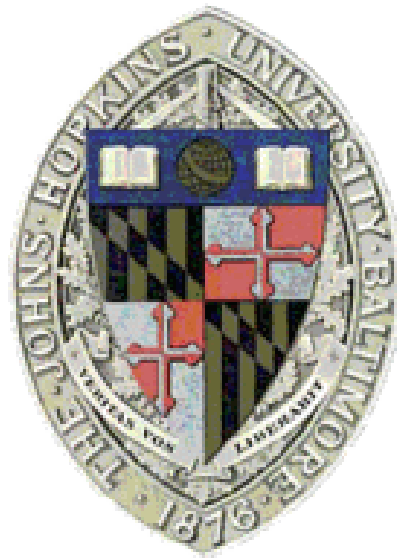


Understanding the Emptiness: Connecting Particle Physics and Cosmology

Andrei Gritsan

Johns Hopkins University



November 3, 2018

RASA-America Conference 2018
George Washington University, DC

In the last 10 years...

General Relativity

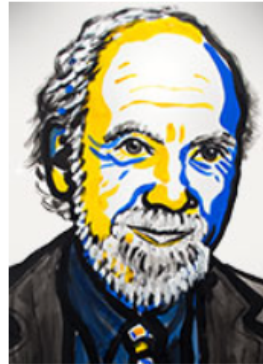
Dark energy?

The Nobel Prize in Physics 2017

gravity waves



© Nobel Media. Ill. N. Elmehed
Rainer Weiss
Prize share: 1/2



© Nobel Media. Ill. N. Elmehed
Barry C. Barish
Prize share: 1/4



© Nobel Media. Ill. N. Elmehed
Kip S. Thorne
Prize share: 1/4

The Nobel Prize in Physics 2017 was divided, one half awarded to Rainer Weiss, the other half jointly to Barry C. Barish and Kip S. Thorne "for decisive contributions to the LIGO detector and the observation of gravitational waves".

The Nobel Prize in Physics 2011

dark energy



Photo: U. Montan
Saul Perlmutter
Prize share: 1/2



Photo: U. Montan
Brian P. Schmidt
Prize share: 1/4



Photo: U. Montan
Adam G. Riess
Prize share: 1/4

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae".

