A possible explanation of dark matter by means of a gluonic Bose-Einstein condensate in an anti de Sitter geometry

Gilles Cohen-Tannoudji (speaker) and Jean-Pierre Gazeau

28/11/2023

Brief historical survey

The birth of relativistic cosmology

- The debates between Einstein, de Sitter, Edington and Lemaître
- The problem of the cosmological constant
- The problem of time
- The expansion of the universe and the Lemaître hypothesis of a primordial atom

The first cosmological standard model, the Hot big Bang Model

- Successes and failures
  - The problems due to the Big Bang singularity
  - The neglect of the cosmological constant

The Cosmic Microwave Background and the cosmology of concordanc

Brief historical survey

The birth of relativistic cosmology

- The first cosmological models obeying the principle of relativity of inertia
  - The Einstein's model (**static universe thanks to repulsion induced by cosmological const system A**)
  - The de Sitter's model (**universe empty of matter and pure cosmological conat, system B**)
- The problem of the cosmological constant
- The problem of time
- The problem of stability
- The problem of the expansion of the universe

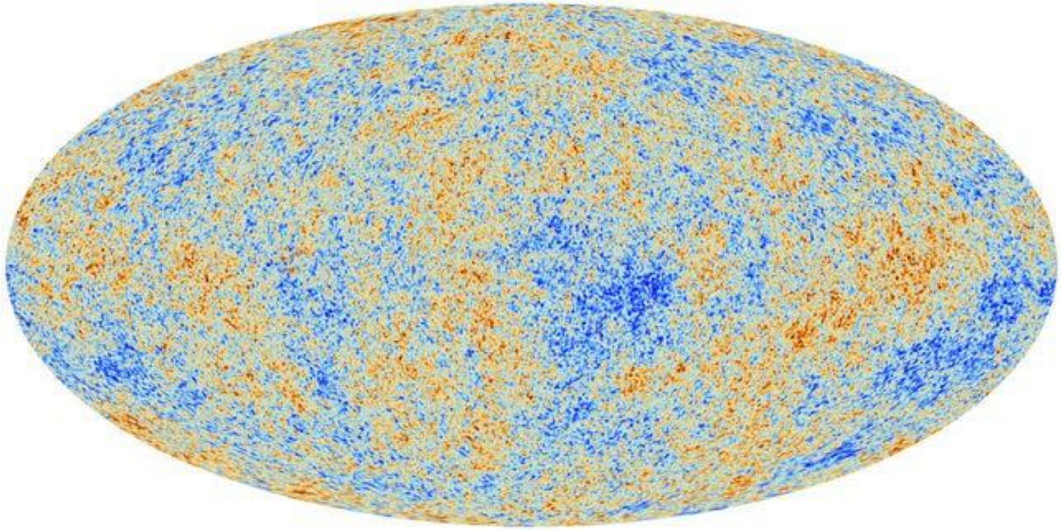
The first cosmological standard model, the Hot big Bang Model

- Despite some successes successes, tough problems:
  - The problems due to the Big Bang singularity
  - The neglect of the cosmological constant

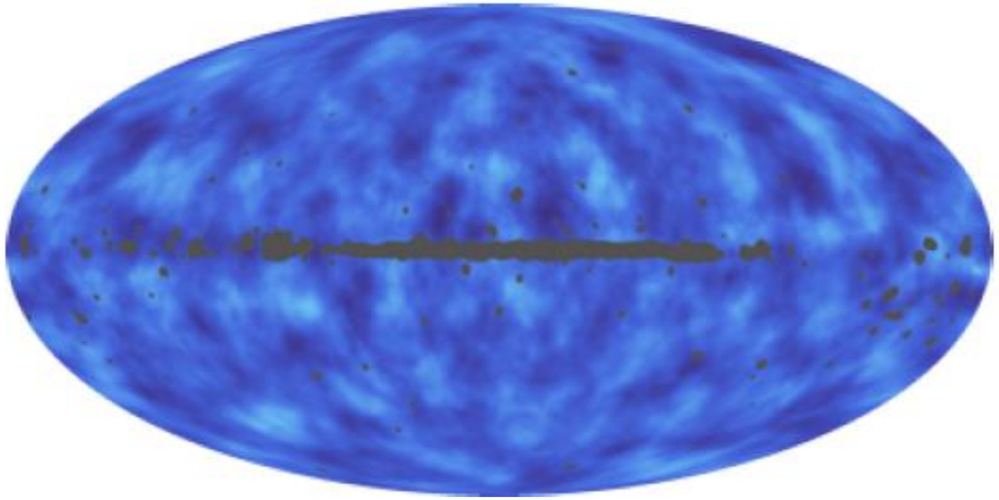
The Cosmic Microwave Background and the new standard model of cosmology ΛCDM

Gilles Cohen-Tannoudji and Jean-Pierre Gaszeau, *Phénoménotechnique du temps et cosmogonie scientigfique,* to appear in Bachelard studies, in French,

