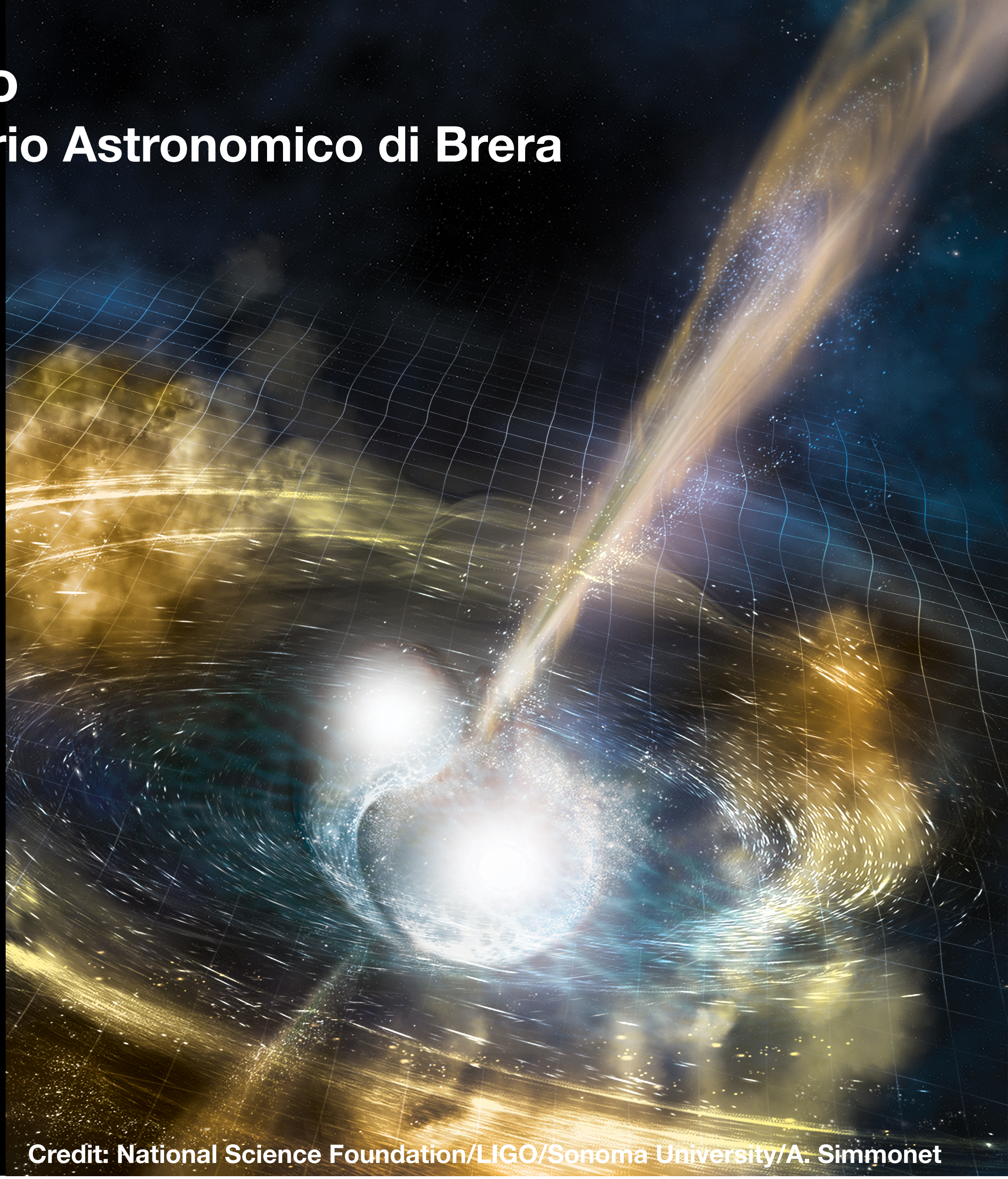
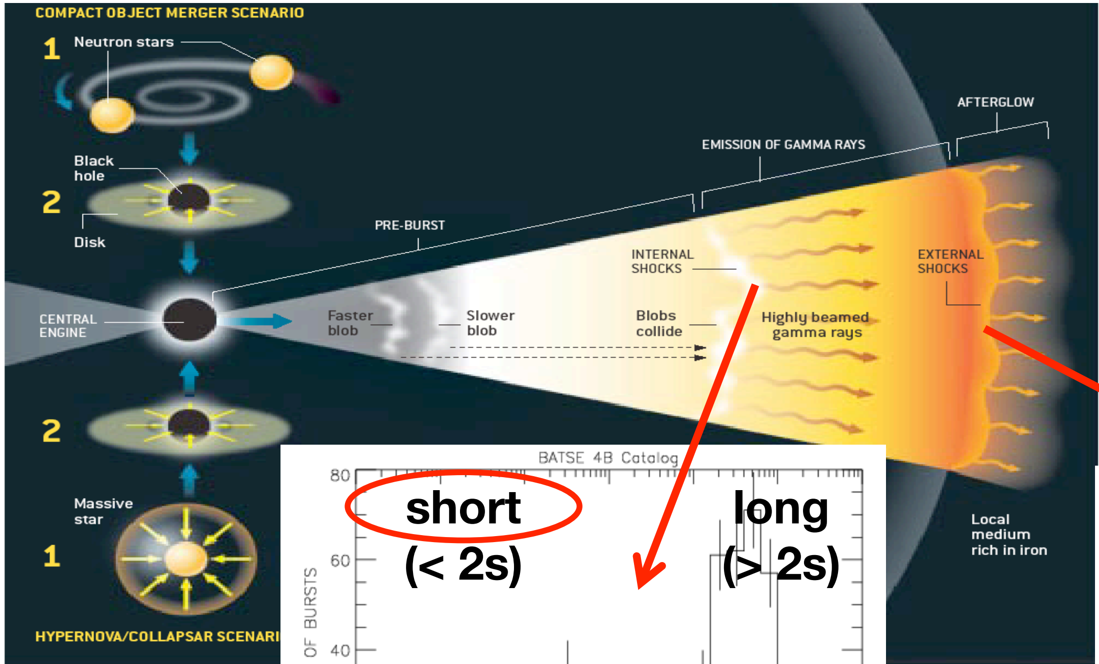
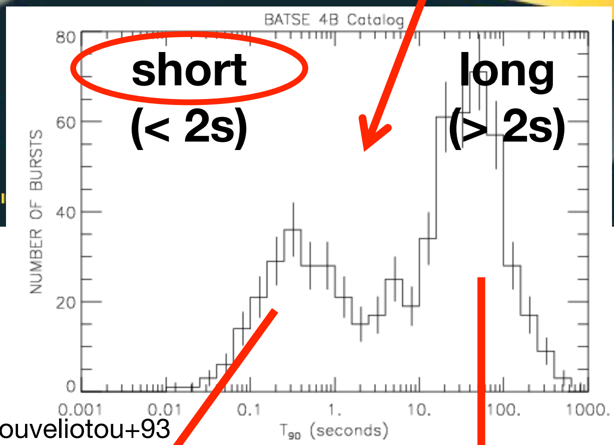
Short GRBs in the multi-messenger era: situation and perspectives

Paolo D'Avanzo
INAF – Osservatorio Astronomico di Brera



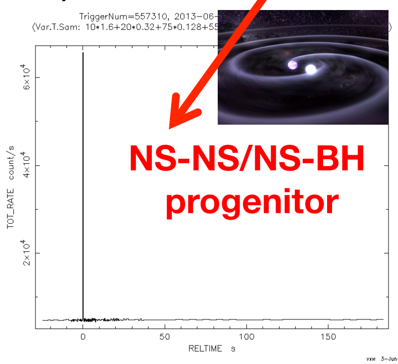
Gamma-ray bursts (GRBs)



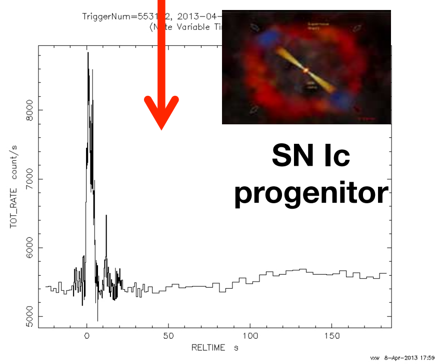


Kouveliotou+93

Prompt emission (gamma)



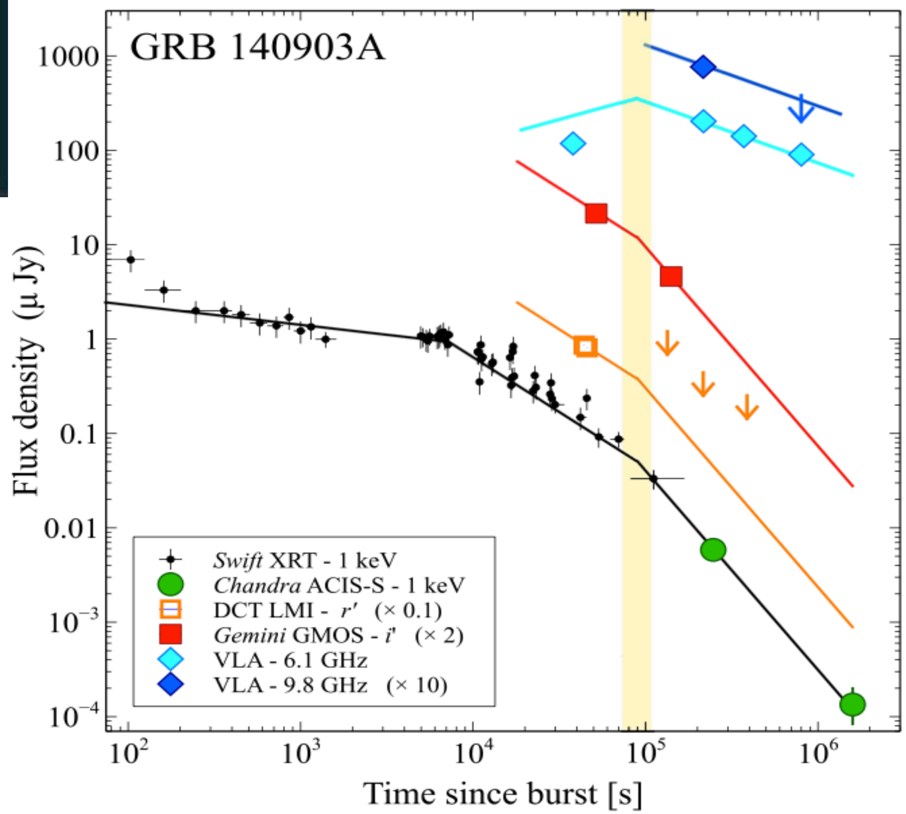
NS-NS/NS-BH progenitor



SN Ic progenitor

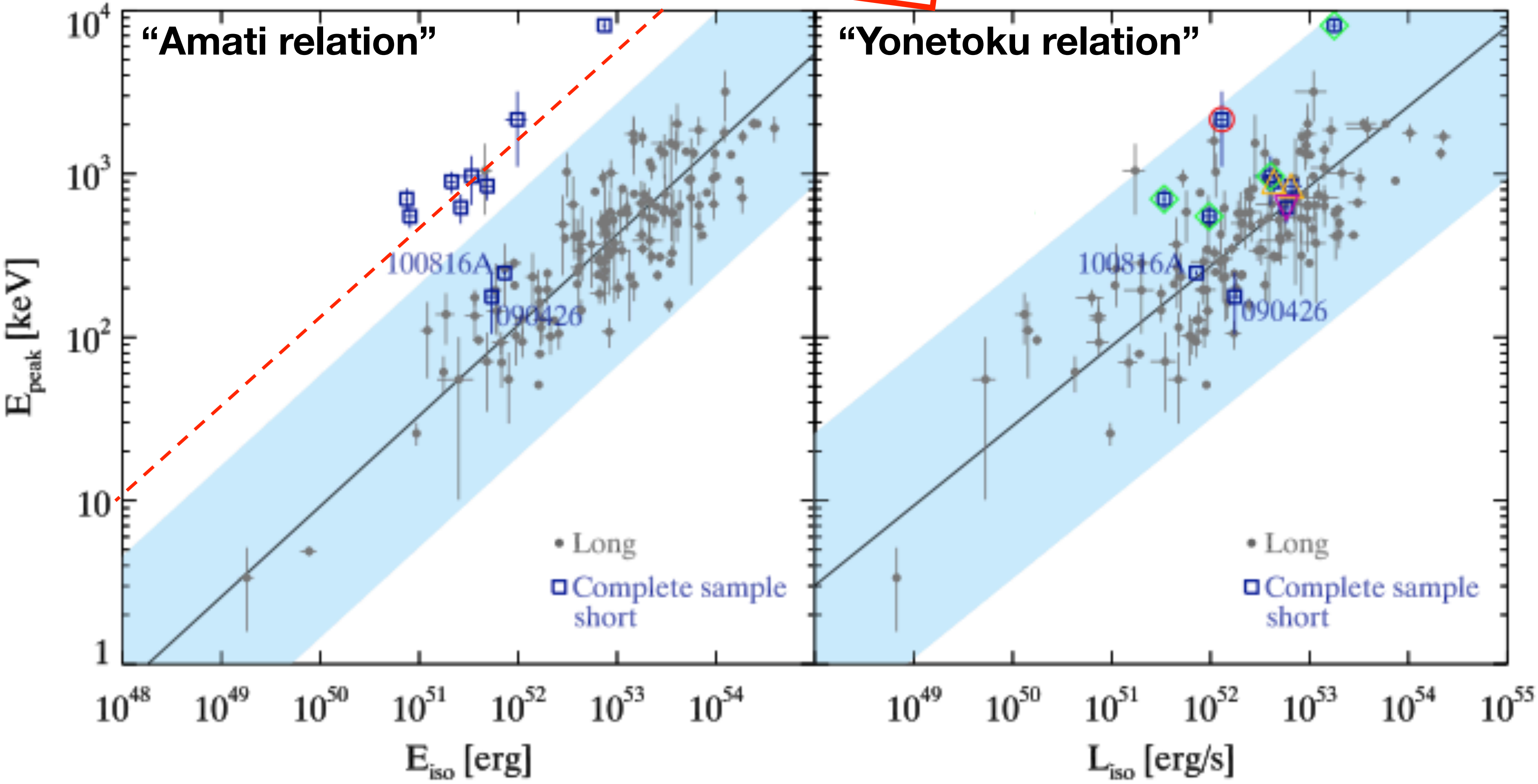
Brief, intense, flash of gamma-ray radiation:
($<z> \sim 2.1$, $E \sim 10^{52}$ erg)

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



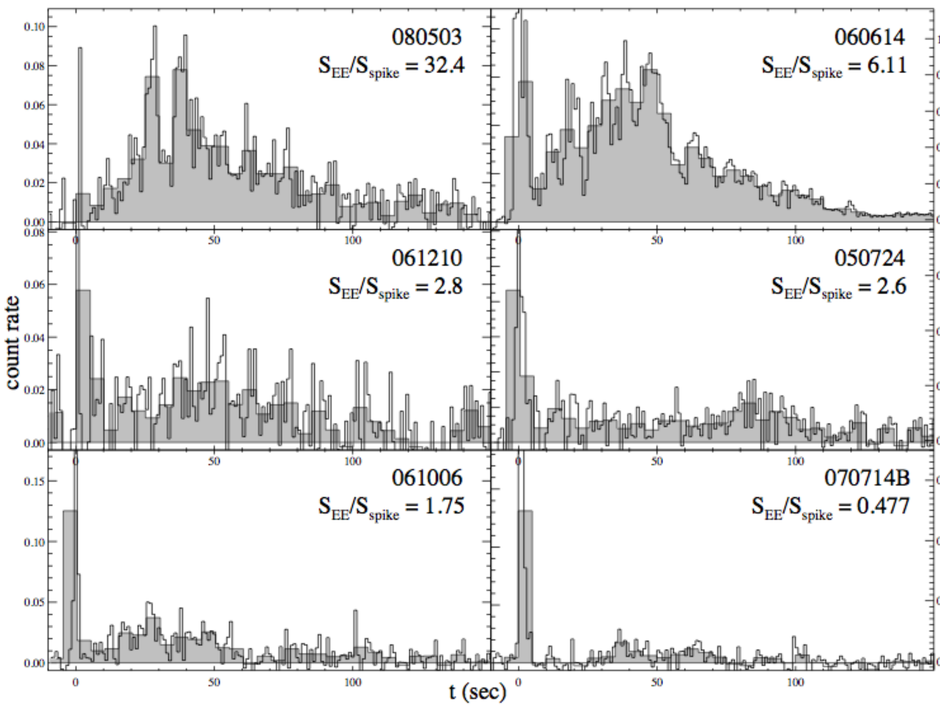
Short GRBs: prompt emission

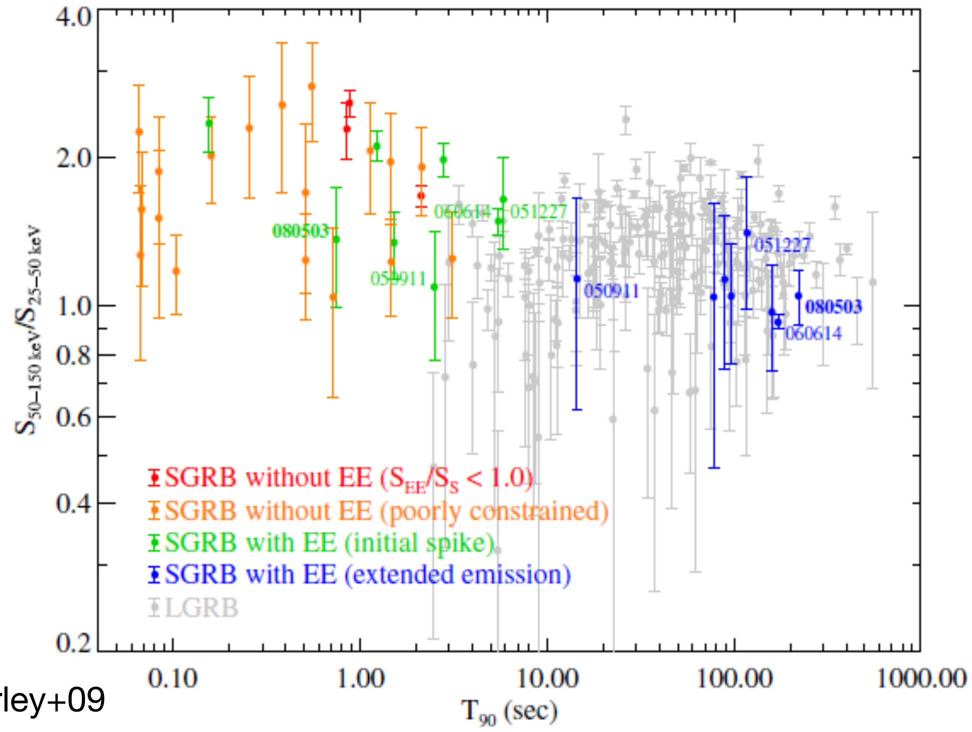
Talk by L. Amati (Mon afternoon)



