LIGO-Virgo's Discovery of a Binary Neutron Star Merger from a Multi-Messenger Perspective

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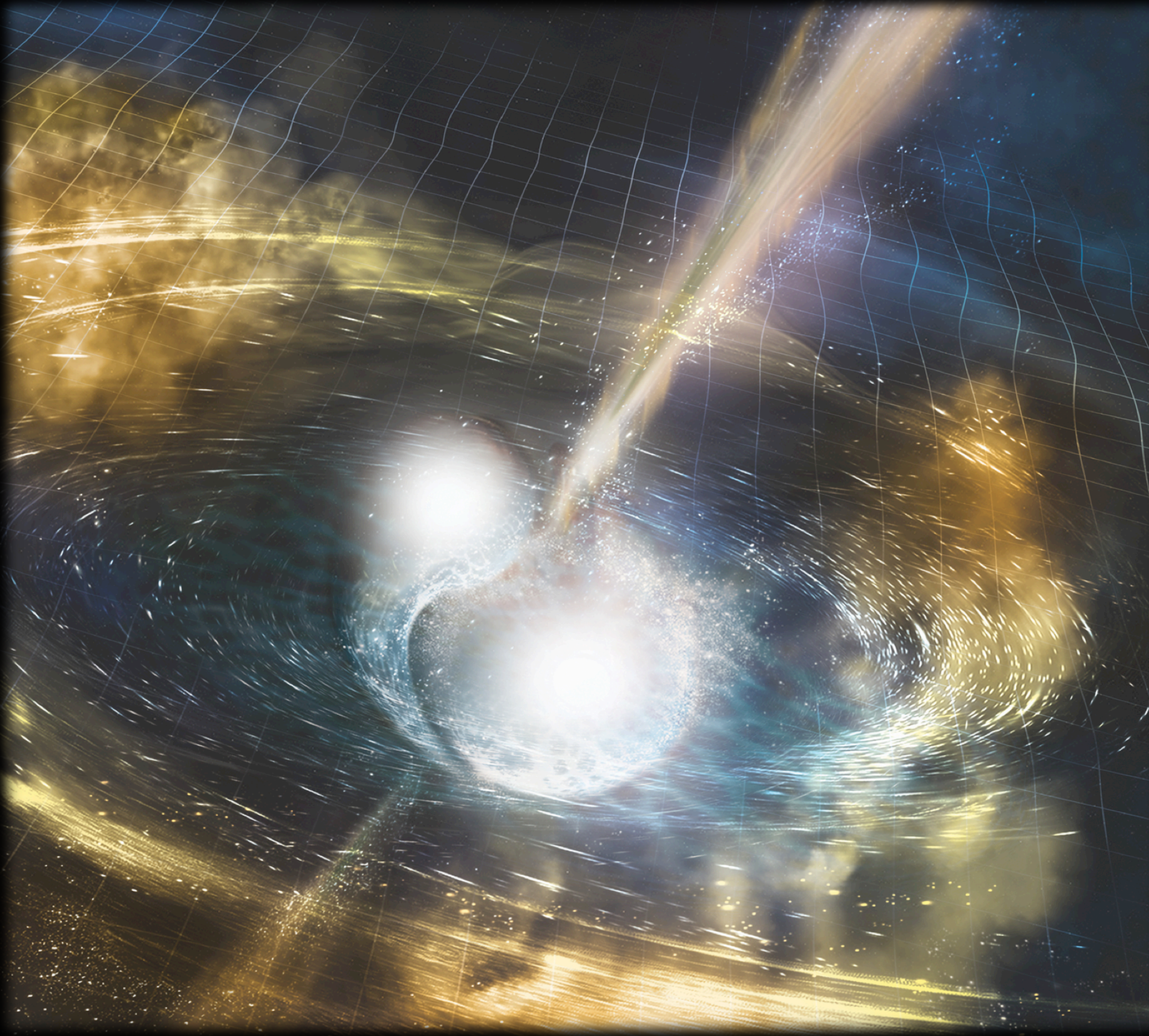
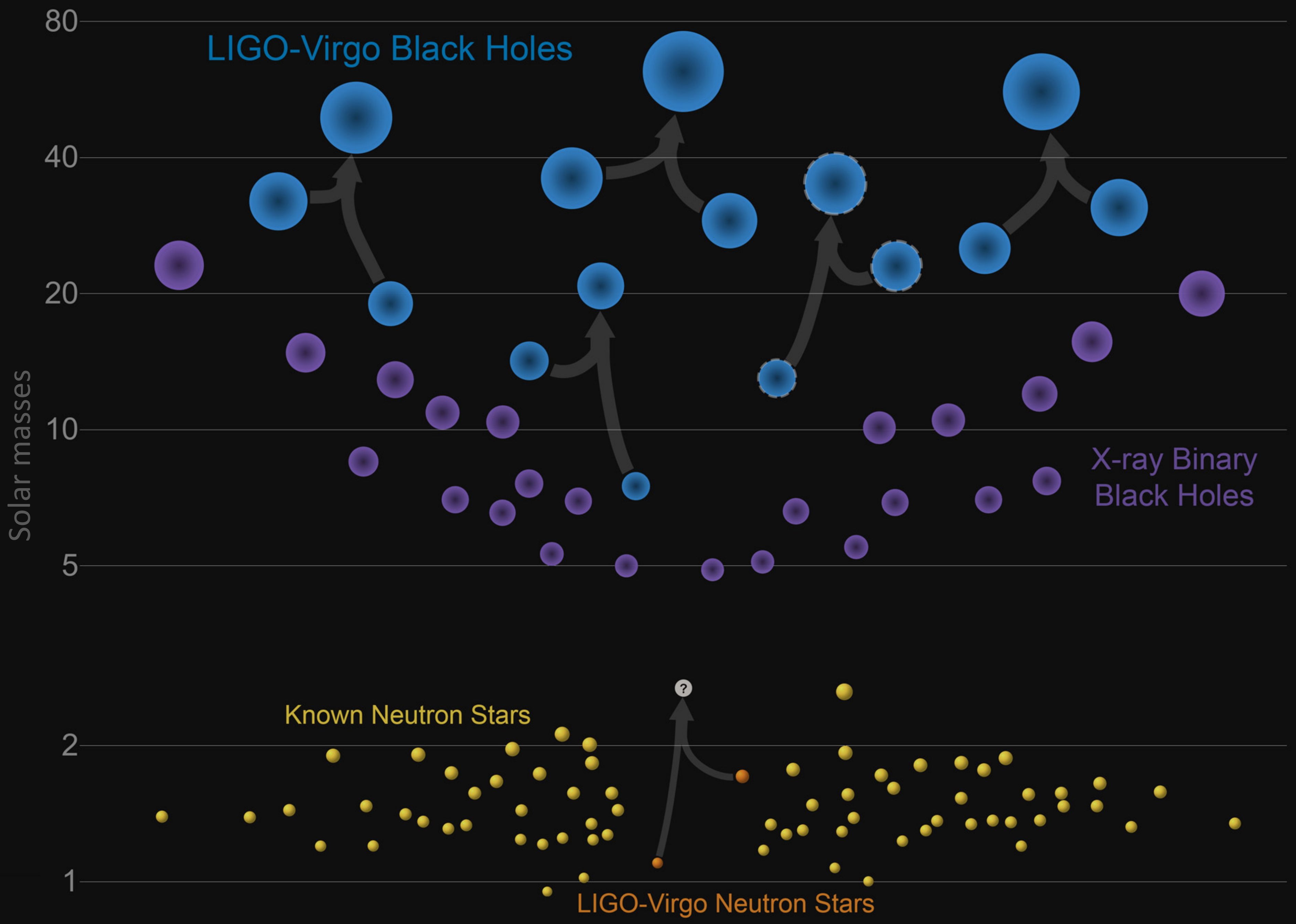
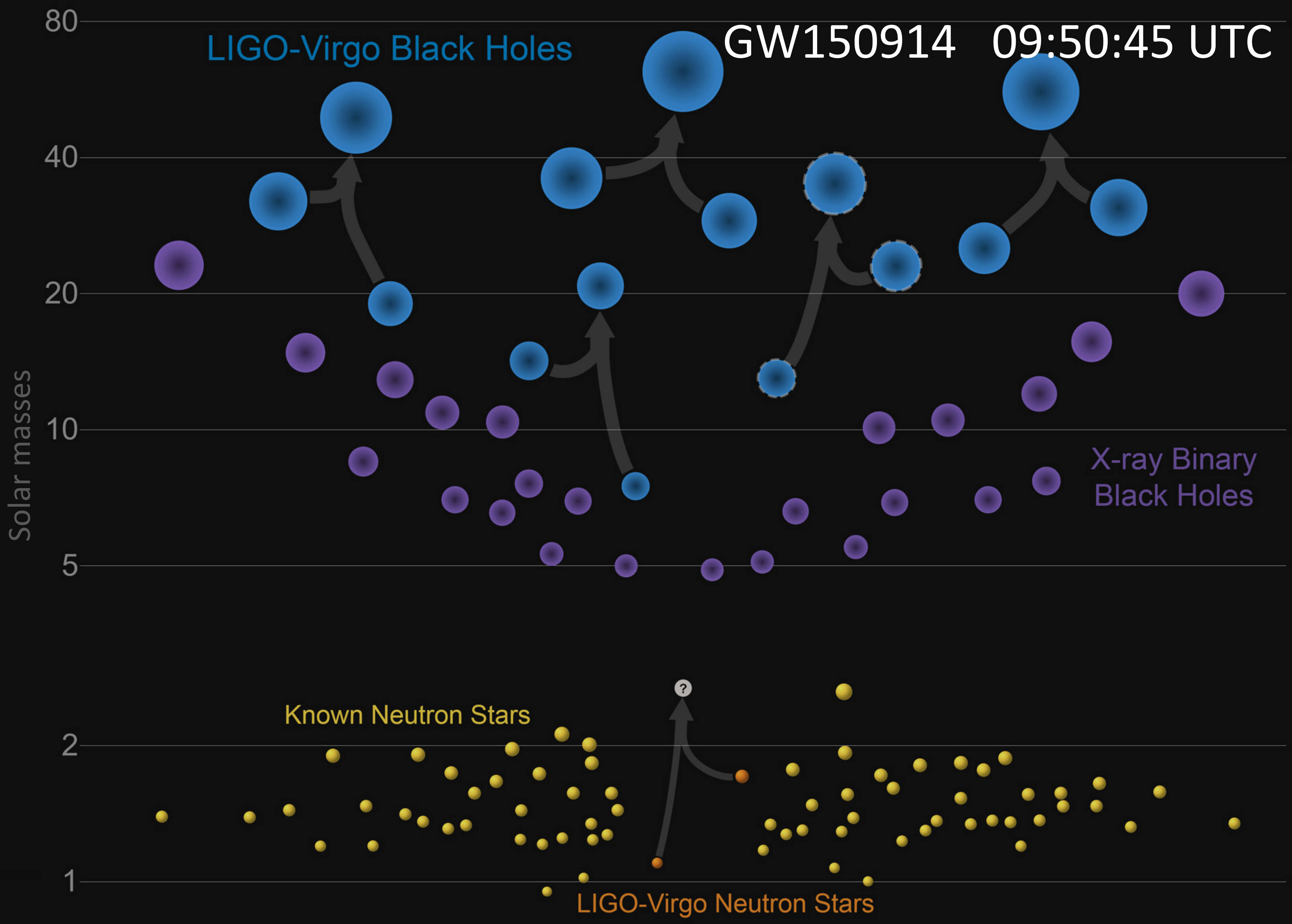
VLVnT 2018 | Dubna, Russia | LIGO-G1800851



