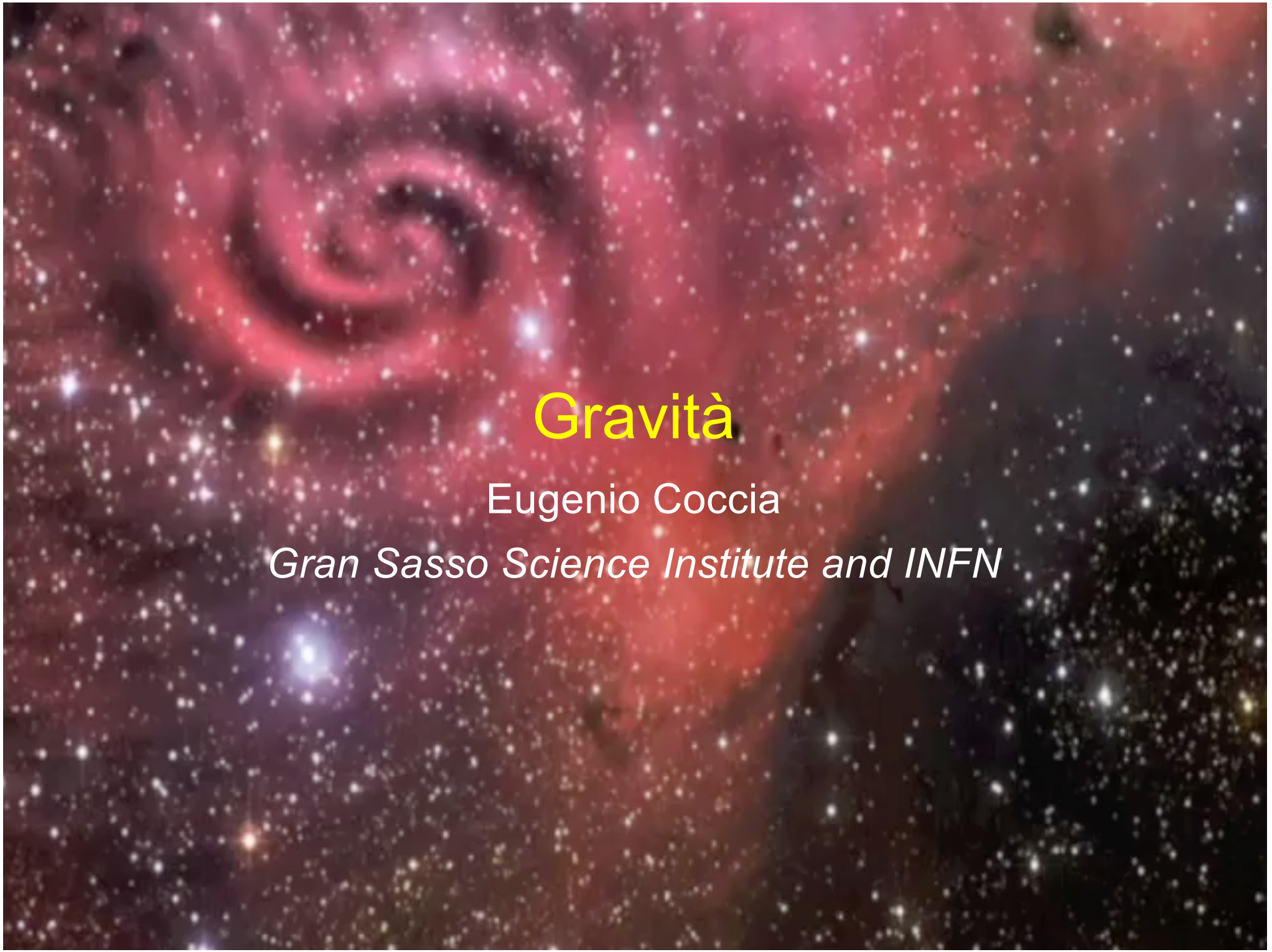
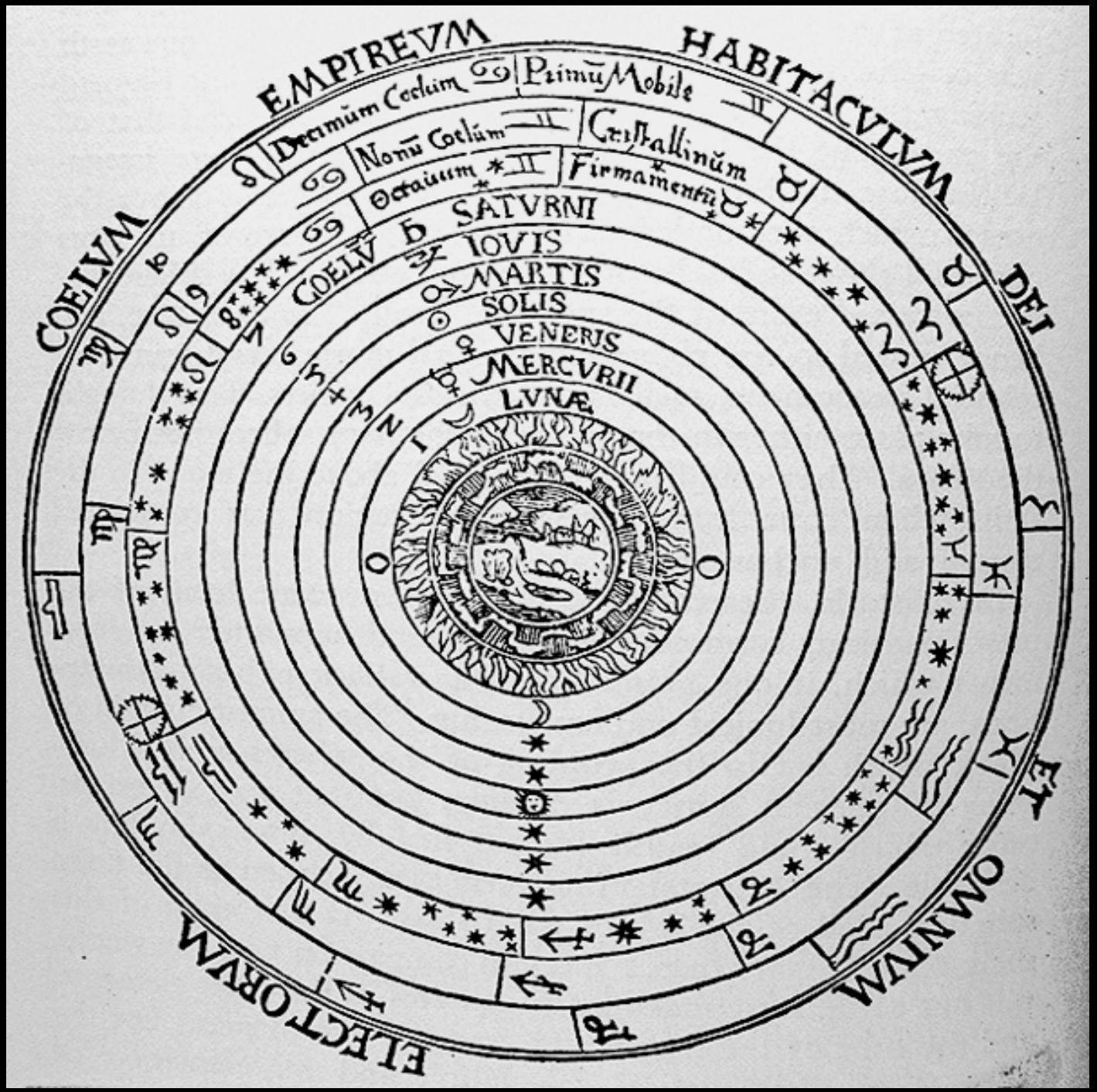


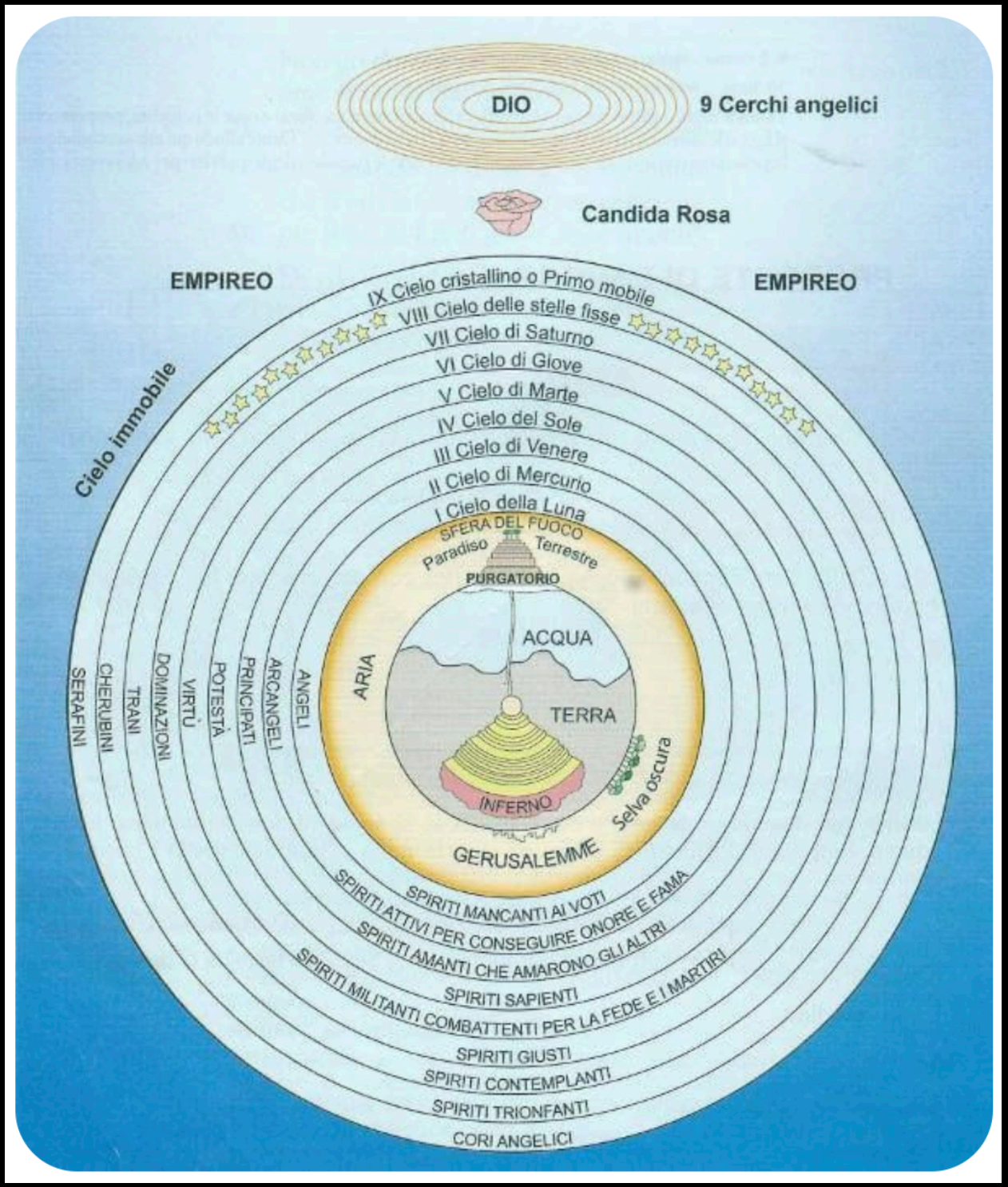
Gravità

Eugenio Coccia

Gran Sasso Science Institute and INFN

Tolomeo - Aristotele
Modello geocentrico




DIO
9 Cerchi angelici
Candida Rosa
EMPIREO
EMPIREO
Cielo immobile
IX Cielo cristallino o Primo mobile
VIII Cielo delle stelle fisse
VII Cielo di Saturno
VI Cielo di Giove
V Cielo di Marte
IV Cielo del Sole
III Cielo di Venere
II Cielo di Mercurio
I Cielo della Luna
SFERA DEL FUOCO
Paradiso Terrestre
PURGATORIO
ACQUA
ARIA
TERRA
INFERNO
Selva oscura
GERUSALEMME
SERAFINI
CHERUBINI
TRONI
DOMINAZIONI
VIRTÙ
POTESTÀ
PRINCIPATI
ARCANGELI
ANGELI
SPIRITI MANCANTI AI VOTI
SPIRITI ATTIVI PER CONSEGUIRE ONORE E FAMA
SPIRITI AMANTI CHE AMARONO GLI ALTRI
SPIRITI SAPIENTI
SPIRITI MILITANTI COMBATTENTI PER LA FEDE E I MARTIRI
SPIRITI GIUSTI
SPIRITI CONTEMPLANTI
SPIRITI TRIONFANTI
CORI ANGELICI

