La matière sombre à la croisée des chemins de deux modèles standards

Gilles Cohen-Tannoudji and Jean-Pierre Gazeau

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Notre modèle:
La composante ‘matière sombre’ de LambdaCDM est interprétée comme un condensat gluonic de Bose-Einstein

L' equation d'Einstein

$$\mathcal{R}_{\mu\nu} - \frac{1}{2} g_{\mu\nu}\mathcal{R} = 8\pi G_N T_{\mu\nu} + \Lambda g_{\mu\nu}$$

World Matter energy density

$$T_{\mu\nu} = -P g_{\mu\nu} + (P+\rho) u_\mu u_\nu$$

$$T^{\Lambda}_{\mu\nu} = -\Lambda g^0_{\mu\nu}$$

$g^0_{\mu\nu}$: Minkowski metric

Λ>0: de Sitter WM

Λ<0: anti-de Sitter WM

La constante cosmologique dans le membre de droite: constante d'intégration

Equation de Friedman-Lemaître

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G_N \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3}$$

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G_N}{3}(\rho + 3P)$$

$$\dot{\rho} = -3H(\rho + P)$$

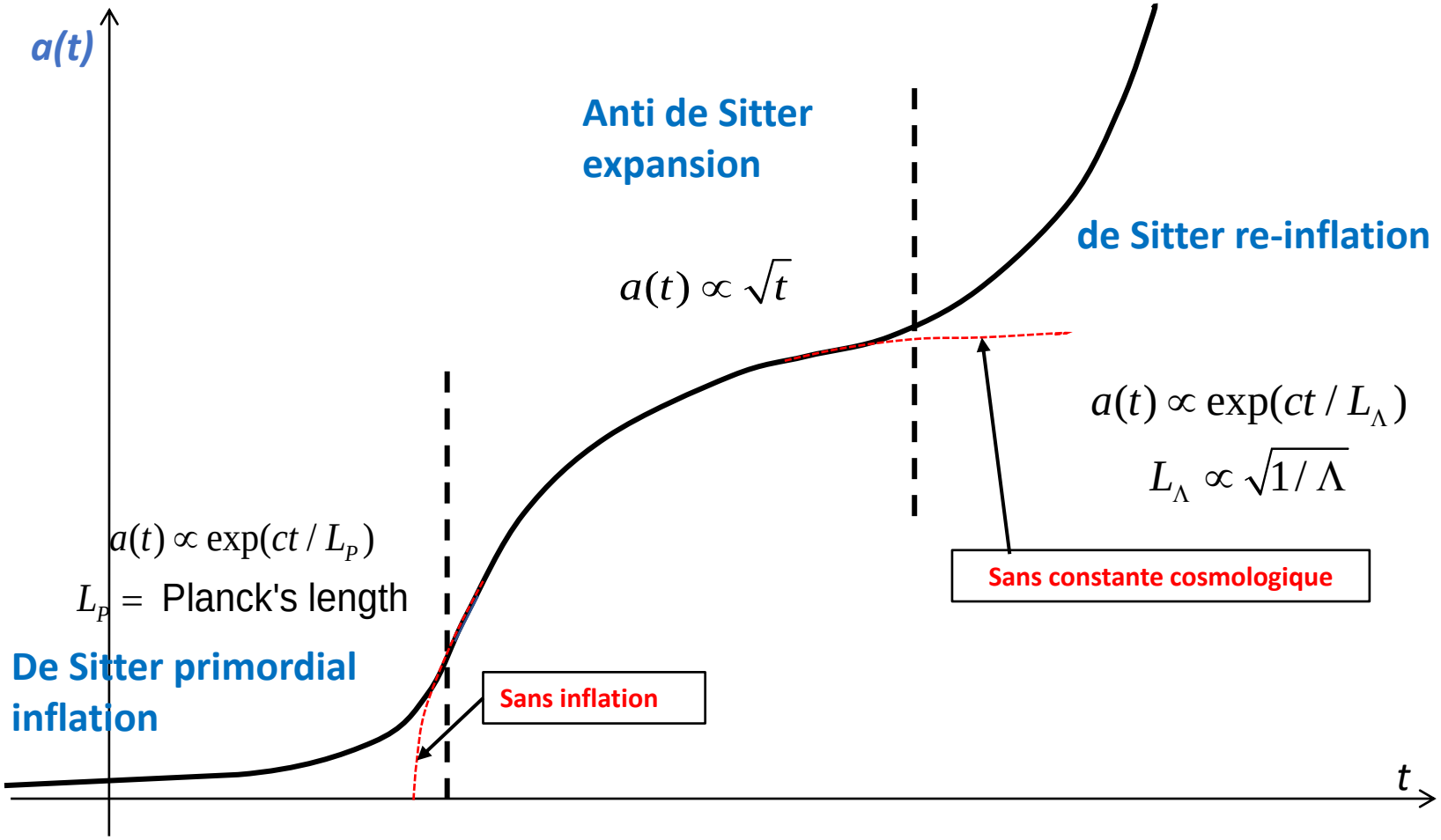
Règle de somme de la platitude

$$\rho_c \equiv \frac{3H^2}{8\pi G_N}$$

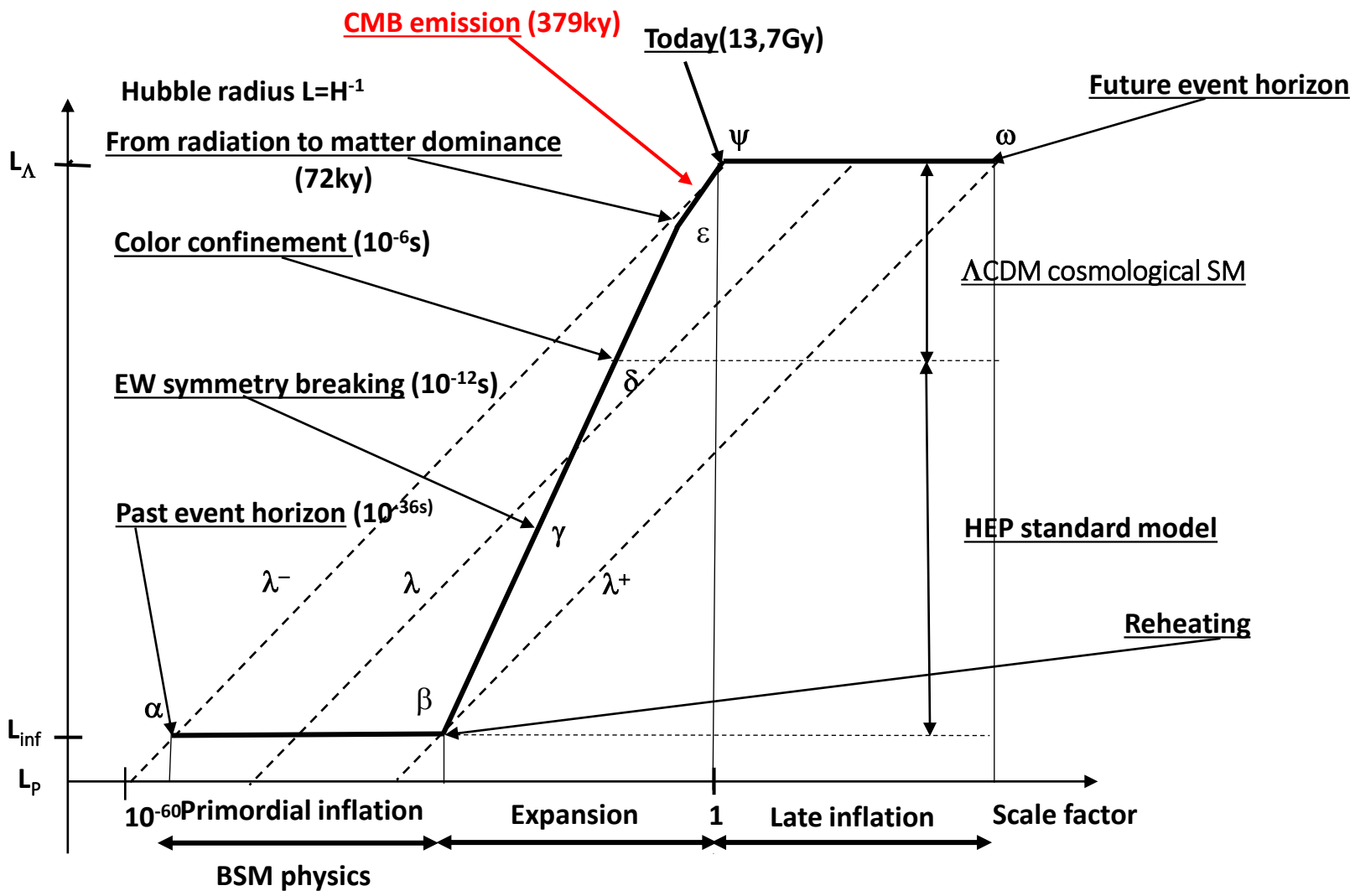
$$\rho_b + \rho_R + \rho_{DM} + \rho_{DE} - \rho_c = 0$$

