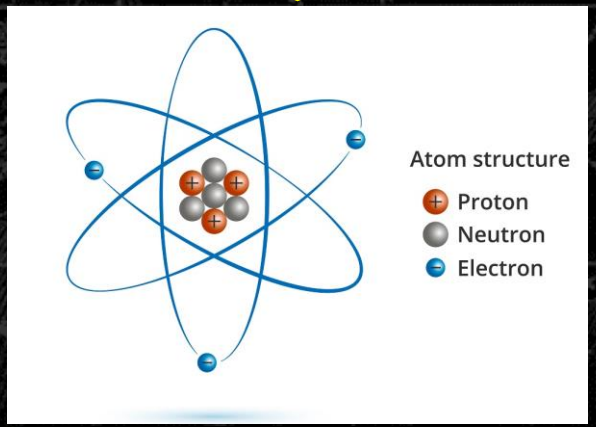
What Makes a Universe Life-Friendly?

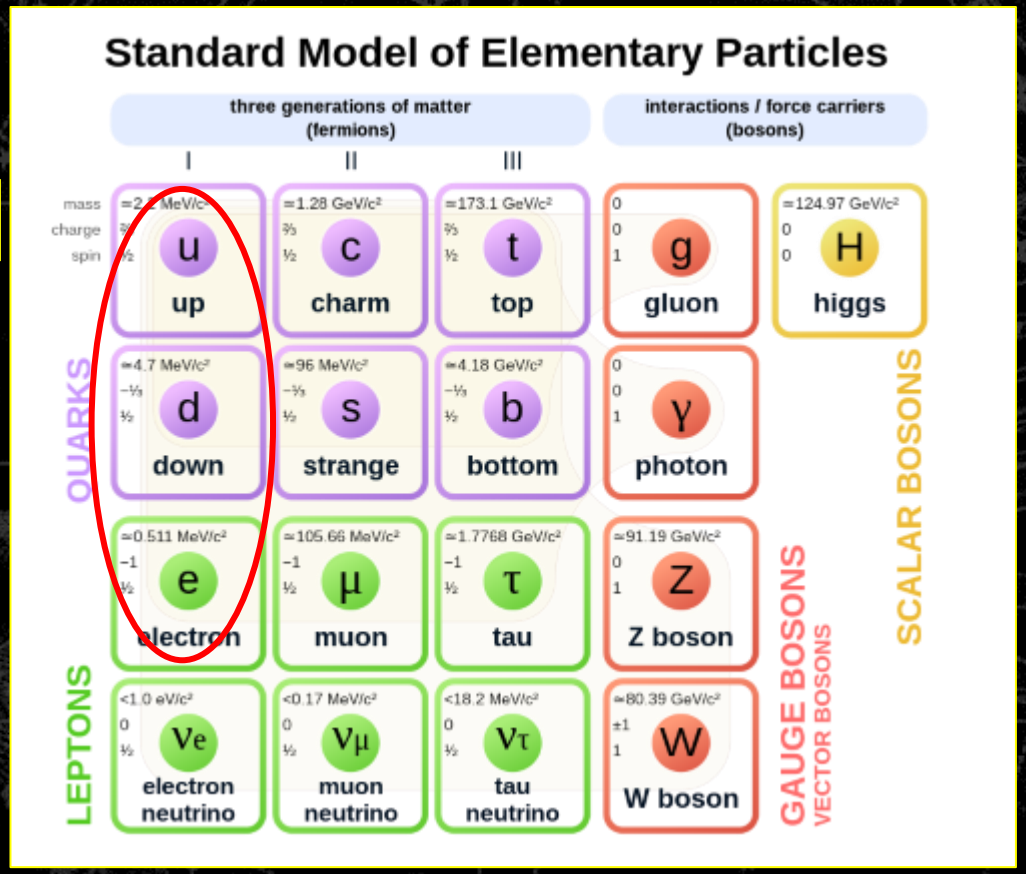
- Stable matter and interactions
- Law-like regularities
- Structures that last
- Complexity – structures built on structures
- Specific arrangements of matter
- → “Physical laws, principles and particles”

Physical Laws, Principles, and Particles

Need stable particles:

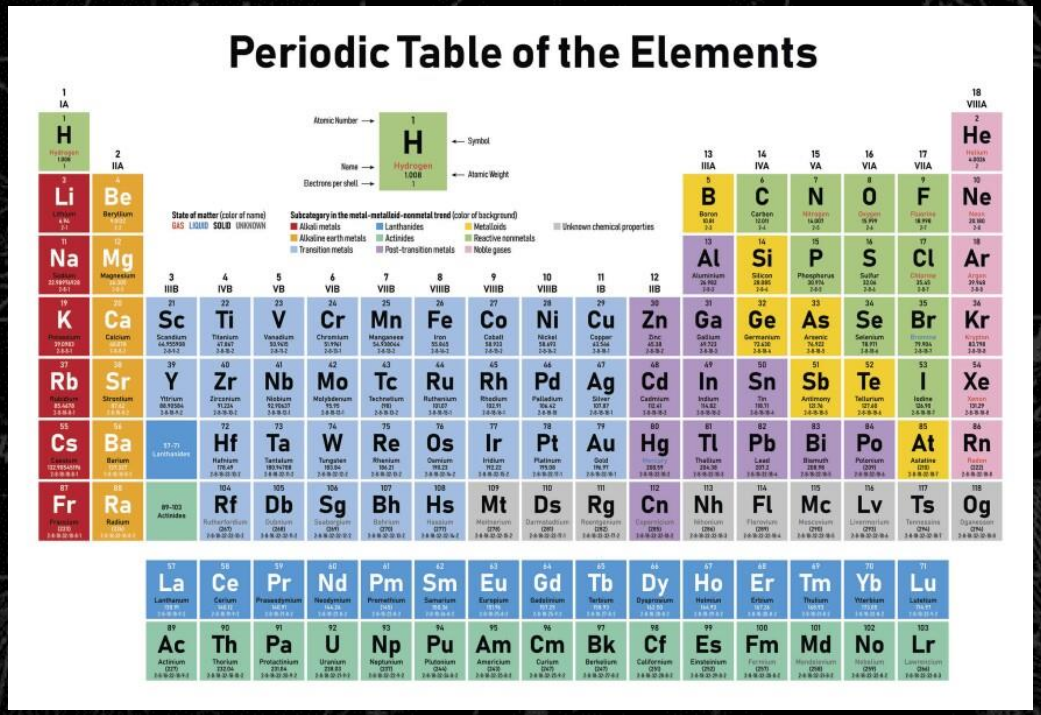




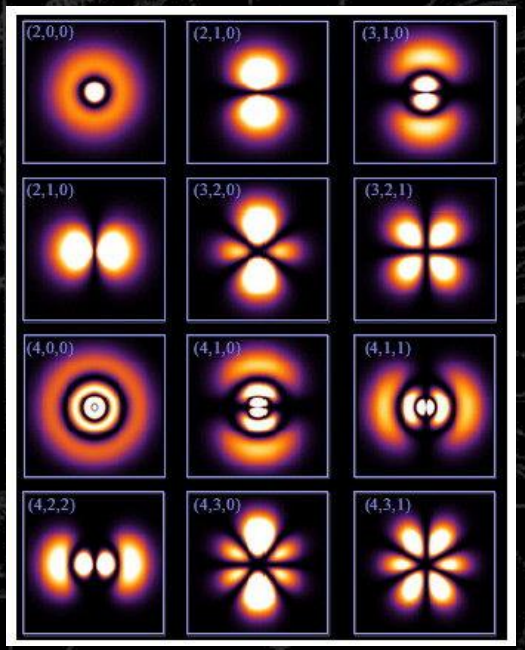


Physical Laws, Principles, and Particles

Need such things as the Pauli Exclusion Principle, Bohr quantization rules, electromagnetic force, and charged particles for atoms and the Periodic Table to exist.



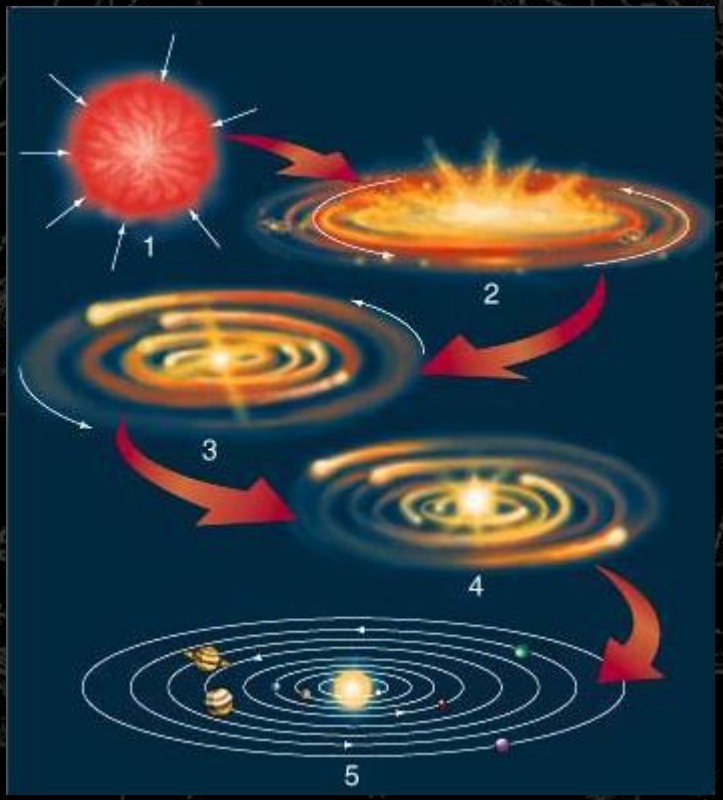
Hydrogen orbitals



Physical Laws, Principles, and Particles

Need such a thing as gravity acting on matter particles to form larger structures needed for life:

- Galaxies
- Stars
- Planets



What's Fighting Gravity?

1. Black holes – nothing
2. Planets – atoms (electromagnetic force)
3. Brown dwarfs, white dwarfs, neutron stars – quantum degeneracy pressure
4. Stars – thermal pressure (+nuclear reactions)
5. Planetary systems and disk galaxies – rotation
6. Globular clusters and elliptical galaxies – random motions
7. The universe – expansion

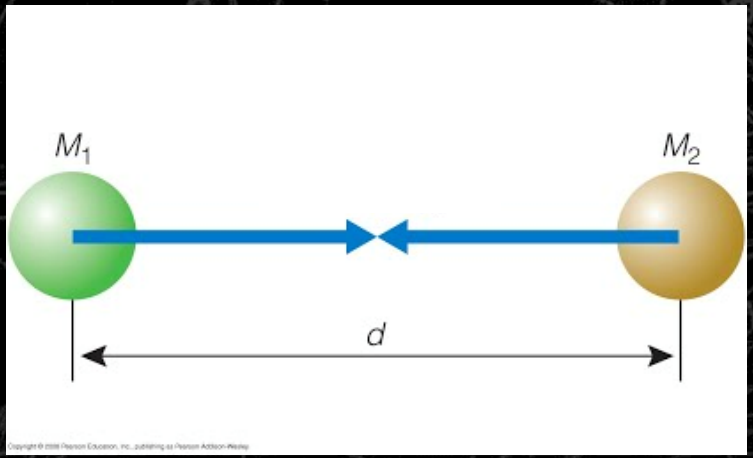
Physical Laws, Principles, and Particles

- Structures result from forces in equilibrium.
- Four forces:
  - -gravity
  - -electromagnetic (EM)
    - binds atoms
    - balances gravity in planets, stars
  - -strong nuclear
    - binds nuclei
    - powers nuclear reactions
  - -weak nuclear
    - protons ←→ neutrons, powers supernovae

Physical Laws, Principles, and Particles

Physical law: the Newton's law of gravity:

$$F_g = \frac{GM_1M_2}{d^2}$$



"G" in the equation is not determined by the equation. Must get the law and the physical constant value by observing nature.

Do the Physical Laws Explain Themselves?

Do the rules of chess explain why the rules are what they are?

What Makes our Universe Life-Friendly?

- Stable matter and interactions
- Law-like regularities
- Structures that last
- Complexity – structures built on structures
- Specific arrangements of matter
- → “Physical laws, principles and particles”
- → “Fine Tuning”

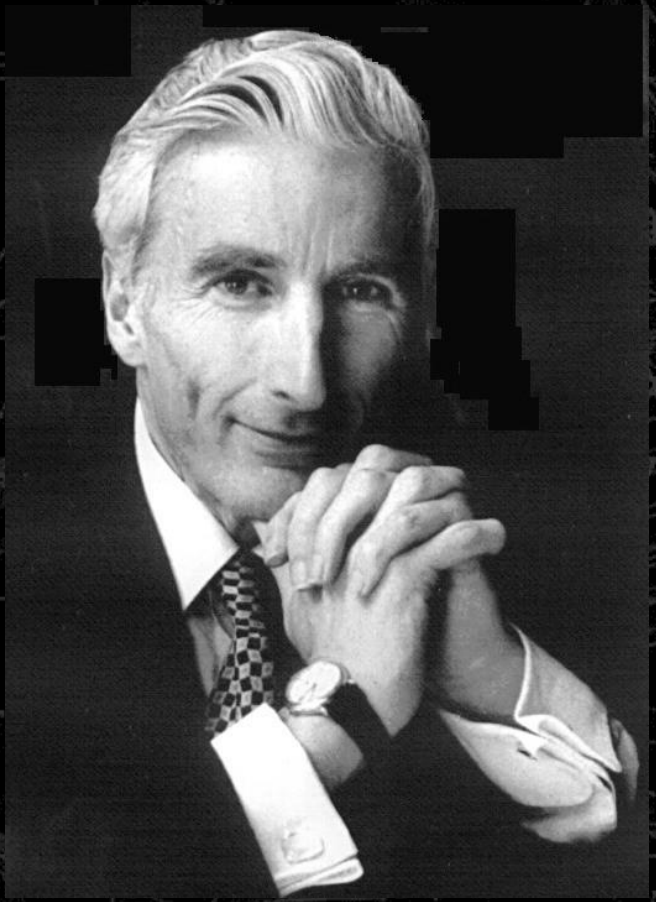
What is Fine Tuning?

