Istituto Nazionale di Astrofisica

Osservatorio Astronomico di Brera

Short Gamma-Ray Bursts punto della situazione e prospettive

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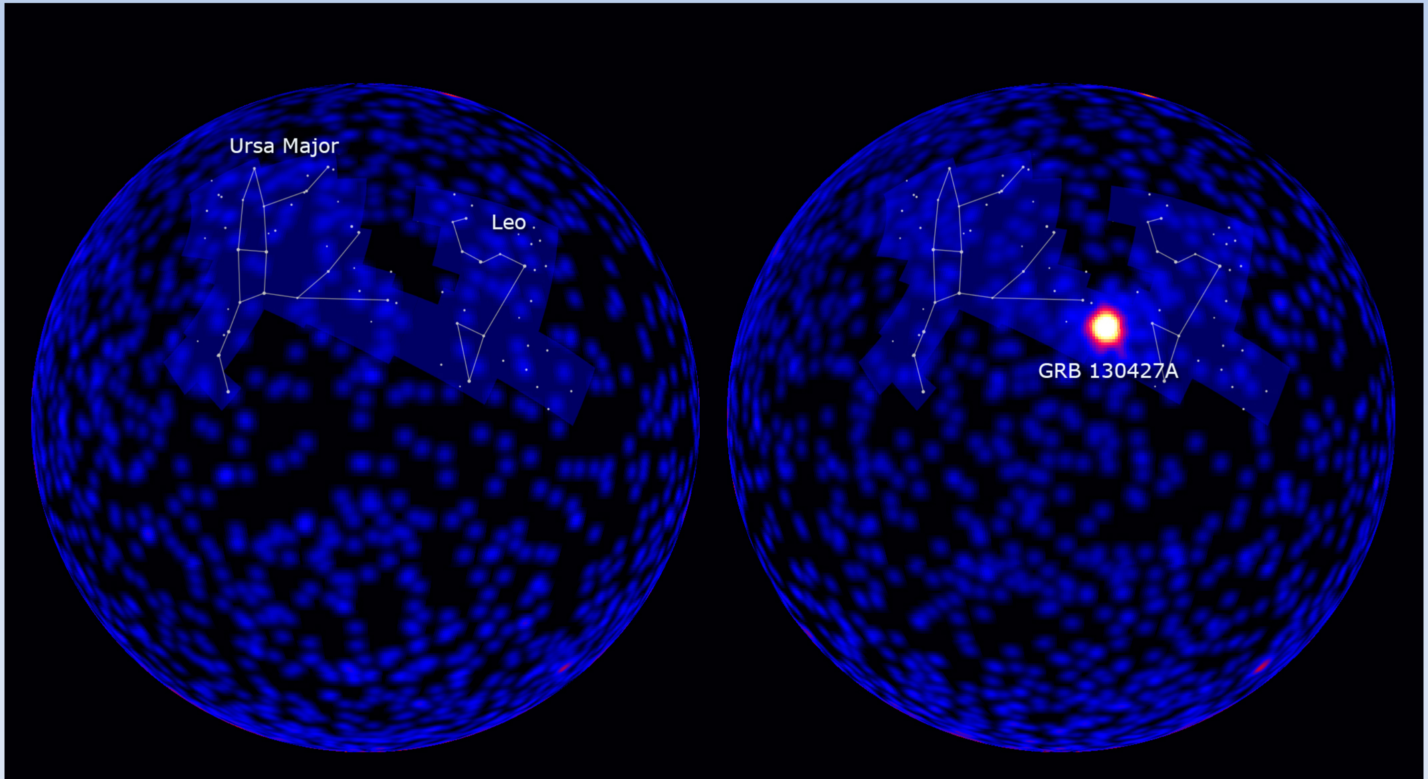
INAF – Osservatorio Astronomico di Brera

What is a Gamma-Ray Burst?

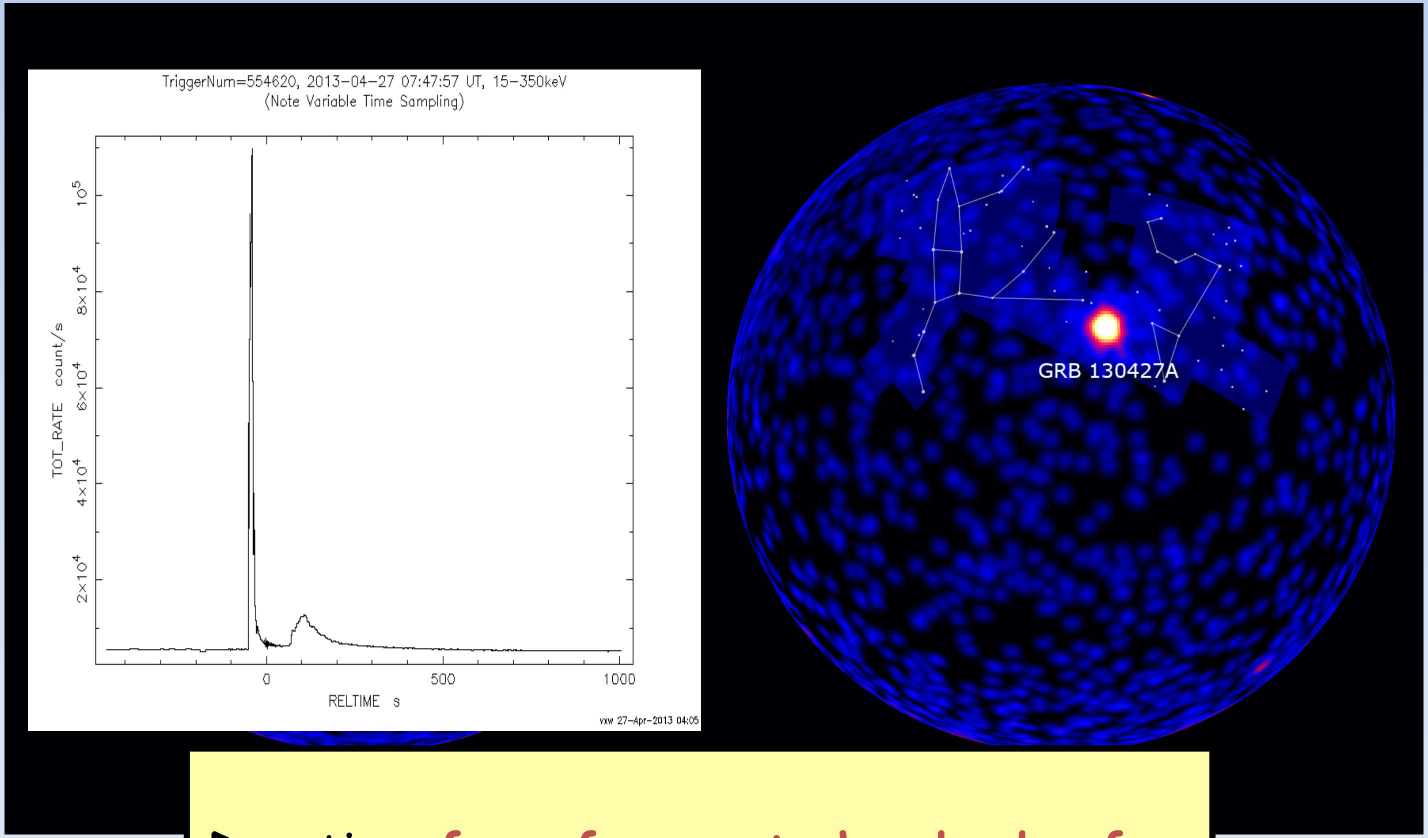
Brief, sudden, intense flash of gamma-ray radiation



Before and after Fermi LAT views of GRB 130427A, centered on the north galactic pole

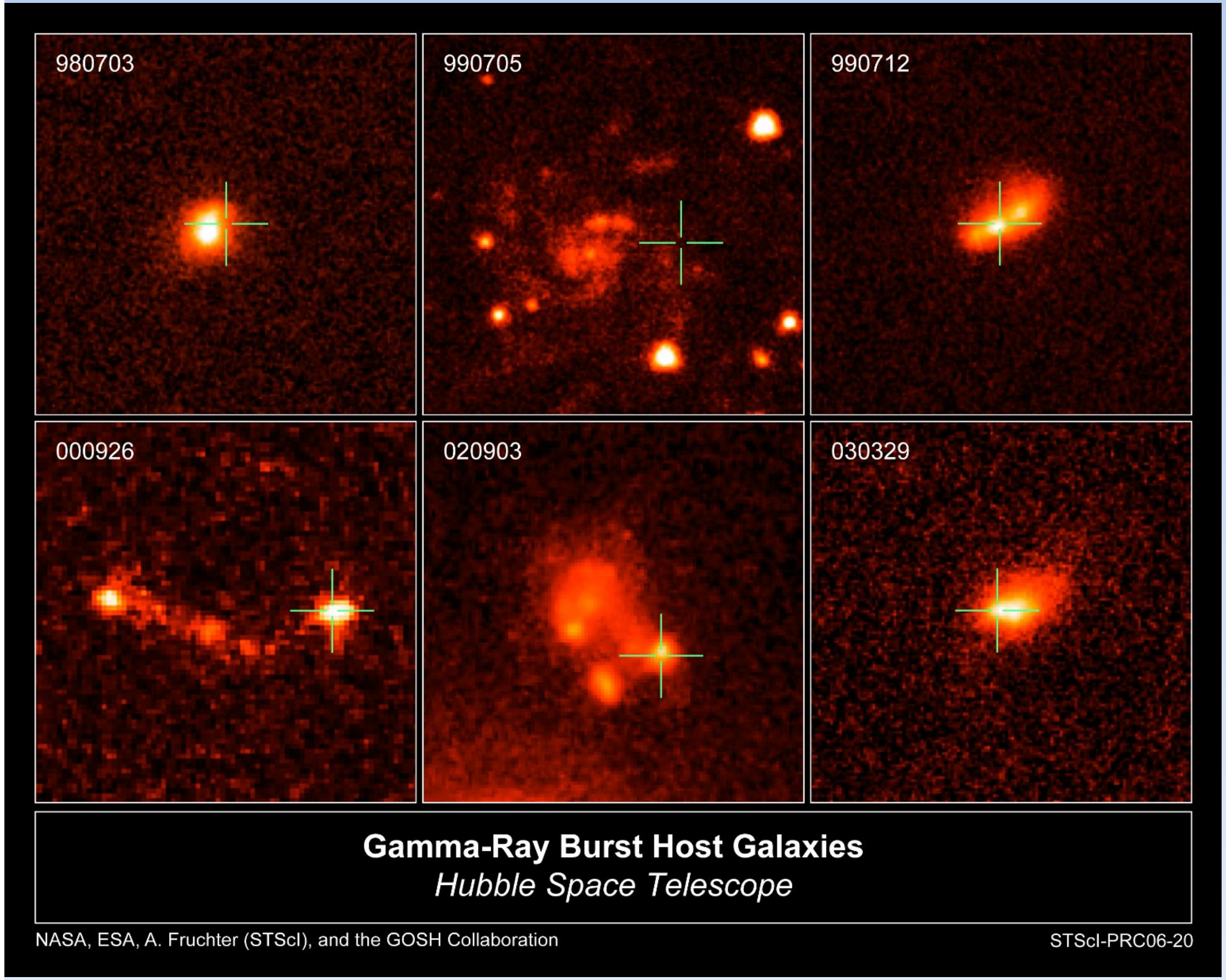
What is a Gamma-Ray Burst?

Brief, sudden, intense flash of gamma-ray radiation



Duration: **from few ms to hundreds of s**
Frequency: **10 keV - 1 MeV**
Fluence: **10^{-7} - 10^{-3} erg cm^{-2}**
Flux: **10^{-8} - 10^{-4} erg cm^{-2} s^{-1}**

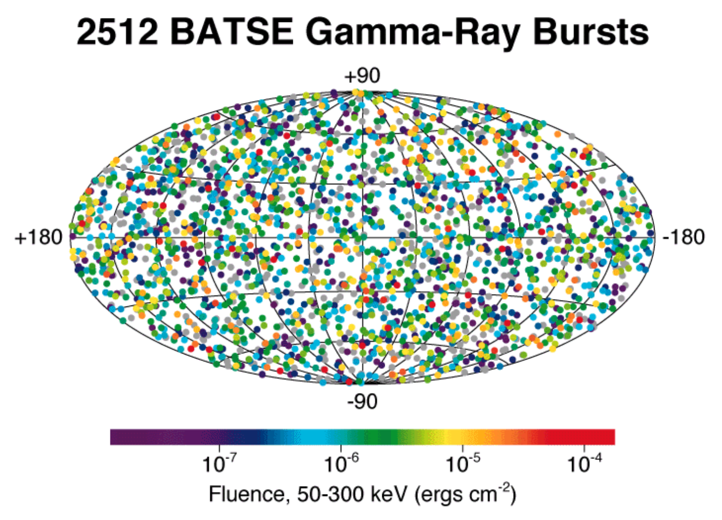
GRBs are cosmological and occur in galaxies



Gamma-Ray Burst Host Galaxies
Hubble Space Telescope

NASA, ESA, A. Fruchter (STScI), and the GOSH Collaboration

STScI-PRC06-20


2512 BATSE Gamma-Ray Bursts

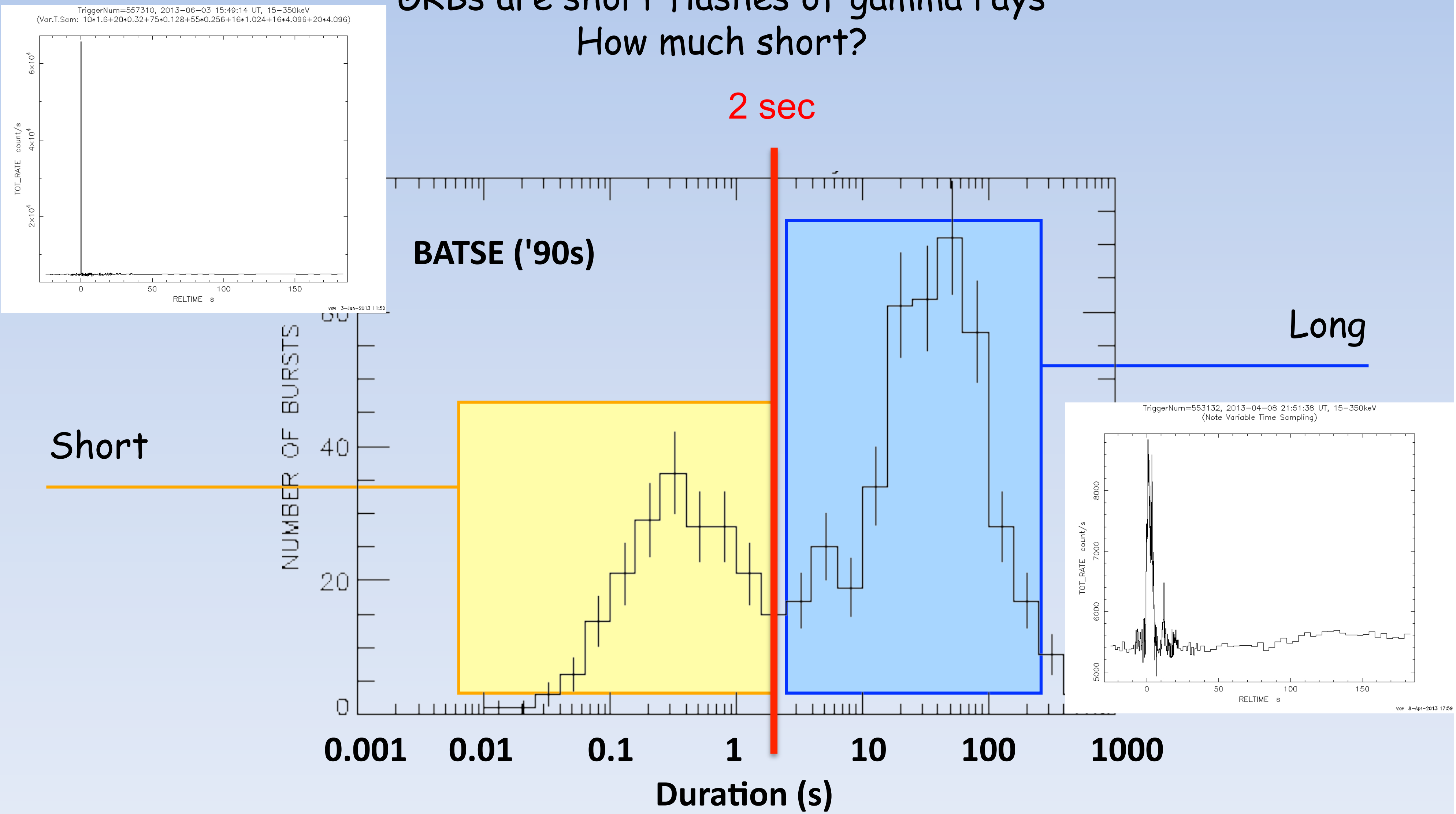
Fluence: 10^{-5} erg cm^{-2}
Distance: $\langle z \rangle = 2.1 \sim 10^{28}$ cm

↓

Energy: ~ 10^{53} erg
Like the energy emitted by our Galaxy in 10 years

Two flavors of GRBs

GRBs are short flashes of gamma rays
How much short?



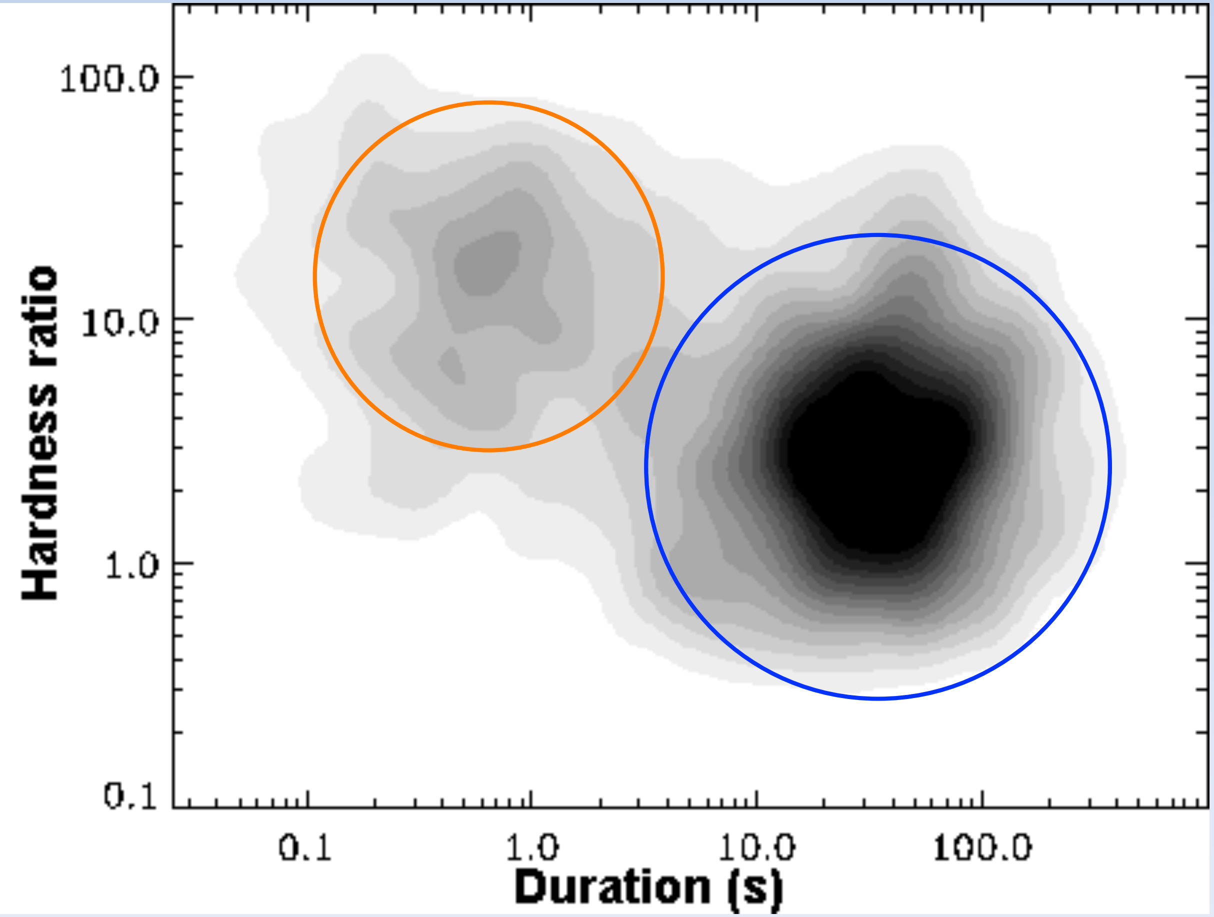
Kouveliotou et al. 1993

Another angle

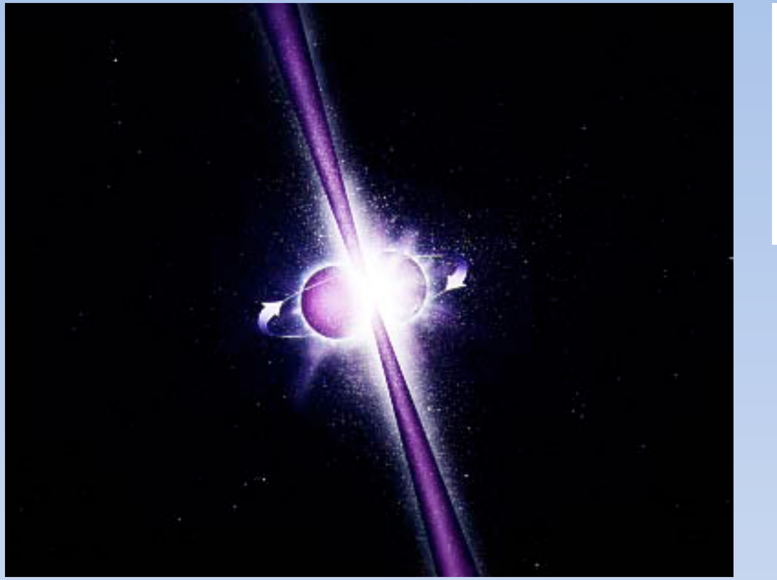
Hardness ratio: $HR = \frac{\text{countrate(hard)}}{\text{countrate(soft)}}$

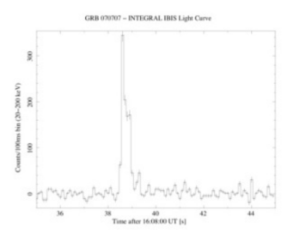
Paradigm:

Long/soft
Short/hard

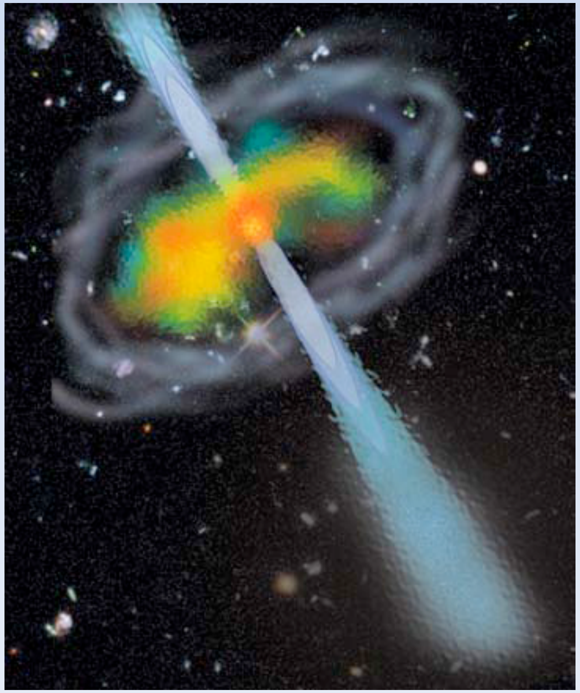


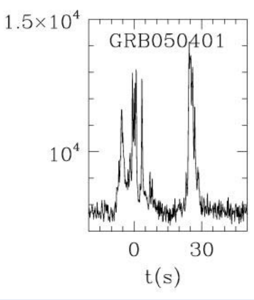
Progenitors





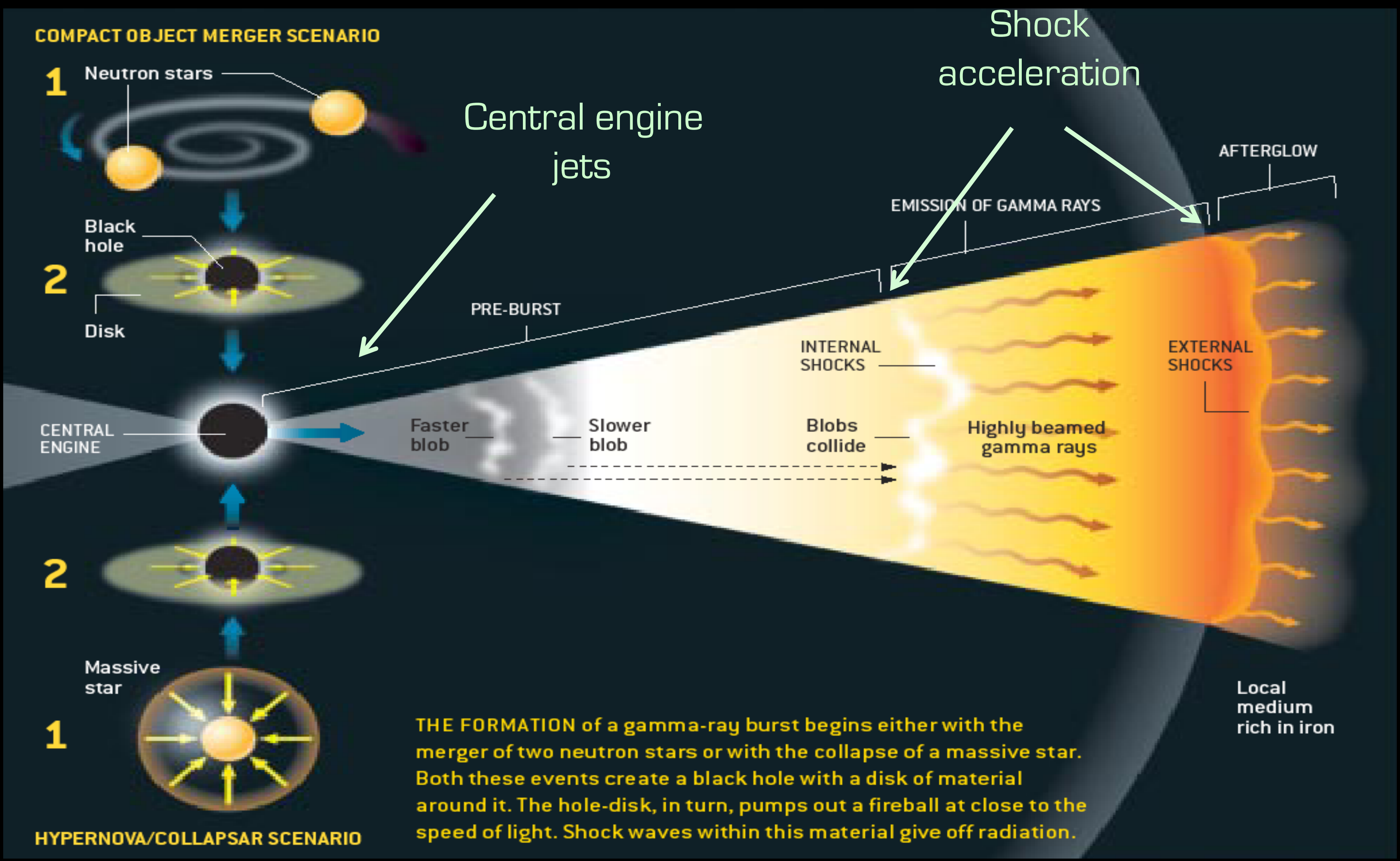
Short/hard GRBs
- in all type of galaxies (or no host galaxy at all)
- older stellar population
- no associated SN
- merger progenitor model (and/or magnetars?)