with $\rho_{DE} = \Lambda / 8\pi G_N$

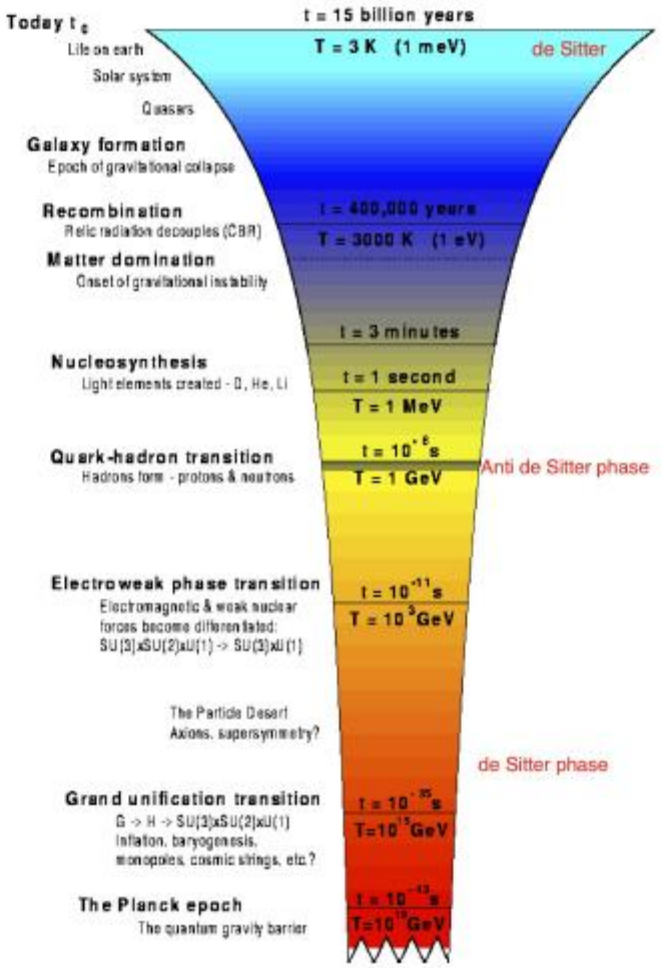
Les trois phases du nouveau modèle standard cosmologique



Oublier le temps? Non, le rendre implicite!



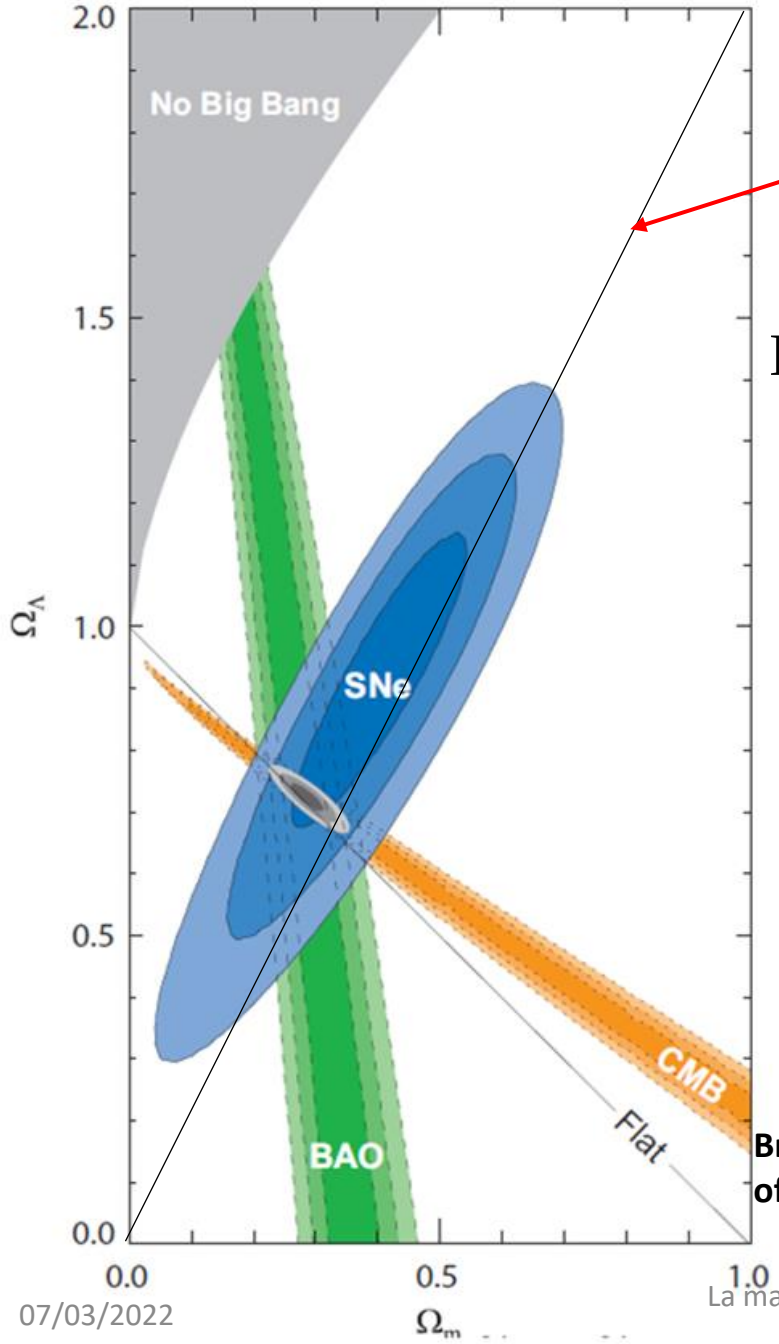
Cosmology chronology : de Sitter and Anti de Sitter phases



