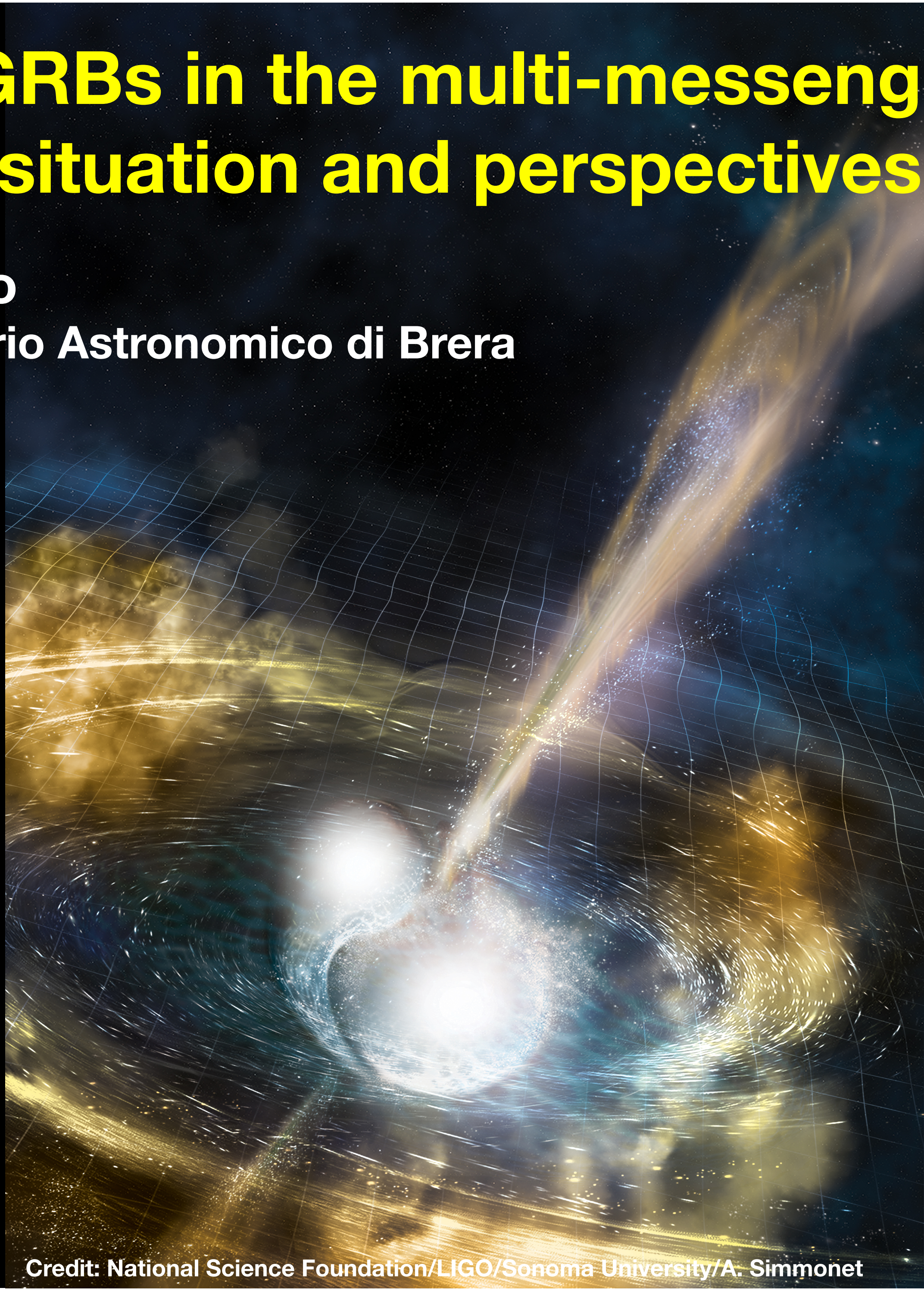
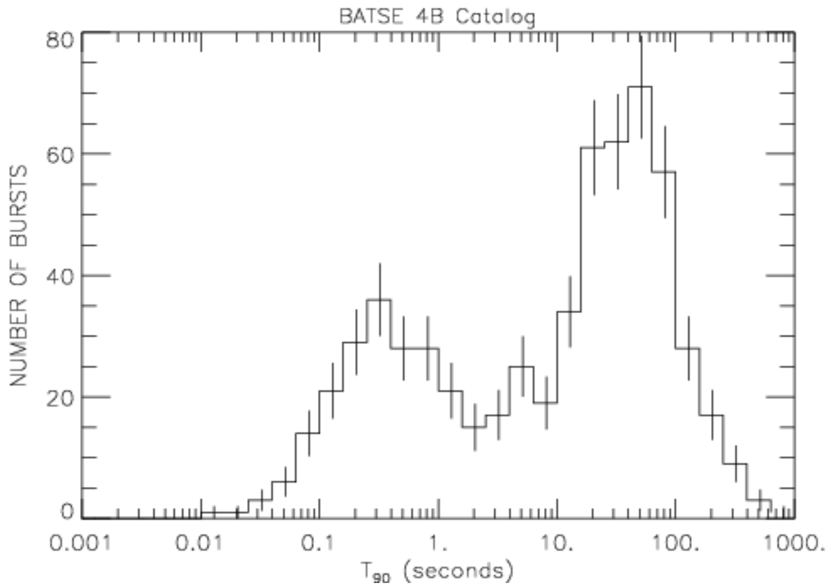
Short GRBs in the multi-messenger era: situation and perspectives

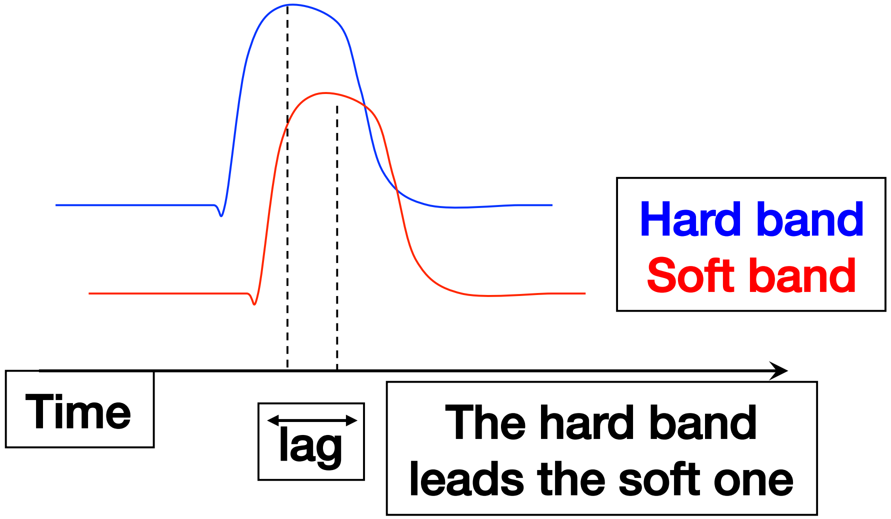
Paolo D'Avanzo
INAF – Osservatorio Astronomico di Brera

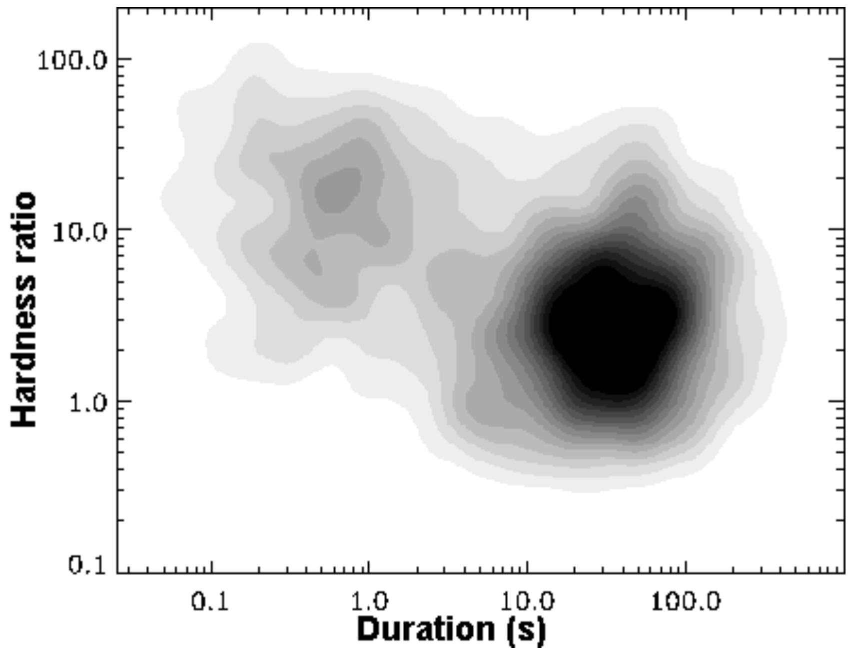


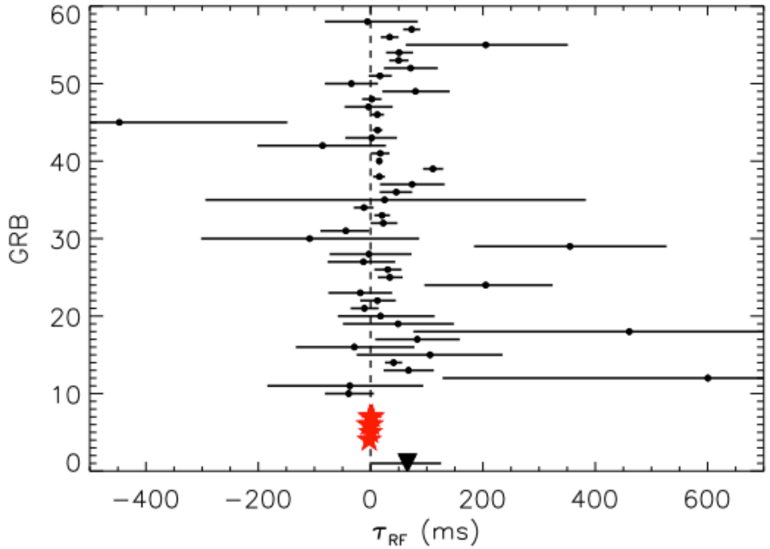
Credit: National Science Foundation/LIGO/Sonoma University/A. Simmonet

Short/hard & long/soft GRBs





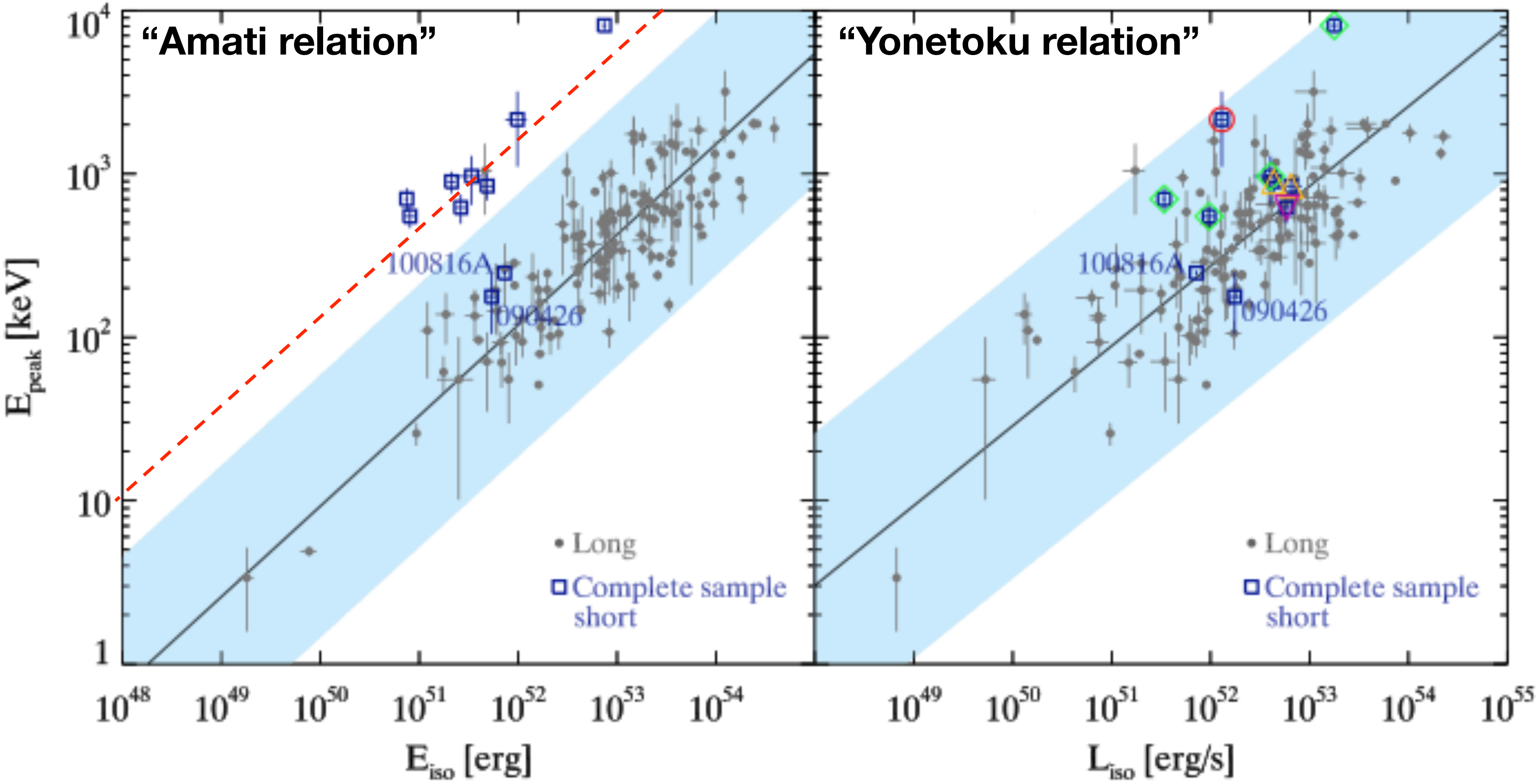




Analysis carried out on rest-frame common energy bands:
- LGRBs can have zero (or negative) lags
- SGRBs lag always consistent with zero

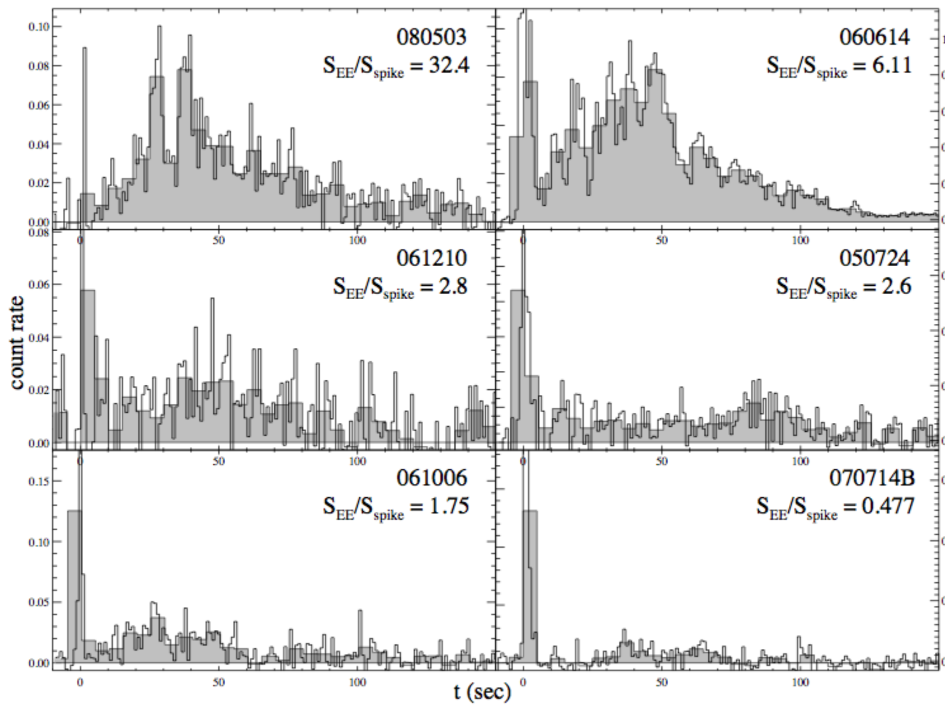
Bernardini et al. 2015

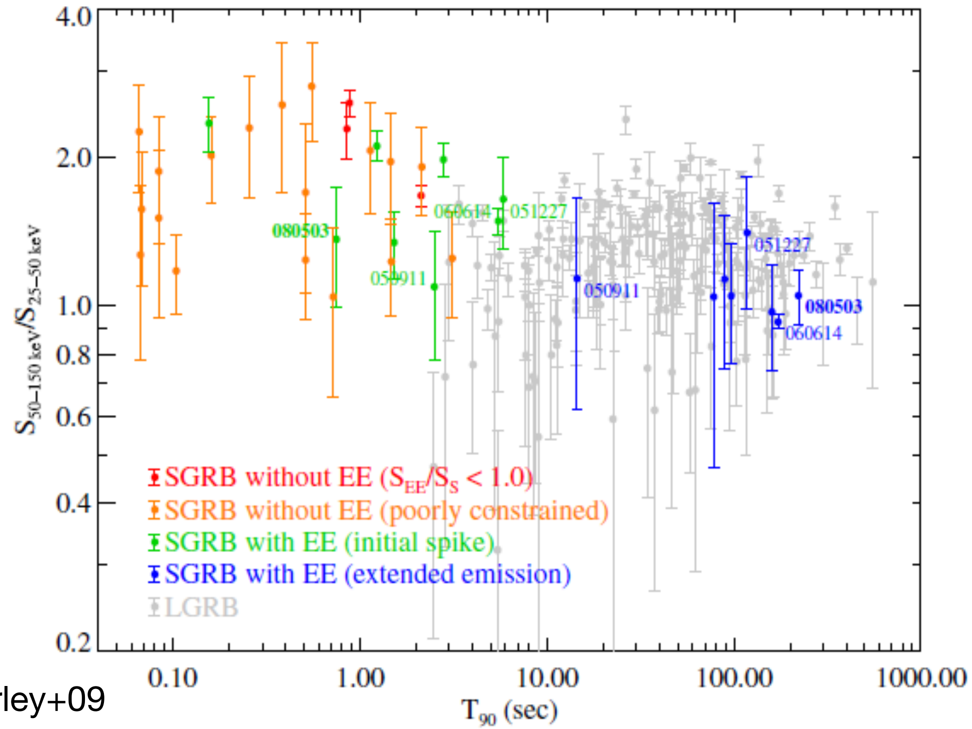
Short GRBs: prompt emission



Amati et al. 2002; Younetoku et al. 2004; Ghirlanda et al. 2009, Zhang et al. 2012, D'Avanzo et al. 2014

Short GRBs: prompt (extended) emission





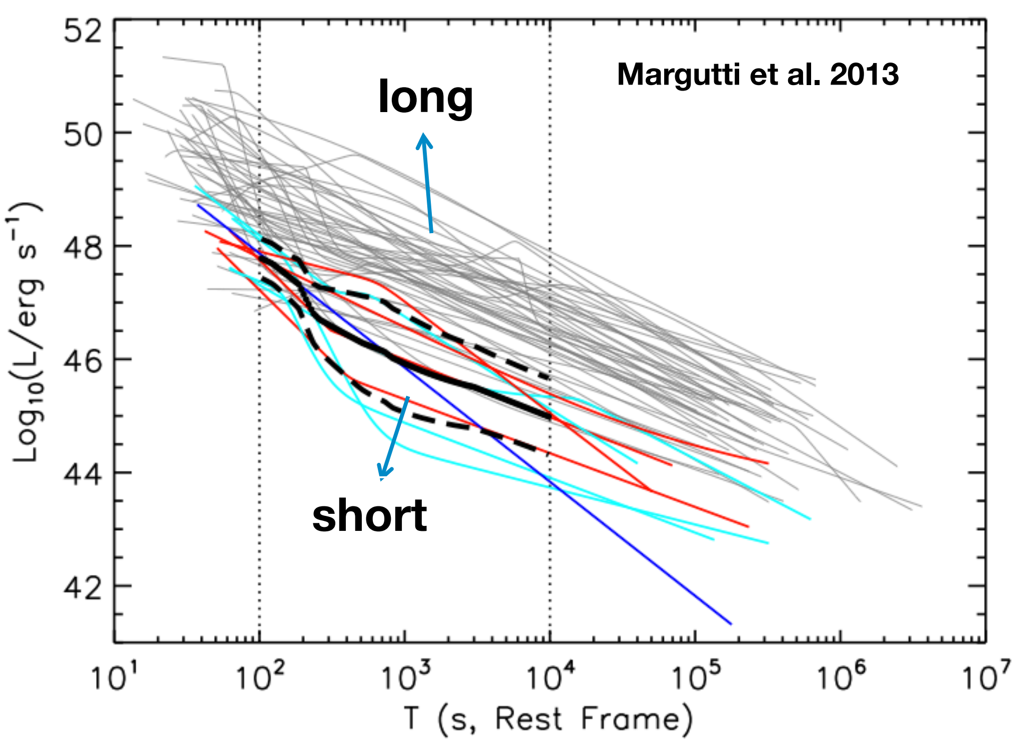
Perley+09

T_{90} >> 2 s

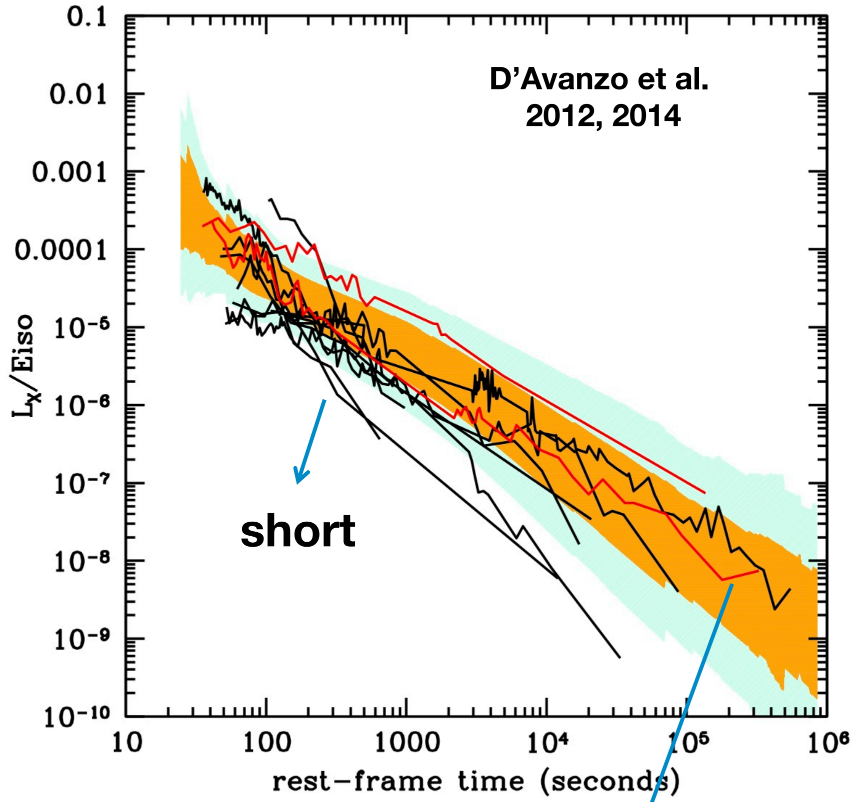
Short/hard spike
Long/soft tail

Short GRBs: afterglow emission

Rest frame X-ray luminosity



Rest frame X-ray luminosity normalized to E_{iso}



The afterglow X-ray luminosity is a good proxy of E_{iso} for both long and short GRBs

1sigma scatter for long GRBs

Swift & Short GRBs

Since 2005, with the advent of the *Swift* satellite, the discovery of short GRB afterglows and the identification of their host galaxies made possible to measure their distances and study their energy scales and environments.

