ECOLE INTERNATIONALE DANIEL CHALONGE HECTOR DE VEGA

SEANCE OUVERTE « DERNIERES NOUVELLES »

Cité Internationale Universitaire de Paris, Maison de l'Argentine,
Paris 14e, 7 JUILLET 2023

Norma G. SANCHEZ

- UNIFICATION DE TOUS LES TROUS NOIRS et L'INTERIEUR QUANTIQUE DE TOUS LES TROUS NOIRS.

- NATURE ET CLARIFICATION de L'ENERGIE NOIRE

"Desde el Origen del Universo al fin de los Agujeros Negros: Una historia de 13.700 millones de años"

Ultimas novedades sobre la fisica del espacio – tiempo *uniendo la teoria de* gravitacion de Einstein de las escalas cosmologicas *con* la fisica de las escalas microscopicas (cuántica) *para describir* el origen del universo, predecir su futuro fisico, el interior y el final de los agujeros negros y sus estados remanentes.

re image du trou noir : l'univers se dévoile

aille de la Terre.
rvations ont eu lieu en
quand huit télescopes
ux trous noirs : Sagit-
n centre de notre voie
n congénère de la ga-
, dont la photo a été

ite ? Huit mois de
n de ce type d'opéra-
pées, les observations
l'aveugle, les astrono-
aucun moyen de sa-
a fonctionné. Il aura
dre de débusquer un
mun à tous les télesco-
t dire, dans l'Univers,
le dans une botte de

an de travail a été
pour reconstruire les
photo. « Pour plus de
travail a été fait quatre
uatre équipes différen-
cise Frédéric Gueth,
e deux des études.

uron du « Seigneur
ux »

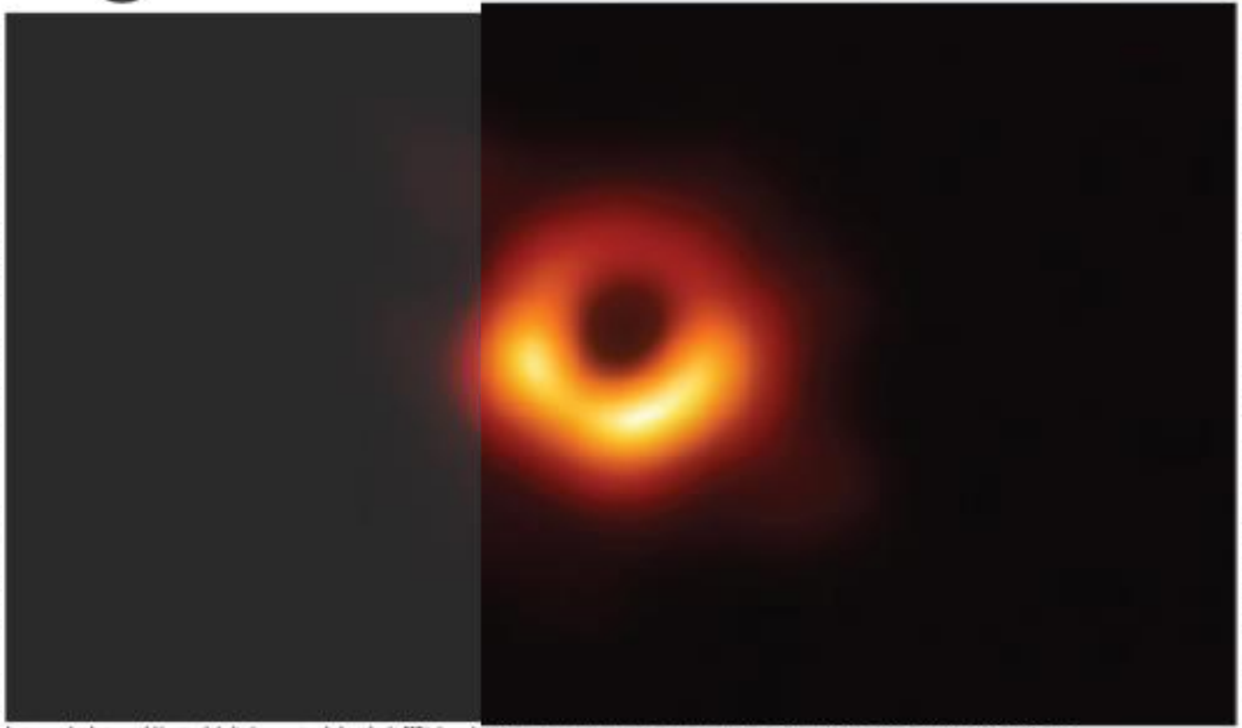
ge du trou noir, depuis
ps recherché, si sou-
lisé - et aussi fantasmé
l'objet de six articles
ercredi dans la revue
cal Journal Letters. Et
nent la même image,
mbre sur un halo sou-
e du trou noir sur le
matière qui l'entoure.
révélation, cette pho-
rmément parler. Beau-
ernautes s'amusent à
ce trou noir avec l'œil
t du « Seigneur des
, l'ignoble Sauron.
50 millions d'années-
univers continue de
ner...

T. L. (avec AFP)

angeté

ermes, ce que vous
t pas forcément où
ez. Un objet peut ap-
formé ou dédoublé.
marée est tellement
l'un astronaute qui
vers l'horizon d'un
erait transformé en
ses pieds accélérant
e sa tête. Et c'est sans
temps qui se dilate, et
qui se décale vers le
'à devenir invisible.
ateur lointain qui re-
chute de ce même
aurait l'impression
ernier náutic puisse
de s'effacer progres-

J.-M.L.



Le trou noir photographié est celui situé au centre de la galaxie M87, à environ 50 millions d'années-lumière de la Terre. Photo EUROPEAN SOUTHERN OBSERVATORY/AFP

REPÈRES

Une existence théorique

Dès la fin du XVIII^e^ siècle, l'astronome anglais John Michell et le marquis de Laplace avaient eu l'intuition de l'existence des trous noirs. Mais il aura vraiment fallu attendre le début du XX^e^ siècle et la théorie de la relativité générale d'Einstein pour que les trous noirs rejoignent le bestiaire cosmologique. Le chemin de la reconnaissance a toutefois été long. Einstein lui-même n'y croyait pas. C'est à un autre astrophysicien allemand, Karl Schwarzschild qu'on doit la démonstration de leur existence. Le terme de « trou noir » n'est toutefois apparu que tardivement, au milieu des années 1960. Pour autant, faute d'observation directe, leur existence restait jusqu'à présent purement théorique.

Des preuves indirectes

Depuis une trentaine d'années, les progrès technologiques ont permis de multiples observations de trous noirs. Mais toujours indirectes. Heureusement, dans l'univers, beaucoup de trous noirs sont aussi discrets qu'un éléphant dans un magasin de porcelaine. Lorsqu'ils « avalent » une étoile voisine, d'immenses jets de matière peuvent se produire. Les plus gros sont entourés de disques d'accrétion tournoyant à des vitesses vertigineuses, et d'où s'échappent latéralement de gigantesques jets de radiations. Leur présence peut également être trahie par l'effet de lentille gravitationnelle, qui peut dédoubler ou déformer l'image d'un objet lointain. Et ne mentionnons même pas le cas de la collision de deux trous noirs : c'est un événement de ce type qui a permis de détecter pour la première fois les ondes gravitationnelles en 2015.

QUESTIONS À

Norma G. Sanchez Physicienne théoricienne, directrice de recherche au CNRS et directrice de l'École internationale d'astrophysique Daniel Chalonge

Le prochain défi est d'aller voir à l'intérieur

Photo DR

La première image du trou noir vient d'être dévoilée. Quelles sont vos impressions ?

Il y a l'exploit scientifique d'avoir assemblé cette image, de reconstituer ce puzzle grâce aux huit télescopes du réseau Event Horizon Telescope. Après, sur l'image en elle-même, à savoir un puits noir entouré de matière qui émet de la lumière, cela n'est pas surprenant. Cette image était pressentie, mais elle reste importante aussi bien pour l'observation de la galaxie que pour la physique théorique.

Quelle est la prochaine étape ?

Depuis Stephen Hawking, on sait que les trous noirs rayonnent, et donc émettent des informations. Désormais, le prochain défi est d'aller voir à l'intérieur d'un trou noir en allant capter ces informations. La première étape sera d'intégrer les nouvelles connaissances scientifiques. Jusqu'à présent, toutes les observations de trous noirs, y compris cette photographie, sont basées sur la théorie d'Albert Einstein sur la relativité générale qui date de 1915 ! Pour comprendre ce que contient un trou noir, il va falloir aller au-delà d'Einstein, et ce, même si sa théorie a été magnifique pour la communauté scientifique, même un siècle plus tard. Nous avons fait des progrès, heureusement !

Peut-on s'attendre à des surprises ?

Je ne pense pas. Ce qui paraissait étrange pour Einstein ou même Hawking devient plus simple au fur et à mesure des nouvelles connaissances. D'où l'intérêt de les intégrer.

Recueilli par Thibault LIESSI

6,5

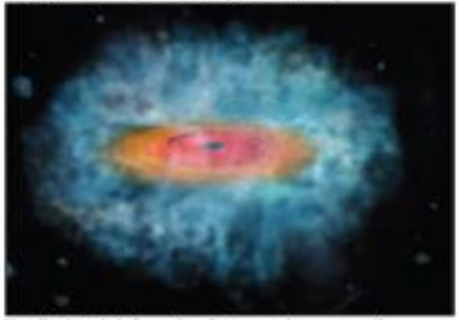
MILLIARDS
de fois la masse du Soleil, telle est le poids du trou noir dont la photo a été observée ce mercredi.
Pour quantifier, la masse du Soleil équivaut à 333 000 fois la masse de la Terre.
Notre planète pèse environ 6 000 quadrillions de kilogrammes.
En masse, un quadrillion, c'est au-delà de mille milliards de milliards de kg.

Un trou noir, c'est quoi ?

Pour comprendre ce qu'est un trou noir, imaginez que vous deviez envoyer une fusée dans l'espace. Pour y parvenir, il vous faudra évidemment atteindre une certaine vitesse. C'est ce qu'on appelle la vitesse de libération, qui permet de s'échapper du champ gravitationnel.

Pour la Terre, cette vitesse est de 11,2 km/s. Vous savez désormais pourquoi les fusées ont de gros moteurs. Si vous décollez d'un corps plus léger, évidemment, pas besoin d'aller aussi vite : les astronautes d'Apollo 11 n'ont eu besoin que d'atteindre 2,4 km/s pour quitter la Lune.

Et si vous vous trouvez à la surface d'un corps plus lourd ? C'est logique, la vitesse de libération augmente. Sur Neptune, elle s'élève à 23,6 km/s, sur Jupiter 59,5 km/s... Mais il y a une limite : la vitesse de la lumière. Que se passe-t-il lorsque le corps est tellement lourd, qu'il faudrait atteindre les 300 000 km/s pour échapper à son attraction ? Eh bien, rien. Rien, car rien ne peut atteindre une telle vitesse, pas même un photon. Si un corps est tellement massif que la vitesse de libération atteint celle de la lumière, rien ne pourra jamais s'en échapper. De l'extérieur, vous ne verrez qu'une sphère obscure. Un trou noir, dont la frontière est baptisée l'« horizon des événements ».



Vue d'artiste de la formation d'un trou noir supermassif.
Nasa/CXC/M. Weiss

Des nains et des géants

Contrairement à une idée reçue, tous n'ont toutefois pas une densité gigantesque. Ce n'est le cas que pour les trous noirs stellaires, nés de l'effondrement d'une étoile, et dont le diamètre peut être ridiculement petit. Dans ces derniers, une masse équivalente à celle de la Terre tiendrait dans le volume d'une cacahuète.

D'autres trous noirs auraient une densité proche de celle de l'eau, mais compenseraient par une taille gigantesque : certains de ces géants pourraient faire plusieurs fois la taille de notre système solaire. Ce sont ces trous noirs dits « supermassifs » qui se trouveraient au centre des galaxies, à l'image de Sagittarius A*. Ils sont même suspectés d'être les véritables architectes de l'Univers, à l'origine de la création des étoiles et des galaxies.

Jean-Michel LANIRE

PHYSICAL REVIEW D **107,** 126018 (2023)

Quantum trans-Planckian physics inside black holes and its spectrum

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We provide a quantum unifying picture for black holes of all masses and their main properties covering classical, semiclassical, Planckian, and trans-Planckian gravity domains: space-time, size, mass, vacuum ("zero-point") energy, temperature, partition function, density of states, and entropy. Novel results of this paper are that black hole interiors are always quantum, trans-Planckian, and of constant curvature. This is so for *all* black holes, including the most macroscopic and astrophysical ones. The black hole interior trans-Planckian vacuum is similar to the earliest cosmological vacuum, where the classical gravity dual is the low energy gravity vacuum—today, dark energy. There is *no* singularity boundary at $r = 0$; the quantum space-time is regular. We display the quantum Penrose diagram of the Schwarzschild-Kruskal black hole. The complete black hole instanton (imaginary time) covers the known classical Gibbons-Hawking instanton plus a new, central, highly dense quantum core of Planck length radius and constant curvature. The complete partition function, entropy, temperature, decay rate, discrete levels, and density of states *all* include the trans-Planckian domain. The semiclassical black hole entropy (the Bekenstein-Hawking entropy) $(\sqrt{n})^2$ "interpolates" between the quantum point particle entropy (n) and the quantum string entropy $\sqrt{n}$, while the quantum trans-Planckian entropy is $1/(\sqrt{n})^2$. Black hole evaporation finishes in a pure (nonmixed) quantum state of particles, gravitons, and radiation.

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I. INTRODUCTION AND RESULTS

Quantum theory is more complete than classical theory; it tells us what values physical observables should have. Planckian and trans-Planckian domains are theoretically allowed and physically motivated in the very early stages of

nonzero commutation relations: The concept of space-time is replaced by quantum algebra. Classical space-time is recovered when the quantum operators are the classical space-time continuum coordinates (c-numbers) with all commutators vanishing.