Long/soft GRBs
- in star-forming galaxies
- younger stellar population
- many with associated SN
- collapsar progenitor model (magnetar engine?)

The standard model

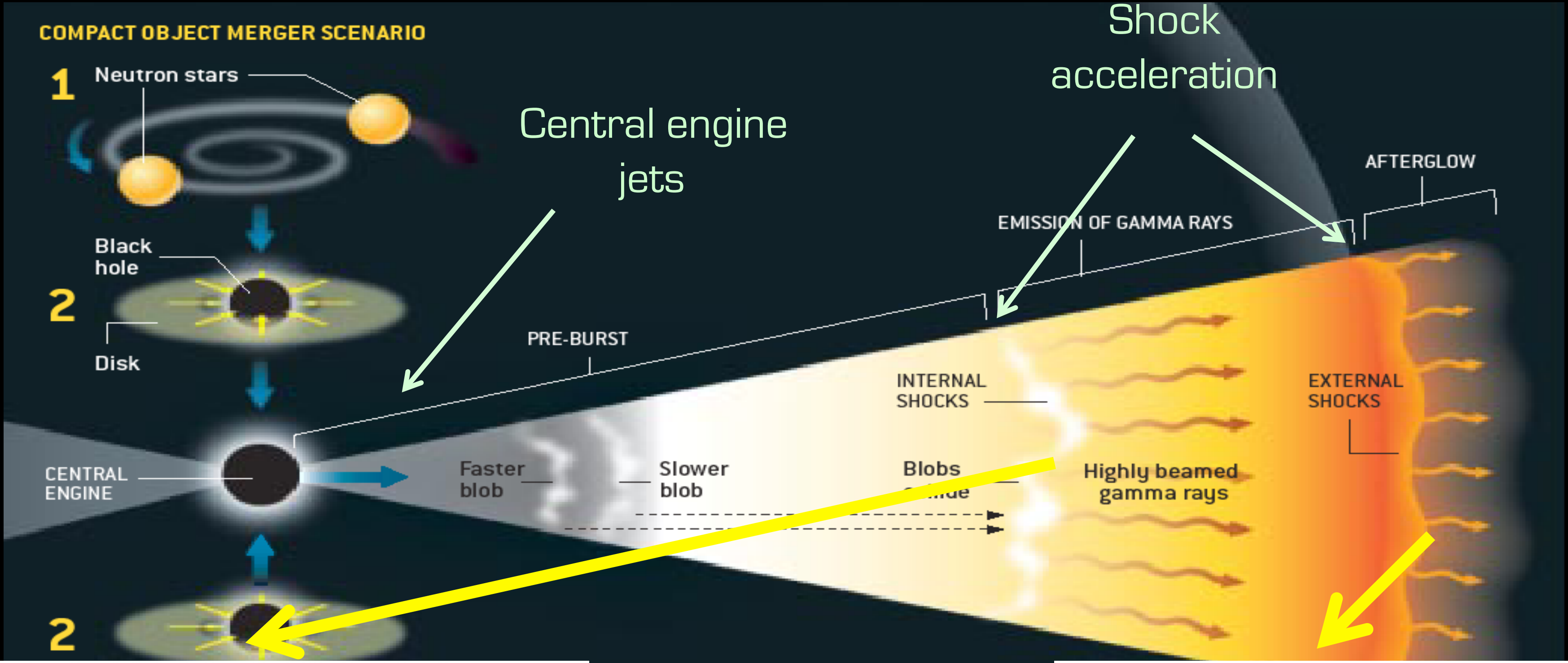


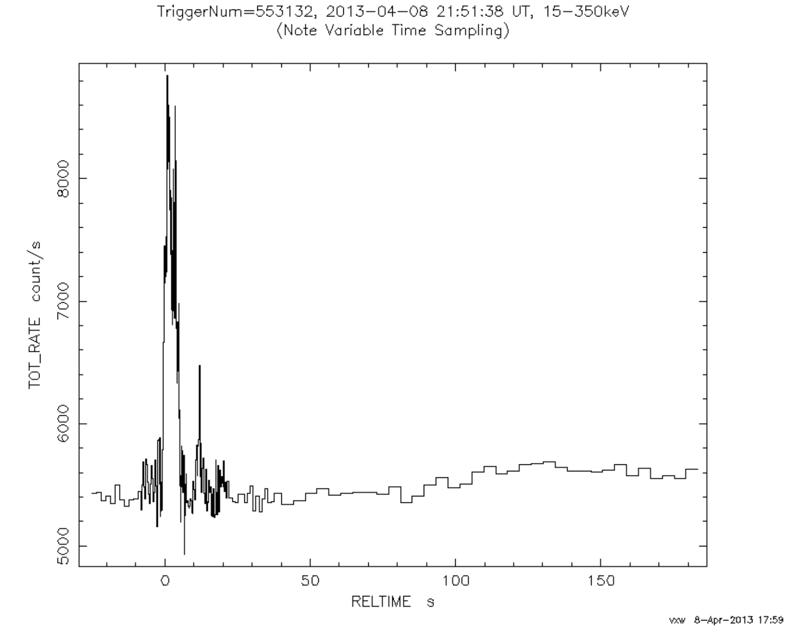
THE FORMATION of a gamma-ray burst begins either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk, in turn, pumps out a fireball at close to the speed of light. Shock waves within this material give off radiation.

The standard model

Central engine jets

Shock acceleration




TriggerNum=553132, 2013–04–08 21:51:38 UT, 15–350keV
(Note Variable Time Sampling)

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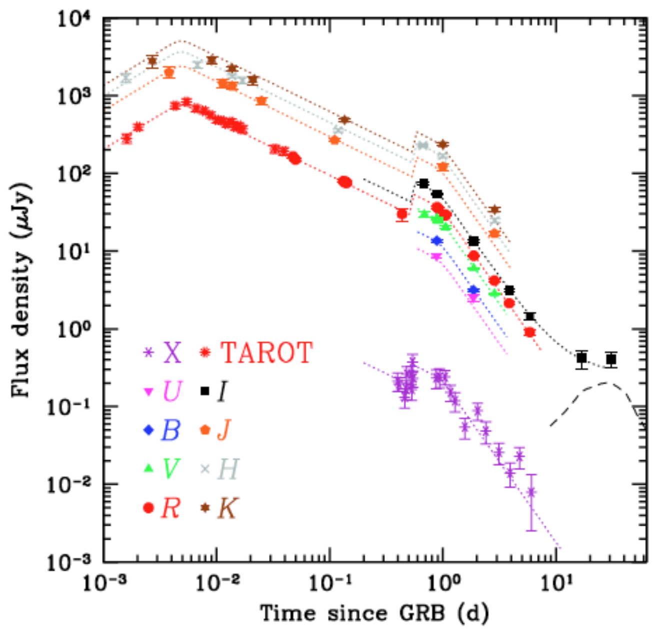
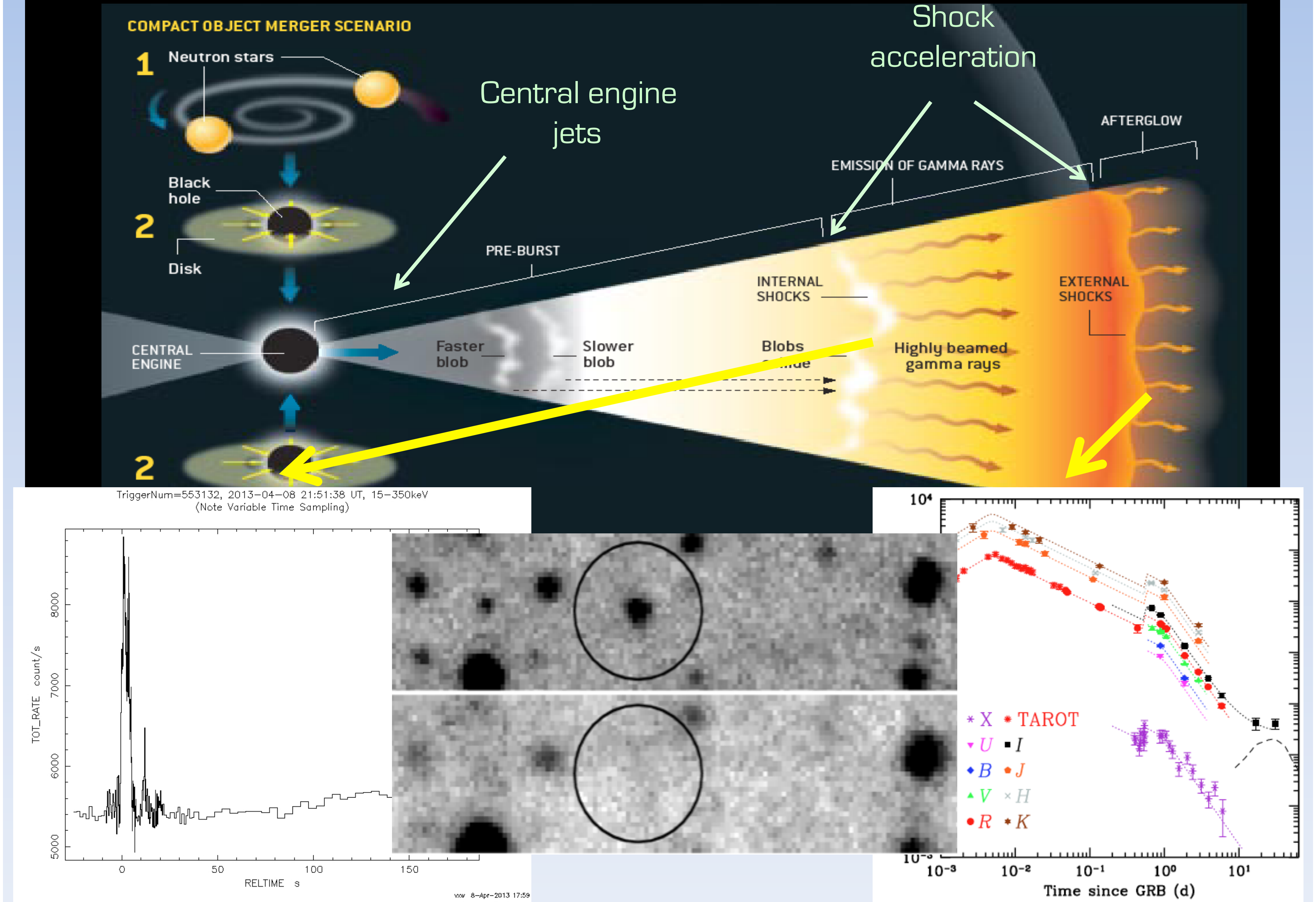


The standard model



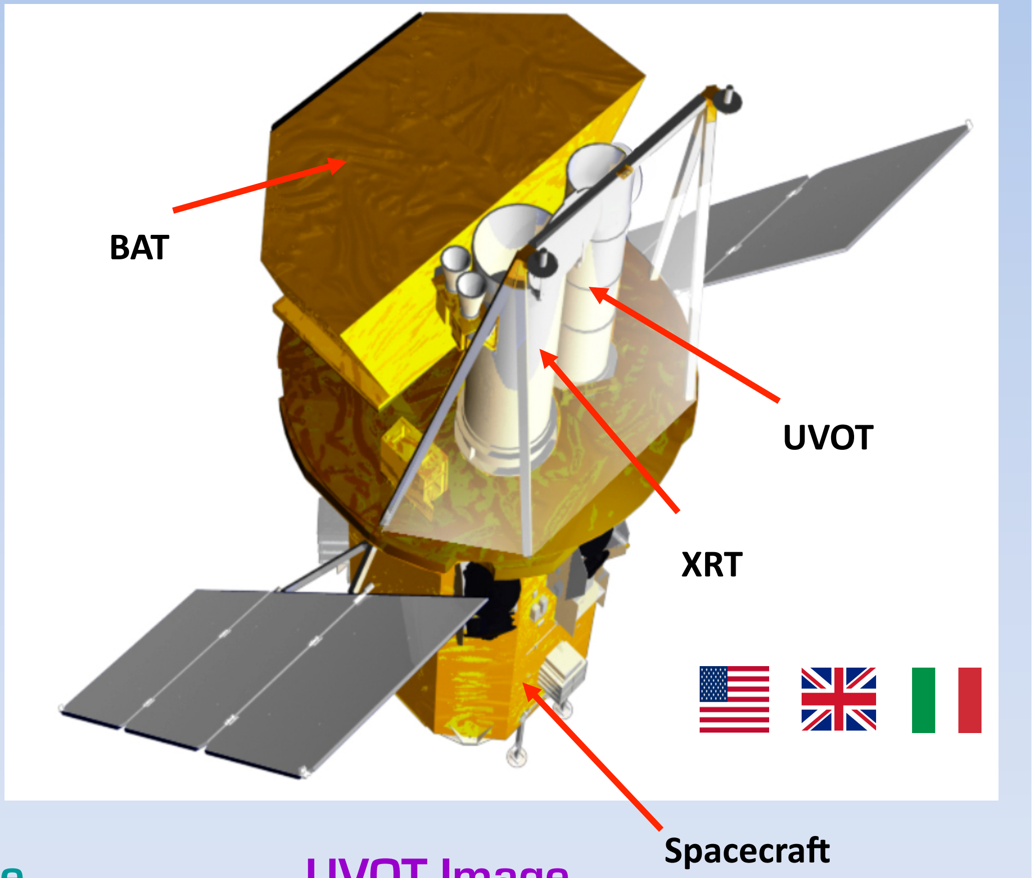
Central engine jets

Shock acceleration

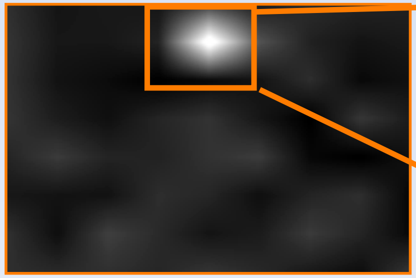
Swift Mission (2004)

Gehrels et al. 2004

- **Burst Alert Telescope (BAT)**
  - 15-150 keV
  - FOV: 2 steradiants
  - Centroid accuracy: 1’ - 4’
- **X-Ray Telescope (XRT)**
  - 0.2-10.0 keV
  - FOV: 23.6’ x 23.6’
  - Centroid accuracy: 5”
- **UV/Optical Telescope (UVOT)**
  - 30 cm telescope
  - 6 filters (170 nm – 600 nm)
  - FOV: 17’ x 17’
  - 24th mag sensitivity (1000 sec)
  - Centroid accuracy: 0.5”

