From the Early Trans-Planckian Vacuum to the Late Dark-Energy

Norma G. Sanchez

CNRS LERMA OP PSL SU Paris

Colloque National Dark Energy

Paris by zoom 13-15 October 2020

The Standard Model of the Universe and its Extension

The Standard Model of the Universe: Inflation, General Relativity, Quantum Field Theory, Dark Matter (outside of the Standard Model of Particle Physics, Warm Dark Matter), Dark Energy (Vacuum Energy).

As in Particle Physics : The Standard Model of Cosmology needs to be Extended or Completed:

And also: Some pieces (eg CDM: recurrently do not agree with observations at galactic and smaller scales , or recurrently not detected in the dedicated energy range with the right detectors) call for a changement.

WDM It yields the same LSS results as CDM and CMB and also agree with SSS and Galaxy observations .

Extending / Completing the Universe History Before Inflation requires Quantum Physics at and beyond the Planck scale

THEORY & OBSERVATIONS

The direction in which data and Theory are pointing:

A Strategy for discoveries:

- **Standard Model of the Universe and its Quantum Precursor**

- **Standard Single field Inflation: Double Well**
  - **r ~ 0.04 - 0.02**
- **RUNNING of the Primordial Spectral Index 10^{-4}**
- **SMALL PRIMORDIAL NON GAUSSIANITY : f_NL ~ 0.02**

- **DARK ENERGY= VACUUM ENERGY = Λ, meV**

DARK MATTER = WARM DARK MATTER = keV

NO CUSP/CORE Problem, Profiles are Cored

And more in this direction….

CONTENTS

Planckian and transplanckian energies are theoretically allowed, physically motivated too

The Universe and its very early stages have all the quantum conditions for such extreme quantum gravitational regimes and energies, the black hole interiors too.

The truly quantum gravity domain is not reduced to be fixed at the planck scale or the neighborhoods of it, but extends deep beyond the planck scale in the highly quantum trans-planckian

Quantum theory is more complete than classical theory and tells us what value a classical observable should have.

The classical-quantum (or wave-particle) duality is a robust and universal concept

(It does not depend on the nature or number of space-time dimensions, compactified or not, nor on particular space-time geometries, topologies, symmetries, nor on other at priori condition.)

Moreover, the quantum trans-planckian eras in the far past universe determine the observables of the post-planckian eras

e.g. the inflation observables, CMB and the cosmological vacuum energy until today dark energy,

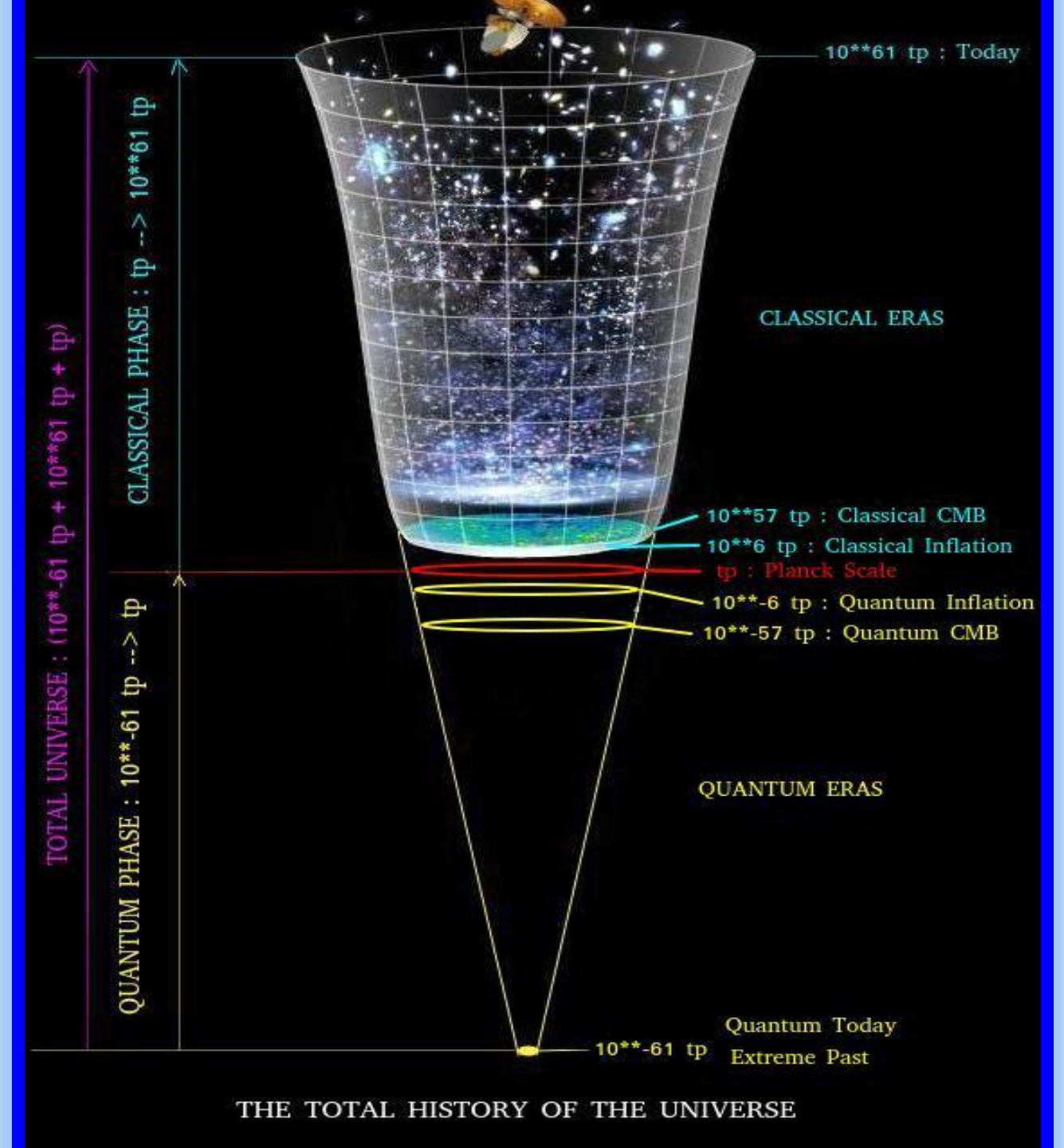
Namely the evolution from the quantum very early phases to the semi-classical and classical phases and the arrow of time as determined by the gravitational entropy.