Higgs

Electro-Weak

The Nobel Prize in Physics 2013

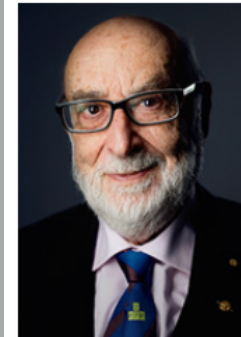


Photo: A. Mahmoud
François Englert
Prize share: 1/2



Photo: A. Mahmoud
Peter W. Higgs
Prize share: 1/2

Higgs boson

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

The Nobel Prize in Physics 2008



Photo: University of Chicago
Yoichiro Nambu
Prize share: 1/2



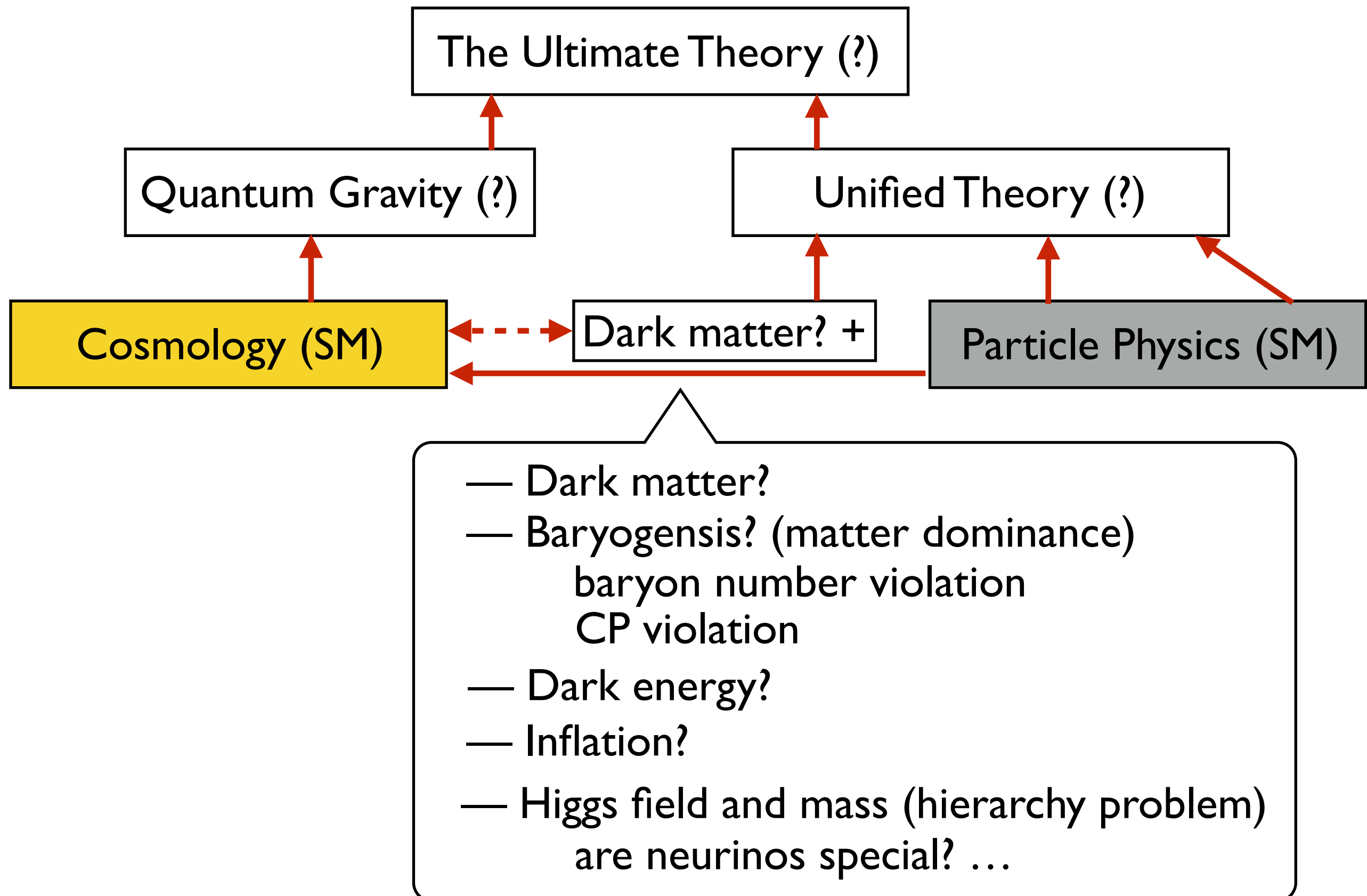
© The Nobel Foundation
Photo: U. Montan
Makoto Kobayashi
Prize share: 1/4



© The Nobel Foundation
Photo: U. Montan
Toshihide Maskawa
Prize share: 1/4

The Nobel Prize in Physics 2008 was divided, one half awarded to Yoichiro Nambu "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics", the other half jointly to Makoto Kobayashi and Toshihide Maskawa "for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature".

