

Announcements

- Problem 2 is due Feb 02 at 11:59pm
- Exploration paper 1 is available and due Feb 07
 - Must be written in your own words!

Today:

- Einstein, general relativity
- *Gravitational* time dilation

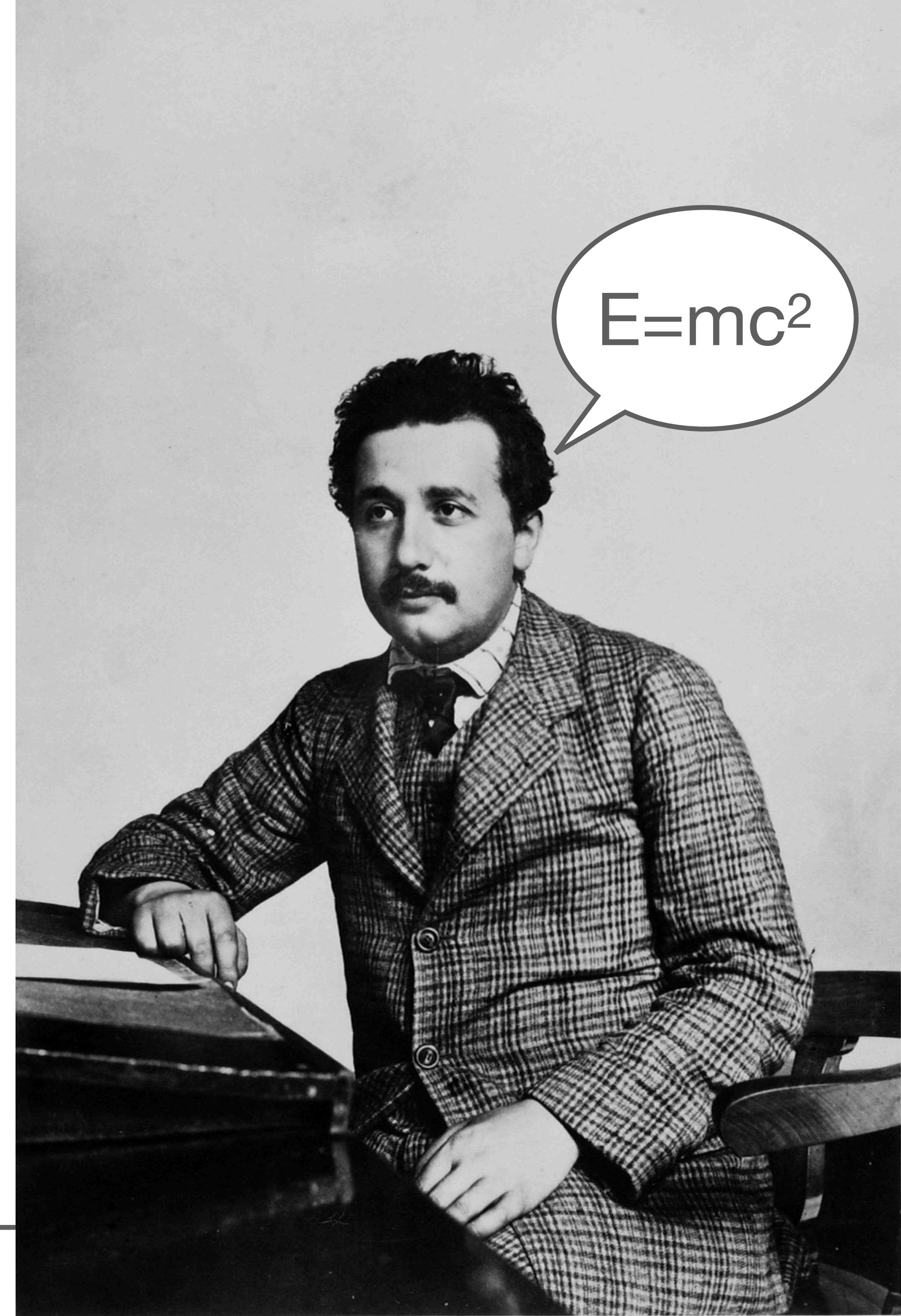
Special relativity: 1905

Nothing travels faster than
the speed of light

Time and space are described as a
single 4-dimensional spacetime

Perception of space and time
depends on relative motion

Time moves slower in moving frames



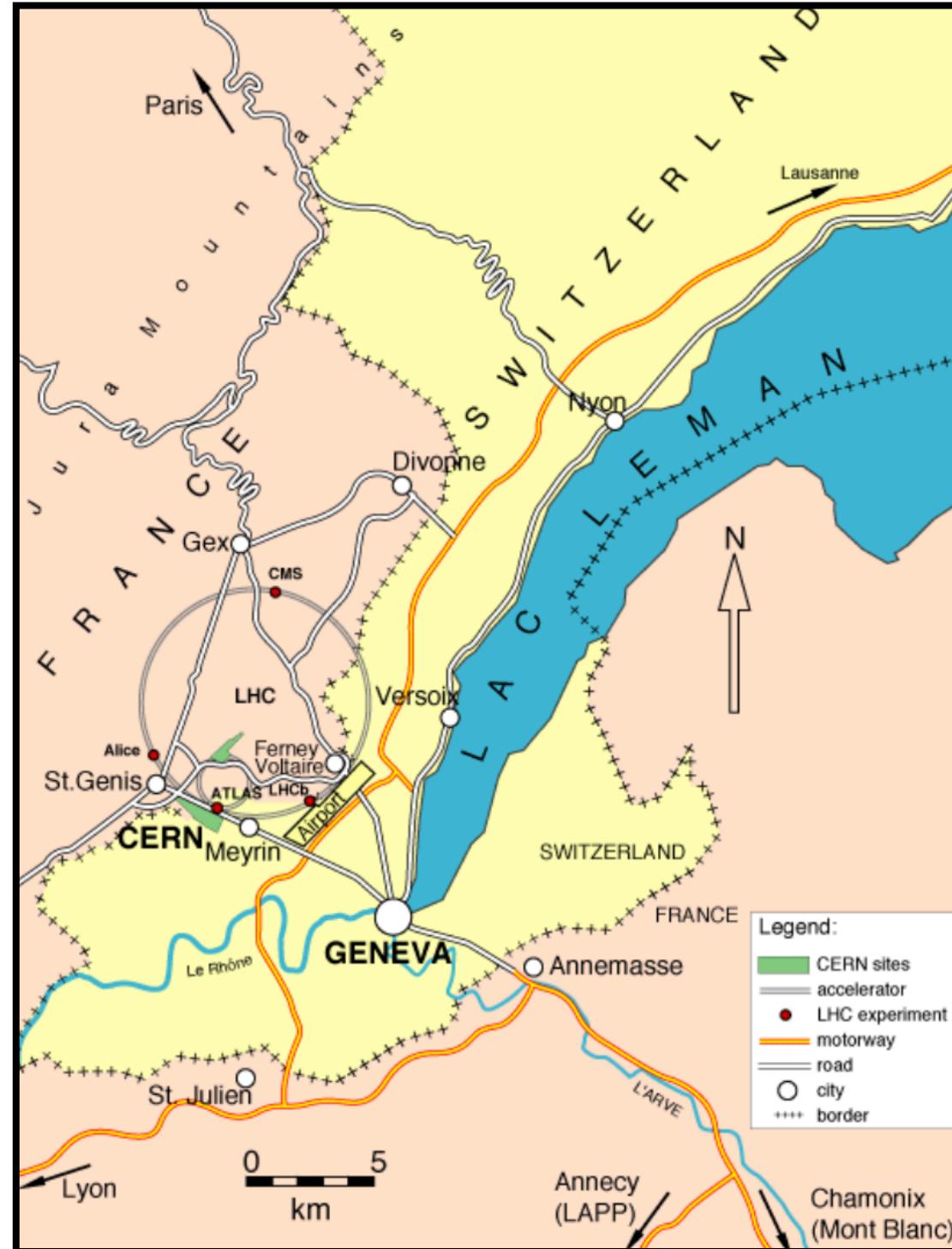


The Big Bang Theory

“The Isolation Permutation”

Directed:
Mark Cendrowski

Warner Brothers
(2011)



