

LA ^{¿MÁS?} NOCHE DE LAS IDEAS

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CONFERENCIA

Desde el origen físico del Universo al fin de los Agujeros Negros:
una historia de 13.700 millones de años".

Dra. Norma Sánchez

Jueves 30/03 | 18h30 | Colegio Nacional Rafael Hernández | La Plata

"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 final de los agujeros negros y
sus estados remanentes.***

re image du trou noir : l'univers se dévoile

de la Terre.
 photos ont eu lieu en
 quand huit télescopes
 aux trous noirs : Sgr A*
 centre de notre voie
 lactaire, dans l'Univers,
 le dans une boîte de

ite ? Huit mois de
 n de ce type d'opéra-
 tions, les observations
 l'aveugle, les astro-
 nautiques moyen de sa-
 à fonctionner. Il aura
 être de déboucher un
 man à travers les télesco-
 piques, dans l'Univers,
 le dans une boîte de

en de travail a été
 pour remanier les
 photos. « Pour plus de
 travail a été fait quatre
 autre équipes différen-
 tes Frédéric Gueth,
 deux des études.

aren du « Seigneur
 et »
 ge du trou noir, depuis
 ps recherché, si sou-
 vent - et aussi tenté
 l'objet de six articles
 accord dans la revue
 Journal Letters. Et
 avant la même image,
 entre sur un halo noir
 du trou noir sur le
 maître qui l'entoure.

révélation, cette pho-
 tographie parler. Beau-
 coup d'années à l'amen-
 ce trou noir avec l'au-
 tre du « Seigneur des
 Ringes Sauron.

50 millions d'années-
 lumière continue de
 ...
 T.L. (avec AFP)

angeté

armes, ce que vous
 pas forcément où
 et. Un objet peut ap-
 parître ou disparaître.
 marée est tellement
 qu'un astronaute qui
 vers l'horizon d'un
 serait transformé en
 une pluie d'étoiles.
 temps qui se dilate, et
 qui se dilate vers le
 qu'il devient invisible.
 pour l'instant qui re-
 chaise de ce même
 aussi l'impression
 venir d'être passé
 de s'échapper 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/EAFF

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 avait fallu attendre le début du XX^e siècle et la théorie de la relativité générale d'Einstein pour que les trous noirs rejoignent le domaine cosmologique. Le chemin de la reconnaissance a toutefois été long. Einstein lui-même n'y croyait pas. C'est 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, sans observation directe, leur existence restait jusqu'à présent purement théorique.

Des preuves indirectes
 Depuis nos premières découvertes, 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 armés de disques d'accrétion tournant à des vitesses vertigineuses, et d'où s'échappent lentement de gigantesques jets de radiations. Leur présence peut également être trahie par l'effet de lentille gravitationnelle, qui peut déformer 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.

PHOTO: V.L.

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

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.



Photo DR

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 au siècle plus tard. Nous avons fait des progrès, heureusement !

Pouvez-vous 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.

Résumé 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.

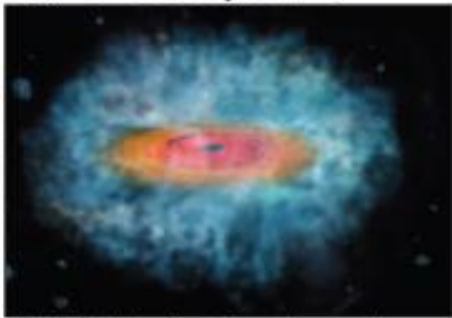
PHOTO: V.L.

Un trou noir, c'est quoi ?

Pour comprendre ce qu'est un trou noir, imaginez que vous devez envoyer une lettre dans l'espace. Pour parvenir, il vous faut 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 23,5 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 attein-



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

dre 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 libé-

ration 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 le bord est baptisé l'« horizon des événements ».

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 ce dernier, une masse équivalente à celle de la Terre tendrait dans le volume d'une noix sèche.
 D'autres trous noirs auraient une densité proche de celle de l'eau, mais compensent 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 Sagittaire 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 LAHIRE

Quantum Trans-Planckian Physics inside Black Holes and its Spectrum

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(Dated: January 6, 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. Black hole **interiors** are always **quantum**, trans-Planckian and of constant curvature: This is so for *all* black holes, macroscopic and astrophysical ones. The quantum hyperbolae $(X^2 - T^2) = \pm 1$ (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 $(BH)_{QG}$

(in Planck units) replace the classical $\chi = \pm 1$ 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 $m_{n\pm} = m_P [\sqrt{2n+1} \pm \sqrt{2n}]$, $n = 0, 1, 2, \dots$, 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 Schwarzschild-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.

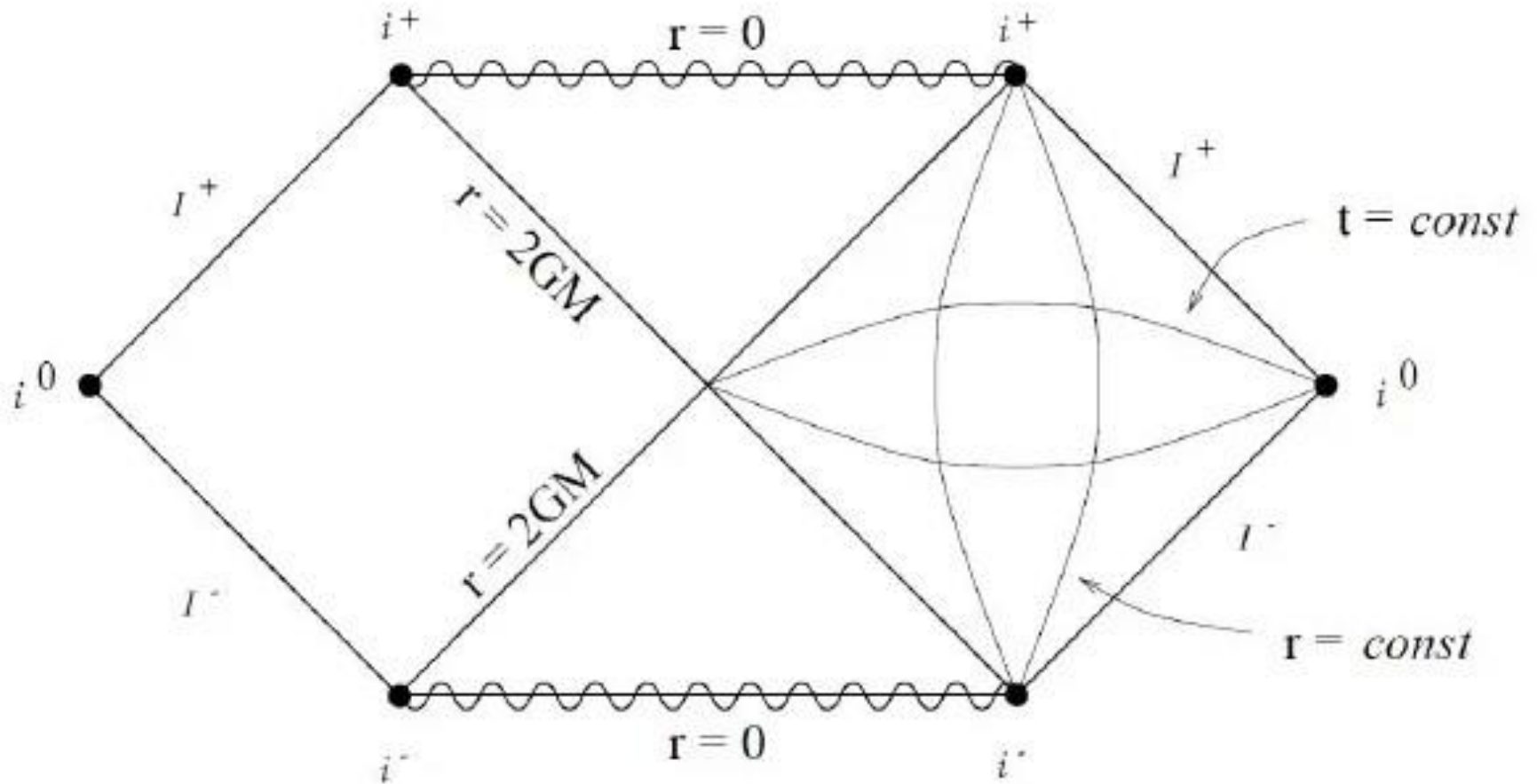
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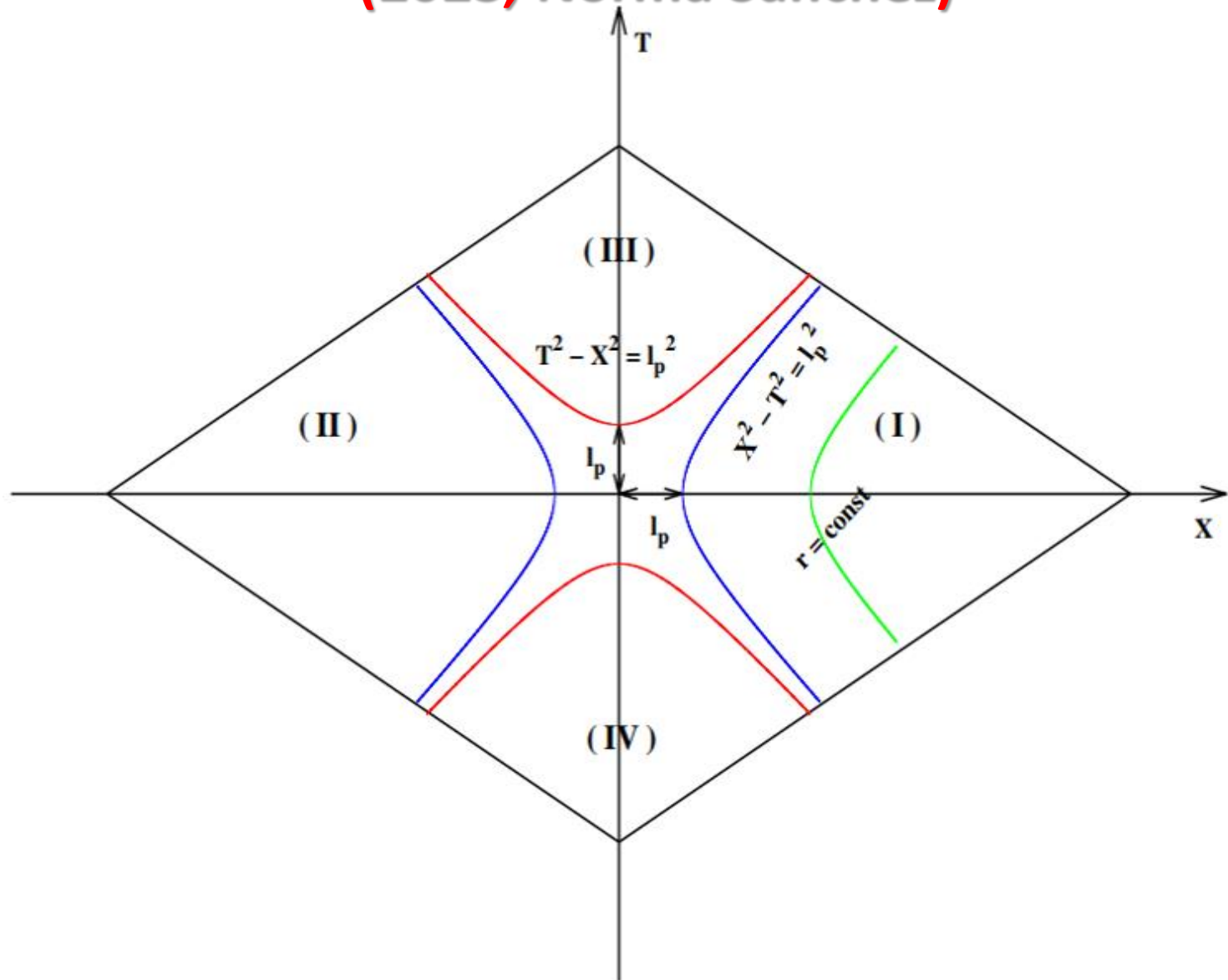
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The (CLASICAL) BLACK HOLE PENROSE DIAGRAM (1967, Roger Penrose)



