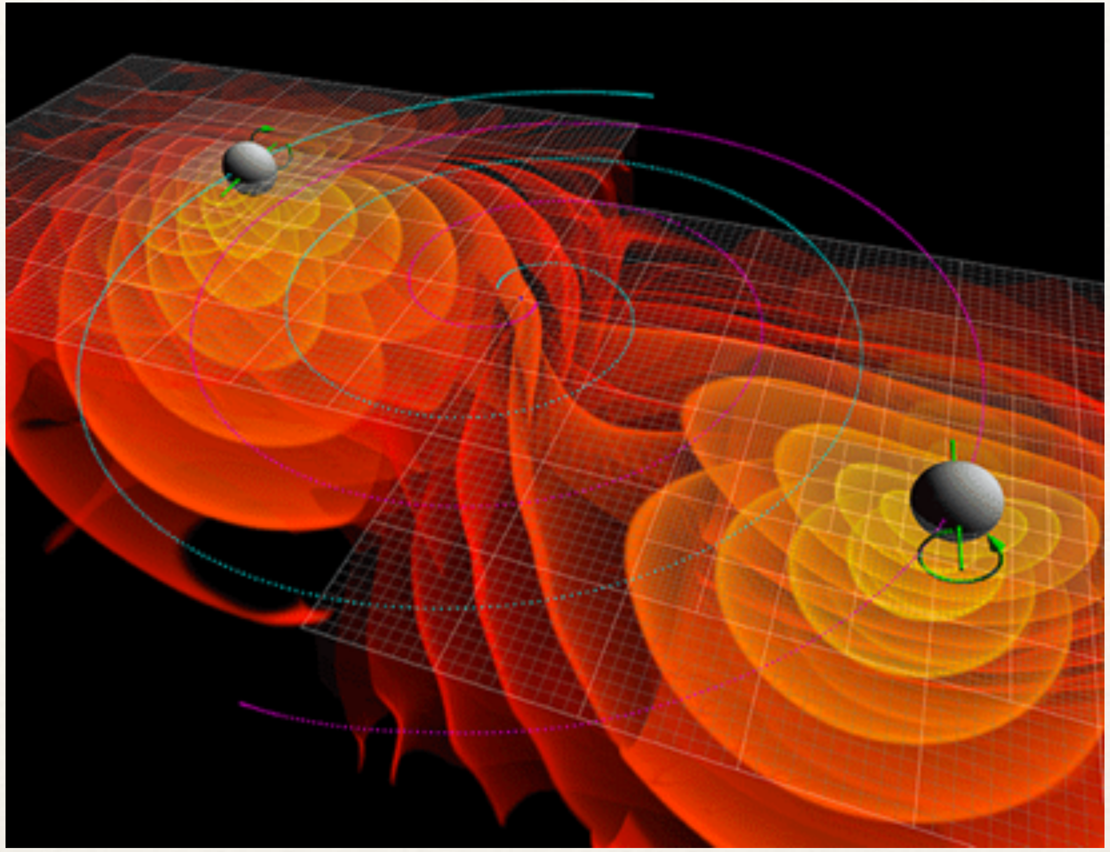
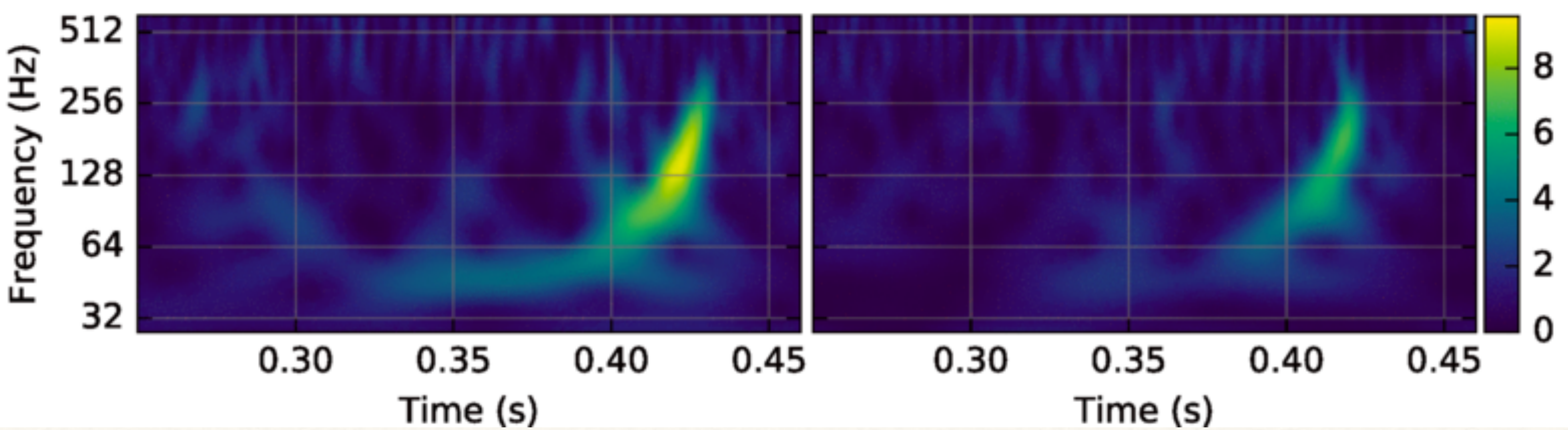


**C. Henze/
NASA Ames
Research
Centre**

Gravitational wave astronomy

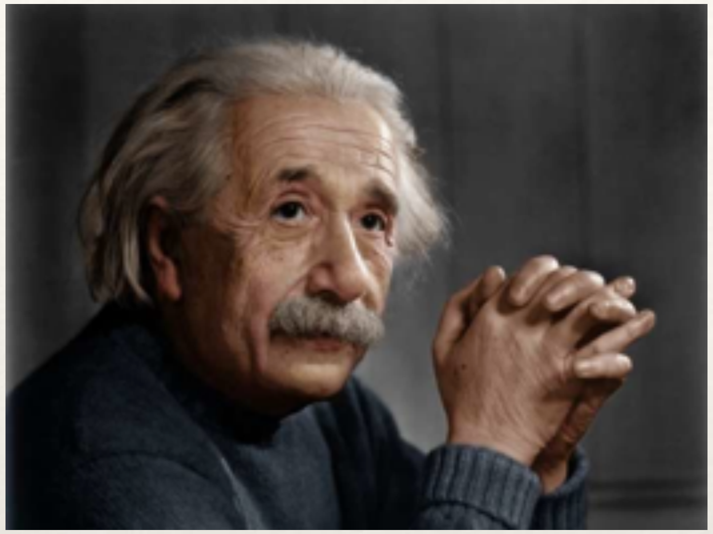
Ian Harry for the LIGO Scientific Collaboration

Max Planck Institute for Gravitational Physics
Potsdam, Germany

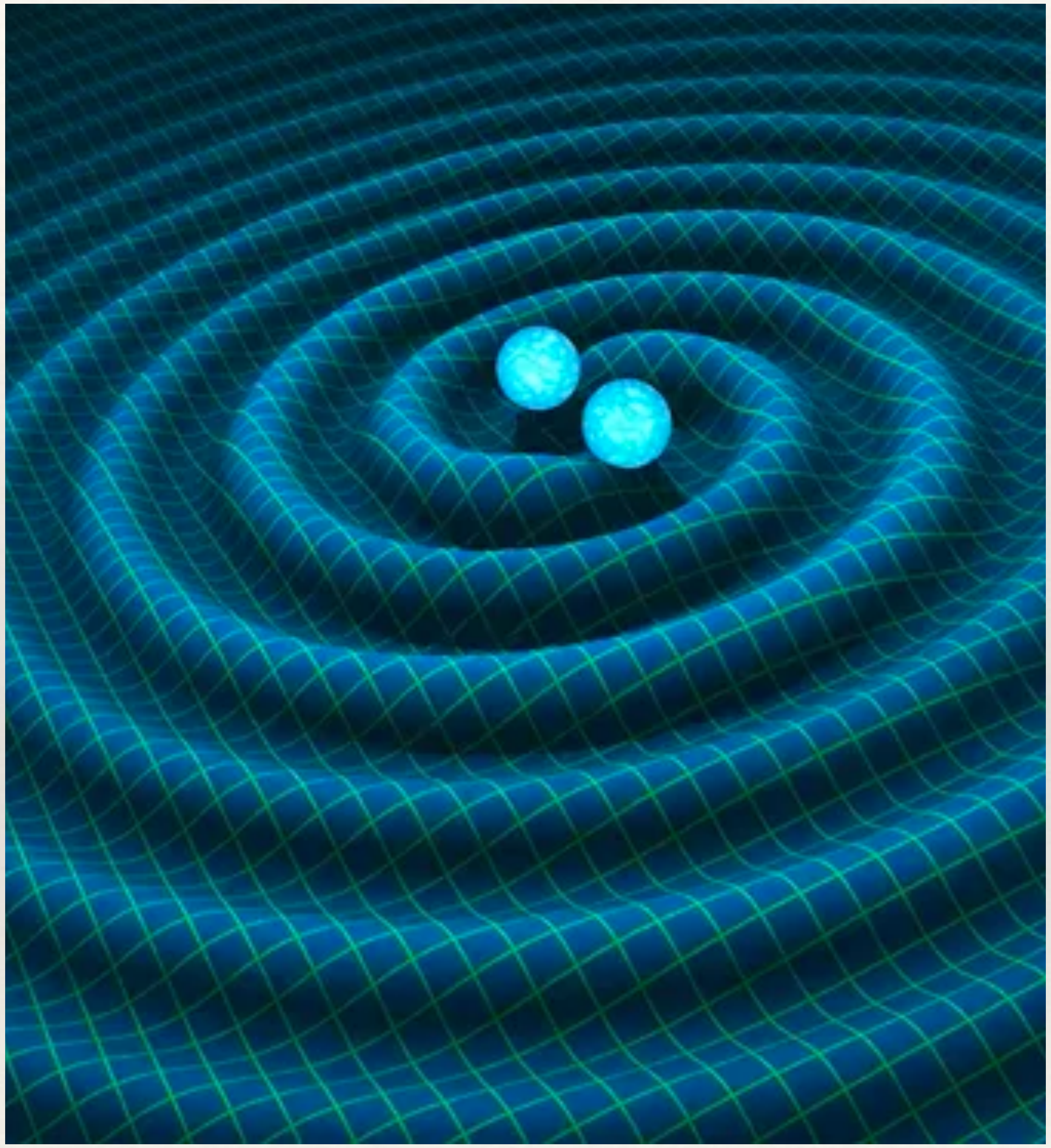


Introduction

Gravitational waves

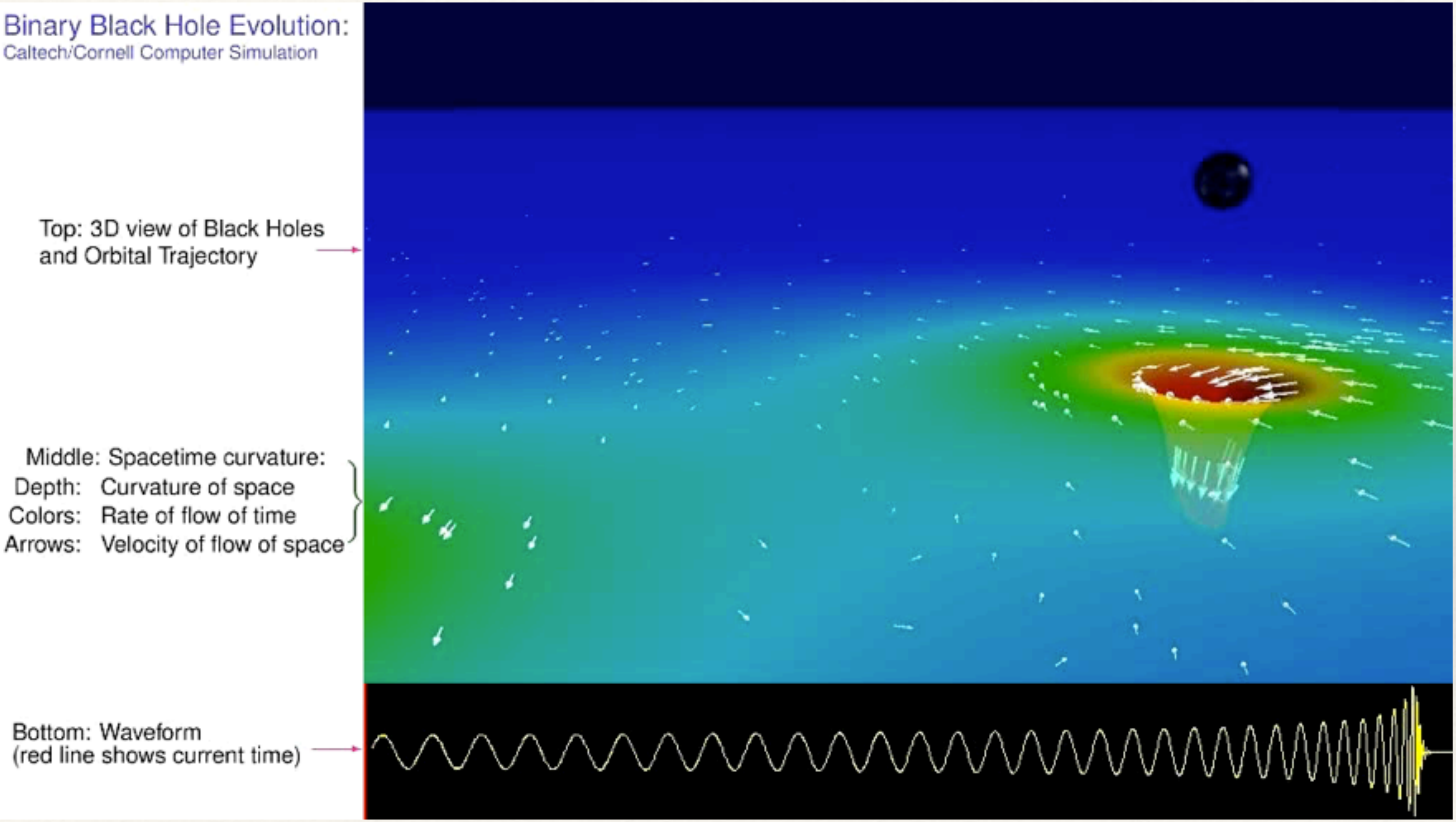


- A new prediction of general relativity, not present in Newtonian physics!
- Wave-like fluctuations in space-time, which propagate at the speed of light
- Emitted by accelerating masses with spherical asymmetry.