Credit: NSF/LIGO/Sonoma State University/A. Simonnet



Credit: LIGO-Virgo/Frank Elavsky/Northwestern University



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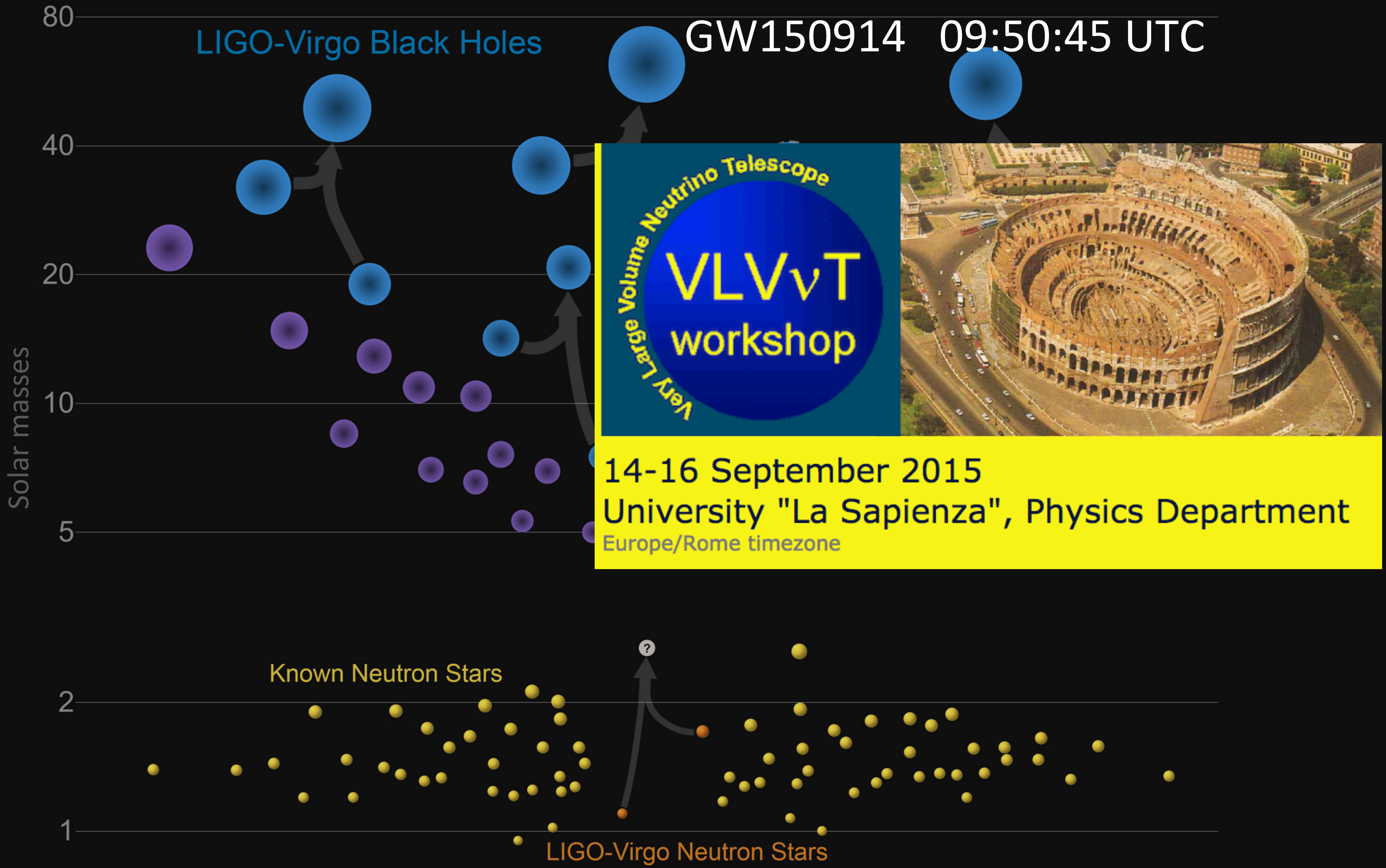
GW150914 09:50:45 UTC