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





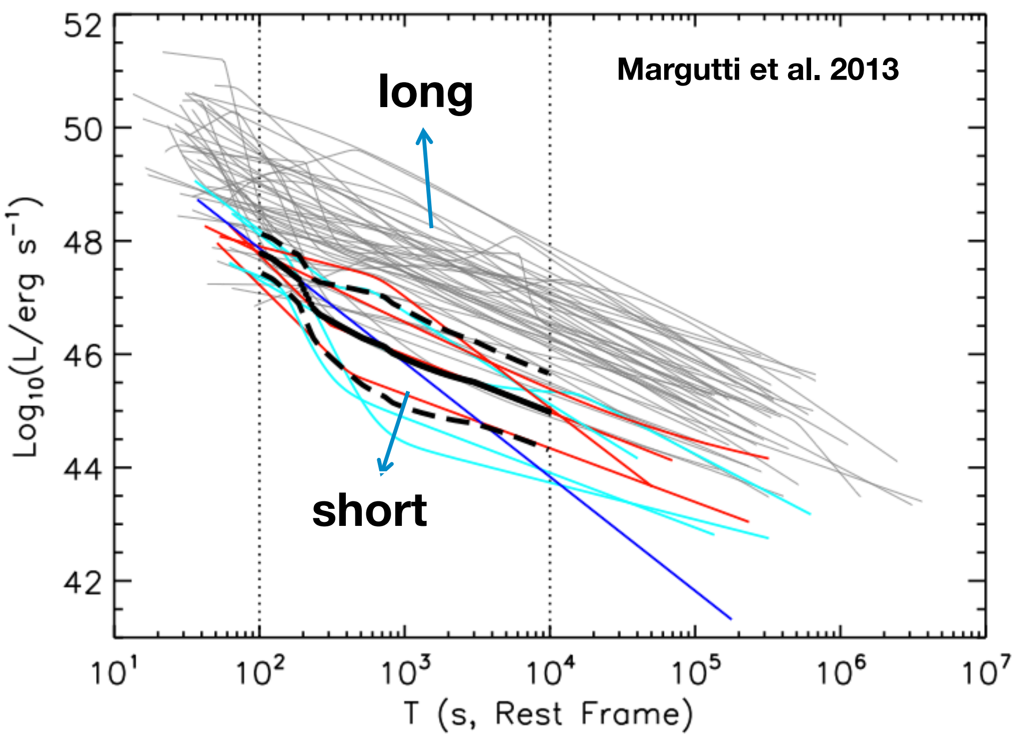
Perley+09

T_{90} >> 2 s

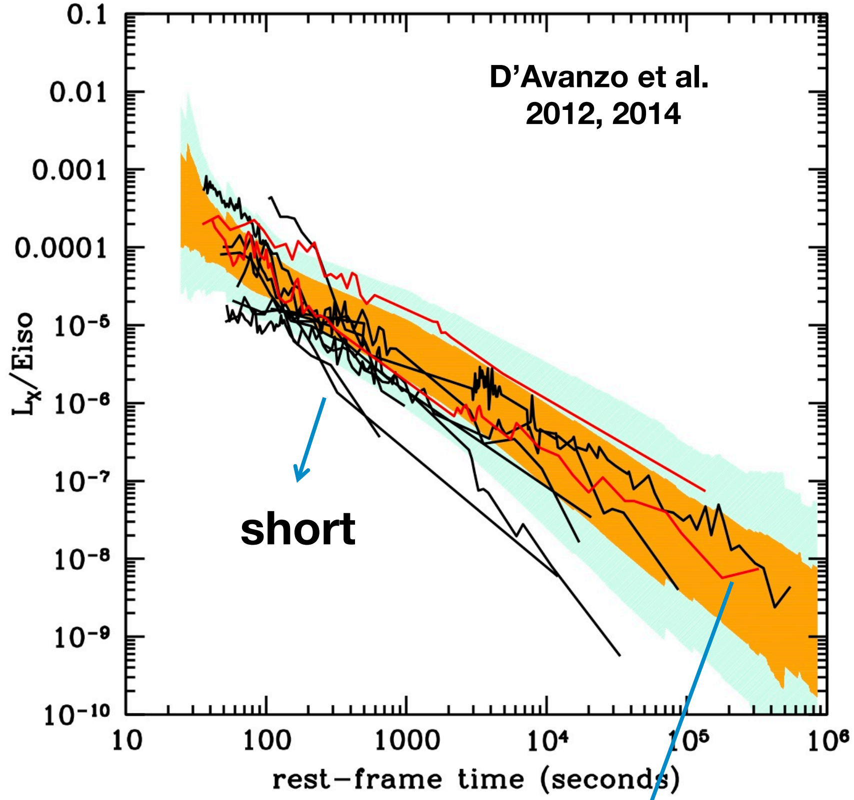
Short/hard spike
Long/soft tail

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 ~160 short GRBs (~10/yr):

- ~15% with an extended emission

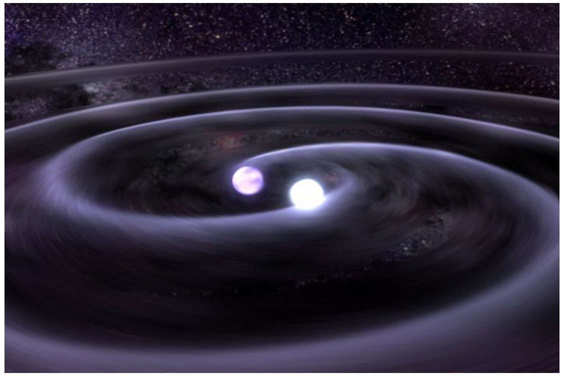
- ~75% with a X-ray afterglow detected

- ~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

<u>Diverse delay times:</u>
- A mix of early and late type host galaxies

<u>Kicks/migration from birth site:</u>
- Offsets
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- Diversity in the environment (ev. channel)

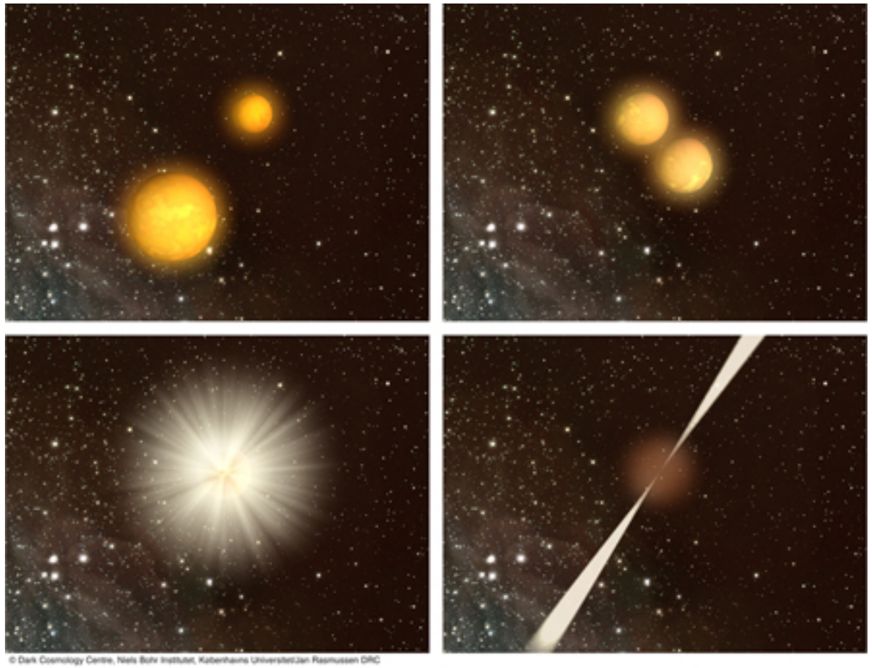
<u>No associated supernova</u>

<u>Remnant (magnetar/BH?)</u>

<u>Emission geometry (jet?)</u>

<u>Kilonova association</u>

<u>Gravitational waves</u>



The Neutron Stars Merging Scenario

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

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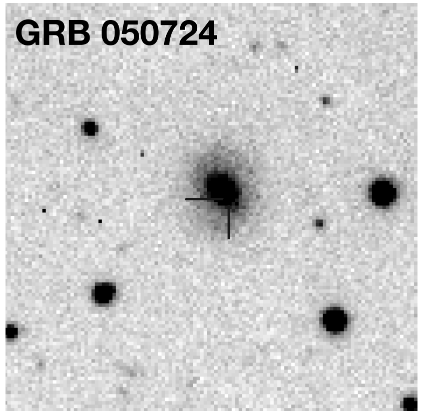
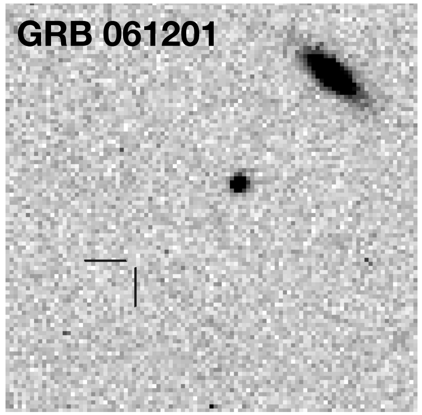


early type

late type



hostless

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

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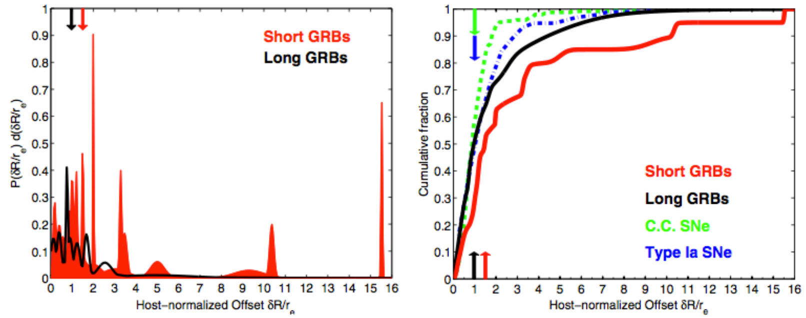
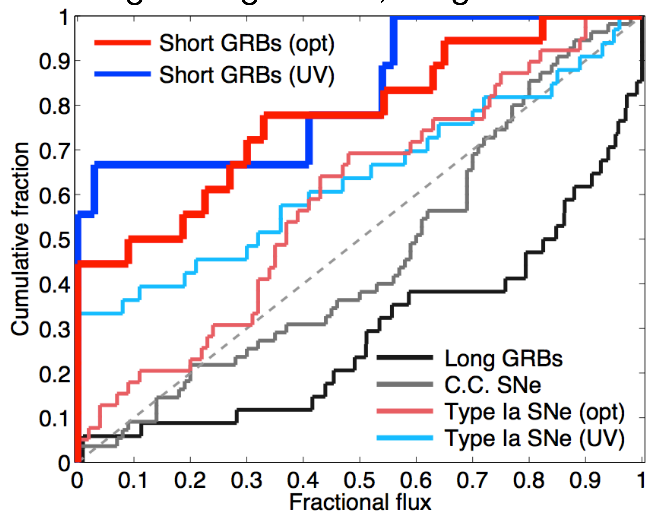
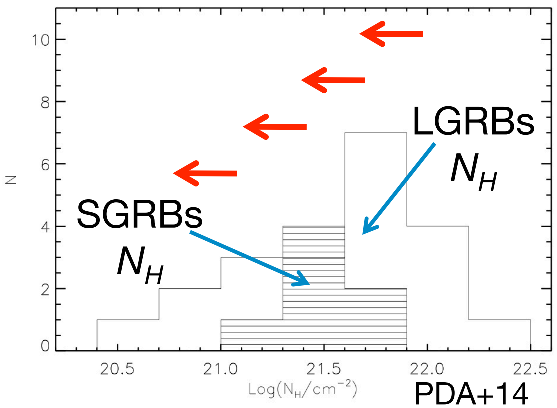
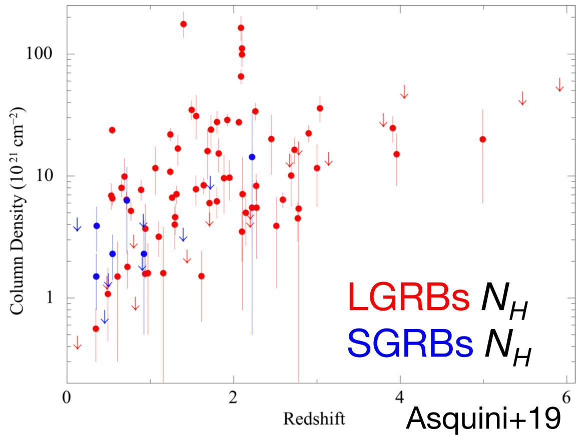


Fong & Berger 2013; Berger 2014





PDA+14



Asquini+19

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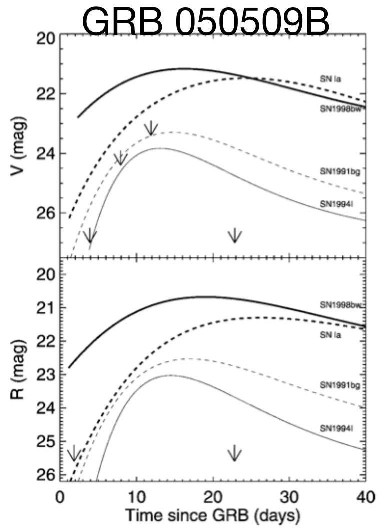
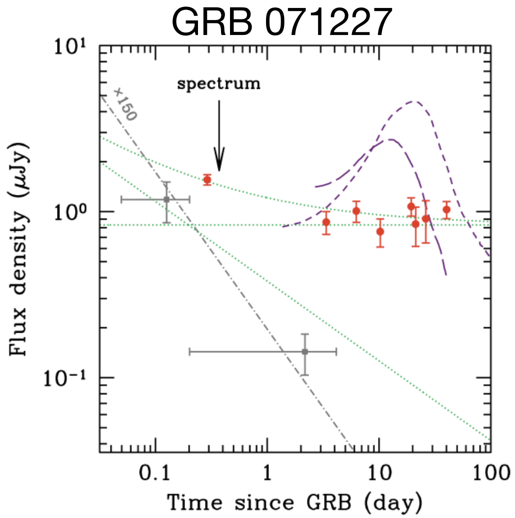
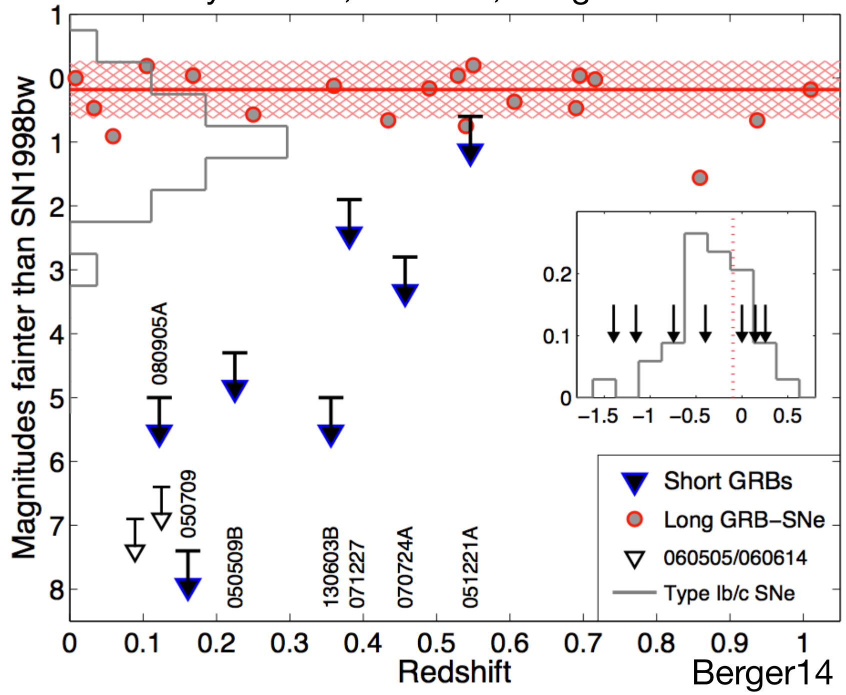




Hjorth+05; Covino+06; Della Valle+06; Fynbo+06; PDA+09; Fong+16



Berger14

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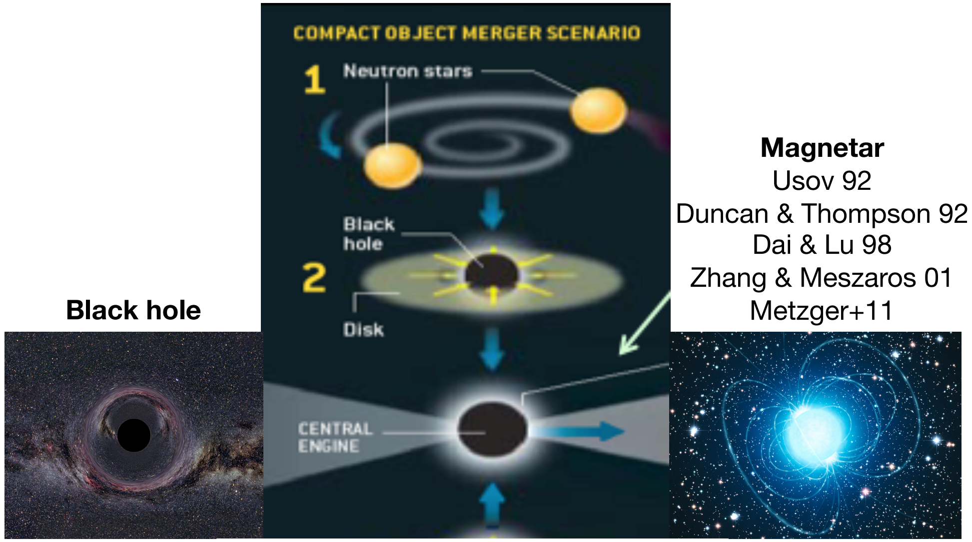
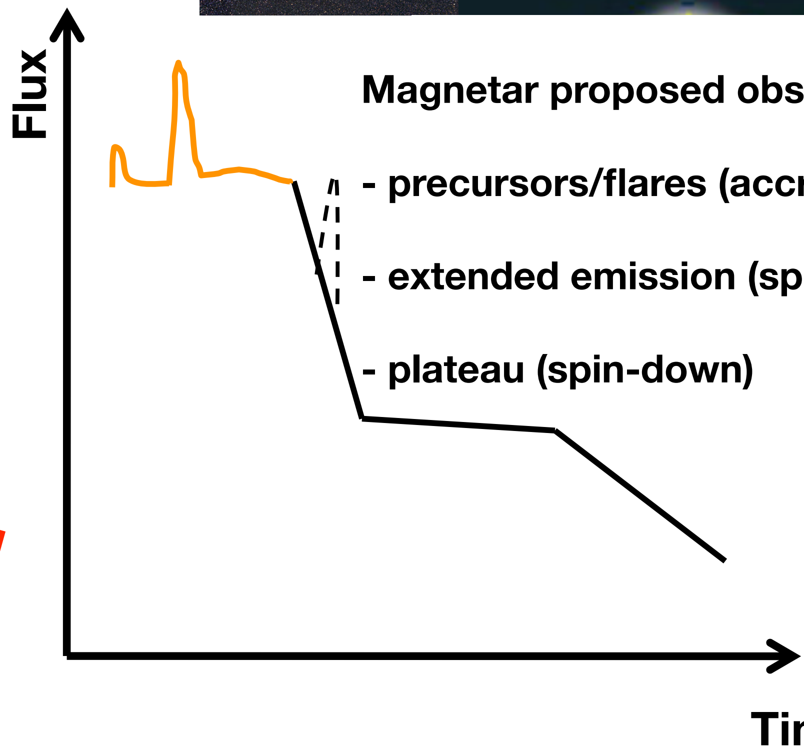
Talks by S. Ascenzi, M.G. Bernardini, S. Dall'Osso (Wednesday)



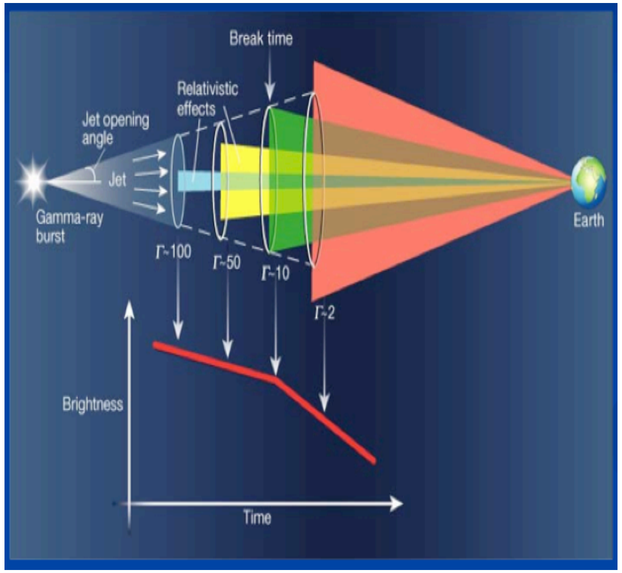
Magnetar
Usov 92
Duncan & Thompson 92
Dai & Lu 98
Zhang & Meszaros 01
Metzger+11



