

Title: Erik Verlinde: A new view on gravity and the dark side of the cosmos

Date: Oct 04, 2017 07:00 PM

URL: <http://pirsa.org/17100057>

Abstract: <p>Are we standing on the brink of a new scientific revolution that will radically change our views on space, time, and gravity?</p>

<p>In most circumstances, the theories of Einstein and Newton adequately describe gravity, but on cosmological scales, big questions arise, particularly surrounding the nature of dark matter and dark energy.</p>

<p>These questions are ushering in a revolution in theoretical physics â€“ a completely new view on spacetime and gravity. Research in string theory and black hole physics, involving key concepts of quantum information theory, reveals a deep connection between the structure of spacetime and the origin of gravity.</p>

<p>This research suggests that gravity is not a fundamental force of nature, but rather an emergent phenomenon, similar to how temperature is an emergent phenomenon that arises from the movement of particles. That is, gravity is a side-effect, not a cause, of what happens in the universe.</p>

<p>In his public lecture, Dr. Erik Verlinde (University of Amsterdam) will explore the core ideas behind this research, and examine the implications of this fast-emerging revolution in our understanding of the universe.</p>

A NEW VIEW ON GRAVITY AND THE DARK SIDE OF THE COSMOS

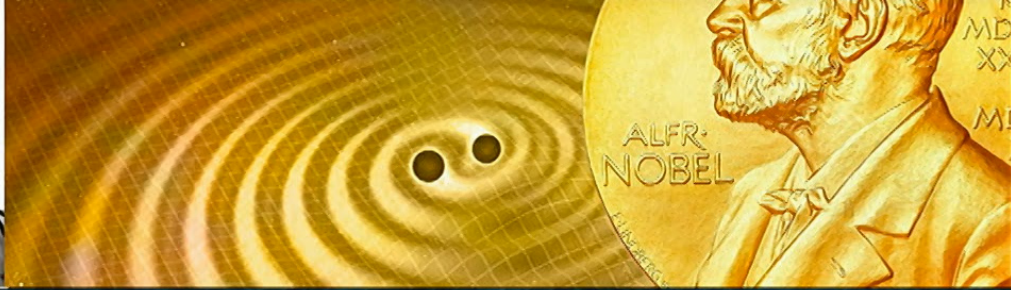
LIVE
WEBCAST

ERIK VERLINDE
Oct. 4 at 7PM ET

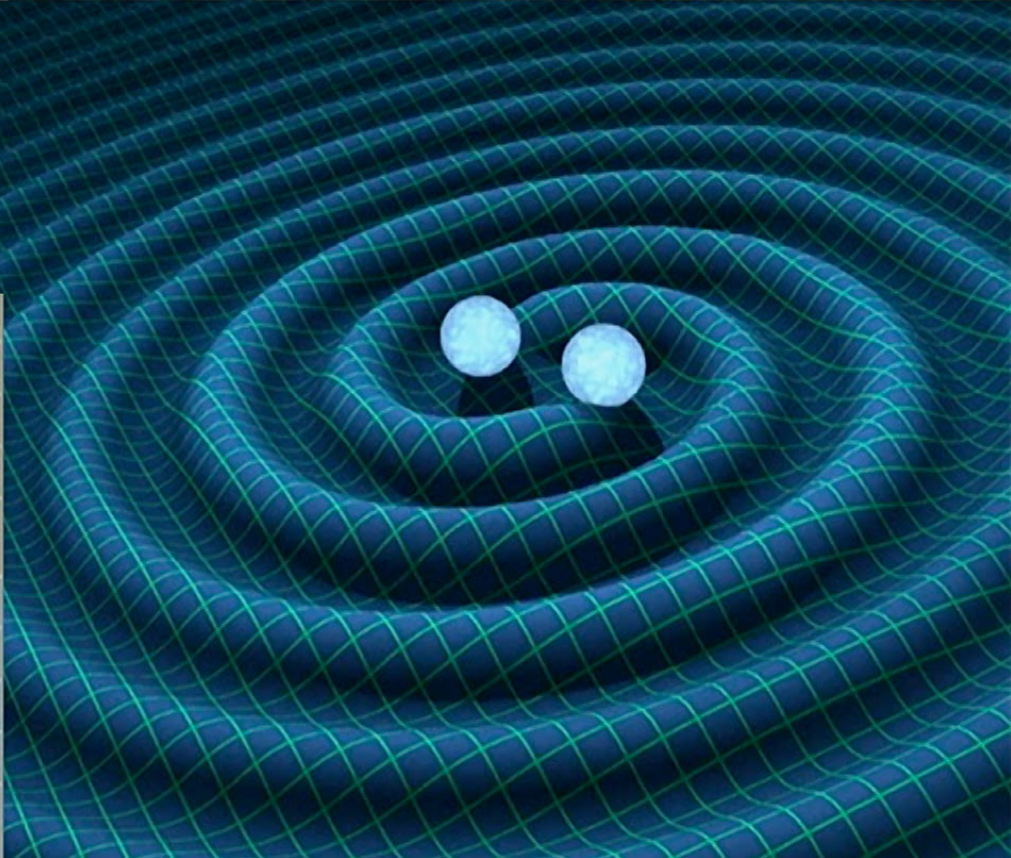
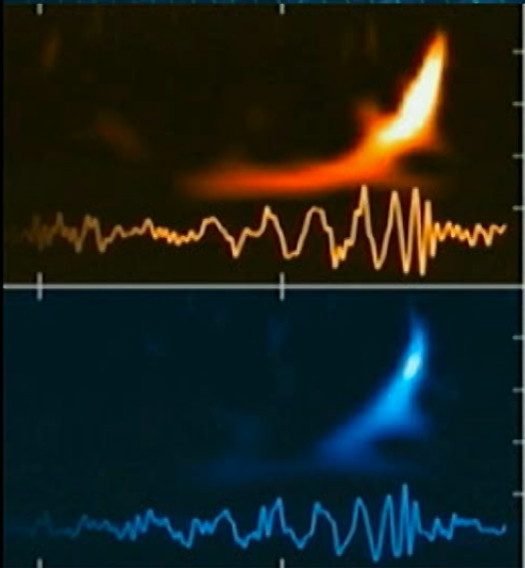
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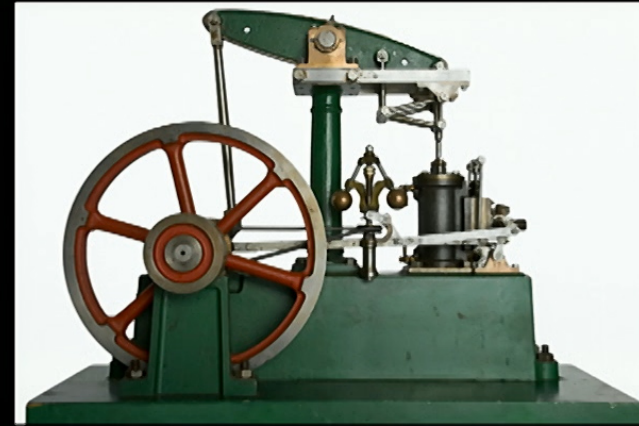


Rainer Weiss, Barry Barish, Kip Thorne



NOBEL PRIZE in Physics 2017





Today's Technology \Leftrightarrow Tomorrow's Science



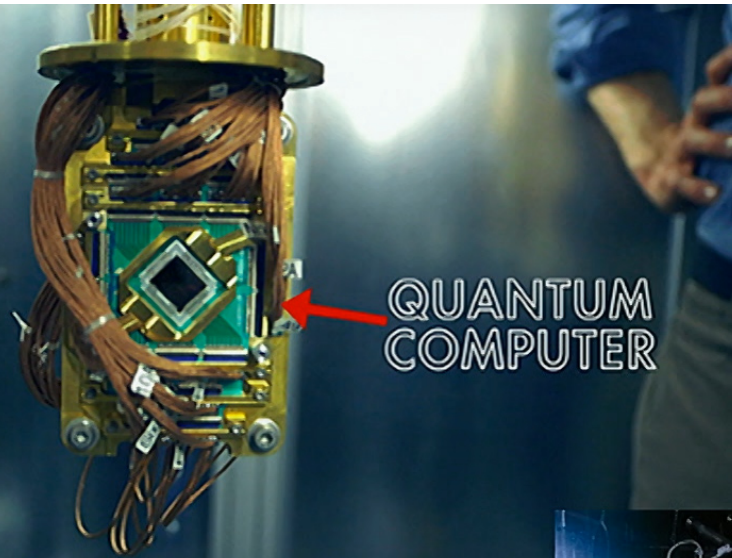
WE LIVE IN AN INFORMATION AGE



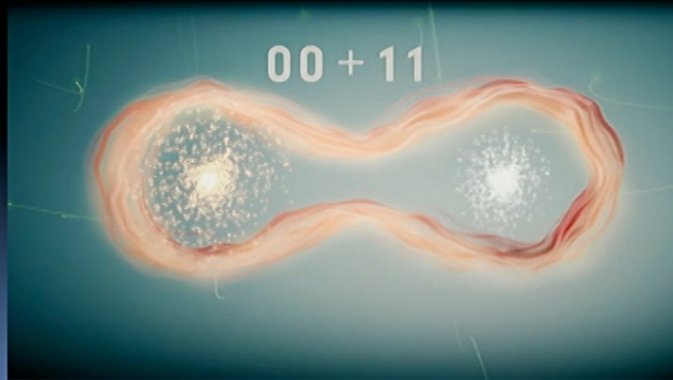
BUT WHAT IS INFORMATION?

INFORMATION IS STORED IN **BITS**

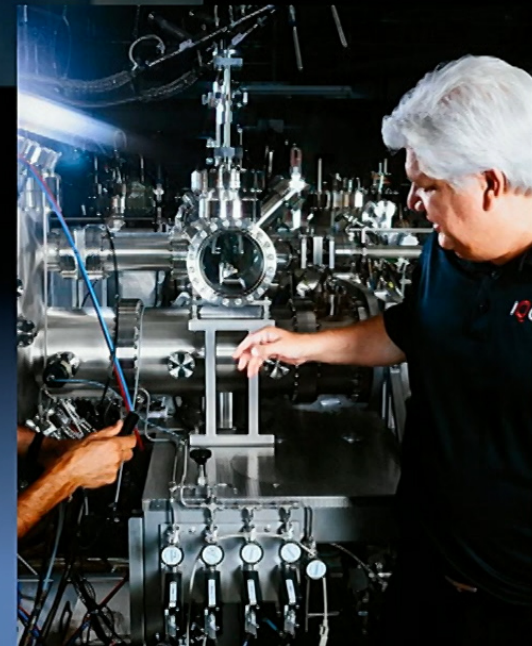
THE AGE
OF QUANTUM
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COMPUTER



ENTANGLED QUBITS

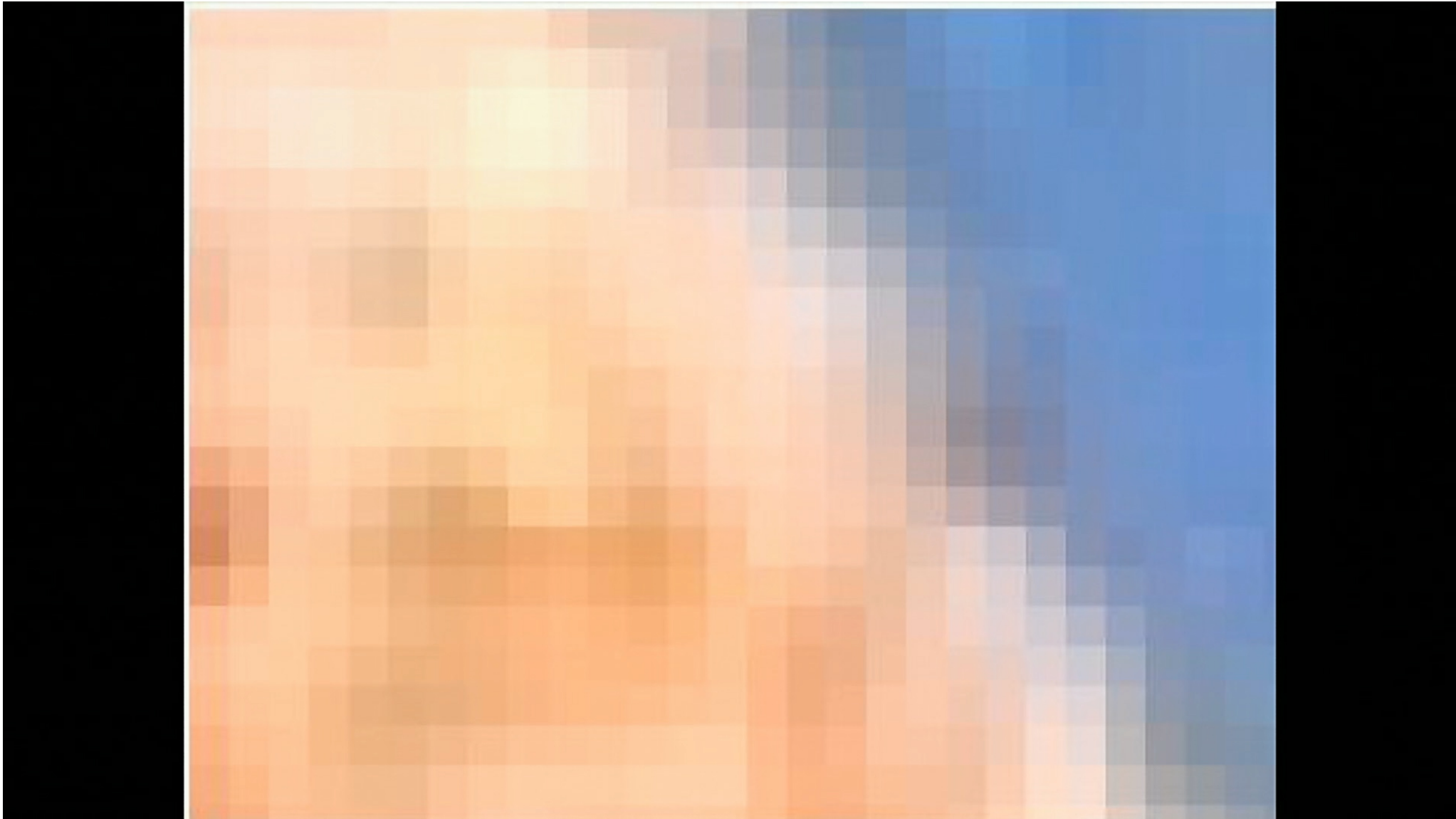


A NEW VIEW ON GRAVITY AND THE DARK SIDE OF THE COSMOS

THE INFORMATION UNIVERSE

ERIK VERLINDE
Oct. 4 at 7PM ET

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EMERGENCE

We use concepts and observe phenomena at a macroscopic scale, which are derived from a microscopic scale where they have no a priori meaning

