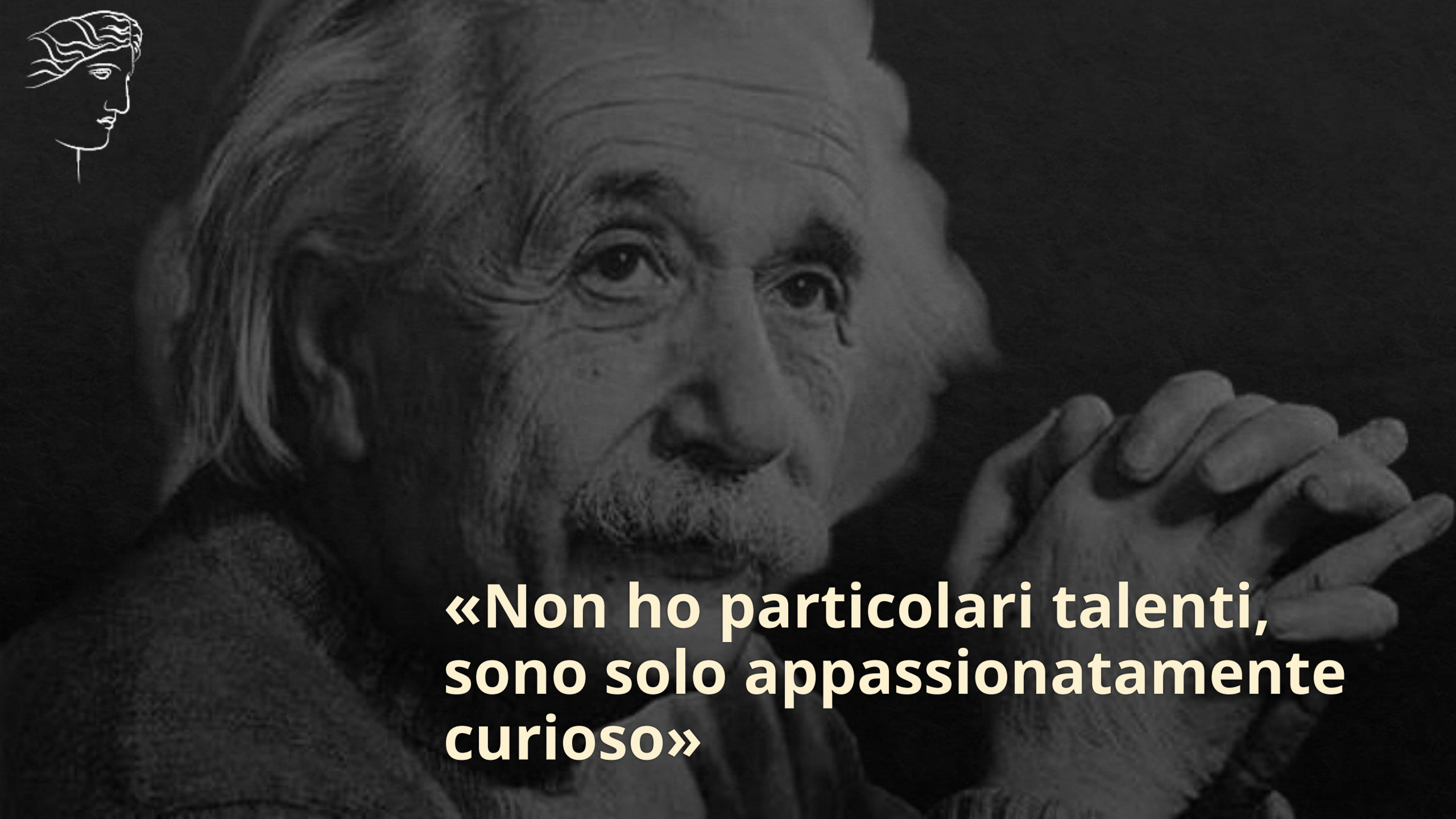

«Non ho particolari talenti,
sono solo appassionatamente
curioso»

Galileo Galilei



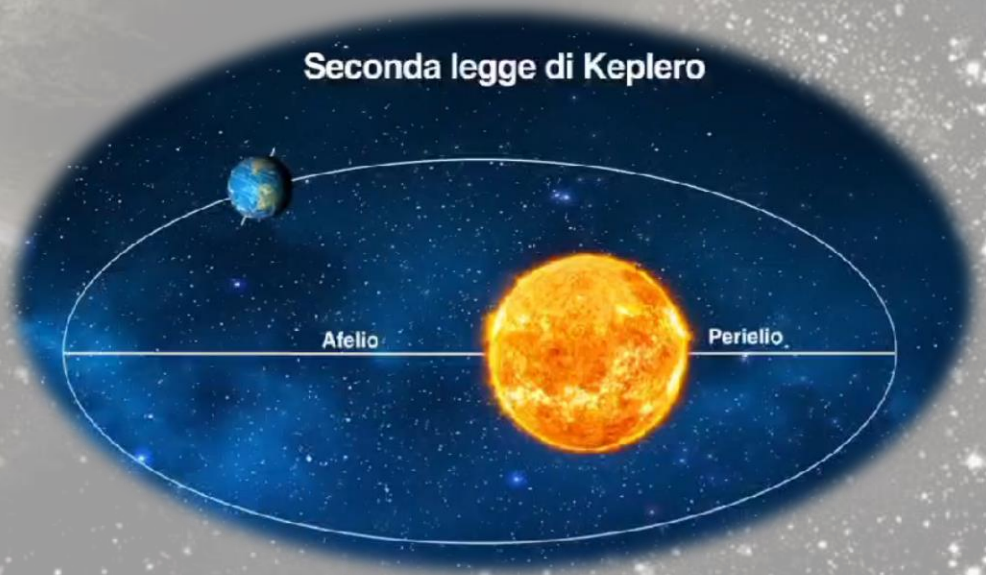
$$g = 9,8\ m/s^2$$



Le leggi di Keplero

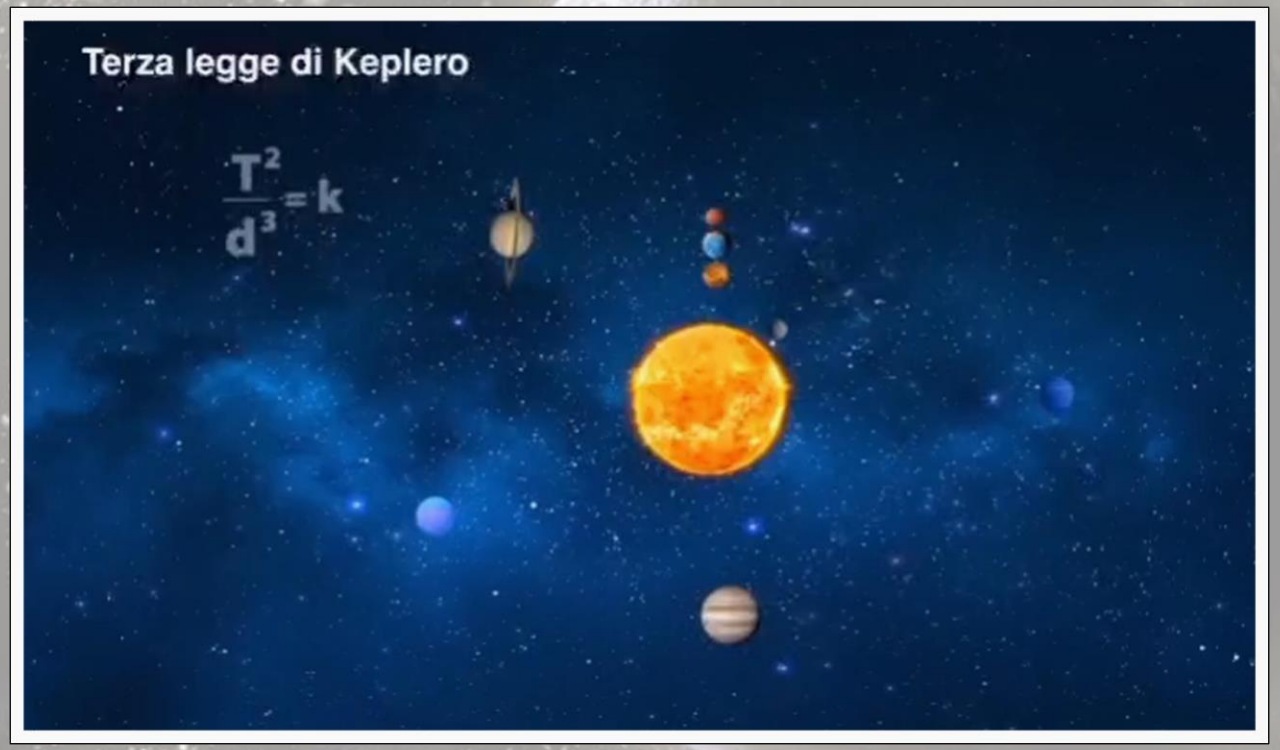


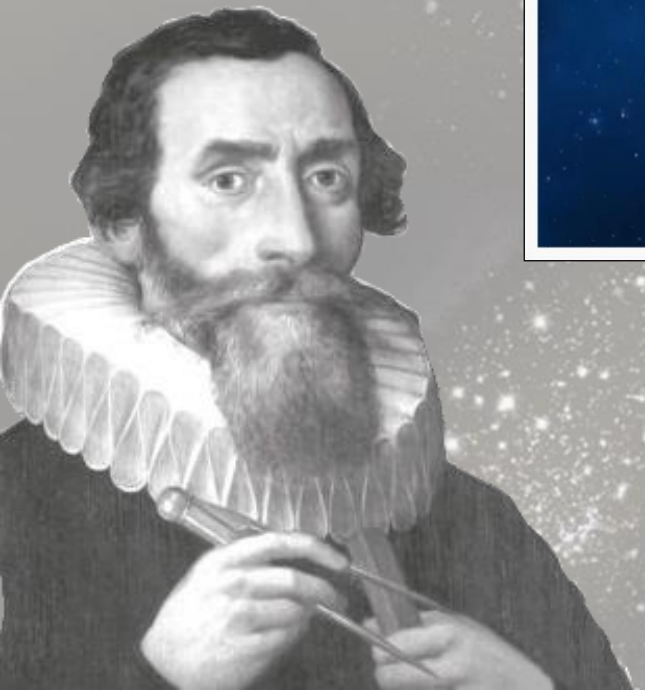






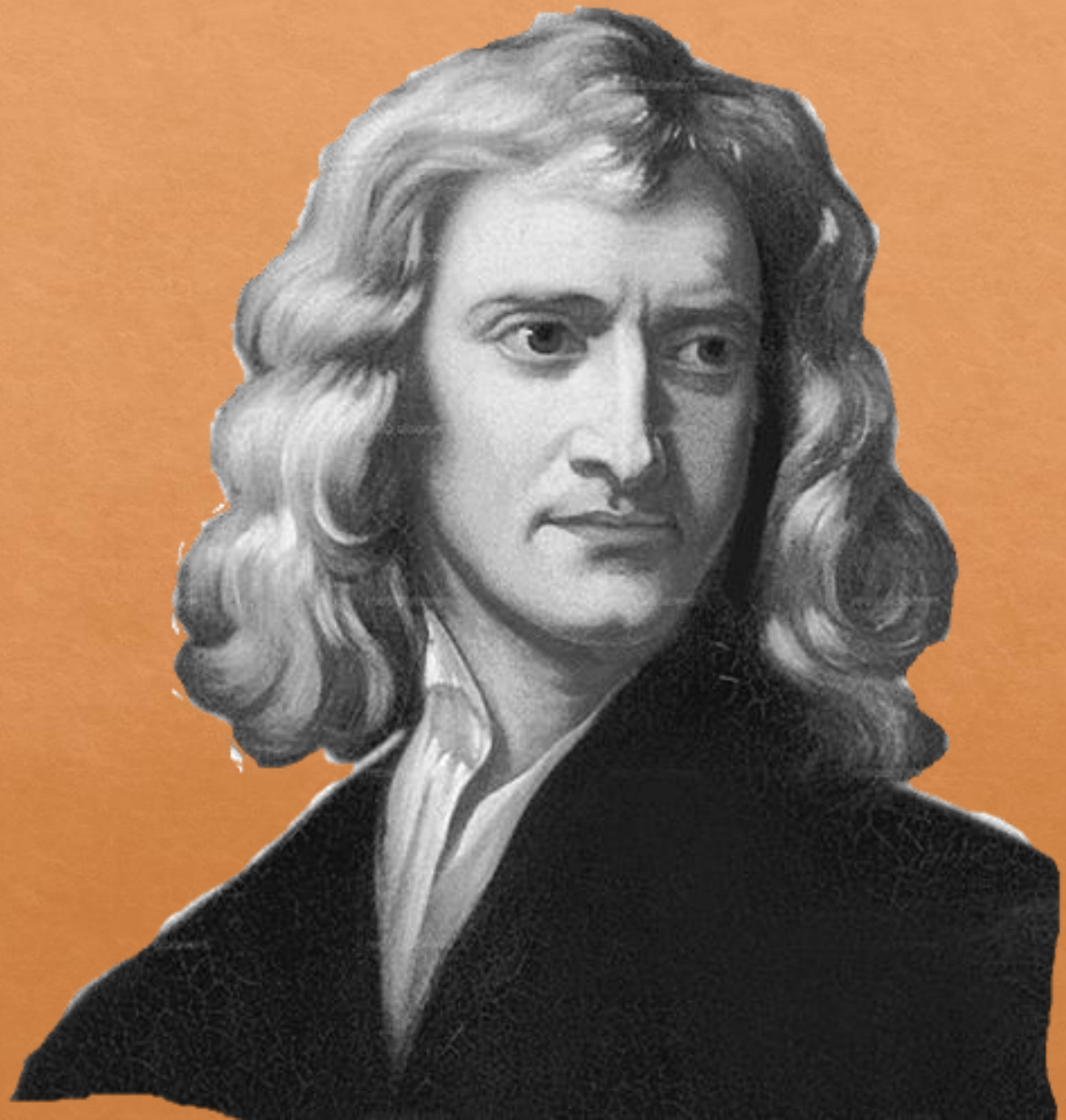
Le leggi di Keplero





«In epoche turbate e angosciate come la nostra, in cui è difficile trovare gioia negli uomini e nel corso degli eventi umani, è particolarmente consolante evocare il ricordo di un uomo così grande, così sereno come Kepler»

