

IL MESE DELLO SPAZIO 2016
Cento anni di relatività generale

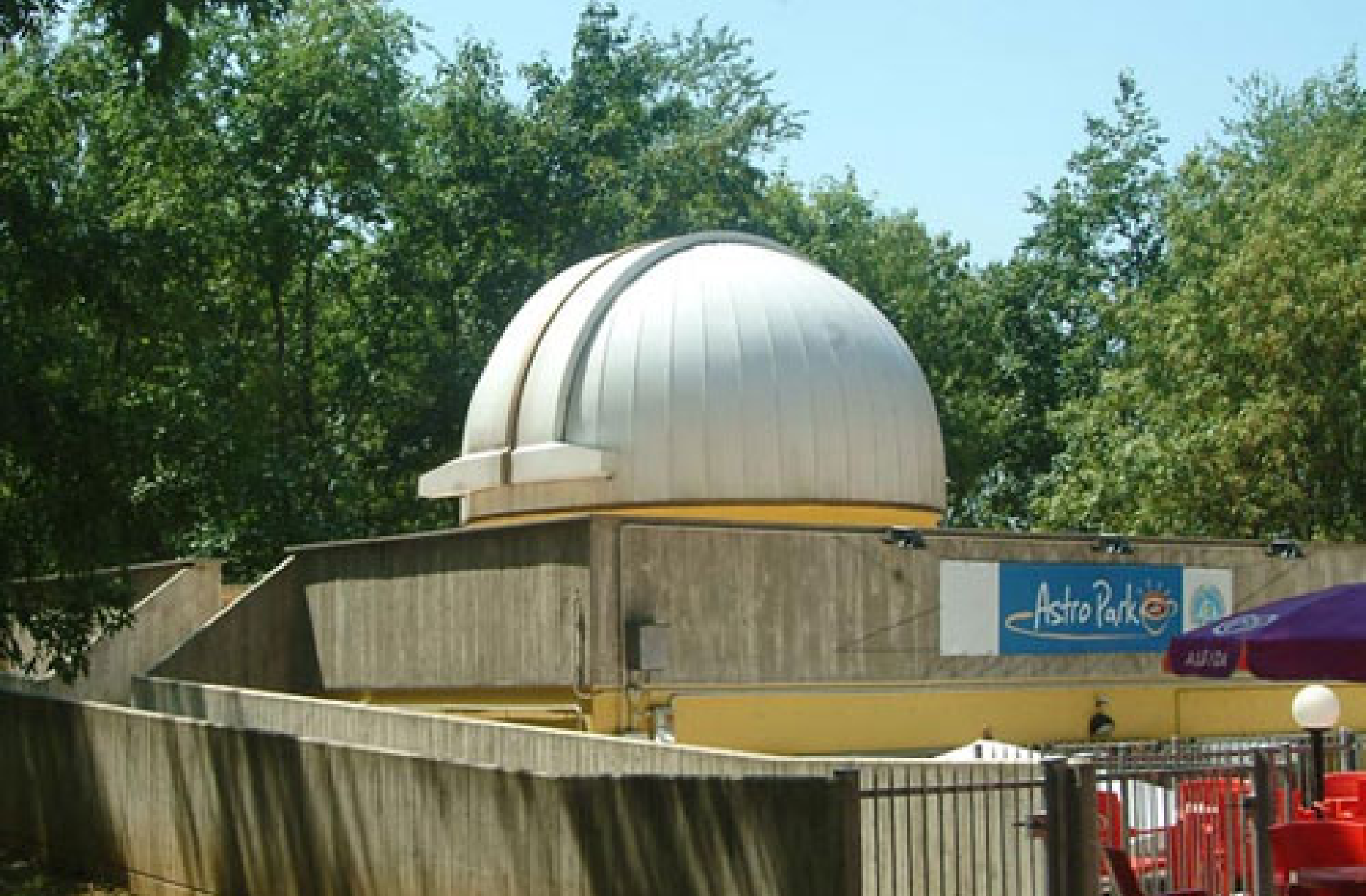
CURVARE LO SPAZIO

Andrea Grieco

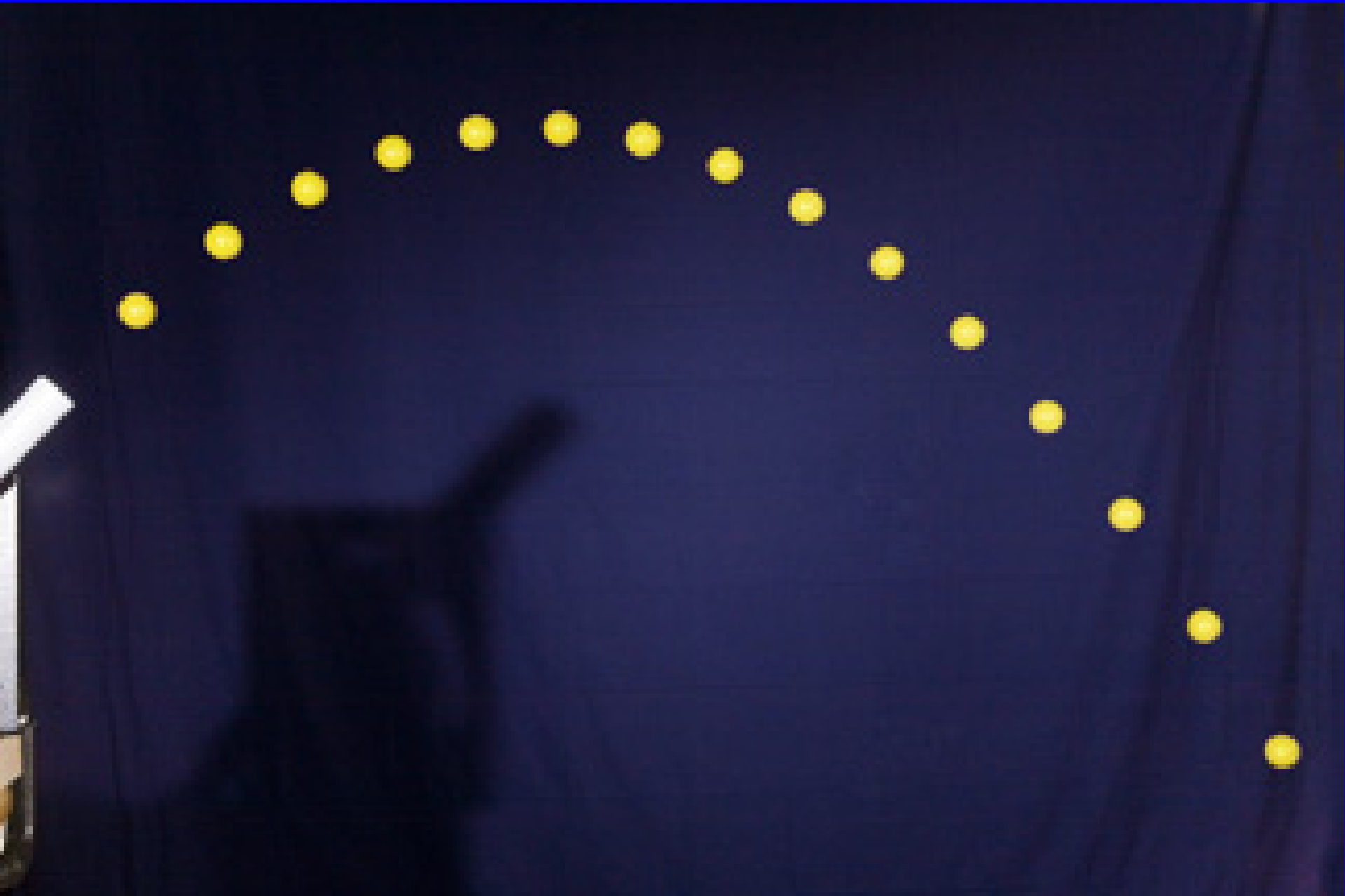


Cernusco sul Naviglio 10 novembre 2016

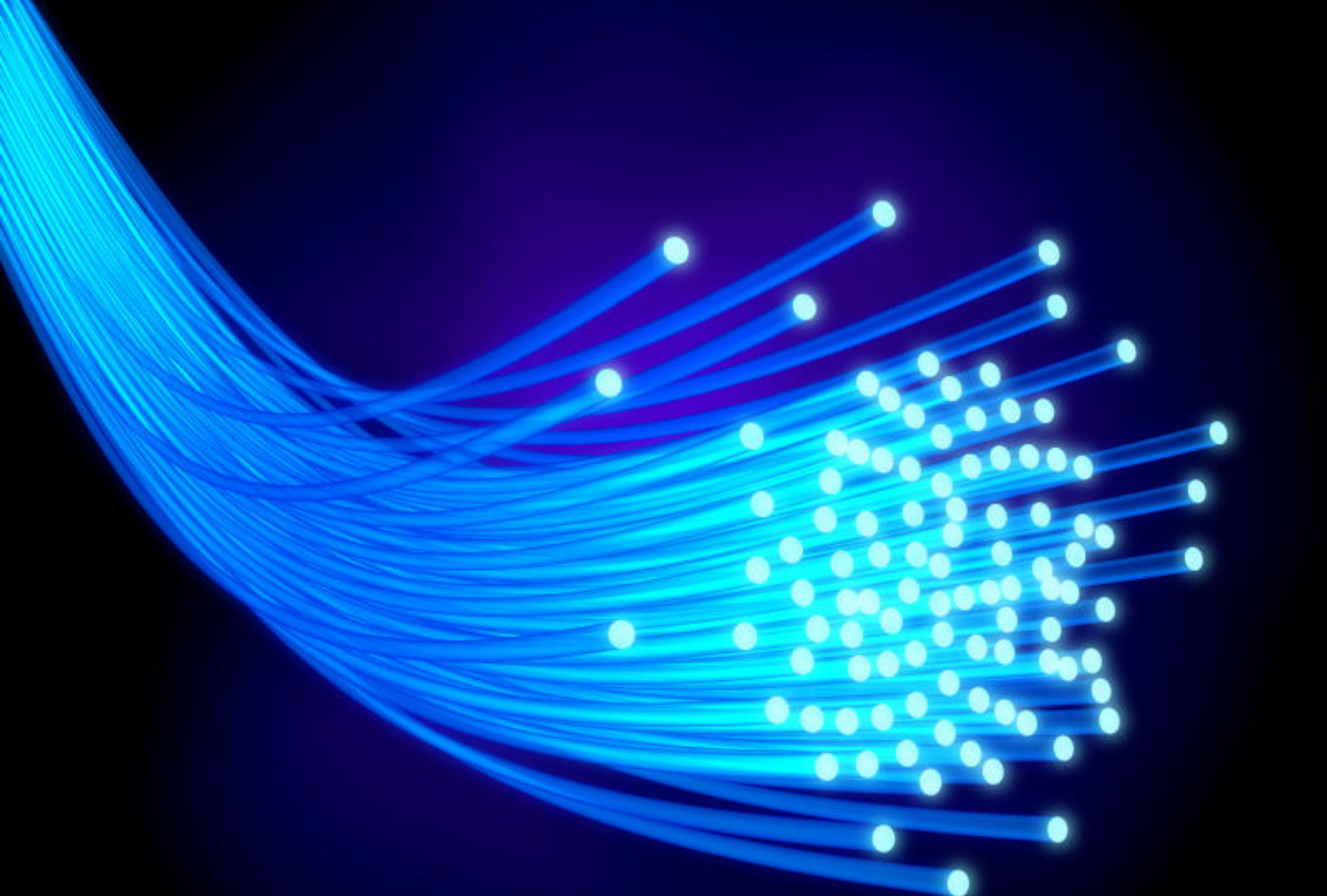




SUPERFICI CURVE E SUPERFICI PIANE



TRAIETTORIA CURVA



LUCE CHE "CURVA" IN UNA FIBRA OTTICA



**COSA SIGNIFICA
"CURVARE LO SPAZIO"?**



100 ANNI



**EINSTEIN CON
MILEVA MARIĆ**

1916.

Nº. 7.

ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

1. *Die Grundlage
der allgemeinen Relativitätstheorie;
von A. Einstein.*

Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als „Relativitätstheorie“ bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren „spezielle Relativitätstheorie“ und setze sie als bekannt voraus. Die Verallgemeinerung der Relativitätstheorie wurde sehr erleichtert durch die Gestalt, welche der speziellen Relativitätstheorie durch Minkowski gegeben wurde, welcher Mathematiker zuerst die formale Gleichwertigkeit der räumlichen

**L'ARTICOLO DEL 1916 SULLA
RELATIVITA' GENERALE**



"L'IDEA PIU' FELICE"

"Stavo seduto in una poltrona nell'Ufficio Brevetti di Berna, quando all'improvviso mi ritrovai a pensare: se una persona cade liberamente, non avverte il proprio peso. Rimasi stupefatto. Questo pensiero così semplice mi colpì profondamente e ne venni sospinto verso una teoria della gravitazione" A. Einstein