Gazeau, J.-P. Mass in de Sitter and Anti-de Sitter Universes with Regard to Dark Matter. Universe 2020, 6, 66. Available online: https://www.mdpi.com/2218-1997/6/5/66

16/18

Jean Pierre Gazeau



$\Omega_{DM}=1/2\Omega_\Lambda$ annulation de la masse active totale

Flatness sum rule $\rho_{\text{vis}} + \rho_{\text{DM}} + \rho_{\text{DE}} = \rho_{\text{c}} = \rho_\phi = \frac{3}{2}\rho_\Lambda$

Equation of state of dilaton field (determinant of the metric) ϕ

$$W_\phi = \frac{P_\phi}{\rho_\phi} = -1/3$$

$$\rho_{\text{vis}} + \rho_{\text{DM}} \equiv \rho_{\text{M}} = -P_\phi ; \rho_{\text{DE}} = -2P_\phi$$

Brout-Englert-Gunzig-mechanism: $\rho_{\text{vis}} + \rho_\phi = 0$

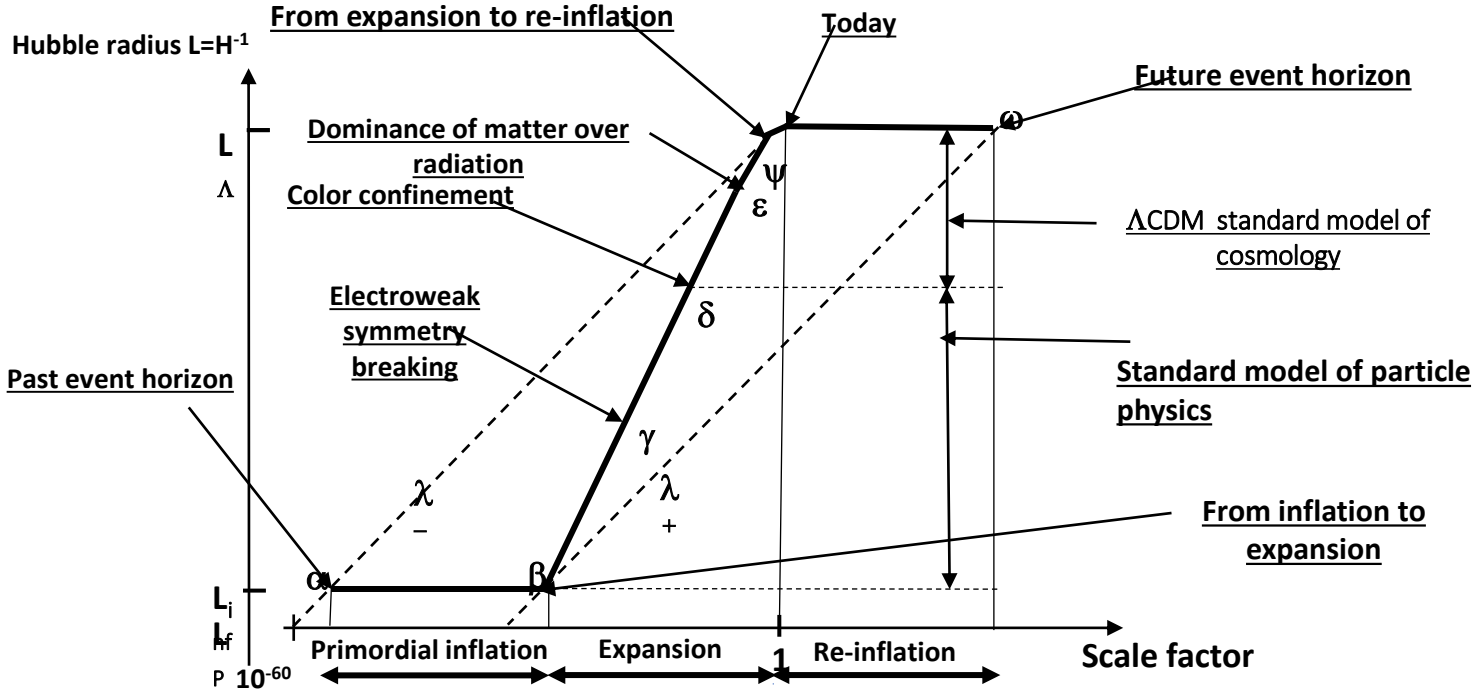
$\Rightarrow \rho_{\text{M}} + P_\phi = 0$ (principle of relativity of inertia);

$\Rightarrow$ Vanishing of total active mass: $\rho_\phi + 3P_\phi = 0$

Brout, R., Englert, F., and Gunzig, E. The Creation of the Universe as a Quantum Phenomenon, Annals of Physics 1978, 115, 78-106.

La consolidation des deux modèles standards

- In the primordial inflation phase (from α to β), here the dilaton field is the Goldstone boson of the matter/antimatter symmetry breaking,
- At the electroweak symmetry breaking (γ), here the dilaton field is the Higgs boson
- At the transition from the quark gluon plasma to the colorless hadron phase (δ), here the dilaton is the Goldstone boson (σ) of the chiral symmetry breaking
- At the Bose-Einstein condensation of gluons (ε) dark matter and the baryonic matter become matter dominated



Beyond Standard Model Physics

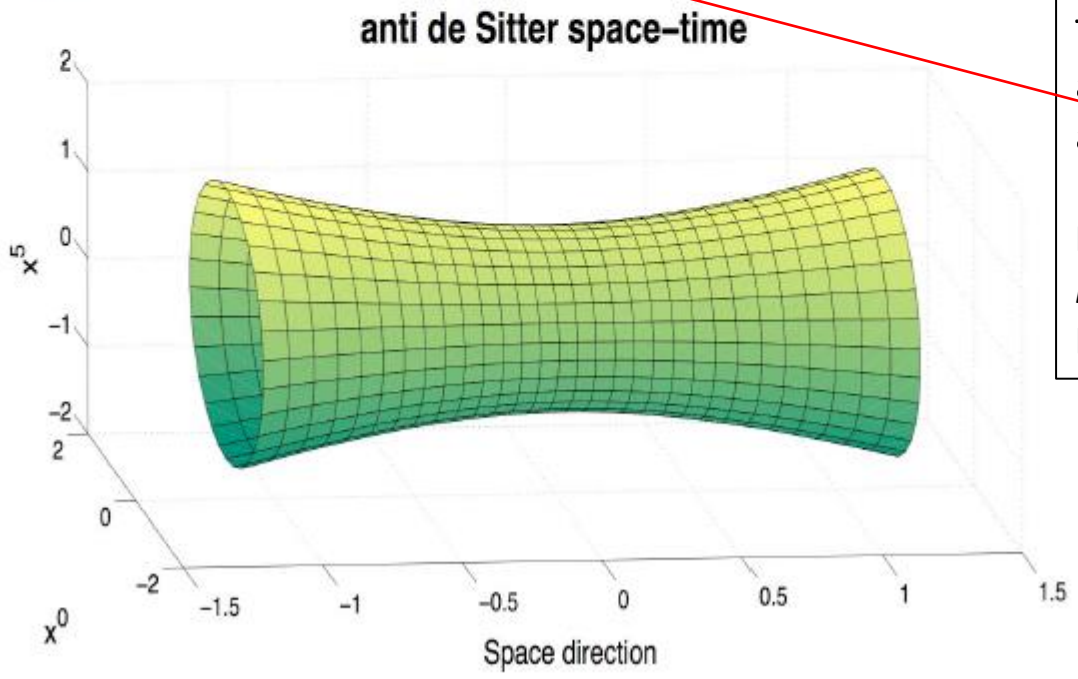
Gilles Cohen-Tannoudji and Jean-Pierre Gazeau https://www.mdpi.com/2218-1997/7/11/402 (ArXiv https://arxiv.org/abs/2111.01130v2)

