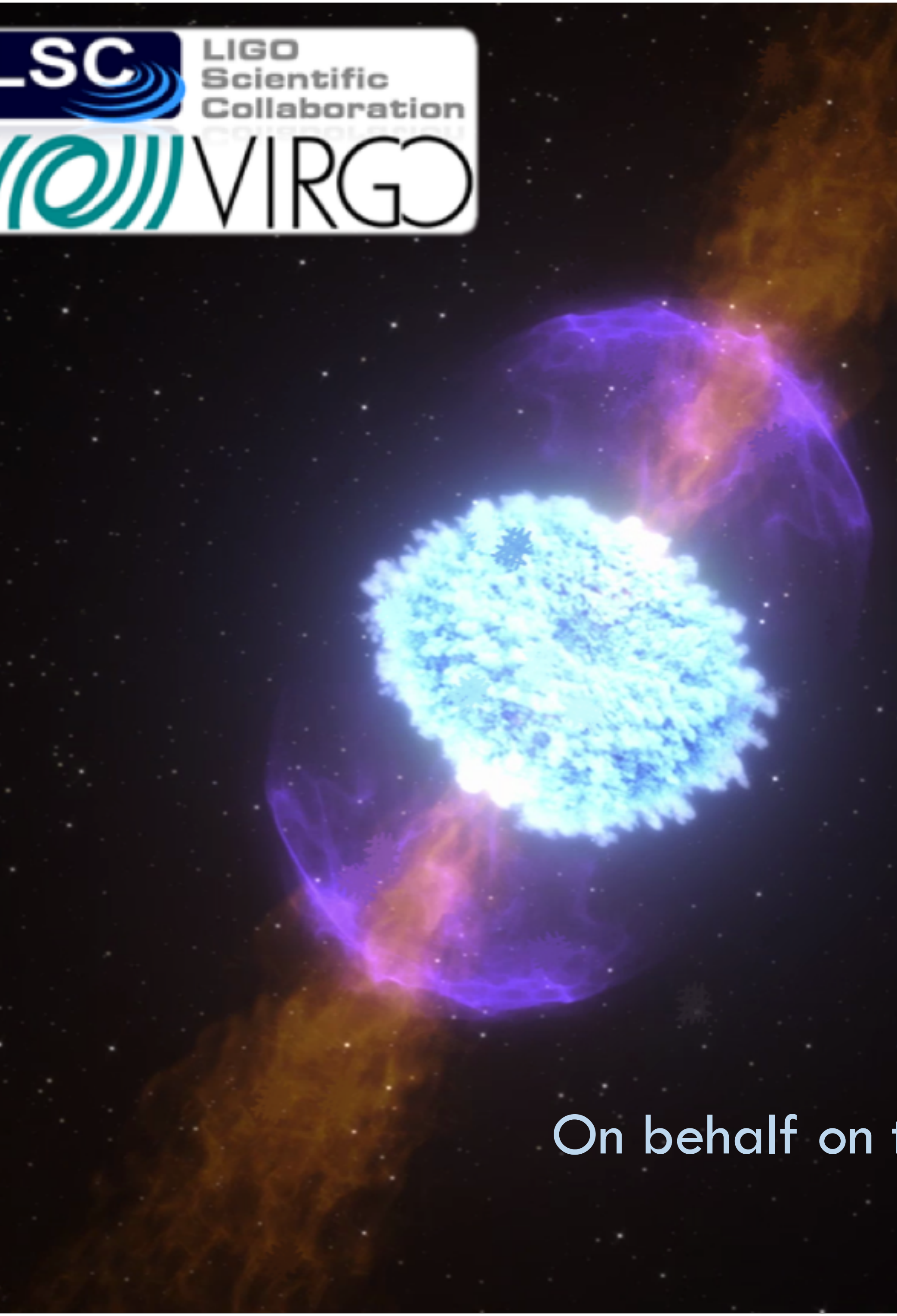


Image Credit: NASA Goddard Space Fight Center / CI Lab

GW170817: Observation of gravitational waves from a binary neutron star inspiral

Sarah Antier

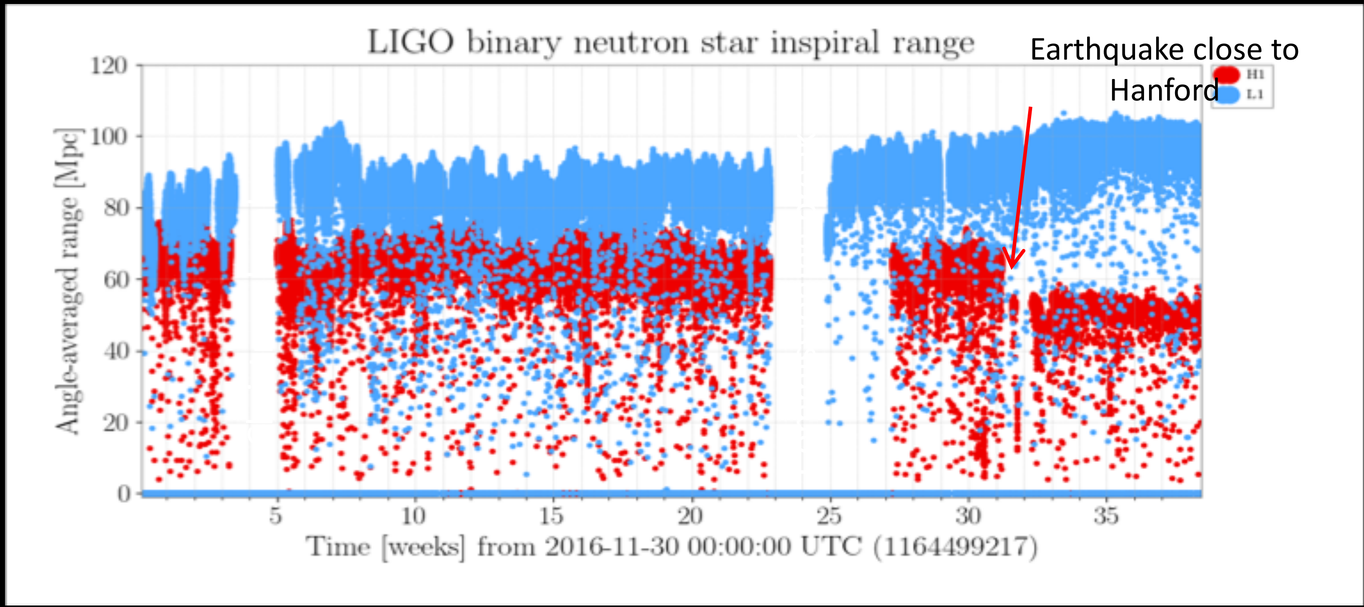
On behalf on the LIGO-Virgo collaboration