Einstein

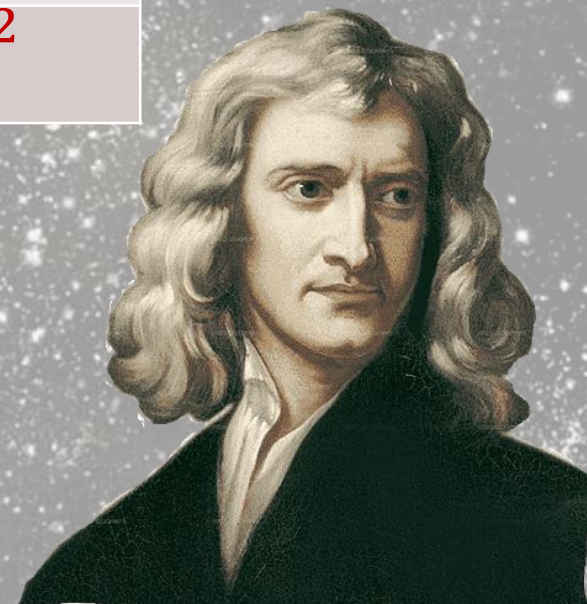




La piccola Luna

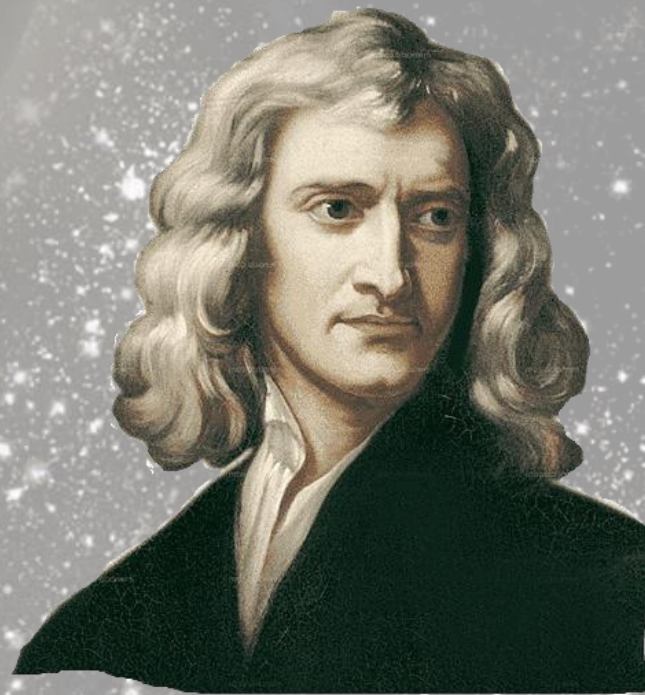


Raggio Terra	$6,4 \cdot 10^6$m
Periodo rivoluzione P. Luna	1h 30 m
Velocità tangenziale PL	7,92 km/s
Accelerazione PL	$9,8\ m/s^2$



La palla di cannone







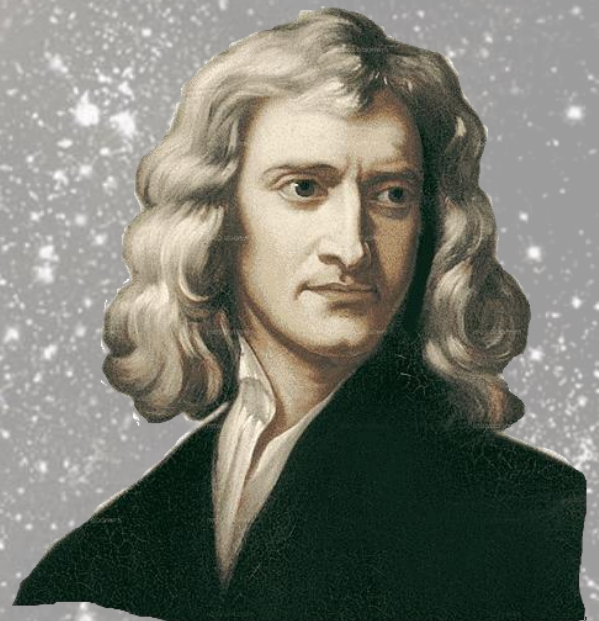
La legge di gravitazione universale



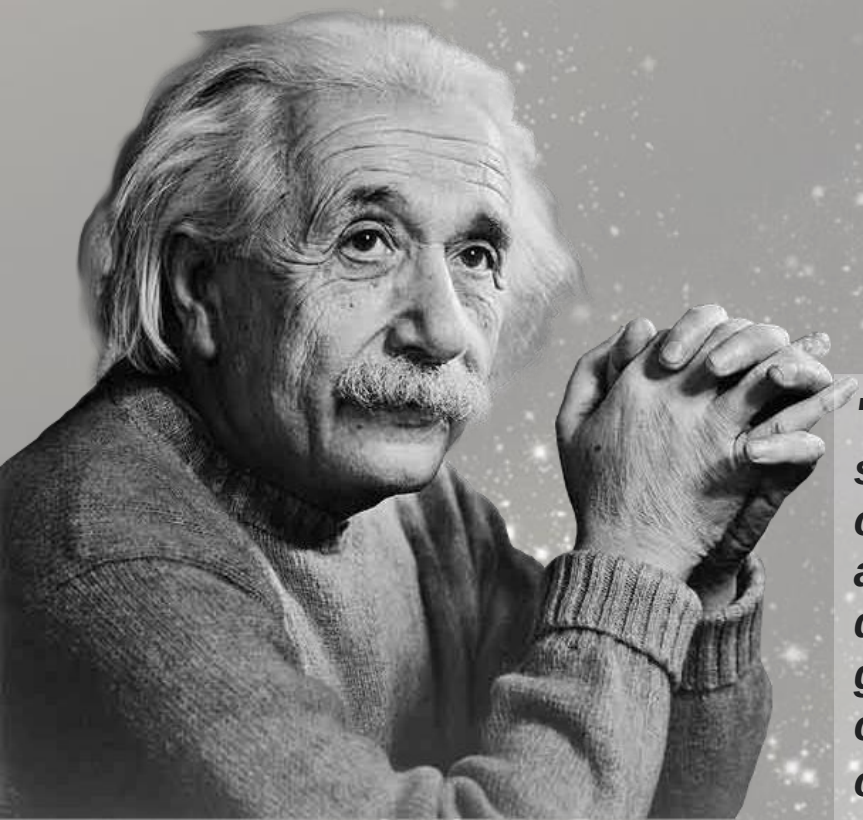
$$F = G\frac{M \cdot m}{R^2}$$



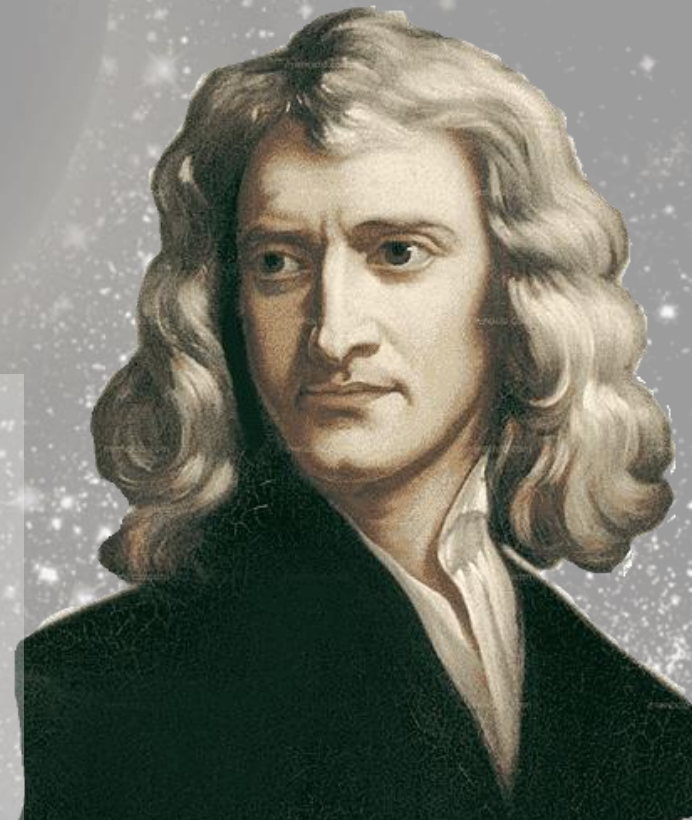
«Sono interessato alla meraviglia di una natura che può obbedire
Ad una legge tanto elegante e semplice come questa
della gravitazione»
Richard Feynman



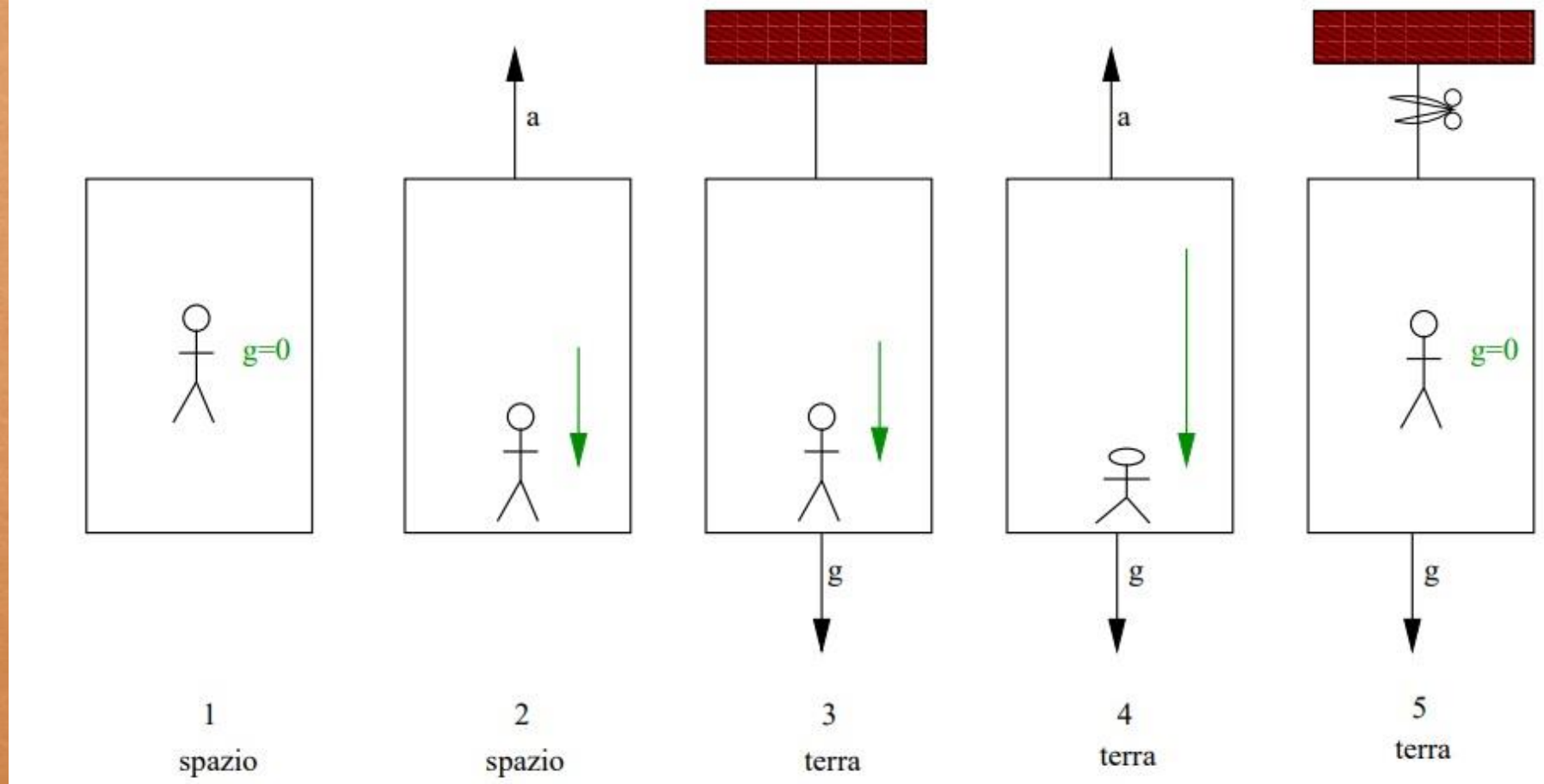
1. Formulazione del principio Spazio e Tempo
2. Introduzione di forze dirette che agiscono istantaneamente a distanza
3. Non dà spiegazione che peso e inerzia di un corpo sono determinati dalla stessa grandezza (massa)



*"Che nel vuoto un corpo possa agire a distanza su un altro senza la mediazione di qualsiasi altra cosa, per mezzo e attraverso la quale la loro azione e la loro forza possano essere trasferite dall'uno all'altro, è per me un'assurdità così grande a cui, credo, nessun uomo con competenze in questioni filosofiche potrebbe mai credere« I*saac*Newton*




« il pensiero più felice della mia vita:
Se una persona cade liberamente
non sente il proprio peso»

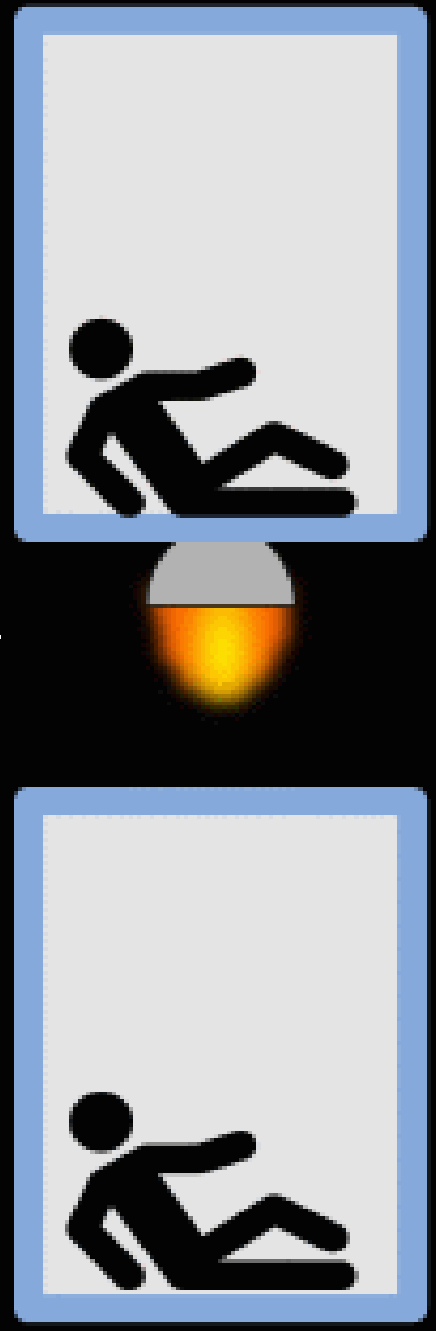

g=0
a
g
a
g
g=0
g
1
spazio
2
spazio
3
terra
4
terra
5
terra











ACCELERAZIONE

?

