(some)

THEORETICAL QUESTIONS IN COSMOLOGY, ASTRO-PARTICLE AND PARTICLE PHYSICS

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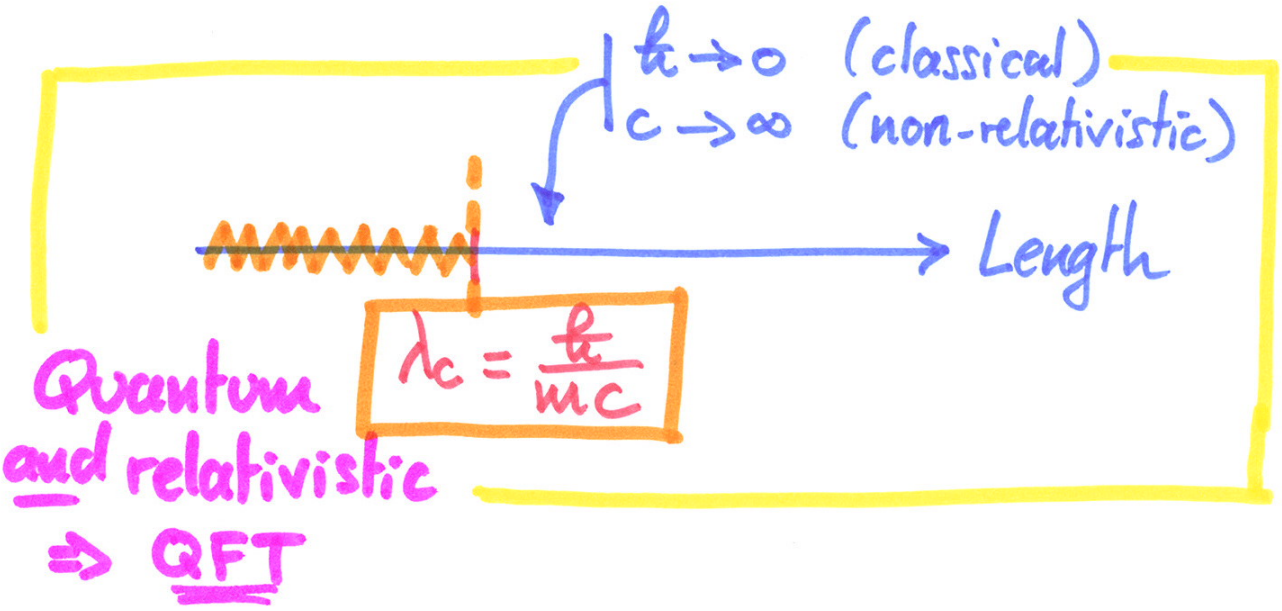
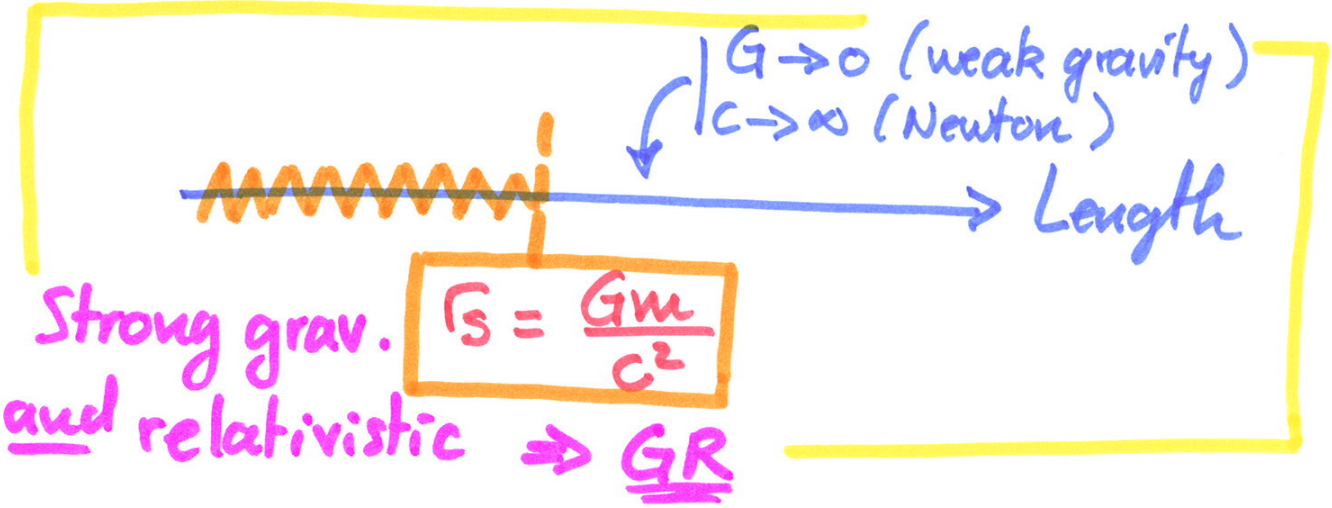
1 : Quantum gravity

