

IL DOPPIO SENSO della SCIENZA

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Ricerca astronomica/fisica



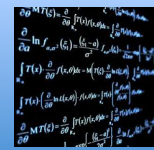
SCOPERTA

$$\begin{aligned}\frac{\partial}{\partial \theta} M T(\xi) &= \frac{\partial}{\partial \theta} \int_{\mathbb{R}^n} T(x) f(x, \theta) dx = \int_{\mathbb{R}^n} \frac{\partial}{\partial \theta} T(x) f(x, \theta) dx \\ \frac{\partial}{\partial a} \ln f_{a, \sigma^2}(\xi) &= \frac{(\xi - a)}{\sigma^2} f_{a, \sigma^2}(\xi) - \frac{1}{\sqrt{2\pi\sigma^2}} \left[\frac{\xi - a}{\sigma^2} \right] \\ \int_{\mathbb{R}^n} T(x) \cdot \frac{\partial}{\partial \theta} f(x, \theta) dx &= M \left(T(x) \cdot \frac{\partial}{\partial \theta} \ln f(x, \theta) \right) = \int_{\mathbb{R}^n} T(x) \left(\frac{\partial}{\partial \theta} \ln f(x, \theta) \right) f(x, \theta) dx \\ \int_{\mathbb{R}^n} T(x) \left(\frac{\partial}{\partial \theta} \ln f(x, \theta) \right) \cdot f(x, \theta) dx &= \int_{\mathbb{R}^n} T(x) \left(\frac{\partial}{\partial \theta} f(x, \theta) \right) dx \\ \frac{\partial}{\partial \theta} M T(\xi) &= \frac{\partial}{\partial \theta} \int_{\mathbb{R}^n} T(x) f(x, \theta) dx = \int_{\mathbb{R}^n} T(x) \left(\frac{\partial}{\partial \theta} f(x, \theta) \right) dx \\ &= \int_{\mathbb{R}^n} T(x) \left(\frac{(\xi - a)}{\sigma^2} \right) f(x, \theta) dx = \frac{\partial}{\partial a} \ln f_{a, \sigma^2}(\xi) \cdot M T(\xi)\end{aligned}$$





La teoria: Newton



1) Principio di inerzia

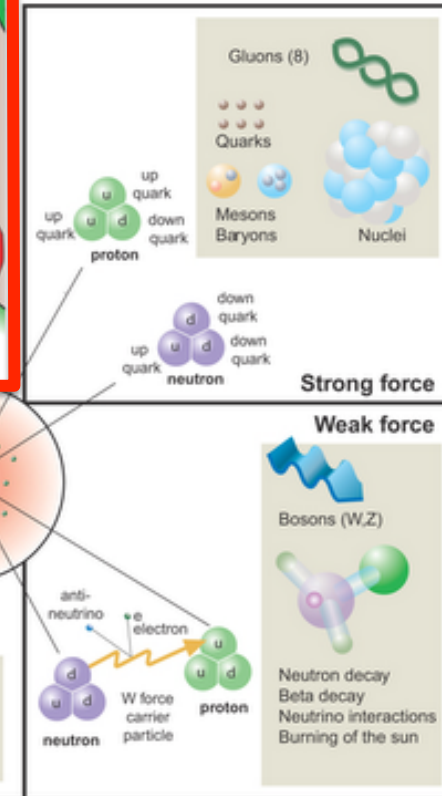
$$2) F = ma$$

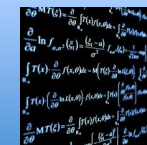
3) Azione e reazione

$$F = G \frac{M_1 M_2}{R^2}$$



Gravity Force





Marzo – Giugno 1905 ANNUS MIRABILIS

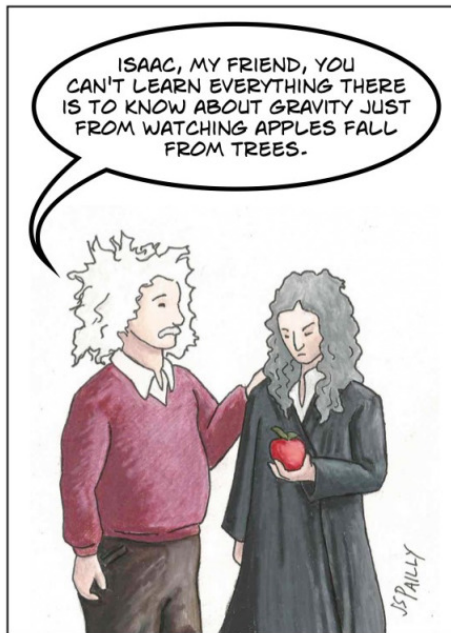
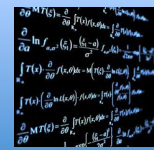
1. “Il primo ha per oggetto la radiazione e le proprieta' energetiche della luce ed e' decisamente rivoluzionario (La luce e' fatta di particelle fotoni ...)
2. Il secondo e' una determinazione delle dimensioni effettive degli atomi
3. Il terzo dimostra che corpi delle dimensioni di 1/1000 di mm in sospensione nei liquidi sono soggetti a un moto casuale generato dall'agitazione termica (moto browniano)
4. Il quarto e' soltanto un abbozzo iniziale ed e' un'elettrodinamica dei corpi in movimento che fa un ricorso ad una modificazione della teoria dello spazio tempo (relativita')”



14/03/1879



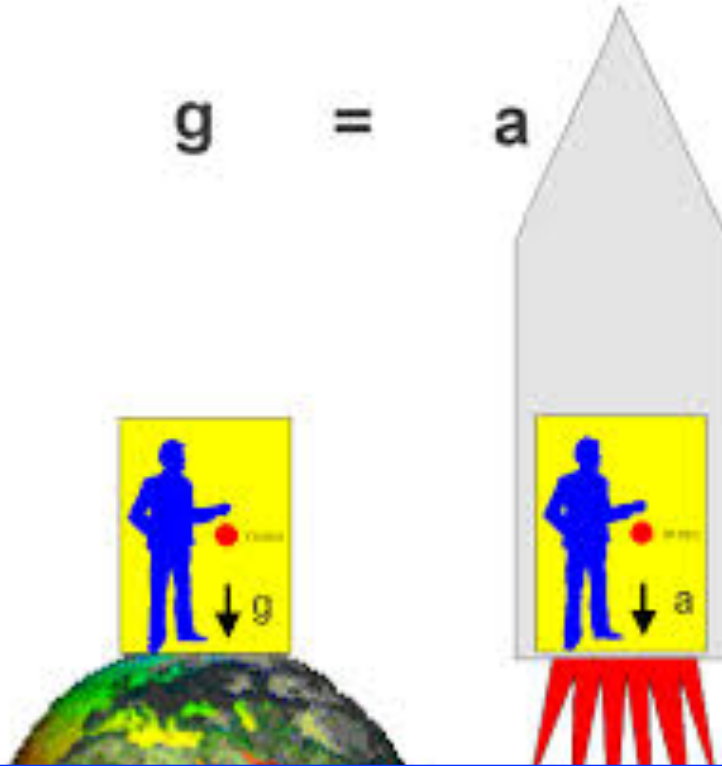
La teoria: verso la relativita' generale



1907... "il pensiero piu' felice della mia vita" = "se una persona cade liberamente non sentirà il proprio peso"

Esperimento Mentale [Gedankenexperiment]

$$g = a$$



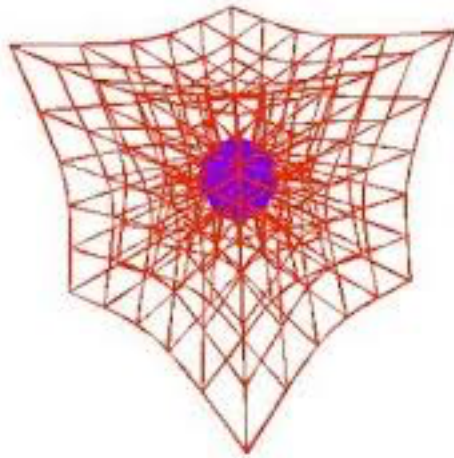
Principio di Equivalenza: gli effetti locali della gravita' (**g**) e dell'accelerazione (**a**) sono equivalenti. Quindi **gravita'** e **accelerazione** sono manifestazione dello stesso fenomeno



La teoria: massa = curvatura spaziotempo

$$\begin{aligned} \frac{\partial}{\partial x^\mu} \left(\frac{\partial}{\partial x^\nu} \right) &= \frac{\partial^2}{\partial x^\mu \partial x^\nu} \\ \frac{\partial}{\partial x^\mu} \left(\frac{\partial}{\partial x^\nu} \right) &= \frac{\partial^2}{\partial x^\mu \partial x^\nu} \\ \frac{\partial}{\partial x^\mu} \left(\frac{\partial}{\partial x^\nu} \right) &= \frac{\partial^2}{\partial x^\mu \partial x^\nu} \end{aligned}$$

1907 ... 1915 verso la relativita' generale



This three-dimensional grid gives a better idea of what curved space-time might look like than the two-dimensional analogies do.



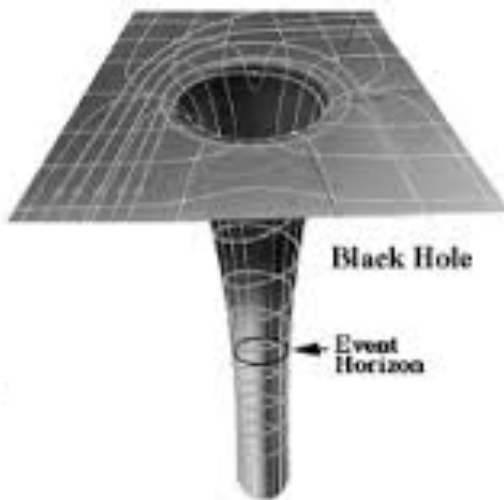
Sun



White Dwarf



Neutron Star



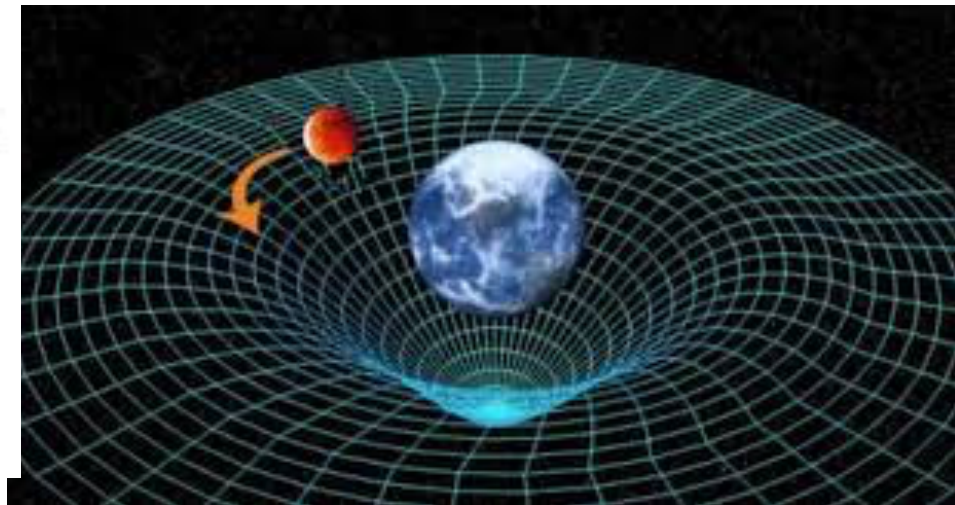
Black Hole

Event Horizon

Massa

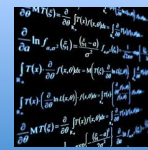
Curvatura dello spazio tempo

Movimento dei corpi





La teoria: equazione di campo di Einstein



1907 ... 1915 verso la relatività generale

25 Novembre 1915
(4° lezione Accademia
Prussiana delle Scienze)

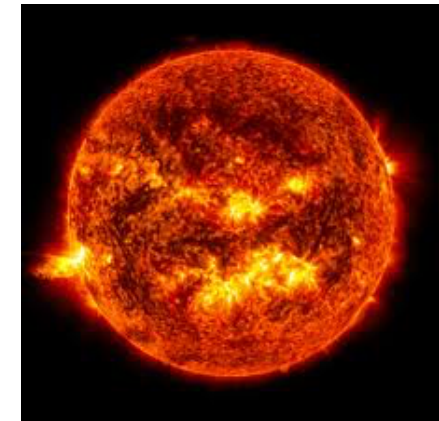
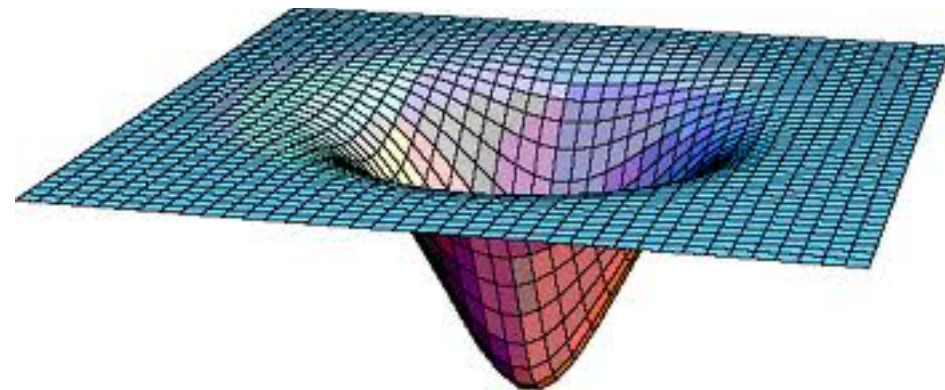
“Le equazioni di campo della gravitazione”

