

Dai Buchi Neri alle Onde Gravitazionali: tutte le vittorie di Einstein

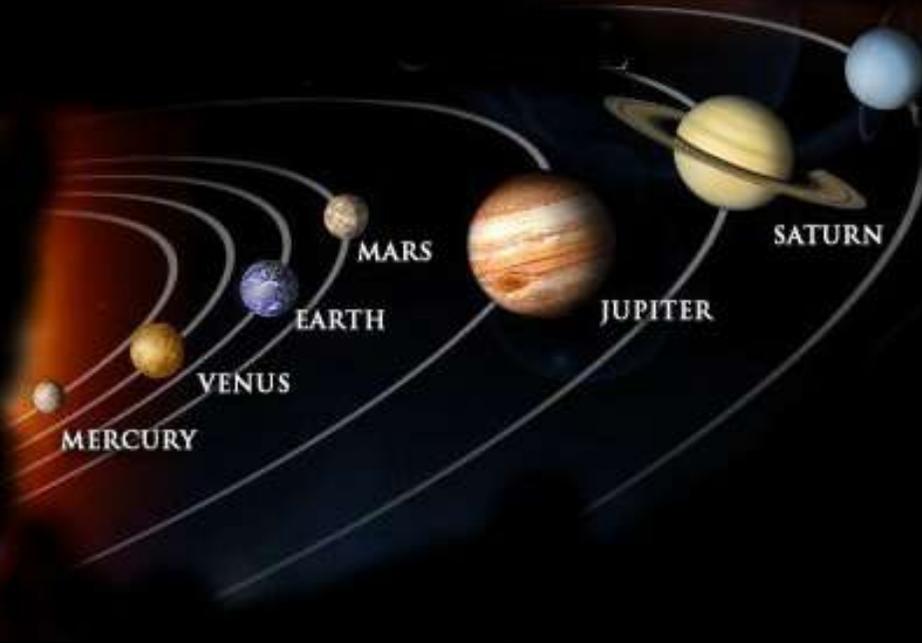
Danilo Domenici

Istituto Nazionale di Fisica Nucleare

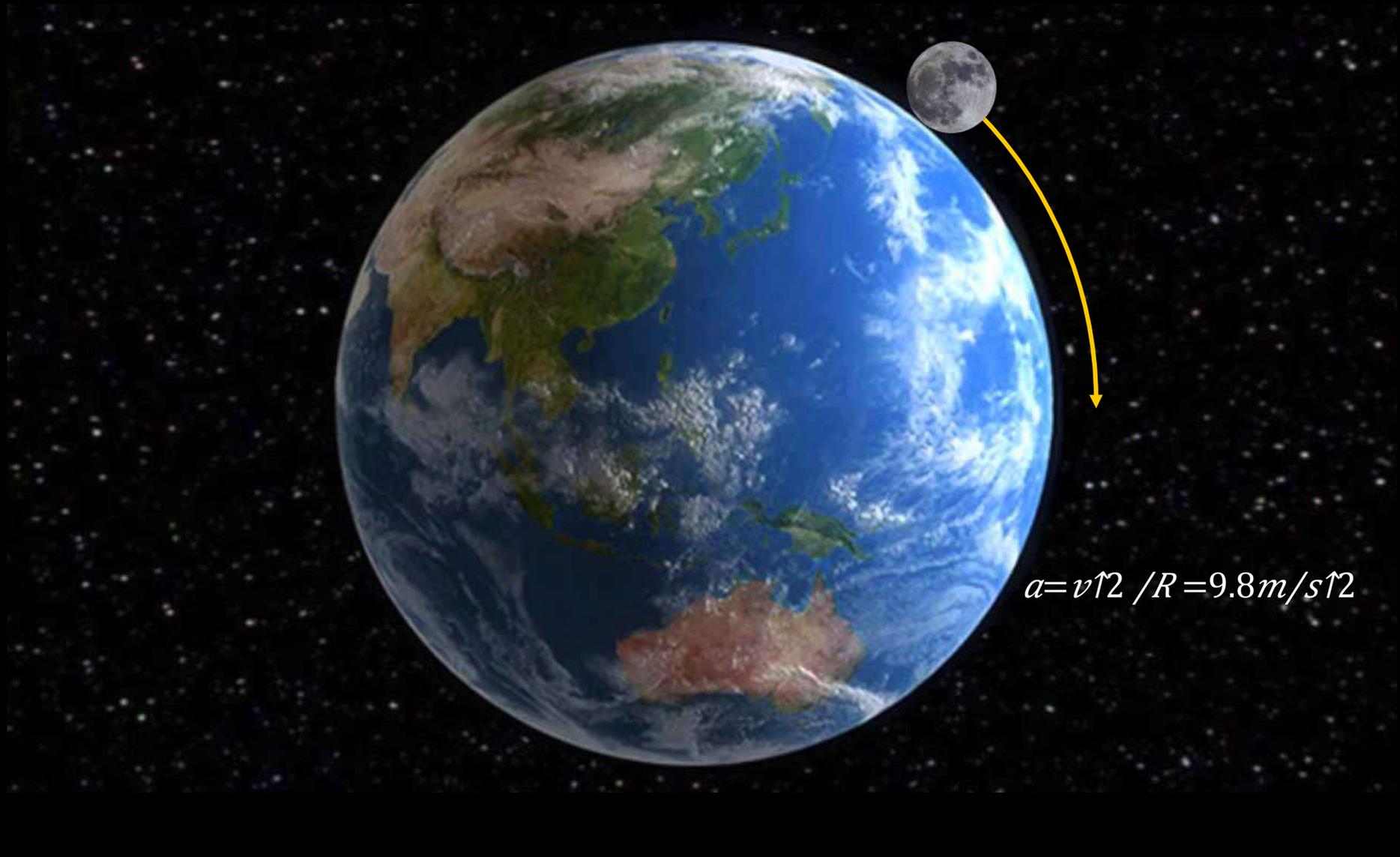


$$a = 9.8 \text{ m/s}^2$$

Leggi di Keplero



Esperimento della Piccola Luna

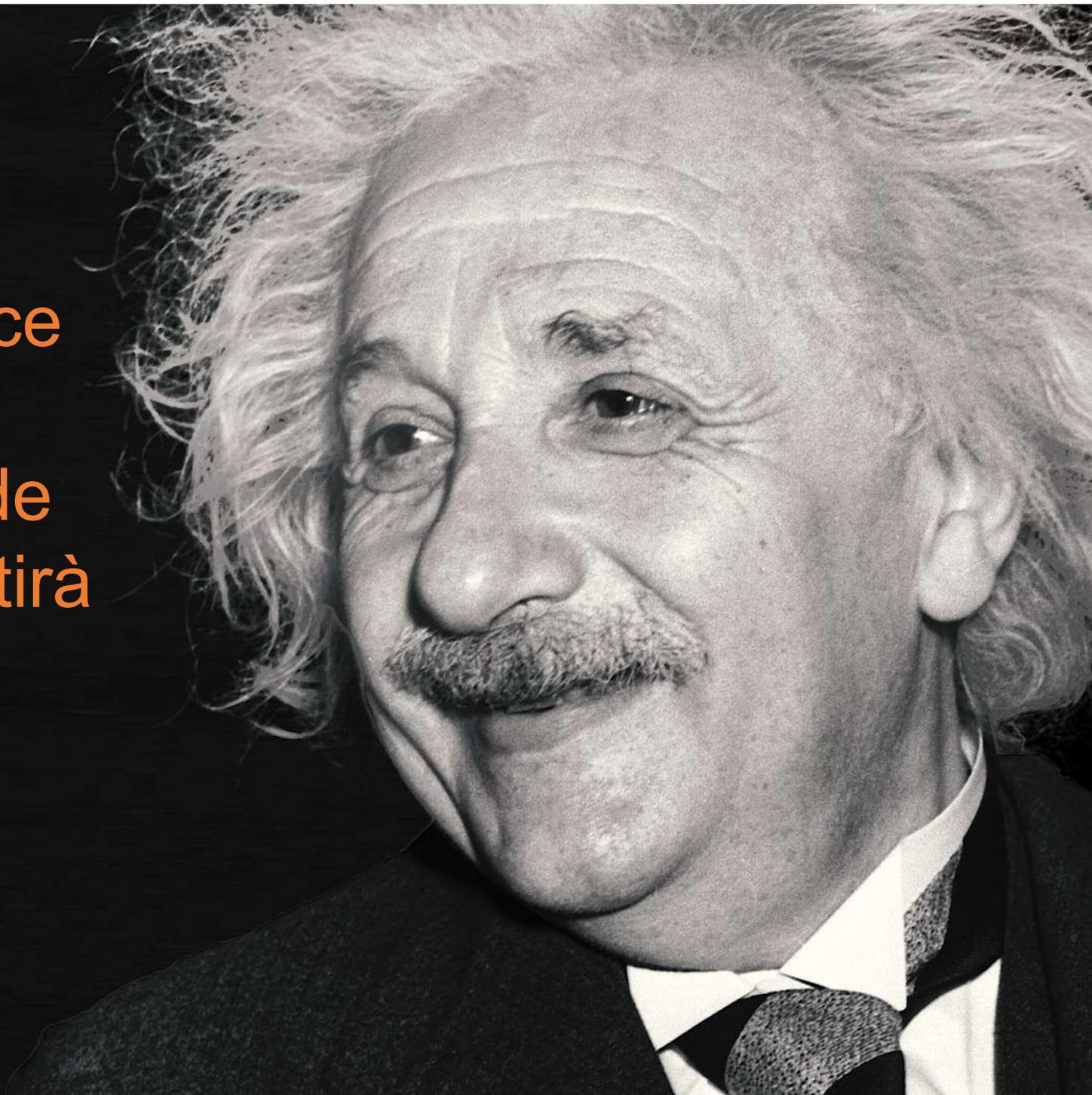


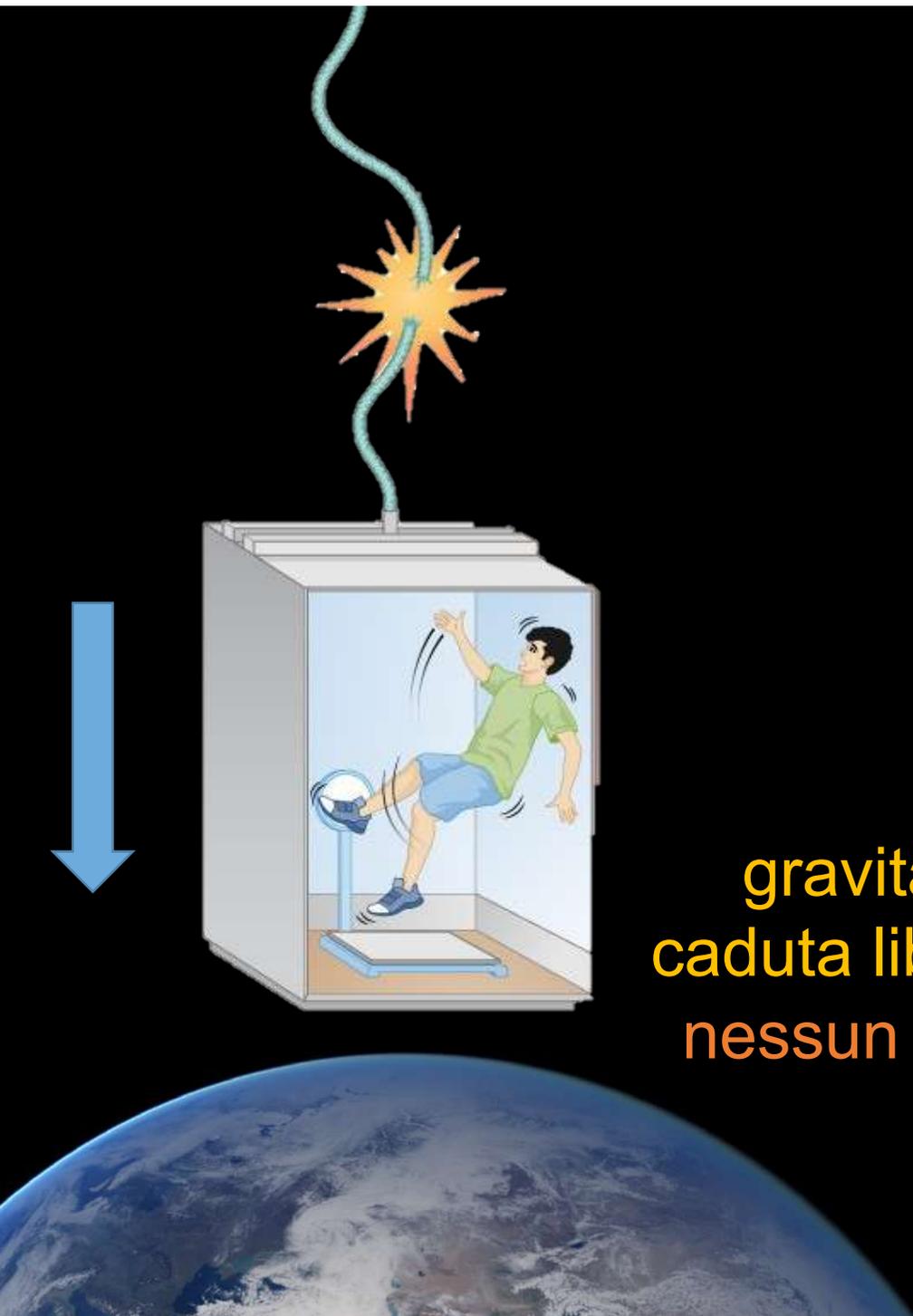
Legge della Gravitazione Universale

$$F = Gm \times M / r^2$$