The CMB and the results of the Planck experiment shown in two full sky maps

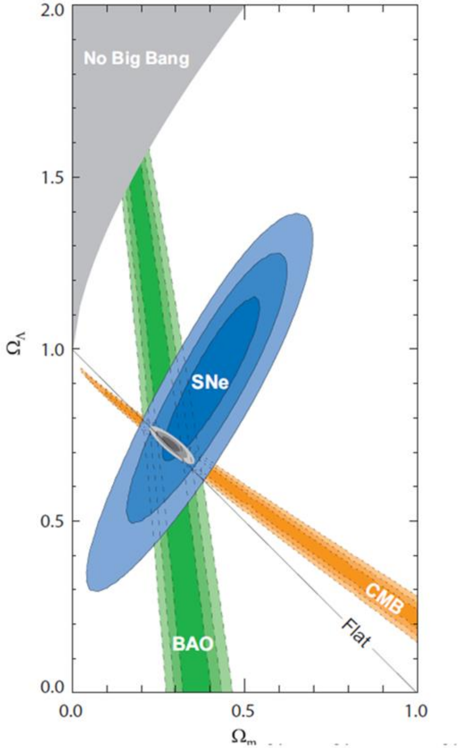


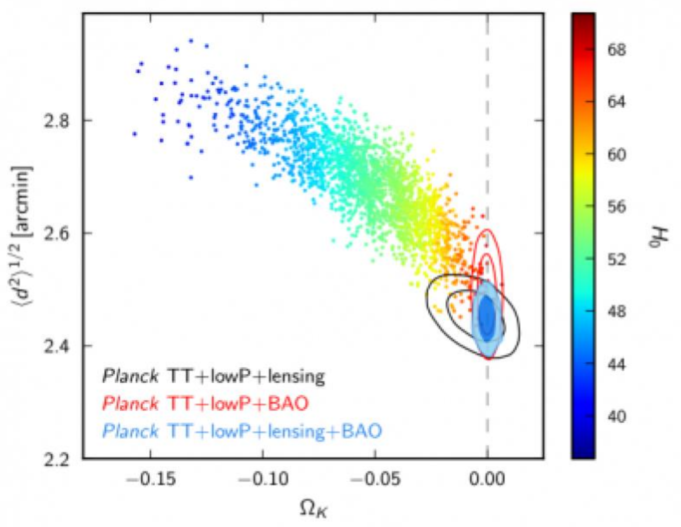
The full sky map of the CMB

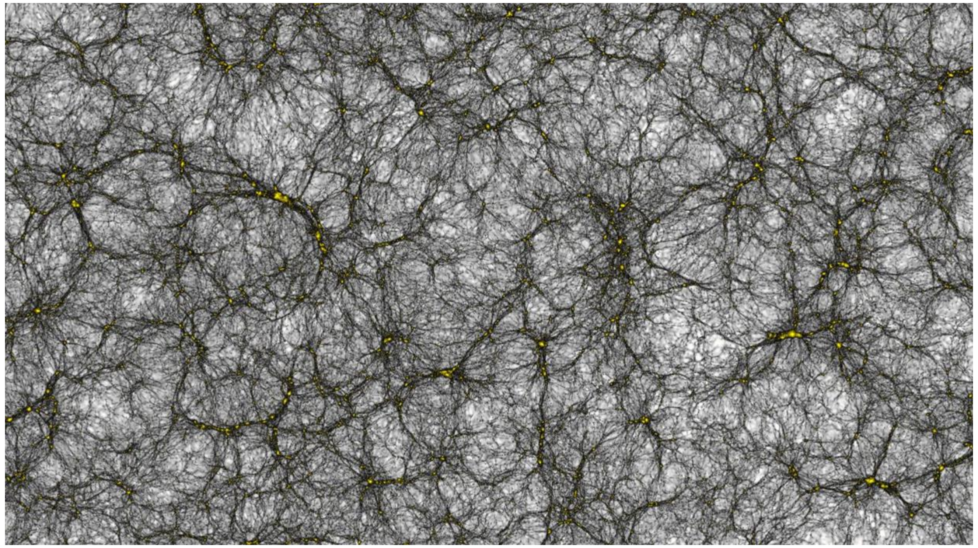


The full sky map of the lensing potential

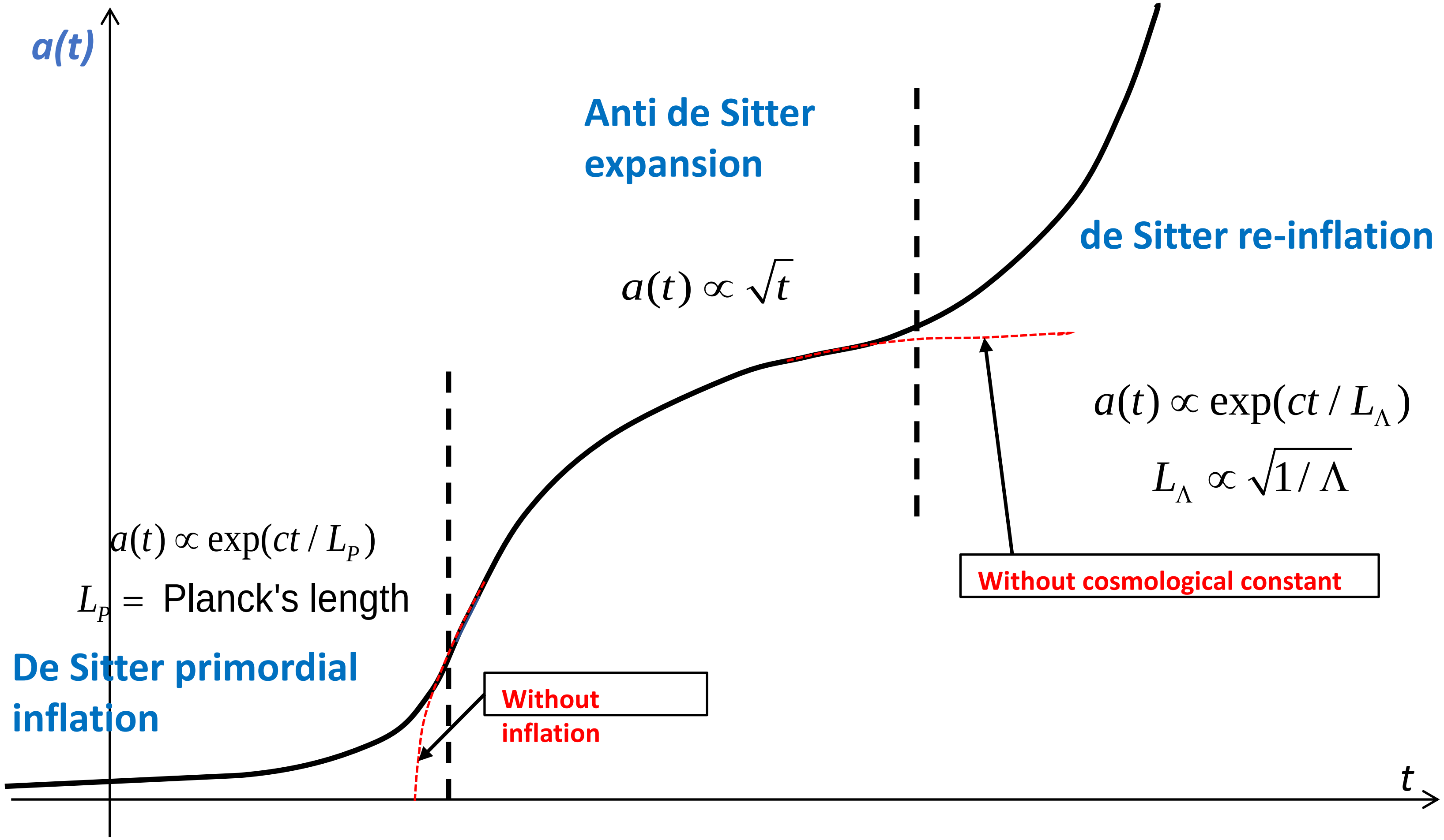
ΛCDM is a gedanken experiment that consists in bringing back into the tableau the visible matter that has been removed as a foreground possibly interfering with the CMB. This is what the reconciliation of all observations (CMB, BAO, SNe) and simulations can do.







The three stages of ΛCDM



De Sitter/Anti-de Sitter Space-time a possible kinematics

Gilles Cohen-Tannoudji and Jean-Pierre Gazeau, *Dark matter as a QCD effect in an anti de Sitter geometry: Cosmogonic implications of de Sitter, anti de Sitter and Poincaré symmetries*
SciPost Phys. Proc. 14, 004 (2023)

Bacry, H. and Lévy-Leblond, J.-M. ***Possible Kinematics*****, J. Math. Phys. 1968, 9, 1605.**

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

Expansion of the universe and the need of an extra dimension of time

The extra-mundane time of de Sitter

The three-dimensional world must, in order to be able to perform "motions", i.e. in order that its position can be a variable function of the time, be thought movable in an "absolute" space of three or more dimensions (*not* the time-space x, y, z, ct). The four-dimensional world requires for its "motion" a four- (or more-) dimensional absolute space, and moreover an *extra-mundane "time"* which serves as independent variable for this motion.