Galileo Galilei

1610

Die 25. Julij summo mane in festo sancti Iacobi Die Dominica Patauij primum obseruaui ♃ᵉ orientalé matutinú cui astabant tres Planetę Medicei orientales omnes ab ipso in hunc ordiné

* * * O

Die 29. sic * * O * *

D. 5. Aug.ⁱ * O * * media occidentalis paululú efferebat

D. 8. * * O *

Die 15. * * ** O prox.ª ♃ attollebat ē Boream

D. 17. * * O * *

D. 20. O *

D. 21. * O* * *

D. 22 * * O *

D. 24 * O* * * media occid. ē Bor. attollebat

D. 25 O* * *

D. 31. * * O *

D. 7. septemb: * O * *

D. 25. 8bris * * O *

D. 4. 9bris. * * * O *

D. 5. * * O *

D. 14. H noctis 7. * *O* *

D. 15. H. 5. * * O * * aer circa ♃ fuit caliginosus, et pro occidentalis.ª stella conspiciebat.

D. 18. H. 5. * O *

D. 19. * O* * *

D. 20. H. 5. * O ** occid. attollebat Borea: et H. 1. 2. occid. sese ferè tangebat

D. 21. * * O *

75

D. 30. * ** O * orientalis ♃ prox.us paululú ē Bor. attollebat, et cū ♃ói prox.º post Hor. 1/3 coniuctus fuit.

D. 2. Decemb. H. 3. * O* * *. Hor. 5. ♃ propius cū eo iunctus est; clariss. aer.

D. 3. H. 5. * O * * * +

D. 4. H. 5. * O * *

D. 6. H. 5 * *O

D. 7. H. 5. * * O

H. 7. ** ** O. extremus orientalis paululú ē Bor. efferebat

D. 9. H. 5. * * O**

D. 10. H. 4. * * O * * +

D. 12. H. 3. * O * *

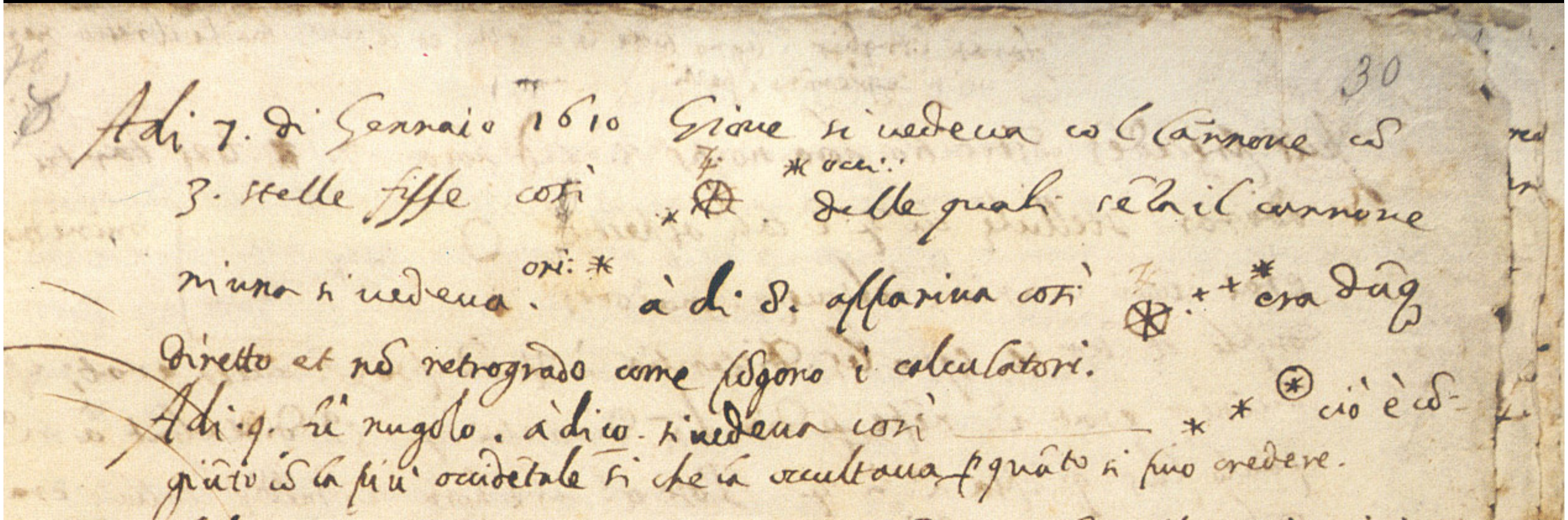
D. 13. H. 3. 30. ** **O. Secunda ā ♃ ē Bor. attollebatur.

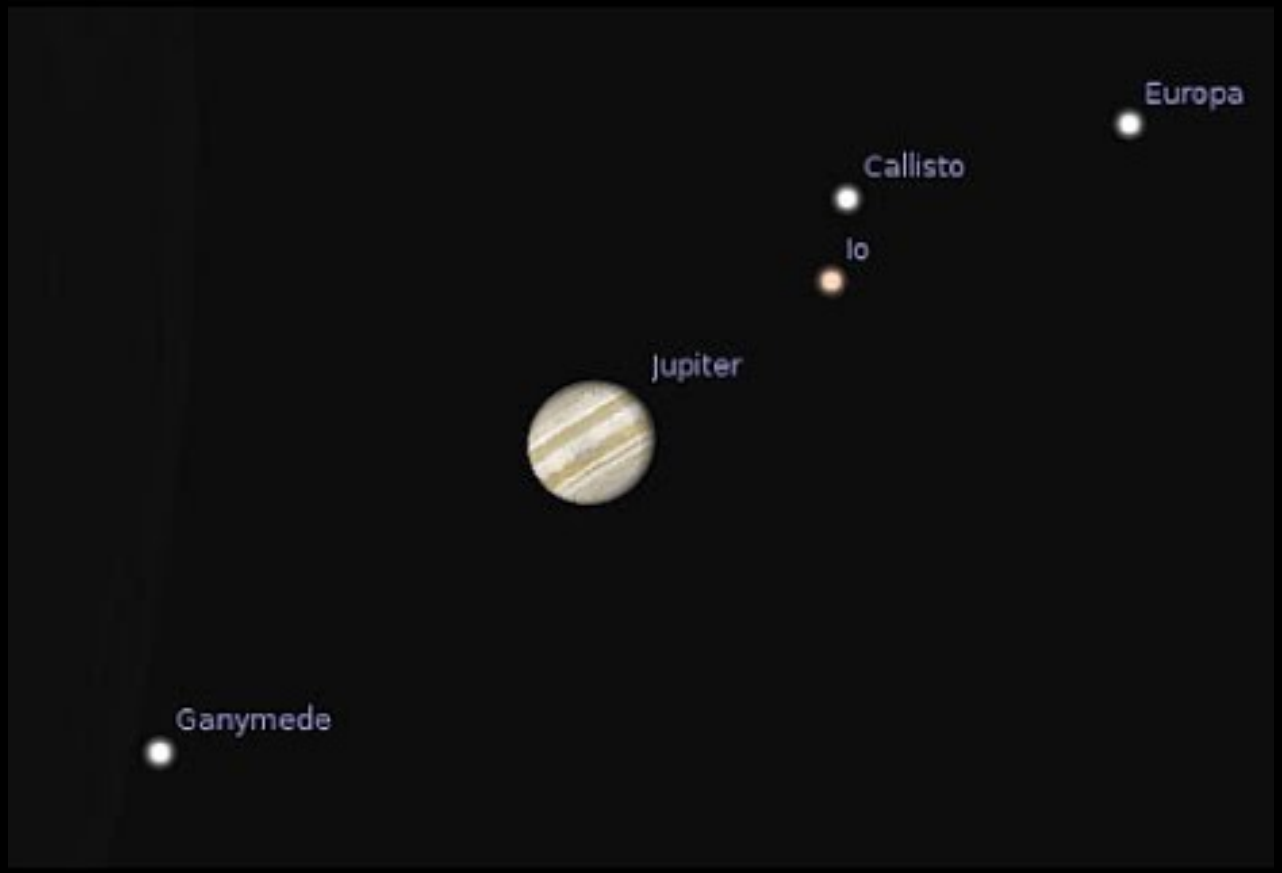
Ho. 4. miniores ♃ coniuncti fuere.

Ho. 5. * * * O medius videbat' in austrū declinare

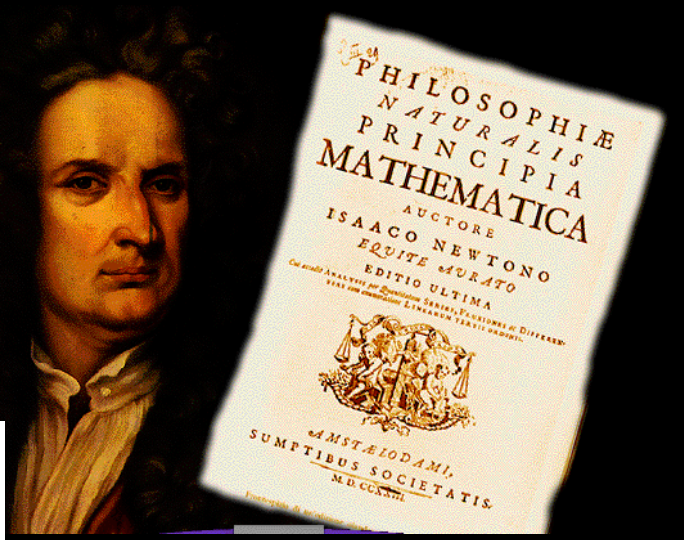
D. 14. H. 3. 30. * * O

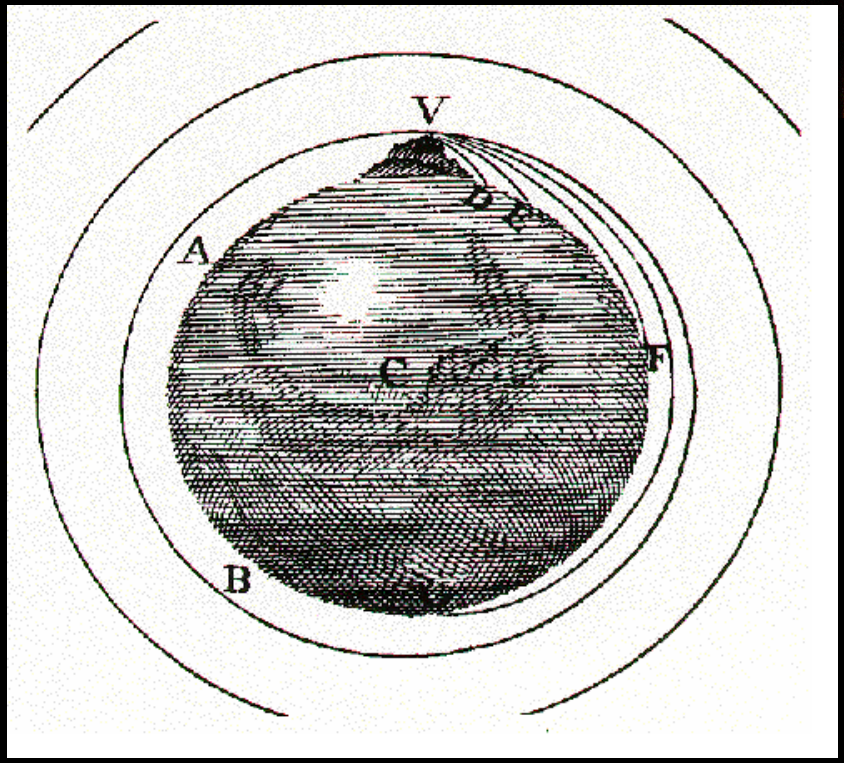
D. 19. H. 3. 30. O** * * Seguì 3 carte doppo


30
Adi 7. di Gennaio 1610 Giove si vedeva col Cannone con
3. stelle fisse così
delle quali senza il Cannone
niuna si vedeva.
a dì 8. appariva così
era dunq
diretto et no retrogrado come sogliono i calculatori.
Adi 9. si nugolò. a dì 10. si vedeva così
ciò è con-
giunto con la più occidentale sì che la occultava per quanto si può credere.


