O nouă fereastră spre univers:

astronomie cu detectoare de unde gravitaţionale

Raffai Péter

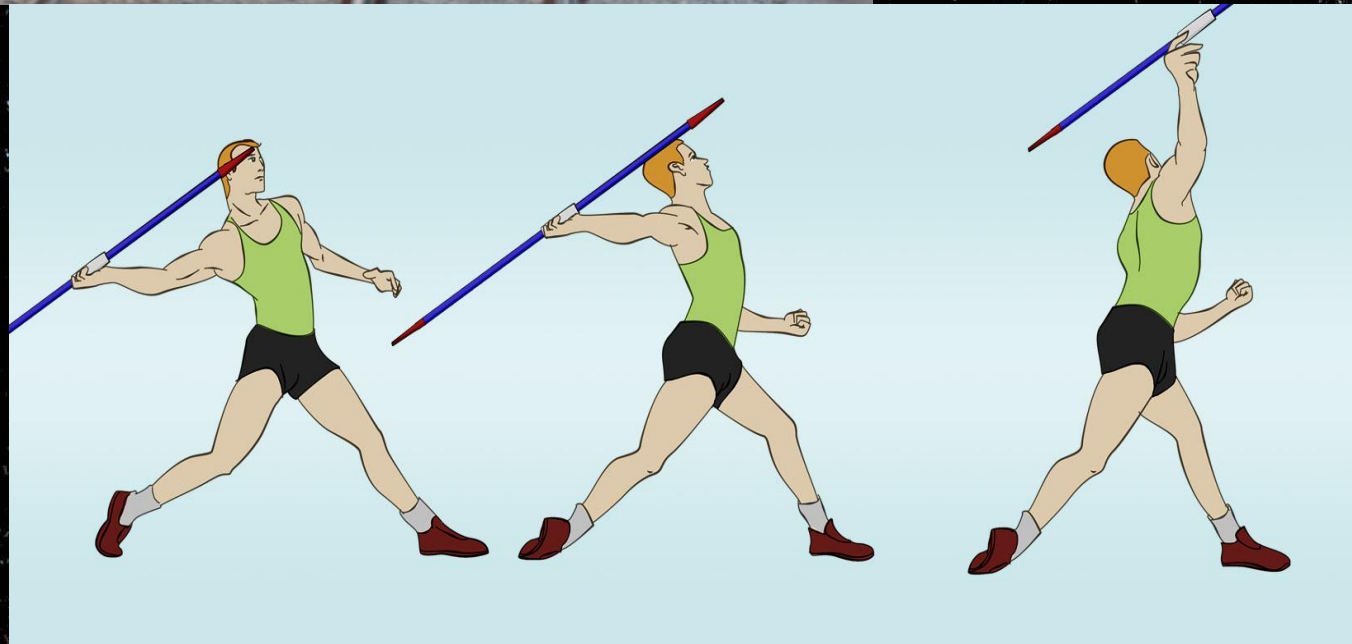
ELTE Catedra de Fizică atomică

15 octombrie 2016

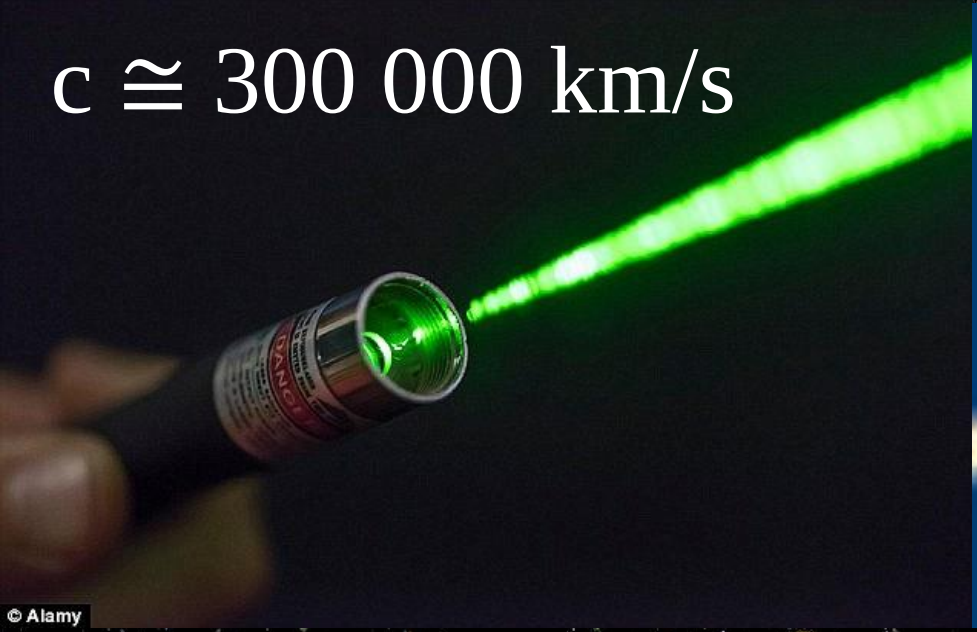
Eötvös Gravity Research Group

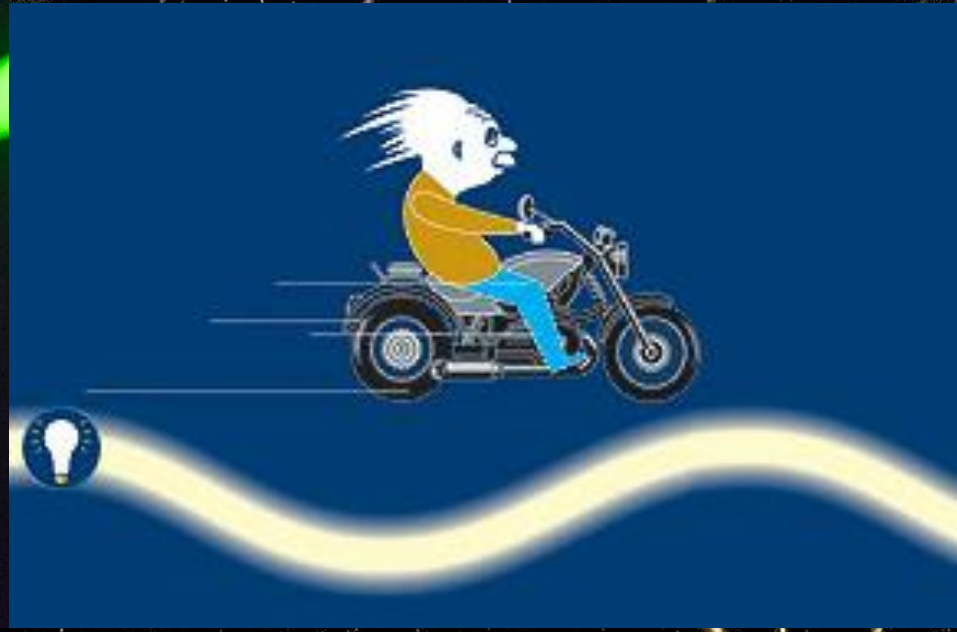
EGRG

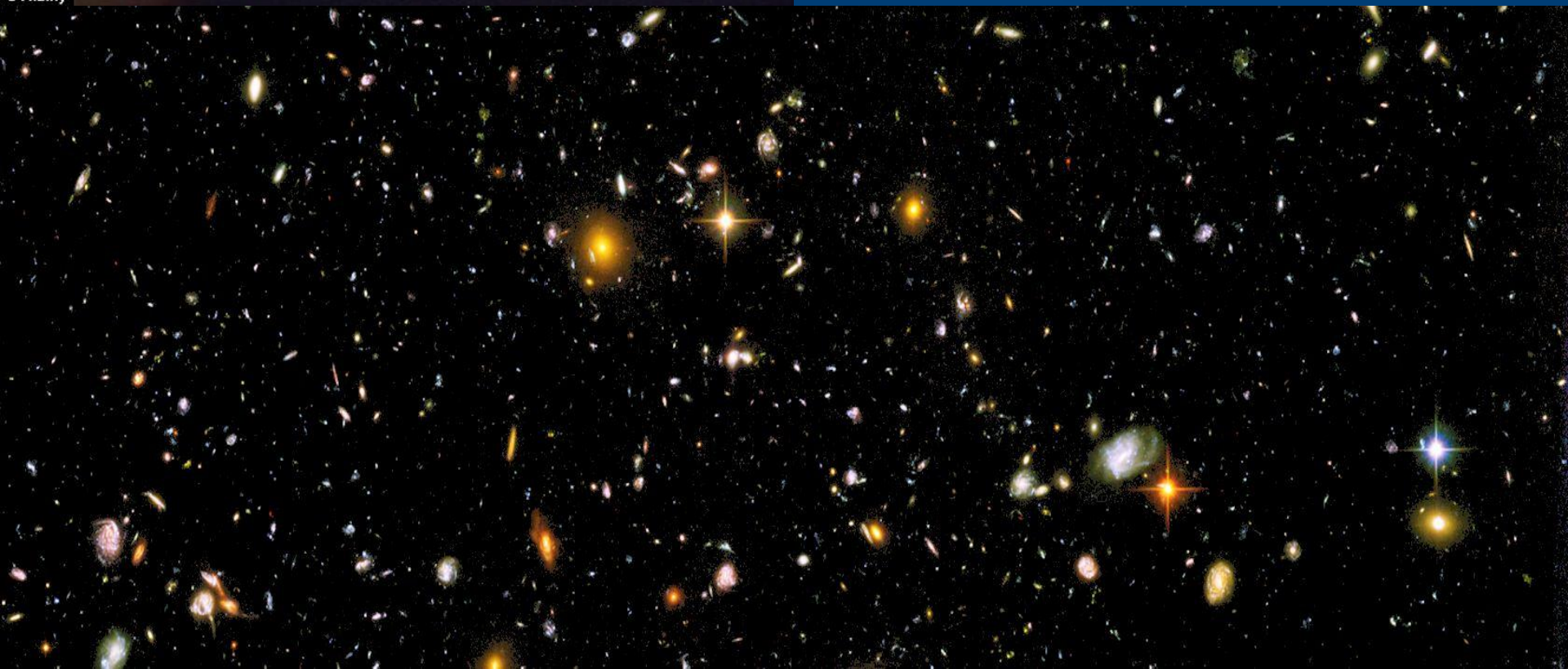
egrg.elte.hu

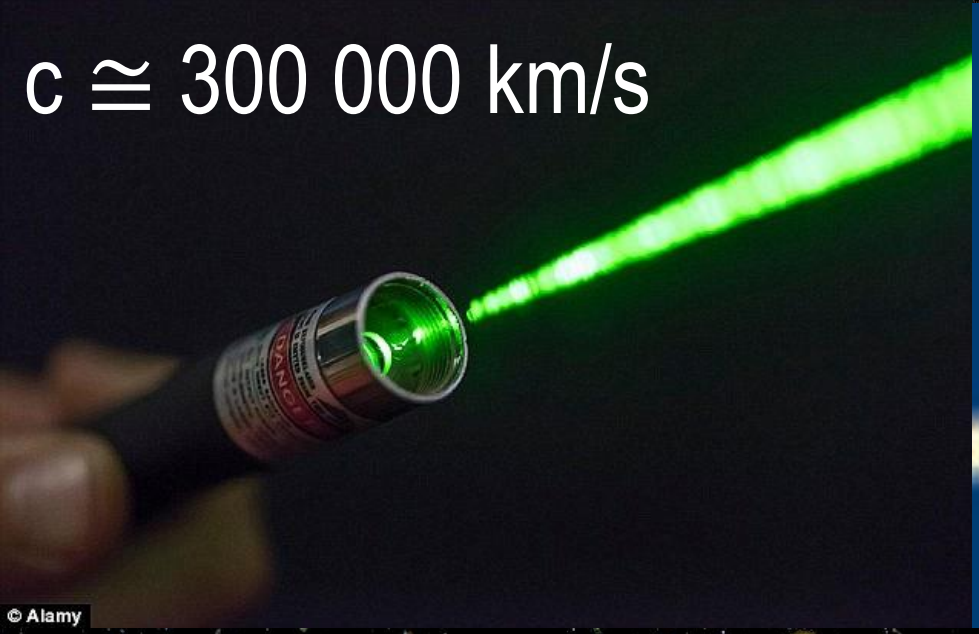


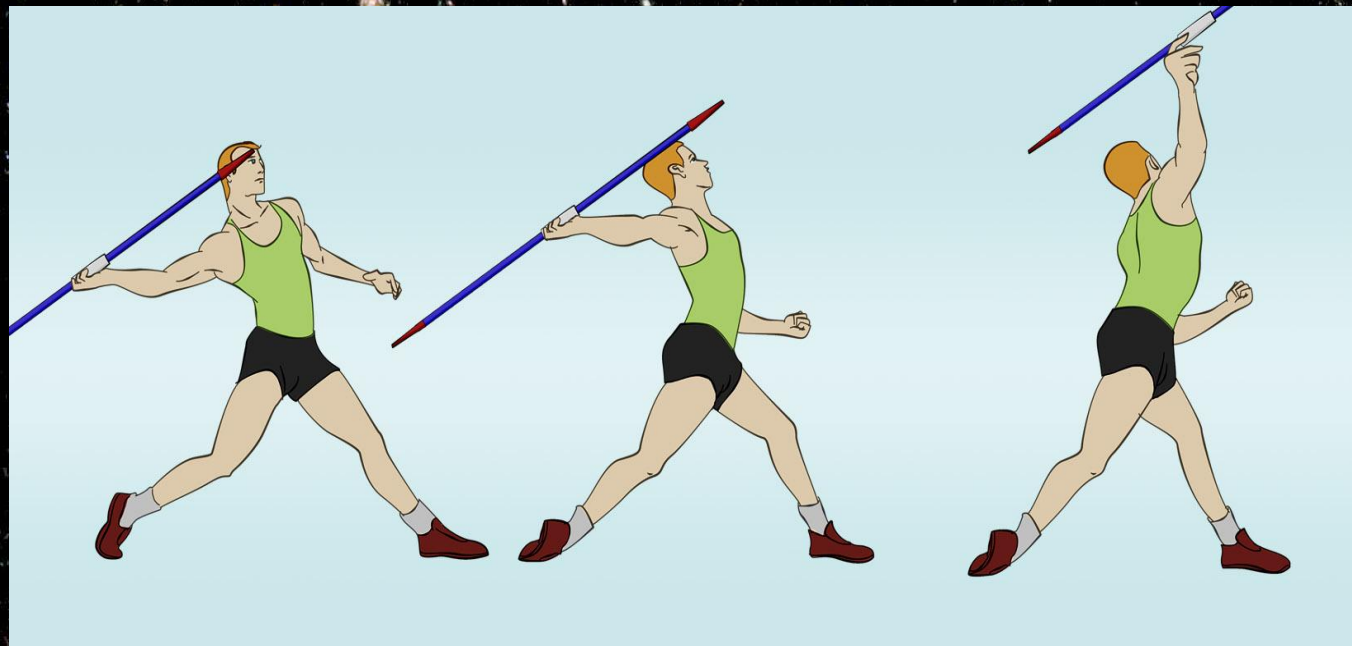
$c \cong 300\,000$ km/s



