



Studium Generale @ Utrecht
14 februari 2018

Zwaartekracht: een illusie?

Erik Verlinde

**Universiteit van
Amsterdam**



The New York Times

“A Scientist takes on Gravity”

By [DENNIS OVERBYE](#)

JULY 12, 2010



ZERO GRAVITY

Dr. Erik Verlinde says, “For me gravity doesn’t exist.” In a recent paper he expounded on his theory.

Credit: Kirsten Luce
for The New York Times



Nigel Calder

The Key to the Universe



a report on the new physics

BBC

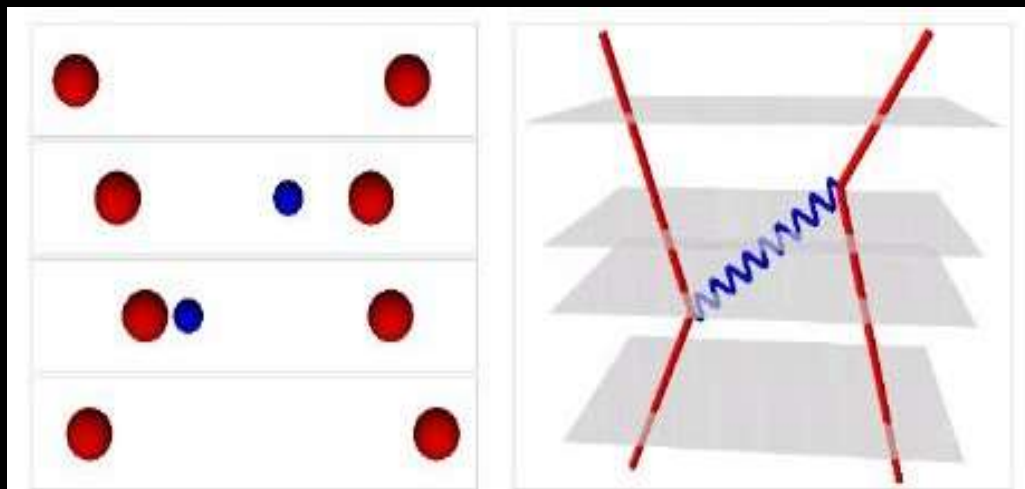
Avondvullende documentaire

'Sleutel tot het Heelal'

