



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:

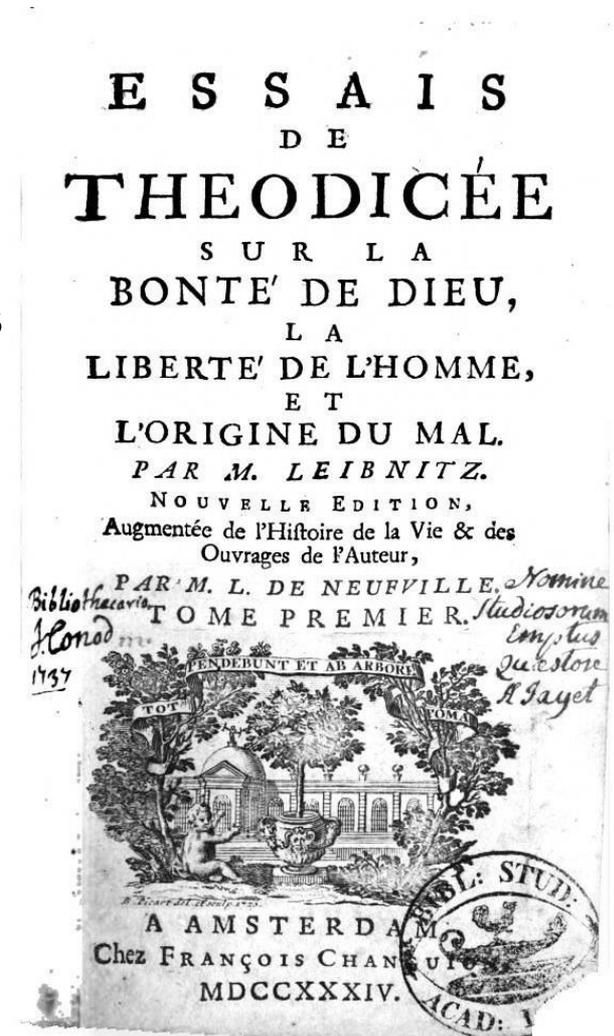
„this supreme wisdom, united to a goodness that is  
no less infinite, **cannot but have chosen the best.**

... 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...“

Gottfried Wilhelm Leibniz: Essais de théodicée sur la bonté de Dieu,  
la liberté de l'homme, et l'origine du mal. Mortier, Amsterdam 1710.

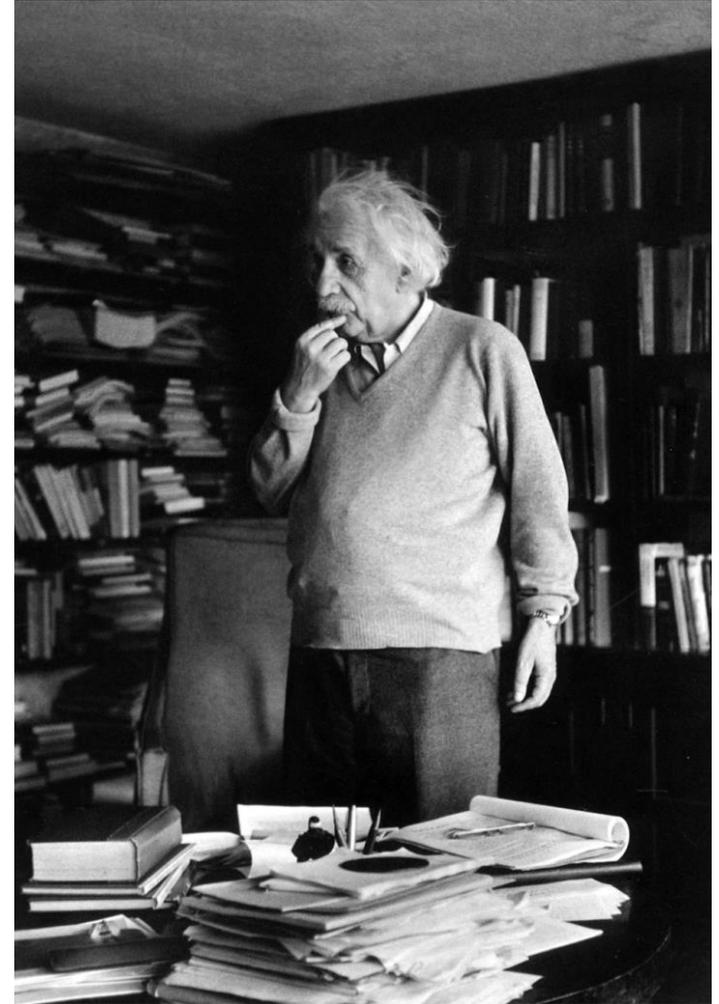
Essays on the Goodness of God, the Freedom of Man and the Origin of  
Evil. Translated by E.M. Huggard from C.J. Gerhardt's [Edition](#) of the  
Collected Philosophical Works, 1875-90.