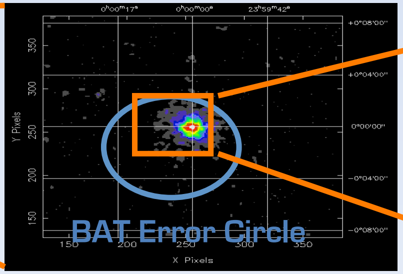


BAT Burst Image



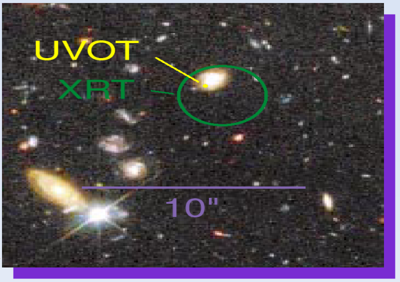
$T<10$ s; $\theta < 4'$

XRT Image



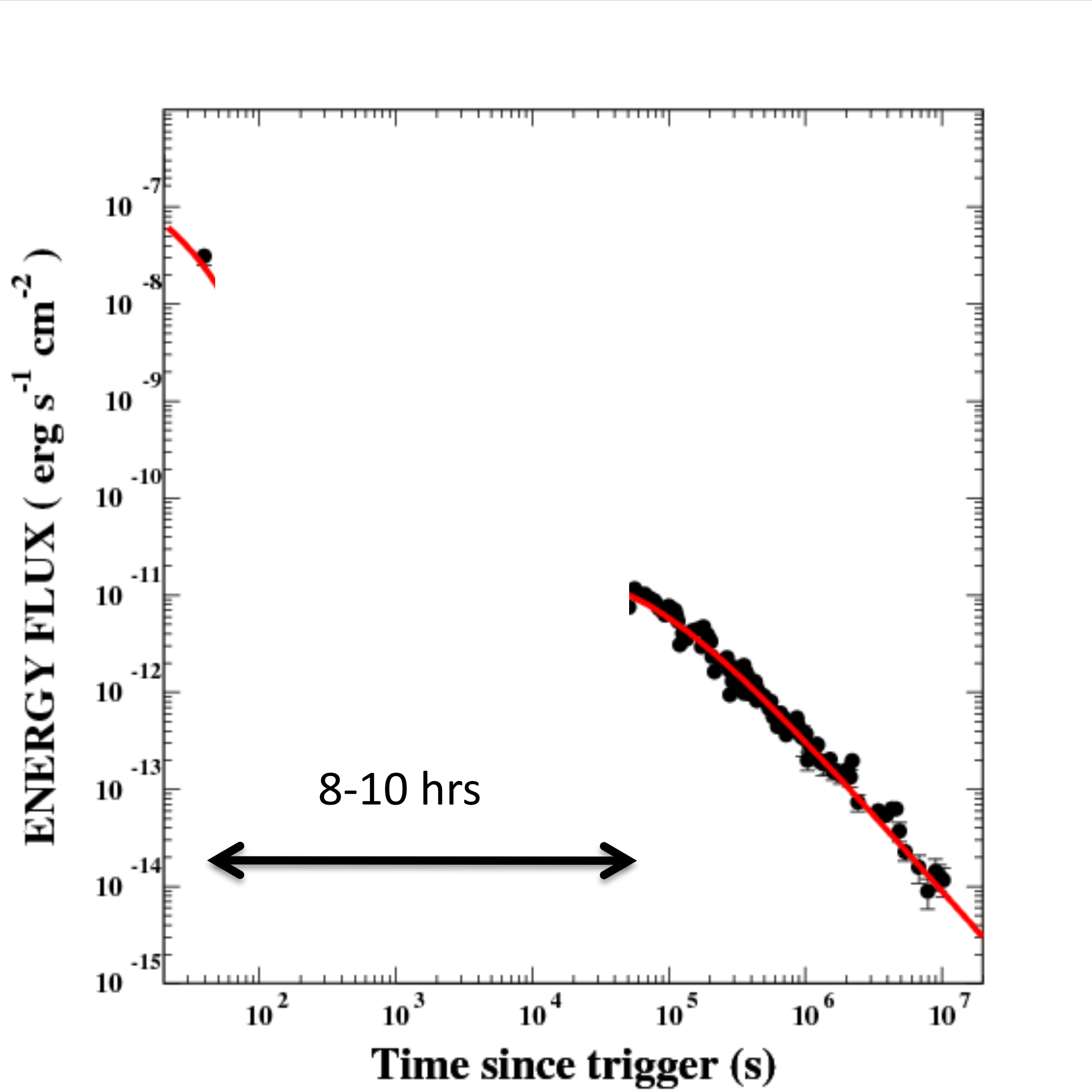
$T<100$ s; $\theta < 5''$

UVOT Image

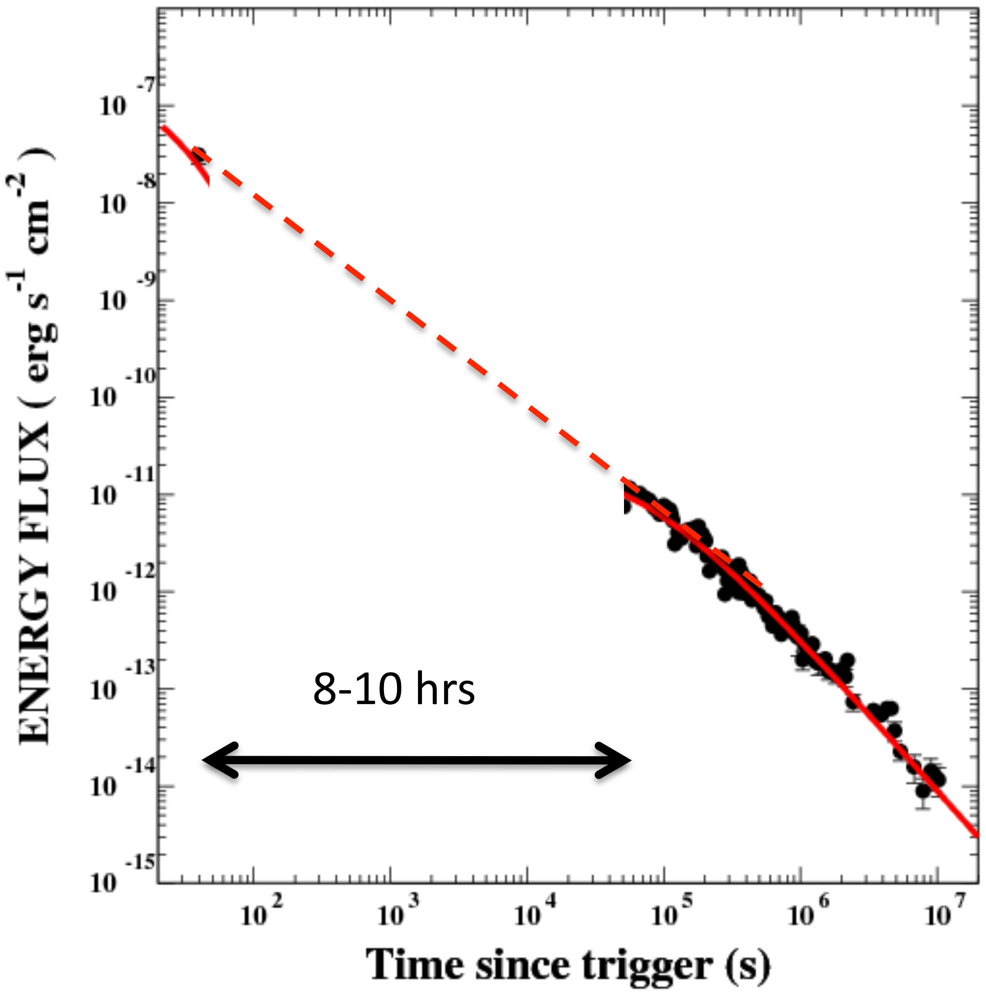


$T<300$ s; $\theta < 0.5'$

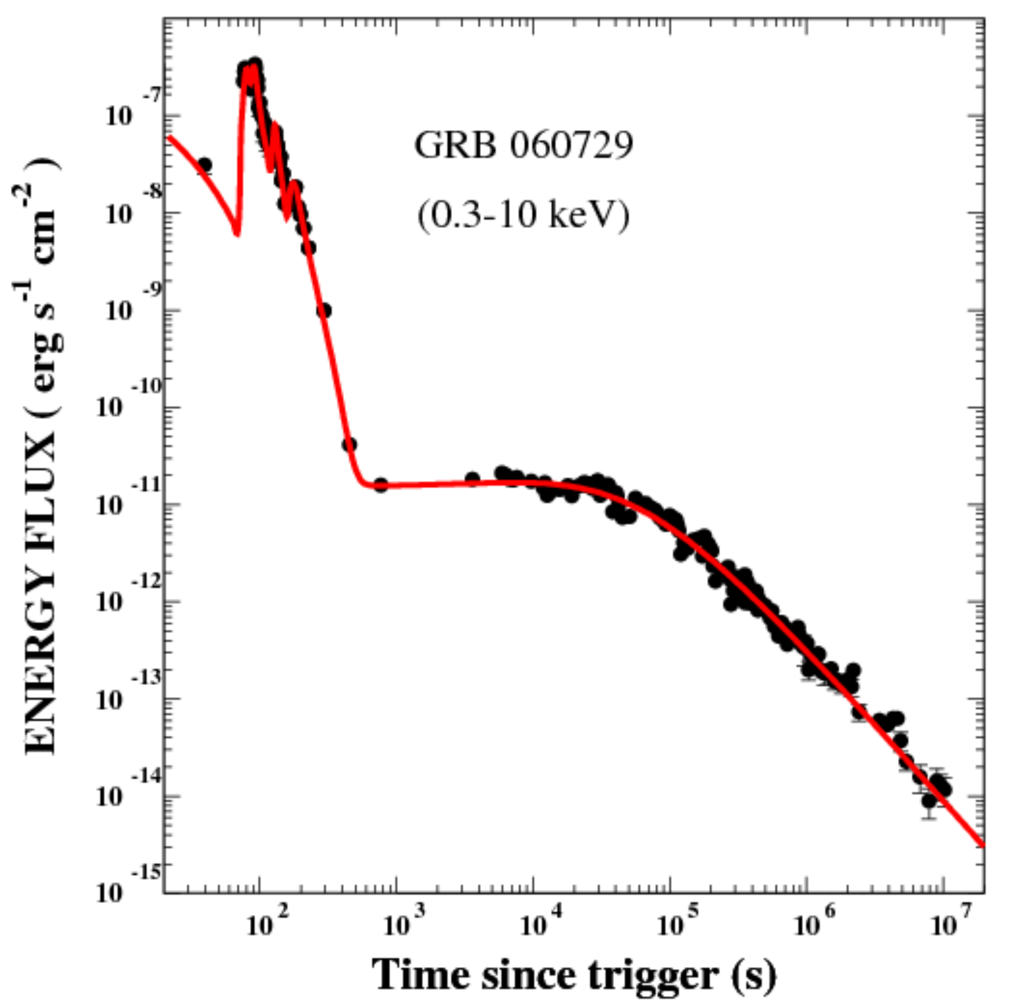
pre-Swift afterglow light curves



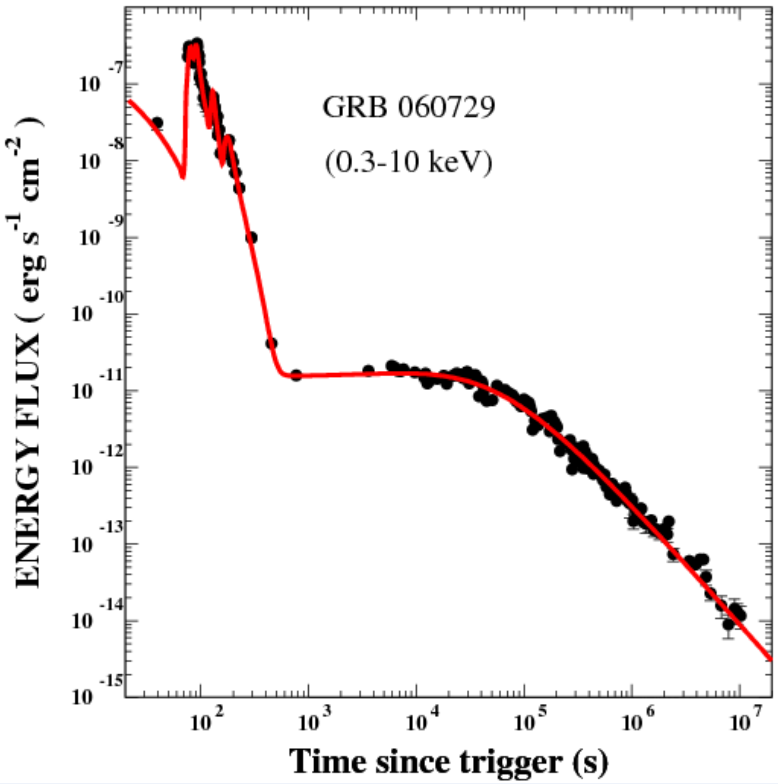
pre-Swift afterglow light curves

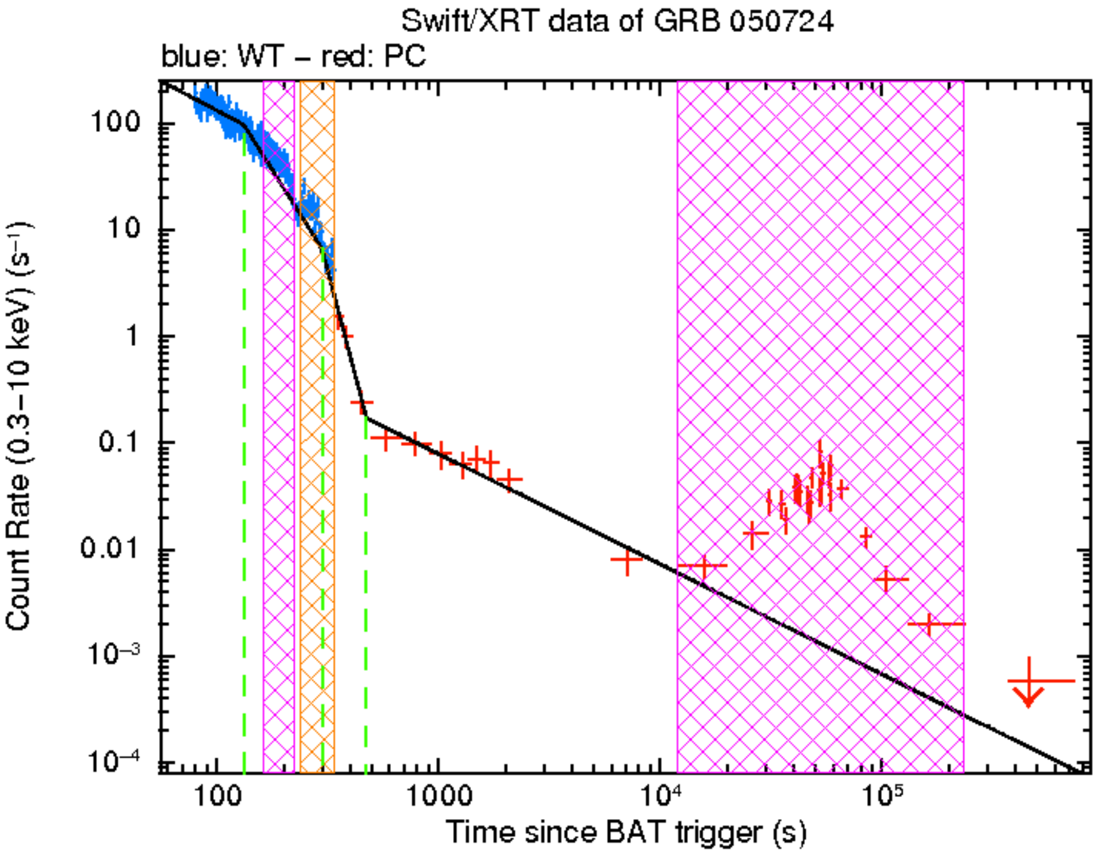


Swift afterglow light curves

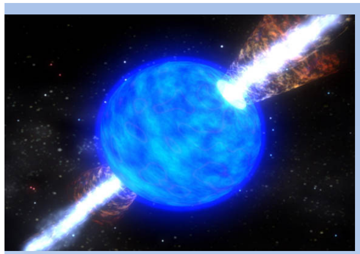


Swift afterglow light curves

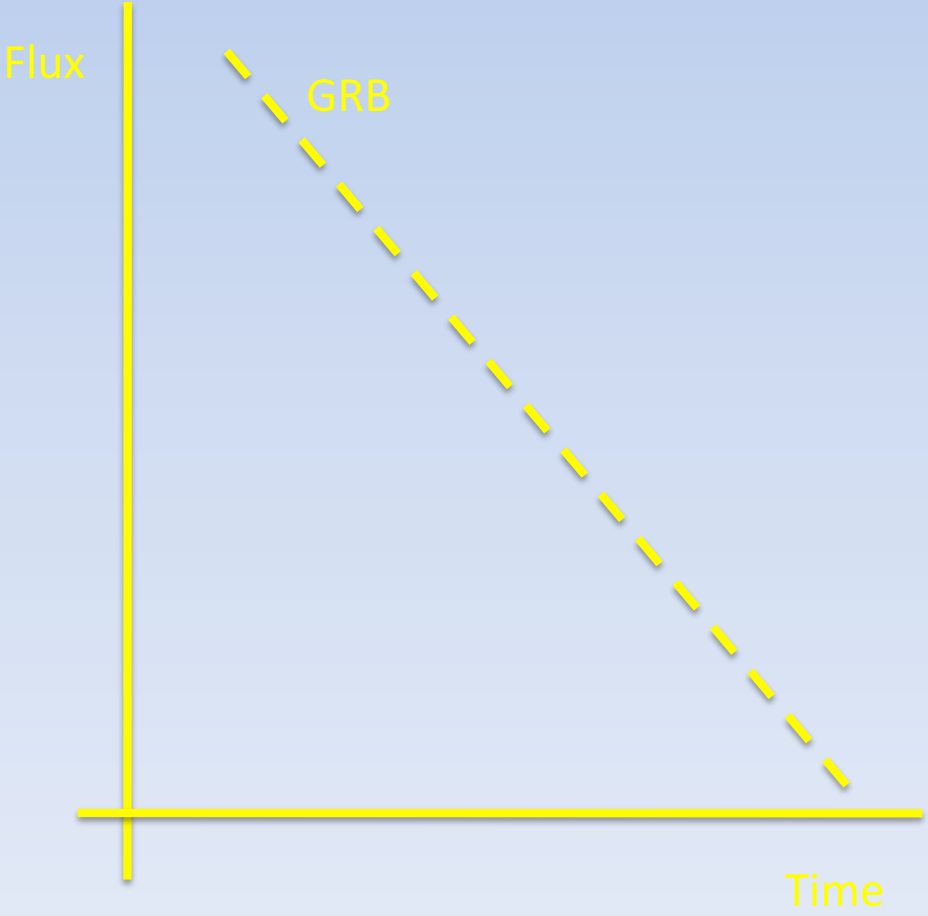


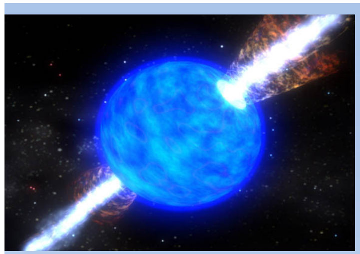


Steep decay, plateaus, flares:
common to long and short GRB afterglow light curves

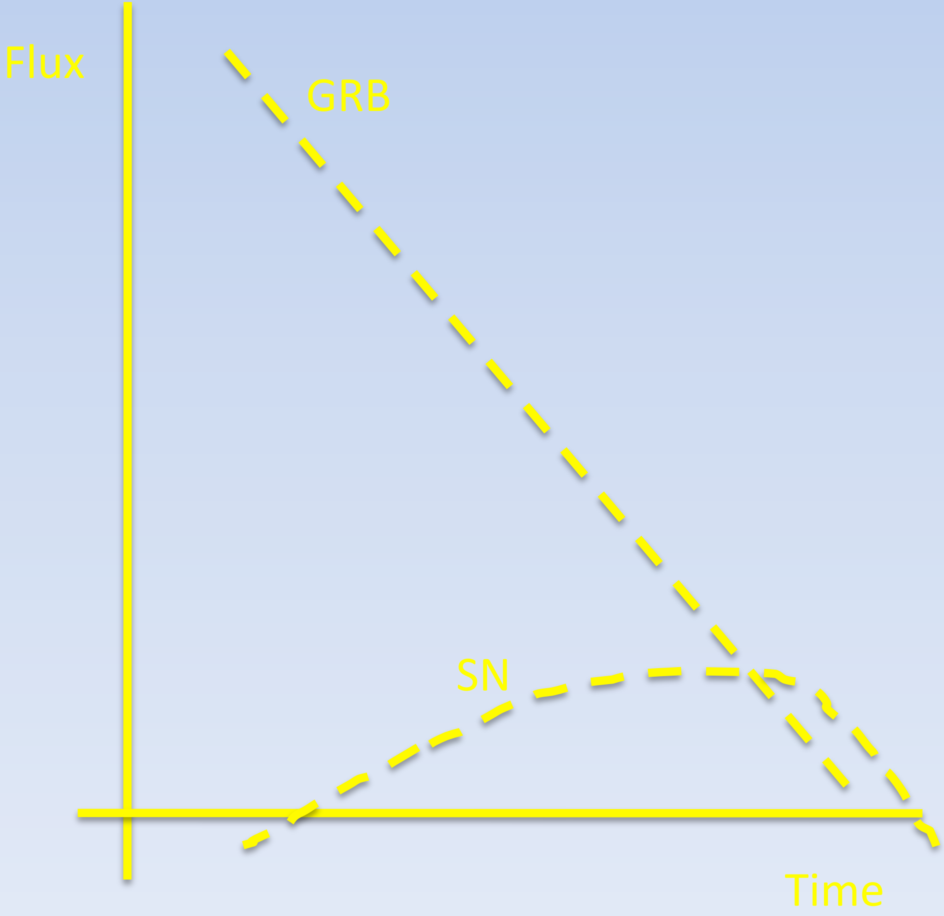


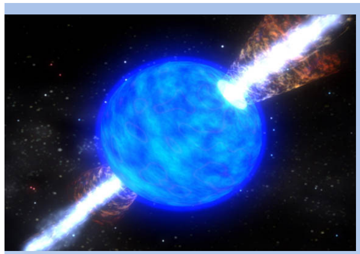
Long GRB & Supernovae



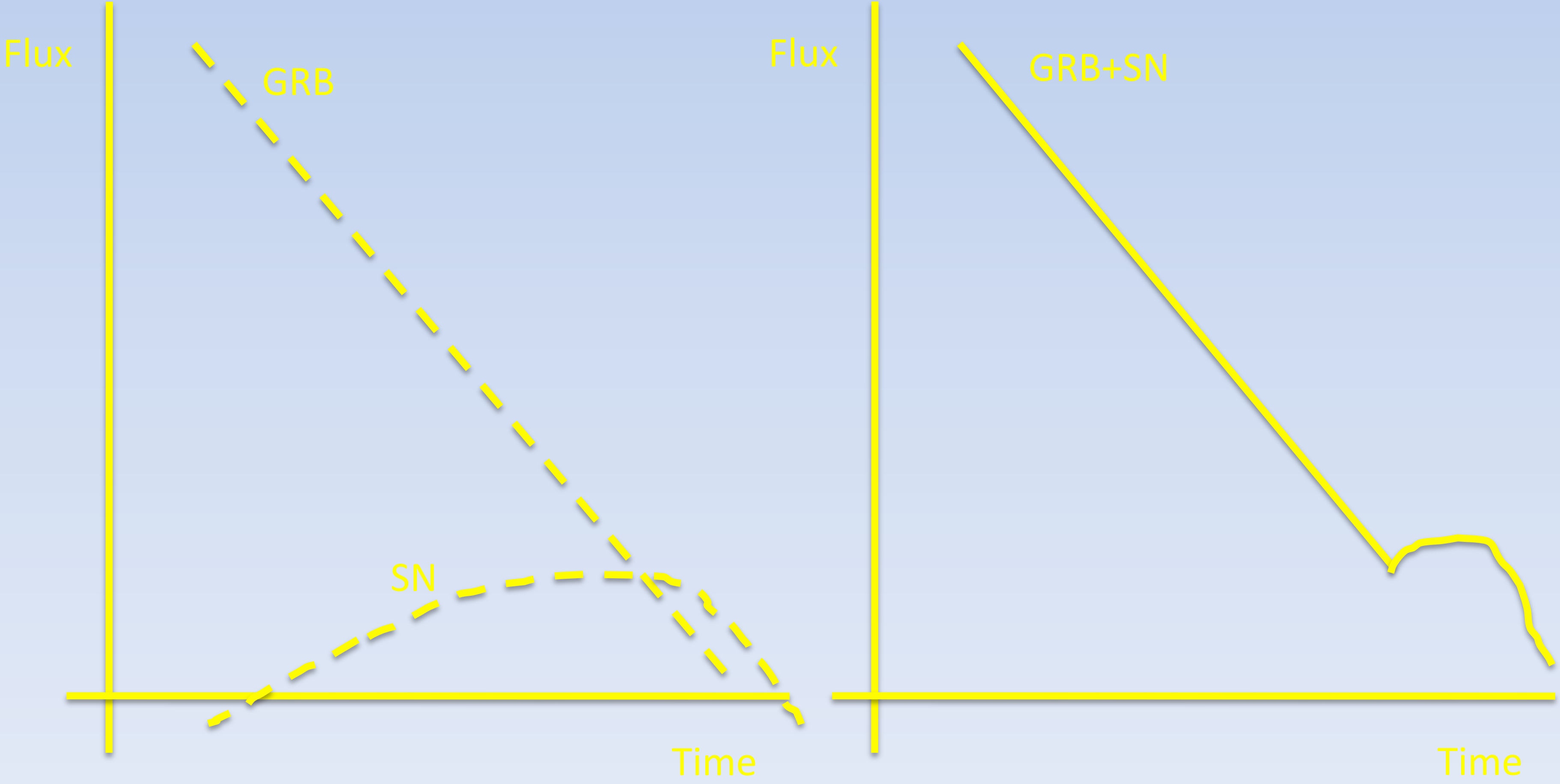


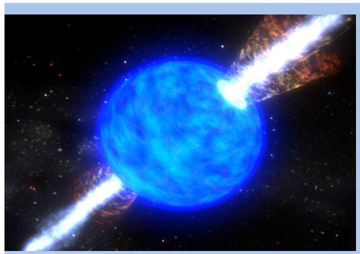
Long GRB & Supernovae



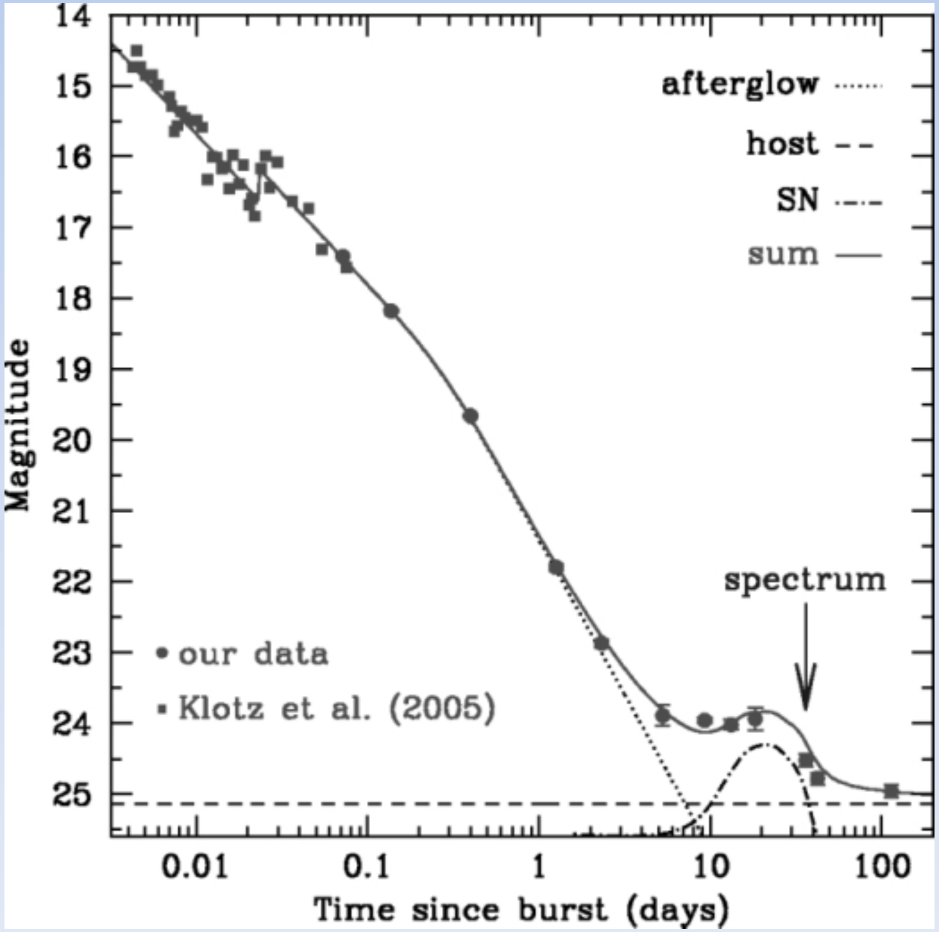


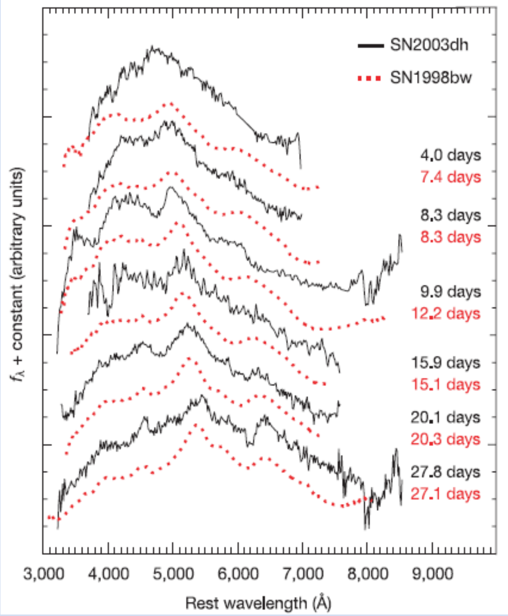
Long GRB & Supernovae

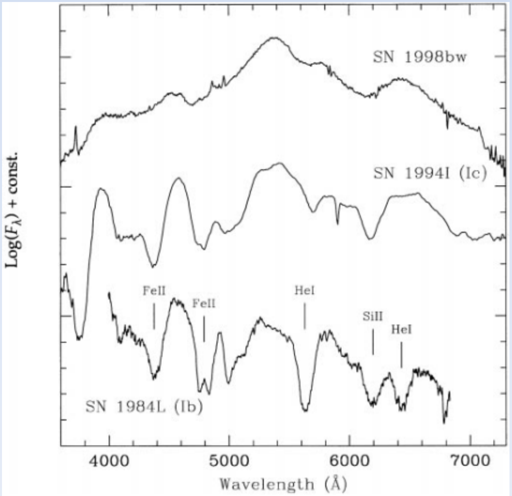




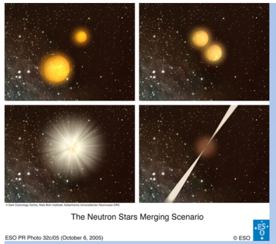
Long GRB & Supernovae





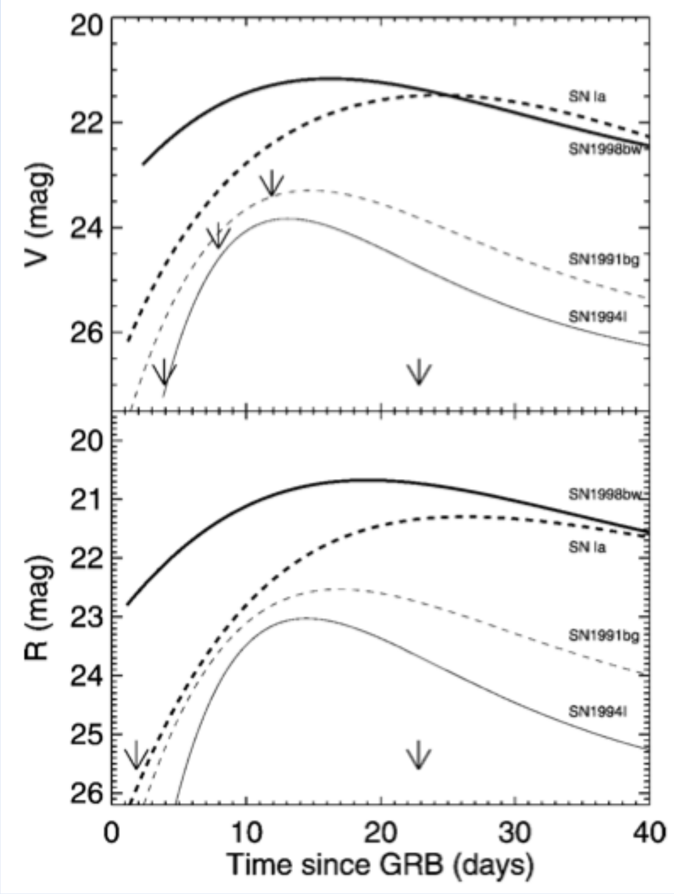


Galama et al. 1998; Stanek et al. 2003; Hjorth et al. 2003; Della Valle et al. 2003; Malesani et al. 2004; Soderberg et al. 2005; Pian et al. 2006; Campana et al. 2006; Della Valle et al. 2006, Bufano et al. 2012, Melandri et al. 2012, Schulze et al. 2014, Melnadri et al. 2014 and others…



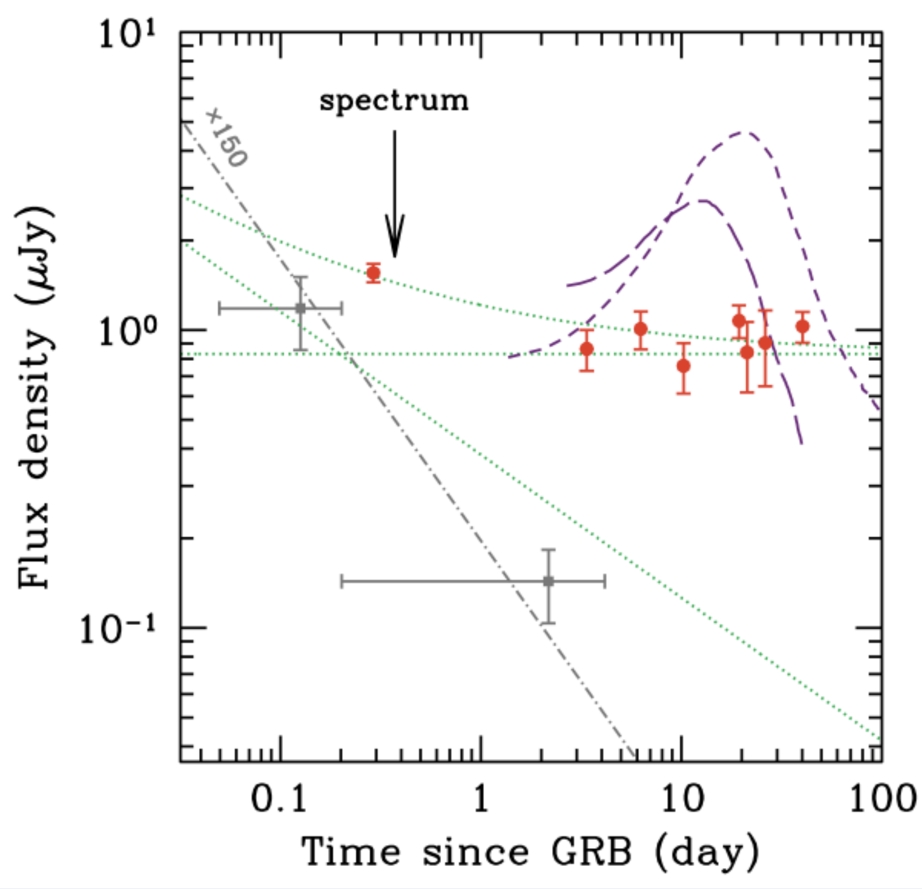
Short GRB & NO Supernovae

GRB 050509B



Hjorth et al. 2005

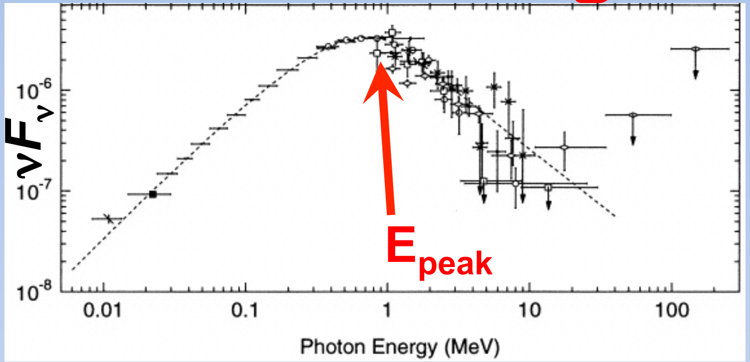
GRB 071227



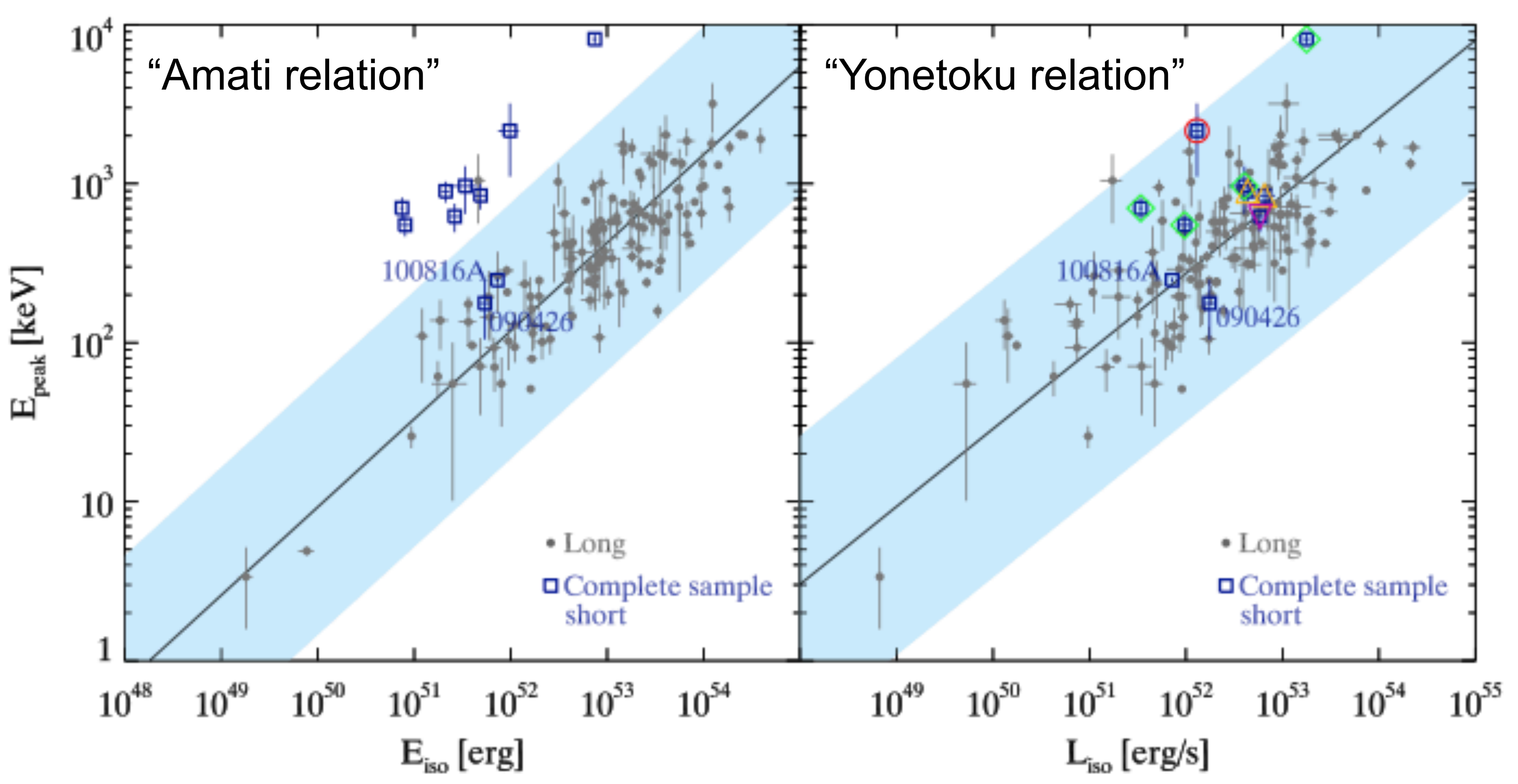
D'Avanzo et al. 2009

See also: Covino et al. 2006; Della Valle et al. 2006; Fynbo et al. 2006

Short vs. long GRBs: the prompt emission

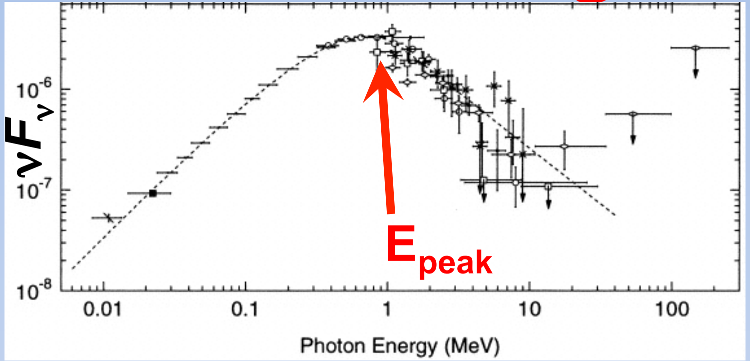


GRB spectra can be described by a smoothly broken power law, characterized by a peak energy

