Doing Astronomy With Gravitational Waves

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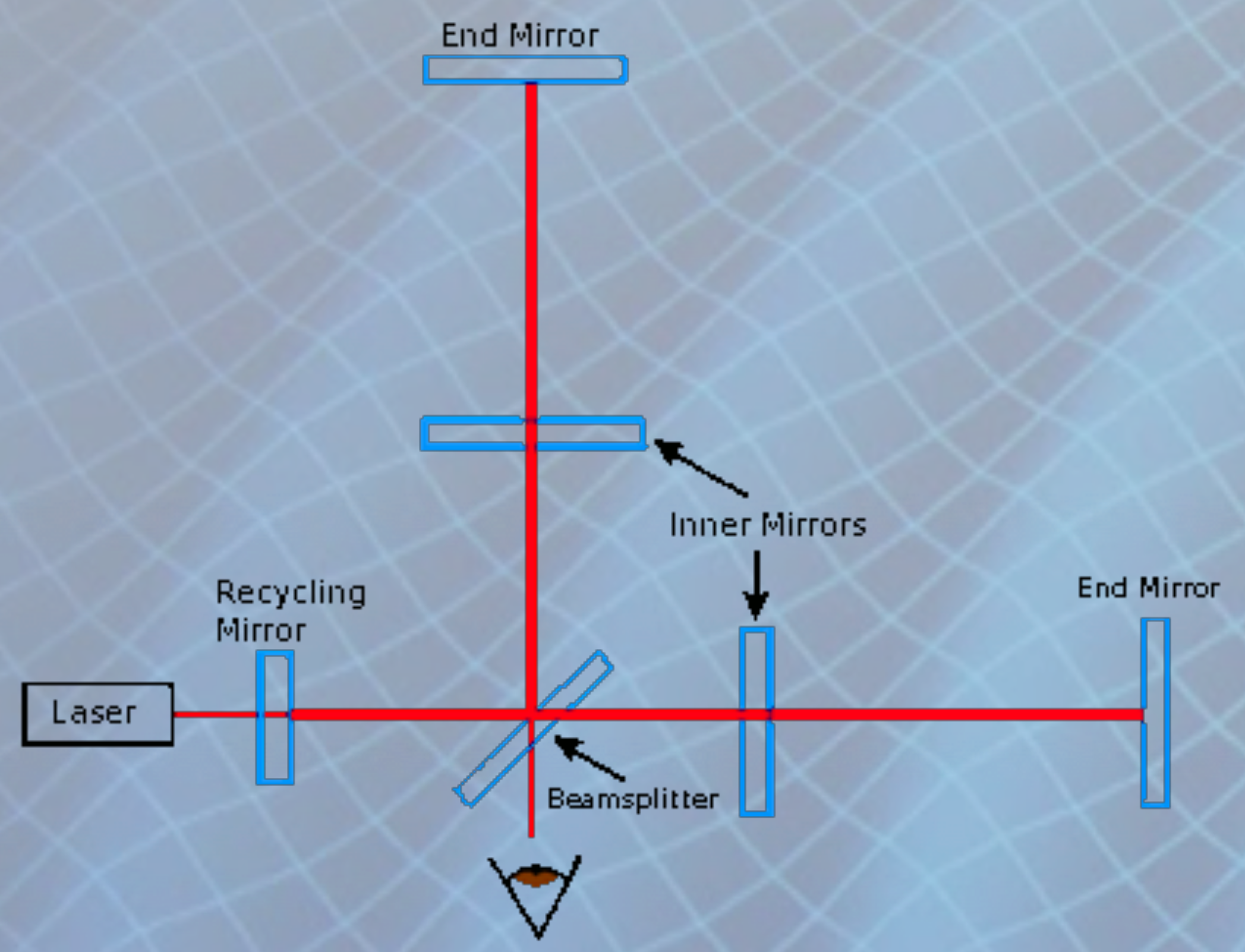
