Gravitational waves:
Opening a new window to the Universe

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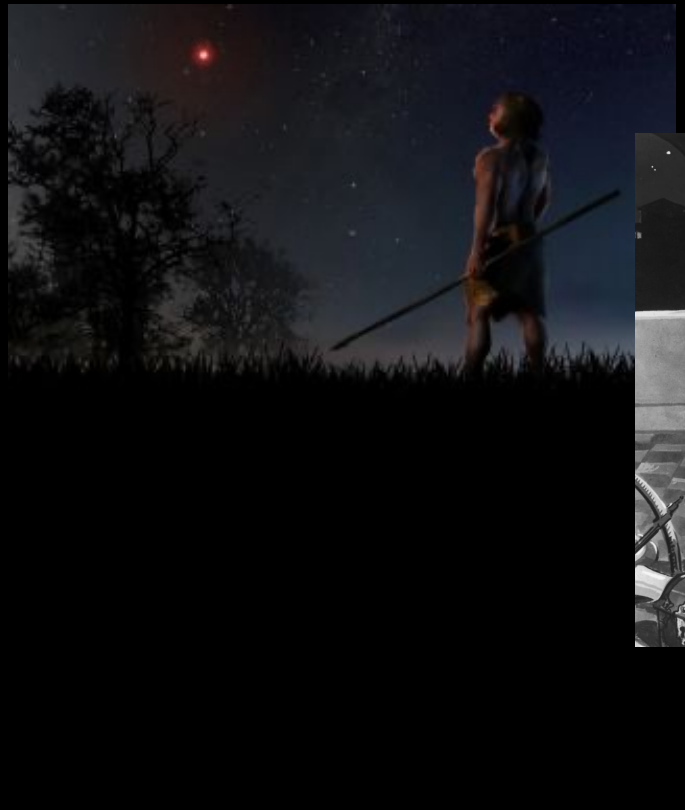
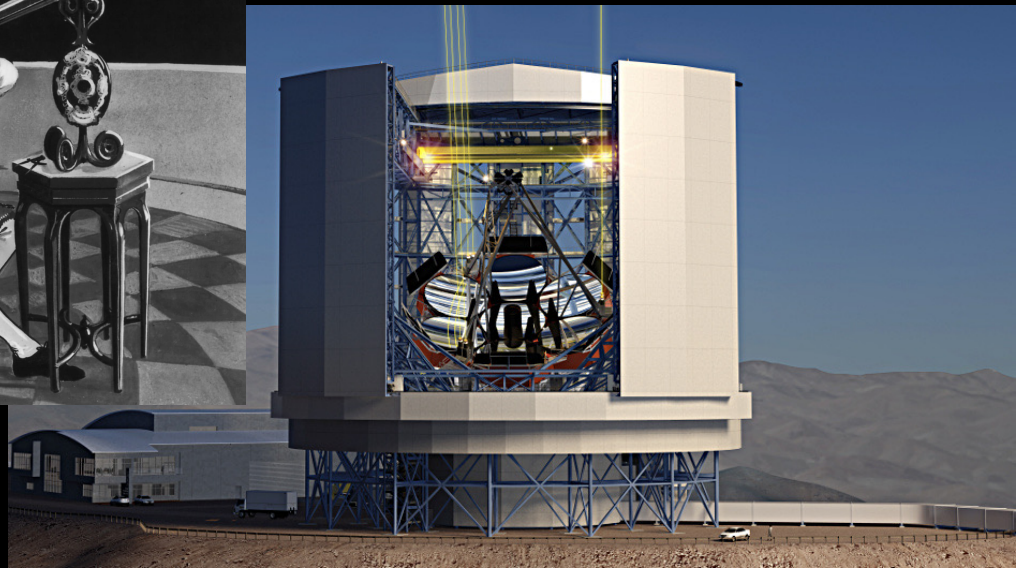
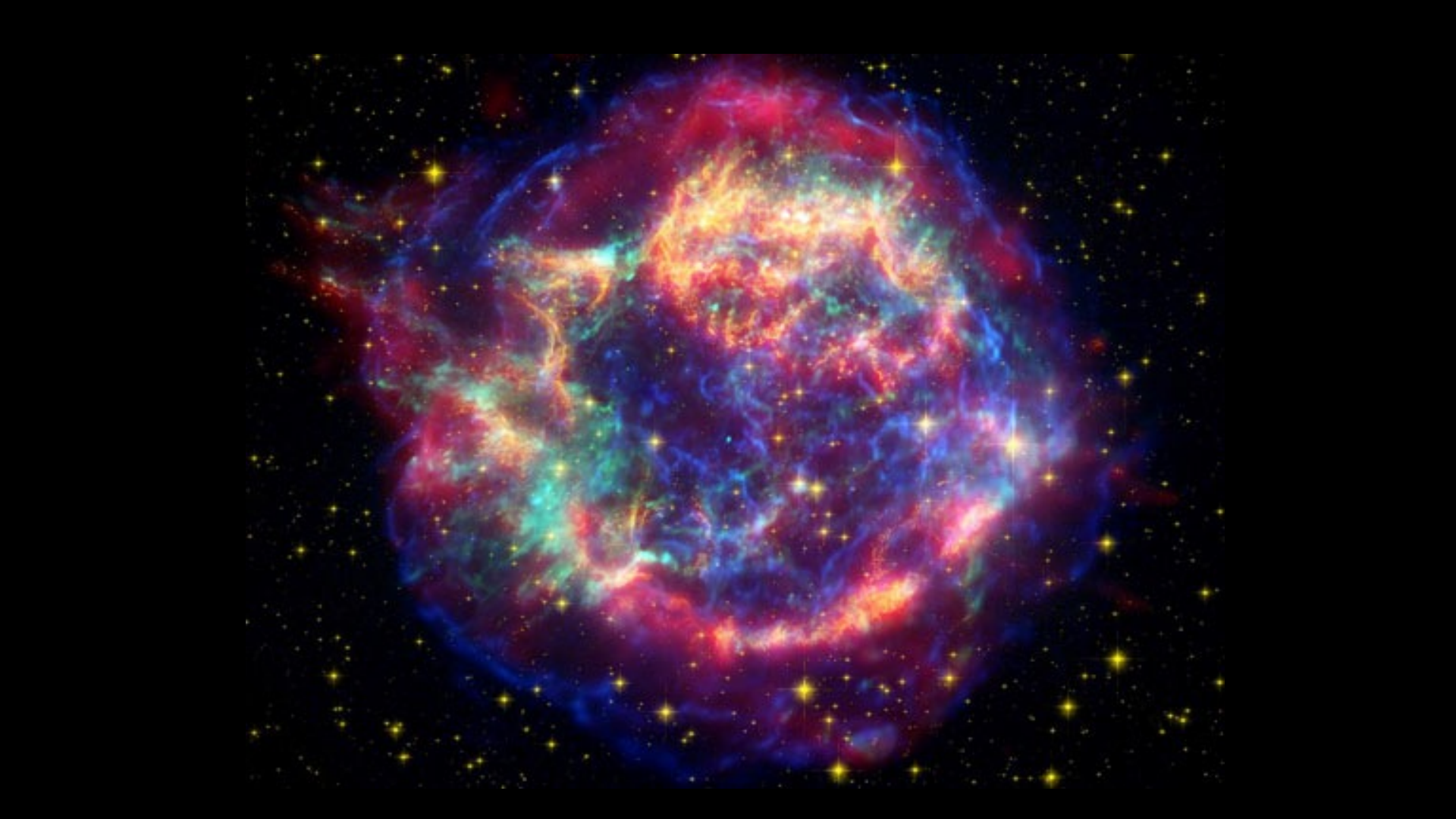
MIT

