The fine tuning of the constants of Nature

Thomas Naumann Deutsches Elektronen-Synchrotron DESY

The Best of all Worlds ?

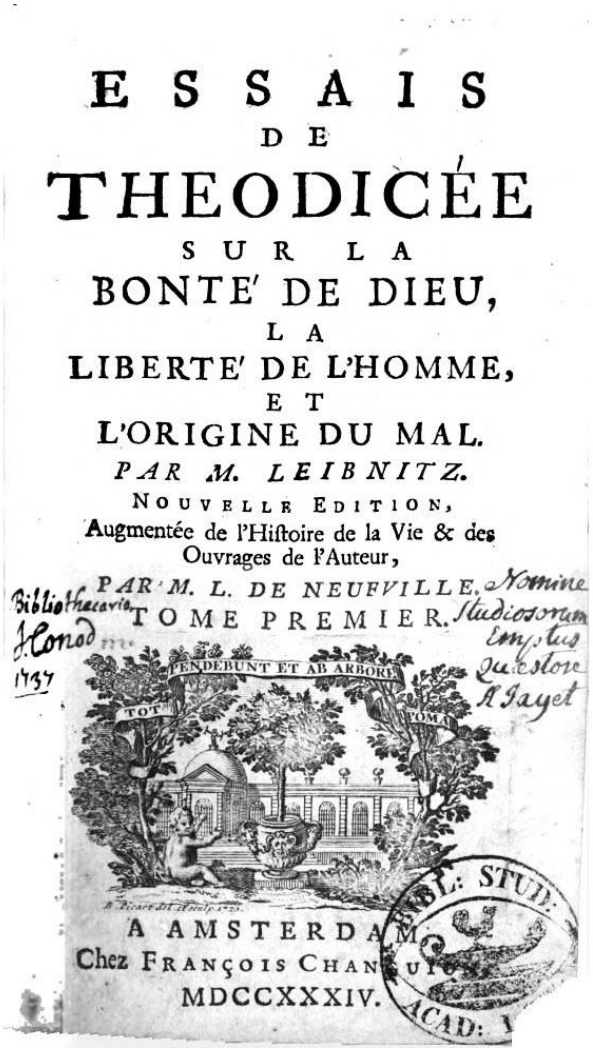
G.W. Leibniz 1710: **Théodicée**

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...“


ESSAIS
DE
THEODICÉE
SUR LA
BONTE' DE DIEU,
LA
LIBERTE' DE L'HOMME,
ET
L'ORIGINE DU MAL.
PAR M. LEIBNITZ.
NOUVELLE EDITION,
Augmentée de l'Hiſtoire de la Vie & des Ouvrages de l'Auteur,
PAR M. L. DE NEUFVILLE.
TOME PREMIER.
PENDEBUNT ET AB ARBORE
A AMSTERDAM,
Chez FRANÇOIS CHANGUION,
MDCCXXXIV.

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

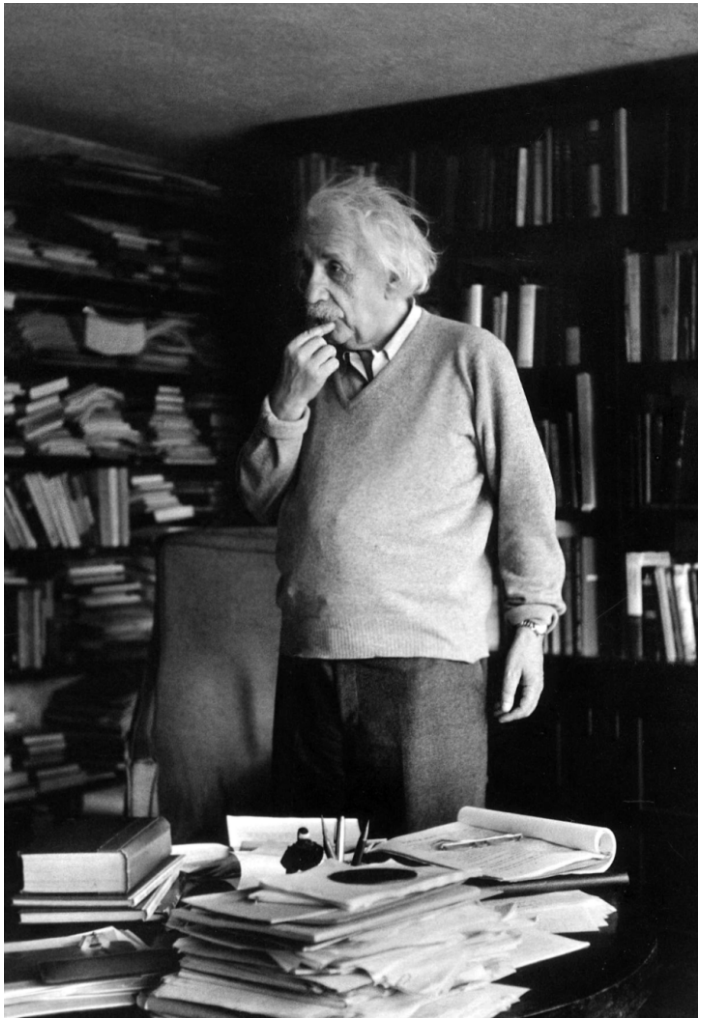
Essays on the Goodness of God, the Freedom of Man and the Origin of Evil. Translated by E.M. Huggard from C.J. Gerhardt's Edition of the Collected Philosophical Works, 1875-90.