GRAVITÀ


« Non esiste nessuna forza di gravità
E’ solo l’effetto del movimento
dei corpi in uno spazio curvo »



Perché due corpi si attraggono?






ALGERIA
LIBIA
NIGER
CIAD
EGITTO
ARABIA SAUDITA
IRAN


Curvatura dello spazio
La geometria dello spazio dipende
Dalla materia che contiene


NEWTON: SPAZIO RIGIDO





Equazione di campo

Geometria dello spazio

Densità di materia

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

Costante molto piccola

$$\frac{8\pi G}{c^4} = \frac{8 \cdot \pi \cdot 6,67 \cdot 10^{-11}}{(2,99 \cdot 10^8)^4} = 2.1 \cdot 10^{-43}$$

0,000000000000000000000000000000000000021

La vita delle stelle



NEBULOSA STELLARE
Una regione più densa della nebulosa inizia a restringersi, a riscaldarsi e diventa una **protostella**

SEQUENZA PRINCIPALE
La stella risplende grazie alle reazioni nucleari che producono luce e calore

SUPERGIGANTE
Le stelle più grandi si espandono, si raffreddano e diventano rosse

GIGANTE ROSSA
Le stelle più piccole si espandono e diventano rosse

SUPERNOVA
La supergigante esplode diventando brillantissima

STELLA DI NEUTRONI
Il nucleo della supernova collassa e diventa densissimo

BUCO NERO
Il nucleo collassa completamente e scompare

NEBULOSA PLANETARIA
I gas più esterni si disperdono

Il nucleo esposto forma una **NANA BIANCA**

NANA NERA
La stella smette di bruciare

Buco nero



Se la gravità riesce a comprimere un corpo in una sfera di raggio inferiore a *Rs* (raggio di Schwarzschild), quel corpo non potrà emettere (né riflettere) luce, né inviare segnali di altro tipo.

Esso apparirà completamente nero.

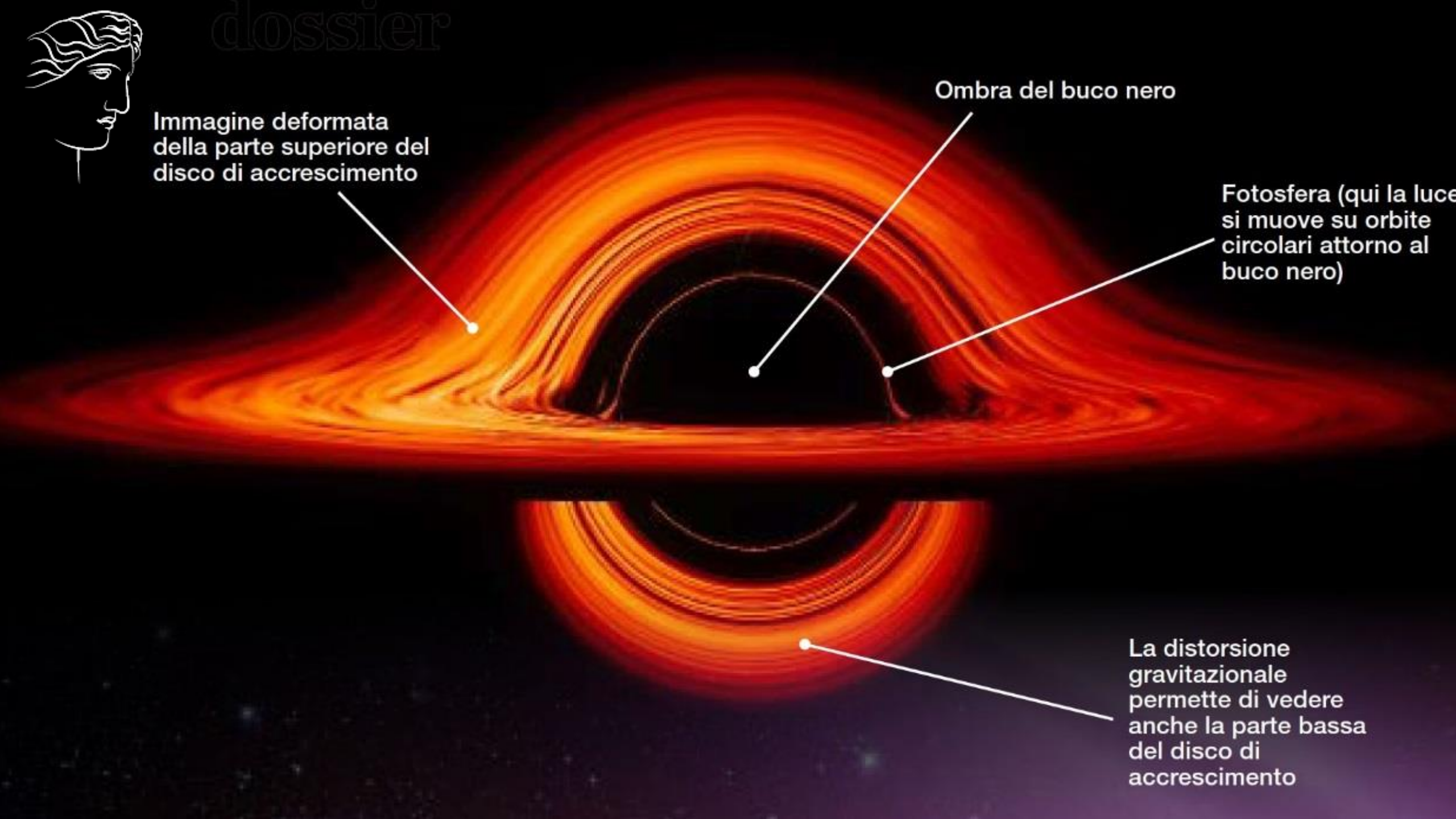
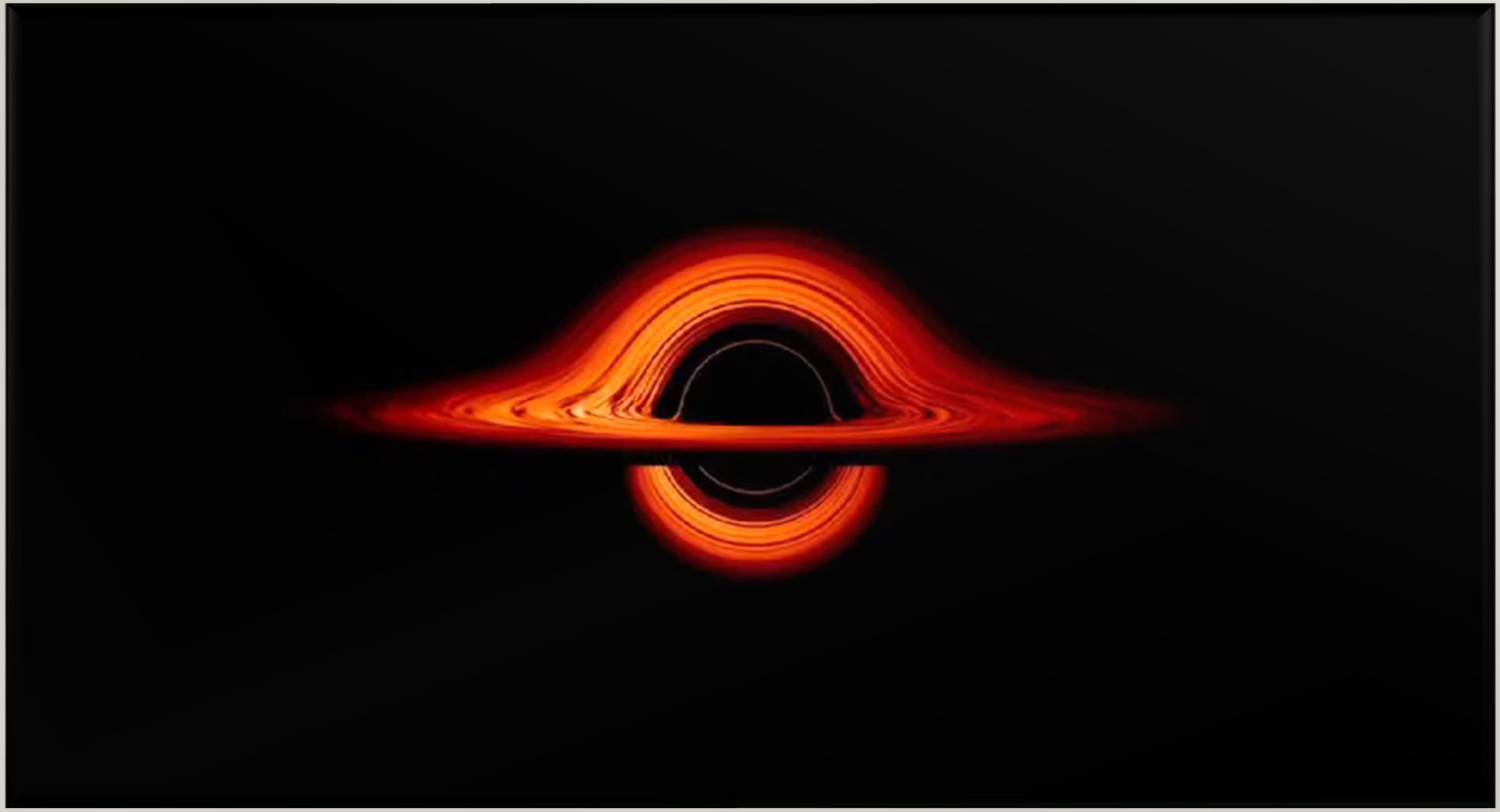
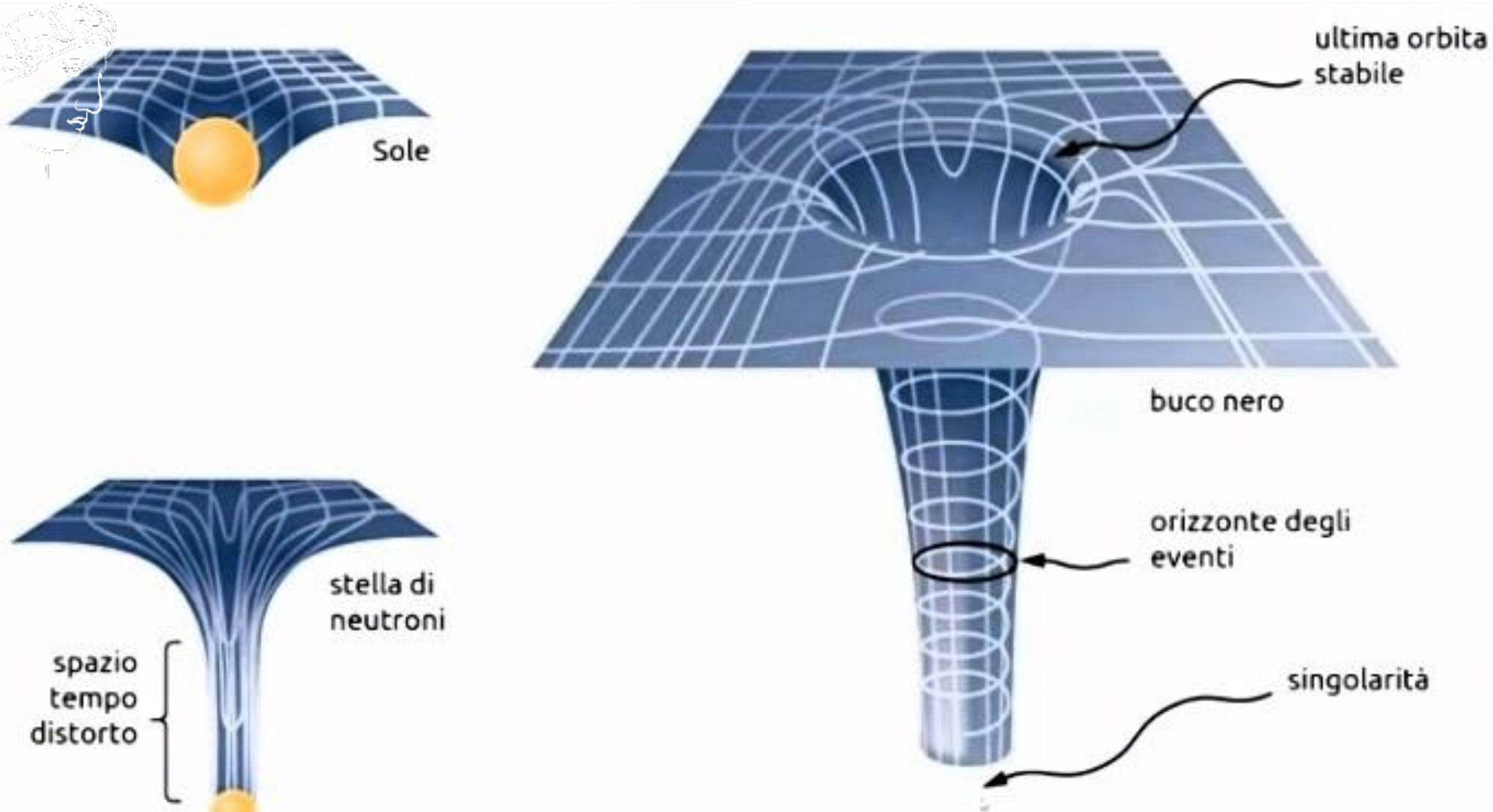
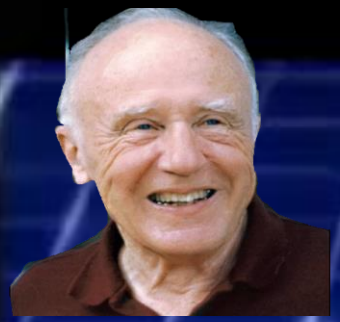