il pensiero più felice
della mia vita:
se una persona cade
bruscamente non sentirà
il proprio peso »

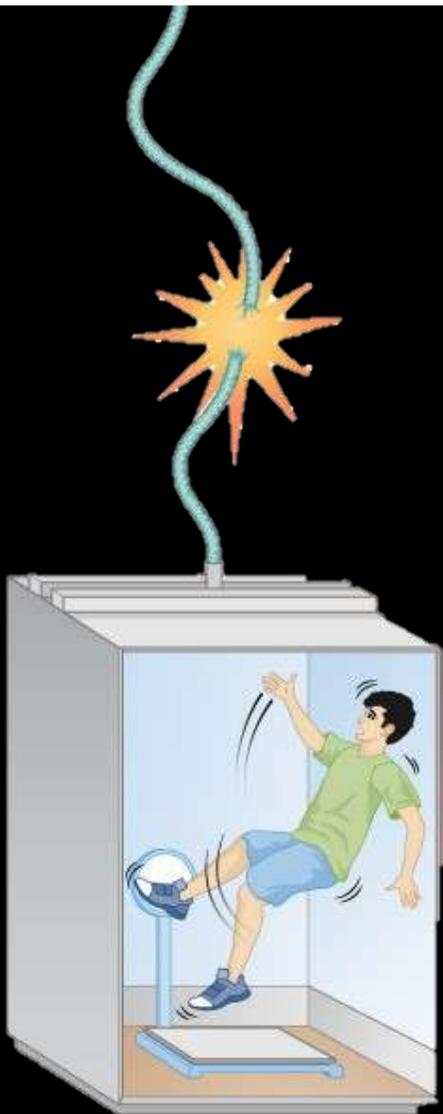
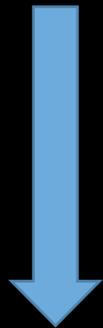




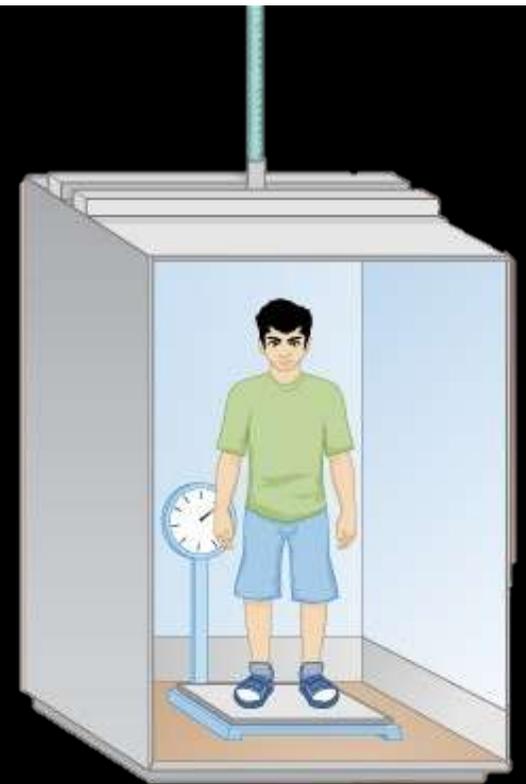
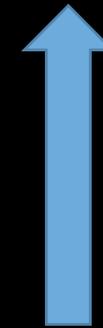
gravità +
caduta libera =
nessun peso



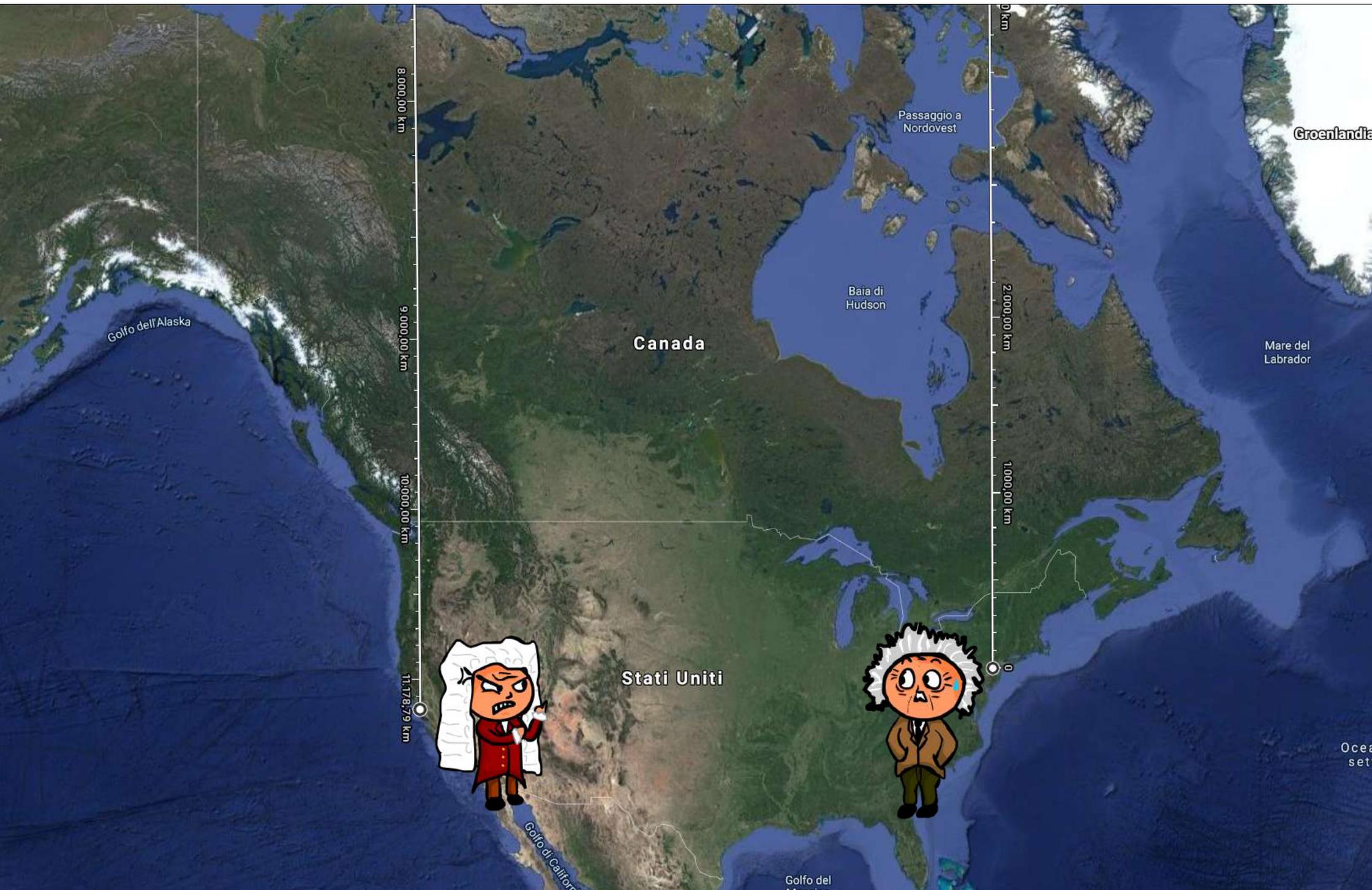
un campo gravitazionale è equivalente ad un sistema di riferimento in accelerazione