v/c : quantifies relativistic effects

$S/\hbar$: ——— quantum effects



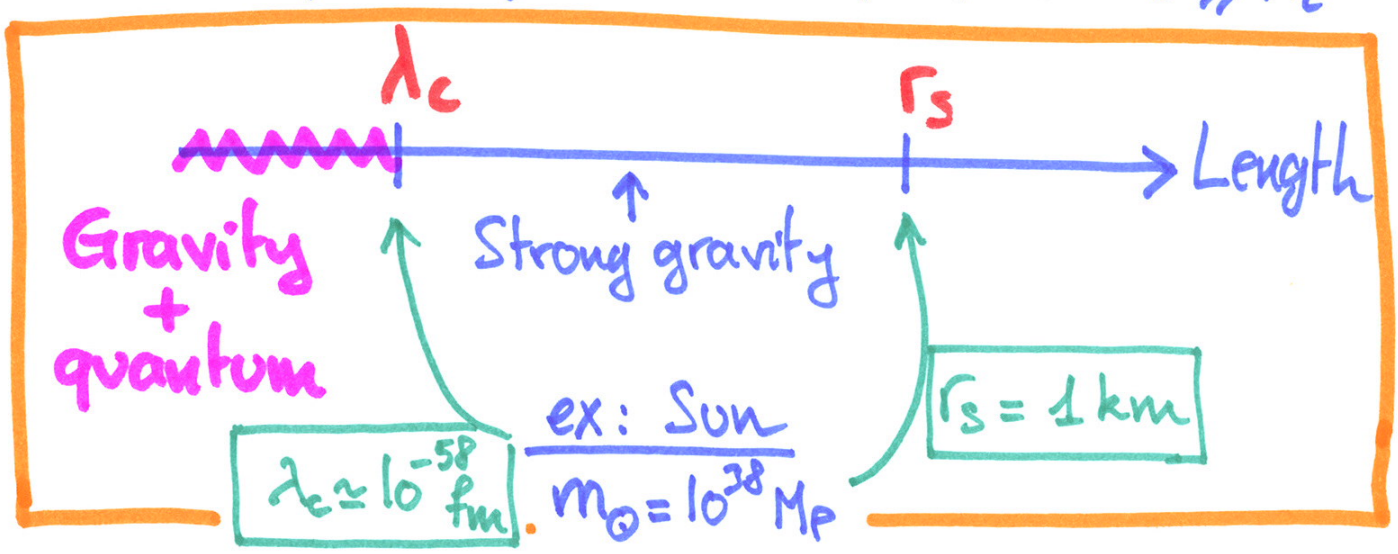
What about gravity ? ⇒ G



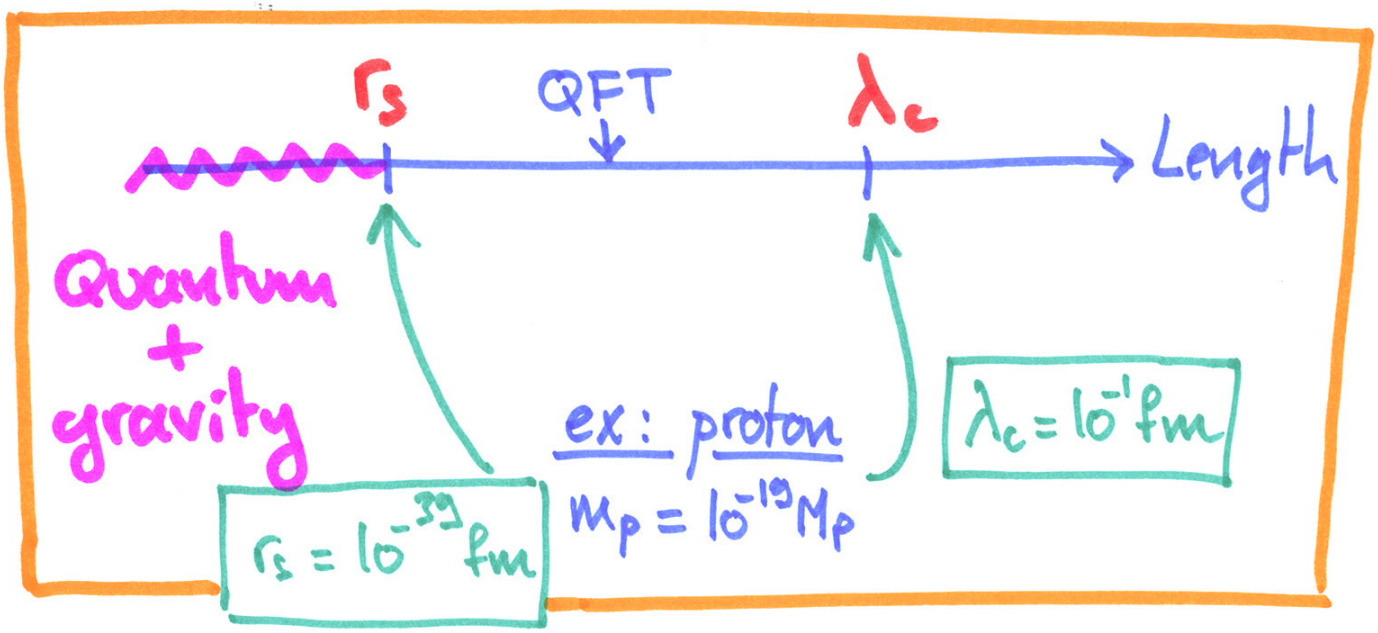
Quantum gravity : where ?

define $M_P = \sqrt{\frac{\hbar c}{G}}$ $\Leftrightarrow$ $r_S = \lambda_c$

- "Macroscopic" objects : $m \gg M_P \Leftrightarrow r_S \gg \lambda_c$



- "Microscopic" objects : $m \ll M_P \Leftrightarrow r_S \ll \lambda_c$



Quantum gravity : When ?

Early Universe : assume matter era

$\epsilon \sim a^{-3}$; $L \sim a$ with $\epsilon_0 = 10^{-29}\ g/cm^3$, $L_0 = 10^{27}\ m$

⇒ Due to blueshift : $L \simeq \lambda_c$ at $z \sim 10^{123}$!