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



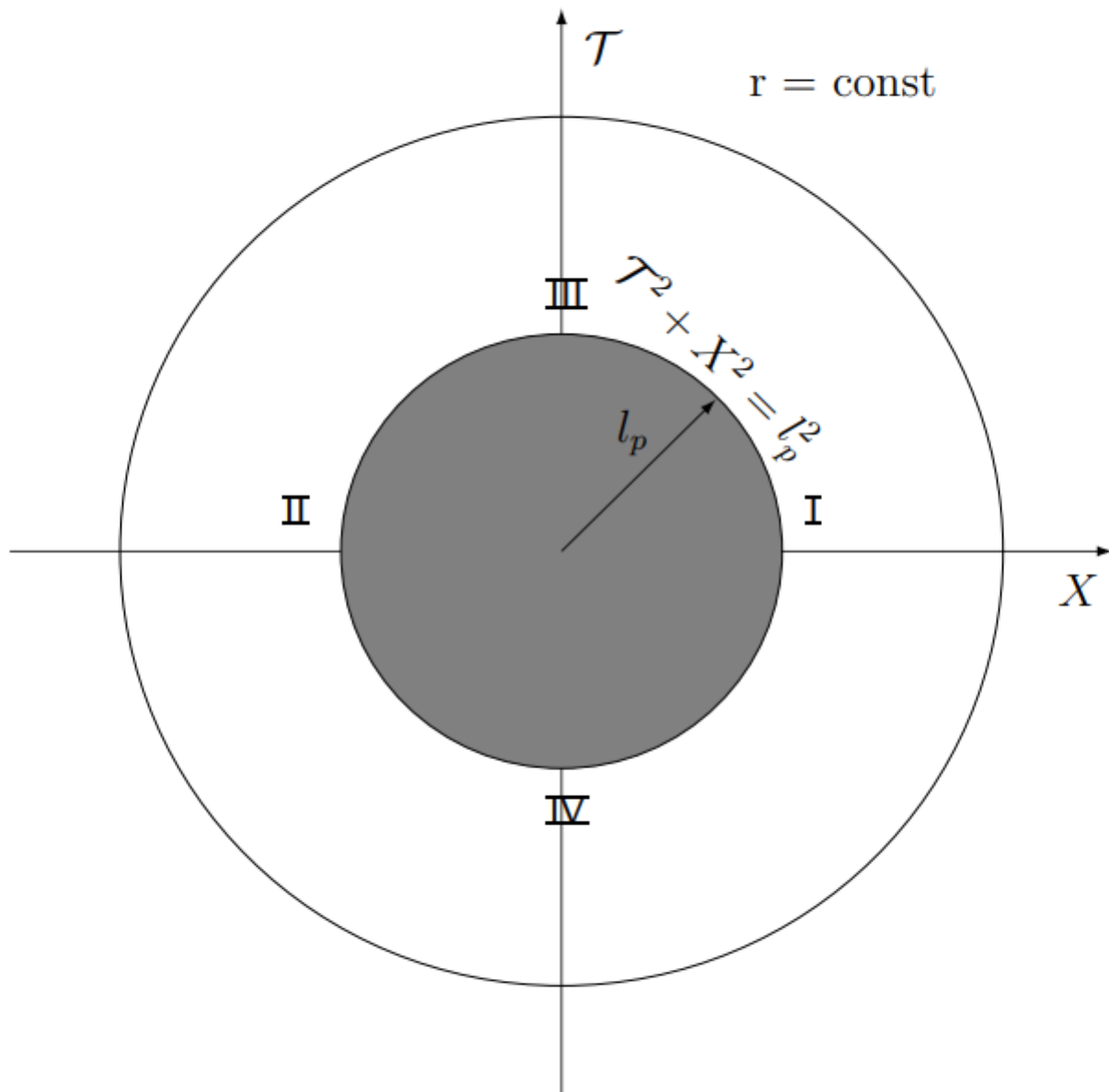
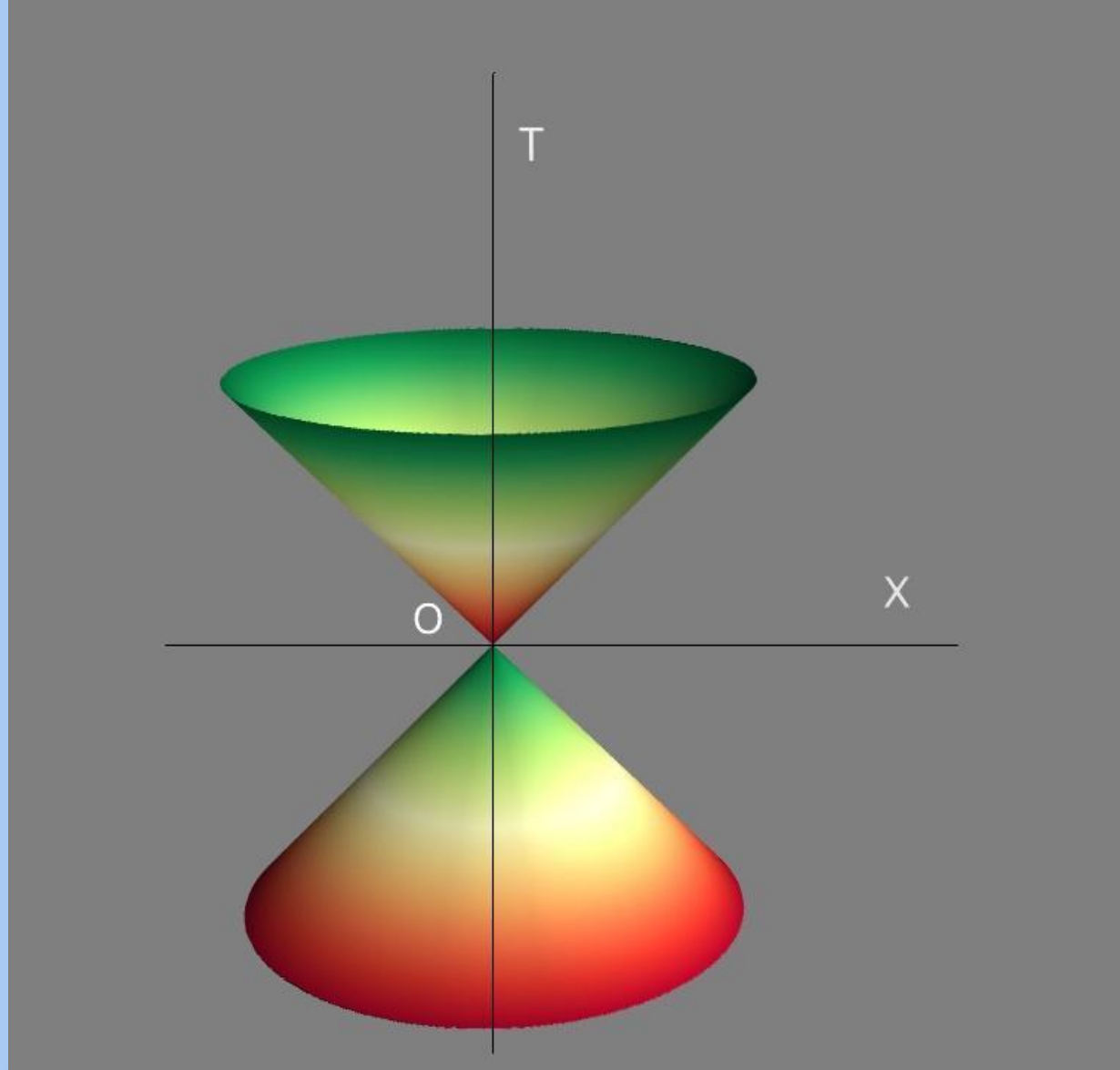
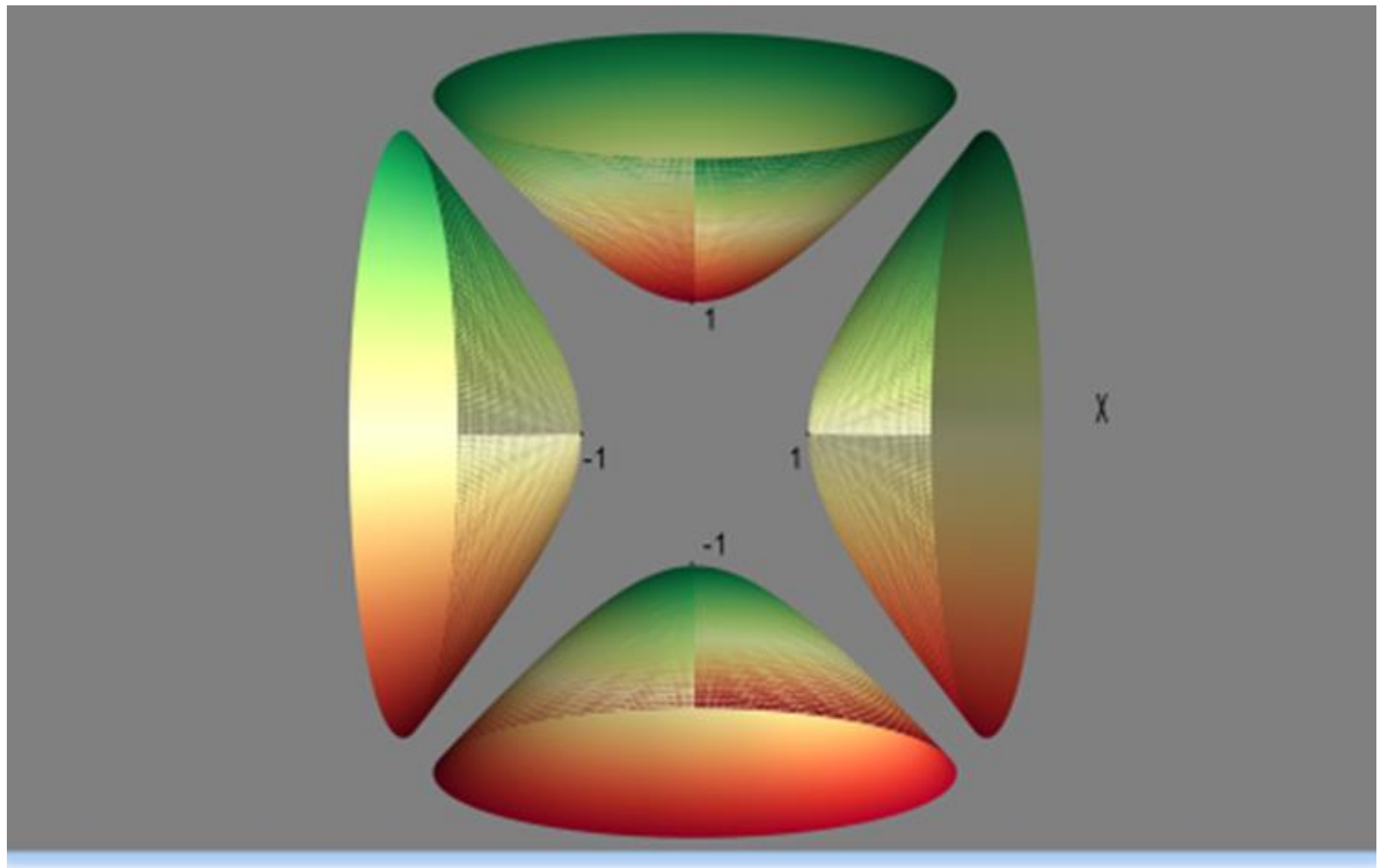


FIG. 2. The quantum gravitational instanton of the Schwarzschild-Kruskal