



Istituto Nazionale di Astrofisica

Osservatorio astronomico di Brera



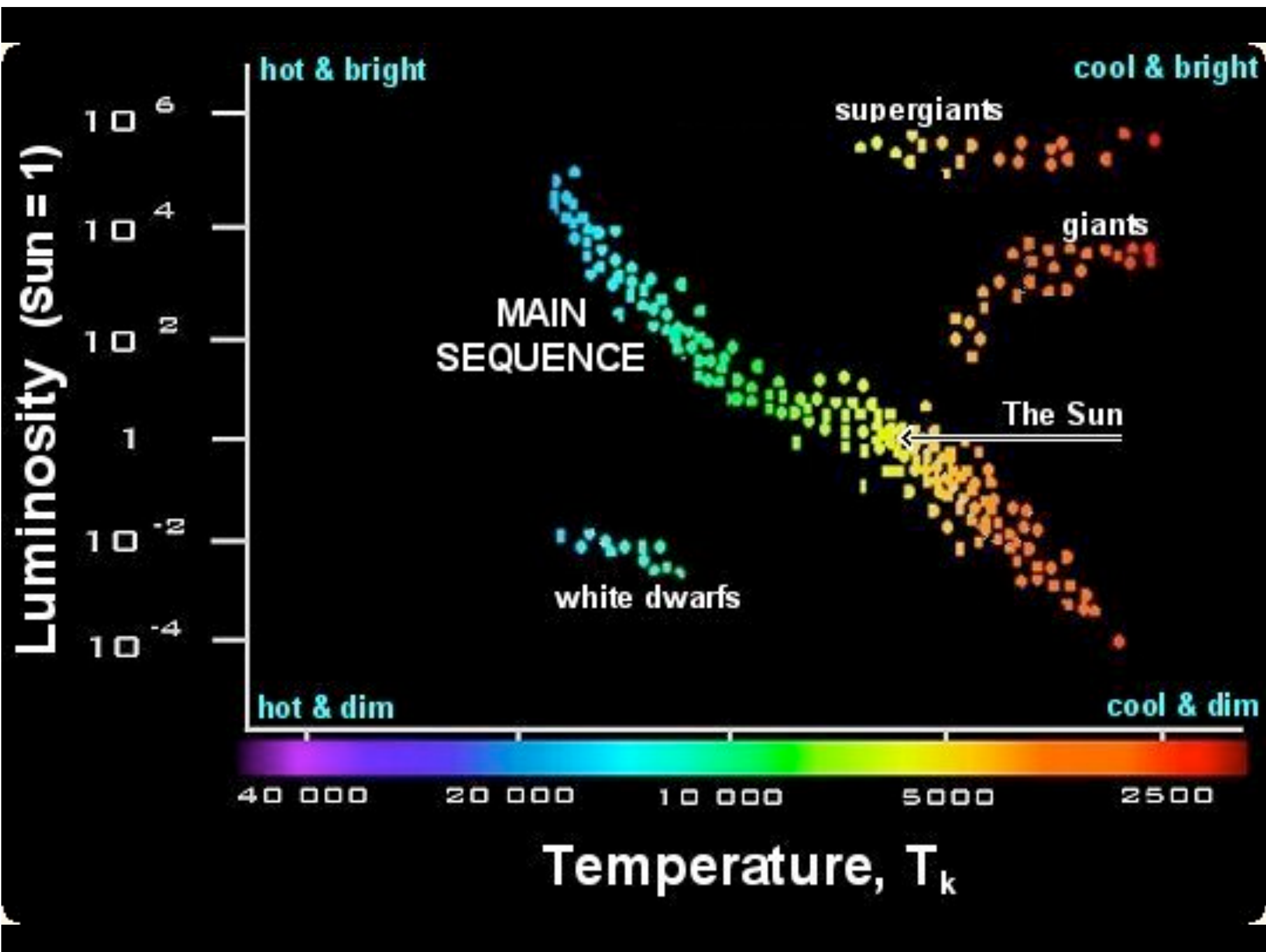
Universo in fiore

Nane bianche, stelle di neutroni e buchi neri: l'attrazione fatale della gravita'