To date, *Swift* detected >150 short GRBs (~10/yr):

- ~15% with an extended emission

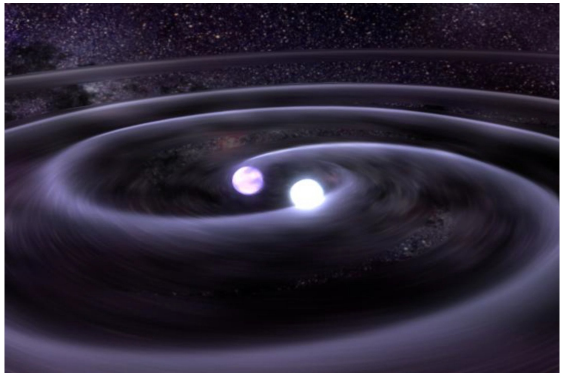
- ~75% with a X-ray afterglow detected

- ~15% with no X-ray afterglow detection in spite of prompt XRT slew

- ~35% with an optical afterglow detected

- ~5% with a radio afterglow detected

- ~25% with a redshift measurement (mainly from host galaxy spectroscopy -> importance of precise, arcsec, position for host galaxy association)



A lot of science cases related to short GRBs
Main issue: the quest for progenitors

Compact object mergers: what we do expect

Diverse delay times:
- A mix of early and late type host galaxies

Kicks/migration from birth site:
- Offsets
- No correlation with UV/optical HG light
- Diversity in the environment (ev. channel)

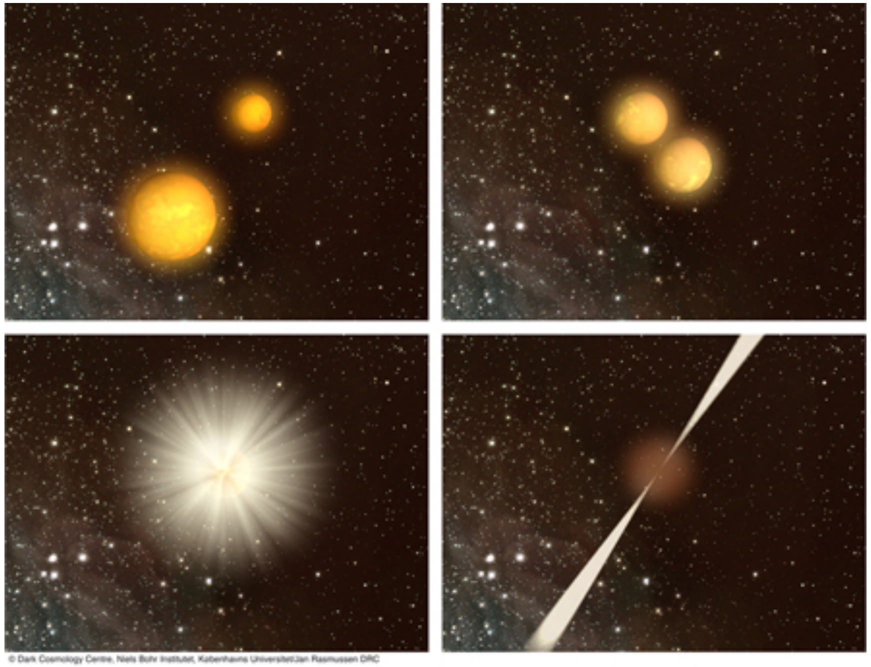
No associated supernova

Remnant (magnetar/BH?)

Emission geometry (jet?)

Kilonova association

Gravitational waves



The Neutron Stars Merging Scenario

ESO PR Photo 32c/05 (October 6, 2005)

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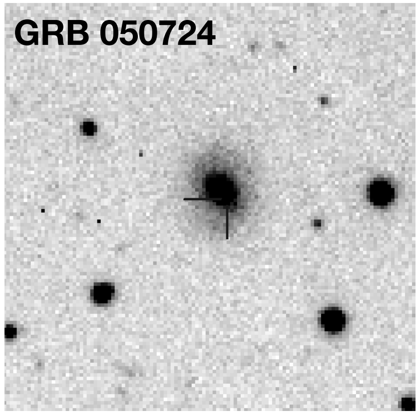
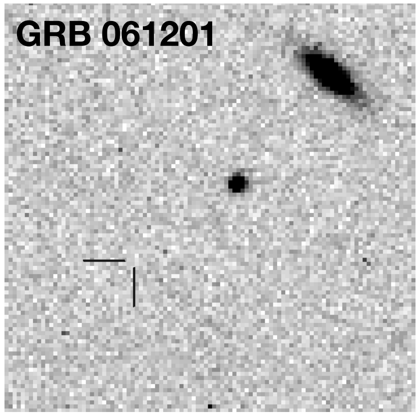


early type

late type



hostless

Barthelmy+05
Malesani+07
Stratta+07
PDA+09
Fong+13
Berger14

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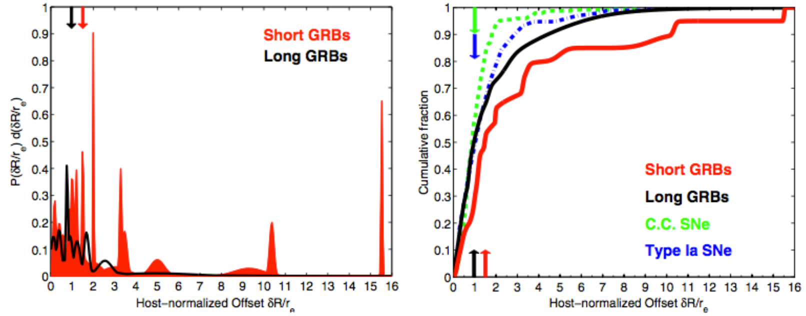
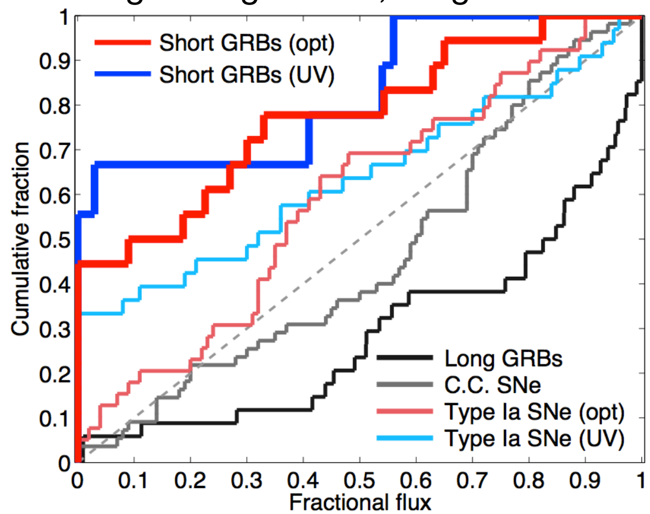
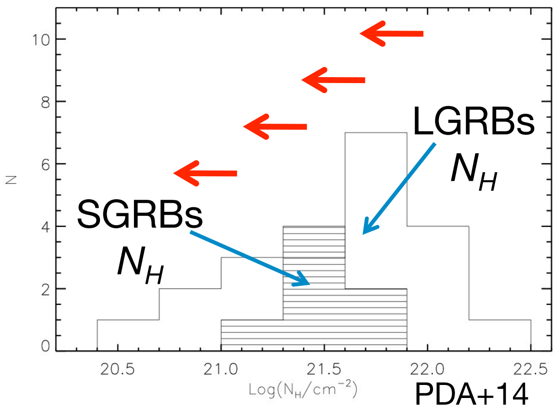
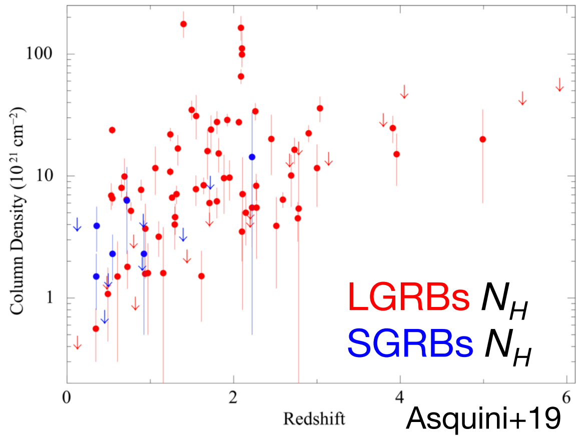


Fong & Berger 2013; Berger 2014





PDA+14



Asquini+19

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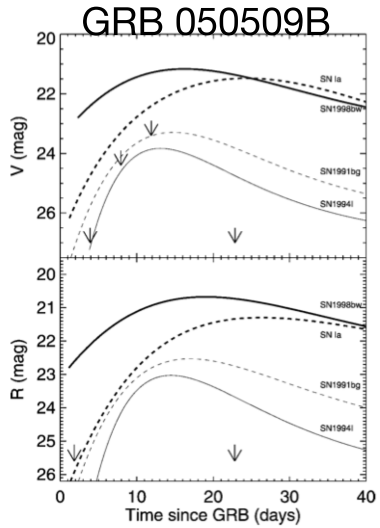
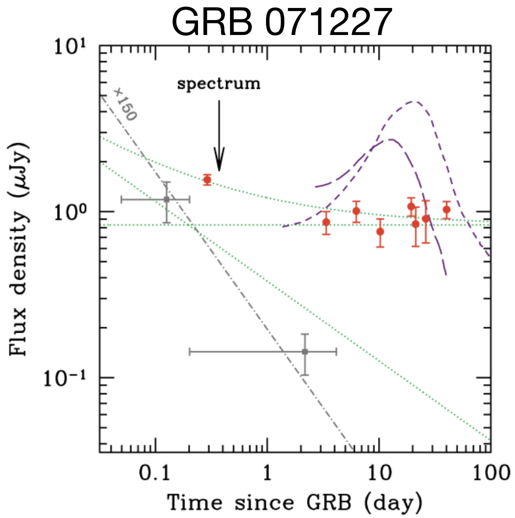
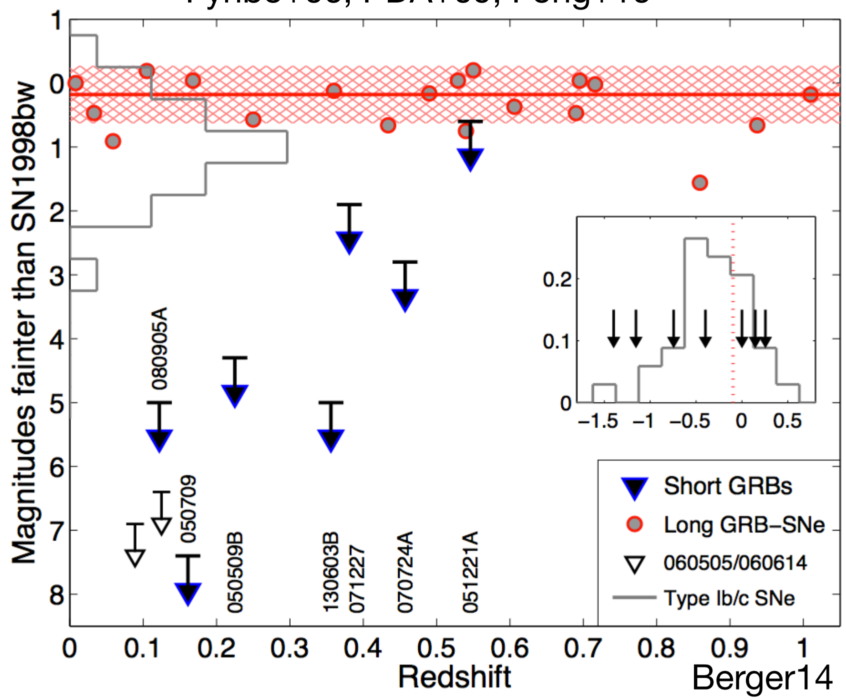




Hjorth+05; Covino+06; Della Valle+06; Fynbo+06; PDA+09; Fong+16



Berger14

Compact object mergers:
what we do expect and see (situation up to 2017)

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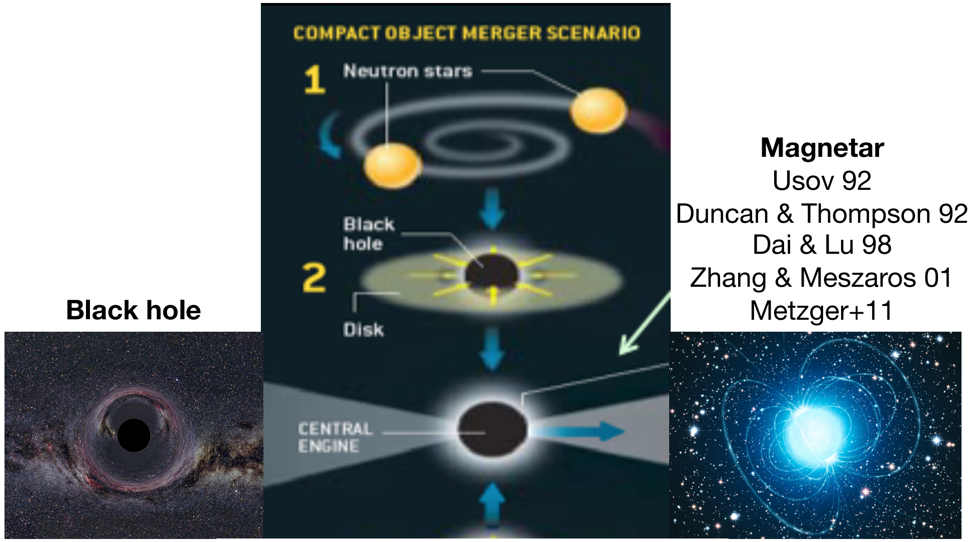
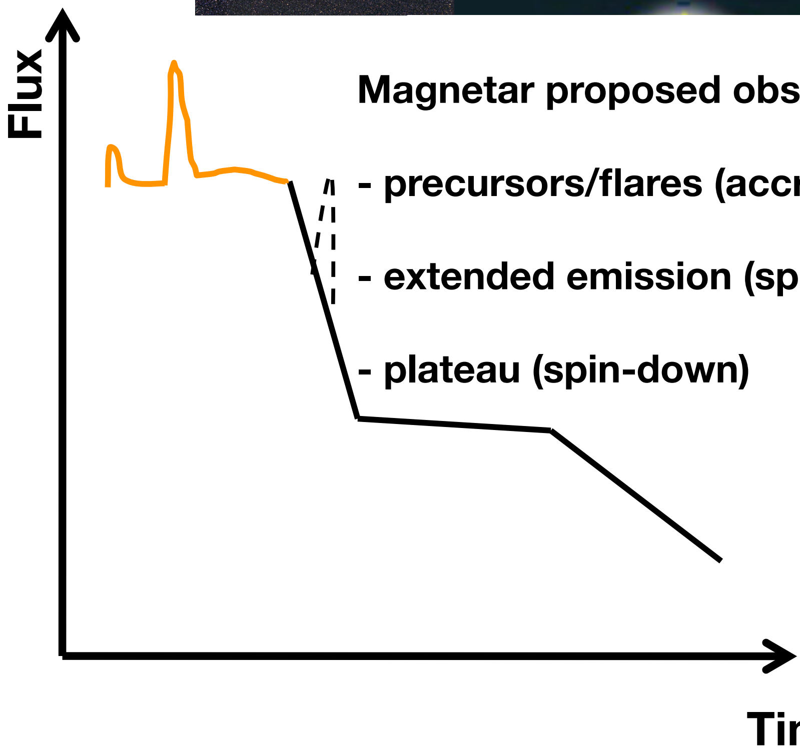
Black hole

Magnetar
Usov 92
Duncan & Thompson 92
Dai & Lu 98
Zhang & Meszaros 01
Metzger+11





Magnetar proposed obs. signatures:

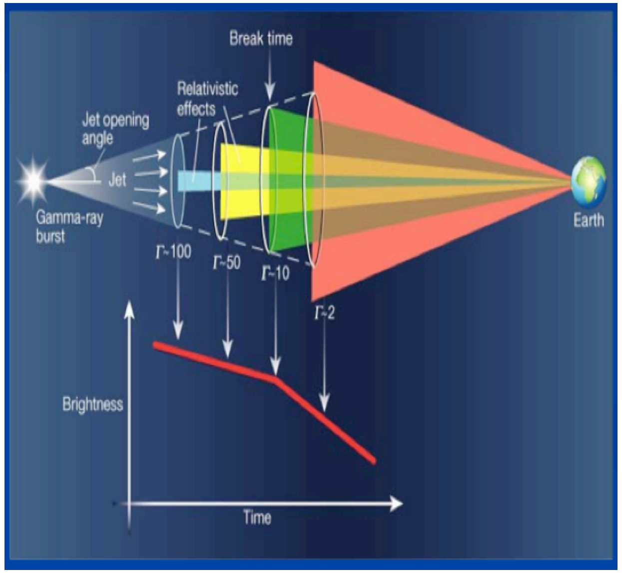
- precursors/flares (accretion)

- extended emission (spin-down/accretion)

- plateau (spin-down)

Metzger+08
Bucciantini+12
Rowlinson+13
Bernardini+13
Gompertz+14

Compact object mergers: what we do expect and see (situation up to 2017)



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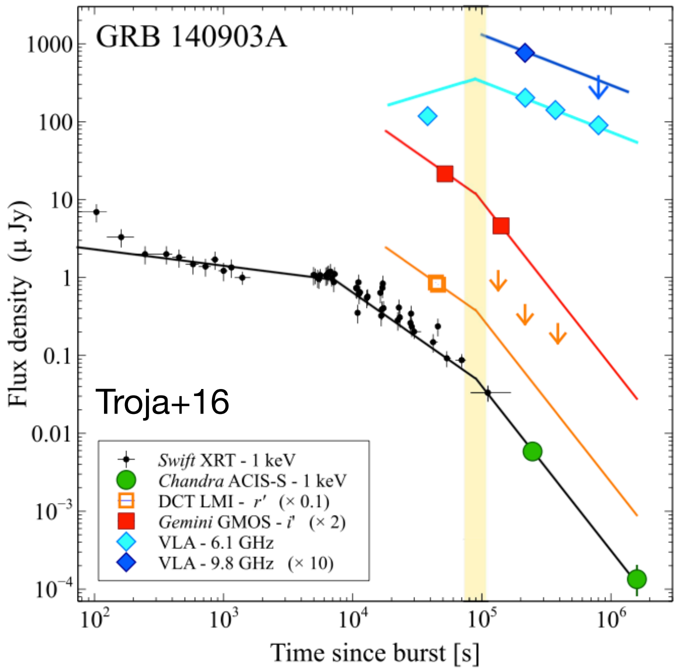
Short GRB Opening Angles

GRB	Band[a]	θ_j (deg)	δt^b_{last} (days)	Reference
050709	O	$\gtrsim 15^\circ$	16.2	1
050724A	X	$\gtrsim 25^\circ$	22.0	2
051221A	X	$6-7^\circ$	26.6	3
090426A	O	$5-7^\circ$	2.7	4
101219A	X	$\gtrsim 4^\circ$	3.9	5, This work
111020A	X	$3-8^\circ$	10.2	6
111117A	X	$\gtrsim 3-10^\circ$	3.0	7, 8
120804A	X	$\gtrsim 13^\circ$	45.9	9, This work
130603B	OR	$4-8^\circ$	6.5	10
140903A	X	$\gtrsim 6^\circ$	3.0	11, This work
140930B	X	$\gtrsim 9^\circ$	23.1	This work

$\langle\theta_{jet}\rangle \sim 10^\circ$ Fong+15
see also Rouco-Escorial+23



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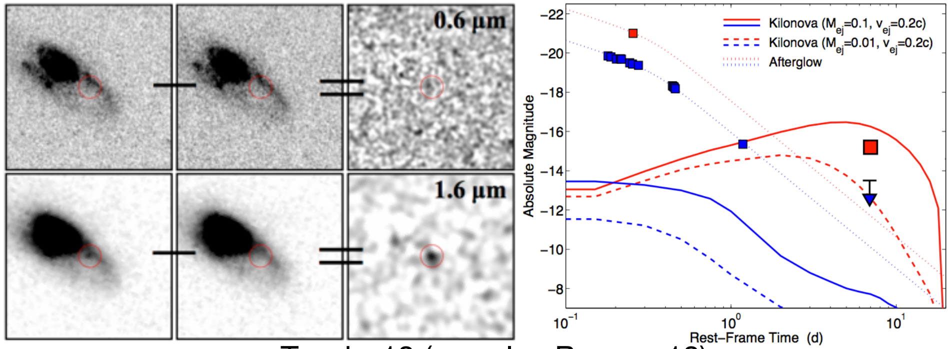
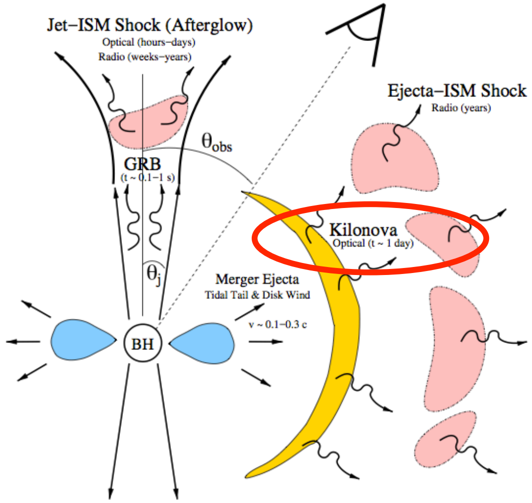
GRB 130613B (z=0.356)

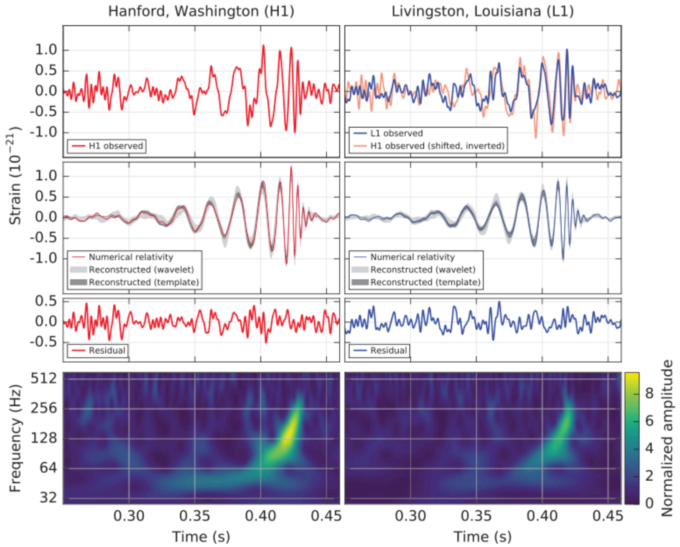


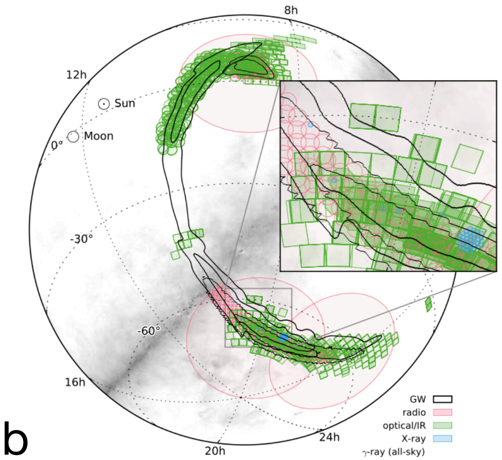
Tanvir+13 (see also Berger+13)



Metzger & Berger 2012

Compact object mergers: what we do expect and see (situation up to 2017)