Januari 1977

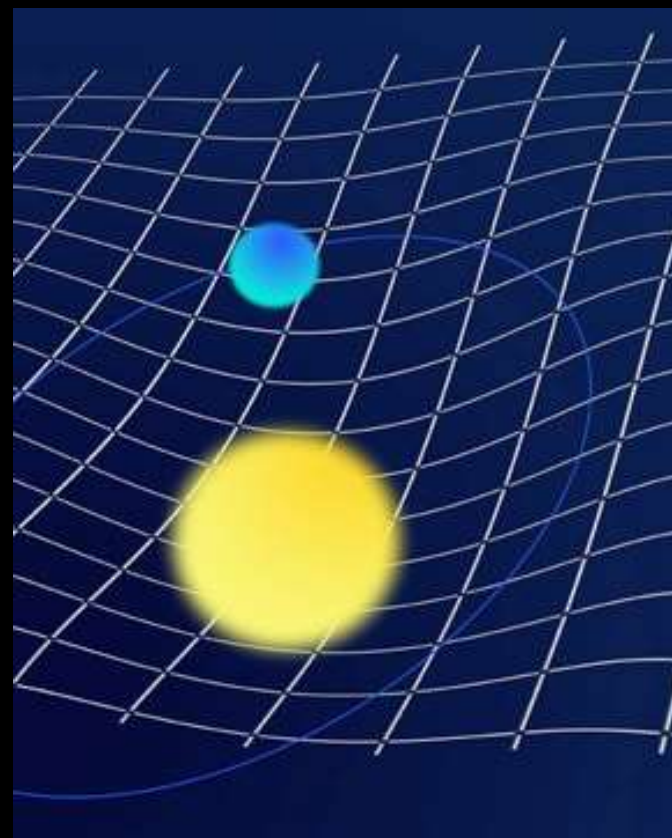
KRO

Elementaire deeltjes



Fundamentele Krachten

Zwaartekracht



Zwarte Gat

Elementaire deeltjes



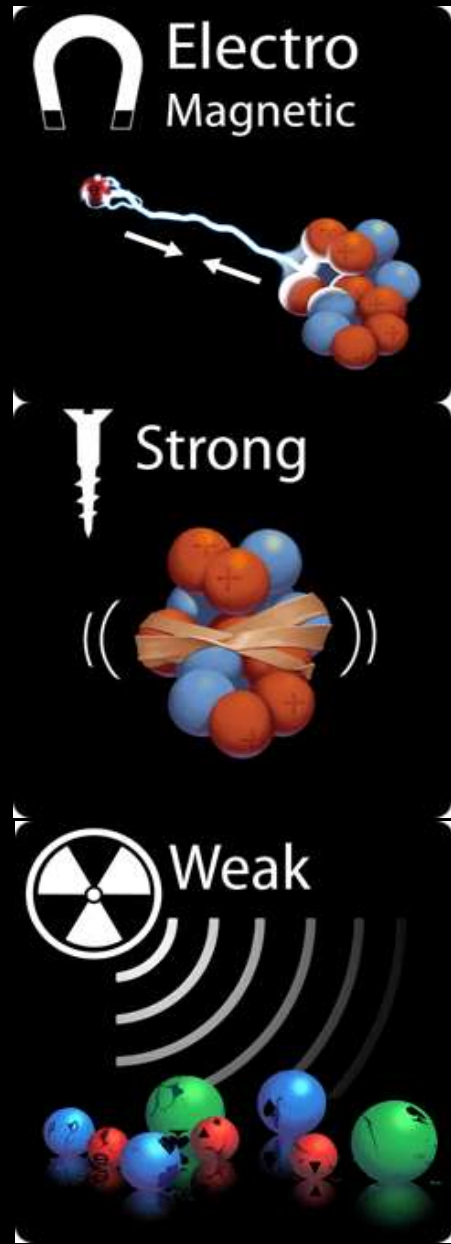
**Gerard
't Hooft**

Zwaartekracht

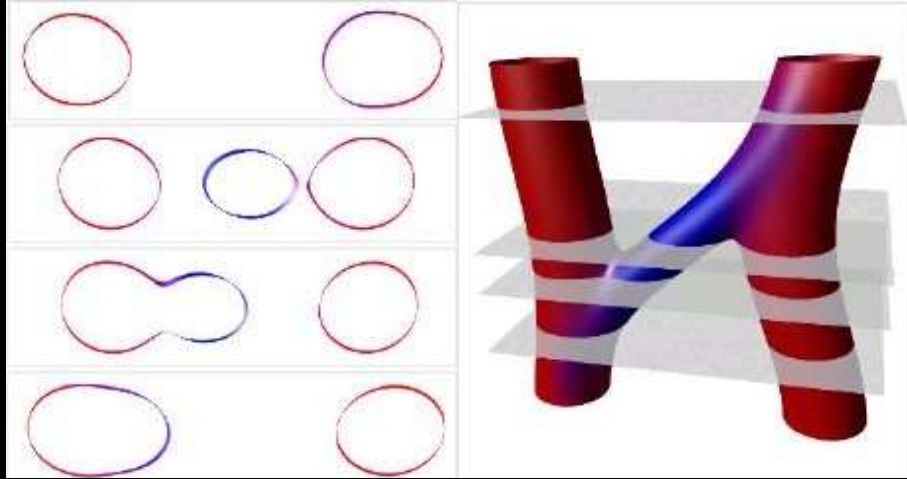


**Stephen
Hawking**

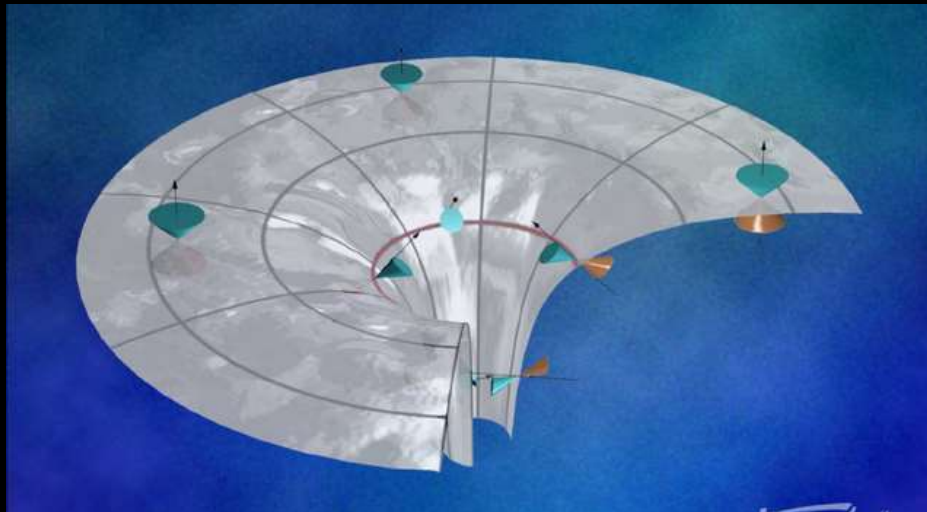
Fundamentele Krachten



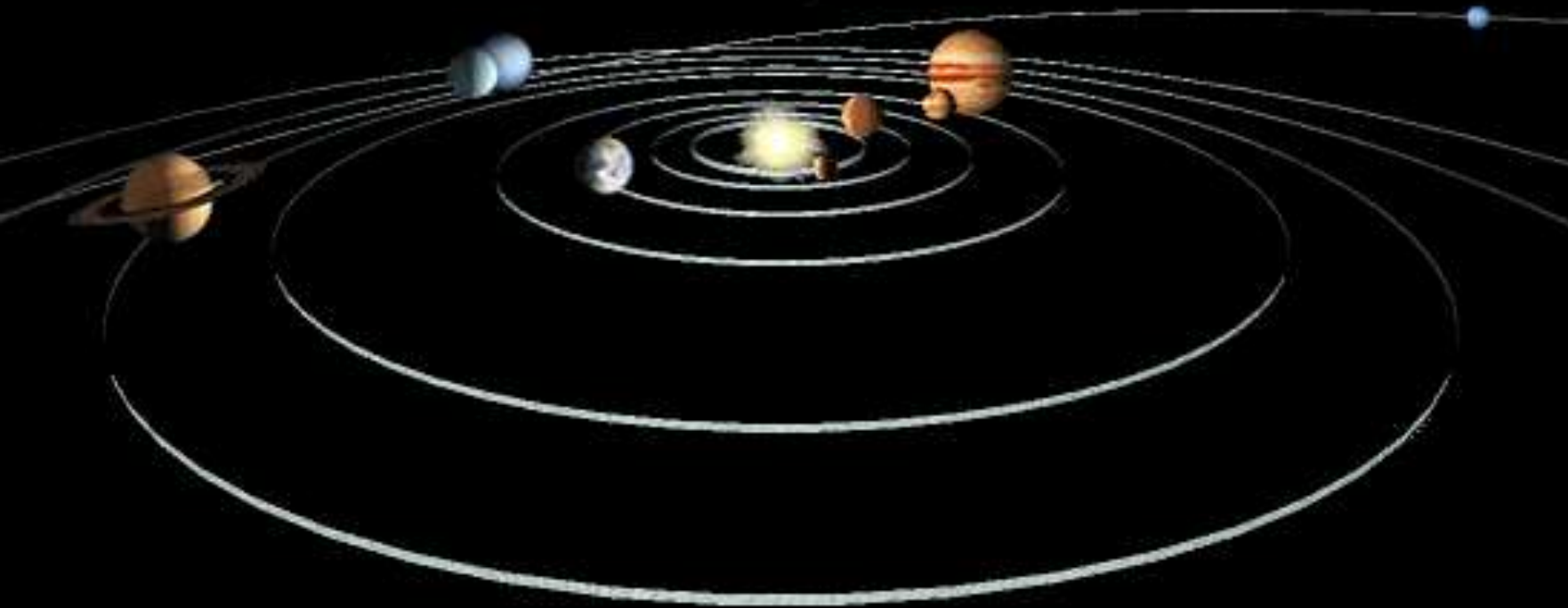
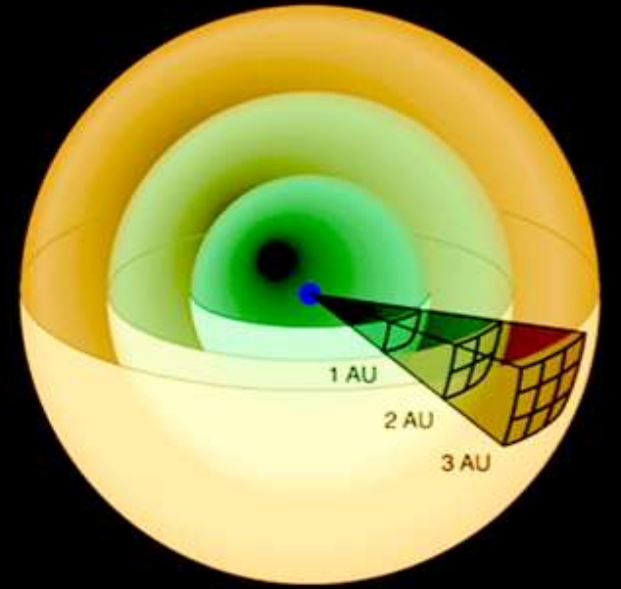
Snaartheorie



Zwarte Gaten

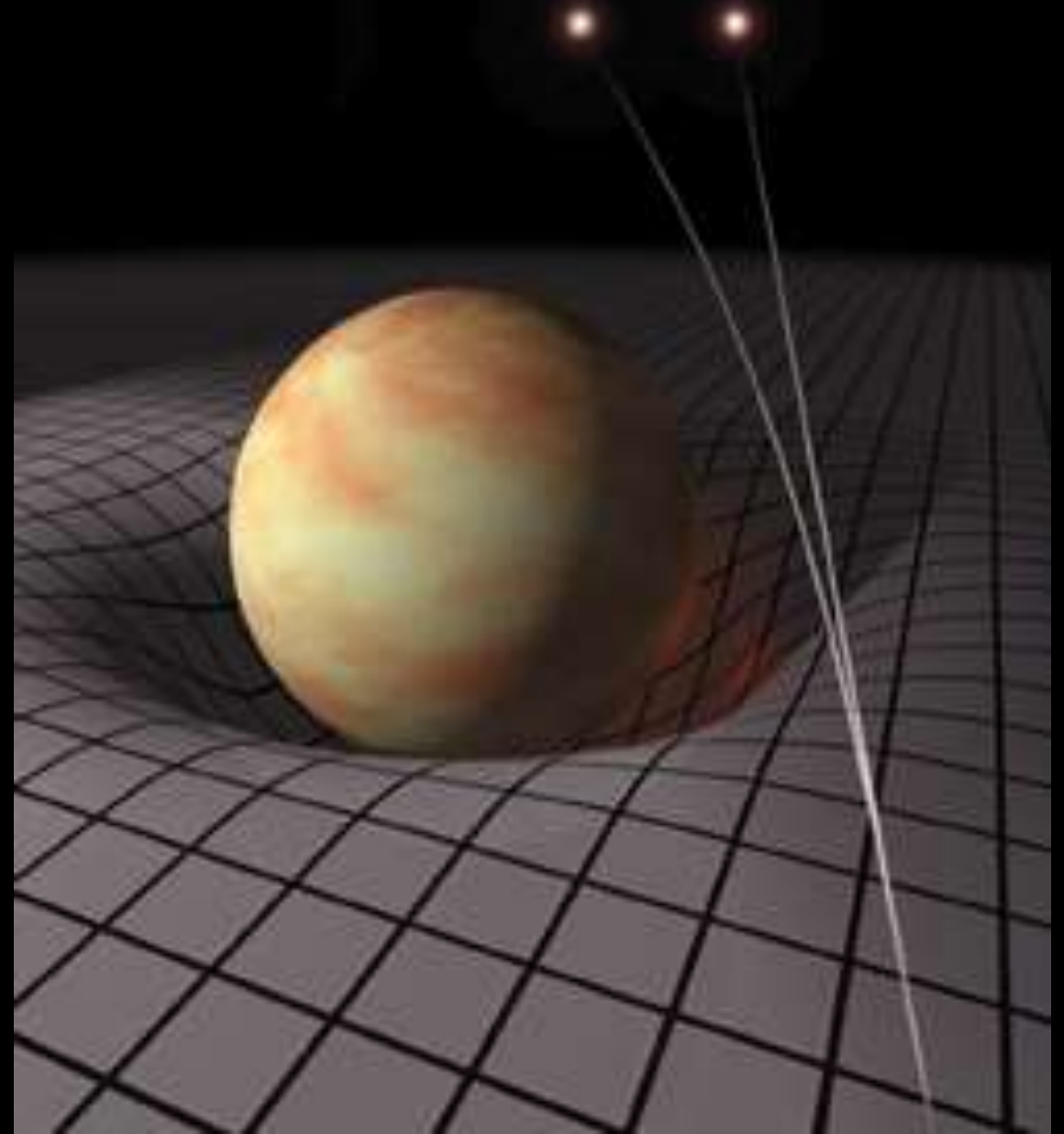
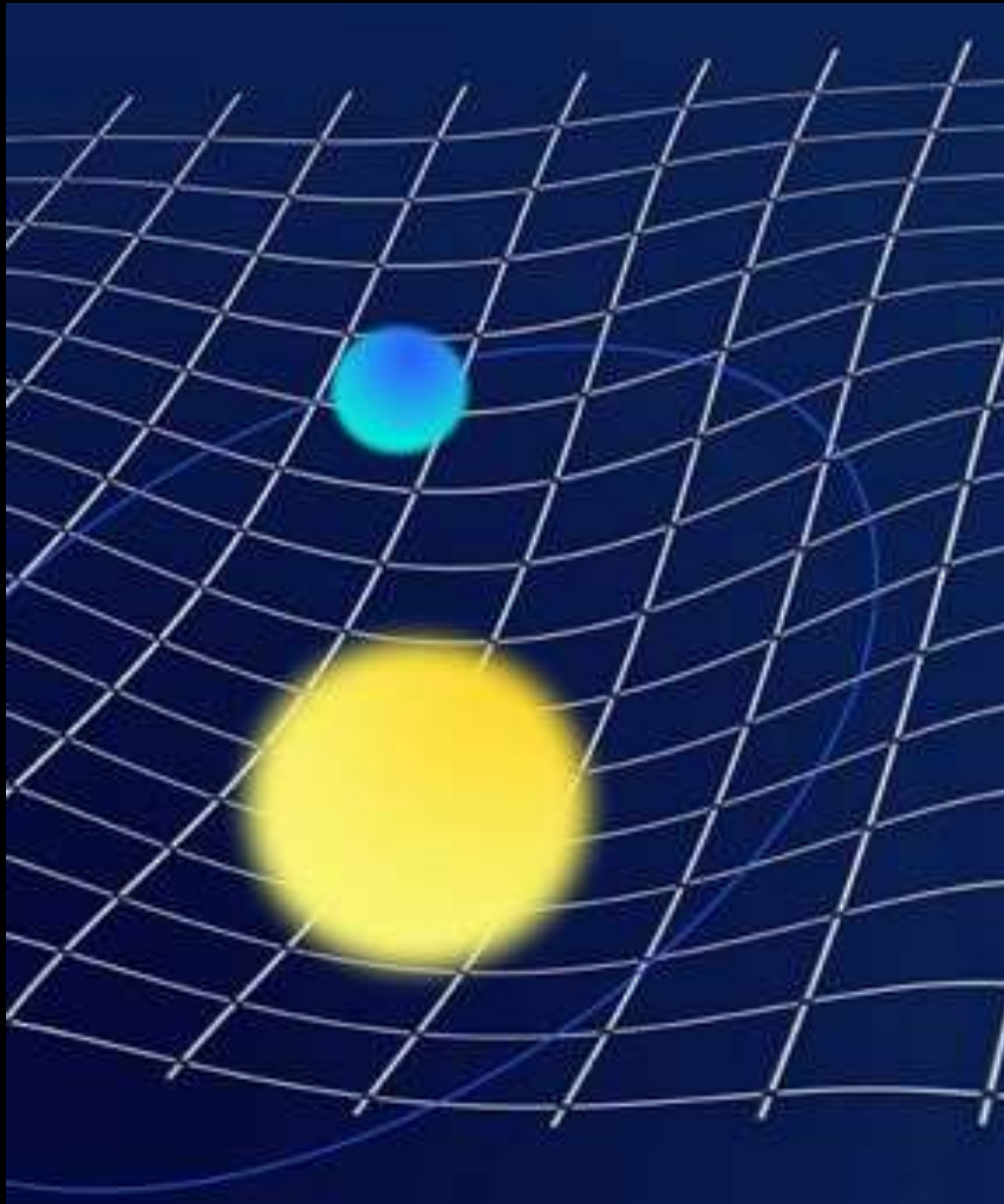