REFERENCES

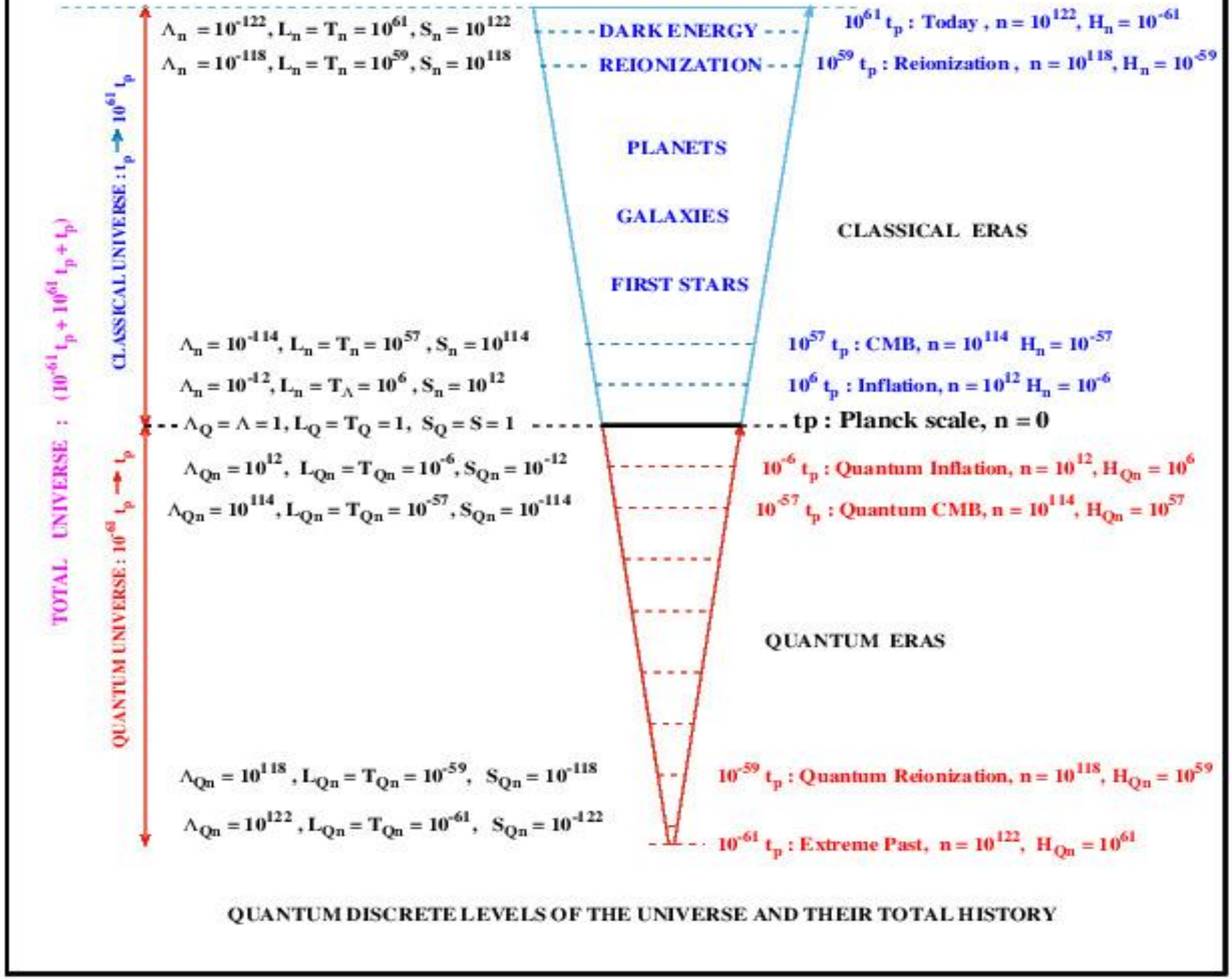
[1] N. G. Sanchez, *Quantum Discrete Levels of the Universe from the early trans-planckian vacuum to the late dark energy* (2020)

- **2019 Trilogy**
- [2] N. G. Sanchez, *New Quantum Phase of the Universe before Inflation and its Cosmological and Dark Energy Implications*
  Int Journal Mod Phys A34, No.27, 1950155 (2019)
- [3] N. G. Sanchez, *The Classical-Quantum Duality of Nature: New variables for Quantum Gravity,*
  Int Journal Mod Phys D18, 1950055 (2019)
- [4] N. G. Sanchez, *The New Quantum structure of the space-time,* J. Grav & Cosmology 25, pp 91-102, (2019)

https://www.researchgate.net/profile/Norma_Sanchez12



THE TOTAL HISTORY OF THE UNIVERSE



QUANTUM DISCRETE LEVELS OF THE UNIVERSE AND THEIR TOTAL HISTORY

Nature is Quantum

That means that the real and complete laws of nature are those of quantum physics. Classical behaviours and domains are particular cases, limiting situations or approximations.

Classical gravity, and thus successful General Relativity are incomplete (non quantum) theories and must be considered as a particular approximation from a more complete theory yet to achieve.

A complete quantum theory should include and account for the physics at the Planck scale and domain.

(i) Instead of starting from gravity, that is General Relativity and quantize it (by applying the different quantization -perturbative and non perturbative- procedures, with the by now well known shortcomings and developpements and its rich bibliography (is not our aim here to review it),

(ii) I start from Quantum theory and try to extend it to the Planck scale domain. (instead of going from classical gravity to quantum gravity, I go from quantum physics to quantum gravity). Of course, in constructing the road (ii) many of the lessons from

The Wave-Particle Duality of Quantum Physics Including Gravity

Nature has a dual behavior of wave and corpuscle:

this *is the well known*

classical-quantum duality or wave-particle duality

of quantum physics (as the light and its photons, the microscopic world of elementary particles, ultradense plasmas, the laser, macroscopic quantum states (as compact stars, dwarfs , black holes), and many other examples).

