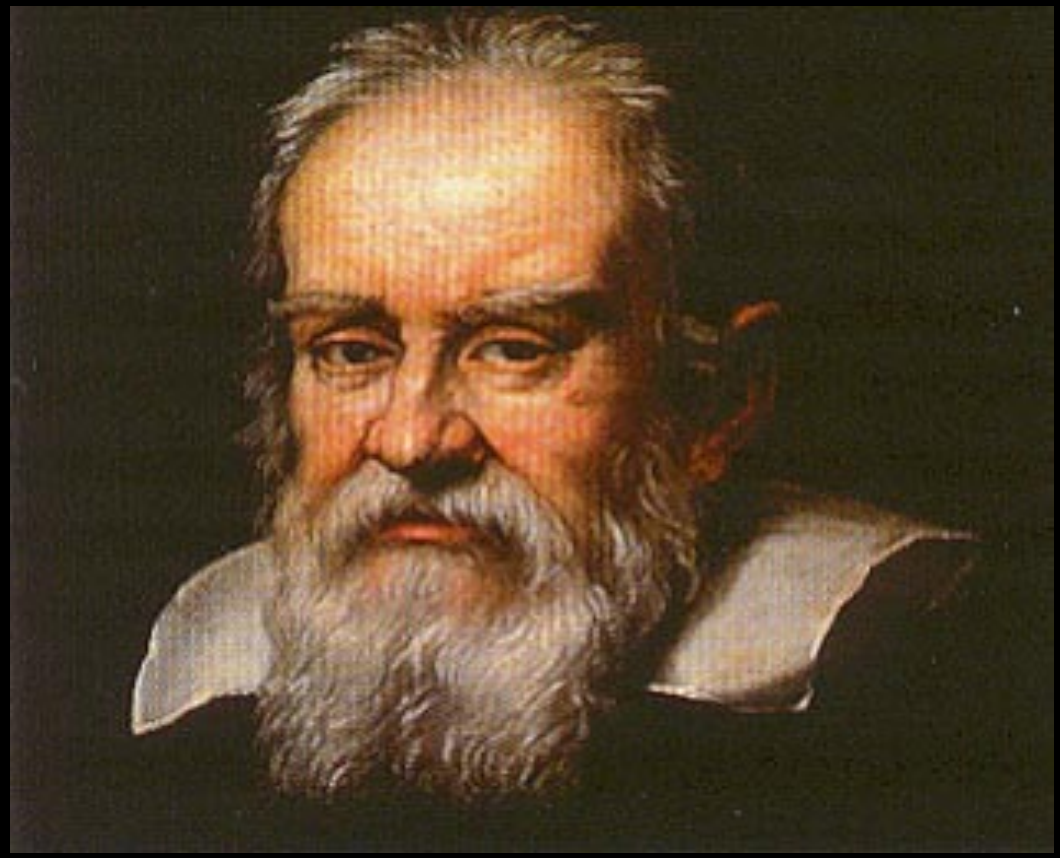


Galileo Galilei
(1564 – 1642)

Riserratevi con qualche amico nella maggior stanza che sia sotto coverta di alcun gran navilio , e quivi fate d' aver mosche , farfalle e simili animaletti volanti ; siavi anco un gran vaso d' acqua , e dentrovi de' pescetti ; sospendasi anco in alto qualche secchiello , che a goccia a goccia vadia versando dell' acqua in un altro vaso di angusta bocca , che sia posto a basso : e stando ferma la nave , osservate diligentemente come quelli animaletti volanti con pari velocità vanno verso tutte le parti della stanza ; i pesci si vedranno andar notando indifferentemente per tutti i versi ; le stille cadenti entreranno tutte nel vaso sottoposto ; e voi , gettando all' amico alcuna cosa , non più gagliardamente la dovrete gettare verso quella parte che verso questa , quando le lontananze sieno eguali ; e saltando voi , come si dice , a piè giunti , eguali spazii passerete verso tutte le parti .

Osservate che avrete diligentemente tutte queste cose , benchè niun dubbio ci sia che mentre il vasello sta fermo non debbano succeder così , fate muover la nave con quanta si voglia velocità ; ché (pur che il moto sia uniforme e non fluttuante in qua e in là) voi non riconoscerete una minima mutazione in tutti li nominati effetti , nè da alcuno di quelli potrete comprender se la nave cammina o pure sta ferma ... " .

PRINCIPIO DI RELATIVITA’

Relativita`
Galileiana

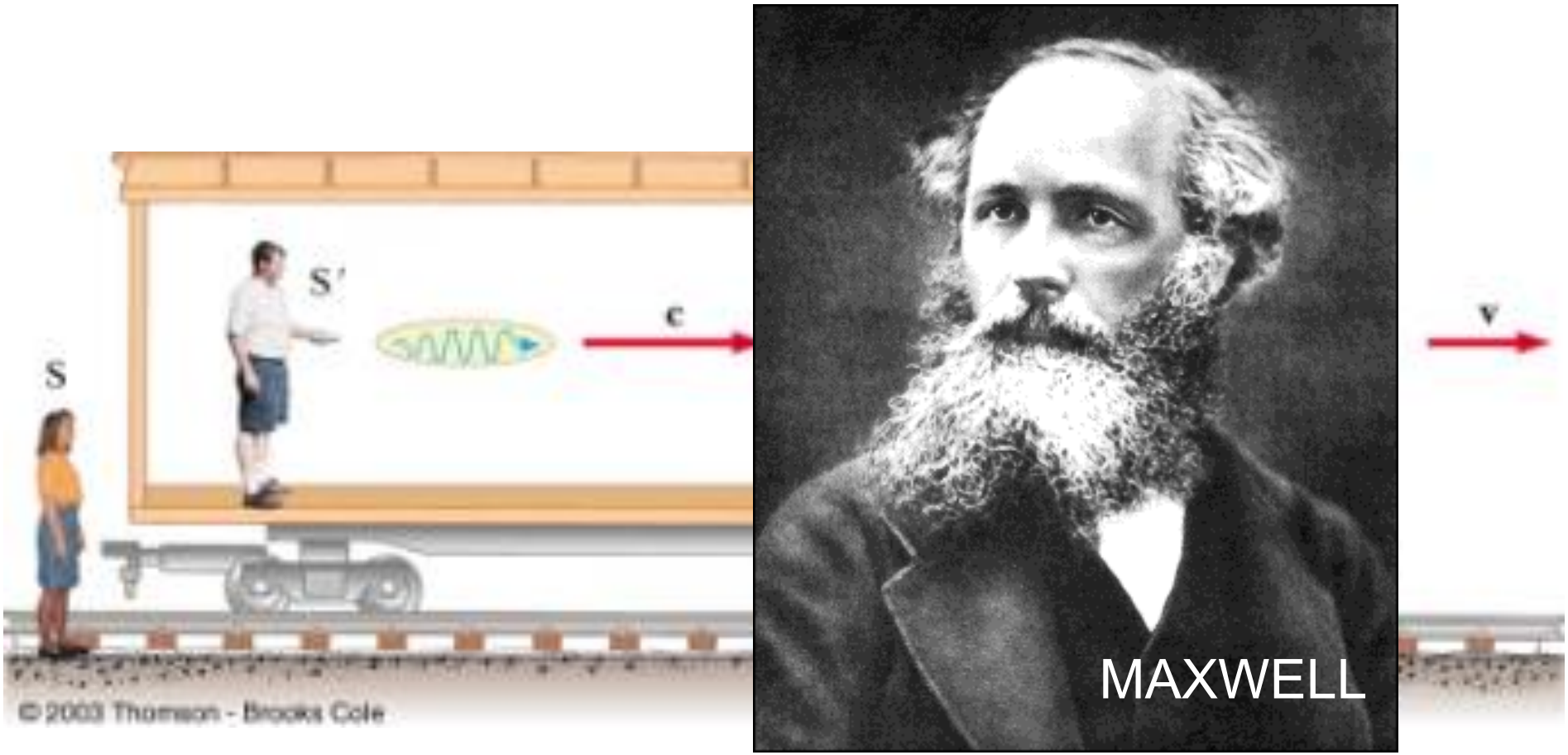
In tutti i sistemi di riferimento inerziali* valgono le stesse leggi

*inerziali=che viaggiano ad una velocita' uniforme

(a)

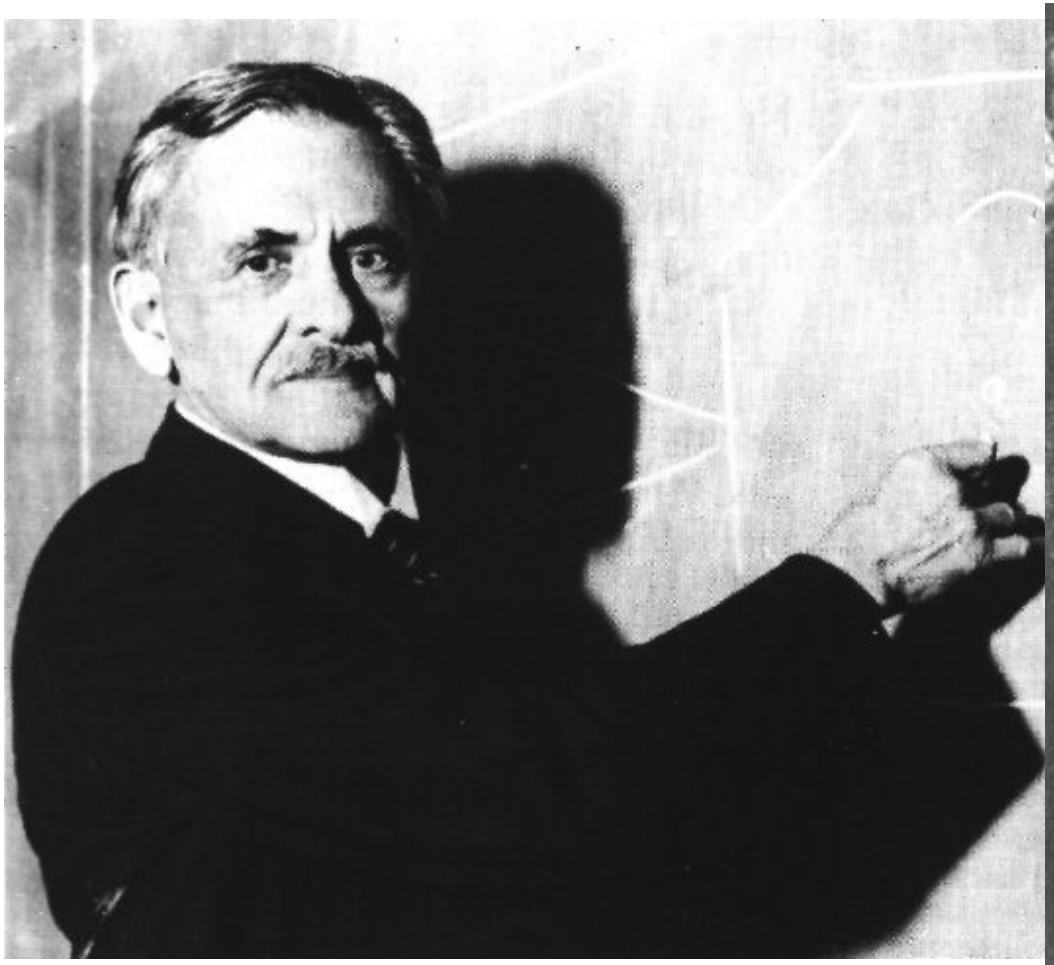
(b)

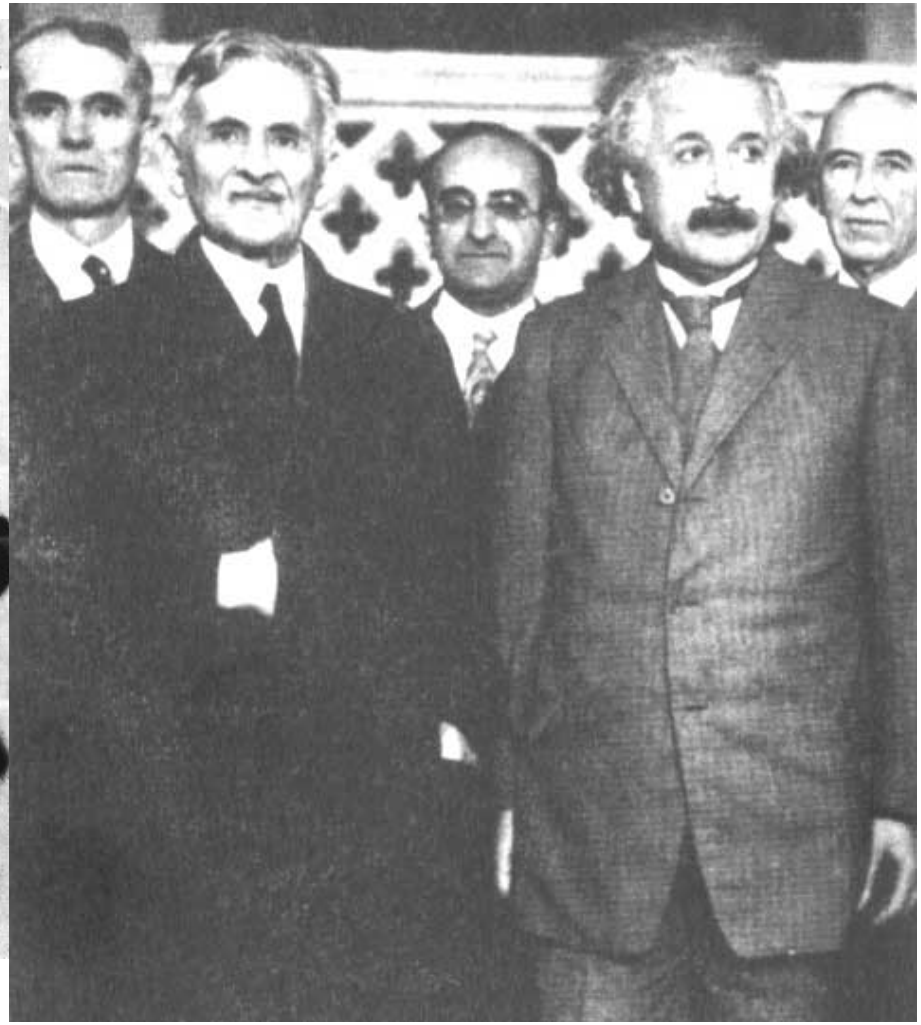
RELATIVITA' DEL MOVIMENTO



Se il treno viaggia a velocita' v
la luce viaggia a velocita' c rispetto al ragazzo
la luce viaggia a velocita' c+v rispetto
alla ragazza

Michelson (1887)

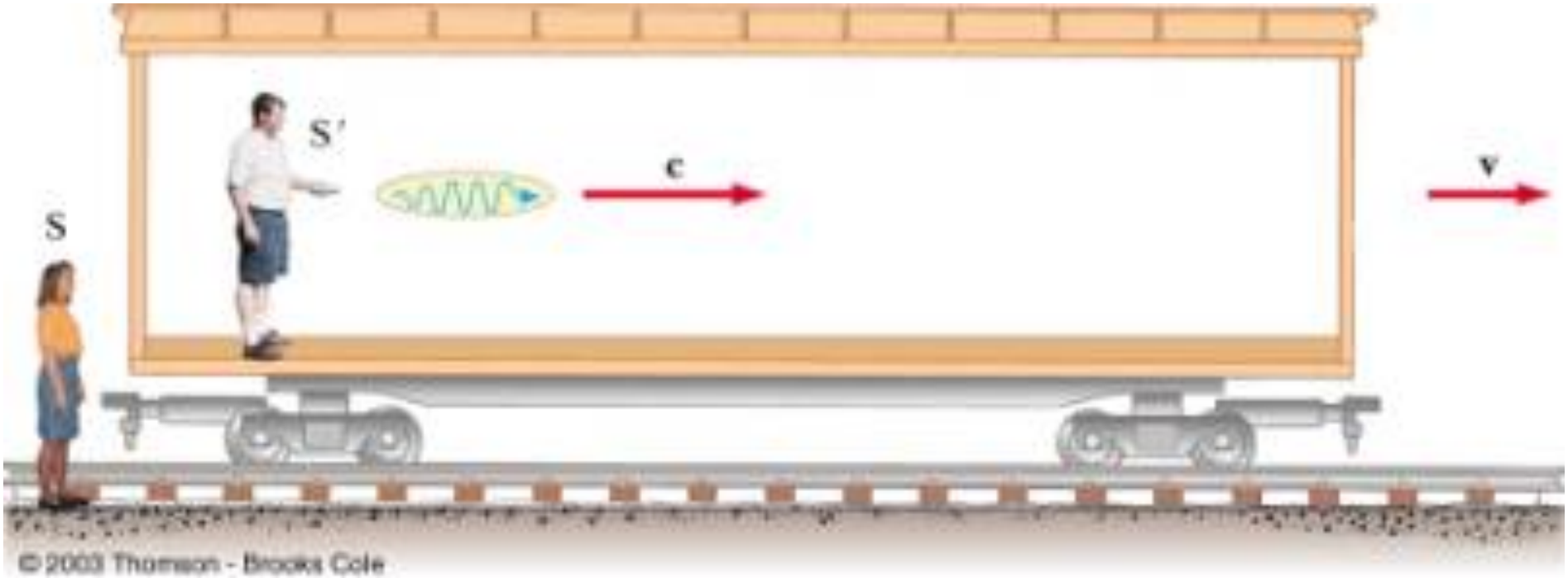




Filmato michelson static

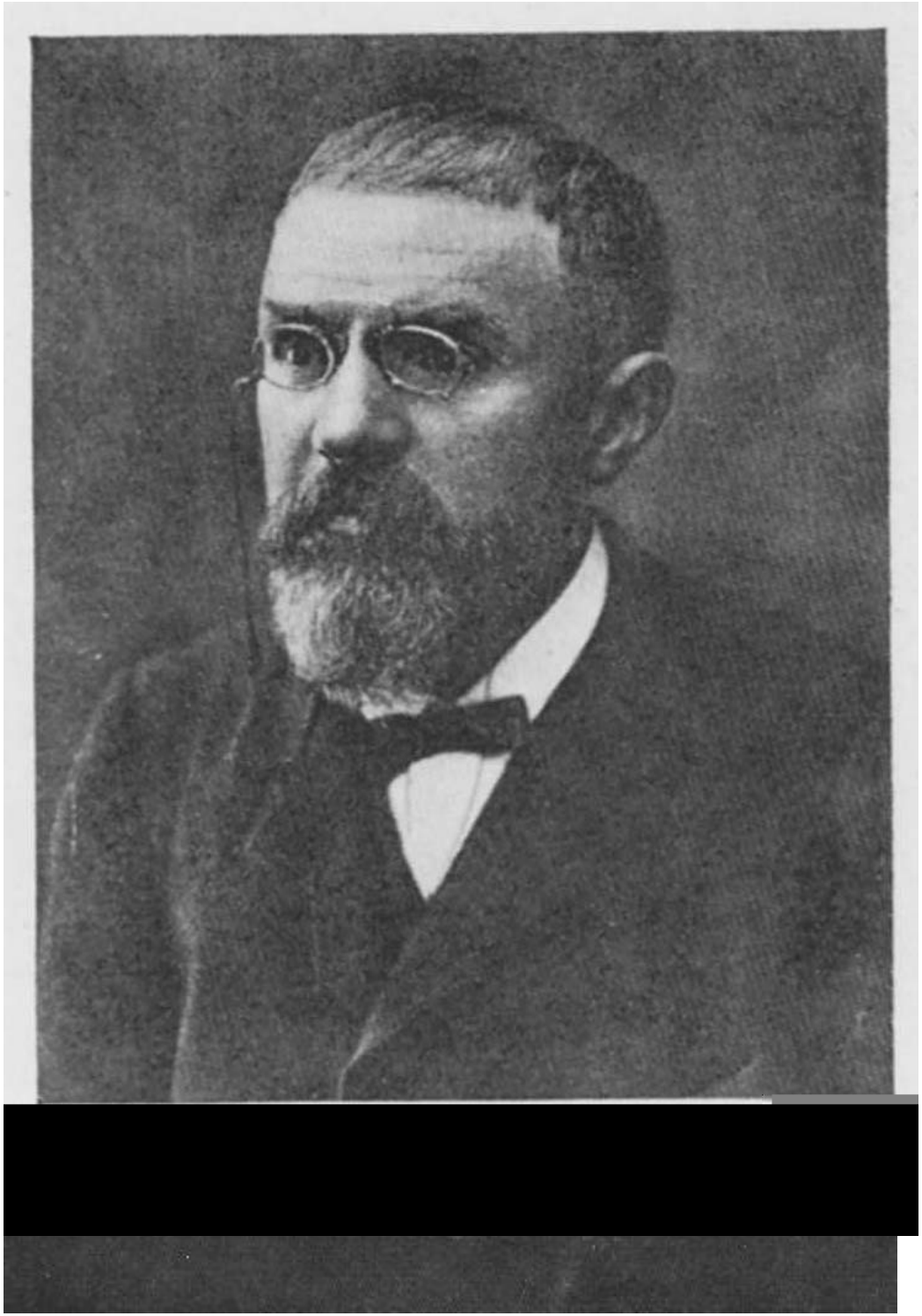
ESPERIMENTO DI MICHELSON-MORELEY
1887

Filmato michelson dinamico



Se il treno viaggia a velocita' v
la luce viaggia a velocita' c rispetto al ragazzo
la luce viaggia a velocita' c+v rispetto
alla ragazza

Non e' vero!



Lorentz: in qualche modo il treno si restringe

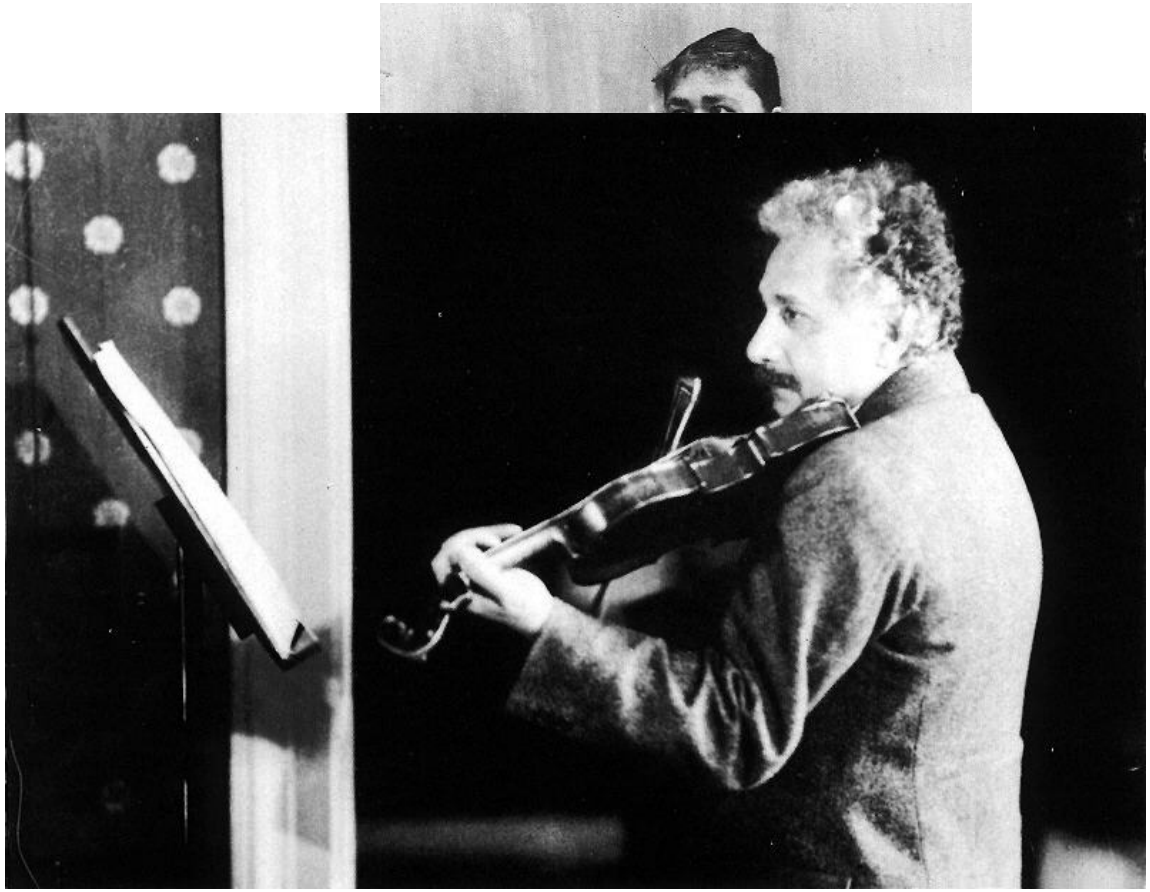
Poincare': gli orologi si de-sincronizzano

EINSTEIN A 4 ANNI

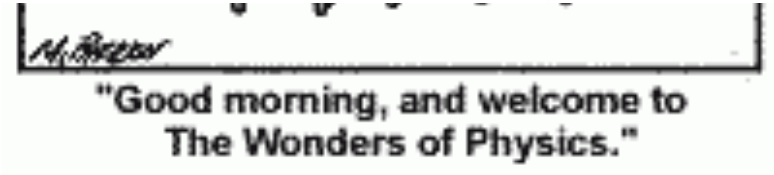
MICHELE BESSO
(1873-1955)

Hermann Ein

Pauline Einstein



Mileva Maric (1875-1948)



Lo zio Jakob Einstein

Der Erziehungsrat des Kantons Aargau

urkundet hiemit:

Herr Albert Einstein, aus Ulm,

geboren den 14. März 1879,

besuchte die aargauische Kantonsschule 4 Jahre die III. & IV. Klasse der Gewerbeschule.

Nach abgelegter schriftl. & mündl. Maturitätsprüfung am 18., 19. & 21. September, sowie am 30. September 1896, erhielt derselbe folgende Noten:

1. Deutsche Sprache und Litteratur	5
2. Französische " " "	5
3. Englische " " "	—
4. Italienische " " "	5
5. Geschichte	6
6. Geographie	4
7. Algebra	6
8. Geometrie [Planimetrie, Stereometrie, Sphärometrie & analytische Geometrie]	6
9. Darstellende Geometrie	6
10. Physik	6
11. Chemie	5
12. Naturgeschichte	5
*13. Im Freihandzeichnen	4
*14. Im technischen Zeichnen	4

*Nicht gelten die Fachklassennoten.

Gestützt hierauf wird demselben das Zeugnis der Reife erteilt.

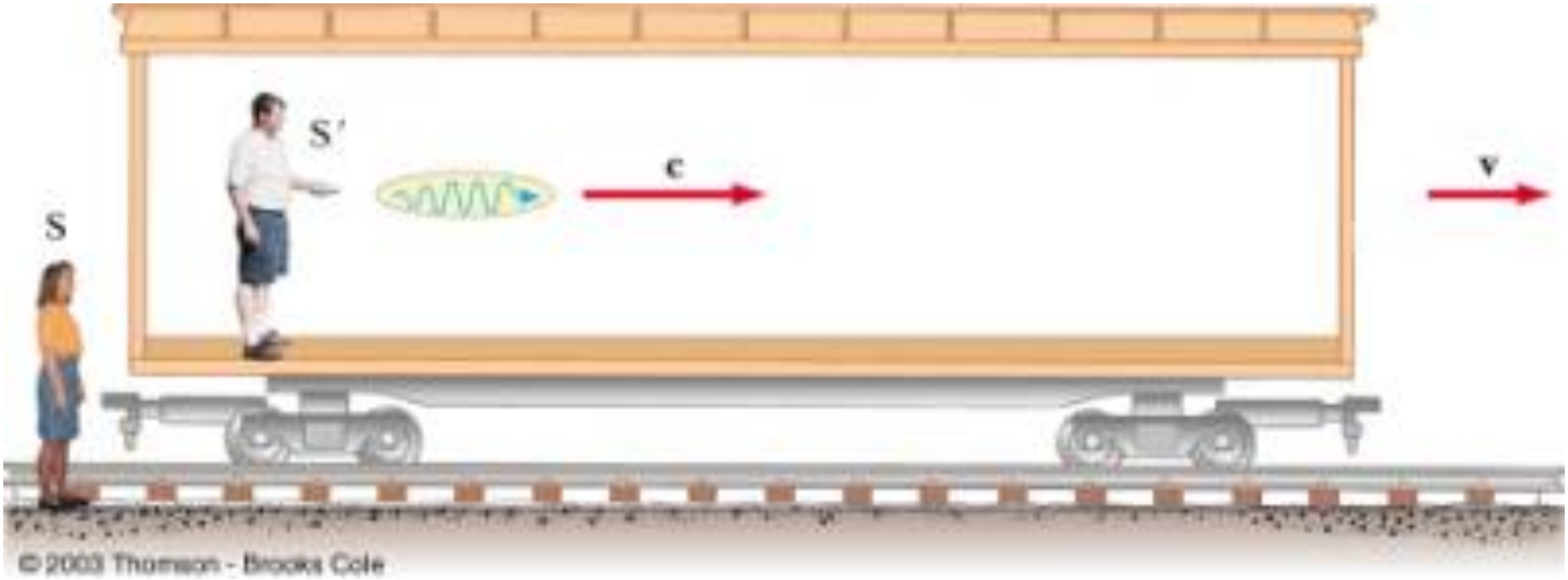
Aarau, den 3. Oktober 1896.

1905 I balbettii di un impiegato di Zurigo

In tutti i sistemi di riferimento inerziali valgono le stesse leggi

La velocita' della luce e' identica in tutti i sistemi ed e' invalicabile

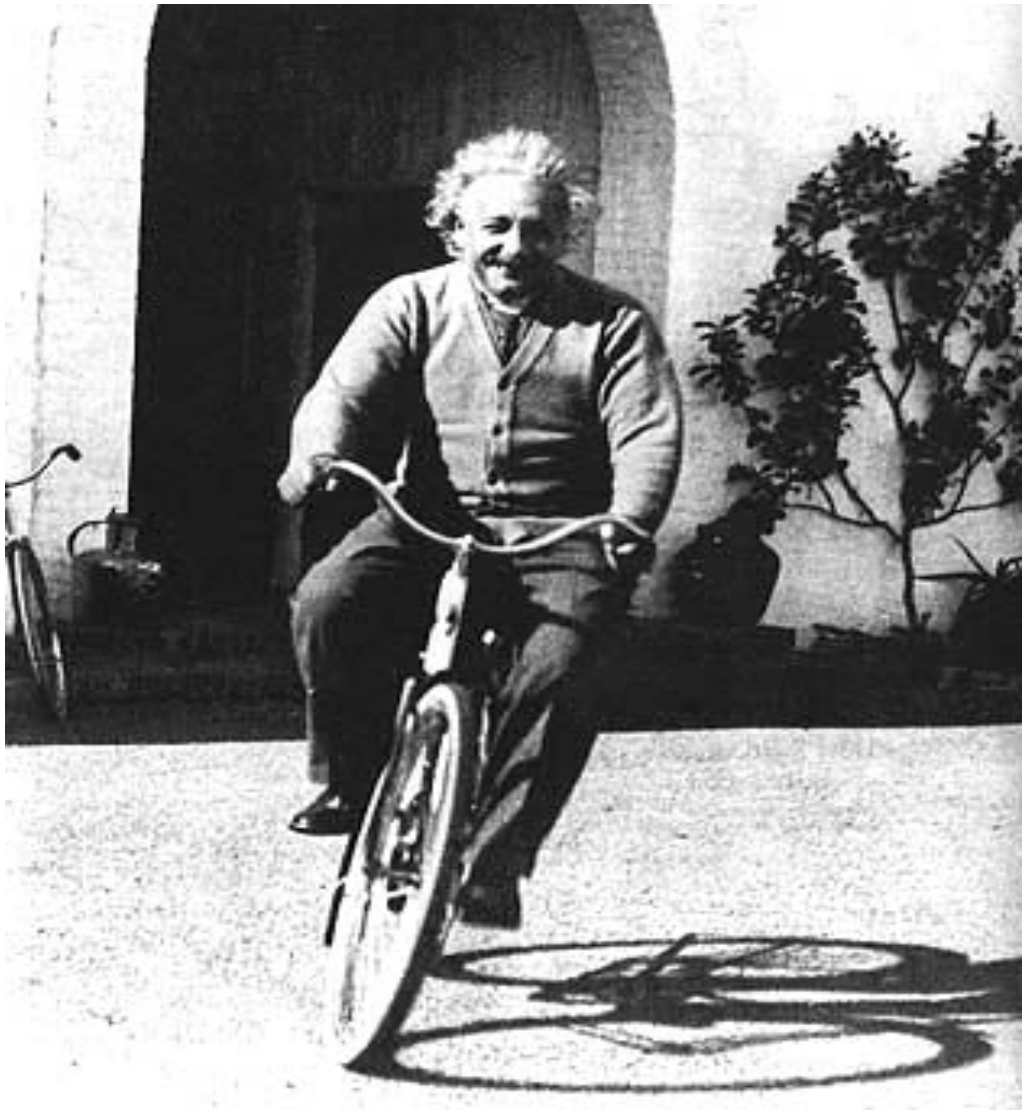
Il tempo e lo spazio sono relativi



Se il treno viaggia a velocita' v
la luce viaggia a velocita' c rispetto al ragazzo
la luce viaggia a velocita' ~~c+v~~ rispetto
alla ragazza

c

Effetti relativistici della velocita’



TRASFORMAZIONI DI LORENTZ

TEMPO E SPAZIO
SONO MISCHIATI!!

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$y' = y$$

$$z' = z$$

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

$$u_x' = \frac{dx'}{dt'} = \frac{\gamma(dx - vdt)}{\gamma\left(dt - \frac{vdx}{c^2}\right)}$$

$$= \frac{\frac{dx}{dt} - v}{1 - \frac{vdx}{c^2 dt}} = \frac{u_x - v}{1 - \frac{vu_x}{c^2}}$$

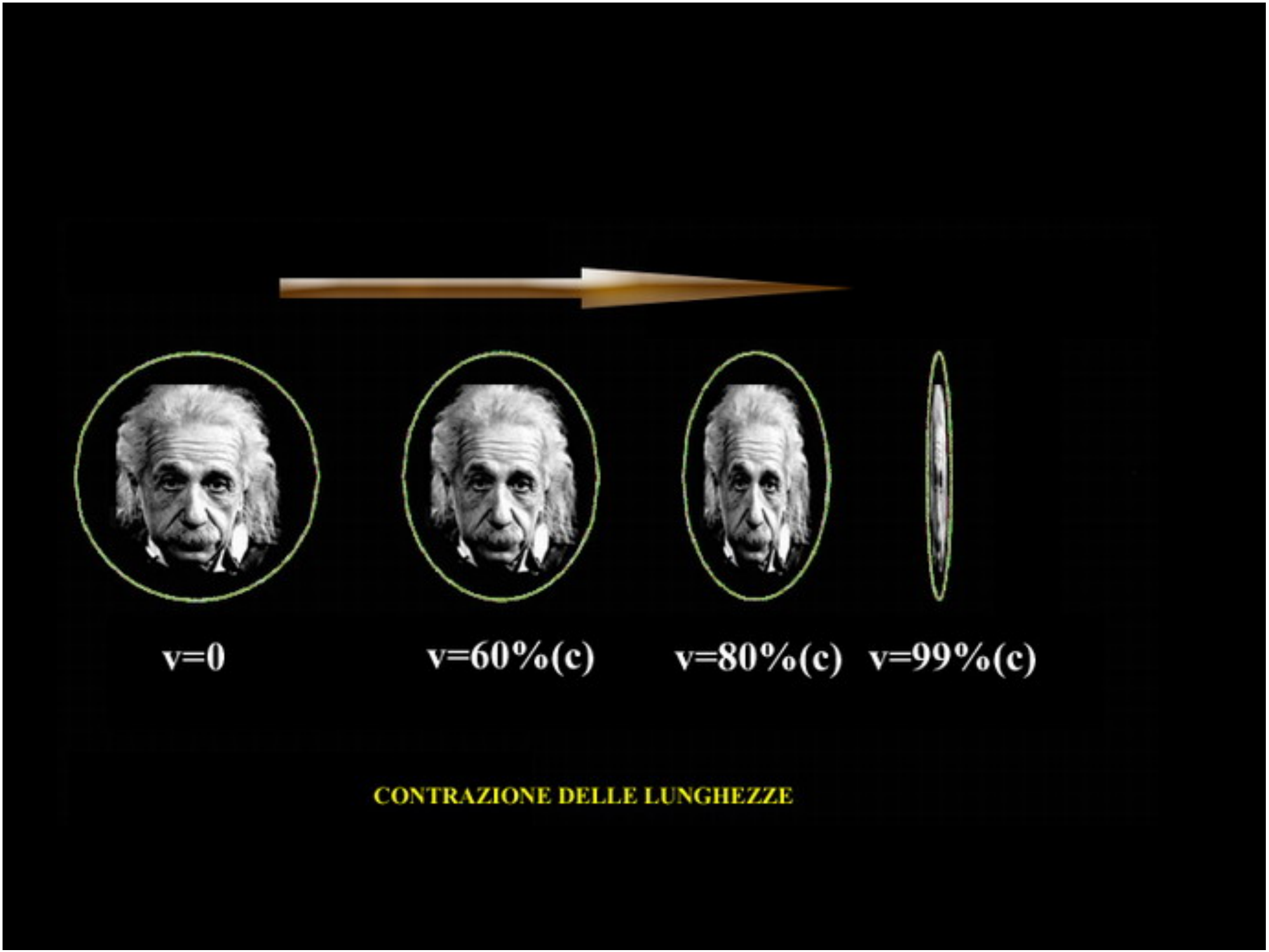
$$\text{or} \quad u_x = \frac{u_x' + v}{1 + \frac{vu_x'}{c^2}}$$

Time Dilation and Length Contraction in Geometric Units

Writing velocity v in geometric units as $\beta = v/c$, we have:

$$\Delta t = \frac{1}{\sqrt{1-\beta^2}}\Delta t' \qquad \text{and} \qquad L = L'\sqrt{1-\beta^2}\ .$$

Dilatazione del tempo contrazione delle distanze

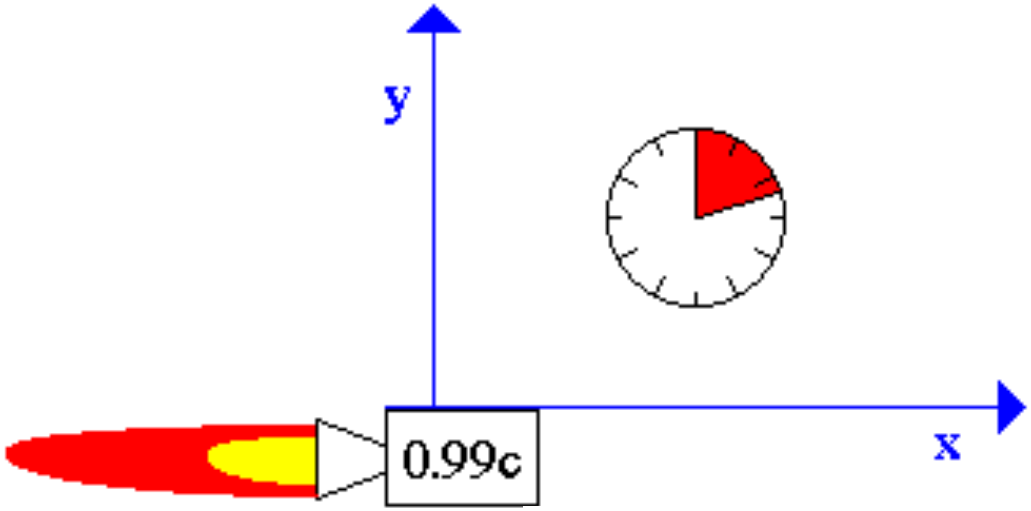

v=0
v=60%(c)
v=80%(c)
v=99%(c)
CONTRAZIONE DELLE LUNGHEZZE

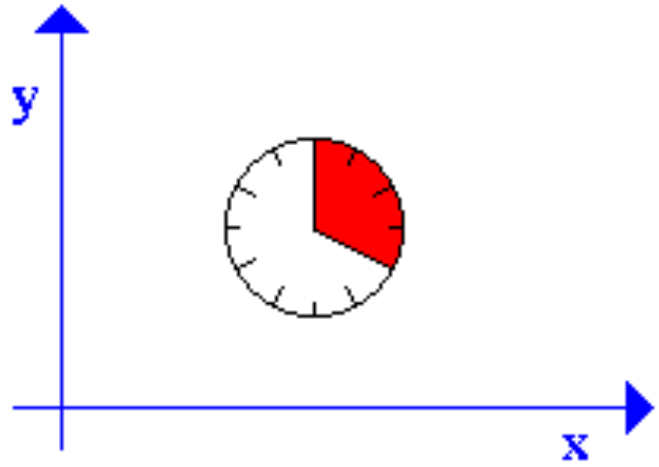
Velocita’ normale

Velocita’ 0.99 c

Il tempo e' una quantita' relativa

Time Dilation





$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

clocks run slower as one approaches the speed of light

PARADOSSO DEI GEMELLI

$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

PARADOSSO DEI GEMELLI

$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

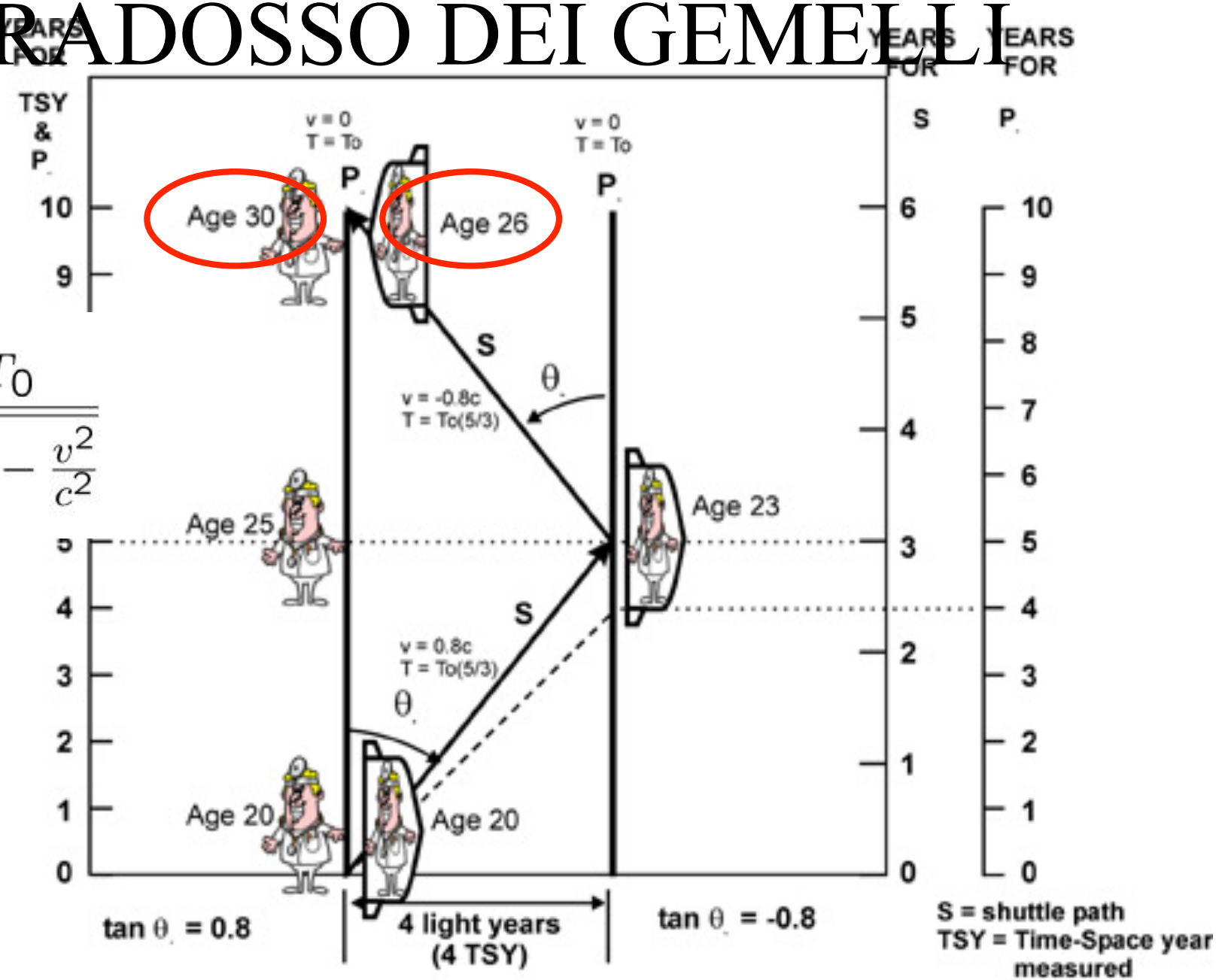


Fig. 1 SPACE PORTS STATIONARY TO FIXED SPACE

Un astronauta viaggia alla velocita' di 240.000 km/s (864 milioni di km/h) per dieci anni (della Terra)

I due gemelli alla partenza hanno 20 anni.