Immagine deformata della parte superiore del disco di accrescimento
Ombra del buco nero
Fotosfera (qui la luce si muove su orbite circolari attorno al buco nero)
La distorsione gravitazionale permette di vedere anche la parte bassa del disco di accrescimento

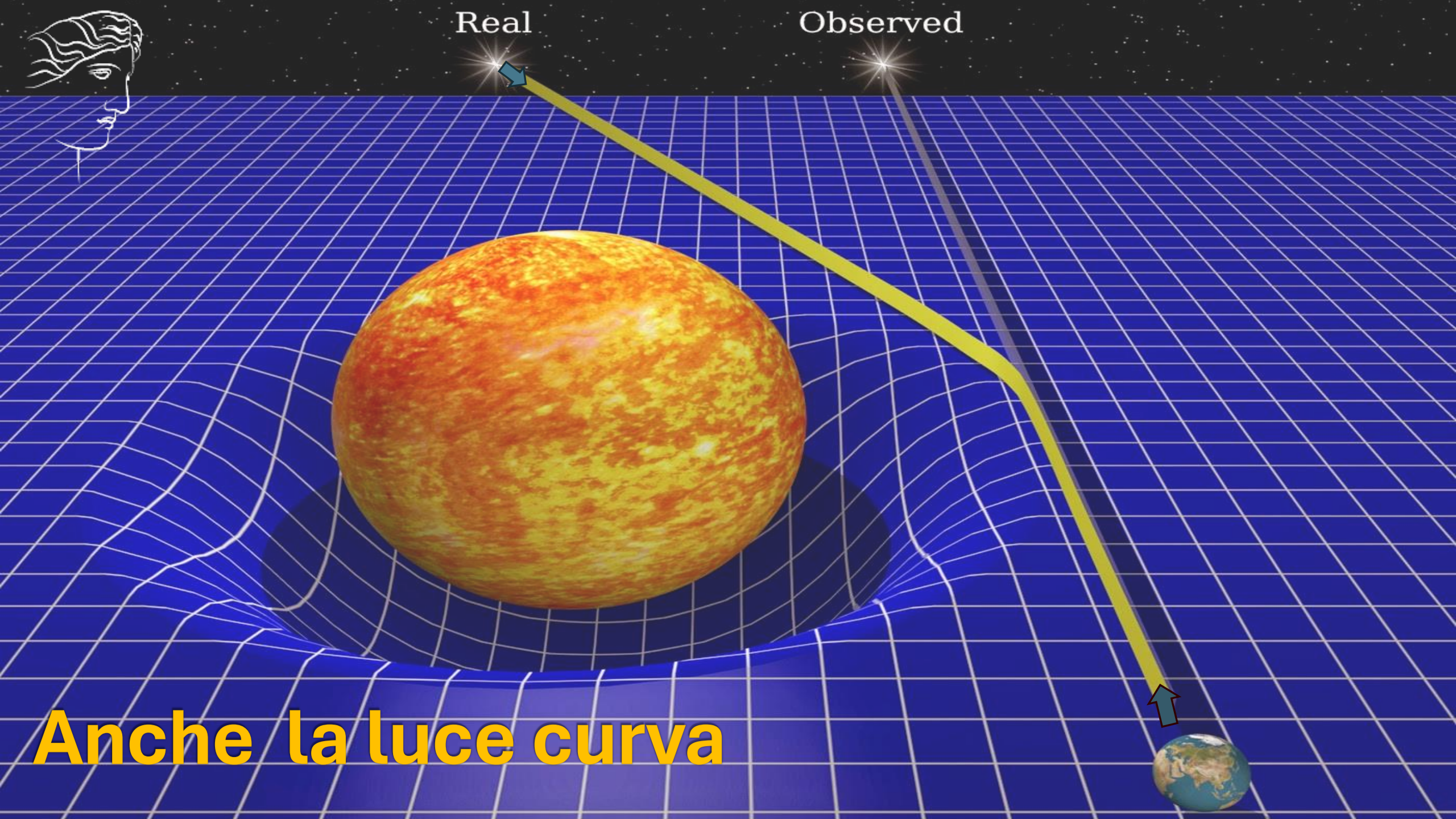



Sole
ultima orbita stabile
buco nero
orizzonte degli eventi
singolarità
stella di neutroni
spazio tempo distorto



John Wheeler

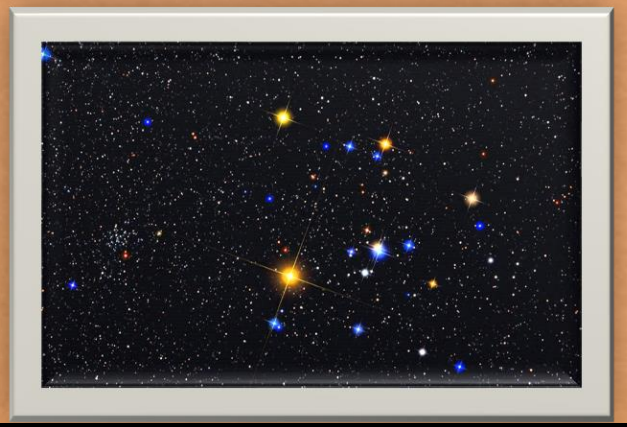
**“lo spaziotempo dice alla materia come muoversi,
la materia dice allo spaziotempo come curvarsi”**

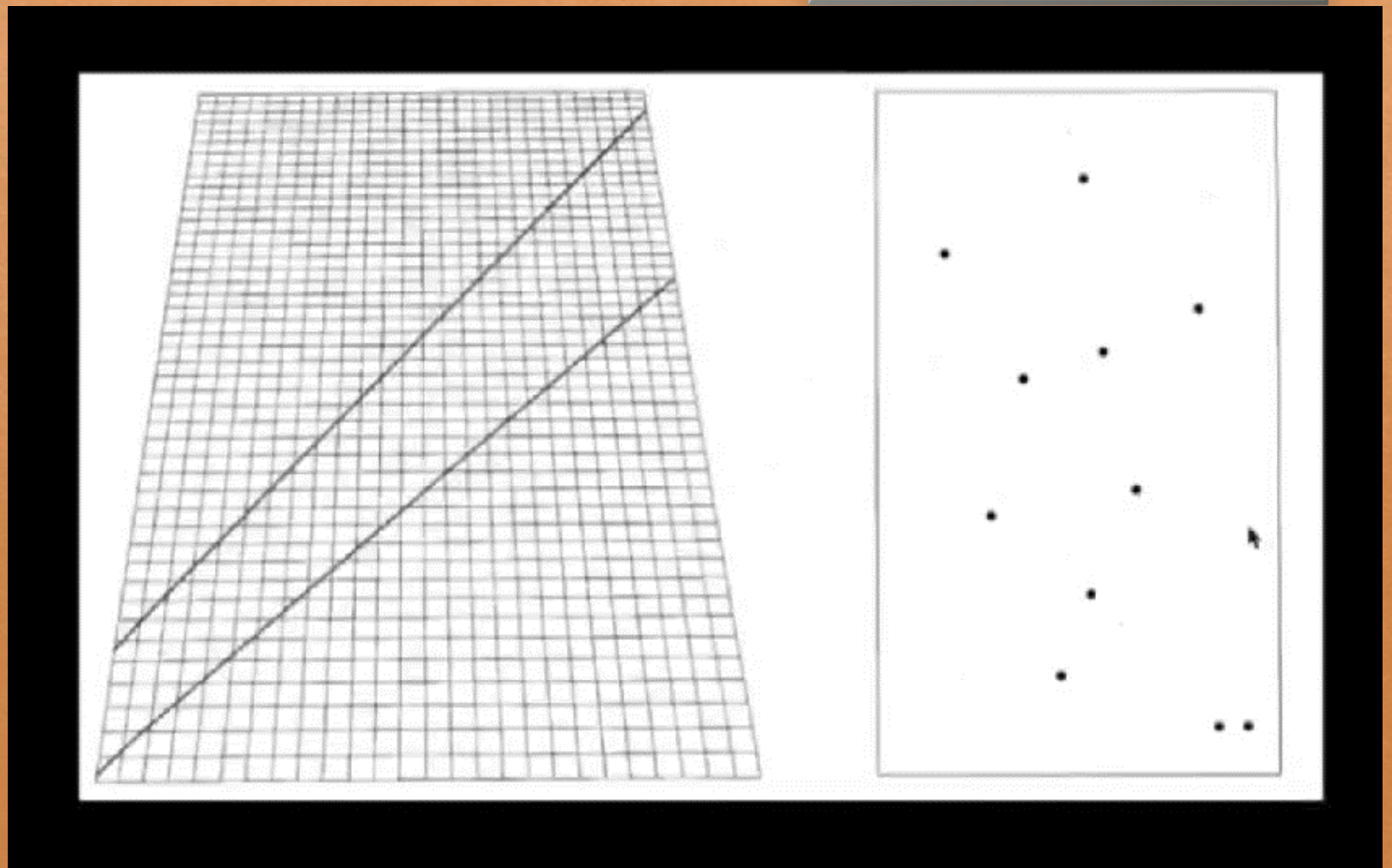


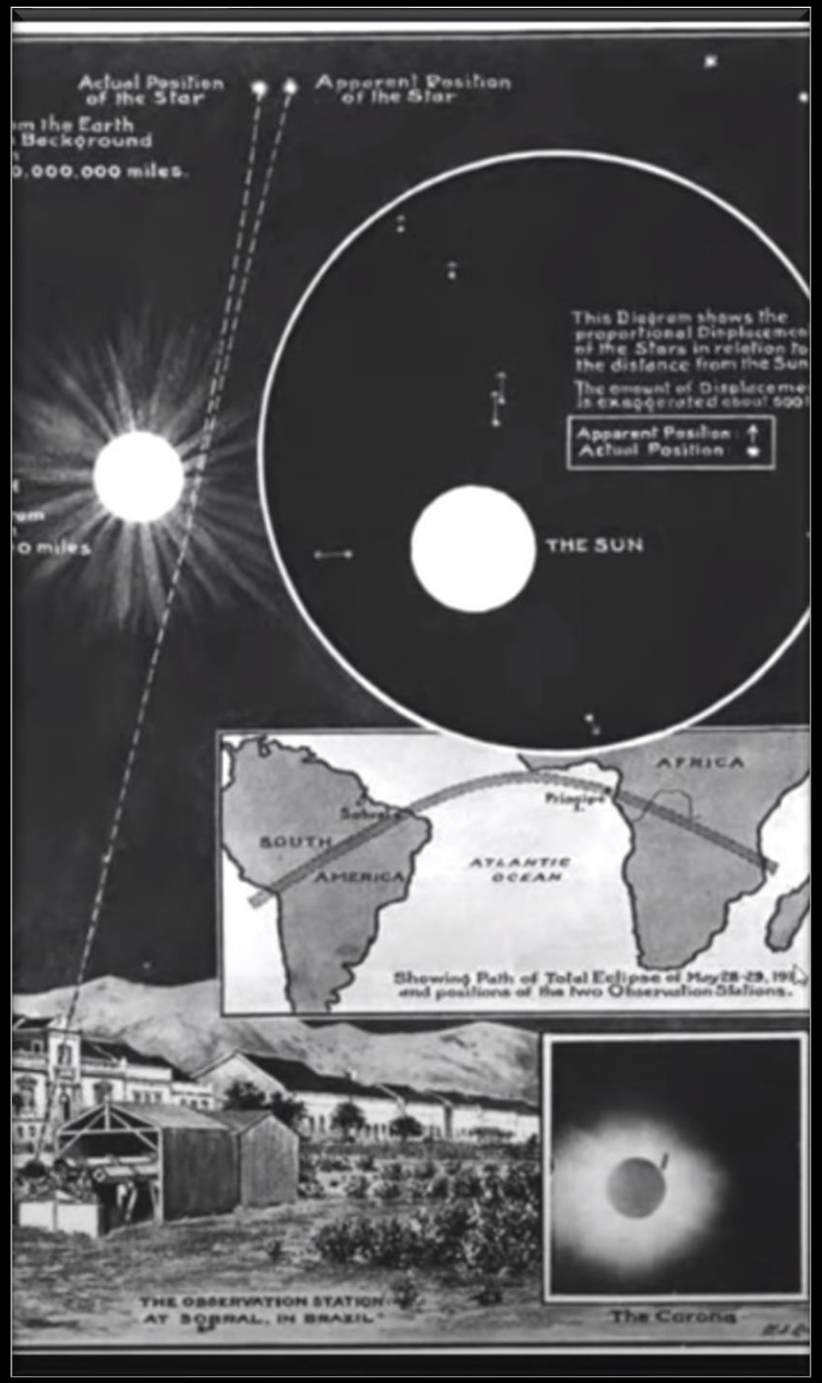
Anche la luce curva



Arthur Eddington guidò una spedizione per fotografare l'ammasso delle Iadi durante l'eclissi solare, il 29 maggio 1919