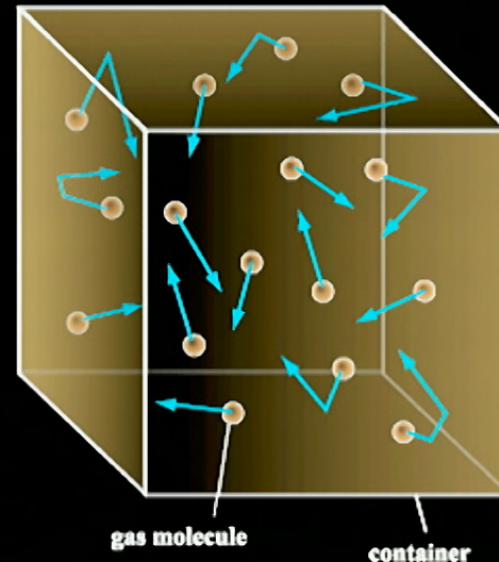


Emergence in Physics

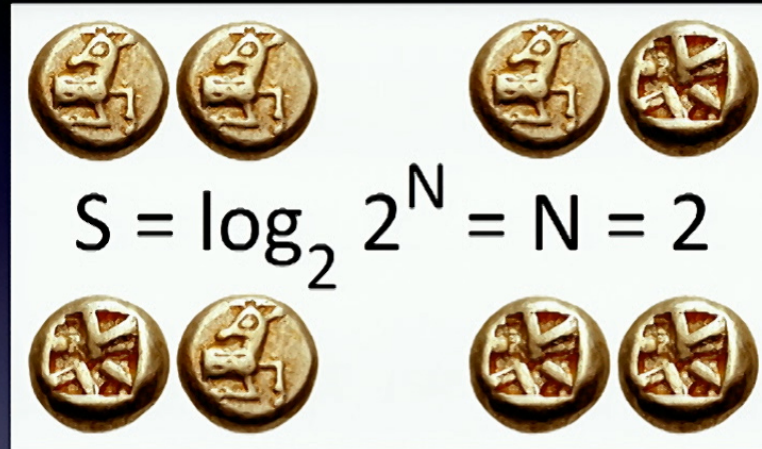
Macroscopic properties is derived from **microscopic** quantities (e.g. by averaging).

Temperature T equals the average energy per molecule

Entropy S measures the number of microscopische possibilities and counts the amount of information needed to describe all the microscopic states.



Entropy and information

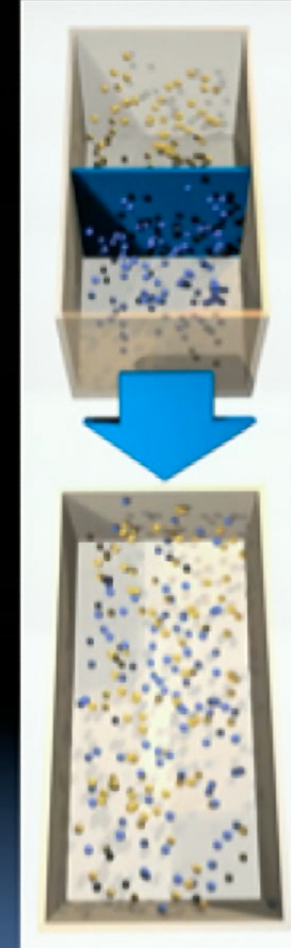
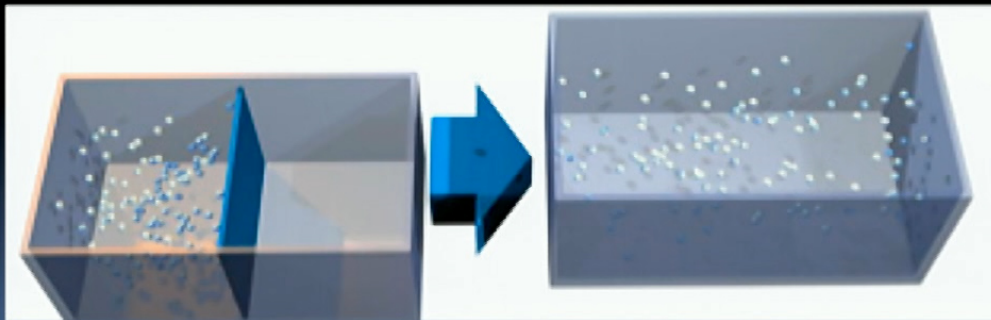


$$S = \log_2 2^N = \# \text{bits}$$

Shannon

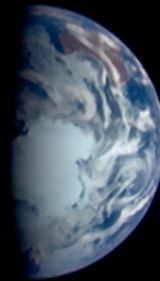
Entropy =
measures the amount of
(inaccessible) information.

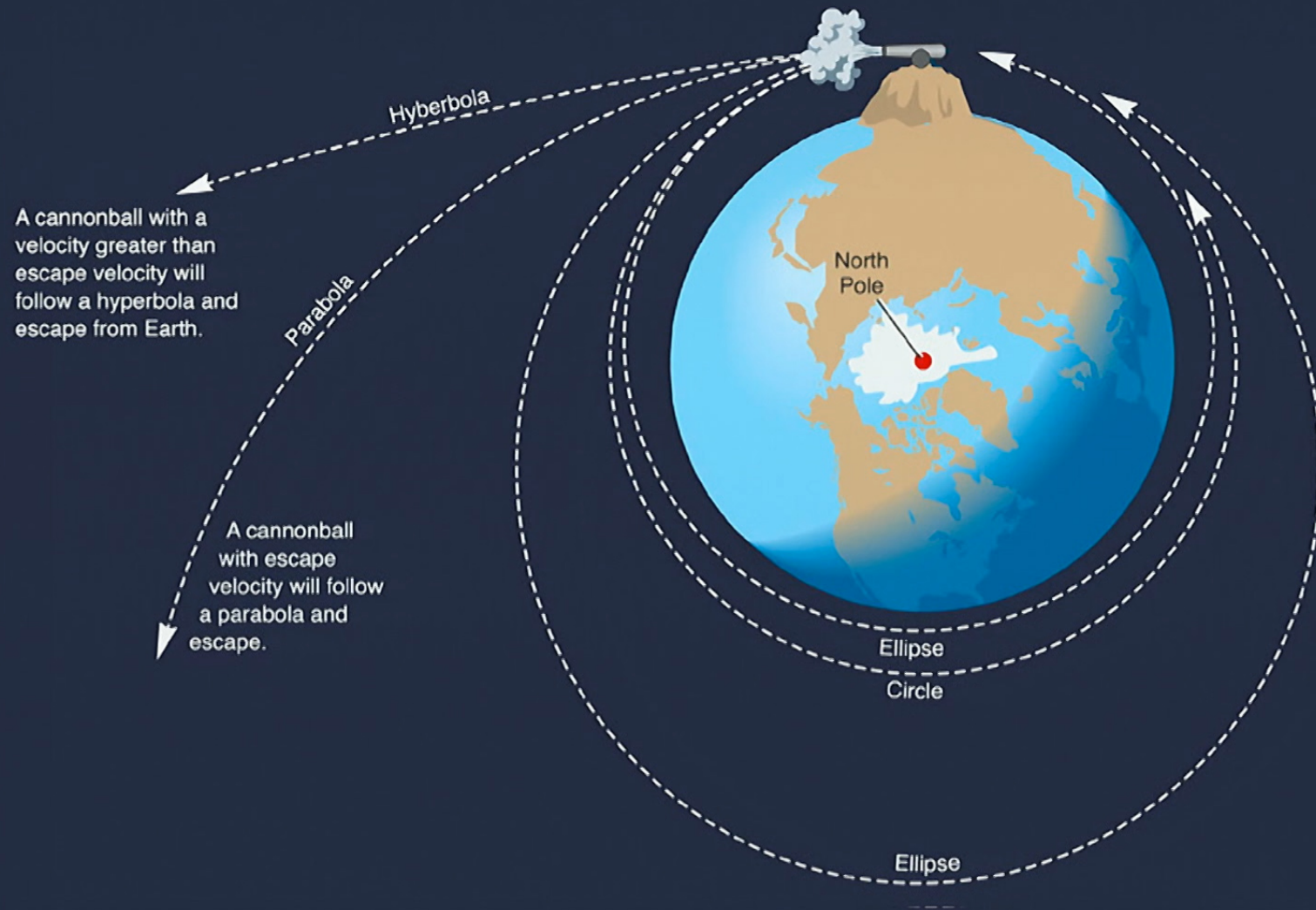
$$S = \# \text{ bits of information}$$





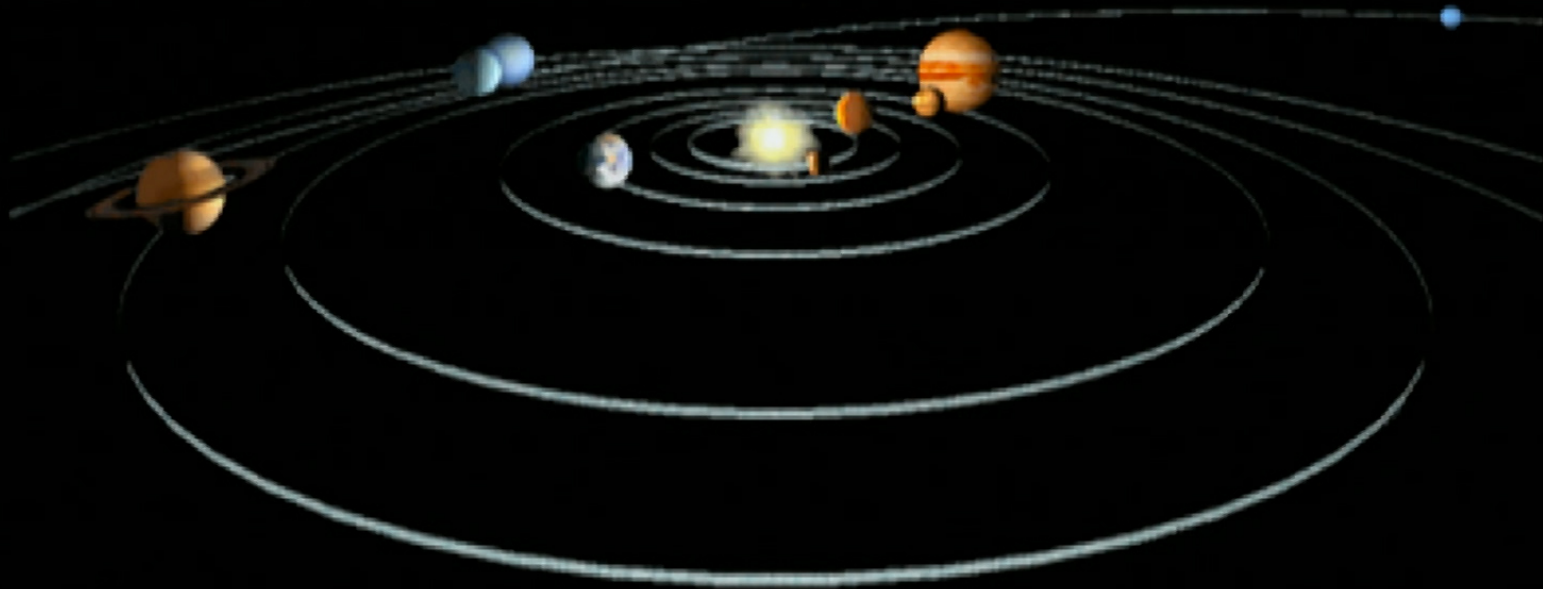
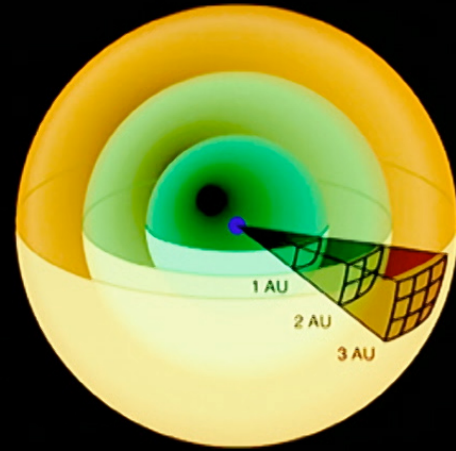
Gravity according to Isaac Newton



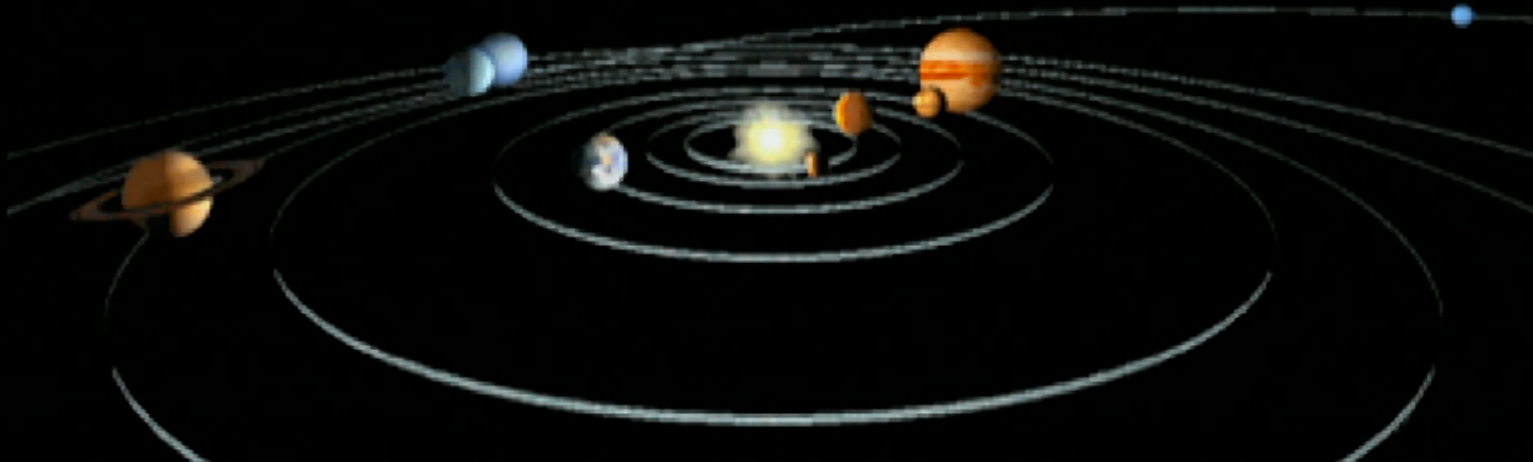
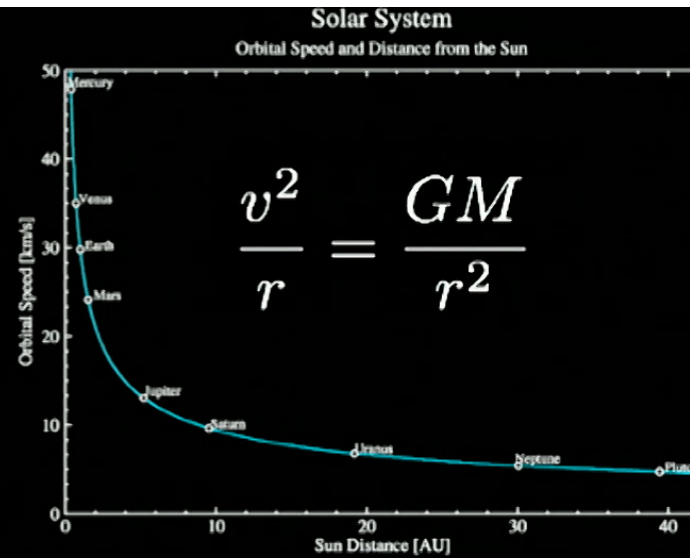