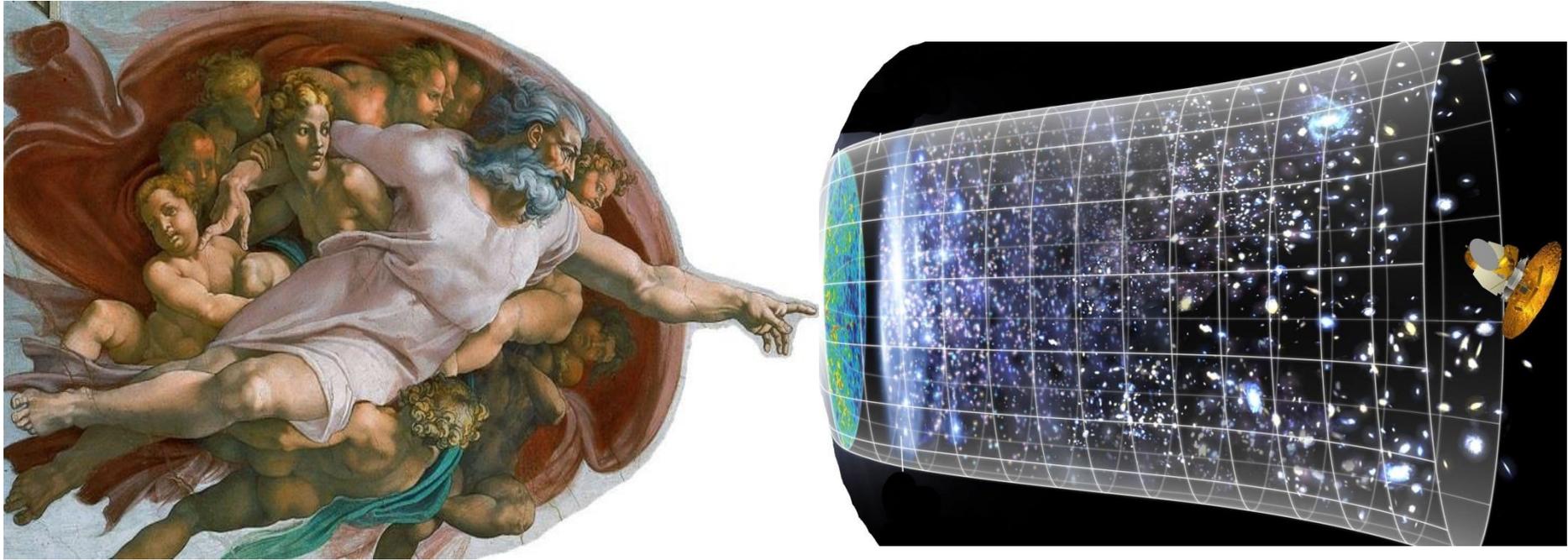
# Had God a choice ?

- 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



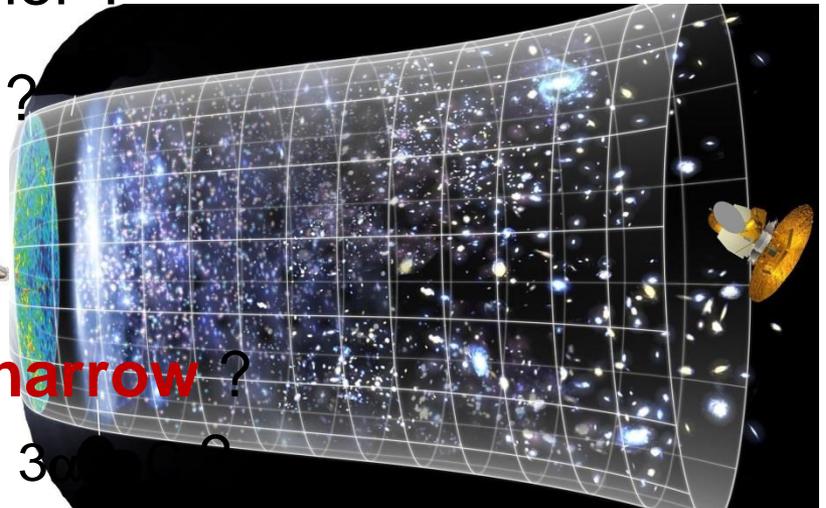
# Had God a choice ?