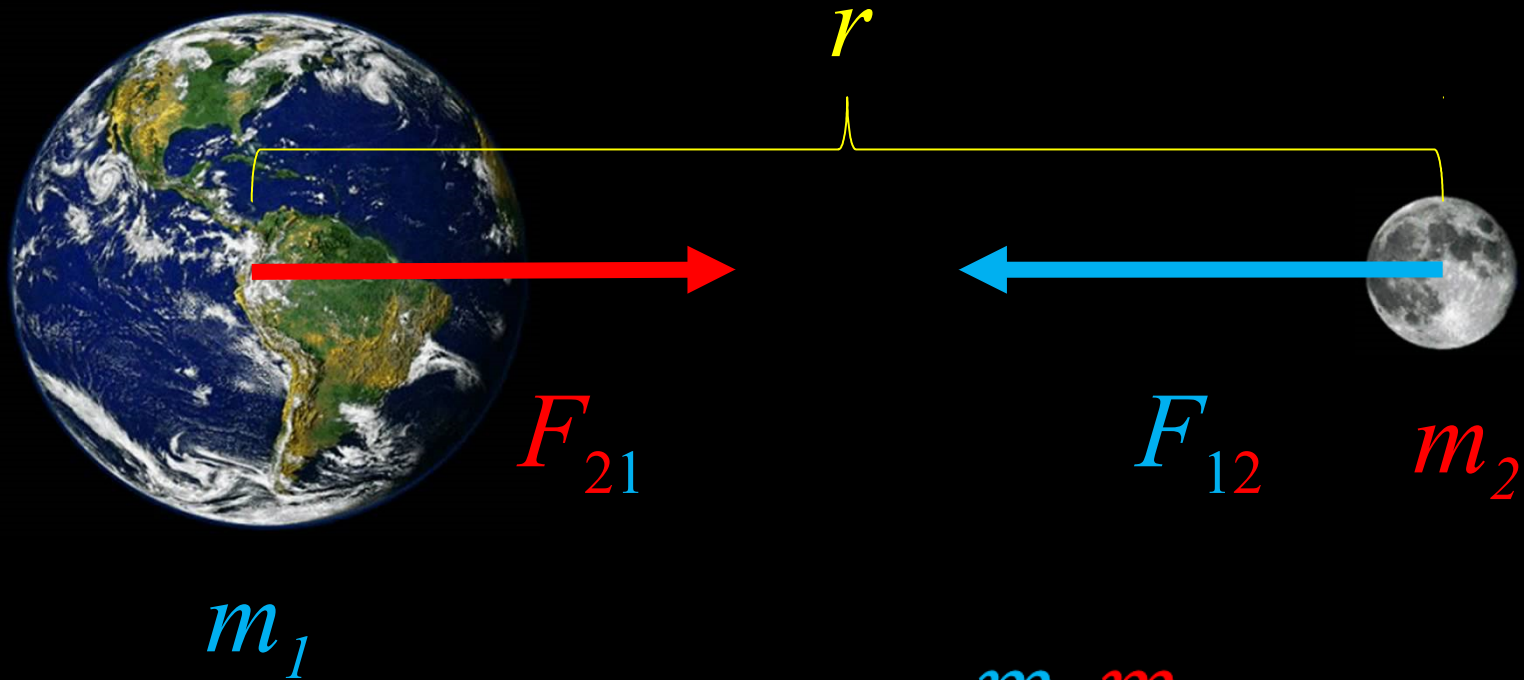




LA MELA



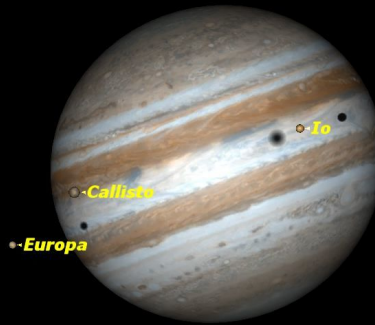
ATTRAZIONE



$$F_{21} = F_{12} = G \frac{m_1 m_2}{r^2}$$



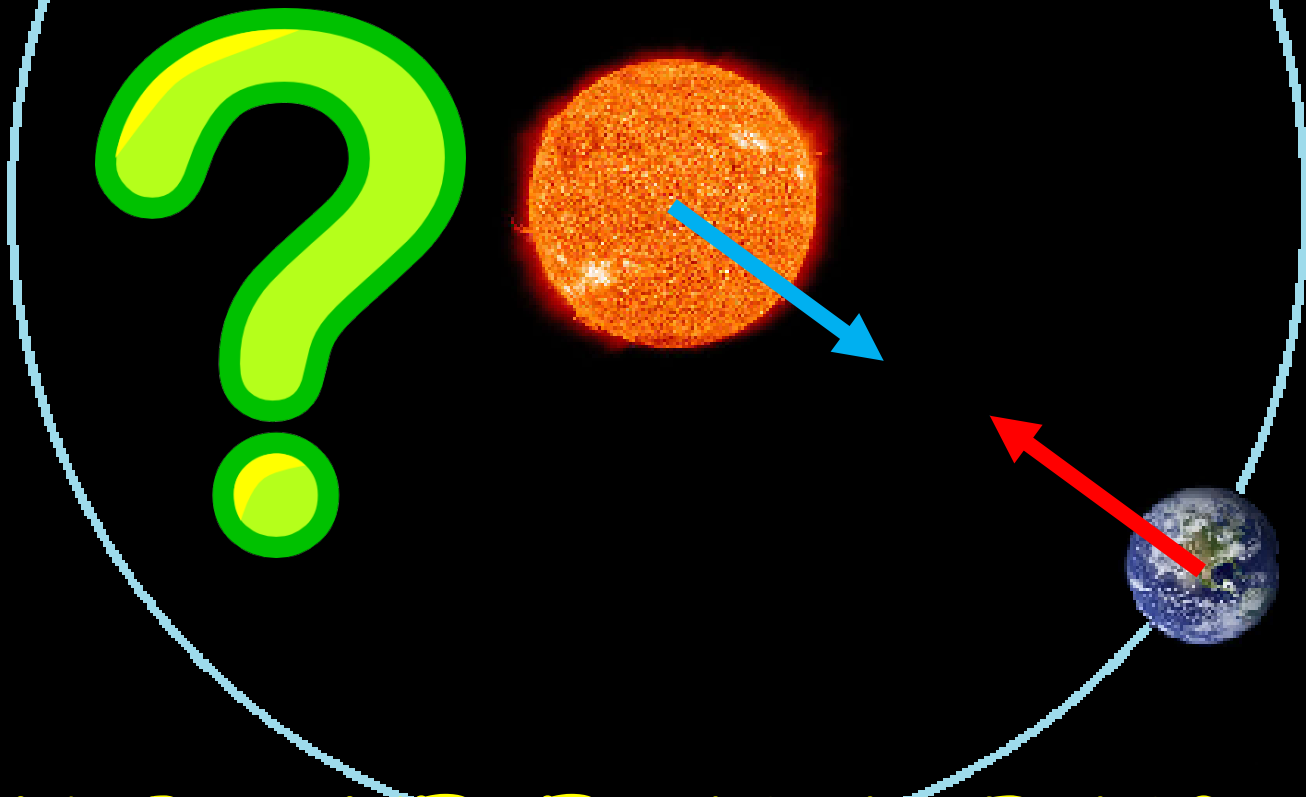
TANTI SUCCESSI





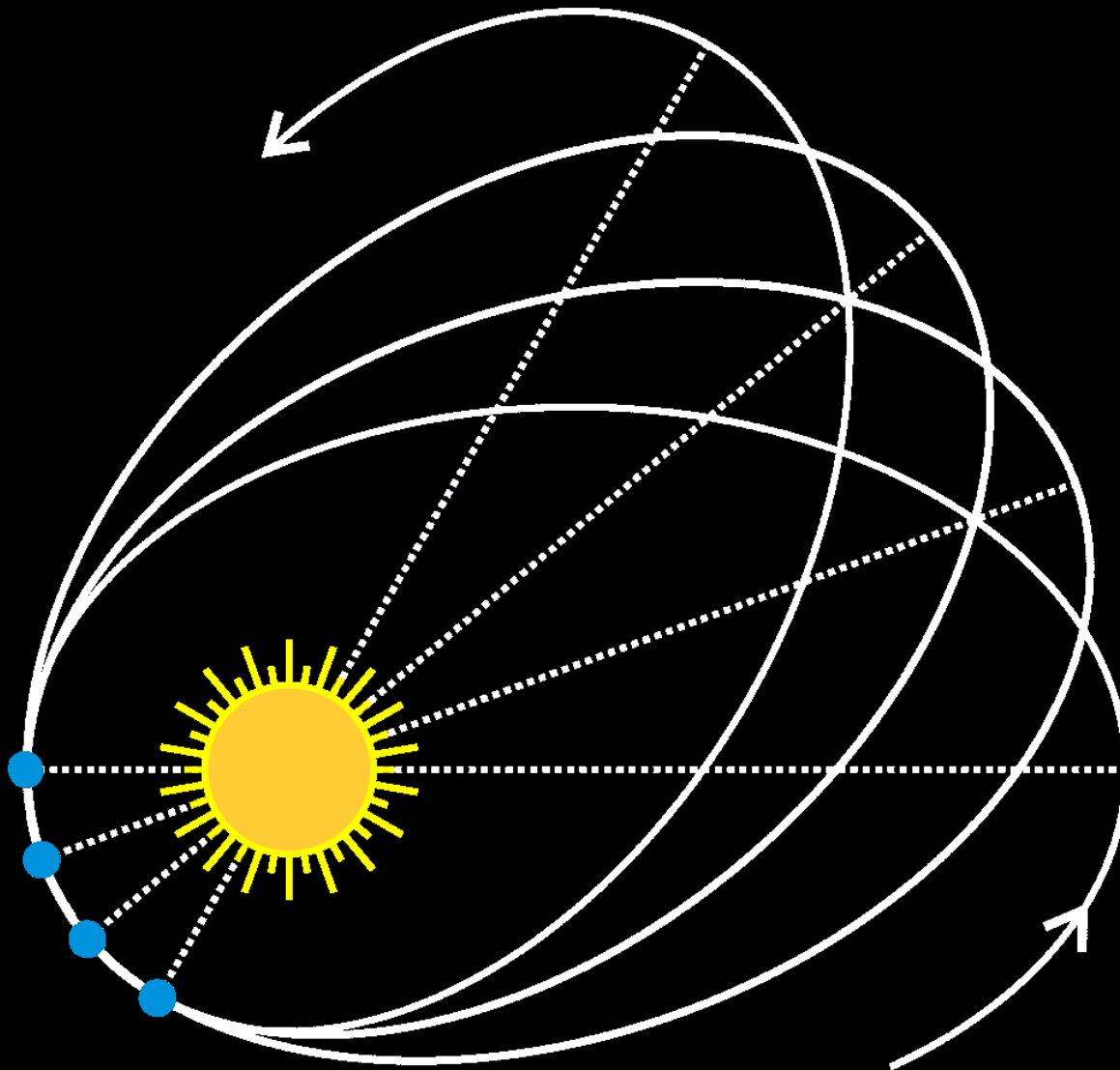
QUALCHE DUBBIO

AZIONE ISTANTANEA A DISTANZA



"HYPOTHESES NON FINGO"

E QUALCHE PROBLEMA



PRECESSIONE DEL
PERIELIO VALORI
IN "/SECOLO

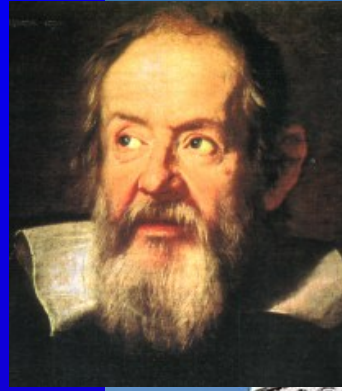
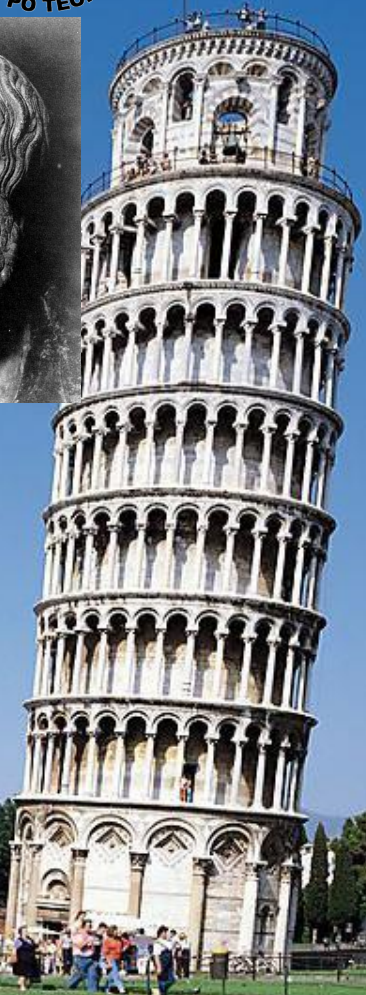
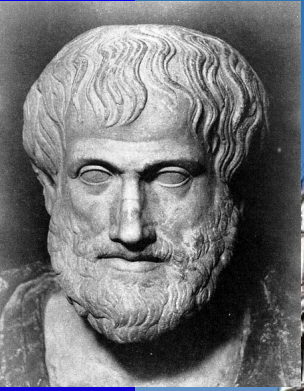
OSS. $\alpha = 574$

TEOR. $\alpha' = 531$

DIFF. $\Delta\alpha = 43$



GIU' DALLA TORRE



ARISTOTELE

GALILEO



MARTELLLO E PIUMA

Apollo 15

Hammer and Feather



ANNULLARE LA GRAVITA'



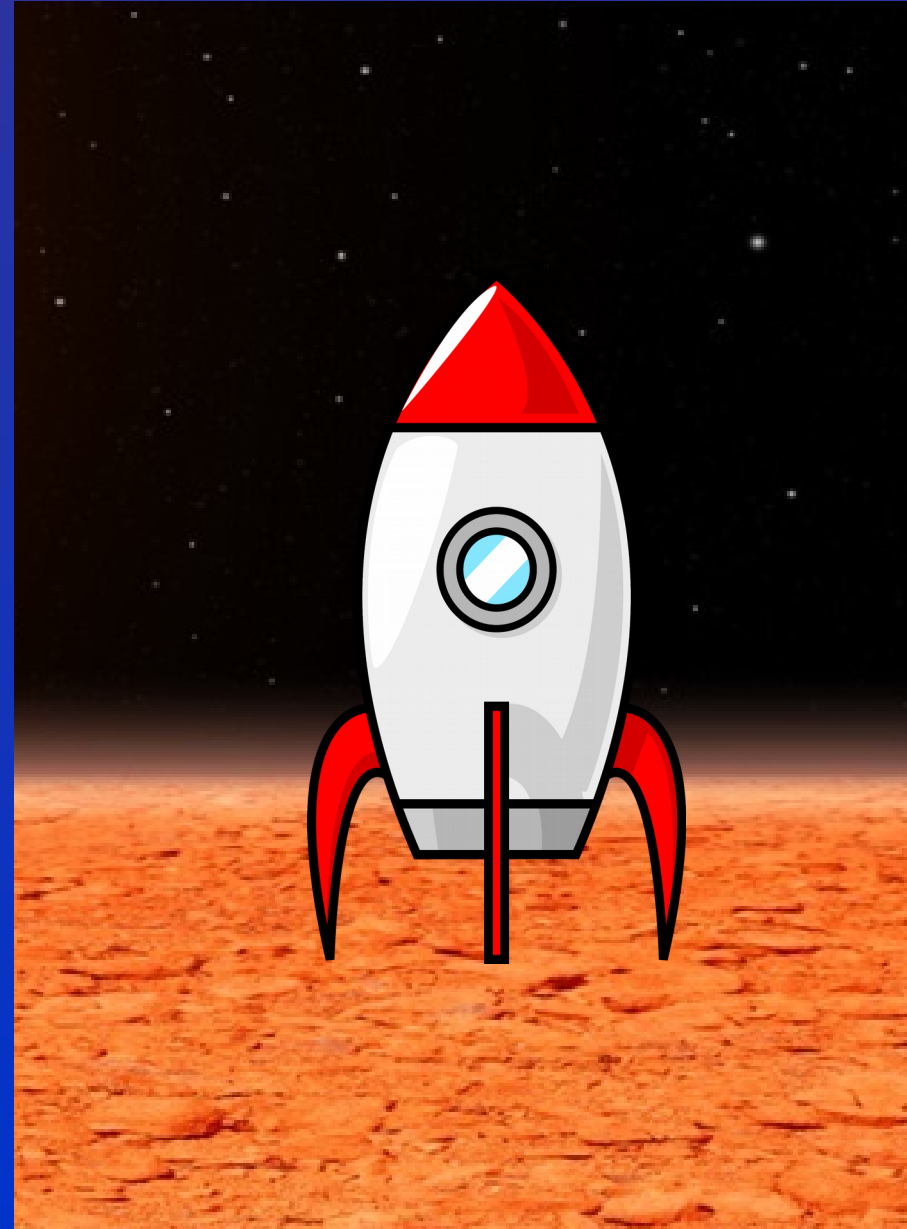


CREARE LA GRAVITA'



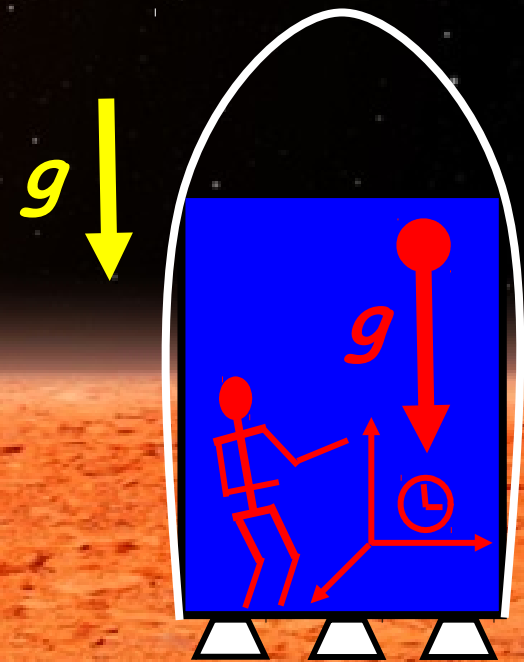
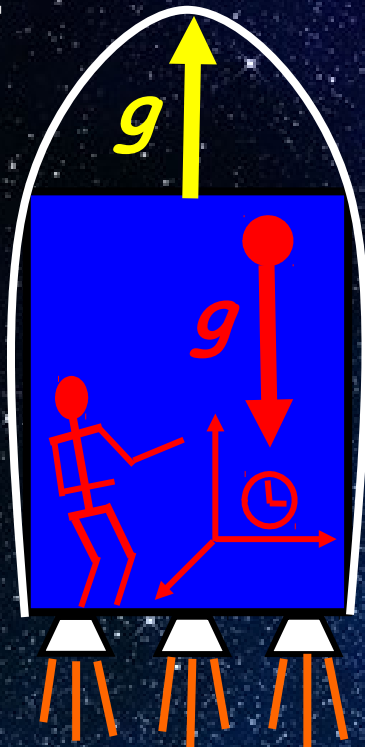
SISTEMA DI RIFERIMENTO ACCELERATO

IN VOLO O TERRA?