Quindi al ritorno dell'astronauta il gemello rimasto sulla Terra avra' 30 anni

240.000 km/s e’ 80% (0.8) della velocita’ della luce

Durata del viaggio
Secondo l’astronauta

$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Durata del
Viaggio secondo
Il terrestre

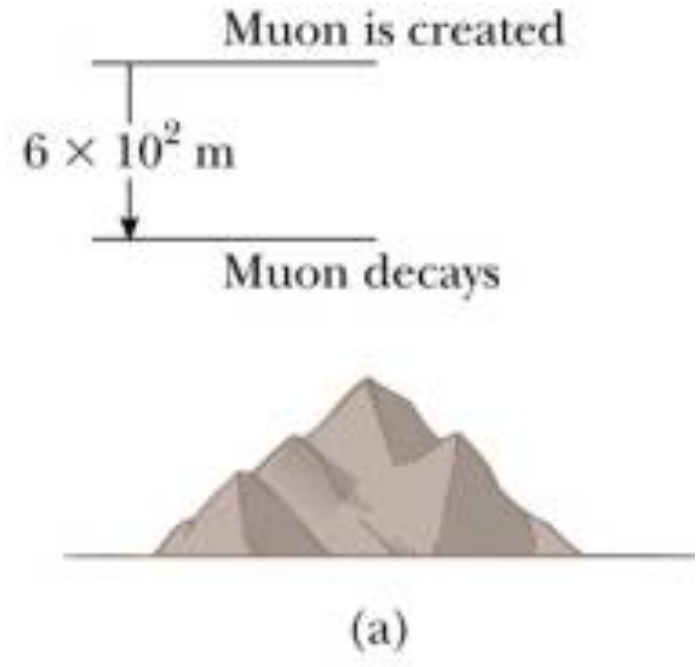
$$T = \frac{T0}{\frac{V}{1-0.64}}$$

$$T = 1.67\ T0 \qquad \text{oppure } T/0.6 = T0$$

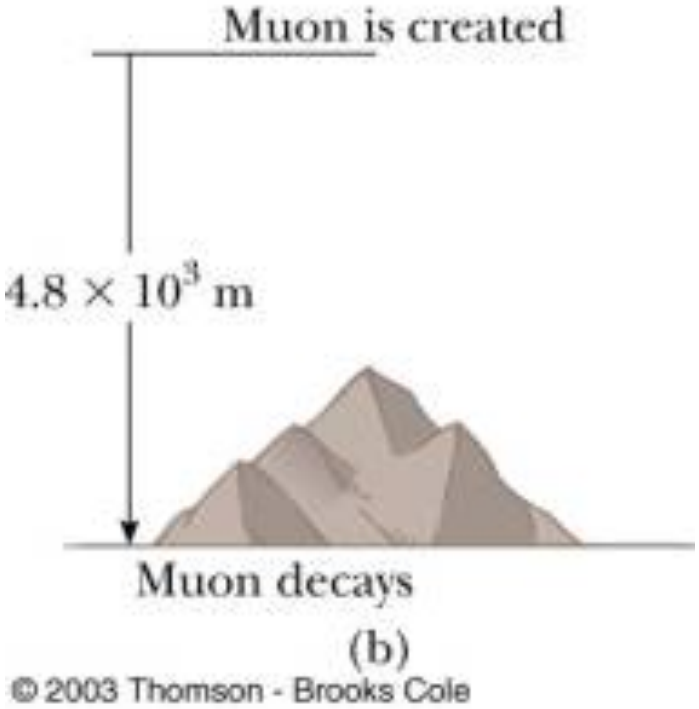
Eta' terrestre $=20+T=20+10=30$ anni

Eta' astronauta $=20+T0=20+T/0.6=$

$20+10/0.6=20+6=26$ anni



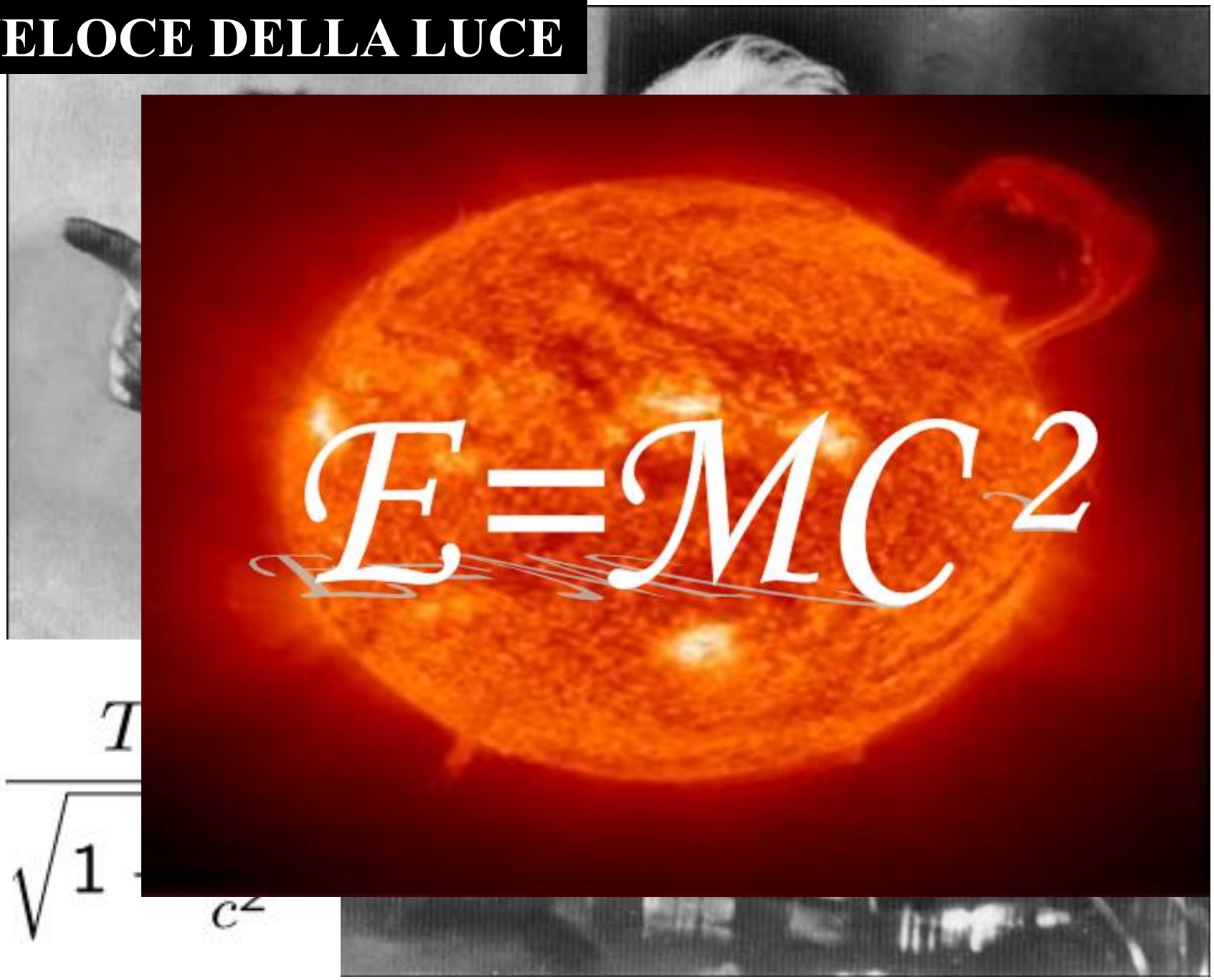
I muoni sono creati nell'alta atmosfera e viaggiano a velocita' prossime a quelle della luce



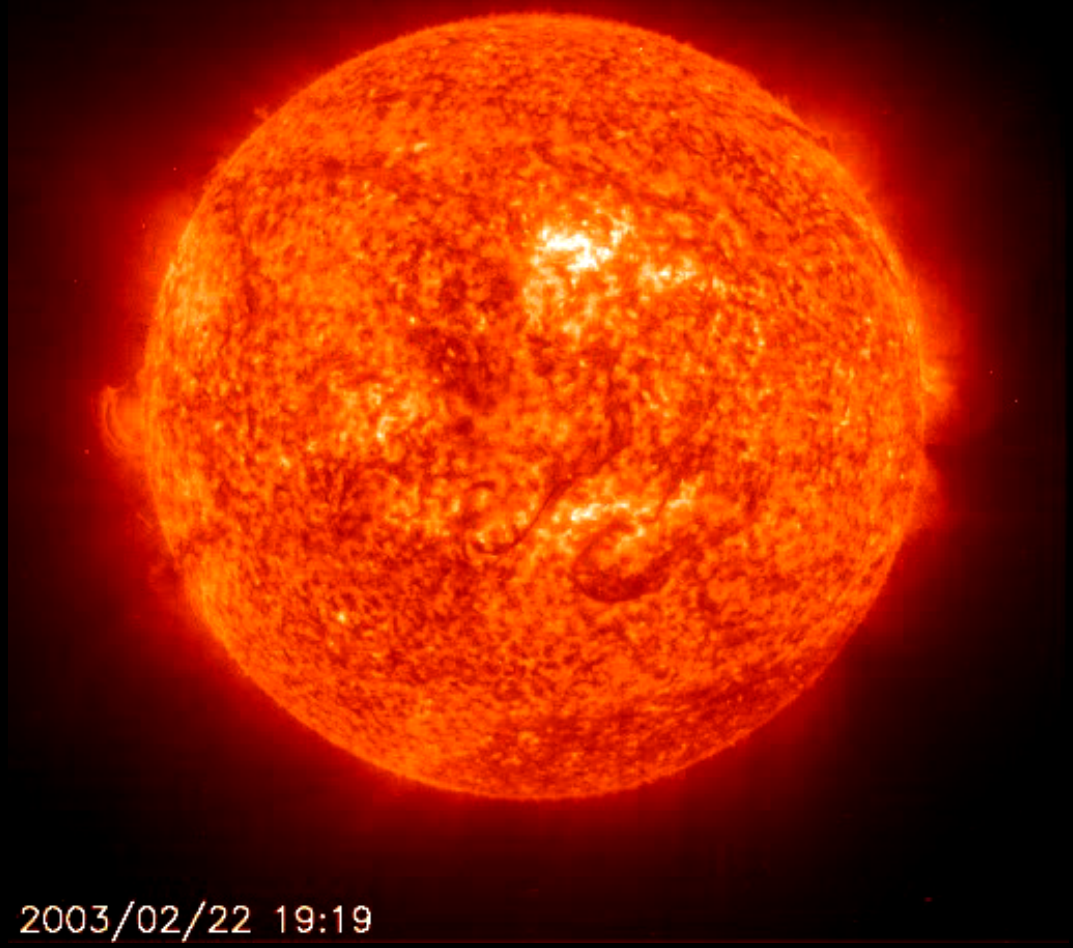
I loro "orologi" sono 10 volte piu' lenti

$$T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

NON SI PUO' VIAGGIARE PIU' VELOCE DELLA LUCE



$$T = \frac{T}{\sqrt{1 - \frac{}{c^2}}}$$



Il Sole è una stella di colore giallo perché la sua temperatura alla superficie è di 5800 gradi.

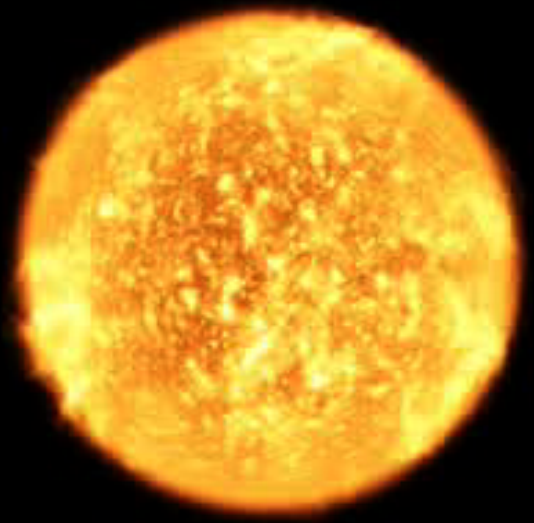
Ha una massa di

$2 \cdot 10^{30}$ Kg

Ha una luminosità di

$4 \cdot 10^{26}$ Watt

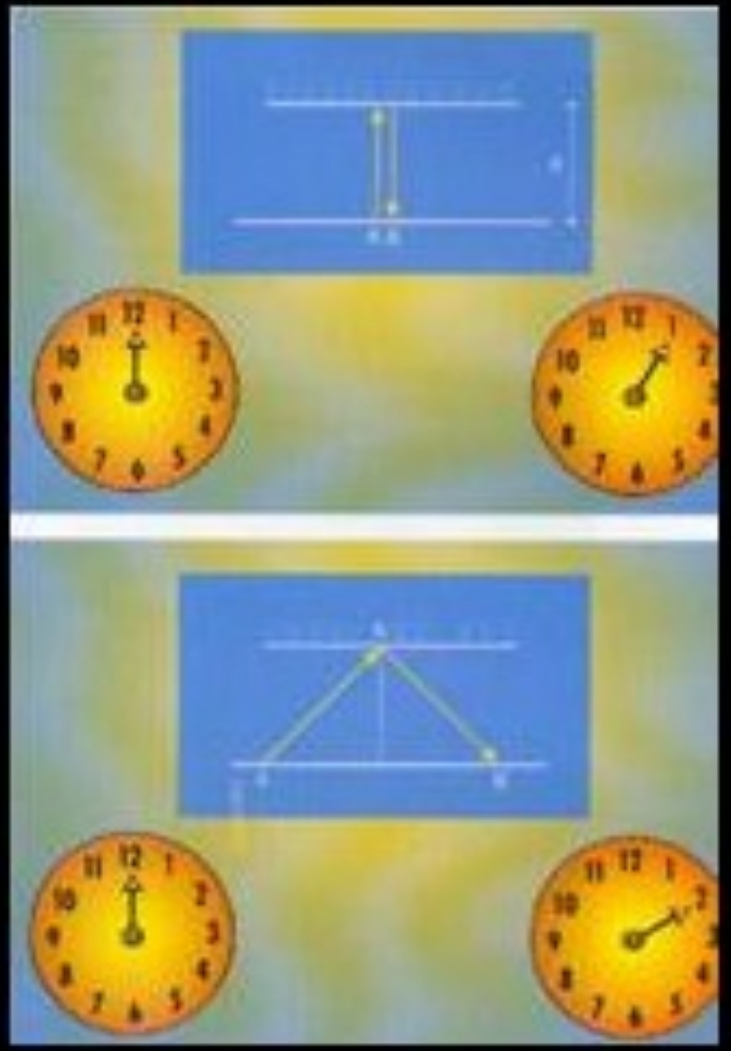
400.000.000.000.000.000.000.000.000 Watt

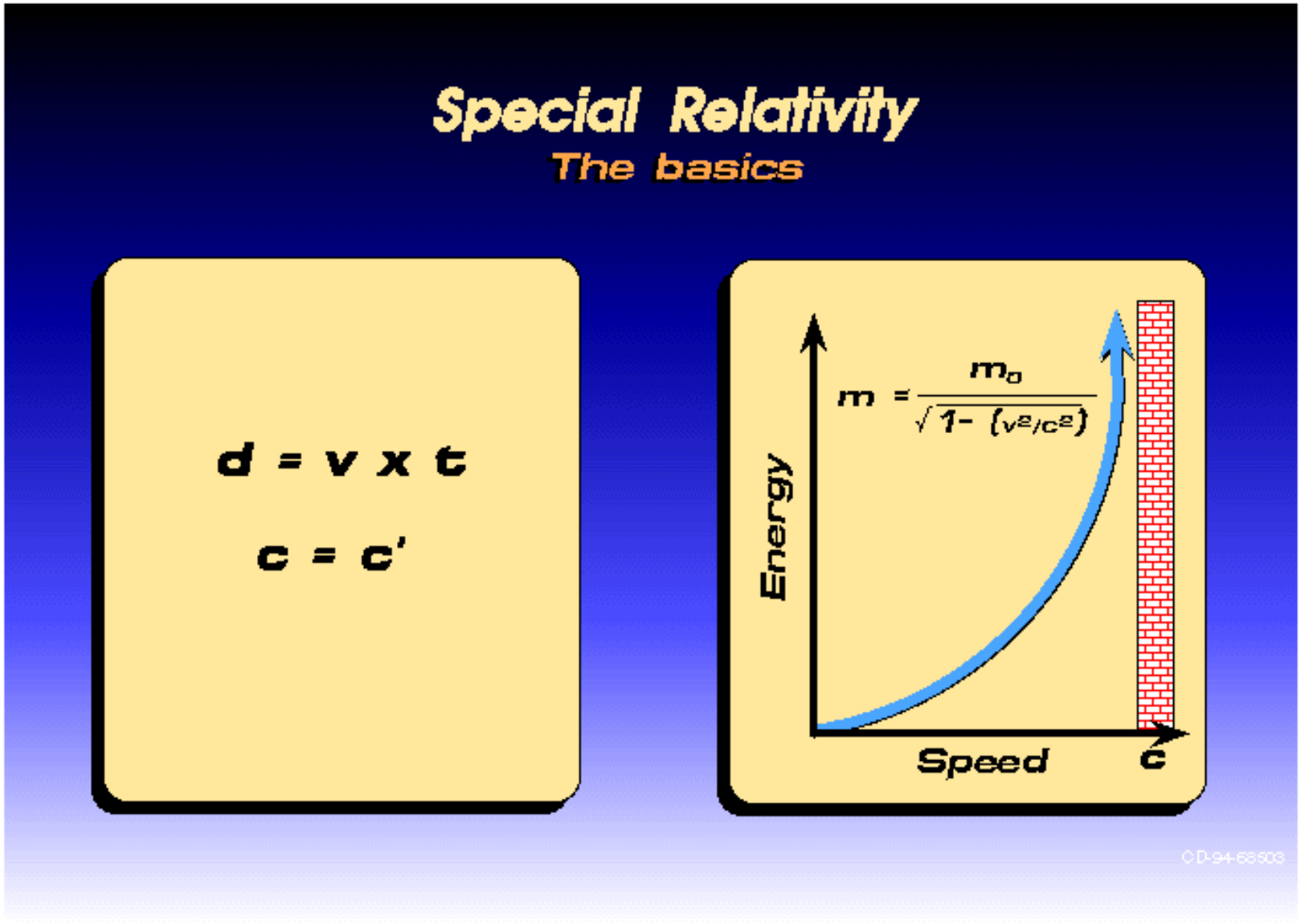


Ogni secondo il Sole “dimagrisce” di 4 milioni di tonnellate

Special Relativity Theory

$$E = \frac{M C^2}{\sqrt{1 - \frac{v^2}{C^2}}}$$



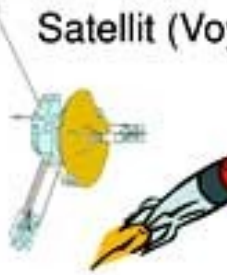


Velocita' della luce e' un limite assoluto

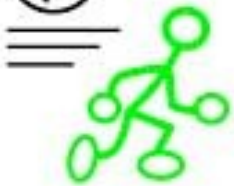
Beschle

Flugzeug

Satellit (Vo



BESSY Elel



Relativistischer Effekt

Auto 100 km/h

Satellit 16 km/s

Elektronen 299 792,40 km/s

Elektronen 299 792,44 km/s

m_0 = 75 kg

75,0000000000003 kg
γ = 1, Δm = 0.3 ng

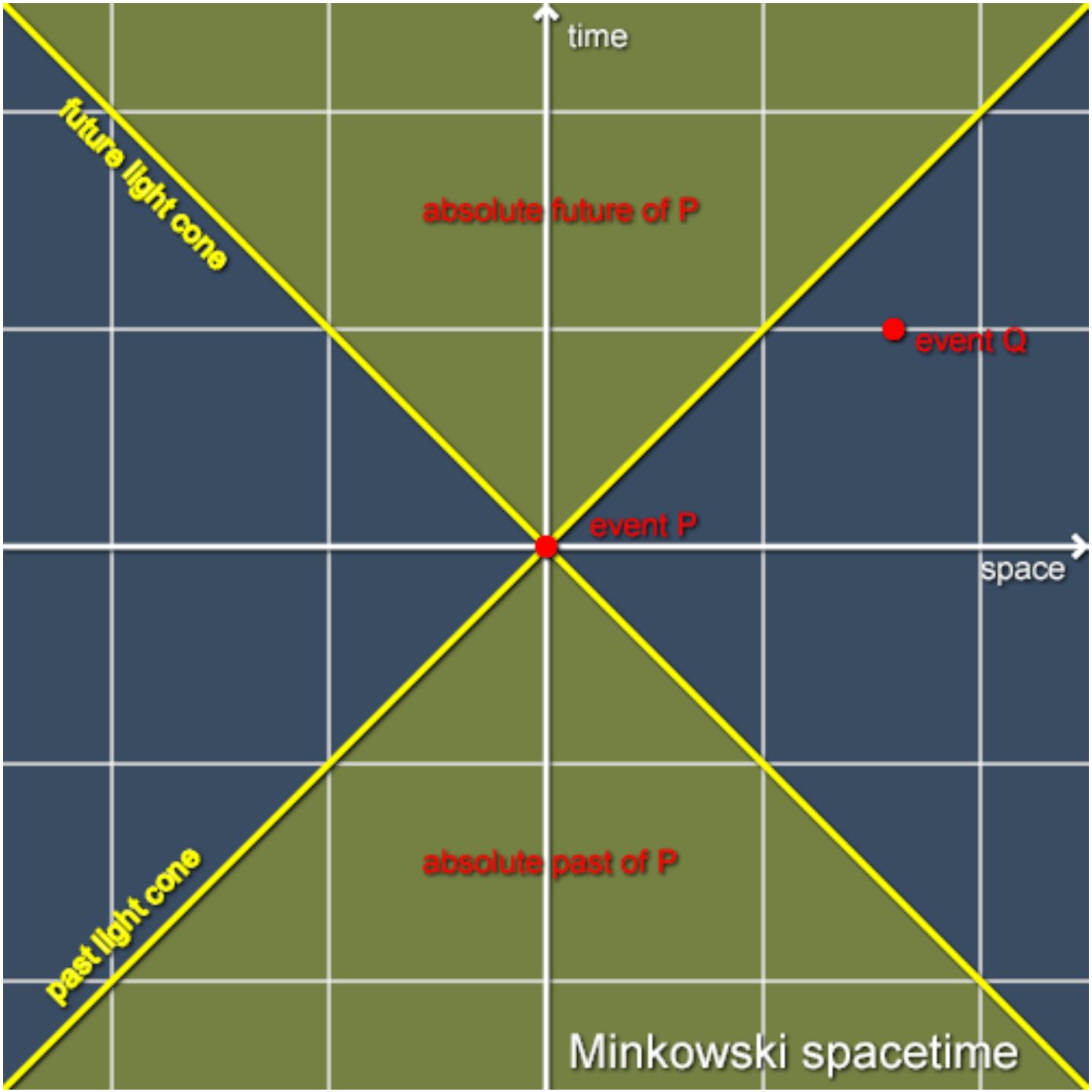
75,0000001 kg
γ = 1, Δm = 0.1 mg

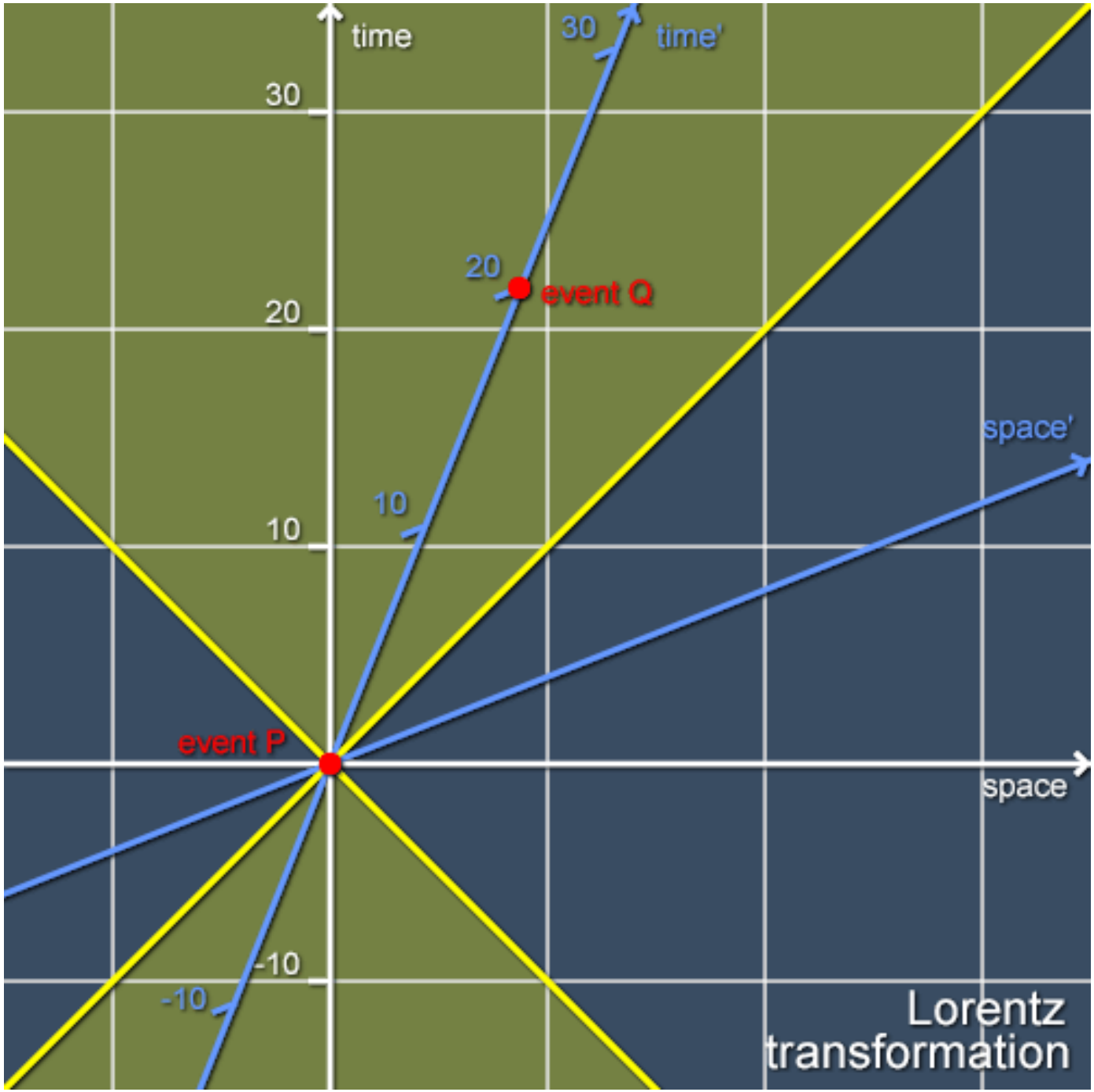
117 417 kg
γ = 1566

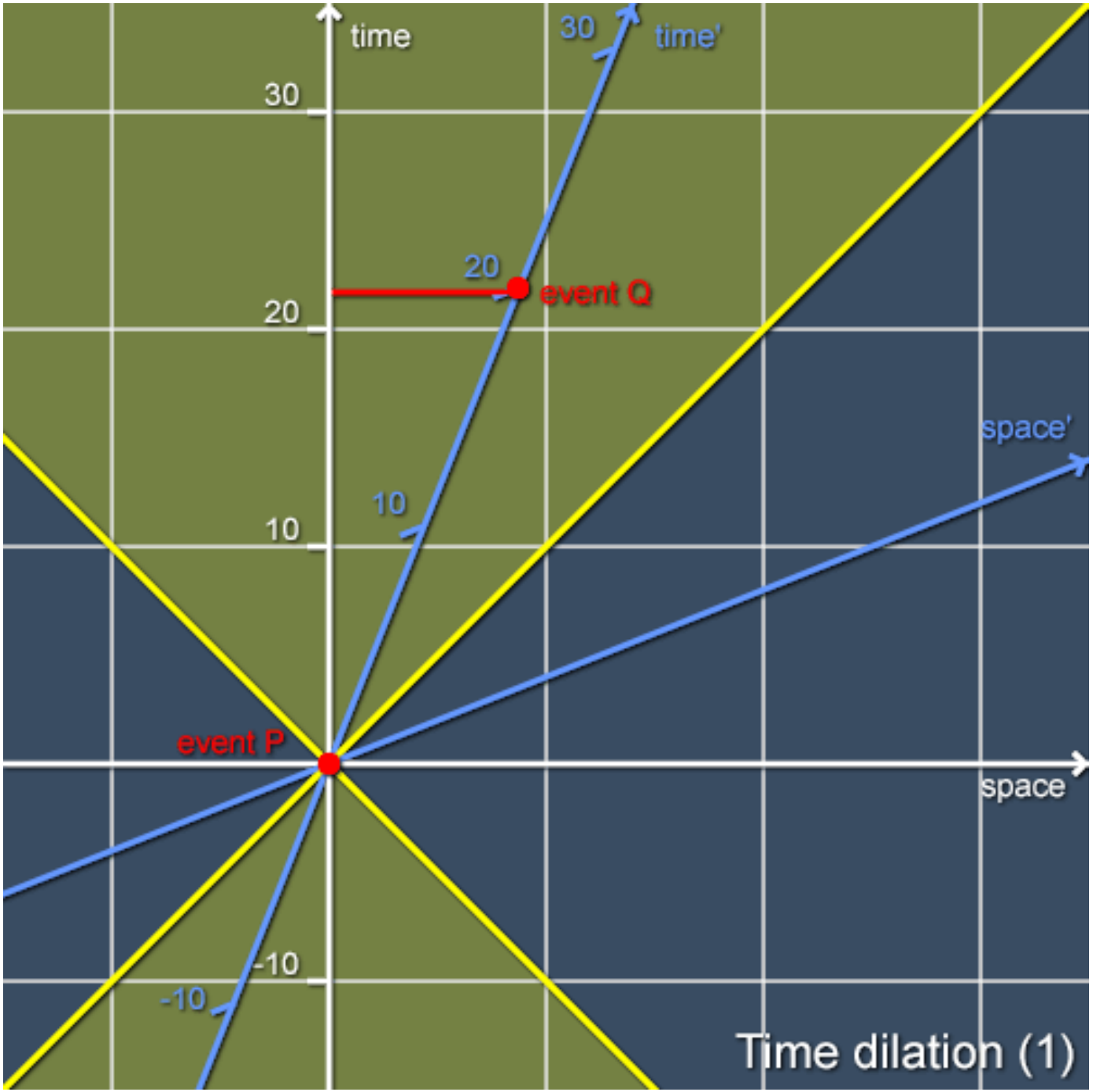
249 511 kg
γ = 3327

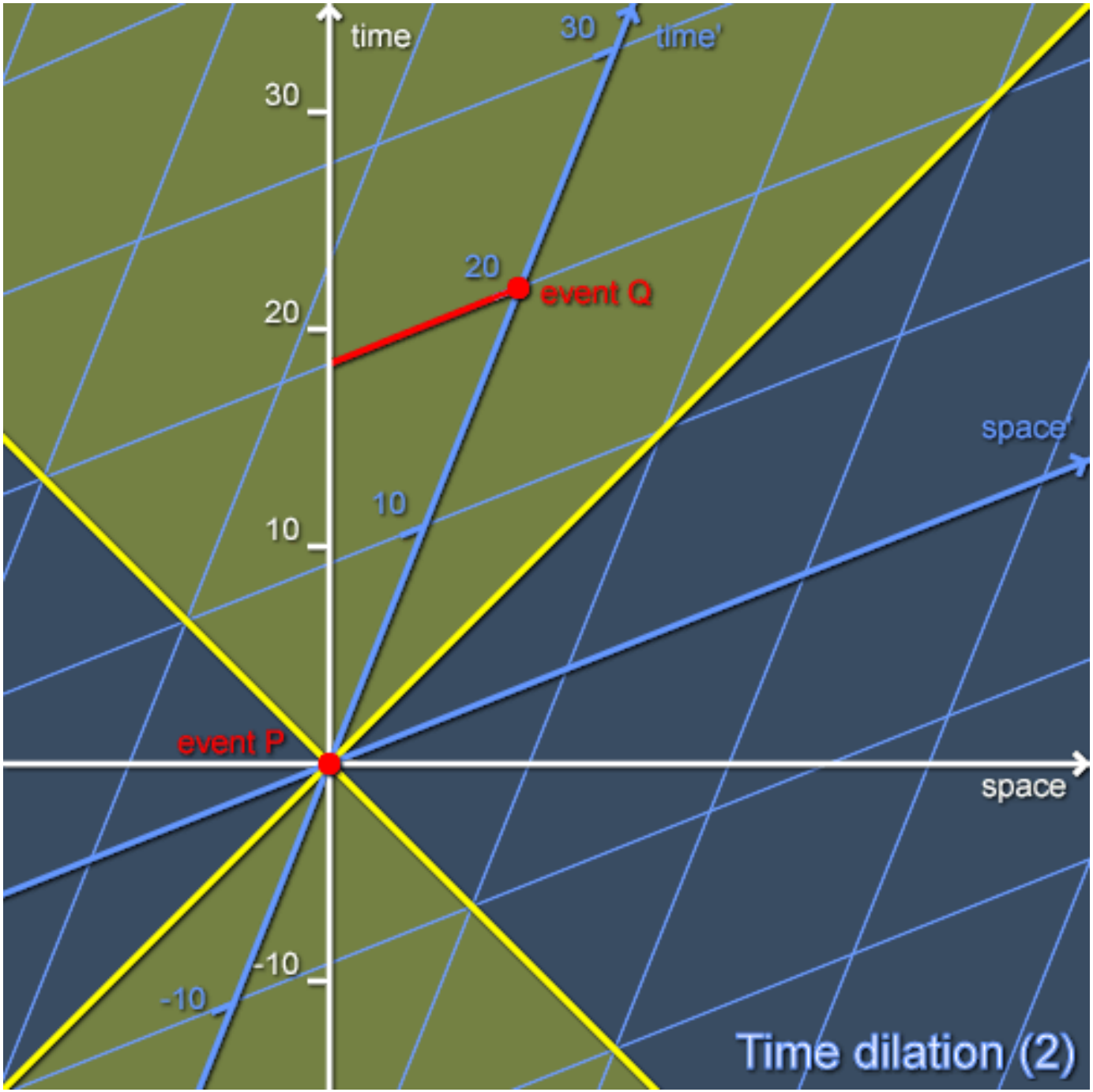
km/s

7.5x/s


time
future light cone
absolute future of P
event Q
event P
space
absolute past of P
past light cone
Minkowski spacetime


time
30
20
10
-10
time'
30
20
10
-10
event Q
event P
space'
space
Lorentz
transformation


time
30
time'
30
20
event Q
20
space'
10
10
event P
space
-10
-10
Time dilation (1)


time
30
time'
30
20
20
event Q
space
10
10
event P
space
-10
-10
Time dilation (2)

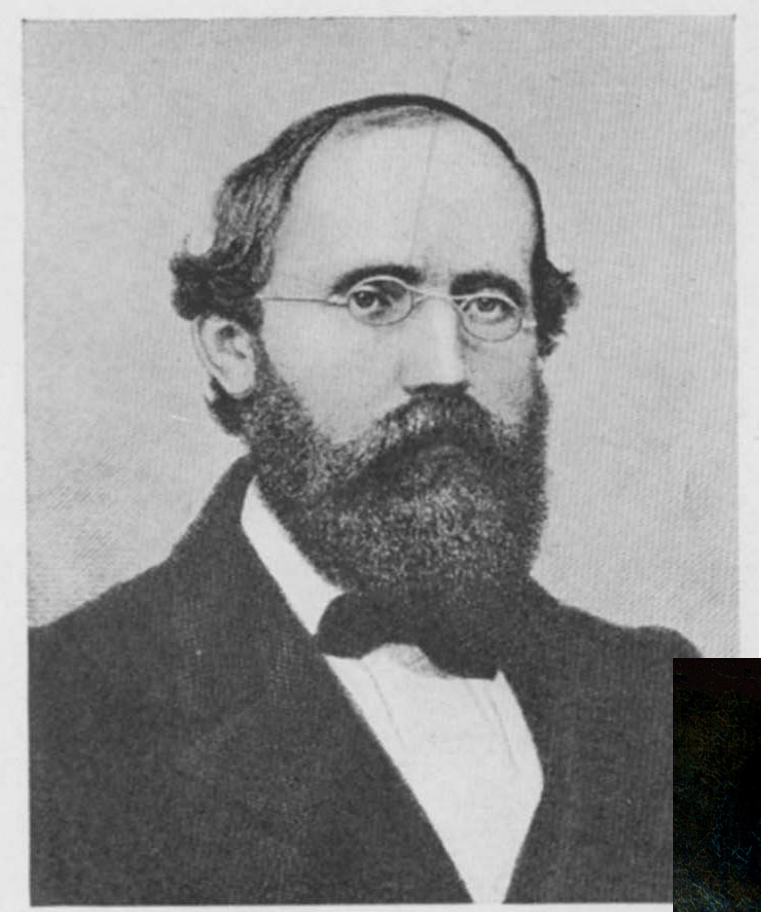
LO SPAZIO

Tre dimensioni:

Altezza
Lunghezza
Larghezza

“giocare” con le dimensioni

Interesse sulla forma della Terra

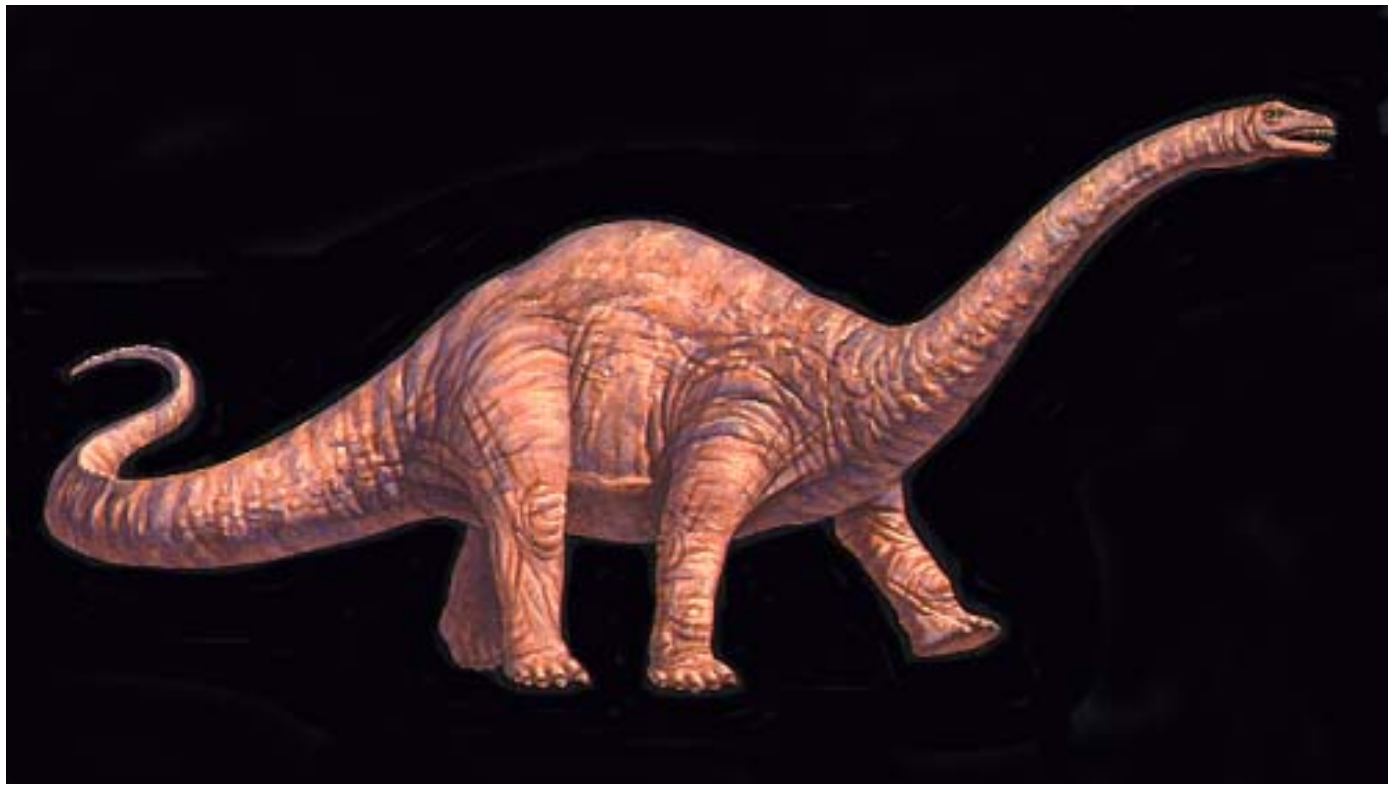


Bernhard Riemann.

