

De l'Infiniment petit à l'Infiniment Grand



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<http://public.web.cern.ch/public/en/Research/Research-en.html>

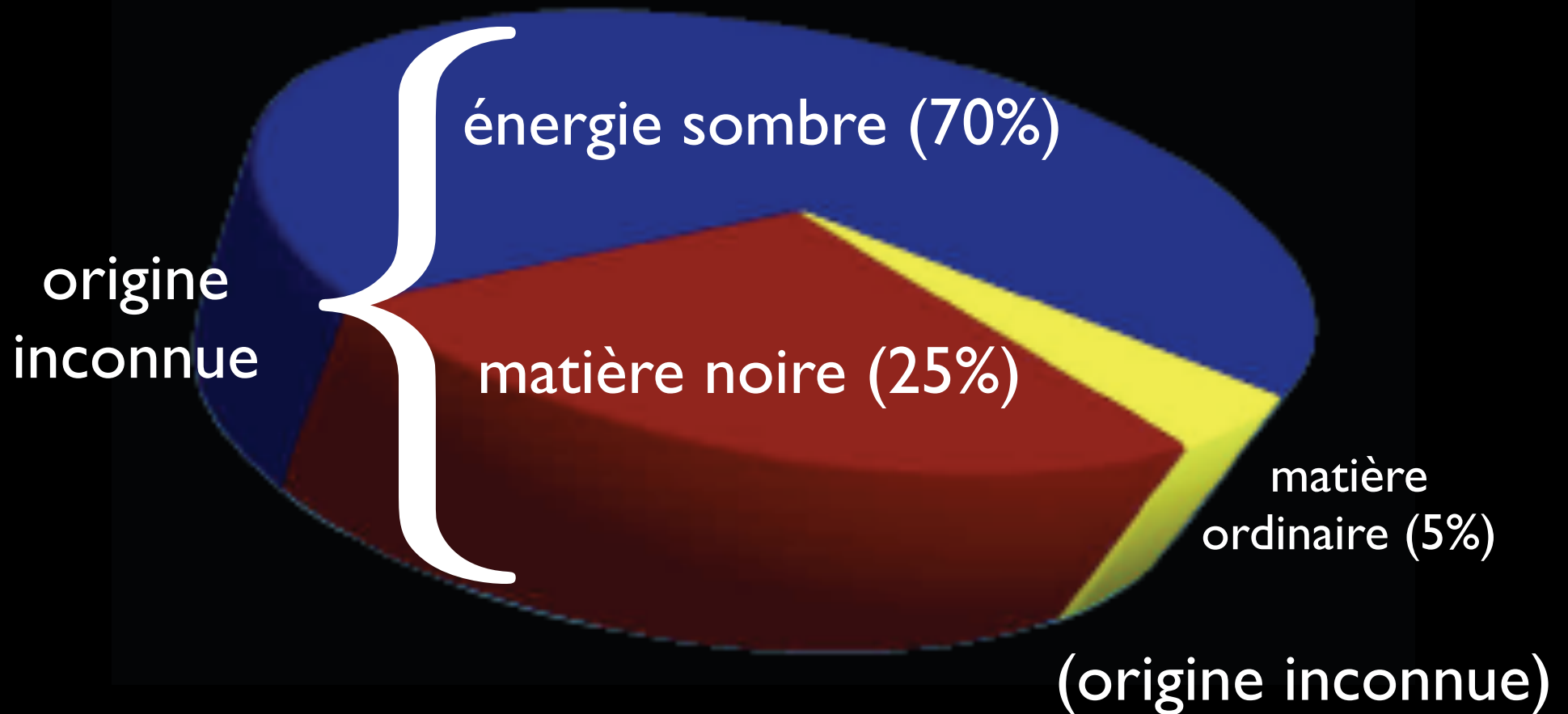
Pourquoi il y a des cosmologistes au CERN?



Les premières collisions au CERN



Les défis que l'Univers nous lance



The image is a composite of two astronomical visualizations. The left side shows a complex, filamentary structure representing the cosmic web, with bright yellow and orange nodes and purple filaments. The right side shows a field of galaxies, including several prominent spiral galaxies with bright yellow cores and purple/blue dust lanes, set against a dark background with scattered stars. A central, bright, multi-colored beam of light connects the two scenes.

Puzzle: Matière noire

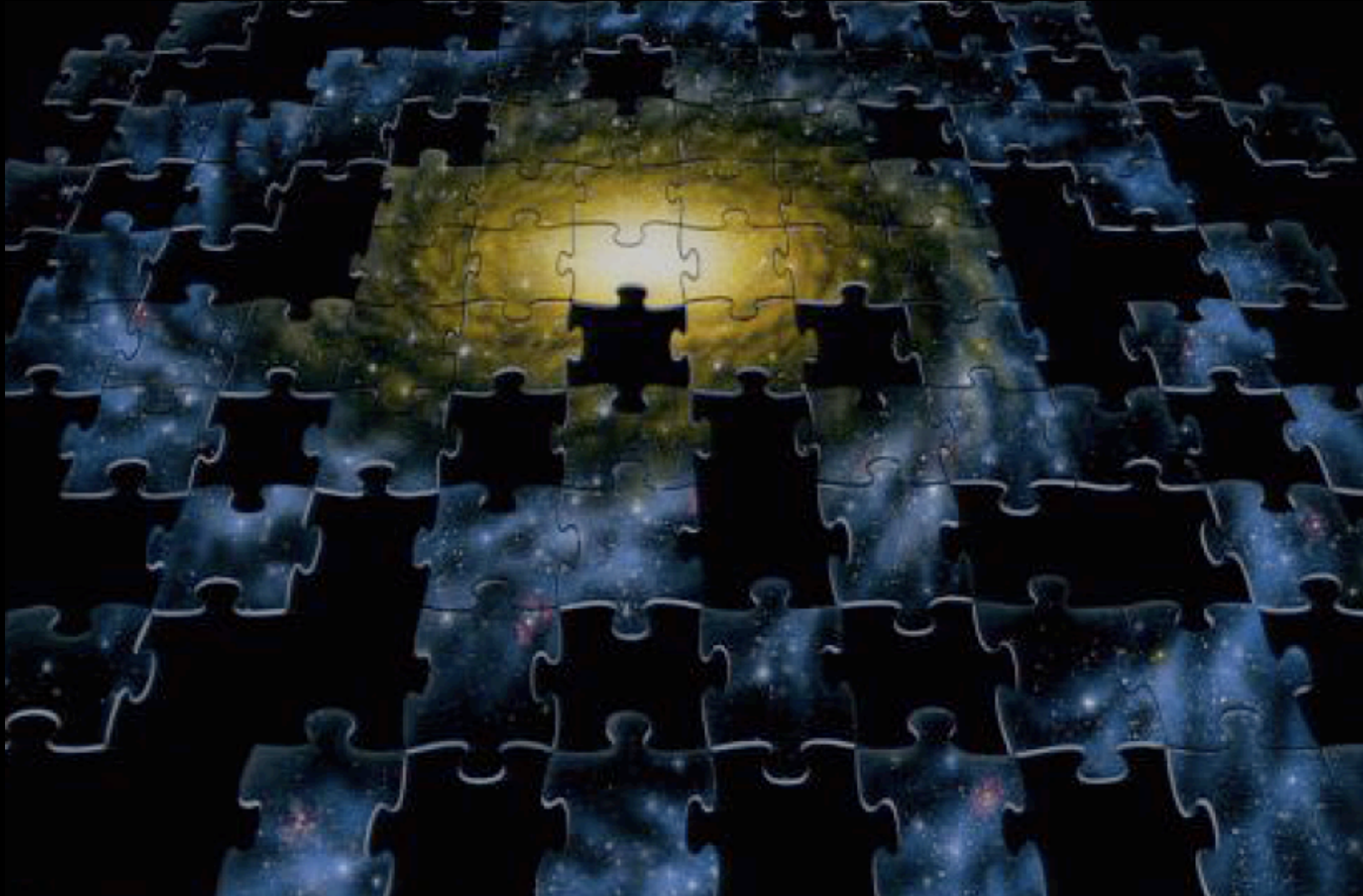
L'Univers Visible



L'Univers Visible

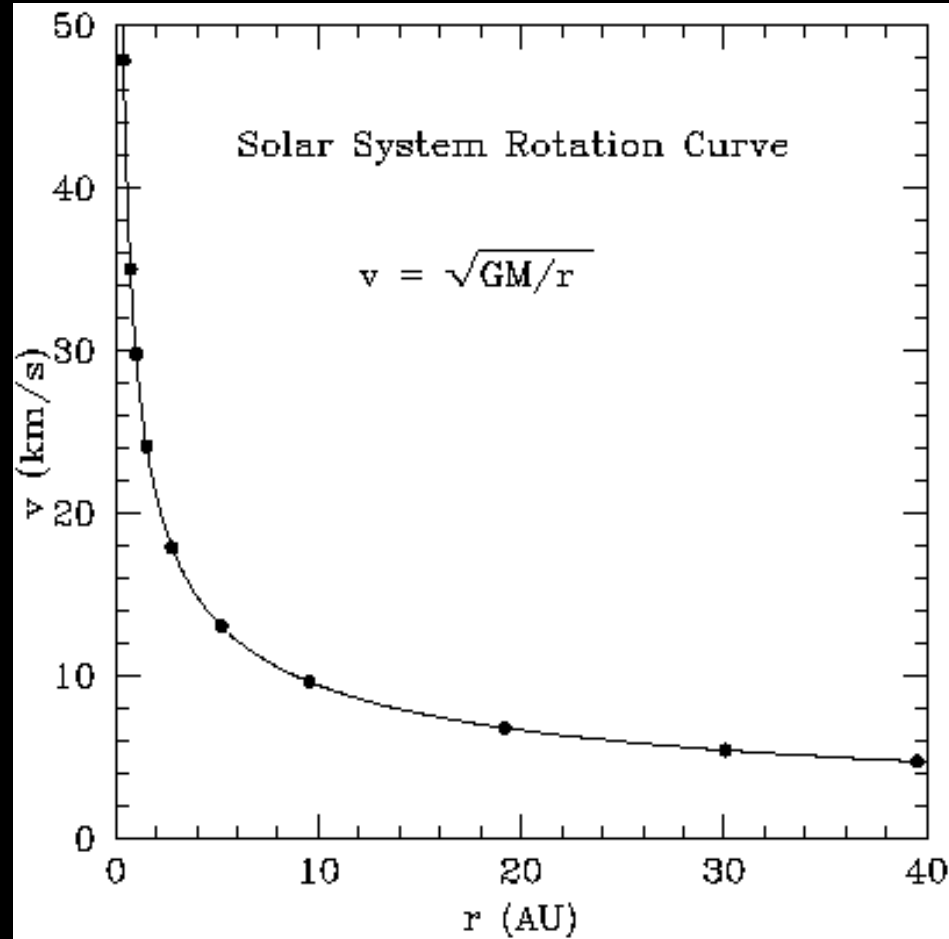


L'Univers invisible



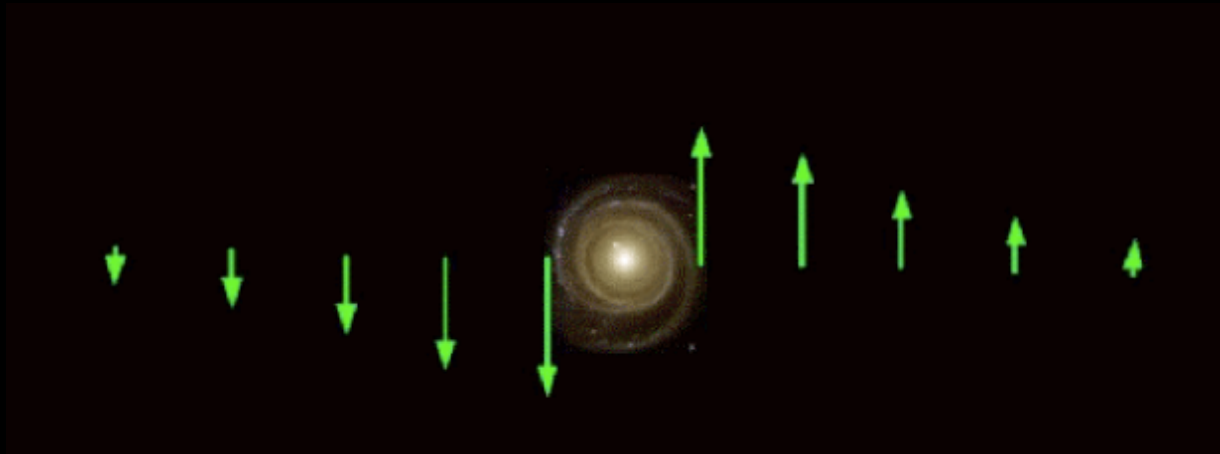
La matière noire est 5 fois plus
abondante que la matière visible