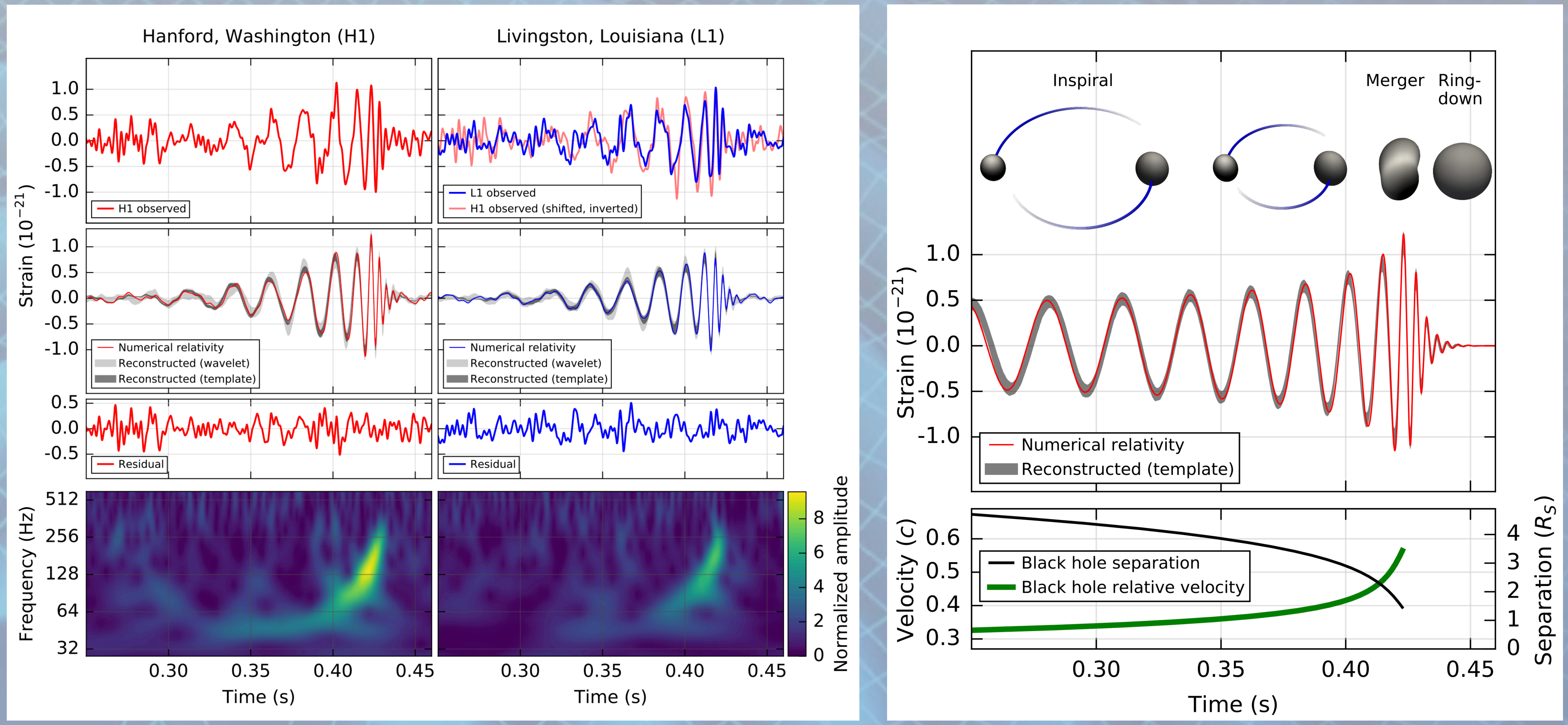
LIGO: the Laser Interferometer Gravitational-wave Observatory