**Neutrinos
from Large
Hadron
Collider
(LHC)**
**Detected at
Gran Sasso
(Rome)**
**in less time
than
expected.
 $v > c$???**



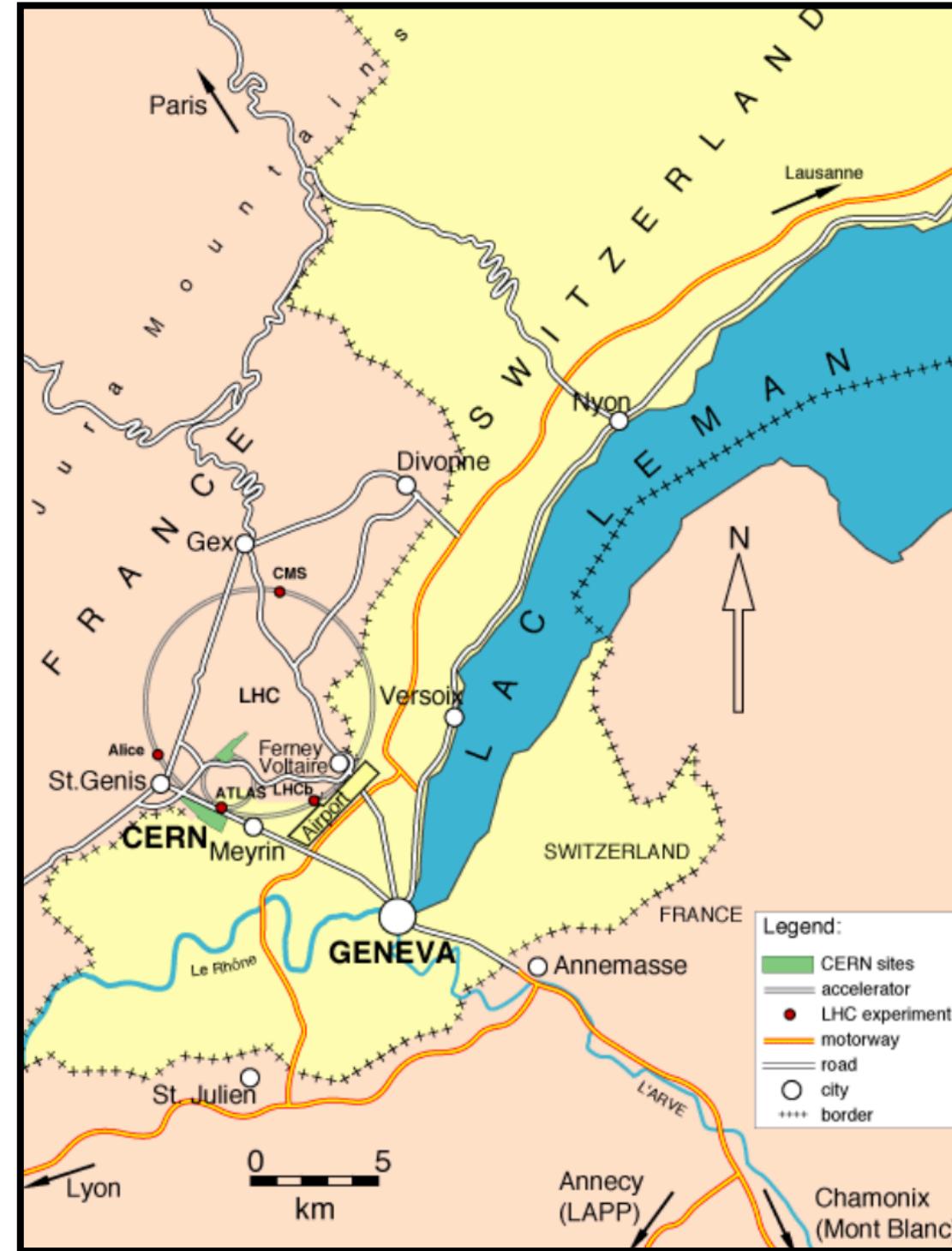
Neutrinos are particles
w/ mass created in
nuclear interactions

Neutrinos created at
CERN appeared to
arrive 60 ns earlier
than light would
have in Rome

“Faster-than-light particles at CERN:
paradigm-shifting discovery, or just another
Swiss export, as full of holes as their cheese?”

- Sheldon Cooper, 11/03/2011

Was Einstein wrong?!



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An excellent window
into scientific process

Theorists claimed
them as an
explanation for
quantum gravity

Experimentalists
replicated the experiment
and eventually found a
faulting timing connection
that took off 73 ns in the
time measurement

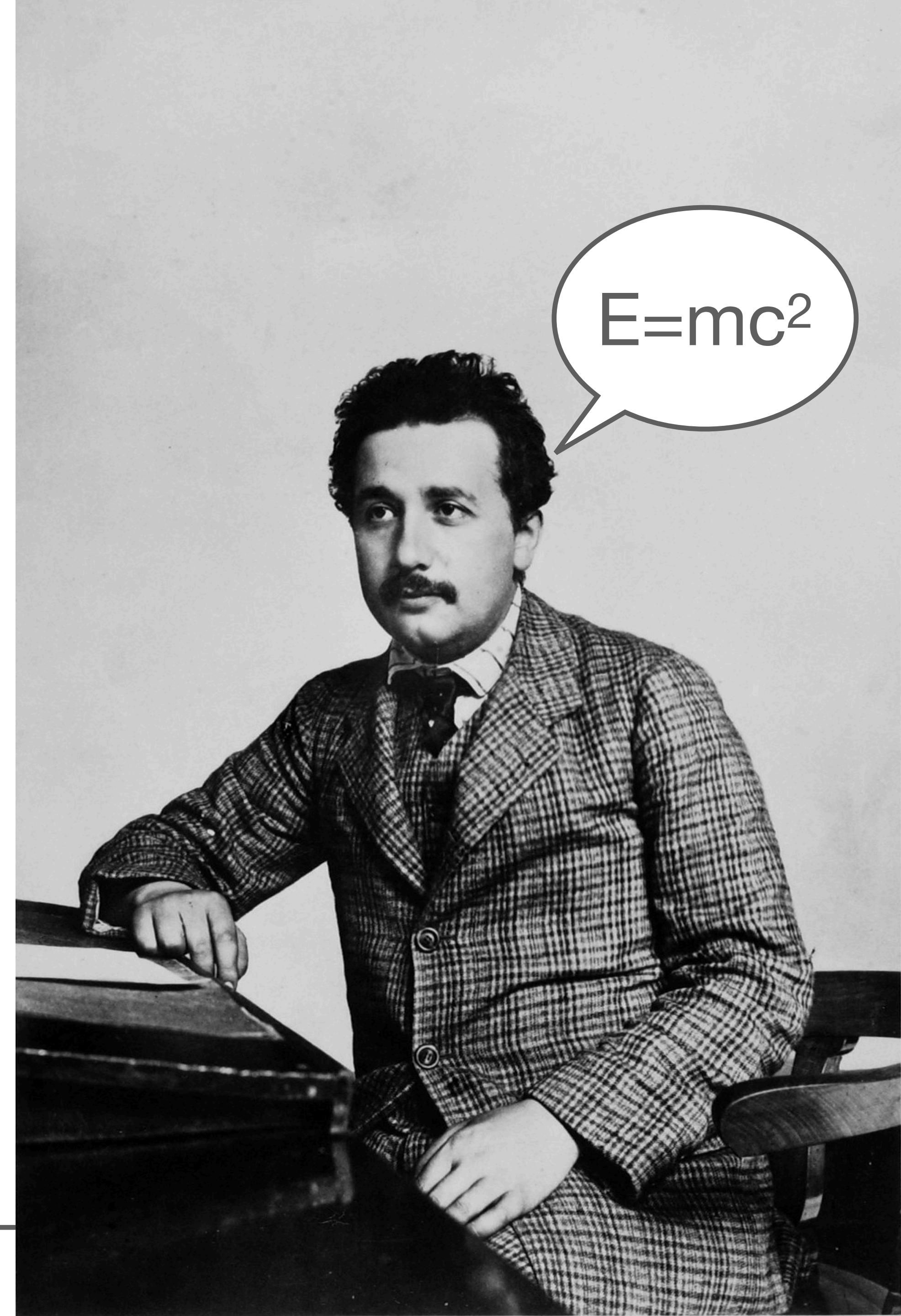
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Newton's Law of (Universal) Gravitation

$$F = G \frac{m_1 m_2}{r^2}$$

*every object with mass in the Universe
is gravitationally attracted to every
other object with mass in the Universe*