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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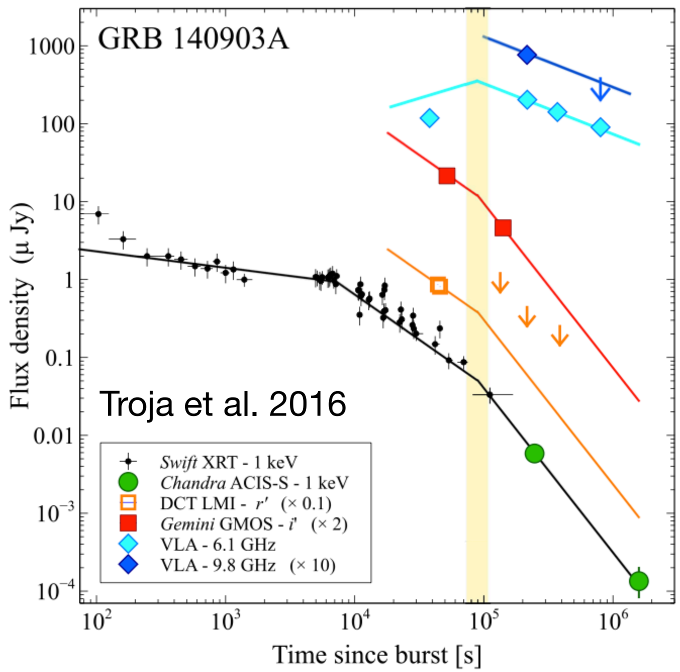
Talk by R. Ciolfi (Tuesday)

Short GRB Opening Angles

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

$<\theta_{jet}>$ ~ 10° Fong et al. 2015



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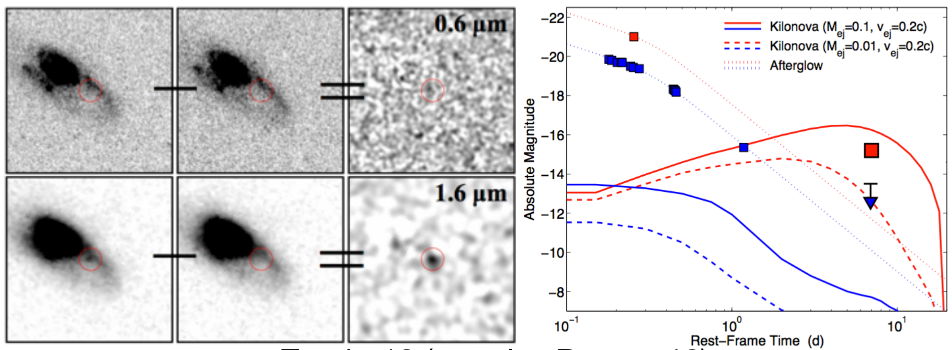
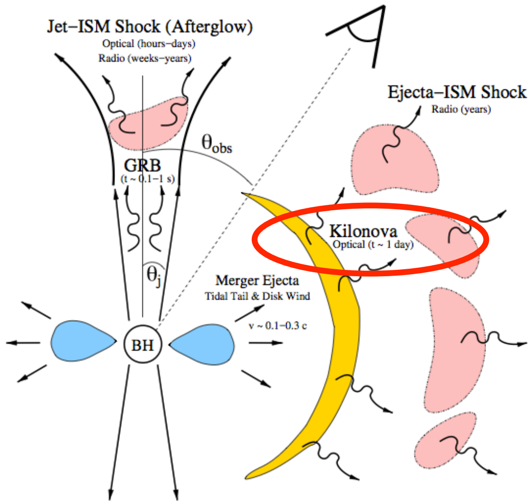
GRB 130613B (z=0.356)



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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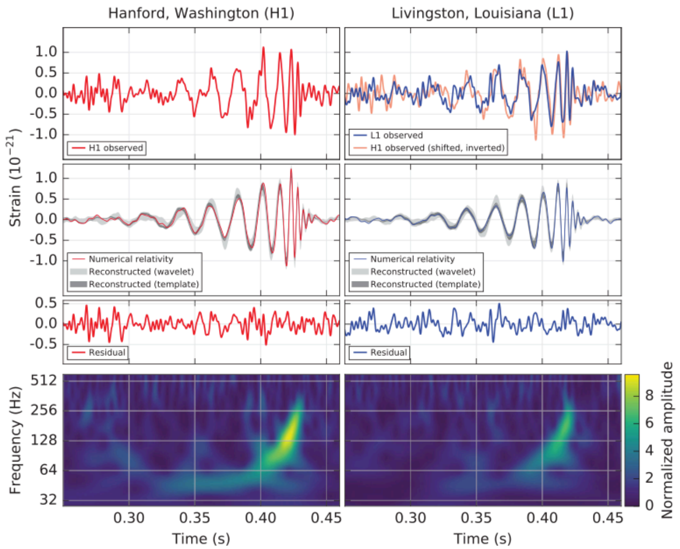

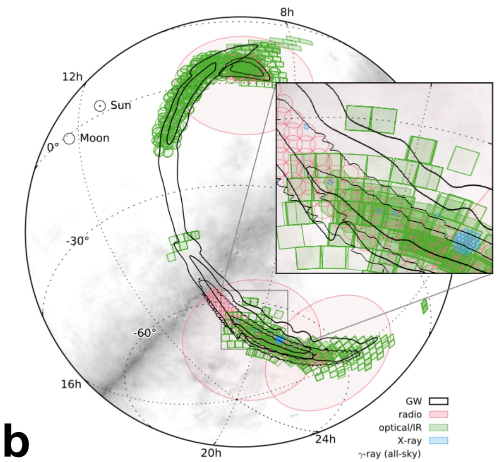

Abbott+16a,b

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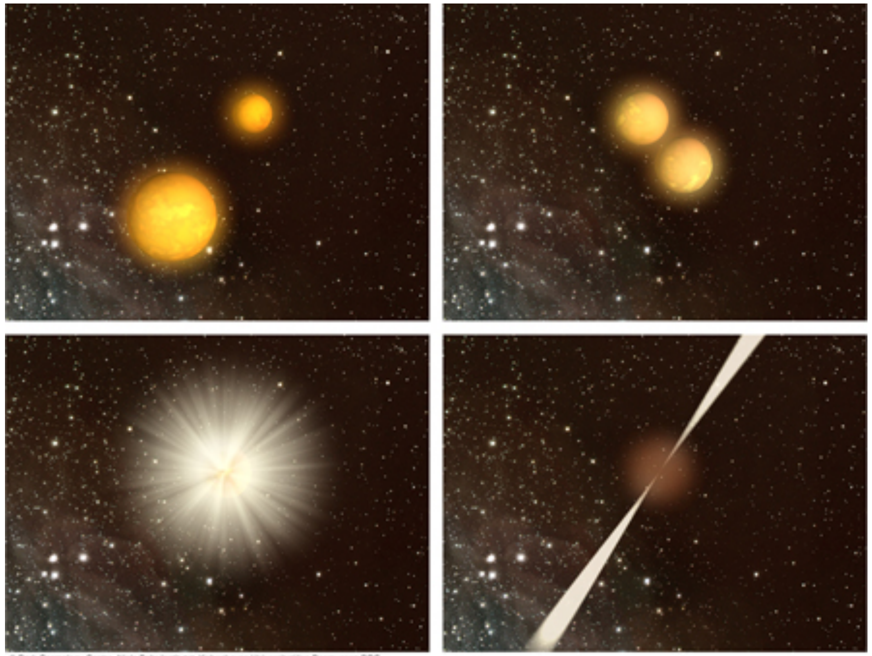
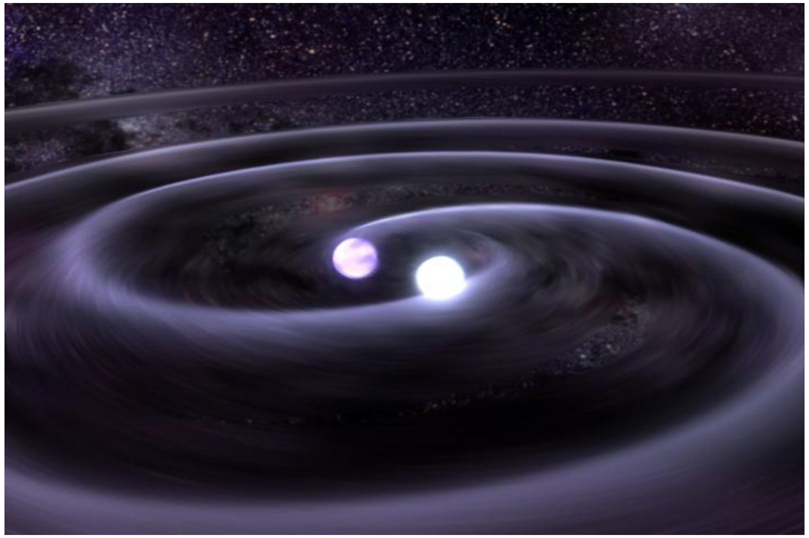
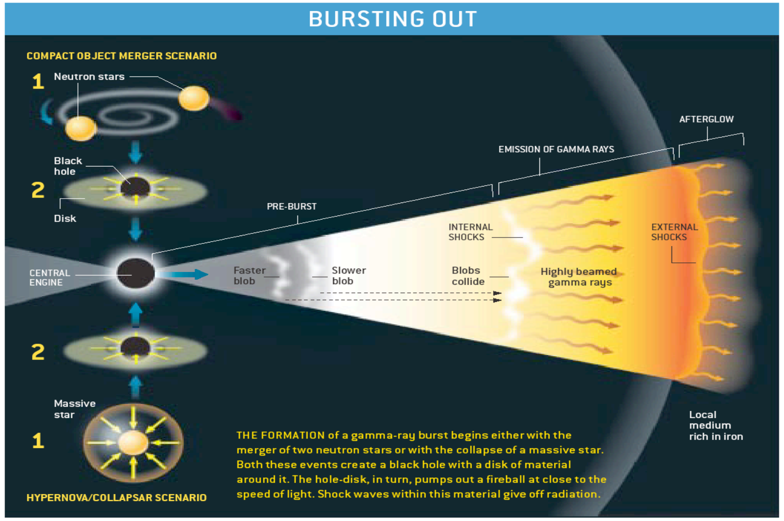


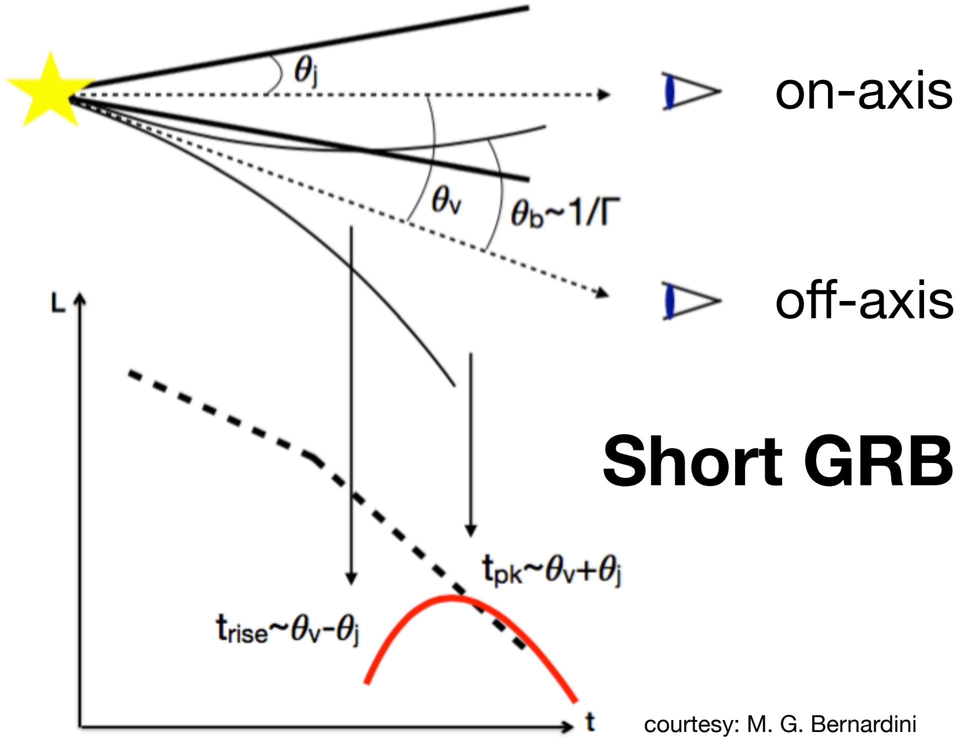
The Neutron Stars Merging Scenario

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

NS-NS / NS-BH electromagnetic counterparts



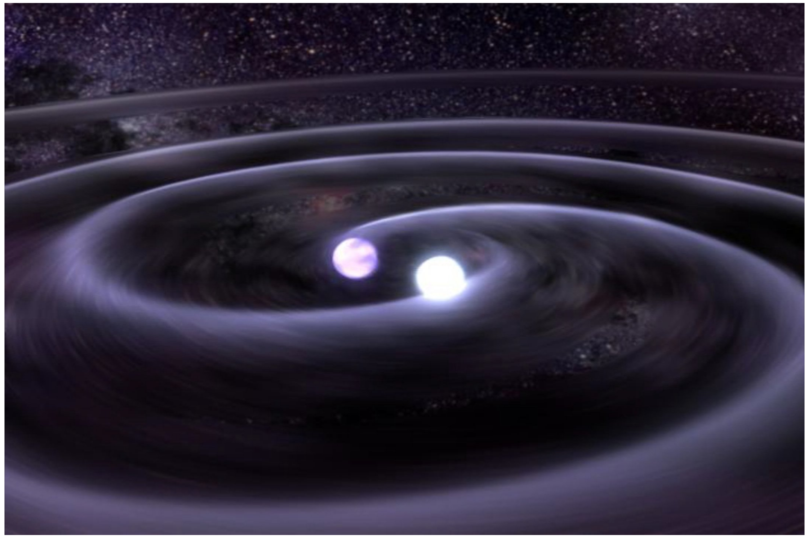




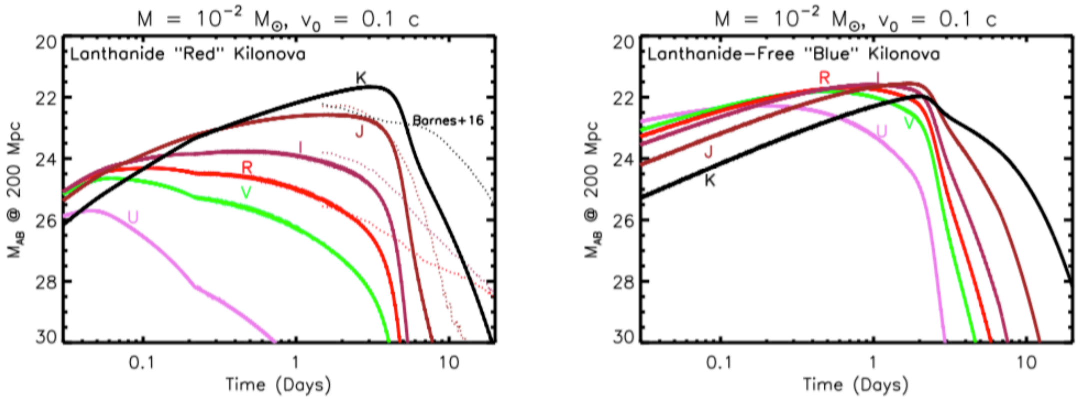
Short GRB

courtesy: M. G. Bernardini

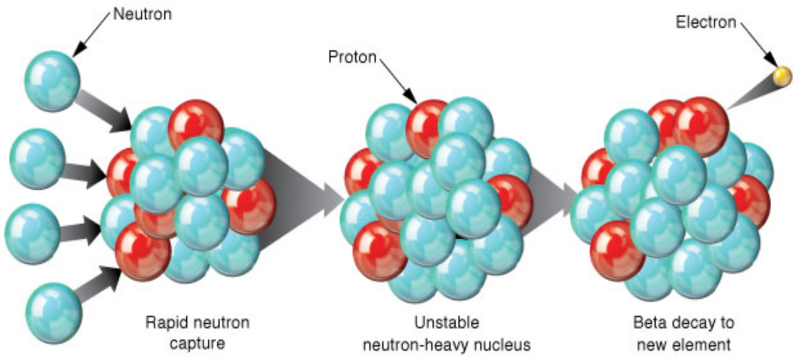
NS-NS / NS-BH electromagnetic counterparts

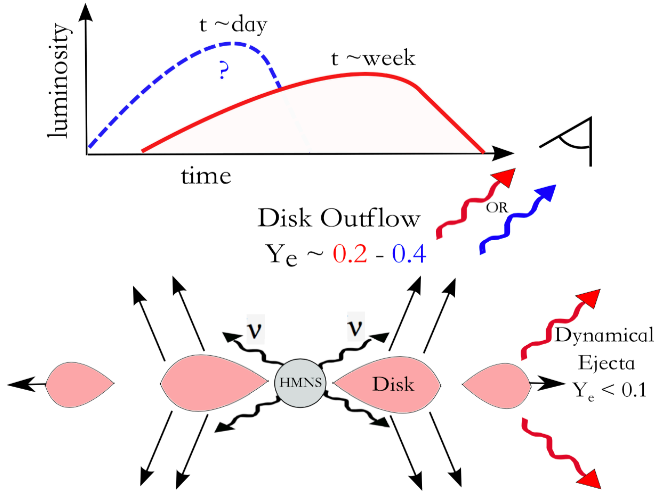


Kilonova



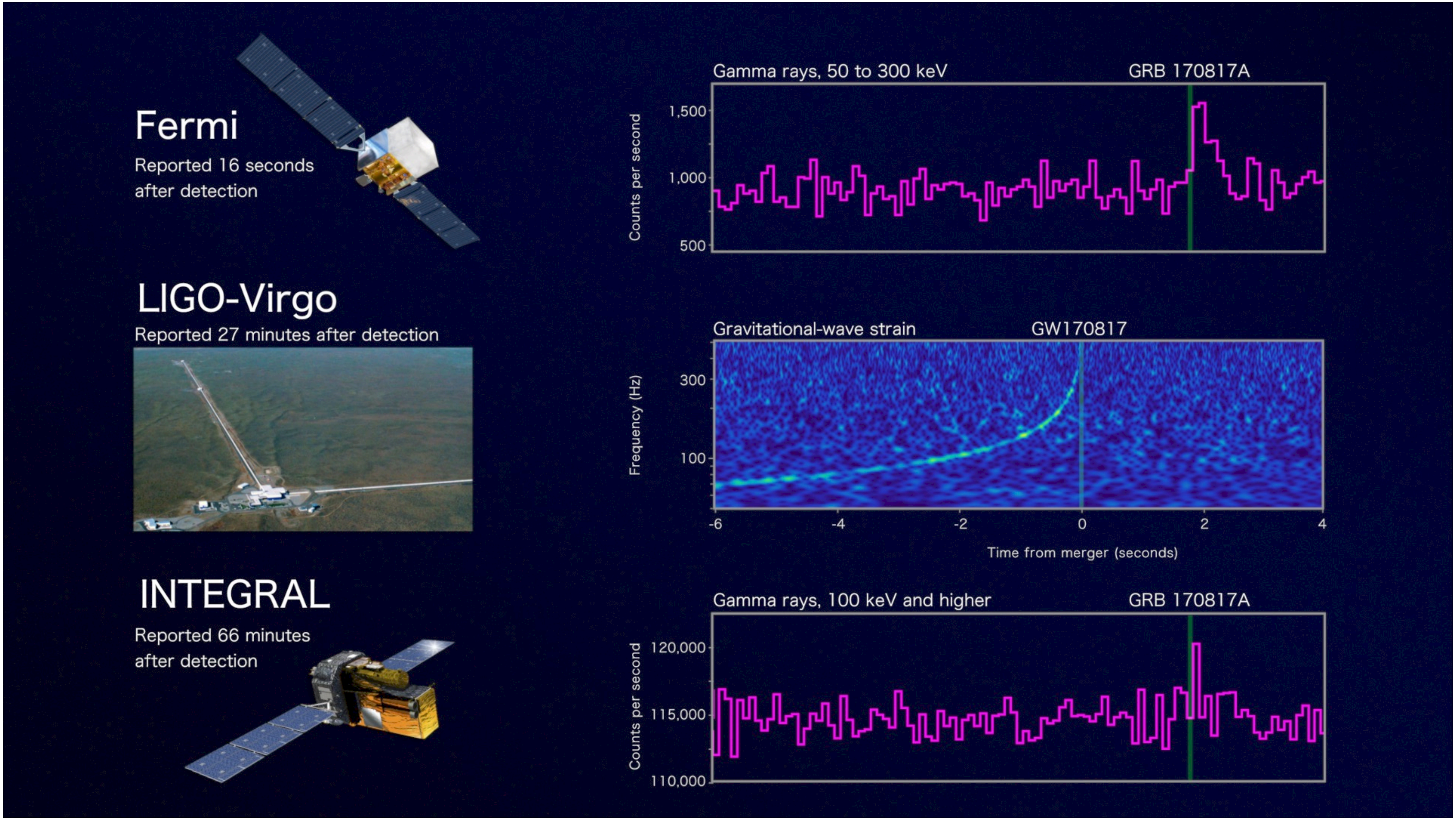
A key signature of an NS–NS/NS–BH binary merger is the production of a so-called "kilonova" (aka "macronova") due to the decay of heavy radioactive species produced by the *r*-process and ejected during the merger that is expected to provide a source of heating and radiation (Li and Paczynski 1998; Rosswog,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