Credit: NASA

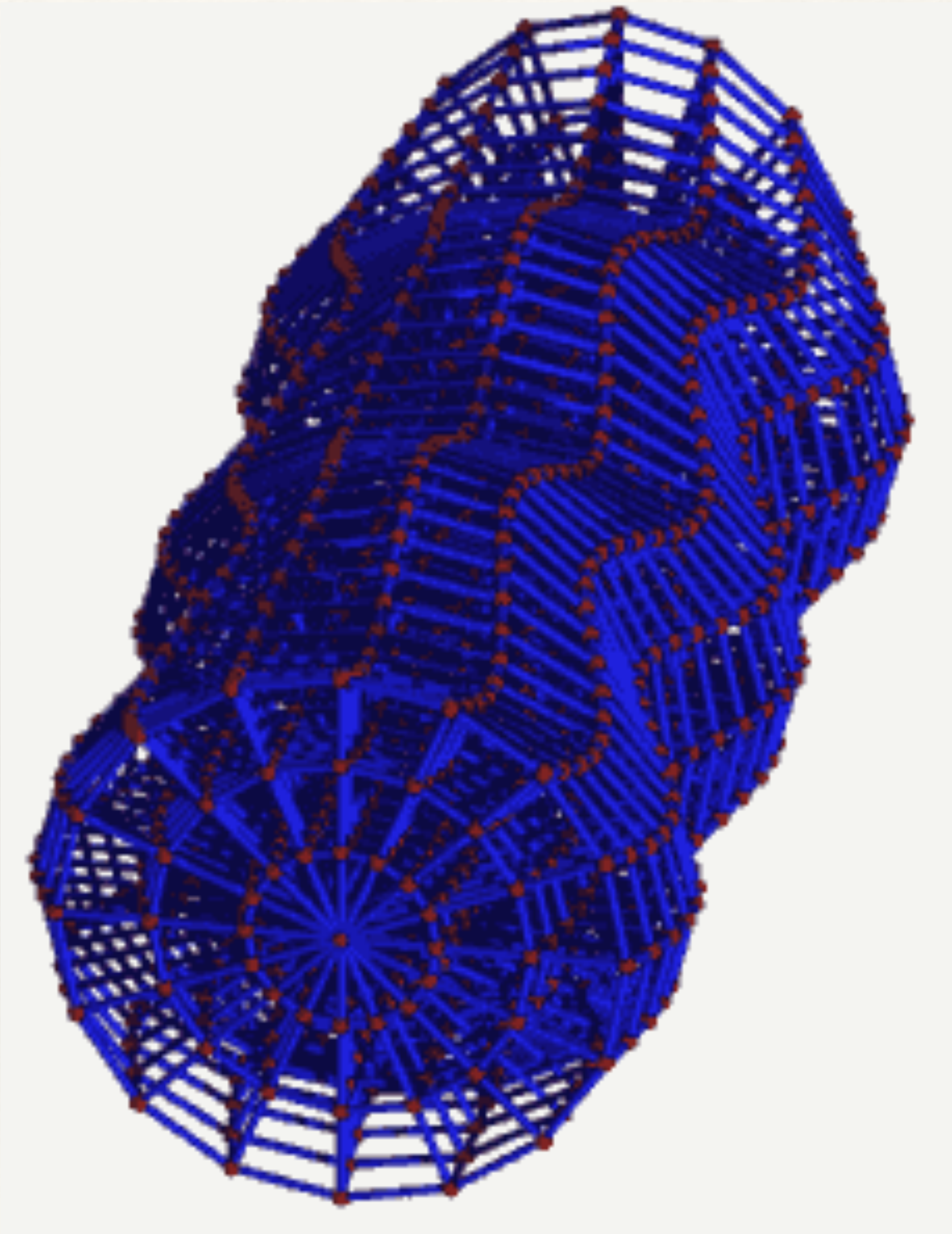
Observable gravitational wave sources



Simulation courtesy of the Simulating eXtreme Spacetimes (SXS) collaboration

Effect of a gravitational-wave passage

- All particles affected by gravitational-wave passage
- Passing wave can cause a deformation in a ring of particles
- However, interaction with matter is *extremely* weak
- Observed signals have a strain of 10^{-21}.
- Equivalent to measuring the distance to the nearest star to an accuracy smaller than the width of a human hair