Credit: LIGO-Virgo/Frank Elavsky/Northwestern University

Earth

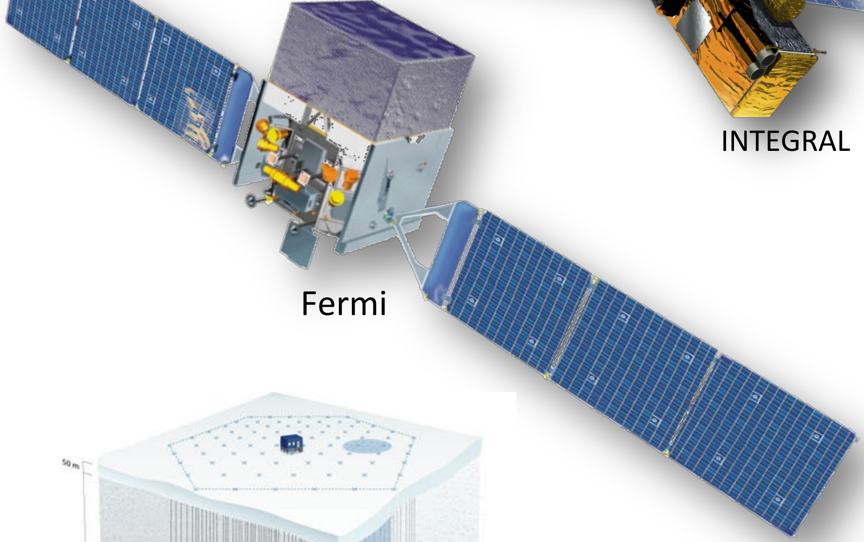
Space

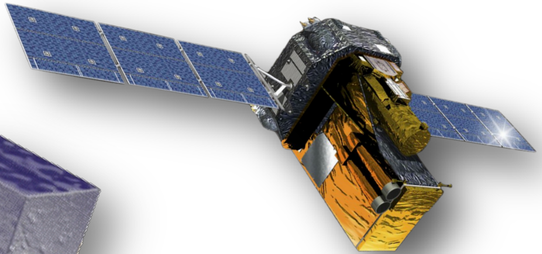
LIGO O2

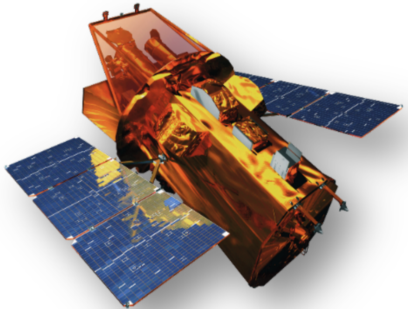
- Nov 30 2016 – Aug 25 2017
- ~20% improved sensitivity
- Virgo (Aug 1 – Aug 25)
- ~100 partner observatories