W. de Sitter, *On the relativity of inertia. Remarks concerning Einstein's latest hypothesis, in:* KNAW, Proceedings, 19 II, 1917, Amsterdam, 1917, pp. 1217-1225

The thermal time of Alain Connes and Carlo Rovelli

In this case we have two independent and compatible definitions of time flow in this system: the thermal time flow αt and the flow $\beta\tau$ determined by the proper time.

A. Connes and C.Rovelli Von Neumann algebra automorphisms and time-thermodynamics relation in general covariant quantum theories http://arxiv.org/abs/gr-qc/9406019v1

de Sitter geometry

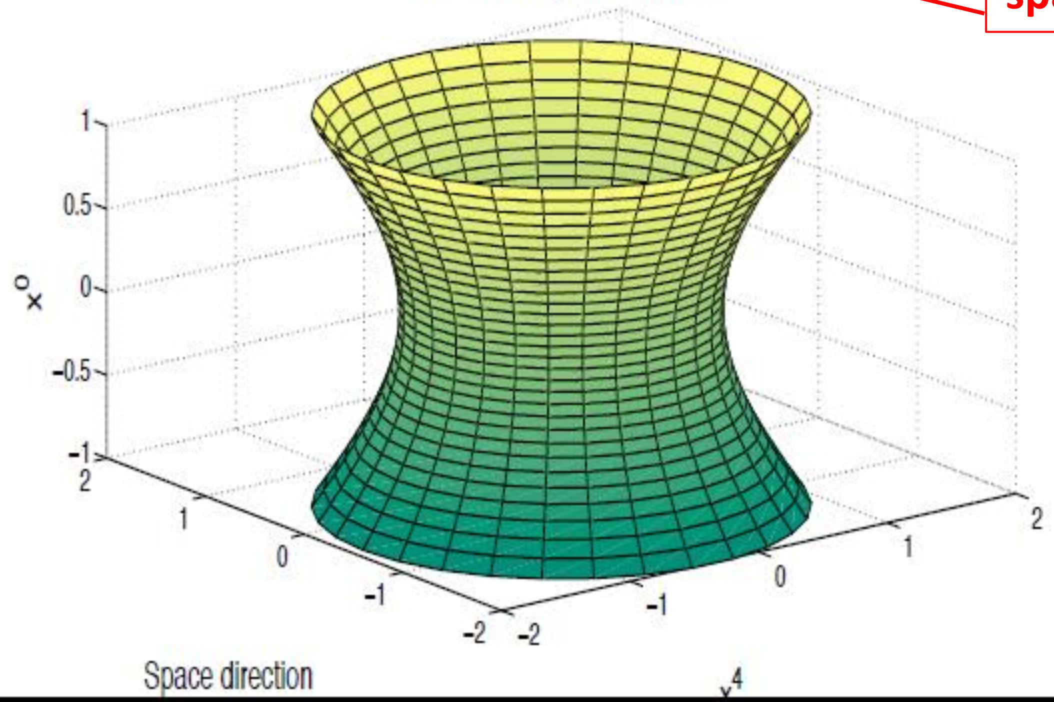
- de Sitter space can be viewed as a one-sheeted hyperboloid embedded in a five-dimensional Minkowski space (but keep in mind that all points are physically equivalent)

$$M_{dS} \equiv \{x \in \mathbb{R}^5;\; x^2 = \eta_{\alpha\beta}\, x^\alpha x^\beta = -\frac{\Lambda_{dS}}{3}\}, \qquad \alpha, \beta = 0, 1, 2, 3, 4,$$

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

In de Sitter, the fifth dimension is **space like**

de Sitter space-time



12/18

Jean Pierre Gazeau

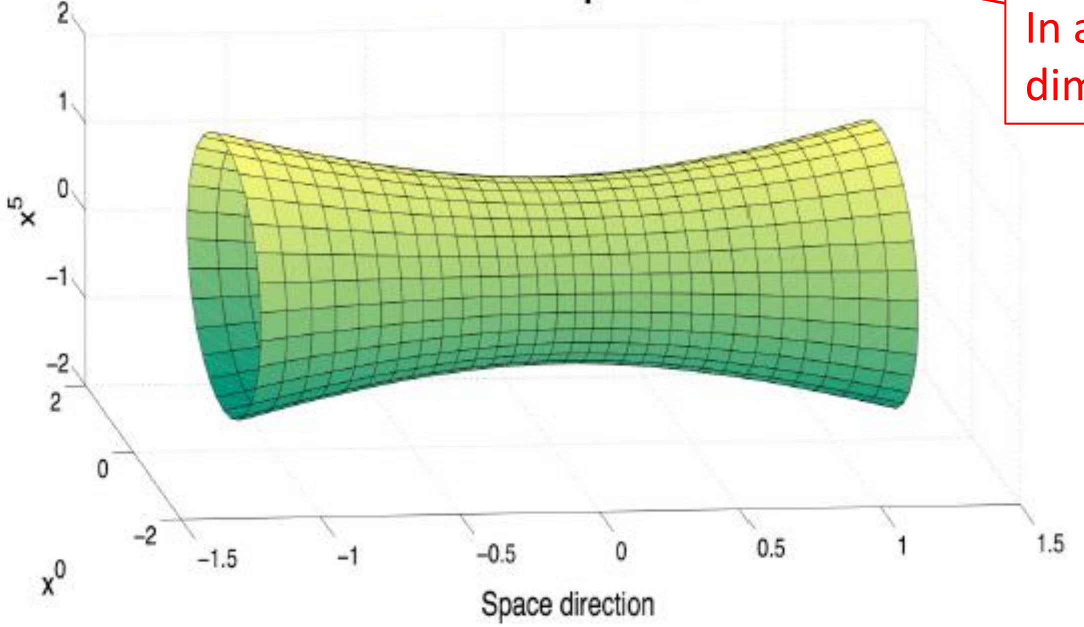
Anti de Sitter geometry

- 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) :

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

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

In anti de Sitter, the fifth dimension is **time like**



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

$$E^{\rm rest}_{\rm AdS} = \left[m^2c^4 + \hbar^2\omega^2_{\rm AdS}\left(s-\frac{1}{2}\right)^2\right]^{1/2} + \frac{3}{2}\hbar\omega_{\rm AdS}\,, \quad (1)$$

with frequency $\omega_{\rm AdS} := \sqrt{\frac{|\Lambda_{\rm AdS}|}{3}}\,c$.