Anti de Sitter geometry

- Anti de Sitter space can be viewed as a one-sheeted hyperboloid embedded in another five-dimensional space with different metric (here too all points are physically equivalent) :

$$M_{AdS} \equiv \{x \in \mathbb{R}^5;\ x^2 = \eta_{\alpha\beta}\, x^\alpha x^\beta = \frac{|\Lambda_{\rm AdS}|}{3}\}, \quad \alpha, \beta = 0, 1, 2, 3, 5,$$

where $\eta_{\alpha\beta}$ =diag$(1, -1, -1, -1, 1)$.



The four-dimensional world requires for its "motion" an absolute space of four (or more) dimensions, and in addition an "extra-mundane time" acting as an independent variable for this motion.
De Sitter, *Remarks concerning Einstein's latest hypothesis*
KNAW Proceedings, 1917

Energy of a free particle in AdS versus dS and Poincaré

- Each **Anti-deSitterian quantum elementary system** (in the Wigner sense) has a rest energy

$$E_{\mathrm{AdS}}^{\mathrm{rest}} = \left[m^2c^4 + \hbar^2c^2\frac{\Lambda_{\mathrm{AdS}}}{3}\left(s-\frac{1}{2}\right)^2\right]^{1/2} + \frac{3}{2}\hbar\sqrt{\frac{|\Lambda_{\mathrm{AdS}}|}{3}}\,c\,, \qquad (1)$$

- Hence, to the order of $\hbar$, an AdS elementary system is a deformation of both a relativistic free particle with rest energy mc^2 and a 3d isotropic quantum harmonic oscillator with ground state energy $\frac{3}{2}\hbar\omega_{\mathrm{AdS}}$, with $\omega_{\mathrm{AdS}} := \sqrt{\frac{|\Lambda_{\mathrm{AdS}}|}{3}}\,c.$.

- In contrast to AdS, for Poincaré and DS symmetries the energy spectrum is continuous. It is possible to define a rest energy for dS as follows :

$$E_{\mathrm{dS}}^{\mathrm{rest}} = \pm\left[m^2c^4 - \hbar^2c^2\frac{\Lambda_{\mathrm{dS}}}{3}\left(s-\frac{1}{2}\right)^2\right]^{1/2}. \qquad (2)$$

- Noticeable simplification in both AdS and dS for **fermions** $s = 1/2$:

$$\text{for dS :} \quad E_{\mathrm{dS}}^{\mathrm{rest}} = \pm mc^2\,, \qquad (3)$$

$$\text{for AdS :} \quad E_{\mathrm{AdS}}^{\mathrm{rest}} = mc^2 + \frac{3}{2}\hbar\omega_{\mathrm{AdS}}\,. \qquad (4)$$

The choice $E_{\mathrm{dS}}^{\mathrm{rest}} = mc^2$ should be privileged for obvious reasons.

15/19

Jean Pierre Gazeau, Sonia Gazeau

La condensation de Bose-Einstein dans l’espace-temps Anti-de Sitter

Equipartition holographique et condensation de Bose-Einstein dans l'horizon anti-de Sitter de Hubble

Holographic equipartition

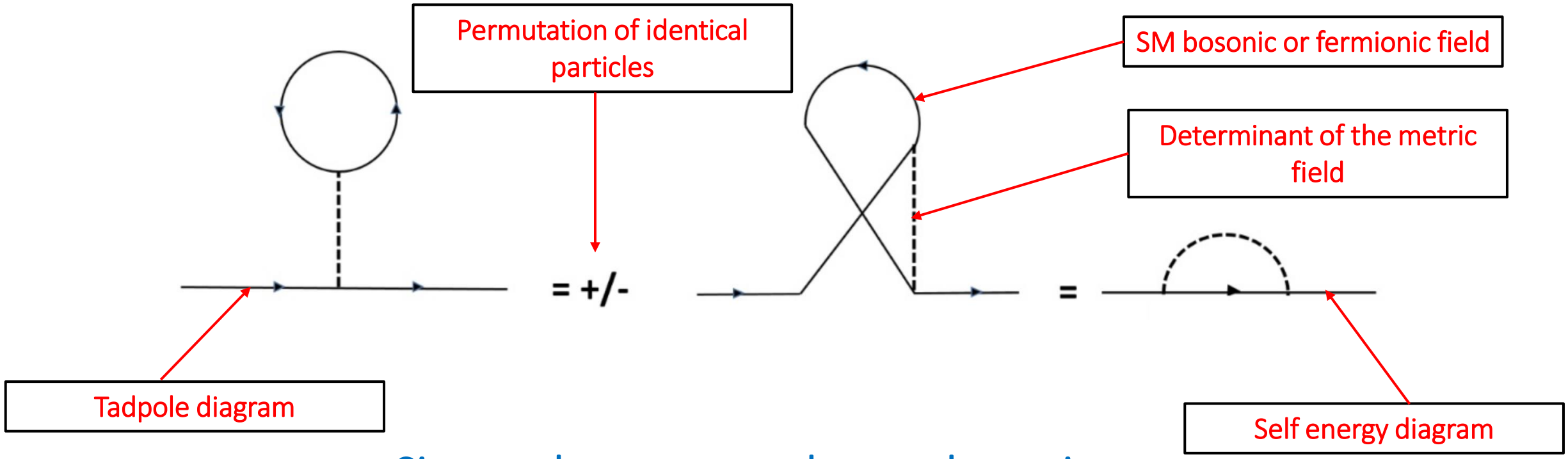
$$N_{\text{sur}} = \frac{4\pi}{L_{\text{P}}{}^2 H^2};\ \text{one degree of freedom (one bit) per Planck area}$$

$$N_{\text{bulk}} = \frac{|E|}{1/2k_{\text{B}}T};\ k_{\text{B}}T = \frac{H}{2\pi};\ |E| = |\rho + 3P|V;\ V = \frac{4\pi}{3H^2}$$

$$\Rightarrow N_{\text{bulk}} = -\frac{E}{1/2k_{\text{B}}T} = -\frac{2(\rho + 3P)V}{k_{\text{B}}T}\ \text{(for positive } \rho\text{)}$$

$$P = -\rho\ \text{(vacuum)} \Rightarrow\ H^2 = 8\pi L_{\text{P}}{}^2 \rho / 3 \Leftrightarrow\ N_{\text{bulk}} = N_{\text{sur}}$$