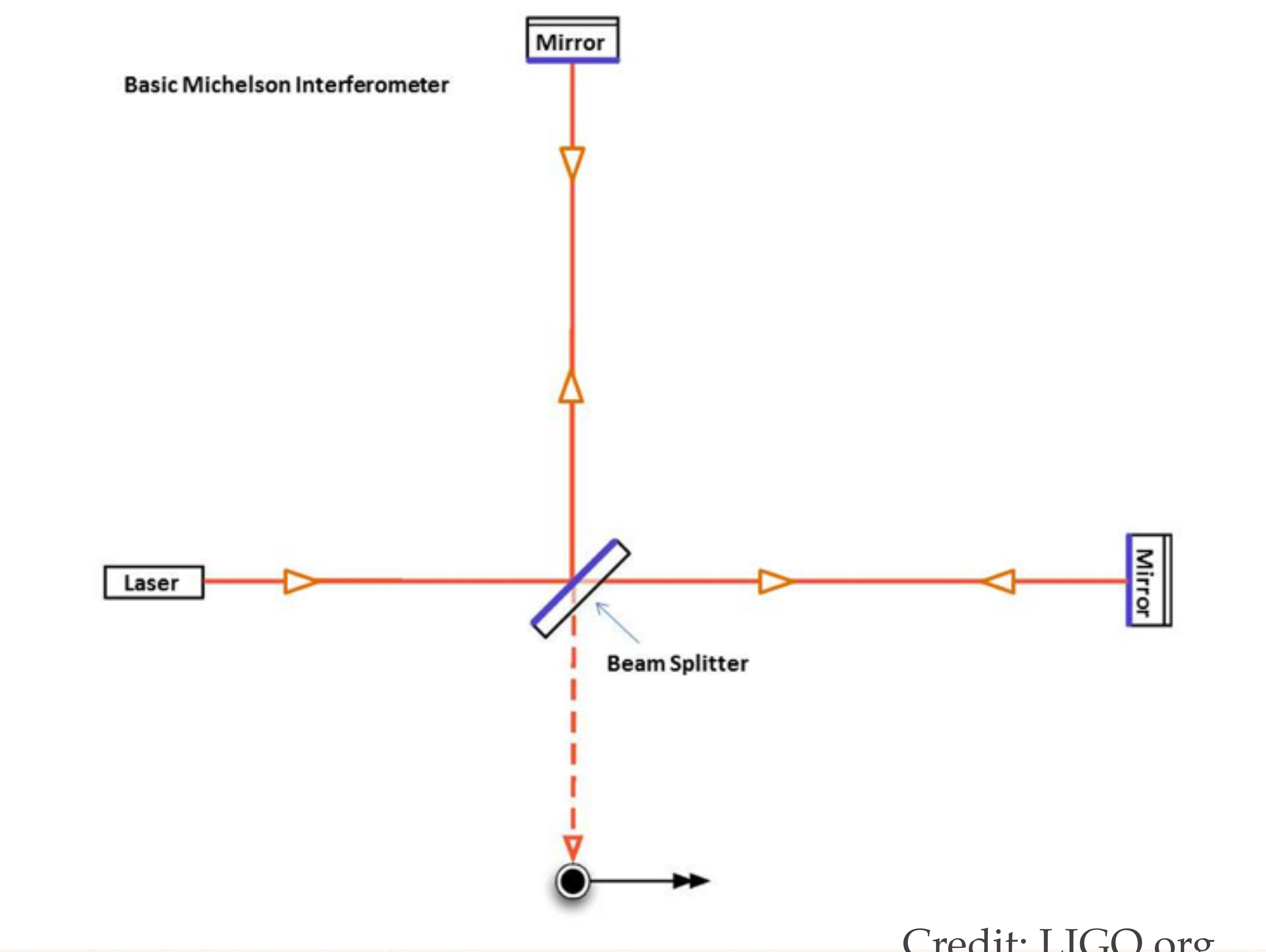
Wikimedia commons

Observing gravitational-waves

LIGO Hanford, WA

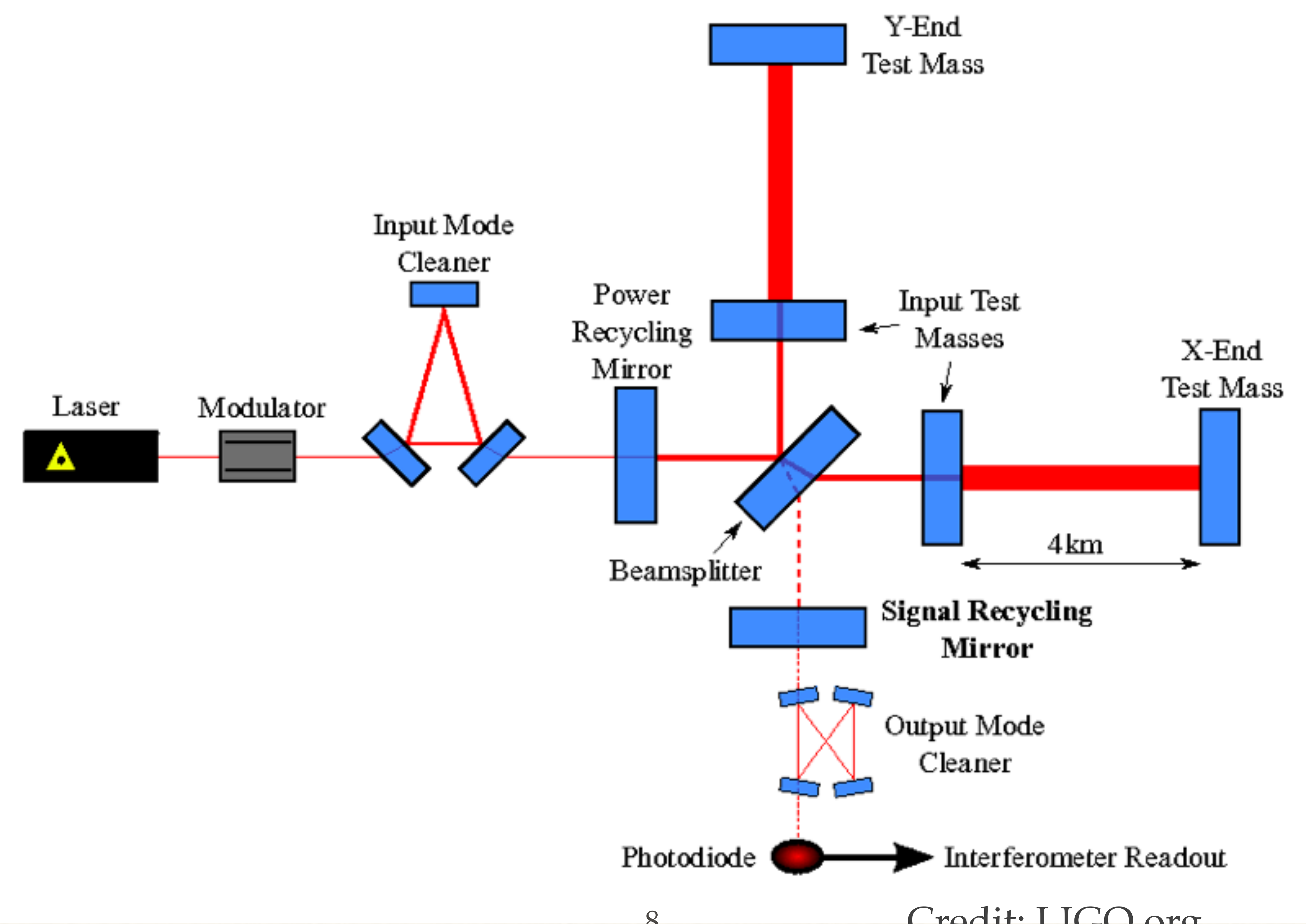
LIGO Livingston, LA

Basic Michelson Interferometer



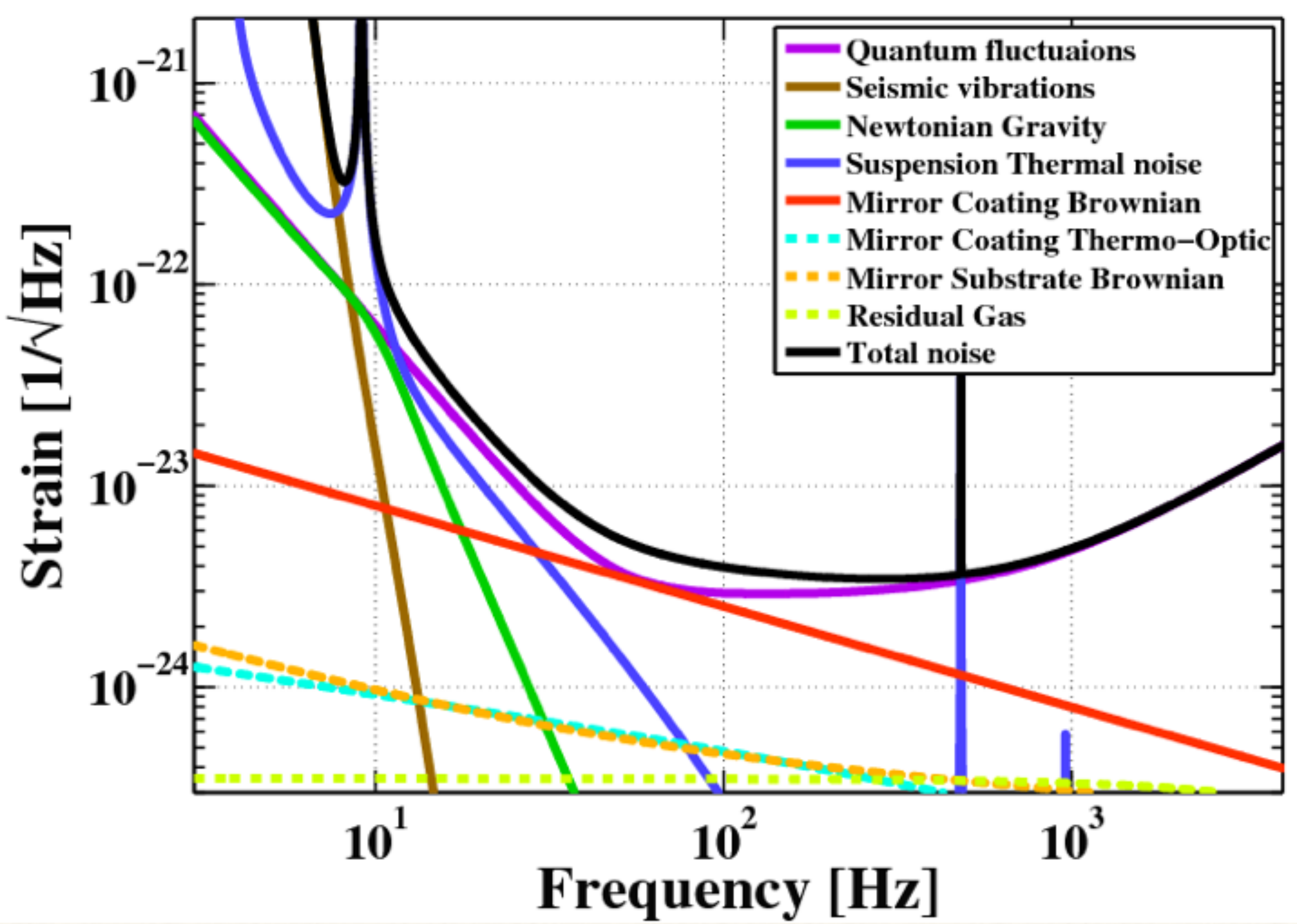
Credit: LIGO.org

Advanced LIGO Optical Layout



Credit: LIGO.org

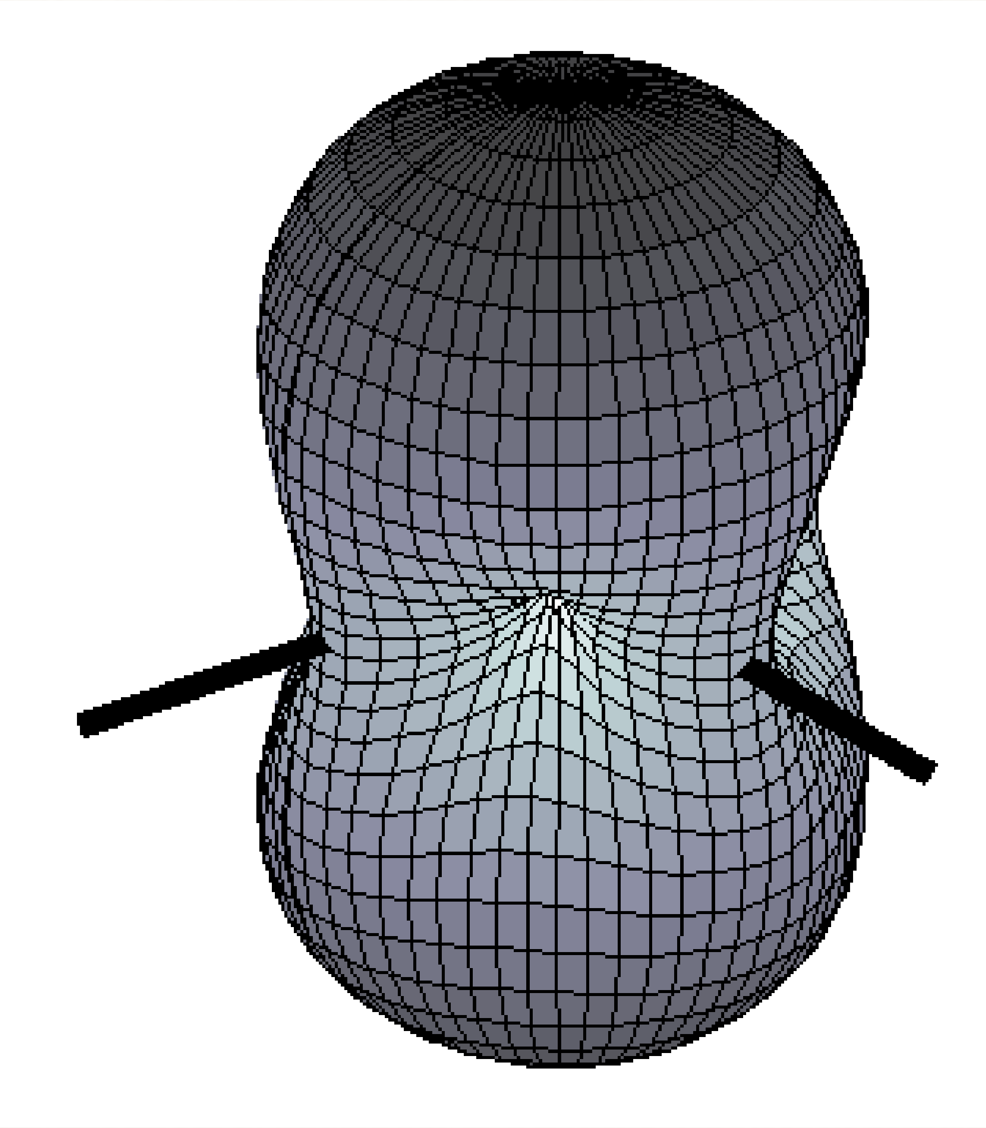
Amplitude Spectral Density (sensitivity)



Adhikari Rev.Mod.Phys. 86 (2014) 121

Broad sky sensitivity

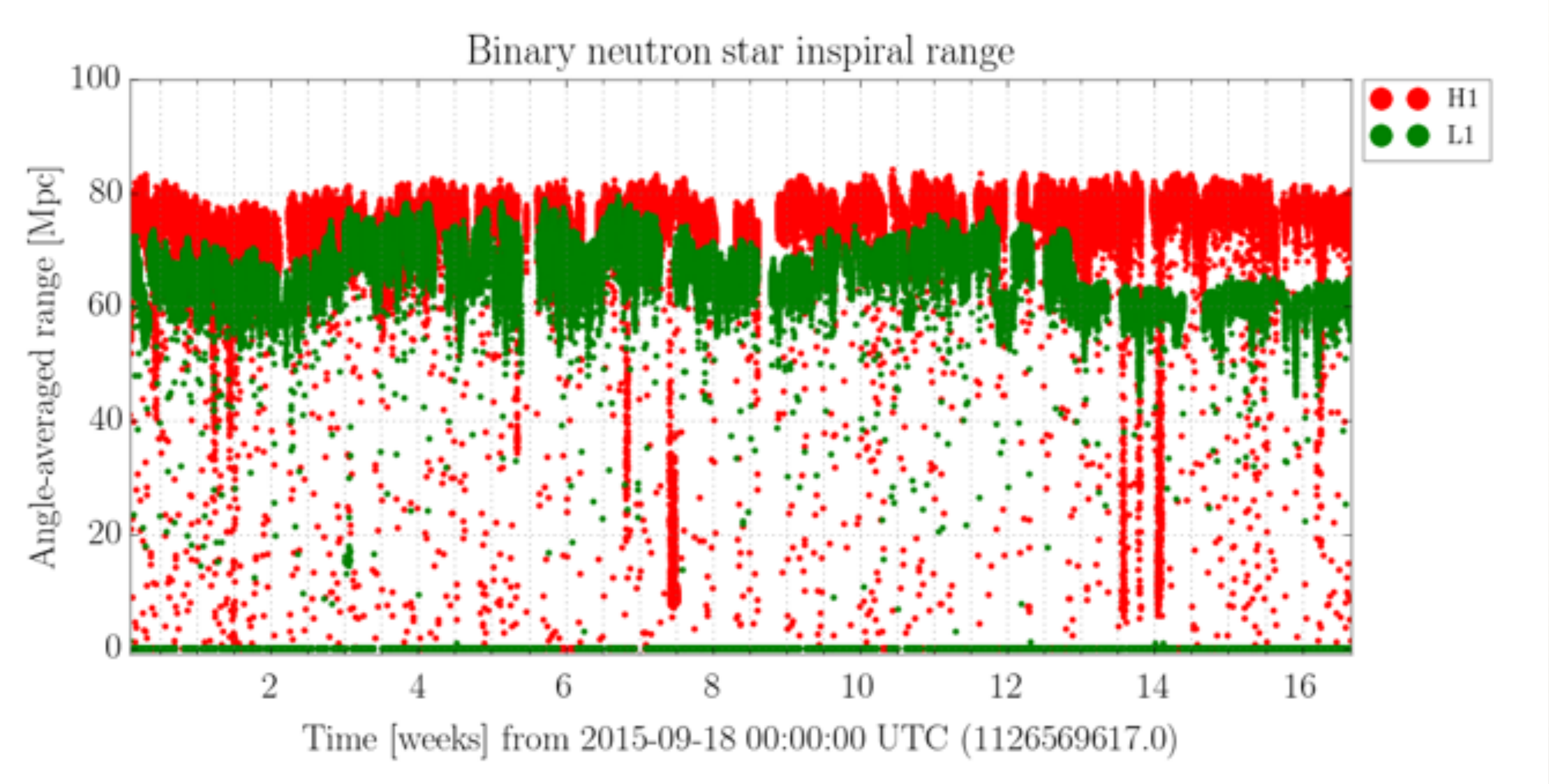
- Sensitivity to most points on the sky
- Best sensitivity to sources overhead (or underhead)
- But difficult to know where in the sky a source came from!



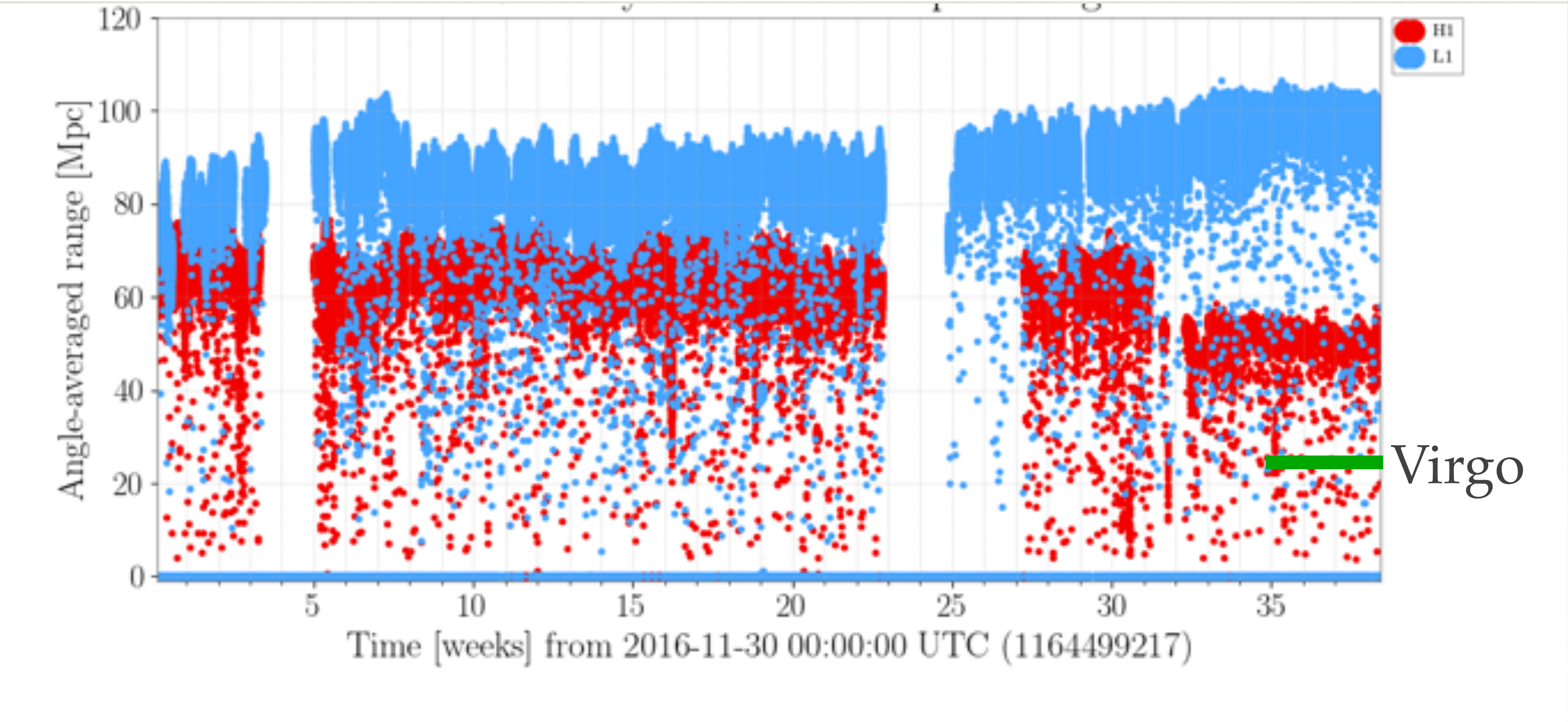
Rept.Prog.Phys. 72 (2009) 076901

A global network

Sensitivity over time



First observing run

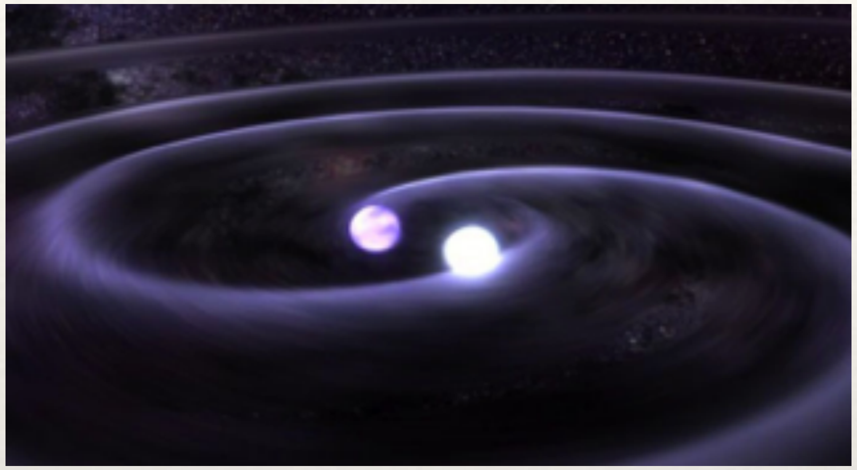


Second observing run

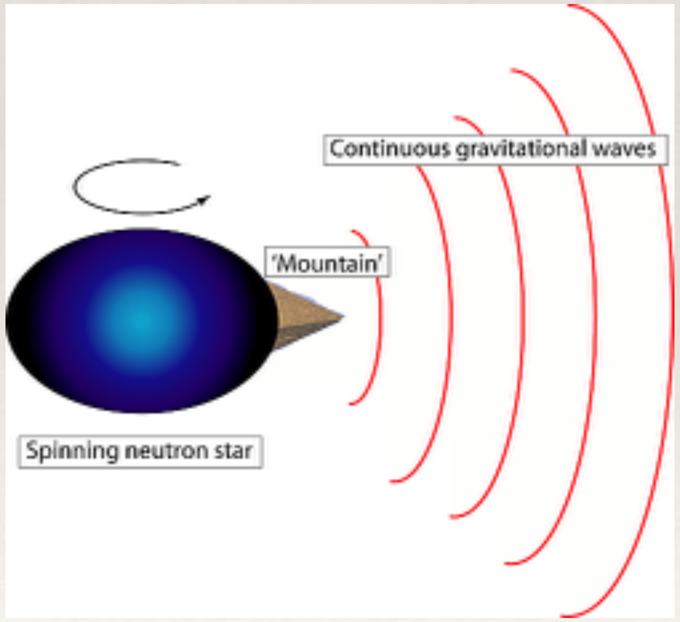
Gravitational-wave astronomy and the first observations