Gravitational waves stretch and squeeze the space they pass through, changing the distances between objects. Therefore, we need a way to measure distance changes very accurately. The LIGO (Laser Interferometer Gravitational-wave Observatory) detectors were built to do just that [1]. Laser light is sent down perpendicular 4 km long arms, reflected from end mirrors and then allowed to recombine and interfere. Changes in the amount of interference indicates changes in the length of the arms.



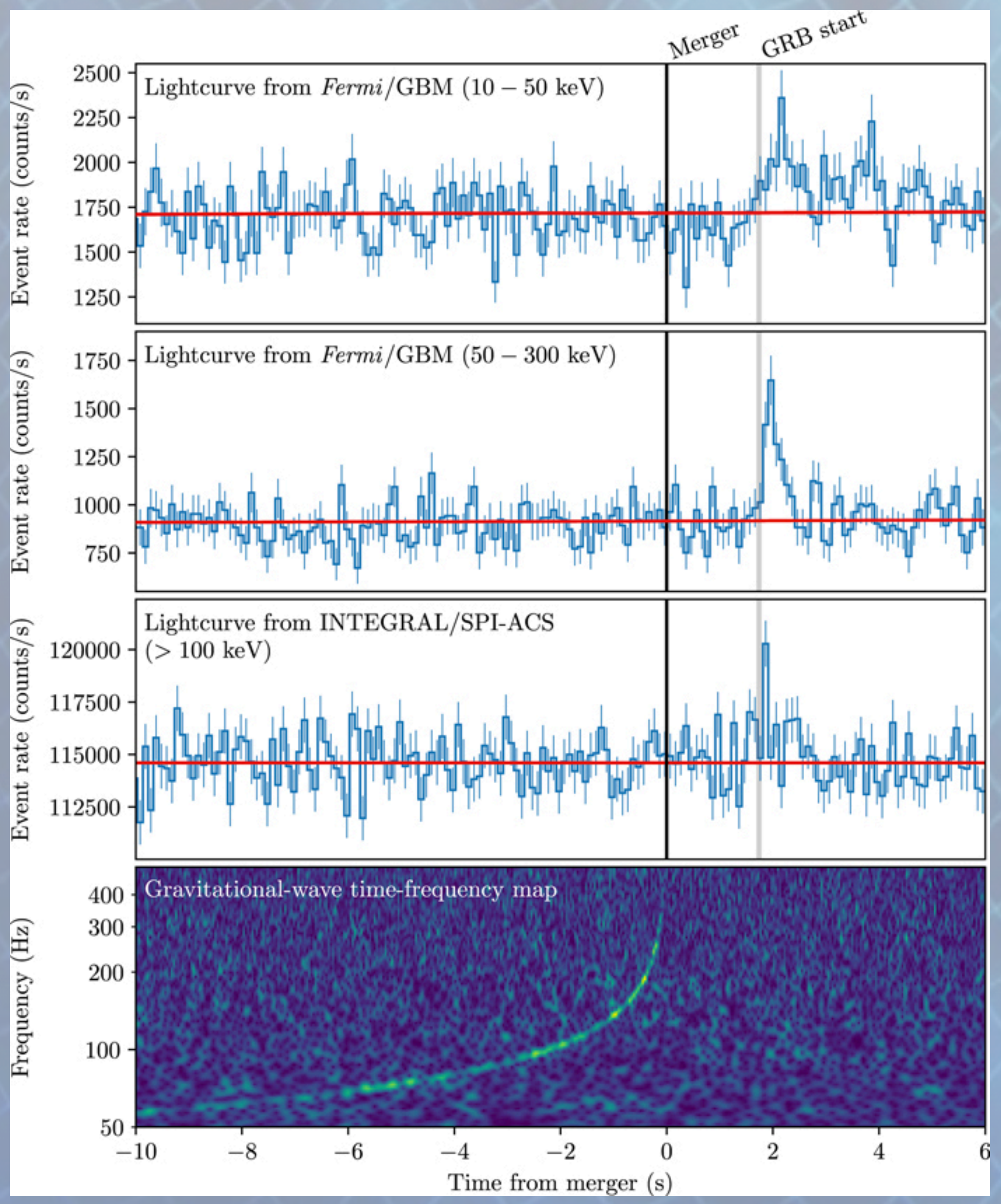
LIGO Hanford Observatory in Hanford, WA (above) and LIGO Livingston Observatory in Livingston, LA (below) Images from [2]