L'univers sombre et l'espace-temps anti-de Sitter



Signe +: la masse sombre est bosonique

Signe -: l'énergie sombre est fermionique

Cold dark matter : Bose-Einstein condensation of gluons in Anti-de Sitter space time

Gilles Cohen-Tannoudji and J-P Gazeau, Universe 2021, 7, 402.
https ://doi.org/10.3390/universe7110402

- A parallel between dark matter and CMB :
  - CMB → photon decoupling, i.e. photons started to travel freely through space rather than constantly being scattered by electrons and protons in plasma (QED effect).
  - Dark matter → gluonic component of the quark epoch (quark-gluon plasma) which freely subsists after hadronization within an effective AdS environment (QCD effect)
- As an assembly of N_G non-interacting entities with individual energies $E_n = (n+2)\hbar\omega_{\mathrm{AdS}}$ and degeneracy $g_n = (n+1)(n+3)$, those remnant gluons are assumed to form a grand canonical Bose-Einstein ensemble whose the chemical potential μ is, at temperature T, fixed by

$$N_G = \sum_{n=0}^{\infty} \frac{g_n}{\exp\left[\frac{\hbar\omega_{\mathrm{AdS}}}{k_B T}(n+2-\mu)\right] - 1}. \tag{8}$$

- Since this number is very large this gas condensates at temperature

$$T_c \approx \frac{\hbar\omega_{\mathrm{AdS}}}{k_B}\left(\frac{N_G}{\zeta(3)}\right)^{1/3} \tag{9}$$

to become the currently observed dark matter.

Jean Pierre Gazeau, Sonia Gazeau

Gazeau, J-P., Habonimana, C., Signal analysis and quantum formalism: Quantizations with no Planck constant, in: Landscapes of Time-Frequency Analysis, Vol. 2, Applied in Numerical and Harmonic Analysis series, New York: Springer International Publishing, 2020. : arXiv:2001.04916 [quant-ph]

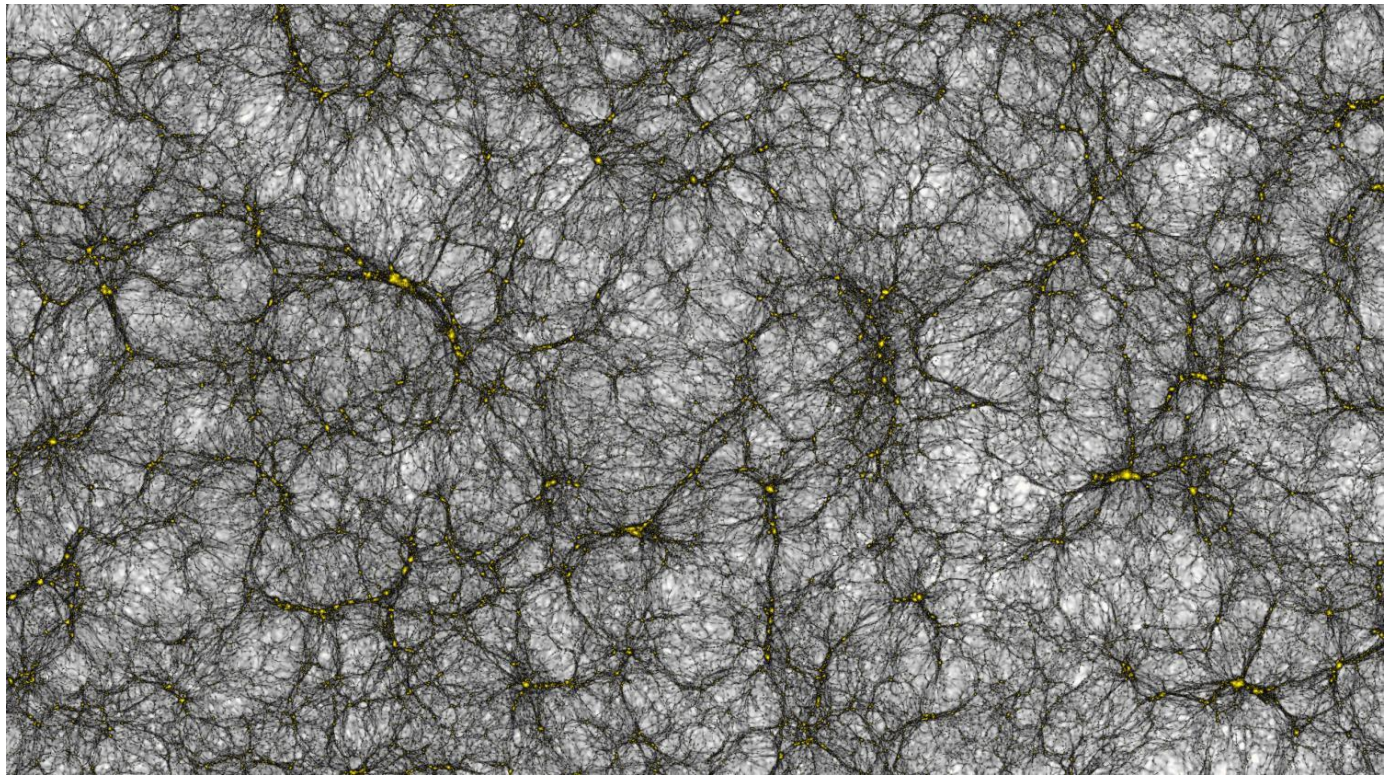
Cohen-Tannoudji, G., Gazeau, J-P., Habonimana, C., and Shabani, J. Quantum models à la Gabor for space-time, in progress.

"Thus, the presence of a nonvanishing energy gap in a superconductor implies the existence of a ground-state condensate of correlated electron pairs."
Adler, S.L. Einstein gravity as a symmetry breaking effect in quantum field theory. Rev. Mod. Phys. 1982, 54, 729.

Our predictions (with $N_c = N_f = 3$) compared with the Planck-2018 results

	Our predictions	Planck 2018 results
Dark Matter/visible matter	**$11N_c/2N_f = 11/2$**	**5,322+/- 0,00091**
$(\Omega_\Lambda - \Omega_{Vis})/2 = \Omega_M$	**0,3157**	**0,3111+/- 0,0056**

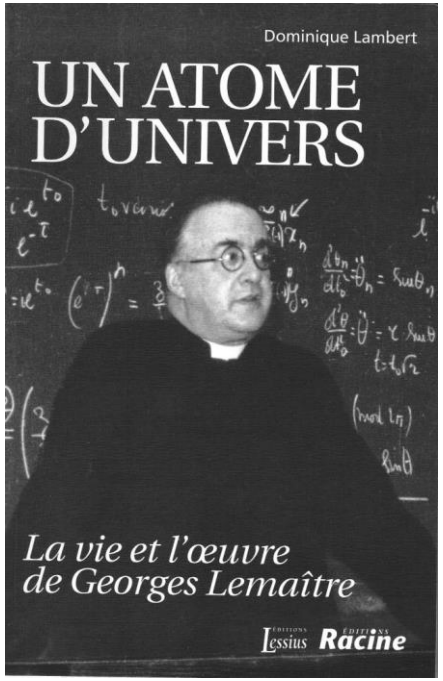
For $\Omega_\Lambda - \Omega_{vis} = 2\Omega_M$ to be exact, $N_f = N_f^{eff} = 4.54$



A section of the largest virtual universe ever simulated.

