The Higgs and The Cosmological Constant: They're Just Not Natural

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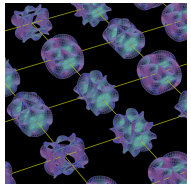
Trinity Science Society

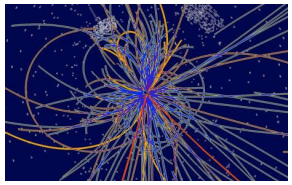
Nature is Organised by Scale

Planck Scale



10^{-33} m

LHC



10^{-18} m

DNA

10^{-9}m

Earth

10^{7}m

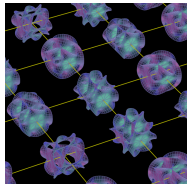
Observable Universe

10^{26} m

Experimental Science

Nature is Organised by Scale

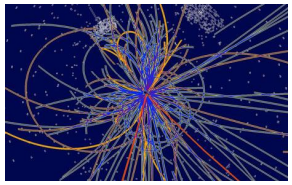
Planck Scale



10^{-33} m

10^{27} eV

LHC



10^{-18} m

10^{12} eV

DNA

10^{-9}m

Earth

10^{7}m

Observable Universe

10^{26} m

10^{-34} eV

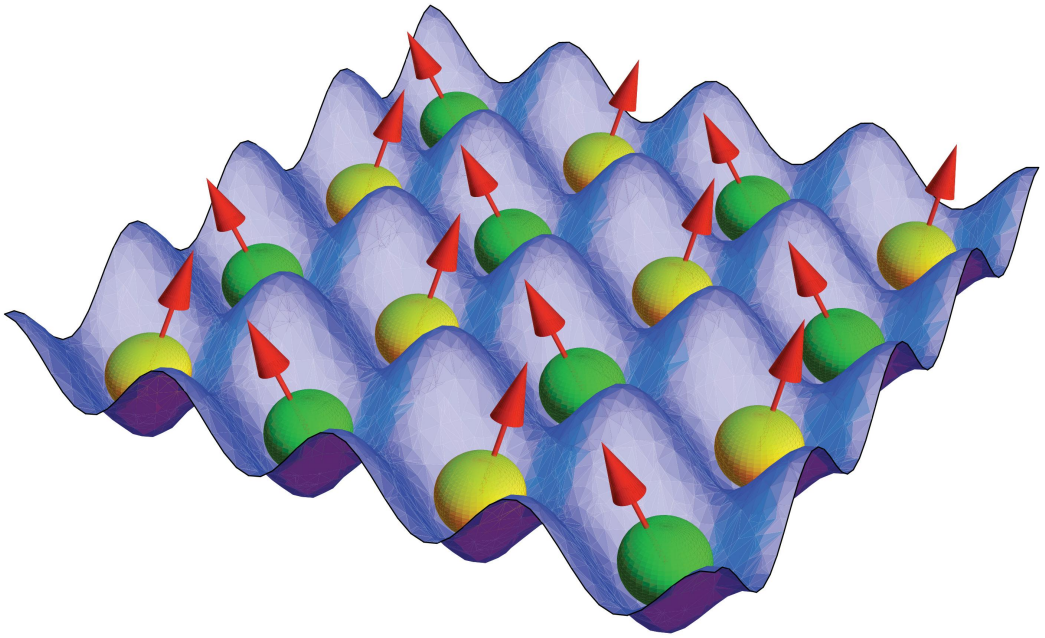
Energy

Renormalization

little things affect big things

Example 1: Fluid mechanics

Example 2: Heavy Fermions



e.g. $CeCu_6$, $CeAl_3$,UPt_3.