2017, a golden year for GW astrophysics

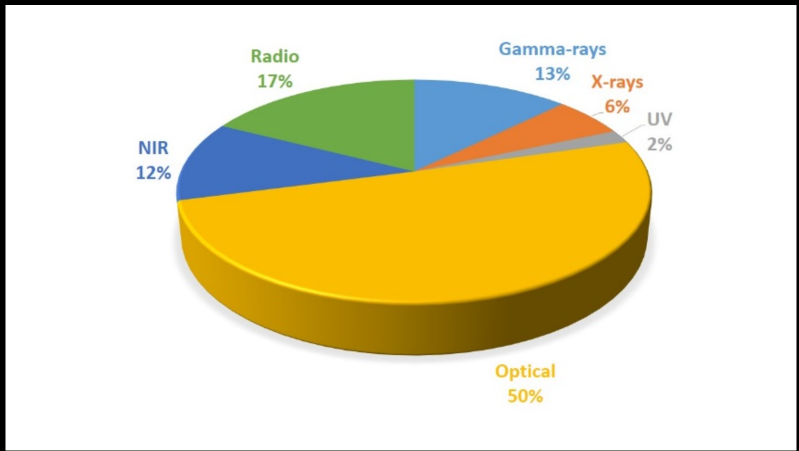
- O2 run : from December 2016 to end of August 2017
- Virgo joined the run for several weeks
  - Allowed localization below 100 deg^2
- New announcements for BBHs
- A new type of source detected : GW170817
- Nobel Prize in physics

O2 EM follow-up campaign

- It started with the two LIGO detector only. Duty cycle ~50 %



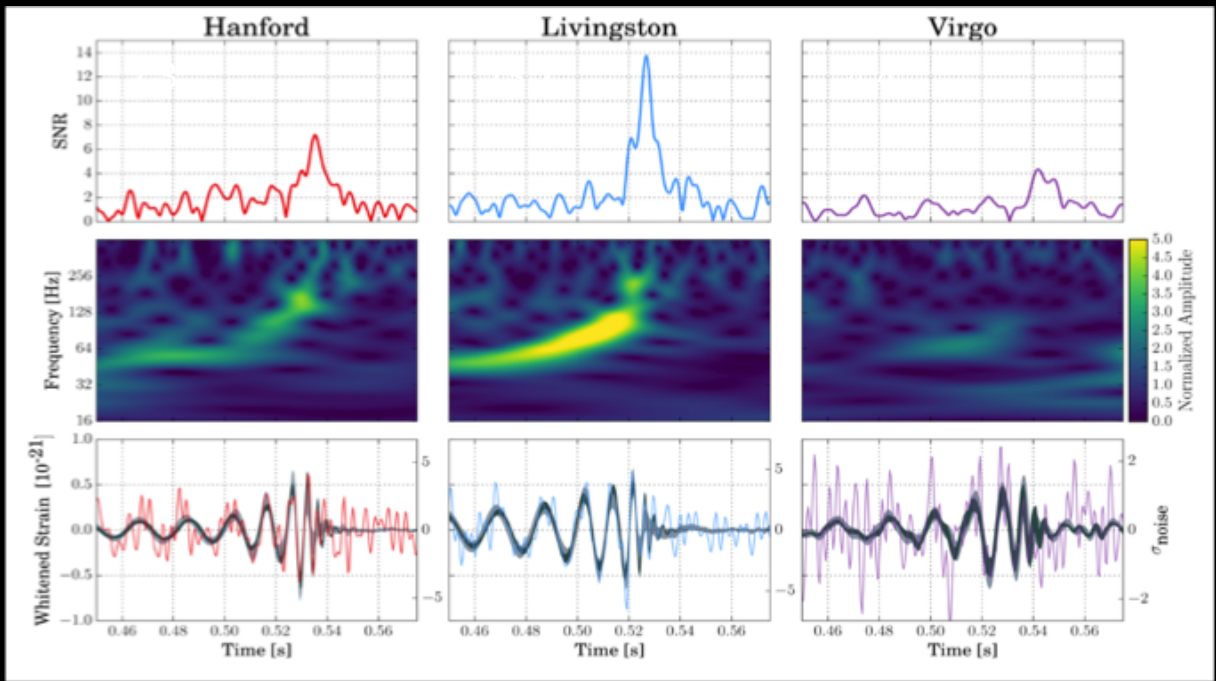
- Send possible candidate with FAR < 1/2 months



- 95 MOUs with different institutions, agencies, groups of astronomers from more than 20 countries
- 88 operational facilities

August 2017, the 3-detector era begins

- Virgo joined August 1st 2017 for 25 days
- Duty cycle in triple coincidence ~60 %
  - Livingston : 77.6 %
  - Hanford : 75.8 %
  - Virgo : 82.4 %
- Several alerts sent during that month



GW170814

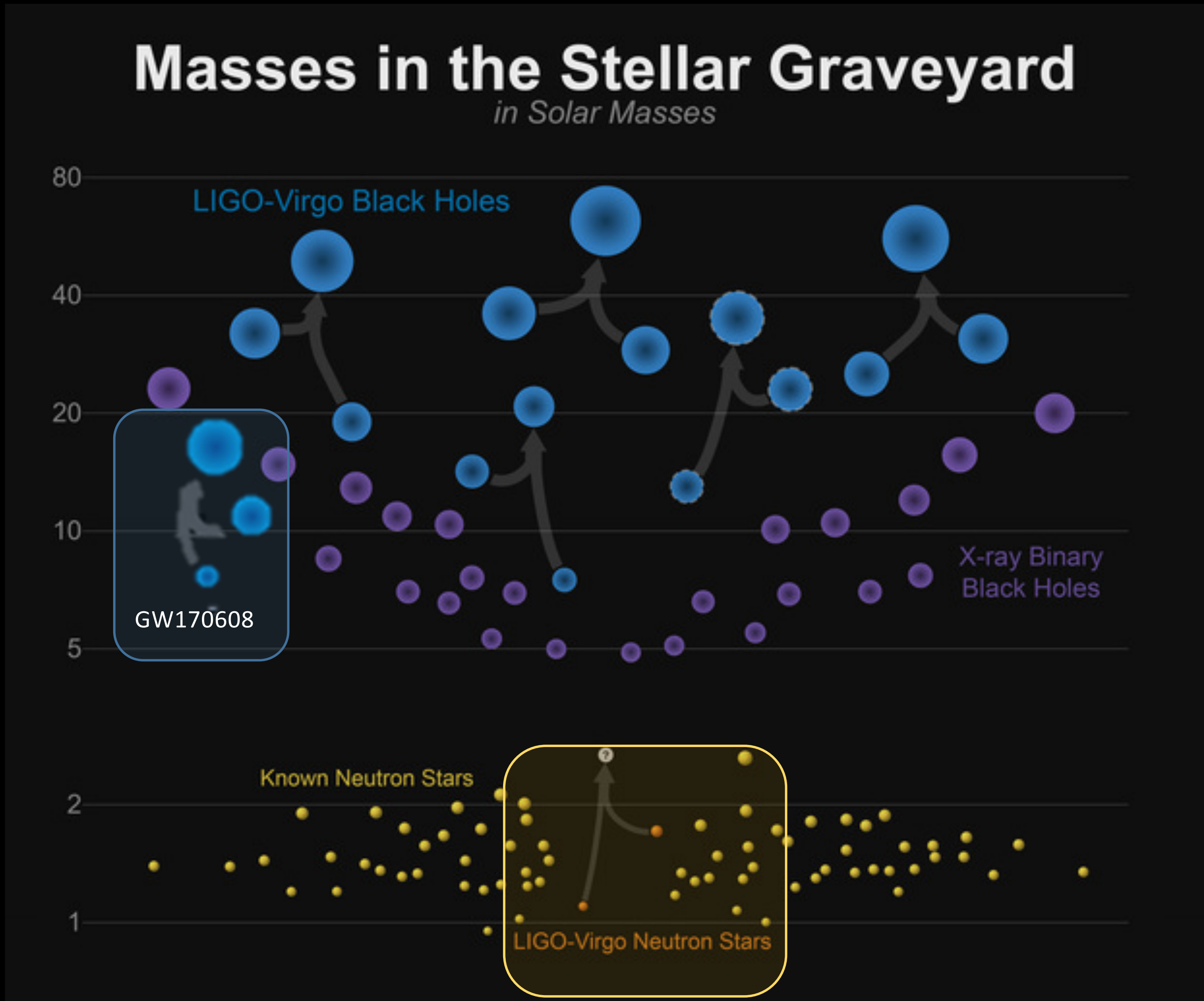
Random chance to have signal in Virgo < 0.3 %