If universe's properties were changed very slightly from what they are, complex life would be impossible. These properties must be fixed within a very narrow range for our universe to be life-friendly (habitable).

A Fine Tuned Universe

"The possibility of life as we know it depends on the values of a few basic physical constants and is, in some respects remarkably sensitive to their numerical values. Nature does exhibit remarkable coincidences."

-MJ Rees, Cambridge University

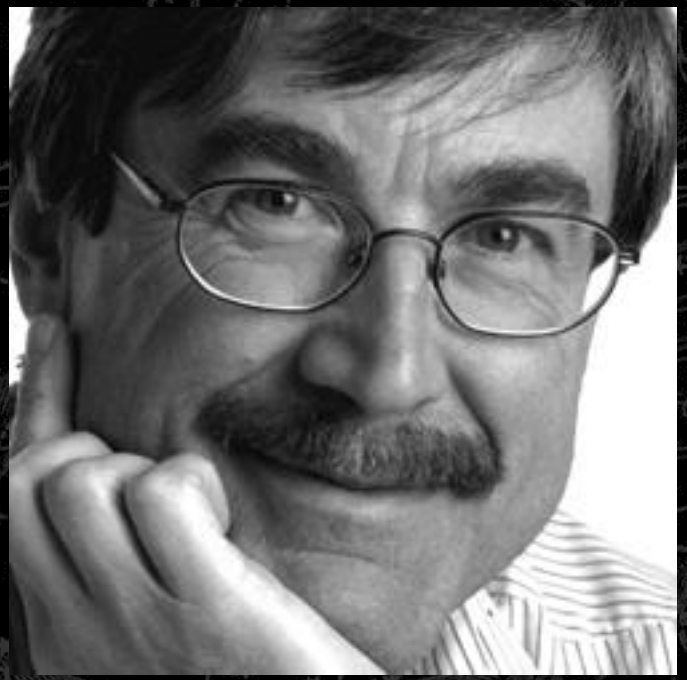


A Fine Tuned Universe

"The present arrangement of matter indicates a very special choice of initial conditions."

"There is now broad agreement among physicists and cosmologists that the Universe is in several respects 'fine-tuned' for life".

-Paul Davies

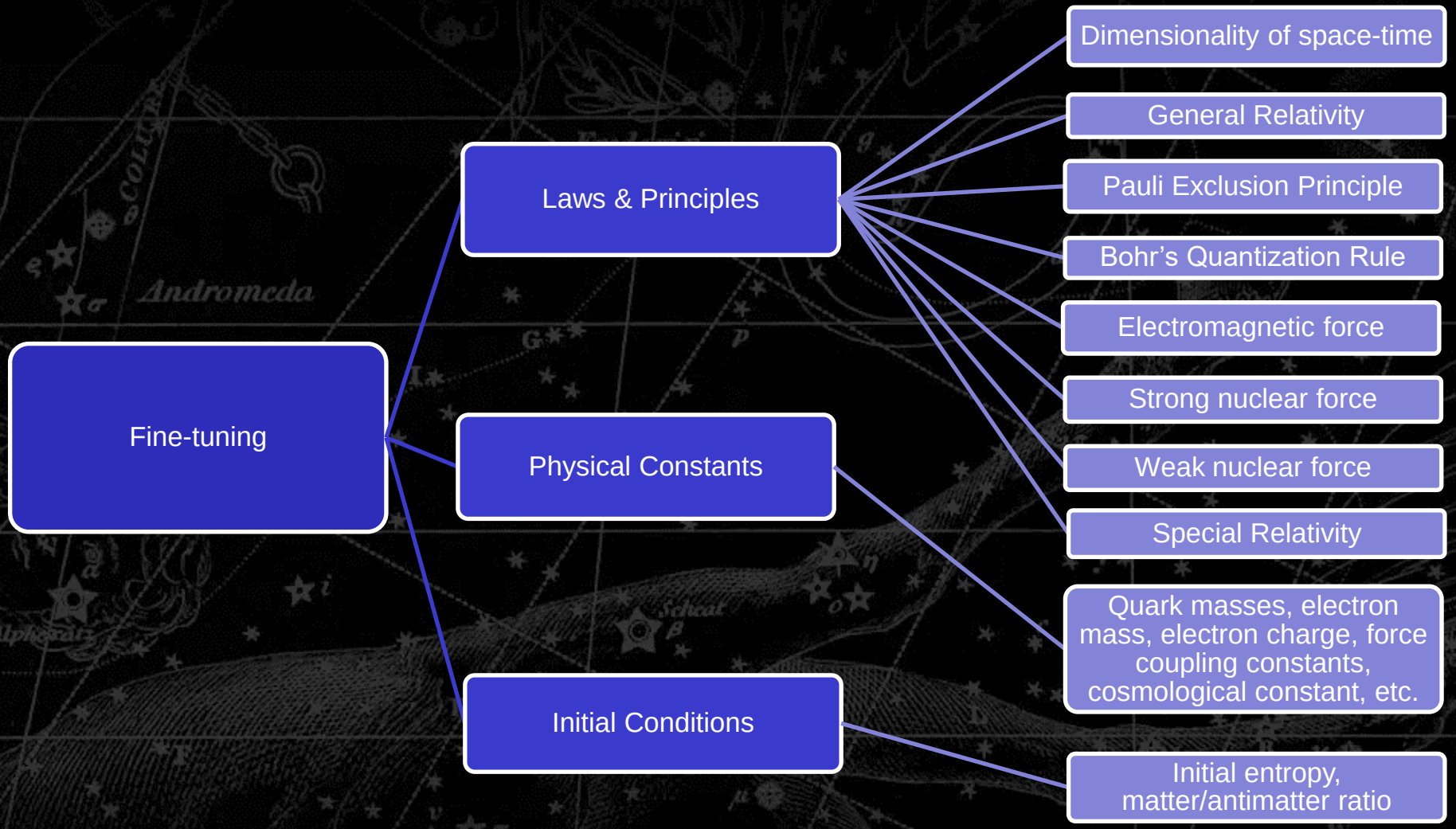


A Fine Tuned Universe

"The remarkable fact is that the values of these numbers [i.e. the constants of physics] seem to have been very finely adjusted to make possible the development of life."