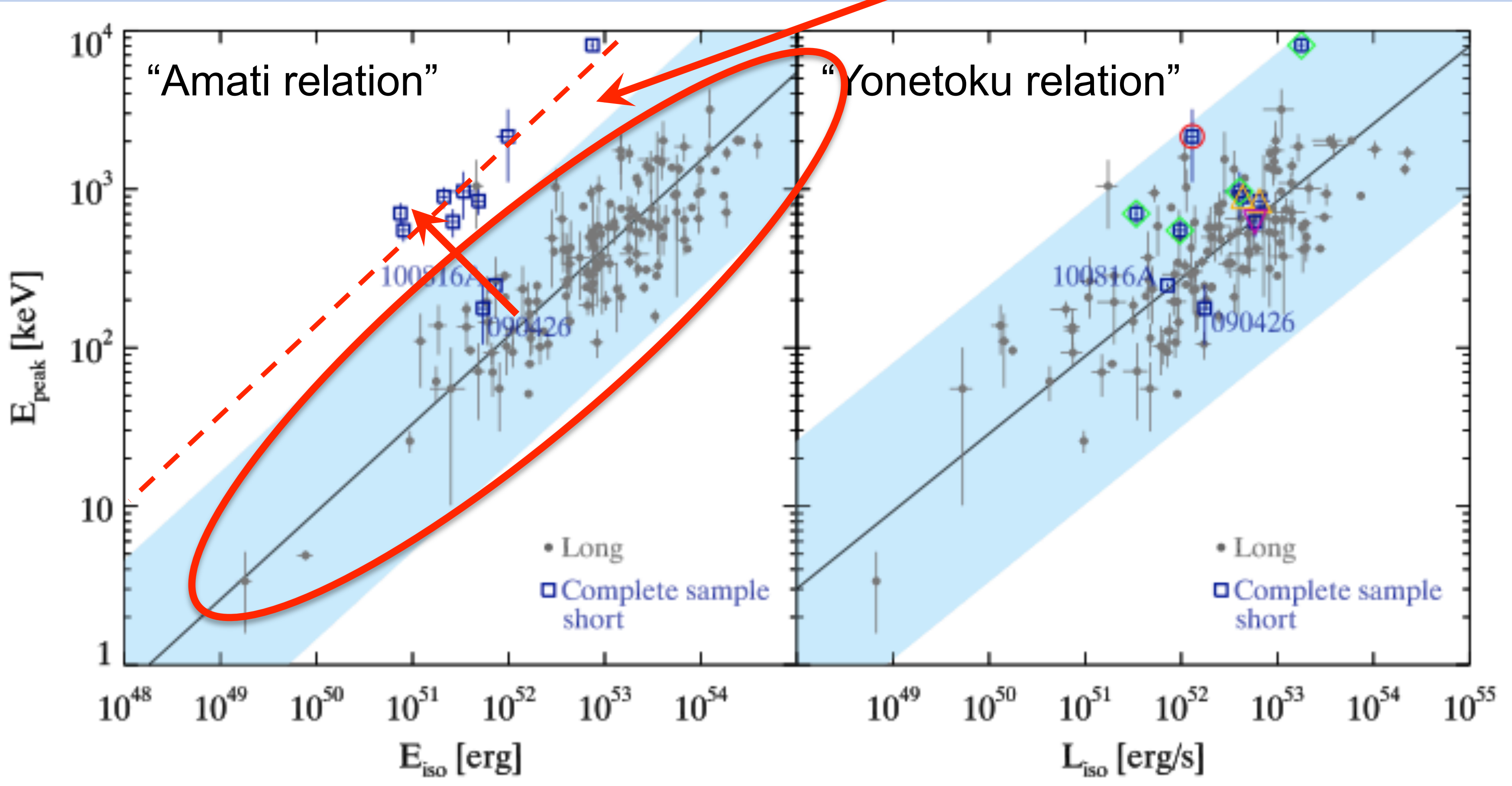


Amati et al. 2002; Younetoku et al. 2004; Ghirlanda et al. 2009, Zhang et al. 2012, D'Avanzo et al. in 2014

Short vs. long GRBs: the prompt emission



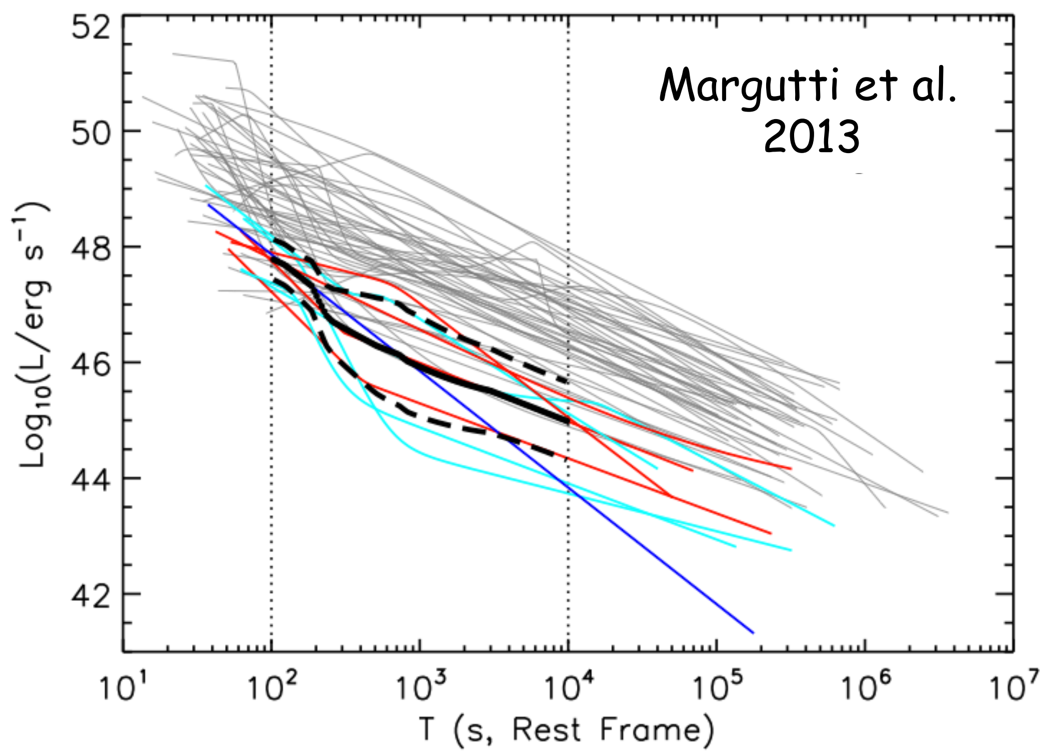
By considering the first 0.3 s only LGRBs are indistinguishable from SGRBs on the Ep-Eiso plane (Calderone et al. 2014)



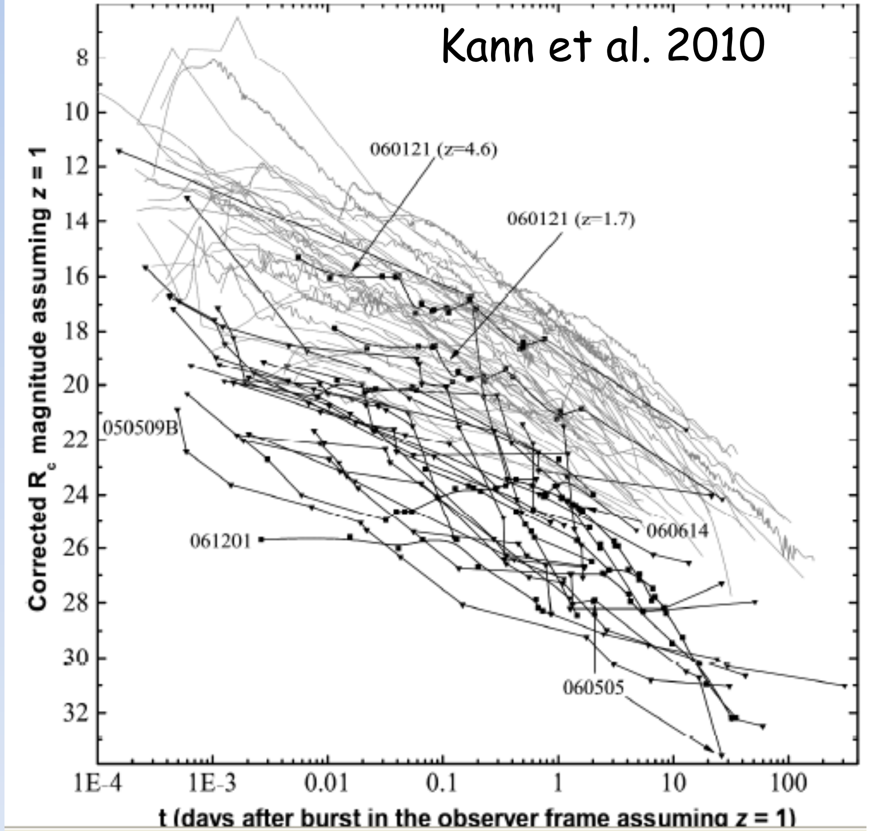
Amati et al. 2002; Younetoku et al. 2004; Ghirlanda et al. 2009, Zhang et al. 2012, D'Avanzo et al. in 2014

Short vs. long GRBs: the afterglow emission

X-ray



optical

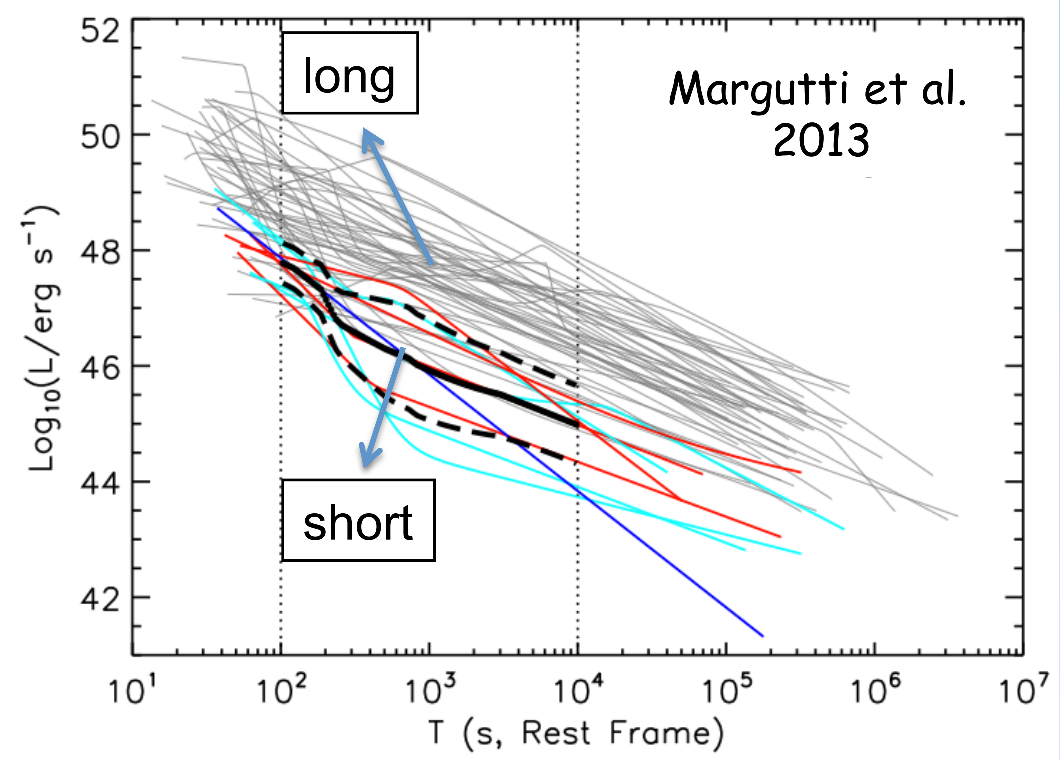


Short GRBs afterglows are fainter:

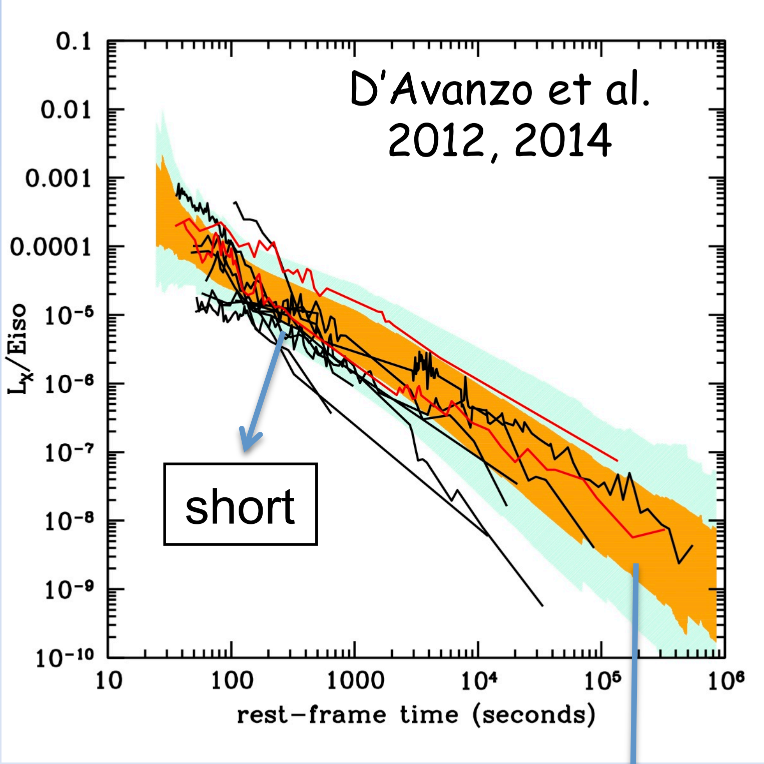
- less dense environment?
- less energetic?

Short vs. long GRBs: the afterglow emission

Rest frame X-ray luminosity



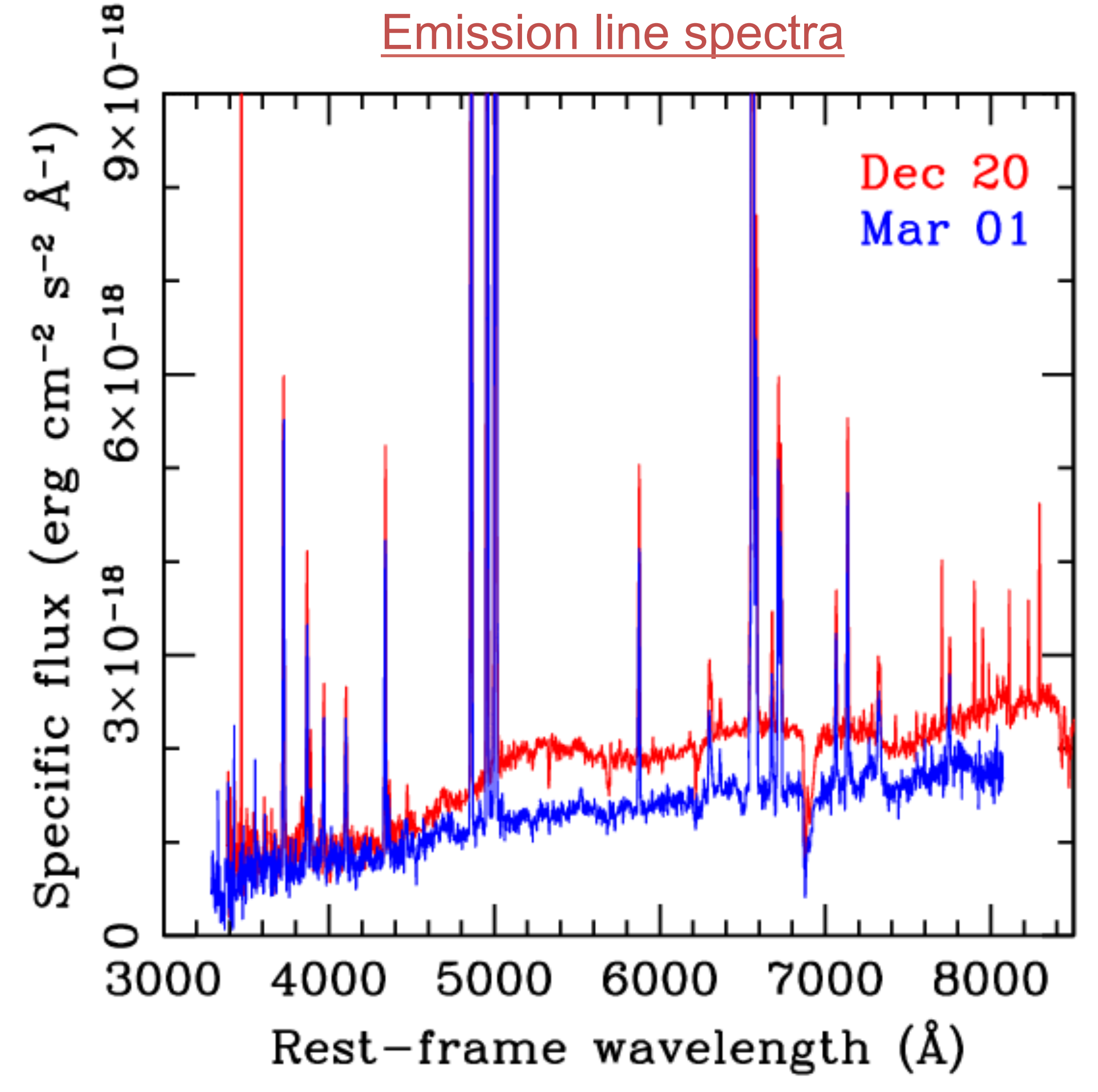
Rest frame X-ray luminosity normalized to Eiso

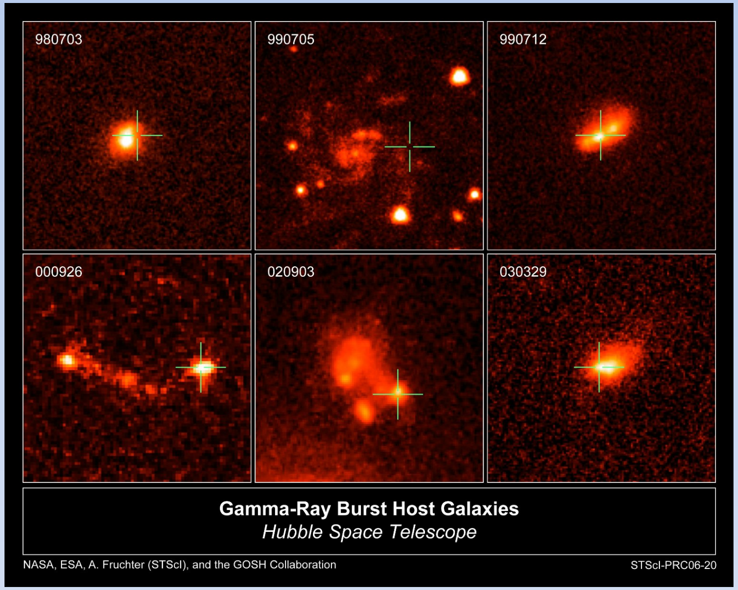


The afterglow X-ray luminosity is a good proxy of Eiso for both long and short GRBs

1sigma scatter for long GRBs

Long GRB hosts





Nebular emission lines excited by hot, young stars

Blue

⇔

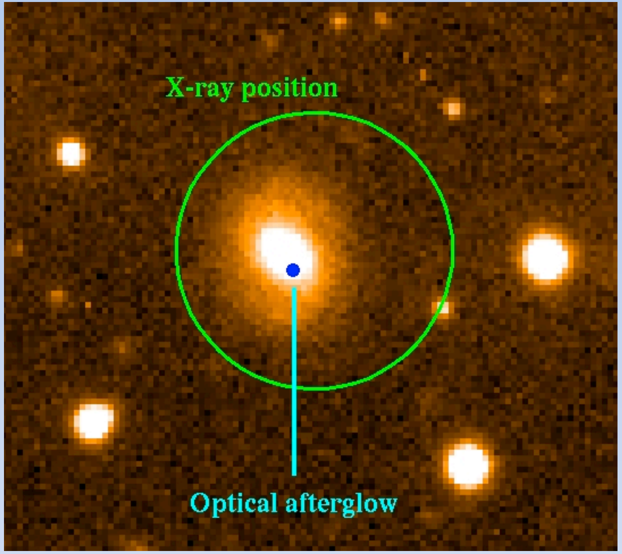
Hot

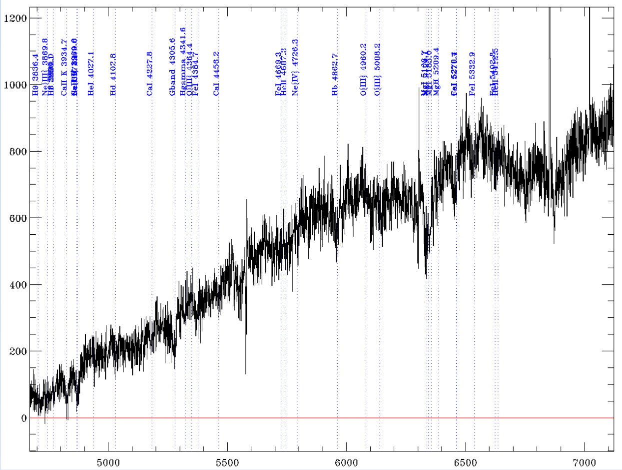
⇔

Young stars

Short GRB hosts

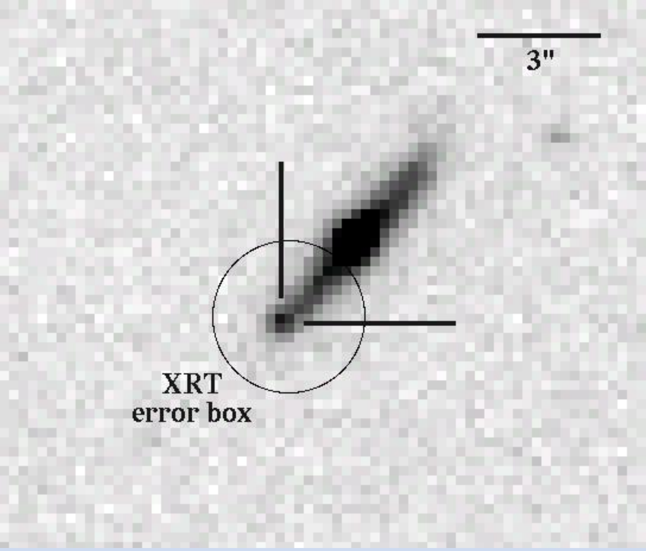
Early-type

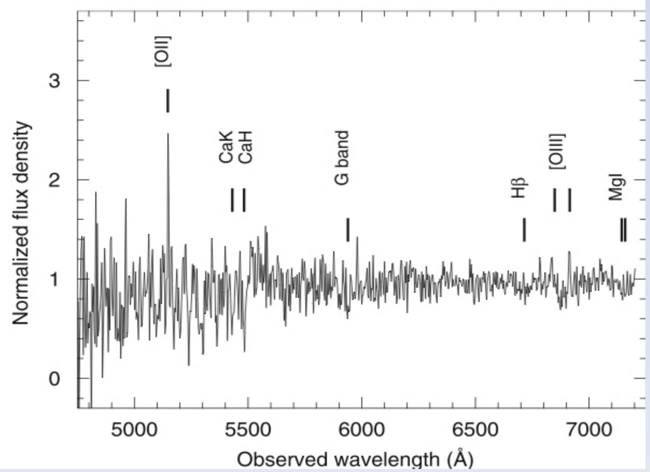




GRB 050724
Barthelmy et al. 2005;
Malesani et al. 2007

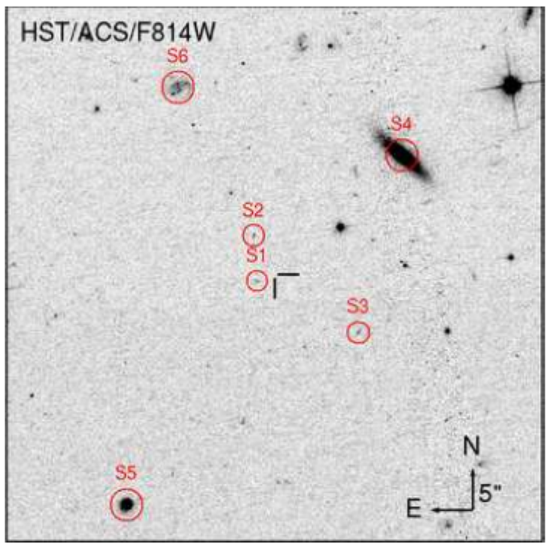
Late-type





GRB 071227
D'Avanzo et al. 2009

Host-less



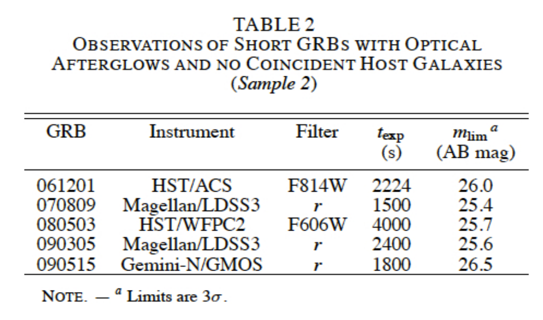


TABLE 2
OBSERVATIONS OF SHORT GRBS WITH OPTICAL AFTERGLOWS AND NO COINCIDENT HOST GALAXIES
(*Sample 2*)

GRB	Instrument	Filter	t_{exp} (s)	m_{lim} [a] (AB mag)
061201	HST/ACS	F814W	2224	26.0
070809	Magellan/LDSS3	*r*	1500	25.4
080503	HST/WFPC2	F606W	4000	25.7
090305	Magellan/LDSS3	*r*	2400	25.6
090515	Gemini-N/GMOS	*r*	1800	26.5

NOTE. — [a] Limits are 3σ.

