THE FIRST THREE MINUTES

A detective story

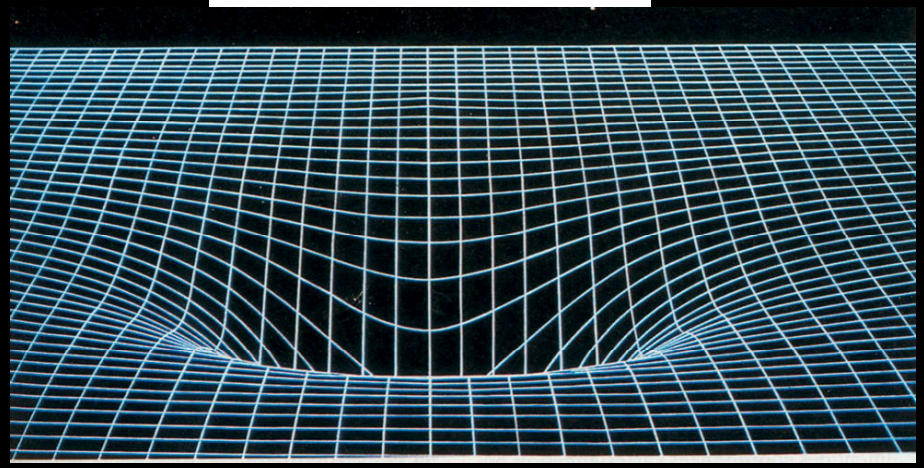
Rolf Landua
CERN

Standard Model of Cosmology

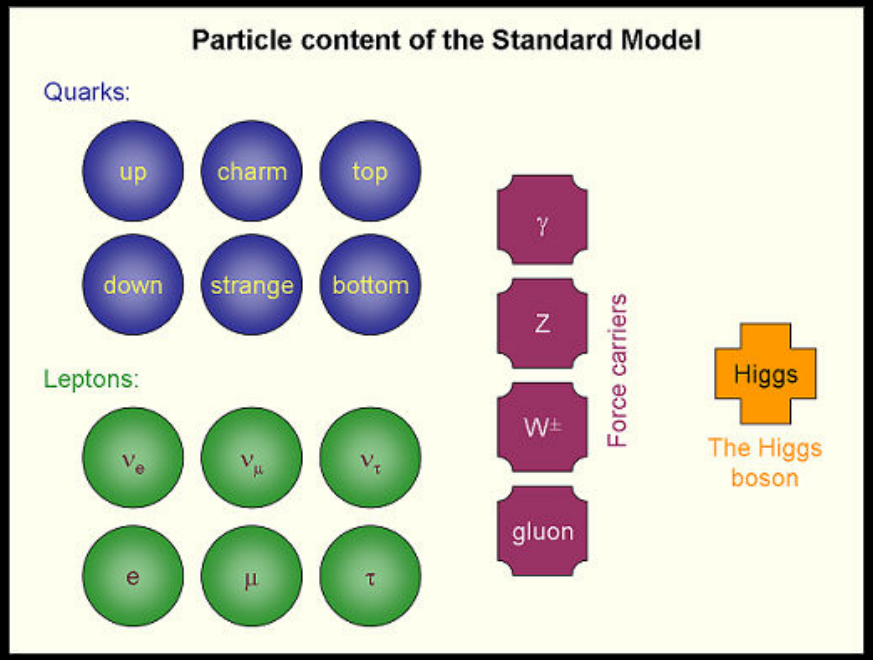
General Relativity

Matter tells Space how to curve
Space tells Matter how to move

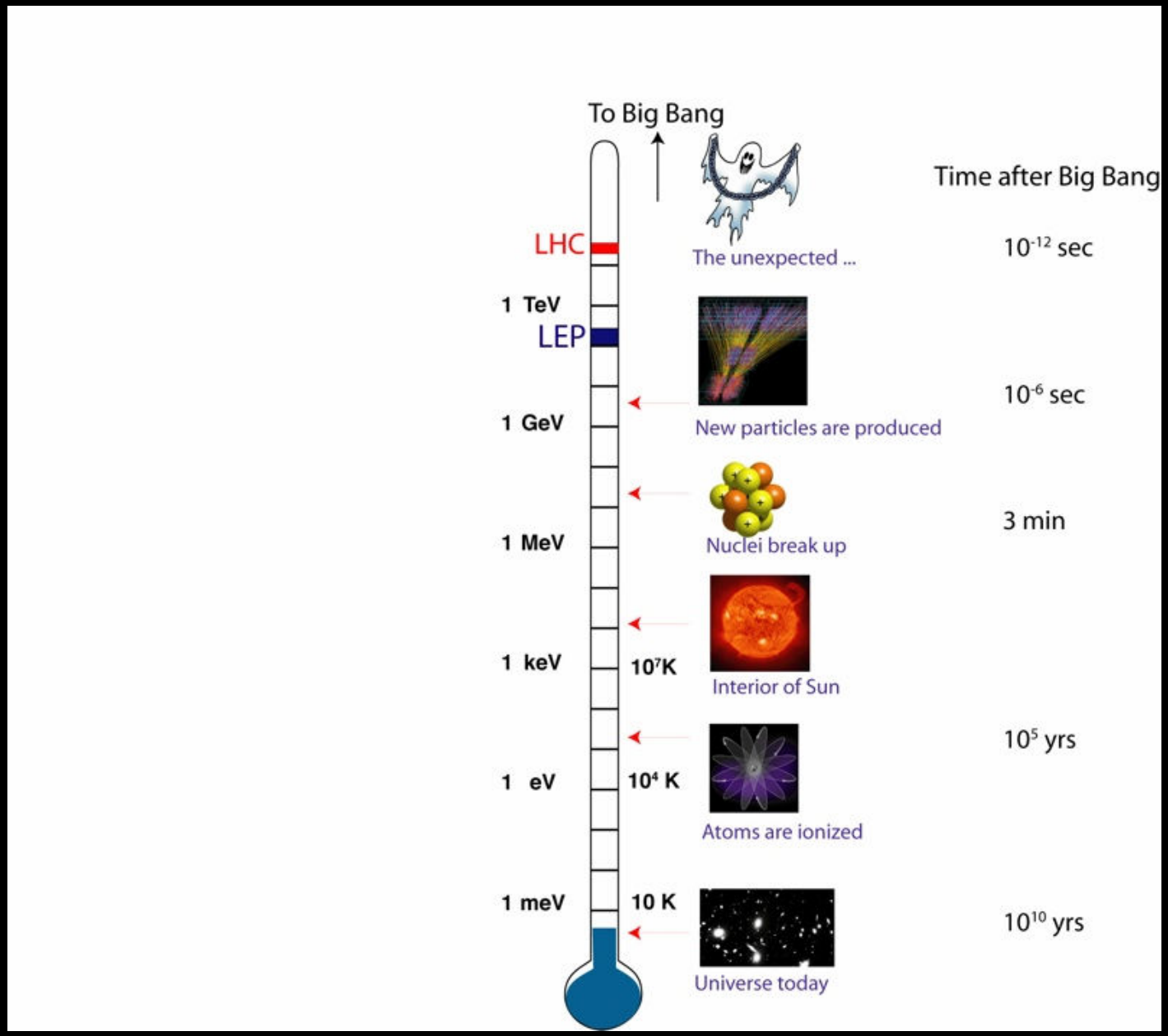
$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