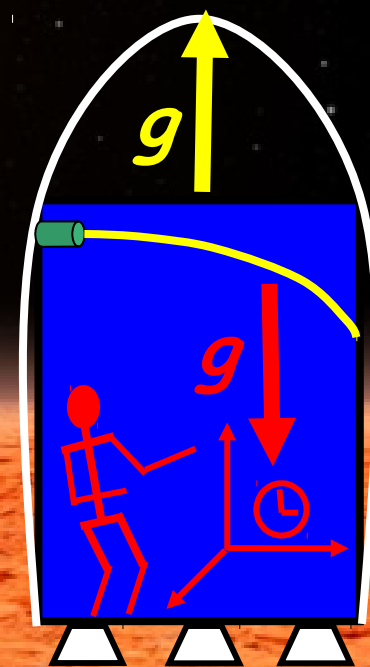
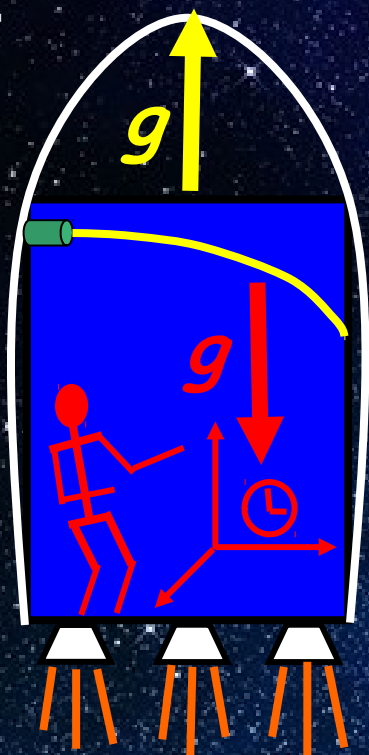
PRINCIPIO DI EQUIVALENZA

GLI EFFETTI PRODOTTI SUI FENOMENI FISICI DA UN SISTEMA DI RIFERIMENTO ACCELERATO SONO EQUIVALENTI A QUELLI DELLA GRAVITA'



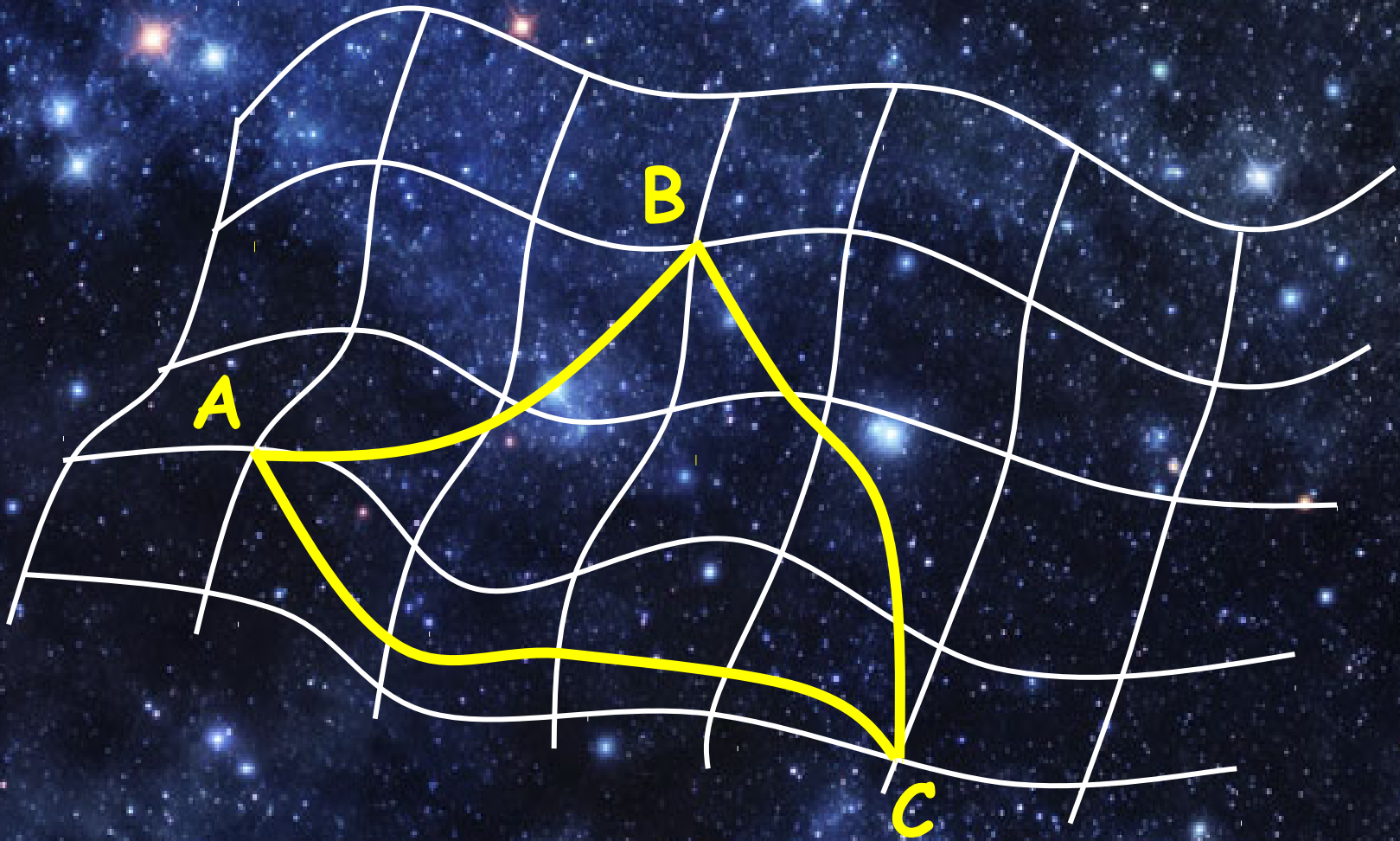
CURVARE LA LUCE

IN UN SISTEMA ACCELERATO E IN UN CAMPO GRAVITAZIONALE, LA LUCE SEGUE UNA TRAIETTORIA CURVA





CURVARE LO SPAZIO



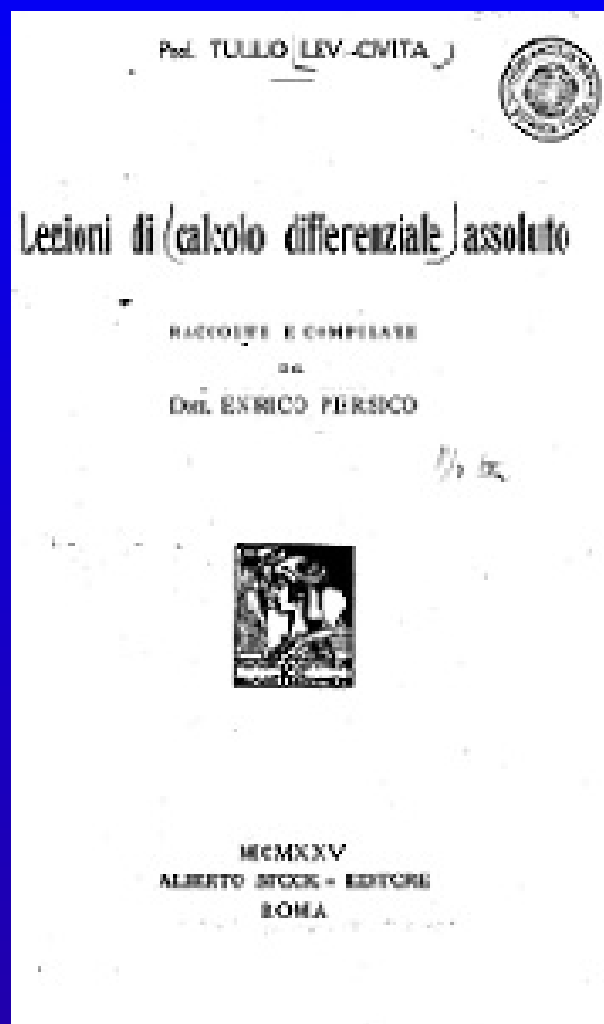
UN CAMPO GRAVITAZIONALE CURVA I RAGGI DI LUCE
E QUINDI CURVA LO SPAZIO



"GLI SPAGHETTI E LEVI-CIVITA"



G. RICCI
CURBASTRO
1853-1925



T. LEVI-CIVITA
1873-1941

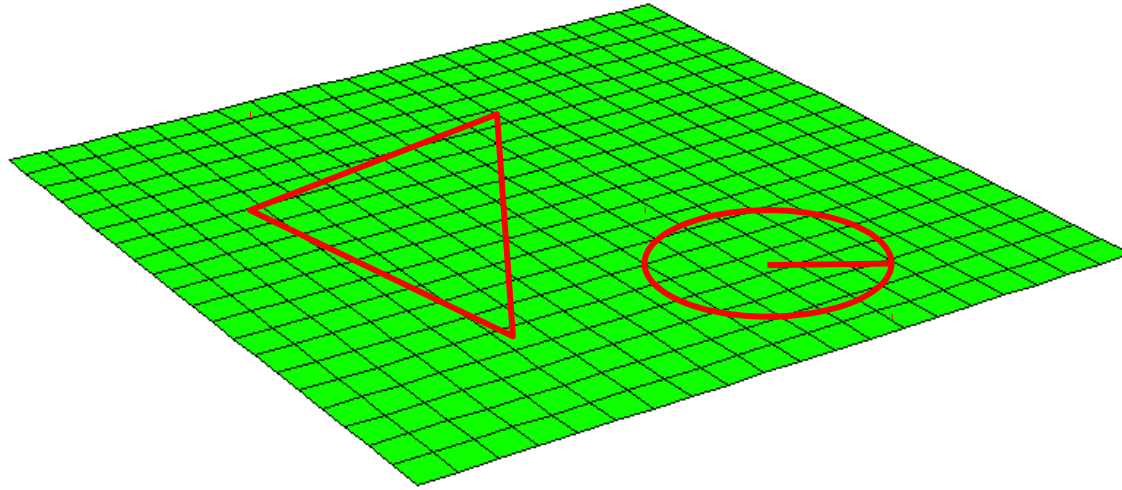
IL CALCOLO DIFFERENZIALE ASSOLUTO E' LO STRUMENTO MATEMATICO CHE SERVIVA AD EINSTEIN



EUCLIDE NON C'E' PIU'

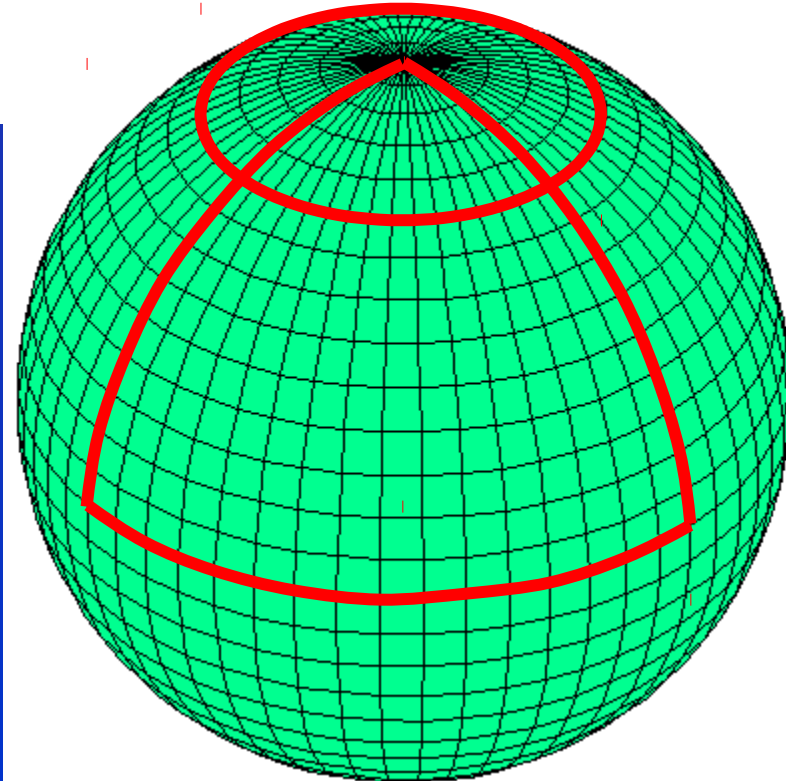


B. RIEMANN
1826-1966

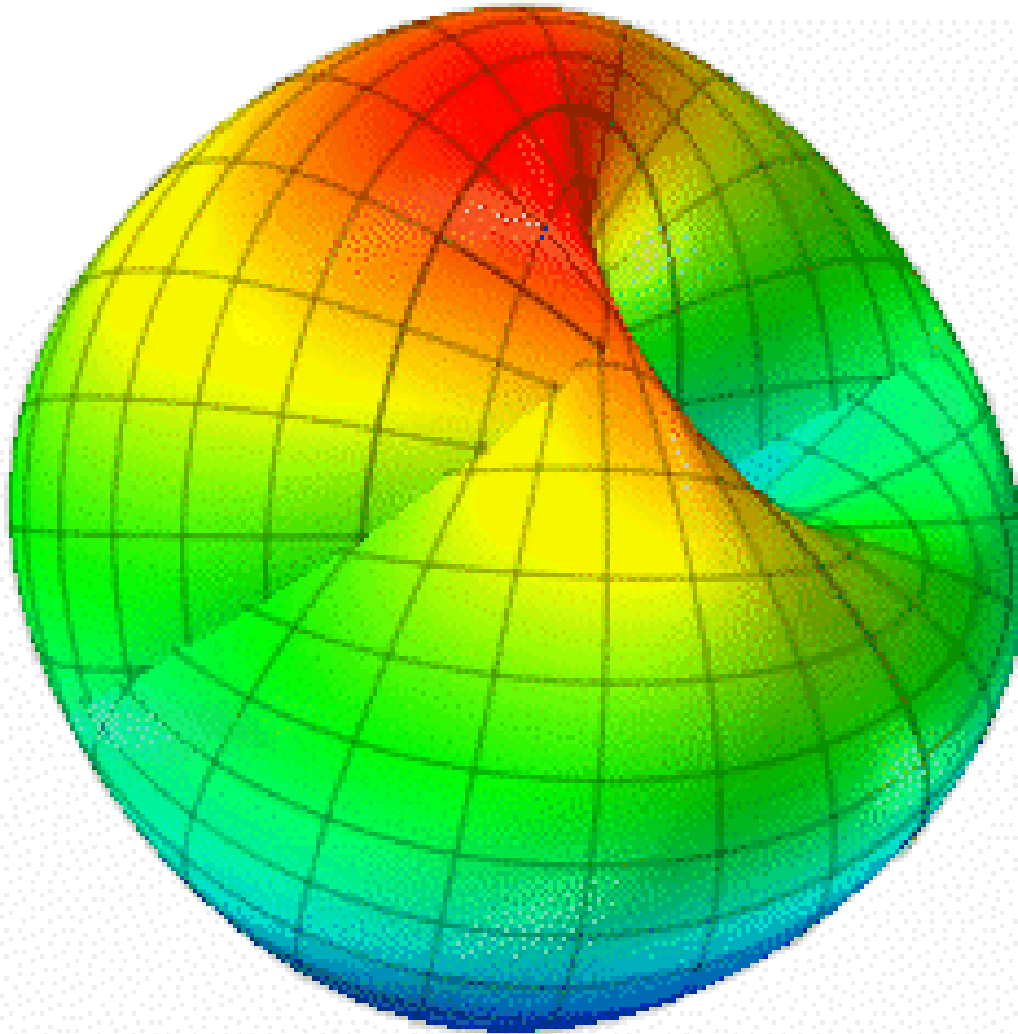


Gli "SPAZI DI RIEMANN"
SONO SPAZI "CURVI"