Renormalization

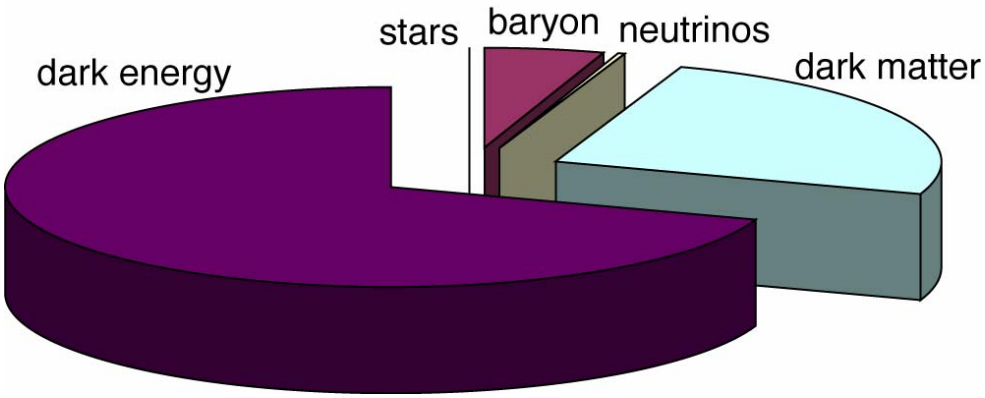
$$m_{\text{observed}} = m_{\text{bare}} + m_{\text{induced}}$$

Ping pong ball: $m_{\text{observed}} \approx 10\, m_{\text{bare}}$

Electron in heavy fermion material: $m_{\text{observed}} \approx 1000\, m_{\text{bare}}$