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Abbott+16a,b

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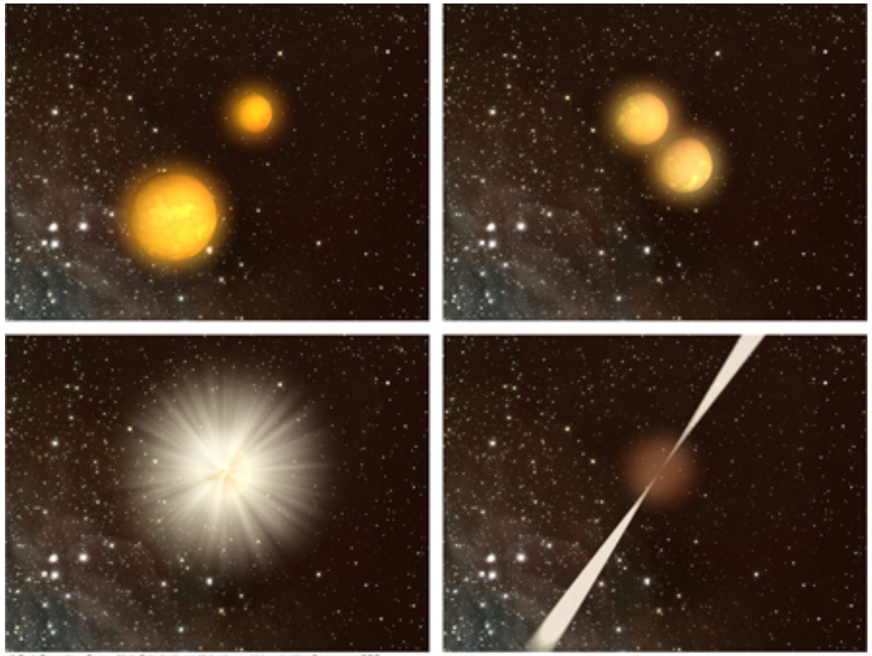
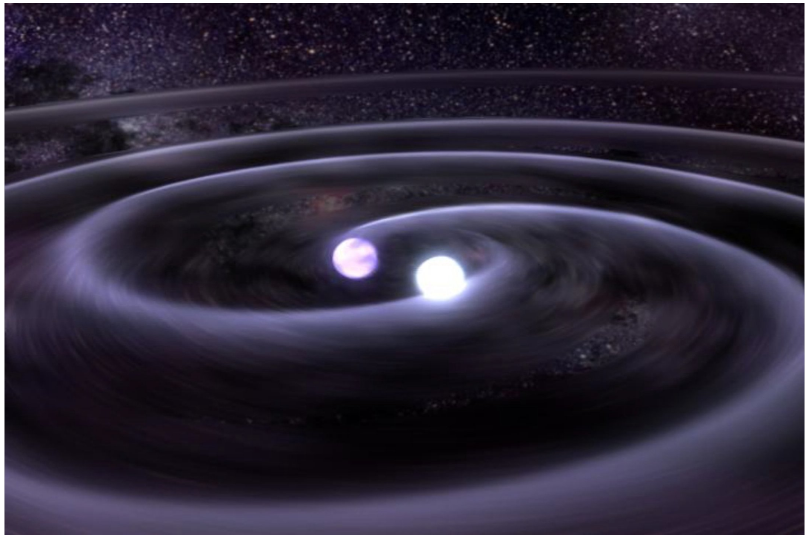
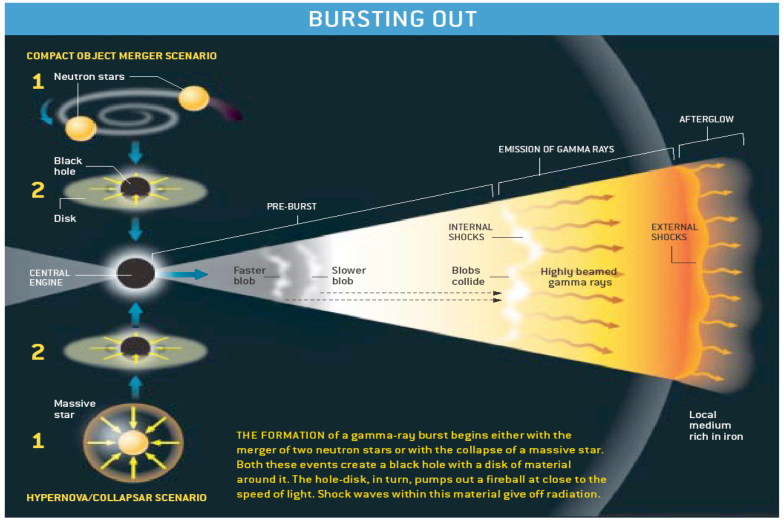


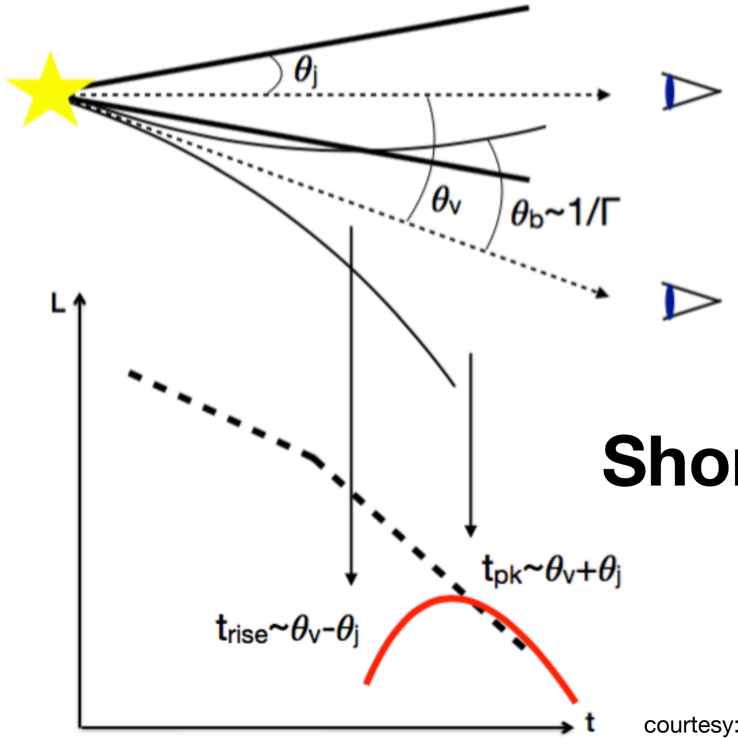
The Neutron Stars Merging Scenario

ESO PR Photo 32c/05 (October 6, 2005)

NS-NS / NS-BH electromagnetic counterparts







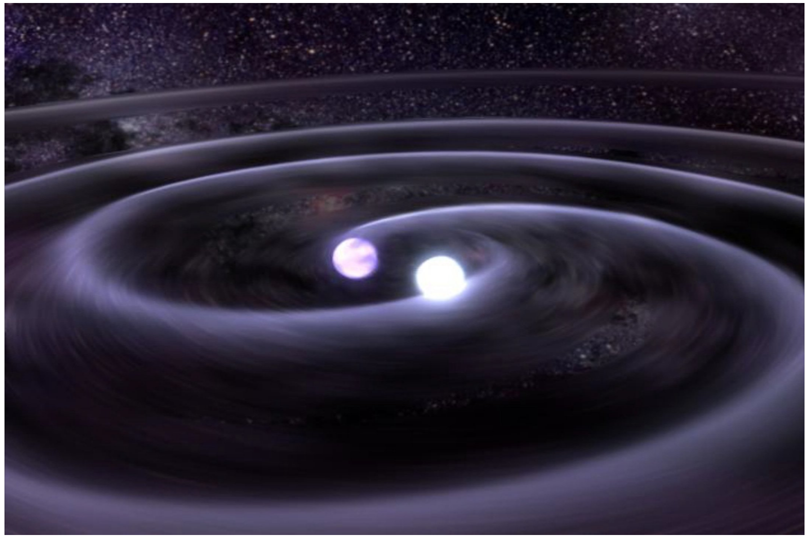
on-axis

off-axis

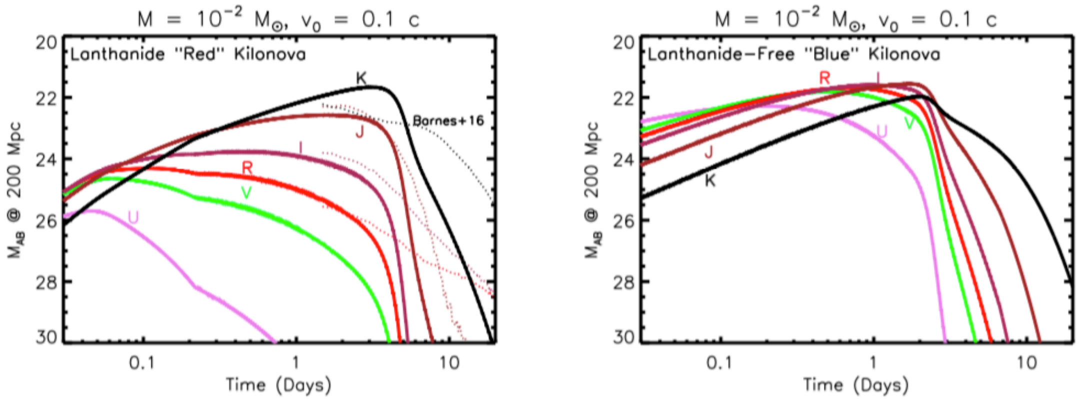
Short GRB

courtesy: M. G. Bernardini

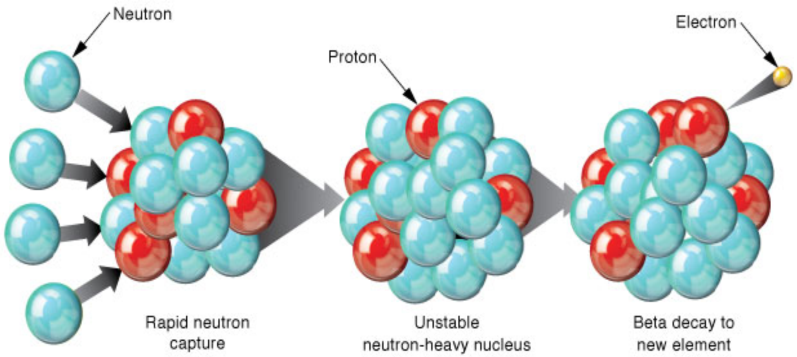
NS-NS / NS-BH electromagnetic counterparts

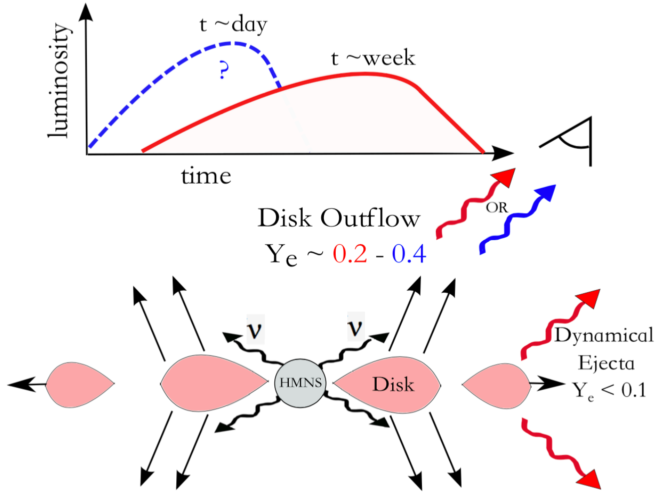


Kilonova



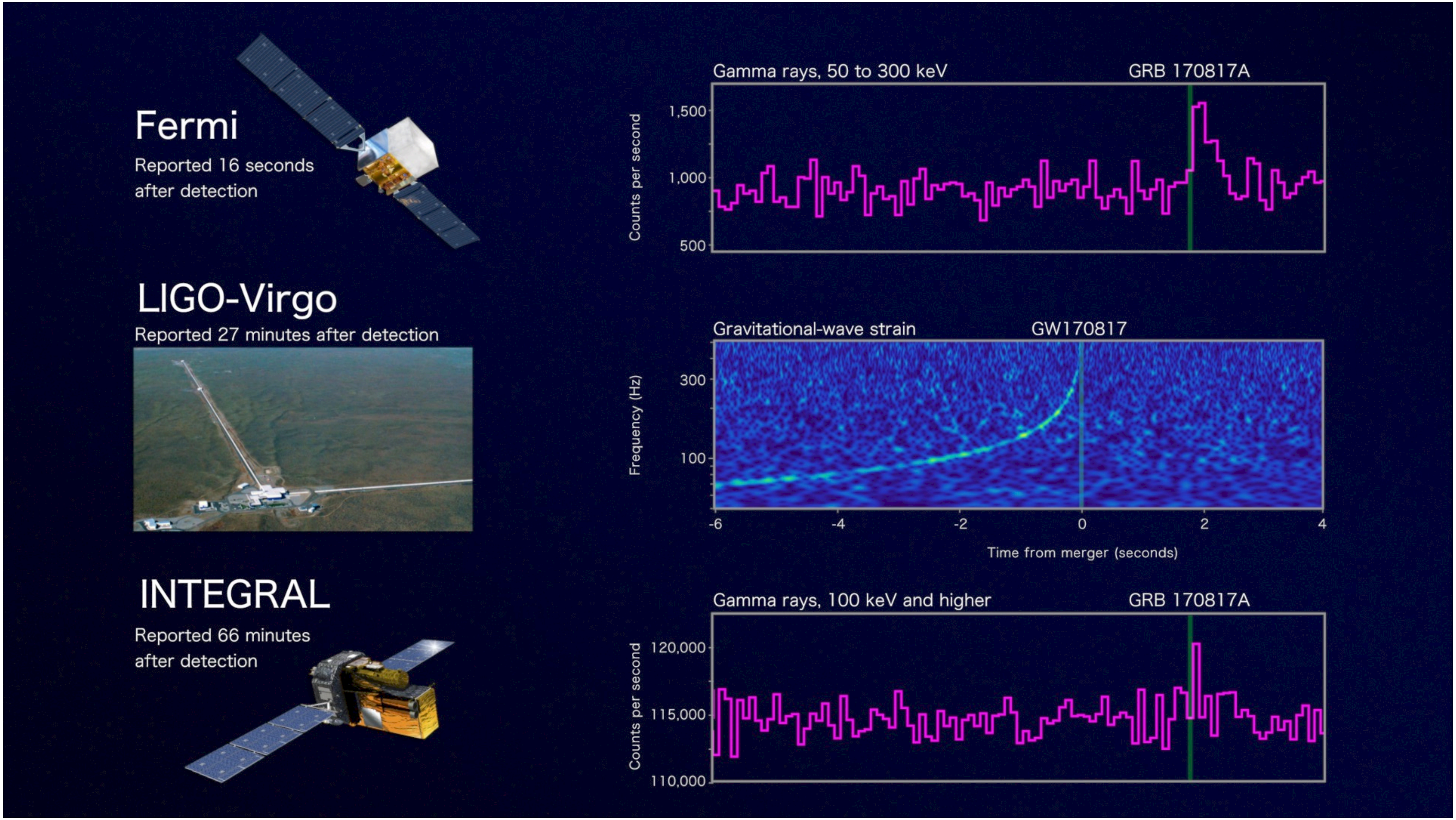
A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "kilonova" (aka "macronova") due to the decay of heavy radioactive species produced by the *r*-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog,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





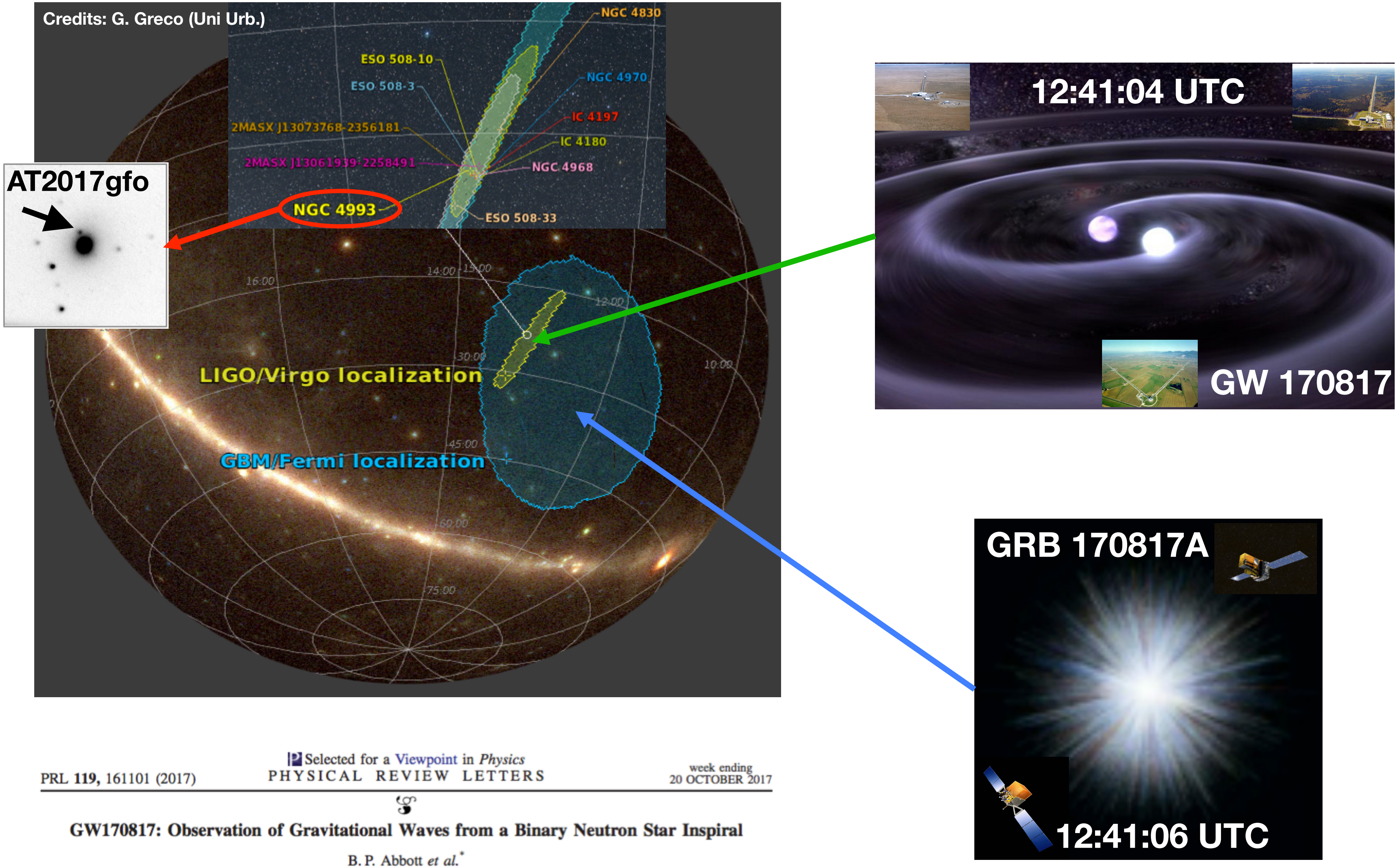
Metzger & Fernandez 2014

GW 170817 & GRB 170817A



Abbott+17; Goldstein+17; Savchenko+17

GW 170817 / GRB 170817A / AT2017gfo



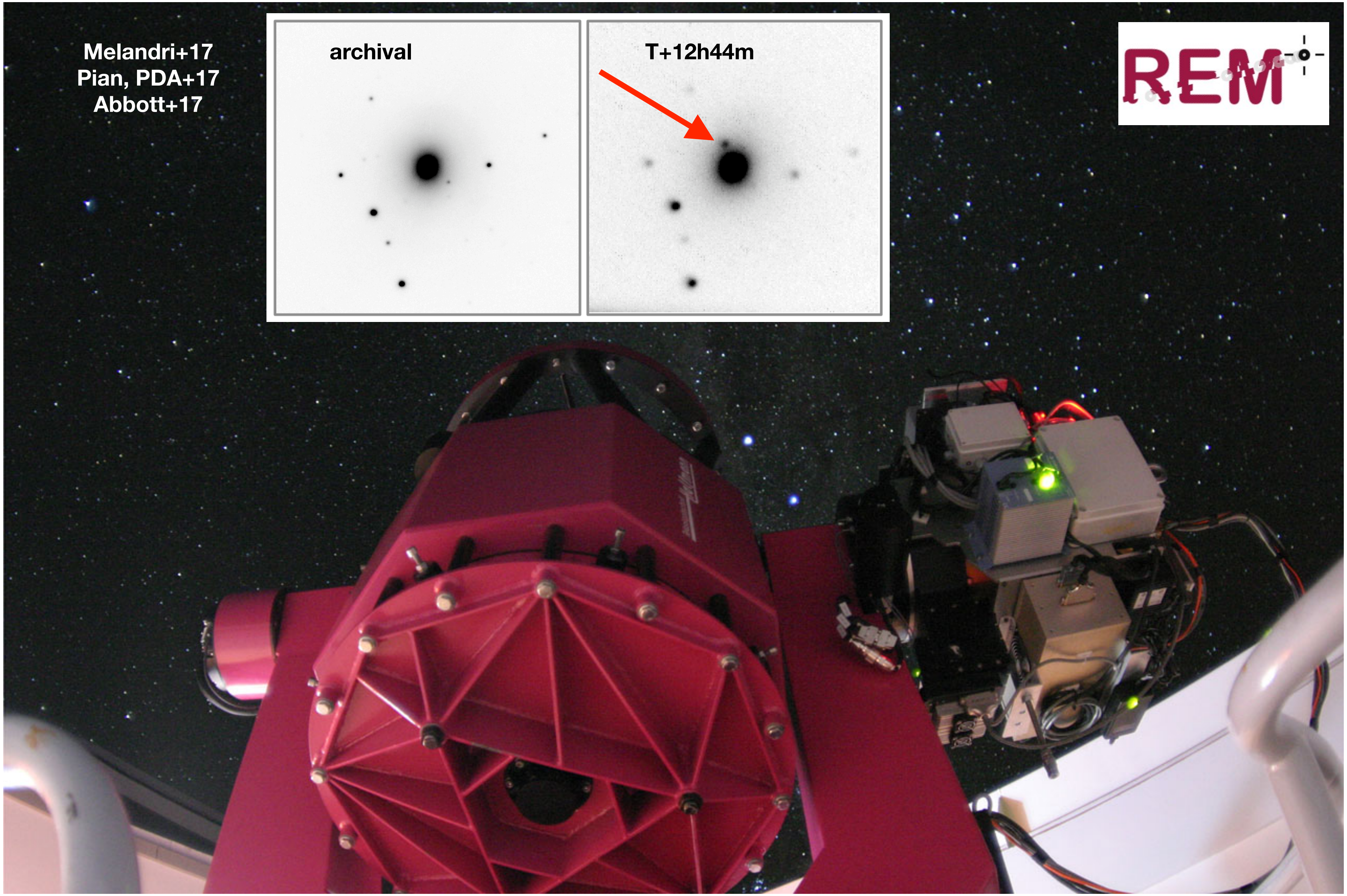
Selected for a Viewpoint in *Physics*
PRL **119,** 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

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

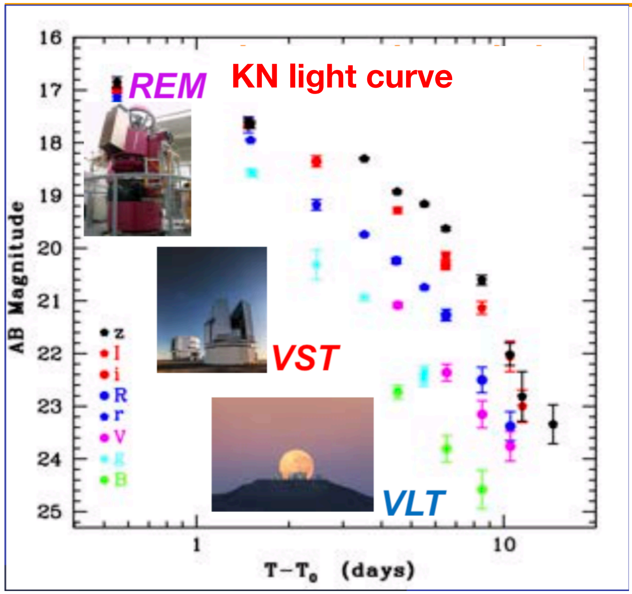
B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)

