

Gravitational Waves: The Nobel Prize of Physics 2017

Odylio Denys Aguiar odylio.aguiar@inpe.br

Divisão de Astrofísica

Instituto Nacional de Pesquisas Espaciais

for the collaborations LIGO (GWINPE- LSC) and Virgo

César A. Costa

Marcos A. Okada

Márcio Constâncio Jr.

Elvis C. Ferreira

Tábata Aira Ferreira

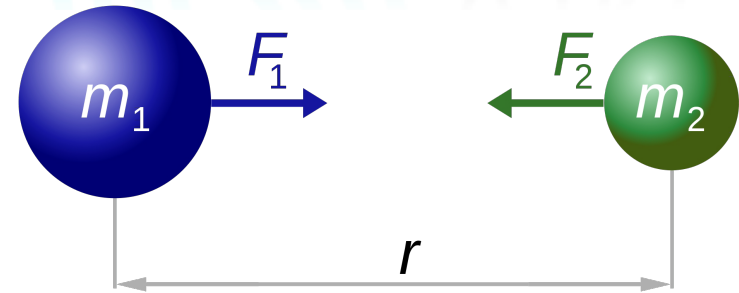


GWINPE



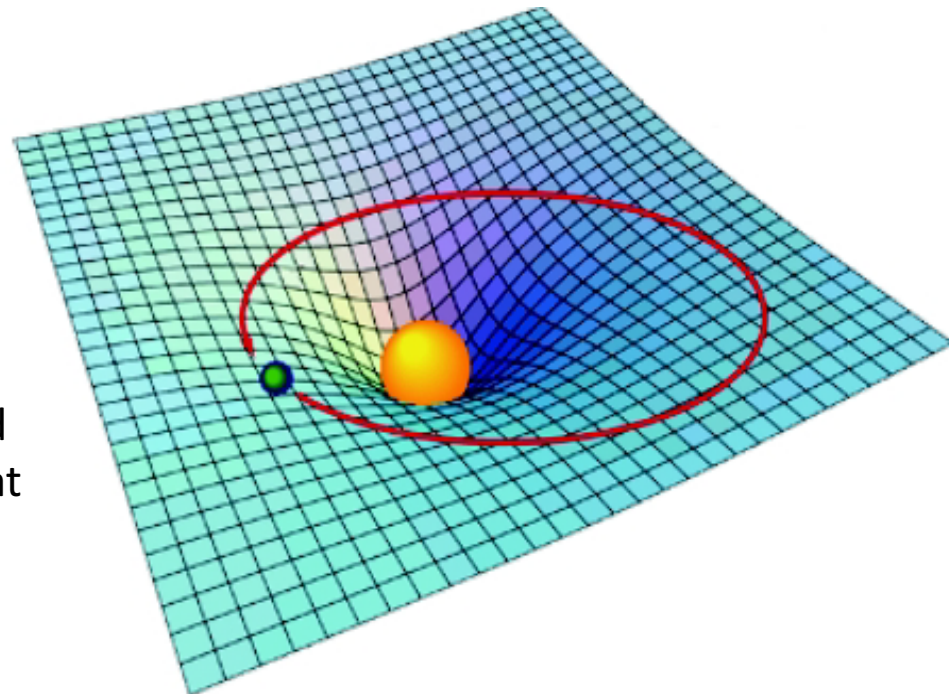
What are Gravitational Waves?

For Newton, Gravity was a force that acted at a distance. If a mass were to change its position, the Universe would receive this information instantly. The space was infinitely rigid.



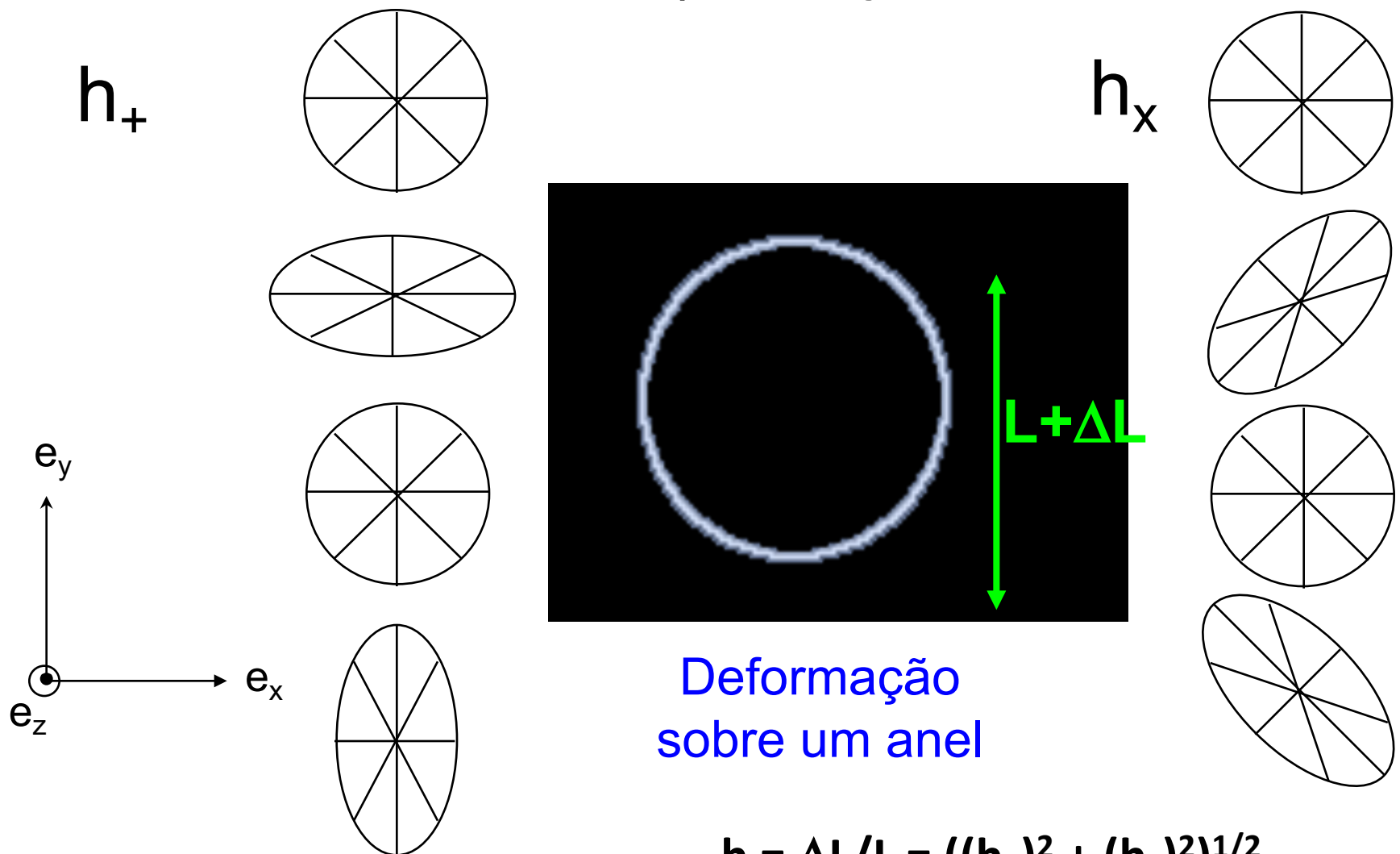
$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$

On the other hand, Einstein claimed that no information could travel at a speed greater than that of light. Space, for Einstein, were to form with time an entity called space-time, which, though very rigid, was not infinitely rigid. The masses, especially the large ones, would cause deformation in this space-time, and this deformed space-time would produce the attractive effects. If a mass were to change its position, this information would be transmitted by ripples in this space-time that would travel at the speed of light. Einstein called these undulations of Gravitational Waves.

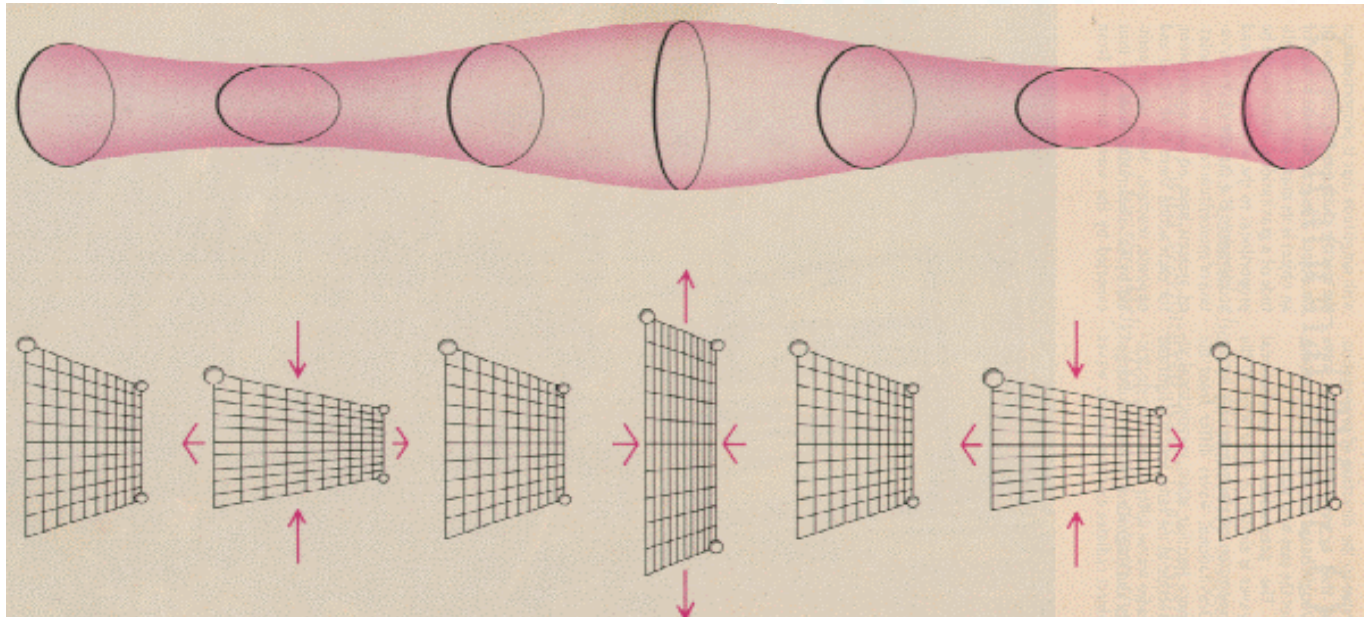


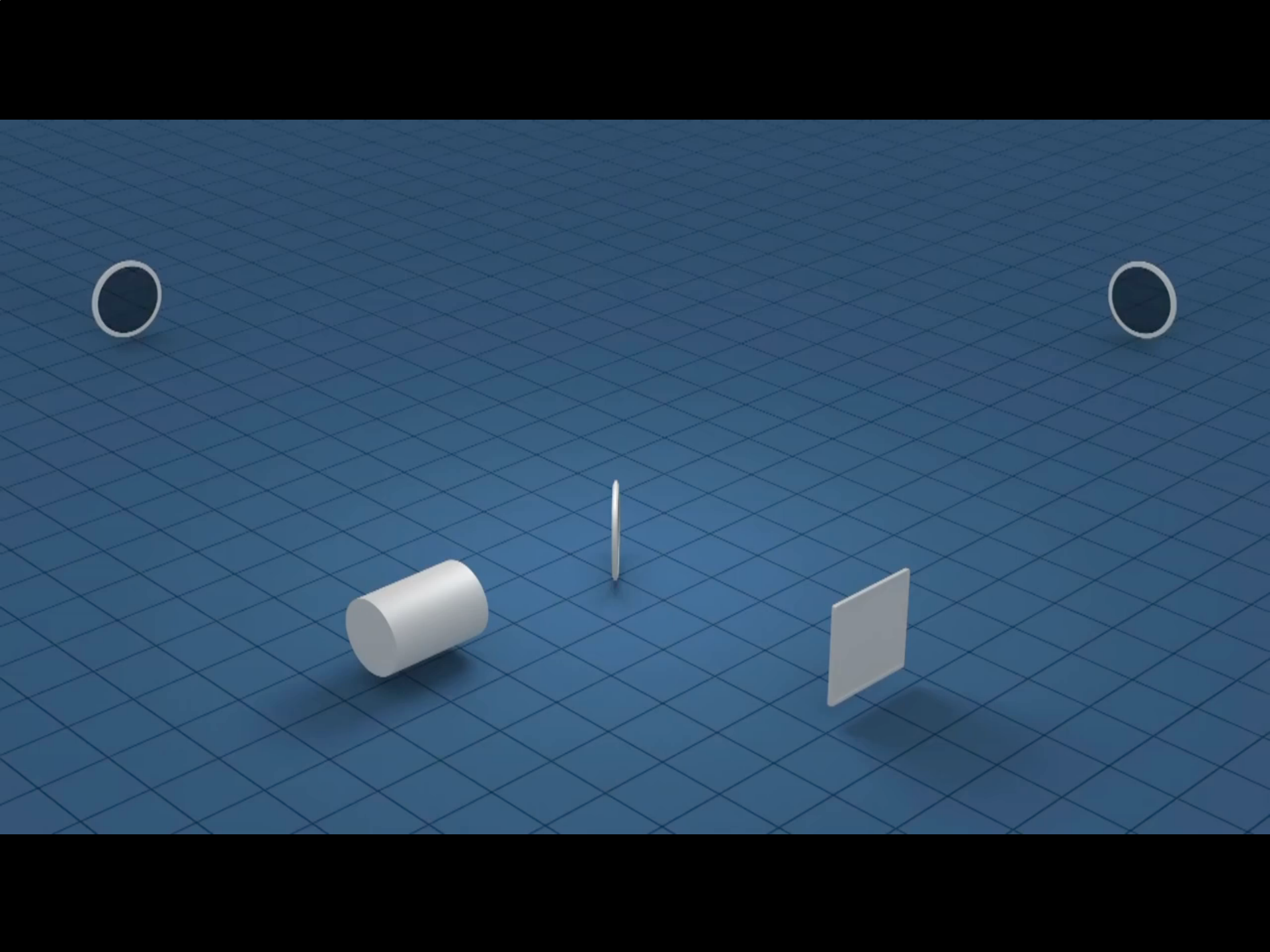
How can we detect/observe
Gravitational Waves?