**What if...?**

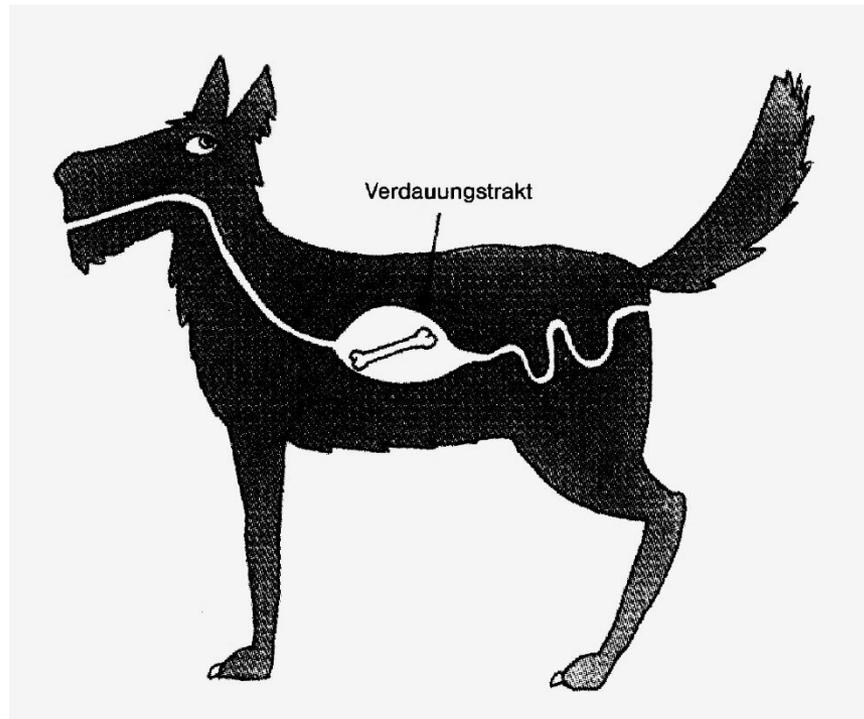
# Fine tuning: What if?

- nr of **dimensions**  $\neq 3$  ?
- **cosmos not flat** ?
- **cosmological constant** not so tiny?
- matter = **antimatter** ?
- **masses: quarks**: down heavier than up ?
- no **Higgs** -  $m_e = 0$  ?
- **electron** lighter, heavier ?
- **forces**: other **symmetries** ?
- other **strengths** ?
- **n-n binding** attractive ?
- **deuterium bottleneck too narrow** ?
- stellar **nucleosynthesis**: no 3 $\alpha$  ?



# Dimensions

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

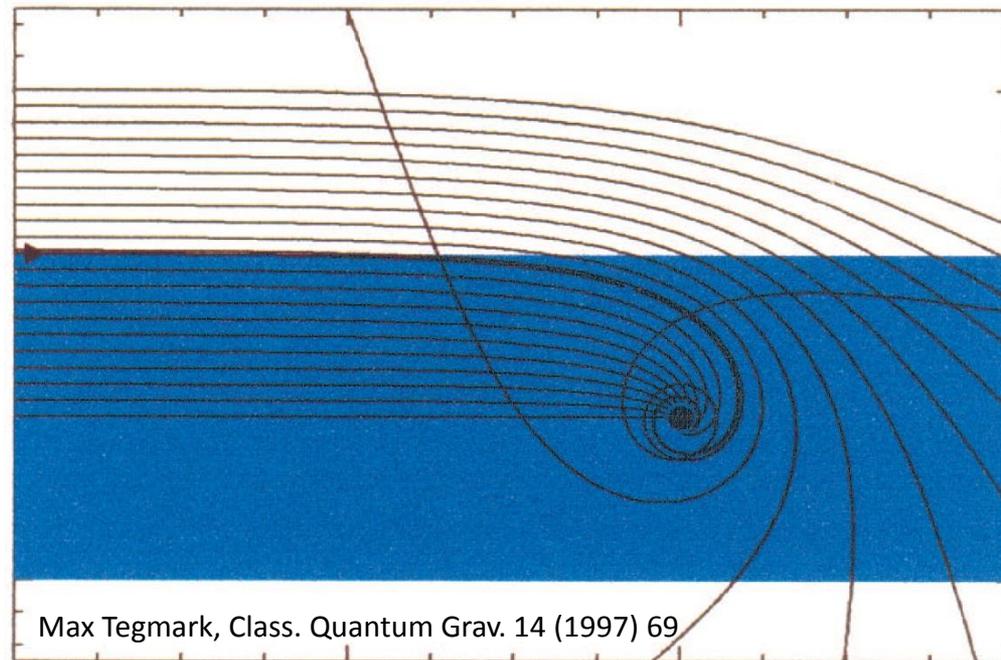


Hawking's two-dimensional dog

# 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 !



also in quantum mechanics no stable atoms !

Paul S. Ehrenfest, Proc. Royal Acad. Amsterdam 20 (1917) 200. Annalen der Physik Vol. 61 Nr. 5 (1920) 440.  
F.R. Tangherlini, Nuovo Cimento 27 (1963) 636.

# Matter : Antimatter

after Big Bang:

$$\gamma \rightarrow q \bar{q}, e^- e^+$$

now:

$$n_b / n_\gamma \sim 10^{-9}$$

10.000.000.00**1** - 10.000.000.00**0**

Do we live from an **accident**?