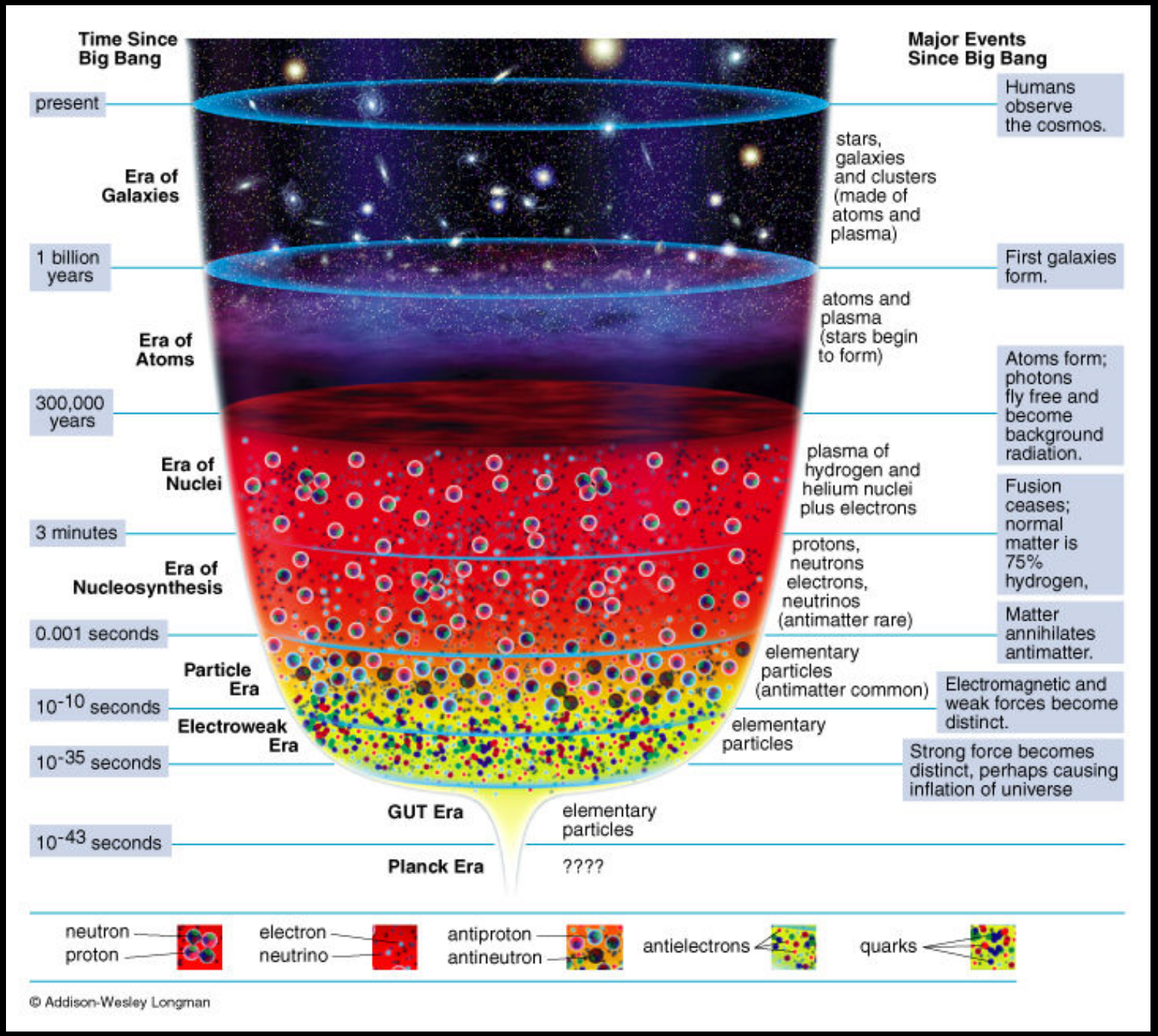
Standard Model of Particle Physics



Phenomena at different 'temperatures'



The reconstruction of the History of the Universe



Main phases for particle physics

Nucleosynthesis (3 min)

Antimatter disappearance (10^{-6} - 1 sec)

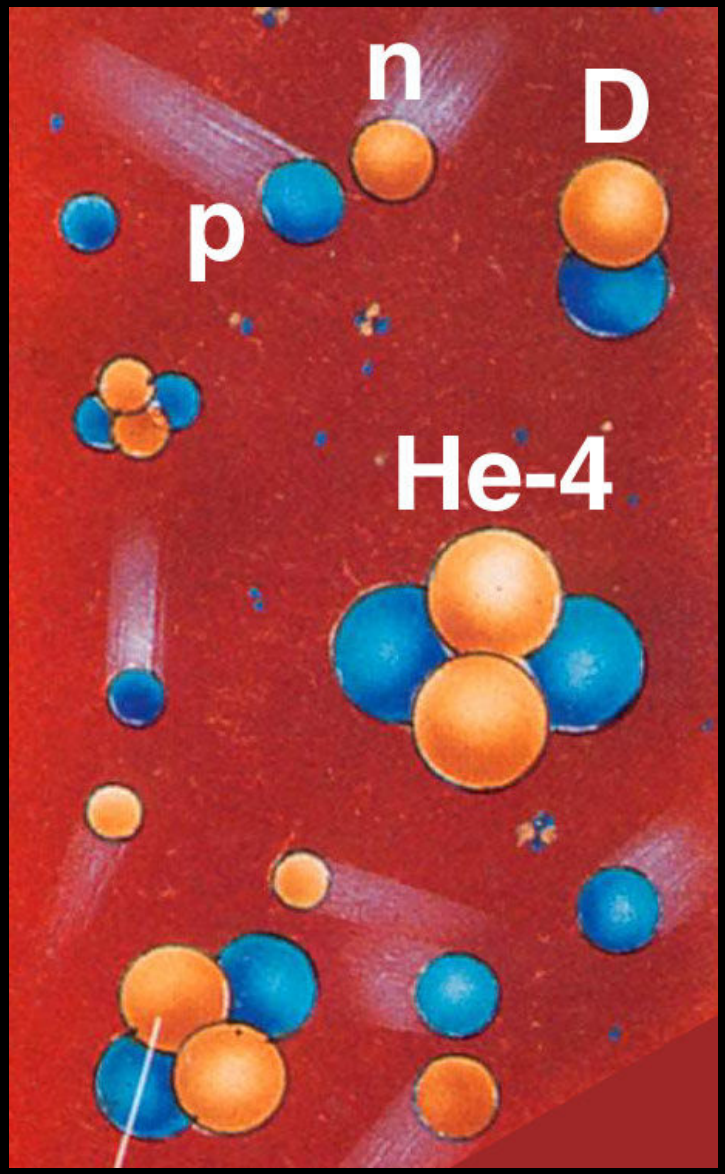
Electroweak symmetry breaking (10^{-12} sec)

Higgs field

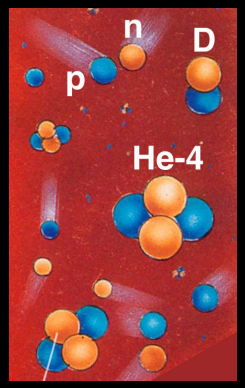
Dark matter - Supersymmetry ?

Surprises ?