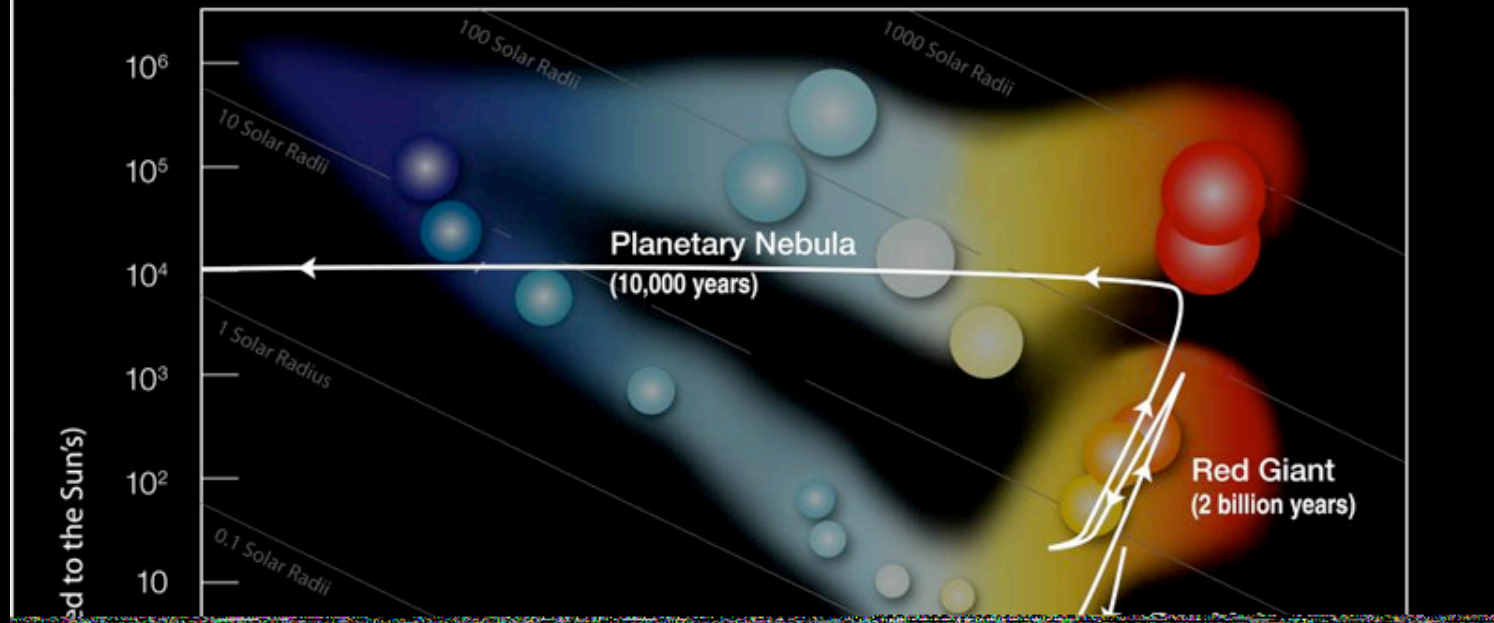
Gabriele Ghisellini

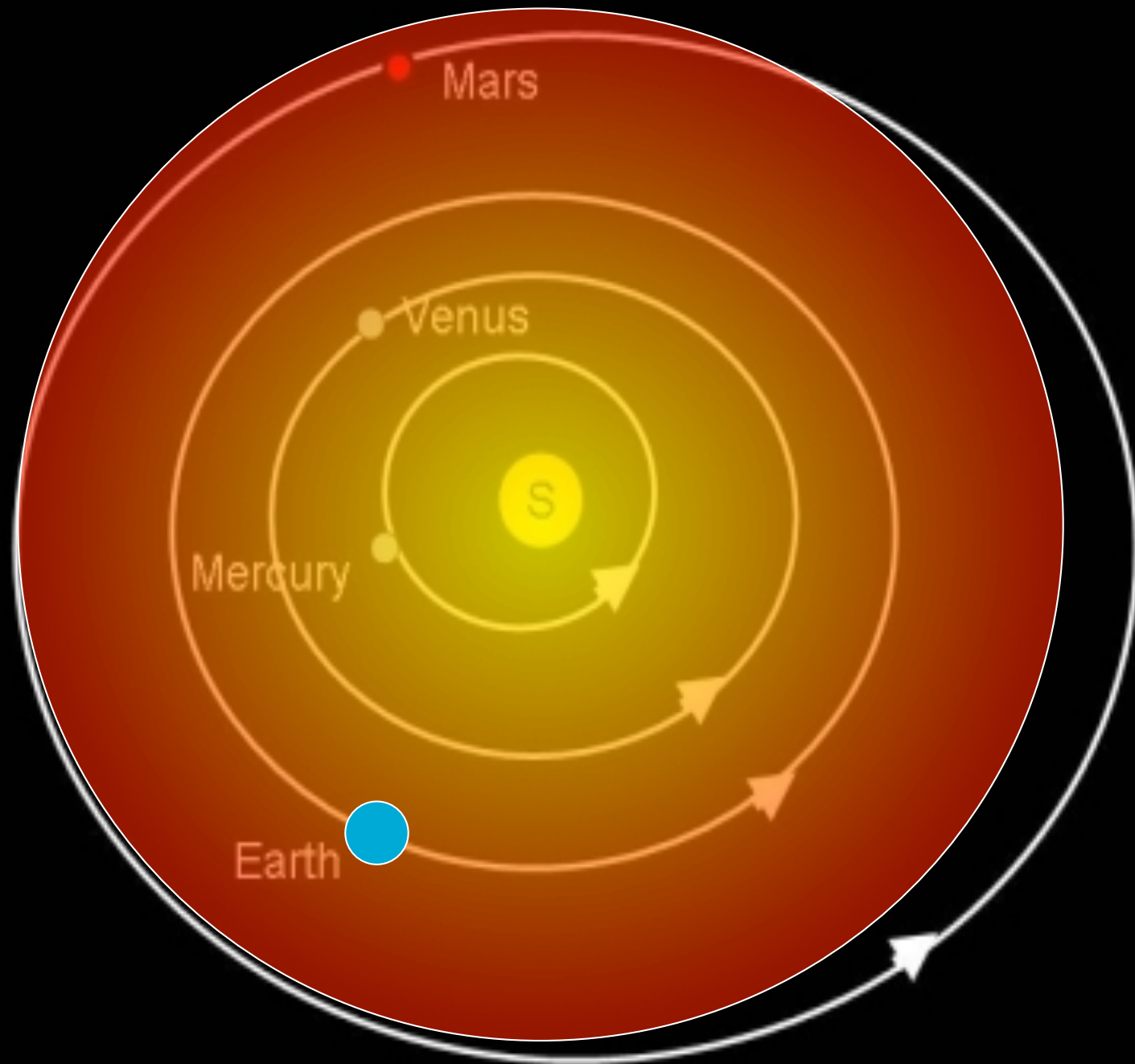
gabriele.ghisellini@brera.inaf.it

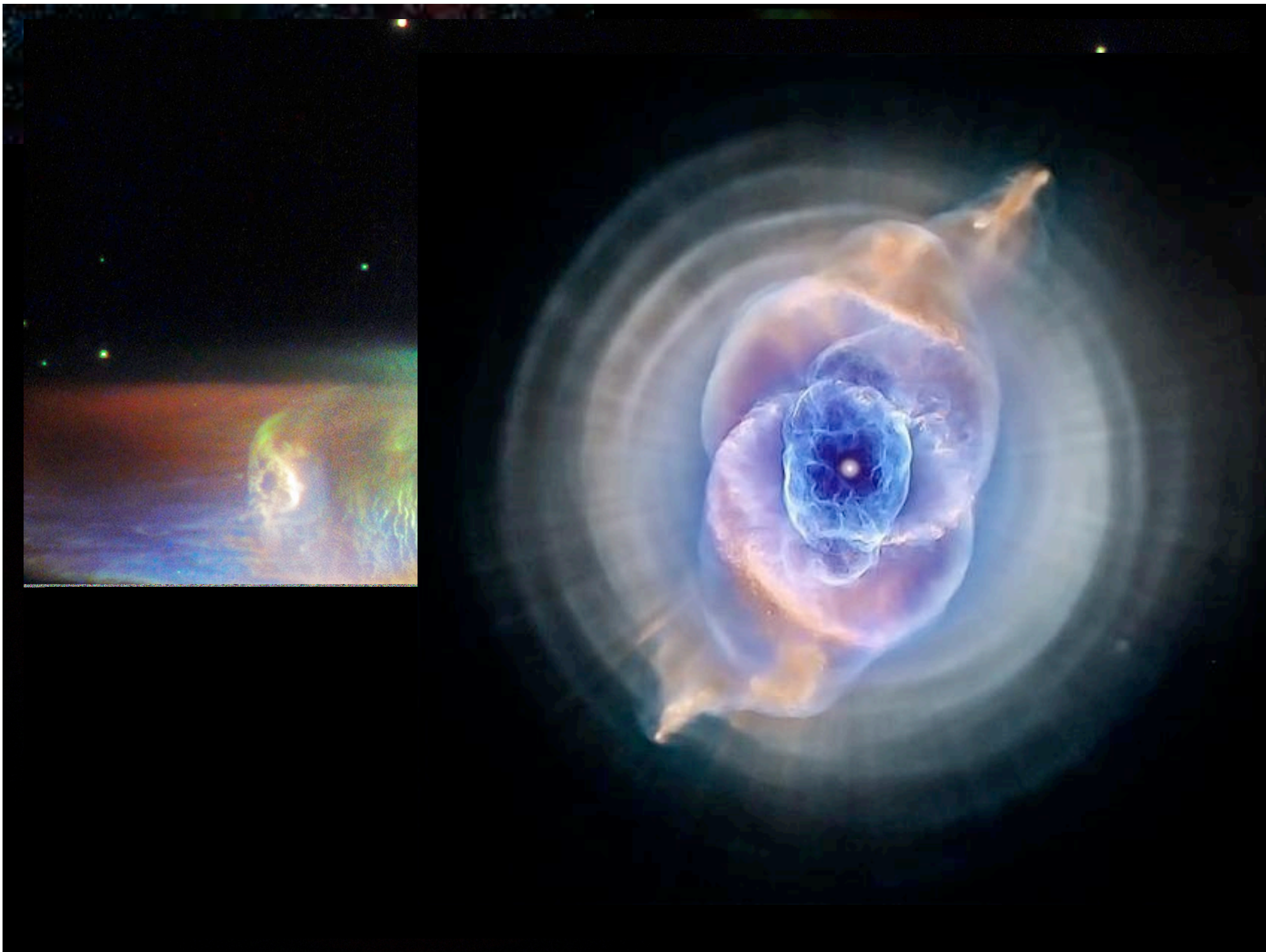
INAF-Osservatorio Astronomico di Brera

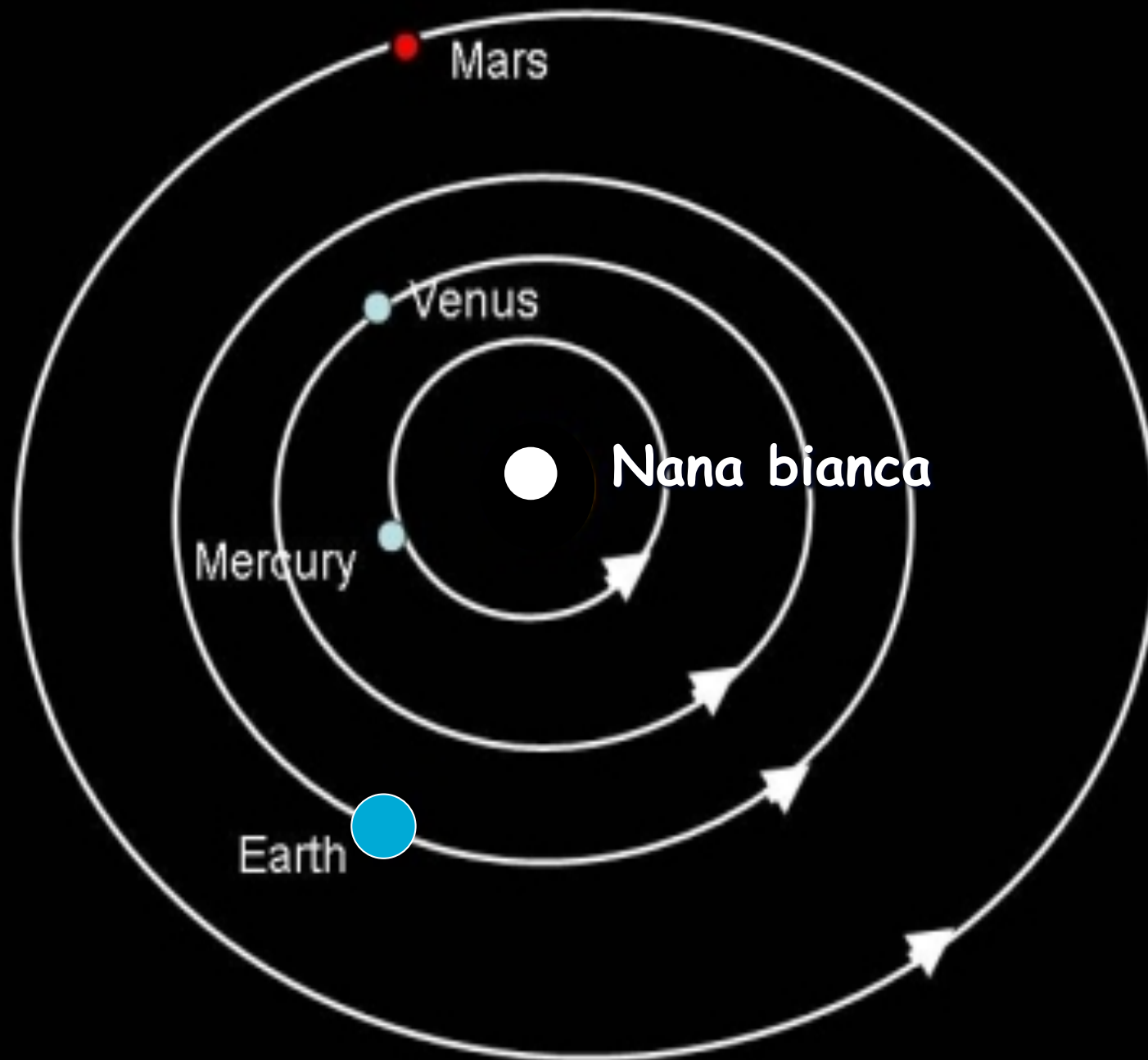


H-R DIAGRAM - SUN'S EVOLUTIONARY TRACK

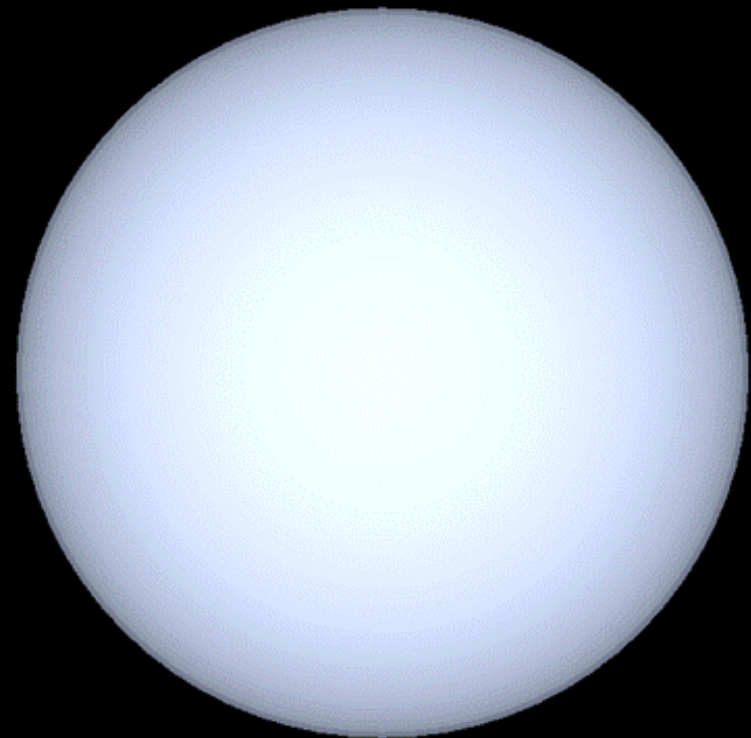








Nana Bianca



$$M \approx 1.0 M_{\text{sun}}$$

$$R \approx 5800 \text{ km}$$

$$V_{\text{esc}} \approx 0.02c$$

Perche' l'implosione si ferma?

Che cosa determina il nuovo equilibrio?

Perche' il raggio e' ~ 10 mila km?

La risposta e' nella meccanica quantistica...

Strano, vero?

Fermioni (spin semintero):

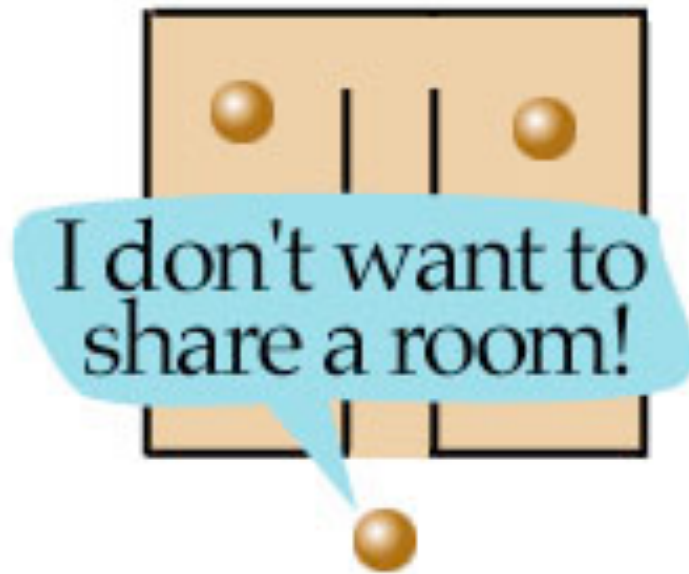
Elettroni

Quark

neutroni

Protoni

Principio di esclusione di Pauli



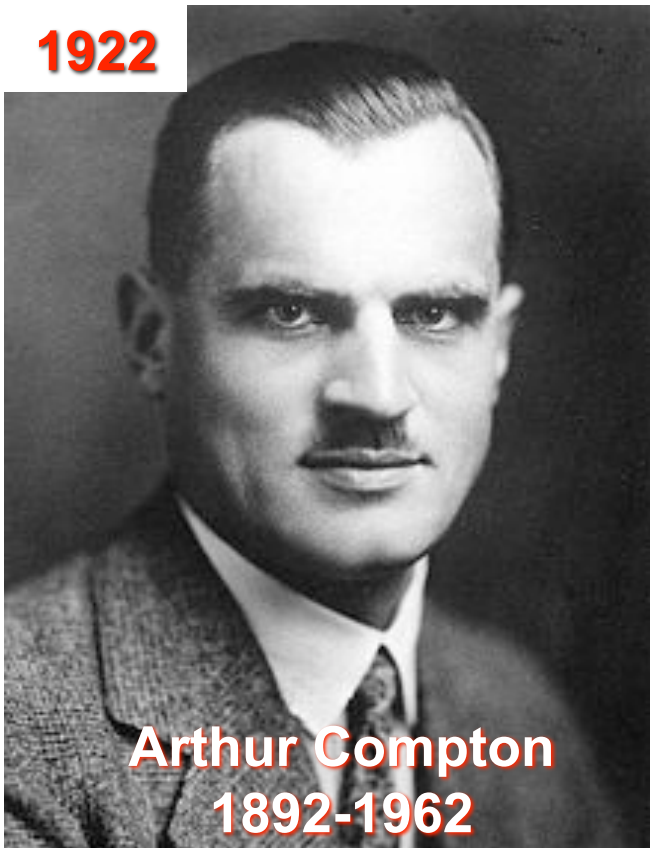
Bosoni (spin intero):

fotoni

nuclei di elio



1922



Arthur Compton
1892-1962

1924



Luis de Broglie
1892-1987

1925



Wolfgang Pauli
1900-1958

$$\lambda_{\text{Compton}} = \frac{h}{mc}$$

Per l'elettrone:
 $\lambda_c = 2.4 \times 10^{-10} \text{ cm}$

Non posso avere due elettroni (con stessa energia e stesso spin) ad una distanza minore di λ_c

In una stella come il Sole ci sono 10^{57} atomi
Per “far funzionare” il principio di esclusione di Pauli,
gli elettroni devono essere a circa una lunghezza
Compton. Il volume totale occupato dagli elettroni (e
dagli atomi) diventa

$$V_{NB} = 10^{57} \lambda_c^3$$

Questo sara' il volume della nuova stella. Il raggio sara'

$$\begin{aligned} R_{NB} &= (V_{NB})^{1/3} = 10^{57/3} \lambda_c \\ &\sim 10^{19} 10^{-10} \text{ cm} \\ &\sim 10^9 \text{ cm} \\ &\sim 10.000 \text{ km} \end{aligned}$$

Nana Bianca

Raggio: ~10.000 km (circa come la terra)

Massa: 0.7-1 volte quella del sole

Alta densità:

1 cucchiaino → 1 tonnellata!

All'inizio: 100.000 gradi (bianca).

Poi si raffredda (nana bruna).

