Observation of gravitational waves from a binary neutron star inspiral

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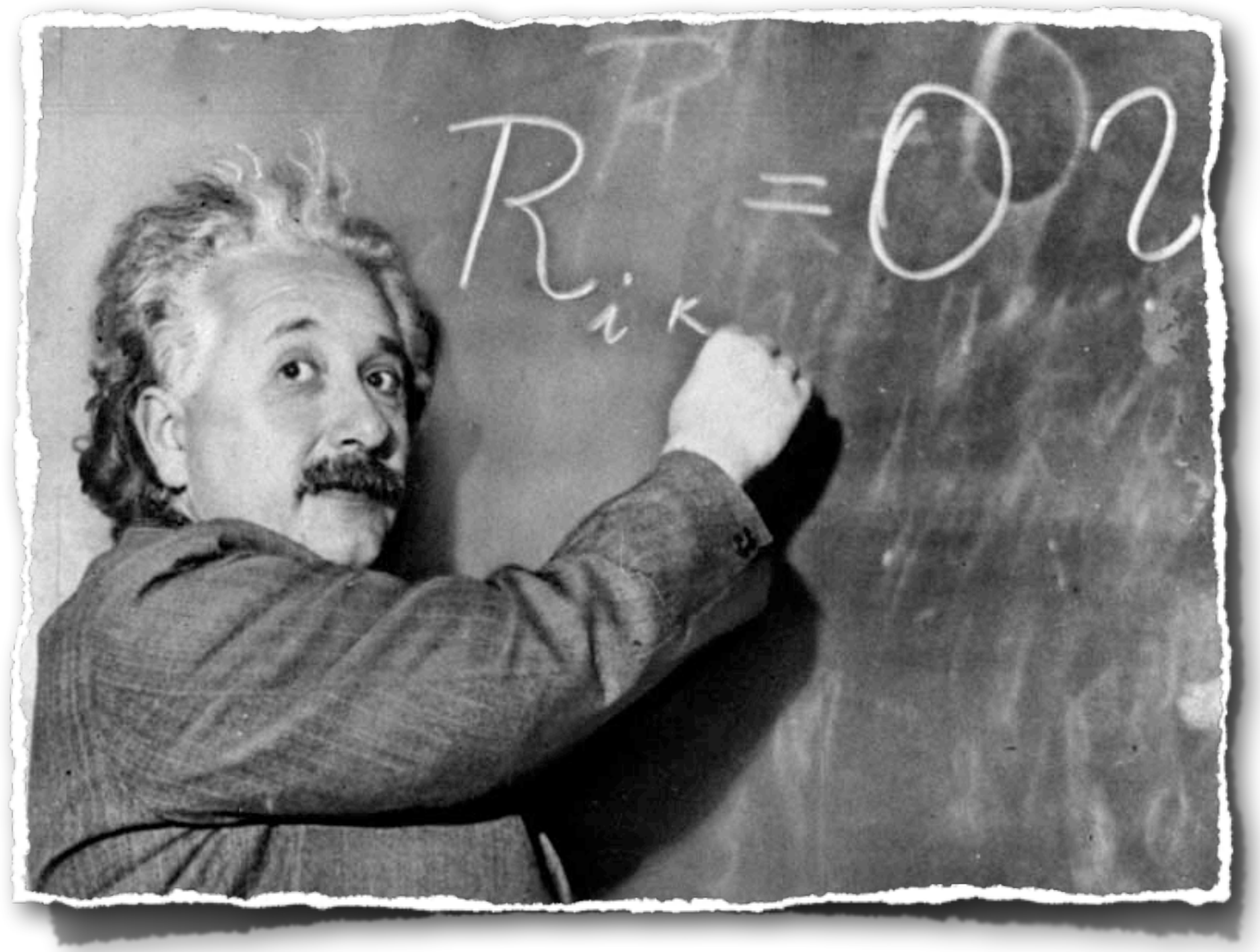
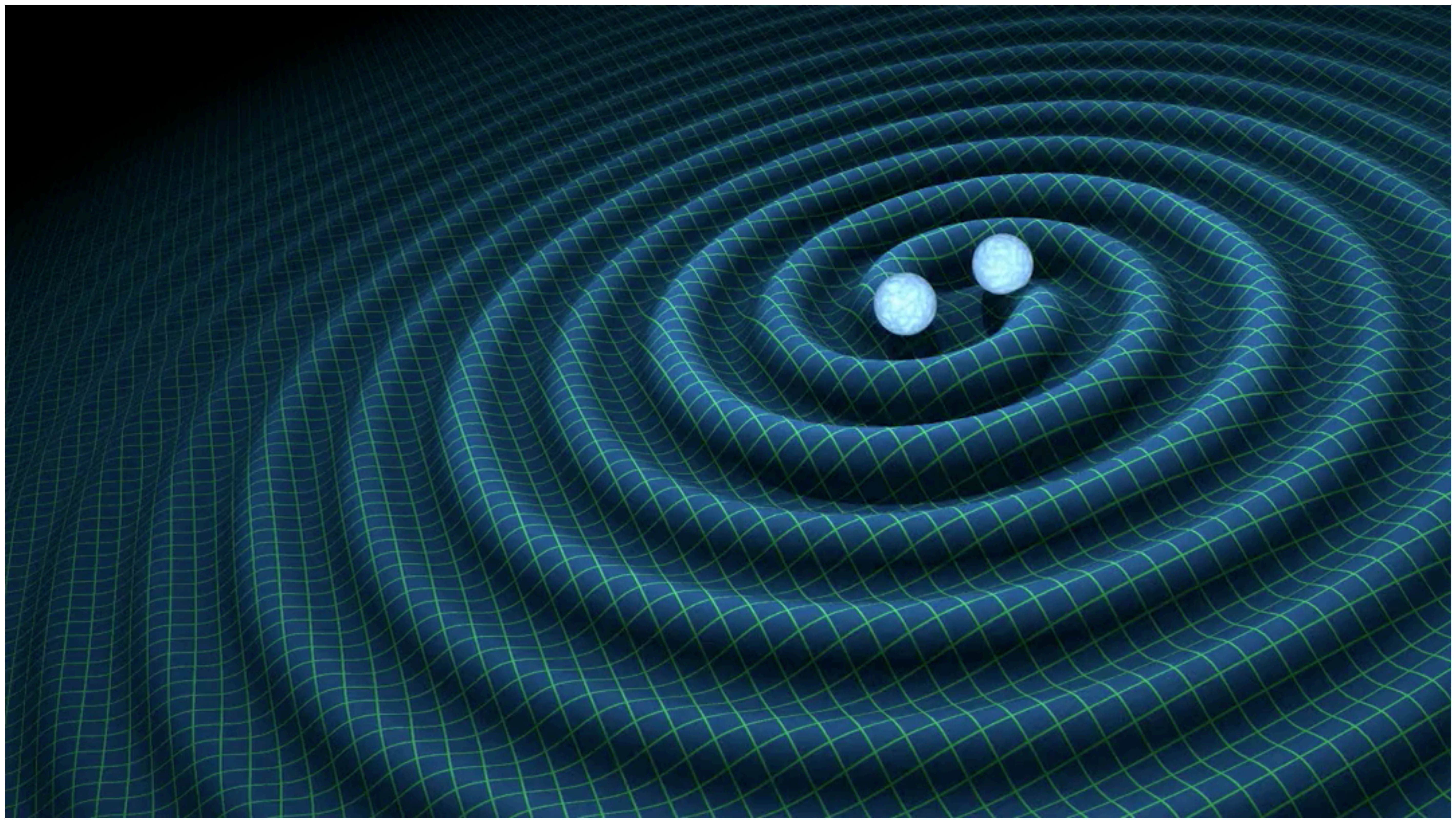
Gravitational waves