black hole (imaginary time: $T = i\mathcal{T}$, $t = i\tau$). The classical null horizons corresponding to the

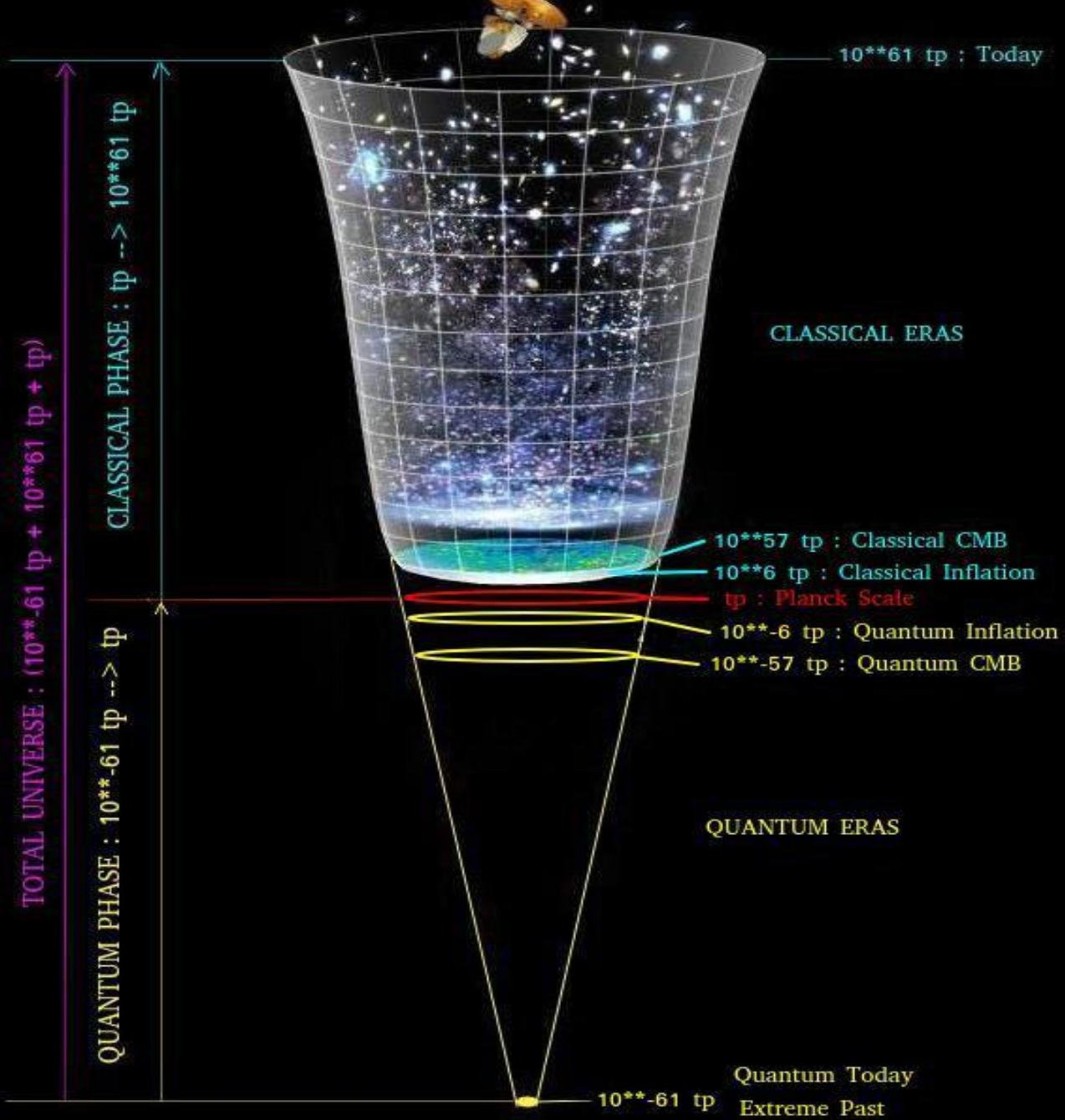


The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of the Quantum light -cone