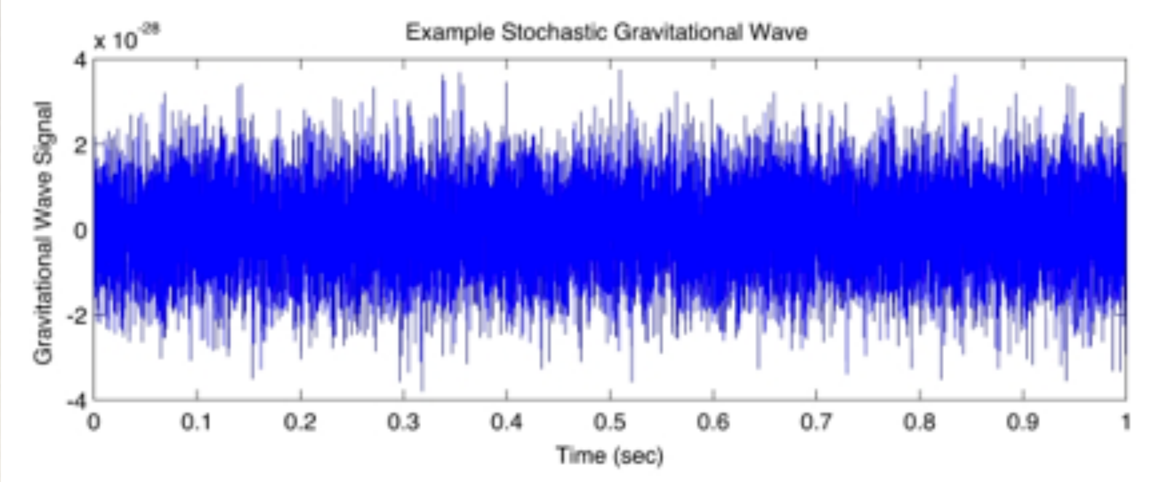
LIGO/Virgo Science Targets

Short Duration



Long Duration

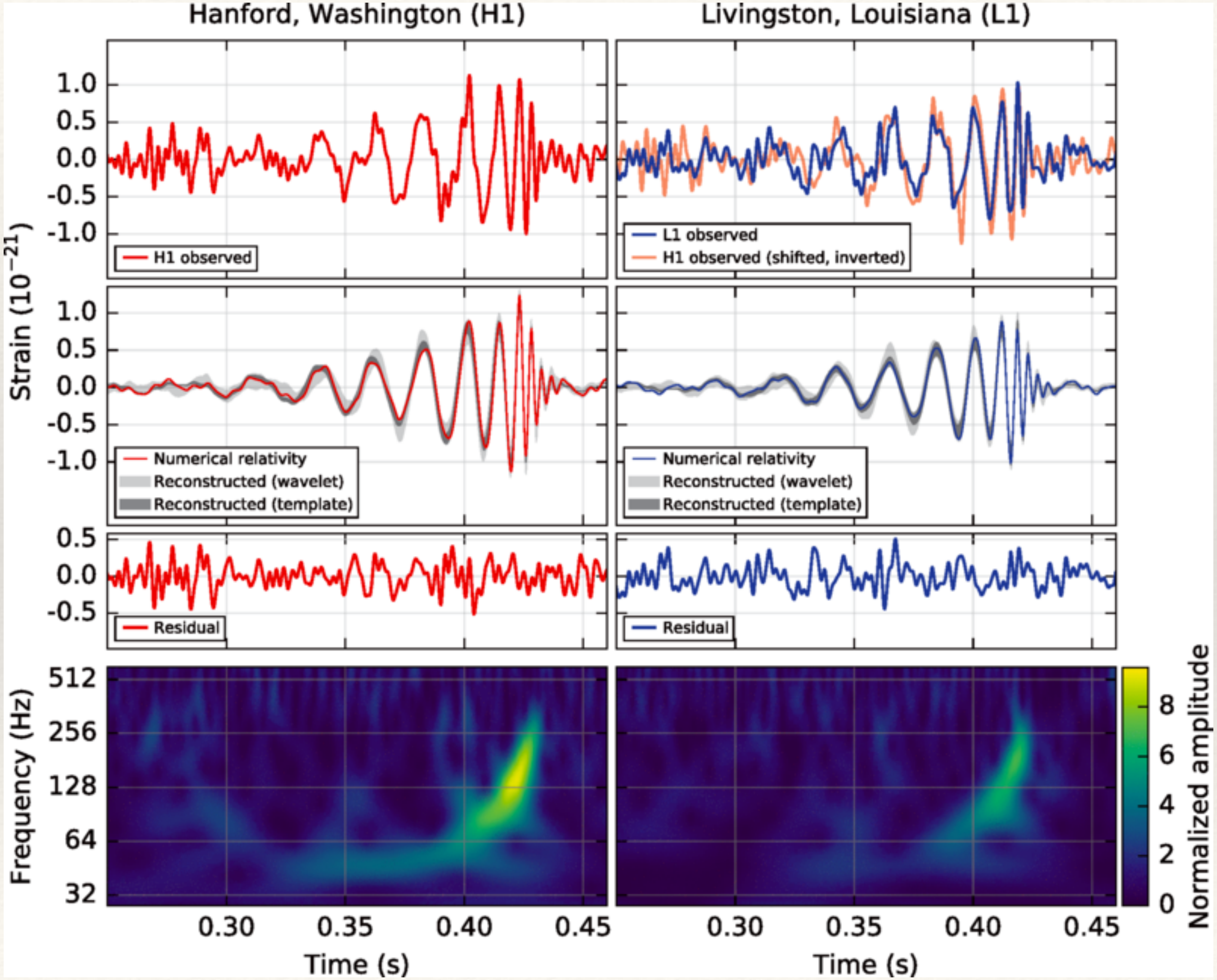




Well Modelled

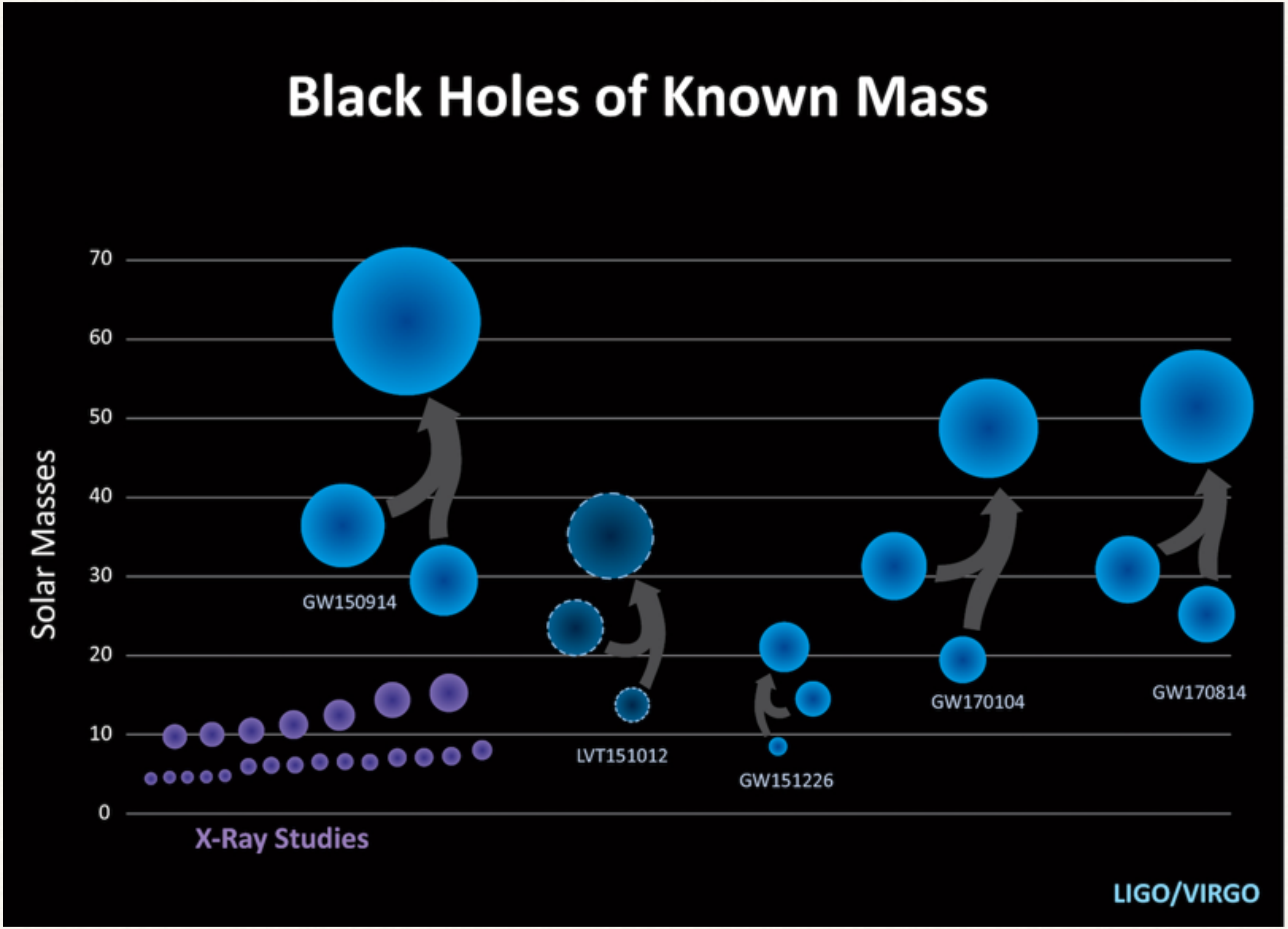
Not well modelled

GW150914



LIGO/Virgo PRL 116, 061102 (2016)

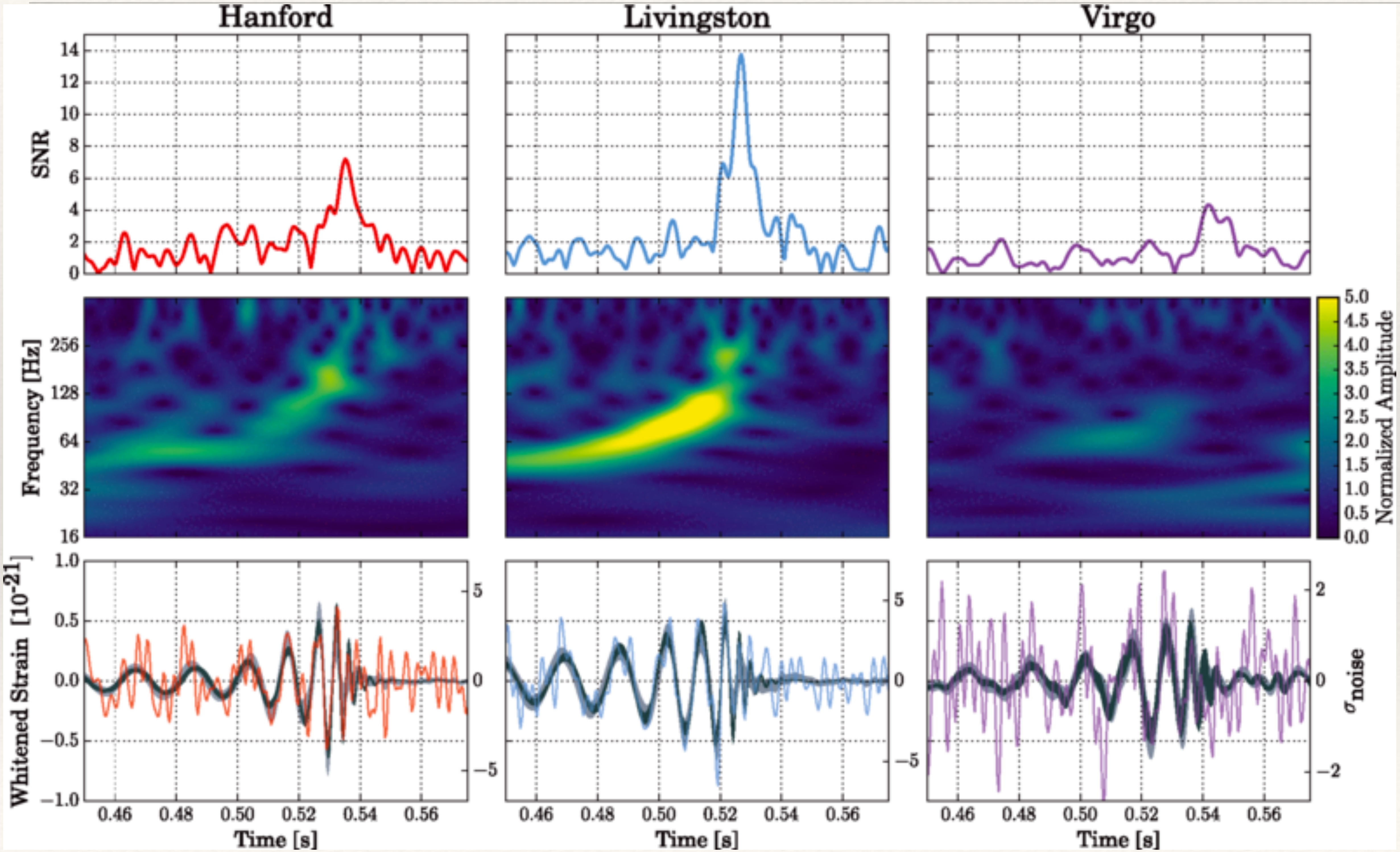
Currently 6 binary-black hole observations



We're still finalising analyses on O2, stand by for final results soon!

