Primordial Wormholes and their Traversability Constraints In the Presence and Absence of Exotic Matter

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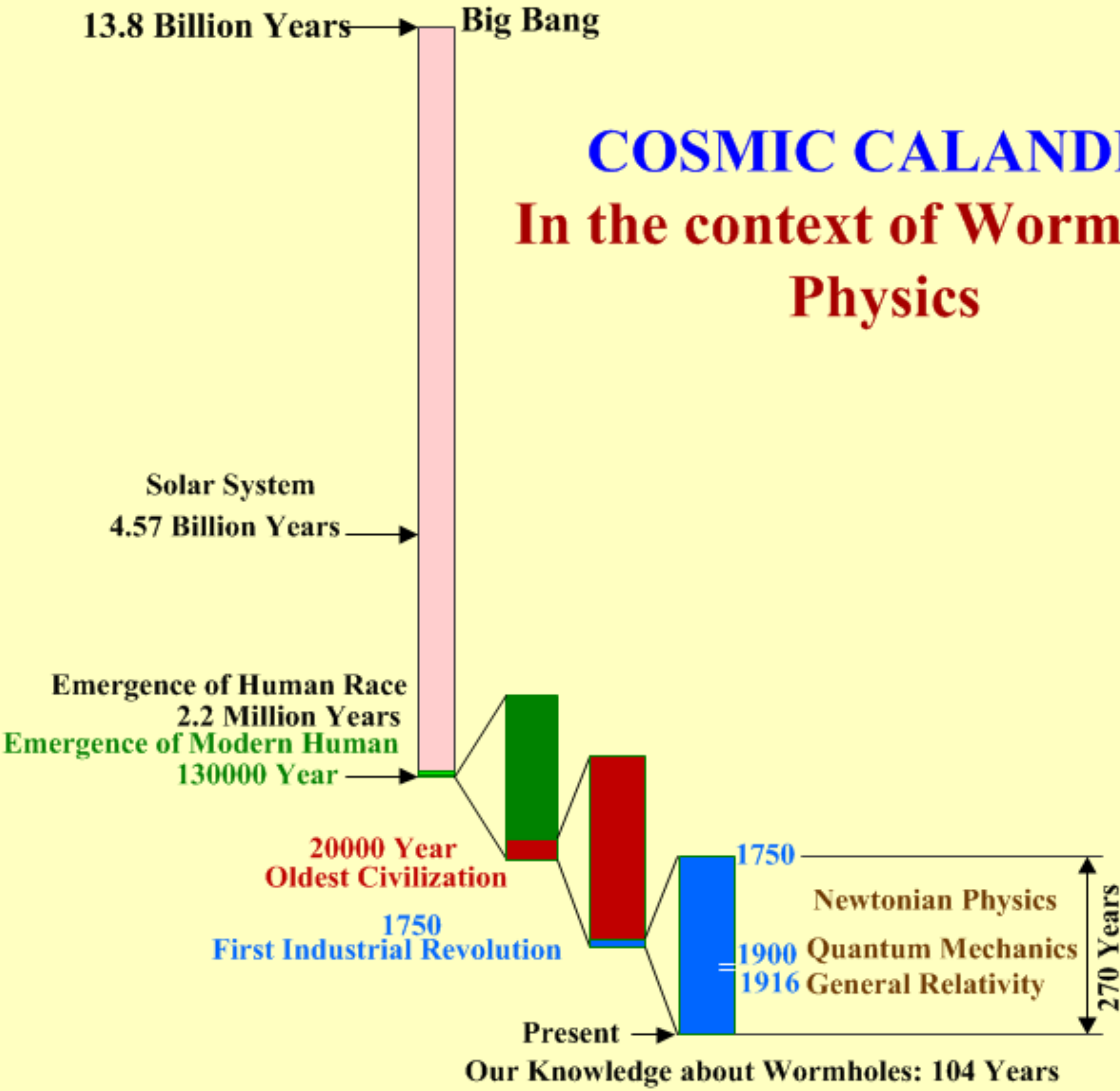
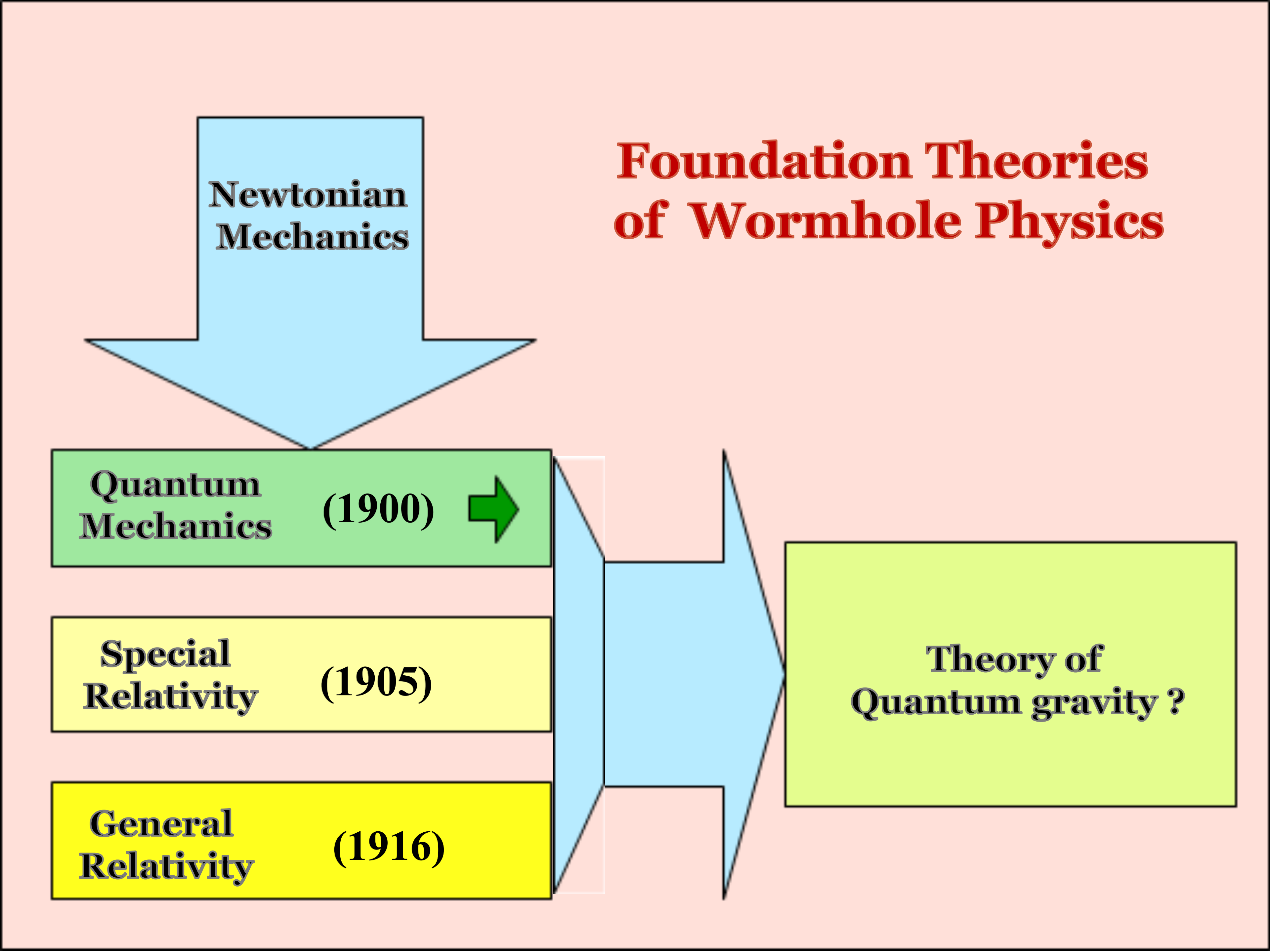