false alarm rate

< 1 in140,000 years

GW170814: A Three-Detector Observation of Gravitational Waves from a Binary Black Hole Coalescence, Abbott *et al.* , PRL 119, 141101

O2 gravitational-waves detections



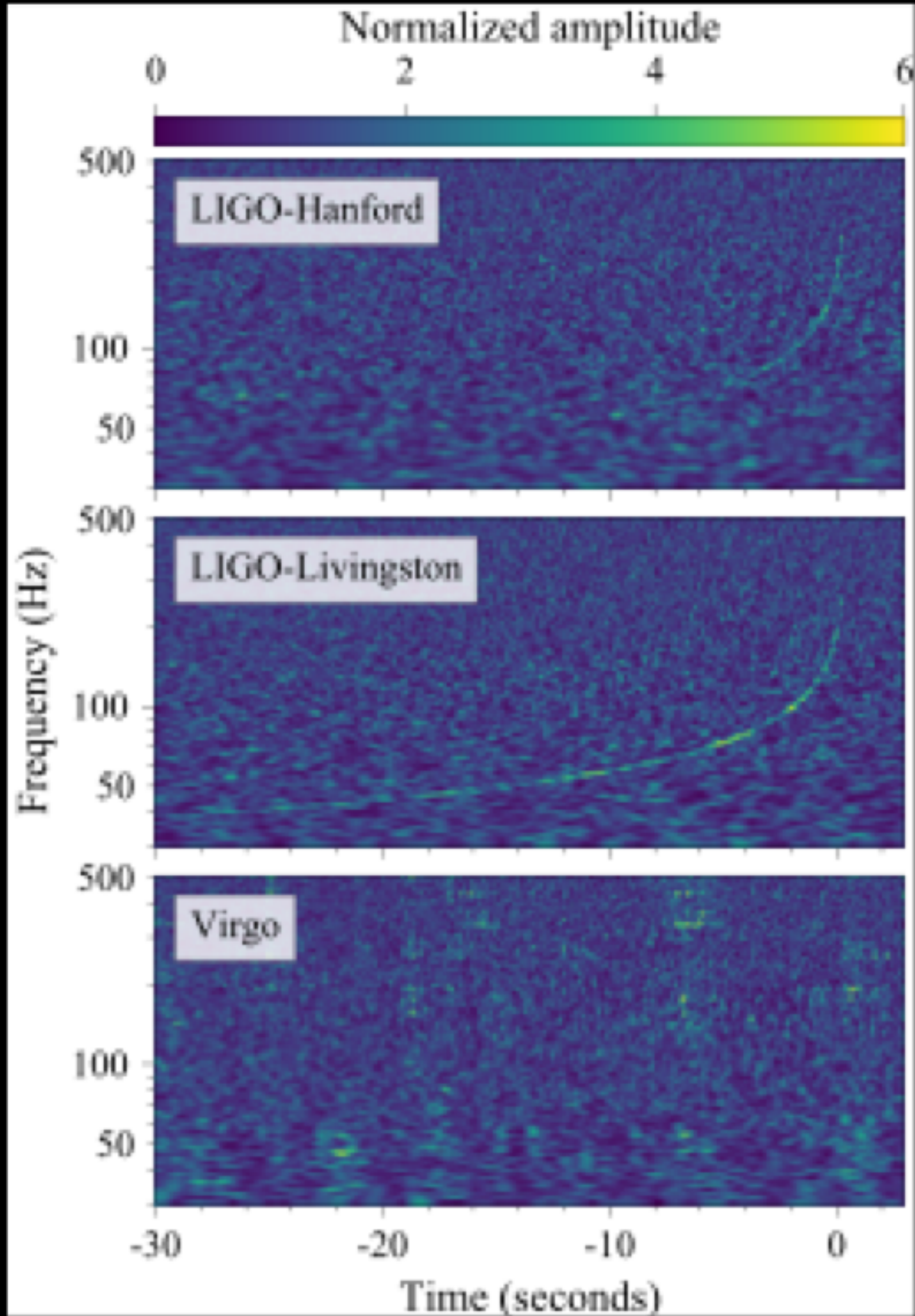
Abbott, Benjamin P.; et al. (LIGO Scientific Collaboration and Virgo Collaboration) (18 December 2017). "GW170608: Observation of a 19-solar-mass Binary Black Hole Coalescence". The Astrophysical Journal Letters

GW170817 discovery

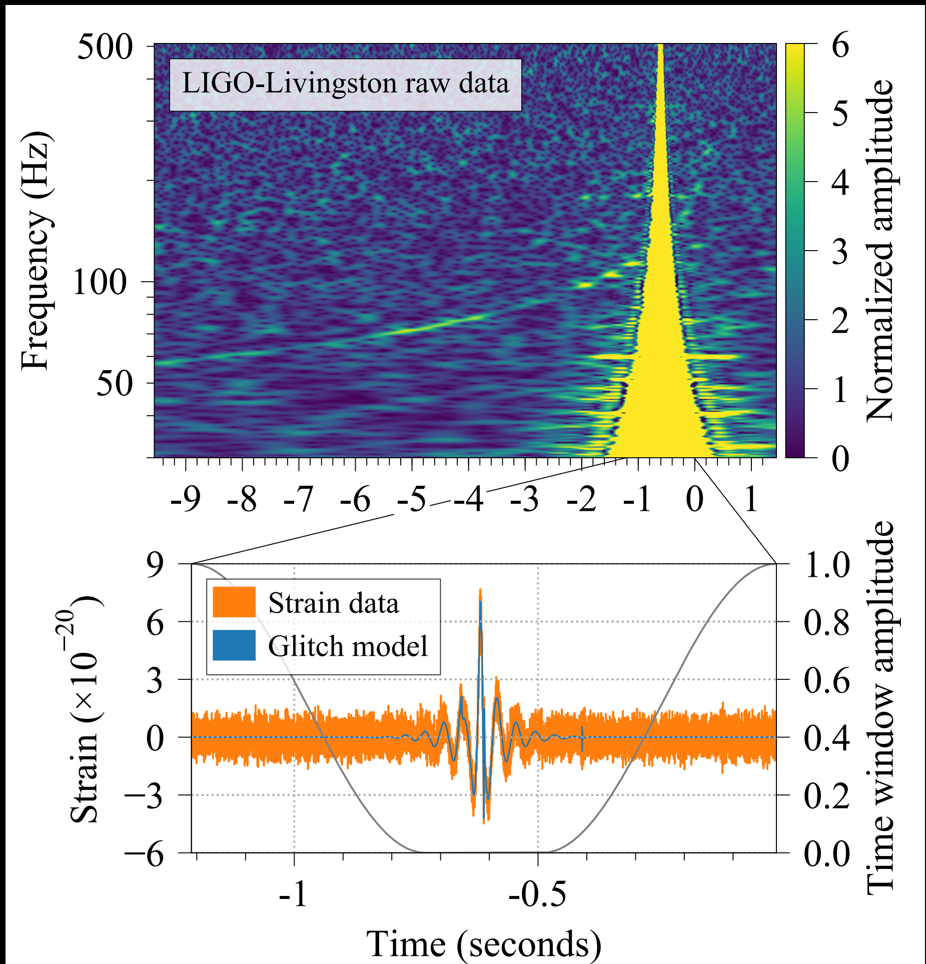
- at 12:41:04 UTC the Advanced LIGO and Advanced Virgo gravitational-wave detectors made the first ever observation of a binary neutron star inspiral
- SNR ~ 32.4,
- Probability that it was due to noise (False Alarm Rate, FAR): 1 in 80000 years

