EGO/Virgo Visit

29 November 2022

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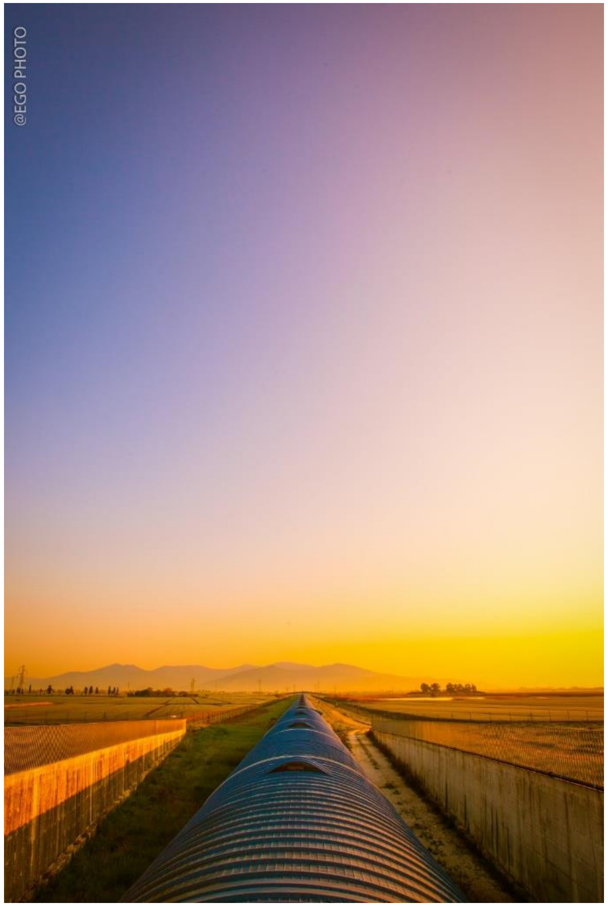
European Gravitational Observatory (CNRS, INFN & NIKHEF Consortium)

Foreword



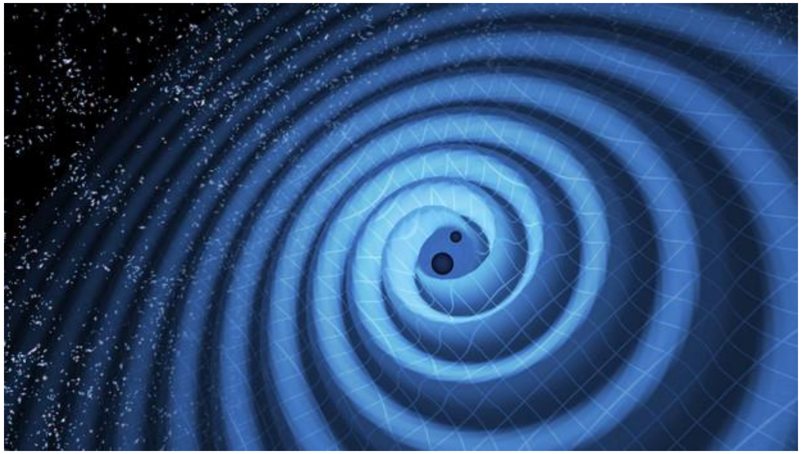
- This is a live virtual visit
  - We may loose the connection from time to time
    - Especially when we transition from place to place
      → Don't panic: we will be back
    - Let us know if this happens unexpectedly
  - Support from the EGO communication staff mandatory to make such visit happen
    → Federica Gerini will be behind the camera today

- Schedule
  - A (not so) short introduction
  - The live virtual tour
  - Q&A session once back in the office
    - I can stay online until 13:50 your time
    → Unless you have an immediate question during the tour, please note it and keep it for the Q&A session

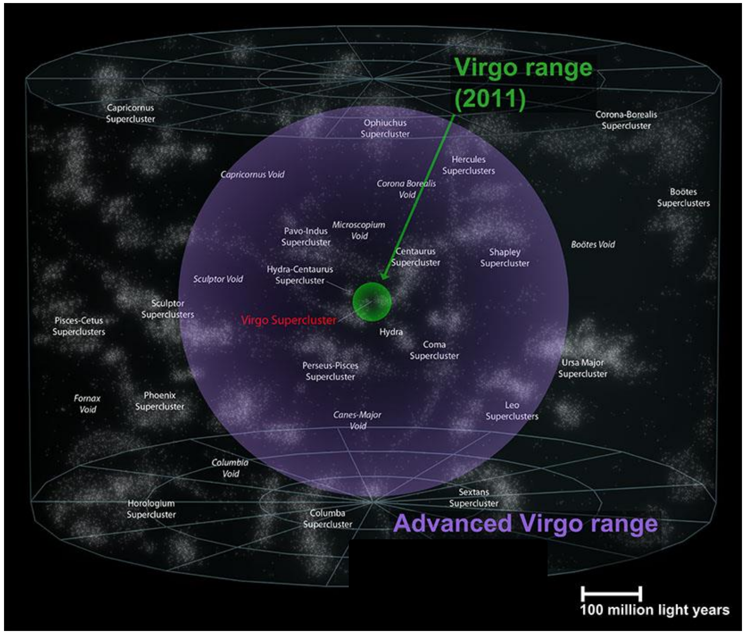
- Slides and links available on the Indico page https://indico.ego-gw.it/event/414
  - I'll send the link to prof. Tosta e Melo