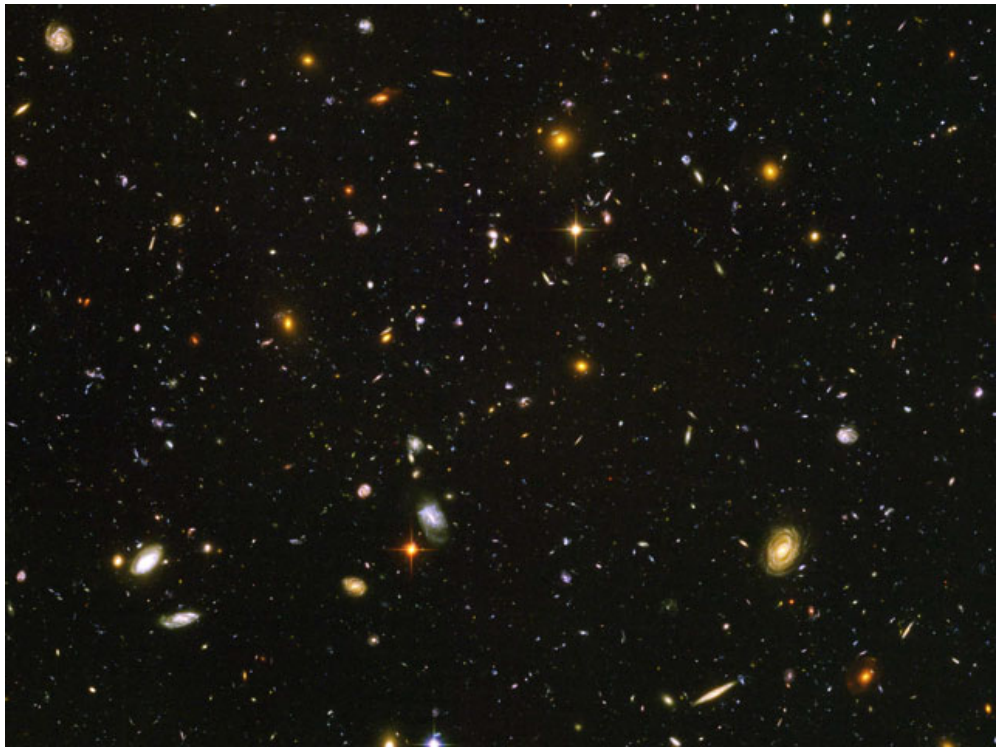
Part I: The Cosmological Constant

Energy budget

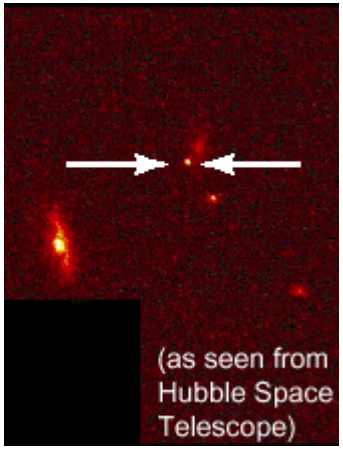


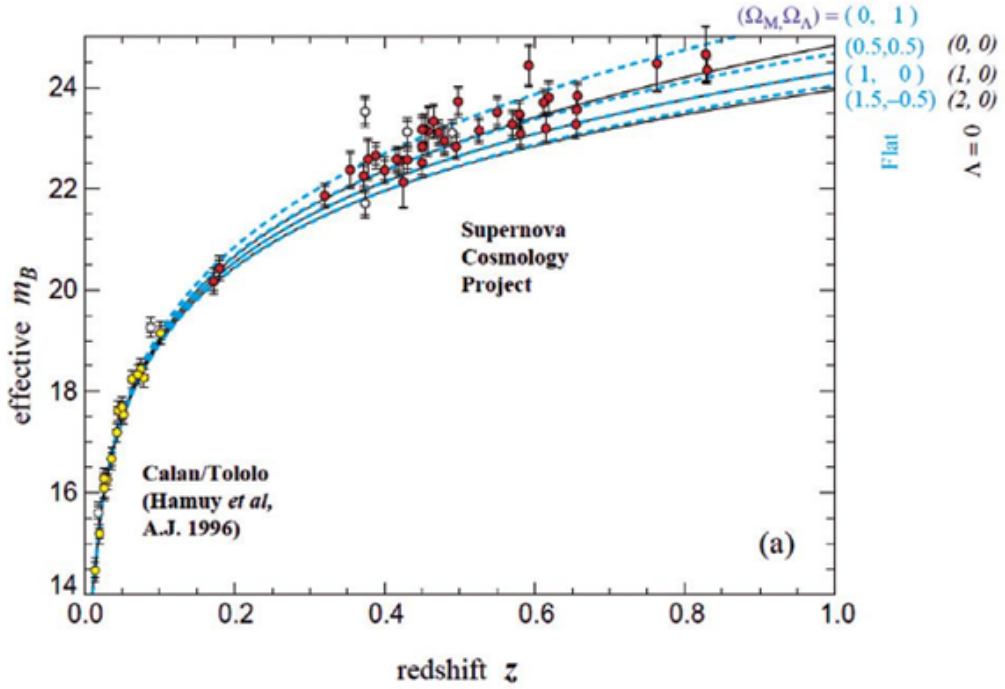
Dark energy

a.k.a the cosmological constant

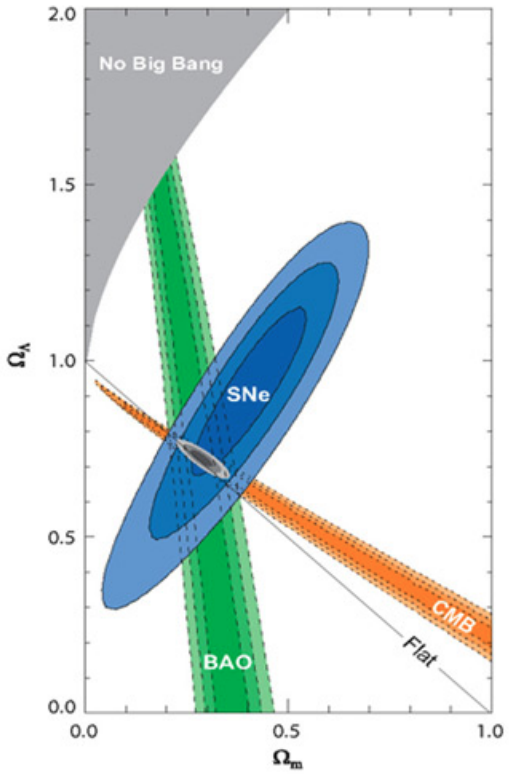


How do we know?





And…


2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
Ω_Λ
Ω_m
No Big Bang
SNe
BAO
CMB
Flat