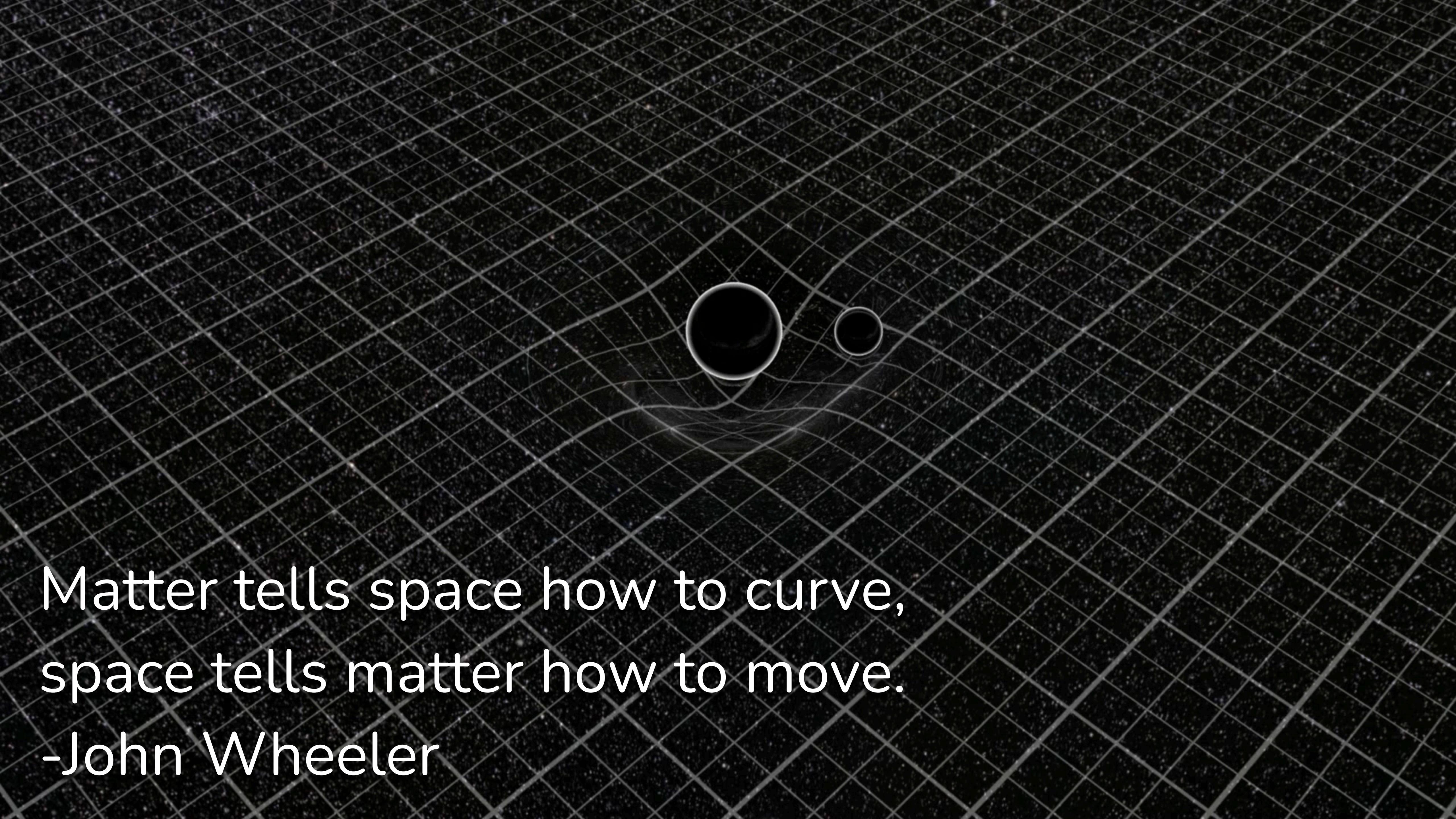
There is no time dependence in this equation

→ This is the *instantaneous* force due to gravity



What happens if the Sun suddenly disappears?

How soon does the Earth know that Sun is gone?



Matter tells space how to curve,
space tells matter how to move.