Quantum gravity : not in accelerators
not in (accessible) Universe

An academic question ?

BUT
- ⇒ An intriguing intellectual quest
- ⇒ Leads to new fundamental ideas
- ⇒ And ...

Quantum gravity : How ?

➡ Superstring theories

- Fundamental d.o.f are extended objects
- SUSY's, Branes, ...
- extra-dimensions

➡ Loop Quantum Gravity (LQG)

- A QFT of connexions
- quantum nature of space and time

➡ Quantum Gravi-Dynamics (QGD)

- A consistent QFT of matter and metric
- running physical constants
  → short distance modifications of gravity.

!

2 - The (strong) cosmological constant problem

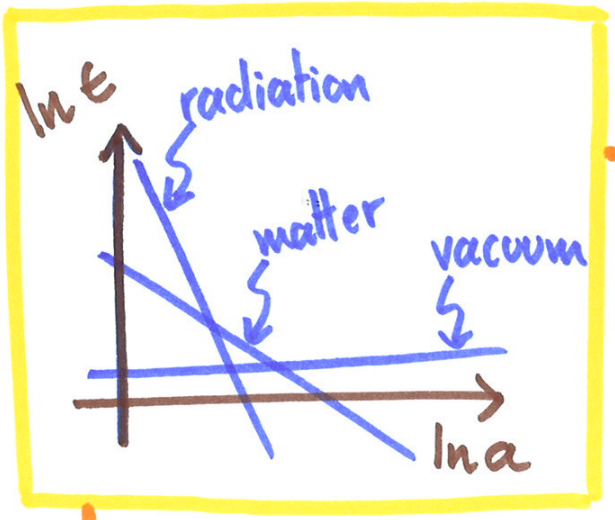
GR $\Rightarrow$ gravity is sourced by energy