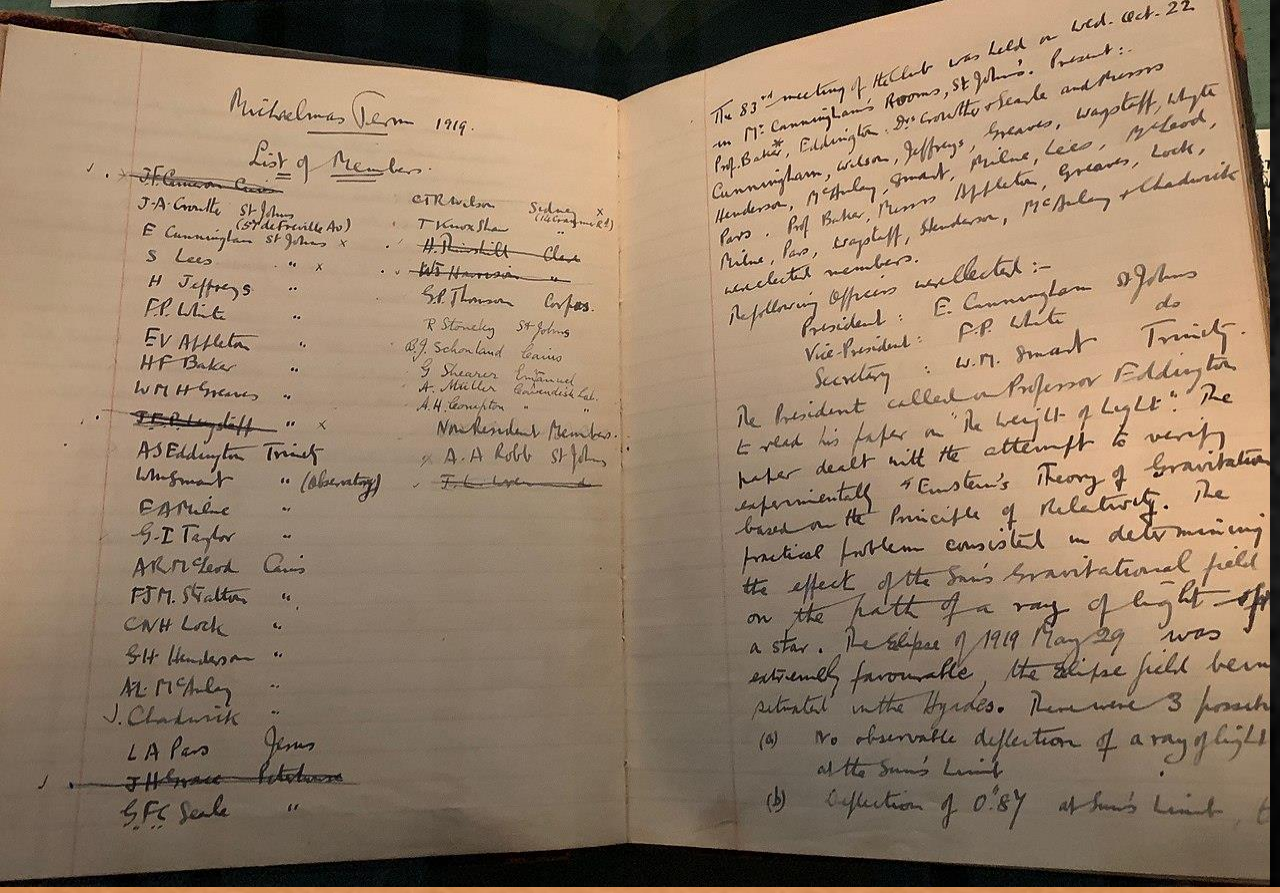




Oh leave the Wise our measures to collate. One thing at least is certain, light has weight. One thing is certain and the rest debate. Light rays, when near the Sun, do not go straight.

Arthur Eddington

Deflessione prevista	Deflessione misurata
Newton	0
Einstein	1.75”
Principe	1.61” ± 0.30
Sobral	1.98” ± 0.12



Michaelmas Term 1919.

List of Members.

J.F. Cameron Lees
J.A. Gaulter St Johns
E Cunningham St Johns (St Catherine's Ad)
S Lees " x
H Jeffreys "
F.P. White "
E.V. Appleton "
H.F. Baker "
W.M.H. Greaves "
F.F. Blagdoff " x
A.S. Eddington Trinity
W. Smart " (Observatory)
E.A. Milne "
G.I. Taylor "
A.R. McLeod Caius
F.J.M. Stratton "
C.N.H. Lock "
S.H. Henderson "
M. McAulay "
J. Chadwick "
L.A. Pars Jesus
J.H. Grace Peterhouse
S.F.C. Searle "

C.T.R. Wilson Sidney (Honorary Member)
T. Kennedy Shaw "
H. Nicholl Clare
W.S. Harrison "
S.P. Thomson Corpus
R. Stoneley St Johns
B.J. Schonland Caius
G. Shearer Emmanuel
A. Muller Emmanuel
A.H. Compton " "

Non-Resident Members.
A.A. Robb St Johns
F.L. Lowe

The 83rd meeting of the Club was held on Wed. Oct. 22 in Mr Cunningham's Rooms, St John's. Present: Prof. Baker, Eddington, Dr Gaulter, Searle and Messrs Cunningham, Wilson, Jeffreys, Greaves, Wagstaff, Blythe, Henderson, McAulay, Smart, Milne, Lees, McLeod, Pars. Prof. Baker, Messrs Appleton, Greaves, Lock, Milne, Pars, Wagstaff, Henderson, McAulay & Chadwick were elected members.

The following Officers were elected:-
President: E. Cunningham St John's
Vice-President: F.P. White do
Secretary: W.M. Smart Trinity.

The President called on Professor Eddington to read his paper on "The Weight of Light". The paper dealt with the attempt to verify experimentally Einstein's Theory of Gravitation based on the Principle of Relativity. The practical problem consisted in determining the effect of the Sun's gravitational field on the path of a ray of light from a star. The Eclipse of 1919 May 29 was extremely favourable, the Eclipse field being situated in the Hyades. There were 3 possible
(a) No observable deflection of a ray of light at the Sun's Limit
(b) Deflection of 0".87 at Sun's Limit



l verbale del Cambridge Club per l'incontro in cui Eddington presentò le sue osservazioni

Conferma sperimentale

Age of the Universe:

COSMIC TIMES

1919

Size of the Universe:
300,000 Light Years

SUN'S GRAVITY BENDS STARLIGHT

Einstein's Theory Triumphs



MT. WILSON ASTRONOMER ESTIMATES MILKY WAY TEN TIMES BIGGER THAN THOUGHT

But Disputes Suggestions that Spiral Nebulae are Other "Island Universes"

EXPANDING OR CONTRACTING?

Einstein's Theory Predicts Universe Must be Doing One or the Other

Einstein Says Neither

In Their Own Words

Periods of 25 Variable Stars in the Small Magellanic Cloud – Miss Henrietta Leavitt

The Relation of the System of Stars to the Spiral Nebulae – G. F. Paddock

THE TIMES, FRIDAY, NOVEMBER 7, 1919.

COAL OUTPUT AND PRICE.

MINERS TO MEET MINISTERS.

SCOPE OF THE INQUIRY.

(From Our Parliamentary Correspondent.)

There was an important development in the ived coal controversy last night.

The miners' leaders accepted an invitation a conference with the Prime Minister, Mr. onar Law, and Sir Auckland Geddes next nday to settle the terms of reference of a mmittee of Inquiry which the Government romised some time ago. The original inten- on was that the Committee should confine s inquiry, which was to be held in public, o the reasons for the declining output of coal. That was not nearly a wide enough field for the miners' leaders, who have consistently de- manded that the Committee should have power to investigate the question of prices, and more particularly the 6s. a ton increase which was put on in the summer.

The Government were greatly impressed by the debate which the Labour Party raised in the House of Commons last Tuesday, ostensibly on the appointment of Mr. A. R. Duncan as Coal Controller. The discussion roamed over every aspect of the coal controversy, and Mr. Brace, on the miners' behalf, demanded the immediate appointment of a Select Committee to investigate and report upon the following matters:—

1. The suitability or otherwise of Mr. Duncan as

REVOLUTION IN SCIENCE.

NEW THEORY OF THE UNIVERSE.

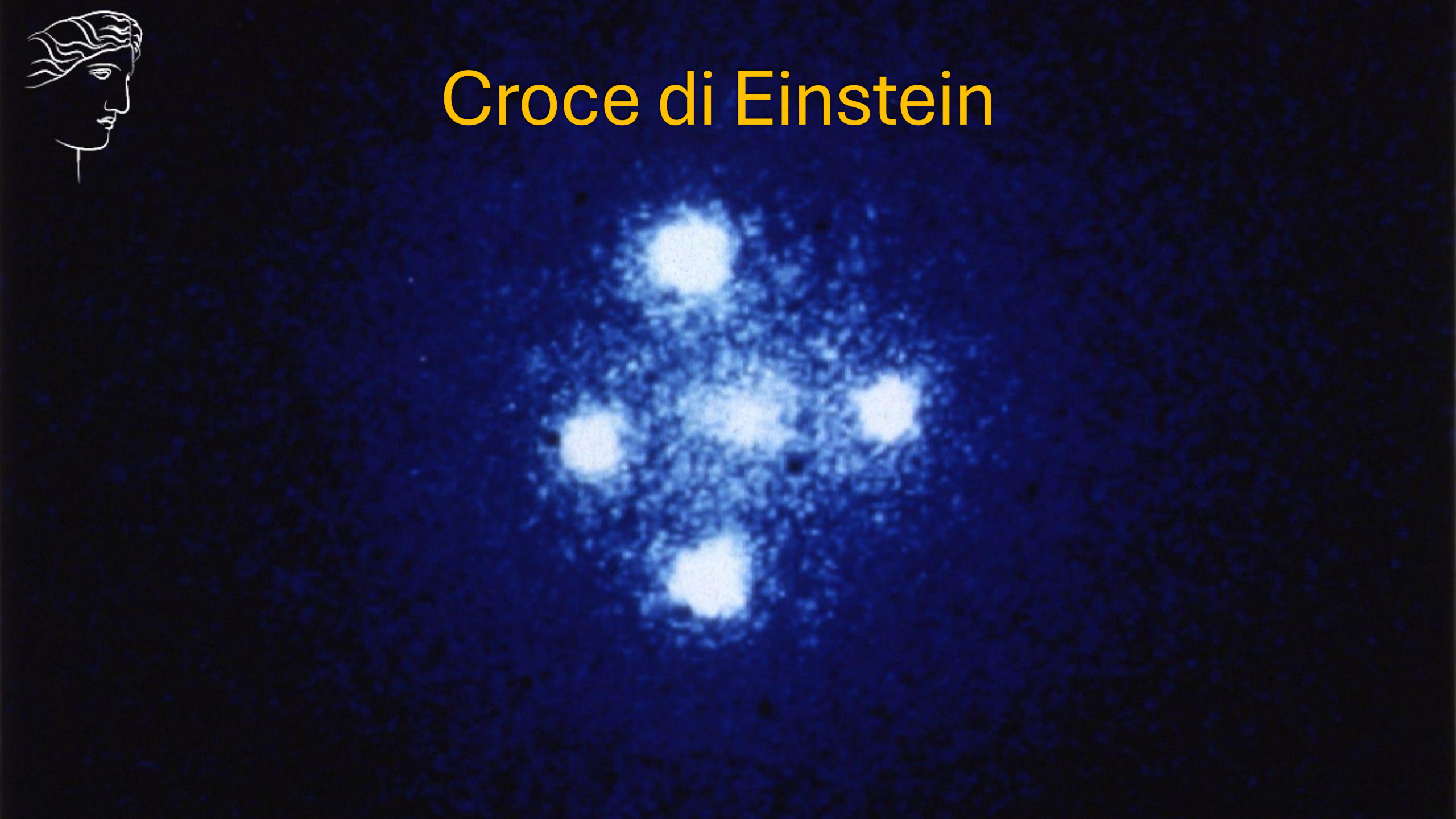
NEWTONIAN IDEAS OVERTHROWN.

Yesterday afternoon in the rooms of the Royal Society, at a joint session of the Royal and Astronomical Societies, the results ob- tained by British observers of the total solar eclipse of May 29 were discussed.