"This figure can be interpreted as showing the complex topology of the **spacetime of the dark universe**: **a web of dark filaments that are tensionless dark cosmic strings freely moving in a void space (the white regions in the figure) with vanishing spatial curvature**, whereas the AdS spacetime inside the filaments has a positive curvature."

What is scientific cosmogony?



« L'objet d'une théorie cosmogonique est de rechercher des conditions initiales idéalement simples d'où a pu résulter, par le jeu des forces physiques connues, le monde actuel dans toute sa complexité » *Georges Lemaître, l'hypothèse de l'atome primitif – Essai de cosmogonie -*

"The object of a cosmogonic theory is to search for ideally simple initial conditions from which, through the play of known physical forces, the current world in its full complexity could have resulted"

Georges Lemaître, the **primitive atom hypothesis** – **Essay of Cosmogony -**

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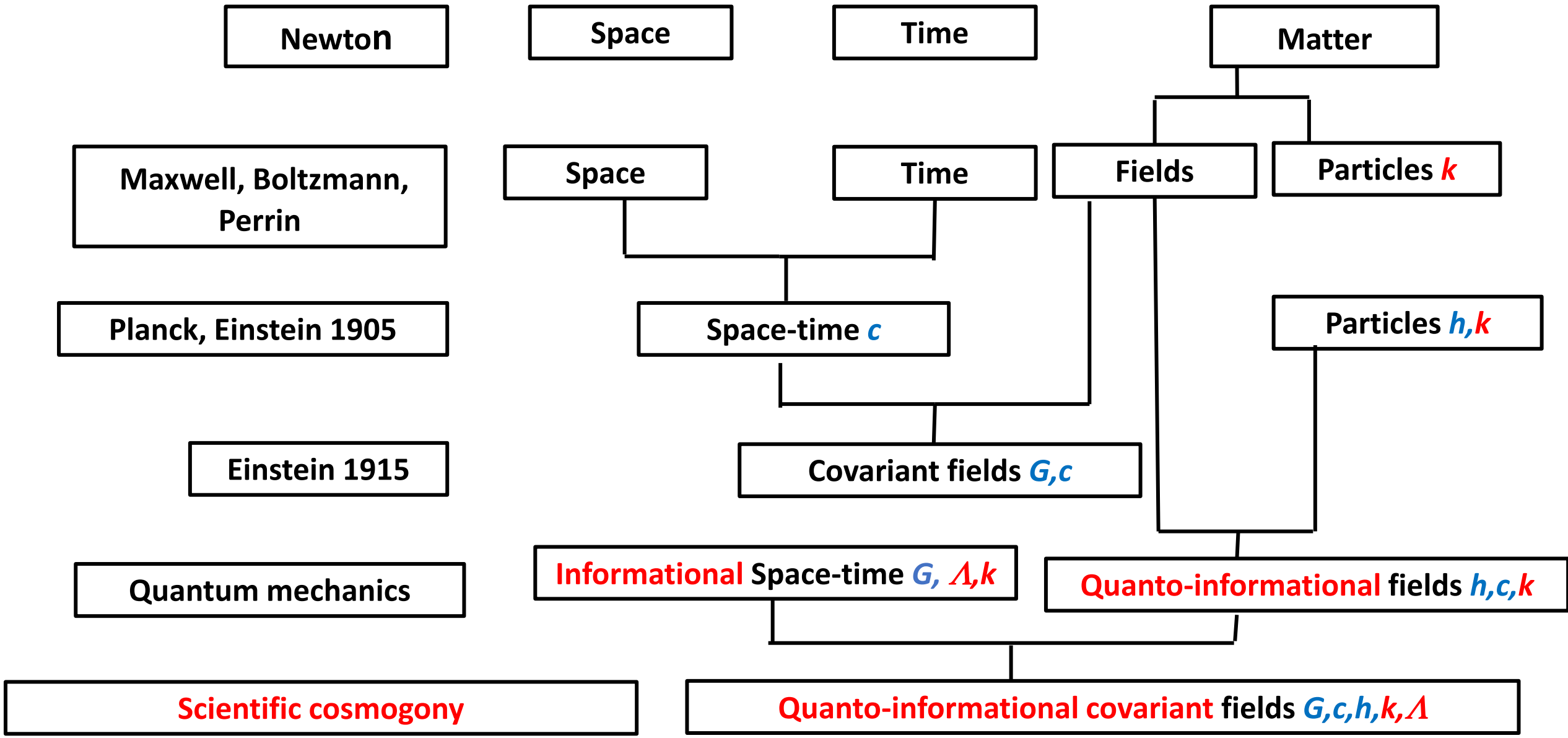
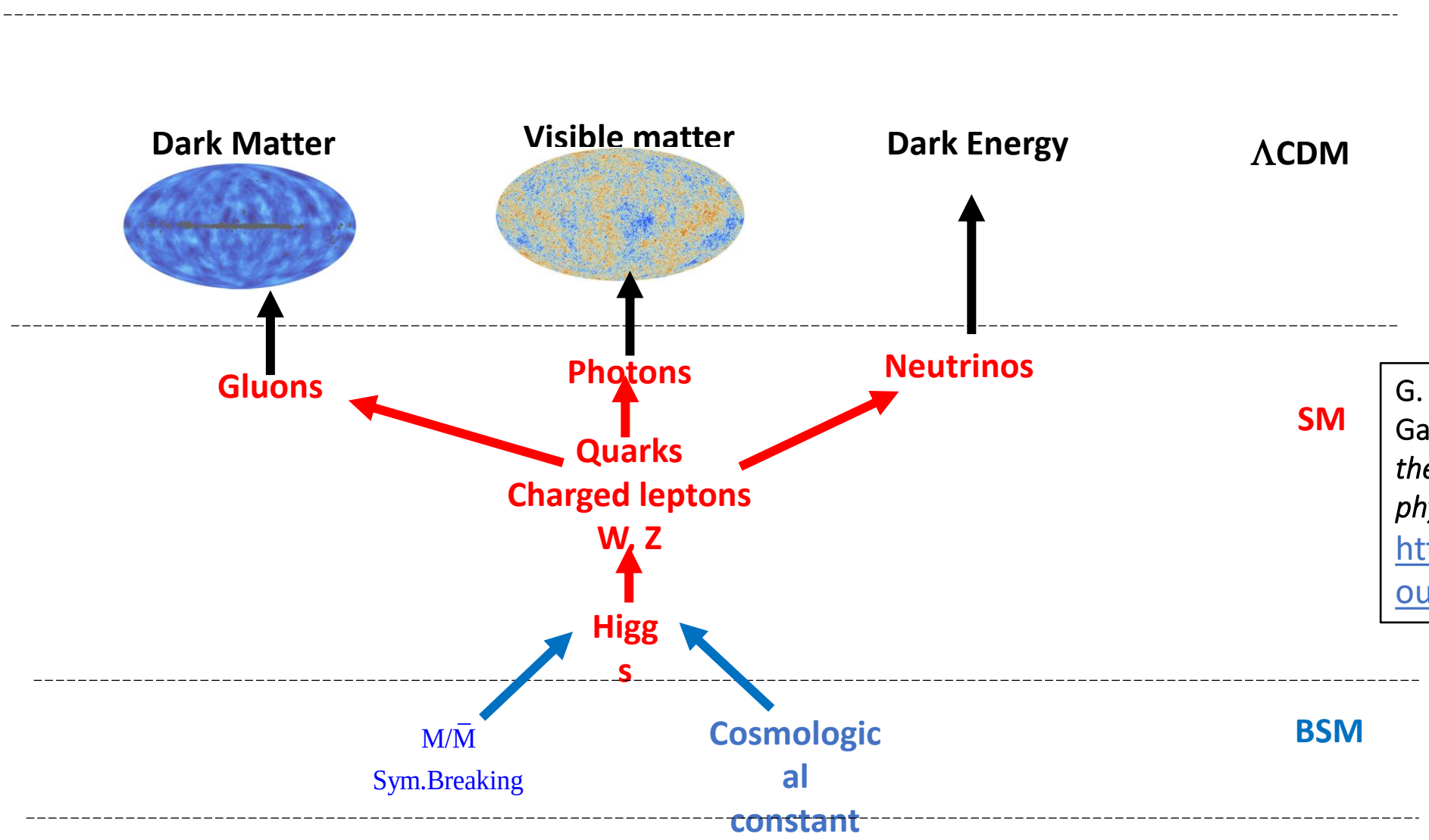
A tribute to Steven Weinberg (1933-2021) RIP