Learning about black holes

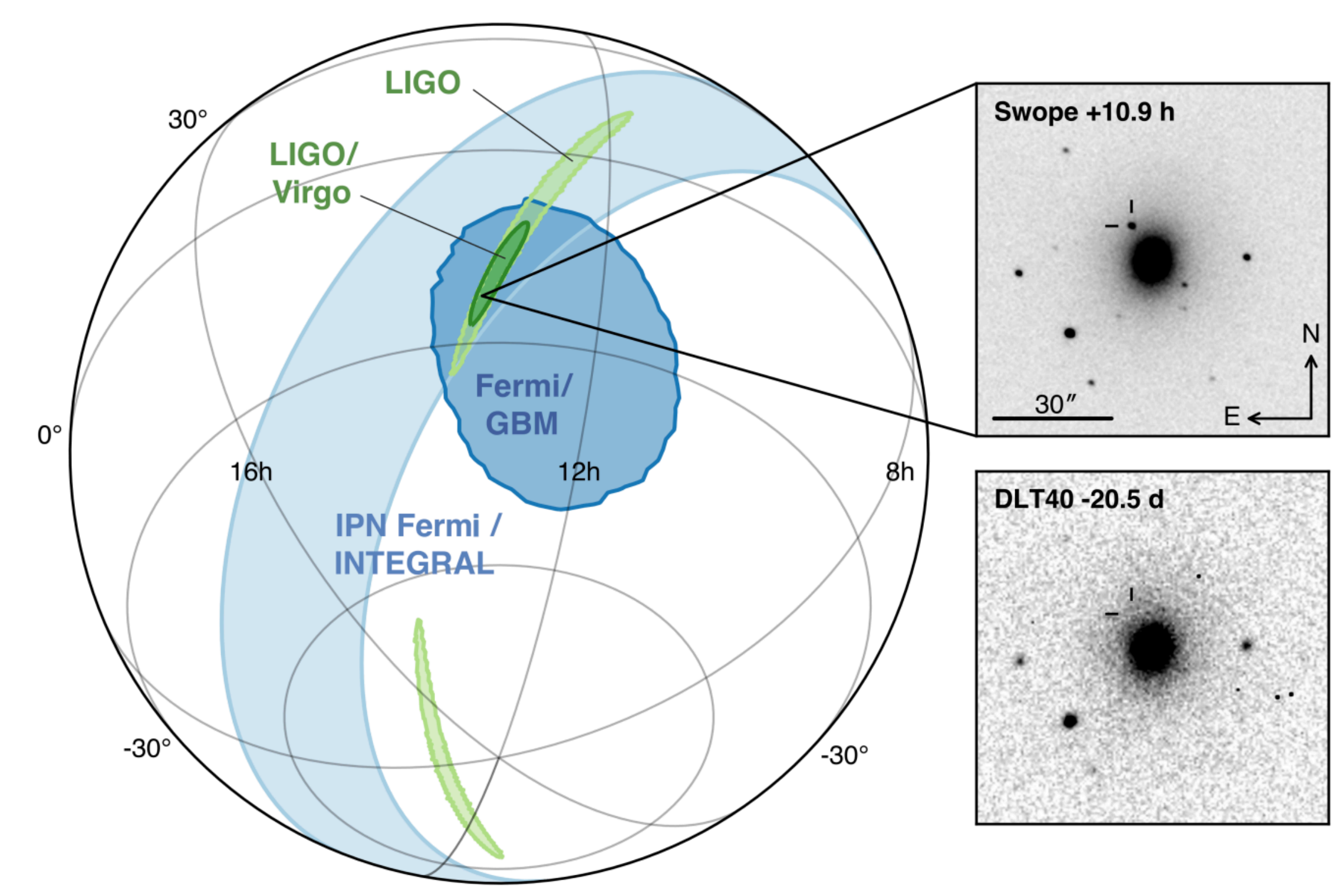


GW150914 was the first gravitational wave signal detection. The gravitational waves, which are ripples in the fabric of spacetime, were produced by a 29 solar mass and a 36 solar mass black hole orbiting and then merging to form a 62 solar mass black hole. The collision happened 1.3 billion light-years from Earth. Images from [3].