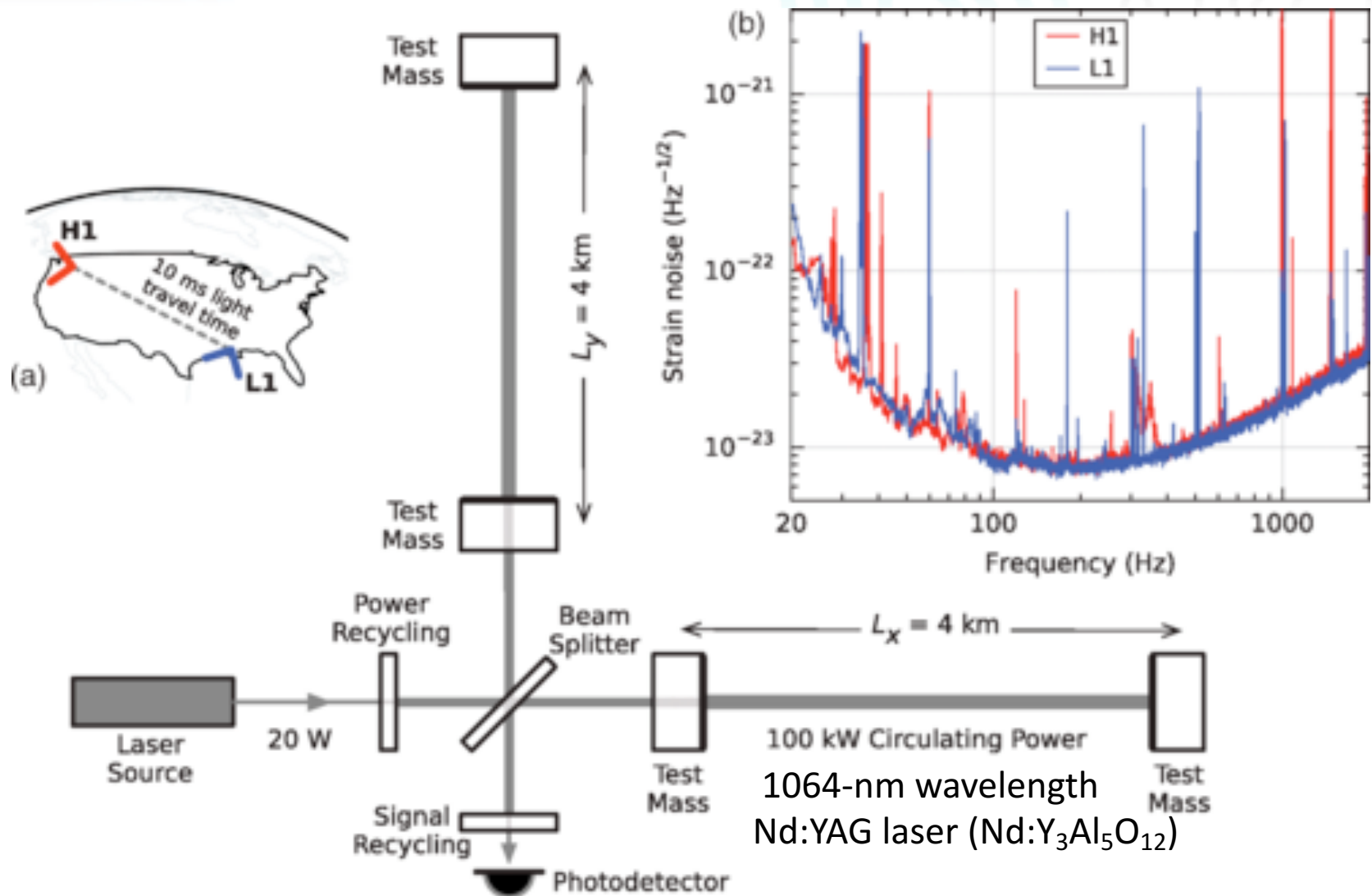
Duas polarizações “+” e “x”



$$h = \Delta L/L = ((h_+)^2 + (h_x)^2)^{1/2}$$











LIGO Scientific Collaboration



Caltech

Andrews University

WASHINGTON STATE UNIVERSITY

CALIFORNIA STATE UNIVERSITY FULLERTON

PennState

SOUTHERN UNIVERSITY AND AGRICULTURAL & MECHANICAL COLLEGE



AMERICAN UNIVERSITY



The University of Sheffield



TEXAS TECH UNIVERSITY



HILLSDALE COLLEGE



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POLYTECHNIQUE MONTREAL



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University of Glasgow



CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD



THE UNIVERSITY OF WESTERN AUSTRALIA



COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

SONOMA STATE UNIVERSITY



UNIVERSITY OF WASHINGTON



LOMONOSOV STATE UNIVERSITY



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Georgia Institute of Technology

Korean Gravitational Wave Group



UNIVERSITÄT HAMBURG



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UTRGV



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Max Planck Institute for Gravitational Physics ALBERT EINSTEIN INSTITUTE



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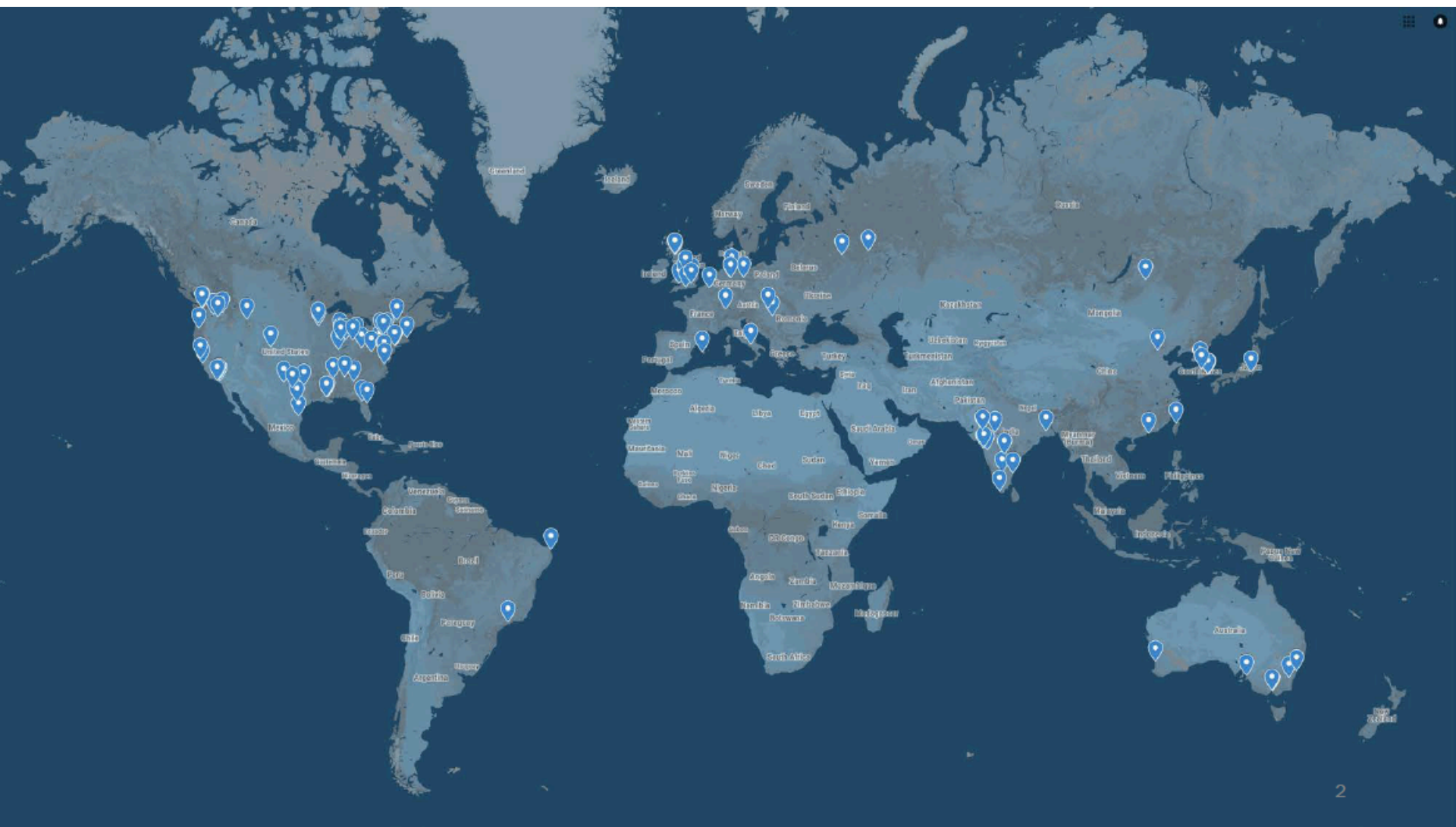
UNIVERSITY OF ZURICH



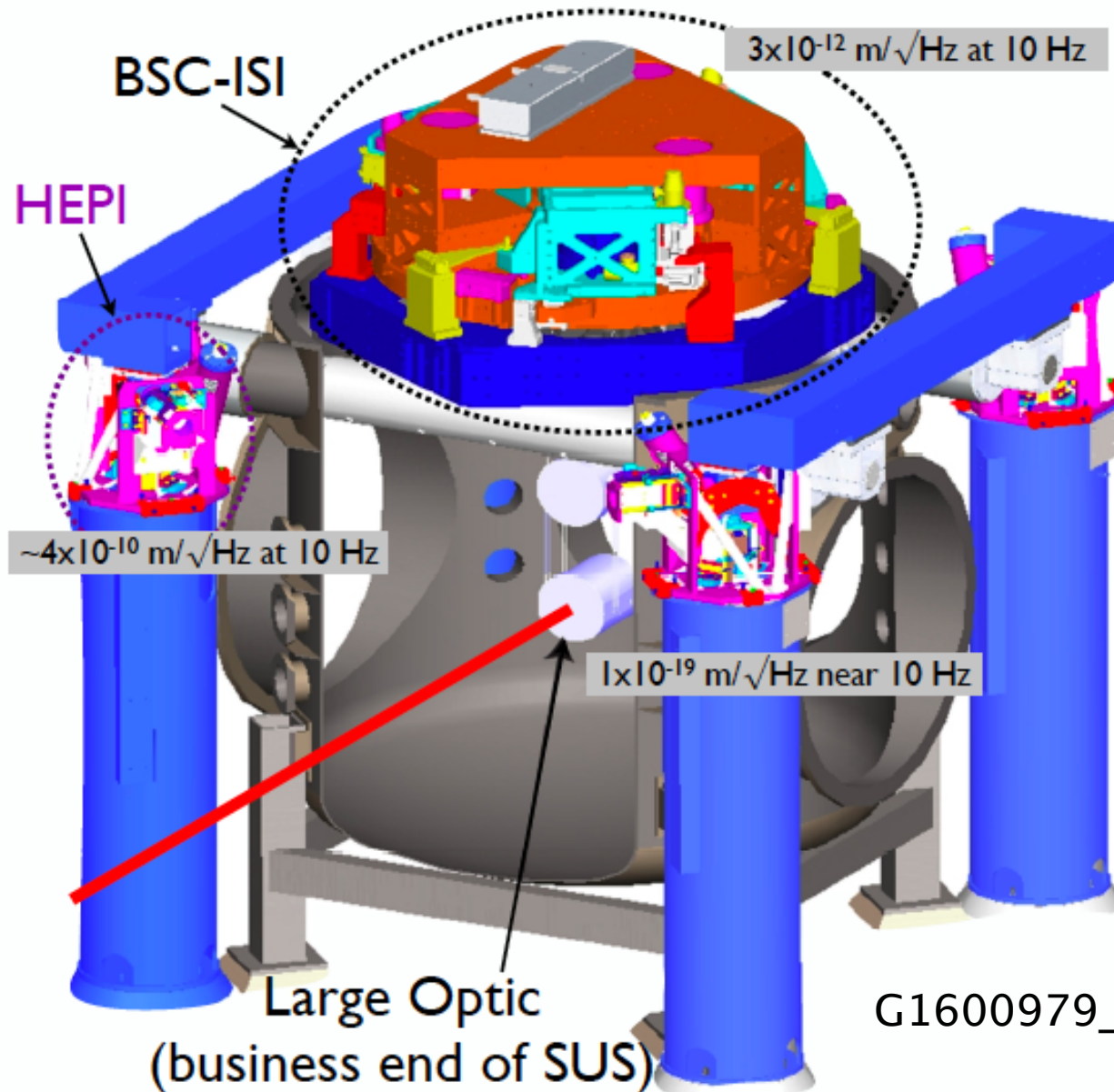
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Overall Isolation of Test Masses