Nucleosynthesis (3 min ~ 1 MeV)

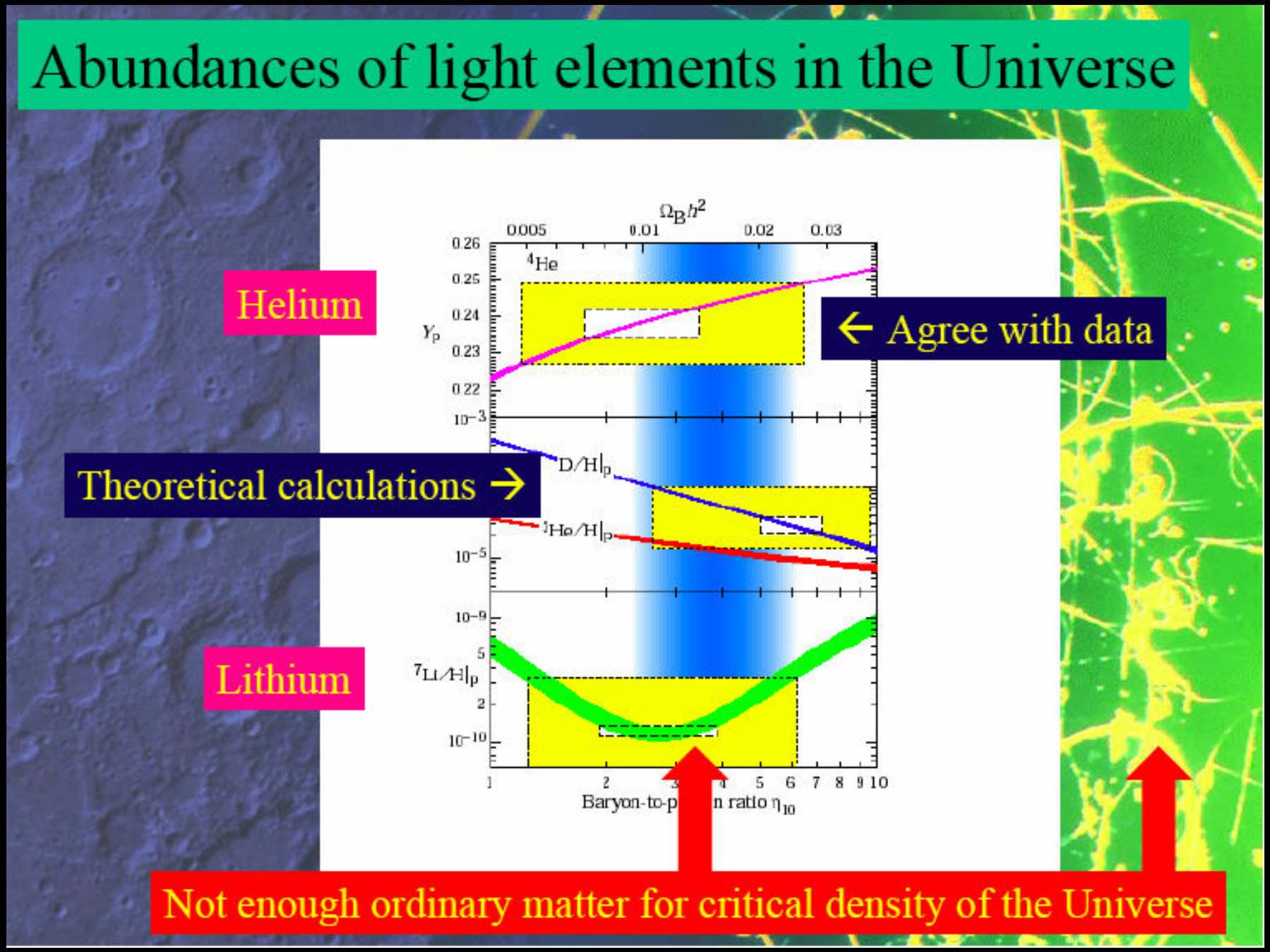


Nucleosynthesis (3 min ~ 1 MeV)



- Universe contains about 24% He-4
  and less D, He-3, Li-7
- Could only have been cooked by nuclear reactions in dense early Universe
  when Universe billion times smaller, hotter than today
- Dependent on amount of matter in Universe
  not enough to stop expansion, explain galaxies
- Dependent on number of particle types
  number of different neutrinos measured at accelerators

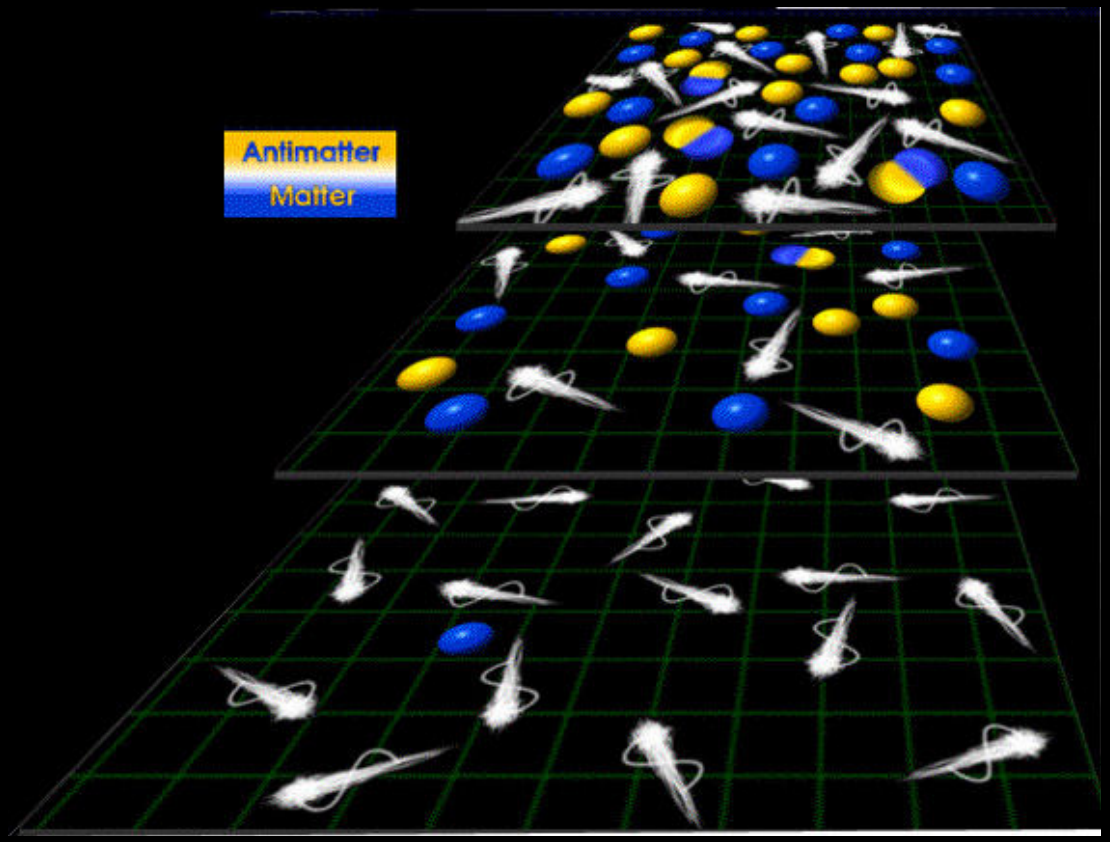
Nucleosynthesis (3 min ~ 1 MeV)