- Hence, to the order of $\hbar$, an AdS elementary system in the Wigner sense 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 $\frac{3}{2}\hbar\omega_{\rm AdS}$.
- In contrast to AdS, for Poincaré and DS symmetries the energy spectrum is continuous $\geq mc^2$. For dS :

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

- Note the noticeable simplification in both AdS and dS for spin $s = 1/2$:

$$\text{for dS :} \quad E^{\rm rest}_{\rm dS} = \pm mc^2\,, \quad (3)$$

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

Holographic equipartition and spacetime thermodynamics

Holographic equipartition

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

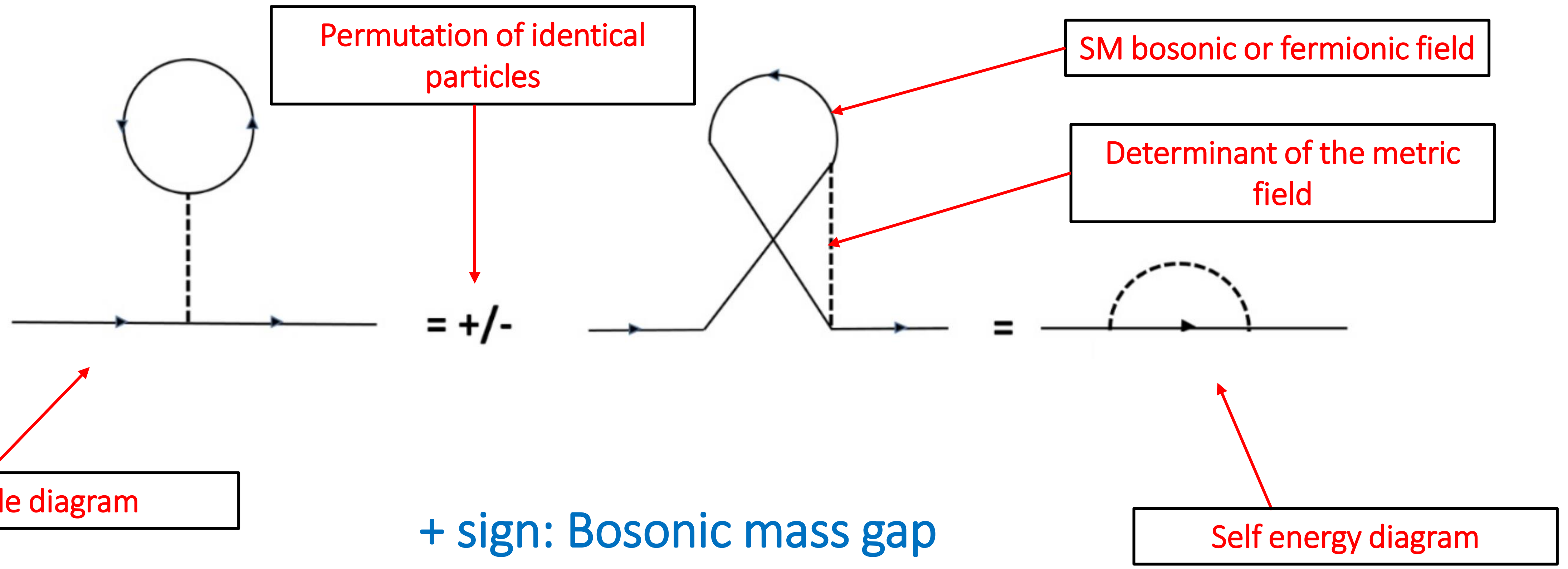
$$N_{\text{bulk}} = \frac{|E|}{1/2k_{\text{B}}T};\ k_{\text{B}}T = \frac{H}{2\pi};\ |E| = |\rho + 3P|V;\ V = \frac{4\pi}{3H^{2}}$$

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

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

Chirco et Al , *Spacetime thermodynamics without hidden degrees of freedom* ArXiv:1401,5262v1 [gr-qc]

Dark matter-energy in AdS spacetime



+ sign: Bosonic mass gap

- sign: Fermionic energy gap

Notice the simplification in AdS spacetime for particles with spin=1/2

QCD Trace anomaly

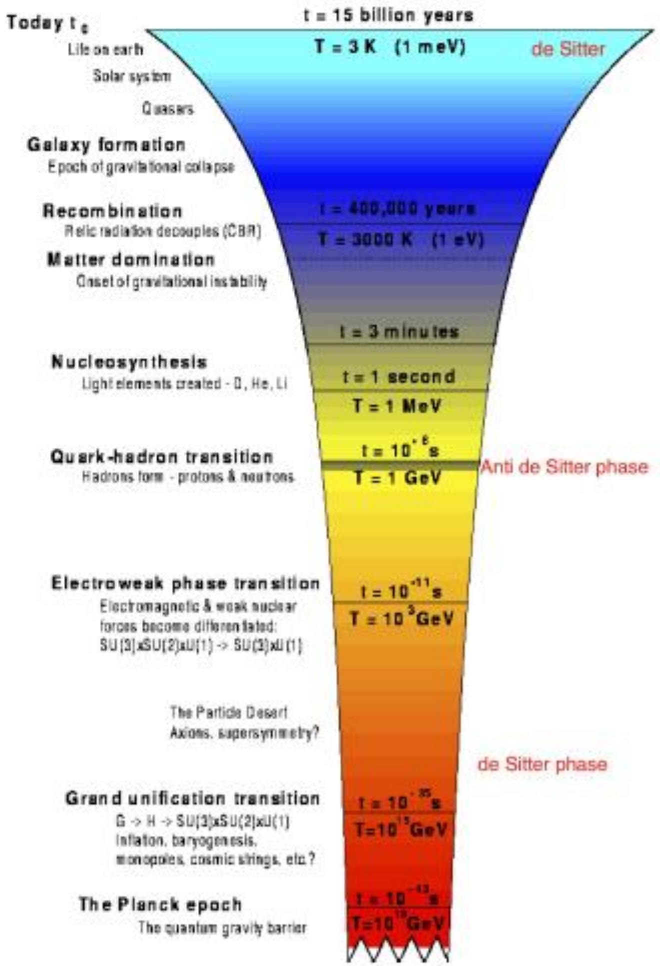
This factor is present in the contributions of all condensates

Gluon loops

Quark loops

Stephan Adler, *Einstein gravity as a symmetry-breaking effect in quantum field theory* *Reviews of Modern Physics, Vol. 54, No. 3, July 1982*