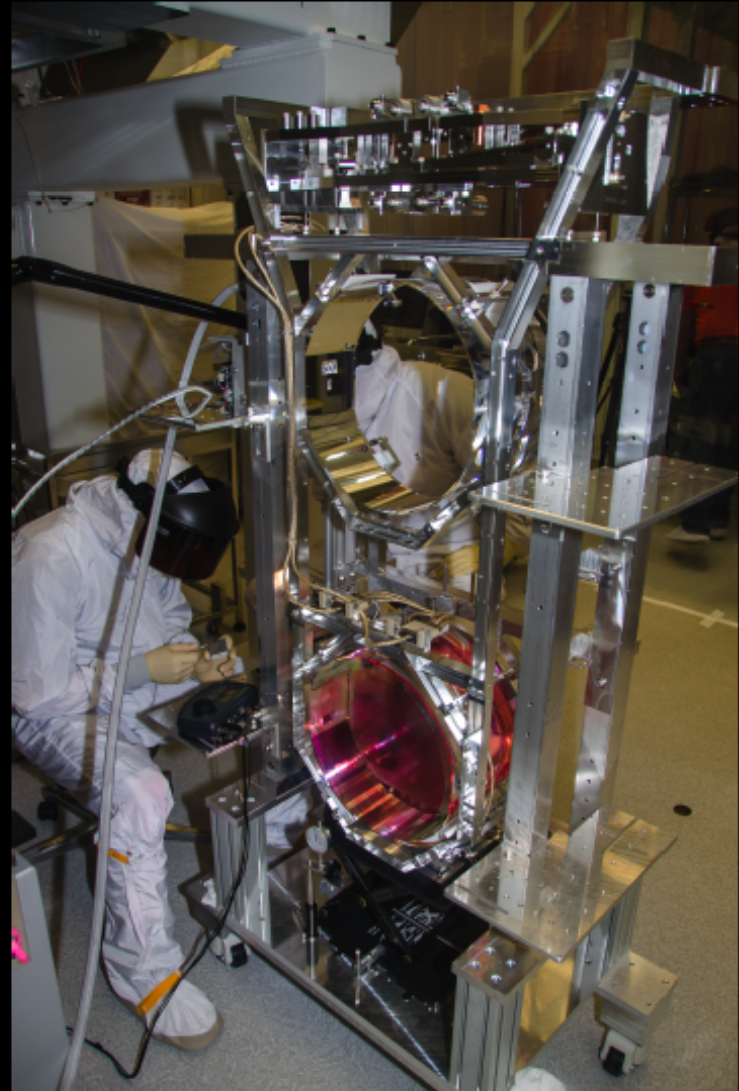
G1600979_Lantz_SLACv3

LIGO

LIGO Vacuum Equipment



Quadruple Pendulum test mass suspension



LIGO Beam Tube



- LIGO beam tube under construction in January 1998
- 16 m spiral welded sections
- girth welded in portable clean room in the field

1.2 m diameter - 3mm stainless
50 km of weld

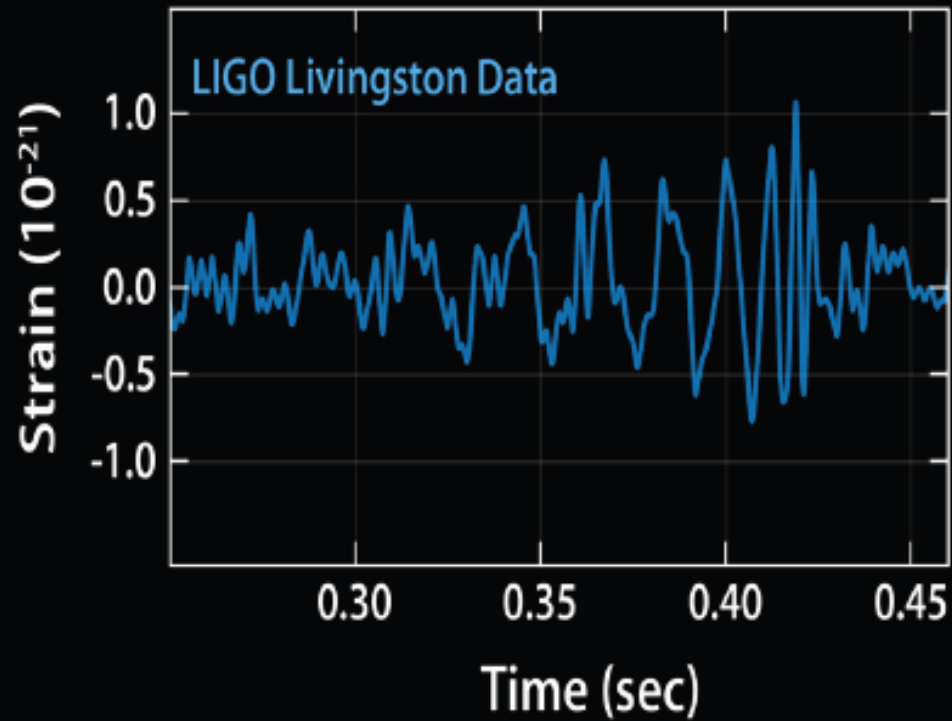
NO LEAKS !!

Gravitational Wave Astrophysics
was inaugurated!

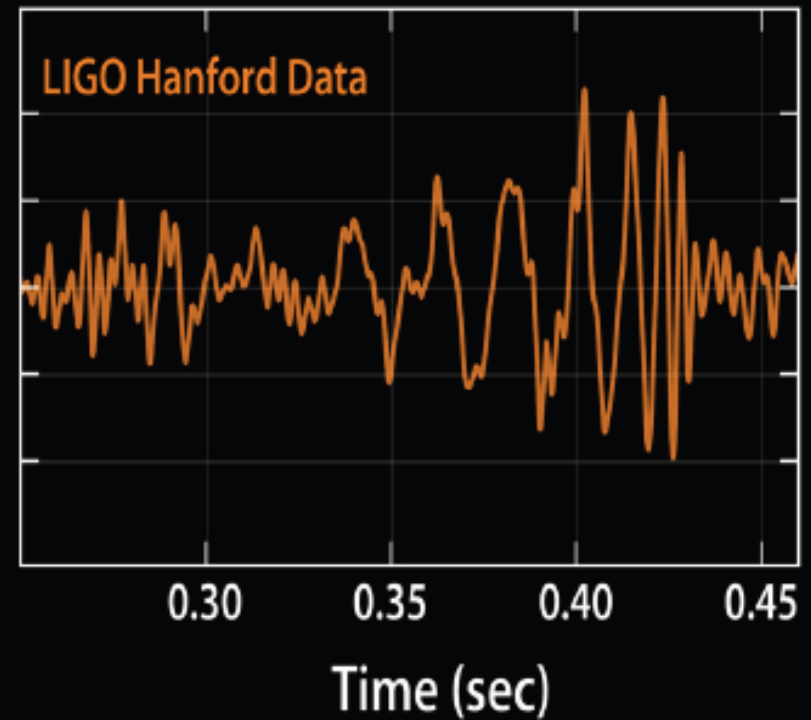
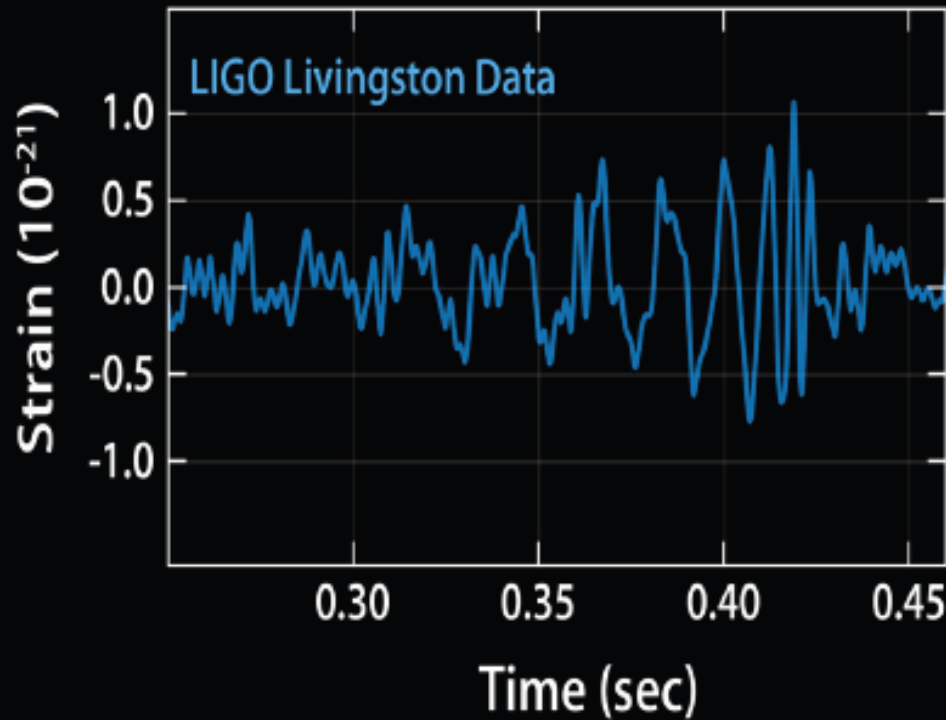