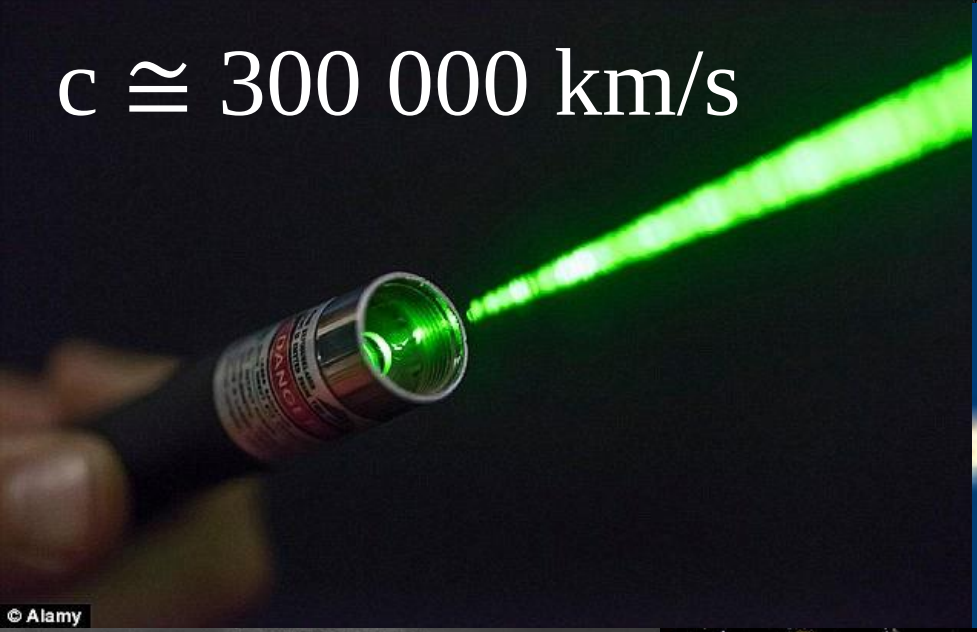


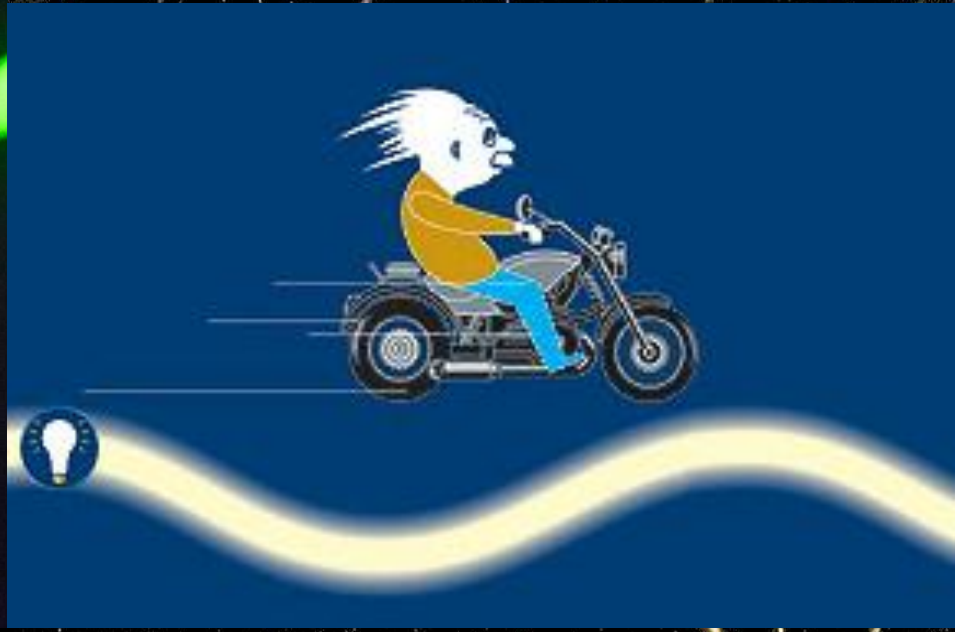


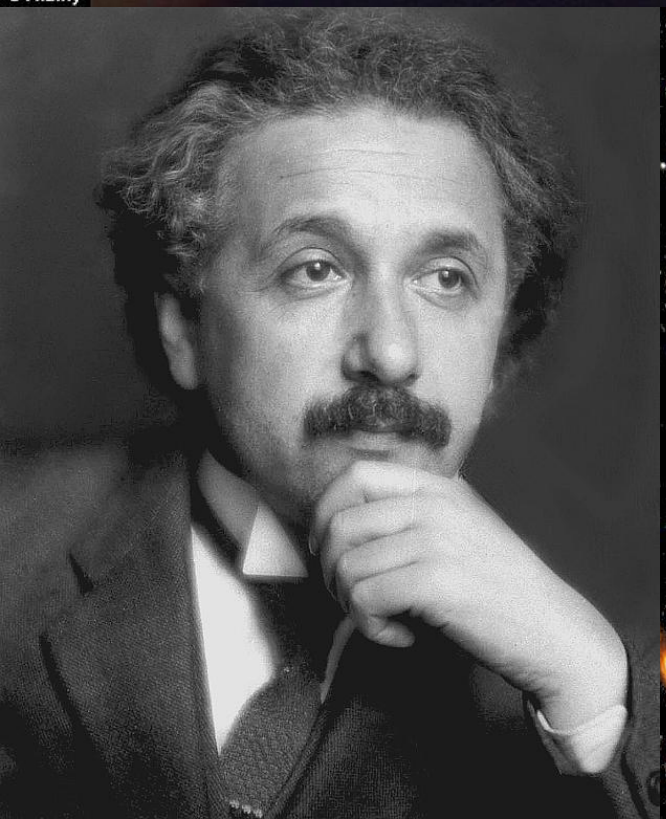

c ≅ 300 000 km/s
© Alamy



$c \cong 300\,000$ km/s



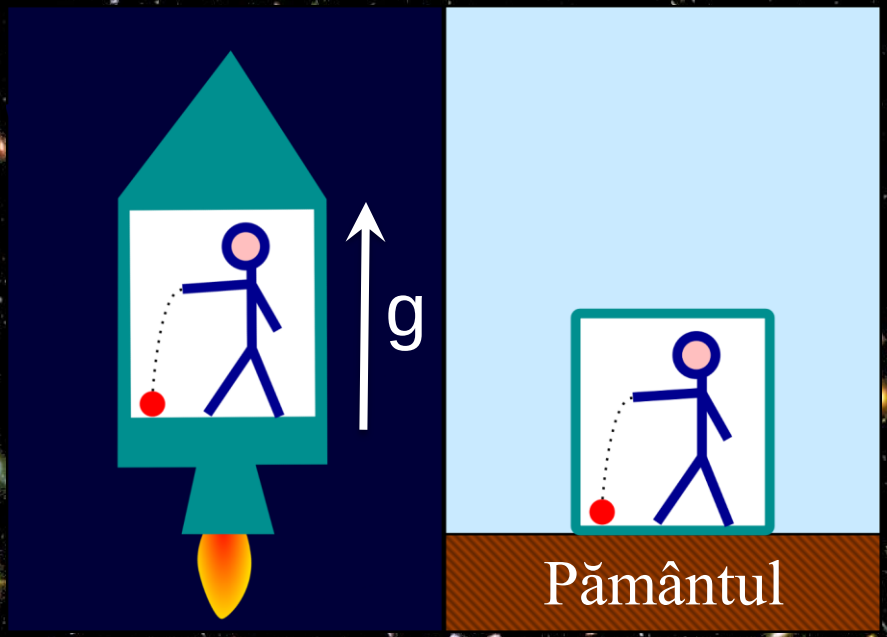




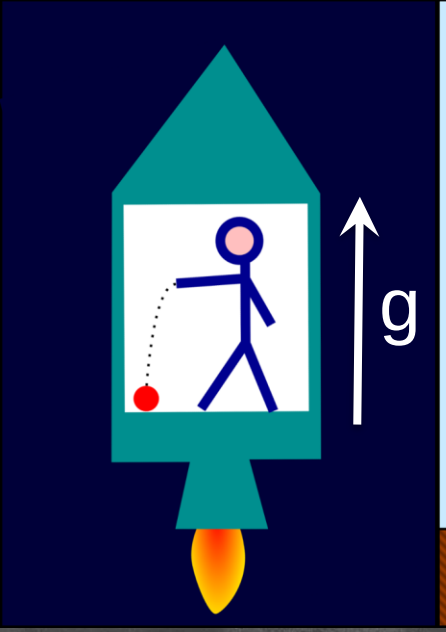
Einstein A., Annalen der Physik 322, 10, 891-921 (1905)

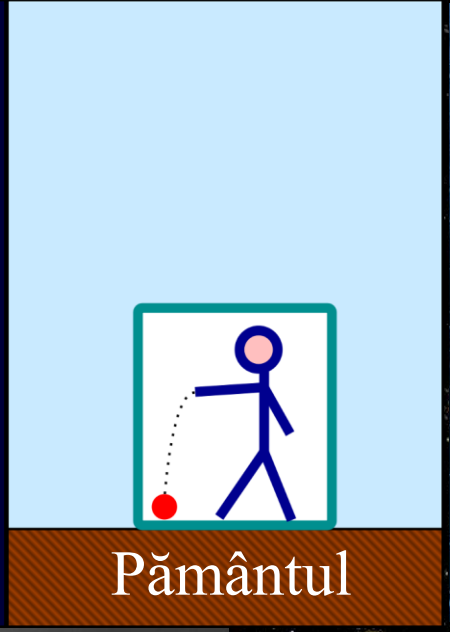
$$v' = \frac{u+v}{1+uv/c^2}$$

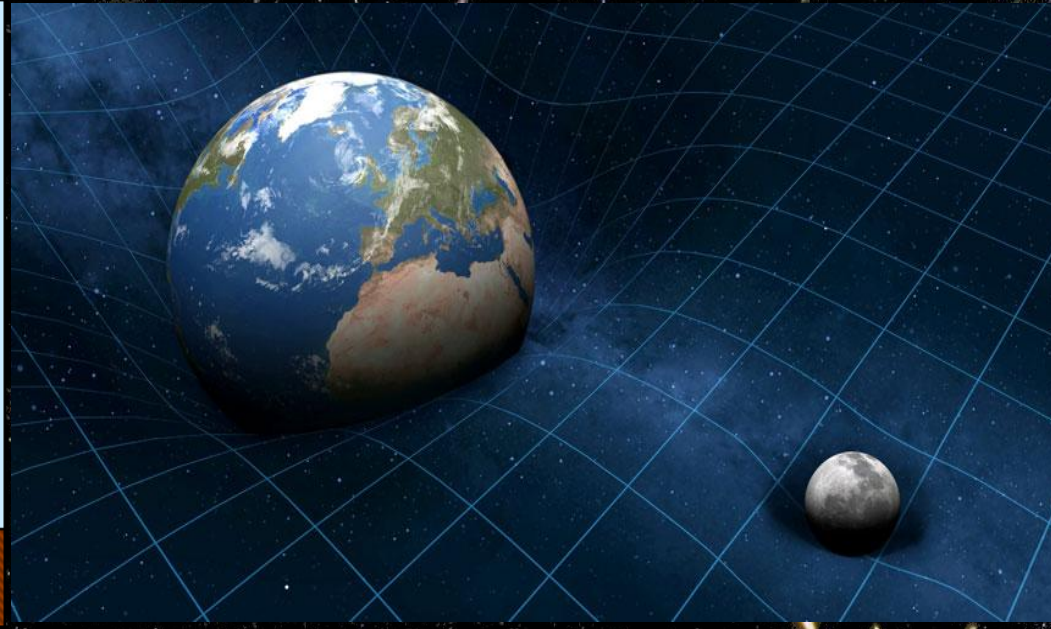
$$t' = t/\sqrt{1-\frac{v^2}{c^2}} \qquad L' = L\sqrt{1-\frac{v^2}{c^2}}$$