Massa

Curvatura dello
spazio tempo

Movimento
dei corpi

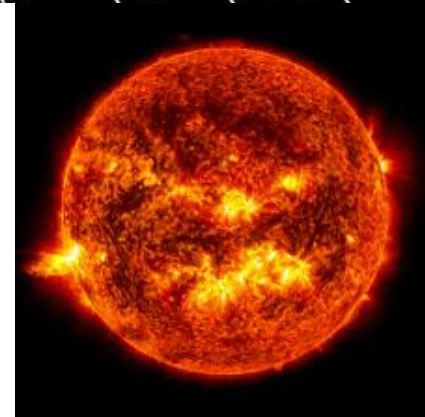
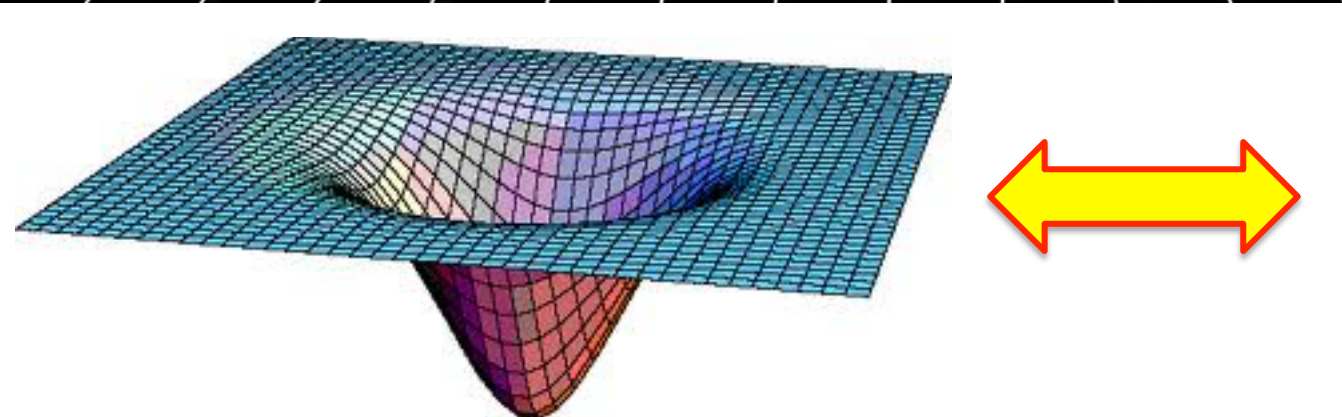
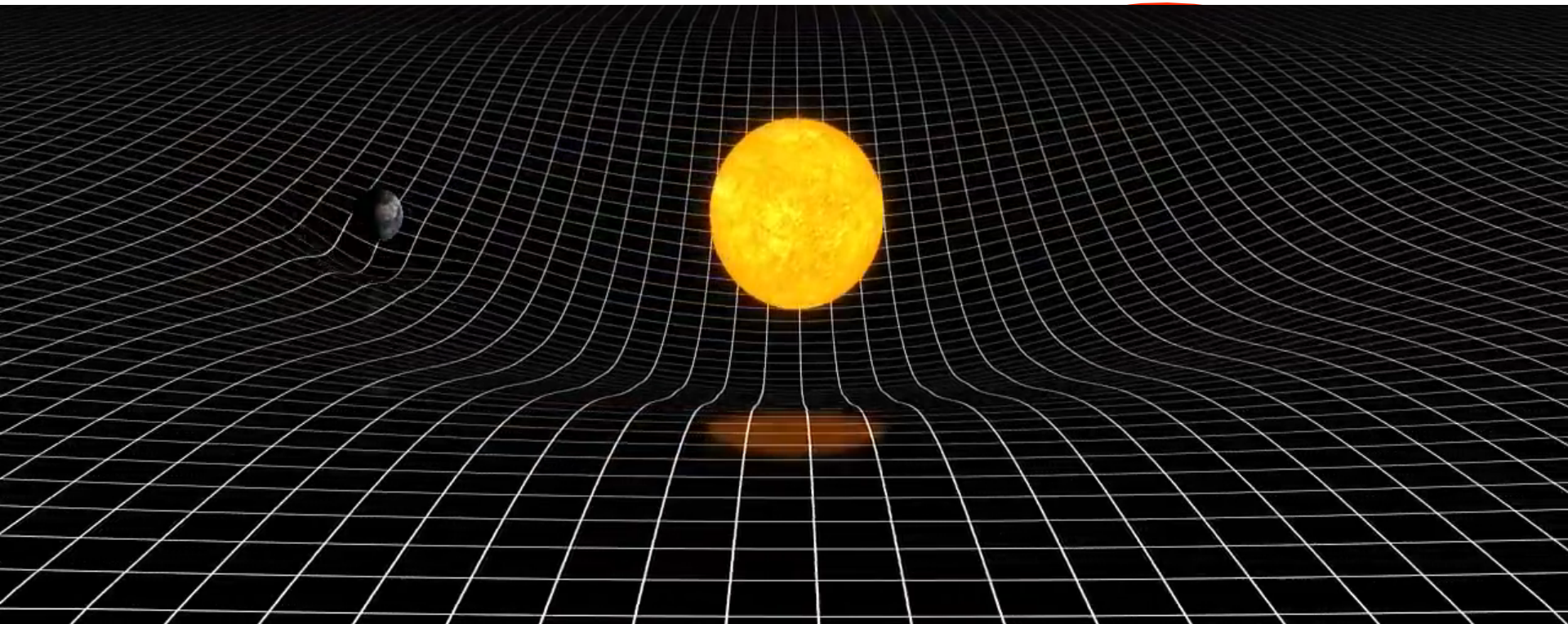
$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = \frac{8\pi G}{c^2} T_{\mu\nu}$$





La teoria: GR

$$\frac{\partial}{\partial t} \left(\frac{1}{\sqrt{-g}} \frac{\partial}{\partial t} \left(\sqrt{-g} \frac{\partial \phi}{\partial t} \right) \right) = \frac{1}{\sqrt{-g}} \frac{\partial}{\partial x^i} \left(\sqrt{-g} \frac{\partial \phi}{\partial x^i} \right) + \frac{\partial^2 \phi}{\partial x^i \partial x^i}$$

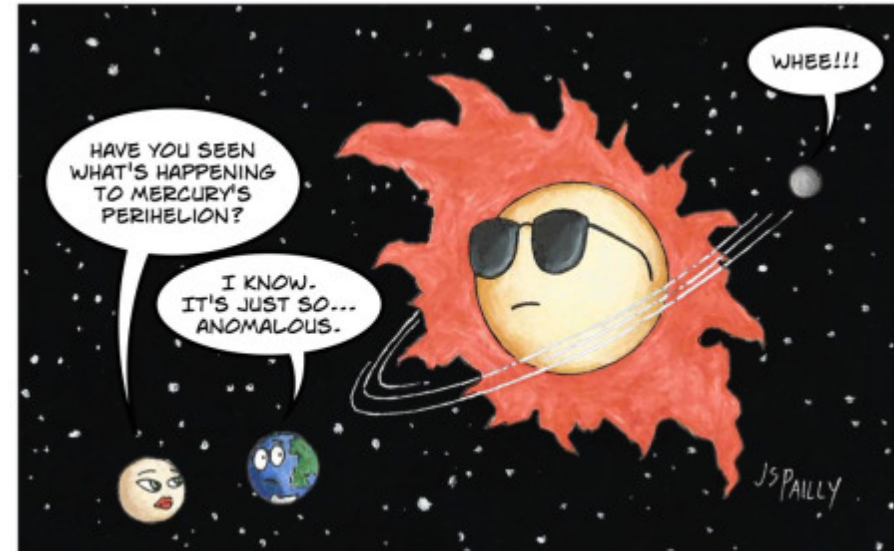
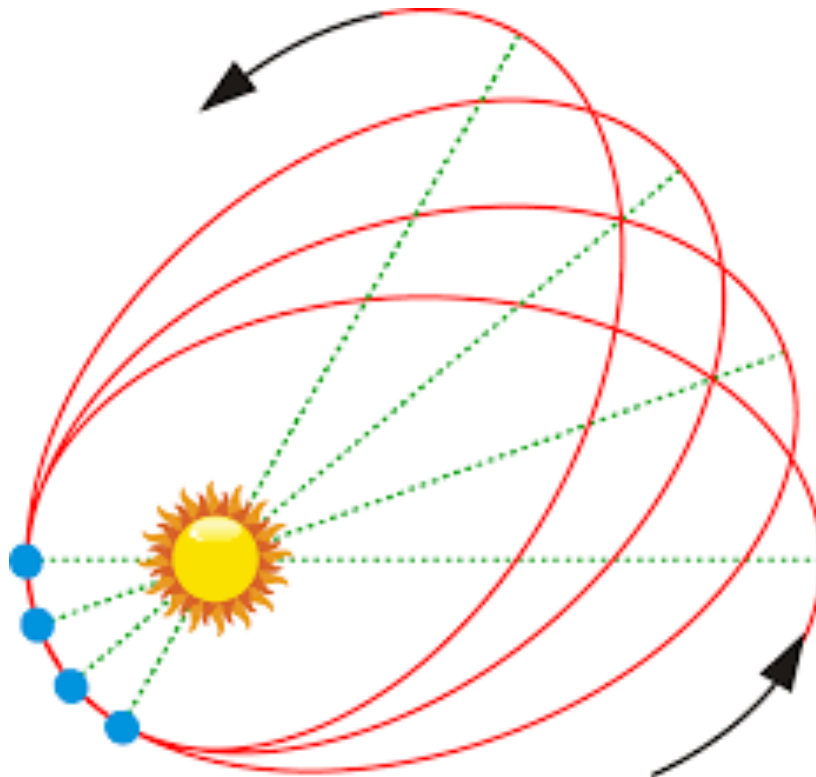




Le prove classiche (1)

$$\begin{aligned} \frac{d}{dt} \left(\frac{1}{r} \right) &= -\frac{1}{r^2} \frac{dr}{dt} \\ \frac{d}{dt} \left(\frac{1}{r} \right) &= -\frac{1}{r^2} \frac{dr}{dt} \\ \frac{d}{dt} \left(\frac{1}{r} \right) &= -\frac{1}{r^2} \frac{dr}{dt} \\ \frac{d}{dt} \left(\frac{1}{r} \right) &= -\frac{1}{r^2} \frac{dr}{dt} \end{aligned}$$