$n_{\text{mat}} / n_\gamma = 0$  : light only       $>10^{-6}$  : collapse

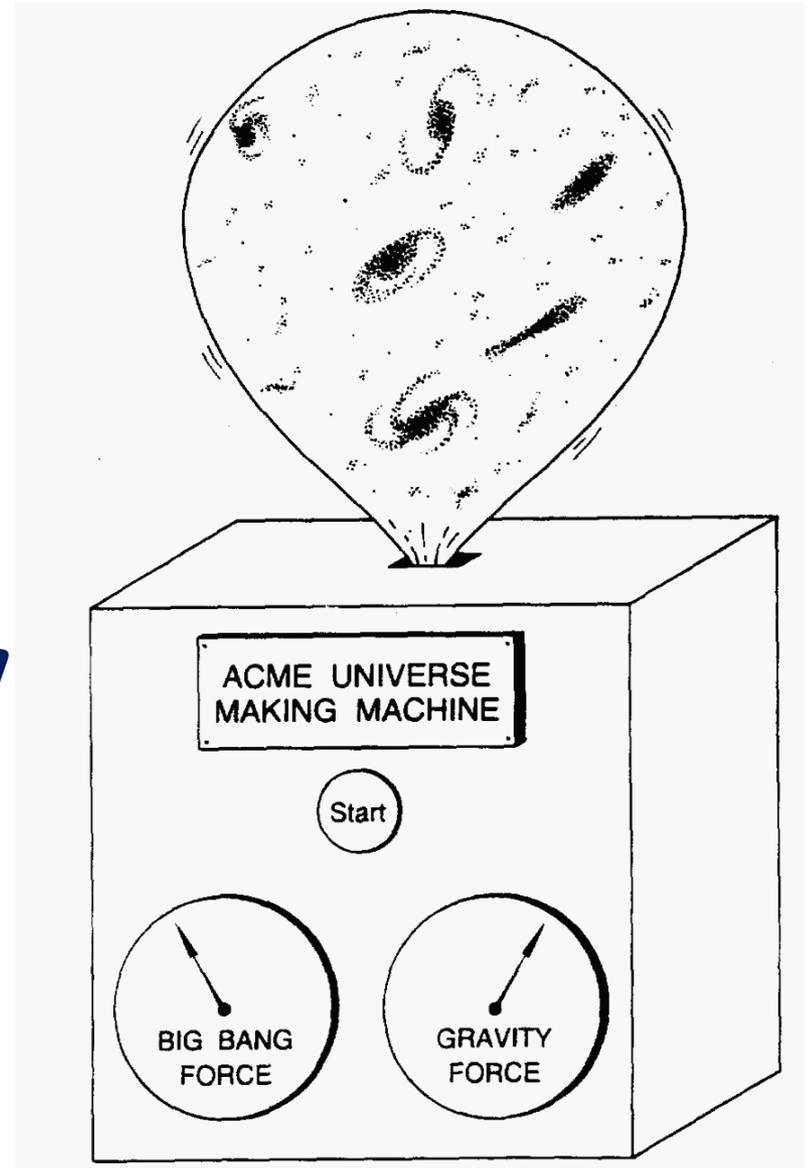
**matter-antimatter asymmetry if:**

- cosmos out of thermal equilibrium
- baryon number violated (proton decay)
- CP violation



Andrei Sakharov

# Cosmic Inventory



# cosmological constant

- **Planck scale** - natural energy scale of gravitation:

$$m_{\text{Pl}} = (\hbar c / G_{\text{N}})^{1/2} = 1.2 \cdot 10^{19} \text{ GeV}/c^2 \quad G_{\text{N}} \dots \text{ gravitation constant}$$

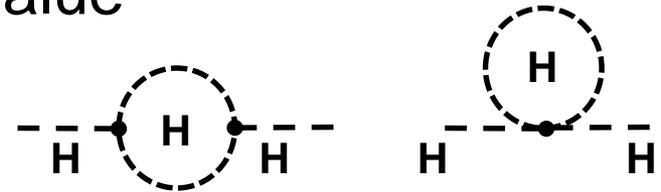
- cosmological constant - dark energy density:

$$\Lambda \sim 3 m_{\text{proton}} / \text{m}^3 \sim (10 \text{ meV})^4 \sim (10^{-30} m_{\text{Pl}})^4 = 10^{-120} m_{\text{Pl}}^4$$

- Why is  $\Lambda$  so tiny ?

- **Higgs field**: vacuum expectation value

$$H^2 \sim m_{\text{H}}^4 \sim (100 \text{ GeV})^4 \sim 10^{52} \Lambda$$



- Why **H** so much larger than  $\Lambda$  ?