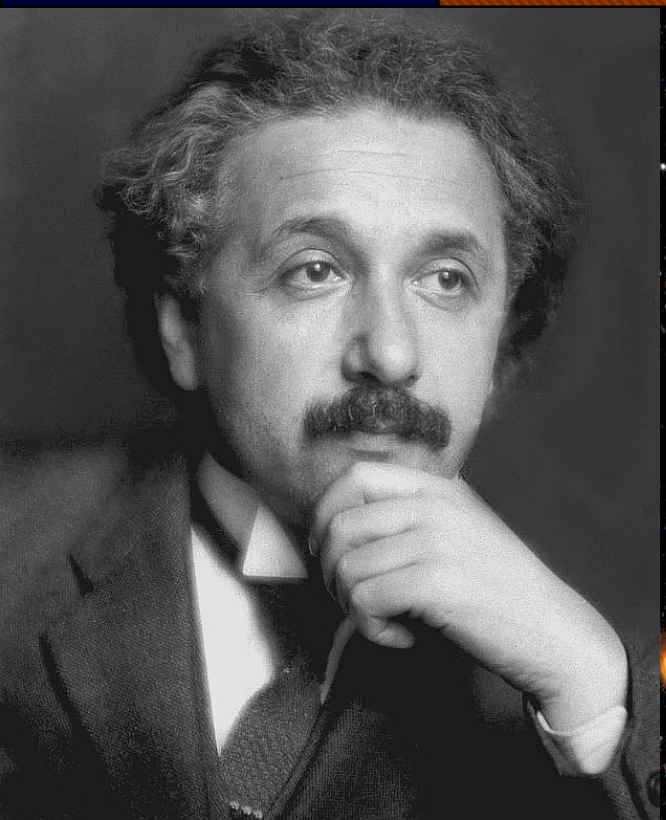

g

Pământul





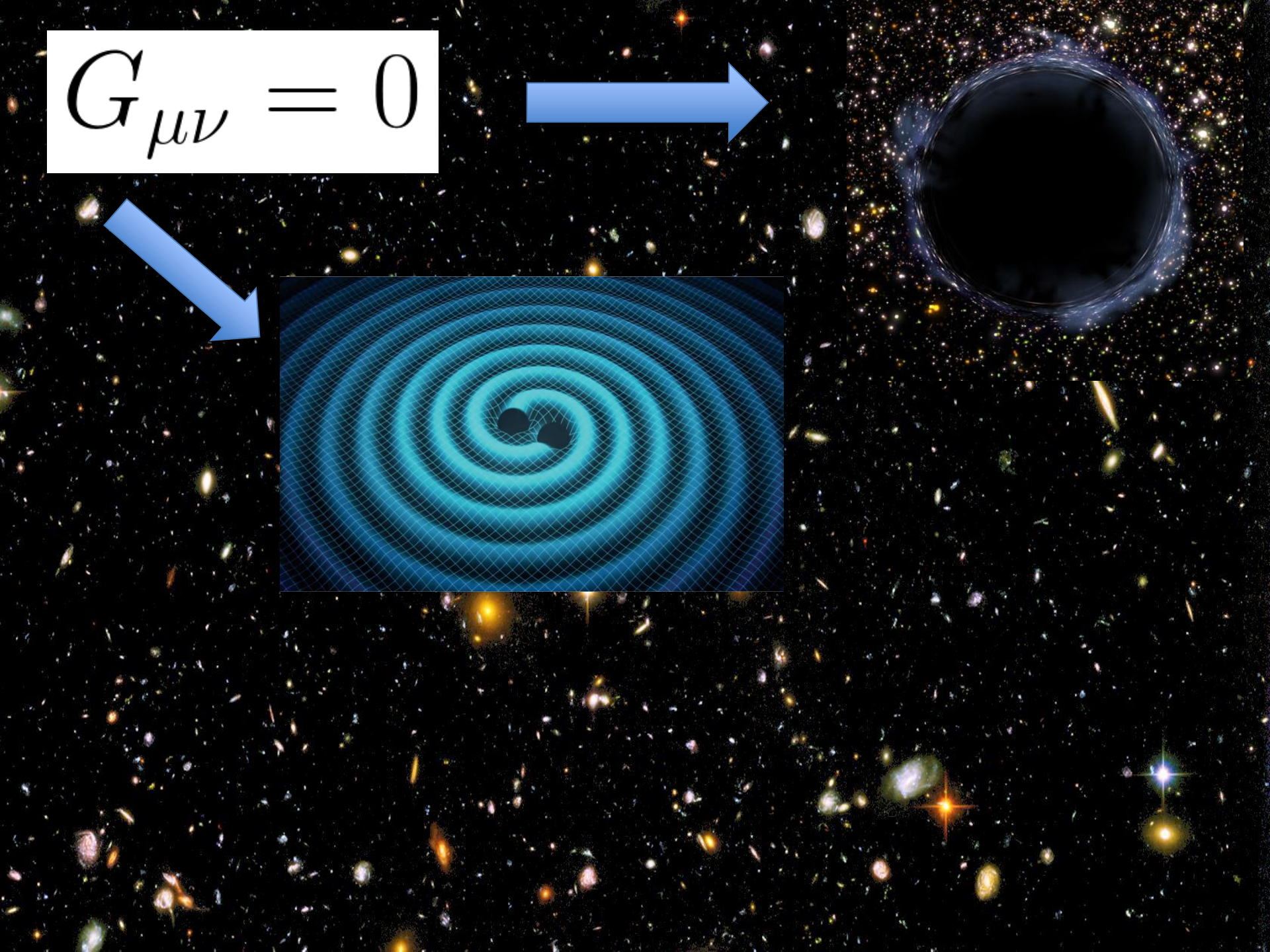




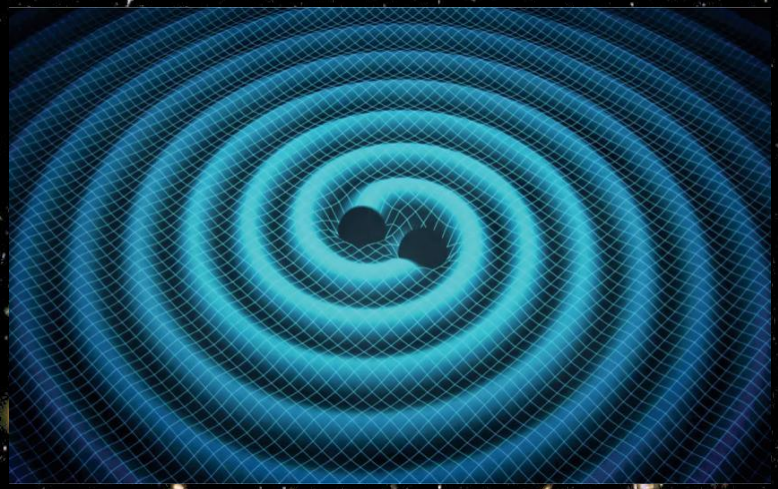
Einstein A., SPAWB, 844-847 (1915)

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

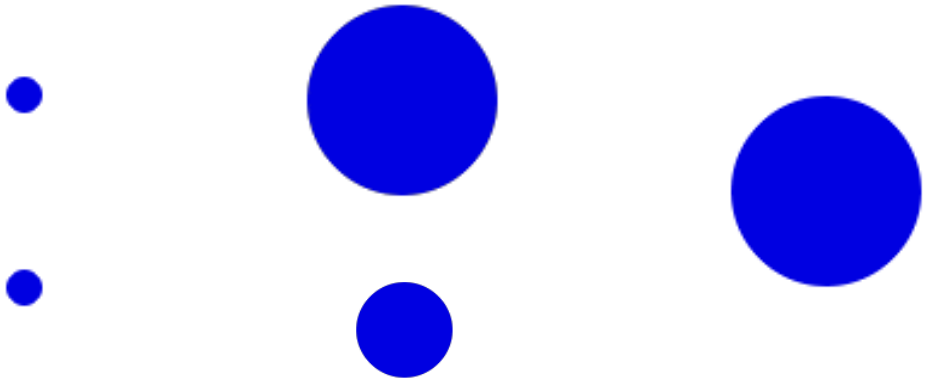
$$G_{\mu\nu} = 0$$

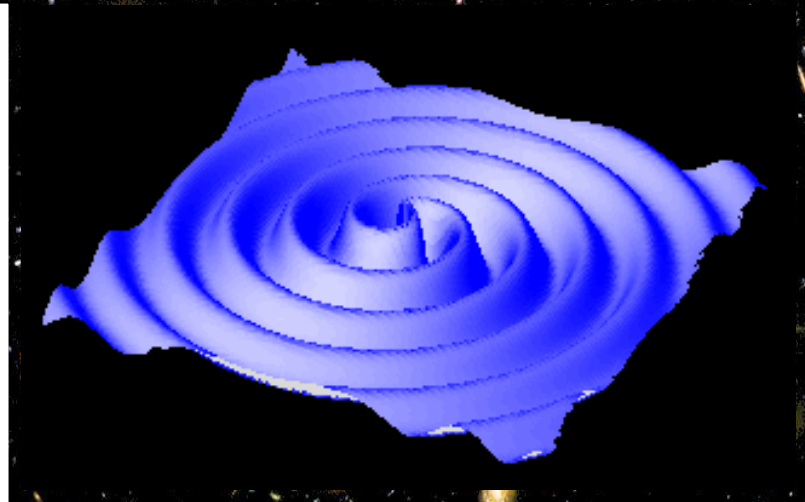


$$G_{\mu\nu} = 0$$



Einstein A., SKPAW
688-696 (1916)
154-167 (1918)

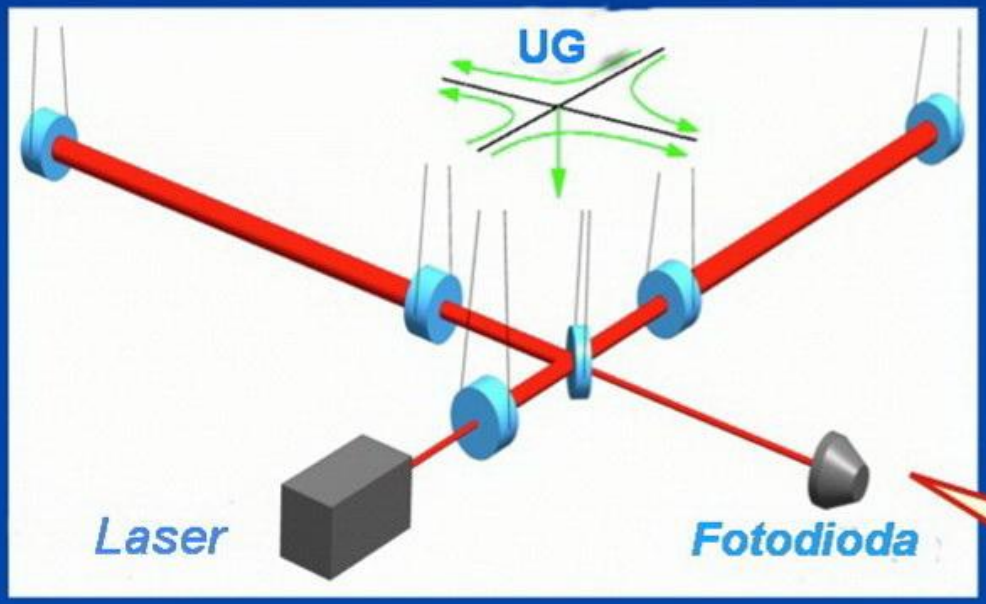


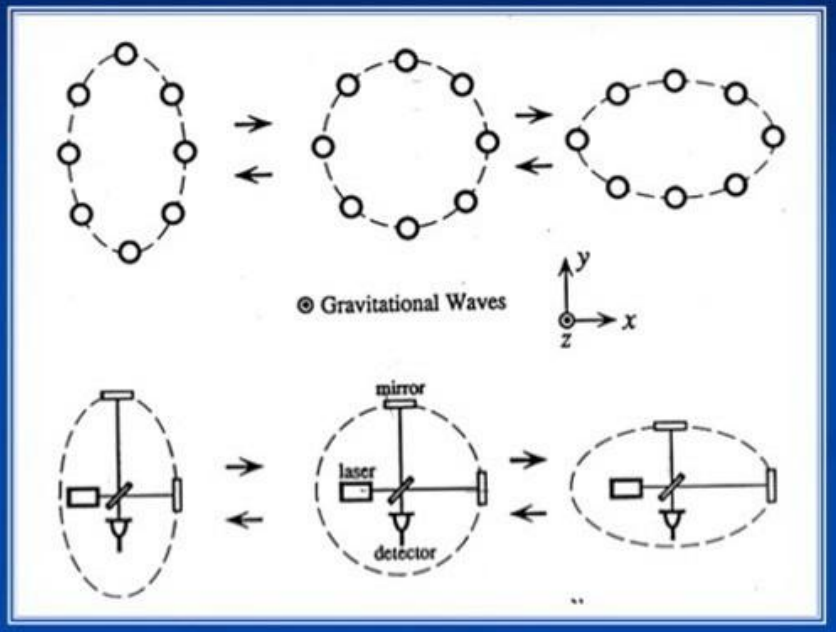


Interferometre

Interferența unui fascicol laser splitat perpendicular pe suprafața fotodiodei

Pe măsură ce unda trece prin dispozitiv brațele suferă o modificare relativă a lungimii...