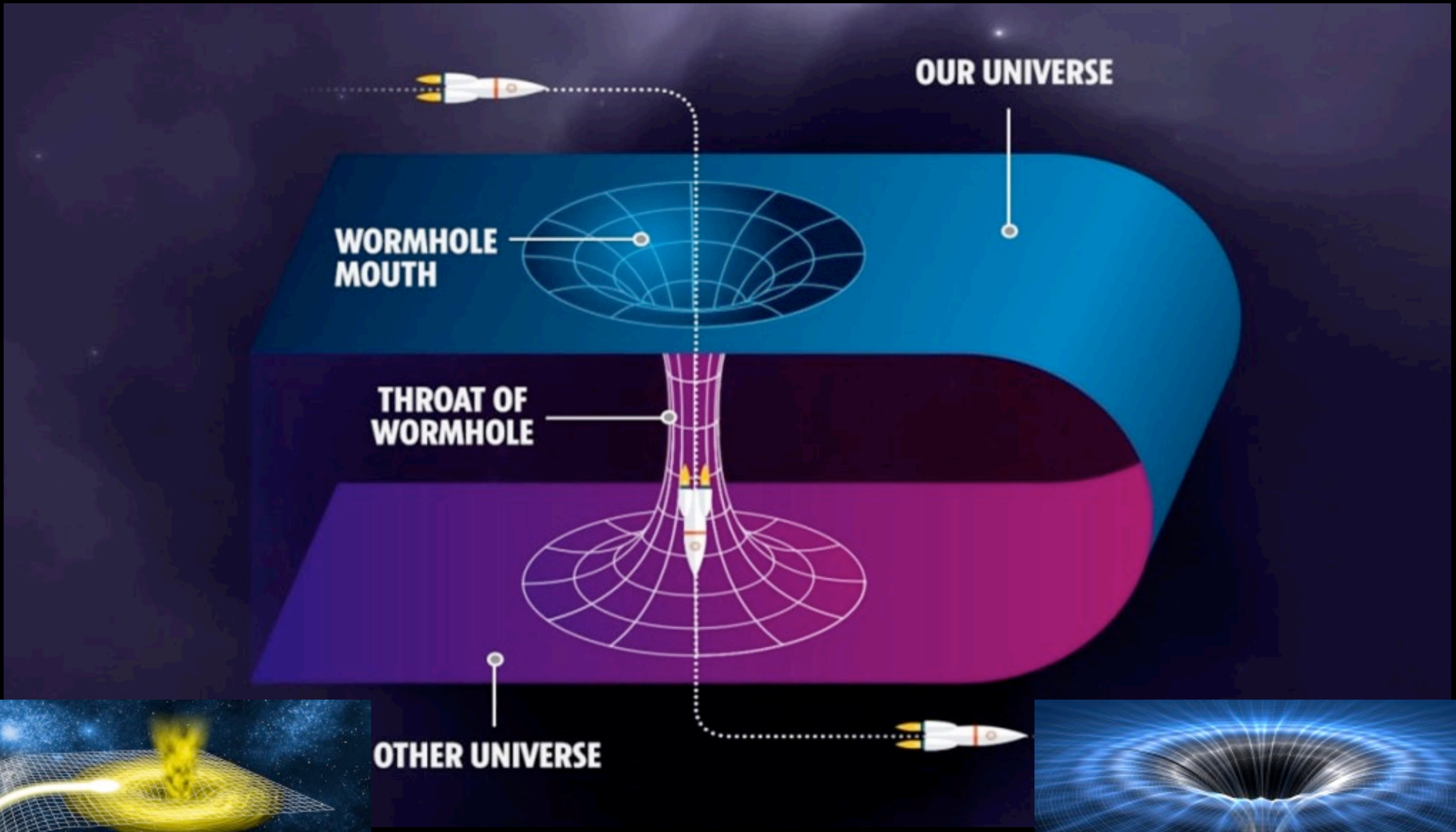
COSMIC CALANDER
In the context of Wormholes Physics