Sole



ξ Puppis

Tipo: **supergigante blu**

Distanza: **~1000 a.l.**

Massa: **50 Soli**

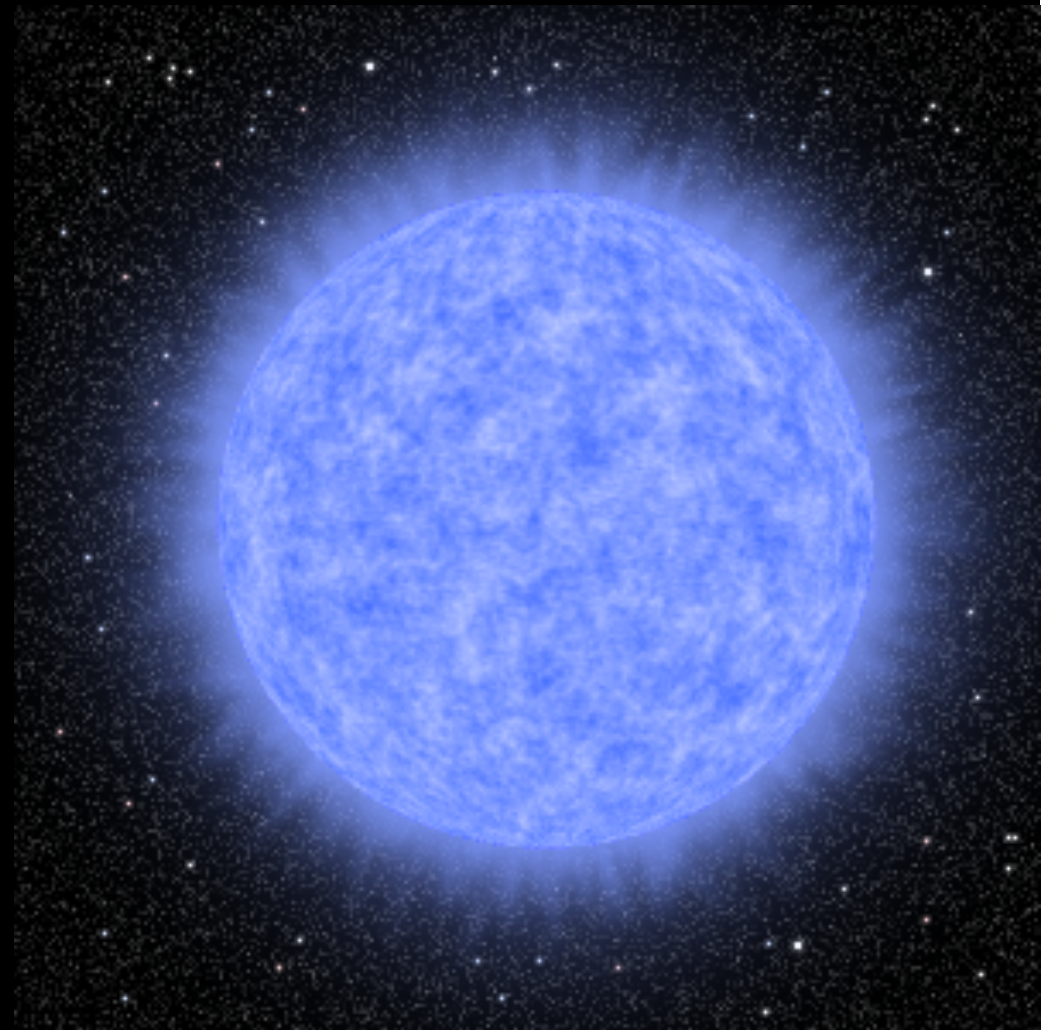
Luminosità: **60.000 Soli**

Raggio: **20 Soli**

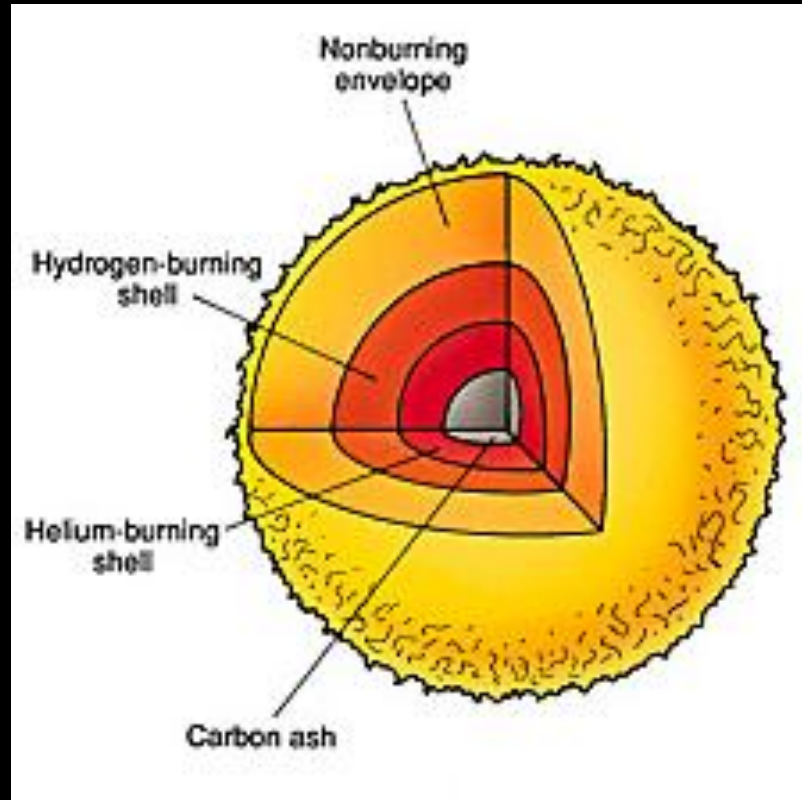
Temperatura: **42.000°**

Eta': **~ 4 milioni di anni**

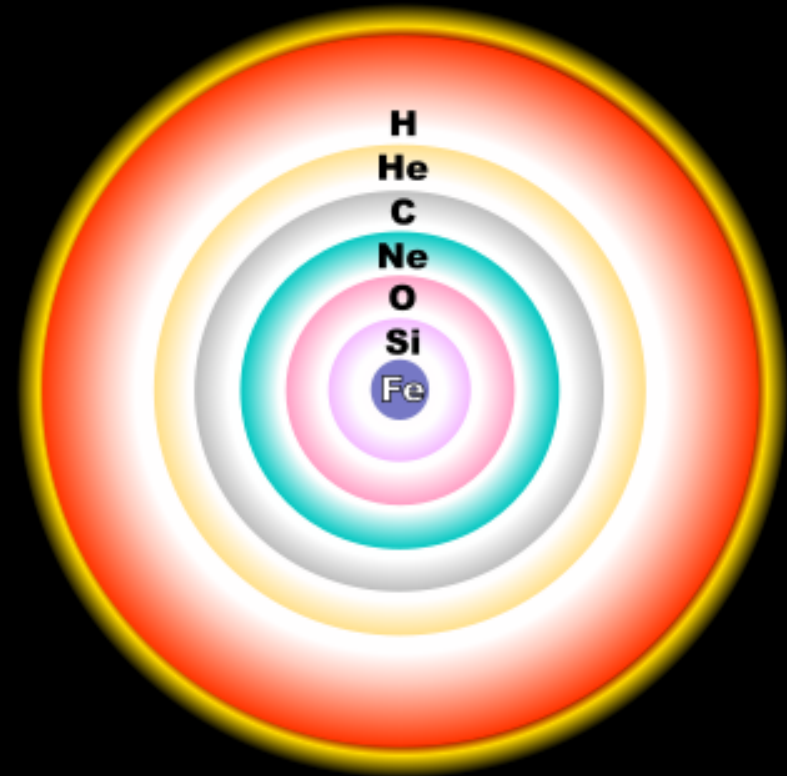
Vita: **~ 6 milioni di anni**



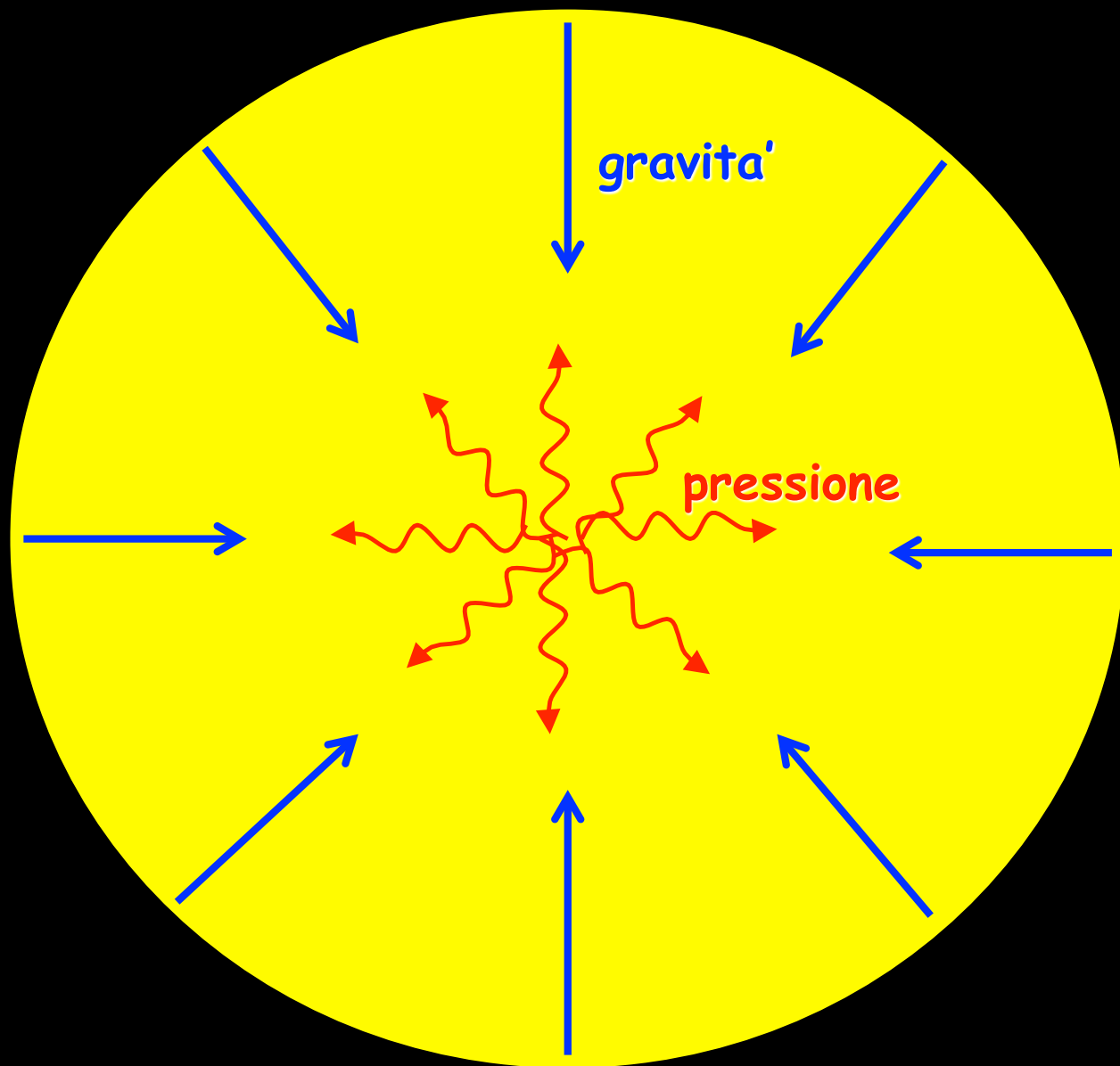
Prima

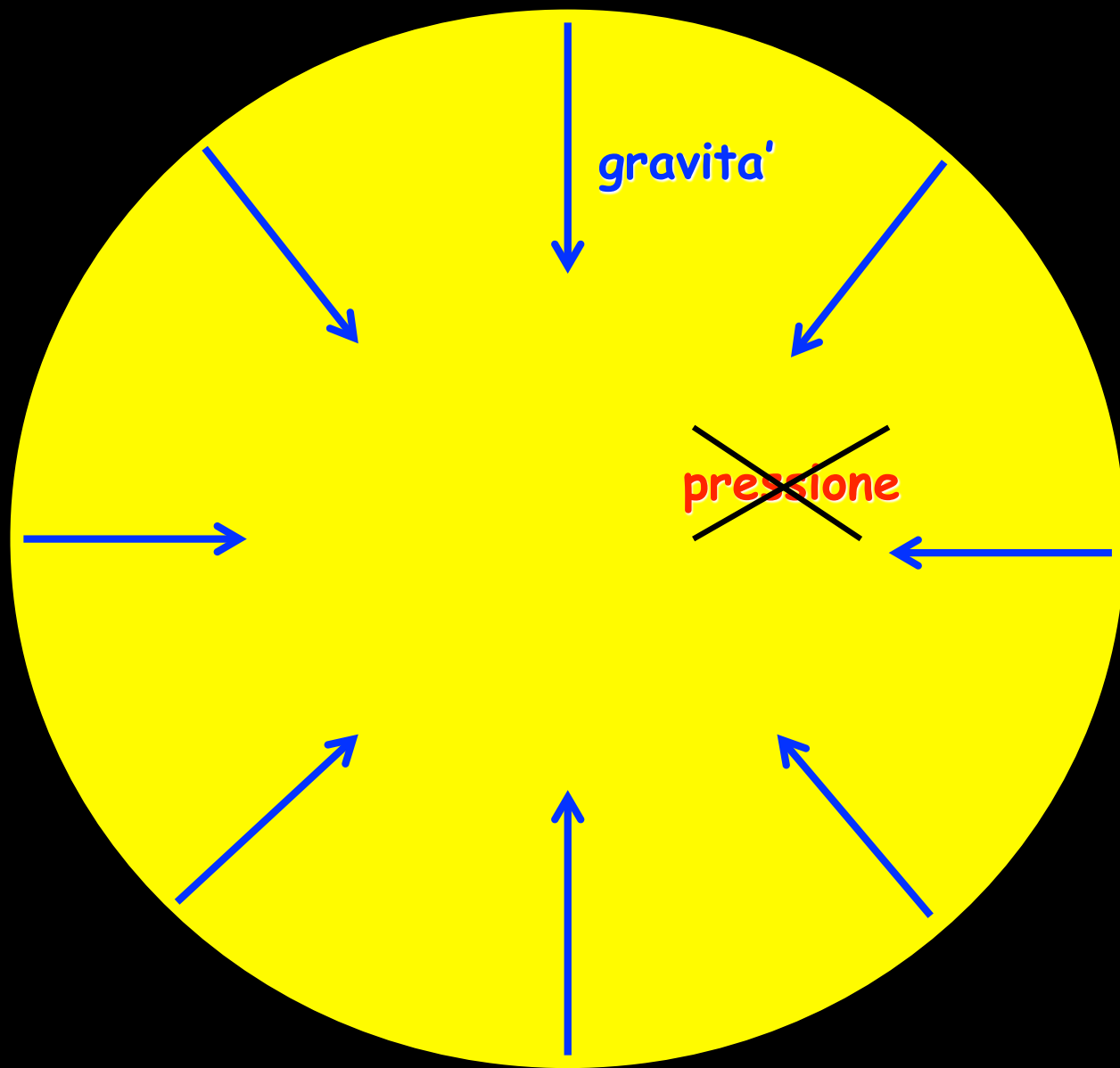


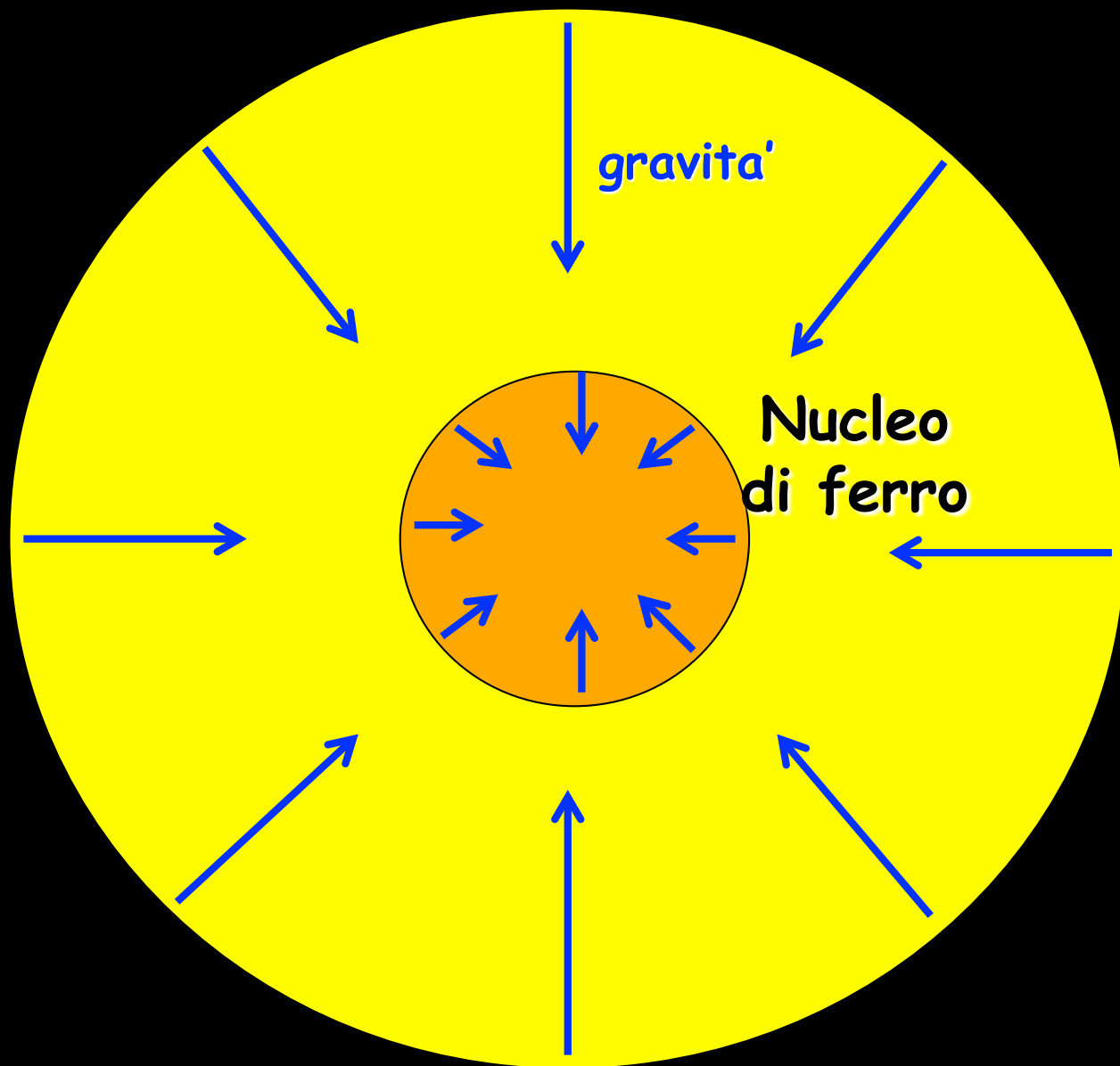
Dopo

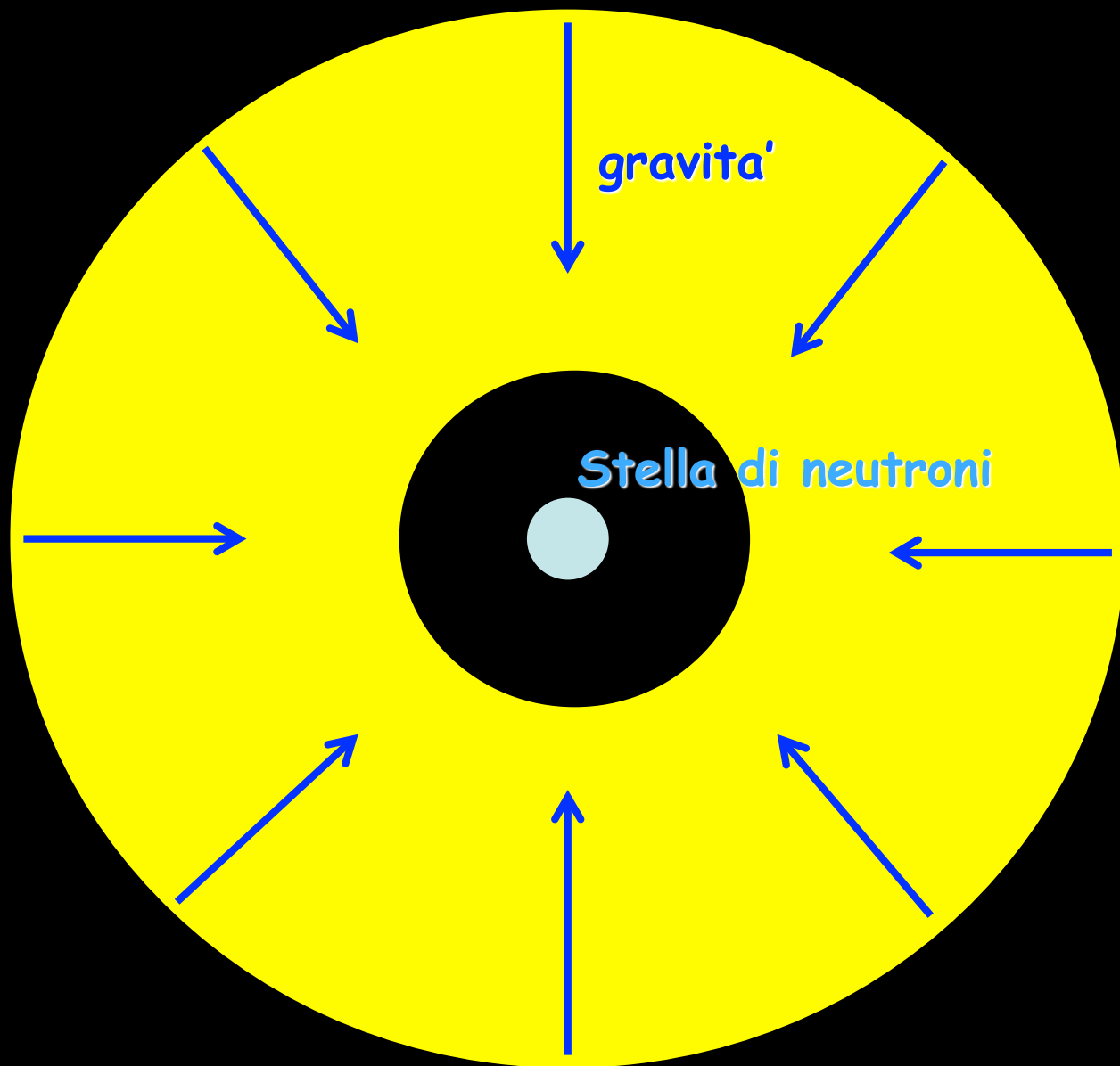


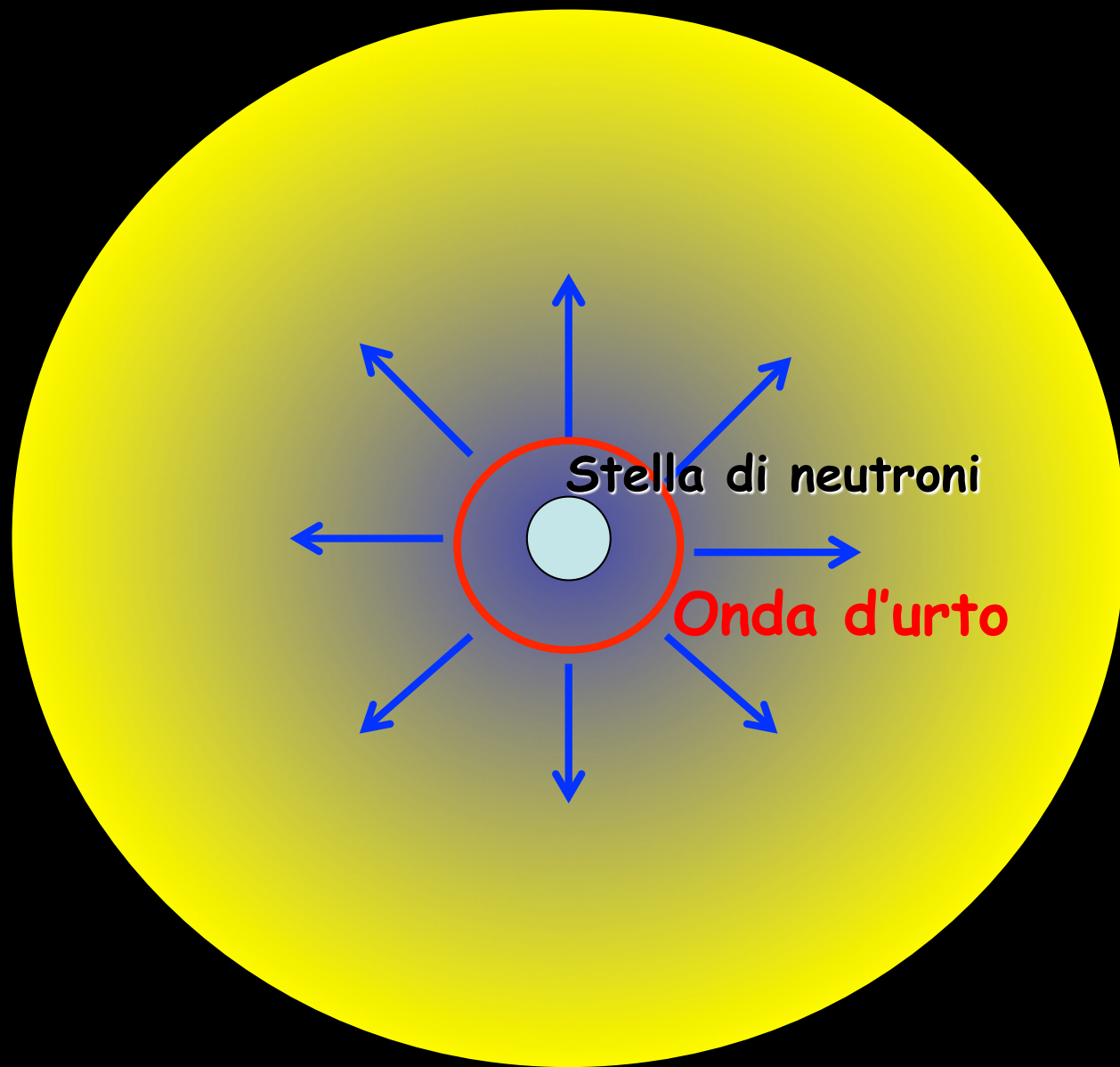
Le stelle grandi sono a cipolla... Ogni guscio brucia un combustibile diverso e produce energia. Fino a quando si produce il ferro. Oltre no. "Il ferro non brucia". Il combustibile finisce. E in fretta! (milioni di anni..)