One of the most intriguing predictions of the General Theory of Relativity

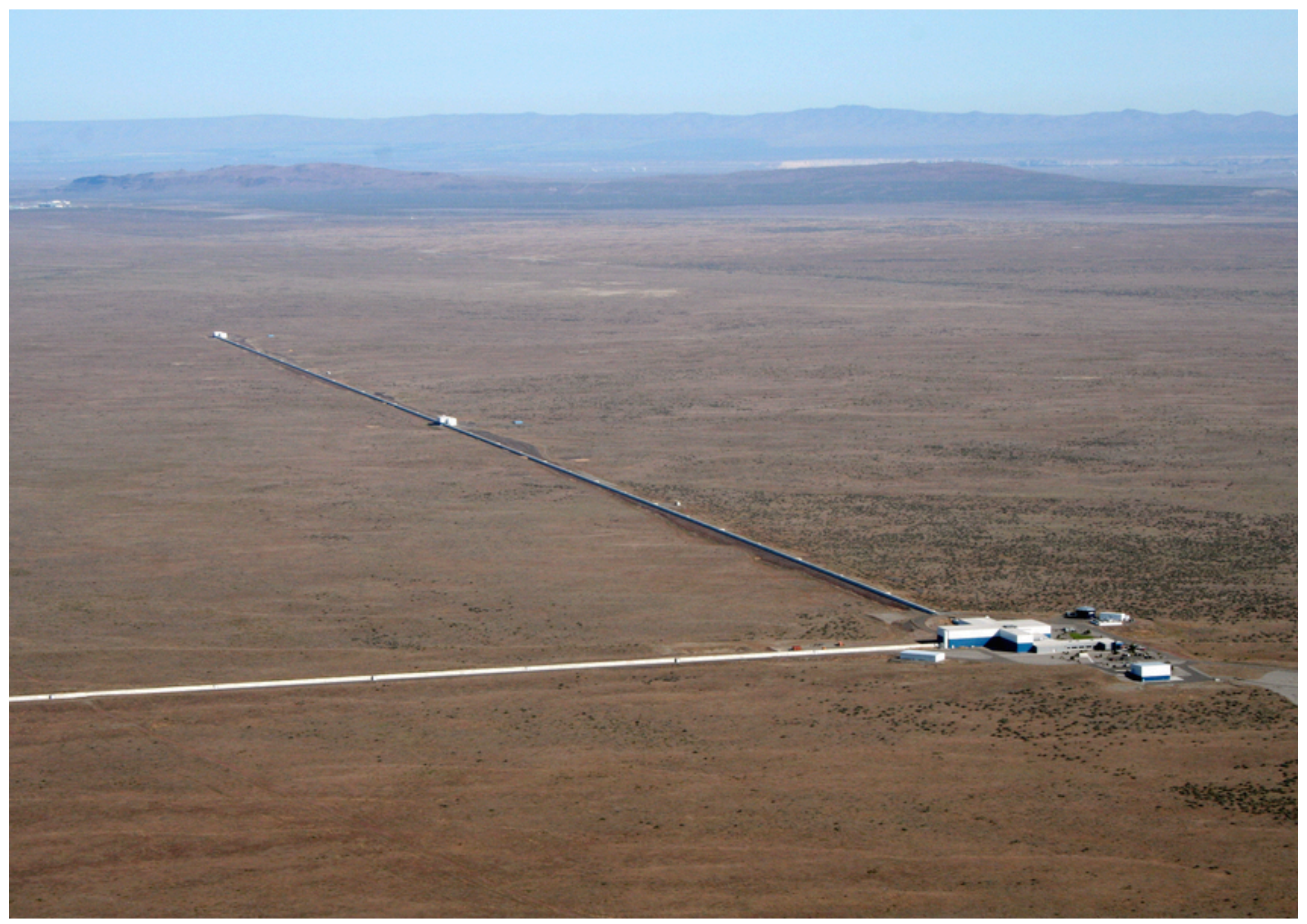
Gravitational waves



[http://ligo.caltech.edu]

Oscillations in spacetime geometry that propagate at the speed of light.