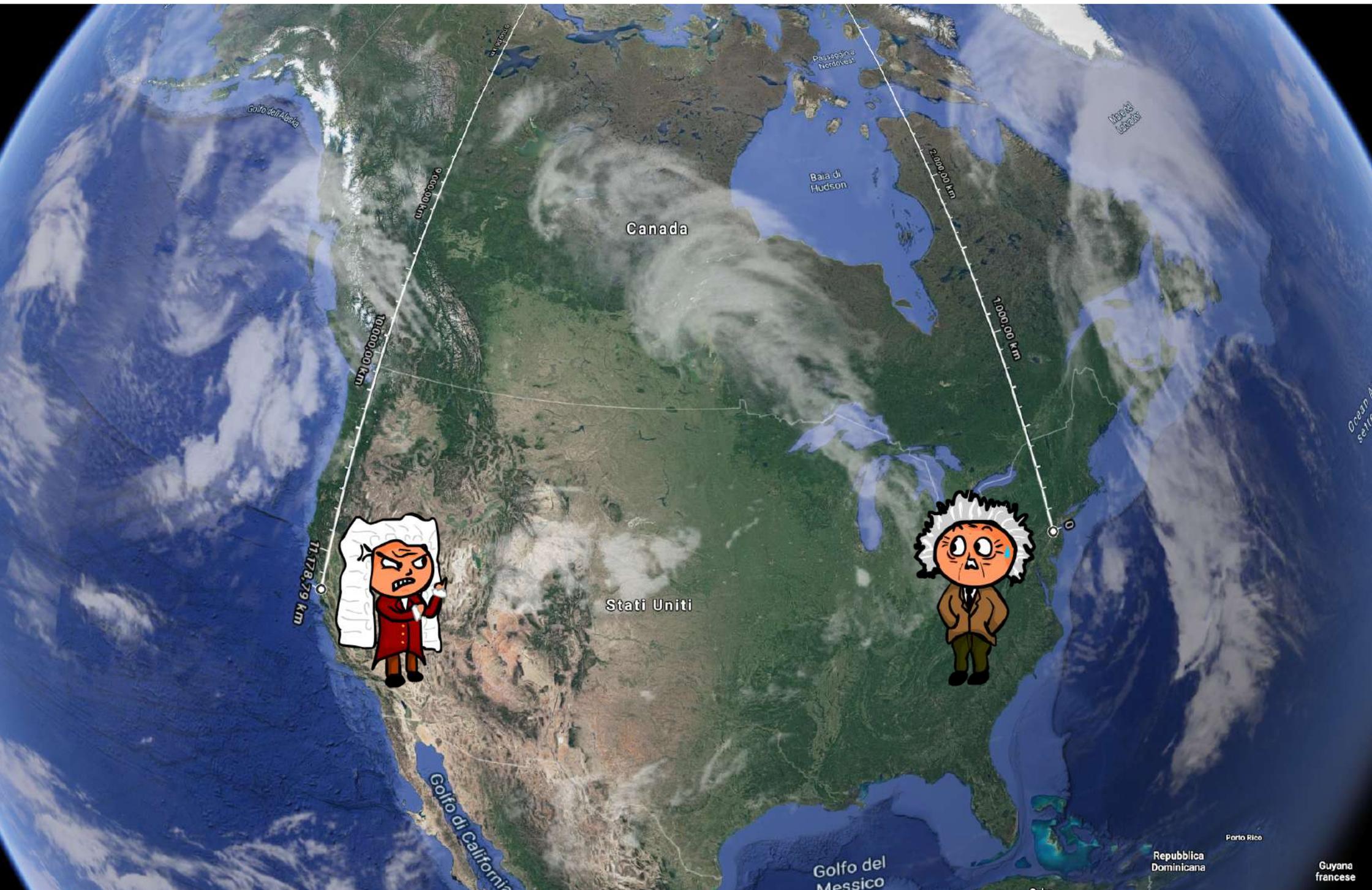


gravità +
caduta libera =
nessun peso



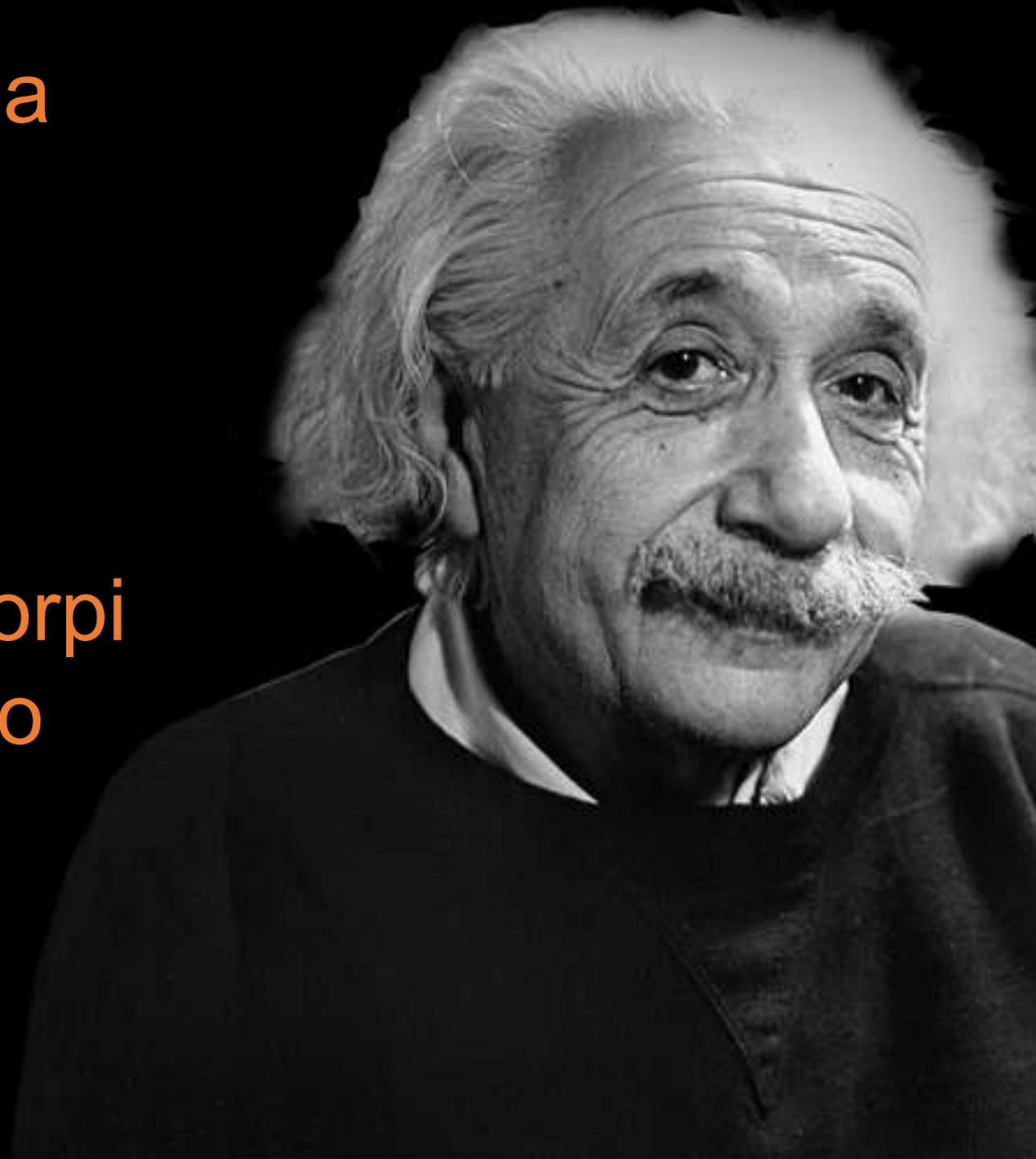
no gravità +
moto accelerato =
peso normale



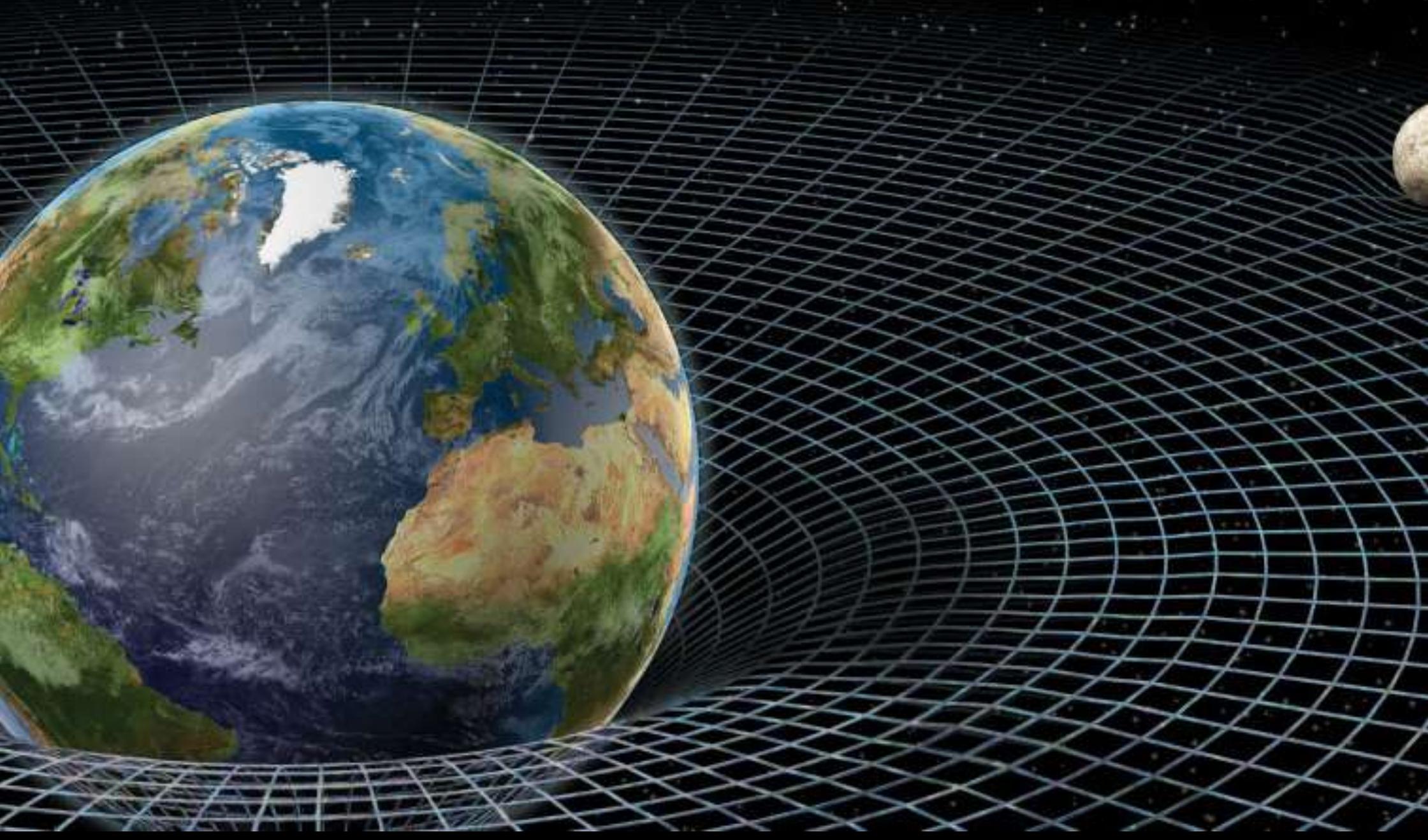


Non esiste nessuna
«forza di gravità»