# Fine tuning of scalar fields

## Inflation - Dark Energy - Higgs - Gravitation

### • flat Universe:

$$\Omega_k = 0.001 \pm 0.006 \quad \text{Why?}$$

Dicke 1961, Weinberg 1987,  
 anthropic argument on  $G_N$ ,  $H_0$ ,  $\Omega$ ;  $\Lambda$ :

### too little inflation:

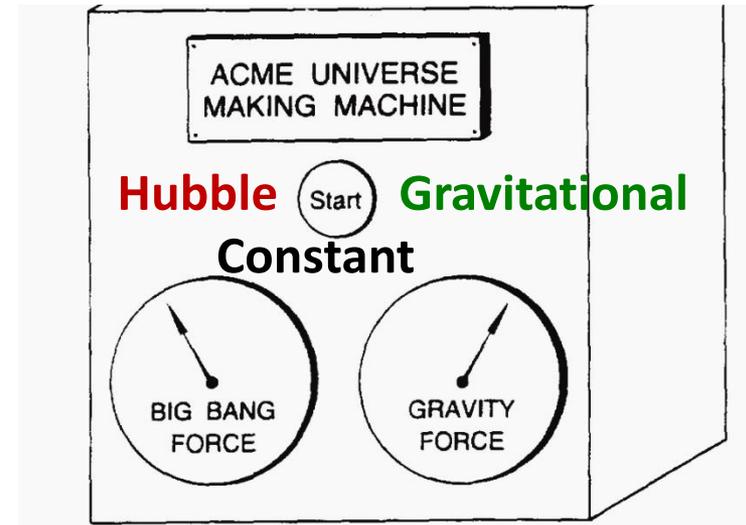
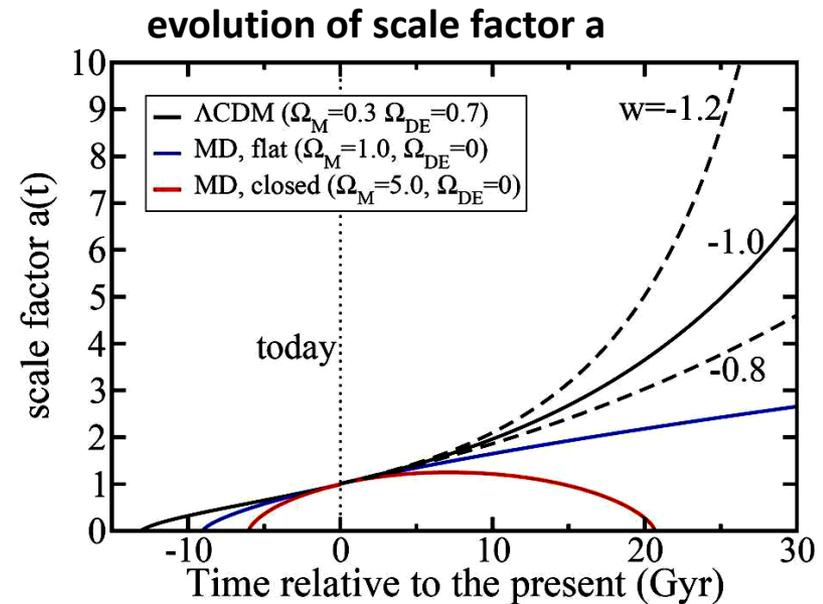
- fast recollapse, no time for life

### too much inflation + Dark Energy:

- no formation of galaxies, stars + life

### Fine tuning of $\Lambda$ :

- to Higgs vacuum:  $10^{52}$
- to Planck mass:  $10^{120}$

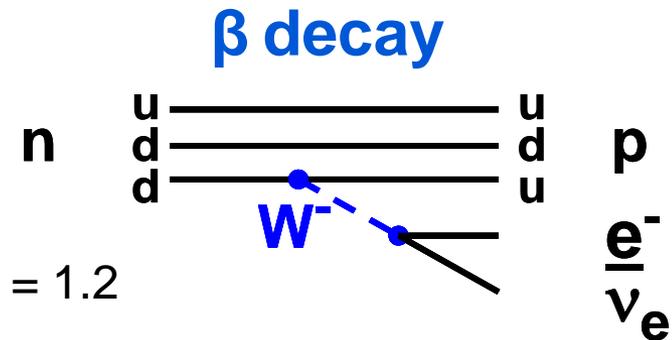


Expansion - Contraction  
 Repulsion - Attraction  
 Anti-Gravity - Gravity

$$\Omega = \rho / \rho_{\text{crit}} = 1$$

# boson masses: $m_W$

- **massless**: photon  $m_\gamma = 0$  and gluon  $m_g = 0$
- **massive**: weak bosons  $m_{W,Z} = 80, 91 \text{ GeV}$ 
  - $m_W$  governs fusion  $p+p \rightarrow d e^+ \nu_e$  in stars
- **increase  $m_W$**  by factor of 2:
  - sun burns slower, less radiation pressure
  - radius  $\sqrt{2}$  smaller, surface temperature up by  $4\sqrt{2} = 1.2$
  - more UV radiation
- **decrease  $m_W$**  by factor of 2:
  - Sun bigger, colder, burns faster  $\sigma \rho \sim (m_W)^{-4} (m_W)^{1.5}$
  - burn-out within  $1.5 \times 10^9$  years - no higher life !
  - W must not be much lighter for higher life on Earth
- **no Higgs** -  $m_W = 0$ :
  - weak Sun burning becomes strong nuclear explosion !