QFT $\Rightarrow$ the vacuum is a medium

$$\epsilon_v = -p_v$$

Natural expectation : $\epsilon_v \sim M^4$

M : the scale of the fundamental theory (GUT, ...)



$\Rightarrow$ For stars to form :

$\epsilon_v \lesssim 10^{-27}\ g/cm^3$

$M \lesssim 10^{-11}\ GeV$!!

Even $M \sim \Lambda_{QCD} \sim 100\ MeV$ is 10 orders of magnitude too large !

The cosmological const. problem : possible solutions ?

From short distance physics .

$$\epsilon_{vac} \sim M^4 + ?$$

$k \lesssim M$ $\qquad$ $k \gtrsim M$

Quantum gravity

(landscape, eternal inflation, short distance modifications of GR, ...)

What about long distance physics ?

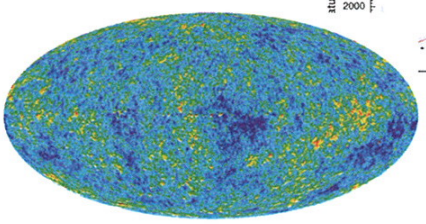
$$\epsilon_{vac} \sim ? + M^4$$

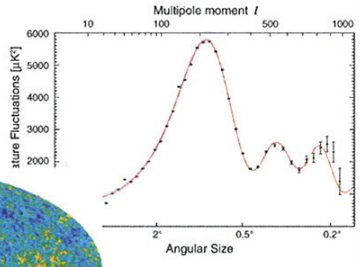
$k \lesssim H$ $\qquad$ $H \lesssim k \lesssim M$

We need to understand what is

QFT in curved space-time

3. Cosmological inflation





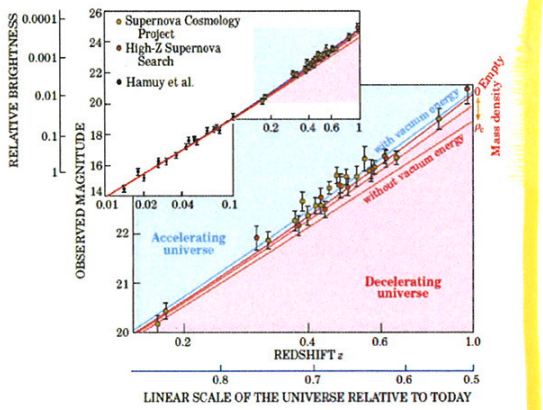
early period of accelerated expansion

Great! But many questions

- What causes inflation ? ⇒ QG
- What's the nature of the inflaton (ϕ, R, ...)?
- A consistent (effective) QFT for inflation ?
- What's the scale of inflation ?
- Decoherence of cosmological perturbations
- Non Gaussinities
- Link with high energy physics (SUSY...)
- Reheating after inflation
- ⋮

4 - Late-time acceleration

(the small cosmological constant problem)



After about 10^{10} years of decelerated expansion, the Universe has entered a new phase of inflation

WHY ?

- Cosmological constant : $\epsilon_v \sim (10^{-12}\,\text{GeV})^4$
  - why so small ? (fine tuning)
- "Dark energy"
  - quintessence, modifications of gravity (fine tuning)
- Change the paradigm
  - inhomogeneous Universe (fine tuning)

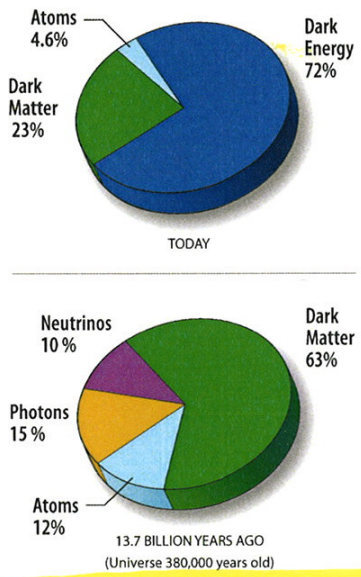
5 - Why do we feel 4 dim.? Are there more?