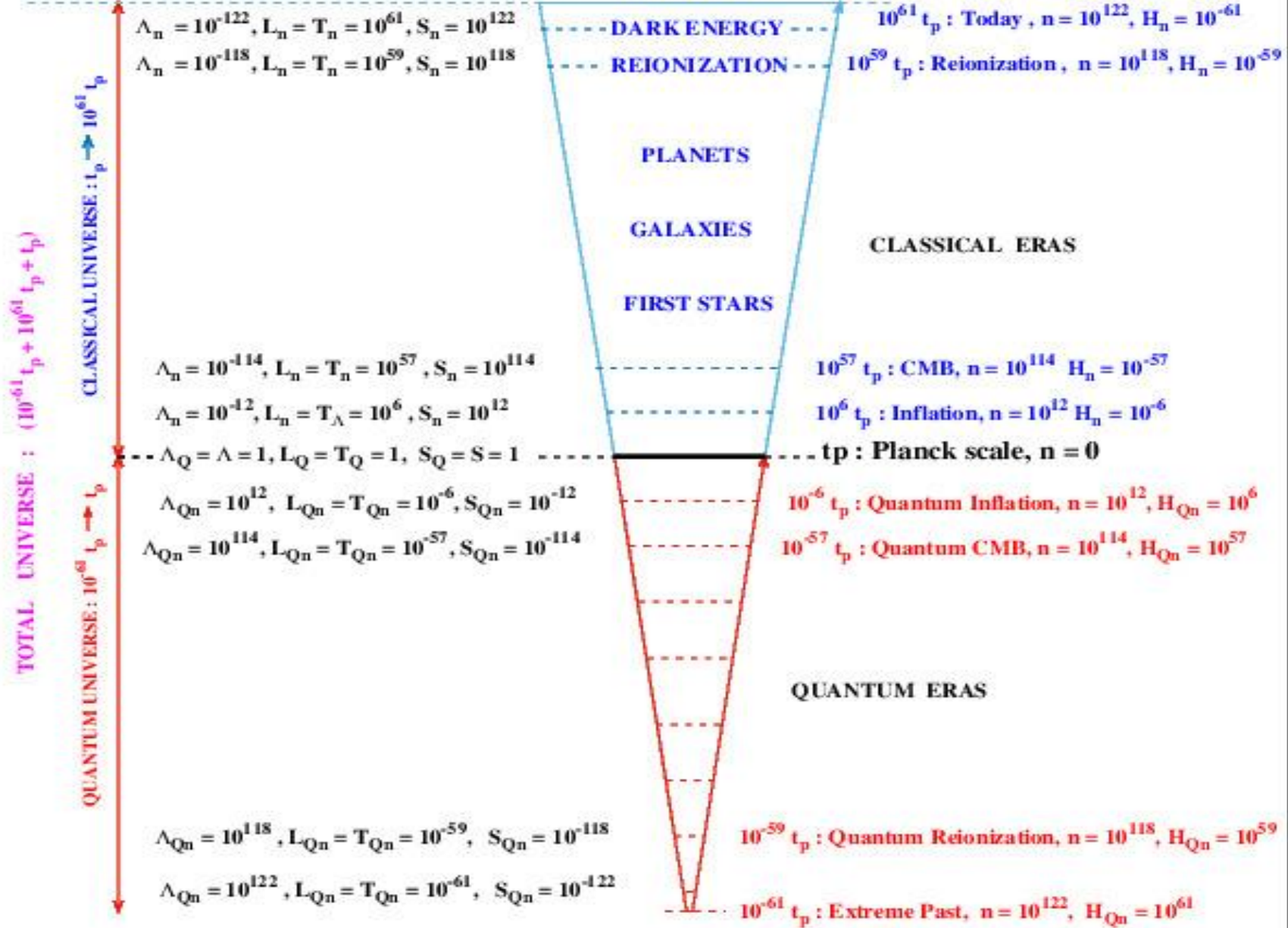


The quantum light-cone in a space-time diagram (time is the vertical axis).

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THE TOTAL HISTORY OF THE UNIVERSE



QUANTUM DISCRETE LEVELS OF THE UNIVERSE AND THEIR TOTAL HISTORY

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 $n = 0, 1, 2, \dots$, the two post- and pre-(trans)-Planckian phases are covered: In the post-Planckian Universe $t_{\text{planck}} \equiv t_P \leq t \leq 10^{61} t_P$, 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 $H_{\text{planck}} = 1 = \Lambda_{\text{planck}} = S_{\text{planck}}$ and enters the post-Planckian phase, e.g., $n = 1, 2, \dots$, $n_{\text{inflation}} = 10^{12}, \dots$, $n_{\text{cmb}} = 10^{114}, \dots$, $n_{\text{reoin}} = 10^{118}, \dots$, and $n_{\text{today}} = 10^{122}$, with the most classical value $H_{\text{today}} = 10^{-61}$, $\Lambda_{\text{today}} = 10^{-122}$, and $S_{\text{today}} = 10^{122}$. 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.

THE QUANTUM STRUCTURE OF THE SPACE-TIME

- THE CLASSICAL - QUANTUM DUALITY OF NATURE :

- $O_G = O_P^2 / O_Q$, $L_G = I_P^2 / L_Q$, $L_G = 2GM / c^2$, $L_Q = h / Mc$

- THE SPACE TIME (X, T) Coordinates as

- QUANTUM NON COMMUTING OPERATORS : $[X, T] = 1$

- ° THE SPACE-TIME AS a QUANTUM HARMONIC OSCILLATOR :

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

P = iT :

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

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".*

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

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

the quantum light cone

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

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 Christian 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

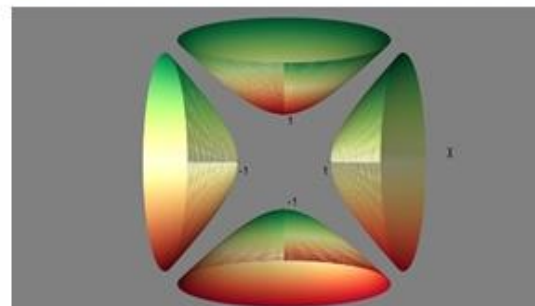


Fig. 1: The quantum light-cone in a space-time diagram (time is the vertical axis). Copyright Norma Sanchez

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.

THE INCOMPLETENESS OF GRAVITY

Again, first described by Newton, the

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

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

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 preemptively given the name 'quantum gravity'. In her research, Dr Sanchez aims to realise such a theory, in which

scales where gravity and quantum effects are of the same importance.

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

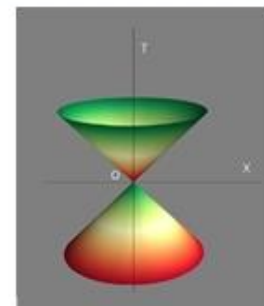
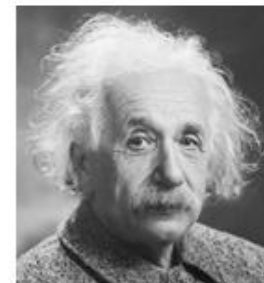


Fig. 2: The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of Fig. 1

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.