Maximum distance to detect a binary neutrons stars system (SNR>8) :

- Hanford 107 Mpc
- Livingston 218 Mpc
- Virgo 58 Mpc

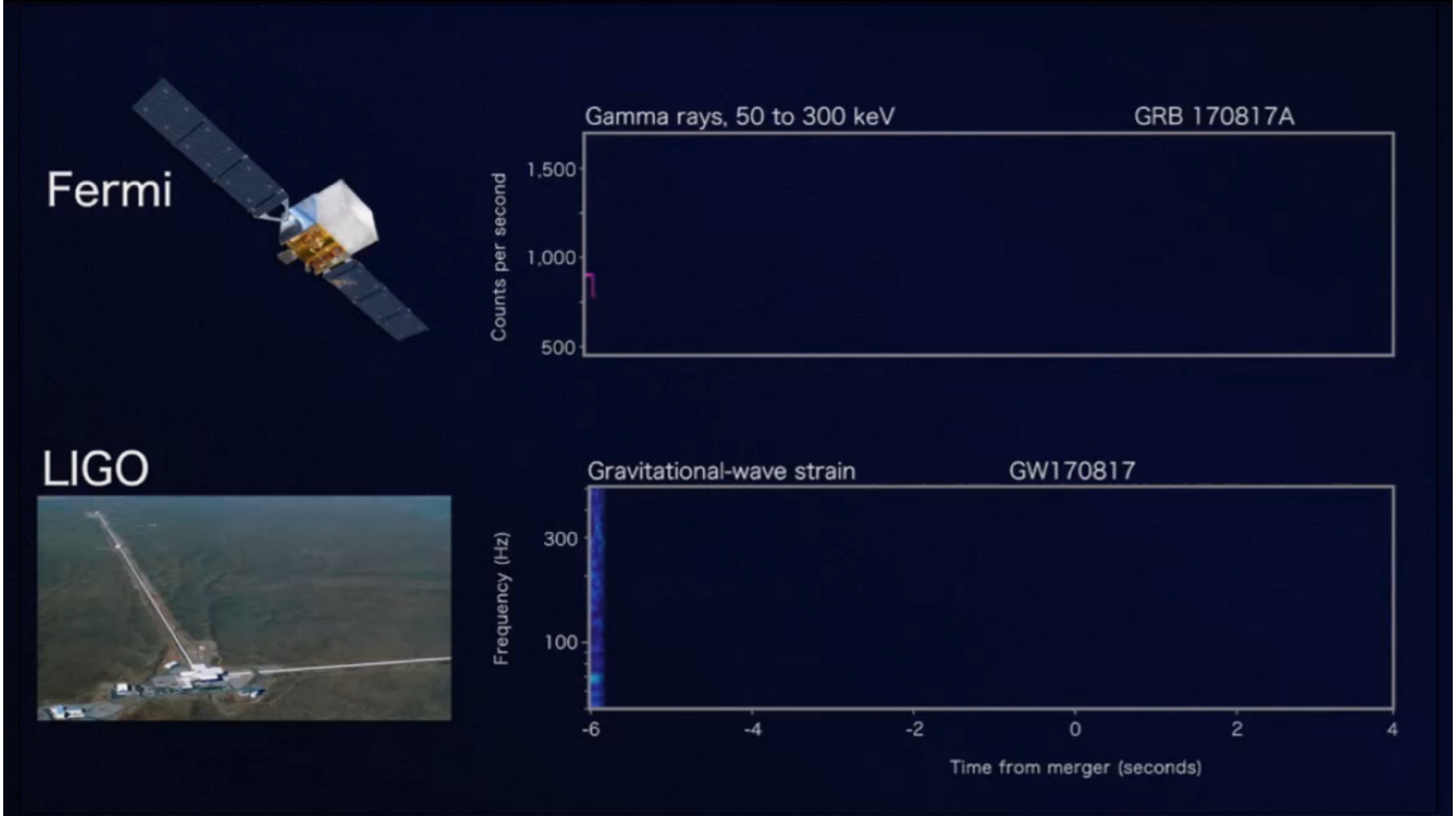


GW170817 data cleaning done in 5 hours



- Initially identified by LIGO Hanford
- Instrumental noise transient in LIGO Livingston 1.1 s before the coalescence time
- Well-known “glitches” without temporal correlation between sites
- Glitch removal to establish coincidence
- No clear signal in Virgo

GW170817 and GRB170817



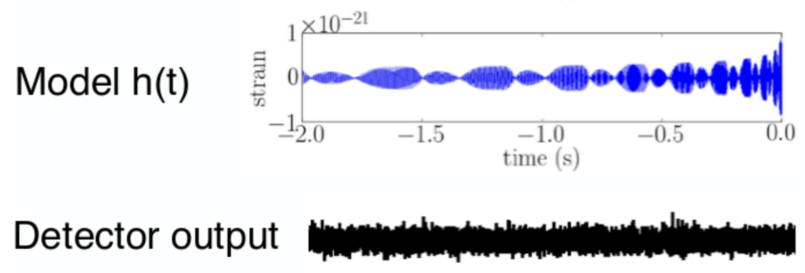
« Gravitational waves and Gamma-rays from binary neutron star merger sky: GW170817 and GRB170817A », Abbott et al., ApJ, 2017

Credit: NASA GSFC & Caltech/MIT/LIGO Lab

Extract source information from GWs

$$h_+(t) = \frac{A[\mathcal{M}\, f(t)]}{D}(1+\cos^2\iota)\cos\Phi_{\rm GW}(t)$$

frequency ($f(t)$); distance (D); inclination angle (ι); GW Phase ($\Phi_{\rm GW}(t)$)