LA GEODETICA E' IL
PERCORSO PIU' BREVE
TRA DUE PUNTI



IPERSFERA

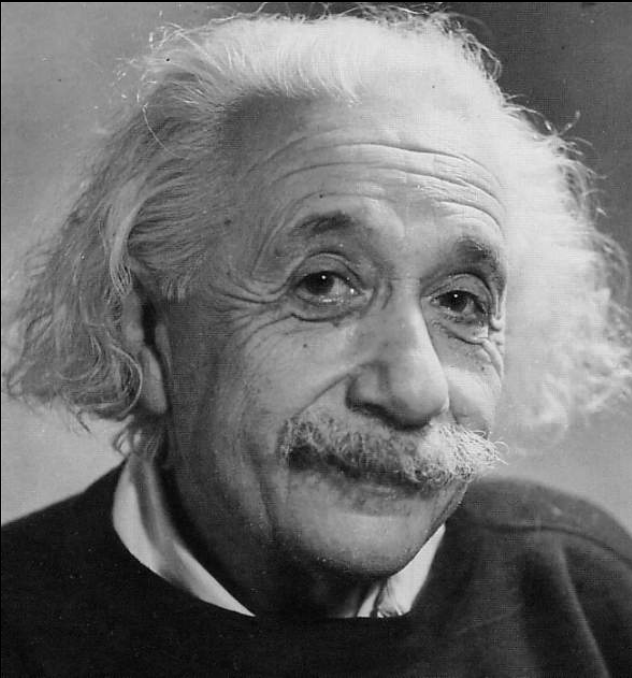


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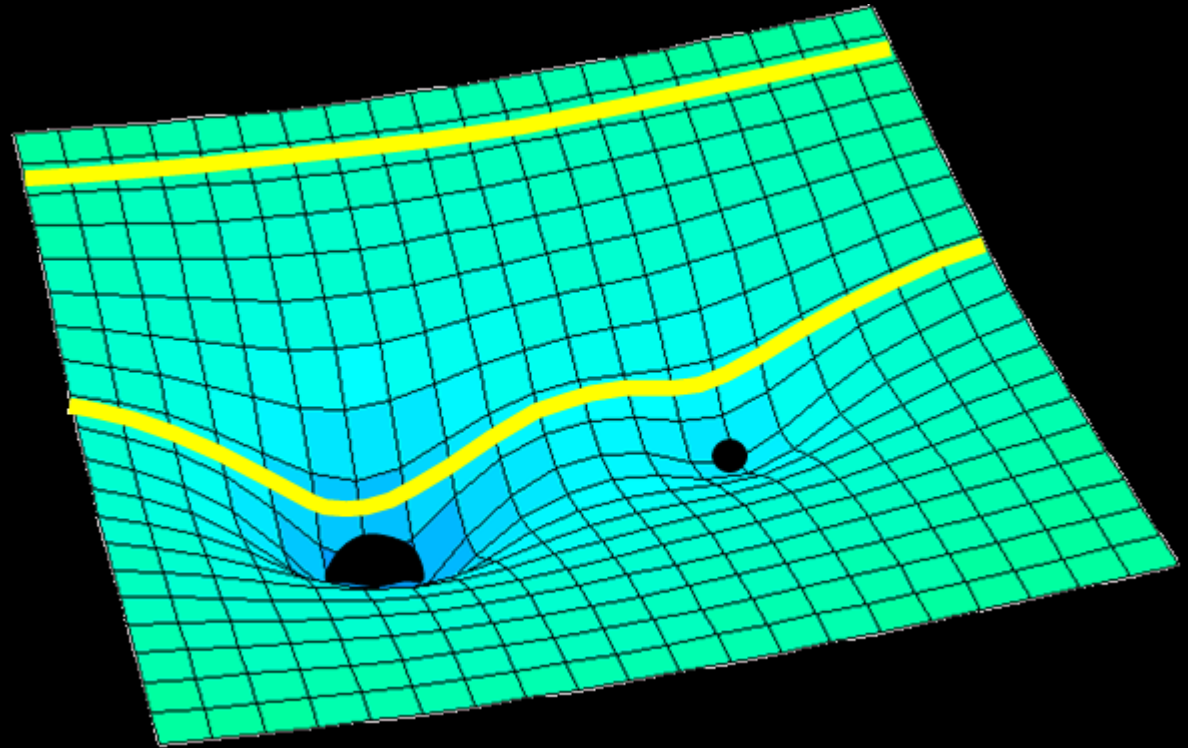


IL PERCORSO PIU' BREVE

1916 - "Die Grundlagen der allgemeinen Relativitätstheorie"



A. EINSTEIN
1879-1955



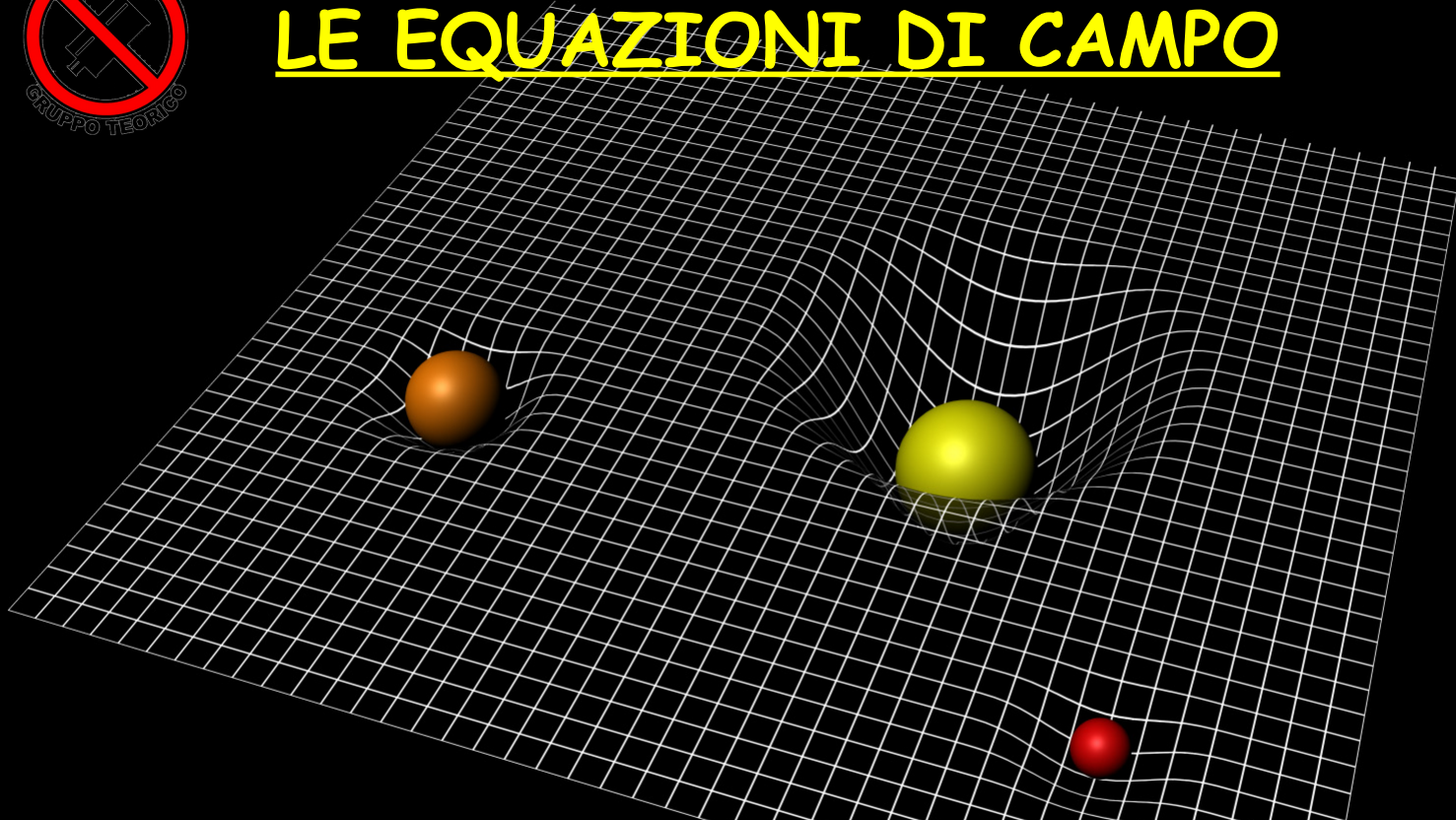
LA LUCE SEGUE LA CURVATURA DELLO SPAZIO-TEMPO
DOVUTA ALLA PRESENZA DI MASSA-ENERGIA

DEFORMARE LO SPAZIO-TEMPO





LE EQUAZIONI DI CAMPO

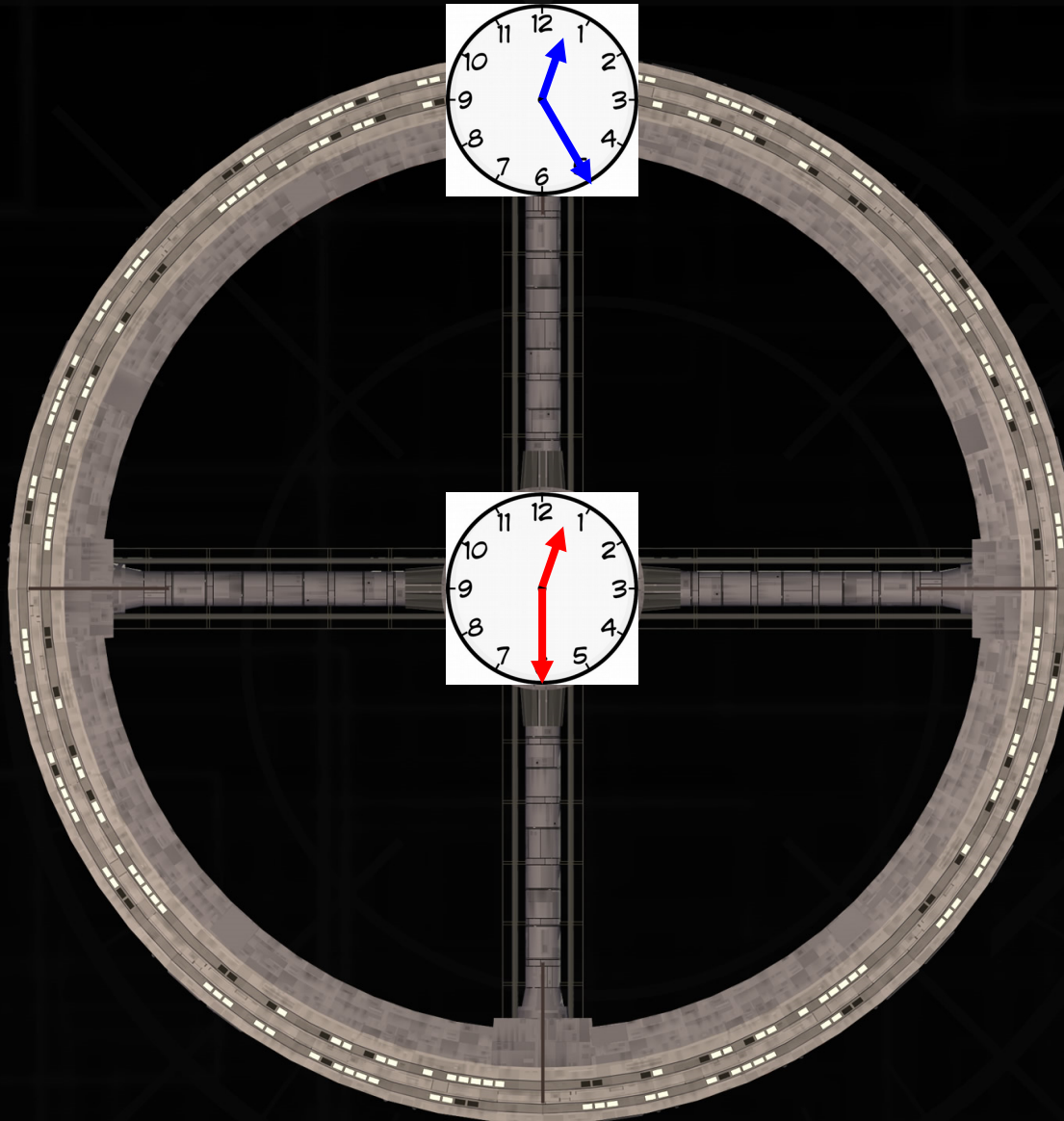


$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

EQUAZIONI DI CAMPO: LEGANO LA CURVATURA DELLO SPAZIO-TEMPO ALLA DENSITÀ DI MASSA-ENERGIA

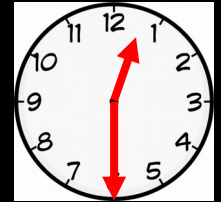
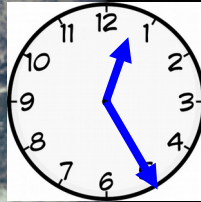
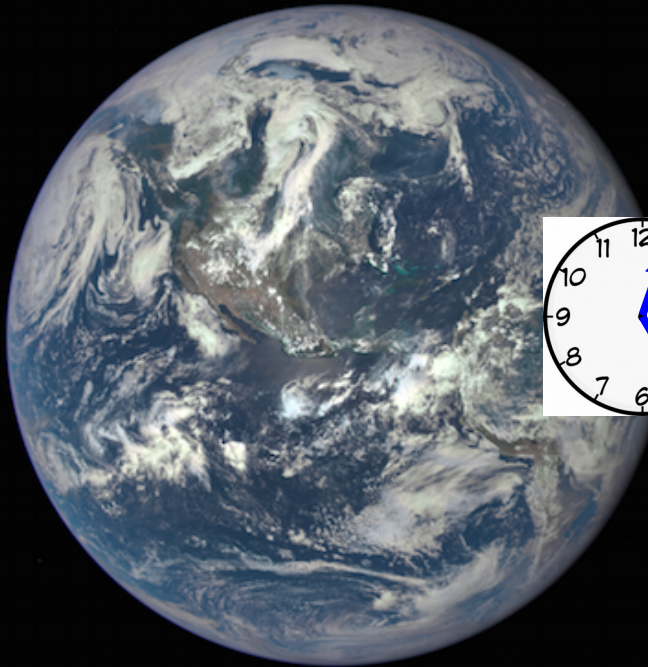