Antimatter disappearance

10^{-6} - 1 sec

Antimatter disappearance 10^{-6} - 1 sec



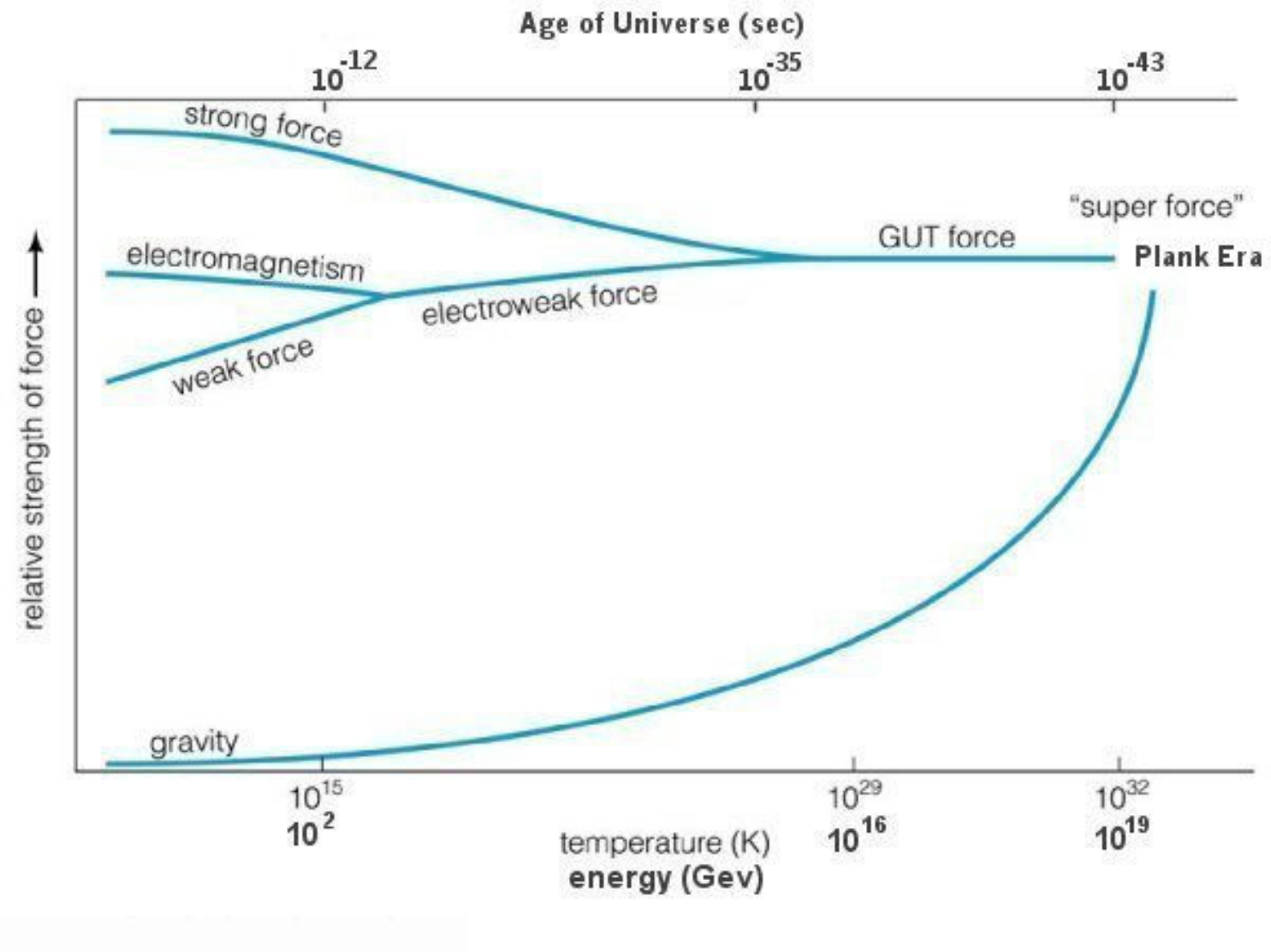
- Transformation of energy into mass
- 50% matter - 50% antimatter
- should have destroyed each other
- leaving only radiation ...

BUT:

- there's something left !

There must be a small difference between matter and antimatter - but was exactly is it? (LHCb experiment)

Electroweak symmetry breaking 10^{-10} sec



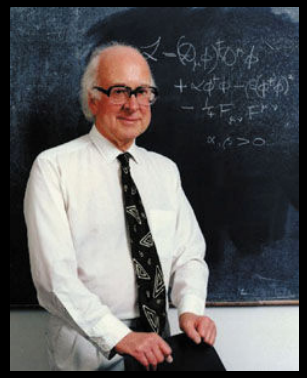
Higgs field

10^{-12} sec ~ 1 TeV (LHC Energy)

HIGGS FIELD

The Standard Model without the Higgs field (or something similar) does not make any sense:

either particles have no masses; or if they are given masses, the mathematics of the theory collapses



Peter Higgs

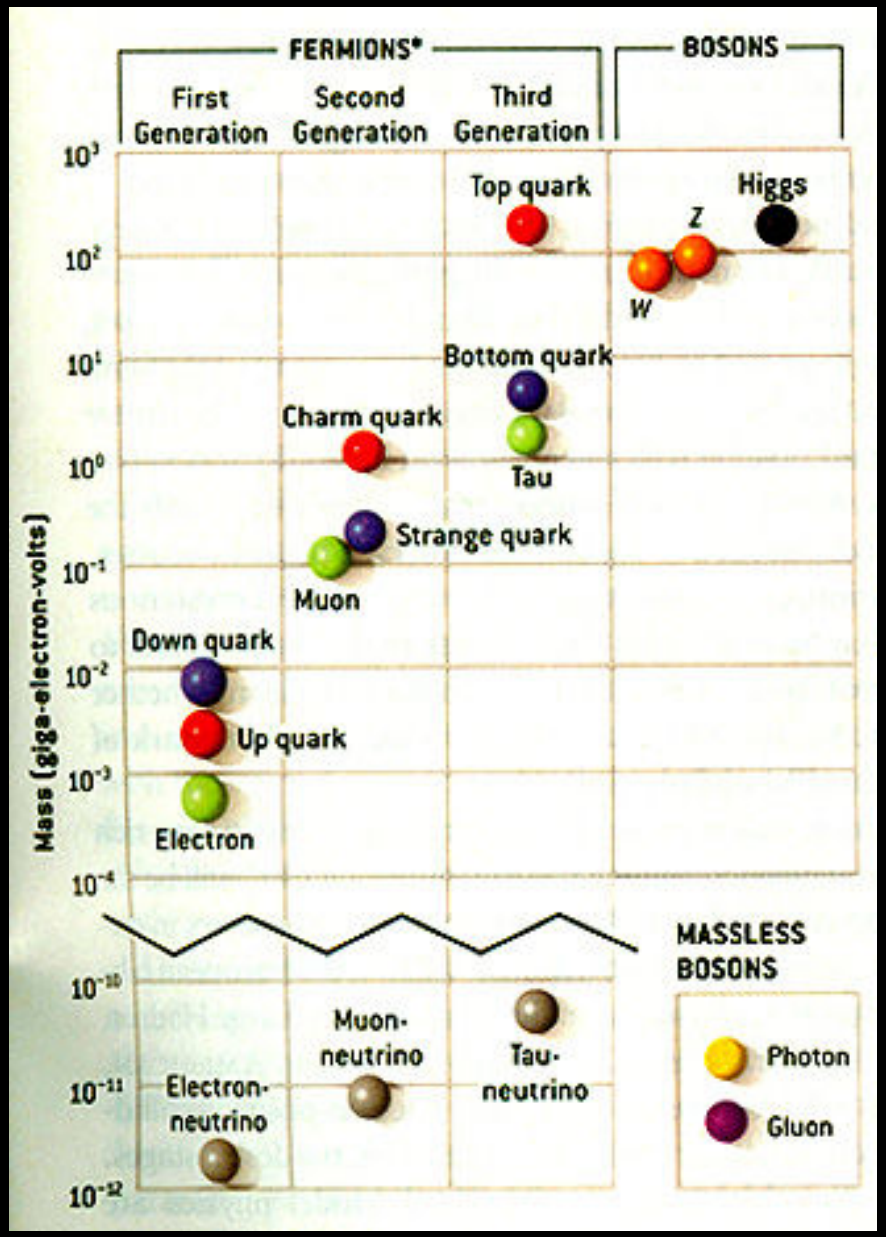
1 TeV →

100 GeV →

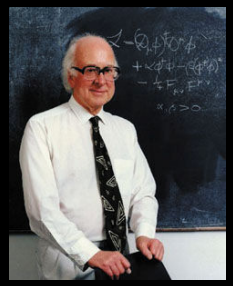
1 GeV →

1 MeV →

0.01 eV →



The Higgs Field



Sir Peter Higgs

- it fills all of space since the ‘spontaneous symmetry breaking’ at Big Bang
- it is a new type of interaction giving their specific mass to all particles
- it is something like a ‘cosmic DNA’

♥David Miller

A cocktail party ...

.. a famous guest wants to cross the room...