Gravitational-wave observations of binary black holes



[Caltech/MIT/LIGO Lab]

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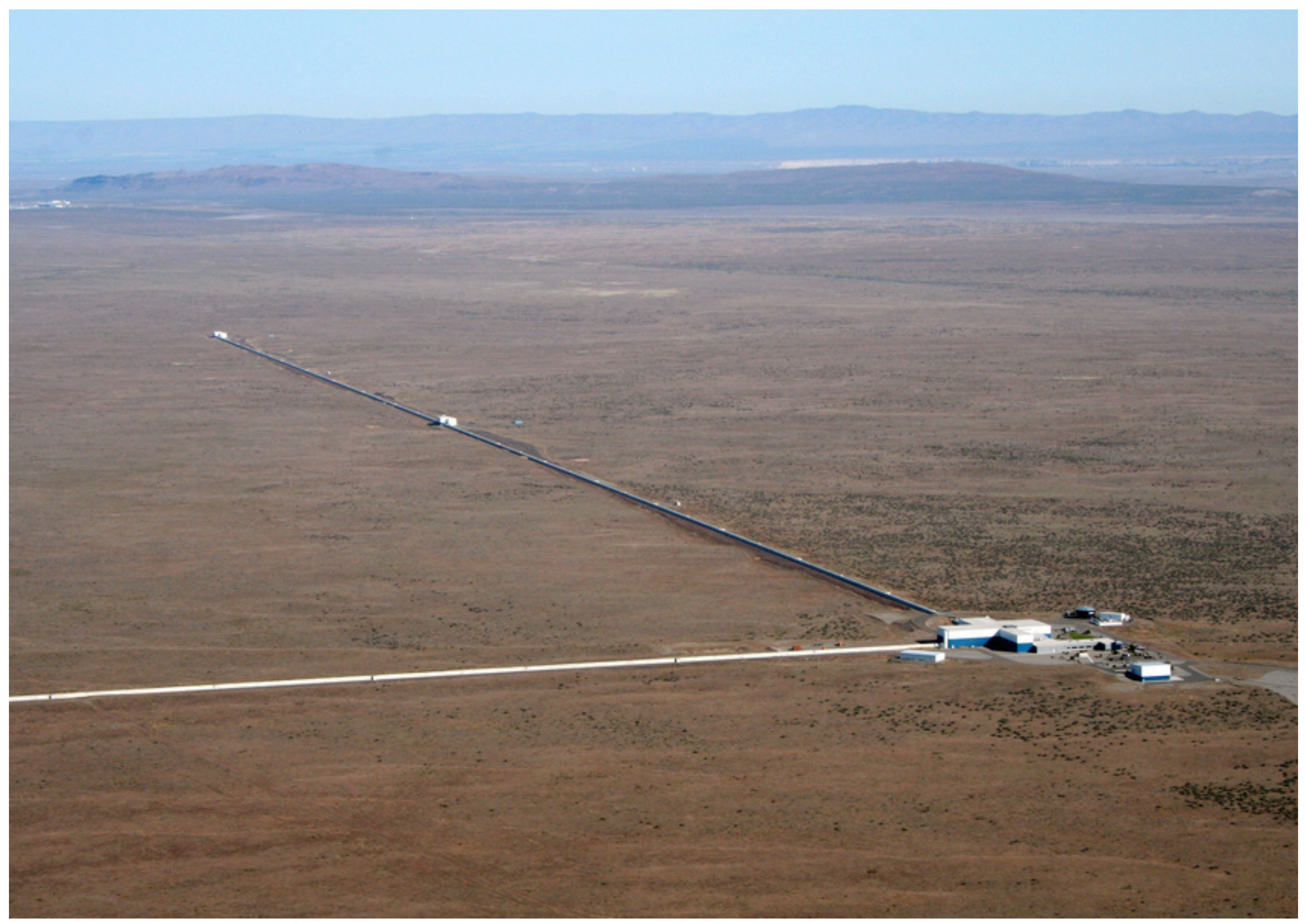

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[The Virgo collaboration/CCO 1.0]