Introduction

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

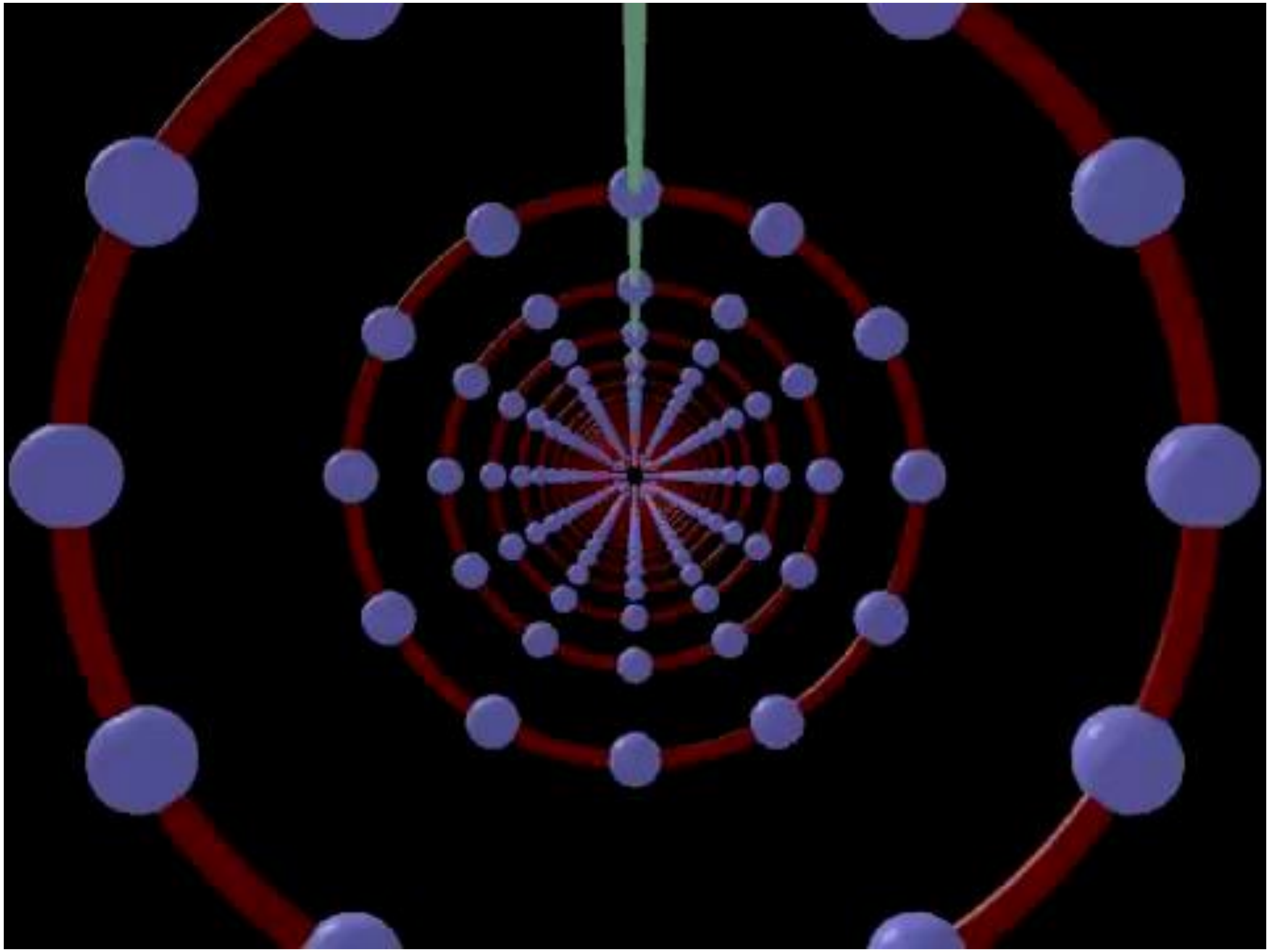


- GW amplitude h
  - Dimensionless
  - Scales down like 1/(distance to source)
- Detectors are directly sensitive to h

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

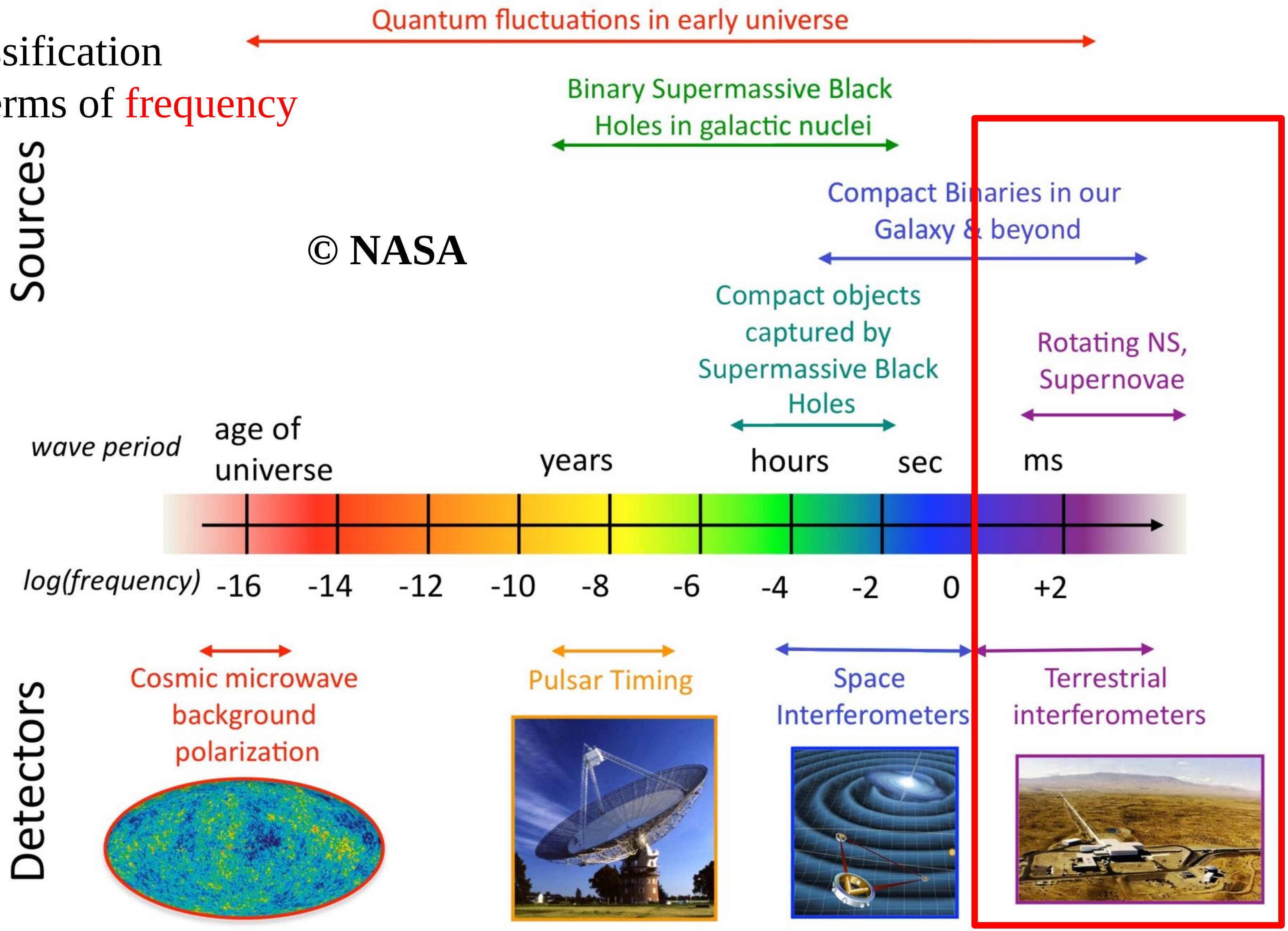
Effect of gravitational waves on test masses