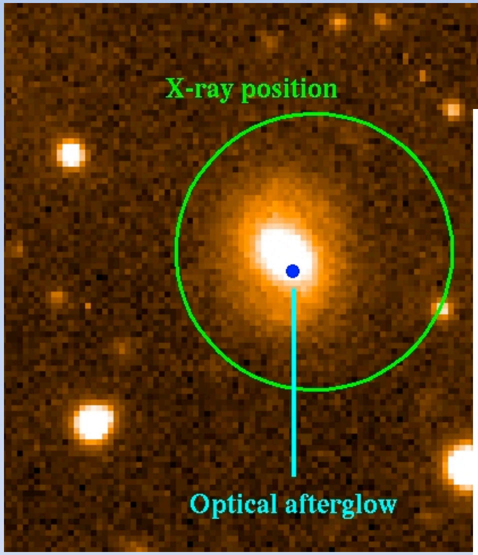
- High-z?
- (very-)low lum HG?
- kicked progenitor?

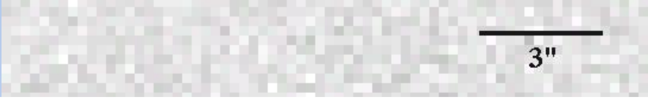
Short GRB hosts

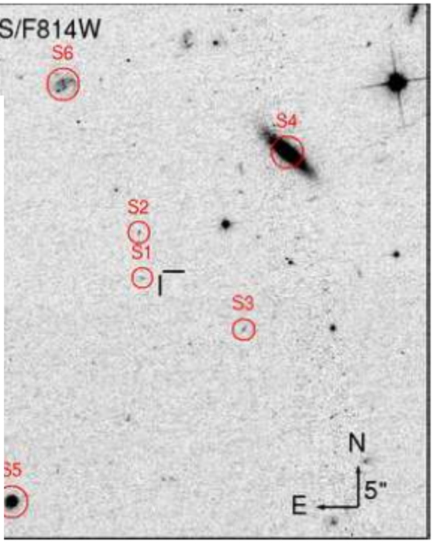
Early-type

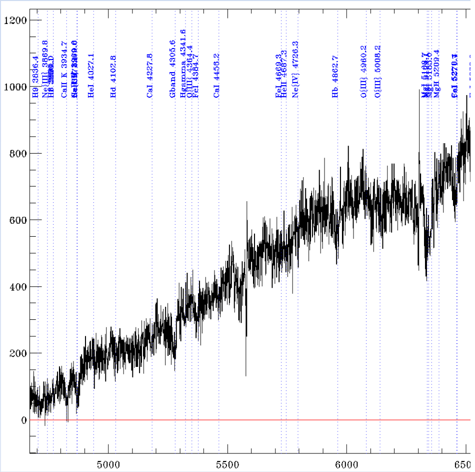
Late-type

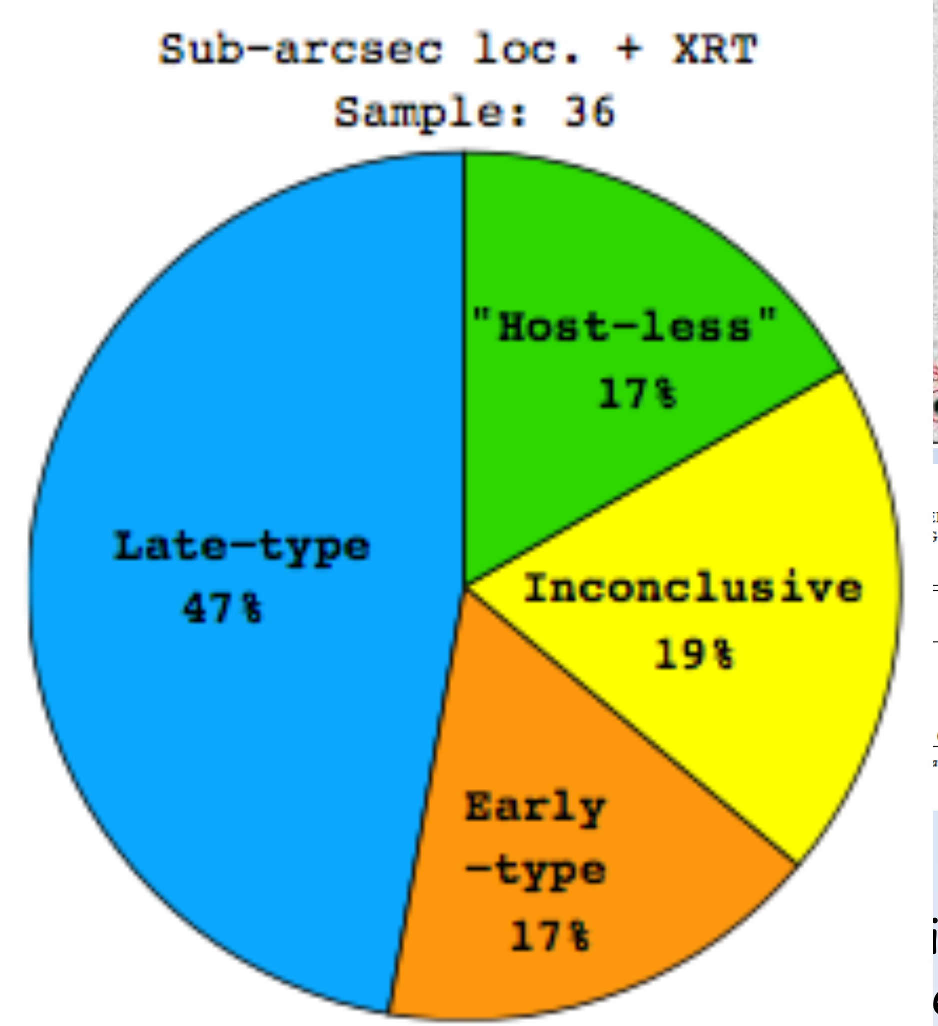
Host-less











Fong et al. 2013; Berger 2014

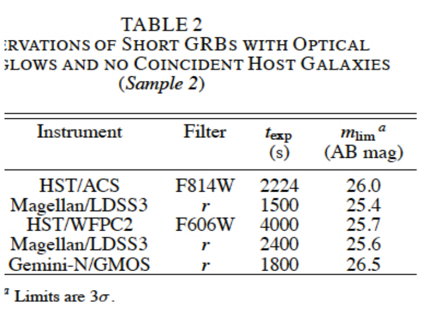


TABLE 2
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LOWS AND NO COINCIDENT HOST GALAXIES
(*Sample 2*)

Instrument	Filter	$t_{\rm exp}$ (s)	$m_{\rm lim}{}^{a}$ (AB mag)
HST/ACS	F814W	2224	26.0
Magellan/LDSS3	r	1500	25.4
HST/WFPC2	F606W	4000	25.7
Magellan/LDSS3	r	2400	25.6
Gemini-N/GMOS	r	1800	26.5

[a] Limits are 3σ.

GRB 050724
Barthelmy et al. 2
Malesani et al. 2007

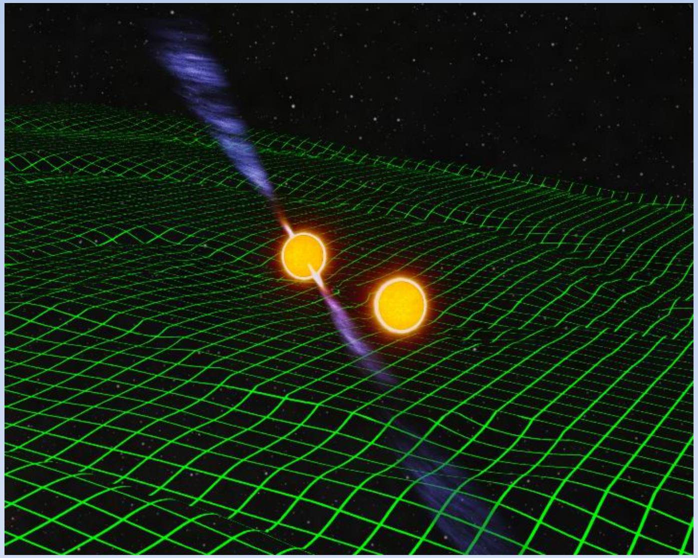
igh-z?
ery-)low lum HG?
cked progenitor?

The progenitors of short GRBs

Most popular model:

Coalescence (merging) of a compact object binary system (NS-NS ; NS-BH)

While orbiting, the two objects emit gravitational waves losing energy: MERGING



NS-NS systems are observed in our Galaxy:

The progenitors of short GRBs

Most popular model:

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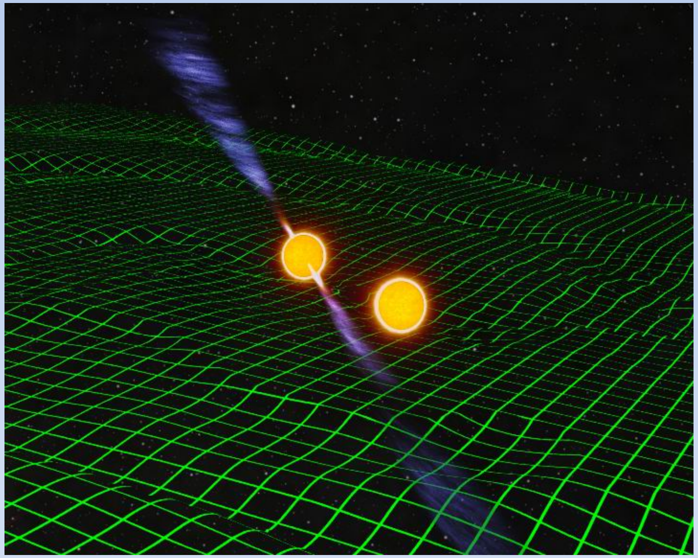


- critical parameter: **merging time** t_m

Time between the formation of the system and its coalescence

$t_m \propto a^4$ (a: system separation) -> ~ 10 Myr $< t_m <$ ~ 10 Gyr

- merging can occur in old and young stellar populations

"primordial binaries"

- **kick velocities**:

Compact objects are the remnants of core-collapse SNe, that can give a "kick"

The system can escape from the HG-> OFFSET! (1÷100 kpc)/low density CBM

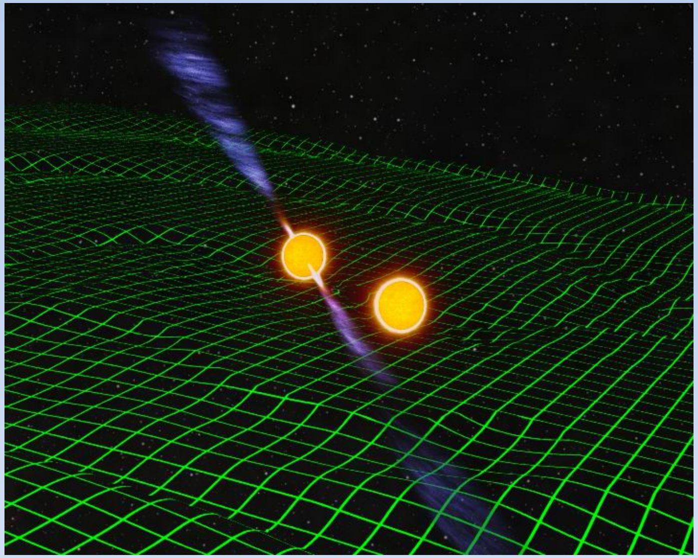
(Belczynski & Kalogera 2001; Perna & Belczynski 2002; Belczynski et al. 2006)

The progenitors of short GRBs

Most popular model:

Coalescence (merging) of a compact object binary system (NS-NS ; NS-BH)

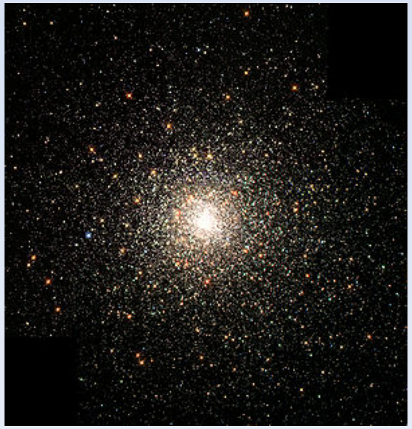
While orbiting, the two objects emit gravitational waves losing energy: MERGING

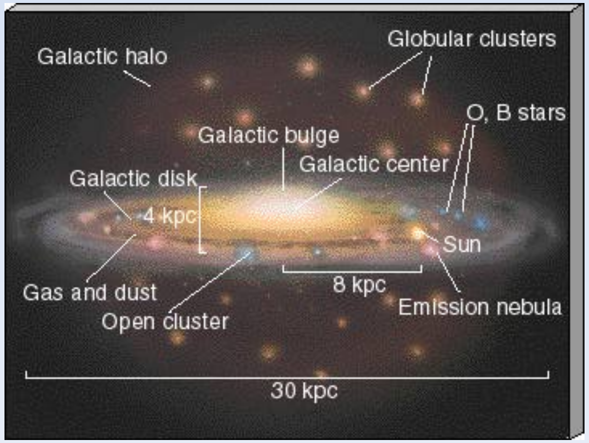


Another possibility: dynamical formation of a double compact object system (e.g. in globular clusters)

(Grindlay et al. 2006; Salvaterra et al. 2008)

"dynamically formed binaries"

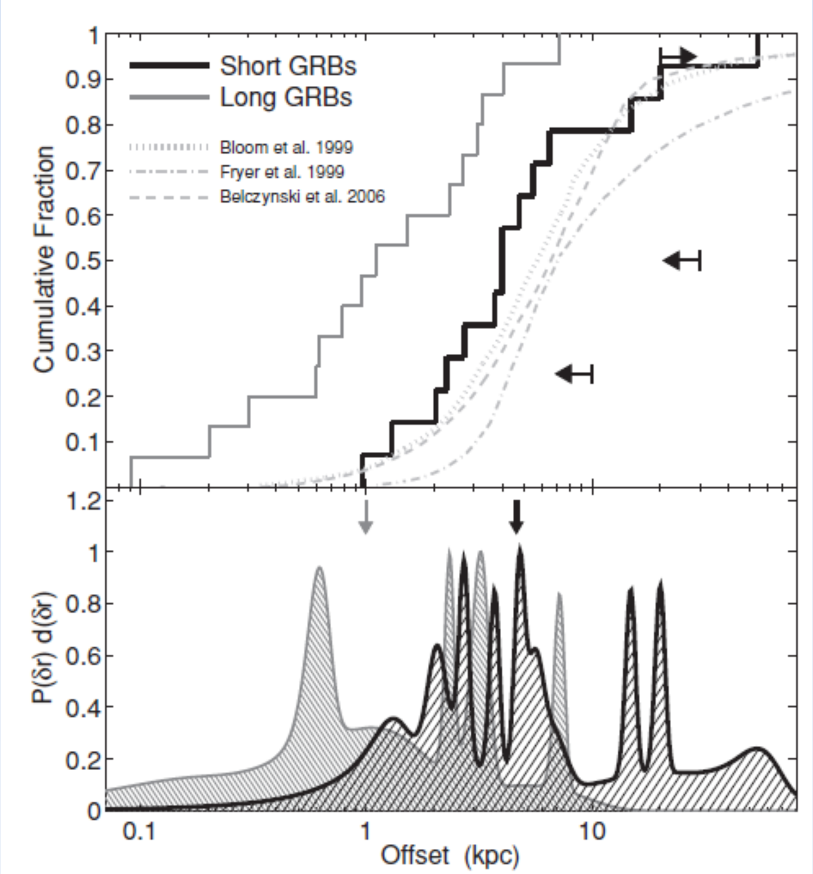




OFFSET/low density CBM

Short GRBs: Offsets

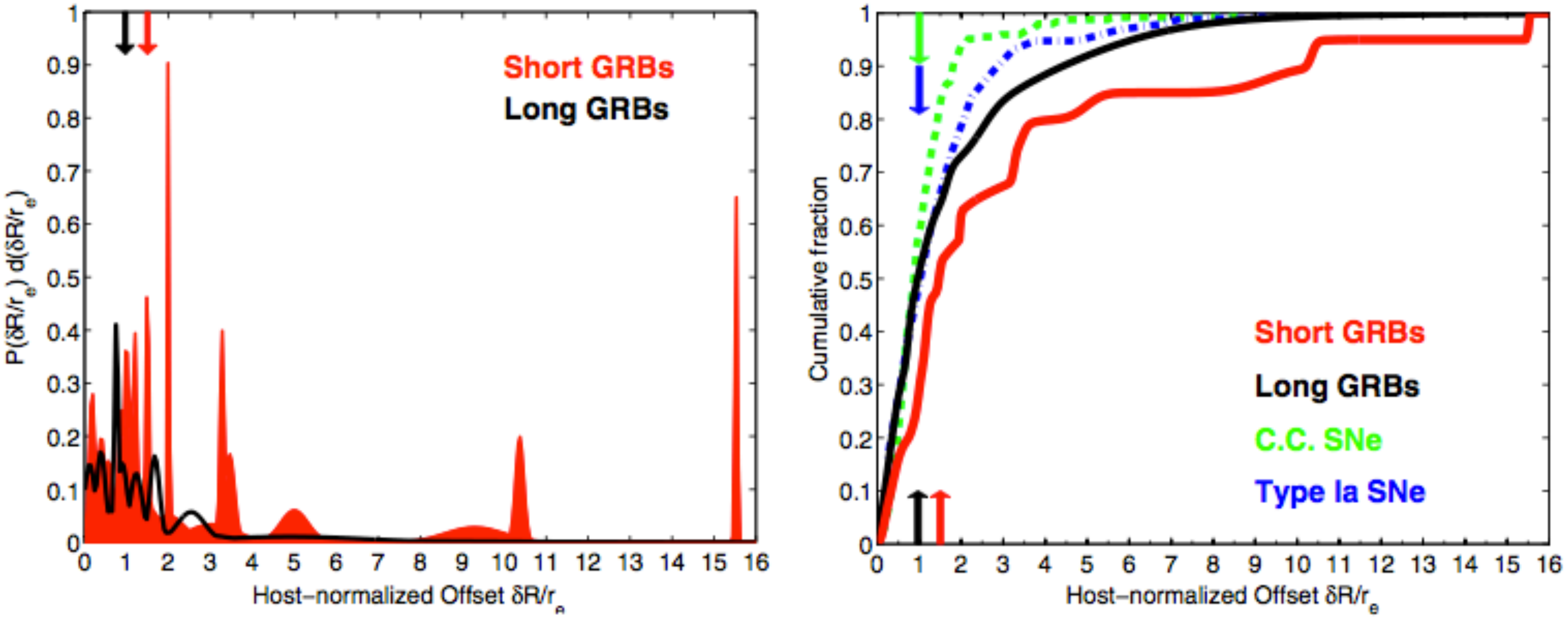
Offset from HG centre



Fong et al. 2010

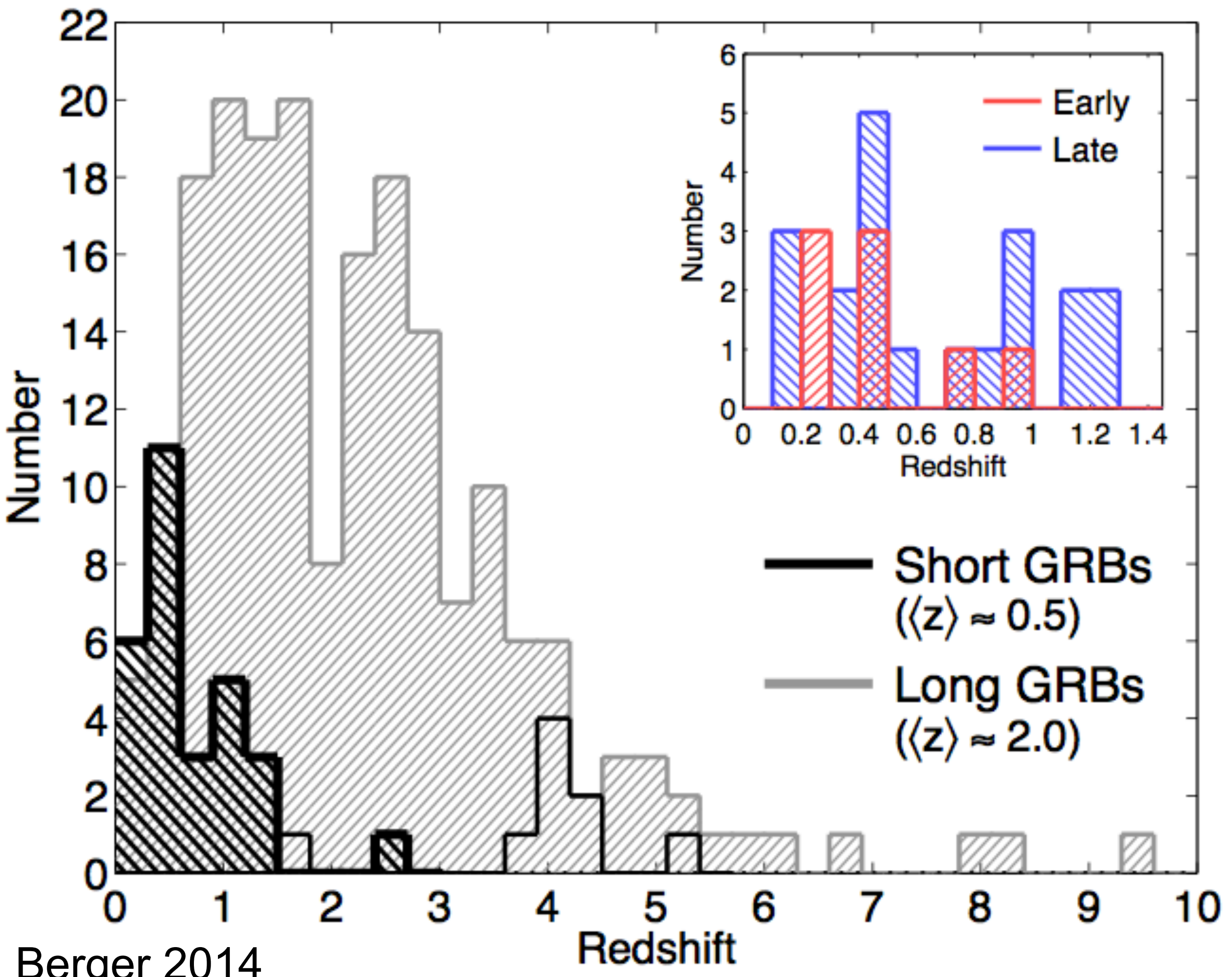
Short GRBs: Offsets

Offset normalized to HG eff. radius



Fong & Berger 2013

Short GRB redshift distribution



Berger 2014

However:
<z> ~ 0.72

If considering *Swift* SGRBs (only) with T_{90} < 2 s

Rowlinson et al. 2013

and:
<z> ~ 0.85

for a complete (flux-limited) sample of bright SGRBs
(D'Avanzo et al. 2014)

Hinting for a "primordial binary" progenitor, expected to have a z distribution peaking at z ≥ 0.8.
(Salvaterra et al. 2008).