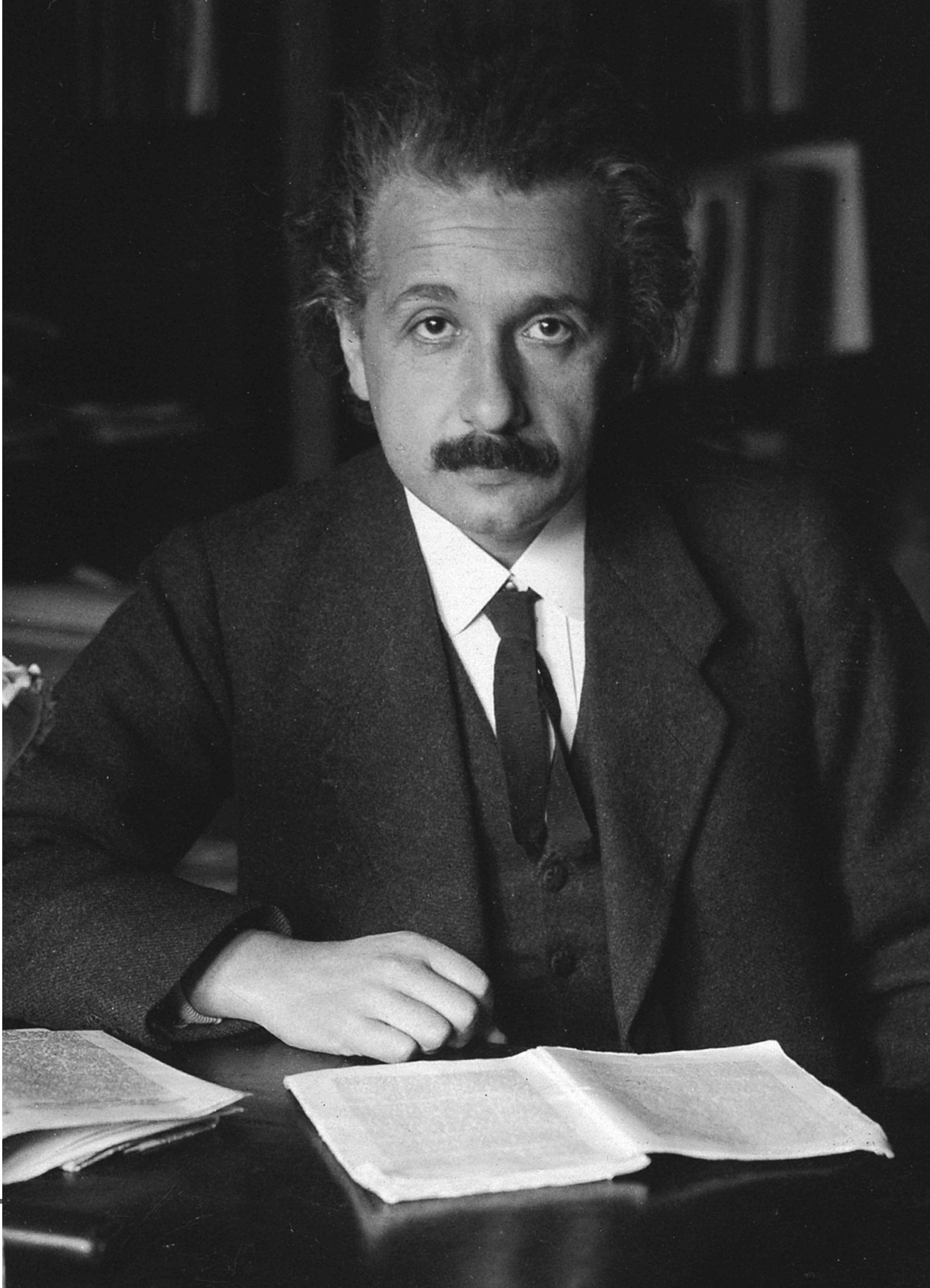
-John Wheeler

General relativity: 1915

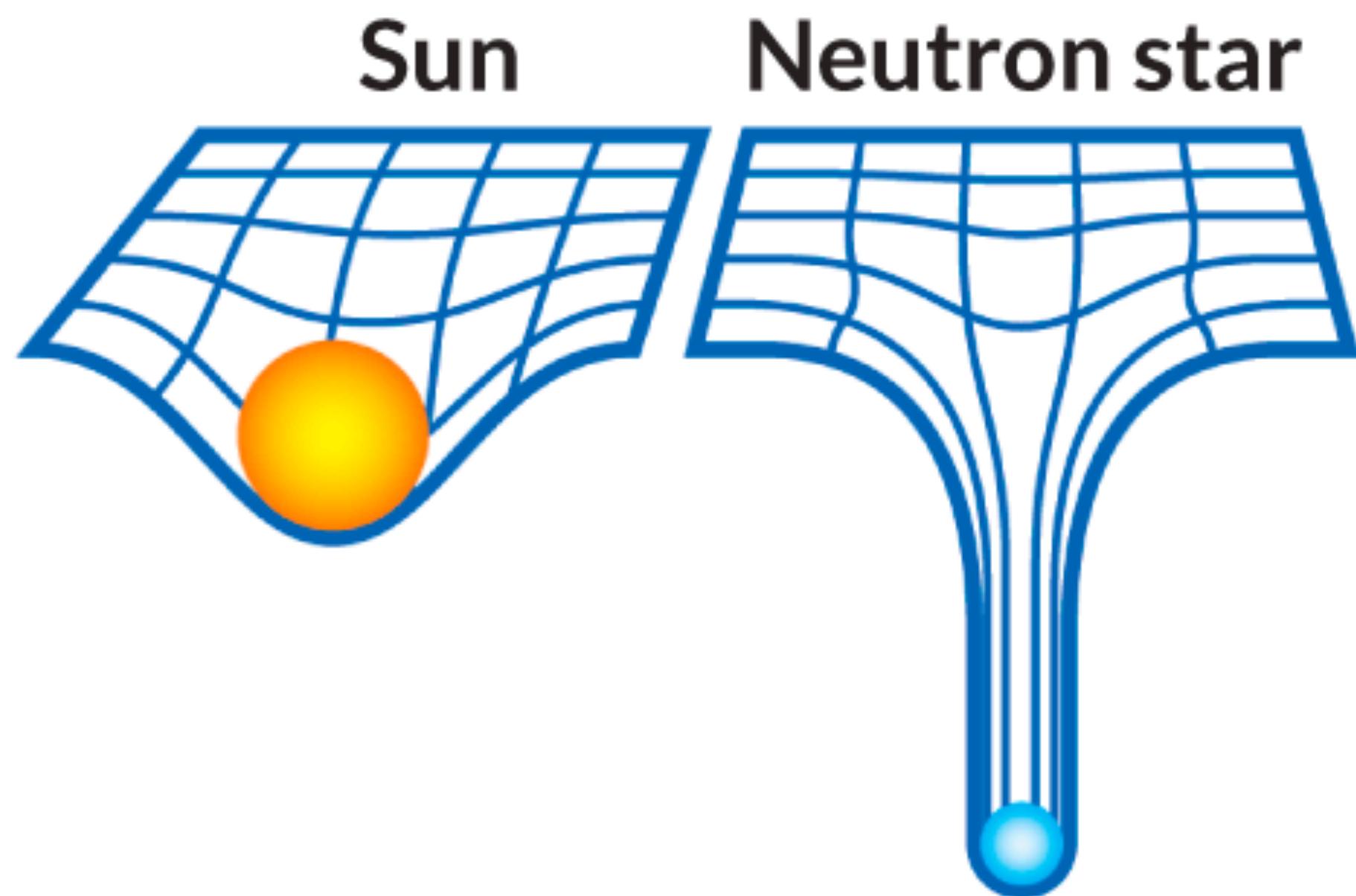
The speed of light is constant in
all reference frames

Time and space are described as a
single 4-dimensional spacetime that
moves at the speed of light

