HOLOGRAPHY

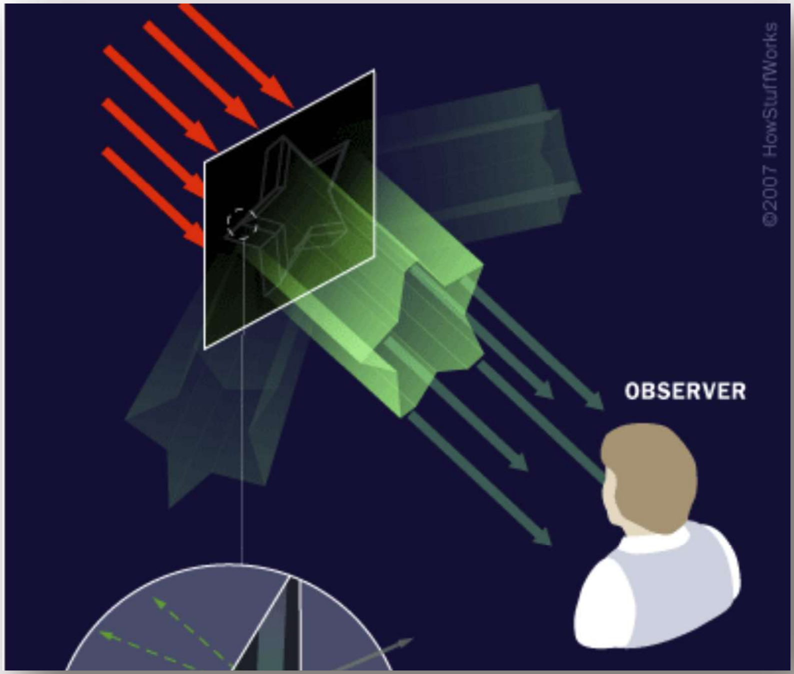
Viva Fysica 2019

Institute of Physics

University of Amsterdam

What is Holography?

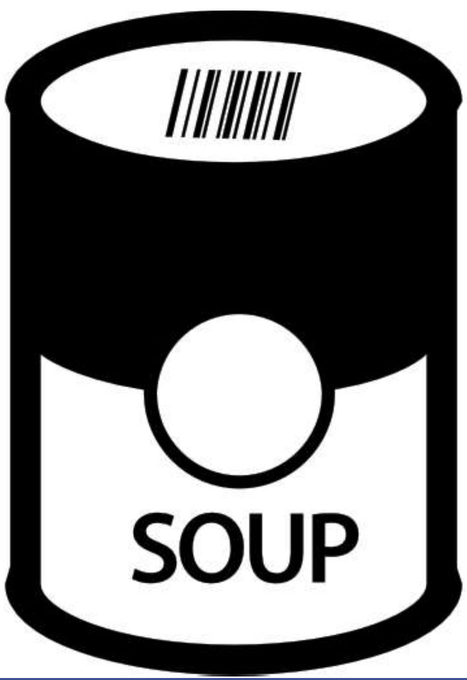
In your daily life: Holograms



2D surfaces that show precise 3D images.

Holographic Principle

Idea to keep in mind:
-projecting on a screen a 3D image.
-collecting information of the volume on a surface.



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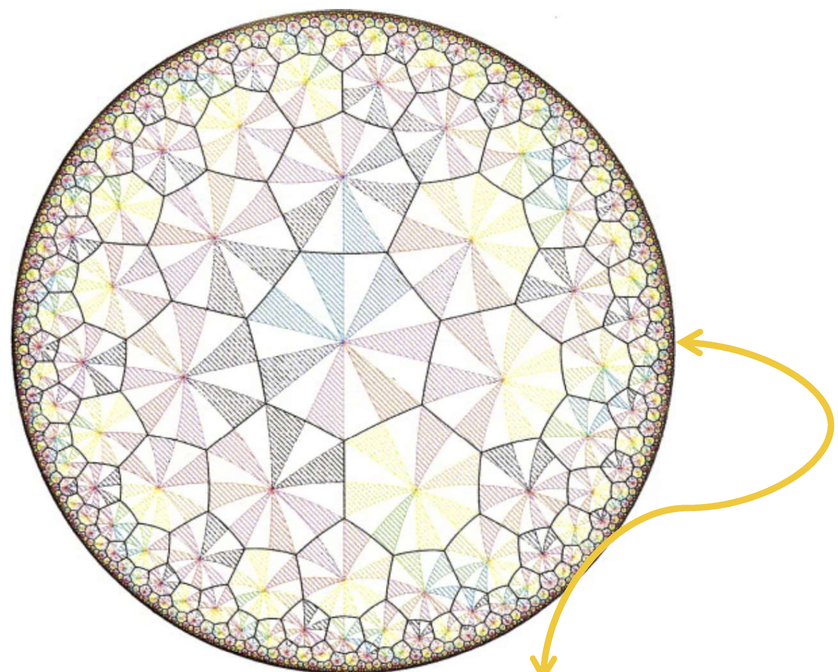
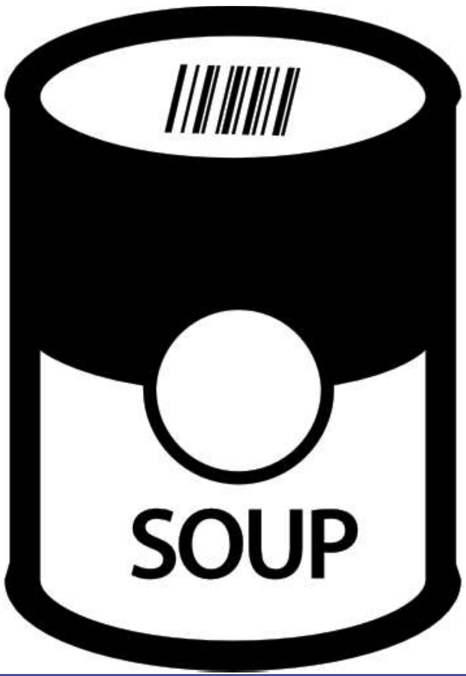


Boundary determines the interior

Holographic Principle

TODAY: How these concepts appear in Gravity.



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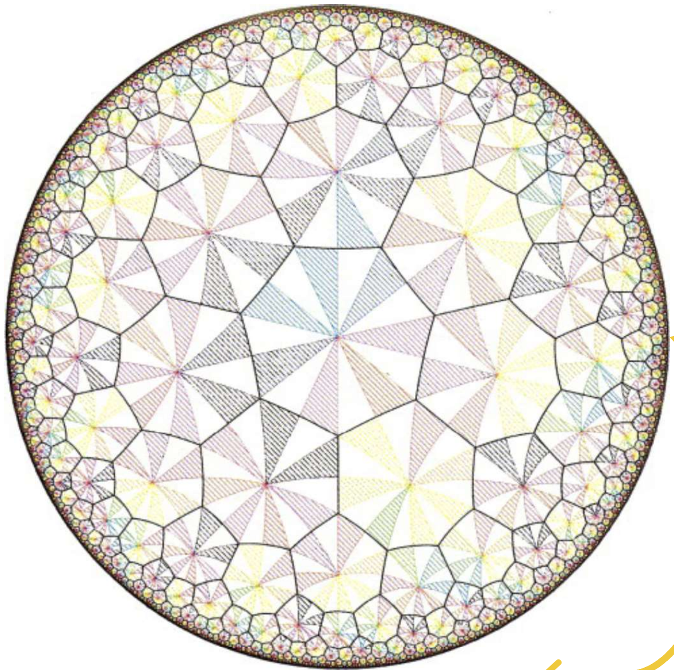
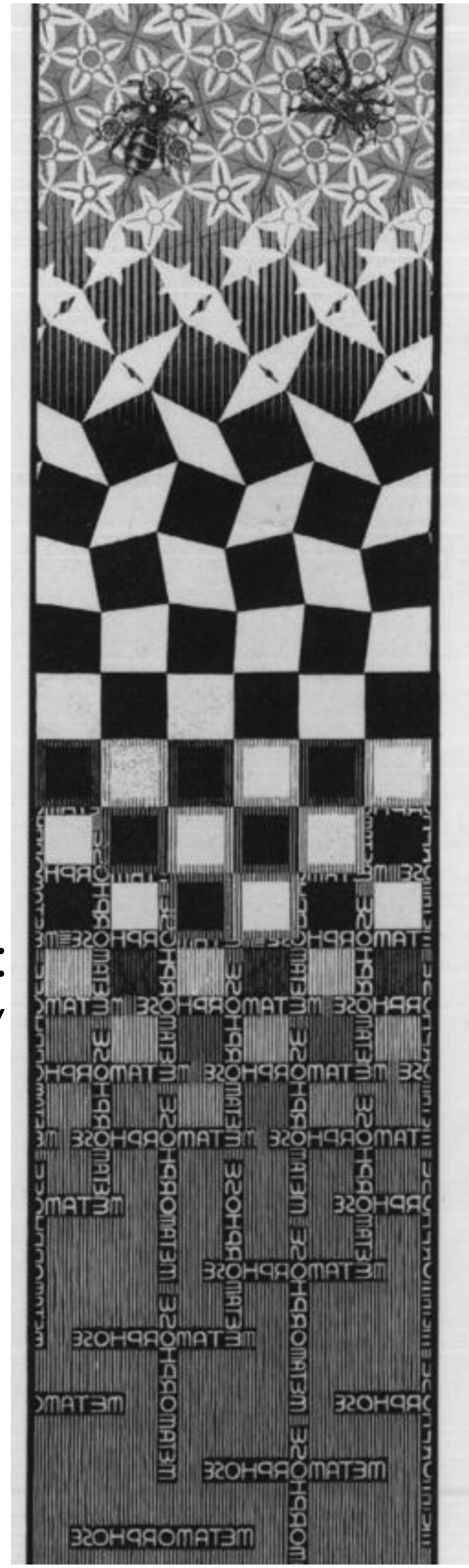


Boundary determines the interior

Quantum
Gravity!

Holographic Principle:
Our modern view



Black Holes:
Quantum meets Classical

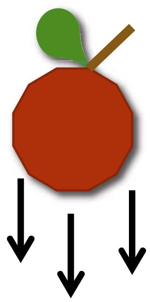
General Relativity:
Einstein's Theory

Classical Mechanics:
Newtonian Gravity

GRAVITY

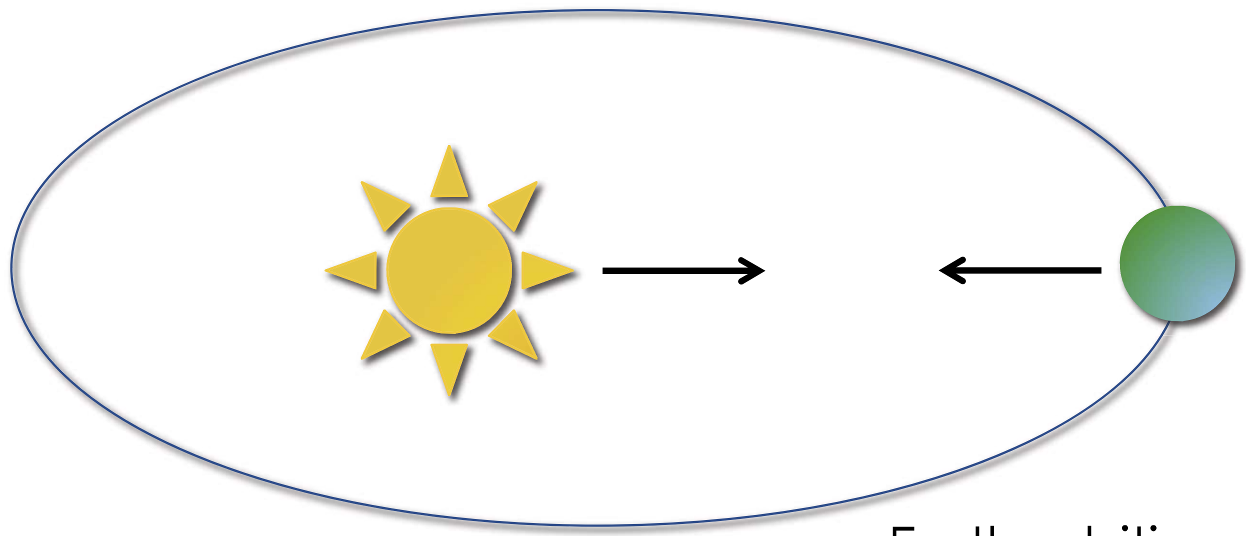
A modern perspective

How does gravity manifest?

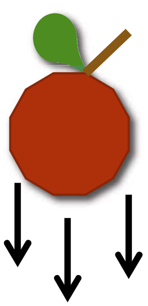


Apple falling to the ground

How does gravity manifest?

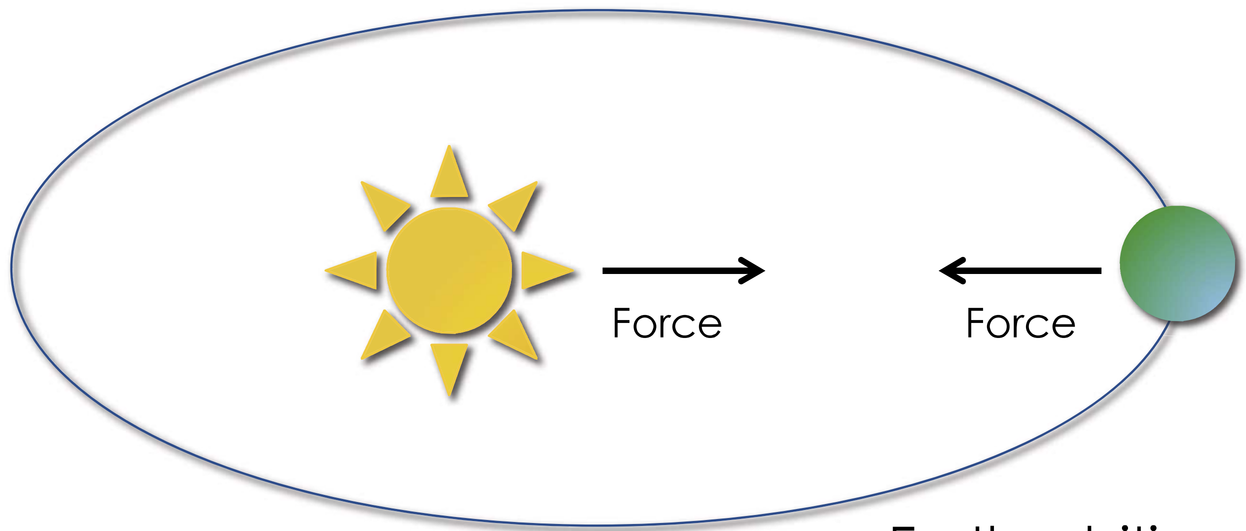


Earth orbiting the Sun

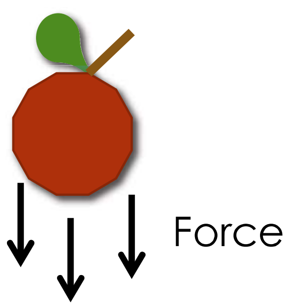


Apple falling to the ground

How does gravity manifest?