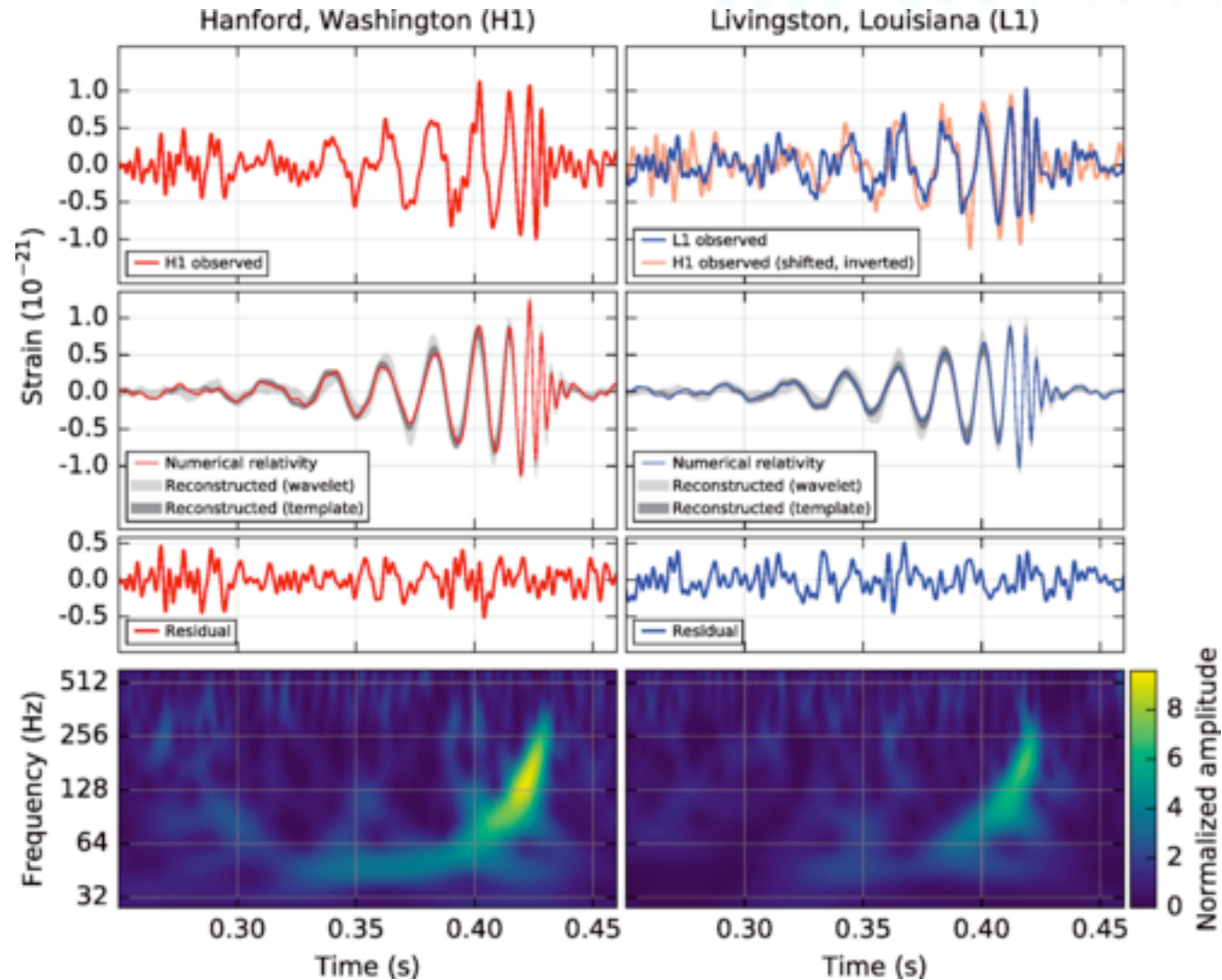
LIGO
Scientific
Collaboration

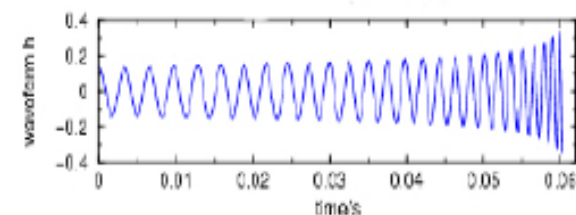
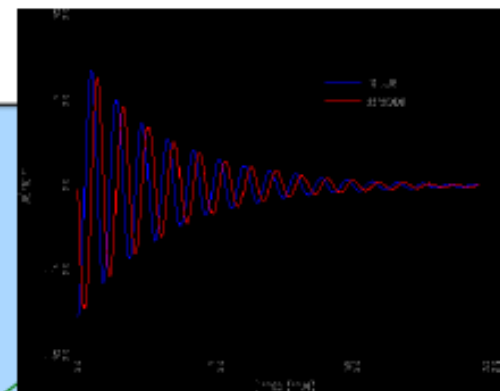
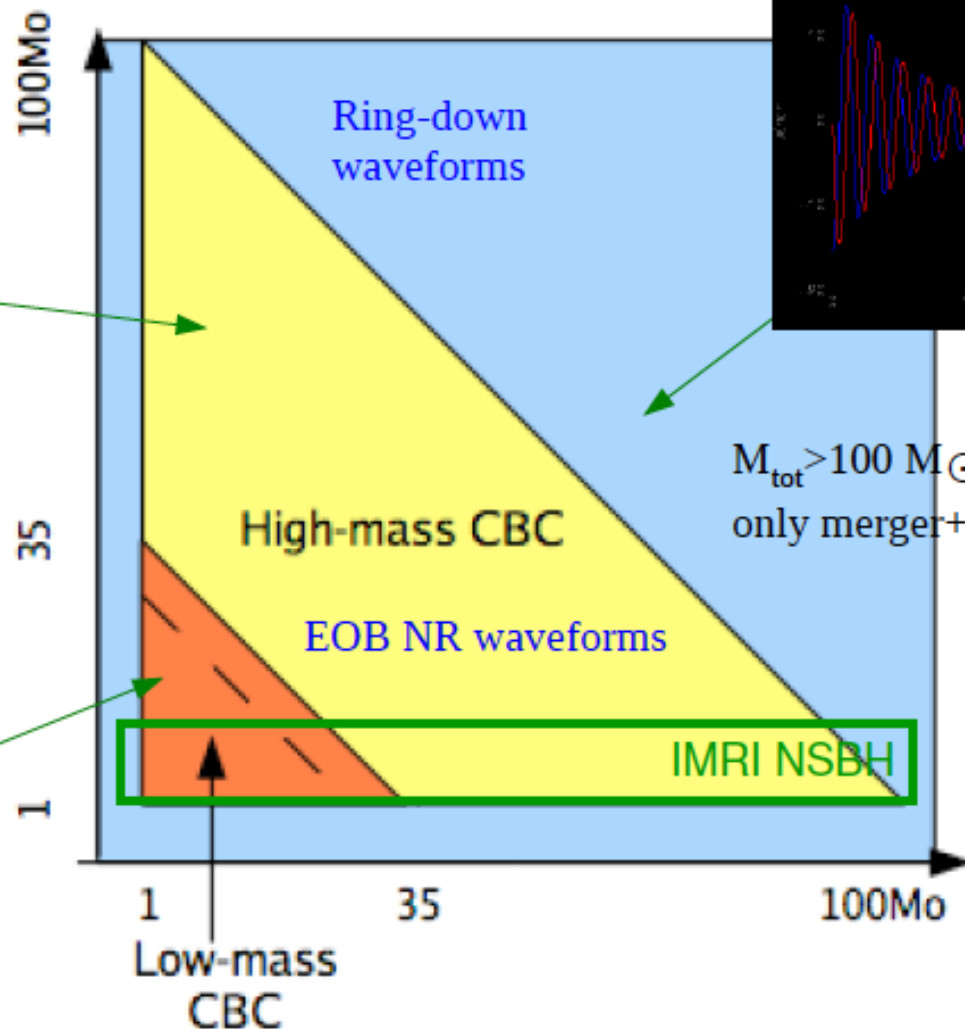
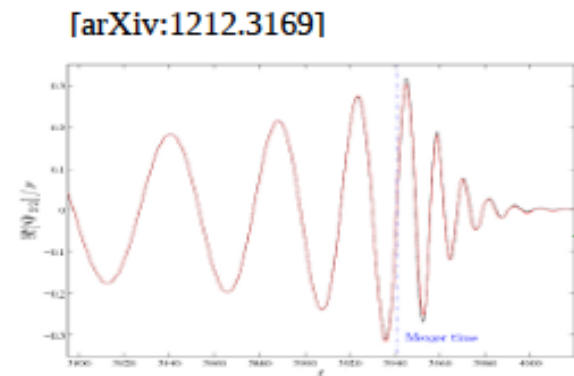
G1701480



and 7 milliseconds later ...