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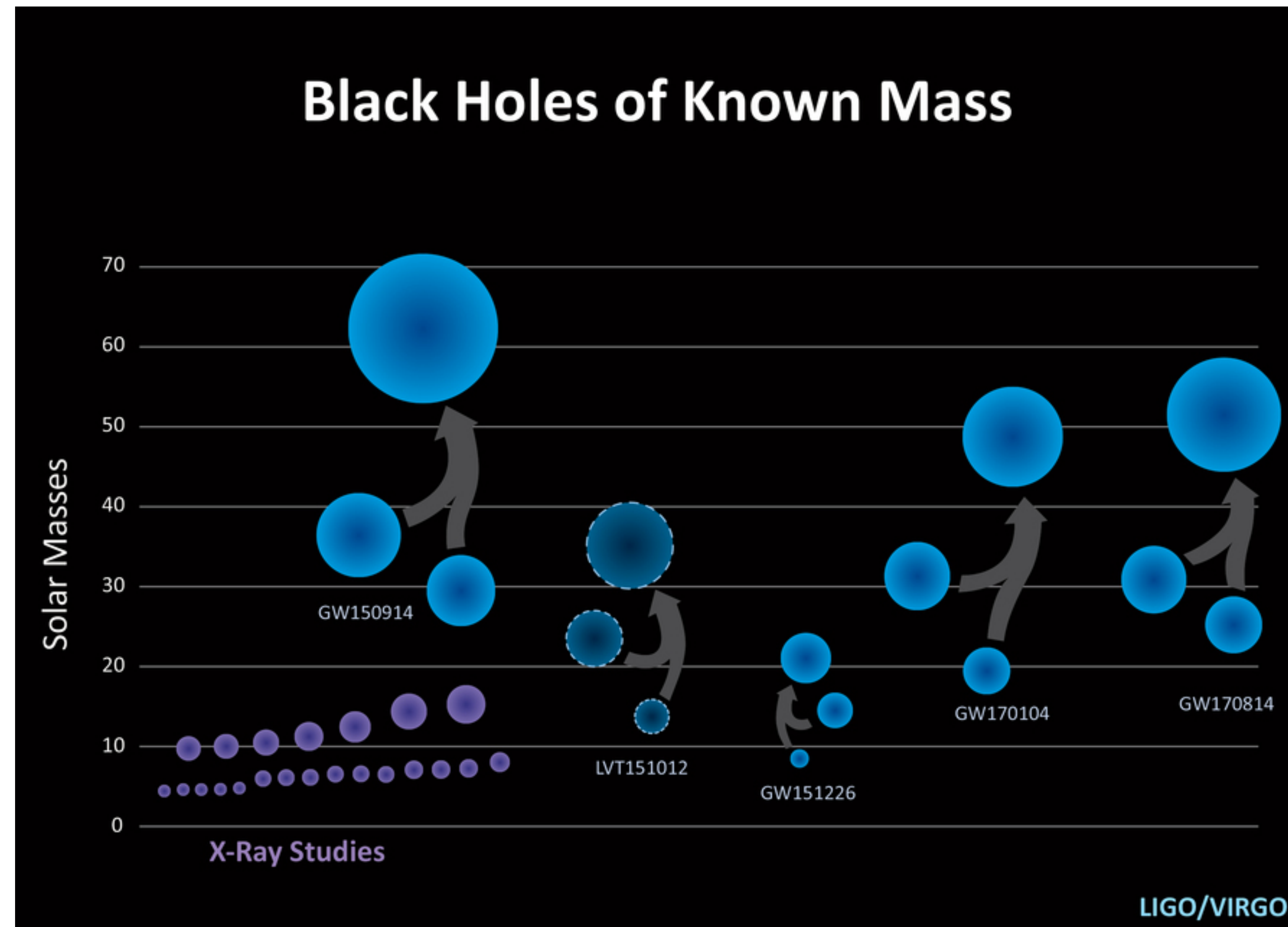
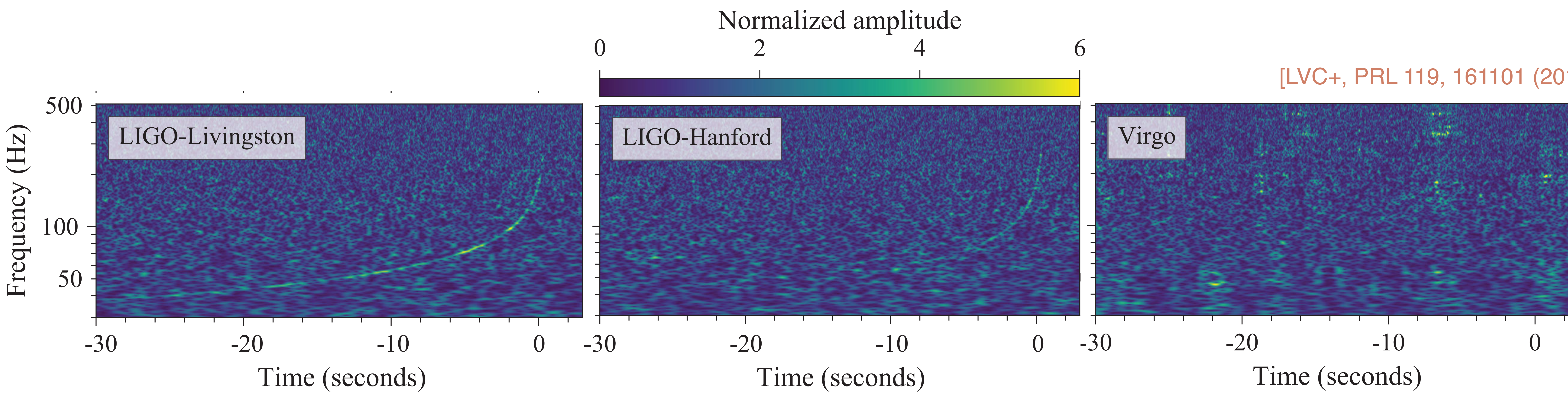
Fourth binary black hole observation in Aug 2017 — jointly with Virgo (Europe).

Gravitational-wave observations of binary black holes

- First detections of binary BHs that merge within the age of the Universe.
- First observations of stellar-mass BHs with mass $\gtrsim 20\ M_{\odot}$
- First tests of General Relativity in the highly relativistic regime.
- Potentially detectable



First GW observation of a binary neutron star inspiral



[LVC+, PRL 119, 161101 (2017)]

On August 17 at 12:41:04 UTC Advanced LIGO and Advanced Virgo made their first observation of a binary neutron star inspiral (GW170817).

First GW observation of a binary neutron star inspiral

- Detected by matched-filtering pipelines using post-Newtonian models of expected signals.
  - Duration of the obs. signal ~ 100s (starting from 24 Hz)
  - Combined SNR ~ 32.4. Loudest signal detected so far!
  - Estimated false alarm rate < 1 in 80,000 yrs.