L'Univers Visible



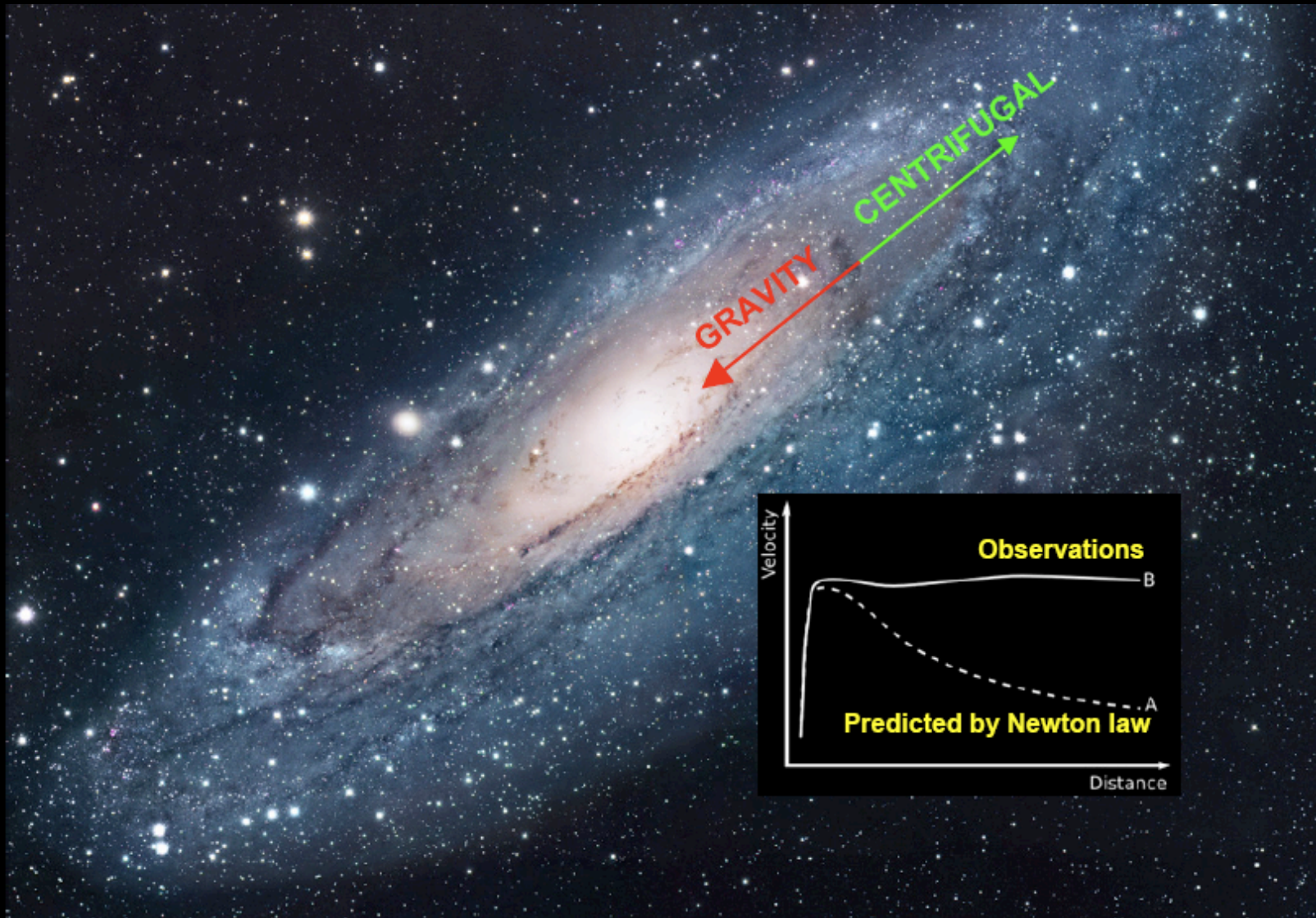
$$v^2(r) = G_N \frac{M}{r}$$

Ce que nous devrions observer

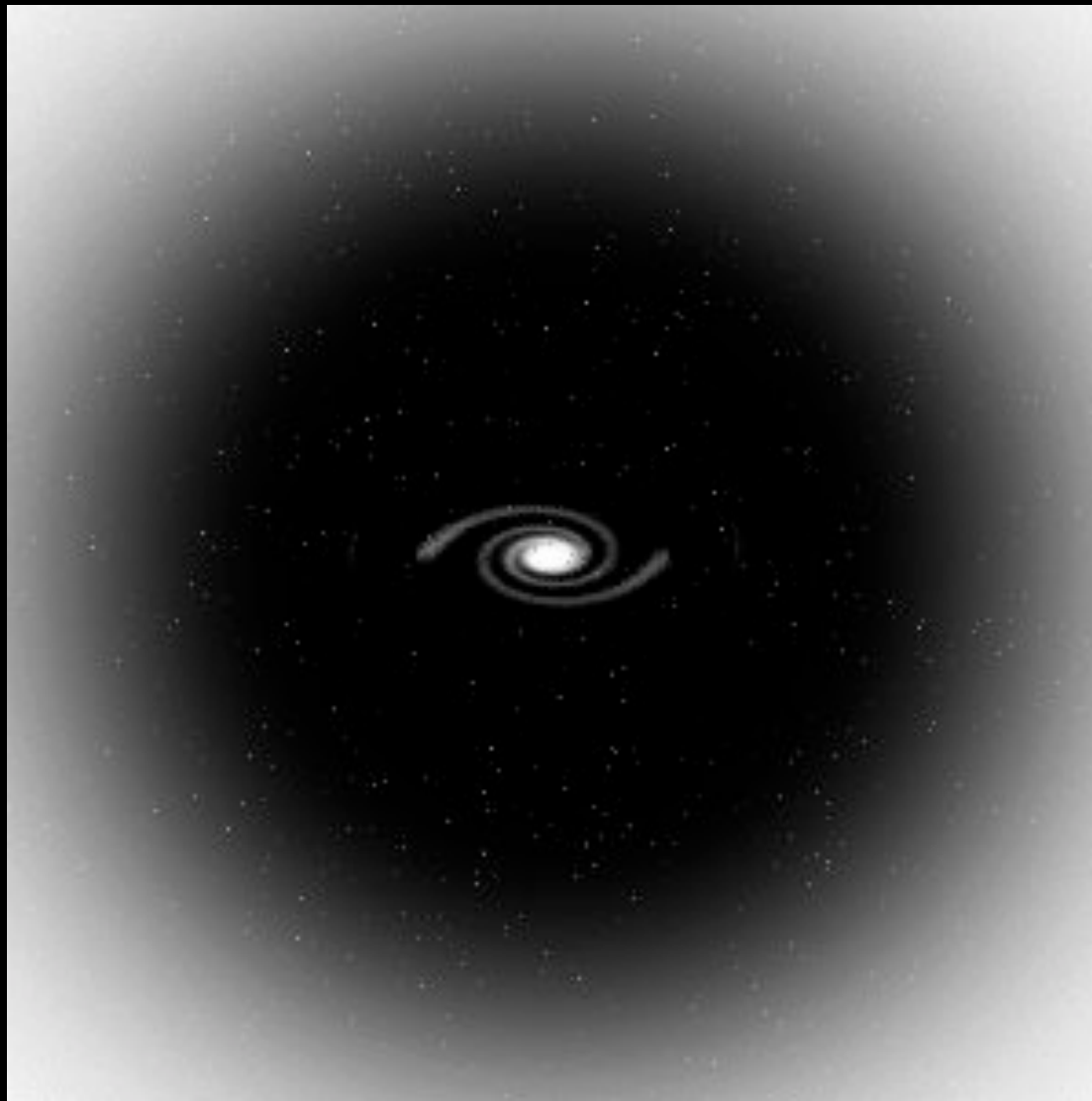


Ce que nous observons



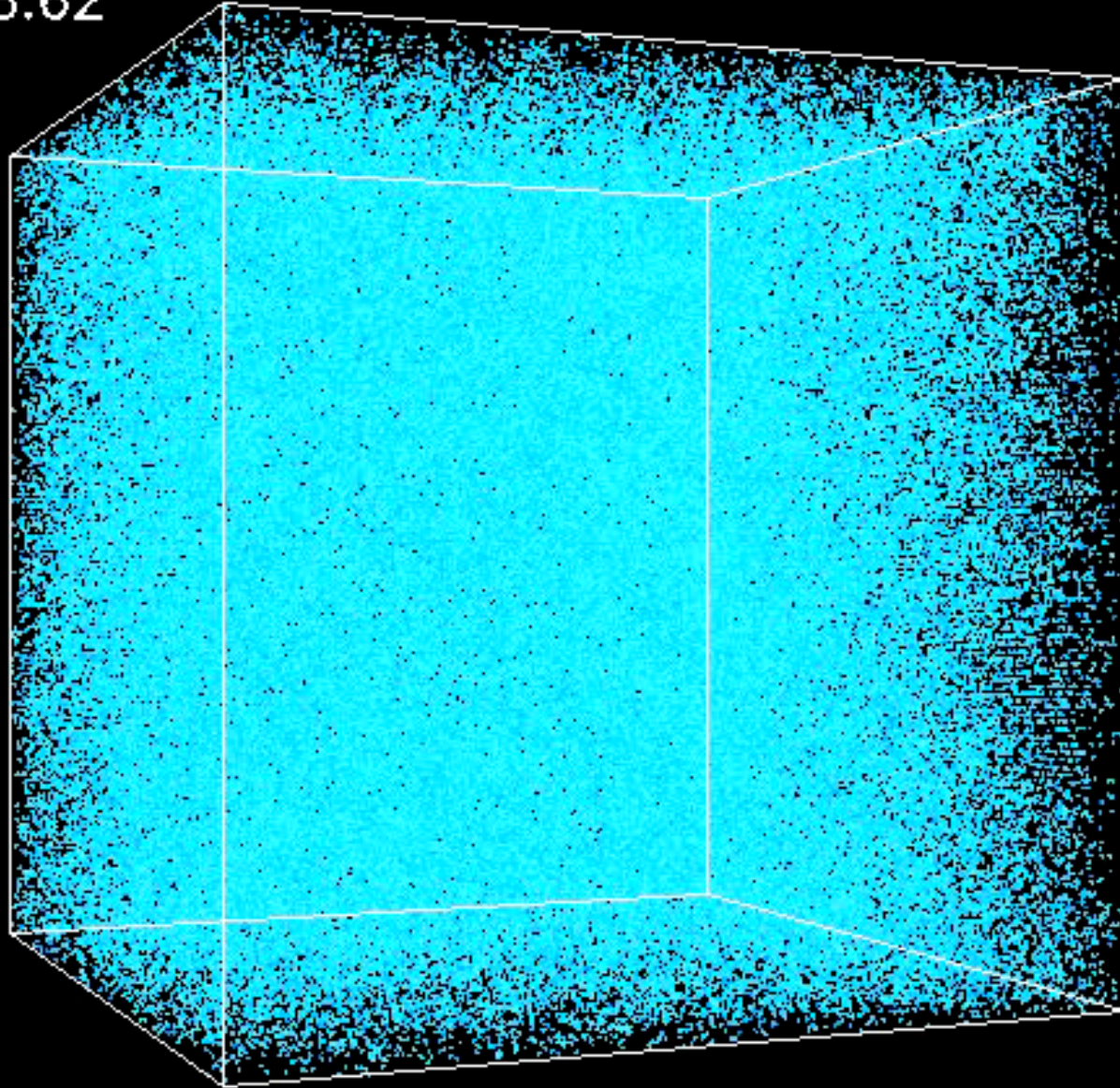


The Andromeda Galaxy (M31)



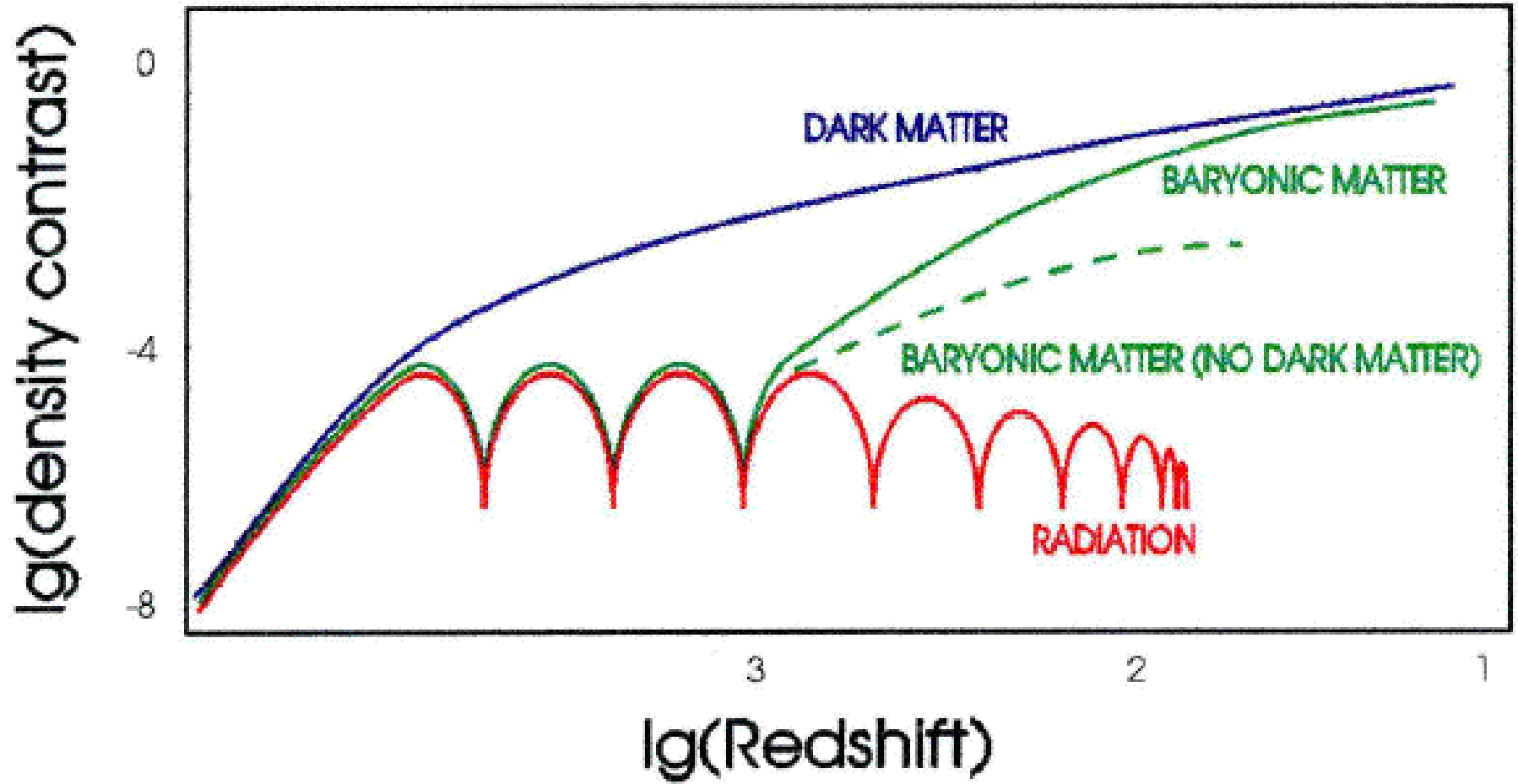
$$v^2(r) = G_N \frac{M}{r} = \text{const.} \Rightarrow M(r) \sim r$$