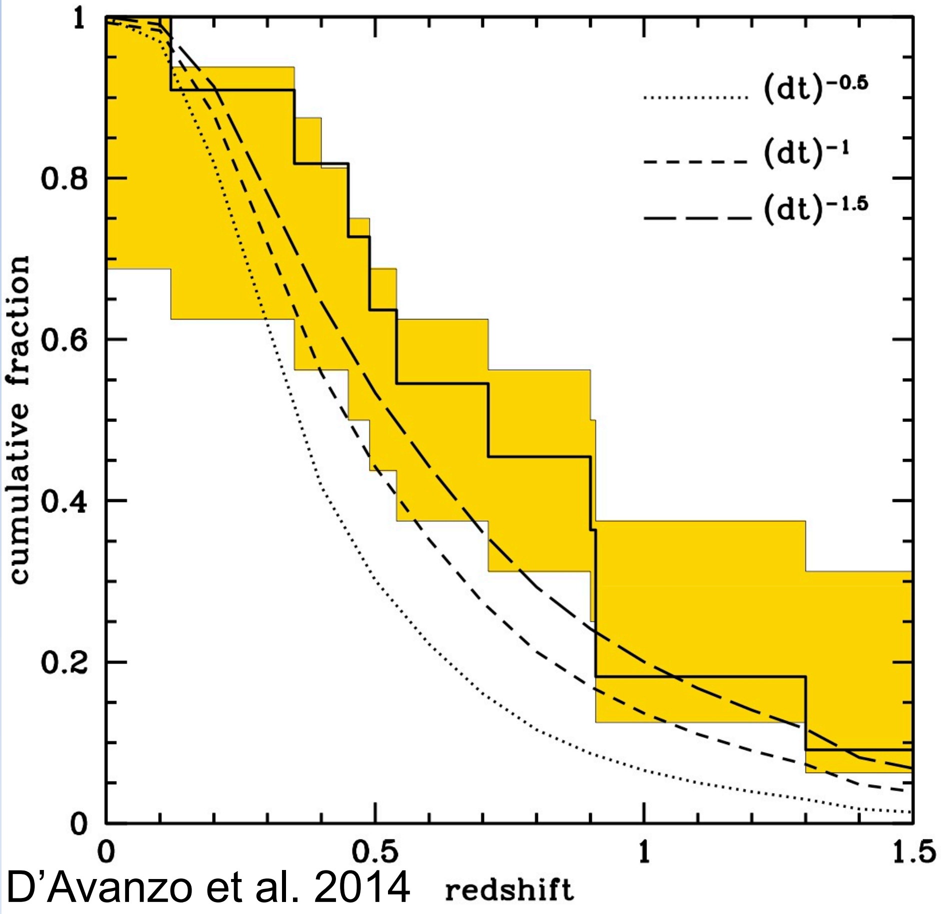
Redshift distribution

Rate of bursts with peak flux $P_1 < P < P_2$

$$\frac{dN}{dt}(P_1 < P < P_2) = \int_0^\infty dz \frac{dV(z)}{dz} \frac{\Delta\Omega_s}{4\pi} \frac{k_{\rm SGRB}\Psi_{\rm SGRB}(z)}{1+z} \times \int_{L(P_1,z)}^{L(P_2,z)} dL'\phi(L'), \qquad (5)$$

Formation rate (# of bursts per unit time and unit comoving volume at redshift z) proportional to massive star binary formation rate and the delay time (interval between binary formation and merging) distribution function:

$$f_{\rm F}(t) \propto t^n$$

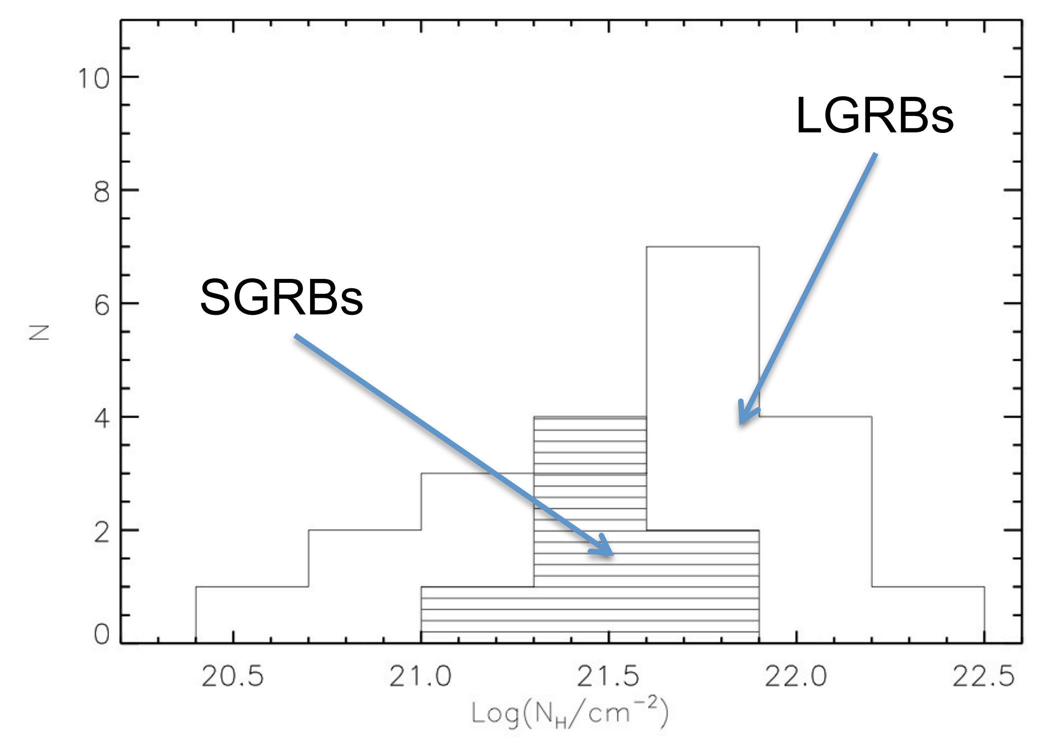


D'Avanzo et al. 2014

We compute the observed distribution of SGRBs for n = -1.5, -1, -0.5, delay times ranging from 20 Myr to ~10 Gyr (Behroozi, Ramirez-Ruiz & Fryer 2014)

Model with n=-1.5 favored in accounting for the observed z distribution of the SGRBs of our sample. Consistent with fast merging primordial binaries progenitors

Intrinsic X-ray absorbing column density of SGRBs



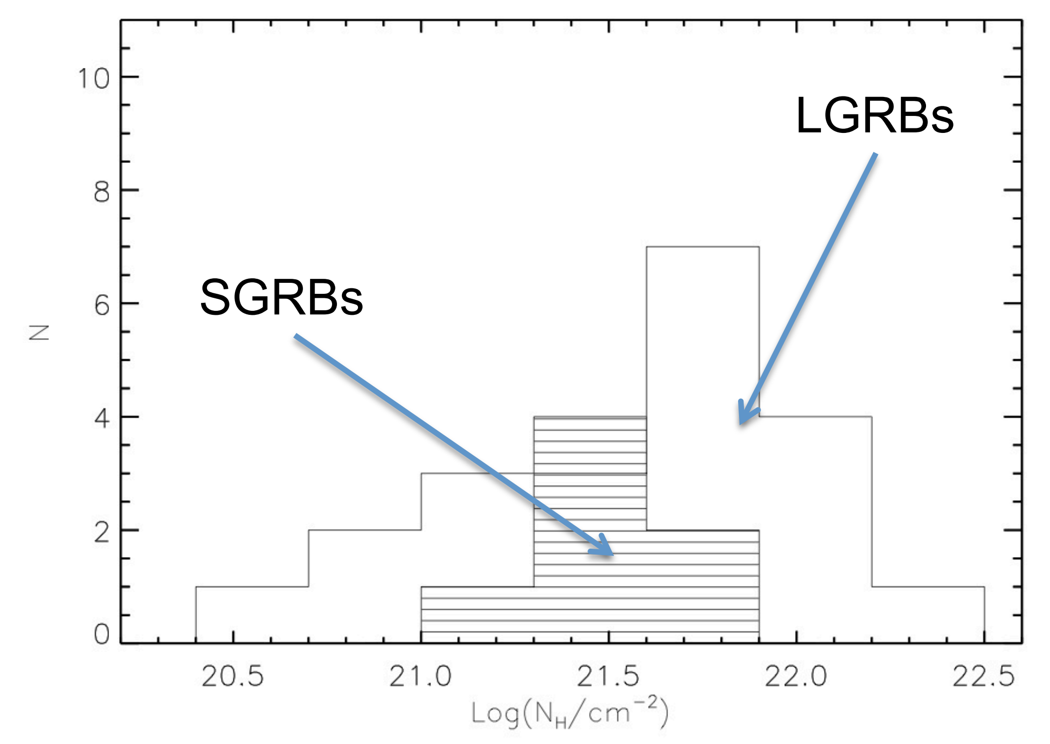
N_H distribution of our complete sample of short GRB ($0.12 < z < 1.30$)

N_H distribution of the BAT6 sample of bright long GRB presented in Campana et al. (2013), reduced to $z < 1.3$

K-S test -> P=34%

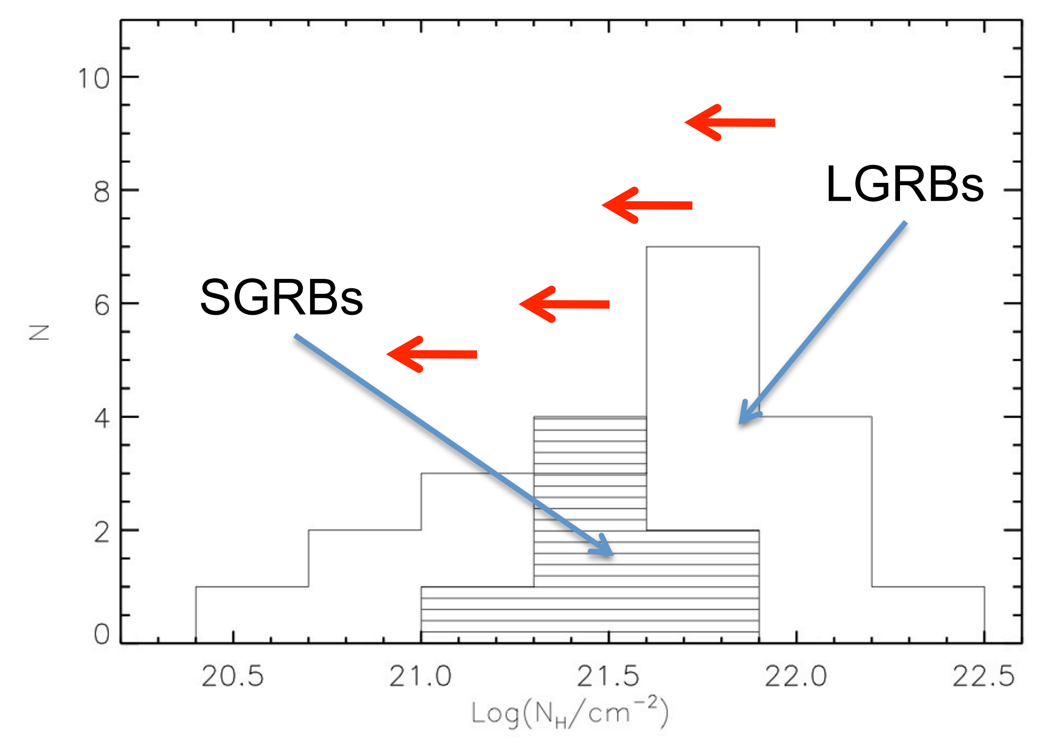
in agreement with Kopac et al. (2012); Margutti et al. (2013)

Intrinsic X-ray absorbing column density of SGRBs



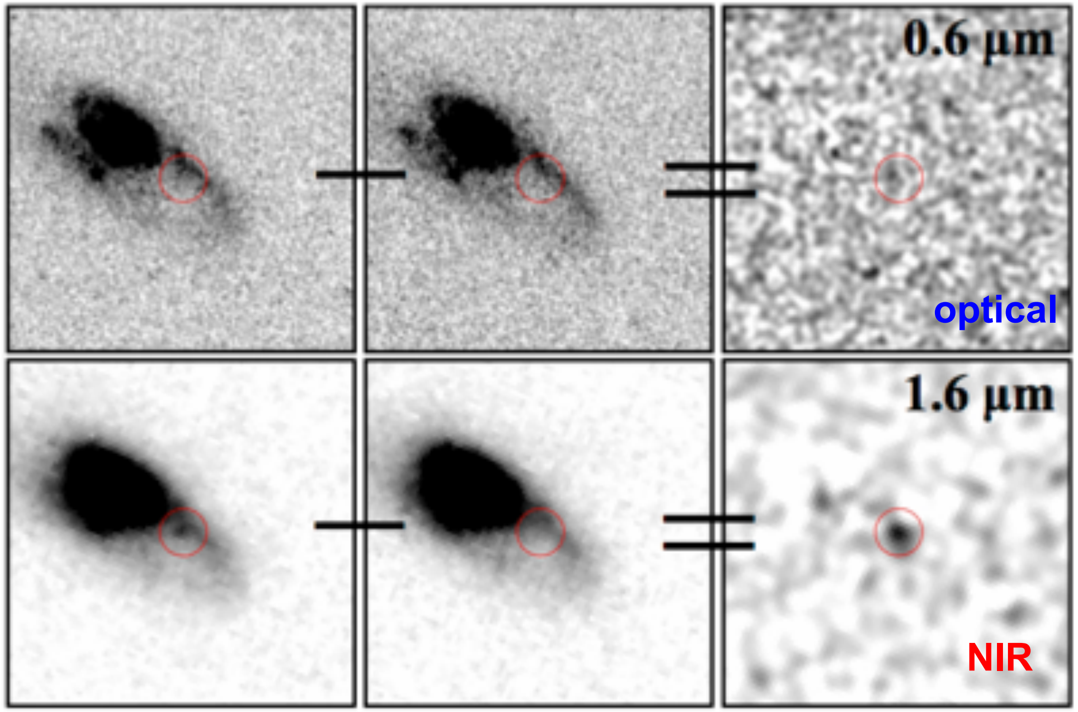
Fast merging "primordial" binaries are expected to merge near their star-forming birthplace (the environment for long and short GRBs may be similar in this case). However, the intrinsic X-ray N_H might be a good proxy of the GRB host galaxy global properties but <u>not</u> for the specific properties of the circum-burst medium.

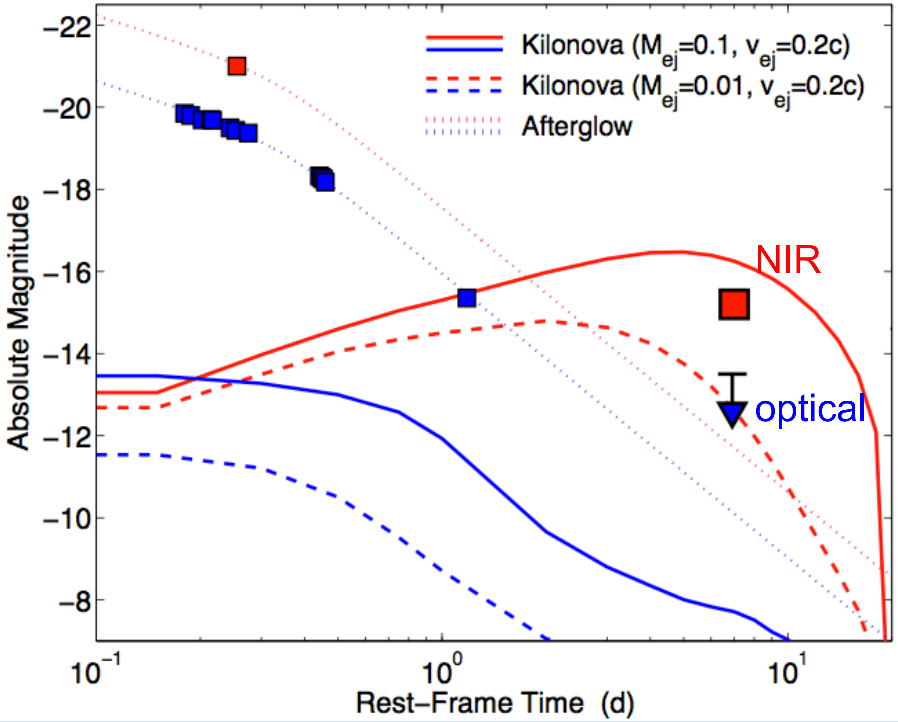
Intrinsic X-ray absorbing column density of SGRBs



25% of the events of the sample have either a deep upper limit on the intrinsic N_H or are "hostless" SGRBs. This can hint for bursts occurred in low-density environments, originated by progenitors kicked out from their HG (e.g. primordial binaries with long coalescing times) or sited in outlying globular clusters (e.g. binaries formed via dynamically capture)

A Kilonova associated to GRB 130603B?



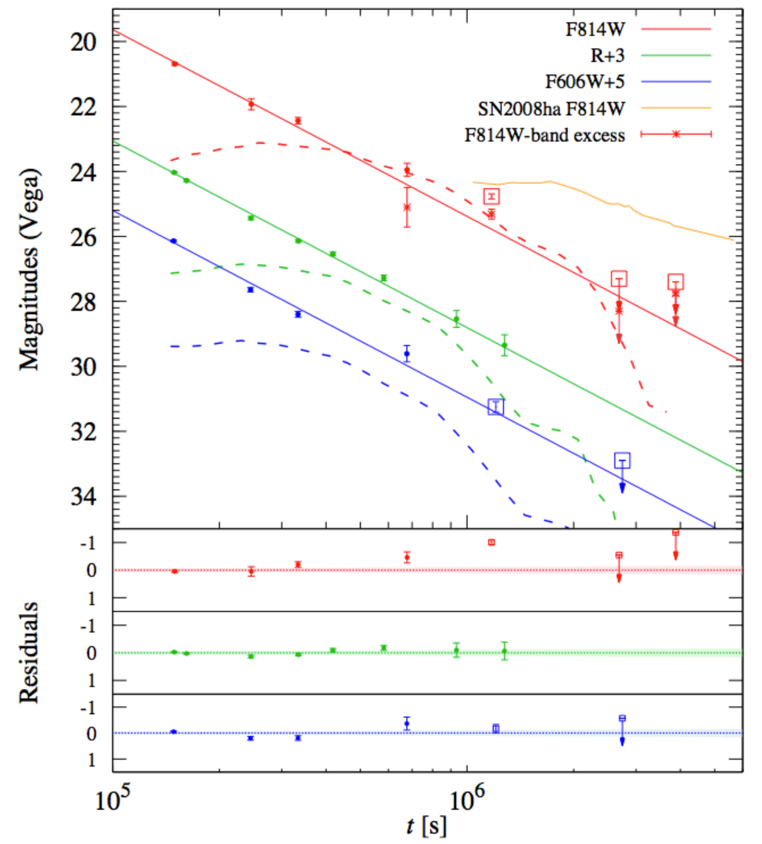


Tanvir et al. 2013; Berger et al. 2013
(but see also Jin et al. 2014)

Photometric evidence ("red excess", HST data) of a possible KN associated to GRB 060614 has been also recently reported by Yang et al. (arXiv:1503.07761)

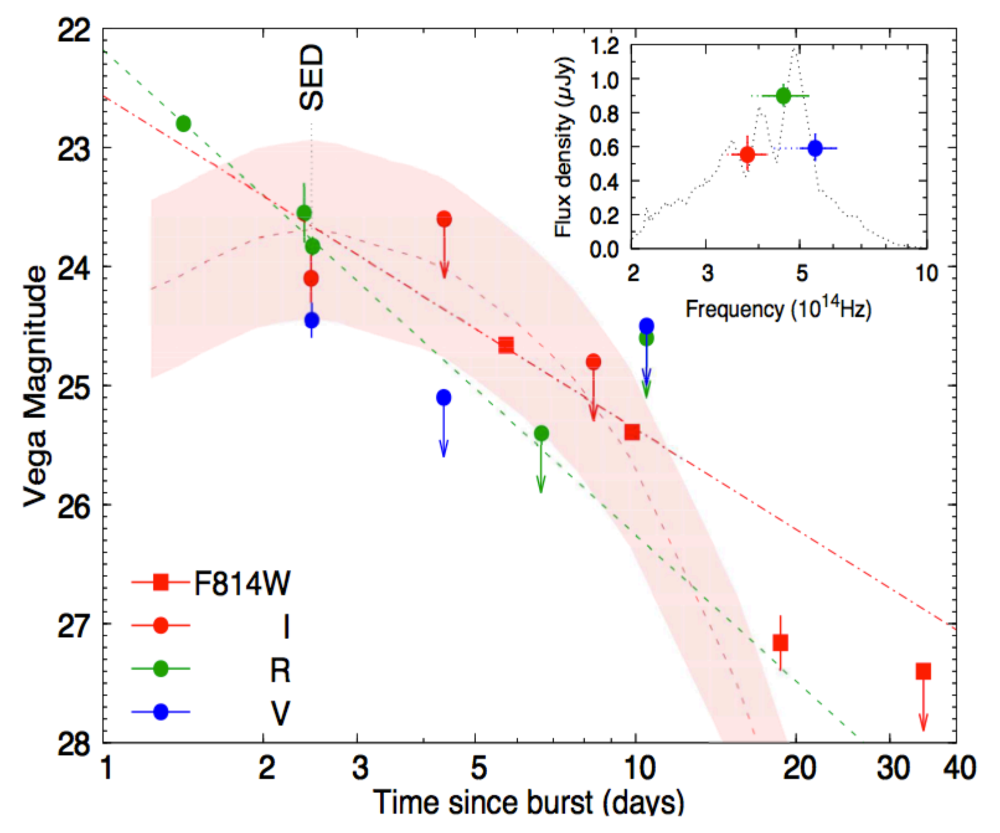
A Kilonova associated to GRB 060614 & GRB 050709?

GRB 060614



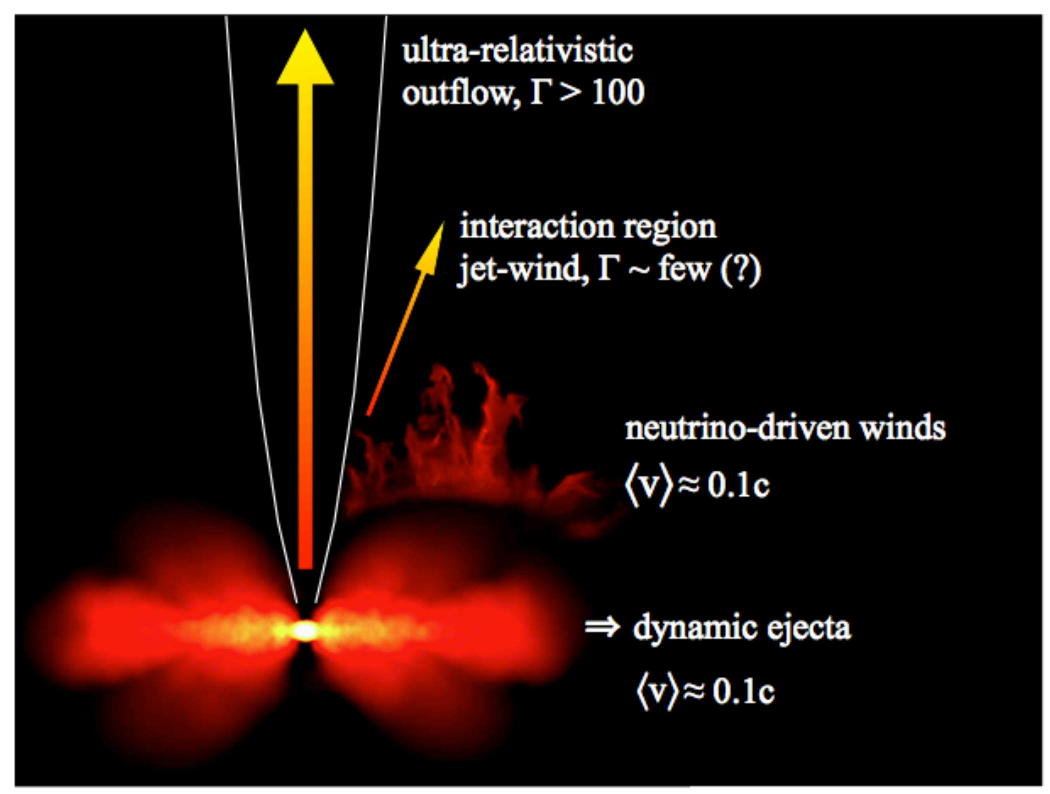
Yang et al. 2015

GRB 050709

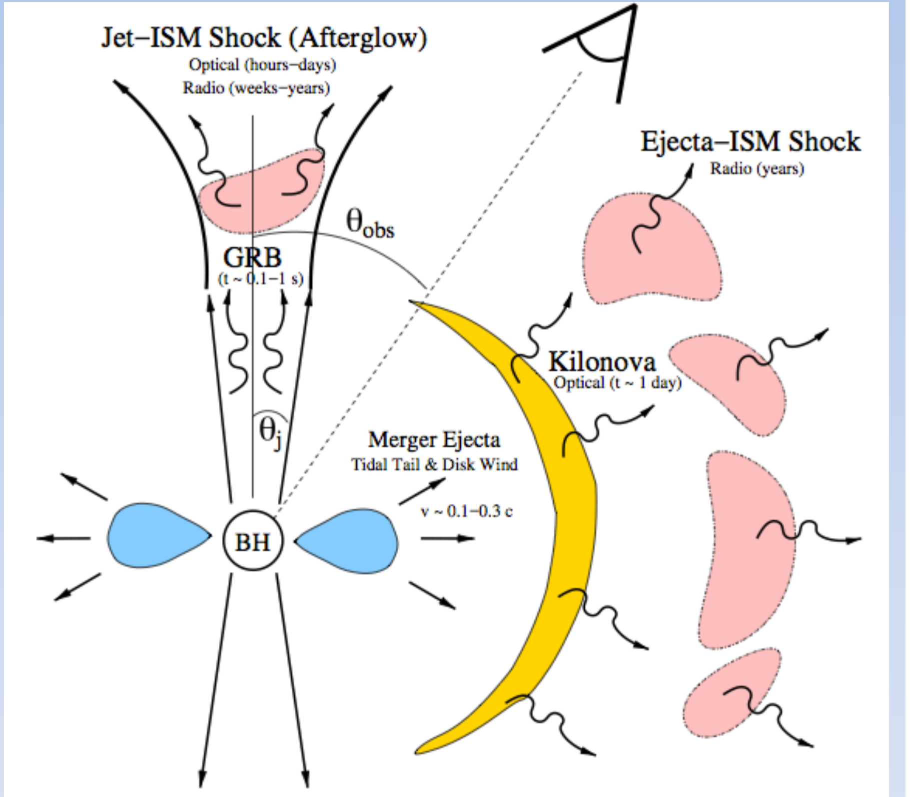


Jin et al., submitted, arXiv: 1603.07869

Jets in SGRBs

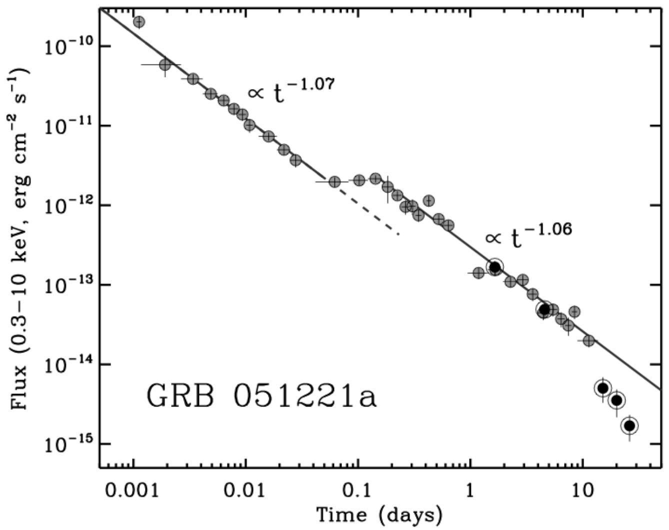


Rosswog 2012

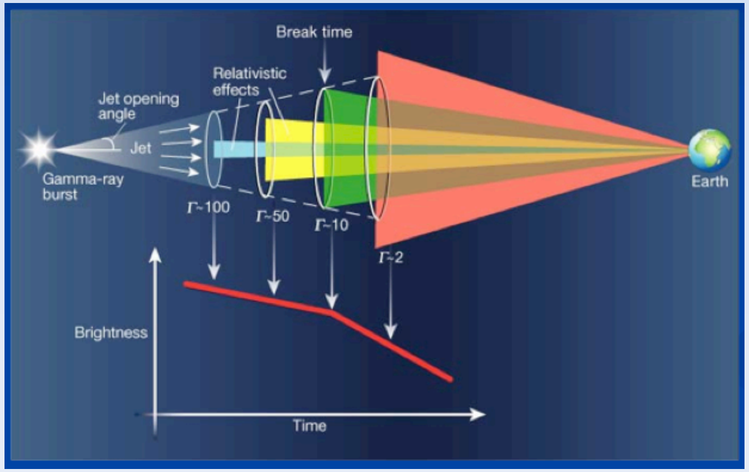


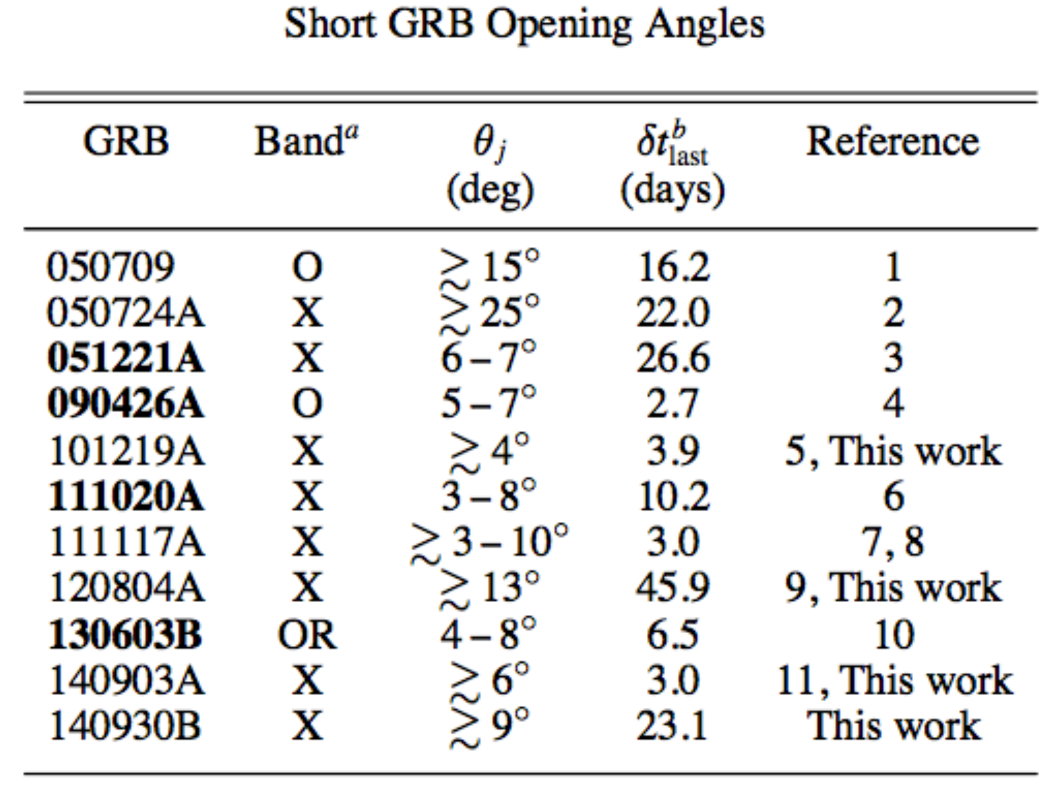
Metzger & Berger 2012

Evidences for jet break in SGRB light curves



Θ_j~ 7 deg
Soderberg et al. (2005)
Burrows et al. (2006)