- In 3D



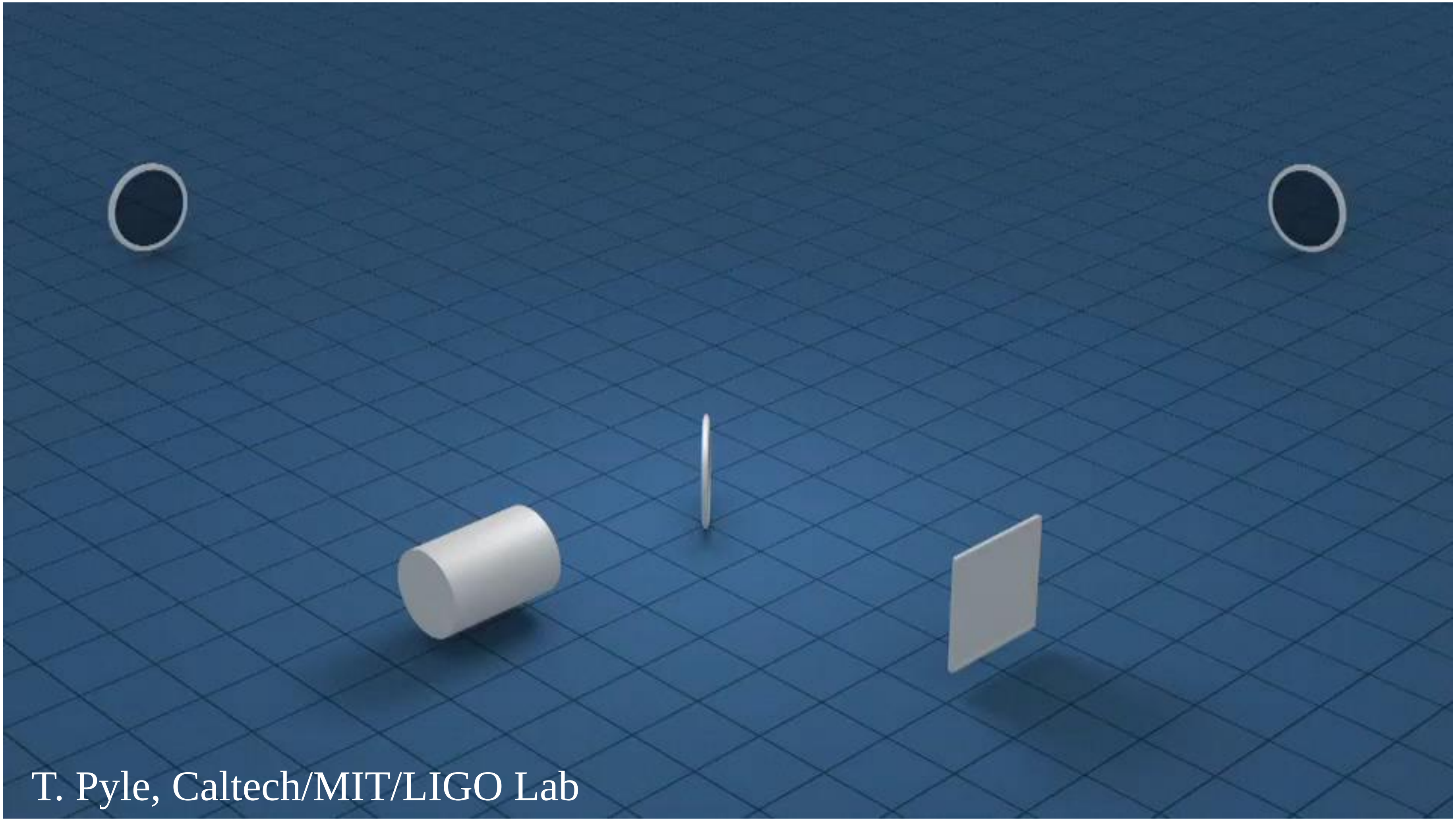
Gravitational wave spectrum

- Classification in terms of frequency



LIGO, Virgo, etc.