Vision of the World by a Physicist



Idea - the Higgs Field

- The **Higgs particle** cluster created from the **Higgs field**

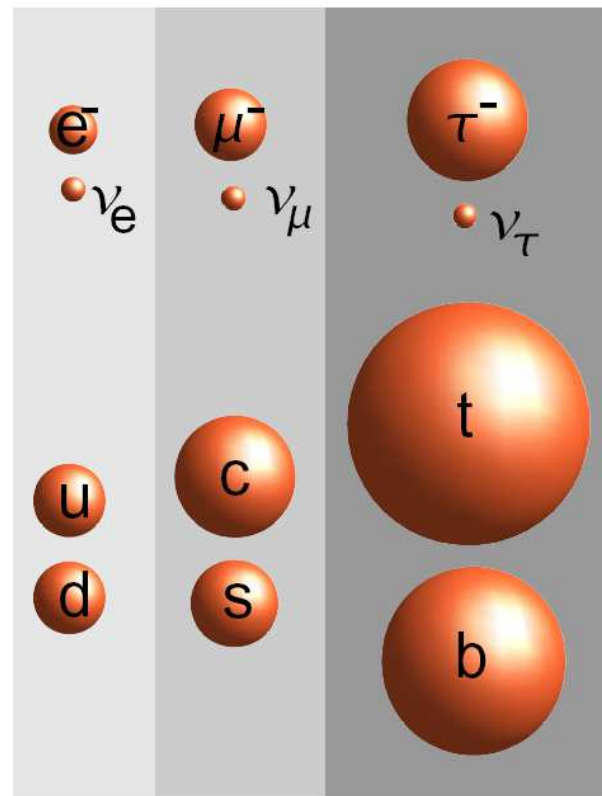


All Elementary Particles get Mass from Higgs Field

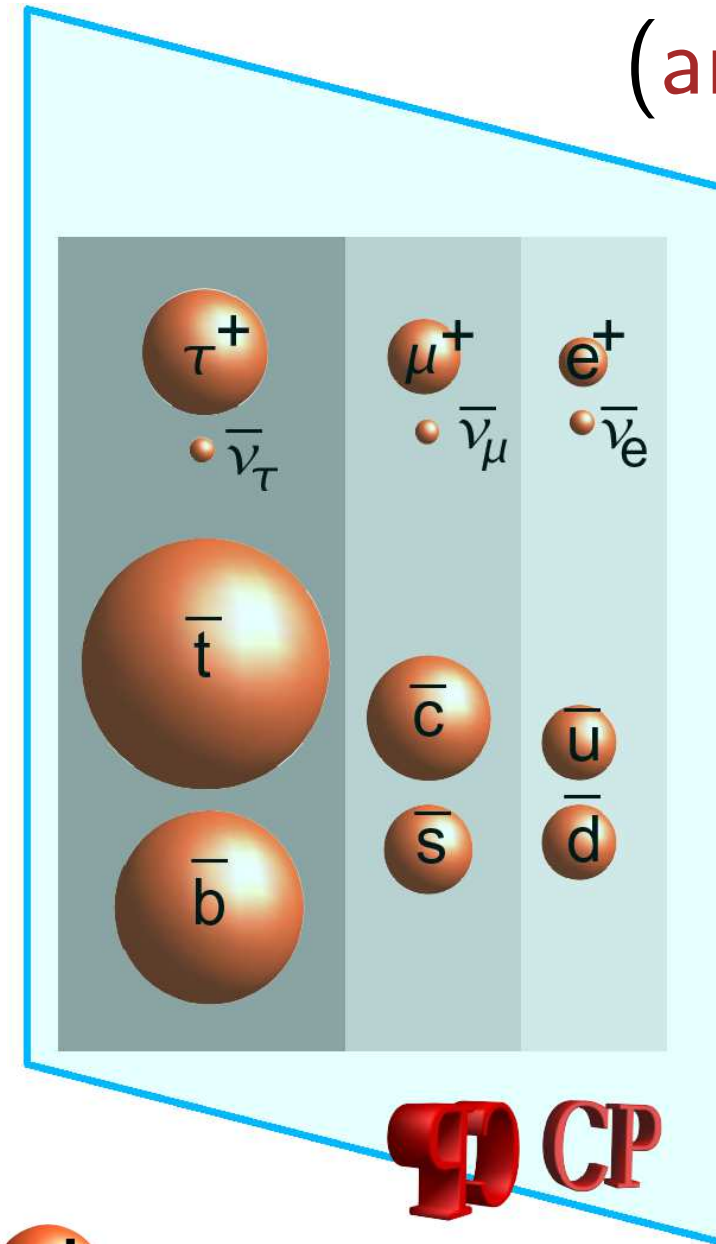
- Fermions $S = \frac{\hbar}{2}$ (matter)

leptons

quarks

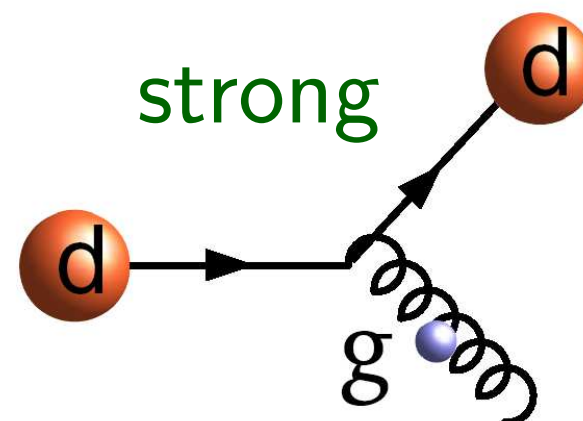
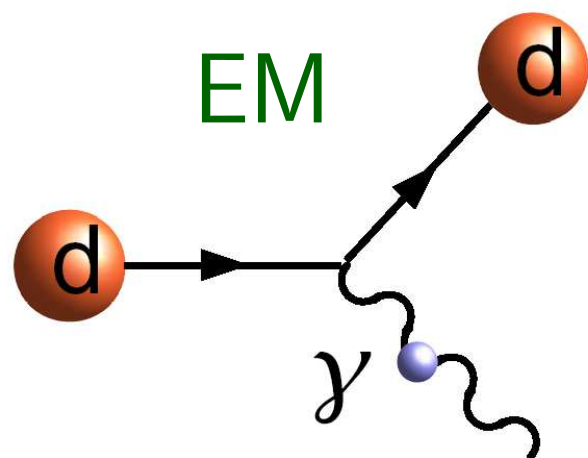


(anti-matter)



CP

- Bosons $S = \hbar$ (force carries):