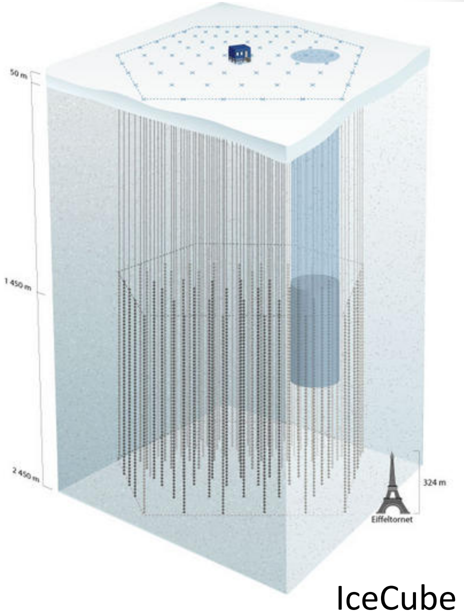
Credit: LIGO-Virgo

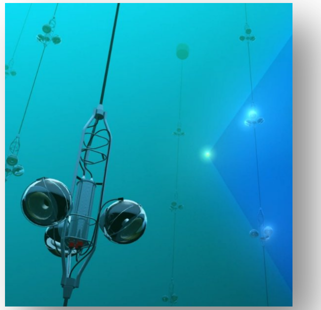
“all-sky” observatories


Fermi

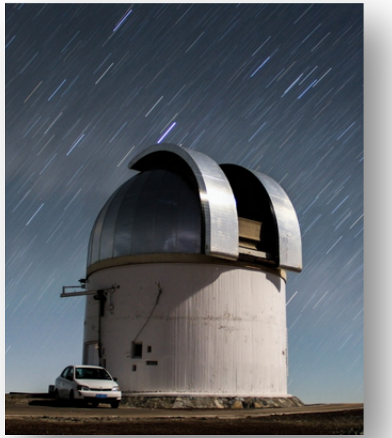

INTEGRAL


Swift

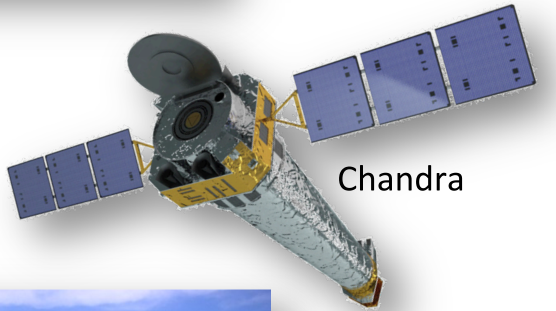

IceCube


ANTARES

follow-up observatories


Swope


DECam

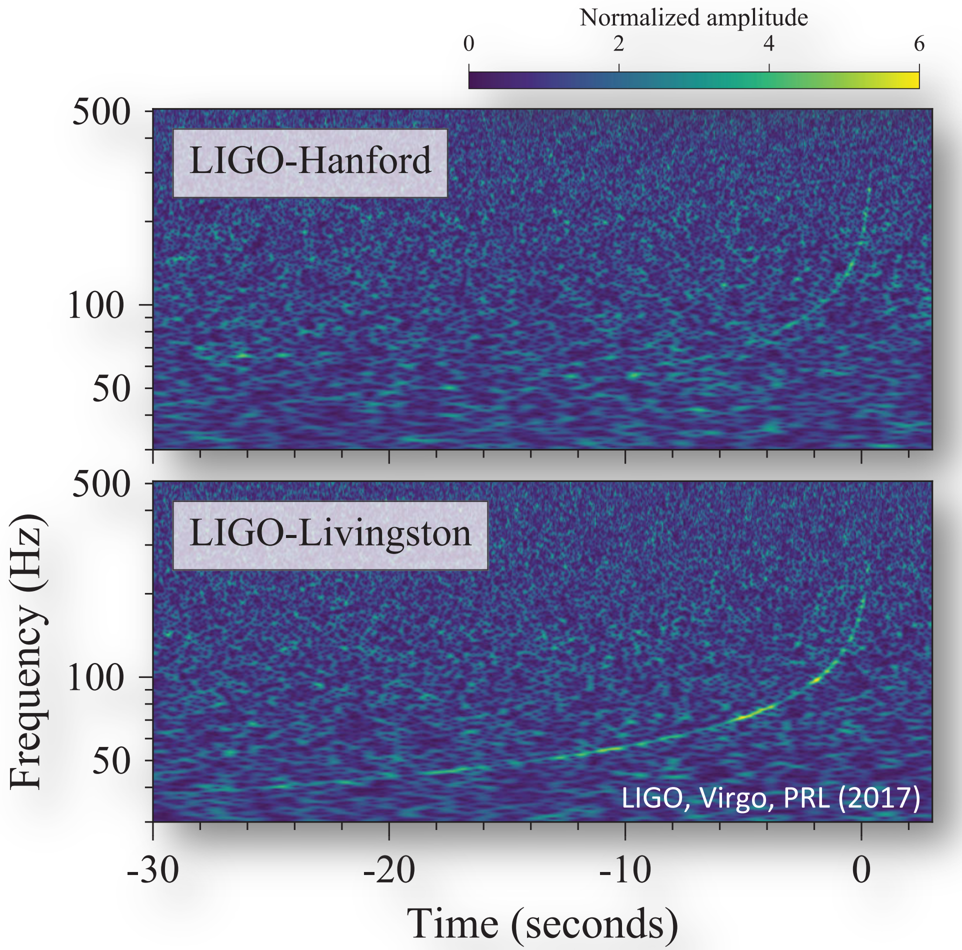

Chandra


Hubble

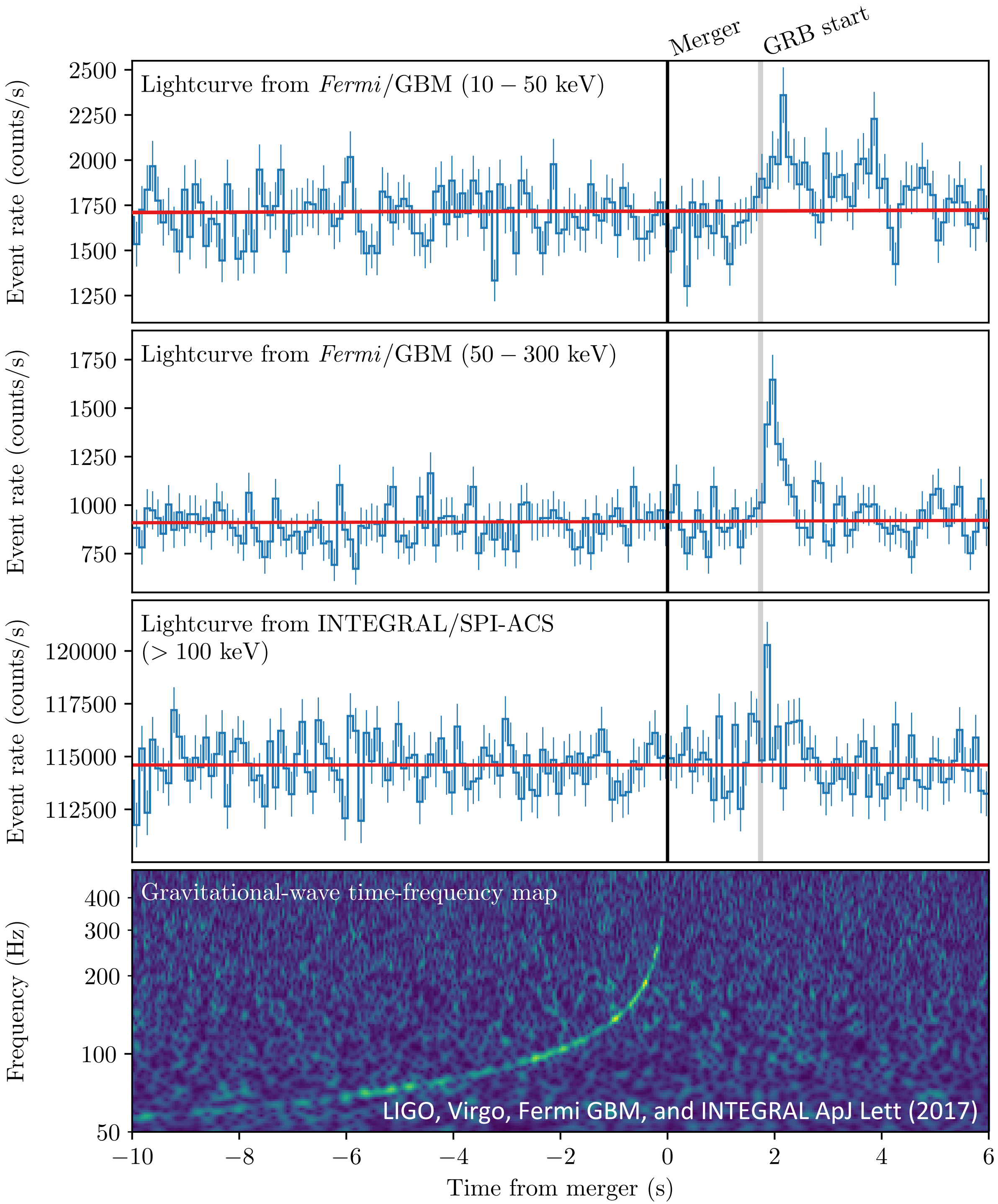

Very Large


Las Cumbres

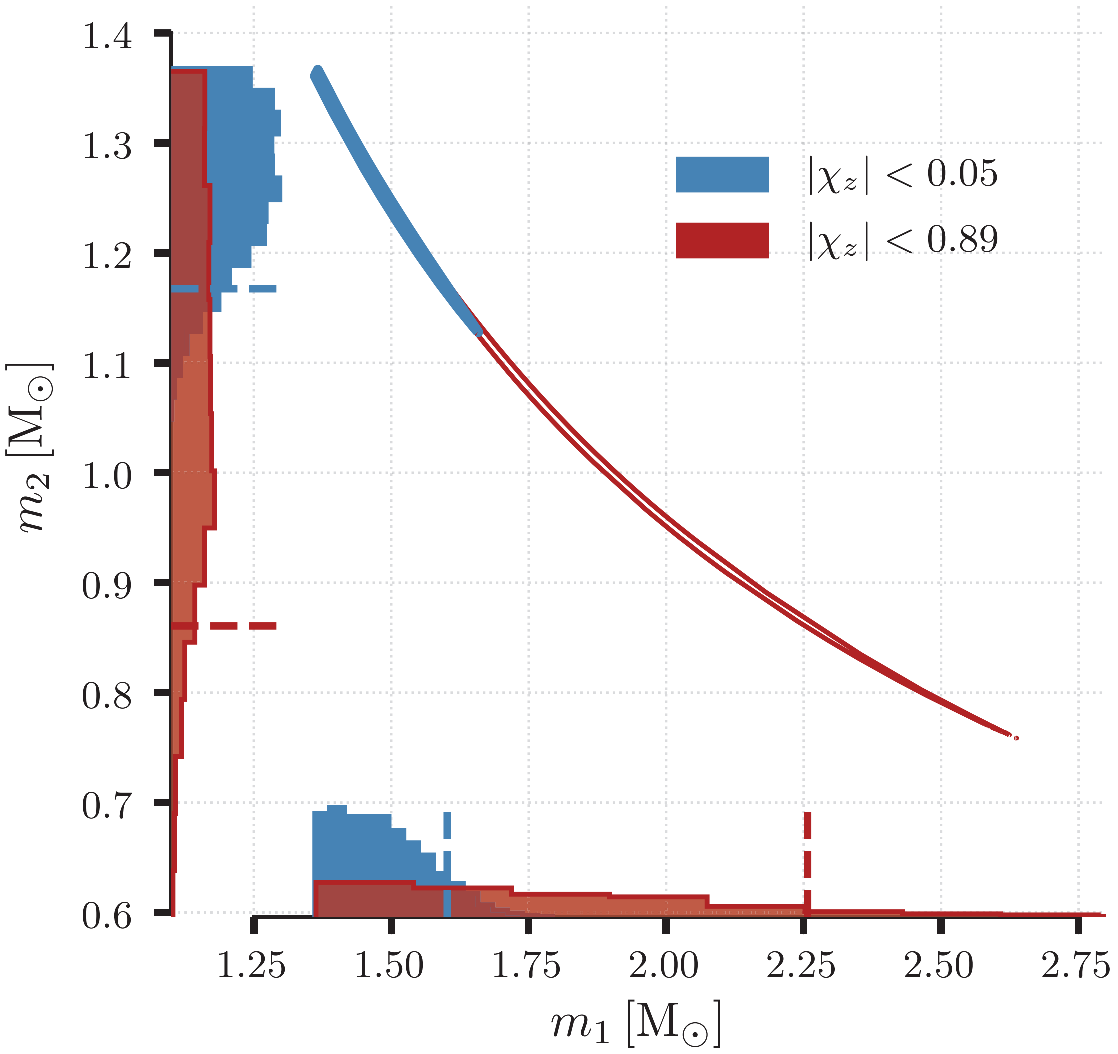
August 17, 2017



- Gravitational-wave trigger in LIGO-Hanford only
- Livingston − noise transient
- No signal in Virgo
- Consistent with BNS merger
- 1.7s later --- GRB alert from Fermi
- Weak GRB (~10^{-7} erg cm^{-2})