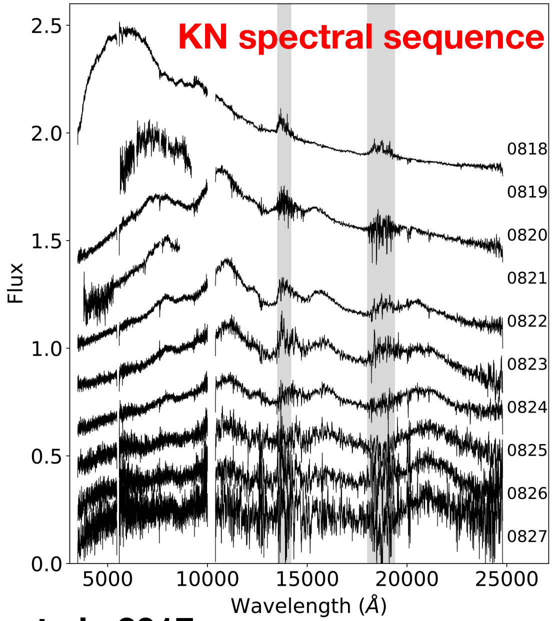
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

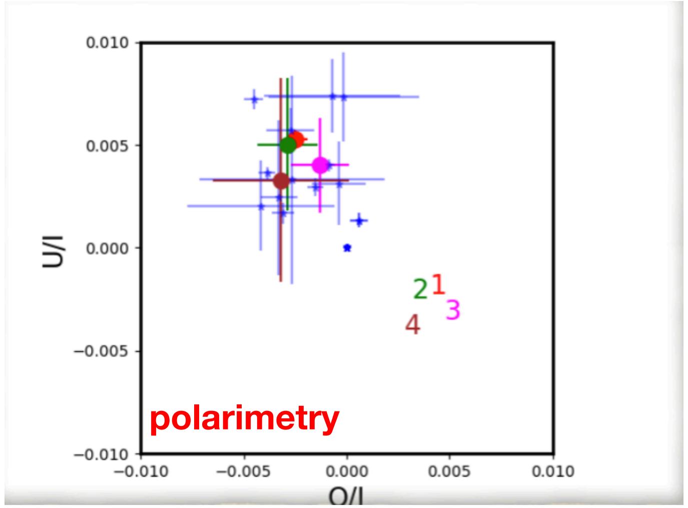
GW 170817 / AT2017gfo



GW 170817 / AT2017gfo



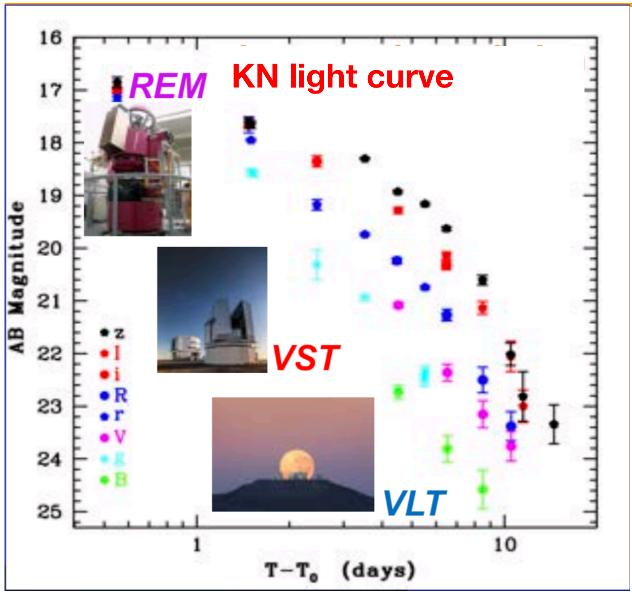


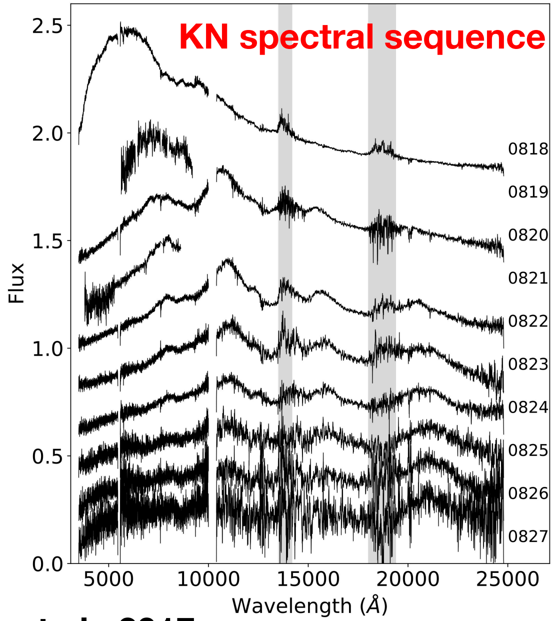


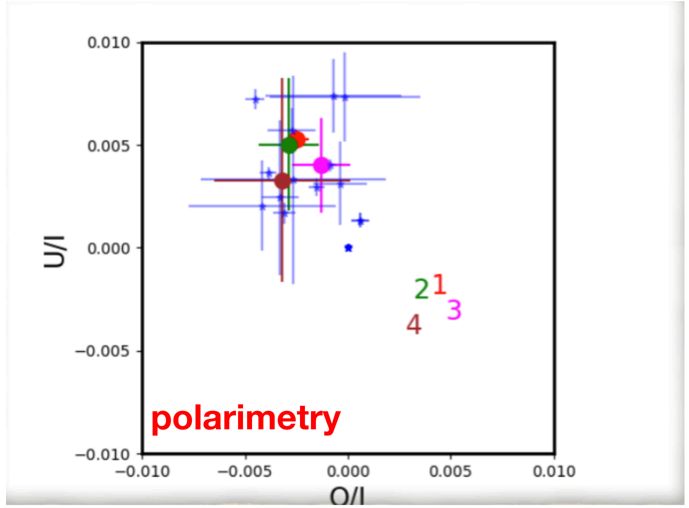
Pian, PDA et al., 2017
(see also Arcavi+17; Coulter+17; Evans+17; Lipunov+17; Smartt+17; Soares-Santos+17; Tanvir+17; Valenti+17 and many others)

Covino et al., 2017

GW 170817 / AT2017gfo







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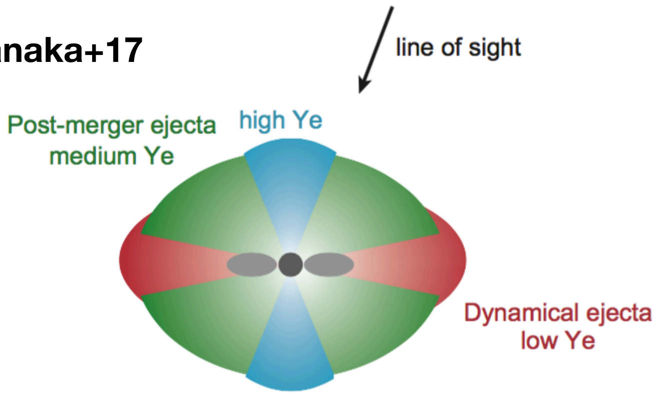
Covino et al., 2017

Full characterization of the KN properties

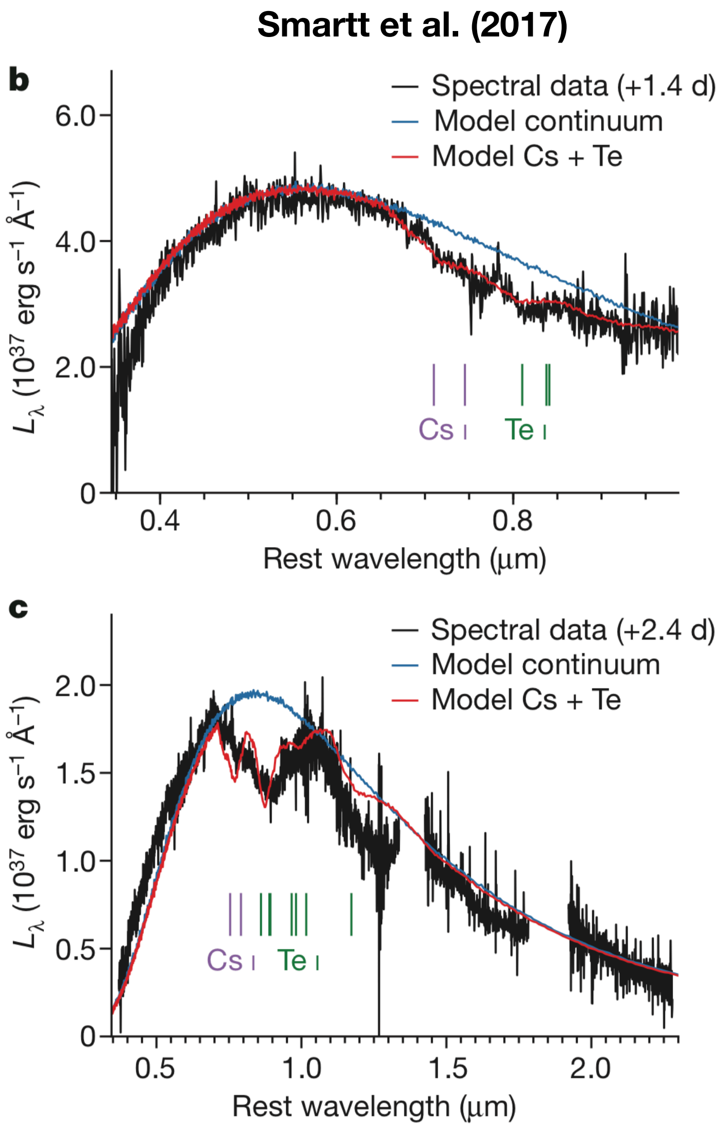
Tanaka+17

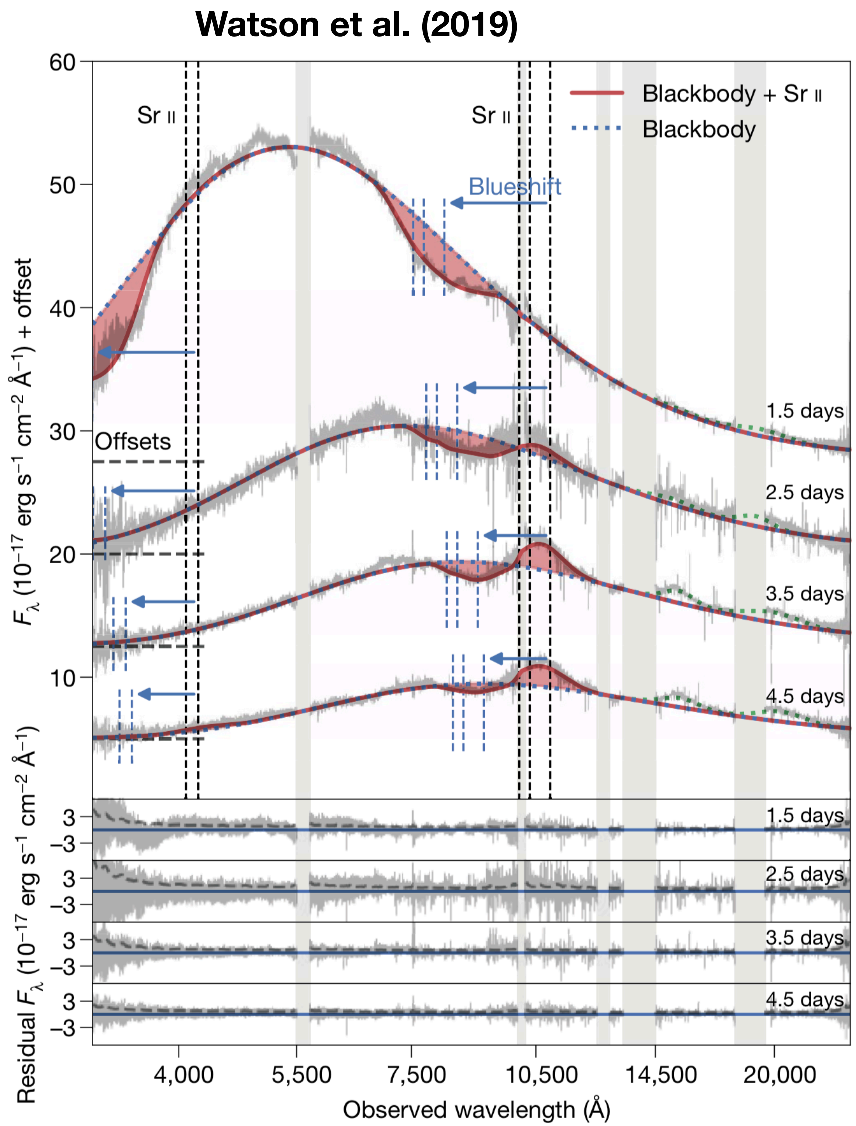


Three components kilonova model with different velocity, composition and electron (proton) fraction (low Ye: lanthanide-rich; high Ye: lanthanide-poor)

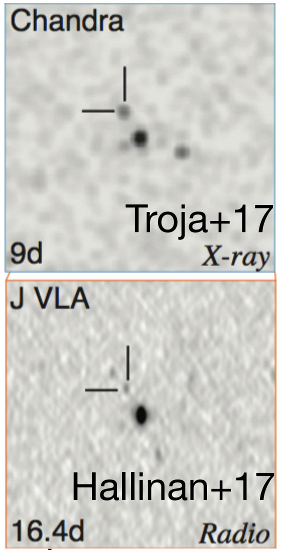
0.03-0.05 M_{Sun} ejected mass
Fast moving dynamical ejecta (0.2c) + slower wind (0.05c)

Heavy elements (possible) signatures



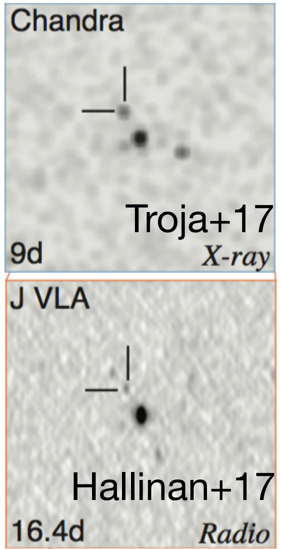


GW 170817 / GRB 170817A

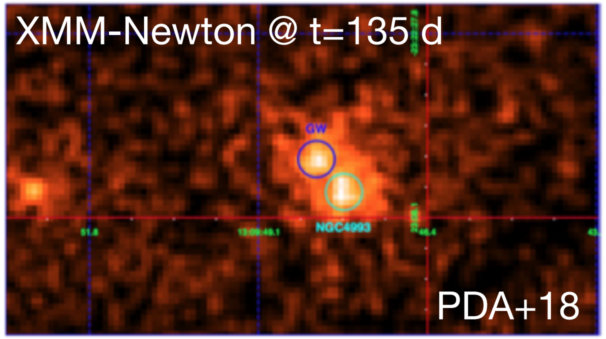


1st detection of the afterglow

GW 170817 / GRB 170817A

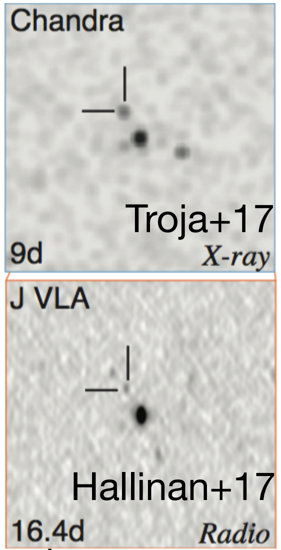


1st detection of the afterglow

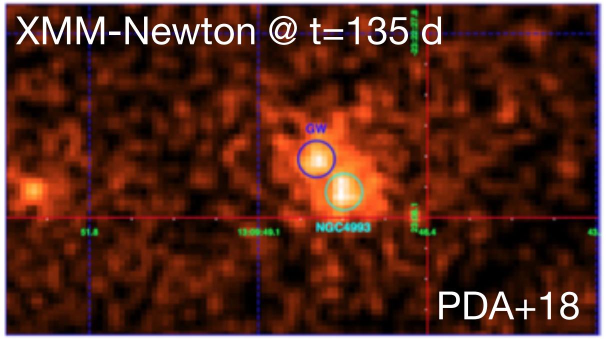


detection of the afterglow at the peak

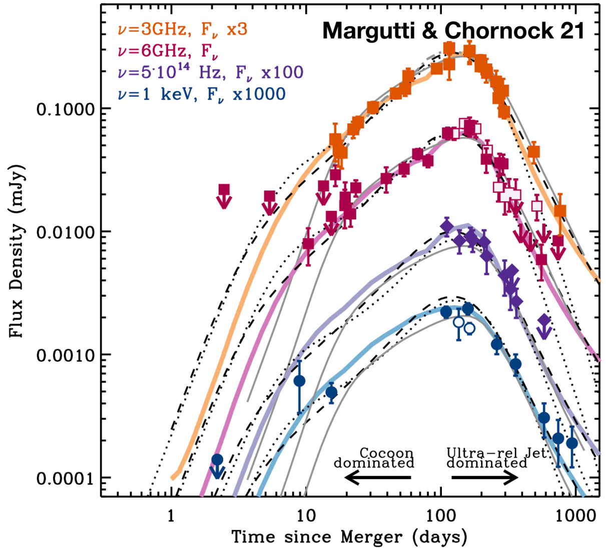
GW 170817 / GRB 170817A



1st detection of the afterglow

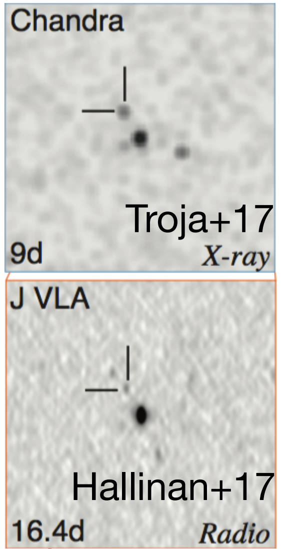


detection of the afterglow at the peak

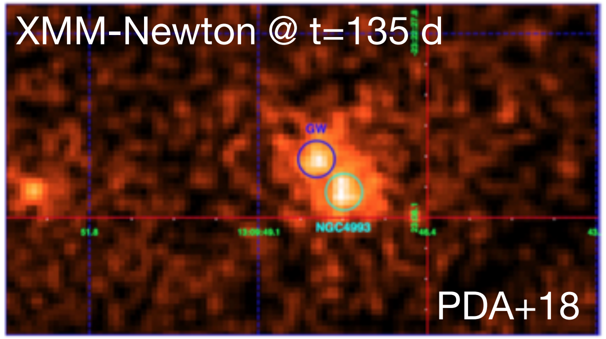


overall afterglow light curve

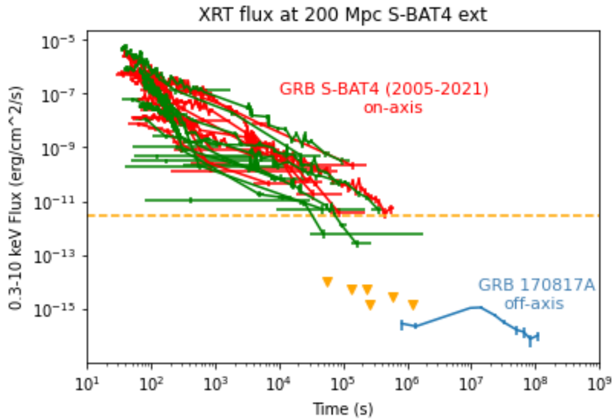
GW 170817 / GRB 170817A



1st detection of the afterglow

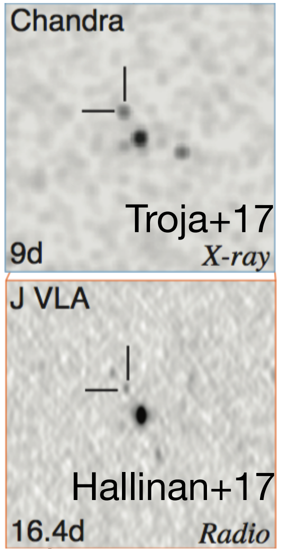


detection of the afterglow at the peak

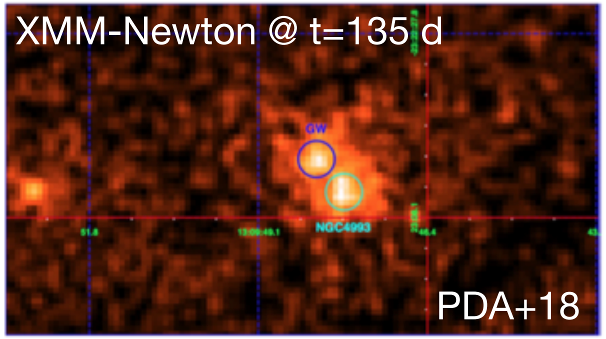


GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

GW 170817 / GRB 170817A



1st detection of the afterglow



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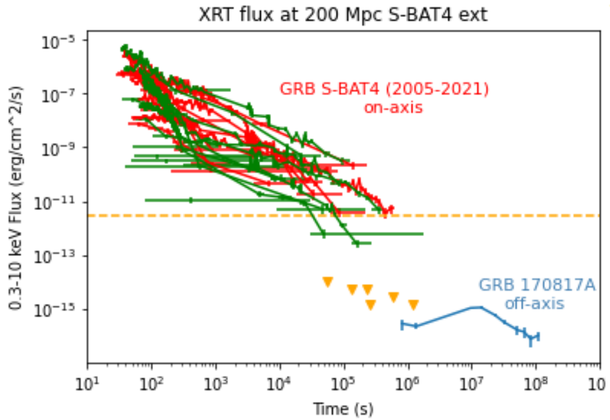
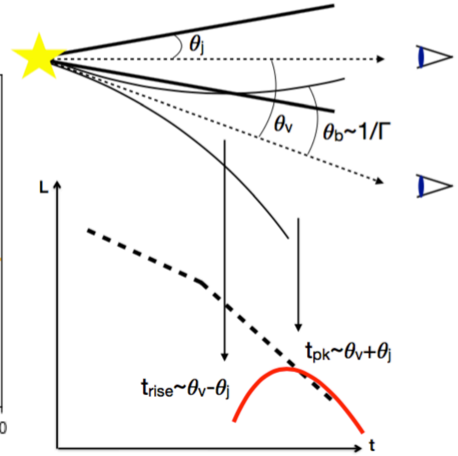
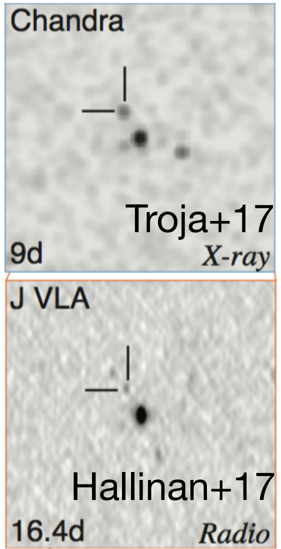


GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19



GW 170817 / GRB 170817A



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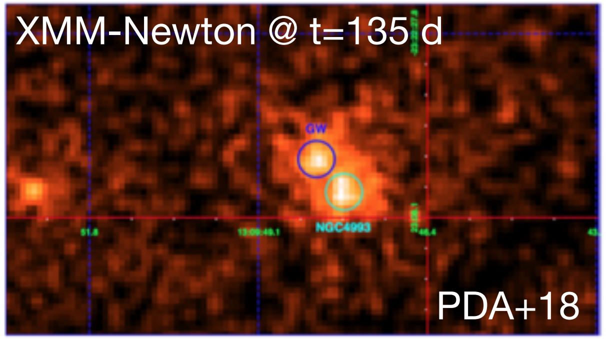

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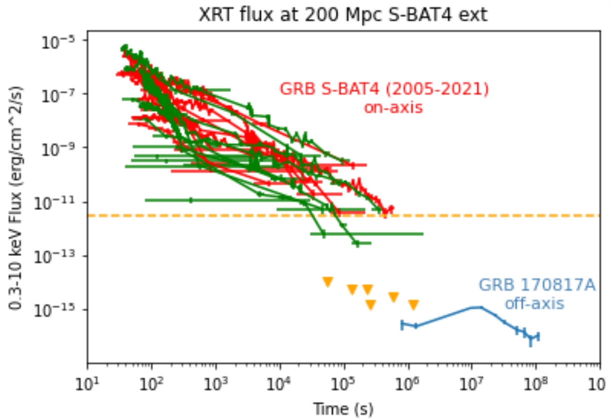
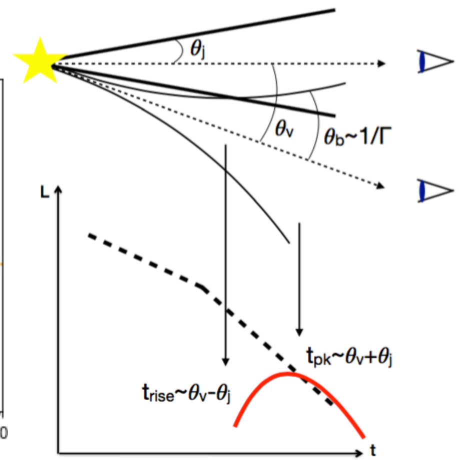
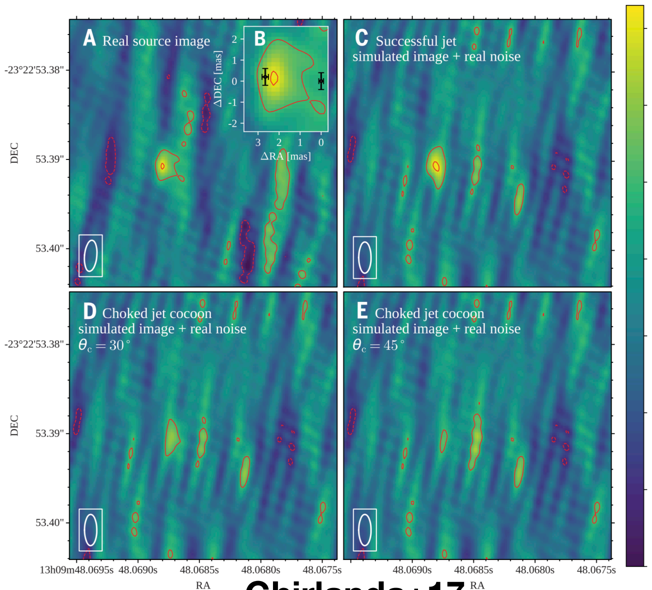




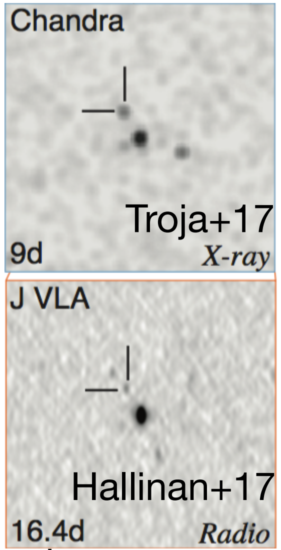
GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19



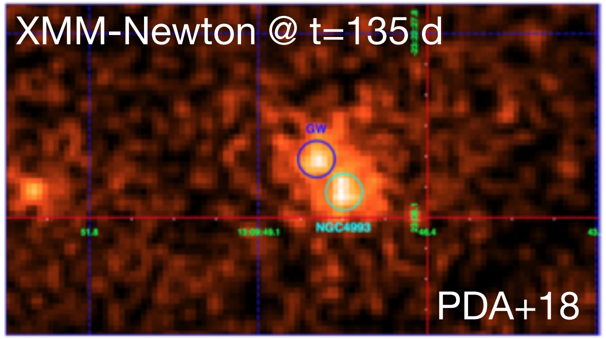
Ghirlanda+17

The radio afterglow is detected with an angular size < 2 mas in VLBI data obtained ~ 207 d after the merger. Evidence for superluminal motion is also found measuring an angular offset between T+75 d and T+235 d.

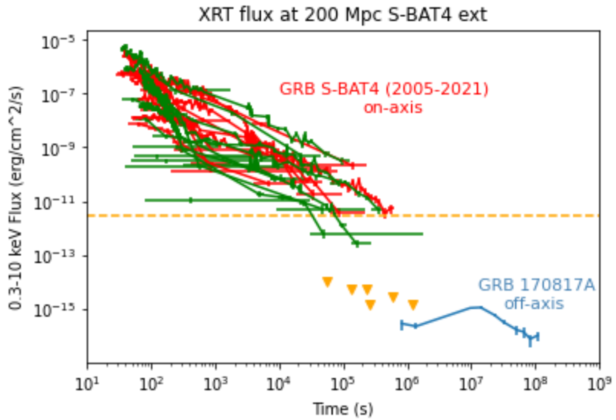
GW 170817 / GRB 170817A



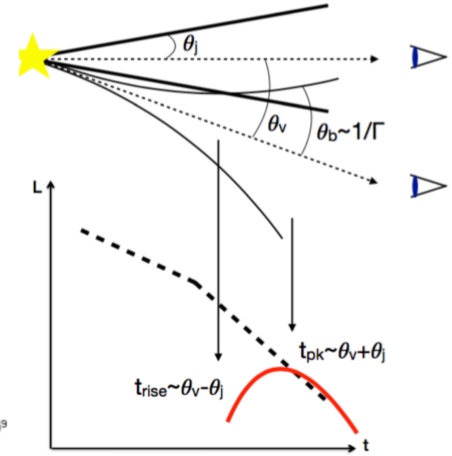
1st detection of the afterglow

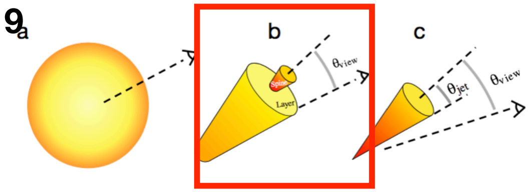


detection of the afterglow at the peak



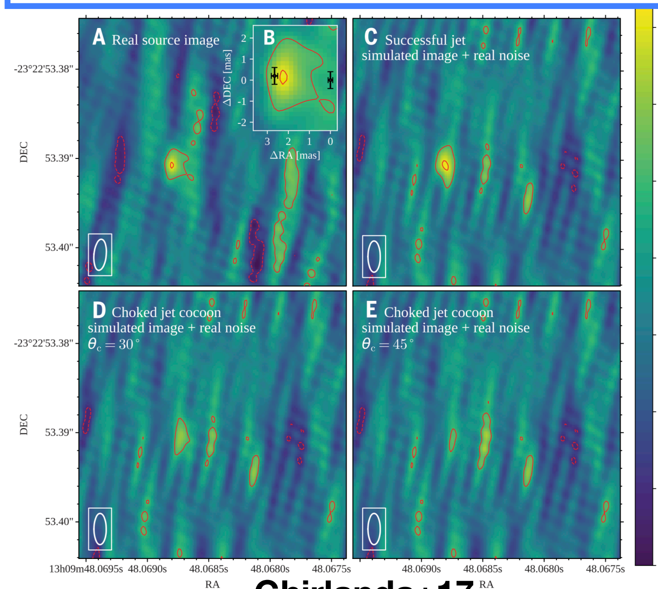
GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19a





Salafia+17

Full characterization of the GRB properties: evidence for a structured jet

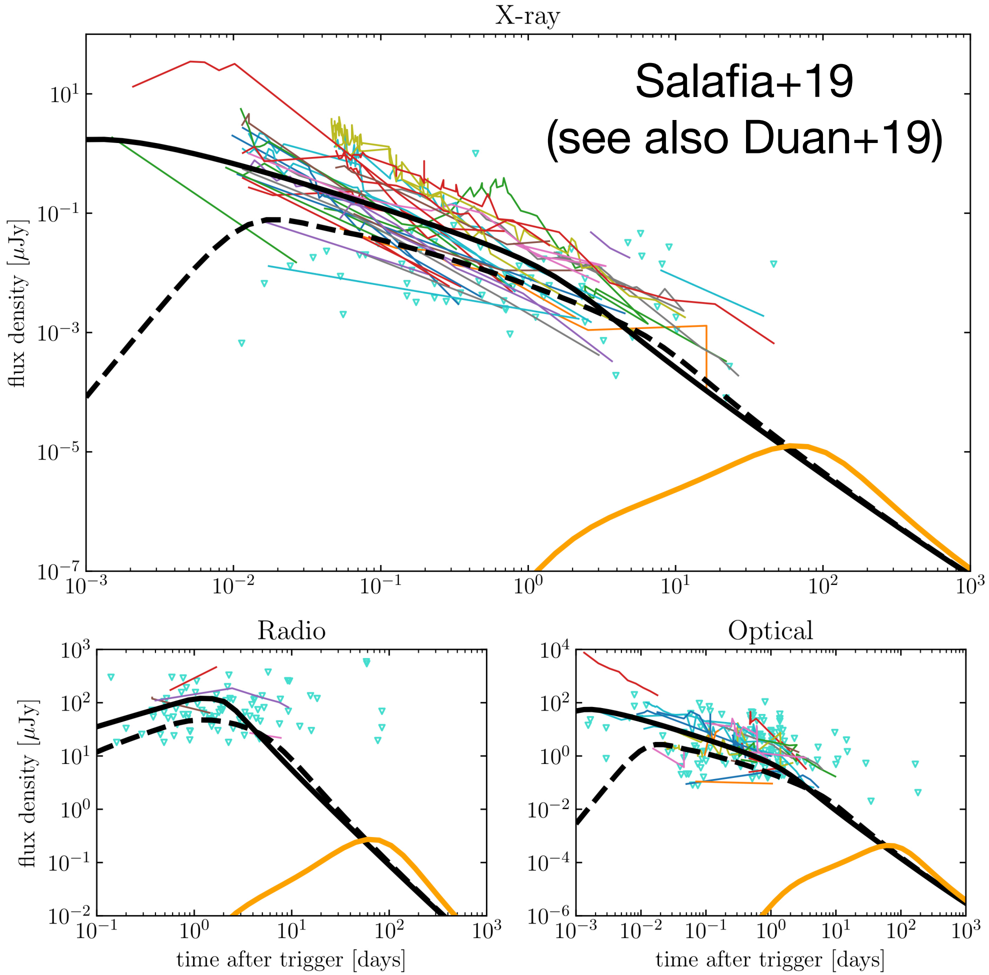


Ghirlanda+17

The radio afterglow is detected with an angular size < 2 mas in VLBI data obtained ~ 207 d after the merger. Evidence for superluminal motion is also found measuring an angular offset between T+75 d and T+235 d.
These findings, together with the afterglow light curve modelling, 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 θ_{jet} < 5 deg and θ_{view} ~ 20 deg.

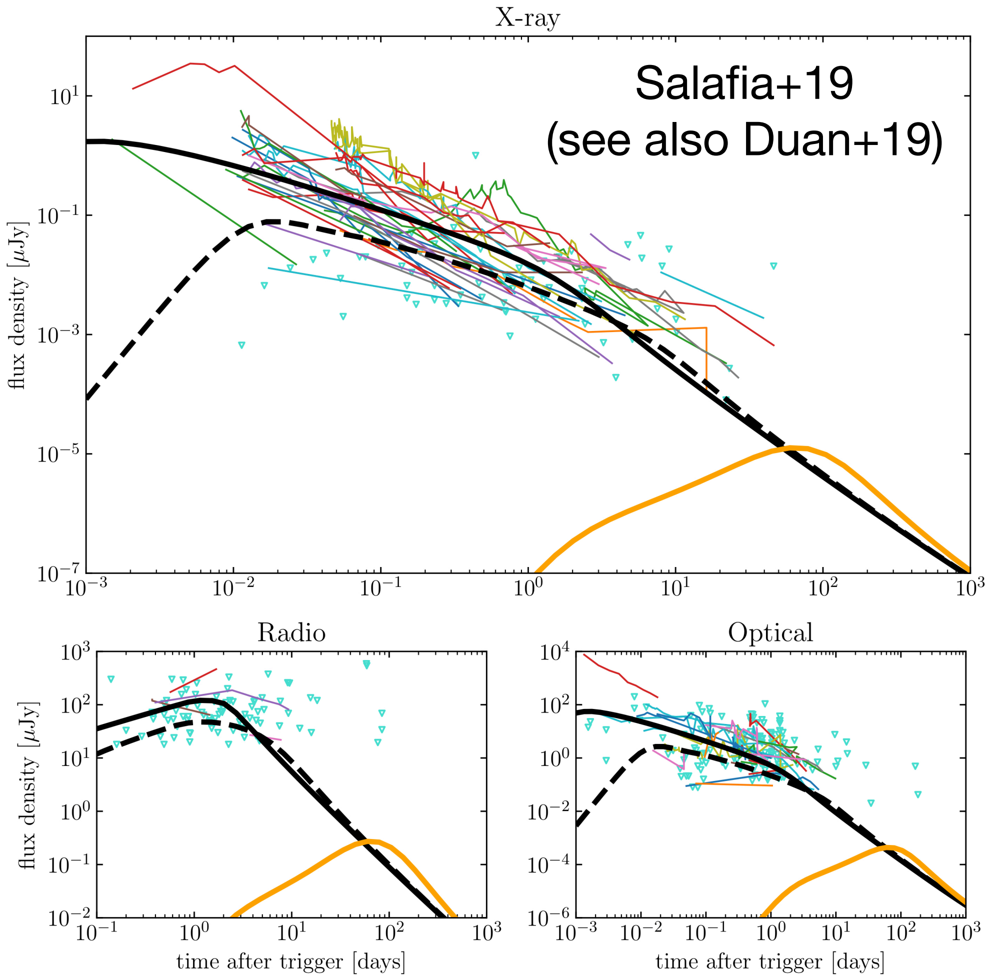
Alexander+17,18; PDA+18; Dobie+18; Fong+19; Haggard+17; Hallinan+17; Hajela+19; Margutti+17,18; Mooley+18a,b; Reasmi+18; Ruan+18; Troja+18a,b, 19,20; Ghirlanda+19; Piro+19; Margutti & Chornock 21 and many others

GRB 170817A: a typical short GRB?



If seen on-axis, the afterglow of a GRB 170817A-like jet is comparable to the typical SGRB afterglows.

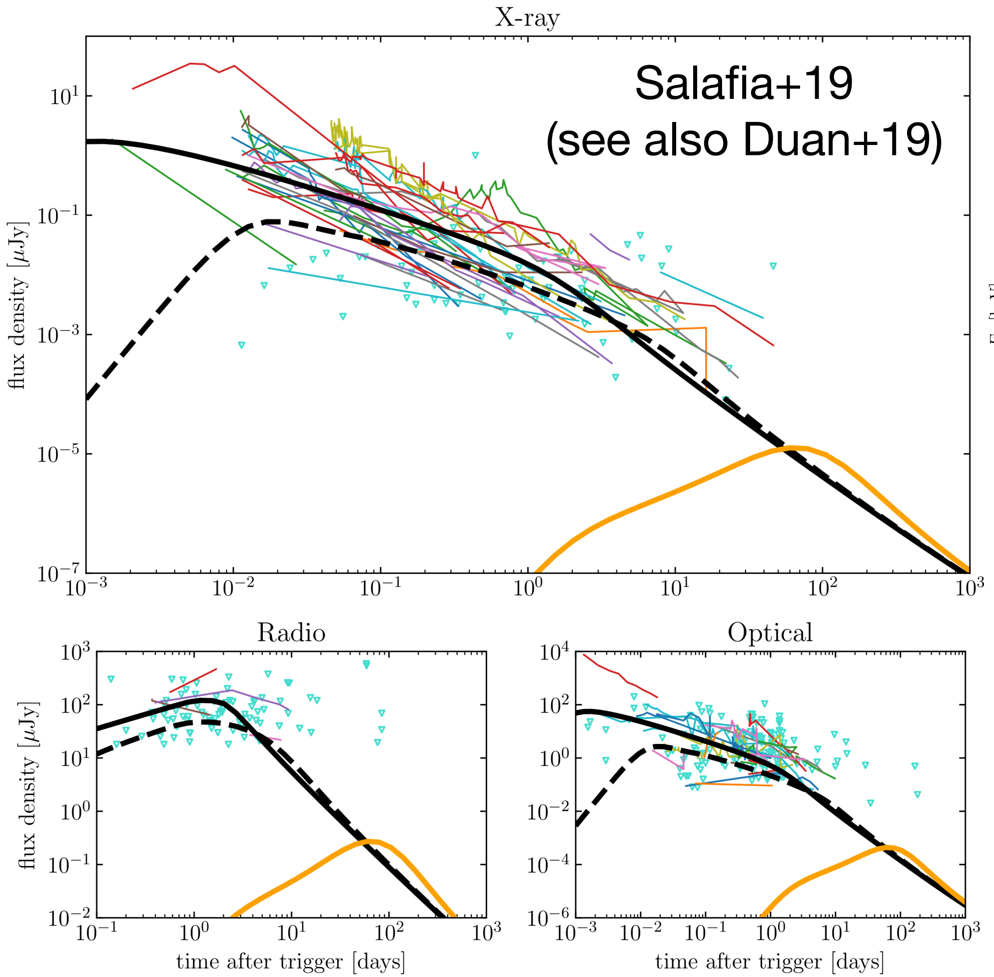
GRB 170817A: a typical short GRB?

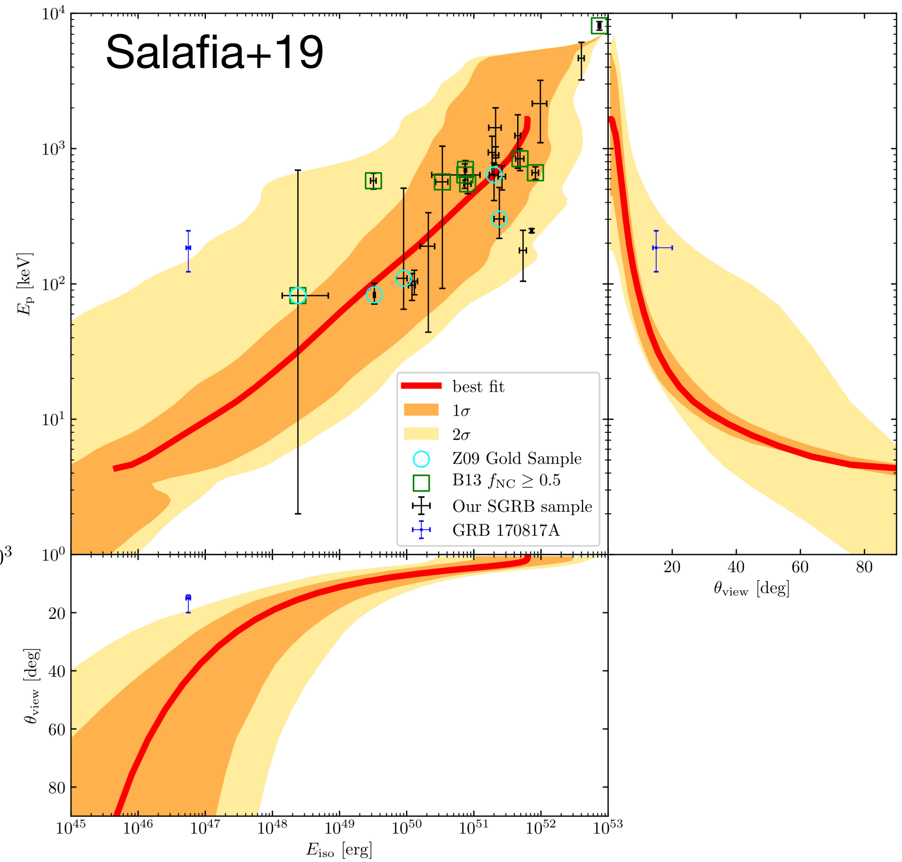


If seen on-axis, the afterglow of a GRB 170817A-like jet is comparable to the typical SGRB afterglows.

This may point towards a quasi-universal jet structure for (S)GRBs, where the diversity in the afterglow population could be mainly ascribed to extrinsic (redshift, density of the surrounding medium, viewing angle) rather than intrinsic properties.

GRB 170817A: a typical short GRB?

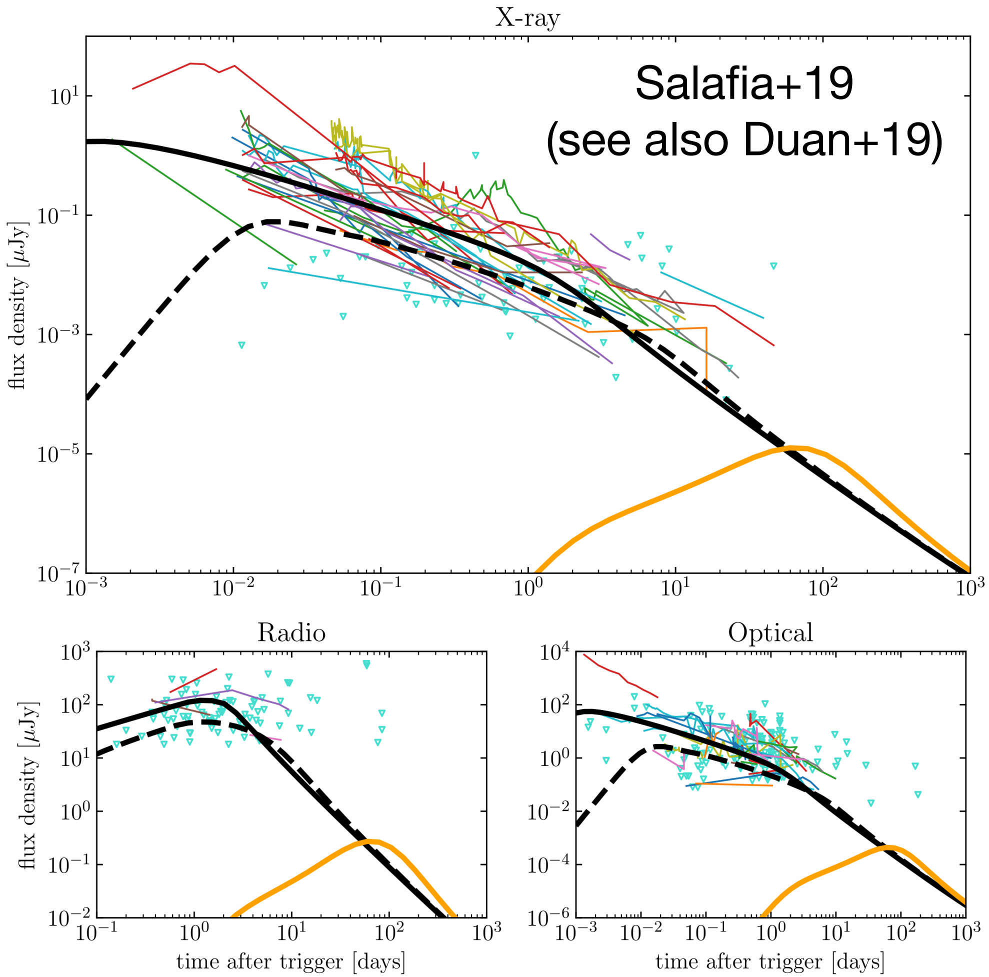


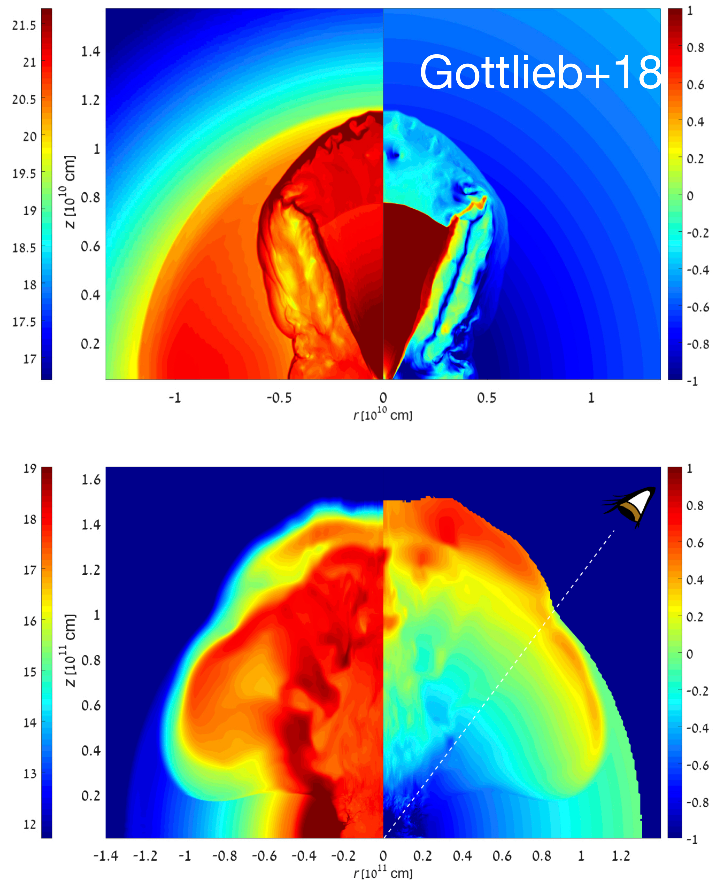


If seen on-axis, the afterglow of a GRB 170817A-like jet is comparable to the typical SGRB afterglows.