UN GIRO DI GIOSTRA





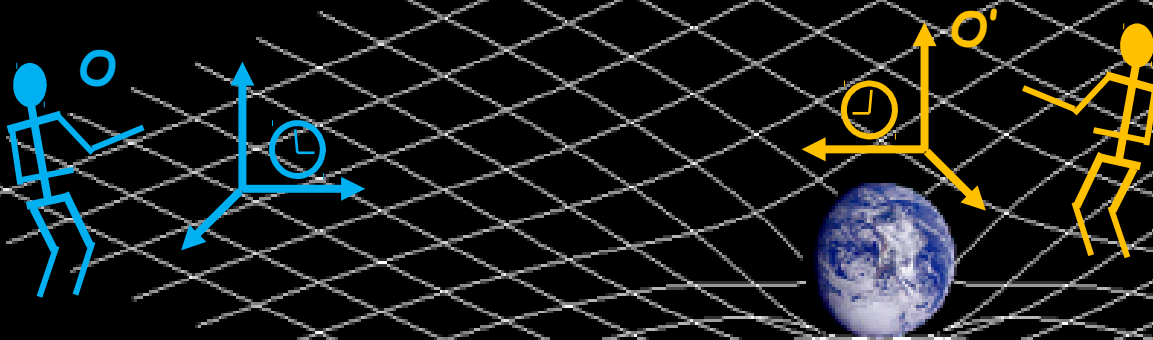
RALLENTARE IL TEMPO



**IL TEMPO FLUISCE PIU' LENTAMENTE DOVE IL CAMPO
GRAVITAZIONALE PIU' INTENSO**



QUALCHE FORMULA



$$l = \sqrt{1 - 2 \frac{GM}{Rc^2}} l_0$$

**CONTRAZIONE
DELLE LUNGHEZZE**

$$\tau = \frac{\tau_0}{\sqrt{1 - 2 \frac{GM}{Rc^2}}}$$

**DILATAZIONE
DEI TEMPI**



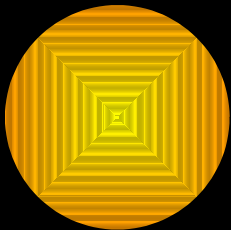
QUALCHE CALCOLO



TERRA $M= 5,97 \times 10^{24}$ Kg $R = 6,37 \times 10^6$ m

$$\tau = 1,00000000007 \tau_0 \quad \Delta\tau = 2 \text{ s}/100 \text{ y}$$

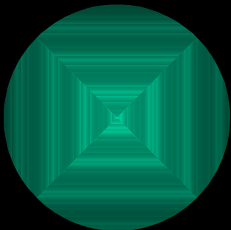
$$L = 0,99999999993 L_0 \quad \Delta L = 6 \text{ cm}$$



SOLE $M= 1,99 \times 10^{30}$ Kg $R = 6,96 \times 10^8$ m

$$\tau = 1,0000021 \tau_0 \quad \Delta\tau = 1 \text{ h } 51 \text{ m}/100 \text{ y}$$

$$L = 0,9999979 L_0$$

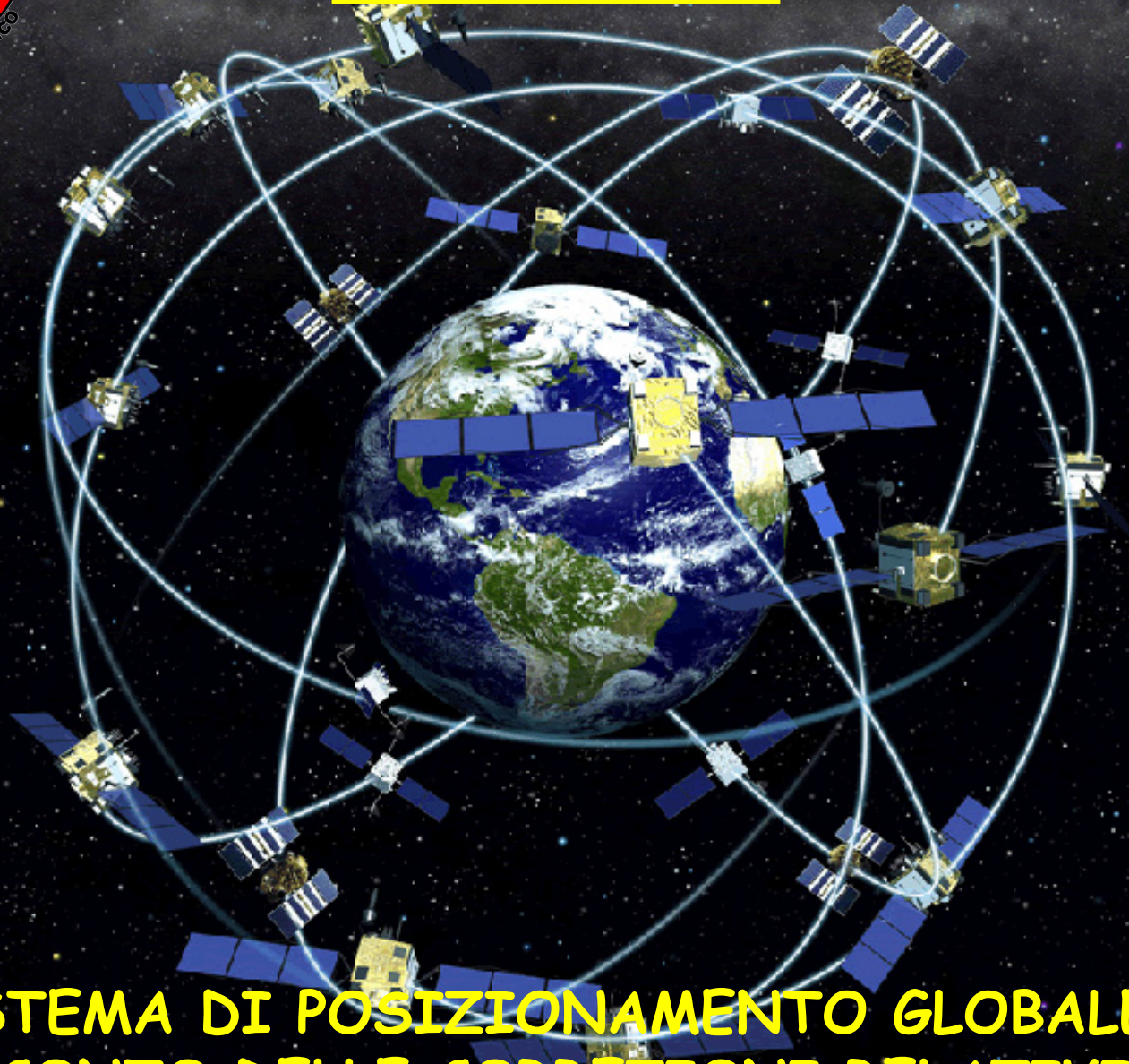


STELLA DI NEUTRONI $M= 1,99 \times 10^{30}$ Kg $R = 6,00 \times 10^3$ m

$$\tau = 1,40 \tau_0 \quad \Delta\tau = 24 \text{ m}/\text{h}$$

$$L = 0,71 L_0$$

CORREZIONI



**IL SISTEMA DI POSIZIONAMENTO GLOBALE (GPS)
TIENE CONTO DELLE CORREZIONI RELATIVISTICHE**

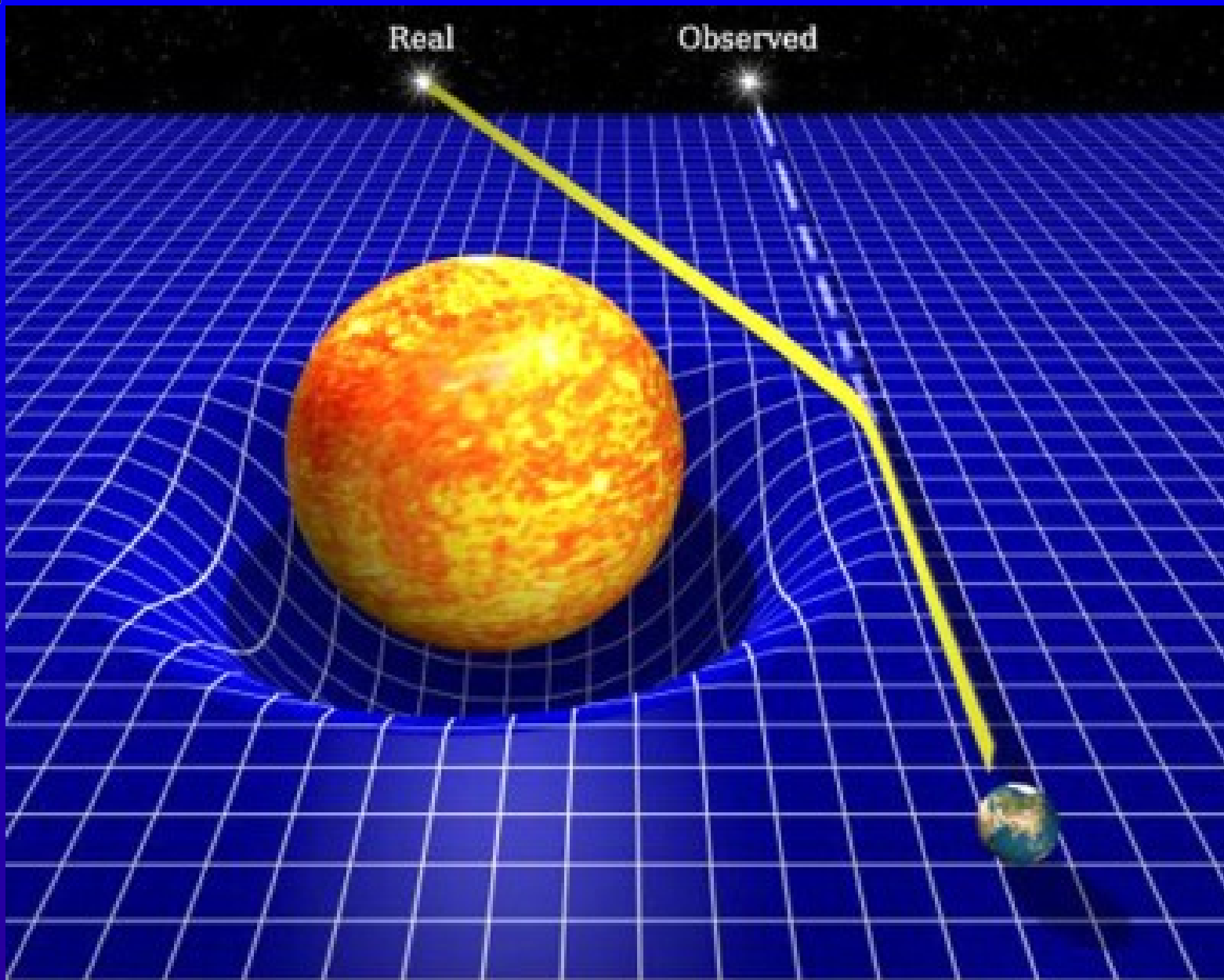


IN CADUTA LIBERA



**I CORPI IN CADUTA LIBERA SEGUONO LE GEODETICHE
NELLO SPAZIO-TEMPO**

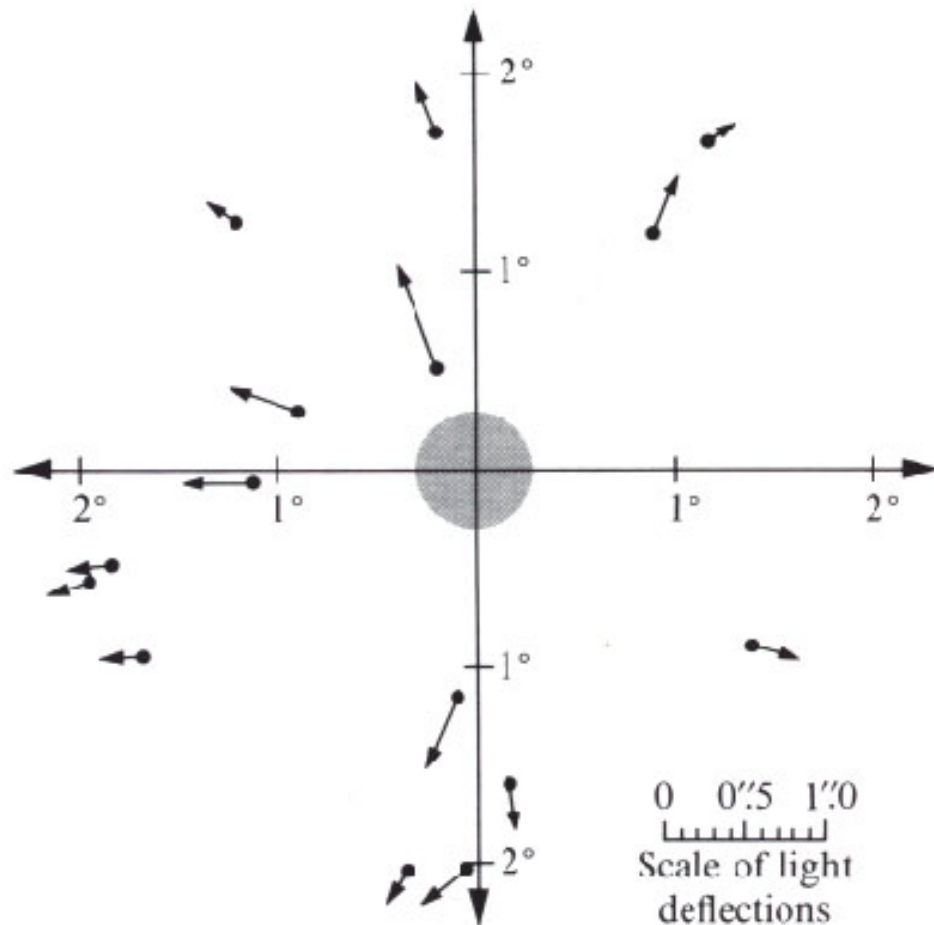
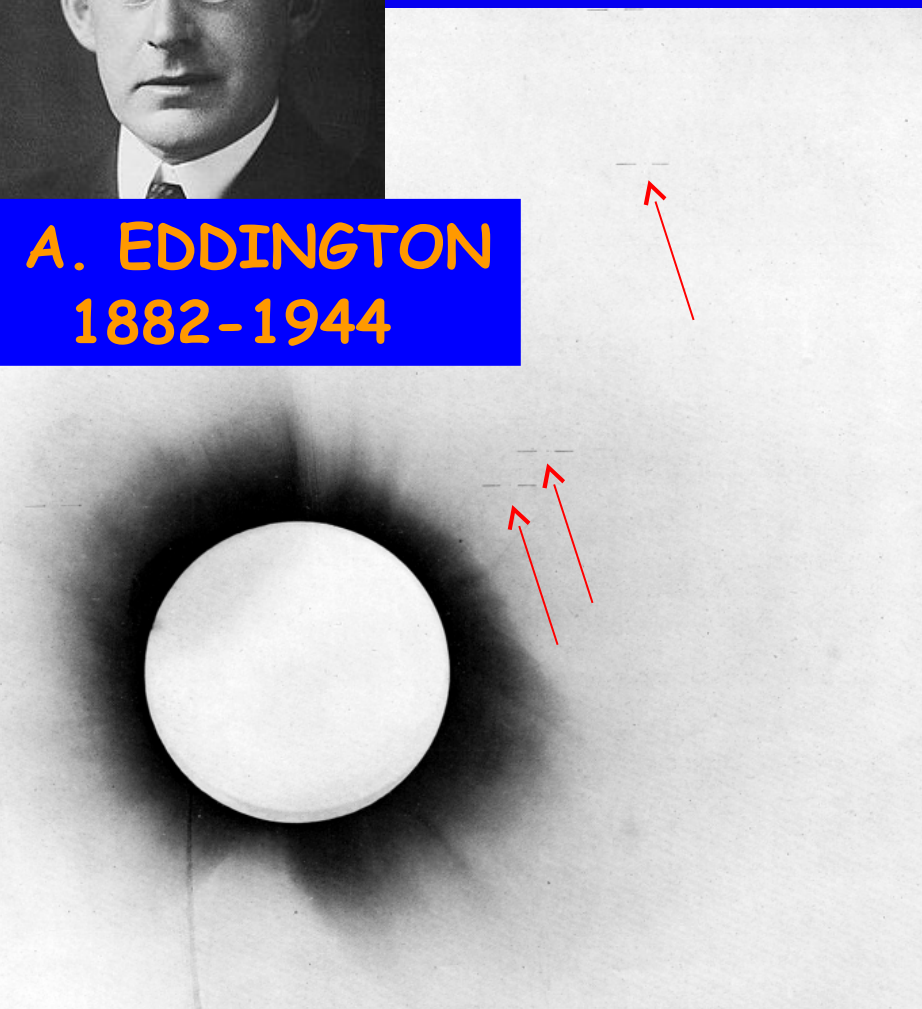
"SPOSTARE" LE STELLE