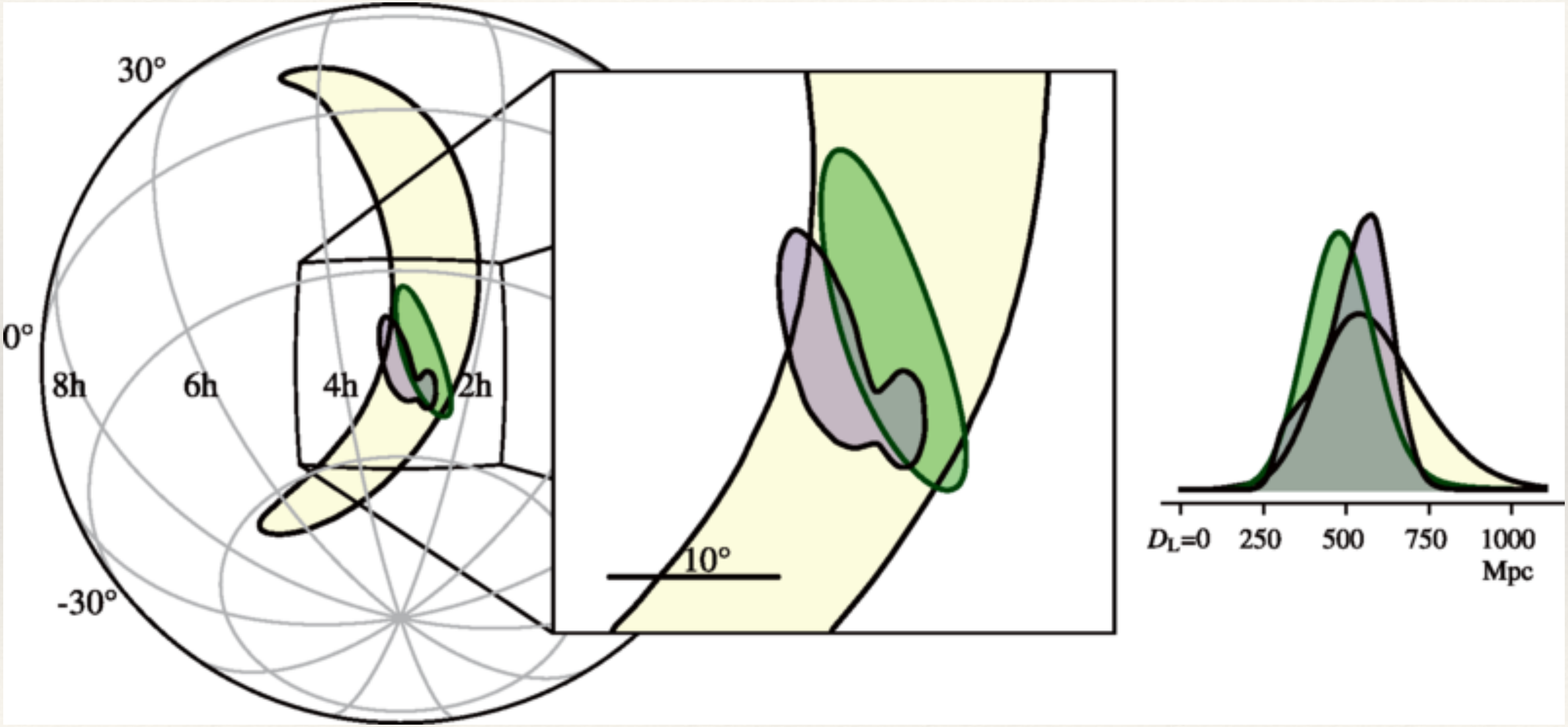
And GW170608, similar to GW151226

GW170814 - The first triple-coincident observation



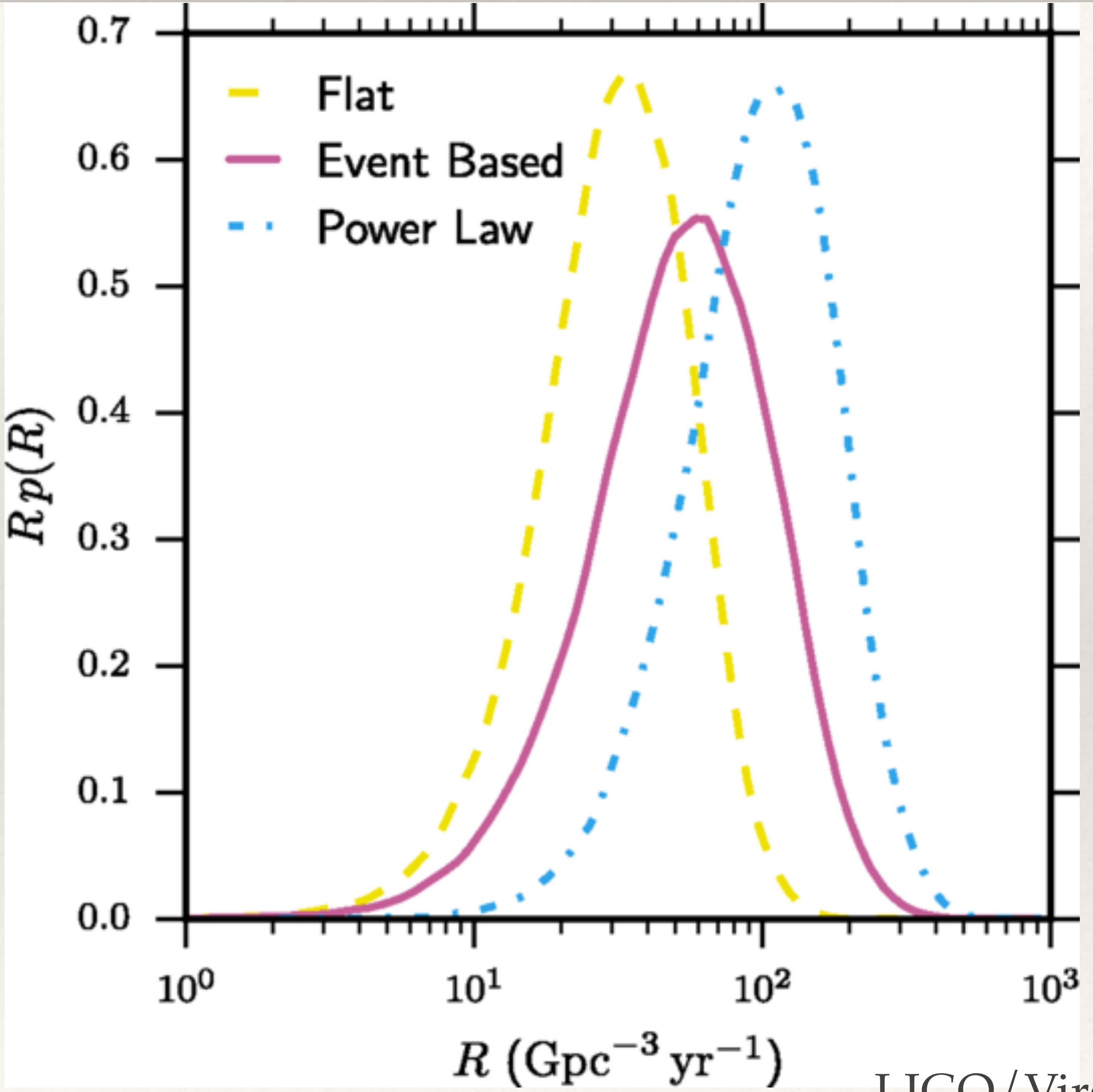
LIGO/Virgo PRL 119, 141101 (2017)

GW170814 - The first triple-coincident observation



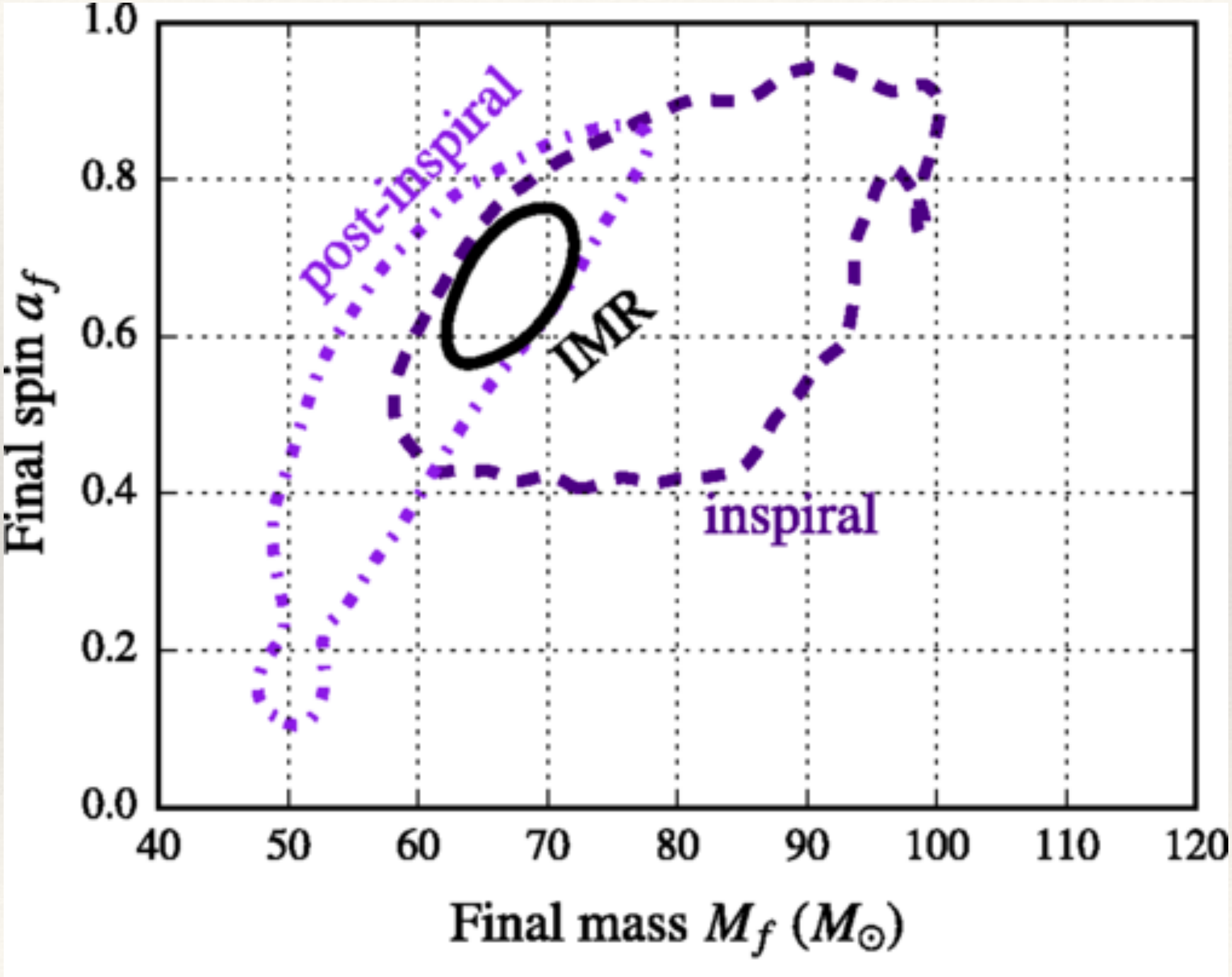
LIGO/Virgo PRL 119, 141101 (2017)

Updated rates of binary black hole mergers



LIGO/Virgo PRX 6, 041015 (2016)
LIGO/Virgo PRL 118, 221101 (2017)

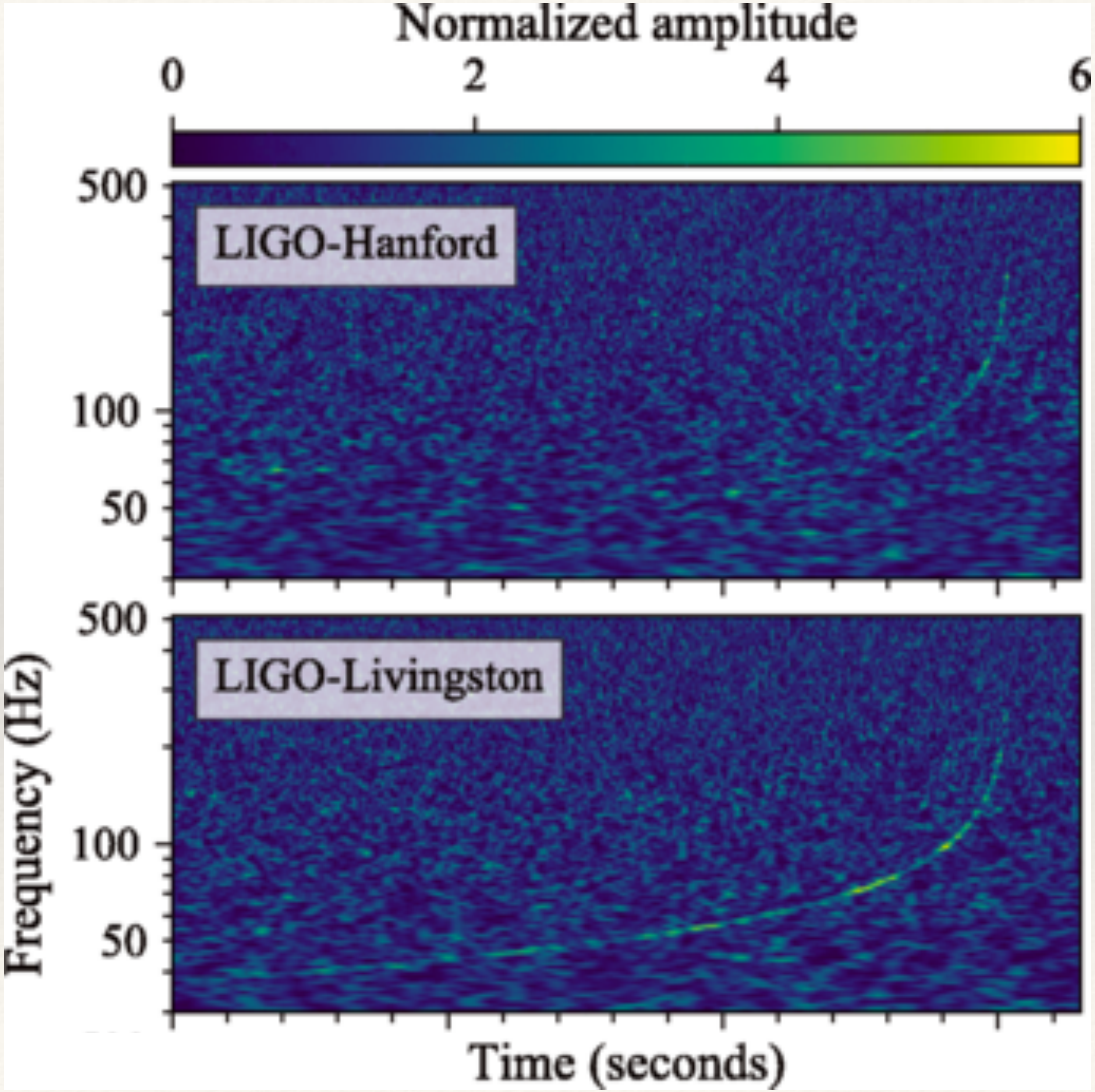
Testing the validity of GR



LIGO/Virgo PRL 116, 221101 (2016)

Multimessenger astronomy

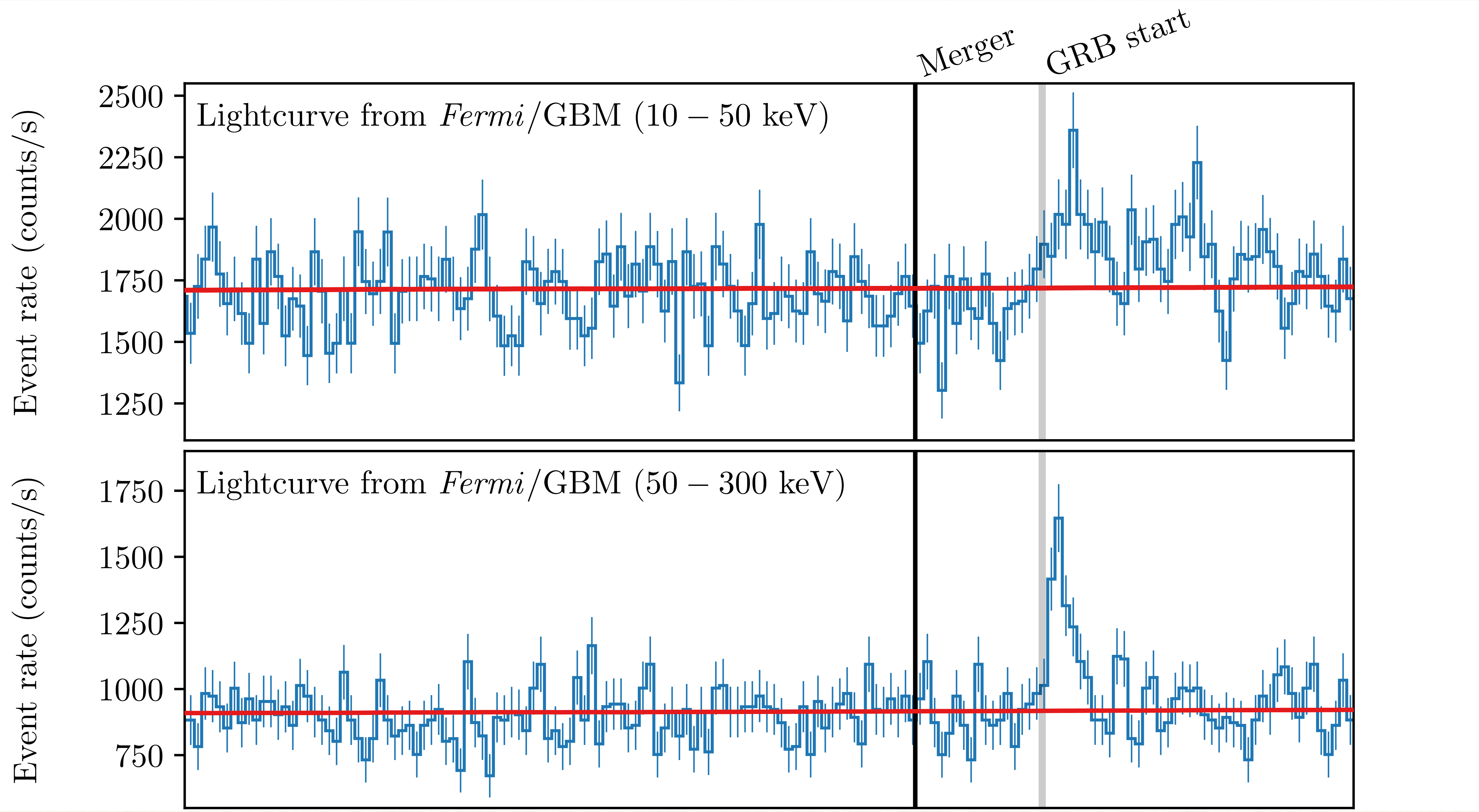
GW170817 - As seen by LIGO/Virgo



LIGO/Virgo PRL 119, 161101 (2017)

