GRAN SASSO
SCIENCE INSTITUTE

Entering the multi messenger area of Astronomy

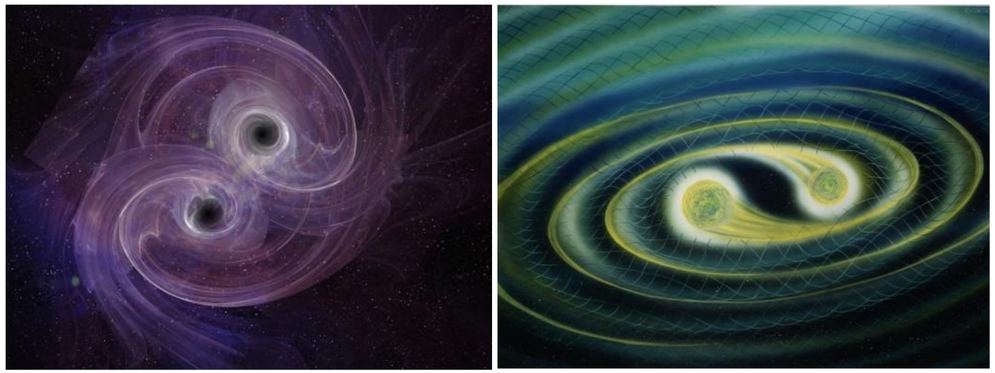
M. Drago

GSSI and INFN-LNGS
for the LIGO and Virgo collaborations

www.gssi.it

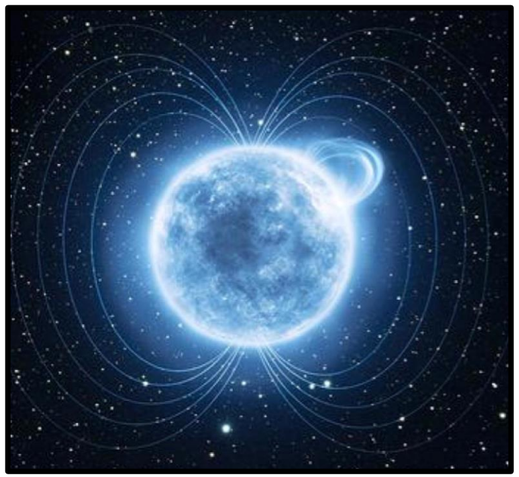
Index

Multi-messenger sources



Coalescence of binary system of neutron stars and/or stellar-mass black-hole

Isolated neutron stars



Core-collapse of massive stars

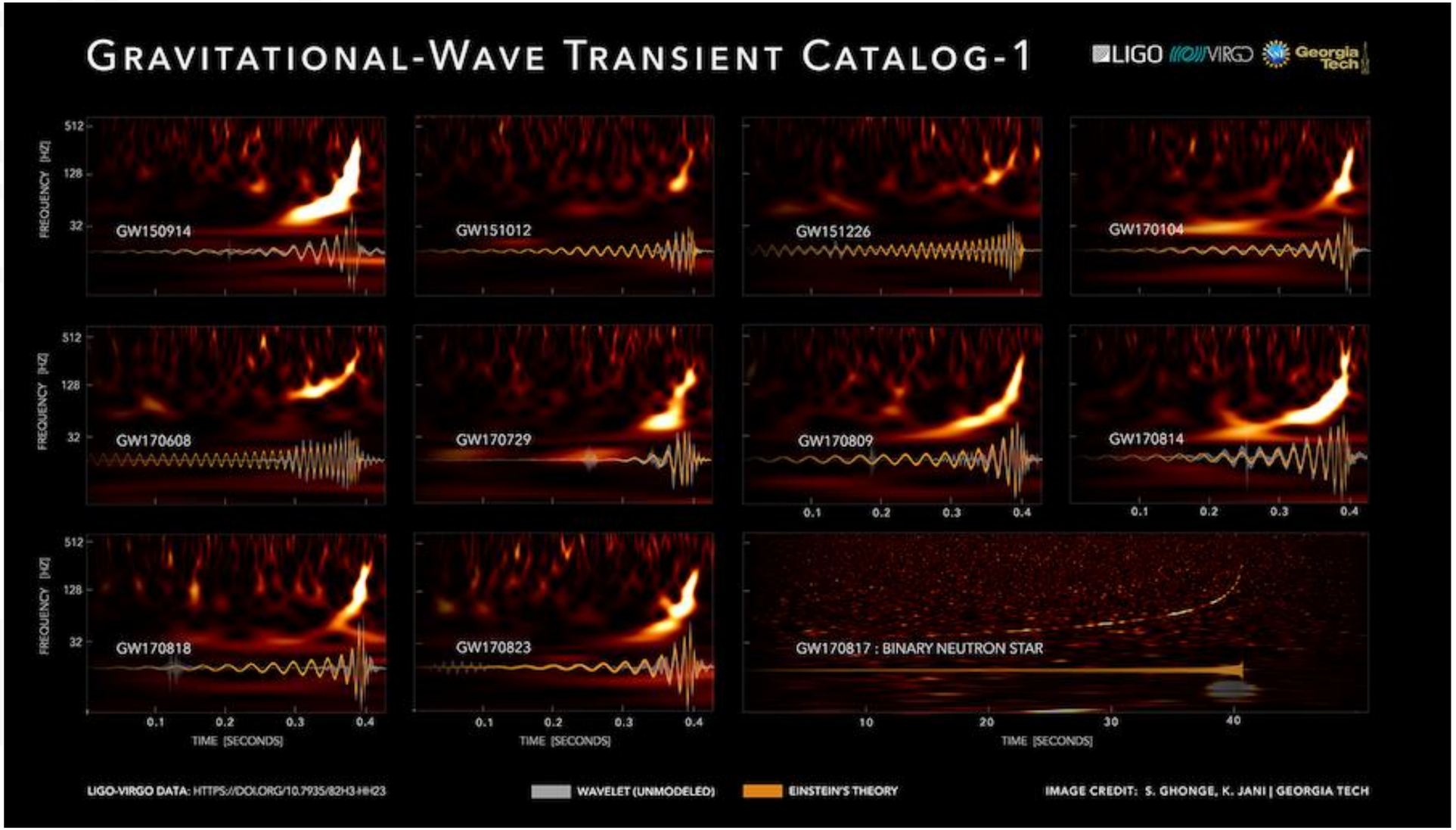
GW point of view

GW answering to counterparts

GW triggering counterparts

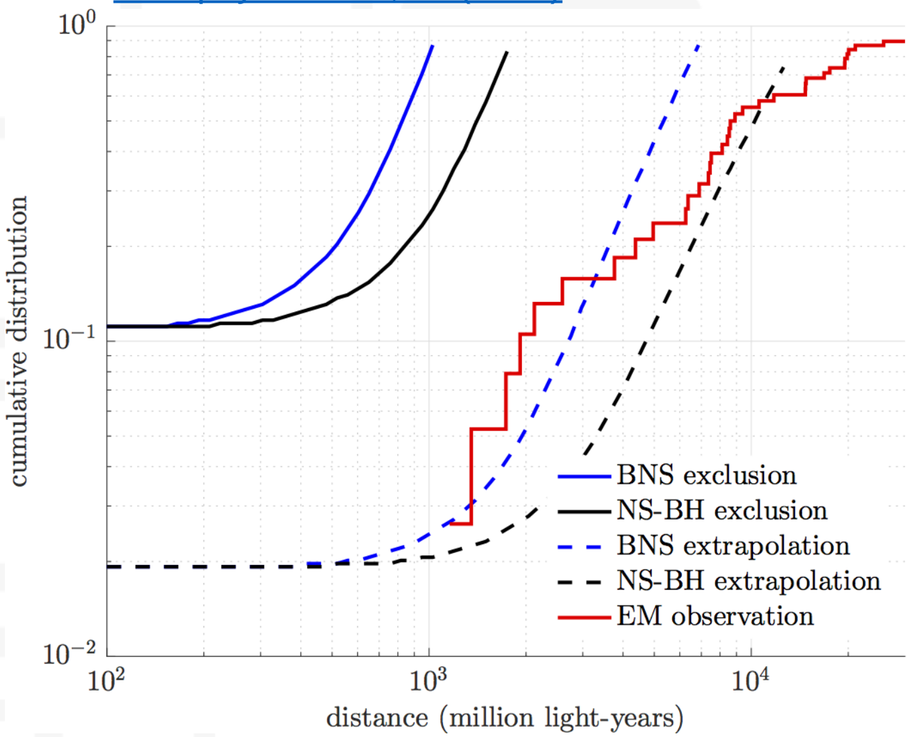
A new window to the universe

LVC arXiv:1811.12907



Ex-triggered

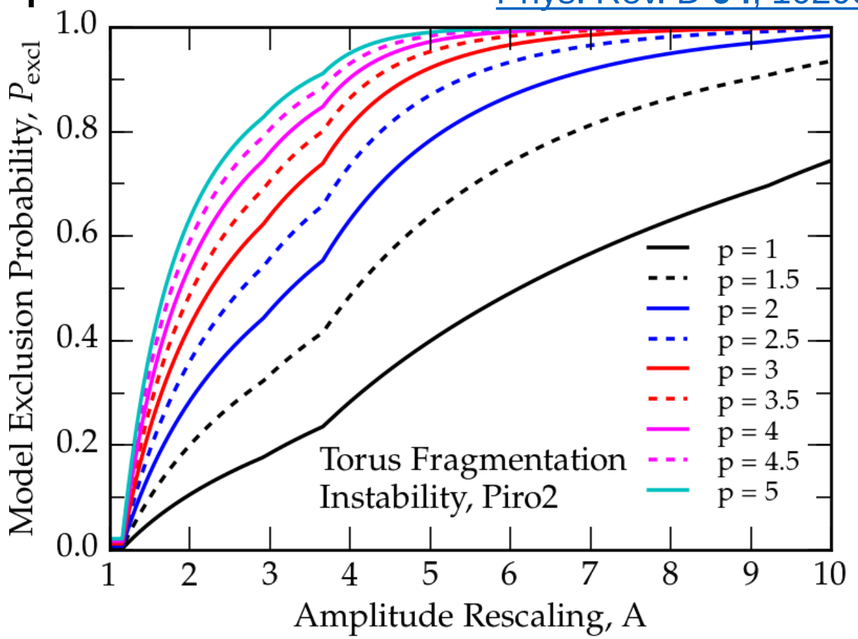
Astrophys. J. **871**, 90 (2019)



Combined exclusion distance for 20 short GRBs analyzed with the coalescence search for both a BNS and an NS-BH progenitor (top) and for all 31 GRBs analyzed with the generic transient search for ADI-A and standard siren CSG GW transients at 150 Hz with an energy of $E_{gw}=10^{-2}M_{\odot}c$ (bottom). We exclude at 90% confidence level cumulative distance distributions that pass through the region above the solid curves