Newton's law of gravity

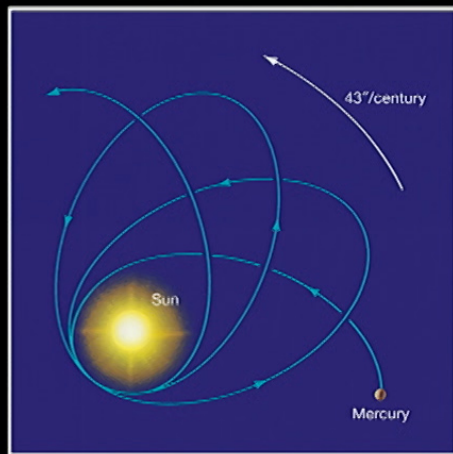
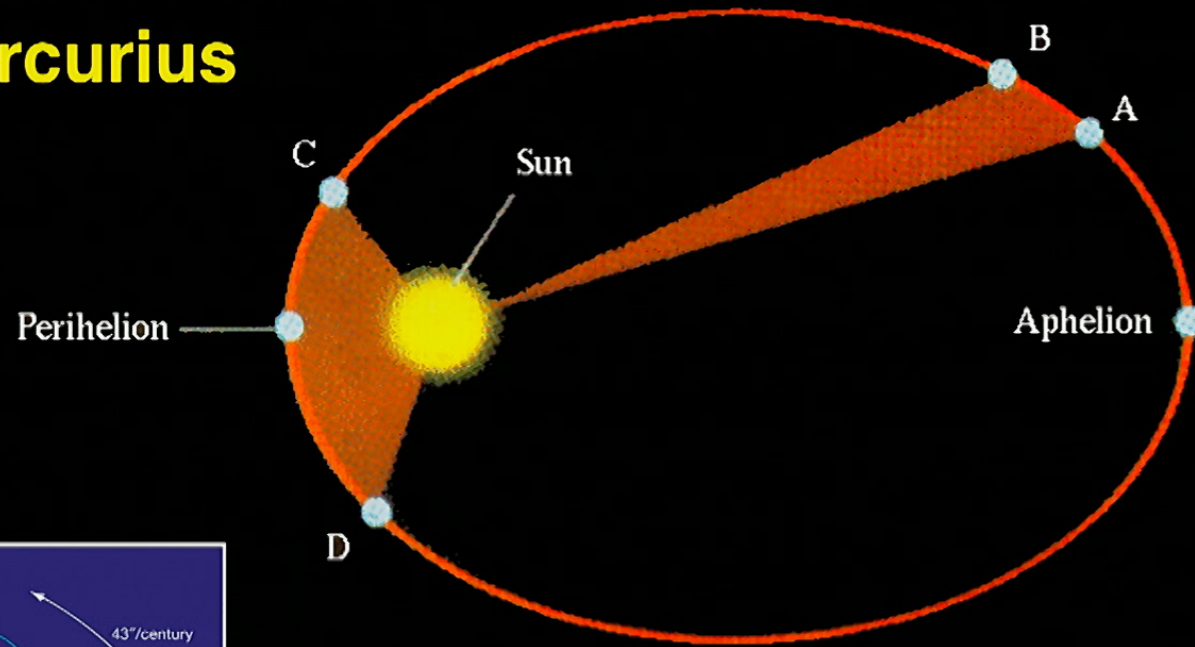
$$F = \frac{GMm}{R^2}$$



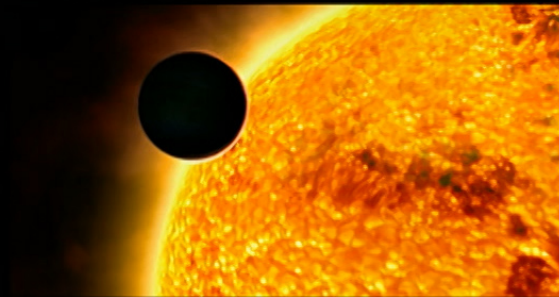
Newton's law of gravity



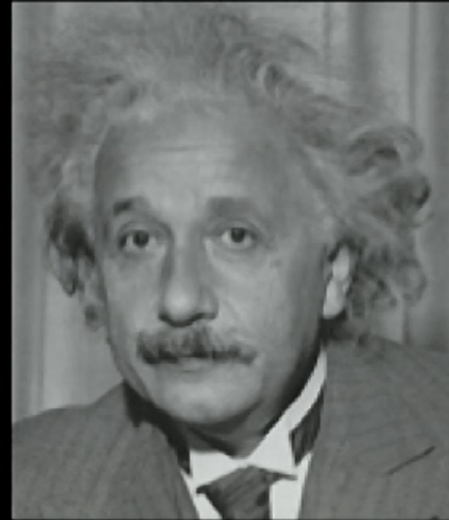
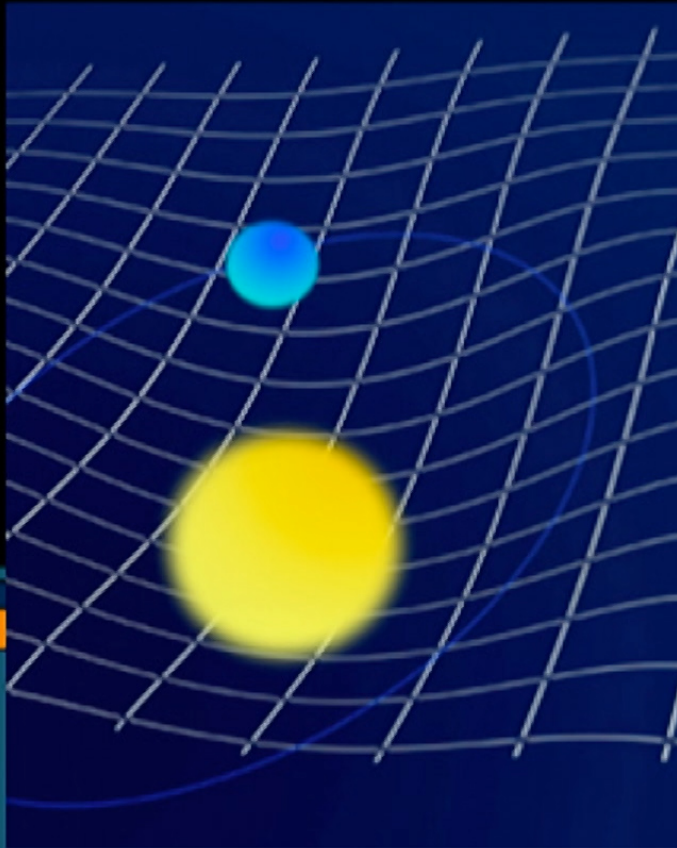
Perihelion shift of Mercurius



Vulcan

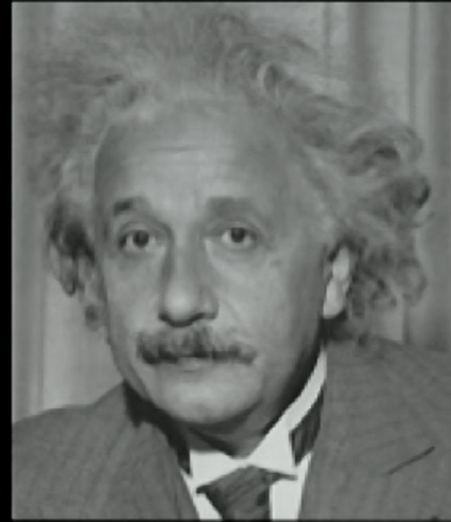
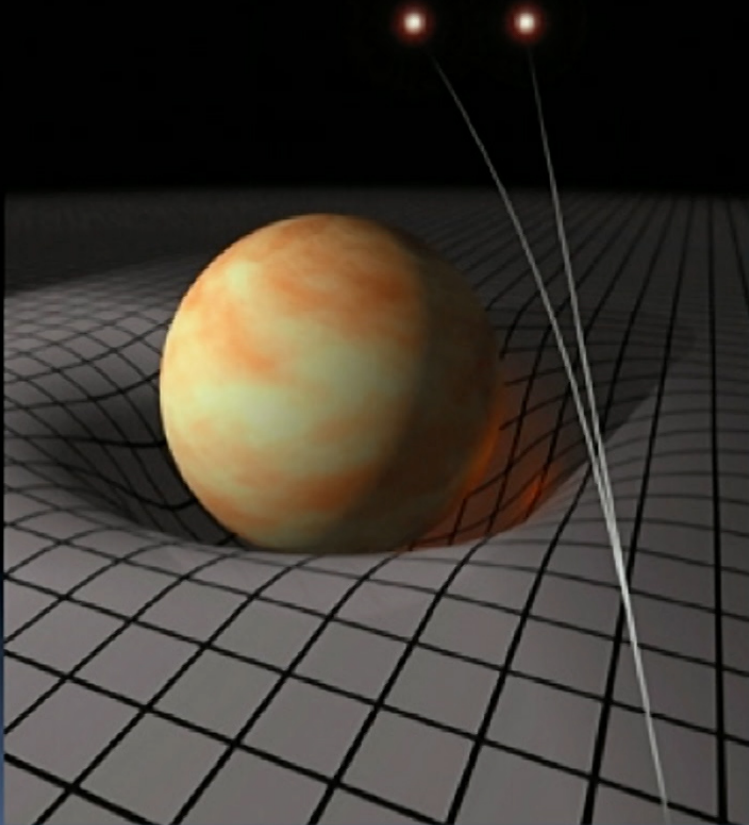


Gravity according to Einstein



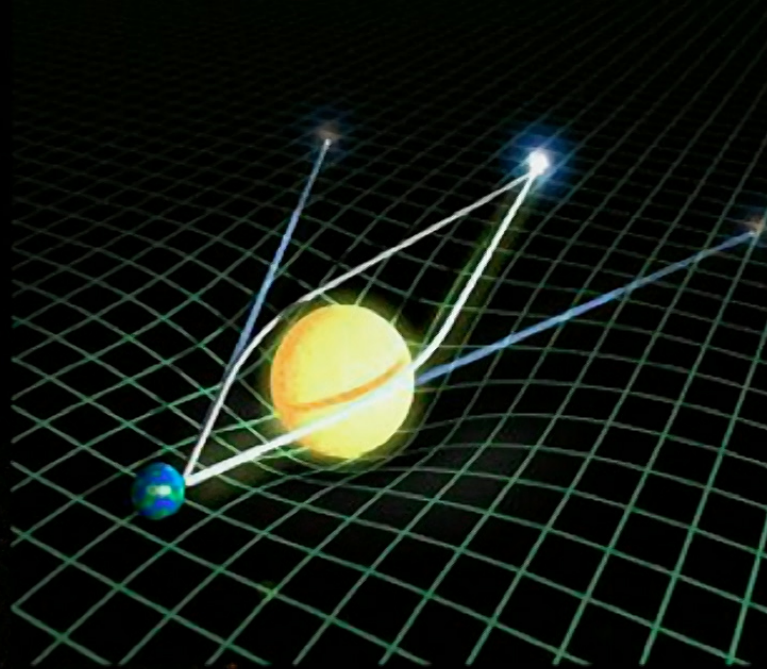
Mass curves
space and time.