E' solo l'effetto
del movimento dei corpi
in uno spazio curvo



la geometria dello spazio dipende dalla materia che contiene



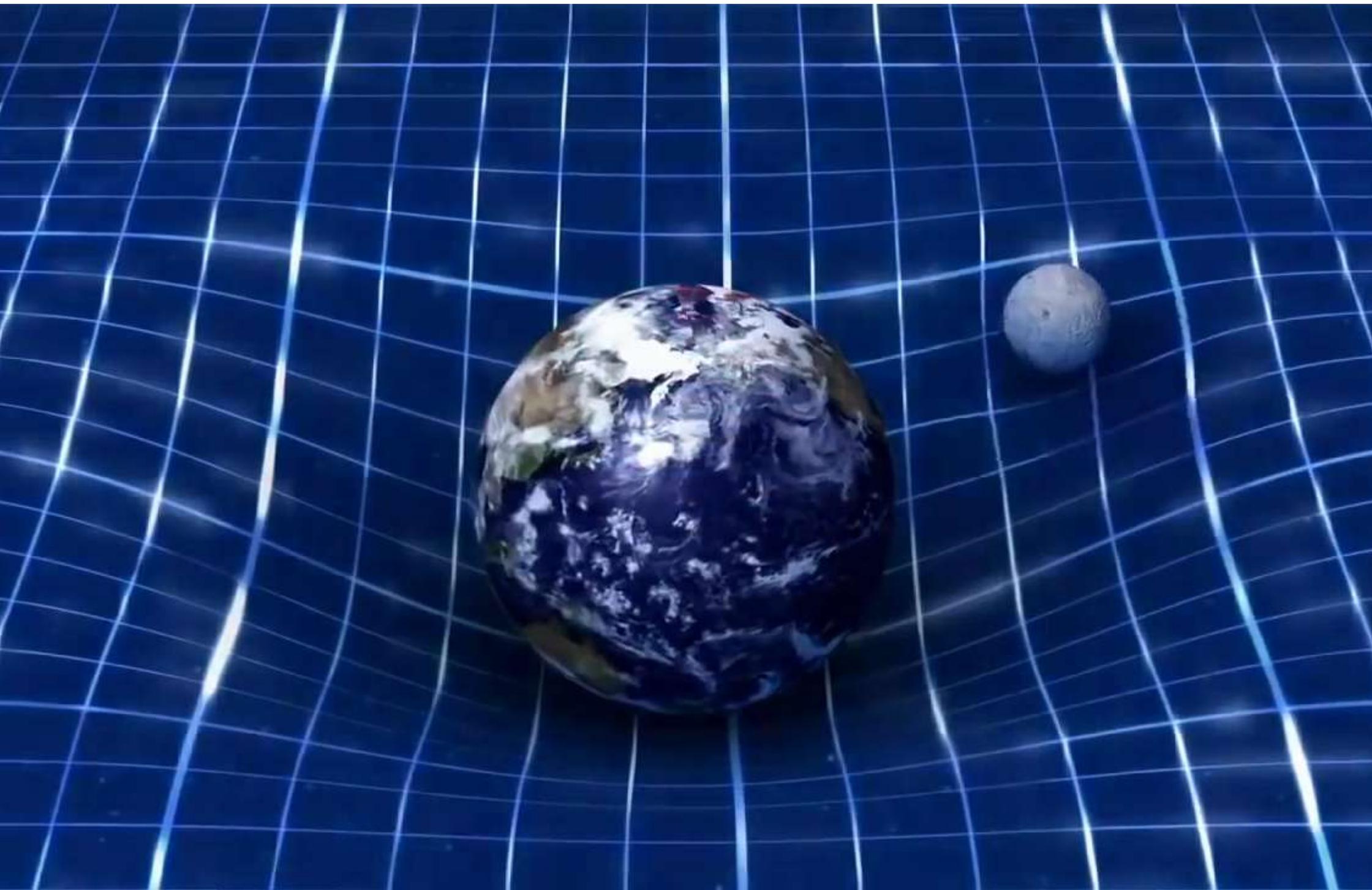
Equazione di campo di Einstein

geometria
dello spazio

densità di
materia

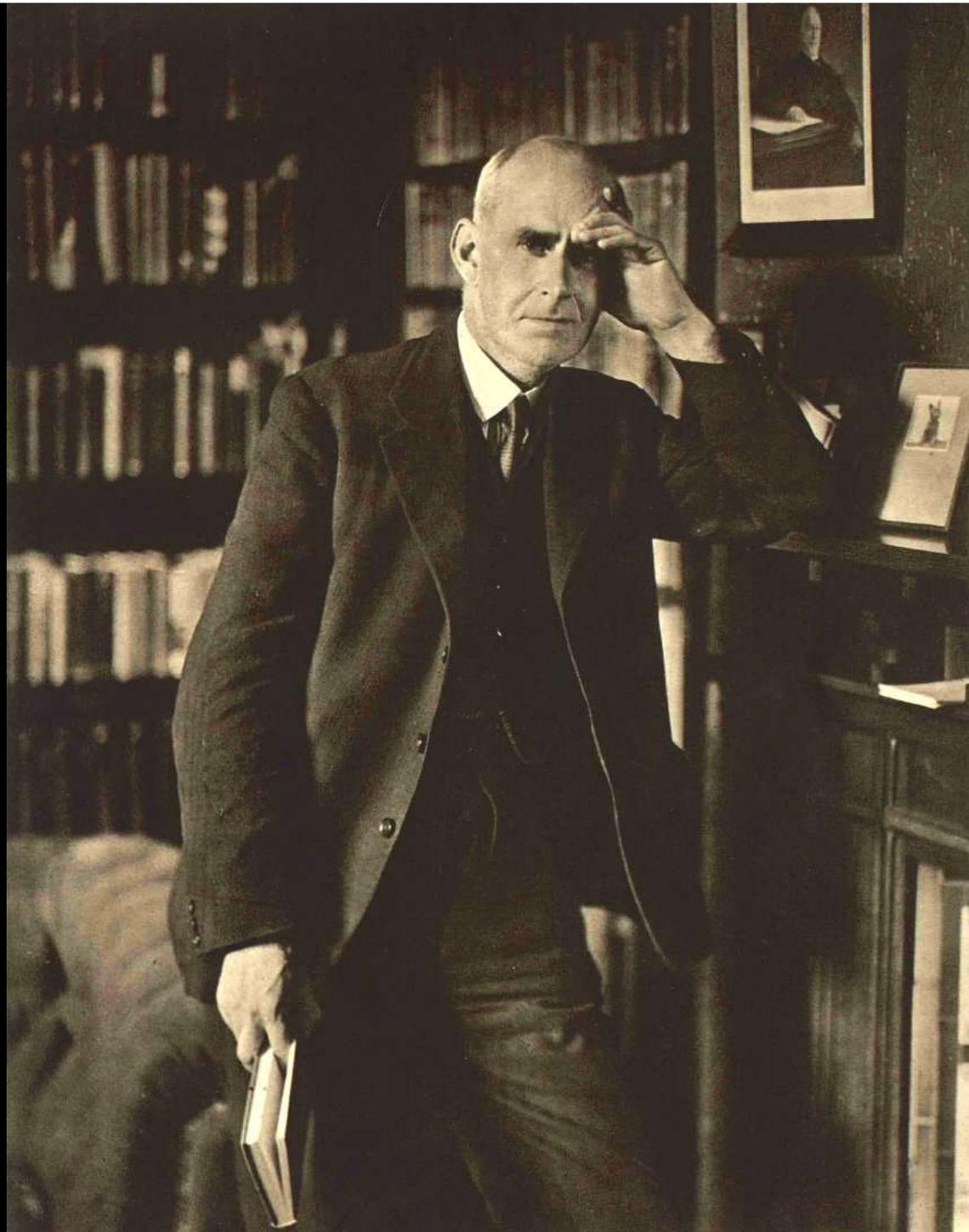
$$G_{\mu\nu} = 8\pi G/c^4 T_{\mu\nu}$$

costante
piccolissima

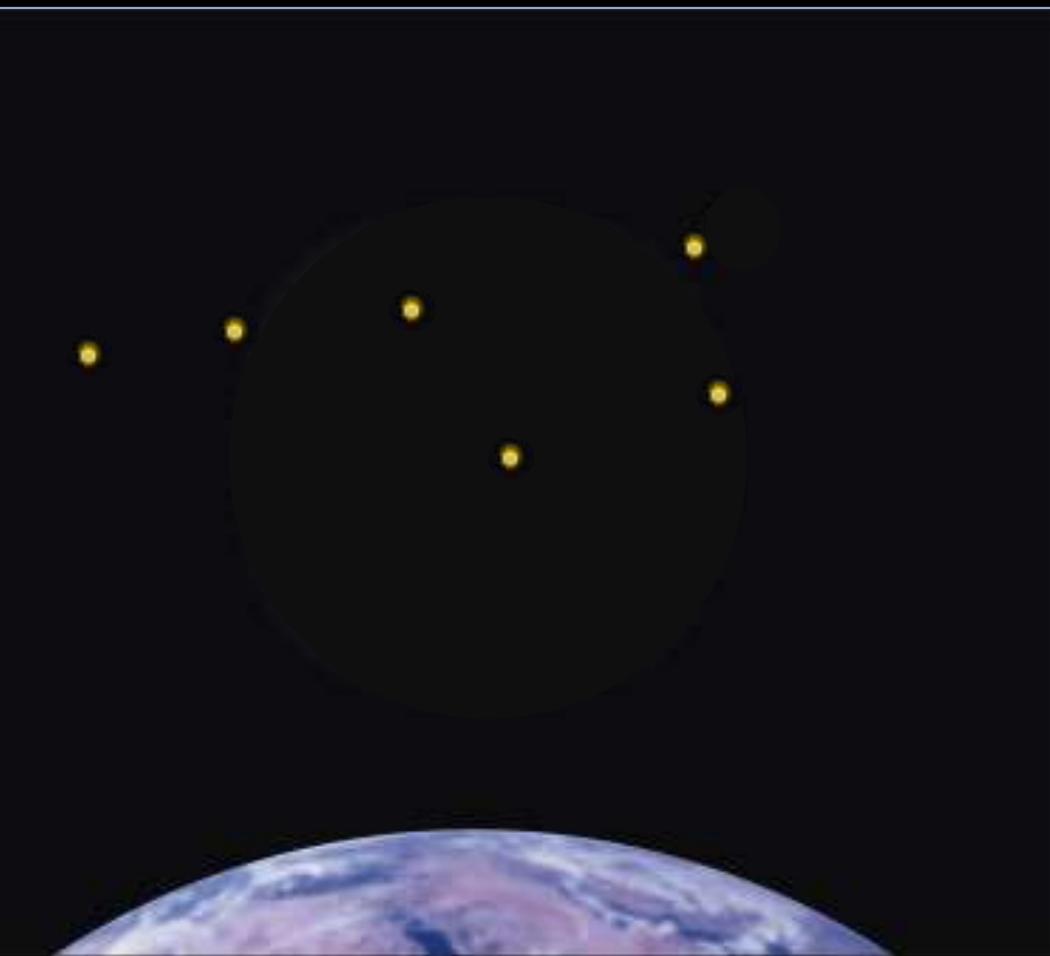




anche la luce curva
in uno spazio curvo



Spostamento delle stelle durante l'eclissi di Sole



Maggio 1919

Actual Position of the Star

Apparent Position of the Star

Distance from the Earth to the Stella Background is more than 93,000,000,000,000 miles.

THE SUN

Distance from the Earth 93,000,000 miles

This Diagram shows the proportional Displacement of the Stars in relation to the distance from the Sun. The amount of Displacement is exaggerated about 600 times.

Apparent Position: ↑
Actual Position: ★

SOUTH AMERICA

AFRICA

ATLANTIC OCEAN

Principe

Sobral

Showing Path of Total Eclipse of May 28-29, 1919, and positions of the two Observation Stations.

