



“Did God have a choice when creating the universe?”

Nils-Erik Bomark

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Outline

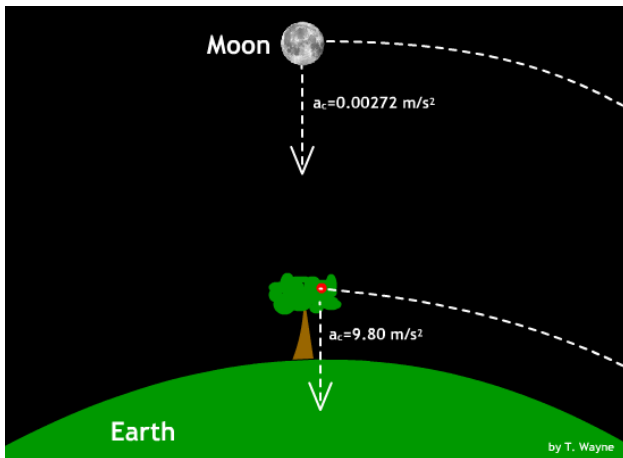
- 1 Theory of Everything
 - Unifying theories
 - How many parameters are there?
 - Mathematical consistency
- 2 Problems with parameters
 - The hierarchy problem
 - Other strange parameters
 - Dark energy
- 3 The three possibilities
 - God had no choice
 - The multivers
 - Something in between?



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Unifying the heavens and earth

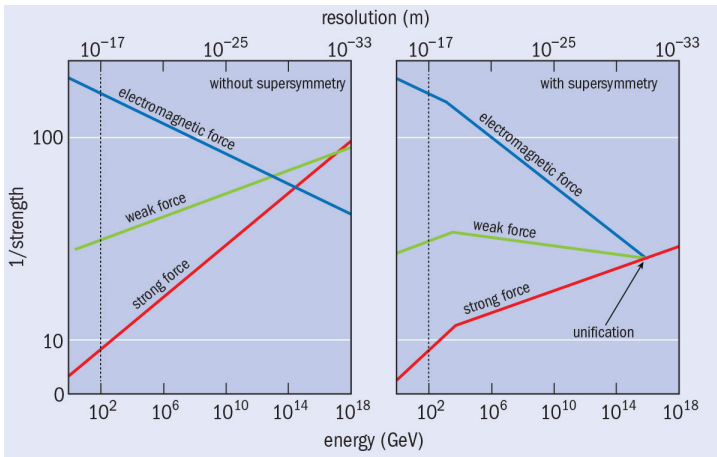


Unifying electricity and magnetism



$$\partial_{\mu} F^{\mu\nu} = J^{\nu}$$

Gauge coupling unification



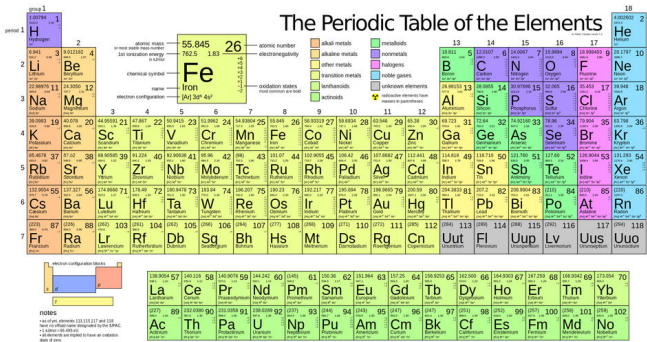


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Before the standard model



A few hundred parameters.