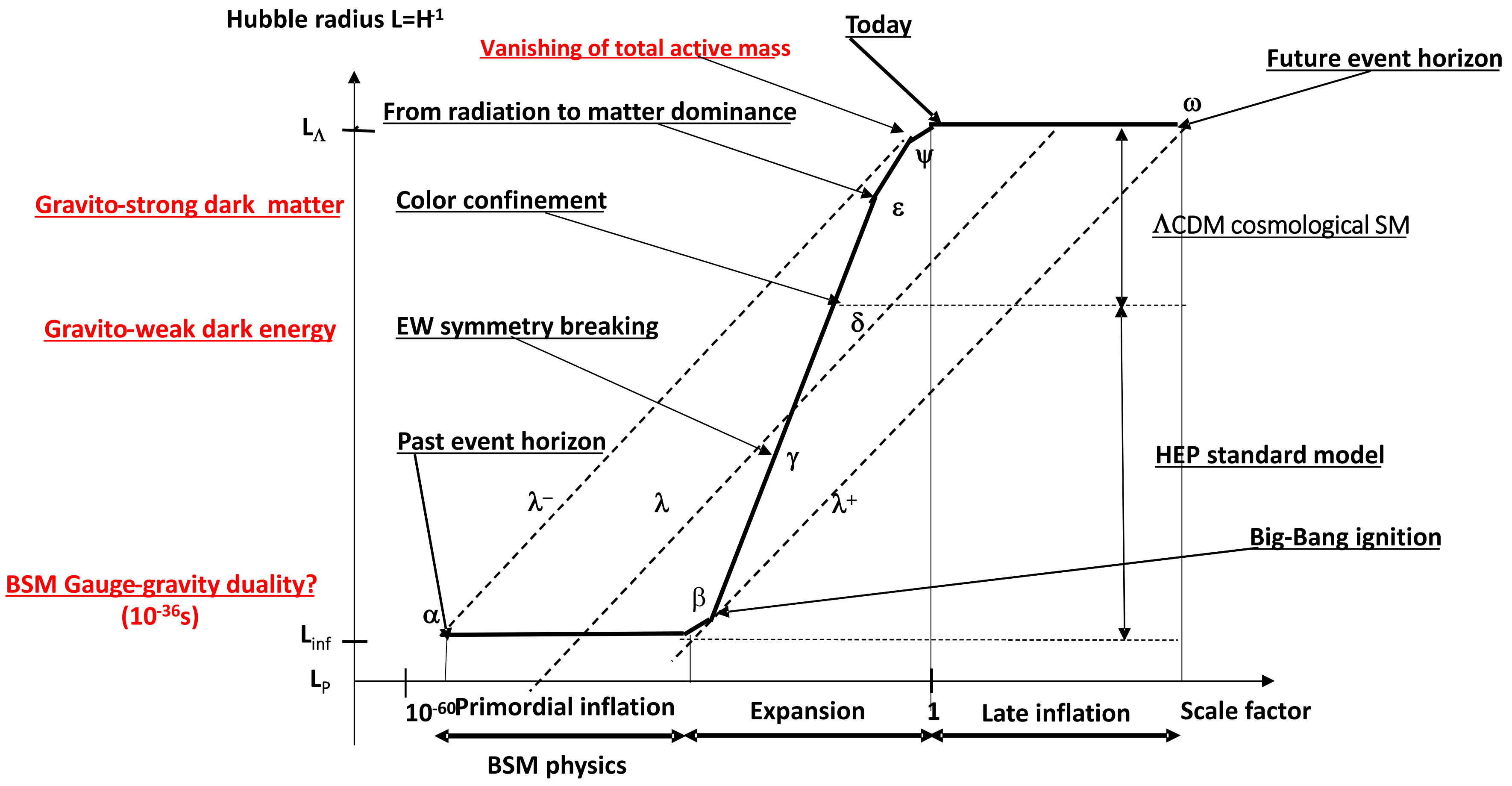
Cosmology chronology : de Sitter and Anti de Sitter phases

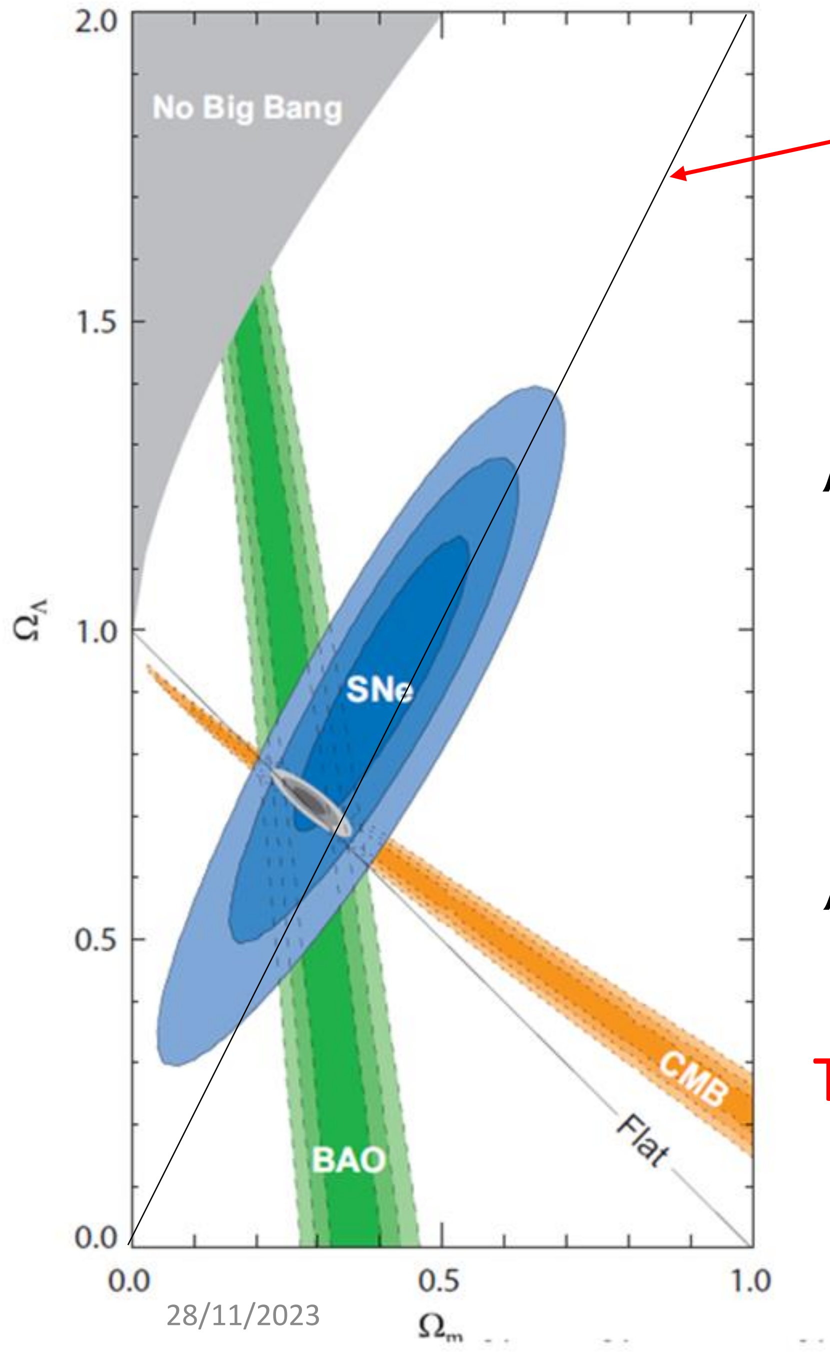


Gazeau, J.-P. Mass in de Sitter and Anti-de Sitter Universes with Regard to Dark Matter. Universe 2020, 6, 66. Available online: https://www.mdpi.com/2218-1997/6/5/66

The methodology of effective theories

All densities and pressures, including the cosmological constant, are replaced by ***effective, comoving quantities, i.e. thermal time dependent***





Ω_{DM}=1/2Ω_Λ vanishing of total active mass

The effective quantum vacuum (visible matter set to zero)

Flatness

Darkness

Emptyness

$$\rho_{\rm DM} + \rho_{\rm DE} = \rho_{\rm Vac} = \rho_{\rm c} \quad \rho_{\rm Vac} + P_{\rm Vac} = 0 \quad \rho_{\rm Vac} + 3P_{\rm Vac} = 0$$

$$\rho_{\rm DE} = \rho_\Lambda \Rightarrow \rho_c = \rho_{\rm Vac} = \frac{3}{2}\rho_\Lambda$$

$$\Omega_\Lambda^{\rm Vac} = \frac{2}{3};\Omega_{\rm M}^{\rm Vac} = \frac{1}{3}$$

$\rho_{\rm Vis}^{\rm as} = 0$: emergence of matter in the remote past and disappearance in the far future

The whole history of the visible universe from point α to point ω is the one of a gigantic fluctuation of the quantum vacuum

ΛCDM = Reconciliation of Einstein' and de Sitter' models !