Einstein's field equations

$$G_{\mu\nu} = \frac{1}{M_{\rm pl}^2} T_{\mu\nu}$$

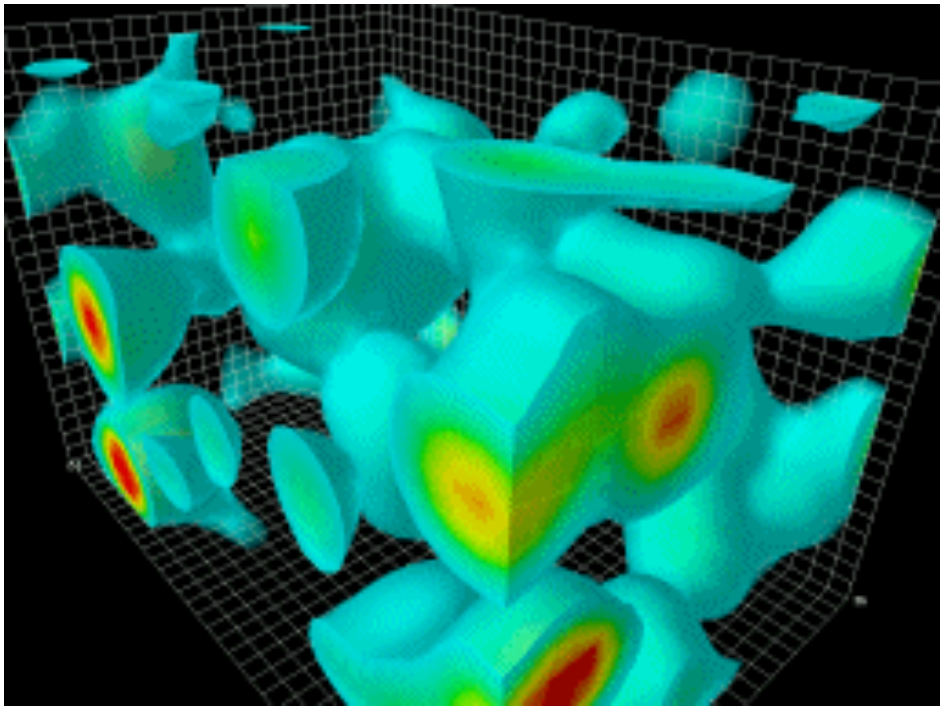
$$M_{\rm pl} \approx 10^{27}\ eV$$

Adding a cosmological constant

$$G_{\mu\nu} = \frac{1}{M_{\rm pl}^2} T_{\mu\nu} - \Lambda g_{\mu\nu}$$

$$\Lambda \approx (10^{-3}\ eV)^4$$

But we don’t get to choose…



What we should see

$$\Lambda_{\text{observed}} = \Lambda_{\text{bare}} + \Lambda_{\text{induced}}$$

$$\Lambda_{\text{observed}} \approx (10^{-3}\ eV)^4$$

$$\Lambda_{\text{induced}} \approx (10^{12}\ \ eV)^4$$
$$= 10^{60}\, \Lambda_{observed}$$

Possible solution 1: fine tuning

$$\Lambda_{\text{observed}} = \Lambda_{\text{bare}} + \Lambda_{\text{induced}}$$

$$\Lambda_{\text{bare}} \approx -(10^{12} \ \ eV)^4$$

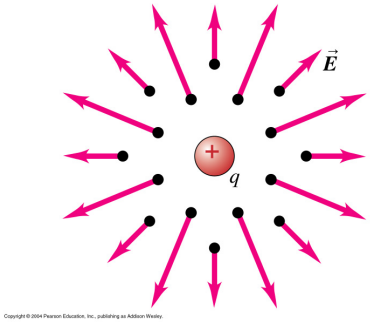
$$\Lambda_{\text{induced}} \approx (10^{12} \ \ eV)^4$$

$$\Longrightarrow \quad \Lambda_{\text{observed}} \approx (10^{-3} \ eV)^4$$

Unnatural!

Possible solution 2:

An analogy: the mass of the electron



$$\vec{E} = \frac{e\hat{\vec{r}}}{4\pi r^2}$$

$$\begin{aligned} \text{Energy} &= \int d^3r \; \vec{E} \cdot \vec{E} \\ &= \int_0^\infty dr \; \frac{e^2}{4\pi r^2} = \infty \end{aligned}$$