Image courtesy of 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

Norma G. Sanchez
CNRS-LERMA, Observatoire de Paris - PSL University, Sorbonne University
77, avenue Denfert-Rochereau
75014 Paris
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 black 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. ”

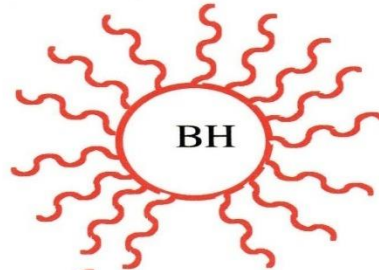


BACK REACTION
IMPORTANT

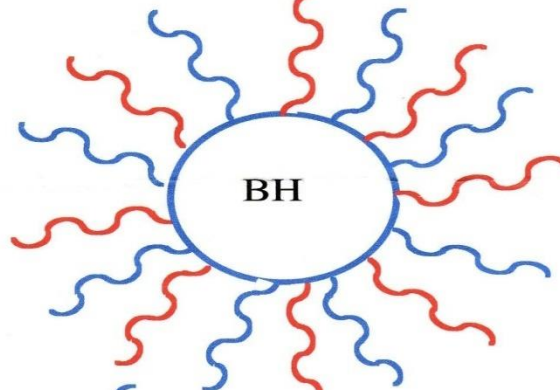


STRING
BACK HOLE
(r_s min, M_{min} , T_s)

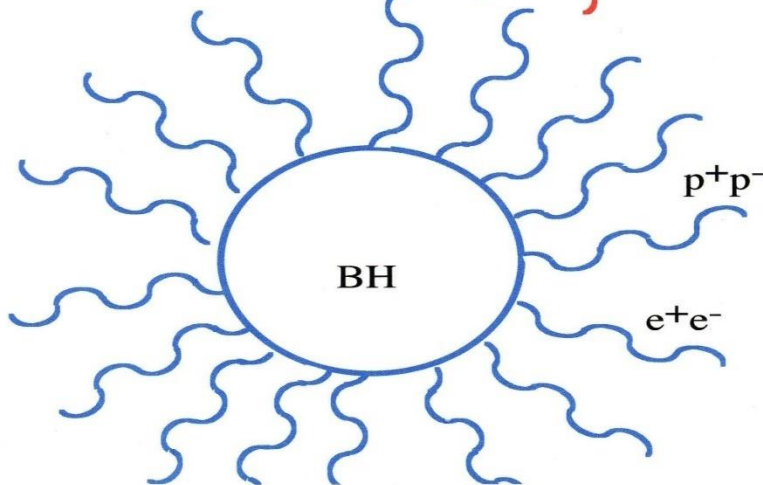
QUANTUM STRING
EMISSION OF
MASSIVES STATES



Γ spectrum
 E_i spectrum
STRING
REGIME



$T_H \uparrow$ increases
(r_s decreases)



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

SEMICLASSICAL
QFT REGIME
(HAWKING RADIATION)

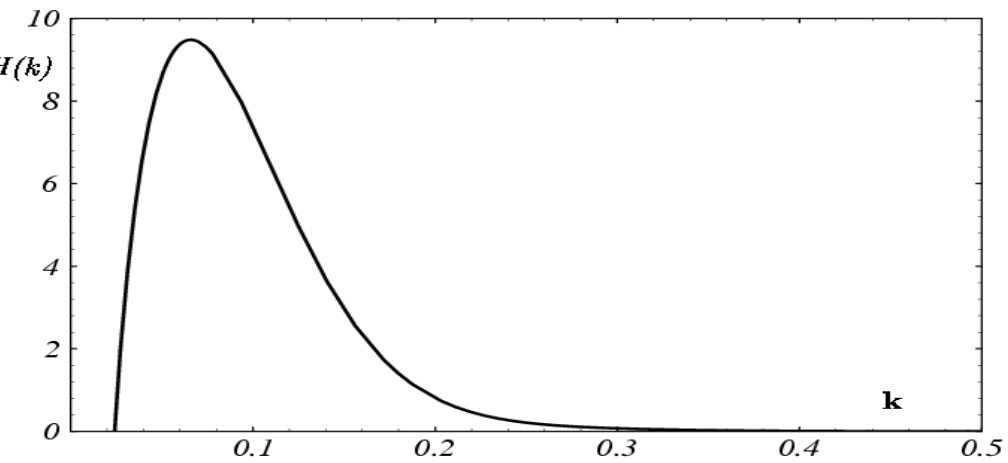


Figure 1: EMISSION BY A BLACK HOLE

4

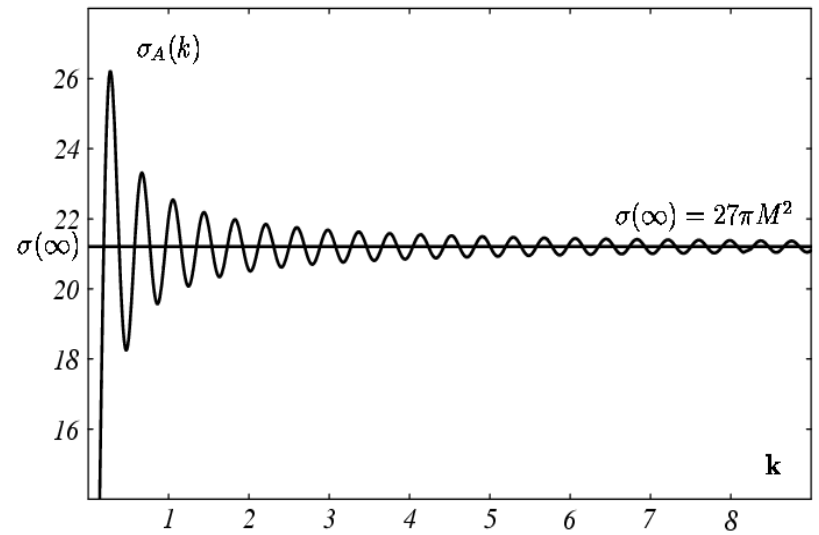


Figure 2: ABSORPTION BY A BLACK HOLE

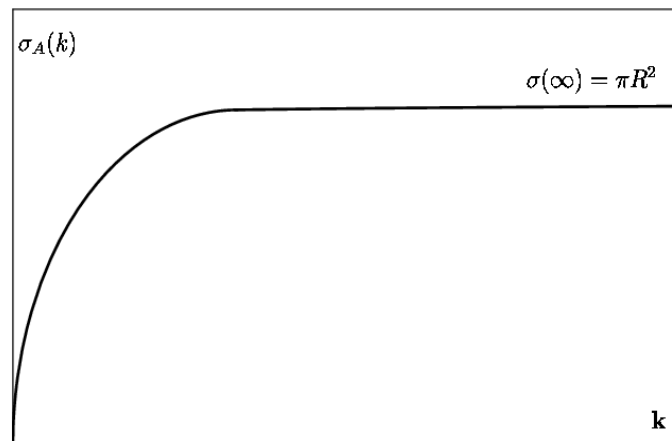


Figure 3: ABSORPTION BY A MATERIAL SPHERE WITH A COMPLEX REFRACTION INDEX

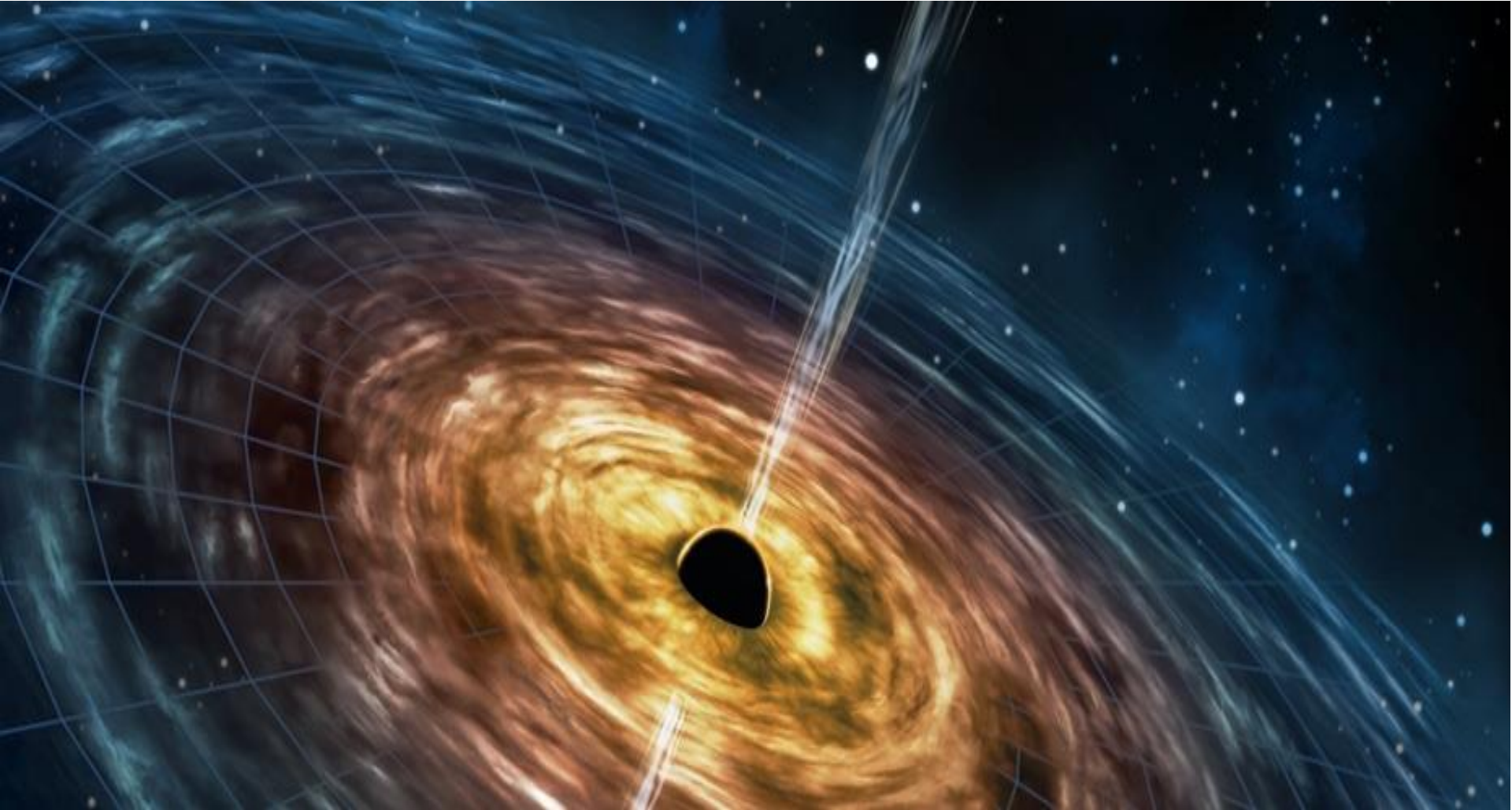
$$\sigma_A(k) = 27\pi M^2 - 2\sqrt{2}M \frac{\sin(2\sqrt{27}\pi kM)}{k}, \quad kM \geq 0.07$$