Quantum description of spacetime should eventually provide an answer.

But in the meantime, these issues inspire many theoretical developments

- modifications of gravity due to Xtra dimensions
- new scenarios for high energy physics
- brane worlds

6 - Dark matter



A key ingredient of the Universe !

What is it ?

- Weakly Interacting Massive Particle ?
  (neutralino ...) To be found at LHC ?!
- Modified gravity effect ?
  (MOND ...)
- Else ? (quintessence ...)

7. Matter-antimatter asymmetry

$$\eta = \frac{n - \bar{n}}{n_\gamma} \sim 10^{-10}$$

- Sakharov conditions for baryogenesis

  → B violation
  → C and CP violation
  → Non equilibrium

  } Possible in the Standard Model

But given the known sources of CP violations, the electroweak phase transition is too weakly first order in the SM.

⇒ New scenarios within SM ?

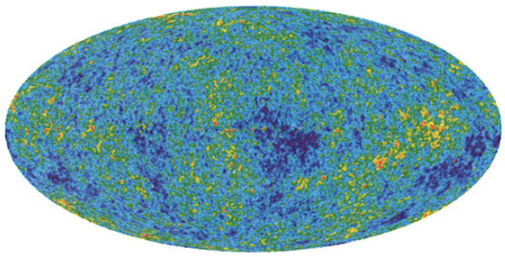
⇒ New physics ?

(SUSY, Leptogenesis ...)

Possible if neutrinos have mass (✓), mixings (✓) and are Majorana particles (?)

8 - Probes of the early Universe

CMB : the ultimate (light) wall



$T_{dec}^{\gamma} \simeq 10^{-1}\,eV \simeq 3000\,K$

$t_{dec}^{\gamma} \simeq 380\,000\,y$

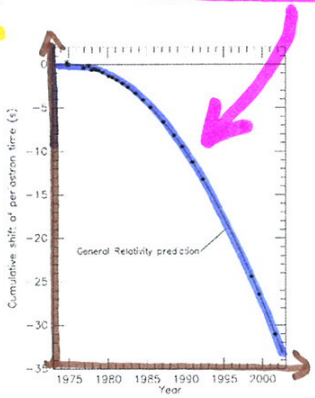
Neutrinos ?

- Relics from ancient supernovae
- Relics from the early Universe

$T_{dec}^{\nu} \simeq 1\,MeV$; $t_{dec}^{\nu} \simeq 1\,sec$!!

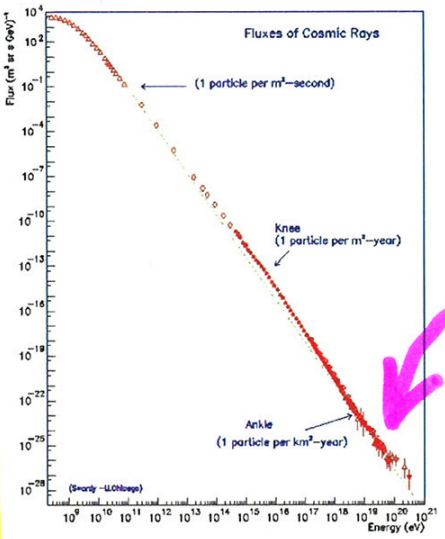
BBN

Gravitational waves ?



- Inflation ↘ affect CMB polarization
- Reheating
- Phase transitions

9. Cosmic Rays



Energies up to 10^{20} eV !!

- What are the acceleration mechanisms ?
- What and where are the sources ?
- How do they propagate ?

10 - Neutrinos

Messengers from outer space and time

- Astrophysical sources (supernovae ...)
  Oscillations in matter, ν-ν interactions, CP-violation effects ...
- Cosmological neutrinos ($t \sim 1$ sec.)

indirect evidence ✓

Direct detection ?

Smoking guns for new physics

- Why are their masses so small ?
- How large is θ_{13} ?
- What is the nature of neutrinos ?

...

11 - What's beyond the door?