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

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

$$\mathrm{W}_{\phi} = \frac{P_{\phi}}{\rho_{\phi}} = -1/3$$

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

$$\rho_{M} = \frac{1}{2}\rho_{\Lambda}$$

$\Rightarrow \rho_{\mathrm{M}} + P_{M} = 0$ (Einstein model, static universe)

$\Rightarrow \rho_{\mathrm{M}} + \rho_{\bar{\mathrm{M}}} = 0$ (de Sitter model, pure cosmological constant)

Confronting our model with data and Planck's results

When adding ρ_{Vis} to $\rho_{\Lambda}^{\text{Vac}}$ to obtain ρ_{Λ} note that,

only half of $\rho_{\text{Vis}} = \rho_{\bar{F}}$ (anti-fermion) has to be taken in account

since the fermion contribution remains in ρ_{Vis}

So, equating $\rho_{\text{M}}^{\text{Vac}} = \frac{1}{2}\rho_{\Lambda}$ with $-\rho_{\bar{M}}$ we have

$$\rho_{\Lambda} = \rho_{\Lambda}^{\text{Vac}} + \frac{1}{2}\rho_{\text{Vis}};\ \rho_{M} = \rho_{\text{M}}^{\text{Vac}} - \frac{1}{2}\rho_{\text{Vis}} \text{ in terms of "omegas"}$$

$$\Omega_{\Lambda} = \frac{2}{3} + \frac{1}{2}\Omega_{\text{Vis}}$$

$$\Omega_{\text{M}} = \frac{1}{3} - \frac{1}{2}\Omega_{\text{Vis}}$$

Then, since $\Omega_{\text{DM}} = \Omega_{\text{M}} - \Omega_{\text{Vis}}$,

$$\Omega_{\text{DM}} = \frac{1}{3} - \frac{3}{2}\Omega_{\text{Vis}}$$

Agreement within the error bars

	Our model	Planck' results
$\Omega_\Lambda = \frac{2}{3} + \frac{1}{2}\Omega_{Vis}$	0,666+0,049/2=0,690	0,6889
$\Omega_M = \frac{1}{3} - \frac{1}{2}\Omega_{Vis}$	0,333-0,049/2=0,309	0,311
$\Omega_{DM} = \frac{1}{3} - \frac{3}{2}\Omega_{Vis}$	0,333-1,5X0,049/2=0,260	0,261

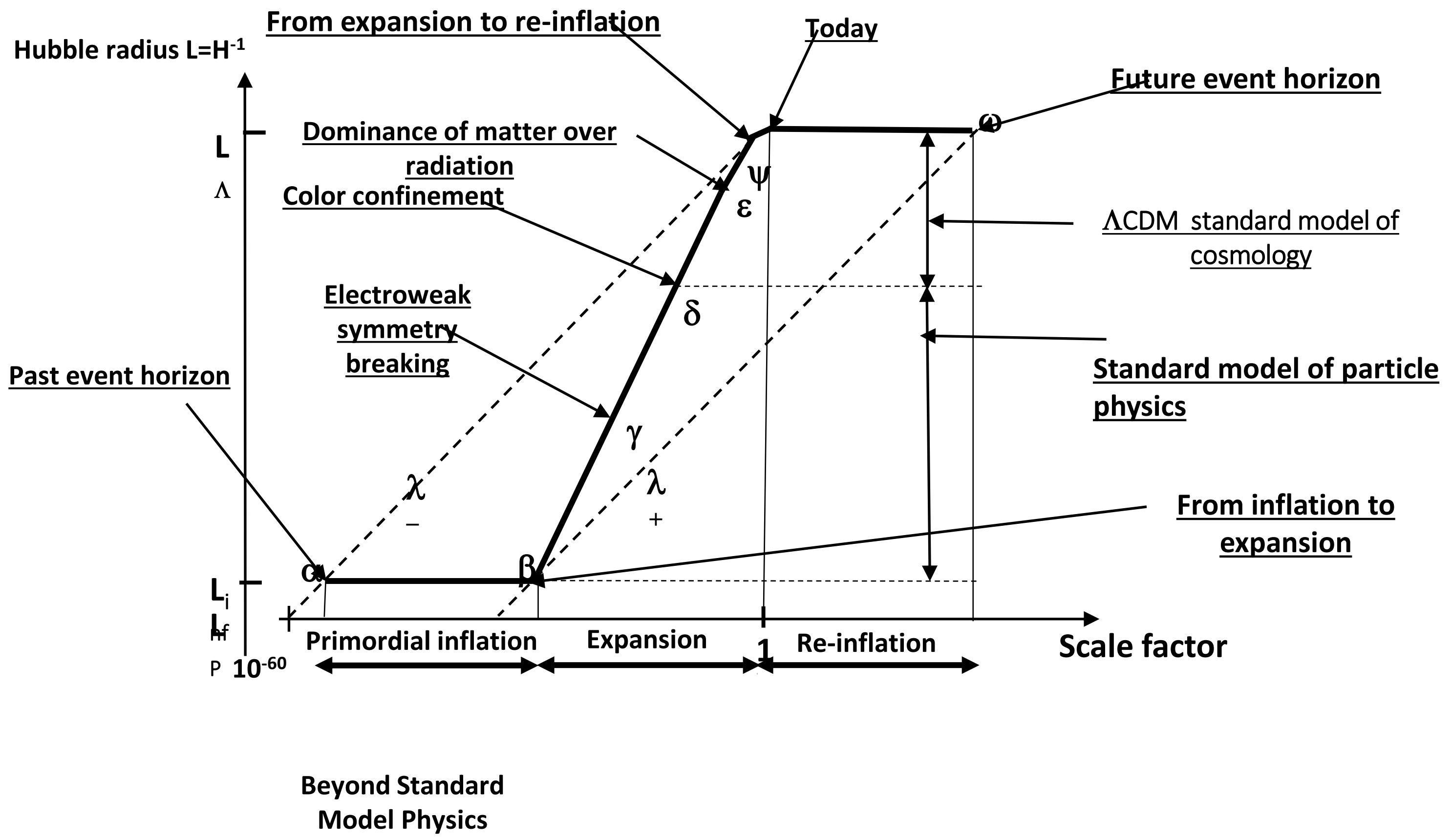
Prediction for the ratio Dark to visible matter

With N_f=3, the ratio is predicted to 5,5 to be compared to 0,261/0,049=5,326. It is reasonable to consider N_f as a parameter allowing to fit the ratio

The matching of the two standard models

- 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



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

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 $\to$ 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 $\to$ 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

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

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

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

to become the currently observed dark matter.