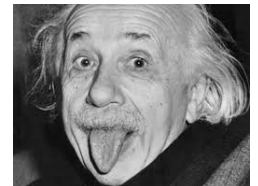
Precessione dell'orbita di mercurio

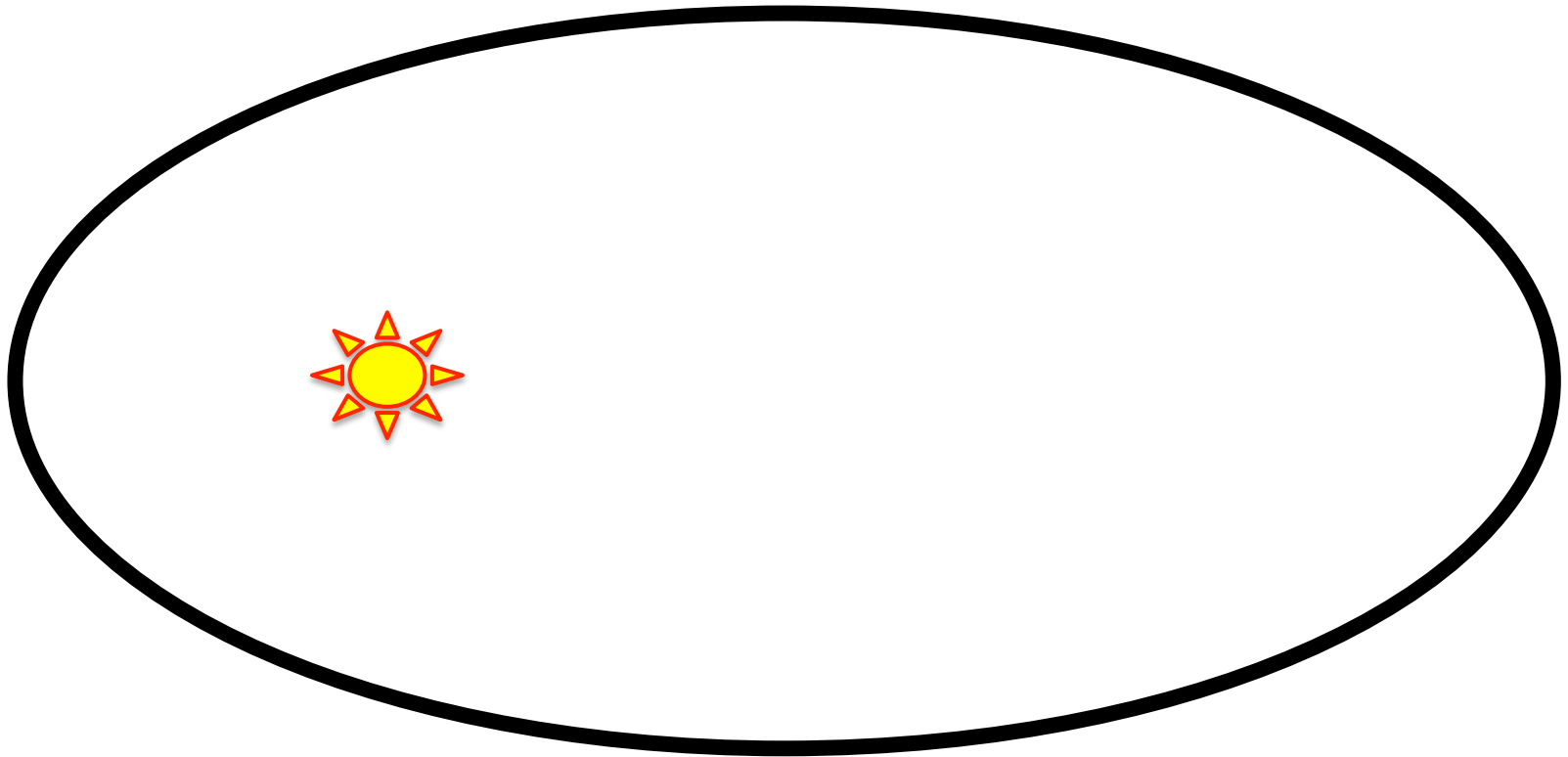


5600 arsec / 100 yr

5557 arsec / 100 yr

43 arsec / 100 yr

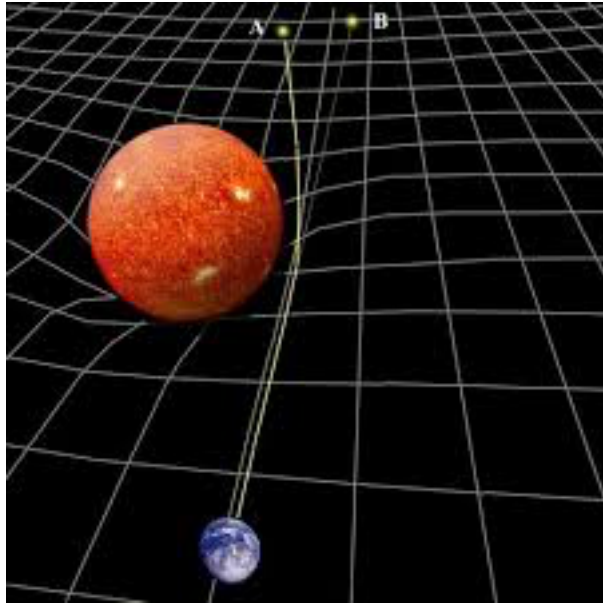




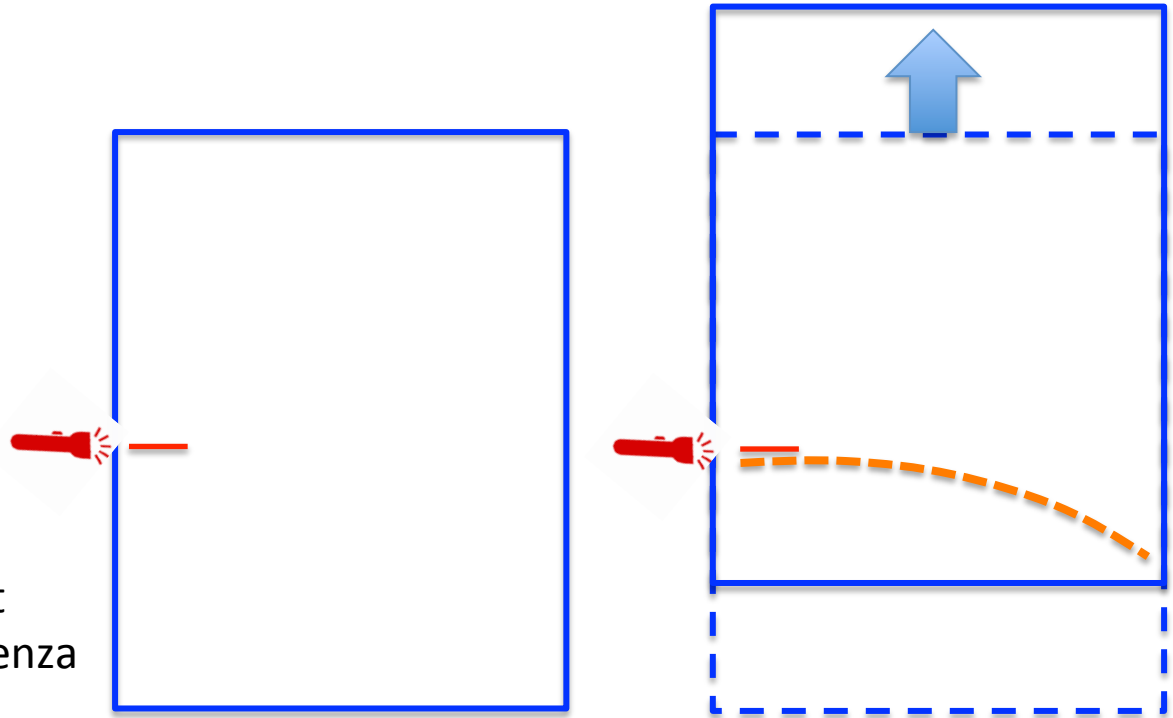


Le prove classiche (2)

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{q}} \right) - \frac{\partial L}{\partial q} &= 0 \\ \frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{q}} \right) &= \frac{\partial L}{\partial q} \\ \frac{\partial}{\partial t} \left(\frac{\partial L}{\partial \dot{q}} \right) &= \frac{\partial L}{\partial q} \end{aligned}$$



La curvatura della luce



Gedankenexperiment
+ principio di equivalenza

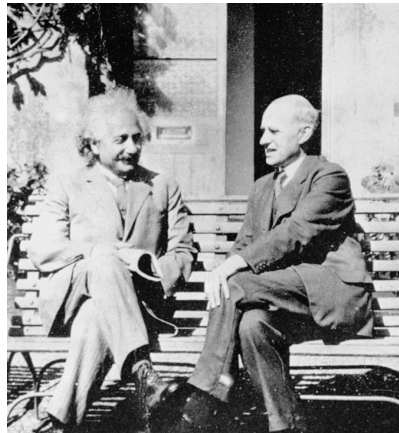
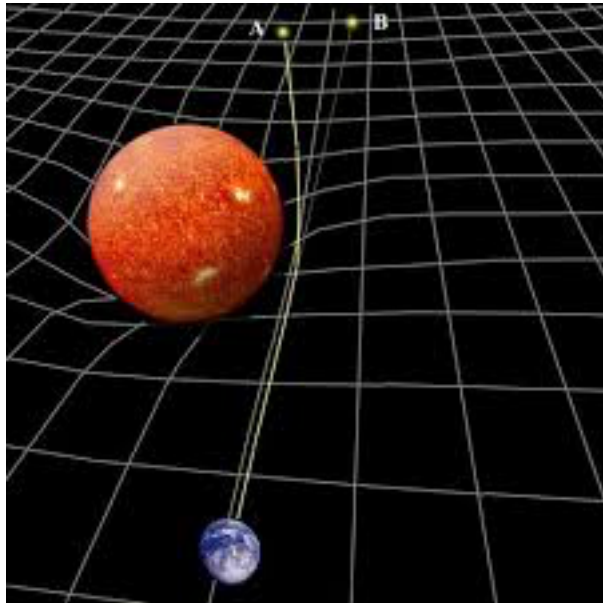


“Do not Bodies act upon Light at a distance and by their action bend its Rays;
and is not this action ... strongest at the least distance?”
[Opticks, I. Newton]



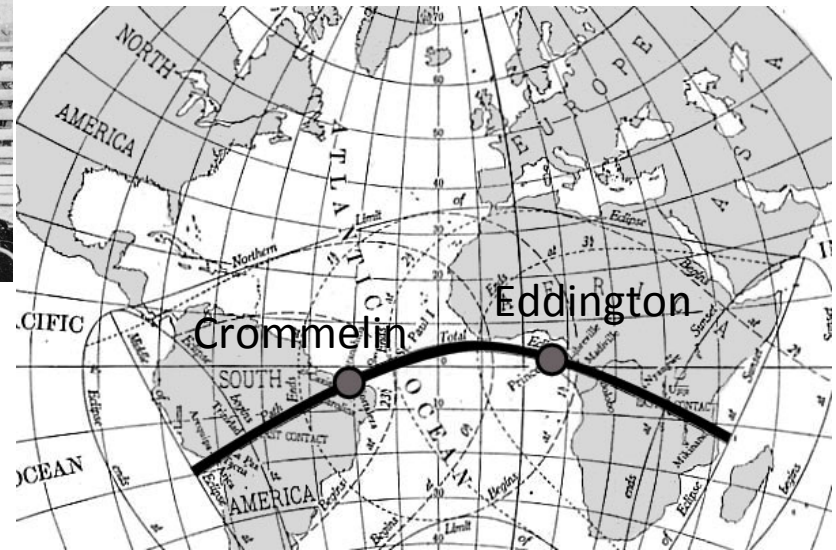
Le prove classiche (2)

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{\rho} \frac{\partial \rho}{\partial t} \right) &= \frac{1}{\rho} \frac{\partial^2 \rho}{\partial t^2} \\ \frac{\partial}{\partial t} \left(\frac{1}{\rho} \frac{\partial \rho}{\partial t} \right) &= \frac{1}{\rho} \frac{\partial^2 \rho}{\partial t^2} \\ \frac{\partial}{\partial t} \left(\frac{1}{\rho} \frac{\partial \rho}{\partial t} \right) &= \frac{1}{\rho} \frac{\partial^2 \rho}{\partial t^2} \end{aligned}$$



29 Maggio 1919

Eclissi di sole ... con dietro le Hyadi



£100 attrezzatura £1000 spedizione

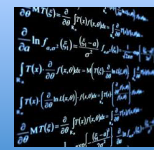
Crommelin: "Eclipse splendid"

Eddington: "Through Cloud. Hopefully"



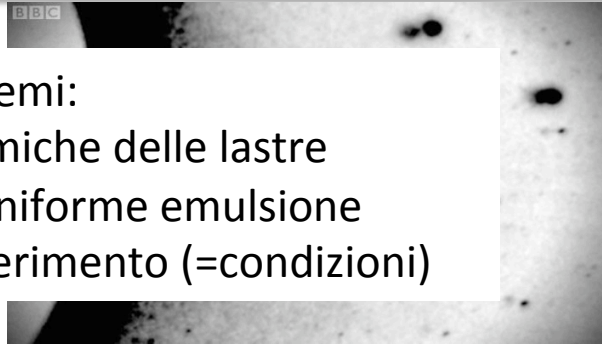


Le prove classiche (2)

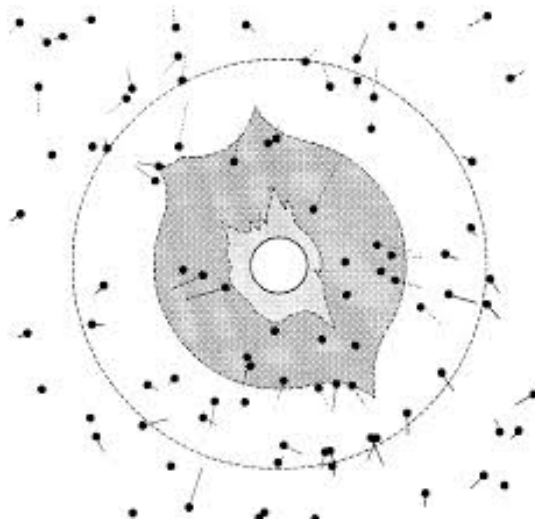


Distorsioni e problemi:

- 1) Distorsioni termiche delle lastre
- 2) Risposta non uniforme emulsione
- 3) Immagini di riferimento (=condizioni)



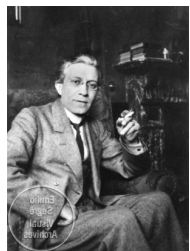
6/10/1919 Royal Society meeting



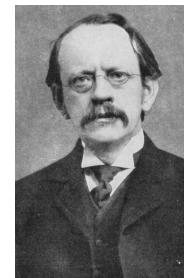
7 stars $\rightarrow 1.98 \pm 0.16''$



5 stars $\rightarrow 1.61 \pm 0.40''$



"We owe it to that great man (Newton) to proceed very carefully in modifying or retouching his Law of Gravitation" (L. Silbersten)



"This is the most important result obtained in connection with the theory of gravitation since Newton's days" (J. J. Thomson)



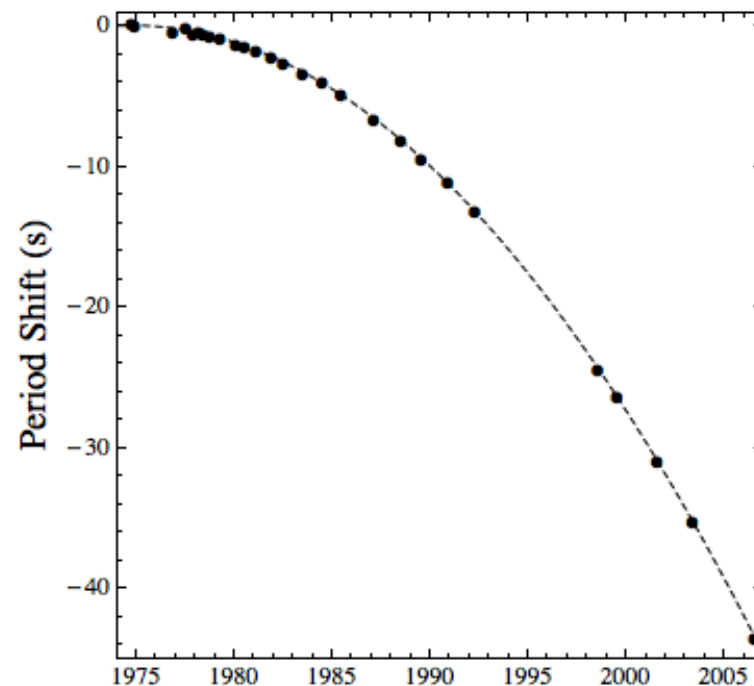
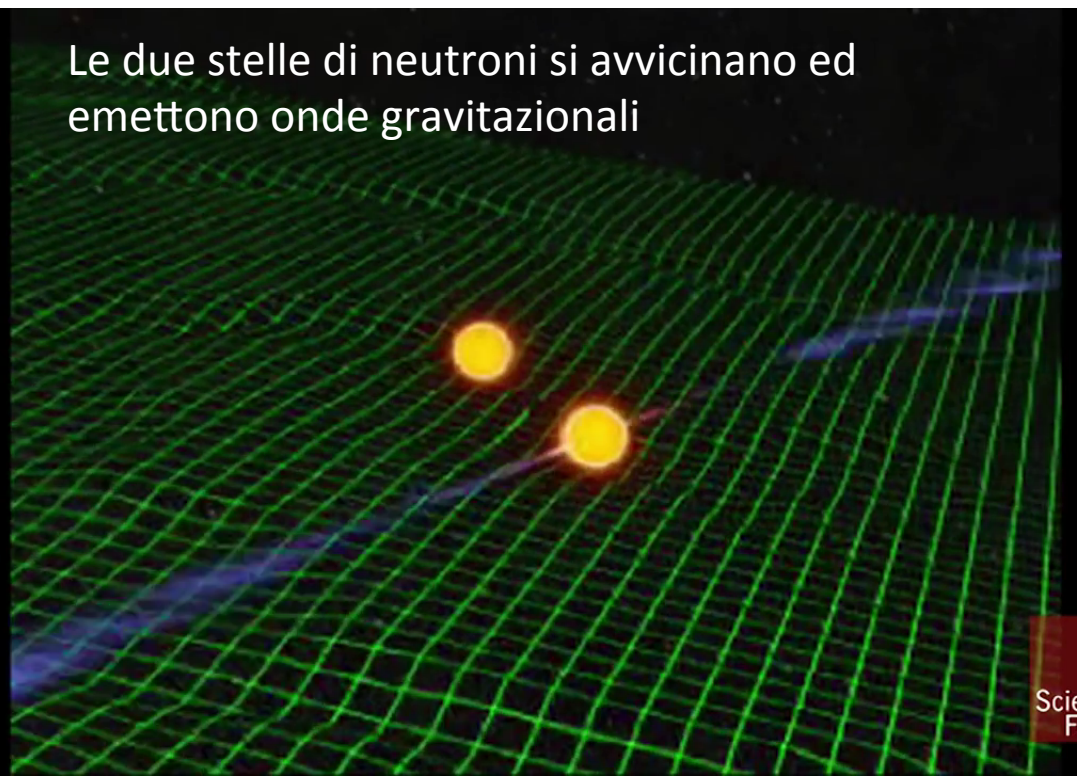
Le prove moderne: test in campo forte

$$\frac{\partial}{\partial x} \left(\frac{\partial \phi}{\partial x} \right) = \frac{\partial}{\partial x} \left(\frac{\partial \phi}{\partial x} \right) = \frac{\partial}{\partial x} \left(\frac{\partial \phi}{\partial x} \right)$$

Hulse & Taylor (NP 1993)



Le due stelle di neutroni si avvicinano ed emettono onde gravitazionali



Le misure (pallini) sono perfettamente sulla linea che e' quanto previsto dalla teoria della relativita' generale.