In this paper we investigate the black hole interior, its

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(Dated: June 21, 2023)

Abstract: We provide a quantum unifying picture for black holes of all masses and their main properties covering classical, semiclassical, Planckian and trans-Planckian gravity domains: Space-time, size, mass, vacuum ("zero point") energy, temperature, partition function, density of states and entropy. Novel results of this paper are: Black hole **interiors** are always **quantum**, trans-Planckian and of constant curvature: This is so for *all* black holes, including the most macroscopic and astrophysical ones. The black hole interior trans-Planckian vacuum is similar to the earliest cosmological vacuum which classical gravity dual is the low energy gravity vaccum: today dark energy. There is *no* singularity boundary at $r = 0$, not at any other place: The quantum space-time is **totally regular**. The *quantum* Penrose diagram of the Schwarschild-Kruskal black hole is displayed. The complete black hole *instanton* (imaginary time) covers the known classical Gibbons-Hawking instanton plus a *new* central highly dense *quantum core* of Planck length radius and *constant curvature*. The complete partition function, entropy, temperature, decay

(in Planck units) replace the classical $X = \pm T$ horizons. The classical/semiclassical gravity domains of Black Holes $(BH)_G$ and the quantum gravity ones $(BH)_Q$ satisfy the classical-quantum gravity duality through the Planck scale (bh_P), the *crossing scale*: $(BH)_G = (bh_P)^2/(BH)_Q$, the total or complete (QG) magnitudes $(BH)_{QG}$ include all domains. Mass quantization $m_{n\pm} = m_P\ [\ \sqrt{2n+1}\ \pm\ \sqrt{2n}\ ]$, $n = 0, 1, 2, ...$, displays two dual branches $(\pm)$ covering *all* masses. For high n in branch $(+)$ the spectrum becomes continuum, and consistently, the space-time classicalizes. There is *no* singularity boundary at $r = 0$, not at any other place: The quantum space-time is **totally regular**. The *quantum* Penrose diagram of the Schwarschild-Kruskal black hole is displayed. The complete black hole *instanton* (imaginary time) covers the known classical Gibbons-Hawking instanton plus a *new* central highly dense *quantum core* of Planck length radius and *constant curvature*. The complete partition function, entropy, temperature, decay rate, discrete levels and density of states all include the trans-Planckian domaine. The semiclassical black hole entropy $(\sqrt{n})^2$ "interpolates" between the quantum point particle (QFT) entropy (n) and the quantum string entropy $\sqrt{n}$, while the quantum trans-Planckian entropy is $1/(\sqrt{n})^2$. Black hole evaporation goes from the $(+)$ branch to the $(-)$ dual branch and ends as *a pure (non mixed)* quantum state of particles, gravitons and radiation.

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Adam G. Riess et al,The Astrophysical Journal Letters, 934: L7, (2022); Astrophys.J. 938, 1, 36 (2022)

Des points clés de cette approche pour une théorie quantique consistante de la gravité sont les suivants :

(i) Au lieu de partir comme d'habitude de la gravité classique en quantifiant la relativité générale ou autre théorie de la gravité, le bon départ est partir de la physique quantique pour atteindre l'échelle de Planck et le domaine trans-planckien. *Pour cela il faut compléter la théorie quantique. (Ce que j'ai fait).*

(ii) La gravité quantique doit être une théorie finie, ce qui est beaucoup plus qu' une théorie renormalisable. Il n'y a pas de coupure d'haute énergie en gravité quantique, due à la dualité onde-particule, que j'ai etendue à la gravite'. La gravité quantique est une théorie des nombres purs.

(iii) L'espace-temps quantique est décrit par une algèbre quantique à niveaux discrets. L'espace-temps classique est récupéré lorsque les opérateurs quantiques sont les coordonnées du continuum espace-temps classique (nombres c) avec tous les commutateurs nuls.

(iv) La structure espace-temps quantique hyperbolique génère le cône de lumière quantique et une nouvelle région de vide quantique au-delà de l'échelle de Planck émerge. Il en est ainsi dans tous les espace-temps, y compris l'espace-temps plat (Minkowski). La pression quantique (due à l'incertitude quantique) plie le vide et génère la courbure quantique. Au niveau quantique, l'espace-temps est nécessairement courbé (non plat).

L'Article :

Norma G. Sanchez, *Quantum trans-Planckian physics inside black holes and its spectrum,* Phys Rev D **107**, 126018 (2023)

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.107.126018

https://chalonge-devega.fr/PhysRevD-Quantum_Trans_Planckian_Physics_inside_Black_Holes_and_its_Spectrum.pdf

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Pour en savoir plus :

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https://chalonge-devega.fr/Unifying_quantum_mechanics_with_Einsteins_general.pdf

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DOI: 10.32907/RO-111-138141 (Harvard Reference)

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https://hal.science/hal-01735421

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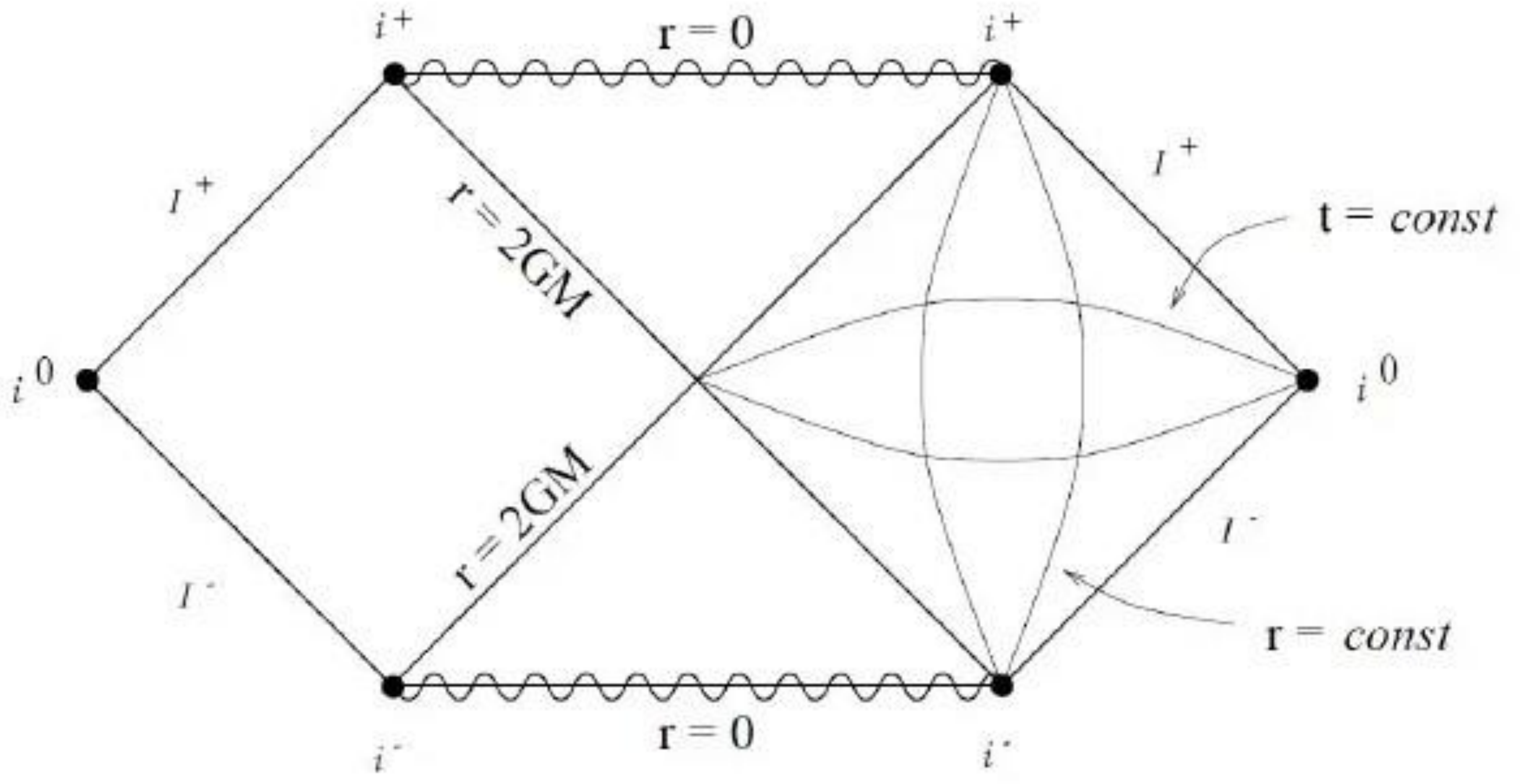
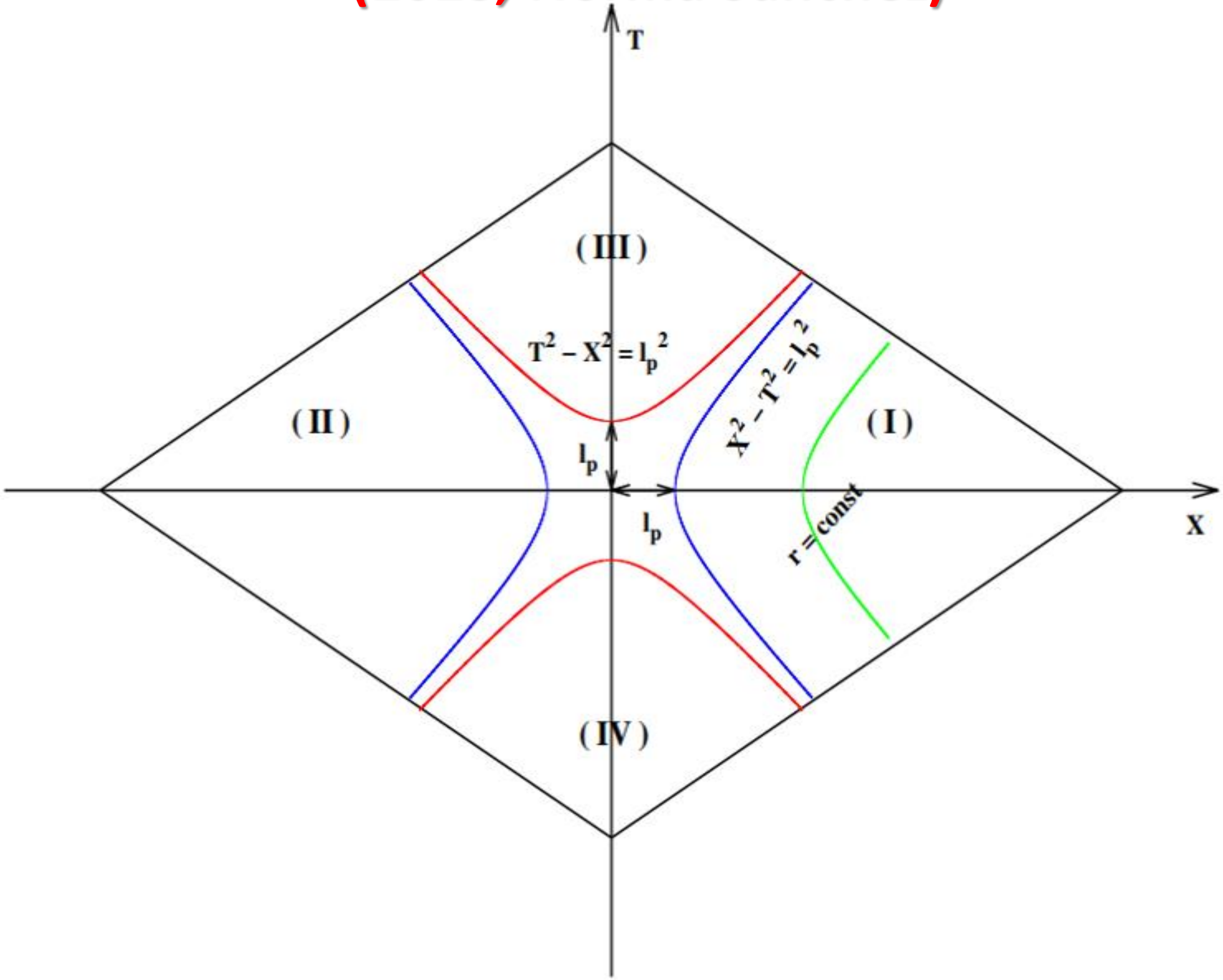
The (CLASICAL) BLACK HOLE PENROSE DIAGRAM (1967, Roger Penrose)



The NEW (QUANTUM) BLACK HOLE PENROSE DIAGRAM (2023, Norma Sanchez)