Levi-Civita

Gauss

EFFETTI DELLA GEOMETRIA

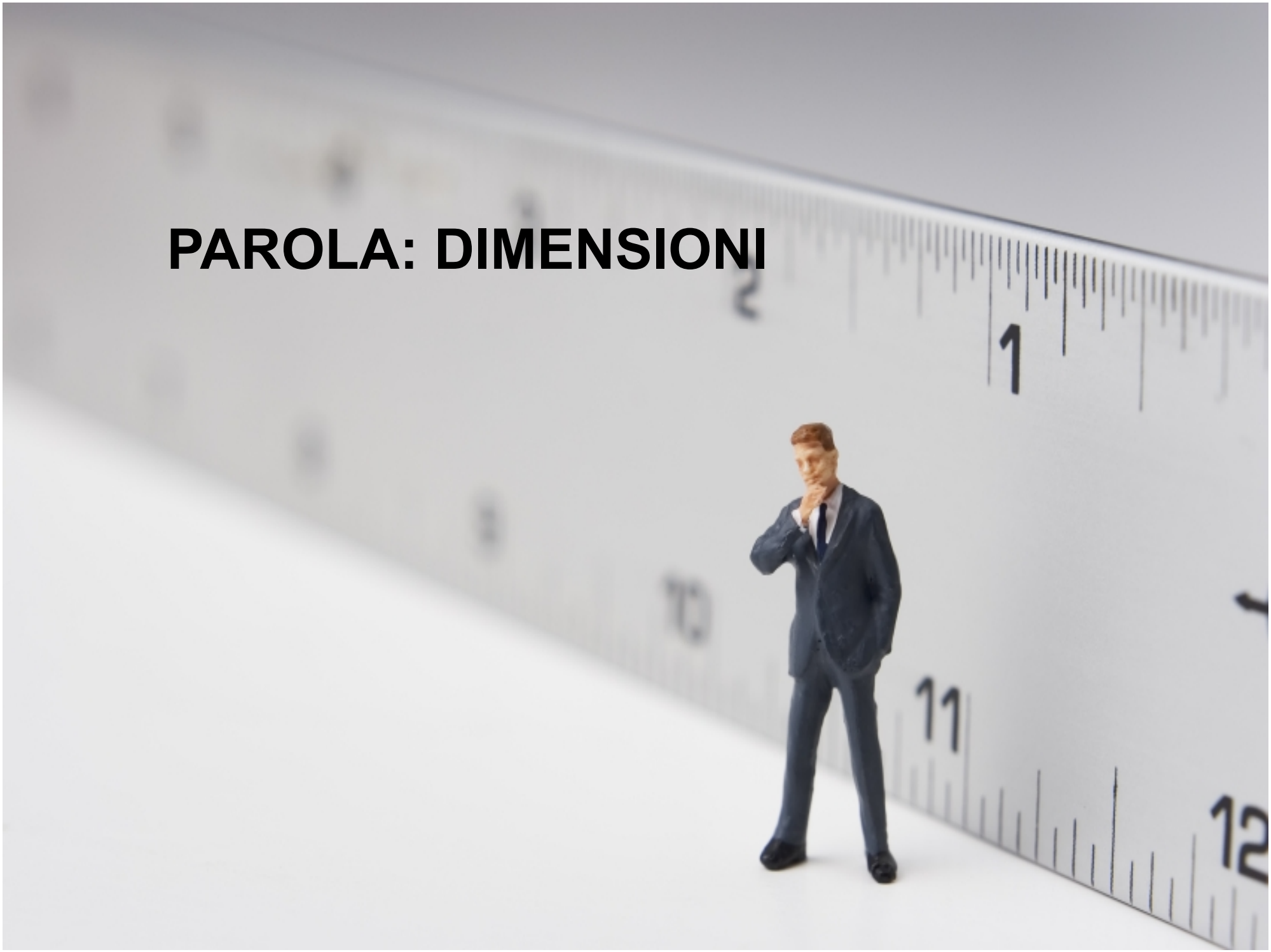


Molto volume, poca area

EFFETTI DELLA GEOMETRIA 2

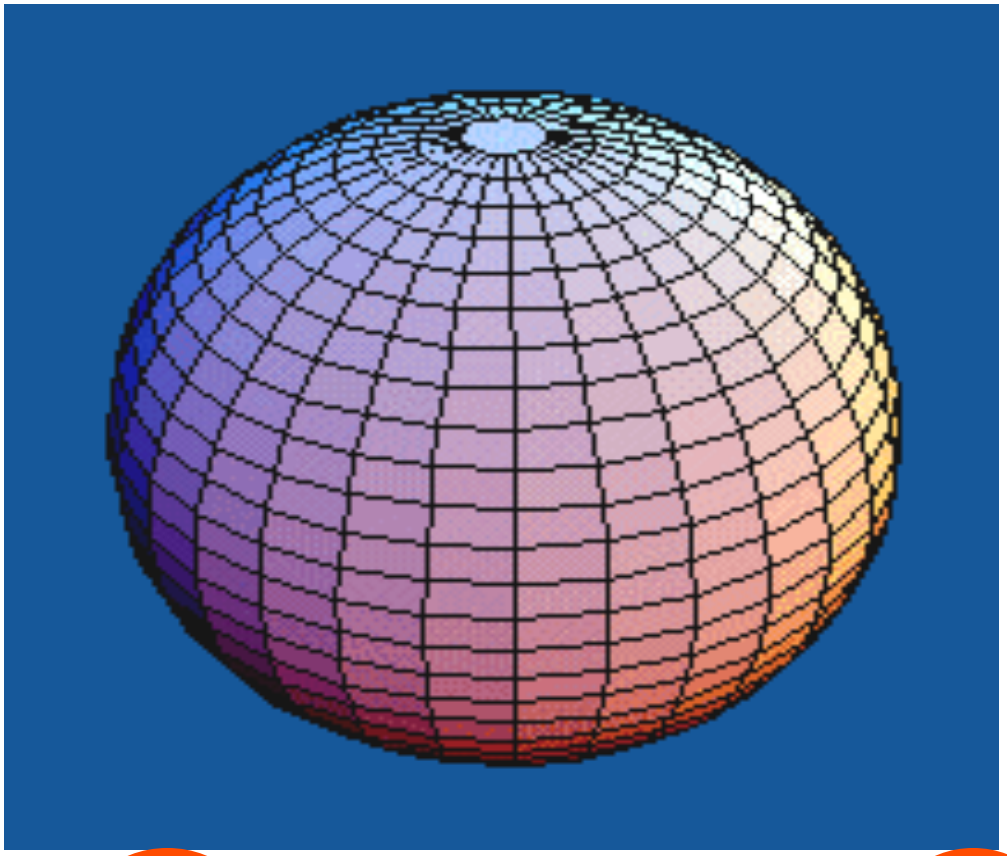
Poco volume, molta area

PAROLA: DIMENSIONI



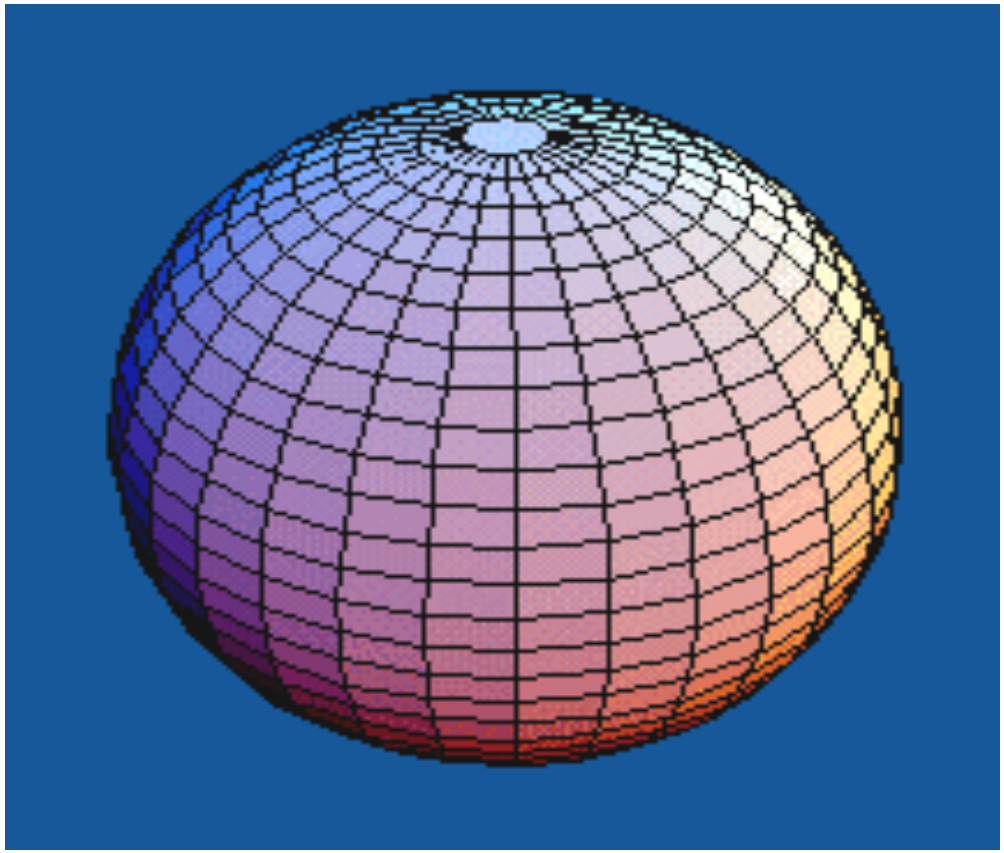
Geometria e Universo

LA SFERA

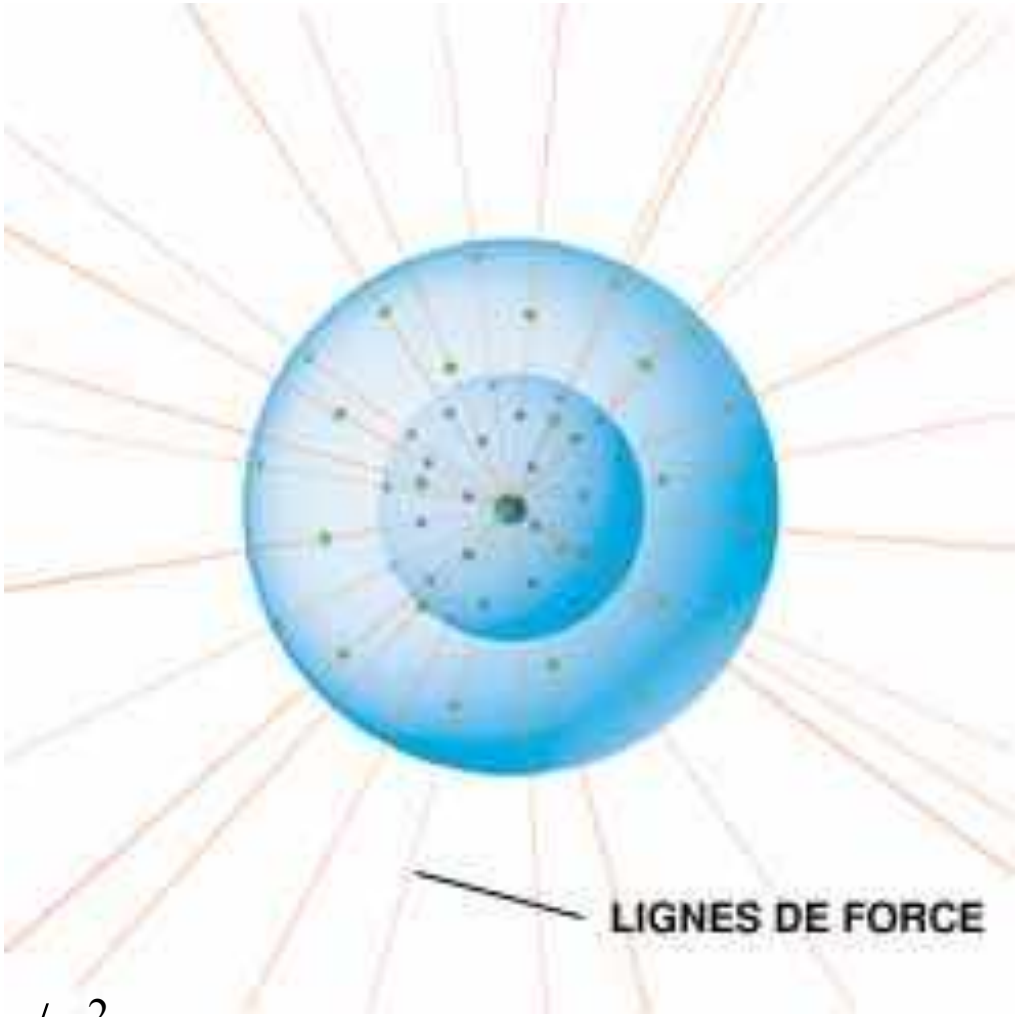


Volume= 4/3 π R^3 **Superficie= 4 π R^2**

Geometria e Universo



Principio cosmologico: L'universo e' omogeneo ed isotropo



$F=G\ m\ m\ /\ r^2$

Edwin Abbott Abbott (1838-1926)

Flatlandia (1884): storia di A. Square

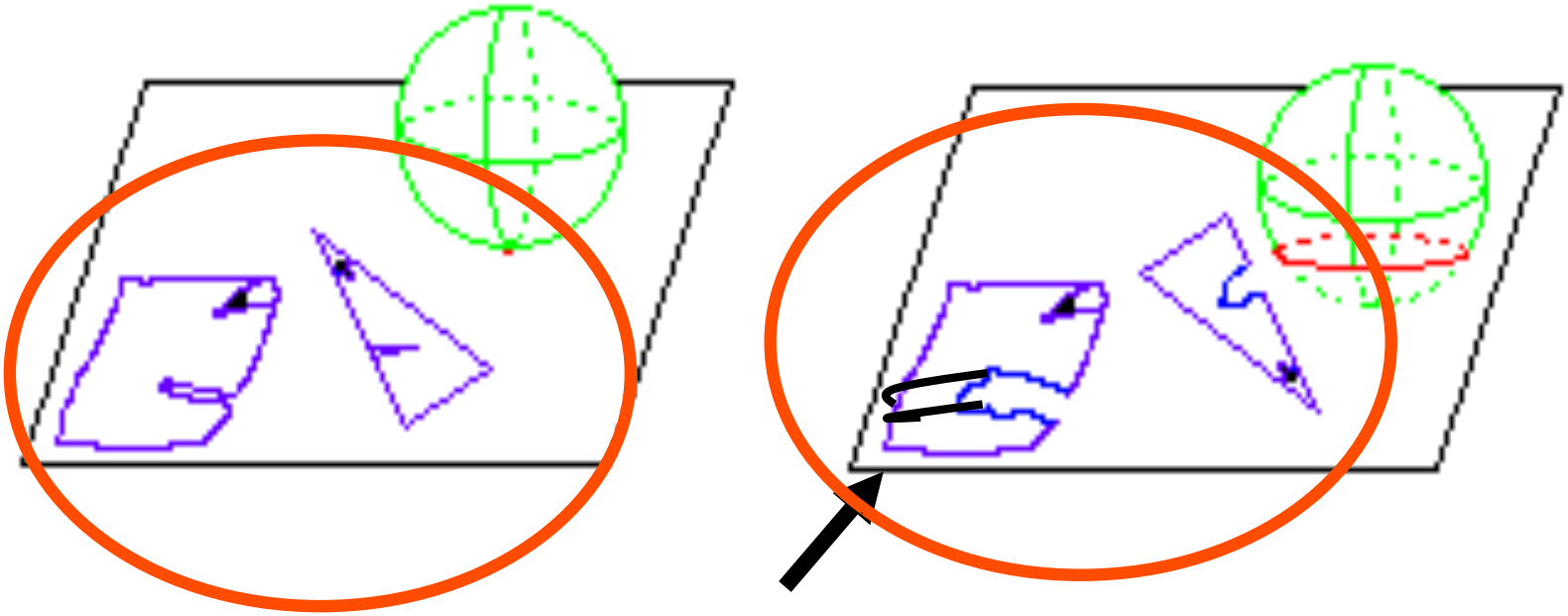
Immaginate un vasto foglio di carta su cui delle linee rette, dei triangoli , dei quadrati ed altre figure geometriche invece di restar ferme al loro posto, si muovano liberamente sulla superficie, ma senza potervisi immergere o sollevare. Cosi' facendo avrete un'idea abbastanza corretta del mio paese e dei miei compatrioti.

Ahime', ancora qualche anno fa avrei detto "del mio universo", ma ora la mia mente si e' aperta a una piu' alta visione delle cose

Imagine A World With Only Two Dimensions

Flatlandia

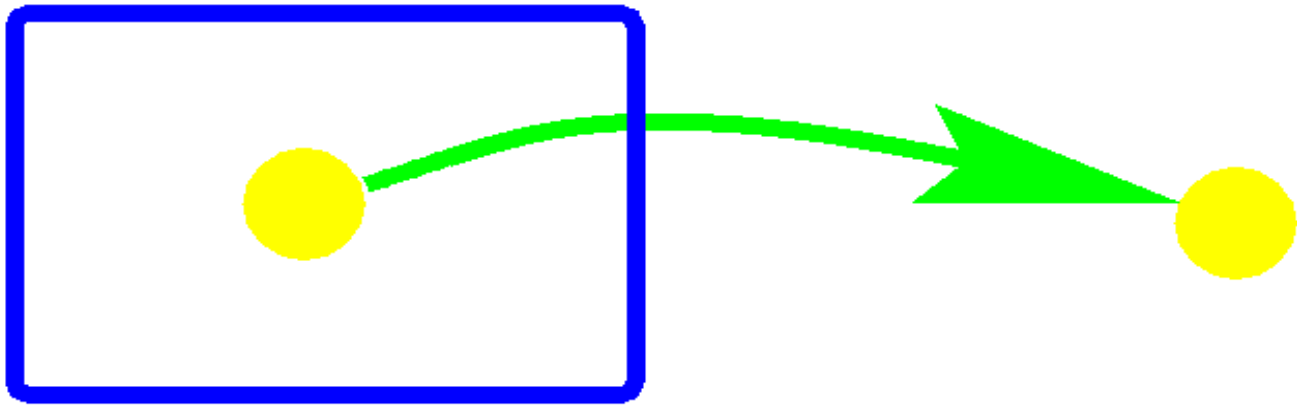
Guardarsi negli occhi (simmetrie):
(i sinistrorsi ed i destrorsi)



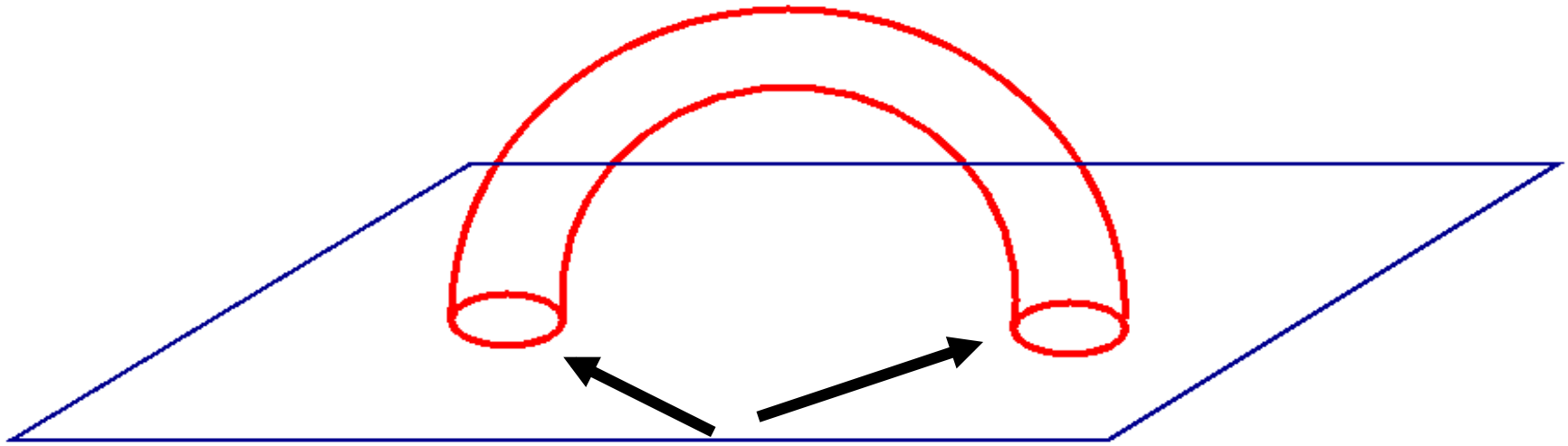
NOTA: PROBLEMI DIGESTIVI


a clip from
flatland the film

Da due a tre dimensioni

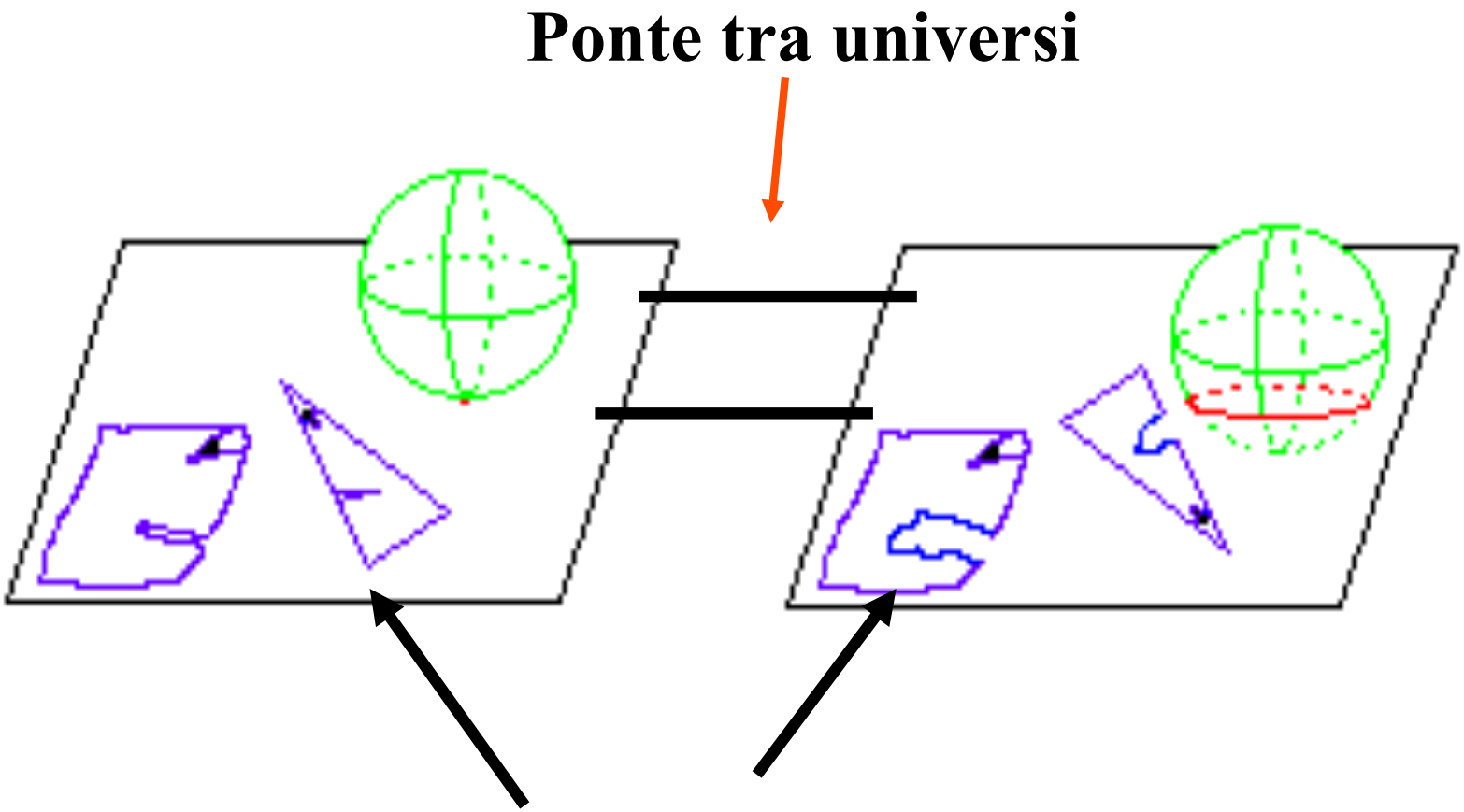


Cassaforte bidimensionale **Furto tridimensionale**



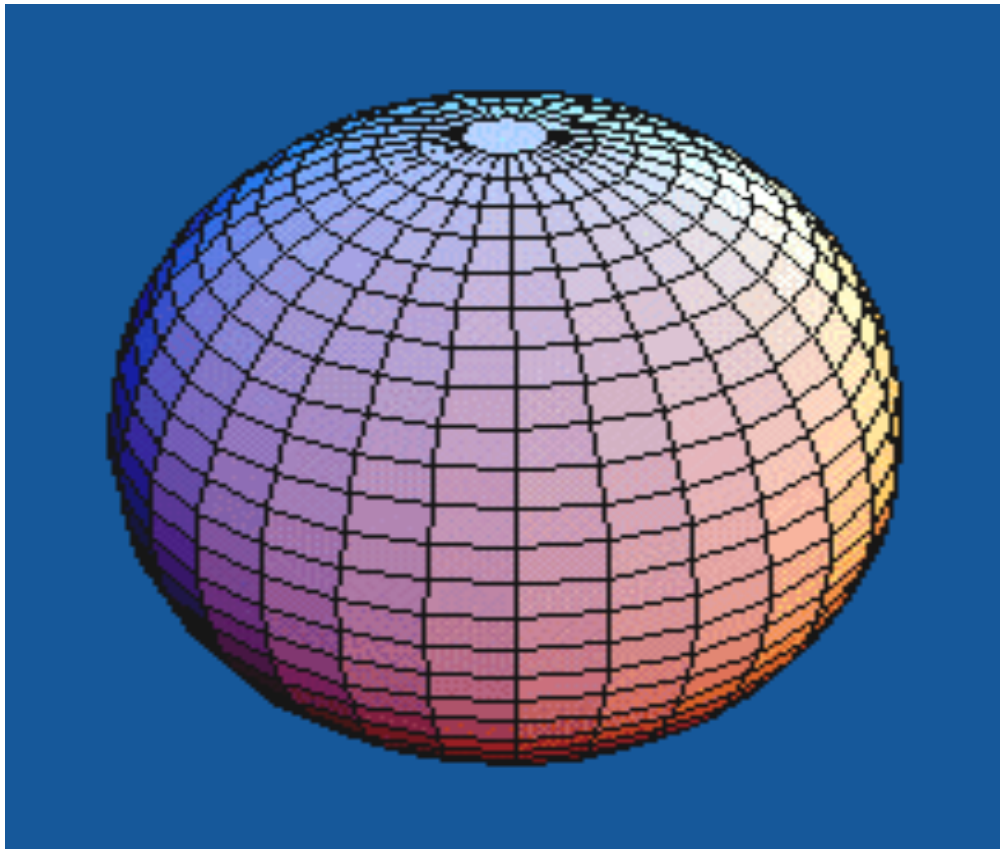
Moltiplicazione dimensionale

Flatlandia



SONO DUE UNIVERSI PARALLELI

Geometria e Universo

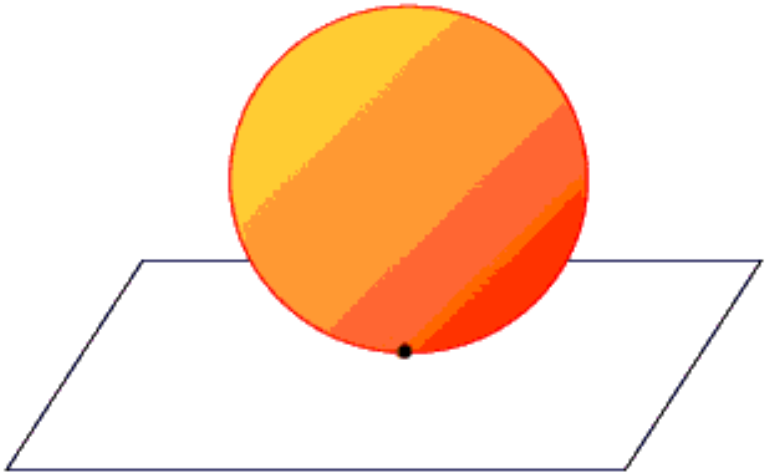


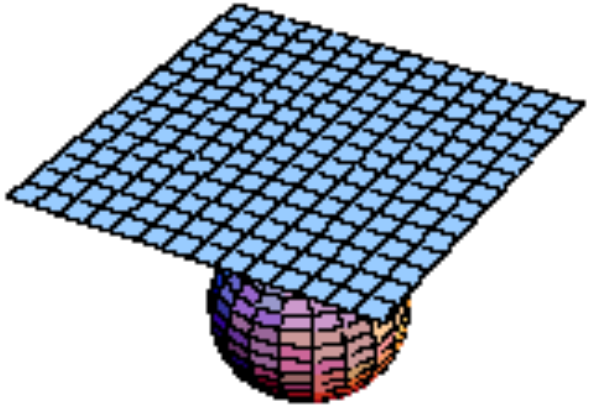
Gravitazione universale = G Mm R^{-2}

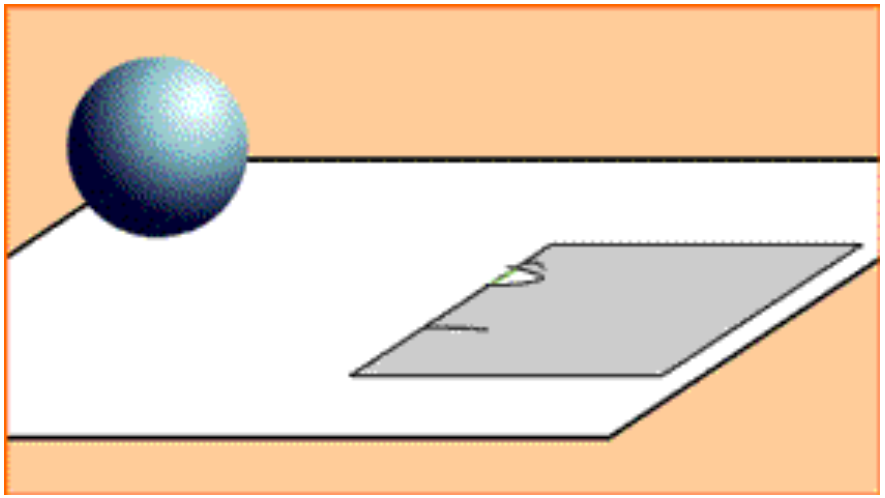
==> FORMA DEI CORPI CELESTI

Assioma di Imerio

Incursione da altre dimensioni

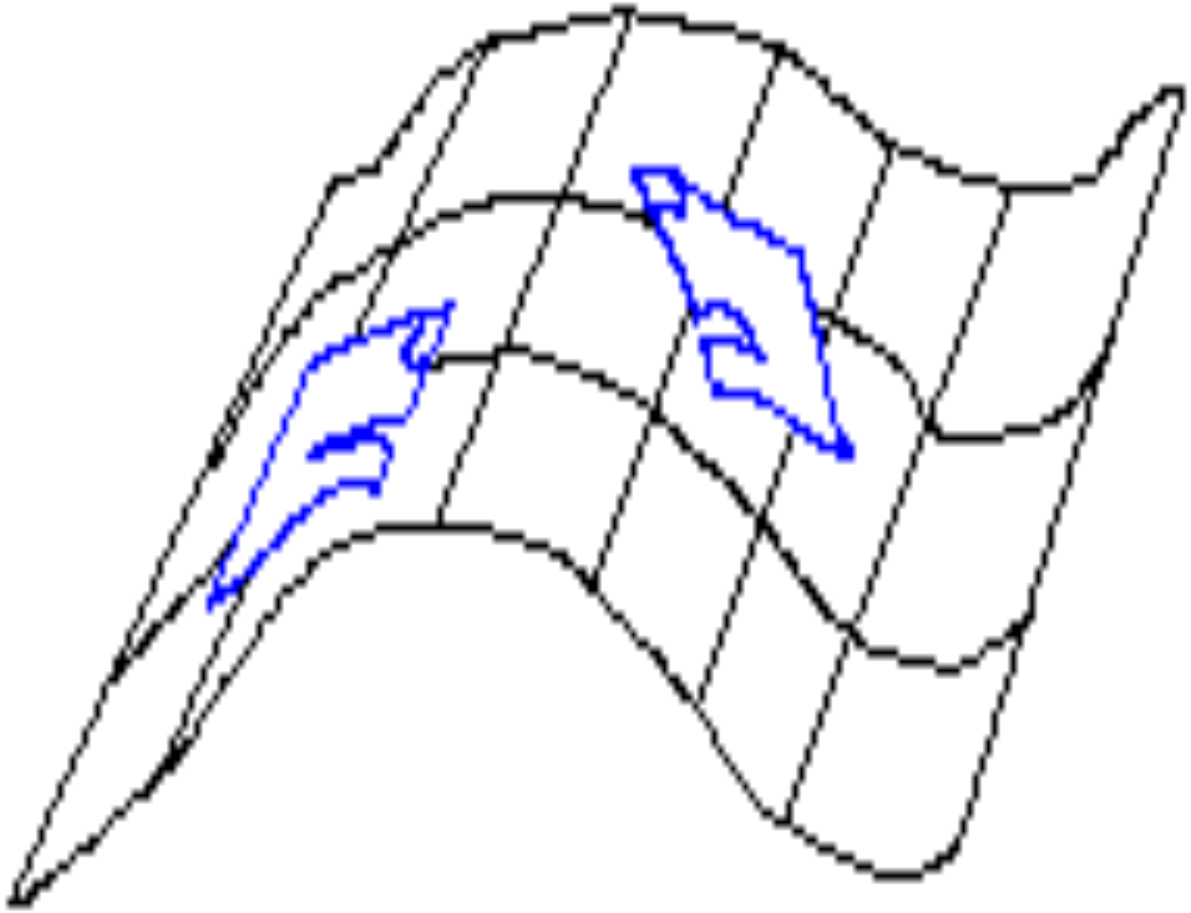




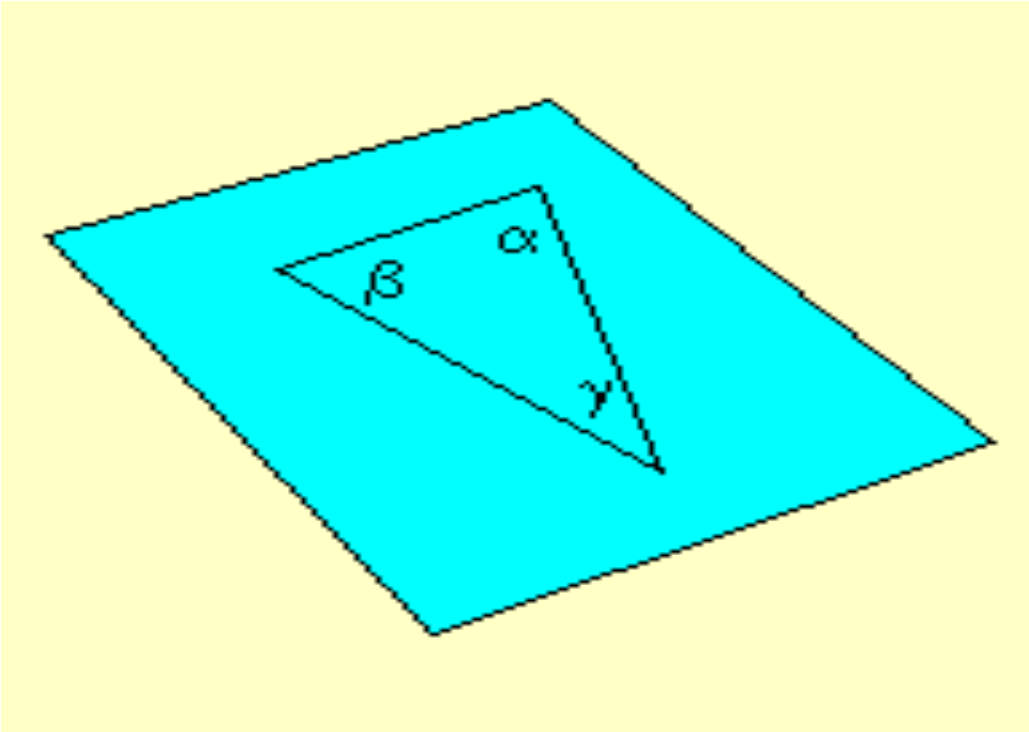


Incursione dalla 4 dimensione

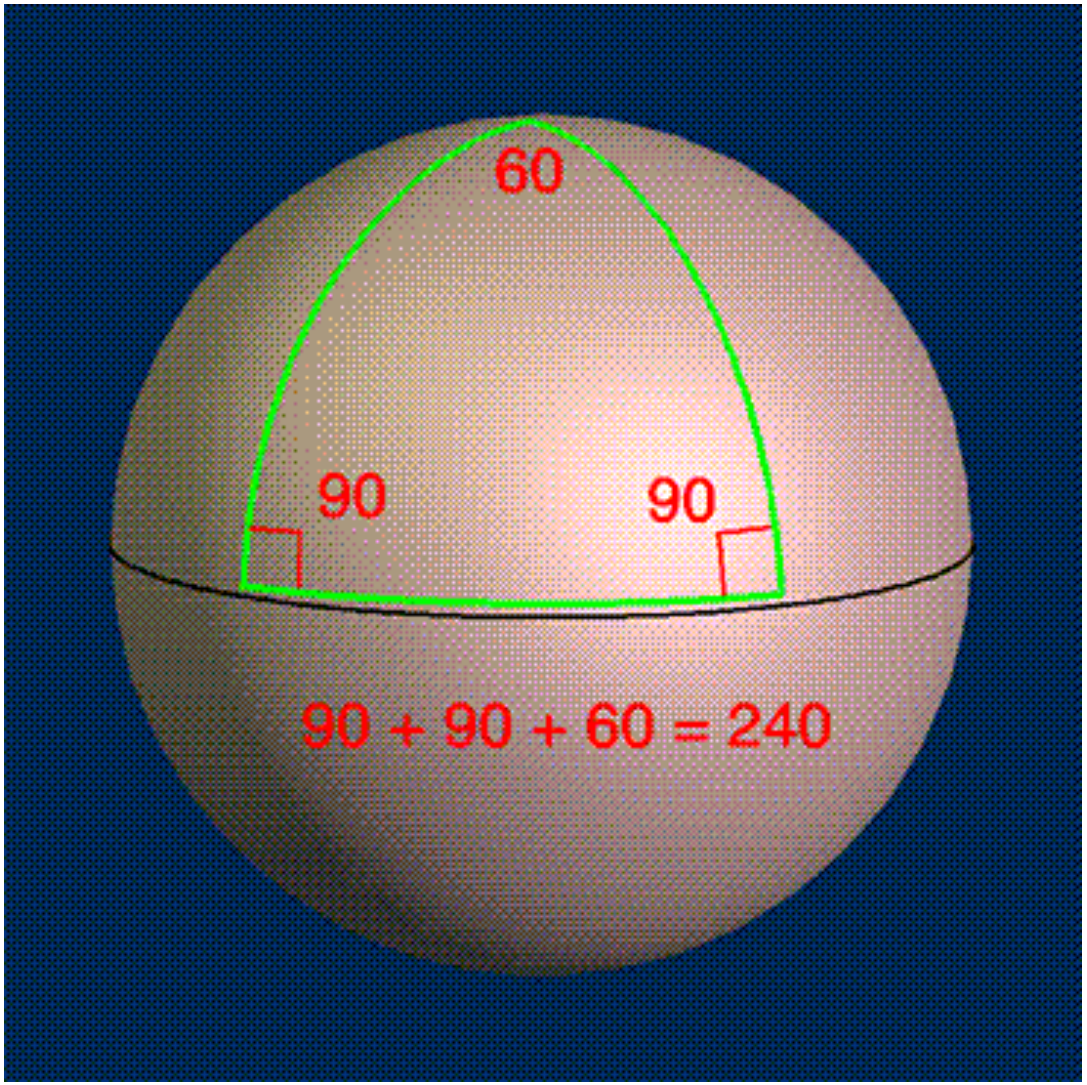
Curvlandia



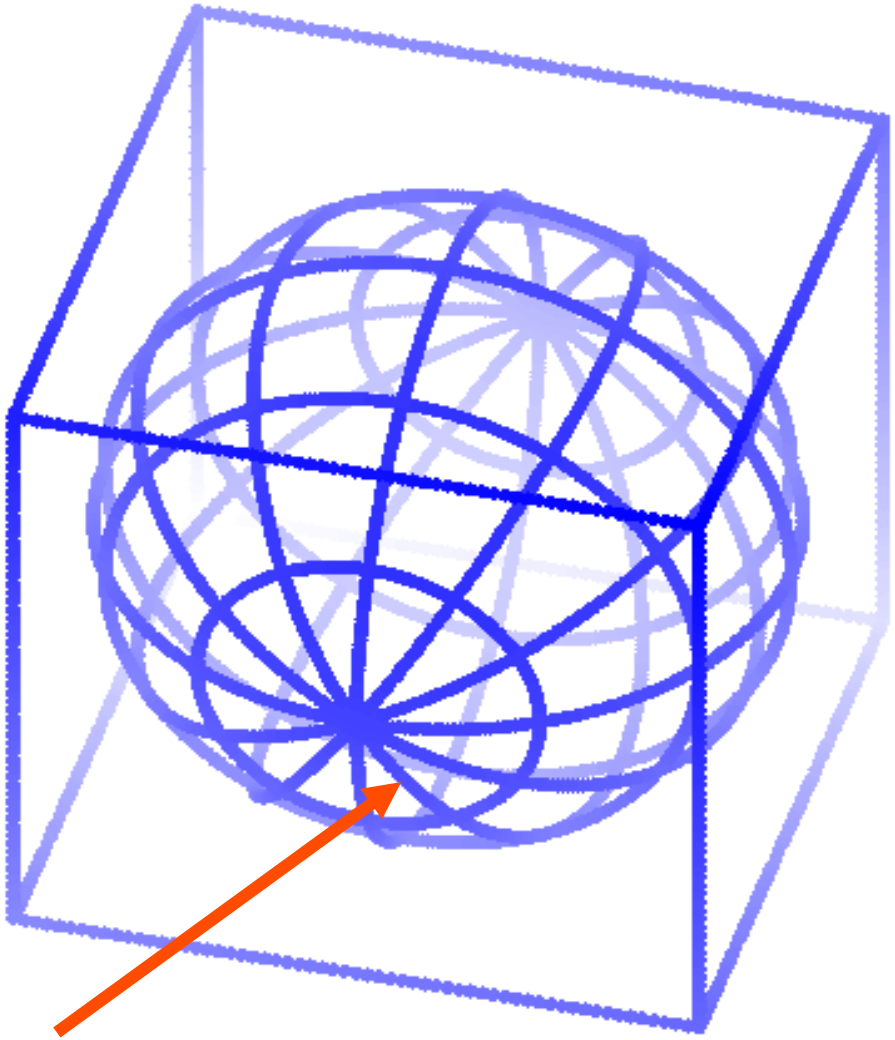
Caro, vecchio Euclide



Triangoli nello spazio curvo 2



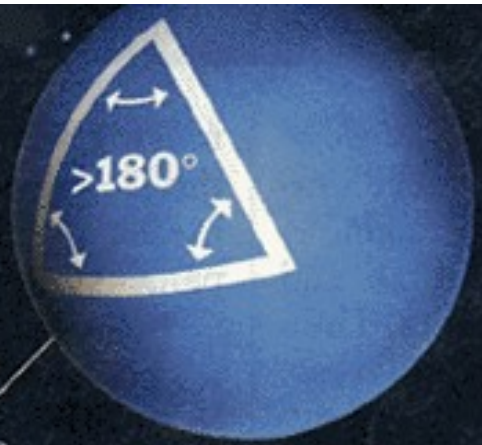
Vedere i fantasmi



Punto particolare

HOW DOES THE UNIVERSE CURVE?