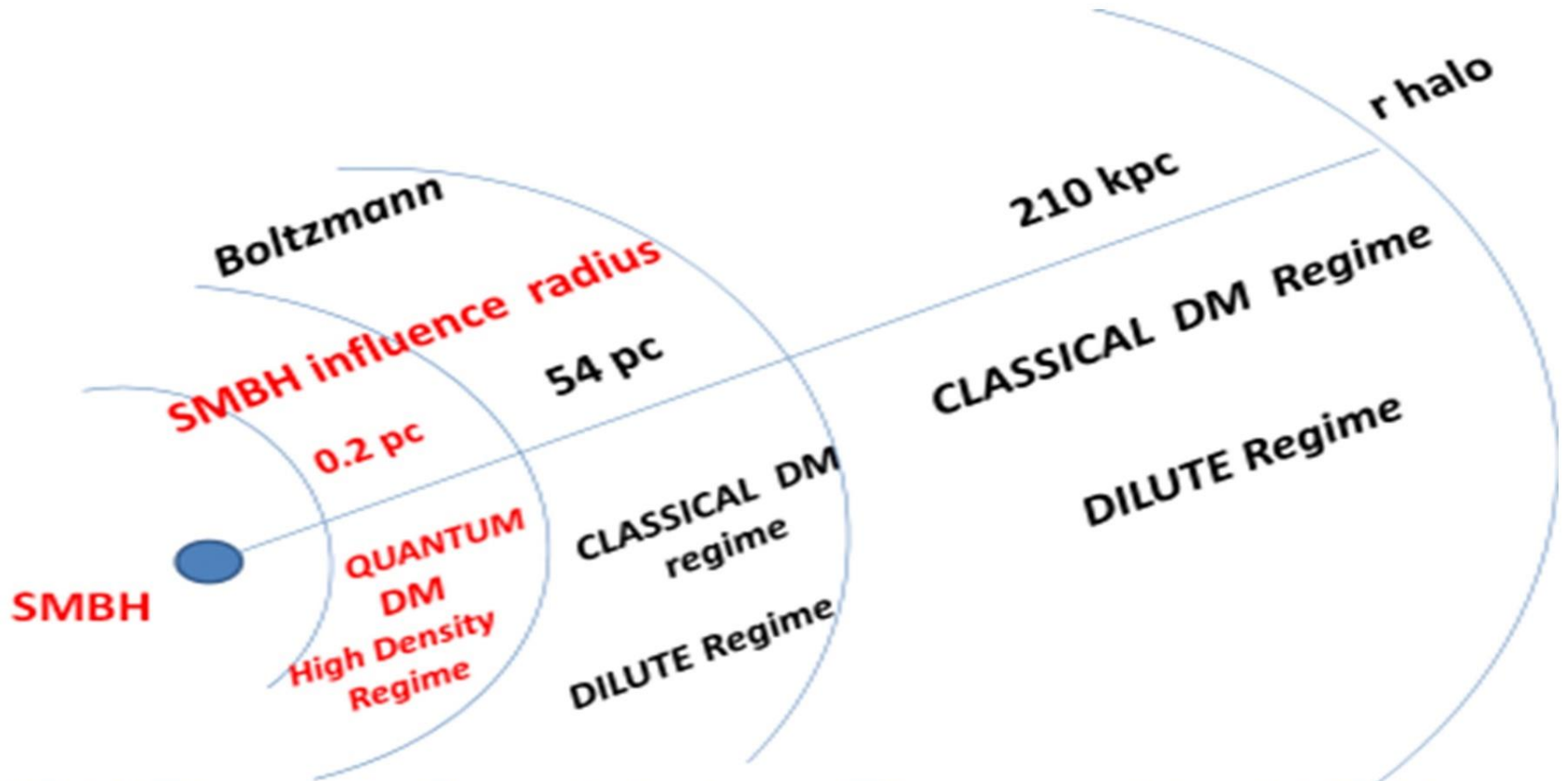
$$\sigma_A(0) = 16\pi M^2$$

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

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

CENTRAL SUPERMASSIVE BLACK-HOLE GALAXY *SYSTEMS*





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>

Article

Warm Dark Matter Galaxies with Central Supermassive Black Holes

Hector J. de Vega ^{1,†} and Norma G. Sanchez ^{2,*} 

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² CNRS LERMA PSL Observatoire de Paris Sorbonne Université and Chalonge—de Vega International School Center, 75014 Paris, France

* Correspondence: Norma.Sanchez@obspm.fr

† Passed away.

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



Citation: de Vega, H.J.; Sanchez, N.G.

Warm Dark Matter Galaxies with

Central Supermassive Black Holes

Article

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

Héctor J. de Vega^{1,†} and Norma G. Sanchez^{2,*} ¹ CNRS LPTHE, Sorbonne Université, Université Pierre et Marie Curie UPMC, CEDEX 05, 75005 Paris, France² CNRS LERMA PSL-Observatoire de Paris, Sorbonne Université and The Chalonge-de Vega International School Center, 75014 Paris, France

* Correspondence: Norma.Sanchez@obspm.fr

† Passed away <https://cshalonge-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 inhomogeneous 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 milli-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



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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Published: 11 August 2022



Featured by Universe :

Héctor J. de Vega, Norma G. Sanchez,

Universe 2022, 8(8), 419;

<https://doi.org/10.3390/universe8080419>

Two key observable numbers :
associated to the primordial density and
primordial gravitons :