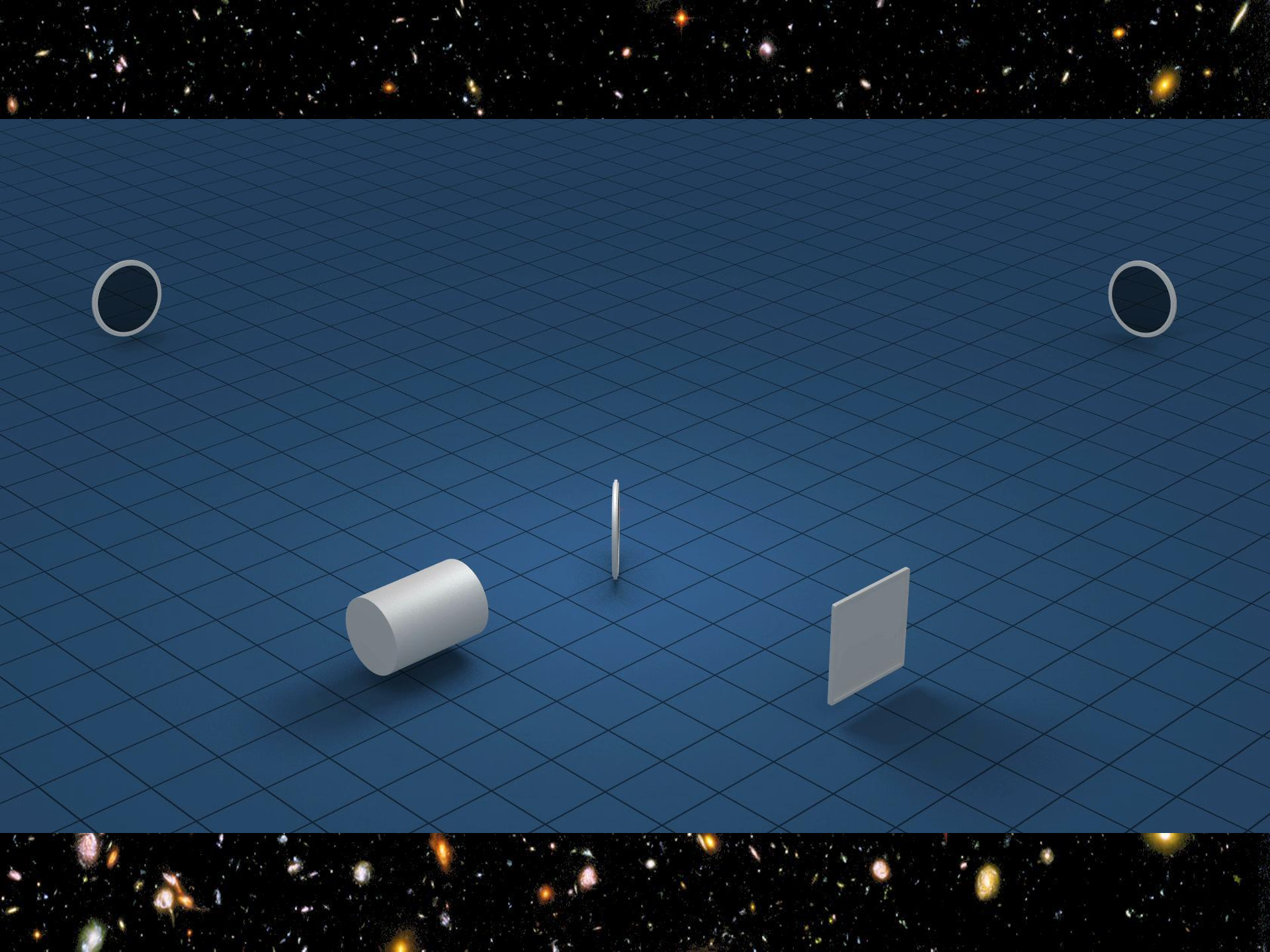


... cea ce duce și la modificarea de figurii de interferență măsurată de fotodiodă

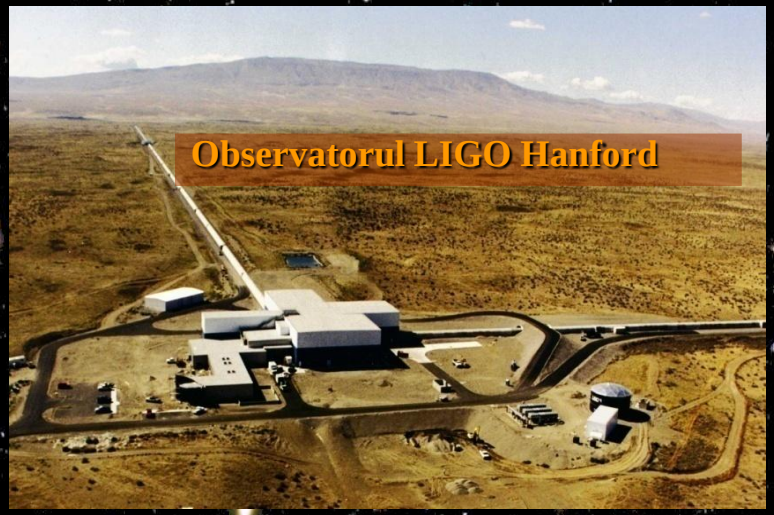
Modificarea relativă a lungimii: $h = \Delta L / L$

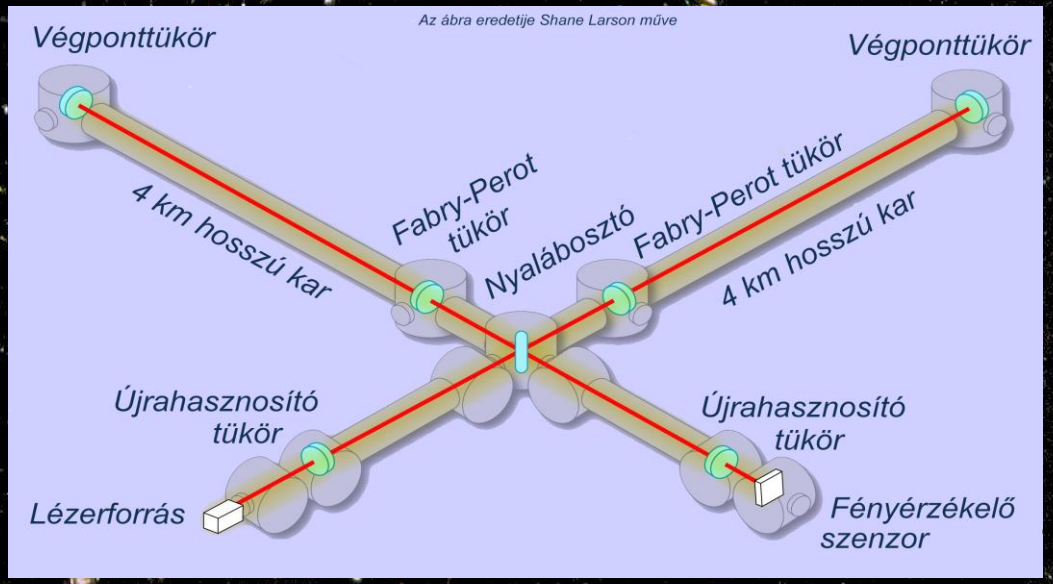
Măsurabil: ΔL

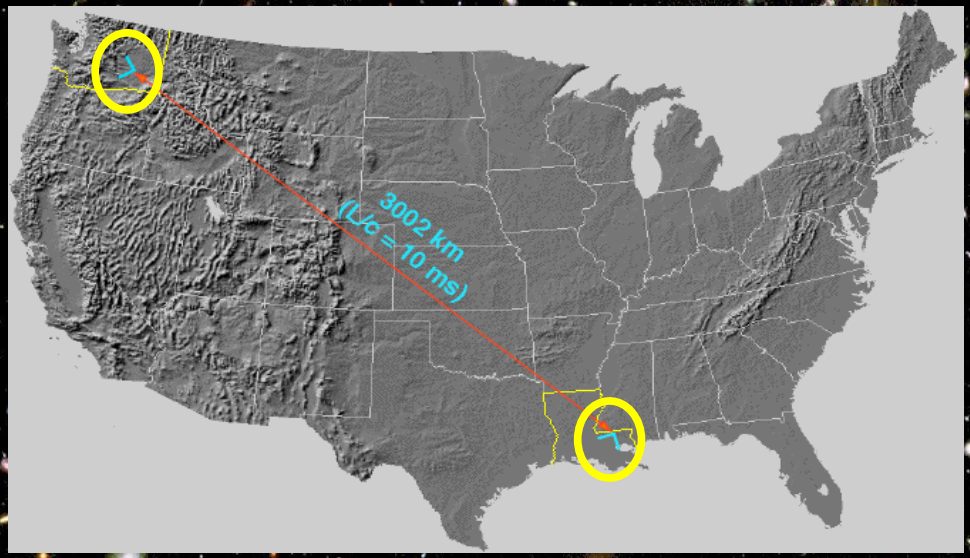
Fiindcă h este mic, L să fie cât mai mare! => L = 4 km; $\Delta L \sim 10^{-19}$m!