Information in Gravitational Waves

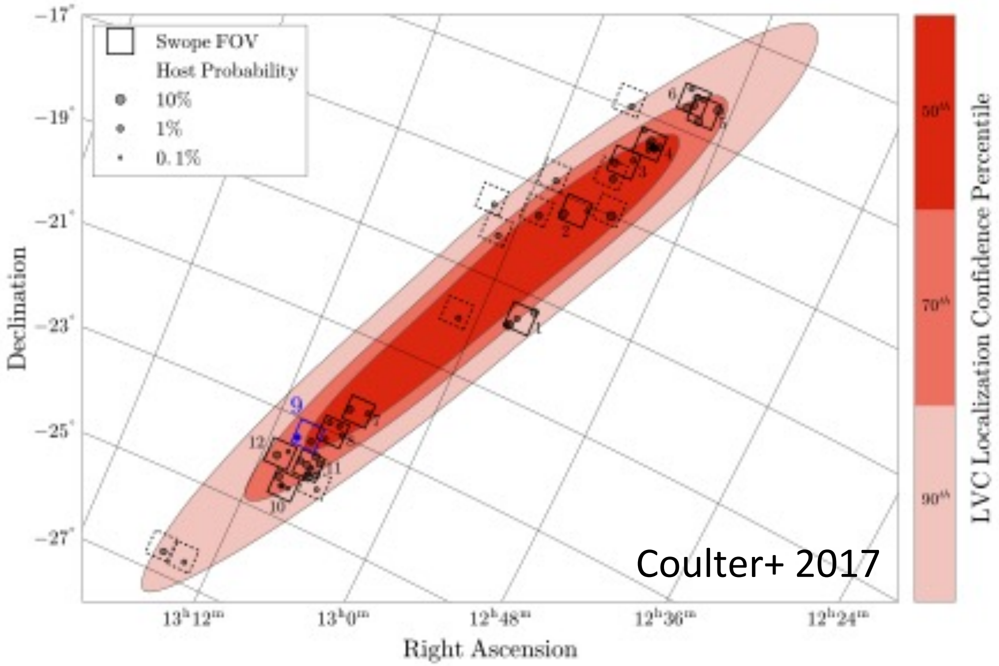


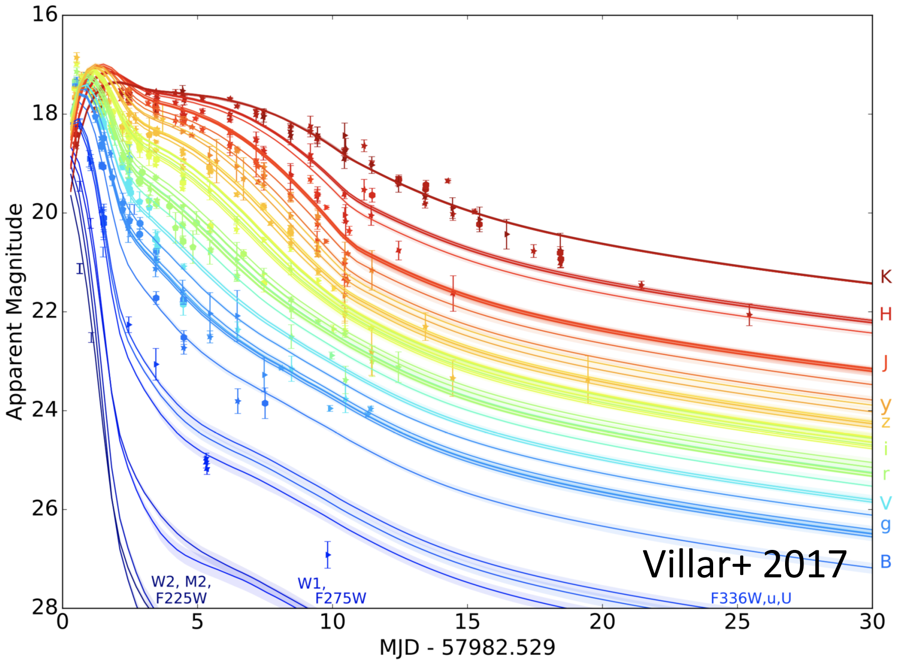
	Low-spin priors ($\|\chi\| \leq 0.05$)
Primary mass m_1	1.36–1.60 $M_\odot$
Secondary mass m_2	1.17–1.36 $M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0
Total mass m_{tot}	$2.74^{+0.04}_{-0.01} M_\odot$
Radiated energy E_{rad}	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc
Viewing angle Θ	$\leq 55°$
Using NGC 4993 location	$\leq 28°$

$$R = 1540^{+3200}_{-1220}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$$

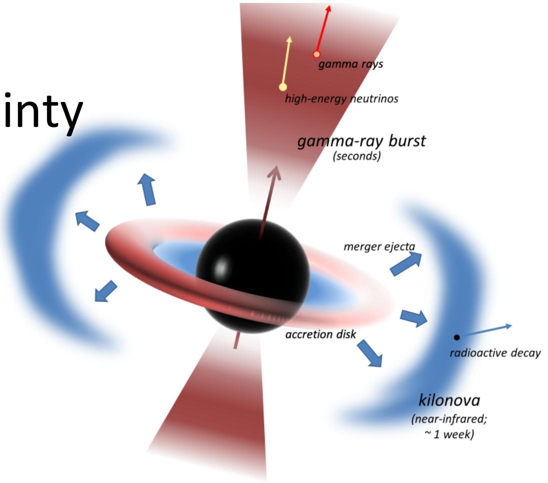
- More common than we expected
- Consistent with galactic BNS observations
- Tidal effects are not taken into account
- Neutron star maximum mass: ~2.2 Msun

Identification of optical counterpart



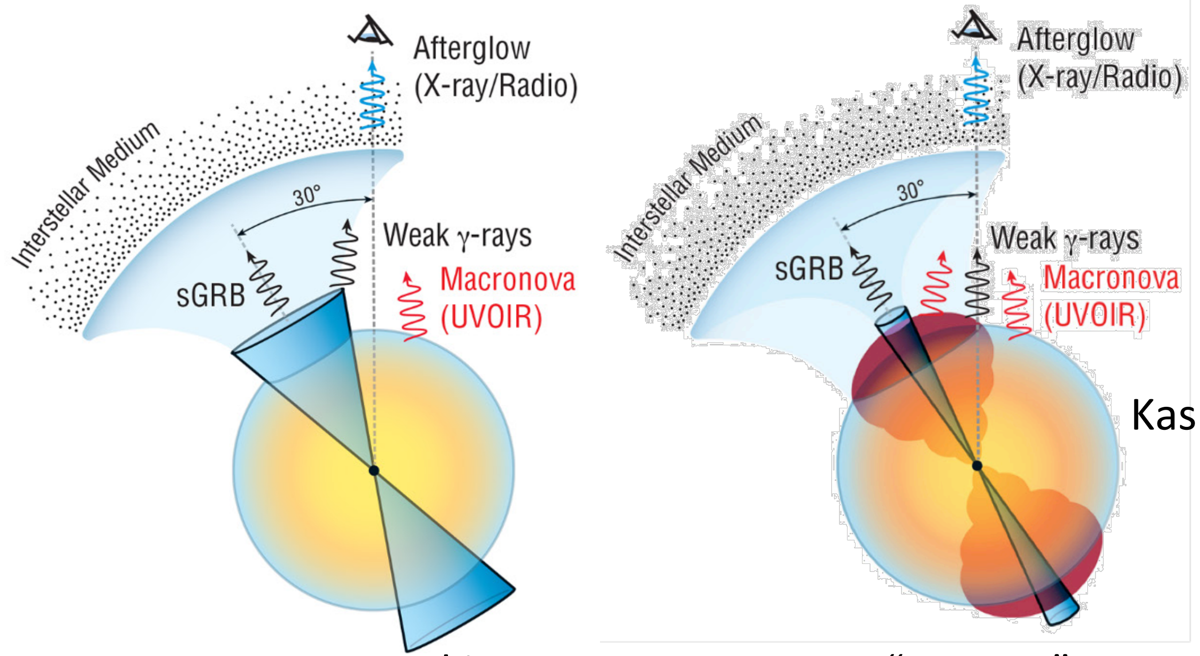


- Gravitational waves → 30 sq deg localization uncertainty
- Swope Telescope – counterpart within 11 hours.
- Host galaxy – 40 Mpc.
- Light curve consistent with kilonova model.
- 0.01-0.05 $M_{\odot}$ ejected from merger.