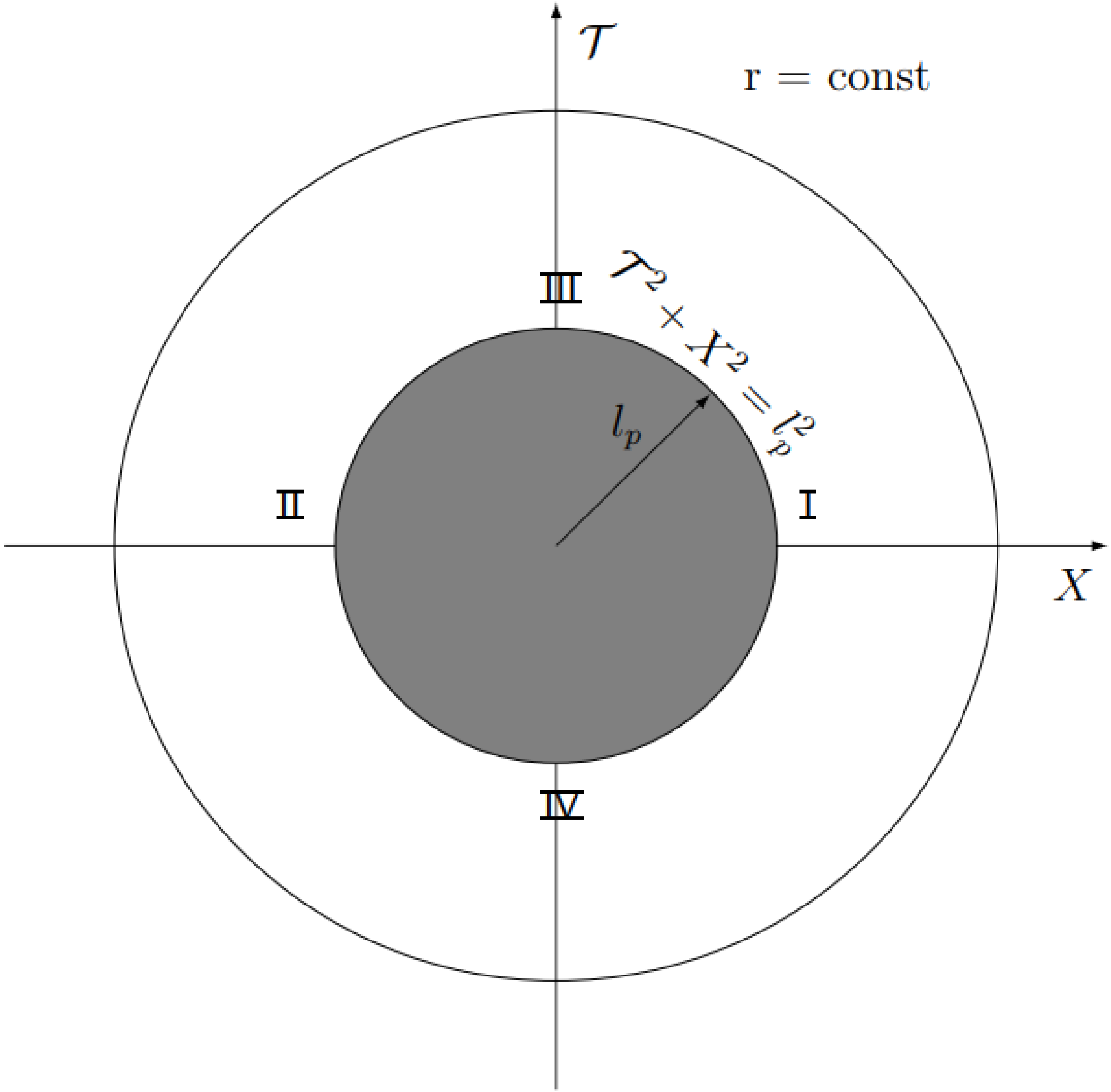
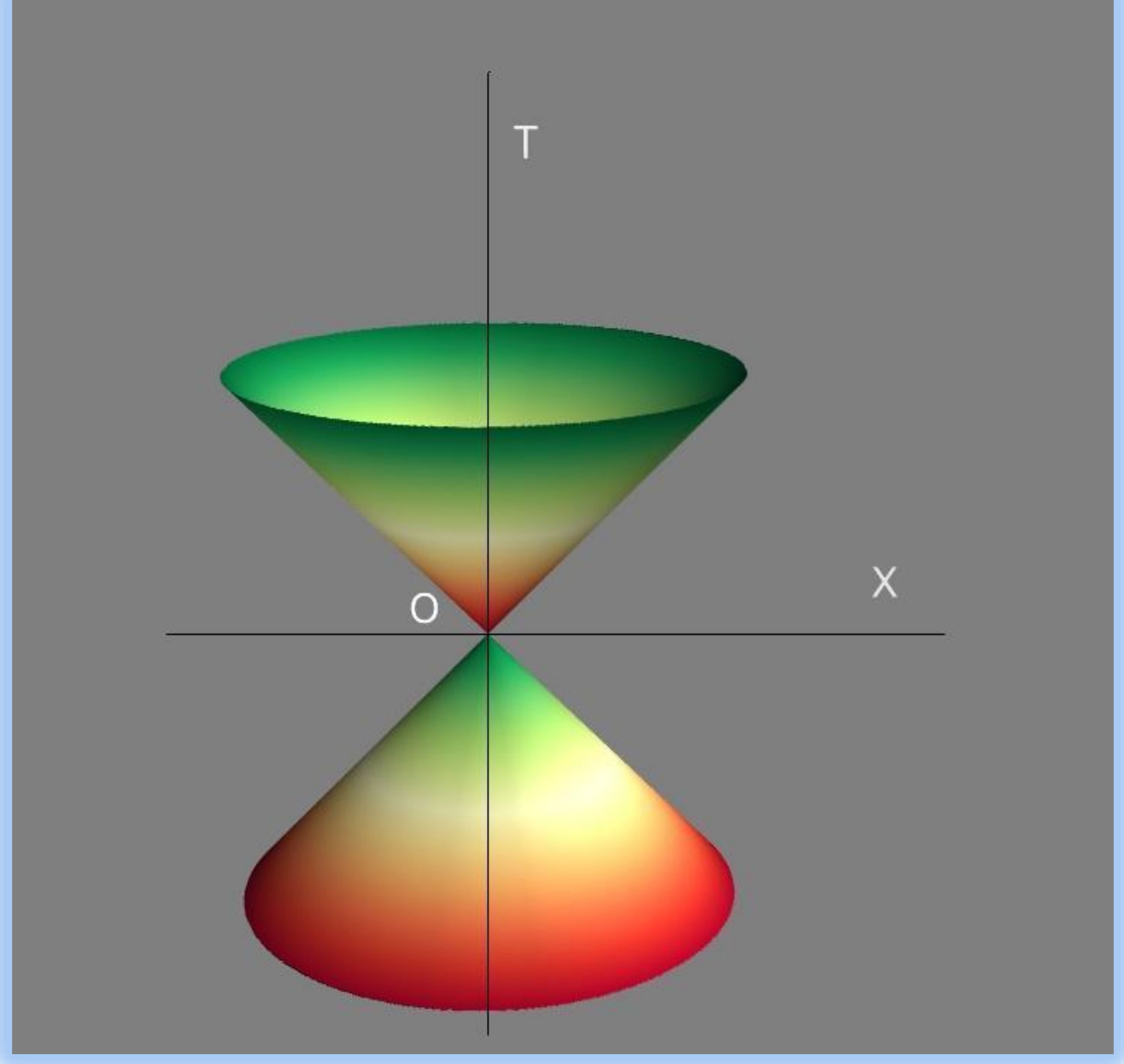
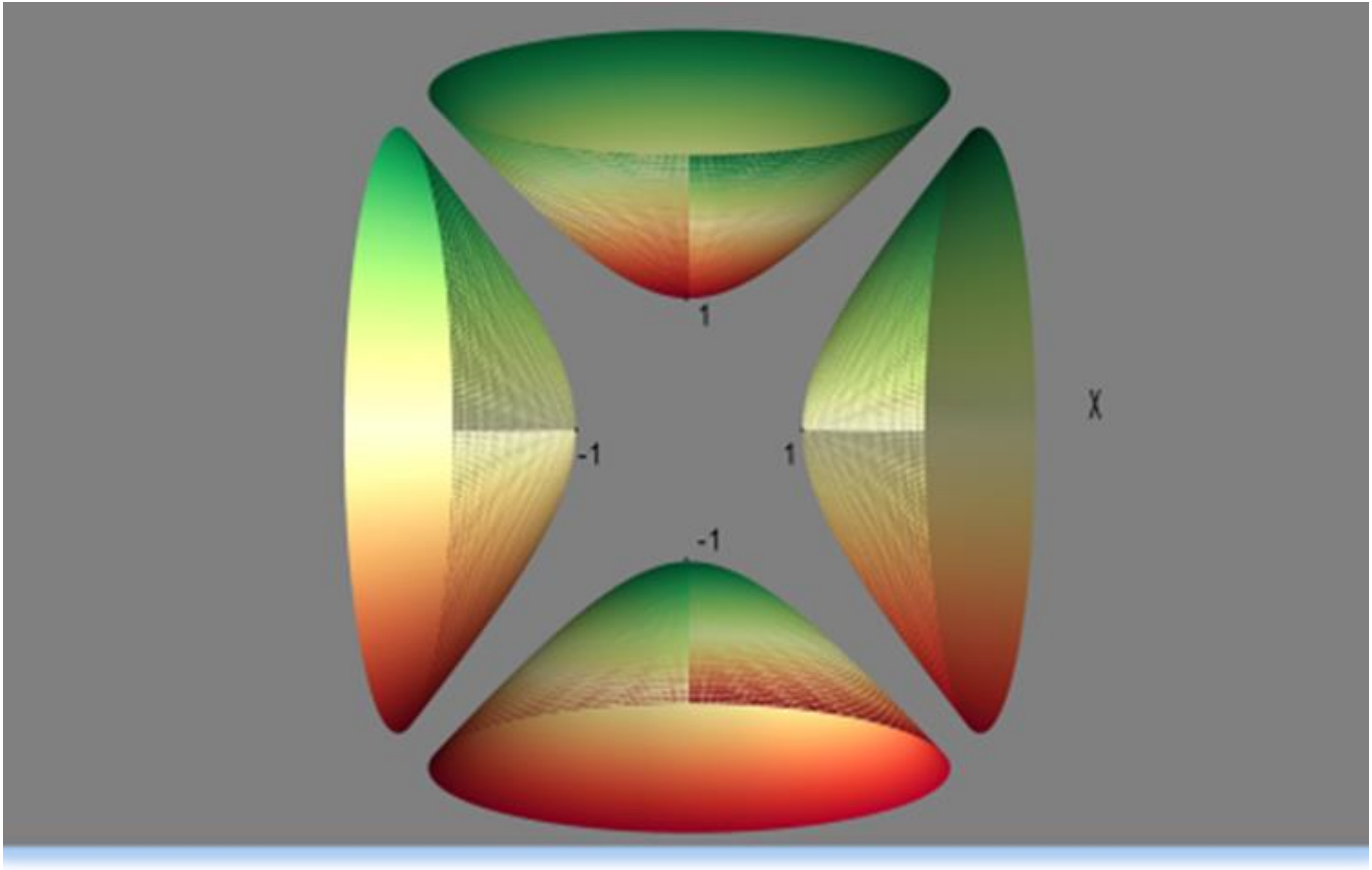


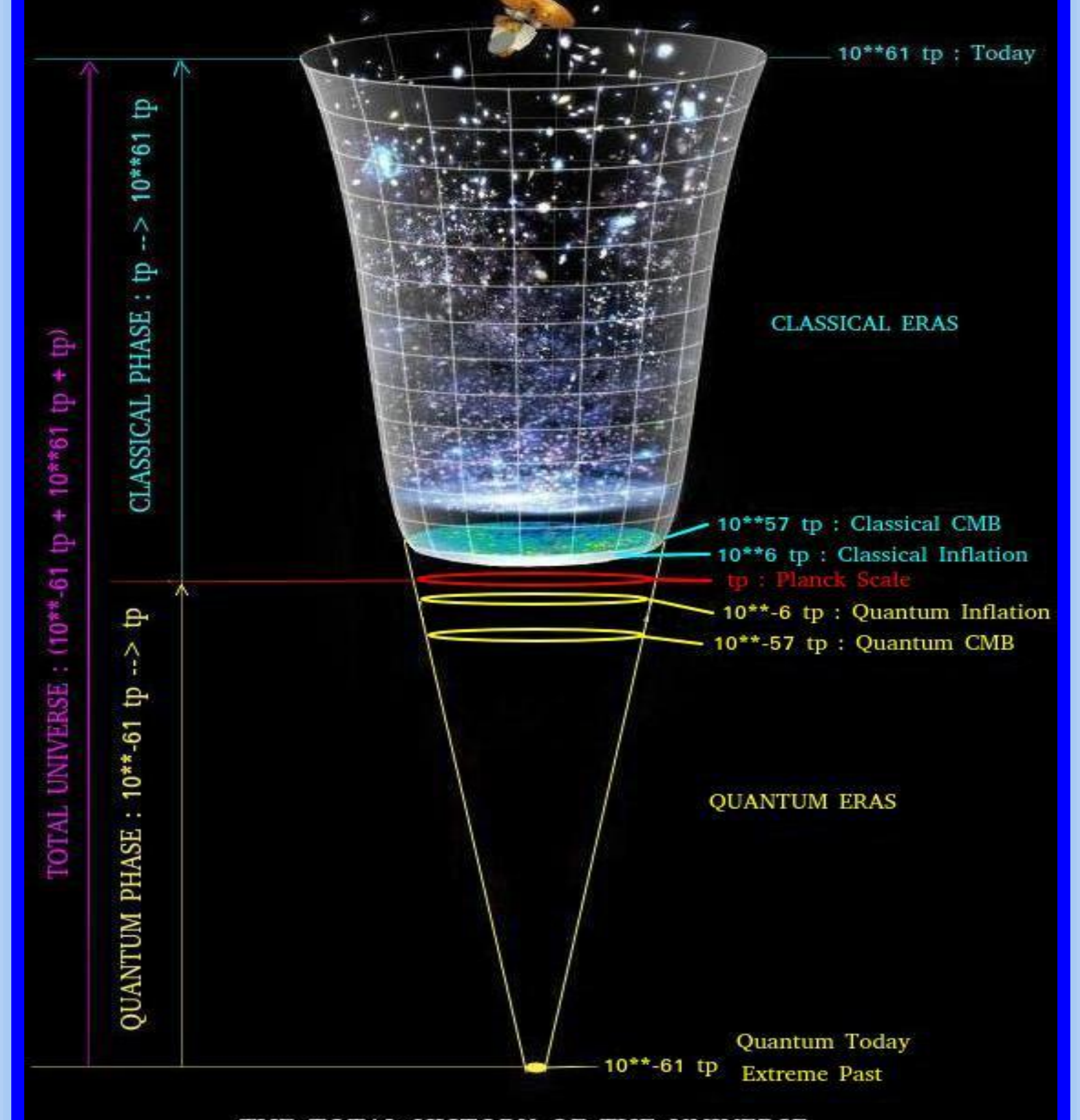
FIG. 2. **The quantum gravitational instanton of the Schwarschild-Kruskal black hole (imaginary time: $T = i\mathcal{T}$, $t = i\tau$).** The classical null horizons corresponding to the