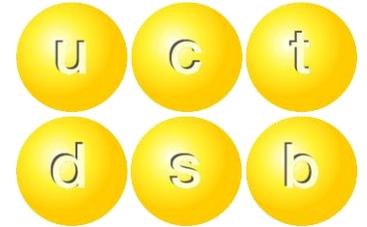


# fermion masses

- **proton stable, neutron decays**

- $n \rightarrow p e^- \bar{\nu}_e$  since  $m_n - m_p = 1.3 \text{ MeV} \approx 1\% m_{n,p}$  as

- quark mass:  $m_d - m_u \approx 3-4 \text{ MeV}$

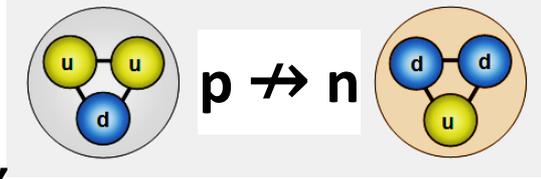


- **what if  $m_u > m_d$  :**

- proton decays:  $p \rightarrow n e^+ \nu_e$ , annihilation  $e^+ e^- \rightarrow \gamma \gamma$

- deuteron unstable:  $d \rightarrow 2n e^+ \nu_e$  as

$$m_p - (m_n + m_e) > 2.2 \text{ MeV} = E_b^d$$

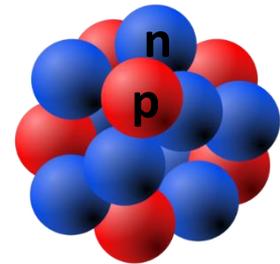


- **cosmos would be neutral :**

**only neutrons, photons + neutrinos**

**no protons + electrons,**

**no atoms, no chemistry, no life !**



- **no Higgs -  $m_e = 0$  :**

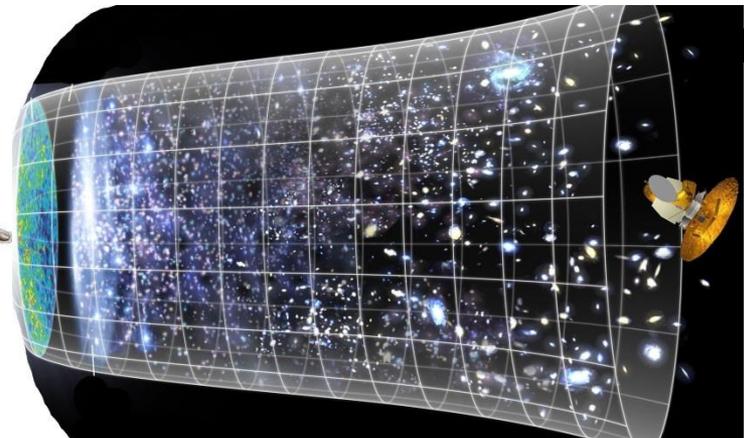
- infinite Bohr radius, no bound atoms, no chemistry + life !