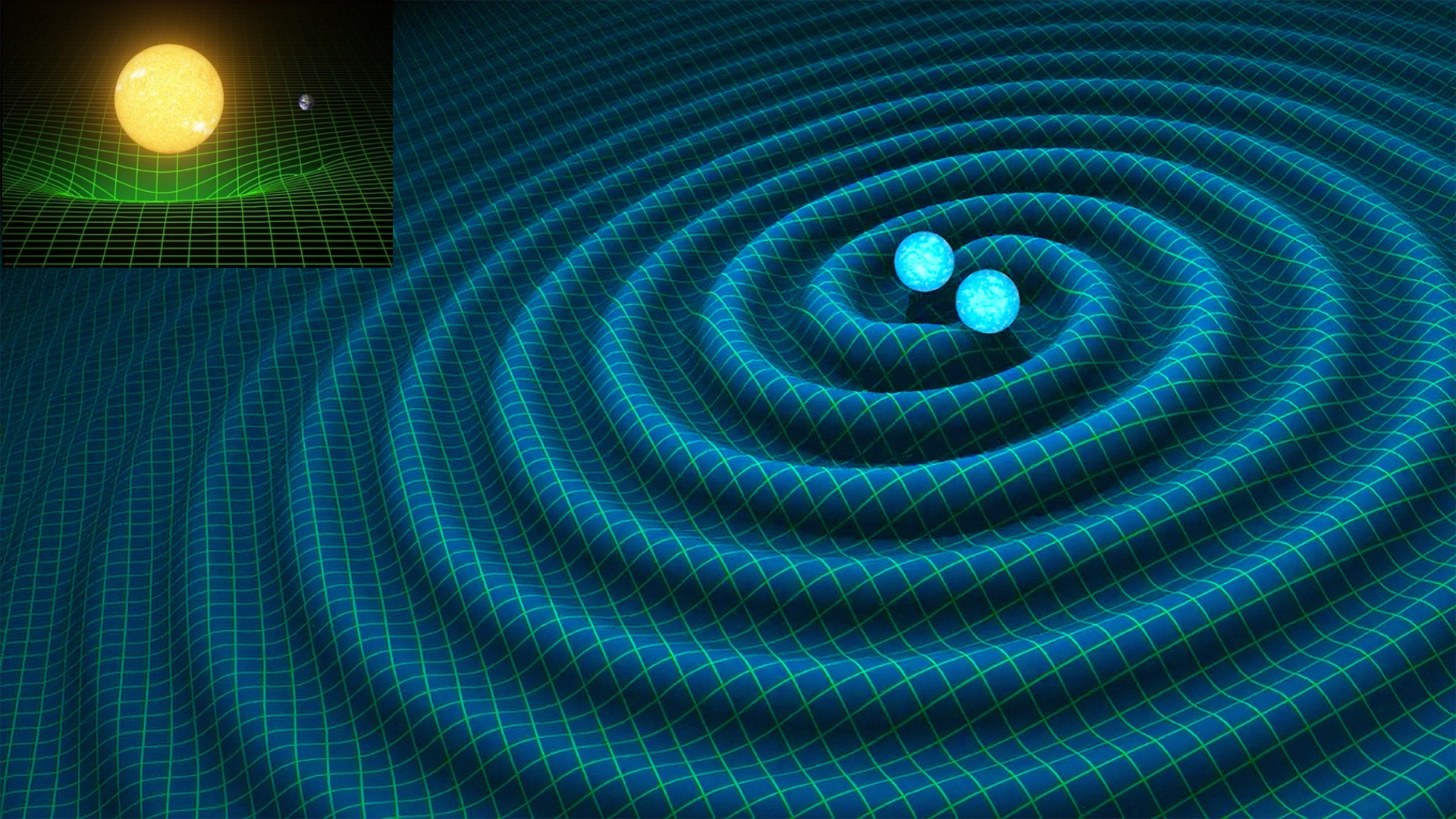
Bisan Lecture 2023

Peering out to the Universe

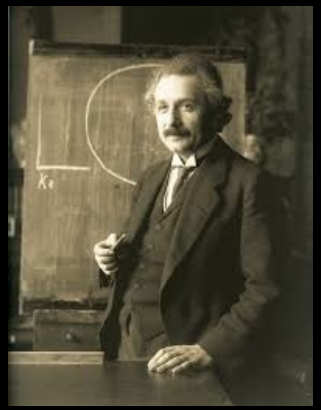




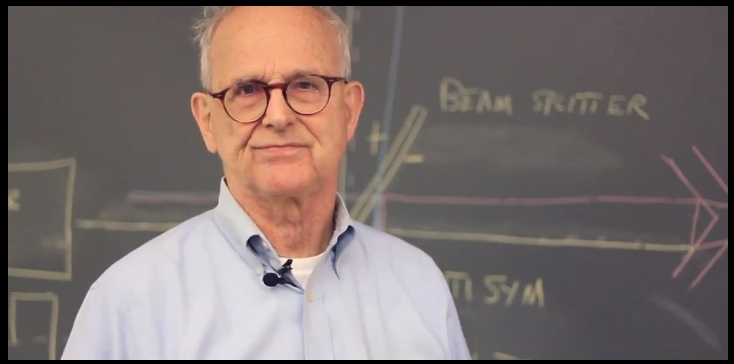




Gravitational waves are…



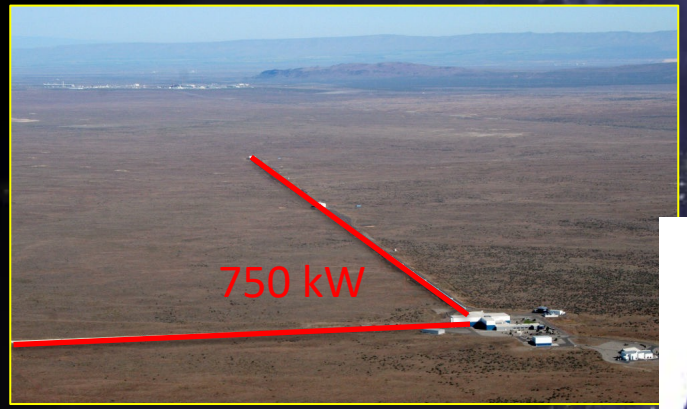
… ripples of spacetime too faint to ever be useful [detectable] (1916)