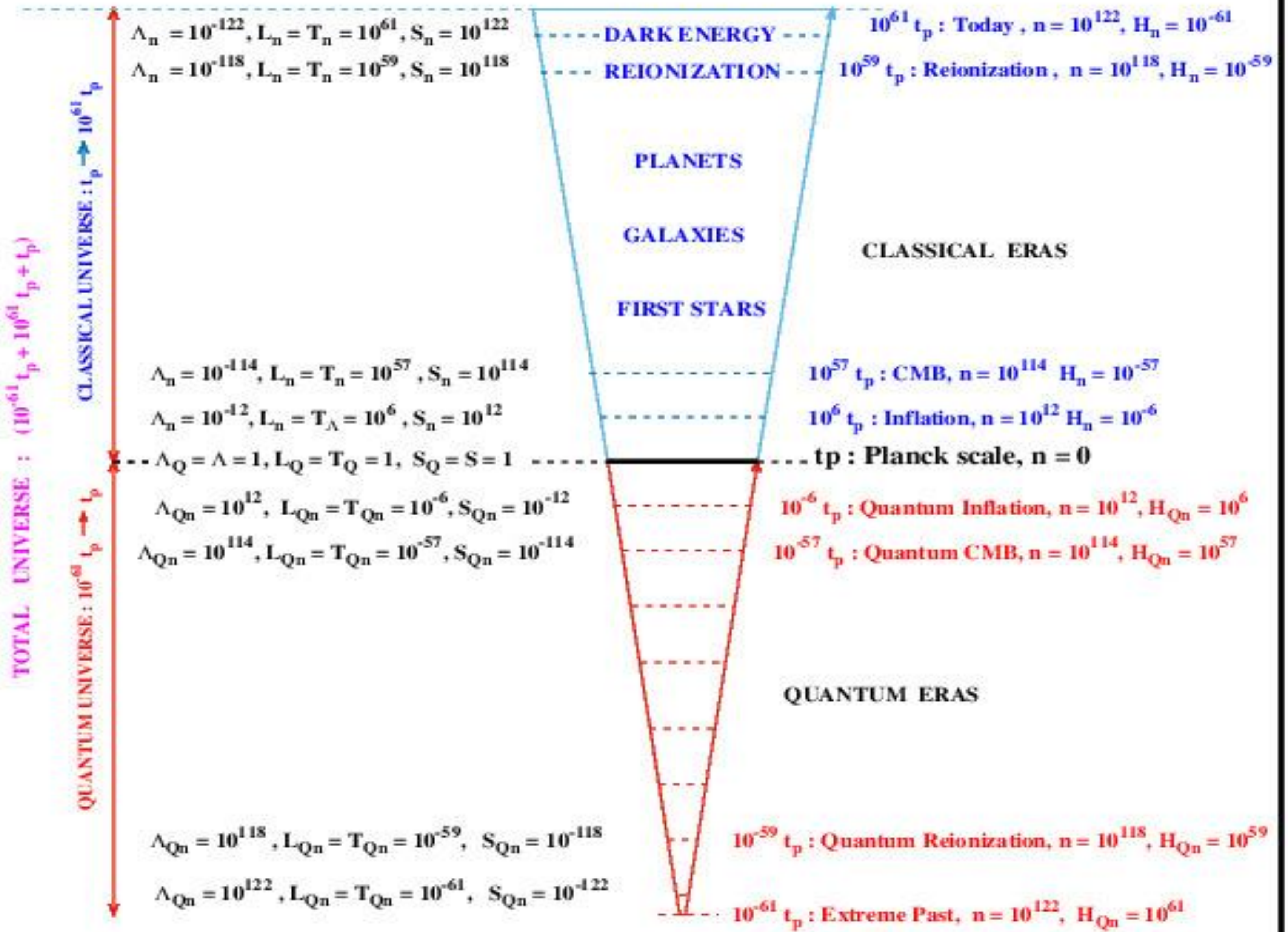
The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of the Quantum light -cone



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



THE TOTAL HISTORY OF THE UNIVERSE



QUANTUM DISCRETE LEVELS OF THE UNIVERSE AND THEIR TOTAL HISTORY

BLACK HOLE INTERIOR: THE QUANTUM TRANS-PLANCKIAN DE SITTER VACUUM

level. This is precisely a constant curvature de Sitter vacuum: The de Sitter
be described as a (inverted, ie with imaginary frequency) harmonic oscillator,
constant being [1],[3]:

$$\kappa_{osc} \;=\; H^2, \qquad H \;=\; \sqrt{(8\pi\, G\, \Lambda)/3} \;=\; c \,/\, l_{osc}$$

Here in the black hole case, the physical magnitudes as the oscillator constant H^2
typical length (c/l_{osc}) are related to the black hole mass M:

$$H = c/l_{osc} = h_P \left(\frac{m_P}{M}\right) \quad \Lambda = \lambda_P \left(\frac{m_P}{M}\right)^2, \quad h_P = c/l_P, \quad \lambda_P = 3h_P^2/c^4$$

$$\rho_{QG} = \frac{\rho_G}{[\,1 + \rho_G/\rho_P\,]^2} = \frac{\rho_Q}{[\,1 + \rho_Q/\rho_P\,]^2},$$

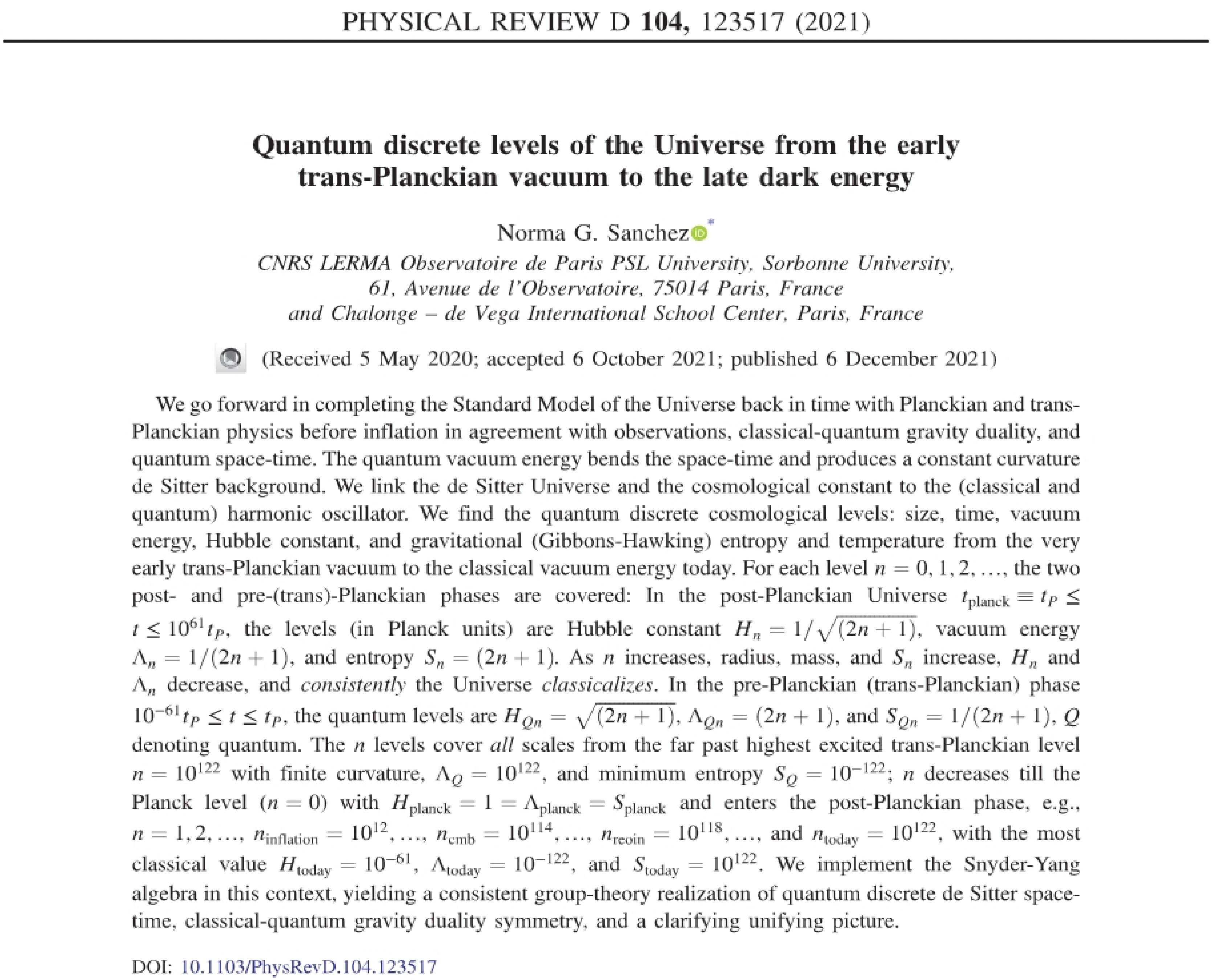
$$\rho_{QG}\,(\rho_G) = \rho_{QG}\,(\rho_Q) = \rho_{QG}\,(\rho_P^2/\rho_G)$$

$$\rho_G = \rho_P\,(H/h_P)^2 = \rho_P\,(\Lambda/\lambda_P)\,, \quad \rho_P = 3\,h_P^2/8\pi G$$

$$\rho_Q = \rho_P\,(H_Q/h_P)^2 = \rho_P\,(\Lambda_Q/\lambda_P) = \rho_P^2/\rho_G$$

$$\frac{\rho_G}{\rho_P} = \left(\frac{l_P}{L_G}\right)^2 = \left(\frac{m_P}{M}\right)^2 = \left(\frac{S_Q}{s_P}\right)$$

$$\frac{\rho_Q}{\rho_P} = \left(\frac{l_P}{\Lambda}\right) = \left(\frac{M}{m_P}\right)^2 = \left(\frac{S_G}{s_P}\right)$$



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Quantum discrete levels of the Universe from the early trans-Planckian vacuum to the late dark energy

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We go forward in completing the Standard Model of the Universe back in time with Planckian and trans-Planckian physics before inflation in agreement with observations, classical-quantum gravity duality, and quantum space-time. The quantum vacuum energy bends the space-time and produces a constant curvature de Sitter background. We link the de Sitter Universe and the cosmological constant to the (classical and quantum) harmonic oscillator. We find the quantum discrete cosmological levels: size, time, vacuum energy, Hubble constant, and gravitational (Gibbons-Hawking) entropy and temperature from the very early trans-Planckian vacuum to the classical vacuum energy today. For each level $n = 0, 1, 2, \ldots$, the two post- and pre-(trans)-Planckian phases are covered: In the post-Planckian Universe $t_{\mathrm{planck}} \equiv t_P \leq t \leq 10^{61} t_P$, the levels (in Planck units) are Hubble constant $H_n = 1/\sqrt{(2n+1)}$, vacuum energy $\Lambda_n = 1/(2n+1)$, and entropy $S_n = (2n+1)$. As n increases, radius, mass, and S_n increase, H_n and Λ_n decrease, and *consistently* the Universe *classicalizes*. In the pre-Planckian (trans-Planckian) phase $10^{-61} t_P \leq t \leq t_P$, the quantum levels are $H_{Qn} = \sqrt{(2n+1)}$, $\Lambda_{Qn} = (2n+1)$, and $S_{Qn} = 1/(2n+1)$, Q denoting quantum. The n levels cover *all* scales from the far past highest excited trans-Planckian level $n = 10^{122}$ with finite curvature, $\Lambda_Q = 10^{122}$, and minimum entropy $S_Q = 10^{-122}$; n decreases till the Planck level ($n = 0$) with $H_{\mathrm{planck}} = 1 = \Lambda_{\mathrm{planck}} = S_{\mathrm{planck}}$ and enters the post-Planckian phase, e.g., $n = 1, 2, \ldots, n_{\mathrm{inflation}} = 10^{12}, \ldots, n_{\mathrm{cmb}} = 10^{114}, \ldots, n_{\mathrm{reoin}} = 10^{118}, \ldots$, and $n_{\mathrm{today}} = 10^{122}$, with the most classical value $H_{\mathrm{today}} = 10^{-61}$, $\Lambda_{\mathrm{today}} = 10^{-122}$, and $S_{\mathrm{today}} = 10^{122}$. We implement the Snyder-Yang algebra in this context, yielding a consistent group-theory realization of quantum discrete de Sitter space-time, classical-quantum gravity duality symmetry, and a clarifying unifying picture.

DOI: 10.1103/PhysRevD.104.123517

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**

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

the quantum light cone

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

Unifying quantum mechanics with Einstein's general relativity

The quantum nature of gravity is an enigma which has eluded even the brightest of physicists for many decades. Now, Dr Norma G. Sanchez at the French CNRS LERMA Observatory of Paris-PSL Sorbonne Université describes a possible solution. Her approach takes the form of a general theory, incorporating both quantum mechanics and Einstein's theory of general relativity. If correct, her results could bring researchers a step forward in their knowledge of how the physics which plays out on the very smallest of scales can be compatible with that which occurs on the very largest cosmological scales.

The question of whether light is a wave or a particle has baffled physicists since the 17th century. The problem first emerged when Isaac Newton developed his 'corpuscle' theory, which described particles of light which must only travel in straight lines; as seen in the reflection in a mirror. At the same time, however, other physicists including Christiaan Huygens and Thomas Young proposed that light must propagate as a wave, as it displays properties like diffraction and interference.

In fact, neither of these theories are necessarily 'wrong', since both of them are consistent with experimental observations when the right context is applied. On quantum scales, light travels in packets which we now call photons, but also reliably follows Maxwell's equations, which describe the dynamics of classical electromagnetic waves. To explain how both theories can be correct at the same time, physicists needed a way to unify both classical electrodynamics and quantum physics into a deeper, more all-encompassing theory. Known among physicists as 'quantum electrodynamics', the theory was by no means simple to develop, but nonetheless, it has been done.

GENERALISING CLASSICAL PHYSICS

At around the beginning of the 20th century, several physicists began work on revolutionary theories to explain why matter appears to behave differently on extremely small scales. In the subsequent decades, the resulting field of quantum mechanics resolved many questions which classical physics didn't have the means to answer. Ultimately, the success of the theory stemmed from the fact that quantum theory is a 'generalised' theory, of which classical physics is just one specialised branch.