Europa
Callisto
Io
Jupiter
Ganymede

Newton


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA
AUCTORE
ISAACO NEWTONO
EQUITE AURATO
EDITIO ULTIMA
AMSTÆLODAMI,
SUMPTIBUS SOCIETATIS.


V
A
B
C
F

$$\vec{F} = G\frac{Mm}{r^2}\vec{u}_r$$

1

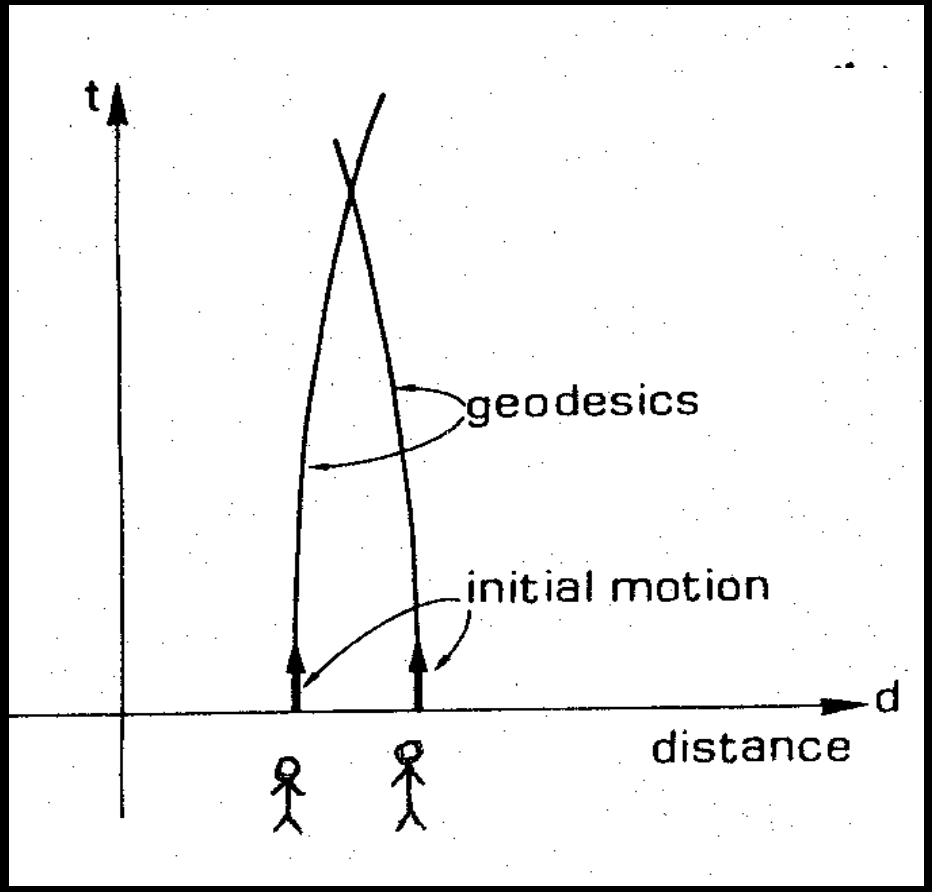
$$F = m_i a \qquad F = G\frac{M\, m_g}{r^2}$$

Experimental result: $\frac{m_i}{m_g} = const = 1$

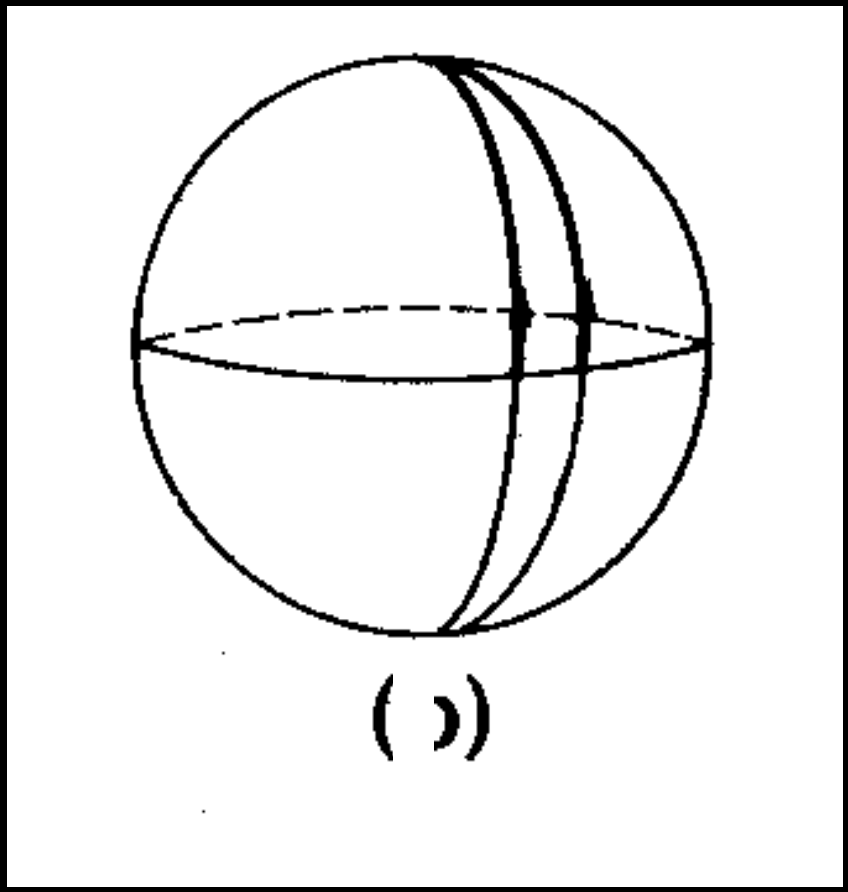
a coincidence?

2

Newtonian gravity propagates with infinite speed!

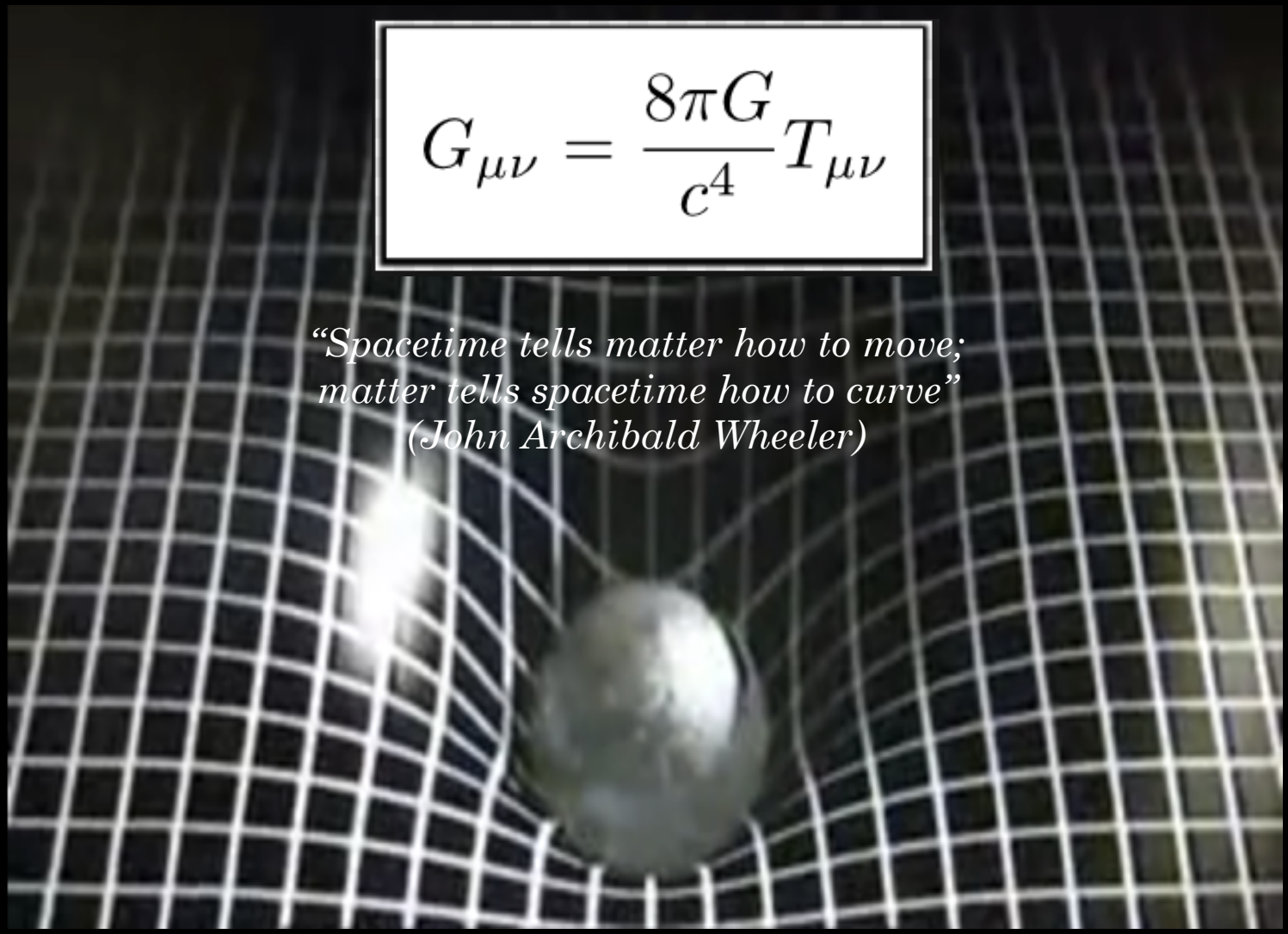


Einstein



Einstein's Theory of Gravitation

Gravity is a manifestation of spacetime curvature induced by mass-energy



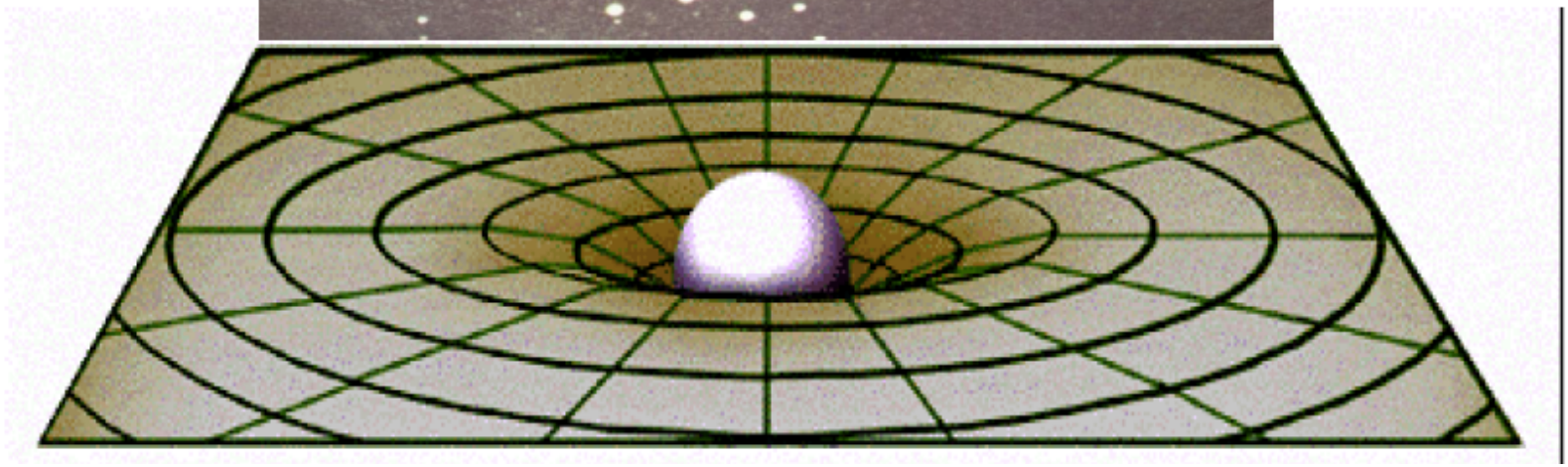
General Relativity (1915)