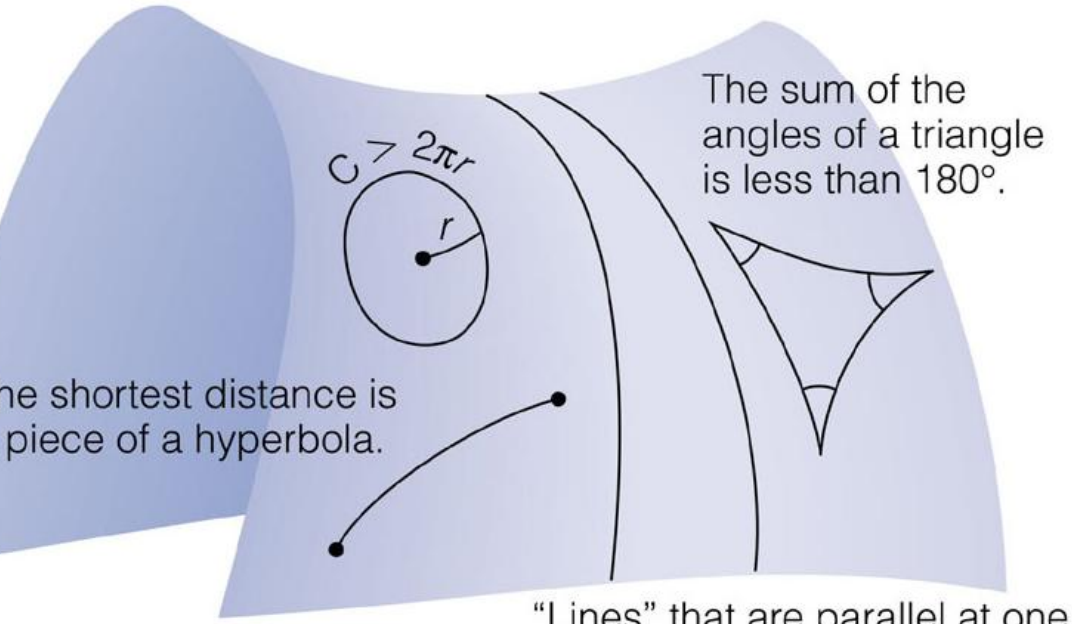
According to Einstein, the universe is a space-time continuum that can take one of three forms, determined by the amount of matter and energy it contains. The best way to visualize them is with a two-dimensional analogy



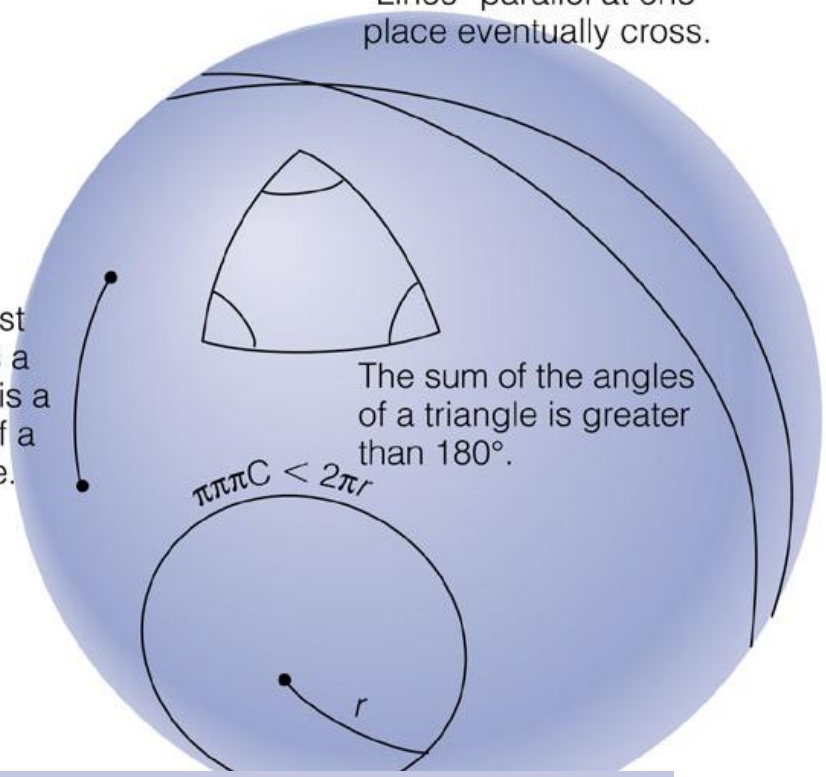
POSITIVE CURVATURE The cosmos is like a sphere. Travel far enough and you'll come back to the starting point. Draw a triangle, and it will have more than 180°. Without dark energy, this universe will slow, stop and recollapse; with it, the expansion will continue

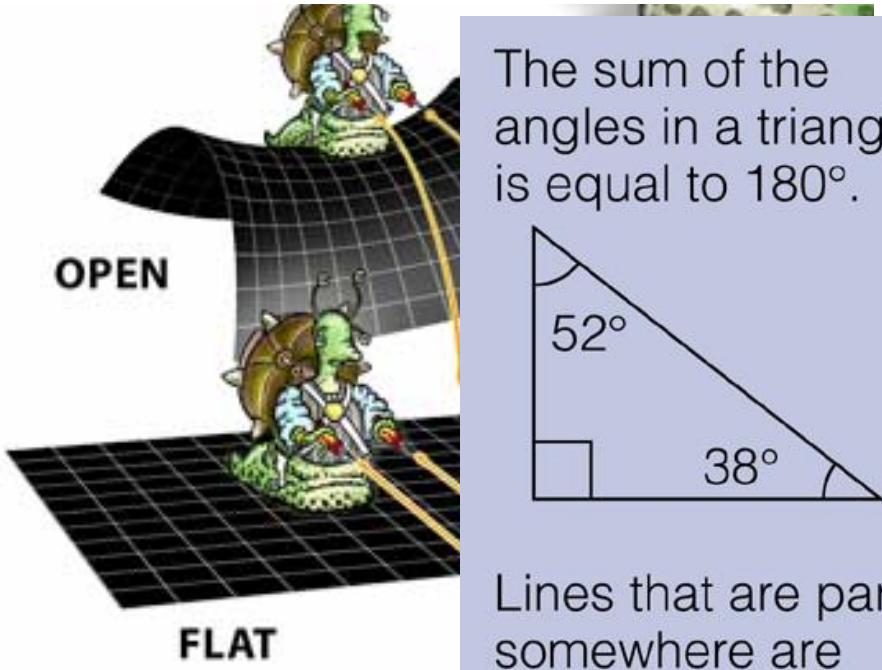
FLAT You'll never return to your starting point; triangles have precisely 180 degrees, as they do in high school geometry. Even without dark energy, this universe will expand forever, but more and more slowly all the time. With it, the expansion gets ever faster. This is the shape of our universe, according to the latest observations

NEGATIVE CURVATURE Travelers never return; triangles always have less than 180°. And expansion will barely slow, even without dark energy. Until recently, most of the astronomical evidence favored this shape



"Lines" that are parallel at one place eventually diverge.

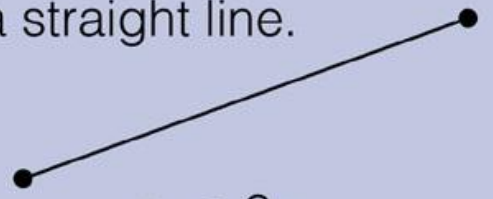


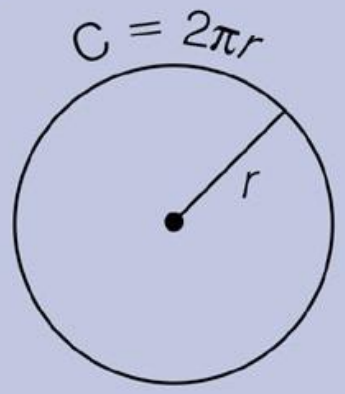


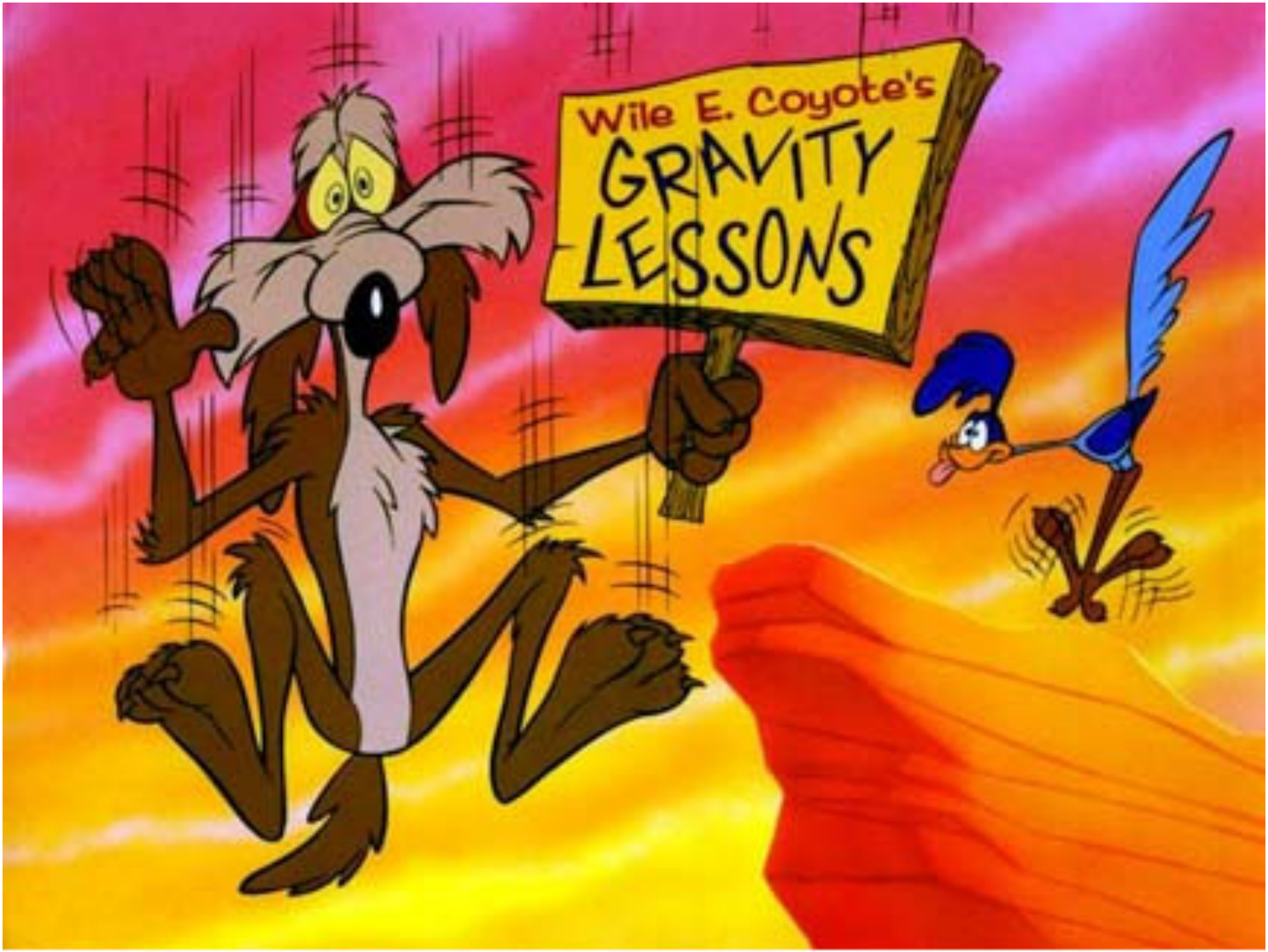
The sum of the angles in a triangle is equal to 180°.

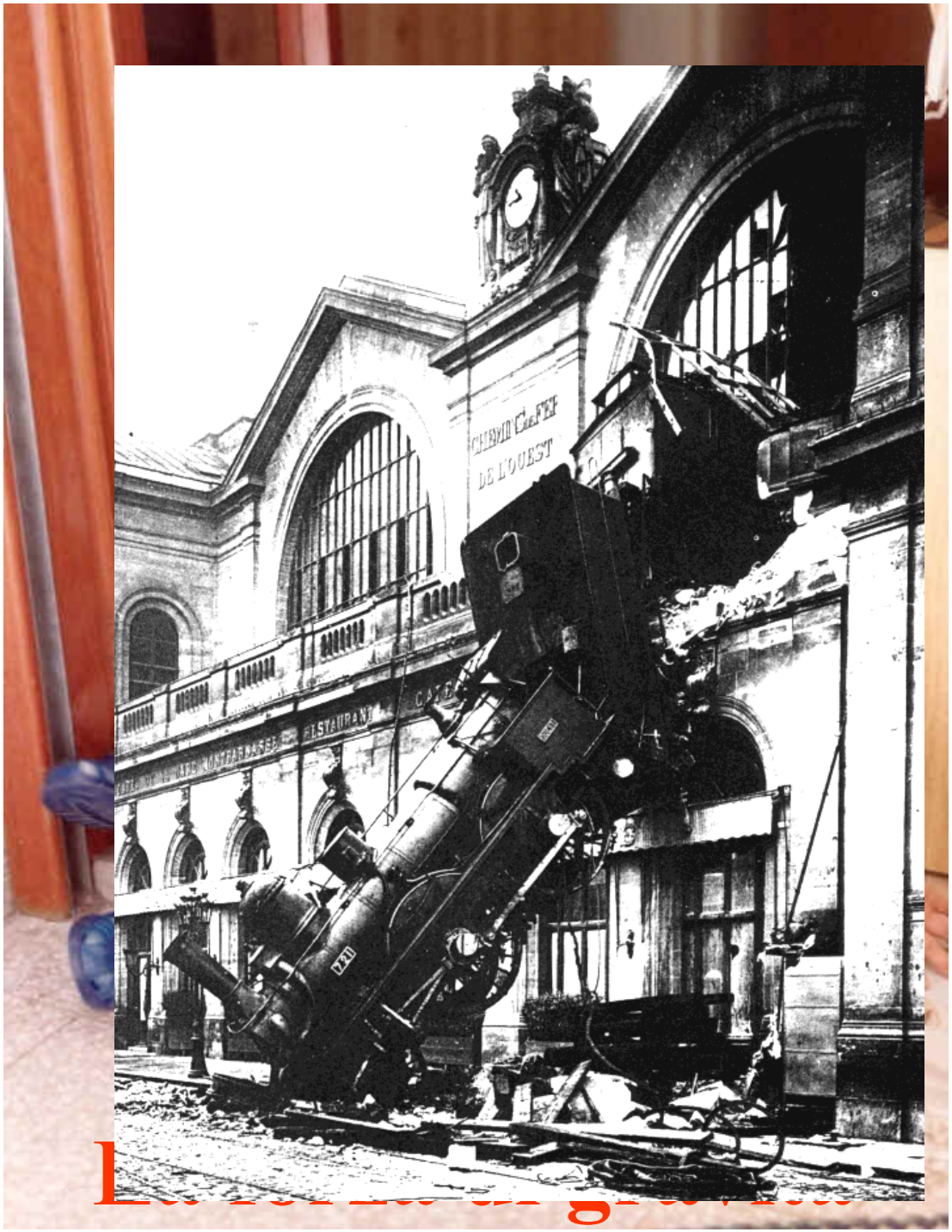
Lines that are parallel somewhere are parallel everywhere.

The shortest distance between two points is a straight line.



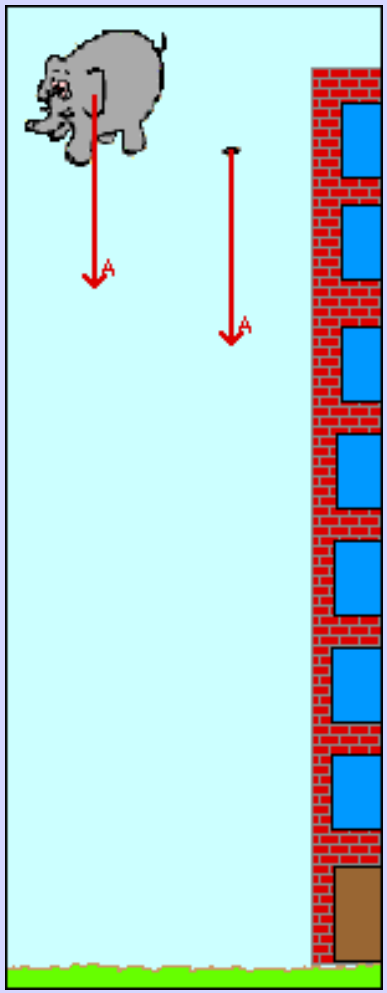



Wile E. Coyote's
GRAVITY
LESSONS

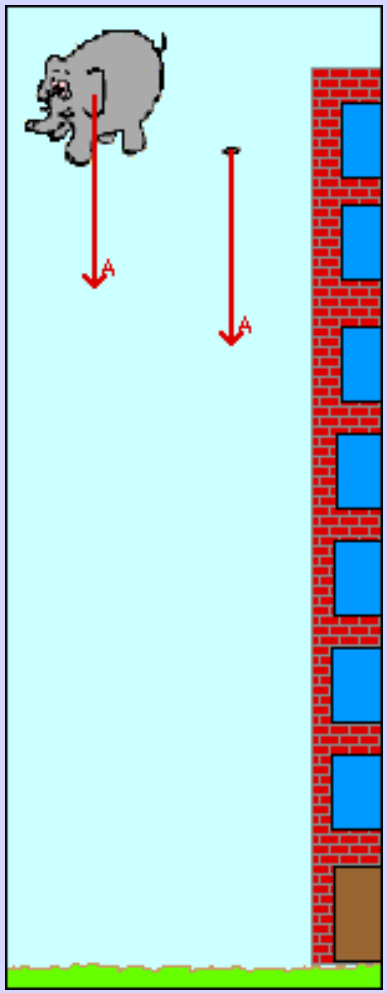

CHEMIN DE FER
DE L'OUEST
CAFÉ
RESTAURANT

Torre di Pisa

Nel Vuoto

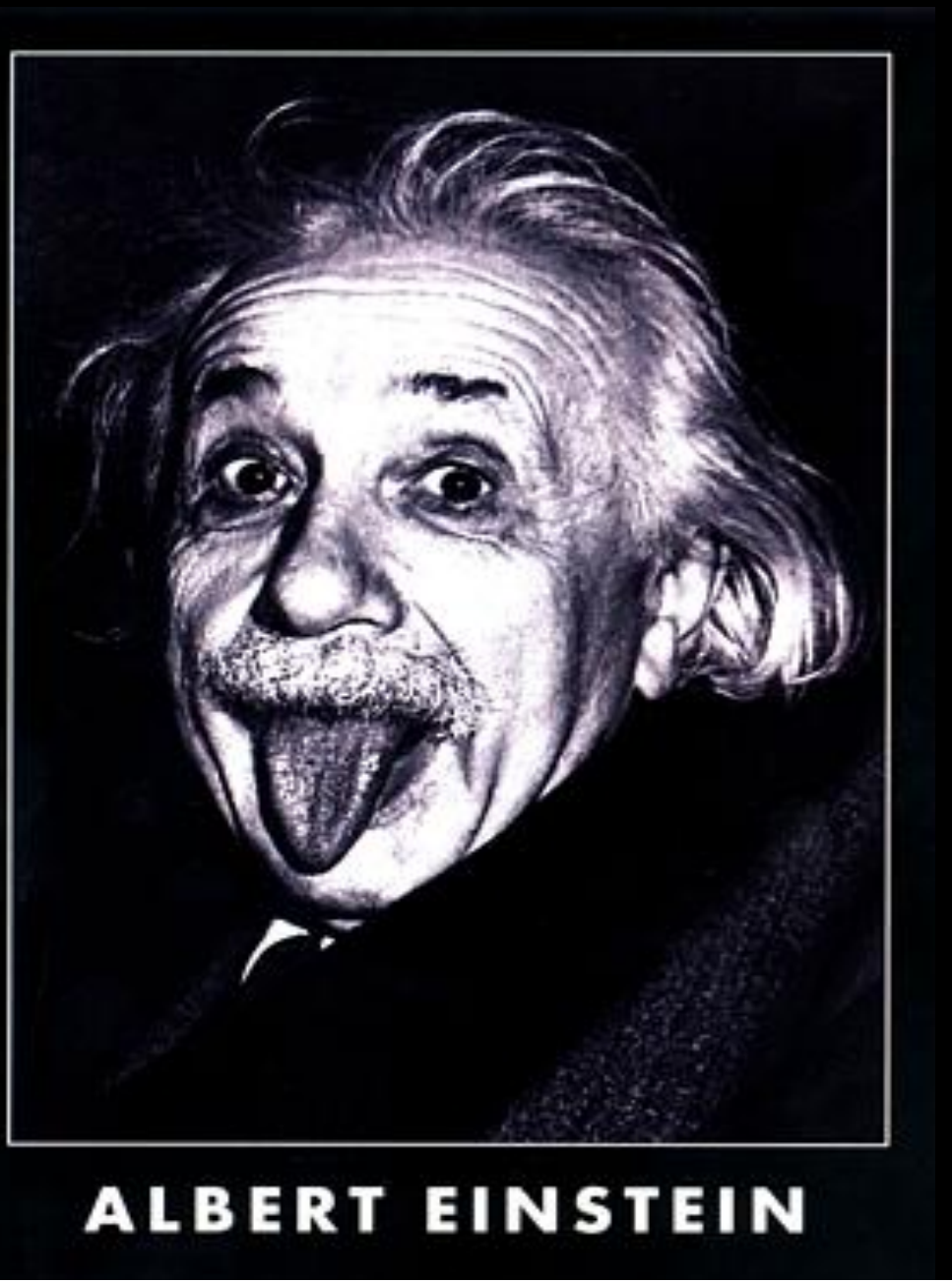


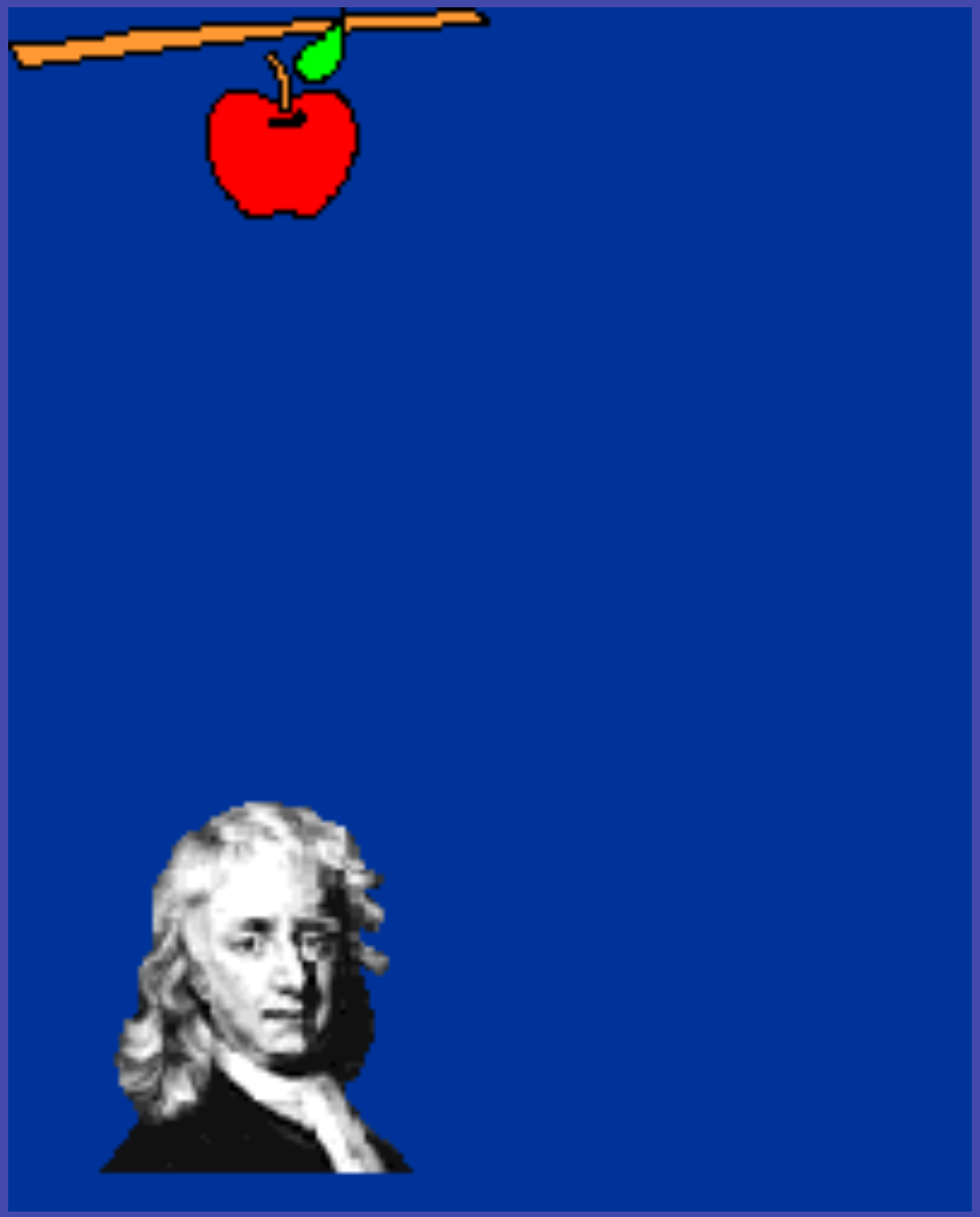
In presenza di aria

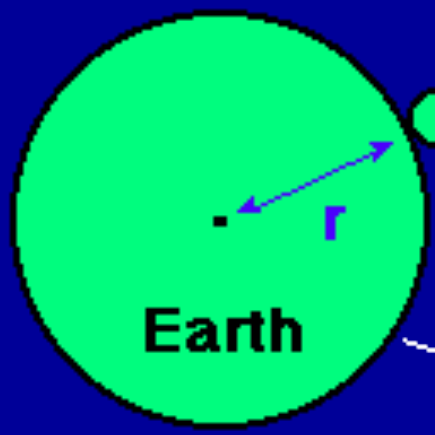


La gravita` e la forma dello spazio

ISAAC NEWTON







$$\text{Weight} = F_g = G\frac{Mm}{r^2} = mg$$

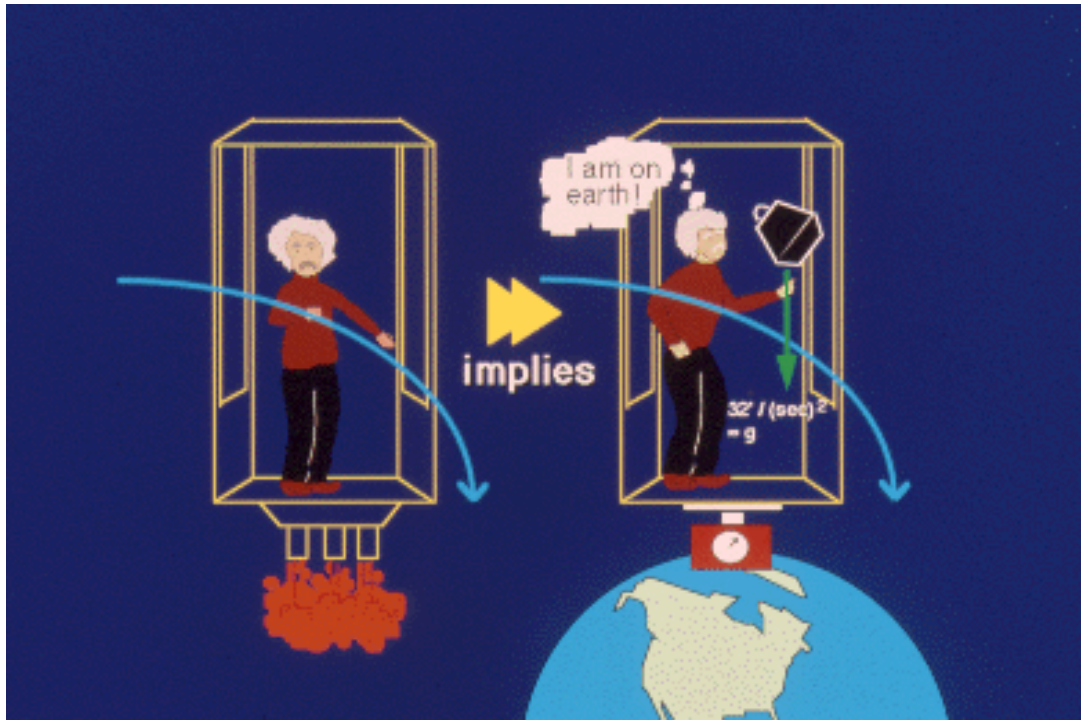
$= g$

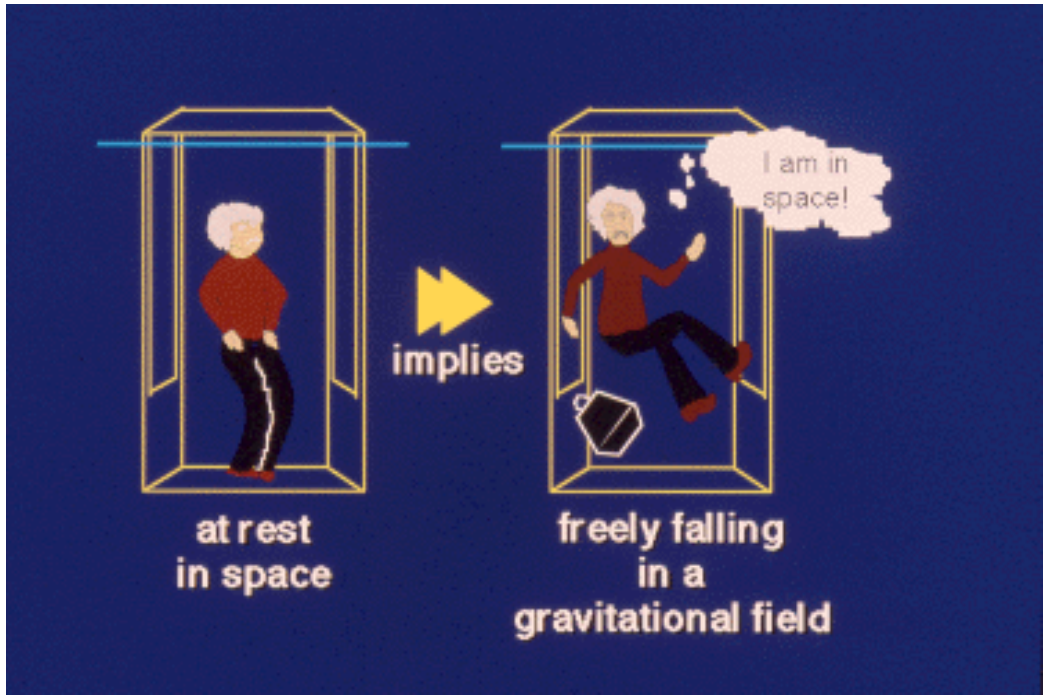
M is the mass of the Earth

m is the mass of the object

r is the radius of the Earth

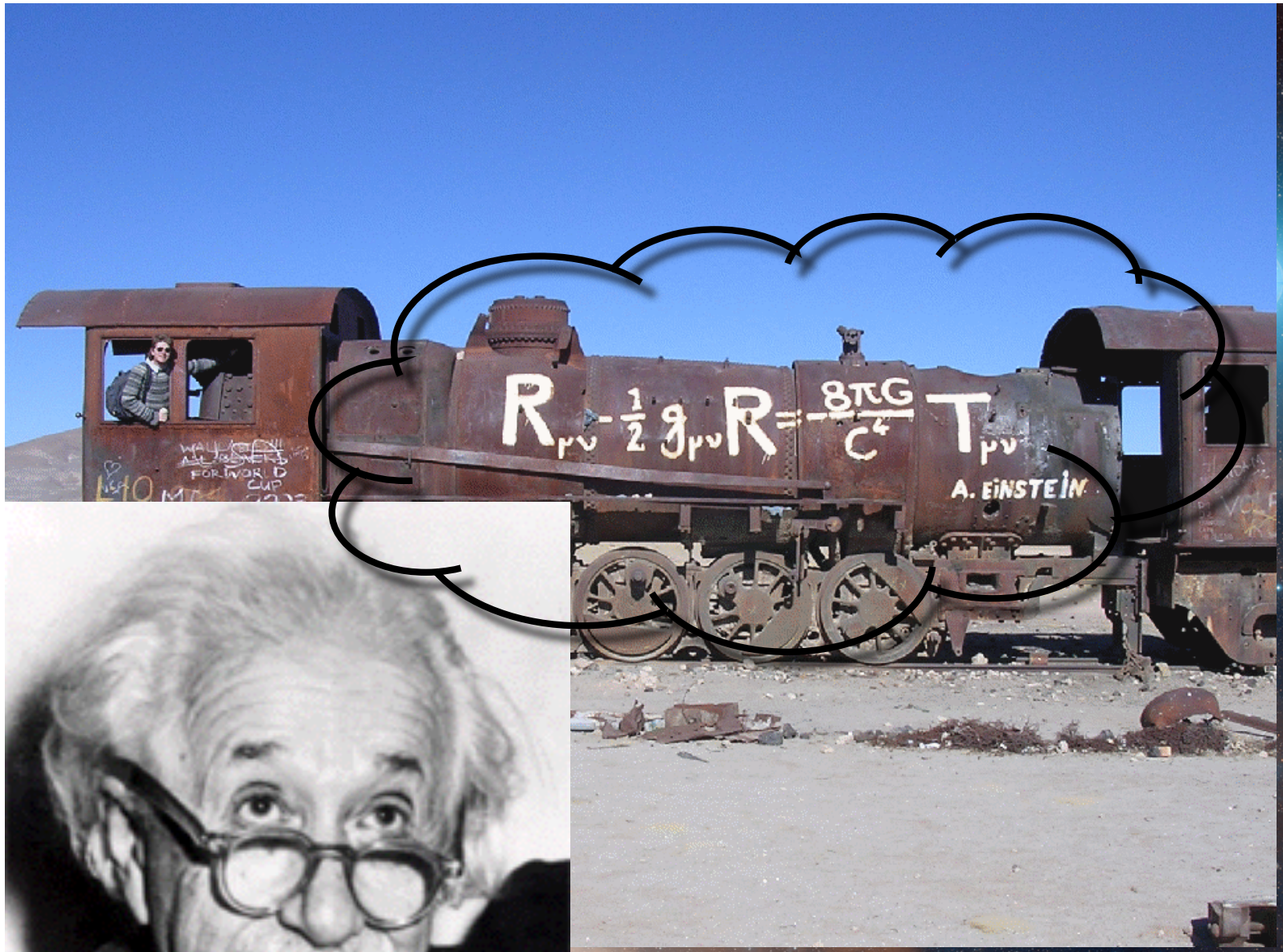
g is the acceleration due to gravity at the Earth's surface

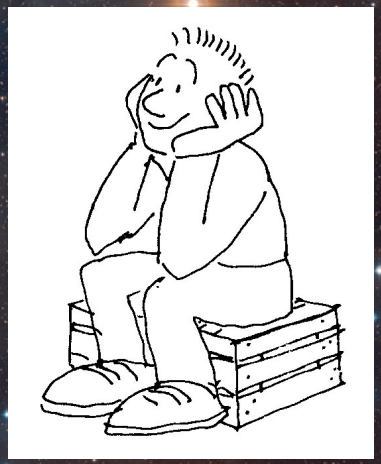




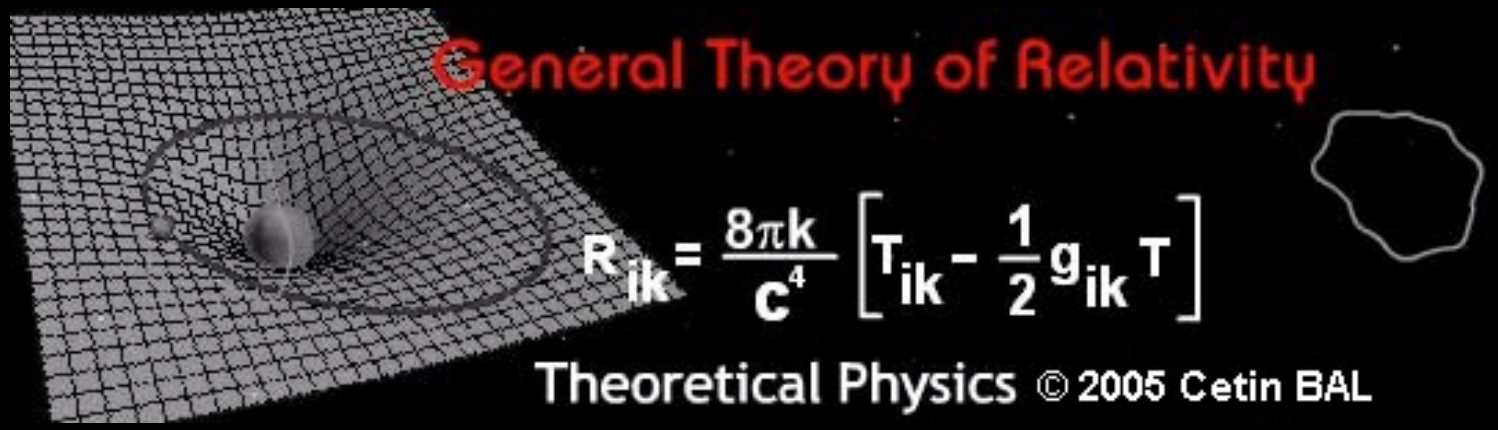
Principio di equivalenza


Science & vie junior, dossier hors série sur Einstein, p 88.





RELATIVITA' GENERALE (1916)



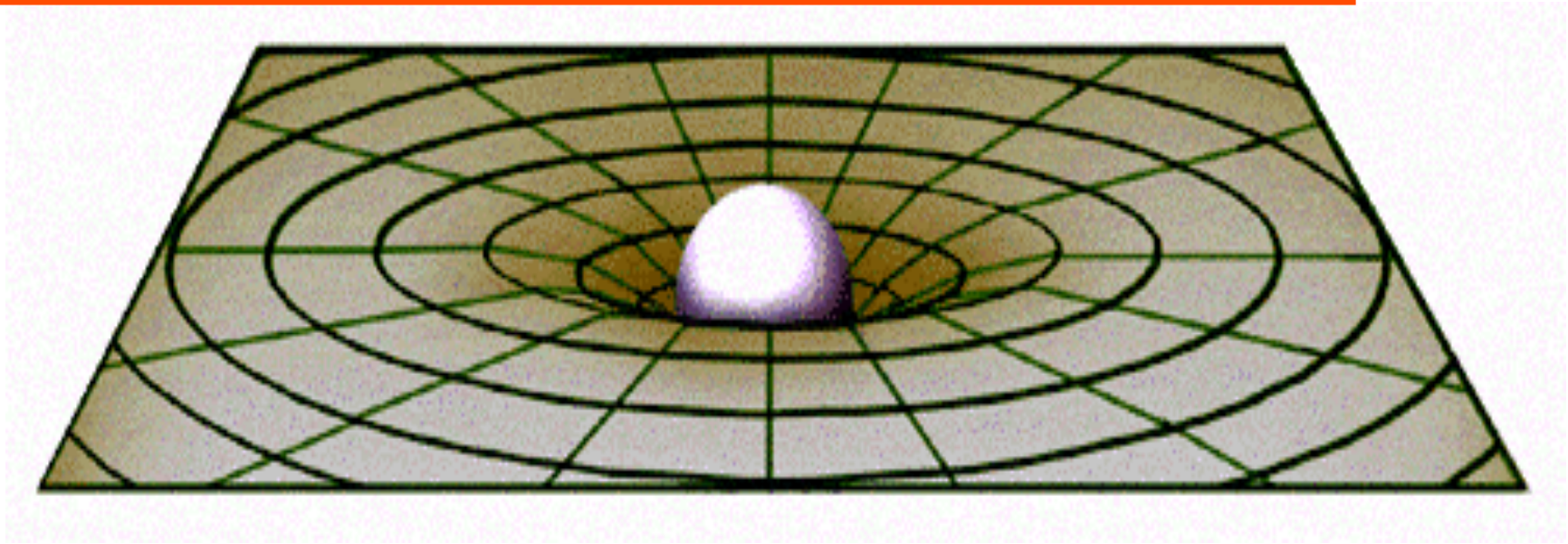
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu}$$

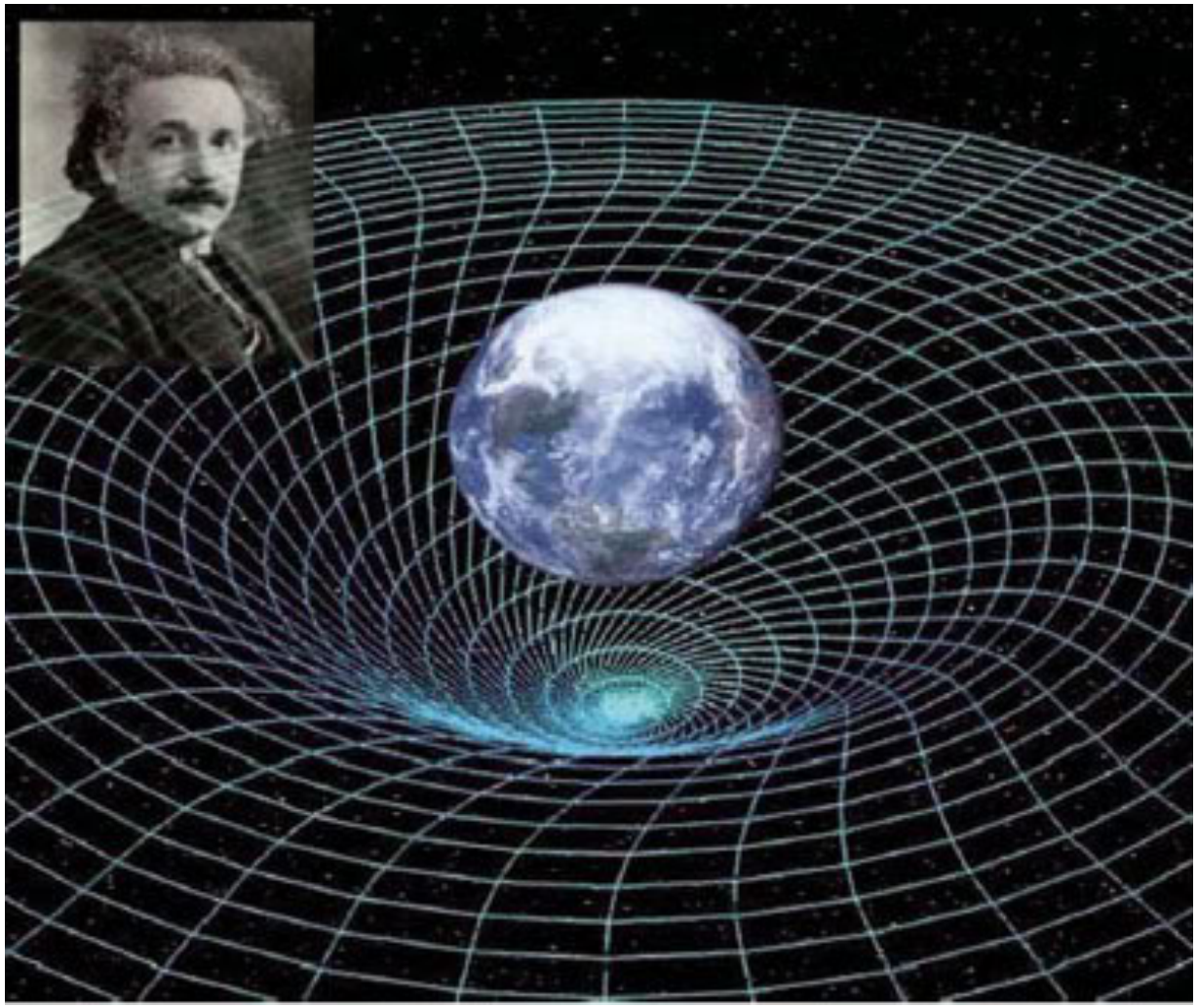
Geometria (curvatura)