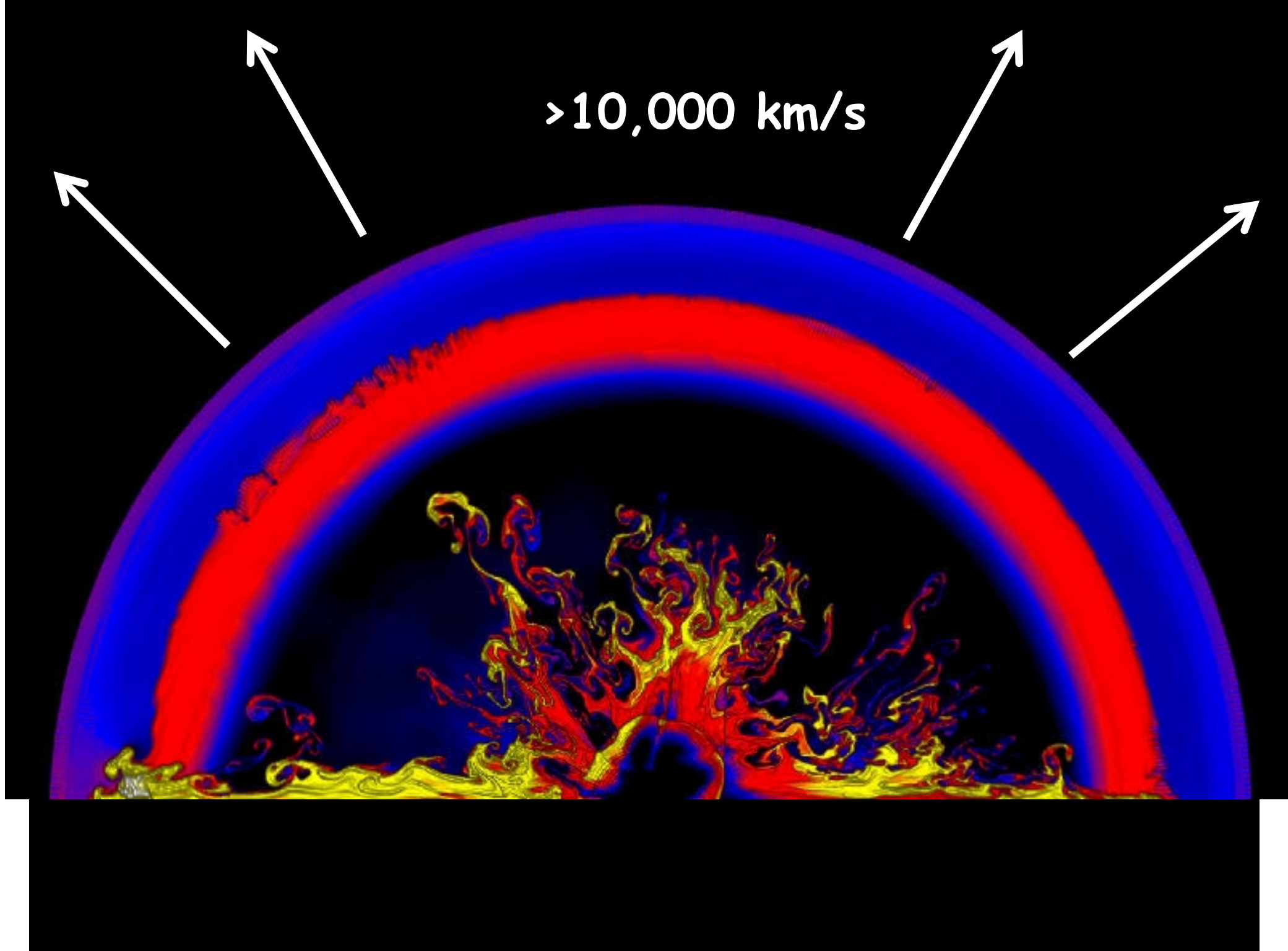








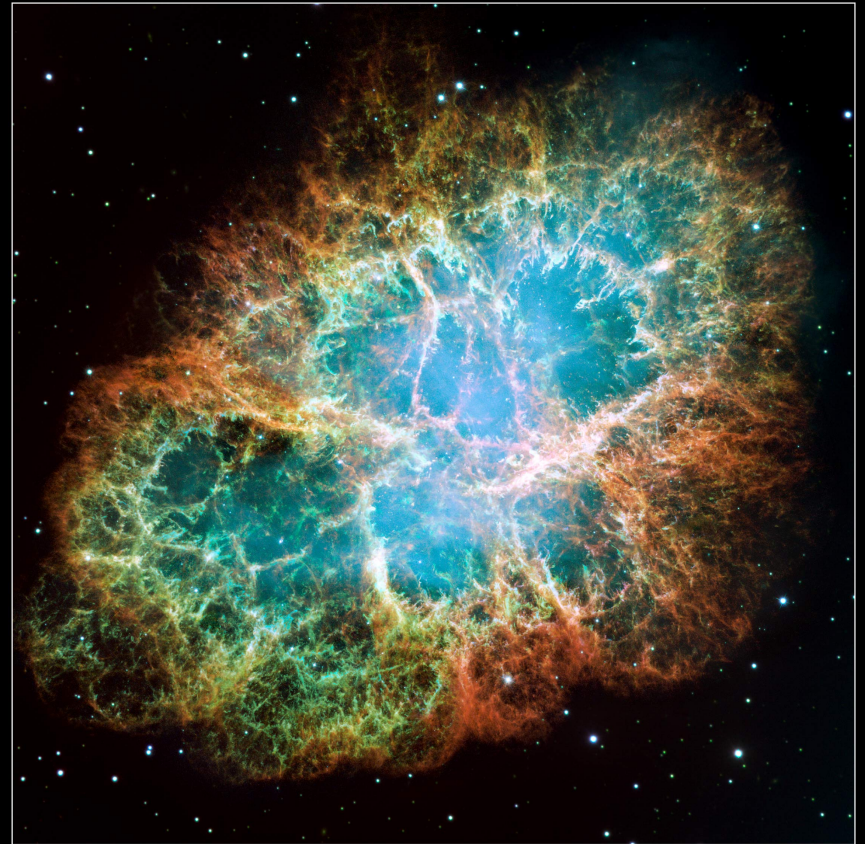
$>10,000 \text{ km/s}$



CRAB NEBULA
Granchio



[HTTP://CHANDRA.HARVARD.ED](http://chandra.harvard.edu)



Crab Nebula • M1
Hubble Space Telescope • WFPC2

NASA, ESA, and J. Hester (Arizona State University)

STScI-PRC05-37

1054 d.C. astronomi cinesi

~6500 anni luce

Il nucleo della stella implode, passa lo stato di nana bianca, ma la forza di repulsione degli e- non e' sufficiente a sostenerla. La stella continua ad implodere. Ad un certo punto gli elettroni e i protoni si uniscono e si trasformano in neutroni. Ma anche per loro vale il principio di esclusione!!!

Quando la loro distanza media diventa circa λ_c , il volume totale diventa

$$V_{NS} = 2 \times 10^{57} \lambda_c^3 \quad \text{ma adesso } \lambda_c \text{ e' circa 1800 volte minore}$$

Questo sara' il volume della stella di neutroni.

Il raggio sara'

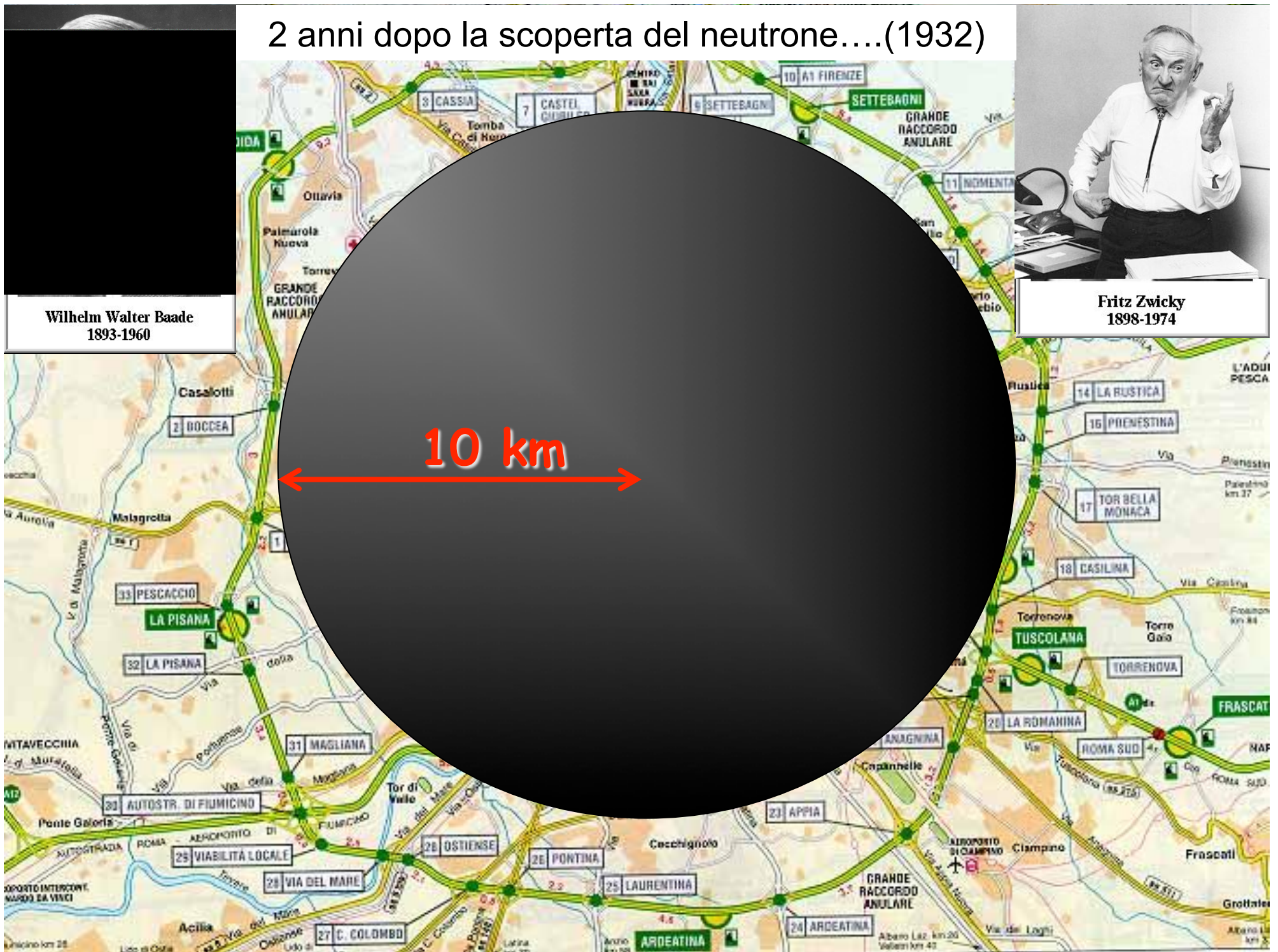
$$R_{NB} = (V_{NB})^{1/3} = 10^{57/3} \lambda_c \sim 10^6 \text{ cm} \sim 10 \text{ km}$$

2 anni dopo la scoperta del neutrone....(1932)

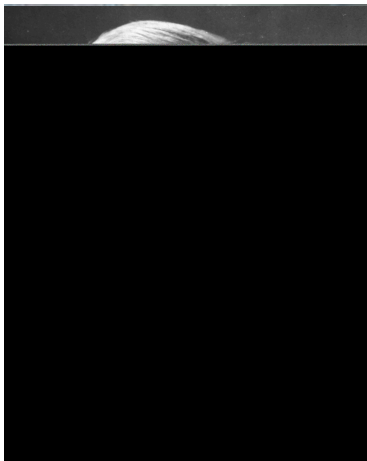
Wilhelm Walter Baade
1893-1960

Fritz Zwicky
1898-1974

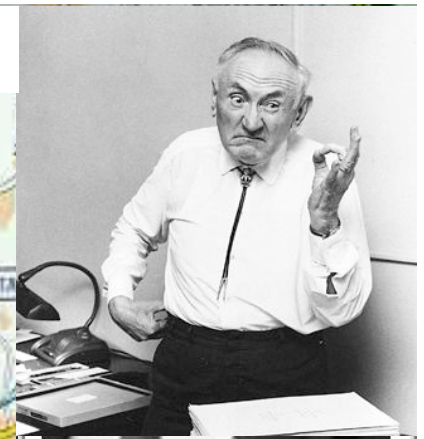
10 km



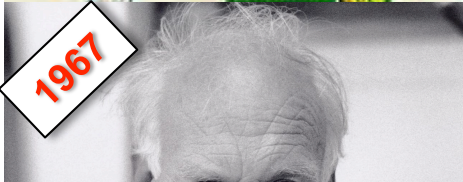
2 anni dopo la scoperta del neutrone....(1932)



