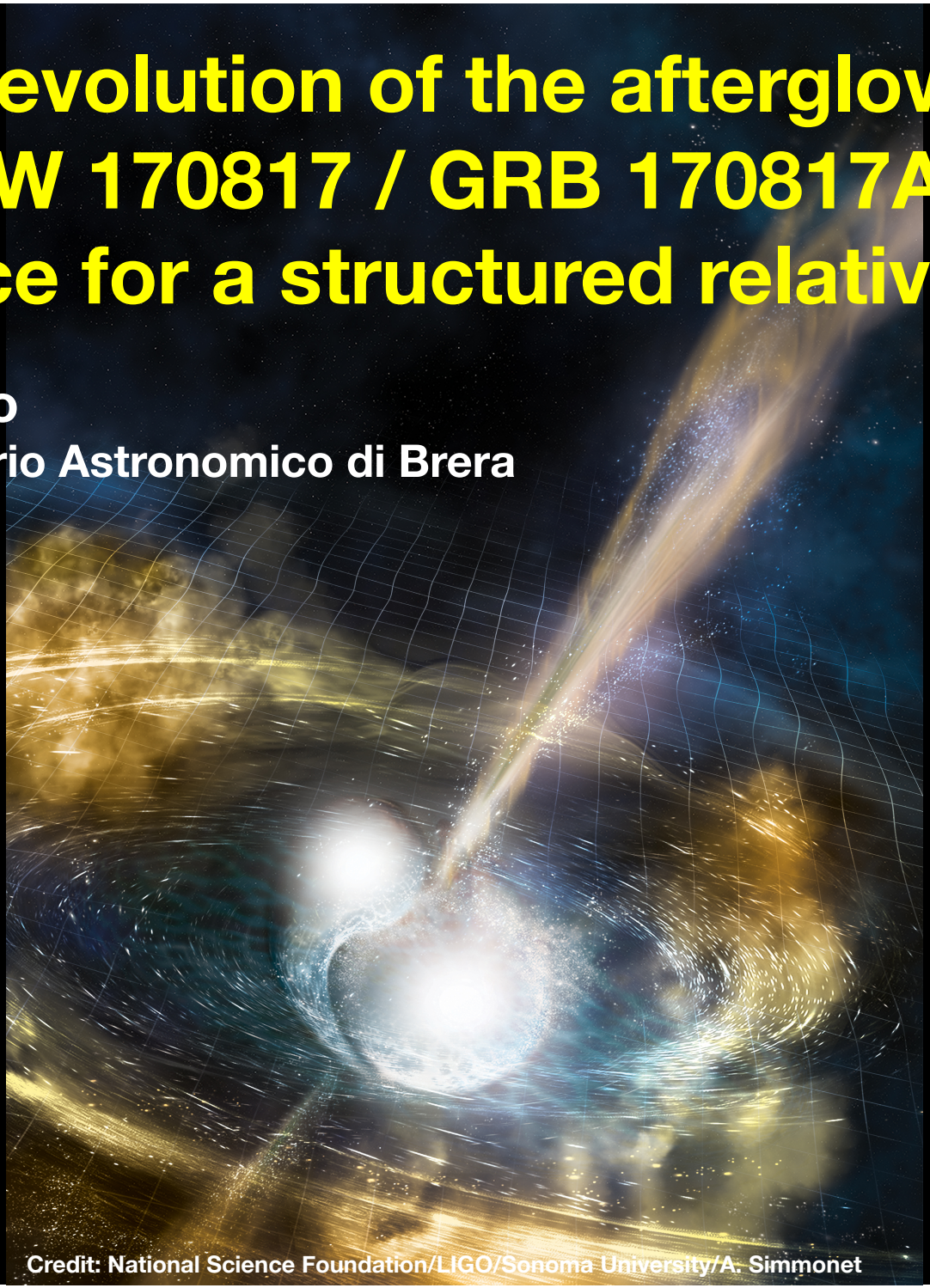
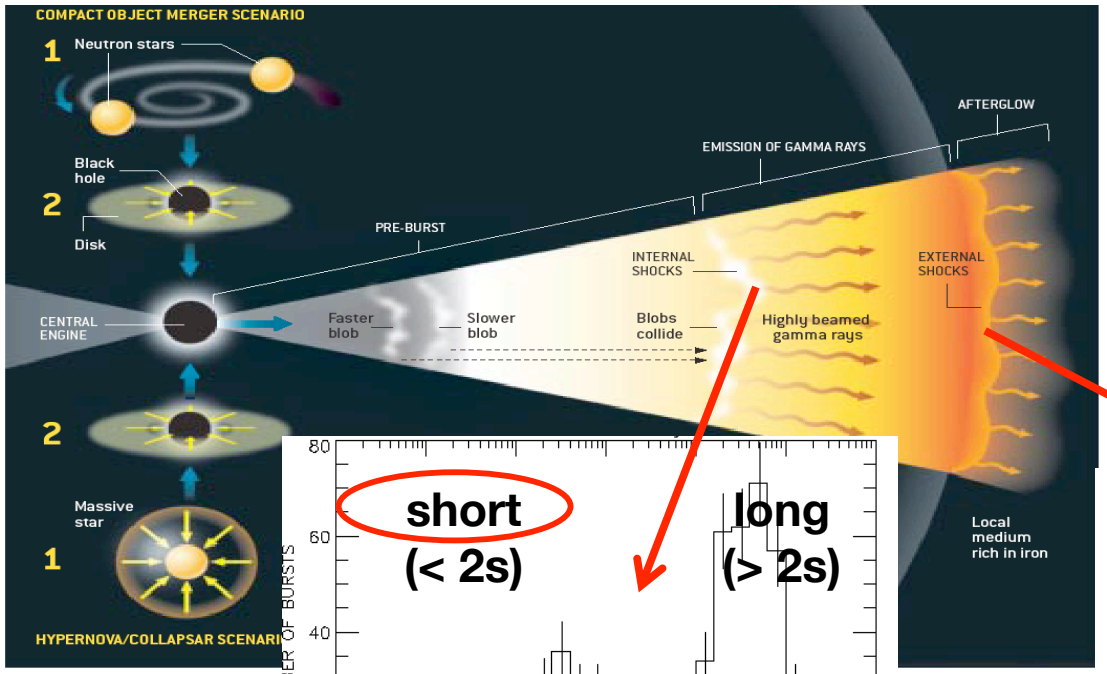
The evolution of the afterglow of GW 170817 / GRB 170817A: Evidence for a structured relativistic jet

Paolo D'Avanzo
INAF – Osservatorio Astronomico di Brera



Credit: National Science Foundation/LIGO/Sonoma University/A. Simmonet

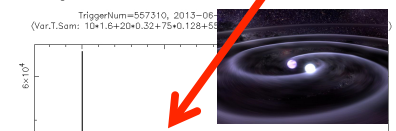
Gamma-ray bursts (GRBs)



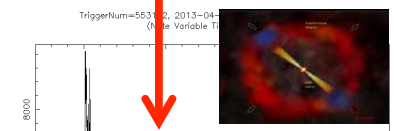
Brief, intense, flash of gamma-ray radiation:
(<z> ~ 2.1, E ~ 10^{52} erg)

Afterglow emission
Long lasting, fading, multiwavelength (X, opt, radio)