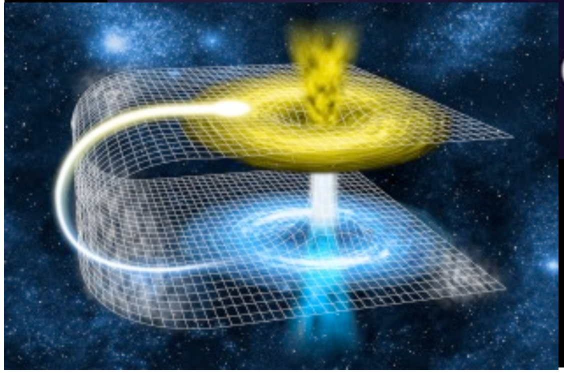




Foundation Theories of Wormhole Physics
Newtonian Mechanics
Quantum Mechanics
(1900)
Special Relativity
(1905)
General Relativity
(1916)
Theory of Quantum gravity ?

What is a Wormhole ?

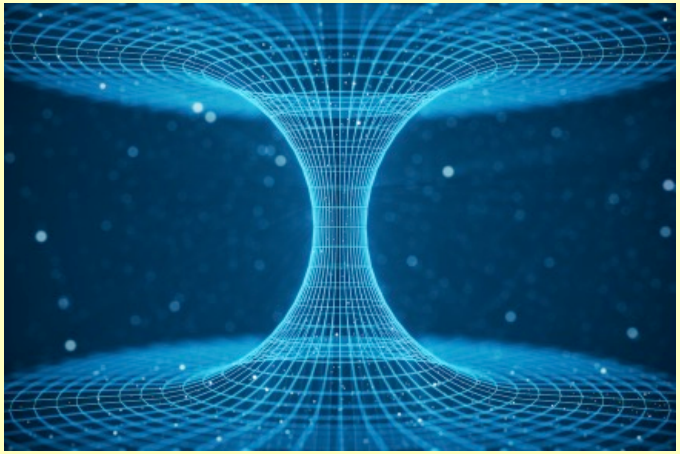




Wormholes, A historical View

- Wormholes, although never directly observed, have been validated as a plausible solution within the framework of the field equations of general relativity.

- In 1935, Einstein and physicist Nathan Rosen extended the implications of the theory of general relativity, introducing the concept of "bridge" within the fabric of spacetime.



- They postulated the existence of bridges, which could serve as cosmic connectors, linking separate points across the expanse of spacetime

Wormhole Physics

- Does the laws of physics permit the topology change necessary for the creation of wormholes.

- Another pivotal question pertains to whether the laws of physics permit the creation of submicroscopic Lorentzian wormholes

- Even though wormhole formation is prohibited on the classical level, it might be allowed quantum-mechanically.

-The formation of submicroscopic wormholes at the early universe and their subsequent enlargement during the inflationary phase to the macroscopic size depends significantly on the nature and topology of spacetime at the Planck scale

Matter at the Subquantum Level

Quantum Foam

Quantum foam represents the volatile and dynamic nature of spacetime on the smallest scales, where the classical notion of space as a smooth and continuous entity crumbles, revealing a complex and intricate structure that flickers and fluctuates incessantly.

The concept of spacetime foam has been first introduced by A. Wheeler [6] in 1957.

