EGO/Virgo Visit

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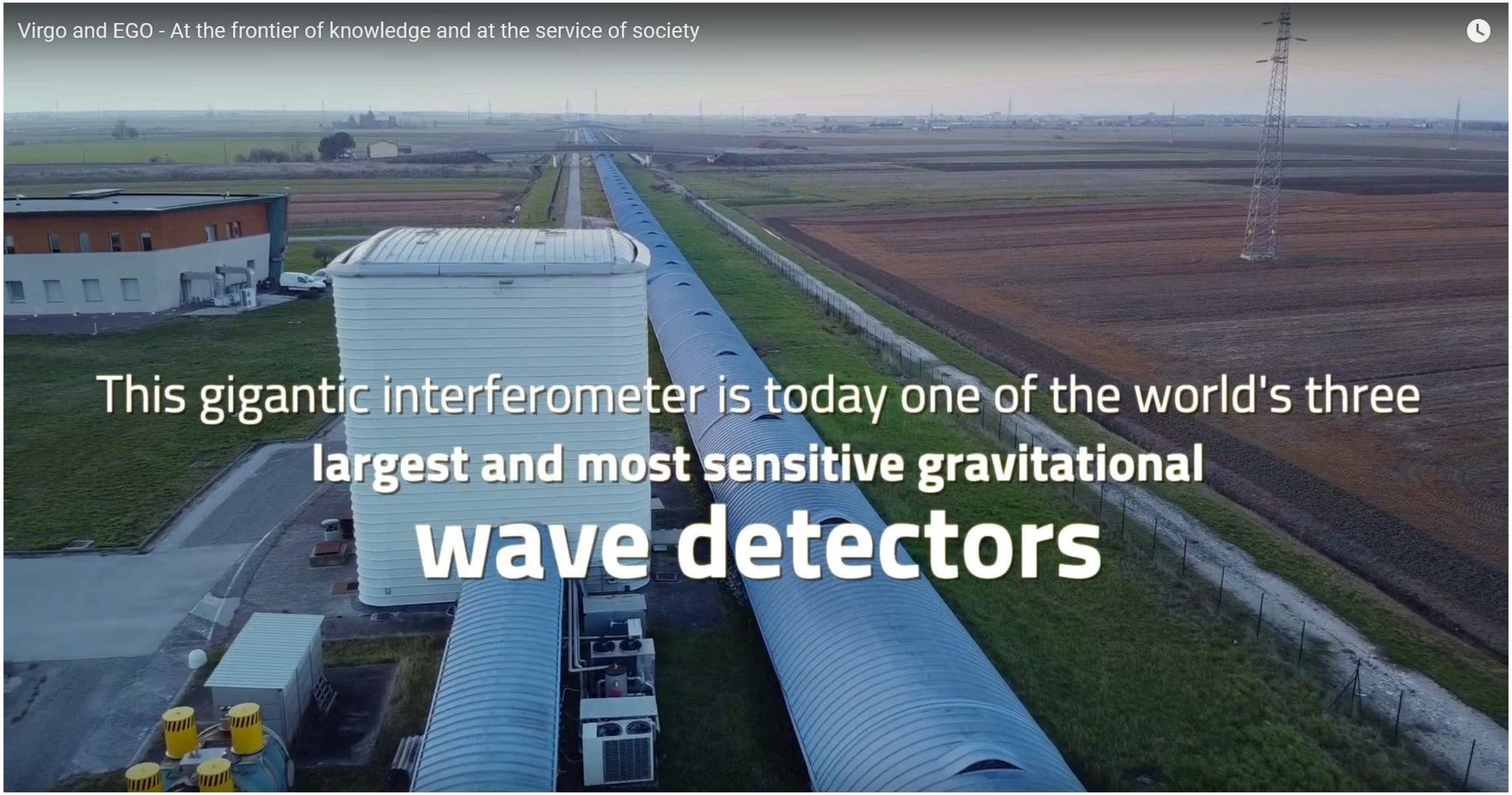
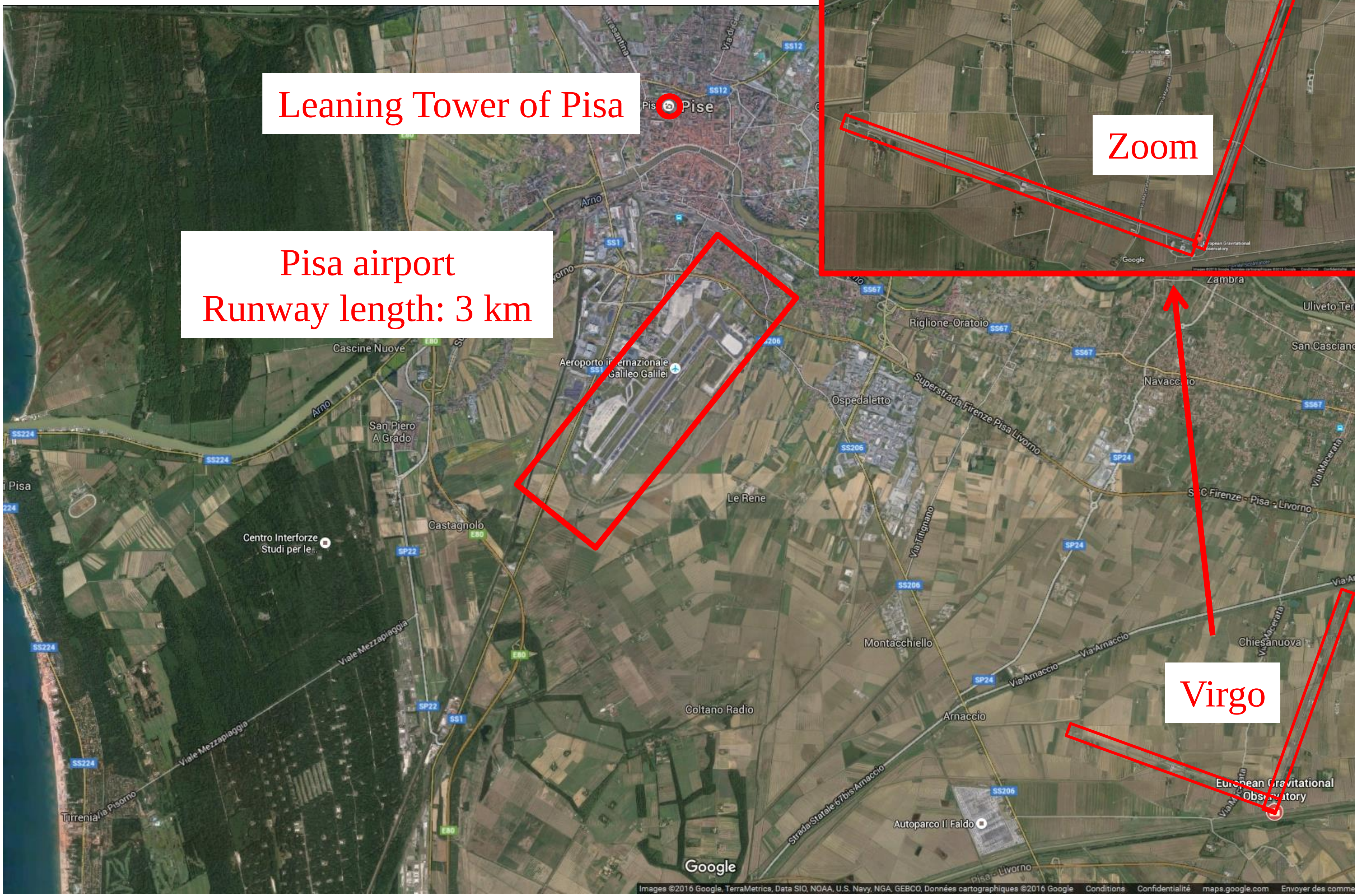
Visit teaser

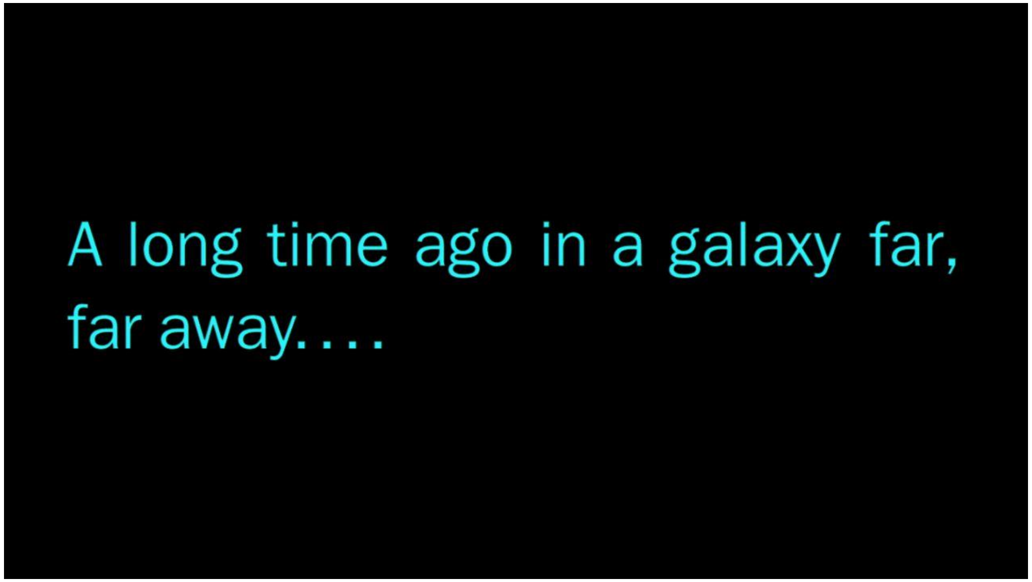
- "Virgo and EGO - At the frontier of knowledge and at the service of society"
  - https://www.youtube.com/watch?v=HeiyXXsTOD0