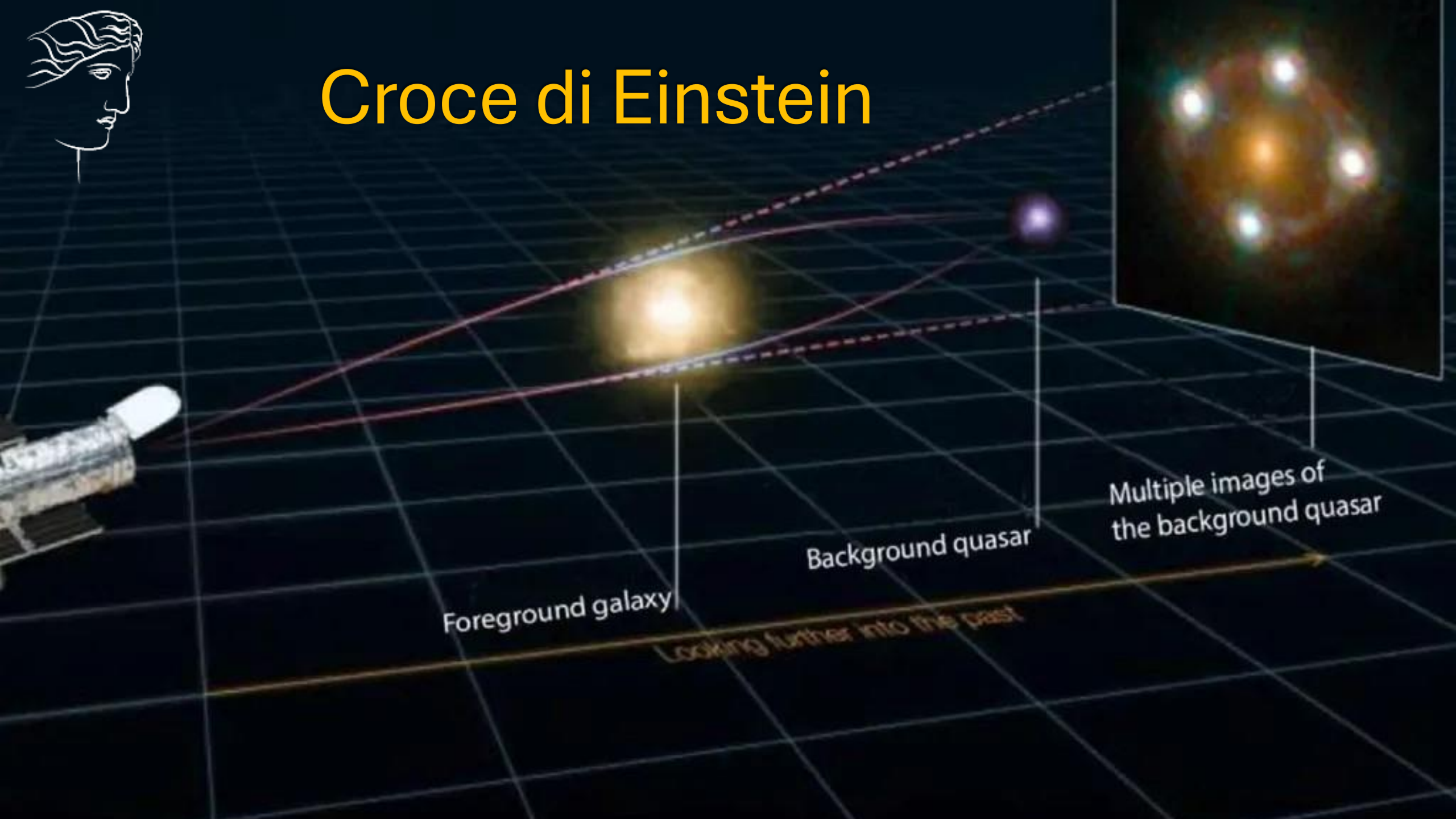
The greatest possible interest had been aroused in scientific circles by the hope that rival theories of a fundamental physical problem would be put to the test, and there was a very large attendance of astronomers and physicists. It was generally accepted that the observations were decisive in the verifying of the prediction of the famous physicist, Einstein, stated by the President of the Royal Society as being the most remarkable scientific event since the discovery of the predicted existence of the planet Neptune. But there was differ- ence of opinion as to whether science had to face merely a new and unexplained fact, or to reckon with a theory that would completely revolutionize the accepted fundamentals of physics.

Sir Frank Dyson, the Astronomer Royal, described the work of the expeditions sent respectively to Sobral in North Brazil and the island of Principe, off the West Coast of Africa. At each of these places, if the weather were propitious on the day of the eclipse, it would be possible to take during

Croce di Einstein



Croce di Einstein

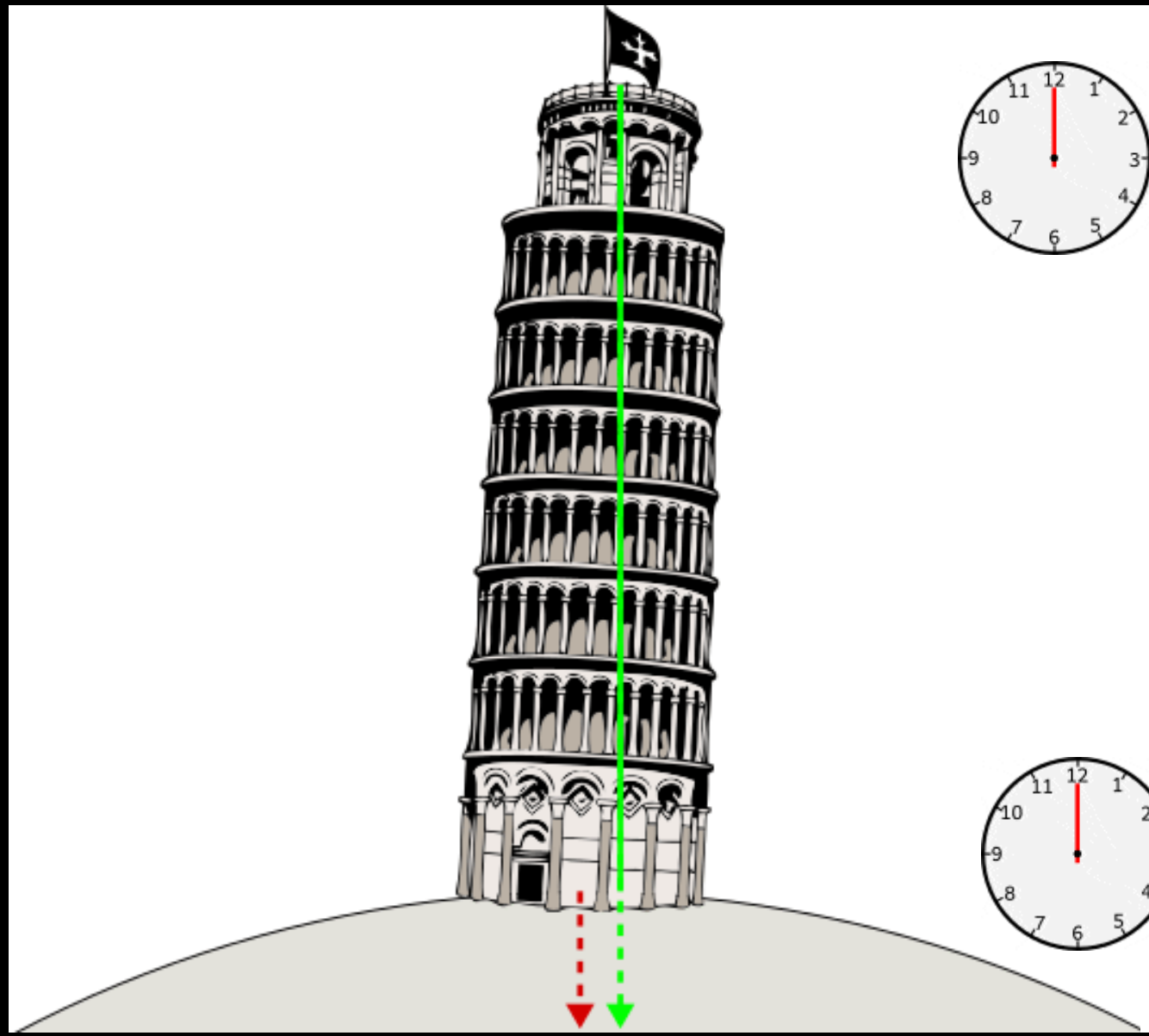


Anello di Einstein



Dilatazione gravitazionale del tempo





Il tempo scorre più lentamente dove la curvatura è maggiore

Correzione relativistica del GPS

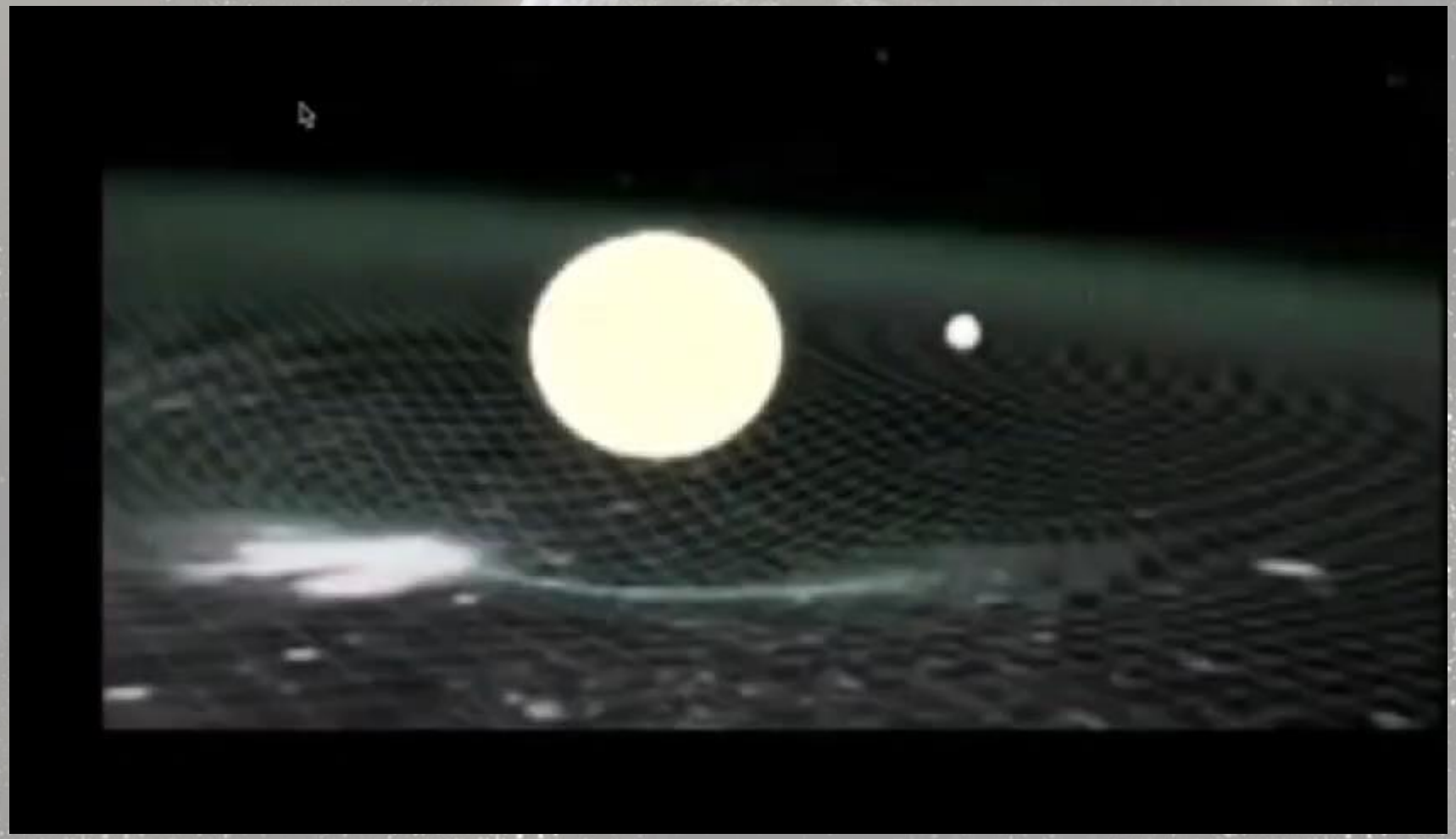


$$\gamma_{speed} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

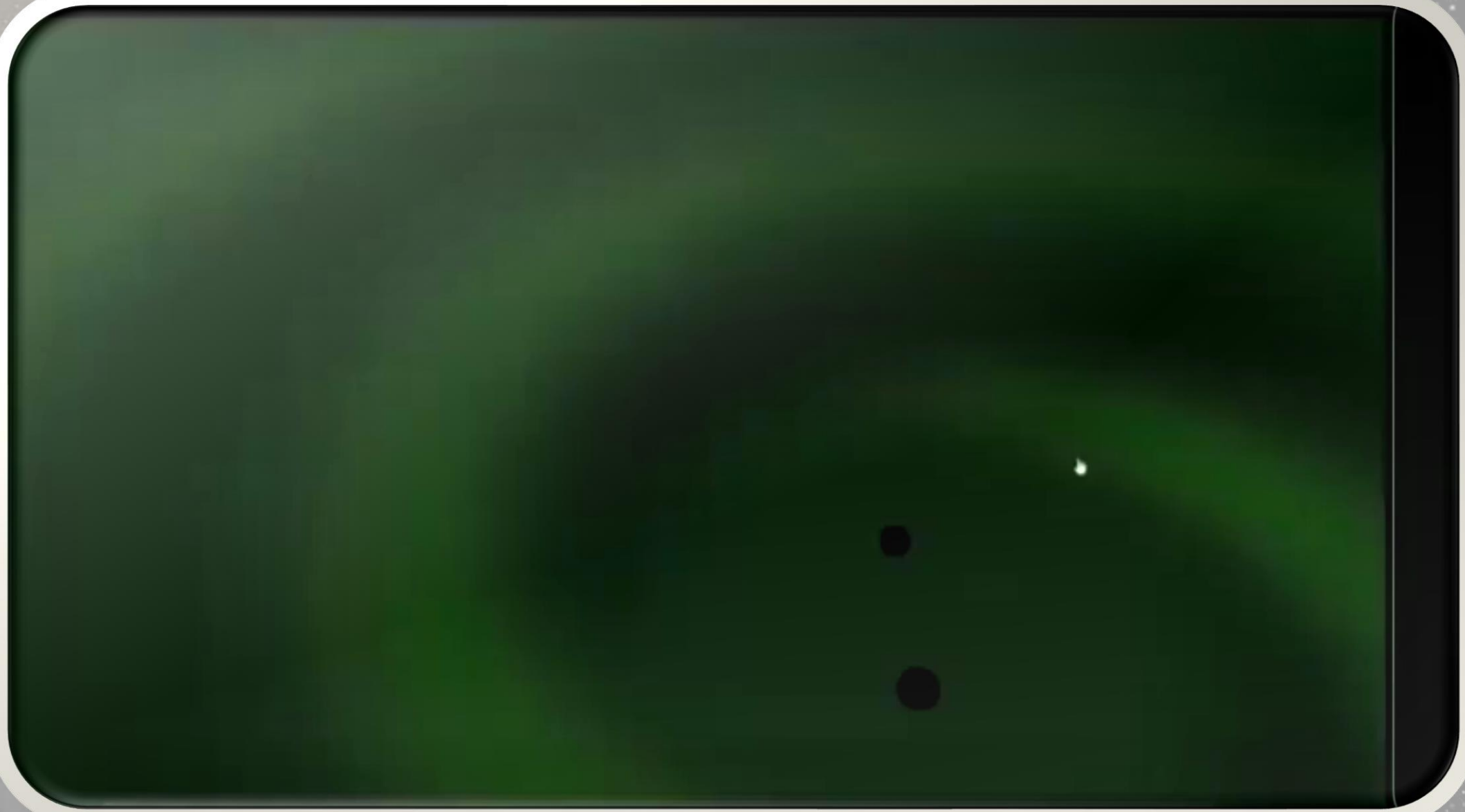
$$\gamma_{gravity} = \frac{1}{\sqrt{1 - \frac{2GM_T}{c^2 r}}}$$