Distribuzione Massa ed energia

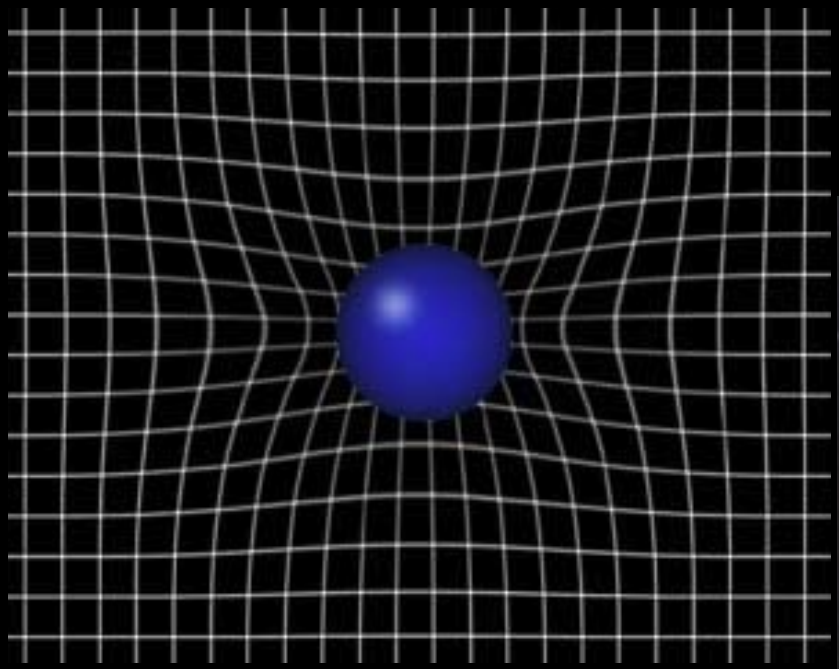
Gravita' e geometria

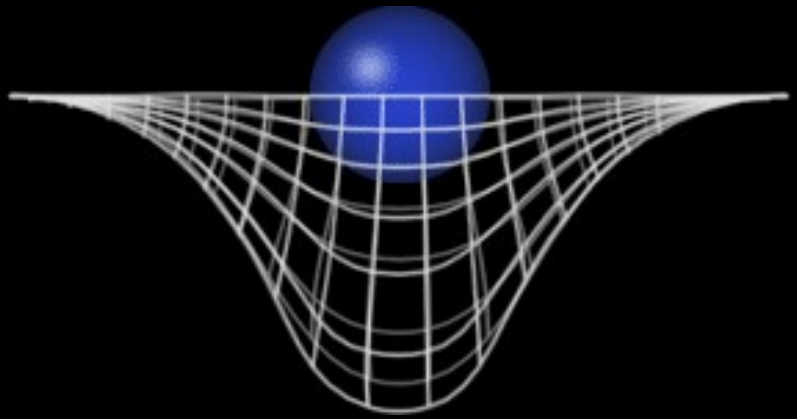
LE MASSE PROVOCANO CURVATURA DELLO SPAZIO-TEMPO (1916)

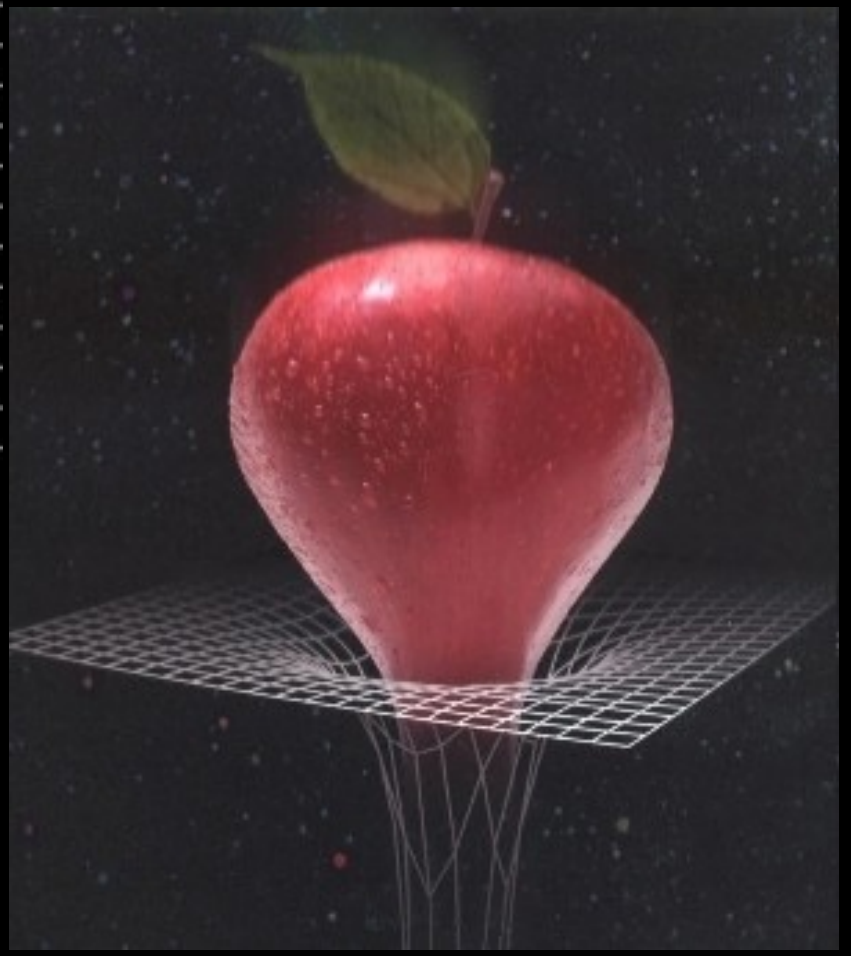




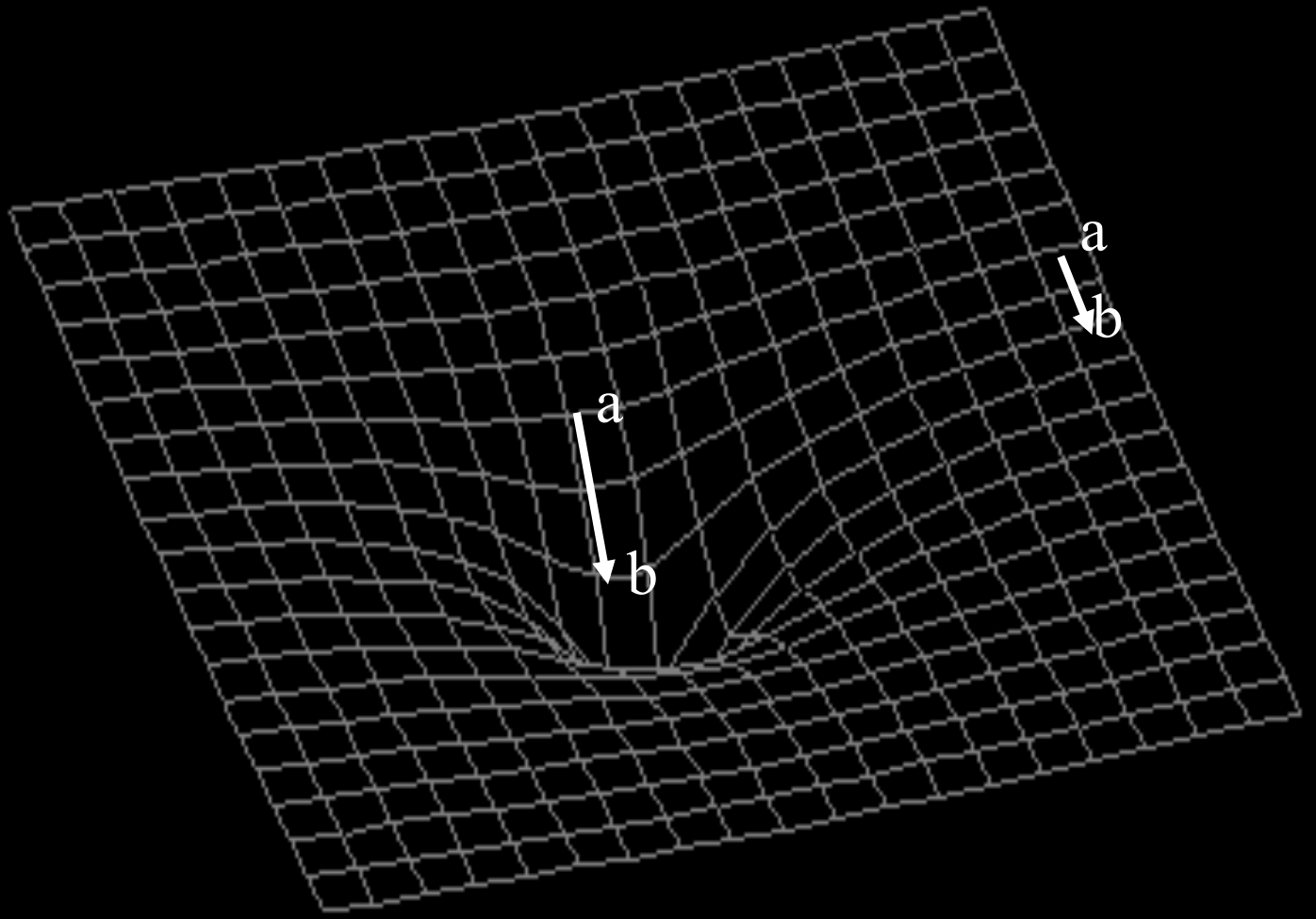
FILMATO BLACK HOLE GRID



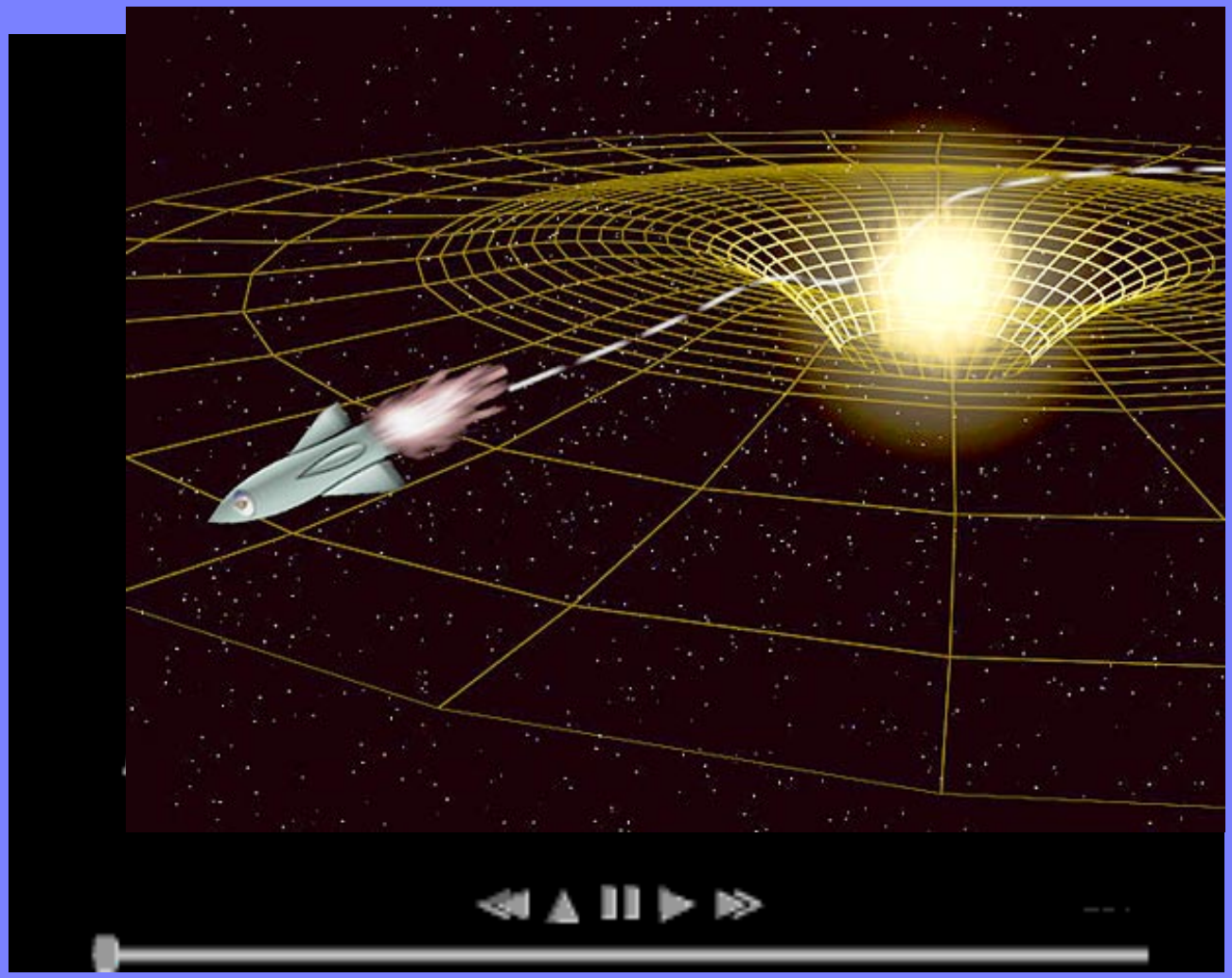




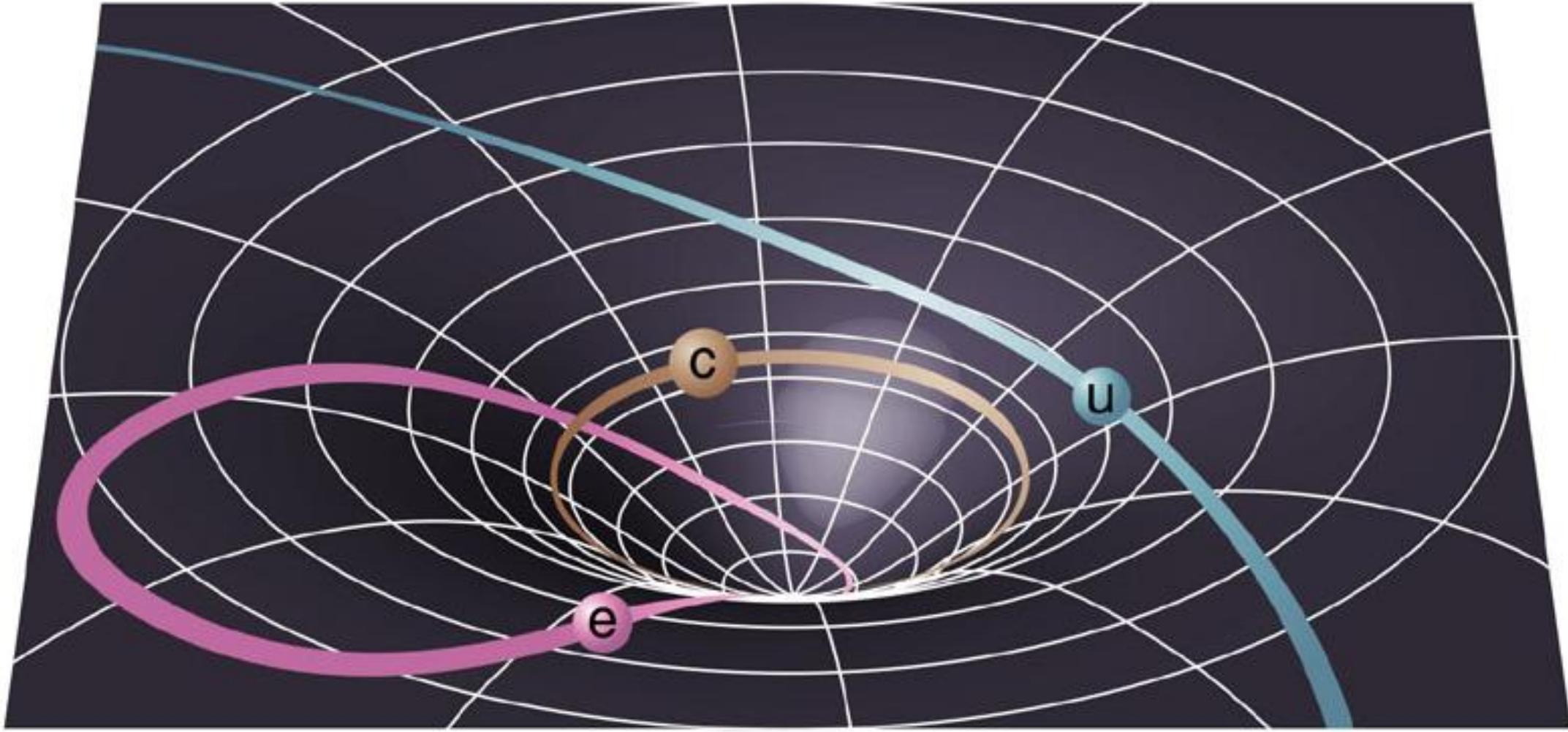
CURVATURA

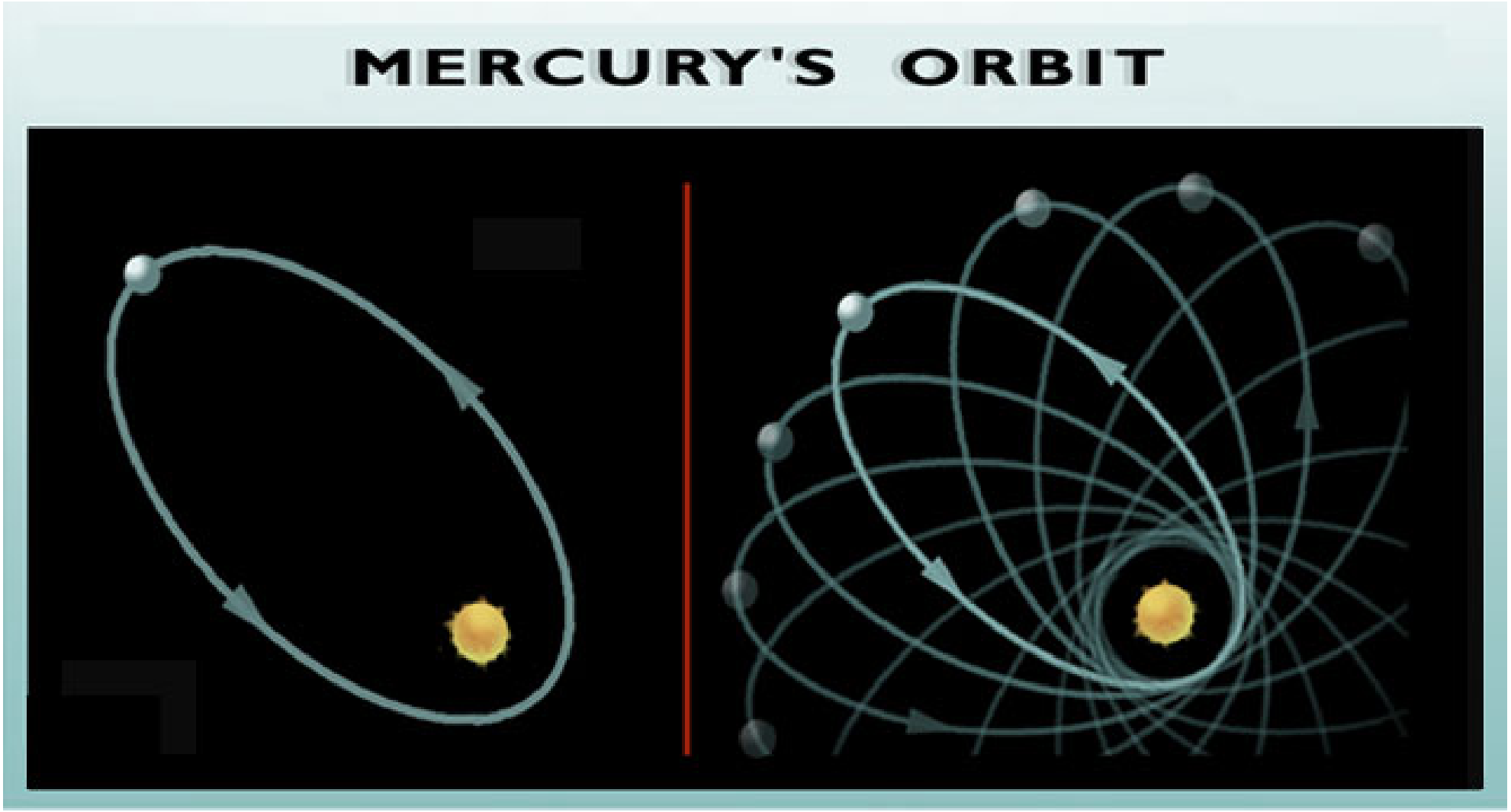


Orbite nello spazio curvo



c circular orbit
e elliptical orbit
u unbound orbit

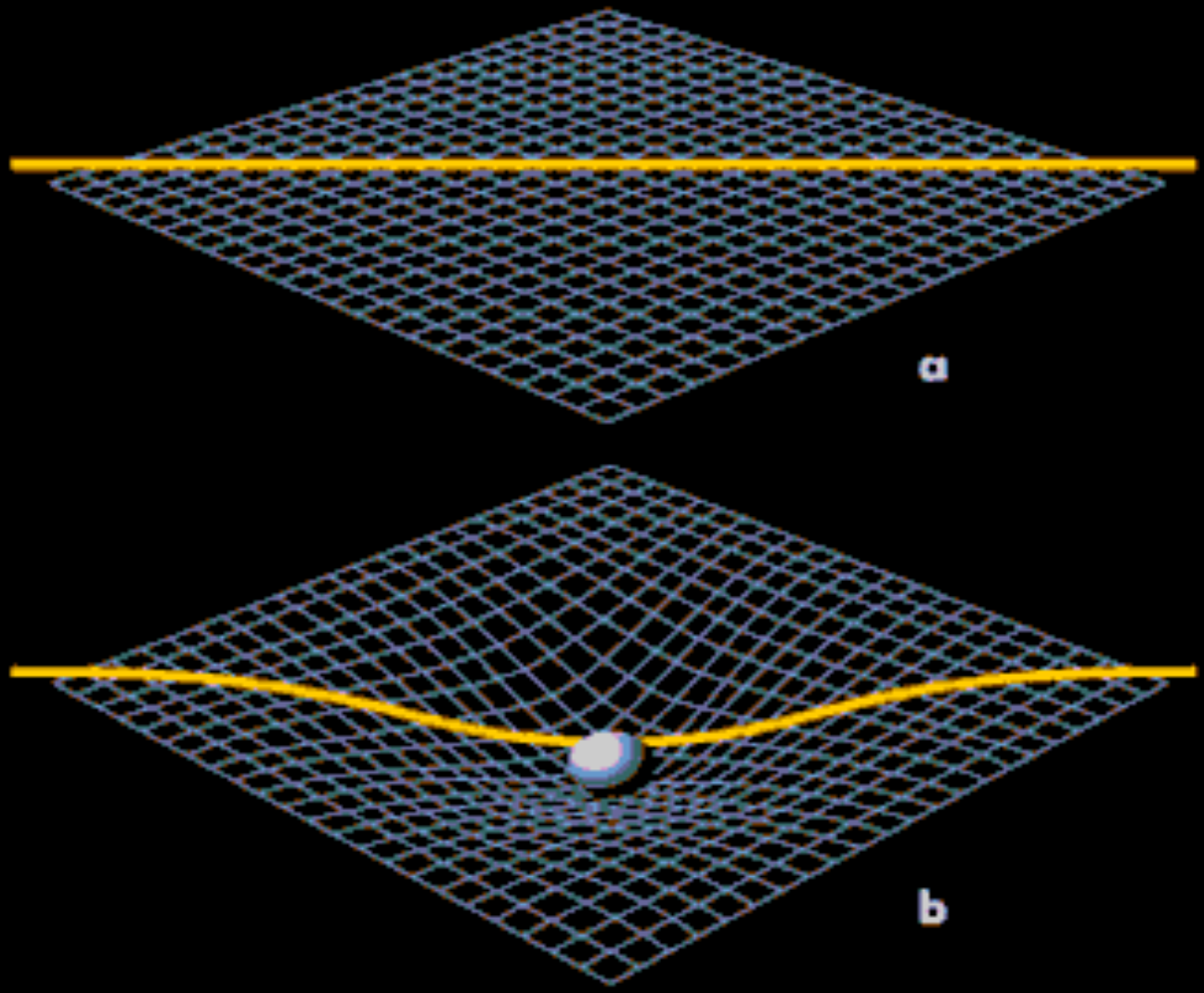




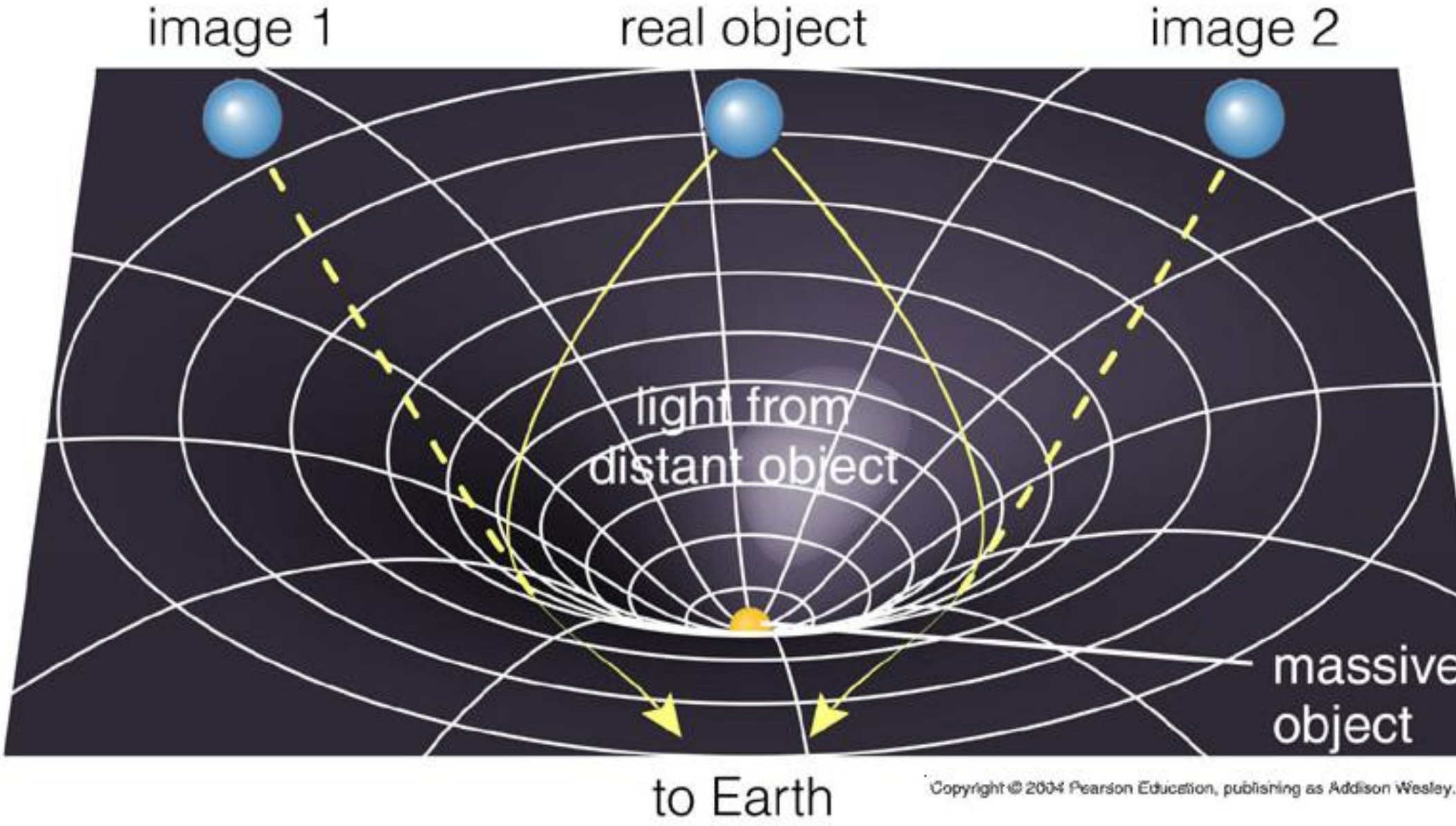
Precessione orbita di Mercurio

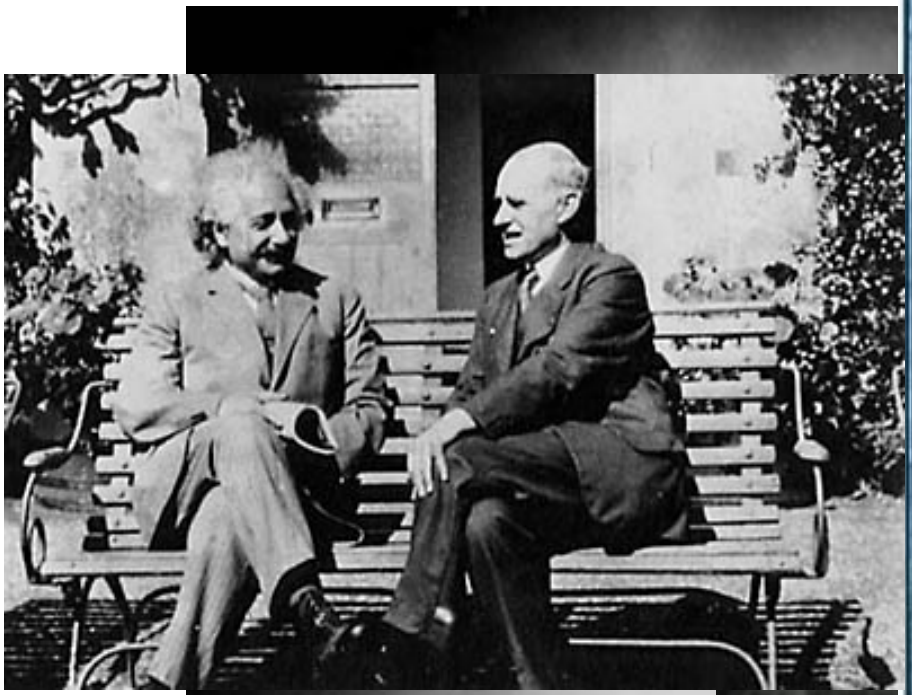
(43 arcsec in piu' rispetto a 5557 arcsec/anno)

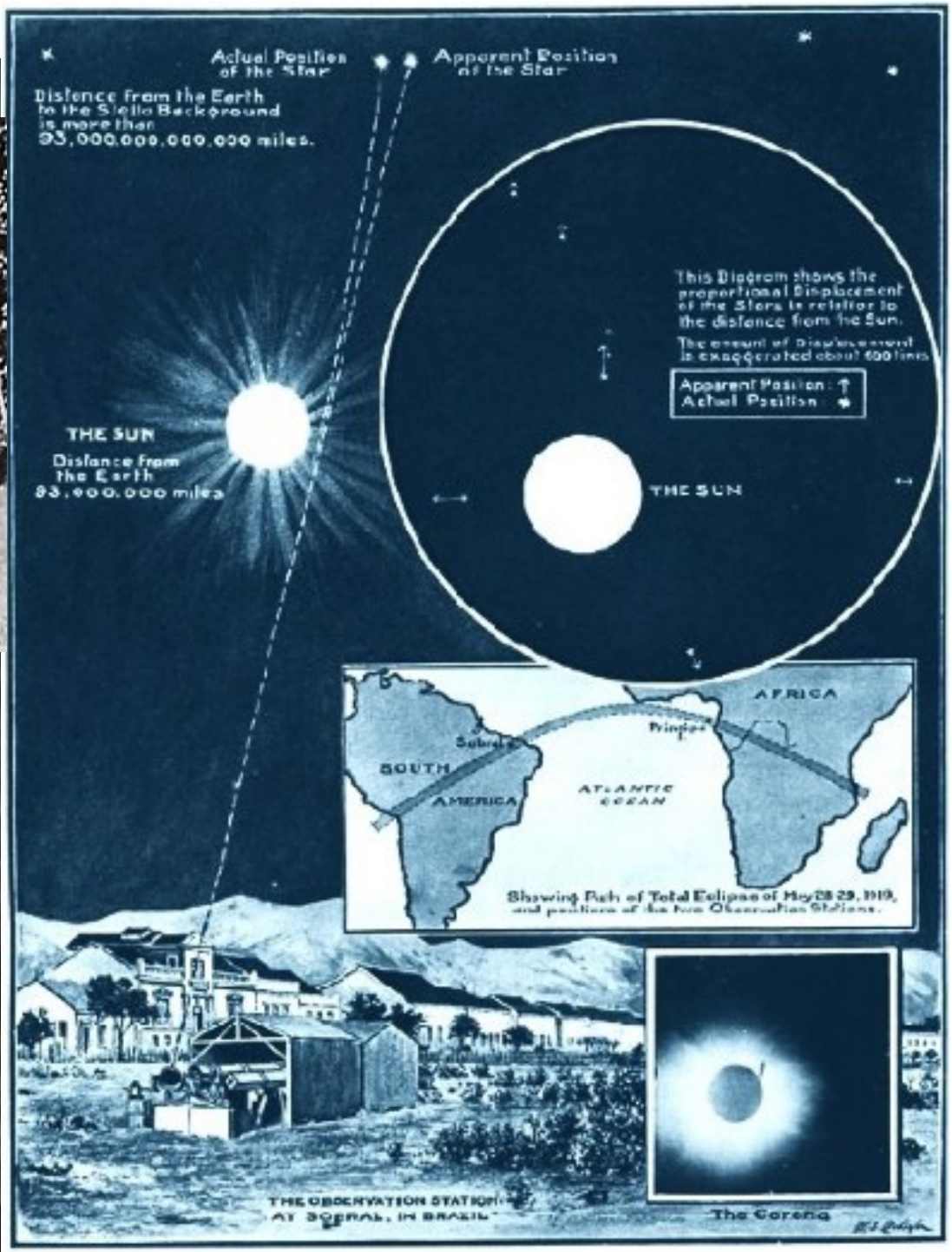
Distanze nello spazio curvo



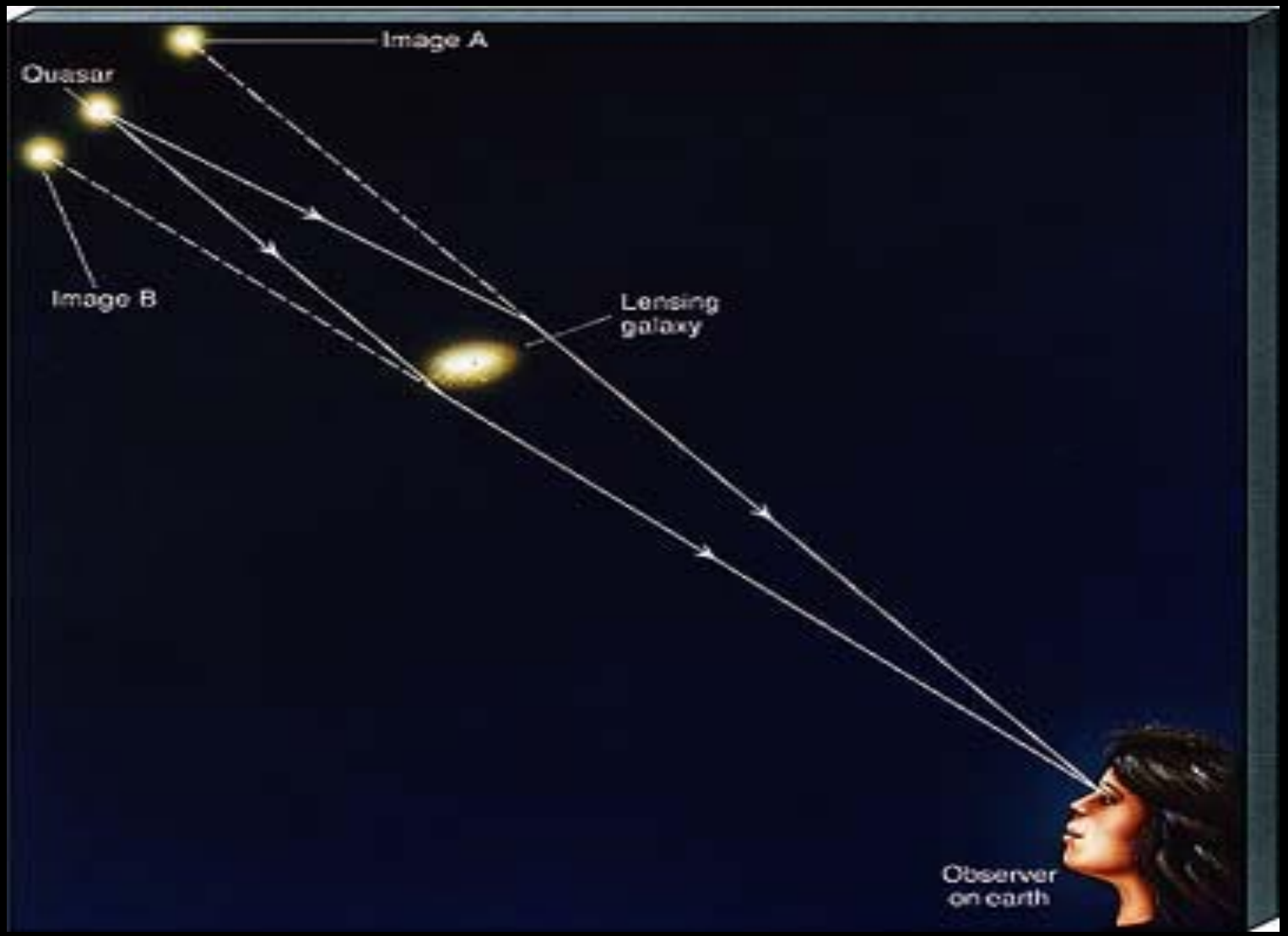
Curvatura dei raggi di luce

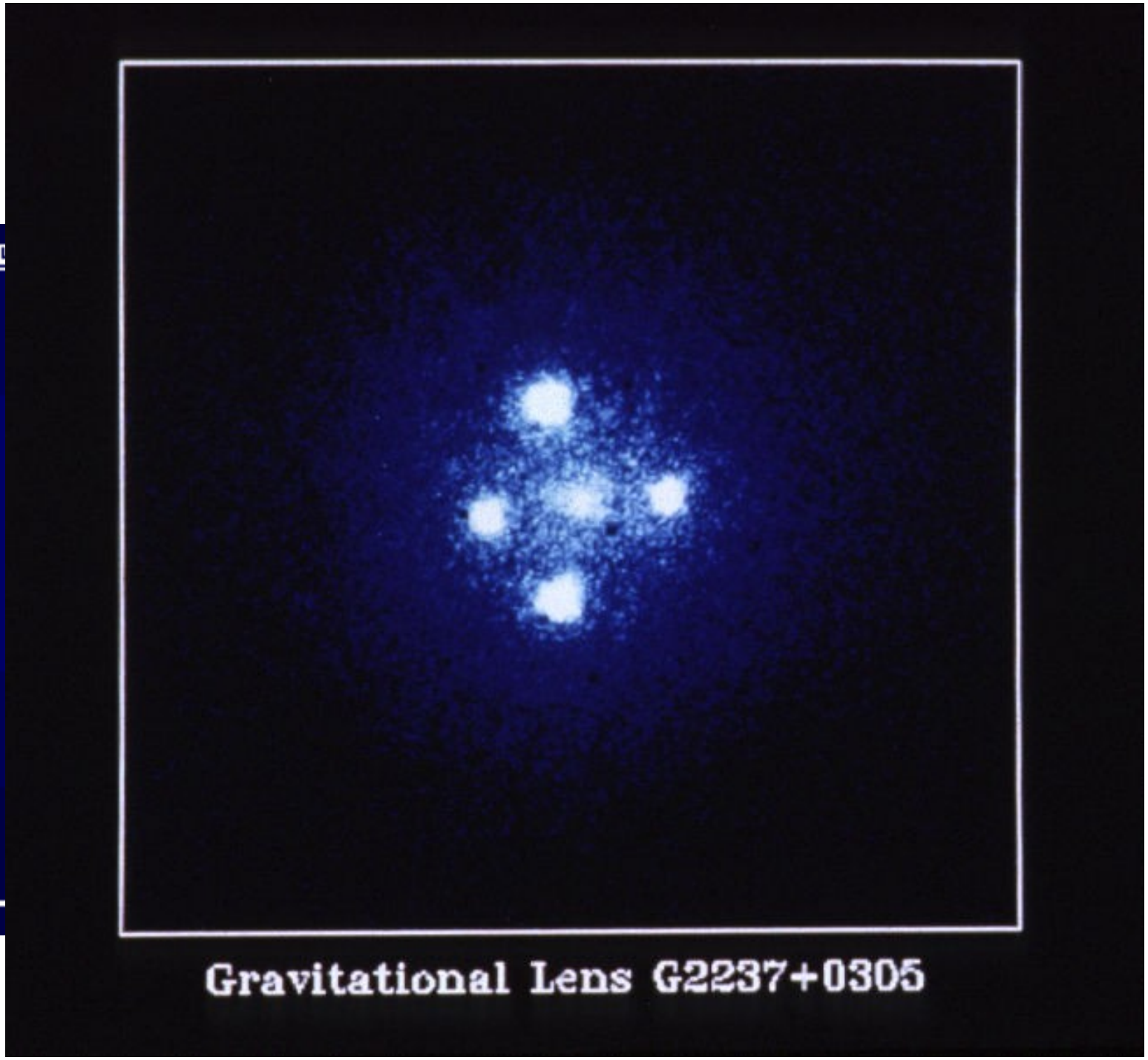


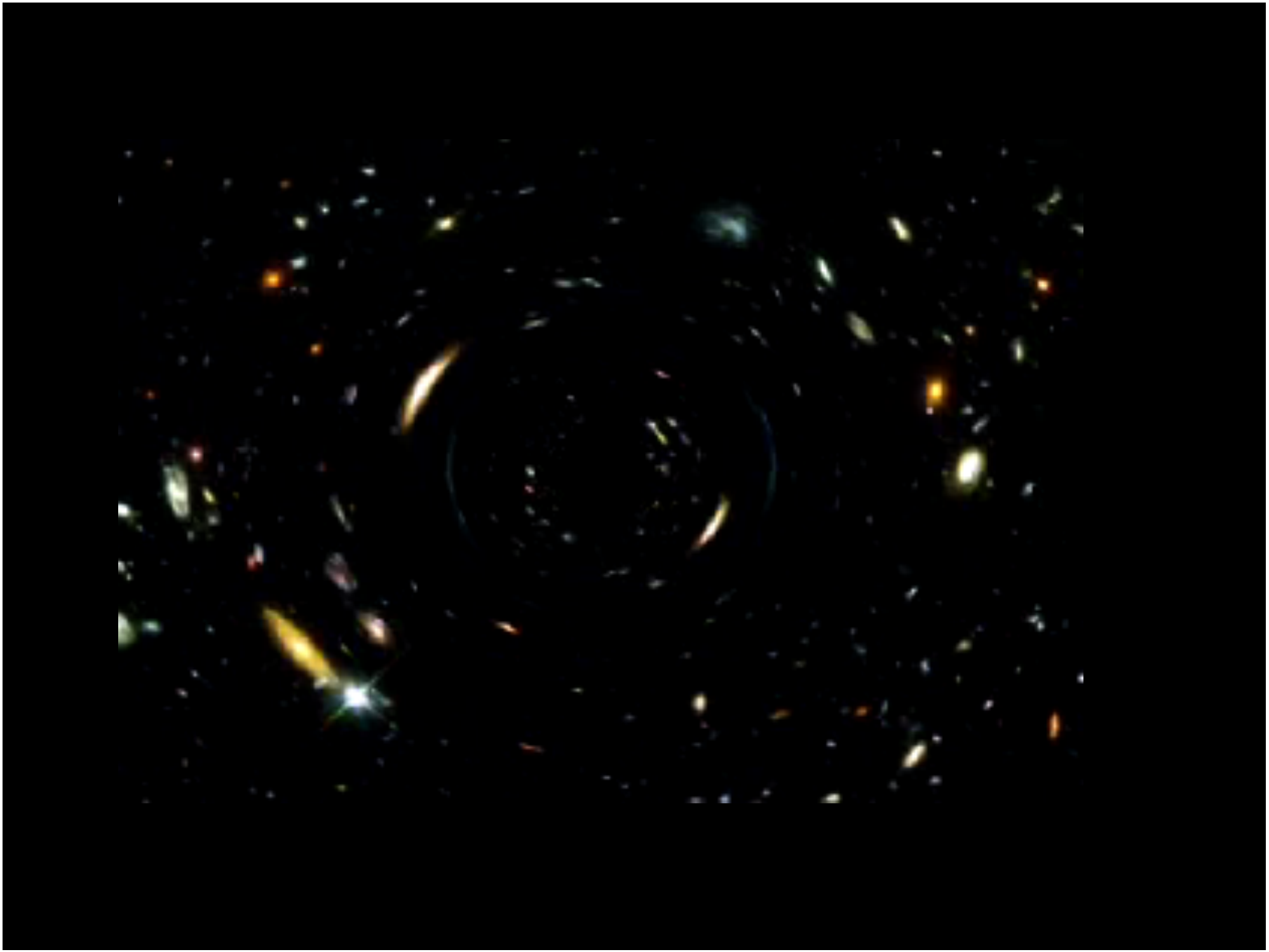


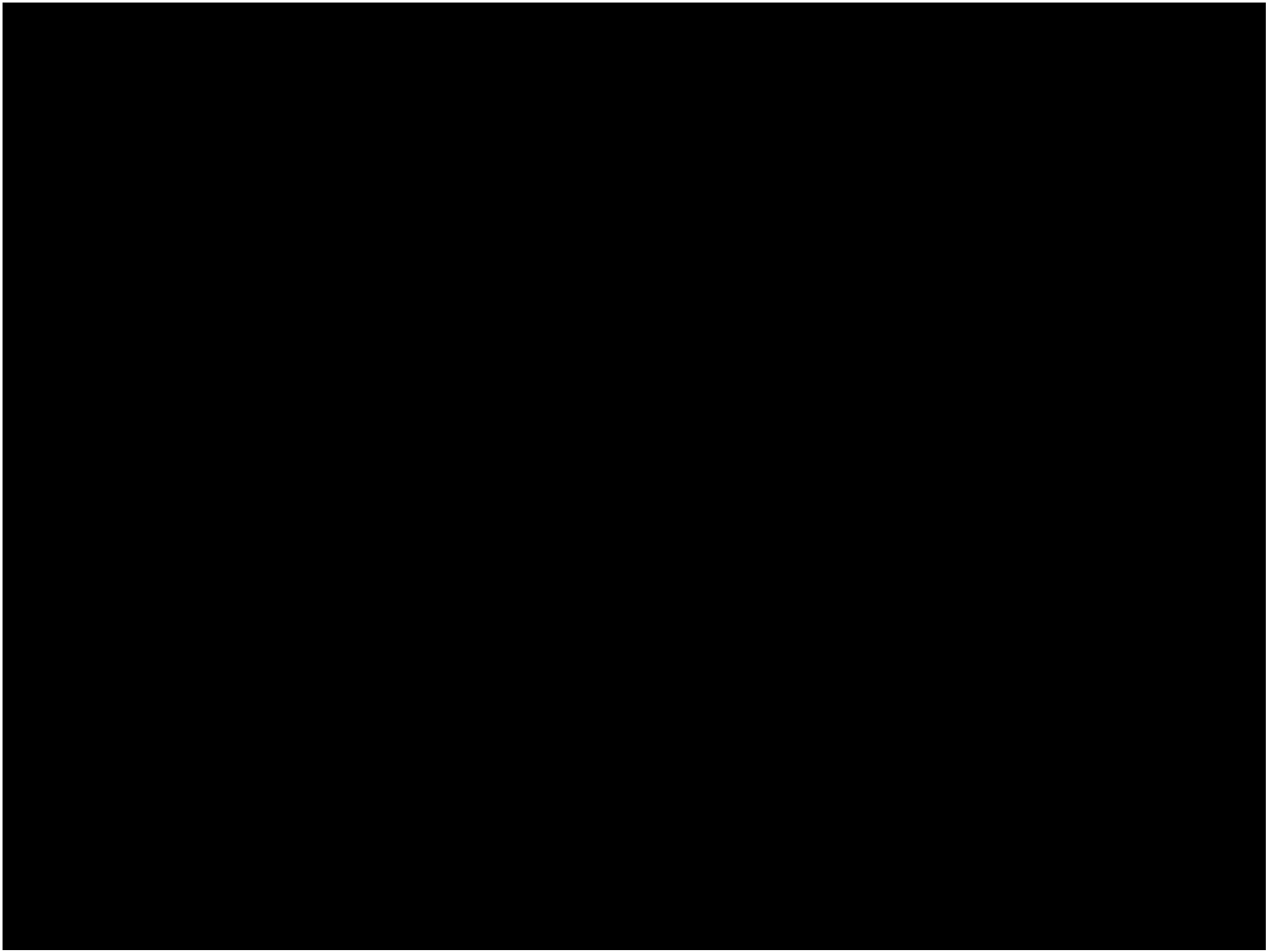

Actual Position of the Star
Apparent Position of the Star
Distance from the Earth to the Stella Background is more than 93,000,000,000,000 miles.
This Diagram shows the proportional Displacement of the Stars in relation to the distance from the Sun.
The amount of Displacement is exaggerated about 600 times
Apparent Position :
Actual Position
THE SUN
THE SUN
Distance from the Earth 93,000,000 miles
AFRICA
SOUTH AMERICA
ATLANTIC OCEAN
Showing Path of Total Eclipse of May 29, 1919,
THE OBSERVATION STATION AT SOBRAL, IN BRAZIL
The Corona