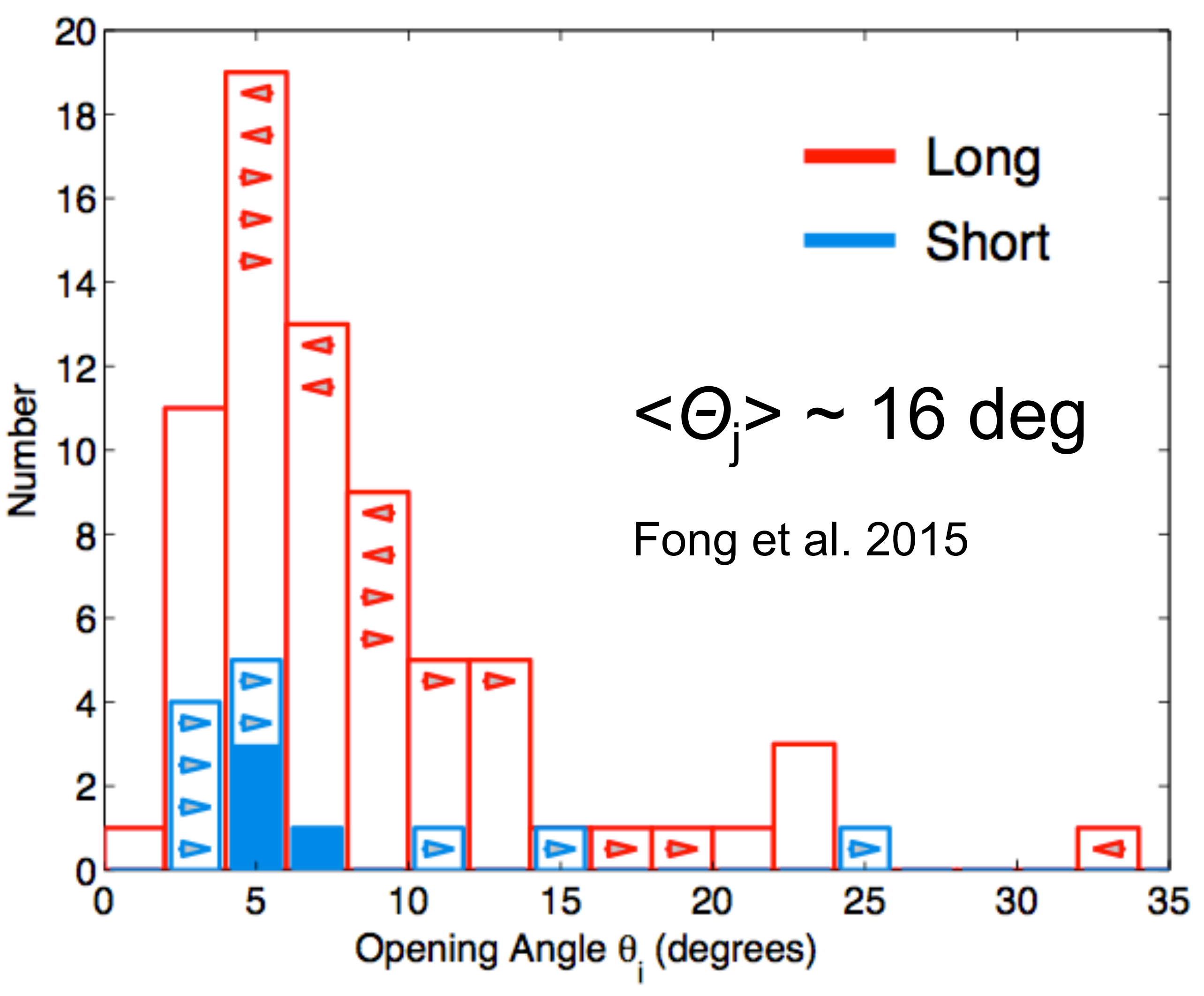



Short GRB Opening Angles

GRB	Band^a	θ_j (deg)	$\delta t^b_{\rm last}$ (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

Fong et al. 2015

The SGRBs rate (and GW EM counterpart search)



$<\Theta_j> \sim 16$ deg

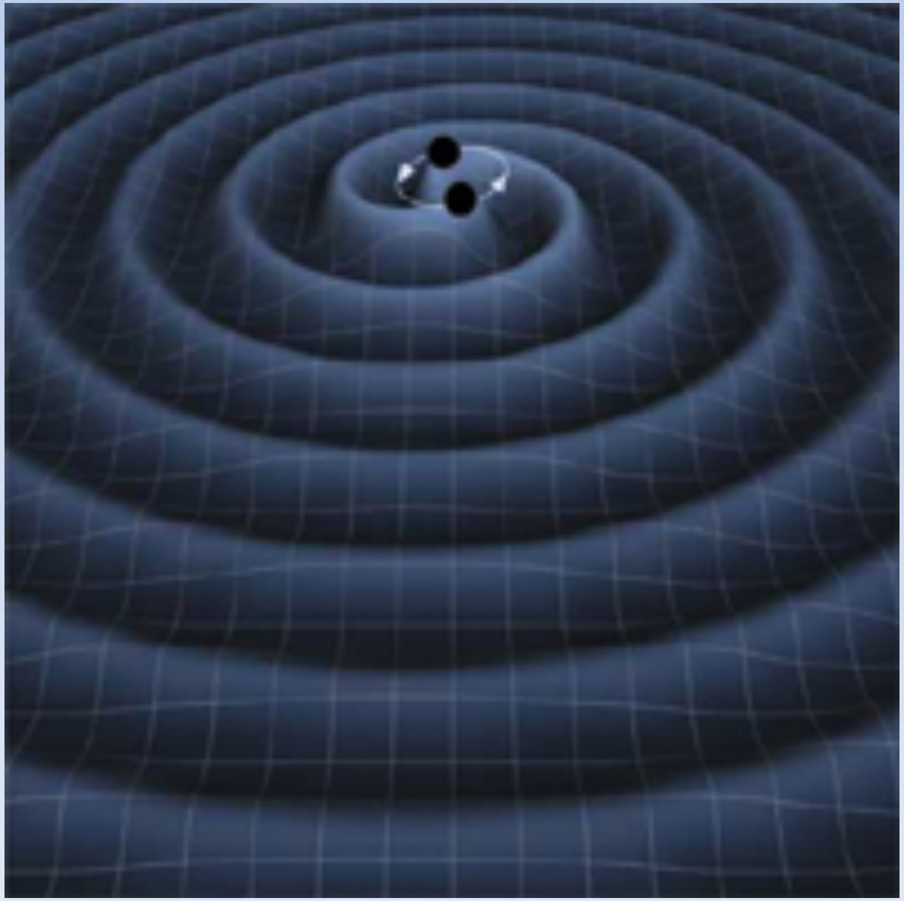
Fong et al. 2015

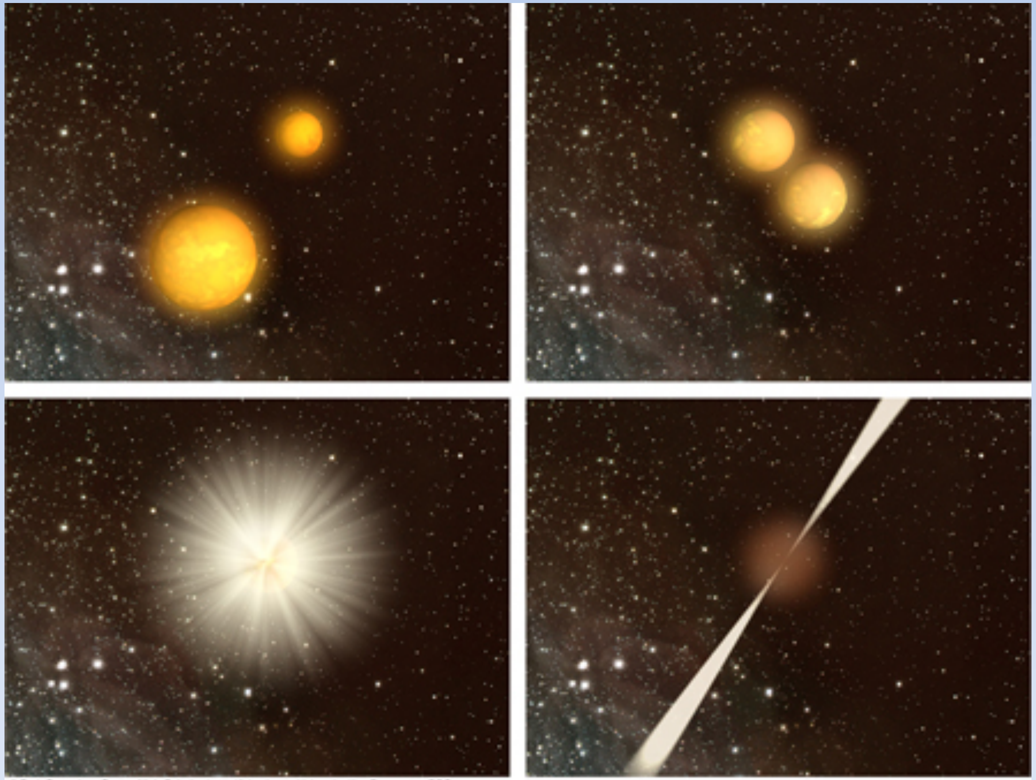
The true SGRB event rate is increased by a factor:

$f_b^{-1} = (1-\cos\Theta_j)^{-1} \sim 30$

The observed (on-axis) all sky rate ~0.3 yr^{-1} within 200 Mpc (Guetta & Stella 2009) becomes ~ 10 yr^{-1} (8^{+45}_{-5} yr^{-1})

Short GRBs as GW sources





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The Neutron Stars Merging Scenario

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

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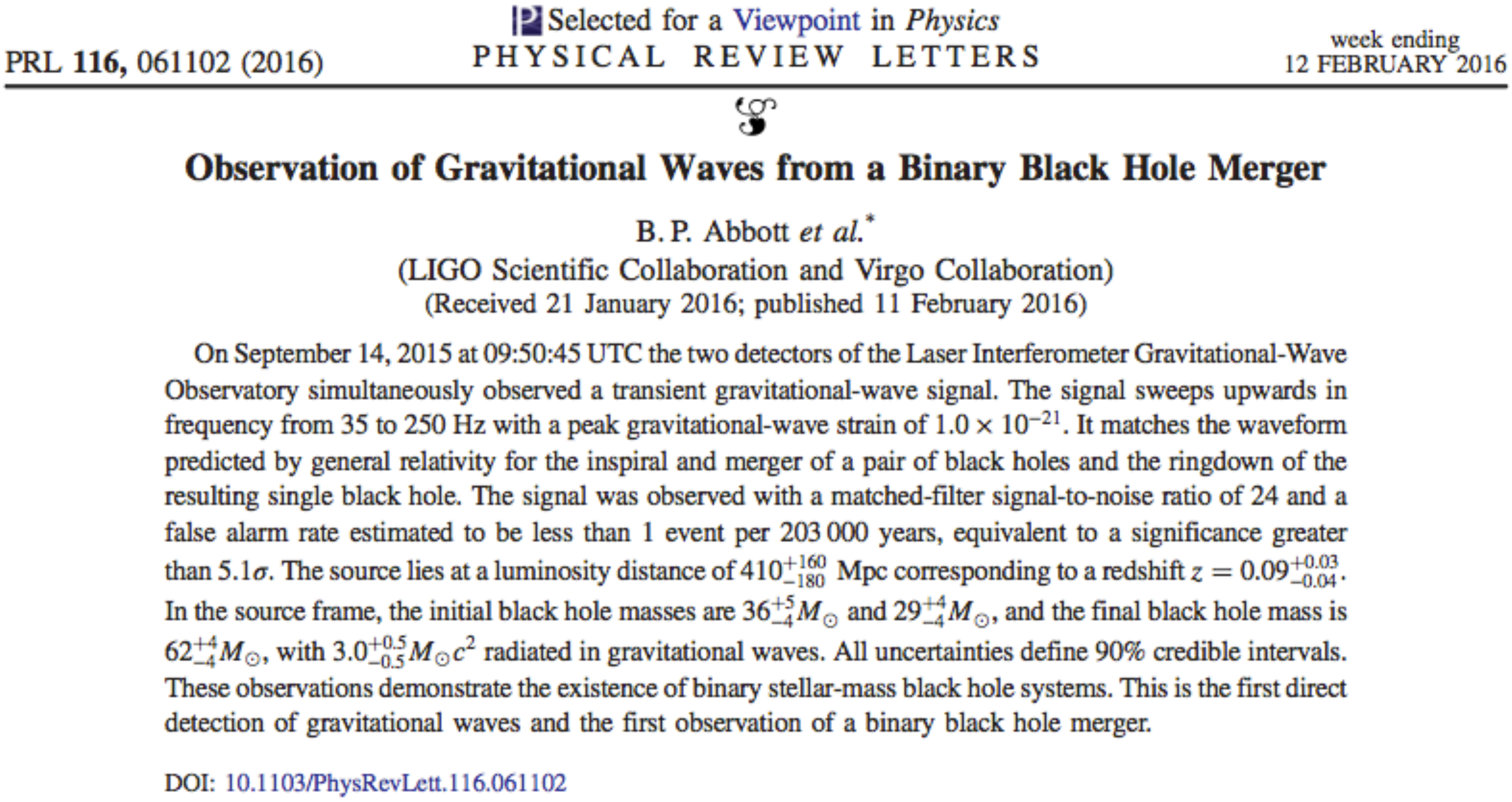
GW 150904



Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

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

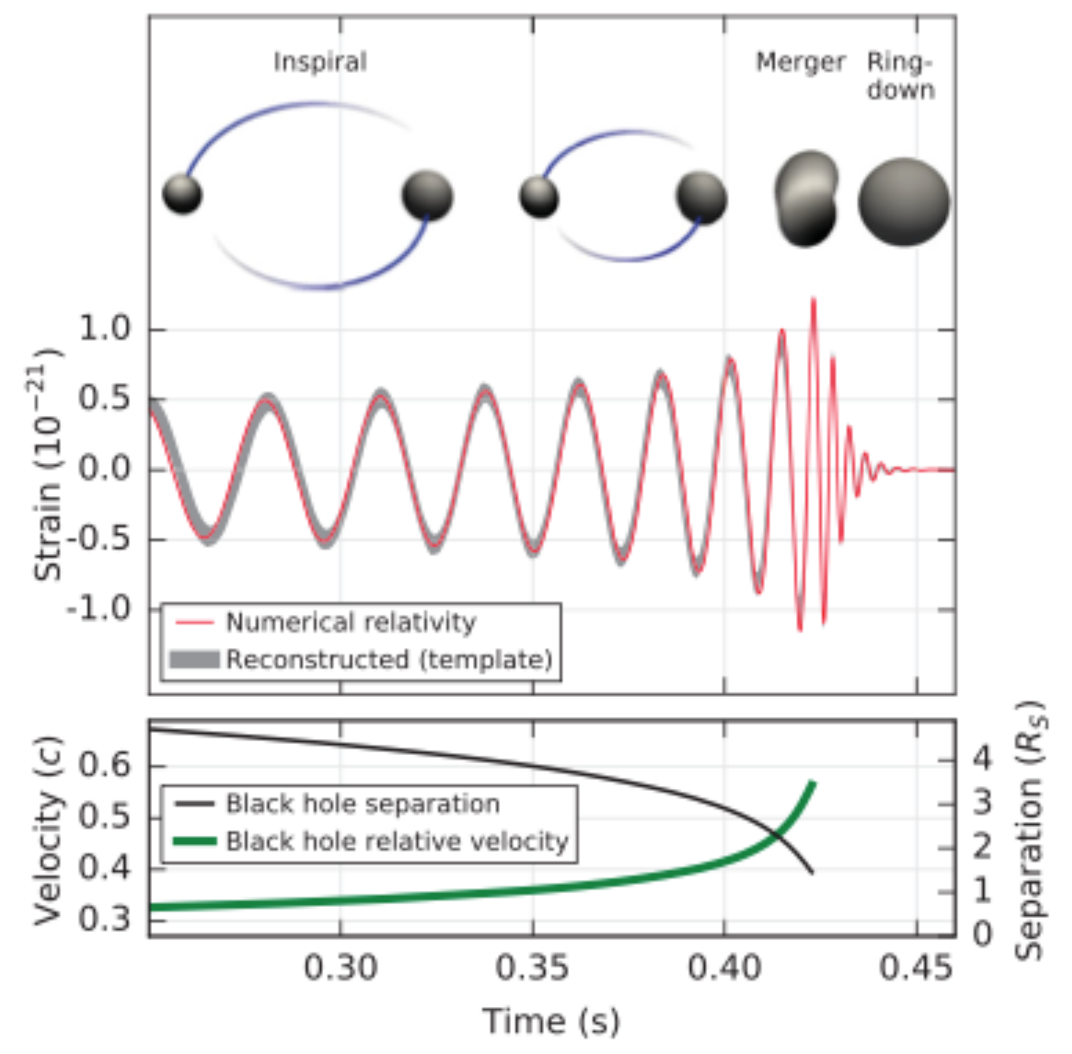
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_{\odot}$ and $29^{+4}_{-4} M_{\odot}$, and the final black hole mass is $62^{+4}_{-4} M_{\odot}$, with $3.0^{+0.5}_{-0.5} M_{\odot} c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

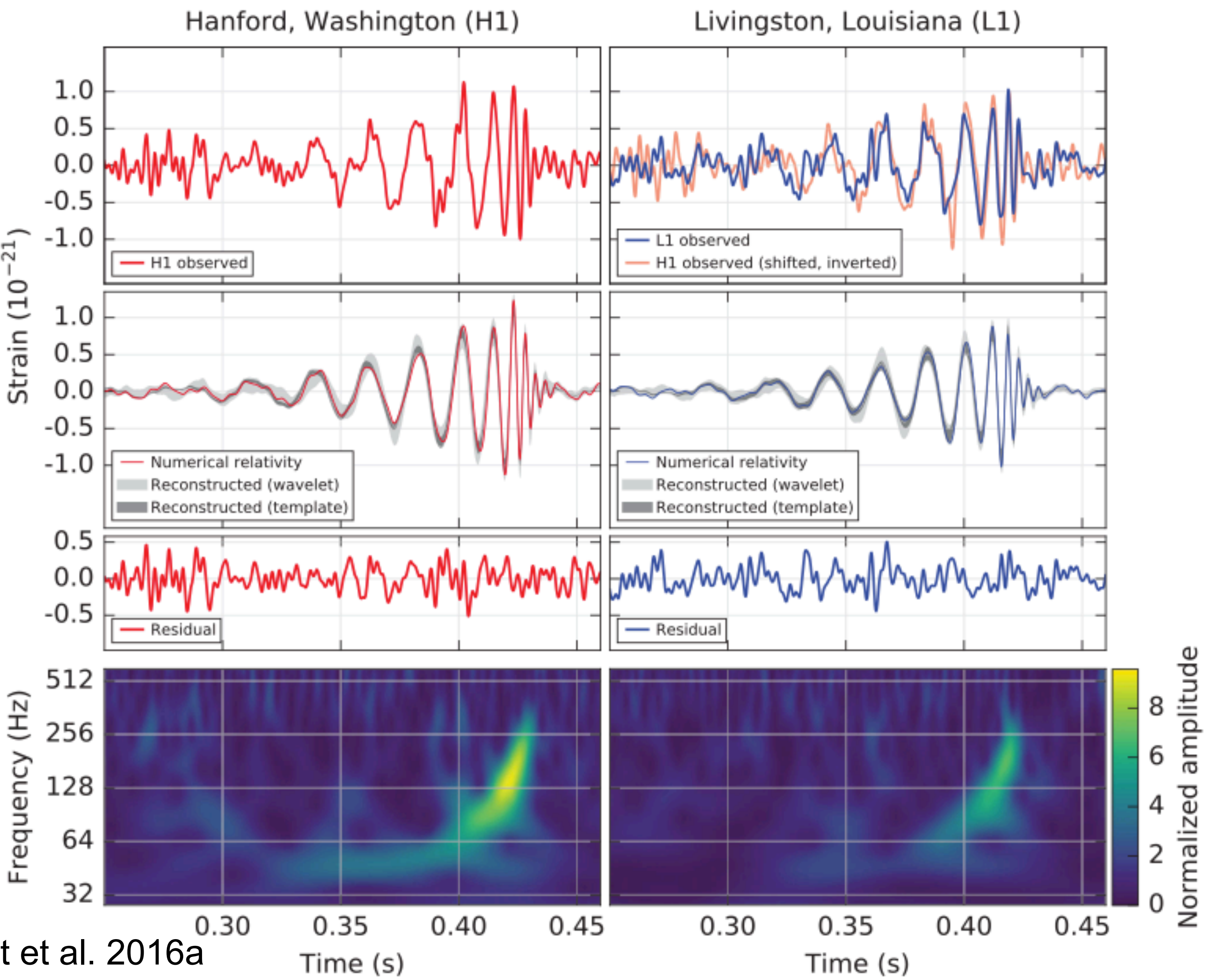
Abbott et al. 2016a

GW 150904



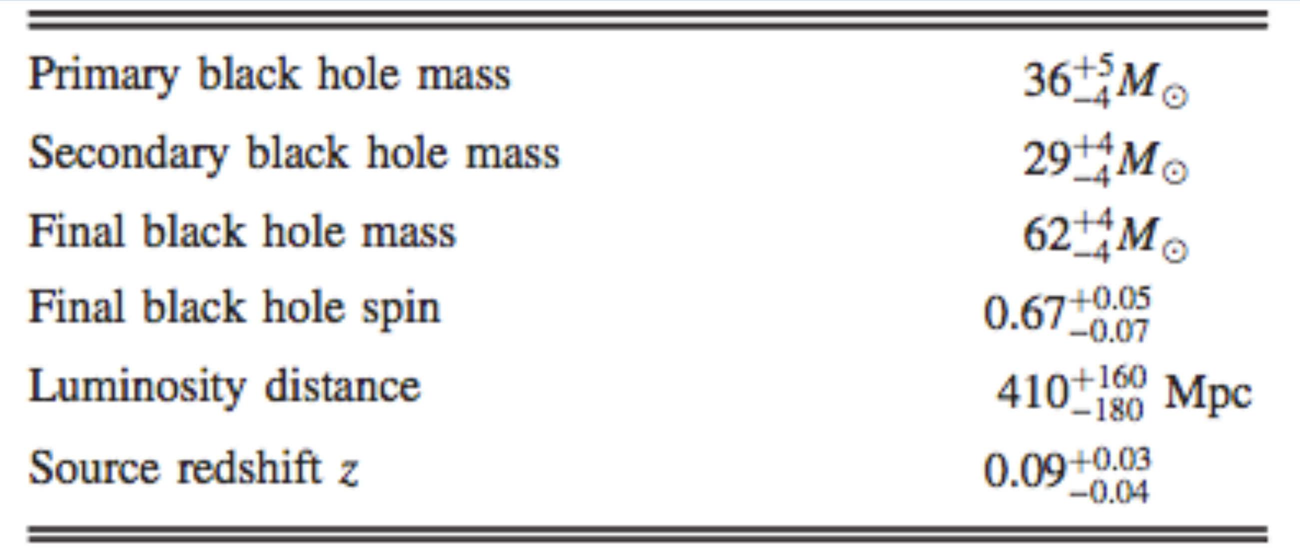
Abbott et al. 2016a

GW 150904



Abbott et al. 2016a

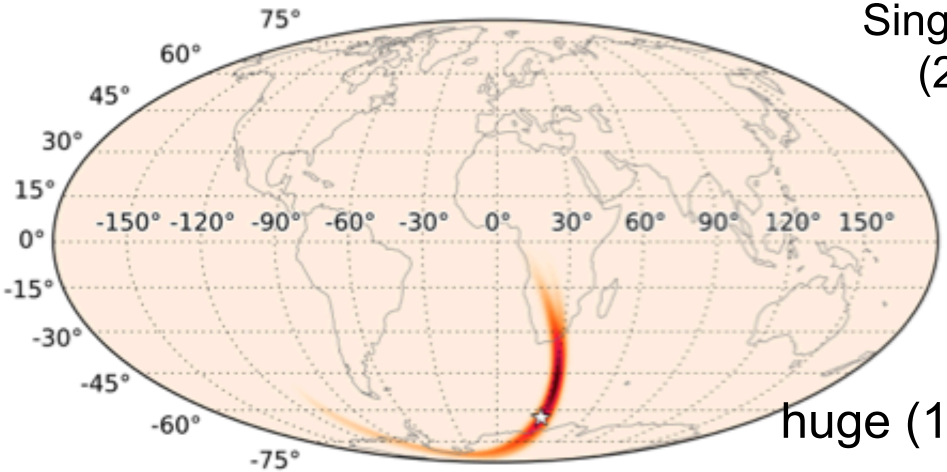
GW 150904



Primary black hole mass	$36^{+5}_{-4} M_\odot$
Secondary black hole mass	$29^{+4}_{-4} M_\odot$
Final black hole mass	$62^{+4}_{-4} M_\odot$
Final black hole spin	$0.67^{+0.05}_{-0.07}$
Luminosity distance	410^{+160}_{-180} Mpc
Source redshift z	$0.09^{+0.03}_{-0.04}$