Newton's Zwaartekrachtwet

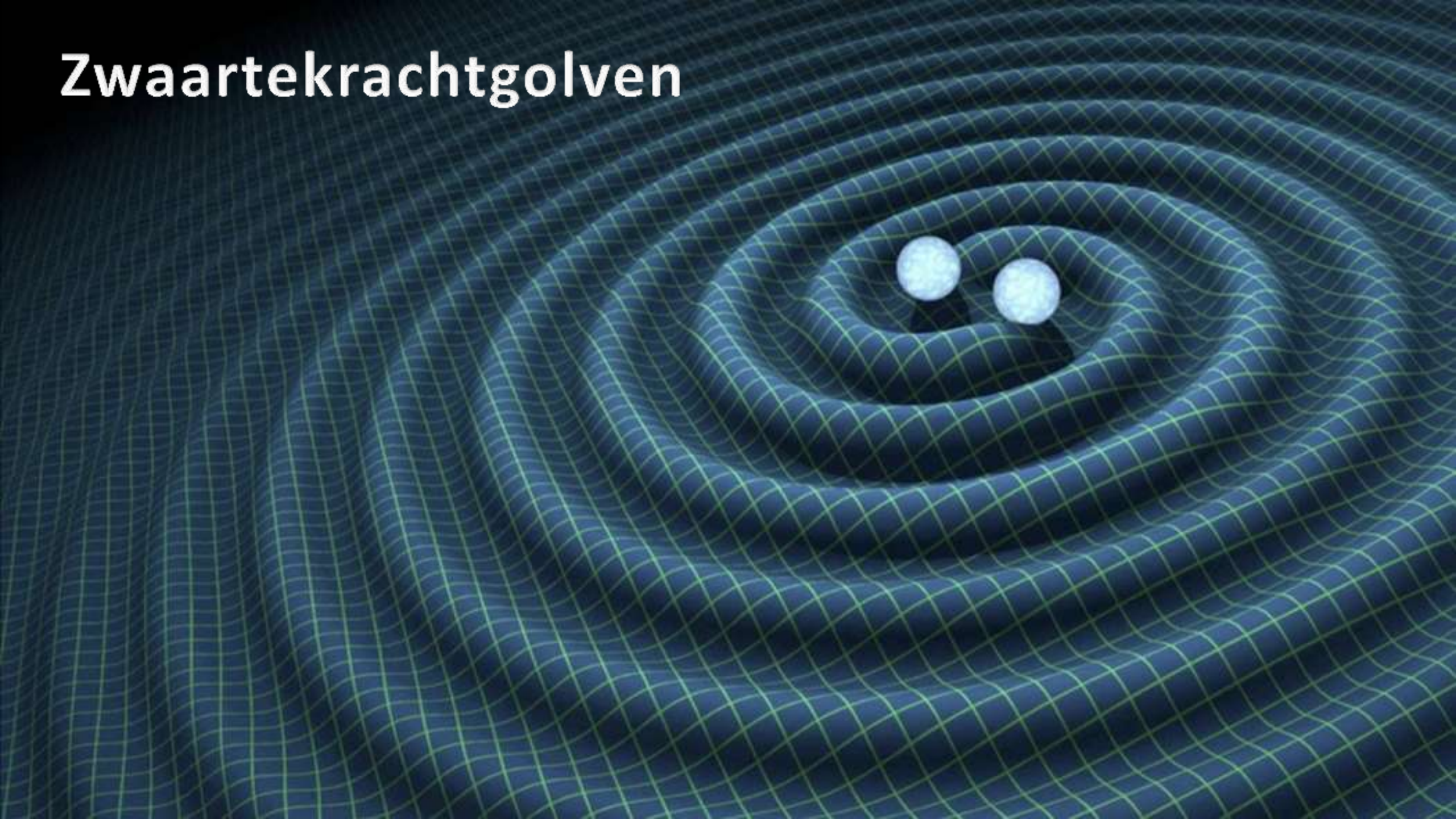


$$F = \frac{GMm}{R^2}$$

Einstein Theorie van de Zwaartekracht

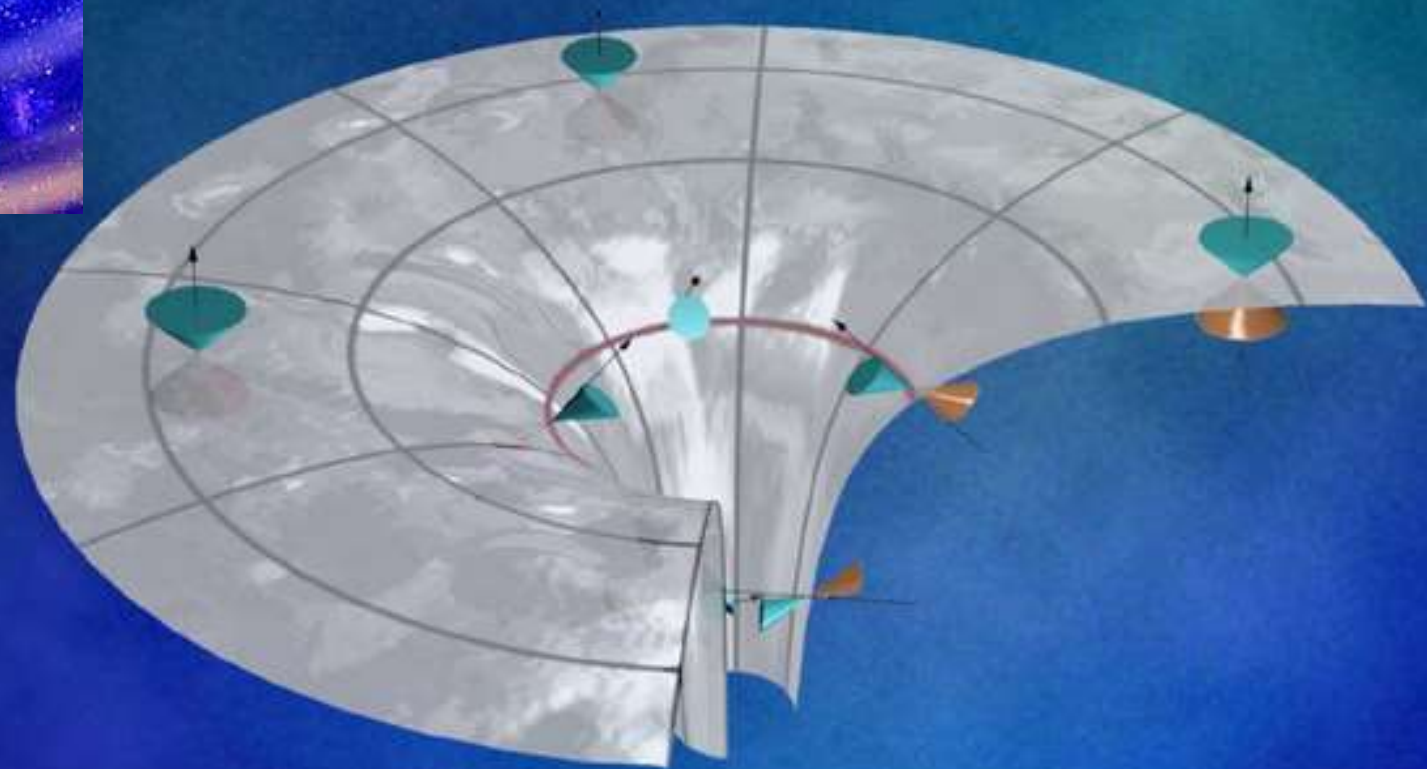


Zwaartekrachtgolven



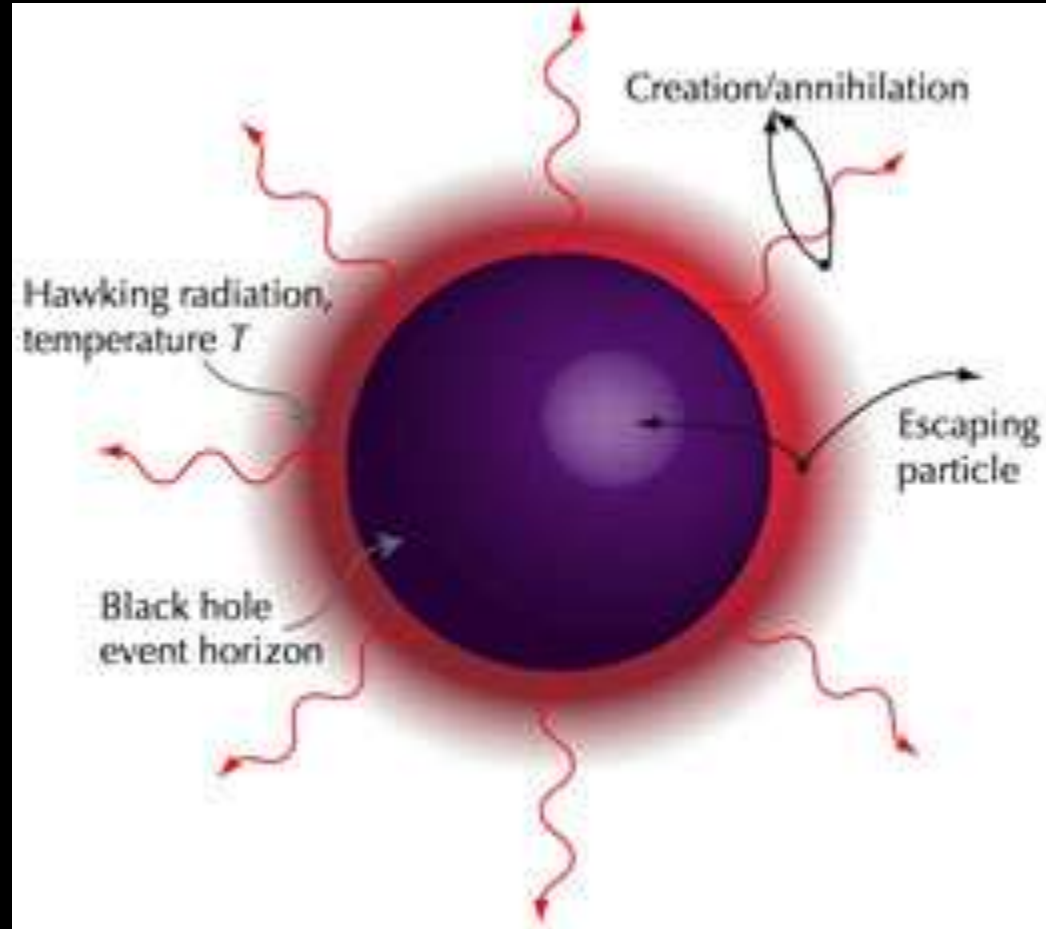
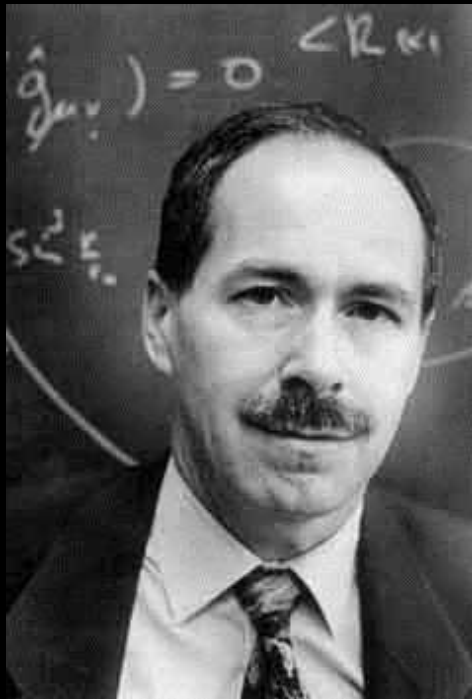