Learning about neutron stars



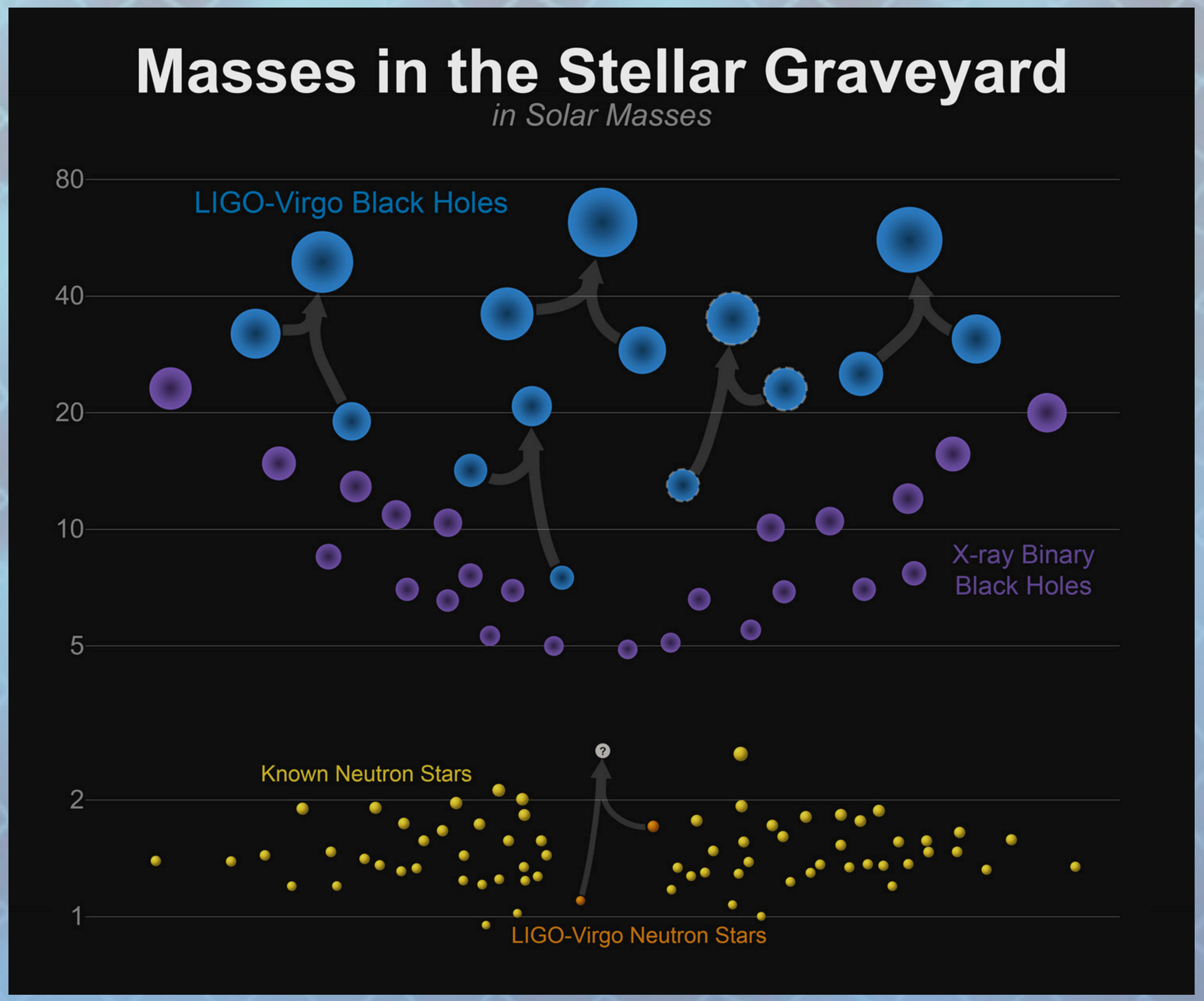
Neutron stars are the remnants left behind by the collapse and supernova explosion of massive stars. The LIGO and Virgo detectors measured gravitational waves from the inspiral of a pair of neutron stars. Two seconds later, the Fermi and INTEGRAL gamma-ray detecting spacecraft saw a burst of gamma rays. Image from [4].