THE OBSERVATION STATION AT SOBRAL, IN BRAZIL

The Corona



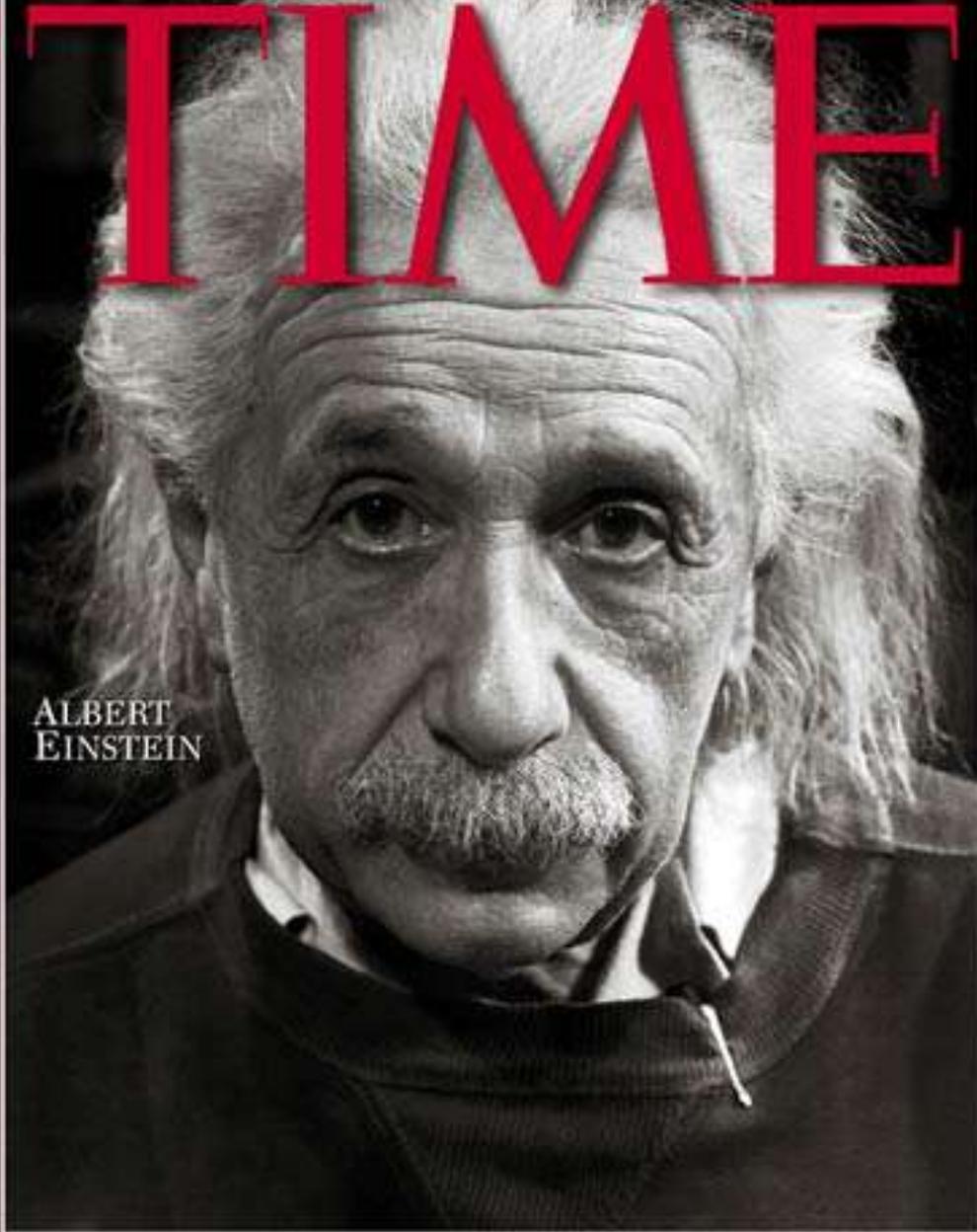
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PERSON OF THE CENTURY

TIME

ALBERT
EINSTEIN





spazio-tempo quadridimensionale curvo

il tempo scorre più lentamente
dove la curvatura è maggiore

Correzione relativistica del GPS

$$\gamma_{\text{speed}} = 1 / \sqrt{1 - v^2 / c^2}$$

$$\gamma_{\text{gravity}} = 1 / \sqrt{1 - 2GM / (c^2 r)}$$



satellite	Altezza orbitale	Velocità orbitale	Rallentamento dovuto alla velocità	Accelerazione dovuta alla gravità	Differenza rispetto alla superficie
GPS	20000 km	4 km/s	-7 μs/d	+46 μs/d	+39 μs/d

Dilatazione gravitazionale del tempo

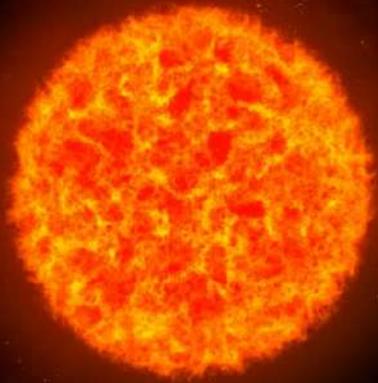
$$\gamma_{\text{gravity}} = 1 / \sqrt{1 - R_{\text{S}} / r}$$

Raggio di Schwarzschild

$$R_{\text{S}} = 2GM / c^2$$



stella di
grande
massa



supergigante

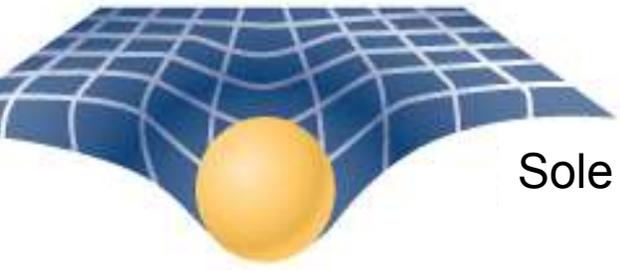


supernova

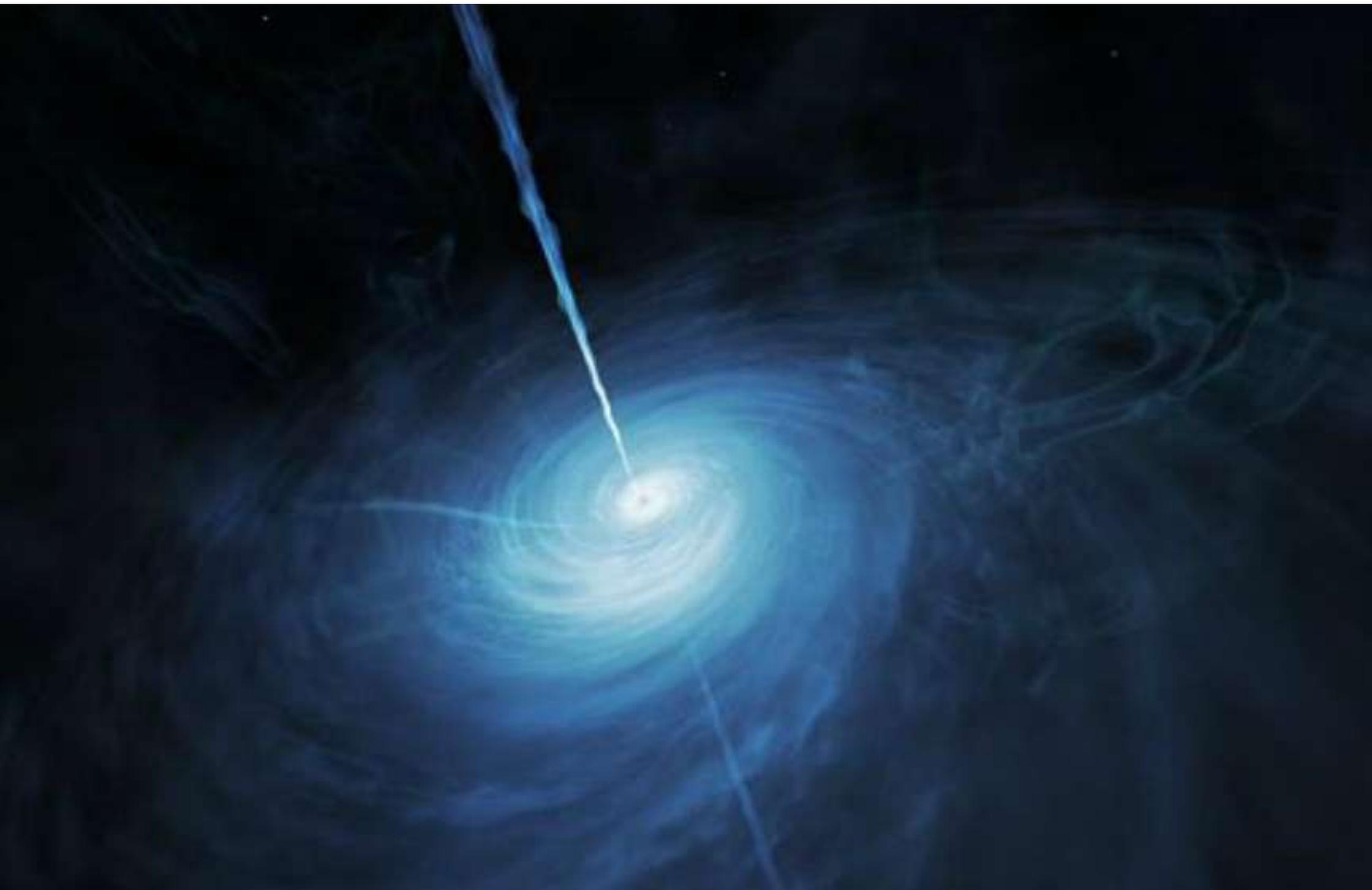


buco
nero





Sole





se lo spazio-tempo è «flessibile» allora può essere messo in oscillazione

le Onde Gravitazionali sono perturbazioni dello spazio-tempo che si propagano come onde che viaggiano alla velocità della luce

LIGO - Hanford (V)