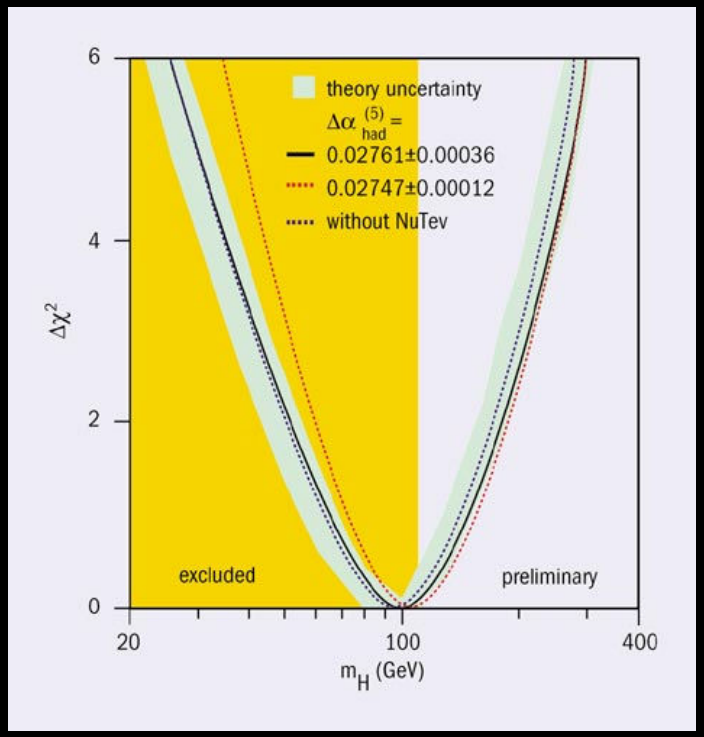
.. but everybody wants an autograph - the guest is difficult to accelerate...

The Higgs field ...

... a new particle is created ...

... the Higgs field gives the particle its ‘inertia’ ...

... and the Higgs boson ?



A rumour originates ...

The Higgs field is excited and receives energy....

.. many guest clump together to discuss the rumour...

... which produces a "real" field particle ...

Indirect evidence ('vacuum fluctuations involving the Higgs particle') predicts that the mass of the Higgs particle should be less than ~200 GeV.

Supersymmetry = Dark Matter ?

10^{-12} sec ~ 1 TeV (LHC Energy)

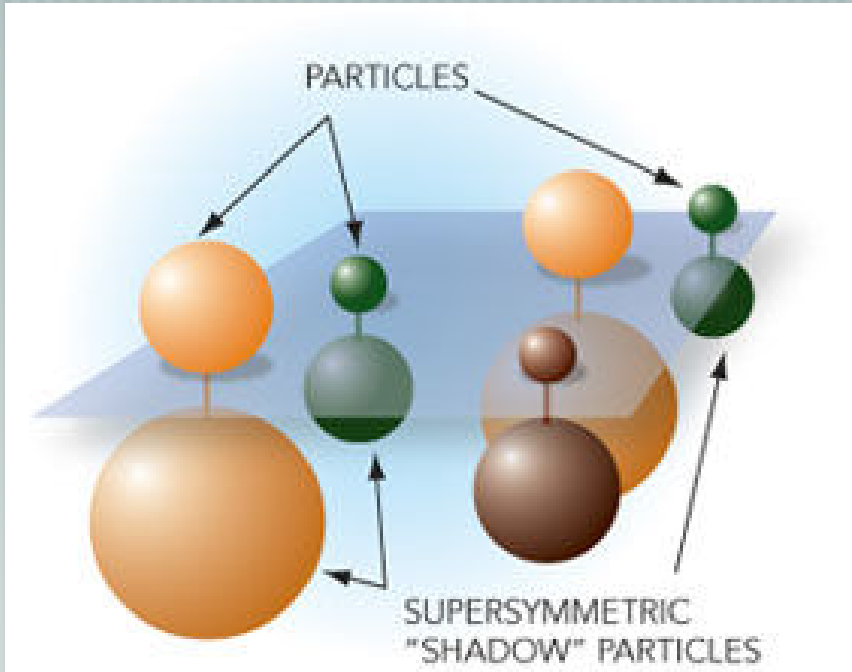
Supersymmetry :
a new symmetry, between particles and fields

'Matter' particles (Spin 1/2=fermion) interact by exchanging 'field' (Spin 1=boson) particles:

Is there a deeper SUPERSYMMETRY between matter and fields? If yes:

all matter particles have a field partner
all field particles have a matter partner

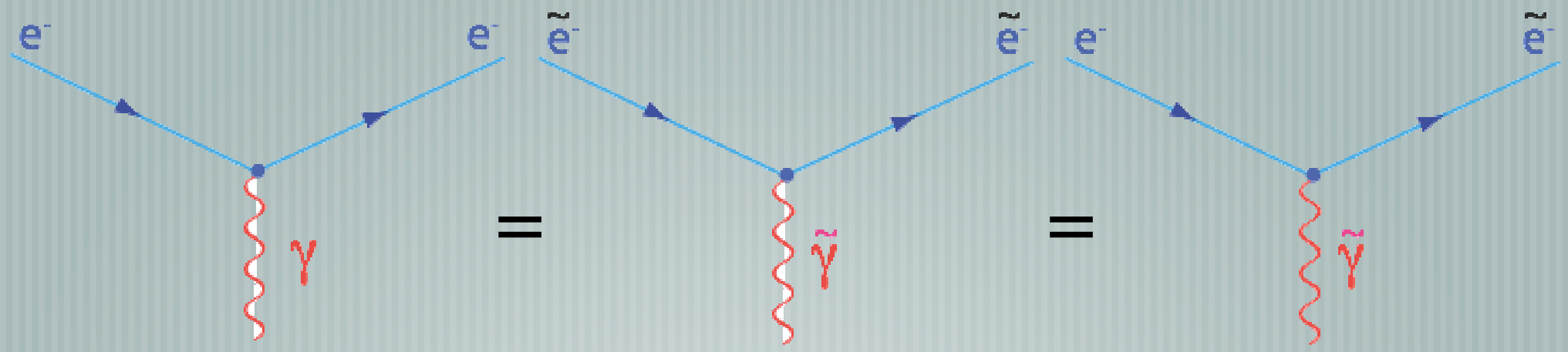
Spin 1/2	Integer spin
electron	selectron (S=0)
quark	squark (S=0)
photino	photon (S=1)
gluino	gluon (S=1)



If they exist - they must be VERY MASSIVE (> 200 GeV)

If Nature was supersymmetric, then:

Particles and their Super-Partners can be interchanged



e = electron

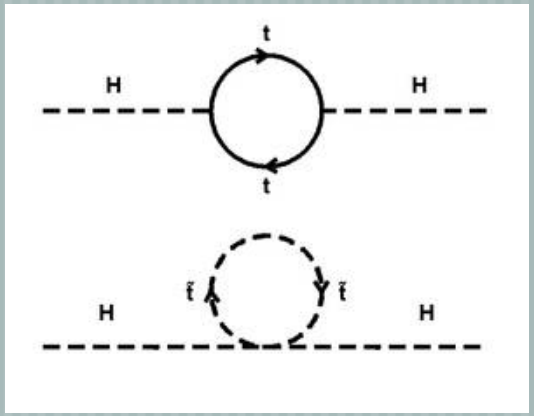
© = photon

ẽ = selectron

© = photino

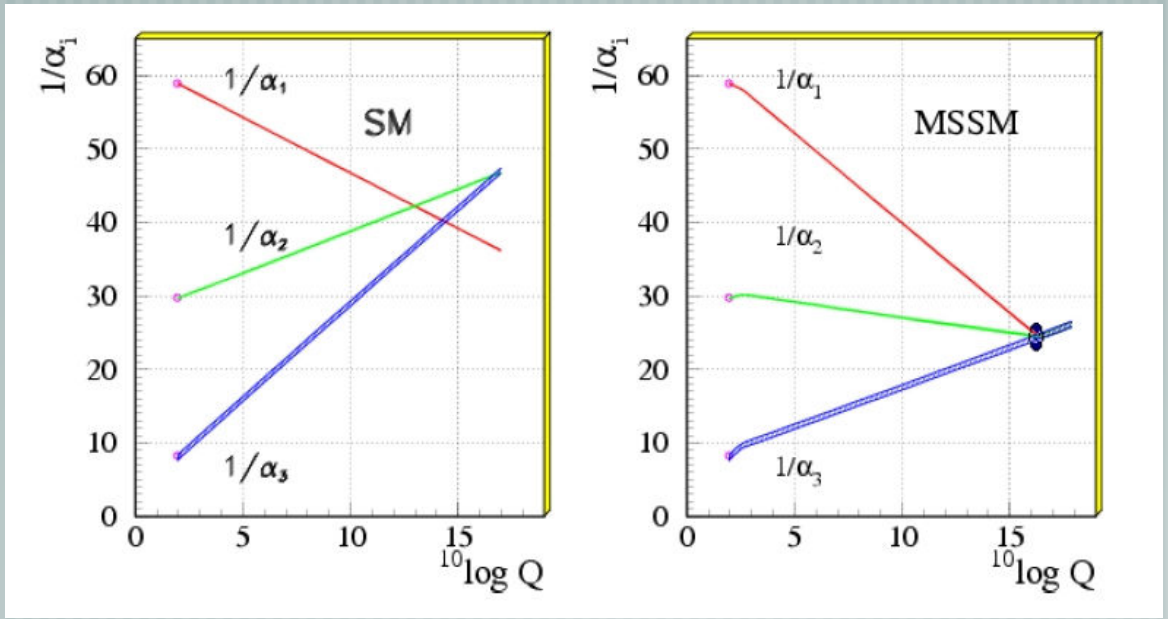
Good reasons for Supersymmetry

1) A fundamental symmetry of space and time



2) "Protection" of SM particle masses (< 10^3 GeV)
from vacuum fluctuations up to Planck Scale (10^{19} GeV)

3) Suggests unification of three forces at a single unification point (~10^{17} GeV)

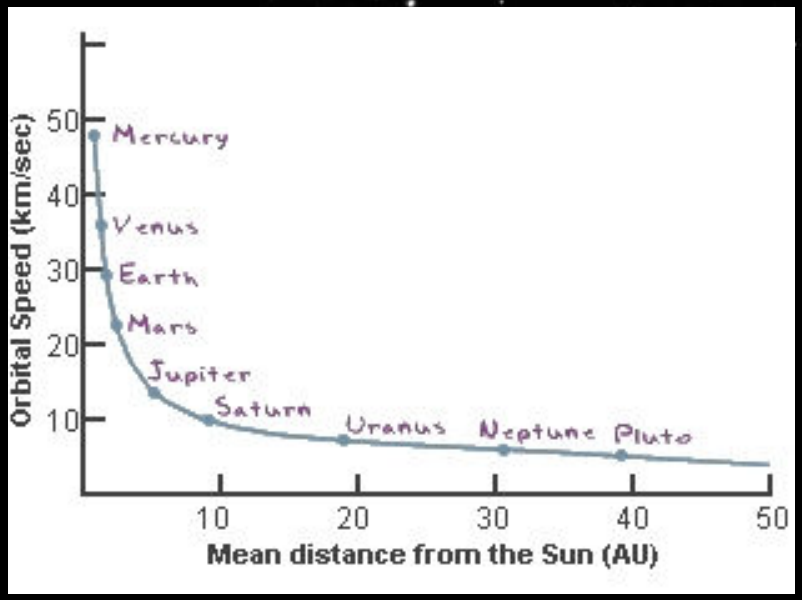


4) Possible explanation of cosmological matter-antimatter asymmetry

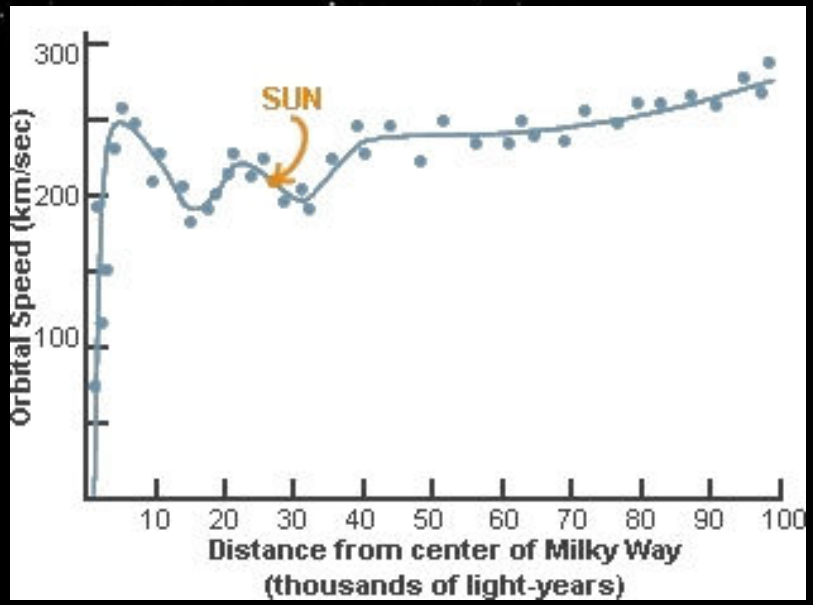
5) **Dark matter** ?

EVIDENCE FOR “DARK MATTER”

Orbital speed vs Distance from center
(Kepler - expect $r^{-1/2}$ dependence)