The situation is a bit less straightforward (though still viable) when considering the prompt emission (Eiso is too low, Epeak is too high w.r.t predictions).

GRB 170817A: a typical short GRB?





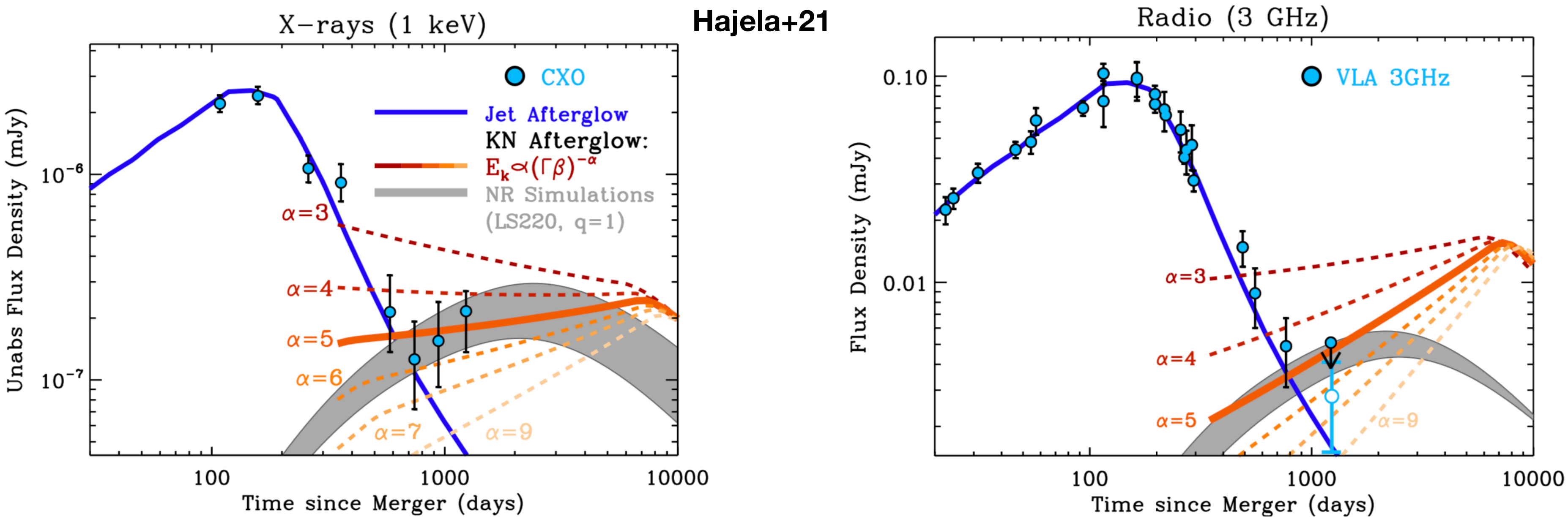
If seen on-axis, the afterglow of a GRB 170817A-like jet is comparable to the typical SGRB afterglows.

The situation is a bit less straightforward (though still viable) when considering the prompt emission (Eiso is too low, Epeak is too high w.r.t predictions).

The shock breakout of a cocoon from the merger's ejecta provides an alternative explanation.

GRB 170817A: a puzzling late time emission

Hajela+21



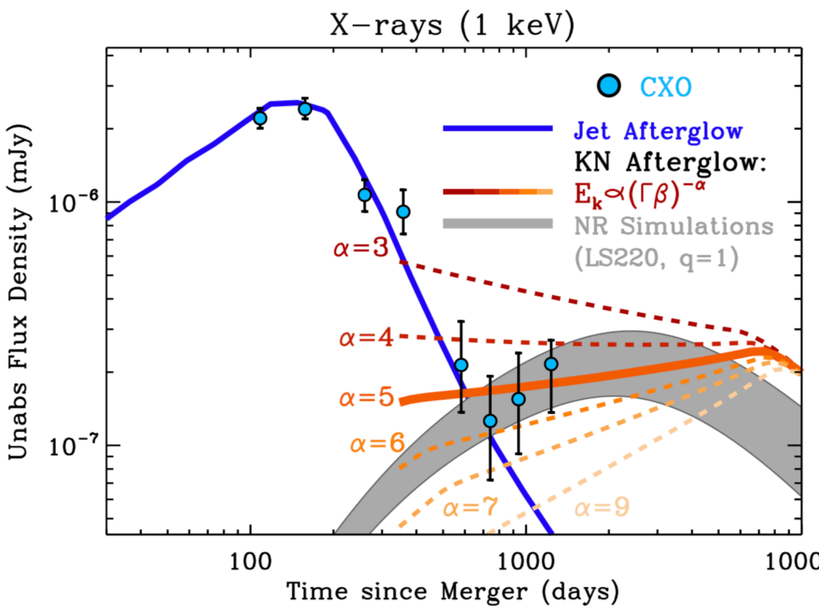
KN afterglow?

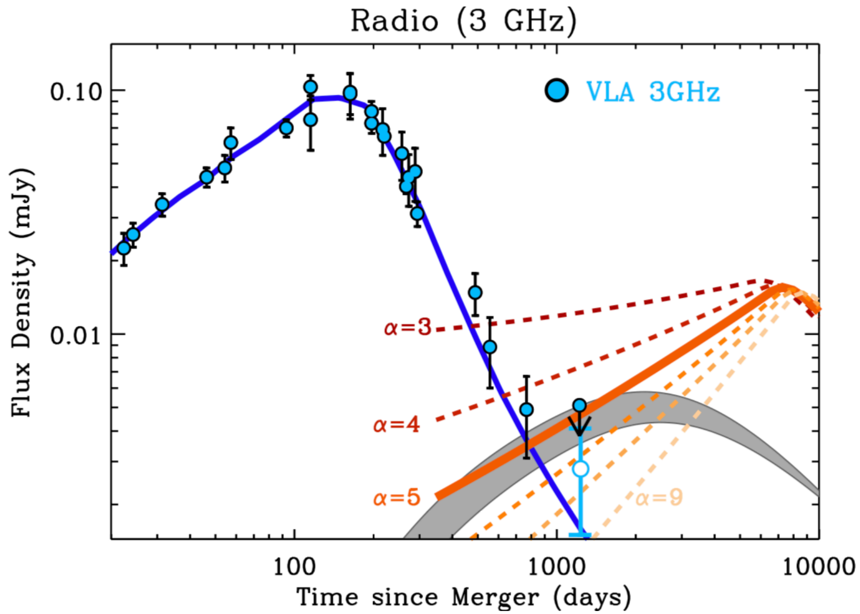
Accretion on compact remnant?

Magnetar?

GRB 170817A: a puzzling late time emission

Hajela+21



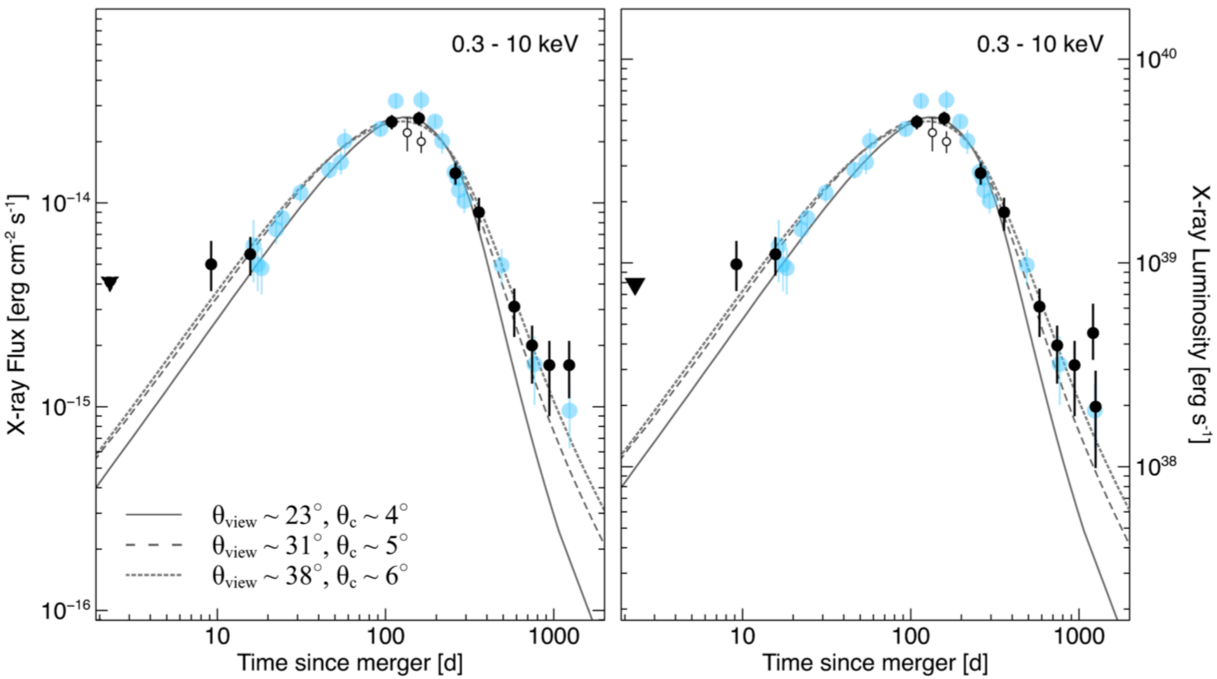


Troja+21

KN afterglow?

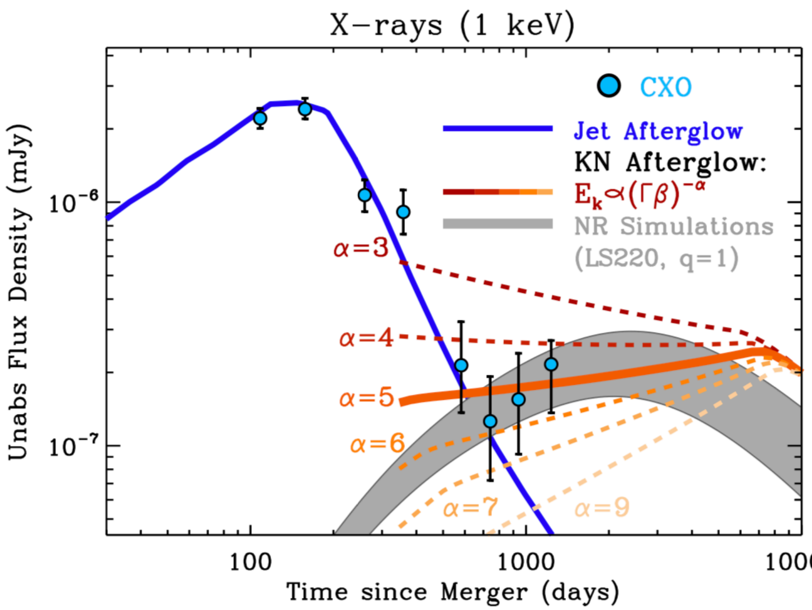
Accretion on compact remnant?

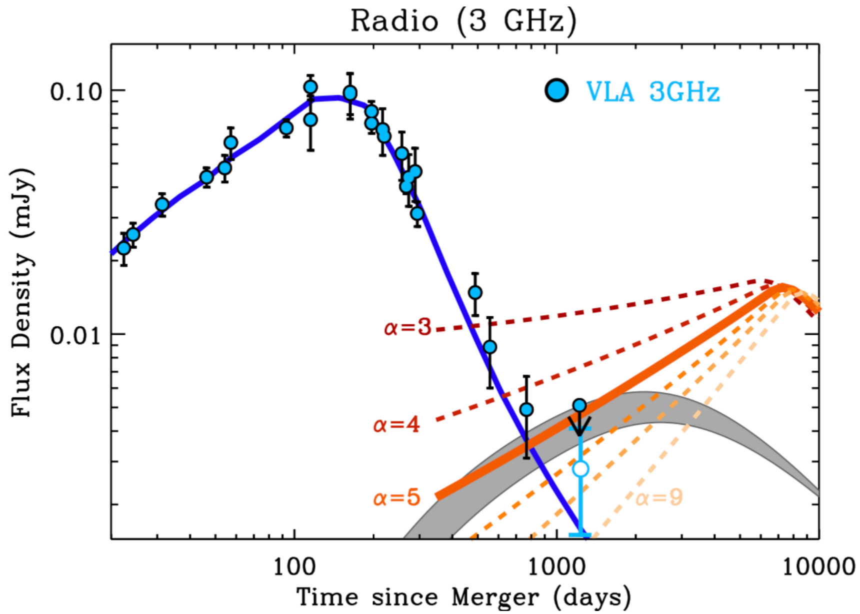
Magnetar?



GRB 170817A: a puzzling late time emission

Hajela+21



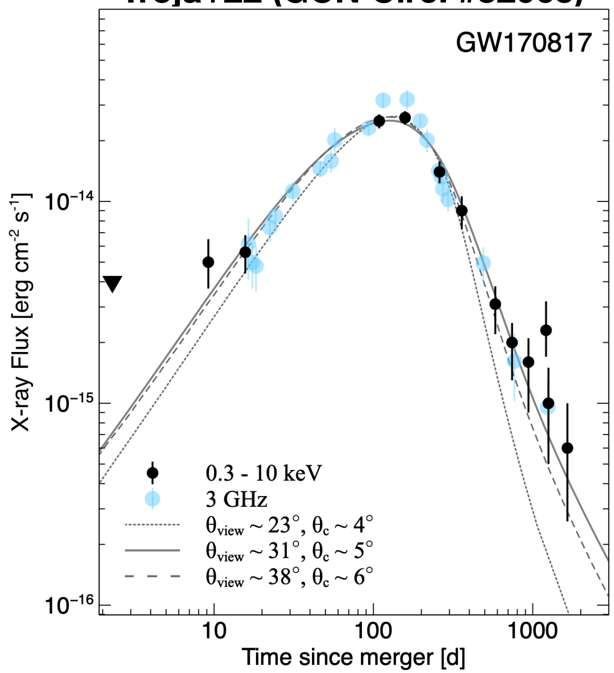


KN afterglow?

Accretion on compact remnant?

Magnetar?

Troja+22 (GCN Circ. #32065)



Waiting for O4 (Spring 2023)

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Observation run	Network	Expected BNS detections	Expected NSBH detections	Expected BBH detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}
		Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.
O3	HLV	270^{+34}_{-20}	330^{+24}_{-31}	280^{+30}_{-23}
O4	HLVK	33^{+5}_{-5}	50^{+8}_{-8}	41^{+7}_{-6}
		Comoving volume (10^3 Mpc^3) 90% c.r.	Comoving volume (10^3 Mpc^3) 90% c.r.	Comoving volume (10^3 Mpc^3) 90% c.r.
O3	HLV	120^{+19}_{-24}	860^{+150}_{-150}	16000^{+2200}_{-2500}
O4	HLVK	52^{+10}_{-9}	430^{+100}_{-78}	7700^{+1500}_{-920}

Abbott+20 (LRR)

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **513,** 4159–4168 (2022)
Advance Access publication 2022 April 28

https://doi.org/10.1093/mnras/stac1167

Prospects for multimessenger detection of binary neutron star mergers in the fourth LIGO–Virgo–KAGRA observing run

Barbara Patricelli,[1,2,3,4★] Maria Grazia Bernardini,[5★] Michela Mapelli,[6,7,8] Paolo D'Avanzo,[5] Filippo Santoliquido ,[6,7] Giancarlo Cella,[3] Massimiliano Razzano[1,3] and Elena Cuoco [2,3,9]

Model			GW+EM (prompt)							
			Swift/BAT		*Fermi*/GBM		*INTEGRAL*/IBIS		*SVOM*/ECLAIRs	
	$\mathcal{R}(0)$ ($\mathrm{Gpc^{-3}\ yr^{-1}}$)	GW ($\mathrm{yr^{-1}}$)	Uniform ($\mathrm{yr^{-1}}$)	Structured ($\mathrm{yr^{-1}}$)	Uniform ($\mathrm{yr^{-1}}$)	Structured ($\mathrm{yr^{-1}}$)	Uniform ($\mathrm{yr^{-1}}$)	Structured ($\mathrm{yr^{-1}}$)	Uniform ($\mathrm{yr^{-1}}$)	Structured ($\mathrm{yr^{-1}}$)
A1	31	5	0.002 (0.01)	0.05–0.08	0.014 (0.06)	0.27–0.46	0.0005 (0.002)	0.009–0.014	0.002 (0.008)	0.05–0.07
A3	258	22	0.01 (0.04)	0.24–0.37	0.06 (0.26)	1.17–2.00	0.002 (0.008)	0.04–0.06	0.009 (0.04)	0.22–0.32
A7	765	61	0.03 (0.12)	0.67–1.05	0.18 (0.74)	3.28–5.65	0.006 (0.02)	0.11–0.18	0.02 (0.10)	0.63–0.90

see also Colombo+22

In the meanwhile: many SGRBs/KNe

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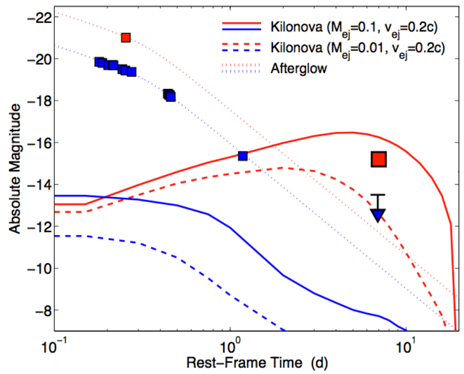
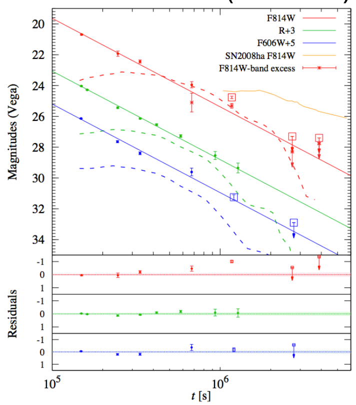
GRB 130613B (z=0.356)

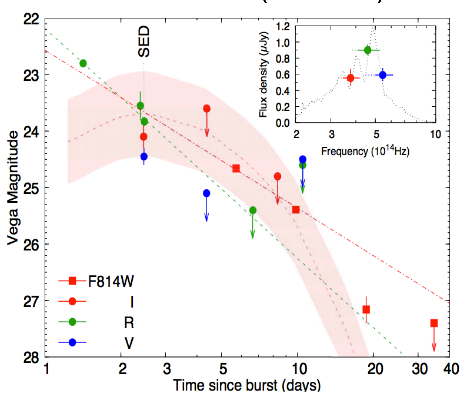
Tanvir+13; Berger+13



GRB 060614 (z=0.125)

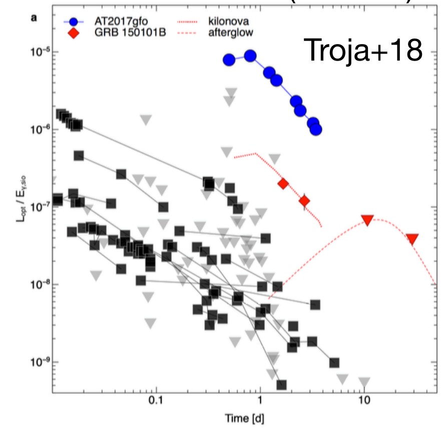


GRB 050709 (z=0.160)

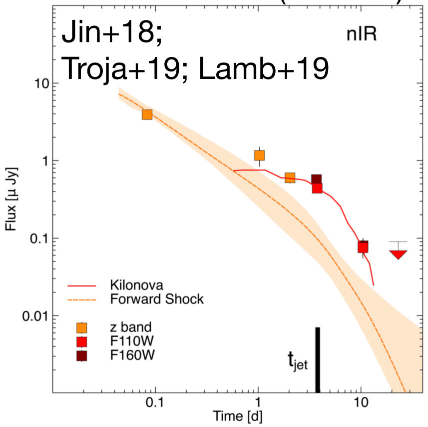


Yang+15; Jin+15; Jin+16

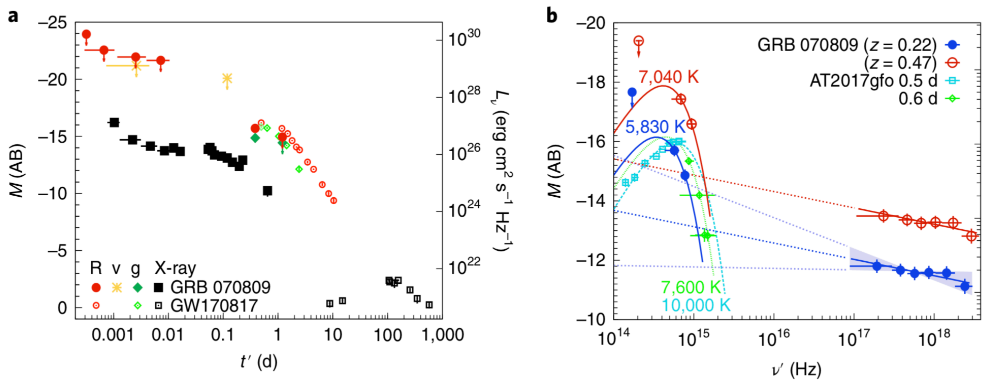
GRB 150101B (z=0.134)