An interferometer in a nutshell

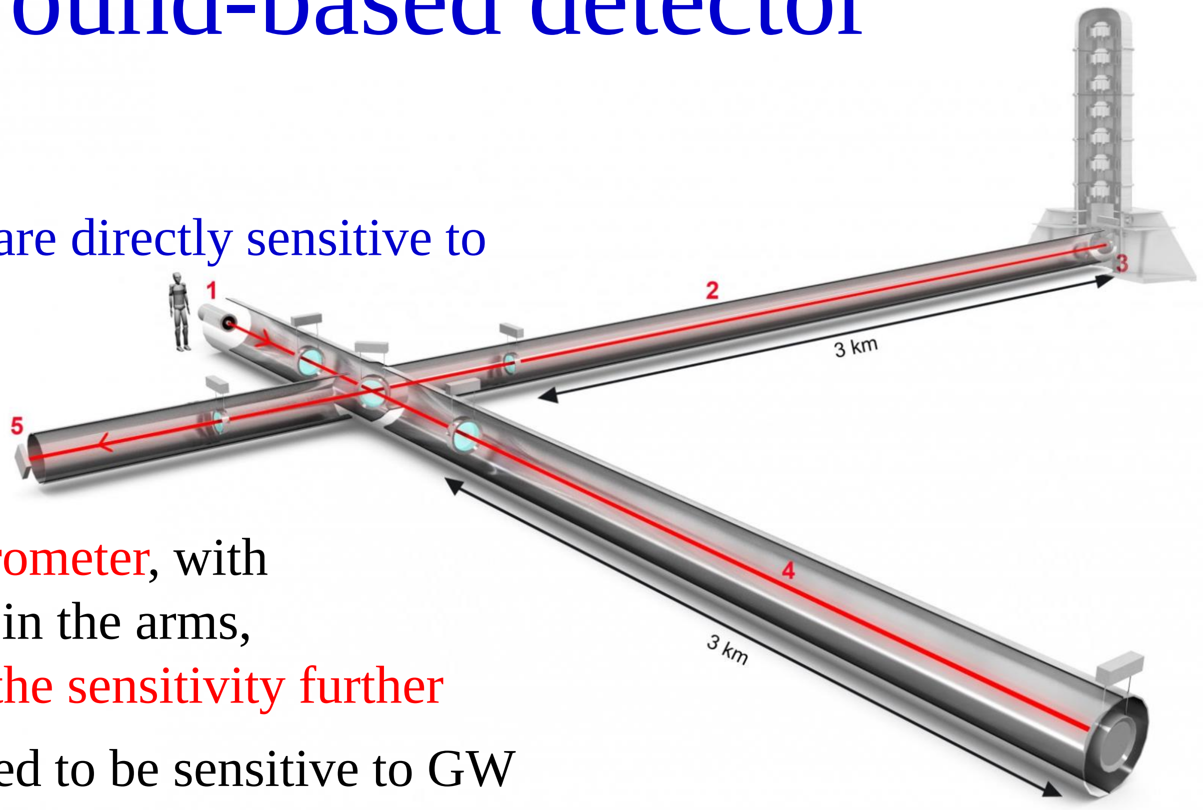


Sensitivity $\propto$ **1 / (arm length) / √(laser power)**

As small as possible

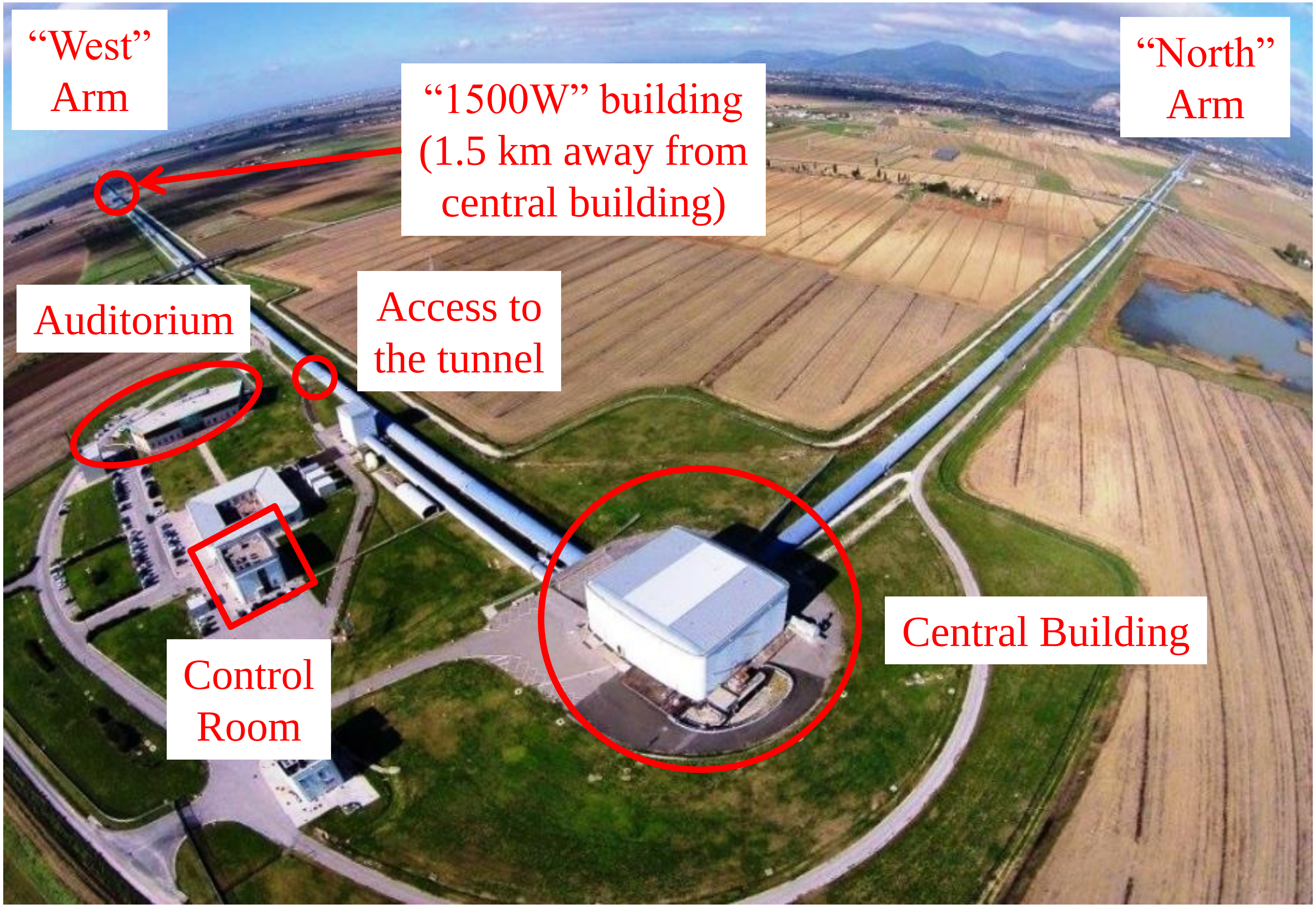
GW & ground-based detector

- GW strain h(t)
  - The quantity GW detectors are directly sensitive to
  - Dimensionless
  - Scales like 1/distance



- Suspended Michelson interferometer, with km-long Fabry-Perot cavities in the arms, recycling mirrors to enhance the sensitivity further
- Specific working point required to be sensitive to GW
  → Active feedback control systems
    - ◆ Bring the detector to its global working point and maintain it
- GW passing through the detector
  - Differential effect on arm optical paths
  → Interference condition changes at interferometer output
  → Variation of the detected power
  → GW strain channel h(t)
    - ◆ Reconstructed from raw data

Virgo from the sky



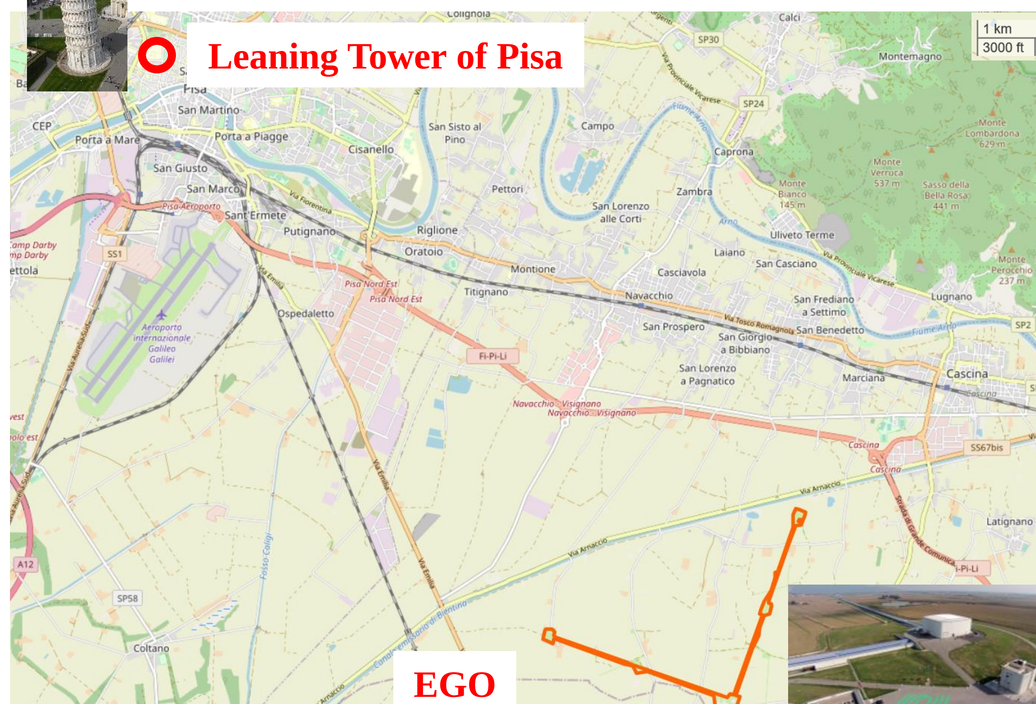
- Virgo seen from a drone: https://www.youtube.com/watch?v=mgjflMsI7qk

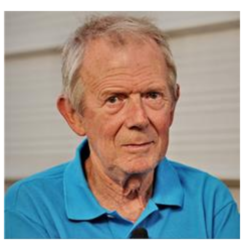
If Virgo were located in Itajubá (Brazil)…

Virgo @ EGO

- European Gravitational Observatory (EGO): the lab hosting the Virgo detector
  - Located in Cascina, about 10 km South-East of Pisa (Italy)

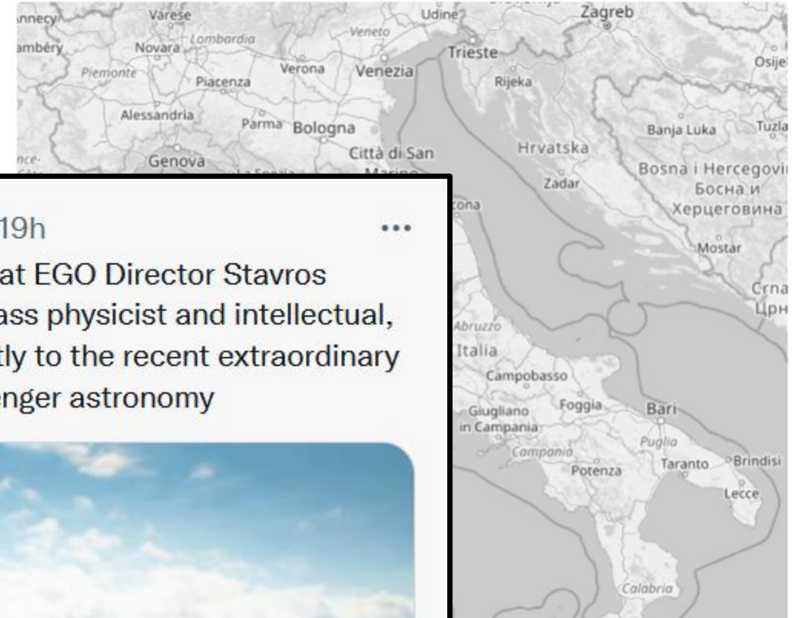
- Virgo timeline
  - End of 80's: proposal
  - Mid-90's: funding
  - 00's: first-generation (initial) detector
  - 10's-now: second-generation (advanced) detector





- Virgo founding fathers
  - Alain Brillet (CNRS)
  - Adalberto Giazotto (INFN, 1940-2017)