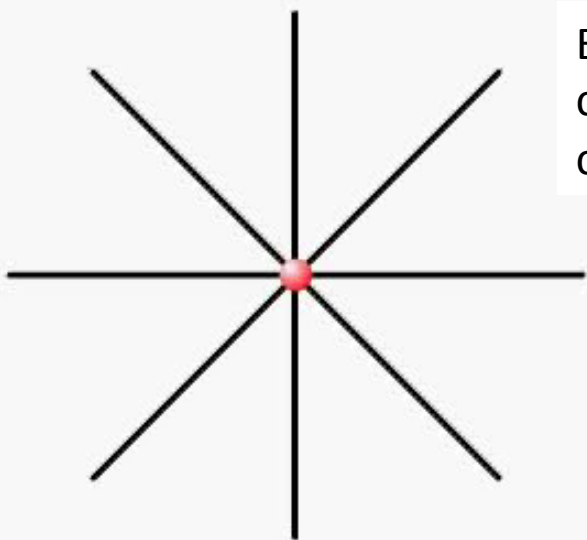


Cosa è un'onda?

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \psi}{\partial t} \right) &= \frac{1}{c} \frac{\partial^2 \psi}{\partial t^2} \\ \frac{\partial}{\partial x} \left(\frac{1}{c} \frac{\partial \psi}{\partial x} \right) &= \frac{1}{c} \frac{\partial^2 \psi}{\partial x^2} \\ \frac{\partial}{\partial y} \left(\frac{1}{c} \frac{\partial \psi}{\partial y} \right) &= \frac{1}{c} \frac{\partial^2 \psi}{\partial y^2} \\ \frac{\partial}{\partial z} \left(\frac{1}{c} \frac{\partial \psi}{\partial z} \right) &= \frac{1}{c} \frac{\partial^2 \psi}{\partial z^2} \end{aligned}$$



The Electric Field of an Oscillating Charge



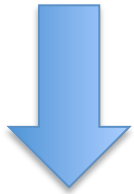
Elettromagnetismo ci dice che una carica elettrica che oscilla produce una perturbazione (onda) nel campo elettrico.



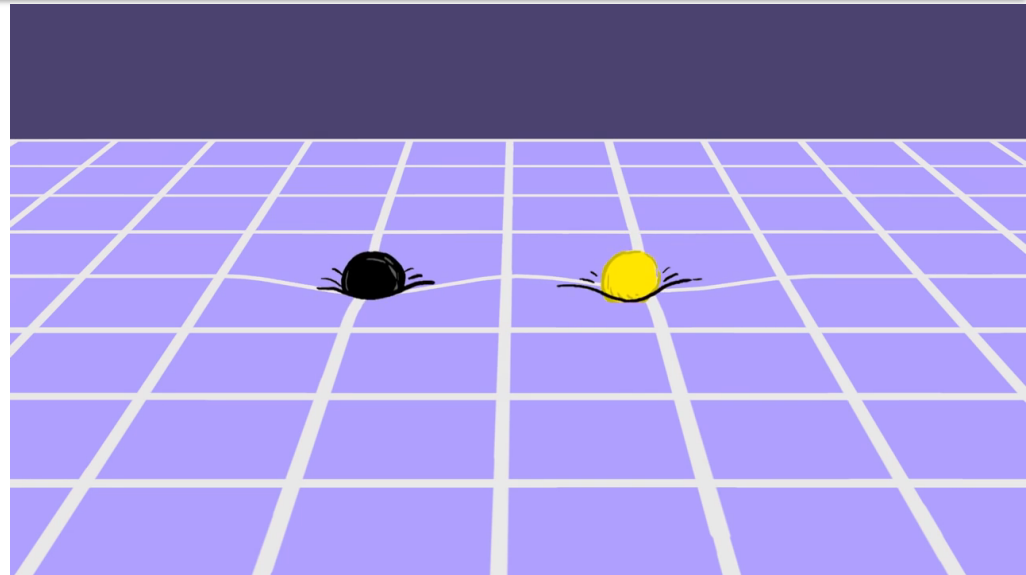
Onde Gravitazionali

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{\sqrt{-g}} \frac{\partial}{\partial t} \left(\sqrt{-g} \frac{\partial \phi}{\partial t} \right) \right) &= \frac{1}{\sqrt{-g}} \frac{\partial}{\partial t} \left(\sqrt{-g} \frac{\partial \phi}{\partial t} \right) \\ &= \frac{1}{\sqrt{-g}} \frac{\partial}{\partial t} \left(\sqrt{-g} \frac{\partial \phi}{\partial t} \right) \\ &= \frac{1}{\sqrt{-g}} \frac{\partial}{\partial t} \left(\sqrt{-g} \frac{\partial \phi}{\partial t} \right) \end{aligned}$$

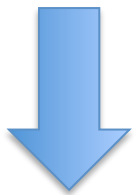
Masse ferme



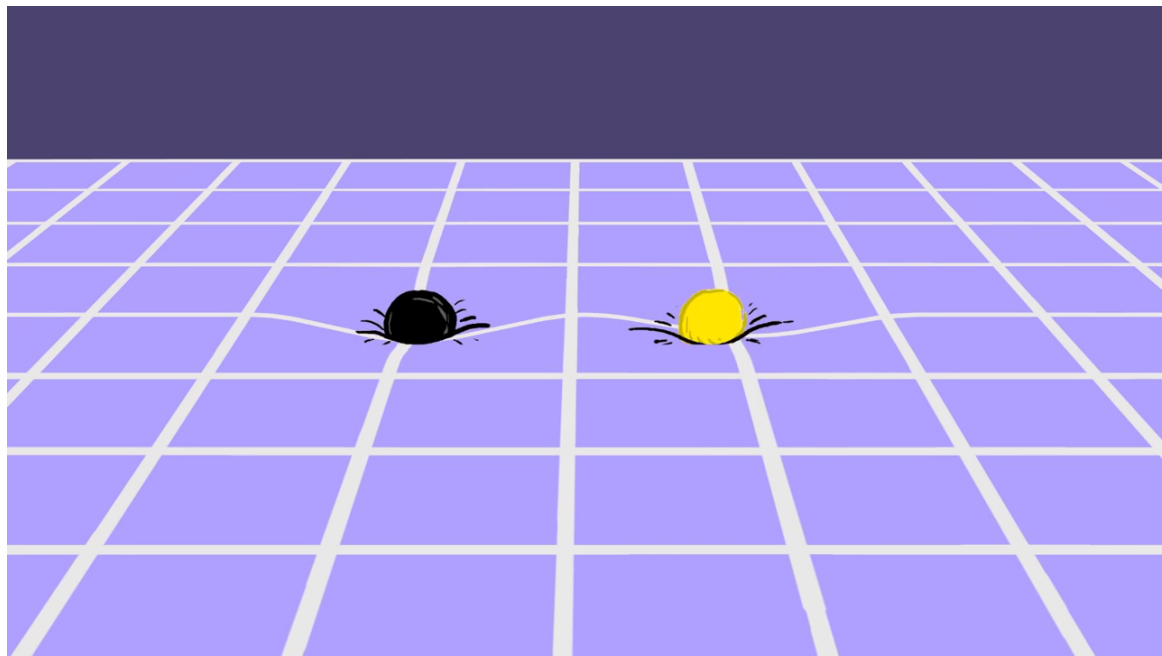
Curvatura dello spazio-tempo



Masse in movimento



Perturbazione della curvatura
dello spazio tempo
ONDE GRAVITAZIONALI (GW)



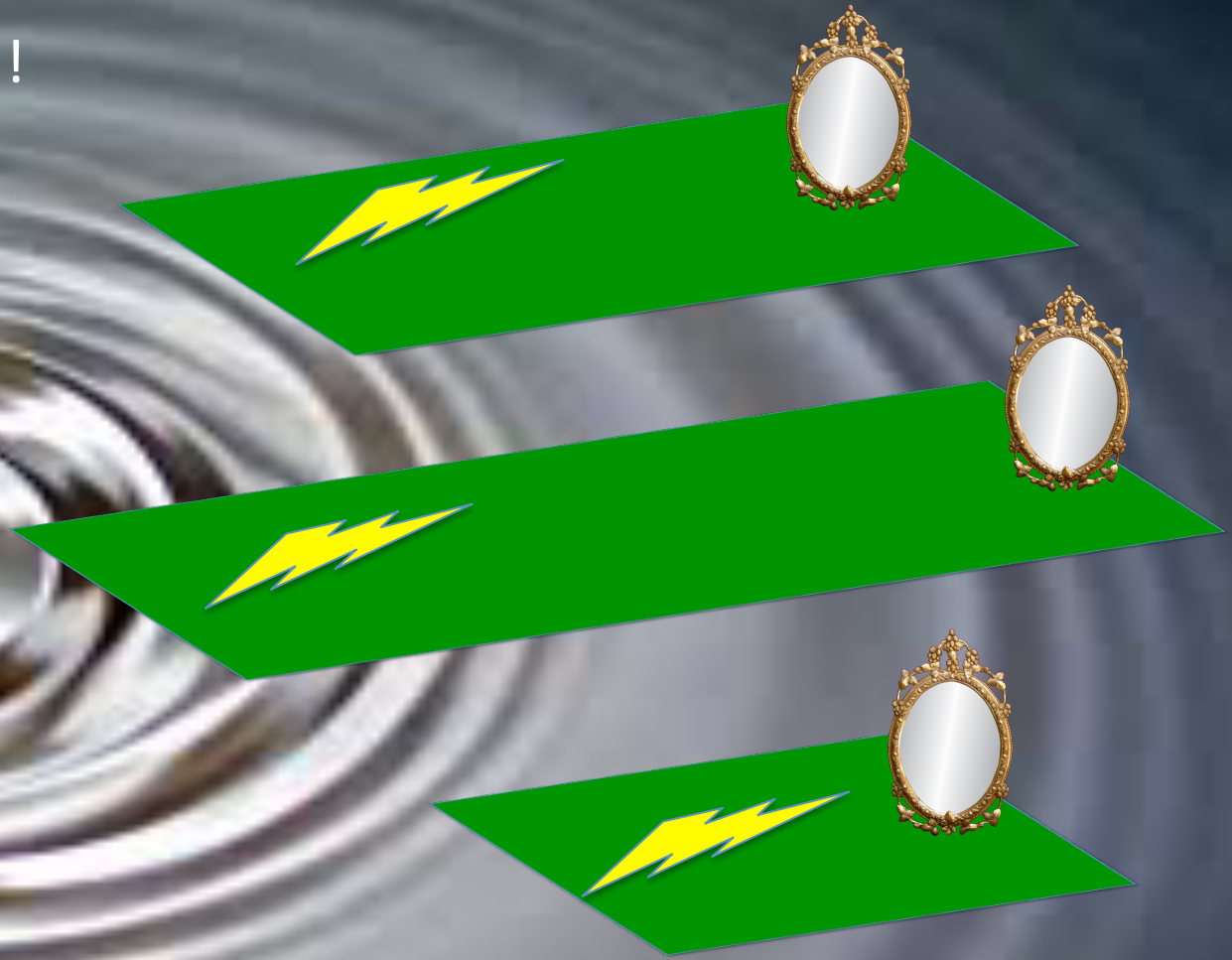


Onde Gravitazionali

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{2} \rho v^2 \right) &= \frac{1}{2} \rho \frac{d}{dt} \left(v^2 \right) \\ &= \frac{1}{2} \rho \left(\frac{dv_x}{dt} v_x + \frac{dv_y}{dt} v_y + \frac{dv_z}{dt} v_z \right) \\ &= \frac{1}{2} \rho \left(\frac{d}{dt} \left(\frac{1}{2} v^2 \right) \right) \\ &= \frac{1}{2} \rho \left(\frac{d}{dt} \left(\frac{1}{2} v^2 \right) \right) \end{aligned}$$

Come si rivelano le onde gravitazionali?

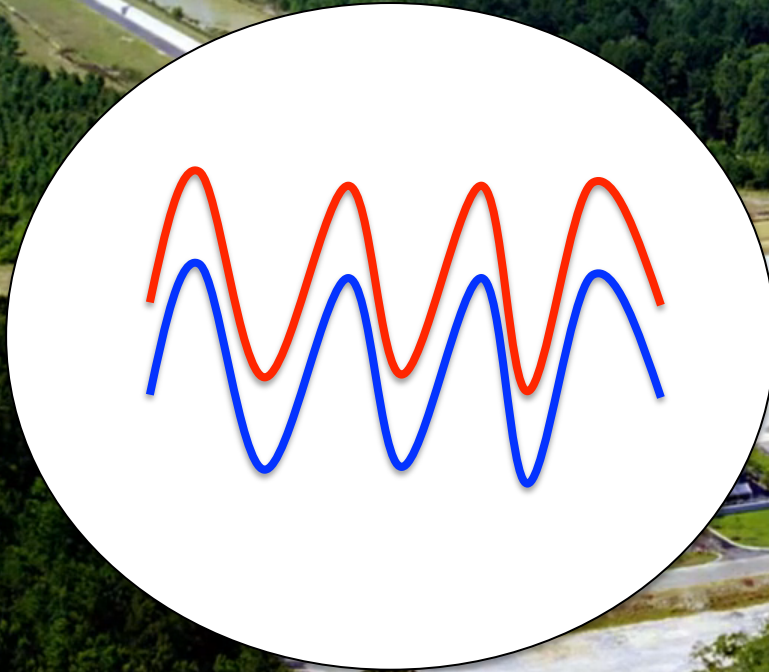
Misurare con la luce!!