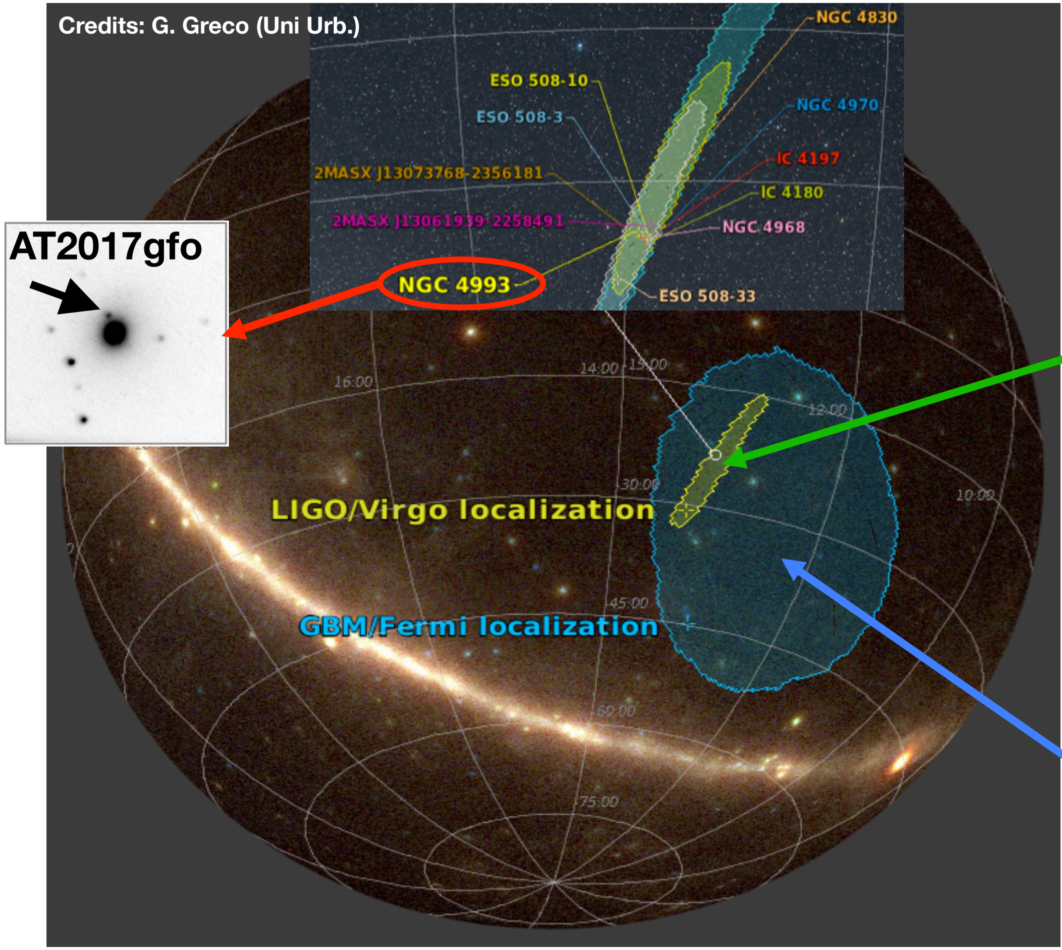
Metzger & Fernandez 2014

GW 170817 & GRB 170817A



Abbott+17; Goldstein+17; Savchenko+17

GW 170817 / GRB 170817A / AT2017gfo



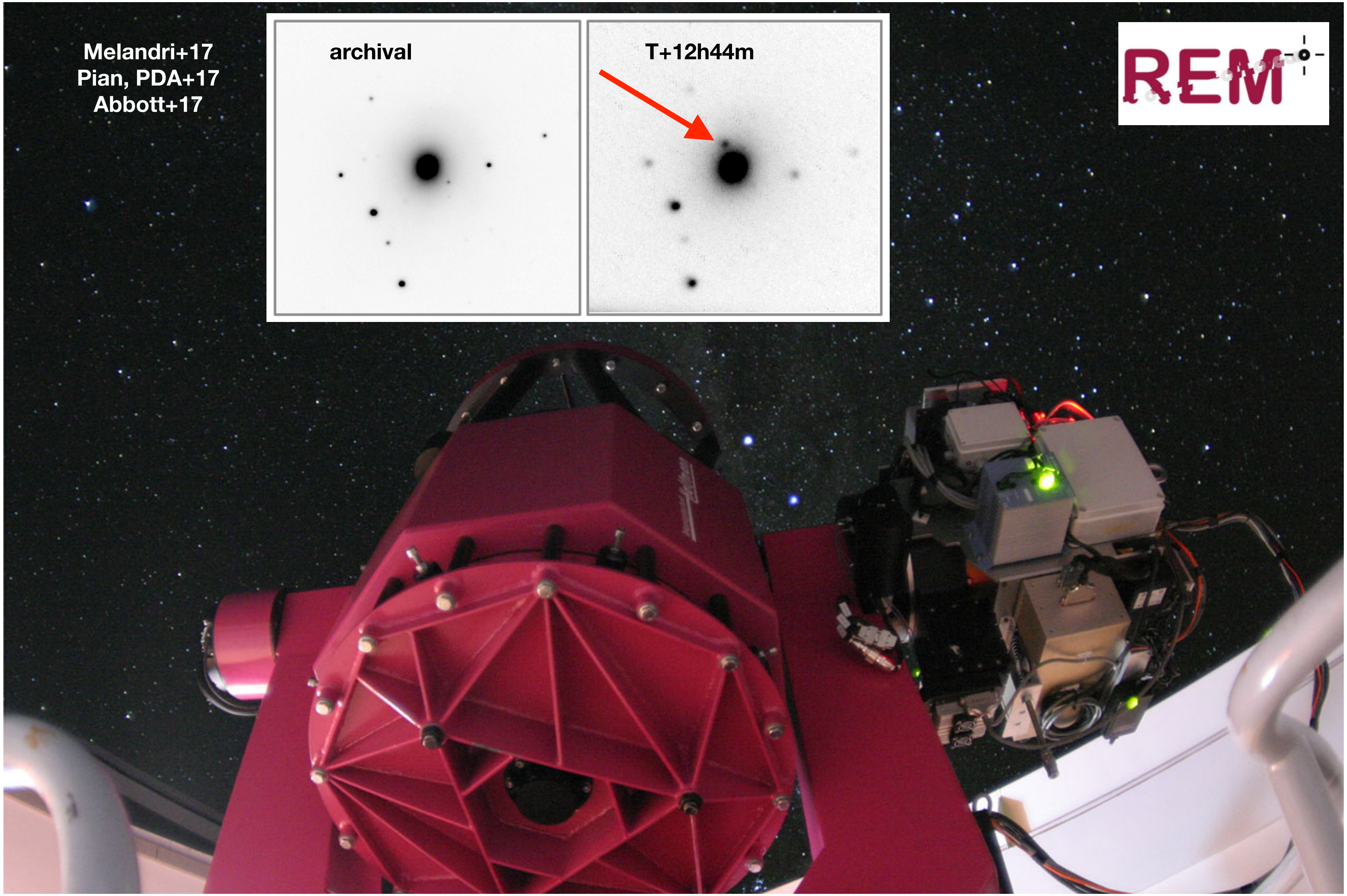
Selected for a Viewpoint in *Physics*
PRL **119,** 161101 (2017) PHYSICAL REVIEW LETTERS week ending 20 OCTOBER 2017

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

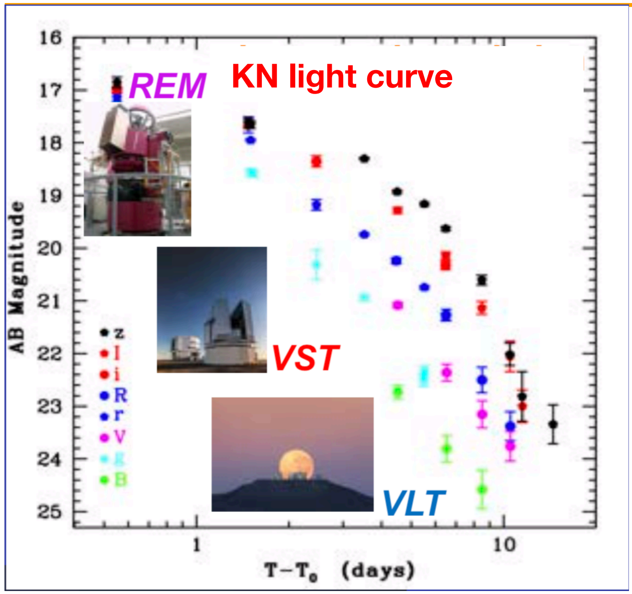
B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)

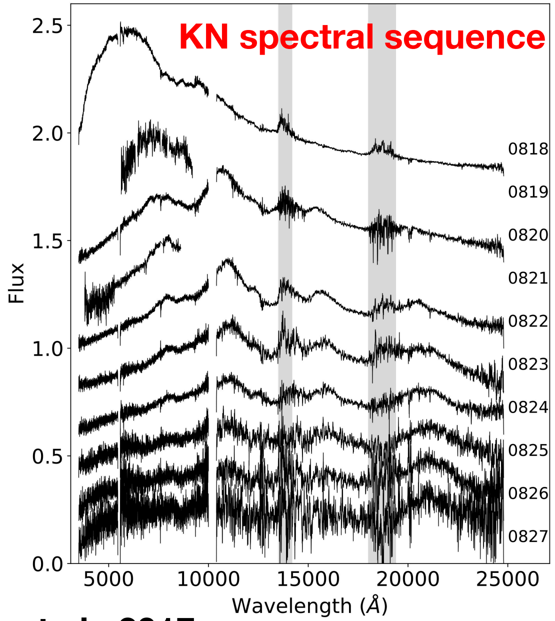
(Received 26 September 2017; revised manuscript received 2 October 2017; published 16 October 2017)

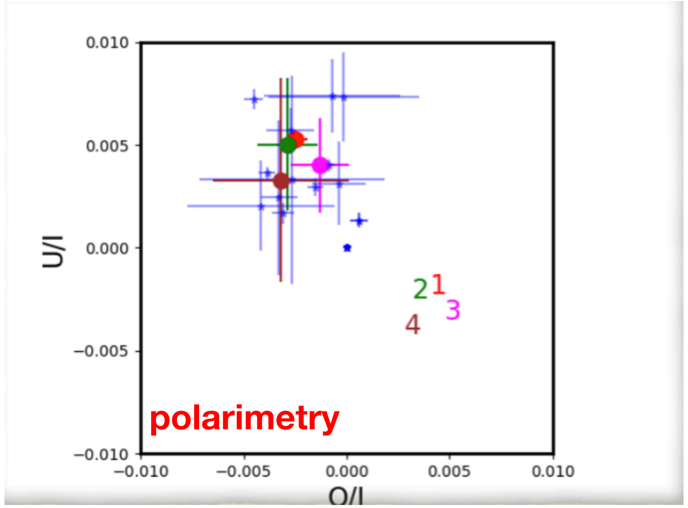
GW 170817 / AT2017gfo



GW 170817 / AT2017gfo



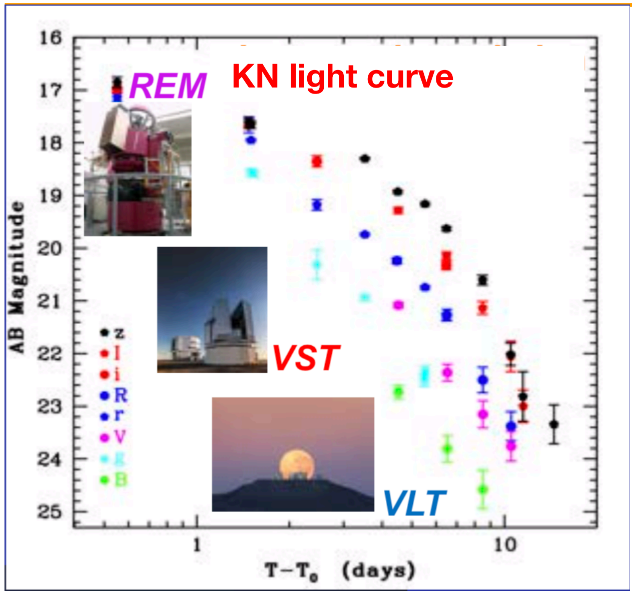


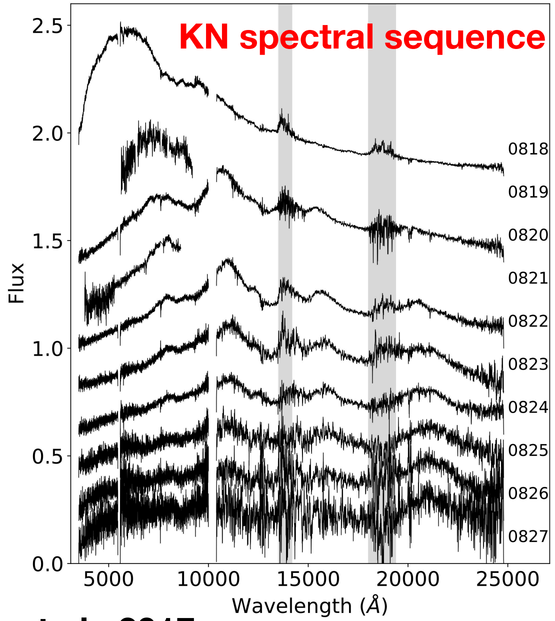


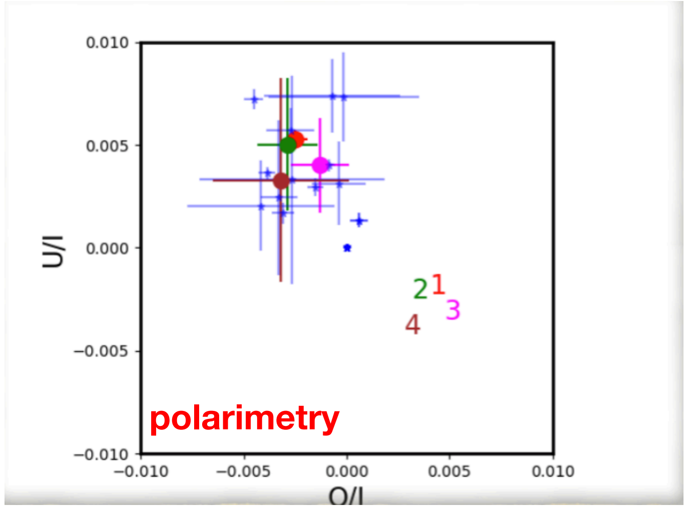
Pian, PDA et al., 2017
(see also Arcavi+17; Coulter+17; Evans+17; Lipunov+17; Smartt+17; Soares-Santos+17; Tanvir+17; Valenti+17 and many others)

Covino et al., 2017

GW 170817 / AT2017gfo







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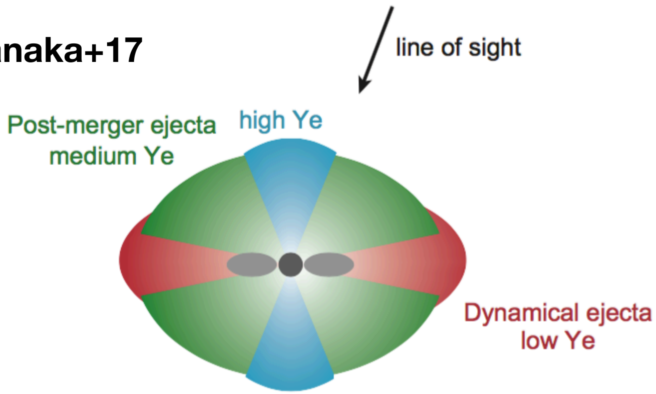
Covino et al., 2017

Full characterization of the KN properties

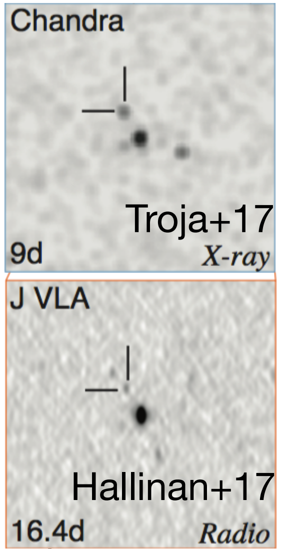
Tanaka+17



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

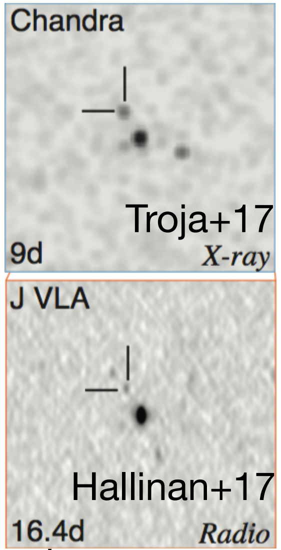
0.03-0.05 M_{Sun} ejected mass
Fast moving dynamical ejecta (0.2c) + slower wind (0.05c)