Had God a choice ?

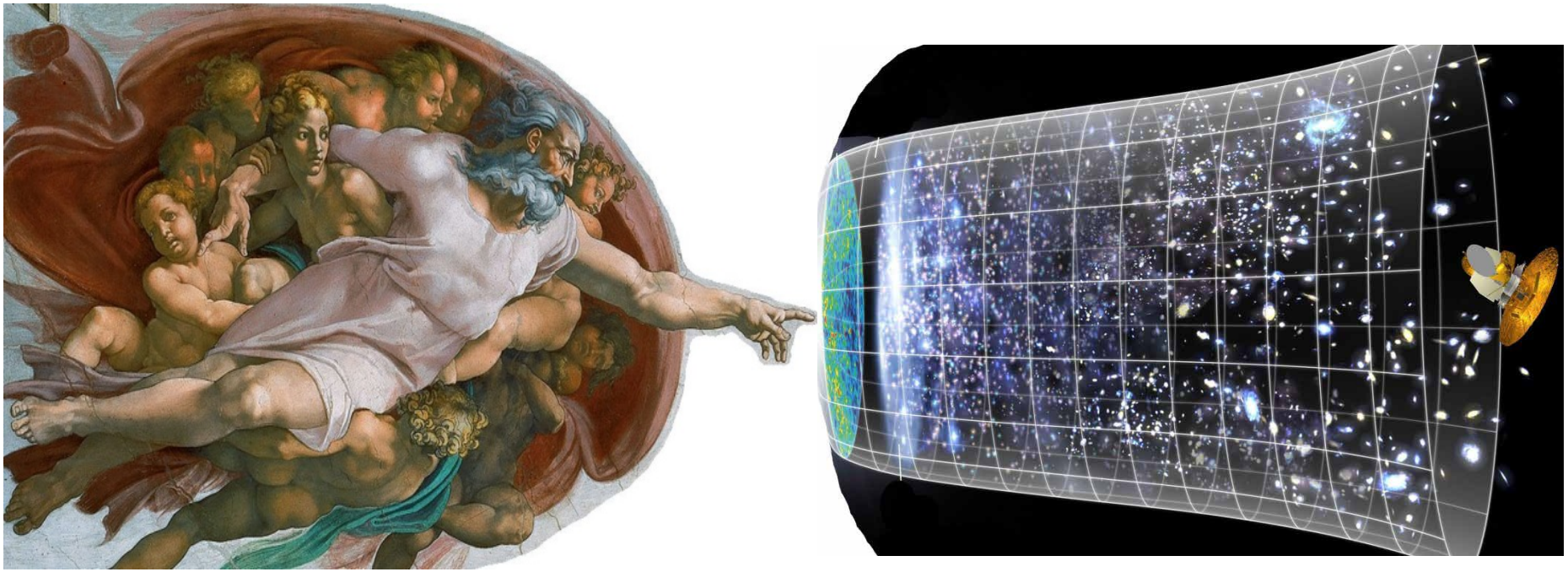
- Einstein to his assistant Banesh Hoffmann:
  When I am judging a theory,
  I ask myself whether, if I were God,
  I would have arranged
  the world in such a way.

- 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 ?

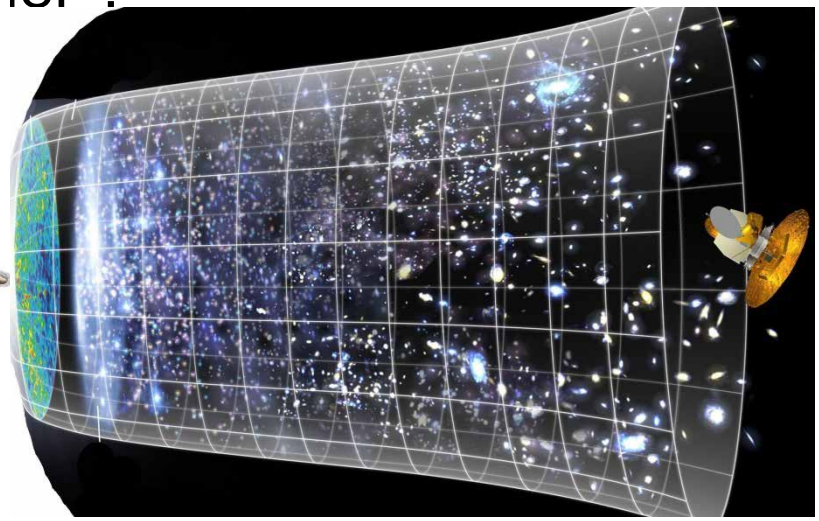


What if…?