An analogy: the mass of the electron

$$\text{Energy} = \int d^3r \; \vec{E} \cdot \vec{E}$$

$$= \int_a^\infty dr \; \frac{e^2}{4\pi r^2} = \frac{e^2}{4\pi a}$$

Size of the electron $a = \dfrac{\hbar}{m_e c}$

Natural if $\dfrac{e^2}{4\pi a} < m_e c^2 \iff \dfrac{e^2}{4\pi\hbar c} < 1$

An analogy: the mass of the electron

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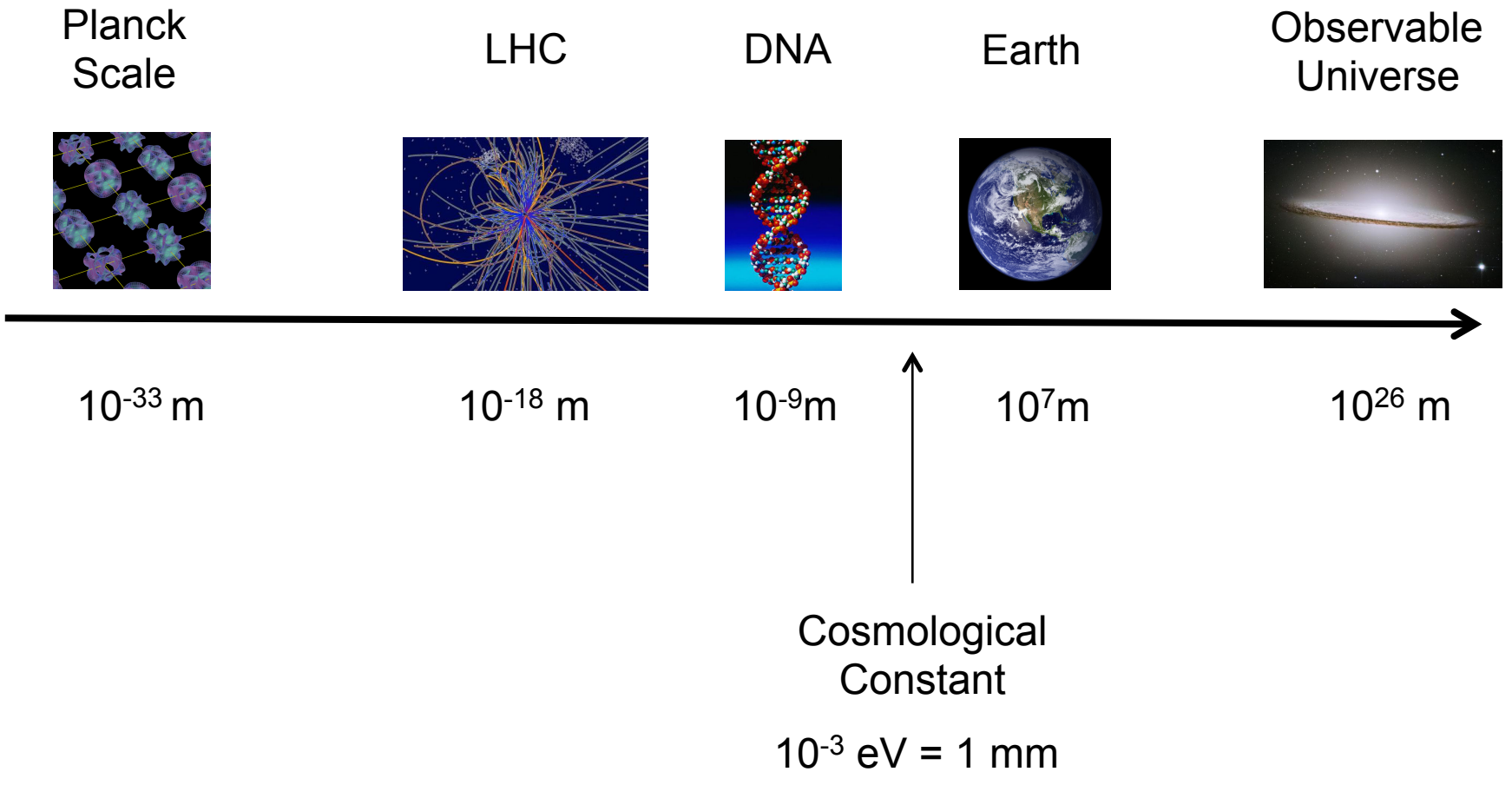
Natural if $\dfrac{e^2}{4\pi a} < m_e c^2 \iff \dfrac{e^2}{4\pi\hbar c} < 1$