-Stephen Hawking

Three Types of Fine Tuning



Fine Tuning Must be Evaluated Locally

Type of host galaxy

Location in host galaxy

Distance from host star

Age of planet

Mass of planet

Asteroid belt in system

Composition of planet

Planet atmosphere

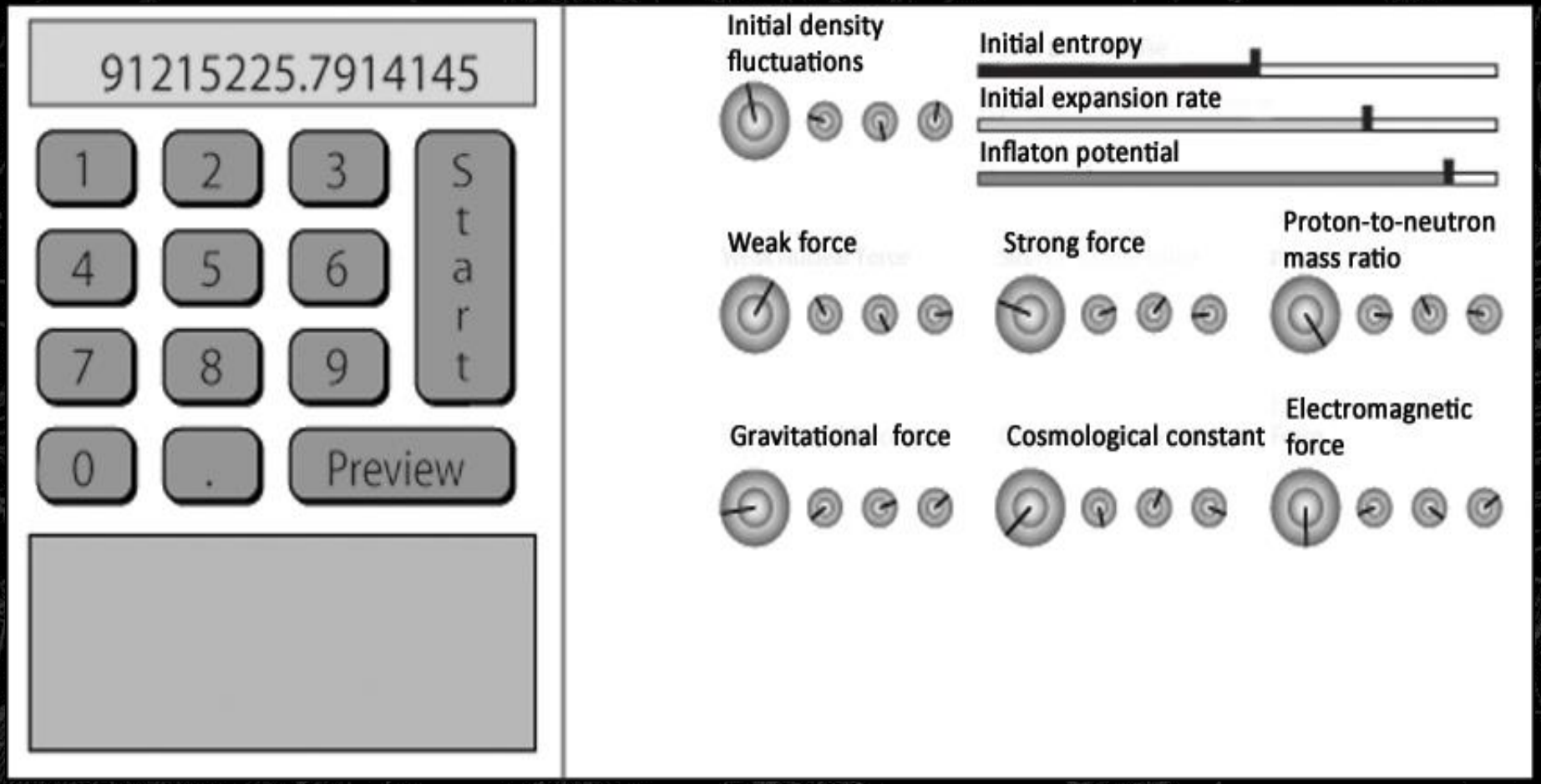
Presence of a moon

Amount of water on planet

Type of host star

Other planets in system

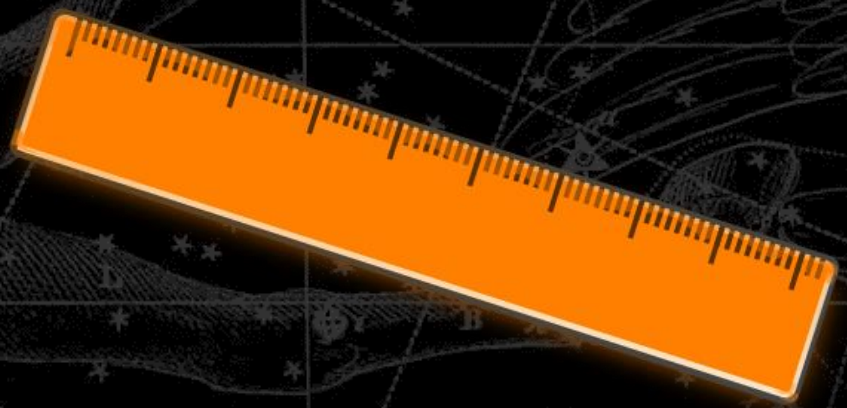
Universe Creating App



Defining Fine Tuning more Carefully

Ruler analogy:

- 10 cm length,
- Precision (error) of construction is 0.01 cm,
- Relative precision is 0.01 cm / 10 cm = 0.1%,
- We want dimensionless quantities when talking about fine tuning.



Defining Fine Tuning more Carefully

How do we define the comparison range for fine tuning of constants to get dimensionless ratios?