- GW community perform searches triggered by counterparts
  - GRB
  - Core collapse supernovae
  - FRB
  - Neutrinos
  - …

Phys. Rev. D **94**, 102001 (2016)

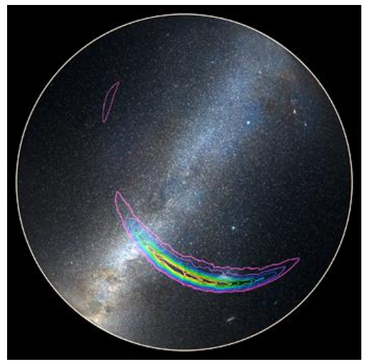


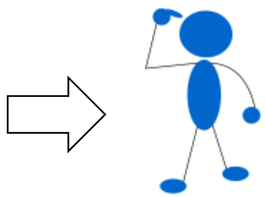
The different curves show how the probability, or confidence, with which we could exclude a CCSN model is expected to scale with the sample size of observed supernovae (denoted by p) and the sensitivity to the waveform amplitude (denoted by A). Currently p=A=1 so we cannot yet make any statements excluding this model.

GW Followup

GW candidates

Sky Localization





Event validation

EM facilities

a few min

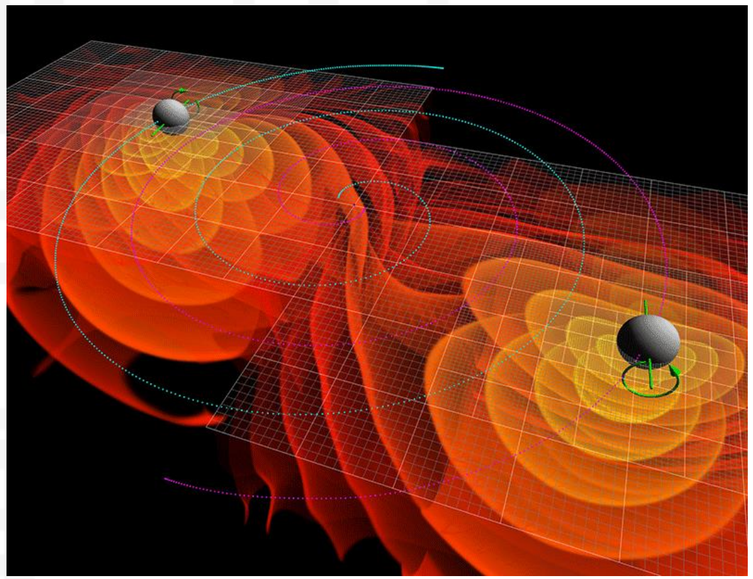
30 min

- GW candidates triggering counterparts
- In O3 OPA (Open Public Alert) Era begins: no more «Event validation»: trigger automatically sent out (and eventually manually retracted)