# The Best of all Worlds

Einstein: **Had God a choice?**

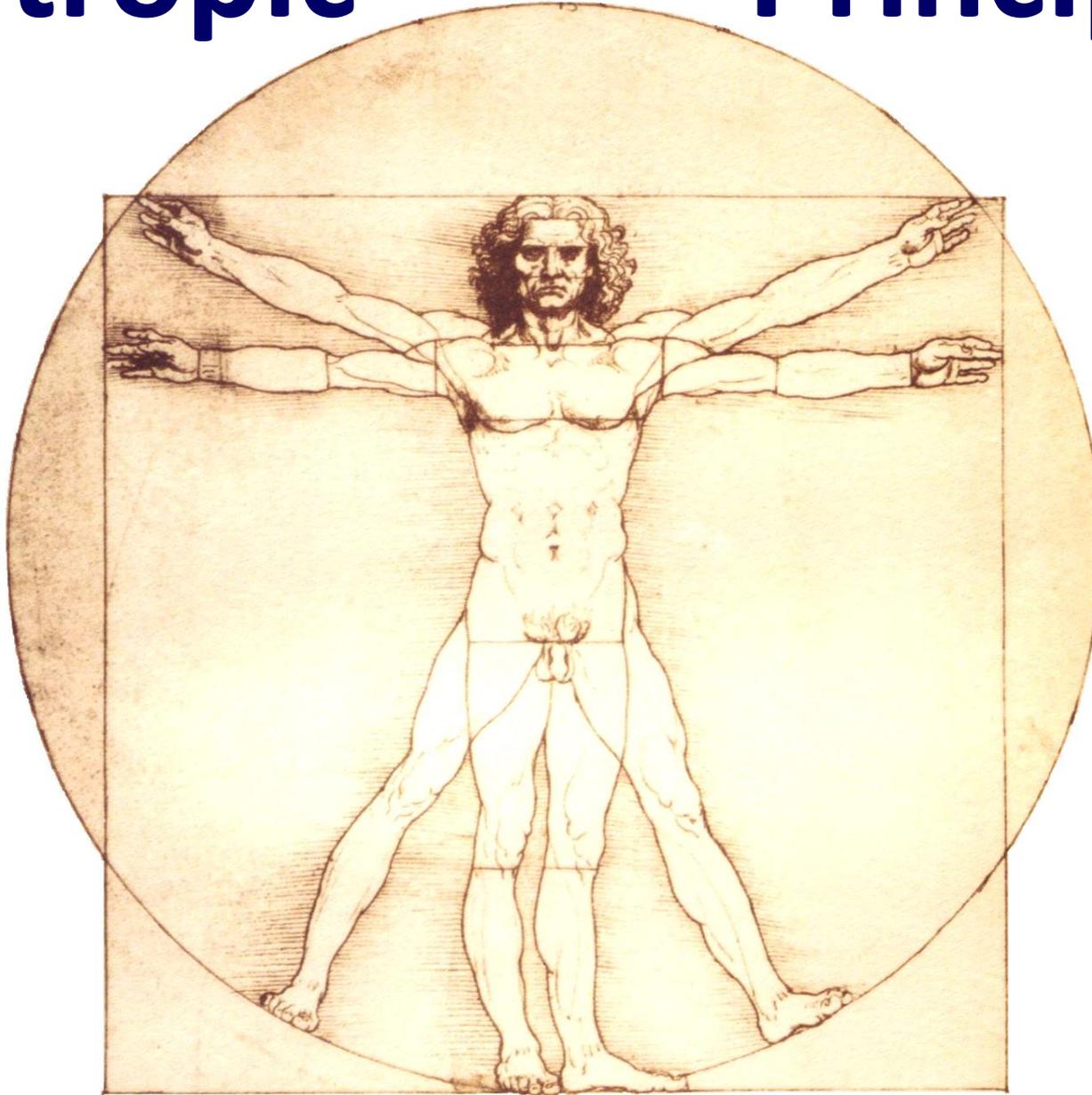
Fine tuning: **What if ?**

- nr of **dimensions** #  
1
- content of **cosmos**  $\Omega_{\text{tot}} = 1, \Omega_k = 0; \Lambda \sim 10^{-120} m_{\text{Pl}}^4$  2
- matter-**antimatter**  $n_{\text{bar}}/n_{\gamma} \sim 10^{-10}$  - otherwise **only light** or collapse 1
- **symmetries** of forces 3  
electr., weak, strong, gravity
- **strengths** of forces 2  
 $G_N/\alpha, G_F$
- **ma** 3
- **nu** 3



# Antropic

# Principle



# Anthropic Principle

Steven **Weinberg**

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.

# Anthropic Principle

R. **Dicke**, Dirac's Cosmology and Mach's Principle, Nature, Nov 1961

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: Anthropic argument for cosmological constant

S. **Weinberg**, Living in the **Multiverse**, 2007

Applied to the **string landscape**, the Anthropic 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.**"