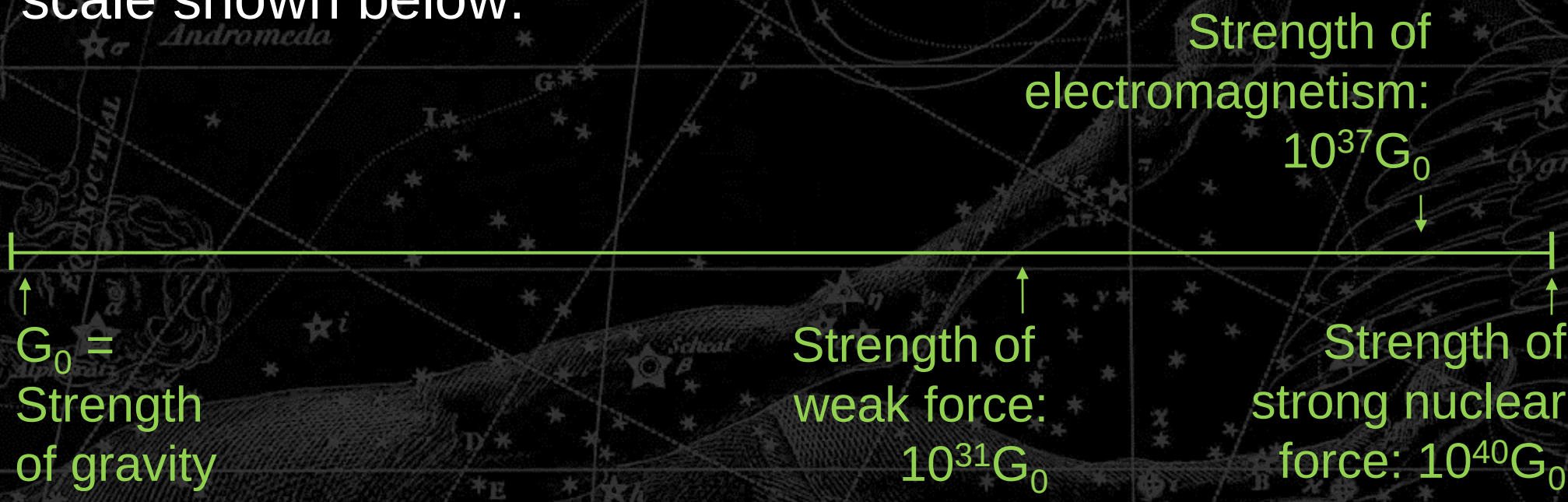
- Lack prior knowledge of the permitted range of the constants and initial conditions; they range over infinity – “normalization problem.”
- Restrict the comparison range to physics “epistemically illuminated” range – where particle physics and cosmology standard models are applicable.

A Sense of Big Numbers

- Human body:
  - 10^{13} cells
- The number of seconds in the entire history of the universe:
  - 10^{17}
- Subatomic particles in the known universe:
  - 10^{80}
- Having a precision of one part in 10^{30} is like firing a bullet and hitting an amoeba at the edge of the Solar System.

Dimensionless Force Strengths Examples

Set the comparison range of force strengths in nature to be $10^{40}G_0$. This "epistemically illuminated range" is a lower limit on the actual comparison range. Logarithmic scale shown below:



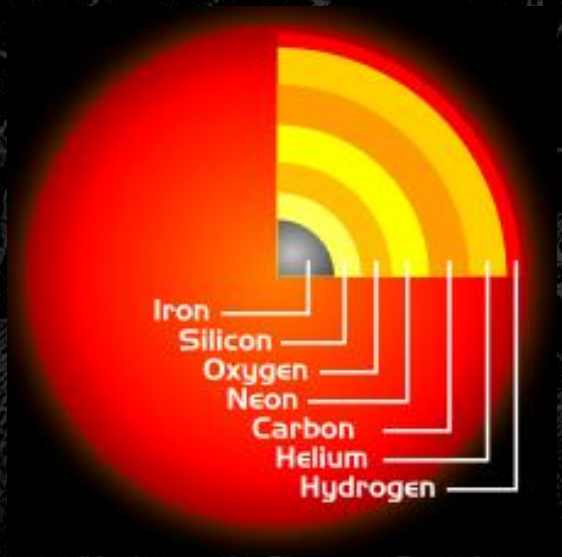
thanks to Robin Collins

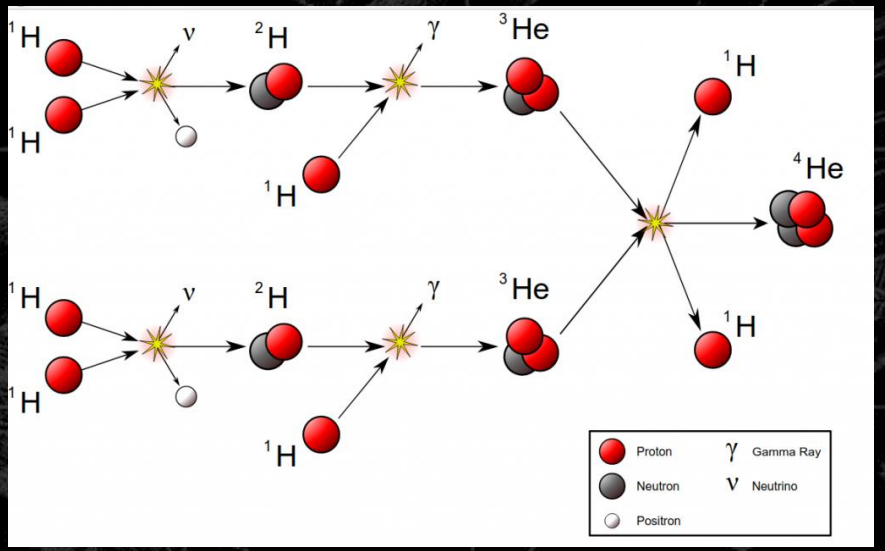
Examples of Fine Tuning

Example: Stars

Stars are needed by life for two reasons:

- Synthesize the elements beyond H, He (Big Bang),
- Provide stable, long-lasting energy of the right form to keep a planet's surface warm and power life's chemistry.