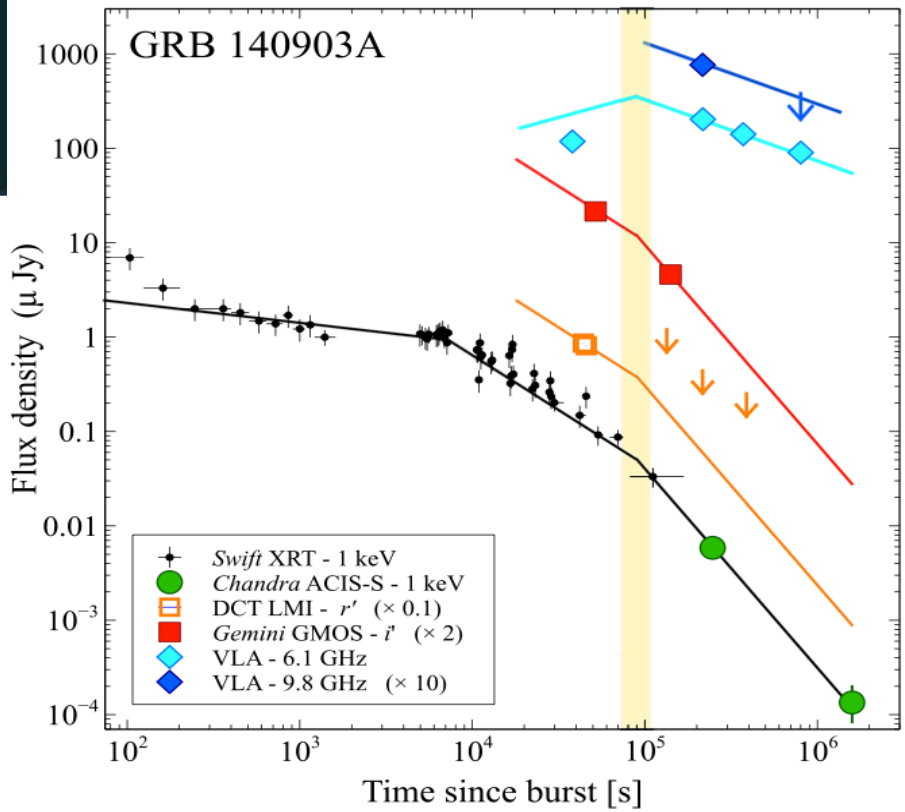
Prompt emission
(gamma)



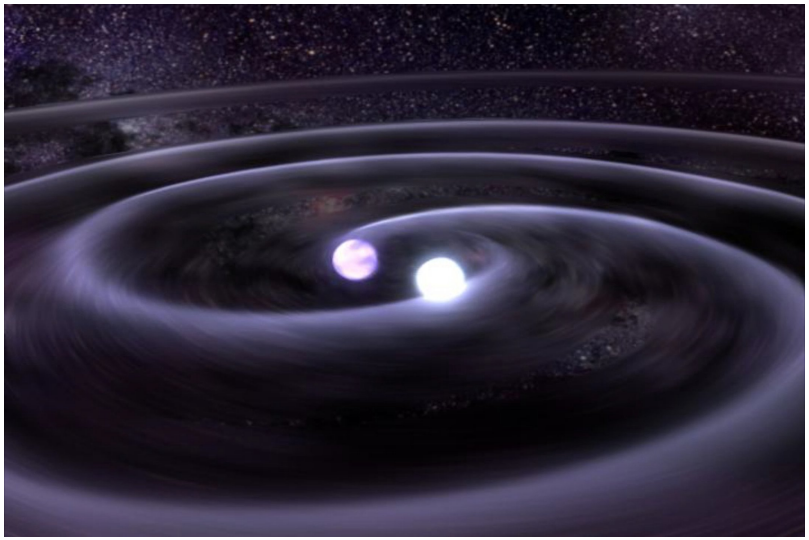
NS-NS/NS-BH progenitor

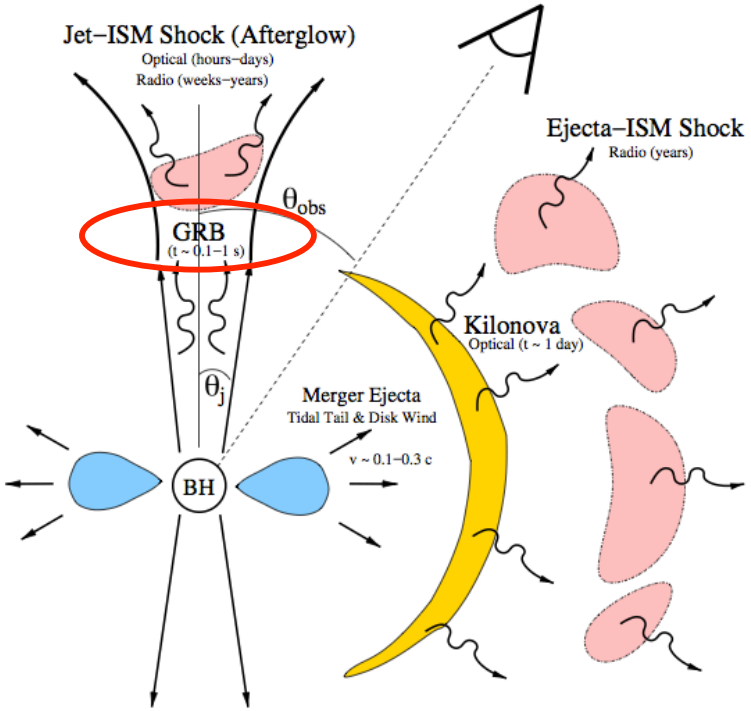


SN Ic progenitor



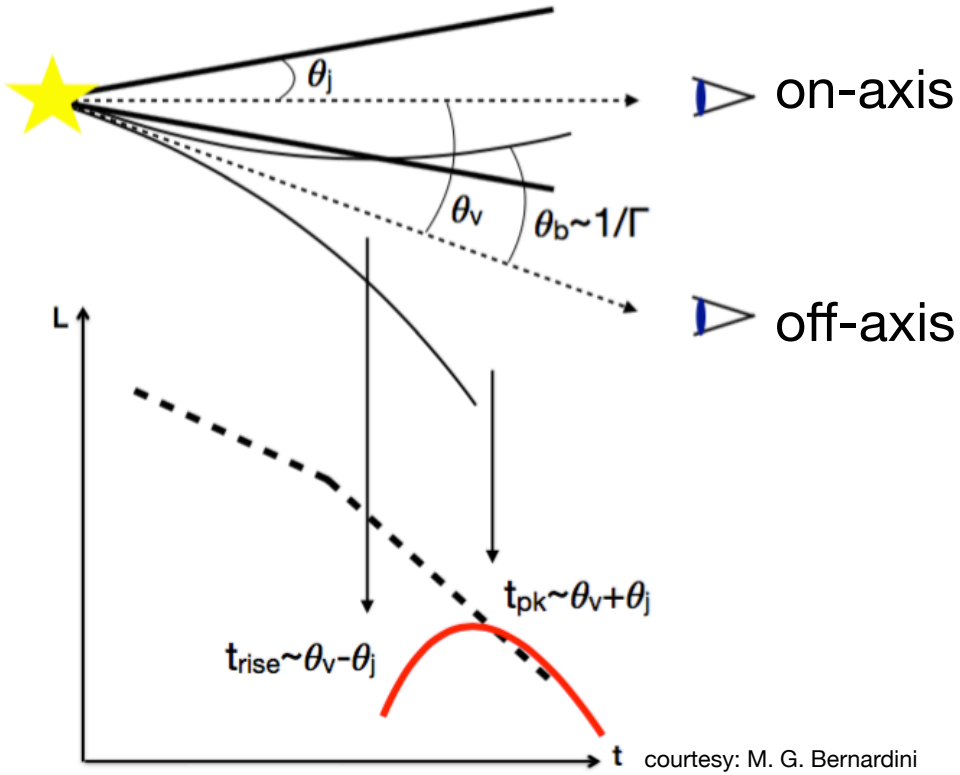
NS-NS / NS-BH electromagnetic counterparts





