The Wave-Particle Duality of Quantum Physics

extended for the first time to Einstein's Gravitation

Nature has a dual behavior of wave and corpuscle: this is the well known classical-quantum duality or wave-particle duality of quantum physics (as the light and its photons, the microscopic world of elementary particles, ultradense plasmas, the laser, macroscopic quantum states (as compact stars), and many other examples).

Dr Norma G. Sanchez (emeritus research director at CNRS, LERMA-Observatoire de Paris-PSL) has for the first time generalized this duality to gravity by including its three regimes: classical, semiclassical and quantum, together with the Planck regime and the elementary particles domain: namely the *"wave-particle-gravity" duality* or the *classical-quantum gravity duality*.

This duality is *universal*, it includes the known duality as a special case and allows a general clarification with numerous results that reveal: (i) the classical-quantum duality of the space-time and black holes, (ii) a totally new quantum domain not present in the classical space-time; and (iii) the quantum light-cone from which the known light-cone of relativity and the classical universe are a special case. A new, more complete vision of space-time does appear.

Quantum physics is more general than classical physics and contains it as an approximation or special case. Thus, classical gravity and therefore the very successful general relativity theory is an incomplete (non-quantum) theory, that is, an approximation to a more complete quantum theory yet to be found.

An interesting intermediate regime is semi-classical gravity, ie semi-classical Einstein equations combining classical gravity and quantum matter. The best-known examples are Hawking's famous black hole radiation, and the primordial inflation of the universe and its fluctuations, seeds of the structures printed in the anisotropies and polarization of the microwave cosmic background (CMB). Moreover, the cosmological quantum vacuum could be the source of the current acceleration of the universe ("dark energy") compatible with a cosmological constant.

In the work described and published here [1] the classical-quantum duality at the basis of quantum theory is extended to the Planck's scale domain and beyond, where gravity becomes quantum and the three fundamental constants of Nature (the h quantum constant, the gravitational constant G and the speed of light c) unify. The classical gravity domain becomes dual to the quantum gravity domain and to the elementary particles domain in the precise and rigorous sense of the classical-quantum duality. This duality is *universal*. It is generic, and does not depend on the type of space-time or object, nor on the chosen number or type of dimensions, nor on any imposed or conjectured symmetry .

This study has revealed the classical-quantum duality of space-time. Moreover, a new unexpected quantum domain not present in the classical structure does appear: The quantum light-cone from which the classical light-cone at the basis of relativity and the classical universe are a particular case. Figures 1 and 2 clearly illustrate these results:

Fig. 1 shows the new universe and its quantum light-cone. The new quantum domain is the gray region inside the four color hyperboloids (1 is the length of Planck in the Planck units natural to the problem). Fig. 2 shows the well-known classical light-cone of relativity and the classical universe, which is found from the quantum Fig 1 as a special case.