$$n_s = 0.9608 , \quad r$$

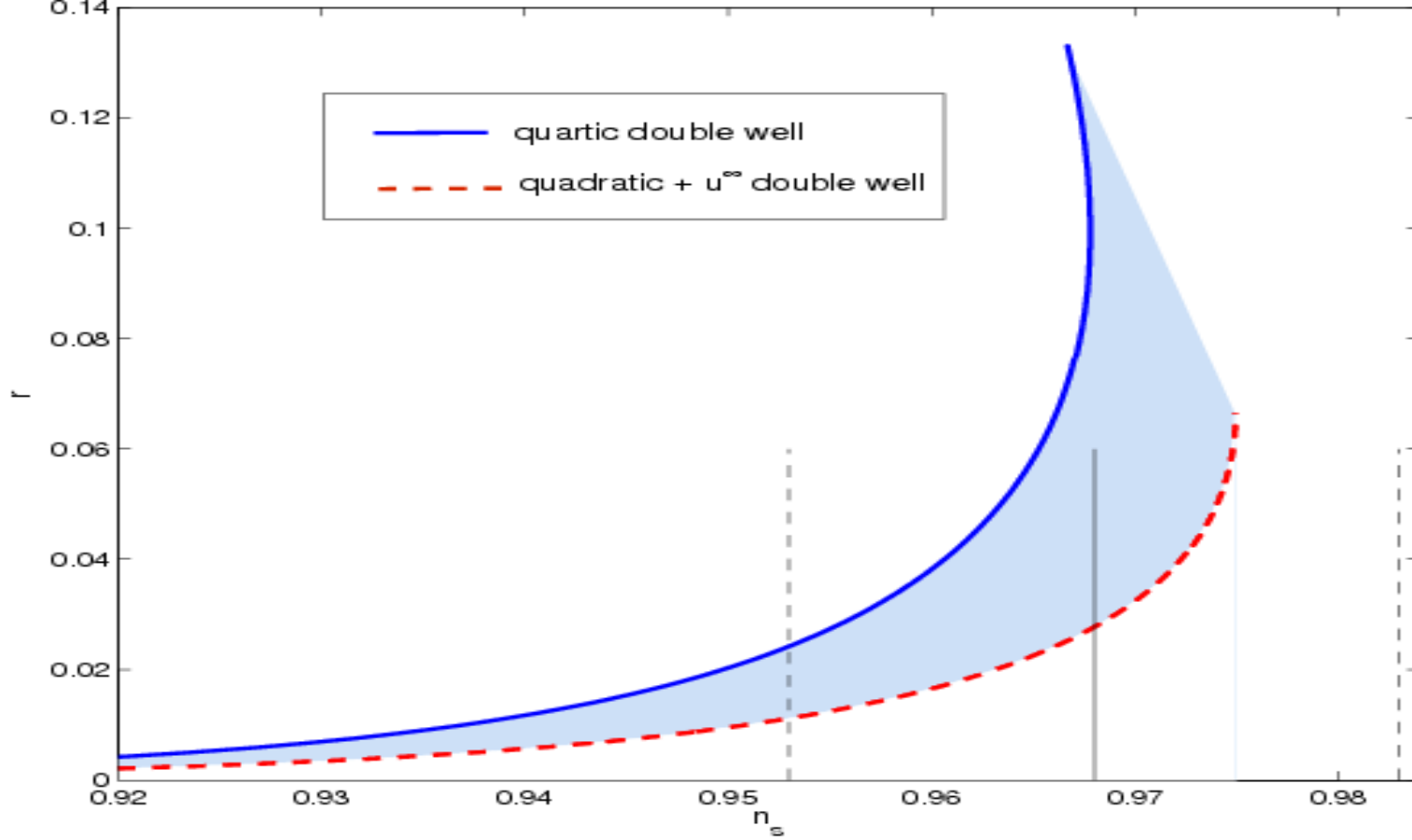
PREDICTIONS

$$r < 0.04$$

$$r > 0.021$$

$$0.021 < r < 0.040$$

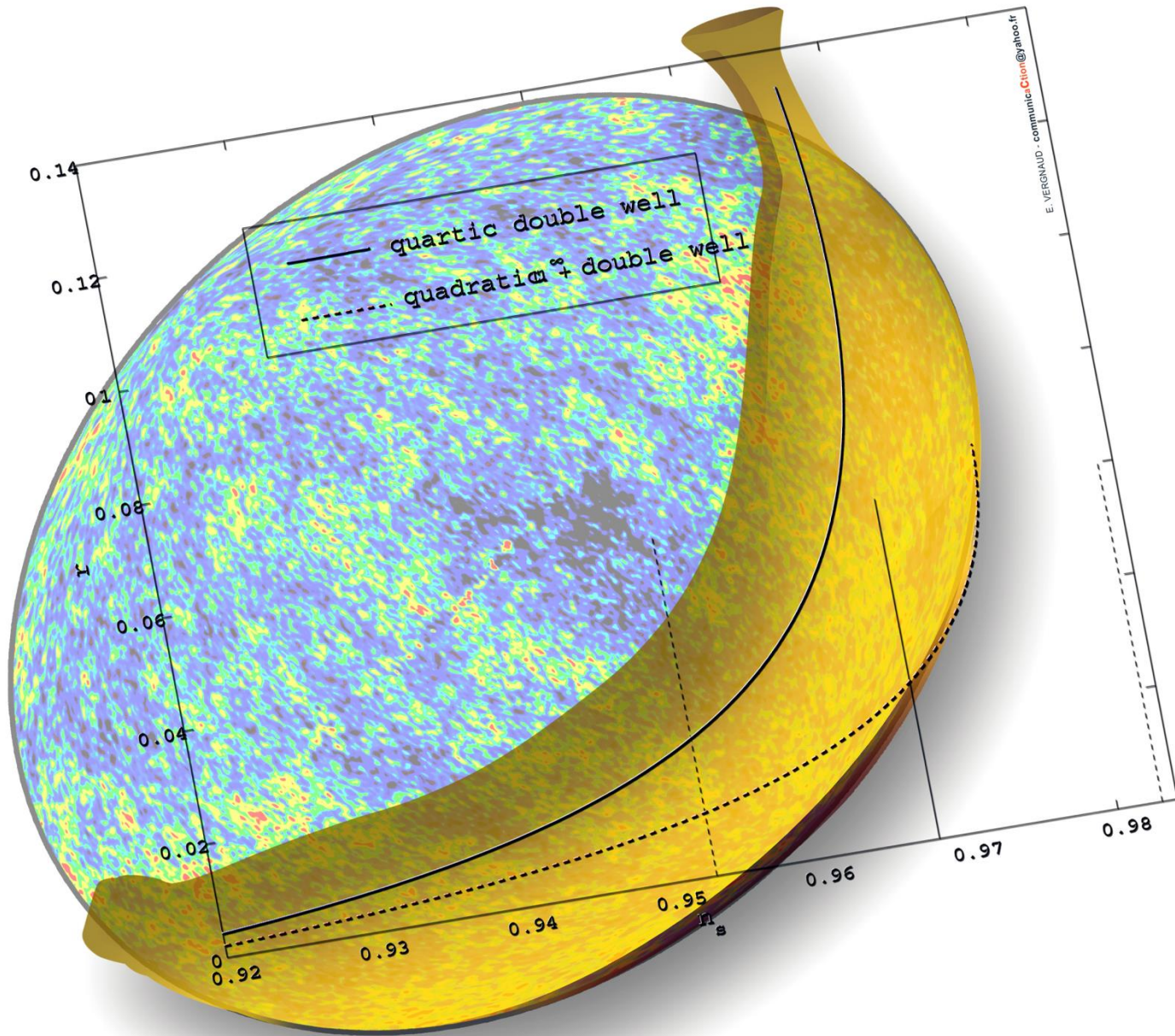
Most probable value: $r \sim 0.03, 0.04$



THE PRIMORDIAL COSMIC BANANA

The tensor to scalar ratio r (primordial gravitons) versus the scalar spectral index n_s . The amount of r is always non zero

H.J. de Vega, C. Destri, N.G. Sanchez, *Annals Phys* 326, 578(2011)



Nobel Chalonge de Vega School Channel

https://www.youtube.com/channel/UC1U2d99QktHcCwJmO_oJt6g

- H0 2022 Award, Adam G. RIESS:

$$H_0 = 73.30 \pm 1.04 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

- SHOES H0 Paper 9 December 2021 (.pdf)

- Recording of the Webinar Pantheon+ SHOES
9 December 2021

**6 December 2022, 16h00 Paris Time CET :
Closing Lecture of the Year : Adam G. RIESS**

The Expansion History of the Universe

H0 Award 2022



Dr. Adam Riess

 **H₀**  **THE EXPANSION HISTORY OF**
THE UNIVERSE
7 December 2022 16:00 Paris Time CET



Article

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

Héctor J. de Vega ^{1,†} and Norma G. Sanchez ^{2,*‡}

- ¹ CNRS LPTHE, Sorbonne Université, Université Pierre et Marie Curie UPMC, Paris, CEDEX 05, France; devega@lpthe.jussieu.fr
- ² CNRS PSL, Observatoire de Paris, Sorbonne Université and the Chalonge - de Vega International School Center 75012 Paris, France
- * Correspondence: Norma.Sanchez@obspm.fr
- † 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

$$a(t) \stackrel{H_0 t \gg 1}{\sim} a_0 \exp [c_1 H_0 t + c_2 (H_0 t)^2],$$

where

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

$$0.00452 < c_2 < 0.00872.$$

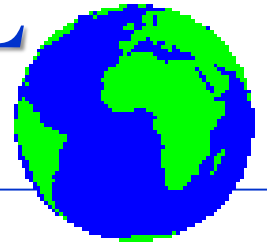
In this accelerated universe, Equation (108) shows that the Hubble radius ($1/H$) decreases with time as

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





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**Prof. Dr. Norma G. SÁNCHEZ, Director of the
School, Director of the Museum**

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Research- Training – Scientific Culture