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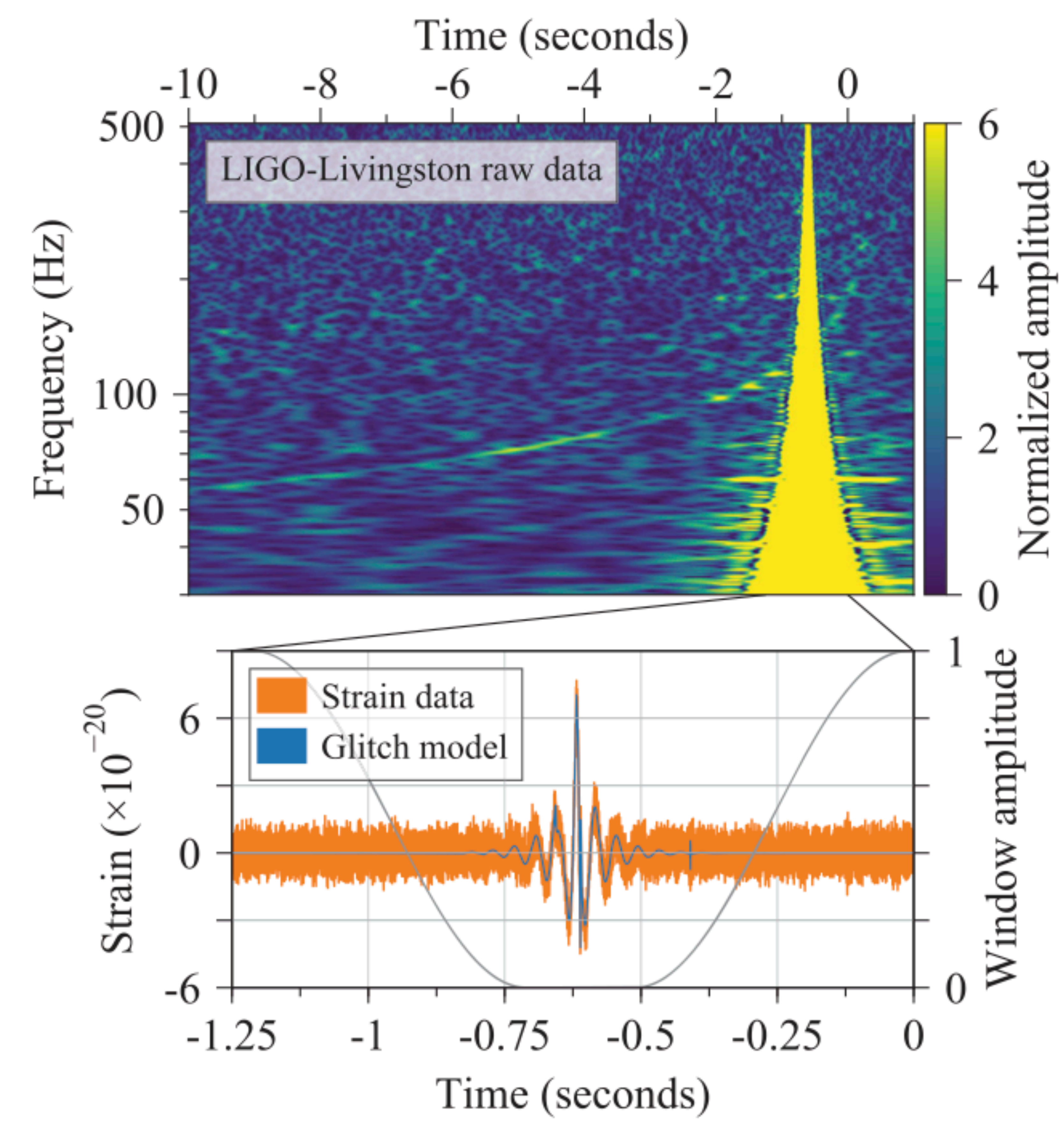
- No disturbance observed by environmental sensors could account for the signal.
  - A **short** instrumental noise transient appeared