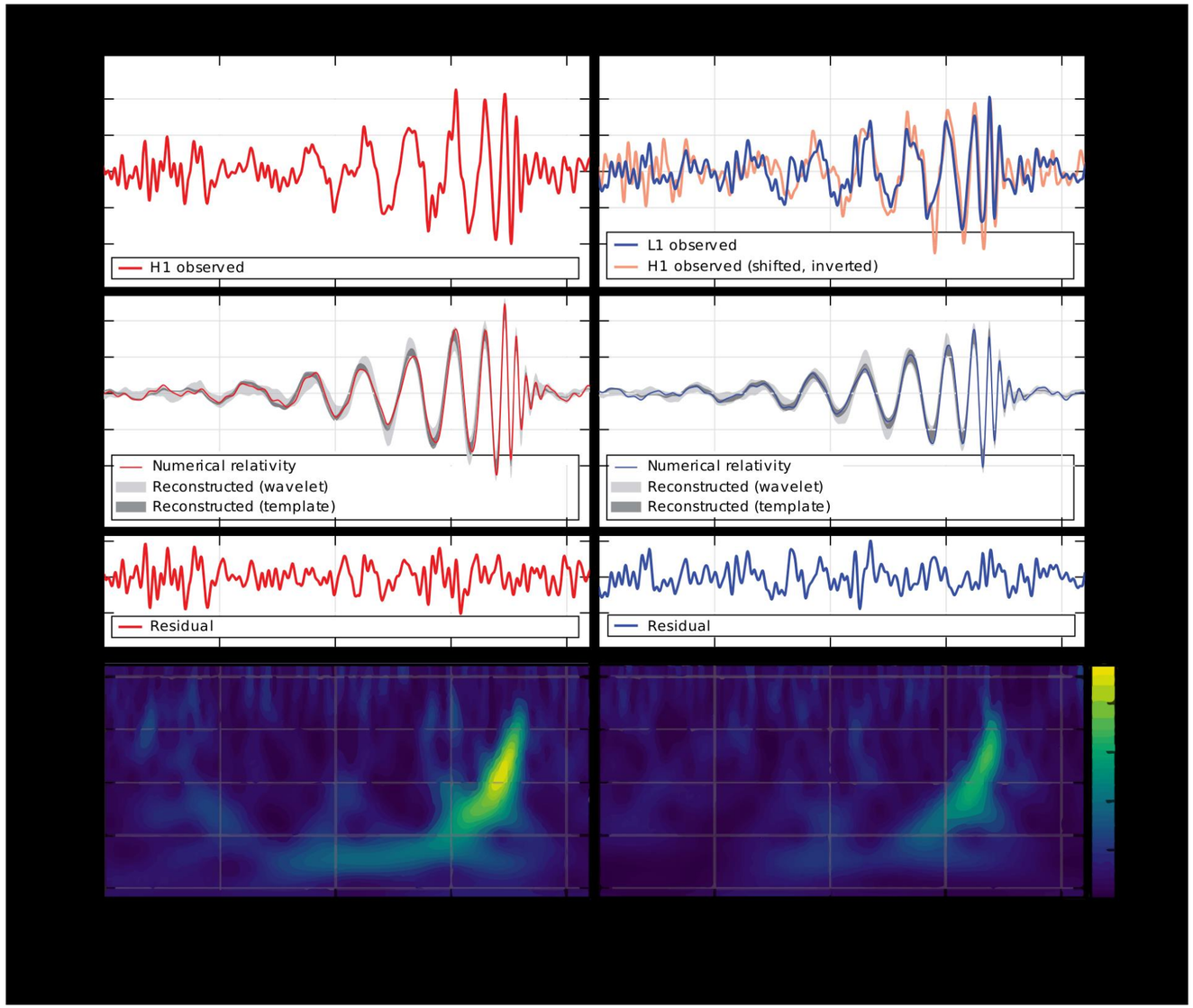
See P. Savina poster on Pierre-Auger Observatory

GW150914

- First detection of GW
- Coalescence of Black Holes
- Only LIGO detectors
- Open the GW astrophysics



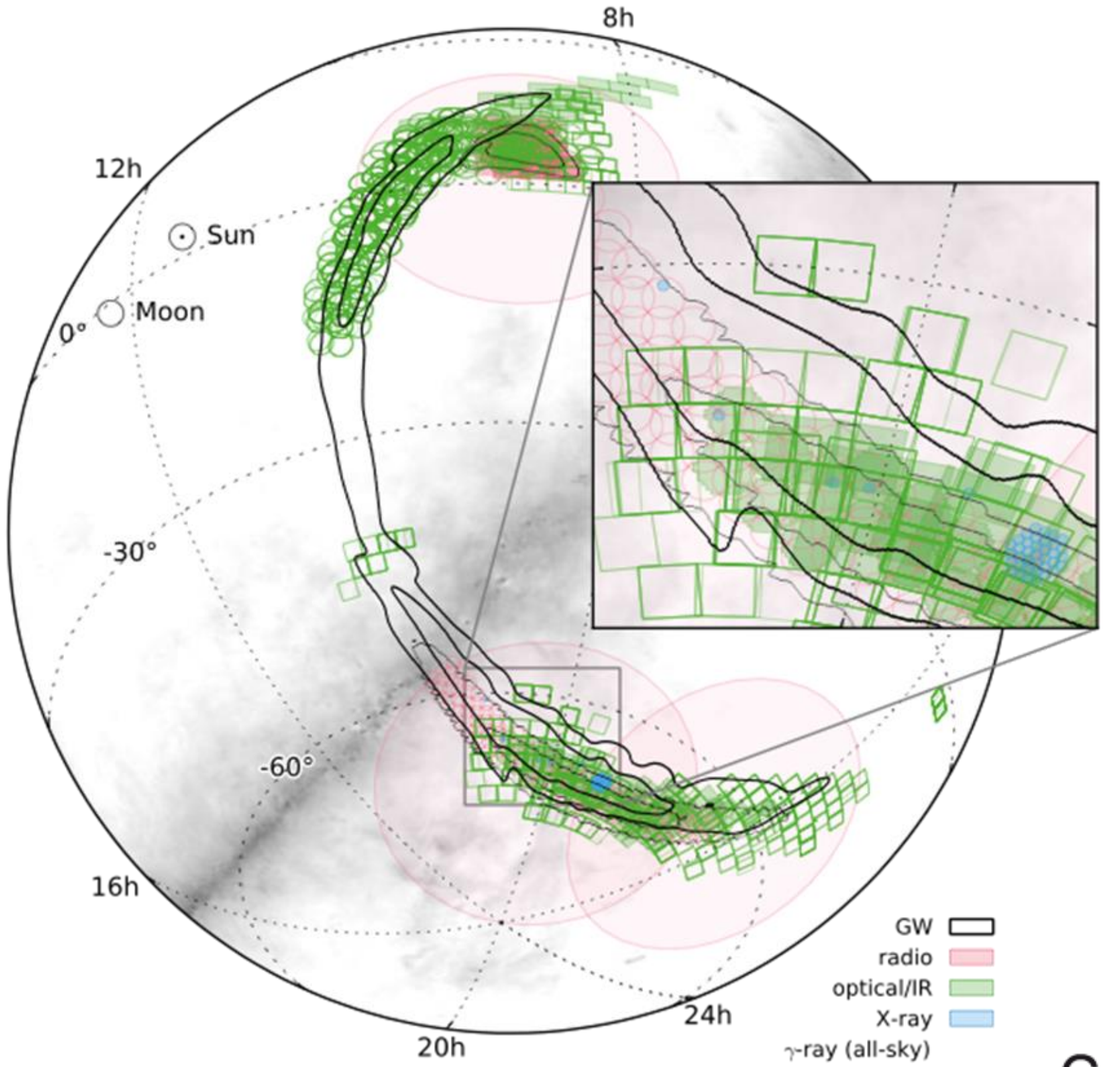
Simulation of merging black holes radiating gravitational waves
Credits: NASA/Ames Research Center/C. Henze



Phys. Rev. Lett. **116** (6): 061102

GW150914 follow-up

- First exercise on a real event event
- Big covered area (230 deg^2)
- No found counterparts (as expected)