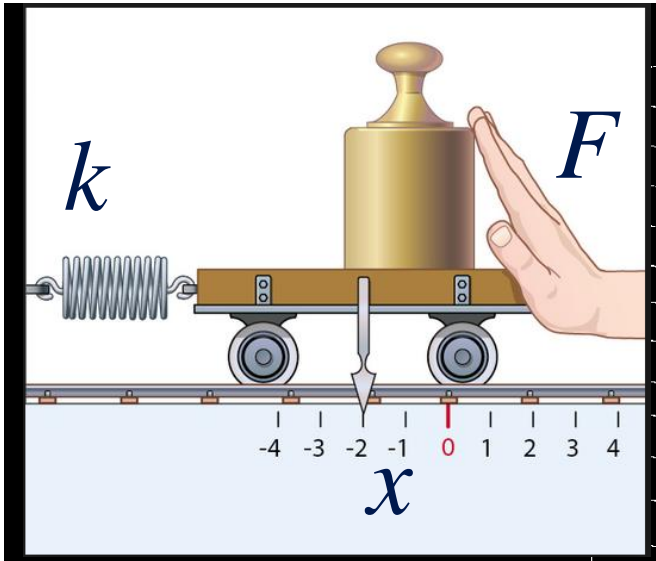
Gravity is a manifestation of spacetime curvature induced by mass-energy

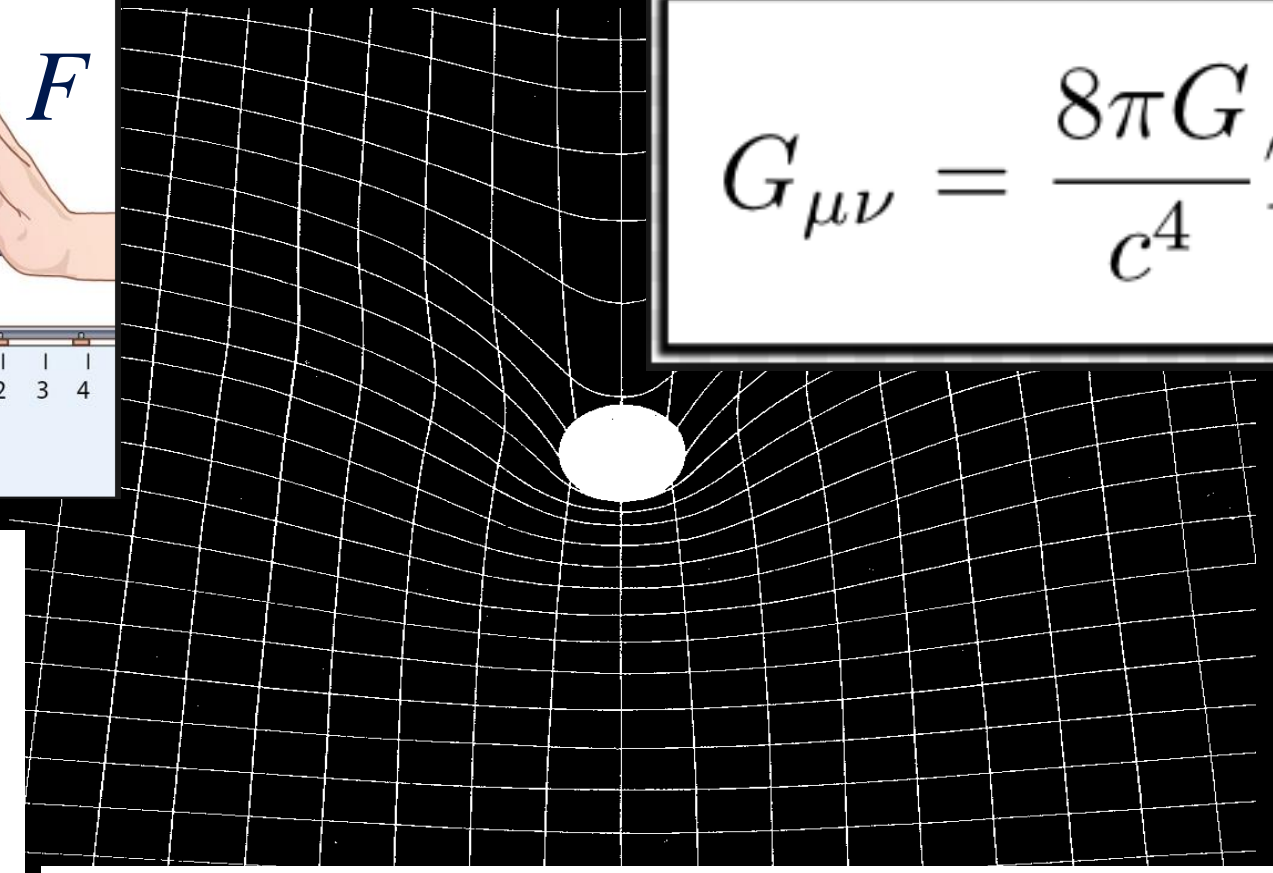
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

10 non linear equations in the unknown $g_{\mu\nu}$

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$$







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

$$F = -kx$$

$$F \Leftrightarrow T_{\mu\nu}$$

$$x \Leftrightarrow G_{\mu\nu}$$

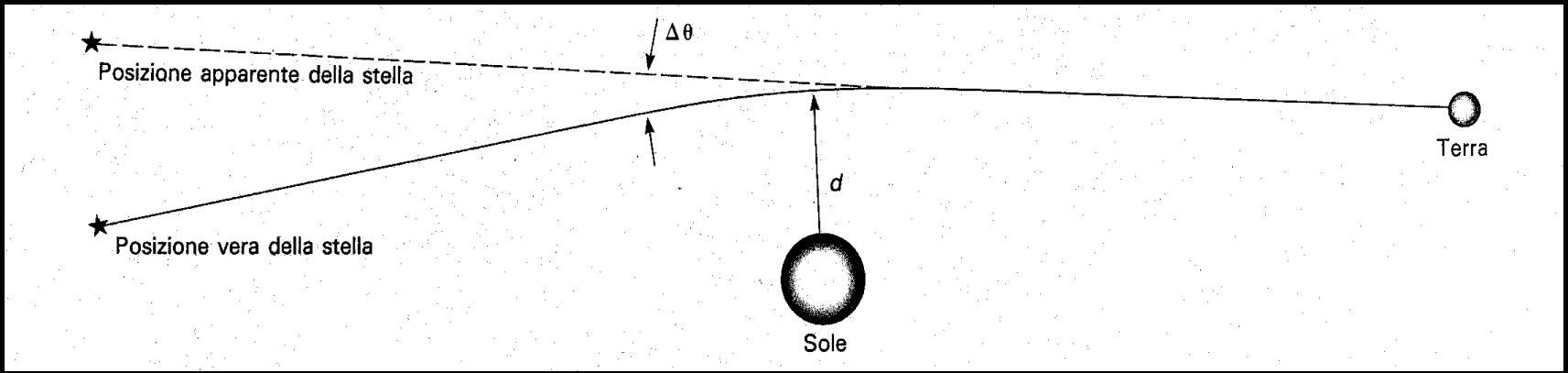
$$k \Leftrightarrow \frac{c^4}{8\pi G}$$

$$c = 299\ 792\ 458\ \ m/s = 3\times10^8\ \ m/s$$

$$G = 0{,}000\ 000\ 000\ 066\ 7\ \frac{m^3}{kg\ s^2} = 6{,}67\times10^{-11}\ \frac{m^3}{kg\ s^2}$$

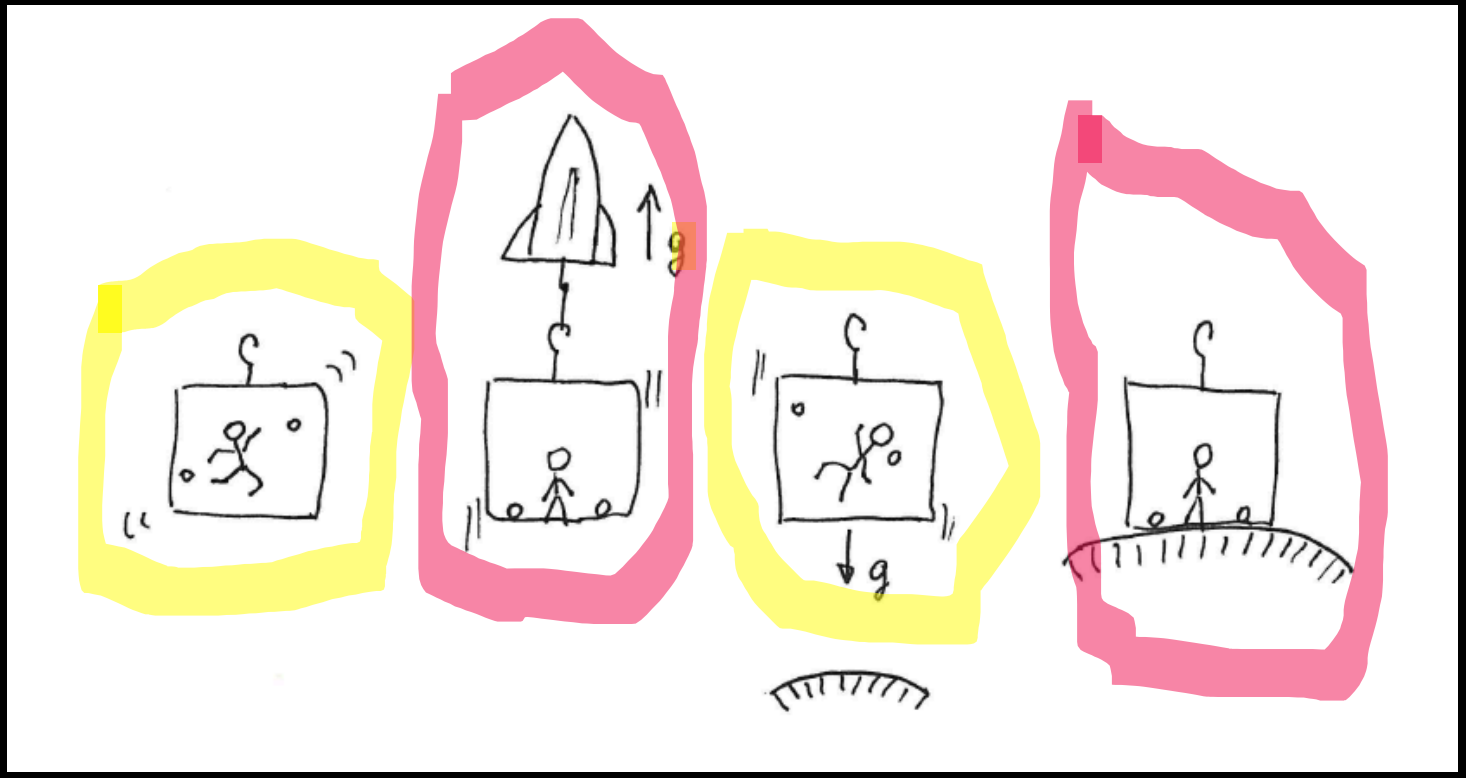
$$k \approx 10^{45}\ \frac{kg}{s^2} \qquad STIFF!$$