**EPERNAY, Champagne
Ardennes , 11 /08/1999**



**Premio Franco-Argentino
Embajada de Francia,
Instituto Francés, AF, Mincyt,
CCC, Oct.Nov 2022**



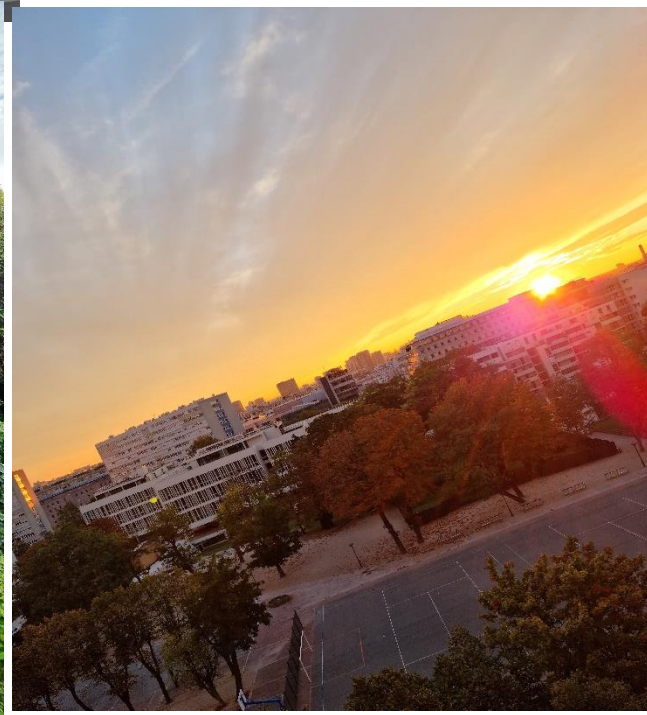
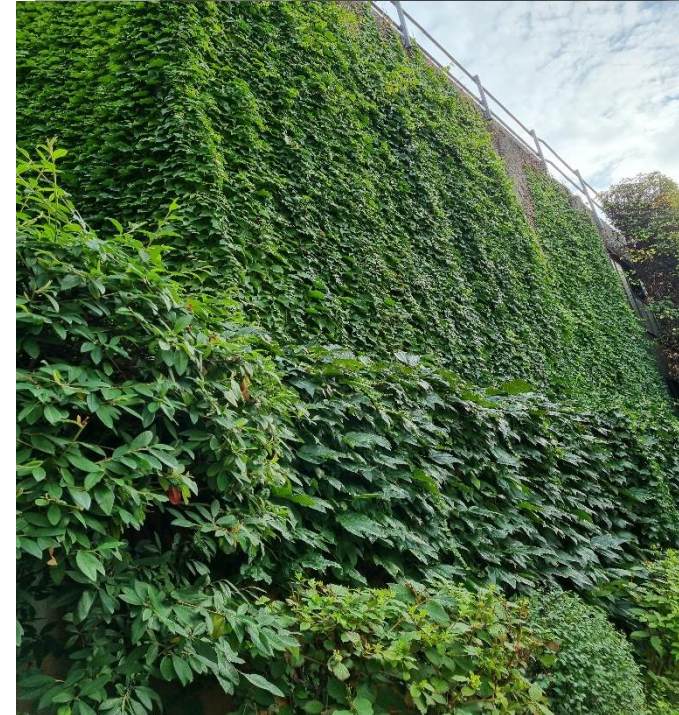


CASA ARGENTINA
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UNO Y EL UNIVERSO





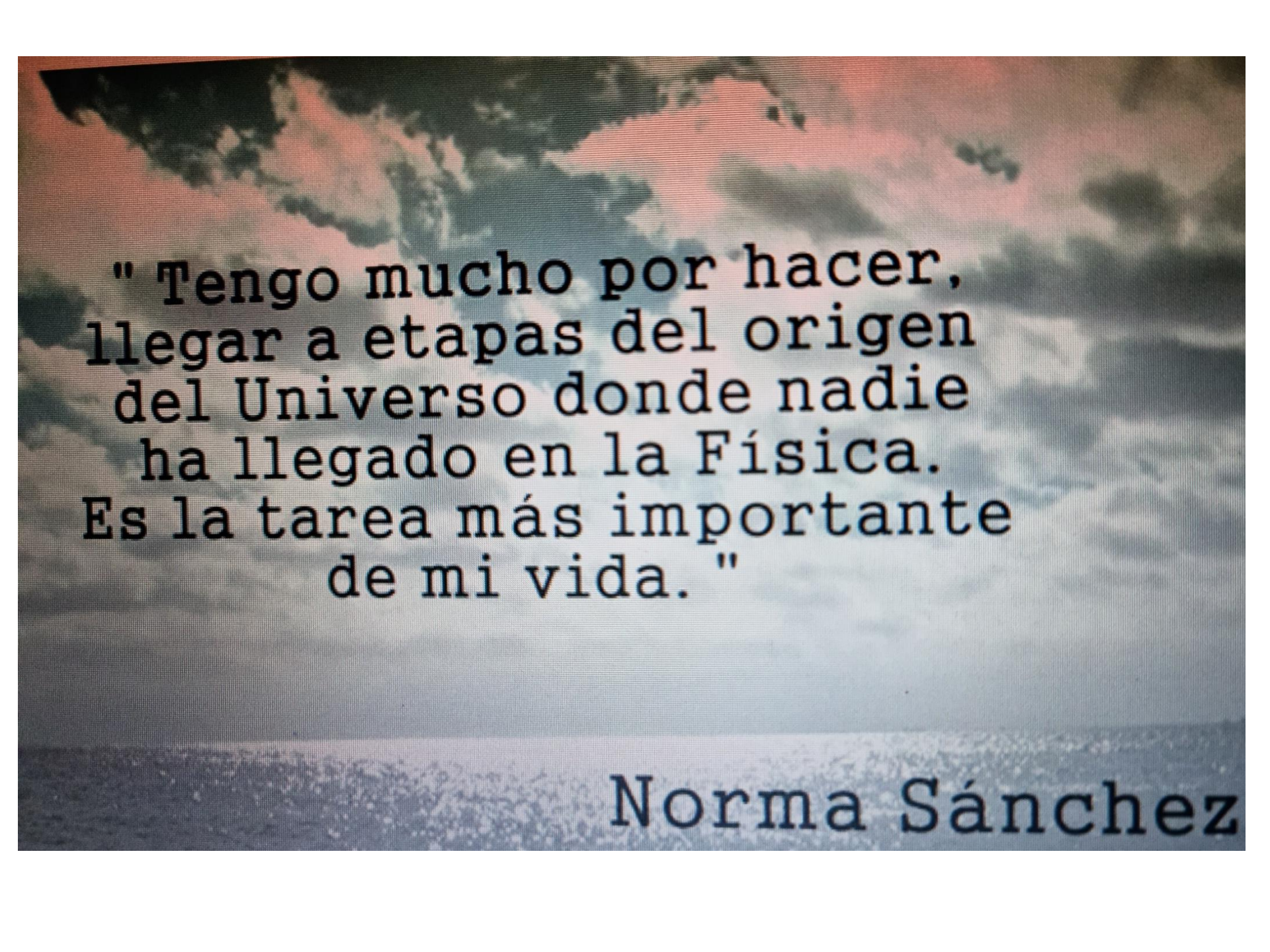
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- Futbol Cientifico

- Poesia Cientifica

- Arte Cientifico

- Cine Cientifico



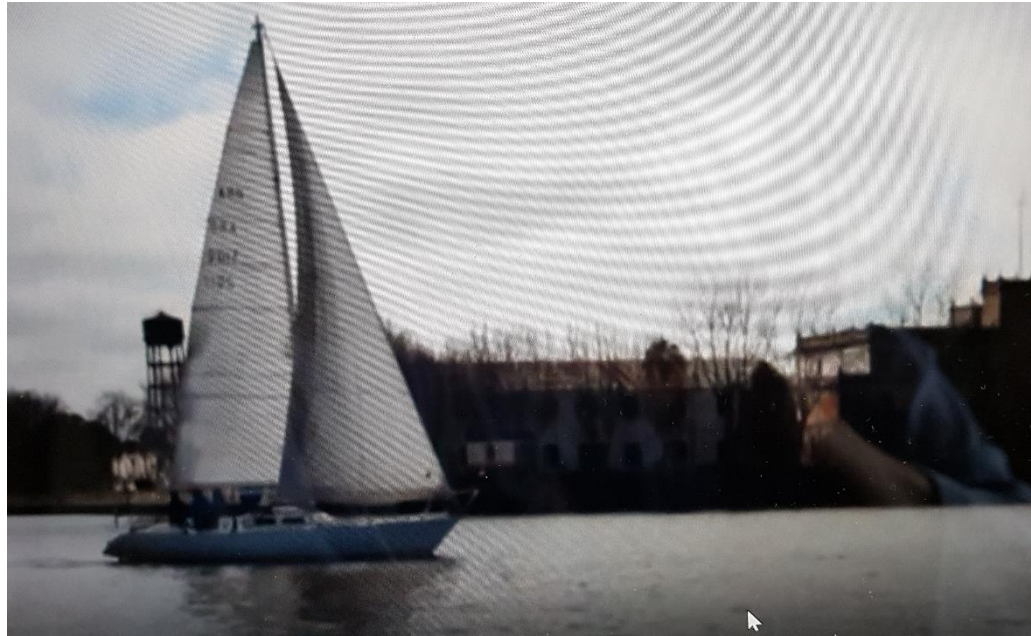
" Tengo mucho por hacer,
llegar a etapas del origen
del Universo donde nadie
ha llegado en la Física.
Es la tarea más importante
de mi vida. "

Norma Sánchez

- **CIENCIA ABIERTA,**
- **MEMORIA Y TRANSMISION**
- **ARCHIVOS ABIERTOS**
- **MUSEO ESCUELA SANCHEZ DE VEGA**



Film de Sandra DILUCA, 25 Mayo 2020



[ctora Norma Graciela Sanchez - YouTube](#)

LA

¿MÁS?

30/31
marzo
2023

NOCHE DE LAS IDEAS

lanochedelasideas.ifargentine.com.ar

LA PLATA



PROYECCIÓN

"LA DAMA DE LA CIENCIA"

Film documental de **Sandra Di Luca** acerca de la **Dra. Norma Sánchez**.

Estarán presentes su Directora y la Protagonista.

viernes 31 de marzo 19 h
Colegio Nacional Rafael Hernández

GRACIAS