GW 170817 / GRB 170817A



1st detection of the afterglow

GW 170817 / GRB 170817A



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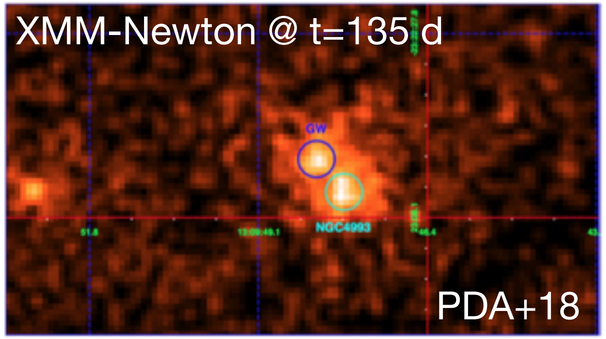
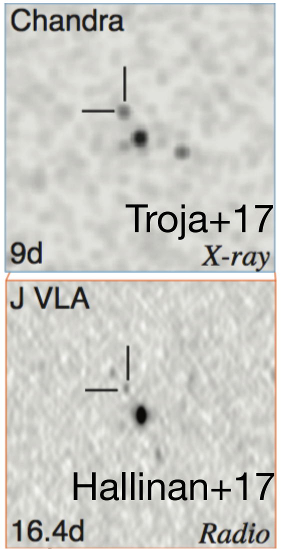
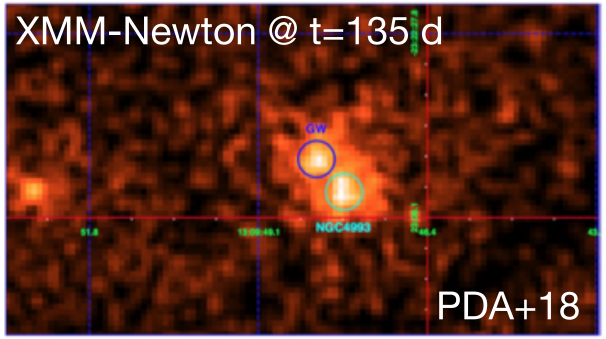


detection of the afterglow at the peak

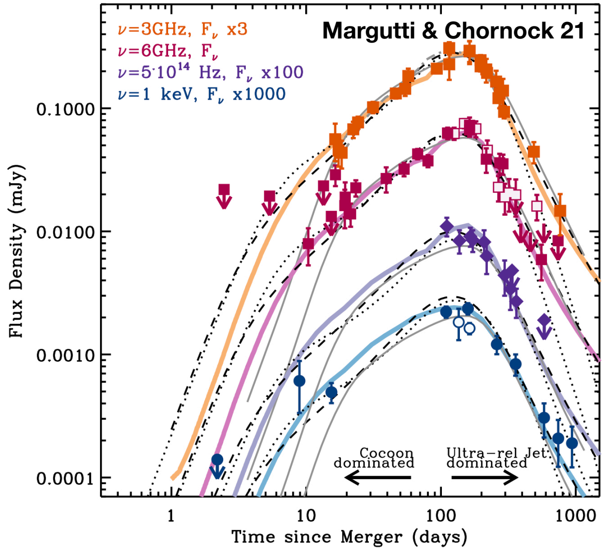
GW 170817 / GRB 170817A



1st detection of the afterglow

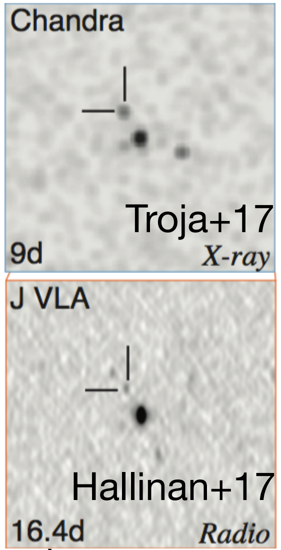


detection of the afterglow at the peak

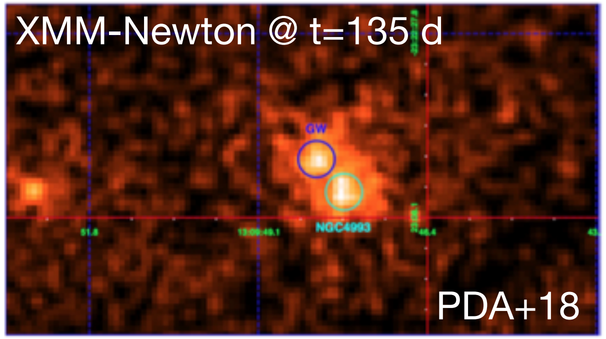


overall afterglow light curve

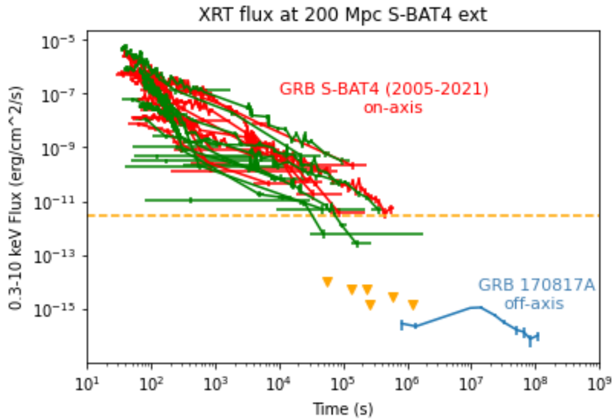
GW 170817 / GRB 170817A



1st detection of the afterglow

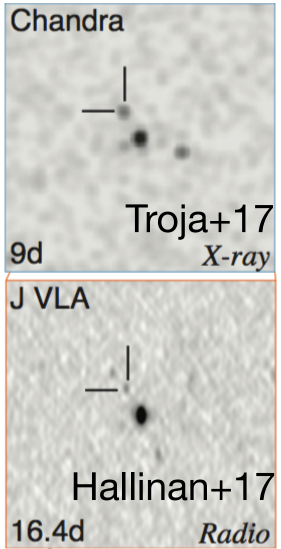


detection of the afterglow at the peak

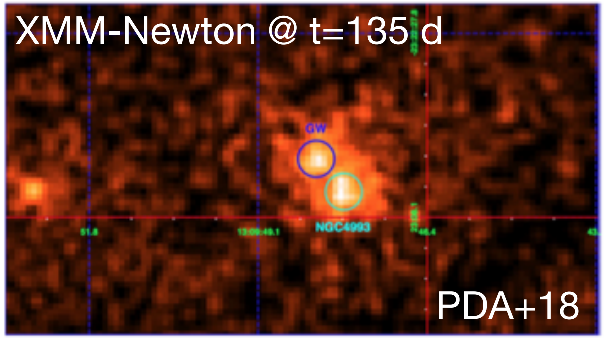


GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

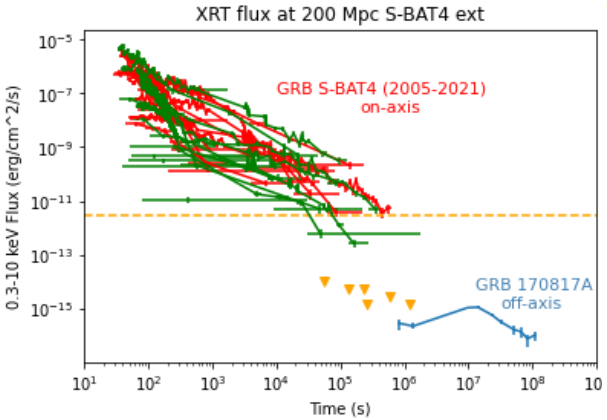
GW 170817 / GRB 170817A

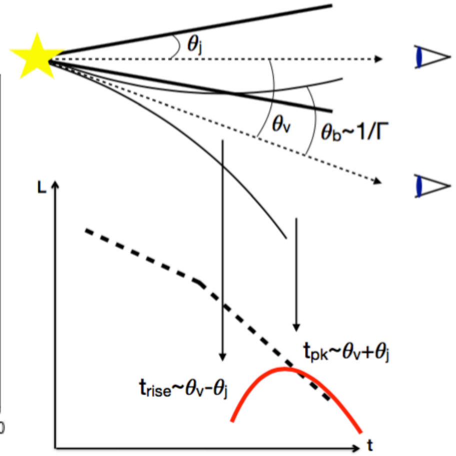


1[st] detection of the afterglow



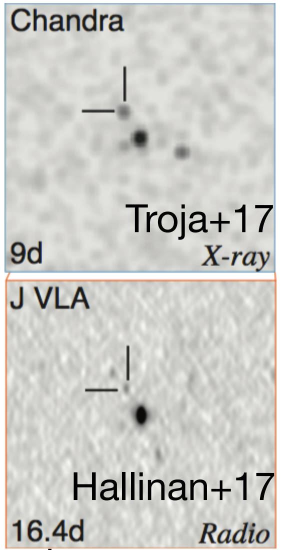
detection of the afterglow at the peak



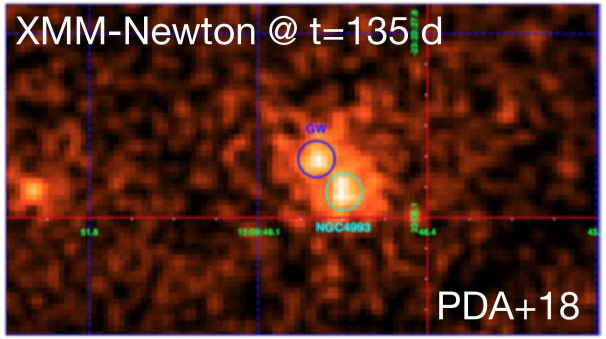


GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19

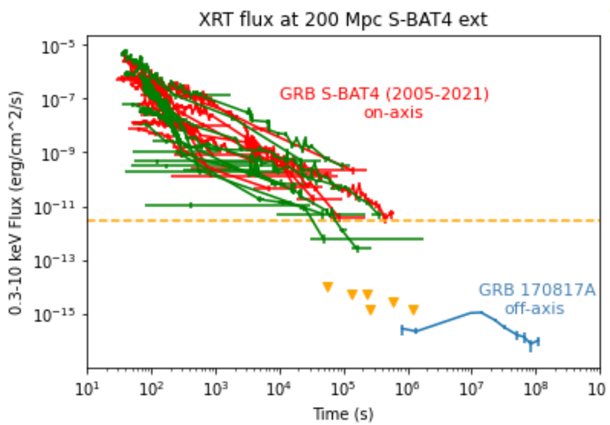
GW 170817 / GRB 170817A



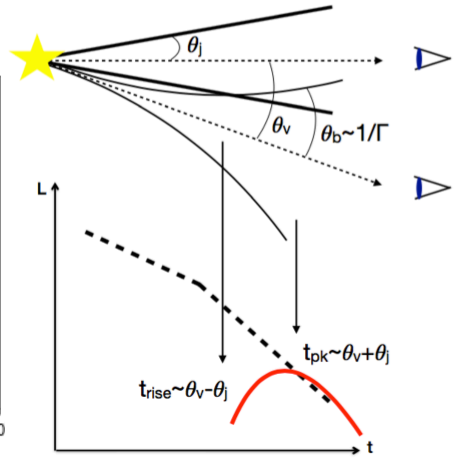
1st detection of the afterglow

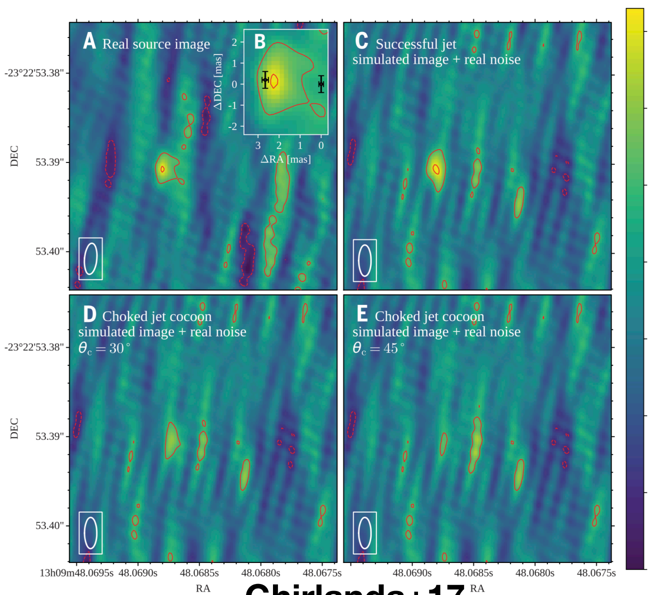


detection of the afterglow at the peak



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

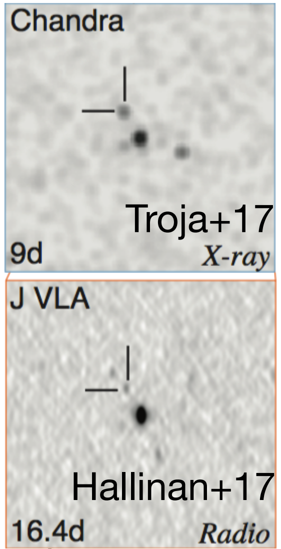




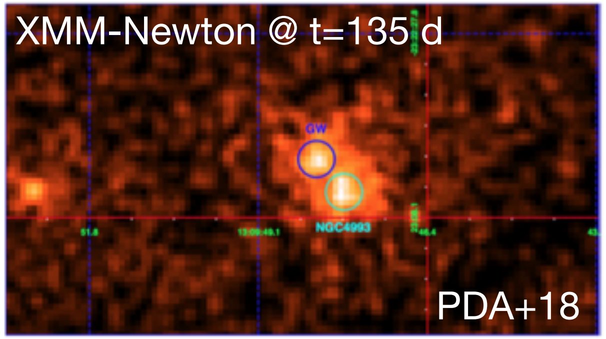
Ghirlanda+17

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.

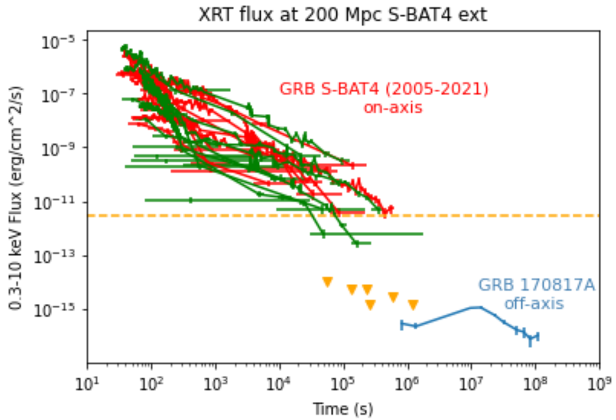
GW 170817 / GRB 170817A



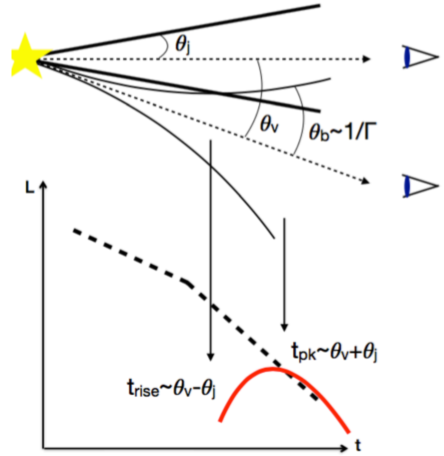
1st detection of the afterglow

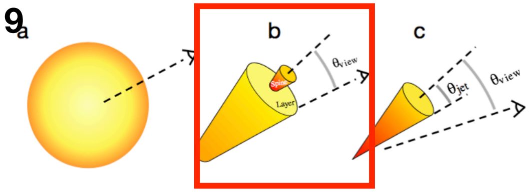


detection of the afterglow at the peak



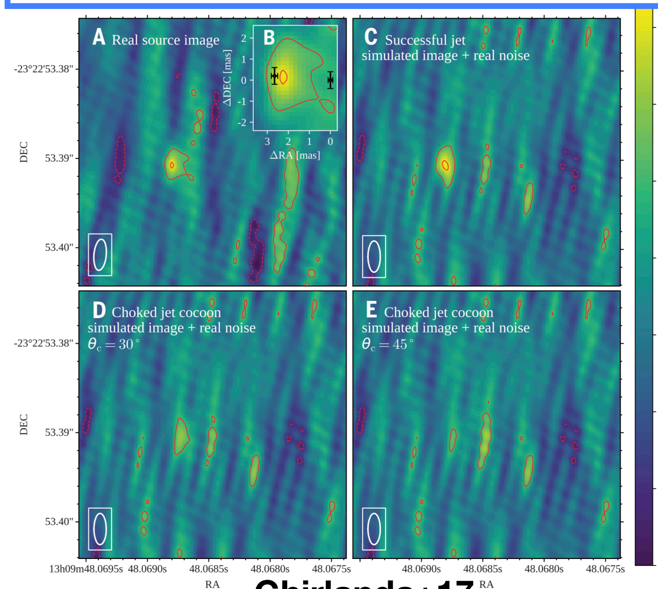
GRB 170817A w.r.t. SGRBs
Michela Di Natolo (Bachelor student)
see also Duan+19; Salafia+19a





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 $\theta_{jet} < 5$ deg and $\theta_{view} \sim 20$ 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 puzzling late time emission

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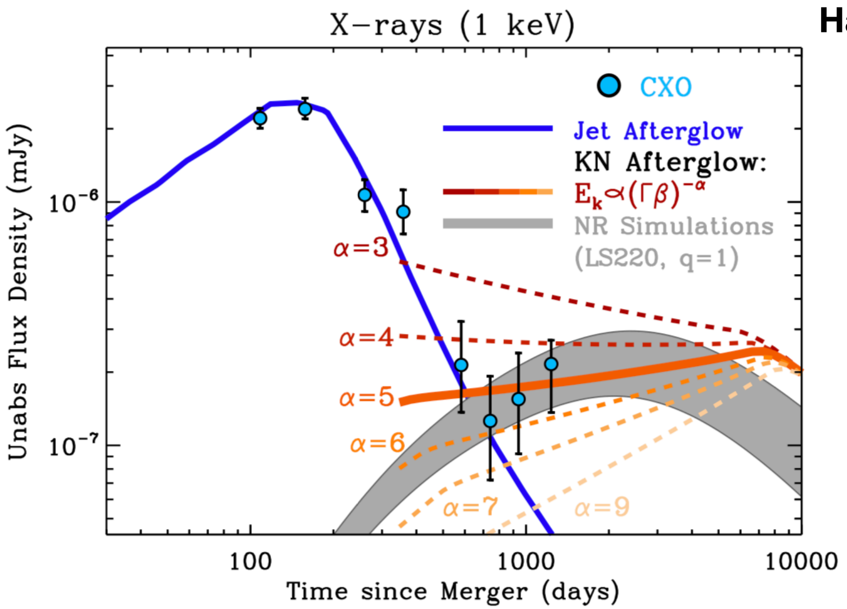
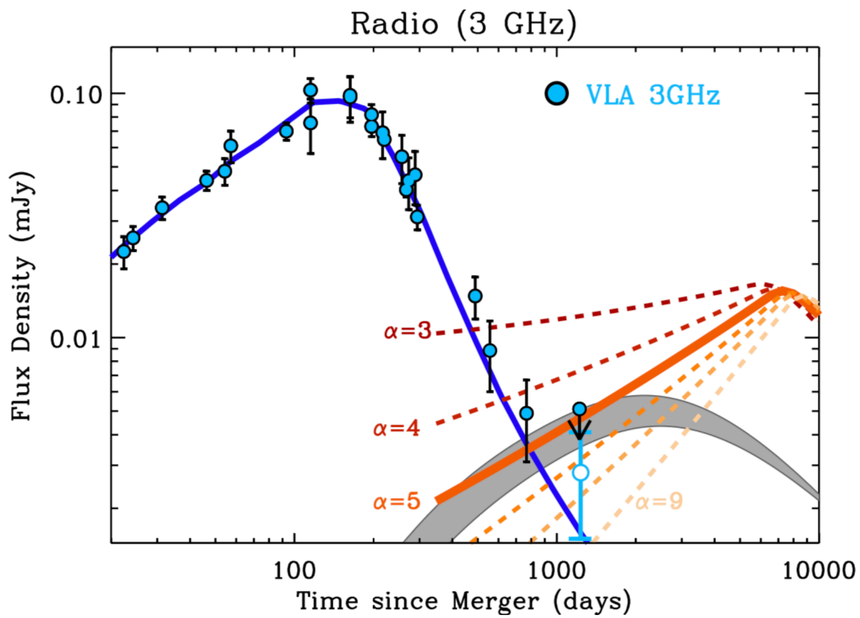


Hajela+21



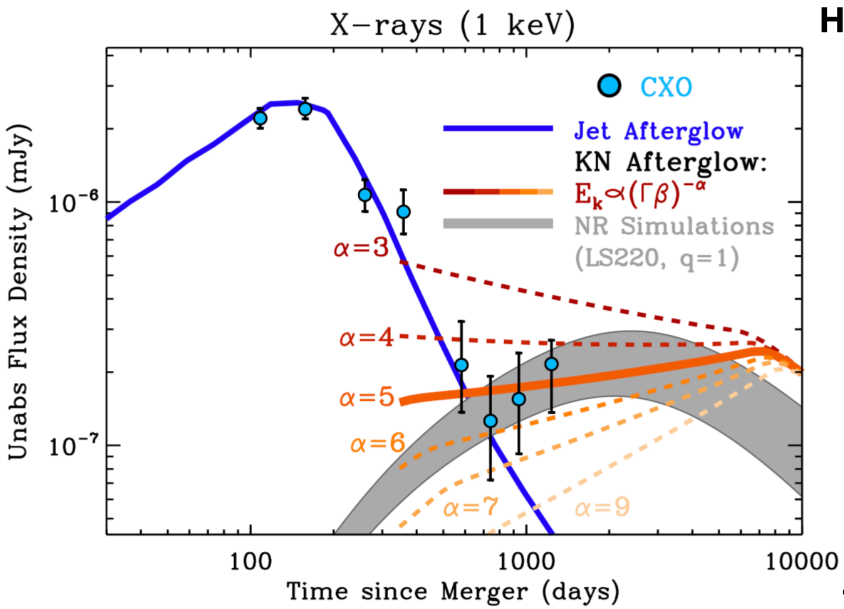
KN afterglow?