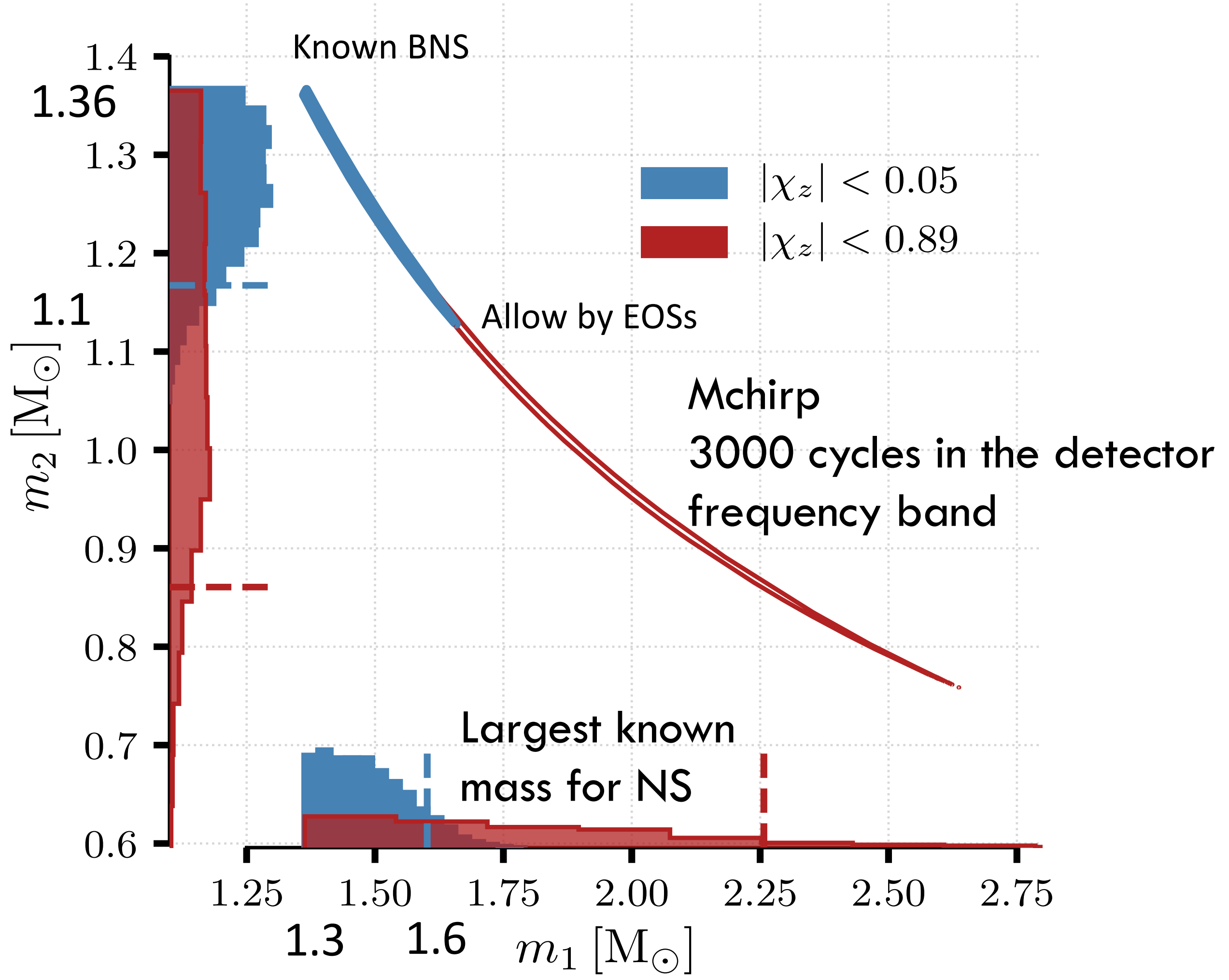
	Low-spin priors ($\lvert\chi\rvert \le 0.05$)	High-spin priors ($\lvert\chi\rvert \le 0.89$)
Primary mass m_1	$1.36 - 1.60\ M_\odot$	$1.36 - 2.26\ M_\odot$
Secondary mass m_2	$1.17 - 1.36\ M_\odot$	$0.86 - 1.36\ M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002}\ M_\odot$	$1.188^{+0.004}_{-0.002}\ M_\odot$
Mass ratio m_2/m_1	$0.7 - 1.0$	$0.4 - 1.0$
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01}\ {\rm M}_\odot$	$2.82^{+0.47}_{-0.09}\ {\rm M}_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025\ {\rm M}_\odot\,{\rm c}^2$	$> 0.025\ {\rm M}_\odot\,{\rm c}^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc
Misalignment of total angular momentum and line of sight	$\lesssim 56°$	$\lesssim 55°$
using counterpart location	$\lesssim 30°$	$\lesssim 30°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	$\lesssim 800$	$\lesssim 700$
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	$\lesssim 800$	$\lesssim 1400$

GW170817: observation of gravitational waves from a binary neutron star inspiral, Abbot et al. 2017

