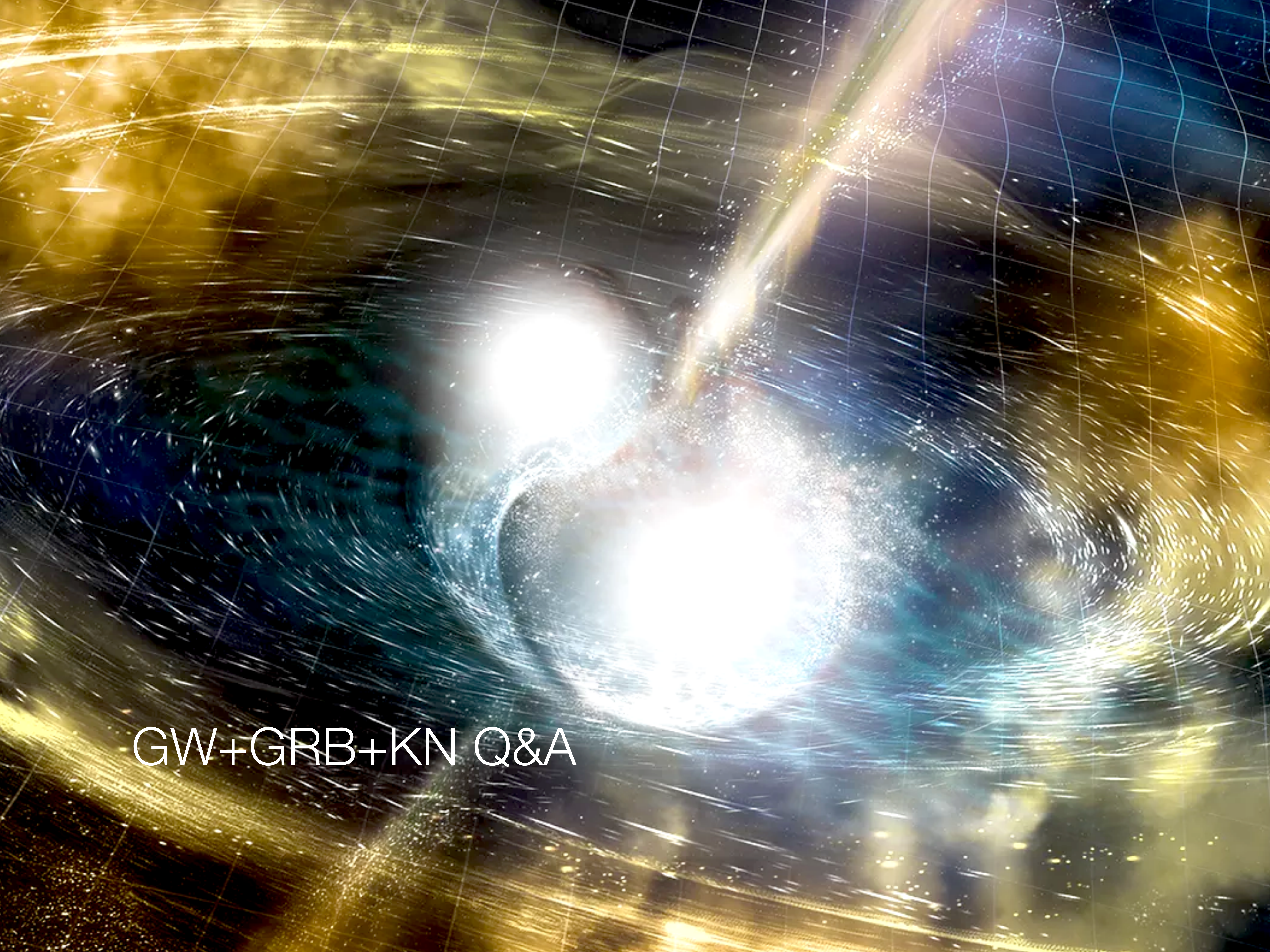
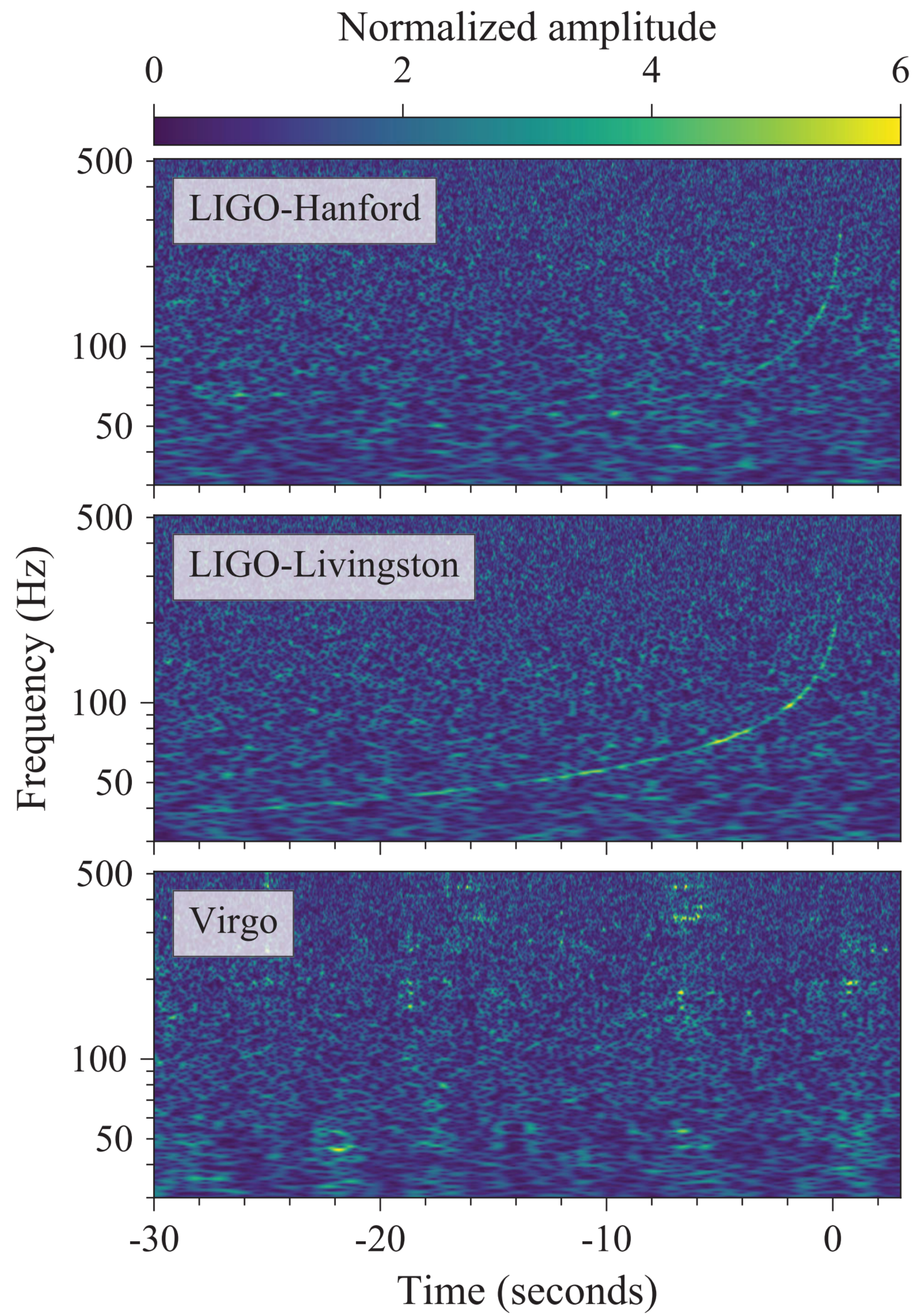

GW+GRB+KN Q&A

Gravitational wave

- *LIGO* detection of GW170817
  Binary neutron star inspiral
  Time 12:41:04.4 UTC

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 $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc
Viewing angle Θ	$\leq 55°$
Using NGC 4993 location	$\leq 28°$