$$\frac{e^2}{4\pi\hbar c} \approx \frac{1}{137}$$

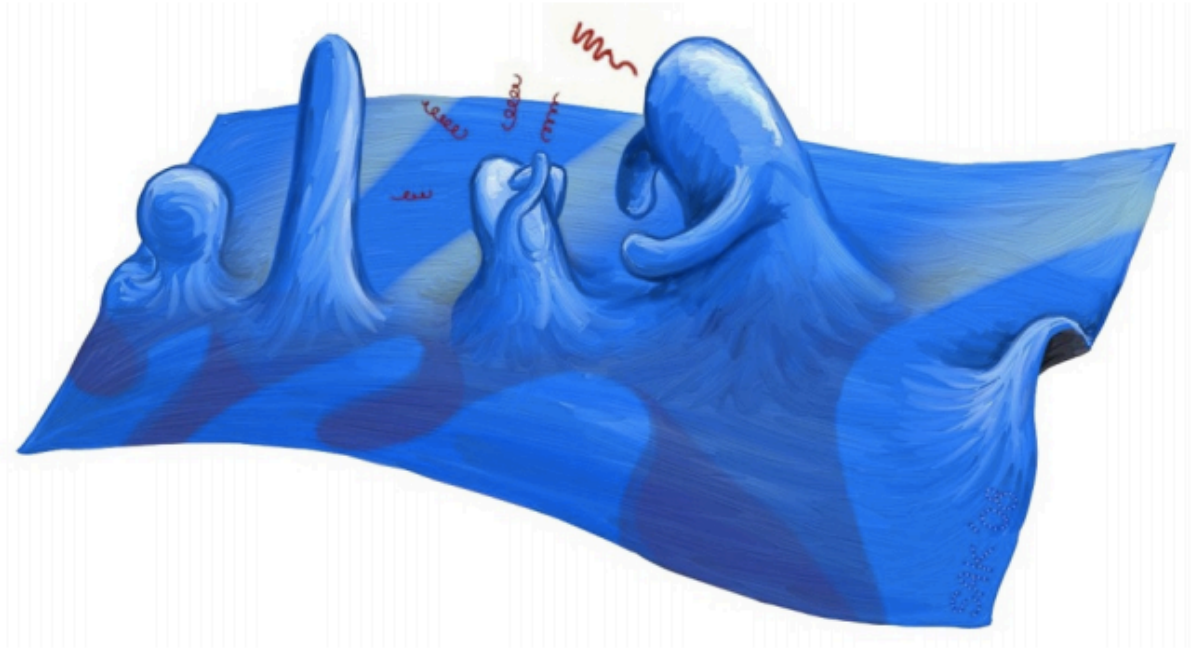
No similar story for dark energy!