This means that while physics appears to be non-classical on quantum scales, classical behaviours emerge on larger scales, where quantum processes become far less relevant overall. Ultimately, therefore, quantum mechanics unites explanations for physical behaviours which are observed on a variety of scales. Yet despite the successes of quantum theory, physicists have realised for some time that even quantum mechanics is not general enough to explain all of the physics we have observed in the universe.

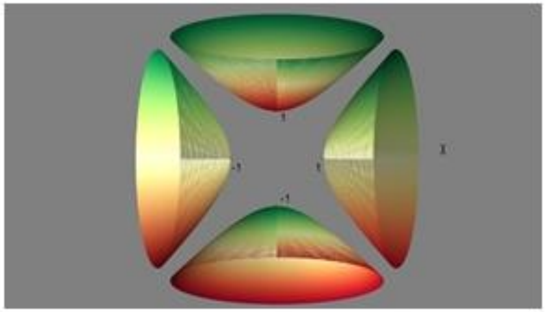


Fig. 1: The quantum light-cone in a space-time diagram (time is the vertical axis). Copyright Norma Sanchez

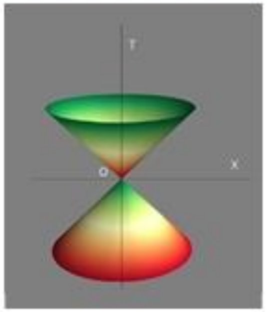


Fig. 2: The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of Fig. 1

THE INCOMPLETENESS OF GRAVITY

Again, first described by Newton, the effects of gravity can be accurately described in many situations using classical physics alone. However, these theories are unable to fully explain all phenomena ever observed by astronomers. Albert Einstein famously resolved this issue through his theory of general relativity. His equations generalised gravity to a more all-encompassing theory; this time, to a geometric model which unites space and time, named spacetime.

Yet although Einstein's theory has been watertight enough to hold up to even the latest astronomical observations, it appears to be completely incompatible with quantum mechanics. For physicists, this calls for an even deeper generalisation, which has been pre-emptively given the name 'quantum gravity'. In her research, Dr Sanchez aims to realise such a theory, in which both quantum mechanics and general relativity are particular branches which are contained on their appropriate scales. To do this, she has incorporated physical theories which have emerged since Einstein first drew out his famous equations. The key point in her approach is that instead of starting from gravity and quantizing it, she starts from quantum theory and extends it to the high energy scales where gravity and quantum effects are of the same importance.

> **Dr Sanchez uses 'semi-classical' gravity as a standard theory, which emerges from her own theories in particular situations.**

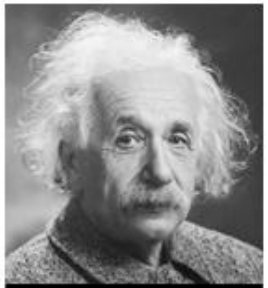
BUILDING ON AN INTERMEDIATE THEORY

Later on in the 20th century, a wide variety of intriguing discoveries about the nature of our universe began to emerge. These included Stephen Hawking's celebrated explanations for how black holes decay through radiation, as well as Cosmic Microwave Background radiation – a faint source of light found across the entire sky, which indicates the density structure of the entire universe.

These theories are united in the approximation that matter displays quantum behaviour, but moves around according to a classical description of spacetime. Known as 'semi-classical' gravity, this model acts as a useful bridge between the separated theories of quantum mechanics and general relativity, and a unified theory of quantum gravity. Because of this, Dr Sanchez uses it as a standard theory, which emerges from her own theories in particular situations.

EXTENDING CLASSICAL-QUANTUM DUALITY

While previous theories which incorporate semi-classical gravity have described vast astronomical structures, Dr Sanchez brings it down to quantum scales in her research. To describe how gravity could work in this regime, she starts from the classical-quantum duality of quantum theory and extends it across and beyond the Planck scale. This is where a unification of three fundamental physical constants occurs: Planck's constant, originating from quantum mechanics; Newton's gravitational constant from classical gravitation; and the speed of light, which Einstein proved to be constant through general relativity.



Einstein's theory of general relativity solved many, but not all, issues relating to gravity.


Dr Sanchez's work could transform our understanding of how the universe works.

Denis Belitsky/Shutterstock.com

Dr Sanchez has now started a theory which incorporates these three constants into one unified structure. In doing this, the property of 'wave-particle-gravity' duality, or 'classical-quantum gravity' duality emerges. If Dr Sanchez's calculations are correct, it could provide a solution to the puzzle which has eluded physicists for centuries.

EMERGING RESULTS FROM GENERALISATION

Within Dr Sanchez's universal theory, wave-particle duality of known quantum physics emerges as a special case for when the right circumstances are applied, instead of being a general rule. This means that instead of being at odds with each other, both theories that light is wave-like and particle-like are simply special branches of the same, more deeply rooted theory.

This also allows for the emergence of properties including the classical-quantum duality of spacetime, whose quantum nature has remained highly elusive so far. In addition, Dr Sanchez claims that an entirely new quantum domain emerges which is not present in the classical description of spacetime – giving physicists a more complete description of its properties. Within this domain, discrete levels of space-time appear at the quantum Planck scale. On classical macroscopic scales, the collective behaviours of these levels appear indistinguishable from the space-time continuum which physicists are more familiar with.

RE-DRAWING THE LIGHT CONE

One particularly important result of Dr Sanchez's theory has been the unexpected emergence of a 'quantum light cone', which doesn't appear within a classical description of the universe. In general relativity, a light cone describes the path taken by light emerging from a single point in time and space; along with all paths taken by the light reaching the point as the flash occurs. The cone shape emerges since all light must reach the same distance from the point at a given time no matter its direction. The boundary of the cone arises because the speed of light is the highest possible velocity throughout the entire universe.

Within Dr Sanchez's theory, the new quantum light cone includes a small space between the tips of the opposite-facing cones, which are, in fact, hyperbola-shaped instead of pointed. Quantum properties then emerge within this space, in the region of time and space immediately surrounding the flash. On larger scales, where quantum effects are no longer relevant, the classical light cone re-emerges; ultimately allowing both previous theories to work in harmony with each other.

CLASSICAL-QUANTUM DUALITY IN BLACK HOLES

Finally, Dr Sanchez has applied her theory of classical-quantum duality to black holes, whose inner workings are masked by an 'event horizon' from which light cannot escape. So far, this has meant that the physical nature of black hole interiors has completely eluded astronomers.

According to Dr Sanchez, the outer regions of black holes are either classical or semi-classical, while the behaviours of their interiors are totally governed by quantum mechanics. The event horizon disappears at the quantum level, a 'quantum border' emerges at which the interiors and exteriors of black holes become the same on quantum scales. Moreover, the classical space-time central singularity – the point at the centre of a black hole at which curvature had been theorised to become infinite, is avoided in this case. According to Dr Sanchez, the singularity must disappear at the quantum level, to remain consistent with the smearing of singularities on quantum scales.

A TRANSFORMATION IN UNDERSTANDING

Over the past decades, potential solutions to quantum gravity and several types of mathematical dualities have been hotly debated, and it has remained uncertain whether or not our fundamental understanding of physics needs to be completely rethought. But Dr Sanchez understood that is the physical and universal wave-particle duality of quantum physics which is at the root of the solution. Ultimately, a unified idea of the quantum nature of astronomical-scale phenomena could transform our understanding of how the universe works, and would set the stage for an exciting new era of theoretical physics and cosmology.

One particularly important result of Dr Sanchez's theory has been the unexpected emergence of a 'quantum light cone'.

Behind the Research

Prof Dr Norma G. Sanchez

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Research Objectives

Prof Dr Norma Sanchez's theory unifies quantum mechanics with Einstein's general relativity.

Detail

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France

Bio

Prof Dr Norma G. Sanchez is director of research at the French National Centre for Scientific Research and director of the International School Daniel Chalonge – Hector de Vega. Her first work was on the scattering and absorption theory by black holes and Hawking radiation, she obtained for the first time the whole absorption spectrum of the back hole, (French These d'Etat, 1978), connected Einstein equations to other known non-linear theories and their solutions, developed new approaches to quantum fields and strings in curved space-times and found new physical effects. Norma does research in Physical Cosmology, Theoretical Physics, The Standard Model of the Universe from the early to the late universe, with Inflation, the CMB and primordial gravitons, Warm Dark Matter, Dark Energy and quantum physics.

References

Sanchez, N.G. (2019). New Quantum Structure of Space-Time. *Gravitation and Cosmology*, 25(2), 91-102.

The present article is one from a trilogy published by the author in 2019 on the subject, and from which much more developments are going on:
Sanchez, N.G. (2019). The classical-quantum duality of nature including gravity. *International Journal of Modern Physics* D28, No. 03, 1950055.

Personal Response

What do you find most inspiring about your work?

> " The fact that it is a creative, endless work with total freedom, motivated by true advance and discovery beyond current knowledge. "

The corresponding **complete** temperature being :

$$T_{QG} = t_P \, \kappa_{QG}/(2\pi\kappa_P), \quad T_Q = t_P^2/T_G, \quad t_P = m_P c^2/(8\pi\kappa_B)$$

$$T_{QG} = \frac{T_G}{[\, 1 + (T_G/t_P)^2 \,]} = \frac{T_Q}{[\, 1 + (T_Q/t_P)^2 \,]}$$

below) and the corresponding *complete* entropy. The Temperature is a measure of the length

(in units of κ_B), $T_G = t_P \ (L_G/l_P)$, $T_Q = t_P \ (L_Q/l_P)$, while the gravitational entropy is a

measur

$$S_{QFT} \ = \ s_P \ (L/l_P)^3 \ => \ n$$

$$S_G \ = \ s_P \ (L/l_P)^2 \ = \ M^2 \ => \ (\sqrt{n})^2$$

$$S_{string} \ = \ s_P \ (L/l_P) \ = \ M \ => \ \sqrt{n}$$

$$S_Q \ = \ s_P \ (l_P/L)^2 \ = \ M^{-2} \ => \ 1/(\sqrt{n})^2$$

and the corresponding *complete* entropy. The Temperature is a measure o

its of κ_B), $T_G = t_P\,(L_G/l_P)$, $T_Q = t_P\,(L_Q/l_P)$, while the gravitational e

re of the area. In this respect, is interesting to notice that:

$$S_{QFT} \;=\; s_P\,(L/l_P)^3 \;=>\; n$$

$$S_G \;=\; s_P\,(L/l_P)^2 \;=\; M^2 \;=>\; (\sqrt{n})^2$$

$$S_{string} \;=\; s_P\,(L/l_P) \;=\; M \;=>\; \sqrt{n}$$

$$S_Q \;=\; s_P\,(l_P/L)^2 \;=\; M^{-2} \;=>\; 1/(\sqrt{n})^2$$

The total gravitational entropy S_{QG} of the total or complete (classical and quantum) black hole euclidean manifold, is the sum of the classical, quantum and Planck scale entropies:

$$P_{QG} \;=\; e^{\,S_{QG}} \tag{6.4}$$

$$S_{QG} \;=\; 2\,[\,s_P + \frac{1}{2}\,(\,S_G + S_Q\,)\,], \tag{6.5}$$

$$S_G = \frac{\kappa_B}{4}\,\frac{A_G}{l_P^2}, \qquad S_Q = \frac{\kappa_B}{4}\,\frac{A_Q}{l_P^2}, \qquad s_P = \frac{\kappa_B}{4}\,\frac{a_P}{l_P^2} = \pi\kappa_B, \tag{6.6}$$

The concept of gravitational entropy is *the same* for any of the gravity regimes: $Area/4l_P^2$ in units of k_B. For a classical object of size L_G, this is the classical area $A_G = 4\pi L_G^2$. For a quantum object of quantum size L_Q, this is the quantum area $A_Q = 4\pi L_Q^2$, (recall $L_Q = l_P^2/L_G$). For the Planck length, this is the Planck area a_P and $s_P = \pi\kappa_B$ is the Planck entropy :

$$A_G = a_P\left(\frac{L_G}{l_P}\right)^2, \qquad A_Q = a_P\left(\frac{l_P}{L_G}\right)^2 = \frac{a_P^2}{A_G}, \qquad a_P = 4\pi\, l_P^2 \tag{6.7}$$

$$S_G = s_P\,\frac{\rho_Q}{\rho_P} \;=\; s_P\,\left(\frac{M}{m_P}\right)^2 \tag{6.8}$$

$$S_Q = s_P\,\frac{\rho_G}{\rho_P} \;=\; s_P\,\left(\frac{m_P}{M}\right)^2 \tag{6.9}$$

The *complete* entropy is:

$$S_{QG} \; = \; = \; 2\, s_P \,[\, 1 \; + \; \frac{1}{2} \,(\; A_G \; + \; A_Q \;)\,]$$

and consistently, the complete partition function is

$$\mathcal{Z}_{QG} \; = \; e^{\,S_{QG}} \; = \; z_P \, \mathcal{Z}_Q \, \mathcal{Z}_G$$