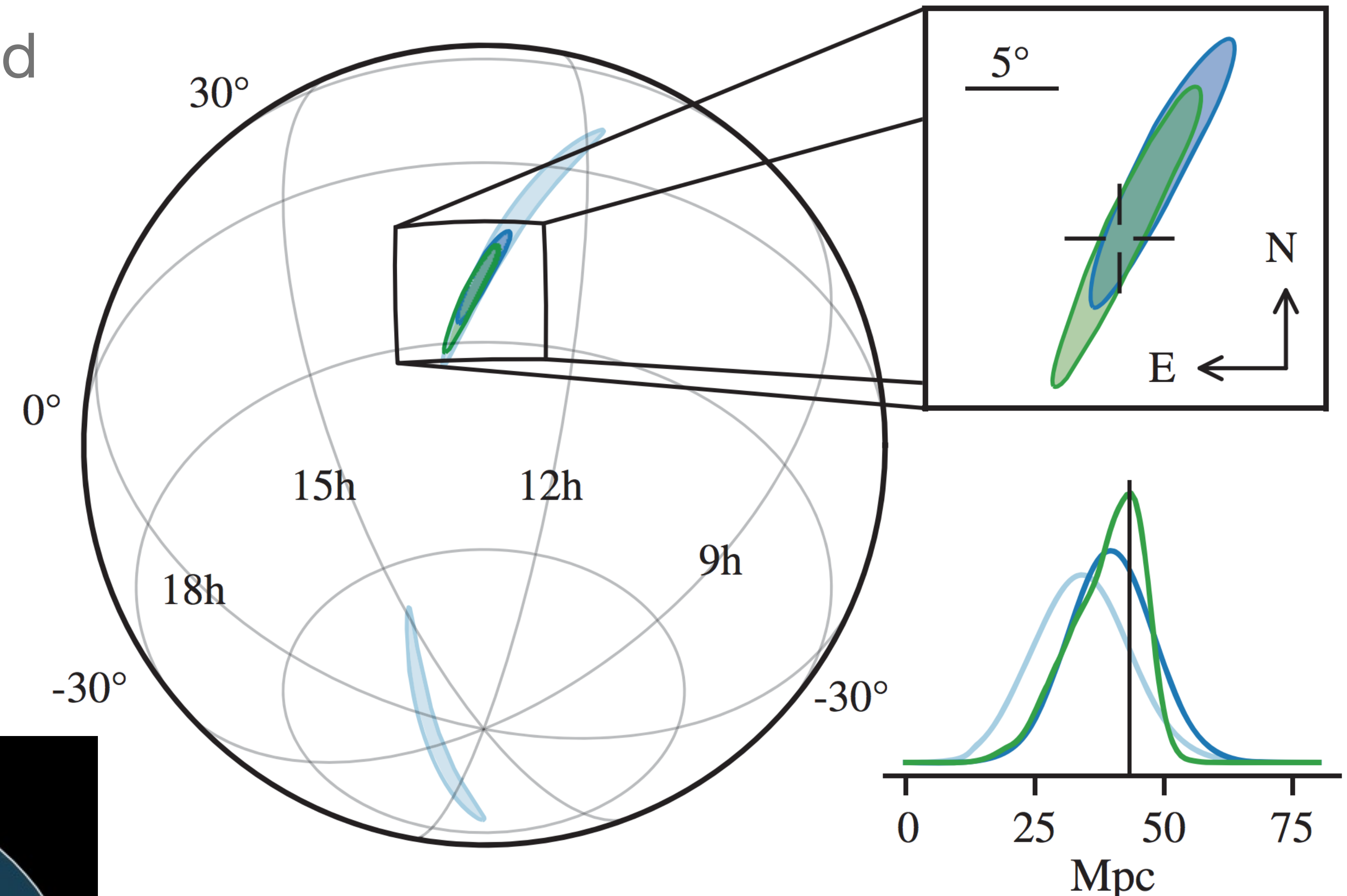
$$\mathcal{M} = (m_1 m_2)^{3/5}(m_1 + m_2)^{-1/5}$$



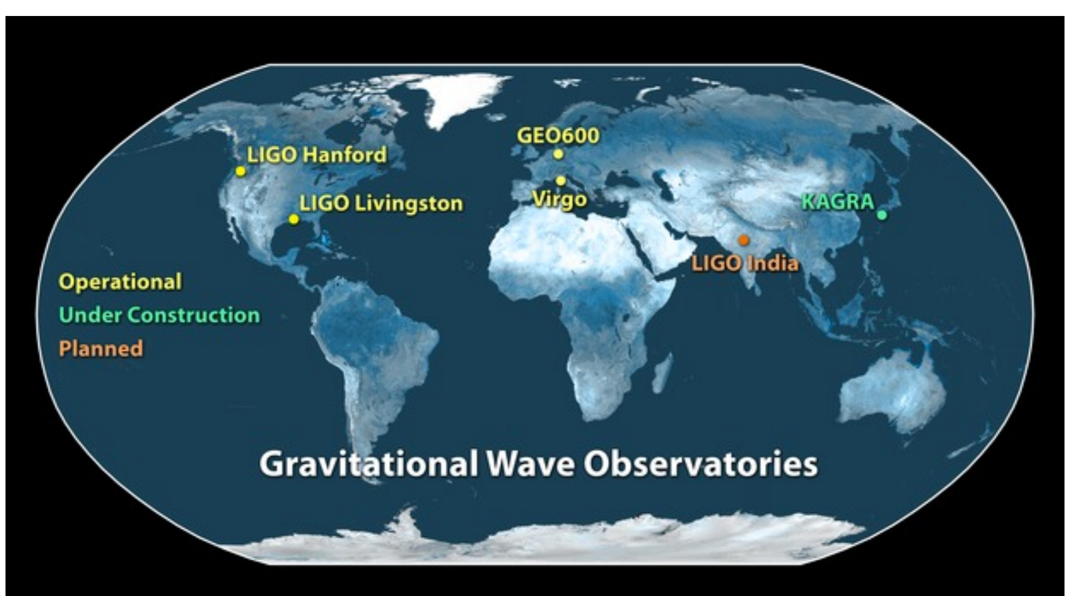
LIGO + Virgo (2017)

Gravitational wave

- Low signal of *Virgo* provided strong constraint on sky position.
- Localized to within 28 sq. deg. (>600 sq. deg in previous GW detections)



LIGO + Virgo (2017)



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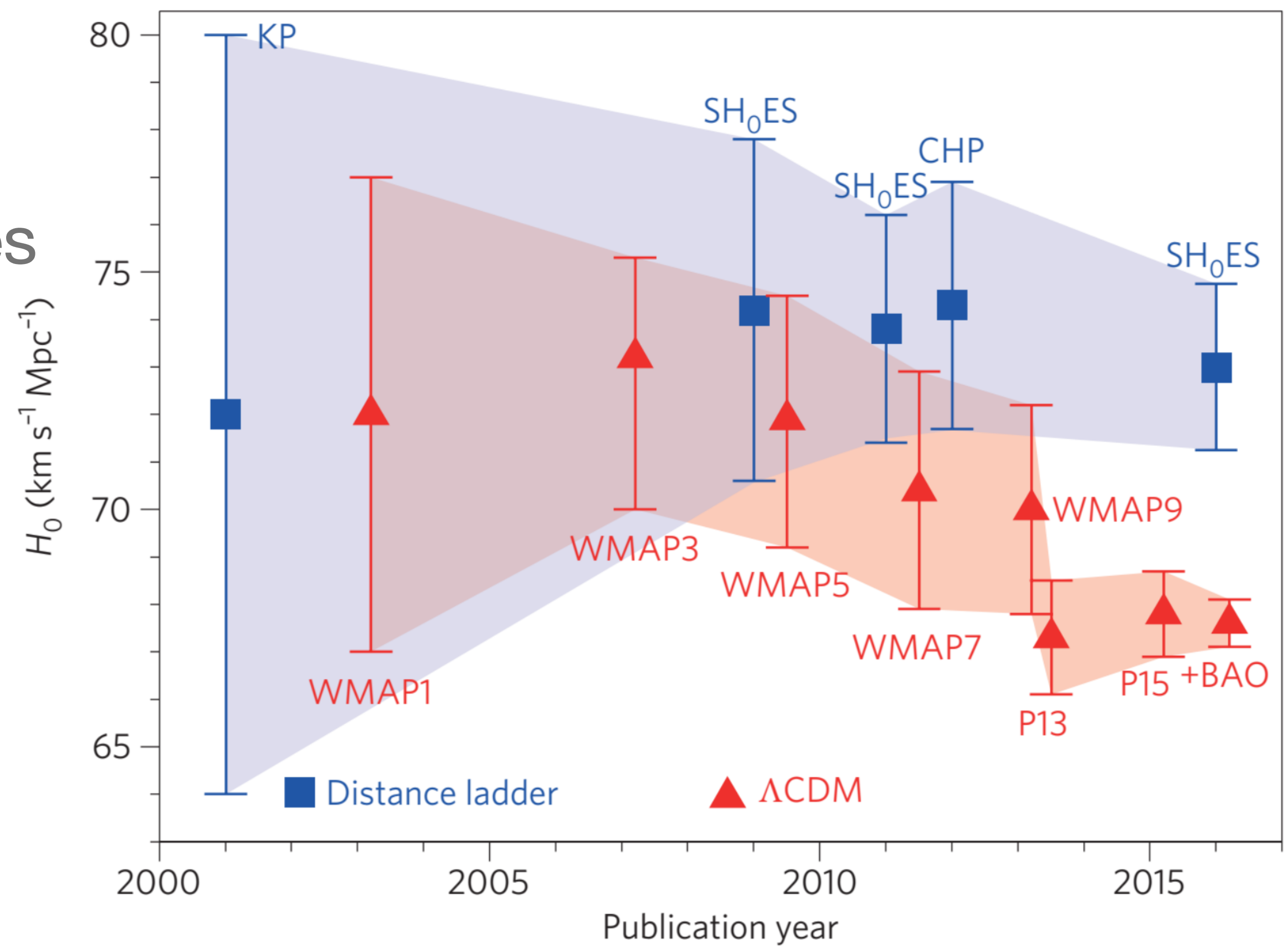
Gravitational wave

