Do we live in the Best of all Worlds?

The fine tuning of the constants of Nature

Thomas Naumann    Deutsches Elektronen-Synchrotron    DESY
The Best of all Worlds?

G.W. Leibniz 1710: Théodicée

1. Part § 8: **Unify** and **Harmonise** science, metaphysics and theology:

„this supreme wisdom, united to a goodness that is no less infinite, cannot but have chosen the best.

... if there were not the best among all possible worlds, God would not have produced any...

... there is an **infinitude of possible worlds** among which God must have chosen the best, since he does nothing without acting in accordance with supreme reason...“


Had God a choice?

- Einstein to his assistant Banesh Hoffmann: *When I am judging a theory, I ask myself whether, if I were God, I would have arranged the world in such a way.*

- Einstein to his assistant Ernst G. Straus: *What really interests me is whether God could have created the world any differently.*

Leibniz‘ question whether we live in the ’Best of all Worlds‘ in physics
fine tuning or accident?

size + distance Sun - Earth - Moon:
exact coverage at eclipse

max angular size:
0.558°  0.545°
Had God a choice?

What if?
Fine tuning: What if?

- nr of dimensions $\neq 3$ ?
- cosmos not flat ?
- cosmological constant not so tiny?
- matter = antimatter ?
- masses: quarks: down heavier than up ?
- no Higgs ?
- electron lighter, heavier ?
- forces: other symmetries ?
- other strengths ?
- n-n binding attractive ?
- deuterium bottleneck too narrow ?
- stellar nucleosynthesis: no $3^{\alpha} + 3^{\alpha}$ ?
Dimensions

Life in 2 dimensions - topologically not connected:
crossing nerves, blood vessels?
digest through one-dimensional boundaries?

Hawking's two-dimensional dog

2 bodies in 4 dimensions

P. Ehrenfest 1917: scattering of light on heavy mass:
particle is either absorbed or escapes to infinity
no stable orbits of planets and classical atoms!

Max Tegmark, Class. Quantum Grav. 14 (1997) 69

also in quantum mechanics no stable atoms!

Matter : Antimatter

after Big Bang:
\[ \gamma \rightarrow q \bar{q}, e^- e^+ \]

now:
\[ n_b / n_\gamma \sim 10^{-9} \]

10.000.000.001 - 10.000.000.000

Do we live from an accident?
\[ n_{mat} / n_\gamma = 0 : \text{light only} \quad >10^{-6} : \text{collapse} \]

matter-antimatter asymmetry if:
- cosmos out of thermal equilibrium
- baryon number violated (proton decay)
- CP violation

Andrei Sakharov
Cosmic Inventory
Fine tuning of scalar fields

Inflation - Dark Energy - Higgs - Gravitation

- flat Universe:
  \[ \Omega_k = 0.001 \pm 0.006 \]
  Why?

Dicke 1961, Weinberg 1987, antropic argument on \( G_N, H_0, \Omega; \Lambda \):

- too little inflation:
  - fast recollapse, no time for life

- too much inflation + Dark Energy:
  - no formation of galaxies, stars + life

Fine tuning of \( \Lambda \):

- to Higgs vacuum: \( 10^{52} \)
- to Planck mass: \( 10^{120} \)

\[ \Omega = \rho / \rho_{crit} = 1 \]
masses

• proton stable, neutron decays
  - \( n \rightarrow p \ e^- \ \nu_e \) since \( m_n - m_p = 1.3 \text{ MeV} \approx 1\% \ m_{n,p} \) as
  - quark mass: \( m_d - m_u \approx 3-4 \text{ MeV} \)

• what if \( m_u > m_d \):
  - proton decays: \( p \rightarrow n \ e^+ \ \nu_e \), annihilation \( e^+ e^- \rightarrow \gamma \gamma \)
  - deuteron unstable: \( d \rightarrow 2n \ e^+ \ \nu_e \) as
    \[ m_p - (m_n + m_e) > 2.2 \text{ MeV} = E_b^d \]

• cosmos would be neutral:
  only neutrons, photons + neutrinos
  no protons + electrons,
  no atoms, no chemistry, no life !
The Best of all Worlds

Einstein: Had God a choice?
Fine tuning: What if?

• nr of dimensions

• content of cosmos \( \Omega_{\text{tot}} = 1, \Omega_k = 0; \Lambda \sim 10^{-120} \cdot m_{\text{Pl}}^4 \)

• matter-antimatter \( n_{\text{bar}}/n_{\gamma} \sim 10^{-10} \) - otherwise only light or collapse

• symmetries of forces electr., weak, strong, gravity

• strengths of forces \( G_N/\alpha \), \( G_F \)

• masses \( e, q \) - otherwise no (heavy) elements

• nuclear binding - otherwise no atoms, Universe neutral!

many constants fine-tuned to \( 10^{-270} \) to \( 10^{-120} \! \\
our Universe EXTREMELY improbable!
Antropic Principle
A physicist talking about the anthropic principle runs the same risk as a cleric talking about pornography:

No matter how much you say you are against it, some people will think you are a little too interested.
Antropic Principle


The existence of physicists ... [is] sufficient to demand that ... relations between the three numbers \([G_N, H, \Omega]\) be satisfied.

J.D. Barrow and F. Tipler, 1986

The Anthropic Cosmological Principle
Man not only fits to the Universe.
The Universe also fits to Man.

S. Hawking, A Short History of Time, 1988

The remarkable fact is that the values of these numbers seem to have been very finely adjusted to make possible the development of life.

S. Weinberg 1987: Antropic argument for cosmological constant

S. Weinberg, Living in the Multiverse, 2007

Applied to the string landscape, the Antropic Principle "may explain how the constants of nature that we observe can take values suitable for life without being fine-tuned by a benevolent creator."
Antropic Principle: Criticism

We only have one Universe.

tautology, causal circle: We only observe Universes that allow an observer.

no prediction: only postdiction

no science: no repeatable experiments
fundamental parameters not derived from first principles

what is tuned: laws, fundamental and environmental parameters?
Universe - Multiverse
Instead of a **Universe** with a single law of physics operating everywhere we are discussing an eternally existing self-reproducing **Multiverse** which consists of many different parts where **all possibilities** can be realized.
Universe - Multiverse

- **Kepler**, *Mysterium Cosmograficum* + *Harmonices Mundi*: orbits of 5 known planets behave like spheres in & around **5 Platonic Solids**
  
  4+1 building blocks of Cosmos:
  tetrahedron, octahedron, cube, icosahedron; dodecahedron (ether, quintessence)

- two ways out of the Mysterium - **both** were true:
  - statistical: more planets + planetary systems
  - fundamental: search for underlying law - from Kepler to Newton!

- **Today**: inflation and landscape
  - statistical: \(10^{500}\) universes - **Multiverse**
  - fundamental: Superstrings

- **Aristotle**: * Physica \(\rightarrow\) Metaphysica*

- **Today**: Universe \(\rightarrow\) **Multiverse**
  Physics of our Meta-Physics
  Best of all Worlds in a positive sense

Raphael: The School of Athens
Plato and Aristotle
Einstein asked whether God had a choice and could have made the World any differently:

• Fine tuning of parameters
  • Antropic principle
  • Multiverse

100 years later still burning questions of physics!