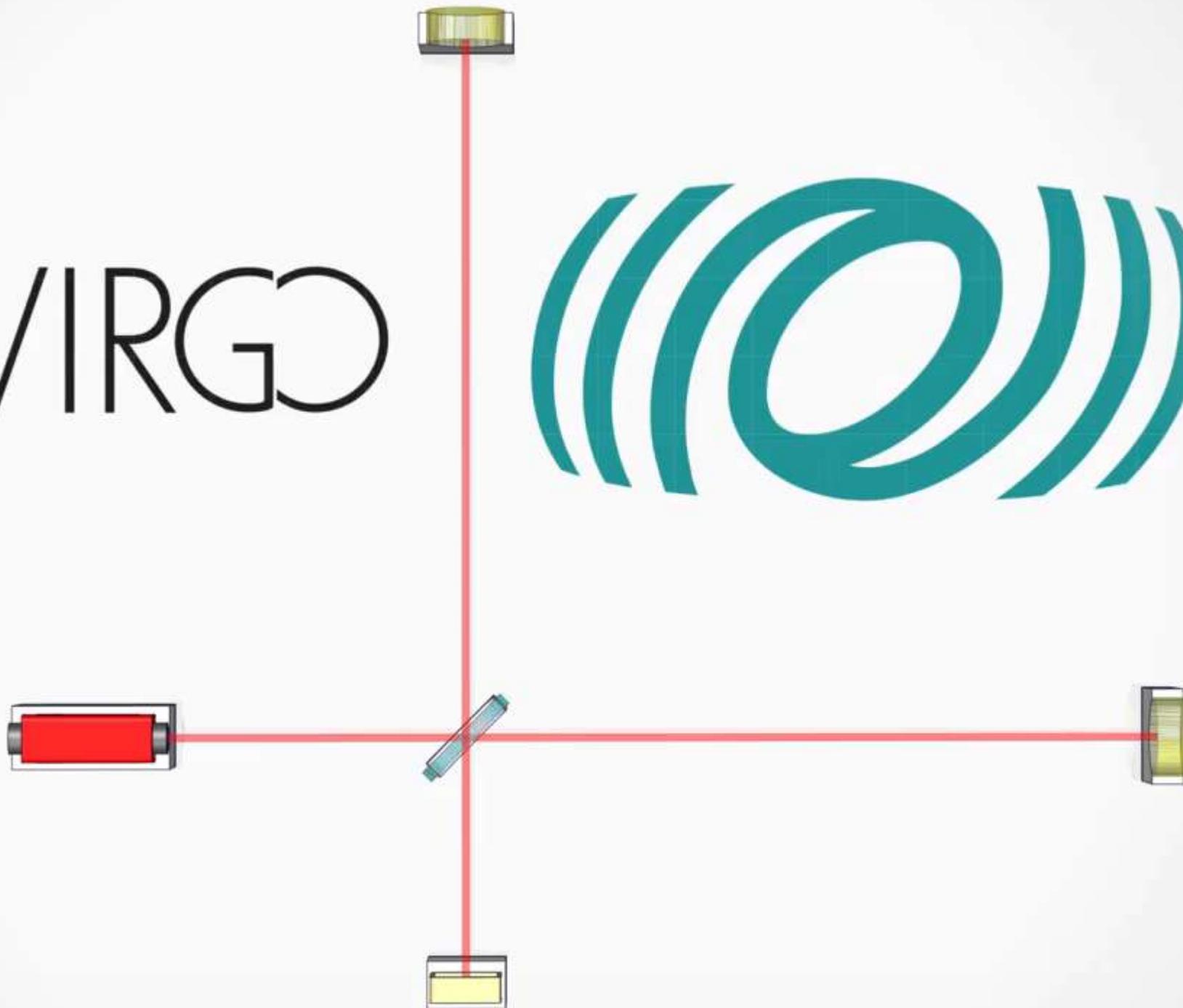
IGO - Livingston (LA)