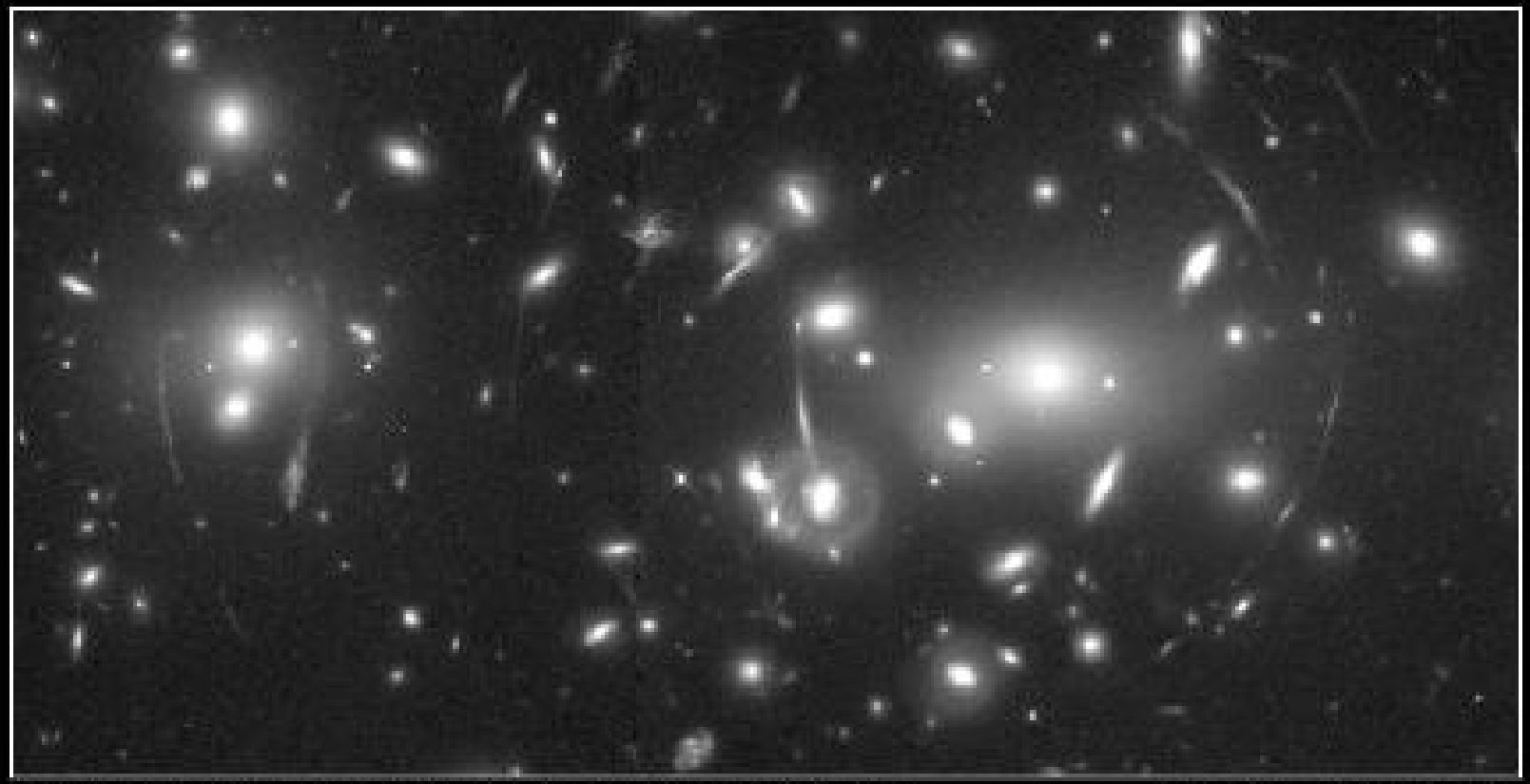


One central mass (Sun)



Milky Way

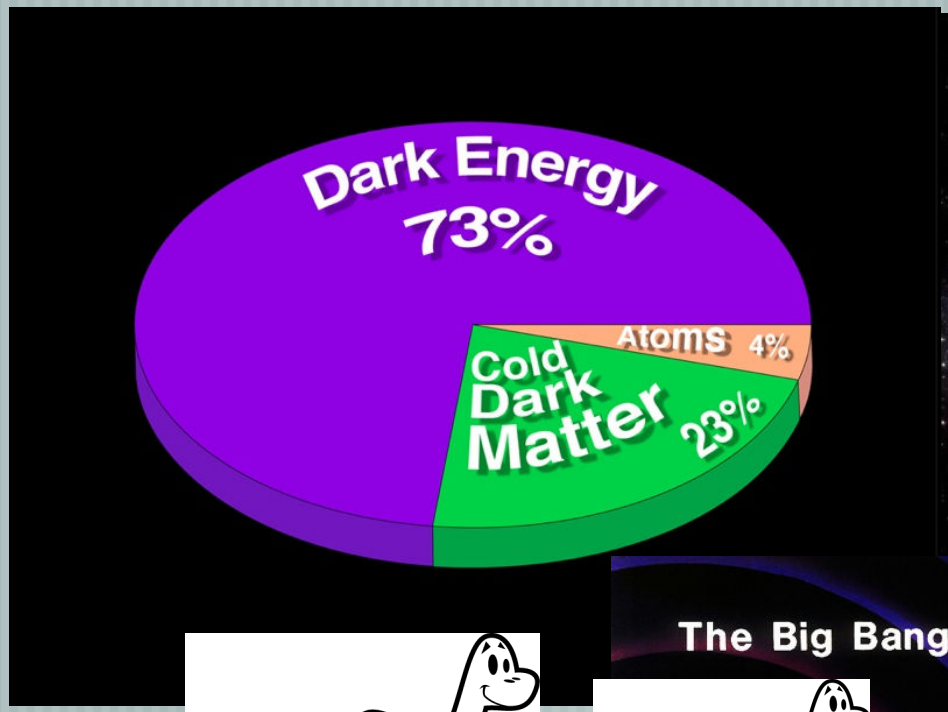
MORE EVIDENCE FOR “DARK MATTER”

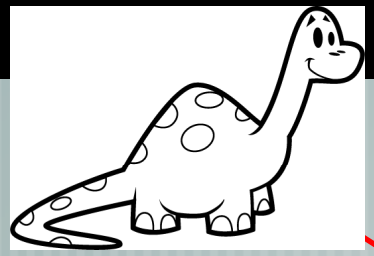


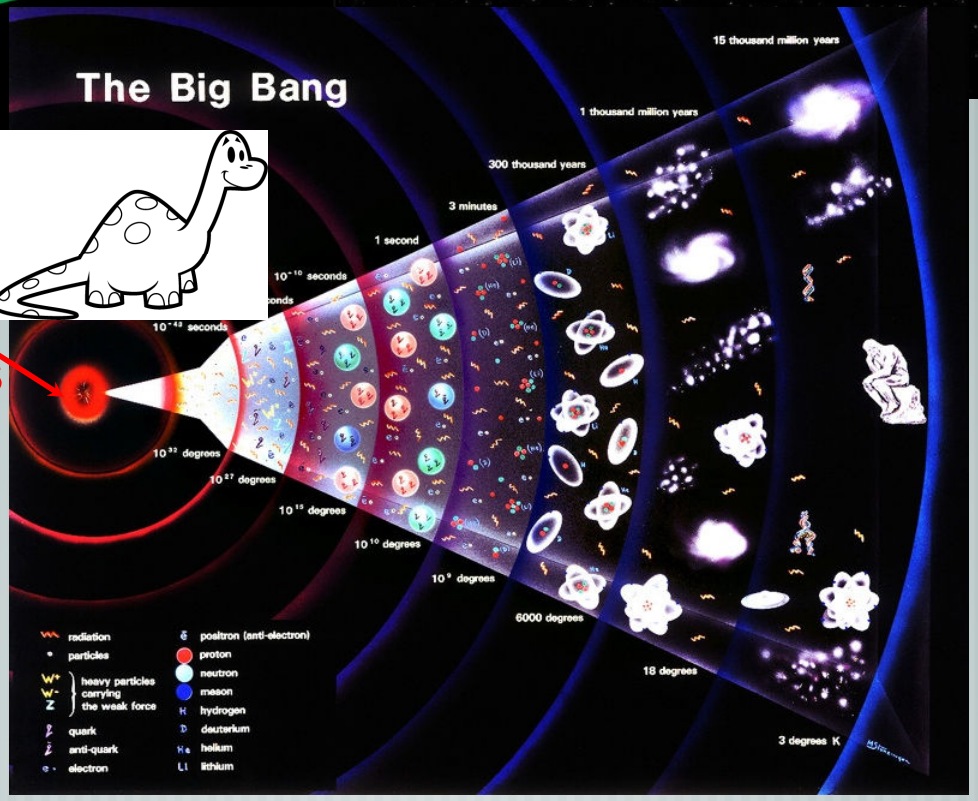
Gravitational Lens in Abell 2218 HST • WFPC2

PF95-14 • ST ScI OPO • April 5, 1995 • W. Couch (UNSW), NASA

GRAVITATIONAL LENSING



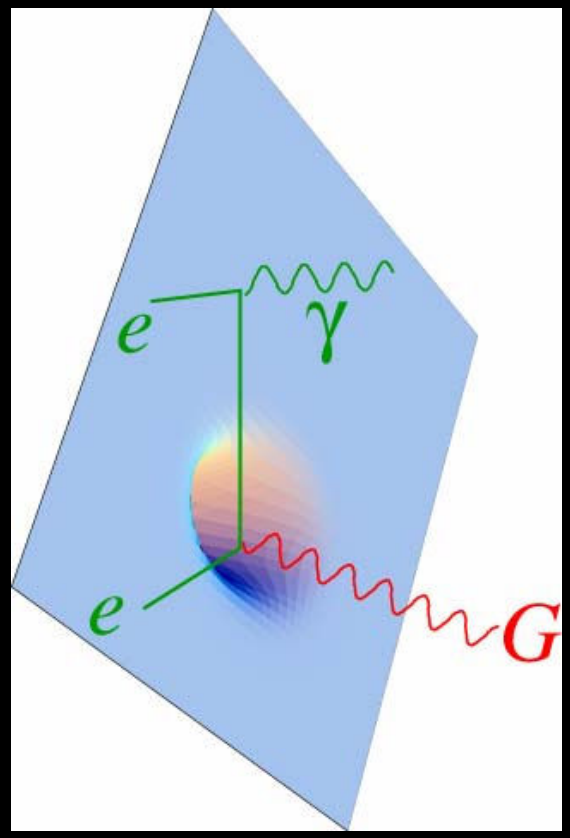




Supersymmetric particles could be responsible for DARK MATTER

Surprises ?