Wilhelm Walter Baade
1893-1960

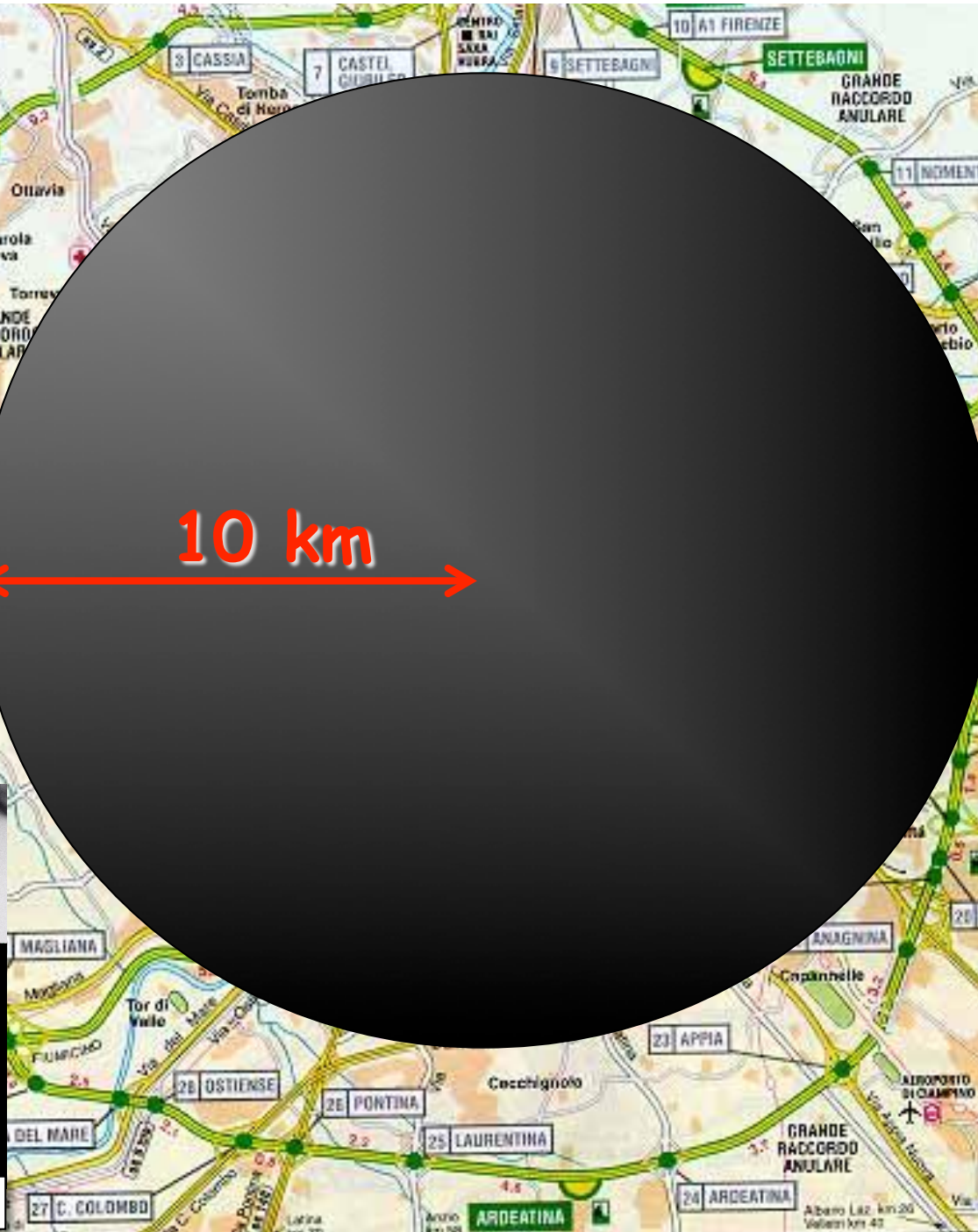


Fritz Zwicky
1898-1974



1967

Franco Pacini 1939-2012



Stella di Neutroni

Un cucchiaino: un miliardo di tonnellate

Campo magnetico alla superficie: 10^{12} (=mille miliardi) di Gauss

Terra: ~ 1 Gauss

Magnetino da frigo: ~ 100 Gauss

massa circa
1,5 masse solari

crosta
solida
1 km

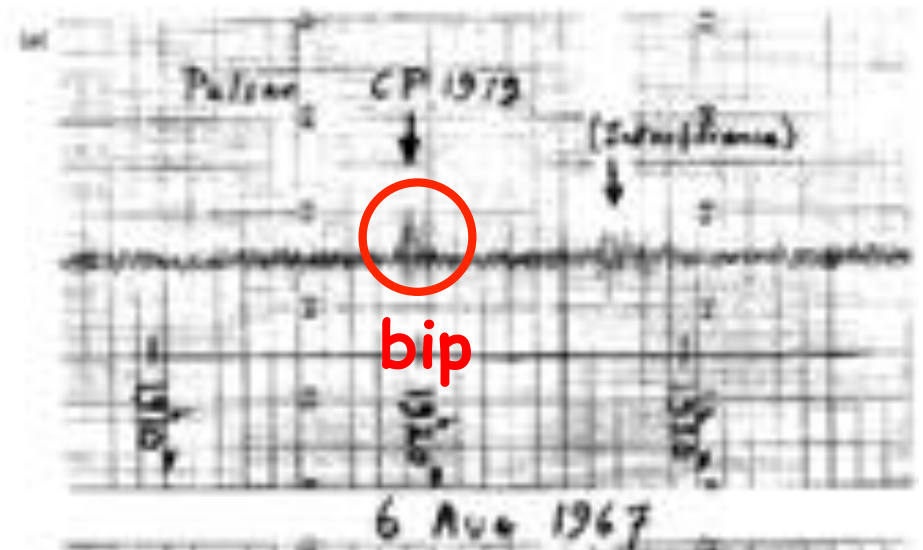
10 km

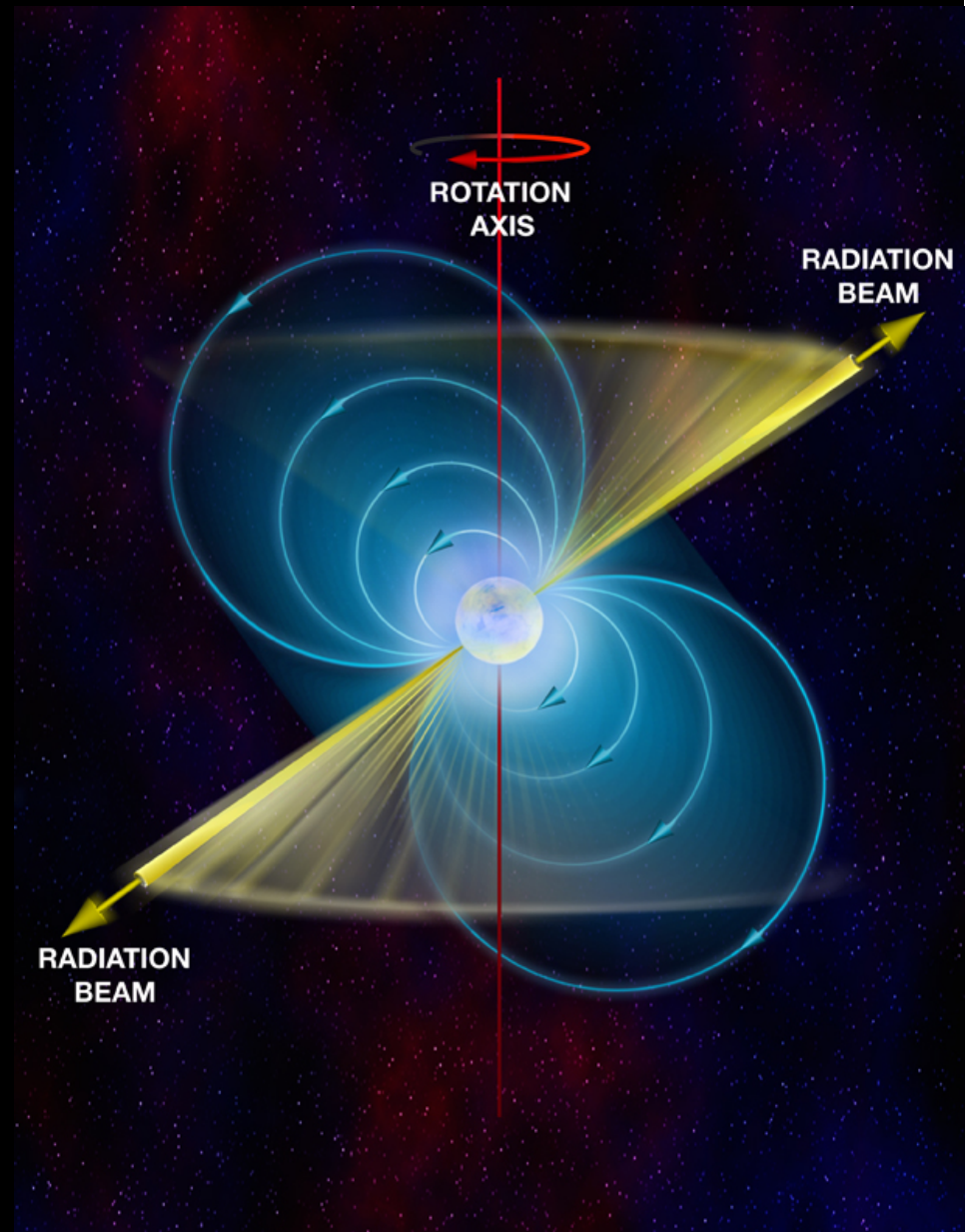
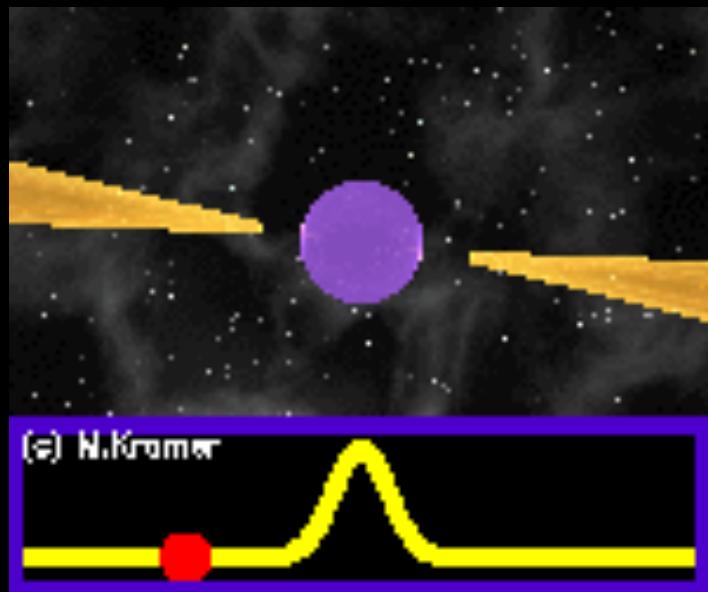
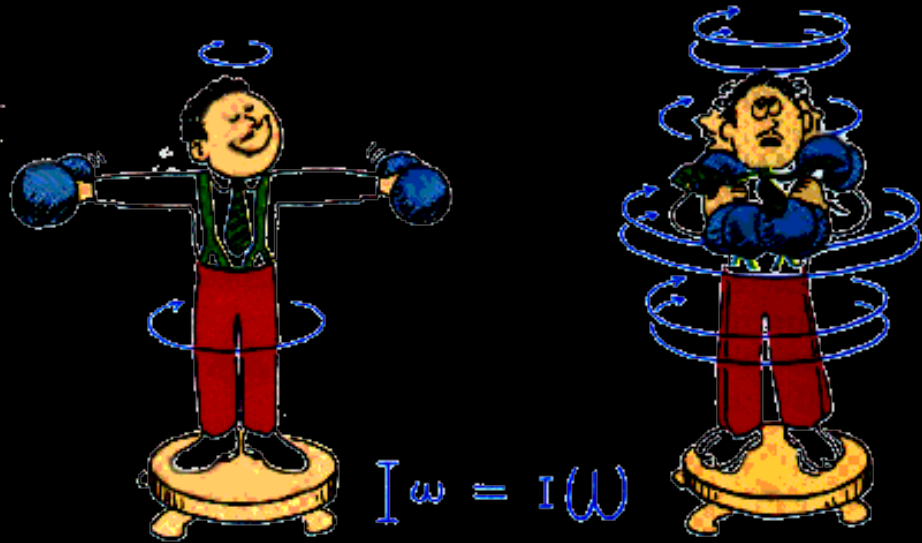
interno liquido
fluido di
neutroni

Non brucia. Come fa ad essere stabile?
Rifiuto dei neutroni a stare vicini
(meccanica quantistica)

4 Agosto 1967

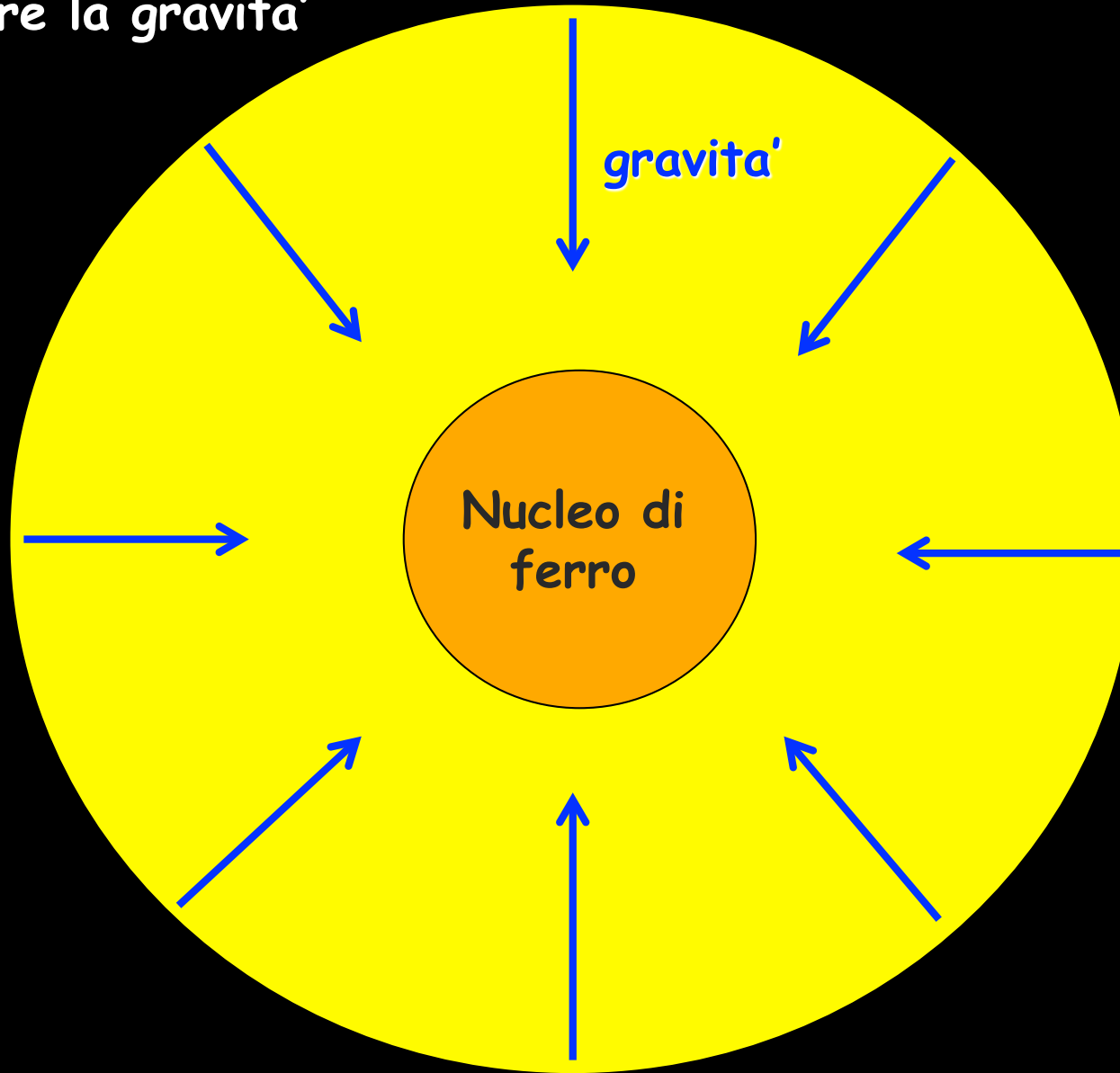
Jocelyn Bell
(allora 24enne),
dottoranda di
Antony Hewish a
Cambridge



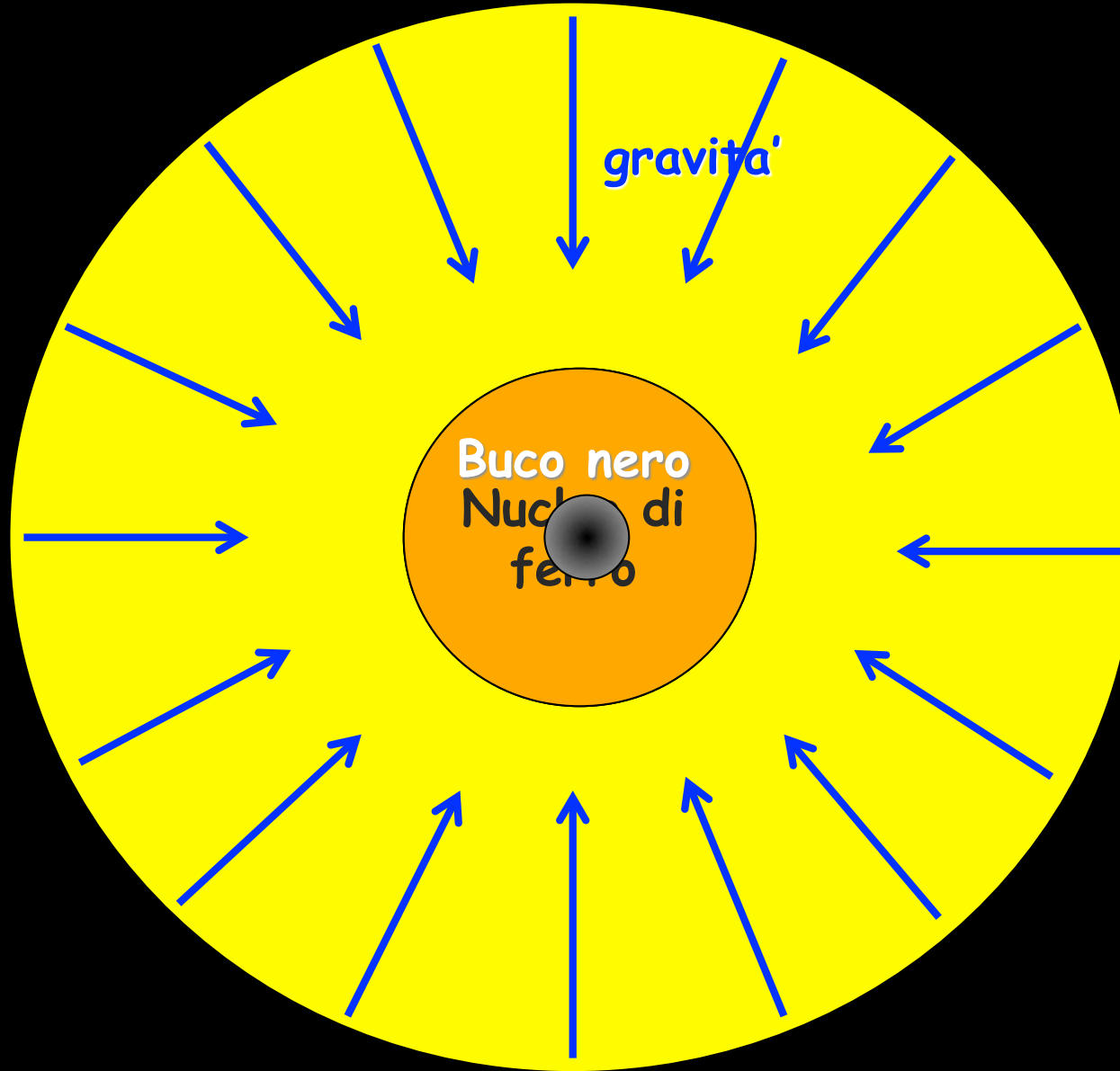


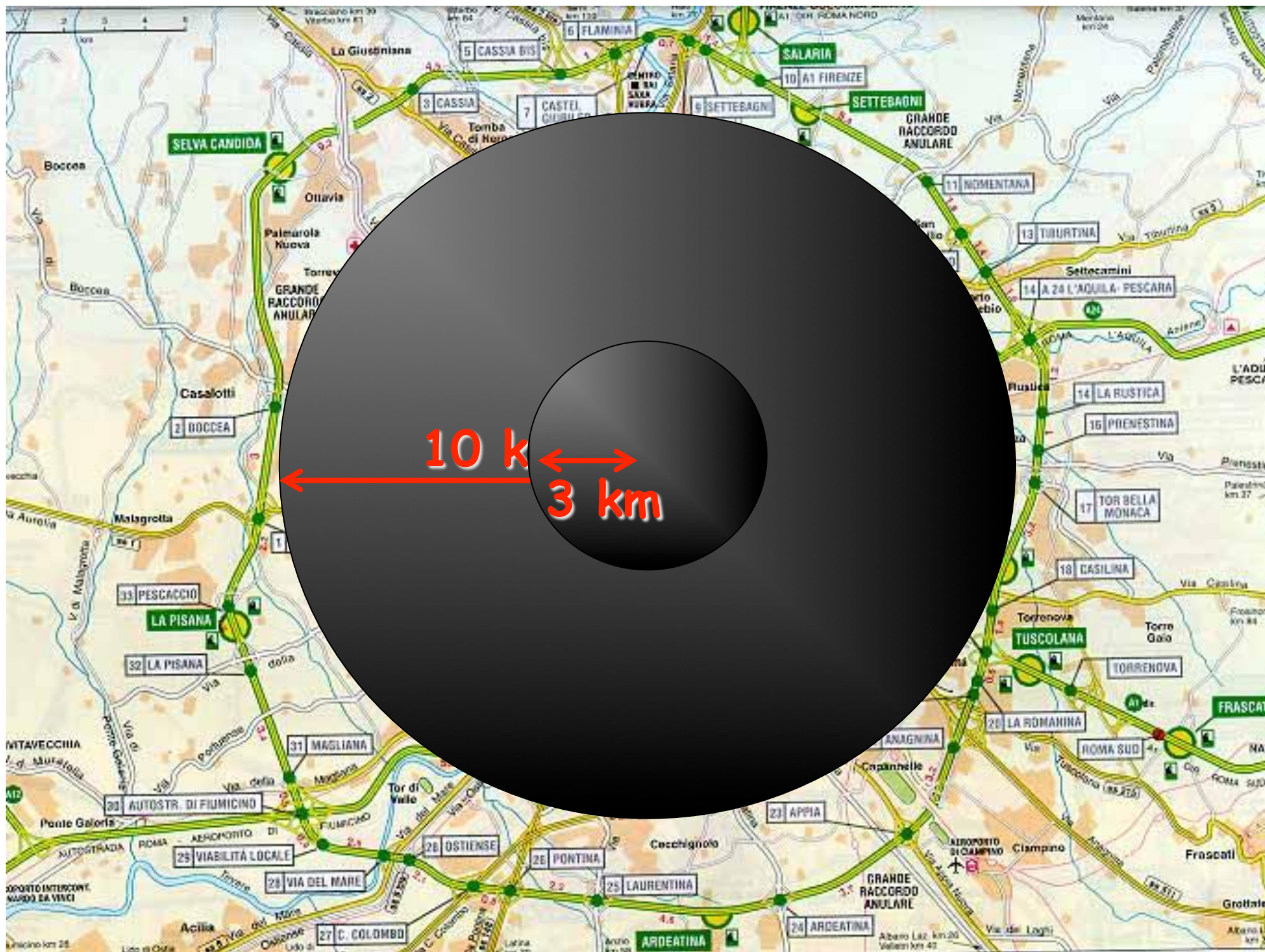
Fastest: $T=1.4 \text{ ms} \rightarrow 716 \text{ giri al sec}$
 $\rightarrow v=0.15 \text{ c}$