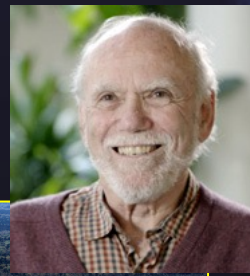


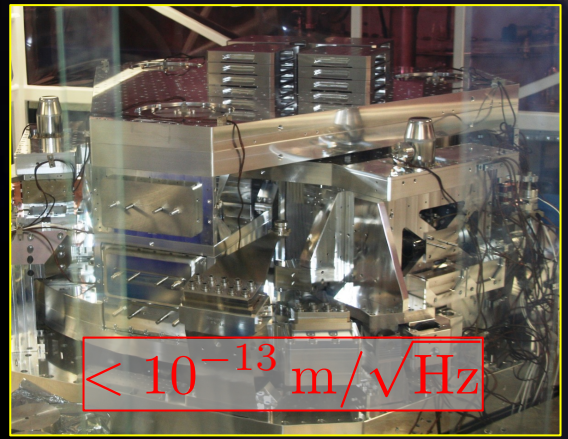
… detectable, we just figure out how to measure changes in distance of 10^{-18} m (late 1960s and 1970s)

… yep, pretty faint; they have an amplitude of 10^{-21} (late 1960s and 1970s)

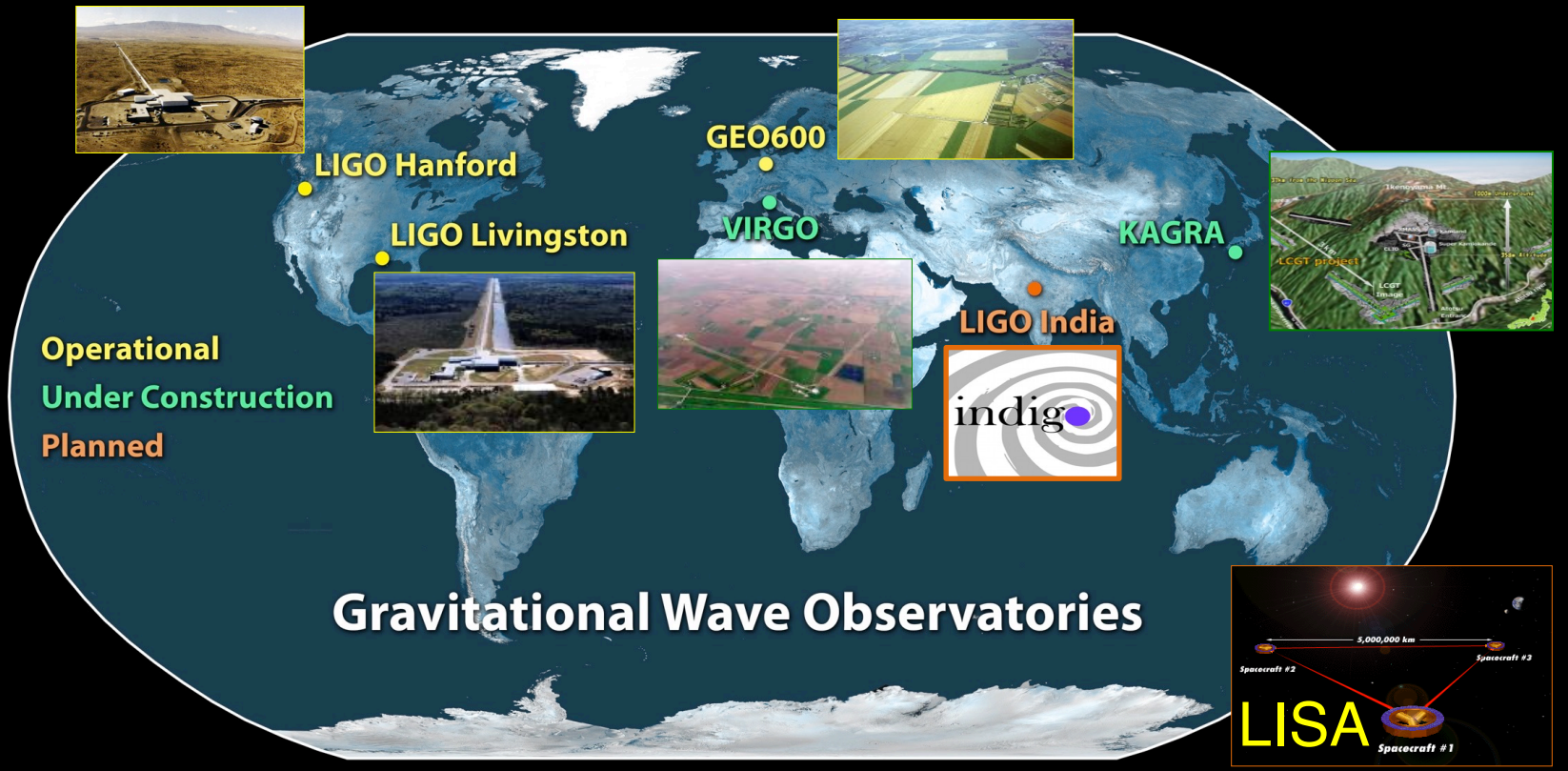
LIGO

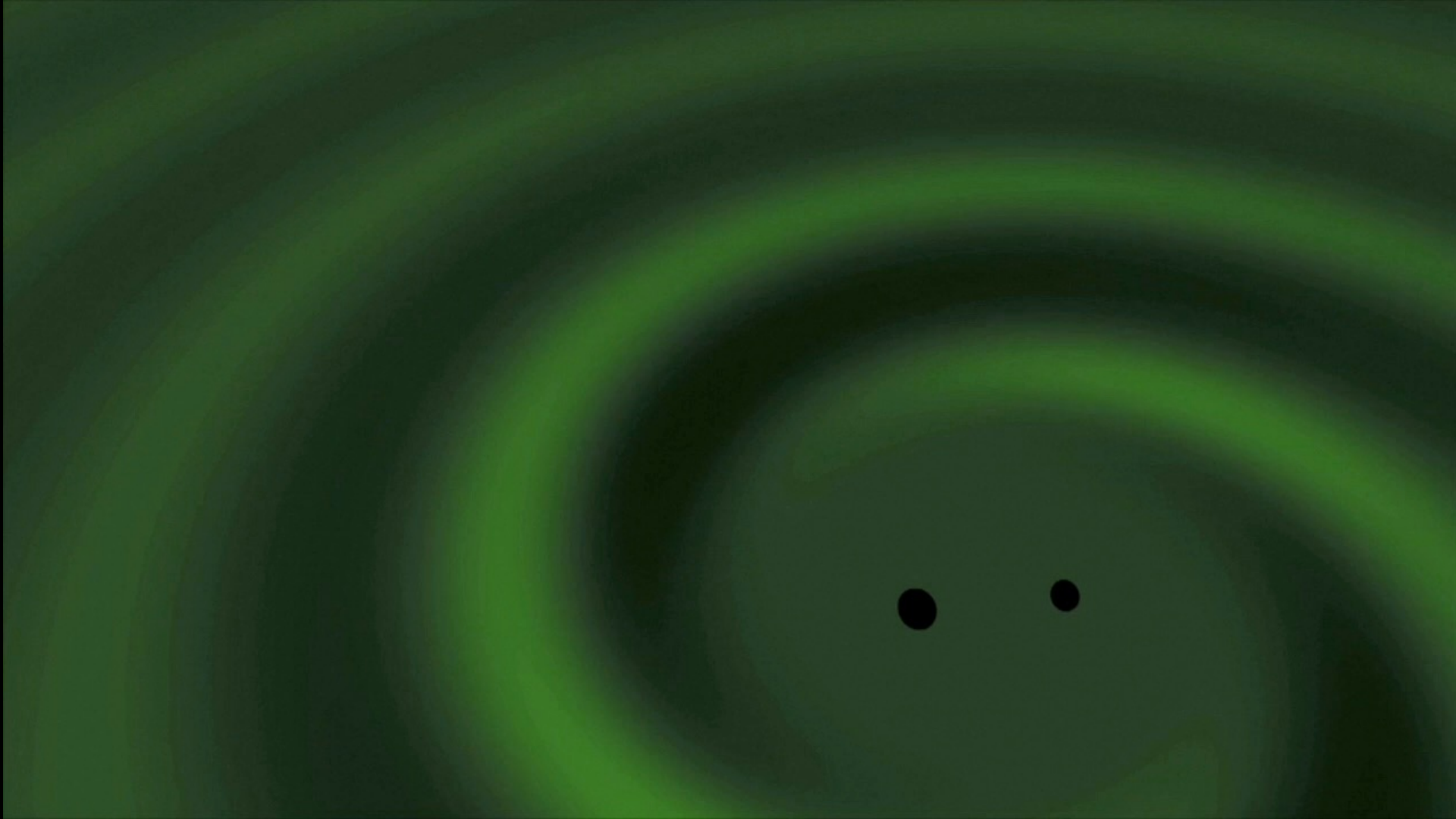




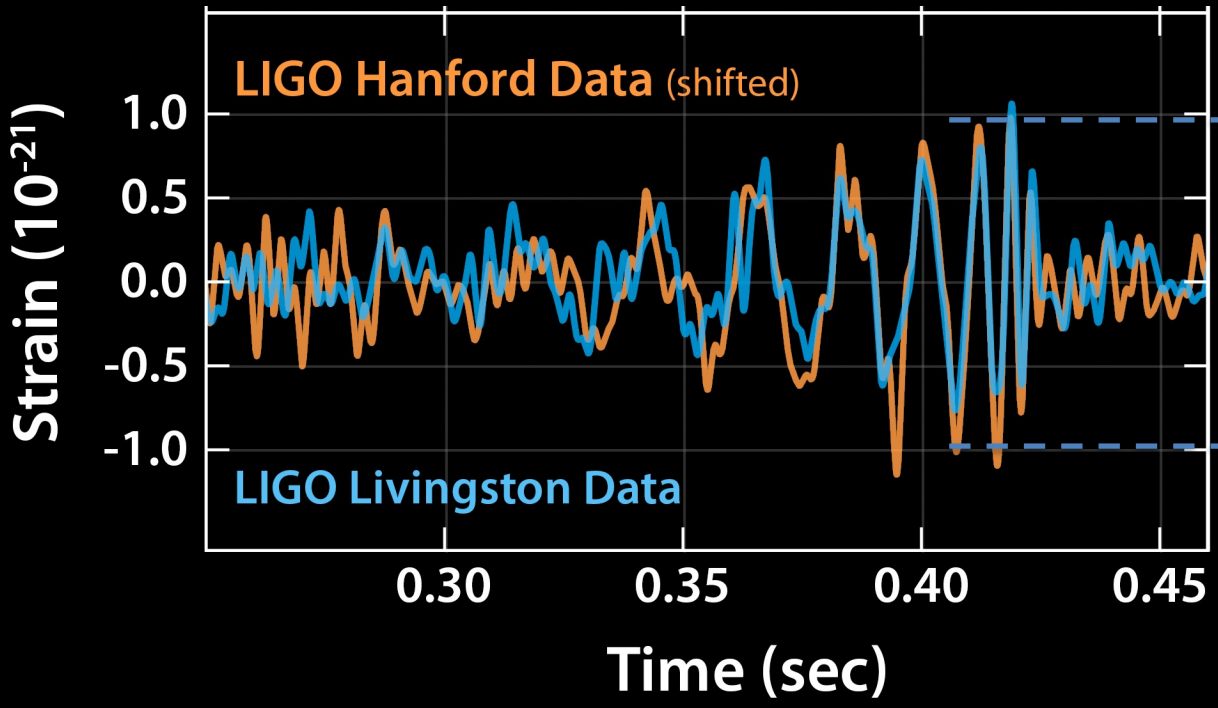


Global network of detectors





GW150914: Two black holes collide



Wave amplitude ~ 10^{-21}

Displacement ~ 4 x 10^{-18} m

The story of two black holes

Once upon a time, 1.3 billion years ago, there existed two black holes

$M \approx 29$ and 36 M_{sun}

$v \approx 0.5\ c$

$D \approx 1.3$ billion l.y.

$\Delta E \approx 3\ M_{sun}$

They did not live happily ever after

“A discovery that shook the world”

The Nobel Prize in Physics 2017

Nobelpriset i fysik 2017

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Med ena hälften till
With one half to:

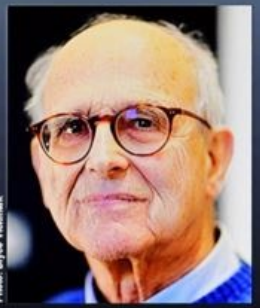


Photo: Bryce Vickmark

Rainer Weiss
LIGO/VIRGO Collaboration

och med den andra hälften gemensamt till
and with the other half jointly to:

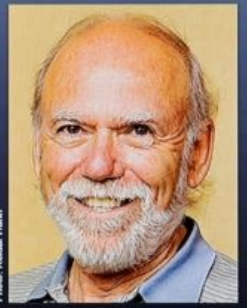


Photo: Reidar Hahn

Barry C. Barish
LIGO/VIRGO Collaboration

Photo: California Institute of California, Caltech

Kip S. Thorne
LIGO/VIRGO Collaboration

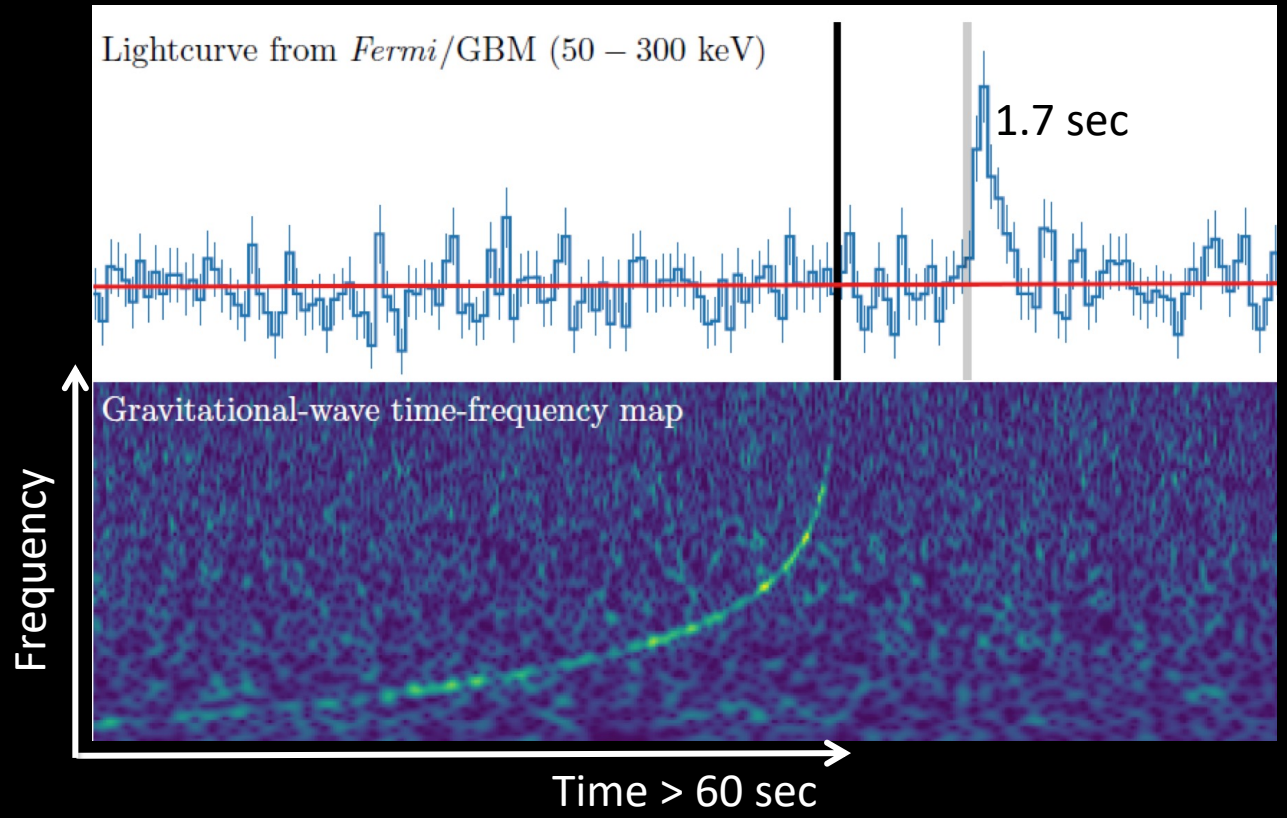
”för avgörande bidrag till LIGO-detektorn och observationen av gravitationsvågor”

“for decisive contributions to the LIGO detector and the observation of gravitational waves”