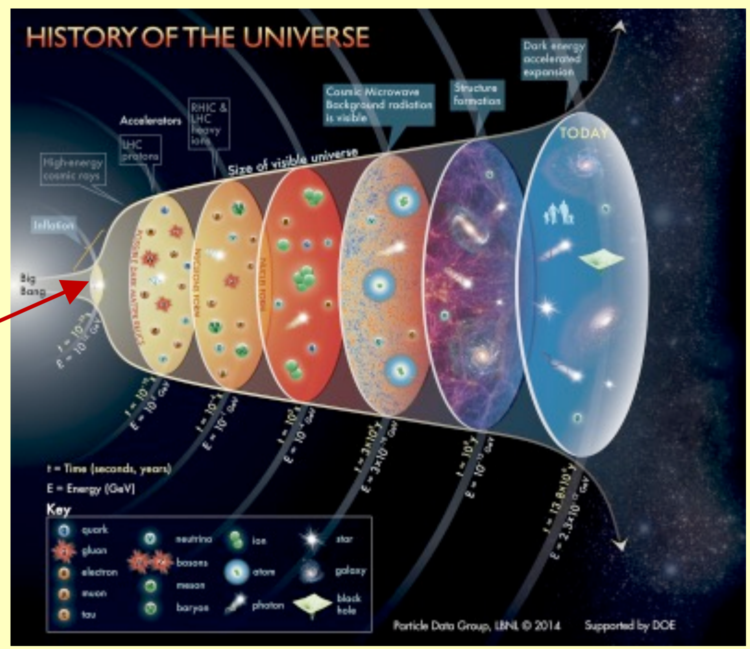
- The idea emerges from precision measurements of the spectrum of the hydrogen atom

Quantum Foam and Inflation

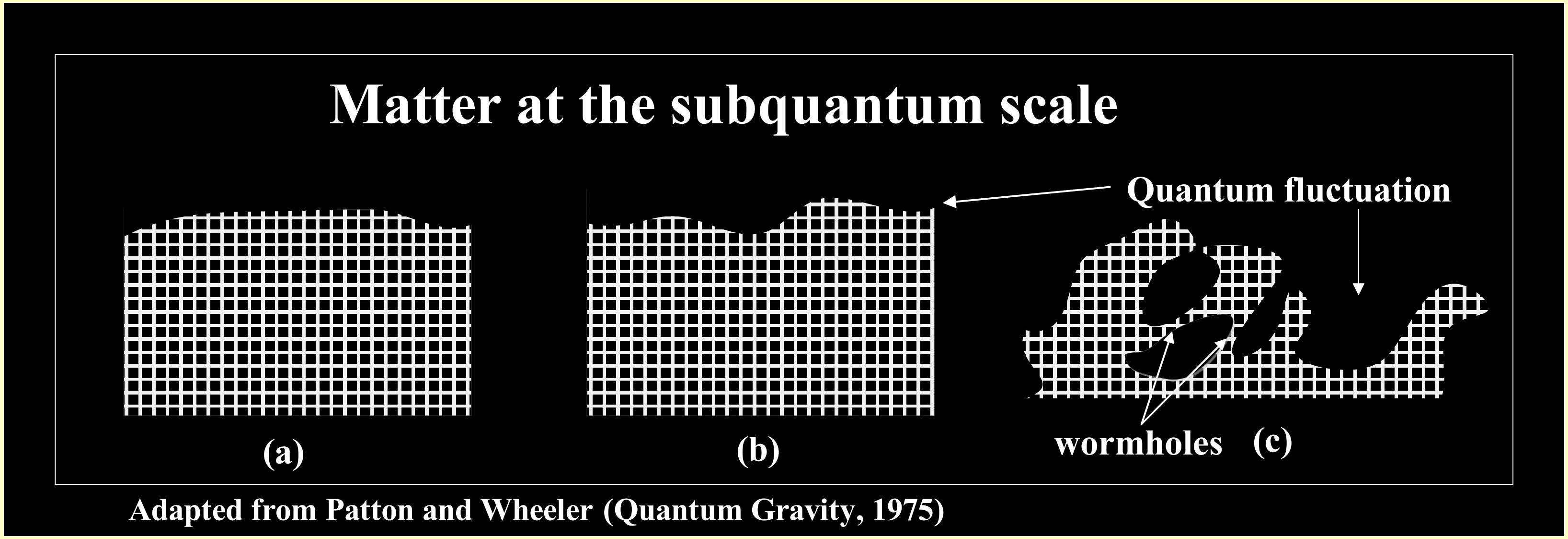
In this work, we envision primordial spacetime foam filling all space at the Planck scale with all sorts of topological fluctuations including microscopic wormholes. These microscopic entities persist for a microscopic time-period, but can be appreciably enlarged by primordial inflation.