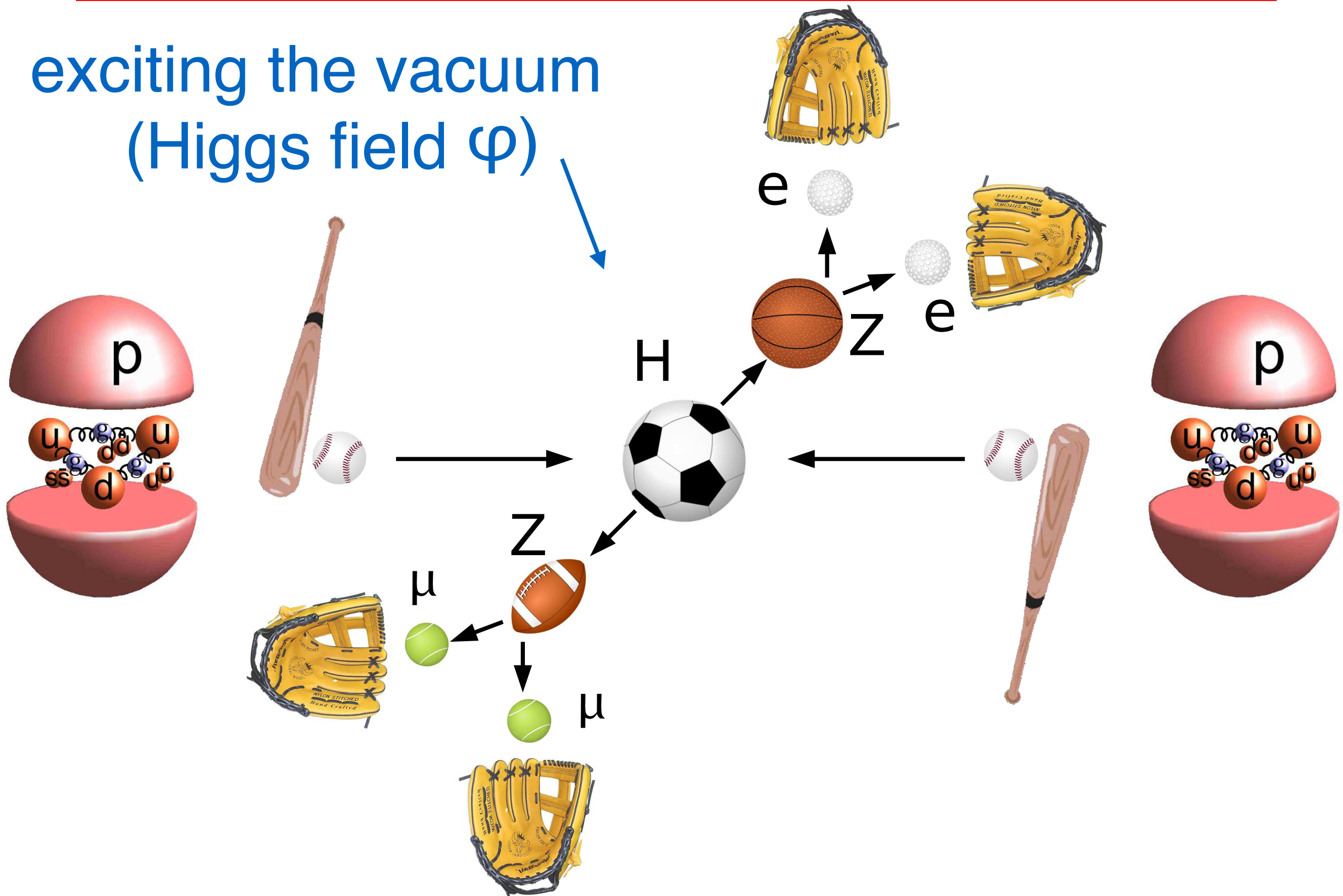


← massless

(weak force bosons mass)

The Experiment

exciting the vacuum
(Higgs field φ)