Virgo @ EGO



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  the lab hosti
  - Located in
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- Virgo timelin
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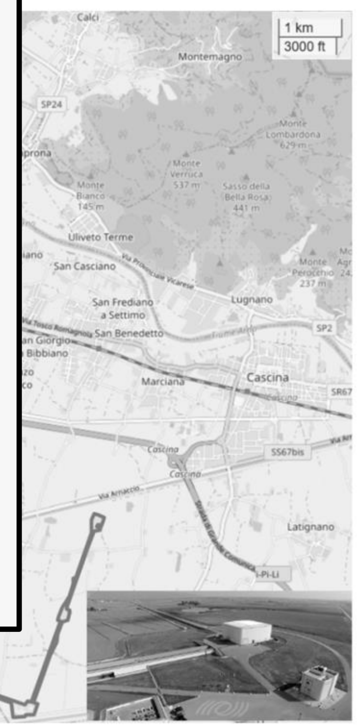

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The Virgo Collaboration

- Recent snapshot: ~800 members
  - ~530 authors

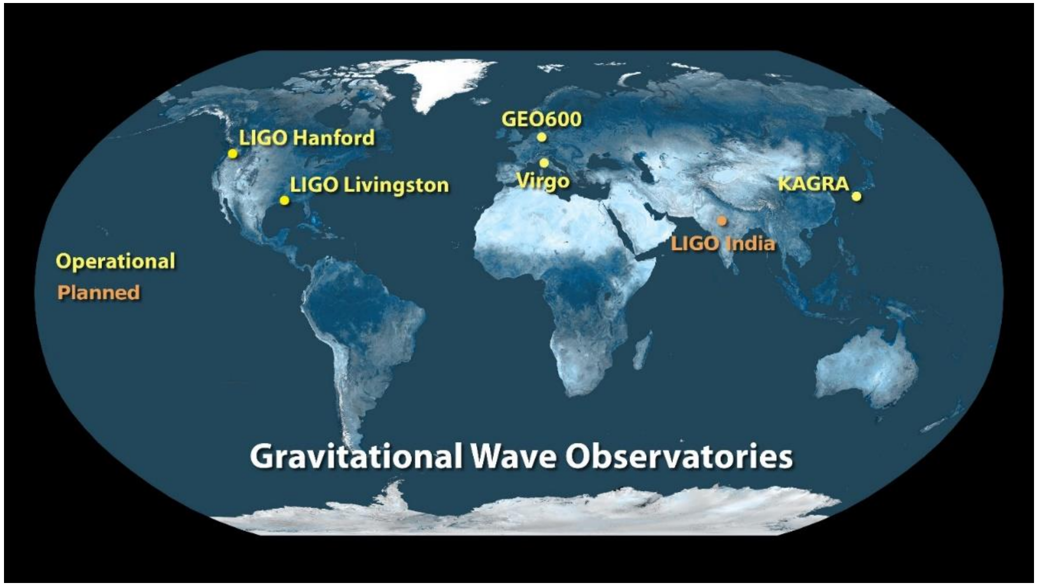
→ Strong growth since first detections
  - GW150914: ~230 Virgo authors
  - GW170817: ~260 ″

- ~140 participating institutions from 15 countries
  - Gathered in ~35 groups from 9 countries

- Websites
  - Virgo: https://www.virgo-gw.eu [New]
  - EGO: https://www.ego-gw.it
  - Public: http://public.virgo-gw.eu [To be moved elsewhere]

Virgo within LIGO-Virgo-KAGRA (LVK)

- A worldwide network of ground-based GW interferometric detectors
  - Joint data analyses & publications
    - → Detection confidence
    - → Sky localization
    - → Polarization determination
    - → Source parameters inference



- GEO600 [Germany]
  - Astrowatch, R&D
- LIGO Hanford [WA, USA]
  LIGO Livingston [LA, USA]
  - Advanced detectors online since September 2015
- Advanced Virgo : since August 2017
- KAGRA [Japan]
  - Underground and cryogenic
- Gravitational Wave Open Science Center (GWOSC): https://www.gw-openscience.org




1916-2022: a century of progress

Theory

- **1916: GW prediction (Einstein)**

1957: Chapel Hill Conference (Bondi, Feynman, Pirani, etc.)

- **1963: rotating BH solution (Kerr)**
- **1990's: CBC PN expansion (Blanchet, Damour, Deruelle, Iyer, Will, Wiseman, etc.)**
- **2000: BBH effective one-body approach (Buonanno, Damour)**
- **2006: BBH merger simulation (Baker, Lousto, Pretorius, etc.)**

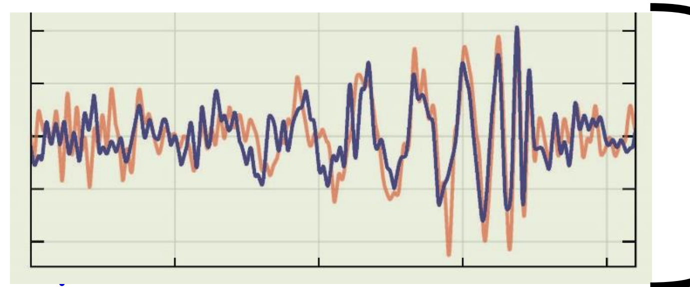
Experiment

- **1960's: first Weber bars**
- **1970: first IFO prototype (Forward)**
- **1972: IFO design studies (Weiss)**
- **1974: PSRB 1913+16 (Hulse & Taylor)**
- **1980's: IFO prototypes (10m-long) (Caltech, Garching, Glasgow, Orsay)**
  → End of 1980's: Virgo (Brillet, Giazotto) and LIGO proposals
- **1990's: LIGO and Virgo funded**
- **2005-2011: initial IFO « science » » runs**
- **2007: LIGO-Virgo MoU**
- **First half of the 2010's: Upgrades**
- **2015: First Advanced LIGO run**
- **2017: First Advanced Virgo run**
- **…**

} First GW Detections

September 14, 2015, 11:51 CEST

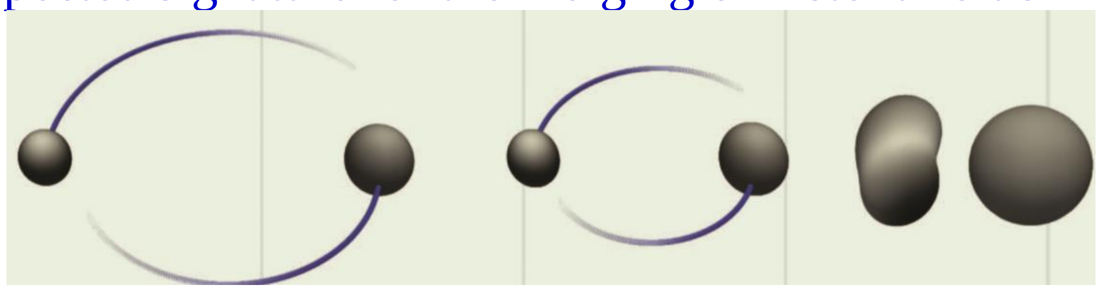
- Signal observed in the two LIGO detectors with a 7 ms delay
  - Extremely short (< 1 s)
  - Very strong
    - With respect to the instrumental noise
    - Very weak in absolute terms

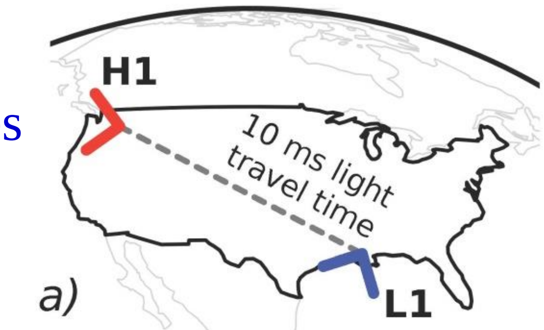


Event called GW150914:

- **Gravitational wave**
- **2015**
- **September**
- **14**

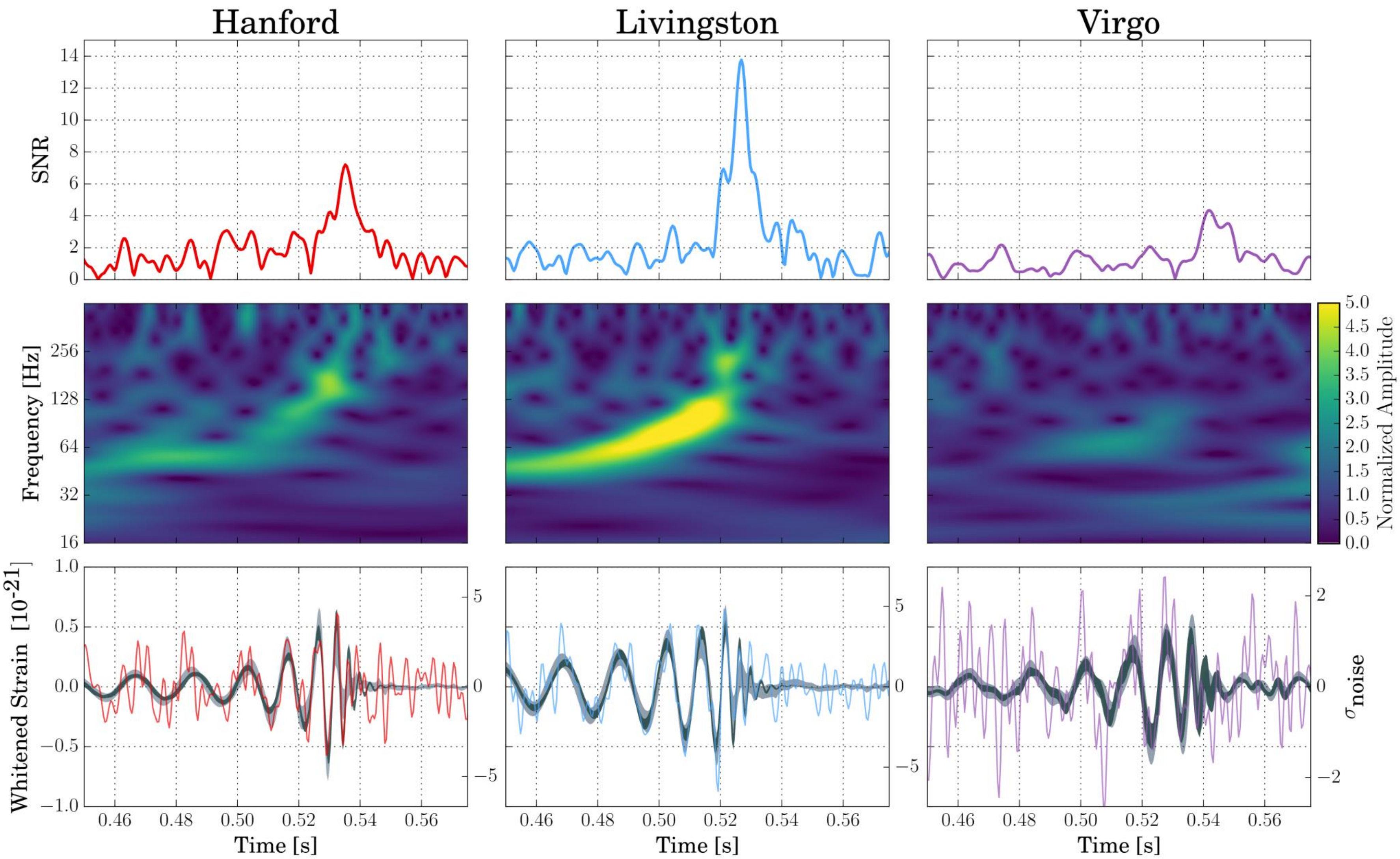
- Expected signature for the merging of 2 stellar black holes