UN'ECLISSE STORICA



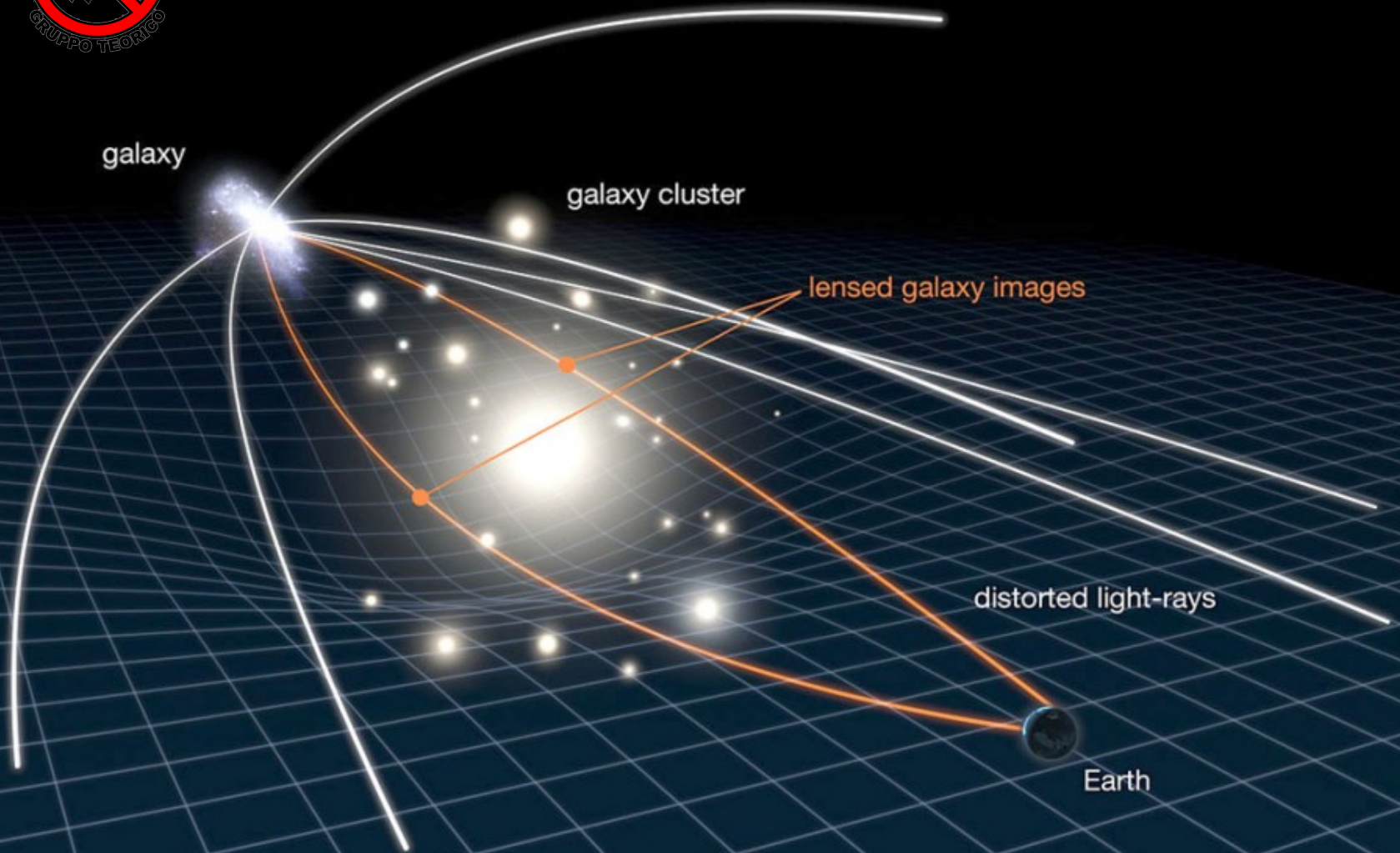
**A. EDDINGTON
1882-1944**



**1919 SPEDIZIONE DI SIR A. EDDINGTON
LASTRA DELL'ECLISSE E SPOSTAMENTI MISURATI**



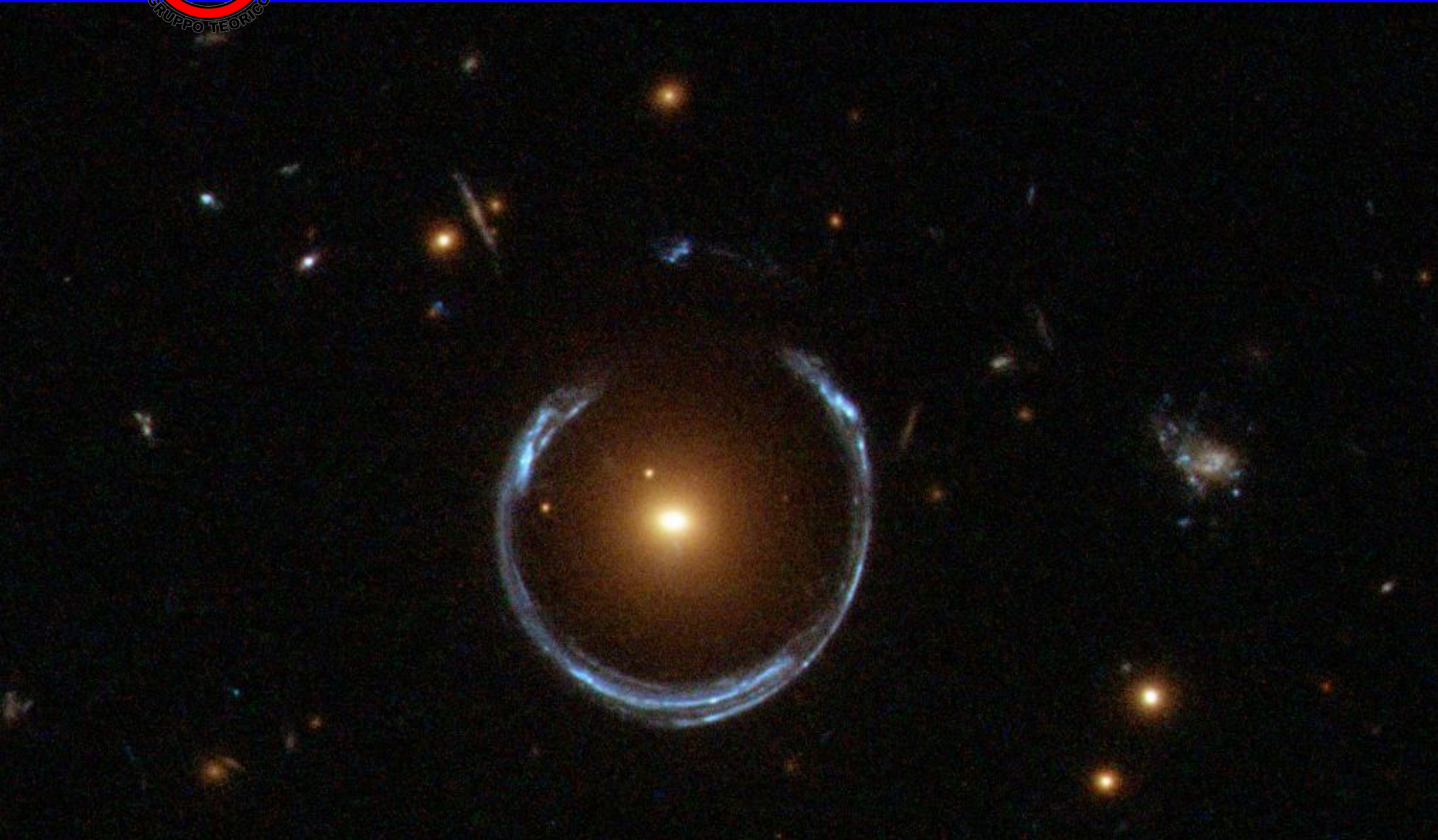
LENTI COSMICHE



LA DISTORSIONE GRAVITAZIONALE IN ALCUNI CASI PRODUCE UN "EFFETTO LENTE"



ANELLI DI LUCE

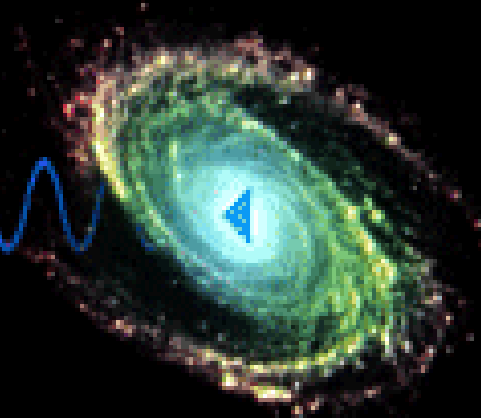


UN "ANELLO DI EINSTEIN" Image Credit: NASA/ESO



ARROSSAMENTO

Einstein's Gravitational Redshift



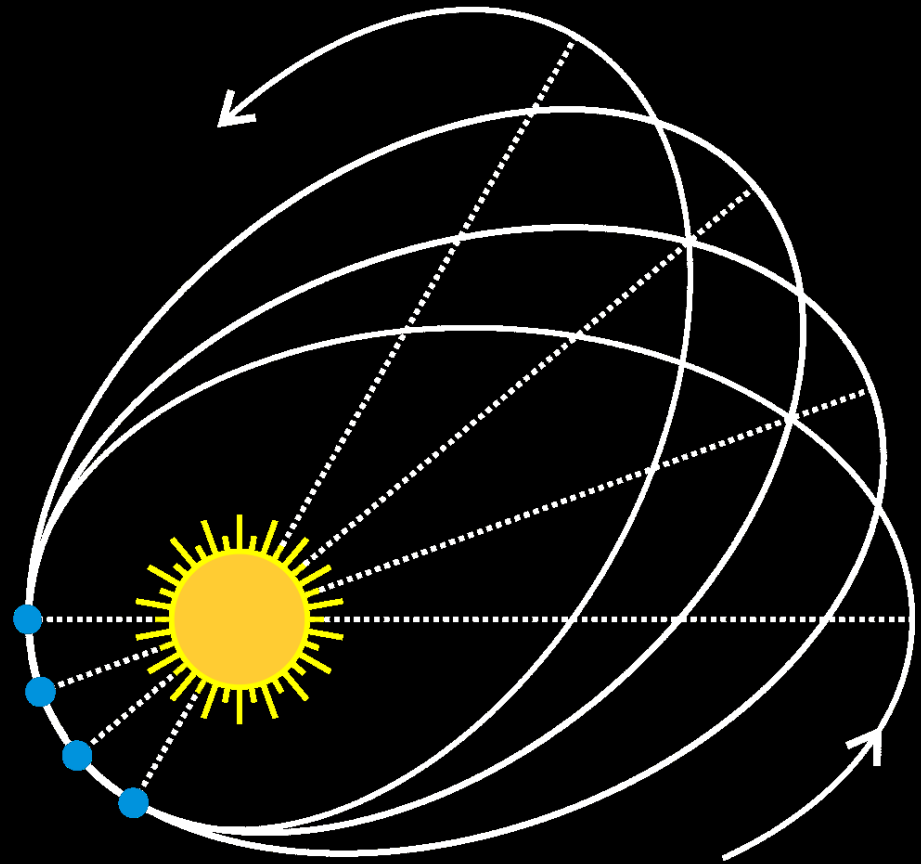
LA LUCE PROVENIENTE DA UN OGGETTO DI
GRANDE MASSA APPARE "SPOSTATA" A
LUNGHEZZE D'ONDA MAGGIORI