Fine tuning: What if?

- nr of **dimensions** ≠ 3 ?
- **cosmos not flat** ?
- **cosmological constant** not so tiny?
- matter = **antimatter** ?
- **masses: quarks**: down heavier than up ?
- no **Higgs** - $m_e = 0$?

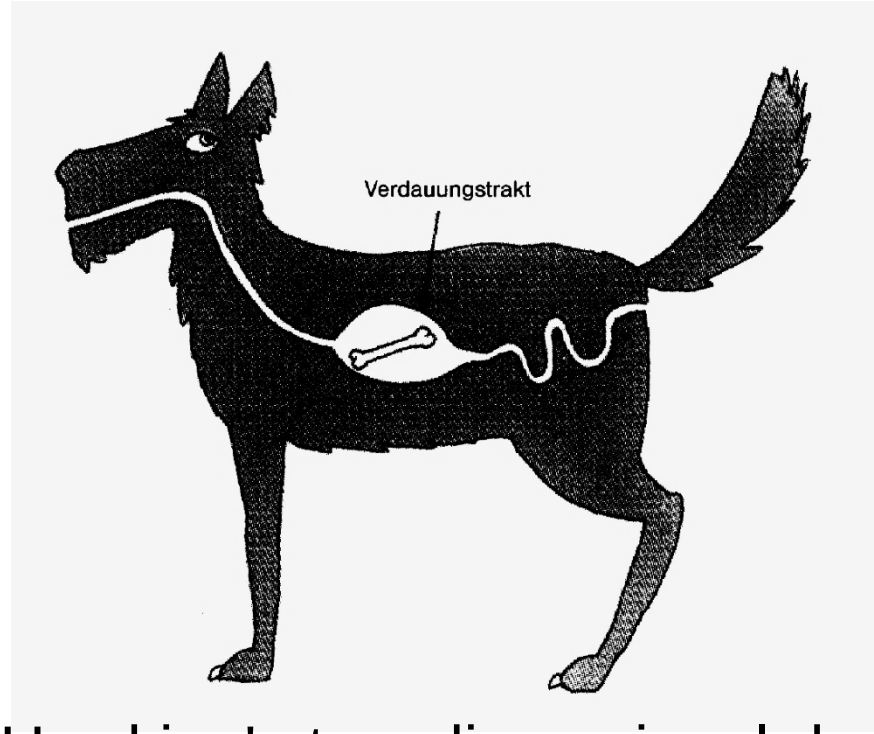
ier ?



Dimensions

Life in 2 dimensions -
topologically not connected:

crossing nerves, blood vessels ?
digest through one-dimensional boundaries ?



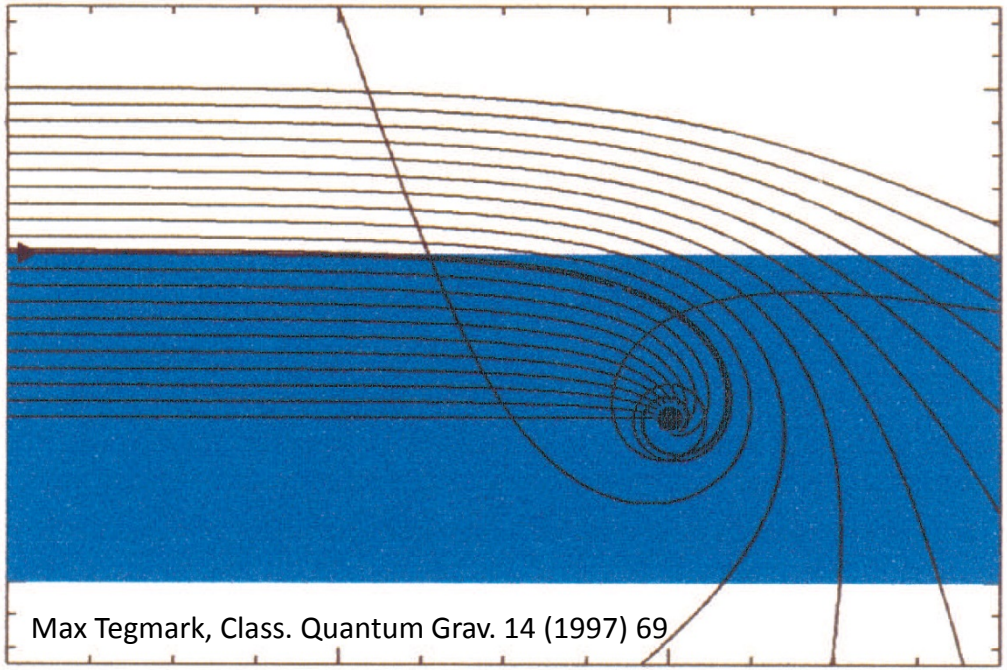
Hawking's two-dimensional dog

J.D. Barrow and F. Tipler, The Anthropic Cosmological Principle, 1986. S. Hawking, A Brief History of Time, 1988.