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.

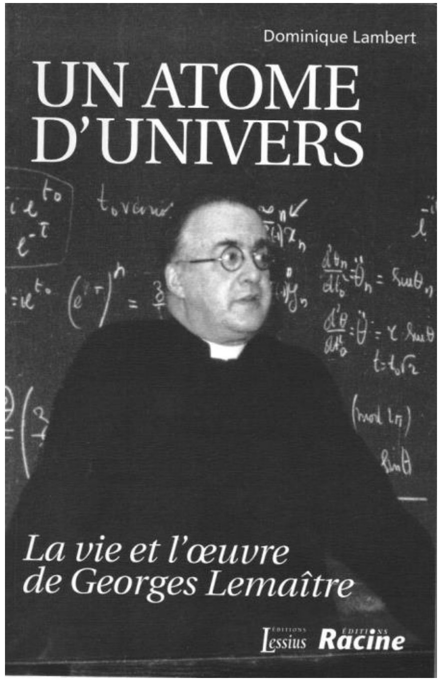
Conclusion

“We have tentatively explained dark matter by actually asking a simple question (!): what becomes the huge amount of gluons after the transition from QGP period to hadronization? Similarly to the emergence of the two validated CMB (QED effect) and CNB (electroweak effect), we propose to consider Dark Matter, observed through its gravitational effects, as a pure QCD effect. From our viewpoint it would be legitimate to replace the puzzling expression “Dark Matter” with the realistic “Cosmic Gluonic Background”.

Gilles Cohen-Tannoudji and Jean-Pierre Gazeau, *Dark matter as a QCD effect in an anti de Sitter geometry: Cosmogonic implications of de Sitter, anti de Sitter and Poincaré symmetries*
SciPost Phys. Proc. 14, 004 (2023)

Theoretical outlook

What is scientific cosmogony?

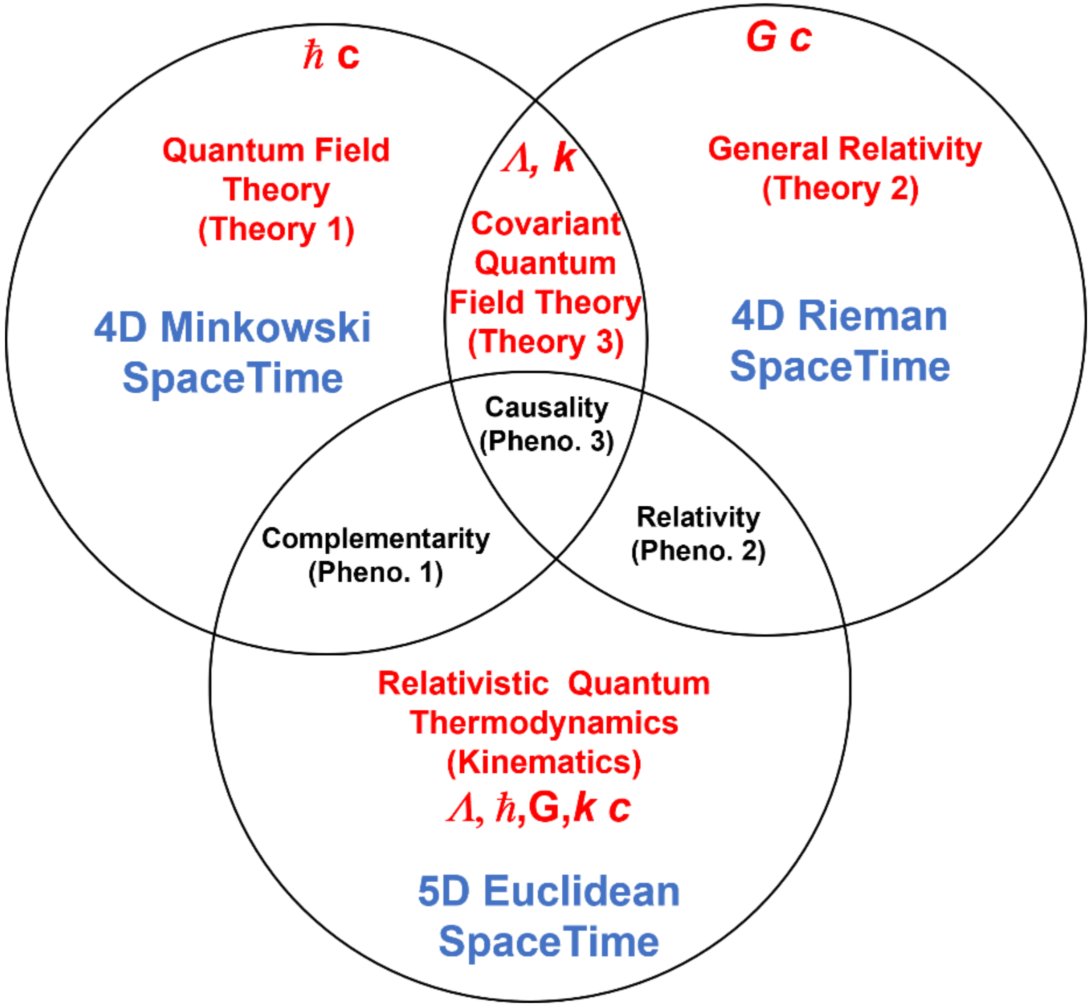


« L'objet d'une théorie cosmogonique est de rechercher des conditions initiales idéalement simples d'où a pu résulter, par le jeu des forces physiques connues, le monde actuel dans toute sa complexité » *Georges Lemaître, l'hypothèse de l'atome primitif – Essai de cosmogonie -*