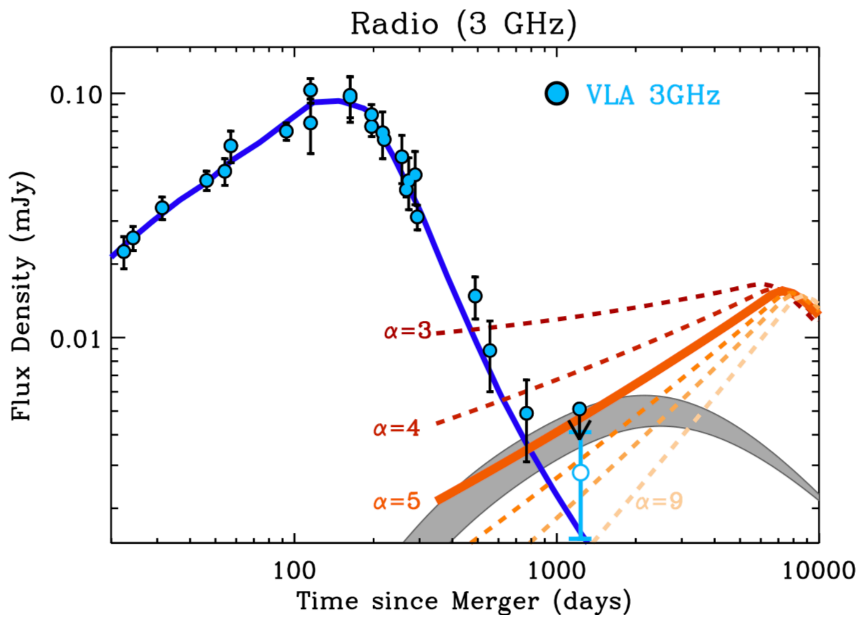
Accretion on compact remnant?

Magnetar?

GRB 170817A: a puzzling late time emission

Hajela+21



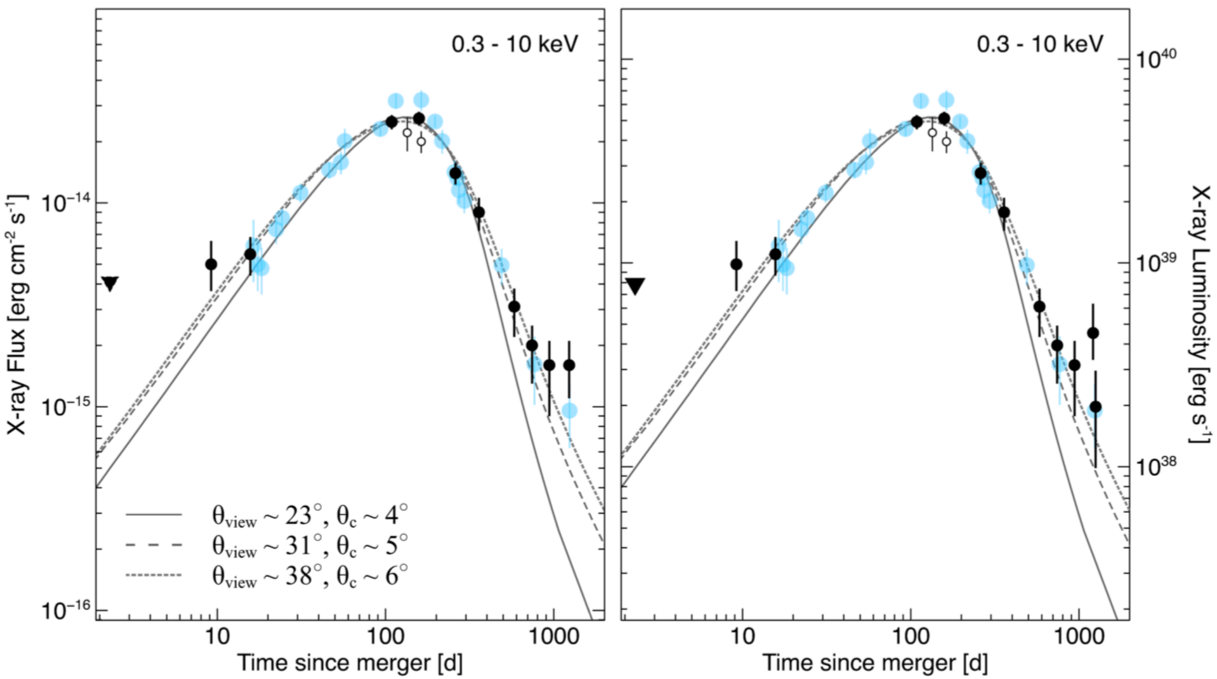


Troja+21

KN afterglow?

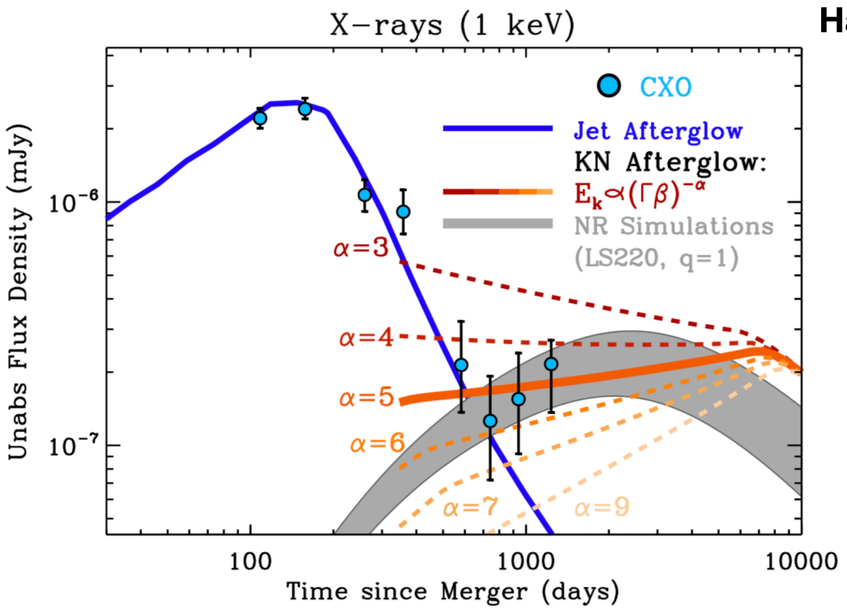
Accretion on compact remnant?

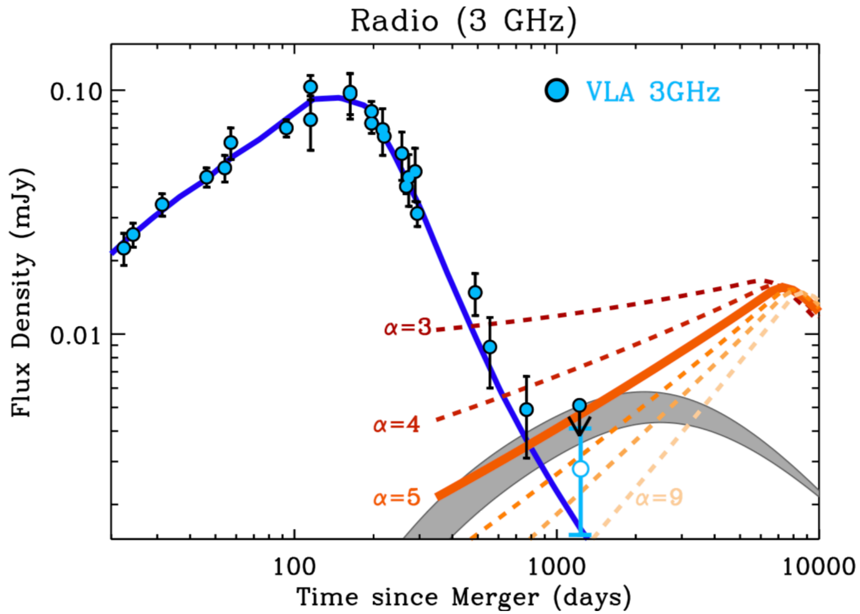
Magnetar?



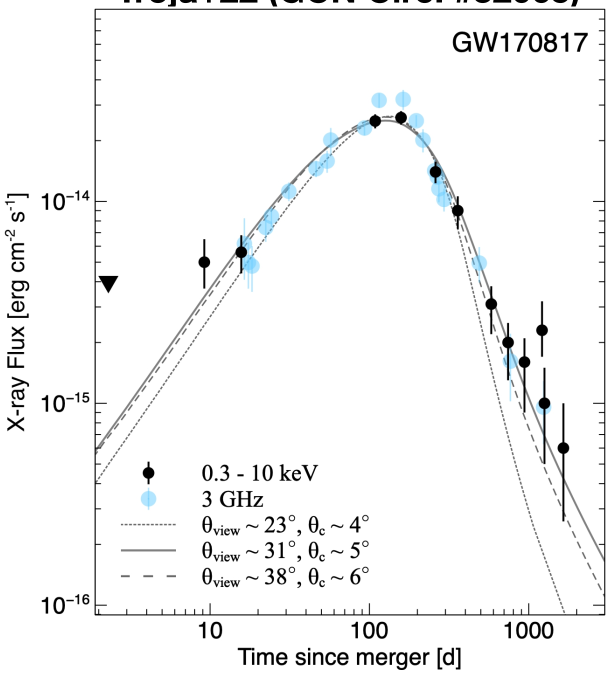
GRB 170817A: a puzzling late time emission

Hajela+21





Troja+22 (GCN Circ. #32065)



KN afterglow?

Accretion on compact remnant?

Magnetar?

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)

Prospects for joint GW – e.m. detection of BNS in O4

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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **513,** 4159–4168 (2022) https://doi.org/10.1093/mnras/stac1167
Advance Access publication 2022 April 28

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	
	$\mathcal{R}(0)$ (Gpc^{-3} yr^{-1})	GW (yr^{-1})	Uniform (yr^{-1})	Structured (yr^{-1})	Uniform (yr^{-1})	Structured (yr^{-1})	Uniform (yr^{-1})	Structured (yr^{-1})	Uniform (yr^{-1})	Structured (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

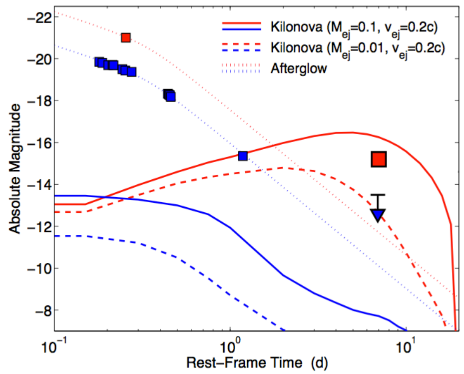
Talk by S. Ronchini (Tuesday)

see also Colombo+22

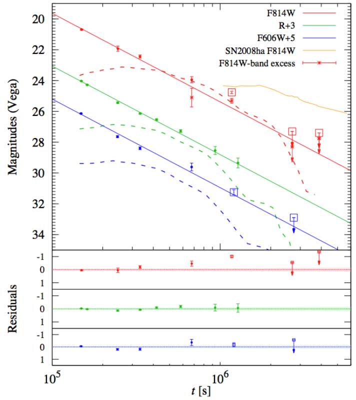
In the meanwhile: many SGRBs/KNe

GRB 130613B (z=0.356)

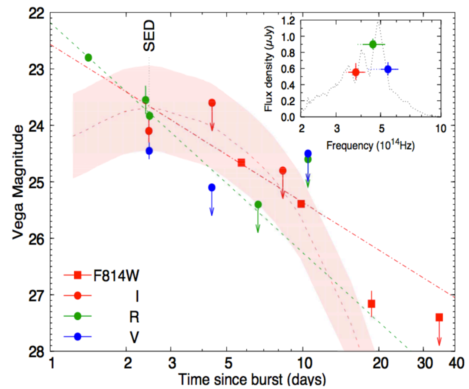
Tanvir+13; Berger+13



GRB 060614 (z=0.125)

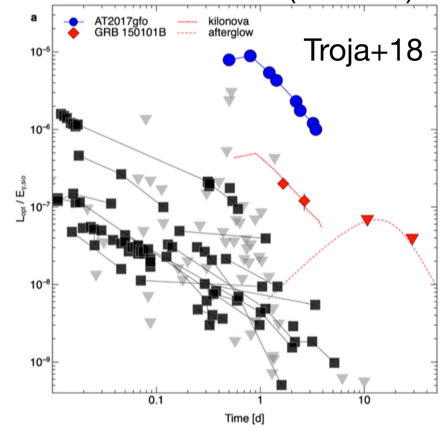


GRB 050709 (z=0.160)

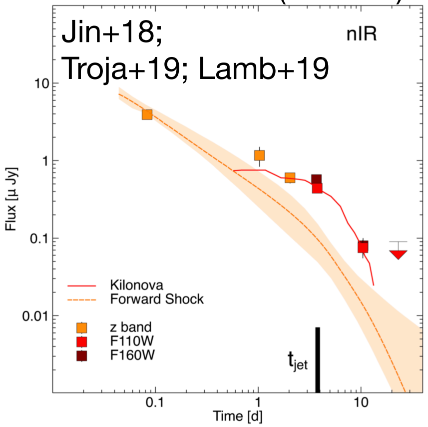


Yang+15; Jin+15; Jin+16

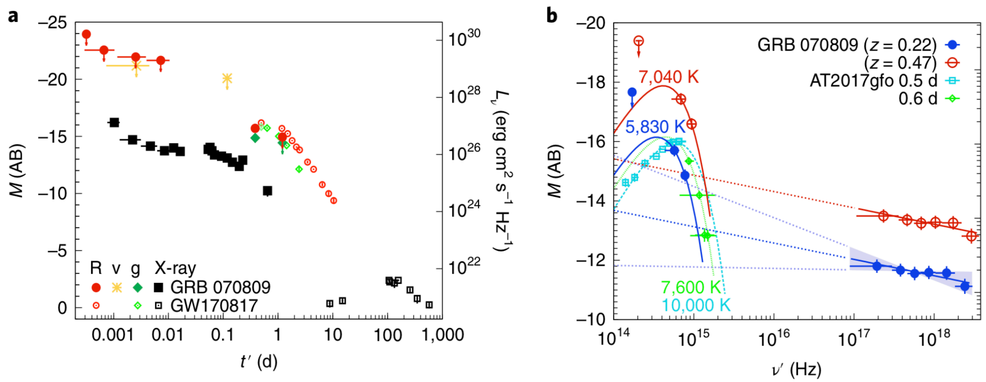
GRB 150101B (z=0.134)



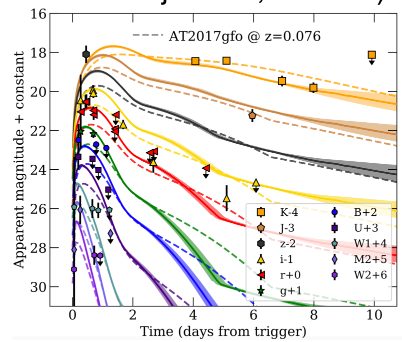
GRB 160821B (z=0.161)



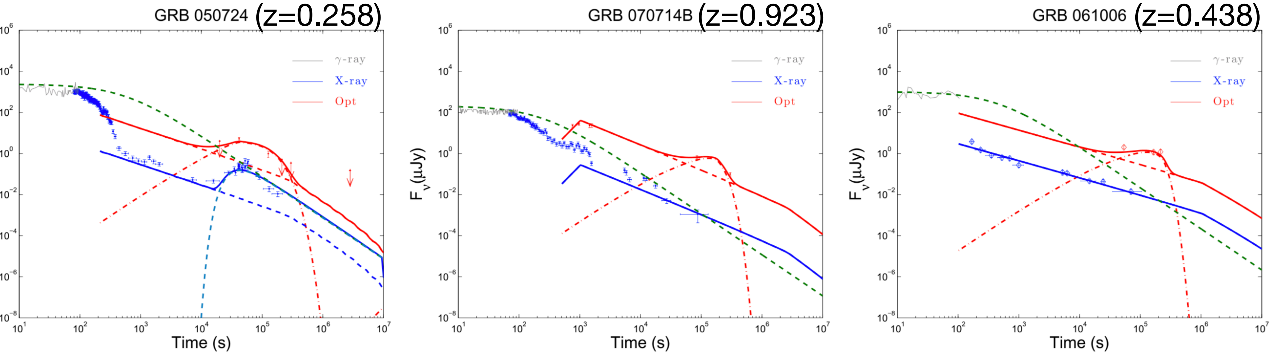
GRB 070809 (z=0.22 / z = 0.47; Jin+20)



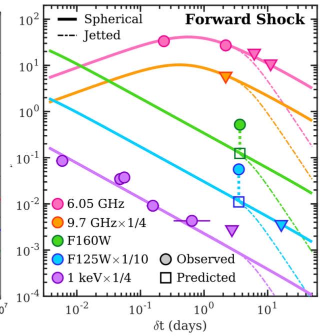
GRB 211211A (z=0.076; Rastinejad+22; Mei+22)

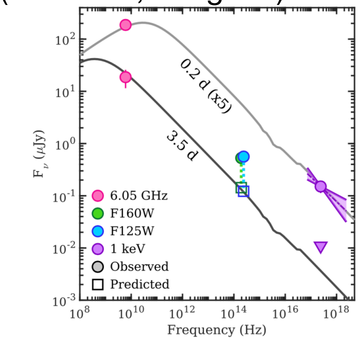


Gao+17



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





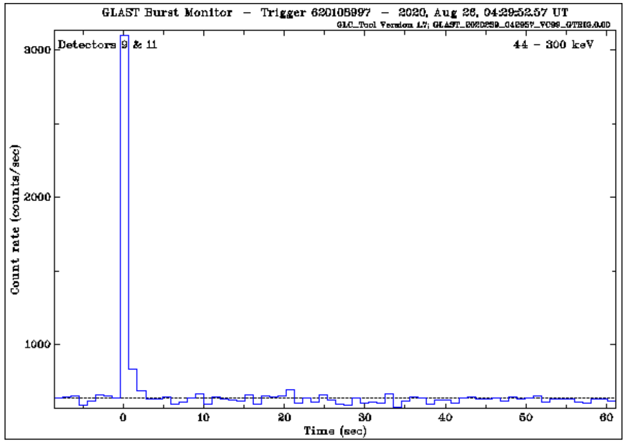
Rossi+20 for a review

SGRBs: still surprising us

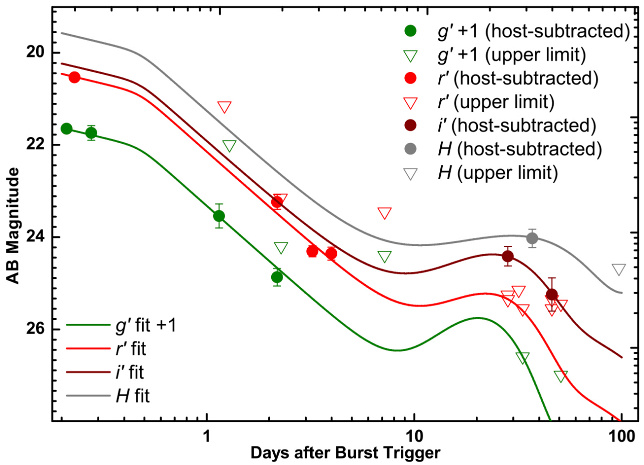
The Astrophysical Journal, 932:1 (15pp), 2022 June 10
https://doi.org/10.3847/1538-4357/ac60a2