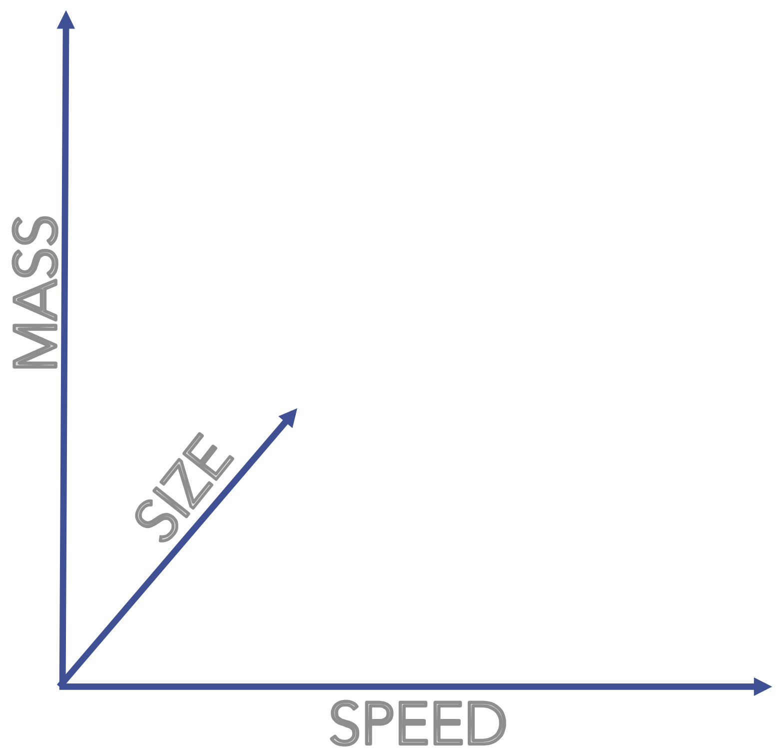
Earth orbiting the Sun

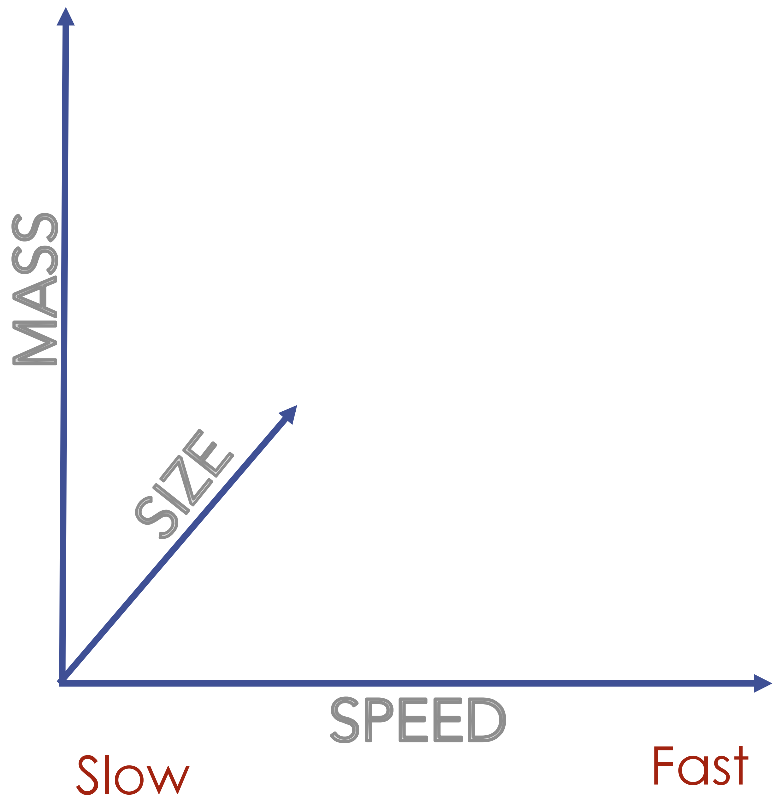


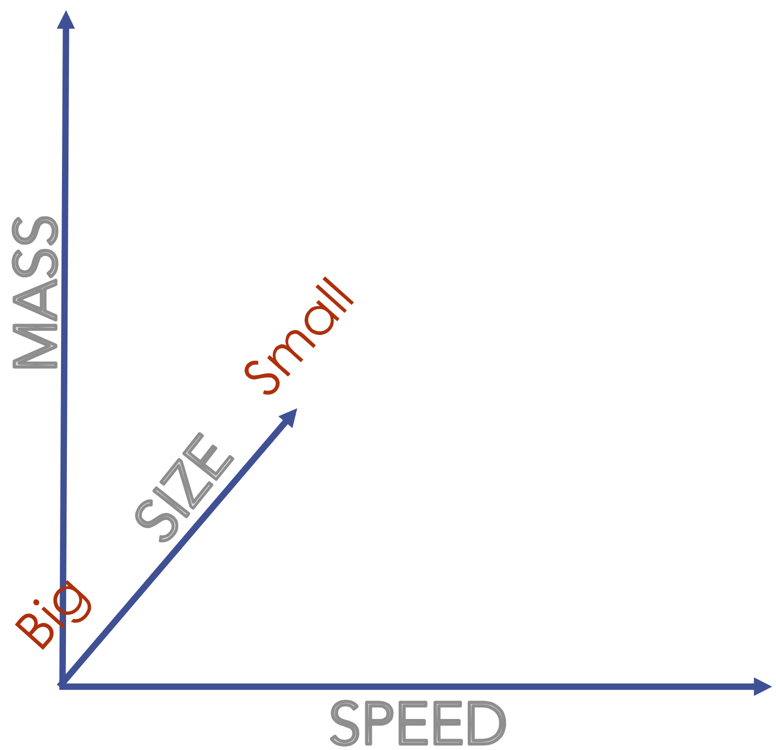
Both effects are described by the laws of Classical Mechanics.