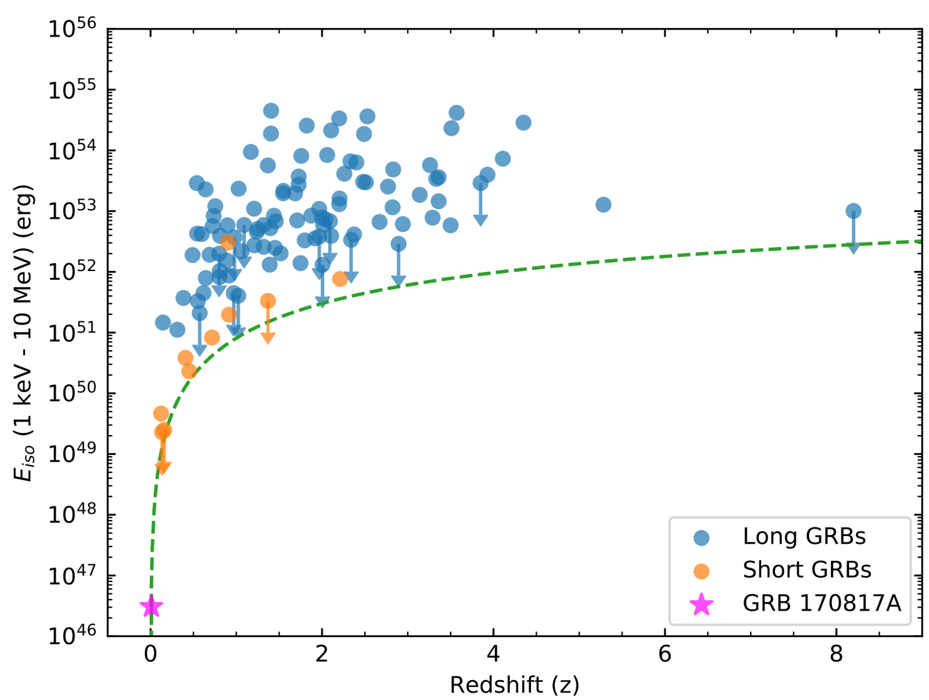
- Distance of 44+3-7 Mpc was determined with only GW from "standard siren," independent from current distance techniques (e.g., standard candles).
- Together with redshift from EM localization (GW does not provide redshift), Hubble constant is 70+12-8 km/s/Mpc.

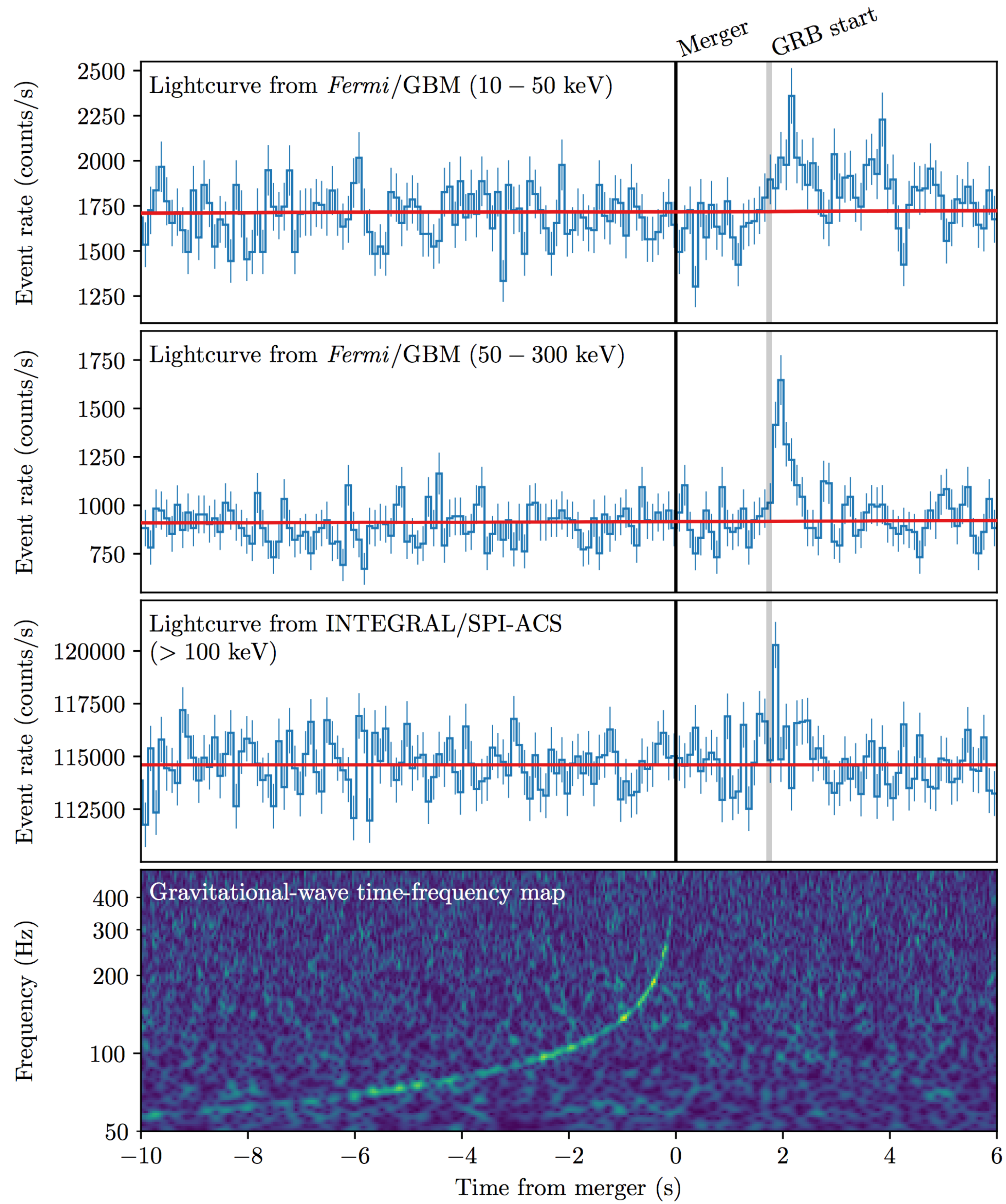


Freedman (2017)

Gamma-ray

- 1.7 seconds later, short GRB, GRB 170817A independently detected by *Fermi* and *INTEGRAL*.
- Unusually faint compared to other short-duration GRBs.
- Short GRBs long suspected to result from NS-NS mergers.