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) 200-209. Annalen der Physik Vol. 61 Nr. 5 (1920) 440-446.
F.R. Tangherlini, Nuovo Cimento 27 (1963) 636.

Matter : Antimatter

after Big Bang:

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

now:

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

10.000.000.001 - 10.000.000.000

Do we live from an accident?

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

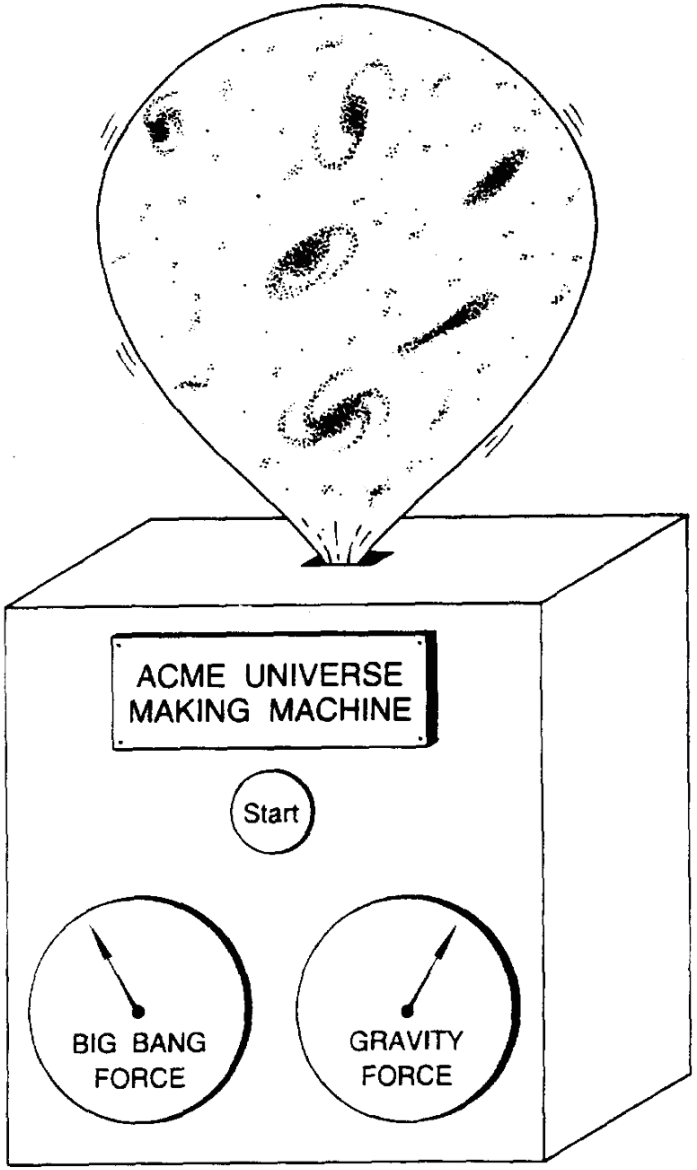
Andrei Sakharov

matter-antimatter asymmetry if:

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

But: cosmos exactly charge-symmetric !

Cosmic Inventory



Fine tuning of scalar fields

Inflation - Dark Energy Λ - Higgs - Gravitation

- **flat Universe:**
  $\Omega_k = 0.000 \pm 0.005$ **Why ?**

anthropic argument on
G_N, H_0, Ω: Dicke 1961
Λ: Weinberg 1987

too little inflation:

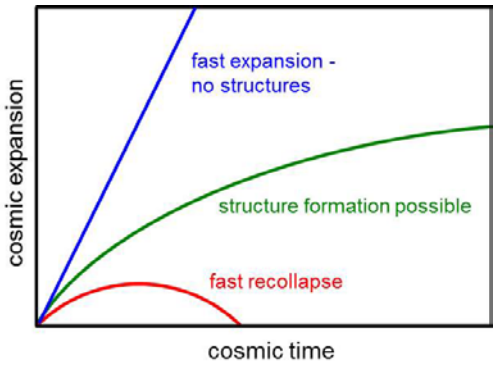
- fast recollapse, no time for life

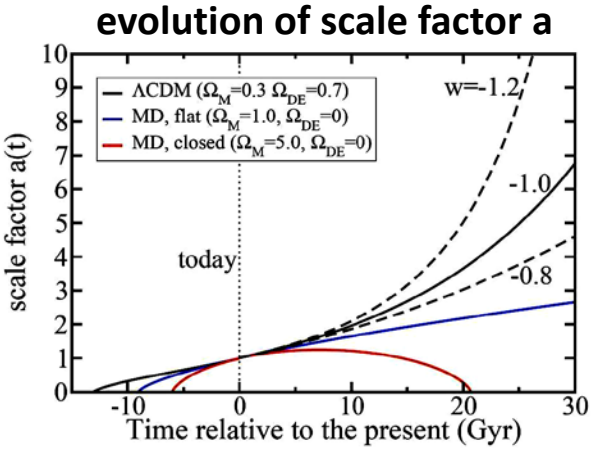
too much inflation + Dark Energy:

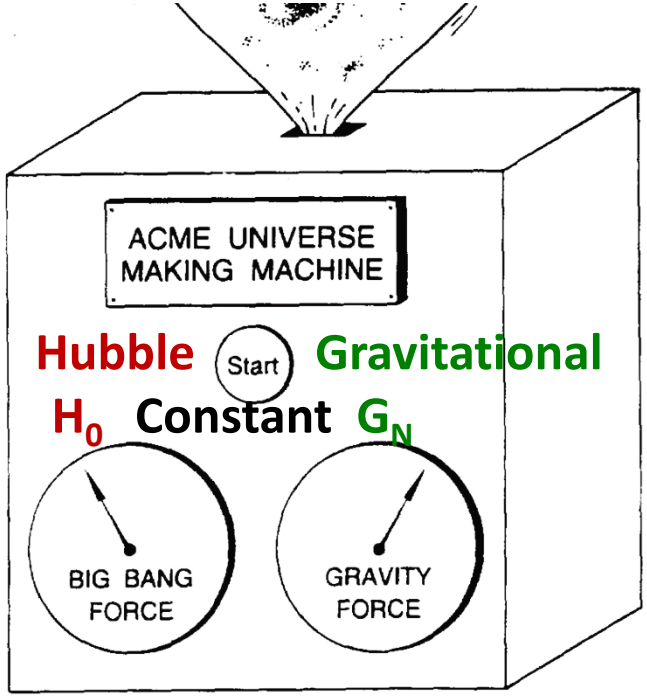
- no formation of galaxies, stars + life

Fine tuning of Λ :

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







Expansion - Contraction
Repulsion - Attraction
Anti-Gravity - Gravity

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

cosmological constant

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

  $\mathbf{m_{Pl}} = (\hbar c/G_N)^{1/2} = 1.2 \cdot 10^{19}$ GeV/c^2 G_N … gravitation constant

- cosmological constant - dark energy density:

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

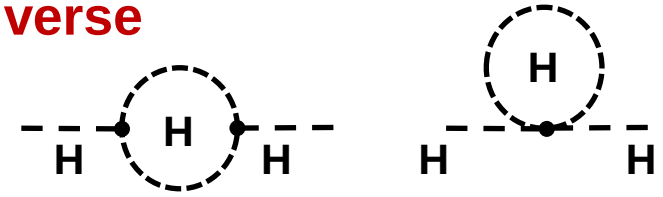
- **hierarchy problem**: Why so different scales for gravity, strong + electroweak force, Dark Energy:

  $\mathbf{\Lambda_{QCD}} \sim 0.2$ GeV $\sim \mathbf{10^{-20}\, m_{Pl}}$ $\mathbf{v_{el.weak}} = (\sqrt{2}\, G_F)^{-1/2} = 246$ GeV $\sim \mathbf{10^{-17}\, m_{Pl}}$

- **different scales** allow for a **complex Universe**

- **Higgs field**: vacuum expectation value

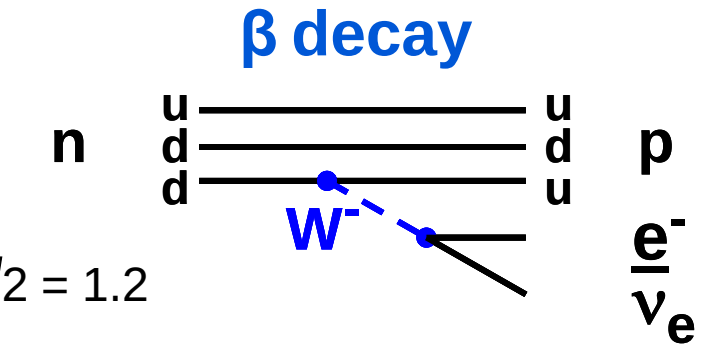
  $H^2 \sim \mathbf{m_H^4} \sim (100 \text{ GeV})^4 \sim \mathbf{10^{52}\, \Lambda}$



- Why **H** so much larger than **Λ ?**

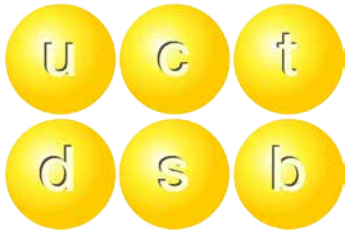
boson masses: m_W

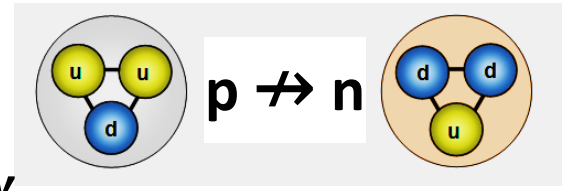
- **massless**: photon $m_\gamma = 0$ and gluon $m_g = 0$
- **massive**: weak bosons $m_{W,Z} = 80, 91$ GeV
  - m_W governs fusion $p+p \rightarrow d\, e^+ \nu_e$ in stars
- **increase m_W** by factor of 2:
  - sun burns slower, less radiation pressure
  - radius $\sqrt{2}$ smaller, surface temperature up by $\sqrt[4]{2} = 1.2$
  - 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 1.5×10^9 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 !