The Large Hadron Collider

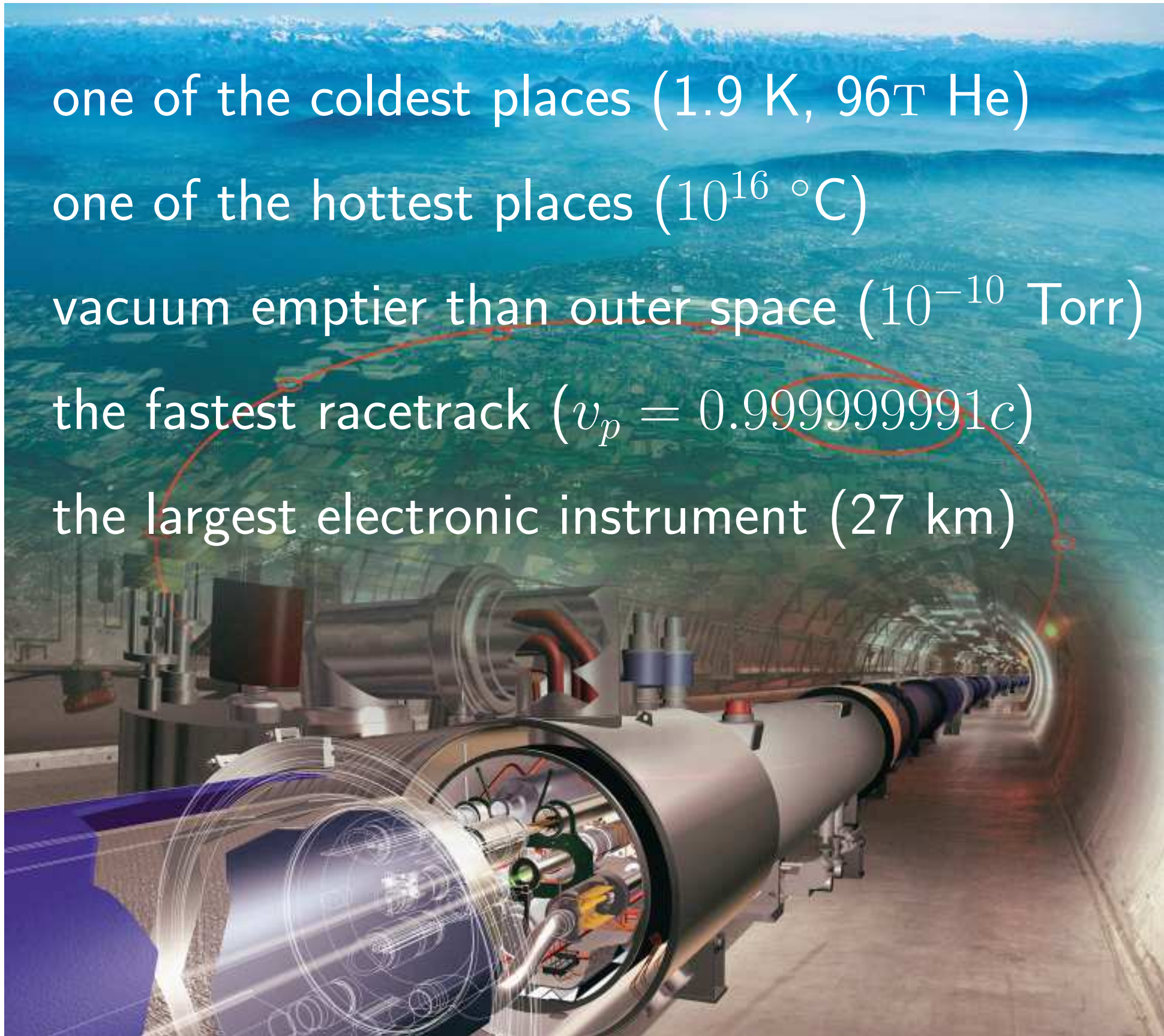
one of the coldest places (1.9 K, 96T He)

one of the hottest places (10^{16} °C)

vacuum emptier than outer space (10^{-10} Torr)

the fastest racetrack ($v_p = 0.9999999991c$)