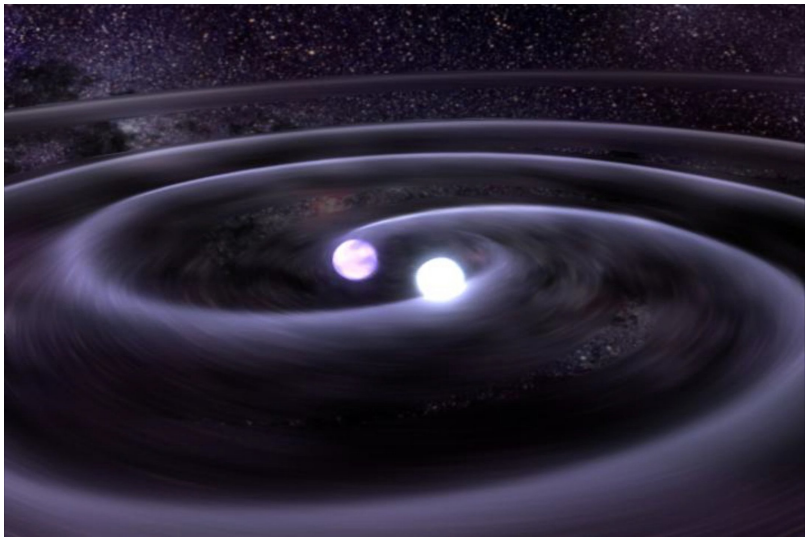
Metzger & Berger 2012

Short GRB

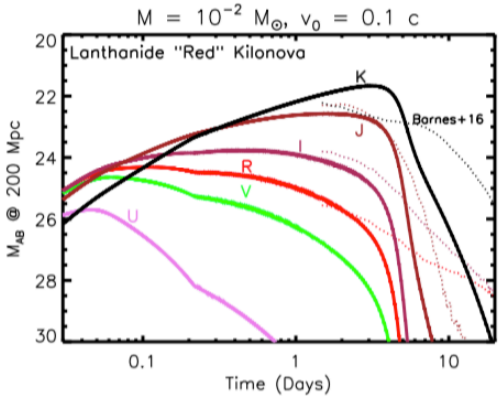


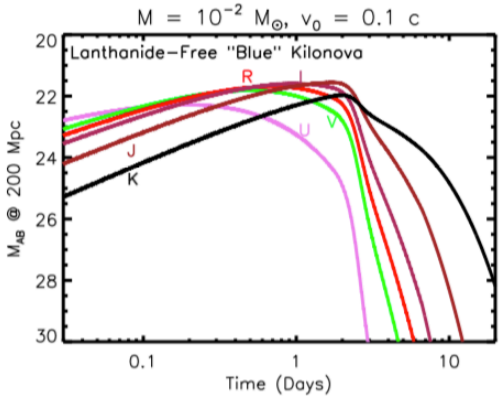
courtesy: M. G. Bernardini

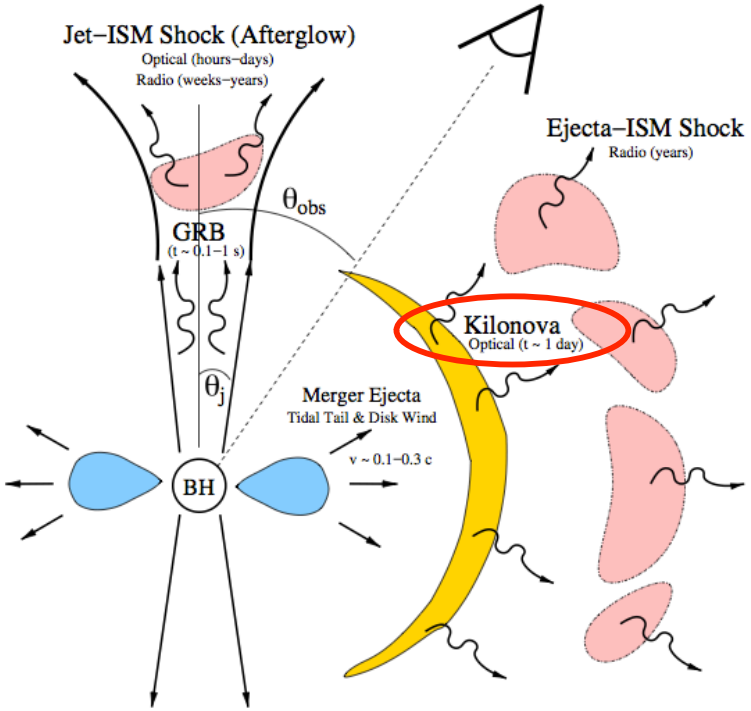
NS-NS / NS-BH electromagnetic counterparts



Kilonova (aka macronova)

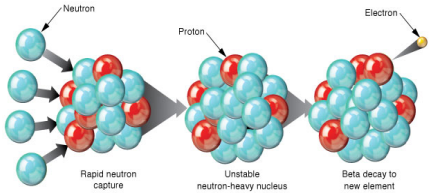


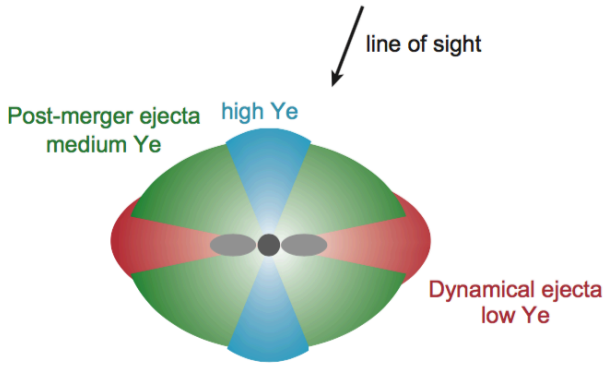




Metzger & Berger 2012

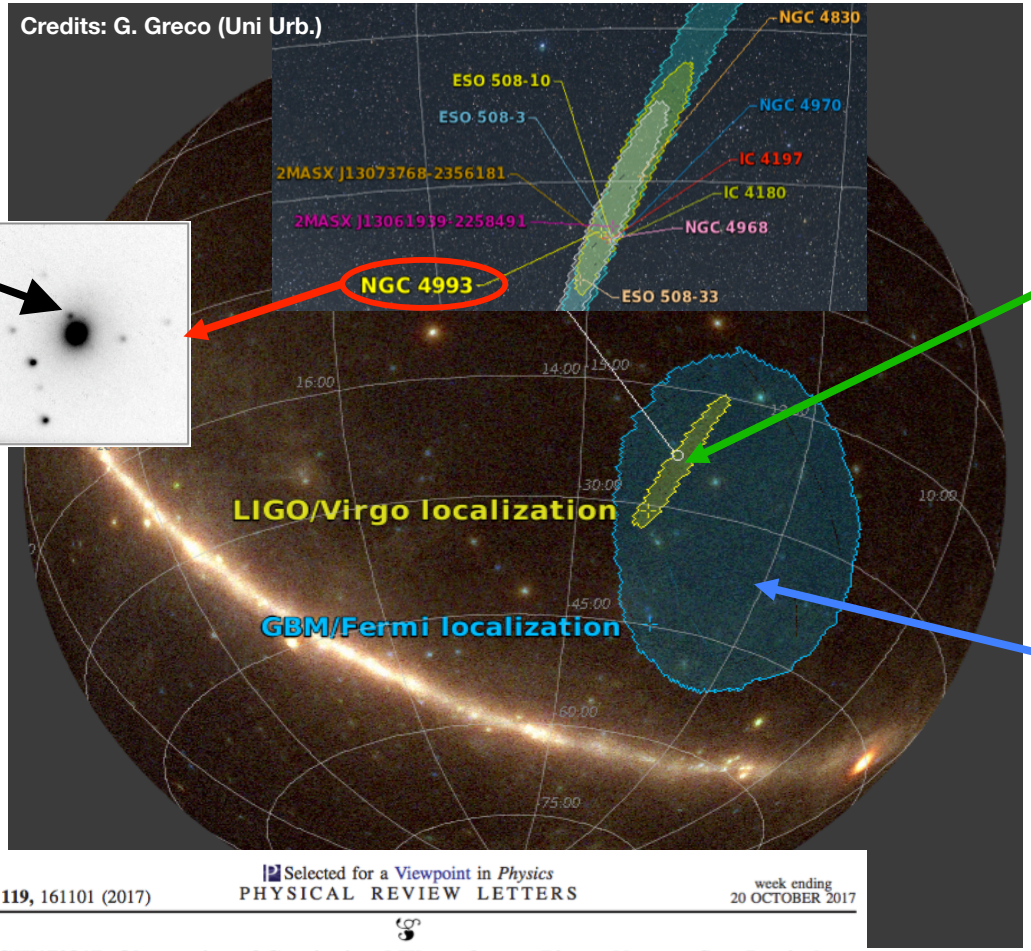
A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "kilonova" (aka "macronova") due to the decay of heavy radioactive species produced by the *r*-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog, 2005; Metzger et al., 2010).