The standard model

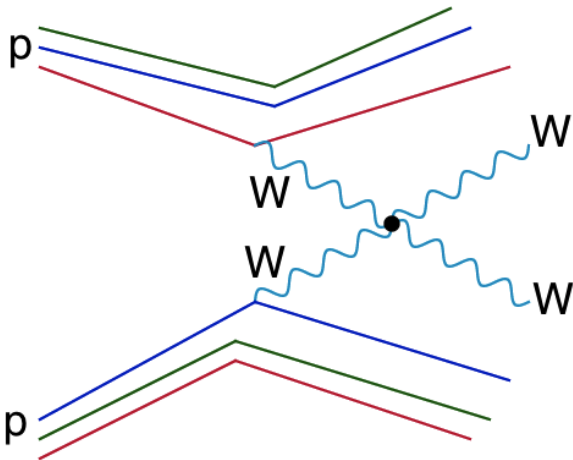
	Quarks
	Leptons
	Anti-Quarks
	Anti-Leptons
	Bosons

Some 20 parameters.

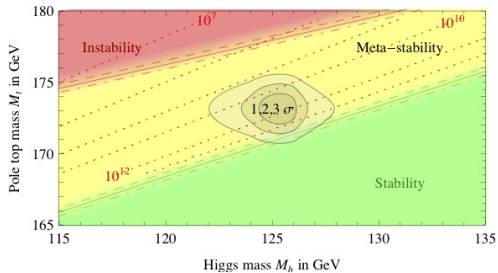
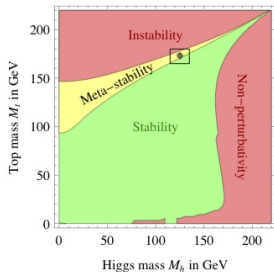
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The SM without the Higgs



Is our universe stable?



All theories are effective

All theories come with a cutoff Λ .
For energies $< \Lambda$ the theory is invalid.

For the SM $100 \text{ GeV} < \Lambda < 10^{18} \text{ GeV}$.

All theories are effective

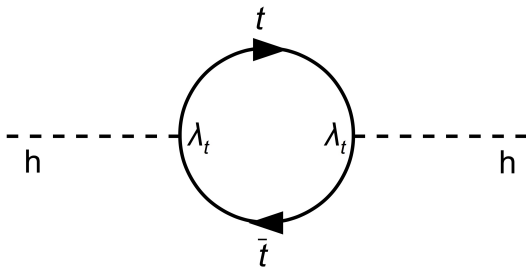
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Loop contributions to the Higgs mass



$$m_H^2 = m_0^2 - \frac{|\lambda_t|^2}{8\pi} \Lambda^2$$
$$\lambda_t \approx 1, \Lambda = \text{maybe } 10^{16} \text{ GeV}$$

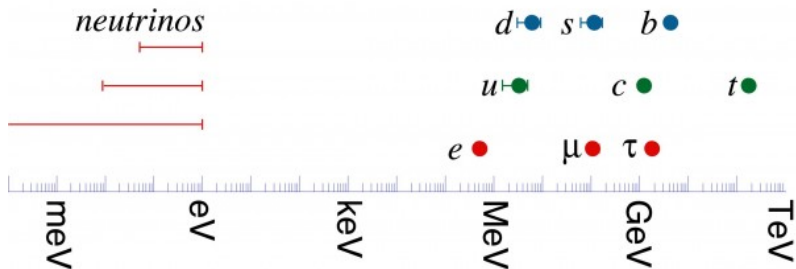


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Neutrino masses

Why are the neutrino masses so small?



Strong CP-problem

The strong force allows a term;

$$\mathcal{L} = \theta \frac{1}{16\pi^2} F_{\mu\nu}^a \tilde{F}^{\mu\nu a}$$

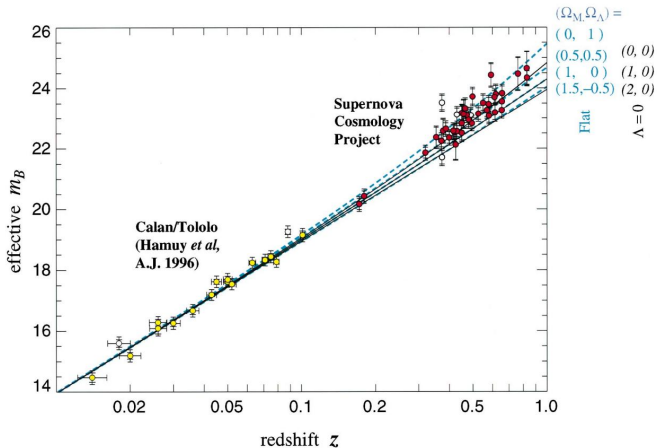
This makes matter and antimatter very different.
Experiments says $\theta \approx 0$, but why?