Light deflection

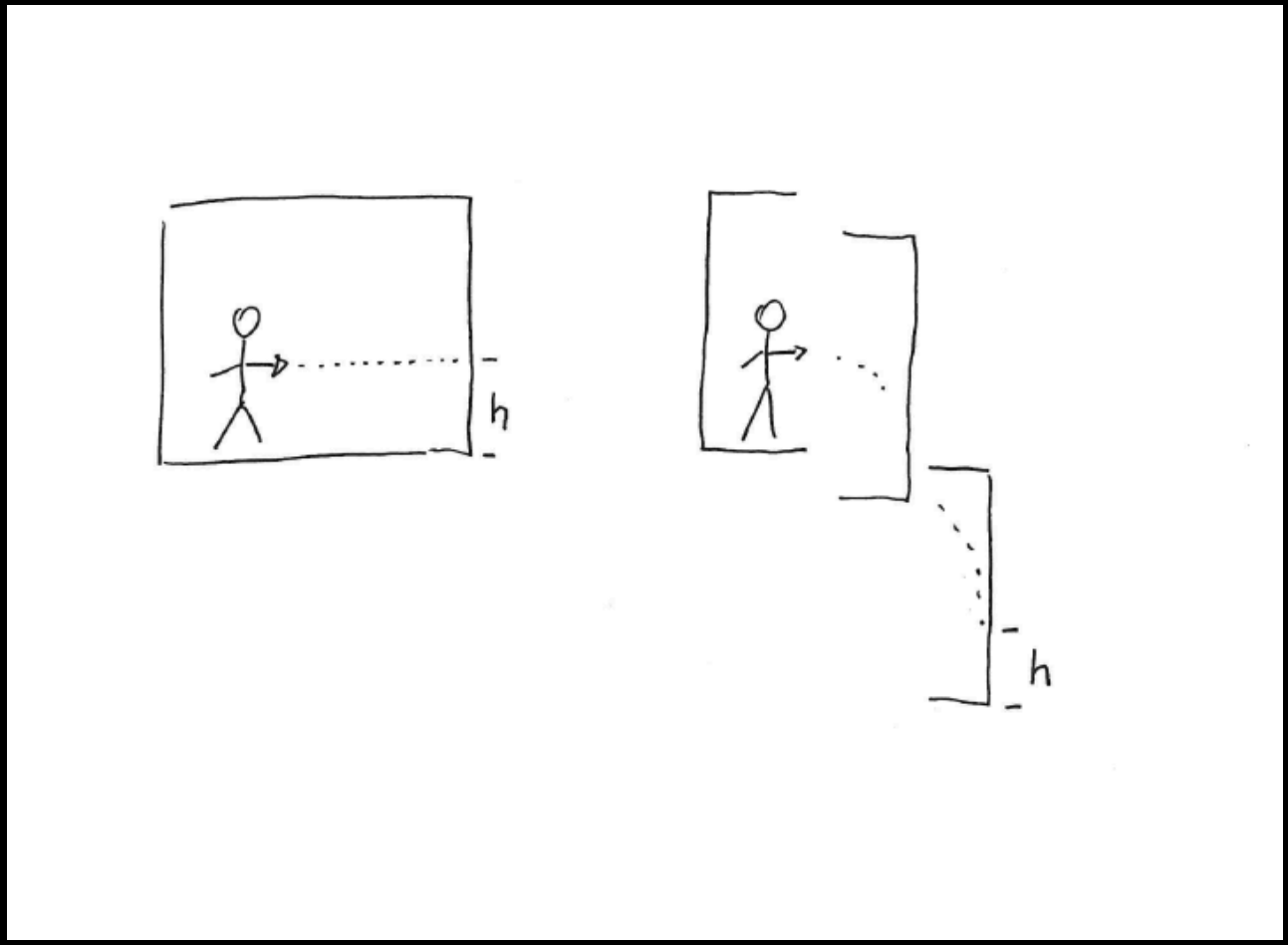


Eddington

«L'idea più felice della mia vita»



Un sistema fermo in un campo gravitazionale
è equivalente a un sistema accelerato.
Un sistema in caduta libera in un campo gravitazionale
è equivalente a un sistema inerziale.
Questo è la nuova formulazione del principio
di equivalenza, che Einstein trasformò in un
principio fondamentale della fisica.



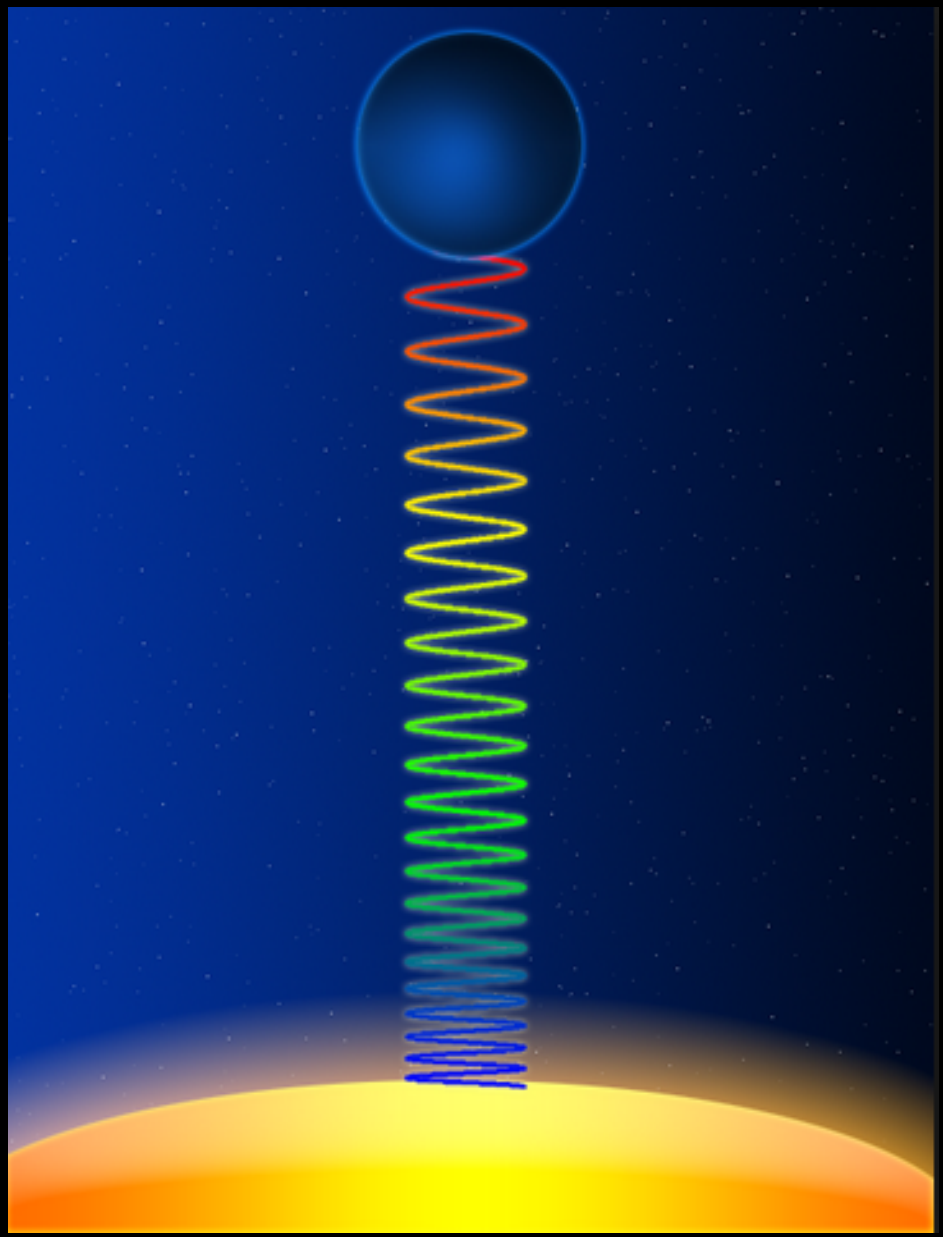
In un campo gravitazionale la traiettoria della luce è una linea curva.
Lo spazio-tempo non è più euclideo e le linee geodetiche non sono più delle rette.

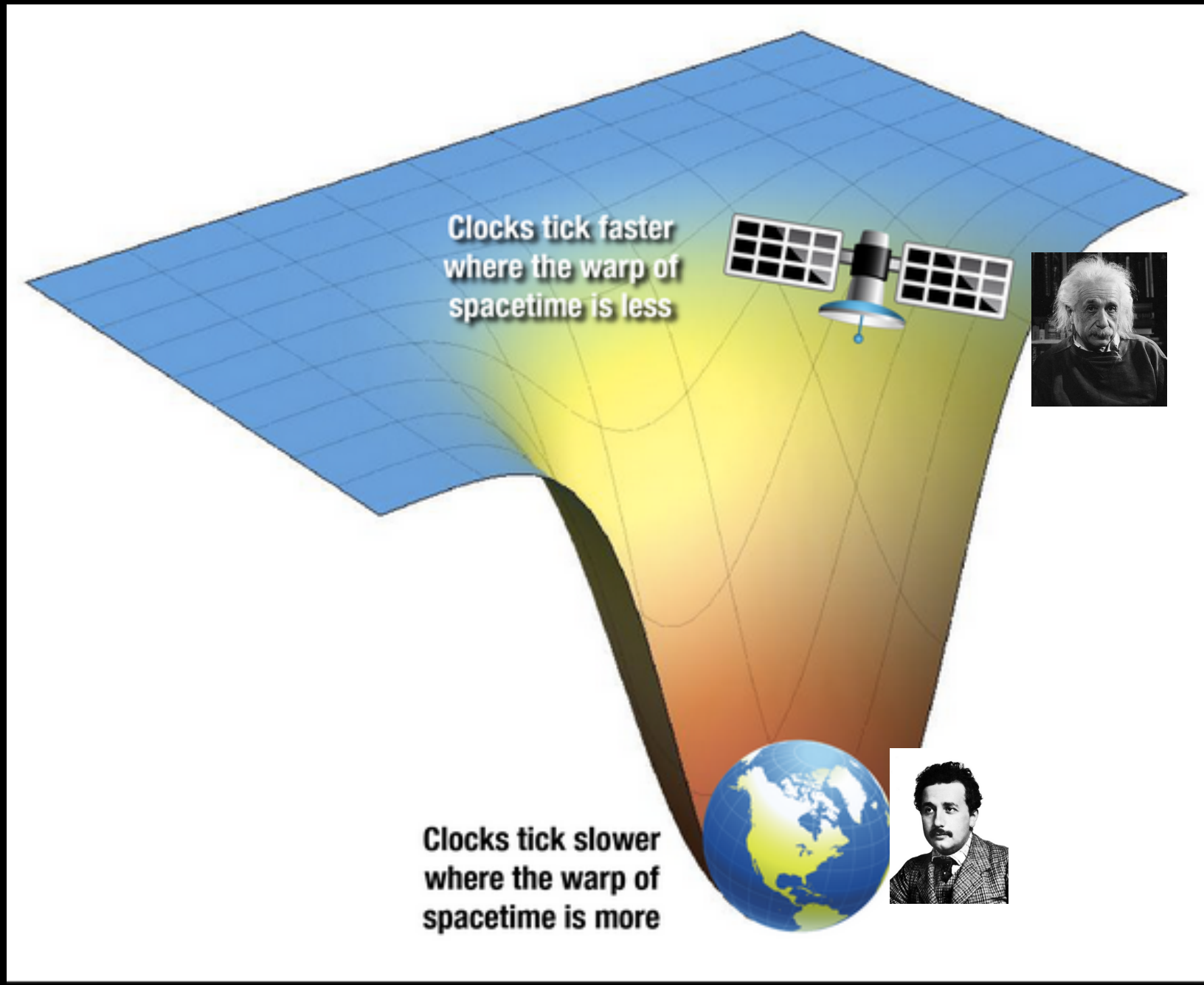
Harvard

Redshift

Pound and Rebka

1959



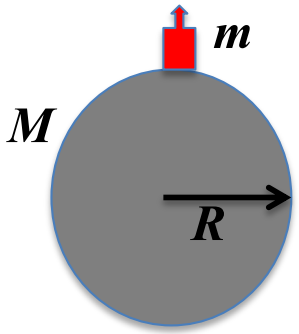

Clocks tick faster
where the warp of
spacetime is less
Clocks tick slower
where the warp of
spacetime is more