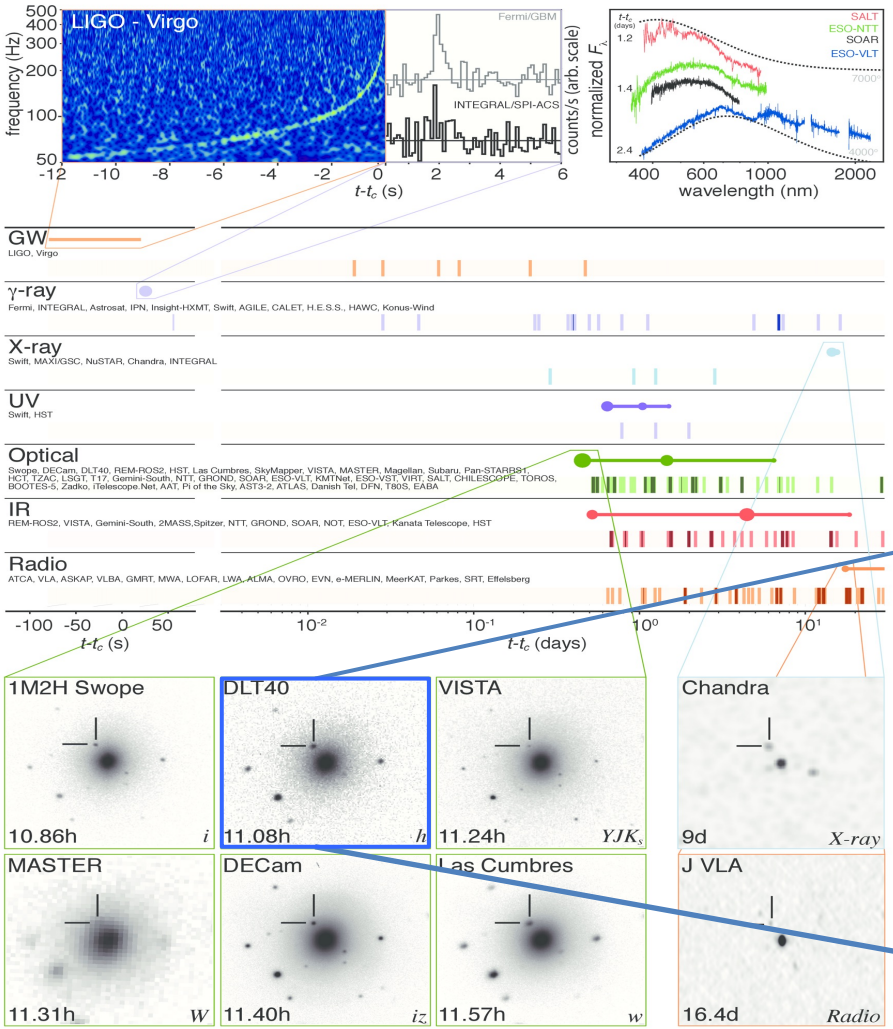
3 October 2017

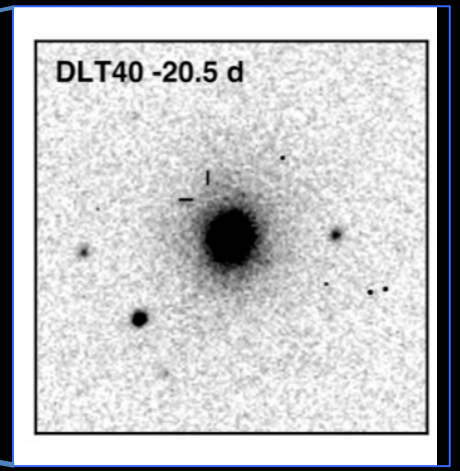
Reuters

GW170817 : Two neutron stars collide

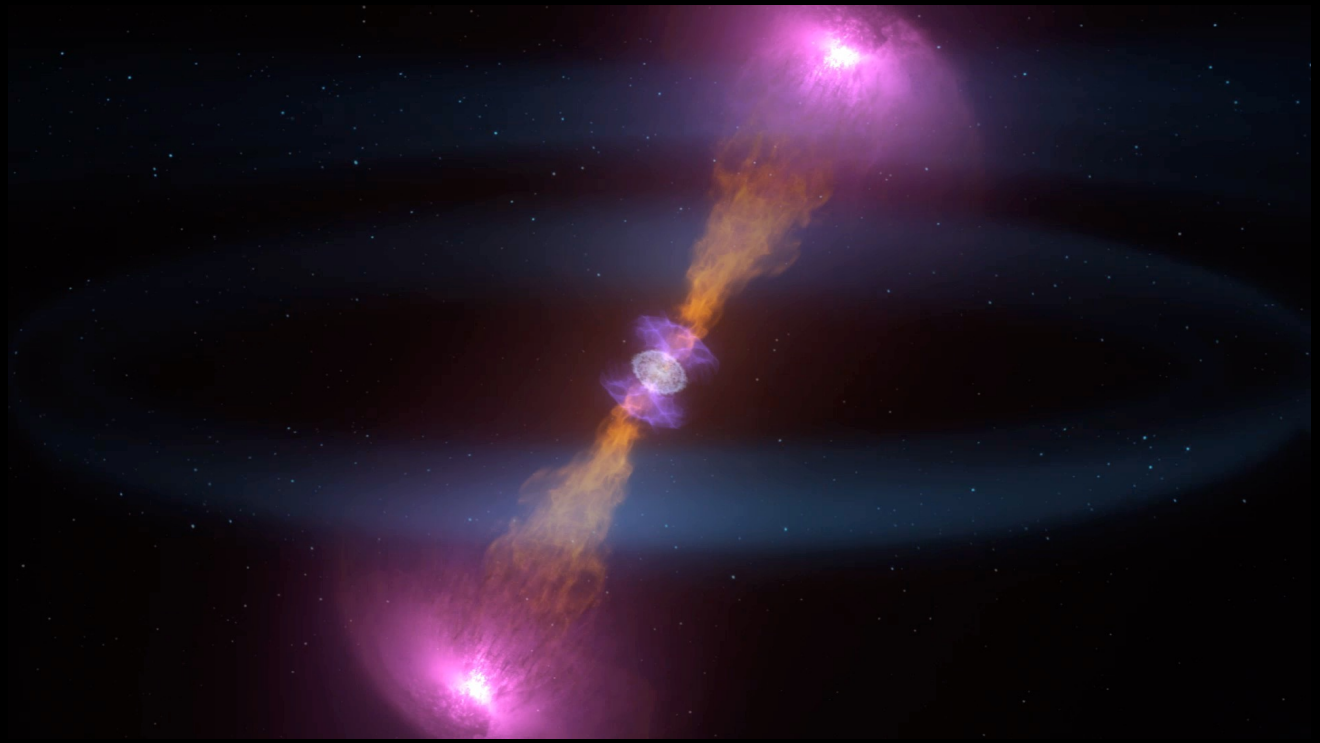


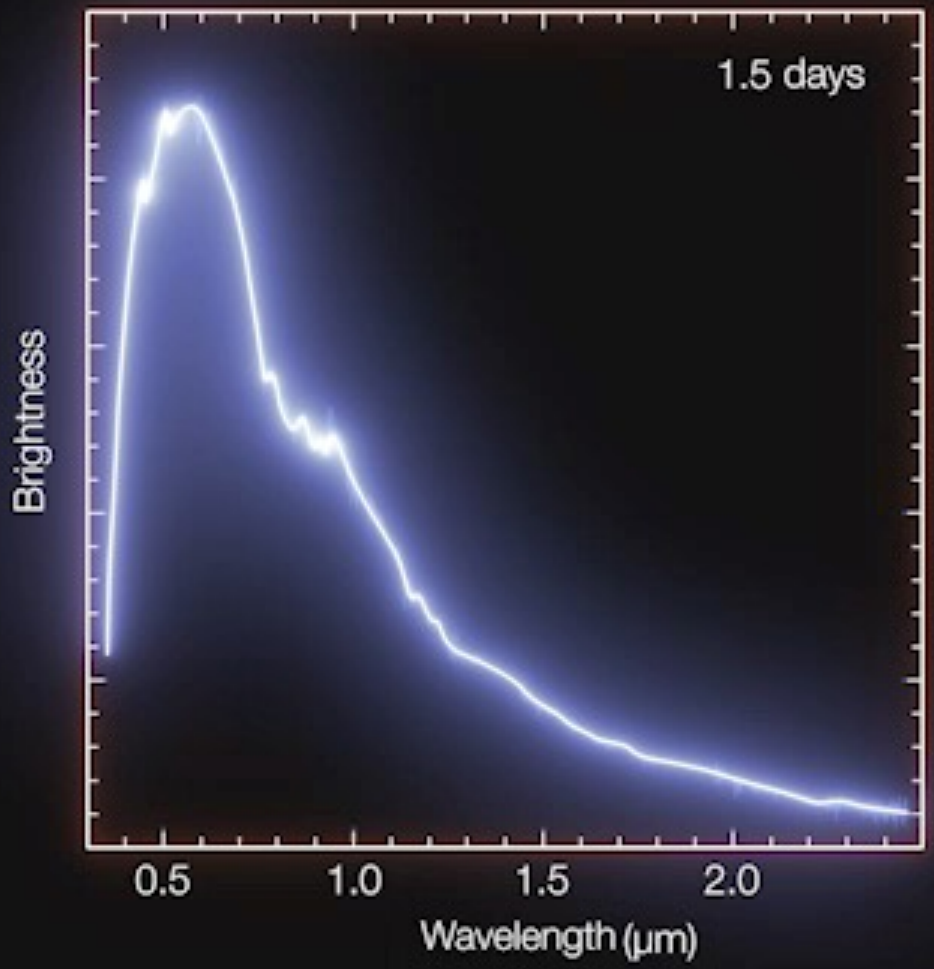
A night to remember





GW170817: two neutron stars collide

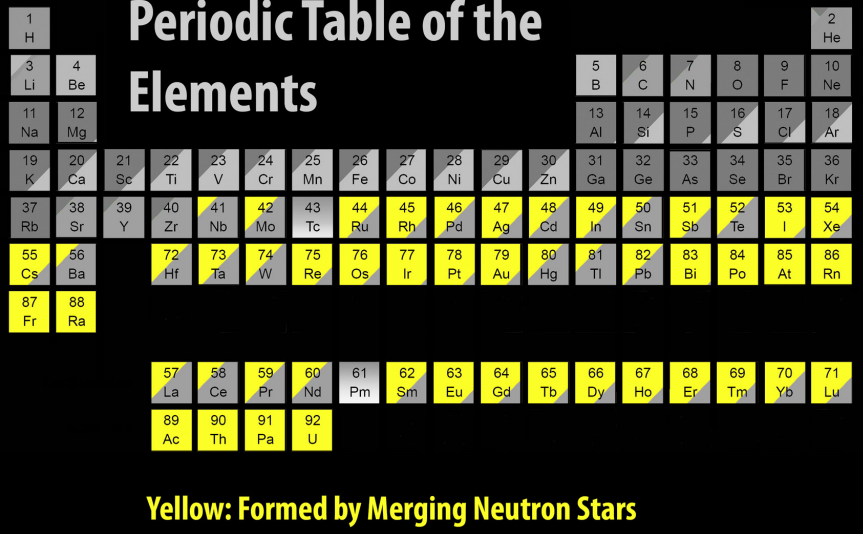




ESO-VLT/X-Shooter

Too much gold on the Earth?