# Anthropic 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

**Question: What is tuned?**

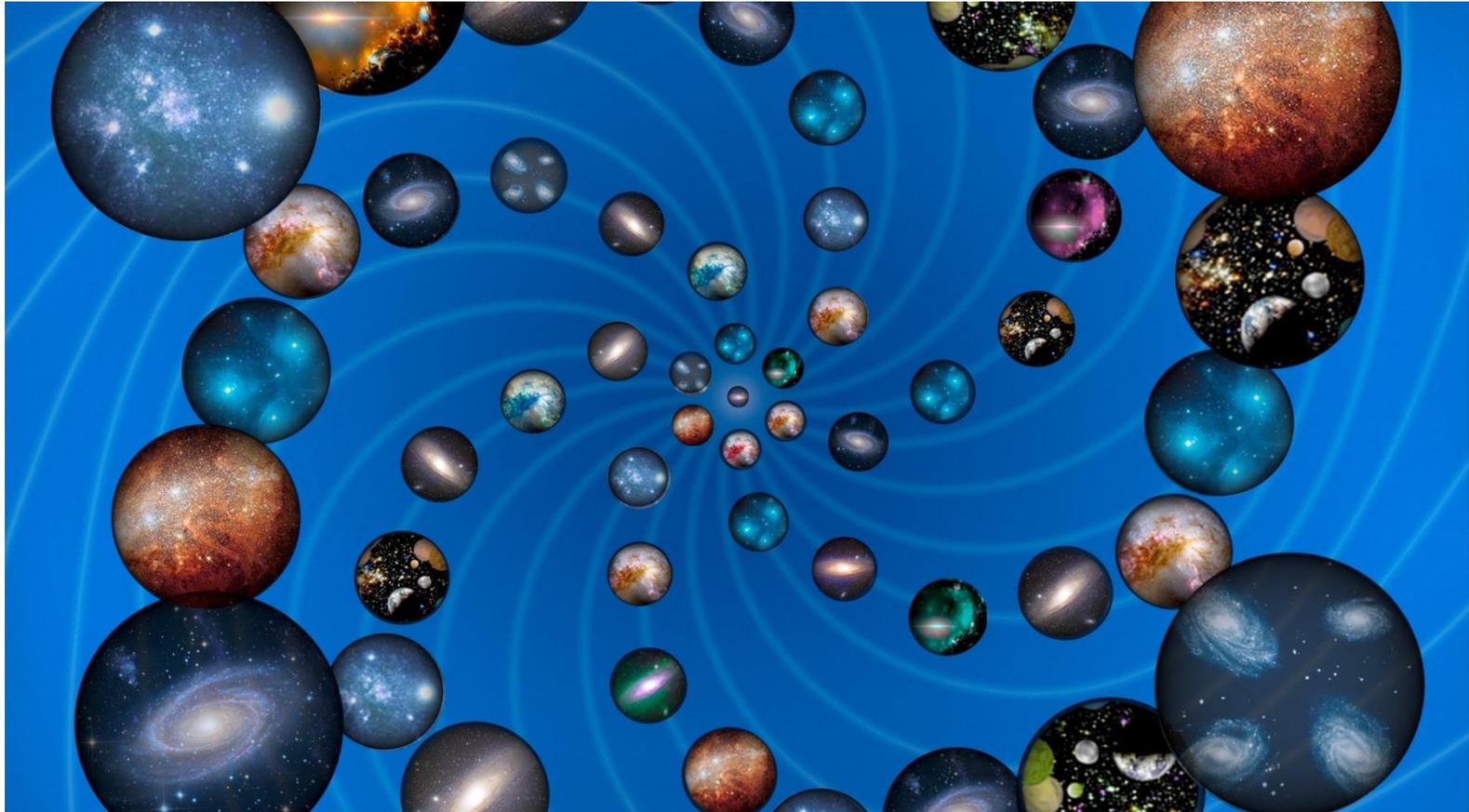
laws, fundamental and environmental parameters?

The image features a multitude of spherical objects of various sizes, each with a complex, multi-colored texture. The colors range from deep purples and blues to bright oranges and yellows, suggesting a rich, multi-dimensional space. The spheres are scattered across the frame, with some appearing larger and more detailed than others, creating a sense of depth. The background is dark, with a prominent purple glow emanating from behind the central text, which adds to the ethereal and cosmic atmosphere of the scene.

# Universe - Multiverse

# Universe - Multiverse

Andrei Linde, Particle Physics and Inflationary Cosmology, 1990



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 Cosmographicum* + *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:

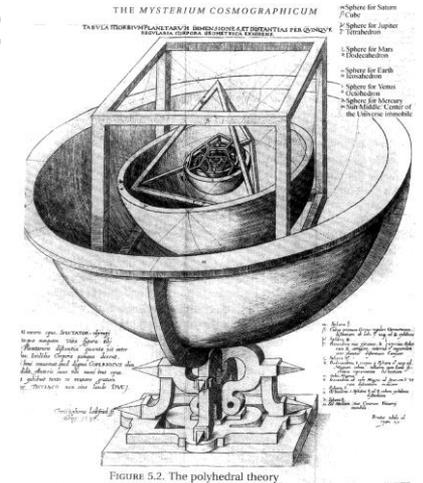
- **statistical**: more planets + planetary systems
- **fundamental**: search for underlying law - from Kepler to Newton !

- **Today**: inflation and landscape

- **statistical**:  $10^{500}$  universes - **Multiverse**
- **fundamental**: Superstrings

- **Aristotle**: *Physica* → *Metaphysica*

- **Today**: **Universe** → **Multiverse**  
**Physics** of our **Meta-Physics**  
**Best of all Worlds** in a positive sense



Raphael: The School of Athens  
Plato and Aristotle

# George Ellis, Does the Multiverse Really Exist ?

As skeptical as I am, I think the contemplation of the multiverse is an excellent opportunity to reflect on the nature of science and on the ultimate nature of existence: why we are here...

In looking at this concept, **we need an open mind, though not too open**. It is a delicate path to tread.

Parallel universes may or may not exist; the case is unproved. We are going to have to live with that uncertainty.

Nothing is wrong with scientifically based philosophical speculation, which is what multiverse proposals are. But we should name it for what it is.

Scientific American, 1 August 2011, **305** (2011) 38-43.

# 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 !**