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

Onde gravitazionali



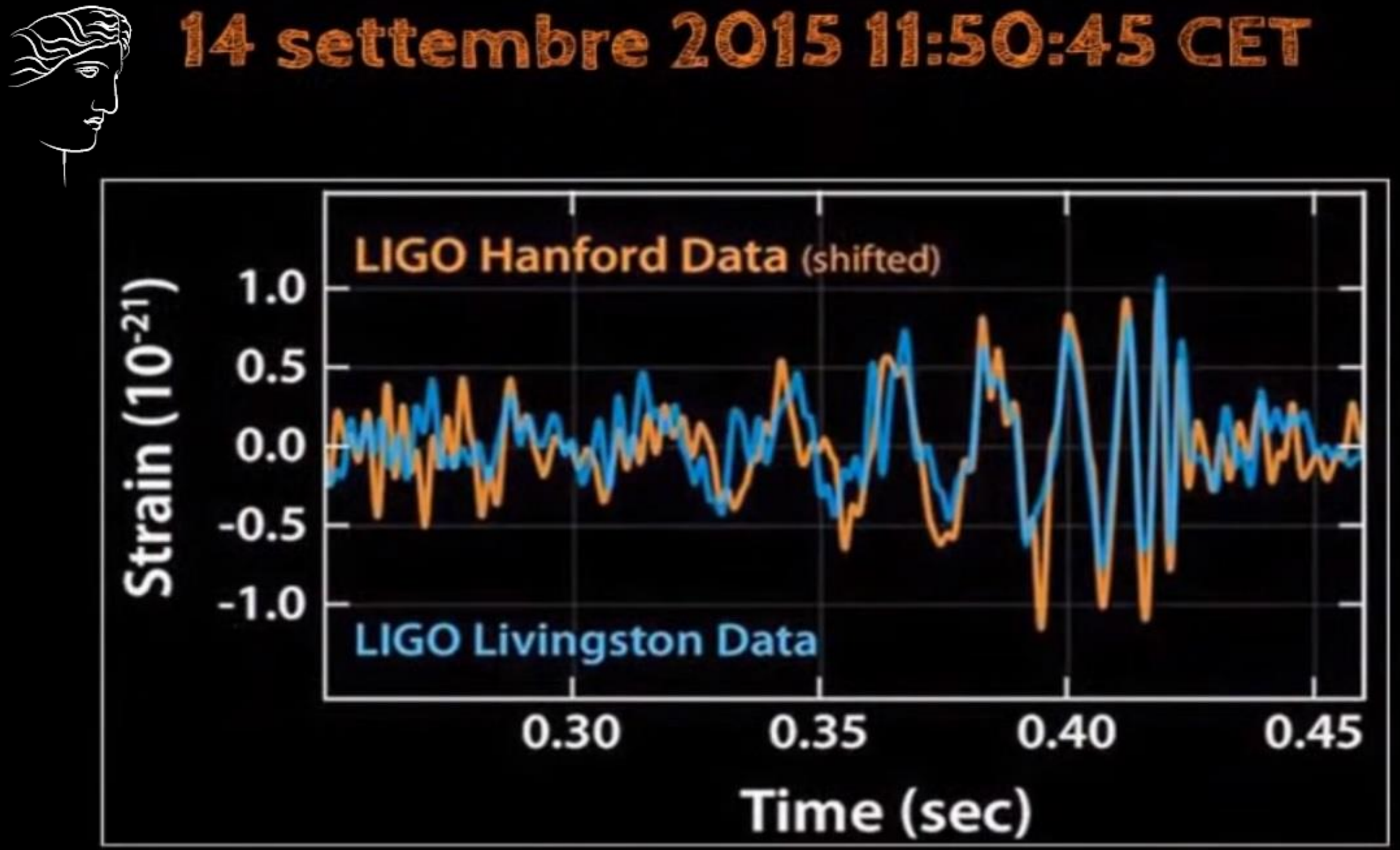
Onde Gravitazionali



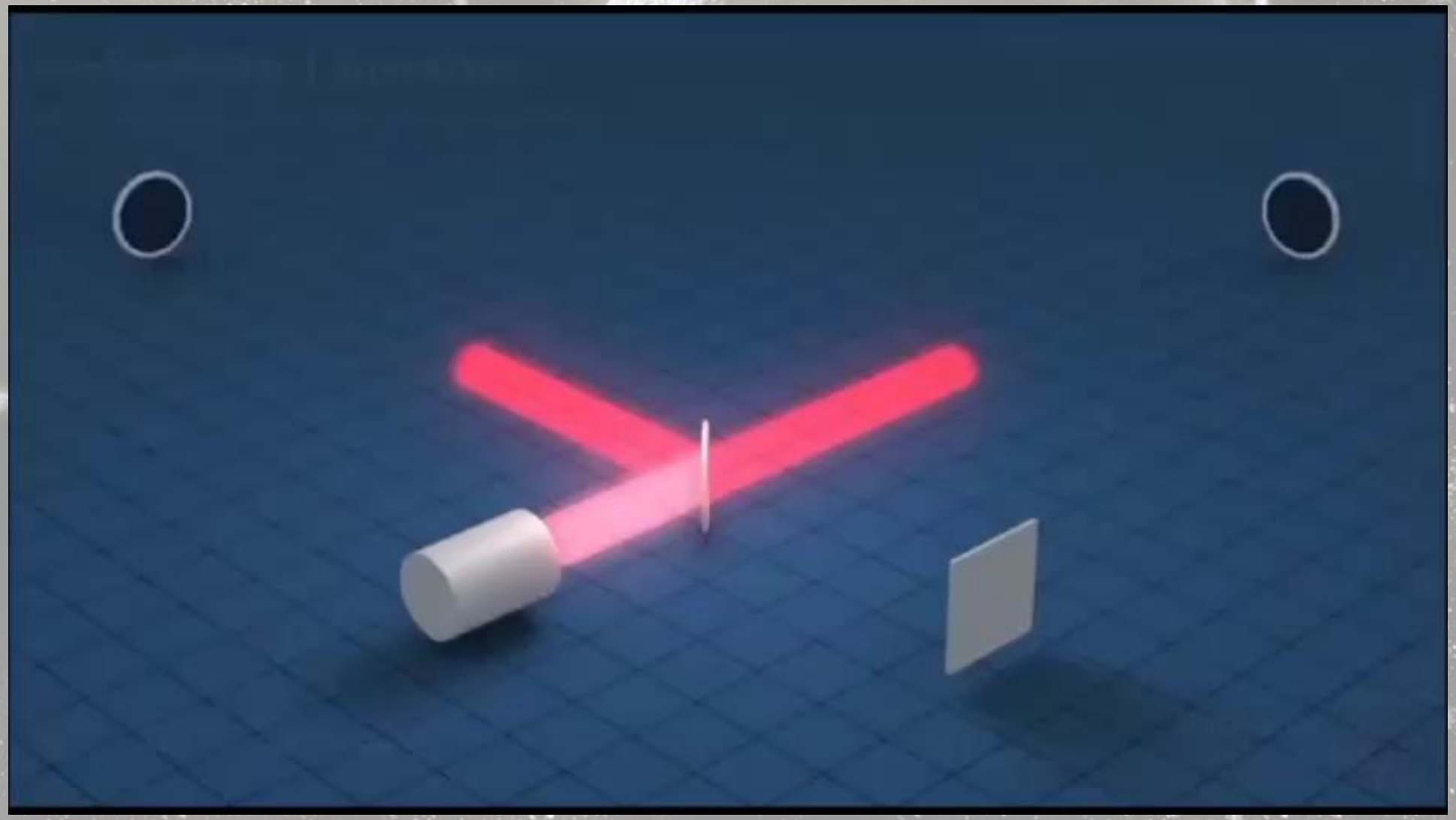


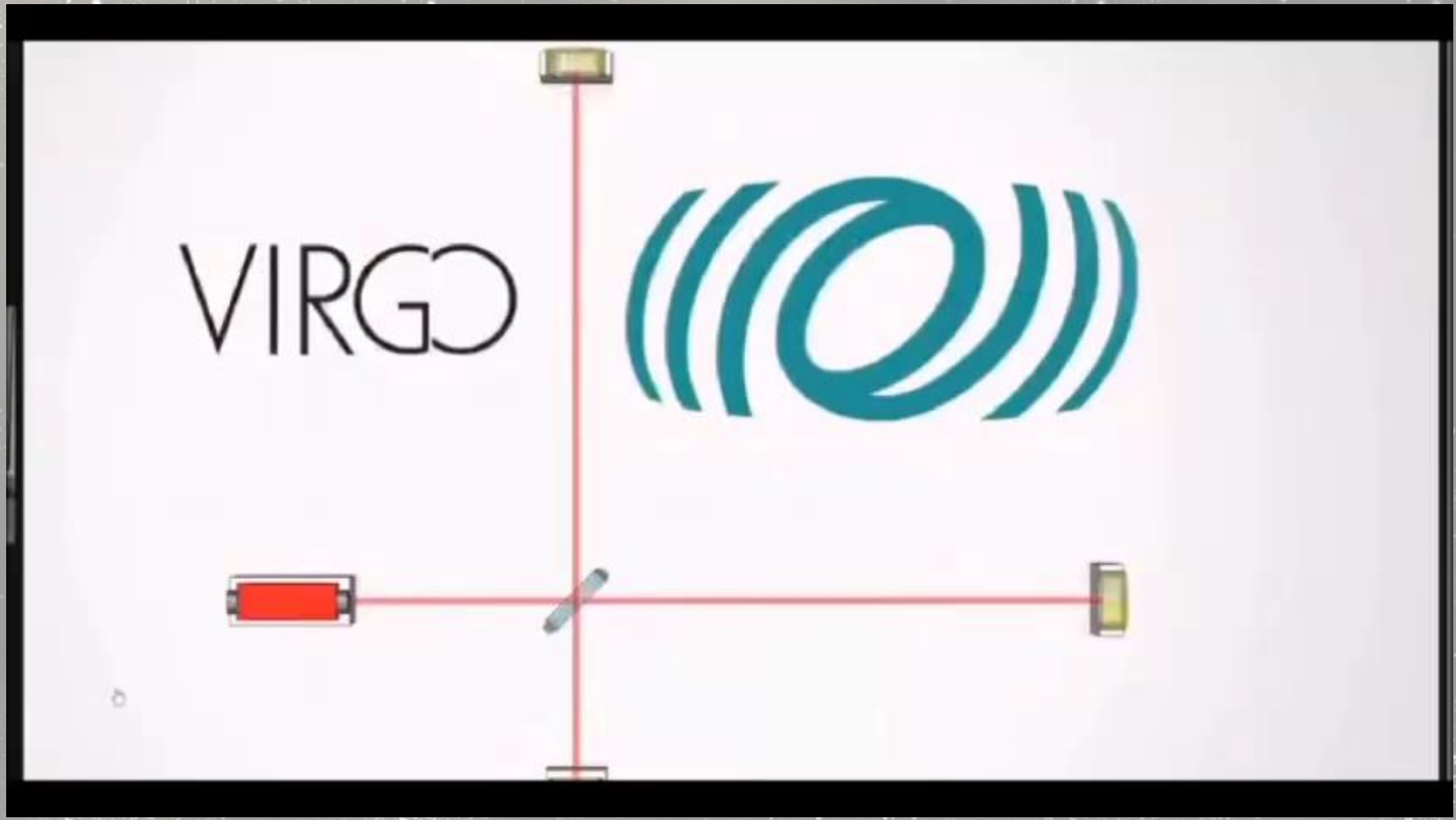
A caccia delle onde gravitazionali

Presso i laboratori di Frascati è stato in funzione dal 1995 al 2017 NAUTILUS, un rivelatore di onde gravitazionali costituito da una barra risonante di 2.3 ton di massa posta a una temperatura di soli 0.13 gradi al di sopra dello zero assoluto.