EGO: the Virgo site

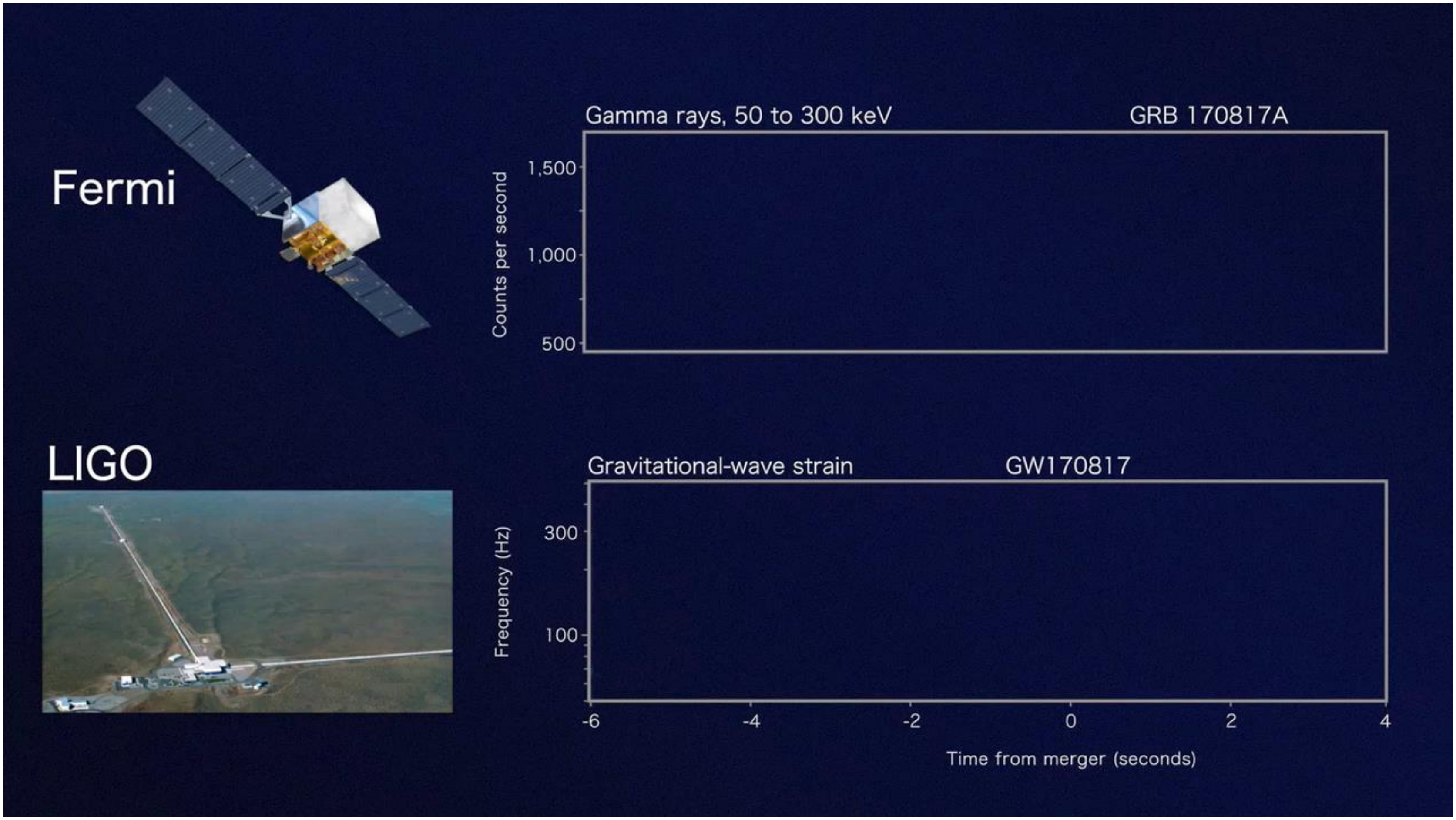


17-18 August 2017:
12 quite extraordinary hours


A long time ago in a galaxy far,
far away....

Thursday August 17, 2017 – 14:41 CEST

- Signals recorded within 1.7 second
  - LIGO (gravitational waves) first
  - Then the GBM instrument (gamma ray burst) on board the Fermi satellite



Later the same day…

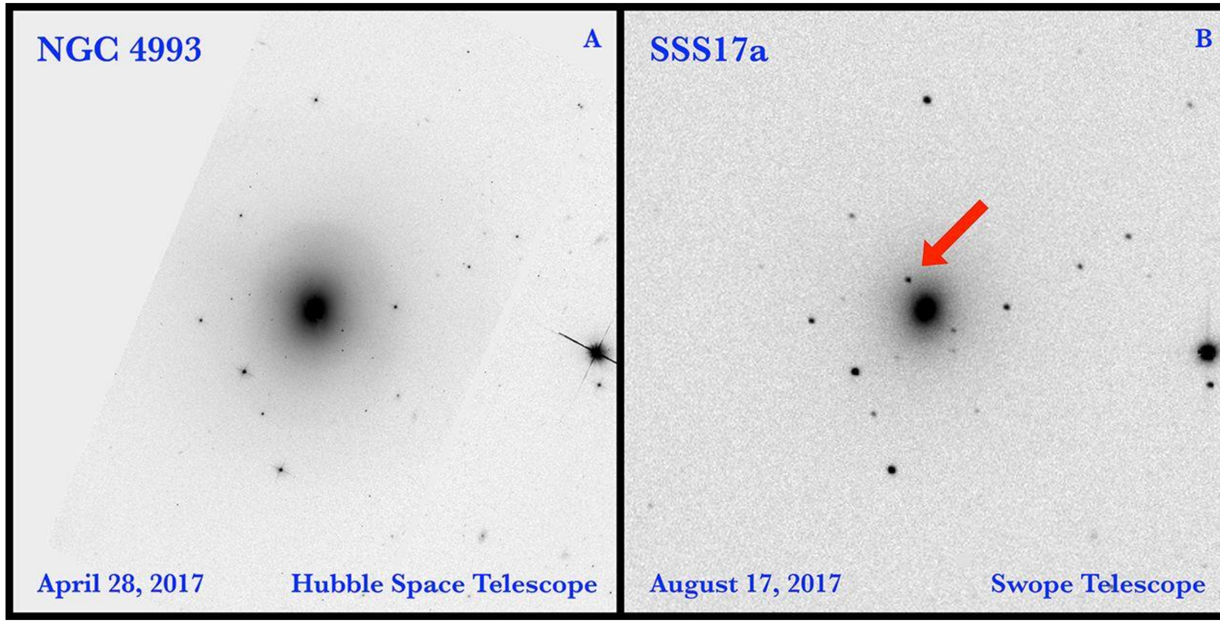
- 19:55 CEST
  - 5 hours later…

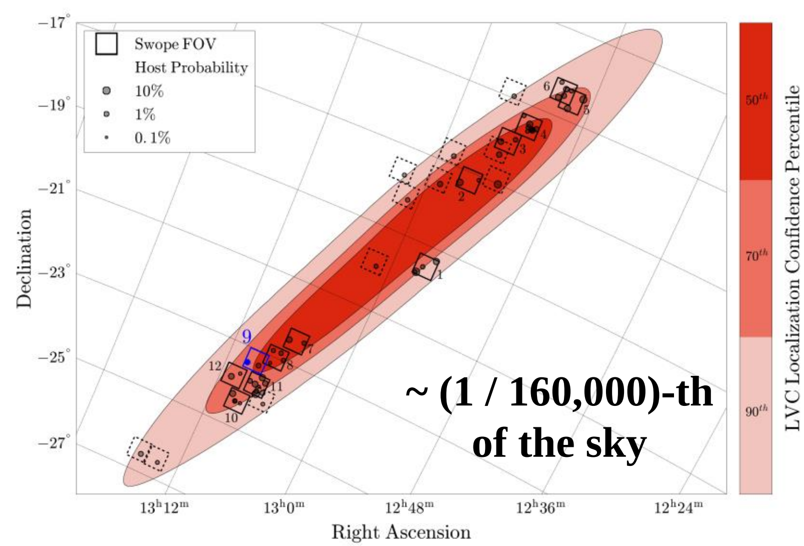
→ LIGO-Virgo localisation
  - Position in the sky: 28 square degrees
  - Estimation of the distance to the source

The following night…

- 2017/08/18
  01:33 CEST

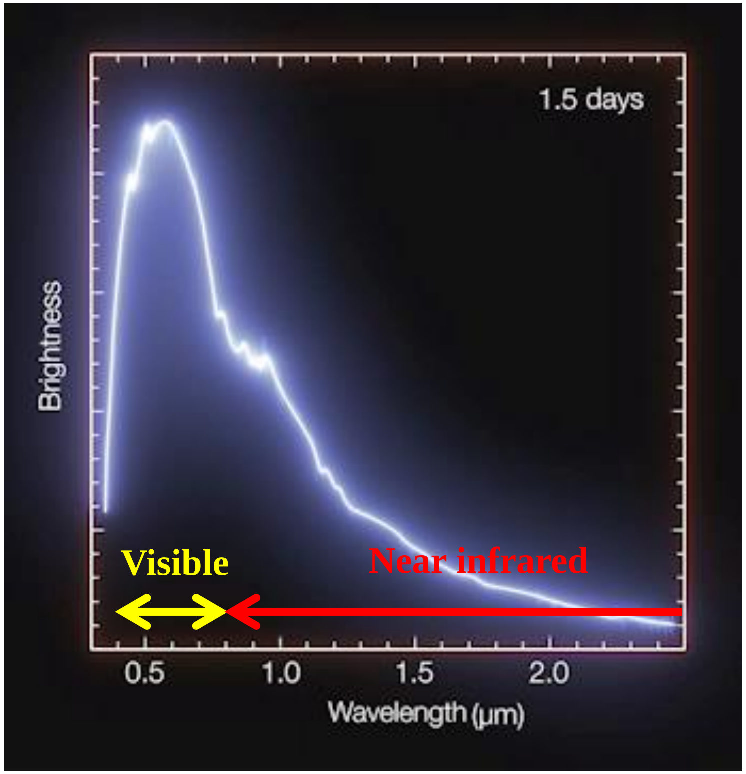
→ Discovery of the optical counterpart by the SWOPE telescope in Chile