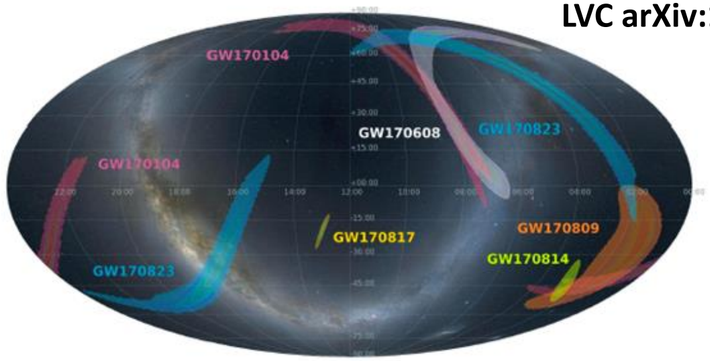
Abbott et al. 2016, ApJL, 826, 13
Abbott et al. 2016, ApJS, 225, 8

O1 vs O2 alerts

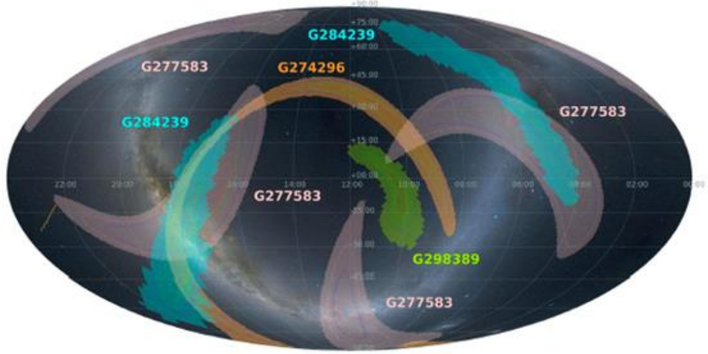
- 3 alerts:
  - GW150914
  - G194575
  - GW151226

- 2 confirmed detection and 1 rejection

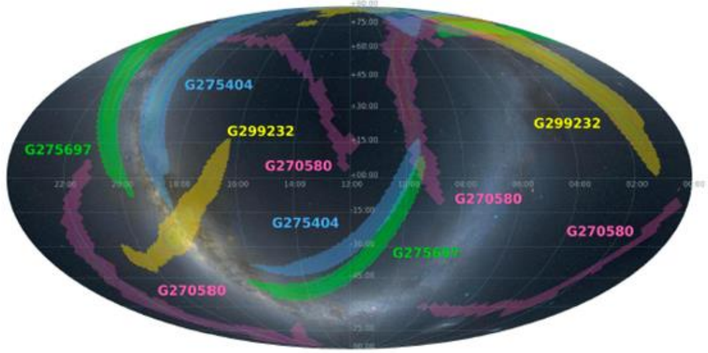
LVC arXiv:1811.12907



- 11 confident detections



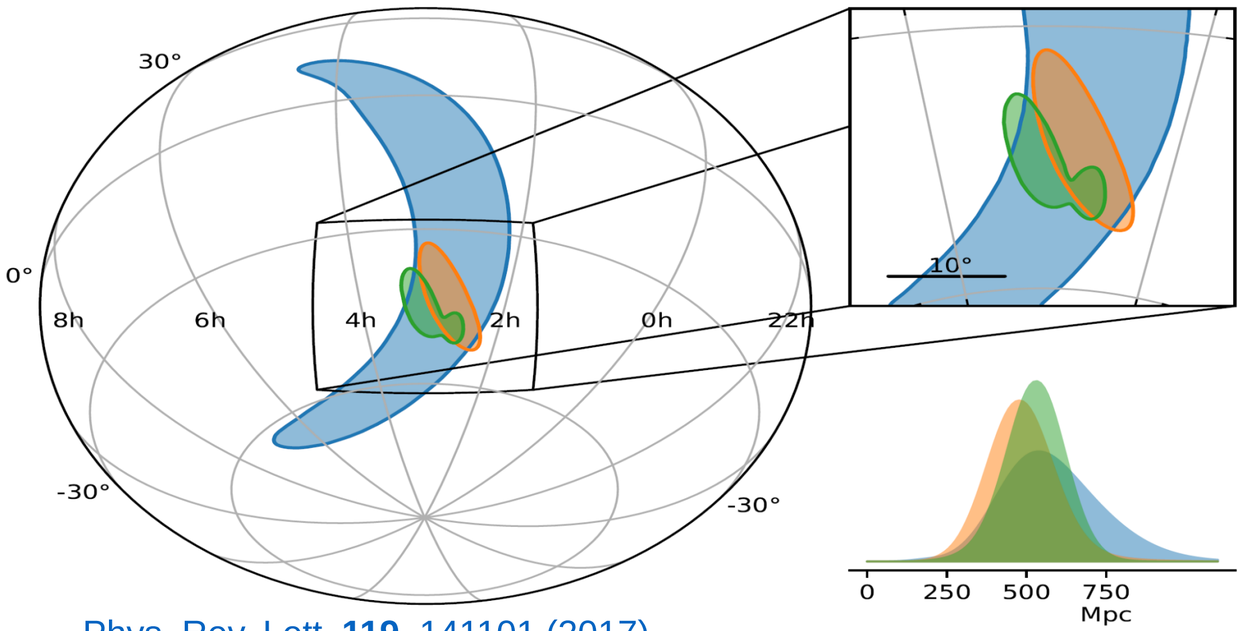
- Consistent with noise



- Rejected by offline analysis

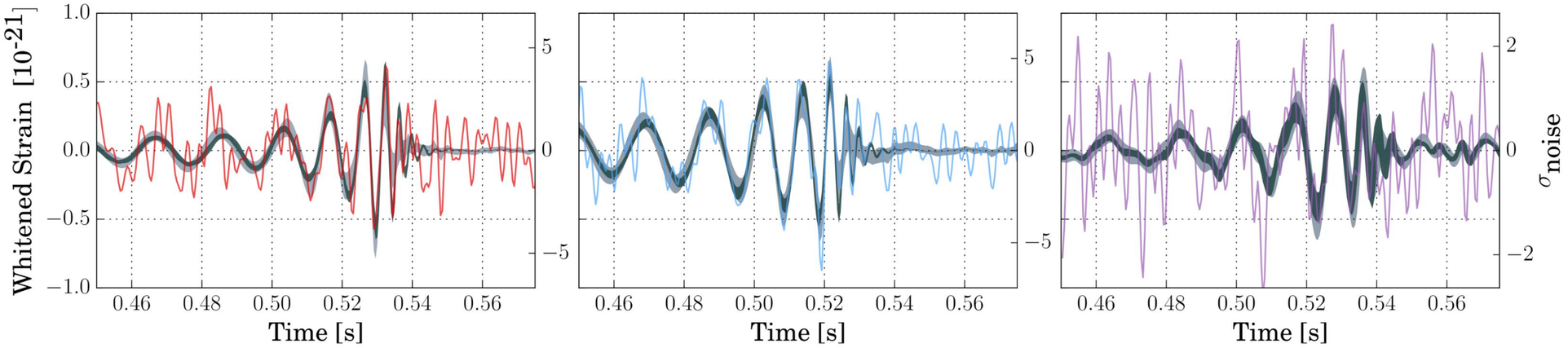
Credits: M. Branchesi

GW170814: the first HLV detection



- Blue: two LIGO detectors only (1160 square degrees).
- Orange: Adding Virgo (100 square degrees).
- Green: full parameter estimation analysis with three detectors (80 square degrees)
- Not shown: full parameter estimation using two LIGO detectors (700 square degrees.