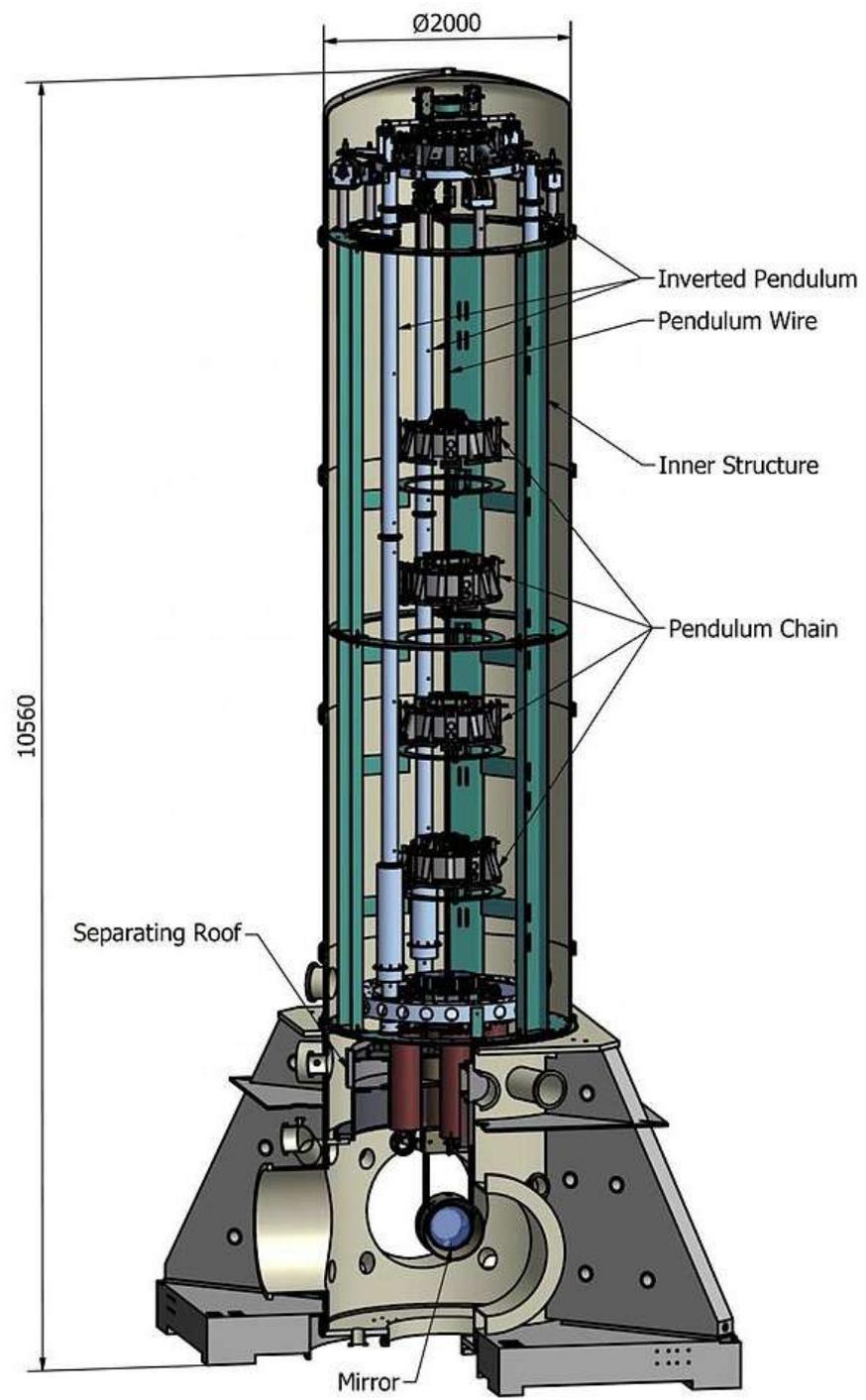
RGO - Pisa

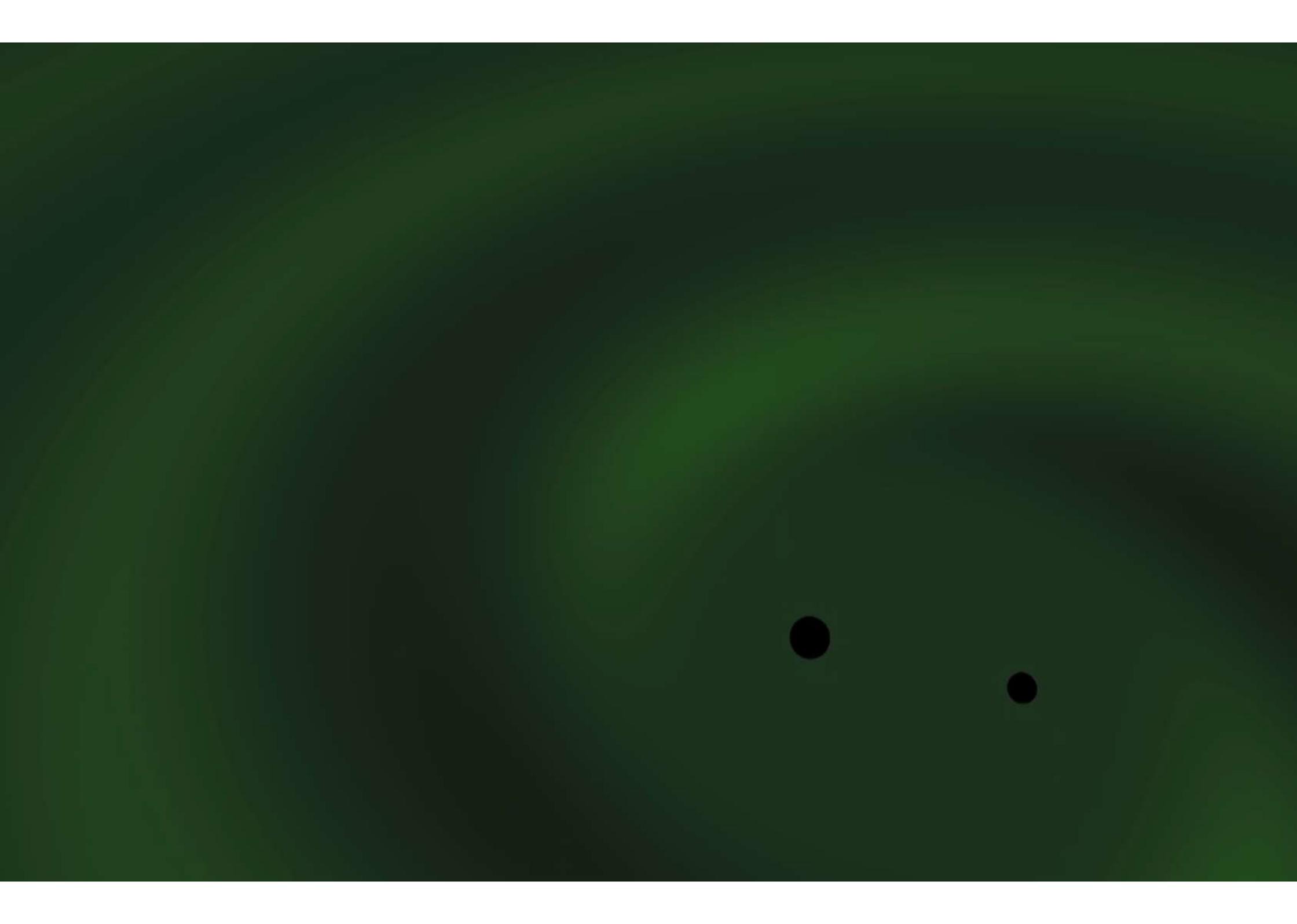


VIRGO

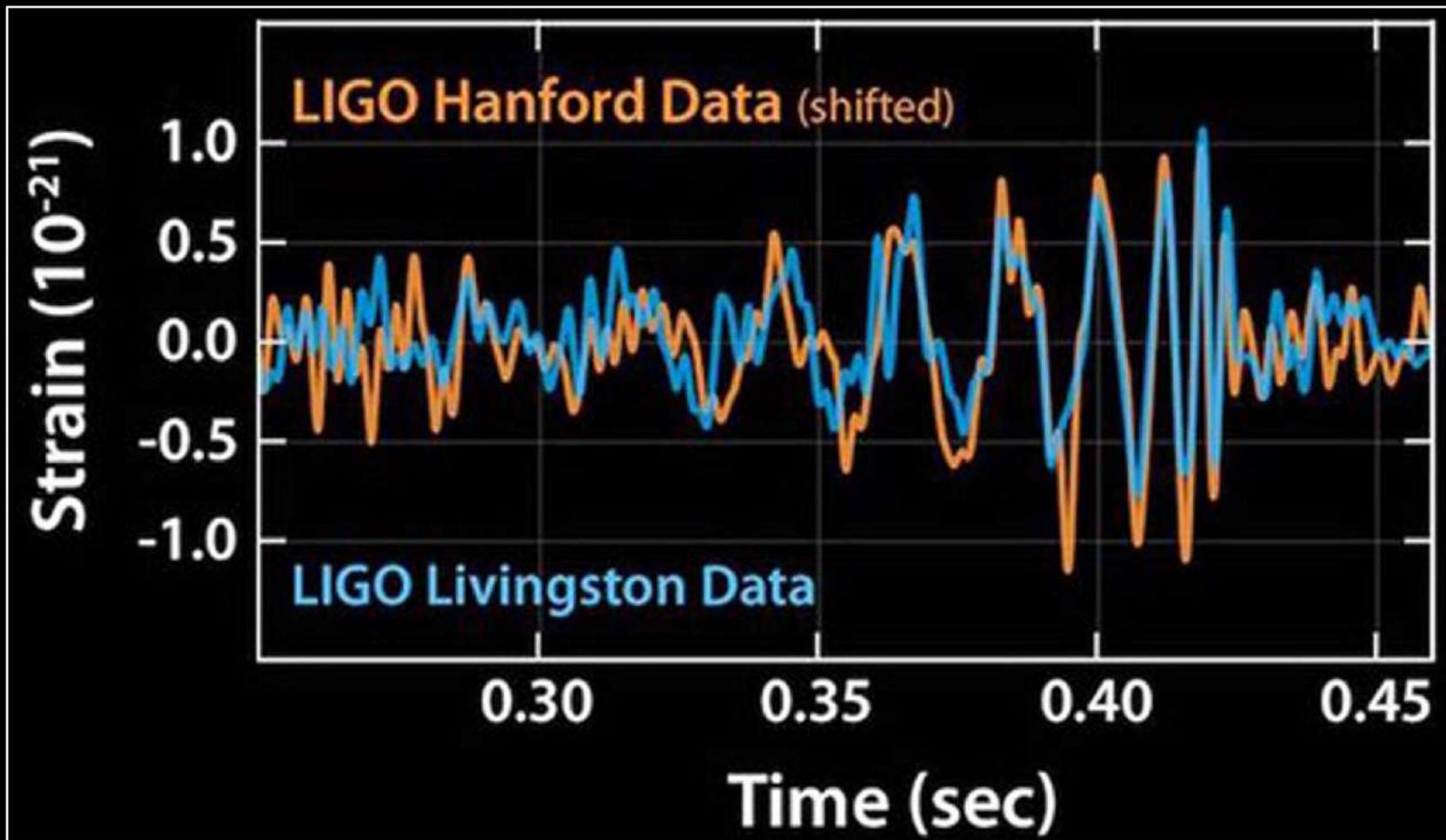








14 settembre 2015 11:50:45 CET



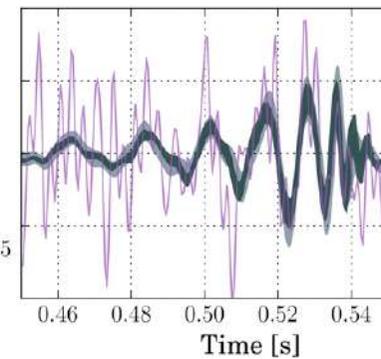
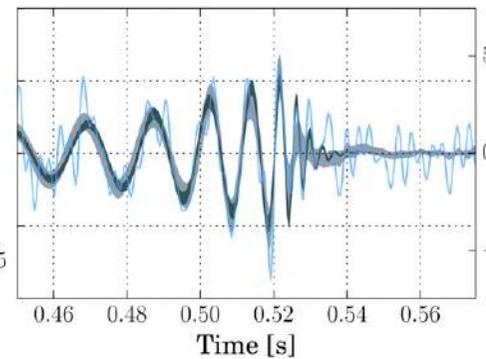
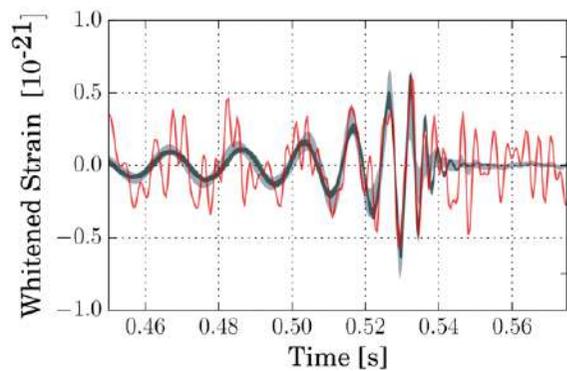