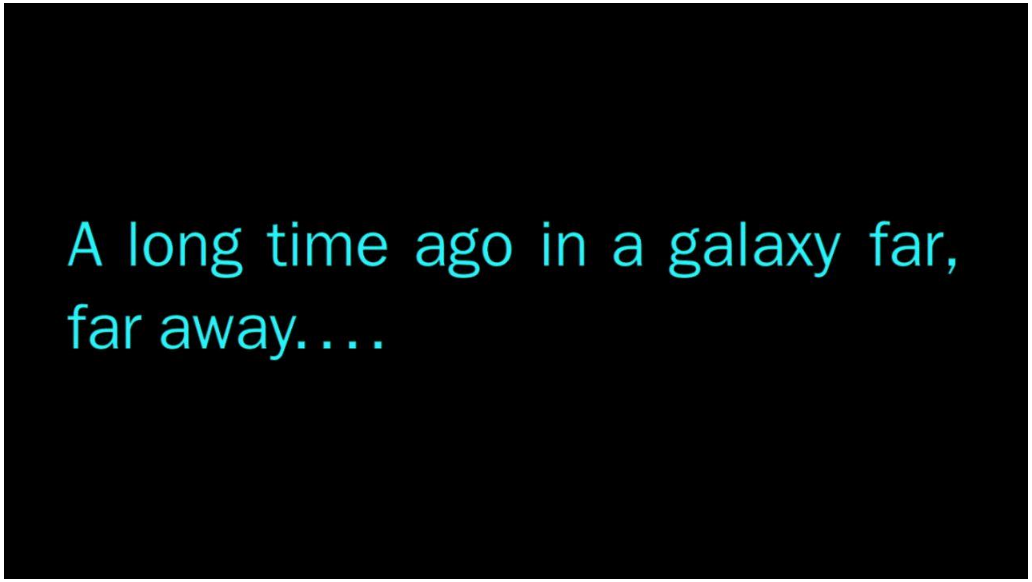




GW170814: first 3-detector signal

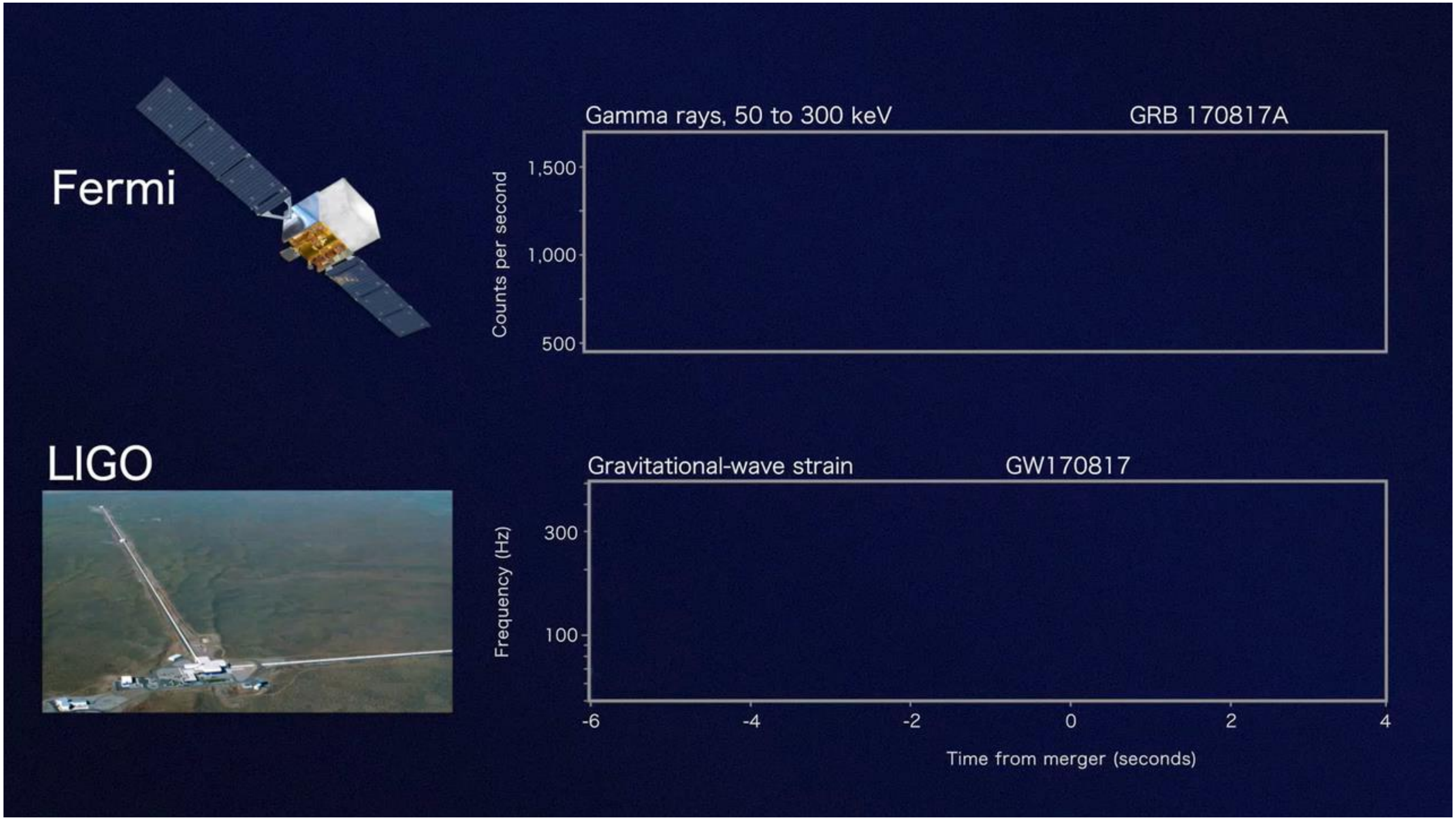
- Detailled studies confirm evidence of a signal in the Virgo detector




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

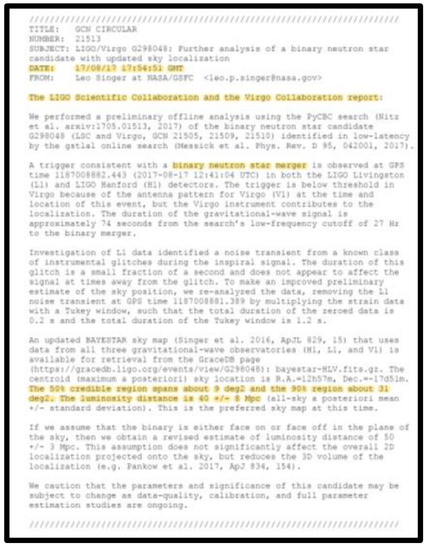
GW170817

- Signals recorded within 1.7 second on Thursday August 17, 2017 – 14:41 CEST
  - LIGO (gravitational waves) first
  - Then the GBM instrument (gamma ray burst) on board the Fermi satellite



GW170817

- From sky localization to the detection of the counterpart



TITLE: GCN CIRCULAR
NUMBER: 21513
SUBJECT: LIGO/Virgo G298048: Further analysis of a binary neutron star candidate with updated sky localization
DATE: 17/08/17 17:54:51 GMT
FROM: Leo Singer at NASA/GSFC <leo.p.singer@nasa.gov>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

We performed a preliminary offline analysis using the PyCBC search (Nitz et al. arxiv:1705.01513, 2017) of the binary neutron star candidate G298048 (LSC and Virgo, GCN 21505, 21509, 21510) identified in low-latency by the gstlal online search (Messick et al. Phys. Rev. D 95, 042001, 2017).

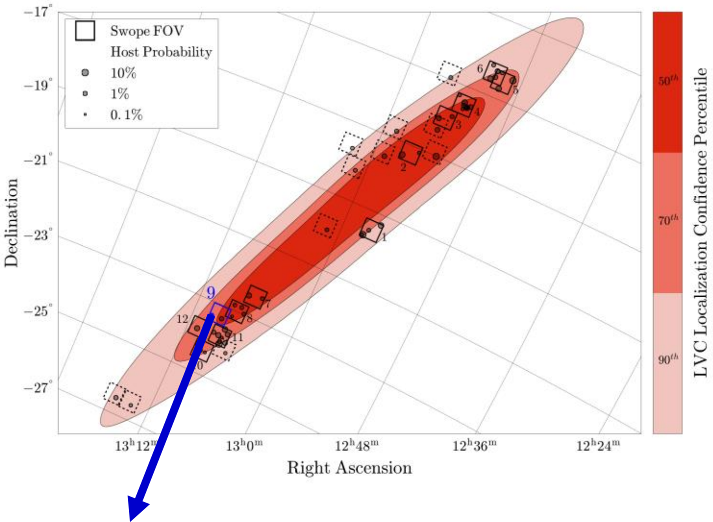
A trigger consistent with a binary neutron star merger is observed at GPS time 1187008882.443 (2017-08-17 12:41:04 UTC) in both the LIGO Livingston (L1) and LIGO Hanford (H1) detectors. The trigger is below threshold in Virgo because of the antenna pattern for Virgo (V1) at the time and location of this event, but the Virgo instrument contributes to the localization. The duration of the gravitational-wave signal is approximately 74 seconds from the search's low-frequency cutoff of 27 Hz to the binary merger.

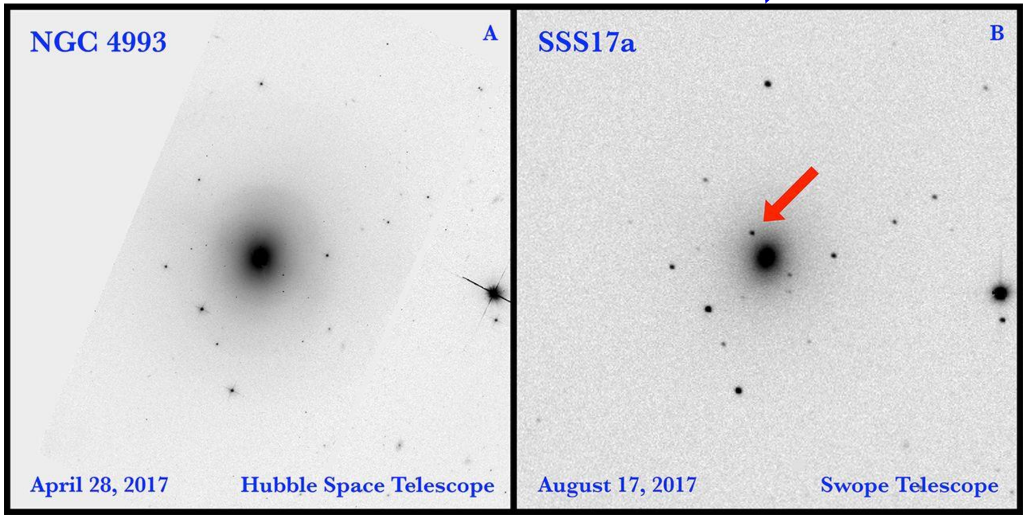
Investigation of L1 data identified a noise transient from a known class of instrumental glitches during the inspiral signal. The duration of this glitch is a small fraction of a second and does not appear to affect the signal at times away from the glitch. To make an improved preliminary estimate of the sky position, we re-analyzed the data, removing the L1 noise transient at GPS time 1187008881.389 by multiplying the strain data with a Tukey window, such that the total duration of the zeroed data is 0.2 s and the total duration of the Tukey window is 1.2 s.