Phys. Rev. Lett. **119**, 141101 (2017)



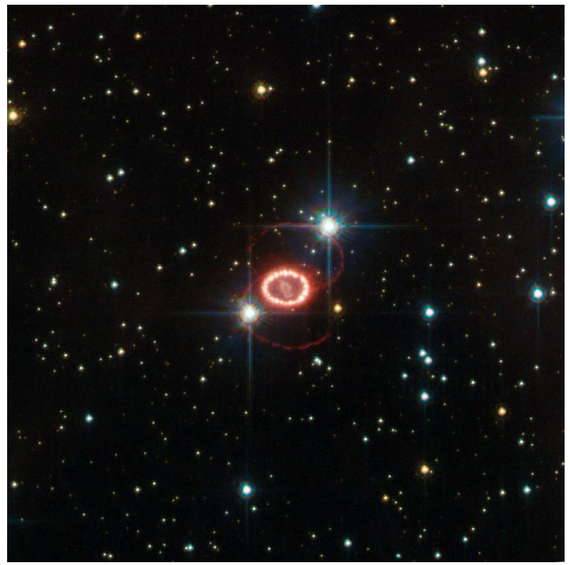
Multimessenger detections

And astrophysics discoveries

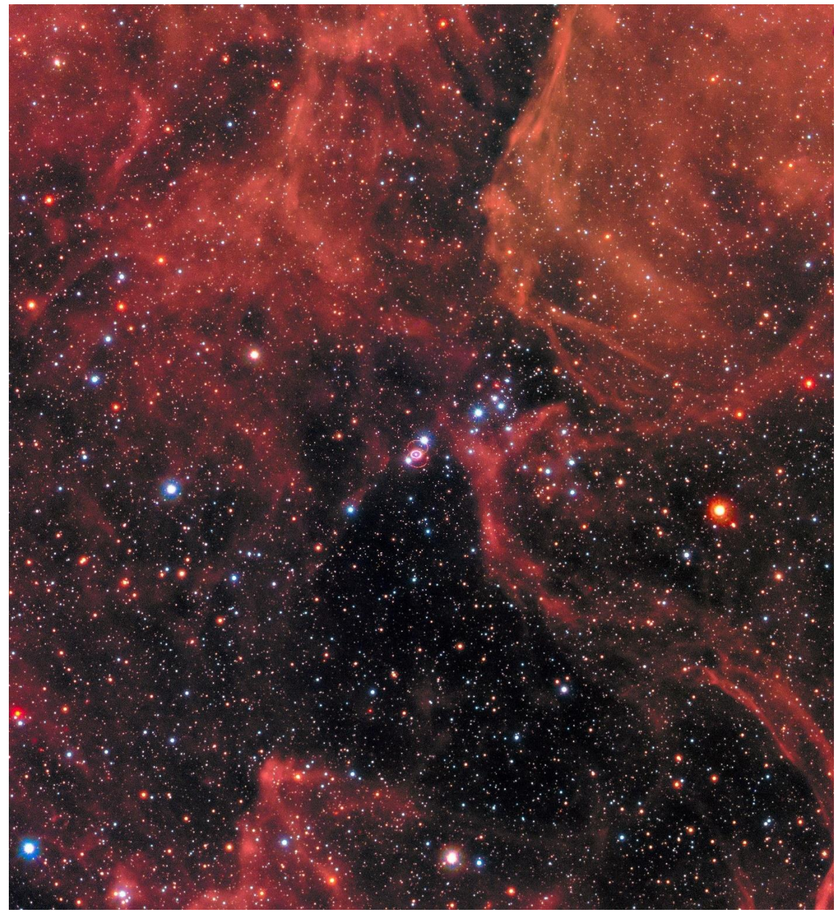
1987 supernova

- Probably the first multi-messenger detection
  - EM spectrum
  - Neutrino

  - No GW observed (Resonant bars)

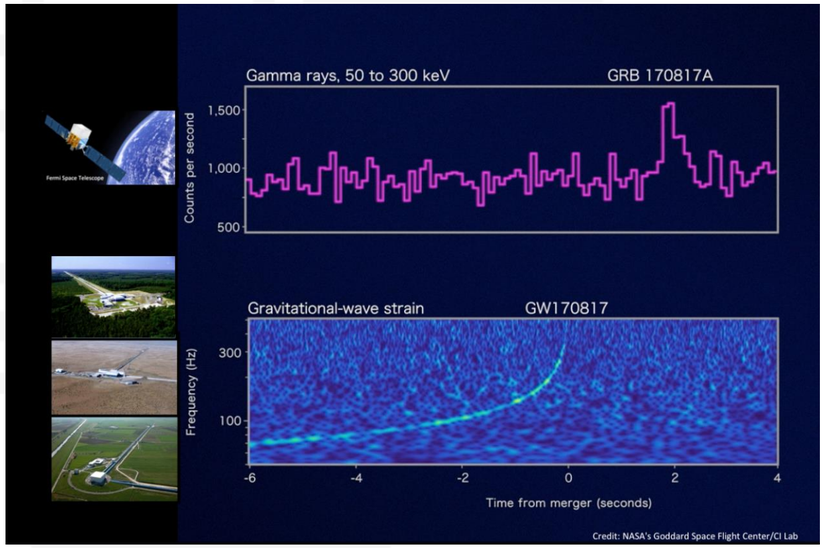


Credits: By NASA, ESA

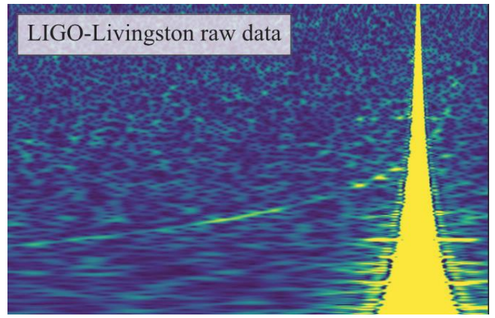


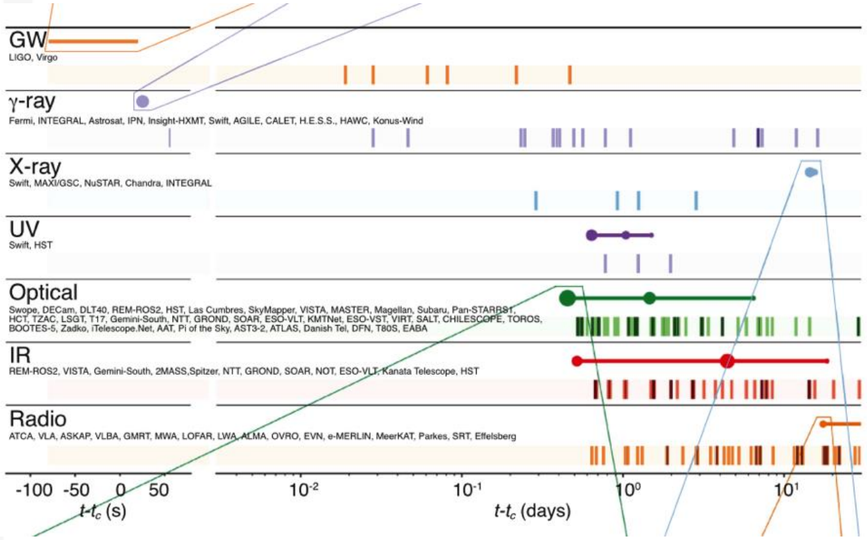
Credits: By NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation) and P. Challis (Harvard-Smithsonian Center for Astrophysics)