Tanaka et al. (2017)

A new era: GW 170817 & GRB 170817A



PRL 119, 161101 (2017) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

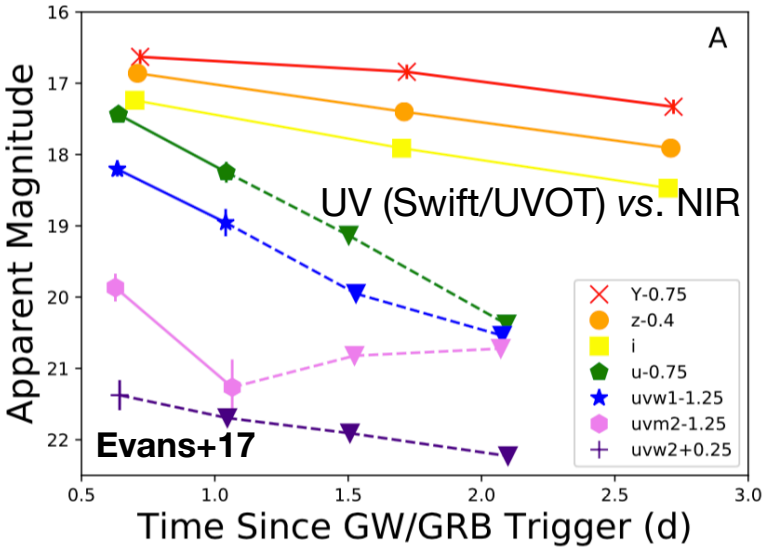
GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

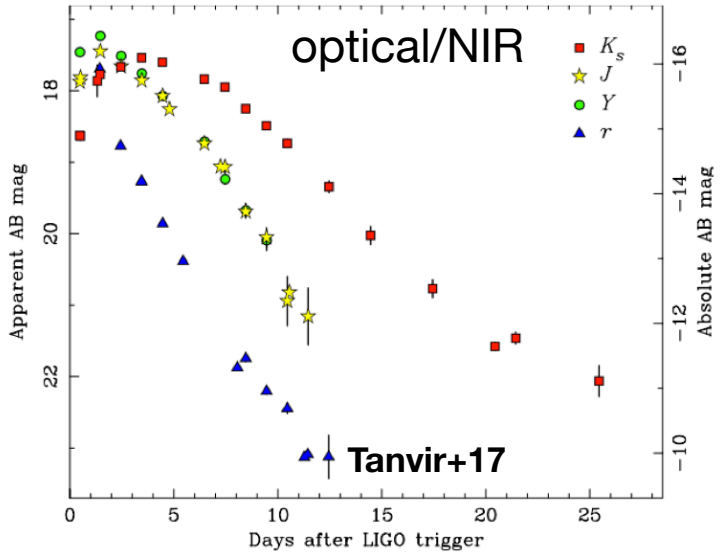
B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

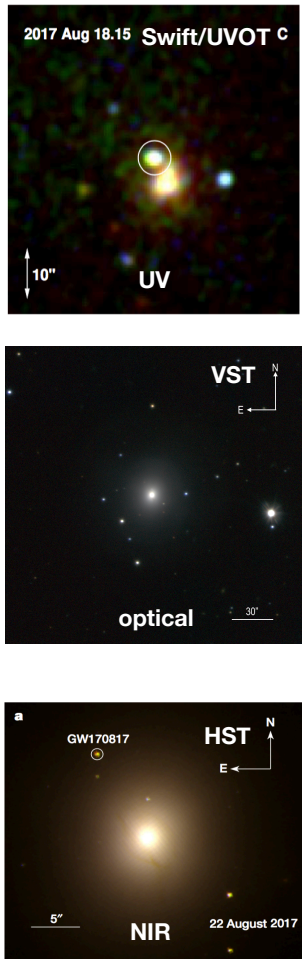
	Low-spin priors ($\|\chi\| \leq 0.05$)	High-spin priors ($\|\chi\| \leq 0.89$)
Primary mass m_1	1.36–$1.60\ M_\odot$	1.36–$2.26\ M_\odot$
Secondary mass m_2	1.17–$1.36\ M_\odot$	0.86–$1.36\ M_\odot$
Chirp mass $\mathcal{M}$	$1.188^{+0.004}_{-0.002} M_\odot$	$1.188^{+0.004}_{-0.002} M_\odot$
Mass ratio m_2/m_1	0.7–1.0	0.4–1.0
Total mass $m_{\rm tot}$	$2.74^{+0.04}_{-0.01} M_\odot$	$2.82^{+0.47}_{-0.09} M_\odot$
Radiated energy $E_{\rm rad}$	$> 0.025 M_\odot c^2$	$> 0.025 M_\odot c^2$
Luminosity distance $D_{\rm L}$	40^{+8}_{-14} Mpc	40^{+8}_{-14} Mpc