Onde Gravitazionali

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) &= \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) \\ \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) &= \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) \\ \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) &= \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) \\ \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) &= \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) \\ \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) &= \frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} \right) \end{aligned}$$



LIGO = LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

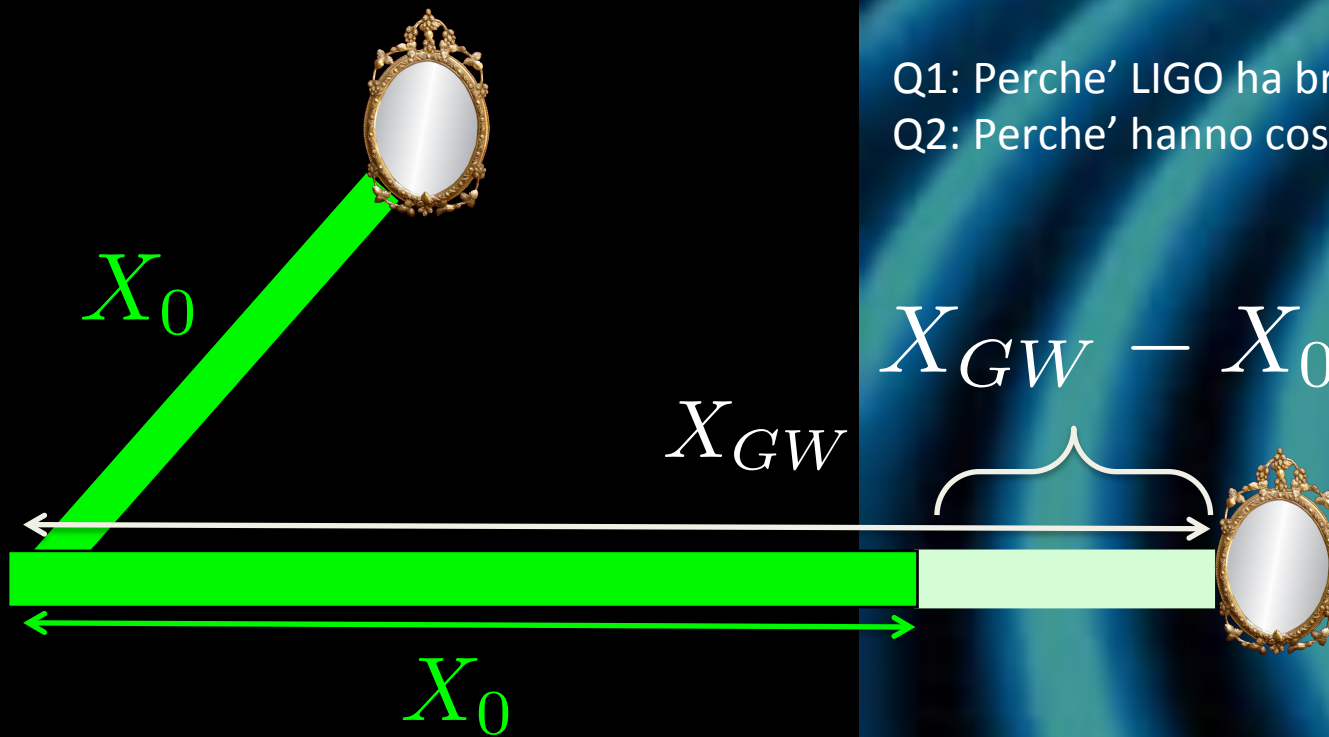


Cosa si misura in pratica

$$\frac{\partial}{\partial t} \ln \left(\frac{f_{\text{obs}}(t)}{f_{\text{emit}}(t)} \right) = \frac{1}{f_{\text{obs}}(t)} \frac{df_{\text{obs}}(t)}{dt} - \frac{1}{f_{\text{emit}}(t)} \frac{df_{\text{emit}}(t)}{dt}$$
$$\left[\frac{1}{f_{\text{obs}}(t)} \frac{df_{\text{obs}}(t)}{dt} - \frac{1}{f_{\text{emit}}(t)} \frac{df_{\text{emit}}(t)}{dt} \right] = \frac{1}{f_{\text{obs}}(t)} \frac{df_{\text{obs}}(t)}{dt} - \frac{1}{f_{\text{emit}}(t)} \frac{df_{\text{emit}}(t)}{dt}$$
$$\frac{\partial}{\partial t} \ln \left(\frac{f_{\text{obs}}(t)}{f_{\text{emit}}(t)} \right) = \frac{1}{f_{\text{obs}}(t)} \frac{df_{\text{obs}}(t)}{dt} - \frac{1}{f_{\text{emit}}(t)} \frac{df_{\text{emit}}(t)}{dt}$$

Q1: Perché LIGO ha bracci lunghi Km?

Q2: Perché hanno costruito 2 LIGO?



$$h = \frac{X_{GW} - X_0}{X_0}$$

$$h \approx 10^{-21}$$

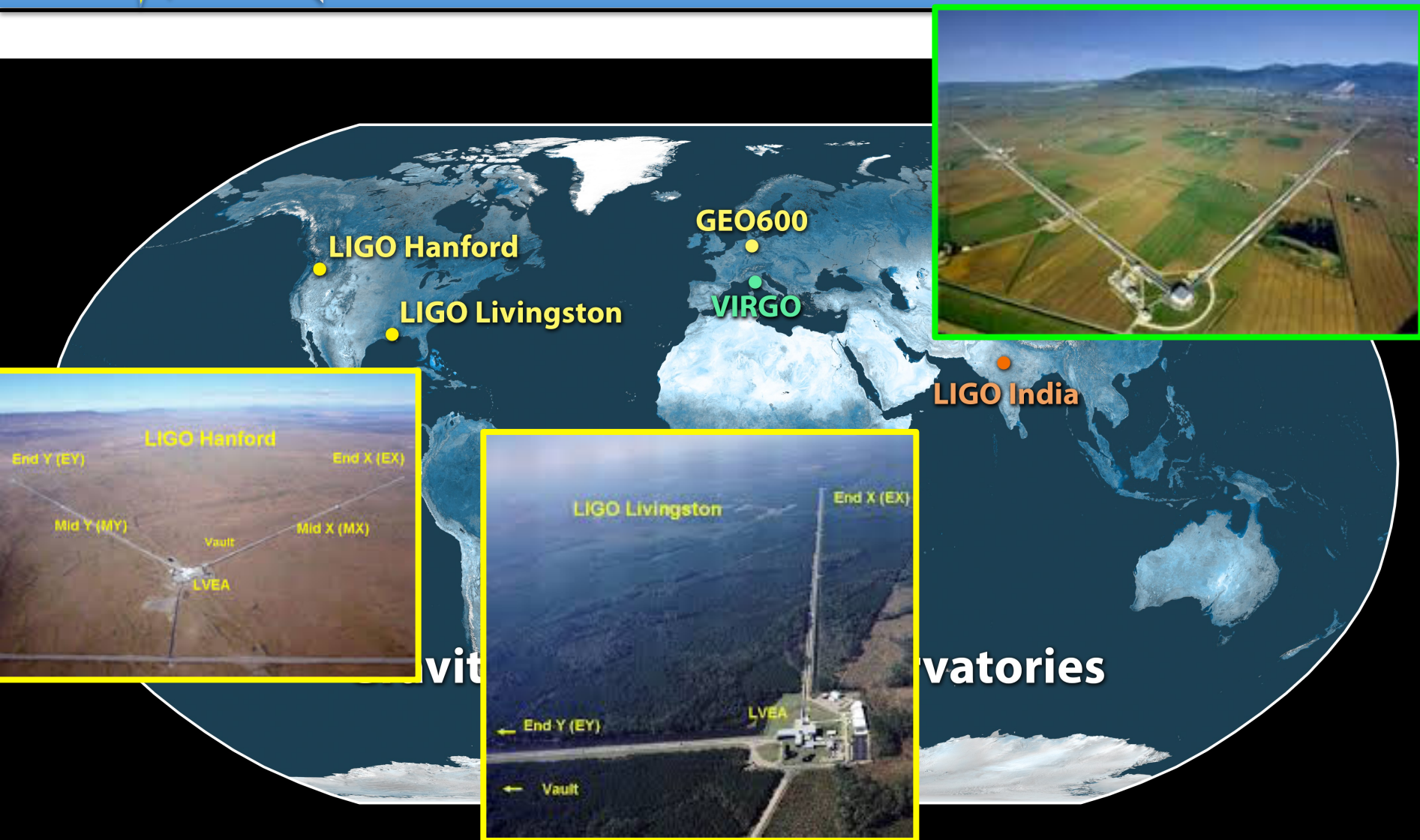
$$X_{GW} - X_0 \simeq 10^{-18} \text{ m}$$

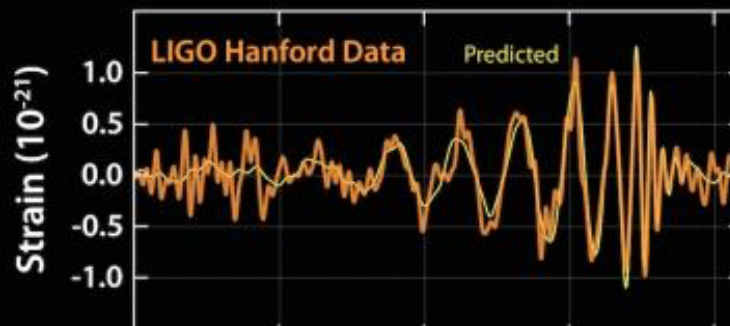




Onde Gravitazionali

$$\frac{\partial}{\partial t} \left(\frac{\partial}{\partial t} h_{\mu\nu} \right) + \dots = 0$$

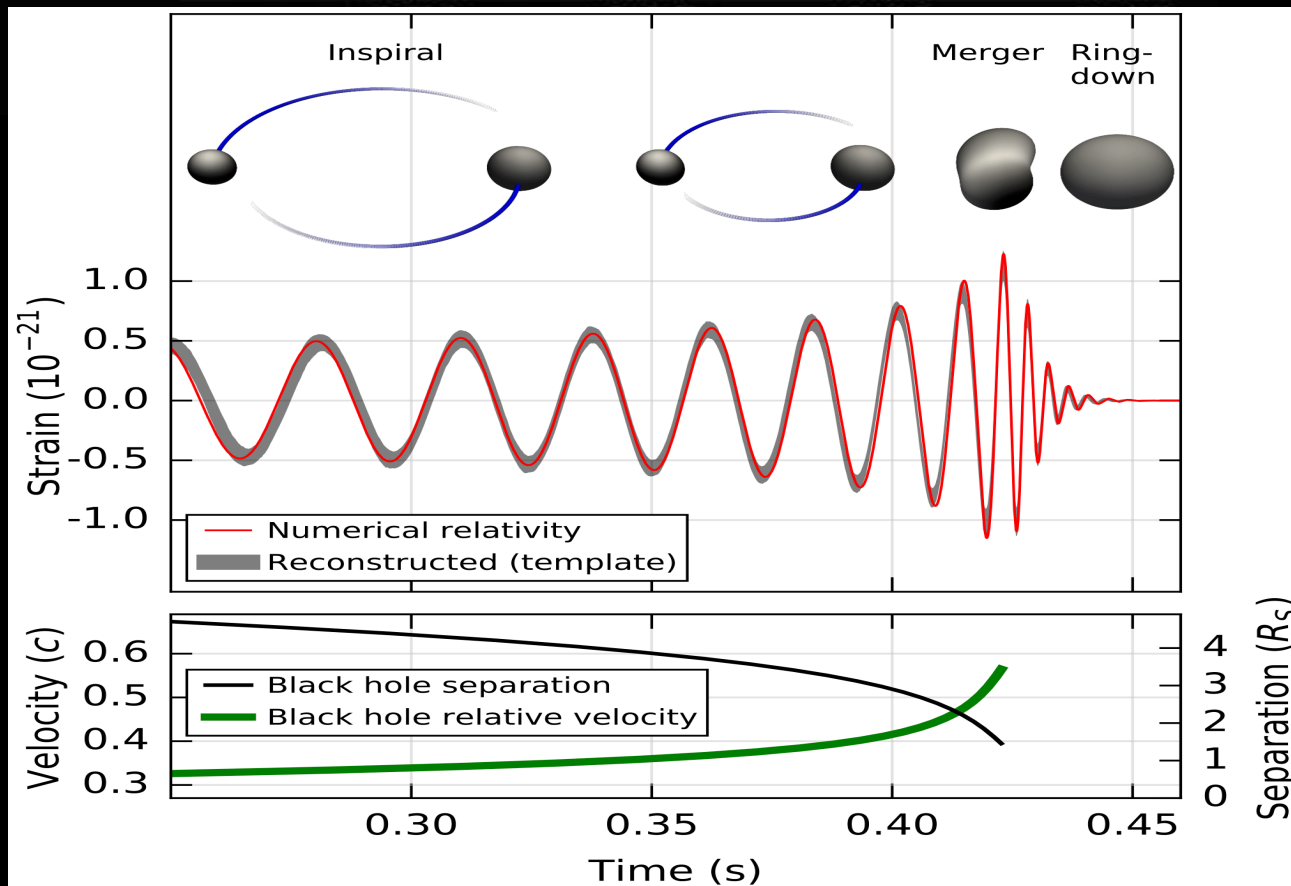
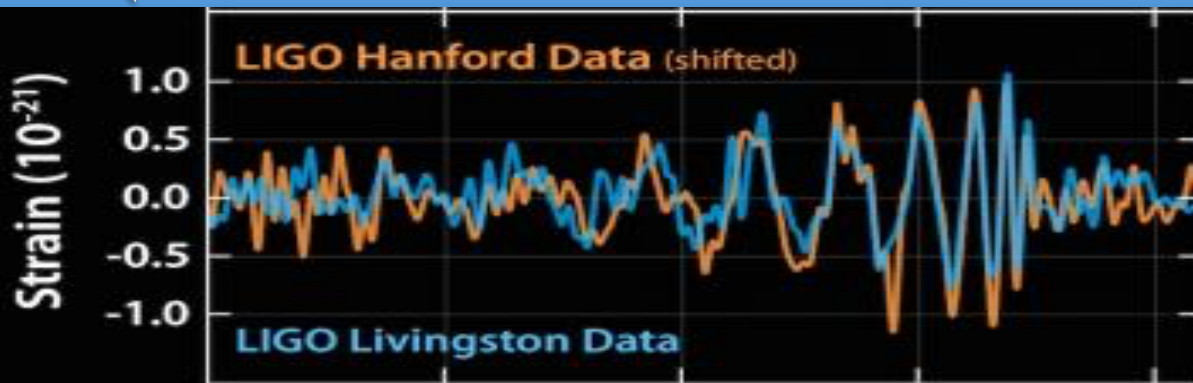



$$\begin{aligned} \frac{\partial}{\partial a} M T(s) &= \frac{\partial}{\partial a} \left[T(s) \exp(-s a) \int_a^\infty \frac{f(t)}{t} \exp(s t) dt \right] \\ &= \int_a^\infty \frac{\partial}{\partial a} \left[T(s) \exp(-s a) \right] f(t) \exp(s t) dt \\ &= \int_a^\infty \left(\frac{\partial}{\partial a} T(s) \exp(-s a) - s T(s) \exp(-s a) \right) f(t) \exp(s t) dt \\ &= \frac{\partial}{\partial a} M T(s) - s M T(s) \end{aligned}$$