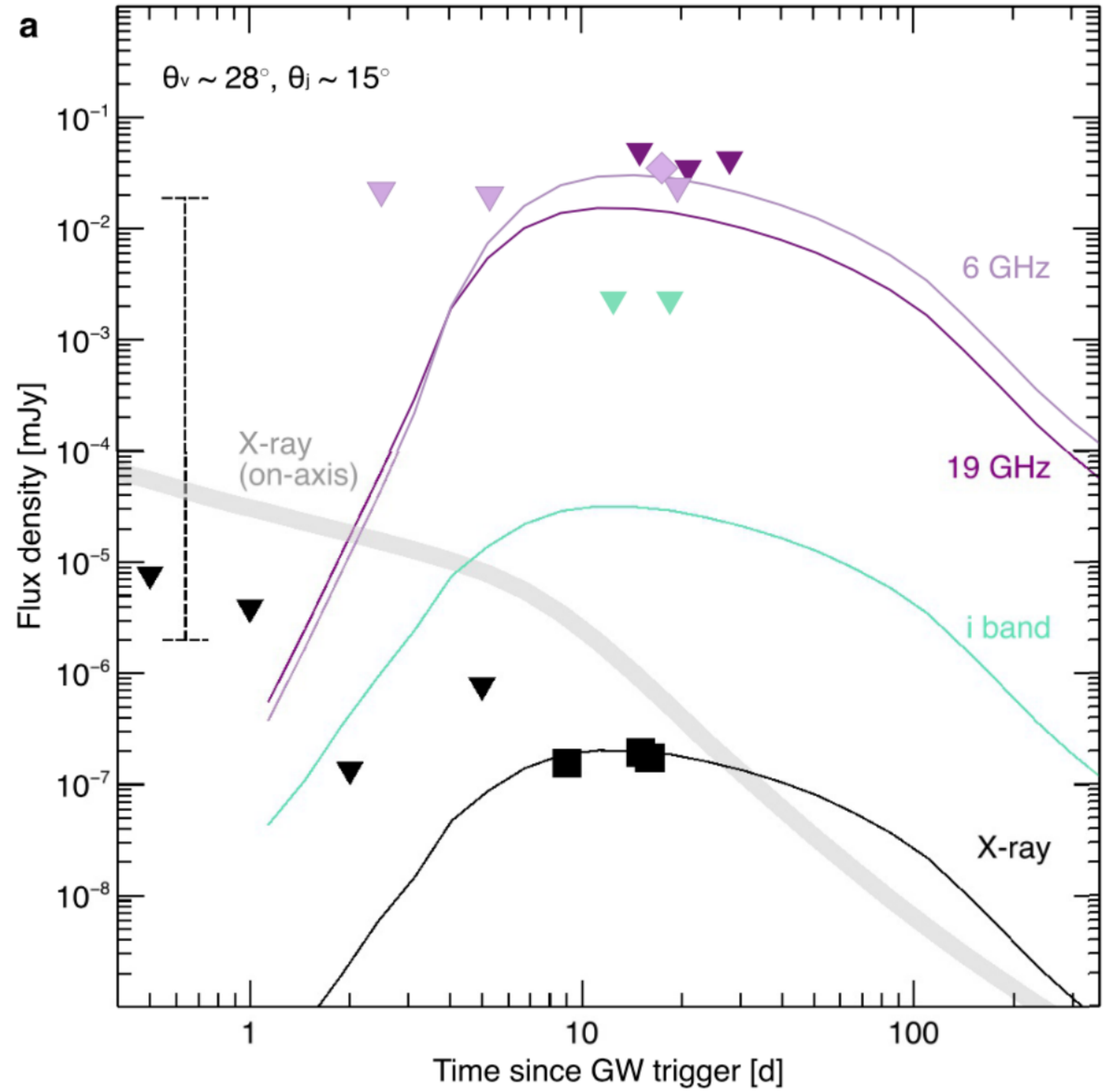




LIGO + Virgo + Fermi + INTEGRAL (2017)

X-ray + radio

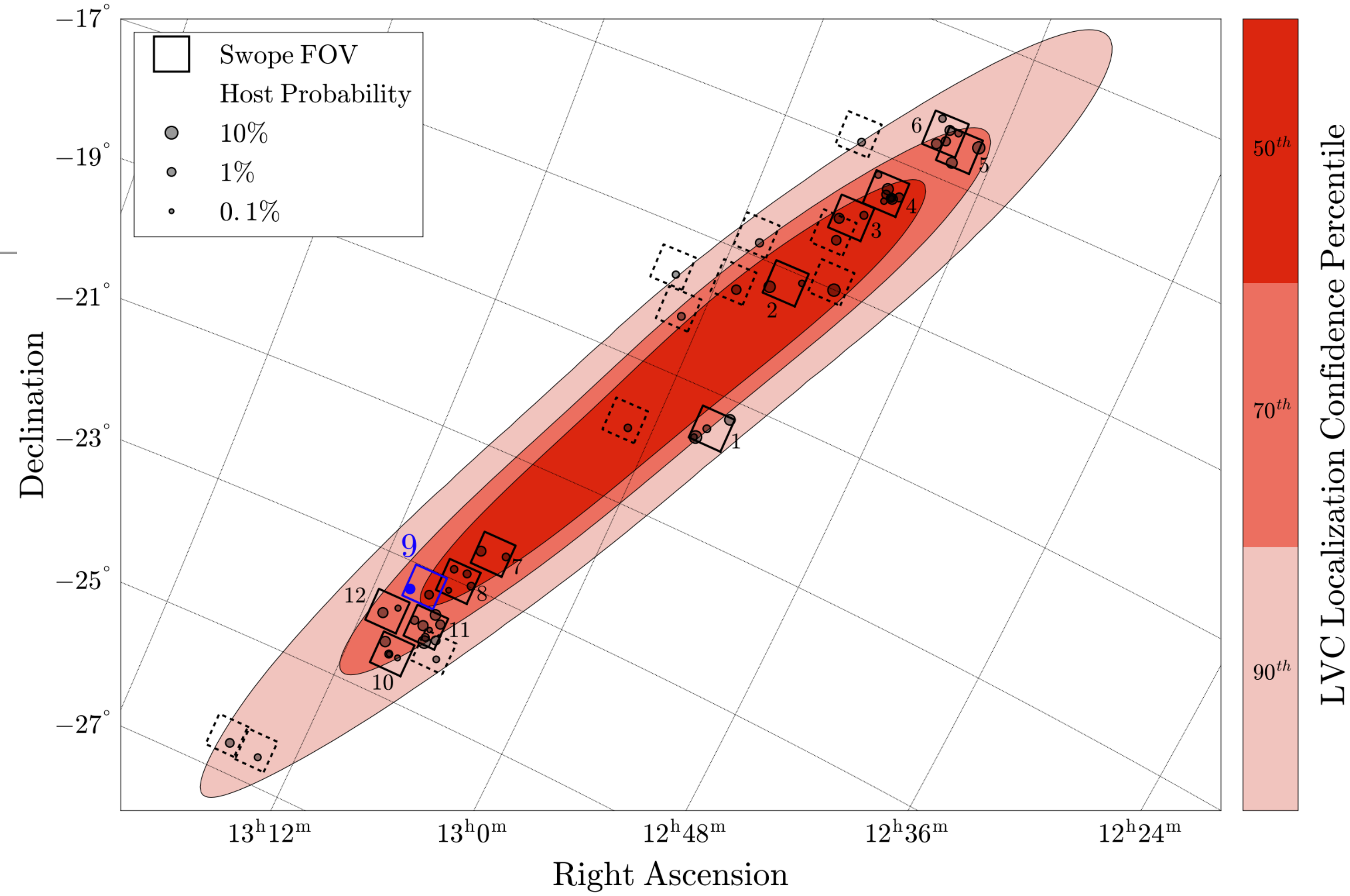
- If the system launches relativistic jets as the detection of short GRB suggests, synchrotron radiation mainly in X-ray and radio is expected.
- Delayed (~10 days) and rising X-ray emission from *Chandra* interpreted as a jet with an opening angle ~15 ° and ~28° off axis.

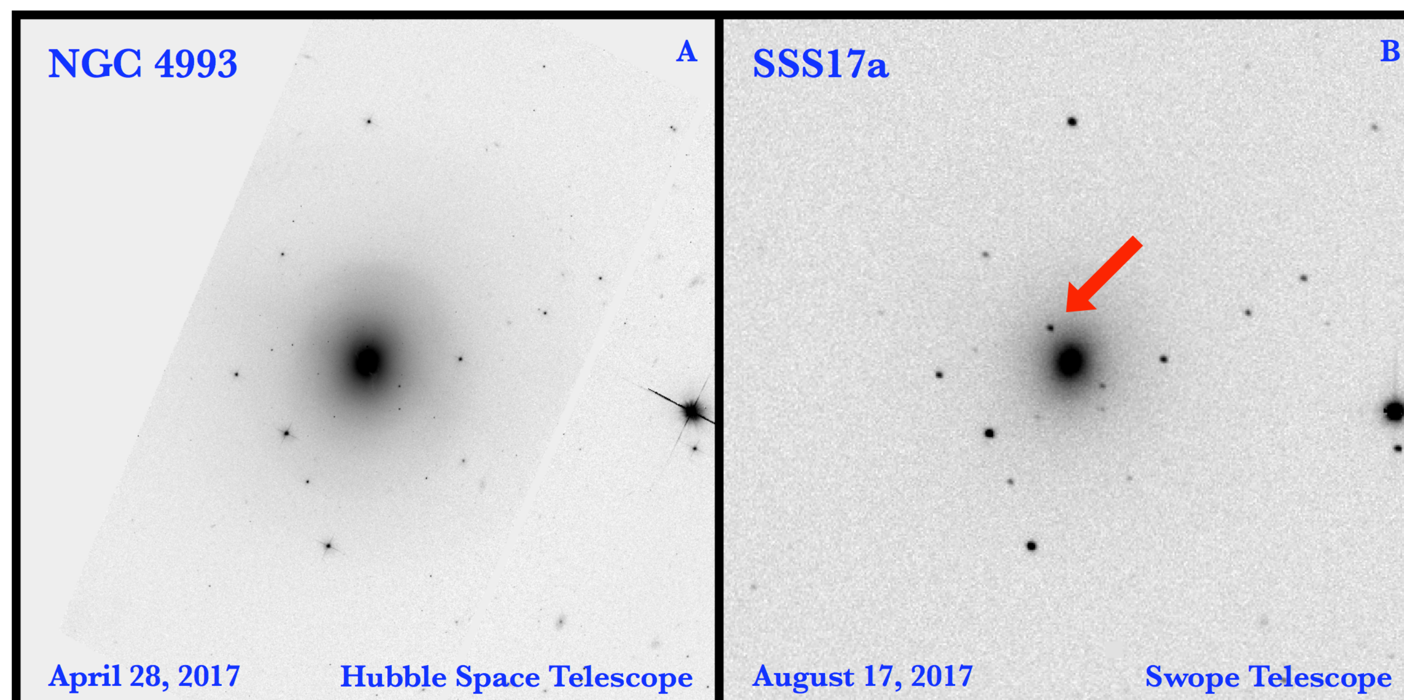


Troja et al. (2017)

Optical + NIR

- After GW+GRB, race is on to localize the source. Swope at Las Campanas won the price.
- SSS17a/AT2017gfo
- RA of 13h in August, setting, ~3hr from Sun!
- Optical observations 10.86 hr after merger provided localization in outskirts of NGC 4993.
- Tully-Fisher distance 41.1 Mpc, redshift z=0.0097.