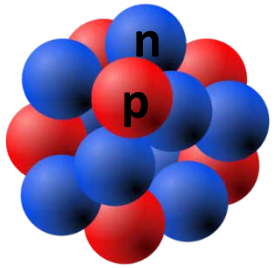
fermion masses

- **proton stable, neutron decays**
  - $n \to p\, e^-\, \bar{\nu}_e$ since $m_n - m_p = 1.3$ MeV $\approx 1‰\, m_{n,p}$ as
  - quark mass: $m_d - m_u \approx 3$ MeV





- **what if $m_u > m_d$:**
  - proton decays: $p \to n\, e^+\, \nu_e$, annihilation $e^+\, e^- \to \gamma\, \gamma$
  - if $m_u - m_d > 1$ MeV deuteron unstable: $d \to 2n\, e^+\, \nu_e$ as $m_p - (m_n + m_e) > 2.2$ MeV $= E_b^d$



- **cosmos would be neutral :**

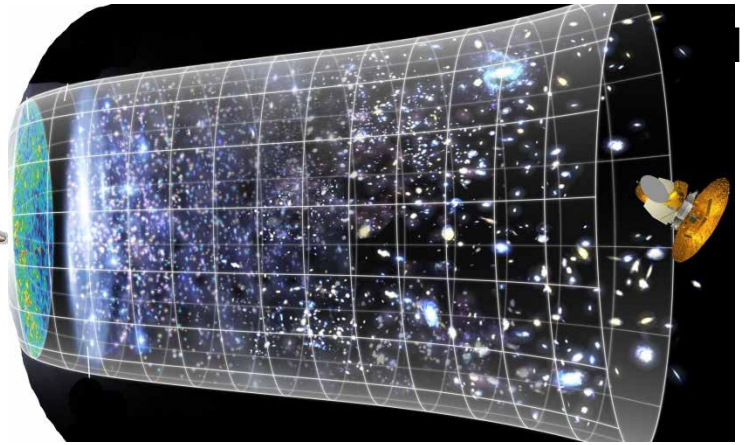
  only neutrons, photons + neutrinos
  no protons + electrons,
  no atoms, no chemistry, no life !

- **no Higgs - $m_e = 0$:**
  - infinite Bohr radius, no bound atoms, no chemistry + life !