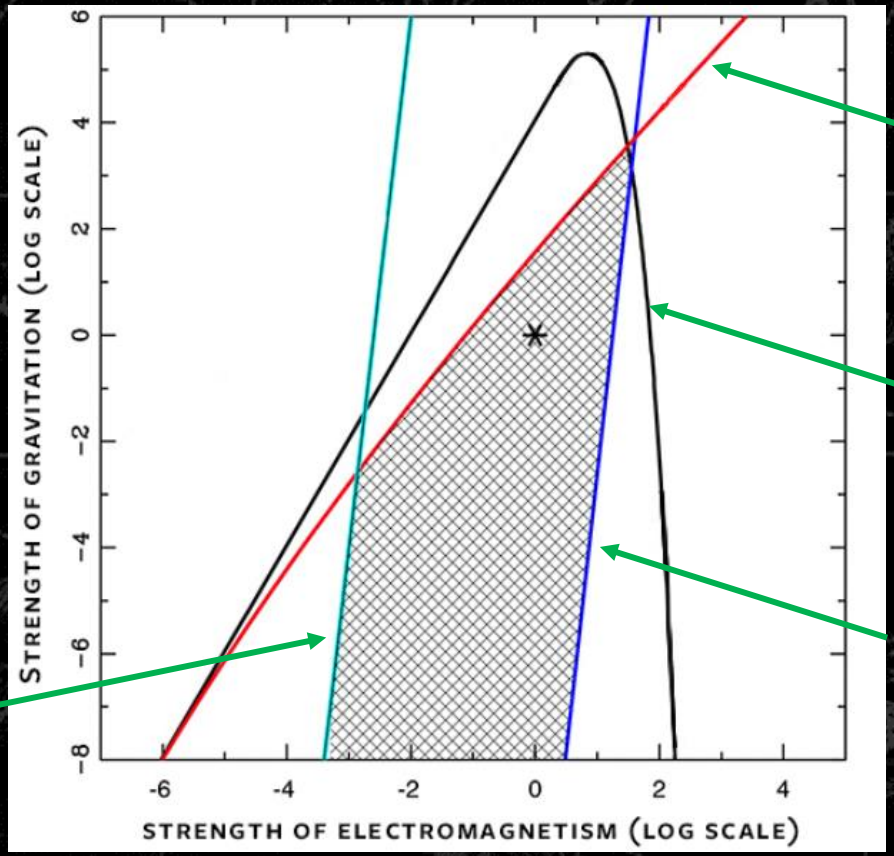




Example: Stars

Gravitational and EM force limits for stars:

$G/G_0 < 3500$



stellar lifetime

undergo fusion

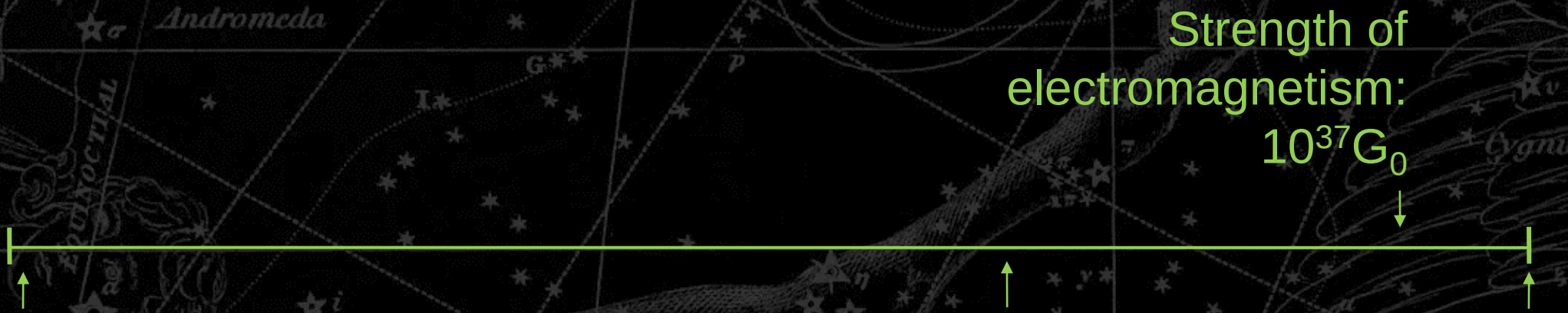
hot enough

smaller than host galaxy

Fred C. Adams (2017)

Gravity Example

Maximum value of gravitational force that allows the kinds of stars needed for life to exist ~ 10^4 G_0. Its degree of fine-tuning is $(10^4\text{-}1) \times G_0/10^{40}G_0 \sim 1/10^{36}$.



thanks to Robin Collins

Fine Tuning Analogy

Radio dial stretched across the universe

You better tune your dial to the first
Ångstrom if you want to tune gravity for life!

(Diagram not drawn to scale!)

+15 billion light years

EM Force Example

Maximum value of electromagnetic force that allows periodic table of sufficient length for life is 14 × $10^{37}G_0$. Its degree of fine-tuning is (14 -1) $10^{37}G_0/10^{40}G_0$ ~1%.

thanks to Robin Collins

Weak Force Example

If weak force is decreased by a factor of 30, initial neutron/proton ratio ~ 0.90, leading to nearly pure helium universe. Degree of fine-tuning is ~ $1/10^9$.

thanks to Robin Collins

The Cosmological Constant (Dark Energy)

"Our current understanding of gravity and quantum mechanics says that empty space should have about 120 orders of magnitude more energy than the amount we measure it to have. That is 1 with 120 zeroes after it! How to reduce the amount it has by such a huge magnitude, without making it precisely zero, is a complete mystery. Among physicists, this is considered the worst fine-tuning problem in physics."

-Lawrence Krauss

The Cosmological Constant Problem 1

$$\tilde{R}_{\mu\upsilon} - \frac{1}{2} R \tilde{g}_{\mu\upsilon} + \Lambda \tilde{g}_{\mu\upsilon} = \frac{8\pi G}{c^4} \tilde{T}_{\mu\upsilon}$$

Effective cosmological constant

The cosmological constant, Λ, is the energy density of the vacuum. The value of Λ predicted by quantum field theory is ~10^{120} times larger than the observed value. Vacuum energy of various particle fields must cancel to 1 part in 10^{120}.

Fine Tuning of the Cosmological Constant 2

The energy density due to Λ, ρ_Λ, must be fine tuned to ~1 part in 10^{90} for a life-friendly universe.

