

Quantum Mechanics in Action: From Bohm to Schrödinger Tapio Ala-Nissilä **5**#Tapio_ala

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- First Quantum Revolution
- Summary of Quantum Mysteries(?)
- Second Quantum Revolution
- Quantum Computers
- Ouantum Thermodynamics











MESSENGER Mission Measures Solar System Expansion

TOPICS: Astronomy Astrophysics Cosmology MESSENGER Planetary Science By ELIZABETH ZUBRITSKY, NASA'S GODDARD SPACE FLIGHT CENTER JANUARY 19, 2018



NASA's MESSENGER mission was active. Credits: NASA's Goddard Space Flight Center



NASA and MIT scientists analyzed subtle changes in Mercury's motion to learn about the Sun and how its dynamics influence the planet's orbit. The position of Mercury over time was determined from radio tracking data obtained while



ARTICLE

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OPEN

Solar system expansion and strong equivalence principle as seen by the NASA MESSENGER mission

Antonio Genova ^{1,2}, Erwan Mazarico ², Sander Goossens^{2,3}, Frank G. Lemoine², Gregory A. Neumann², David E. Smith¹ & Maria T. Zuber¹

The NASA MESSENGER mission explored the innermost planet of the solar system and obtained a rich data set of range measurements for the determination of Mercury's ephemeris. Here we use these precise data collected over 7 years to estimate parameters related to general relativity and the evolution of the Sun. These results confirm the validity of the strong equivalence principle with a significantly refined uncertainty of the Nordtvedt parameter $\eta = (-6.6 \pm 7.2) \times 10^{-5}$. By assuming a metric theory of gravitation, we retrieved the post-Newtonian parameter $\beta = 1 + (-1.6 \pm 1.8) \times 10^{-5}$ and the Sun's gravitational oblateness, $J_{2\odot} = (2.246 \pm 0.022) \times 10^{-7}$. Finally, we obtain an estimate of the time variation of the Sun gravitational parameter, $G\dot{M}_{\odot}/GM_{\odot} = (-6.13 \pm 1.47) \times 10^{-14}$, which is consistent with the expected solar mass loss due to the solar wind and interior processes. This measurement allows us to constrain $|\dot{G}|/G$ to be $<4 \times 10^{-14}$ per year.



Accurate expansion rate 1.5 cm/year (no space expansion)





Quantum Mechanics is a mathematical theory of Physics that describes the properties of the smallest constituents of matter and interactions between them





Quantum Mechanics



First Quantum Revolution

NIELS BOHR

Everything we call real is made of things that connot be regarded as real.

If quantum mechanics have't profoundly shocked you, you haven't understood if yet:













Max Planck (1858-1947)



 $\left(\beta mc^2 + \sum_{k=1}^3 \alpha_k p_k c\right) \psi(\mathbf{x}, t) = i\hbar \frac{\partial \psi(\mathbf{x}, t)}{\partial t}$









• For single particles, quantumness is usually associated with quantum interference, wave function collapse,...





Quantum Mysteries?

Position in Space

Position in Space







- wave function collapse,...
- However, it was recently proven that all quantum-mechanical interferometric "quantumness" [Blasiak, Phys. Rev. A (2018)]





Quantum Mysteries?

• For single particles, quantumness is usually associated with quantum interference,

effects can be *explained classically* by a *local ontological model* that imitates





• This indicates that "true" quantumness lies in entanglement of many-particle (more than one) systems



Quantum Mystery











• Entanglement of particles leads to *non-locality* of measurements

EINSTEIN ATTACKS **QUANTUM THEORY**

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

NYT 1935



Entanglement Mysteries I



Entanglement Mysteries I • Entanglement of particles leads to *non-locality* of measurements

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• Entanglement of particles leads to *non-locality* of measurements





LETTERS INCIDED ONLINE: 23 MARCH 2014 | DOI: 10.1038/NPHOTOR.2014.50

Experimental three-photon quantum nonlocality under strict locality conditions

C. Erven12*, E. Meyer-Scott', K. Fisher', J. Lavoie', B. L. Higgins', Z. Yan', C. J. Pugh', J.-P. Bourgoin', R. Prevedel¹⁴, L. K. Shalm¹⁵, L. Richards¹, N. Gigov¹, R. Laflamme¹, G. Weihs¹⁴, T. Jennewein¹ and K. J. Resch'*





nature







Entanglement Mysteries II

• Entanglement of particles leads to *emergence of time?*

PHYSICAL REVIEW A 89, 052122 (2014)

Time from quantum entanglement: An experimental illustration

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Entanglement Mysteries III

• Entanglement of particles leads to *emergence of gravity (space-time)?*

PRL 114, 221601 (2015)

PHYSICAL REVIEW LETTER

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Locality of Gravitational Systems from Entanglement of Conformal Field Theories

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not *exploit* quantumness (except maybe for lasers)



Coming Soon - Second Quantum Revolution

• Our current (high) technology is *based* on QM phenomena but does





Coming Soon - Second Quantum Revolution • Our current (high) technology is *based* on QM phenomena but does not *exploit* quantumness (except maybe for lasers)

- New quantum technology will *exploit quantumness*



Qubit







• *A traditional computer* is based on binary operations 001110101..., that can be realised with any technology, even by mechanical means





Computer





(superposition & entanglement)



Quantum Computer • A quantum computer is based on components that exploit quantumness





Quantum Computer • A quantum computer is based on components that exploit quantumness (superposition & entanglement)





Classical Bit







Quantum Computer • A quantum computer is based on components that exploit quantumness (superposition & entanglement)











D-Wave Quantum Computer (Quantum Annealer)











IBM Q 20-qubit Quantum Computer 2019









Thermodynamics is a mathematical theory of Physics that describes the properties of *macroscopic* systems









Quantum Thermodynamics?











Need to define QM energy, entropy, heat & work!



Quantum Heat Engine





Hamilton-Jacobi-Bohm Formalism















Thank you!