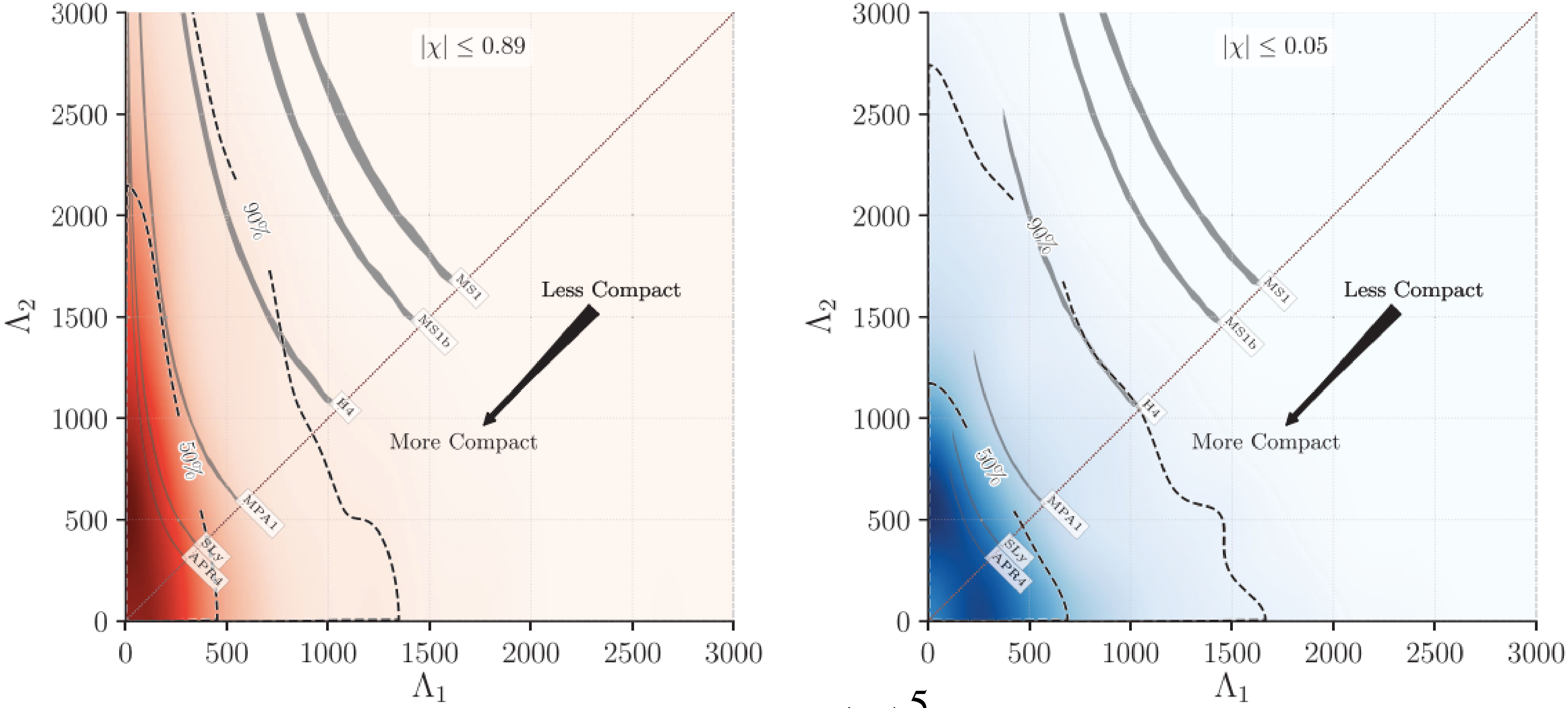
Masses

Largest known
mass for NS

$$M_{Chirp} = \frac{(m_1 m_2)^{3/5}}{(m_1+m_2)^{1/5}} = 1.188^{+0.004}_{-0.002} M$$



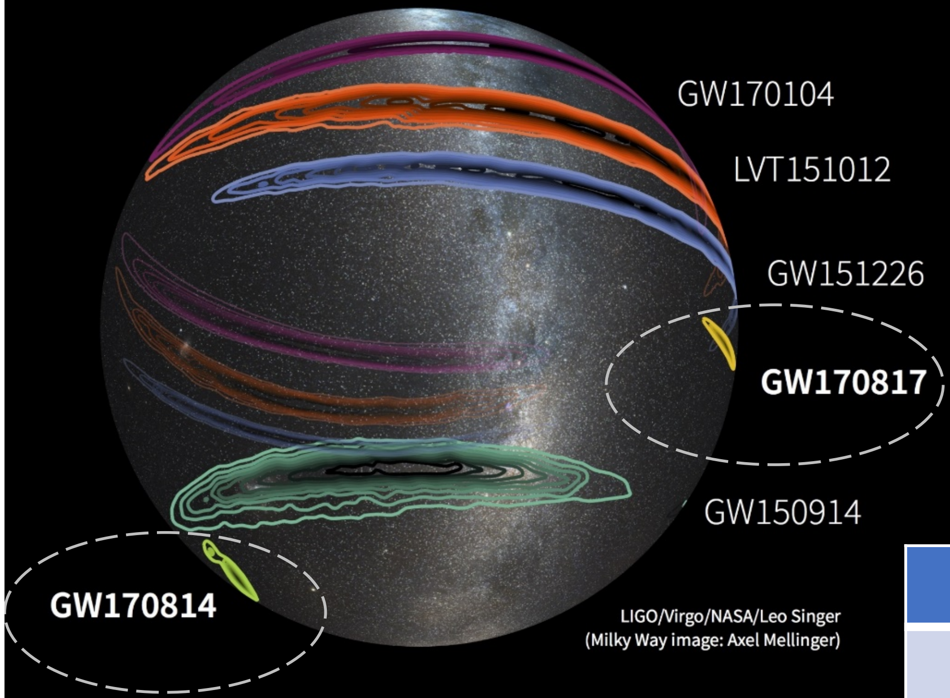
Equation of state (EOS)