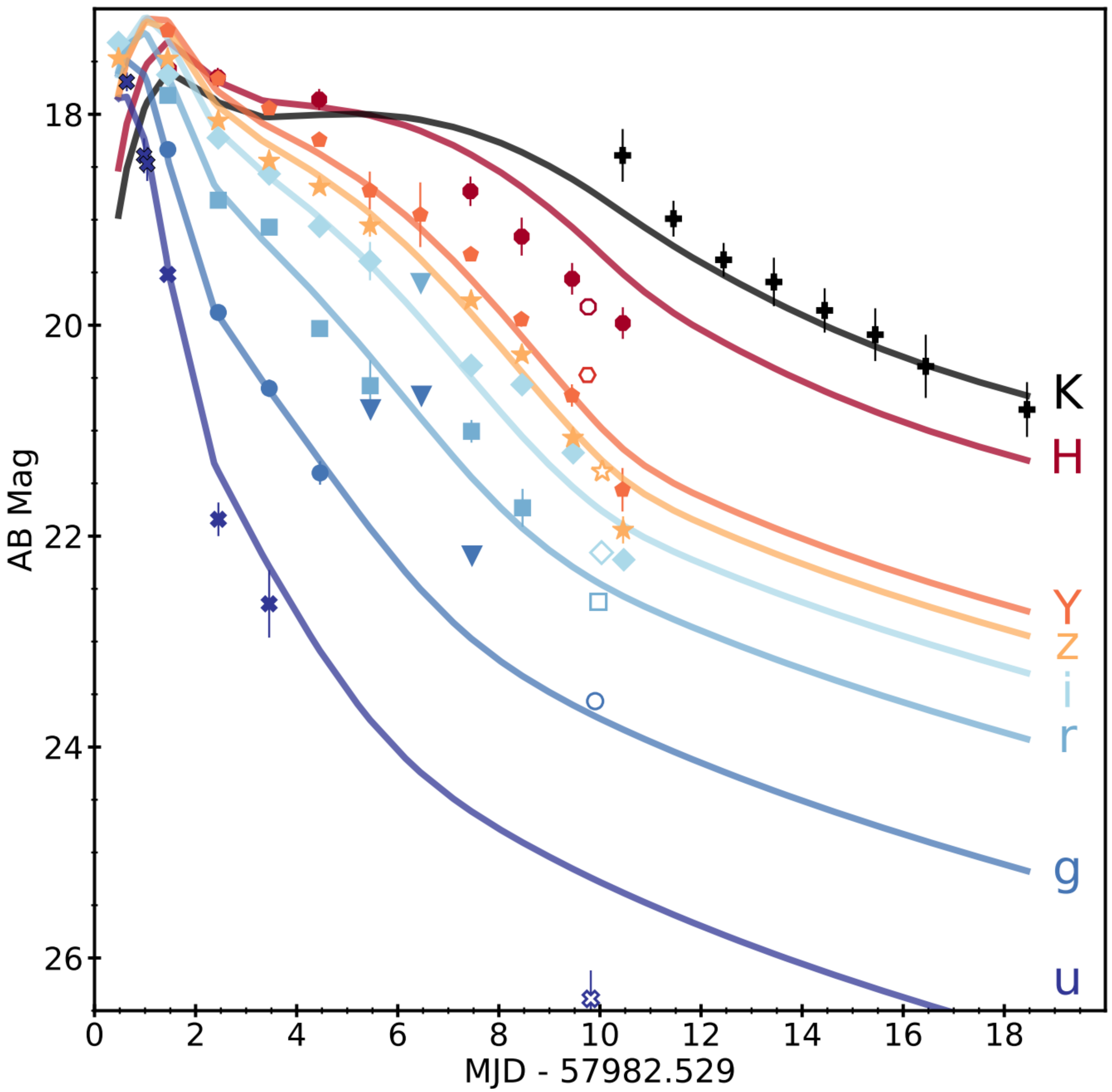




Coulter et al. (2017)

Optical + NIR

- Evolution follows theoretical “kilonova,” powered by radioactive decay of r-process nuclei synthesized in neutron rich merger ejecta.
- Initial rapid peak in optical, followed by broad peak in NIR.



Cowperthwaite et al. (2017)

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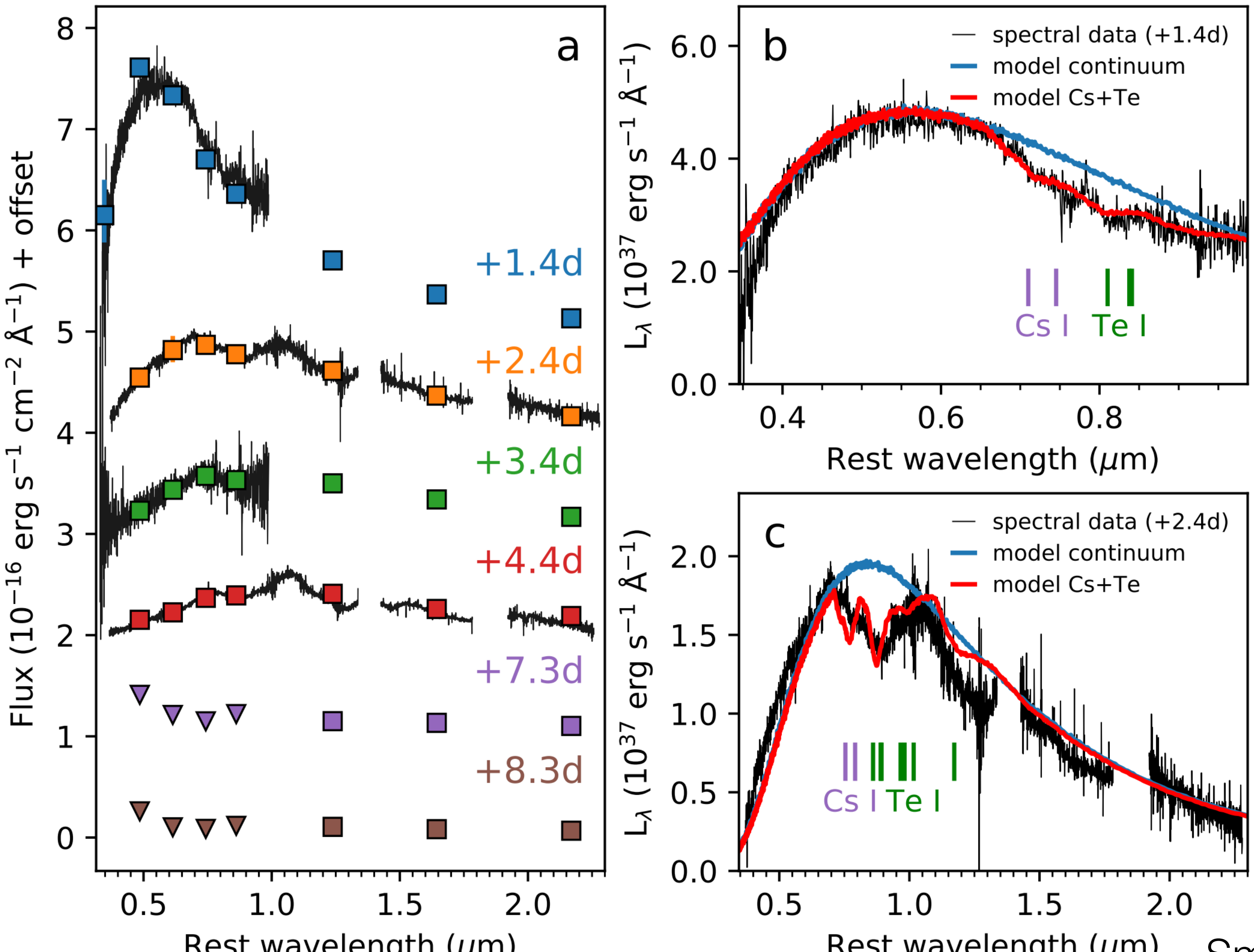
Optical + NIR

- Lines are broad (high velocity) and some light r-process elements were identified in the spectra.