And that’s the cosmological constant problem

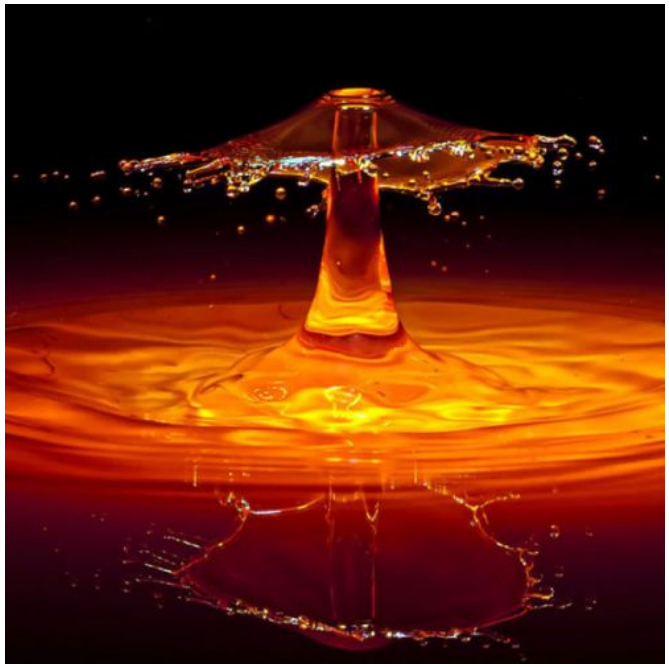
Part II: The Higgs Boson

Fields are primary, particles secondary

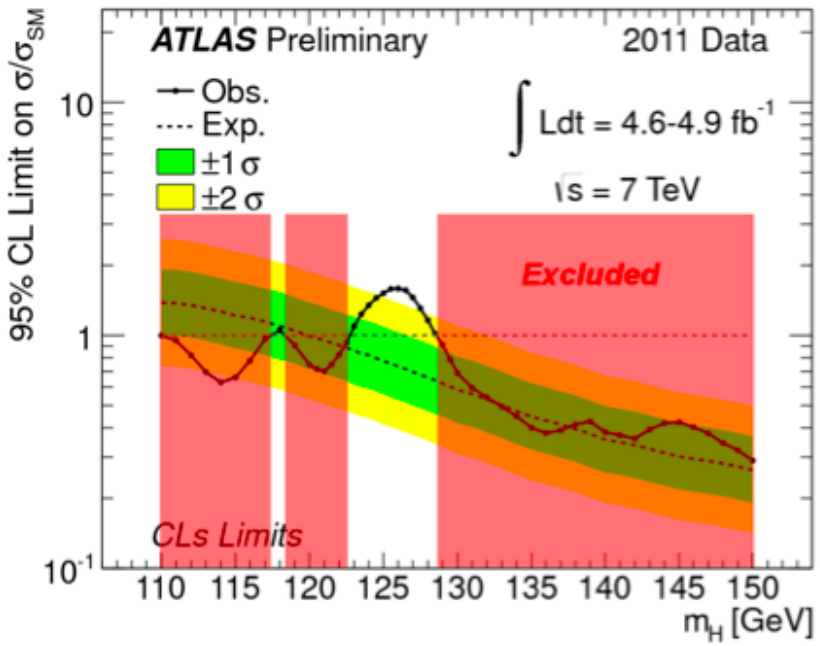


The Higgs field

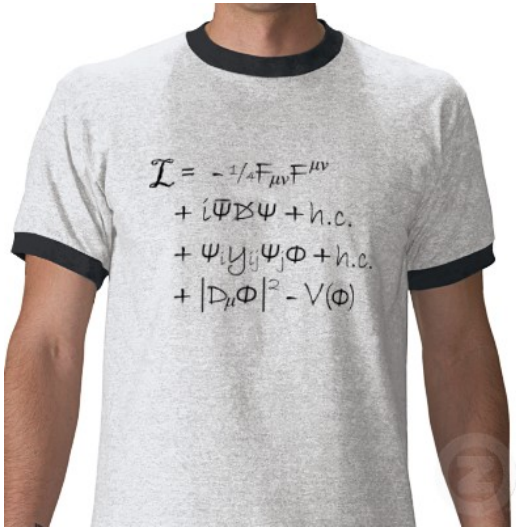
The Higgs particle



The Higgs particle?