Gravity according to Einstein



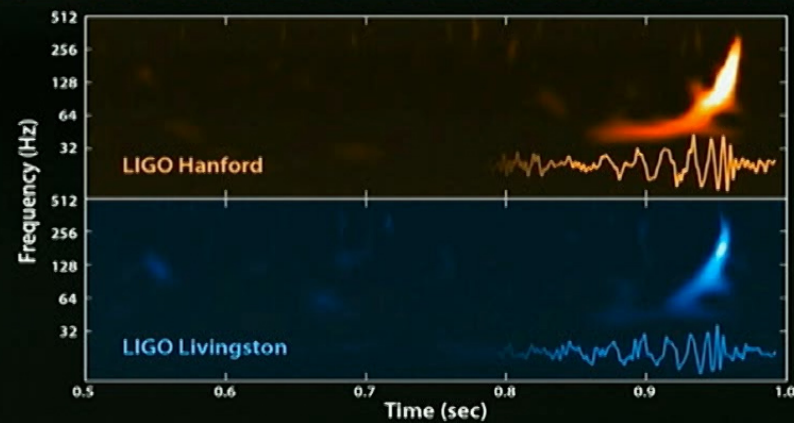
**Light bends
due to gravity**

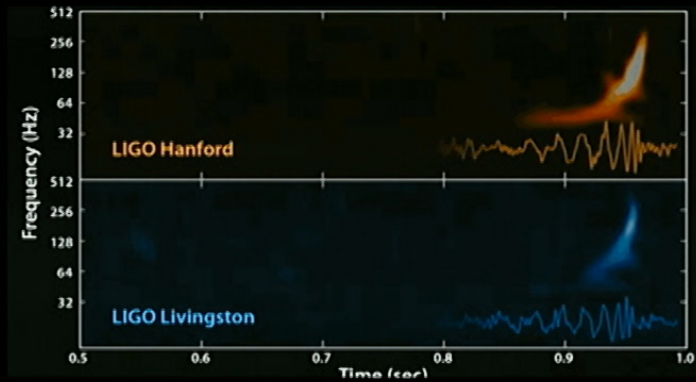
Gravitational lensing



Einstein Ring

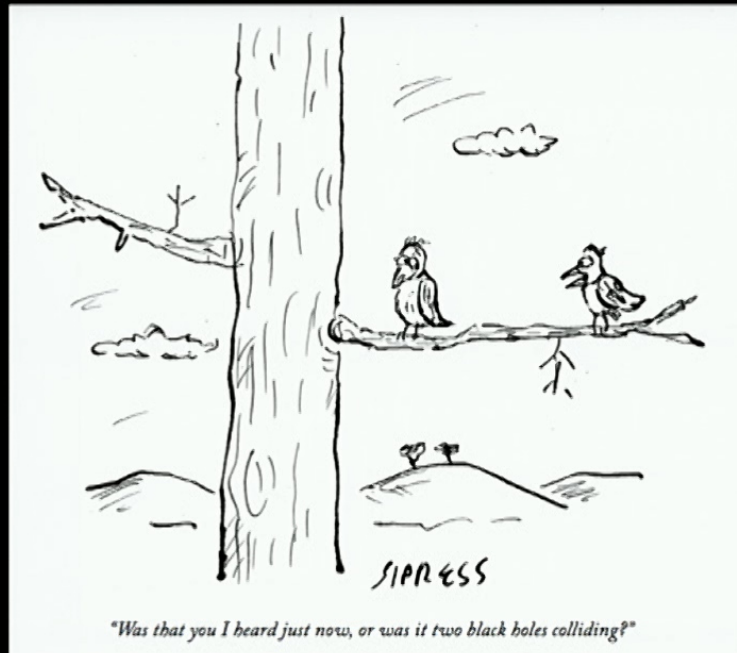
Detection of Gravitational Waves from Merging Black Holes

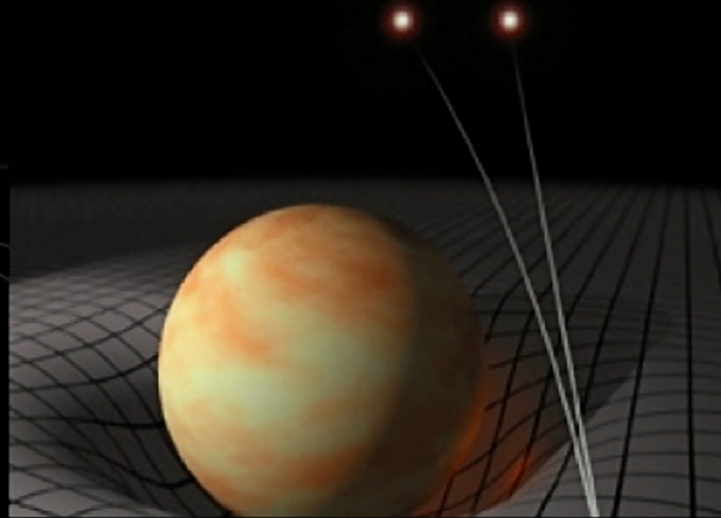
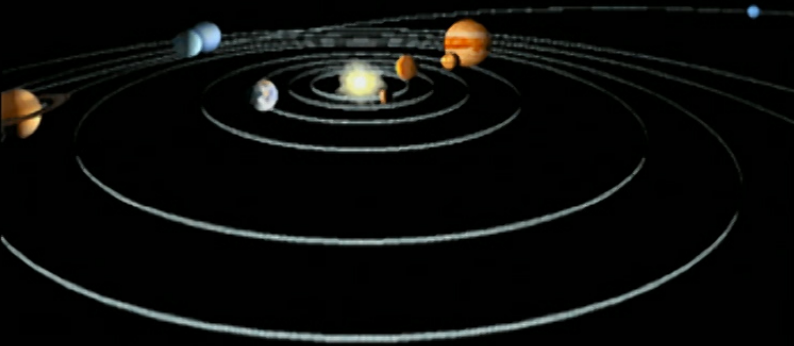
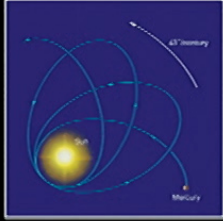




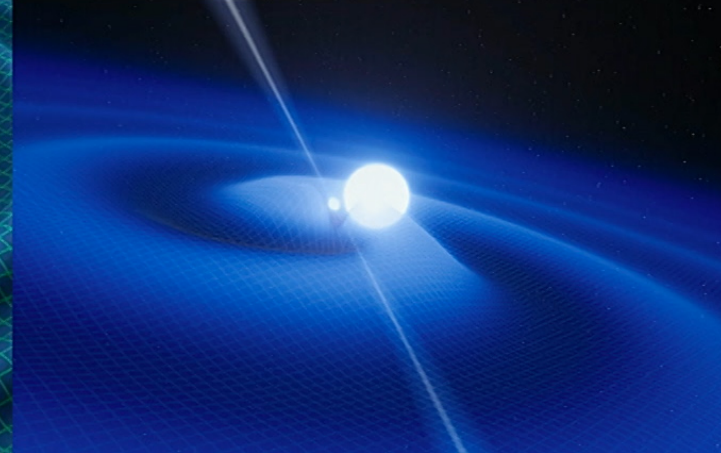
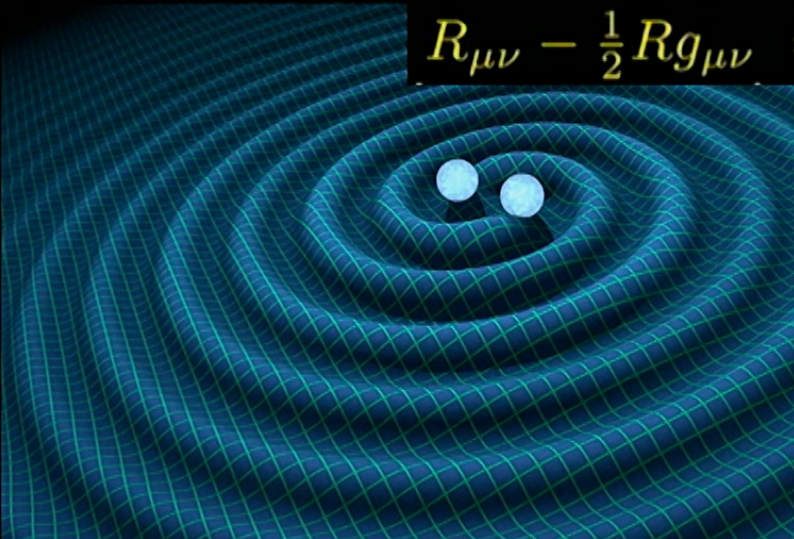
`Chirp`

“Space is enormously stiff”
(Rainer Weiss)





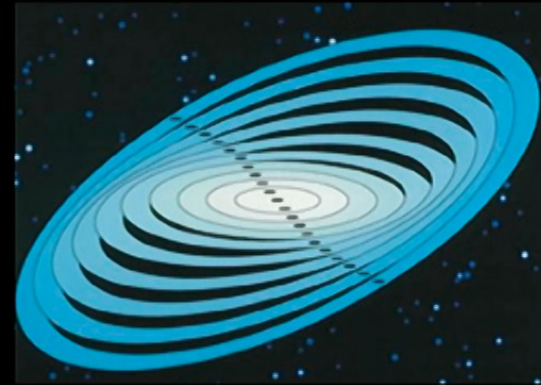
$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = (8\pi G)T_{\mu\nu}$$



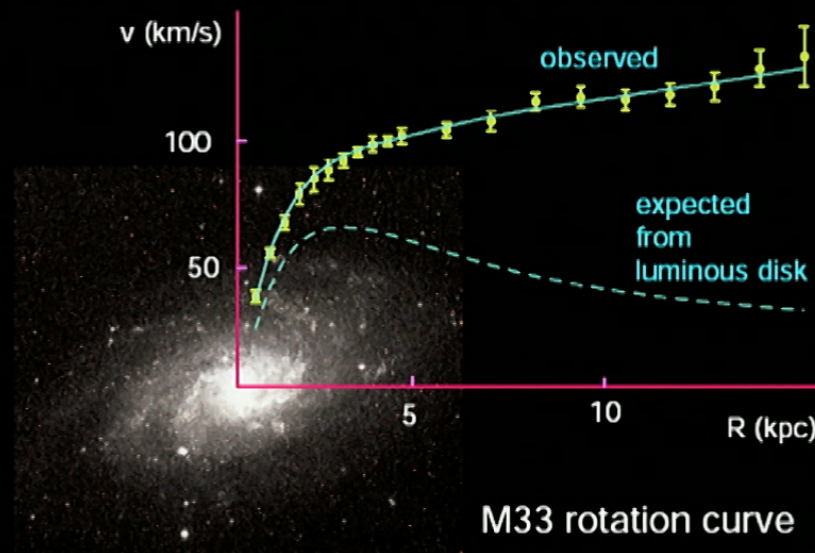
Galaxy

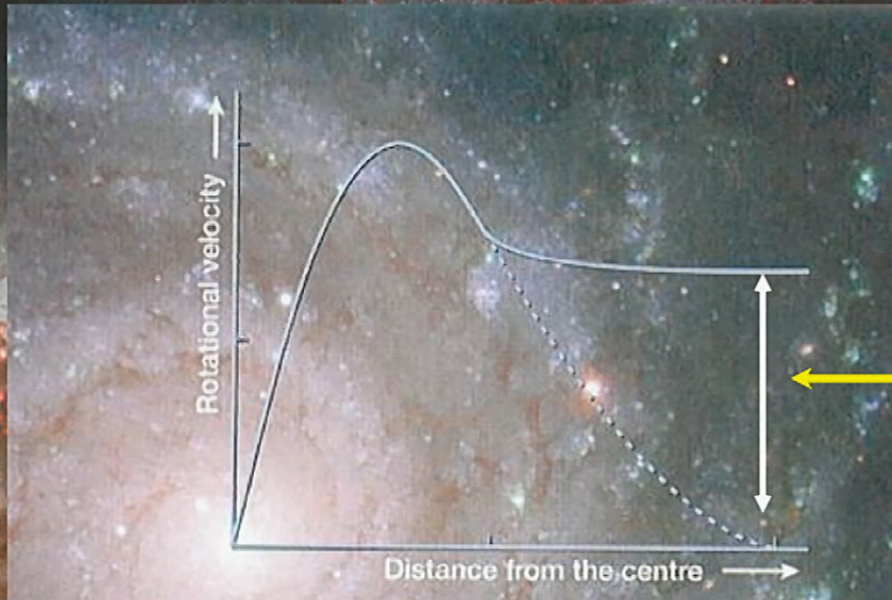


**Does gravity
work the same
at galaxy scales?**



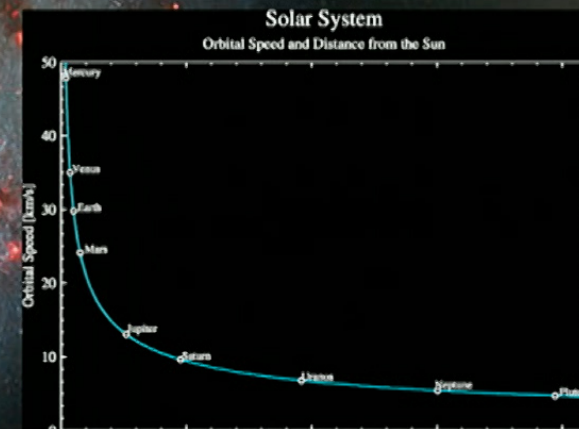
**Rotation velocity
deviates from
expected result**