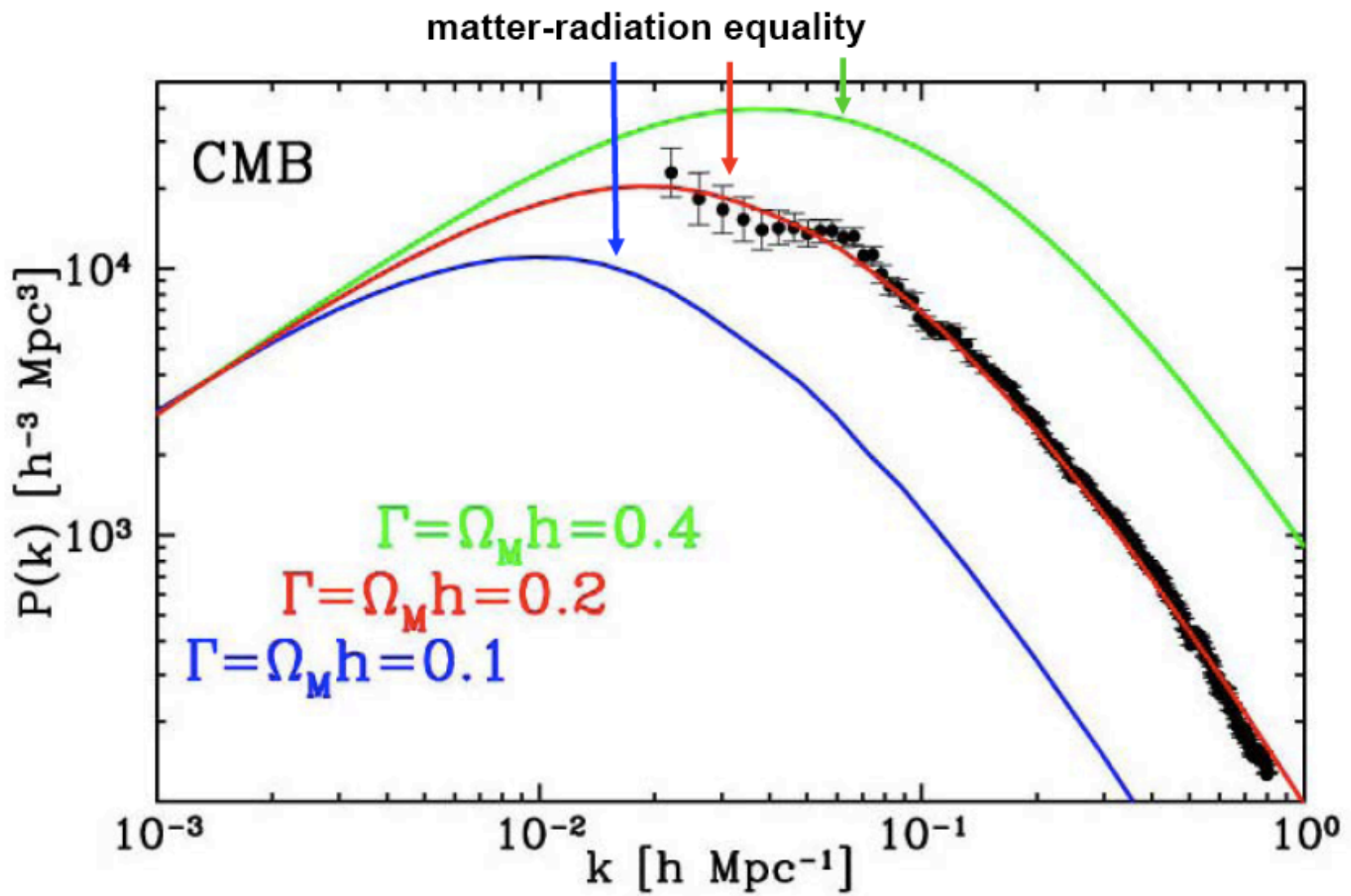
$Z=28.62$



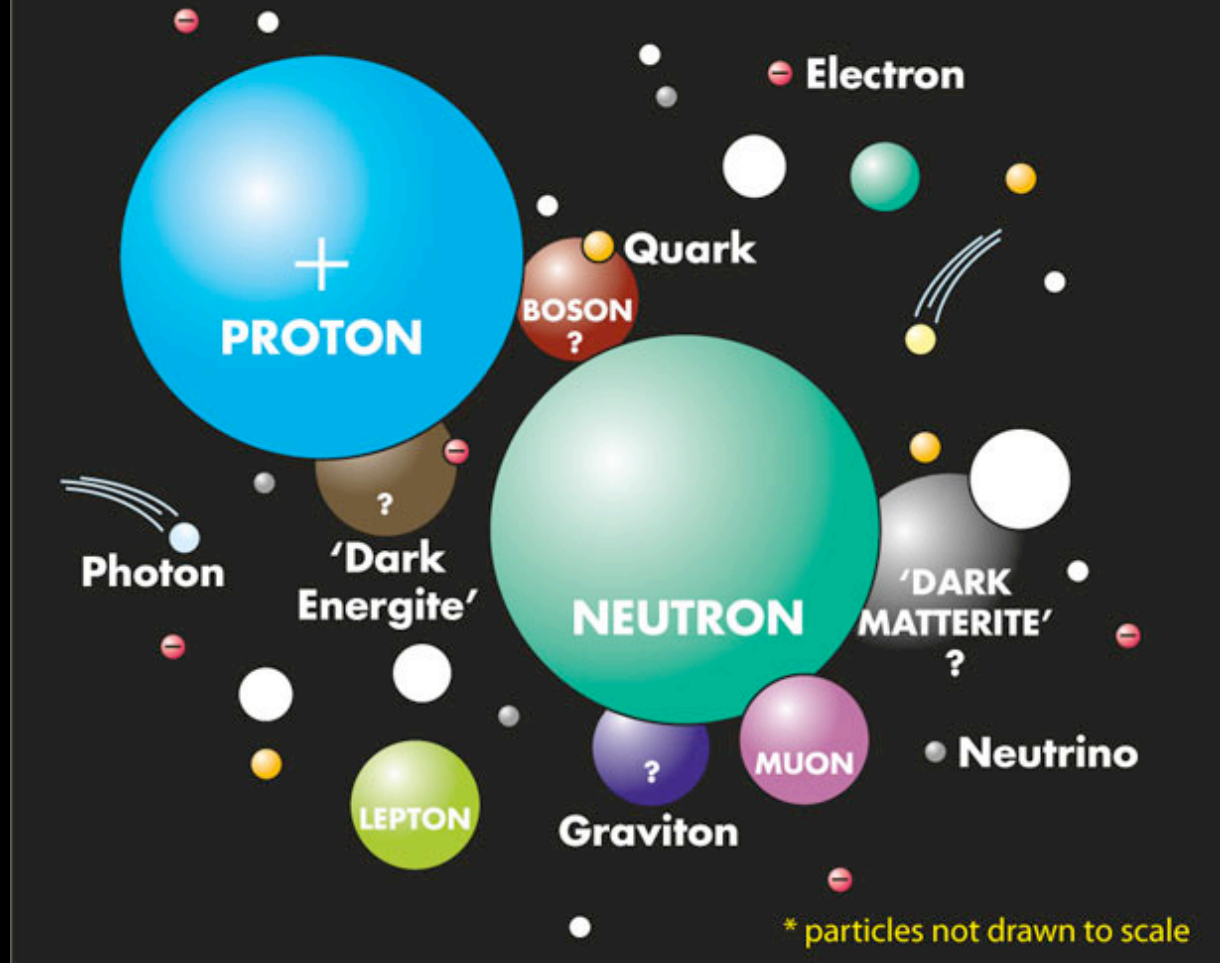
La matière noire est responsable de la
formation des structures

GROWTH OF DENSITY PERTUBATIONS IN A DARK MATTER DOMINATED UNIVERSE



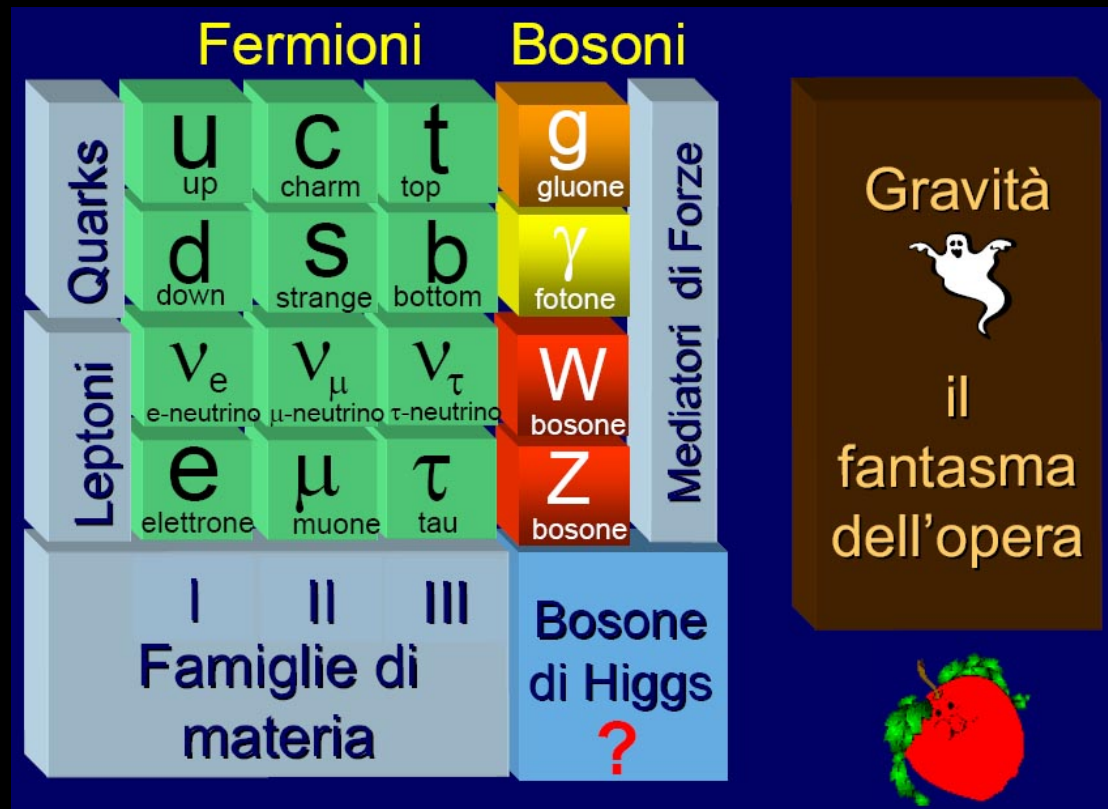


Particle Zoo

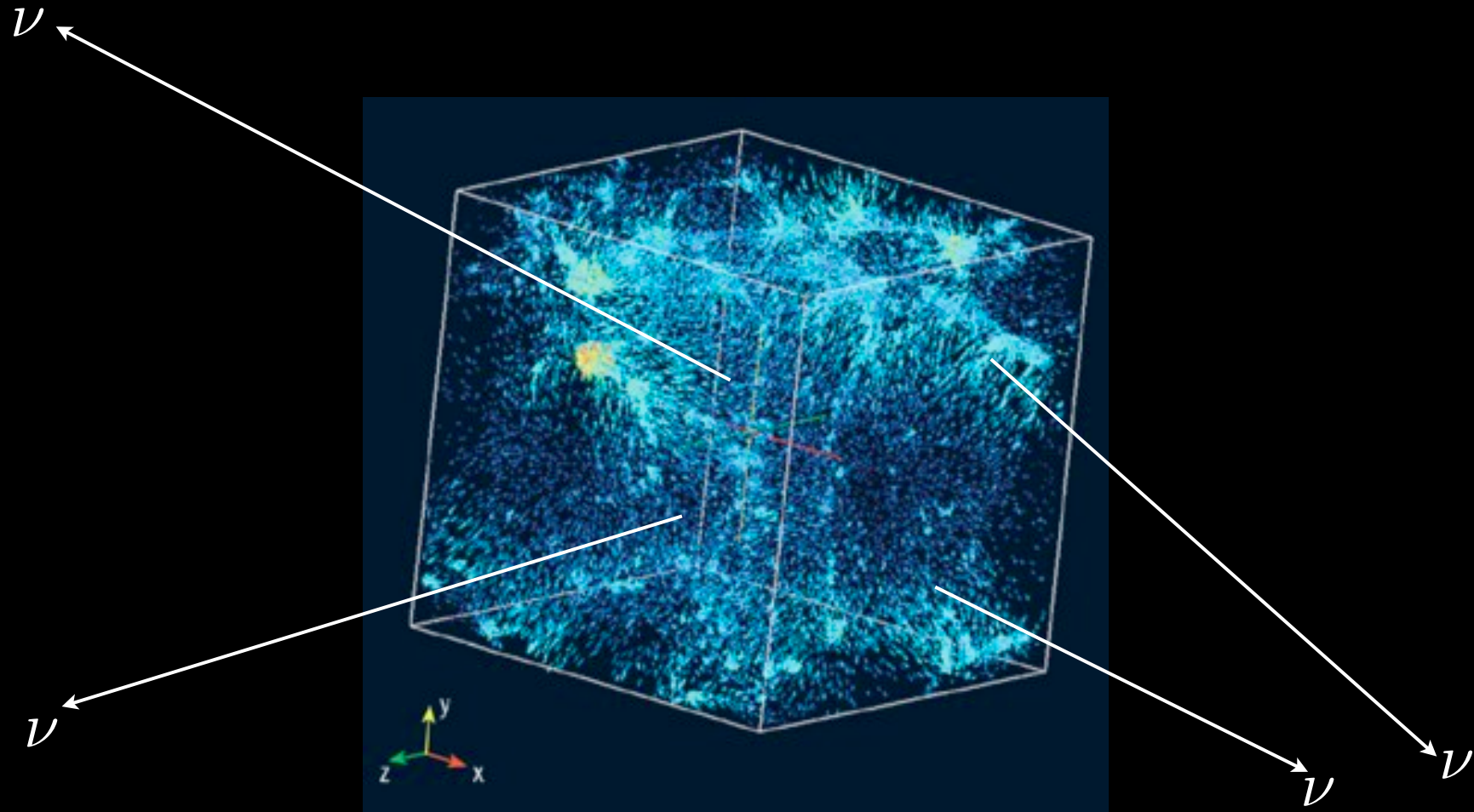


La matière noire est
probablement une particule
(stable et sans charge)
à nous encore méconnue