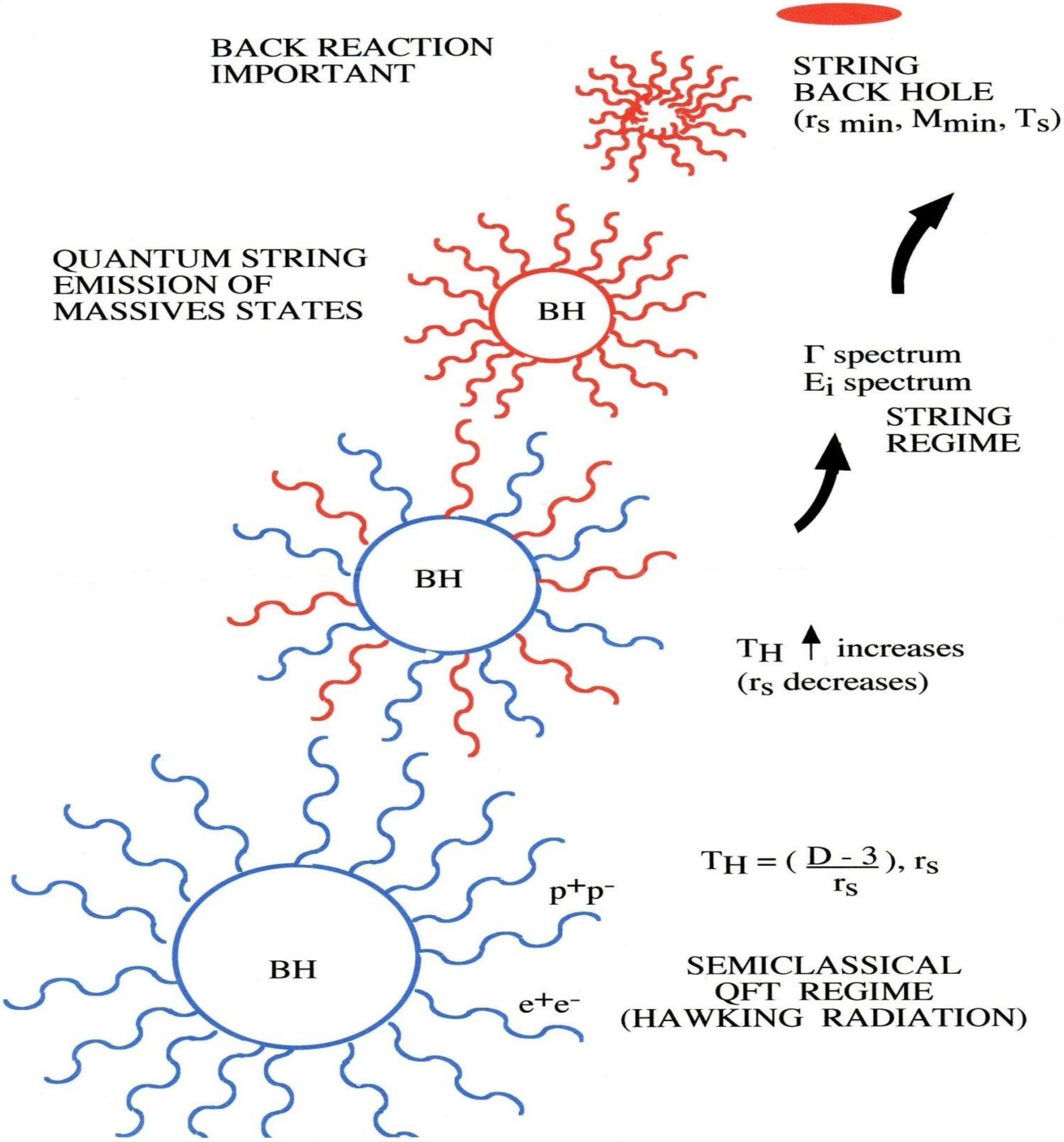
The respective associated mass levels are:

$$M_n = \sqrt{(2n+1)}, \qquad M_{Qn} = 1/\sqrt{(2n+1)}$$

The density of states in the classical and quantum gravity phases are thus

$$d_{Gn} = \exp\;(2n+1) = \exp\;(M_n)^2, \qquad d_{Qn} = \exp\;[1/(2n+1)] = \exp\;(M_{Qn})^2$$

$$d_{QGn} = \exp\;[(2n+1) + 1/(2n+1)] = \exp\;[M_n^2 + \; M_{Qn}^2]$$



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)

$T_H = \left(\frac{D-3}{r_s}\right), r_s$

p^+p^-

BH

e^+e^-

SEMICLASSICAL
QFT REGIME
(HAWKING RADIATION)

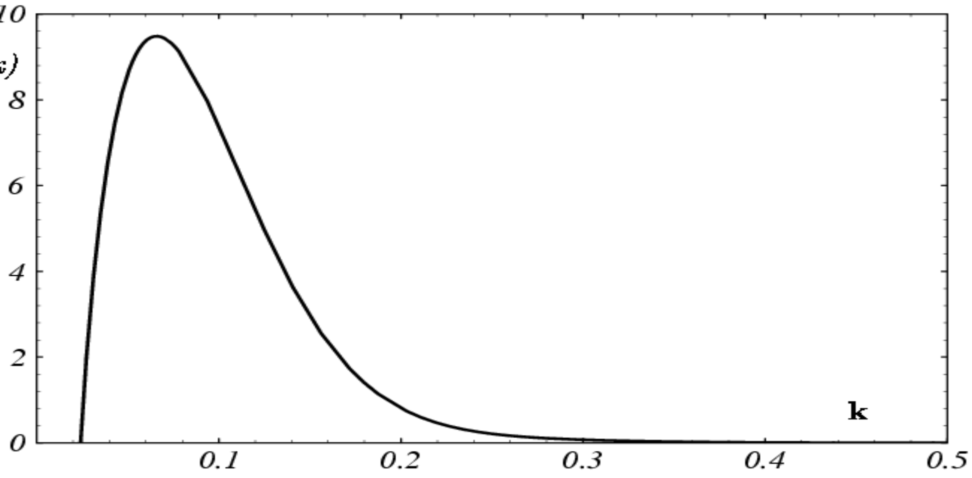


Figure 1: EMISSION BY A BLACK HOLE

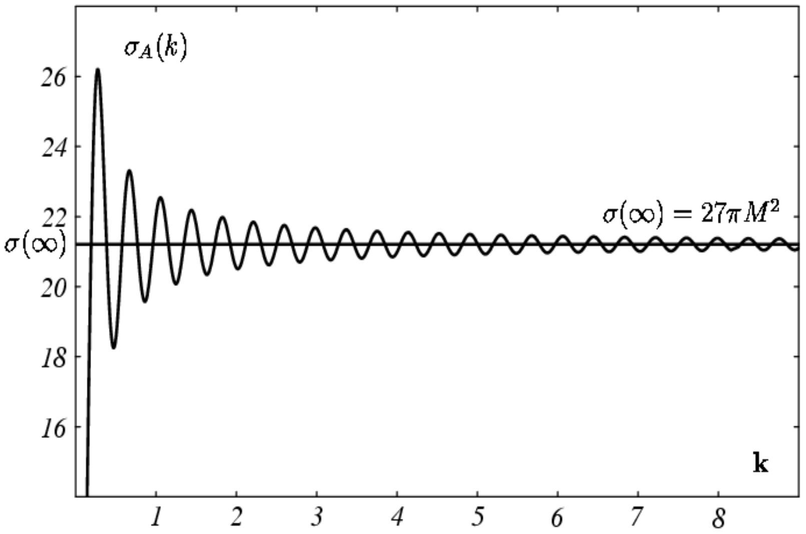


Figure 2: ABSORPTION BY A BLACK HOLE

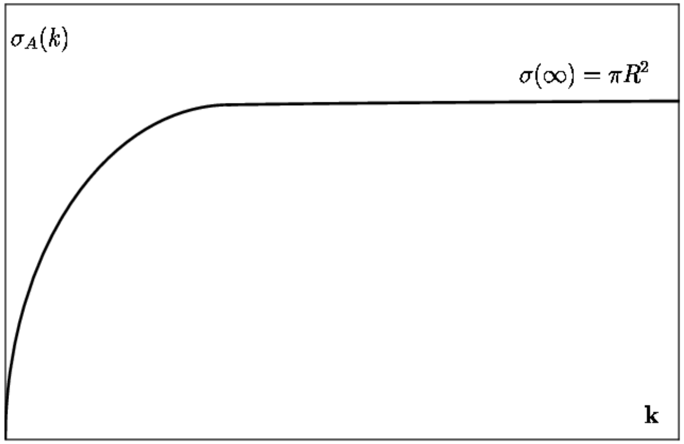


Figure 3: ABSORPTION BY A MATERIAL SPHERE WITH A COMPLEX REFRACTION INDEX

$$\sigma_A(k) = 27\pi M^2 - 2\sqrt{2}M\frac{\sin(2\sqrt{27}\pi kM)}{k} \quad , \qquad kM \ \geq 0.07 \qquad (2$$

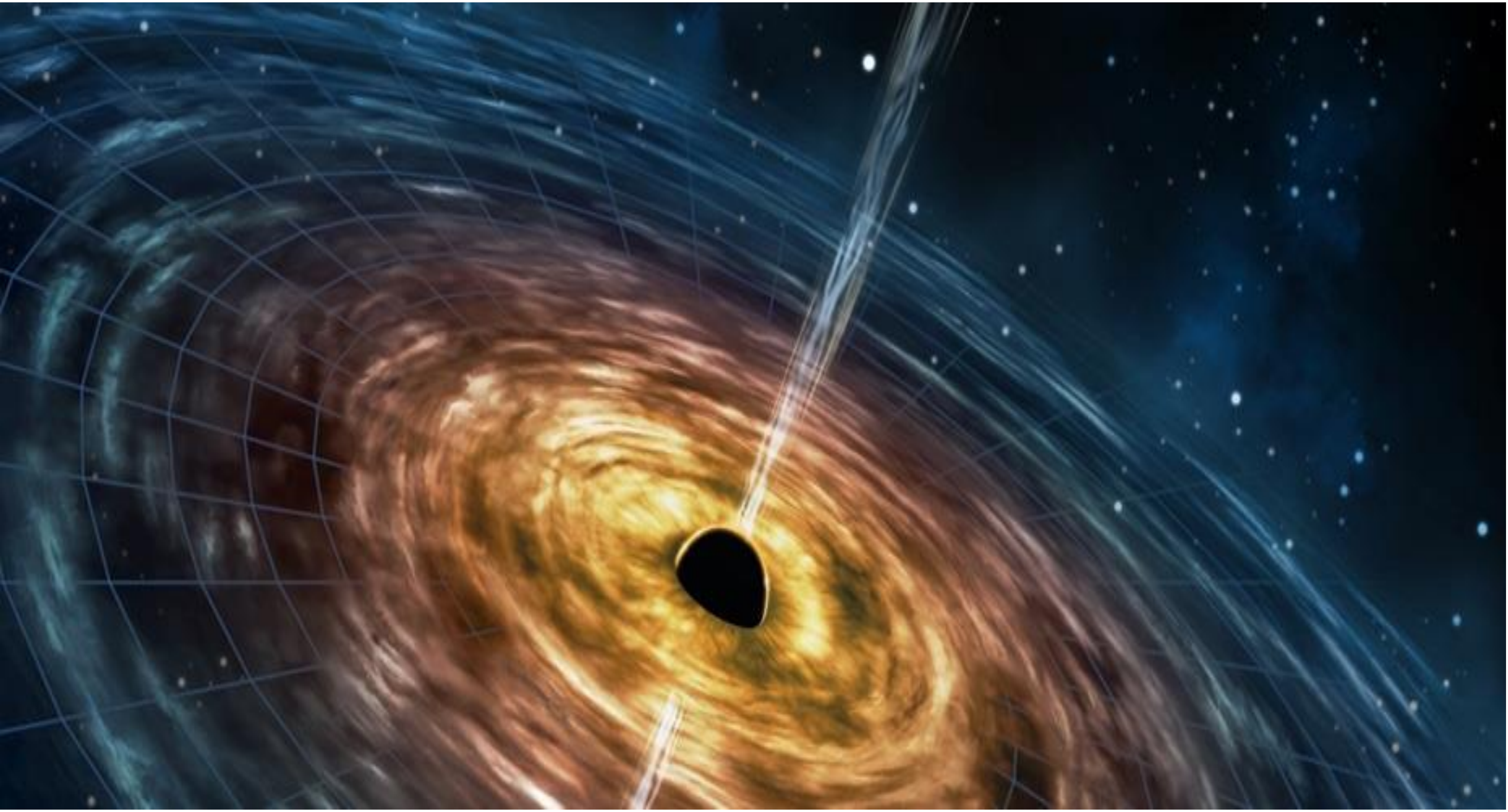
$$\sigma_A(0) = 16\pi M^2$$

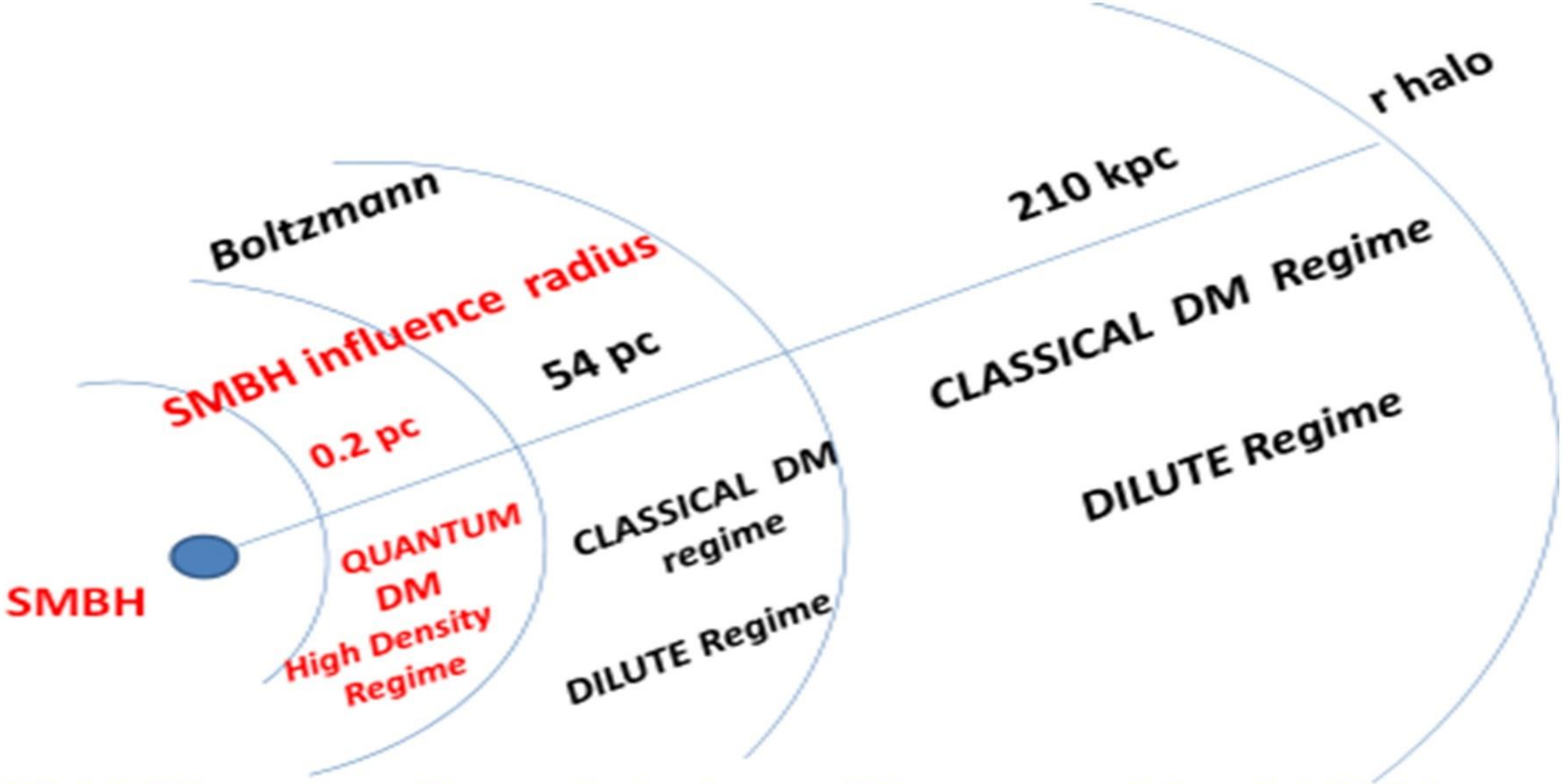
The absorption spectrum presents, as a function of the frequency, a remarkable oscillatory behaviour characteristic of a diffraction pattern (Fig.2). It osci
lates around its constant geometrical optics value $\sigma(\infty) = 27\pi M^2$ with decreasin
amplitude (as $\frac{1}{(\sqrt{2}kM)}$) and constant period ($\frac{2}{3}\sqrt{3}$). The value of $\sigma_A(0)$ is exactl
given by $16\pi M^2$. See below.