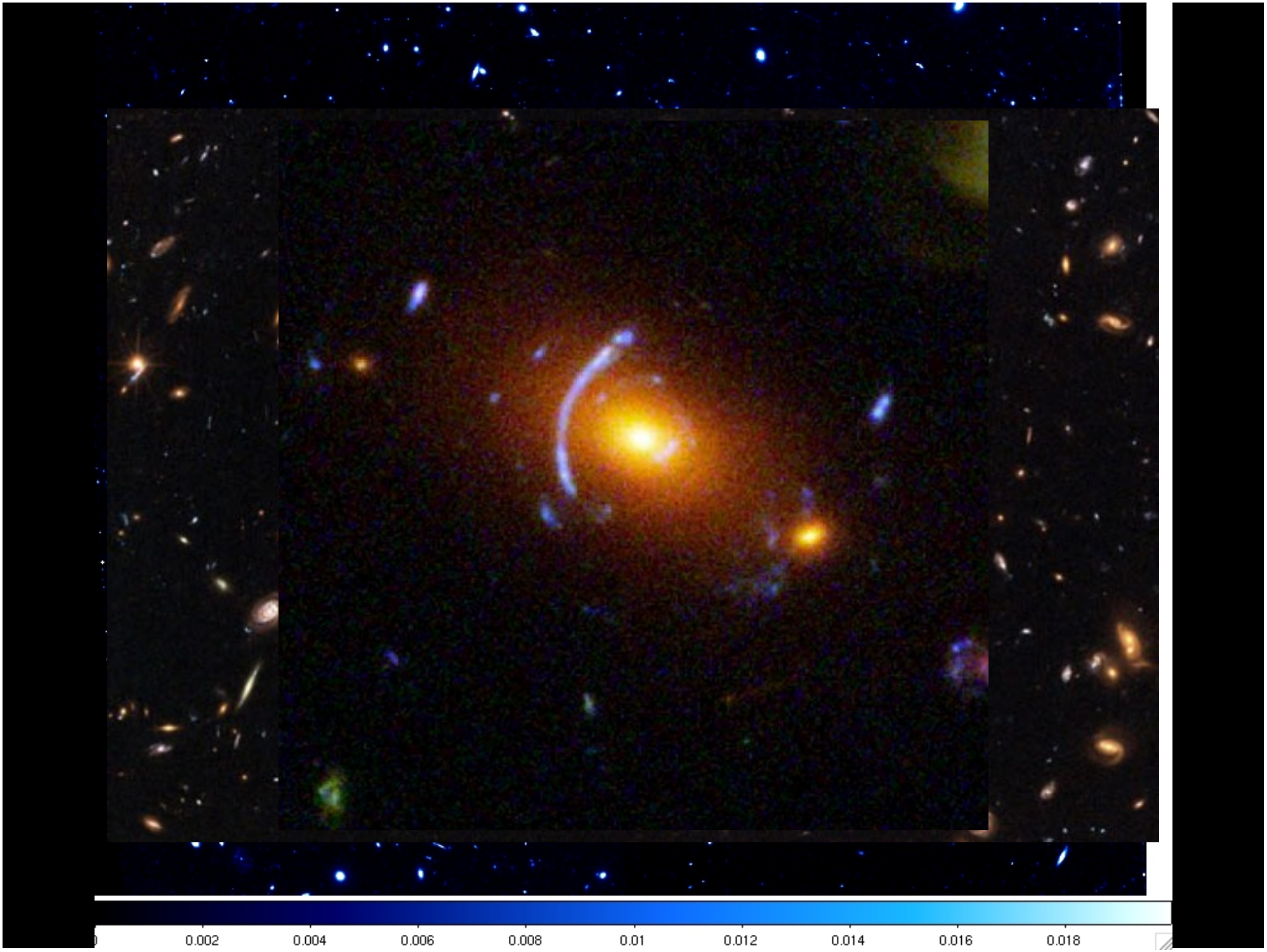
Einstein cross



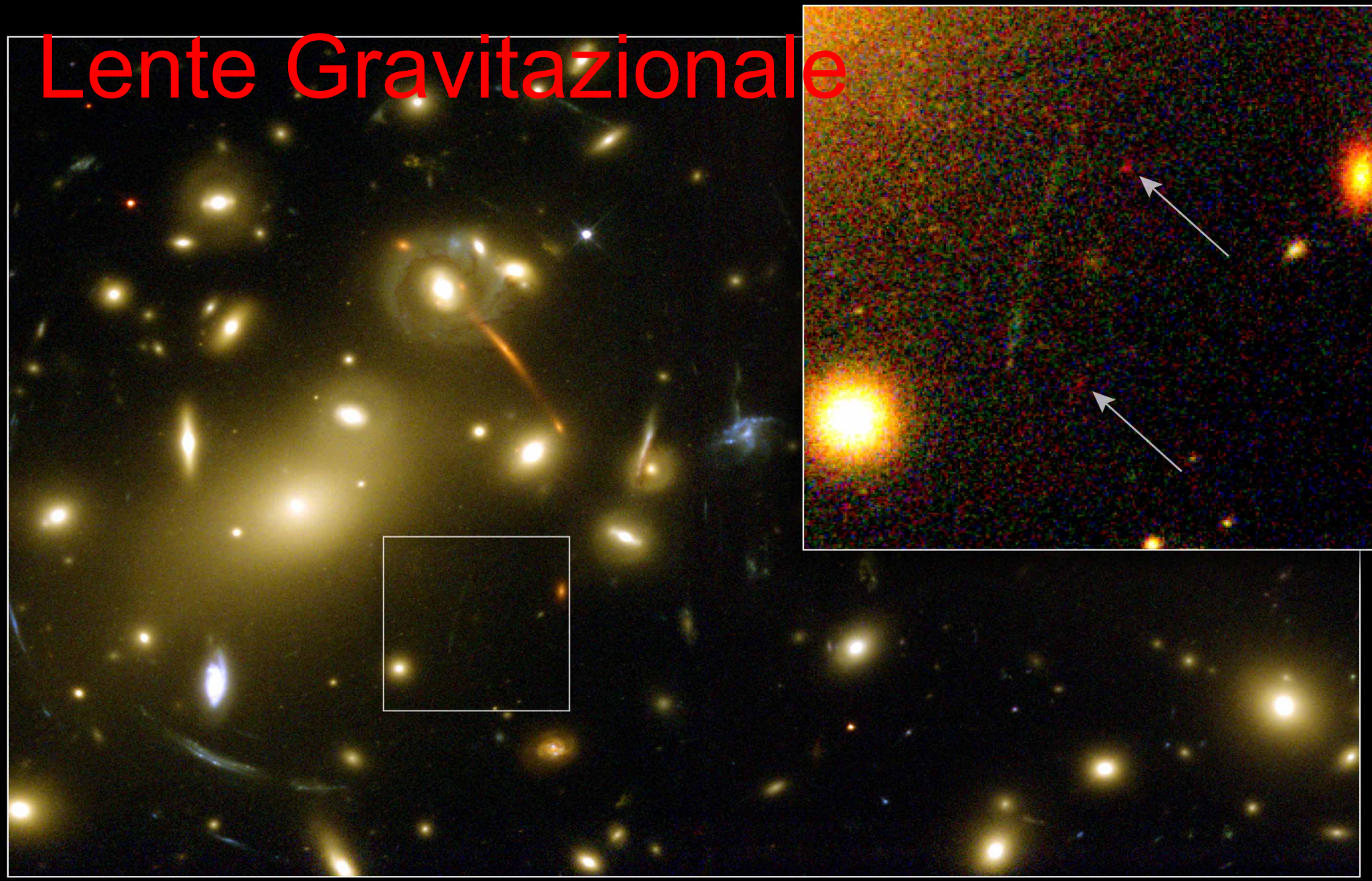

Gravitational Lens G2237+0305





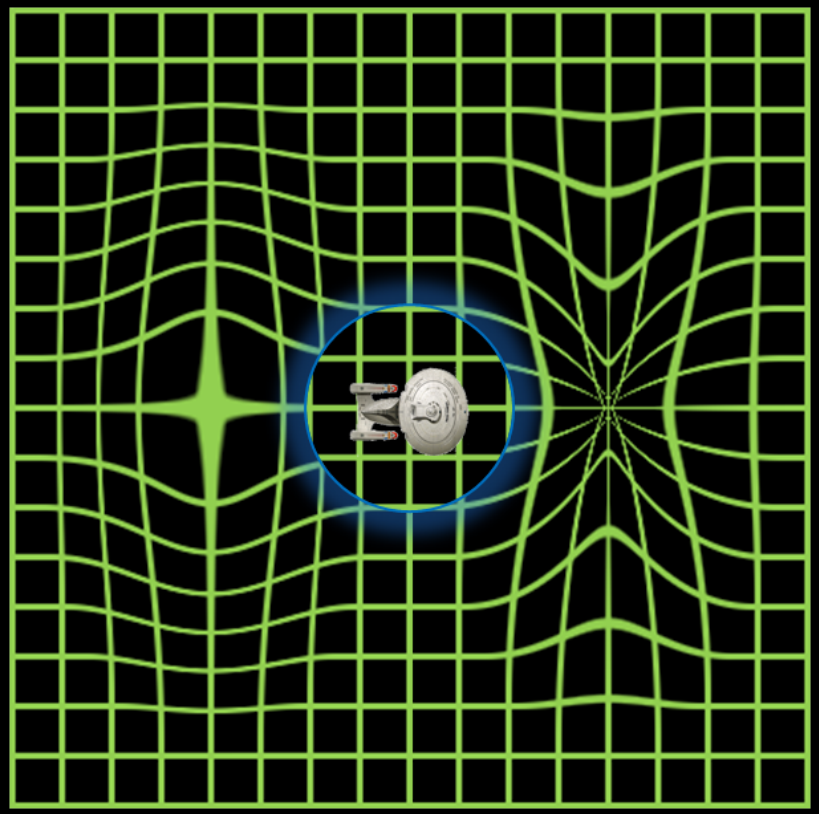

0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018

Lente Gravitazionale

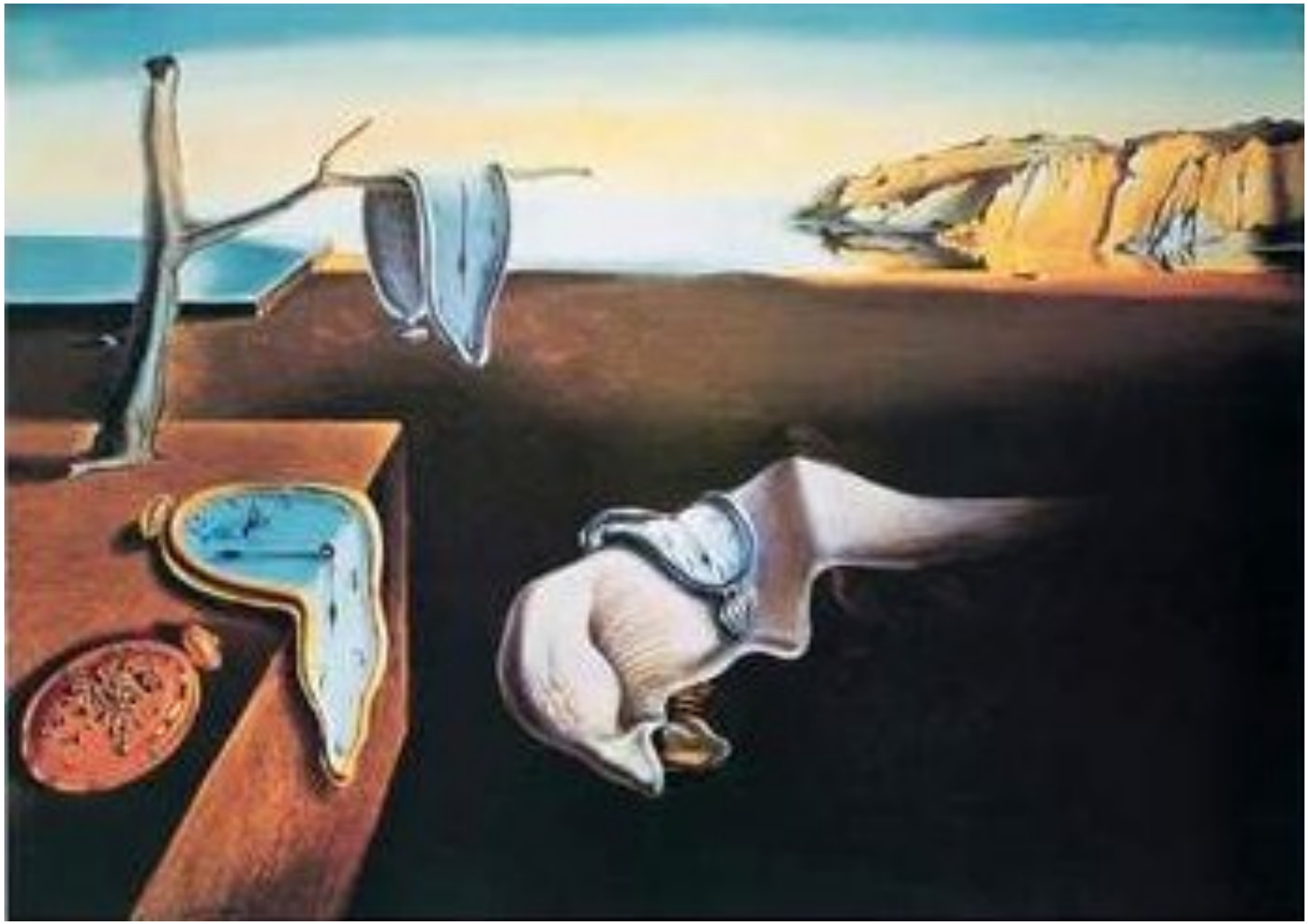


Distant Object Gravitationally Lensed by Galaxy Cluster Abell 2218
Hubble Space Telescope • WFPC2

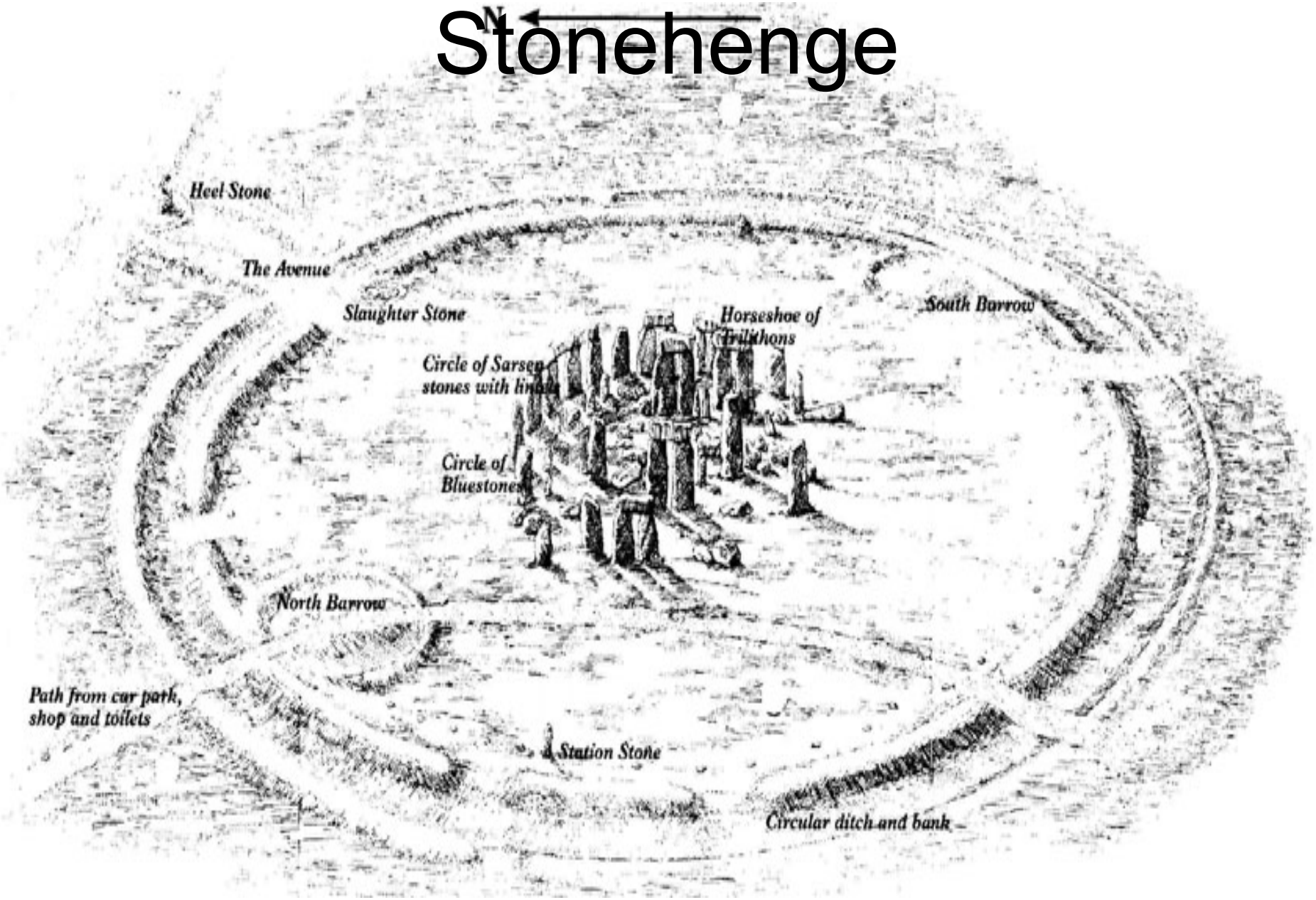
NASA, ESA, R. Ellis (Caltech) and J.-P. Kneib (Observatoire Midi-Pyrenees) • STScI-PRC01-32



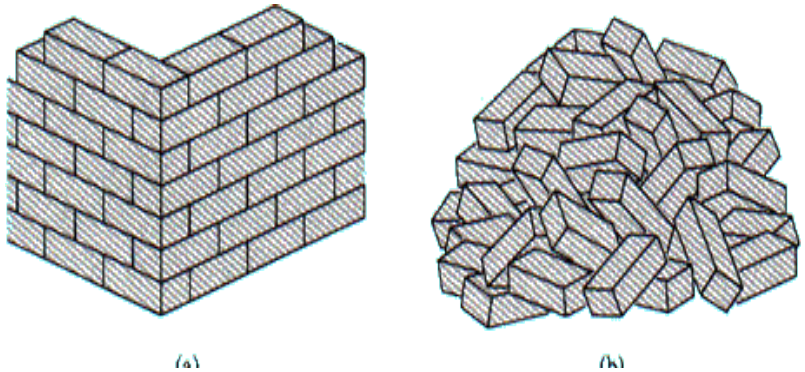
IL TEMPO
una dimensione “speciale”

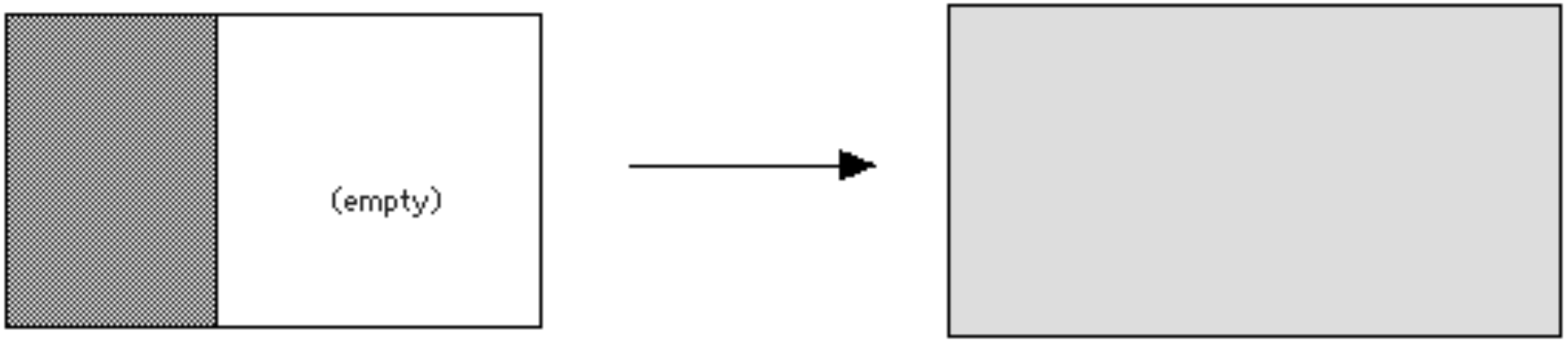


Stonehenge


N
Heel Stone
The Avenue
Slaughter Stone
Horseshoe of
South Barrow
Circle of Sarsen
stones with lin
Circle of
Bluestones
North Barrow
Path from car park,
shop and toilets
Station Stone
Circular ditch and bank

Il tempo e l'entropia





Il tempo va in una sola direzione

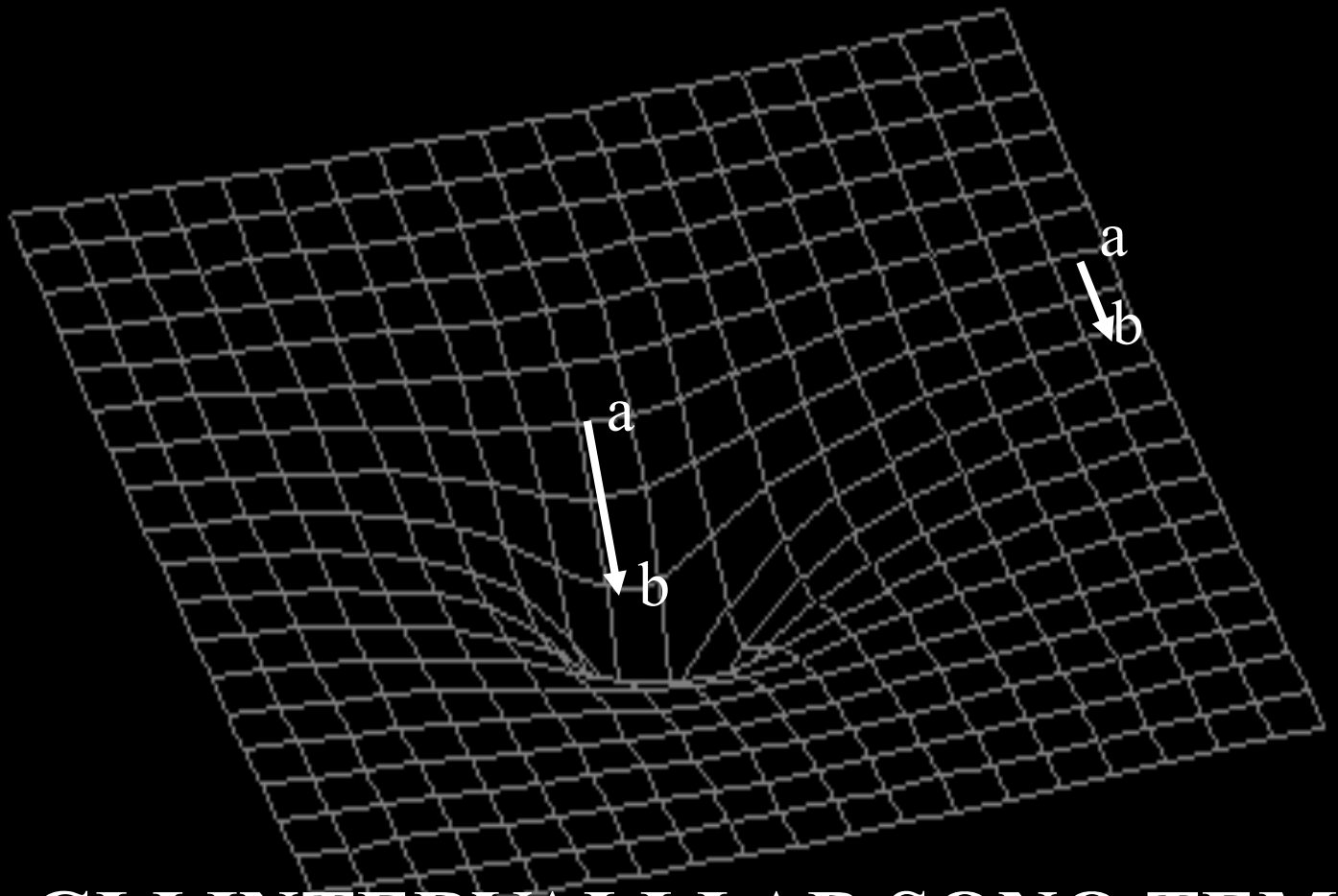
Ci vuole più energia a incollare i pezzi di un vaso rotto che a romperlo

Ci vuole più energia a perdere dei chili di troppo che a metterli su

Ci vuole meno energia ad un bimbo a mettere in disordine la sua stanza che ai suoi genitori a rimetterla in ordine

Il tempo
e` una quantita` relativa

CURVATURA (tempo)



ORA GLI INTERVALLI AB SONO TEMPO

$$T = \frac{T_0}{\sqrt{1 - \frac{2GM}{Rc^2}}}$$

$$\frac{t_0}{t} = \sqrt{1 - \frac{2GM}{rc^2}}$$

t_0 - Time interval as measured at a radial position of r from the object creating the gravitational field in(s).

t - Time interval as measured by a distant observer in(s).

G - Gravitational constant in$\left(Nm^2/kg^2\right)$.

M - Mass of the object creating the gravitational field in(kg).

r - Radial position where t_0 is being measured in(m).

c - Speed of light in a vacuum in(m/s).

Object	Mass	Radius	Gravity at Surface	Gravitational Escape Velocity	Time dilation	Equivalent Lorentz/Time Dilation Velocity	Escape - Equivalent Velocity Error
	M	R	g	v_e	t_v	v_f	$v_e - v_f$
	kg	m	m/s^2	m/s	s	m/s	
Sun	2.00E+30	6.90E+08	274.98	621,946	1.00000215195969	621,946	0.0000000%
Mercury	3.59E+23	2.44E+06	3.70	4,431	1.00000000010922	4,431	0.0000153%
Venus	4.90E+24	6.07E+06	8.87	10,383	1.00000000059976	10,383	0.0000018%
Earth	5.98E+24	6.38E+06	9.80	11,187	1.00000000069626	1,187	-0.0000080%
Mars	6.58E+23	3.39E+06	3.71	5,087	1.00000000014395	5,087	0.0000245%
Jupiter	1.90E+27	7.14E+07	23.12	59,618	1.00000001977343	59,618	0.0000002%
Saturn	5.68E+26	5.99E+07	8.96	35,566	1.00000000703708	35,566	-0.0000002%
Uranus	8.67E+25	2.57E+07	7.77	21,201	1.00000000250060	21,201	-0.0000005%
Neptune	1.03E+26	2.47E+07	11.00	23,552	1.00000000308580	23,552	-0.0000019%
Pluto	1.20E+22	1.15E+06	0.72	1,178	1.00000000000772	1,178	0.0001586%

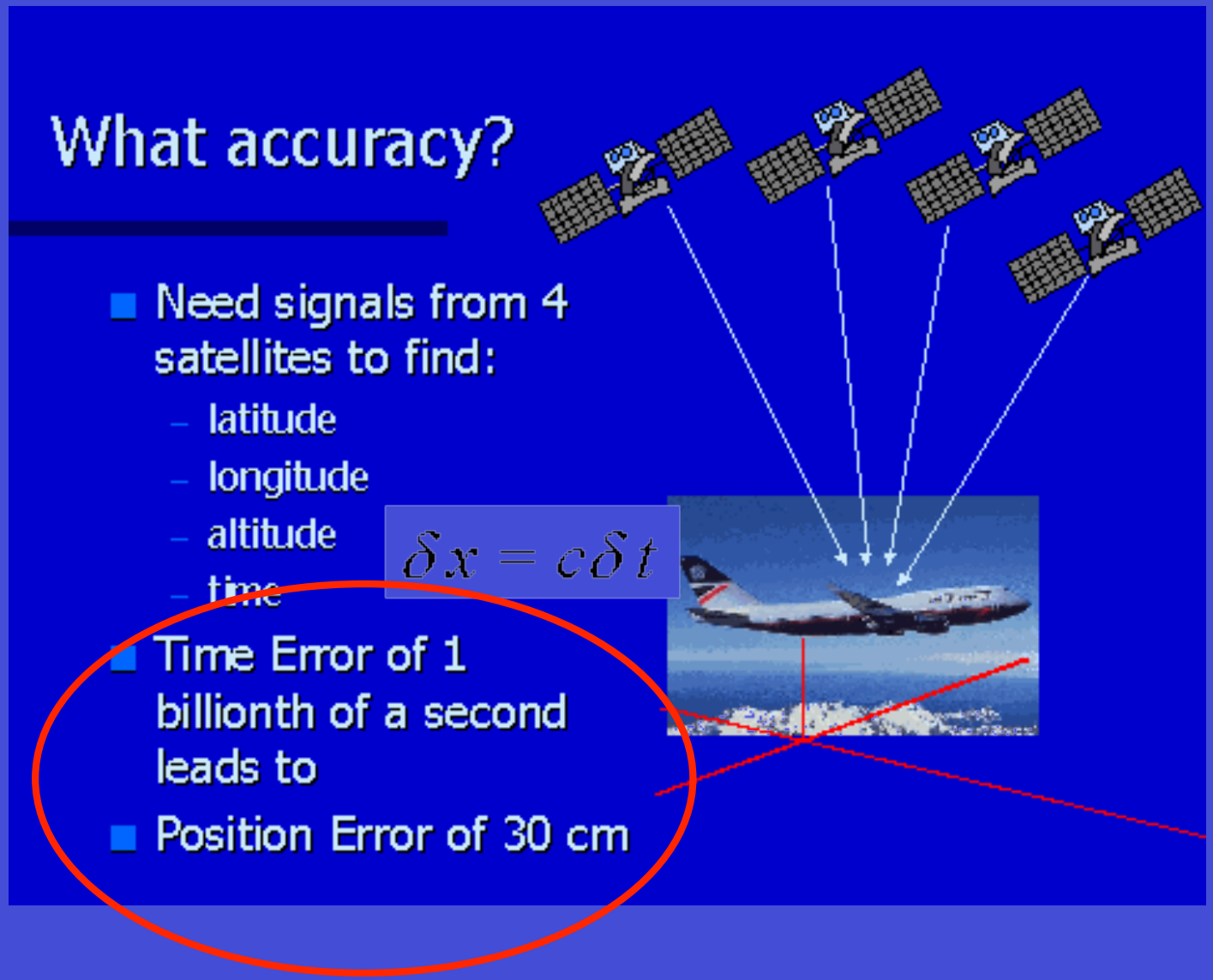
Table 1. Gravitational Escape Velocity versus Equivalent Lorentz/Time Dilation Velocity*

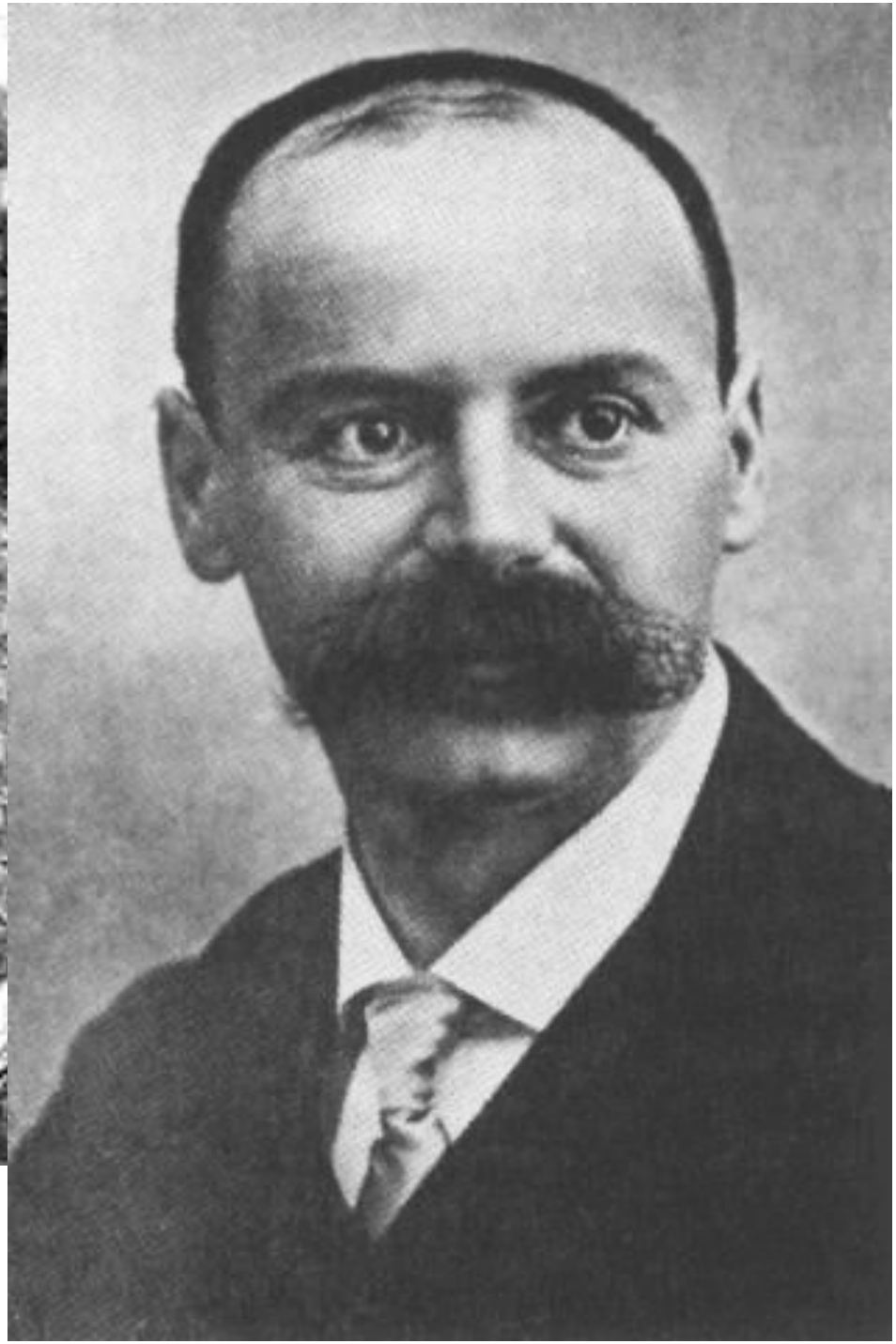
Sole = 2 milionesimi

Terra=0.6 miliardesimi nanosecondi

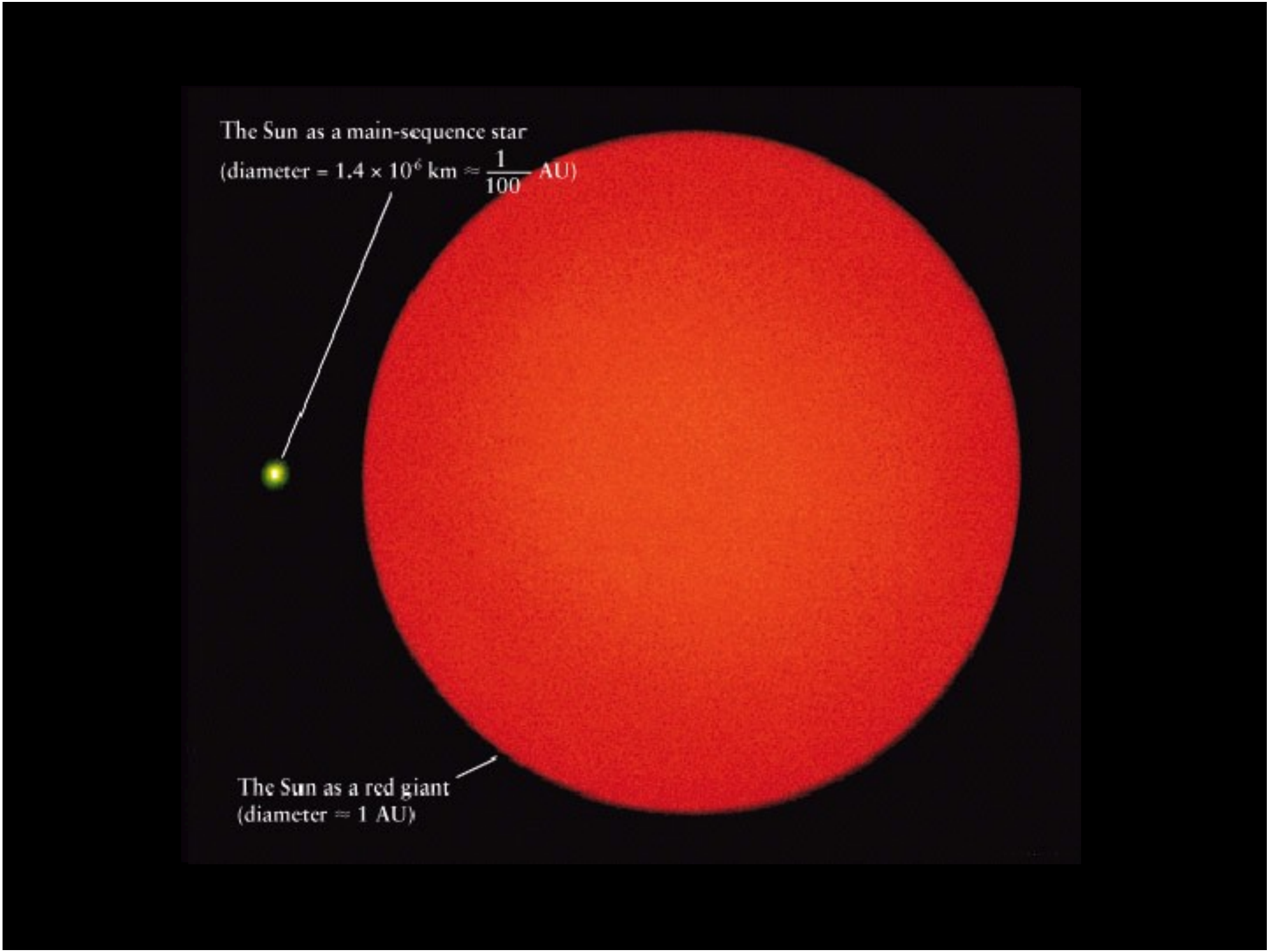
Nel 1971 furono usati due orologi al cesio di cui uno posto su un Boeing 707. Dopo 40 ore a circa 800 km/h l'orologio sul Boeing rimase indietro di 0.00000008 (8 nsec)