Gravity is the manifestation of mass
distorting spacetime



Larger masses and densities create
larger distortions

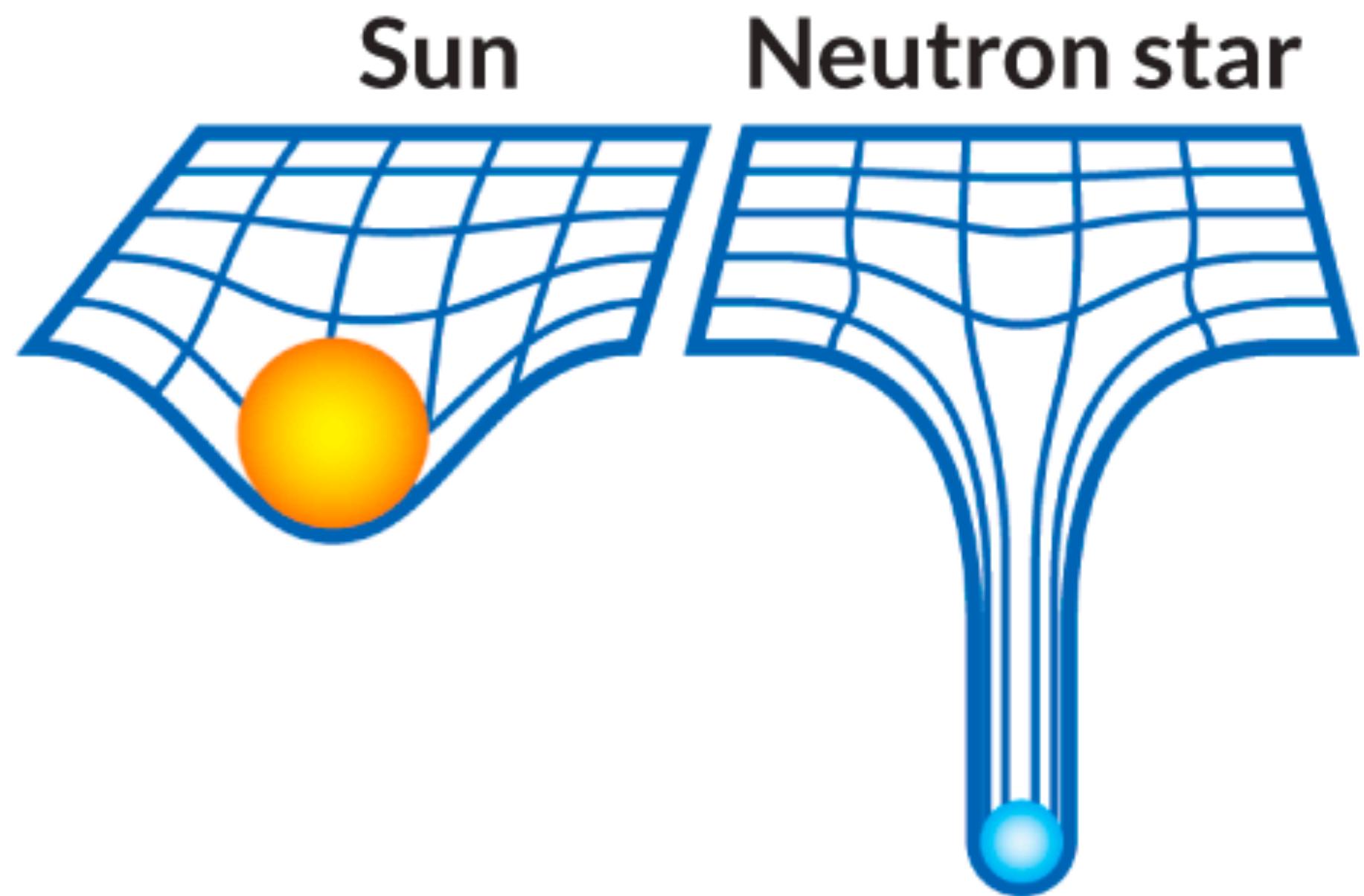


$$t_r = t_\infty \sqrt{1 - \frac{2Gm}{rc^2}}$$

t_∞ is the time
'infinitely far' away
from the mass

t_r is the time at radius: r
from the mass

Larger masses and densities create
larger distortions

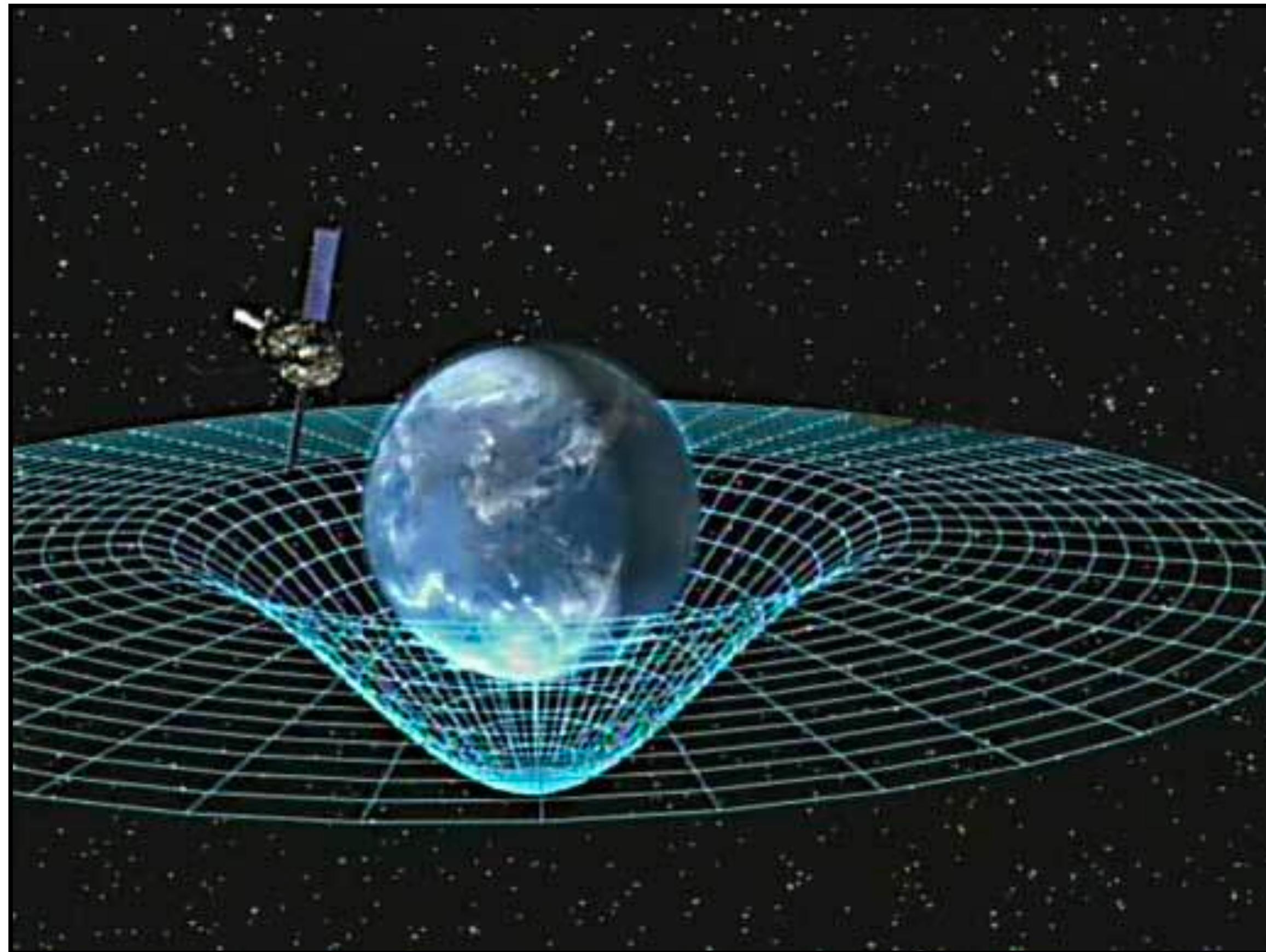


$$t_r = t_\infty \sqrt{1 - \frac{2Gm}{rc^2}}$$

A neutron star and the
Sun have similar masses

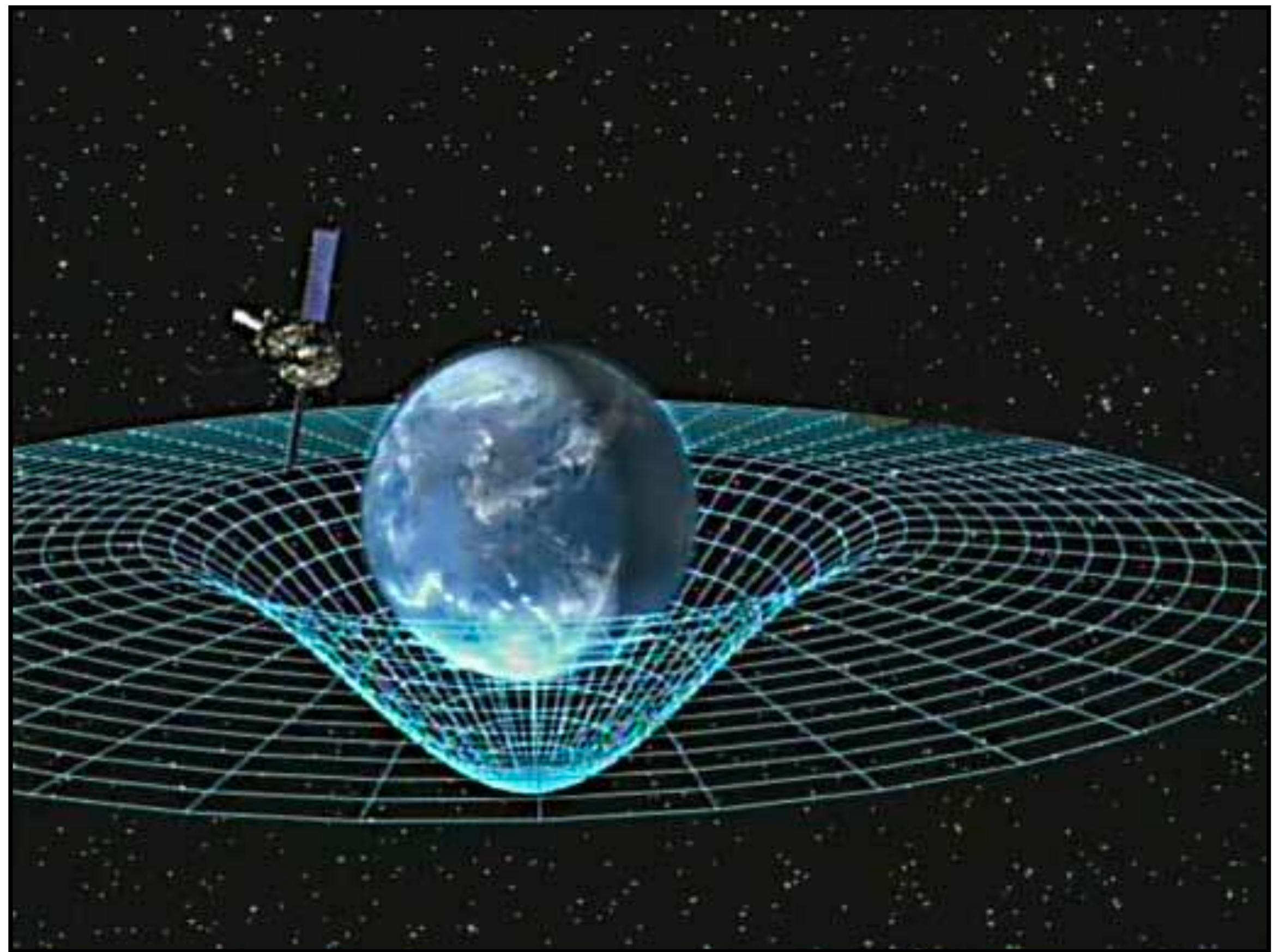
So why is there a
stronger distortion
for the neutron
star?