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

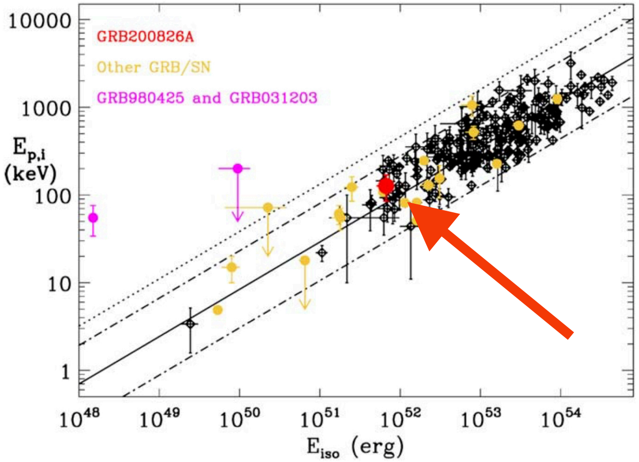
A. Rossi[1], B. Rothberg[2,3], E. Palazzi[1], D. A. Kann[4], P. D'Avanzo[5], L. Amati[1], S. Klose[6], A. Perego[7,8], E. Pian[1], C. Guidorzi[1,9,10], A. S. Pozanenko[11,12,13], S. Savaglio[14], G. Stratta[1,15,16], G. Agapito[17], S. Covino[5], F. Cusano[1], V. D'Elia[18,19], M. De Pasquale[20,21], 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

Talk by A. Rossi (Wednesday)

see also Ahumada+21

SGRBs: still surprising us

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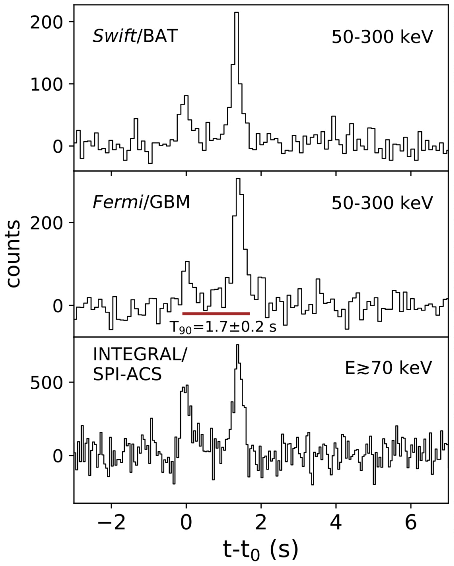
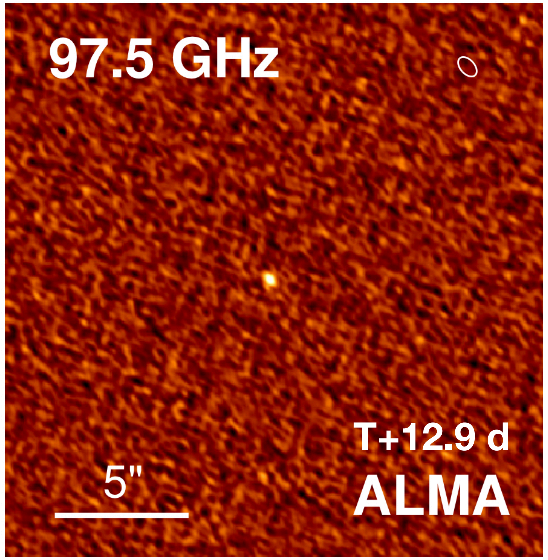
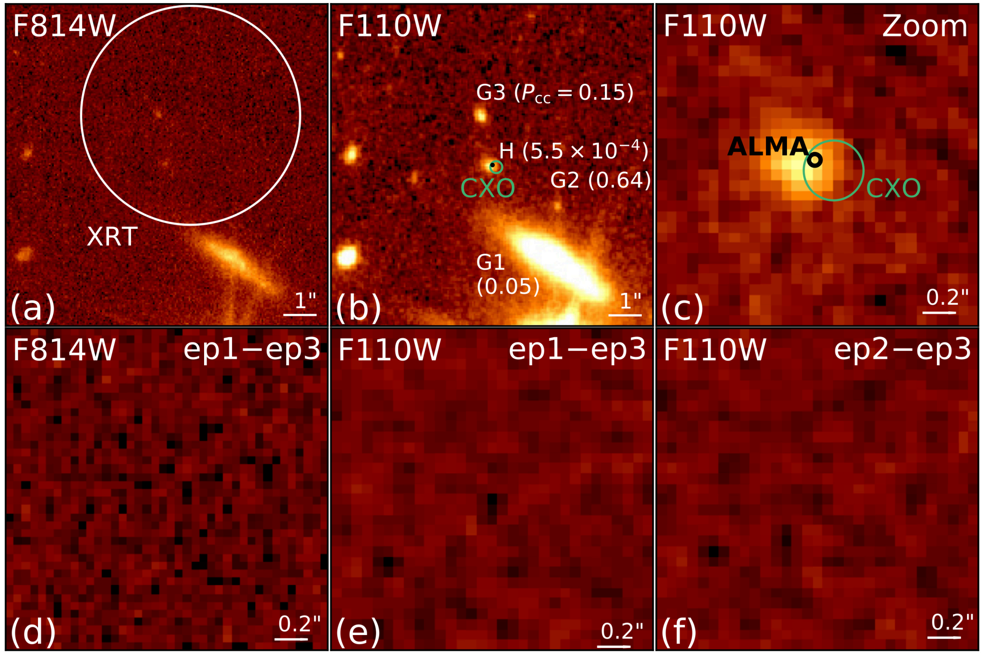
The First Short GRB Millimeter Afterglow: The Wide-Angled Jet of the Extremely Energetic SGRB 211106A

Tanmoy Laskar,[1] Alicia Rouco Escorial,[2] Genevieve Schroeder,[2] Wen-fai Fong,[2] Edo Berger,[3] Péter Veres,[4] Shivani Bhandari,[5,6,7] Jillian Rastinejad,[2] Charles D. Kilpatrick,[2] Aaron Tohuvavohu,[8] Raffaella Margutti,[9] Kate D. Alexander,[2] James DeLaunay,[10,11,12] Jamie A. Kennea,[13] Anya Nugent,[2] K. Paterson,[14] and Peter K. G. Williams[3,15]







mm afterglow detection with ALMA

HST faint host galaxy detection
$T-T_0$ ~ 19.1, 25.3, 48.2 d

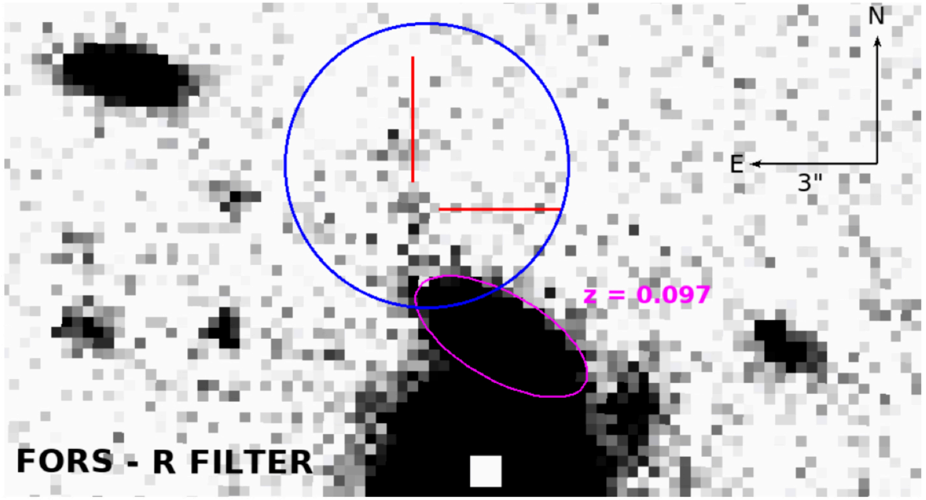
Assuming z = 1 -> log($E_{K,iso}$/erg) = 53.2, $theta_{jet}$ = 16 deg,
Evidence for high intrinsic extinction: A_V > 2.6 mag

SGRBs: still surprising us

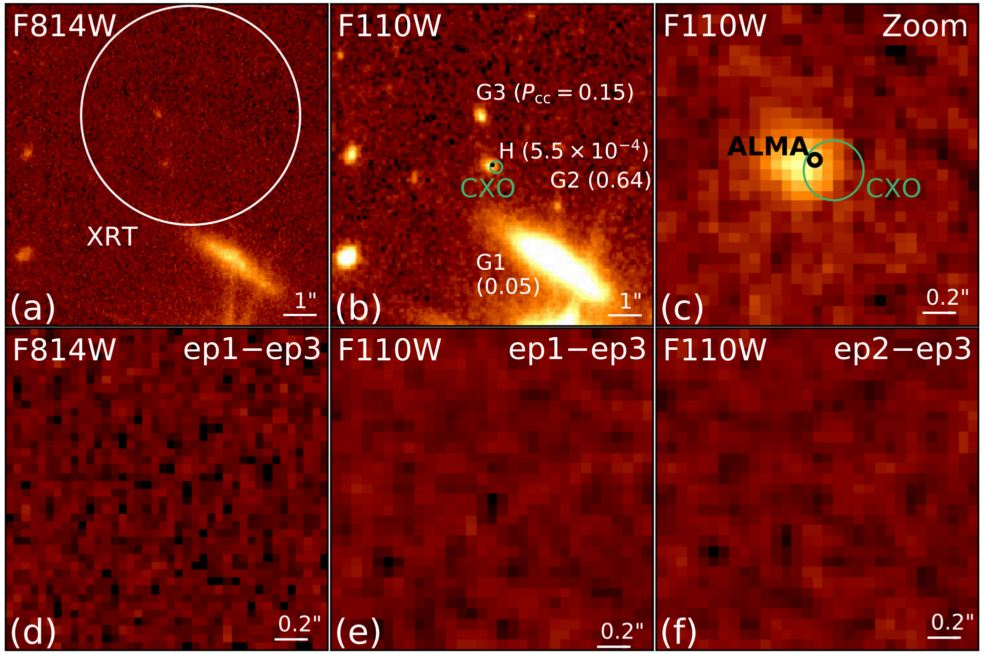
GRB 211106A: VLT host galaxy detection and early-time afterglow & KN limits
(Ferro et al., in preparation)

The First Short GRB Millimeter Afterglow: The Wide-Angled Jet of the Extremely Energetic SGRB 211106A

Tanmoy Laskar,[1] Alicia Rouco Escorial,[2] Genevieve Schroeder,[2] Wen-fai Fong,[2] Edo Berger,[3] Péter Veres,[4] Shivani Bhandari,[5,6,7] Jillian Rastinejad,[2] Charles D. Kilpatrick,[2] Aaron Tohuvavohu,[8] Raffaella Margutti,[9] Kate D. Alexander,[2] James DeLaunay,[10,11,12] Jamie A. Kennea,[13] Anya Nugent,[2] K. Paterson,[14] and Peter K. G. Williams[3,15]



ESO-VLT faint host galaxy detection; R_{HG} ~ 26.5 mag



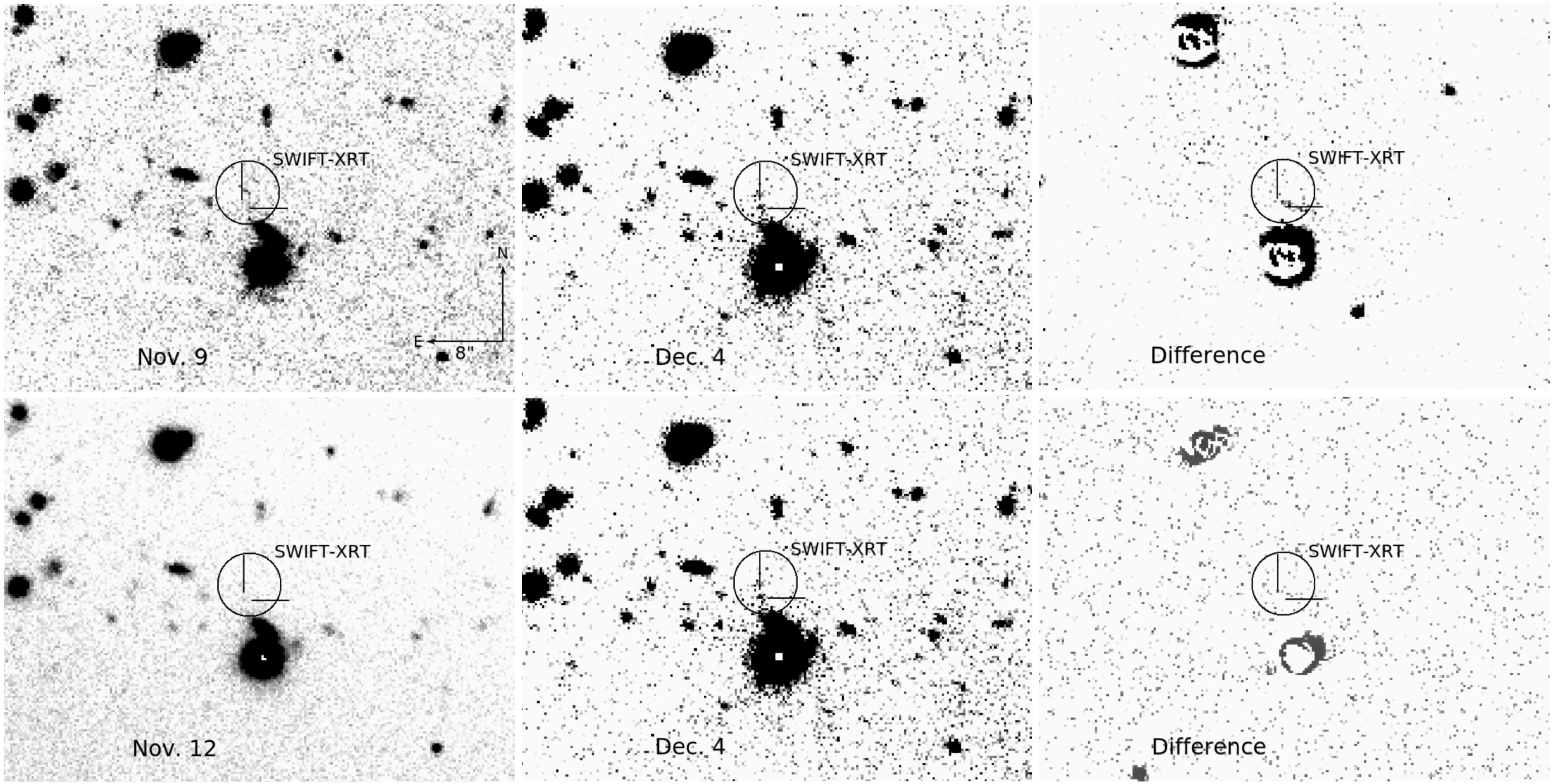
Talk by M. Ferro (Tuesday)

SGRBs: still surprising us

Talk by M. Ferro (Tuesday)

GRB 211106A: VLT host galaxy detection and early-time afterglow & KN limits

(Ferro et al., in preparation)



ESO-VLT: $T-T_0$ ~ 2.9, 5.9, 27.9 d

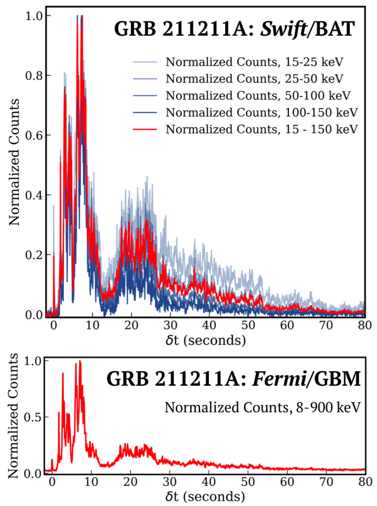
limits on afterglow / KN: R > 26.8 mag

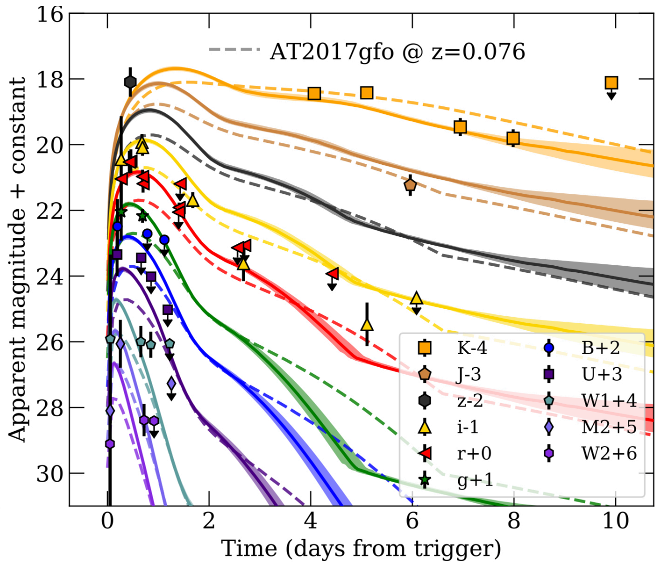
SGRBs: still surprising us

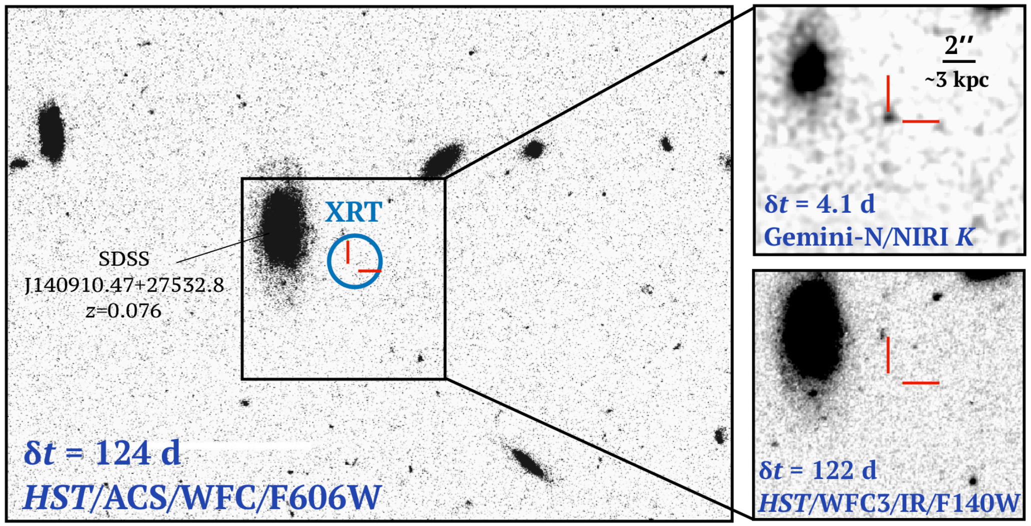
A Kilonova Following a Long-Duration Gamma-Ray Burst at 350 Mpc

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]

T_{90} ~ 51 s
(possible EE)