I generalized this duality to gravity

by including its three regimes: classical, semiclassical and quantum, together with the Planck regime and the elementary particles domain: namely the

wave-particle-gravity duality* or *the classical-quantum gravity duality.

NGS, IJMPD18, (January 2019), June 2019

This Duality is Universal

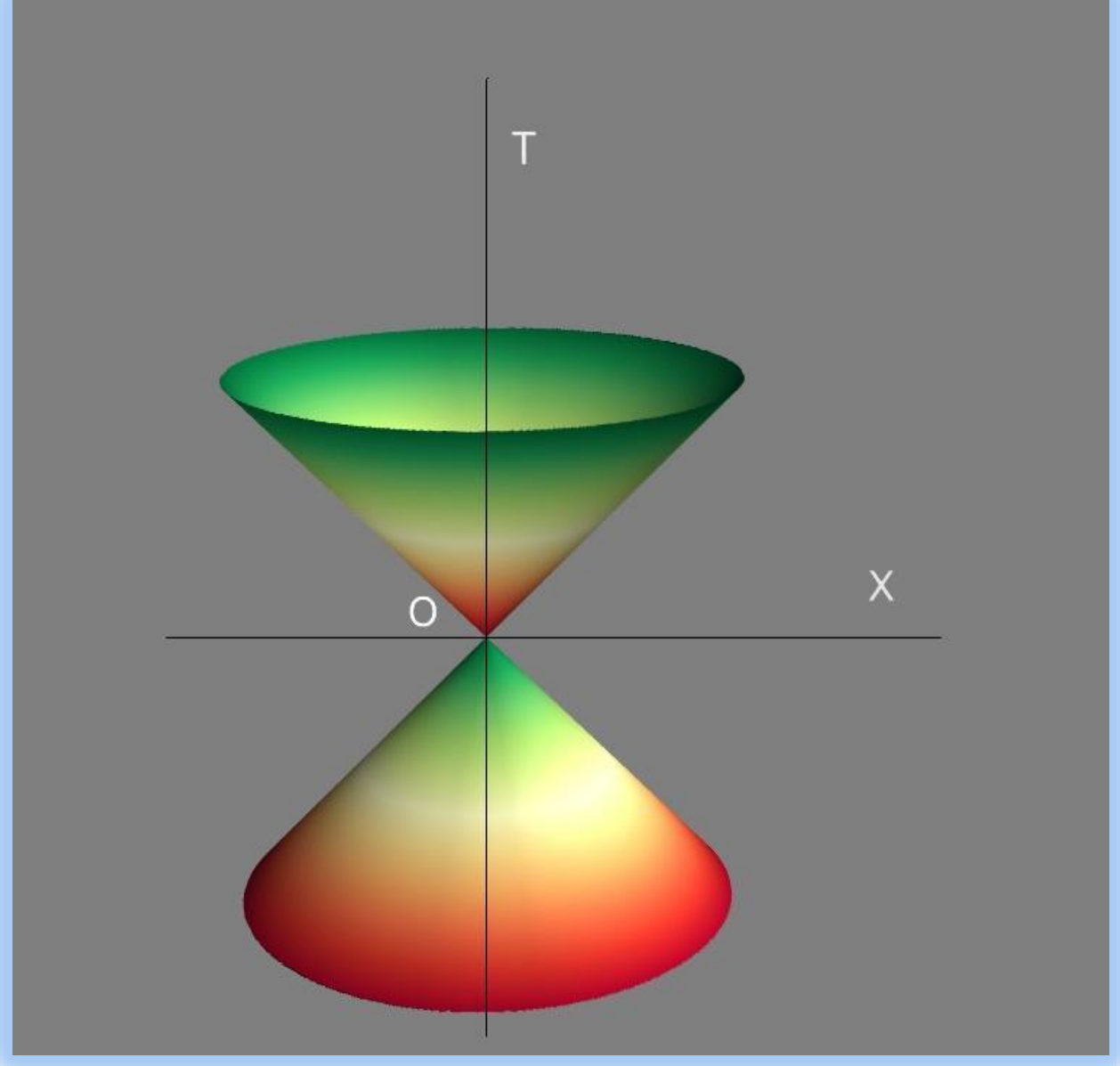
it includes the known duality and allows a general clarification and new results which reveal:

(i) The classical-quantum duality of the space-time and black holes

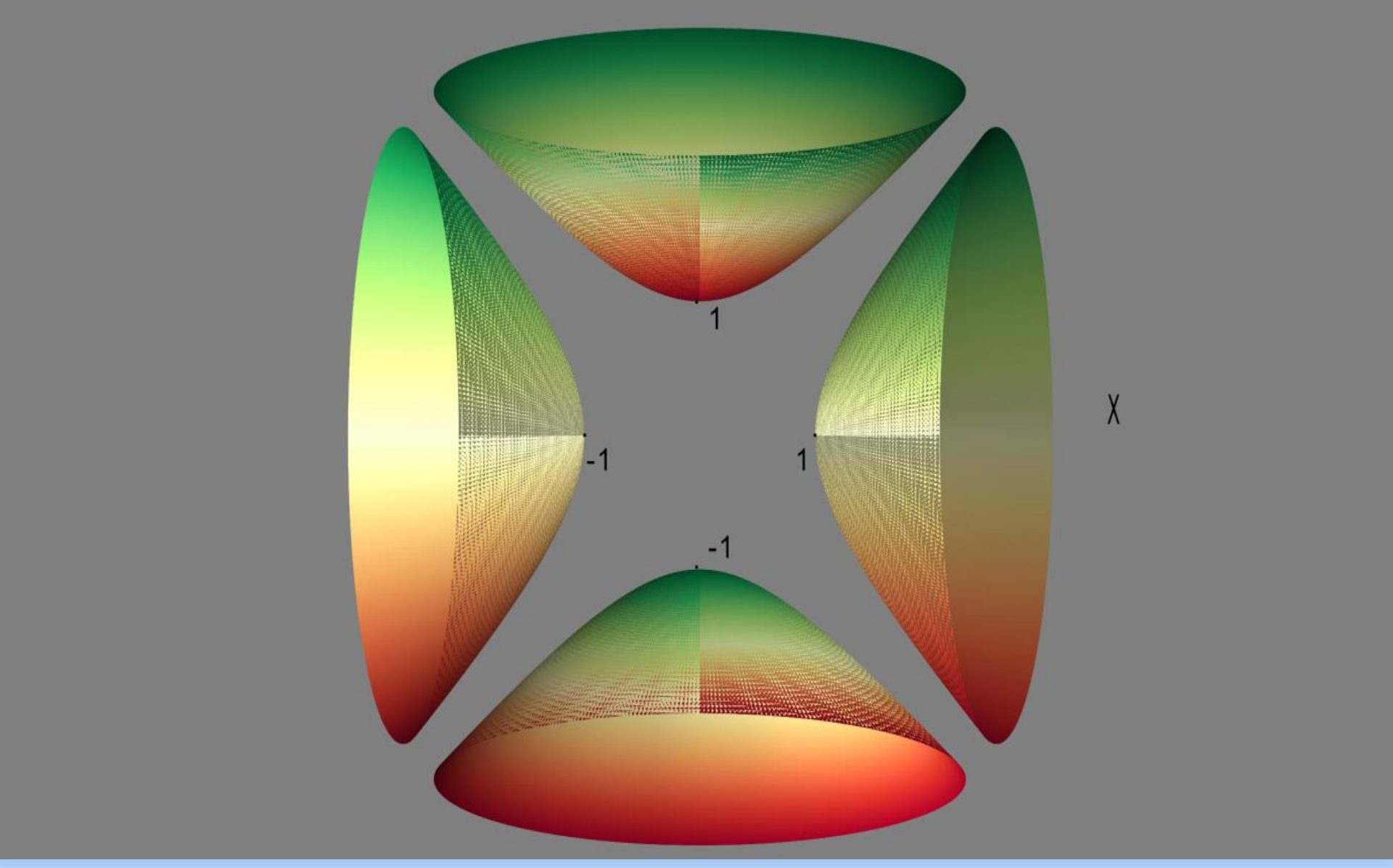
(ii) A new quantum domain not present in classical gravity does appear

(iii) The quantum light-cone from which the known classical light-cone of relativity and the classical universe are a special case.

A more complete vision of space-time does



The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of the Quantum light -cone



The quantum light-cone in a space-time diagram (time is the vertical axis).

THE FUNDAMENTAL PLANCK SCALE

(h, c, G): $L_G = 2GM/c^2$, $L_Q = h/Mc$

$$l_P = (hG/c^3)^{1/2}, \qquad m_p = (hc/G)^{1/2}$$

$$G/c^2 = l_P/m_p, \quad l_P m_p = h/c$$

$l_P = 10^{-33}$ cm, $m_p = 10^{-5}$ gr, $t_p = 10^{-44}$ sec

$L_Q = l_P^2 / L_G$, $M_Q = m_P^2 / M$, $O_Q = o_P^2 / O_G$

New Variables : $L_{QG} = L_Q + L_G$, $O_{QG} = O_Q + O_G$, $Q \leftrightarrow G$

N.G.S, Int J. Mod Phys D18, 1950055 (2019) $O_{QG} = o_P (O_G/o_P + o_P/O_G)$

The classical Universe today U_Λ:

set of physical gravitational observables (age or size, mass, density, temperature, entropy) (L, M, ρ, T, S)

$U_\Lambda = (L_\Lambda, M_\Lambda, \rho_\Lambda, T_\Lambda, S_\Lambda)$: Classical Universe

The very early quantum Universe U_Q:

set of corresponding quantum dual physical quantities $(L_Q, M_Q, \rho_Q, T_Q, S_Q)$:

$U_Q = (L_Q, M_Q, \rho_Q, T_Q, S_Q)$: Quantum Universe

$$U_Q = u_P^{\,2} / U_\Lambda$$

$u_P = (l_P, m_P, \rho_P, t_P, s_P)$: Planck Scale

The crossing scale between the two gravity domains

Precursor Quantum phase of the known Classical Inflation era and of the classical standard eras and today Dark Energy

NEW RESULTS FOR INFLATION

$$[\Delta^S{}_{QH}] = [\Delta^S{}_H] \frac{1}{[1+(H/h_p)^2]} \frac{1}{(1-\delta\varepsilon_{QH})^{1/2}}$$

$$[\Delta^T{}_{QH}] = [\Delta^T{}_H] \frac{1}{[1+(H/h_p)^2]}$$

H: classical known Inflation (classical H) era,

Q : stands for its Quantum dual precursor,

QH stands for the Complete Inflation era : classical known Inflation and its Quantum precursor Inflation.

The QH factor modifying the Hubble constant and the inflationary pectra can be written

as the summation of the series:

$$QH \equiv \frac{H}{[\,1+(H/h_P)^2\,]} = H\,\sum_{n=0}^{\infty}(-1)^n\left(\frac{H}{h_P}\right)^2 \qquad (1)$$

The QH factor covers

the FULL CLASSICAL and QUANTUM RANGE, namely:

If $H < h_P$, Eq.(1) yields the usual corrections in $(H/h_P)^2$.

If $H >> h_P$, Eq.(1) precisely *changes to the quantum regime*, **ie to the uantum Hubble rate H_Q, which is the** *super-Planckian domain:*

$$HQ \equiv \frac{H_Q}{[\,1+(H_Q/h_P)^2\,]} \qquad (2)$$

NEW RESULTS FOR DARK ENERGY

This framework reveals enlighting for the issue of *Dark Energy, and allows clarification into the cosmological constant as the vacuum energy.*

The classical Universe today U_Λ is precisely a *classical dilute gravity vacuum dominated by voids and supervoids as shown by observations:* The observed value of ρ_Λ or Λ today is *precisely the classical dual* of its quantum precursor values ρ_Q, Λ_Q in the quantum very early precursor vacuum U_Q as determined by our dual Equations.