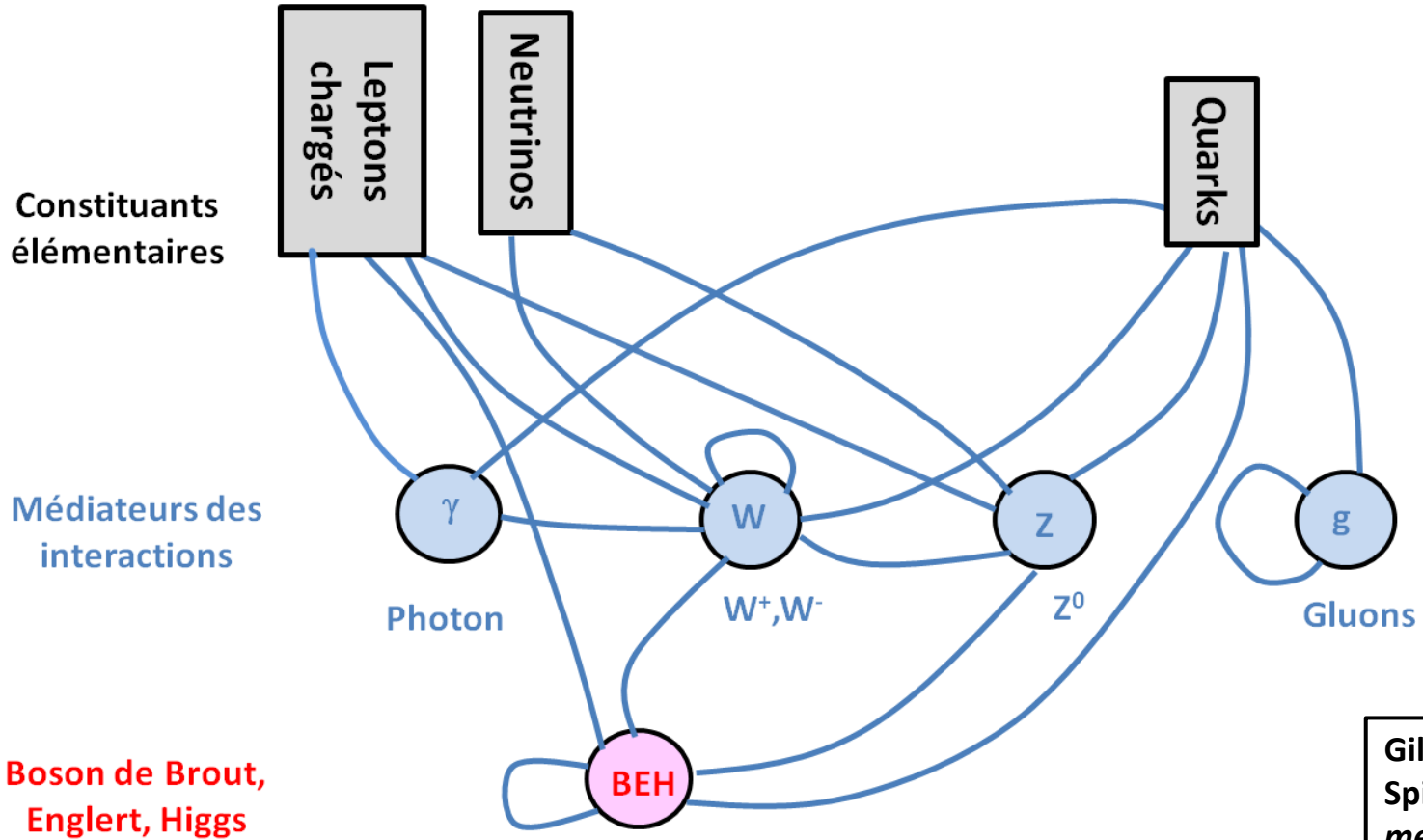
What is quantum field theory, and what did we believe it is?

"In its mature form, the idea of quantum field theory is that quantum fields are the basic ingredients of the universe, and particles are just bundles of energy and momentum of the fields. In a relativistic theory the wave function is a functional of these fields, not a function of particle coordinates. Quantum field theory hence led to a more unified view of nature than the old dualistic interpretation in terms of both fields and particles"


Newton
Space
Time
Matter
Maxwell, Boltzmann, Perrin
Space
Time
Fields
Particles k
Planck, Einstein 1905
Space-time c
Particles h,k
Einstein 1915
Covariant fields G,c
Quantum mechanics
Informational Space-time G, Λ,k
Quanto-informational fields h,c,k
Scientific cosmogony
Quanto-informational covariant fields G,c,h,k,Λ