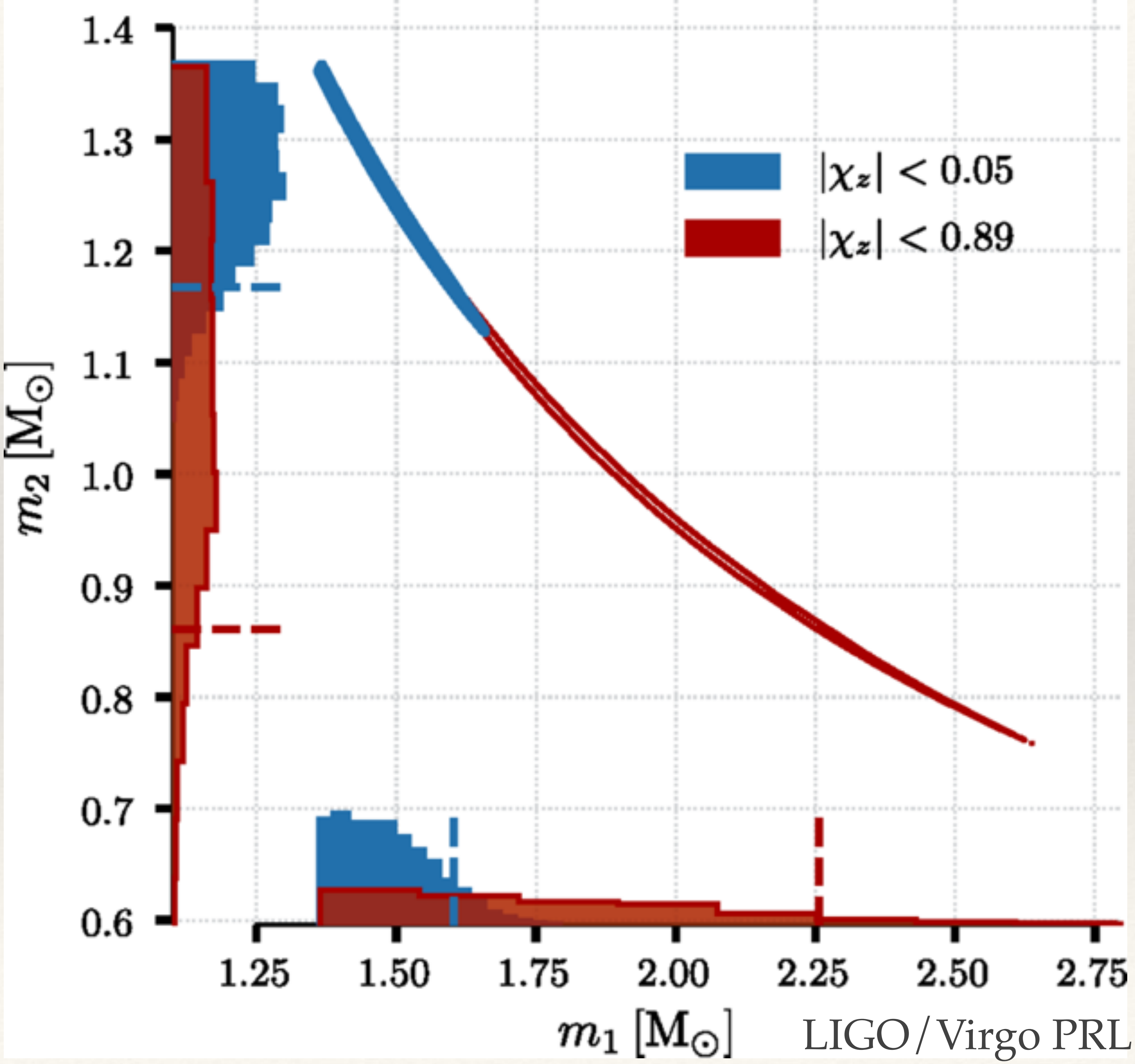
GW170817 - As seen by Fermi

Fermi Satellite: Gamma-ray burst observatory



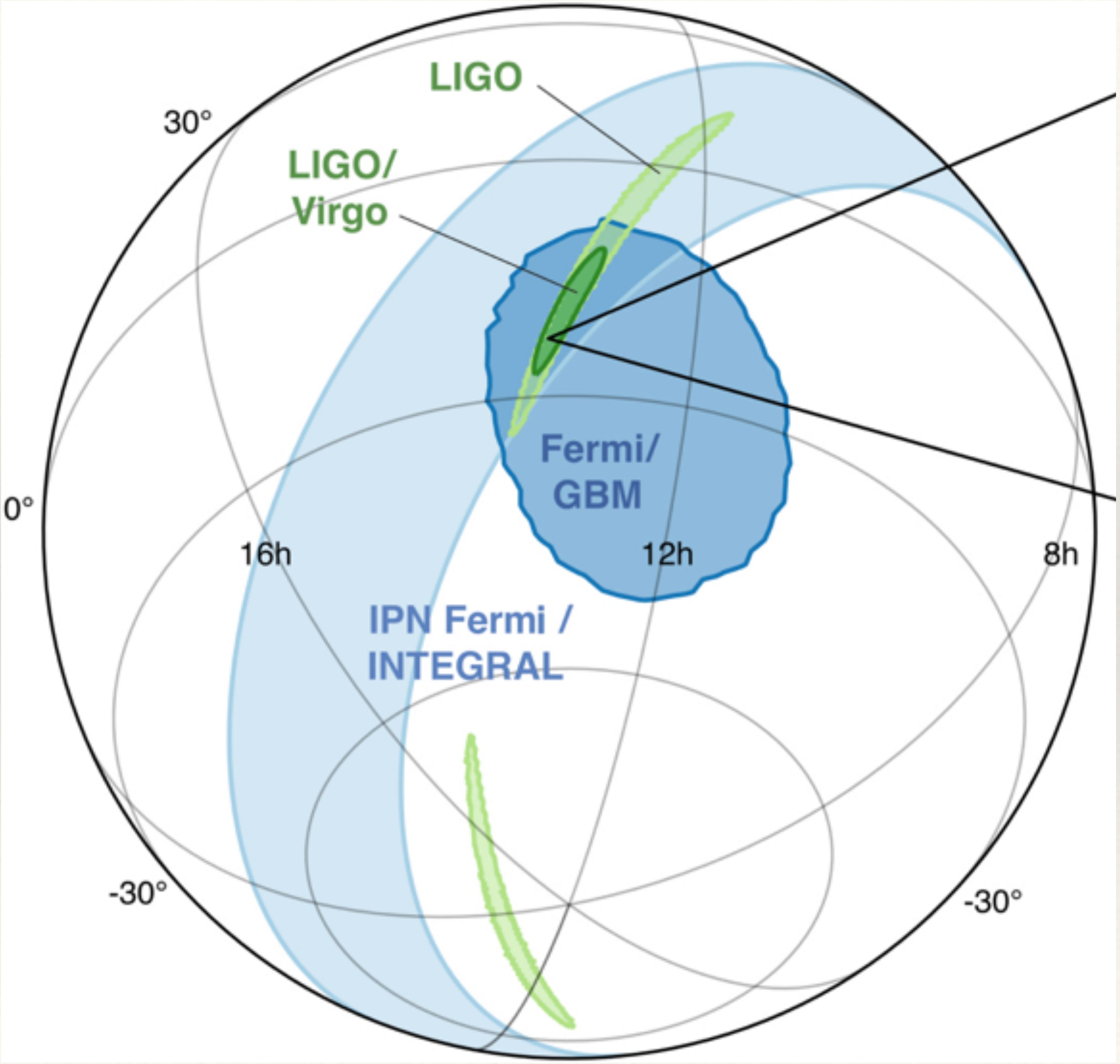
LIGO/Virgo/Fermi/INTEGRAL ApJL. 848, L13 (2017)

GW170817 - Mass estimation



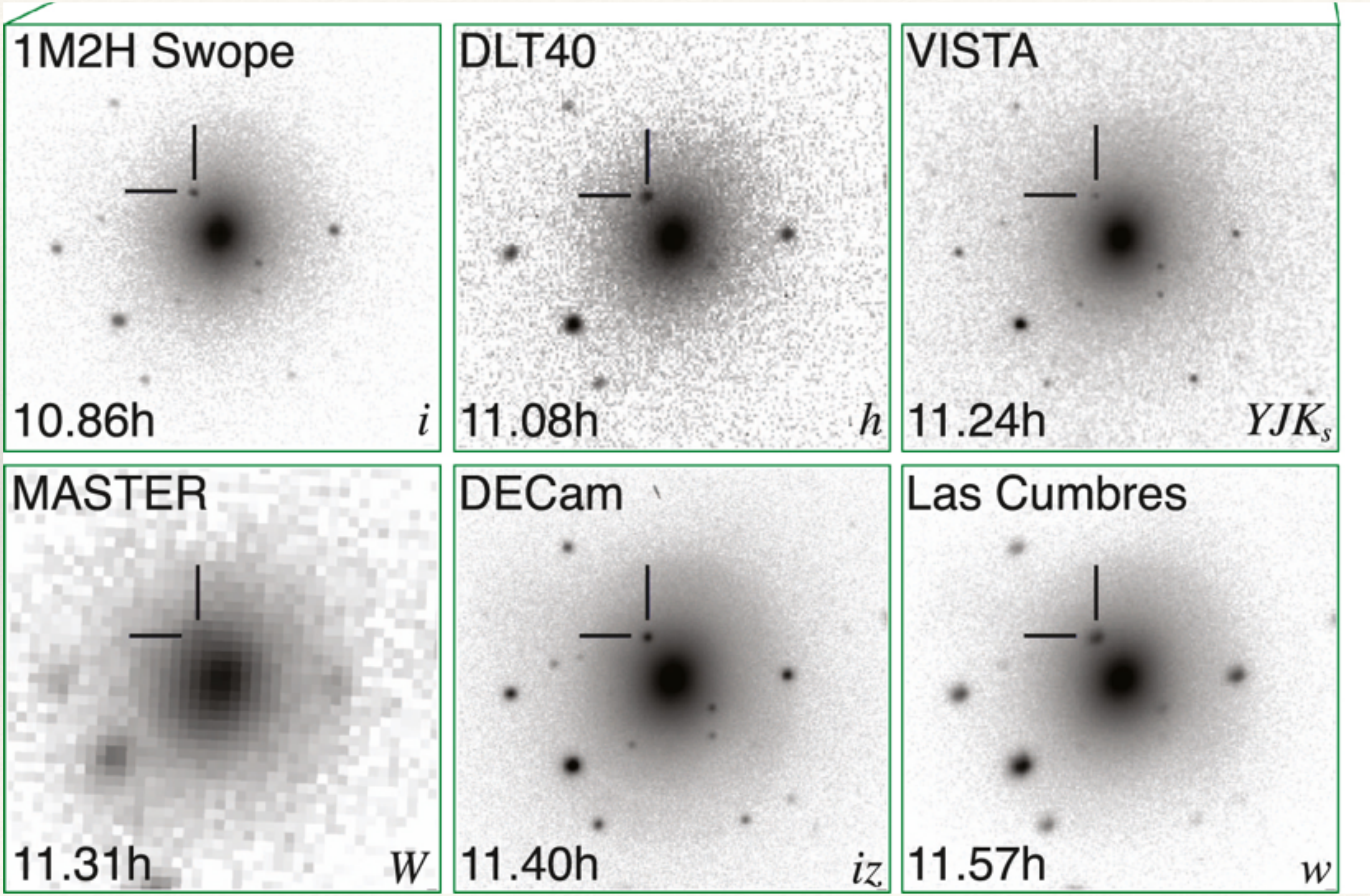
LIGO/Virgo PRL 119, 161101 (2017)

GW170817 - Locating the source



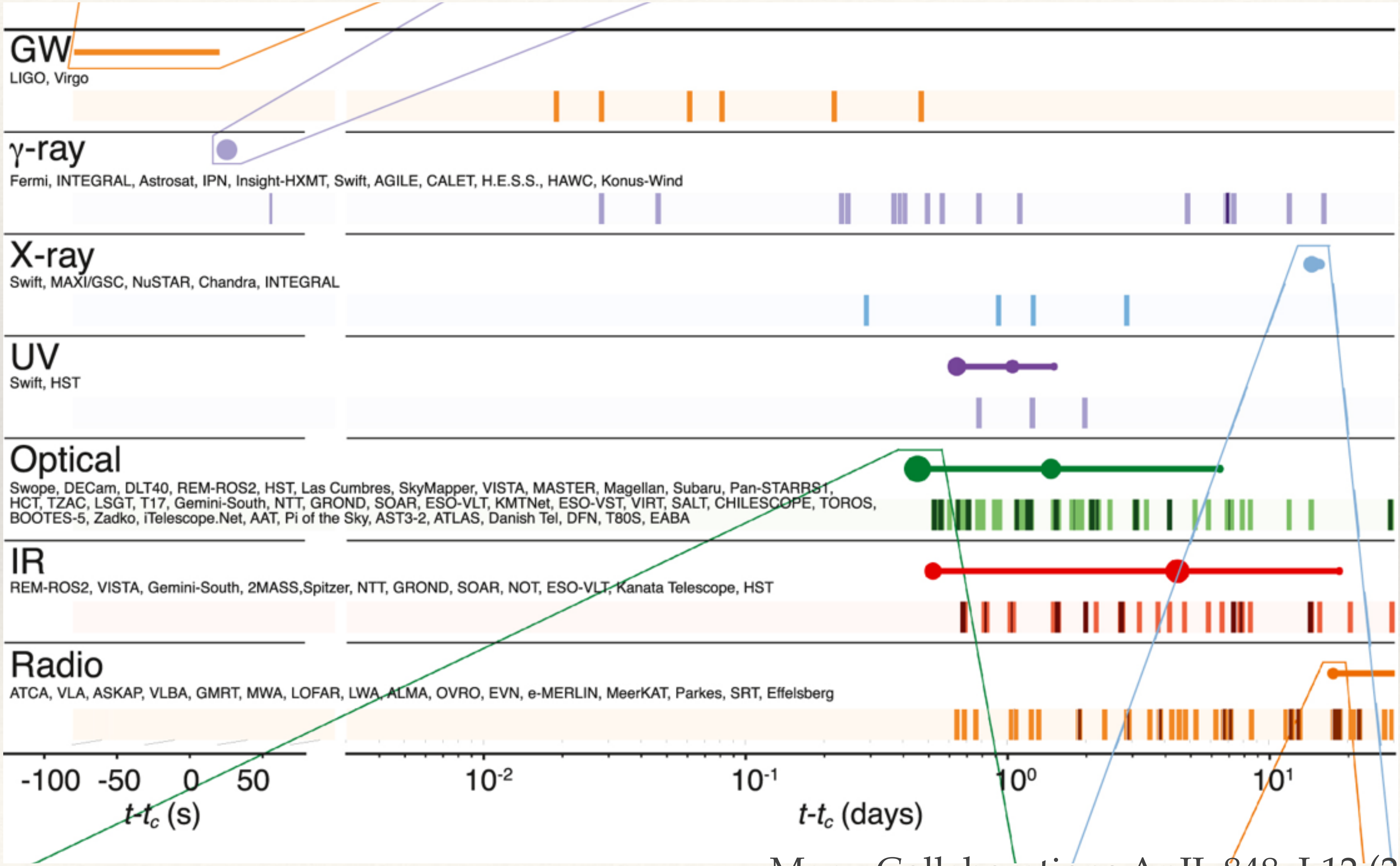
LIGO/Virgo/Fermi/INTEGRAL ApJL. 848, L13 (2017)