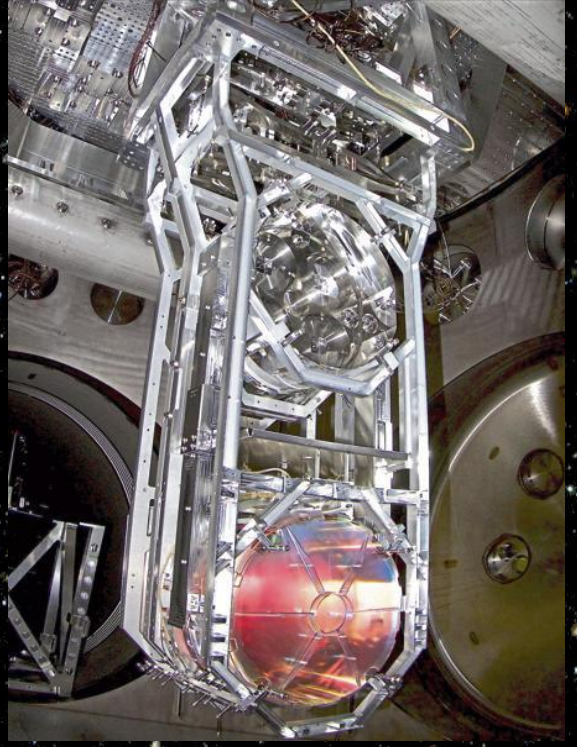


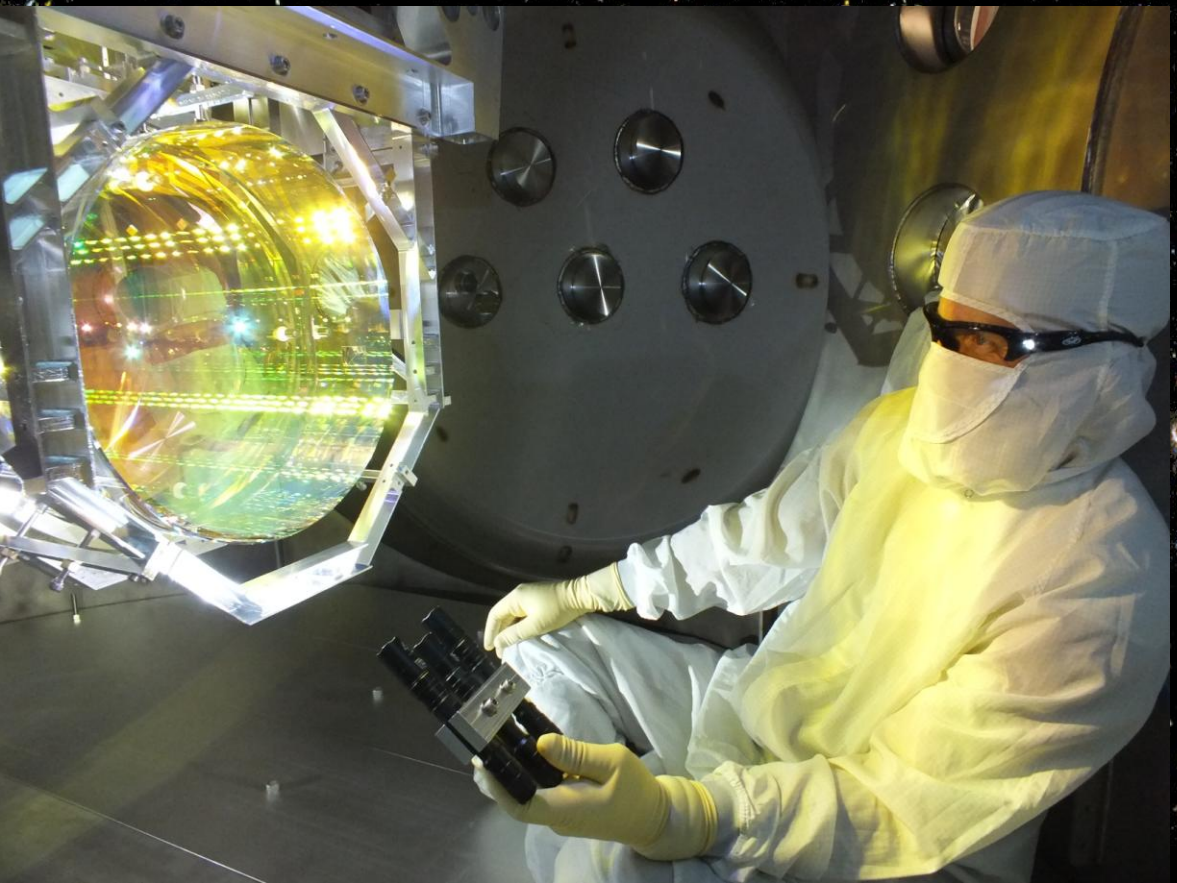
Laser Interferometer Gravitational-wave Observatory (LIGO)

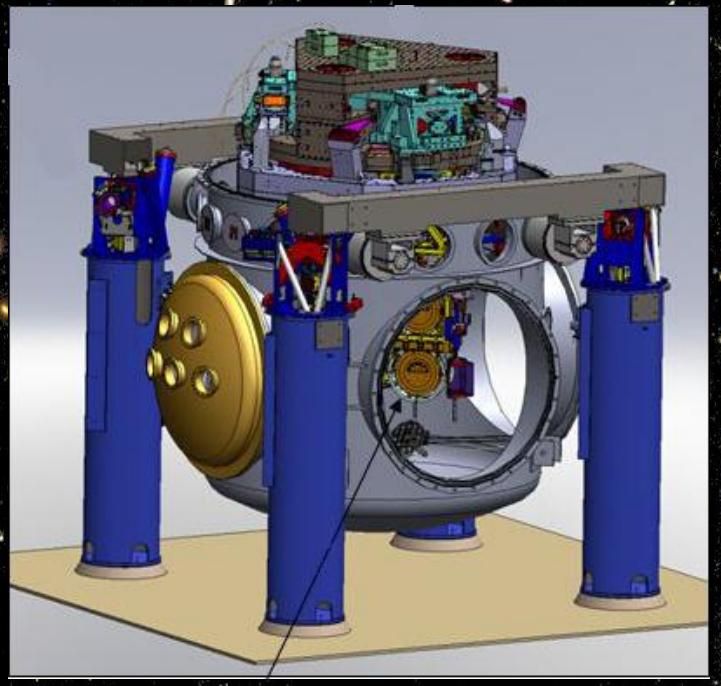






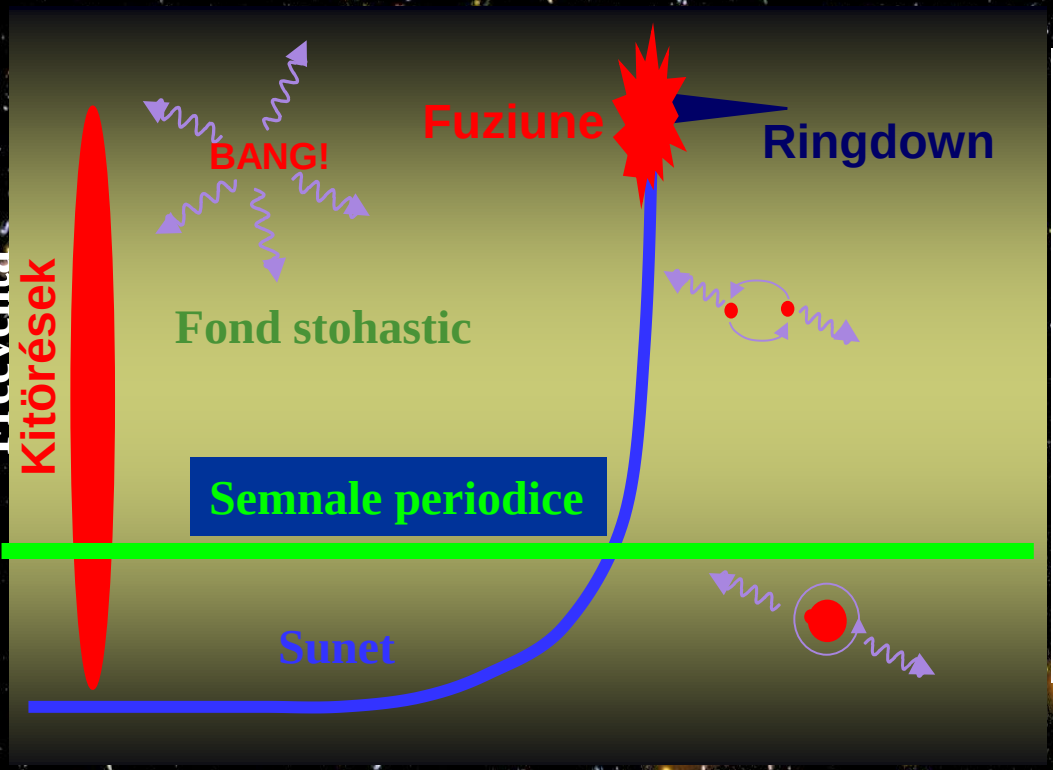


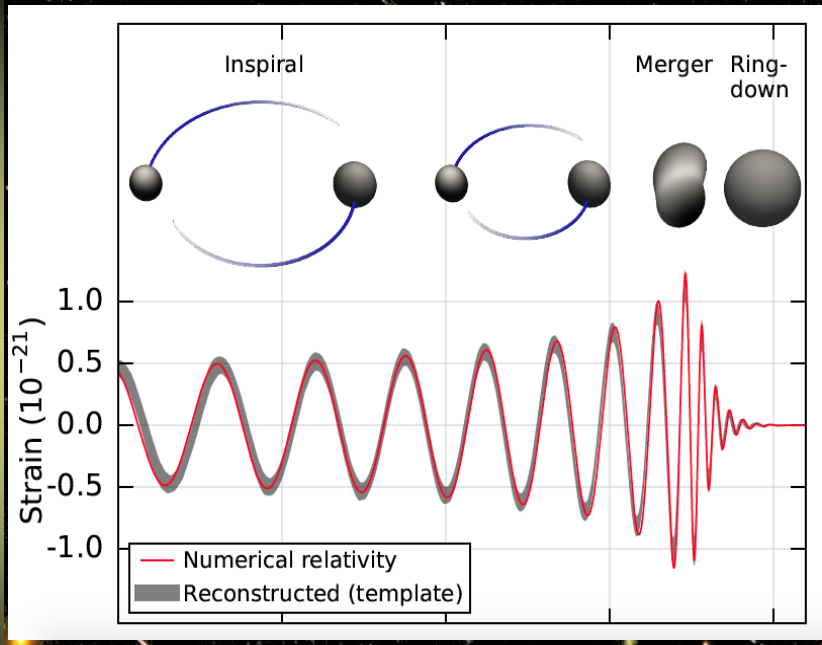


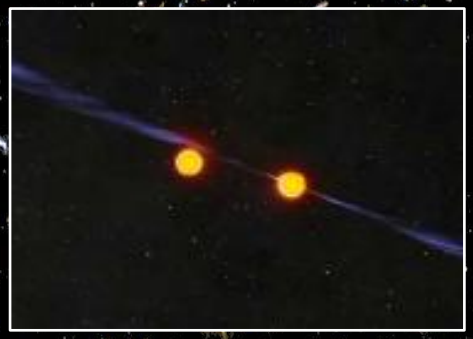


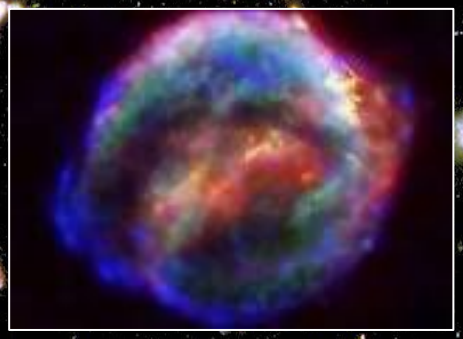
Egy gravitációshullám-detektor háttérzajának hangja

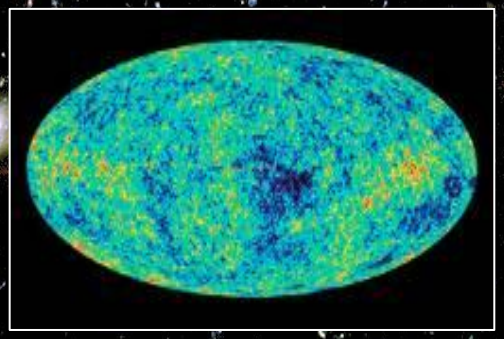
Tipurile de bază ale semnalelor observate cu LIGO











GW150914

LIGO a sesizat din nou o undă gravitațională
A doua sesizare din GW151226 datorată fuziunii găurilor negre

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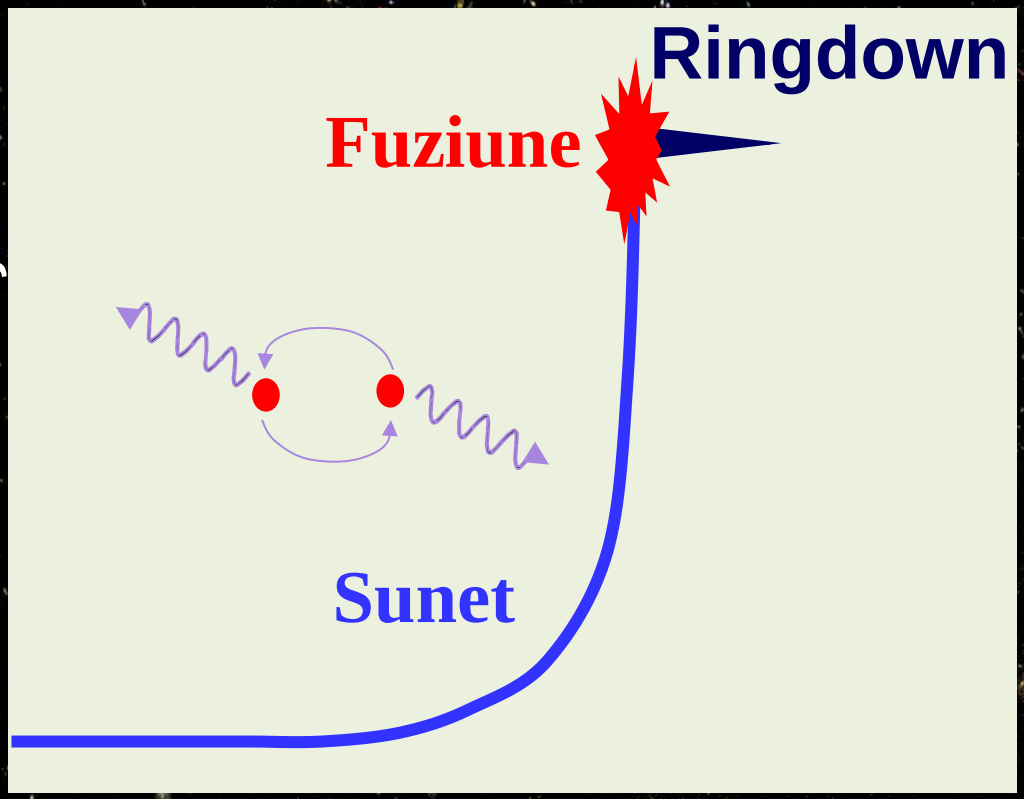
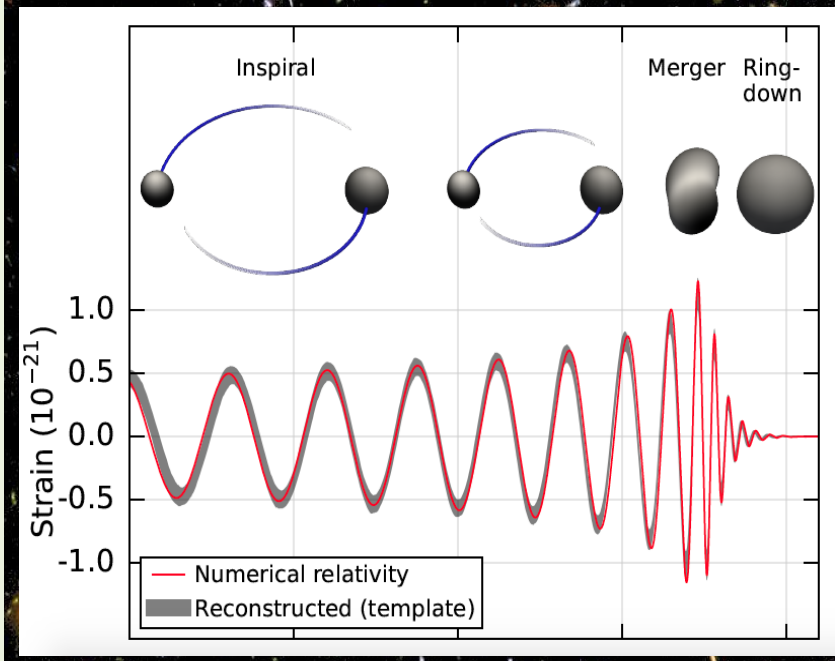