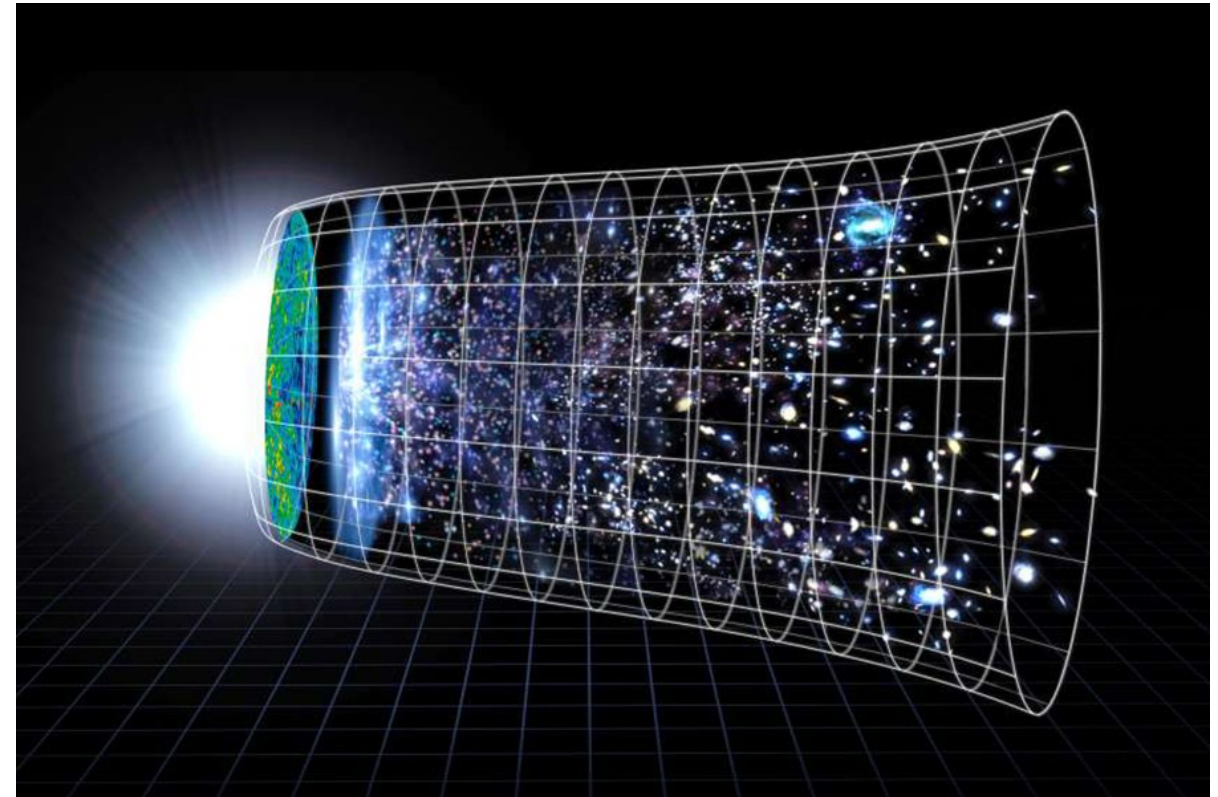
the largest electronic instrument (27 km)



Recently in the News



Adam Riess (JHU)



Hubble's constant

Question

Cosmology (SM)

Particle Physics (SM)

What could mismatch mean? Increase radiation density, expansion rate...

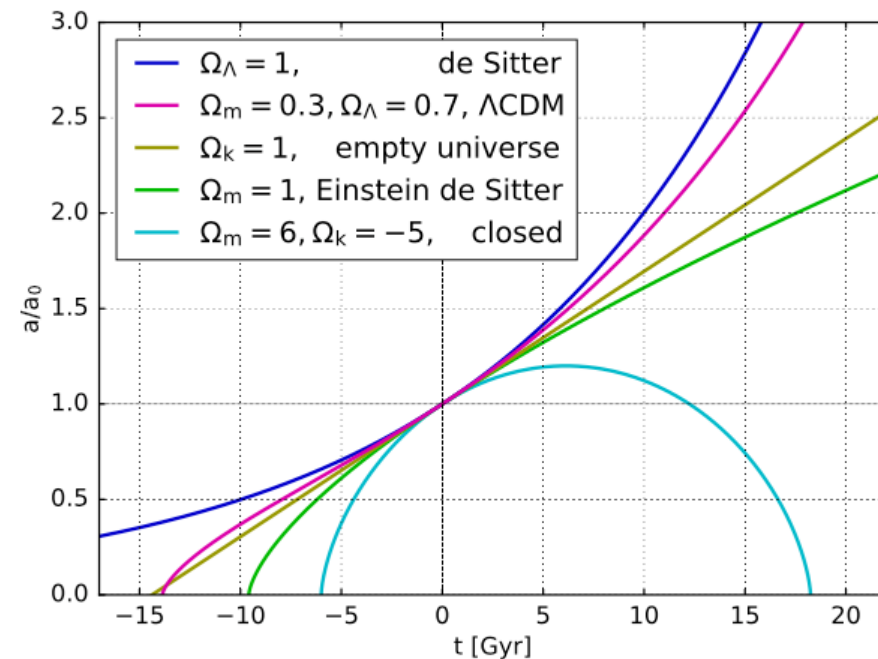
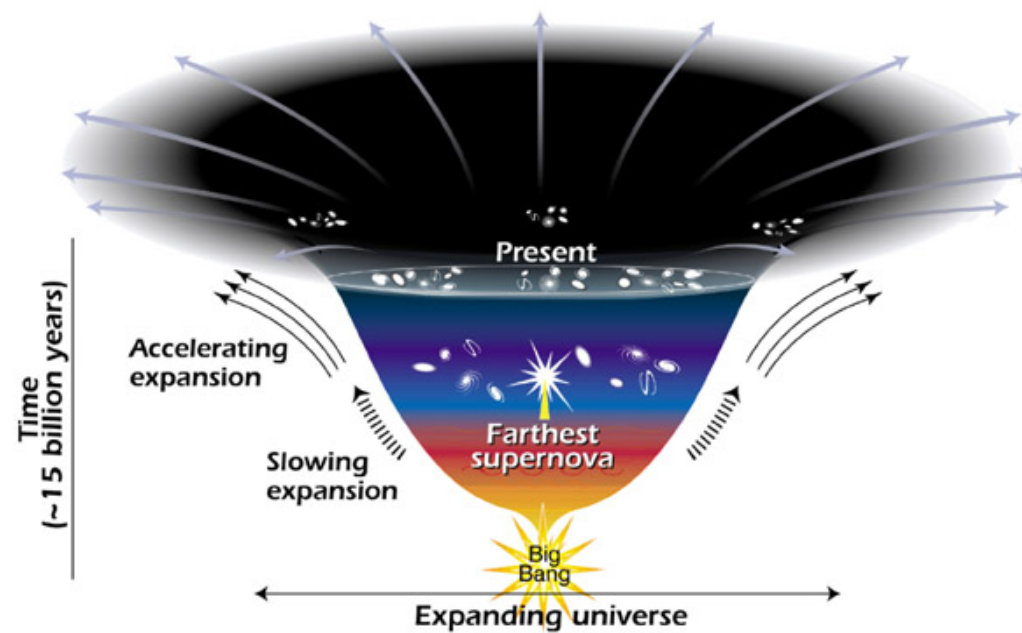
- existence of sterile neutrino? (not yet detected)
- stronger interaction of dark matter?
- dark energy more exotic?