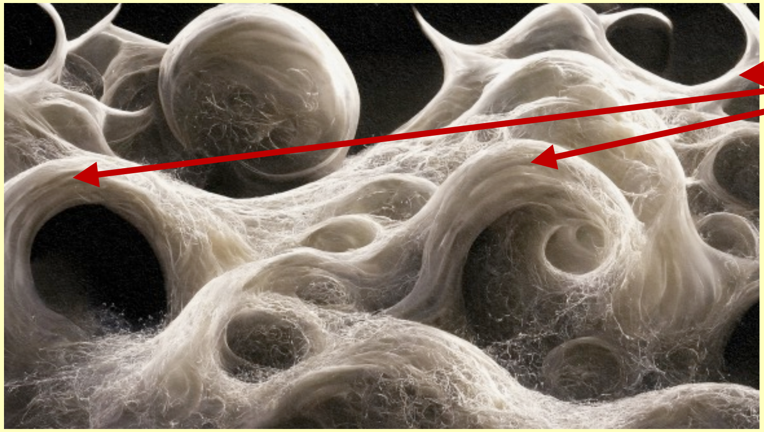
Quantum Foam

Inflation



Matter as seen from different size scales





Potential wormhole structures

Hypothesis

- The existence of quantum foam

J. A. Wheeler, *On the Nature of Quantum Geometrodynamics*, Ann. Phys. (NY) 2, 604 (1957).

S. W. Hawking, D. N. Page and C. N. Pope, *The propagation of particles in spacetime foam*, Phys. Lett., Vol. 86B, number 2, (1979).

Ian H. Redmount and Wai-Mo Suen, *Quantum Dynamics of Lorentzian Spacetime Foam, arXiv:gr-qc/9309017v1 14 Sep 1993.*

- Certain proportion of topological foam structures, such are wormholes, survive inflation.

T. Roman, *Inflating Lorentzian Wormholes*, arXiv.gr-qc/9211012v1 9Nov.1992.

The Static Morris-Thorne Wormholes

Static Morris-Thorne (MT) metric is given by [20]

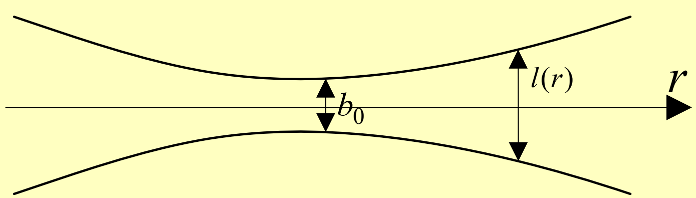
$$ds^2 = -e^{2\Phi(r)}dt^2 + \frac{dr^2}{(1-b(r)/r)} + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)$$

Here, $b(r)$ and are adjustable functions referred to as the "shape function" and $\Phi(r)$ the "redshift function", respectively.

As evident from the metric, there is a coordinate singularity at the throat where $r = b$. At this point, the metric coefficient g_{rr} becomes divergent.

However, the radial proper distance must be finite everywhere,

$$l(r) = \pm\int_{b_0}^{r} \frac{dr}{(1-b(r)/r)^{1/2}}$$



Roman's Inflating Wormhole

$$ds^2 = -e^{2\Phi(r)}dt^2 + e^{2\chi t}\left[\frac{dr^2}{(1-b(r)/r)} + r^2(d\theta^2 + \sin^2\theta\, d\phi^2)\right]$$

where $\chi = (\Lambda/3)^{1/2}$, and Λ is the cosmological constant

For Φ(r) = b(r) =0, Roman's metric reduces to a flat deSitter metric, whereas for χ = 0, it reduces to the static wormhole metric of (**MT**)