Ringdown
Fuziune
Sunet
Frecventa
Timp


Inspiral
Merger
Ring-
down
1.0
0.5
0.0
-0.5
-1.0
Strain (10^{-21})
Numerical relativity
Reconstructed (template)

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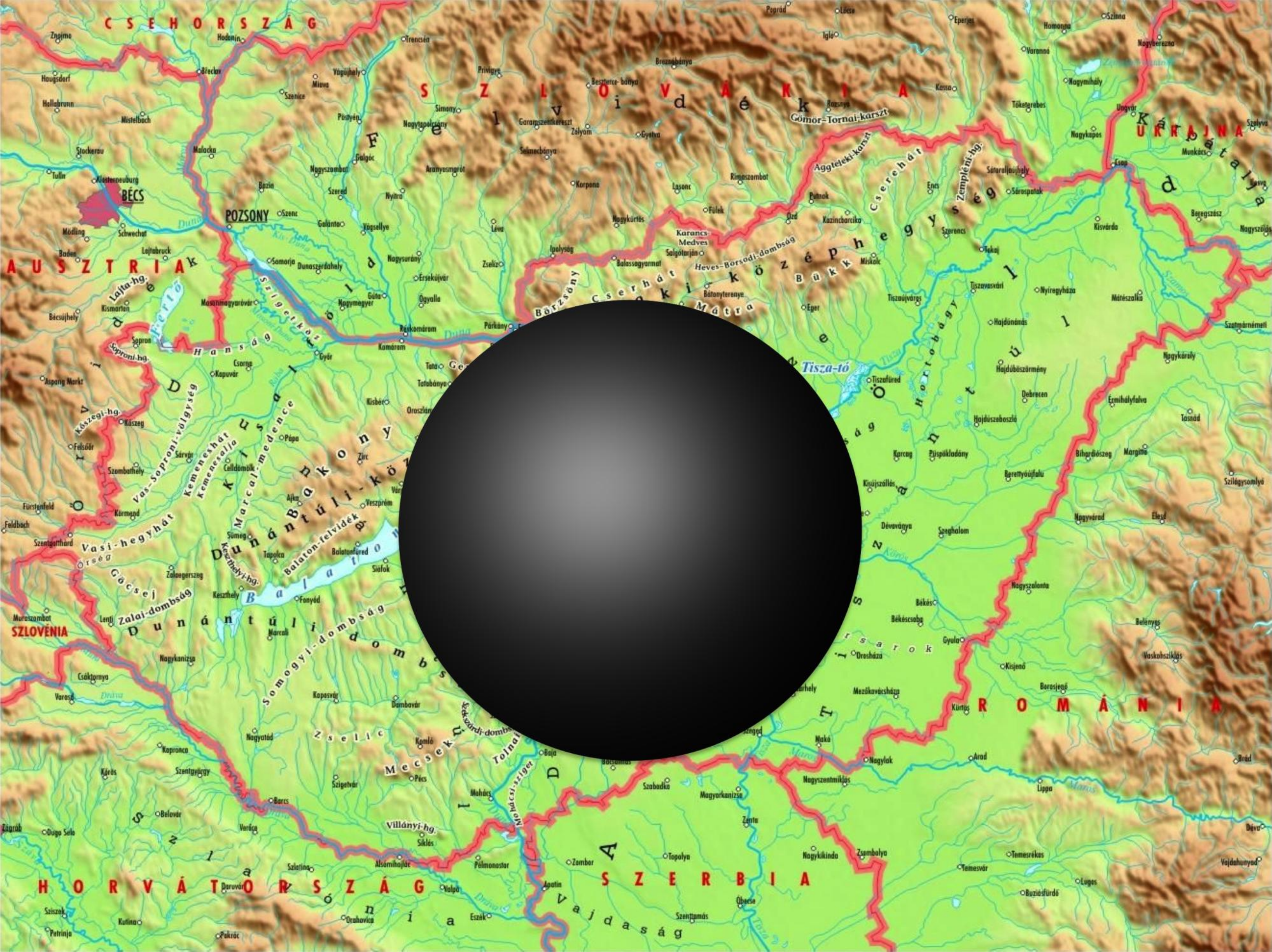
GW150914: FACTSHEET

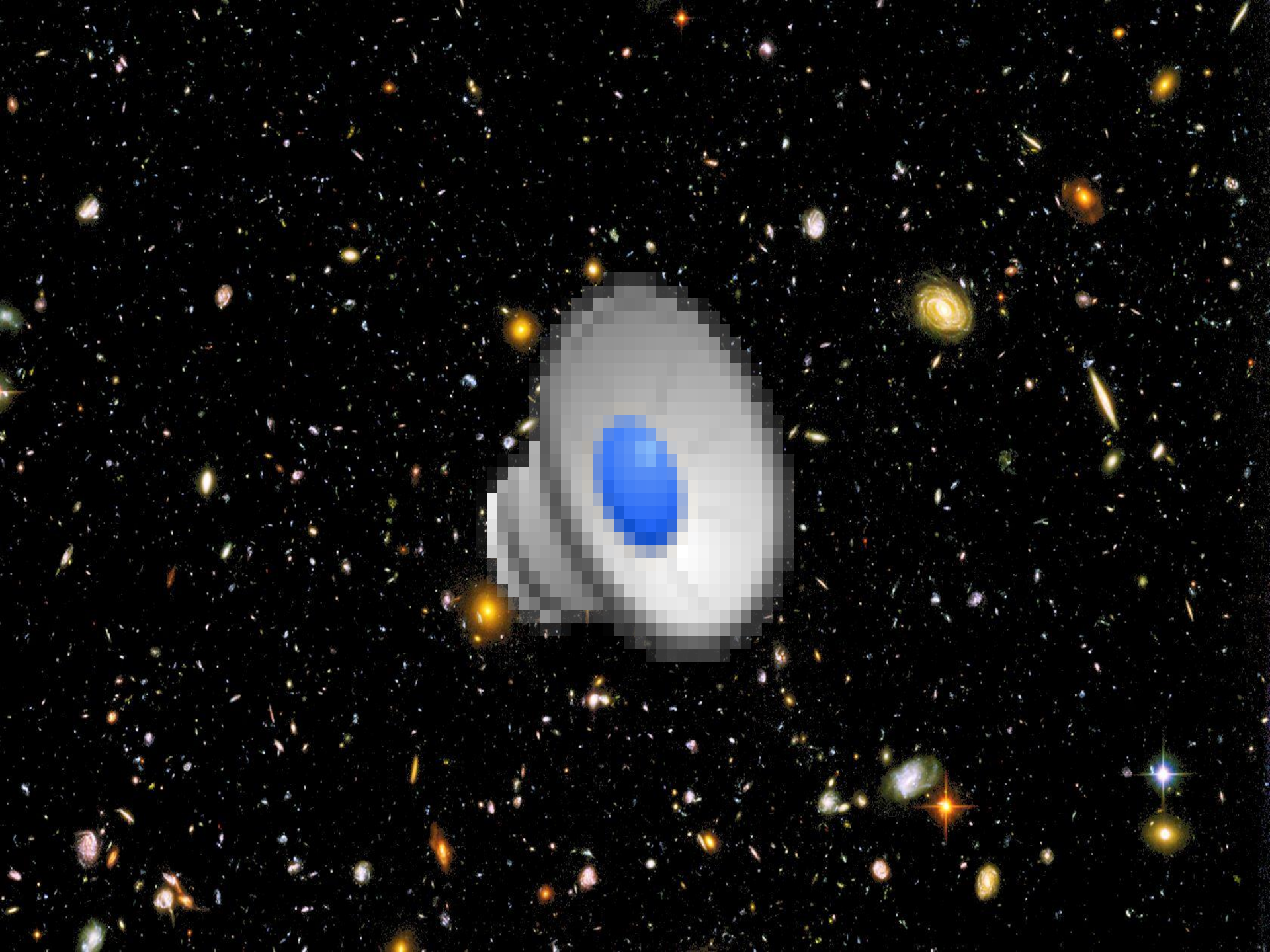
ligo.elte.hu

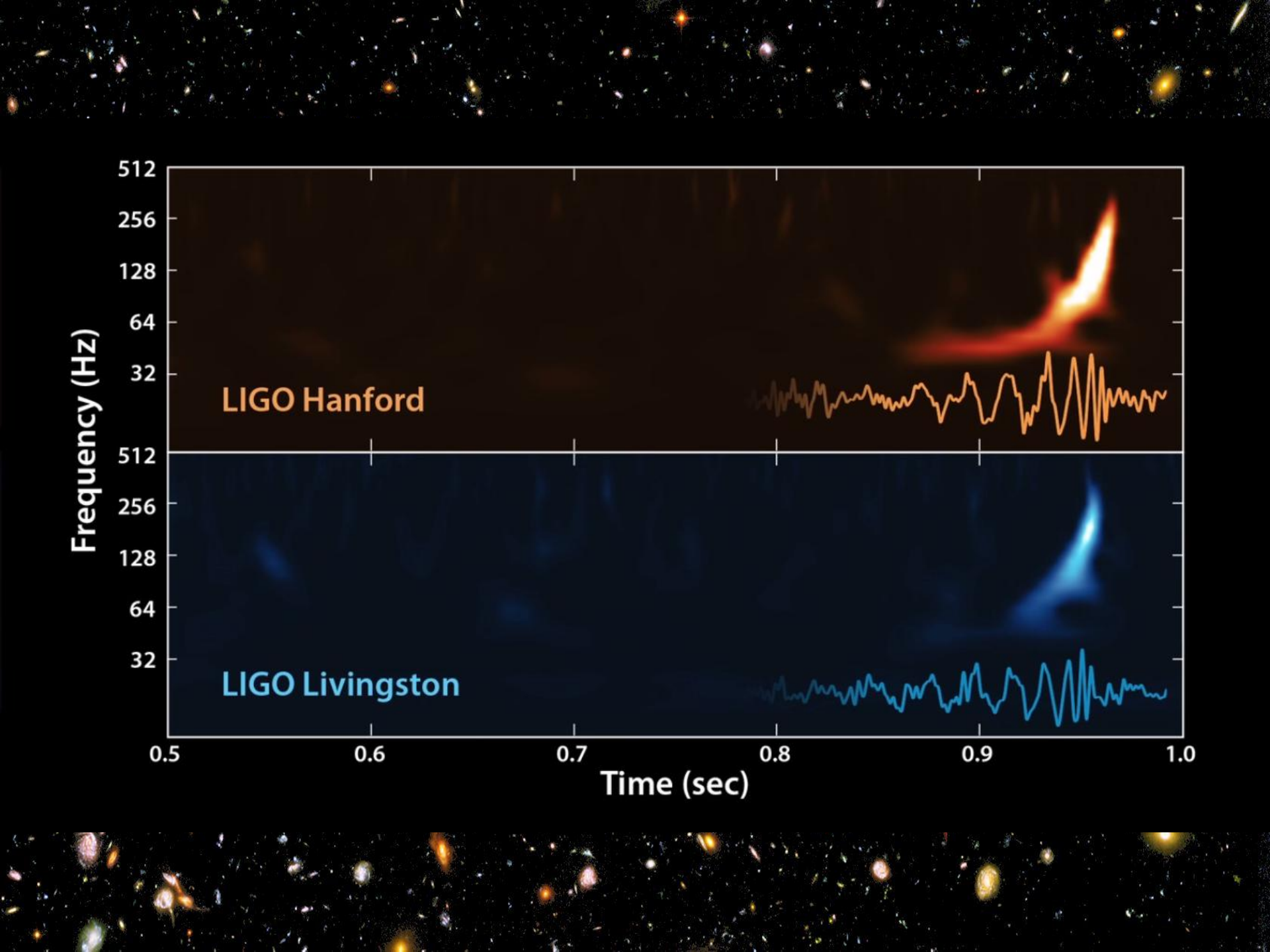
observed by	LIGO L1, H1
source type	black hole (BH) binary
date	14 Sept 2015
time	09:50:45 UTC
likely distance	0.75 to 1.9 Gly 230 to 570 Mpc
redshift	0.054 to 0.136
signal-to-noise ratio	24
false alarm prob.	less than 1 in 5 million
false alarm rate	1 in 200,000 yr
Source Masses	**M⊙**
total mass	65
chirpmass	28
primary BH	32 to 41
secondary BH	25 to 33
remnant BH	62
mass ratio	0.6 to 1
primary BH spin	< 0.7
secondary BH spin	< 0.9
remnant BH spin	0.7
signal arrival time delay	arrived in L1 7 ms before H1
likely sky position	Southern Hemisphere
likely orientation resolved to	face-on/off ~600 sq. deg.