The high density ρ_Q and cosmological constant Λ_Q are precisely the quantum particle physics superplanckian value 10^{122}. This is precisely expressed by our dual Equations.

$$\Lambda = 3H^2 = \lambda_P (H / h_P)^2 = \lambda_P (l_P / L_H)^2$$
$$= (2.846 \pm 0.076)\ 10^{-122}\ m_P^2$$

$$\Lambda_Q = 3H_Q^2 = \lambda_P (h_P / H)^2 = \lambda_P (L_H / l_P)^2$$
$$= (0.3516 \pm 0.094)\ 10^{122}\ m_P^2$$

$$\Lambda_Q \Lambda = \lambda_P^2 \quad , \quad \lambda_P = 3\ h_P^2 \ .$$

The quantum dual value Λ_Q is precisely the quantum value from particle physics:

$$\rho_Q = \rho_P\ (\Lambda_Q / \lambda_P) = \rho_P^2 / \rho_\Lambda = 10^{122}\ \rho_P$$

The two huge different values 10^{+122} and 10^{-122} are explained by the fact that they are exactly, mathematically and physically, the classical-quantum dual of each other:

The Λ_Q value that is to say, the vacuum value computed from particle physics is exactly the quantum dual value of the classical Λ value observed today

The two huge different values: 10^{-122} and 10^{+122} refer to ***two huge physically different vacuum states*** **of the Universe** corresponding to **two huge different eras,** to **two huge different physical cosmological conditions (present time and very early eras), and consistently, they *must be different.*** *Such enormous difference* must be in such way and is **not a problem or inconsistency.**

Moreover and consistently, one value is the ***quantum transplanckian physics dual*** *of the other -**as exactly*** expressed by **the dual Equations.**

This is not fortuitous, that is to say, this is not pure chance or unexplained coincidence. **This is not trivial, that is to say, this is simple, deep and robust.**

THE COSMOLOGICAL CONSTANT:

GRAVITATIONAL ENTROPY

AND TEMPERATURE

OF THE UNIVERSE

GRAVITATIONAL ENTROPY AND TEMPERATURE

$$S = (\text{Area} / 4\, a_P)\, s_P\,, \quad s_P = \pi\, k_B$$

$$T = (\text{Area} / a_P)^{1/2}\, t_P = L\, t_P$$

Classical: CLASSICAL Lengths

Quantum: QUANTUM Lengths

THE COSMOLOGICAL CONSTANT: VACUUM ENERGY, ENTROPY AND TEMPERATURE OF THE UNIVERSE

$$\frac{\Lambda}{\lambda P} = \frac{\rho\Lambda}{\rho P} = \frac{SQ}{sP} = \frac{\lambda P}{\Lambda Q} = \left(\frac{TQ}{tP}\right)^2 = 10^{-122}$$

$$\frac{\Lambda Q}{\lambda P} = \frac{\rho Q}{\rho P} = \frac{S\Lambda}{sP} = \frac{\lambda P}{\Lambda} = \left(\frac{T\Lambda}{tP}\right)^2 = 10^{+122}$$

$$\Lambda_{\Lambda Q} = \Lambda + \Lambda_Q + \lambda P = \lambda P \left(\frac{\Lambda}{\lambda P} + \frac{\lambda P}{\Lambda} + 1\right)$$

$$\Lambda_{\Lambda Q} = \lambda P \left(10^{-122} + 10^{+122} + 1\right)$$

THE ENTROPY OF THE UNIVERSE

Component	Entropy S [k]
Cosmic Event Horizon	$2.6 \pm 0.3 \times 10^{122}$
SMBHs	$1.2^{+1.1}_{-0.7} \times 10^{103}$
$*$Stellar BHs ($42-140\ M_\odot$)	$1.2 \times 10^{98^{+0.8}_{-1.6}}$
Stellar BHs ($2.5-15\ M_\odot$)	$2.2 \times 10^{96^{+0.6}_{-1.2}}$
Photons	$2.03 \pm 0.15 \times 10^{88}$
Relic Neutrinos	$1.93 \pm 0.15 \times 10^{88}$
Dark Matter	$6 \times 10^{86 \pm 1}$
Relic Gravitons	$2.3 \times 10^{86^{+0.2}_{-3.1}}$
ISM & IGM	$2.7 \pm 2.1 \times 10^{80}$
Stars	$3.5 \pm 1.7 \times 10^{78}$
Total	$\mathbf{2.6 \pm 0.3 \times 10^{122}}$

Important: H_0 value

Important: H(z) Measurements

$$E(z) = H(z) / H_0$$

We already know from Observations:

$$H(z = 1.5) = 2.69\ H_0$$

(Reiss et al, 2018, 2019)

$$H(z = 1.5) \sim 3\ H_0$$

THE QUANTUM STRUCTURE OF THE SPACE-TIME

- **THE CLASSICAL - QUANTUM DUALITY OF NATURE :**

- $O_G = o_P^2 / O_Q$, $L_G = l_P^2 / L_Q$, $L_G = 2GM/c^2$, $L_Q = h/Mc$

- **THE SPACE TIME (X, T) Coordinates as**
- **QUANTUM NON COMMUTING OPERATORS :** $[X, T] = 1$

° THE SPACE-TIME AS a QUANTUM HARMONIC OSCILLATOR :

$[X, P] = i$, $2H = X^2 + P^2 = 2N + 1$, $[2H, X] = -iP$, $[2H, P] = iX$

P = iT :

$[X, T] = 1$, $2H = X^2 - T^2 = 2N + 1$, $[2H, X] = T$, $[2H, T] = X$

QUANTUM SPACE-TIME

- $(T^2 - X^2) - 1 \geq 0$: ***timelike***
- $(X^2 - T^2) - 1 \geq 0$: ***spacelike***
- $(T^2 - X^2) - 1 = 0$, ***null : the "quantum light- cone".***

$$\mathbf{(X^2 - T^2)_n = 2n + 1}$$ **: discrete levels**

$$(X^2 - T^2) = \pm[X, T] = \pm 1, \quad 1 = 2\varepsilon_0, \quad (n = 0)$$

the quantum light cone

- $[X, T] = 0$: $X = \pm T$ **the classical light cone.**

Quantum discrete cosmological levels

size, time, vacuum energy, Hubble constant and gravitational (Gibbons-Hawking) entropy.