An updated BAYESTAR sky map (Singer et al. 2016, ApJL 829, 15) that uses data from all three gravitational-wave observatories (H1, L1, and V1) is available for retrieval from the GraceDB page (https://gracedb.ligo.org/events/view/G298048): bayestar-HLV.fits.gz. The centroid (maximum a posteriori) sky location is R.A.=12h57m, Dec.=-17d51m. The 50% credible region spans about 9 deg2 and the 90% region about 31 deg2. The luminosity distance is 40 +/- 8 Mpc (all-sky a posteriori mean +/- standard deviation). This is the preferred sky map at this time.

If we assume that the binary is either face on or face off in the plane of the sky, then we obtain a revised estimate of luminosity distance of 50 +/- 3 Mpc. This assumption does not significantly affect the overall 2D localization projected onto the sky, but reduces the 3D volume of the localization (e.g. Pankow et al. 2017, ApJ 834, 154).

We caution that the parameters and significance of this candidate may be subject to change as data-quality, calibration, and full parameter estimation studies are ongoing.

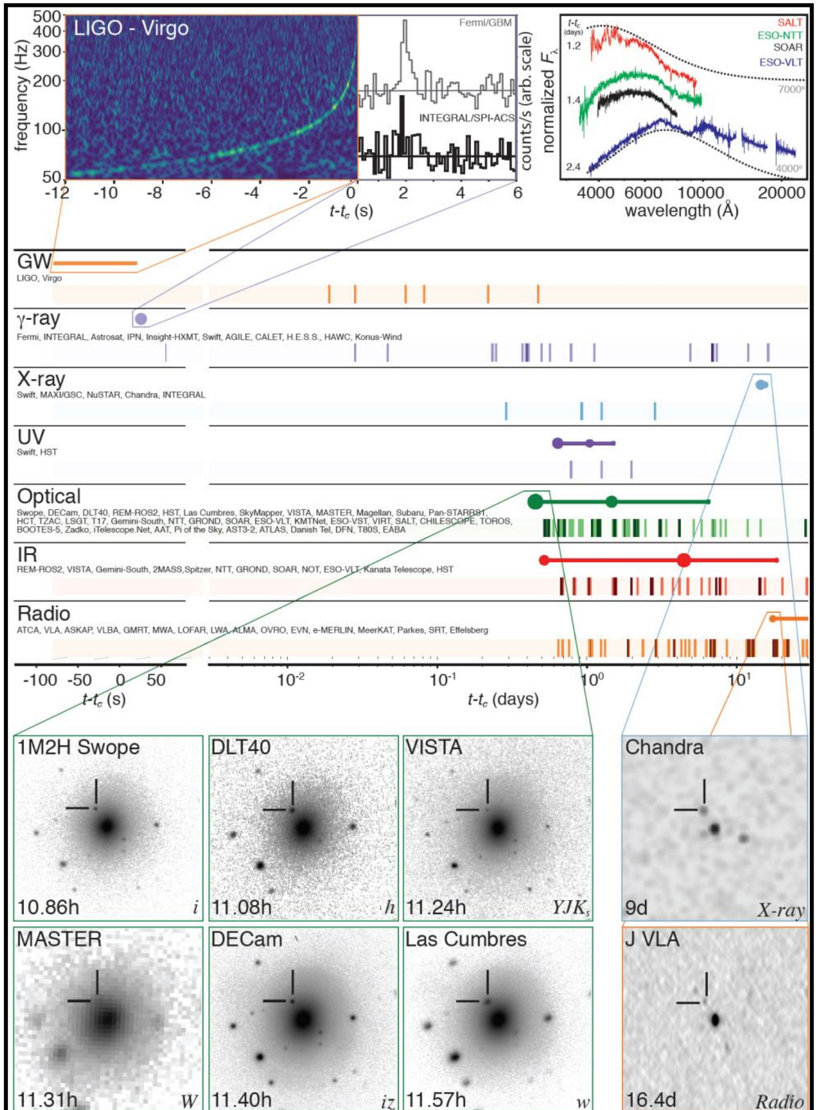


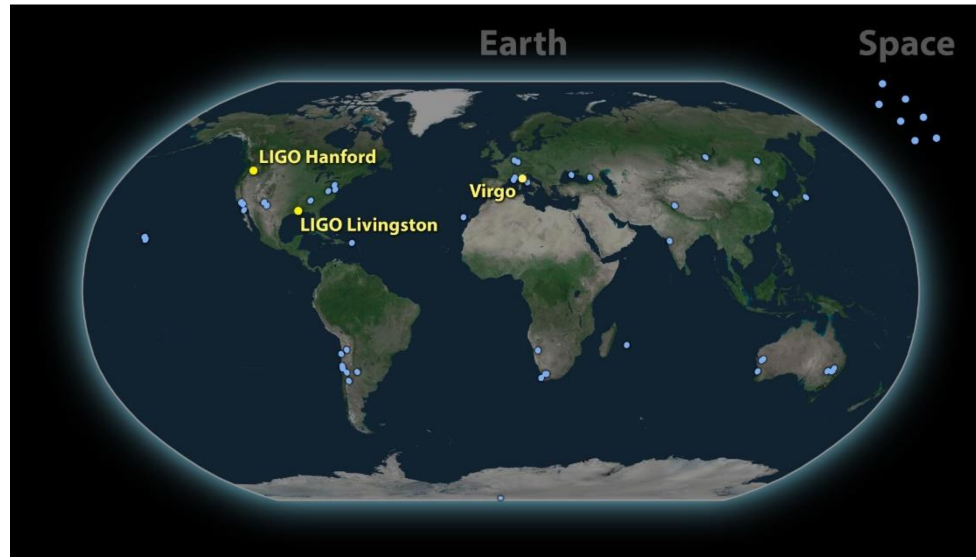


Telescope
field of view:
~1 / 160,000-th
of the sky

Multi-messenger astronomy with gravitational waves

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





To be continued…

- LIGO, Virgo & KAGRA observing plans: https://observing.docs.ligo.org/plan

(16 November 2022 update; next update by 15 January 2023)

LIGO, Virgo, and KAGRA continue to work to prepare the detectors for the start of O4. Our ability to start O4 in March 2023 is currently under review. Unanticipated delays in some construction elements of LIGO has delayed the remaining detector commissioning. Virgo has achieved a stable operation of the interferometer and is now working to improve the sensitivity. Until we have more experience with full interferometer commissioning, large uncertainties remain in the readiness date and the sensitivity. In early January, we expect to be more confident about the plan for starting O4. We will update this page on 15 January 2023. We are watching deadlines for proposals for telescope observing, and will strive to have a plan that allows next proposals to be made knowing the state of the gravitational-wave network.

The projected sensitivity of the detectors remains unchanged: LIGO projects a sensitivity goal of 160-190 Mpc for binary neutron stars. Virgo projects a target sensitivity of 80-115 Mpc. KAGRA should be running with greater than 1 Mpc sensitivity at the beginning of O4, and will work to improve the sensitivity toward the end of O4.