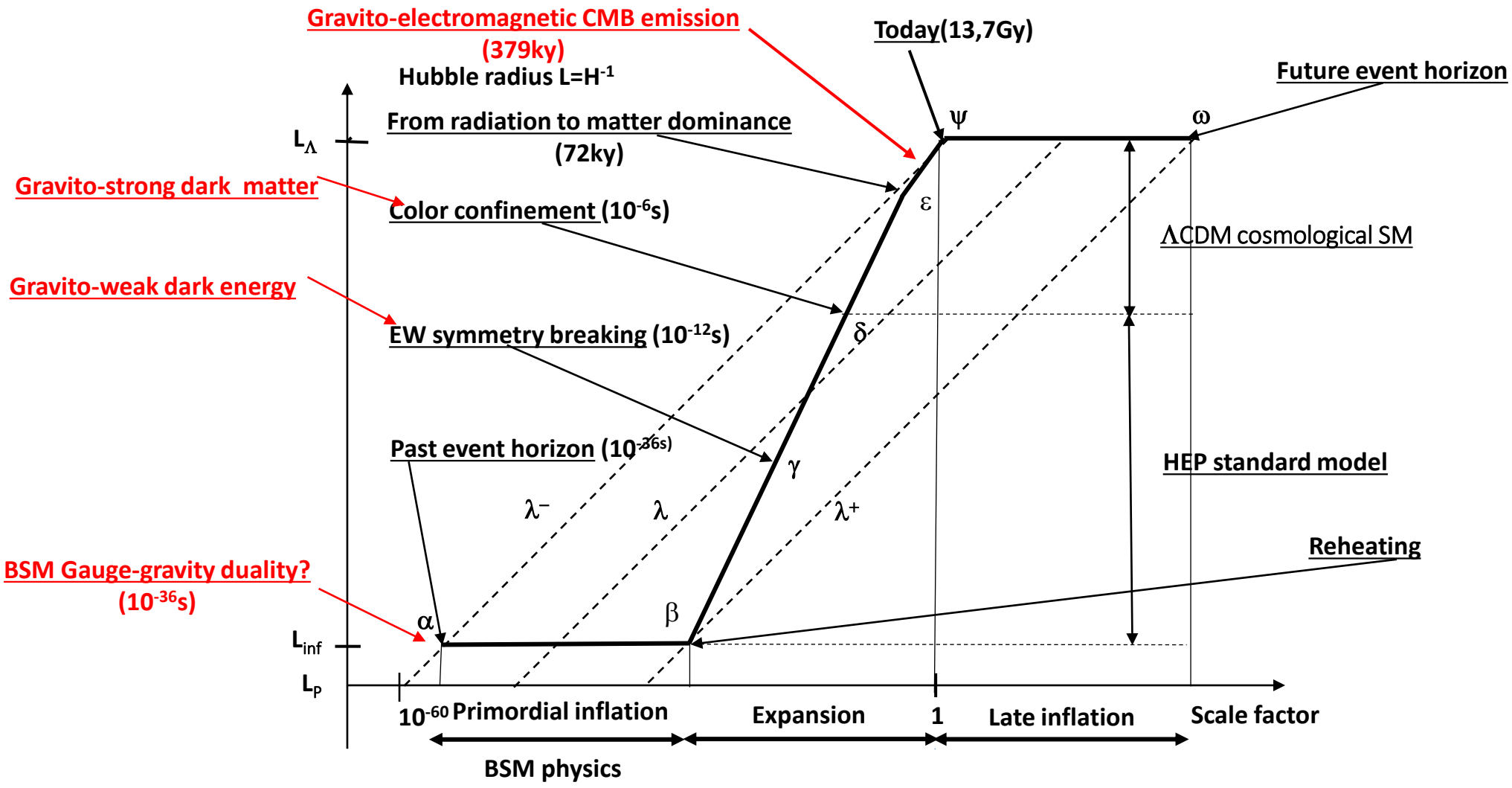
G. Cohen-Tannoudji and J.P. Gazeau, *Scientific cosmogony, the time in quantum relativistic physics* https://hal.archives-ouvertes.fr/hal-03538740



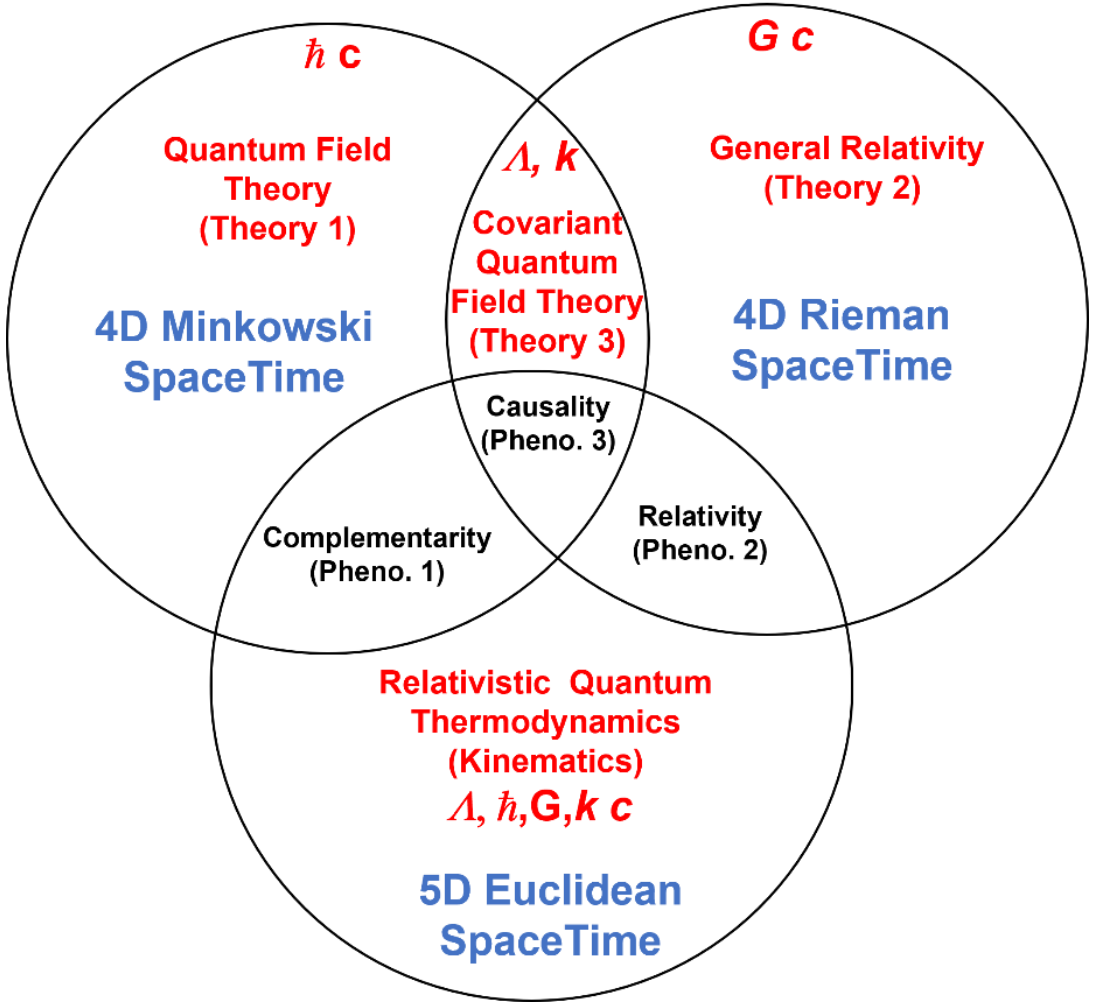
Gilles Cohen-Tannoudji and M. Spiro, *Le boson et le chapeau mexicain,* Gallimard , 2013

L'atome primitif de Lemaître ne serait-il pas un boson BEH covariant?!

La dualité jauge-gravité et le modèle standard de la cosmogonie scientifique



Le paysage de la cosmogonie scientifique impliqué par ses cinq constantes universelles



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