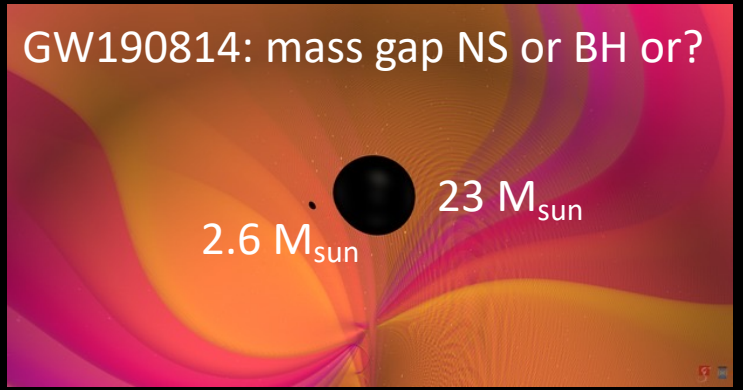
- Formation of heavy elements like gold and platinum needs neutron-rich environments
- Not formed in stars like our Sun or in supernovae
- They are formed in neutron star mergers



Gravitational wave detections

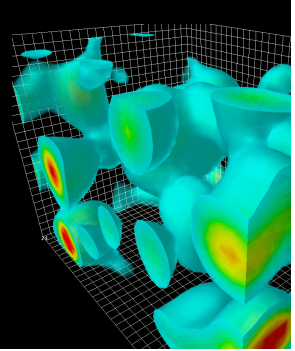
- More than 70 sources detected
- Many mysteries

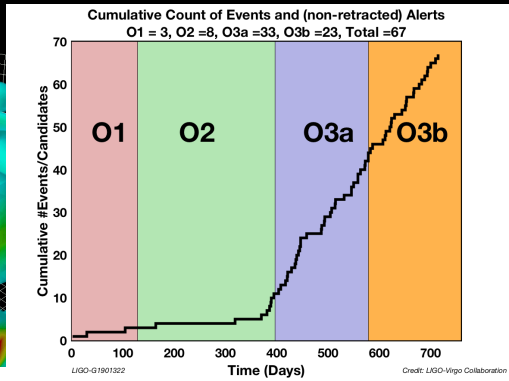
Continually improving the detectors so we can see fainter objects farther away

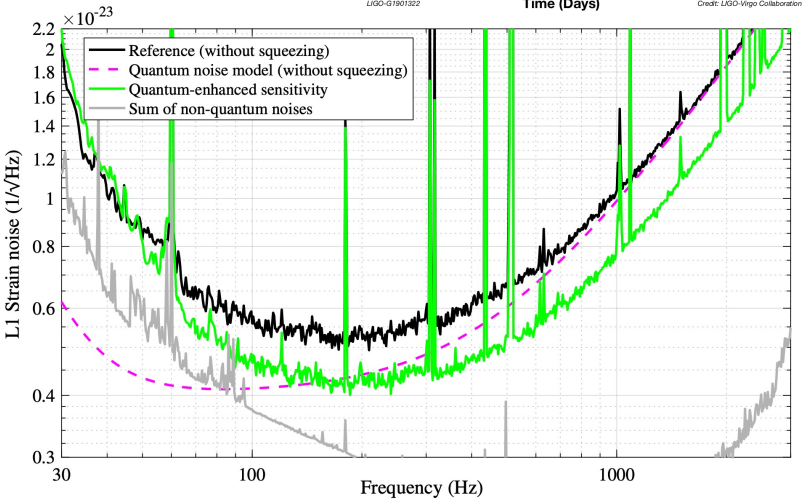


Sub-quantum precision

- Quantum fluctuations
- Specially engineered quantum states of light
- Sub-quantum ruler
  - O3 detects ~ 1 merger/week



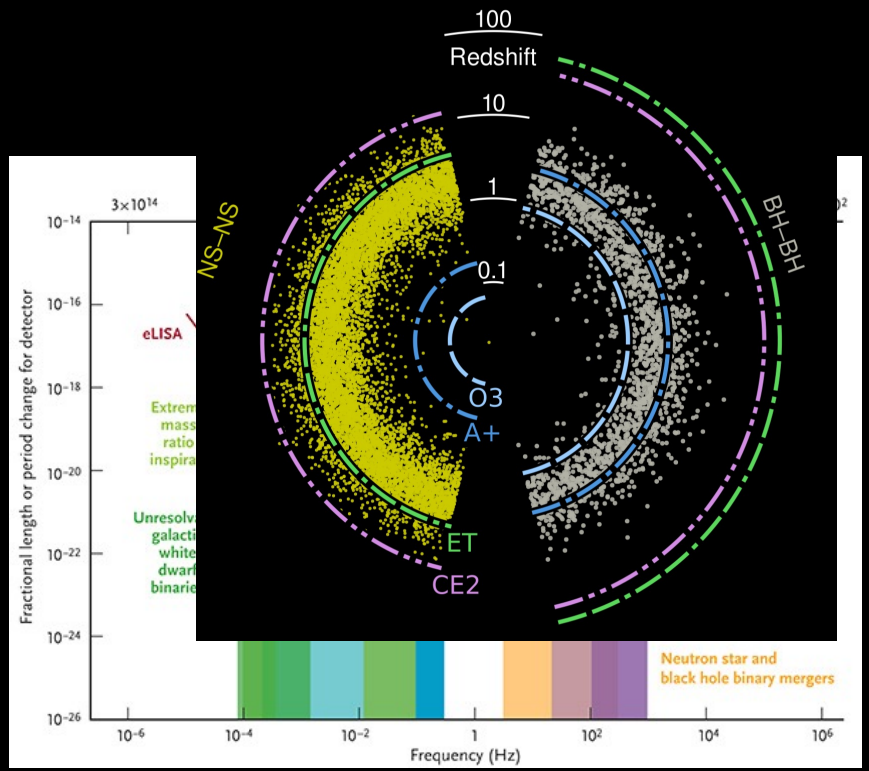




A brilliantly dark and warped future

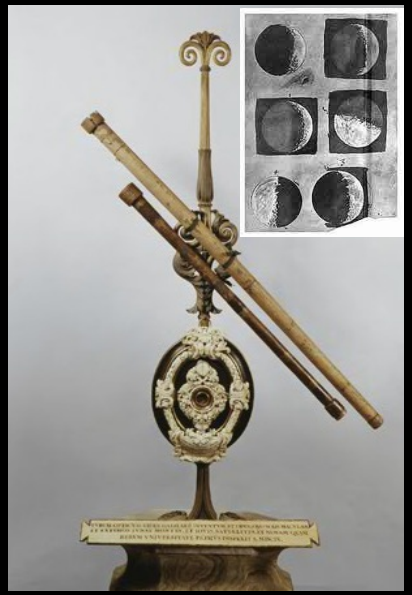
- Future earth-based observatories: Cosmic Explorer, Einstein Telescope