**What causes
this difference?**

**More gravity is required.
This mean more mass.
Or something else?**

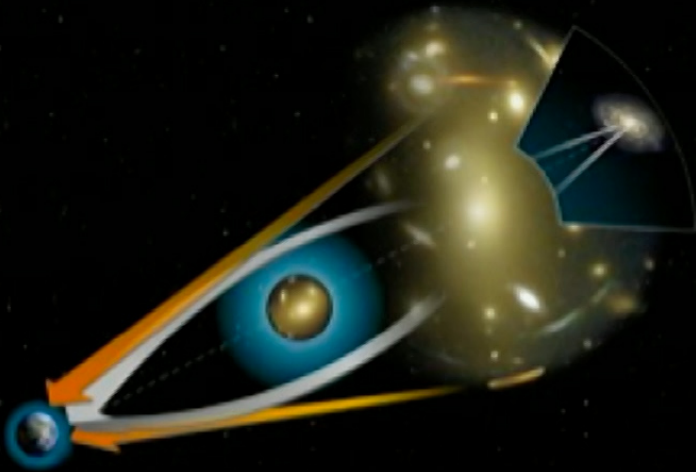


The Dark Matter Hypothesis

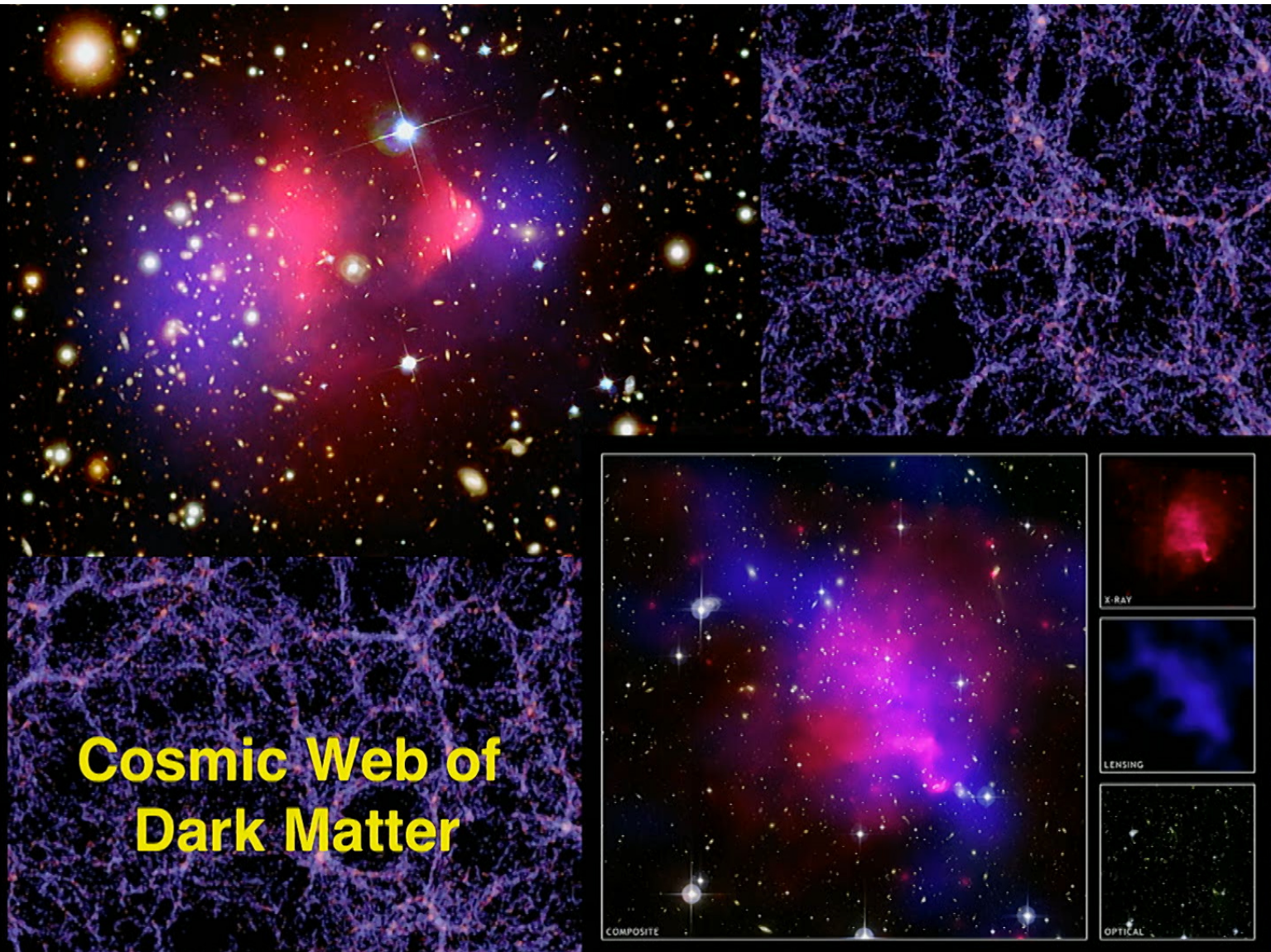


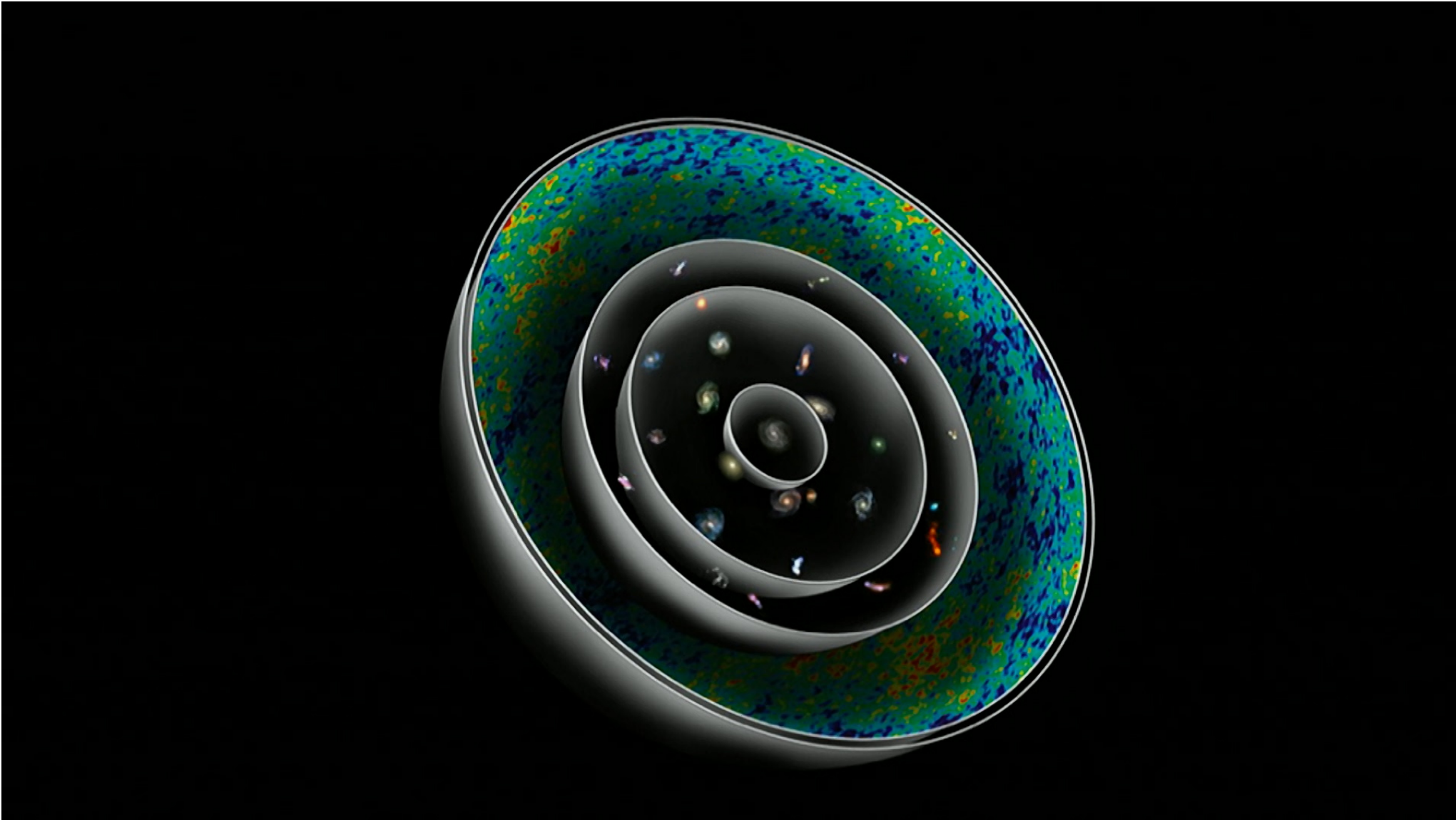
Or is there another explanation?

Gravitational lensing

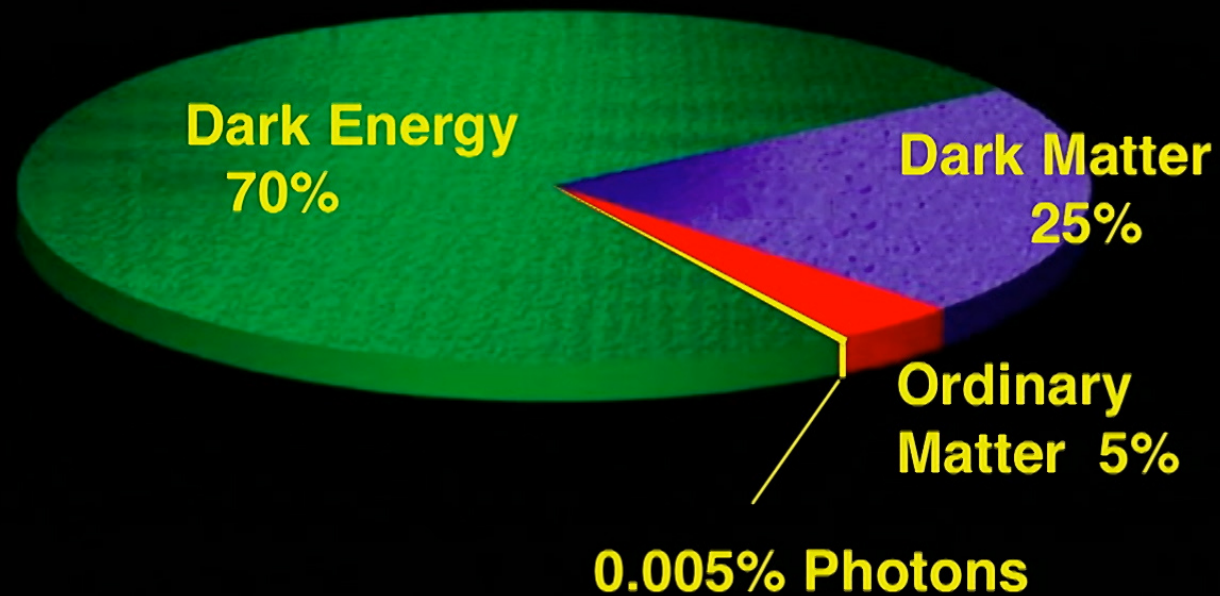


**Mass curves
space and
bends light**





Cosmological energy budget

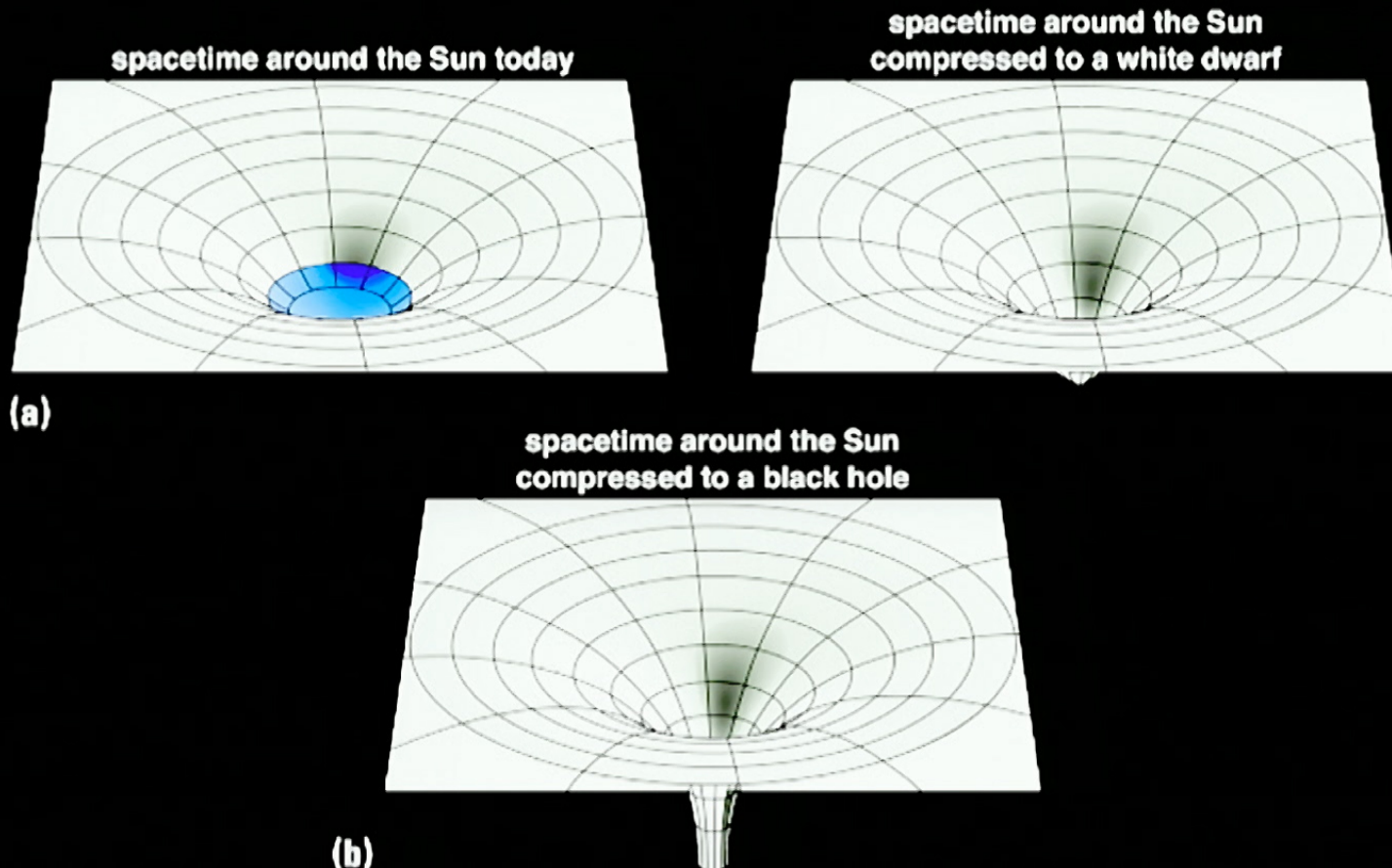


95% is 'missing'!