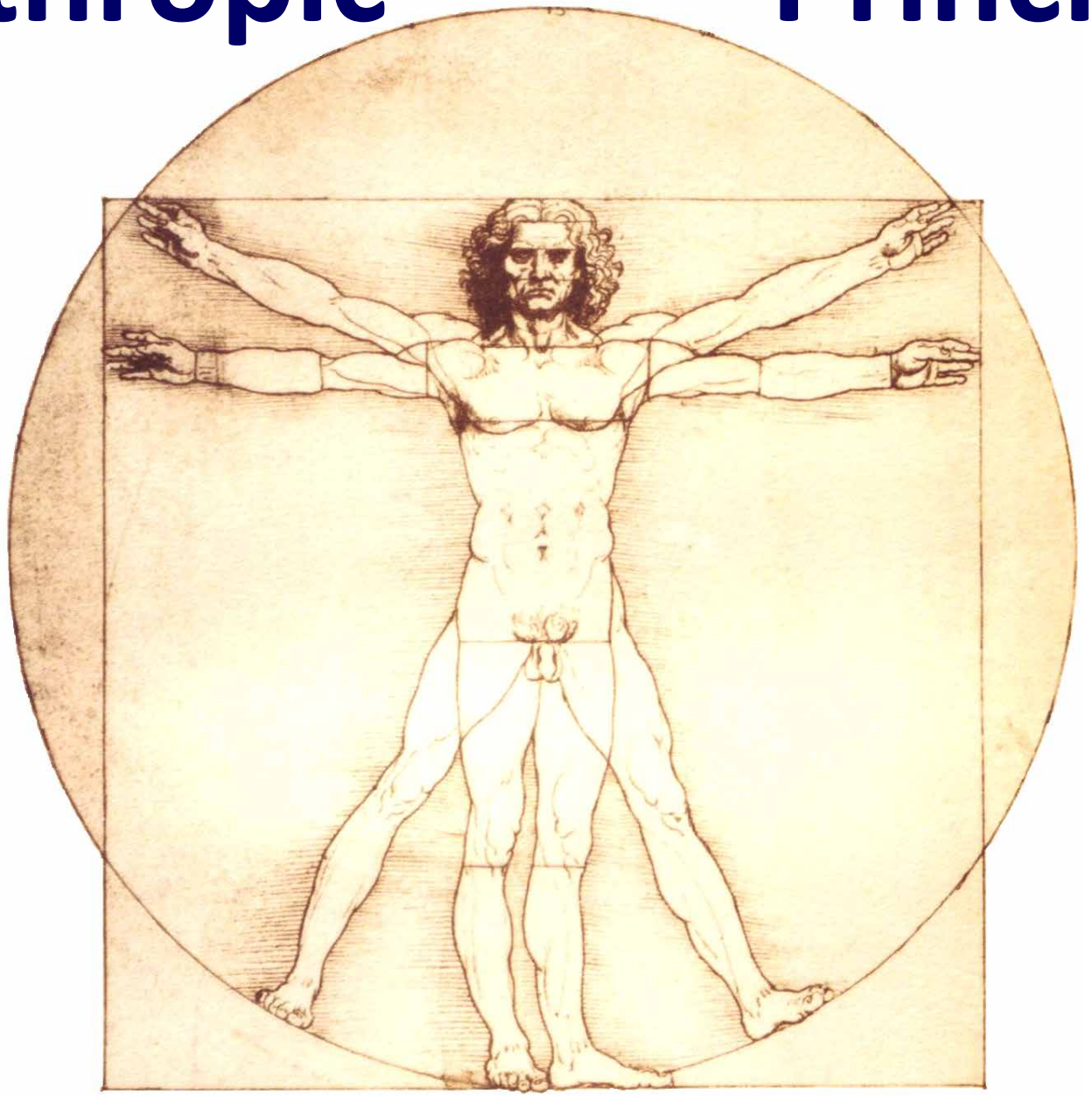
The Best of all Worlds

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

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



Anthropic 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, Ω] 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 Brief 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**, Anthropic bound on the cosmological constant, 1987

anthropic arguments to estimate Λ a decade before its observation: prediction!

L. **Susskind**, The anthropic string theory landscape, 2003

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 science:

no repeatable experiments

multiverse: anything goes - no prediction, only postdiction

fundamental parameters not derived from first principles

Question: What is tuned?

laws, fundamental or environmental parameters (initial cond.s) ?

be more creative: vary several parameters!

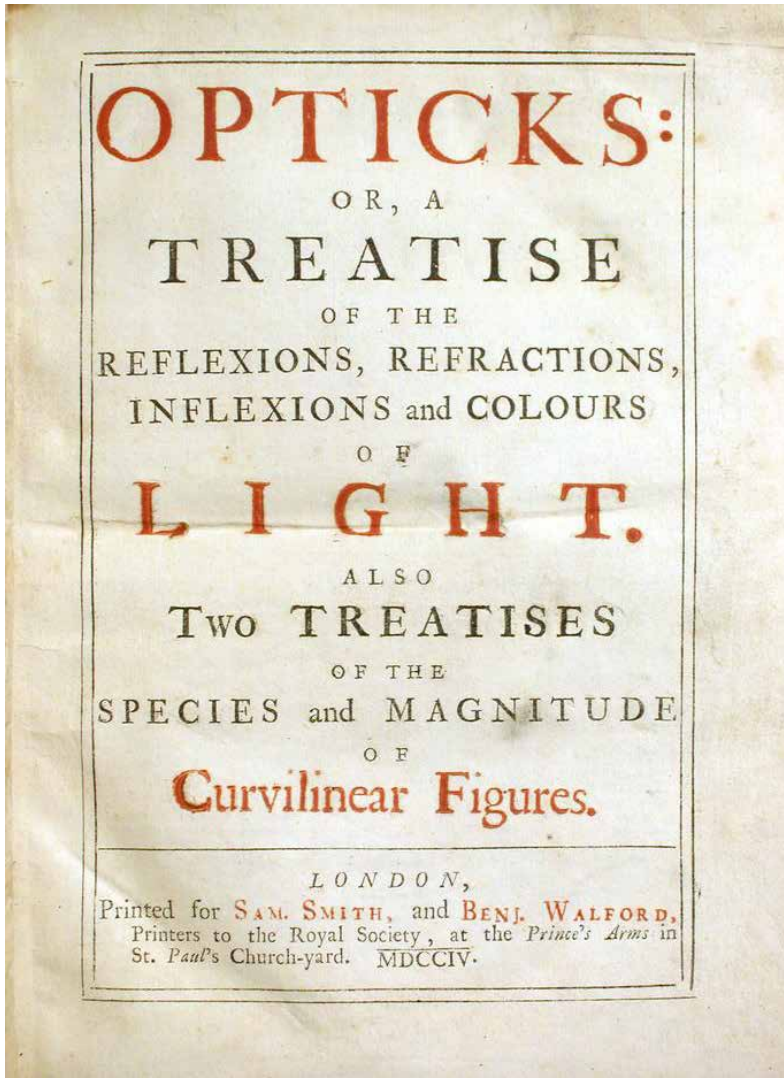

Universe -
Multiverse

Newton: Opticks, 1704

It may be also allow'd
that God is able to
Create Particles and Matter
of several Sizes and Figures,
and in several Proportions to
Space, and perhaps
of different Densities and Forces,