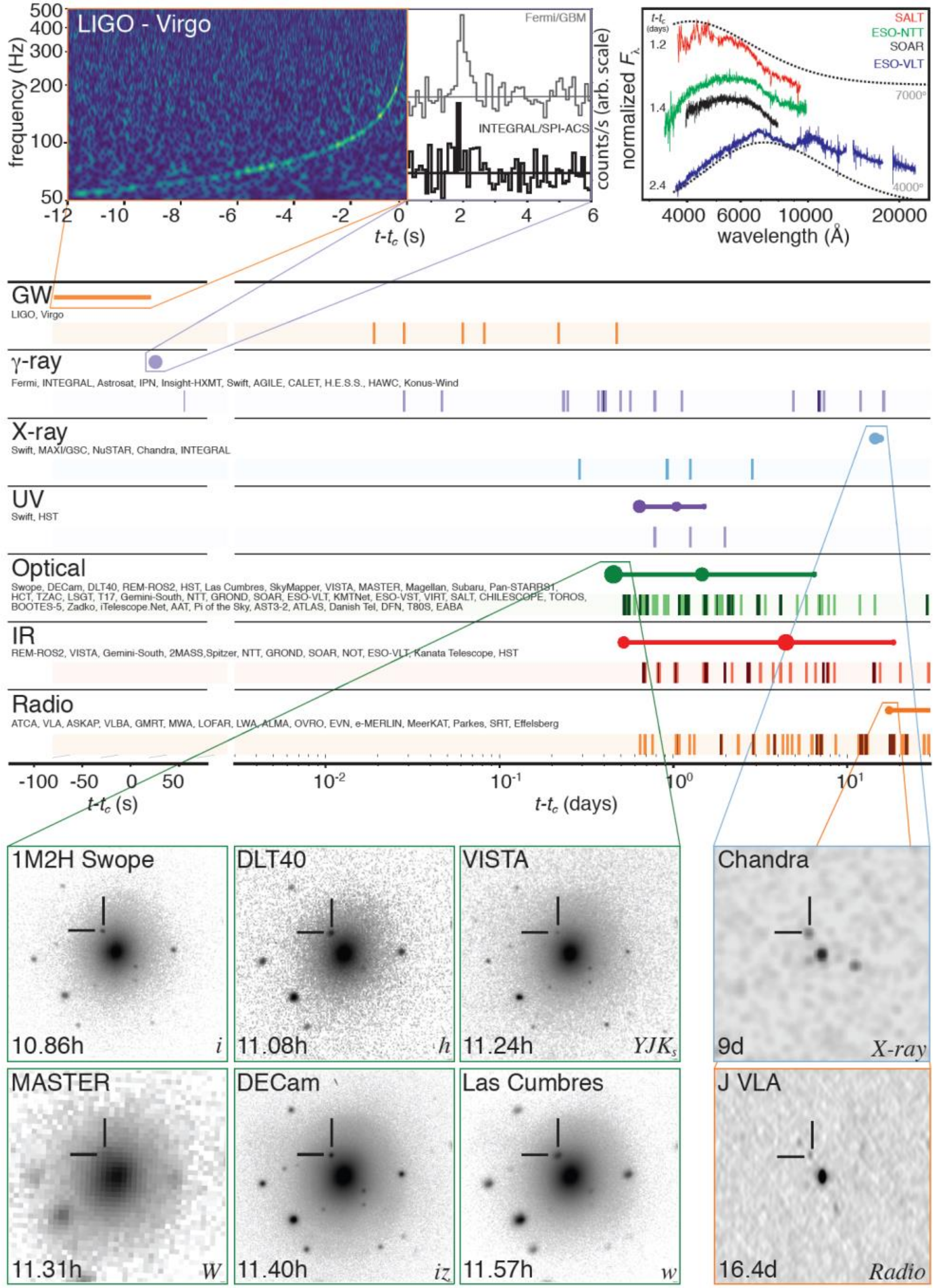




Multi-messenger Astronomy

- Gravitational waves, gamma-ray burst, the whole electromagnetic spectrum



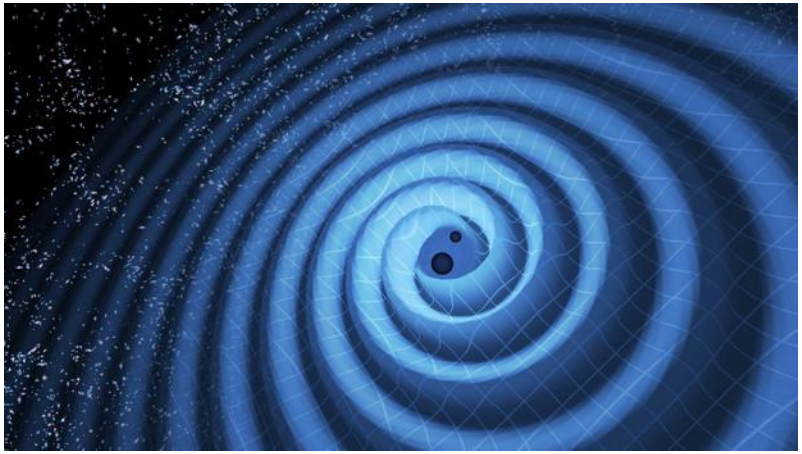


Detecting gravitational waves

Thanks to the many colleagues from the LAL (now IJCLab) Virgo group, Virgo and LIGO, from wich I borrowed ideas and material for this talk

Gravitational waves

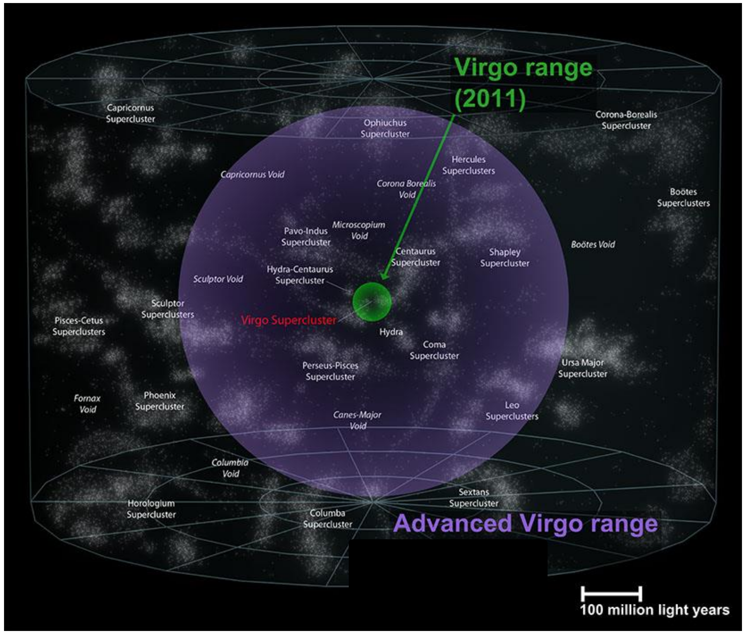
- One of the first predictions (1916) of general relativity (1915)
  - Accelerated masses induce perturbations of the spacetime that propagate at the speed of light



- No gravitational wave (GW) emission if the source is axisymmetrical
  - A « good » source must have an asymmetrical mass distribution

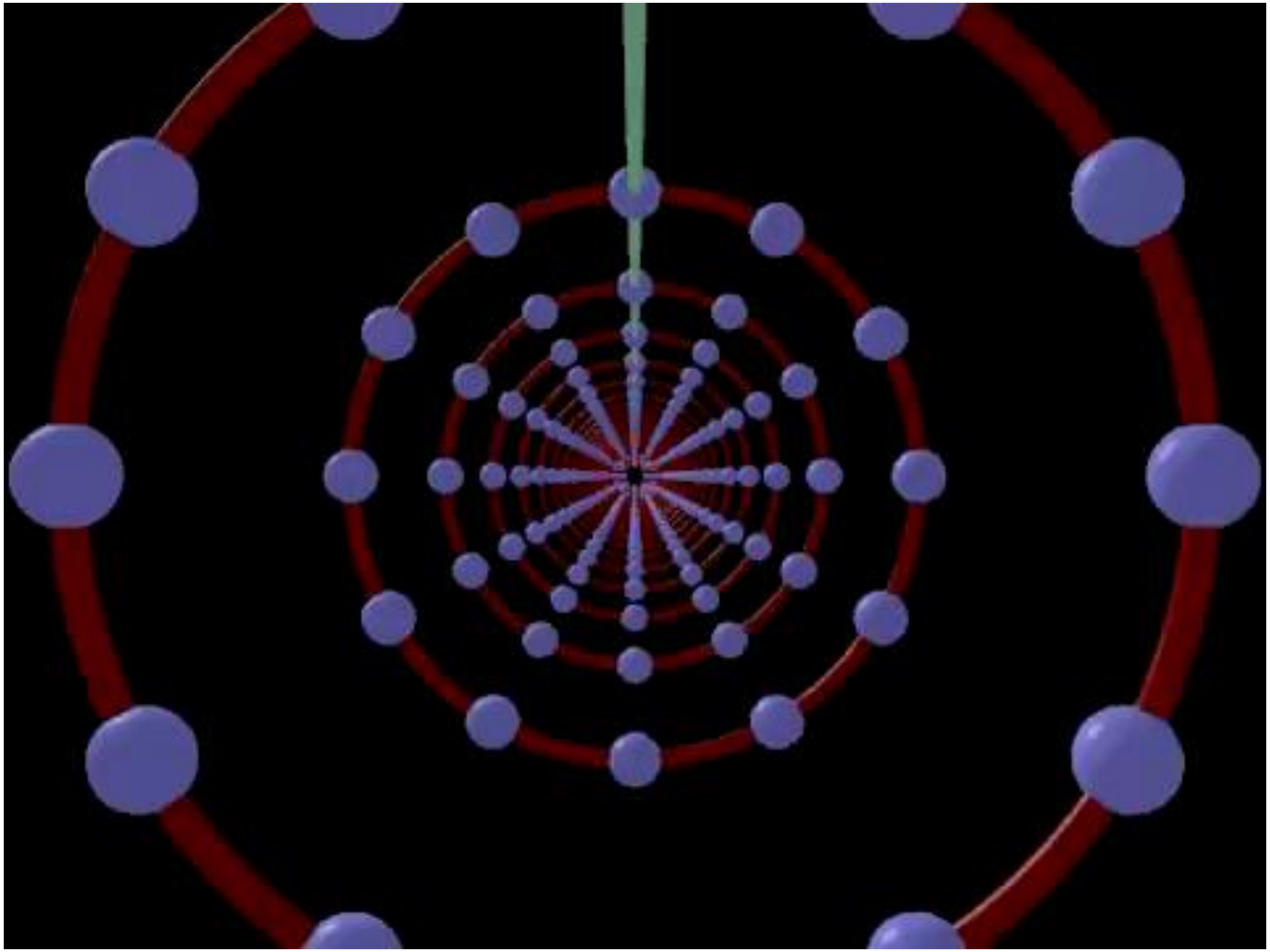
- GW amplitude h
  - Dimensionless
  - Scales down like 1/(distance to source)
- Detectors are directly sensitive to h

→ Factor 2 (10) gain in sensitivity
⇔ Gain of a factor 2 (10) in distance
⇔ Observable Universe volume scales by a factor 8 (1000)