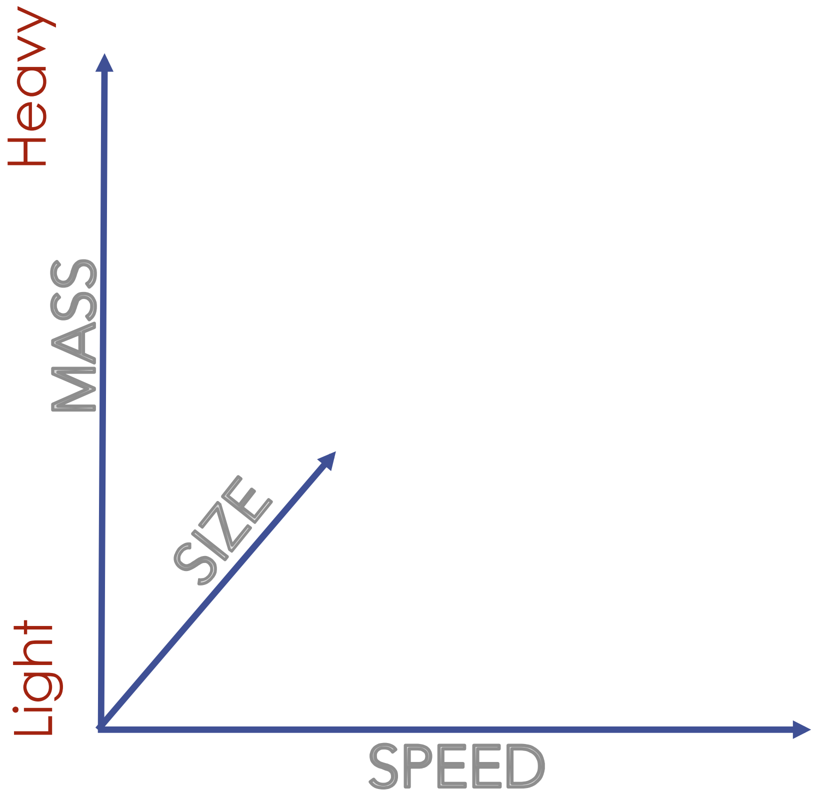
Apple falling to the ground

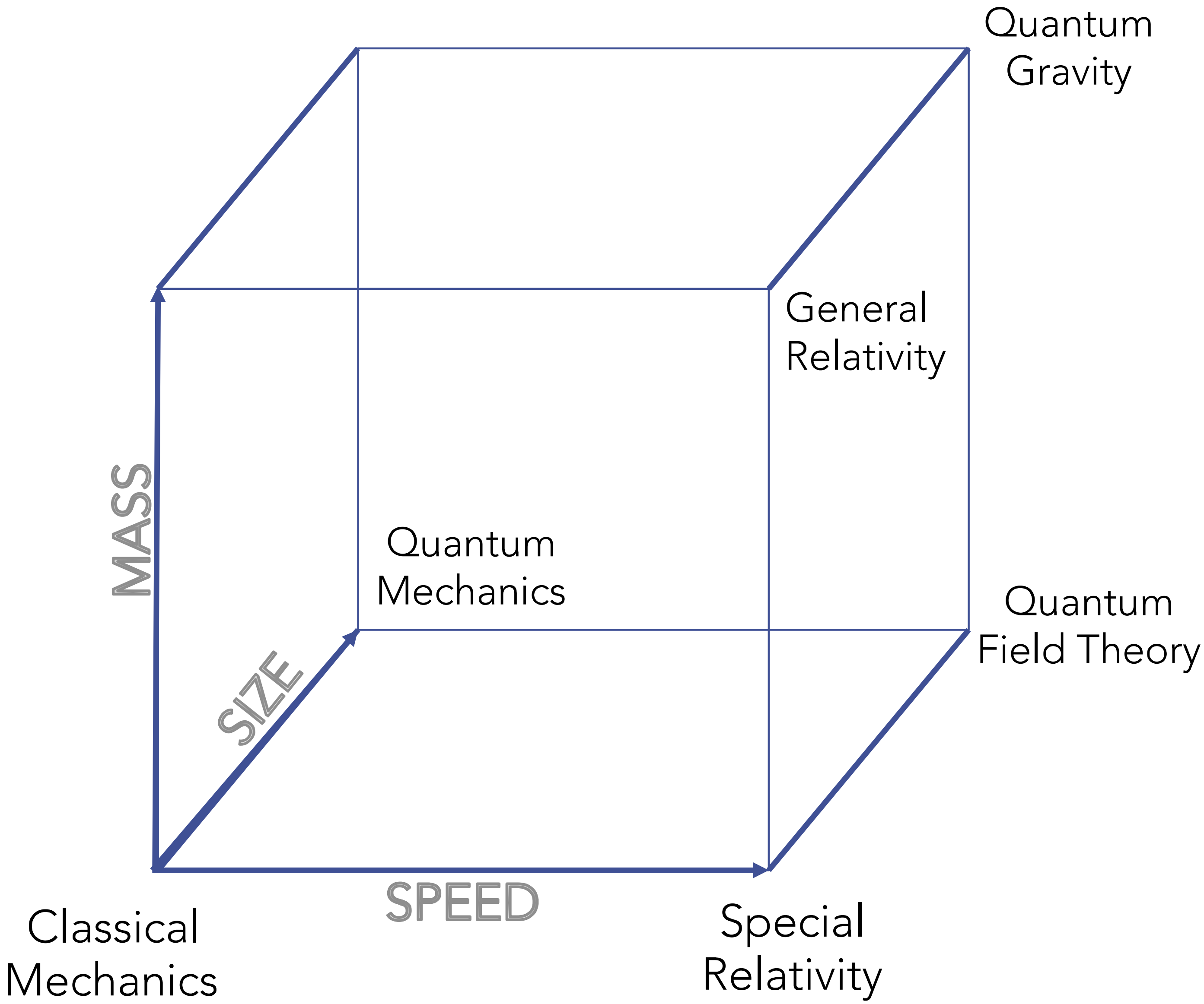
Exploring Physics in all directions

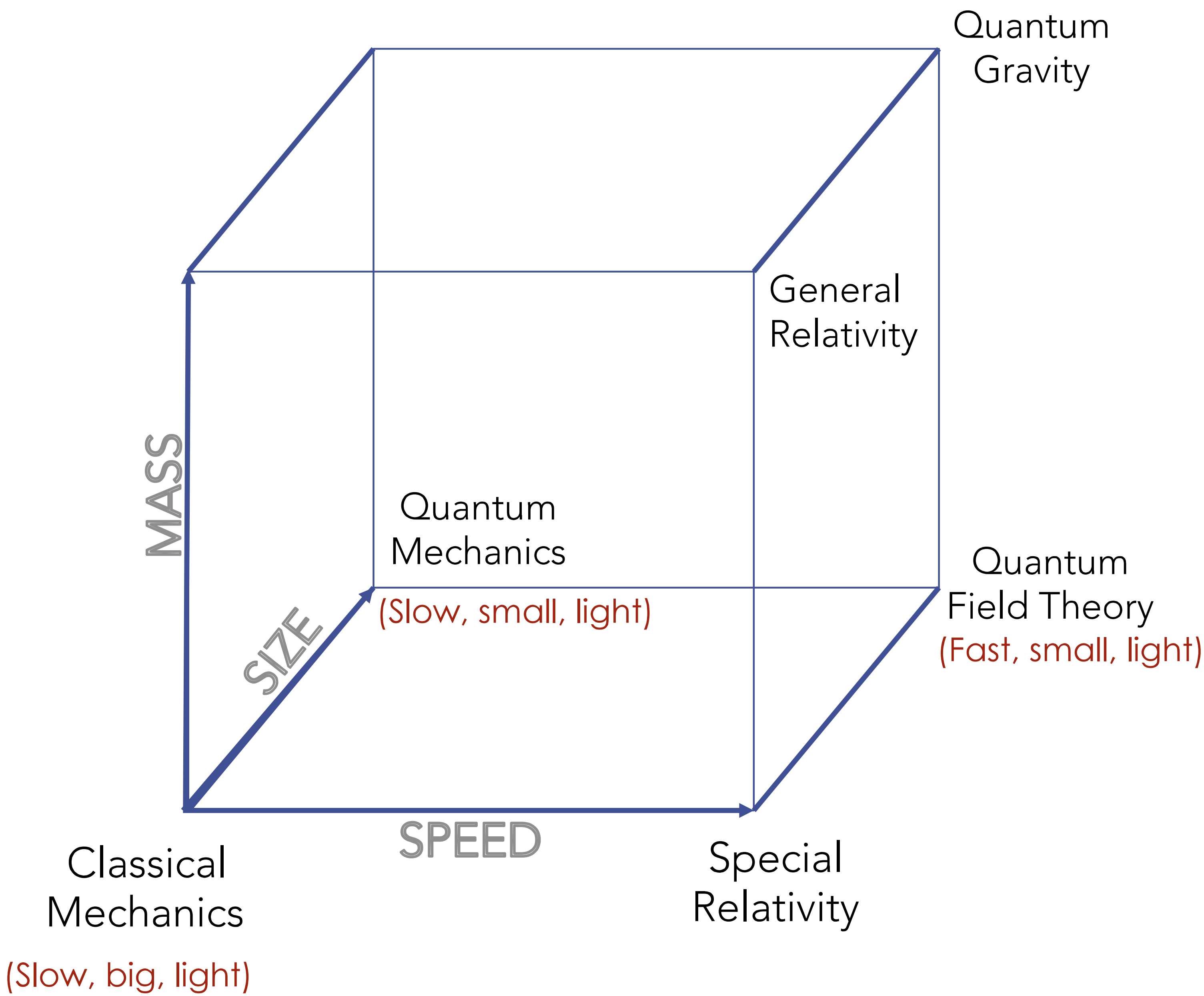



MASS
SIZE
SPEED
Slow
Fast


MASS
Small
SIZE
Big
SPEED


Heavy
MASS
SIZE
Light
SPEED


Quantum
Gravity
General
Relativity
MASS
Quantum
Mechanics
Quantum
Field Theory
SIZE
SPEED
Classical
Mechanics
Special
Relativity


Quantum
Gravity
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Mechanics
(Slow, small, light)
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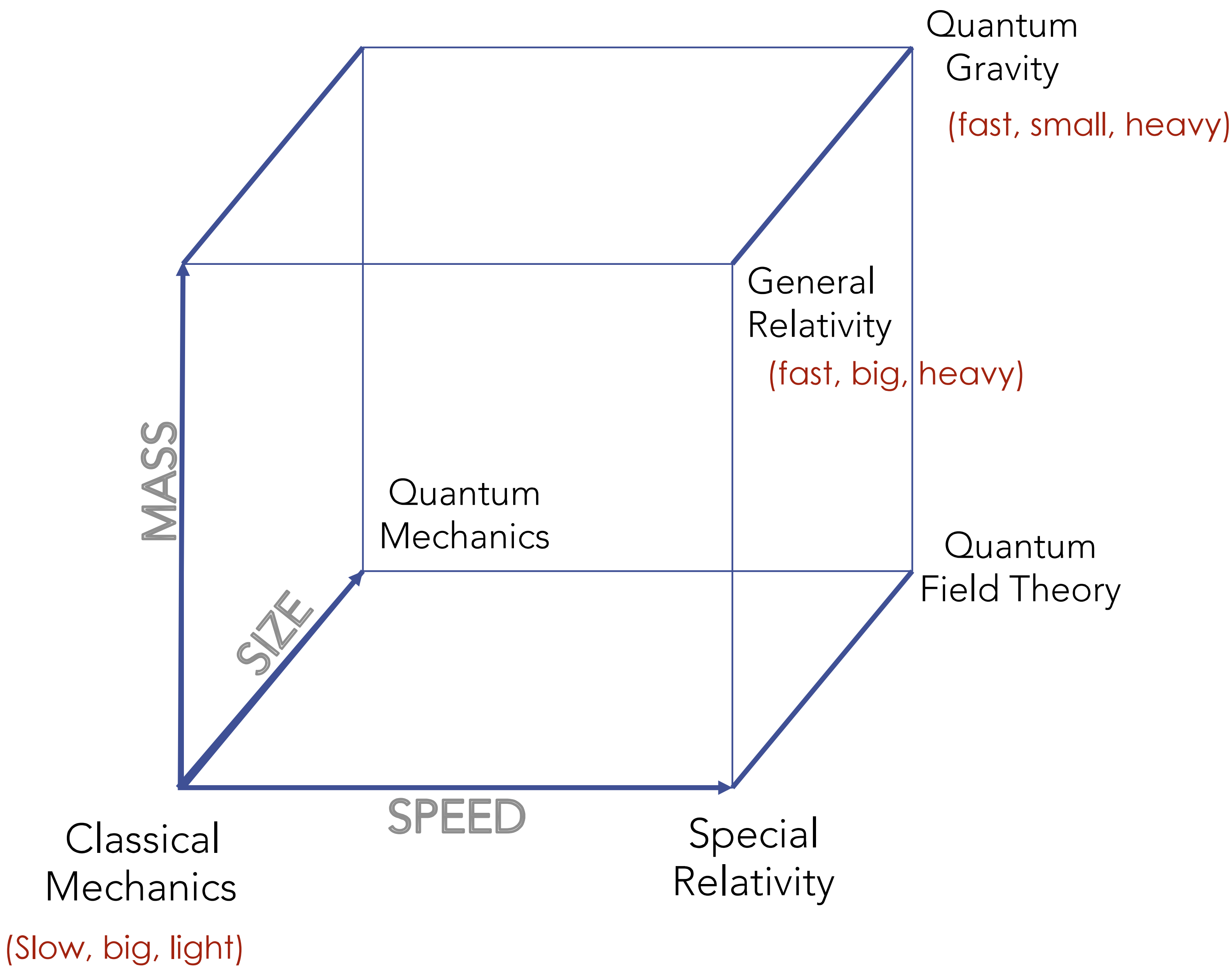
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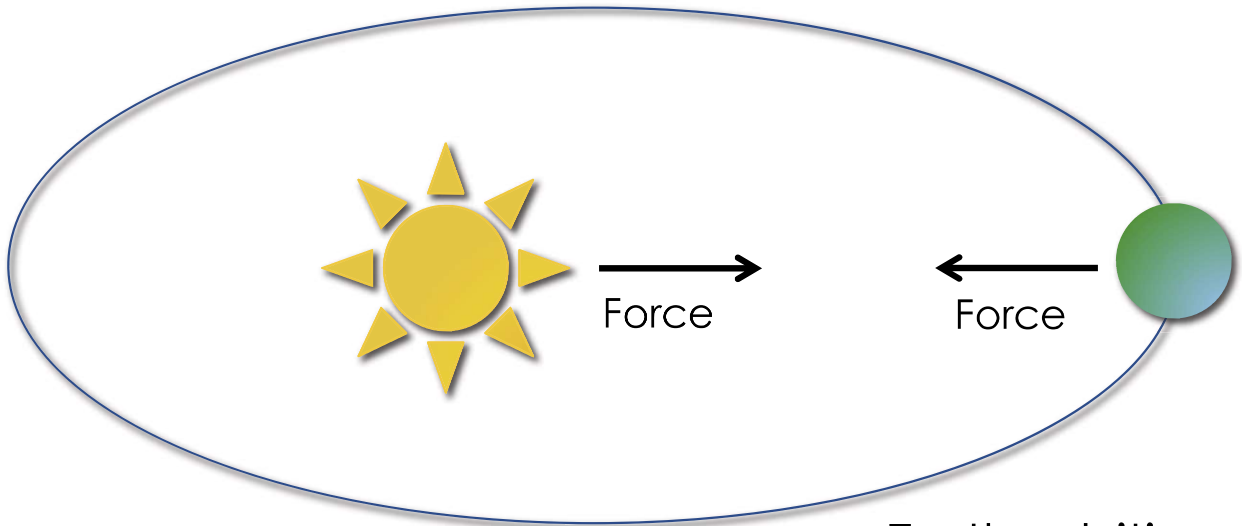
Modern view of Gravity: General Relativity

(fast, big, heavy)

In classical mechanics, we had

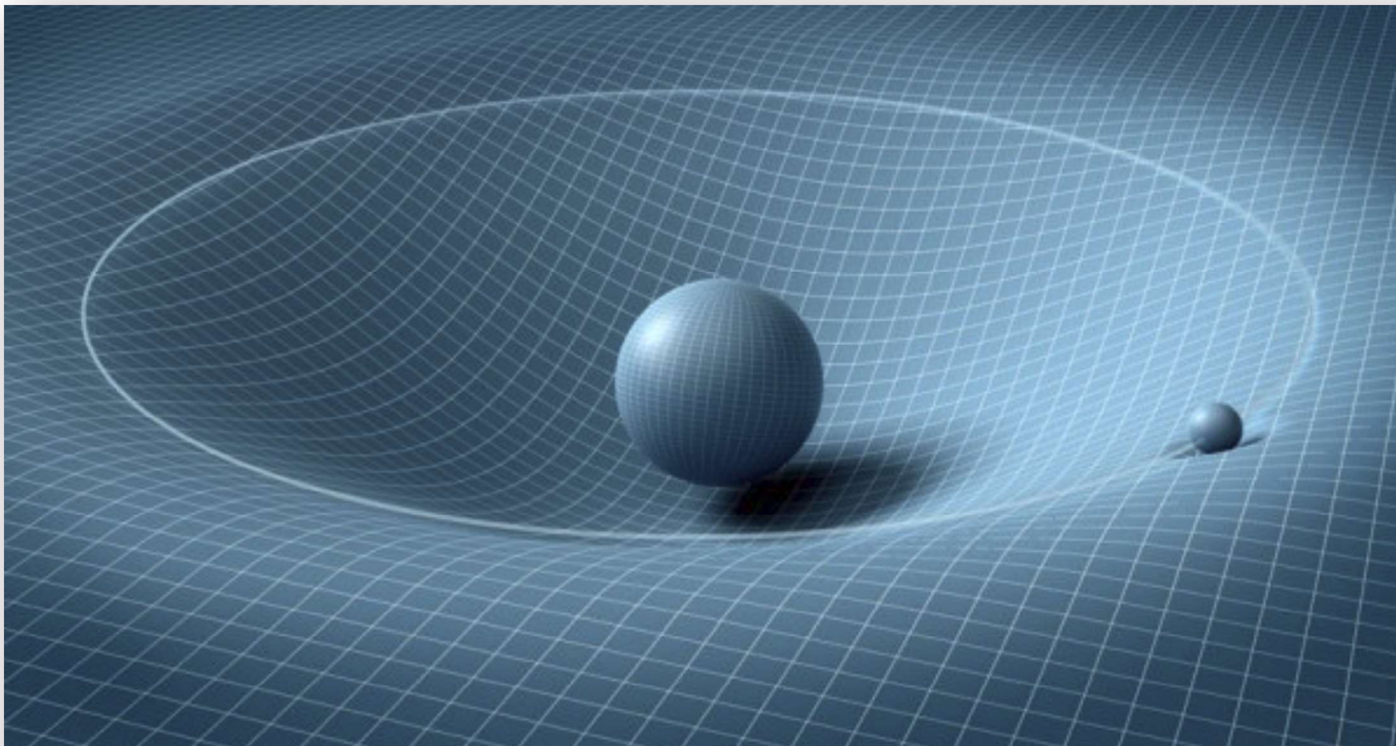


Earth orbiting the Sun

Modern view of Gravity: General Relativity

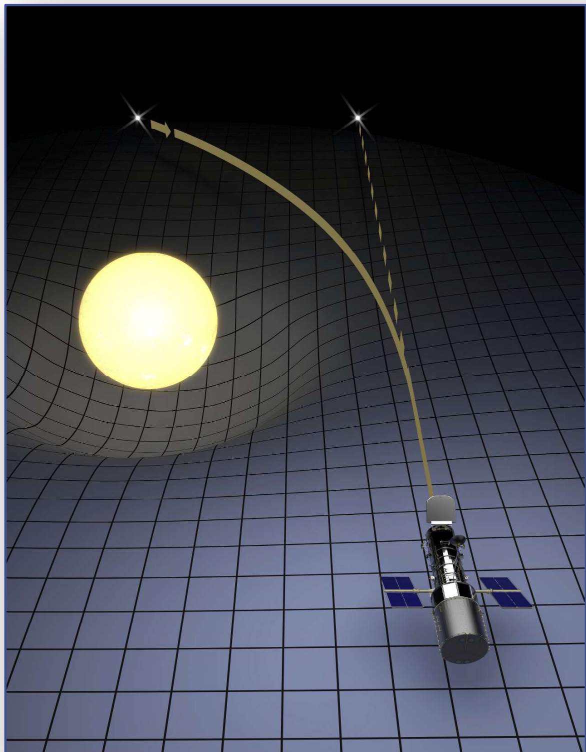
(fast, big, heavy)

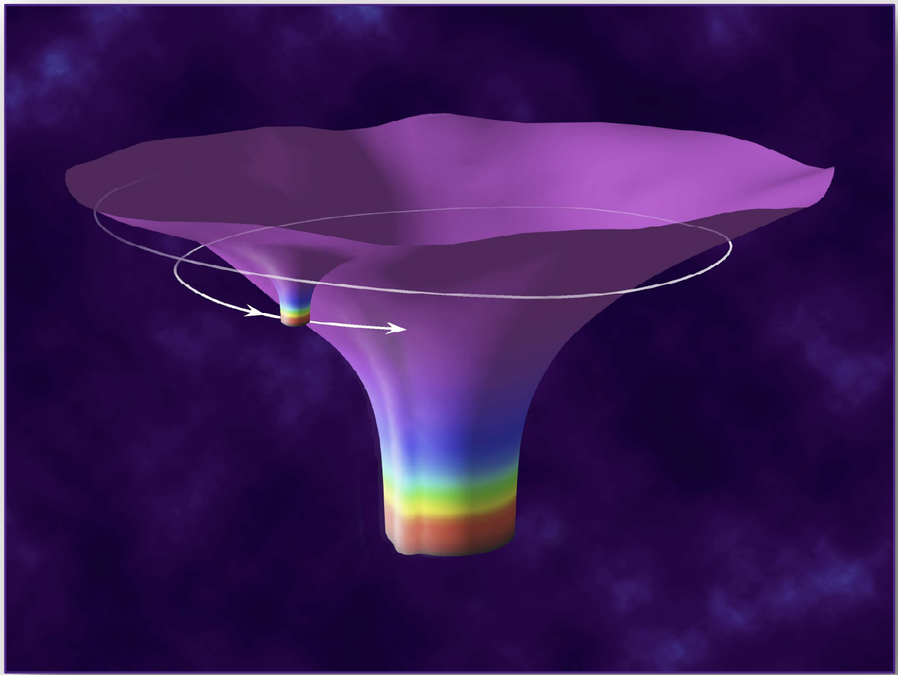
In general relativity, we have



Earth orbiting the Sun. Please remove arrows.