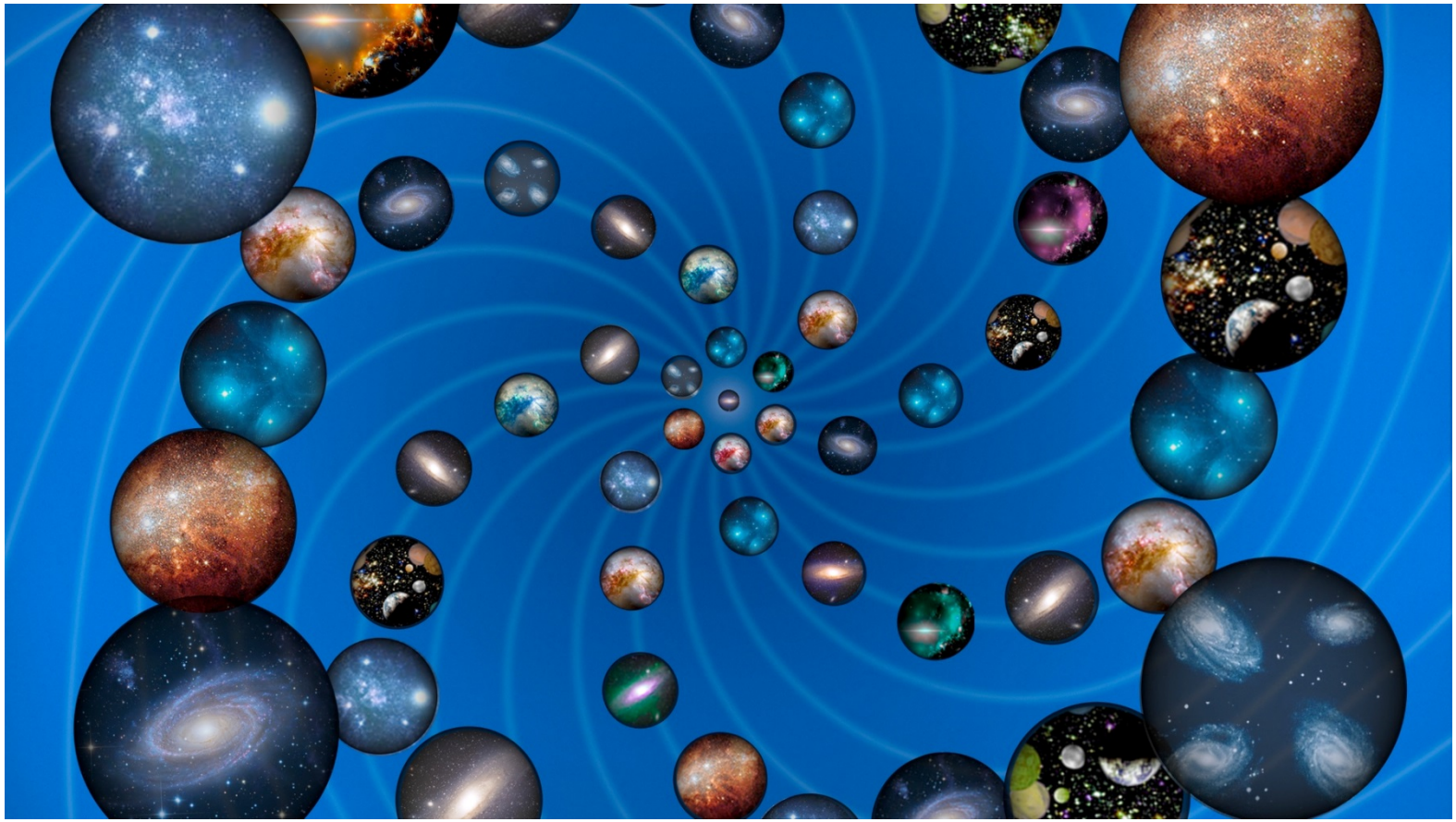
and thereby to
vary the Laws of Nature,

and make Worlds of several sorts
in several Parts of the Universe.


OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.
LONDON,
Printed for Sam. Smith, and Benj. Walford,
Printers to the Royal Society, at the Prince's Arms in
St. Paul's Church-yard. MDCCIV.

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 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)

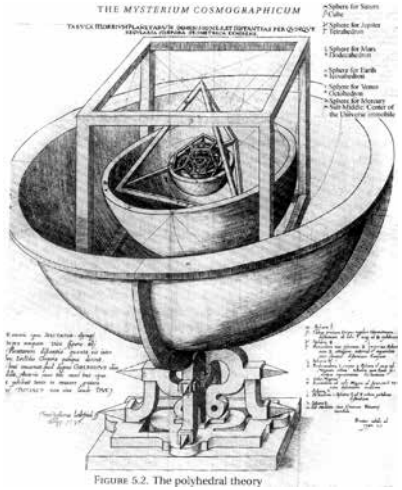


FIGURE 5.2. The polyhedral theory

- 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**
  - **Anthropic principle**
    - **Multiverse**

100 years later still
burning questions
of physics !