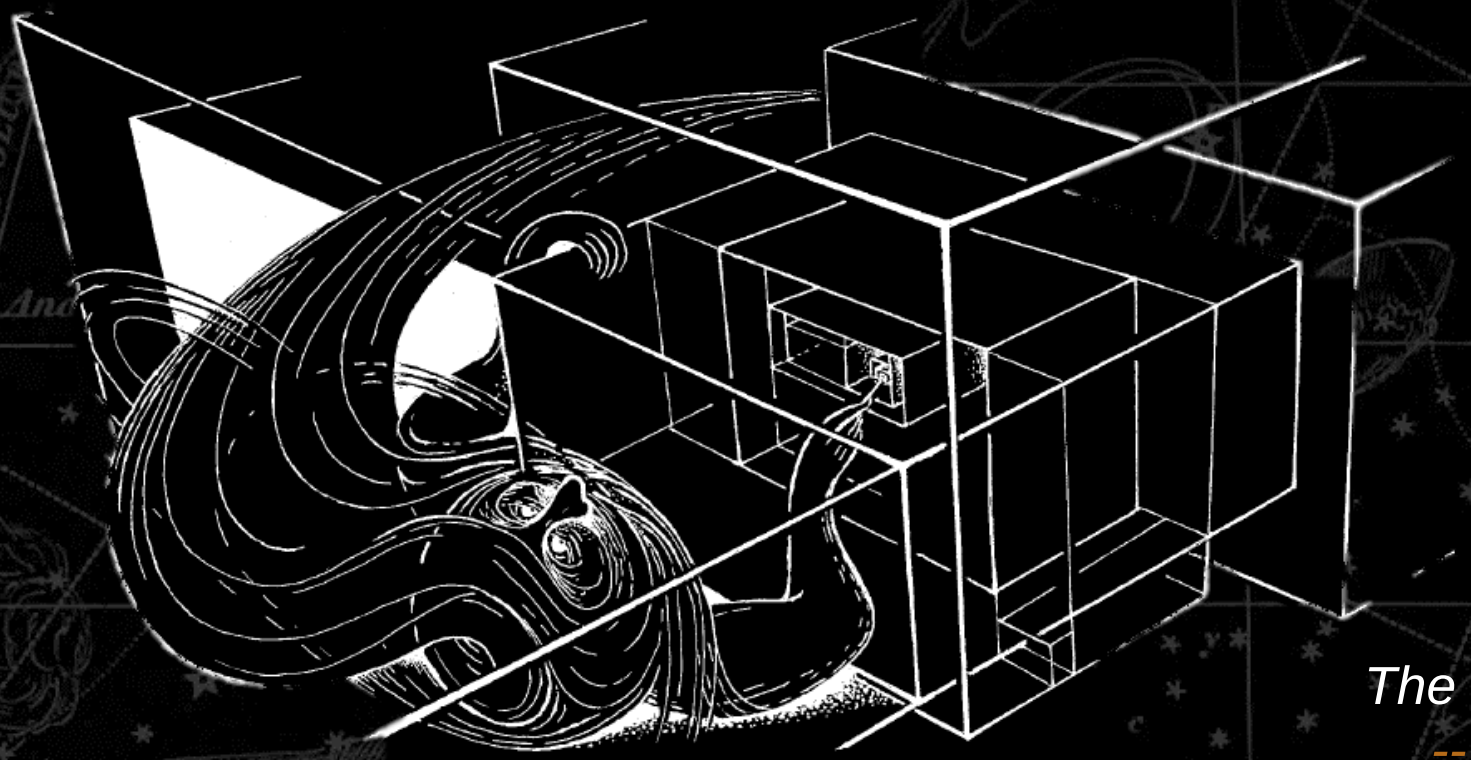
1. If $\rho_\Lambda/\rho_{Planck} < -10^{-90}$, universe collapses after 1 sec.
2. If $\rho_\Lambda/\rho_{Planck} > 10^{-90}$, structure formation stops after 1 sec.

This is $10^{-90} / 10^{-120} = 10^{30}$ times greater than the observed value.

The Initial Entropy of the Universe

- Initial entropy of the universe is far smaller than it needs to be for life.
  - Need initially low entropy (smoothly distributed matter) in order to have enough free energy and form structures.
- For life, at most you just need a patch of low entropy order containing one galaxy. The rest of the universe could be high entropy (e.g., black holes).
- Penrose #: Suppose low entropy part of universe with life is only 10% of the universe. What are chances that the rest of universe is as low entropy as the 10%?
  - 1 part in 10^10^123

The Initial Entropy of the Universe

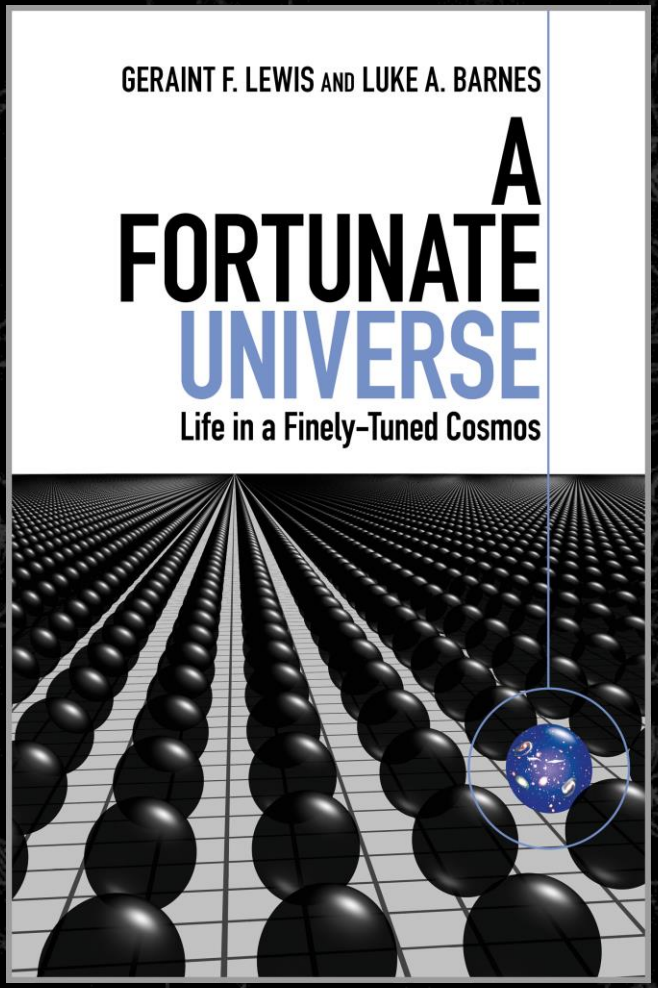


The Road to Reality
-- Roger Penrose

Fig. 27.21 Creation of the universe: a fanciful description! The Creator's pin has to find a tiny box, just 1 part in $10^{10^{123}}$ of the entire phase-space volume, in order to create a universe with as special a Big Bang as that we actually find.

Recent Work

- Best recent (2016) book on fine tuning.
- Many other examples of fine tuning.
- Geraint is an atheist.
- Barnes is a theist.



Single Universe Probability

- A Bayesian formulation: epistemic probability of our universe from fine tuning*:

$$P\left(E \,\middle|\, T \,\&\, B\right)$$

"probability of the evidence E, given a theory T and background knowledge B." E is our Life Permitting Universe (LPU).

- Compare two theories:
  - Naturalistic single universe hypothesis (NSU)
  - God/Theism (G)

*Following Barnes, Luke A. "A reasonable little question: A formulation of the fine-tuning argument." *Ergo* (2020): 1220-1257.