Binary Black Hole (BBH) merger

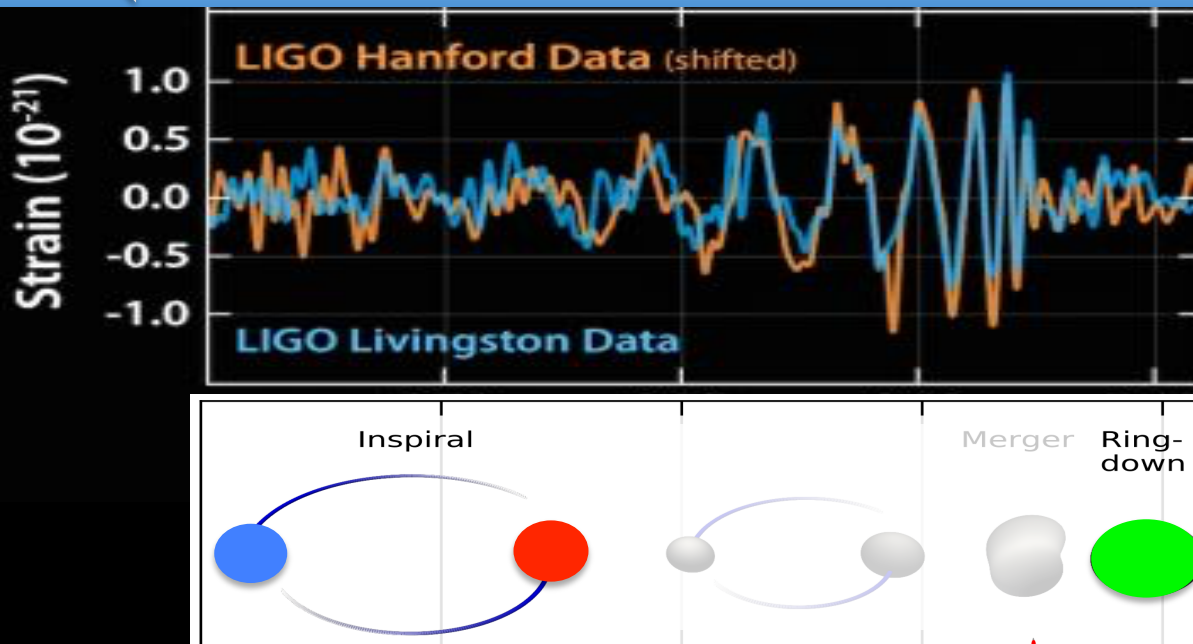
$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \psi}{\partial r} \right) \right) &= -\frac{1}{r} \frac{\partial}{\partial \theta} \left(\frac{1}{r} \frac{\partial}{\partial \theta} \left(r^2 \frac{\partial \psi}{\partial \theta} \right) \right) \\ &= -\frac{1}{r} \frac{\partial}{\partial \theta} \left(\frac{1}{r} \frac{\partial}{\partial \theta} \left(r^2 \frac{\partial \psi}{\partial \theta} \right) \right) \\ &= -\frac{1}{r} \frac{\partial}{\partial \theta} \left(\frac{1}{r} \frac{\partial}{\partial \theta} \left(r^2 \frac{\partial \psi}{\partial \theta} \right) \right) \end{aligned}$$





BBH: tutto si conserva ...

$$\frac{\partial}{\partial t} \int_{\Sigma} T_{\mu\nu} n^\mu d\Sigma^\nu = - \int_{\Sigma} T_{\mu\nu} \xi^\mu d\Sigma^\nu$$



$$E = Mc^2$$

$$29 M_{\odot} + 36 M_{\odot} = 62 M_{\odot} + 3 M_{\odot}$$

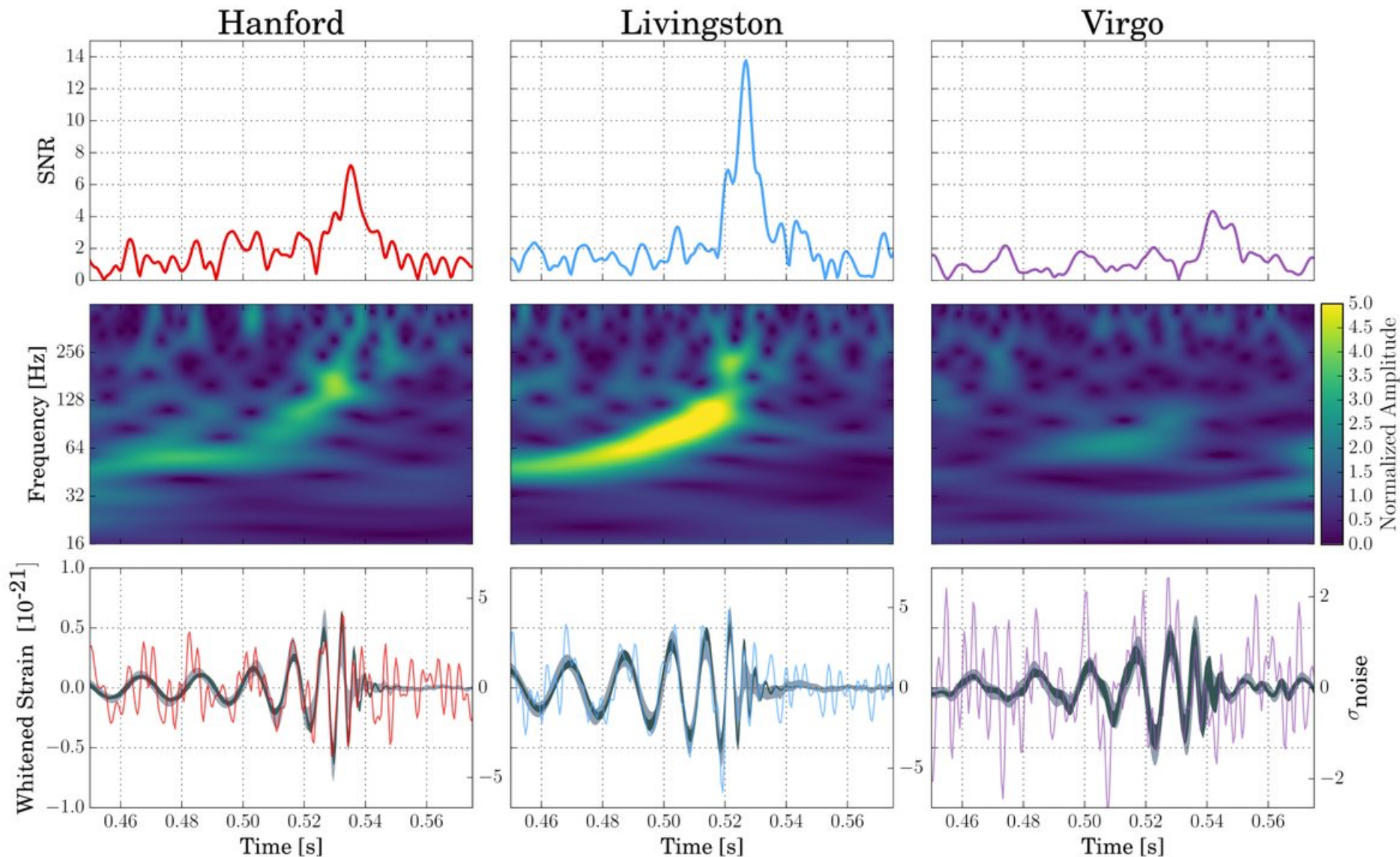
$$E = 3 \times 2 \times 10^{33} \times (3 \times 10^{10})^2 = 54 \times 10^{53} \simeq 5.4 \times 10^{54} \text{ erg}$$

$$L = \frac{E}{t} = \frac{5.4 \times 10^{54}}{0.2} \simeq 3 \times 10^{55} \text{ erg/sec}$$



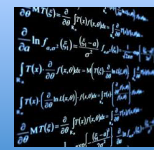
Virgo entra in gioco: GW 170814

$$\begin{aligned} \frac{\partial}{\partial \theta} \ln \mathcal{L}(\theta) &= \frac{1}{\mathcal{L}(\theta)} \frac{\partial \mathcal{L}(\theta)}{\partial \theta} \\ \mathcal{L}(\theta) &= \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2} \sum_{i=1}^N \left(\frac{h_i(\theta) - y_i}{\sigma_i} \right)^2 \right) \\ \ln \mathcal{L}(\theta) &= -\frac{1}{2} \sum_{i=1}^N \left(\frac{h_i(\theta) - y_i}{\sigma_i} \right)^2 - \frac{N}{2} \ln(2\pi) \\ \frac{\partial}{\partial \theta} \ln \mathcal{L}(\theta) &= \frac{1}{\mathcal{L}(\theta)} \frac{\partial \mathcal{L}(\theta)}{\partial \theta} \end{aligned}$$





Ricapitoliamo

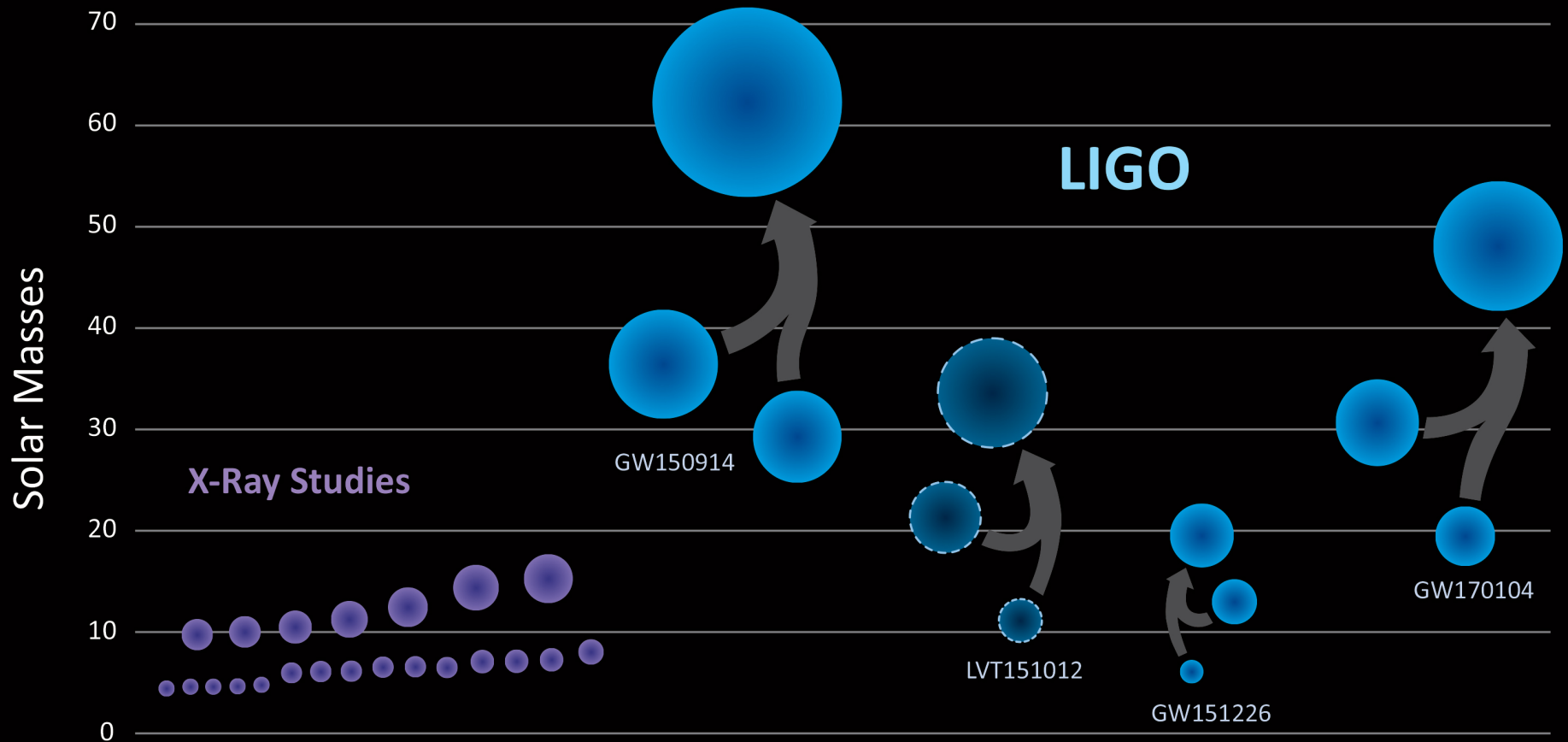


GRAVITATIONAL WAVE EVENT CATALOGUE

Name	GW150914	GW151226	GW170104	GW170814
Type	BH+BH	BH+BH	BH+BH	BH+BH
Mass 1 (solar mass)	36 Msun	14 Msun	31 Msun	31.5 Msun
Mass 2 (solar mass)	29 Msun	8 Msun	20 Msun	25 Msun
Final Mass	62 Msun	21 Msun	49 Msun	53 Msun
Energy Radiated	3 Msun	1.1 Msun	2 Msun	2.7 Msun
Distance (Mpc)	400 Mpc	440 Mpc	880 Mpc	540 Mpc
Duration (seconds)	~ 0.2 sec	~ 1 sec	~ 0.3 sec	~ 0.25 sec
Detectors	LIGO	LIGO	LIGO	LIGO+Virgo