Perhaps unaccounted systematic uncertainties?

Perhaps a third method based on gravitational wave detection could help?

Quiz

- What is the age of our Universe?
~14 billion years, according to SM of Cosmology

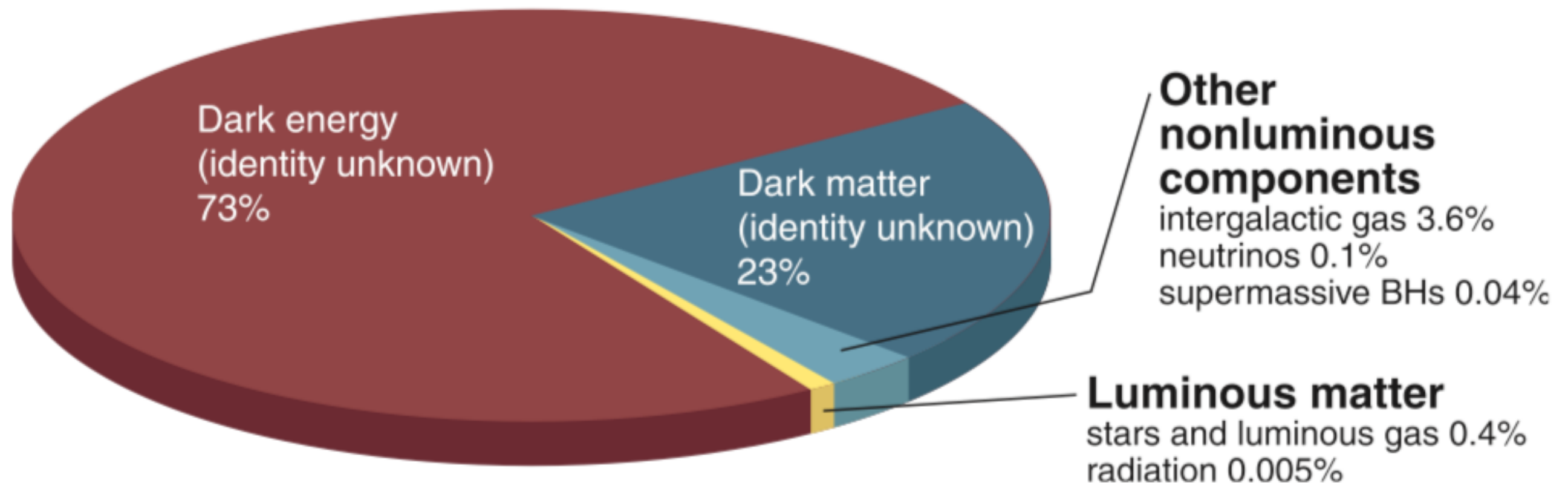


- Did it start from a single point at Big Bang?
no, it started from a high-density, high-temperature state
metric expanded $R(t)$, but still not a point (infinite if flat $k=0$)

$$ds^2 = dt^2 - R^2(t) \left[\frac{dr^2}{1 - kr^2} + r^2 (d\theta^2 + \sin^2 \theta d\phi^2) \right]$$