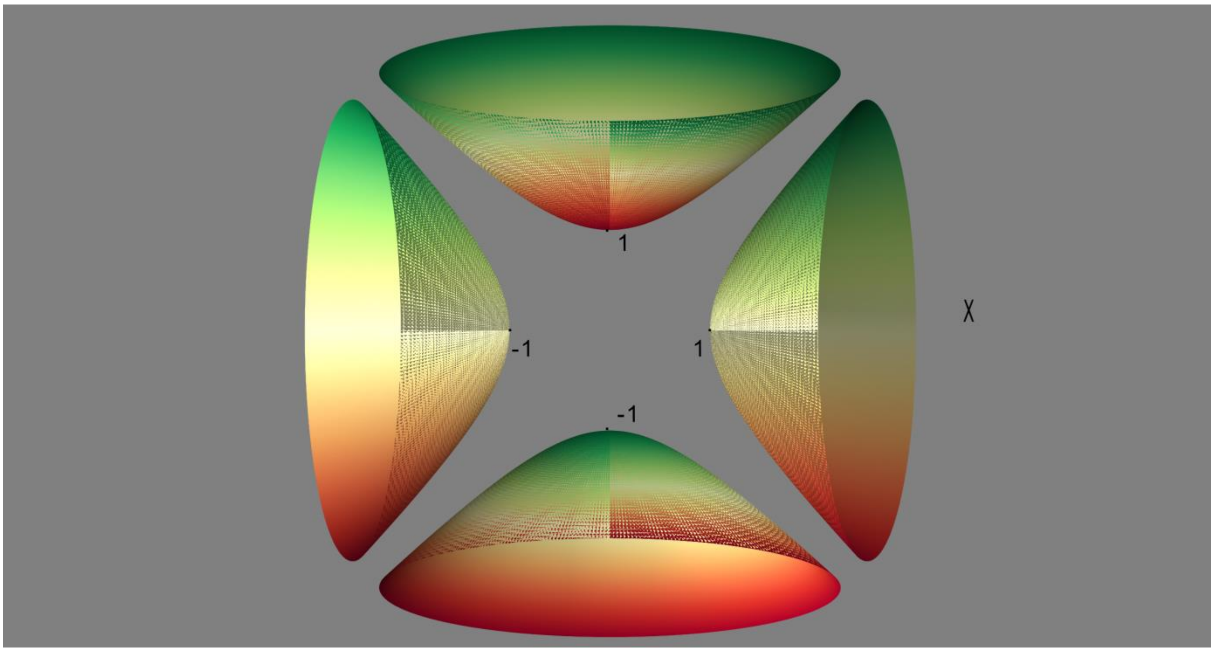

Fig.1: The quantum light-cone in a space-time diagram (time is the vertical axis). Copyright Norma Sanchez

This also allowed to,reveal the classical-quantum duality of black holes: the outer black hole regions are classical or semi-classical while the black hole *interior* is *totally quantum* and the horizon acquires a quantum border or "wrapping" (*"dressed horizon"*), exterior and interior losing their difference near the Planck scale.

Reference [1]: Norma G. Sanchez, ***ñ****The Classical-Quantum Duality of Nature including Gravity***ò** International Journal of Modern Physics D, IJMPD Vol 18, 1950055 (18 pages), (2019).
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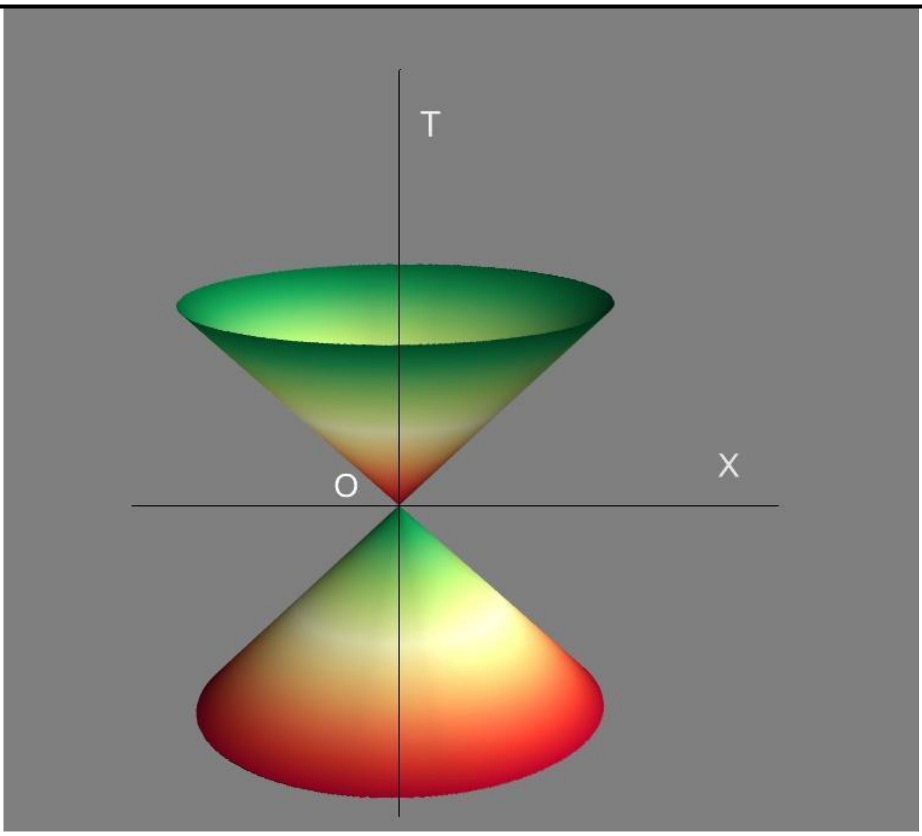

Fig. 2. The known classical light-cone (future and past) of classical relativity in a space-time diagram is a special case of Fig.1