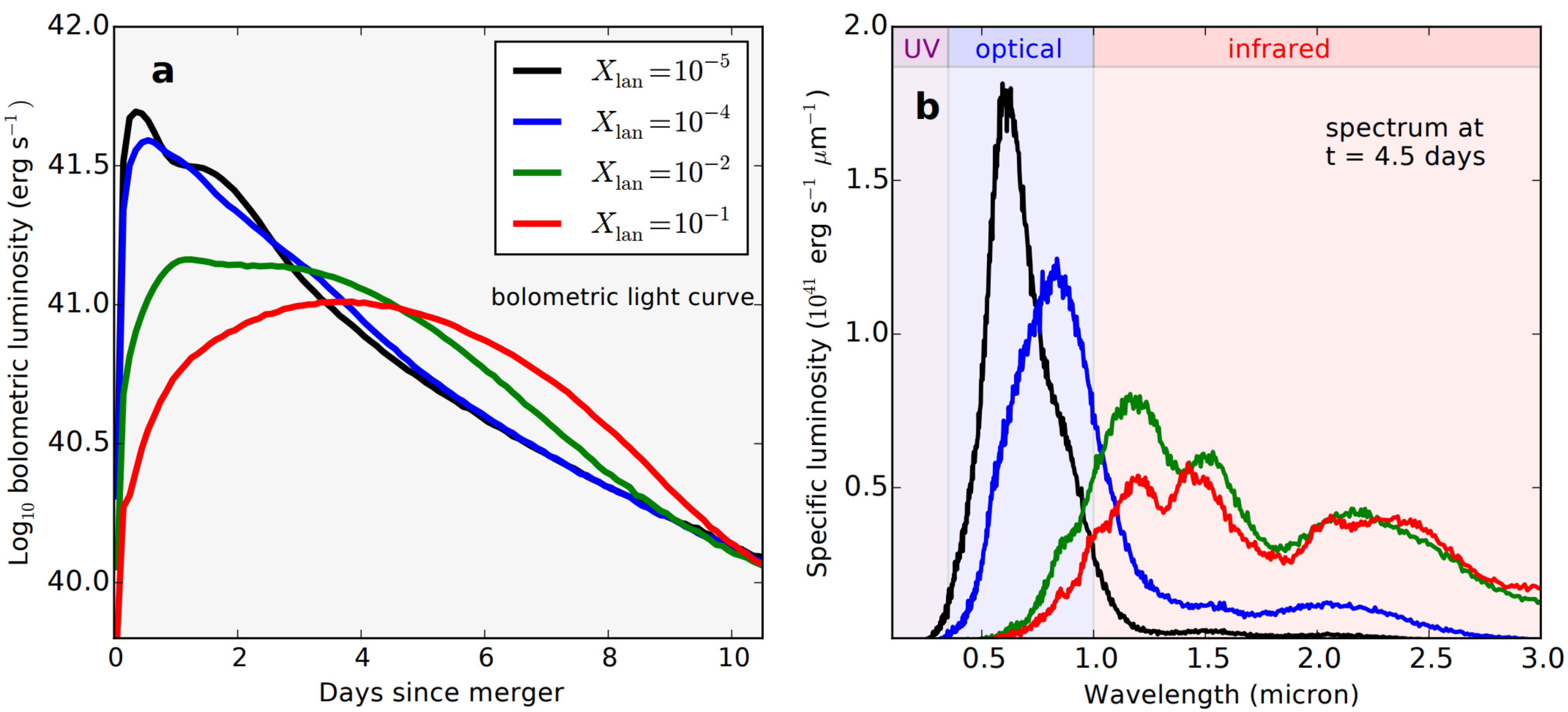


Smartt et al. (2017)

Kilonova

- NS-NS or NS-BH mergers should produce neutron-rich radioactive species, whose decay should result in a faint transient, “kilonova,” main source of stable r-process elements in the Universe.

- Ejecta rich in heavy r-process elements expected to peak in the NIR because of high optical opacity.



Kasen et al. (2017)

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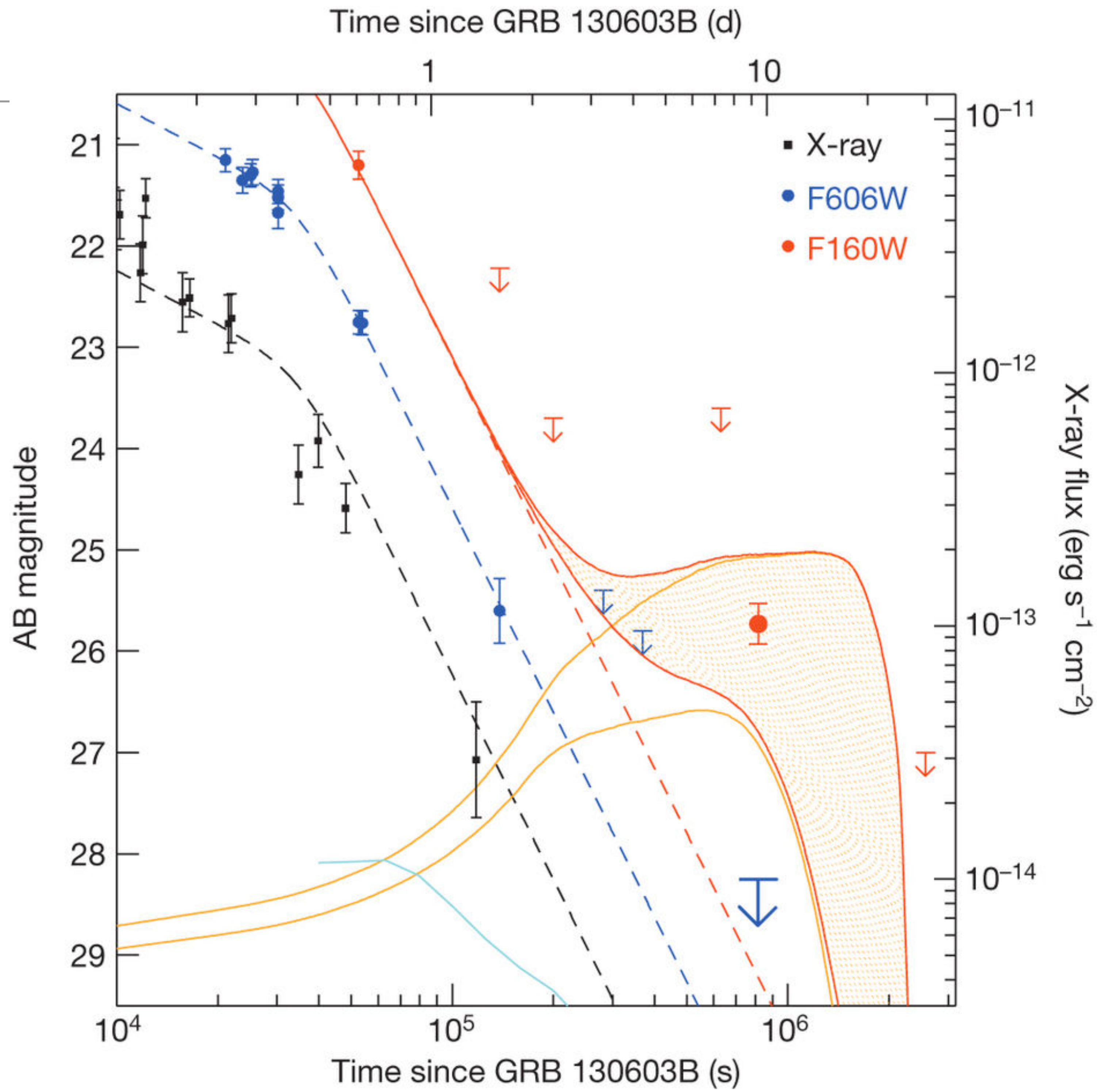
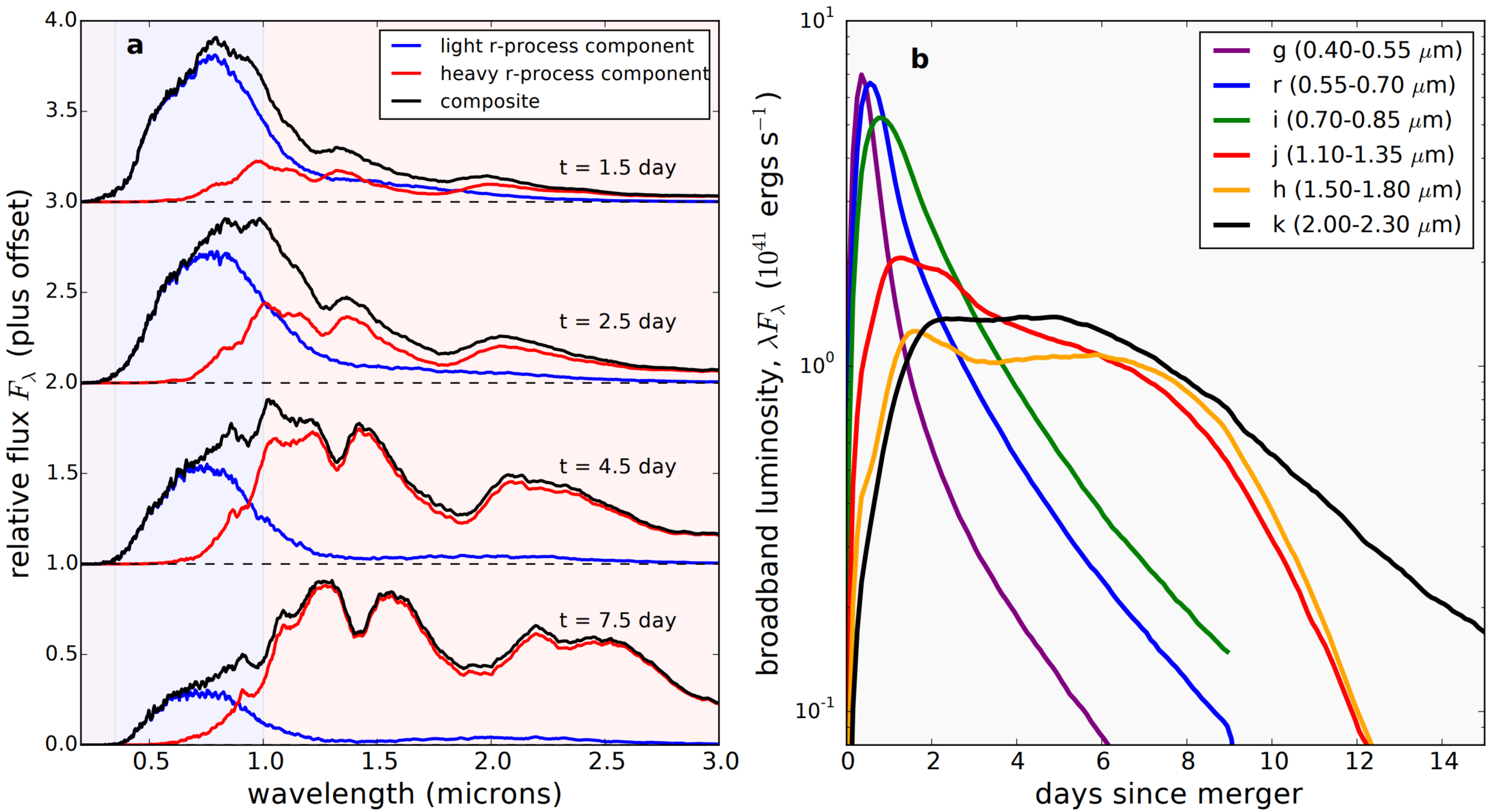
Kilonova