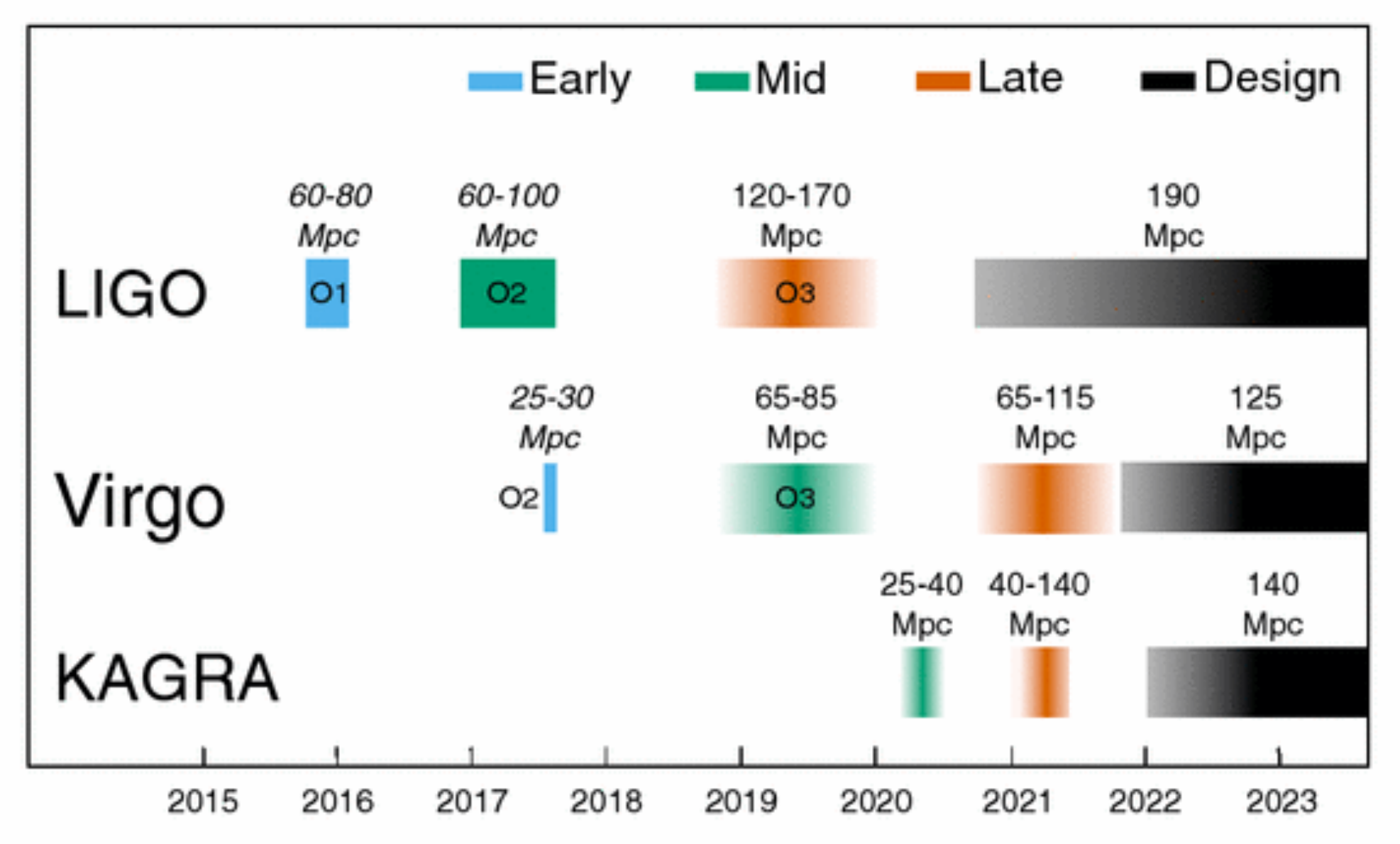


Above is shown the sky location of the gravitational wave (green) and gamma ray burst (blue). Where the regions overlap, a new source of light was seen, first by the Swope telescope and soon by many others. Image from [5].

The Hubble Space Telescope also took an image of the galaxy where the neutron star collision was seen (left). Later radio and x-ray telescopes measured light from the same source. This multi-messenger observation has taught us that neutron star collisions produce gamma −ray bursts, the ensuing explosion can make heavy elements, and has provided a new way of measuring the expansion of the universe [6].

Summary and future plans





Left: A diagram of all of the gravitational wave sources detected thus far, which have been produced by pairs of different stellar remnants merging. Black holes that have collided and resulted in a larger black hole are shown in blue. The purple circles represent black holes found by the x-rays emitted by the matter being consumed by them. Yellow circles are neutron stars that emit pulses of radio waves and the orange circles are the neutron stars that merged and were detected via gravitational waves. The end product of this merger is uncertain. Image credit LIGO.

Above: The timeframe of past and future observing runs for the LIGO (USA), Virgo (Italy) and KAGRA (Japan) detectors. Also shown is the expected distance (in Mega-parsecs) to which neutron star collisions should be detected. Image from [7].

References

[1] The LIGO Scientific Collaboration. “LIGO: The Laser Interferometer Gravitational-Wave Observatory”, Rept. Prog. Phys., 72, 076901 (2009) arXiv:0711.3041
[2] http://www.ligo.caltech.edu/~beckett/LIGO_Images
[3] The LIGO and Virgo Collaborations, “Observation of Gravitational Waves from a Binary Black Hole Merger”, Phys. Rev. Lett. 116, 061102 (2016)
[4] B. P. Abbott et. al., “Gravitational Waves and Gamma−Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A”, Ap. J. Lett. 848, L13 (2017) arXiv: 1710.05834
[5] B. P. Abbott et. al. “Multi-messenger Observations of a Binary Neutron Star Merger”, Ap. J. Lett. 848, L12 (2017) arXiv: 1710.05833
[6] The LIGO and Virgo Collaborations, et. al. “A gravitational-wave standard siren measurement of the Hubble constant”, Nature 551, 85 (2017) arXiv: 1710.05835
[7] B. P. Abbott et. al. “Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA, Living Reviews in Relativity 21, 3 (2018) arXiv:1304.0670

Background picture by Swinburne Astronomy Productions

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