GPS satellites



An every-day application of the importance of general relativity via gravitational time dilation is the global positioning system (GPS)

GPS satellites



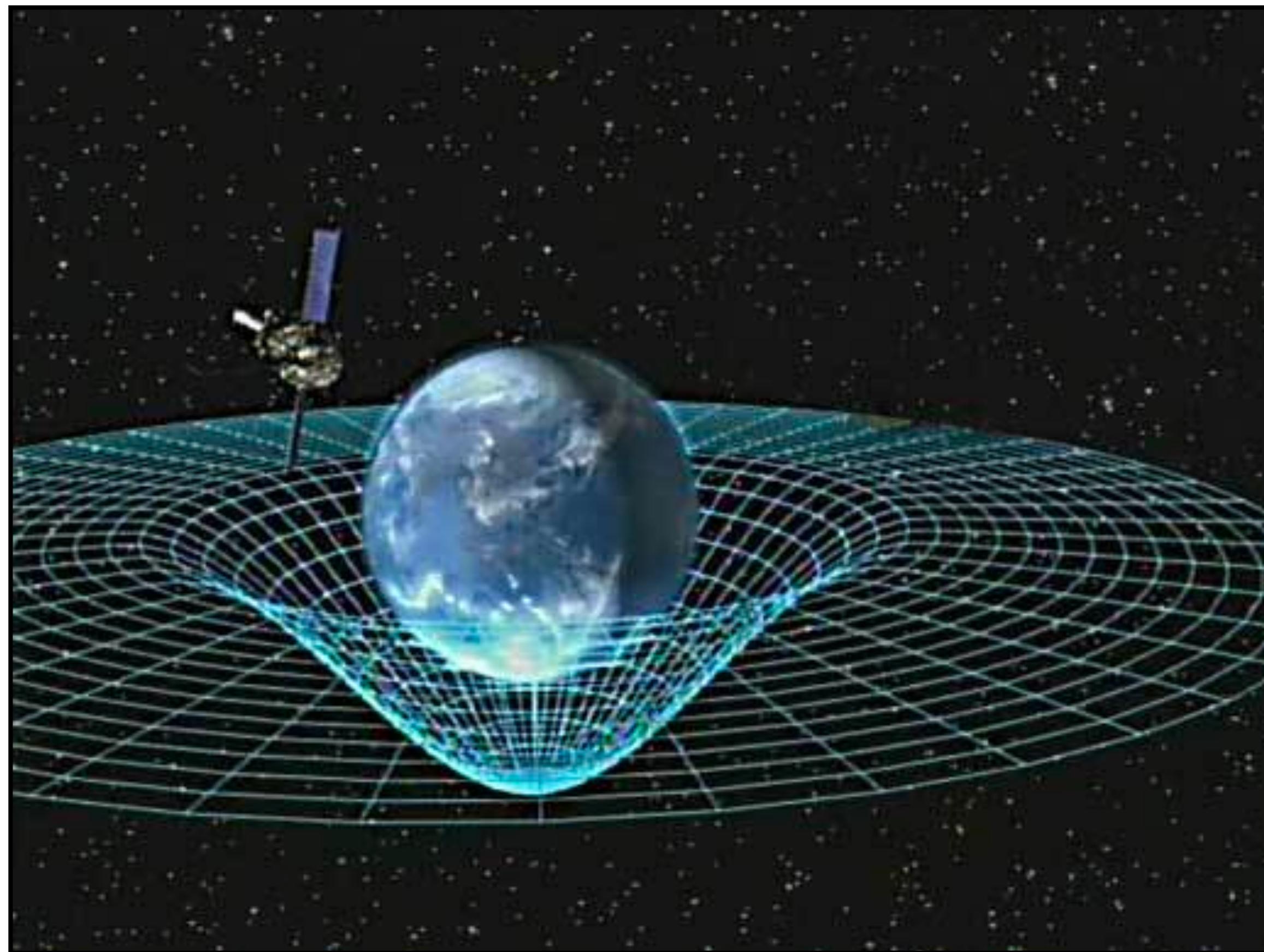
time dilation

$$t = \frac{t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Gravitational time dilation