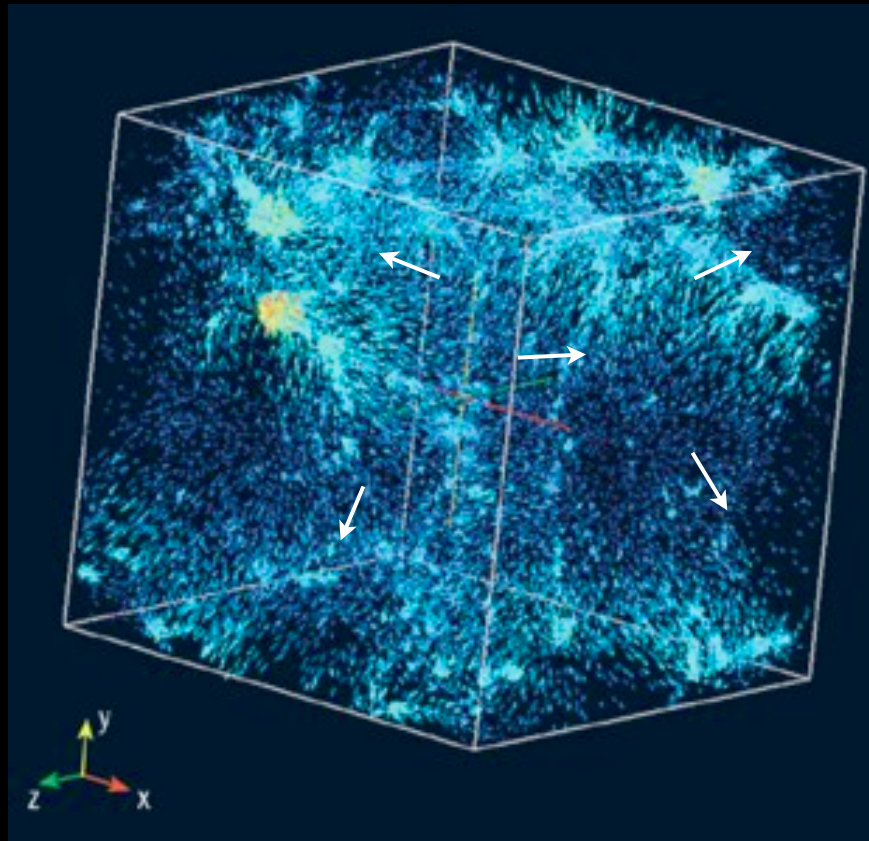
Les constituants élémentaires de la matière



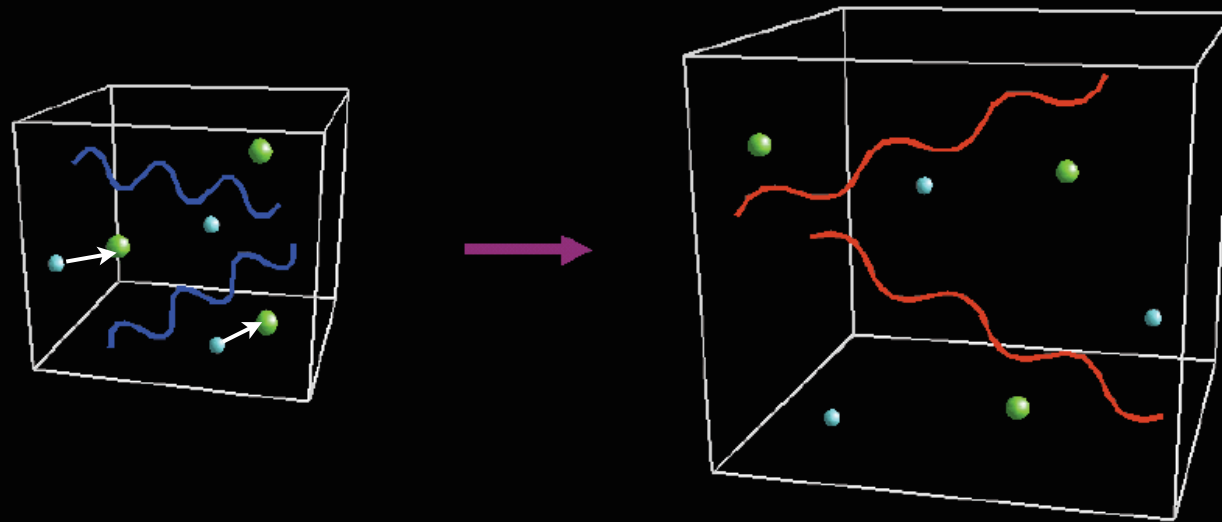
La matière noire n'est pas
composée des neutrinos:
matière noire chaude



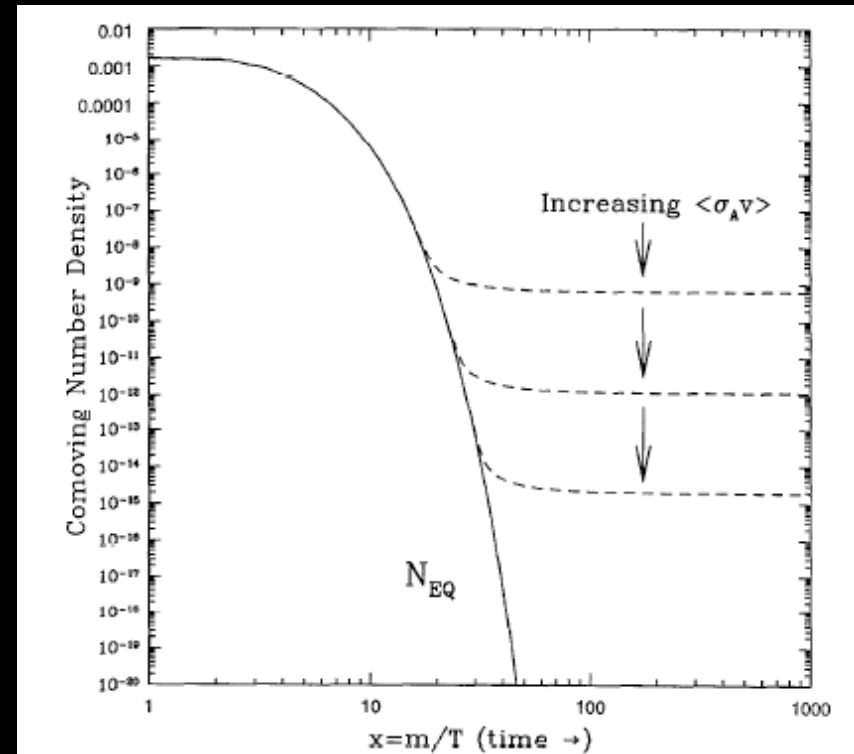
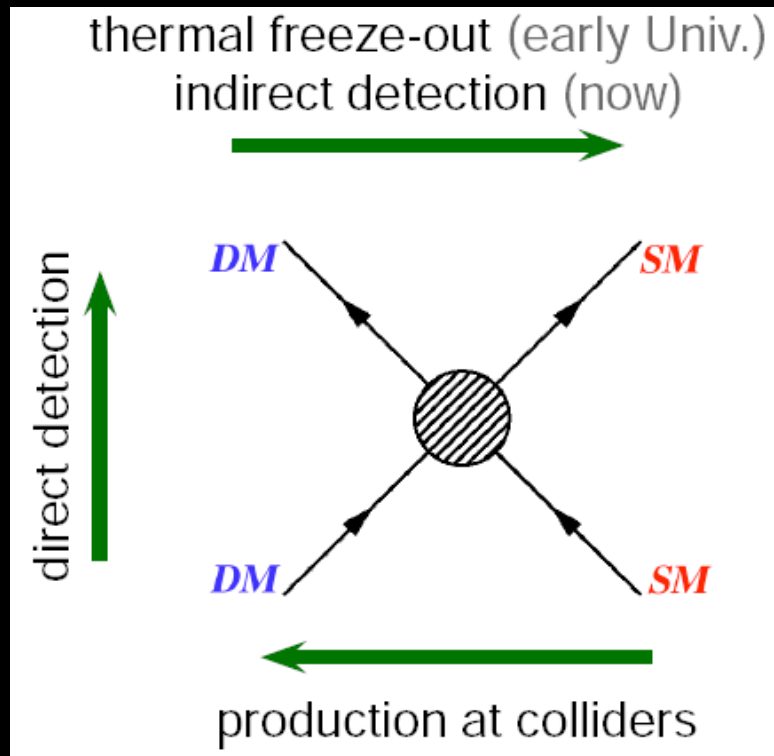
**Weakly Interacting
Massive Particle miracle
(WIMP)
Matière noire froide**



**Weakly Interacting
Massive Particle miracle
(WIMP)
Matière noire froide**



WIMP miracle



$$\Omega \sim (0.2 - 0.3) \Rightarrow \langle \sigma_{\text{ann}} v \rangle \simeq 10^{-9} \text{ GeV}^{-2} \simeq \frac{\pi \alpha^2}{m^2} \text{ for } m \simeq 300 \text{ GeV}$$

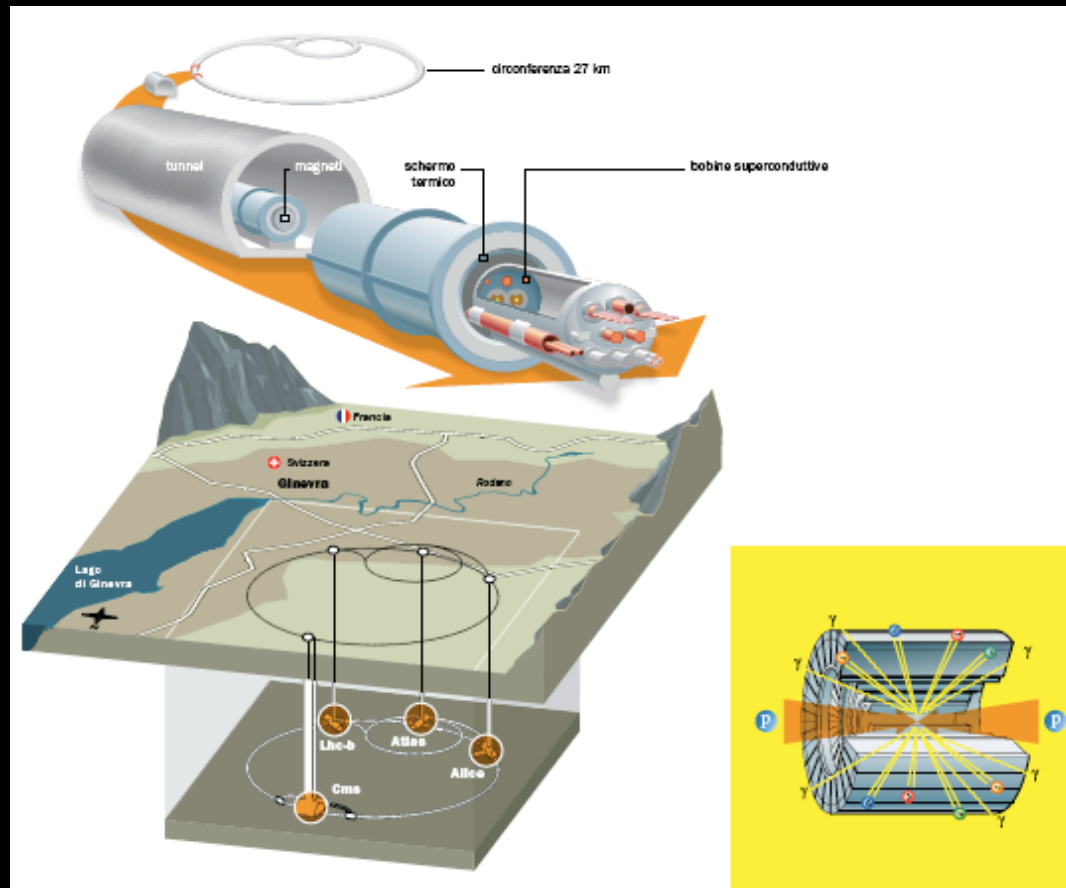
LHC !!