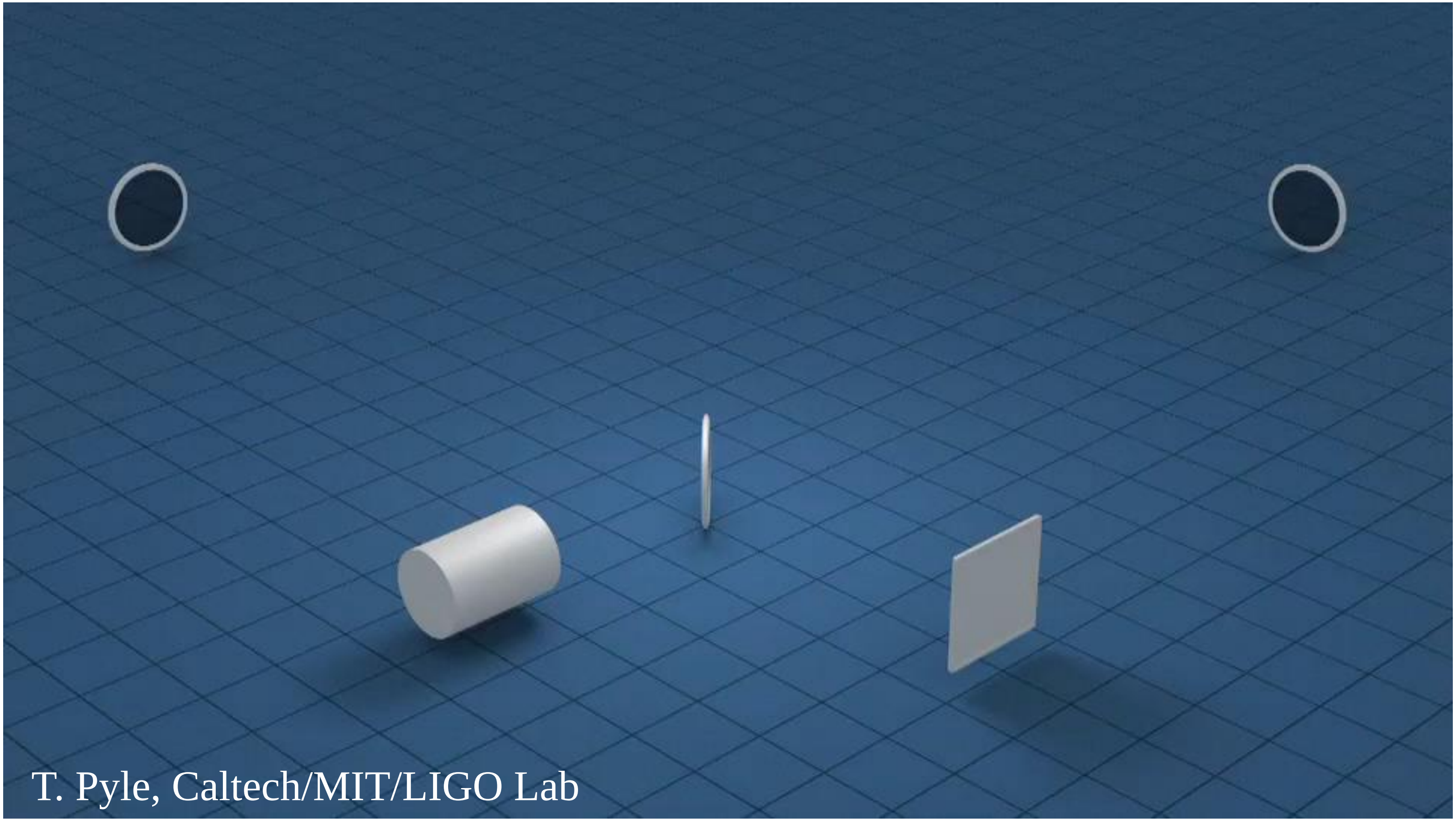


Effect of gravitational waves on test masses

- In 3D



An interferometer in a nutshell

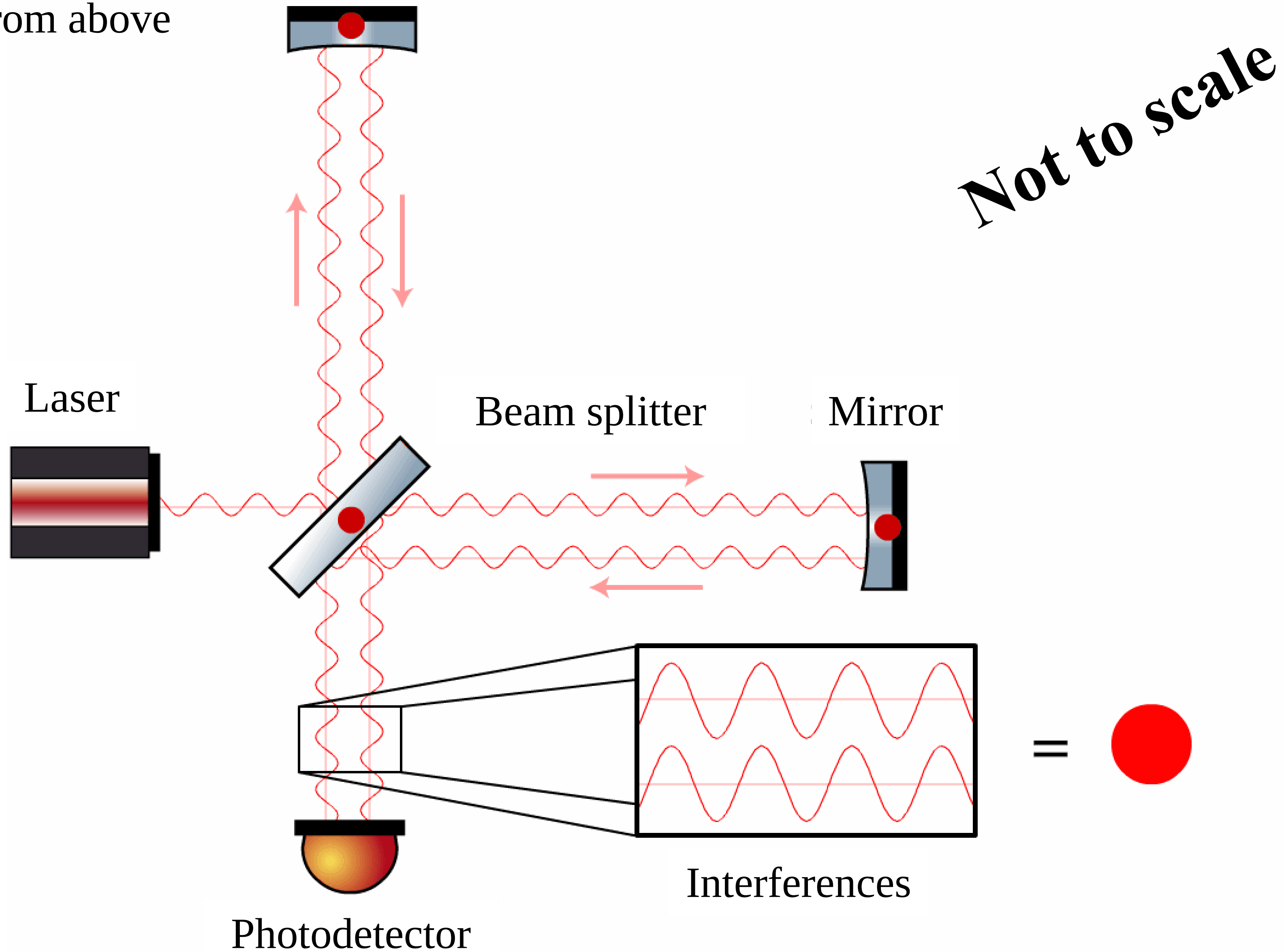


Sensitivity $\propto$ **1 / (arm length) / √(laser power)**

As small as possible

An interferometer in a nutshell

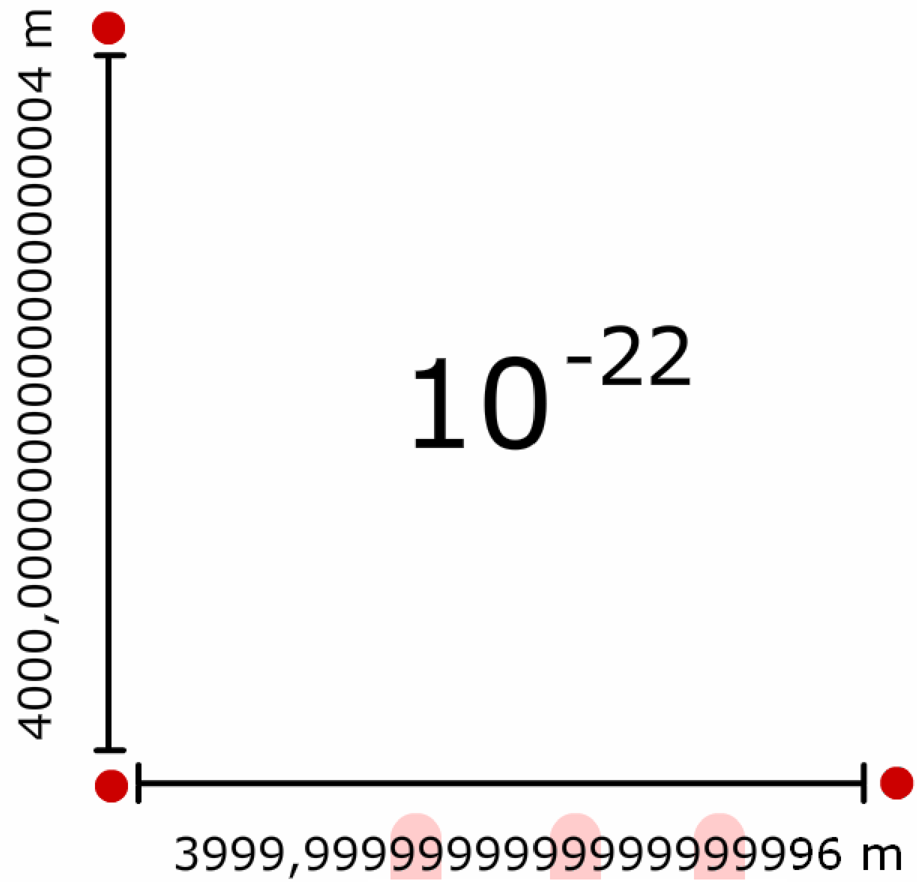
- From above



A record sensitivity

- Extremely tiny relative variation of length ($\Delta L/L$)
  - About a fraction of a thousandth of a bilionth of a bilionth (a fraction of 10^{-21})!

- What is 10^{-21} ?
  - Size of an atom compared to the Earth-Sun distance
  - Distance between the Sun and the Proxima Centauri star, measured with a 0.02 mm accuracy