Se la stella non e' troppo pesante i neutroni riescono a sostenere la gravita'



Se la stella e' piu' pesante la gravita' vince tutte le resistenze





1842-1933

Annus mirabilis:

1905

Gravitazione:

1919



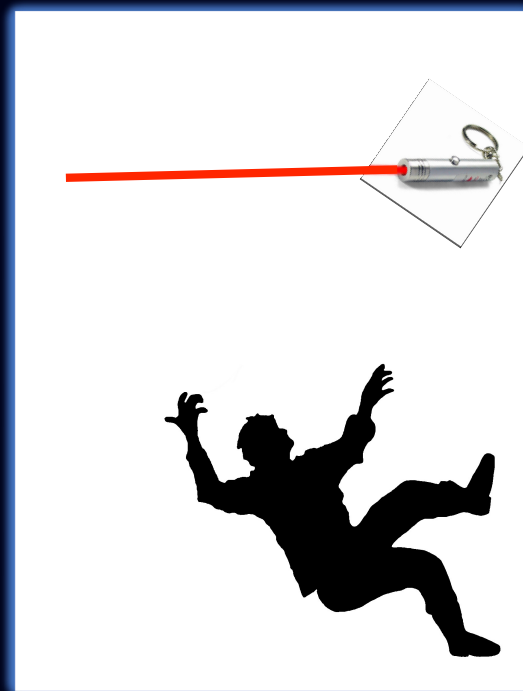
1907: The happiest thought of my life....

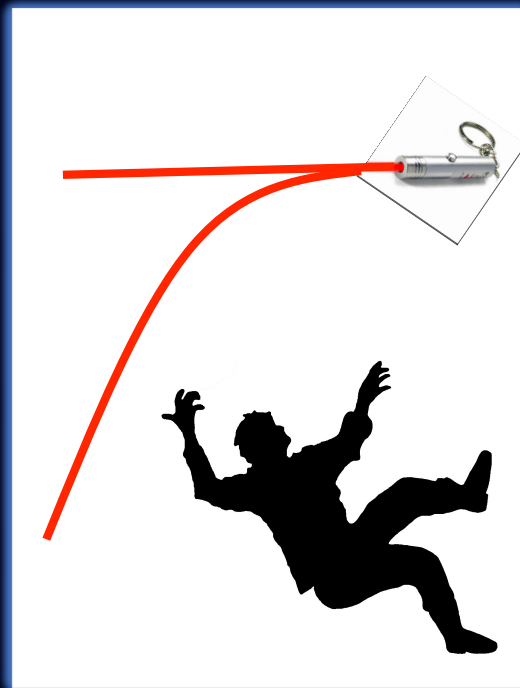


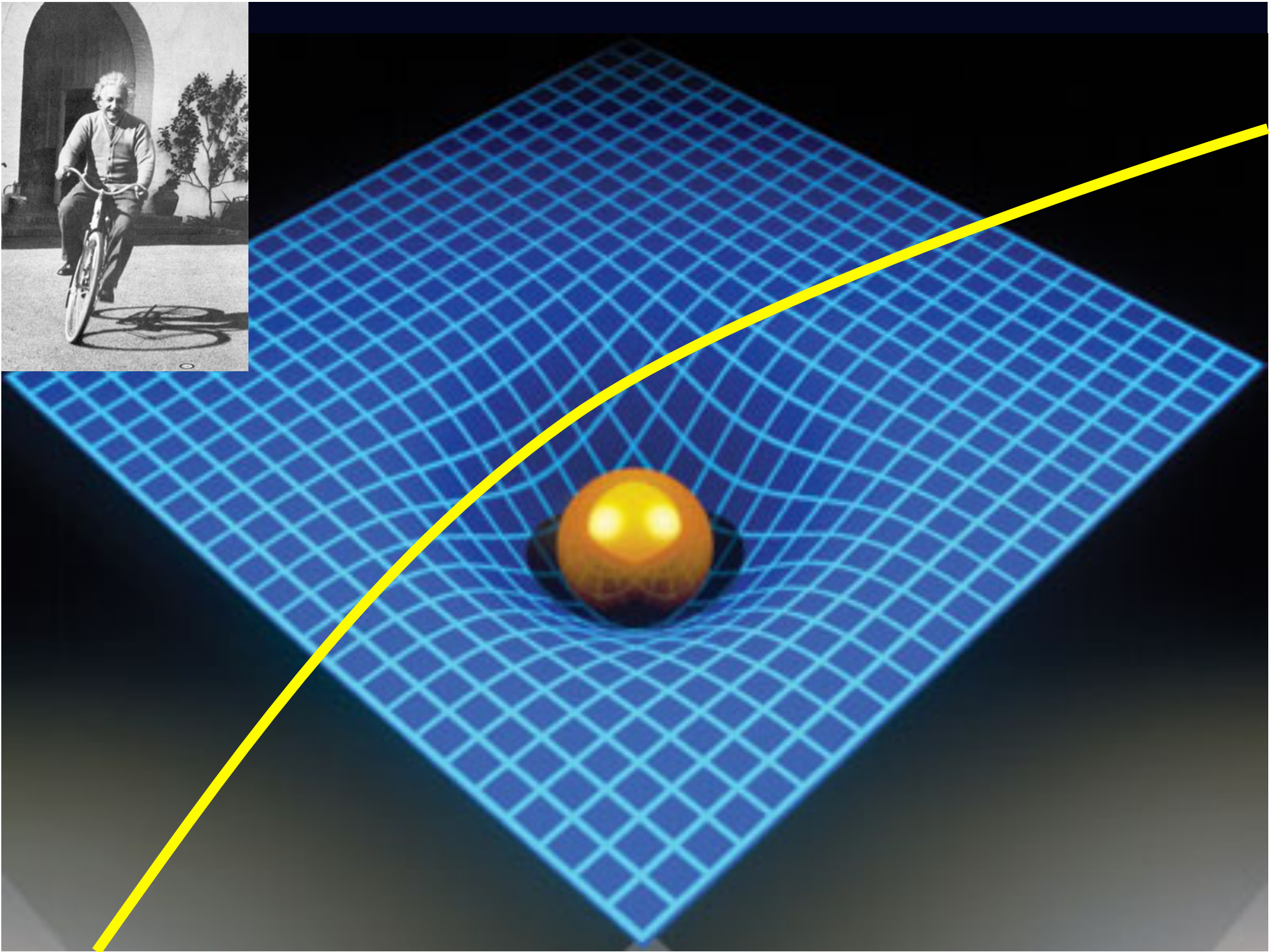
Cosa succede quando cado dal tetto?

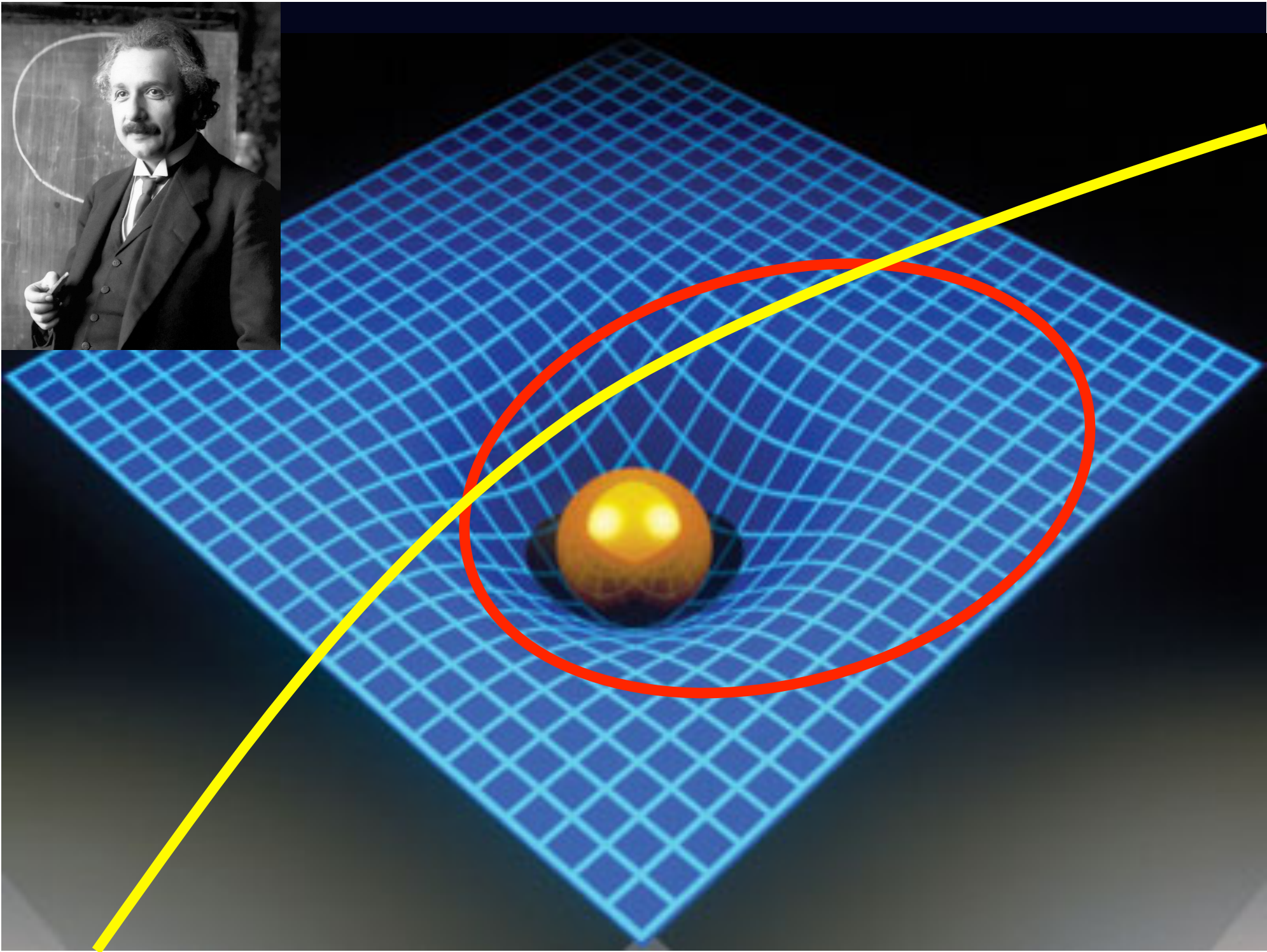
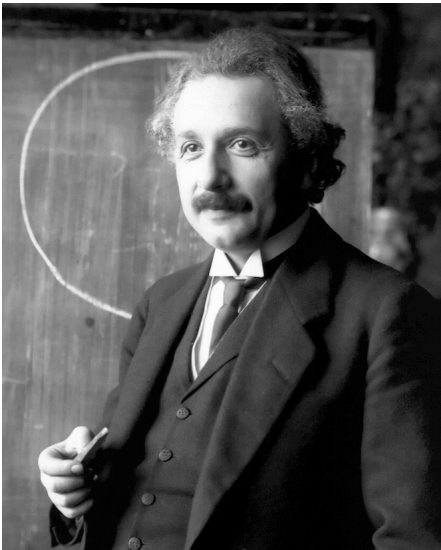