L'Infiniment Petit

Lorsque on a un
marteau en main
tout a la forme d'un clou



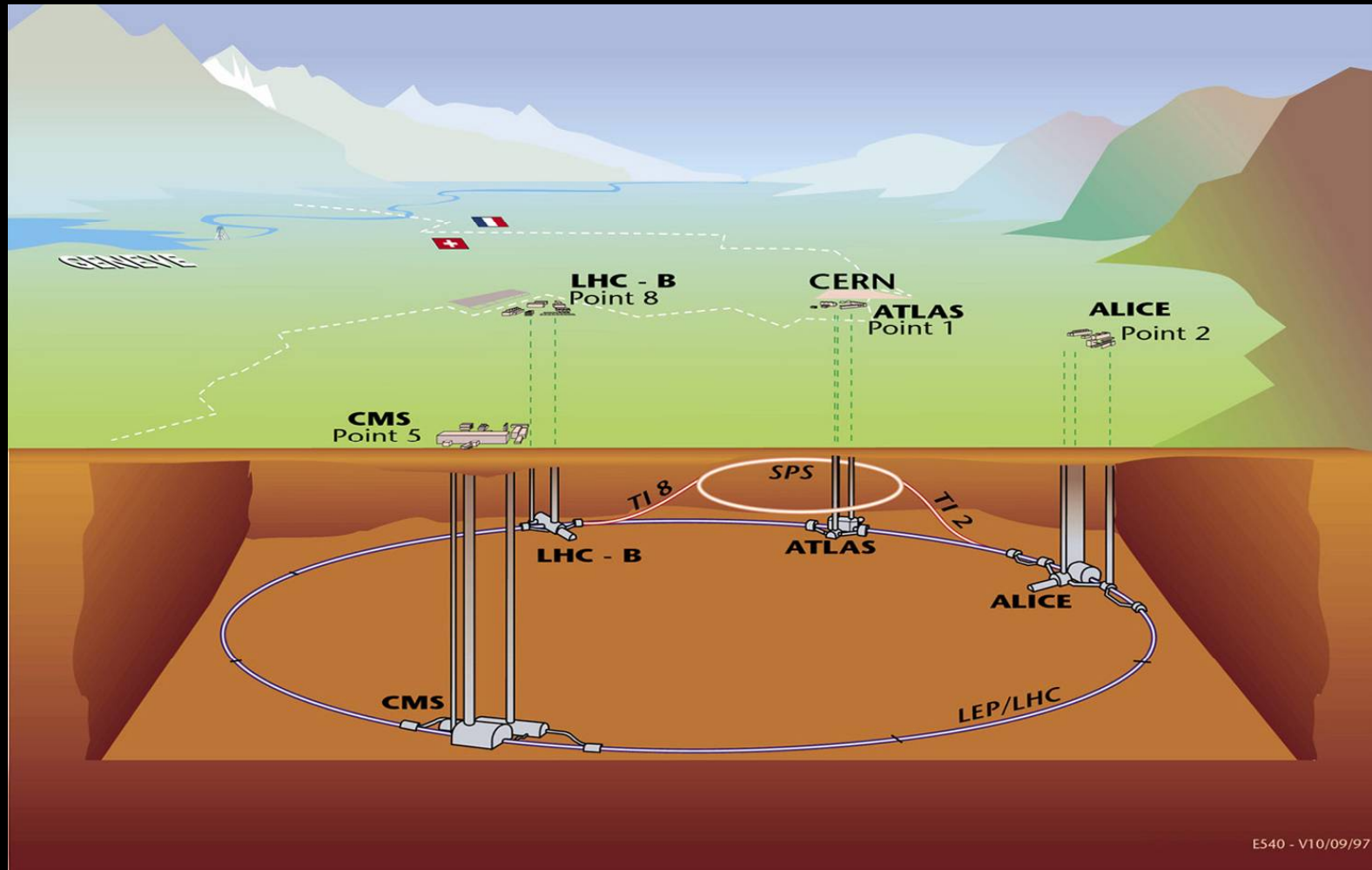
Notre marteau: Large Hadron Collider (LHC)



Fondé en 1954

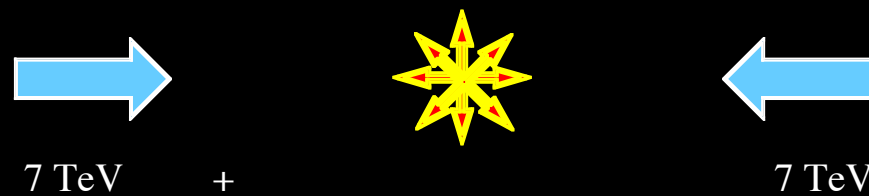


Vue générale du LHC

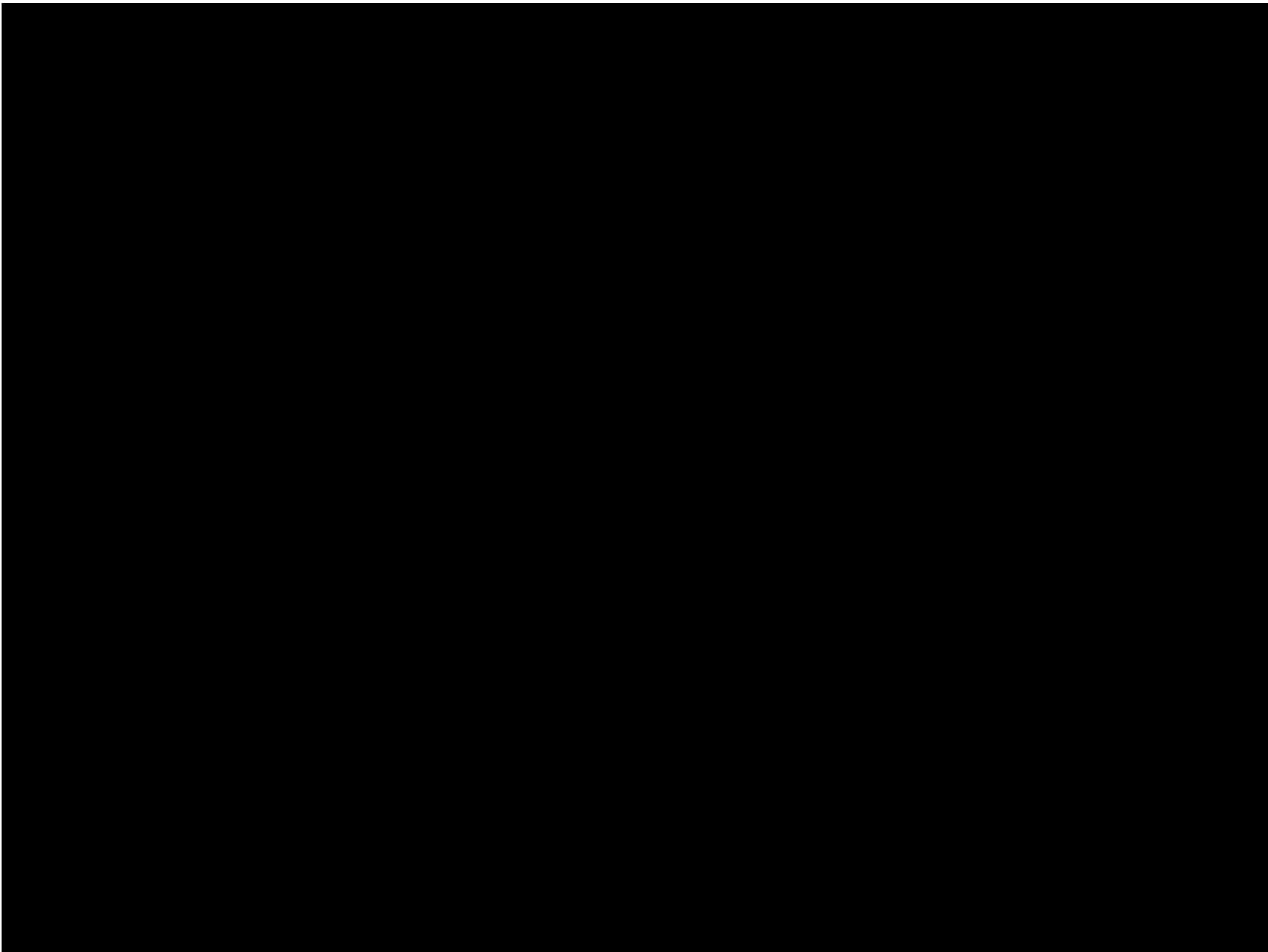


Longueur 27 Km, profondeur 100 m





énergie d'un Mercedes qui voyage à une
vitesse de 1700 Km/h



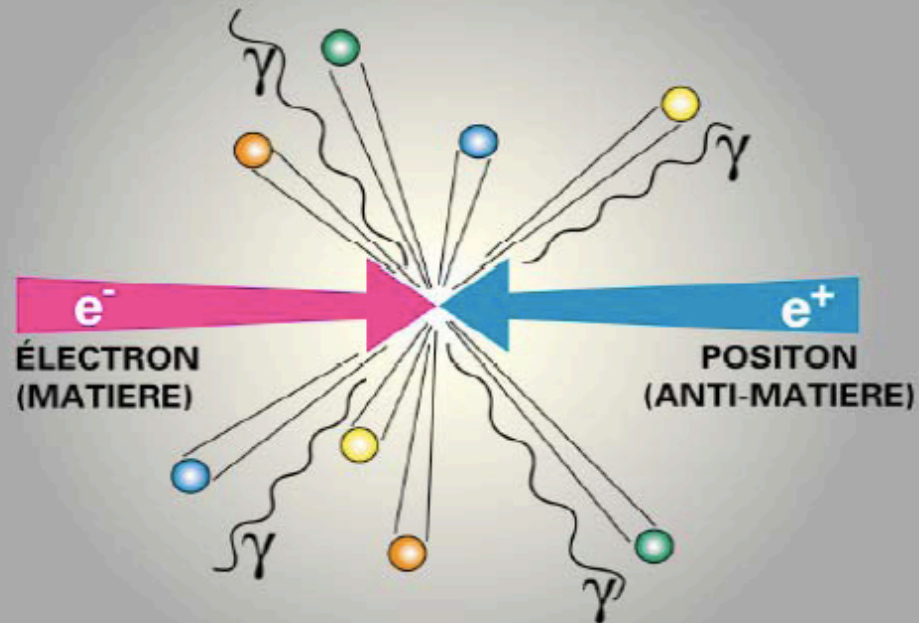
LHC est une formidable machine du temps

On peut recréer
la matière qui existait
au temps du Big Bang

$$t_{\text{LHC}} \sim 10^{-14} \text{ sec}$$

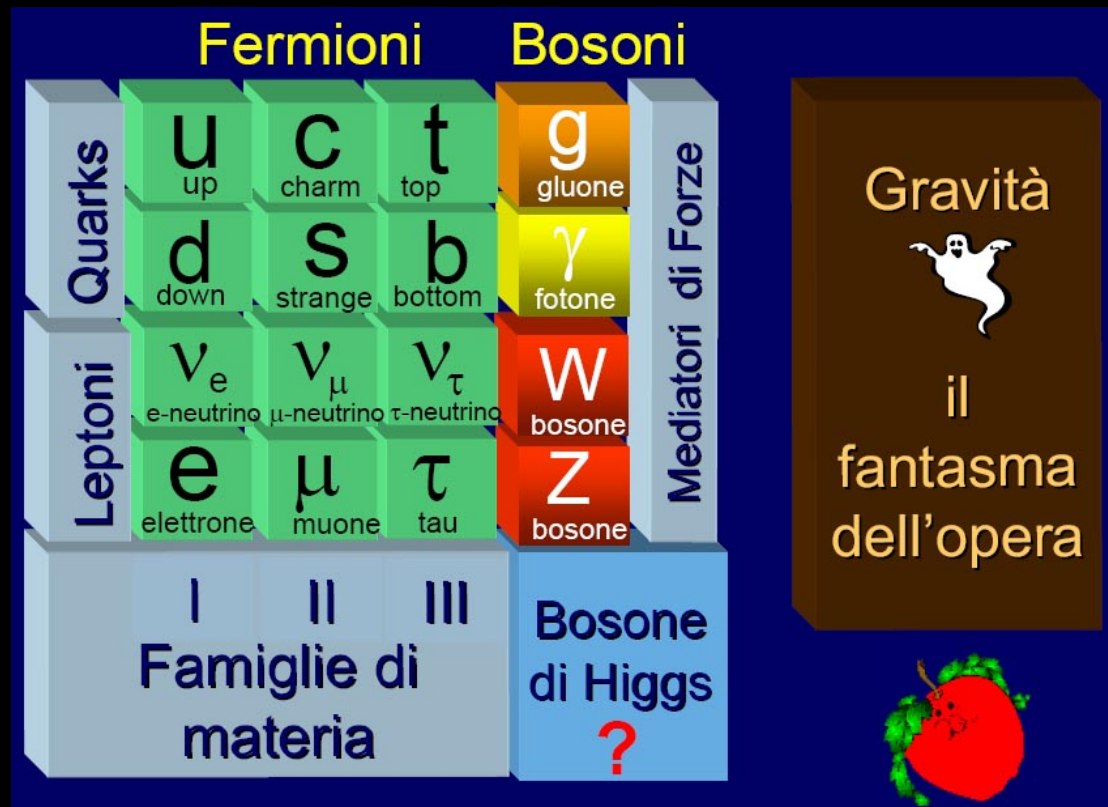
CONCENTRATION D'ÉNERGIE

⇒ "MINI BIG-BANG"