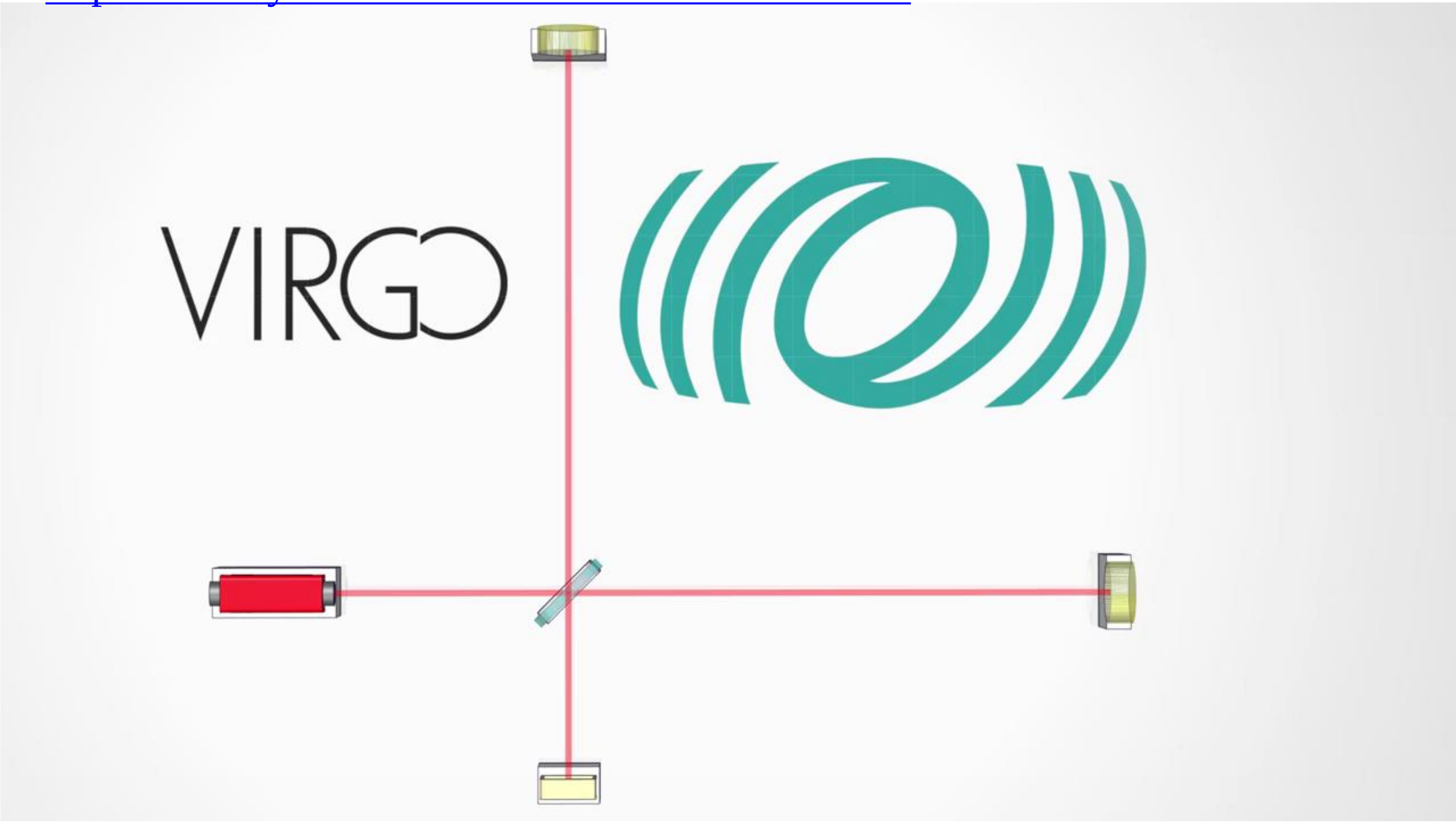


- Effect on 4 km lengths
  - Size of the LIGO detectors

→ A billionth of a billionth of meter

The Advanced Virgo detector revealed

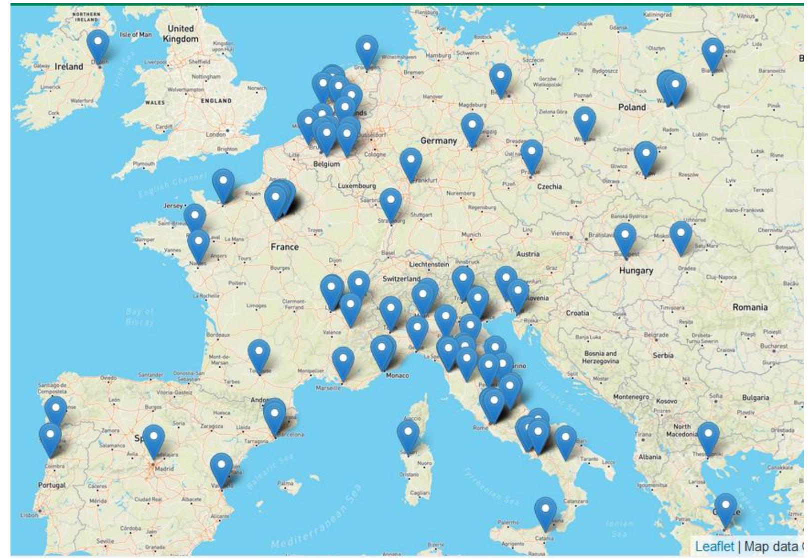
- Animation by Marco Kraan, NIKHEF
  - https://www.youtube.com/watch?v=6raomYII9P4



Virgo, LIGO and co.

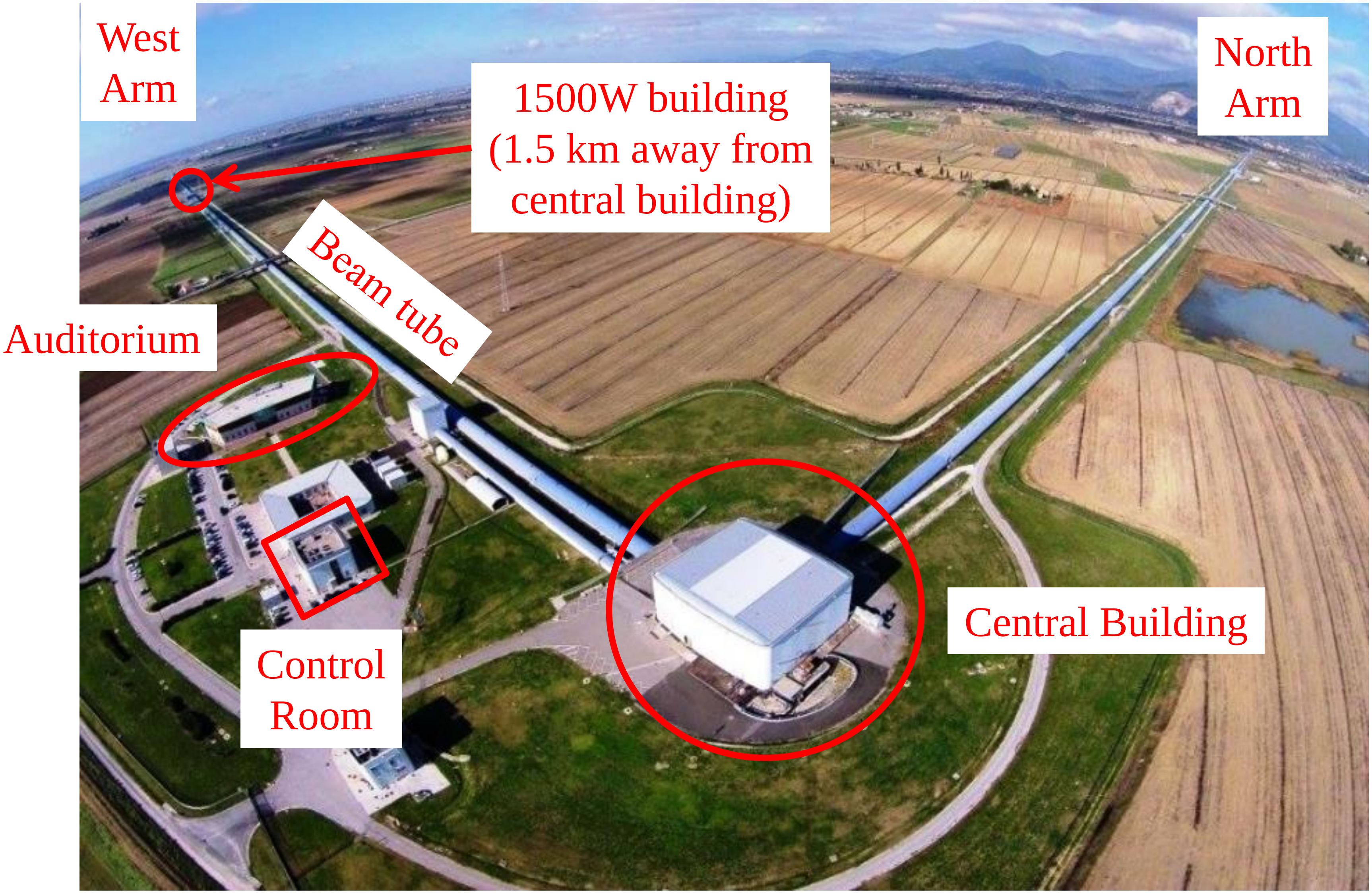
The Virgo Collaboration

→ A recent snapshot
  - Possibly (slightly) outdated

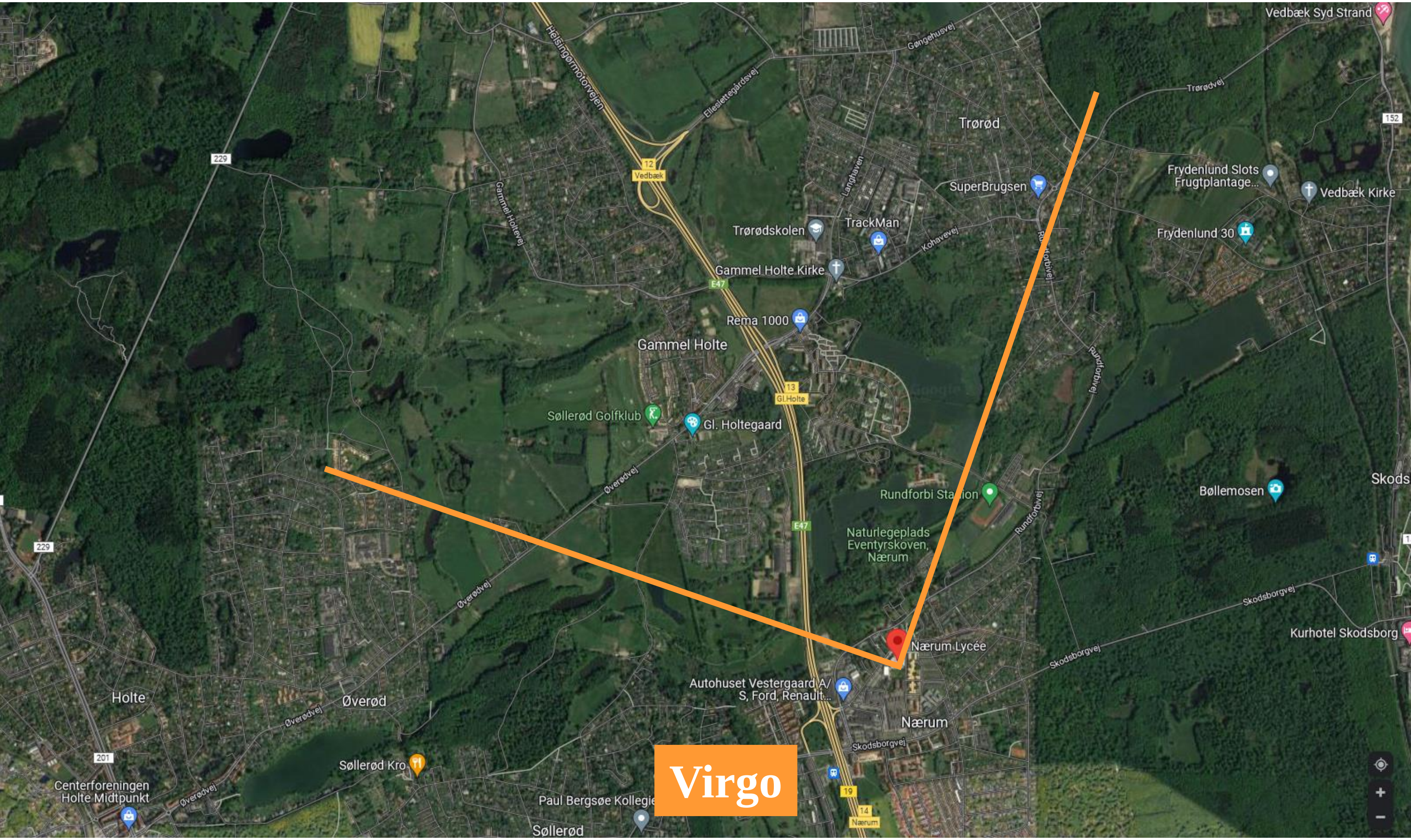


- ~800 members
  - Among which ~450 authors
- Representing ~140 institutions from 15 countries
- 9 countries represented in the Virgo governance board
  - ~35 groups total