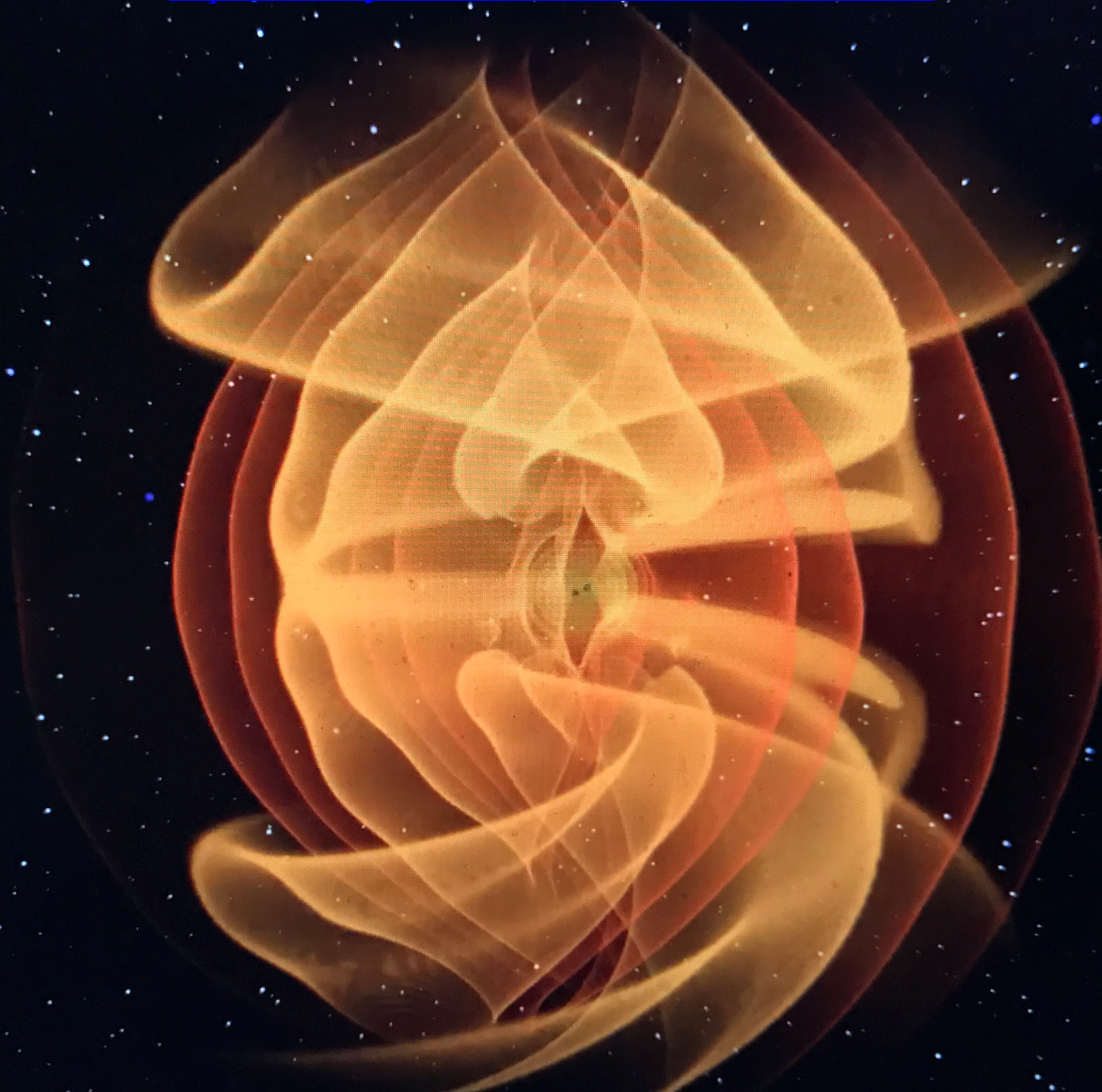






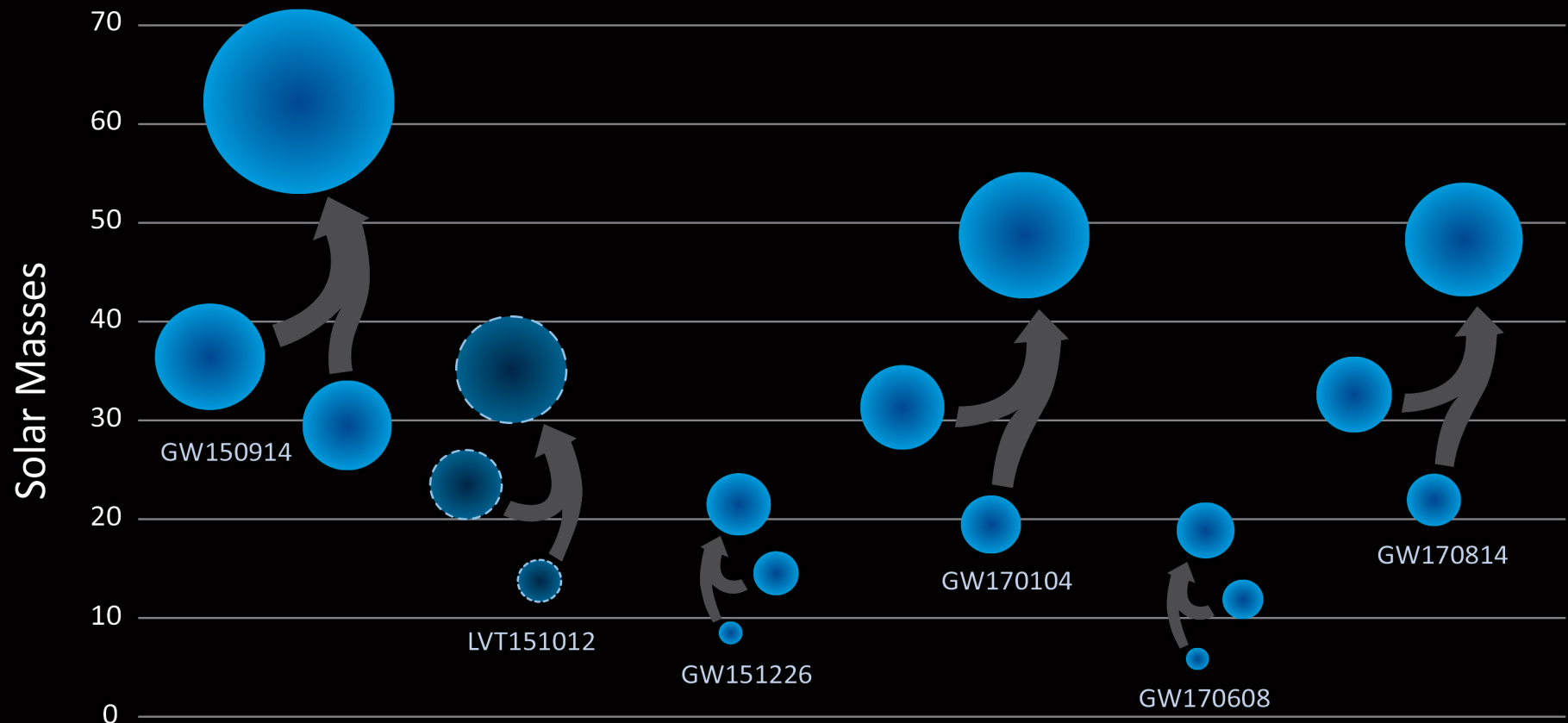
SPA PN waveforms

<https://www.youtube.com/watch?v=kkKDs59zcdI>

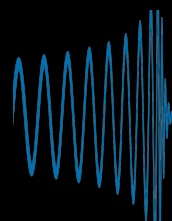


Black Holes of Known Mass

<http://www.ligo.org/detections/GW170608.php>



http://ligo.org/detections/images/GW170814_reconstruction_comparison.png



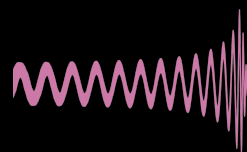
GW150914



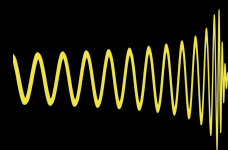
LVT151012



GW151226



GW170104



GW170814

GW170817: the longest (~ 56 seconds),
The most reliable (h small,
but ~3000 cycles → SNR ~ 32),
The nearest (40 Mpc).

0 sec.

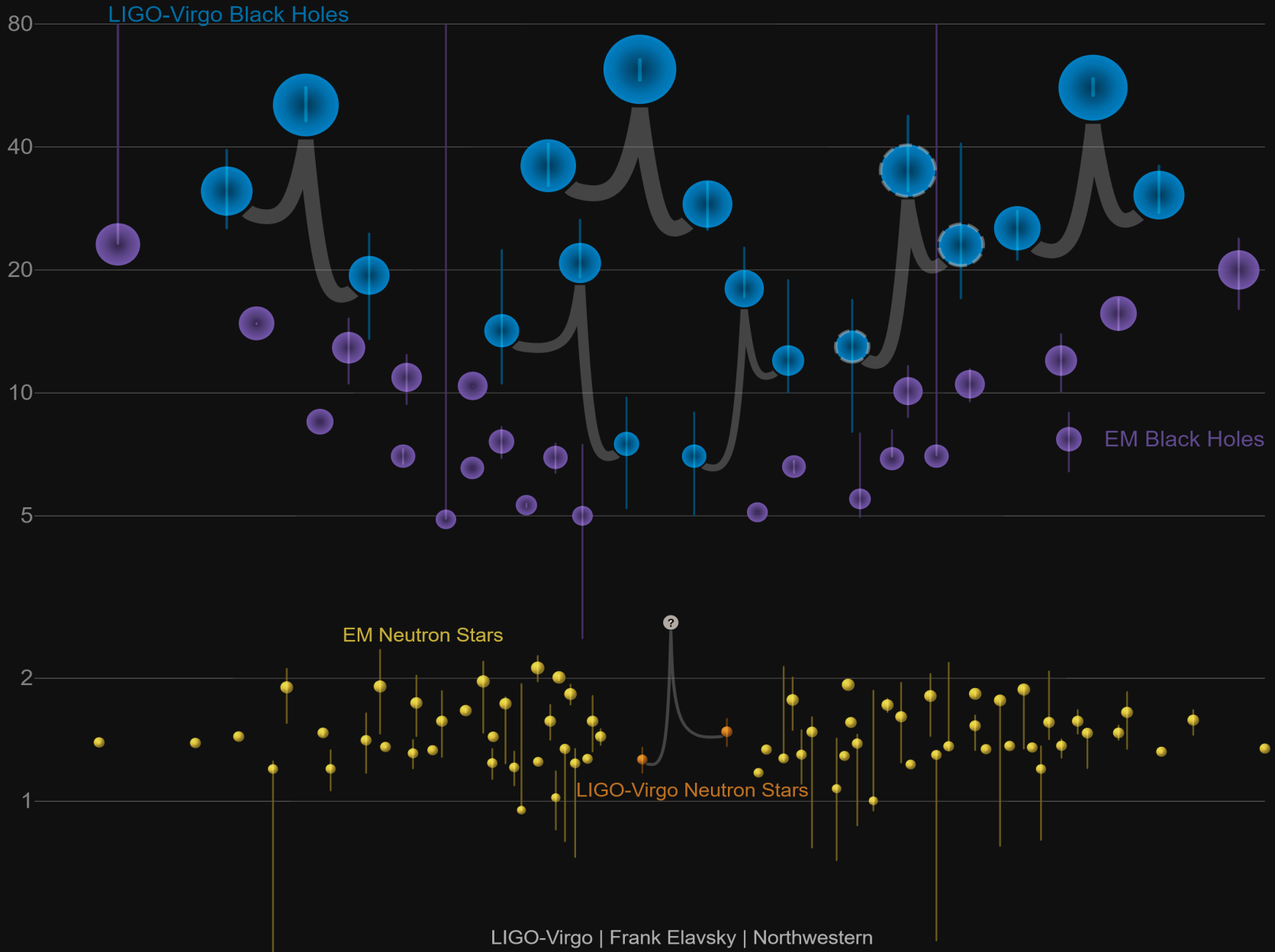
1 sec.

2 sec.

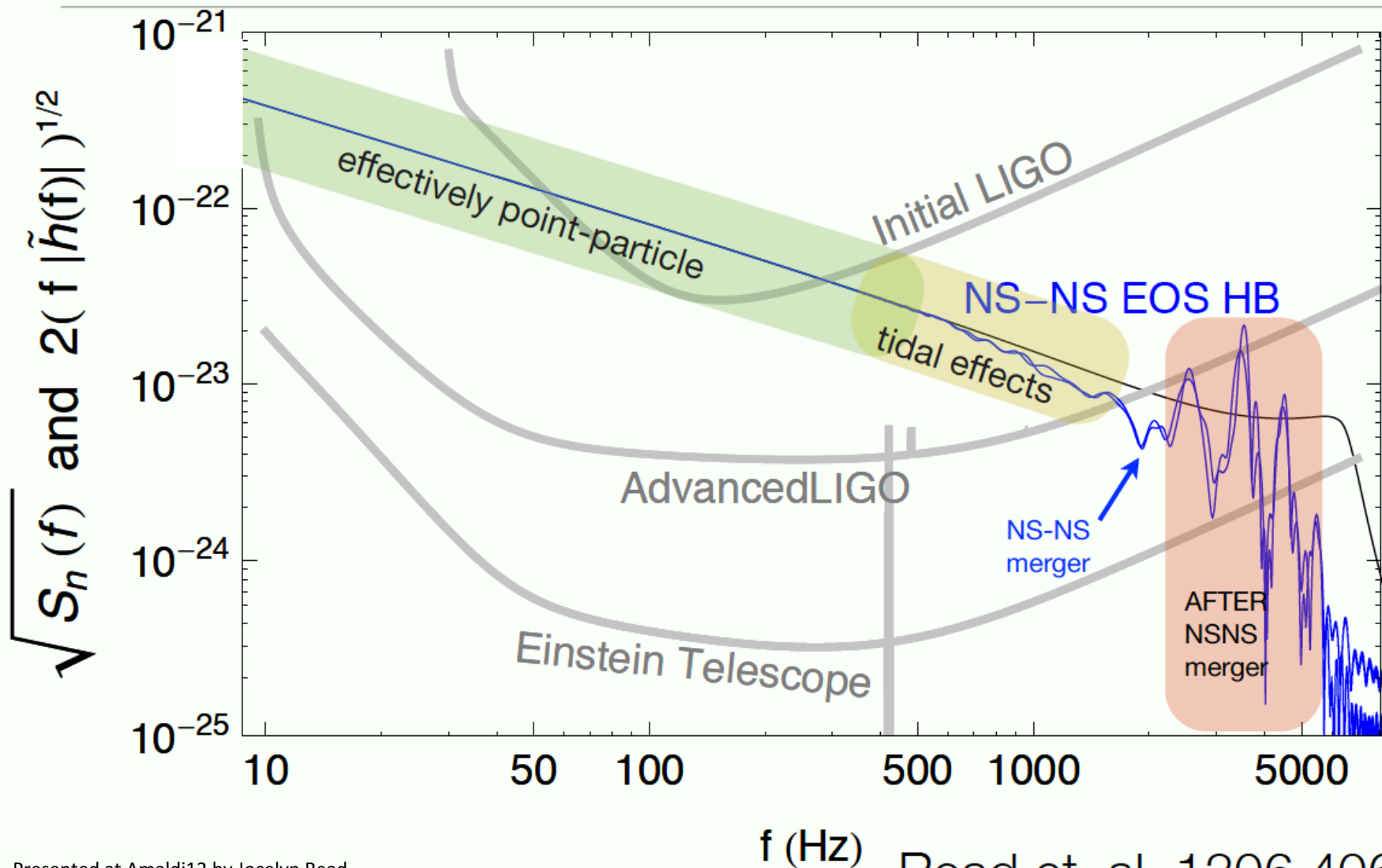
time observable by LIGO-Virgo

Masses in the Stellar Graveyard

in Solar Masses



Gravitational-wave spectrum of BNS





Barry C. Barish (Caltech)



Kip S. Thorne (Caltech)



Rainer Weiss (MIT)



2017 Nobel Prize in Physics

	GW150914	GW151226	GW170104	GW170608	GW170814
Razão S/R	23,7	13,0	13	13	15
Taxa de falso alarme	(~ 400 mil anos) ⁻¹	(~ 400 mil anos) ⁻¹	(70 mil anos) ⁻¹	(160 mil anos) ⁻¹	(140 mil anos) ⁻¹
M primária	36,2 M _⊙	14,2 M _⊙	31,2 M _⊙	12 M _⊙	30,5 M _⊙
M secundária	29,1 M _⊙	7,5 M _⊙	19,4 M _⊙	7 M _⊙	25,3 M _⊙
Massa total	65,3 M _⊙	21,8 M _⊙	50,7 M _⊙	19 M _⊙	55,9 M _⊙
Massa final	62,3 M _⊙	20,8 M _⊙	48,7 M _⊙	18,0 M _⊙	53,2 M _⊙
Spin final	0,68	0,74	0,64	0,69	0,70
E irradiada	3,0 M _⊙ c ²	1,0 M _⊙ c ²	2,0 M _⊙ c ²	0,85 M _⊙ c ²	2,7 M _⊙ c ²
Pico de Luminosidade	3,6 x 10 ⁵⁶ erg/s	3,3 x 10 ⁵⁶ erg/s	3,1 x 10 ⁵⁶ erg/s	3,4 x 10 ⁵⁶ erg/s	3,7 x 10 ⁵⁶ erg/s
Distância de luminosidade	420 Mpc (1,4 G a-l)	440 Mpc (1,4 G a-l)	880 Mpc (2,9 G a-l)	340 Mpc (1,1 G a-l)	540 Mpc (1,8 G a-l)
<i>Redshift</i>	0.09	0,09	0,18	0,07	0,11

Tab. 10.1–Parâmetros dos eventos envolvendo pares de buracos negros (a-l é anos-luz)

Razão S/R	32,4
Taxa de falso alarme	$(1,1 \text{ milhões anos})^{-1}$
M primária	$1,48 M_{\odot}$
M secundária	$1,26 M_{\odot}$
Massa total	$2,74 M_{\odot}$
Massa final	$2,71 M_{\odot}$
E irradiada	$> 0,025 M_{\odot} c^2$
Pico de Luminosidade	$3,6 \times 10^{56} \text{ erg/s}$
Distância de luminosidade	40 Mpc (130 M a-l)
<i>Redshift</i>	0,008

Tabela 10.2–Parâmetros do evento GW170817 (a-l é anos-luz).