SGRBs: still surprising us

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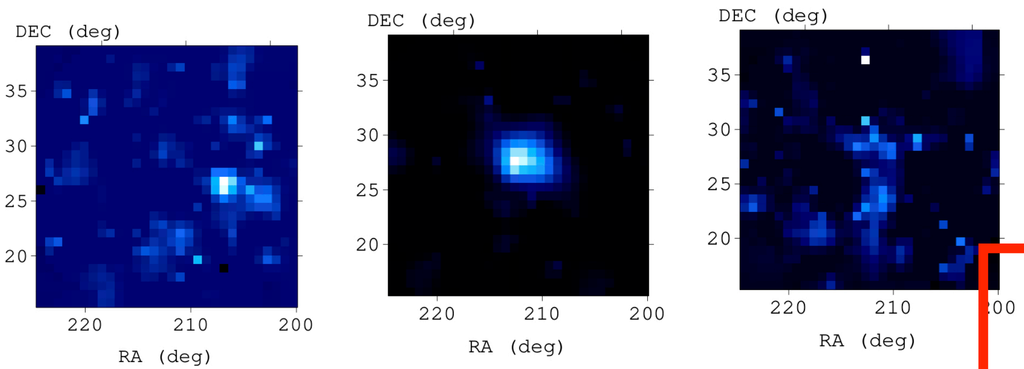
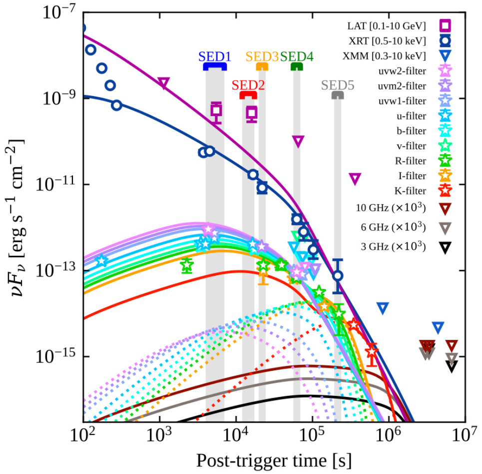
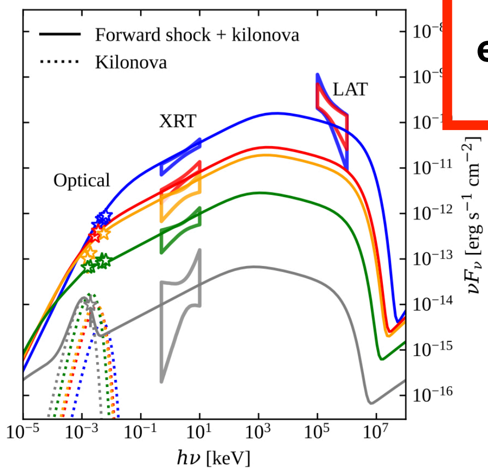
GeV emission from a compact binary merger

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]

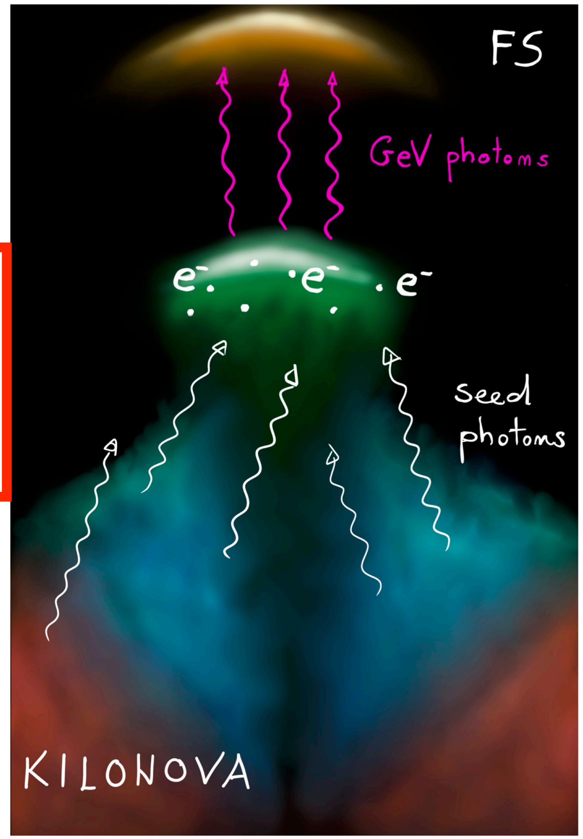






late time [T+(6 – 14) ks] GeV emission, in excess to afterglow emission

Talk by A. Mei (Tuesday)

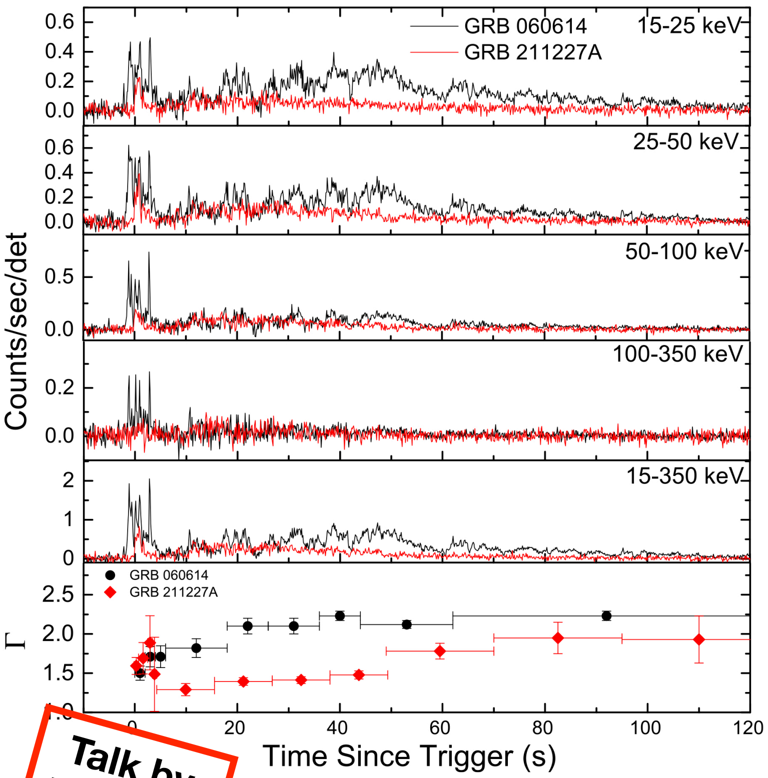


SGRBs: still surprising us

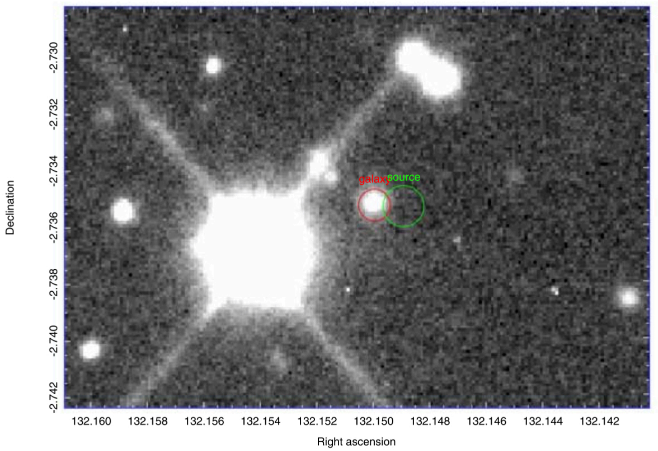
THE ASTROPHYSICAL JOURNAL LETTERS, 931:L23 (9pp), 2022 June 1 https://doi.org/10.3847/2041-8213/ac6e3a

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]

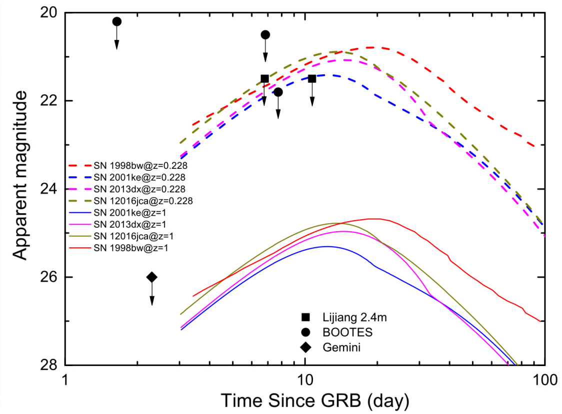


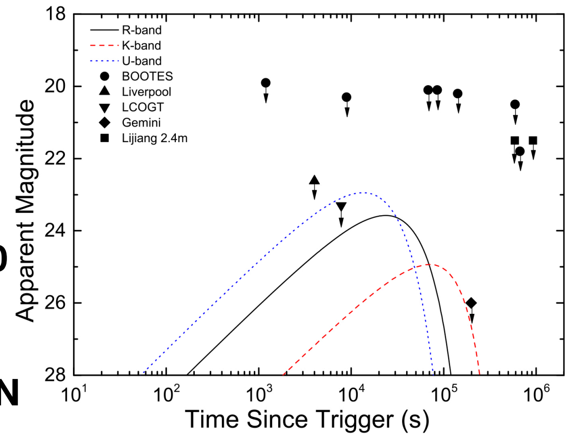
Talk by M. Ferro (Tuesday)



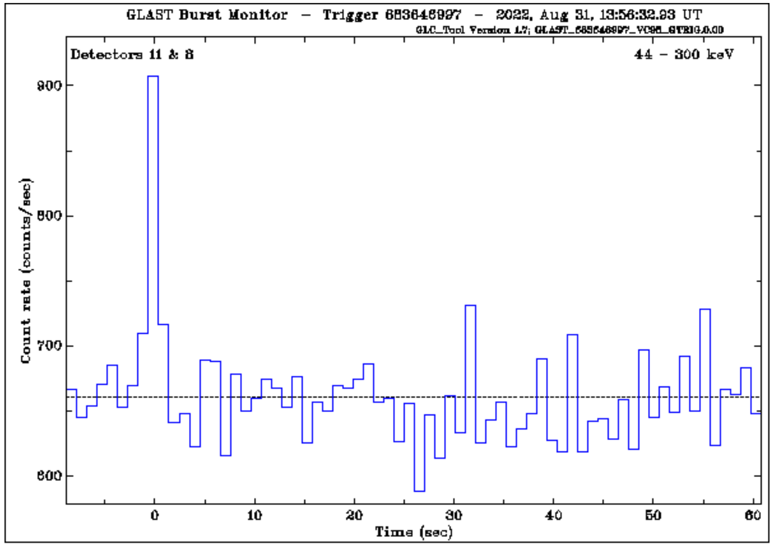
Peculiar GRB with T_{90} = 84 s

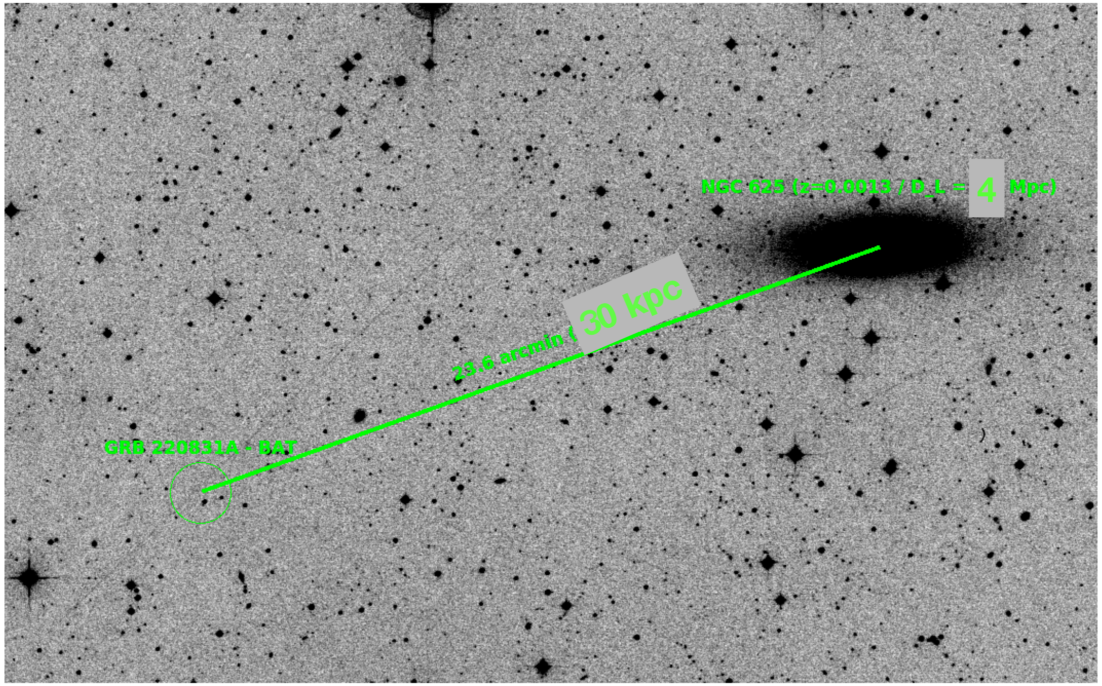
- **prompt emission similar to 060614**
- **possible EE**
- **close to a z = 0.228 galaxy (offset 20 kpc)**
- **no associated SN**
- **limits compatible with AT2017gfo KN**





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

A sub-sample of *Swift* SGRBS with:
- prompt XRT observation (no need for a X-ray detection)
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→

(Nov 2004 – Jun 2013)

16 SGRBs, 11 with redshift (~70%)

The SBAT4 sample

A sub-sample of *Swift* SGRBS with:
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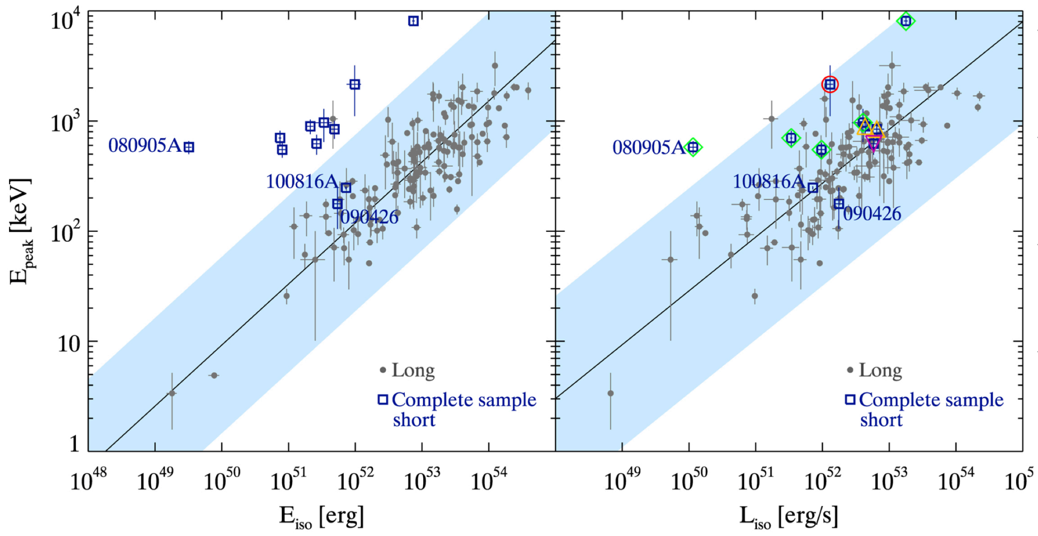
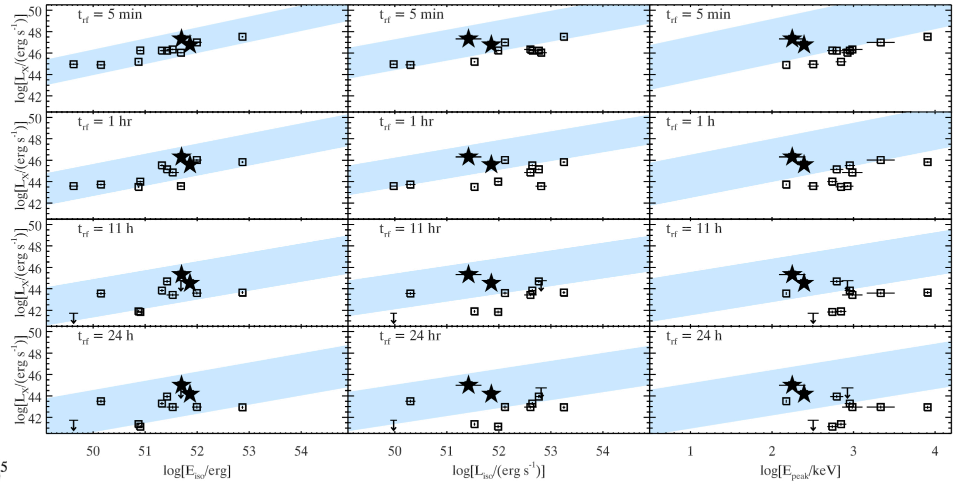
- P_{64} > 3.5 *ph/s/cm²* (15-150 kev*)*

→ (Nov 2004 – Jun 2013)

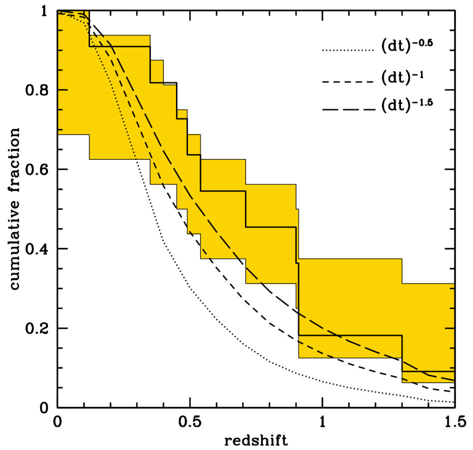
16 SGRBs, 11 with redshift (~70%)

correlations

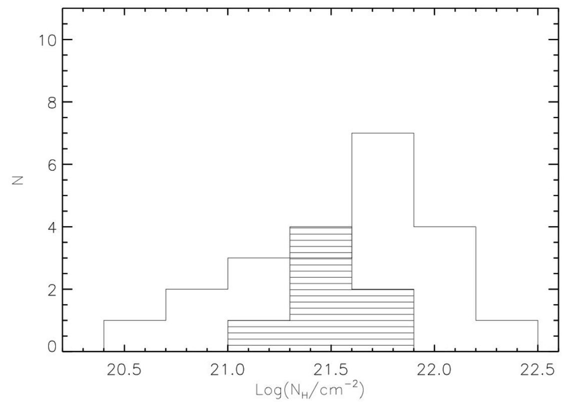


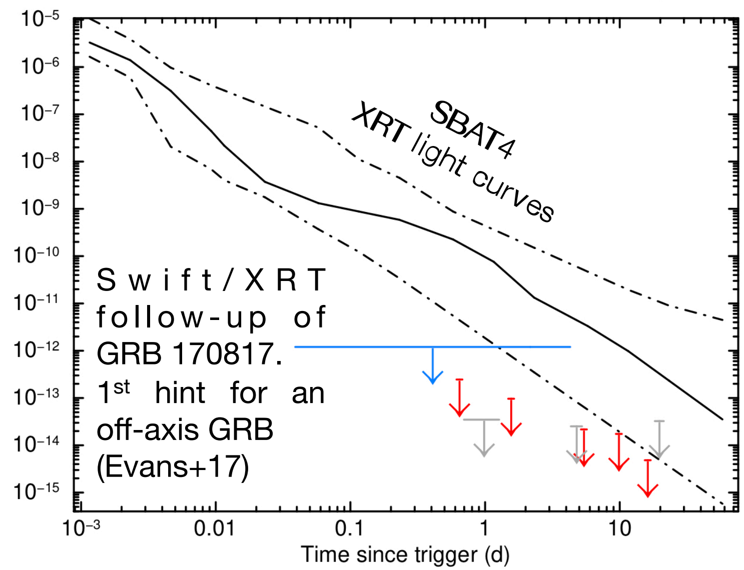


redshift distribution



N_H distribution





PDA+14

The extended 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 – 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

- 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?
  - GeV emission from GRB 211211A?
  - how to identify genuine short (i.e. merger-driven) GRBs?
  - (…)

We are at the dawn of a new, exciting, promising, era for (multi-messenger) studies of SGRBs. No doubt that there is a lot of attention, efforts, planning, expectations from the community.