Virgo from the sky



If Virgo were located in Nærum (DK)…

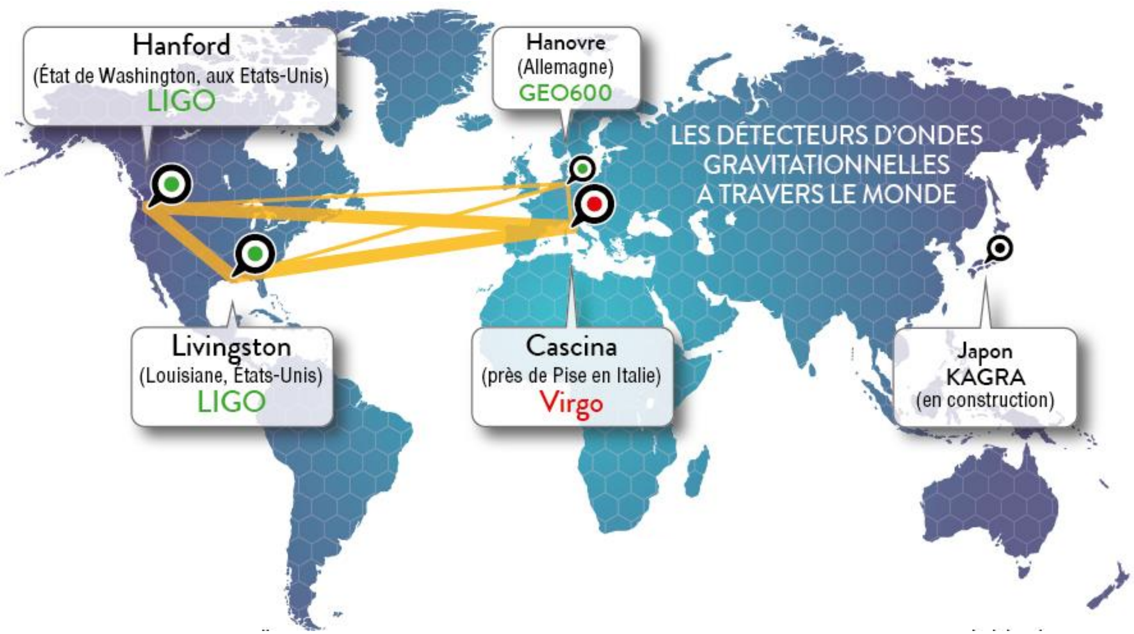


A network of interferometric detectors

A network of interferometric detectors

- A single interferometer is not enough to detect GW
  - Difficult to separate a signal from noise confidently
  - There have been unconfirmed claims of GW detection

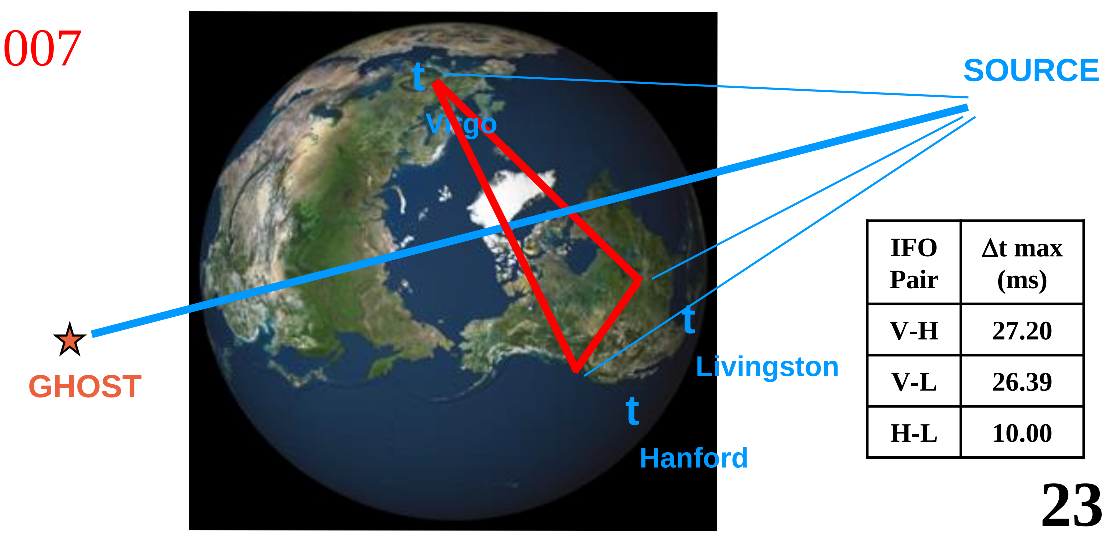
→ Need to use a network of interferometers



- Agreements (MOUs) between the different projects – Virgo/LIGO: 2007
  - Share data, common analysis, publish together

- IFO: non-directional detectors; non-uniform response in the sky

- Threefold detection: reconstruct source location in the sky

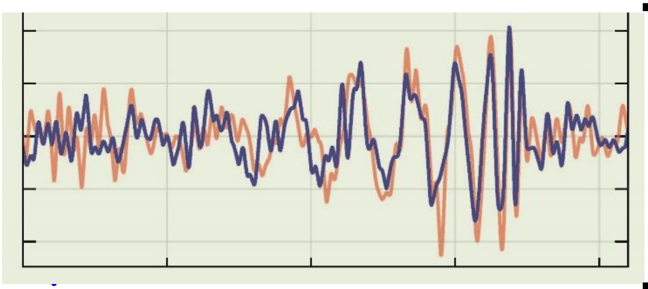


IFO Pair	Δt max (ms)
V-H	27.20
V-L	26.39
H-L	10.00

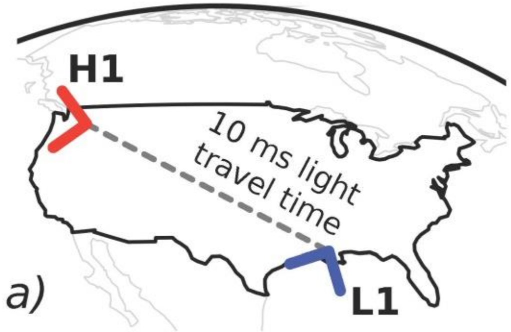
September 14, 2015, 11:51 CEST

Event called GW150914:

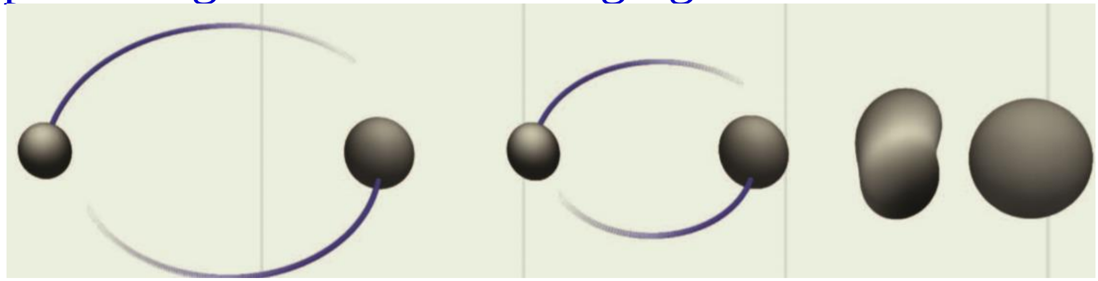
- Gravitational wave
- 2015
- September
- 14



- Signal observed in the two LIGO detectors with a 7 ms delay
  - Extremely short (< 1 s)
  - Very strong
    - With respect to the instrumental noise
    - Very weak in absolute terms



- Expected signature for the merging of 2 stellar black holes

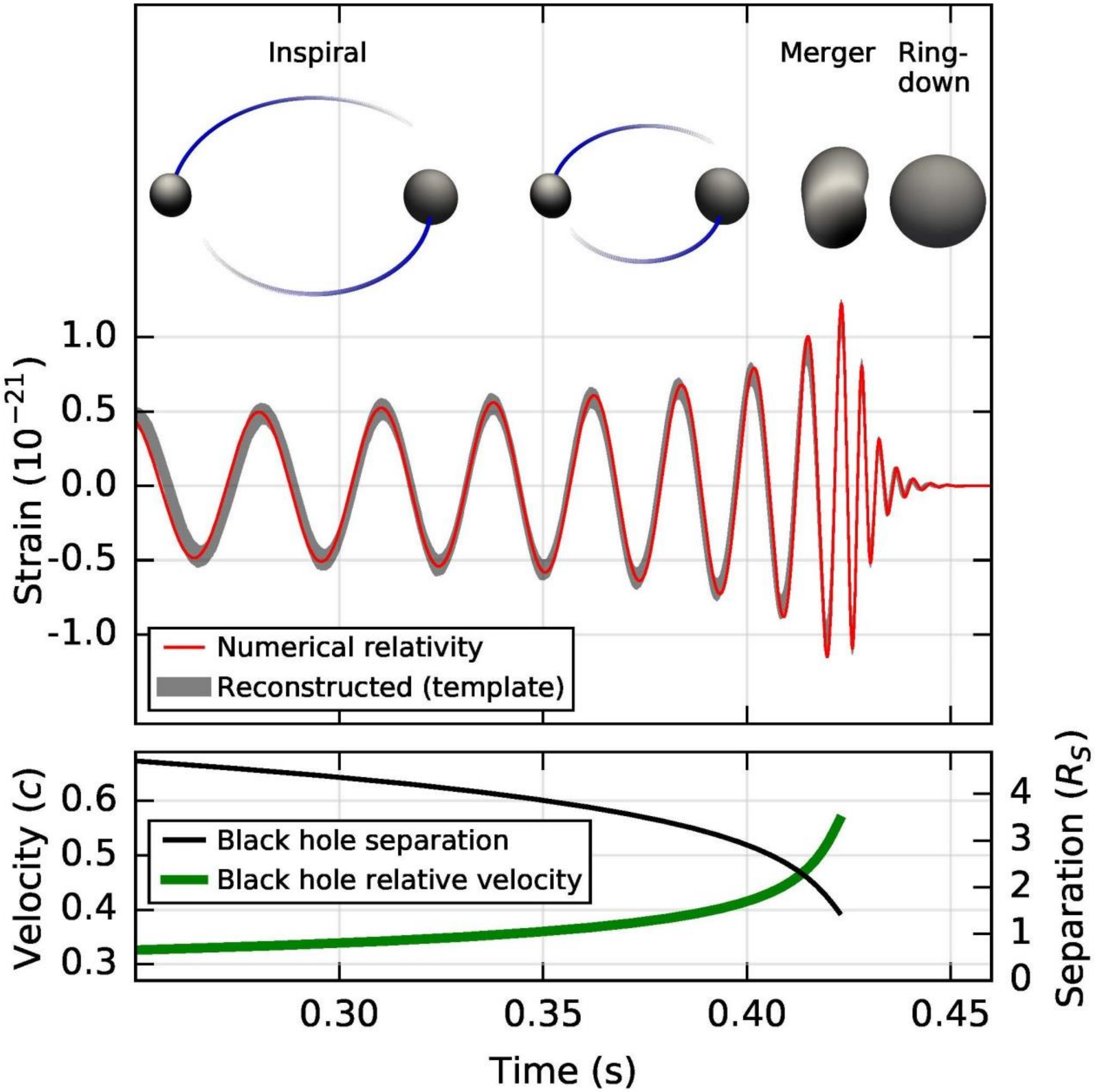


Why two black holes?

- Result of matched filtering!
  - Excellent match between the best template and the measured signal
- Two massive compact objects orbiting around each other at 75 Hz (half the GW frequency), hence at relativistic speed, and getting very close before the merging: only a few R_S away!