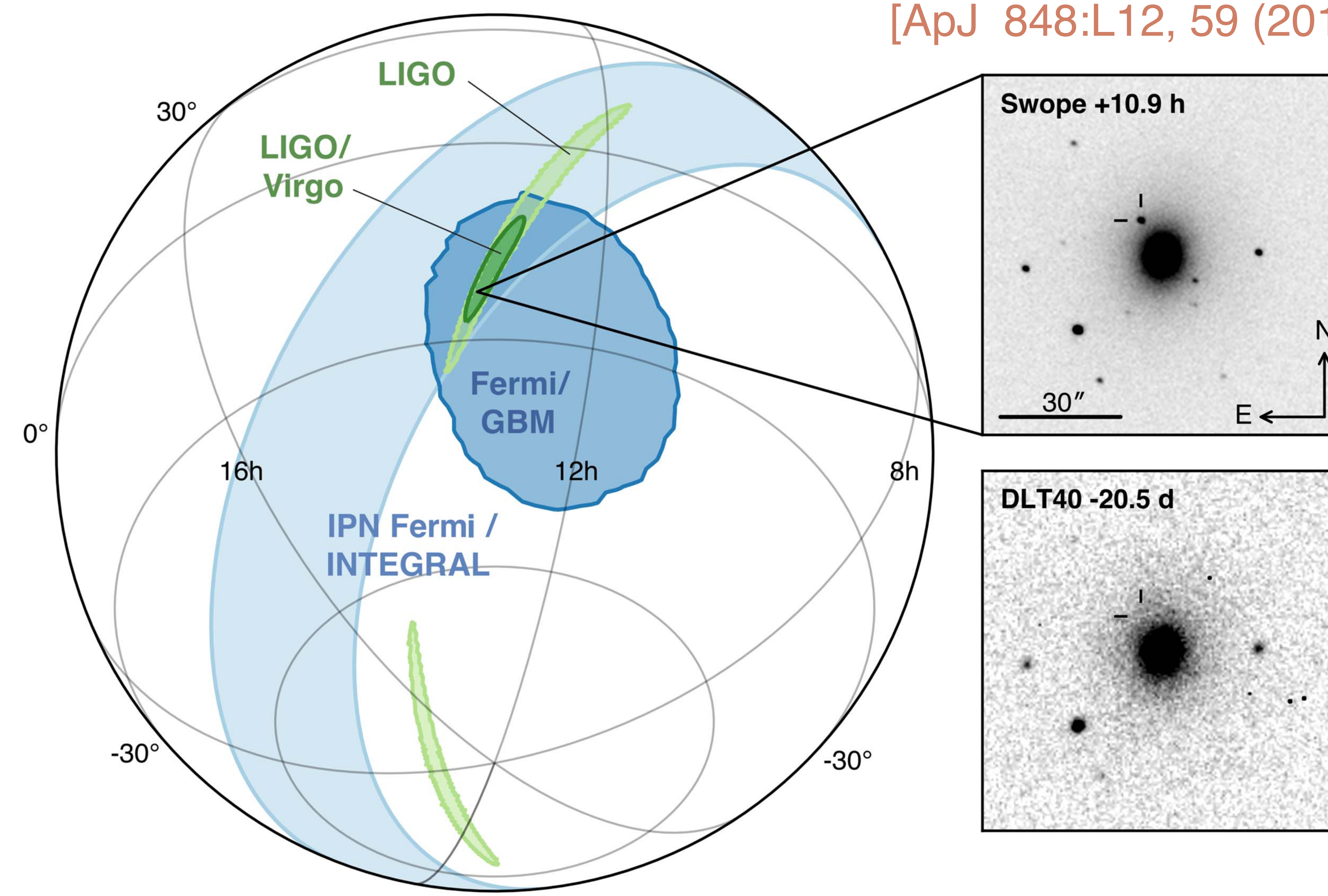
[LVC+, PRL 119, 161101 (2017)]



Coincident observation of a gamma ray burst!

- The source was localized to ~28 sq deg using LIGO-Virgo data, near to the southern end of Hydra.
- Independent observation of a gamma ray burst (GRB 170817A) by Fermi GBM 1.7 s after the coalescence.

[ApJ 848:L12, 59 (2017)]



[Varun Bhalerao's talk]

Source properties

[LVC+, PRL 119, 161101 (2017)]

- Inferred using a Bayesian framework.
  - Chirp mass, the combination of masses that primarily determines the chirp-like evolution of the frequency, is best constrained.

$$\mathcal{M} = 1.188^{+0.004}_{-0.002} M_\odot$$

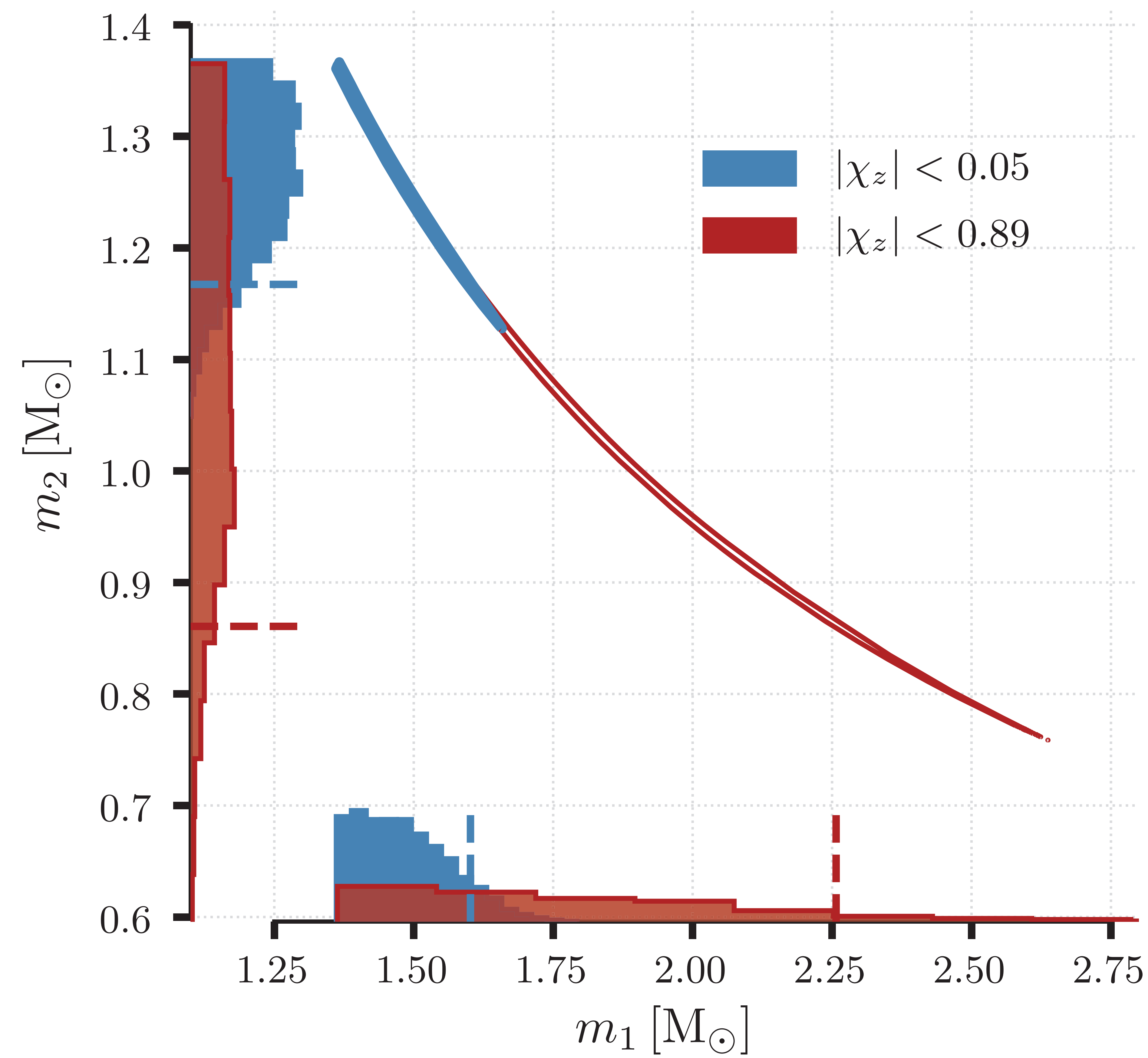
  - Measurement of component masses limited