Gravity = Geometry



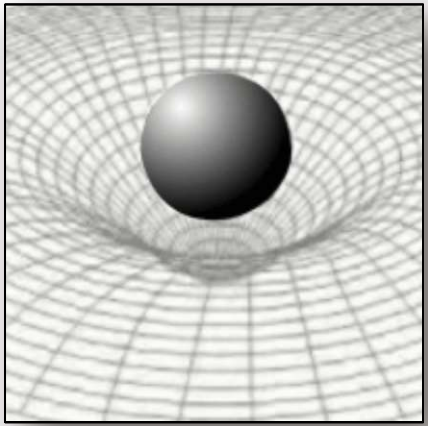


$$E = mc^2 \longrightarrow$$

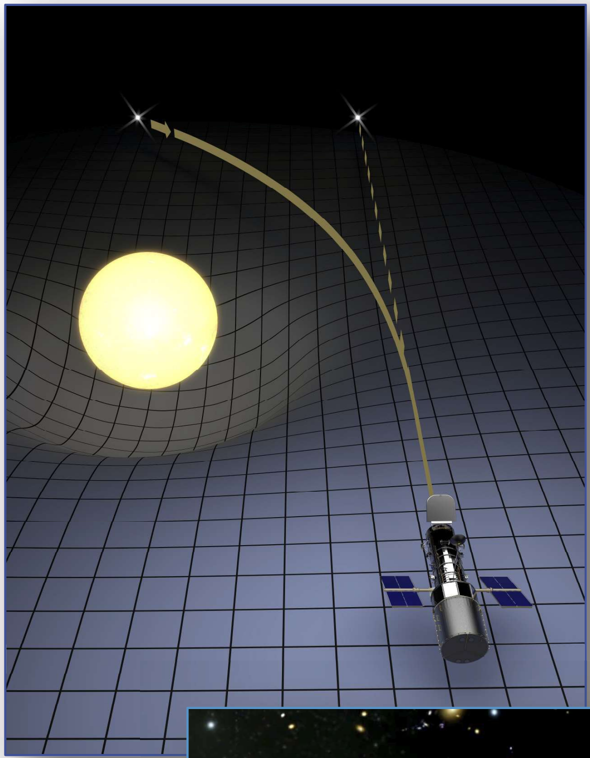
Energy = mass
Special Relativity

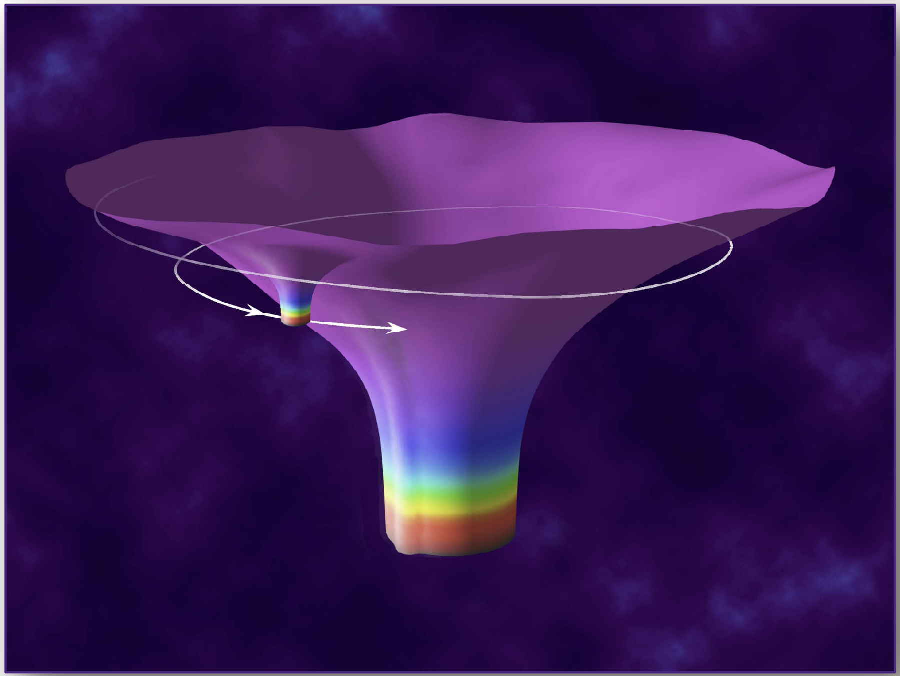
$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \longrightarrow$$

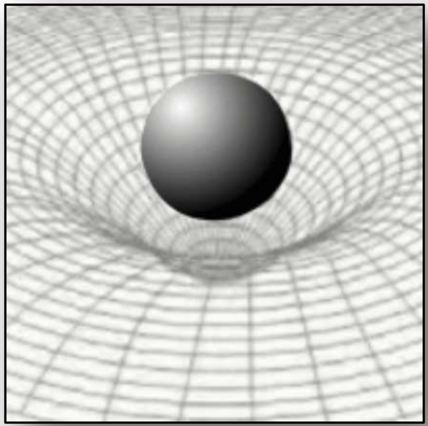
Geometry = Energy
General Relativity



Gravity = Geometry

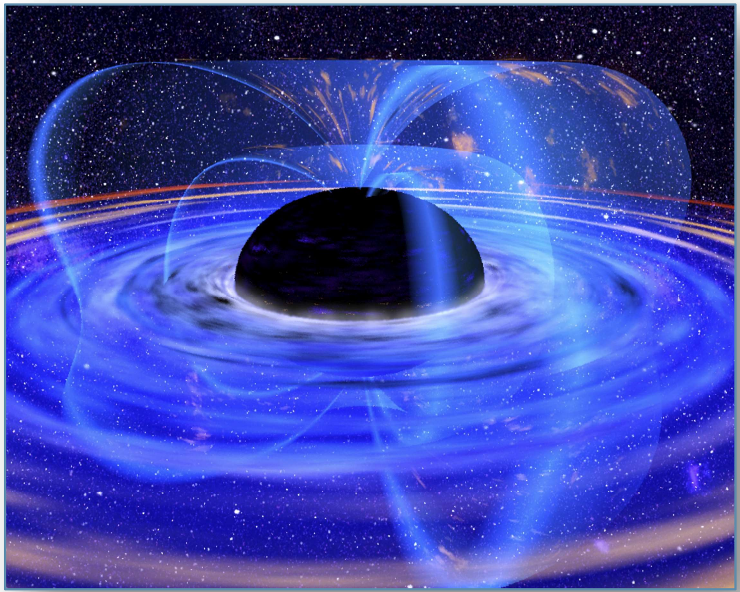
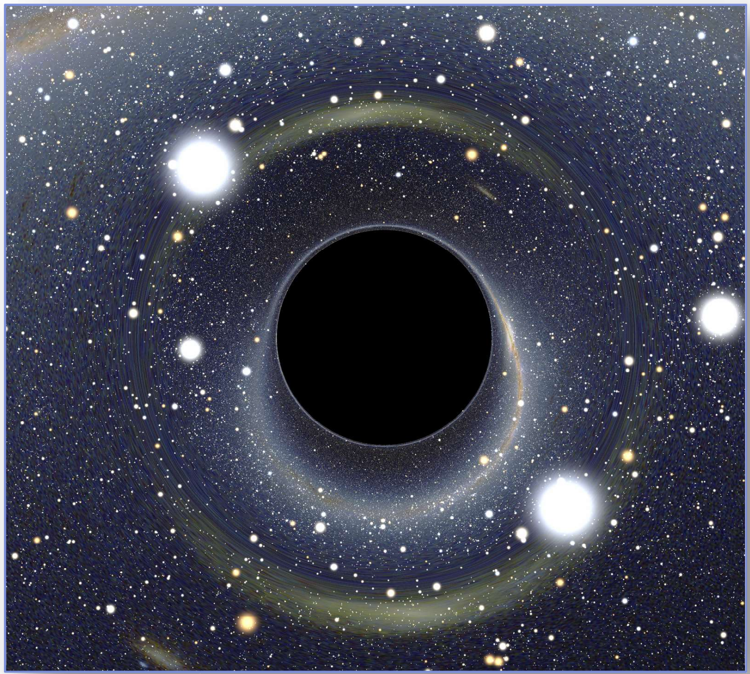
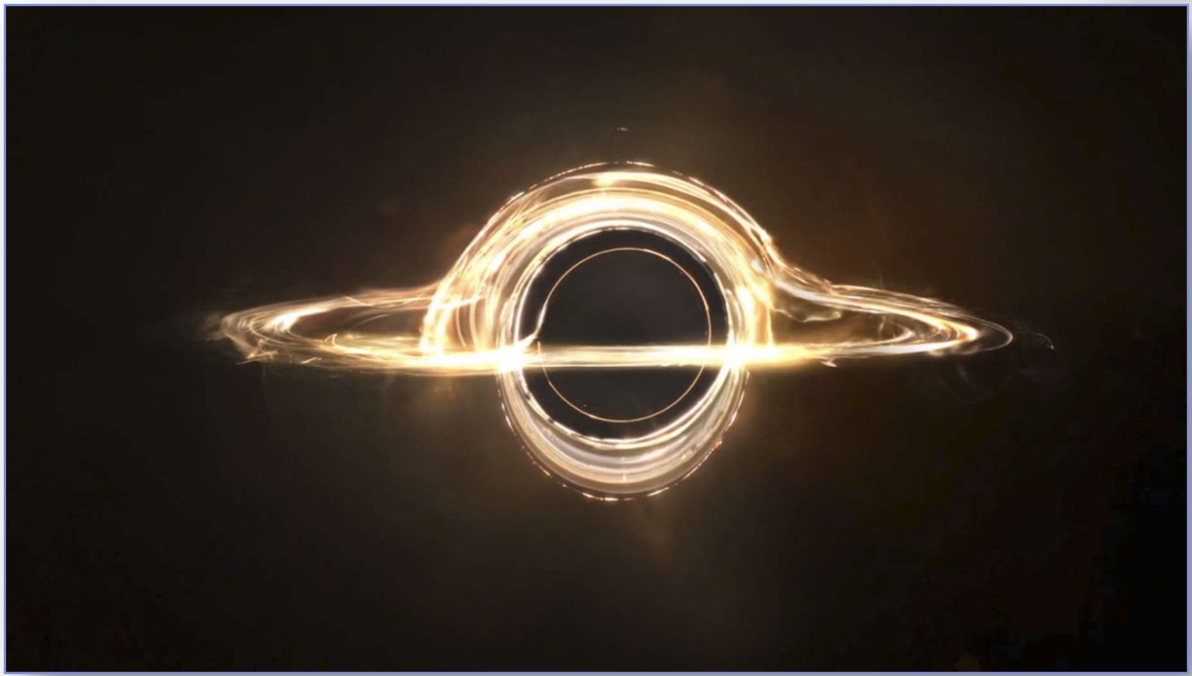