Single Universe Probability

- With the standard models of particle physics and cosmology forming B*:

$$P\left(LPU \,\middle|\, NSU \,\&\, B\right) < 10^{-136} \ll 1$$

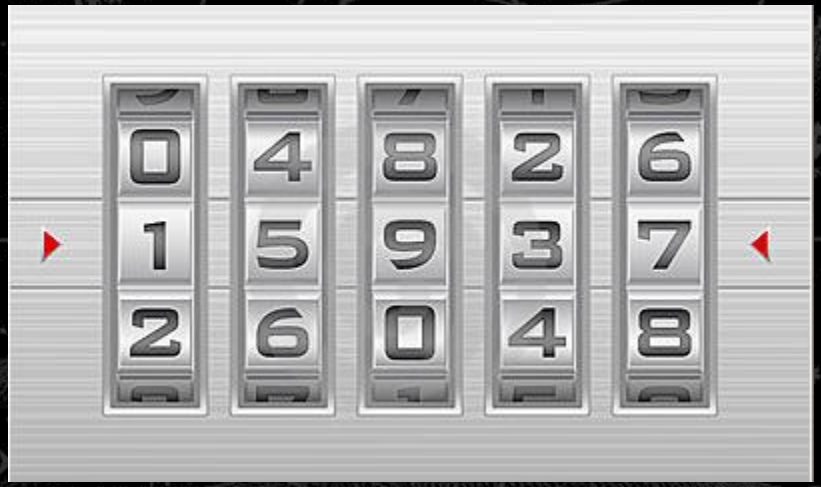
$$P\left(LPU \,\middle|\, G \,\&\, B\right) = ?$$

- Can the naturalist come up with positive reasons to make the probability of the God hypothesis < 10^{-136}?
- There are plausible reasons for God to create a life-permitting universe:
  - the moral worth of embodied moral agents.

*Based on just 3 well-established cases of fine tuning of fundamental constants: cosmological constant, Higgs vev, up-quark, down-quark, electron Yukawa couplings (Barnes 2020).

Single Universe Probability

The conditions that allow for a life-permitting universe are highly improbable if you only have one try.



The Multiverse to the Rescue?

"The advantage of the multiverse theory is that it provides a natural and easy explanation of why the universe is so uncannily fine-tuned for life: observers arise only in those universes where, like Goldilocks' porridge, things are by accident "just right." Bio-hostile universes overwhelmingly proliferate, but they are by definition sterile, so they go unseen. The disadvantage of the multiverse theory is that it invokes an overabundance of entities, most of which could never be observed, even in principle. This profligacy strikes many people as an extravagant way to explain bio-friendliness. The theory is also very hard to test. Observers are treated simply as selection agents, so the mysterious comprehensibility of the universe (to the human mind at least) is left unexplained. The multiverse does not provide a complete account of existence because it still requires a lot of unexplained and very "convenient" physics to make it work. For example, there has to be a universe-generating mechanism, quantum mechanics has to describe everything, and unified laws of some sort (such as those that arise from string/M theory) have to be simply accepted as "given." … Some sort of ingenious selection still has to be made, not of a universe but of a multiverse. The problem of existence has therefore not gone away, but only been shifted up one level.

-*The Goldilocks Enigma*, Paul Davies

The Multiverse – Criticisms

1. Is it Science?
   - Best case: a well-tested theory of our universe predicts universe creating mechanism: inflation?, string/M-theory?
   - These theories require fine tuning themselves.
   - Inflation has some observational support, but string theory is more speculative.
2. Already (indirectly) falsified
   - Observed value of Λ is 10^{30} times smaller (10^{-120}) than maximum value required for universe to be life-friendly (10^{-90}).
   - Initial entropy of universe was much smaller than it needed to be to contain observers:
     - Typical universe in the multiverse with observers is much smaller.
     - Extreme case: Boltzmann Brain problem.

The Multiverse

Small universes are more probable.

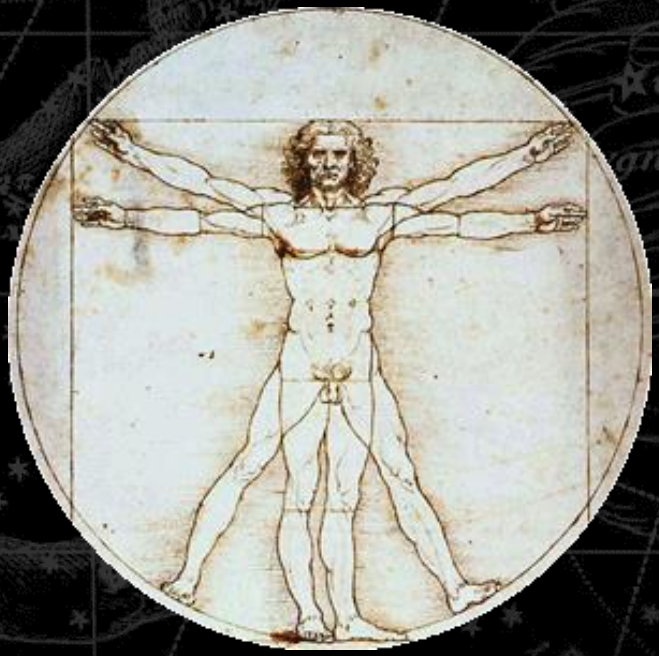
You are here.

The Multiverse – Criticisms

3. Laws and constants are constant
   - Constants measured to be constant: G, fine structure, m_e/m_p
   - Much more constant than they need to be for life.
4. Violates Occam's Razor in the extreme
   - You have to posit near infinite/infinite unseen universes to explain our one universe.
5. Other fine tuning is not explained:
   - Fine tuning for discoverability (Robin Collins),
   - The Privileged Planet thesis (Gonzalez/Richards).
6. The Weak Anthropic Principle is weak:
   - It's tautological (only observe what we observe),
   - It doesn't actually provide an explanation.

What is the Weak Anthropic Principle?

- The Weak Anthropic Principle (WAP) is the recognition that our very existence constrains the properties of the universe we observe to be those that allow our existence.
- We can only observe ourselves to be living in a life-permitting universe!
- Does not explain why there exists a life-permitting universe in the first place.



Why Can't the Anthropic Principle Explain Us?

- Quasars were discovered to be very distant in 1963 from their large redshifts.
- Why are quasars so luminous?
- Wrong answer: because if they weren't, we wouldn't be able to see them. If we see an object in the distant universe, then it must be very luminous.
- Right answer: Quasars are powered by the gravitational energy released by matter falling into a supermassive black hole.

Why Can't the Anthropic Principle Explain Us?

- Pointing out that the universe must have certain properties or we wouldn't be able to see it does not explain why such a universe exists.
- The question is not, Why do we see a universe consistent with our existence? The question is, Why does a universe hospitable to complex life exist (especially a fine tuned one)?

Summary

- There are multiple strong examples of cosmological fine tuning.
- The probability of our life-friendly universe arising from chance is very small (<< 10^{-136}).
- The multiverse fails to explain our universe on multiple counts.
- Theism is more probable than naturalism in explaining the fine tuning of our universe.