Early time UV/Opt/NIR emission: Kilonova

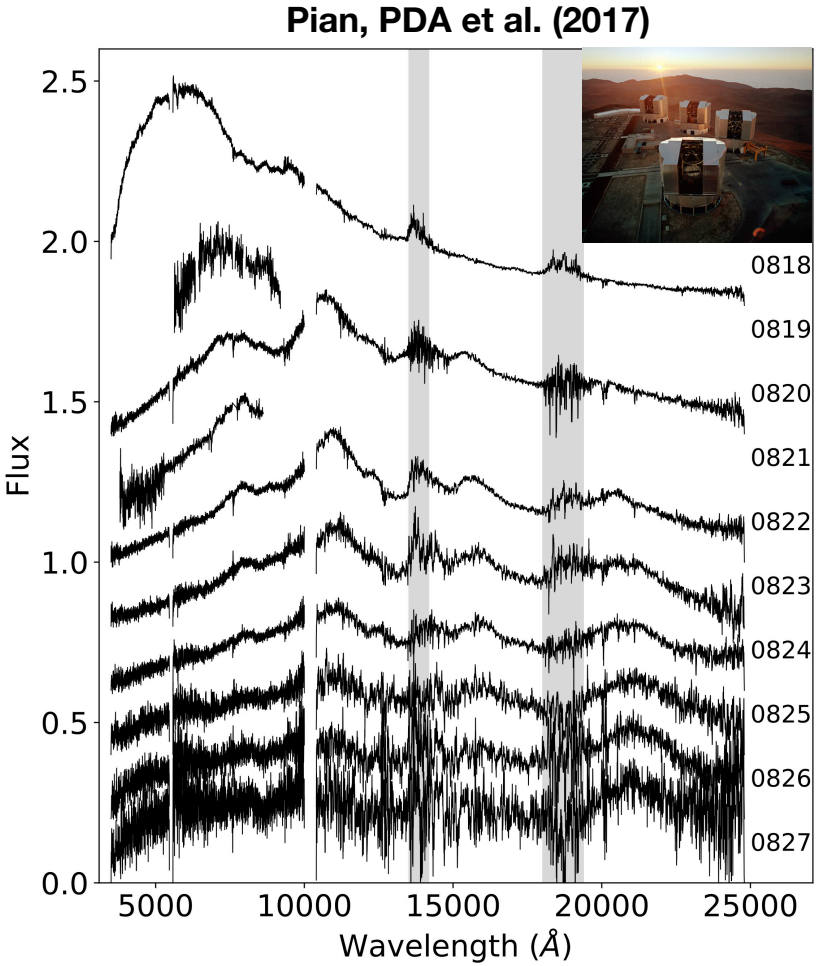
Light curves



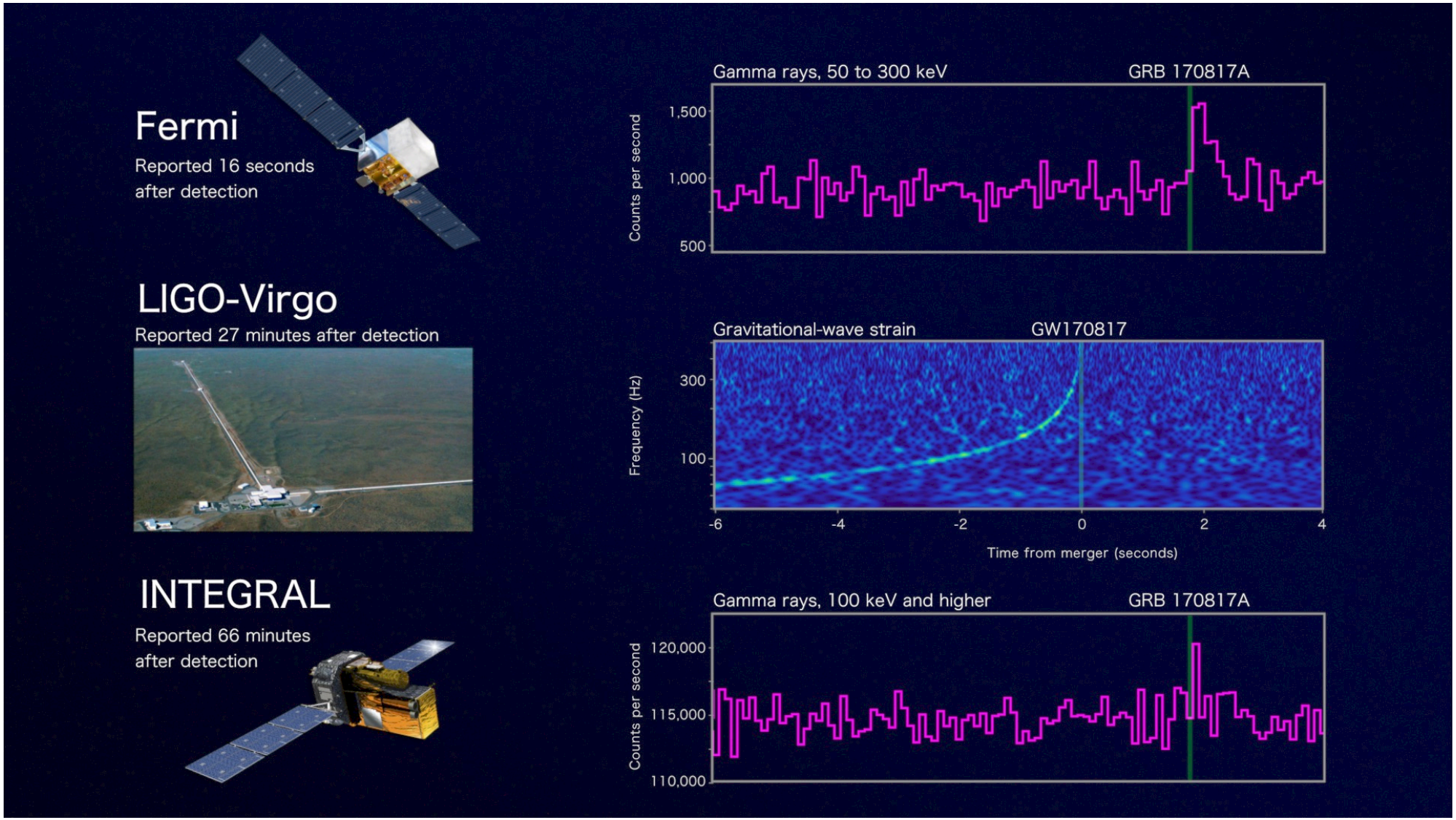




Spectra



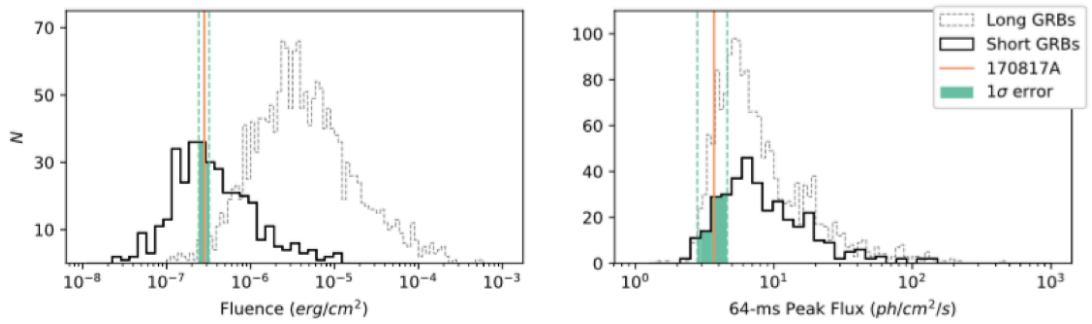
What about the GRB?



Goldstein et al. (2017); LVC + "partner astronomy groups" (2017); Savchenko et al. (2017)

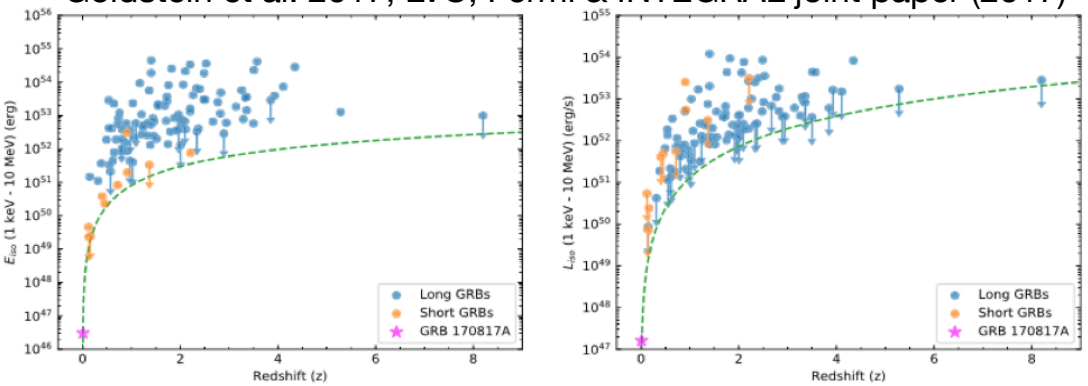
GRB 170817A: an off-beam short GRB?

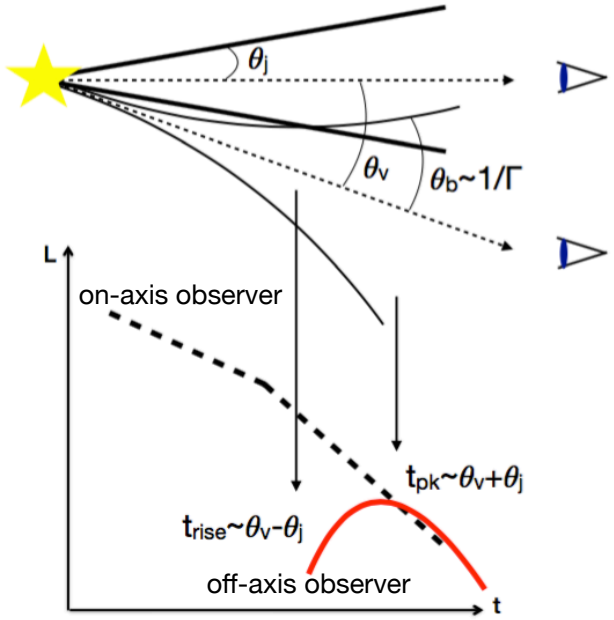
observer-frame properties



Goldstein et al. 2017; LVC, Fermi & INTEGRAL joint paper (2017)