L’equazione di Einstein si rivela una miniera d’oro. Da questa miniera sono state estratte nel tempo altre pepite preziose come i buchi neri, le onde gravitazionali, l’universo in espansione.

John Michell
1783 → 'dark star'

KINETIC Energy

POTENTIAL Energy



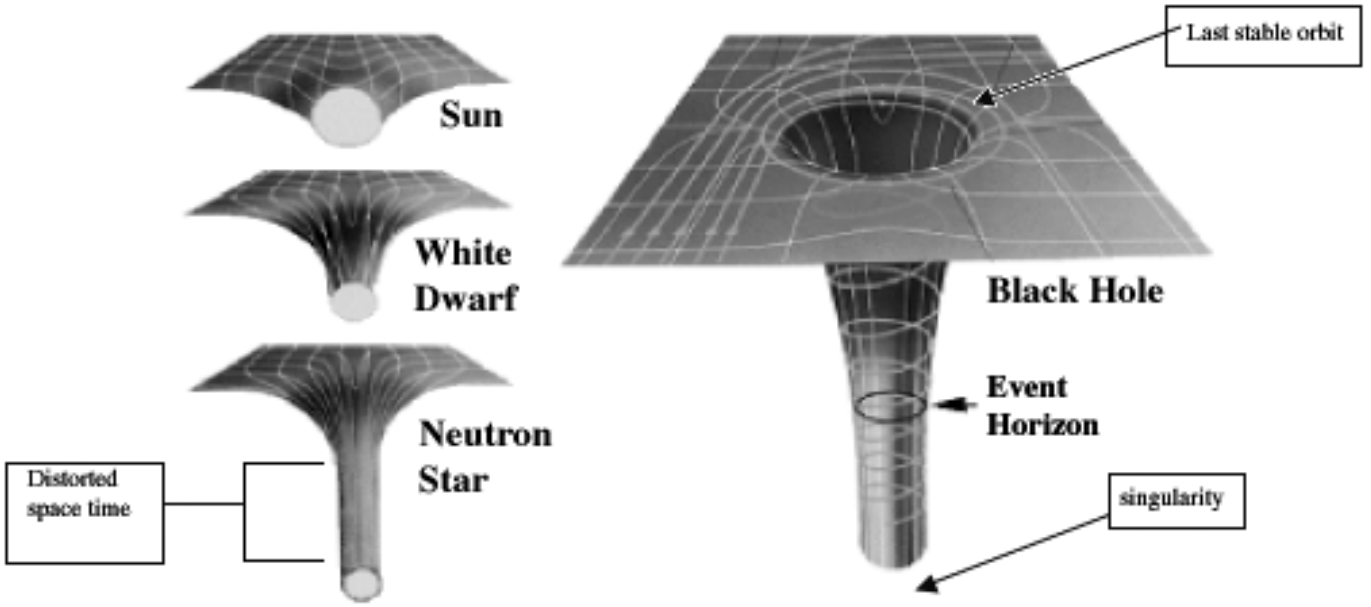
if $\frac{1}{2}mv^2 \geq G\frac{mM}{R}$ → *m* escapes

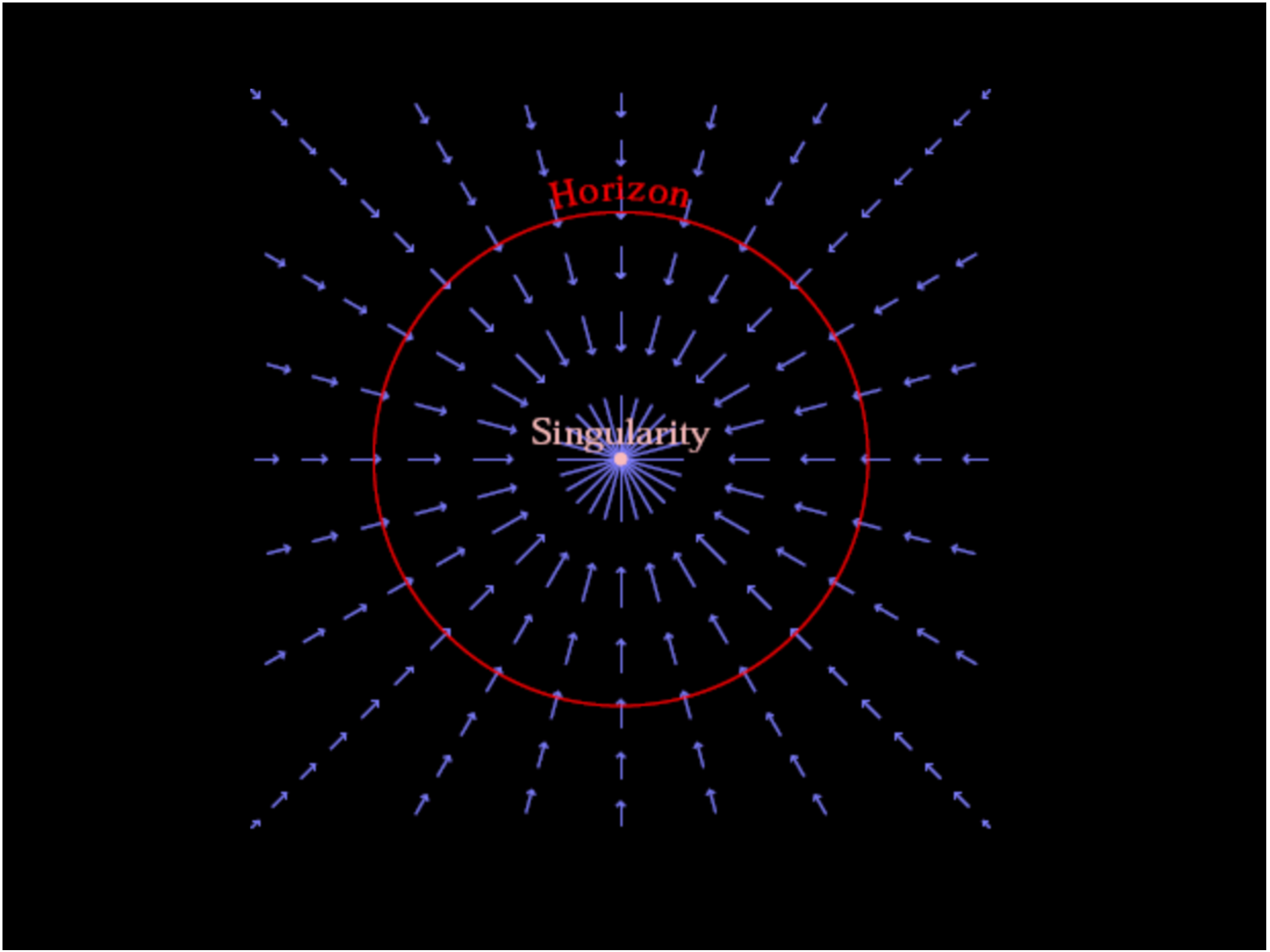
But not even the light can escape if $G\frac{M}{R} \geq \frac{1}{2}c^2$ → *M* is dark

i.e. if matter in squeezed inside a sphere of radius

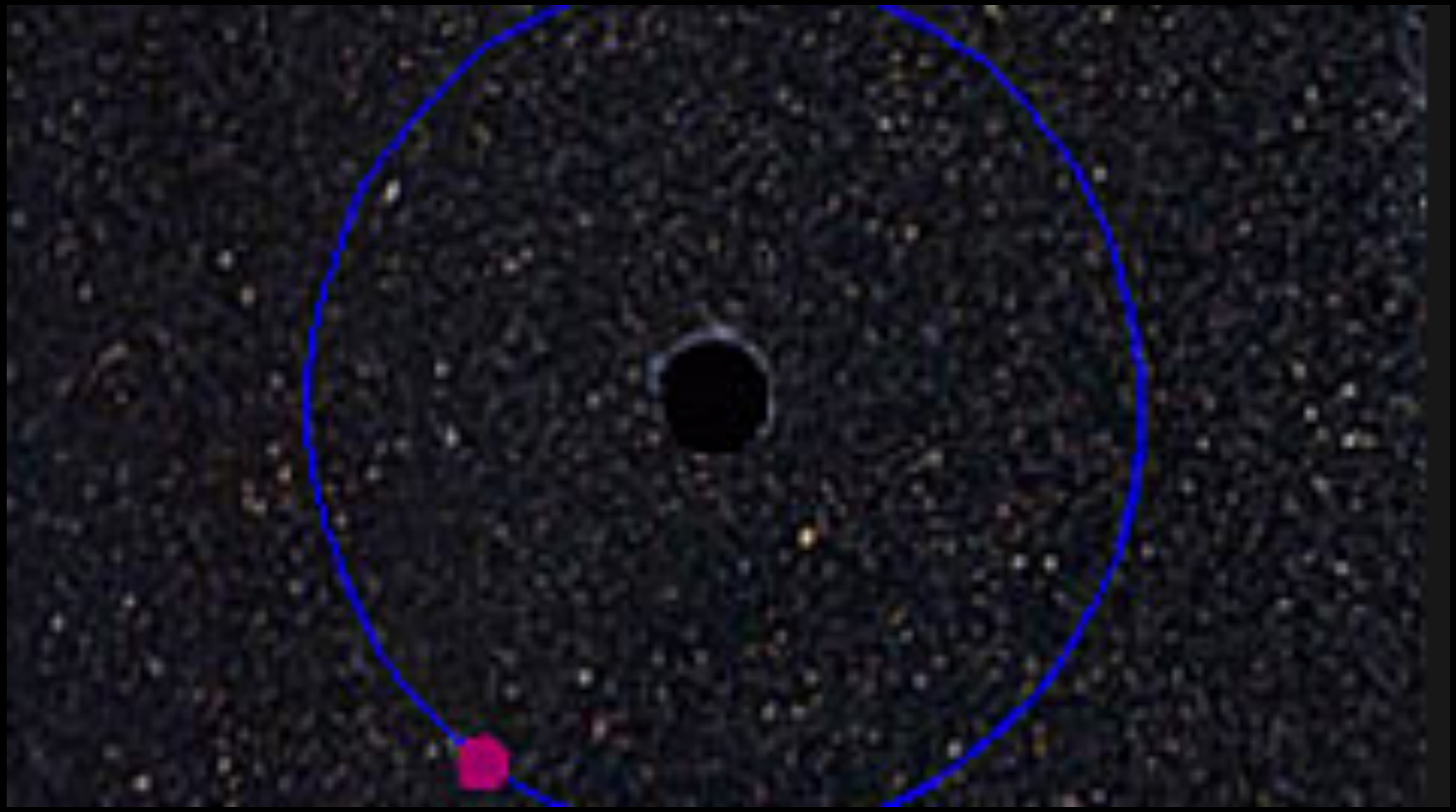
$$R = R_s = \frac{2GM}{c^2}$$

Schwarzschild radius


Sun
White
Dwarf
Neutron
Star
Distorted
space time
Last stable orbit
Black Hole
Event
Horizon
singularity