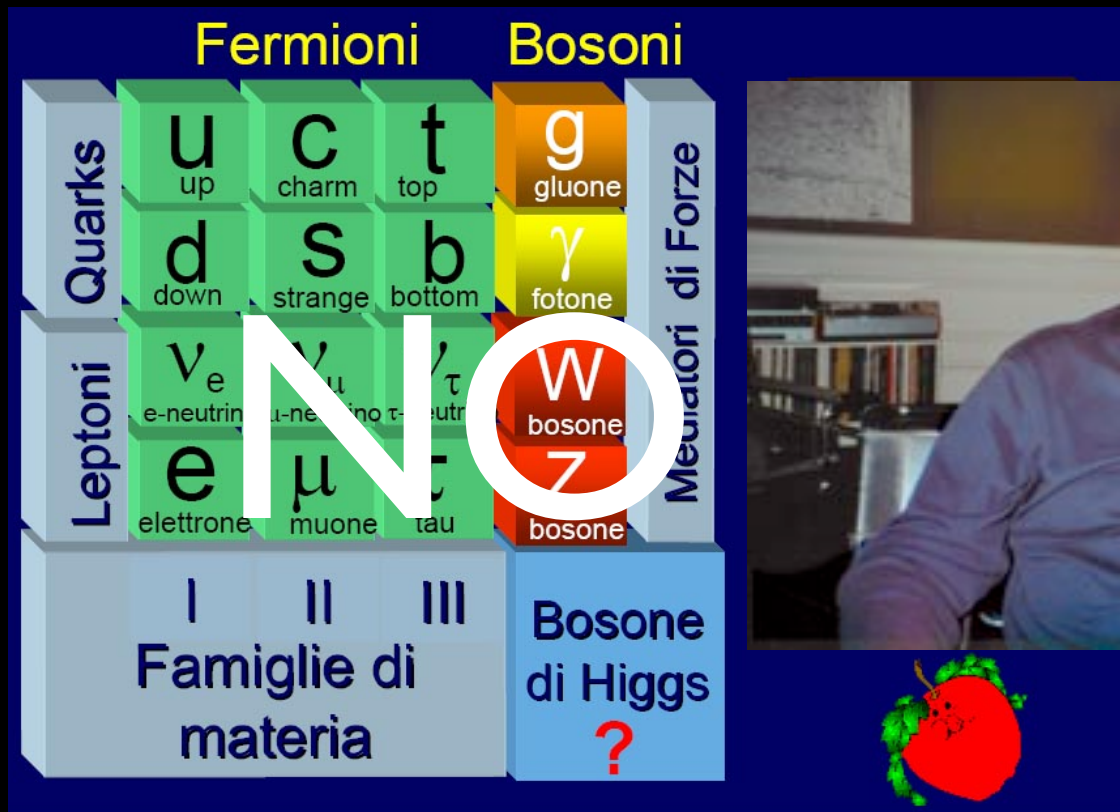


Le LHC ne reproduit pas le
BIG-BANG!

Les constituants élémentaires de la matière



Avons-nous une description complète?



Brisure de la Symétrie Electrofaible

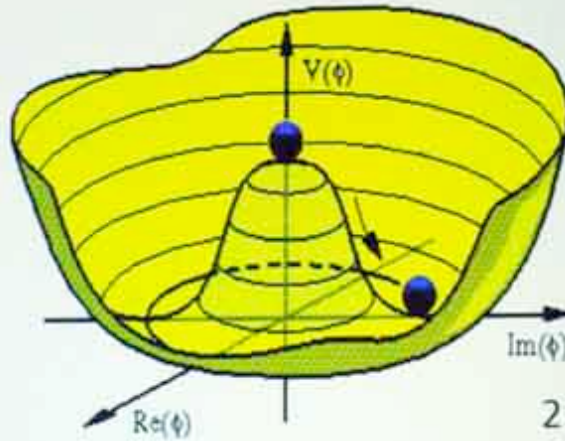
Il existe un champ scalaire présent dans tout l'univers

Ce champ est responsable de la brisure spontanée de la symétrie électrofaible

Les bosons Z^0 et W^\pm acquièrent une masse

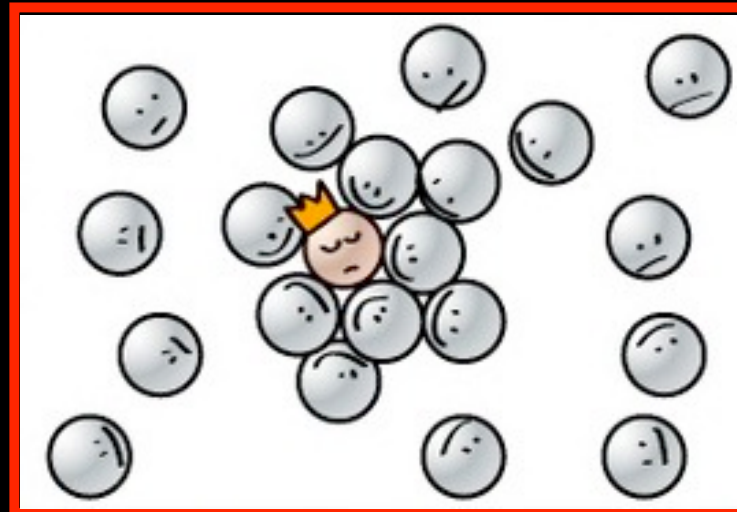
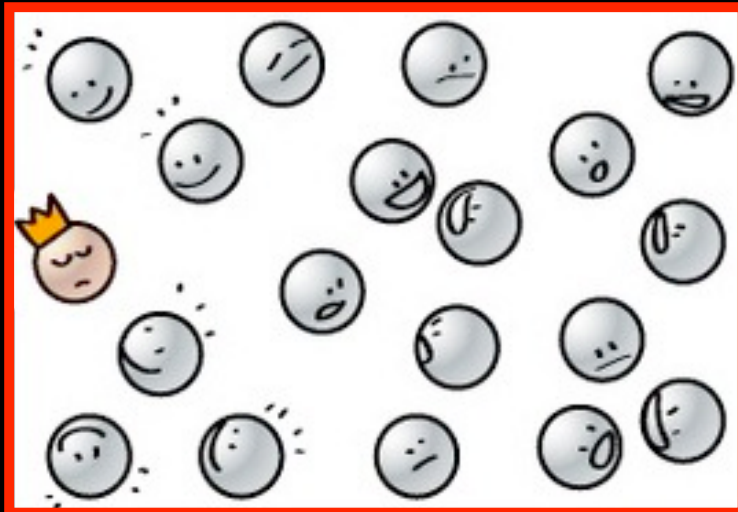
Les fermions élémentaires sont "ralentis" et acquièrent une masse

(i.e. les composantes gauches et droites se mélangent !)



Il doit exister au moins un boson scalaire associé au champ, le boson de Higgs

mass
=
inertie



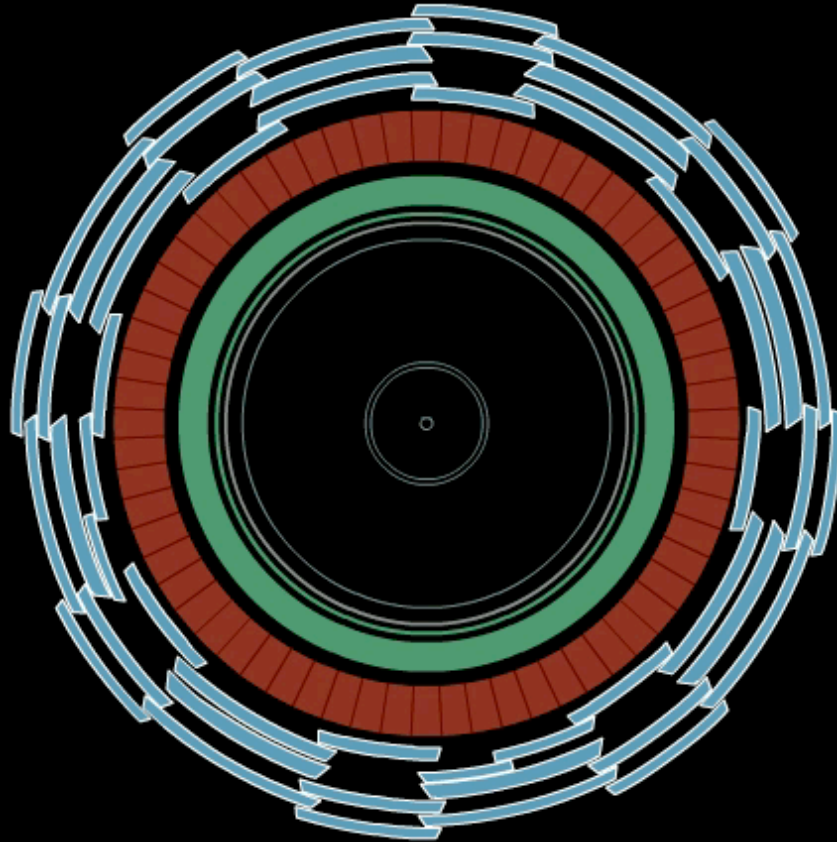
Le LHC peut nous aider à découvrir le boson de Higgs et la matière noire



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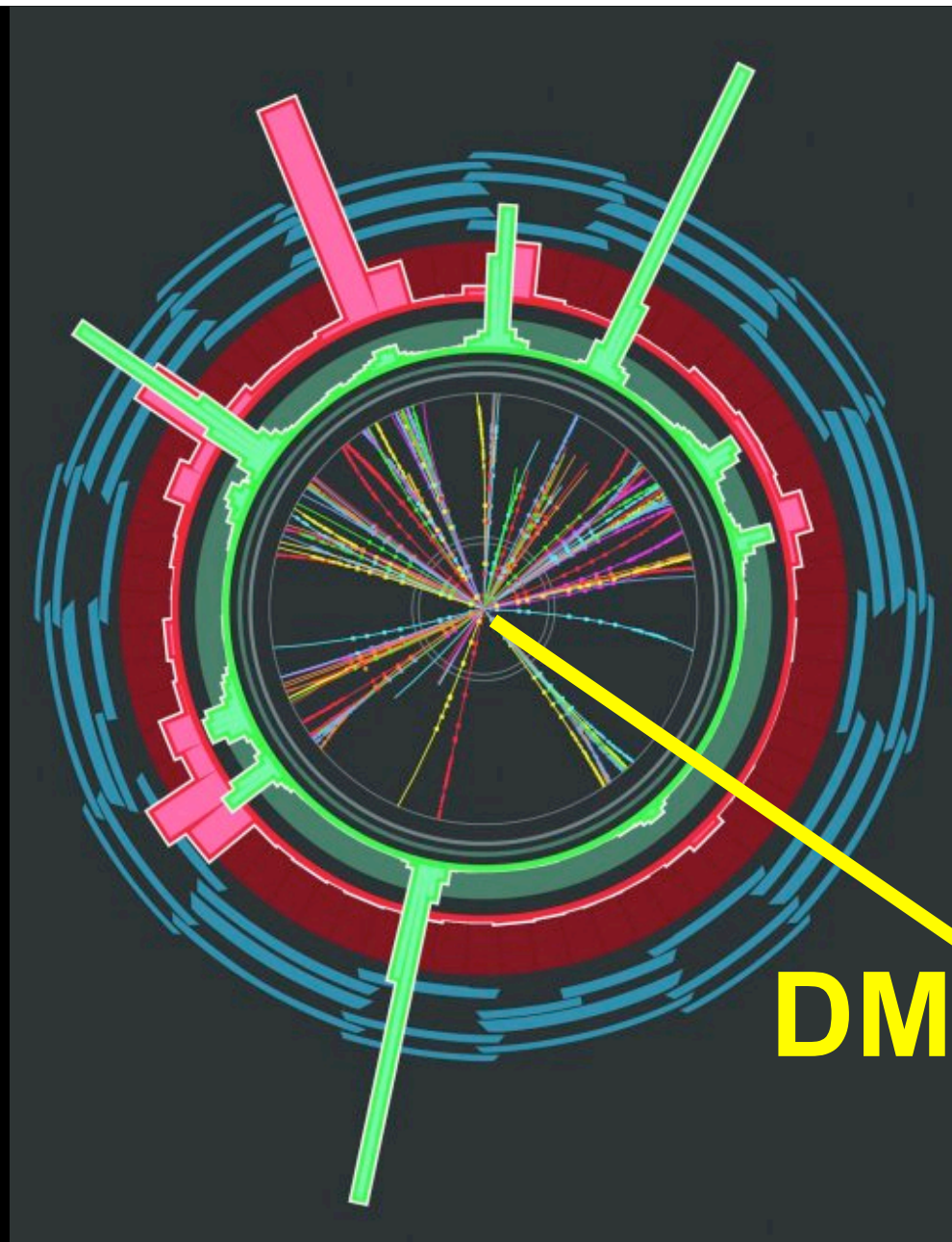
$$E \rightleftharpoons mc^2$$