Black Holes of Known Mass

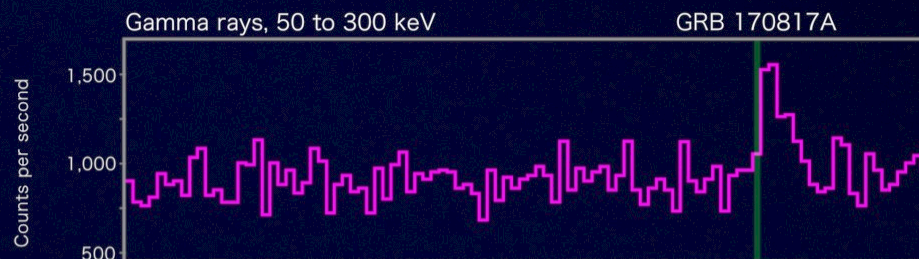




Reported 16 seconds
after detection



Reported 27 minutes after detection



Gamma rays, 50 to 300 keV

GRB 170817A

Counts per second

Gravitational-wave strain

GW170817

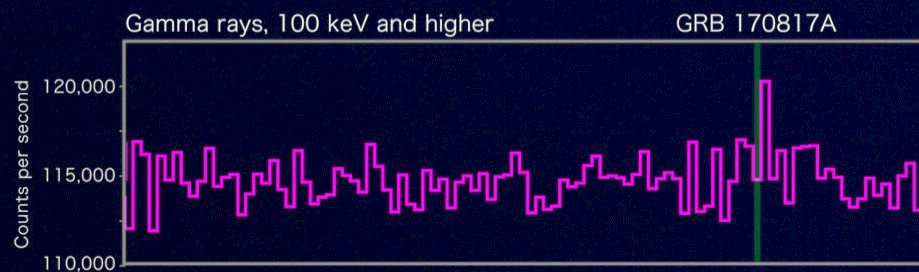
Frequency (Hz)

300
100

Time from merger (seconds)

INTEGRAL

Reported 66 minutes
after detection



Gamma rays, 100 keV and higher

GRB 170817A

Counts per second



GW170817: si apre la caccia alla luce

$$\begin{aligned} \frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \phi}{\partial t} \right) &= -\frac{1}{c} \frac{\partial^2 \phi}{\partial t^2} \\ \frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \phi}{\partial t} \right) &= -\frac{1}{c} \frac{\partial^2 \phi}{\partial t^2} \\ \frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \phi}{\partial t} \right) &= -\frac{1}{c} \frac{\partial^2 \phi}{\partial t^2} \end{aligned}$$

Earth

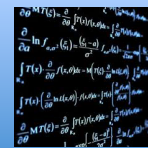
Space



70 telescopii da terra + 8 satelliti

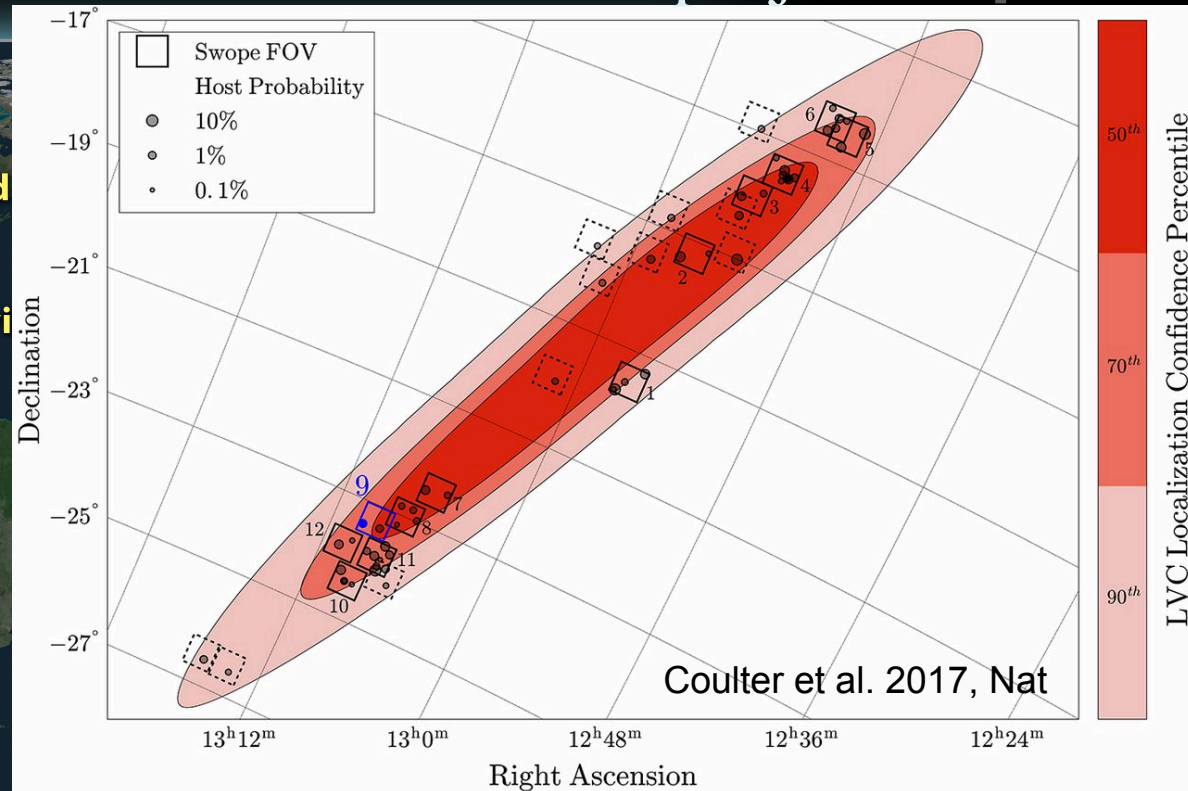


GW170817: fra i primi ...



Lista dei sospetti:
~100 galassie @ 40 Mpc

Earth 1M2H project Space



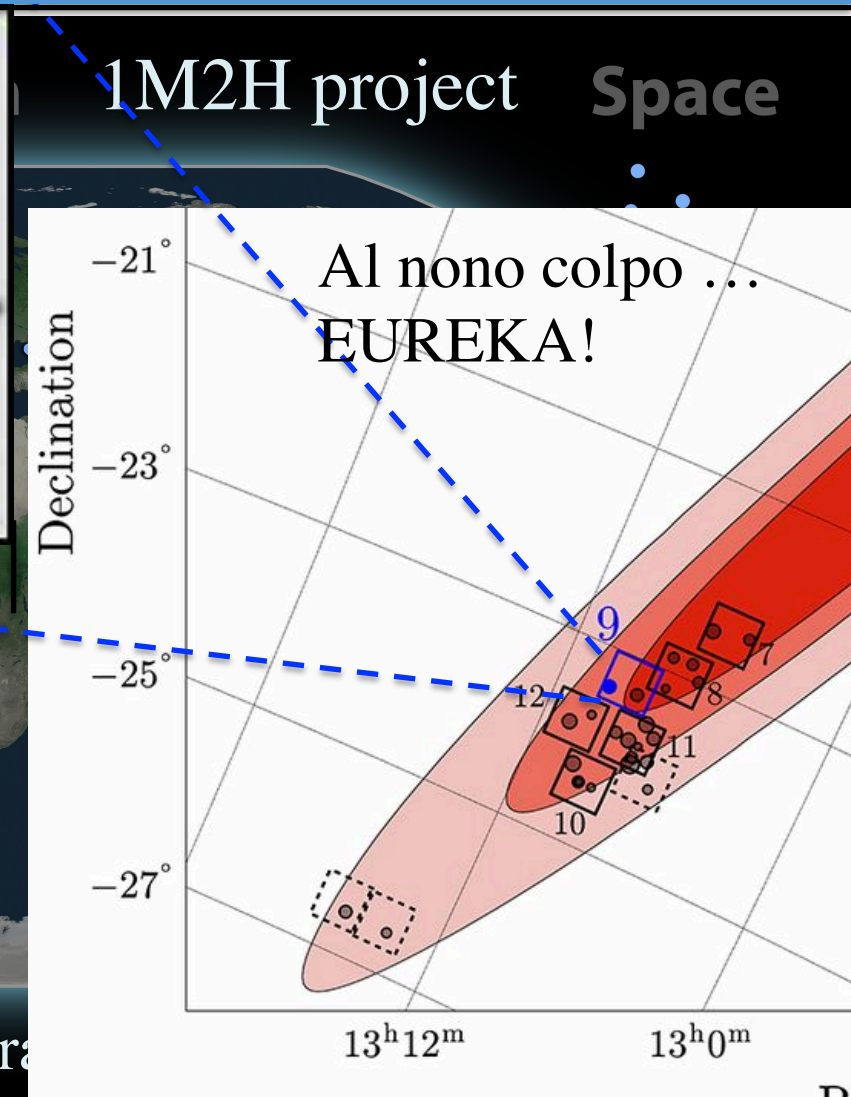
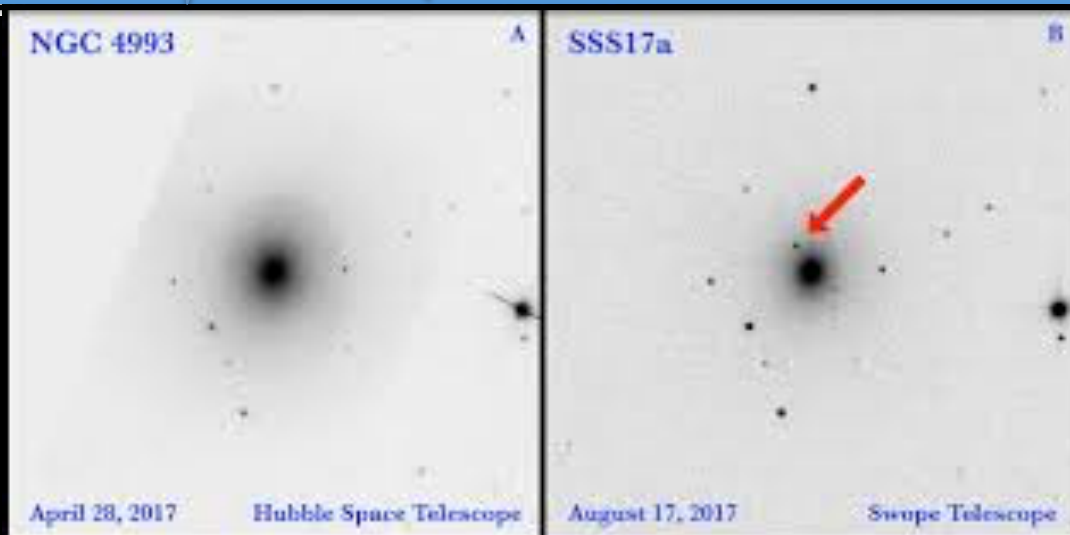
70 telescopi da terra + 8 satelliti

35 gradi quadri ... ricerca guidata (D=40 Mpc)



GW170817: fra i primi ...

$$\begin{aligned} \frac{\partial}{\partial t} \ln \left(\frac{\rho}{\rho_0} \right) &= -\frac{1}{\rho} \frac{\partial \rho}{\partial t} \\ \frac{\partial}{\partial t} \ln \left(\frac{\rho}{\rho_0} \right) &= -\frac{1}{\rho} \frac{\partial \rho}{\partial t} \\ \frac{\partial}{\partial t} \ln \left(\frac{\rho}{\rho_0} \right) &= -\frac{1}{\rho} \frac{\partial \rho}{\partial t} \end{aligned}$$



70 telescopii da terra

Due stelle di neutroni a 40 Mpc

“Prima luce” = flash di fotoni gamma ($E > 50\text{keV}$) di durata < 2 secondi

“Seconda luce” (10.9 h) = Sorgente ottica nuova SSS17a vicino (2kpc) NGC 4993 (S0)



GW170817

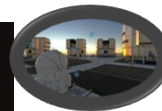
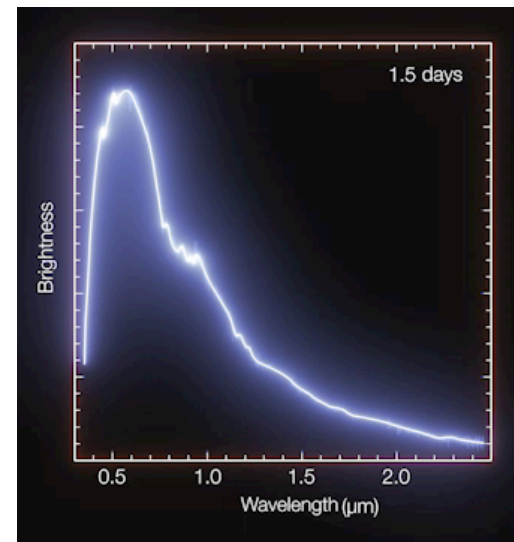
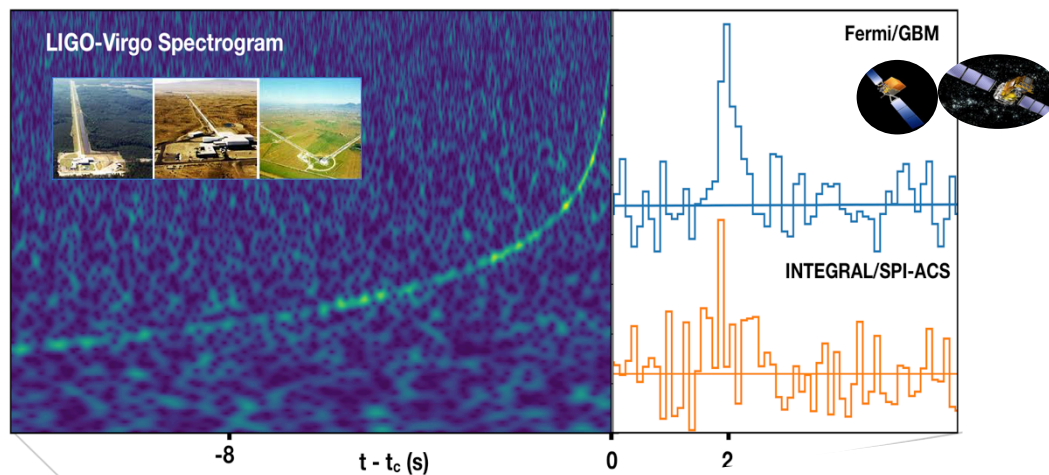
$$\frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{1}{c} \frac{\partial^2 \phi}{\partial t^2}$$
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$$\frac{\partial}{\partial t} \left(\frac{1}{c} \frac{\partial \phi}{\partial t} \right) = \frac{1}{c} \frac{\partial^2 \phi}{\partial t^2}$$