14 settembre 2015 11:50:45 CET
LIGO Hanford Data (shifted)
LIGO Livingston Data
Strain (10^{-21})
1.0
0.5
0.0
-0.5
-1.0
0.30
0.35
0.40
0.45
Time (sec)

Interferometro




VIRGO





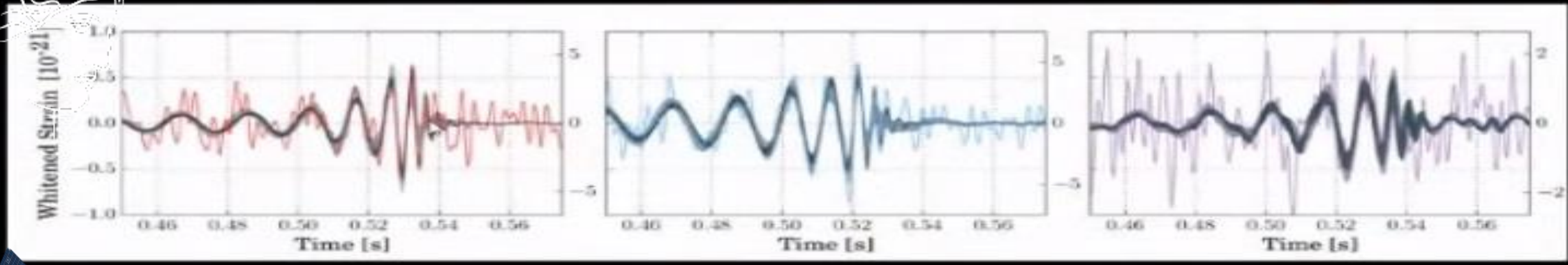






Stelle di neutroni

Hanford Livingstone Virgo



17 agosto 2017 13:41:06 CET







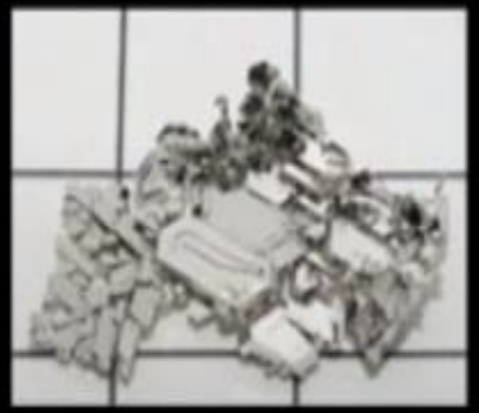
Cosa abbiamo capito:

(i) Dallo studio della successiva emissione UV, visibile e IR

→ le fusioni di stelle di neutroni sono le fabbriche degli elementi pesanti presenti nell'Universo

Iridio
Z= 77, A= 192





Platino
Z= 78, A= 195

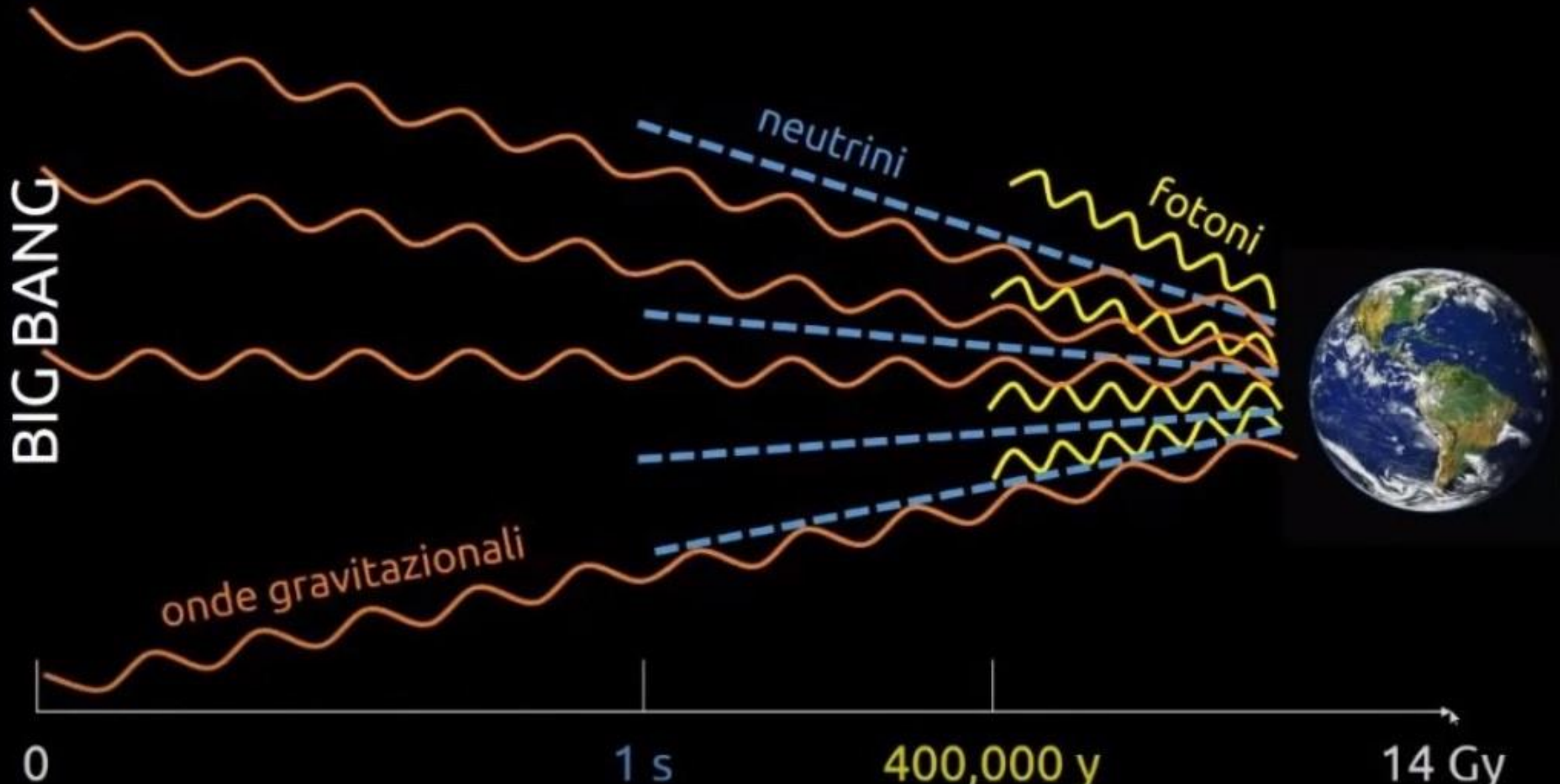


Piombo
Z= 82, A= 207

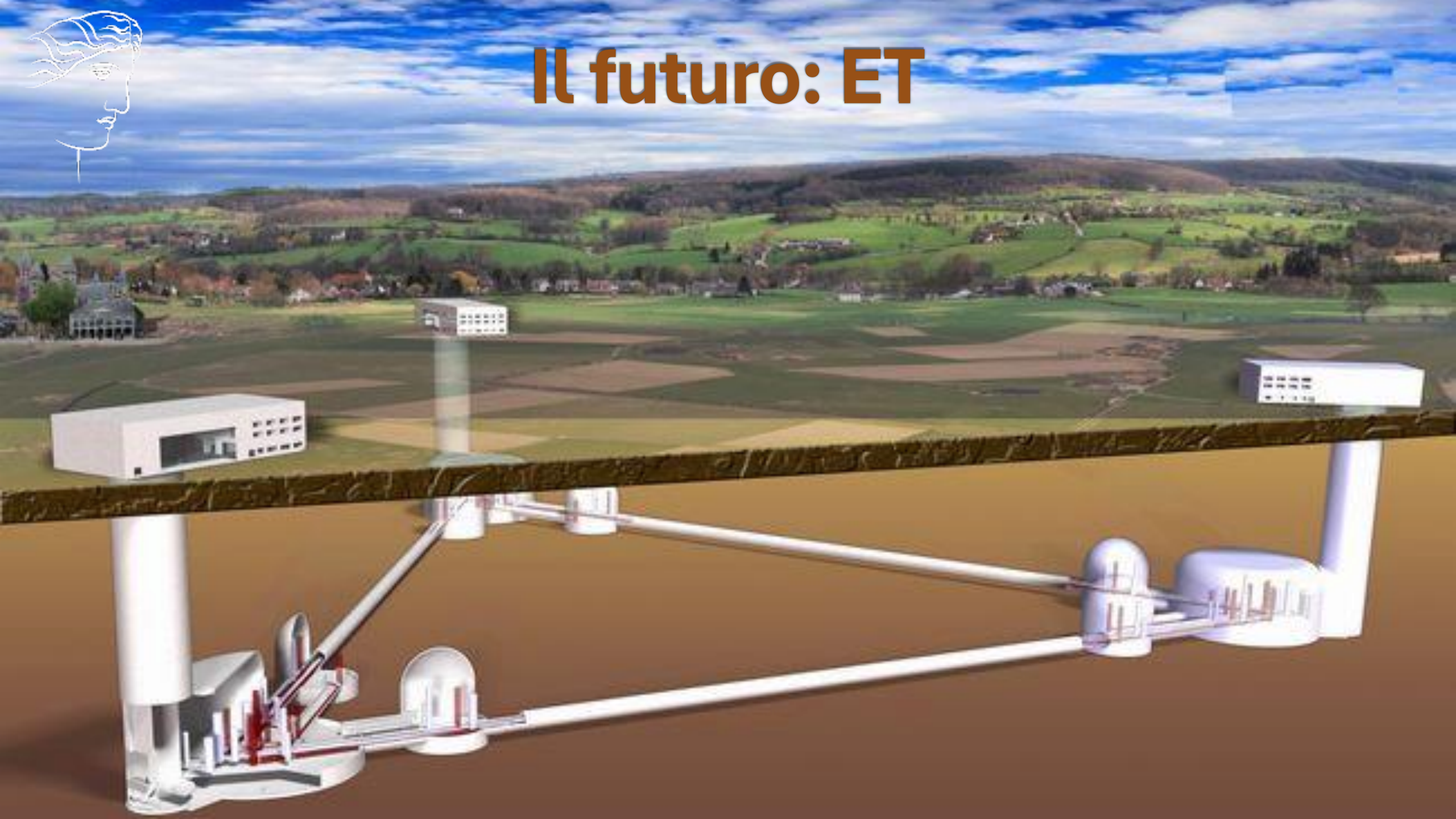
Oro
Z= 79, A= 197

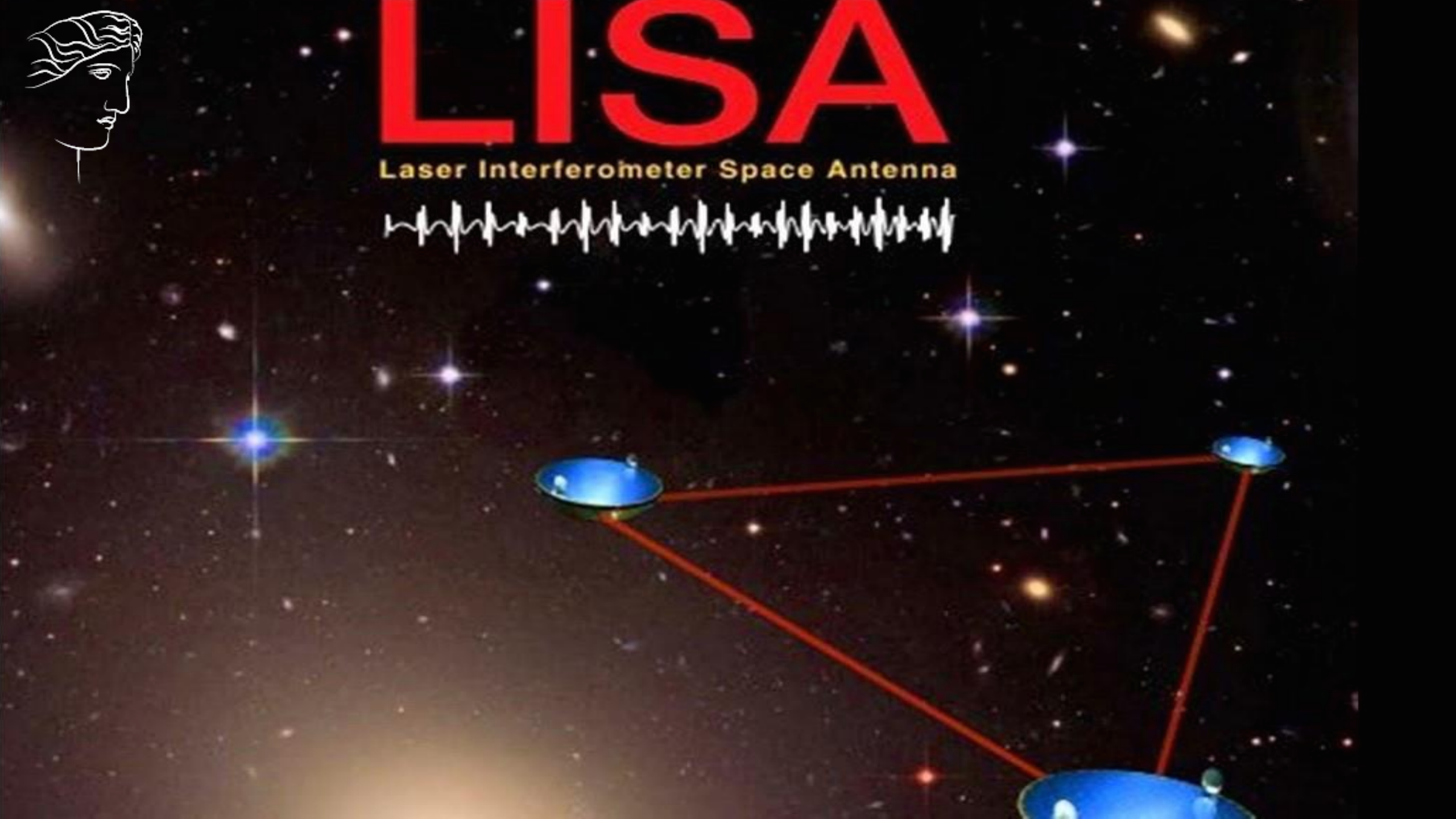


Astronomia multi messaggera



Il futuro: ET




LISA
Laser Interferometer Space Antenna