$$t = t_\infty \sqrt{1 - \frac{2Gm}{rc^2}}$$

GPS satellites



time dilation

$$\frac{t}{t'} = 0.999999999999$$

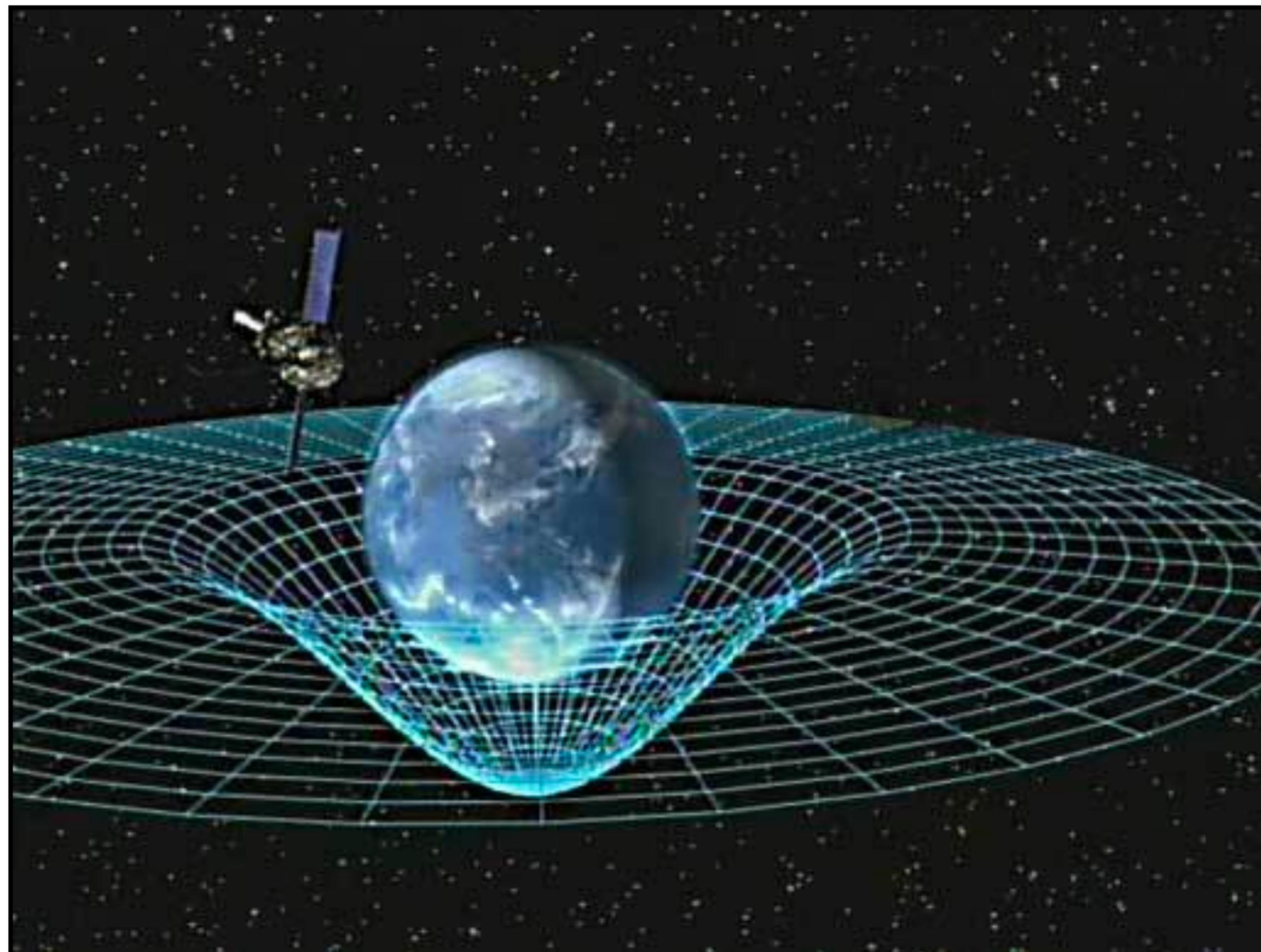
1 part in 10^{10}

Gravitational time dilation

$$\frac{t_r}{t_\infty} = 0.999999999995$$

5 parts in 10^{10}

GPS satellites



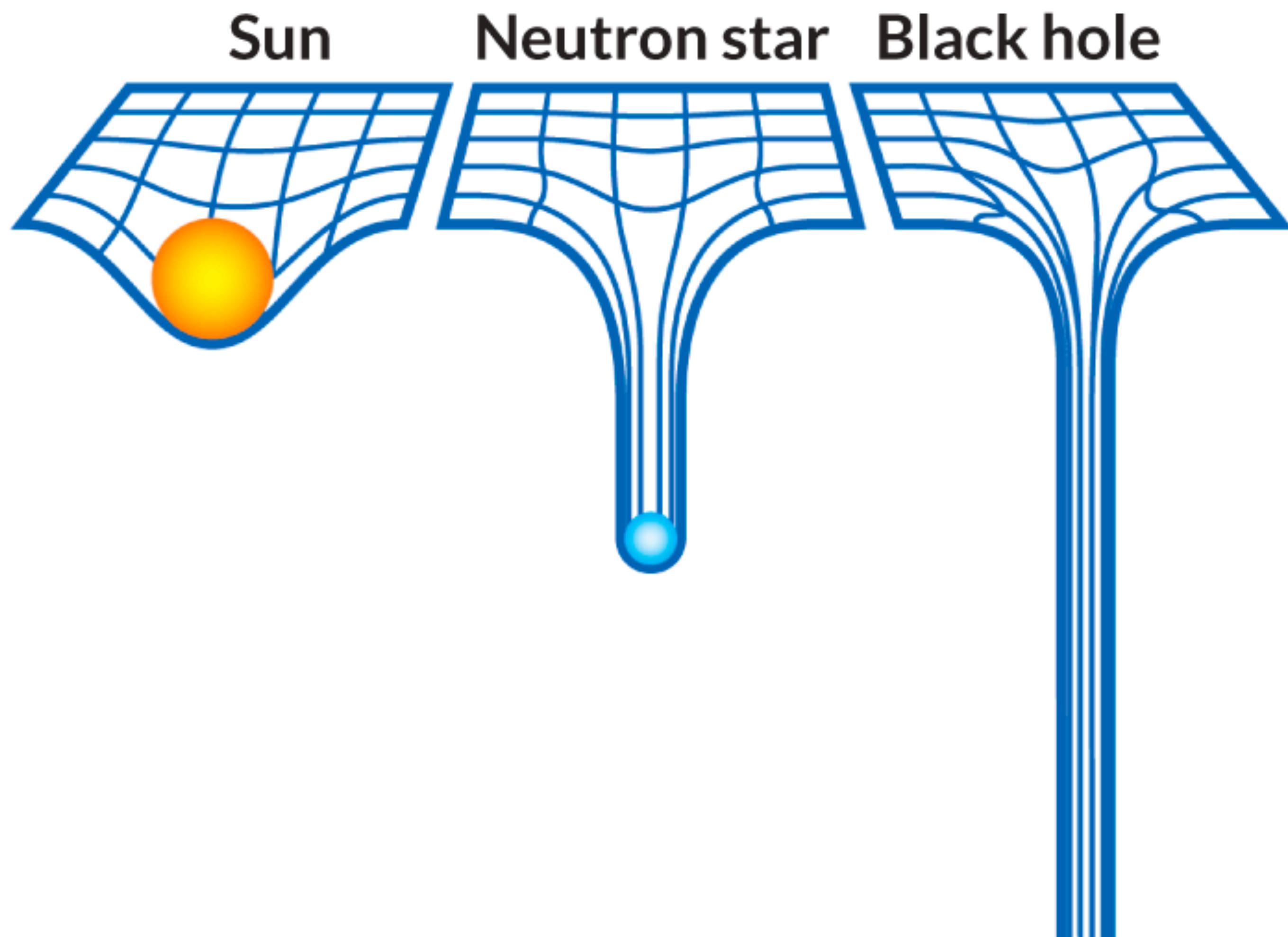
Special relativity

Clocks run slow on
satellites by 1 part in 10^{10}

General relativity

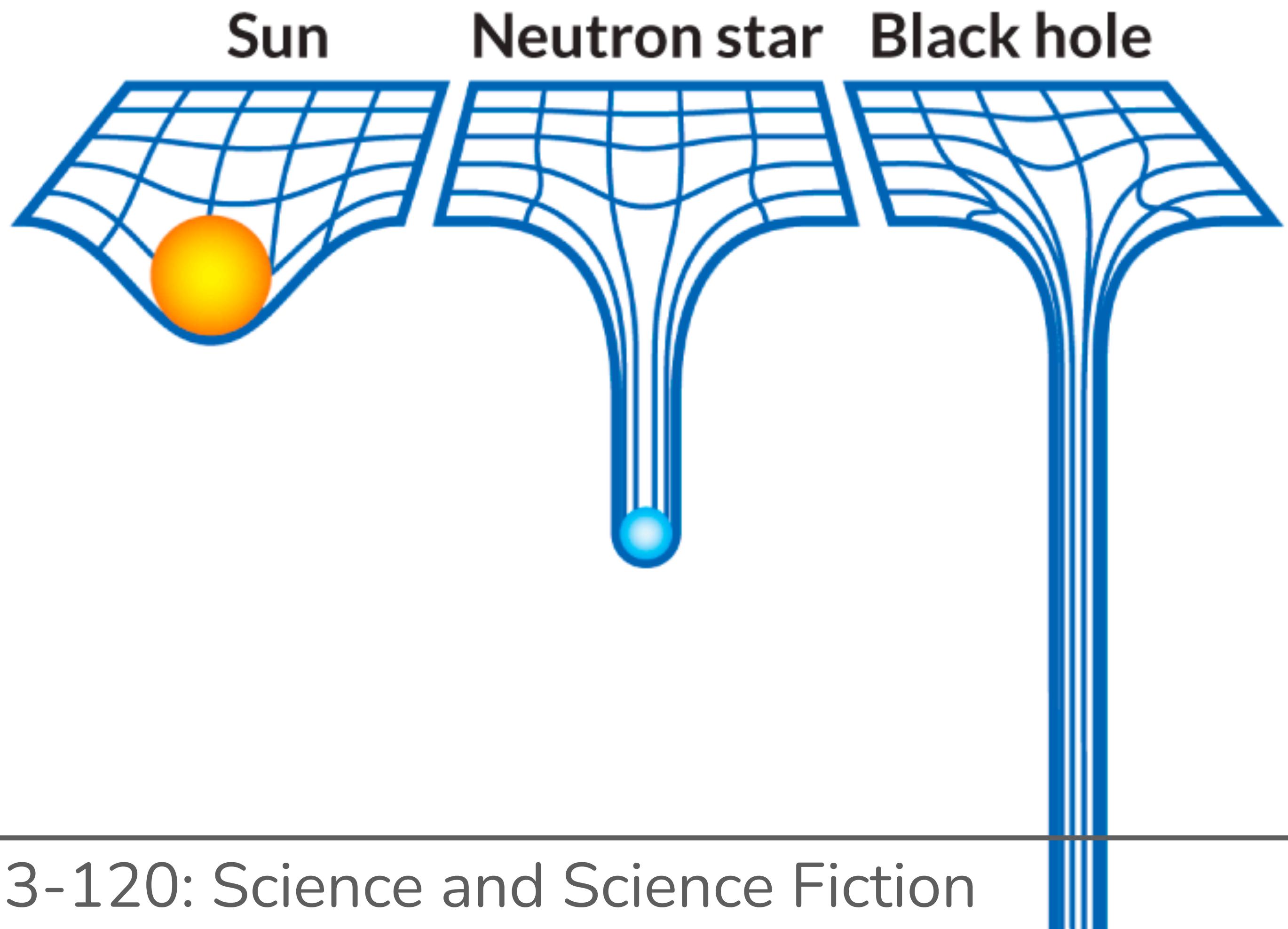
Clocks run slow on
Earth by 5 parts in 10^{10}

Black holes



- ▶ Gravitationally completely collapsed objects
- ▶ Cause spacetime curvature that strong enough that light cannot escape
- ▶ “event horizon”

Black holes



- ▶ Foreshadowed in Sci-Fi in January 1967: “black star”
- ▶ “black hole” first coined in scientific context in December 1967 by John Wheeler “the hero of the black hole story”
- ▶ Took hold because it’s easier to say!