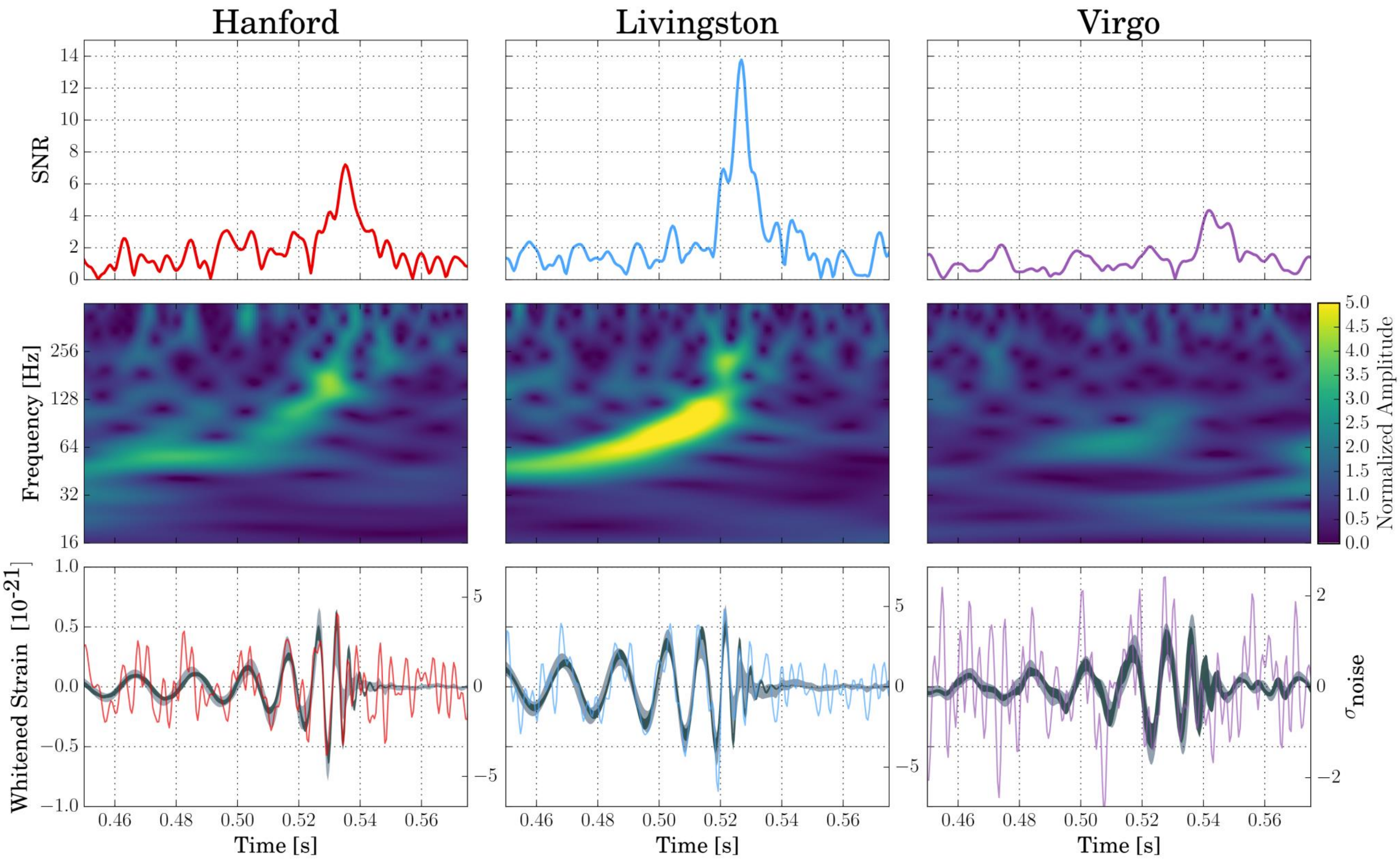
→ Black holes are the only known objects which can fit this picture

- About 3 M_{Sun} radiated in GW
- The « brighest » event ever seen
  - More powerful than any gamma-ray burst detected so far
  - Peak power larger than 10 times the power emitted by the visible Universe



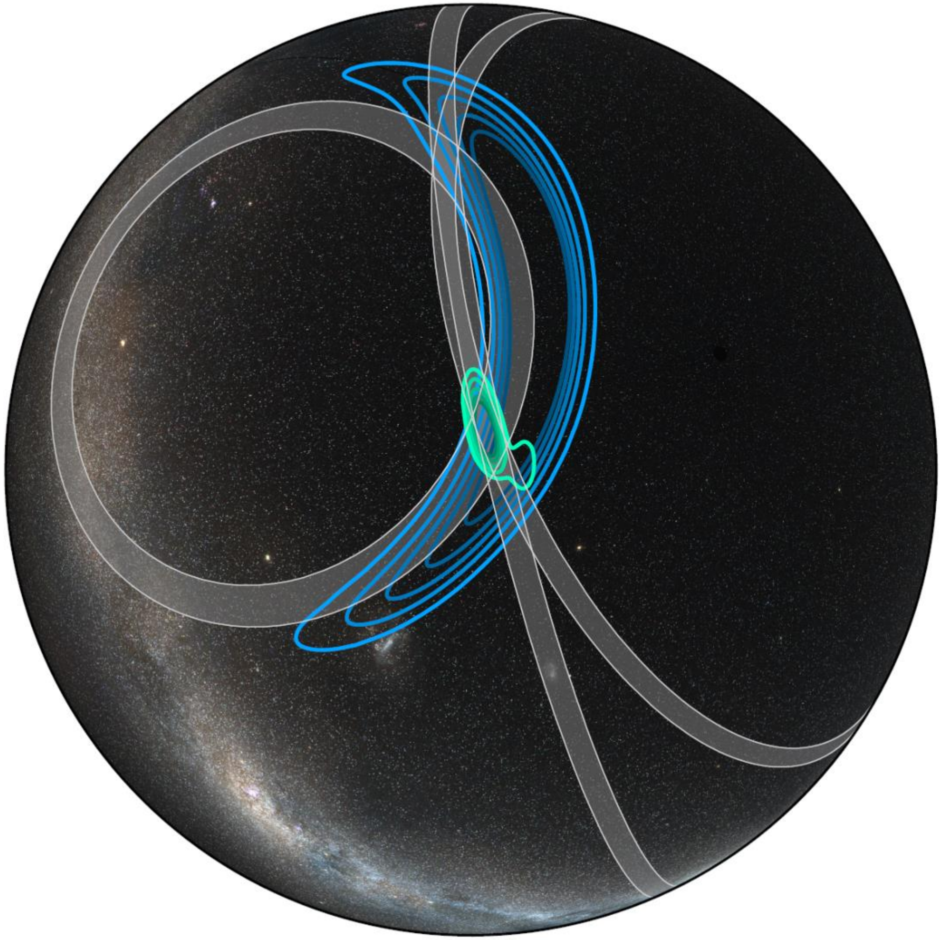
GW170814: first 3-detector signal

- Detailled studies confirm evidence of a signal in the Virgo detector



GW170814: LIGO-Virgo sky localization

- Triangulation
  - Delays in the signal arrival time between detectors
  - Difference in shape and amplitude for the detected signals

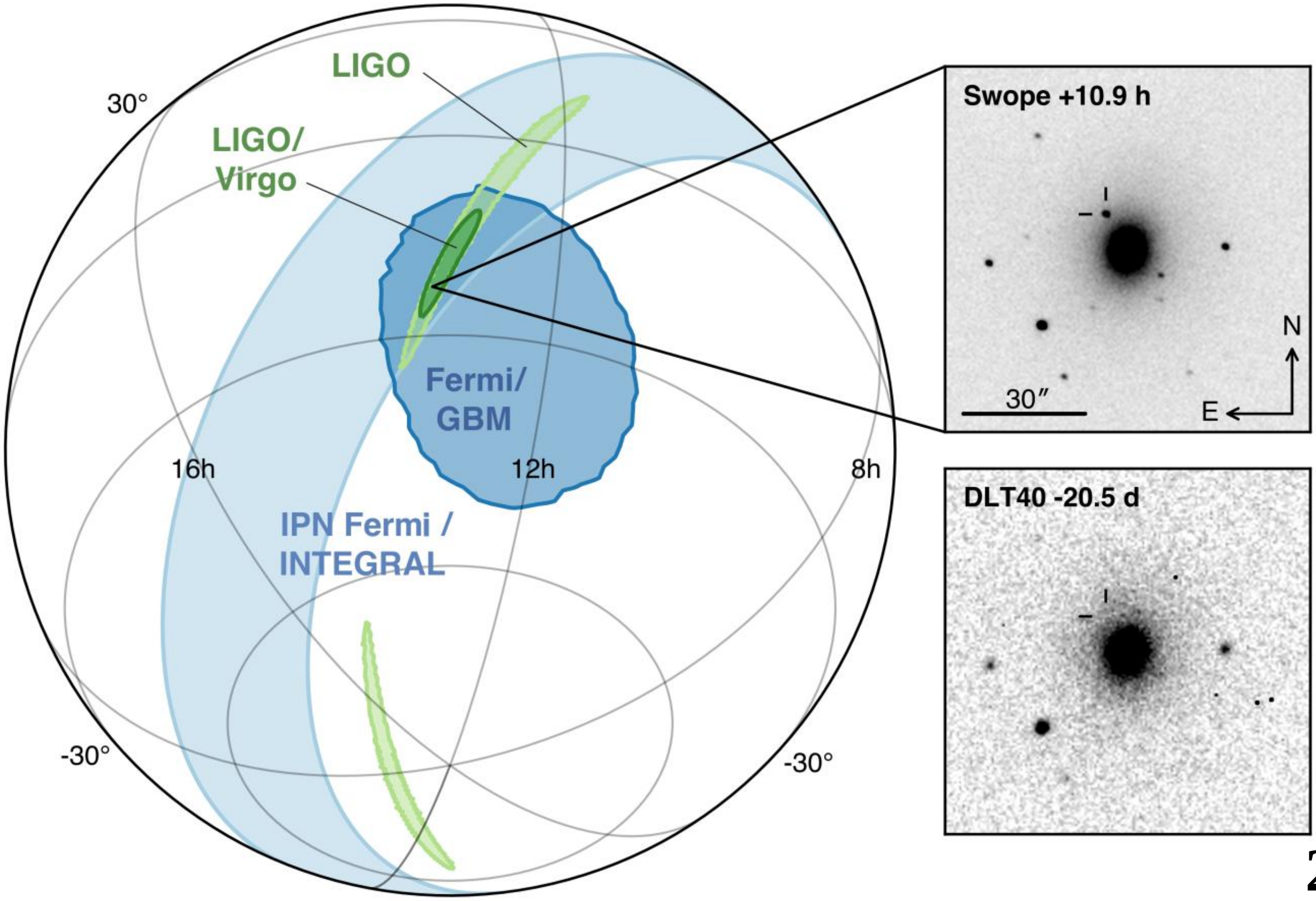


Sky localizations & source position

- Combined Signal / Noise Ratio of 32.4
- Source close to one of the Virgo blind spots