$m_1 = 1.36 - 1.60 M_\odot$
$m_2 = 1.17 - 1.36 M_\odot$

Assuming Low spin priors

$m_1 = 1.36 - 2.26 M_\odot$
$m_2 = 0.86 - 1.36 M_\odot$

Assuming High spin priors

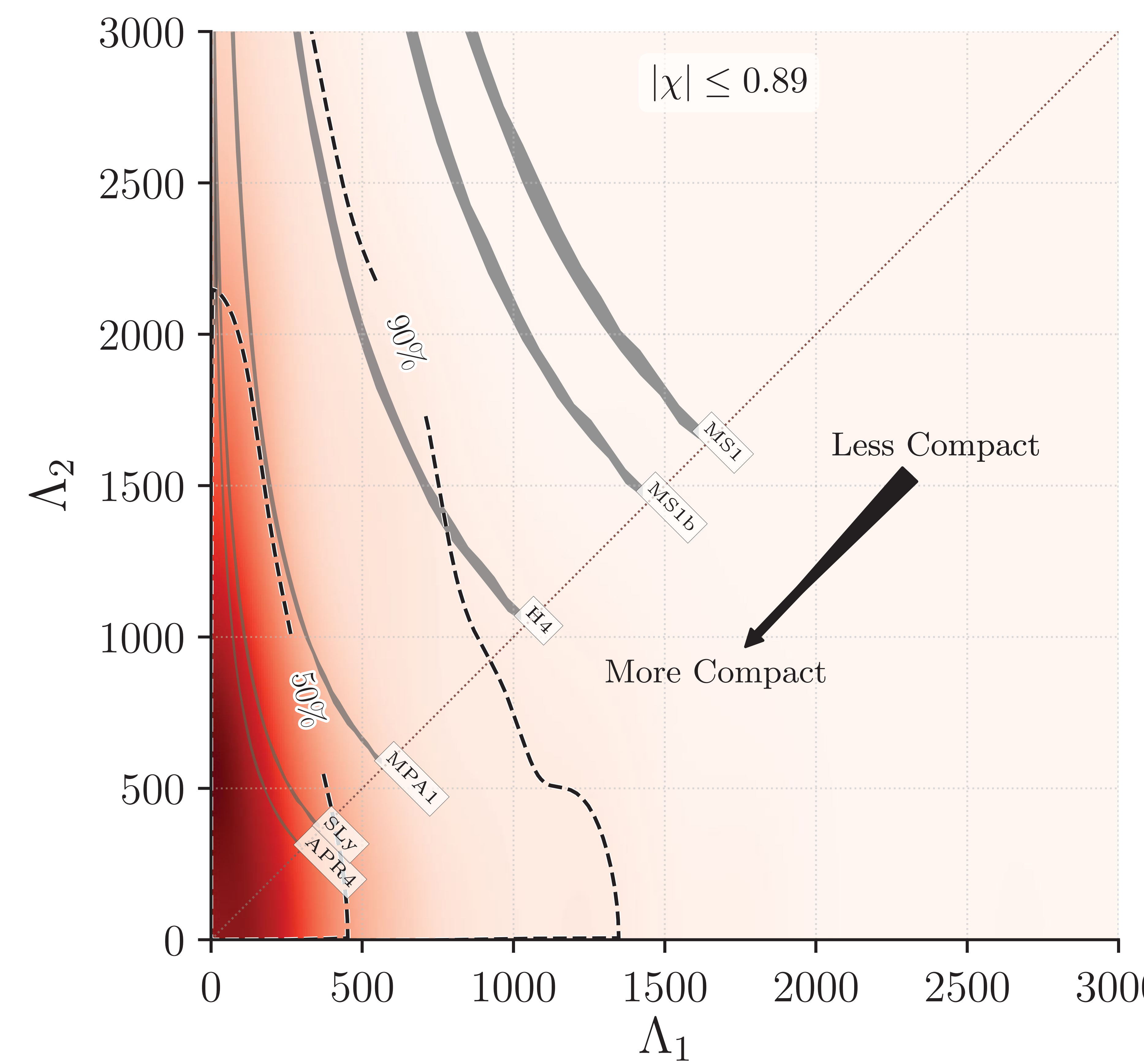


Posterior distributions of component masses.

Source properties

- Details of the internal structure of the objects (equation of state) becomes at close separations.
  - Tidal deformability Λ: Ratio of the induced quadruple moment to the external tidal field.
- Constraints on Λ disfavor EoSs

[LVC+, PRL 119, 161101 (2017)]



[Sukanta Bose's talk]

Source properties

[LVC+, PRL 119, 161101 (2017)]

Independent measurement of the luminosity distance and redshift. New estimation of Hubble constant!