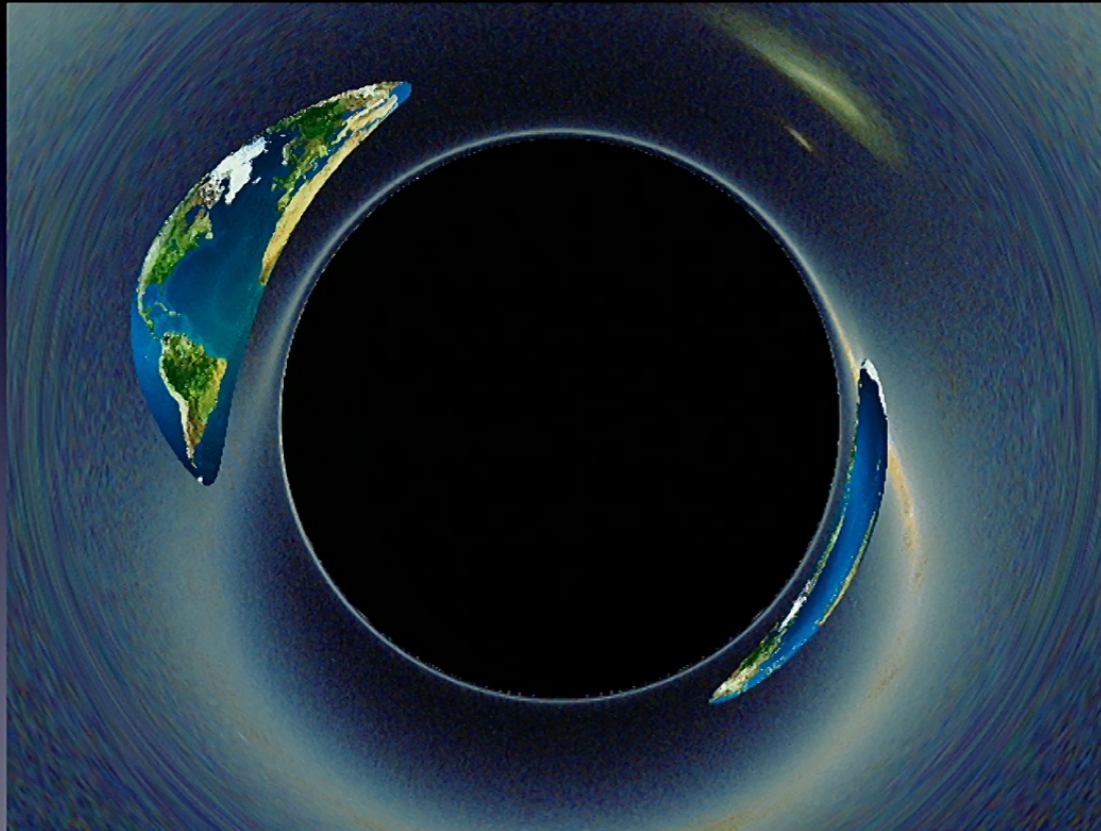
Black Holes



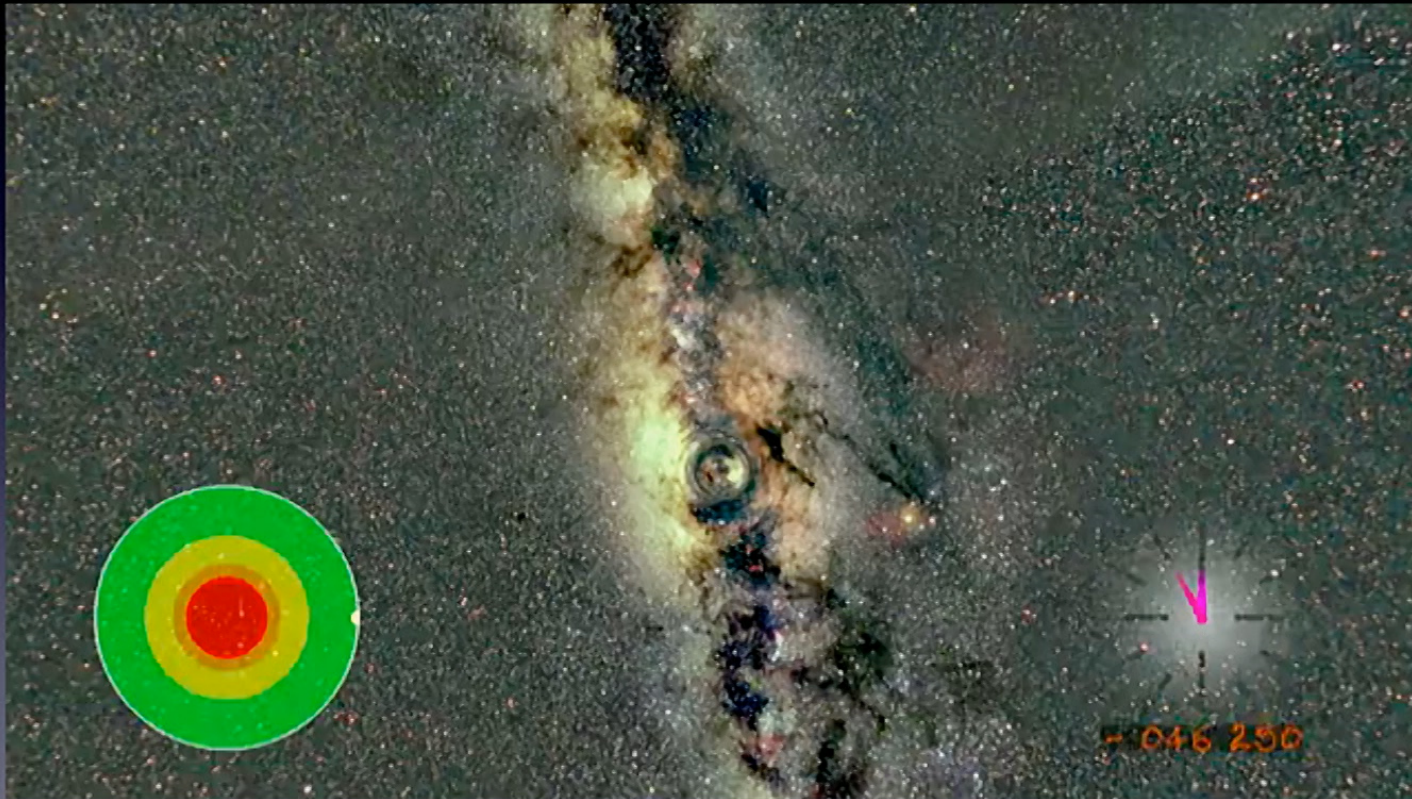
Curved Spacetime near a Black Hole



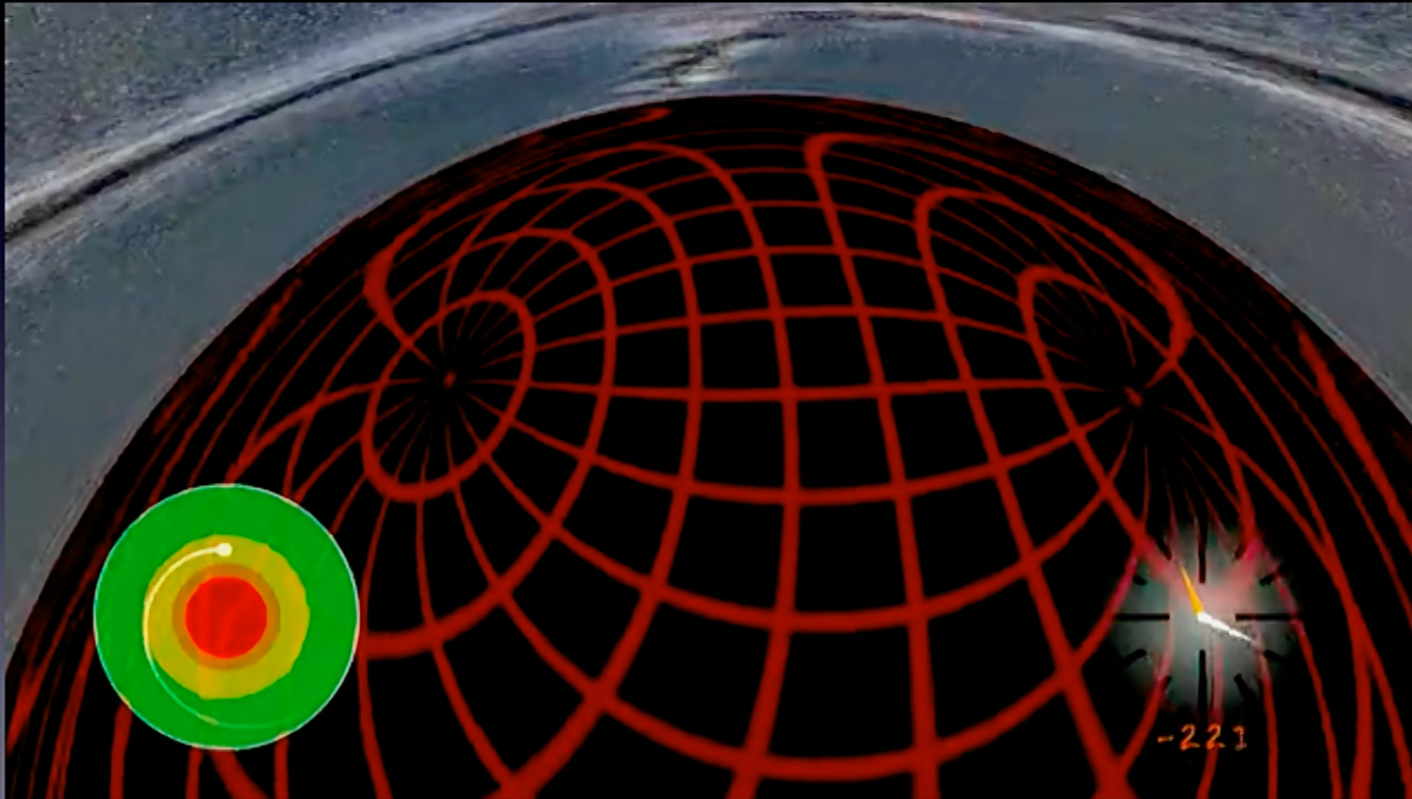
Earth rotating around a black hole

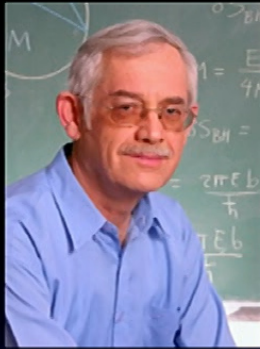


What do you see when falling in a black hole?



What do you see when falling in a black hole?



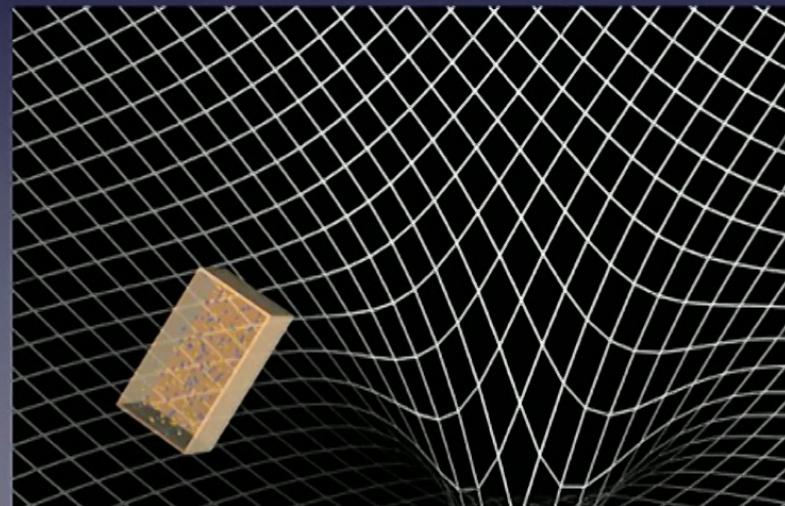
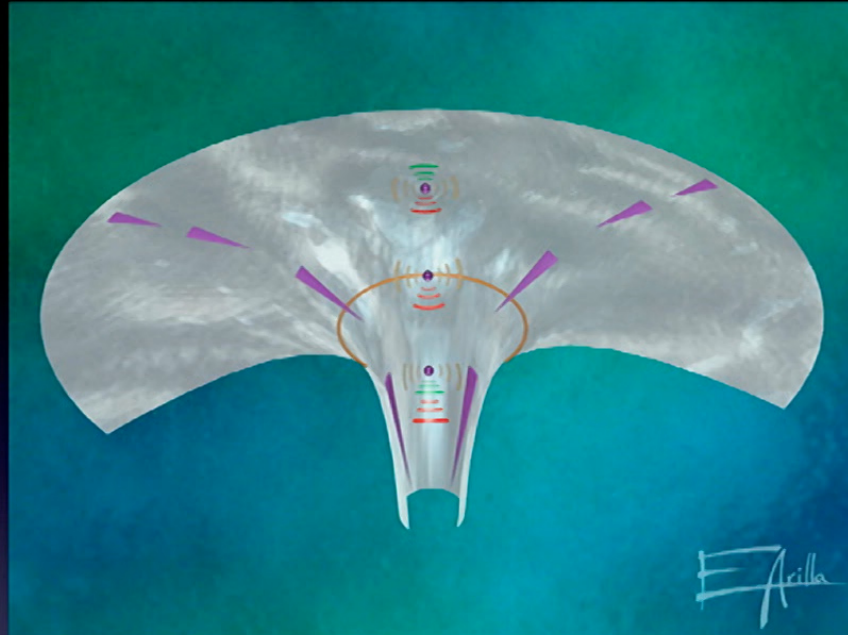


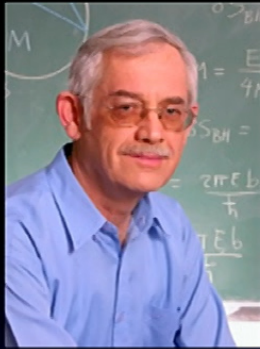
Bekenstein



Hawking

Black Hole Thought Experiments



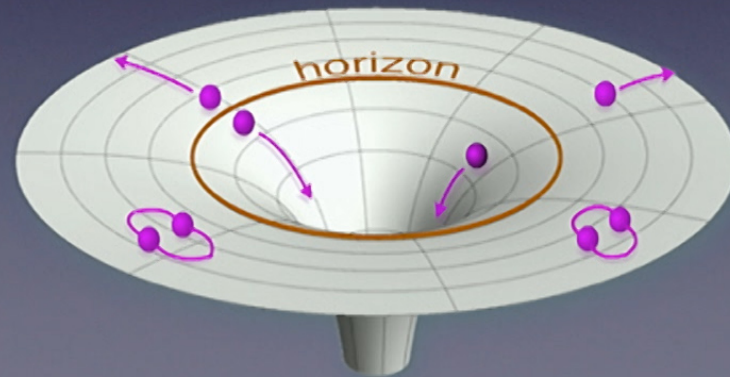
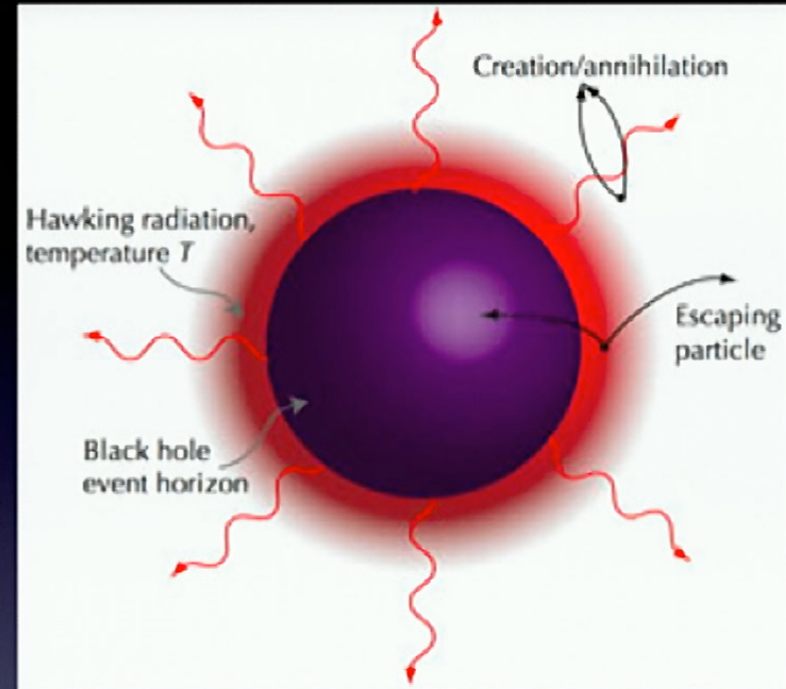