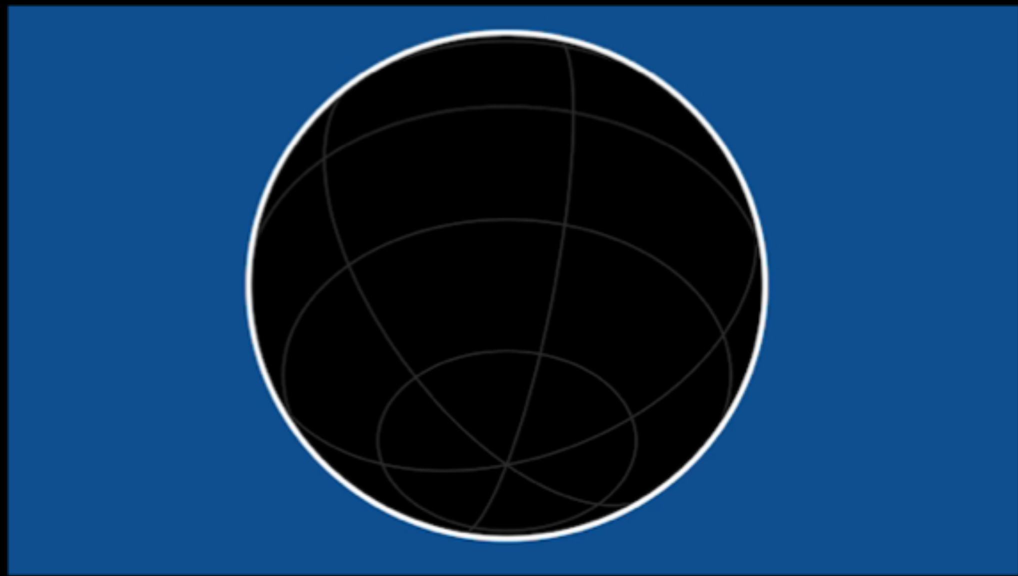


$$\Lambda \propto k_2 \left(\frac{R}{m} \right)^5$$

- Signal observed favor EOS for compact NS

Key role of Virgo in GW170817 localization

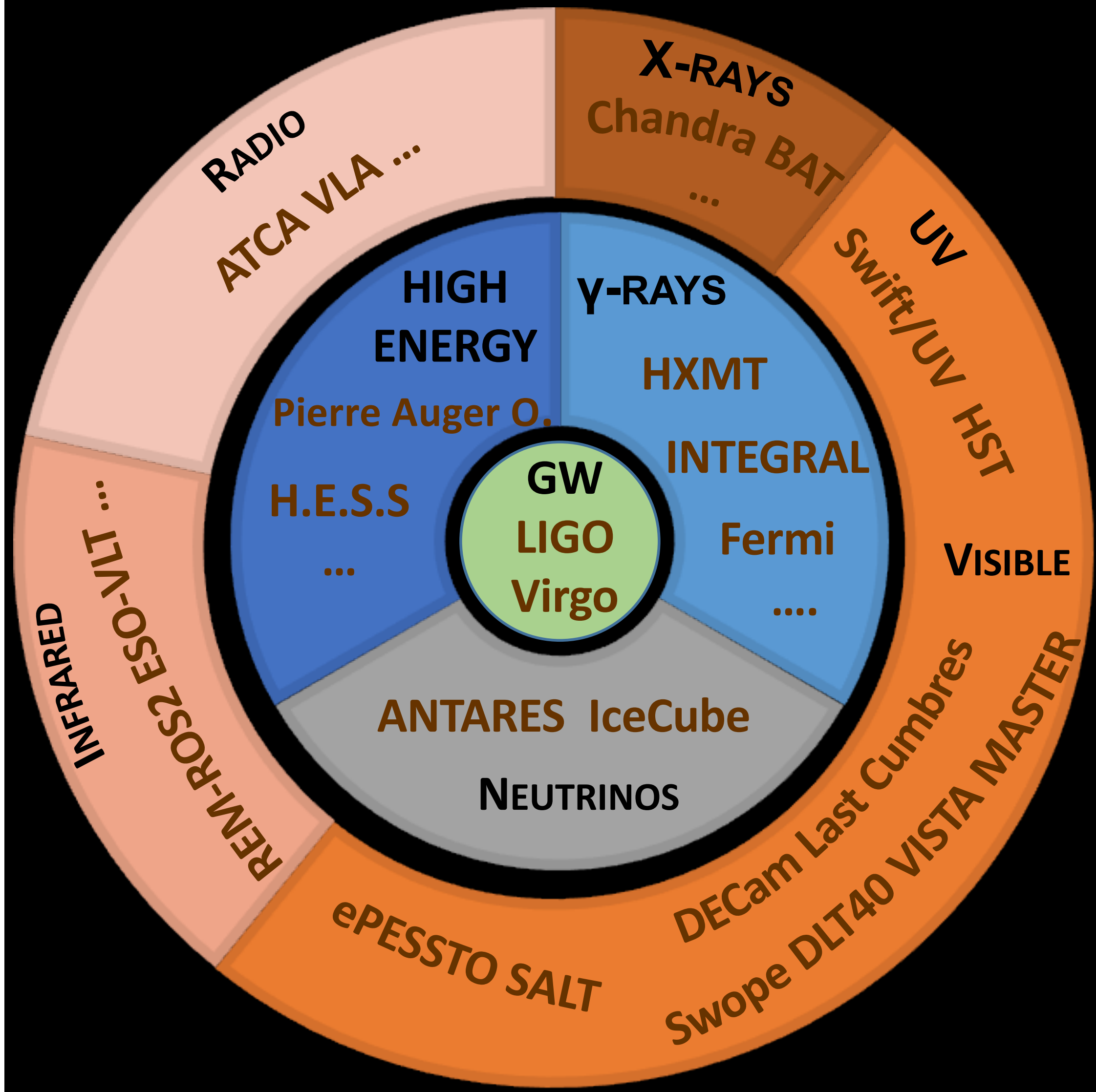


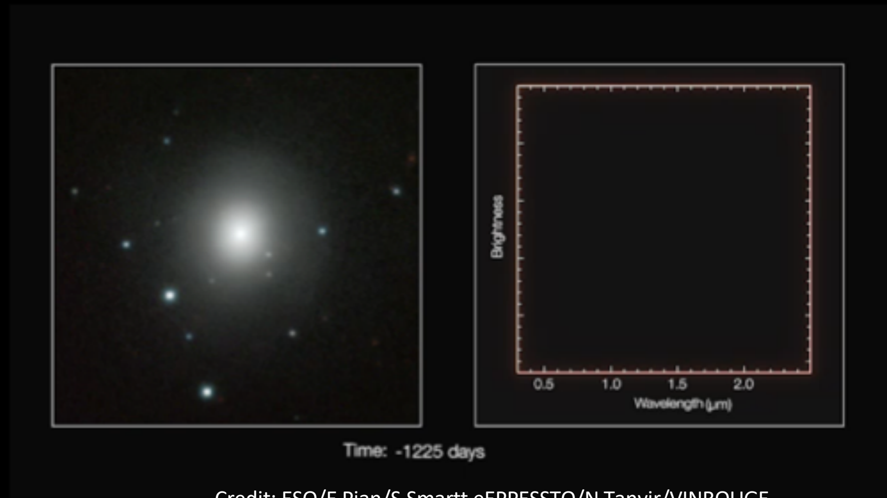


Credit: LIGO-Virgo

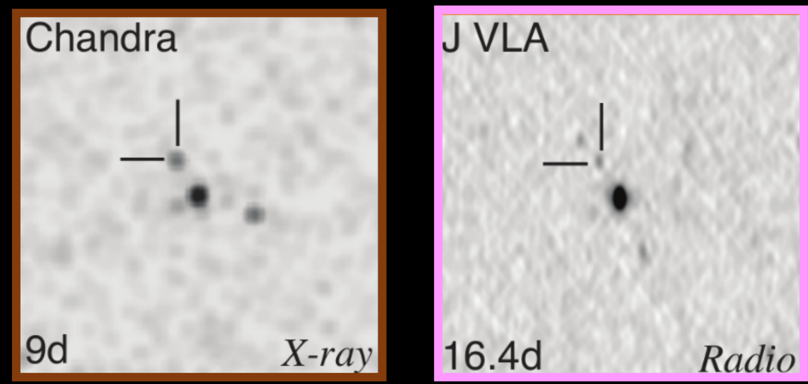
GW170817 localization	
2 interferometers (HL)	AddingVirgo (HLV)
190 deg^2, distance 40 Mpc	28 deg^2, distance 40 Mpc Volume : 380 Mpc^3