Onde gravitazionali



Flash raggi gamma

Luce ottica/infrarossa



tempo



Gamma Ray Burst



Kilonova



Una nuova sorgente astrofisica: Kilonova

$$\frac{d}{dt} \left(\frac{1}{a} \right) = - \frac{\dot{a}}{a^2}$$
$$\frac{d}{dt} \left(\frac{1}{a} \right) = - \frac{\dot{a}}{a^2}$$
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$$\frac{d}{dt} \left(\frac{1}{a} \right) = - \frac{\dot{a}}{a^2}$$



Big Bang

H
1

He
2

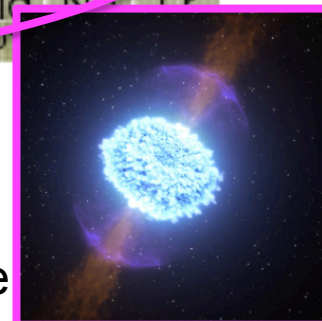
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56		Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88																
			La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
			Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	Nr 102	Lr 103



Supernovae

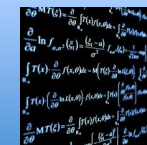


Kilonovae

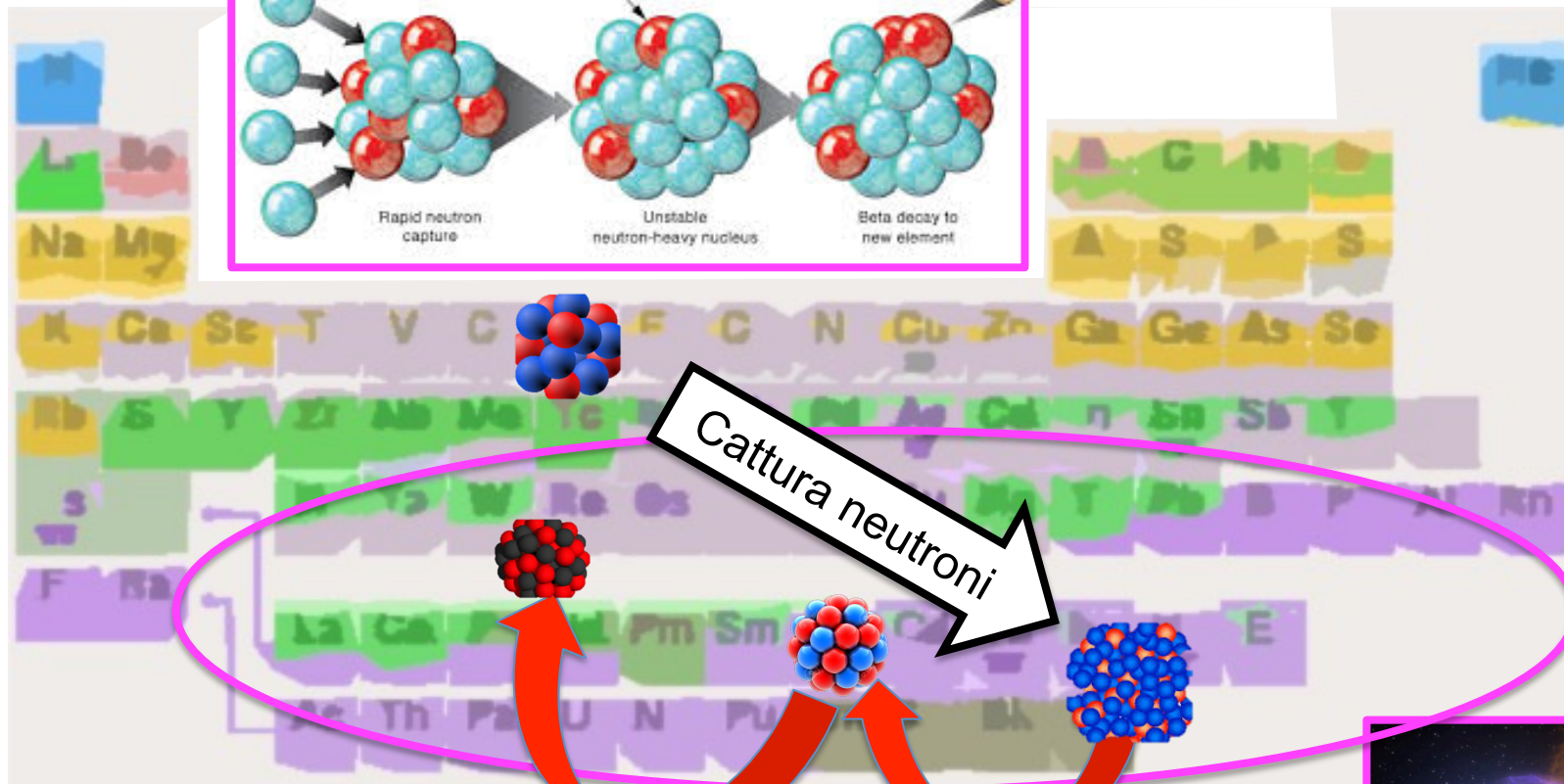
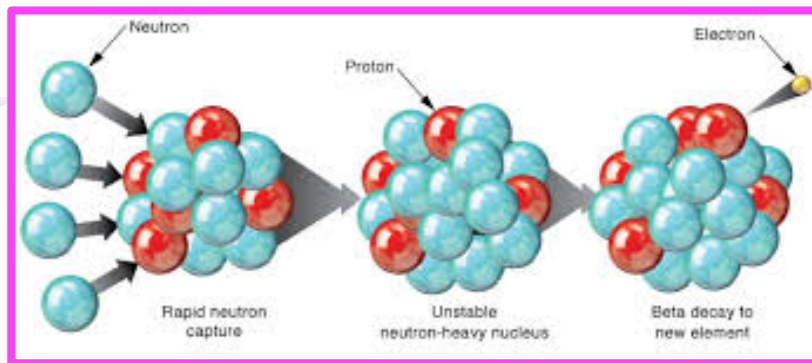




Oro, platino et al.

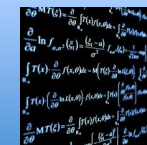


r-process = processi rapidi di cattura di neutroni



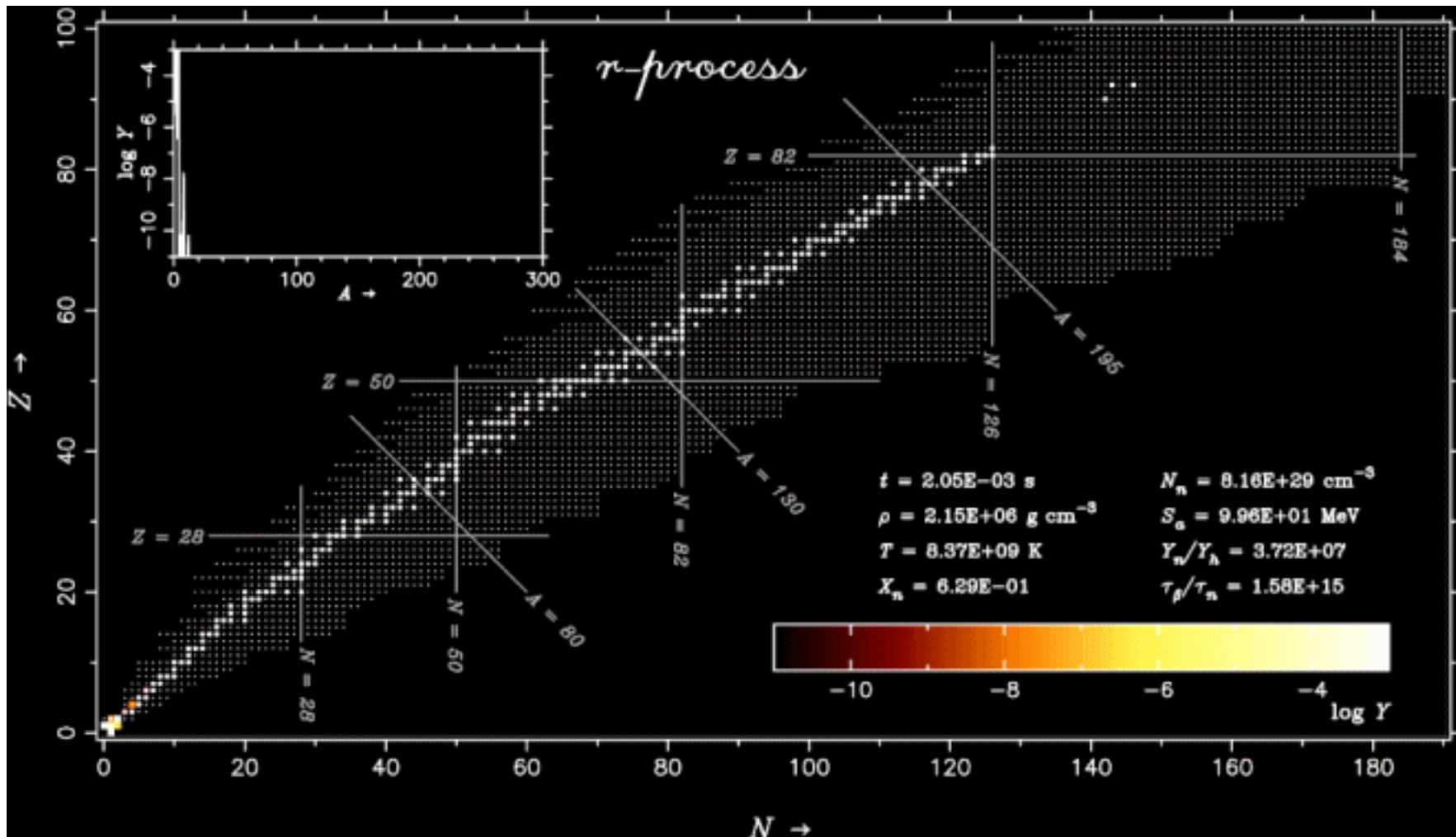


Oro, platino et al.



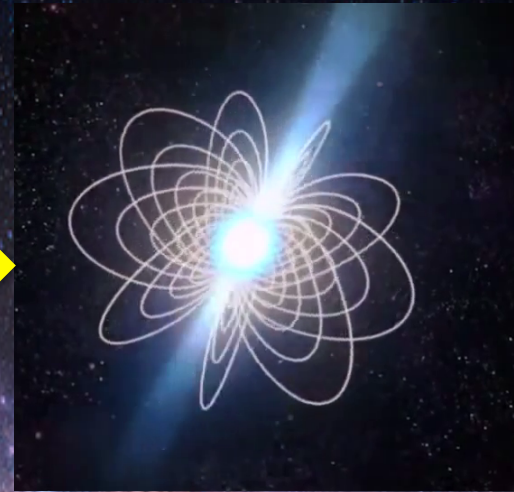
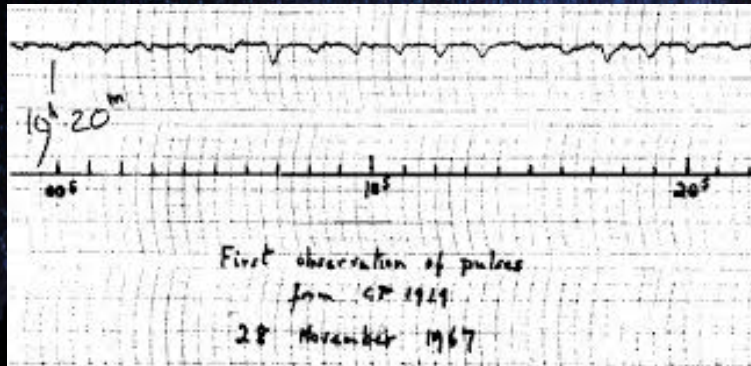
r-process = processi rapidi di cattura di neutroni

NUMERO DI PROTONI

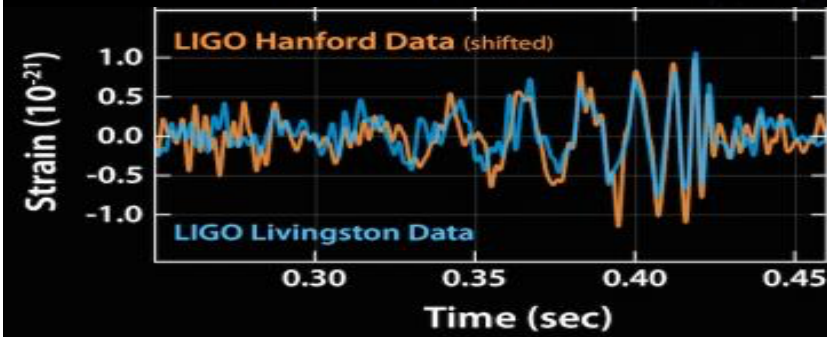


NUMERO DI NEUTRONI

IL DOPPIO SENSO DELLA SCIENZA



GRAZIE



Il doppio senso della scienza (G. Ghirlanda – Brera 2017)

- 1) J. Bell Burnell racconta la storia della scoperta delle pulsar (con commento sul Nobel) <http://www.bigear.org/vol1no1/burnell.htm>
- 2) Archivio digitalizzato dei lavori di Einstein:
<http://einsteinpapers.press.princeton.edu>
- 3) “Einstein, Eddington and the Eclipse” (Peter Coles)
<http://arxiv.org/pdf/astro-ph/0102462v1.pdf>
- 4) Caltech site on GW detection (with videos):
<https://www.caltech.edu/news/gravitational-waves-detected-100-years-after-einstein-s-prediction-49777>
- 5) Einstein. Le Scienze, Novembre 2015 Numero speciale
- 6) Brian Green site: <http://www.briangreene.org>
- 7) GW170817 → <https://www.universetoday.com/137629/gw170817-update-surprises-first-gravitational-wave-observed-independently/>
- 8) GW170817 → <http://www.media.inaf.it/2017/10/17/editoriale-damico/>