- SSS17a is not the first observed: GRB130603B + kilonova
- z=0.356 or 1800 Mpc or distance modulus 41 mag
- “Kilo”nova is ~1000x brighter than nova or —15 absolute mag
- Magnitude of 26 mag, exceedingly difficult observation.



Tanvir et al. (2013)

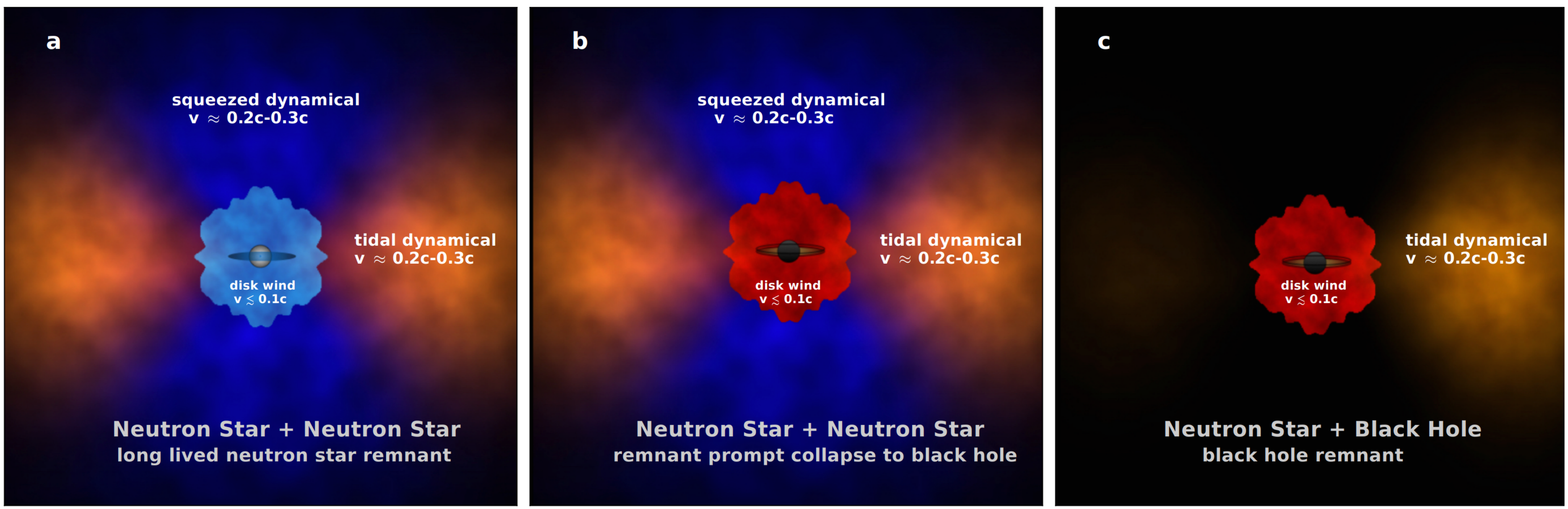
Kilonova



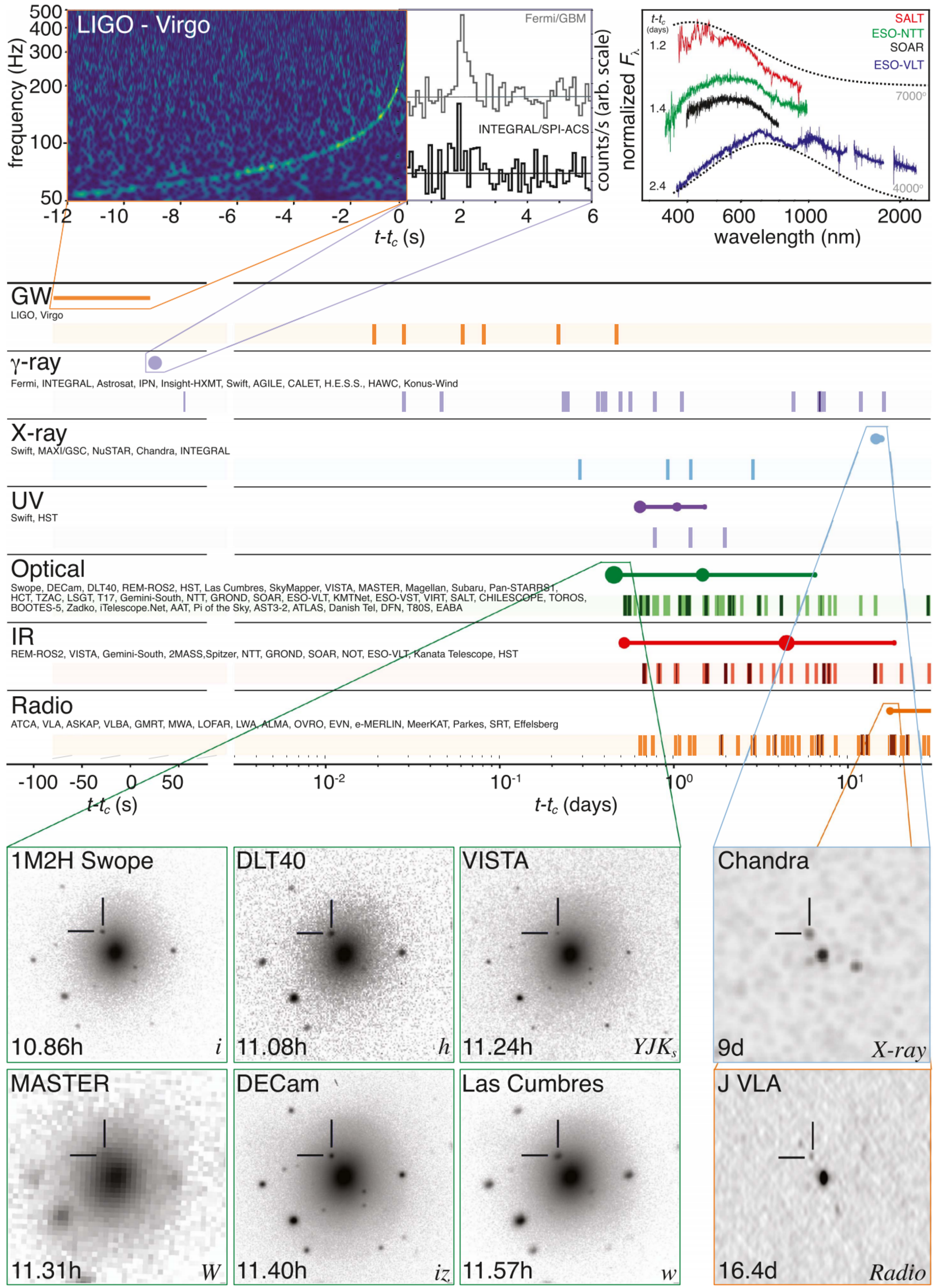
Kasen et al. (2017)

What's left?

