WORMHOLES AND FACTORISATION

A Puzzle in Quantum Gravity and Holography

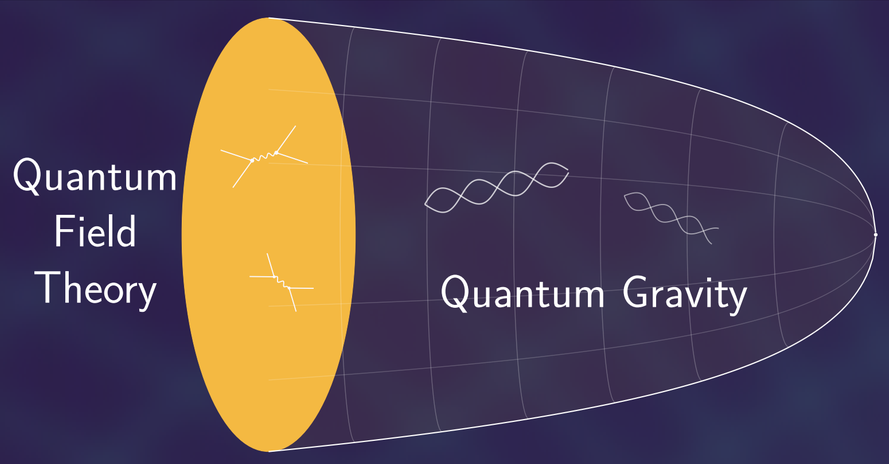
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THE PUZZLE

- Roll two separate dice: one represents system A, the other system B. Seeing the first die should not help you predict the second.
- These dice can represent quantum systems. Through holography, we can also describe them using gravity. In that description, a wormhole can appear to connect them.
- How can they be independent if holography appears to link them?

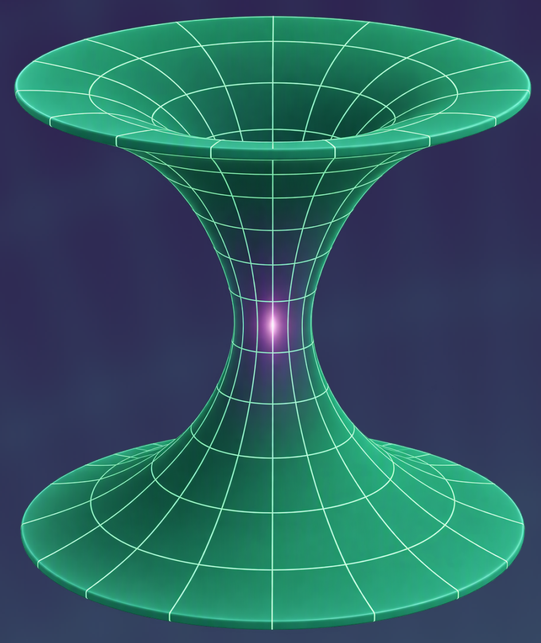


WHAT IS HOLOGRAPHY?



- In certain theories, a quantum system and a theory of gravity are two descriptions of the same physics.
- Holography is a tool that allows us to use quantum systems to study quantum gravity and vice versa.

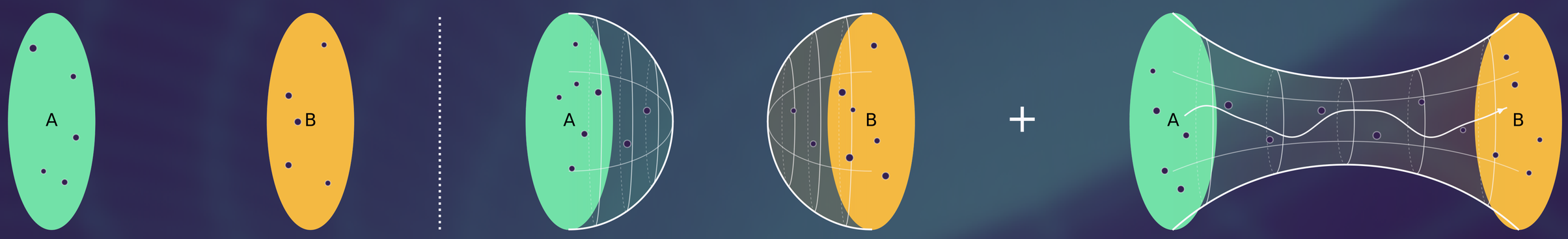
EUCLIDEAN WORMHOLES



- Euclidean wormholes are not shortcuts in spacetime like regular traversable wormholes.
- They are mathematical geometries used in gravity calculations, where time is treated as imaginary.
- Contribute as corrections to standard gravitational physics.

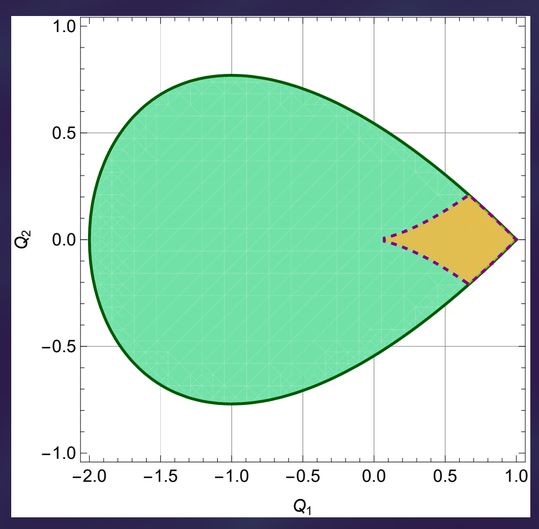
$$Z_{\text{gravity}} \sim Z_{\text{separate}} + Z_{\text{wormhole}}$$

THE FACTORISATION PARADOX



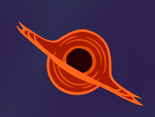
- Computing observables using only the boundary tells us that the two worlds are completely independent: $\langle Z_A Z_B \rangle = \langle Z_A \rangle \langle Z_B \rangle$
- But the quantum gravity calculation with wormholes suggests they are intimately linked: $\langle Z_A Z_B \rangle = \langle Z_A \rangle \langle Z_B \rangle + \langle Z_A Z_B \rangle_{\text{connected}}$

OUR WORK

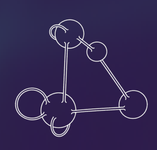


- We look at explicit wormhole examples in string theory.
- Helps improve our understanding of the factorisation paradox.

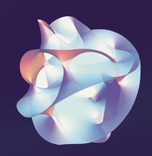
INTERPRETATION



Explains where information goes when it enters a black hole.



Suggests that the universe may be an average of possible universes.



Challenges the conventional understanding of holography.

REFERENCES

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S Coleman (1988). In: *Nuclear Physics B*.

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