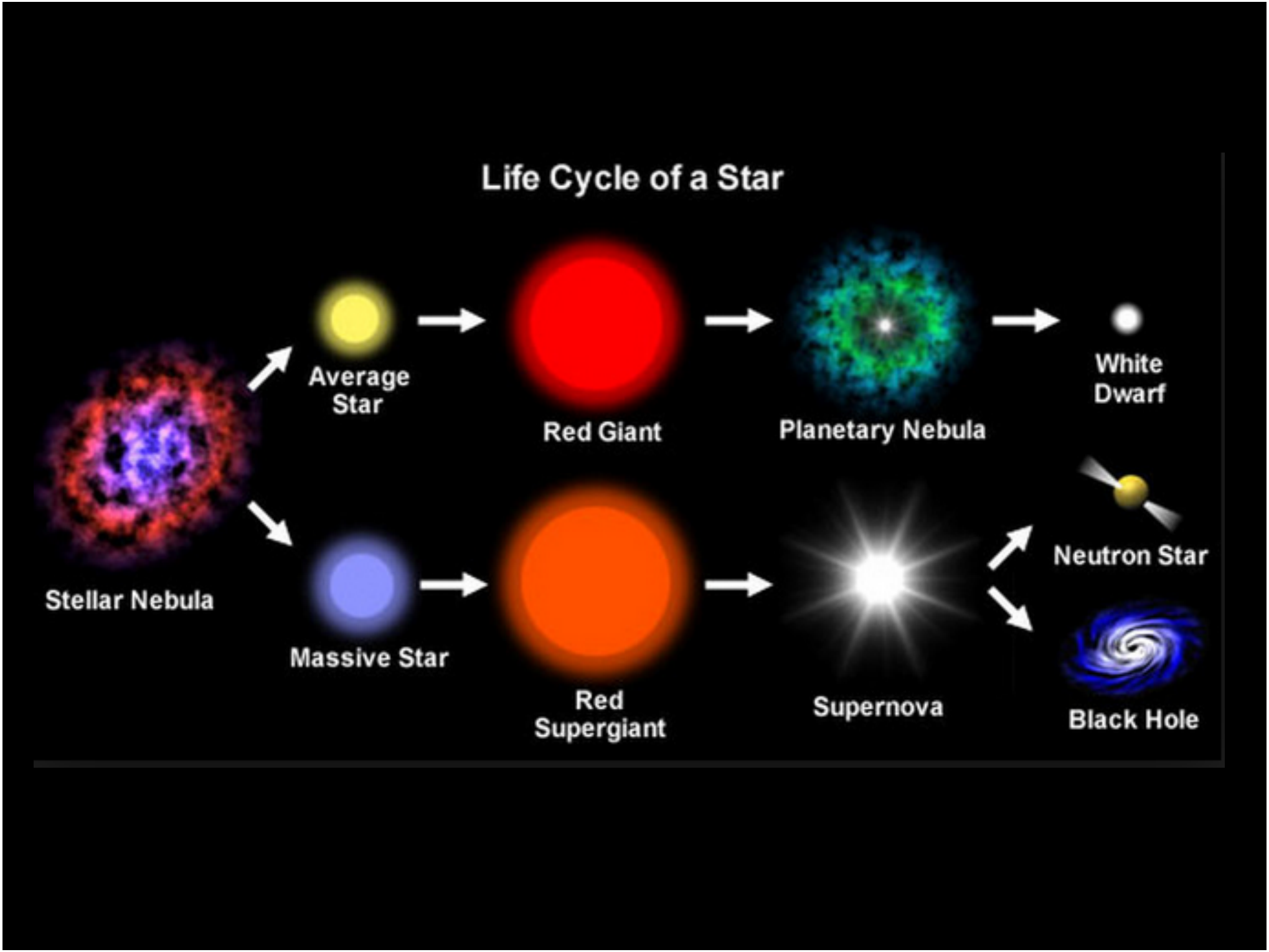

Horizon
Singularity

Time traveling



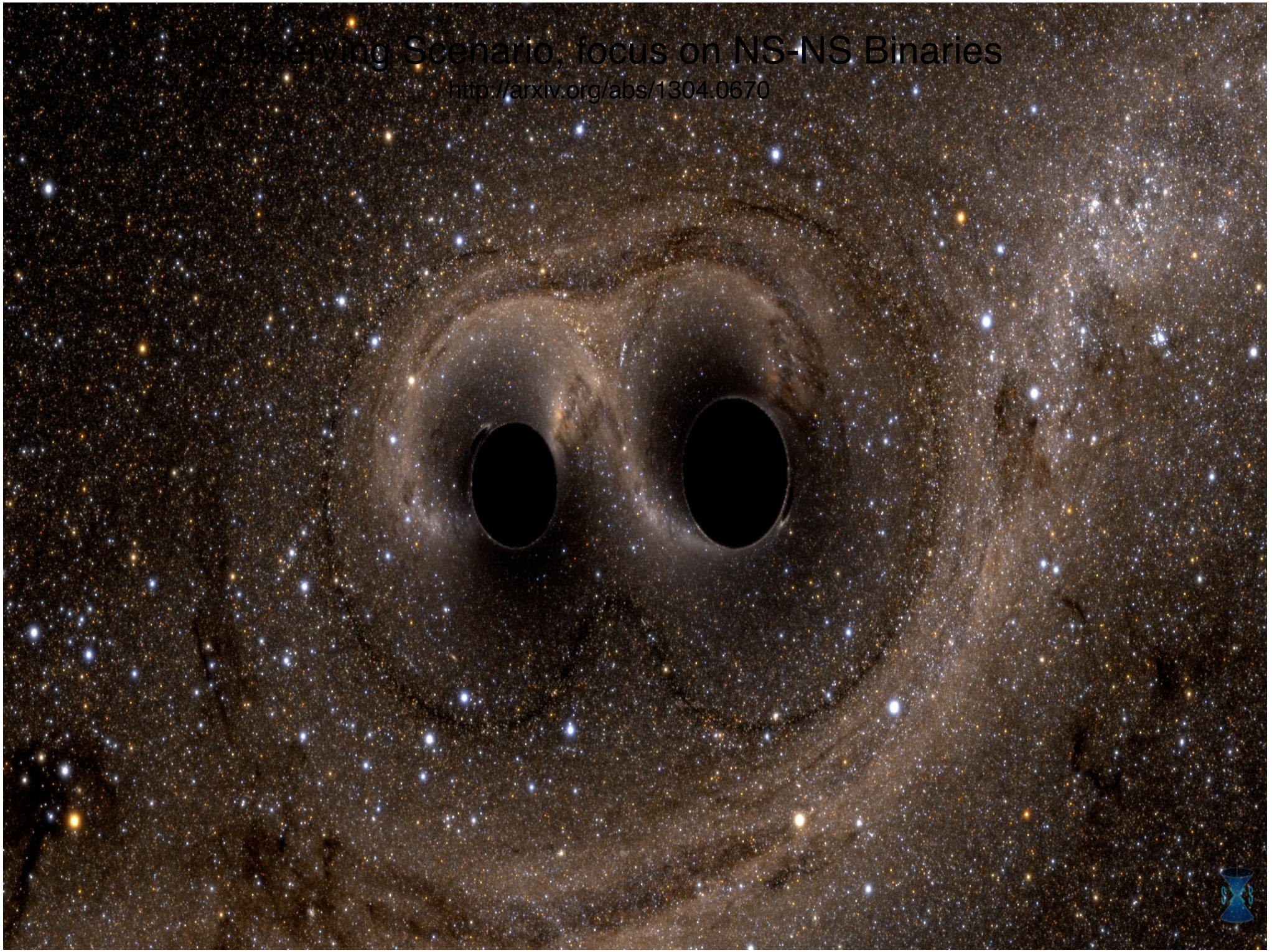
Spaghettification!

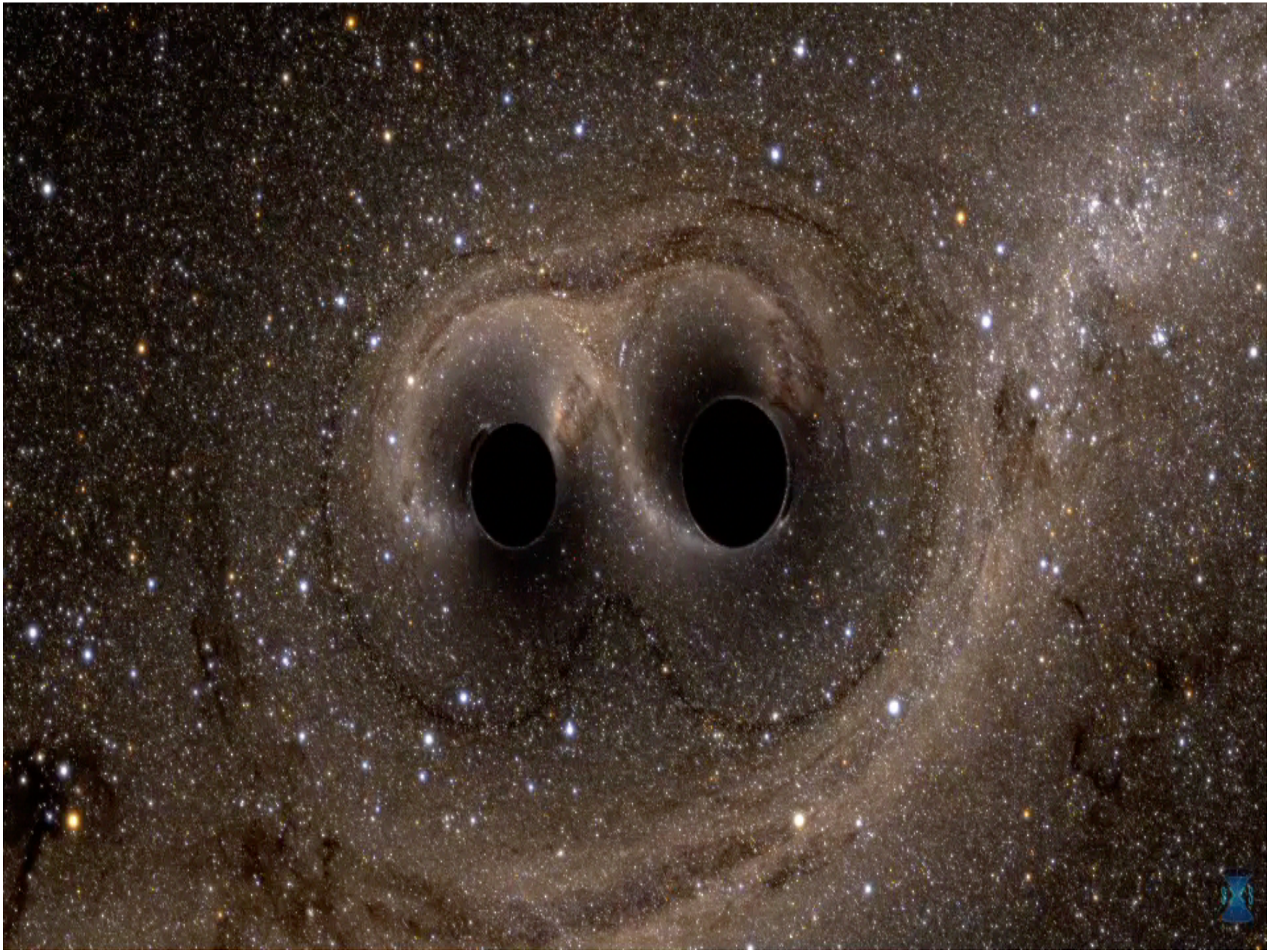
To Black Hole


Life Cycle of a Star
Average Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Nebula
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole

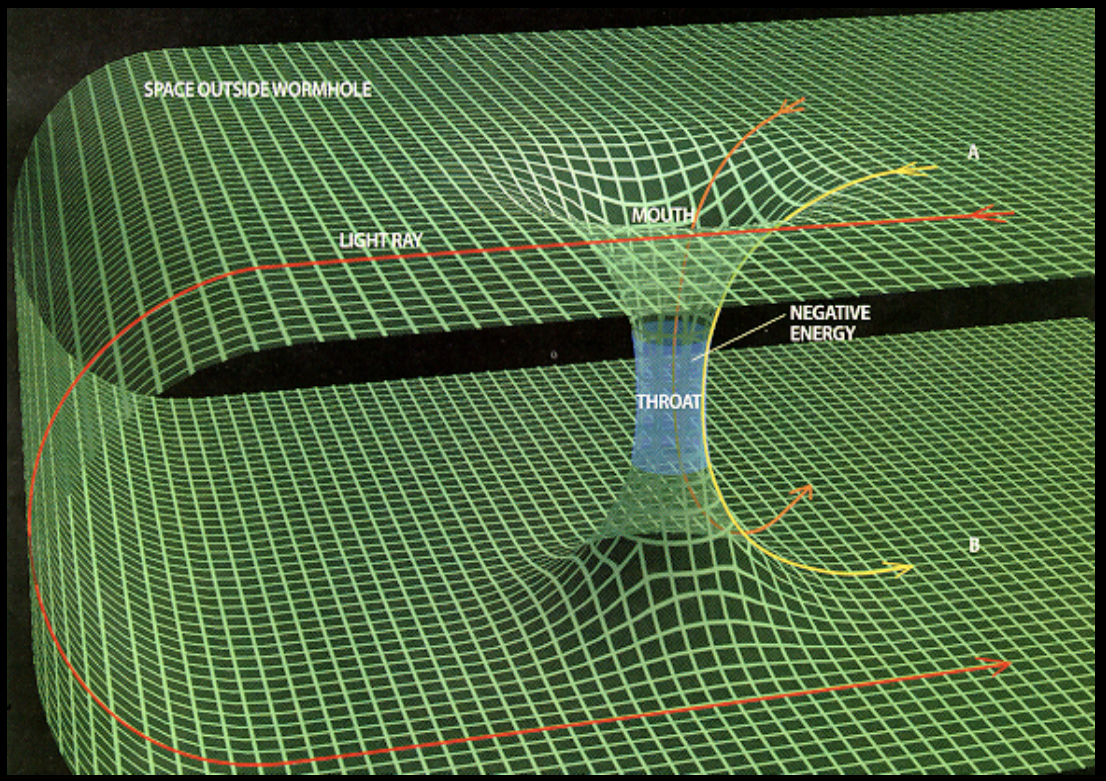
Observing Scenario, focus on NS-NS Binaries

http://arxiv.org/abs/1304.0670

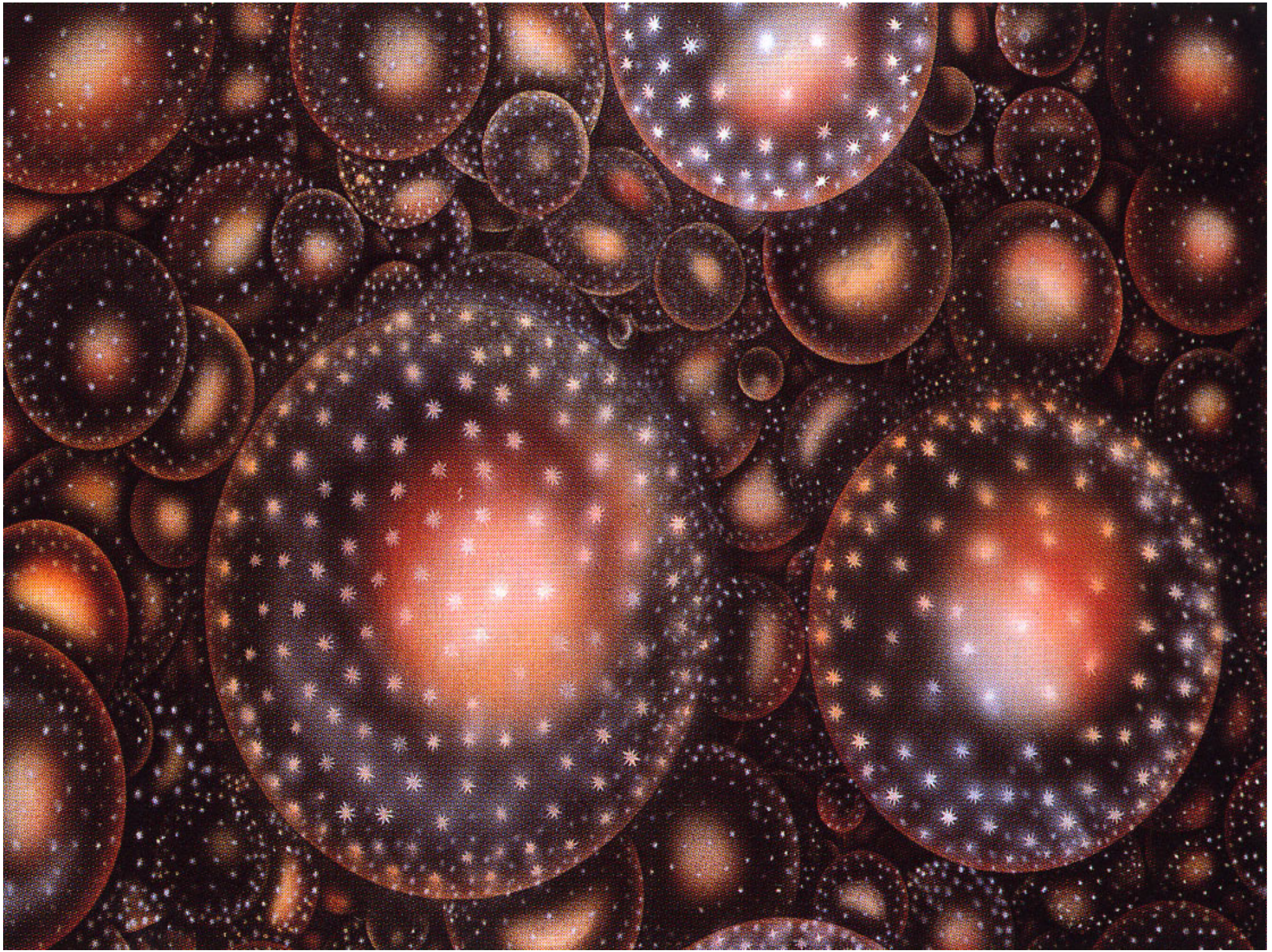


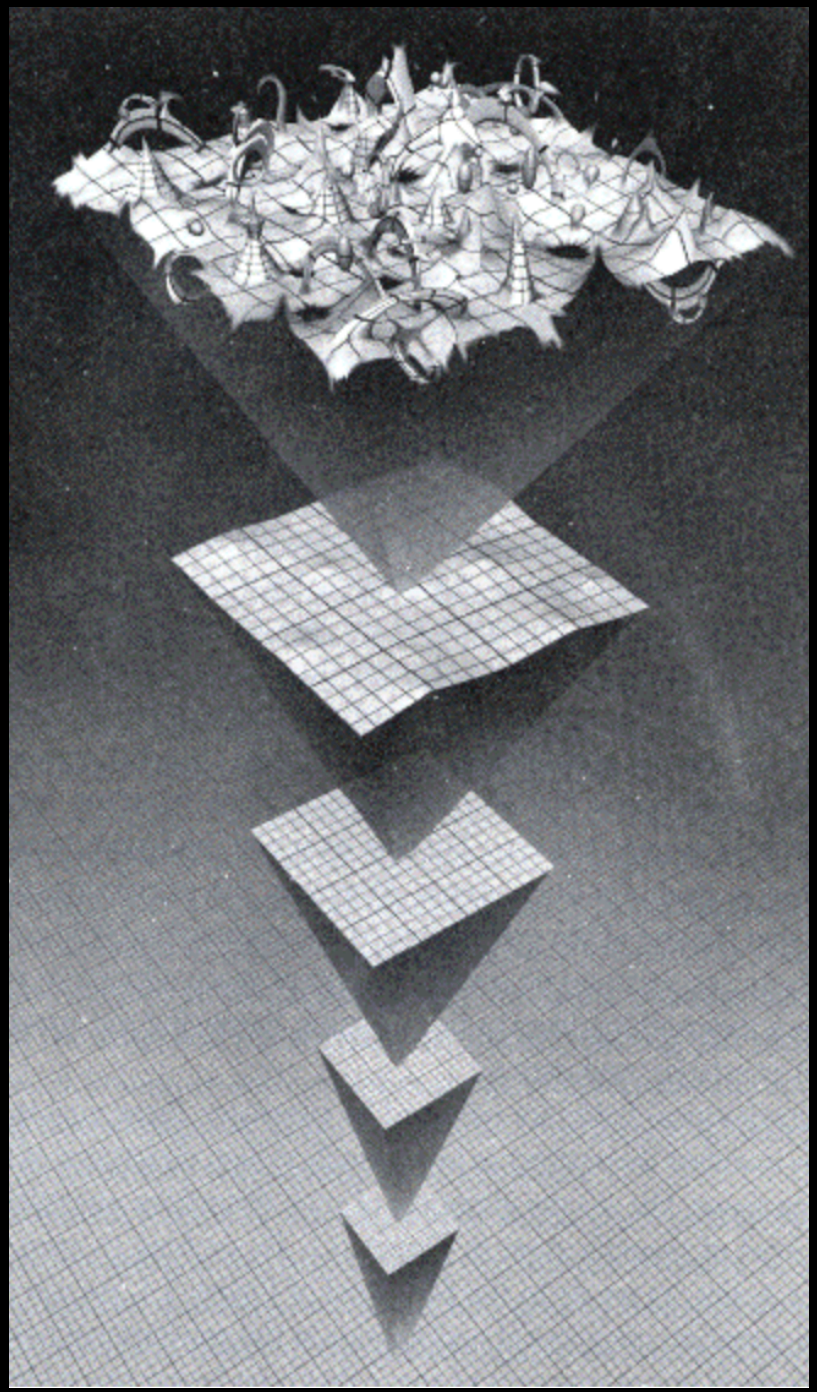


In relatività generale, al centro del buco nero la materia è compressa a densità infinita, e lo spazio tempo ha una curvatura infinita.



Questo significa che la massa del buco nero viene compressa in una regione con zero volume: la singolarità gravitazionale.
Attorno alla singolarità c'è un confine sferico chiamato l'orizzonte degli eventi. Questo segna il punto di non ritorno oltre il quale tutto precipità inevitabilmente verso la singolarità.





$$T_{\mathrm{H}} = \frac{\hbar c^3}{8\pi G M k_{\mathrm{B}}}$$