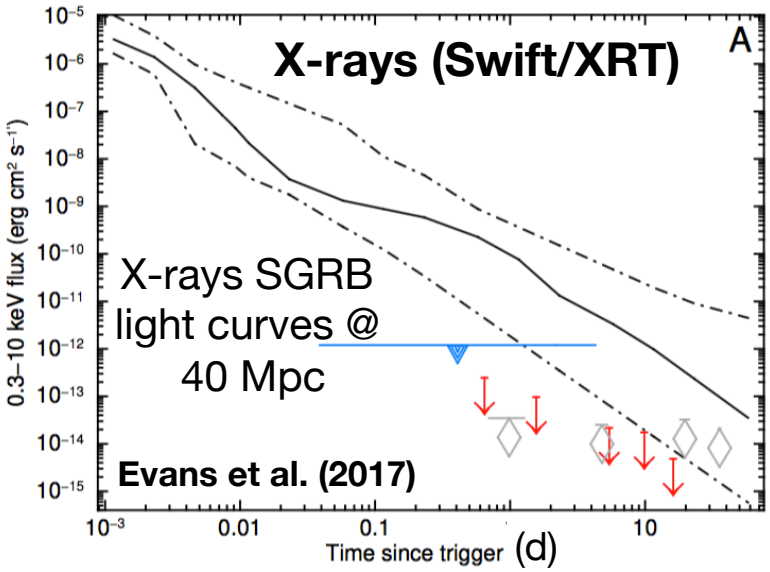
rest-frame properties



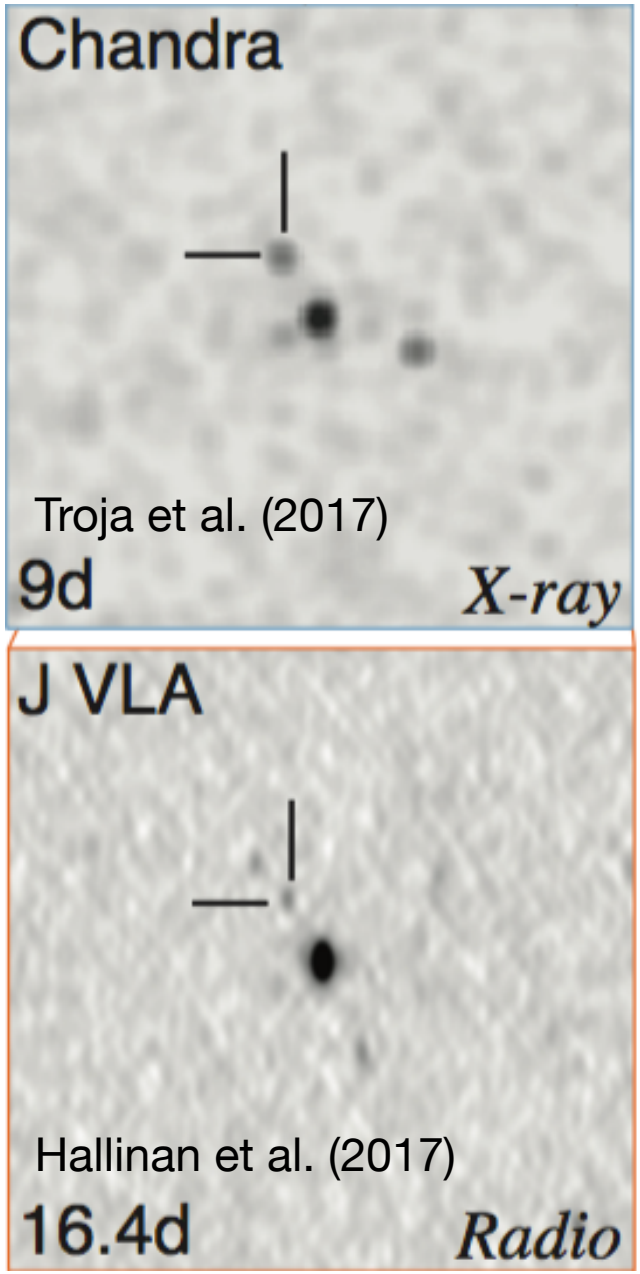


ordinary fluence and peak flux but E_{iso} = 3 x 10^{46} erg
--> 3-6 orders of mag less than other SGRBs

Upper limits with Swift/XRT and NuSTAR:
- X-ray afterglow of GRB 170817A dimmer than for typical SGRBs (PDA+14)
- possibly consistent with the orphan afterglow scenario

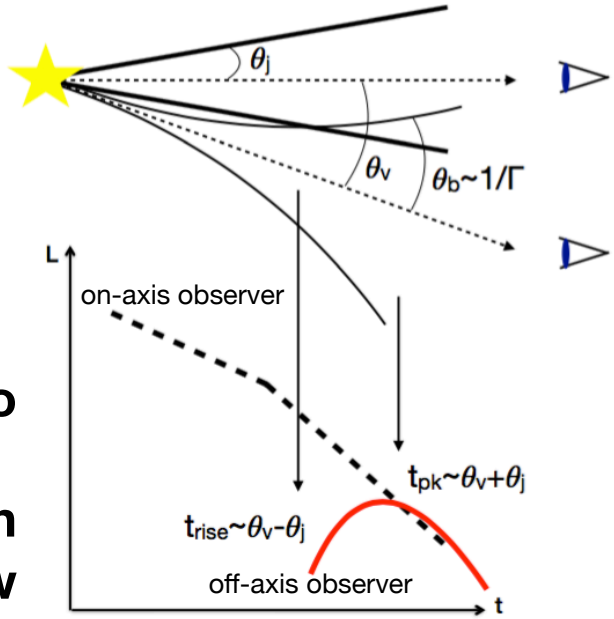


GRB 170817A: an off-beam short GRB?

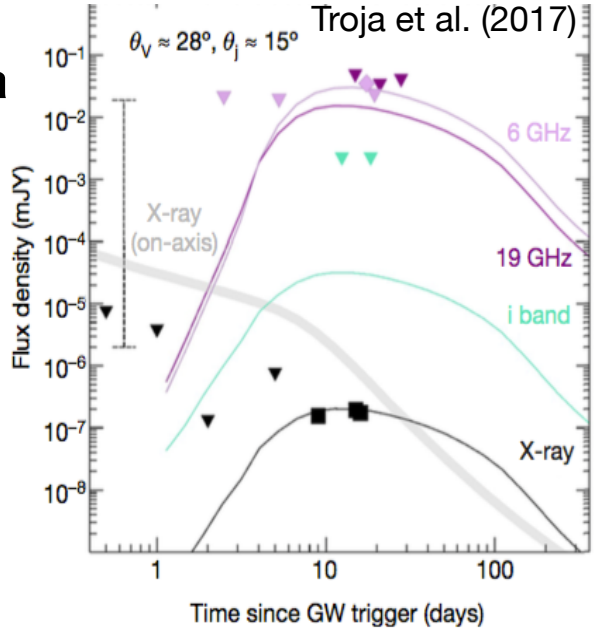


Late-time X-ray and radio detection:

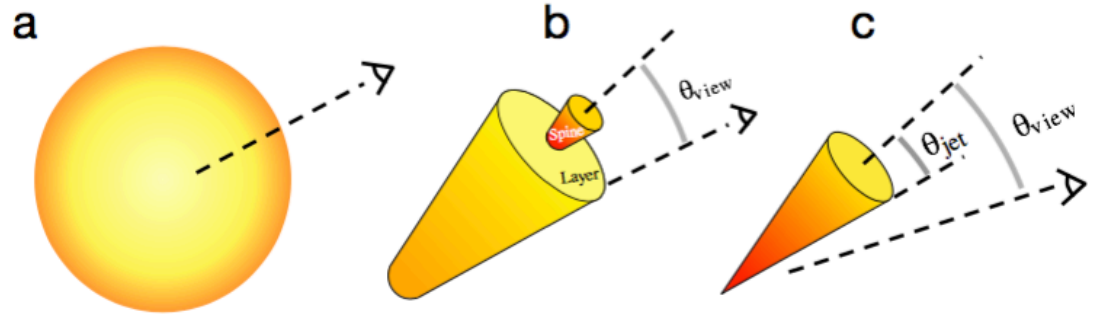
- **possibly consistent with the orphan afterglow scenario**
- **supported by Chandra and VLA observations**



Troja et al. (2017)



GRB 170817A: emission geometry



Salafia+17

Different scenarios:

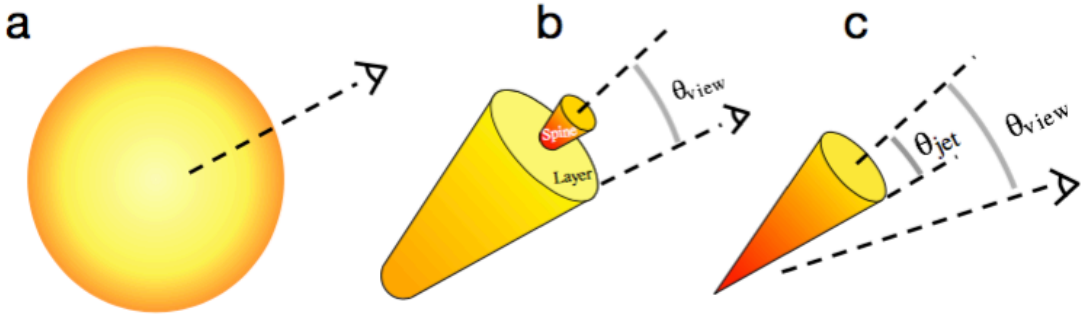
a) Isotropic fireball or hot cocoon from a failed jet

b) Structured jet: standard jet + less energetic cocoon/layer

c) Uniform (top hat) jet with unusually low Lorentz factor

(Gottlieb+17, Kathirgamaraju+17, Lazzati+17, Pian+17, Kasliwal+17; Salafia+17, Mooley+18, PDA+18, Lyman+18, Margutti+18, Nakar & Piran 18)

GRB 170817A: emission geometry



Salafia+17

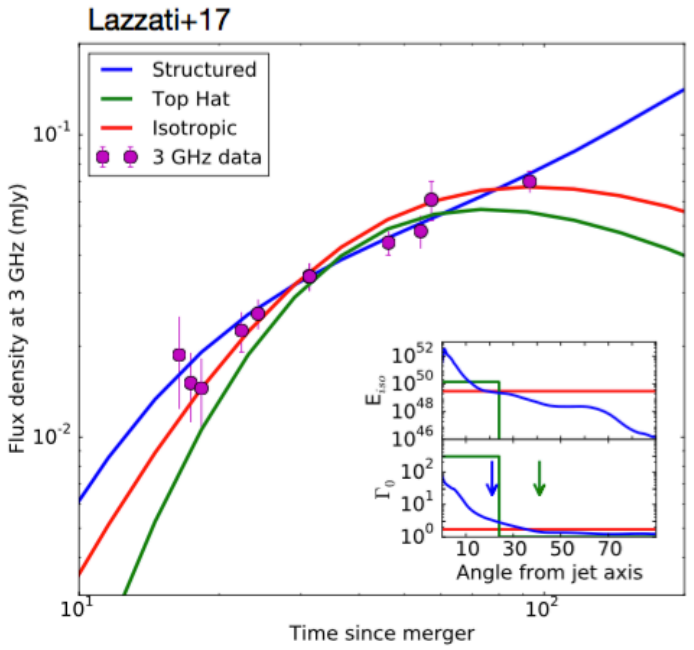
Different scenarios:

a) **Isotropic fireball or hot cocoon from a failed jet**
b) **Structured jet: standard jet + less energetic cocoon/layer**
c) ~~**Uniform (top hat) jet with unusually low Lorentz factor**~~

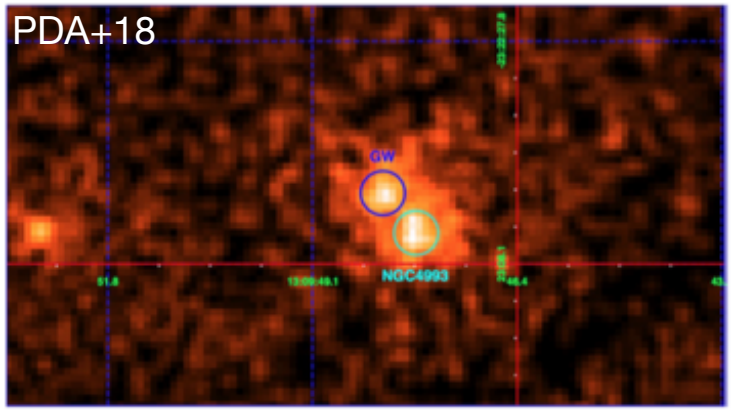
(Gottlieb+17, Kathirgamaraju+17, Lazzati+17, Pian+17, Kasliwal+17, Salafia+17, Mooley+18, PDA+18, Lyman+18, Margutti+18, Nakar & Piran 18)

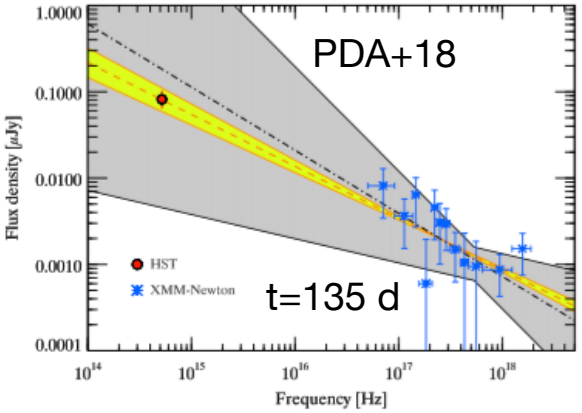
Radio observations up to t~107 d
(Mooley et al. 2017)

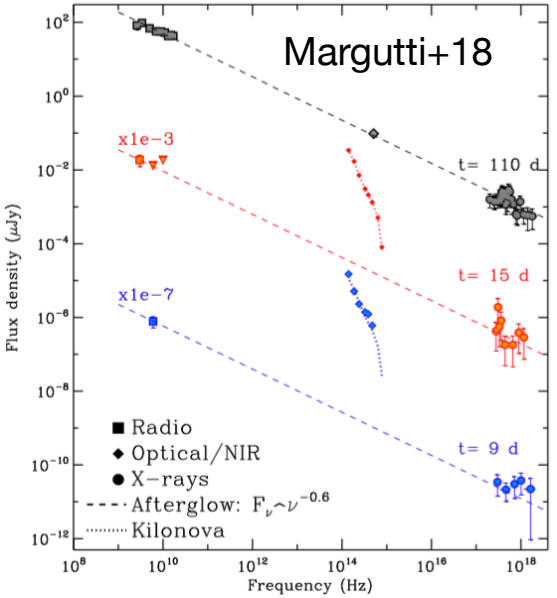
-> the emission is still rising



GRB 170817A: evidence for a turnover in the light curve



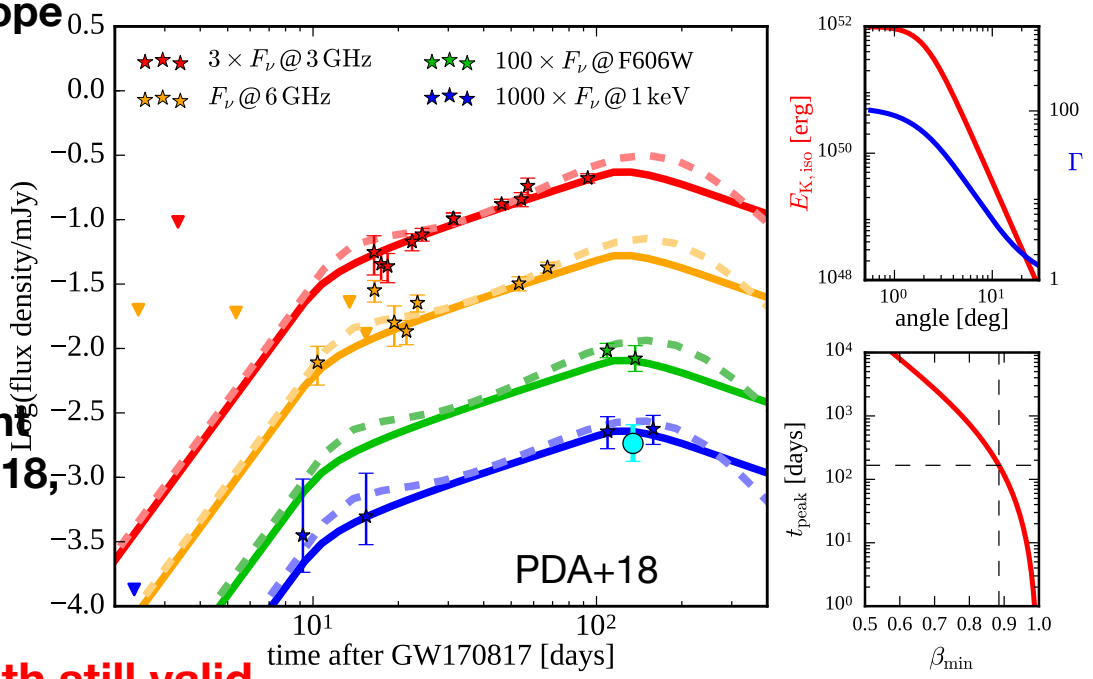




XMM-Newton detection at t=135 d (PDA+18):
- opt/X-ray spectral slope unchanged w.r.t. previous epochs: no passage of the cooling frequency
- evidence for a change in the light curve slope (flattening): likely geometrical effect