GW170817 multi-messenger campaign



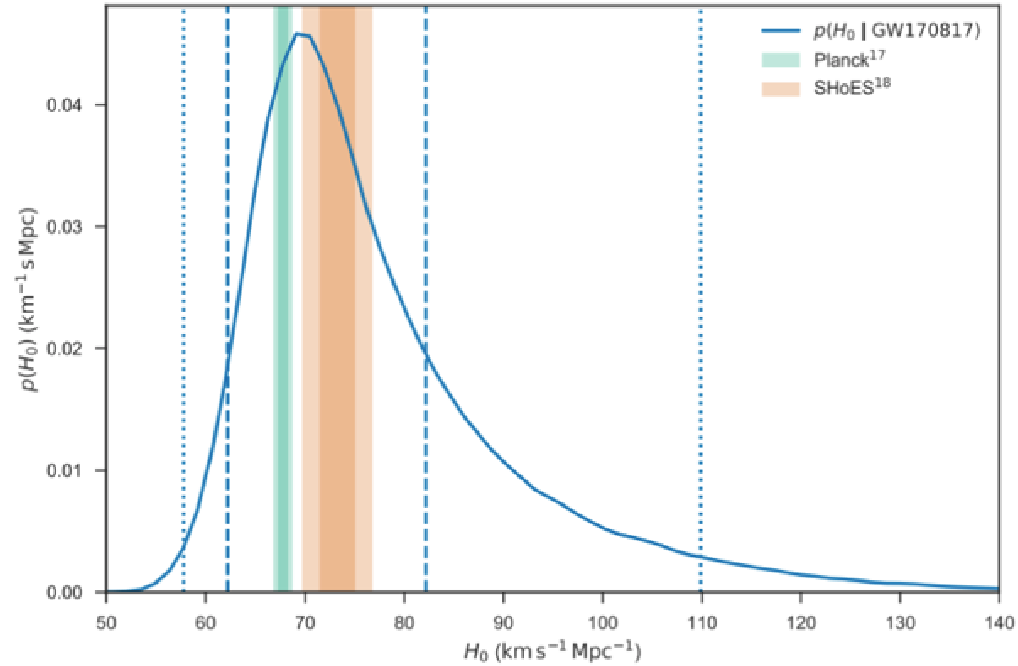


Credit: ESO/E Pian/S.Smartt eEPPESSTO/N Tanvir/VINROUGE



Hubble constant measurement

- For closed-by source : $v=H_0D$



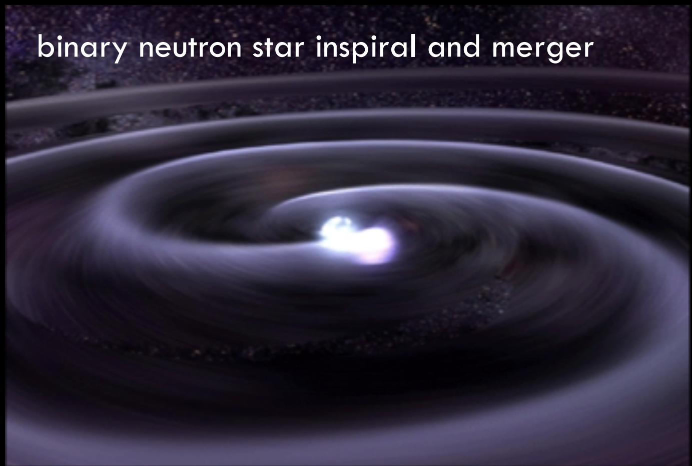
$$h(t) \propto \frac{M_{chirp}^{5/6}}{D} f(\cos i)$$

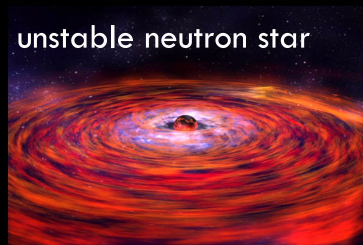
$$H_0 = 70^{+12}_{-8} \, km\, s^{-1} \, Mpc^{-1}$$

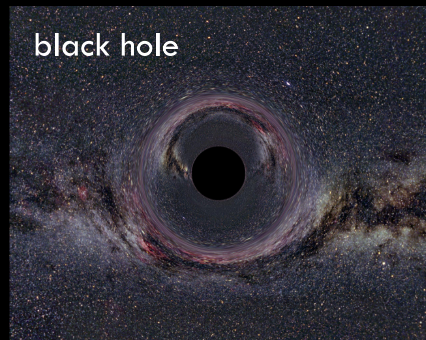
"A standard siren measurement of the Hubble constant with GW170817", Nature in press (2017)

What happened after the merger?

- The newly formed black hole or neutron star (stable or unstable) will emit a distinct gravitational wave signature
- Too weak to be observed for this merger
  - Search for short (< 1s) / intermediate duration (< 500 s)
  - Can be BH or NS (long-lived or too massive for stability)
  - Post merger emission from similar event may be detectable when advanced detectors reach design sensitivy







« Search for Post-merger GW from the Remnant of the Binary Neutron Star Merger GW170817, Astrophy J. Letter, 851, L16

The future multi-messenger area

In the PAST

- Relation between neutron star and GRBs Gravitational wave and Gamma-rays from binary neutron star merger sky: GW170817 and GRB170817A », Abbott et al., ApJ, 2017
- Production of heavy elements in kilonovae Partner Paper,s Arcavi et al. Soares-Santos et al. Cowperthwaite et al. Pian et al., Smartt et al 2017 ….
- Electromagnetic emission related to compact merger/collapse events Partners Paper, Goldstein et al. Troja et al Alxander et al., Evans et al. … 2017
- Equation of state of neutron stars
- Estimation of the compact object rate
- Cosmology (Hubble constant measurement) A gravitational-wave standard siren measurement of the Hubble constant, Abbot et al, 2017
- ….

BH-BH mergers

NS-NS merger (GW170817: observation of gravitational waves from a binary neutron star inspiral, Abbot et al. 2017)

O1/O2 campaign

Mergers

Collapse of massive star

Isolated neutrons star instabilities

Populations studies

Remanent studies

In the future

O3 and beyond

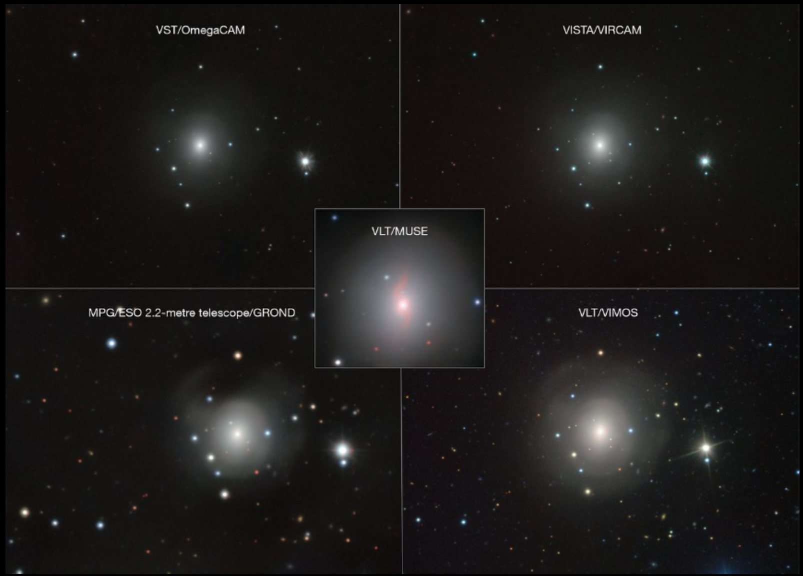
Further on GW170817 multi-messenger observations And LIGO/Virgo projects

Gamma-ray observations : Roland Diehl

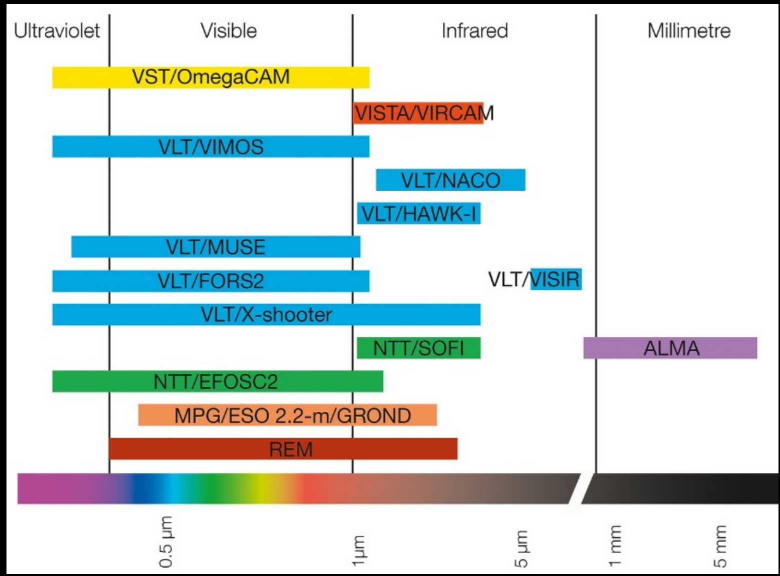
X-ray observations: Maria Grazia Bernardini

Optical/Near-Infrared observations : Stephen Smartt

Virgo next science runs: Marica Branchesi



Credit: VLT/VIMOS, VLT/MUSE, MPG/ESO 2.2-m teles/GROND, VISTA/VIRCAM, VST.OmegaCam



Credit: ESO


LSC LIGO Scientific Collaboration
VIRGO
Thanks
Image Credit: LSC/Sonoma State University/Aurore Simonnet