Ci sono 24 satelliti in orbita ad una altezza di 20.000 km con una velocita' orbitale di 14.000 km/h. Hanno a bordo orologi atomici





Schwarzschild (1873-1916)
1916


The Sun as a main-sequence star
(diameter = 1.4 × 10^6 km ≈ 1/100 AU)
The Sun as a red giant
(diameter ≈ 1 AU)

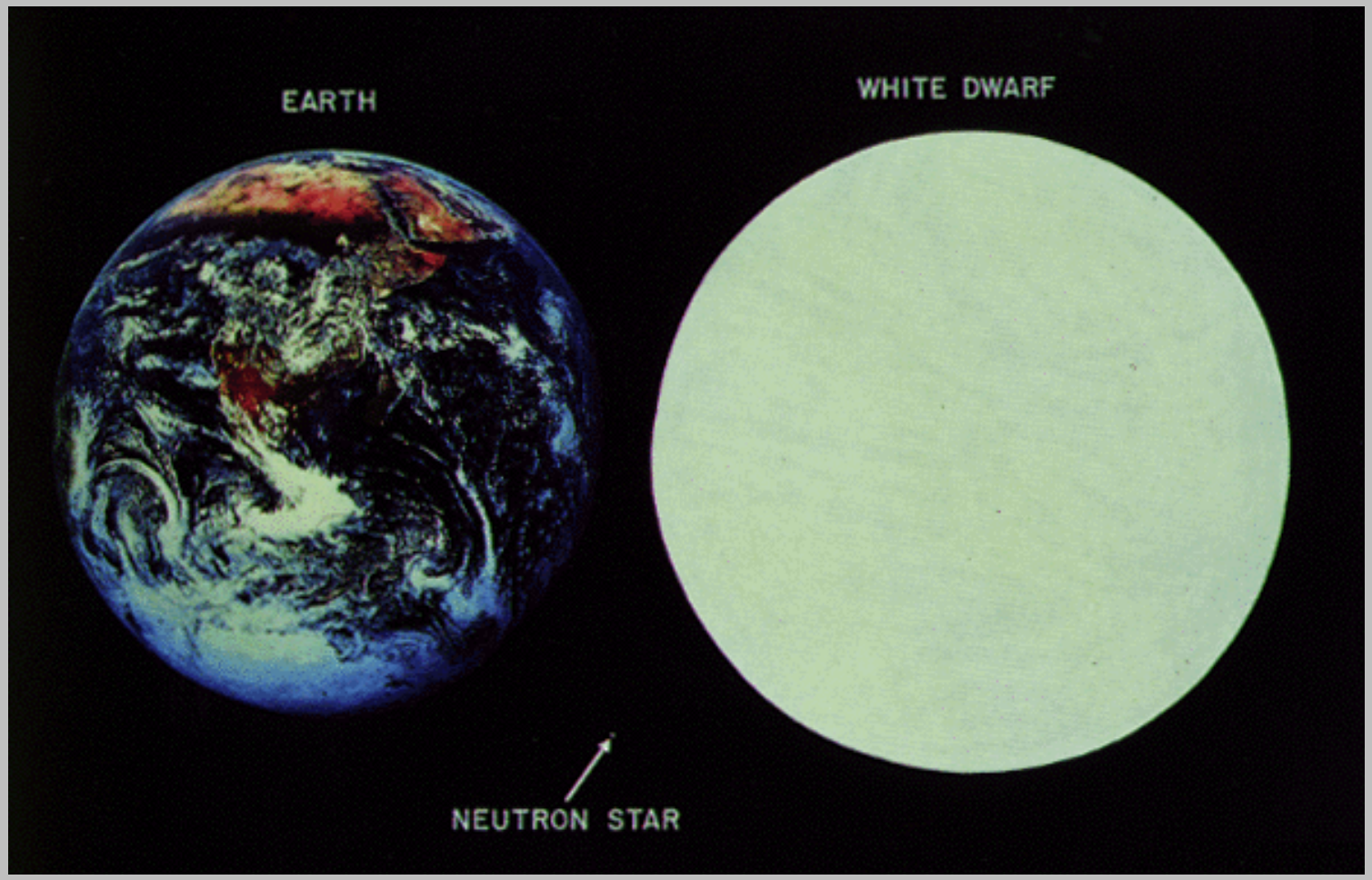
Extreme Gravity I:
White Dwarfs

1 cm^3 pesa
1 tonnellata

$M \approx 1.0\ M_{sun}$
$R \approx 5800$ km
$V_{esc} \approx 2\%$ speed of light

(Left: NASA Photo)

Limite di Chandrasekar (1.4 Msolari)



circa massa solare

Vfuga=100.00 km/s 30 % c
Volkoff-Oppenheimer limit 1.5-3.0 Msolari

Neutron Star & Black Hole

Manhattan
(spaceimaging.com)

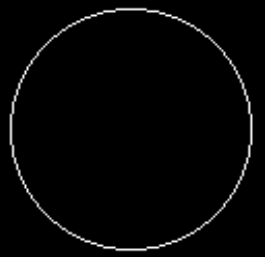
Neutron Star
M=1.5 M_{sun}
R≈10 km

D=5 millimetri pesano 5 miliardi di tonnellate

Neutron Star & Black Hole

Manhattan
(spaceimaging.com)

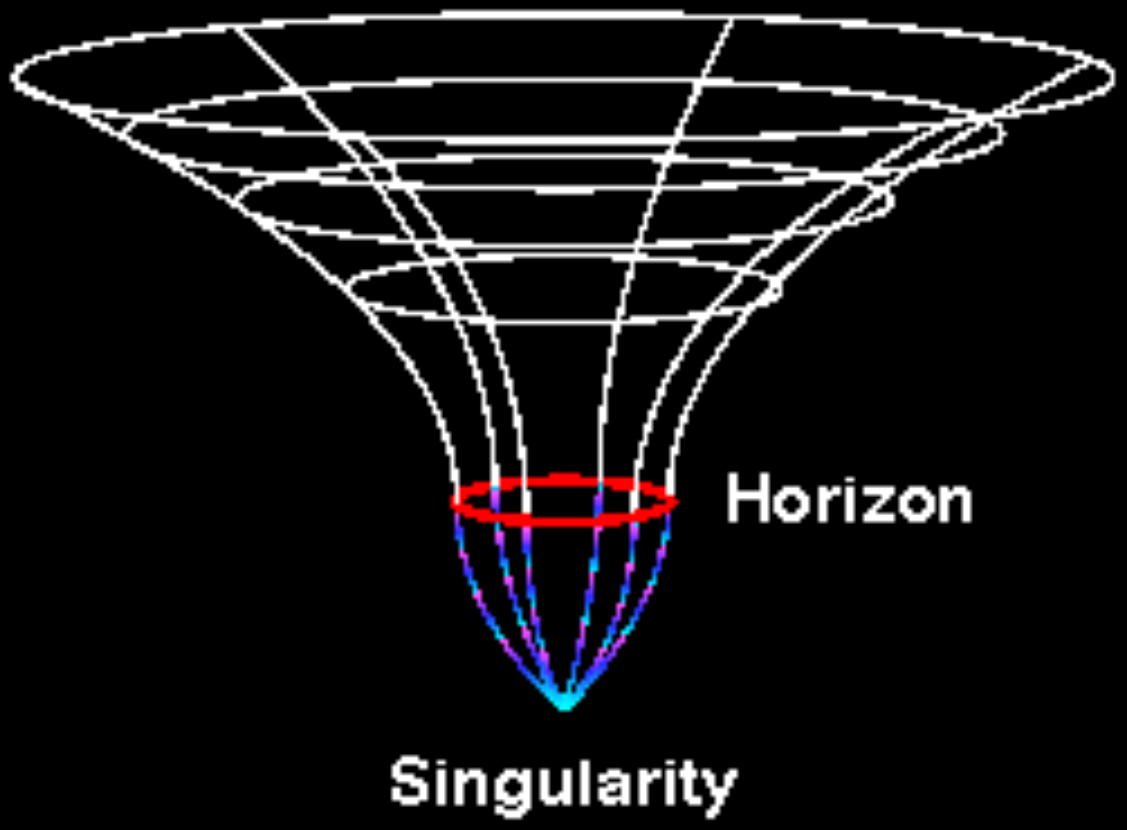
Neutron Star
M=1.5 M_{sun}
R≈10 km



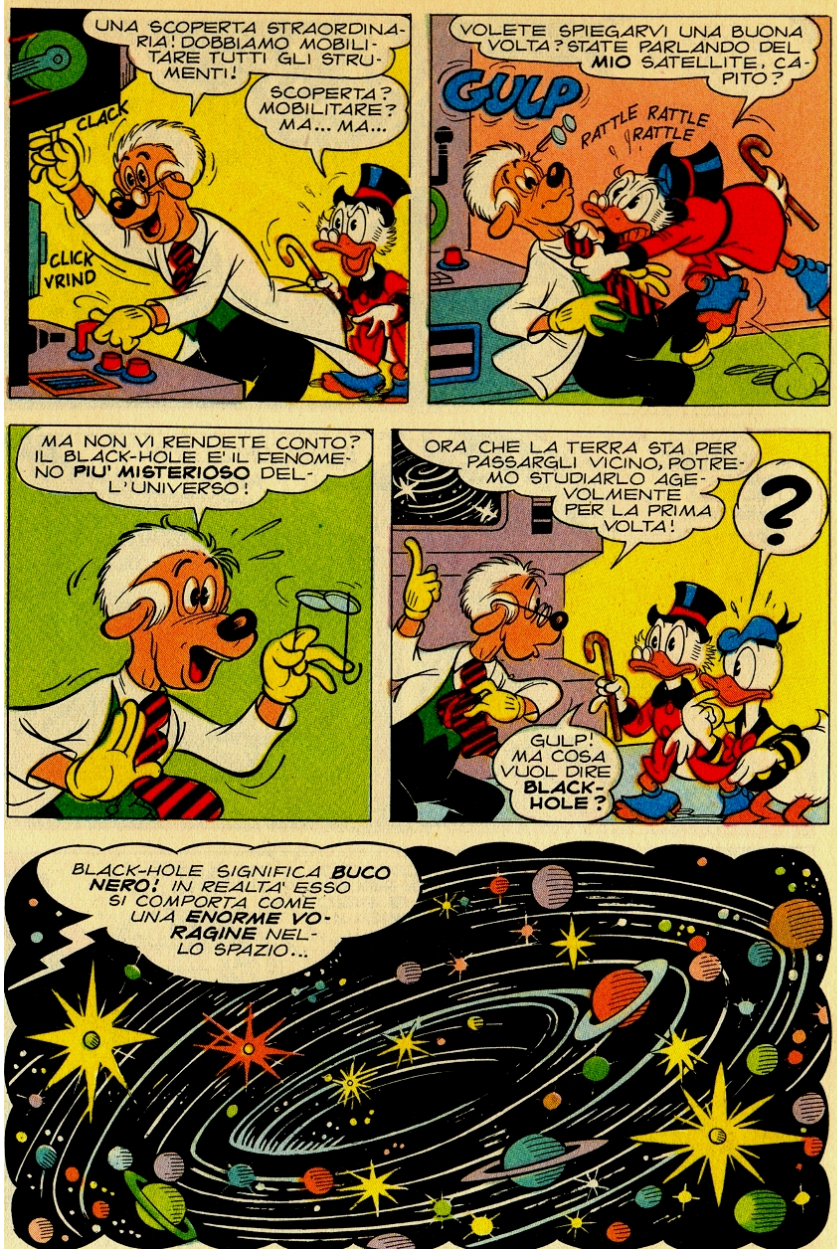
Black Hole
M = 1.5 M_{sun}
R_S = 4.5 km

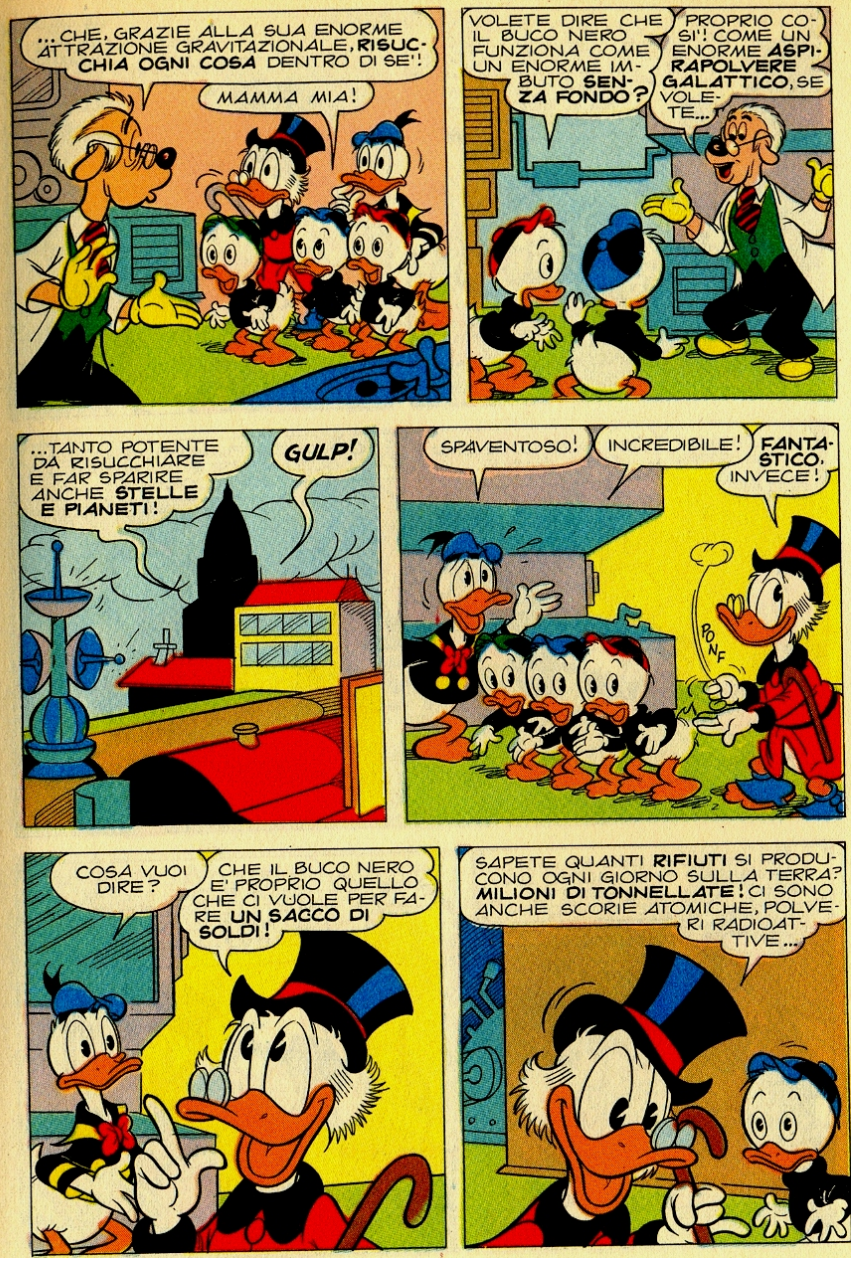
$$R = \frac{2GM}{c^2}$$

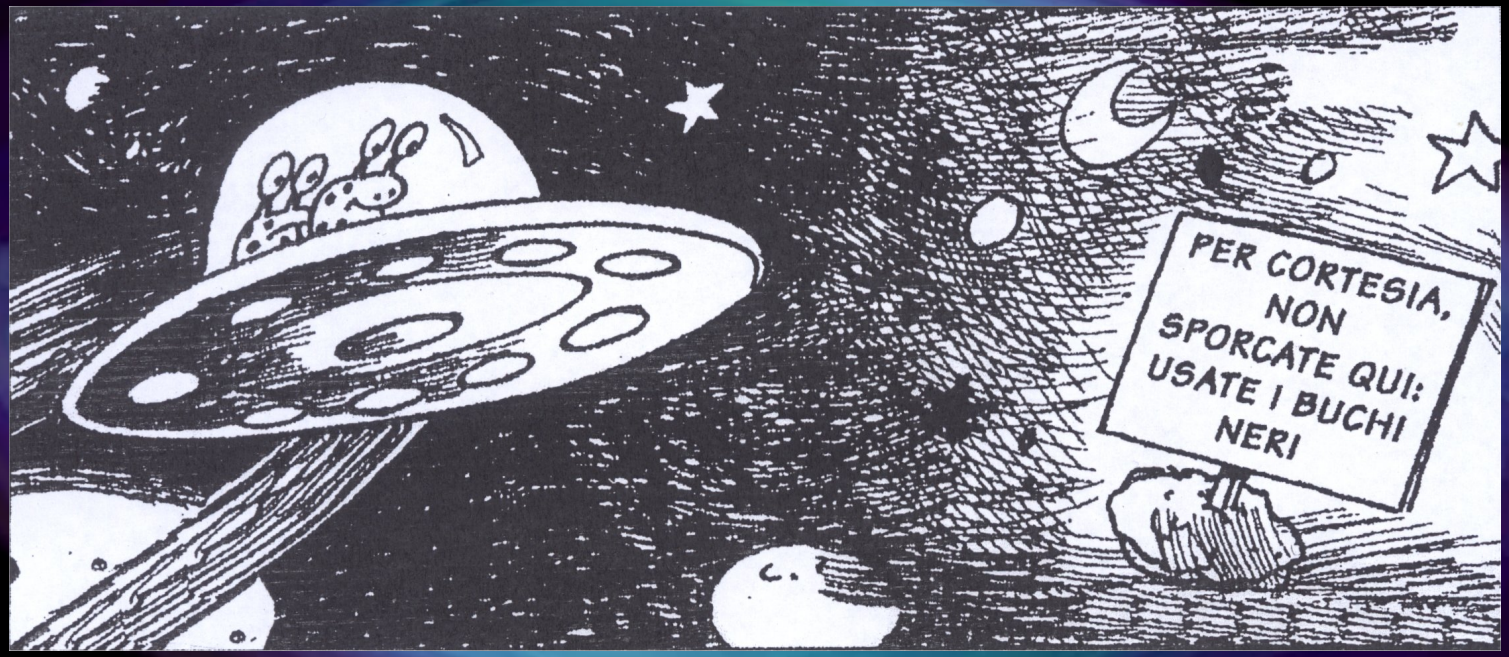
ORIZZONTE DEGLI EVENTI



se il Sole fosse un buco nero
L'orizzonte avrebbe un raggio di 3 km

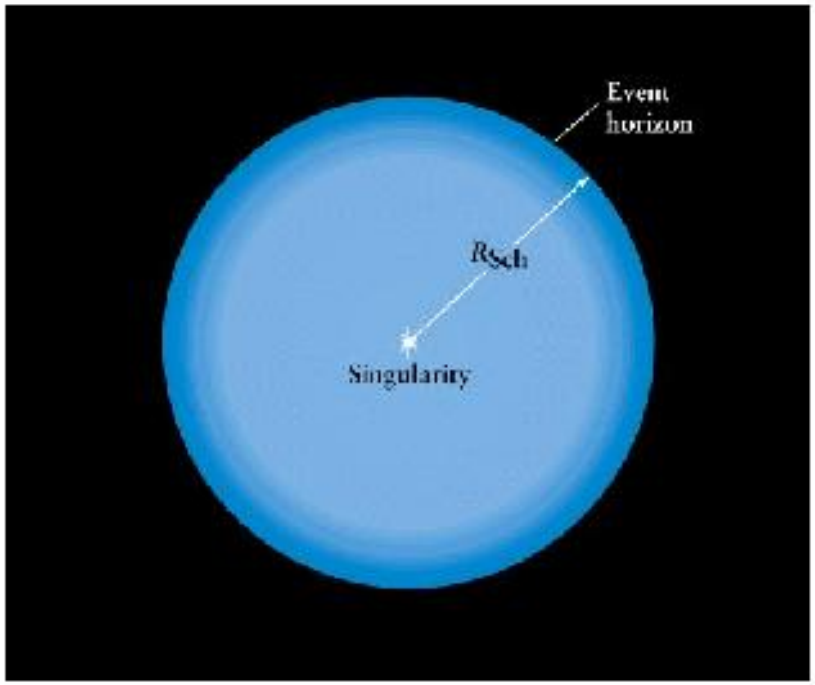

UNA SCOPERTA STRAORDINARIA! DOBBIAMO MOBILITARE TUTTI GLI STRUMENTI!
CLACK
CLICK VRIND
SCOPERTA? MOBILITARE? MA... MA...
VOLETE SPIEGARVI UNA BUONA VOLTA? STATE PARLANDO DEL MIO SATELLITE, CAPITO?
GULP
RATTLE RATTLE RATTLE
MA NON VI RENDETE CONTO? IL BLACK-HOLE E' IL FENOMENO PIU' MISTERIOSO DELL'UNIVERSO!
ORA CHE LA TERRA STA PER PASSARGLI VICINO, POTREMO STUDIARLO AGEVOLMENTE PER LA PRIMA VOLTA!
?
GULP! MA COSA VUOL DIRE BLACK-HOLE?
BLACK-HOLE SIGNIFICA BUCO NERO! IN REALTA' ESSO SI COMPORTA COME UNA ENORME VORAGINE NELLO SPAZIO...

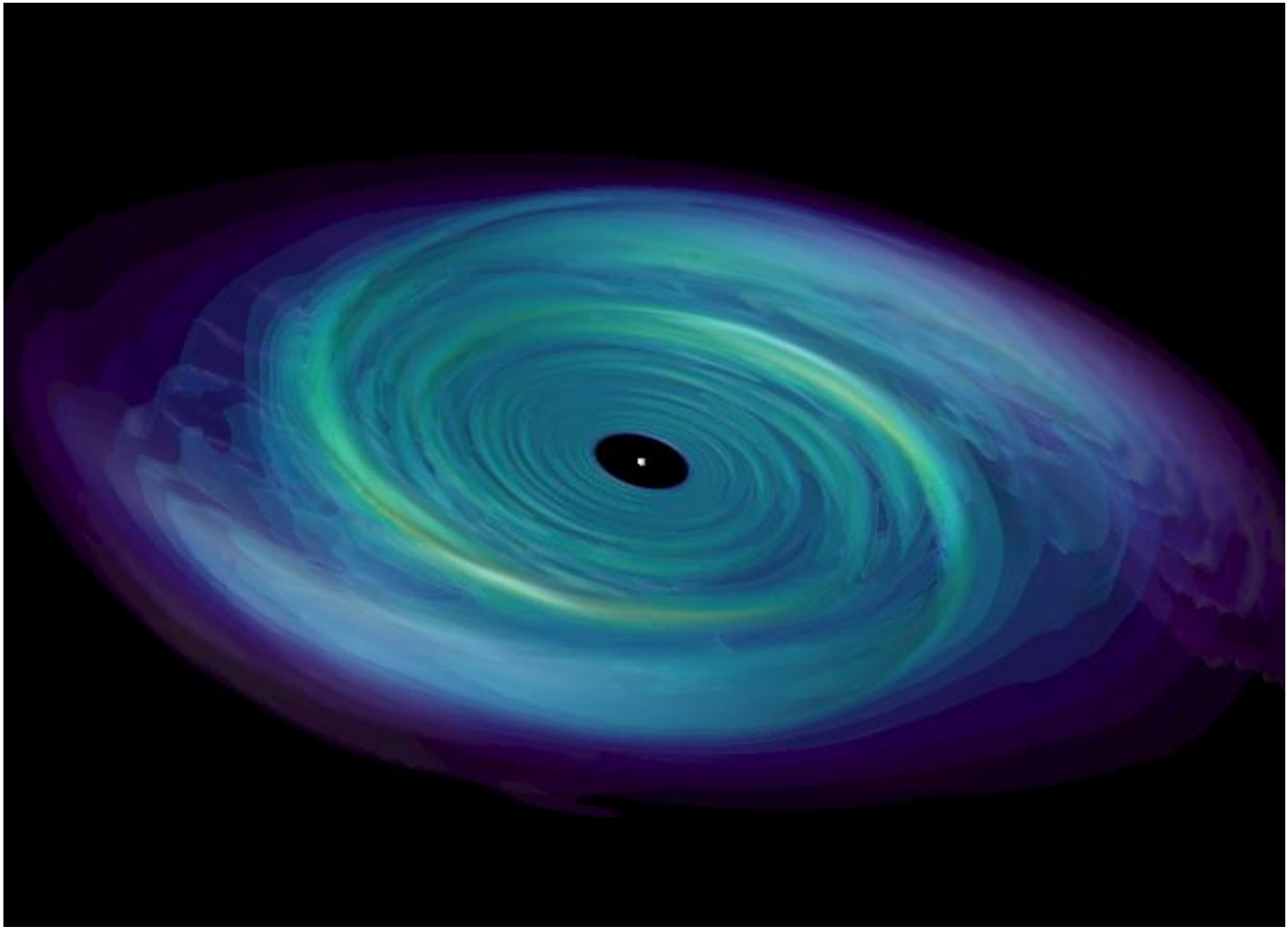

...CHE, GRAZIE ALLA SUA ENORME ATTRAZIONE GRAVITAZIONALE, RISUCCHIA OGNI COSA DENTRO DI SE'!
MAMMA MIA!
VOLETE DIRE CHE IL BUCO NERO FUNZIONA COME UN ENORME IMBUTO SENZA FONDO?
PROPRIO COSI'! COME UN ENORME ASPIRAPOLVERE GALATTICO, SE VOLETE...
...TANTO POTENTE DA RISUCCHIARE E FAR SPARIRE ANCHE STELLE E PIANETI!
GULP!
SPAVENTOSO!
INCREDIBILE!
FANTASTICO, INVECE!
BONK
COSA VUOI DIRE?
CHE IL BUCO NERO E' PROPRIO QUELLO CHE CI VUOLE PER FARE UN SACCO DI SOLDI!
SAPETE QUANTI RIFIUTI SI PRODUCONO OGNI GIORNO SULLA TERRA? MILIONI DI TONNELLATE! CI SONO ANCHE SCORIE ATOMICHE, POLVERI RADIOATTIVE...


PER CORTESIA, NON SPORCATE QUI: USATE I BUCHI NERI

Inside a Black Hole

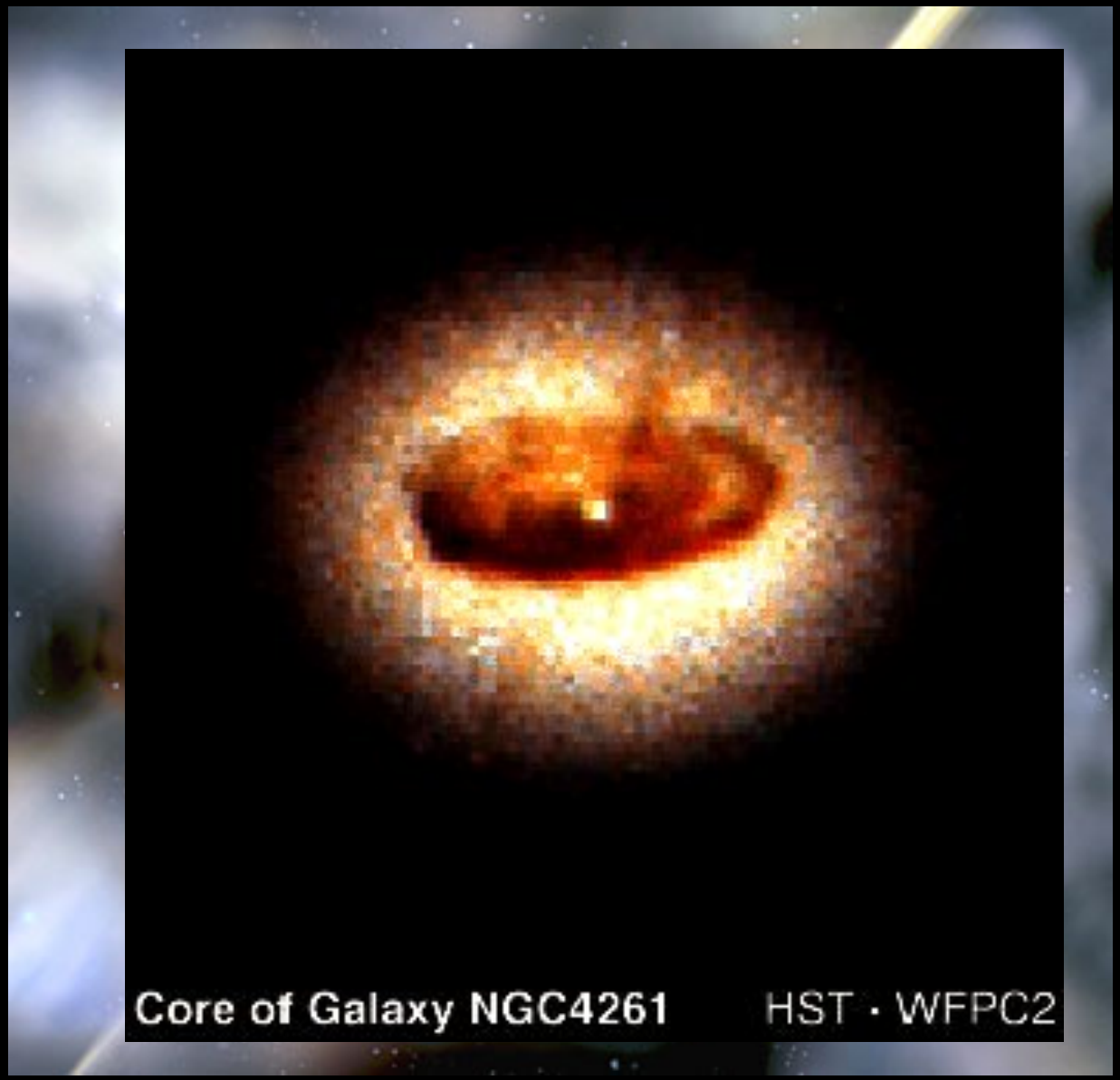
- The mass of a black hole is concentrated at the singularity
- The size of the black hole is defined by the surface defining the trapped interior region form which nothing can escape- - the event horizon
  - The Schwarzschild radius

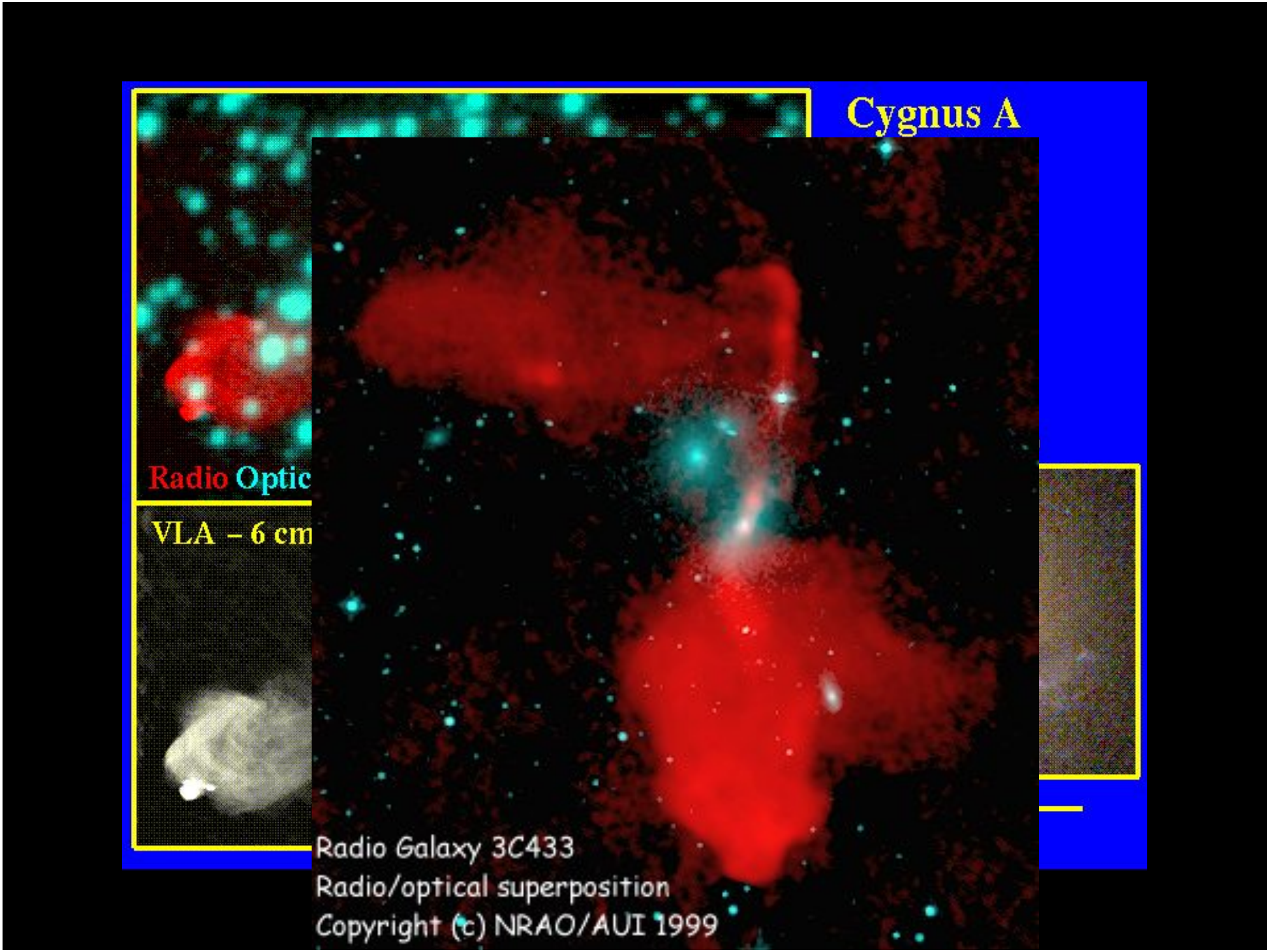




FILMATO HST15_BLACKHOLE

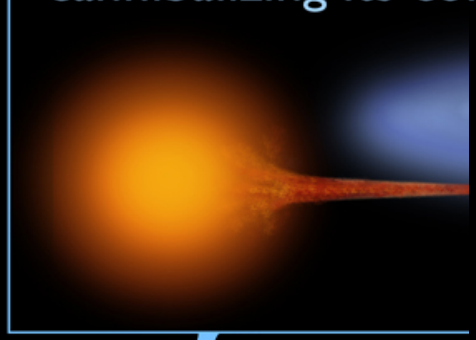
FILMATO HEIC0409a

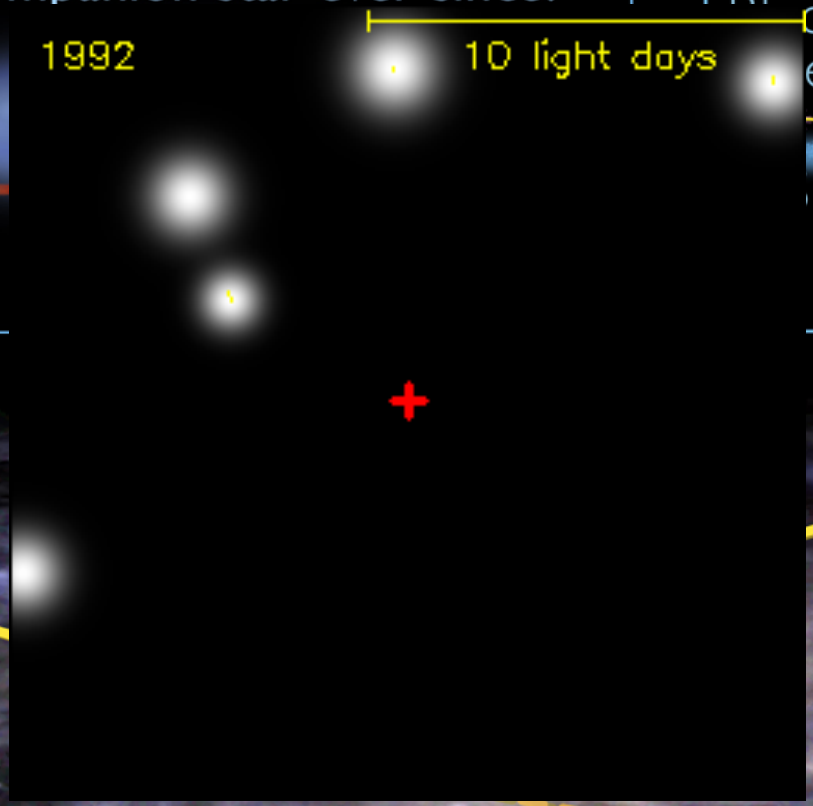

Core of Galaxy NGC4261
HST · WFPC2


Cygnus A
Radio Optic
VLA – 6 cm
Radio Galaxy 3C433
Radio/optical superposition
Copyright (c) NRAO/AUI 1999

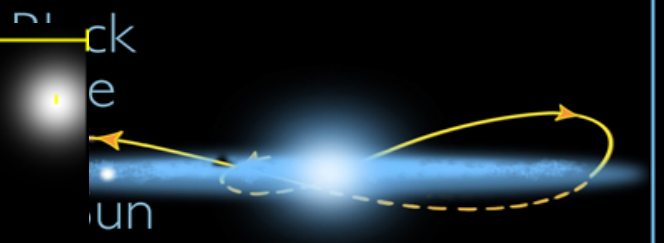
Black hole's wild ride through the Milky Way

The black hole, liberated from a globular cluster some 7 billion years ago, has been cannibalizing its companion star ever since.





Edge-on view of orbit



Black hole's orbit

Our Sun

Artist's conception of the Milky Way


AVETE RACCOLTO TUTTE LE IMMONDIZIE? MA VO
AMMATTI


BRRRU


I SISMOGRAFI SONO IMPAZ
BRA CHE UN SISMA STIA C
CONTEMPORANEAMENTE T
TER


ABBIAMO INVITATO QUI IN STUDIO IL CELEBRE ASTRONOMO VON COMETEN CHE CI DIRA' COSA FARE PER CAVARSELA!


MA... DOV'E' IL CELEBRE ASTRONOMO? ERA QUI UN MOMENTO FA!


COSA E' SUCCESSO?
E' SVENUTO DI PAURA APPENA GLI ABBIAMO DATO LA NOTIZIA!

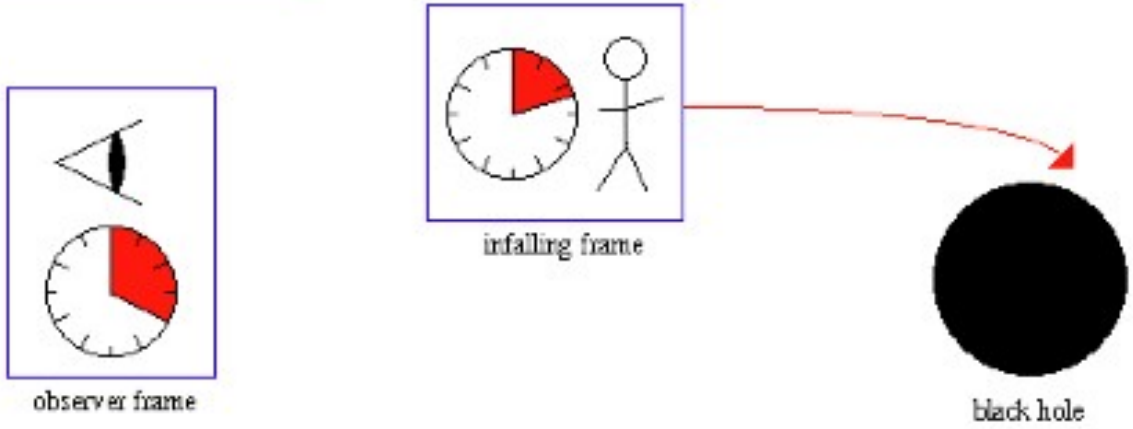

OLE E' CALATO... LA
STA SPO-
IDO!


QUALCOSA LA STA SBILANCIANDO! STIAMO USCENDO DALL'ORBITA E ALLONTANANDOCI DAL SOLE!