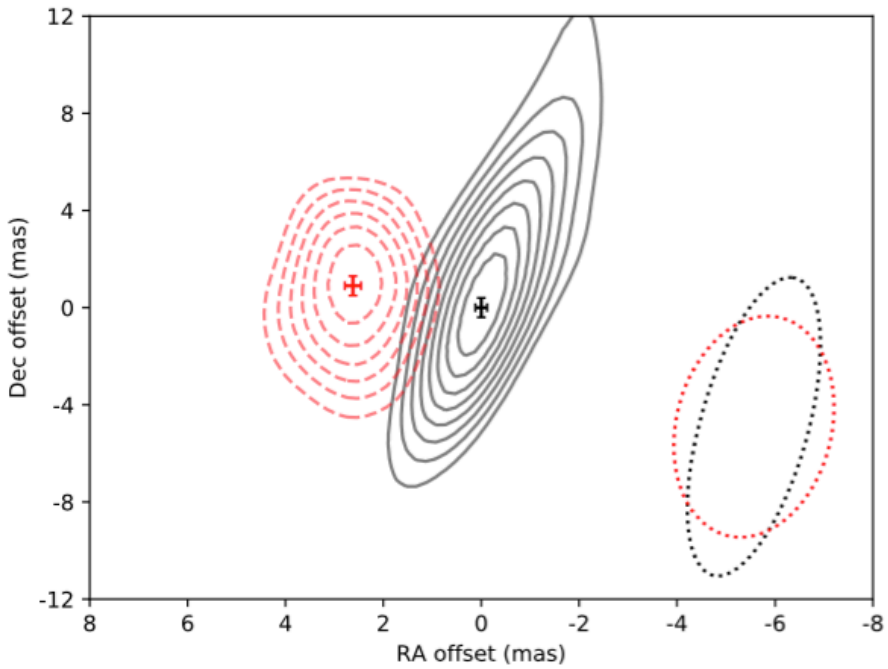
Chandra detection at t=153-164 d (Haggard+18; Troja+18): still consistent with light curve flattening

X-ray, optical and radio observations at t = 200-264 d confirm the turnover in the light curve and show evidence for decay (Dobie+18, Troja+18, Alexander+18).



Structured jet and isotropic emission both still valid.

GRB 170817A: evidence for a structured jet



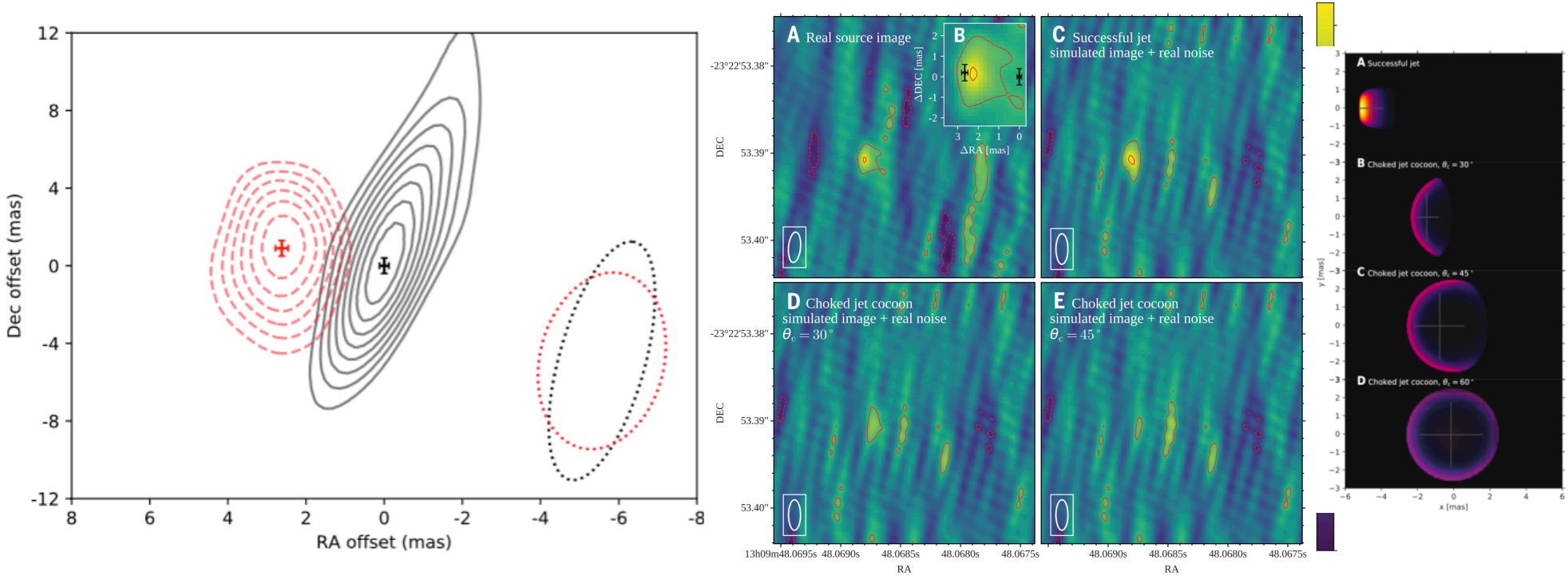
- Mooley+18 find evidence for proper motion in VLBI radio data of GRB 170817A taken at T+75 d and T+230 d

- The measured offset implies $\beta = 4.1 +/- 0.5$ (superluminal motion)

- The source is unresolved in VLBI data

The above findings support the structured jet model. Fit to the data and numerical simulations are in agreement with the scenario of a structured jet with a relativistic core with $\theta_{jet} < 5$ deg and $\theta_{view} \sim 20$ deg

GRB 170817A: evidence for a structured jet



- Mooley+18 find evidence for proper motion in VLBI radio data of GRB 170817A taken at T+75 d and T+230 d

- The measured offset implies β = 4.1 +/- 0.5 (superluminal motion)

- The source is unresolved in VLBI data

The above findings support the structured jet model. Fit to the data and numerical simulations are in agreement with the scenario of a structured jet with a relativistic core with $\theta_{jet} < 5$ deg and $\theta_{view} \sim 20$ deg

- Ghirlanda+19 find evidence that a relativistic structured jet successfully emerged from GW 170817 / GRB 170817A

- Evidence with size measurement in VLBI data obtained ~207 d after merger

- A source size < 2 mas excludes that a nearly isotropic, mildly relativistic outflow is responsible for the emission, as in this case its apparent size, after more than six months of expansion, should have been significantly larger and resolved by the VLBI observation.

Conclusions

- GW 170717 / GRB 170817A results:
    - Definition and consolidation of successful follow-up strategies
    - First EM counterpart (at all wavelengths)
    - First unambiguous observational evidence for a kilonova
    - Evidence for kilonovae as a heavy elements factory
    - `Smoking gun' for short GRB progenitors (but is GRB 170717A a 'classical' short GRB?)
    - Clues on short GRB outflow geometry and properties: first evidence for a structured jet (Chandra observations 581 d after merger provide further confirmation! Hajela+19)

- the dawn of multi-messenger astronomy era

- O3 LVC run just started (April 2019)
    - how many NS-NS? (we had already: S190425z and the possible S190510g)
    - NS-BH? (we had a possible one: S190426c)
    - how many KN flavours? Are KN associated to every short GRB?
    - how many short GRB flavours? Unique emission geometry?

More during this afternoon's Panel Discussion