GW170817 - Optical counterpart



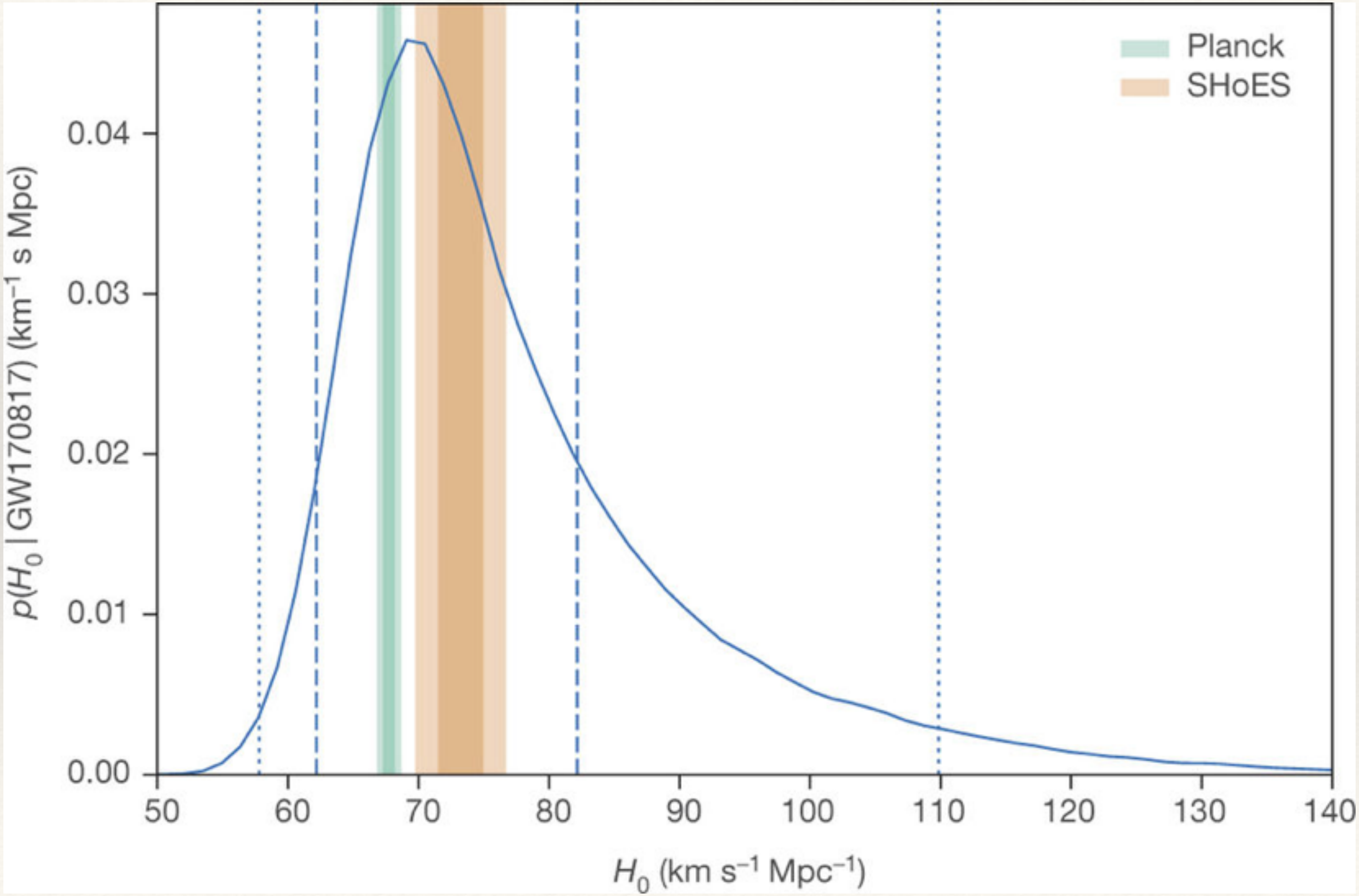
Many Collaborations ApJL 848, L12 (2017)

GW170817 - Multimessenger astronomy



Many Collaborations ApJL 848, L12 (2017)

GW170817 - Measuring Hubble's constant



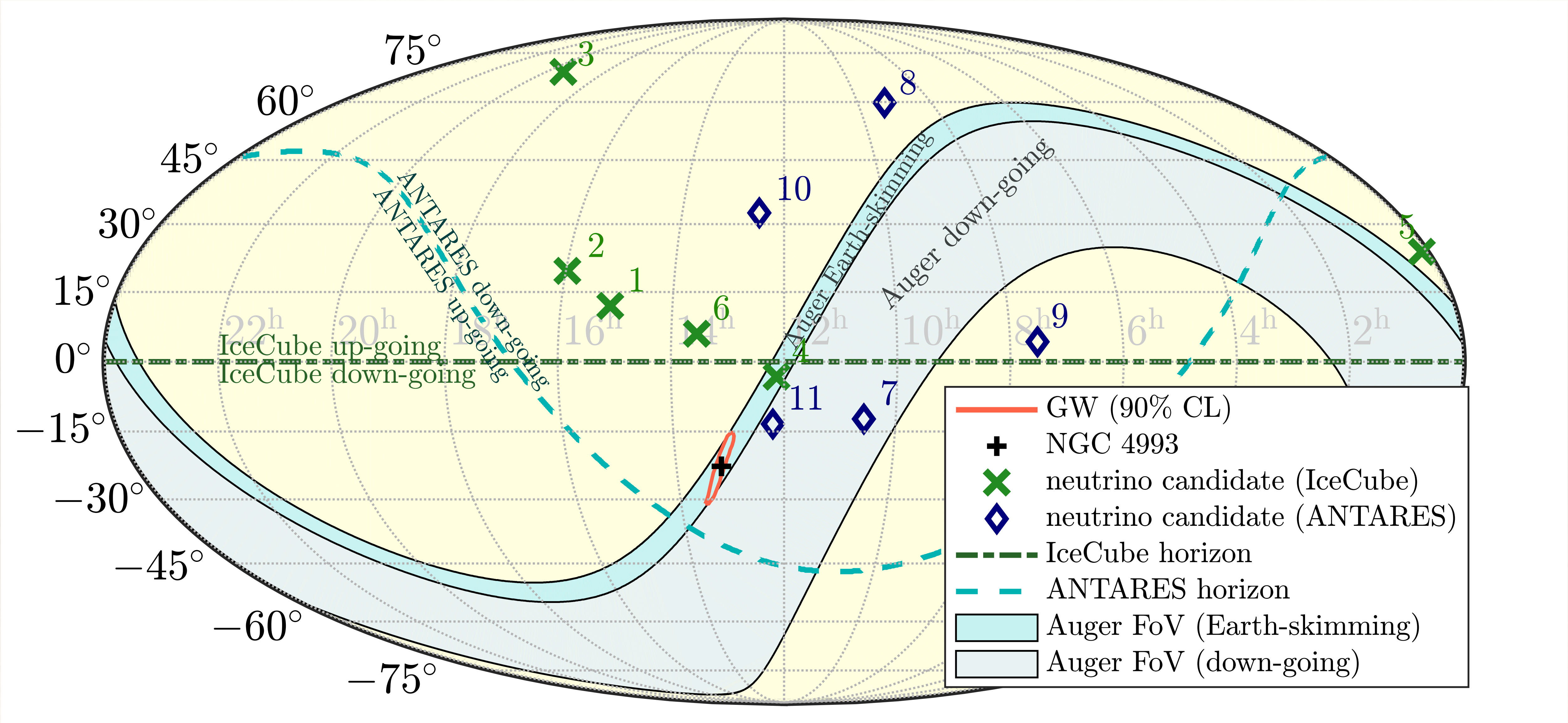
LIGO/Virgo Nature 551, 85 (2017)

Gravitational waves and neutrinos

- Multiple potential GW + Neutrino sources
  - Gamma-ray bursts, core-collapse supernovae, soft-gamma repeater outbursts and, potentially cosmic string cusps in the early Universe
- First joint gravitational-wave + neutrino search published in 2013: No detections
- Have published searches for neutrinos in coincidence with numerous GW observations: No detections
  - Papers published with with Antares, Ice Cube and Pierre Auger.
  - Some analyses still in progress

Astrophys. J. Lett. 850, L35 (2017)
Phys. Rev. D 96, 022005 (2017)
Phys. Rev. D 93, 122010 (2016)
Phys. Rev. D 90, 102002 (2014)
JCAP, volume 2013, issue 6, 008 (2013)

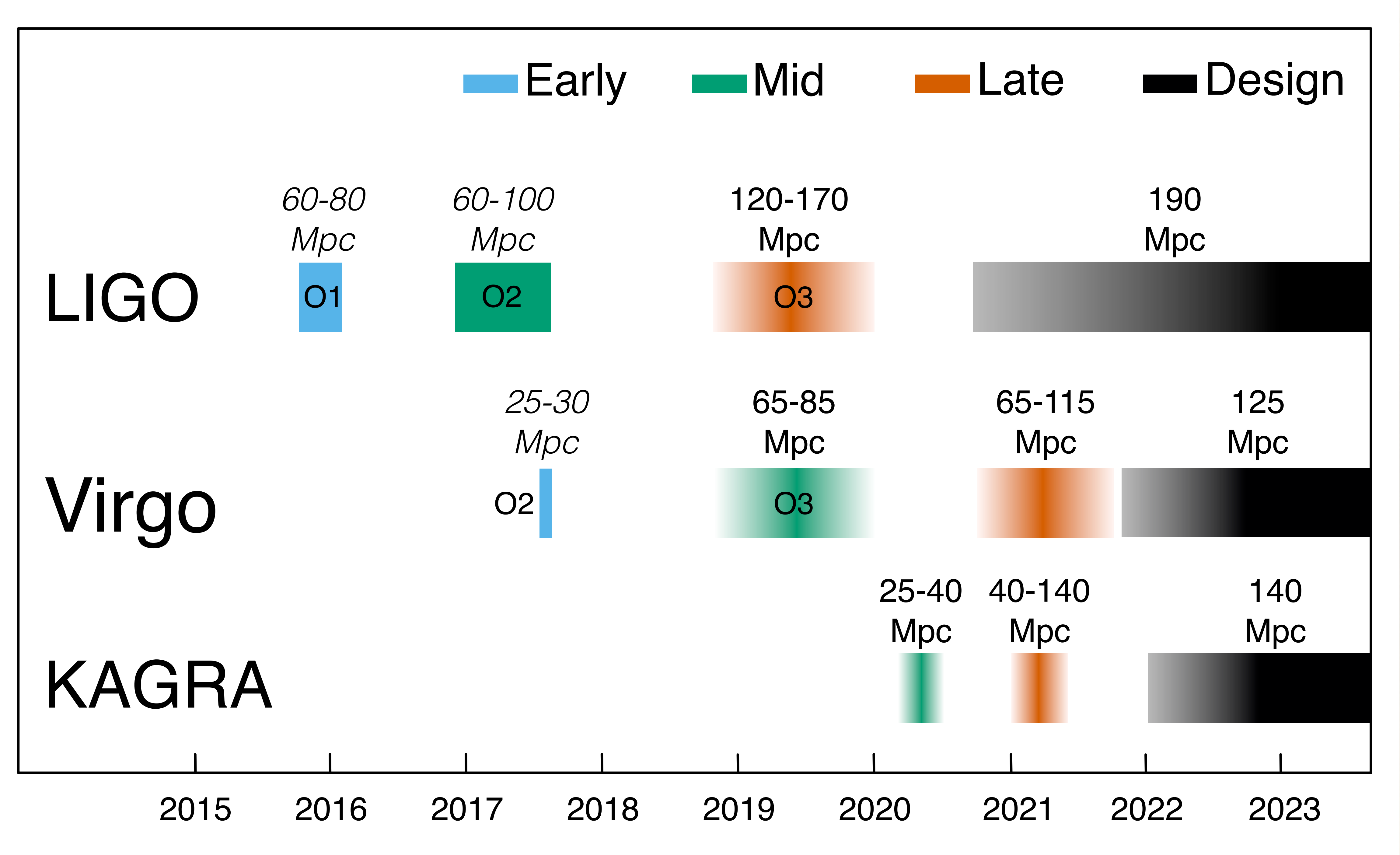
Neutrinos and GW170817



Astrophys. J. Lett. 850, L35 (2017)

Thinking to the future

Looking forward



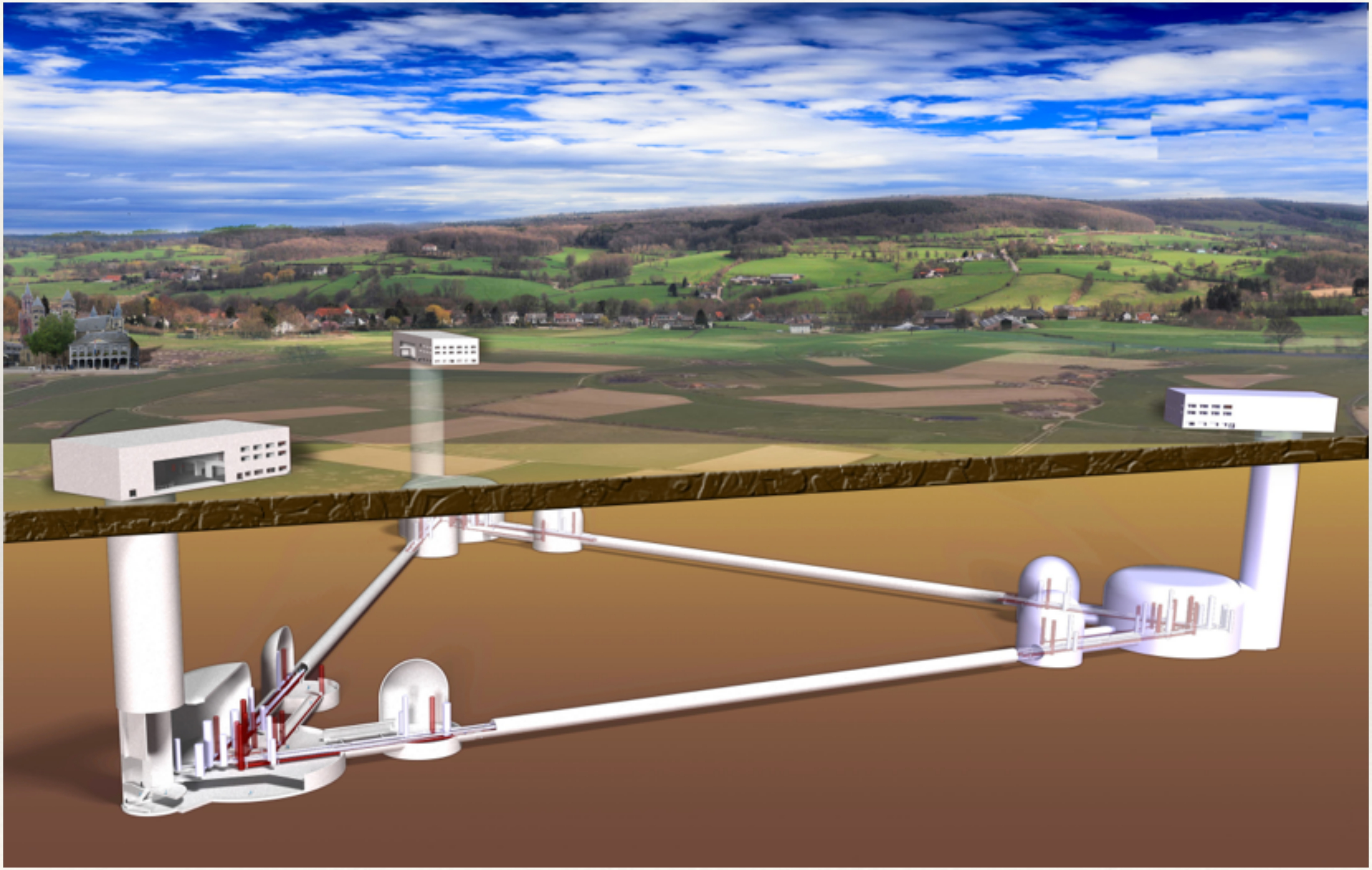
Living Reviews in Relativity 21, 3 (2018)