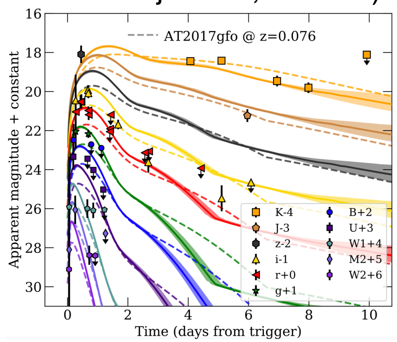
GRB 160821B (z=0.161)



GRB 070809 (z=0.22 / z = 0.47; Jin+20)

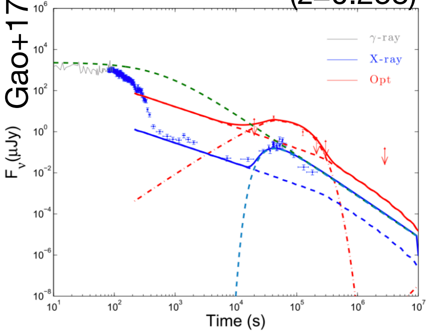


GRB 211211A (z=0.076; Rastinejad+22; Mei+22)

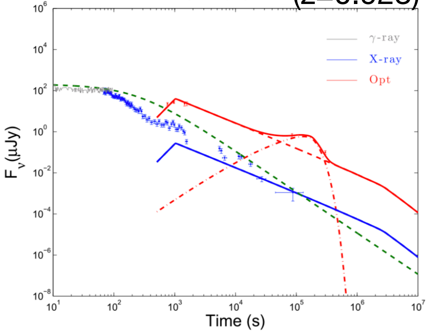


Gao+17

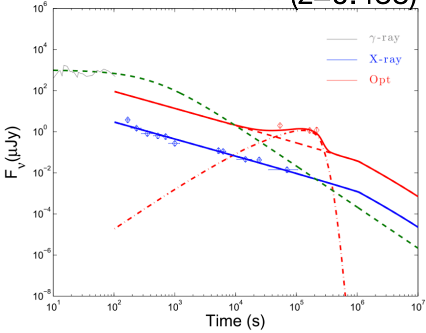
GRB 050724 (z=0.258)



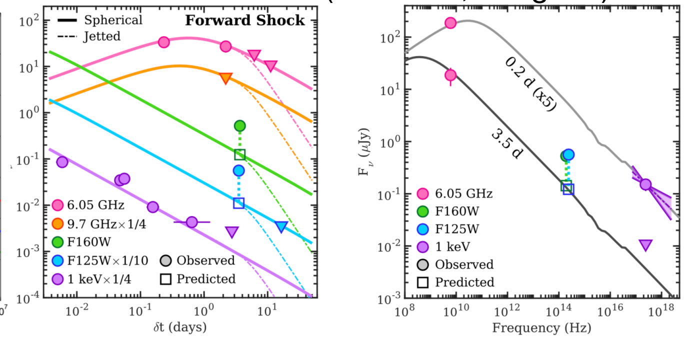
GRB 070714B (z=0.923)



GRB 061006 (z=0.438)



GRB 200522A (z=0.5536; Fong+20)



Rossi+20 for a review

SGRBs: still surprising us

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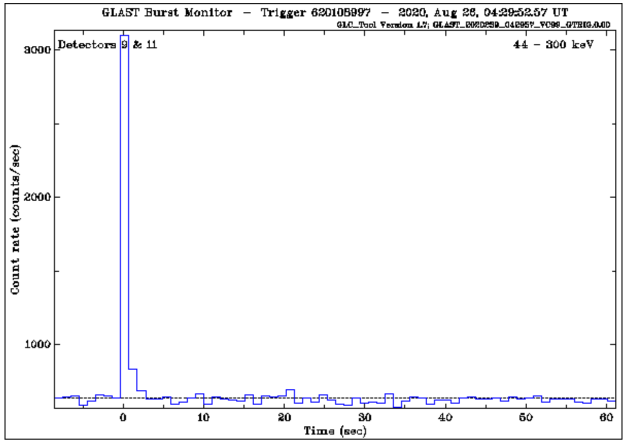
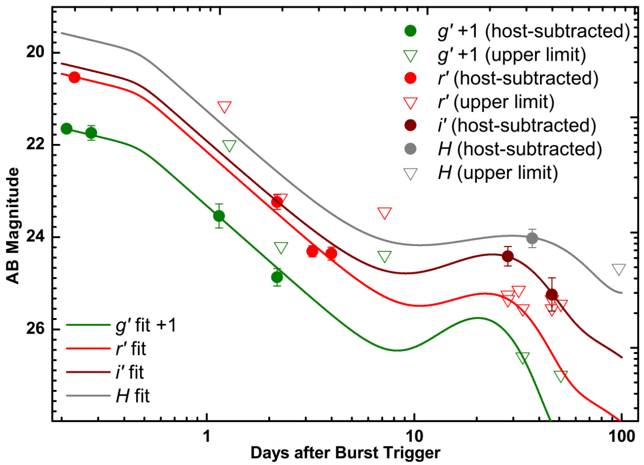
The Astrophysical Journal, 932:1 (15pp), 2022 June 10 https://doi.org/10.3847/1538-4357/ac60a2

The Peculiar Short-duration GRB 200826A and Its Supernova*

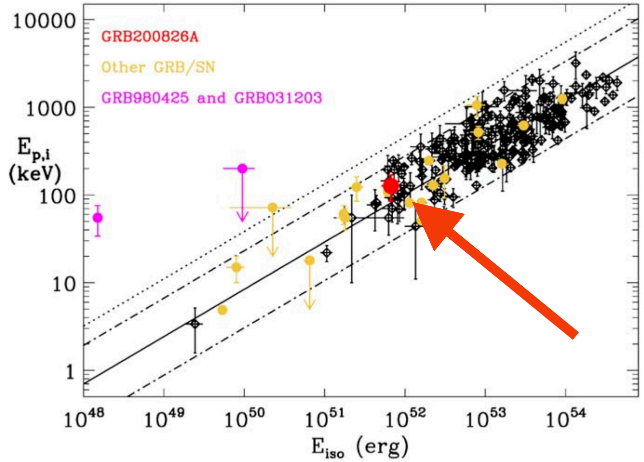
A. Rossi[1], B. Rothberg[2,3], E. Palazzi[1], D. A. Kann[4], P. D'Avanzo[5], L. Amati[1], S. Klose[6], A. Perego[7,8], E. Pian[1], C. Guidorzi[1,9,10], A. S. Pozanenko[11,12,13], S. Savaglio[14], G. Stratta[1,15,16], G. Agapito[17], S. Covino[5], F. Cusano[1], V. D'Elia[18,19], M. De Pasquale[20,21], M. Della Valle[22], O. Kuhn[2], L. Izzo[23], E. Loffredo[24,25], N. Masetti[1,26], A. Melandri[5], P. Y. Minaev[11,12,27], A. Nicuesa Guelbenzu[6], D. Paris[19], S. Paiano[19,28,29], C. Plantet[17], F. Rossi[17], R. Salvaterra[29], S. Schulze[30], C. Veillet[2], and A. A. Volnova[11]



Fermi/GBM t_{90} = 1.1 s



afterglow + SN 1998bw model



consistent with the $E_p - E_{iso}$ (Amati) relation for LGRBs

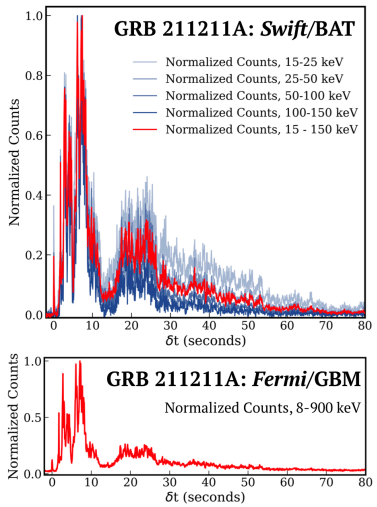
see also Ahumada+21

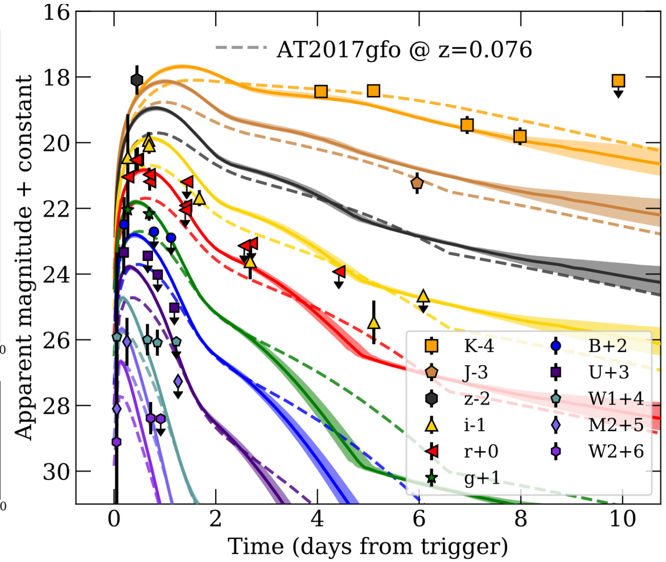
SGRBs: still surprising us

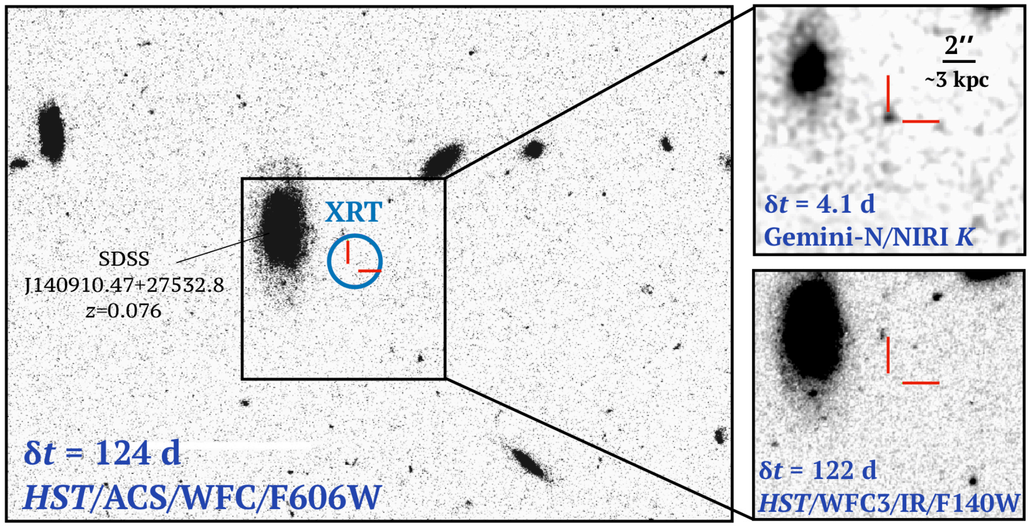
T_{90} ~ 51 s (possible EE)

A Kilonova Following a Long-Duration Gamma-Ray Burst at 350 Mpc

Jillian Rastinejad[1*], Benjamin P. Gompertz[2], Andrew J. Levan[3], Wen-fai Fong[1], Matt Nicholl[2], Gavin P. Lamb[4], Daniele B. Malesani[3,5,6], Anya E. Nugent[1], Samantha R. Oates[2], Nial R. Tanvir[4], Antonio de Ugarte Postigo[7], Charles D. Kilpatrick[1], Christopher J. Moore[2], Brian D. Metzger[8,9], Maria Edvige Ravasio[3,10], Andrea Rossi, Genevieve Schroeder[1], Jacob Jencson[12], David J. Sand[12], Nathan Smith[12], José Feliciano Agüí Fernández[13], Edo Berger[14], Peter K. Blanchard[1], Ryan Chornock[15], Bethany E. Cobb[16], Massimiliano De Pasquale[17], Johan P. U. Fynbo[5,6], Luca Izzo[18], D. Alexander Kann[13], Tanmoy Laskar[3], Ester Marini[19], Kerry Paterson[1,20], Alicia Rouco Escorial[1], Huei M. Sears[1] and Christina C. Thöne[21]







SGRBs: still surprising us

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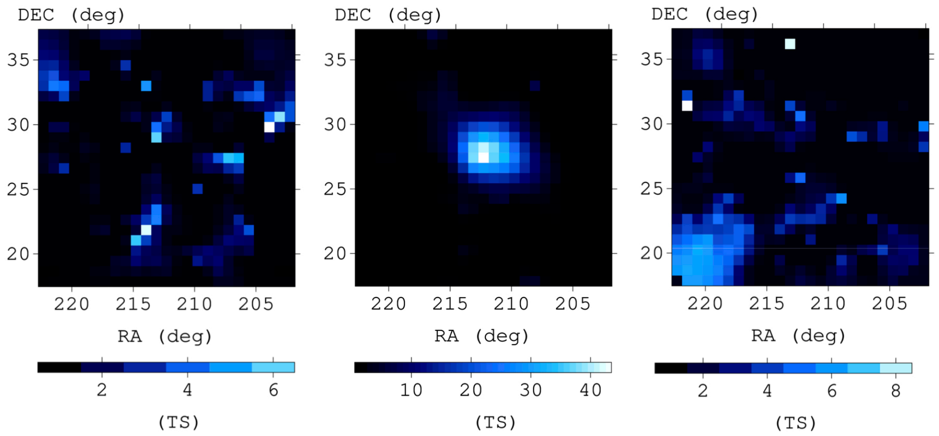
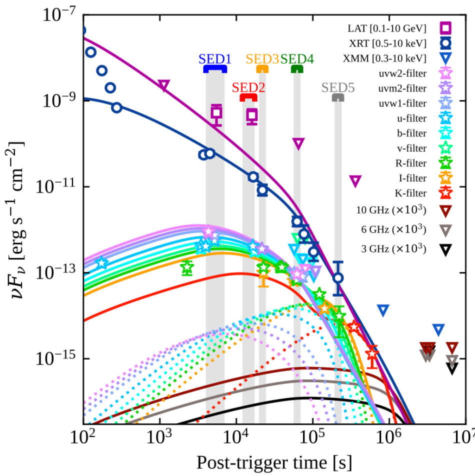
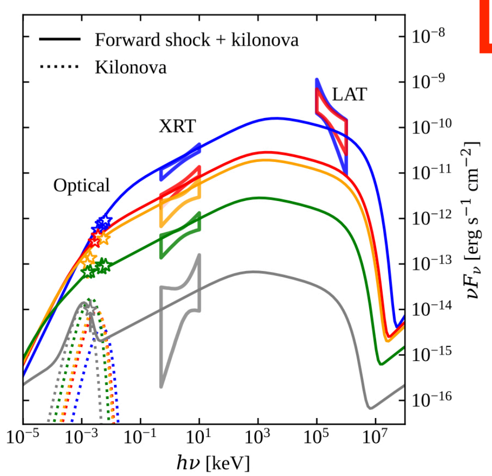
GeV emission from a compact binary merger

Alessio Mei[1,2*], Biswajit Banerjee[1,2], Gor Oganesyan[1,2], Om Sharan Salafia[3,6], Stefano Giarratana[4,5], Marica Branchesi[1,2], Paolo D'Avanzo[6], Sergio Campana[6], Giancarlo Ghirlanda[3,6], Samuele Ronchini[1,2], Amit Shukla[7] and Pawan Tiwari[7]

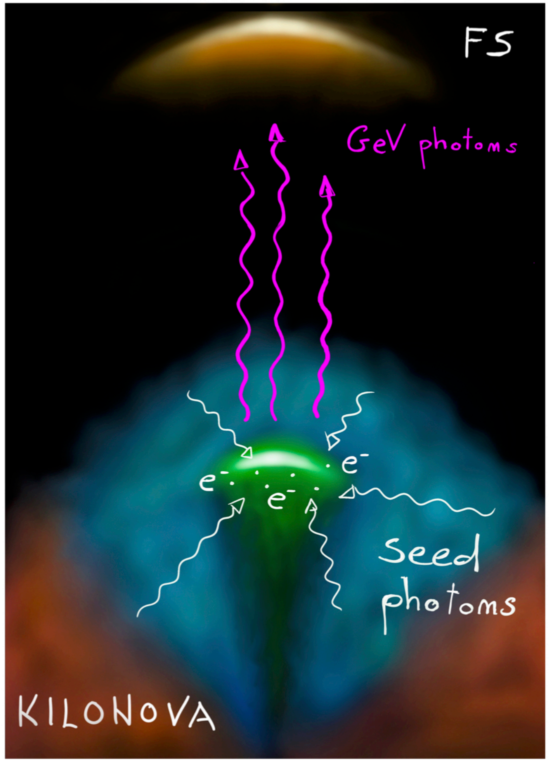


(a) $t_0 - 1\text{d}$ to t_0 (b) t_0 to $t_0 + 20$ ks (c) $t_0 + 1\text{d}$ to $t_0 + 2\text{d}$

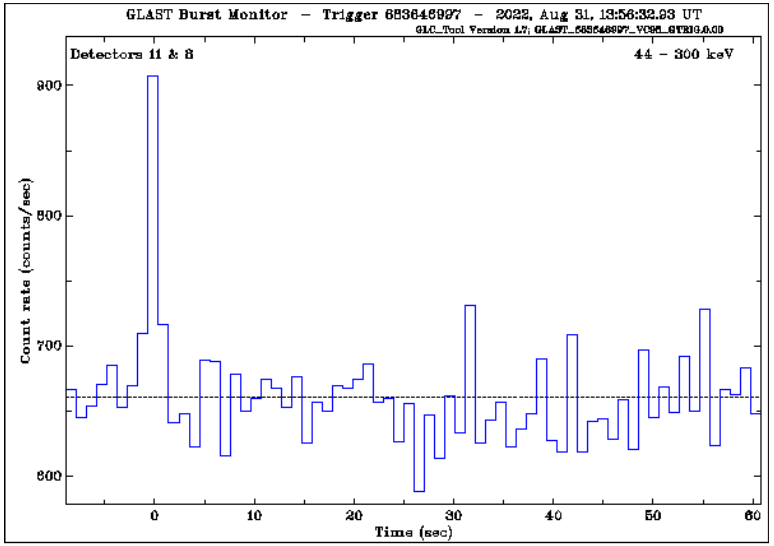


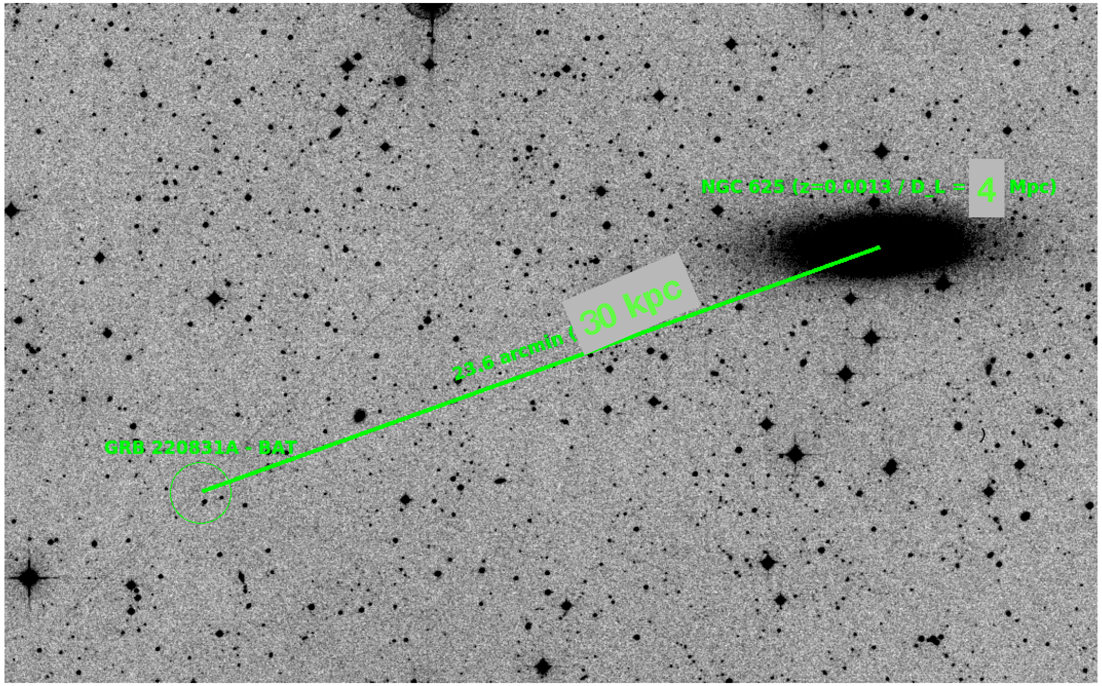


late time [T+(6 – 14) ks] GeV emission, in excess to afterglow emission



SGRBs: still surprising us





GRB 220831A

- detected by Fermi/GBM e Swift/BAT-GUANO
- T_{90} ~ 1.7 s
- E_p = 46 keV
- close to NGC 625 (D_L ~ 4 Mpc; 30 kpc offset in projection)
- possible color evolution of the optical/NIR counterpart (r – J > 2 mag at late time)

The SBAT4 sample

A sub-sample of *Swift* SGRBS with:
- prompt XRT observation (no need for a X-ray detection)
- A_V < 0.5 mag
- P_{64} > 3.5 *ph/s/cm*^{2} (15-150 kev)

The SBAT4 sample

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A sub-sample of *Swift* SGRBS with:
- prompt XRT observation (no need for a X-ray detection)
- A_V < 0.5 mag
- P_{64} > 3.5 *ph/s/cm²* (15-150 kev)

→

(Nov 2004 – Jun 2013)

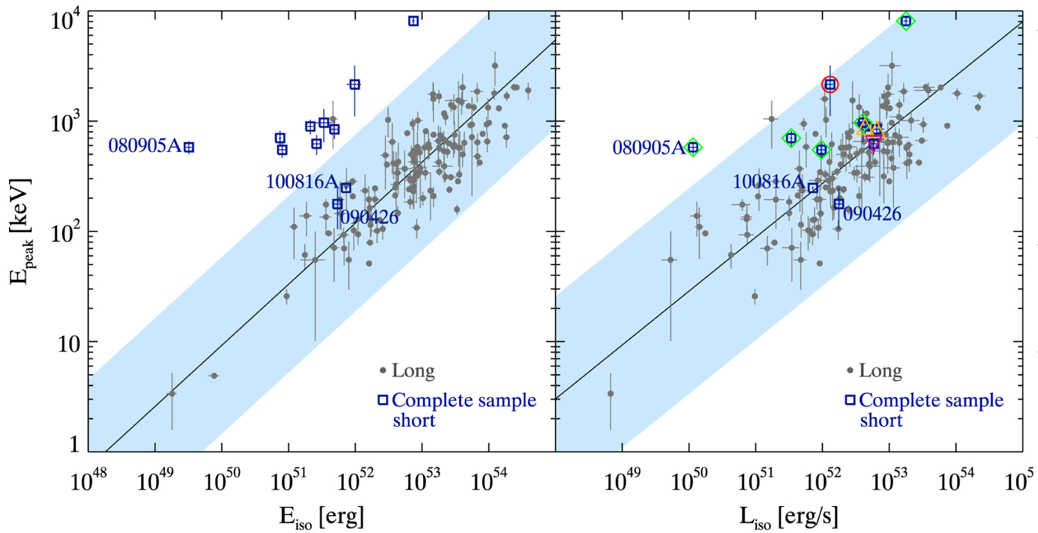
16 SGRBs, 11 with redshift (~70%)