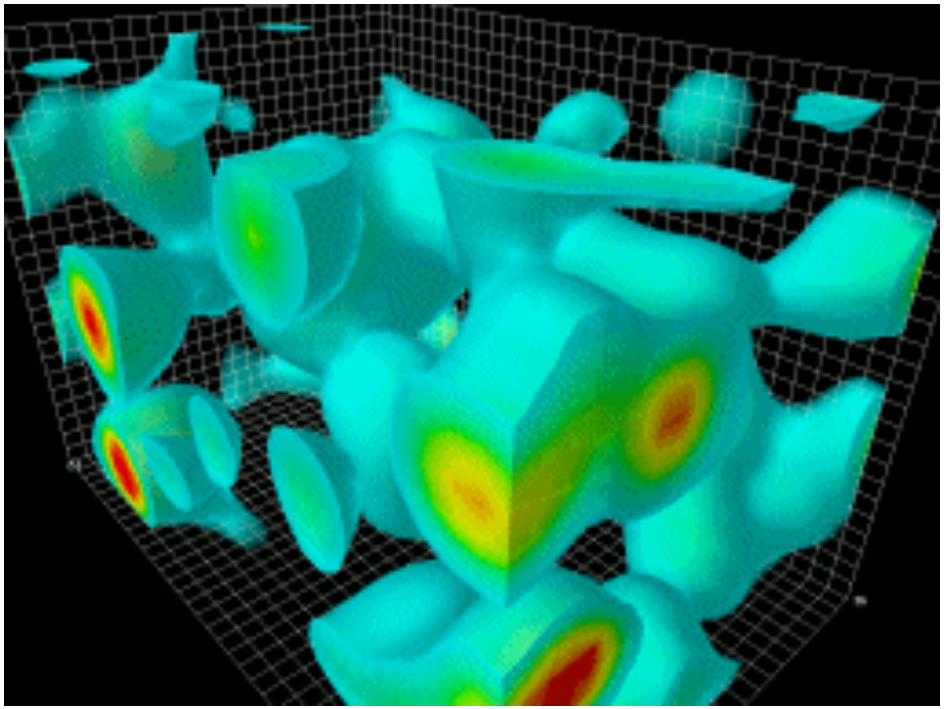
The standard model



$$V(\phi) = m^2\phi^2 + \lambda\phi^4$$

$$m \approx 125\,GeV$$

But we don’t get to choose…



What we should see

$$m_{\text{observed}} = m_{\text{bare}} + m_{\text{induced}}$$

$$m_{\text{observed}} \approx 10^{11}\ eV$$

$$m_{\text{induced}} \approx 10^{27}\ eV$$

$$\approx 10^{16}\, m_{\text{observed}}$$

Possible solution 1: fine tuning

$$m_{\text{observed}} = m_{\text{bare}} + m_{\text{induced}}$$

$$m_{\text{bare}} \approx -10^{27}\ eV$$

$$m_{\text{induced}} \approx 10^{27}\ eV$$

$$\Longrightarrow \quad m_{\text{observed}} \approx 10^{11}\ eV$$

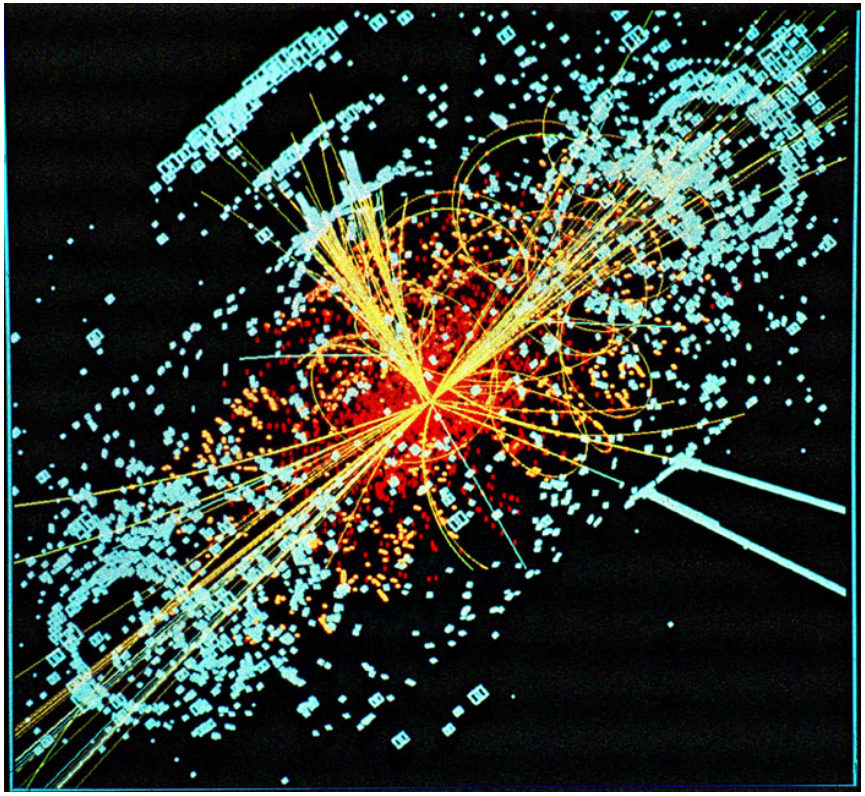
Unnatural!

Possible solutions 2,3,4,5…

- Supersymmetry
- Extra Dimensions
- Technicolor
- Deconstruction
- Many many more

But…

Where are they?



Part III: Living With Fine Tuning

Coincidences Happen

Anthropic principle: live where you can

$$\Lambda_{\text{max}} \approx \Lambda_{\text{observed}}$$

Weinberg

The Multiverse

Part IV: A Better Solution…