Il tempo rallenta
Non posso piu’
Rimanere fermo
Nello spazio

FILMATO earth mangiata

Falling into a Black Hole



the outside observer watchs the infalling's frame clock slow until it freezes just above the event horizon

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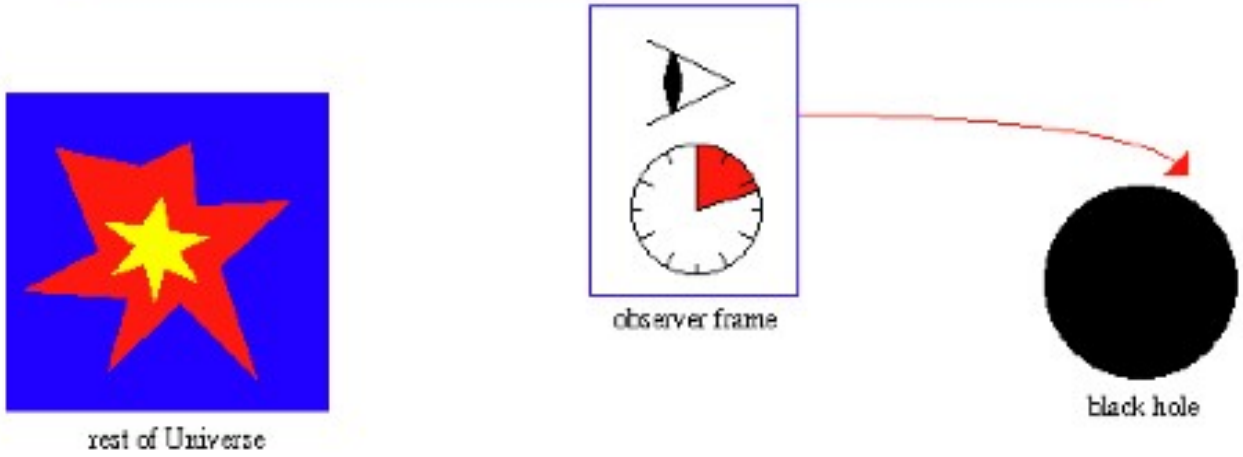
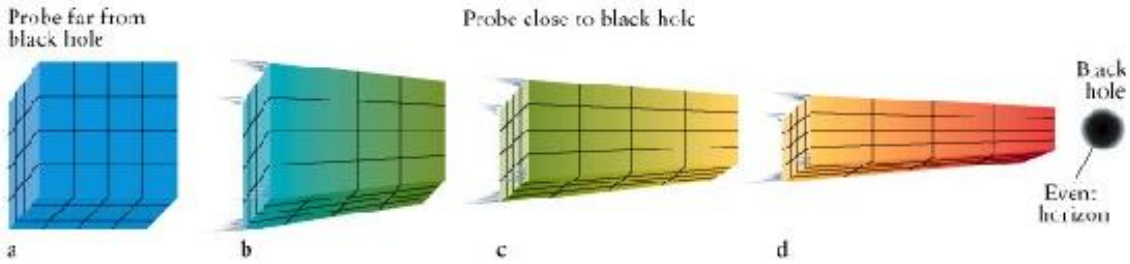
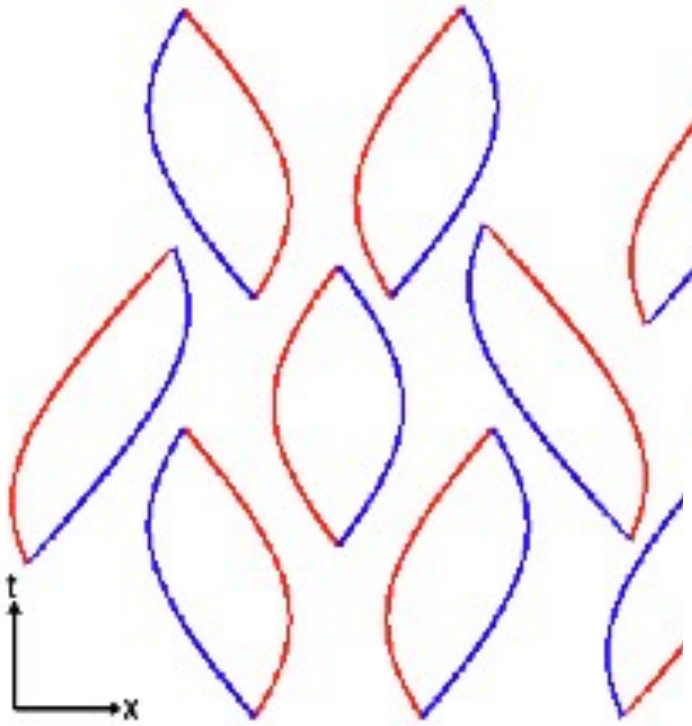


on the other hand, the infalling observer sees the rest of the Universe speeding up, watching the end of time just before falling into the event horizon

Falling into a Black Hole

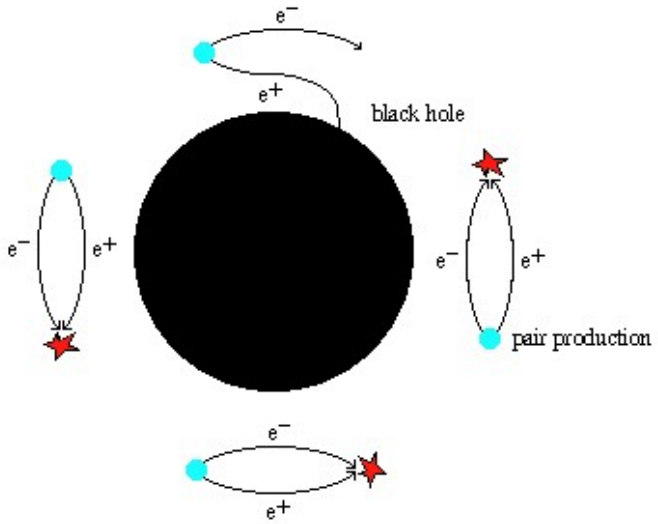
- The tidal forces of gravity near a black hole distort any matter that falls into it





Hawking Radiation

the strong gravitational field around a black hole causes pair production



if a pair is produced outside the event horizon, then one member will fall back into the black hole, but the other member will escape and the black hole loses mass

the amount of mass lost is greater for small black holes, therefore quantum sized black holes disintegrate in very short timescales

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

$$\rho = \frac{3c^6}{32\pi M^2 G^3}$$

$$t = \frac{30720\pi^2 M^3 G^2}{3hc^4}$$

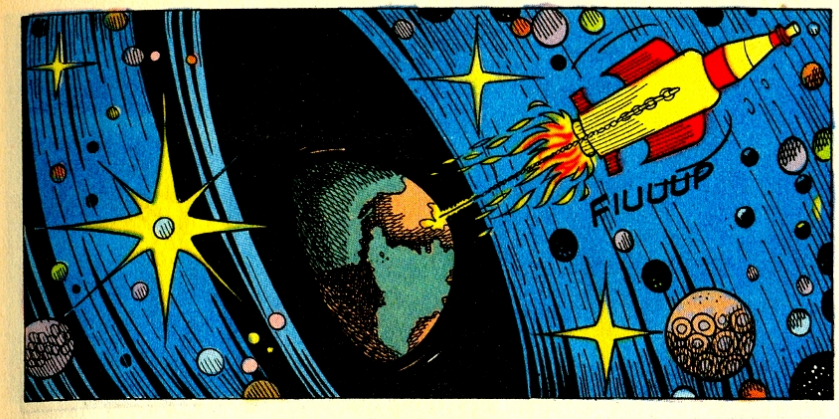
$$T = \frac{hc^3}{16\pi^2 kGM}$$

$$E = \frac{hc^3}{16\pi GM}$$

$$f = \frac{E}{h} = \frac{c^3}{16\pi GM}$$

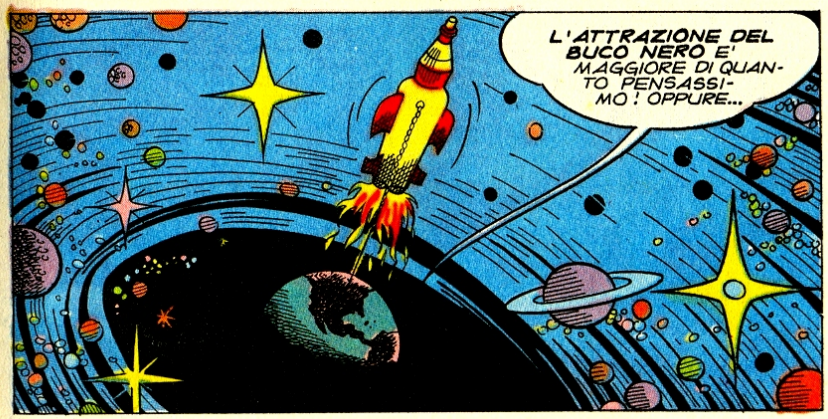
$$L = \sigma AT = \frac{32\pi^6 k^4 G^2 M^2 T^4}{15h^3 c^6} = \frac{hc^6}{30720\pi^2 G^2 M^2} = P$$

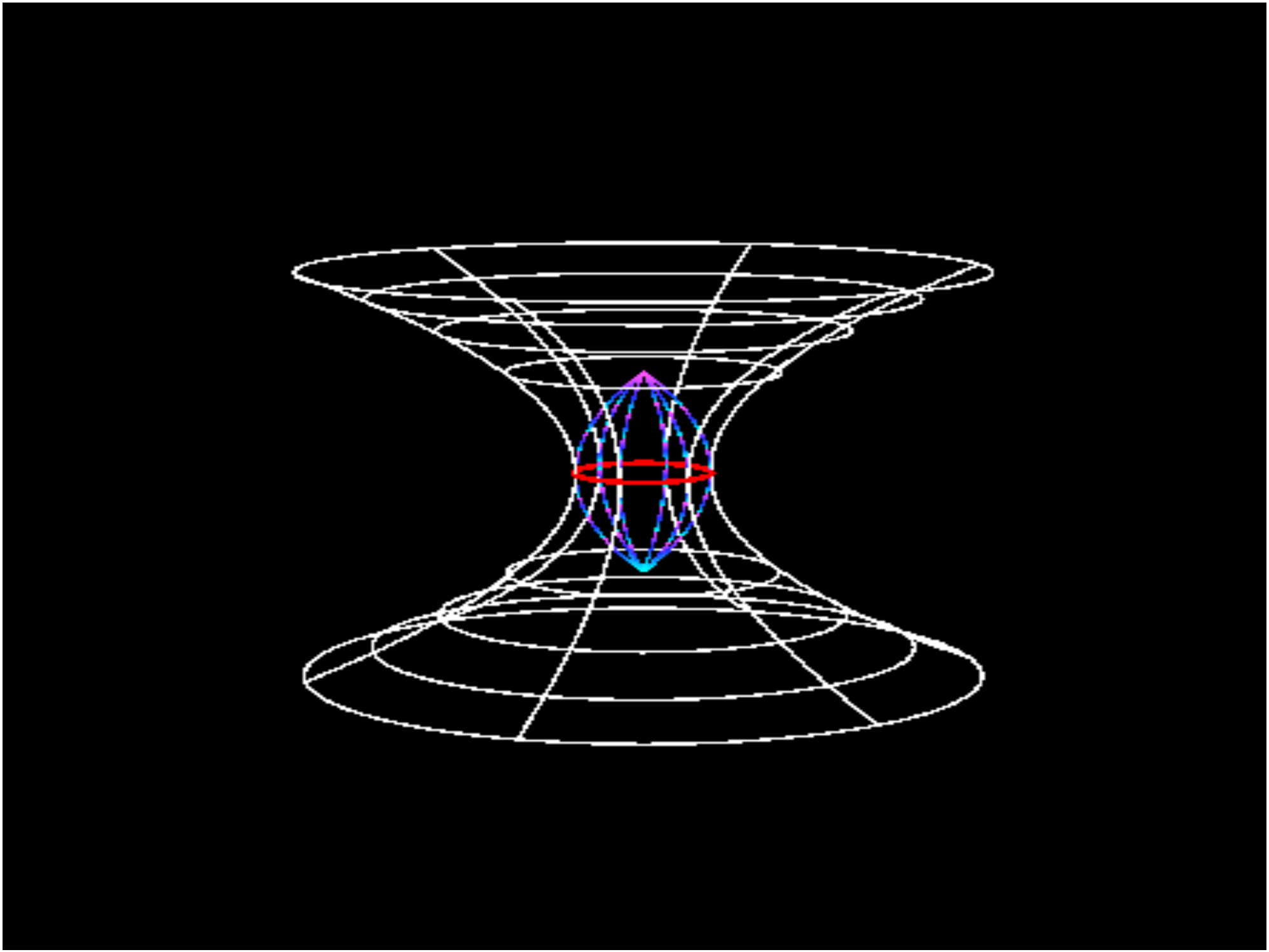

!
...VIA!
ZAC
CRINGLE
BROMBROM
CRRRUUUNK
ATTENTI ALLO STRATTONE!
ULP!
ABBIAMO LANCIATO IL RAZZO APPENA IN TEMPO! STIAMO PER ENTRARE NEL BUCO NERO!

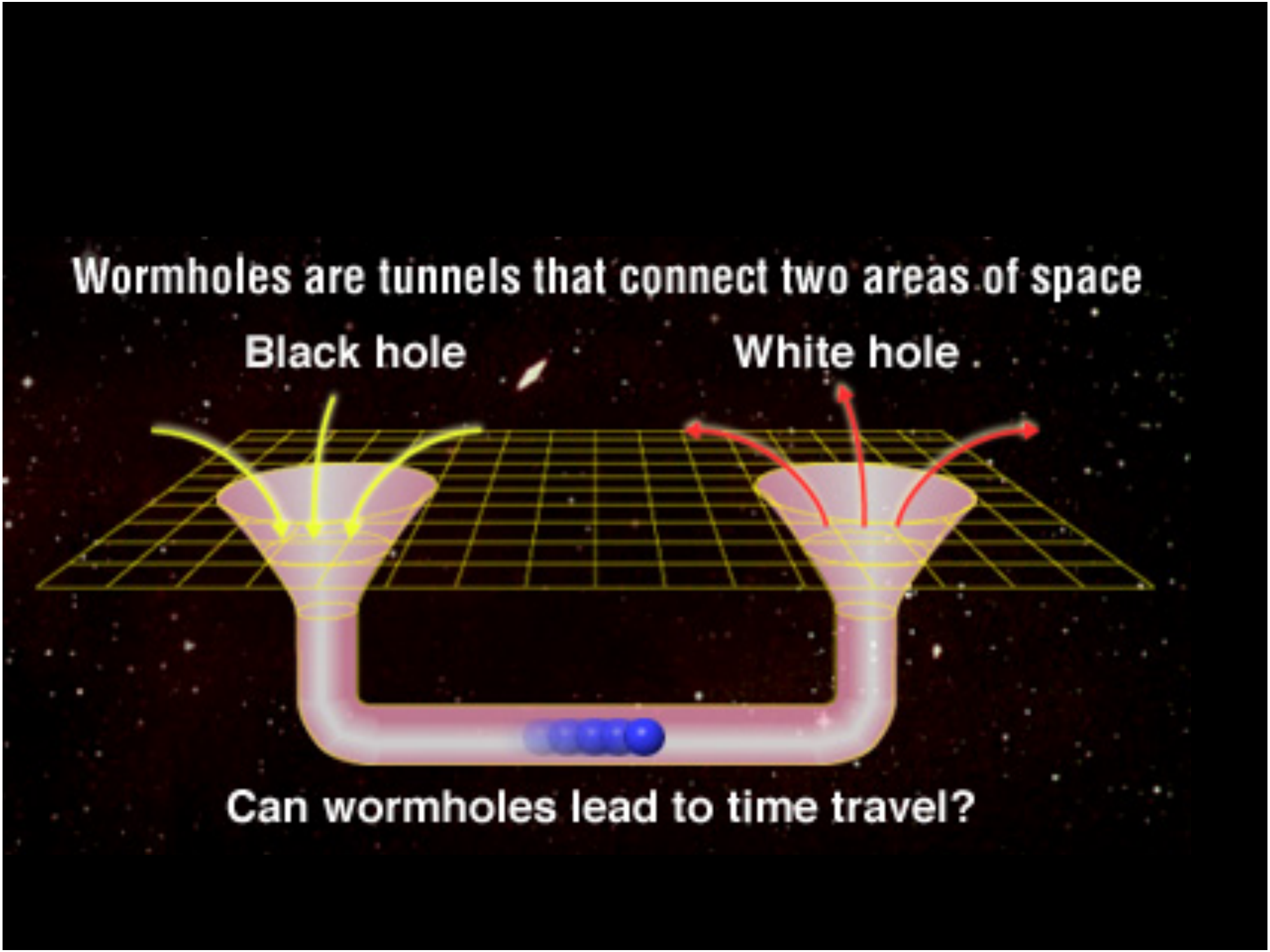

FIUUUP

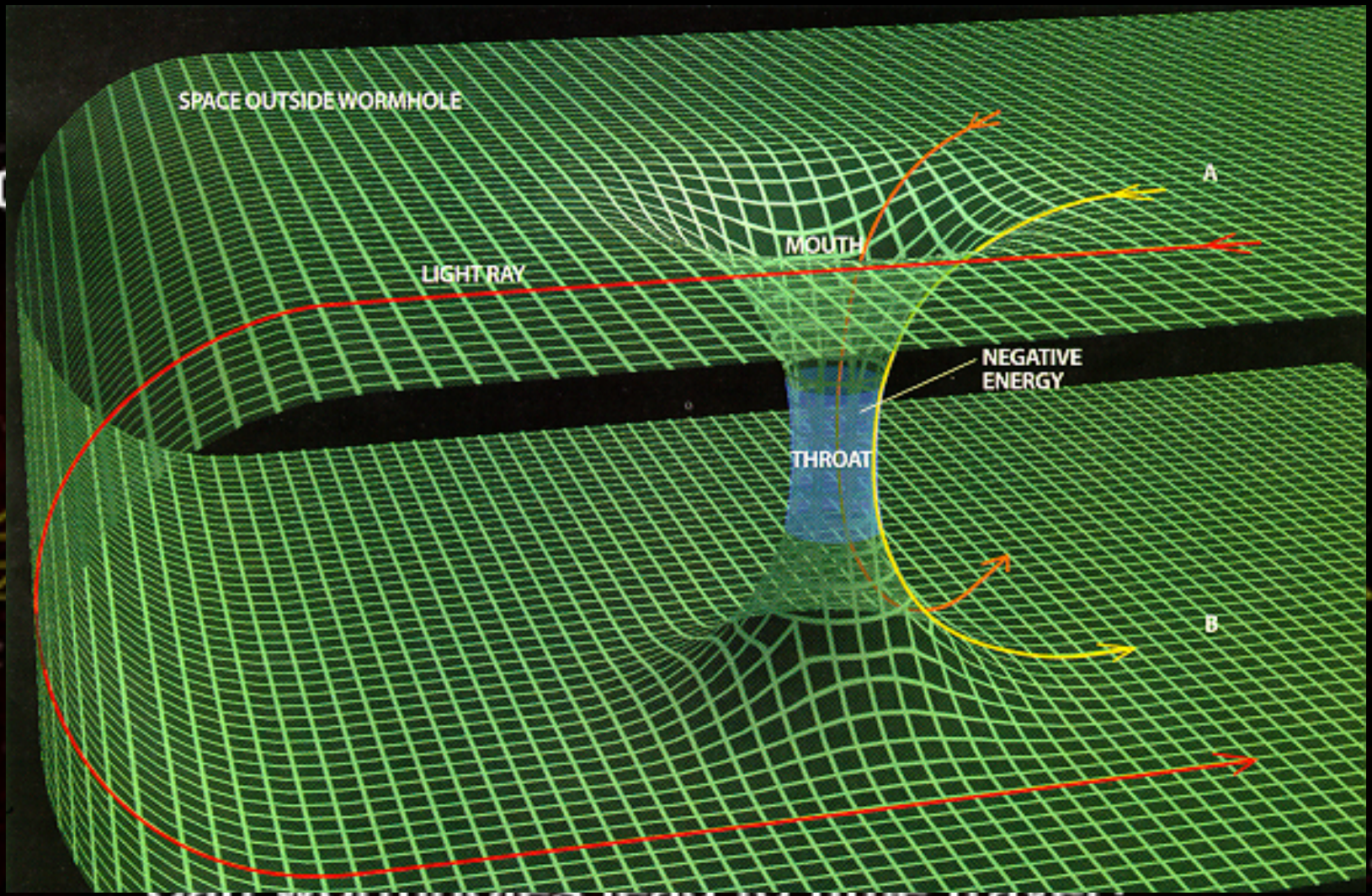

COS'E' SUCCESSO?
NON SIAMO ANCORA CADUTI NEL BUCO NERO!


LA POTENZA DEL MISSILE E' AL MASSIMO, MA NON CI SPOSTIAMO DI UN MILLIMETRO!

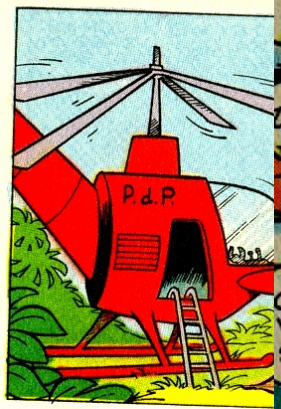

L'ATTRAZIONE DEL BUCO NERO E' MAGGIORE DI QUANTO PENSASSIMO! OPPURE...



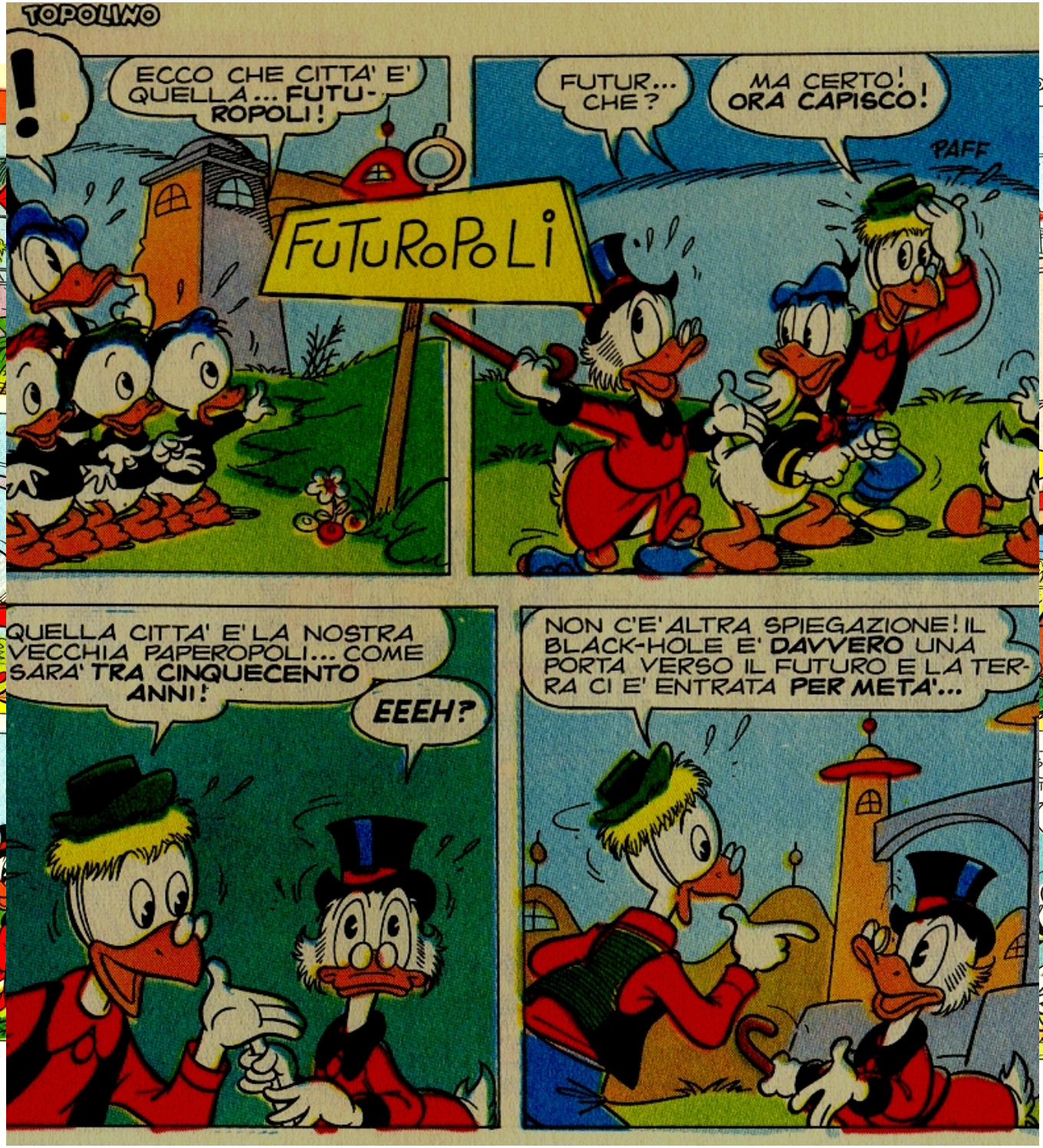

Wormholes are tunnels that connect two areas of space
Black hole
White hole .
Can wormholes lead to time travel?


SPACE OUTSIDE WORMHOLE
A
MOUTH
LIGHT RAY
NEGATIVE
ENERGY
THROAT
B

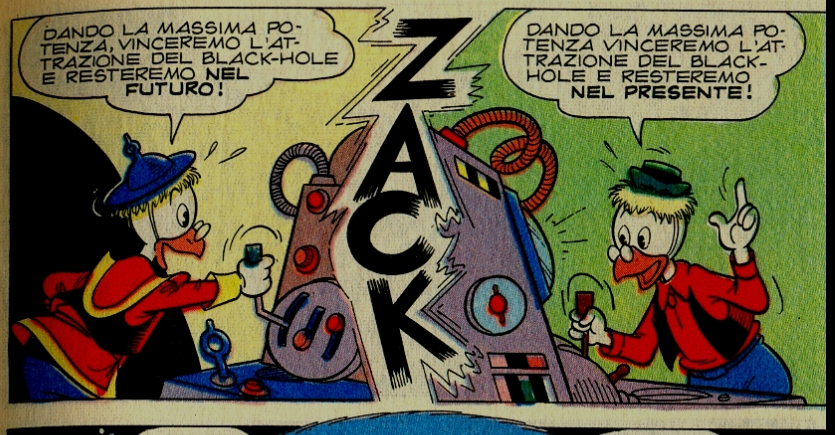

TEMPO DOPO...

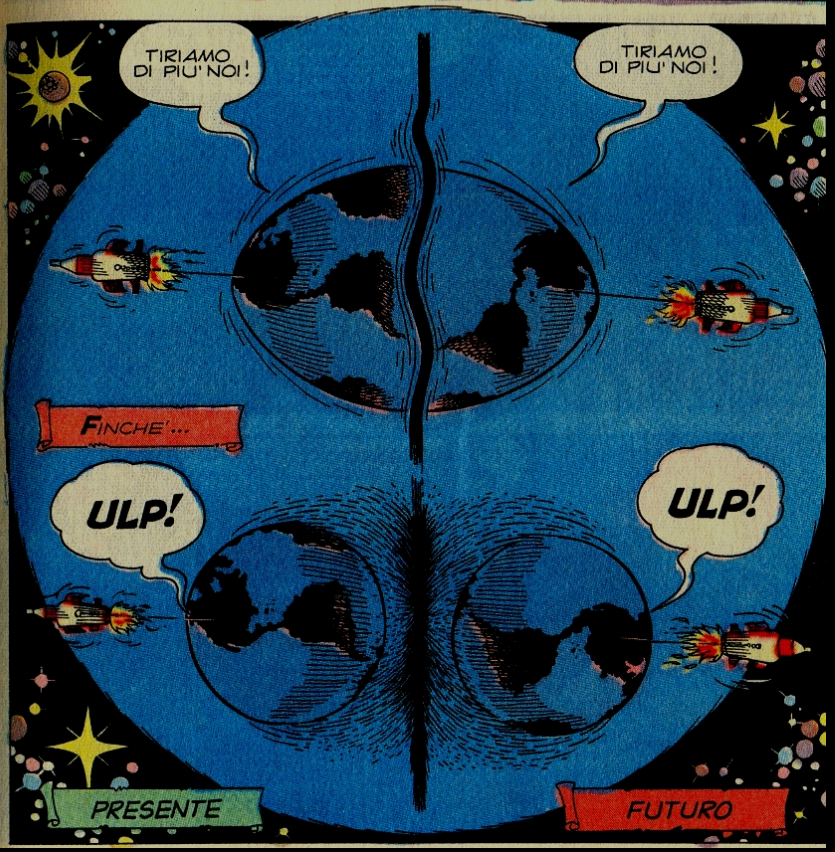

P.d.P.


QUINDI, TANTO VALE ANDARE AVANTI!


!
ECCO CHE CITTA' E' QUELLA... FUTU-ROPOLI!
FUTUROPOLI
FUTUR... CHE?
MA CERTO! ORA CAPISCO!
PAFF
QUELLA CITTA' E' LA NOSTRA VECCHIA PAPEROPOLI... COME SARA' TRA CINQUECENTO ANNI!
EEEH?
NON C'E' ALTRA SPIEGAZIONE! IL BLACK-HOLE E' DAVVERO UNA PORTA VERSO IL FUTURO E LA TERRA CI E' ENTRATA PER META'...

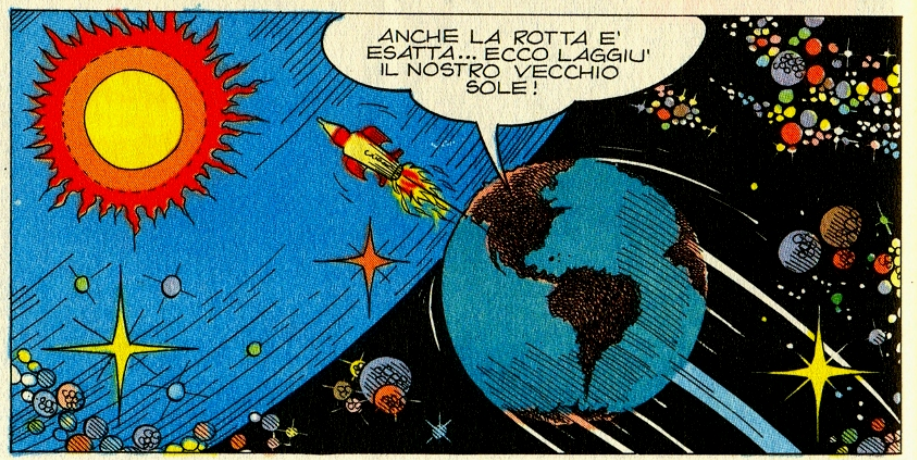

OPRAELE-UTOMOBI-TI!
DOVE SIAMO FINITI?

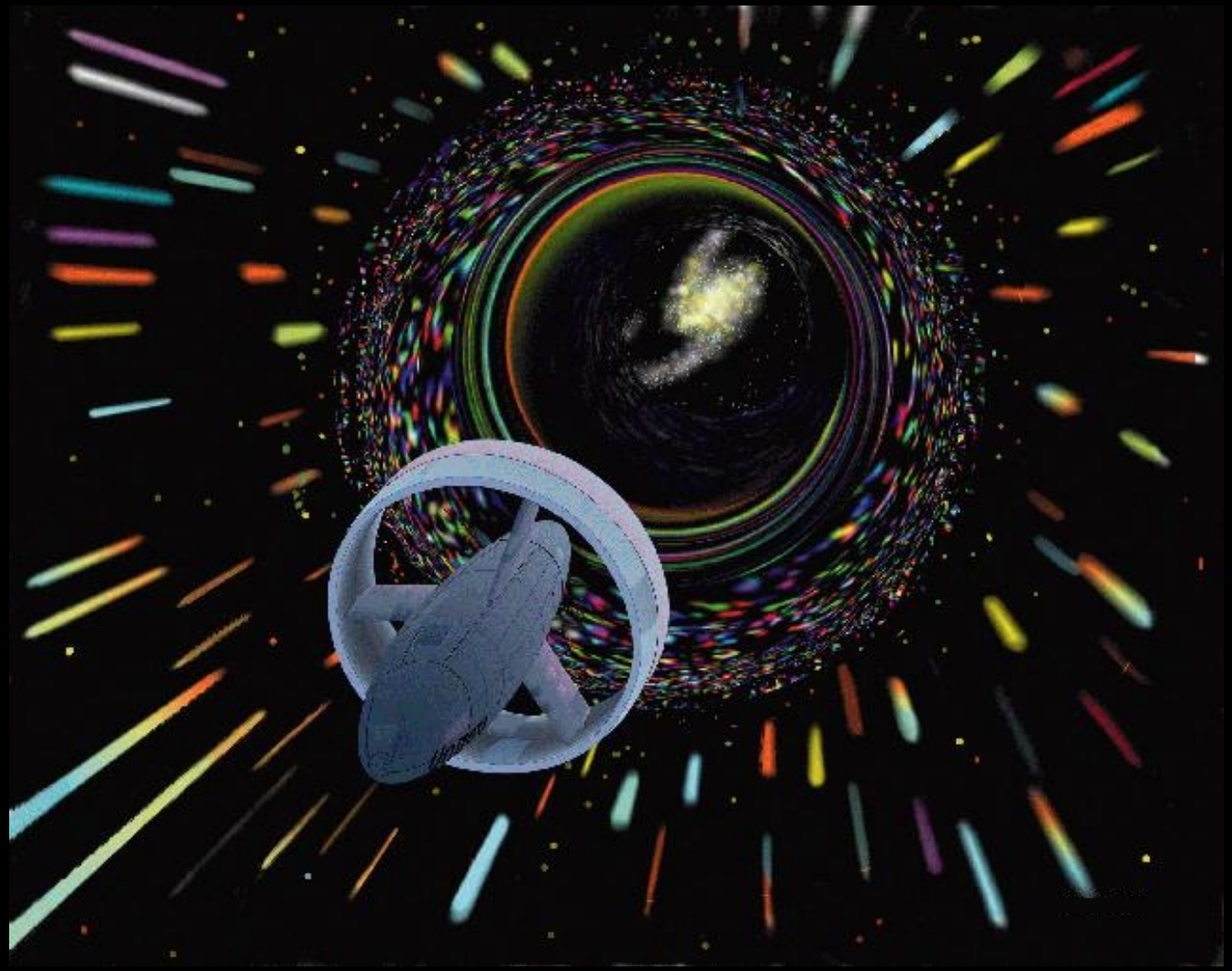

DANDO LA MASSIMA POTENZA, VINCEREMO L'ATTRAZIONE DEL BLACK-HOLE E RESTEREMO NEL FUTURO!
ZACK
DANDO LA MASSIMA POTENZA VINCEREMO L'ATTRAZIONE DEL BLACK-HOLE E RESTEREMO NEL PRESENTE!

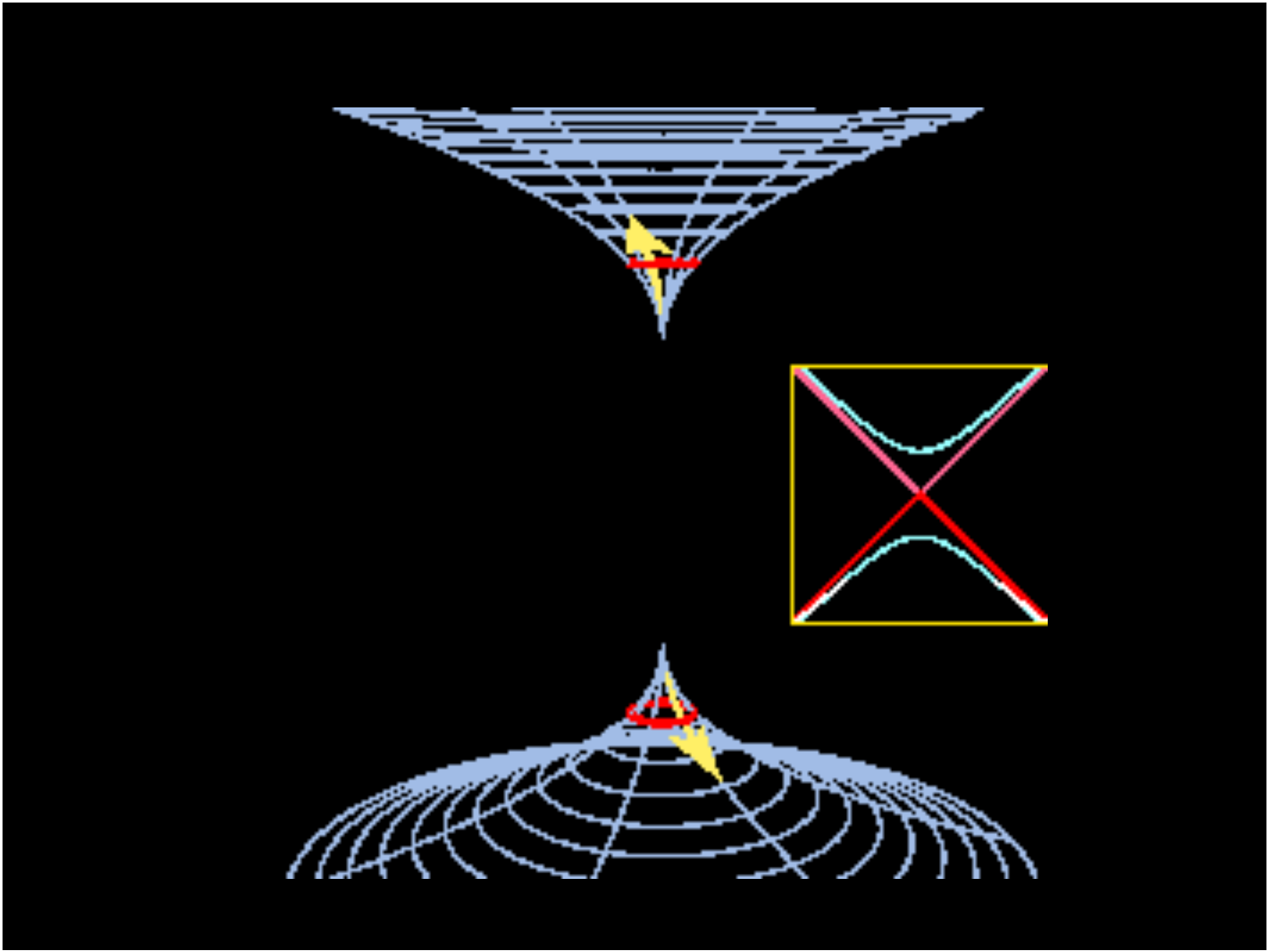

TIRIAMO DI PIU' NOI!
TIRIAMO DI PIU' NOI!
FINCHE'...
ULP!
ULP!
PRESENTE
FUTURO


CE L'ABBIAMO FATTA! ABBIAMO VINTO L'ATTRAZIONE DEL BLACK-HOLE! RESTEREMO NEL FUTURO!


CE L'ABBIAMO FATTA! ABBIAMO VINTO L'ATTRAZIONE DEL BLACK-HOLE, COSI' RESTEREMO NEL PRESENTE!


ANCHE LA ROTTA E' ESATTA... ECCO LAGGIU' IL NOSTRO VECCHIO SOLE!





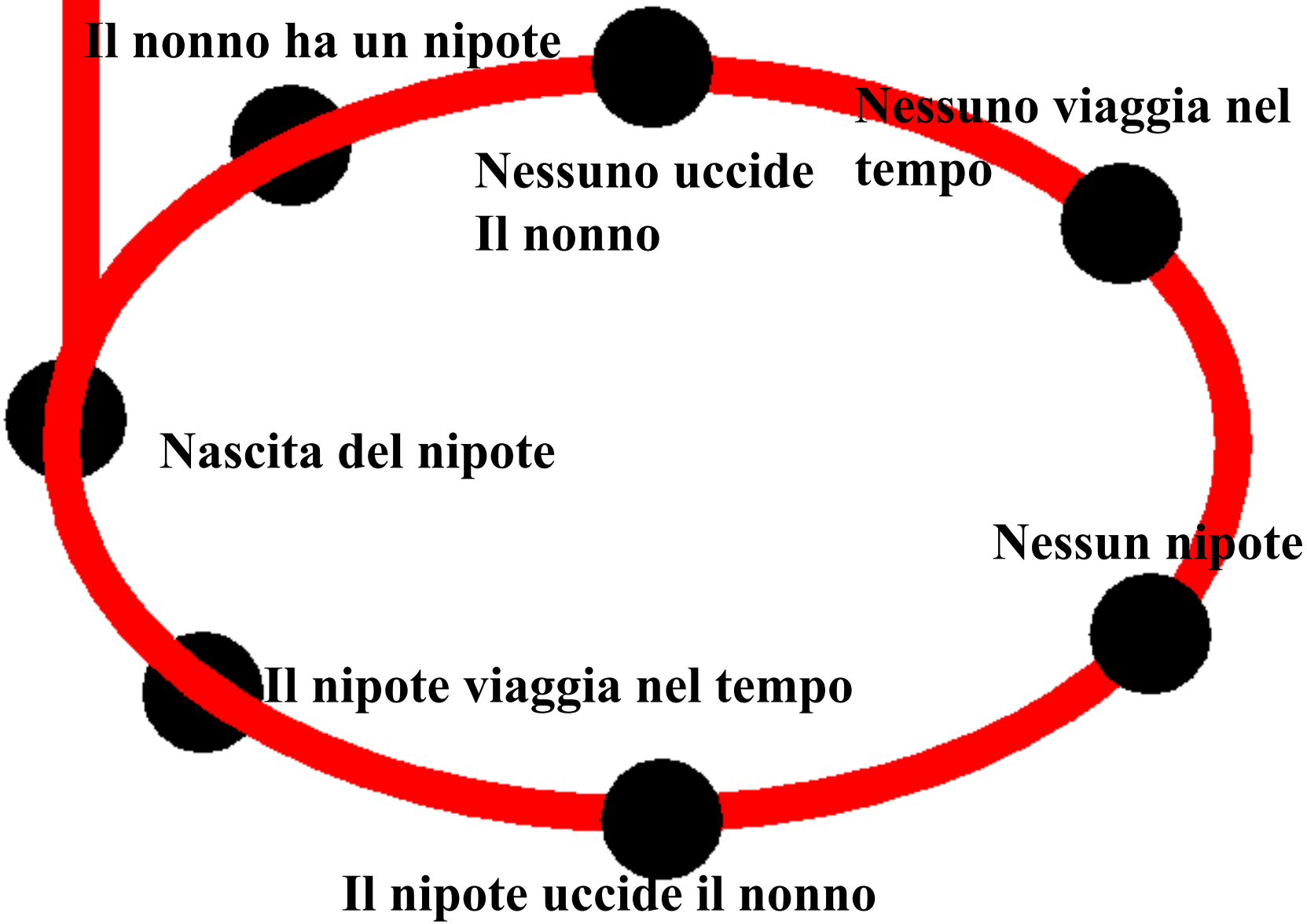
FILMATI WORMHOLES

PARADOSSO TEMPORALE

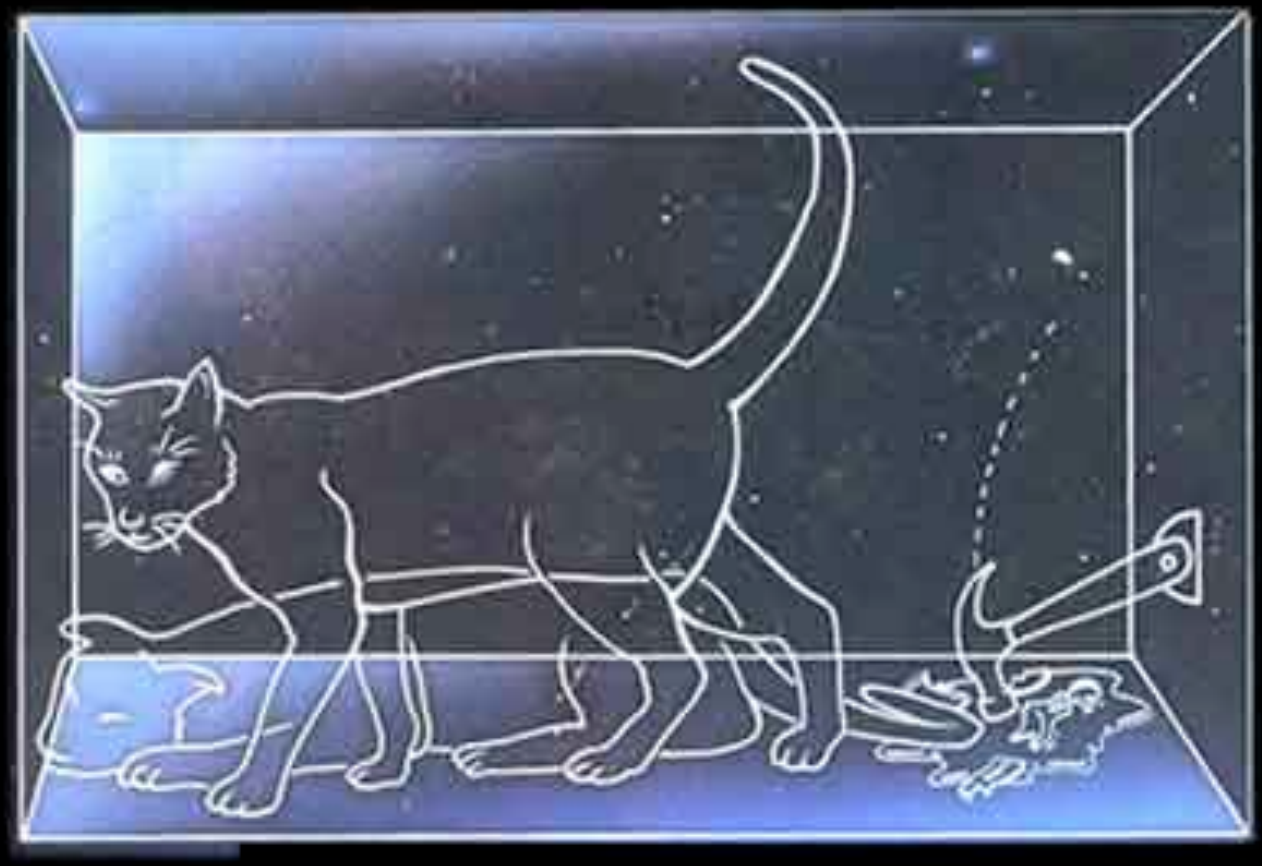
Un tizio inventa una macchina del tempo e torna nel passato per uccidere suo nonno.
Suo nonno non avra' un figlio che non generera' piu' il nipote che non inventera' una macchina del tempo.

…E IL RAPPORTO CAUSA-EFFETTO?

CIRCOLO TEMPORALE



IL GATTO DI SCHROEDINGER



TEMPO E QUANTI

Il nipote costruisce
La macchina del tempo

Il nonno ha un nipote

onno ha un nipote

Il nonno ha un figlio

IL MODELLO STANDARD