Zwarte Gatzen



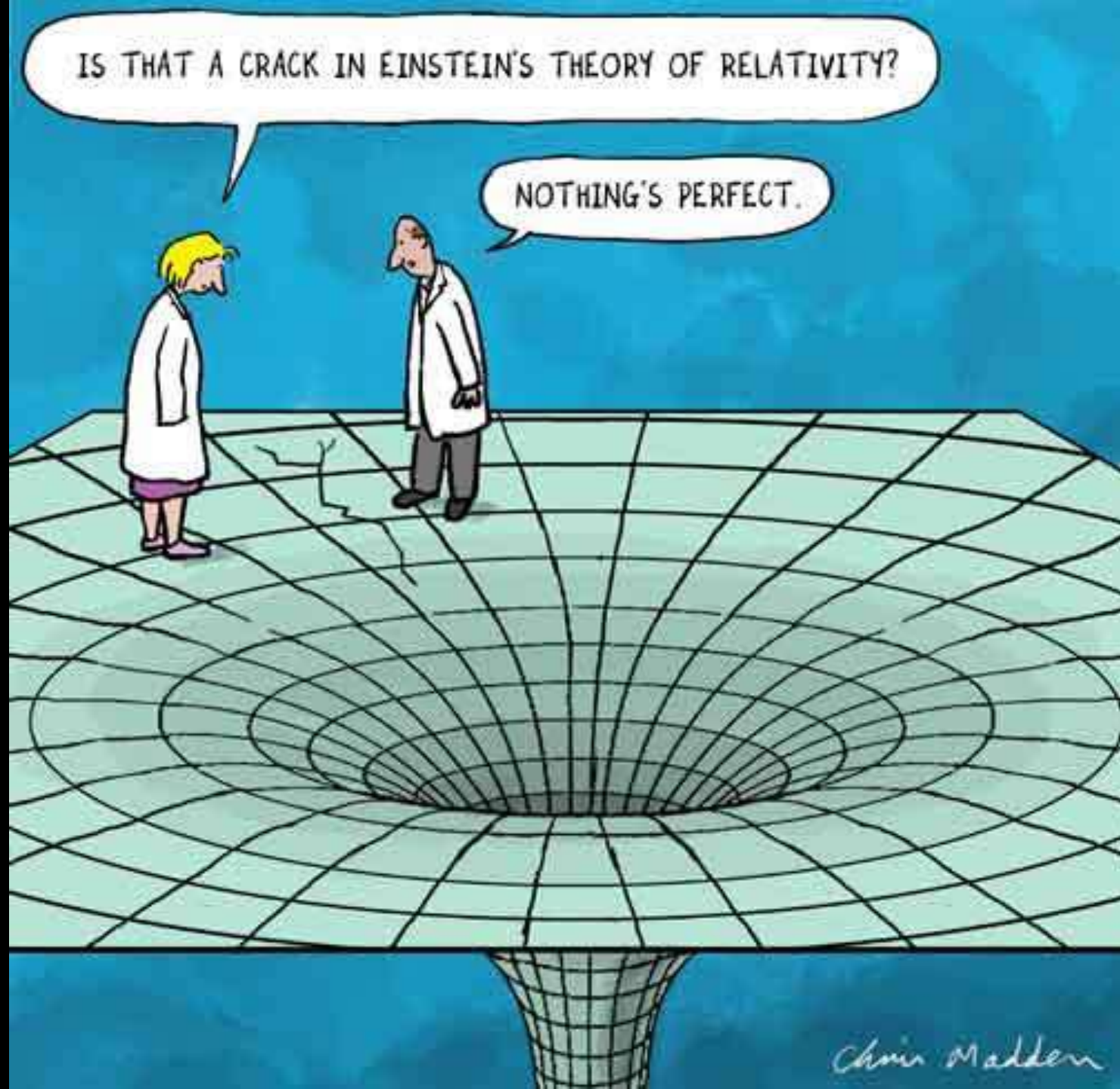


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IS THAT A CRACK IN EINSTEIN'S THEORY OF RELATIVITY?

NOTHING'S PERFECT.

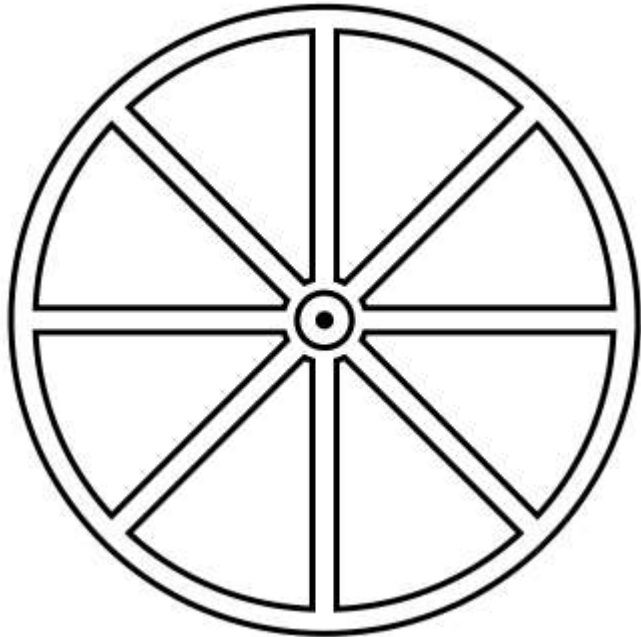
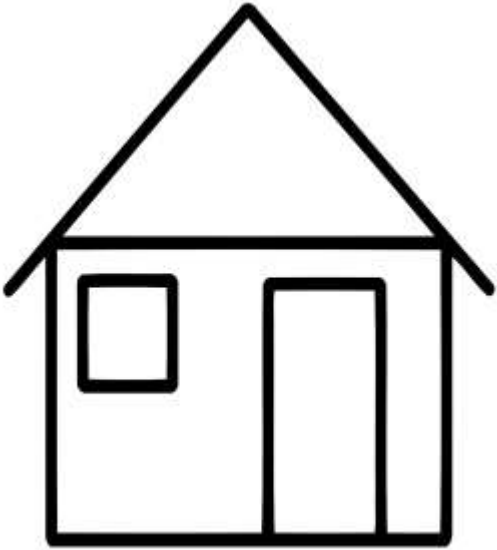


Chin Madden



Abstraheren =

vergeten van informatie



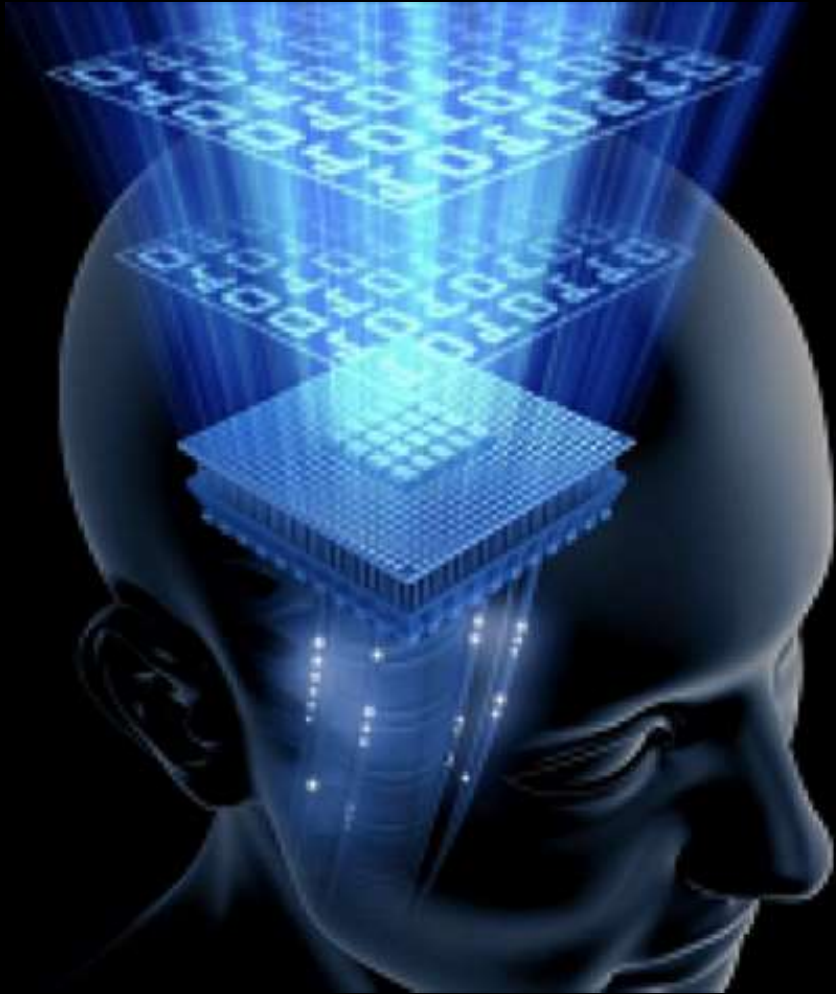
Natuurkunde en Realiteit

- Natuurkunde beschrijft de 'Fysische Realiteit' in termen van **Natuurwetten**.
- **Fysisch Wereldbeeld** verandert door de eeuwen heen: mechanica, stromingsleer, deeltjes en krachten, nu: **informatietijdperk**



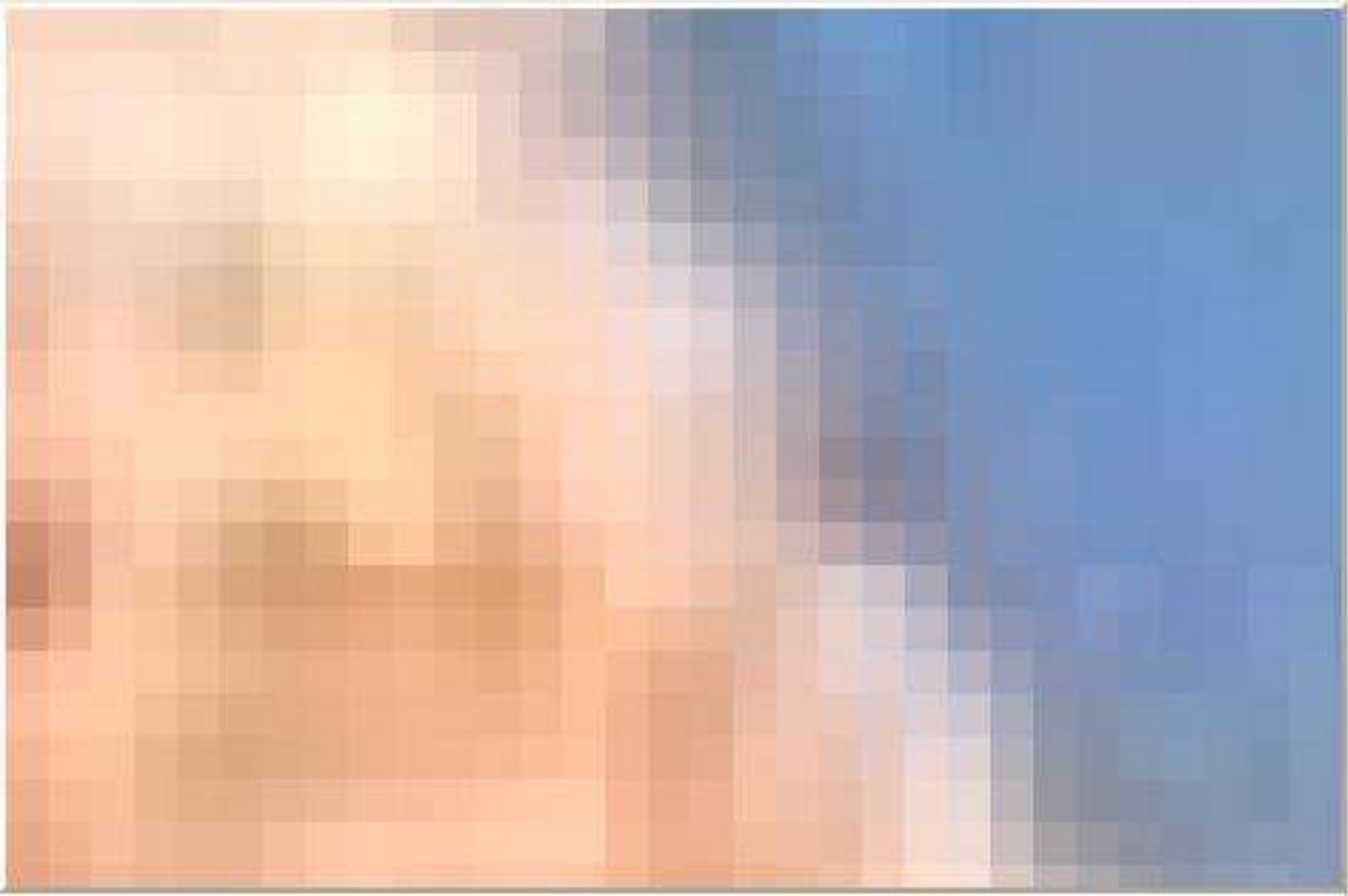
- Natuurkunde vermijdt complexe aspecten: bijv. Leven en Bewijstzijn.