We have also calculated the Hawking radiation. This is only important i
the interval $0 \leq k \leq \frac{1}{M}$. The emission spectrum (Fig.1) does not show any
the interference oscillations characteristic of the absorption cross section, becaus
the contribution of the S-wave dominates the Hawking radiation. The rapidl
decrease of the Planck factor for $kM \ \geq 1$ supresses the contribution of highe
partial waves.

Thus, for a black hole the emission follows a planckian spectrum, given b

CENTRAL SUPERMASSIVE BLACK-HOLE GALAXY *SYSTEMS*





r halo

210 kpc

Boltzmann

SMBH influence radius

54 pc

0.2 pc

CLASSICAL DM Regime

DILUTE Regime

CLASSICAL DM regime

DILUTE Regime

QUANTUM DM High Density Regime

SMBH

WDM Thomas-Fermi Galaxy Theory with SMBH

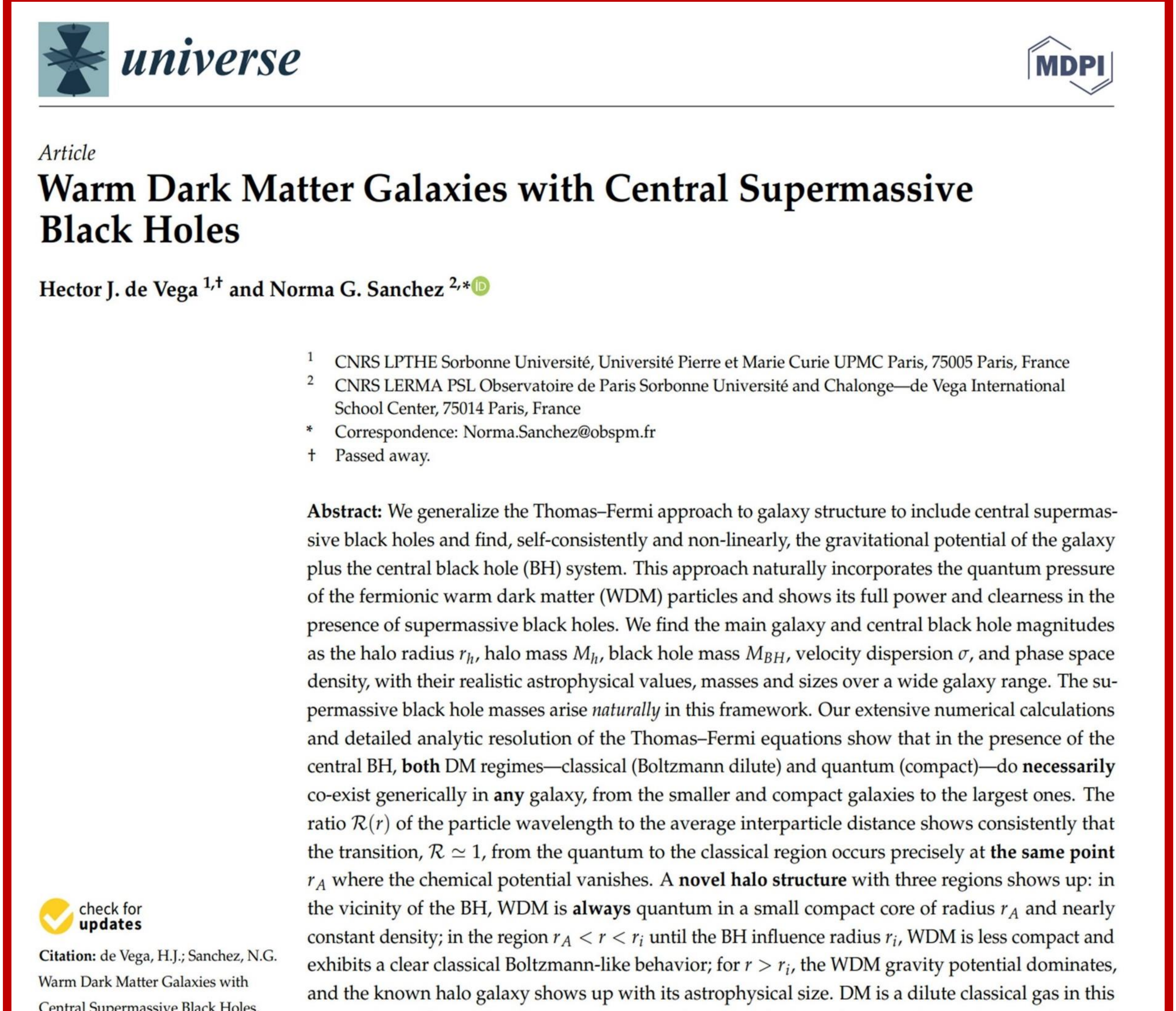
SMBH: Super Massive Black holes

H.J. de Vega & N.G. Sanchez

Warm Dark Matter Galaxies with Central Supermassive Black Holes

Universe 2022, 8, 154.

https://doi.org/10.3390/universe8030154



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Article

Warm Dark Matter Galaxies with Central Supermassive Black Holes

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Abstract: We generalize the Thomas–Fermi approach to galaxy structure to include central supermassive black holes and find, self-consistently and non-linearly, the gravitational potential of the galaxy plus the central black hole (BH) system. This approach naturally incorporates the quantum pressure of the fermionic warm dark matter (WDM) particles and shows its full power and clearness in the presence of supermassive black holes. We find the main galaxy and central black hole magnitudes as the halo radius r_h, halo mass M_h, black hole mass M_{BH}, velocity dispersion σ, and phase space density, with their realistic astrophysical values, masses and sizes over a wide galaxy range. The supermassive black hole masses arise *naturally* in this framework. Our extensive numerical calculations and detailed analytic resolution of the Thomas–Fermi equations show that in the presence of the central BH, **both** DM regimes—classical (Boltzmann dilute) and quantum (compact)—do **necessarily** co-exist generically in **any** galaxy, from the smaller and compact galaxies to the largest ones. The ratio $\mathcal{R}(r)$ of the particle wavelength to the average interparticle distance shows consistently that the transition, $\mathcal{R} \simeq 1$, from the quantum to the classical region occurs precisely at **the same point** r_A where the chemical potential vanishes. A **novel halo structure** with three regions shows up: in the vicinity of the BH, WDM is **always** quantum in a small compact core of radius r_A and nearly constant density; in the region $r_A < r < r_i$ until the BH influence radius r_i, WDM is less compact and exhibits a clear classical Boltzmann-like behavior; for $r > r_i$, the WDM gravity potential dominates, and the known halo galaxy shows up with its astrophysical size. DM is a dilute classical gas in this

check for updates

Citation: de Vega, H.J.; Sanchez, N.G. Warm Dark Matter Galaxies with Central Supermassive Black Holes.

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MDPI

Article

Galaxy Phase-Space Density Data Preclude That Bose–Einstein Condensate Be the Total Dark Matter

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† Passed away https://chalonge-devega.fr/HdeV.html.

Abstract: Ultralight scalars with a typical mass of the order $m \sim 10^{-22}$ eV and light scalars forming a Bose–Einstein condensate (BEC) exhibit a Jeans length in the kpc scale and were therefore proposed as dark matter (DM) candidates. Our treatment here is generic, independent of the particle physics model and applies to all DM BEC, in both in or out of equilibrium situations. Two observed quantities crucially constrain DM in an inescapable way: the average DM density ρ_{DM} and the phase-space density Q. The observed values of ρ_{DM} and Q in galaxies today constrain both the possibility to form a BEC, and the DM mass m. These two constraints robustly exclude the axion DM that decouples after inflation. Moreover, the value $m \sim 10^{-22}$ eV can only be obtained with a number of ultrarelativistic degrees of freedom at decoupling in the trillions, which is impossible for decoupling in the radiation dominated era. In addition, we find for the axion vacuum misalignment scenario that axions are produced strongly out of thermal equilibrium and that the axion mass in such a scenario turns to be **17 orders of magnitude** too large to reproduce the observed galactic structures. Moreover, we also consider inhomogenous gravitationally bounded BEC's supported by the bosonic quantum pressure independently of any particular particle physics scenario. For a typical size $R \sim$ kpc and compact object masses $M \sim 10^7\ M_\odot$ they remarkably lead to the same particle mass $m \sim 10^{-22}$ eV as the BEC free-streaming length. However, the phase-space density for the gravitationally bounded BEC's turns out to be more than **sixty orders of magnitude** smaller than the galaxy-observed values. We conclude that the BEC cannot be the total DM. The axion can be candidates to be only part of the DM of the universe. Besides, an axion in the mili-eV scale may be a relevant source of dark energy through the zero point cosmological quantum fluctuations.

Keywords: dark matter; axions; Bose-Einstein condensate; phase-space density; galaxy structure; galaxy data

check for updates

Citation: de Vega, H.J.; Sanchez, N.G. Galaxy Phase-Space Density Data Preclude That Bose–Einstein Condensate Be the Total Dark Matter. *Universe* **2022**, *8*, 419. https://doi.org/10.3390/universe8080419

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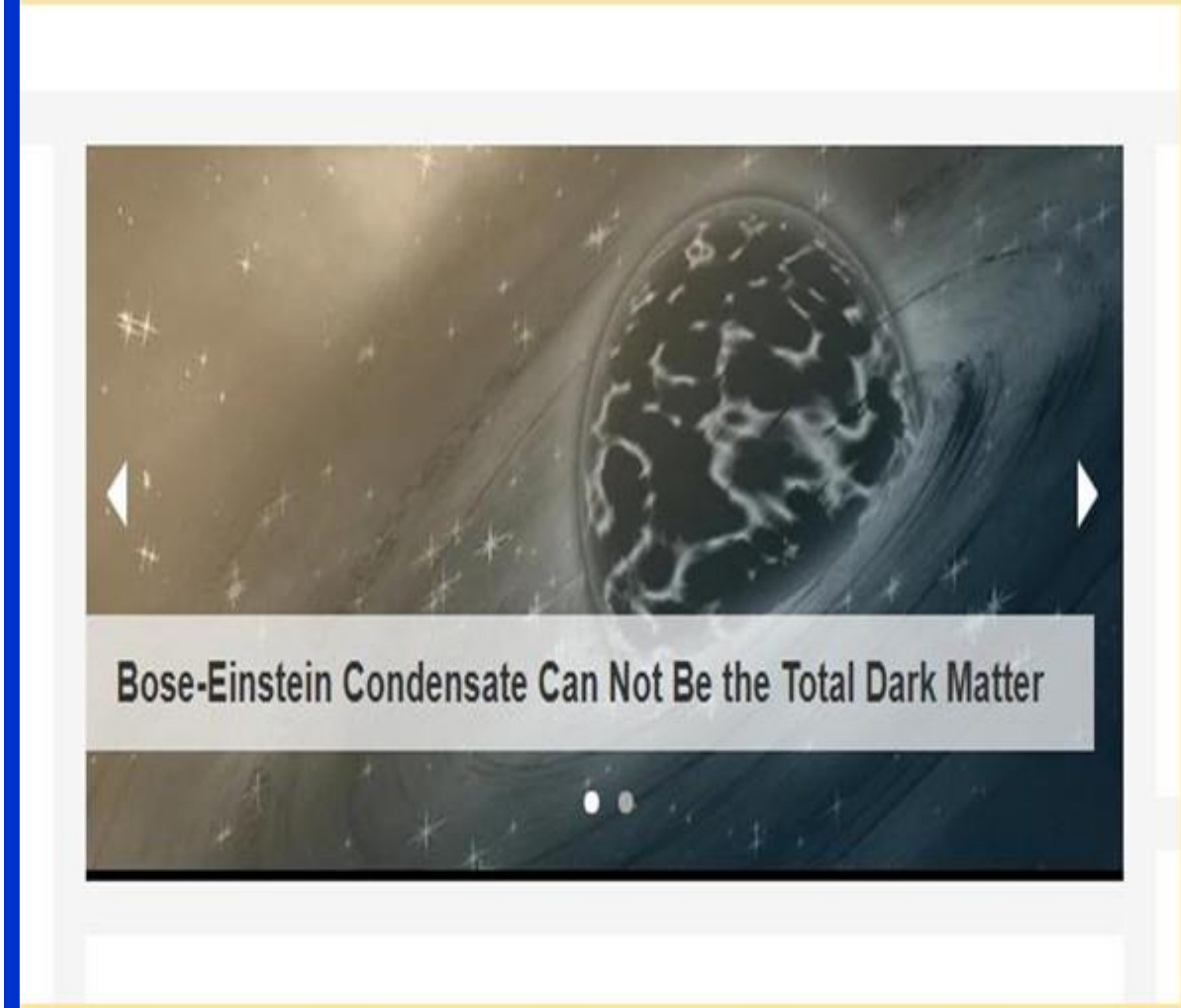