- Standard Model : an excellent description of the vast majority of observed phenomena.

But it is not a fundamental theory !

⇒ SUSY ? GUT ? ...

↪ A job for LHC

What is to be found there might have important consequences for our understanding of

- Inflation
- Dark energy
- Dark matter
- Baryogenesis
- ...

12. The (true) origin of mass

Mass of the speaker = M_{atom} × Nb of atoms

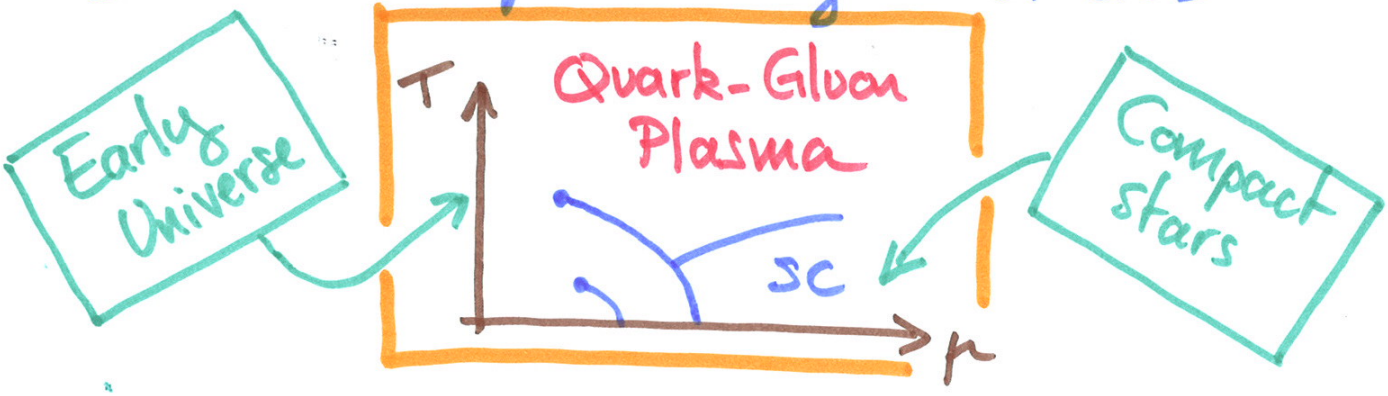
$M_{atom} = M_{nucleus} + Z M_e + B_A$

$M_{nucleus} = Z M_p + N M_n + B_N$

$M_{p,n} = \sum_q M_{quarks} + B$

QCD

- We still do not understand confinement !
- The rich phase diagram of QCD



- QCD at high energies ⇒ saturation

Cosmic rays interactions

Theory @ APC : people

Permanent Staff

Univ. Paris 7
- Binétruy
- Gazeau
- Hugvet
- Mourad (head)
- Nitti
- Renaud
- Serreau
- Steer

CNRS
- Bucher
- Deffayet
- Derrelle
- Hertog
- Kiritsis
- Langlois (head)
- Semikoz

Bouquet, Lachièze-Rey, Kaplan

Associates

Dudas, Volpe (Parentani, Reinosa), Novi

PhD

- Battaza (Binétruy)
- Bohe (Binétruy)
- Faci (Gazeau)
- Giacinti (Semikoz)
- Giraud (Serreau)
- Renaux-Petel (Langlois)
- Ribassin (Huguet)
- Siegl (Gazeau)
- Yousef (Gazeau)

Postdoc

- Dufaux
- Francia

Theory @ APC : activities

- Teaching
- Administration (UFR, CdL ...)
- Finding offices (visitors, students ...)
- Finding keys of offices
- Complaining
- Applying for grants
- Re-applying for grants
- Research

Theory@APC : research

Astroparticle

- UHECR
- Magnetic Fields
- Neutrinos

Cosmology

- Braneworlds . Quantum cosmo
- Inflation . Non-Gauss. Reheating
- Topological defects . Grav. waves

Gravity

- Quantum gravity
- modifications of GR

Quantization methods

- QFT in curved spacetime
- Loop Quantum Gravity

String and Field Theory

- String theory . Higher spin QFT
- Nonequilibrium QFT . Non perturbative methods
- AdS-CFT . Quark-Gluon Plasma physics