We leven in een informatietijdperk



**Wat is
informatie?**





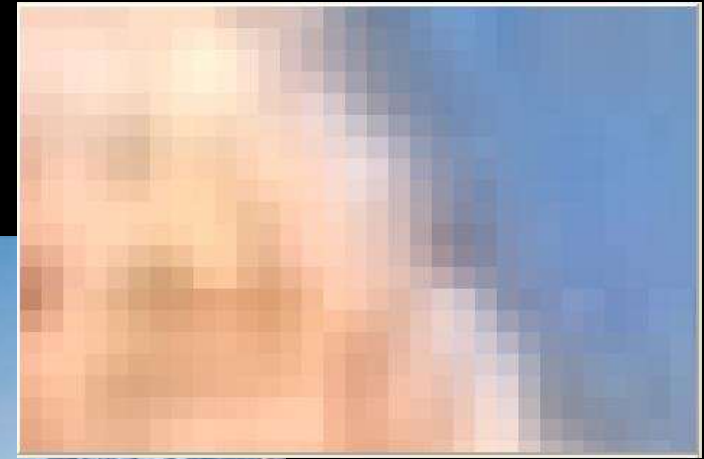




Emergentie

Als mens nemen we verschijnselen waar en gebruiken begrippen op macroscopische schaal.

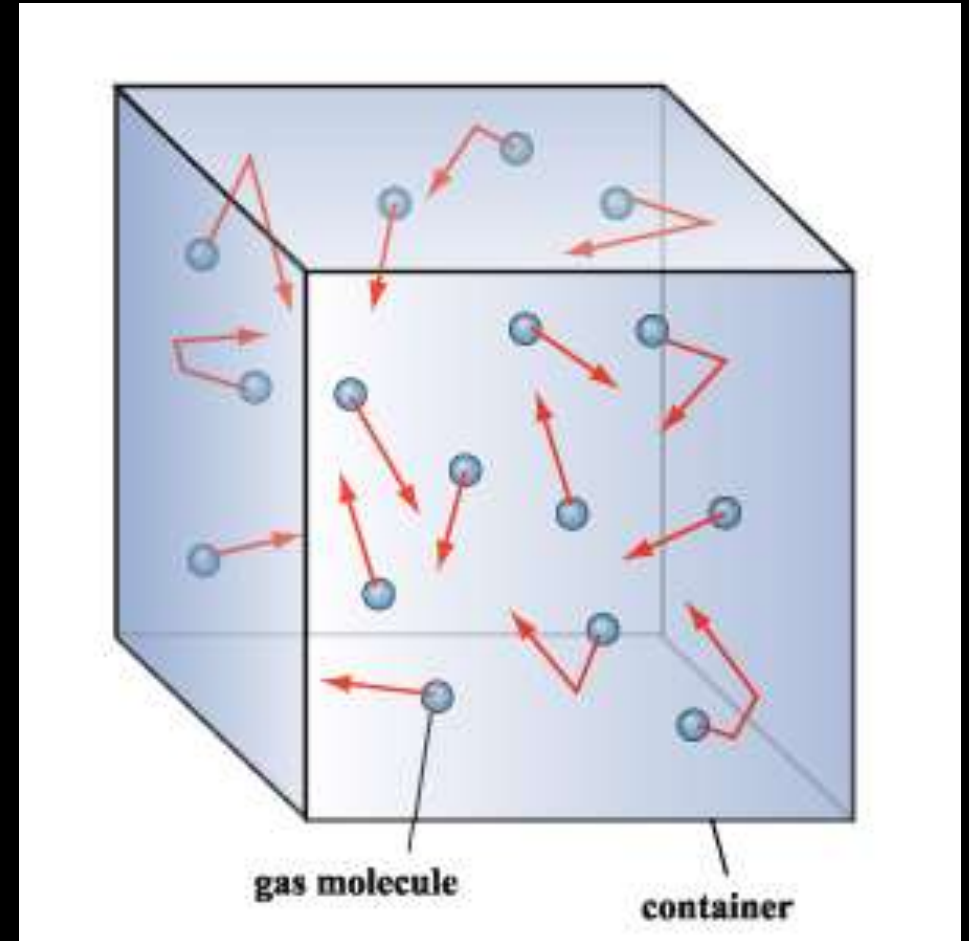
Maar deze begrippen zijn afgeleid uit een microscopisch wereld waarin deze geen betekenis hebben.



'Het geheel is meer dan de som der delen.'

THERMODYNAMICA & STATISTISCHE FYSICA

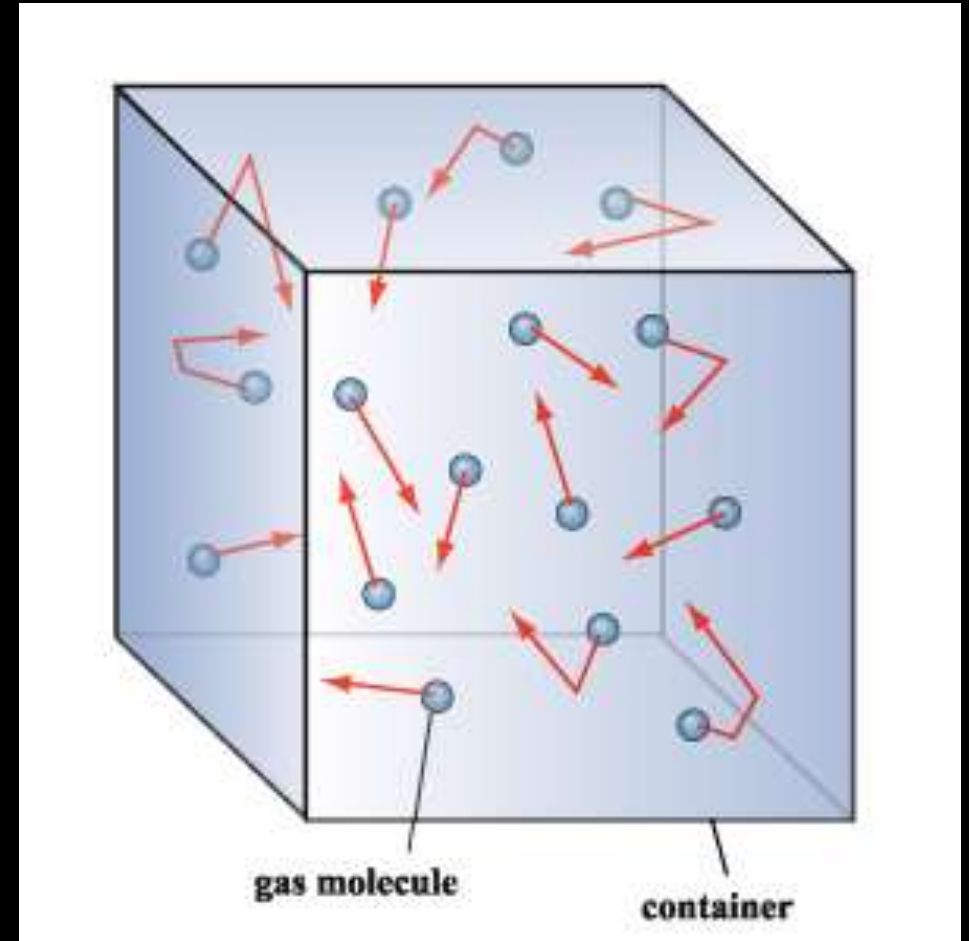
De macroscopische eigenschappen van een gas van deeltjes wordt bepaald door statistische middeling over de microscopische bewegingen.



THERMODYNAMICA & STATISTISCHE FYSICA

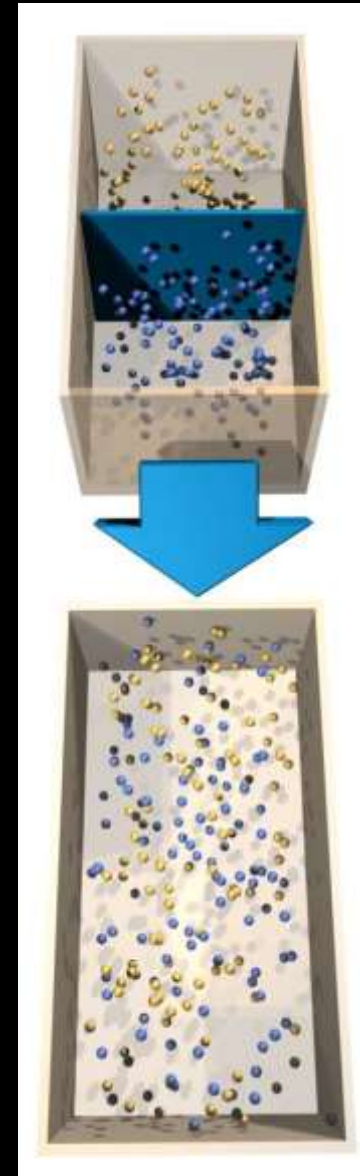
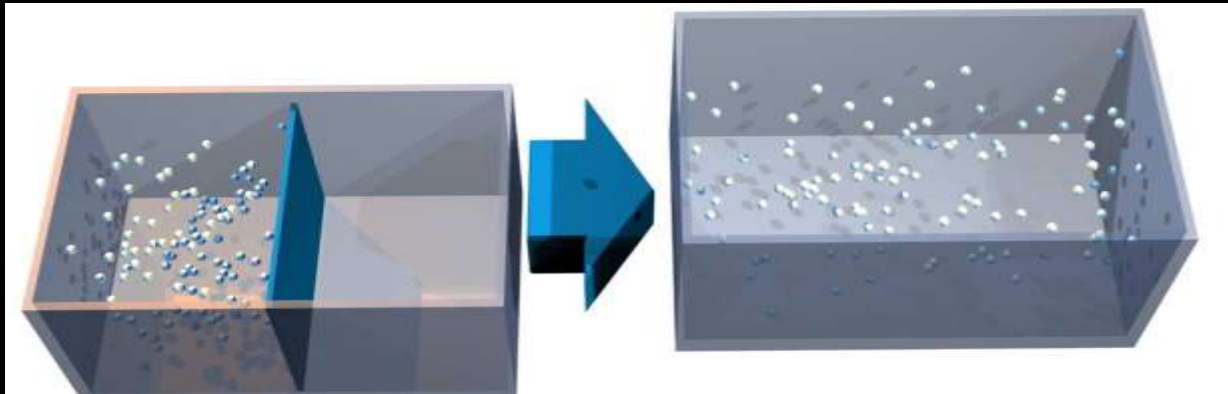
Voorbeeld:

Temperatuur is een
maat voor de
gemiddelde energies
per deeltje.