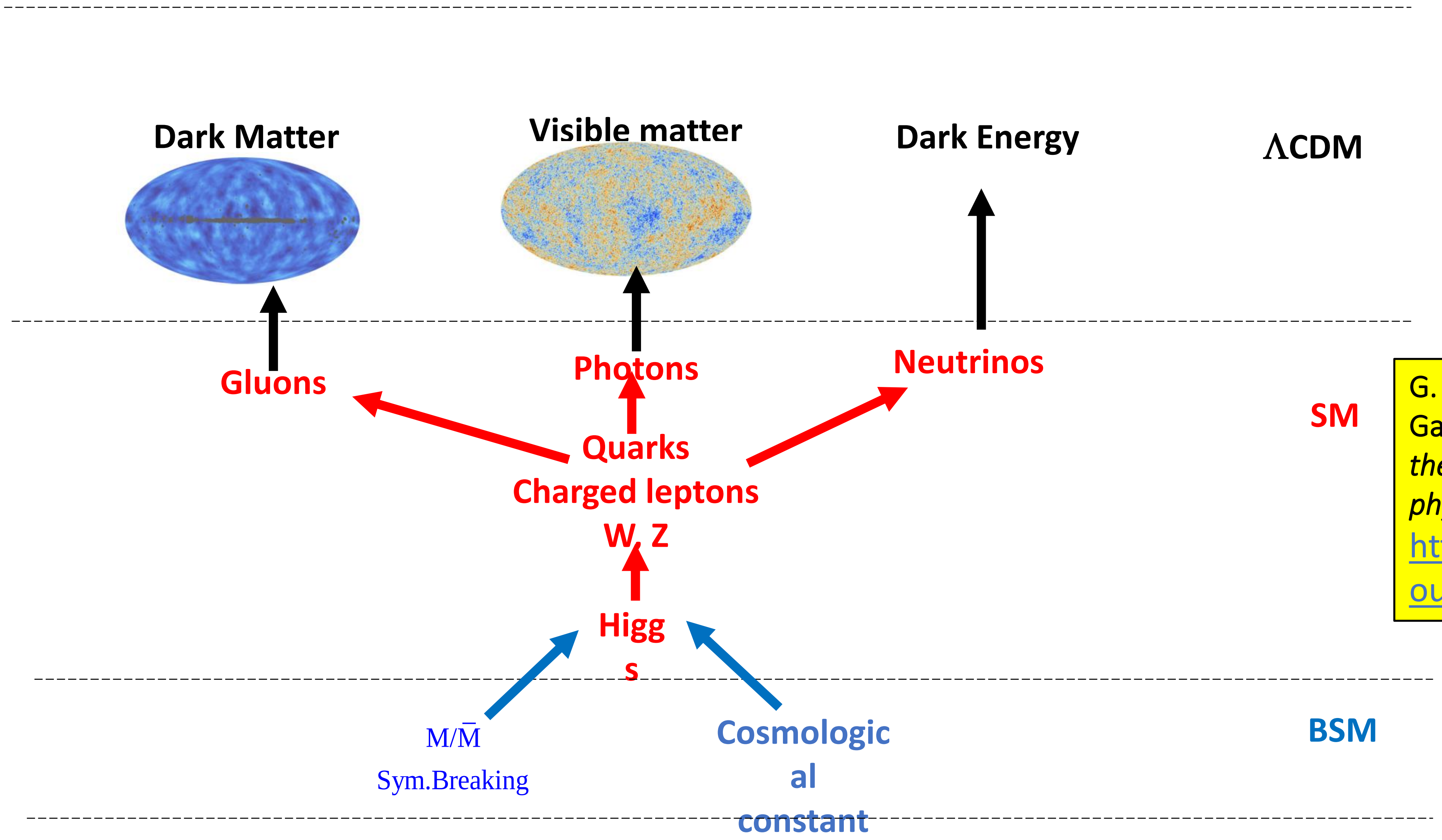
"The object of a cosmogonic theory is to search for ideally simple initial conditions from which, through the play of known physical forces, the current world in its full complexity could have resulted“

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

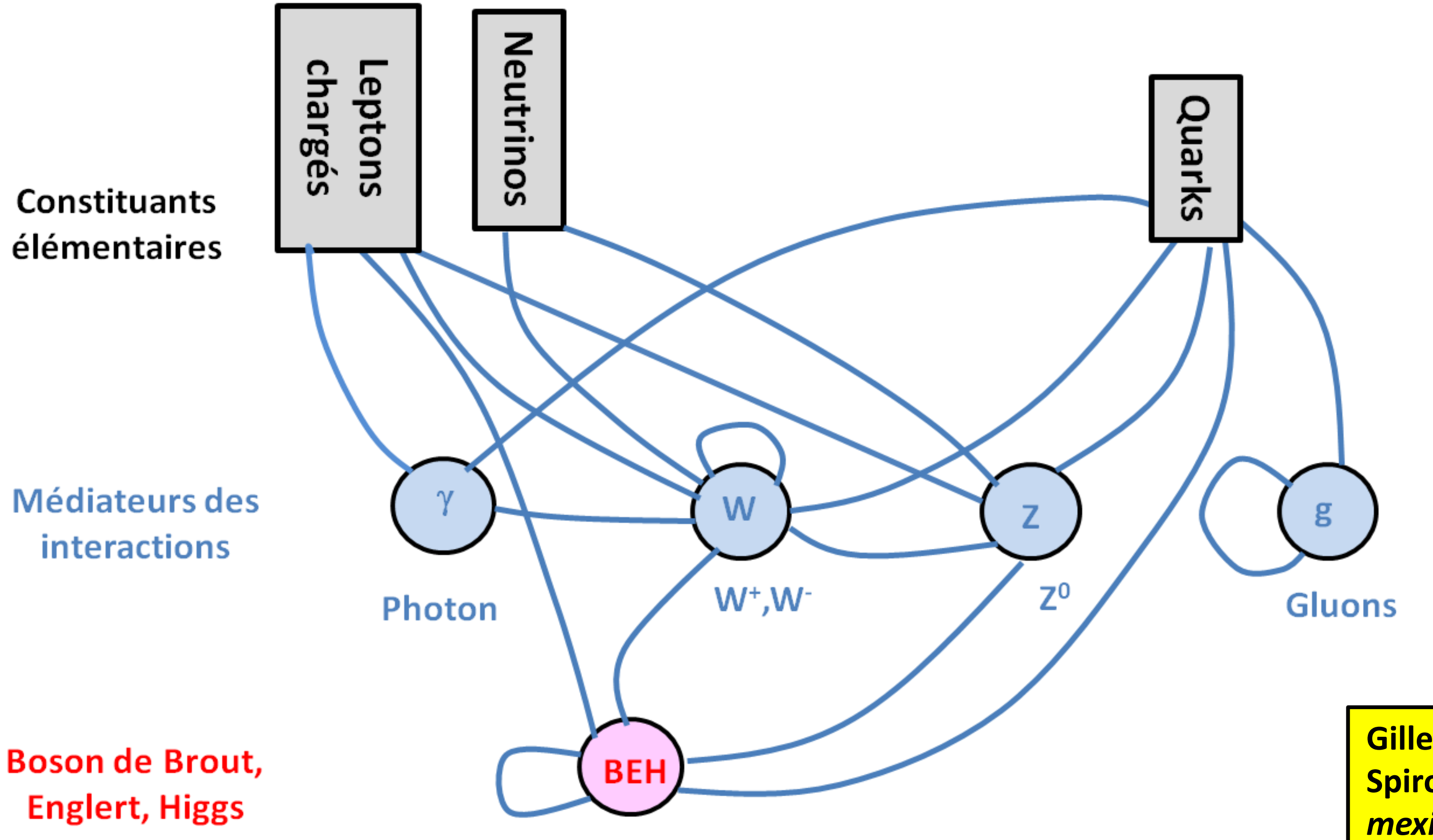
The landscape of scientific cosmogony implied by its five universal constants



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



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

Is it not a comoving Higgs mechanism, the Primitive Atom of Lemaître?