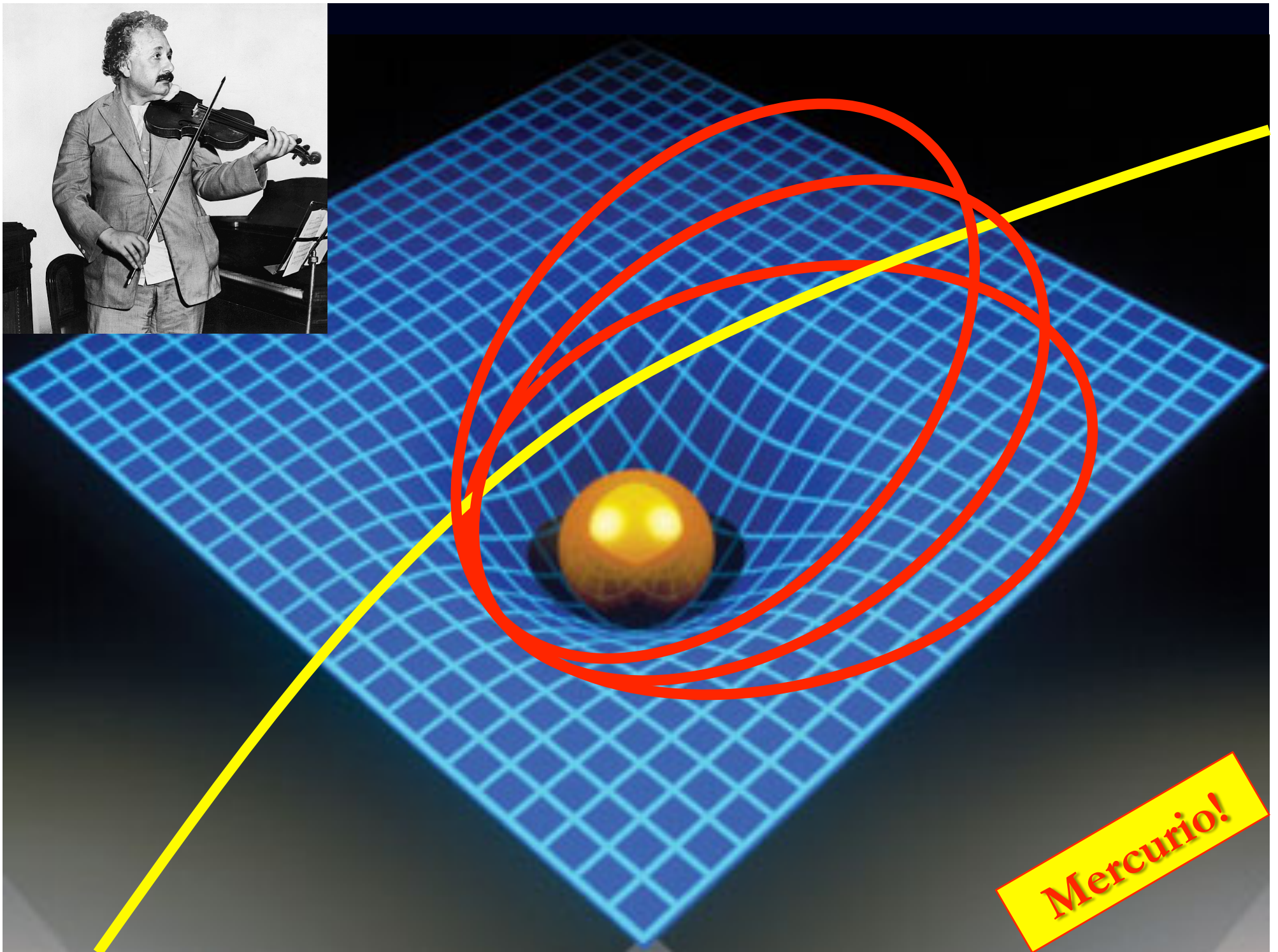




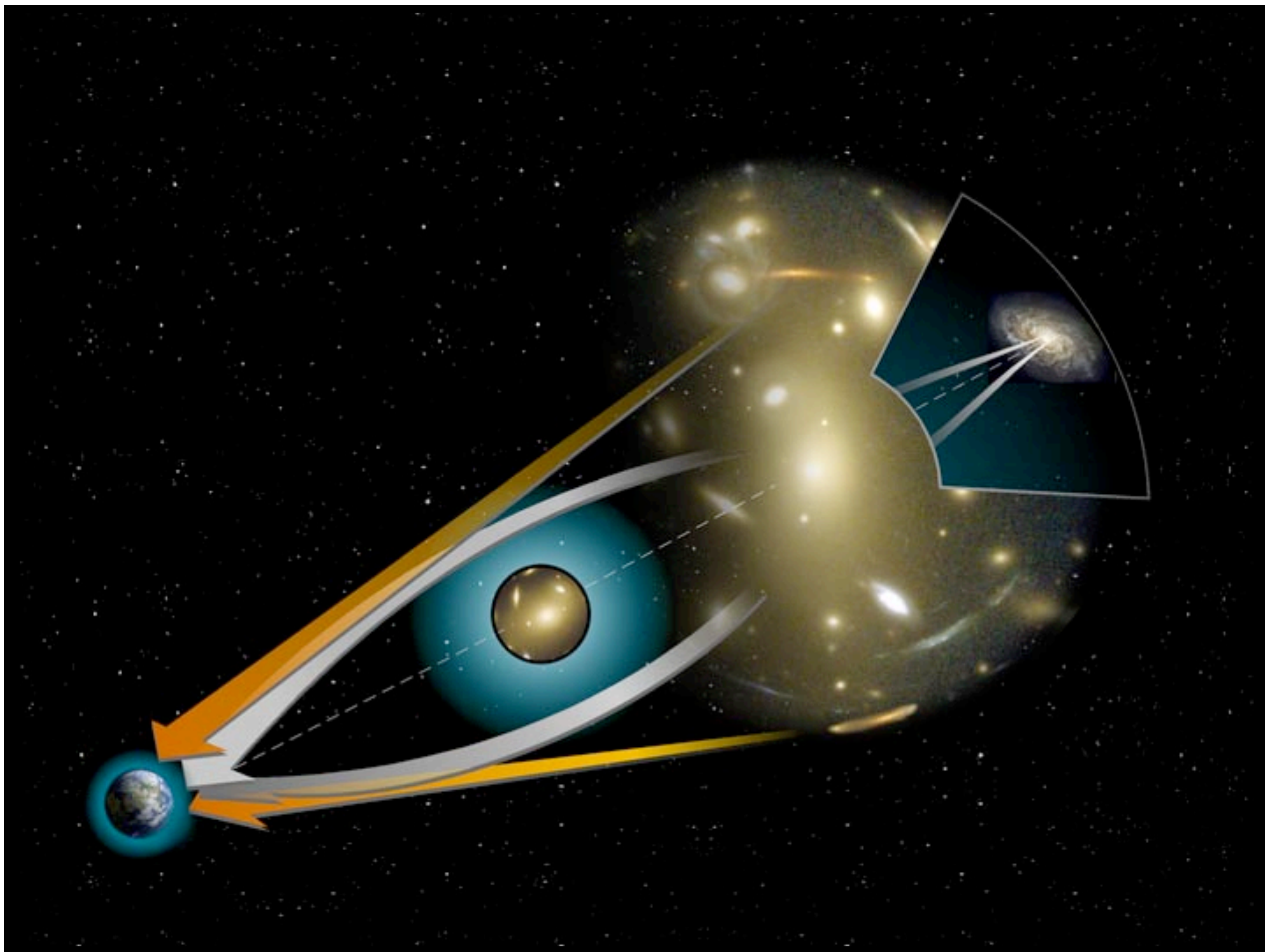








Mercurio!



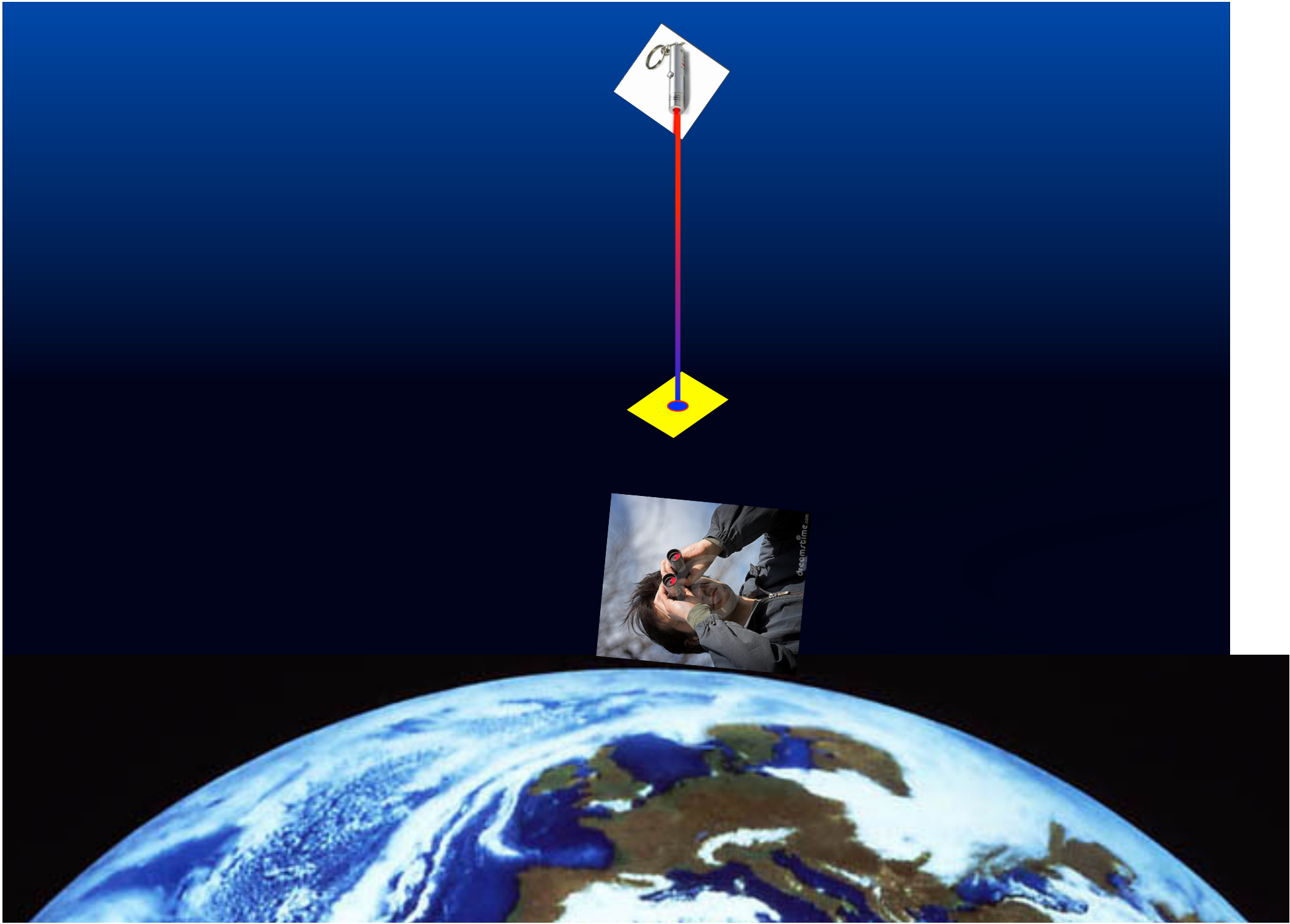


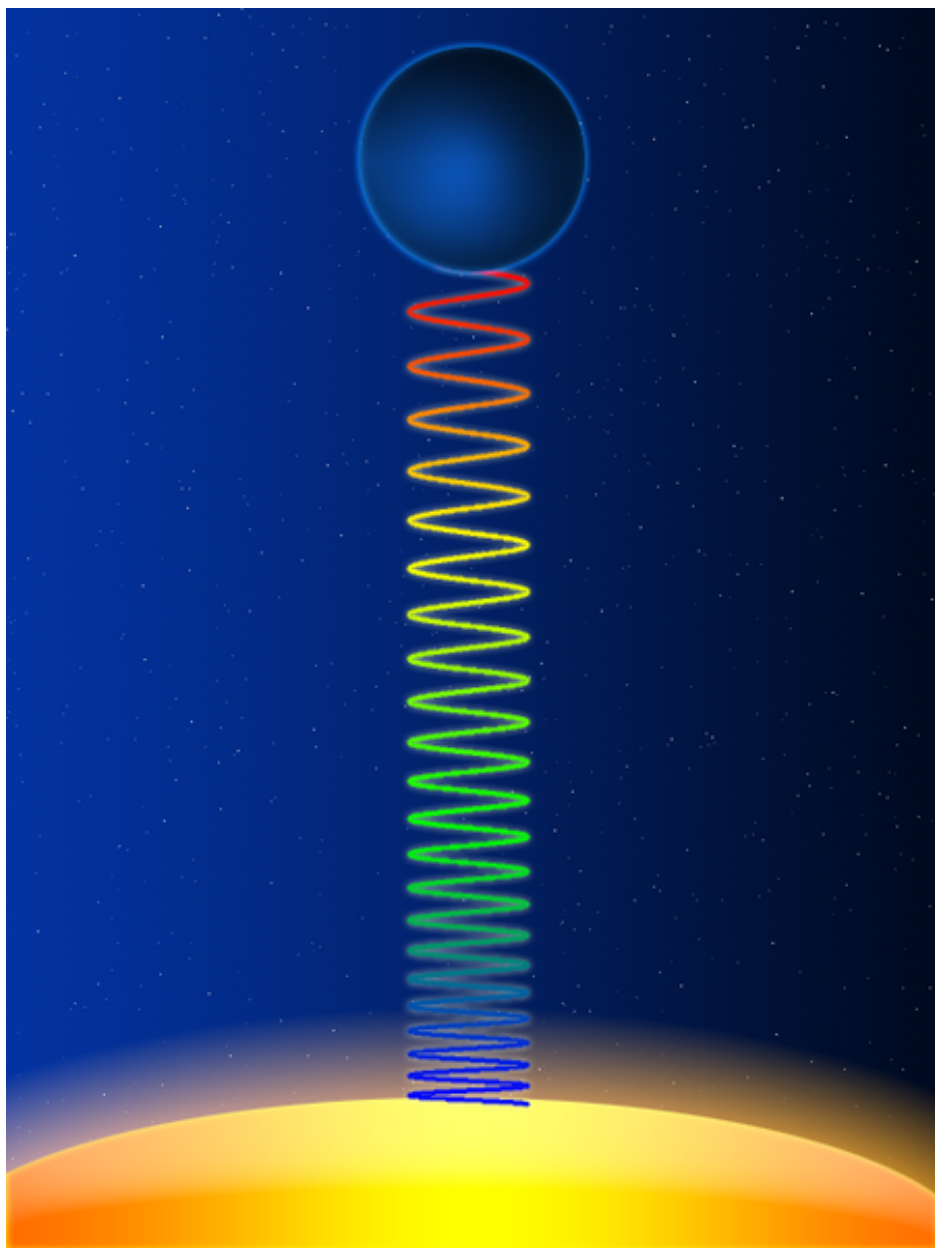
Gravitational Lens in Abell 2218

HST · WFPC2

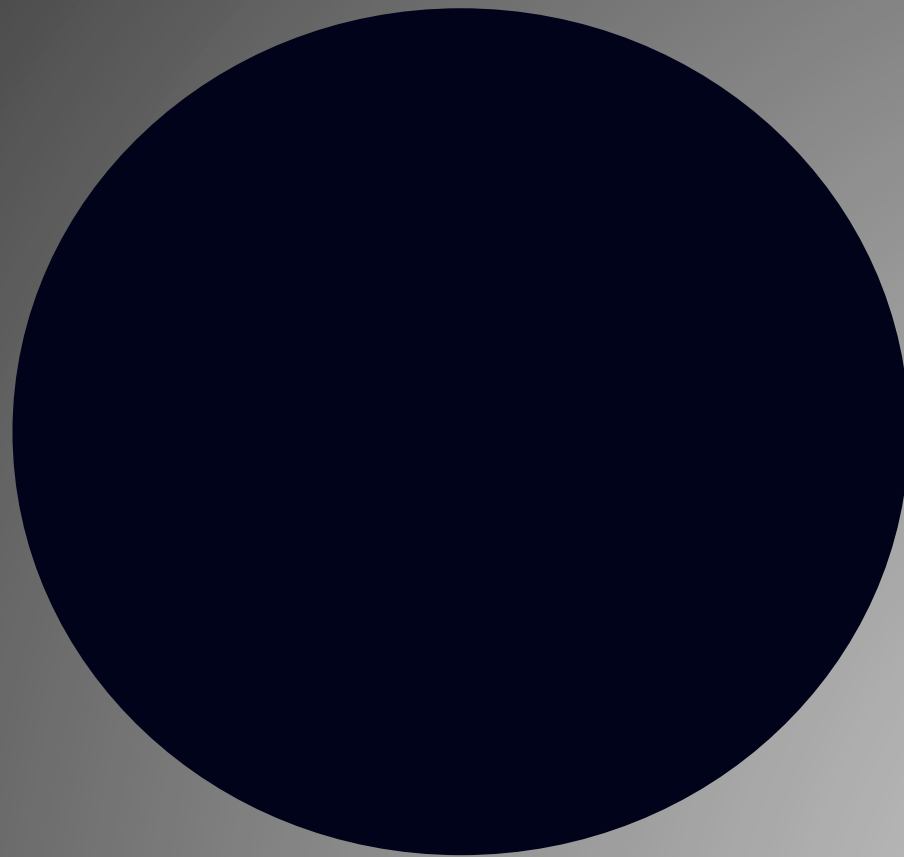
PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA







Buco. Nero.



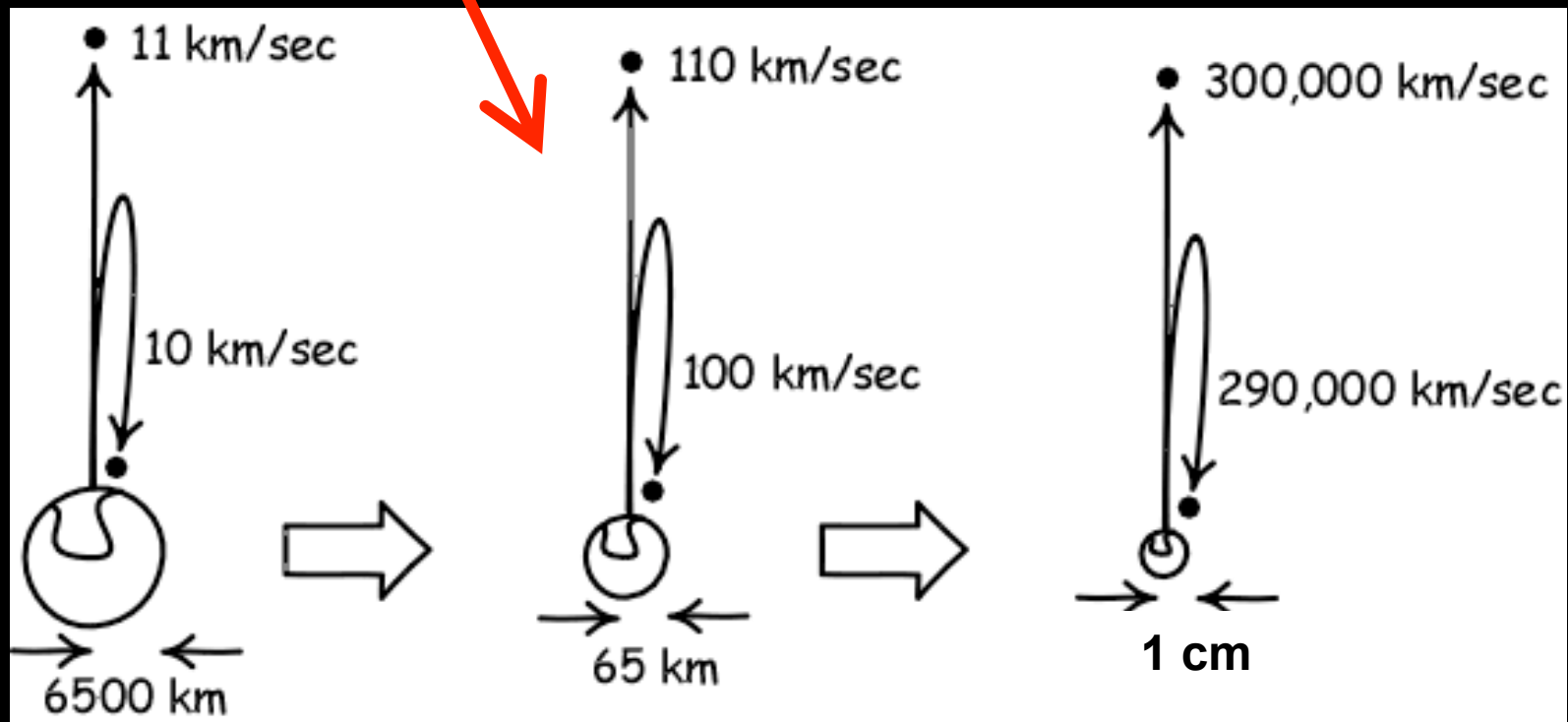
$$F_{\text{gravita}}' = \frac{GMm}{R^2}$$