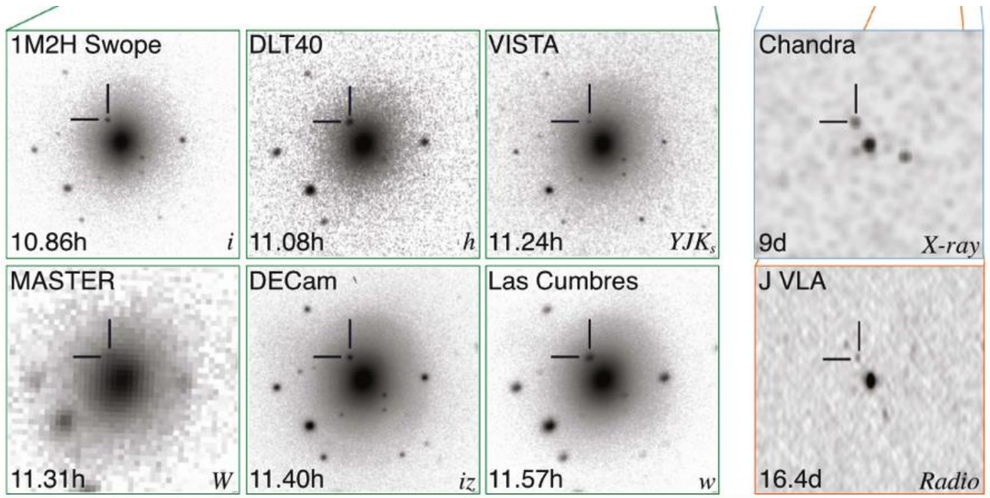
GW170817

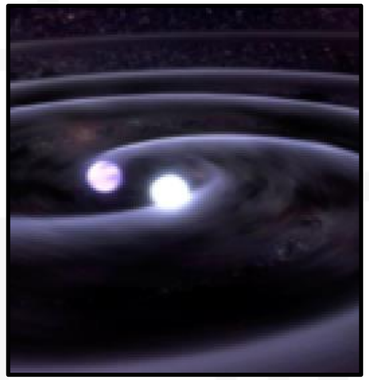


- Coincident detection between GW and GRB
- Ligo-L showing a glitch occurring during the event
- Follow-up campaign found EM counterparts