For each level $n = 0, 1, 2, \ldots$,

the two: post and pre (trans)-planckian phases are covered:

post-planckian universe levels: (in planck units):

Hubble constant $H_n = 1/\sqrt{(2n+1)}$

Vacuum energy $\Lambda_n = 1/(2n+1)$

Entropy $S_n = (2n+1)$

As n increases, radius, mass and Sn increases, Hn and Λn decreases and *consistently* the universe *classicalizes*:

n = 10^122: H today = 10^{–61}

Λ today = 10^{-122}, S today = 10^{-122}

In the pre-planckian (trans-planckian) phase, the quantum levels are:

$H_{Qn} = \sqrt{(2n+1)}$, $\Lambda_{Qn} = (2n+1) = \mathcal{R}_{Qn}$, $S_{Qn} = 1/(2n+1)$

Q denoting quantum. The n - levels cover *all* scales from the far past highest excited trans-planckian level

n = 10^[122} with finite curvature,

$H_Q = 10^{61}$, $\Lambda_Q = 10^{122}$ and $S_Q = 10^{-122}$,

n decreases till the planck level (n=0)

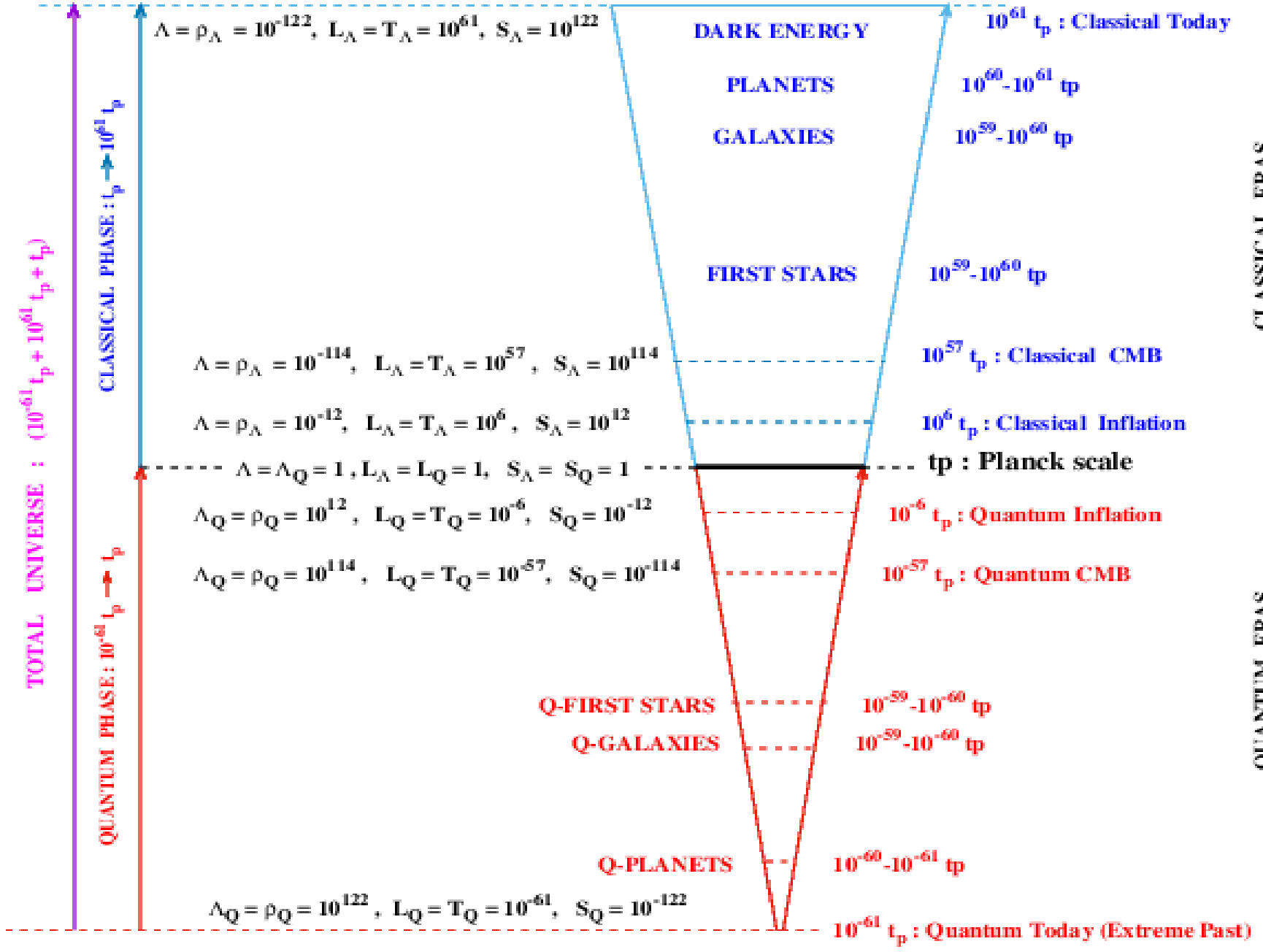
H planck = 1, Λ planck = 1, S planck = 1

and then enters the post-planckian phase e.g:

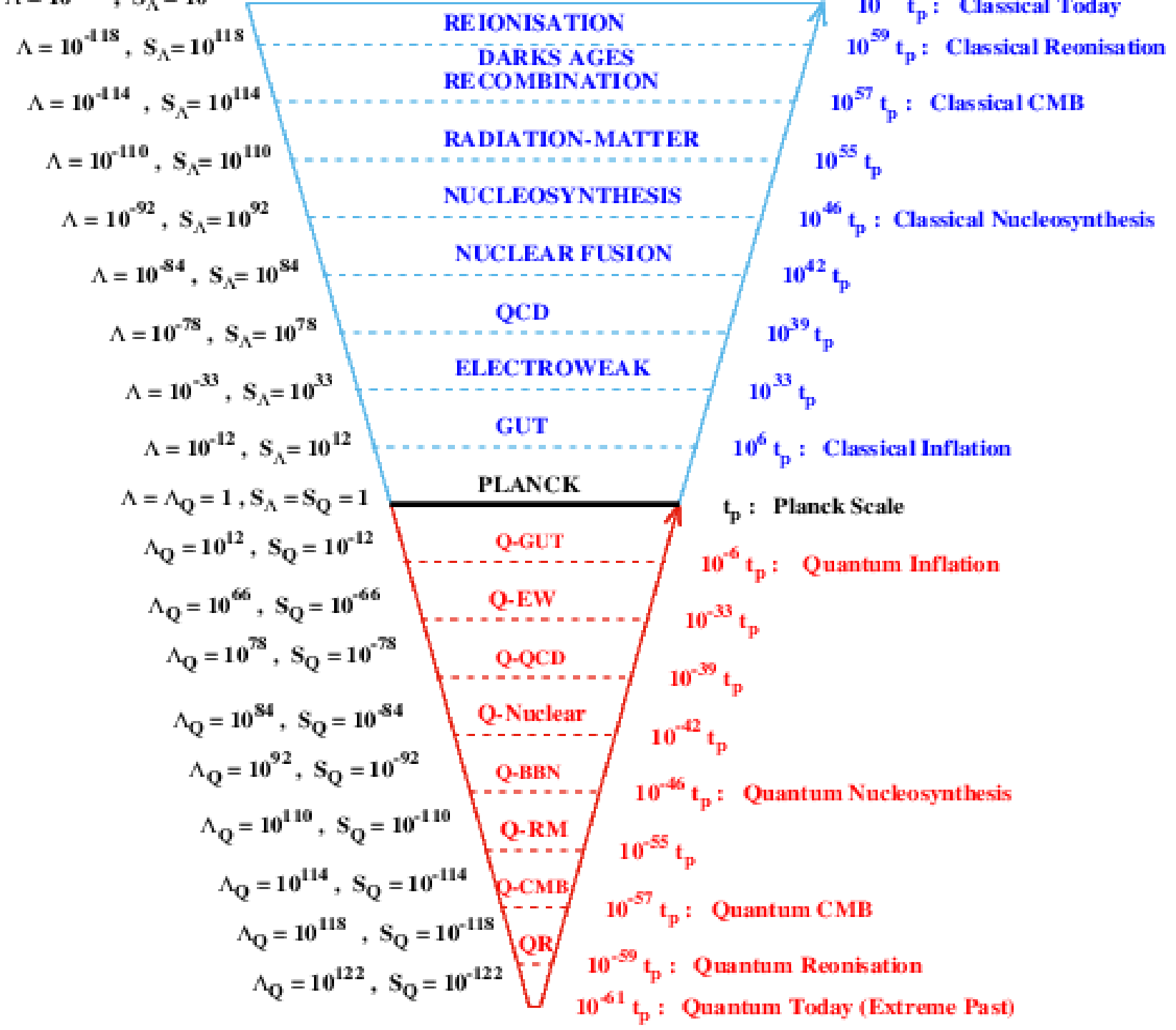
n = 1, 2,..., n inflation = 10^{12},..., n cmb = 10^{114},...,

n reoin = 10^{118},..., n today = 10^{122}:

H today = 10^{−61}, Λ today = 10^{-122}, S today = 10^{122}



THE TOTAL HISTORY OF THE UNIVERSE


REIONISATION
DARKS AGES
RECOMBINATION
RADIATION-MATTER
NUCLEOSYNTHESIS
NUCLEAR FUSION
QCD
ELECTROWEAK
GUT
PLANCK
Q-GUT
Q-EW
Q-QCD
Q-Nuclear
Q-BBN
Q-RM
Q-CMB
QR
$\Lambda = 10^{-118}$, $S_\Lambda = 10^{118}$
$\Lambda = 10^{-114}$, $S_\Lambda = 10^{114}$
$\Lambda = 10^{-110}$, $S_\Lambda = 10^{110}$
$\Lambda = 10^{-92}$, $S_\Lambda = 10^{92}$
$\Lambda = 10^{-84}$, $S_\Lambda = 10^{84}$
$\Lambda = 10^{-78}$, $S_\Lambda = 10^{78}$
$\Lambda = 10^{-33}$, $S_\Lambda = 10^{33}$
$\Lambda = 10^{-12}$, $S_\Lambda = 10^{12}$
$\Lambda = \Lambda_Q = 1$, $S_\Lambda = S_Q = 1$
$\Lambda_Q = 10^{12}$, $S_Q = 10^{-12}$
$\Lambda_Q = 10^{66}$, $S_Q = 10^{-66}$
$\Lambda_Q = 10^{78}$, $S_Q = 10^{-78}$
$\Lambda_Q = 10^{84}$, $S_Q = 10^{-84}$
$\Lambda_Q = 10^{92}$, $S_Q = 10^{-92}$
$\Lambda_Q = 10^{110}$, $S_Q = 10^{-110}$
$\Lambda_Q = 10^{114}$, $S_Q = 10^{-114}$
$\Lambda_Q = 10^{118}$, $S_Q = 10^{-118}$
$\Lambda_Q = 10^{122}$, $S_Q = 10^{-122}$
10^{61} t_p : Classical Today
10^{59} t_p : Classical Reonisation
10^{57} t_p : Classical CMB
10^{55} t_p
10^{46} t_p : Classical Nucleosynthesis
10^{42} t_p
10^{39} t_p
10^{33} t_p
10^{6} t_p : Classical Inflation
t_p : Planck Scale
10^{-6} t_p : Quantum Inflation
10^{-33} t_p
10^{-39} t_p
10^{-42} t_p
10^{-46} t_p : Quantum Nucleosynthesis
10^{-55} t_p
10^{-57} t_p : Quantum CMB
10^{-59} t_p : Quantum Reonisation
10^{-61} t_p : Quantum Today (Extreme Past)
CLASSICAL ERAS
QUANTUM ERAS

QUANTUM DECAY RATES

Unifying formula : $\Gamma = \frac{g^2\, m}{\text{numerical factor}}$

g = coupling constant, m = typical mass in the theory (mass of the unstable particle or quantum object) and the (numerical factor) often contains relevant mass ratios for the decay process.