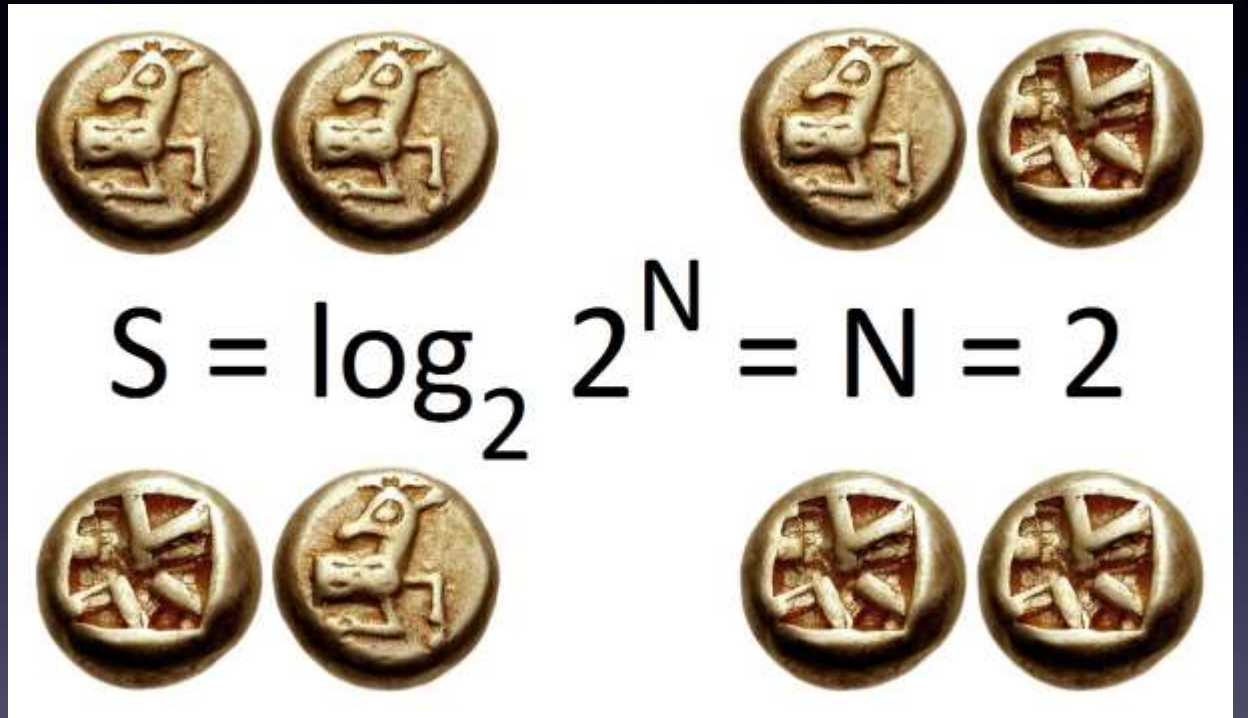
Entropie =
maat voor de hoeveelheid
(verborgen) informatie.

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



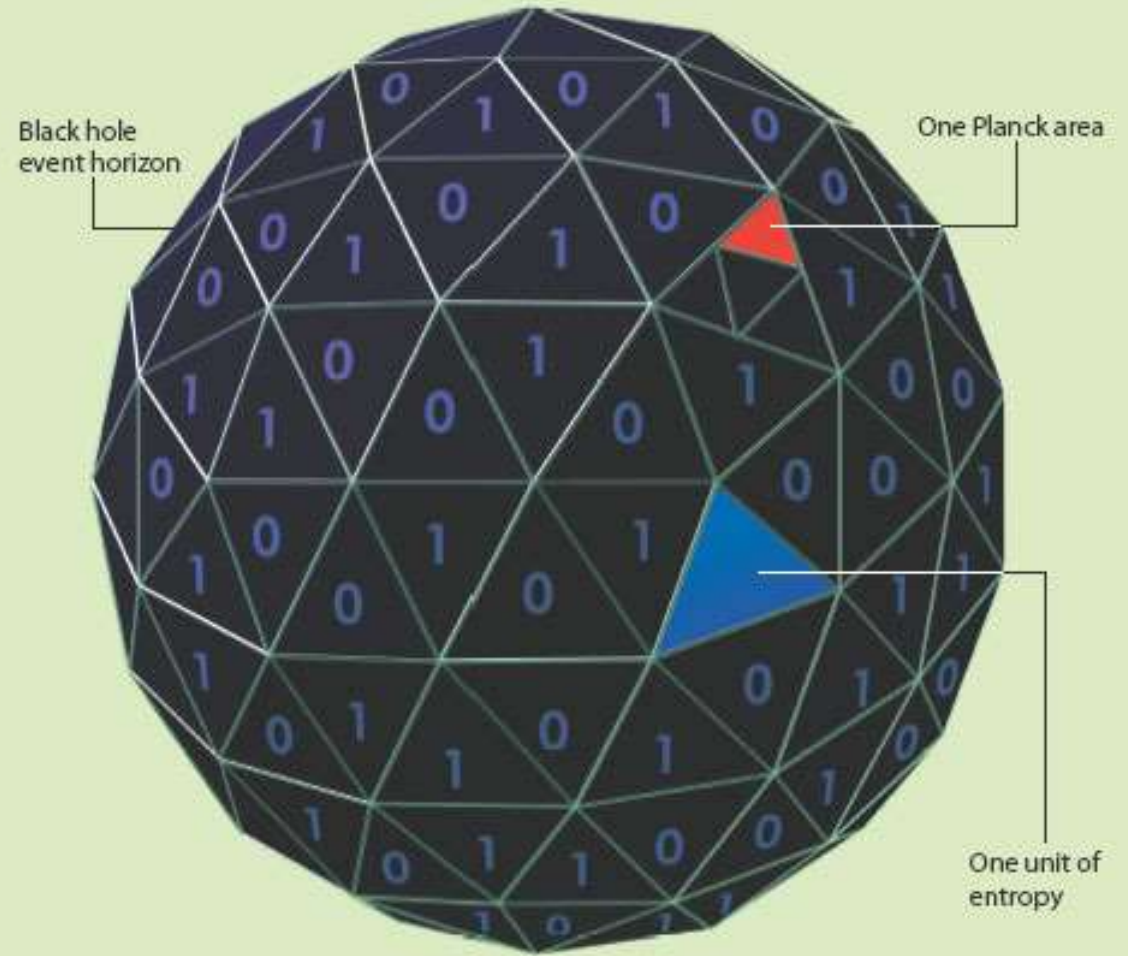
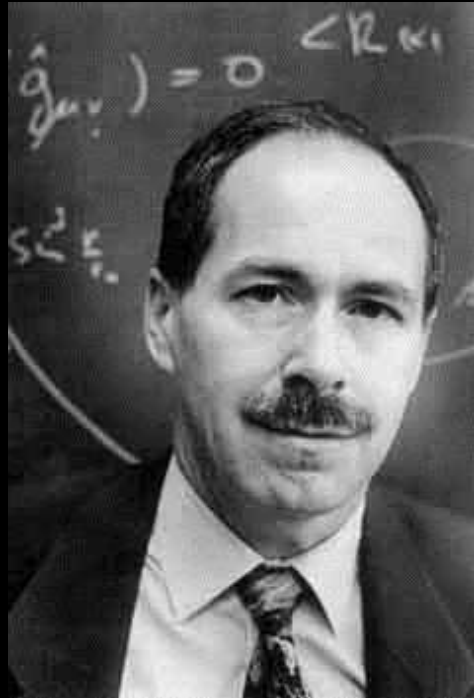


Entropie and Informatie



S = # bits

(Shannon)



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.

On the origin of gravity and the laws of Newton

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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.

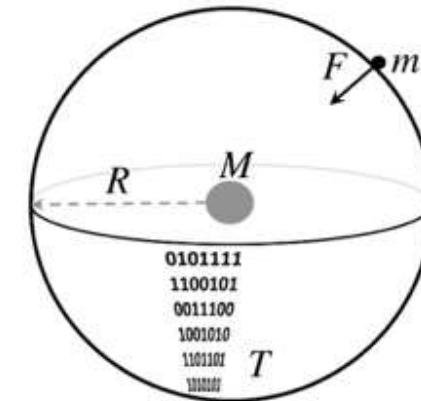
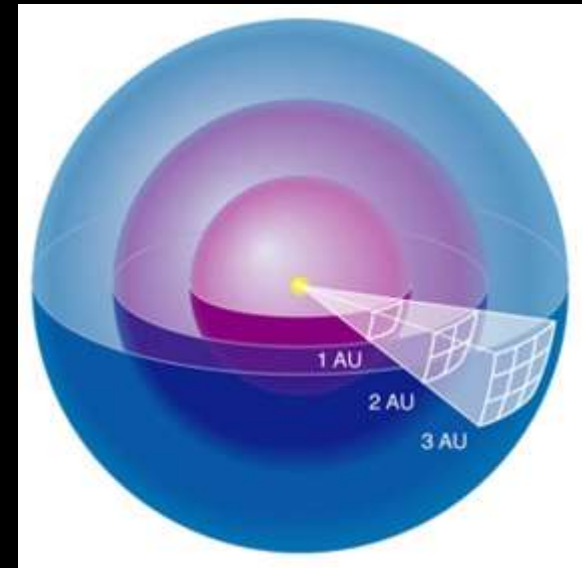


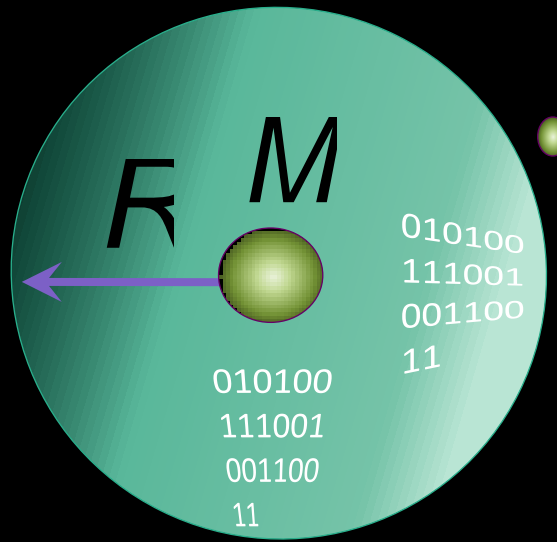
Figure 3. A particle with mass m near a spherical holographic screen. The energy is evenly distributed over the occupied bits, and is equivalent to the mass M that would emerge in the part of space surrounded by the screen.

and one obtains the familiar law:

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

We have recovered Newton's law of gravitation, practically from first principles!