Star Trek (original)

“Tomorrow is
Yesterday”

Directed:
D.C. Fontana

Paramount (1967)



The Black Hole

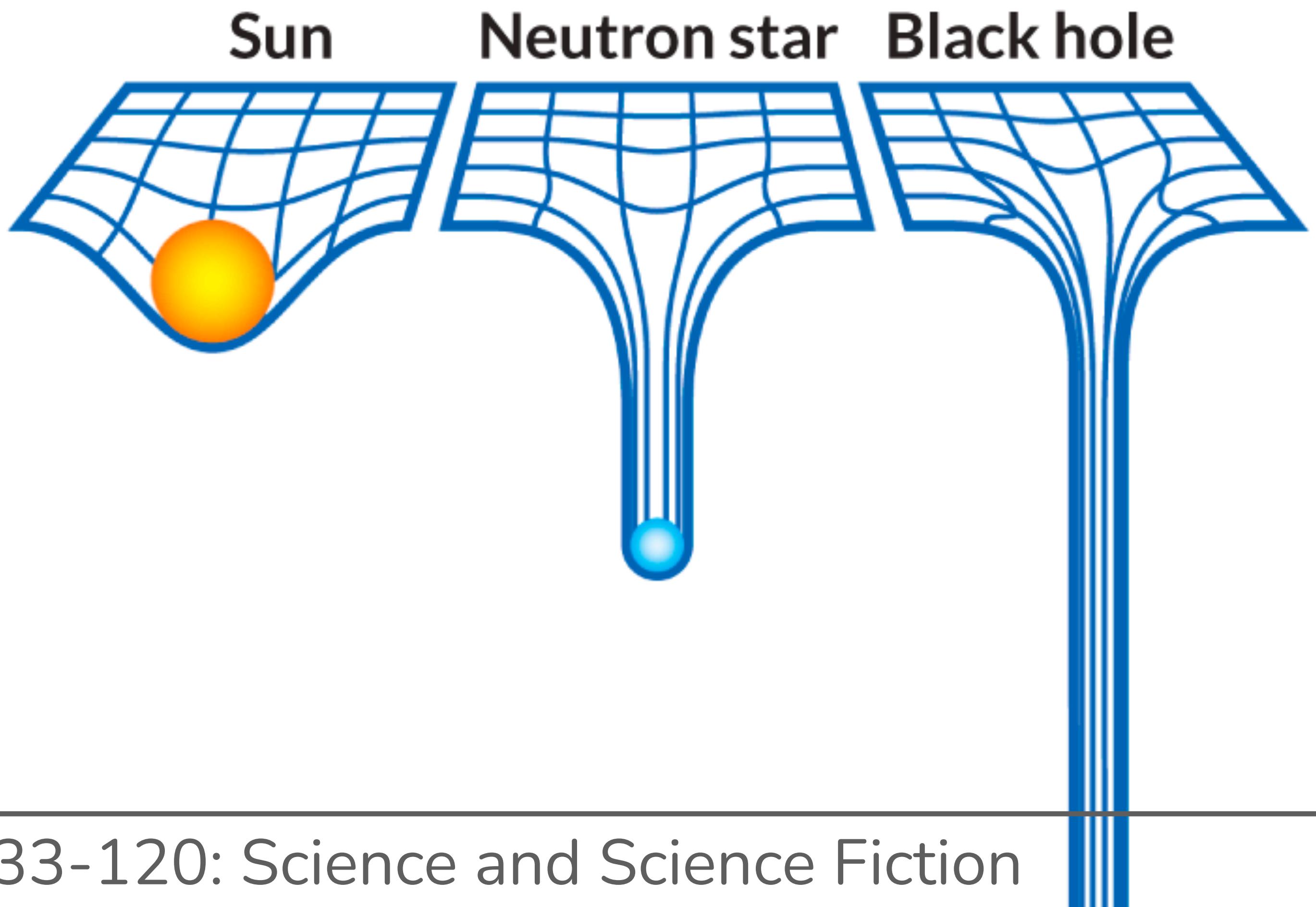
Directed:
Tibor Takács

Equity Pictures
(2005)



On Sept 10, 2008, the large hadron collider was scheduled to be turned on — led to protests across Europe based on concern that the LHC could create “micro black holes” according to some theories for beyond the standard model physics

Black holes

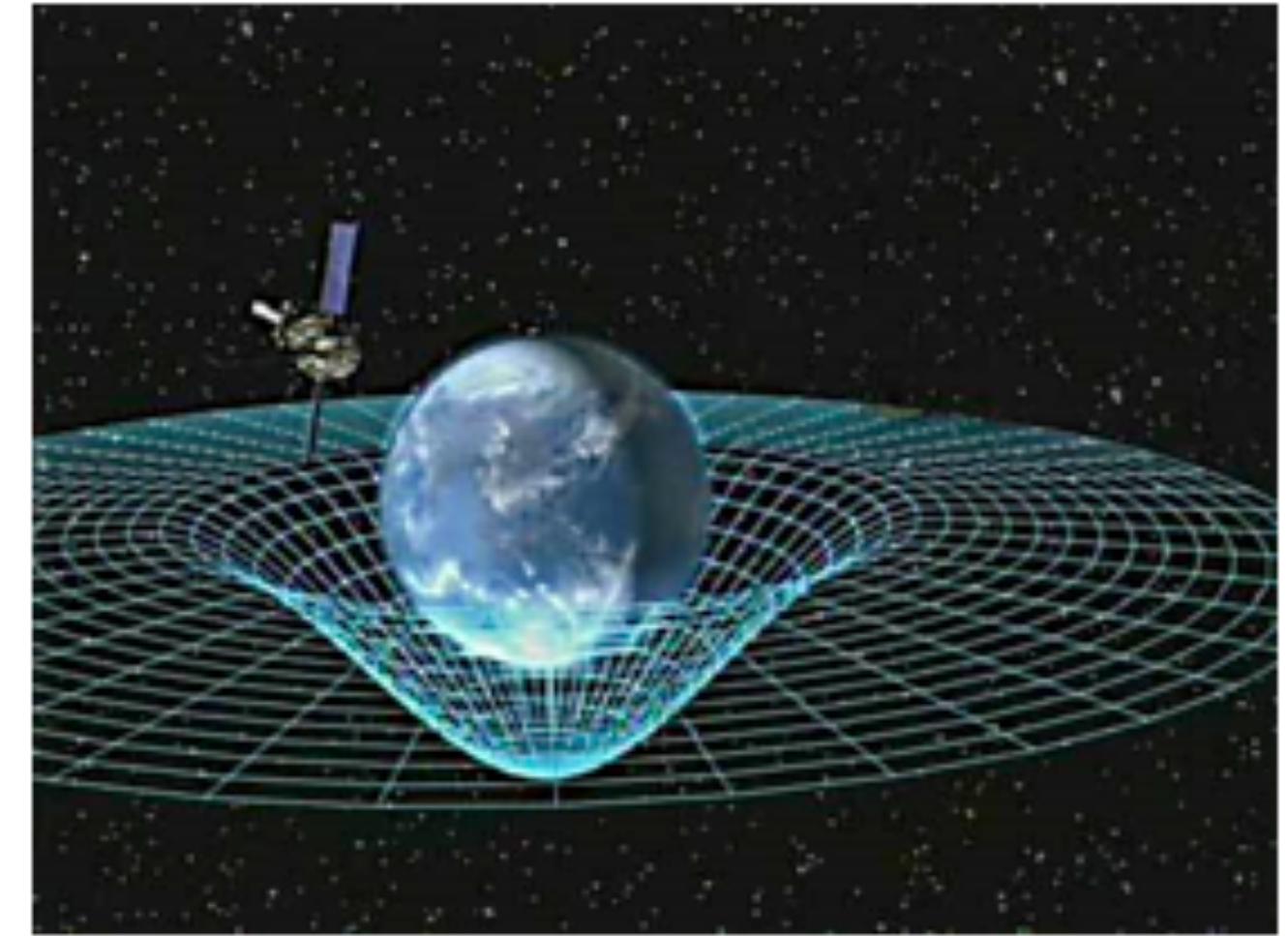


Hawking radiation

- ▶ First introduced by Hawking in 1974
- ▶ Particles created near the horizon are not reabsorbed and cause evaporation
- ▶ faster for lower masses
- ▶ Masses of up to 10^{12} kg will evaporate within age of Universe

Next time:

- ▶ Continue astrophysical black holes
- ▶ Gravitational waves



What is the nature of space and time?