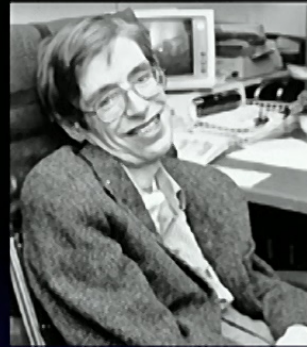
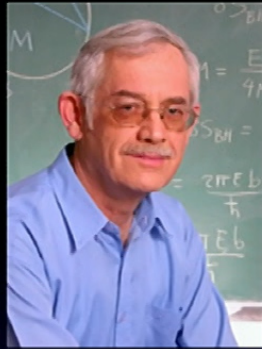
Bekenstein

Hawking

**Black holes
emit radiation**

Temperature

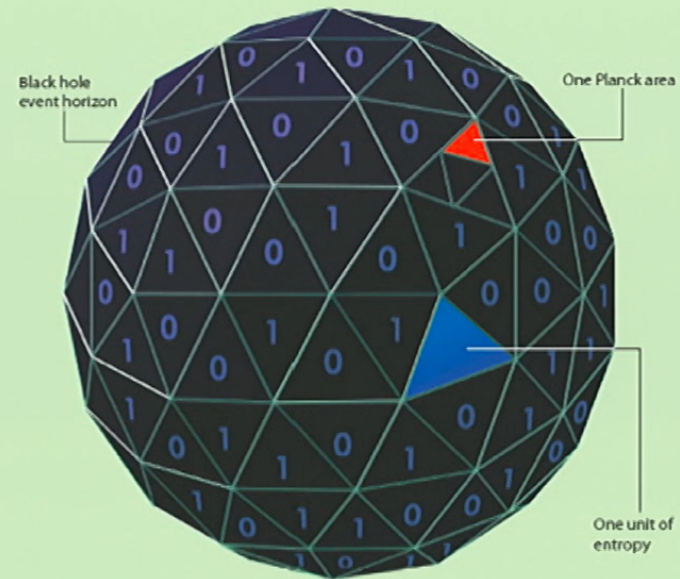




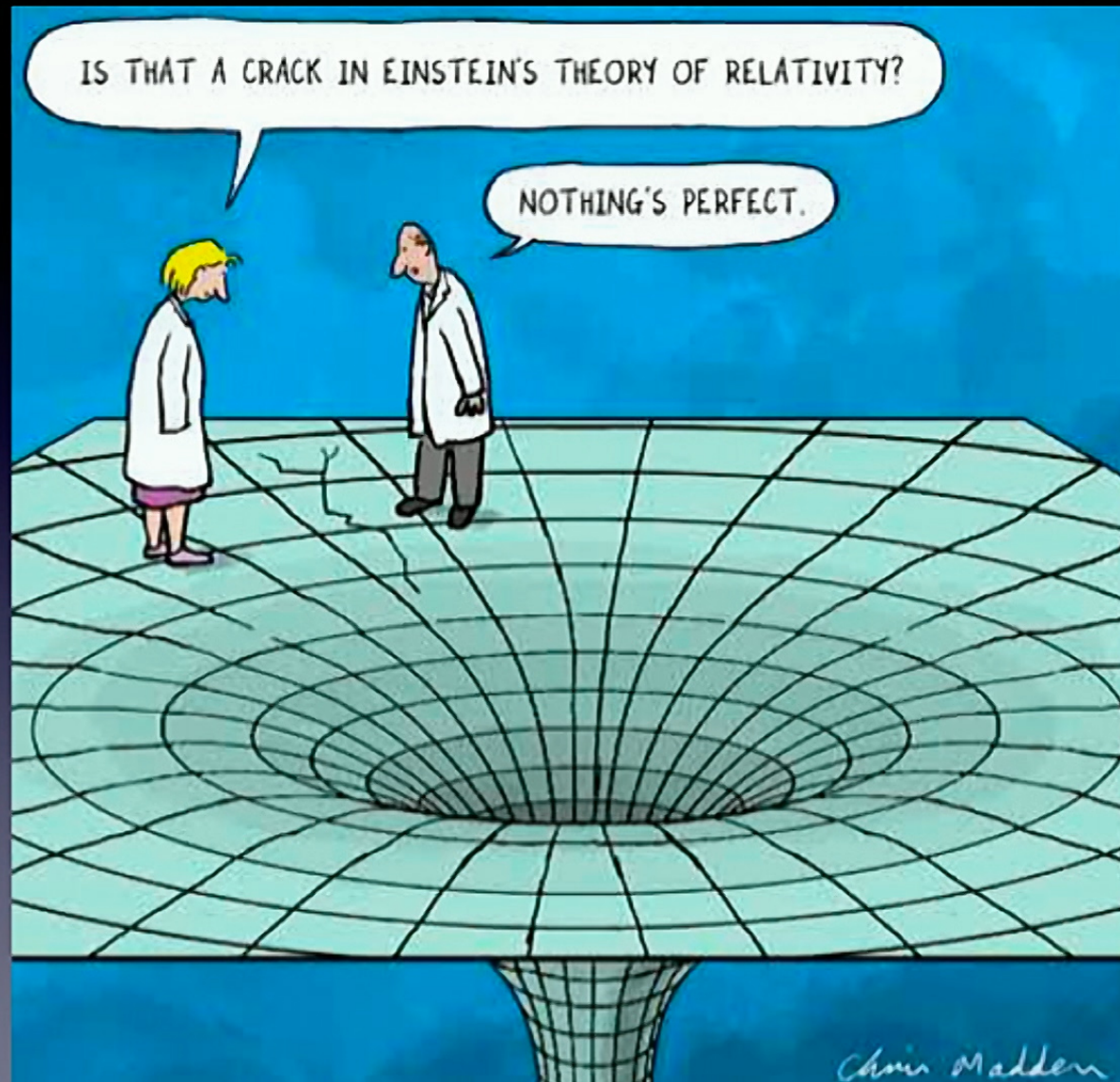
Bekenstein Hawking

**Black holes
carry (or hide)
information.**

Entropy



ENTROPY OF A BLACK HOLE is proportional to the area of its event horizon, the surface from within which even light cannot escape the gravity of the hole. Specifically, a hole with a horizon spanning A Planck areas has $A/4$ units of entropy. (The Planck area, approximately 10^{-66} square centimeter, is the fundamental quantum unit of area determined by the strength of gravity, the speed of light and the size of quanta.) Considered as information, it is as if the entropy were written on the event horizon, with each bit (each digital 1 or 0) corresponding to four Planck areas.



**Black holes hide
(or carry)
information**



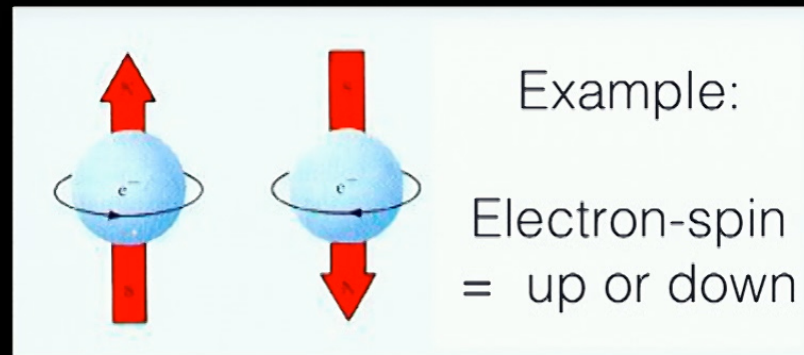
$$S = \log_2 2^N = \# \text{bits}$$



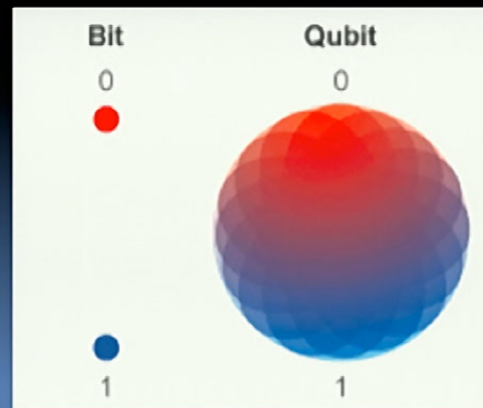
$$S = \frac{\text{Area}}{4G\hbar} c^3$$

**The amount of information
is determined by the area of
the black hole horizon.**

Quantum-information:



Bits vs. Qubits

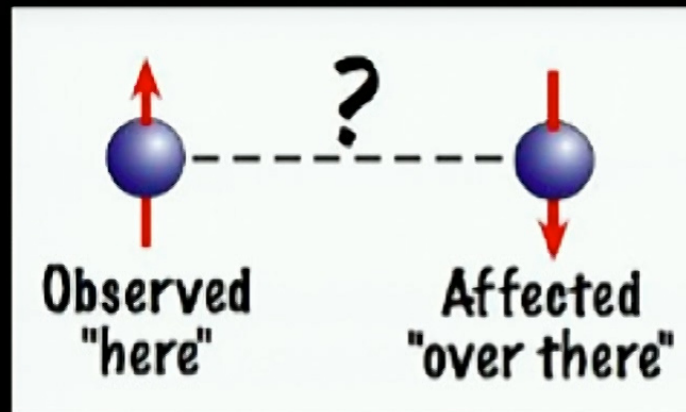


Qubits allow
superposition
of up and down
or
of 0 and 1.

Quantum Entanglement



The result of the first measurement determines instantaneously the outcome of the second measurement.

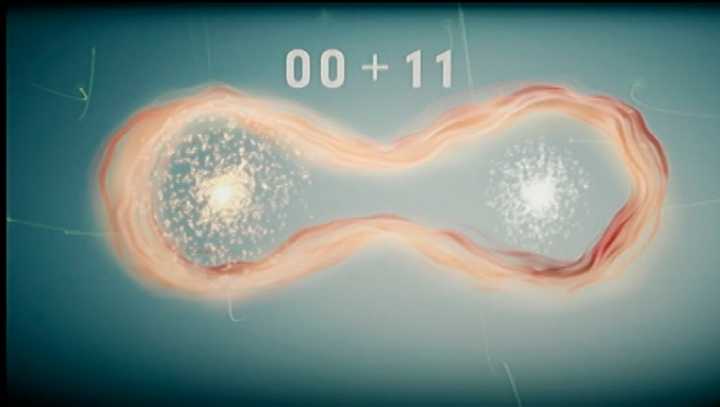


Entanglement is a property of the quantum state before the measurements are done.

Quantum entanglement



Einstein-Podolsky-Rosen

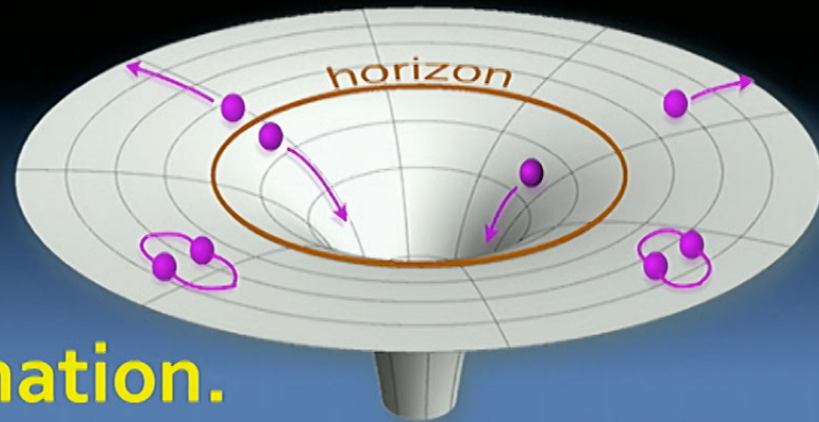


Entangled qubits

**What kind of
information
is this?**

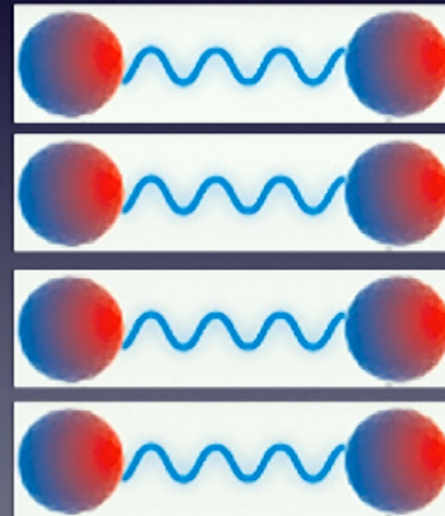


**Answer:
Entangled
Quantum Information.**

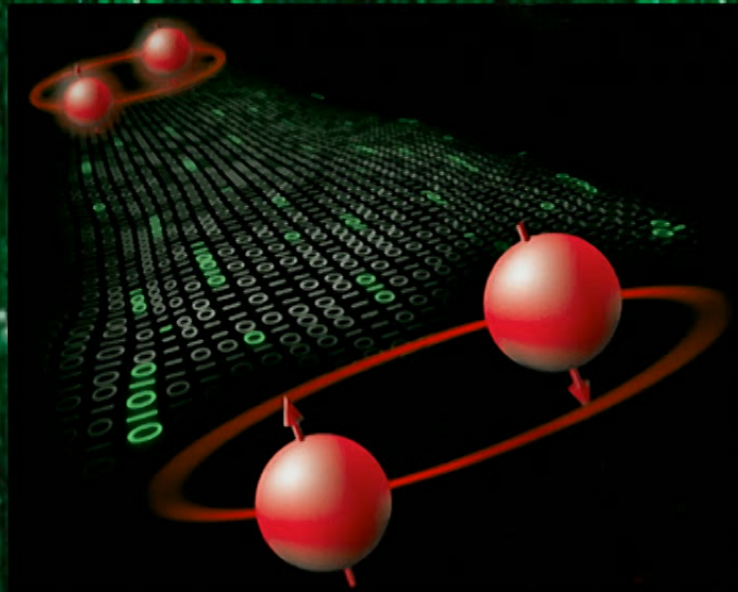


Building blocks of space time = entangled qubits

$$S = \frac{Area}{4G\hbar} c^3 = \# \text{ entangled qubits}$$



**Space time & gravity are emergent
and are derived from
entangled quantum information?**



Is there any observational evidence?