A HEURISTIC ARGUMENT



$$\# \text{ bits} = \frac{4\rho R^2}{\square^2}$$

$$\square^2 = \frac{G\square}{c^3}$$

$$F\Delta x = T\Delta S$$

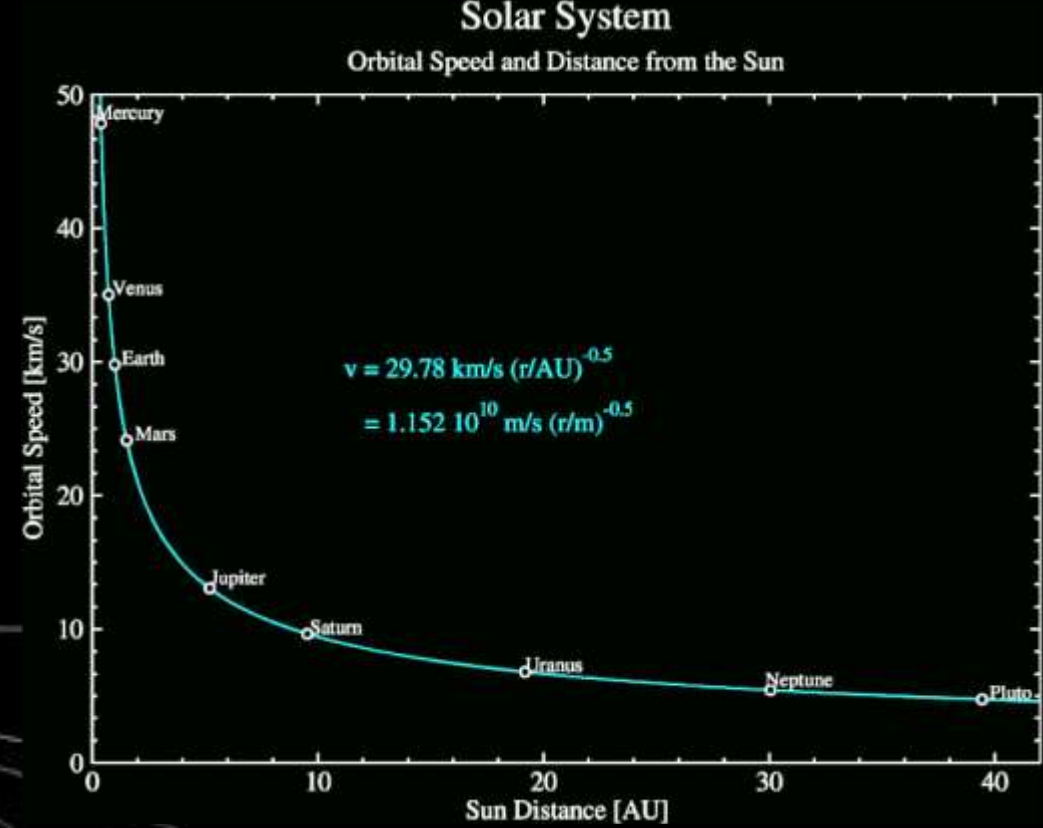
$$\Delta S = 2\pi k_B \frac{mc}{\hbar} \Delta x$$

$$\frac{1}{2} k_B T = E / \# \text{ bits}$$

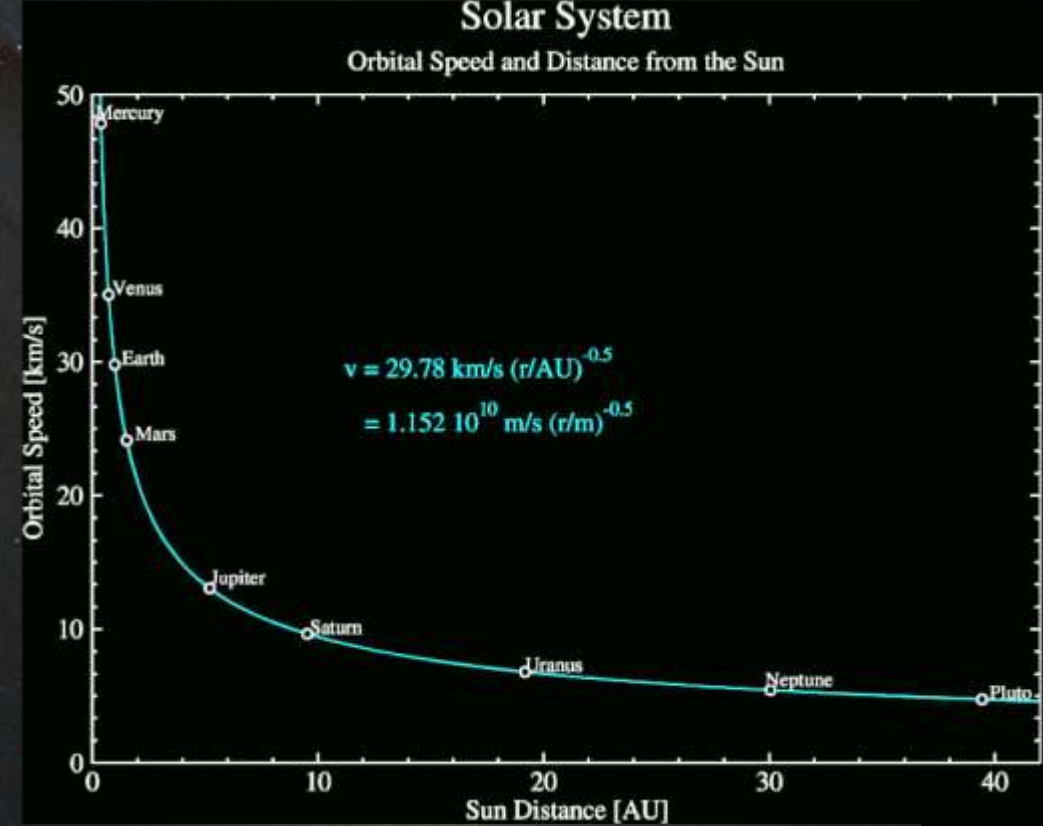
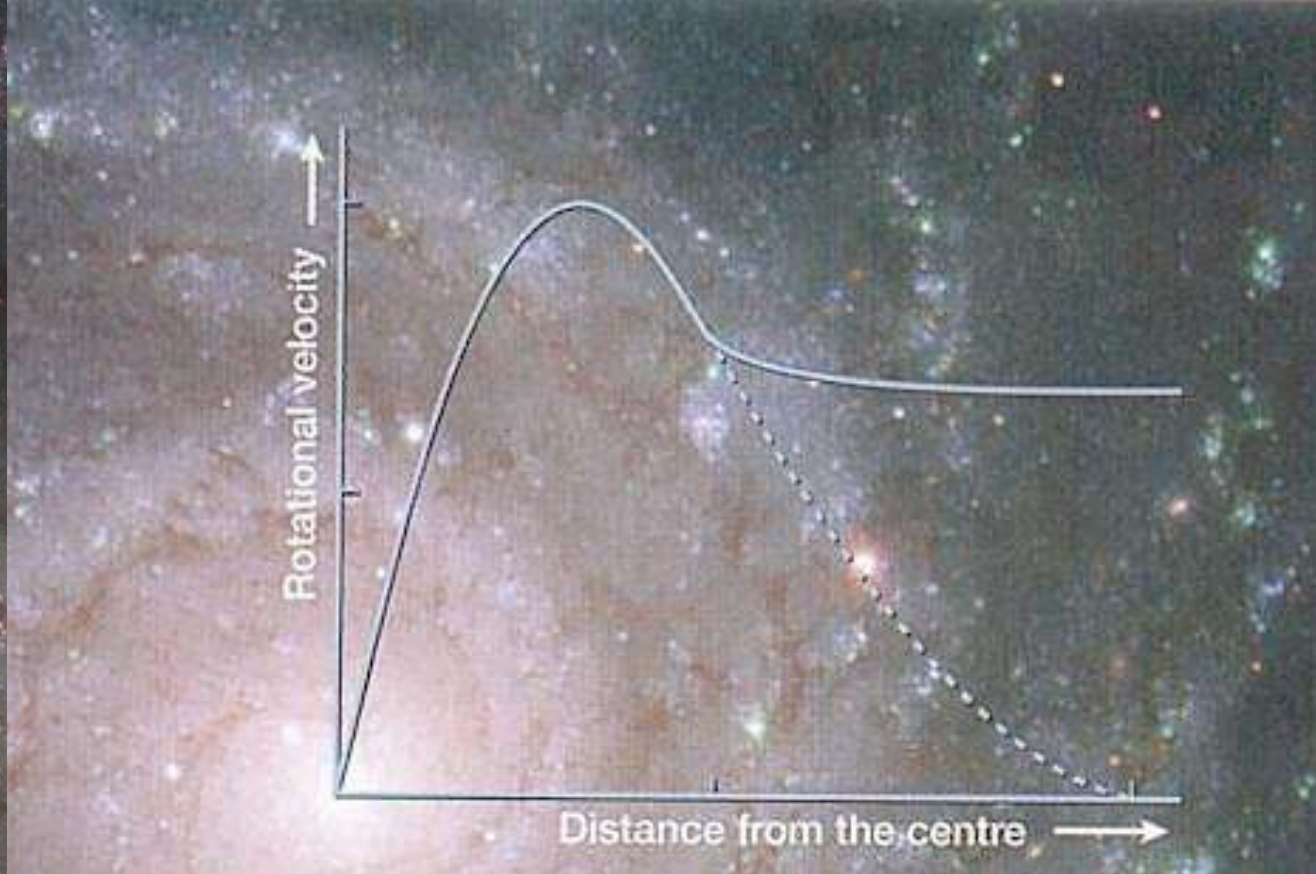
$$F = \frac{GMm}{R^2}$$