<https://doi.org/10.3847/2041-8213/aa920c>

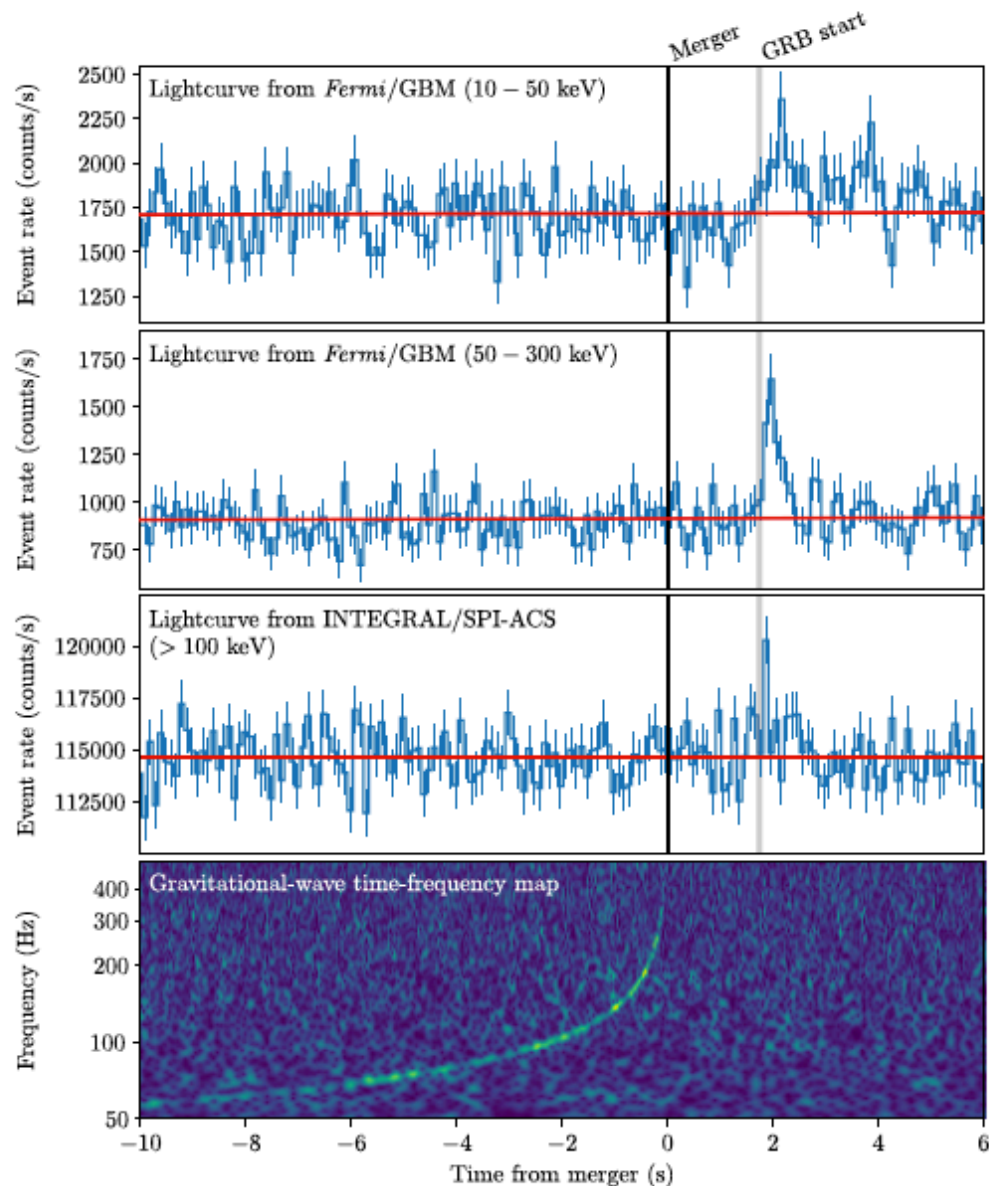


Figure 2. Joint, multi-messenger detection of GW170817 and GRB 170817A. Top: the summed GBM lightcurve for sodium iodide (NaI) detectors 1, 2, and 5 for GRB 170817A between 10 and 50 keV, matching the 100 ms time bins of the SPI-ACS data. The background estimate from Goldstein et al. (2016) is overlaid in red. Second: the same as the top panel but in the 50–300 keV energy range. Third: the SPI-ACS lightcurve with the energy range starting approximately at 100 keV and with a high energy limit of least 80 MeV. Bottom: the time-frequency map of GW170817 was obtained by coherently combining LIGO-Hanford and LIGO-Livingston data. All times here are referenced to the GW170817 trigger time T_0^{GW} .

THE ASTROPHYSICAL JOURNAL LETTERS, 848:L12 (59pp), 2017 October 20

Abbott et al.

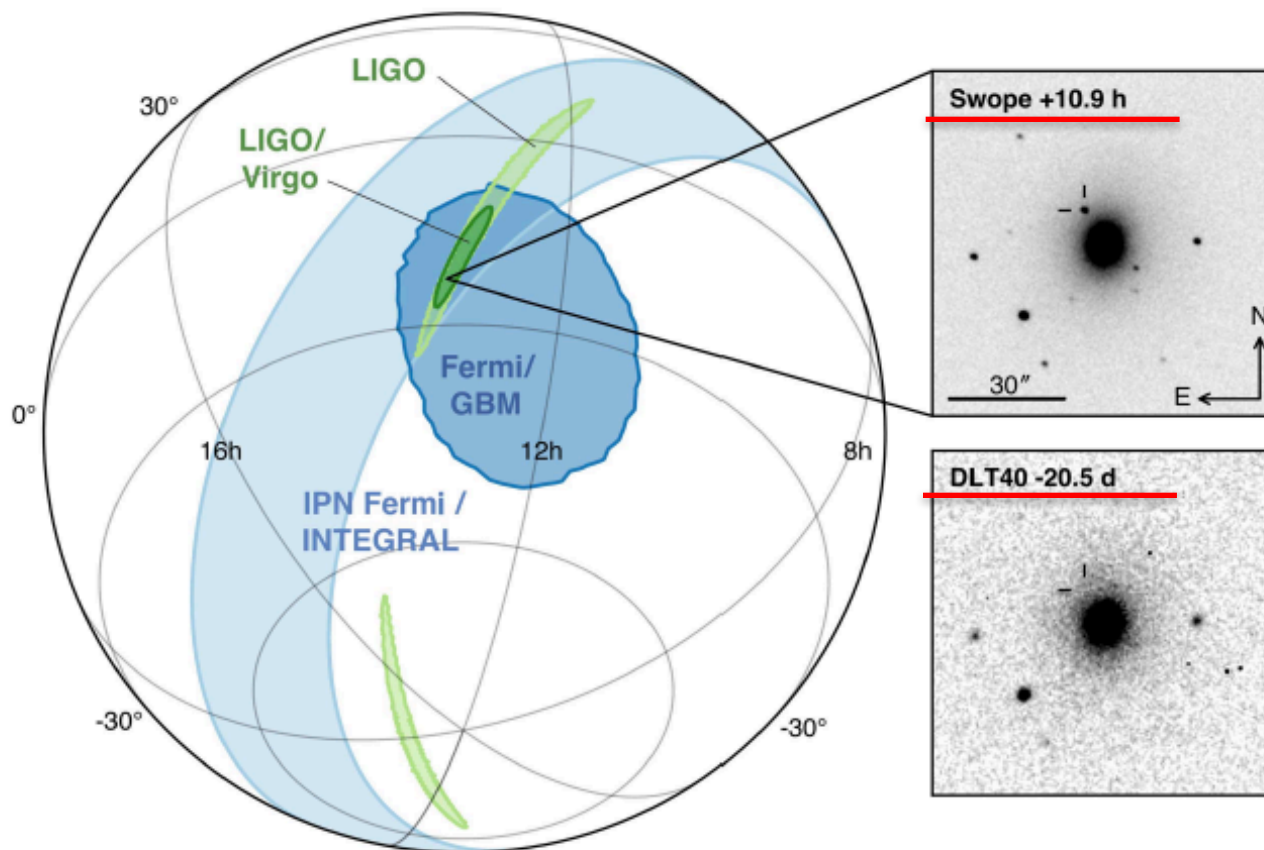


Figure 1. Localization of the gravitational-wave, gamma-ray, and optical signals. The left panel shows an orthographic projection of the 90% credible regions from LIGO (190 deg²; light green), the initial LIGO-Virgo localization (31 deg²; dark green), IPN triangulation from the time delay between *Fermi* and *INTEGRAL* (light blue), and *Fermi*-GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hr after the merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right). The reticle marks the position of the transient in both images.

Multimessenger Astrophysics: Simultaneous search with instruments in the electromagnetic window

Less than two years after the inauguration of the gravitational wave astrophysics, GW170817 marks a new era of discover.