Bose-Einstein Condensate Can Not Be the Total Dark Matter

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Héctor J. de Vega, Norma G. Sanchez,

Universe 2022, 8(8), 419;

https://doi.org/10.3390/universe8080419

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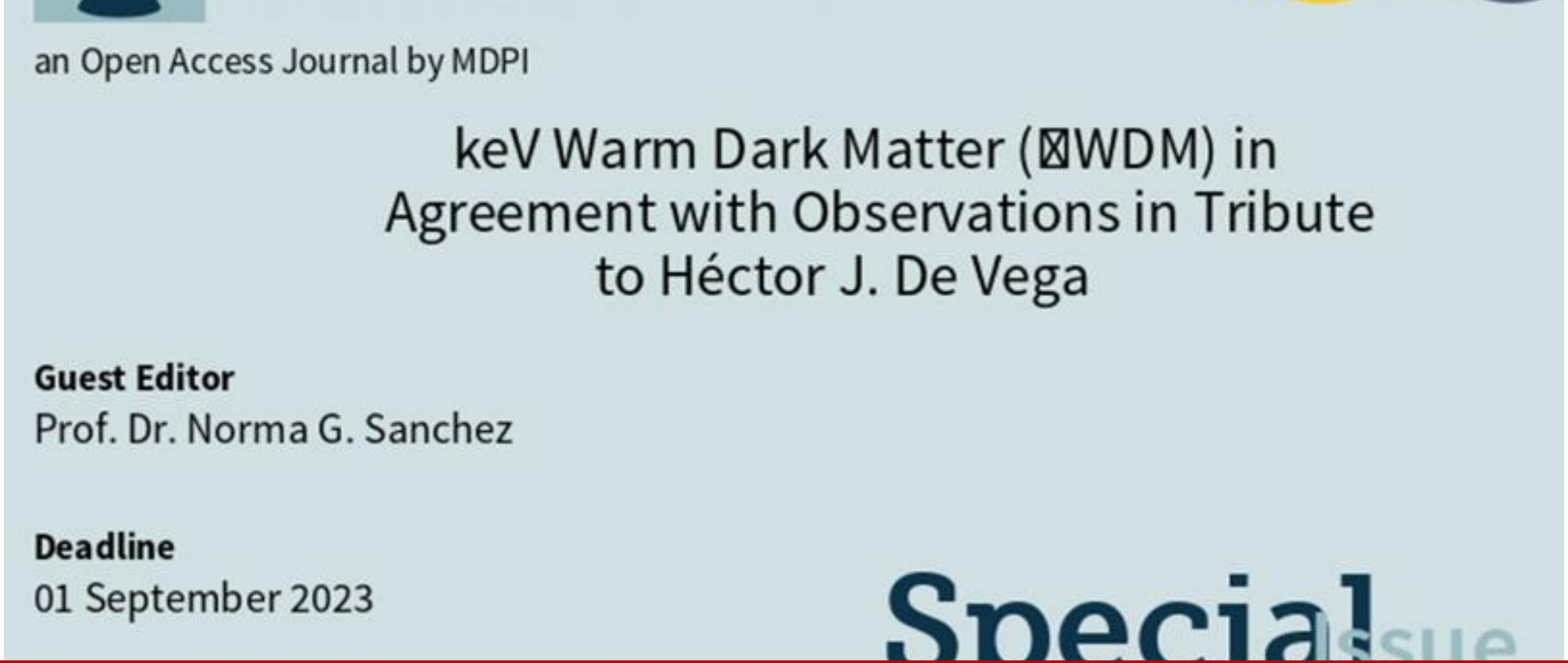

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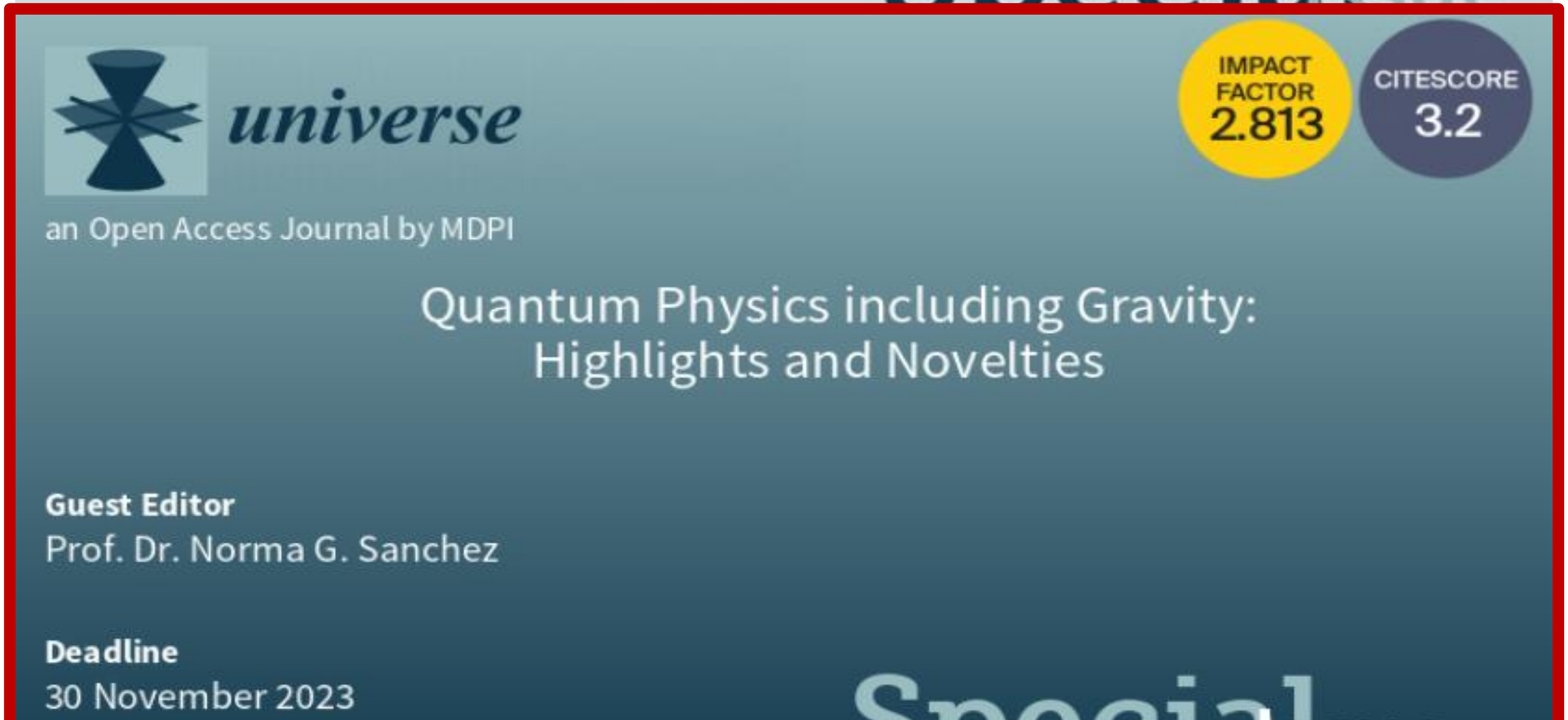

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- The H0 Award 2023

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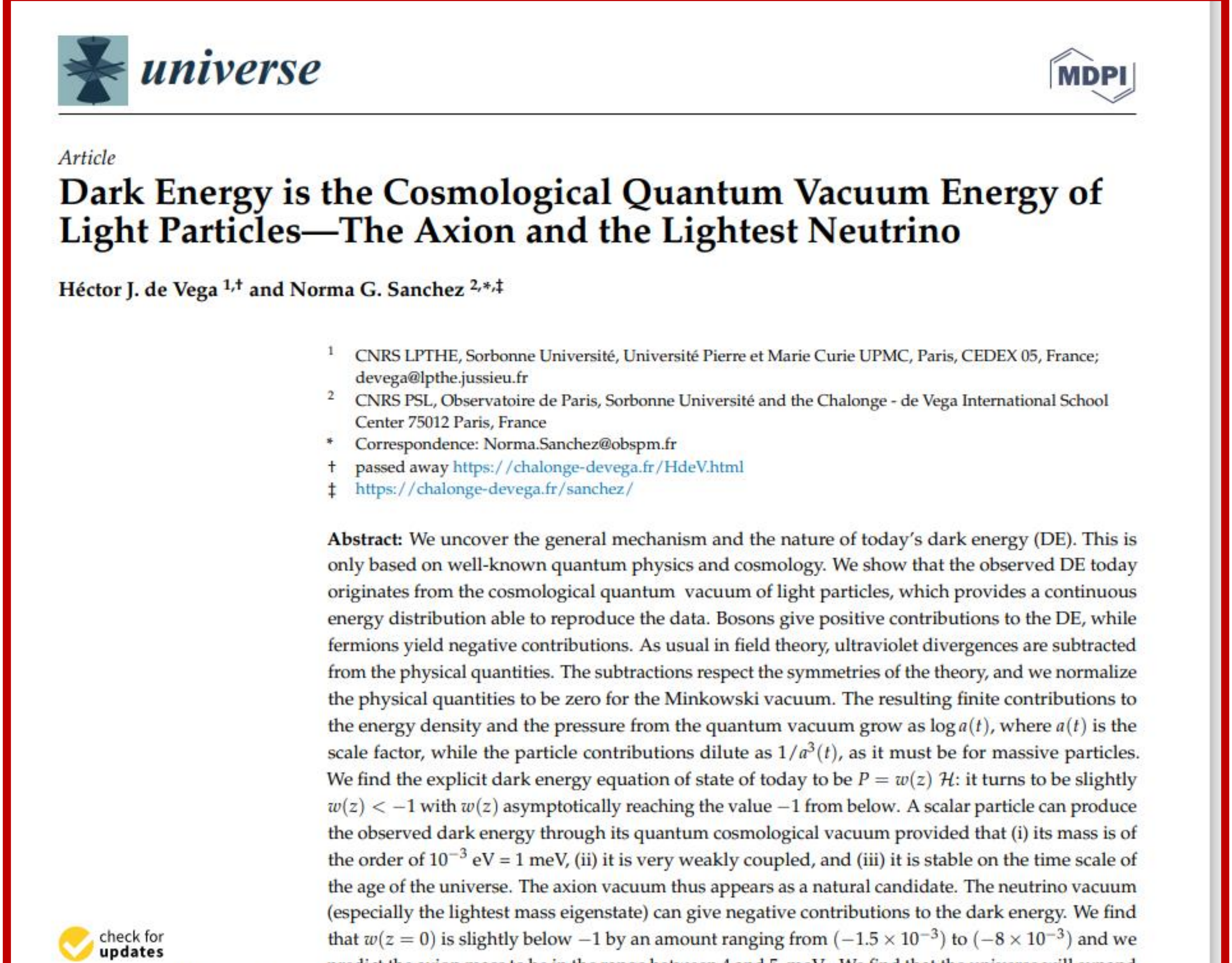

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Article

Dark Energy is the Cosmological Quantum Vacuum Energy of Light Particles—The Axion and the Lightest Neutrino

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[†] passed away https://chalonge-devega.fr/HdeV.html
[‡] https://chalonge-devega.fr/sanchez/

Abstract: We uncover the general mechanism and the nature of today's dark energy (DE). This is only based on well-known quantum physics and cosmology. We show that the observed DE today originates from the cosmological quantum vacuum of light particles, which provides a continuous energy distribution able to reproduce the data. Bosons give positive contributions to the DE, while fermions yield negative contributions. As usual in field theory, ultraviolet divergences are subtracted from the physical quantities. The subtractions respect the symmetries of the theory, and we normalize the physical quantities to be zero for the Minkowski vacuum. The resulting finite contributions to the energy density and the pressure from the quantum vacuum grow as $\log a(t)$, where $a(t)$ is the scale factor, while the particle contributions dilute as $1/a^3(t)$, as it must be for massive particles. We find the explicit dark energy equation of state of today to be $P = w(z)\ \mathcal{H}$: it turns to be slightly $w(z) < -1$ with $w(z)$ asymptotically reaching the value -1 from below. A scalar particle can produce the observed dark energy through its quantum cosmological vacuum provided that (i) its mass is of the order of 10^{-3} eV = 1 meV, (ii) it is very weakly coupled, and (iii) it is stable on the time scale of the age of the universe. The axion vacuum thus appears as a natural candidate. The neutrino vacuum (especially the lightest mass eigenstate) can give negative contributions to the dark energy. We find that $w(z=0)$ is slightly below -1 by an amount ranging from (-1.5×10^{-3}) to (-8×10^{-3}) and we

THE FUTURE OF THE UNIVERSE

$$a(t) \overset{H_0\, t \gtrsim 1}{\simeq} a_0 \exp\left[c_1\, H_0\, t + c_2\, (H_0\, t)^2\right],$$

where

$$c_1 = \sqrt{\Omega_\Lambda} = 0.87, \quad c_2 = \frac{1}{4}\, \Omega_\Lambda\, \beta_N = 0.19\, \beta_N,$$

$$0.00452 < c_2 < 0.00872.$$

In this accelerated universe, Equation (108) shows that the Hubble radius $(1/H)$ decreases with time as

$$\frac{1}{H} \sim \frac{1}{H_0\, \sqrt{\log a(t)}}.$$

Two key observable numbers :

associated to the primordial density and primordial gravitons :

$$n_s = 0.9608\ ,\quad r$$

PREDICTIONS

$r < 0.04$

$r > 0.021$

$$0.021 < r < 0.040$$

Most probable value: $r \sim 0.03,\ 0.04$

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