duration from 30 Hz	~ 200 ms
# cycles from 30 Hz	~10
peak GW strain	1×10^{-21}
peak displacement of interferometers arms	±0.002 fm
frequency/wavelength at peak GW strain	150 Hz, 2000 km
peak speed of BHs	~ 0.6 c
peak GW luminosity	3.6×10^{56} erg s^{-1}
radiated GW energy	2.5-3.5 M⊙
remnant ringdown freq.	~ 250 Hz
remnant damping time	~ 4 ms
remnant size, area	180 km, 3.5×10^5 km^2
consistent with general relativity?	passes all tests performed
graviton mass bound	$< 1.2 \times 10^{-22}$ eV
coalescence rate	2 to 400 Gpc^{-3} yr^{-1}
online trigger latency	~ 3 min
# offline analysis pipelines	5
CPU hours consumed	~ 50 million (=20,000 PCs run for 100 days)
papers on Feb 11, 2016	13
# researchers	~1000, 80 institutions in 15 countries



CSEHORSZÁG
SZLOVÁKIA
AUSZTRIA
UKRAJNA
ROMÁNIA
SZERBIA
HORVÁTORSZÁG
SZLOVÉNIA
BÉCS
POZSONY
Felvidék
Kárpátalja
Kisalföld
Dunántúli-középhegység
Dunántúli-dombság
Északi-középhegység
Alföld
Tiszántúl
Délvidék
Vajdaság
Szlavónia
Őrvidék
Gömör–Tornai-karszt
Aggteleki-karszt
Cserehát
Zempléni-hg.
Bükk
Mátra
Cserhát
Börzsöny
Heves–Borsodi-dombság
Karancs-Medves
Hortobágy
Tisza-tó
Bakony
Balaton
Balaton-felvidék
Keszthelyi-hg.
Marcal-medence
Kemeneshát
Kemenesalja
Vas–Soproni-síkság
Vasi-hegyhát
Őrség
Göcsej
Zalai-dombság
Somogyi-dombság
Zselic
Mecsek
Villányi-hg.
Mohácsi-sziget
Szekszárdi-dombság
Szigetköz
Hanság
Fertő
Lajta-hg.
Soproni-hg.
Kőszegi-hg.
Dráva
Duna
Tisza
Maros




512
256
128
64
32
LIGO Hanford
512
256
128
64
32
LIGO Livingston
Frequency (Hz)
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)

GW151226

LIGO a sesizat din nou o undă gravitațională
A doua sesizare din GW151226 datorată fuziunii găurilor negre

ligo.elte.hu

GW151226: FACTSHEET

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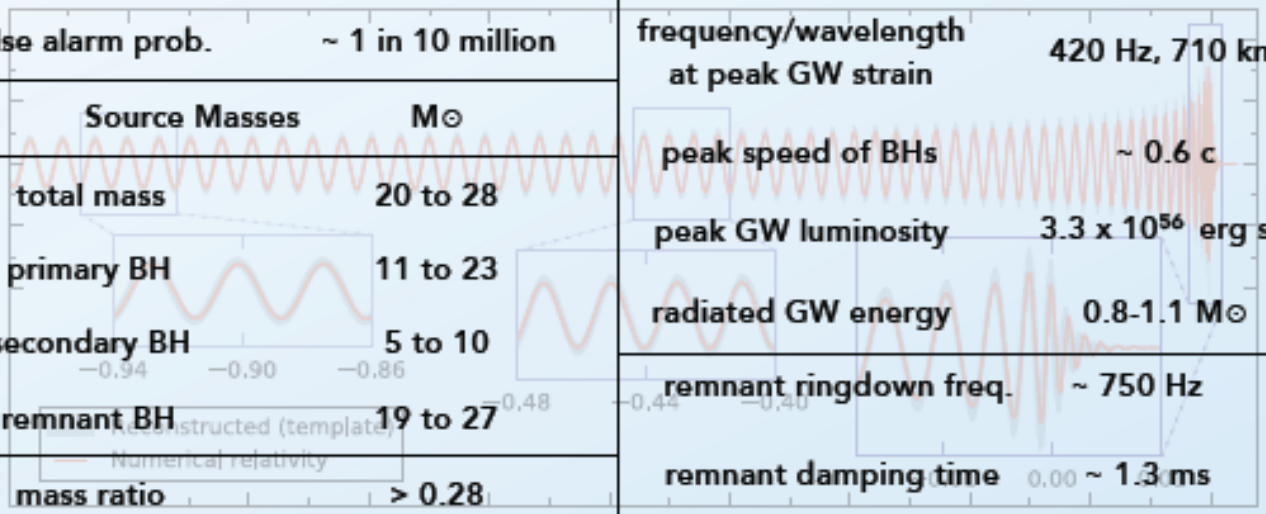
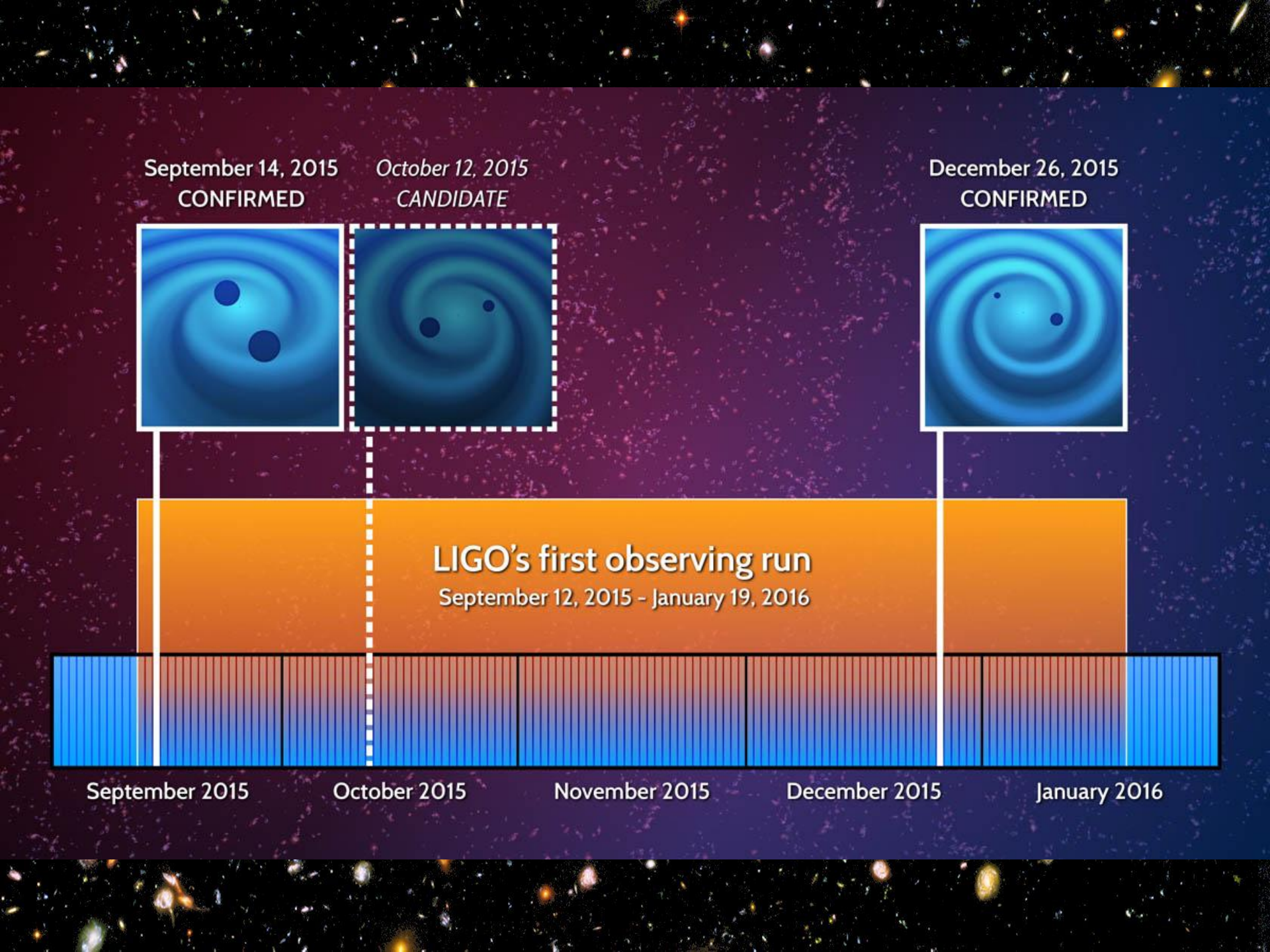
observed by	LIGO L1, H1
source type	black hole (BH) binary
date	26 Dec 2015
time	03:38:53 UTC
likely distance	250 to 620 Mpc
redshift	0.05 to 0.12
signal-to-noise ratio	13
false alarm prob.	~ 1 in 10 million
Source Masses	**M⊙**
total mass	20 to 28
primary BH	11 to 23
secondary BH	5 to 10
remnant BH	19 to 27
mass ratio	> 0.28
primary BH spin	> 0.2
remnant BH spin	0.7 to 0.8
resolved to	~850 sq. deg.

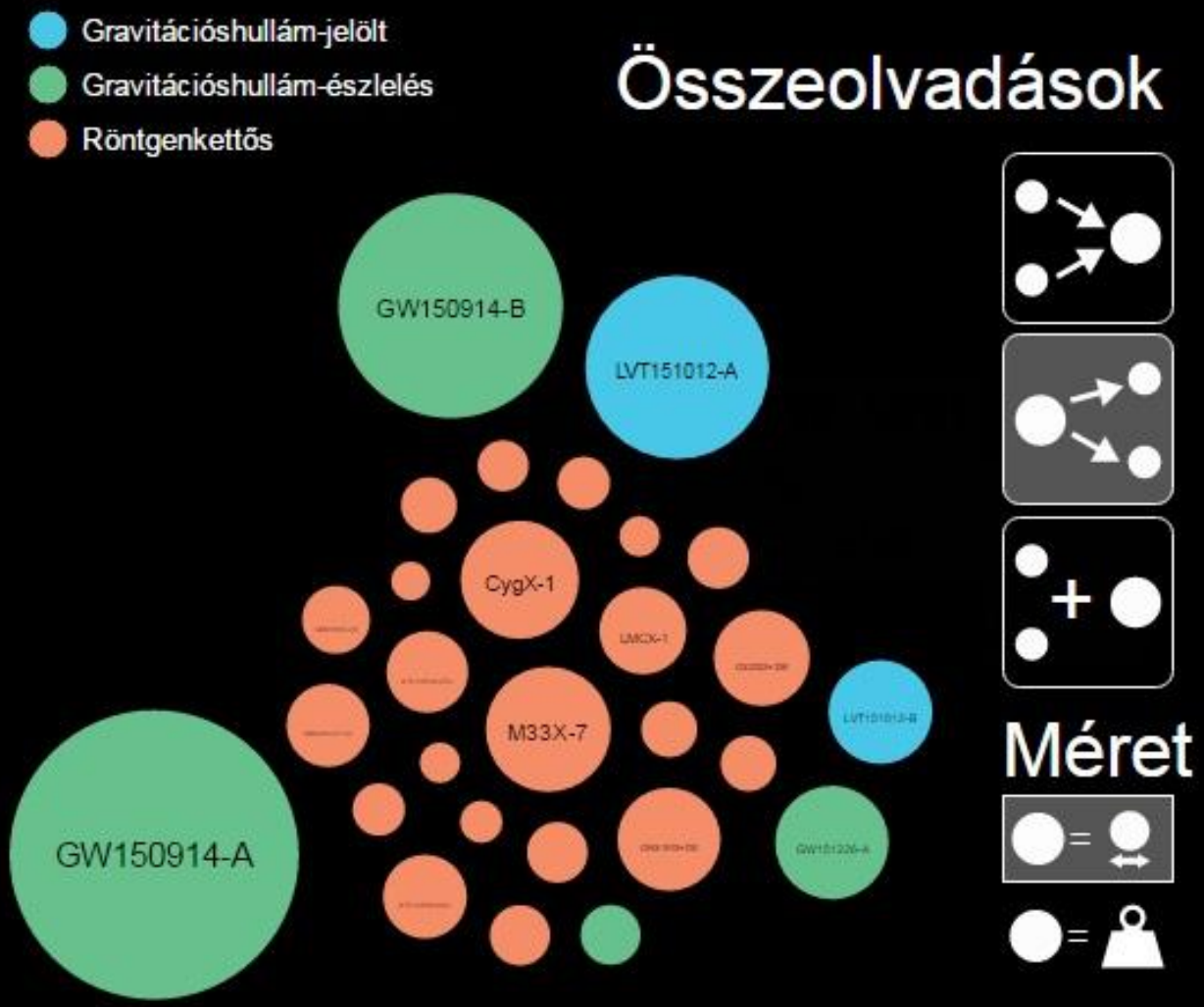
duration from 35 Hz	1.0 s
# cycles from 35 Hz	55
signal arrival time delay	arrived in H1 1 ms after L1
peak GW strain	3.5×10^{-22}
peak displacement of interferometers arms	±0.7 am
frequency/wavelength at peak GW strain	420 Hz, 710 km
peak speed of BHs	~ 0.6 c
peak GW luminosity	3.3×10^{56} erg s^{-1}
radiated GW energy	0.8-1.1 M⊙
remnant ringdown freq.	~ 750 Hz
remnant damping time	~ 1.3 ms
remnant size, area	60 km, 3.5×10^4 km^2
online trigger latency	~ 3 min
# offline analysis pipelines	2