Information from GRB & afterglow

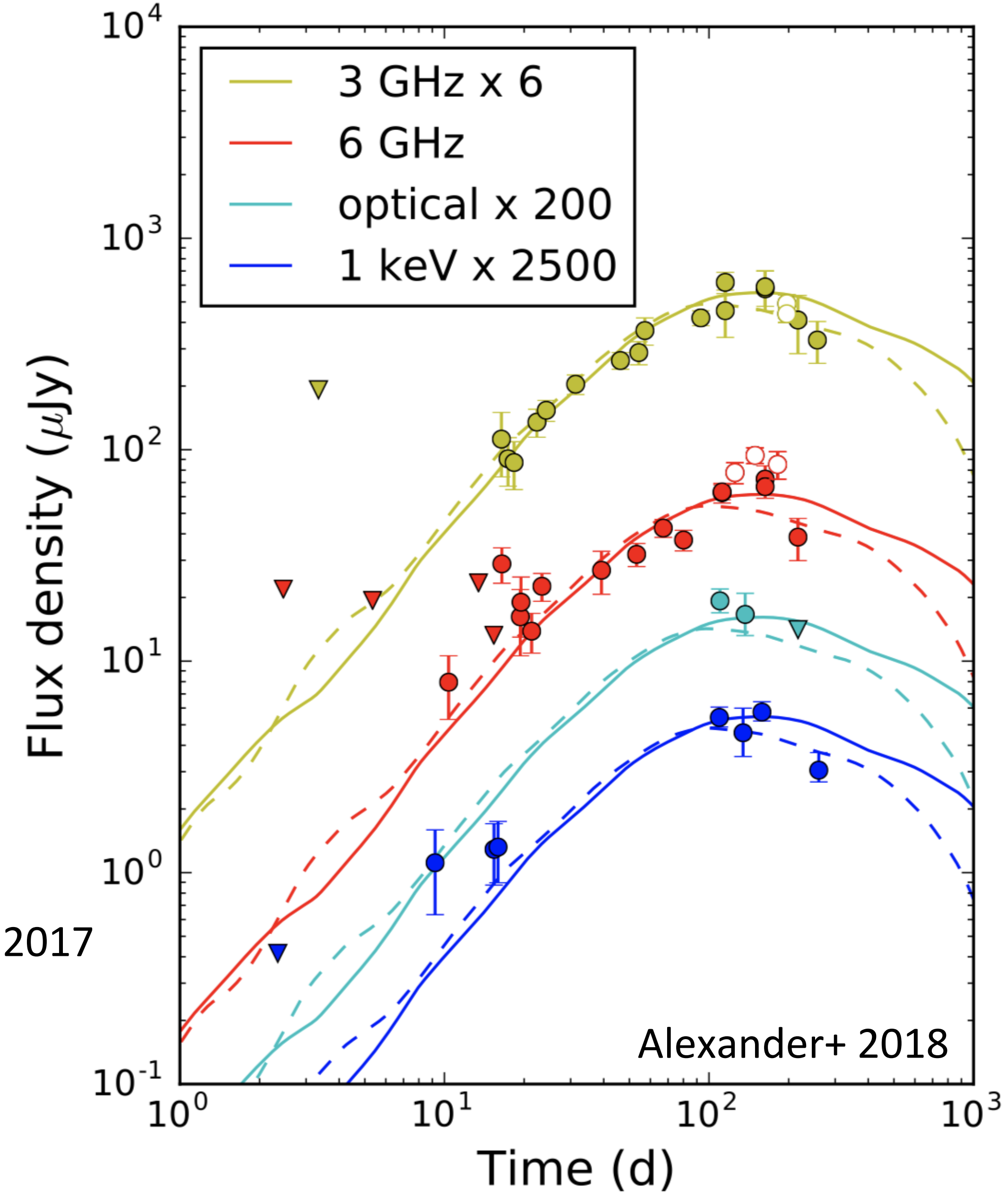
- Weak GRB --- orders of magnitude below weakest detected.
- Delayed afterglow (9/15 days for X-ray/radio) --- off axis?
- Afterglow brightness grows until ~200 days.
  - Simple (on-axis, “top-hat”) models ruled out.
  - Outflow is structured likely due to interaction with kilonova ejecta.



Kasliwal+ 2017

Structured jet
(e.g. Lazzati+2017, Margutti+ 2018)

“Cocoon”
(e.g. Gottlieb 2017, Mooley 2018)

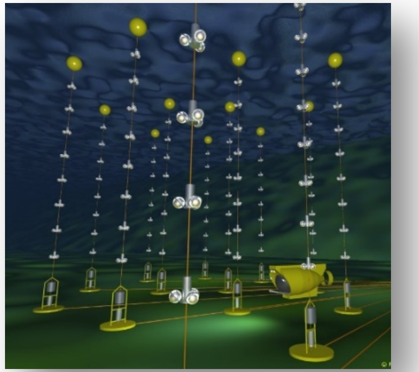


Alexander+ 2018

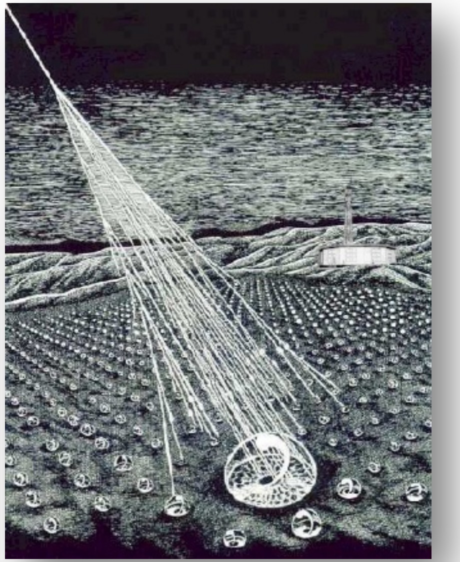
High-energy emission (neutrinos)

Rationale:

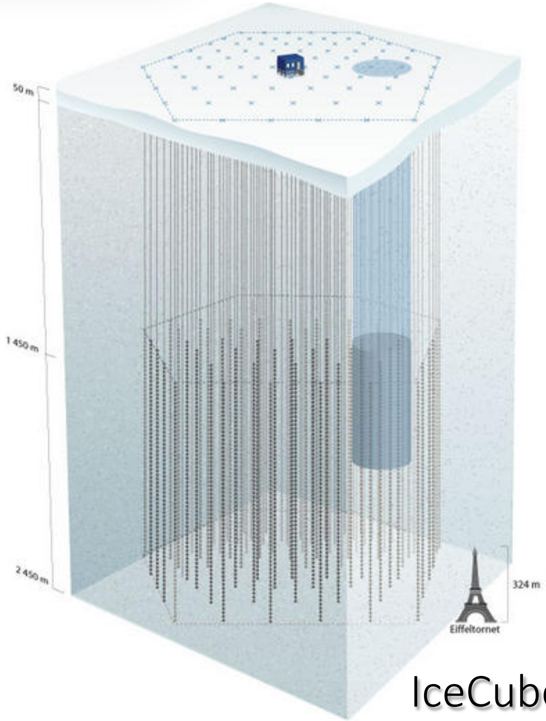
- Very nearby GRB – potentially strong emission.
- GRB model unclear (e.g. structured vs cocoon, on-axis / off-axis) – neutrinos may help differentiate.
- Interaction between GRB and kilonova ejecta --- interesting site for neutrino production.