Quantum Gravity in 4+1 dimensions?



Does gravity act in **more than 3 spatial dimensions?**

Is gravity so weak because ‘gravitons’ escape into the small extra-dimensions?

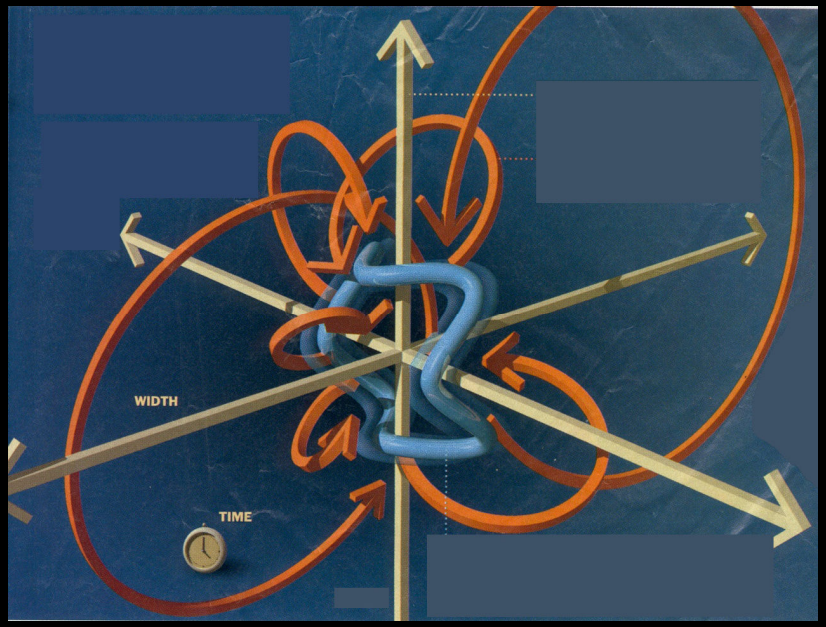
Then:
LHC collisions may produce ‘micro’ Black Holes

SUPERSTRINGS in 9+1 dimensions

Superstring theory only works in 9-dimensional space

Particles + fields are oscillating 'strings' (size ~10^{-35} m)

Different vibration patterns correspond to different particles

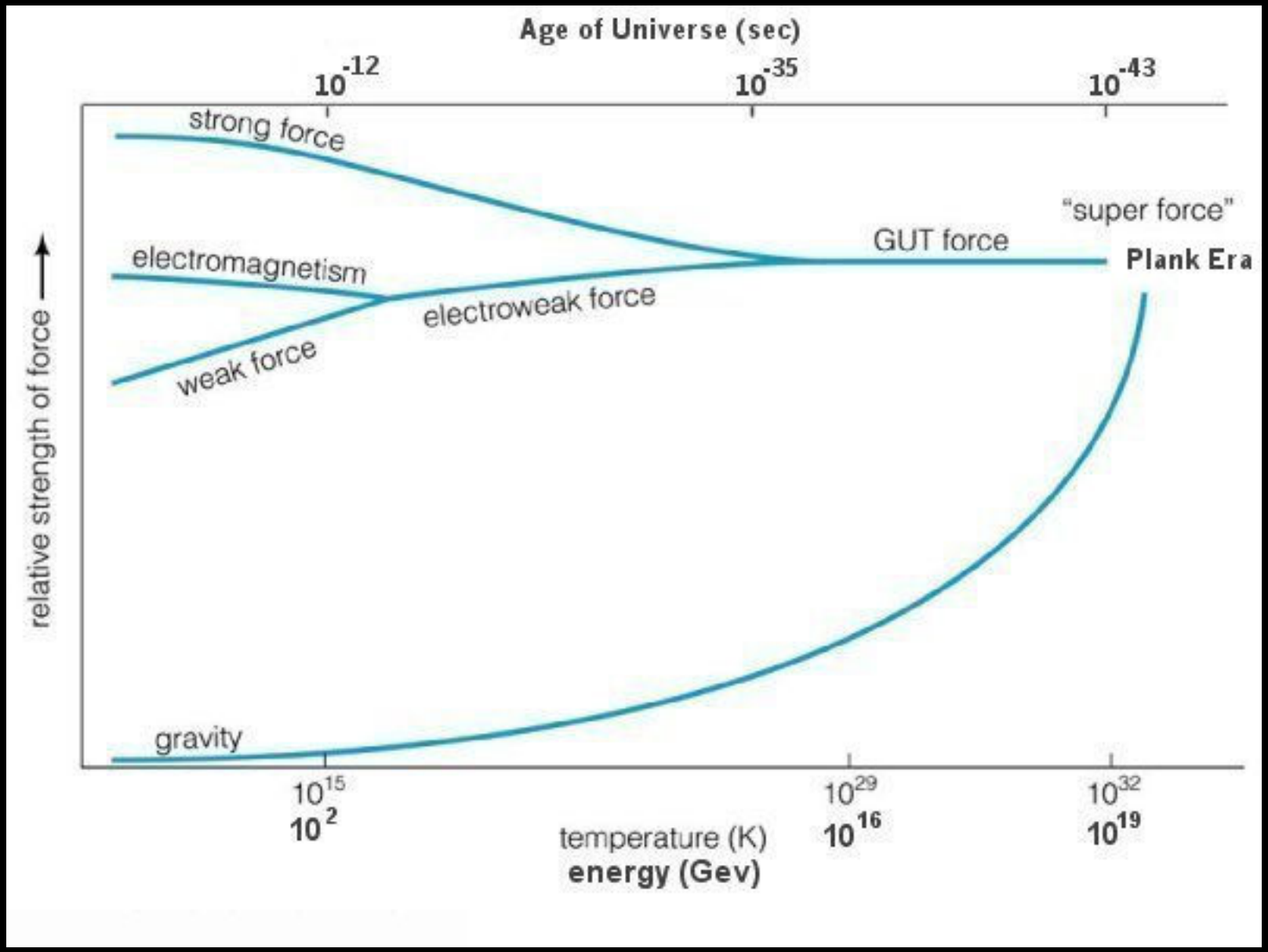


String theory 'contains' all known particles (including graviton) and fields

But: no AB-INITIO prediction on how the additional dimensions are curled up

No prediction on the scale of the supersymmetry breaking

Unified theory?



OUTLOOK

1900 - 2000: Phantastic progress in understanding matter and the Universe

We know what matter is made of.
We know the principle steps in the evolution of the Universe.

Now we have a set of new, deeper questions:

Are quarks and leptons elementary?
Where is the link (remember: charge of proton + charge of electron =0)
Are there different kinds of matter?
Are there new forces of a novel kind?
What do generations mean? How many?
What is the origin and relation of the fundamental constants?
Is life in the Universe an accident? (“Anthropic principle”)
Where is the antimatter gone? (Matter-Antimatter asymmetry)
What caused inflation? (Connection cosmological constant?)
How and why did the initial symmetry break? (Unification of forces)
The worst understood part of the Universe: the VACUUM !

This is the physics of the 21st century !

QUESTIONS FOR THE 21st CENTURY

First LHC collisions in 2009

new answers !