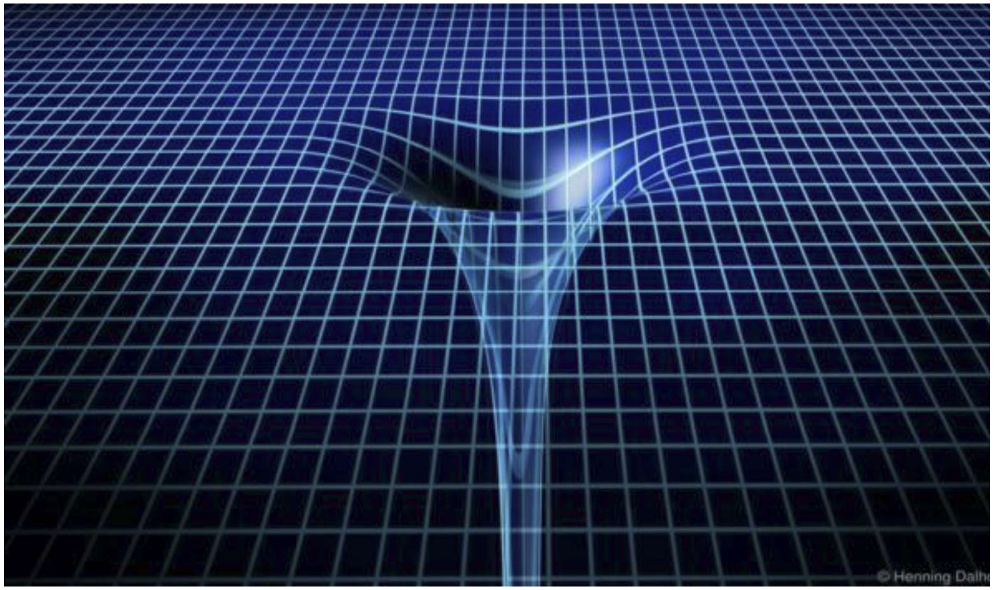


BLACK HOLES

The origin of holography

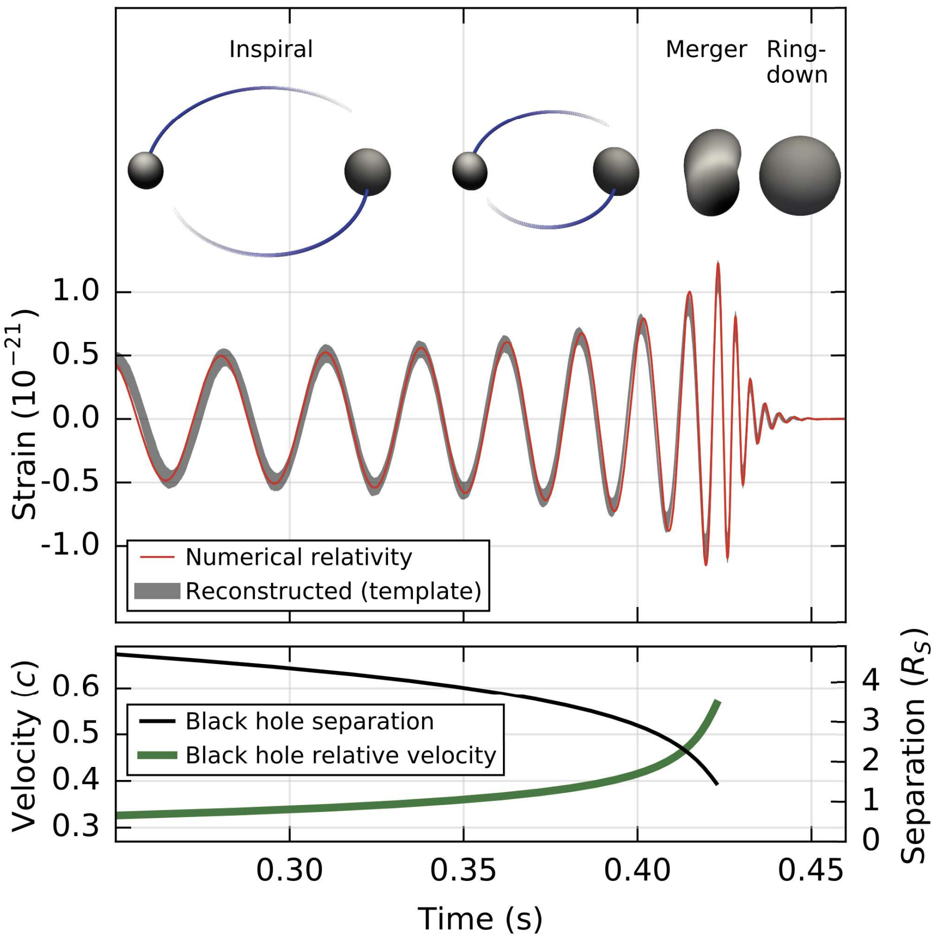
Black holes

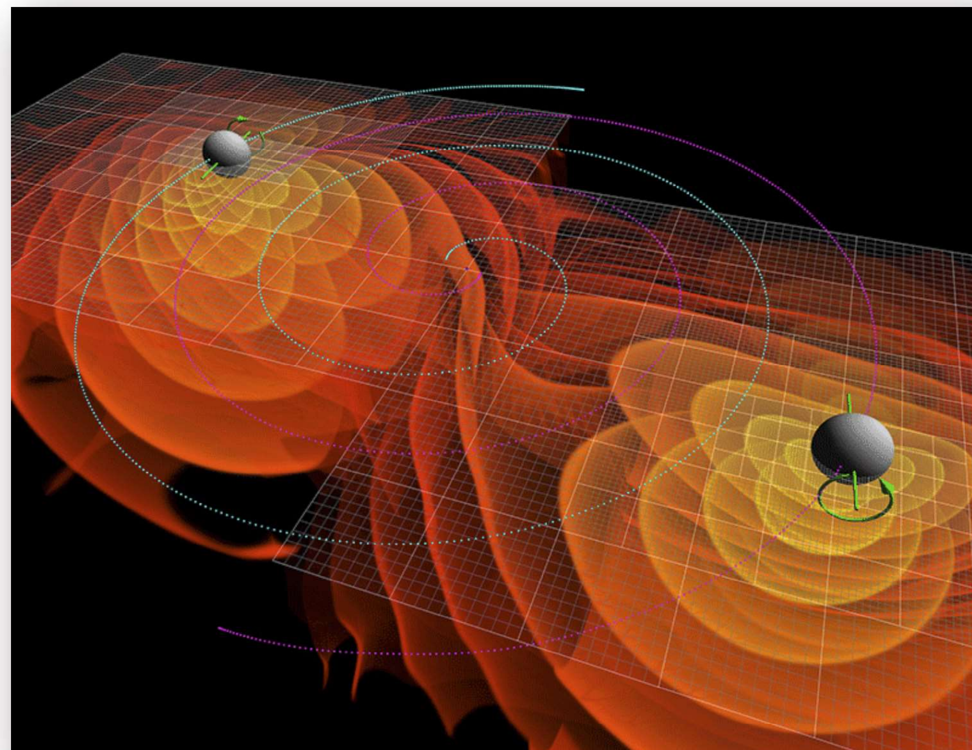


Space curves to an extreme.
Black hole is a region of immense gravity.
Not even light can escape.

And they are very real!

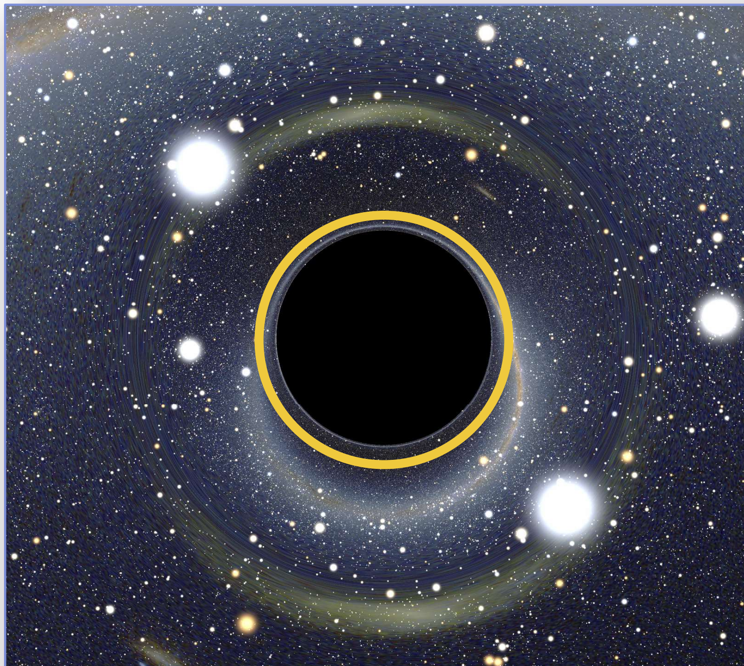
In our universe, we hear them



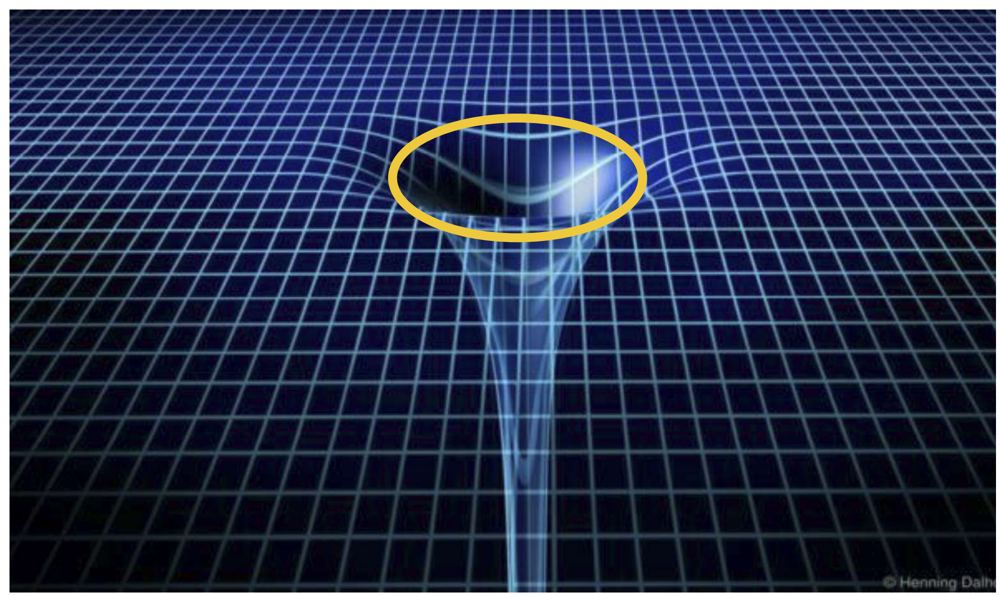


Measurement of gravitational waves by LIGO-Virgo Collaboration

Black hole in theory

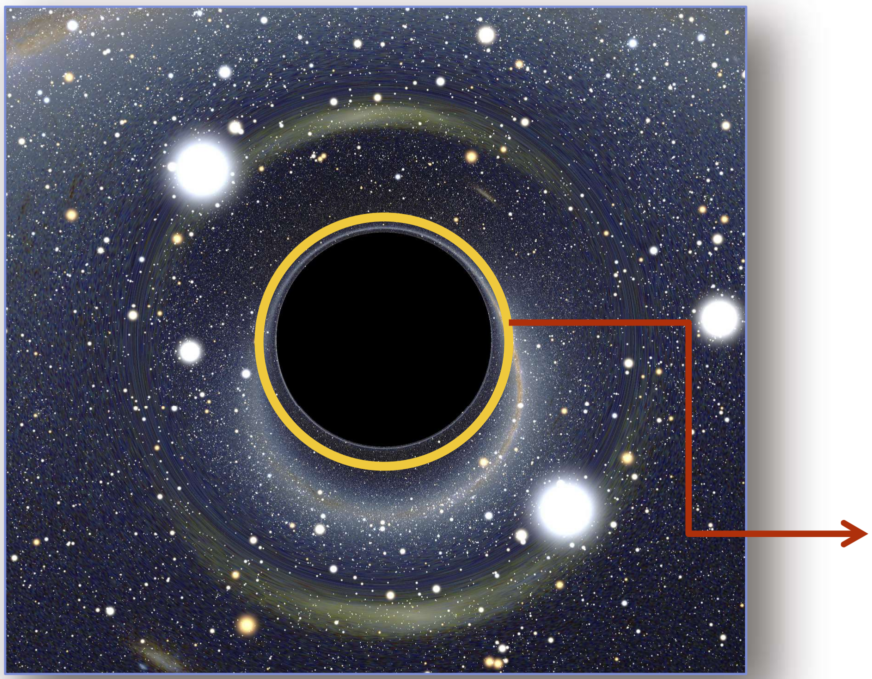


Many aspects of black holes are simple.



Event Horizon: passed that surface, nothing escapes!

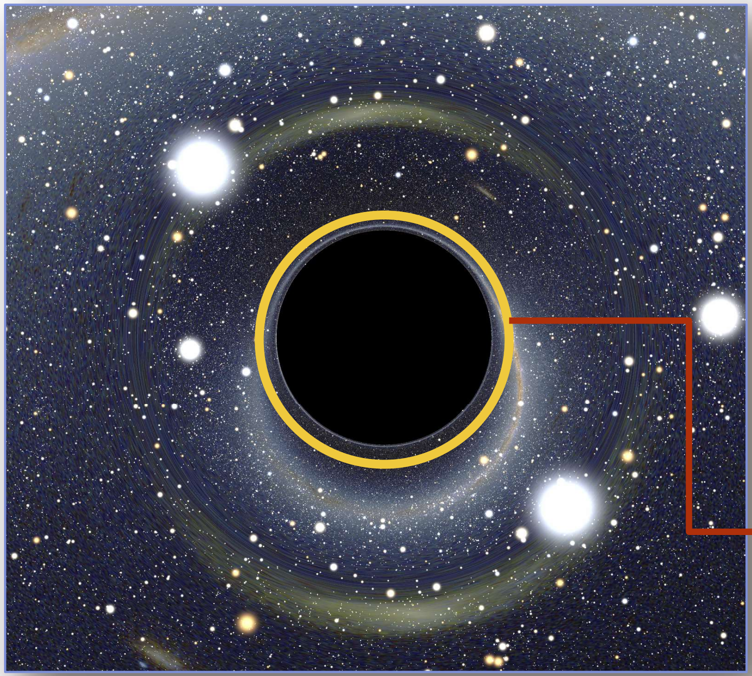
Black hole in theory



Many aspects of black holes are simple.