ANTARES



Pierre Auger

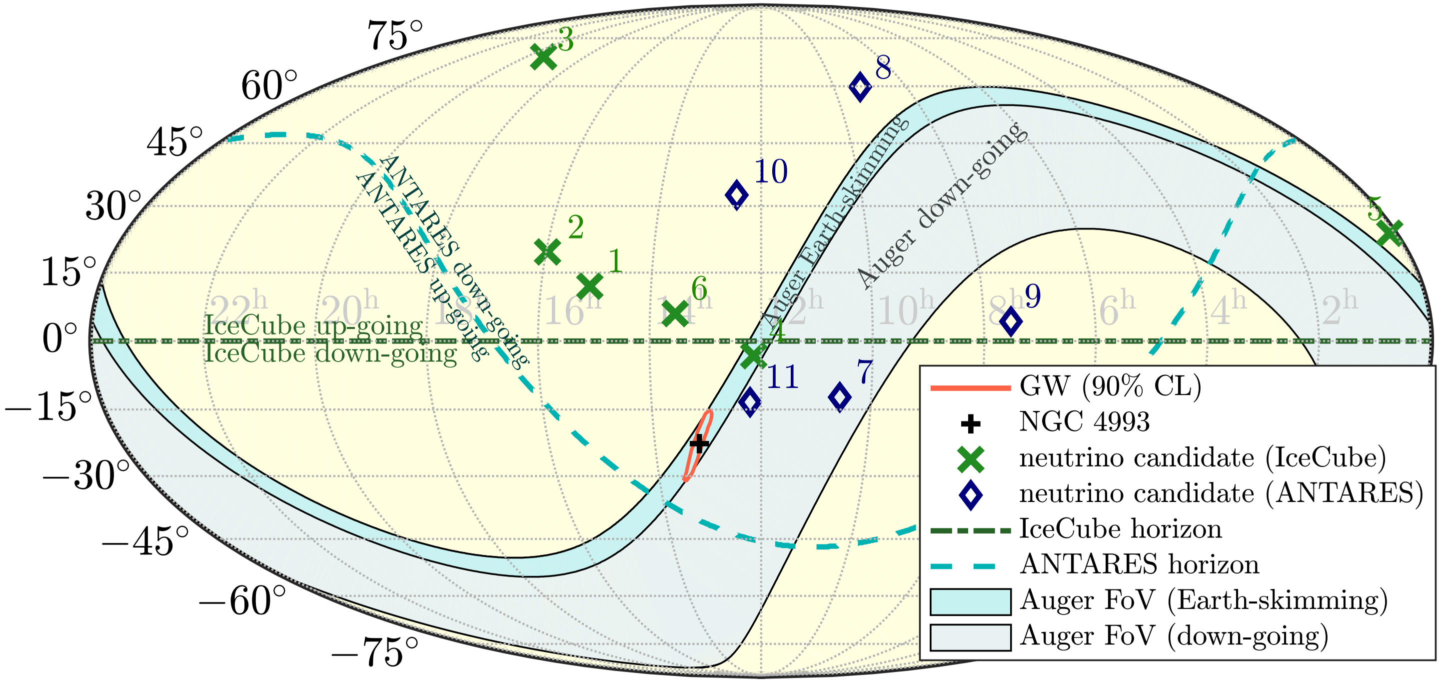


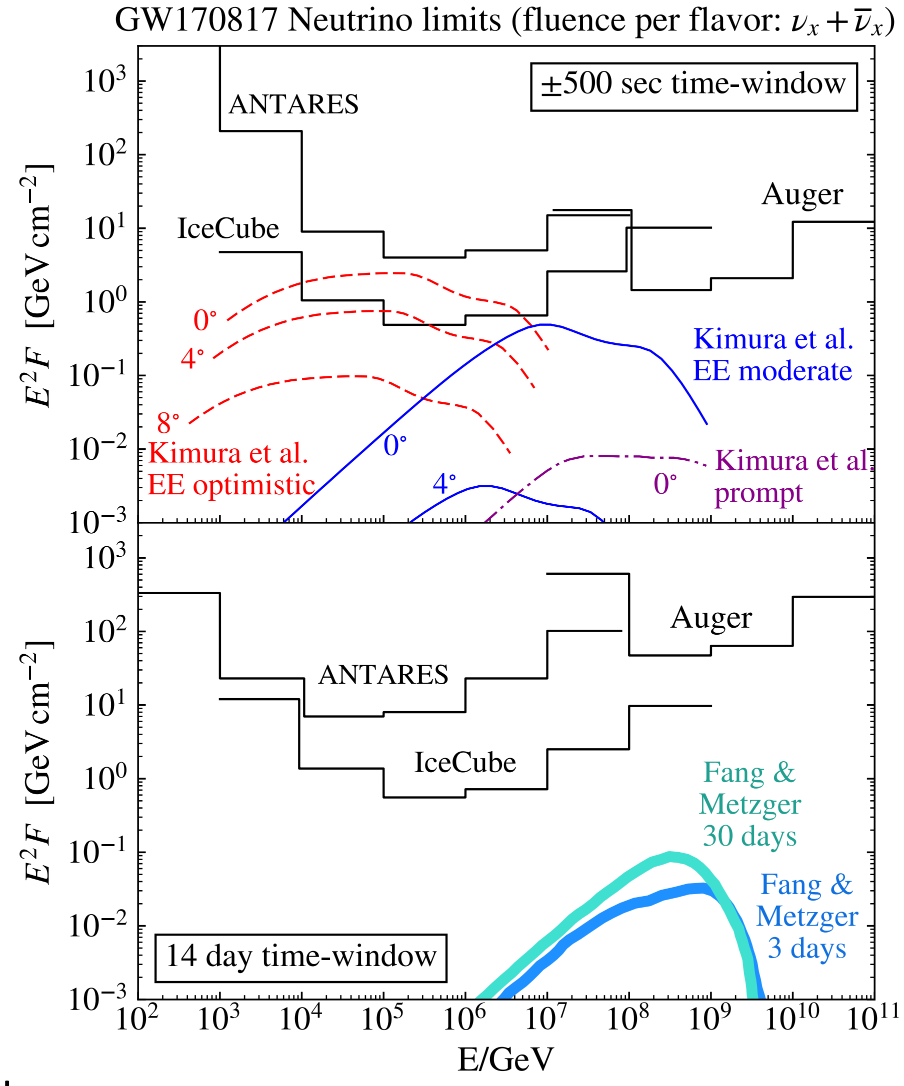
IceCube

Multi-messenger search:

- Rapid reaction is critical – joint event can immediately help localization.
- Required close collaboration of multiple observatories – logistics, data sharing, etc.
- Participating observatories: ANTARES, IceCube, Pierre Auger.