All decays, whatever the objects: heavy relics from the early universe, topological and non-topological solitons, black-holes, microscopic fundamental strings, (g ^2= G/ a'), as well as heavy particles in the standard model (muons, Higgs, etc)

$\Gamma_n = m_n$, $\Gamma_n = (2n+1)$,

$\Gamma_{Q\,n} = 1/(2n+1)$: des excitation: $\exp(-\Gamma)$

CONCLUSIONS and IMPLICATIONS

- The Hawking temperature and usual (mass) temperature are shown to be precisely the same concept in the different classical and quantum gravity regimes respectively. Similarly, it holds for the Bekenstein-Gibbons and Hawking entropy.
- Unifying clarifying picture :

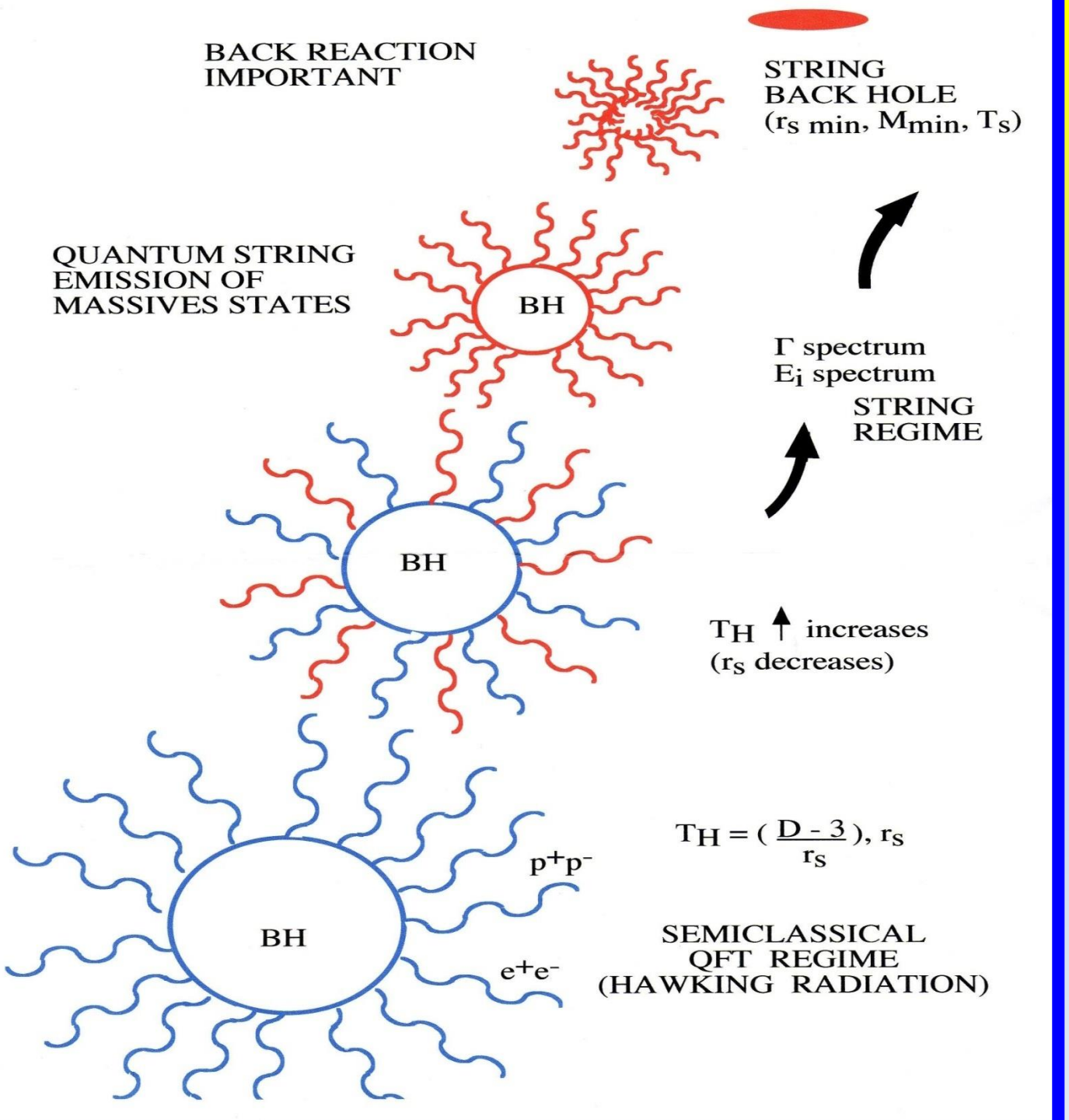
main physical gravitational intrinsic magnitudes of the Universe: age, size, mass, vacuum density, temperature, entropy, in terms of vacuum energy covering the relevant gravity regimes or cosmological stages: classical, semiclassical and quantum-planckian and superplanckian - eras.

- **Cosmological evolution goes from a quantum precursor phase to a semiclassical accelerated de Sitter era (field theory inflation), then to the classical phase untill the present de Sitter era.**

- **The wave-particle-gravity duality precisely manifests in this evolution, between the different gravity regimes : mapping between asymptotic (in and out) states characterized by the sets U_{Λ} (or U_{H}) and U_{Q}, and thus as a Scattering-matrix description: The Evolution of the Universe as a Scattering problem in time.**

- **There is no singularity at the Universe's origin.**

Because the more earlier known stages of the Universe are de Sitter (or quasi de Sitter) eras : The extreme past (at 10^{-61} tP) is a


BACK REACTION
IMPORTANT
STRING
BACK HOLE
($r_{S\,min}$, M_{min}, T_S)
QUANTUM STRING
EMISSION OF
MASSIVES STATES
BH
Γ spectrum
E_i spectrum
STRING
REGIME
BH
T_H ↑ increases
(r_S decreases)
BH
p^+p^-
e^+e^-
$T_H = \left(\frac{D-3}{r_S}\right), r_S$
SEMICLASSICAL
QFT REGIME
(HAWKING RADIATION)

.

MERCI BEAUCOUP !!

THANK YOU VERY MUCH

FOR YOUR ATTENTION !!