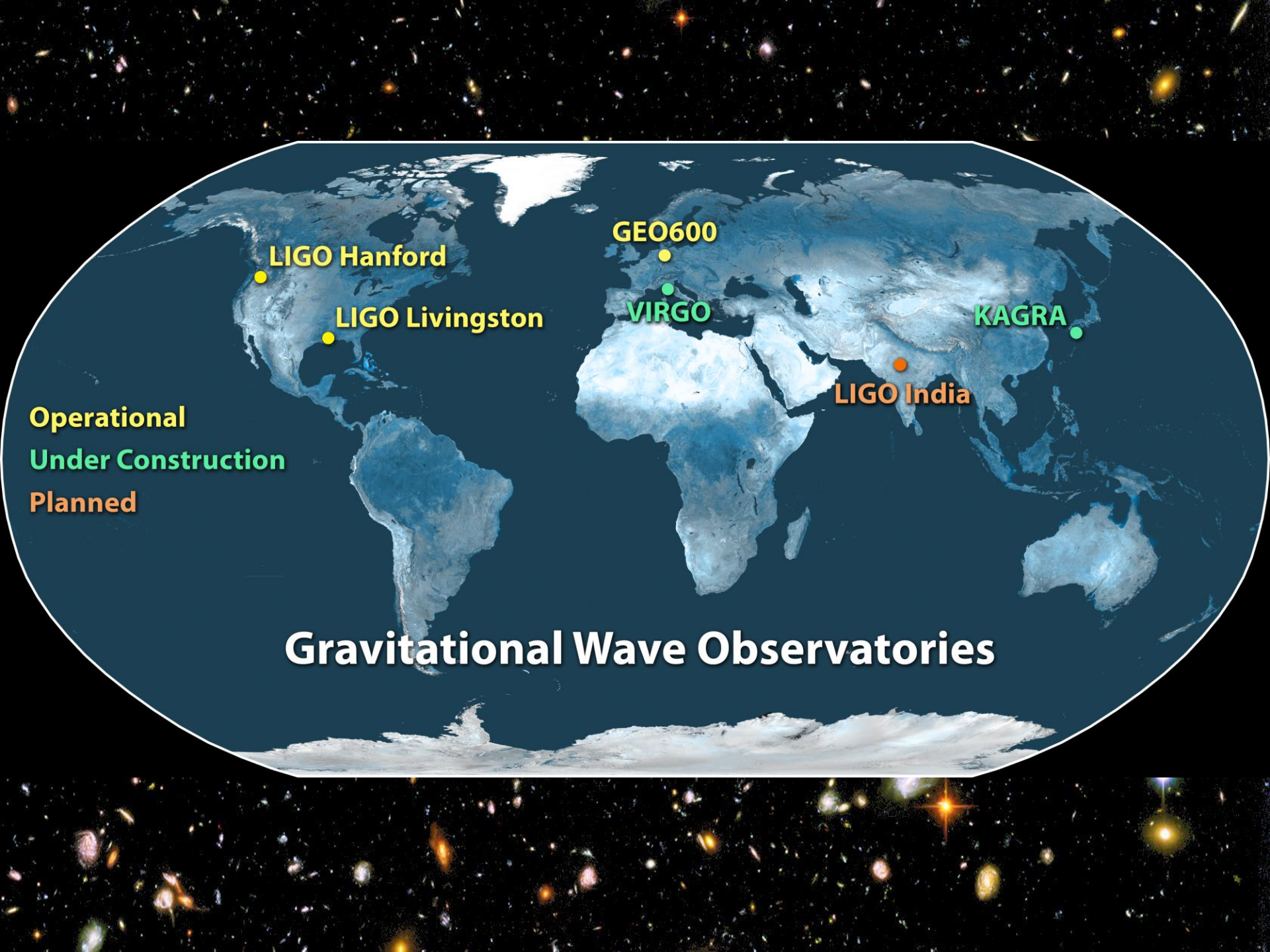

September 14, 2015
CONFIRMED
October 12, 2015
CANDIDATE
December 26, 2015
CONFIRMED
LIGO's first observing run
September 12, 2015 - January 19, 2016
September 2015
October 2015
November 2015
December 2015
January 2016

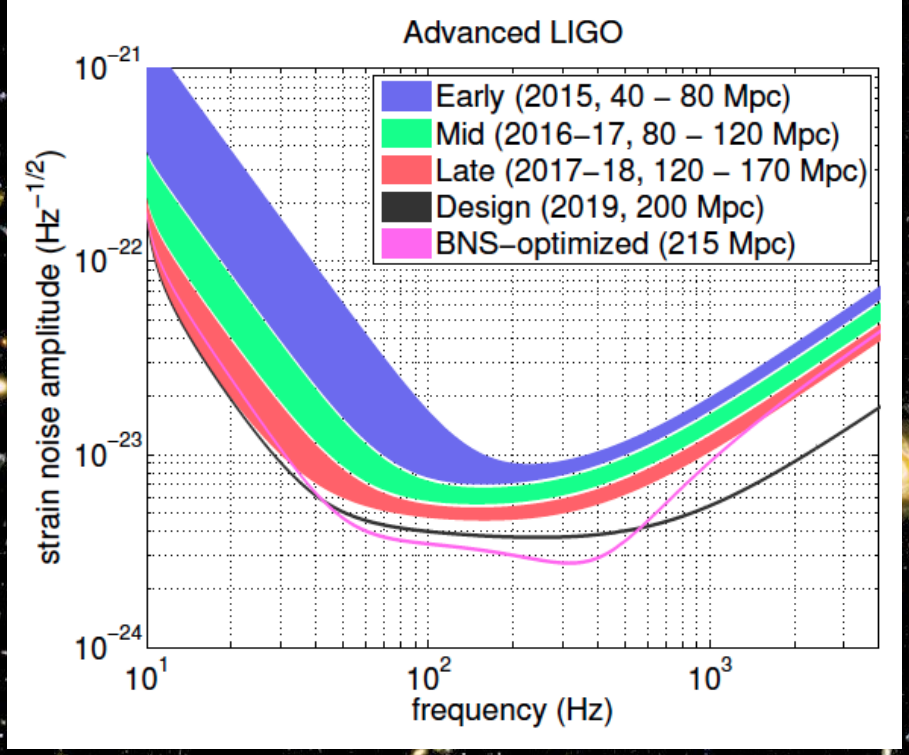
ligo.elte.hu

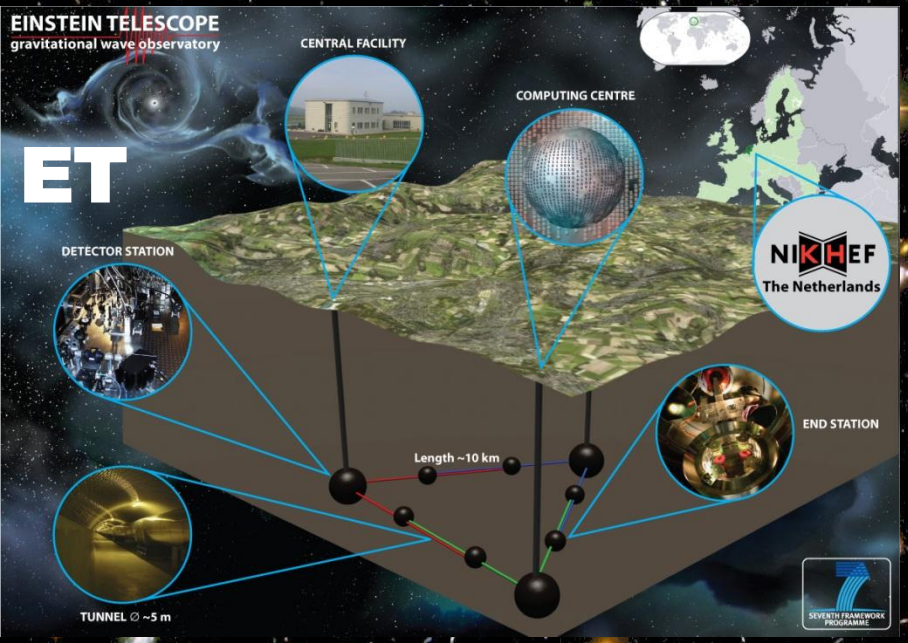
Ismert sztelláris fekete lyukak

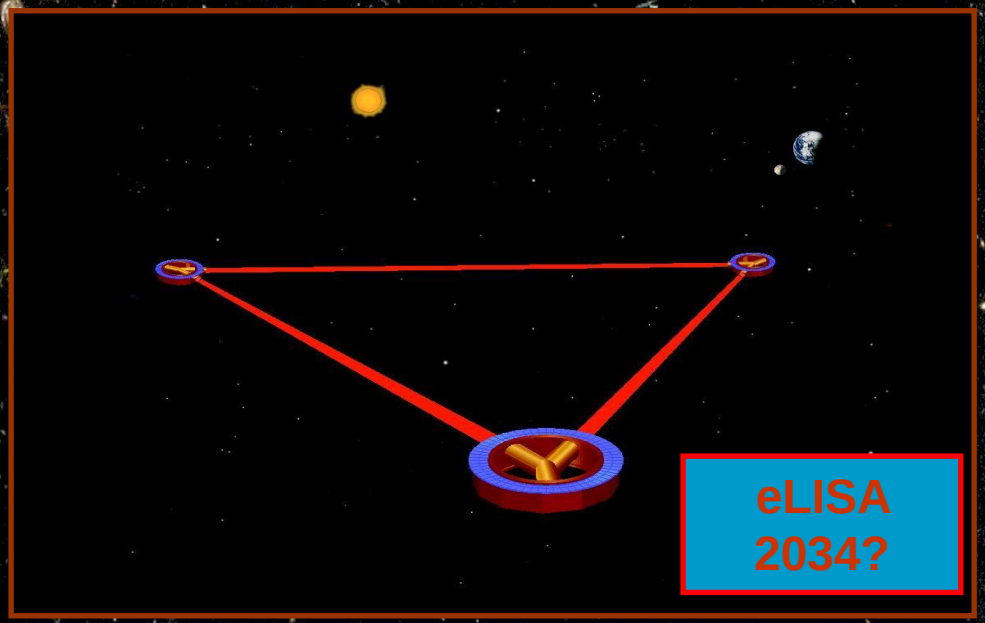


Forrás: Cardiff University School of Physics and Astronomy
Magyar szöveg: Szölgyén Ákos, Dálya Gergely, Raffai Péter
Fejlesztő: Chris North a LIGO Scientific Collaboration megbízásából.
Forráskód megtekintése a GitHub-on.
A röntgenkettősök adatainak forrása: stellarcollapse.org


LIGO Hanford
LIGO Livingston
GEO600
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories


Advanced LIGO
Early (2015, 40 – 80 Mpc)
Mid (2016–17, 80 – 120 Mpc)
Late (2017–18, 120 – 170 Mpc)
Design (2019, 200 Mpc)
BNS–optimized (215 Mpc)
strain noise amplitude (Hz$^{-1/2}$)
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
frequency (Hz)


EINSTEIN TELESCOPE
gravitational wave observatory
ET
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
NIKHEF
The Netherlands
END STATION
Length ~10 km
TUNNEL ∅ ~5 m
SEVENTH FRAMEWORK PROGRAMME


eLISA
2034?

O nouă fereastră spre univers

Verificarea teoriei relativității generale

- Câmp gravitațional puternic
- Propagarea undelor gravitaționale

Astrofizica

- Găuri negre, ciocniri NS
- Structuri NS, WD
- Pulsari
- Explozii de supernove
- Străfulgerări Gamma
- Fizica creșterii
- Proporție Eddington

Cosmologie de precizie

- "Sirene standard"

Structură la scară mică

- Formațiuni sferice
- Nuclee de galaxii

Structură la scară mare

- Formarea de structuri ierarhizate

Bing Bang

- Fond gravitațional

Muzica Universului...

Radiotelescopul ARECIBO 305m

R. Hulse

J. Taylor