Closest GW source observed. Closest gamma-ray burst with distance measurement

	Low-spin priors $(\|\chi\| \leq 0.05)$	High-spin priors $(\|\chi\| \leq 0.89)$
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_{tot}	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy E_{rad}	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance D_L	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc
Viewing angle Θ	$\leq 55°$	$\leq 56°$
Using NGC 4993 location	$\leq 28°$	$\leq 28°$
Combined dimensionless tidal deformability $\tilde{\Lambda}$	≤ 800	≤ 700
Dimensionless tidal deformability $\Lambda(1.4 M_\odot)$	≤ 800	≤ 1400

Interesting implications on GRB astrophysics

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[Archisman Ghosh's talk]

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Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
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Interesting implications on GRB astrophysics

[K. G. Arun's talk]

Implications: Fundamental physics

- Constraints on the speed of GWs from the near simultaneous arrival (delay 1.7 s) of GW and gamma ray signal.
  - Test of the equivalence principle.
  - Tests of Lorentz violation.

$$-3 \times 10^{-15} \leqslant \frac{\Delta v}{v_{\mathrm{EM}}} \leqslant +7 \times 10^{-16}$$

$$-2.6 \times 10^{-7} \leqslant \gamma_{\mathrm{GW}} - \gamma_{\mathrm{EM}} \leqslant 1.2 \times 10^{-6}$$

Shapiro delay of gravitational waves and photons

- Constraints of the EoS of dense nuclear matter.

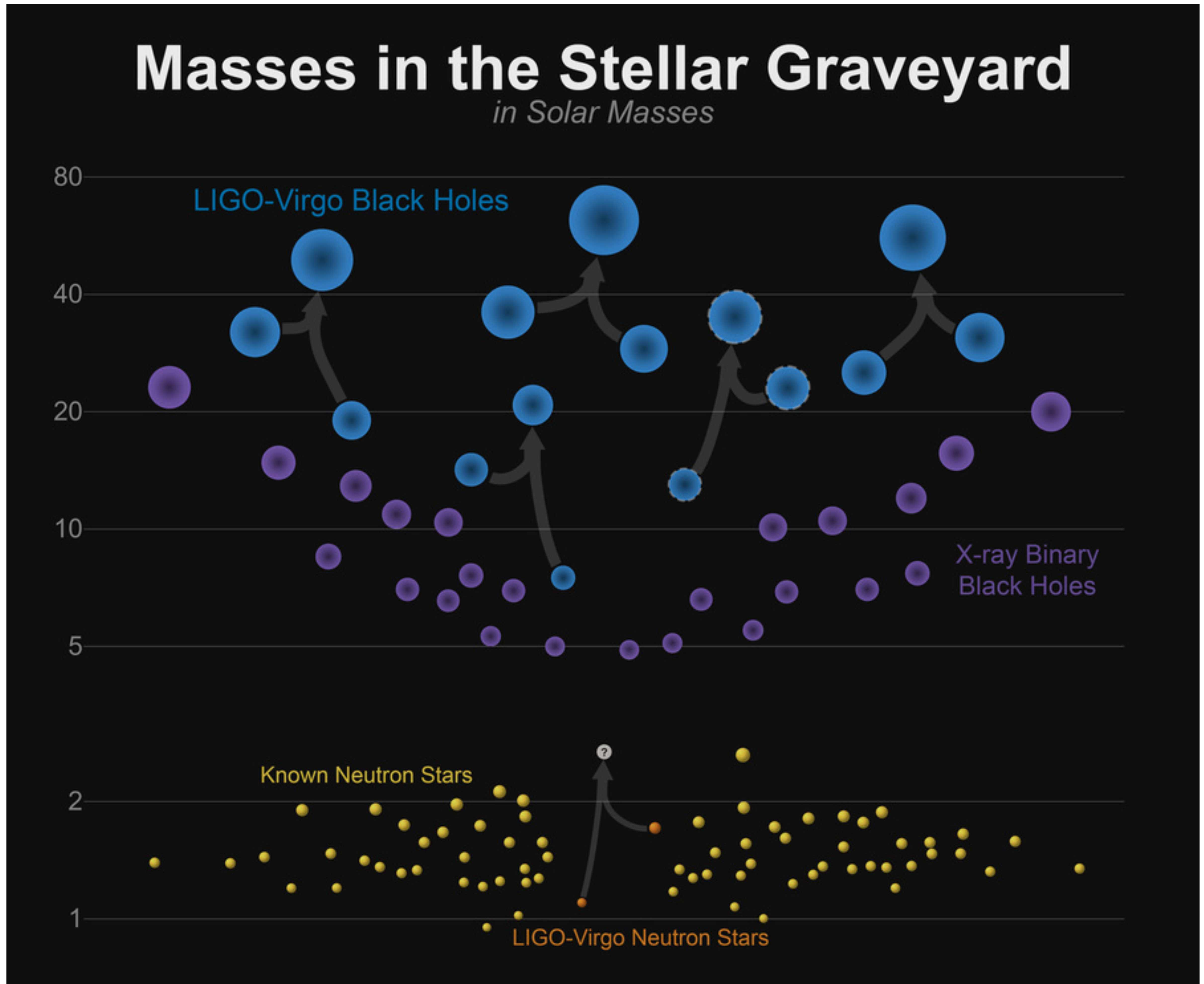
[Sukanta Bose's talk]

Implications: Astrophysics and Cosmology

[K. G. Arun's talk]

- Strong evidence for the BNS engine of short-gamma-ray bursts.
  - Constraints on the GRB physics.
- Merger rates of BNSs: $R = 1540^{+3200}_{-1220}\ \mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$
  - Consistent with the inferred rate from galactic BNS systems.
  - Stochastic GW background from BNS and BBH mergers potentially detectable by advanced detectors.
- Upper limit on GW emission from the post-merger phase.

[Archisman Ghosh's talk]



LIGO-Virgo/Frank Elavsky/Northwestern University