LA DANZA DI MERCURIO



Image Credit: NASA/ESO



DIFFERENZA DA SPIEGARE 43 "/SEC

VALORE CALCOLATO 43,03 "/SEC



ONDE DI SPAZIO-TEMPO

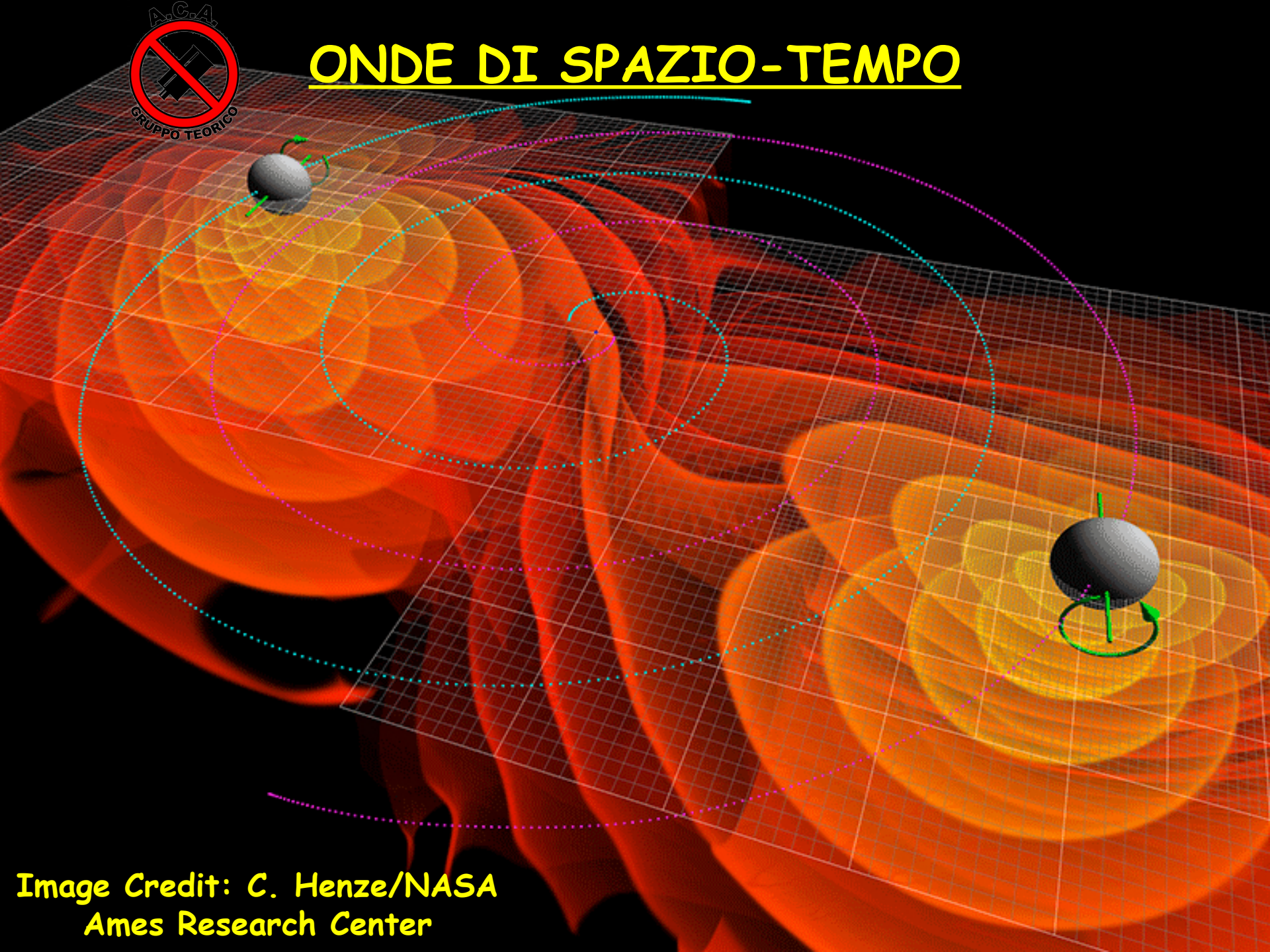
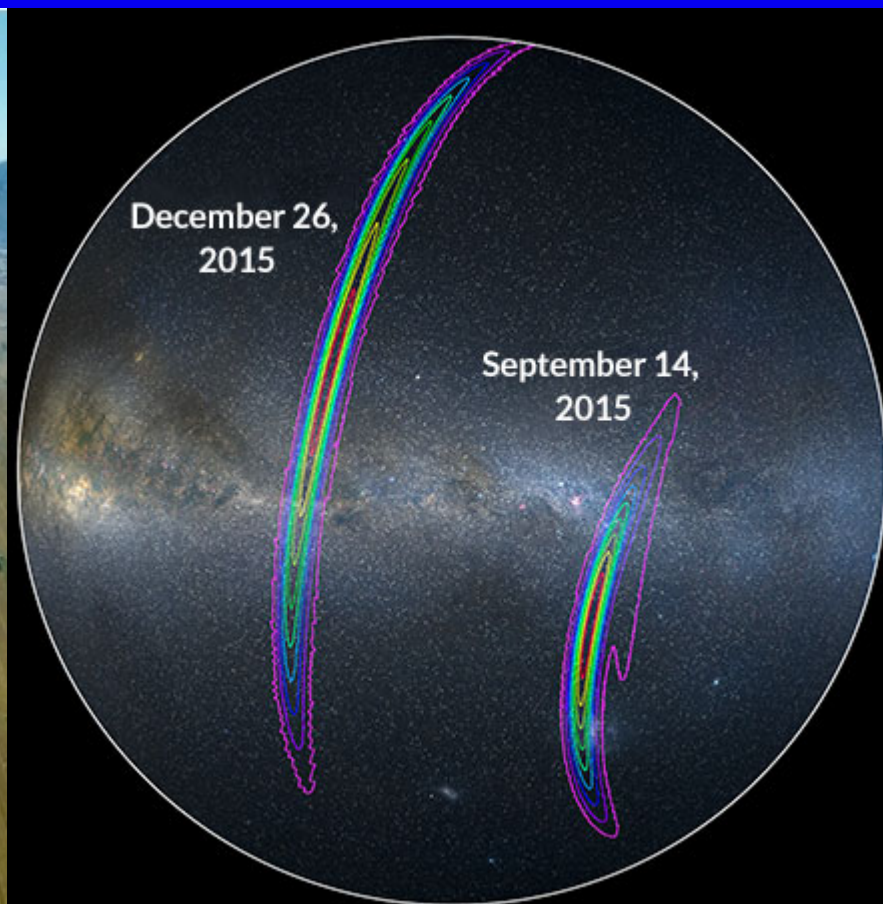


Image Credit: C. Henze/NASA
Ames Research Center



CATTURARE LE ONDE

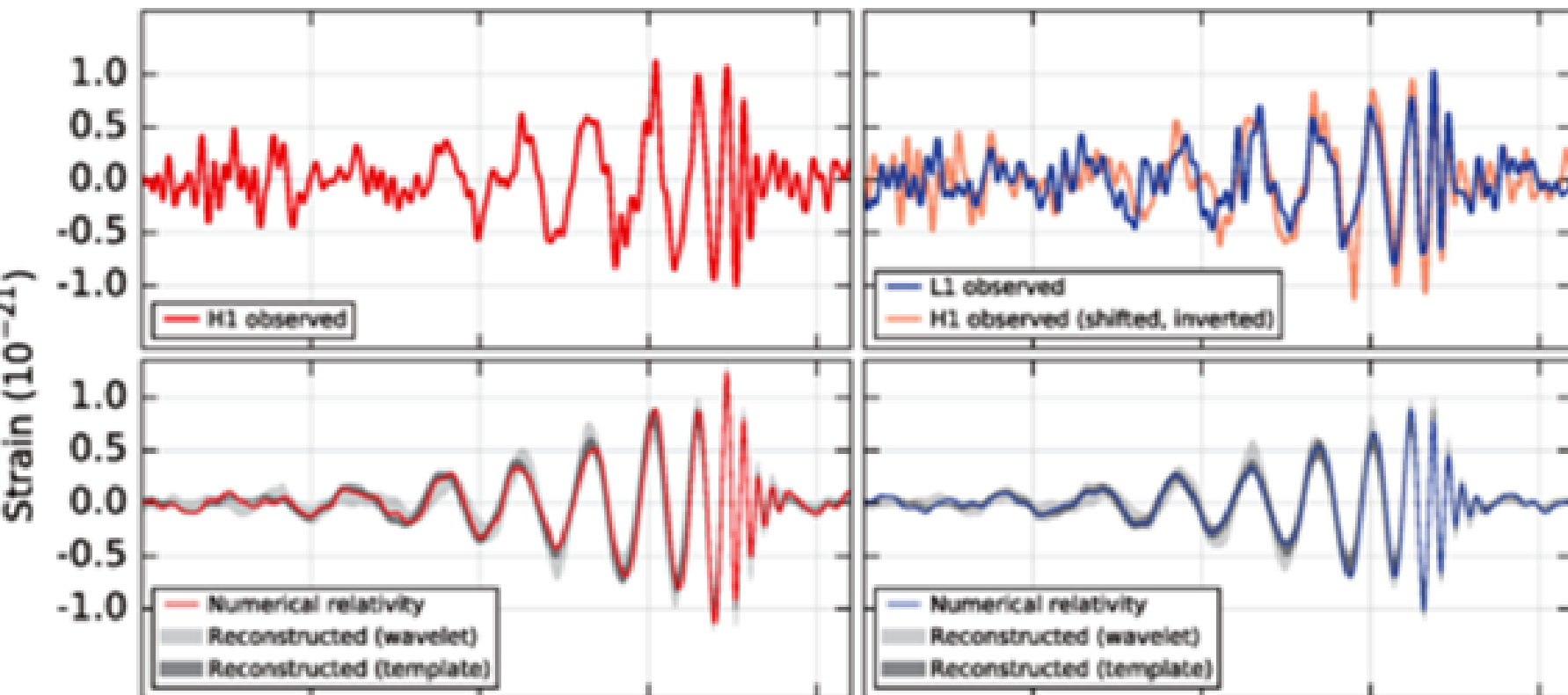


**VEDUTA AEREA DI "VIRGO" E REGIONE DELLA VOLTA
CELESTE DA DOVE SONO STATE RVELATE LE ONDE
GRAVITAZIONALI**

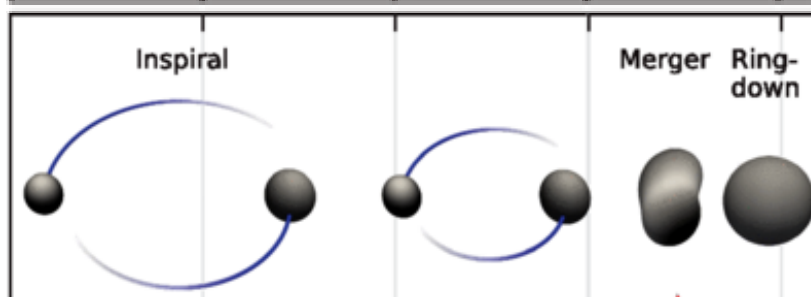
UN LIEVE TREMORE

Hanford, Washington (H1)

Livingston, Louisiana (L1)



**IL SEGNALE
RILEVATO DA "LIGO"
DELLA FUSIONE DI
DUE BUCHI NERI**





IL SUONO DELLO SPAZIO-TEMPO

Image Credit: C. Henze/NASA Ames Research Center

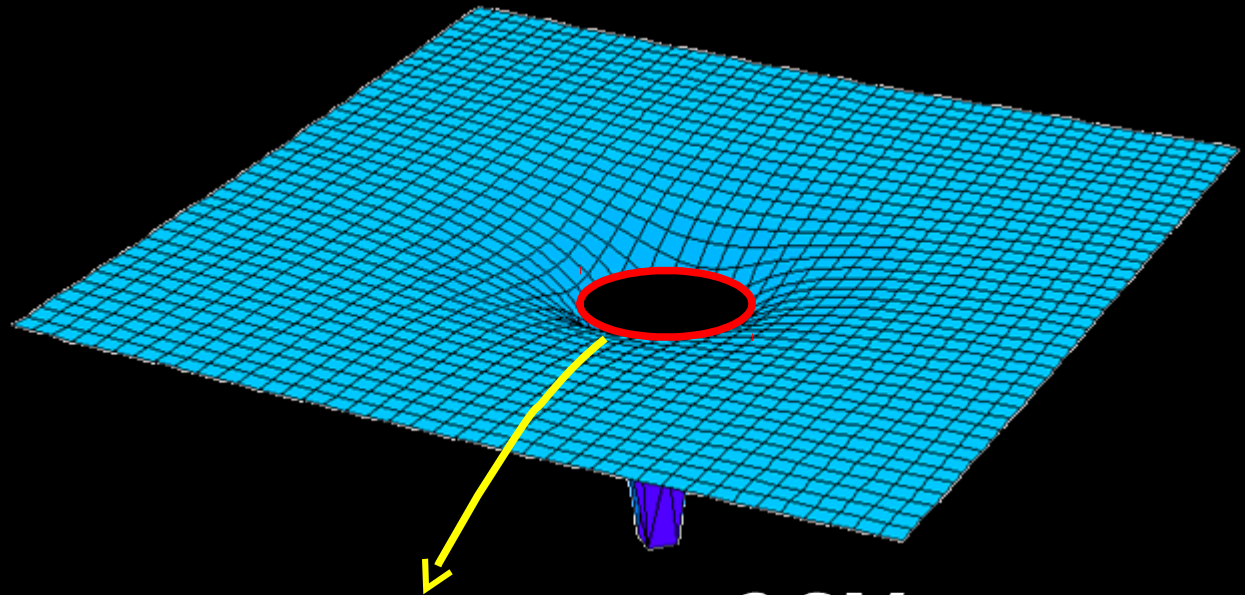


INTRAPPOLARE LA LUCE

1916 - "Über das Gravitationsfeld eines Massenpunktes nach der Einstein'schen Theorie"



K. SCHWARZSCHILD
1873-1916



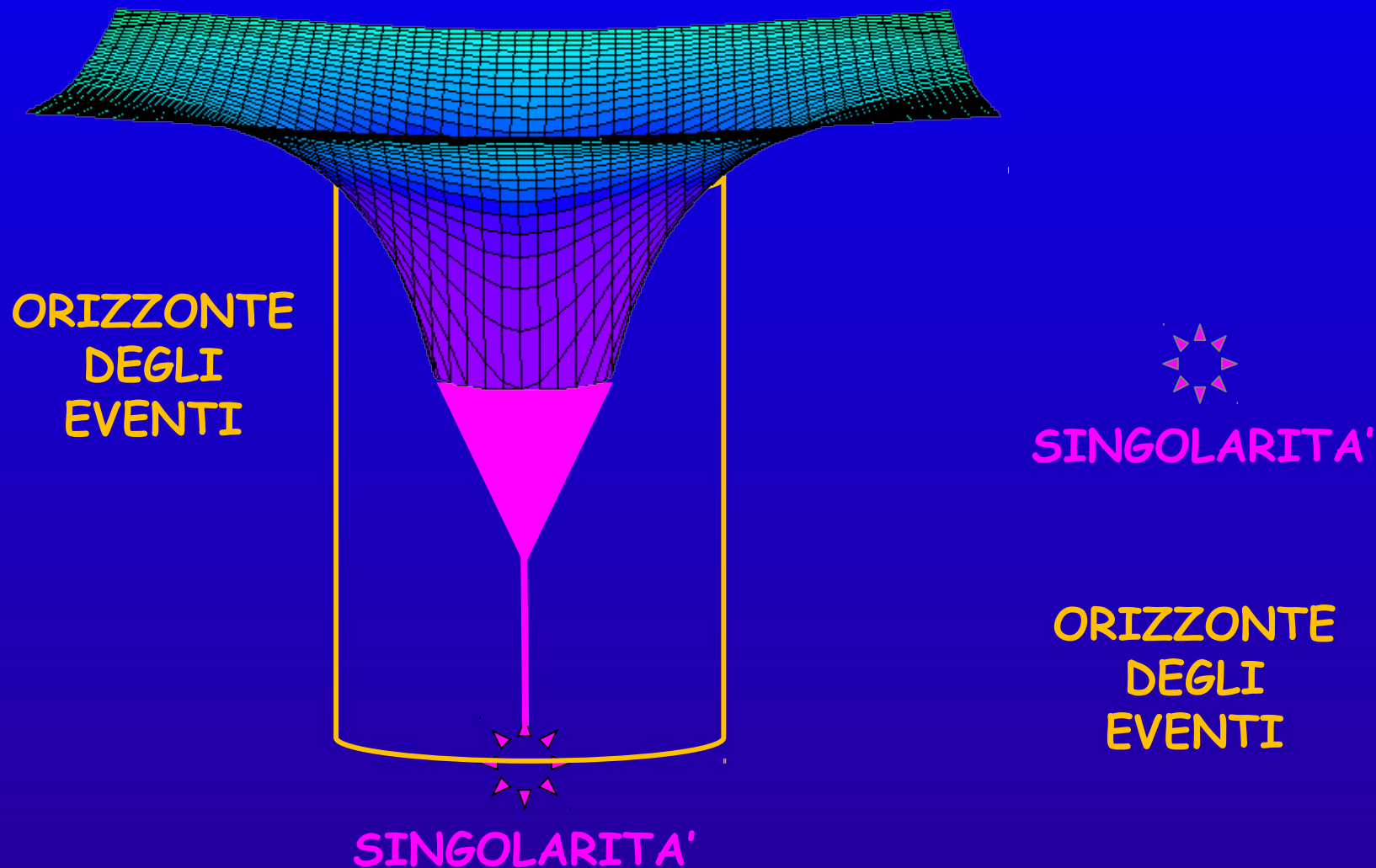
$$R_S = \frac{2GM}{c^2}$$

LA VELOCITA' DI FUGA DIVENTA UGUALE A QUELLA DELLA LUCE ALLA DISTANZA R_S



SINGOLARITA'