$R=6500 \text{ km}$

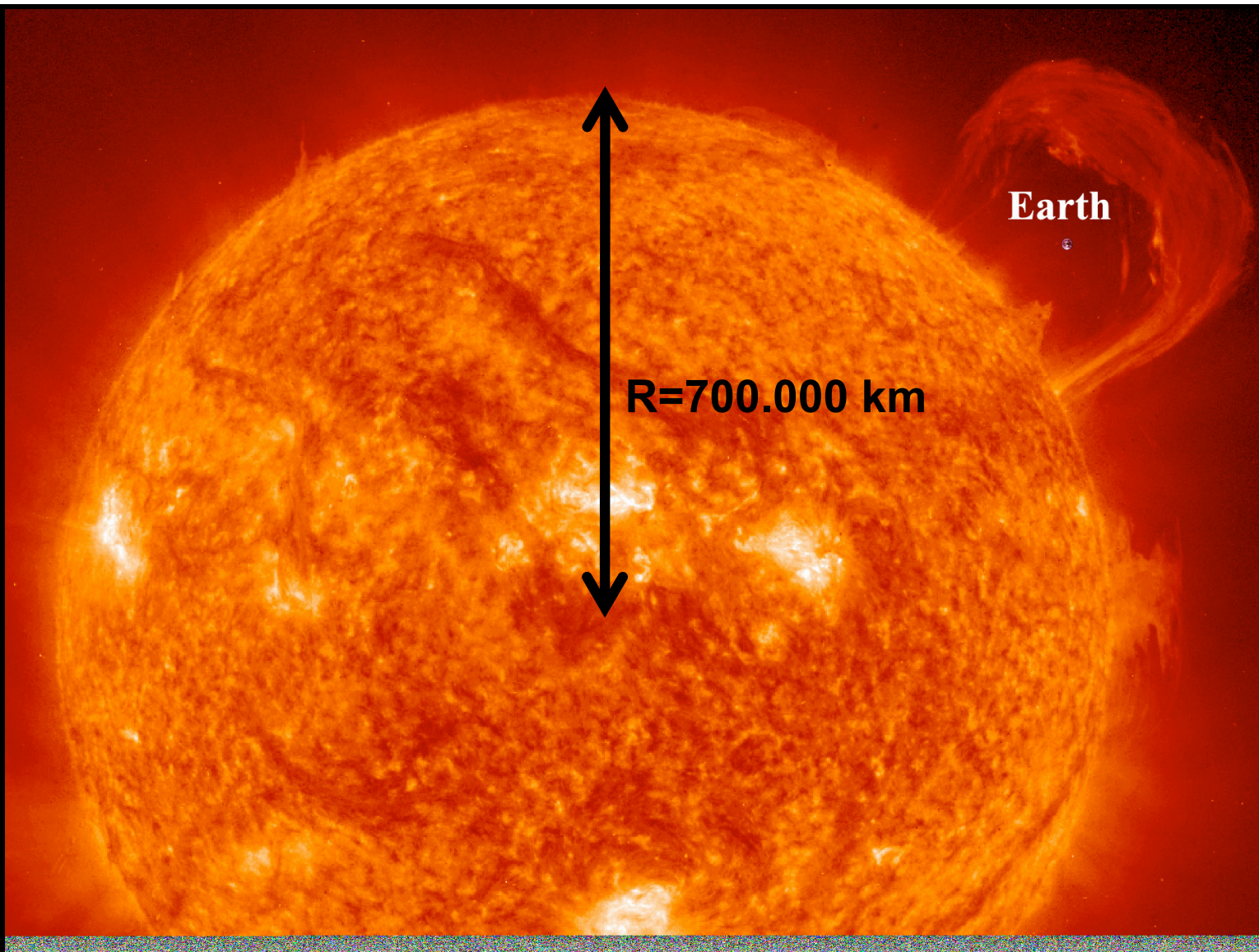
$$F_{\text{gravita}}' = \frac{GMm}{R^2}$$

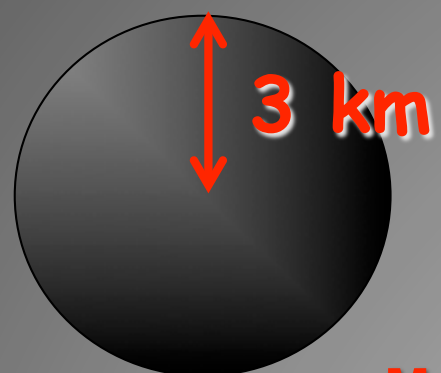
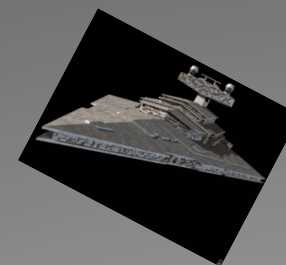
Newton!



Einstein

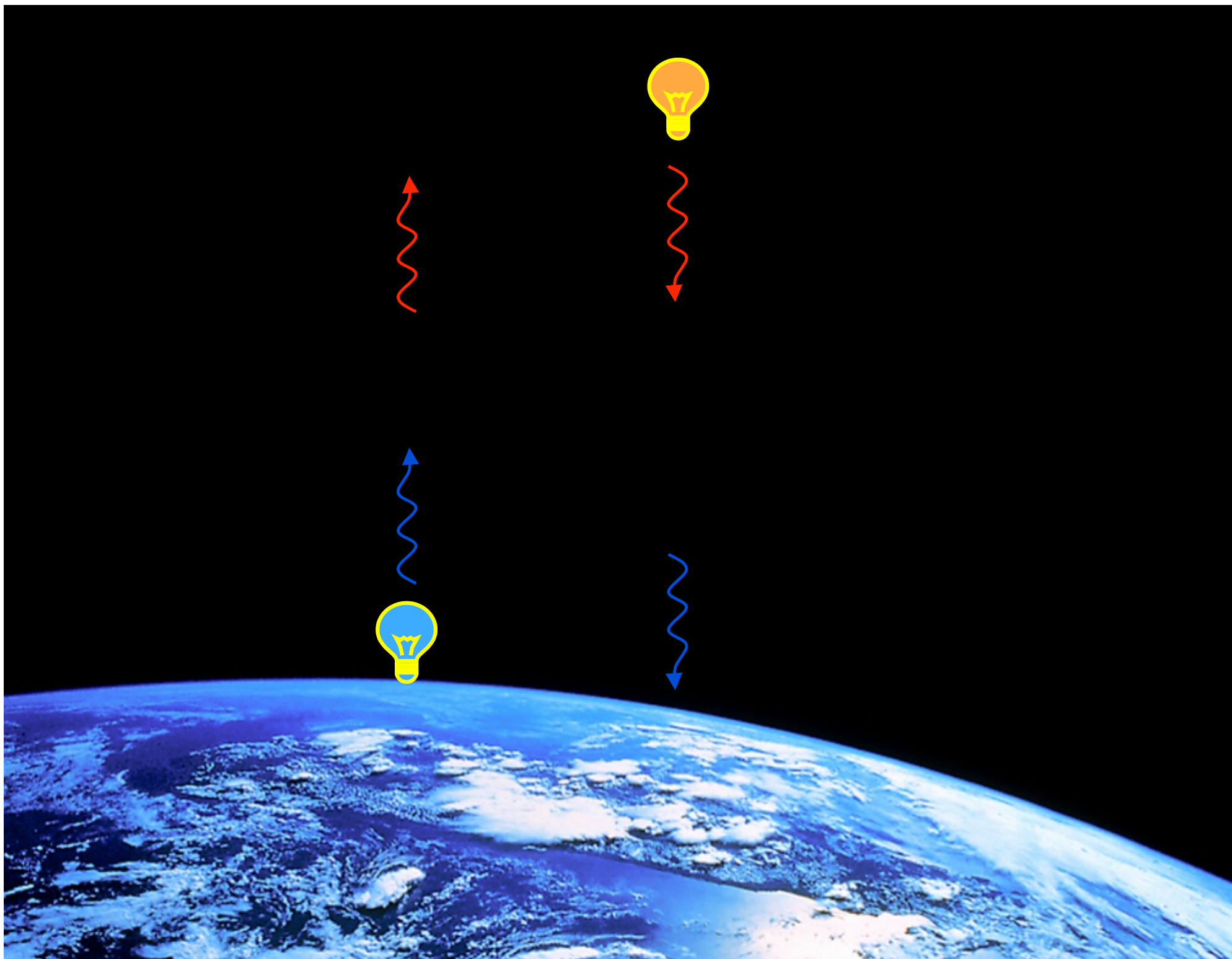






Mayday..
Mayday..

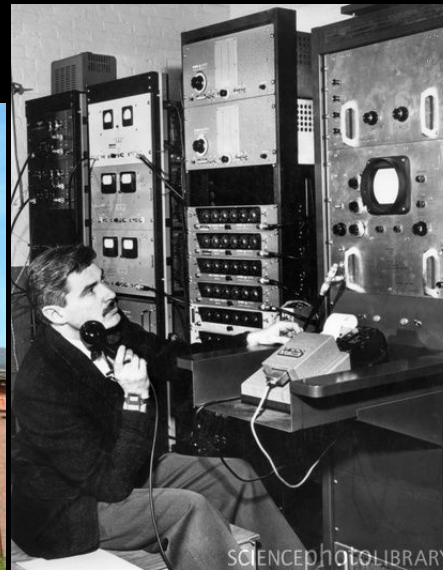
Il tempo e' una bestia strana



Pound & Rebka, 1959



Jefferson lab, Harvard Univ.

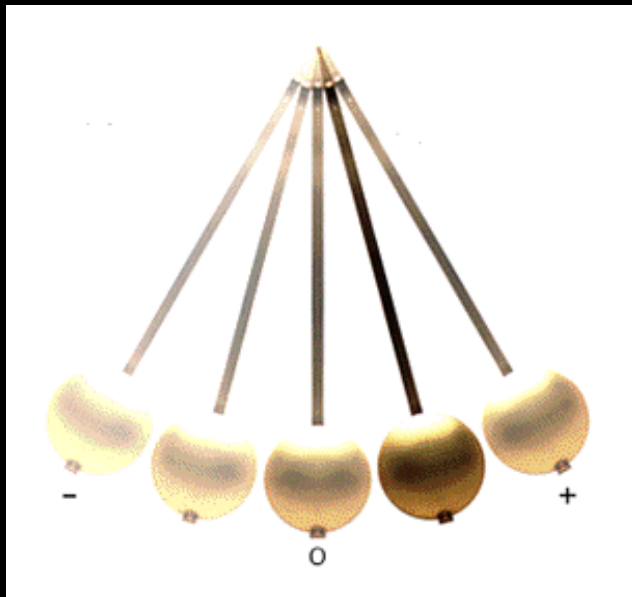
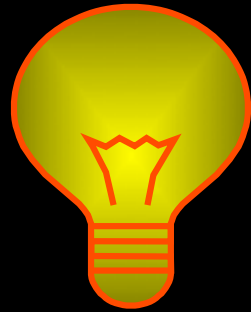


Robert Pound



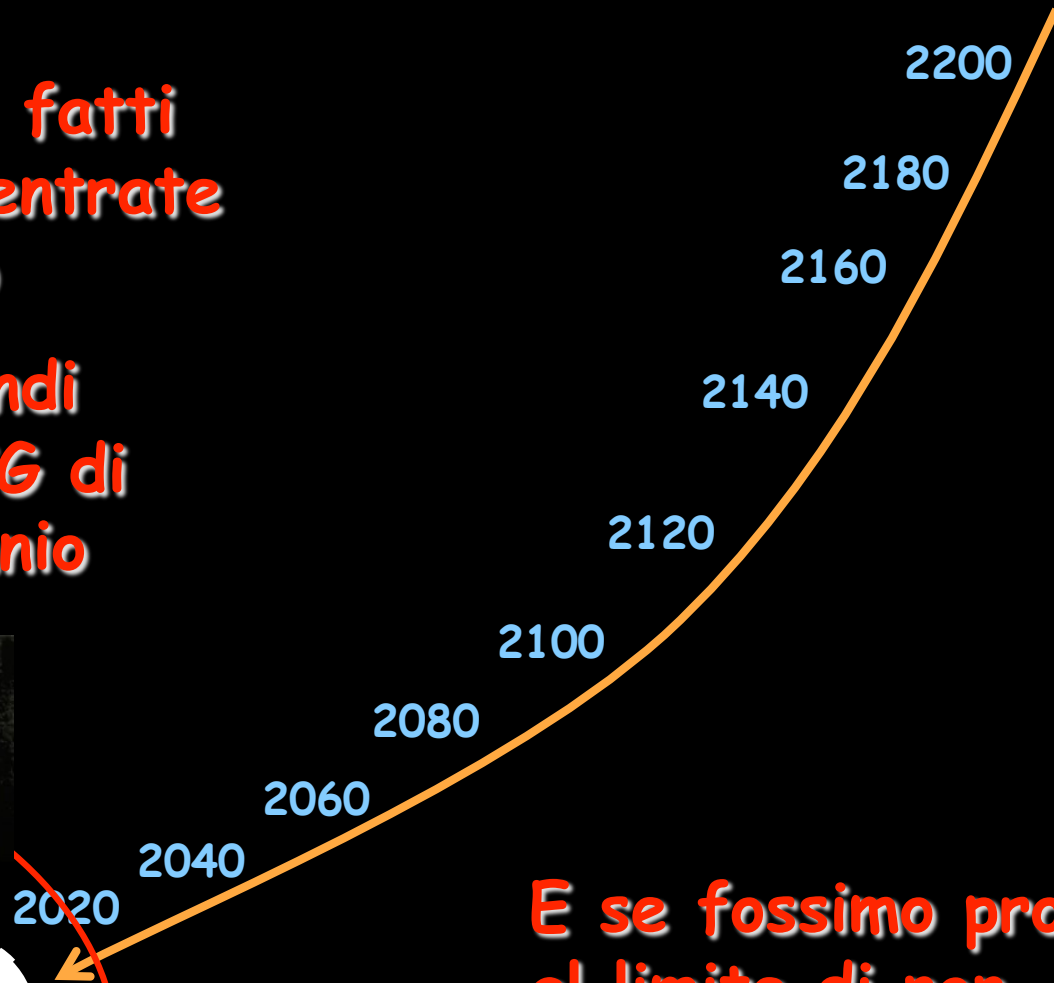
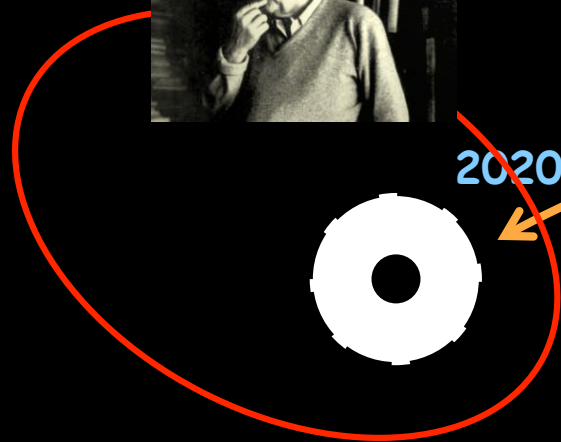
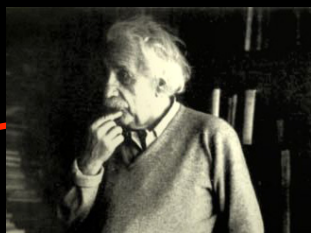
Glen Rebka





**Le notizie dei fatti
arrivano concentrate
in poco tempo**

**In pochi secondi
vedremmo i TG di
qualche millennio**



**E se fossimo proprio
al limite di non
ritorno? Vedremmo
TUTTO il tempo...**

**In una lettera di condoglianze alla famiglia del suo amico
Michele Besso (morto il 15 marzo 1955)**



In una lettera di condoglianze alla famiglia del suo amico Michele Besso (morto il 15 marzo 1955), Albert Einstein (che morirà il 18 aprile 1955) scrive:

“Ora Besso e’ dipartito da questo strano mondo, precedendomi di poco. Questo non significa niente. Gente come noi, che crede nella fisica, sa che la distinzione tra passato, presente e futuro e’ solo un’ostinata e persistente illusione”

"Now Besso has departed from this strange world a little ahead of me. That means nothing. People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion"

Grazie dell'attenzione!

Libri divulgativi:

Difficoltà ↓	*	<i>I misteri del tempo</i>	Paul Davies
	*	<i>Questo bizzarro Universo</i>	Dennis Sciama
	*	<i>$E=mc^2$</i>	David Bodanis
	*	<i>In search of the big bang</i>	John Gribbin
	*	<i>The extravagant Universe</i>	Robert Kirshner
	*	<i>The accelerating Universe</i>	Mario Livio
	*	<i>The inflationary Universe</i>	Alan Guth
	**	<i>Nelle pieghe del tempo</i>	George Smoot
	**	<i>Il mistero della massa mancante nell'universo</i>	Lawrence Krauss
	**	<i>Le origini dell'Universo</i>	John Barrow
	**	<i>I signori del tempo</i>	John Boslough
	**	<i>Cosmologia moderna</i>	Dennis Sciama
	**	<i>The stuff of the Universe</i>	J.Gribbin & M.Rees
	***	<i>L'Universo elegante</i>	Brian Greene
	***	<i>The structure of the Universe</i>	Jayant Narlikar
	***	<i>La trama del cosmo</i>	Brian Greene