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The universe expansion is accelerating!



What about a cosmological constant?

$$G_{\mu\nu} = \kappa T_{\mu\nu} - \Lambda g_{\mu\nu}.$$

But vacuum energy should make $\Lambda \approx 10^{120}$ times too large!

So why is it so small?

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The theory of everything

Is there a theory with:

- no free parameter,
- no freedom in its construction,
- no infinities,

to which all present theories are approximations?

How to find the TOE?

Nature needs a way of producing the right parameters.

By studying why the parameters are what they are, we might find the TOE.

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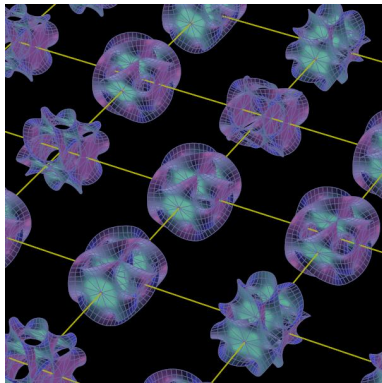
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The first attempt; string theory

Different particles are different vibration modes on a string.
Only one parameter; the string tension.

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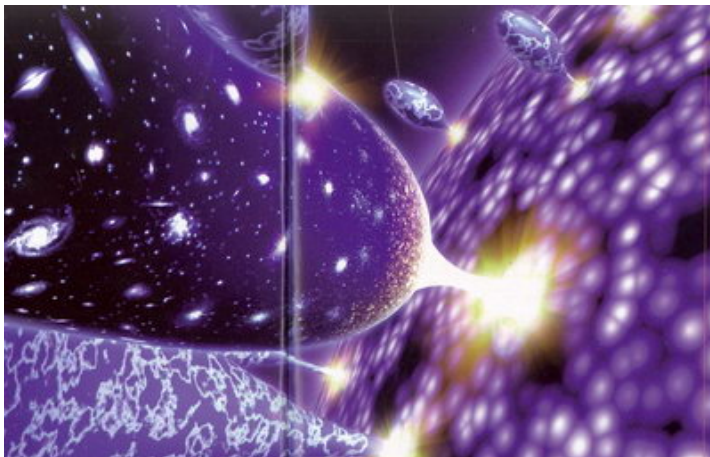
But we need 10 dimensions!
Can be compactified in
 $\approx 10^{1000}$ ways.



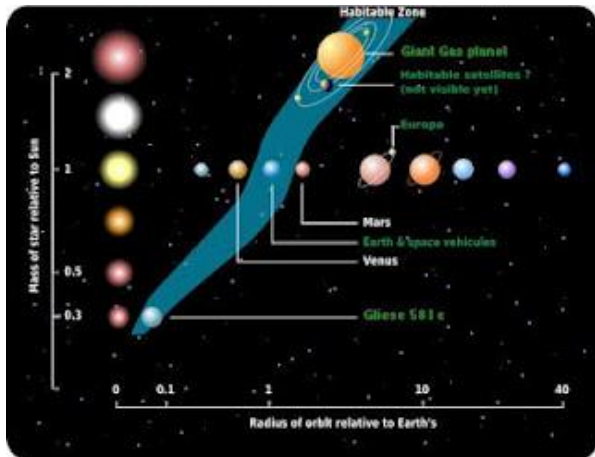
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Multivers



The anthropic principle



Does fine-tuning matter i the universe?

Is it easier to find theories that solve the fine-tuning than the cost of the fine-tuning?

Nobody knows.

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Truly free parameters?

We will never be satisfied with this!