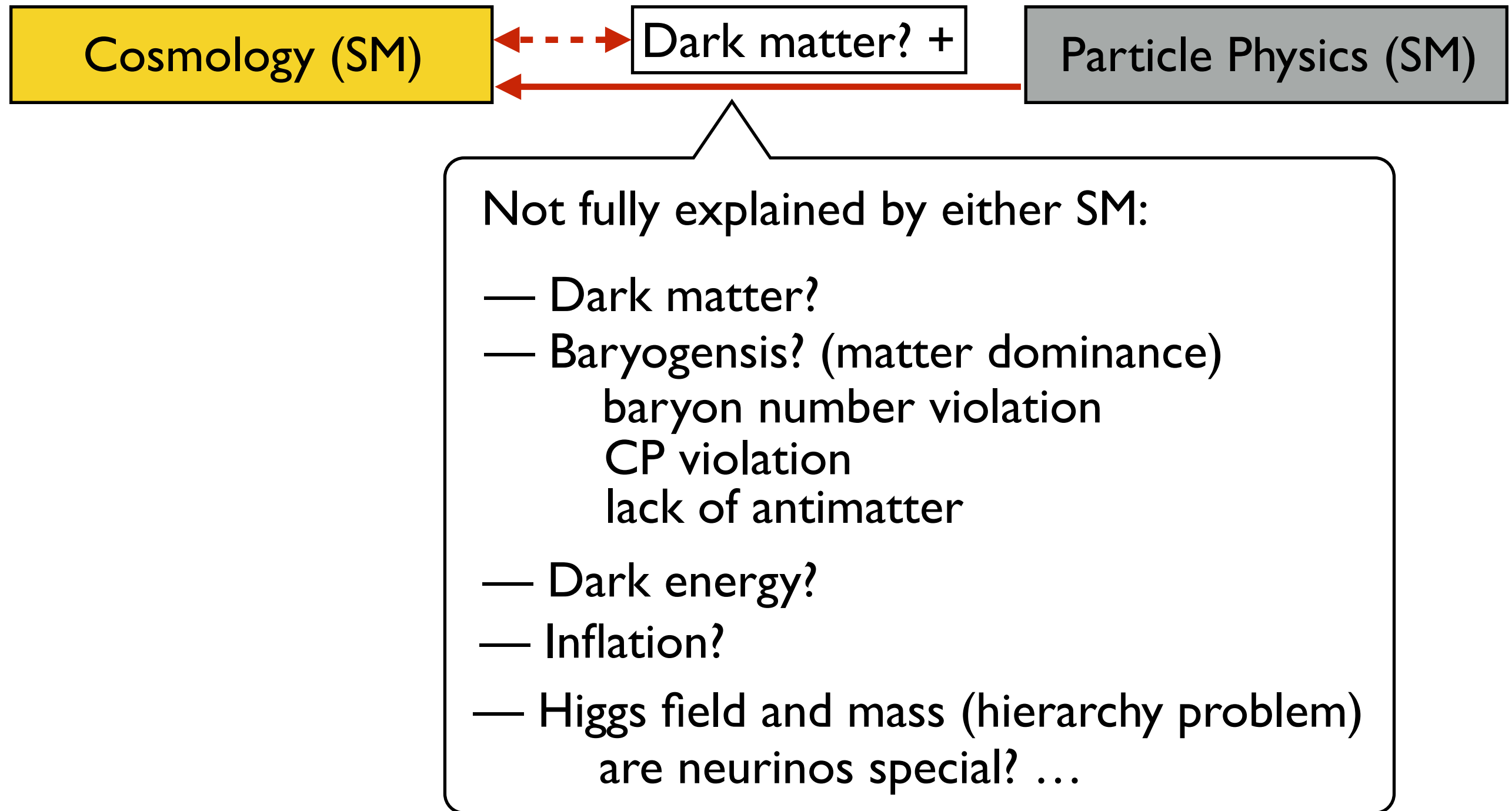
Quiz: relative to the total mass-energy balance

- Fraction of luminous matter in our Universe 0.4%
- Fraction of known matter in our Universe 4%
- Fractions of antimatter in our Universe $\sim 0\%$
- Fraction of dark matter in our Universe 23%
- Fraction of dark energy in our Universe 73%



<http://science.sciencemag.org/content/sci/300/5627/1909.full.pdf>

Recap: Current confusion in Standard Model(s)



Trying to approach from both directions
scalar field(s) may be at the core of solutions, Higgs field is the first observed