On the origin of gravity and the laws of Newton

Erik Verlinde

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ABSTRACT: Starting from first principles and general assumptions we present a heuristic argument that shows that Newton's law of gravitation naturally arises in a theory in which space emerges through a holographic scenario. Gravity is identified with an entropic force caused by changes in the information associated with the positions of material bodies. A relativistic generalization of the presented arguments directly leads to the Einstein equations. When space is emergent even Newton's law of inertia needs to be explained. The equivalence principle suggests that it is actually the law of inertia whose origin is entropic.

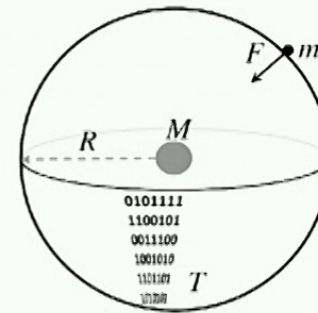
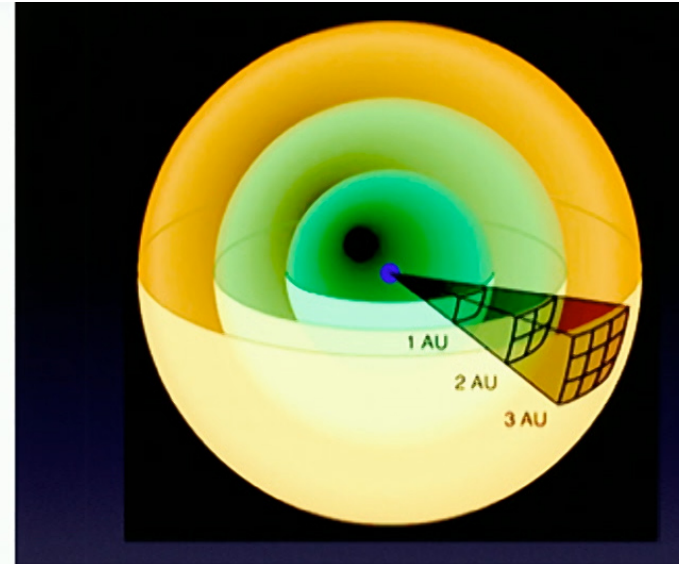
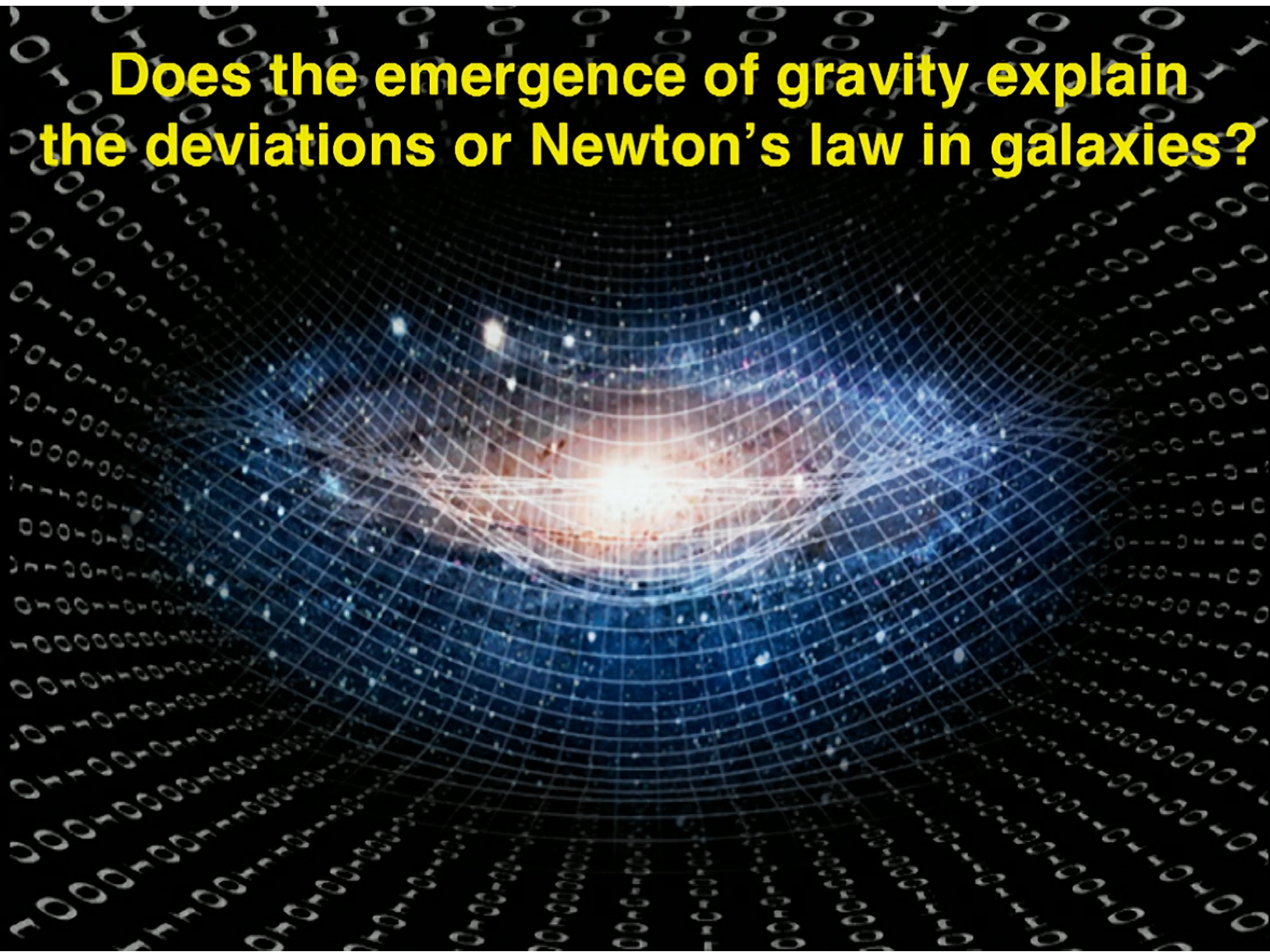


Figure 3. A particle with mass m near a spherical holographic screen. The energy is evenly distributed over the occupied bits, and is equivalent to the mass M that would emerge in the part of space surrounded by the screen.

and one obtains the familiar law:

$$F = G \frac{Mm}{R^2}. \quad (3.9)$$

**Does the emergence of gravity explain
the deviations or Newton's law in galaxies?**

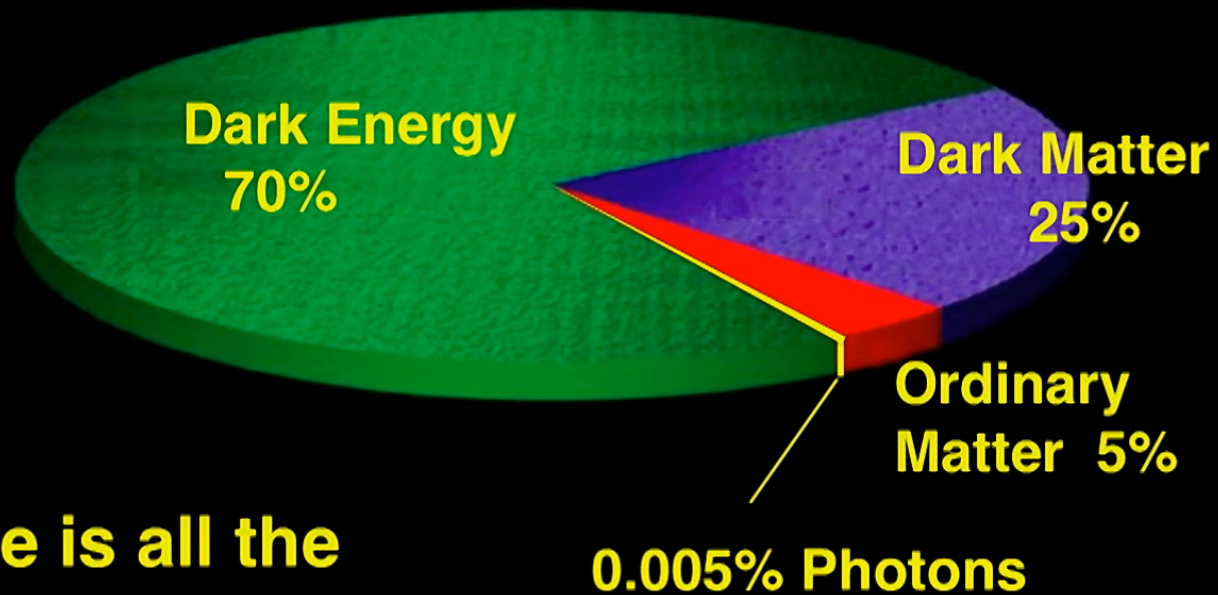
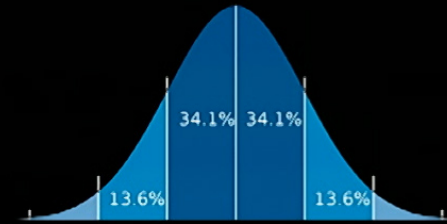




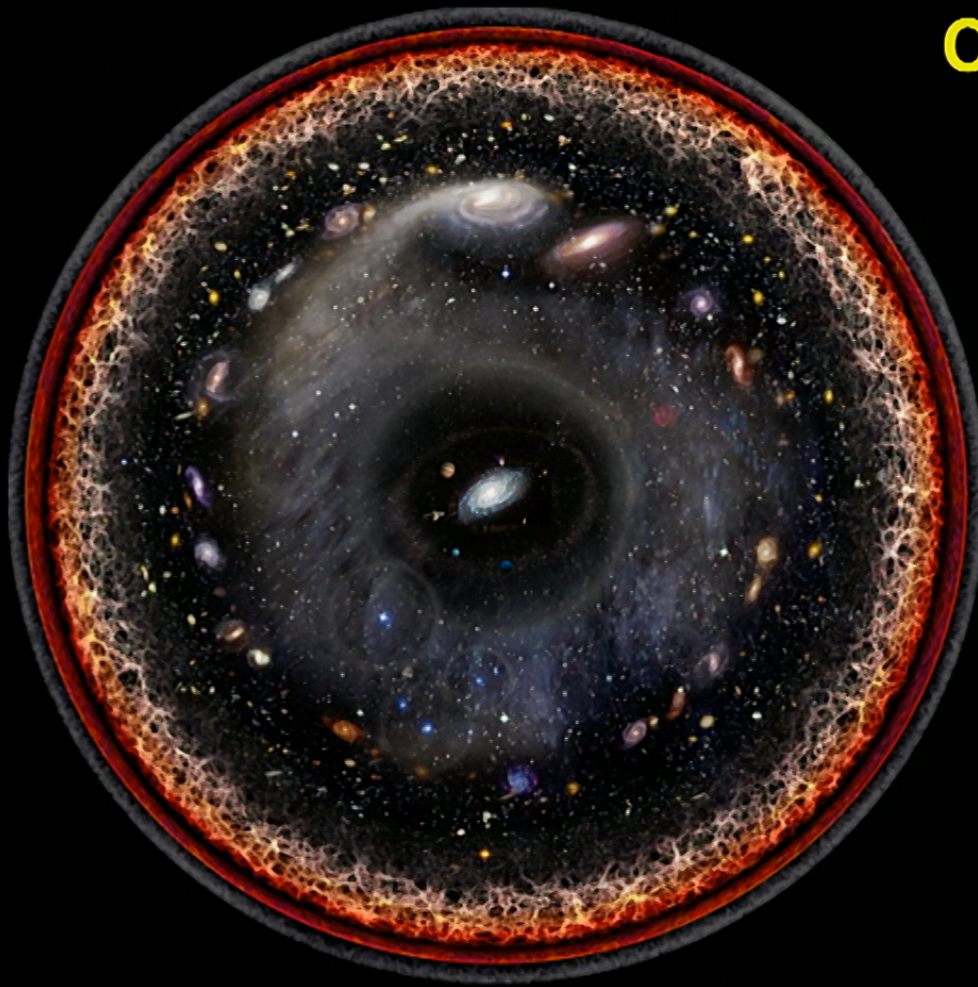
If you're to scale the history of the earth to a single year, humans wouldn't appear till December 31, 11.58 pm on New Year's Eve!

On that same timescale we have observed the Universe for only a fraction of a second.

Cosmological energy budget



Where is all the information?



Cosmological Horizon

Hubble's law

$$v = Hd$$

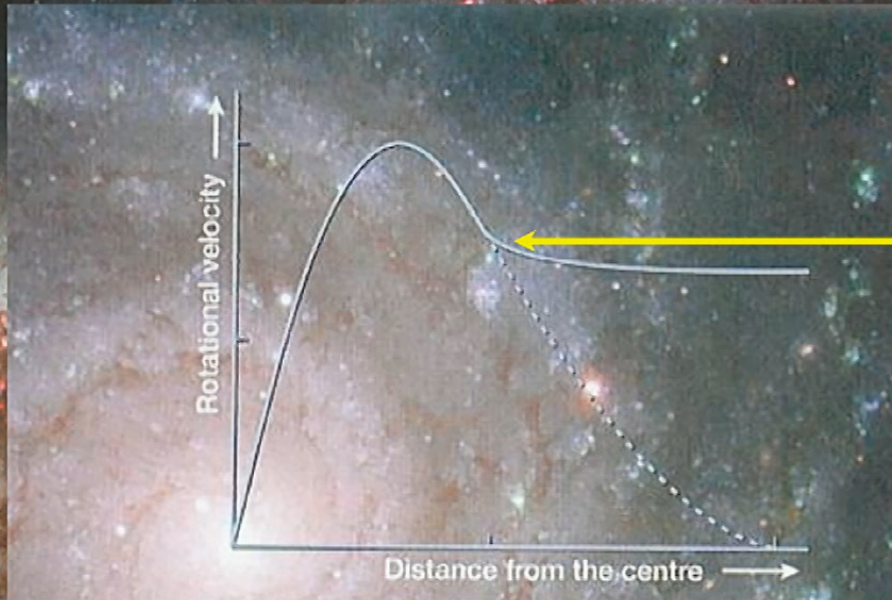
Distance to horizon

$$d_{hor} = \frac{c}{H}$$

$H =$ Hubble constant

**Matter pushes out the quantum information
contained in the Dark Energy**

**The Dark Energy pushes back and leads
to the observed extra gravitational force.**



**What does
this difference
occur?**

**When the gravitational
acceleration drops below
a value related to
the Hubble constant!**

$$\frac{GM}{R^2} < cH$$



A NEW VIEW ON GRAVITY AND THE DARK SIDE OF THE COSMOS

**THANK
YOU**

ERIK VERLINDE
Oct. 4 at 7PM ET

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