Looking forward

Epoch			2015 – 2016	2016 – 2017	2018 – 2019	2020+	2024+
Planned run duration			4 months	9 months	12 months	(per year)	(per year)
Expected BNS range/Mpc		LIGO	40 – 80	80 – 120	120 – 170	190	190
		Virgo	—	20 – 65	65 – 85	65 – 115	125
		KAGRA	—	—	—	—	140
Achieved BNS range/Mpc		LIGO	60 – 80	60 – 100	—	—	—
		Virgo	—	25 – 30	—	—	—
		KAGRA	—	—	—	—	—
Estimated BNS detections			0.05 – 1	0.2 – 4.5	1 – 50	4 – 80	11 – 180
Actual BNS detections			0	1	—	—	—
90% CR	% within	5 deg^2	< 1	1 – 5	1 – 4	3 – 7	23 – 30
		20 deg^2	< 1	7 – 14	12 – 21	14 – 22	65 – 73
	Median/deg^2		460 – 530	230 – 320	120 – 180	110 – 180	9 – 12
Searched area	% within	5 deg^2	4 – 6	15 – 21	20 – 26	23 – 29	62 – 67
		20 deg^2	14 – 17	33 – 41	42 – 50	44 – 52	87 – 90

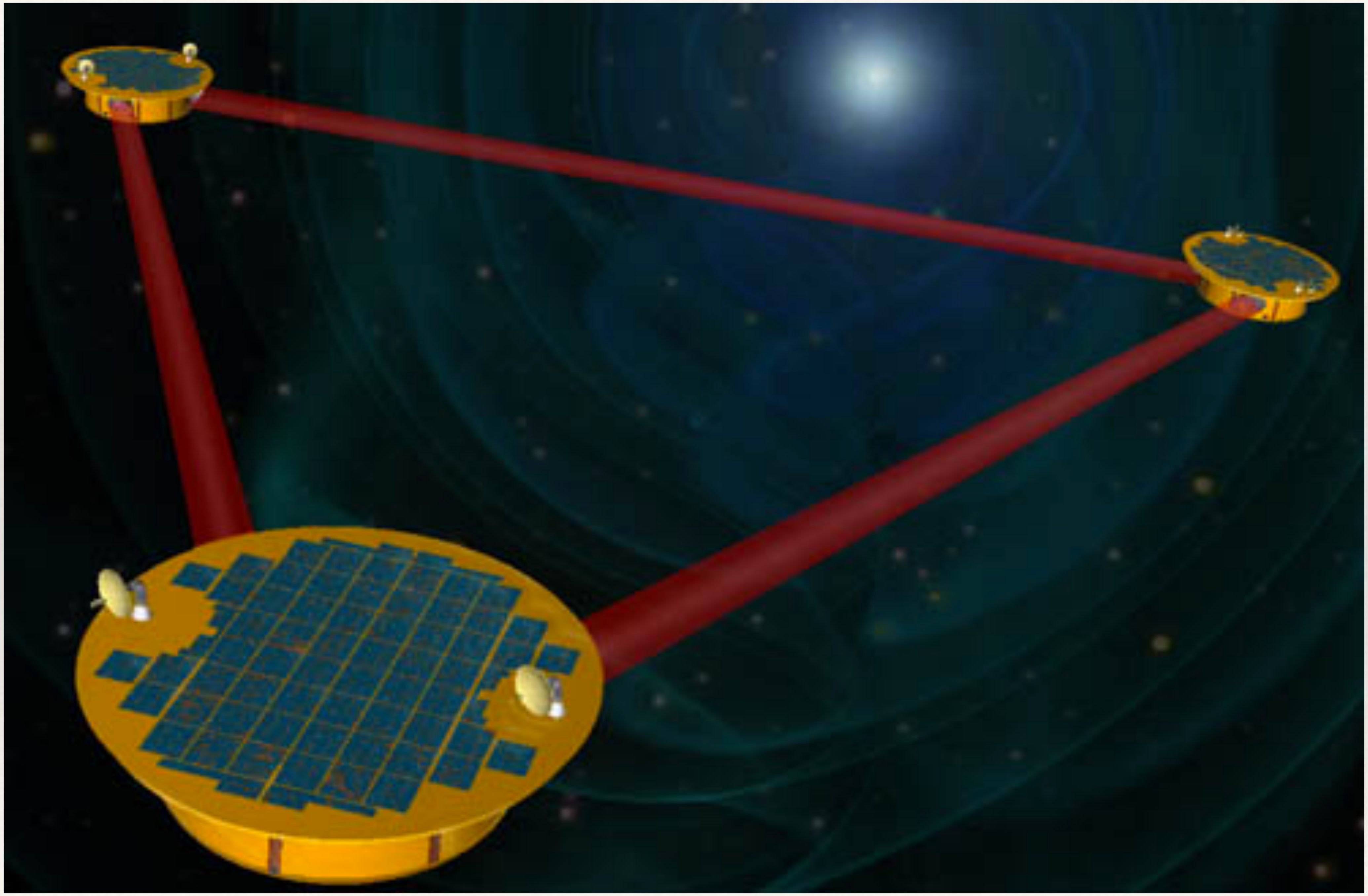
Living Reviews in Relativity 21, 3 (2018)

Einstein Telescope



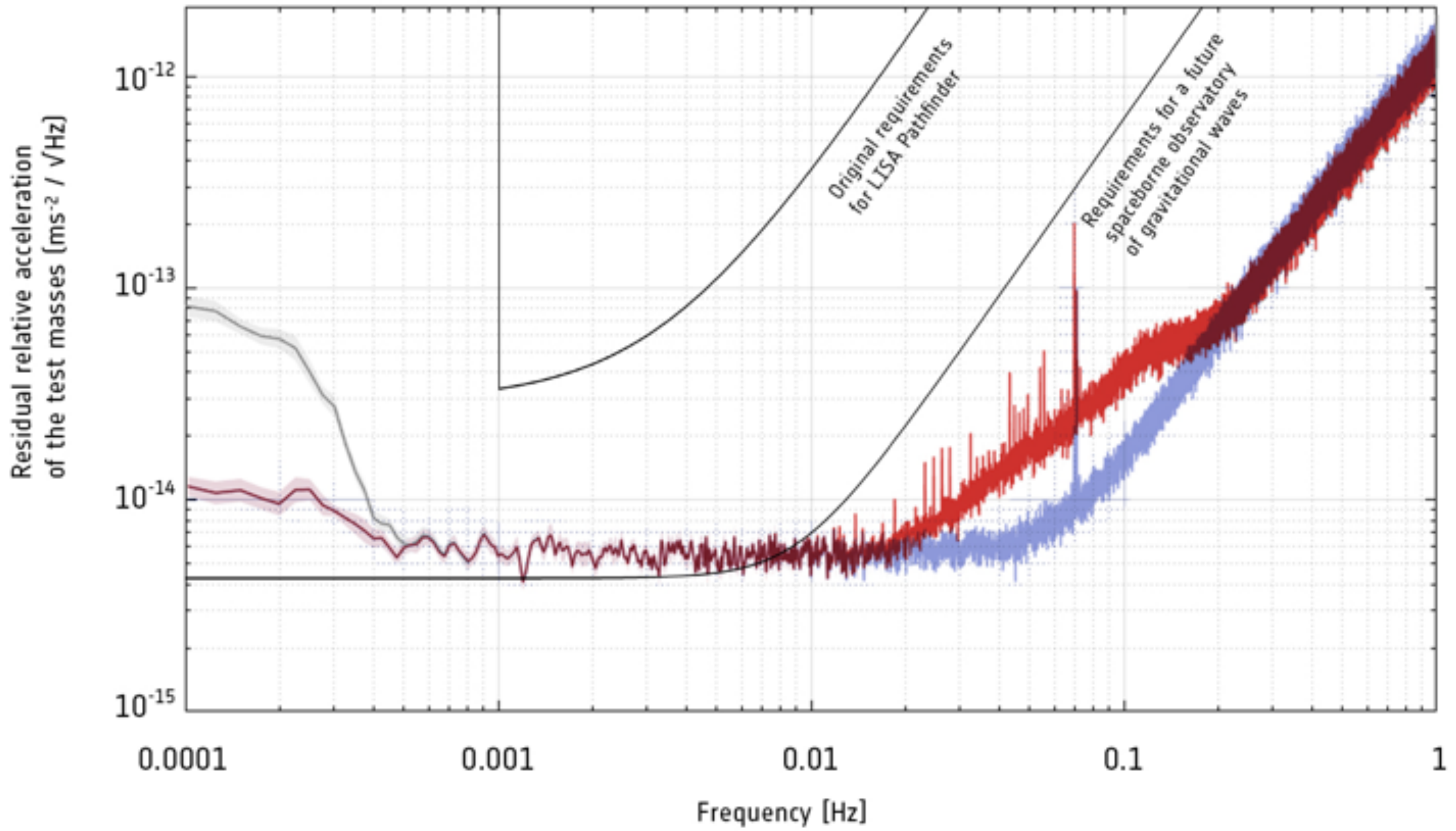
Regimbau et al. PRL 118, 151105 (2017)

LISA - Space-based GW astronomy

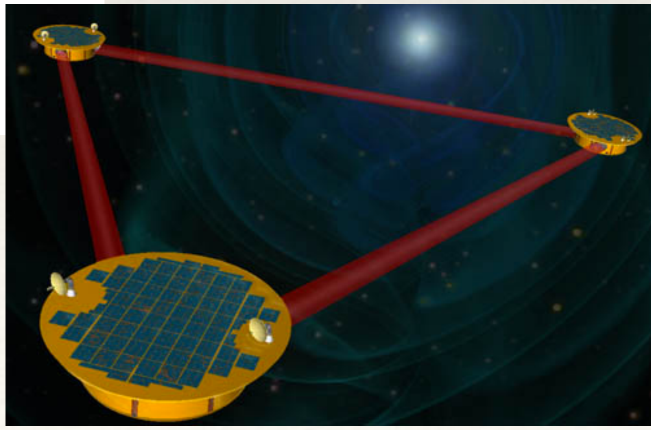


5 Million kilometer arm length

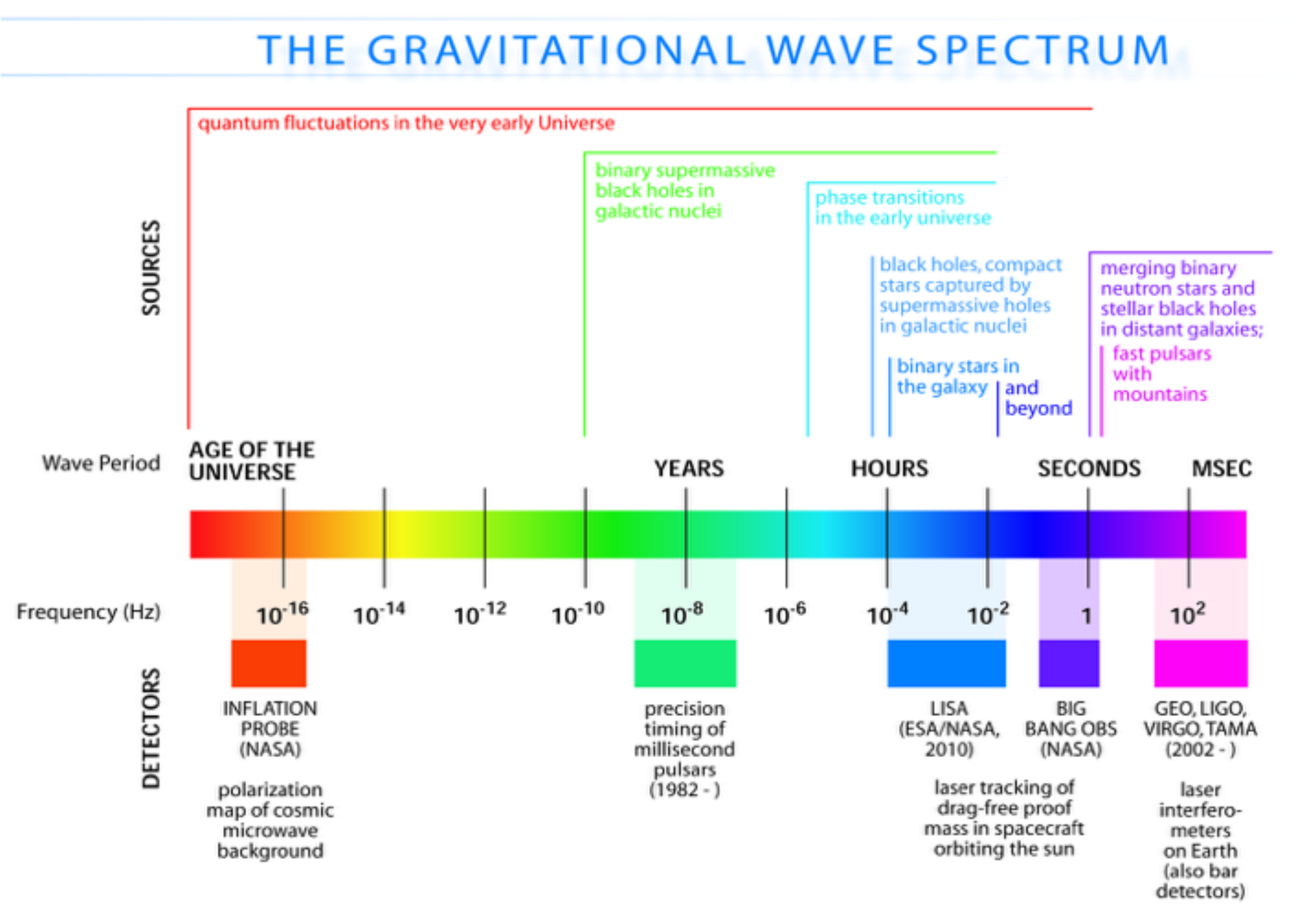
The future is (gravitationally) bright



LISA pathfinder sensitivity
greatly exceeds expectations
ESA / LISA Pathfinder Collaboration



The gravitational-wave spectrum



Credit: University of Glasgow

END