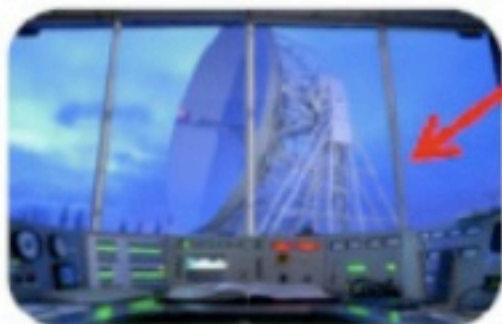
optical



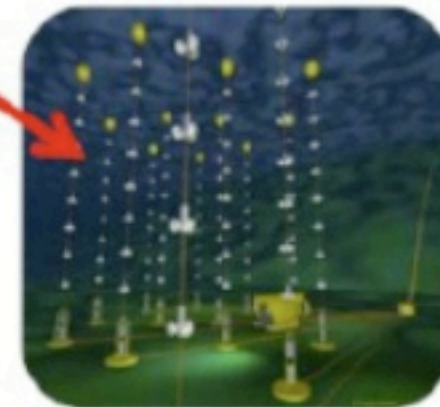
gamma rays,
x-rays



radio



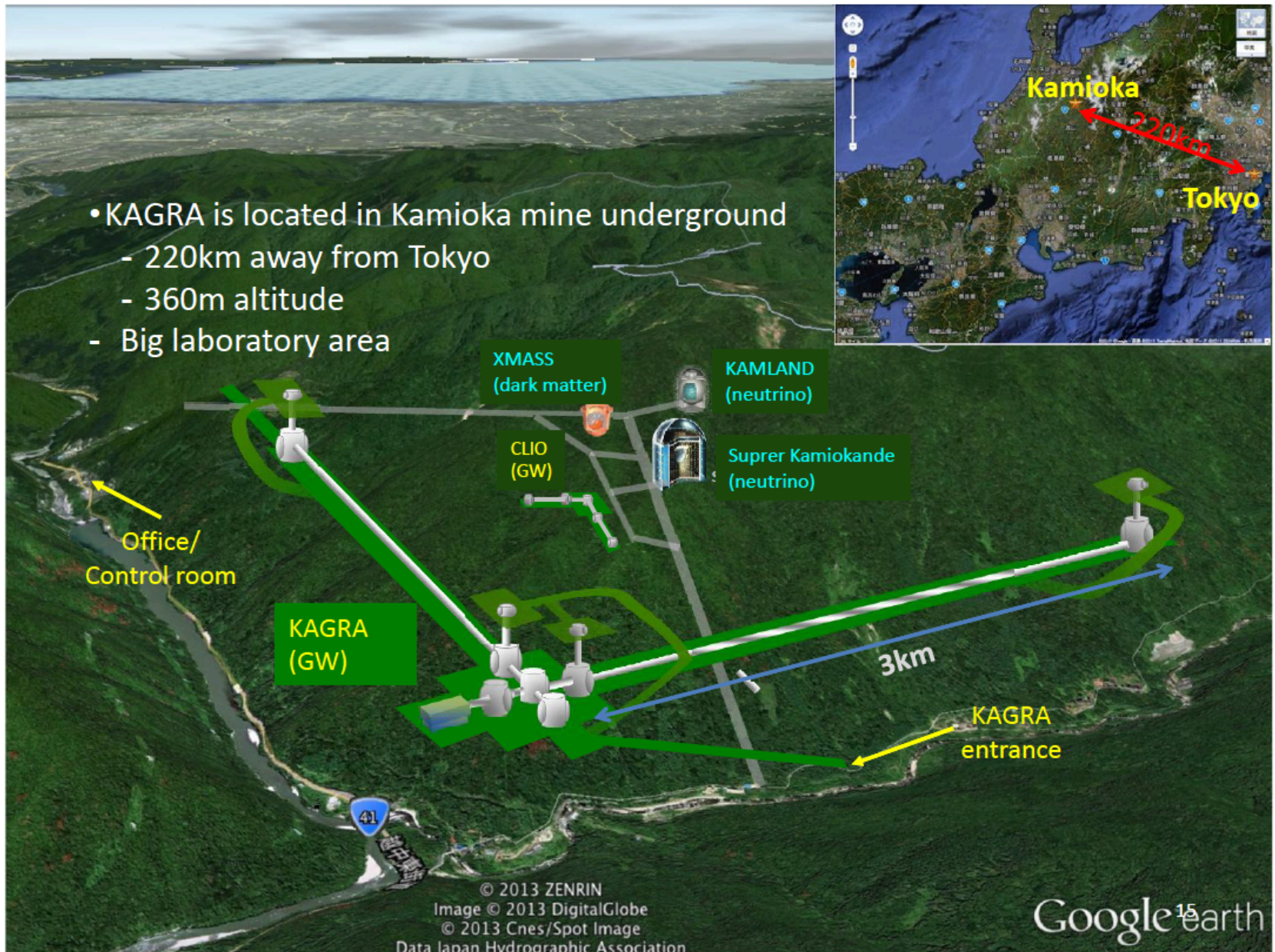
neutrinos



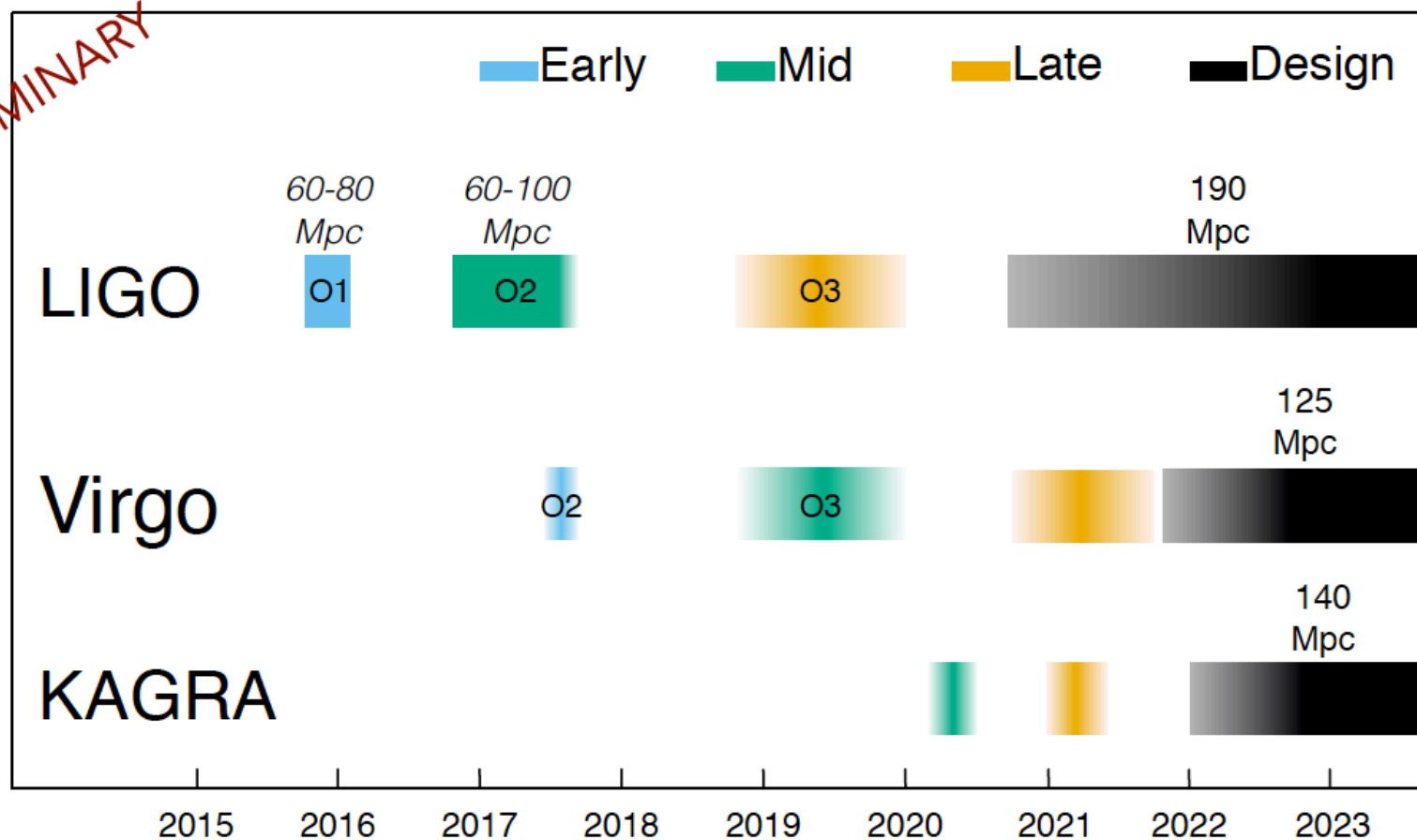
What is the future of Gravitational
Wave Astrophysics?



crédito: LIGO lab



PRELIMINARY



...and LIGO India plans to come on line with Advanced LIGO sensitivity – with any upgrades incorporated – in 2024

B.P. Abbott et al. "Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA" (in preparation)

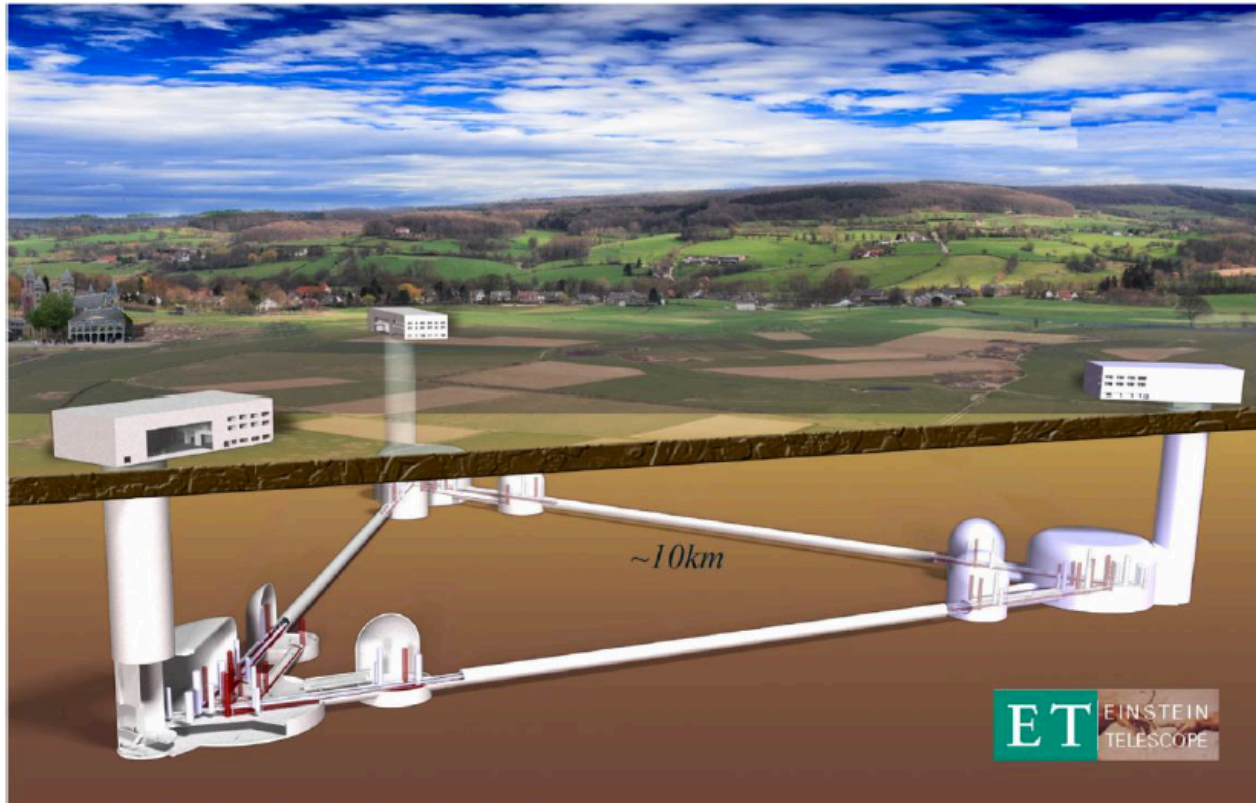
Cosmic Explorer (US)

- Third-generation GW observatory
- Target sensitivity a factor of > 10 improvement in comparison to current advanced detectors
- Above ground, 40 km arm length, L configuration

Formal Design Study: not yet, but proposal under development (M. Evans, MIT, PI)



The Einstein Telescope



Scientific objectives of Einstein Telescope

Sathyaprakash, B. and Ajith, P. and Corsi, A. and Favata, M. and Harms, J. and Ott, C. D. and Santamaría, L.
(2012) *Scientific objectives of Einstein Telescope*. Classical and Quantum Gravity

Abstract

The advanced interferometer network will herald a new era in observational astronomy. There is a very strong science case to go beyond the advanced detector network and build detectors that operate in a frequency range from 1 Hz to 10 kHz, with sensitivity a factor 10 better in amplitude. Such detectors will be able to probe a range of topics in nuclear physics, astronomy, cosmology and fundamental physics, providing insights into many unsolved problems in these areas.



LIGO
Scientific
Collaboration

G1600858



Perspectives for the future of the just inaugurated *Gravitational Wave Astrophysics*

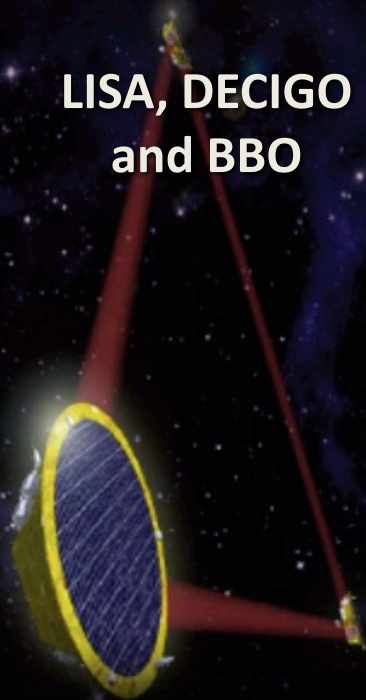
Long baseline
Interferometers



Milliseconds

Interferometers in
no Space:

LISA, DECIGO
and BBO



Minutes to Hours

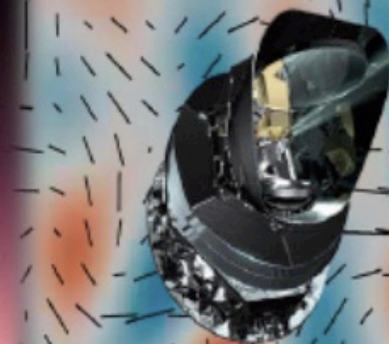
Pulsar Timing
Arrays

with
Radiotelescopes



Years to Decades

Cosmic
Microwave
Background
Radiation



Billions of Years

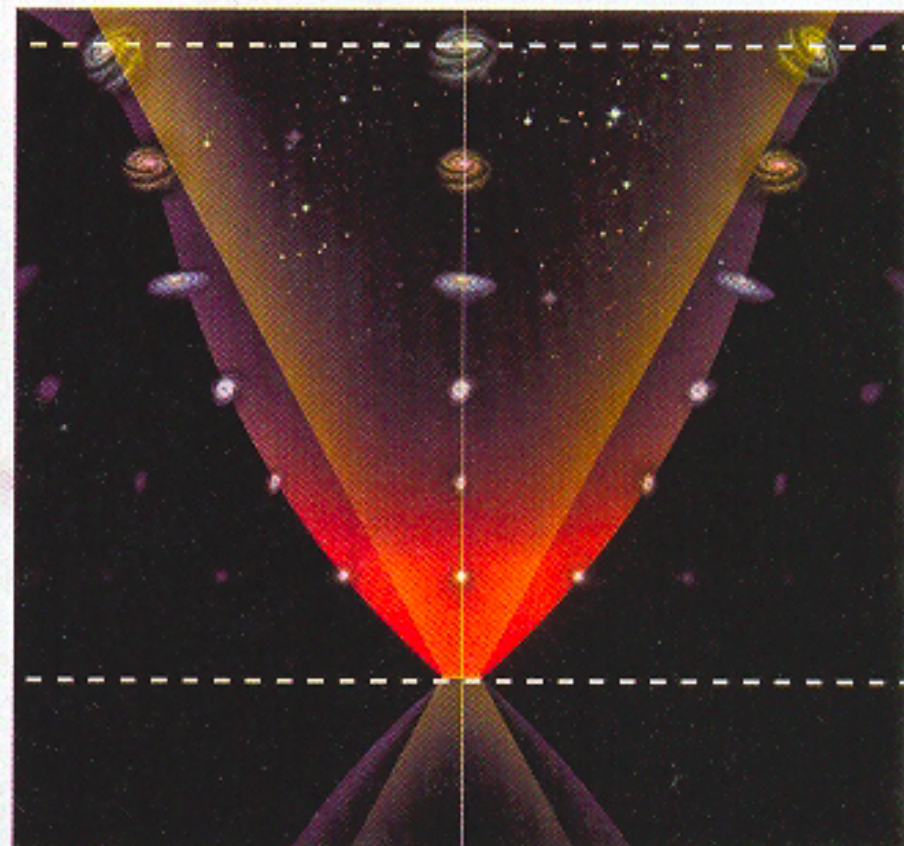
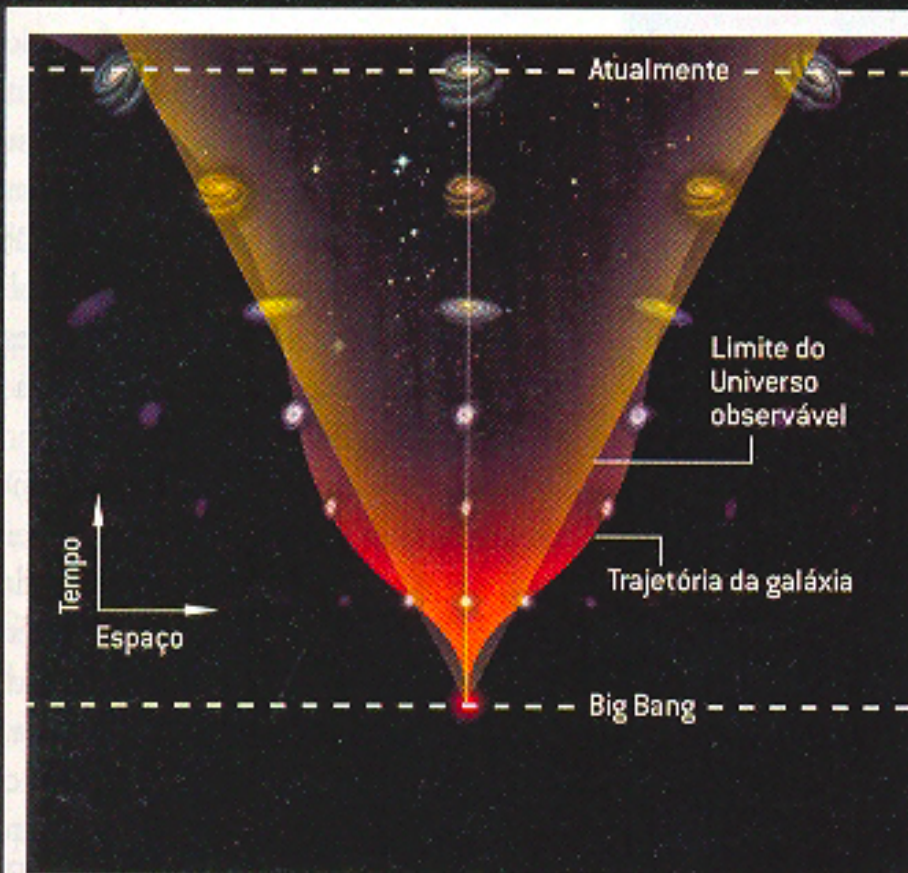
Period of the gravitational waves

DUAS VISÕES DO PRINCÍPIO

Como o Universo teve início?

Credit: Scientific American Brasil

Em nosso Universo em expansão, as galáxias se afastam rapidamente umas das outras, a uma velocidade proporcional à distância entre elas: duas galáxias separadas por uma distância de 500 milhões de anos-luz se afastam a uma velocidade duas vezes maior do que duas galáxias separadas por uma distância de 250 milhões de anos-luz. Por isso, todas as galáxias que vemos devem ter se originado em um mesmo ponto e ao mesmo tempo – o Big Bang. A conclusão é válida mesmo quando a expansão cósmica passou por períodos de aceleração e desaceleração; em diagramas de espaço-tempo (abaixo), as galáxias seguem trajetórias sinuosas que as levam para dentro e para fora da região observável do espaço (*triângulo amarelo*). No entanto, a situação torna-se incerta no instante exato em que as trajetórias das galáxias (ou suas predecessoras) começaram a divergir.

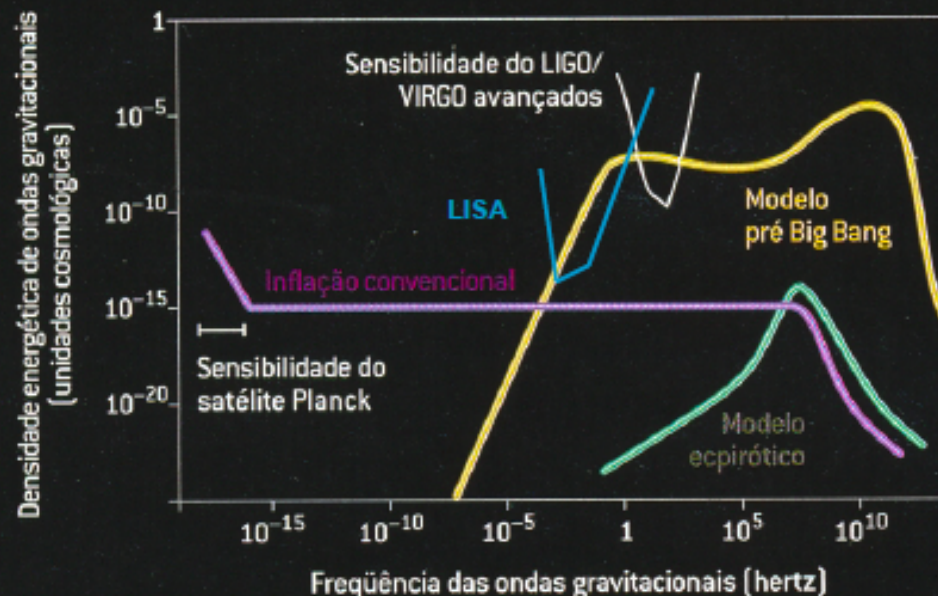
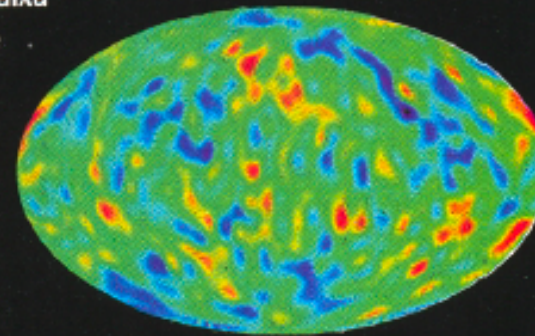


Na cosmologia do Big Bang convencional, que se baseia na teoria da relatividade geral de Einstein, a distância entre quaisquer duas galáxias era zero há um tempo finito. O tempo perde significado antes desse instante.

Nos modelos mais sofisticados, que incluem efeitos quânticos, quaisquer duas galáxias devem ter surgido a uma certa distância mínima uma da outra. Esses modelos abrem a possibilidade de um Universo pré-Big Bang.

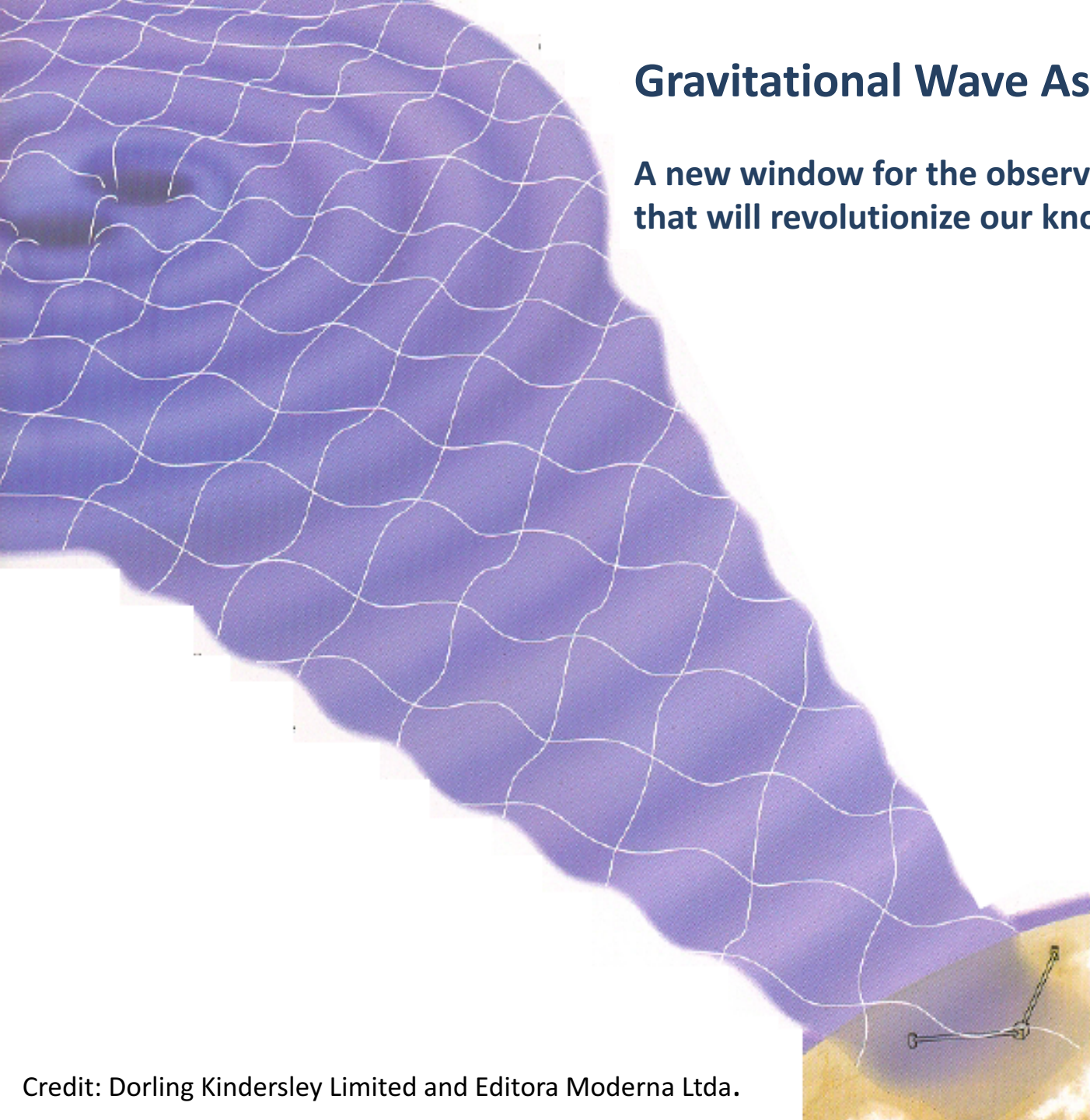
EFEITO DE FUNDO

Observar o Universo pré-Big Bang pode parecer uma tarefa sem futuro, mas uma forma de radiação poderia sobreviver desde aquela época: a radiação gravitacional. Essas variações periódicas na campo gravitacional poderiam ser detectadas indiretamente, por seu efeito na polarização do fundo cósmico de microondas (*vista simulada, abaixo*), ou diretamente, em observatórios terrestres. Os cenários pré-Big Bang e ecpirótico prevêm mais ondas gravitacionais de alta freqüência e menos de baixa freqüência do que os modelos convencionais de inflação (*abaixo*). Medidas existentes de vários fenômenos astronômicos não conseguem fazer a distinção entre esses modelos, mas futuras observações do satélite Planck, assim como dos observatórios LIGO e VIRGO, devem ser capazes disso.



Gravitational Wave Astrophysics

**A new window for the observation of the universe
that will revolutionize our knowledge of it.**



Credit: Dorling Kindersley Limited and Editoria Moderna Ltda.

Thank you
for the attention!