Size (radius) of event horizon and Mass

Black hole in theory



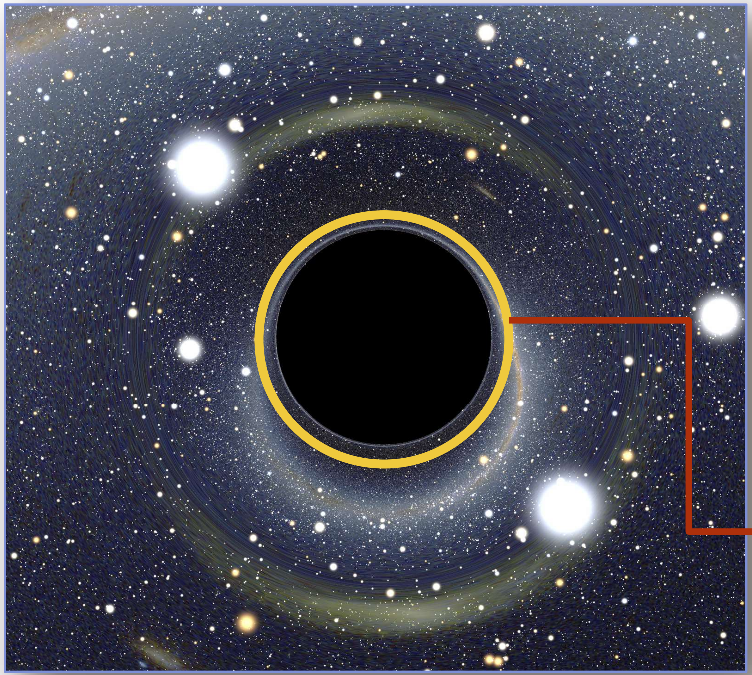
Many aspects of black holes are simple.

Size(radius) of event horizon and Mass

If the a black hole is as massive as:

- Sun, its radius is 3000 m
- Earth, its radius is 0.8 cm
- Human (70kg), its radius is 10^{-25} m.

Black hole in theory



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Size(radius) and Mass

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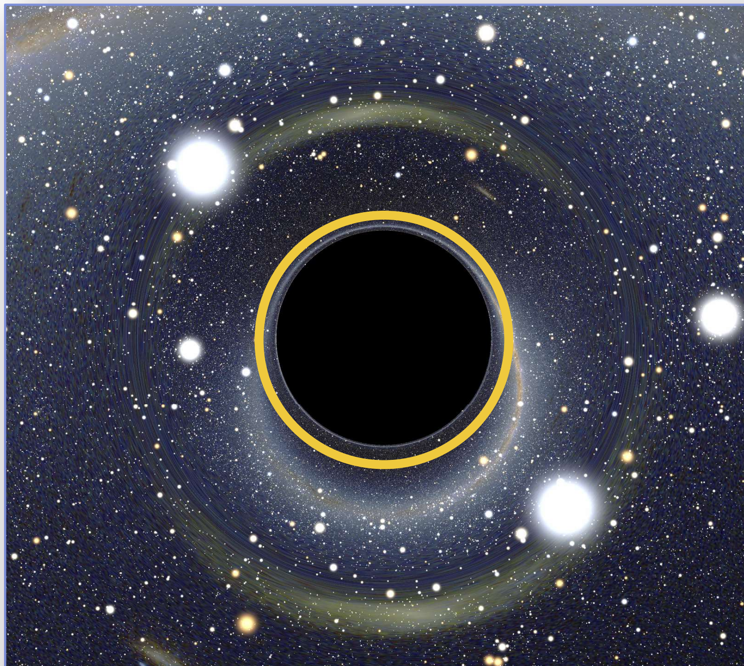
Compare!

Actual size:

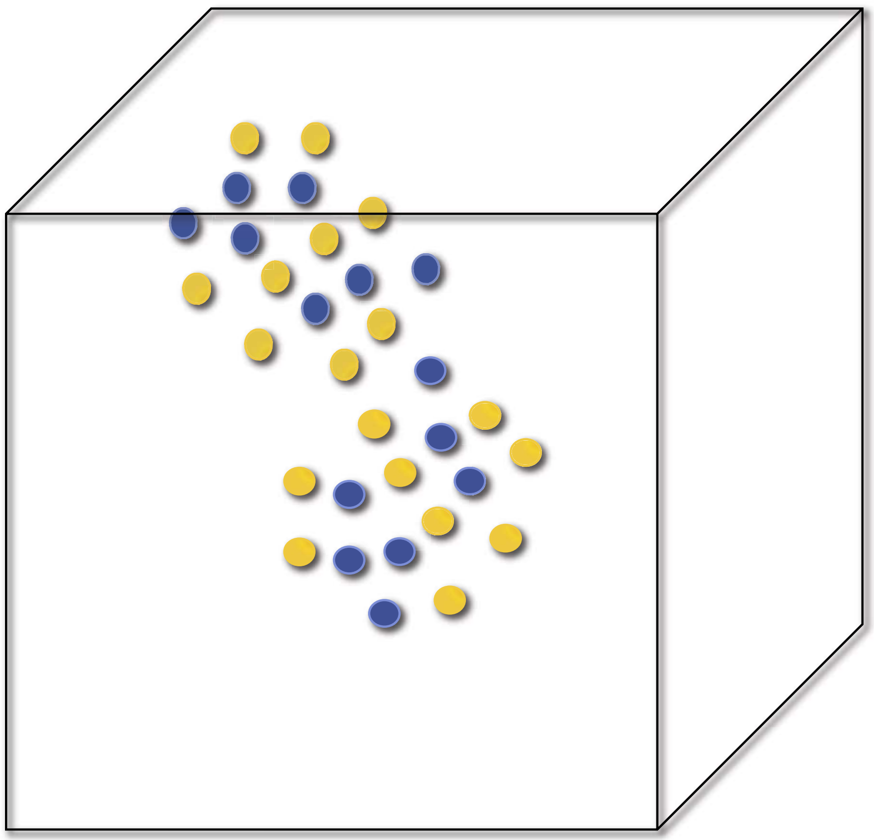
700000 m
6400 m
1.7 m

Black hole in theory



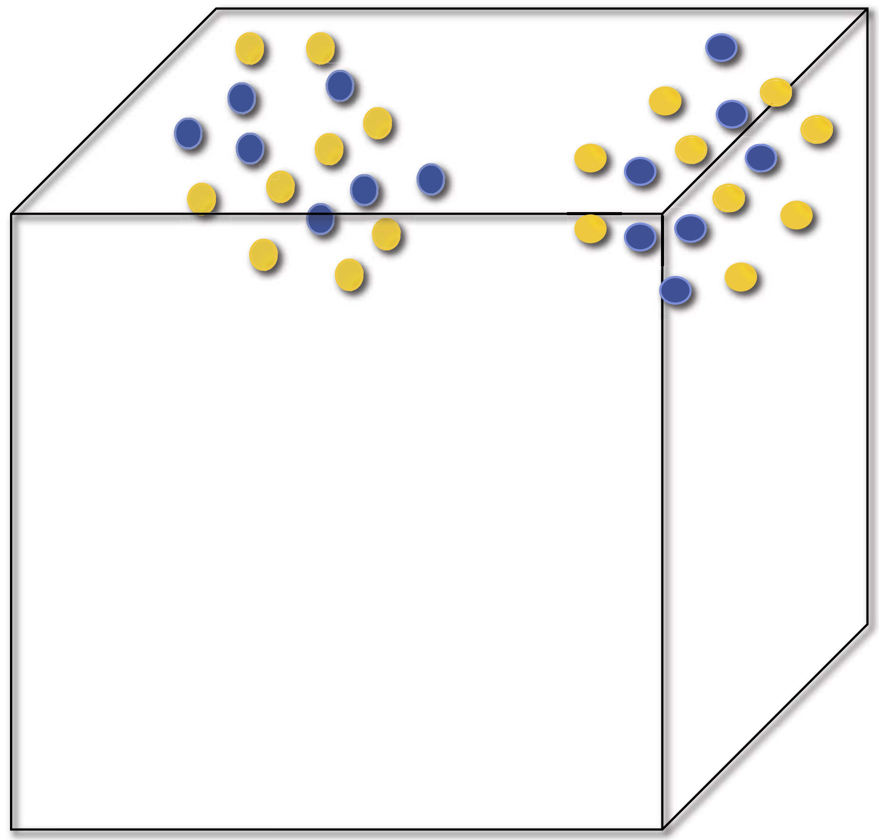
One of the revolutions in theoretical physics was the discovery that black holes carry information.

Entropy: how to quantify information



Number of configurations of particles in the box. What is the most likely configuration?

Entropy: how to quantify information



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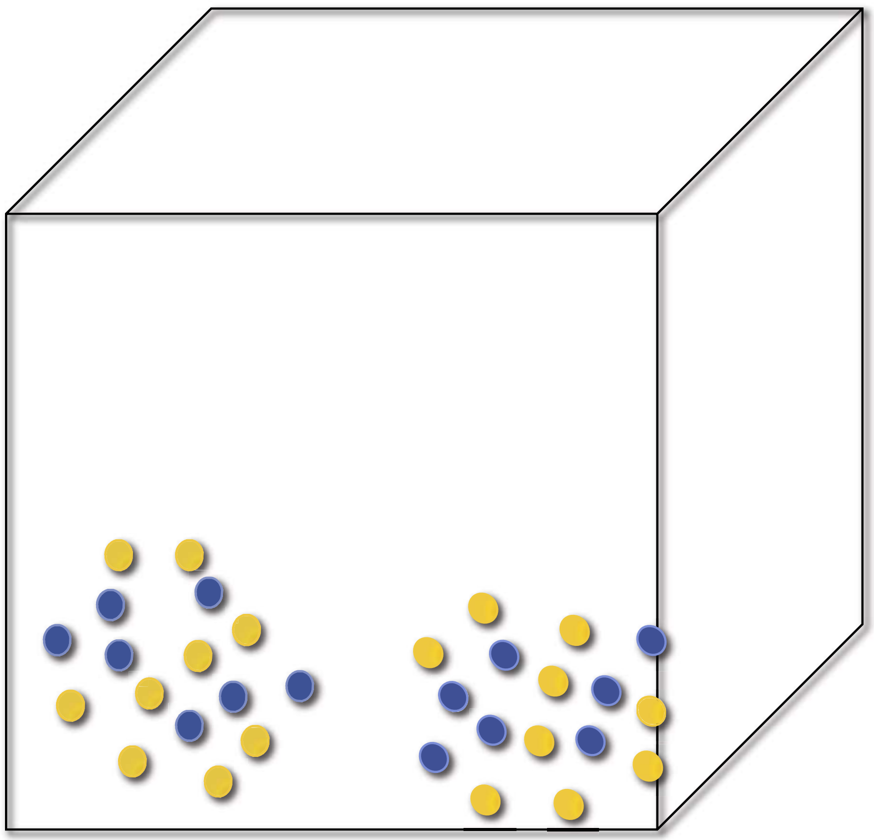

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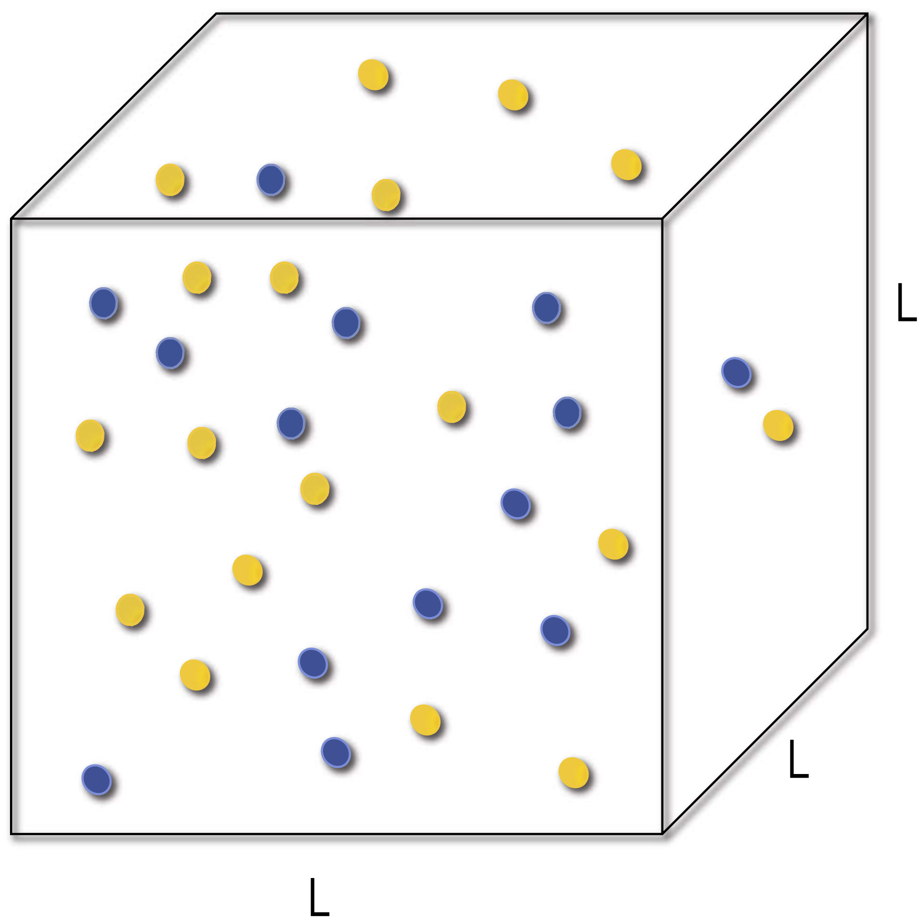
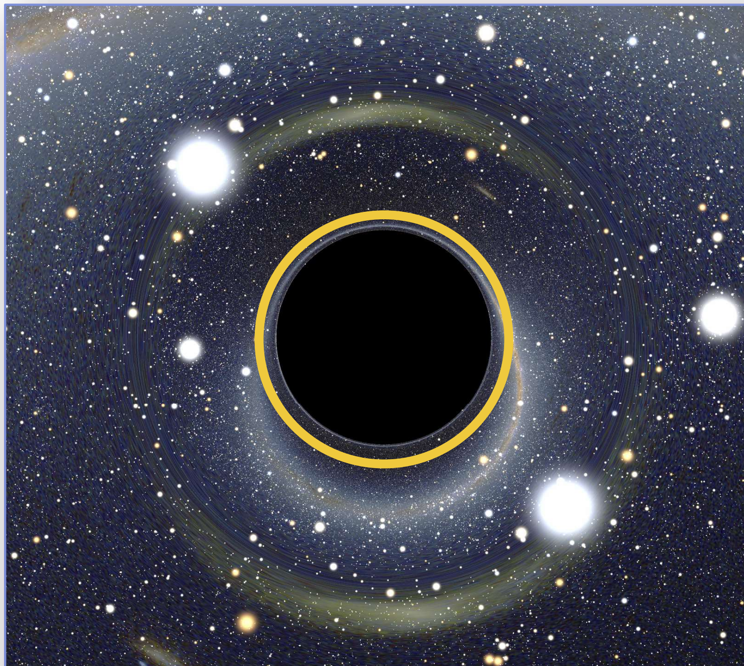
Entropy: how to quantify information



Number of configurations of particles in the box. What is the most likely configuration?