The enlargement process can be visualized by considering the proper circumference c of the wormhole throat, where $r = b = b_0$ for $\theta = \pi/2$, at any time t = const. The time-dependence of the conference is given by

$$c = \int_0^{2\pi} e^{\chi t}\, b_0\, d\phi = e^{\chi t}\,(2\pi b_0)$$

The radial proper length through the wormhole between any two points *A* and *B* at any time *t* = const. is given by

$$l(t) = \pm e^{\chi t} \int_{r_B}^{r_A} \frac{dr}{(1 - b(r)/r)^{1/2}}$$

In a flat 3D Euclidean space with metric

$$ds^2 = d\bar{z}^2 + d\bar{r}^2 + e^{2\chi t} r^2 \, d\phi^2$$

The Roman metric on the slice (*t* = const., *ϑ* = π/2) becomes

$$ds^2 = \frac{e^{2\chi t} dr^2}{(1 - b(r)/r)} + e^{2\chi t} r^2 \, d\phi^2$$

Comparing the coefficients of , $d\phi^2$ **we have**

$$\bar{r} = e^{\chi t} r \Big|_{t=const.} \quad \Rightarrow \quad d\bar{r}^2 = e^{2\chi t} dr^2 \Big|_{t=const.}$$

Expansion of the Wormhole

It can be shown that the relation between the embedding space at any time *t* and the initial embedding space at *t* = 0 is

$$ds^2 = d\bar{z}^2 + d\bar{r}^2 + r^2 \, d\phi^2 = e^{2\chi t}(dz^2 + dr^2 + r^2 d\phi^2)$$

Accordingly, relative to the coordinate system the wormhole will always remain the same size, but it will change size relative to the initial *t* = 0 embedding space.

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Accordingly, relative to the $(\bar{z}, \bar{r}, \phi)$ **coordinate system the wormhole will always remain the same size, but it will change size relative to the initial *t* = 0 embedding space.**

Wormholes Traversability Constrains

Dark energy

Dark energy, known for its repulsive gravitational effect, drives the accelerated expansion of the universe and could potentially counteract the gravitational collapse that might threaten the stability of a wormhole

At prtesent, there is no empirical evidence currently supporting this concept.

Gravitational signature of antimatter

- The speculative utilization of antimatter stems from its capacity to generate negative energy densities, a requisite feature for counteracting the gravitational forces that may lead to the collapse of wormholes

- The violation of CPT symmetry, if substantiated, could lead to the emergence of exotic properties such as negative energy densities crucial for preventing the collapse of wormholes.

Many arguments have been advanced either emphasizing or refuting the idea of antimatter possessing anti-gravitational signature.

Arguments against anti-gravitational signature of matter-antimatter interaction:

Morrison: Is based on energy conservation of a matter-antimatter pair created at the Earth's surface,

Schiff argument: It stems from the principle of equivalence and quantum field theory

Myron L. Goode: He argued that antigravity would lead to unacceptable level of CP violation in the anomalous regeneration of Kaons.

Arguments support anti-gravitational signature of matter-antimatter interaction:

Santilli: He showed that the isodual theory predicts that antimatter in the field of matter experience antigravity

Cabbolet at al.:Published the first non-classical principles governing matter-antimatter gravitational repulsion

Villata : He argued that antigravity appears as a prediction of general relativity when CPT theory is applied.

The Tumultuous Road of Experimental Findings

The discrepancies in identifying the signature of the gravitational field of antimatter have prompted scientists to adopt the realm of experimental physics to solve this issue.

Witteborn and Fairbank set up an experiment to compare the gravitational acceleration of electrons and positrons by analyzing the time of flight.

However, the Schiff and Barnell effect caused electrons inside the metal of the drift tube to sag under gravity, until the gravitational force was balanced by the electrostatic force of compression.

Subsequently, the production of antihydrogen was proposed to overcome the above difficulties.