- Inferred mass of the "red kilonova" large, suggests that it is produced in post-merger disk wind and the remnant collapsed rapidly => black hole.
- If remnant is a hot neutron star that survived longer than 10s ms, neutrino irradiation would reduce neutron fraction => "blue kilonova"



Kasen et al. (2017)



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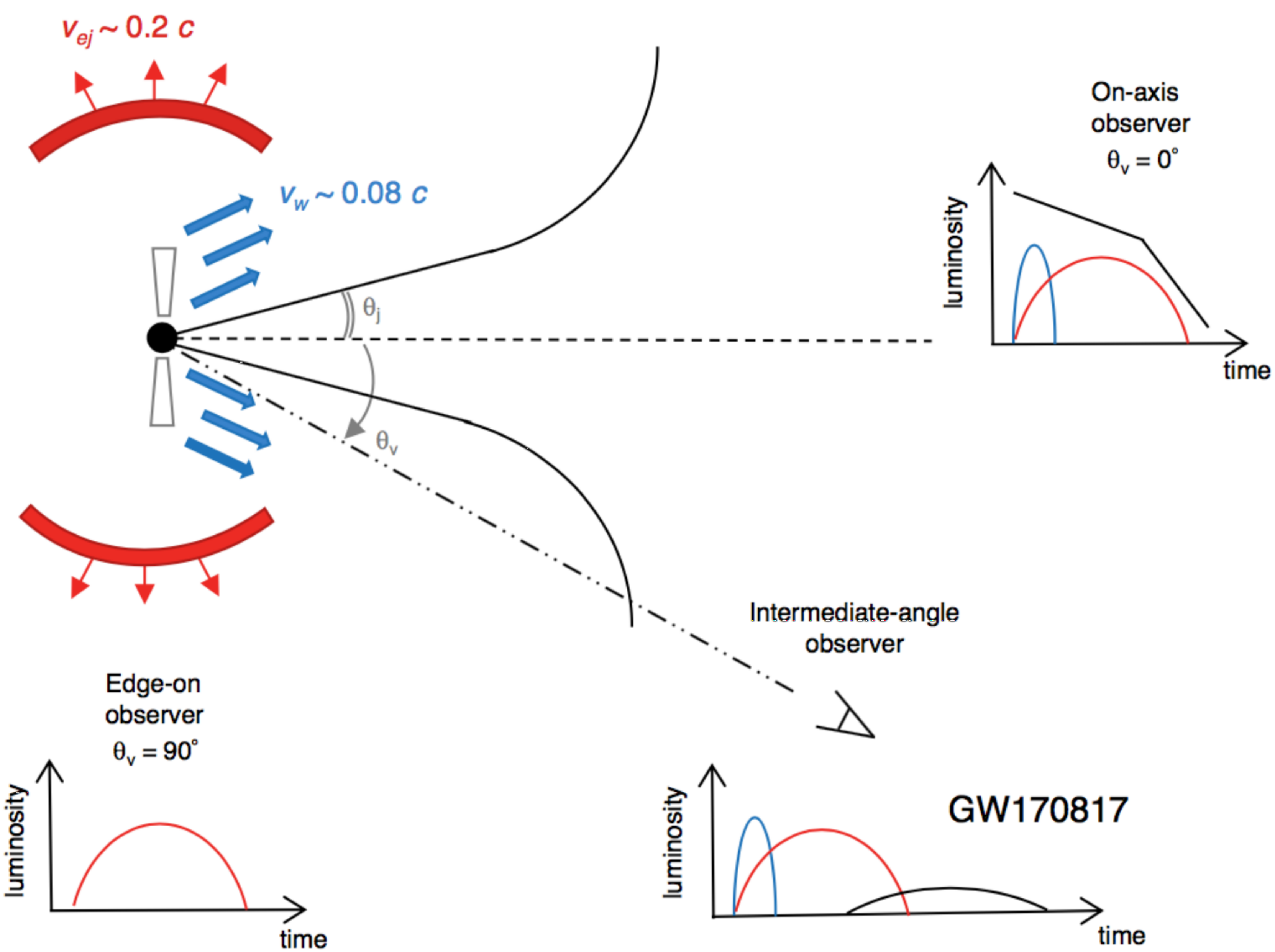
LIGO + Virgo (2017)

Summary

- During merger, tidal force strips matter, form torus.
- Red: neutron-rich heavy r-process ejecta produces optical-NIR emission peaking in NIR.
- Blue: neutron-poor light r-process ejecta produces optical emission.
- Black: collimated jet with synchrotron radiation emitting radio and X-ray. Faint short GRB due to viewing angle.



Troja et al. (2017)

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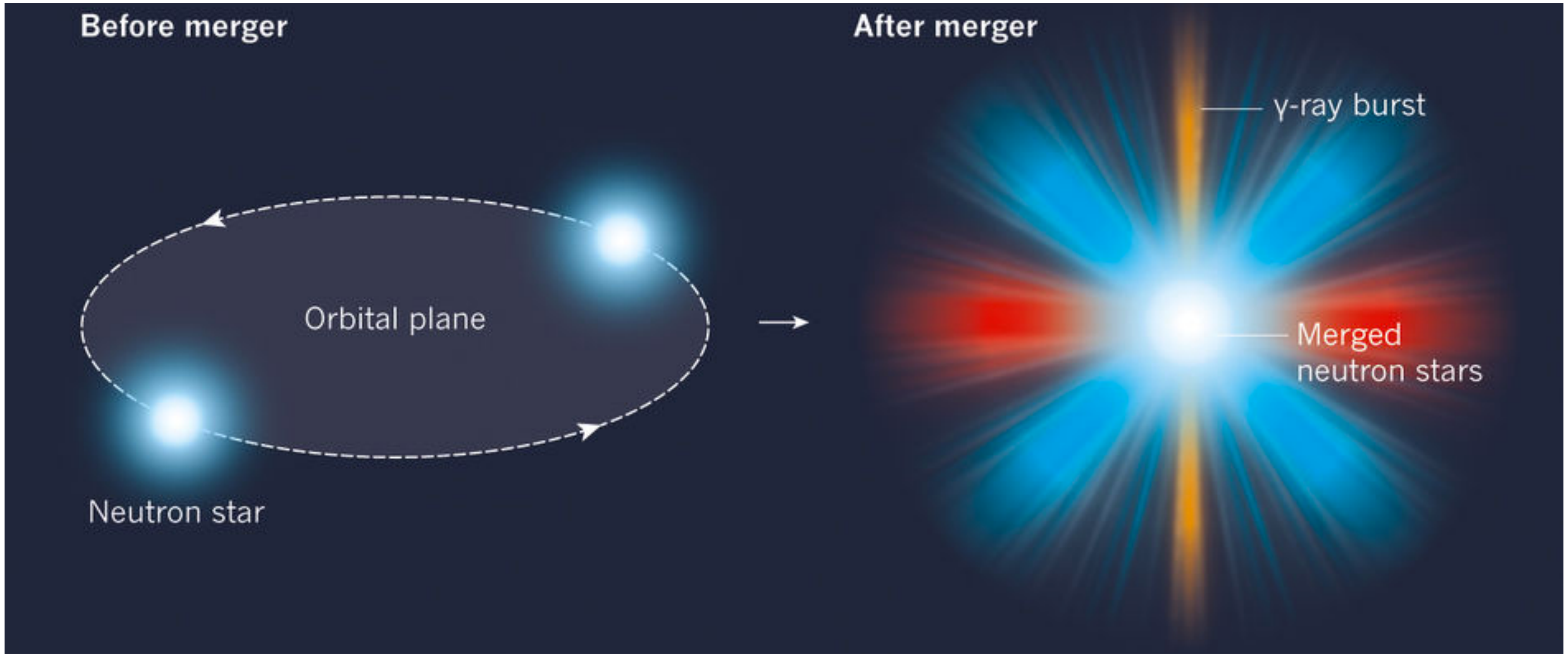
We got lucky!

- Virgo was online.
- It is the most nearby short-duration GRB.
- "Favorable" viewing angle to obtain lots of information.
- It would have been behind the Sun in 1.5 months.



Miller (2017)

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