Matière noire



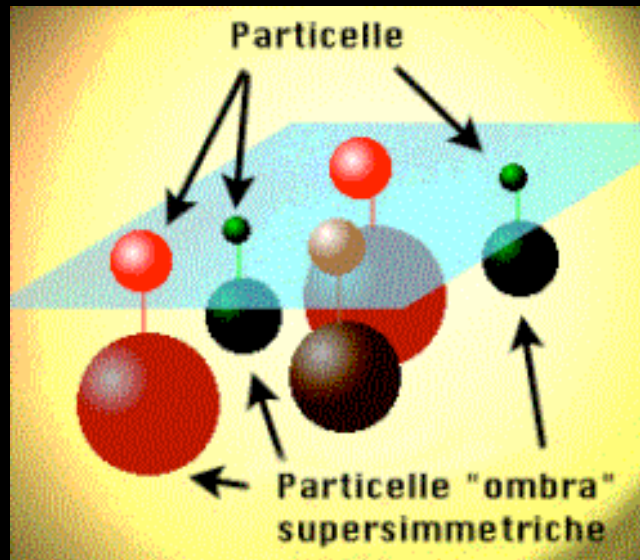
=

énergie manquante



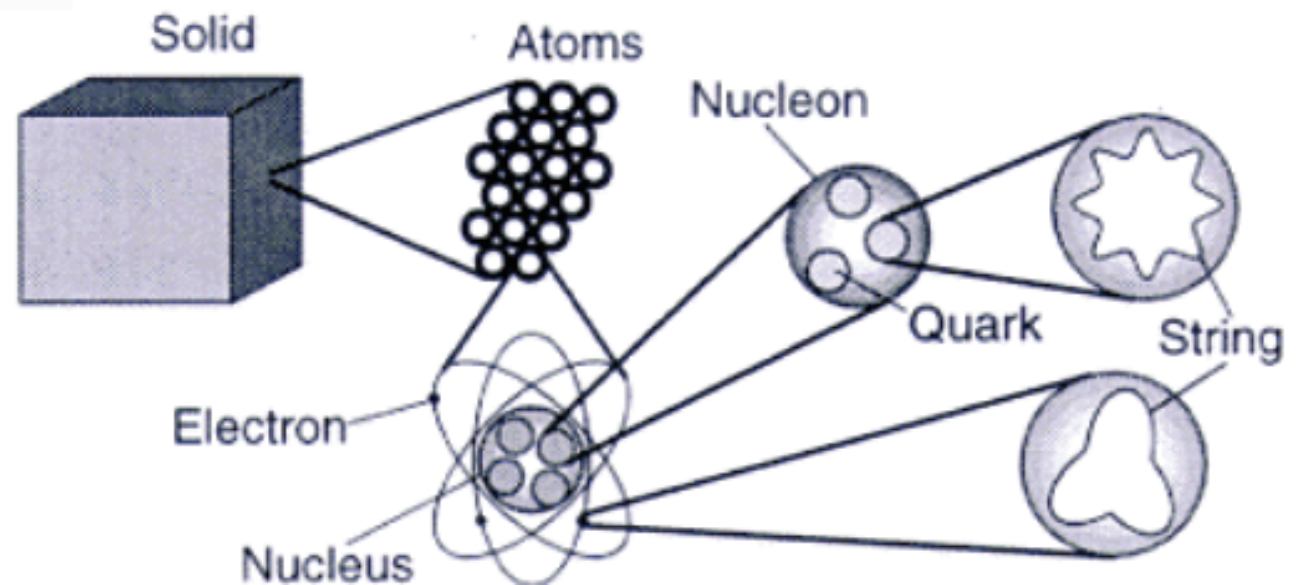
$$\sum_i E_i \neq \sum_f E_f$$

Supersymétrie

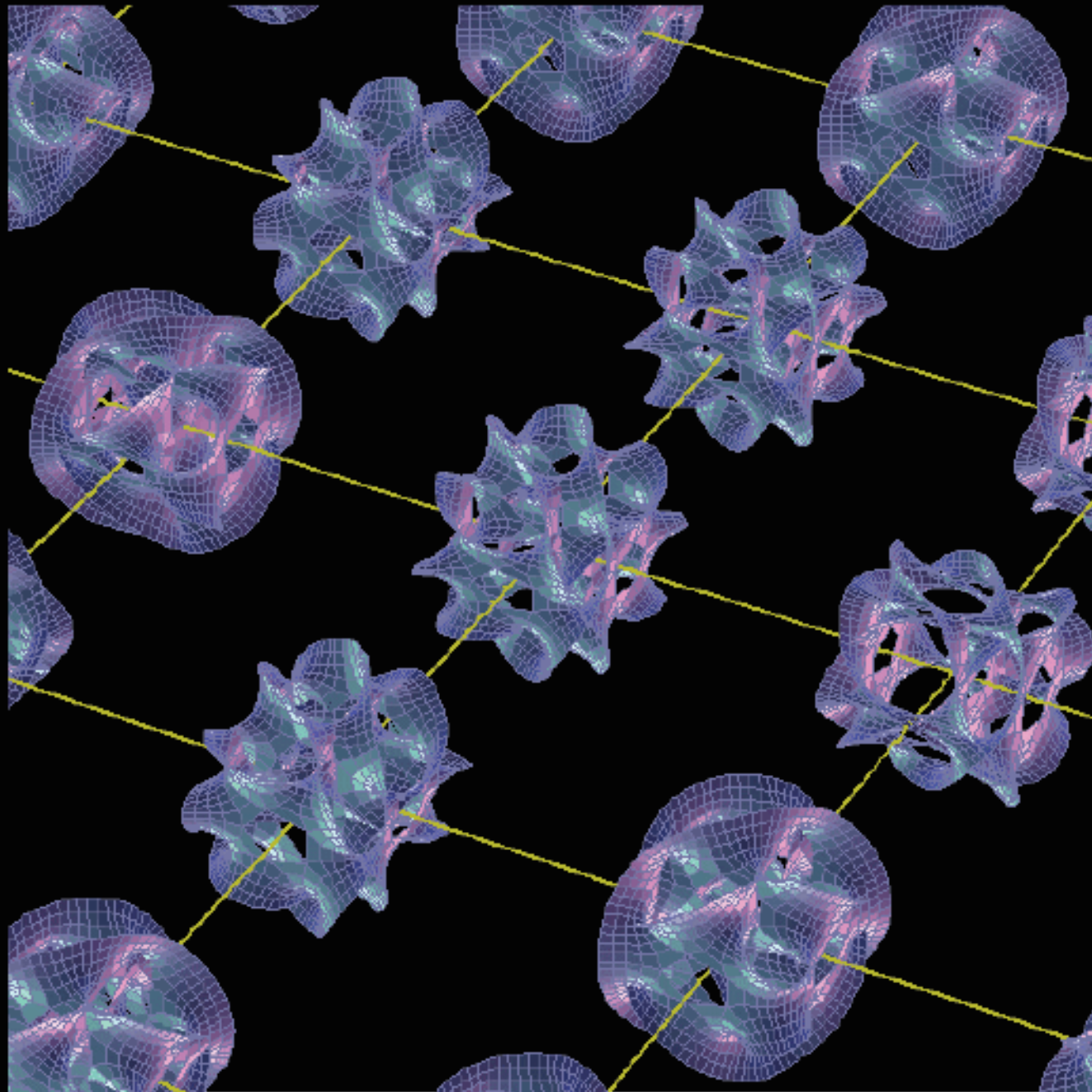


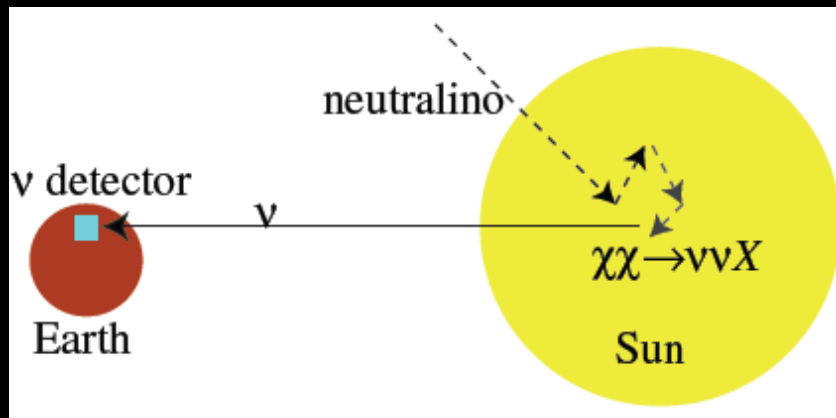
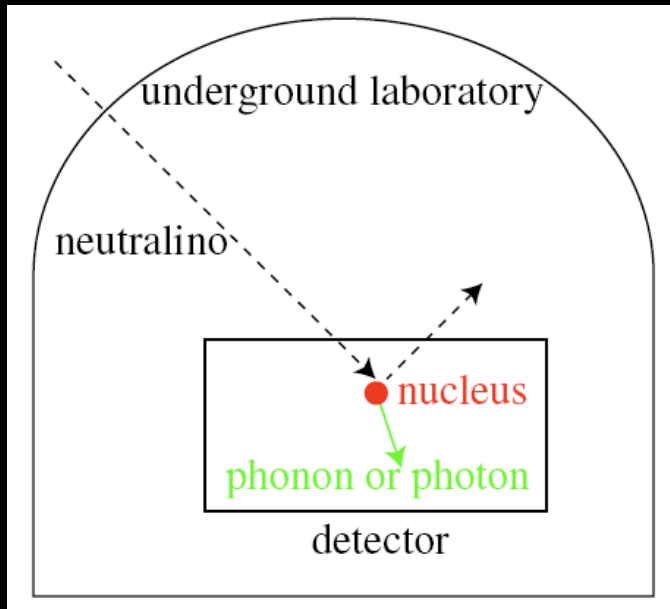


A world made of strings:



An 11-dimensional Universe







Puzzle: Pourquoi il y a pas des antigalaxies?

Antimatière

P. Dirac, 1929



It's try it anyway...
$$(i\gamma^\mu \partial_\mu - m)\psi = 0$$

uhoh, want this, but $i\gamma^\mu$ not ferm

Deux solutions: matière ($E > 0$) et antimatière ($E < 0$)