ALL'INTERNO DELL'ORIZZONTE SI FORMA UNA SINGOLARITA' SPAZIO-TEMPORALE DI VOLUME NULLO E DENSITA' INFINITA





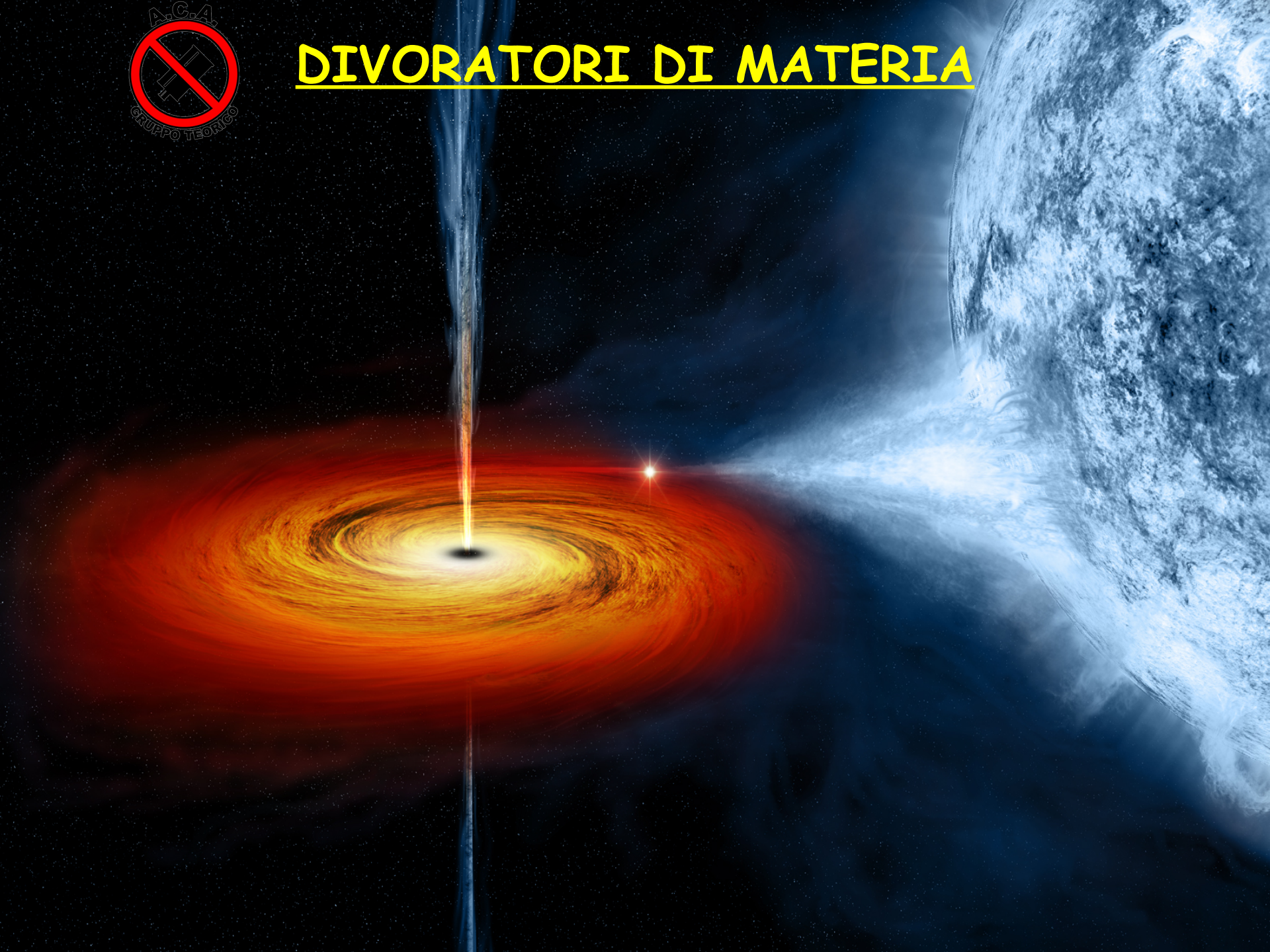
AL CINEMA



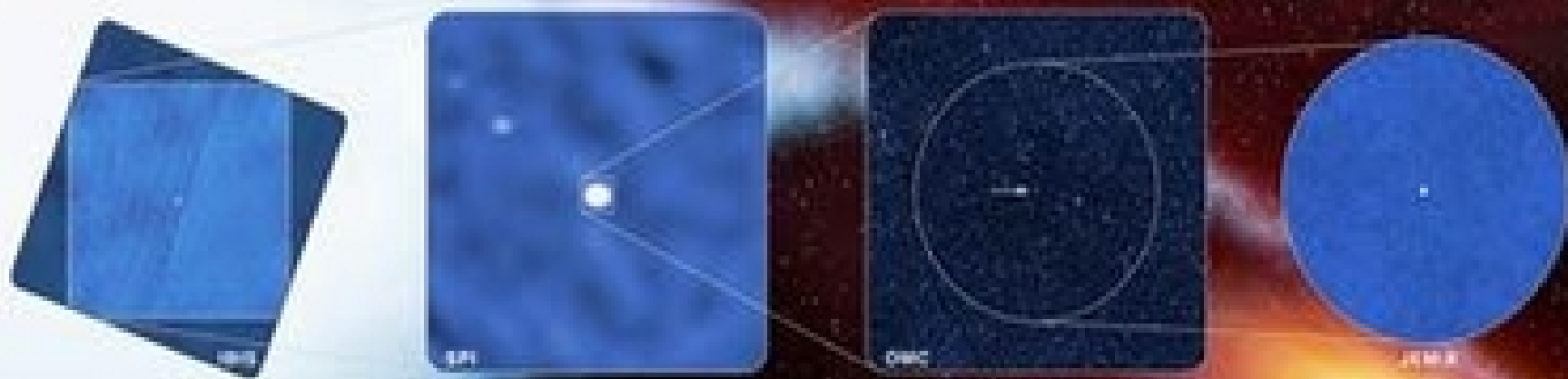
**IL PIANETA "DI MILLER" IN ORBITA ATTORNO AL
BUCO NERO "GARGANTUA" NEL FILM "INTERSTELLAR"**



DIVORATORI DI MATERIA



IL PRIMO CANDIDATO



1964 SCOPERTA LA SORGENTE CYG X-1 6,1 kly

Image Credit: Integral Team ESA



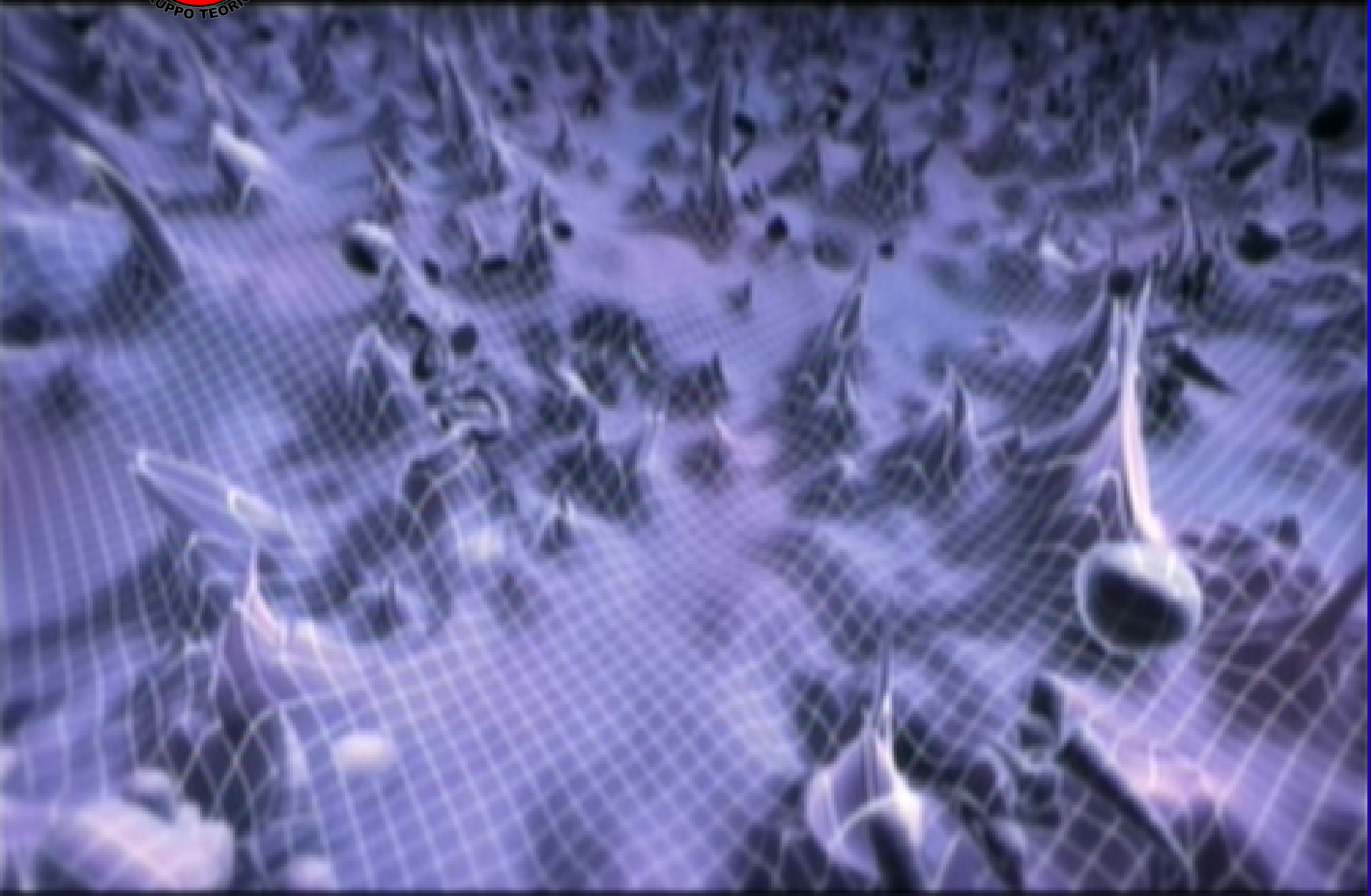
GETTI DI MATERIA



GETTI DI MATERIA EMESSI DA UN BUCO NERO
SUPERMASSIVO Image Credit: NASA/HST



QUANTUM GRAVITY?



"La logica vi porterà da A a B.
L'immaginazione vi porterà dappertutto"

A. Einstein

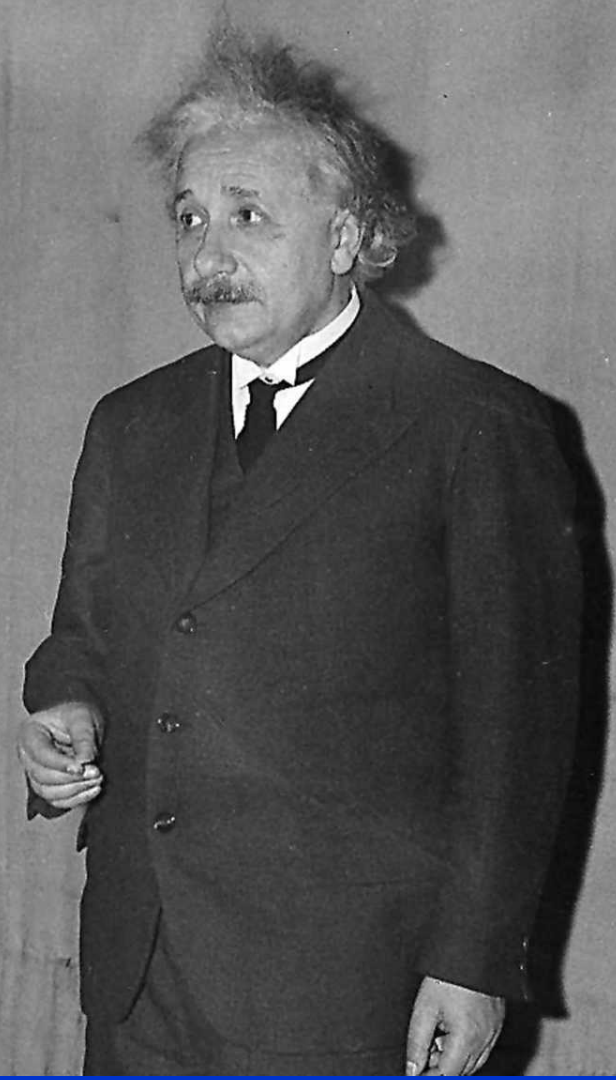
$$\begin{array}{|l} \left(\frac{m}{1-u^2}, \frac{m u_i}{\sqrt{1-u^2}} \right) \\ \left(m + \frac{1}{2} m u^2, m u_i \right) \end{array} \quad \left| \begin{array}{l} \frac{m u_i}{\sqrt{1-u^2}} \text{ Impuls} \\ m \left(\frac{1}{\sqrt{1-u^2}} - 1 \right) \text{ Kin Energy} \end{array} \right.$$

$$= \frac{t' + v x'}{\sqrt{1-v^2}} \quad \left| \quad x = \frac{x' + v t'}{\sqrt{1-v^2}} \quad y = y' \quad z = z' \right.$$

$$\sum \frac{u_i}{\sqrt{1-u^2}} = \frac{2v}{\sqrt{1-u^2} \sqrt{1-v^2}}$$

$$\text{Hyp. } \sum \mathcal{L}_v = \sum \mathcal{L}_v \text{ Cons.}$$
$$\sum \mathcal{E} = \sum \mathcal{E} \quad \mathcal{L}_i$$

$$\mathcal{L}_v = \dot{m} u_v F(u)$$
$$\mathcal{E} = \mathcal{E}_0 + m \mathcal{E}_f(u)$$



GRAZIE PER
L'ATTENZIONE