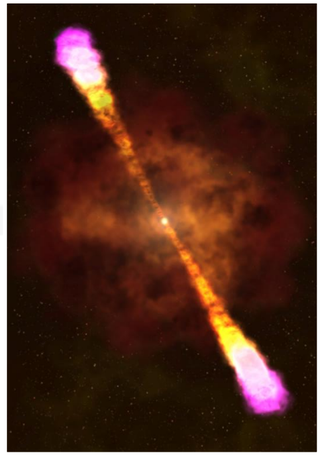




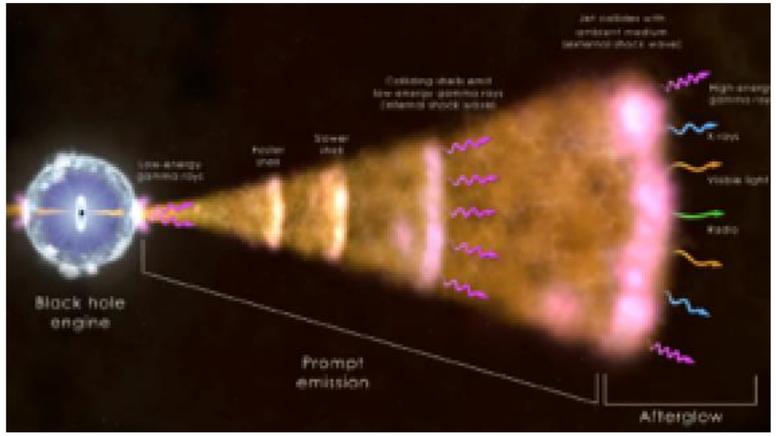




NS merger



Short GRB

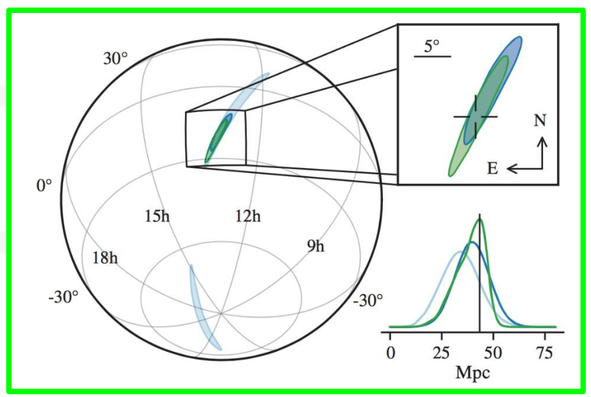


X-ray afterglow

Radio

t0 1.7s +5.23hrs +10.87 hrs +9 days +16 days

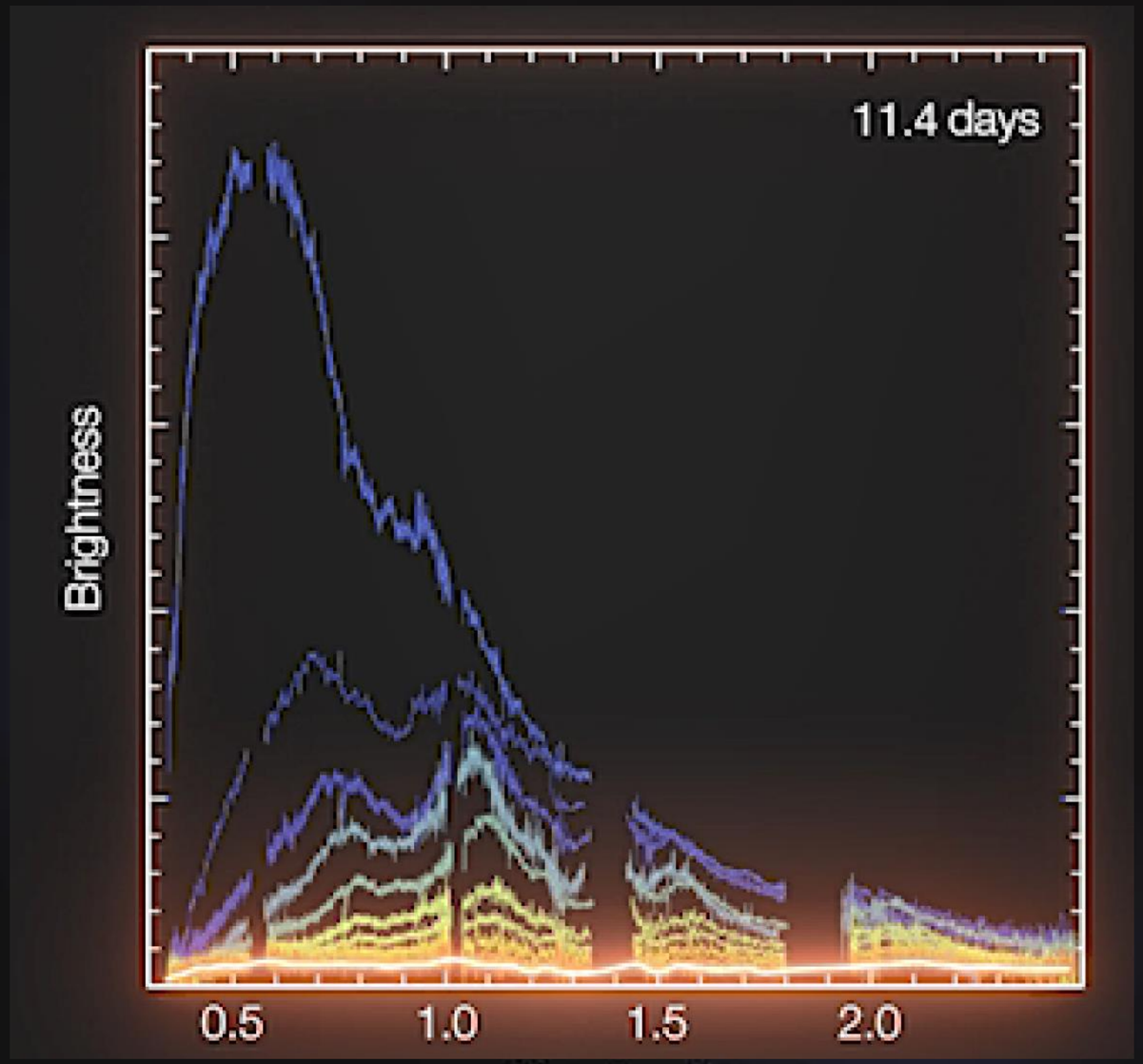
LHV sky localization



Kilonova

Credits: M. Branchesi

LVC + astronomers, ApJL, 848, L12



EJECTED MASS $\sim 0.03 - 0.05\ M_{\odot}$

EXPANSION VELOCITY $\sim 0.1 - 0.3\ c$

First spectral identification of the kilonova emission

- the data revealed signatures of the radioactive decay of **r-process nucleosynthesis**

(Pian et al. 2017, Smartt et al. 2017)

- BNS merger **site for heavy element production in the Universe!**

(Cote et al. 2018, Rosswog et al. 2017)

Credits: M. Branchesi

GW velocity

Constraining velocity rules out modified gravity models

Considering the delay between GW and GRB, and the distance they travelled

- $\Delta t = 1.74 \pm 0.05$ s
- d ~ 40 Mpc

we have:

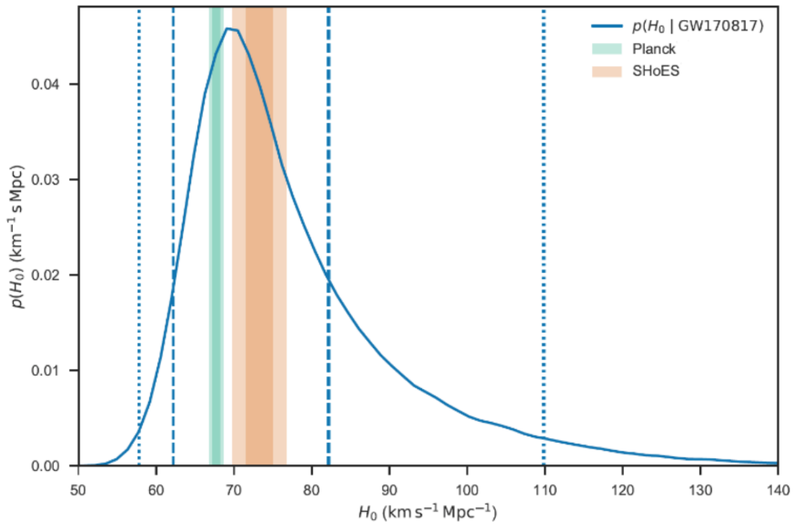
- $-3 \cdot 10^{-15} \leq \Delta c/c \leq 7 \cdot 10^{-16}$

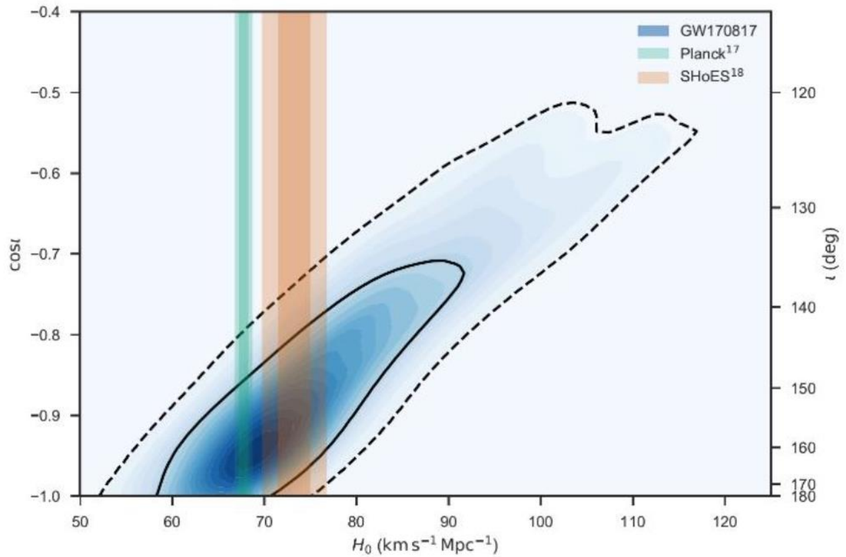
LVC 2017, APJL, 848, L13

H_0 measurement

Combine distance from GW:

$$d = 43.8^{+2.9}_{-6.9}\ \text{Mpc}$$





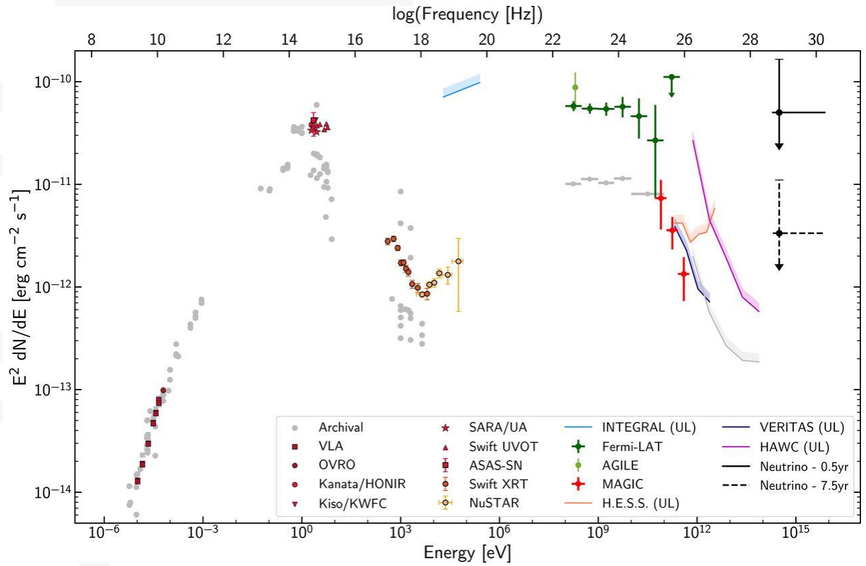
And NGC4993 recession velocity we have:

$$H_0 = 70^{+12.0}_{-8.0}\ \text{Mpc}$$

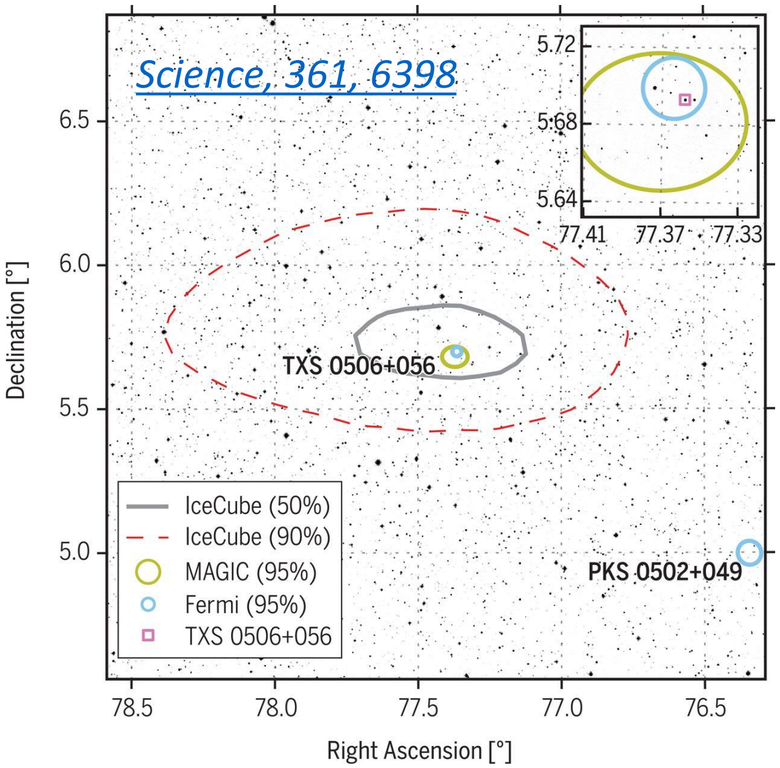
Abbott et al. 2017, Nature, 551, 85A

Neutrino + EM

- **September 22nd, 2017**: Trigger alert from IceCube of a high energy neutrino event
- *Fermi*-LAT detects a blazar in a high gamma-ray state in the neutrino field of view
- IACTs observations triggered
- MAGIC detected a **significant signal** (just before the full moon break)



The SED is based on observations obtained within 14 days of the detection of the IceCube-170922A event. The vertical axis is equivalent to a scale Differential flux upper limits (shown as colored bands and indicated as "UL" in the legend) are quoted at the 95% CL, while markers indicate significant detections. Archival observations are shown in gray to illustrate the historical flux level of the blazar in the radio-to-keV range as retrieved from the ASDC SED Builder (62), and in the γ-ray band as listed in the Fermi-LAT 3FGL catalog (23) and from an analysis of 2.5 years of HAWC data.. Representative neutrino flux upper limits that produce on average one detection like IceCube-170922A over a period of 0.5 (solid black line) and 7.5 years (dashed black line) are shown, assuming a spectrum of at the most probable neutrino energy (311 TeV).



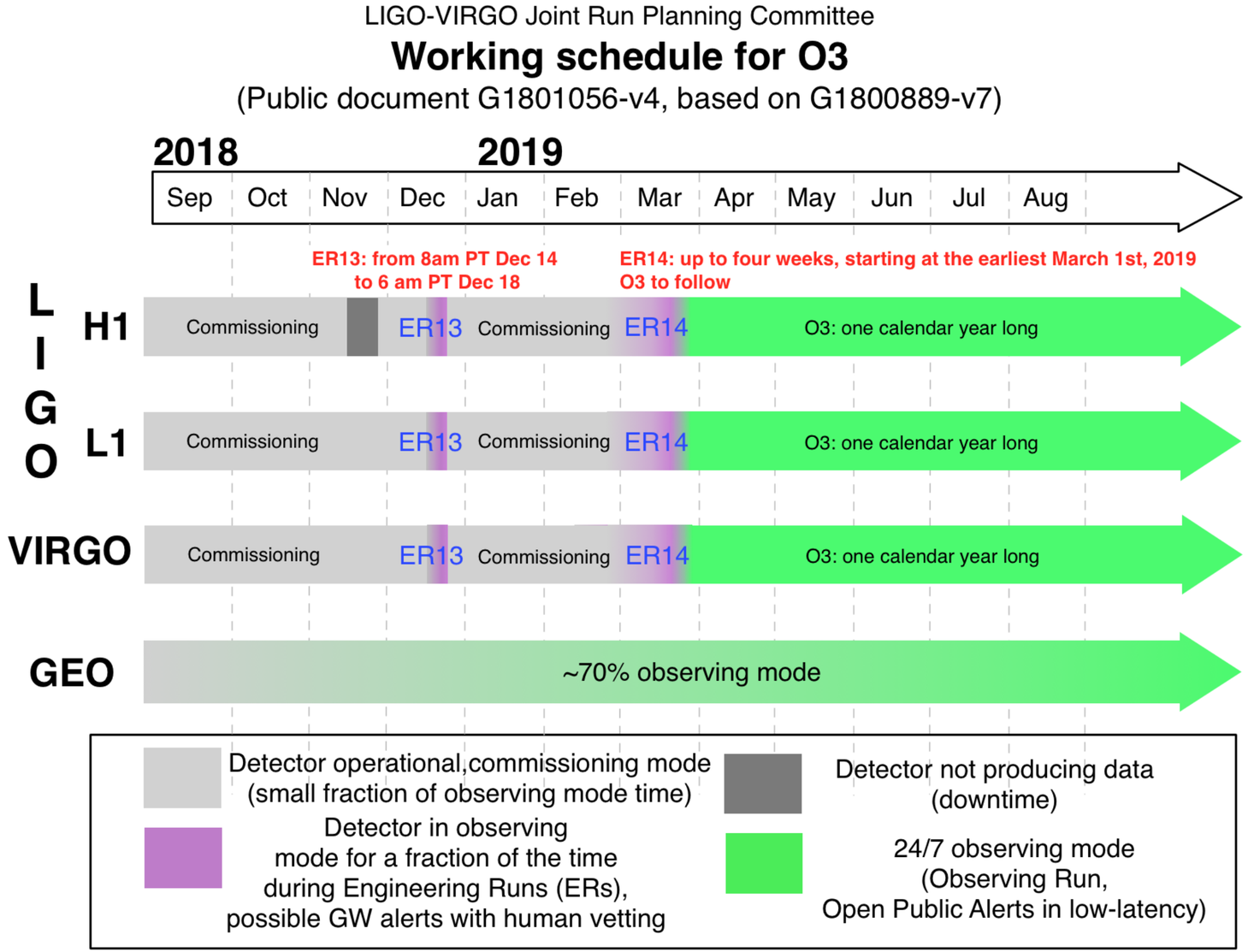
The 50% and 90% containment regions for the neutrino IceCube-170922A (dashed red and solid gray contours, respectively. Gamma-ray sources in this region previously detected with the *Fermi* spacecraft are shown as blue circles, with sizes representing their 95% positional uncertainty and labeled with the source names. The yellow circle shows the 95% positional uncertainty of very-high-energy γ-rays detected by the MAGIC telescopes during the follow-up campaign.

The future is now

Waiting for GW+EM+Neutrino…

O3 has started April 1st

Epoch			2018 – 2019
Planned run duration			12 months
Expected burst range/Mpc		LIGO	75 – 90
		Virgo	40 – 50
		KAGRA	—
Expected BNS range/Mpc		LIGO	120 – 170
		Virgo	65 – 85
		KAGRA	—
Achieved BNS range/Mpc		LIGO	—
		Virgo	—
		KAGRA	—
Estimated BNS detections			1 – 50
Actual BNS detections			—
90% CR	% within	5 deg^2	1 – 4
		20 deg^2	12 – 21
	Median/deg^2		120 – 180
Searched area	% within	5 deg^2	20 – 26
		20 deg^2	42 – 50



FIRST O3 EVENT YESTERDAY!!!