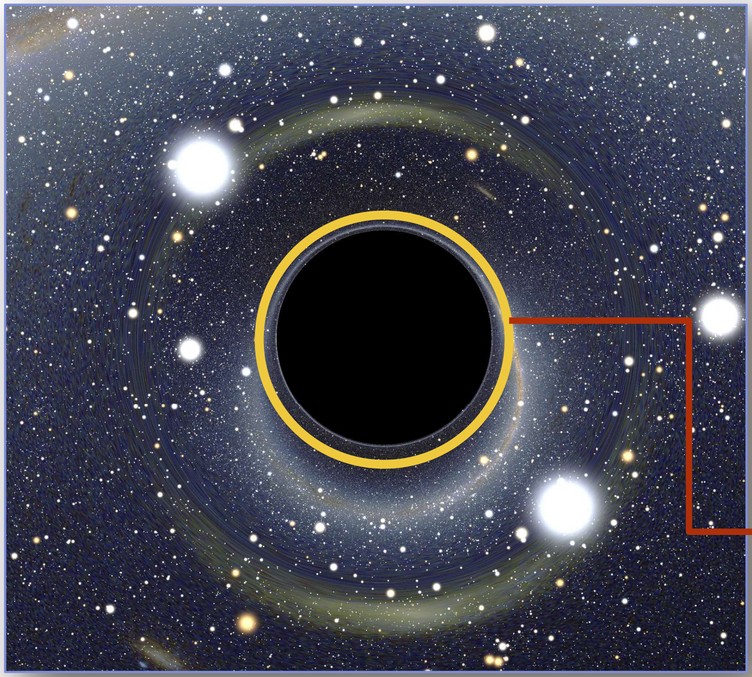
Entropy= Volume = L^3

Black hole entropy



Intuitive reasons why they carry information, but how much?
Reconciling General relativity with Quantum Mechanics gave hints.

Black hole entropy



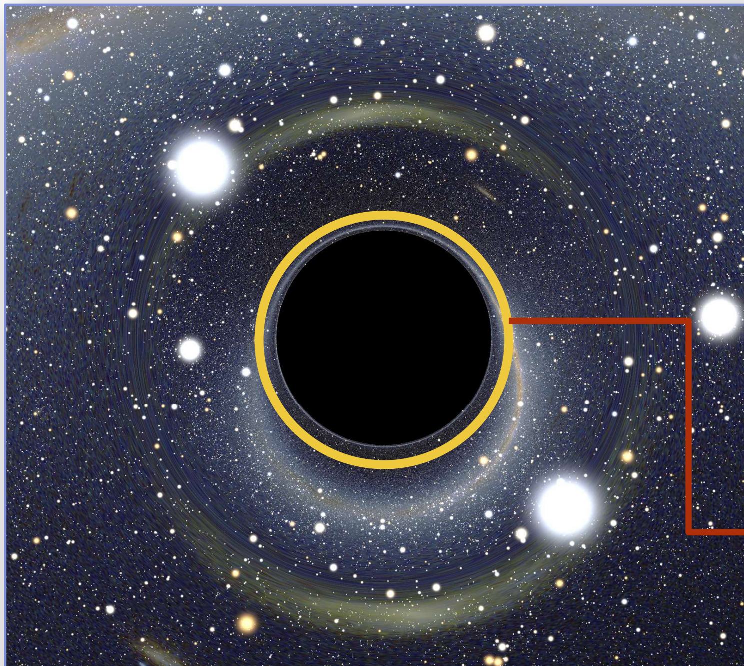
Entropy BH = Size^3 ?

OR

Entropy BH = Size^2 ?

Size and Mass

Black hole entropy



Entropy BH = Size^3 ?

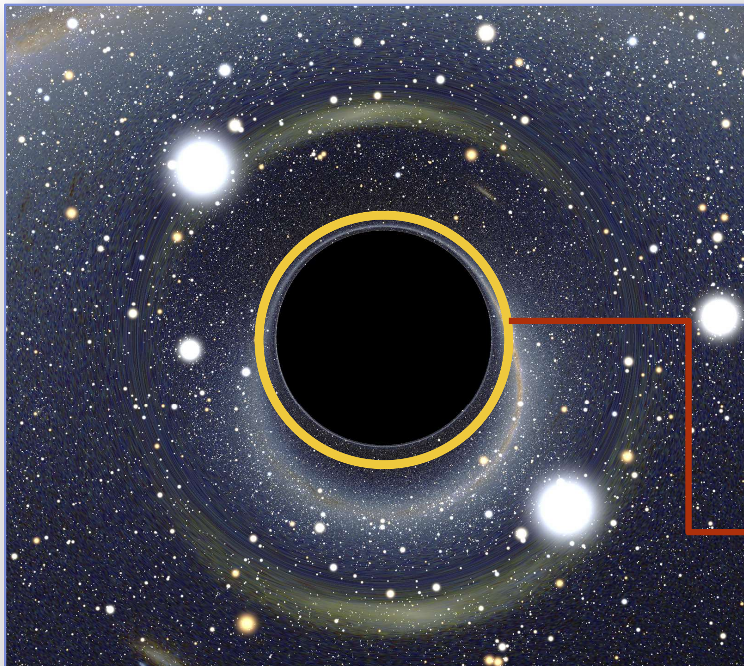
OR

Entropy BH = Size^2

Size and Mass

$$S_{\mathrm{BH}} = \frac{c^3}{G\hbar}\frac{A_H}{4}$$

Black hole entropy



Entropy BH = Size^3 ?

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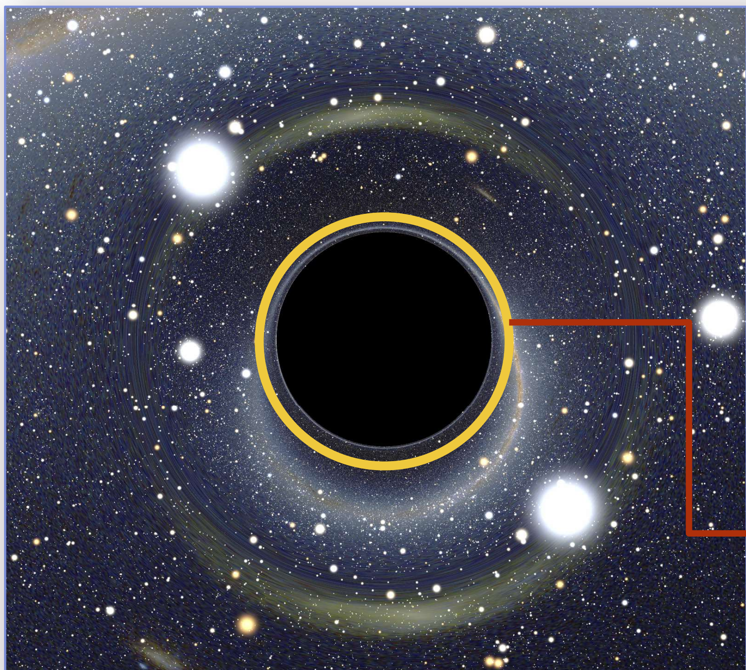
Size and Mass

$$S_{\mathrm{BH}} = \frac{c^3}{G\hbar}\frac{A_H}{4}$$

Area event horizon

Black hole entropy



Entropy BH = Size³ ?

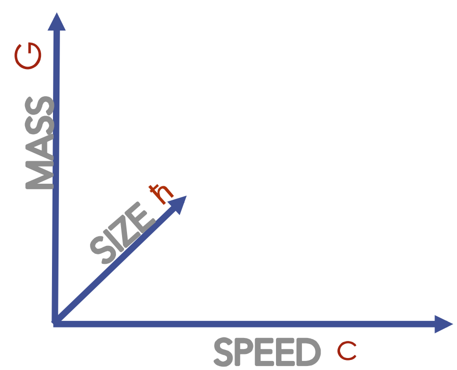
OR

Entropy BH = Size² ?

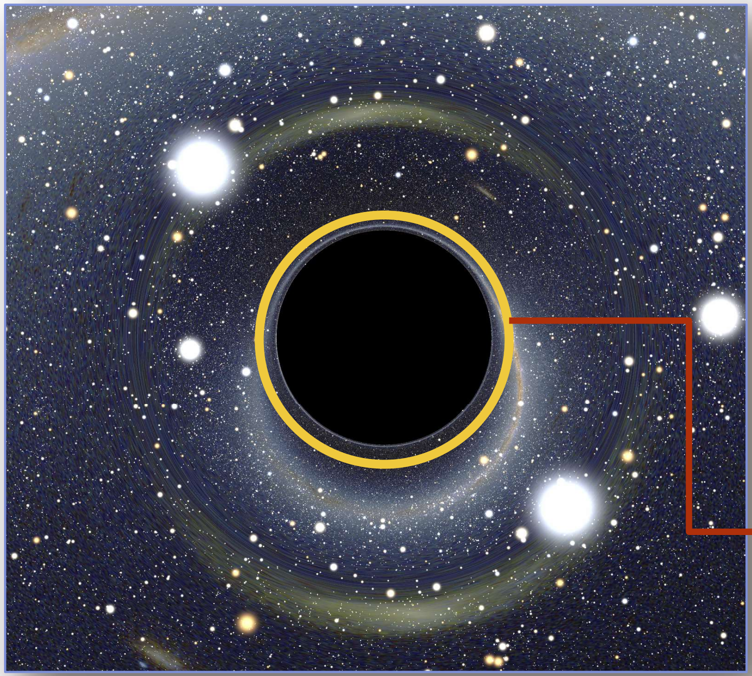
Size and Mass

$$S_{\rm BH} = \frac{c^3}{G\hbar}\frac{A_H}{4}$$

Fundamental constants



Black hole entropy



Entropy BH = Size³ ?

OR

Entropy BH = Size² ?

Size and Mass

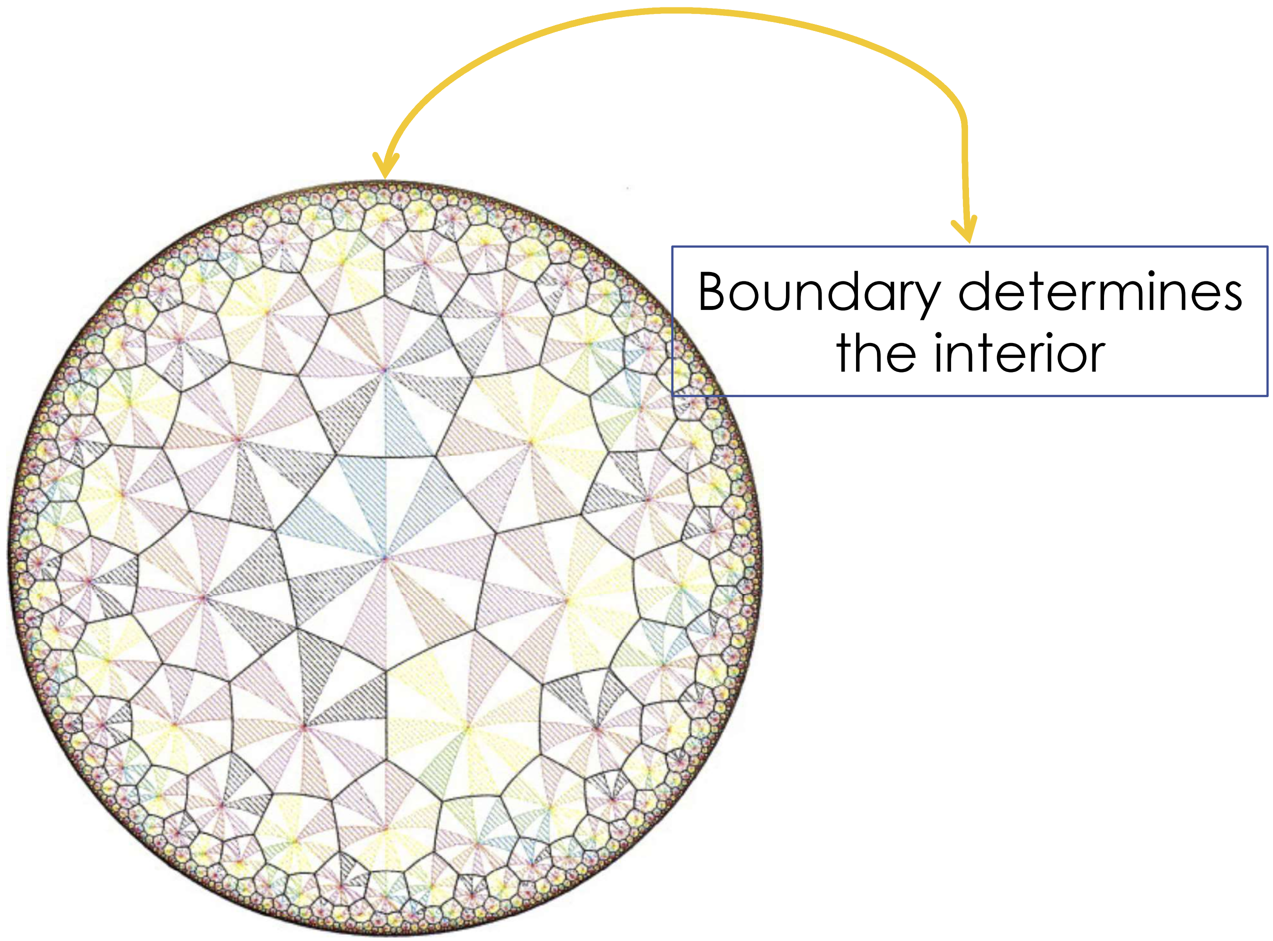
$$S_{\rm BH} = \frac{c^3}{G\hbar}\frac{A_H}{4}$$

ALL of the information is contained on the surface!