Quarks



Anti-quarks



Leptons



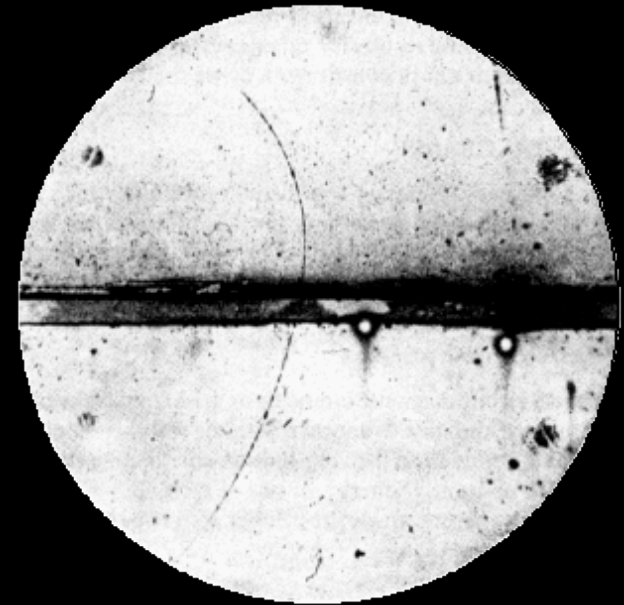
Anti-leptons



Deux solutions: matière et antimatière

Antimatière dans les rayons cosmiques

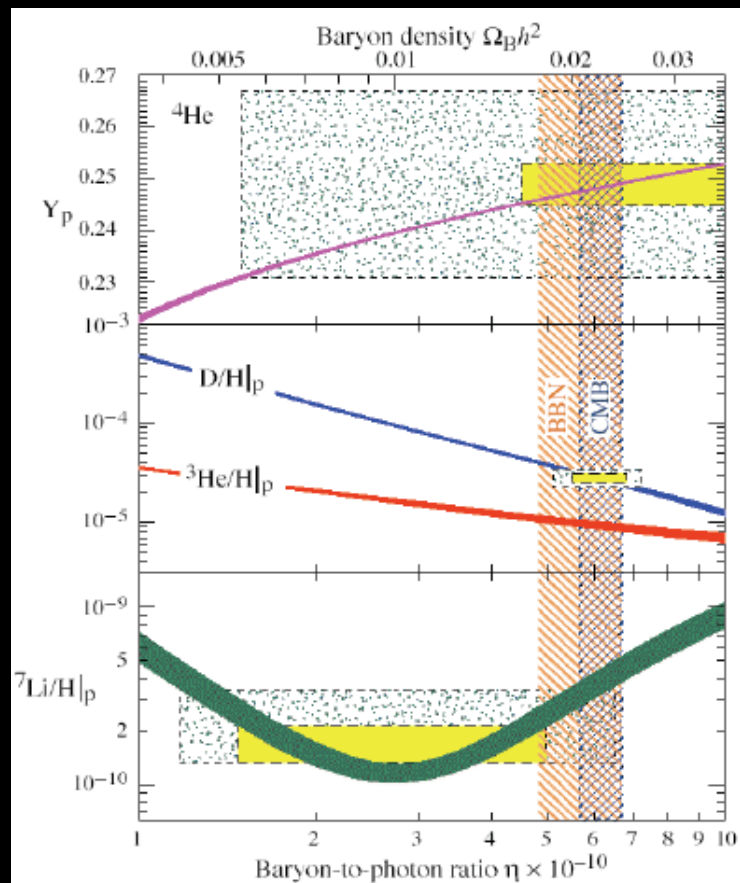
C. Anderson, 1932



Asymétrie baryon

$$\frac{n_B}{s} = \frac{n_b - n_{\bar{b}}}{s} = (8.7 \pm 0.3) \cdot 10^{-11}$$

En accord avec la CMB anisotropy, LSS et nucléosynthèse primordiale



Baryogénèse

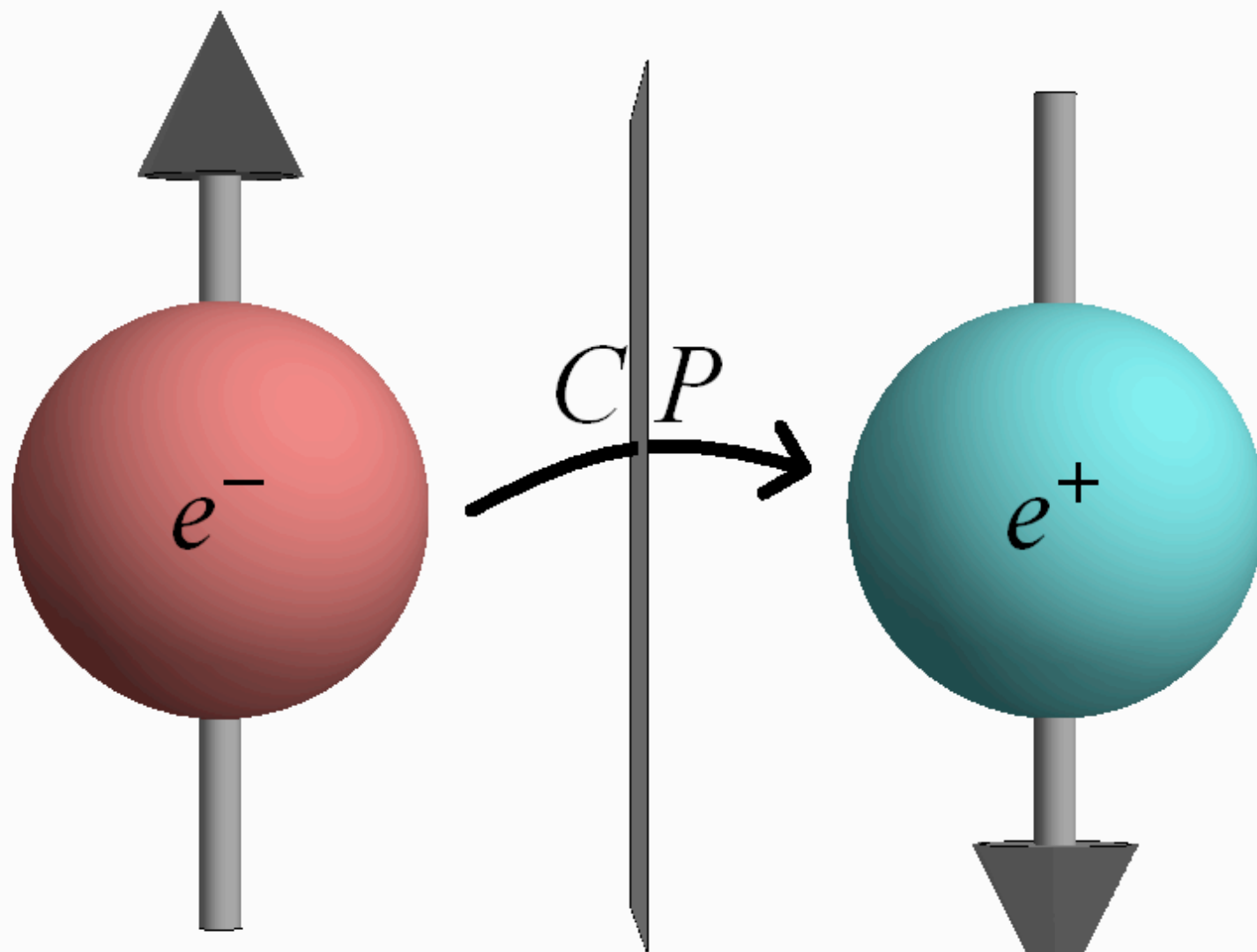


$$\frac{n_B}{s} = \frac{n_b - n_{\bar{b}}}{s} = 0 \Rightarrow \frac{n_B}{s} = \frac{n_b - n_{\bar{b}}}{s} = (8.7 \pm 0.3) \cdot 10^{-11}$$

Conditions de Sacharov (1967)



- Qu'il existe un processus violant la conservation du nombre baryonique
- Que la matière et l'antimatière obéissent à des lois physiques différentes: violation de la symétrie C et de la symétrie CP
- Qu'il y ait rupture de l'équilibre thermique



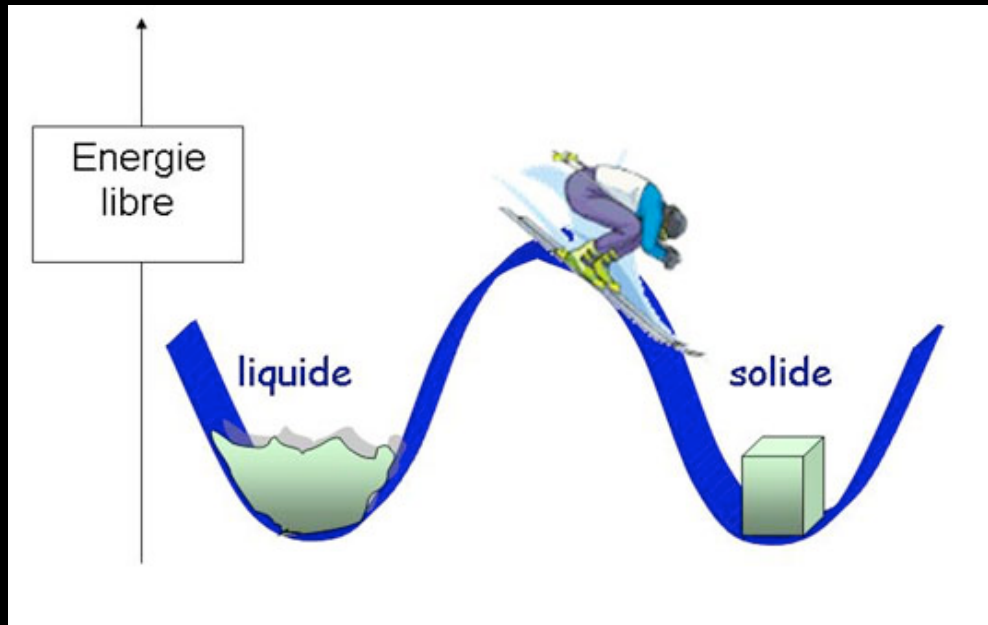
Spin-Up
Electron

Spin-Down
Positron

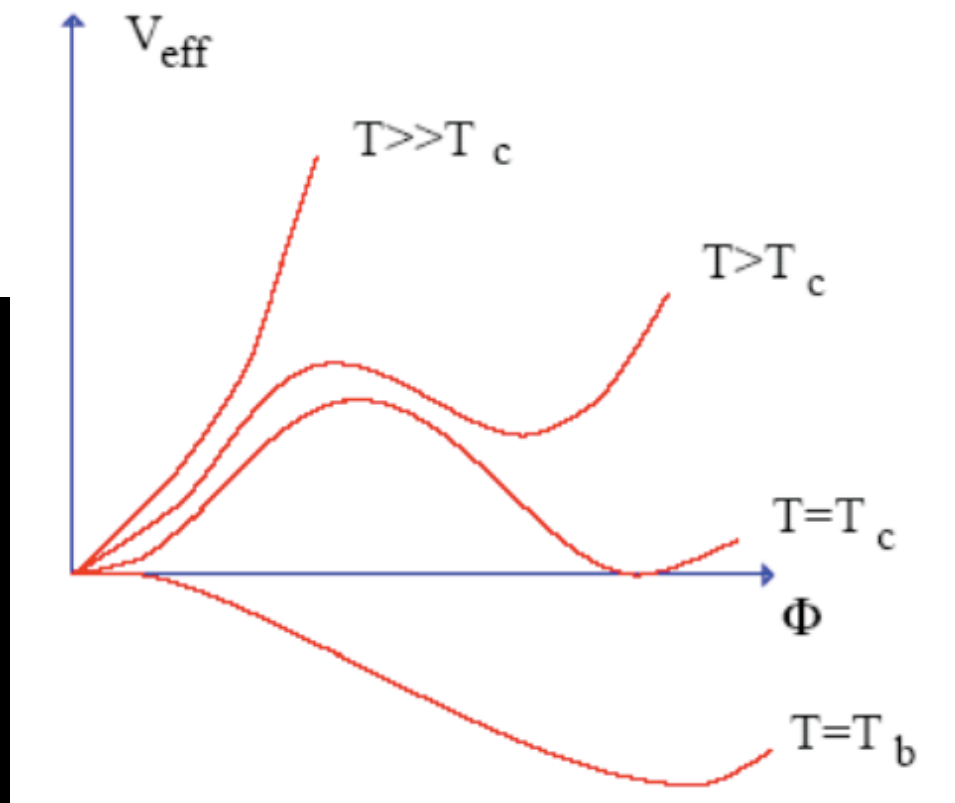
La violation de CP dans le Modèle Standard

$$\begin{aligned}\delta_{\text{CP}} &\sim \frac{(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_u^2 - m_t^2)}{T^6} \\ &\times \frac{(m_b^2 - m_s^2)(m_s^2 - m_d^2)(m_d^2 - m_b^2)}{T^6} \\ &\sim \frac{m_t^4 m_c^2 m_b^4 m_s^2}{T^{12}} \\ &\sim 10^{-20}\end{aligned}$$

Rupture de l'équilibre thermique: Transition de Phase

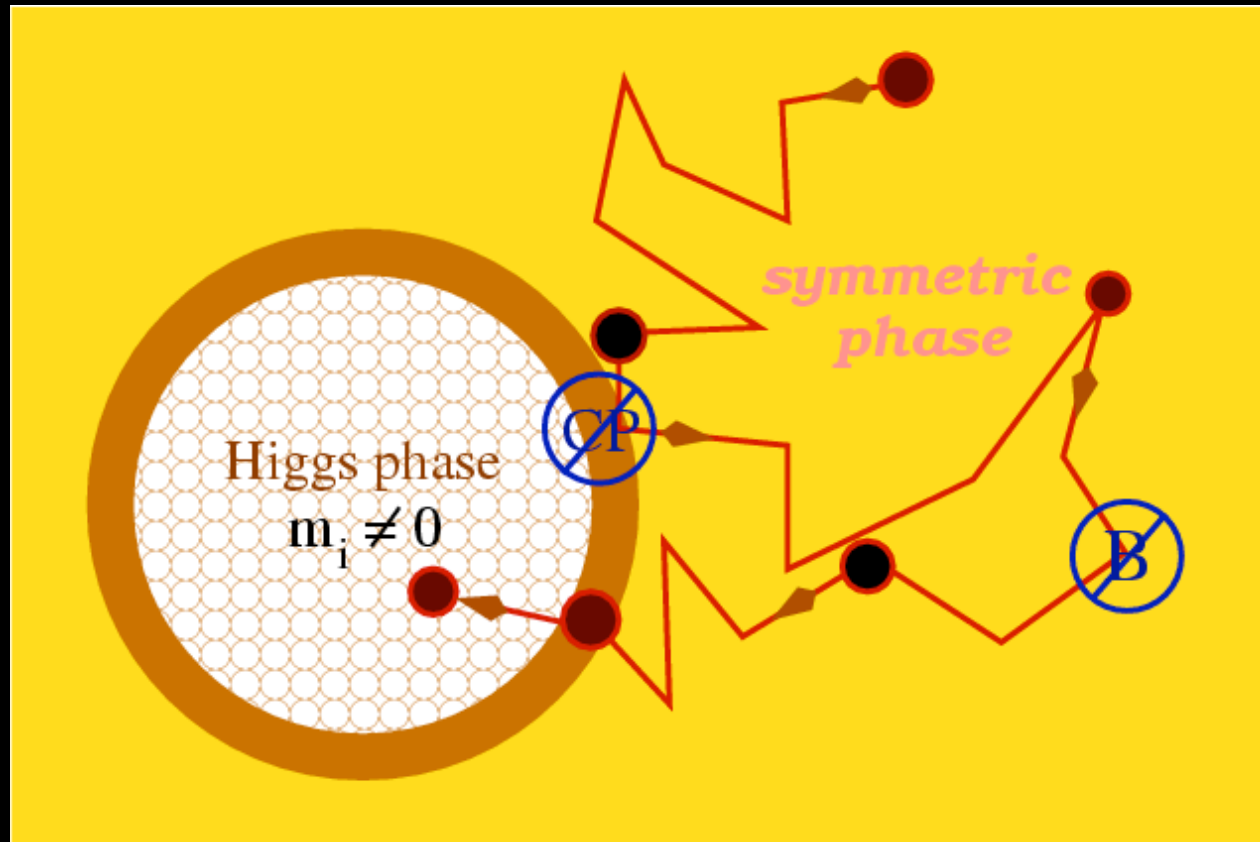


champ scalaire
(Higgs)
brisure de la symétrie



$$\frac{n_b - n_{\bar{b}}}{s} \neq 0$$

Conditions de Sacharov en action



$$M_h^{\text{SUSY}} < 130 \text{ GeV} \quad \text{LHC!!}$$

LHCb



Meson $D(c\bar{u})$: $\Gamma_D \neq \Gamma_{\bar{D}}$:

$$A_{CP} = [-0.82 \pm 0.21 \text{ (stat.)} \pm 0.11 \text{ (sys.)}]$$

**La matière noire
et
la Baryogénèse
impliquent que il y a
de physique au là du
Model Standard**

**L'Univers est
sombre,
mais le future
est plus brillant**

Bolla bulle
annichilazione annihilation
confini frontiers
somma somme
coda queue
valle di potenziale vallée de potentiel
inerzia inertie
decadere se disintegrer
ruotare turner
lifetime durée de vie