- Antihydrogen atoms were first brought into existence in CERN in 1995.

- The first experiment was performed using the Low Energy Antiproton Ring (LEAR). It turns out that these antihydrogen atoms are too "hot" to be used for gravitational studies.

- In the late 1990s, two collaborations were formed, namely, ATHENA and ATRAP.

- The ALPHA collaboration announced in 2010 the trapping of 38 antihydrogen atom for 0.167 s .

- In April 2011 they announced the trapping of 309 antihydrogen atoms for about 1000 s.

- Other experiments (AEGIS) and collaborations such as GBAR failed at having a definite answer to solve this issue.

- Lately, a group at CERN conducted antihydrogen experiment on antihydrogen atoms released from magnetic confinement in the ALPHA-g apparatus, and claim that they behave in a way consistent with gravitational attraction to the Earth.

Traversable Wormholes without Exotic Matter

Various studies have proposed alternative mechanisms that circumvent the need for exotic matter, thereby offering the possibility of realizing these hypothetical structures within the framework of known physical principles.

J. L. Bazqurs-Salcedo et al. (BSKR wormhole) constructed a specific example of a class of traversable wormholes in Einstein-Dirac-Maxell theory in four spacetime dimensions, without the need of any form of exotic matter.

Nevertheless, the solution to the Einstein-Dirac-Maxwell theory for traversable wormhole was criticized by D. L. Danielson et al. on the basis that the metric fails on the wormhole throat at $r = 0$.

M. Hohman proposed a static, spherically symmetric, traversable wormhole solution to multimetric gravity sustained solely by only non-exotic matter, i.e., matter that satisfies all energy conditions.

N. Geodani and G. C. Samanta proposed a traversable wormhole supported by non-exotic matter in general relativity.

F. S. N. Lobo and M. A. Oliveira constructed traversable wormhole geometries in the context of f(R) modified theories of gravity.

Saiedi and Esfahani determined exact wormhole solutions in the context of f(R) theory of relativity using power low expansion and a specific shape function.

Traversable wormholes without Exotic Matter….continued

M. S. Churilova et al. found an analytic solution representing traversable asymptotically flat and symmetric wormholes without the addition of exotic matter in two different theories independently: in the Einstein-Maxwell-Dirac theory and in the second Randall-Sundrum brane-world model.

R. Sengupta et al. explored the possibility of the construction of a traversable wormhole on the Randall-Sundrum braneworld with no exotic matter, utilizing the Kuchowicz potential.

F. R. Klinkhamer presented a traversable–wormhole solution of the gravitational field equation of general relativity without the need for exotic matter.

M. Zubair et al. developed a wormhole solution with non-exotic matter.

Hence, the literature is rich with proposed solutions of traversable wormholes without exotic matter.

CONCLUSION

- The hypothetical quantum foam, symbolizing the volatile and dynamic nature of spacetime on the smallest scales, has been postulated as the origin of intricate structures harboring wormholes in the early universe

- The Roman model has been utilized to demonstrate the expansion of microscopic wormholes into macro-scale one propelled by inflation during the very early age of the universe.

- Assuming the survival of certain proportion of the enlarged wormholes, we examined their subsequent stability against gravitational collapse.

- It was concluded that utilizing dark energy to sustain a wormhole post-inflation remains a speculative yet tantalizing possibility in cosmological discourse.

- Antimatter, characterized by its unique properties of possessing the opposite charge and quantum numbers to ordinary matter, has been postulated as a potential exotic material that could play a crucial role in maintaining the traversability of wormholes. However, the gravitational signature of antimatter remains an elusive subject, and experimental approaches suggesting the gravitational equivalence between matter and antimatter need confirmation by other research groups.

- We further discussed models proposed for traversable wormholes that don't require exotic matter. These models follow different theoretical approaches to solve the problem.

- Future work may involve seeking a unifying model of traversable wormholes based on quantum gravity theory to enhance our understanding of the different stages of wormhole evolution from the microscopic to the macroscopic scale.