Hanford

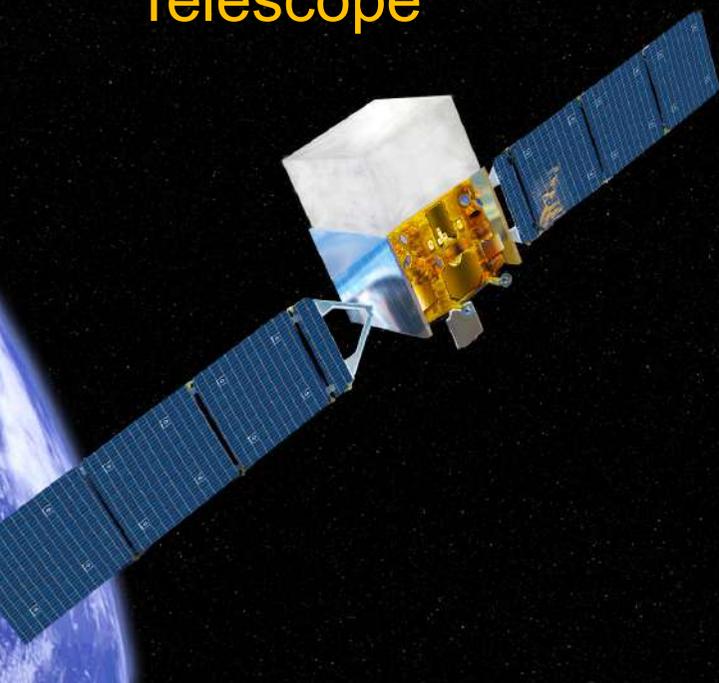
Livingstone

Virgo



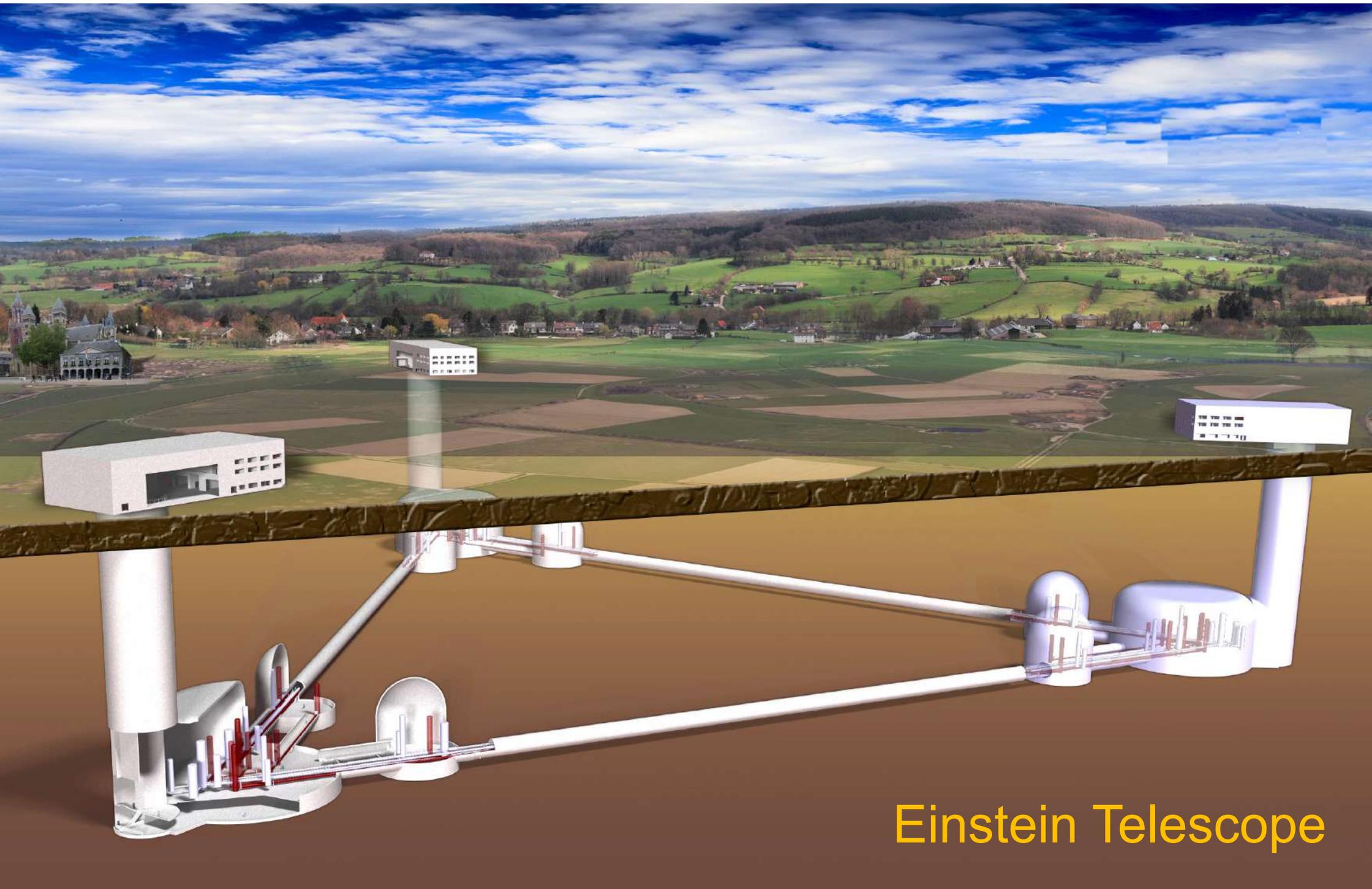
17 agosto 2017 13:41:06

Fermi Gamma Ray Telescope



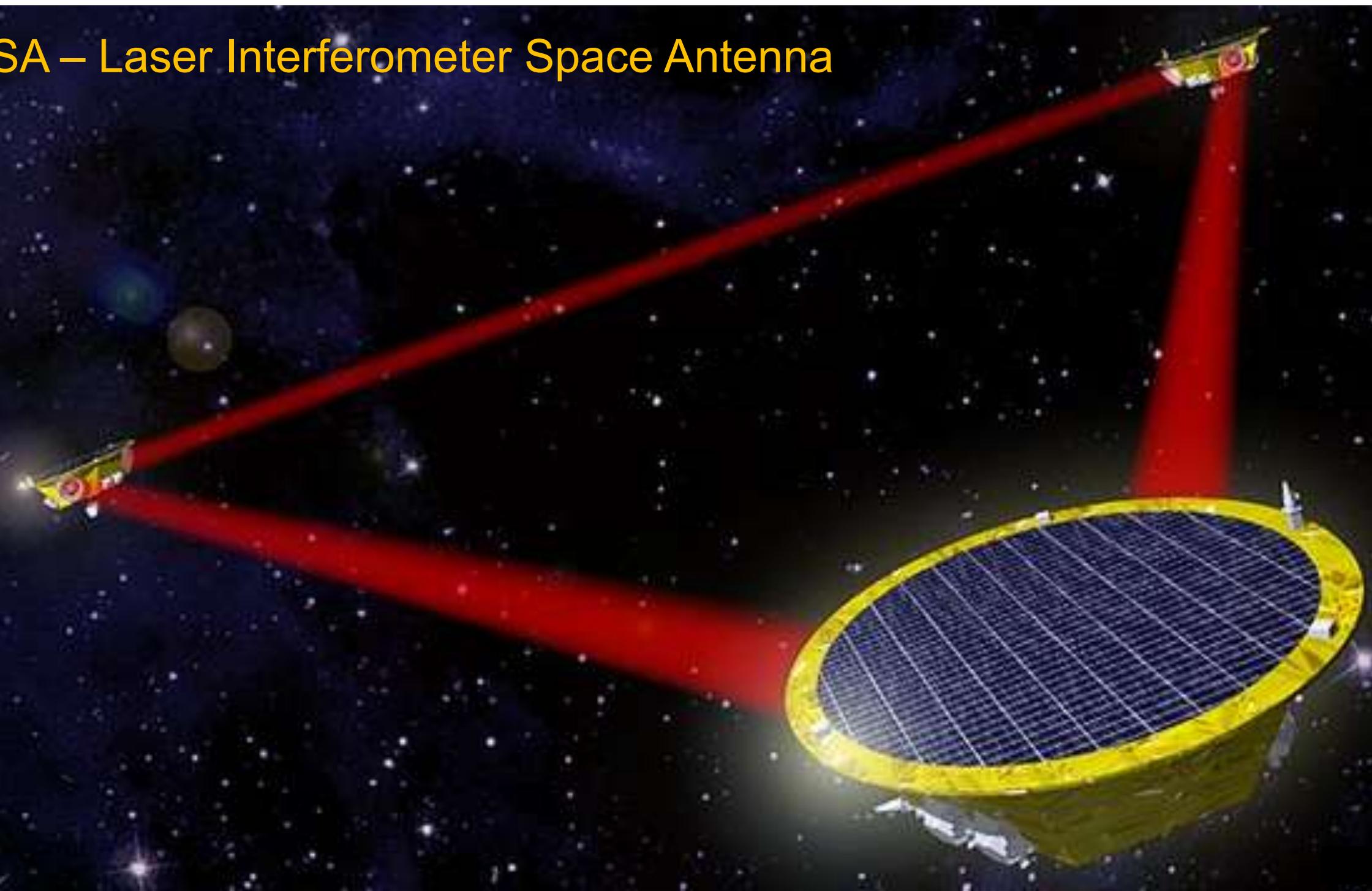
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Einstein Telescope

SA – Laser Interferometer Space Antenna



BIG BANG

onde gravitazionali

neutrini

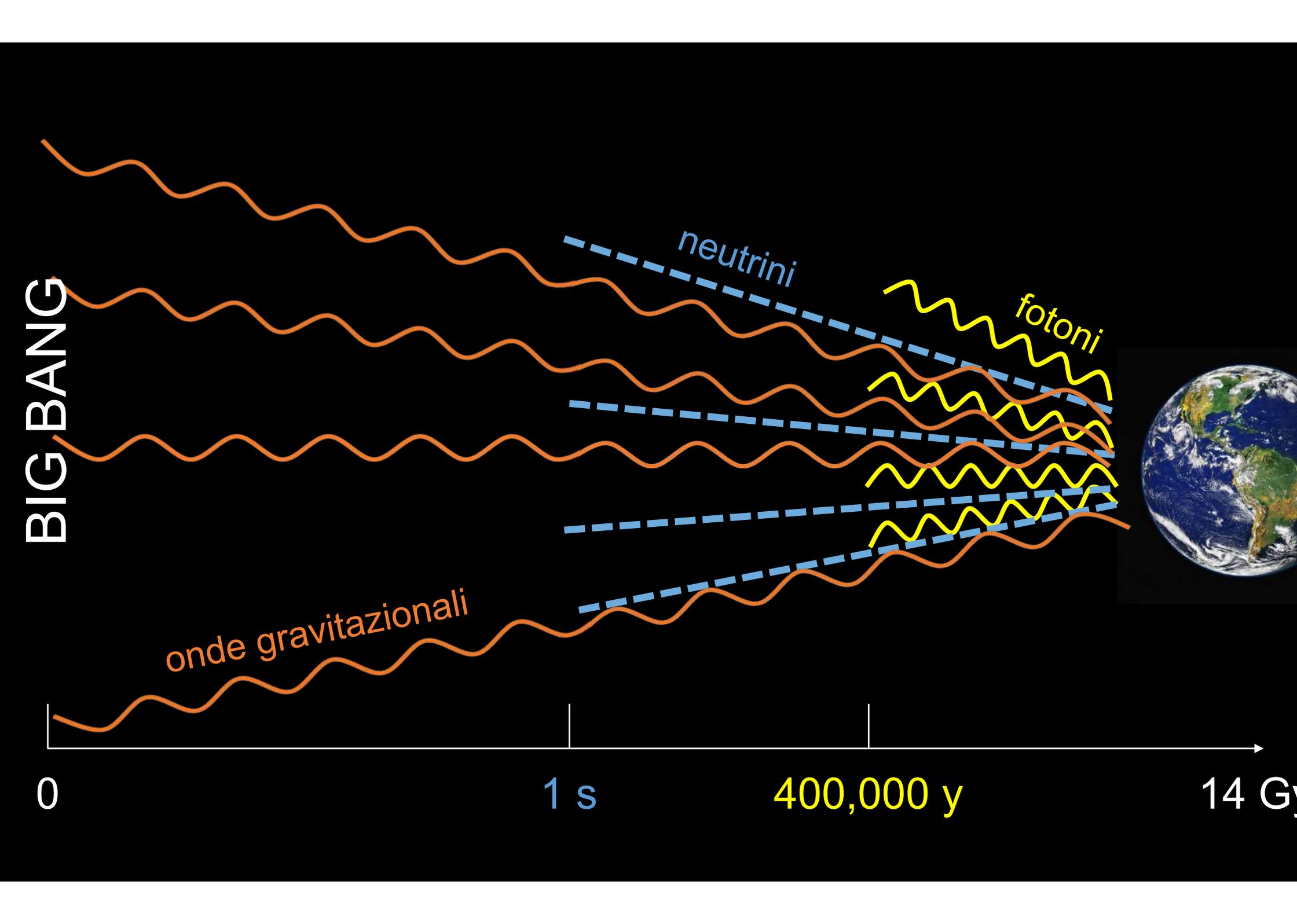
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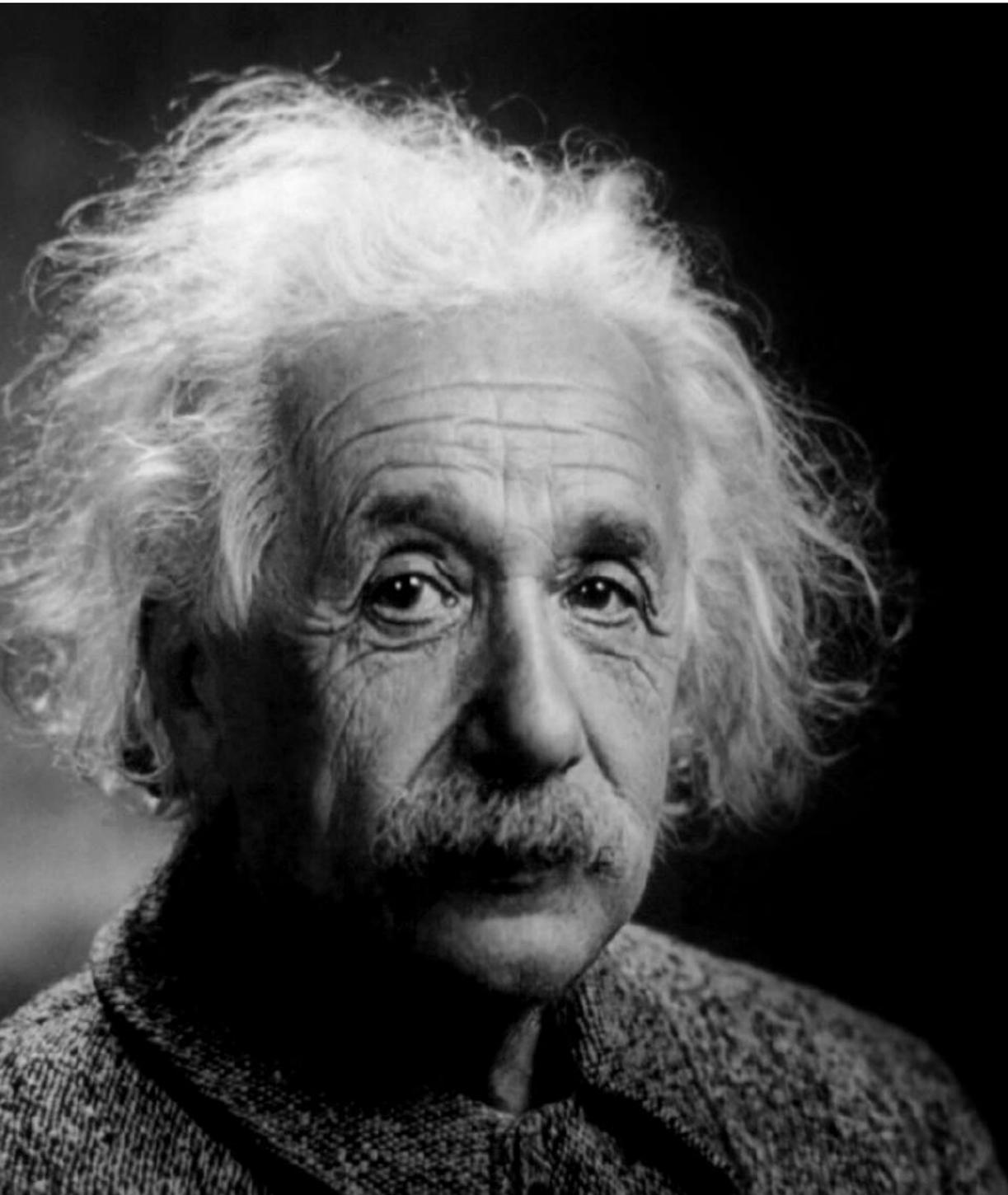
0

1 s

400,000 y

14 Gy





la più bella
di tutte le teorie