- Space-based observatory: LISA

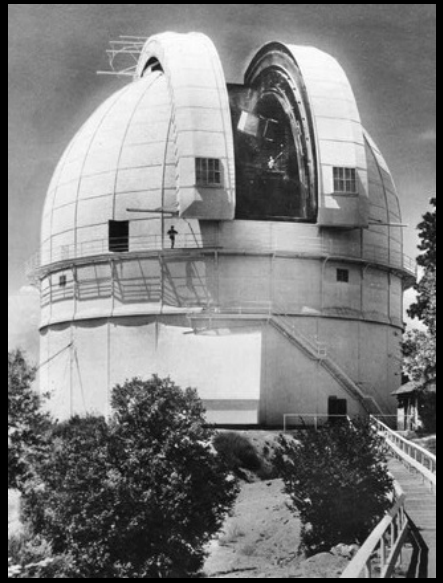


400 years after Galileo

1.5” (Galileo, 1609)

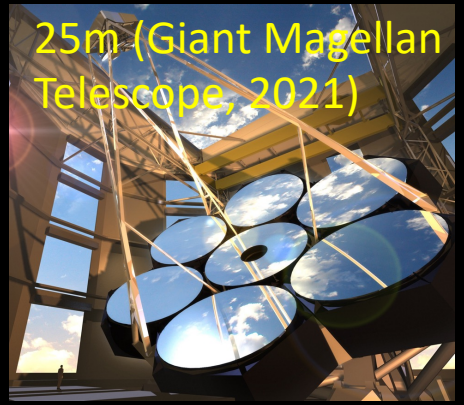


100”
(Mt. Wilson, 1917)

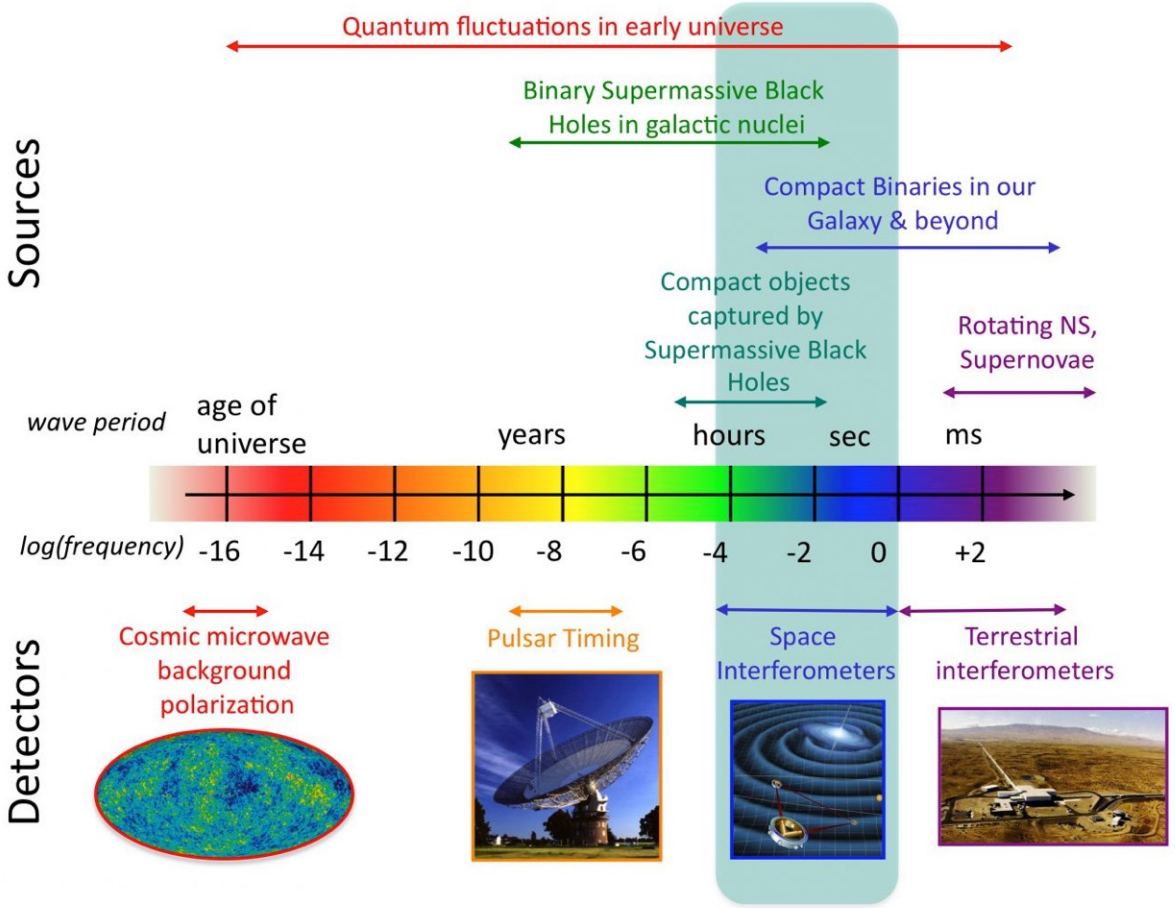


95” (Hubble Space Telescope, 1990)

25m (Giant Magellan Telescope, 2021)

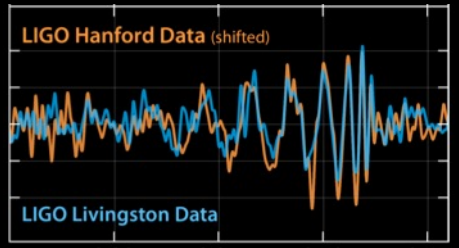


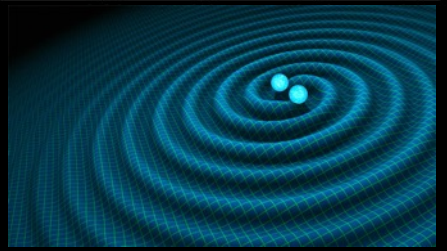
The Gravitational Wave Sky



Launching a new era of GW astrophysics

- First direct observations of gravitational waves
- Einstein's general relativity theory confirmed
- Binary black hole and binary neutron star collisions observed in real time
- The machine works with sub-attometer precision, phew!





Turned on a completely new sense with which to study the Universe

Using gravity alone, or with light – a new tool for unimagined new discoveries

A new window to the Universe

Promises a brilliantly dark and warped future