Search for high-energy neutrinos

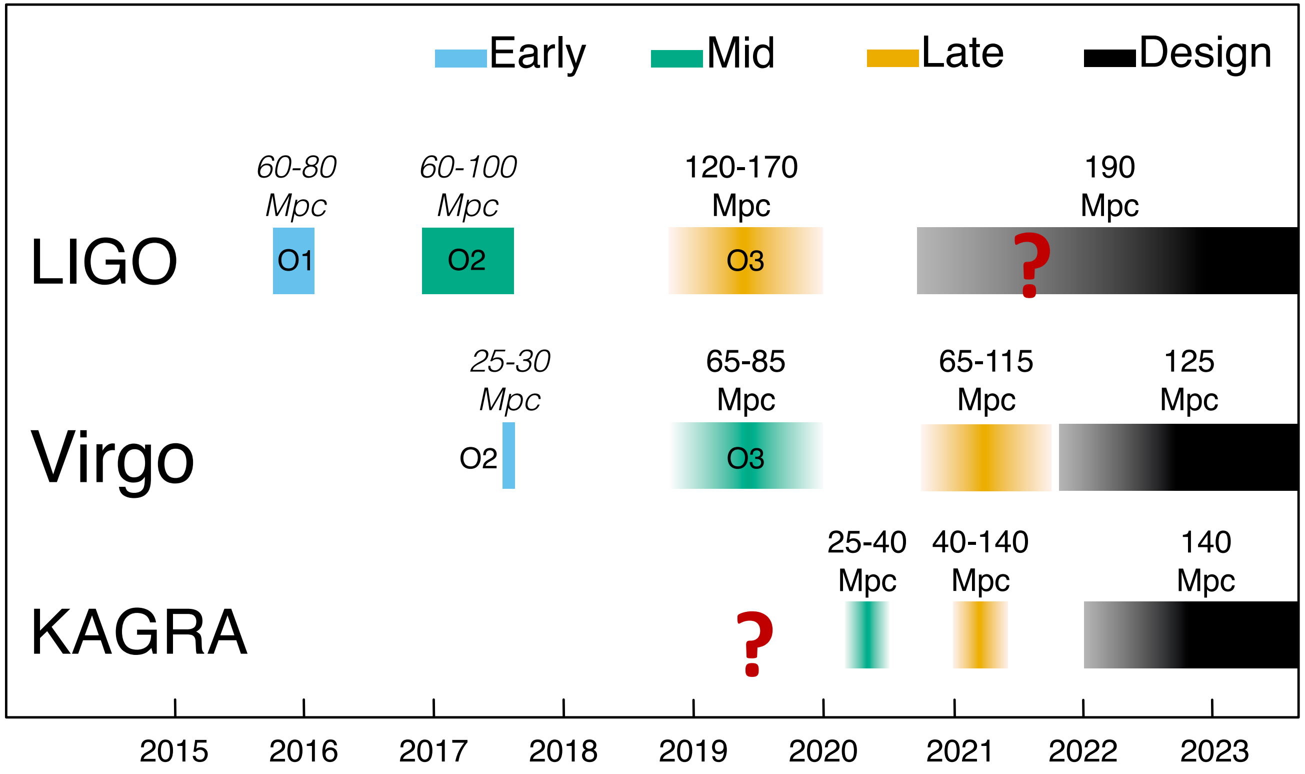


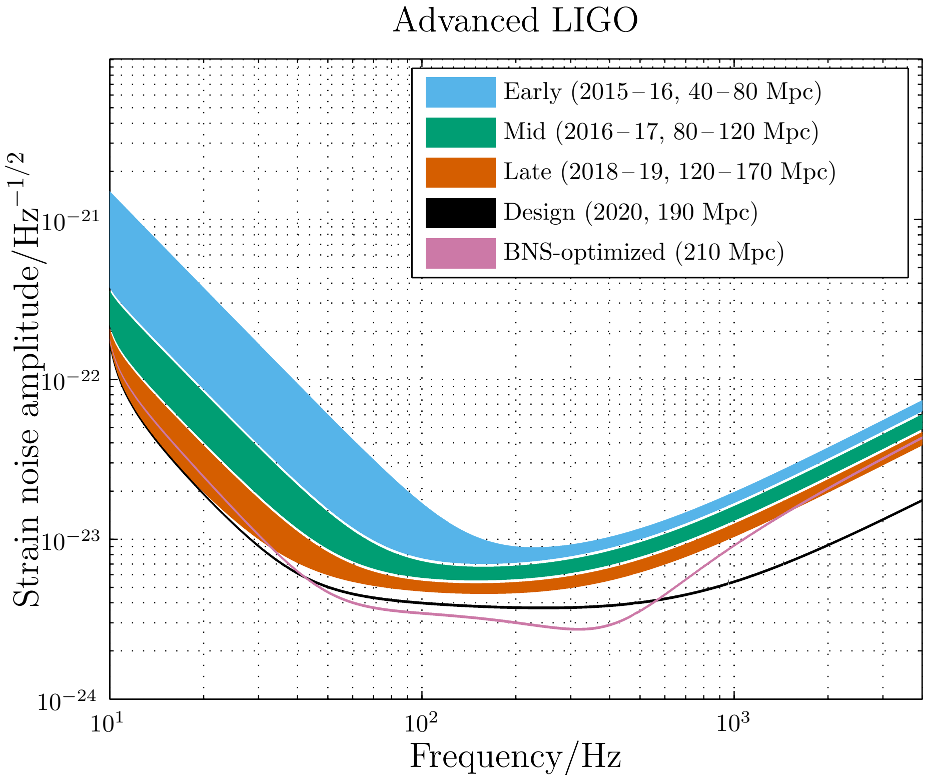


- Search within 1000 s and 2-week time windows (model motivated).
- Complementary sensitivity from the three detectors.
- No significant coincident detection.
- On-axis emission could have produced detectable emission in some models.

ANTARES, IceCube, Auger, LIGO, Virgo 2017

sensitivity timeline





	LIGO		Virgo		KAGRA	
	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc	BNS range/Mpc	BBH range/Mpc
Early	40 – 80	415 – 775	20 – 65	220 – 615	8 – 25	80 – 250
Mid	80 – 120	775 – 1110	65 – 85	615 – 790	25 – 40	250 – 405
Late	120 – 170	1110 – 1490	65 – 115	610 – 1030	40 – 140	405 – 1270
Design	190	1640	125	1130	140	1270

KAGRA, LIGO, Virgo 2017

- Improving detectors
- Increasing observation time
- More detectors → better localization

Summary

GW170817 / GRB170817

- Successful multi-messenger campaign.
- Several surprises (GRB structure, off axis, ...).
- Still observable afterglow.
- Many unknowns. analysis still ongoing.

Gravitational-wave observations:

✓ O3 will commence early 2019

✓ Improved sensitivity

✓ Should expect multiple BNS mergers!

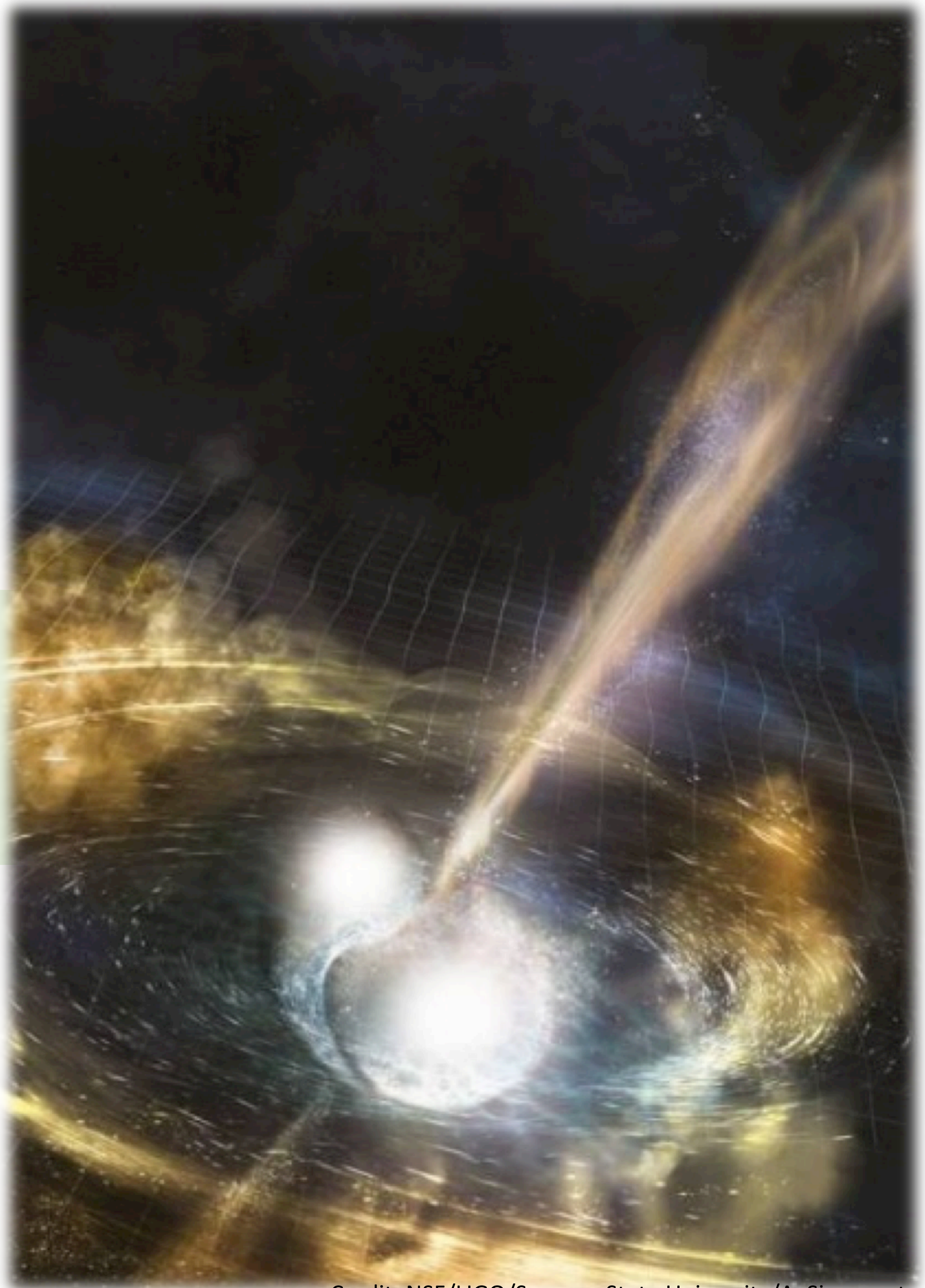
Road ahead:

✓ Discoveries at rates challenging to follow-up/analyze.

✓ Will need to interpret an ensemble of observations

✓ Neutrino observations will help with:

  - quick identification of source direction
  - Interpretation of outflow properties.



Credit: NSF/LIGO/Sonoma State University/A. Simonnet