HOLOGRAPHIC PRINCIPLE

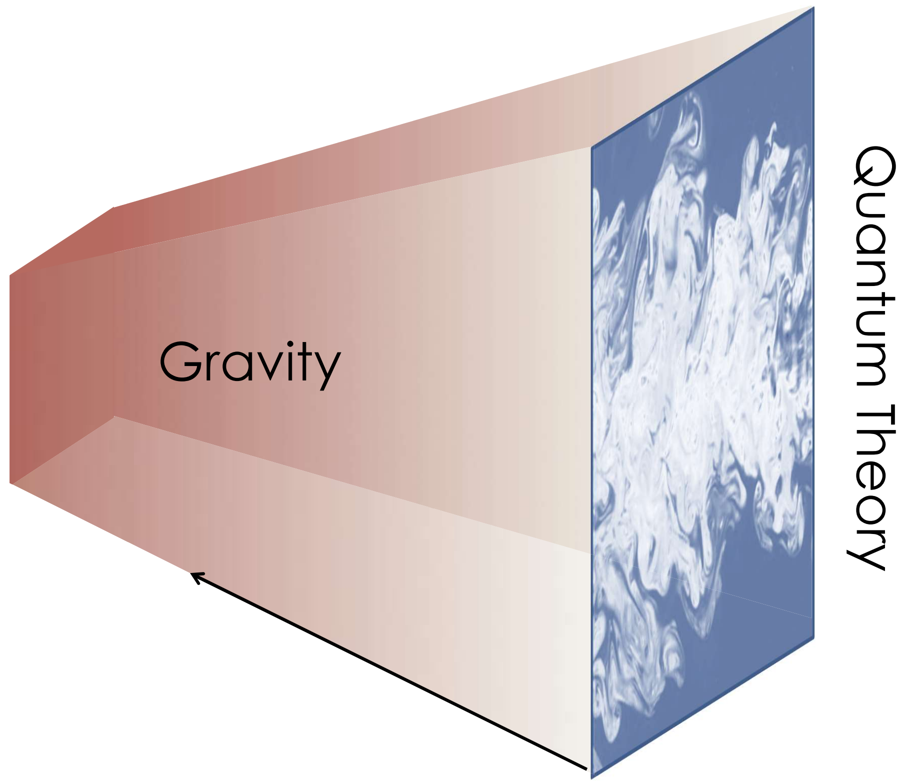
Why is holography exciting?

Holography: the proposal



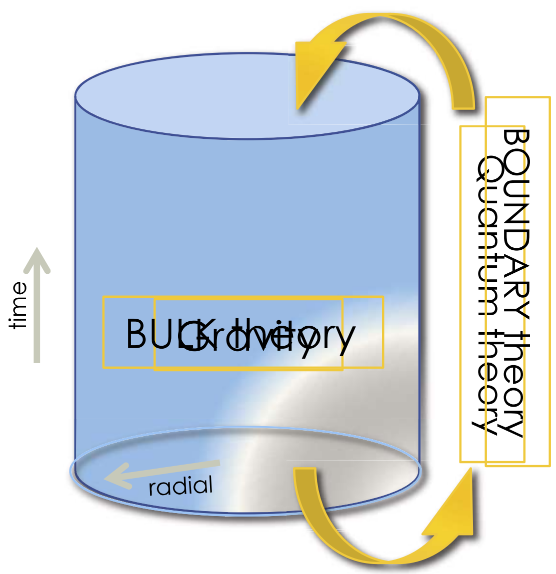
Systems that are described by fewer dimensions than expected.

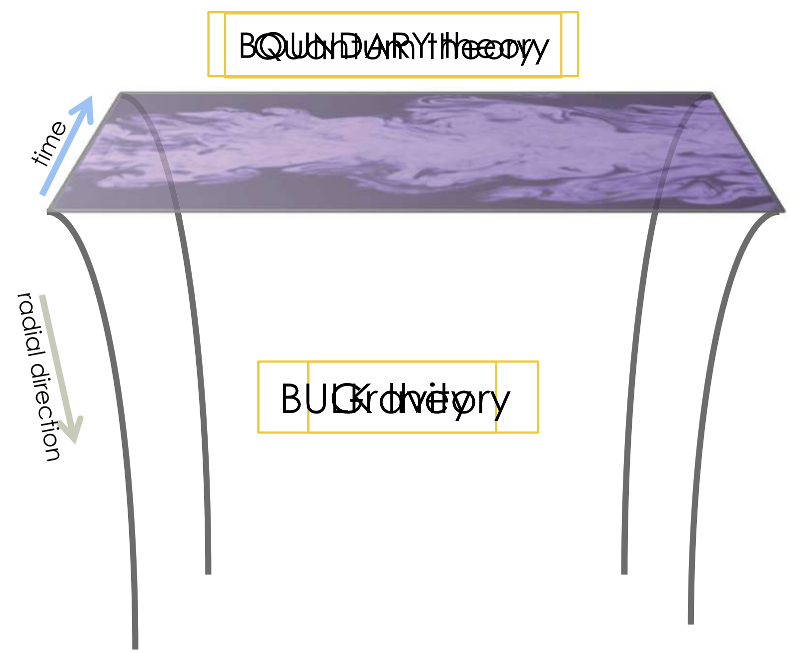
Holography: the proposal



Holography: definition

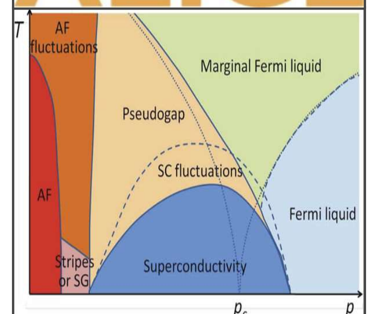
Gravitational theory in D dimensions is equivalent to quantum field theory in (D-1) dimensions

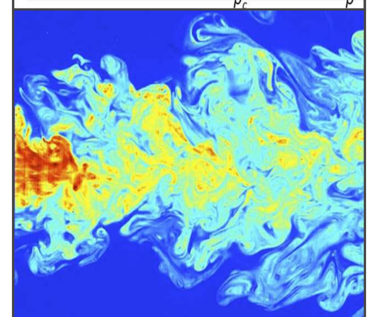


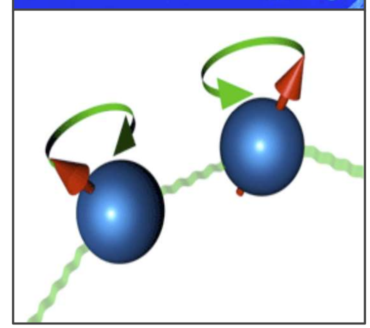


Holography: Practical uses

- Quark-gluon plasma
- High T_c superconductors
- Relativistic hydrodynamics
- Non-relativistic strongly coupled systems
- Quantum information

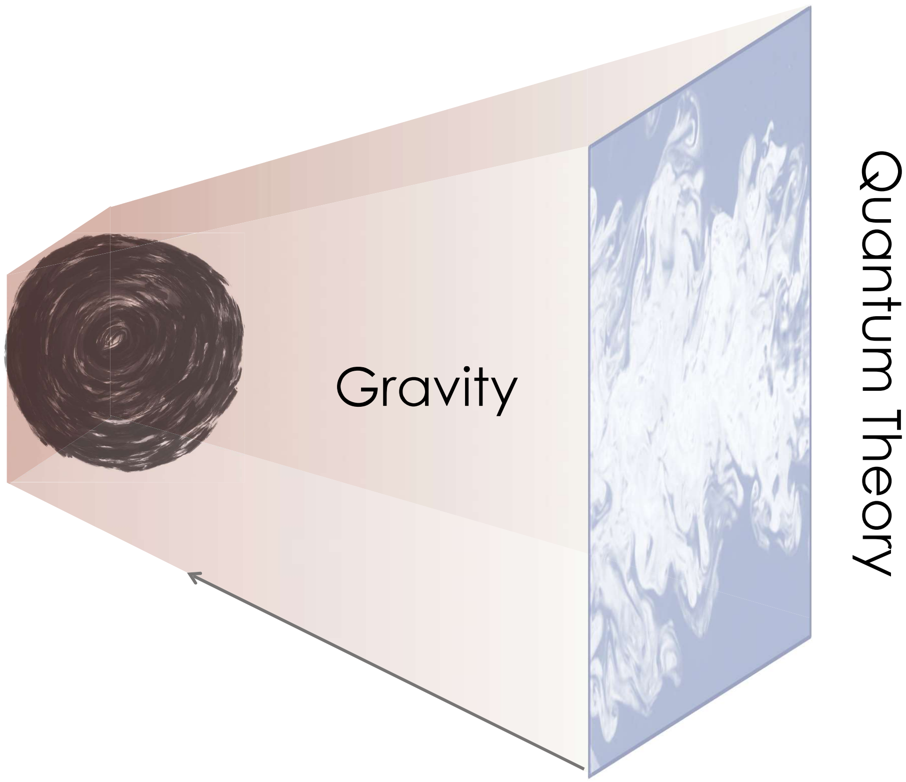




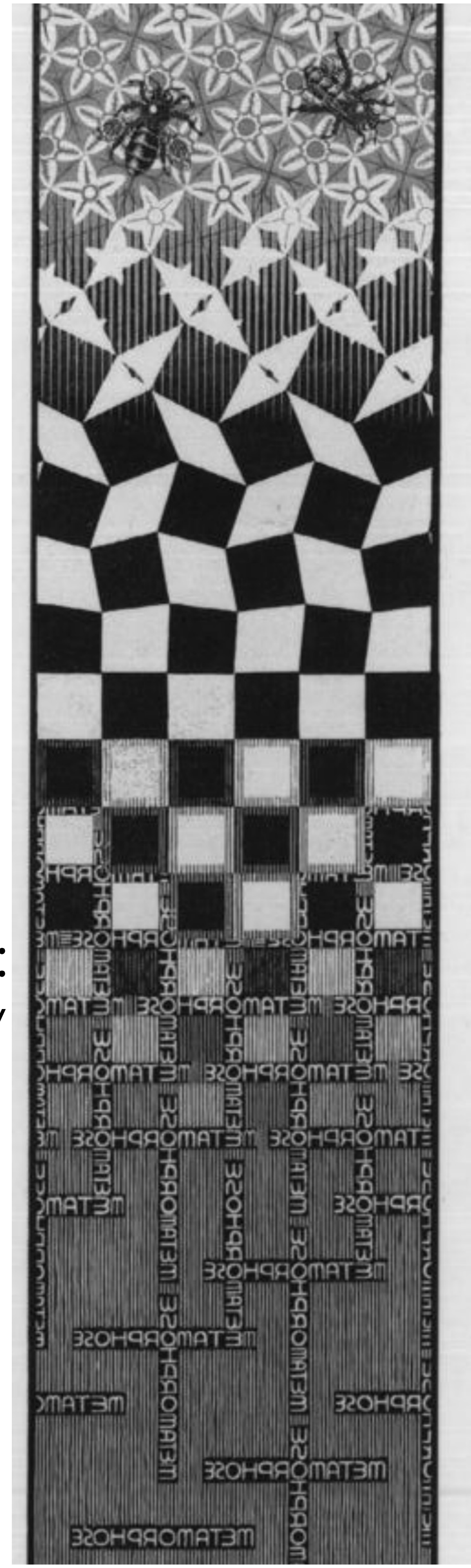


Gravity teaches us about quantum phenomena!

Holography: fundamental questions

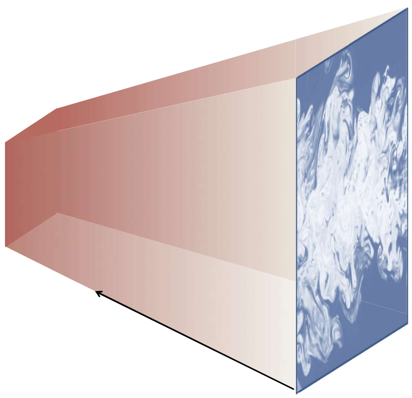


Holography is something we observed (theoretical).
Starting from the Quantum Theory (surface), can we really reconstruct gravity?
Can we go behind the horizon?

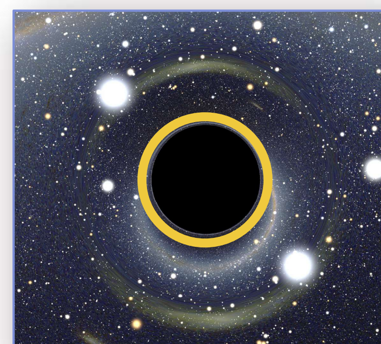


Quantum
Gravity!

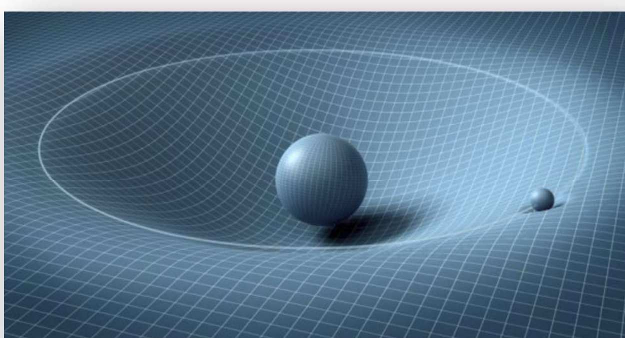
Holographic Principle:
Our modern view



Black Holes:
Quantum meets Classical



General Relativity:
Einstein's Theory



Classical Mechanics:
Newtonian Gravity