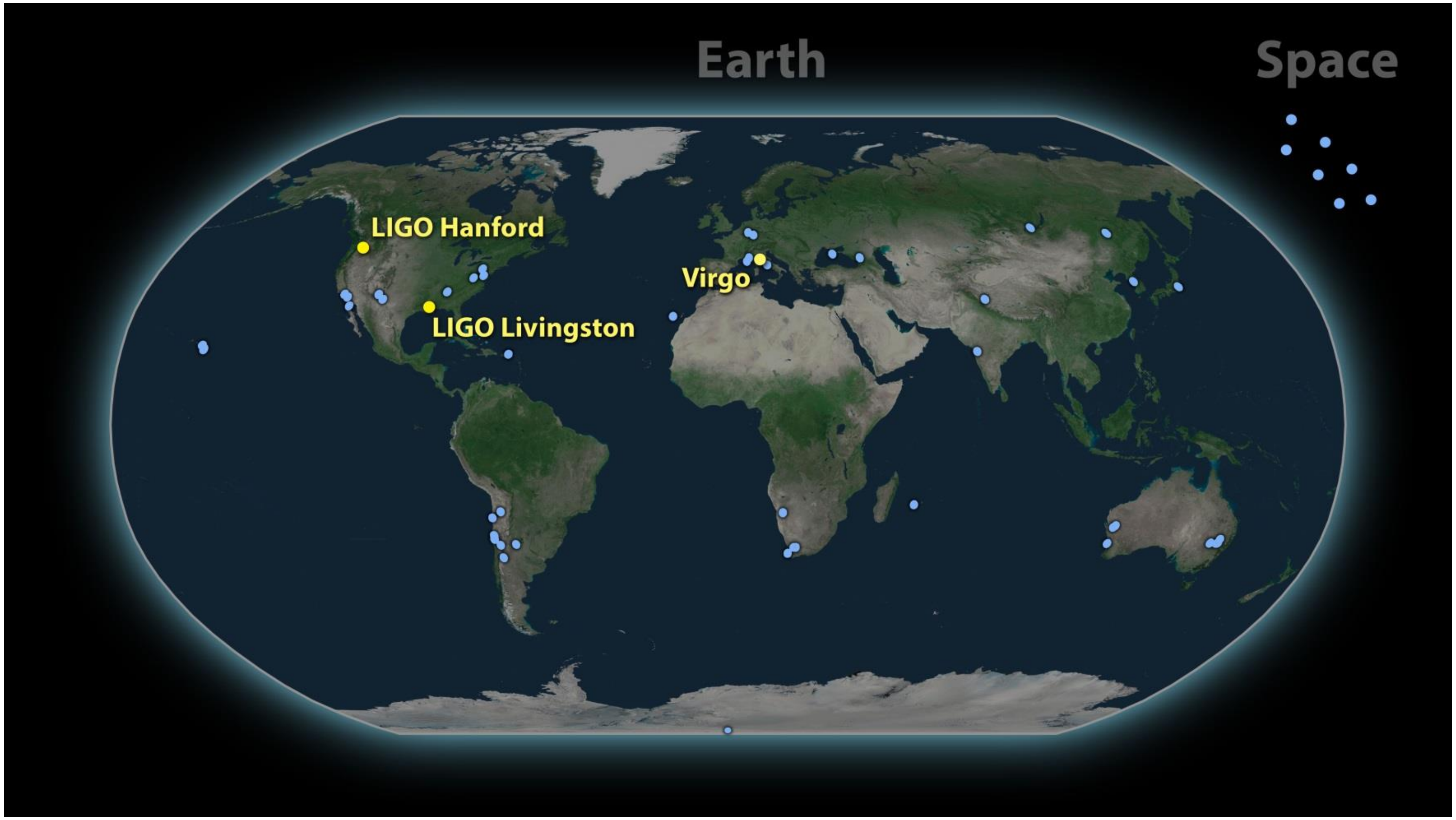
→ Accurate sky localization sent at 19:55 CEST (+ 05:14 after GW was recorded)

- Green: LIGO and LIGO + Virgo
- Blue : information from gamma ray burst satellites
- Optical discovery (Swope)



Worldwide astronomy

- Three gravitational-wave detectors
- Tens of partner observatories



The LIGO-Virgo O3 run

- 01 April 2019 → 27 March 2020
  - 1 month commissioning break: October 2019
  - → Ended 1 month earlier than anticipated due to the covid-19 pandemic

- Ox: Observing Run x
  - O1: LIGO detectors
  - O2: Mostly LIGO, Virgo in August'17
  - O3: LIGO-Virgo

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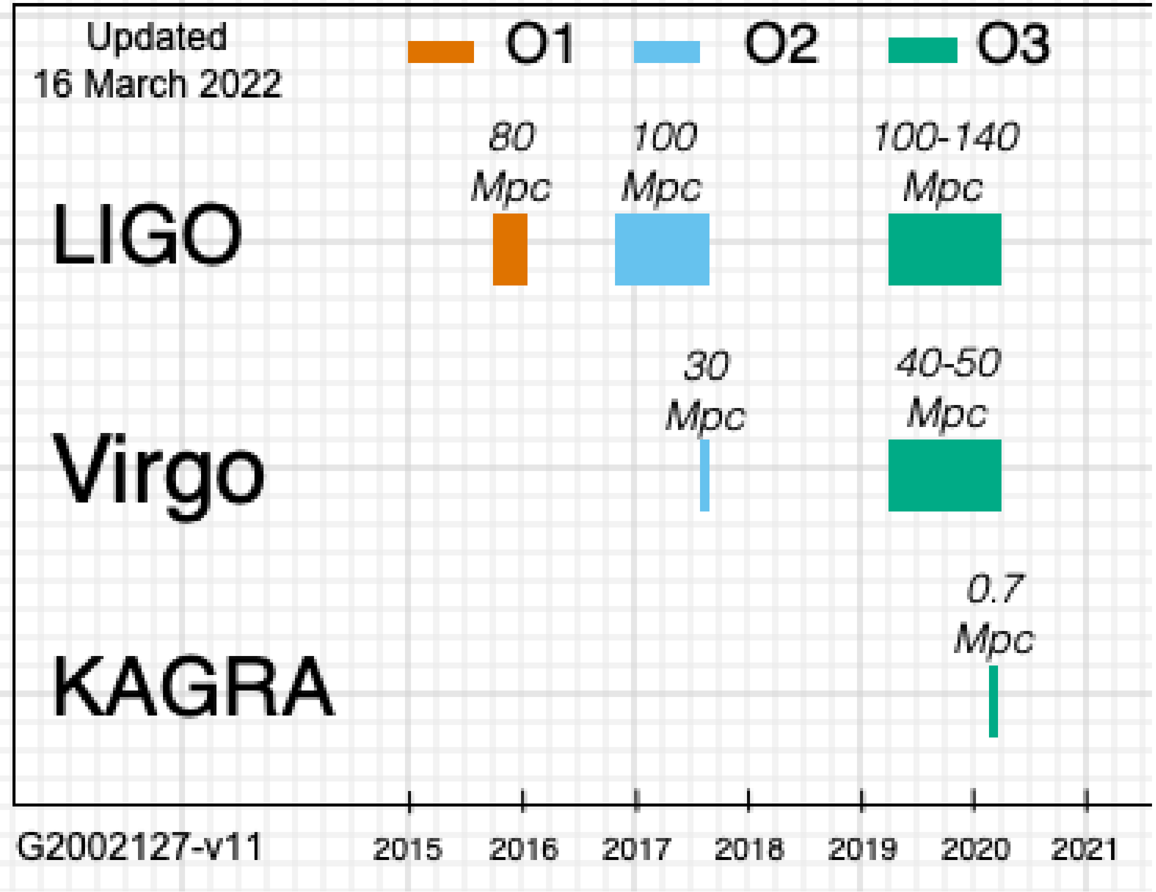
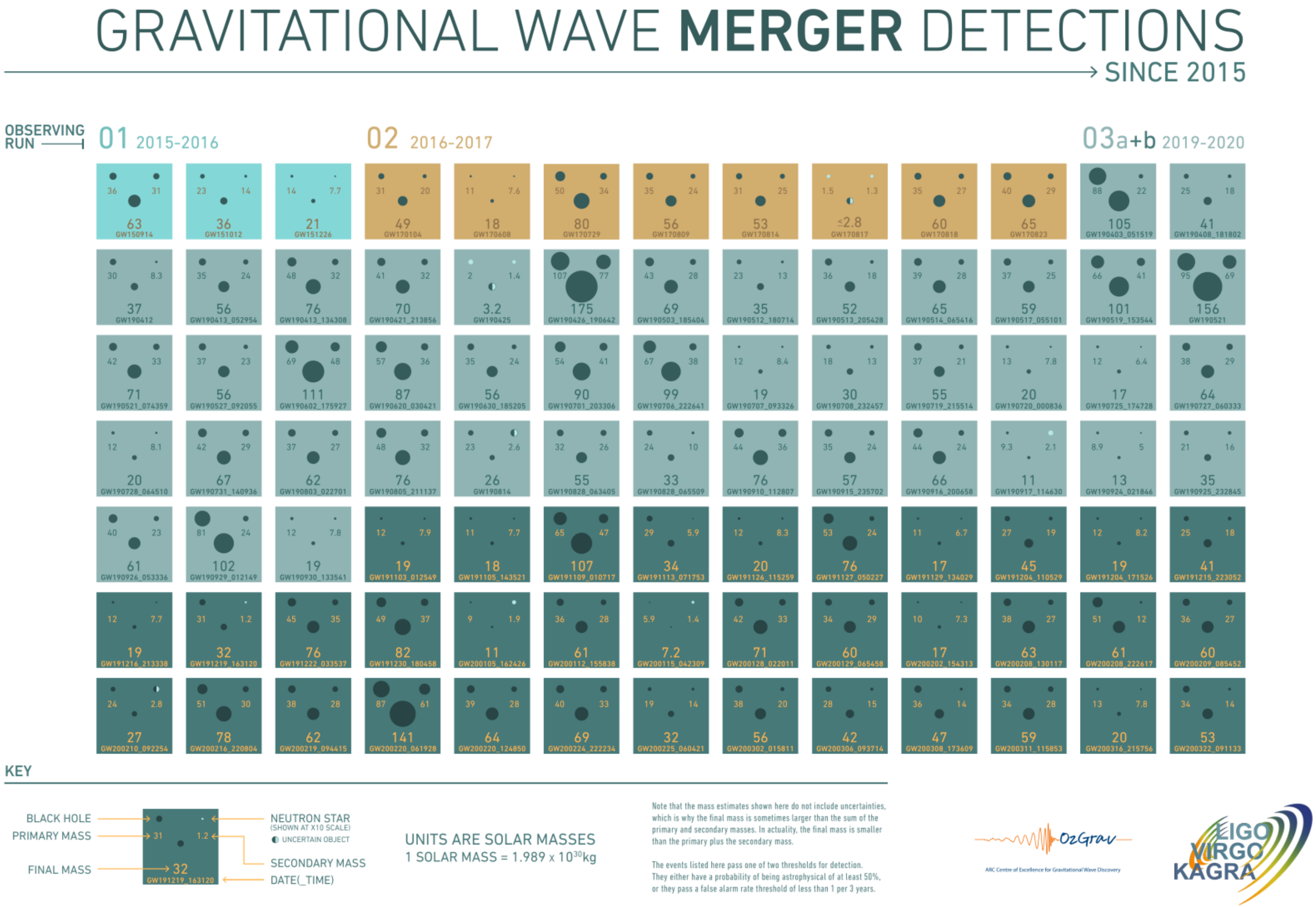
  - O4: Should be LIGO + Virgo + KAGRA



A harvest of detections

- 90 signals in the latest edition of the LIGO-Virgo-KAGRA catalog: GWTC-3



To be continued…

- Observing plans: https://www.ligo.org/scientists/GWEMalerts.php

(15 September 2022 update; next update by 15 November 2022)

LIGO, Virgo, and KAGRA are closely coordinating to start the O4 Observing run together. As a result of the most recent evaluation of the schedule for O4 readiness, we project to start the O4 Observing Run in March 2023, with an Engineering Run to start one month before the observing run begins; low-latency alerts for candidate events identified during engineering time may be released, both to exercise the system and to exploit their scientific value.