The SBAT4 sample

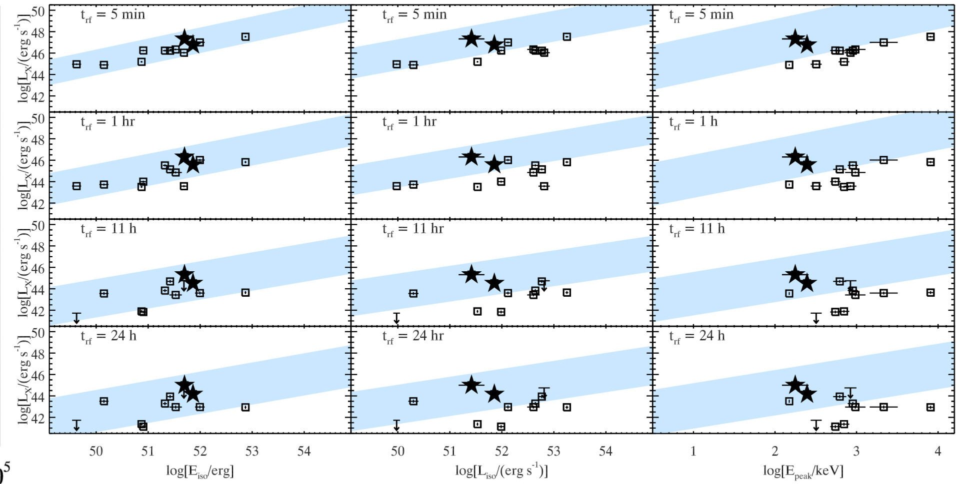
A sub-sample of *Swift* SGRBS with:
- prompt XRT observation (no need for a X-ray detection)
- A_V < 0.5 mag
- P_{64} > 3.5 *ph/s/cm²* (15-150 kev*)*

→ **(Nov 2004 – Jun 2013)**

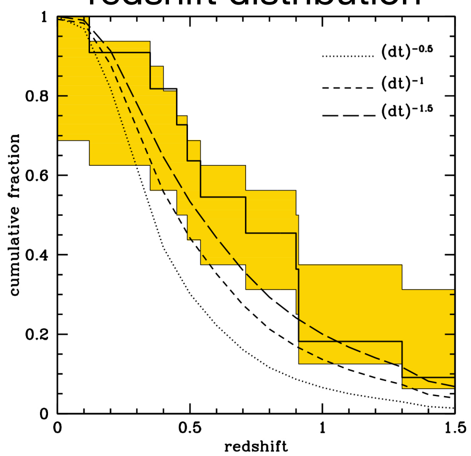
16 SGRBs, 11 with redshift (~70%)



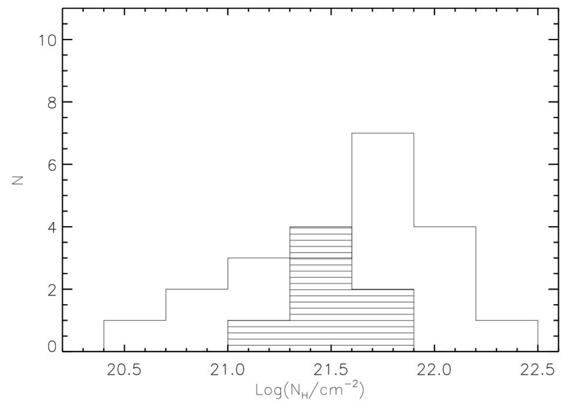
correlations



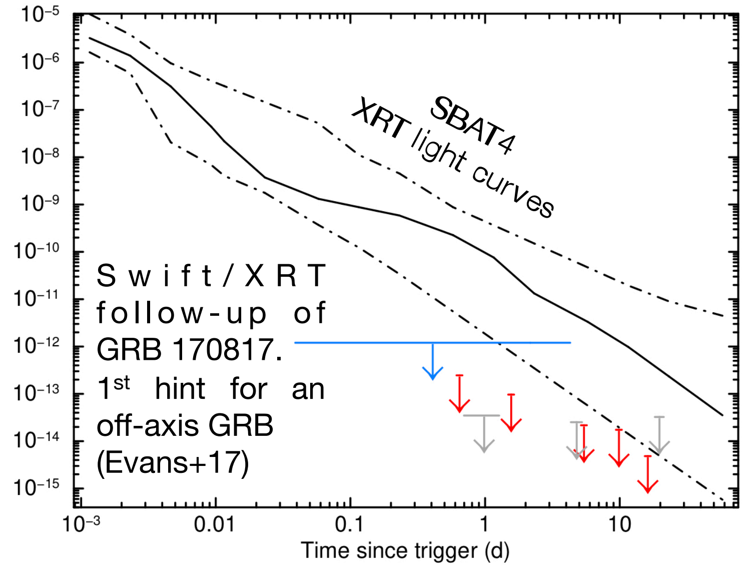
redshift distribution



N_H distribution



PDA+14



The SBAT4 sample

A sub-sample of *Swift* SGRBS with:
- prompt XRT observation (no need for a X-ray detection)
- $A_V < 0.5$ mag
- $P_{64} > 3.5\ ph/s/cm^2$ (15-150 kev)

(Nov 2004 – Jun 2013)

16 SGRBs, 11 with redshift (~70%)

(Nov 2004 – Dec 2021)

42 SGRBs, 24 with redshift (~60%)

The sample almost doubled its size w.r.t. the one presented in 2014
A useful and powerful tool to study SGRB properties

Conclusions & Future

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- The knowledge of SGRBs experienced an impressive boost in the past two decades. After the recent major breakthroughs, we now have direct evidence for:
    - the NS-NS / SGRB association
    - the existence of NS-BH systems (from GWs)
    - SGRB outflows shaped as structured jets
    - off-axis afterglow emission
    - the existence of r-process kilonovae and their association with SGRBs

- The search for SGRB/KN events (old and new events) looks promising

- No good events in O3, waiting for O4

- Still a number of open issues:
    - can NS-BH power SGRBs?
    - what is the origin of the blue KN component?
    - are KNe associated to every short GRB?
    - how to unveil the nature of the NS-NS remnant?
    - is GRB 170817A a typical short GRB?
    - can the viewing angle explain the diversity observed in (S)GRBs?
    - how to identify genuine short (i.e. merger-driven) GRBs?
    - (…)

SGRBs: still surprising us

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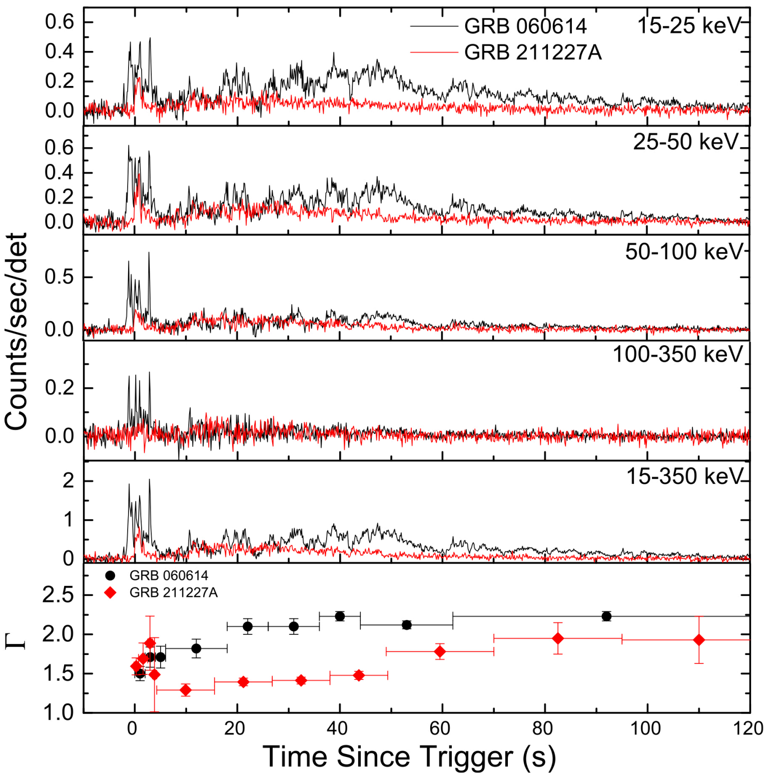
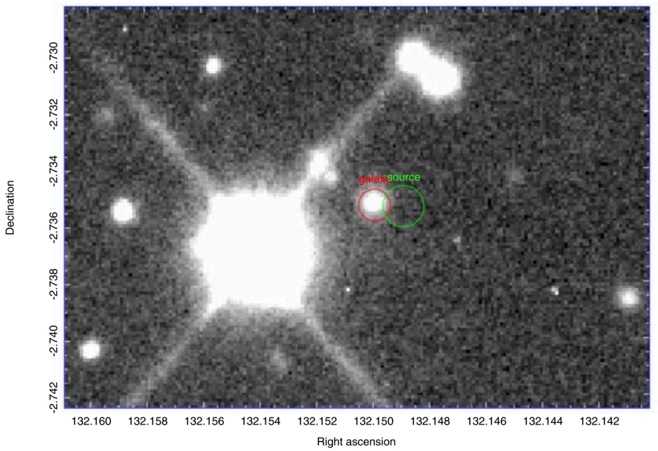
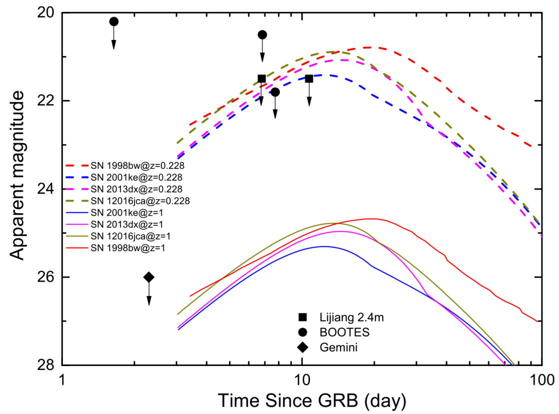
https://doi.org/10.3847/2041-8213/ac6e3a

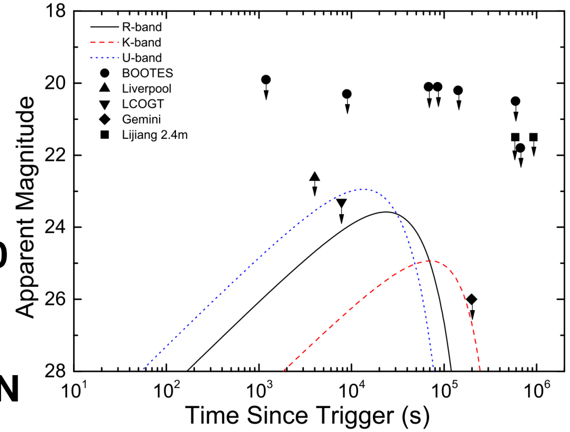
GRB 211227A as a Peculiar Long Gamma-Ray Burst from a Compact Star Merger

Hou-Jun Lü[1], Hao-Yu Yuan[1], Ting-Feng Yi[2], Xiang-Gao Wang[1], You-Dong Hu[3], Yong Yuan[4], Jared Rice[5], Jian-Guo Wang[6], Jia-Xin Cao[1], De-Feng Kong[1], Emilio Fernandez-García[3], Alberto J. Castro-Tirado[3,7], Ji-Shun Lian[1], Wen-Pei Gan[1], Shan-Qin Wang[1], Li-Ping Xin[8], M. D. Caballero-García[3], Yu-Feng Fan[6], and En-Wei Liang[1]







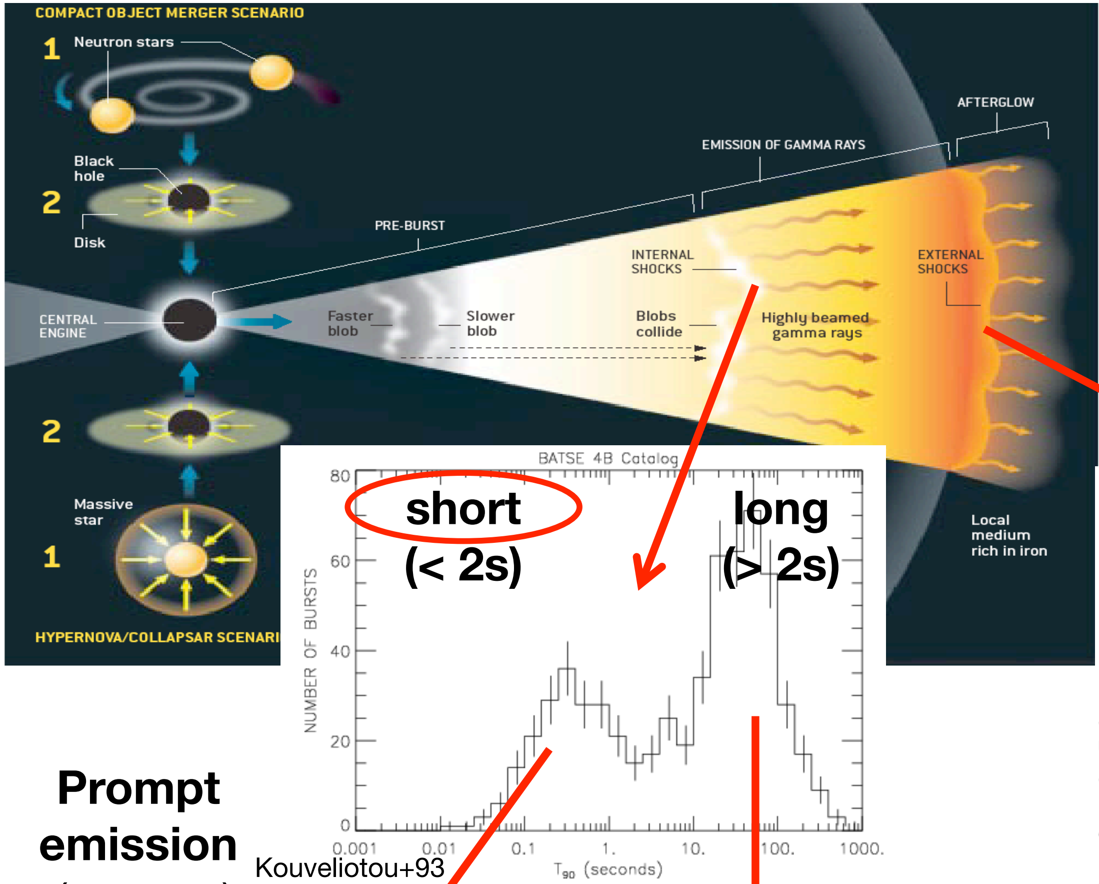


Peculiar GRB with T_{90} = 84 s

- **prompt emission similar to 060614**
- **possible EE**
- **close to a z = 0.228 galaxy (offset 20 kpc)**
- **no associated SN**
- **limits compatible with AT2017gfo KN**

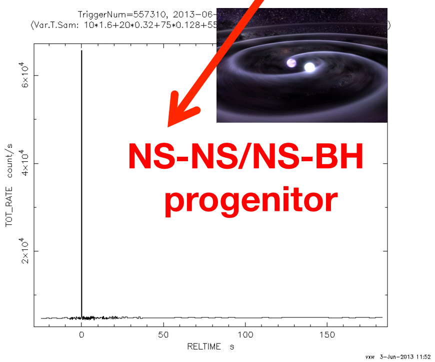
Gamma-ray bursts (GRBs)

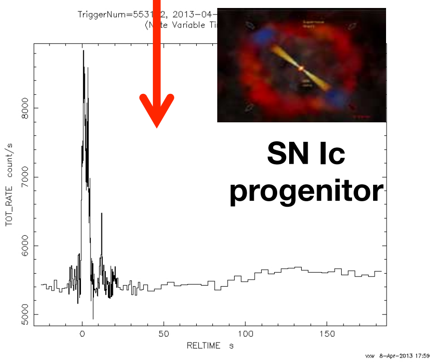
Brief, intense, flash of gamma-ray radiation:
($\langle z \rangle \sim 2.1$, $E \sim 10^{52}$ erg)



Kouveliotou+93

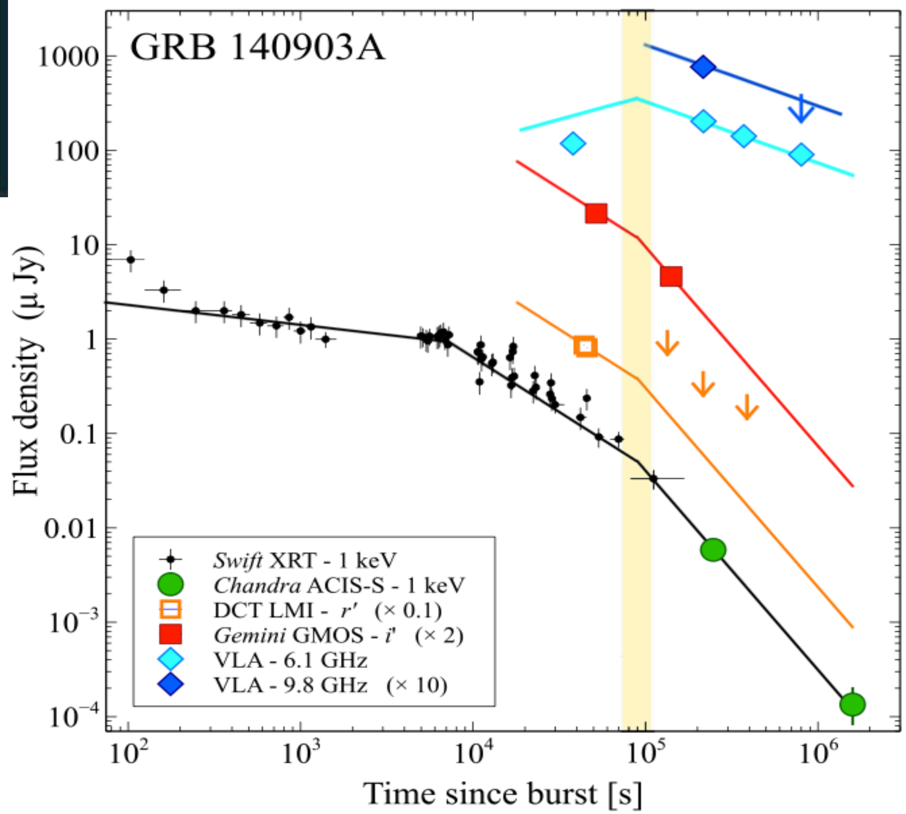
Prompt emission
(gamma)





Afterglow emission

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



Searching for GRB 170817A – like events

von Kienlin+19

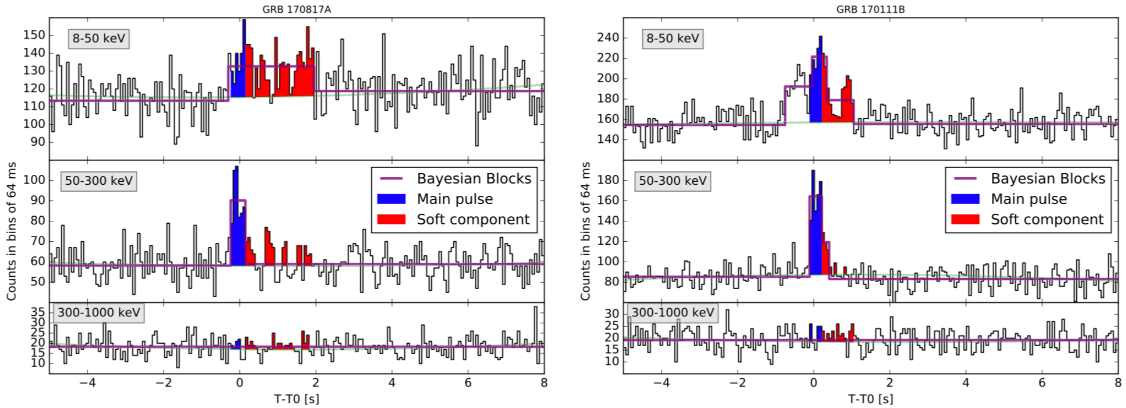


Figure 1. Left: composite light curves using NaI(Tl) detectors in the 8–50 keV (top panel), 50–300 keV (middle panel), and 300–1000 keV (bottom panel) energy ranges for GRB 170817A. Right: same, but for GRB 170111B. Blue marks the main pulse, red is the soft tail, and the procedure to find their span is given in Section 2.3. The observed pretrigger soft emission of GRB 170111B is later discussed in Section 4.

Table 2

Standard *Fermi*-GBM Burst Catalog Parameters of the Final Sample of 13 Candidate GRBs, which Includes the Reference GRB 170817A

GRB Name	Trigger ID[a]	Time (UTC)	Durations		Localization			Total Fluence	Peak Flux	Detect.[b]	References
			T90 (s)	T50 (s)	R.A. (deg.)	Decl. (deg.)	Error (deg.)	(erg cm^{-2}) $\times 10^{-7}$	(64 ms) (ph cm^{-2} s^{-1})		
GRB 081209A[c]	bn081209981	23:41:56.39	0.192 ± 0.143	0.128 ± 0.143	45.3	63.5	4.9	14.66 ± 1.49	25.4 ± 1.2	KW, S,[d] A	Golenetskii et al. (2008a, 2008b)
GRB 100328A[c]	bn100328141	03:22:44.60	0.384 ± 0.143	0.192 ± 0.091	155.9	47.0	4.8	10.01 ± 0.24	13.4 ± 0.8		Abadie et al. (2012)
GRB 101224A	bn101224227	05:27:13.86	1.728 ± 1.68	0.192 ± 0.286	285.9	45.7	0.1[e]	1.92 ± 0.27	6.7 ± 1.0	S	Krimm et al. (2010), Nugent & Bloom (2010), Xu et al. (2010), Golovnya et al. (2011)
GRB 110717A[c]	bn110717180	04:19:50.66	0.112 ± 0.072	0.032 ± 0.023	308.5	−7.9	7.5	2.51 ± 0.12	18.5 ± 1.8	KW, IA	*Fermi*-GBM Only
GRB 111024C[c]	bn111024896	21:30:02.24	0.960 ± 1.032	0.256 ± 0.143	91.2	−1.8	13.2	3.80 ± 0.16	7.4 ± 1.2	IA	*Fermi*-GBM Only
GRB 120302B[c]	bn120302722	17:19:59.08	1.600 ± 0.779	0.512 ± 0.466	24.1	9.7	13.9	1.19 ± 0.16	6.2 ± 1.5		*Fermi*-GBM Only
GRB 120915A[f]	bn120915000	00:00:41.64	0.576 ± 1.318	0.320 ± 0.091	209.4	67.3	5.9	5.06 ± 0.26	6.0 ± 0.9	IA, SW	*Fermi*-GBM Only
GRB 130502A	bn130502743	17:50:30.74	3.328 ± 2.064	2.304 ± 0.572	138.6	−0.1	0.0[e]	6.27 ± 0.35	6.6 ± 1.4	S, OT	Troja et al. (2013), Malesani et al. (2013), de Ugarte Postigo et al. (2013), Gorosabel et al. (2013), Breeveld & Troja (2013)
GRB 140511A[f]	bn140511095	02:17:11.56	1.408 ± 0.889	0.256 ± 0.181	329.8	−30.1	8.8	3.71 ± 0.32	9.4 ± 1.0		*Fermi*-GBM Only
GRB 150101B	bn150101641	15:23:34.47	0.08 ± 0.928	0.016 ± 0.023	188.0	−11.0	0.0[e]	2.38 ± 0.15	10.5 ± 1.3	S, IA, C, X, *z*	Troja et al. (2018), Burns et al. (2018), Fong et al. (2016)
GRB 170111B[f]	bn170111815	19:34:01.39	3.072 ± 1.318	0.32 ± 0.091	270.9	63.7	6.7	5.96 ± 0.12	7.6 ± 1.0		*Fermi*-GBM Only
GRB 170817A	bn170817529	12:41:06.47	2.048 ± 0.466	1.28 ± 0.405	197.5	−23.4	0.0[e]	2.79 ± 0.17	3.7 ± 0.9	L, *z*, C, IA, *HST* and more	Abbott et al. (2017a)
GRB 180511A[f]	bn180511364	08:43:35.79	0.128 ± 1.207	0.032 ± 0.045	250.4	−8.2	15.1	1.53 ± 0.21	9.2 ± 1.0	IA	*Fermi*-GBM Only