$$E = Mc^2$$

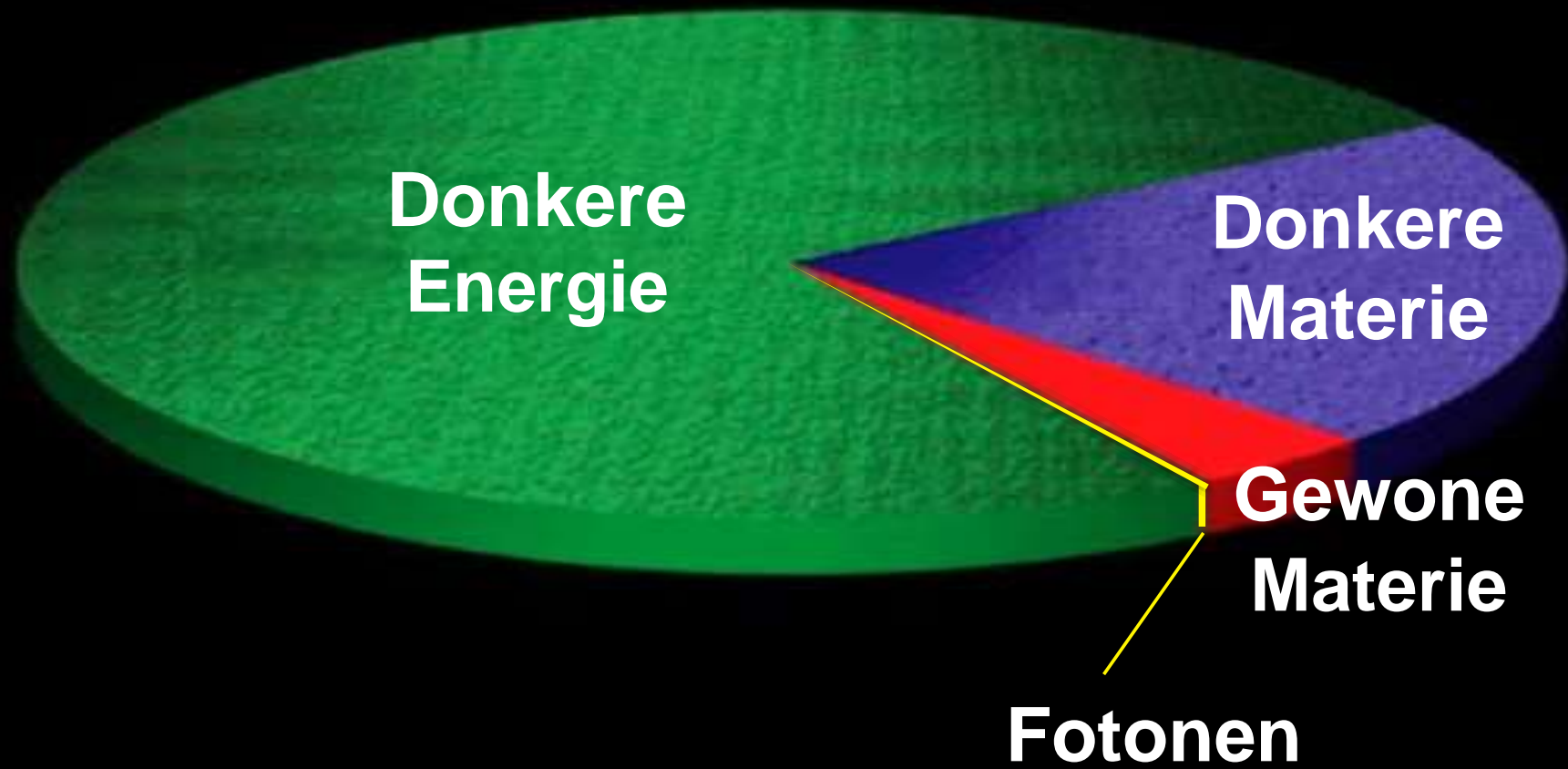
Newton's Zwaartekrachtwet







Energie-inhoud van de Kosmos





Story of the Universe

In the beginning of time, nature exploded out of nothingness. In a flash the ever-expanding universe was created. It took billions of years for the stars to appear.

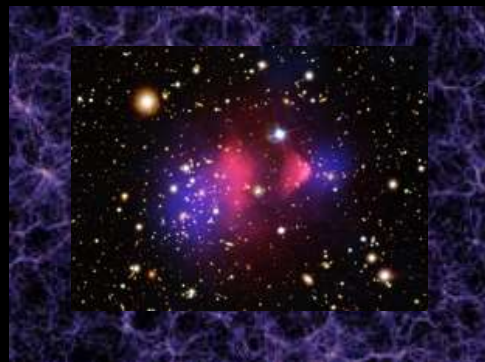
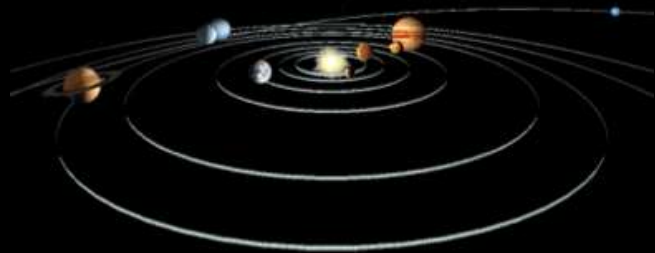


YOU ARE HERE

RECOGNIZABLE EXPANSION
A little more than 1 billion years ago, dark energy began to pull the universe apart, making it more homogeneous.

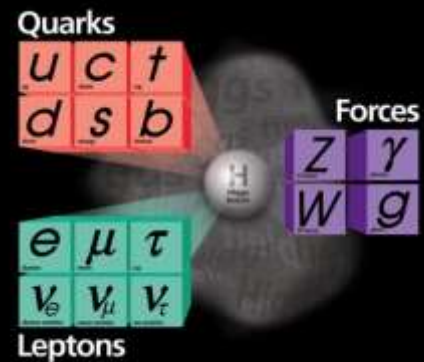
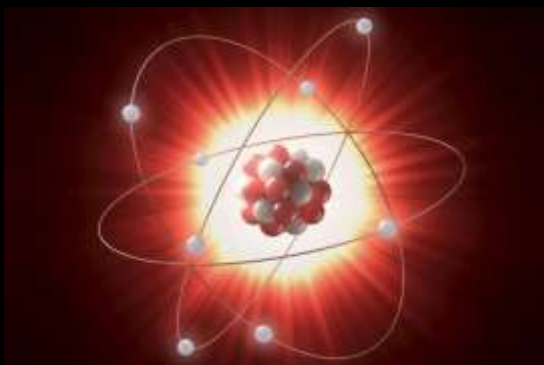
REVELATION
In less than 10^{-33} of a second after the Big Bang, the universe burst apart, expanding faster than the speed of light and filling up the matter and energy of the universe apart in all directions.

THE BEGINNING
The universe expanded rapidly from an extremely hot and dense initial state more than 13.7 billion years ago.



Complex

Simple

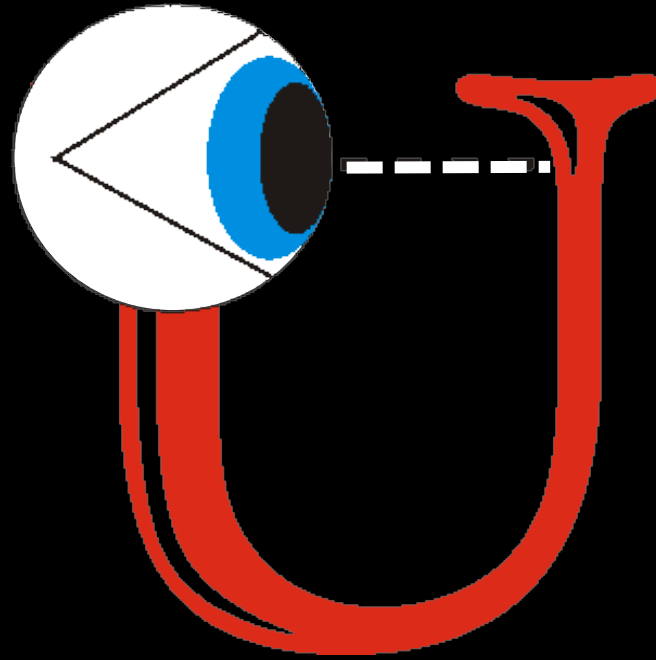
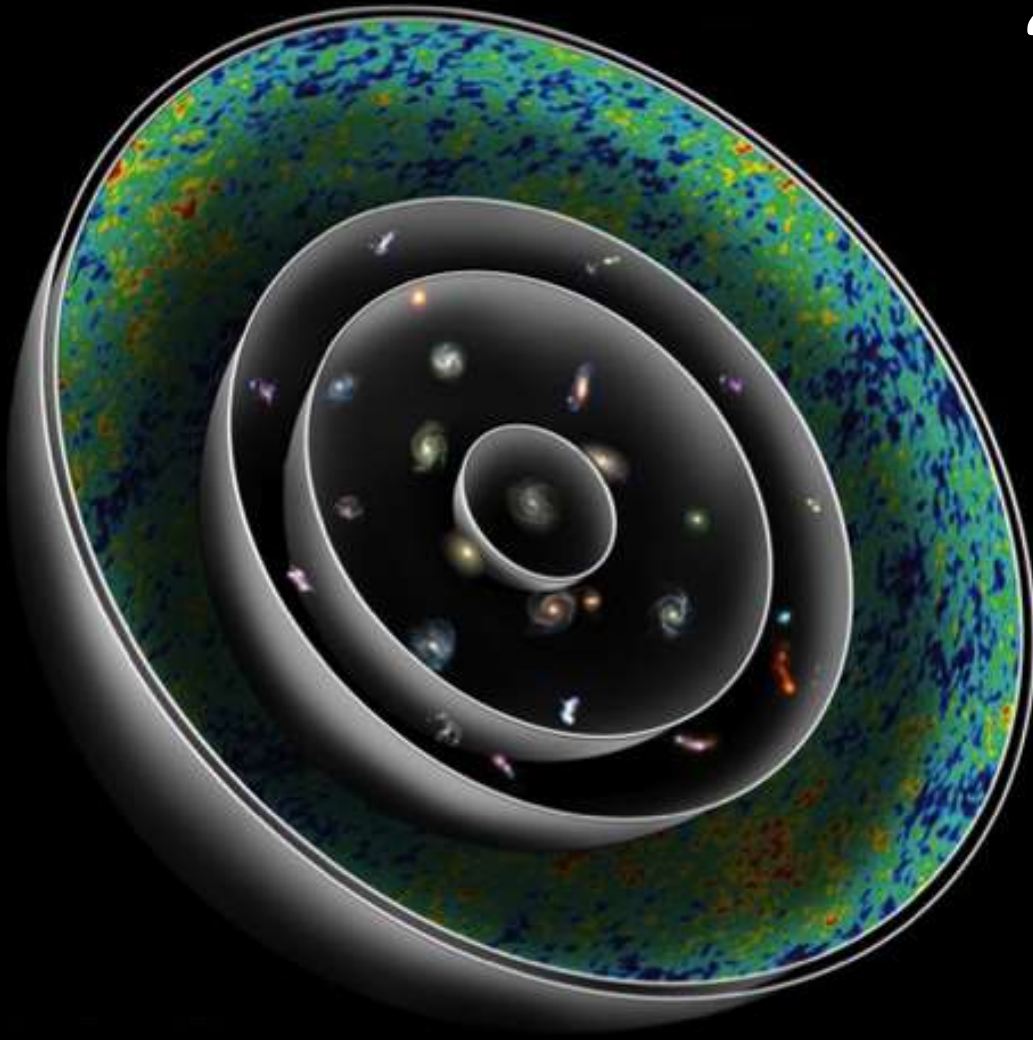




If you're to scale the history of the universe to a single year, humans wouldn't appear till December 31, 11.59 pm on New Year's Eve!

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

'The Participatory Universe'



“We are participants in bringing into being not only the near and here, but the far away and long ago.”



John Wheeler

THE INFORMATION UNIVERSE