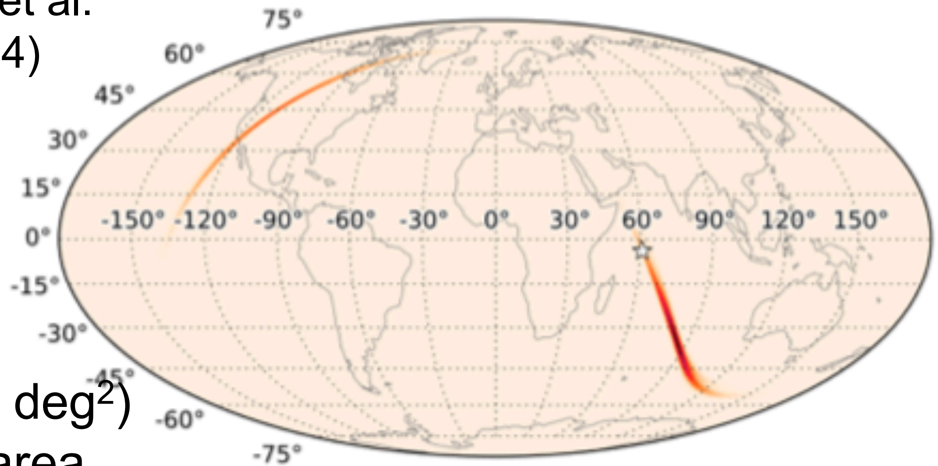
Abbott et al. 2016a

GW electromagnetic counterpart search



Singer et al. (2014)

huge (100 deg^2) search area

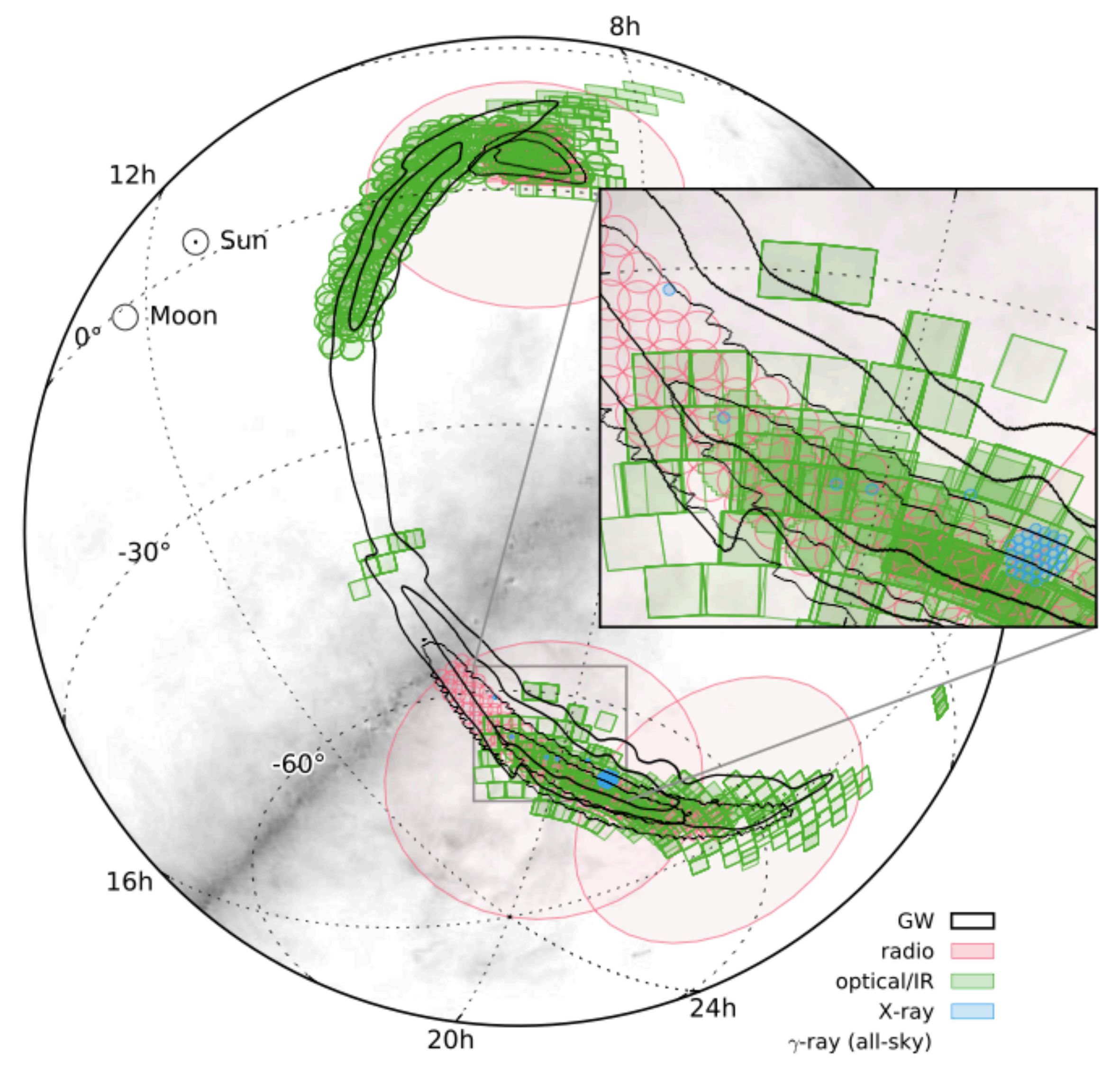


Strategy: observe only galaxies with D < 200 Mpc within the search area

X-ray (Swift/XRT)
N fields with short (50-500s) exposures
600 fields, 500s each (~4 days) give a
20-30% probability of detecting a SGRB afterglow (Evans et al. 2015).
Few contaminants.

Optical/NIR
One week observations with large FoV (2-3 deg^2) instruments down to i~24, z~23 mag can give a 95% kilonova detection rate.
However, hundreds of contaminats (Cowperthwaite & Berger 2015)

GW electromagnetic counterpart search: GW 150904



Abbott et al. 2016b

GW electromagnetic counterpart search: GW 150904

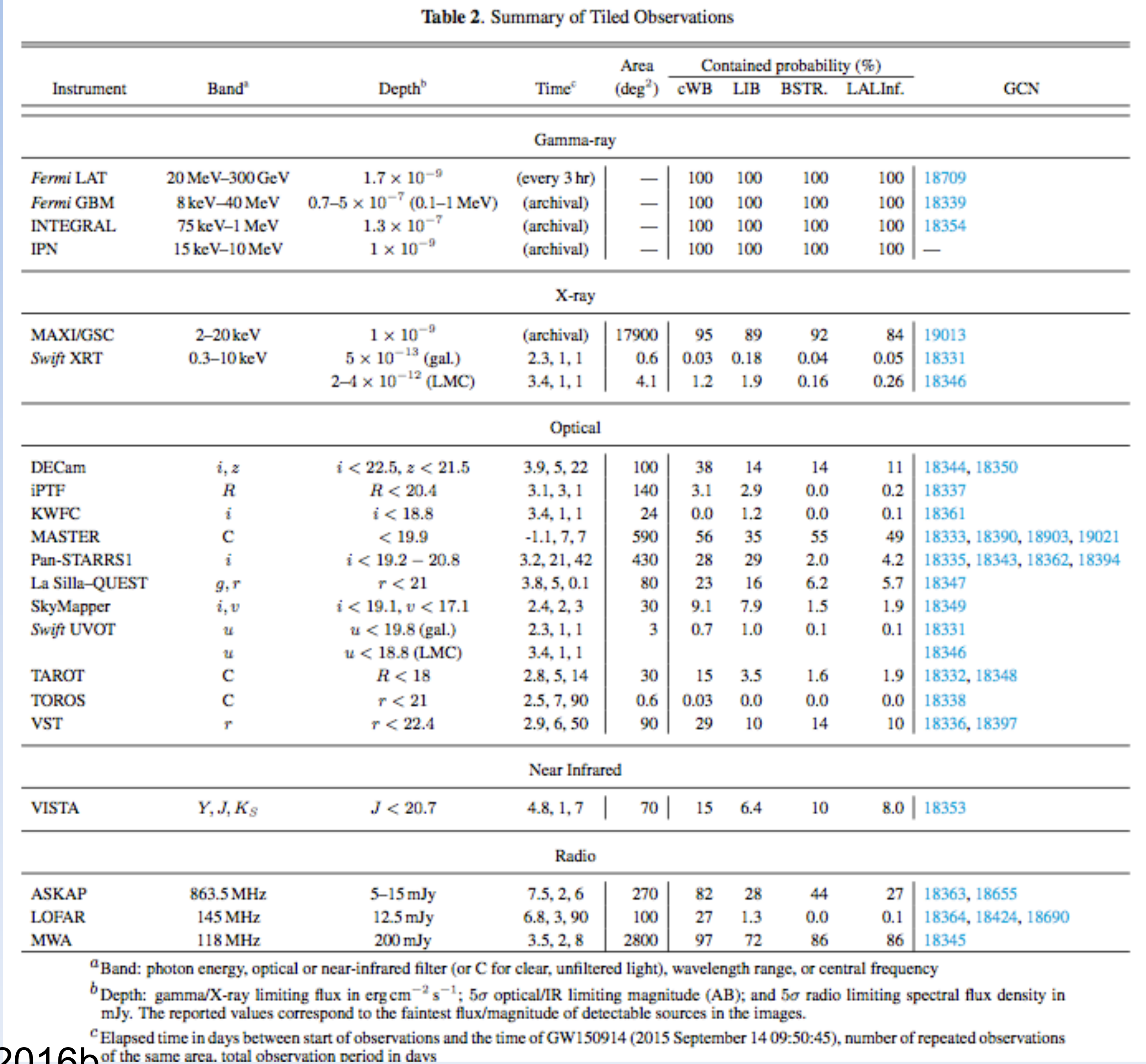


Table 2. Summary of Tiled Observations

Instrument	Band[a]	Depth[b]	Time[c]	Area (deg^2)	Contained probability (%) cWB	LIB	BSTR.	LALInf.	GCN
Gamma-ray									
Fermi LAT	20 MeV–300 GeV	1.7×10^{-9}	(every 3 hr)	—	100	100	100	100	18709
Fermi GBM	8 keV–40 MeV	$0.7–5 \times 10^{-7}$ (0.1–1 MeV)	(archival)	—	100	100	100	100	18339
INTEGRAL	75 keV–1 MeV	1.3×10^{-7}	(archival)	—	100	100	100	100	18354
IPN	15 keV–10 MeV	1×10^{-9}	(archival)	—	100	100	100	100	—
X-ray									
MAXI/GSC	2–20 keV	1×10^{-9}	(archival)	17900	95	89	92	84	19013
Swift XRT	0.3–10 keV	5×10^{-13} (gal.)	2.3, 1, 1	0.6	0.03	0.18	0.04	0.05	18331
		$2–4 \times 10^{-12}$ (LMC)	3.4, 1, 1	4.1	1.2	1.9	0.16	0.26	18346
Optical									
DECam	i, z	$i < 22.5, z < 21.5$	3.9, 5, 22	100	38	14	14	11	18344, 18350
iPTF	R	$R < 20.4$	3.1, 3, 1	140	3.1	2.9	0.0	0.2	18337
KWFC	i	$i < 18.8$	3.4, 1, 1	24	0.0	1.2	0.0	0.1	18361
MASTER	C	< 19.9	-1.1, 7, 7	590	56	35	55	49	18333, 18390, 18903, 19021
Pan-STARRS1	i	$i < 19.2 - 20.8$	3.2, 21, 42	430	28	29	2.0	4.2	18335, 18343, 18362, 18394
La Silla–QUEST	g, r	$r < 21$	3.8, 5, 0.1	80	23	16	6.2	5.7	18347
SkyMapper	i, v	$i < 19.1, v < 17.1$	2.4, 2, 3	30	9.1	7.9	1.5	1.9	18349
Swift UVOT	u	$u < 19.8$ (gal.)	2.3, 1, 1	3	0.7	1.0	0.1	0.1	18331
	u	$u < 18.8$ (LMC)	3.4, 1, 1						18346
TAROT	C	$R < 18$	2.8, 5, 14	30	15	3.5	1.6	1.9	18332, 18348
TOROS	C	$r < 21$	2.5, 7, 90	0.6	0.03	0.0	0.0	0.0	18338
VST	r	$r < 22.4$	2.9, 6, 50	90	29	10	14	10	18336, 18397
Near Infrared									
VISTA	Y, J, K_S	$J < 20.7$	4.8, 1, 7	70	15	6.4	10	8.0	18353
Radio									
ASKAP	863.5 MHz	5–15 mJy	7.5, 2, 6	270	82	28	44	27	18363, 18655
LOFAR	145 MHz	12.5 mJy	6.8, 3, 90	100	27	1.3	0.0	0.1	18364, 18424, 18690
MWA	118 MHz	200 mJy	3.5, 2, 8	2800	97	72	86	86	18345

[a] Band: photon energy, optical or near-infrared filter (or C for clear, unfiltered light), wavelength range, or central frequency

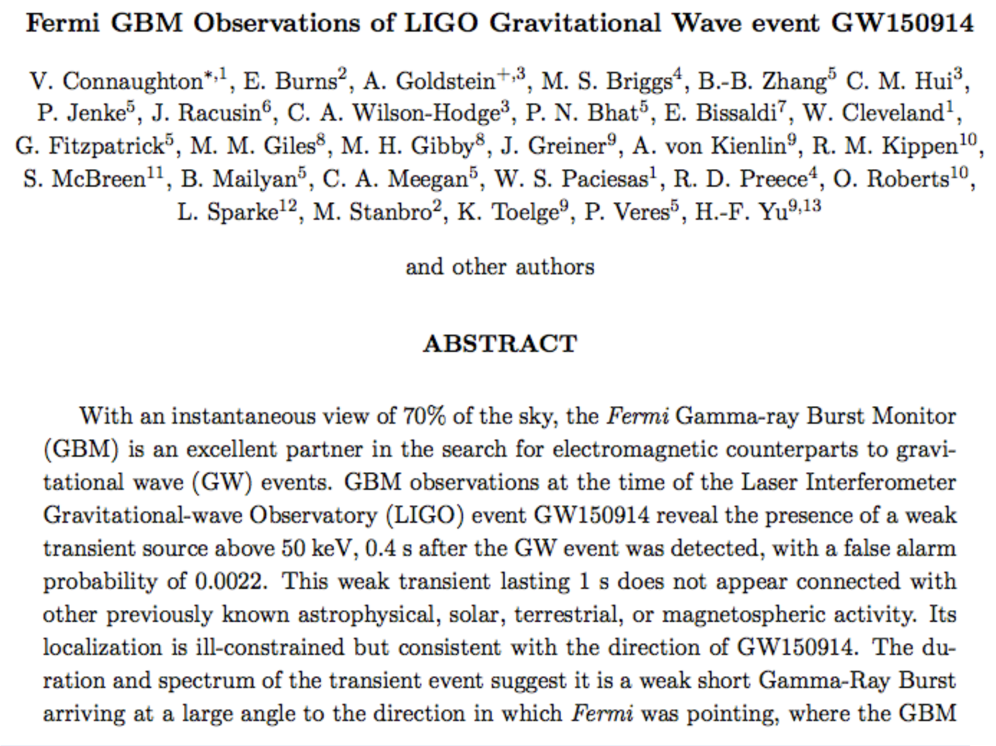
[b] Depth: gamma/X-ray limiting flux in erg cm^{-2} s^{-1}; 5σ optical/IR limiting magnitude (AB); and 5σ radio limiting spectral flux density in mJy. The reported values correspond to the faintest flux/magnitude of detectable sources in the images.

[c] Elapsed time in days between start of observations and the time of GW150914 (2015 September 14 09:50:45), number of repeated observations of the same area, total observation period in days

Abbott et al. 2016b

GW electromagnetic counterpart search: GW 150904

What if the GW source is a BH-BH binary???



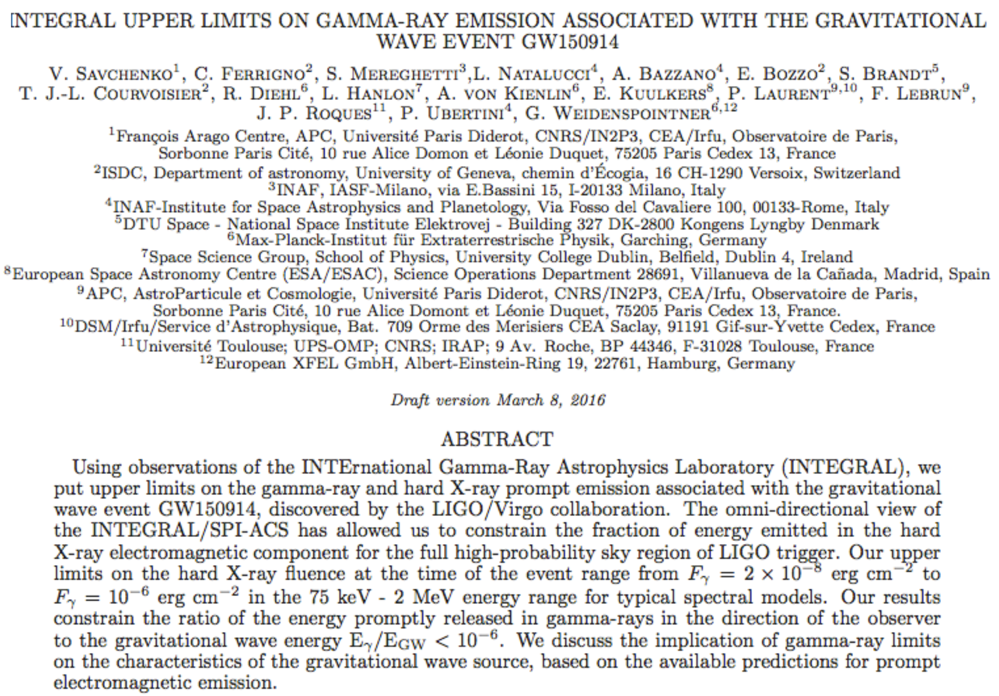
Fermi GBM Observations of LIGO Gravitational Wave event GW150914

V. Connaughton*[,1], E. Burns[2], A. Goldstein[+,3], M. S. Briggs[4], B.-B. Zhang[5] C. M. Hui[3],
P. Jenke[5], J. Racusin[6], C. A. Wilson-Hodge[3], P. N. Bhat[5], E. Bissaldi[7], W. Cleveland[1],
G. Fitzpatrick[5], M. M. Giles[8], M. H. Gibby[8], J. Greiner[9], A. von Kienlin[9], R. M. Kippen[10],
S. McBreen[11], B. Mailyan[5], C. A. Meegan[5], W. S. Paciesas[1], R. D. Preece[4], O. Roberts[10],
L. Sparke[12], M. Stanbro[2], K. Toelge[9], P. Veres[5], H.-F. Yu[9,13]

and other authors

ABSTRACT

With an instantaneous view of 70% of the sky, the *Fermi* Gamma-ray Burst Monitor (GBM) is an excellent partner in the search for electromagnetic counterparts to gravitational wave (GW) events. GBM observations at the time of the Laser Interferometer Gravitational-wave Observatory (LIGO) event GW150914 reveal the presence of a weak transient source above 50 keV, 0.4 s after the GW event was detected, with a false alarm probability of 0.0022. This weak transient lasting 1 s does not appear connected with other previously known astrophysical, solar, terrestrial, or magnetospheric activity. Its localization is ill-constrained but consistent with the direction of GW150914. The duration and spectrum of the transient event suggest it is a weak short Gamma-Ray Burst arriving at a large angle to the direction in which *Fermi* was pointing, where the GBM



INTEGRAL UPPER LIMITS ON GAMMA-RAY EMISSION ASSOCIATED WITH THE GRAVITATIONAL WAVE EVENT GW150914

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T. J.-L. Courvoisier[2], R. Diehl[6], L. Hanlon[7], A. von Kienlin[6], E. Kuulkers[8], P. Laurent[9,10], F. Lebrun[9],
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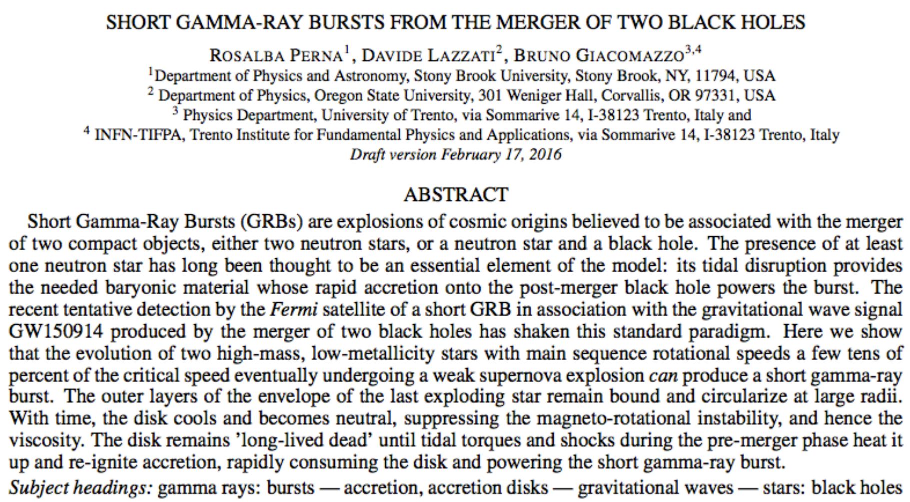
Draft version March 8, 2016

ABSTRACT

Using observations of the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL), we put upper limits on the gamma-ray and hard X-ray prompt emission associated with the gravitational wave event GW150914, discovered by the LIGO/Virgo collaboration. The omni-directional view of the INTEGRAL/SPI-ACS has allowed us to constrain the fraction of energy emitted in the hard X-ray electromagnetic component for the full high-probability sky region of LIGO trigger. Our upper limits on the hard X-ray fluence at the time of the event range from $F_\gamma = 2 \times 10^{-8}$ erg cm^{-2} to $F_\gamma = 10^{-6}$ erg cm^{-2} in the 75 keV - 2 MeV energy range for typical spectral models. Our results constrain the ratio of the energy promptly released in gamma-rays in the direction of the observer to the gravitational wave energy $E_\gamma/E_{GW} < 10^{-6}$. We discuss the implication of gamma-ray limits on the characteristics of the gravitational wave source, based on the available predictions for prompt electromagnetic emission.

GW electromagnetic counterpart search: GW 150904

What if the GW source is a BH-BH binary???



SHORT GAMMA-RAY BURSTS FROM THE MERGER OF TWO BLACK HOLES

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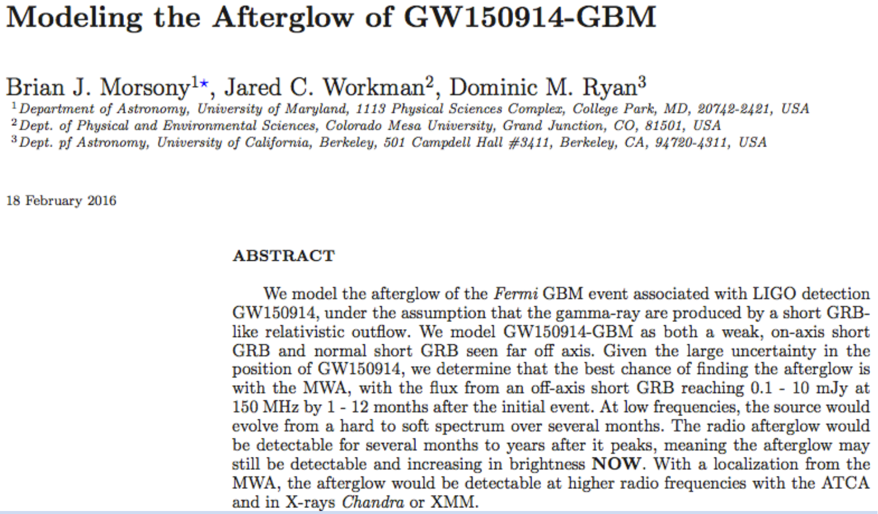
Draft version February 17, 2016

ABSTRACT

Short Gamma-Ray Bursts (GRBs) are explosions of cosmic origins believed to be associated with the merger of two compact objects, either two neutron stars, or a neutron star and a black hole. The presence of at least one neutron star has long been thought to be an essential element of the model: its tidal disruption provides the needed baryonic material whose rapid accretion onto the post-merger black hole powers the burst. The recent tentative detection by the *Fermi* satellite of a short GRB in association with the gravitational wave signal GW150914 produced by the merger of two black holes has shaken this standard paradigm. Here we show that the evolution of two high-mass, low-metallicity stars with main sequence rotational speeds a few tens of percent of the critical speed eventually undergoing a weak supernova explosion *can* produce a short gamma-ray burst. The outer layers of the envelope of the last exploding star remain bound and circularize at large radii. With time, the disk cools and becomes neutral, suppressing the magneto-rotational instability, and hence the viscosity. The disk remains 'long-lived dead' until tidal torques and shocks during the pre-merger phase heat it up and re-ignite accretion, rapidly consuming the disk and powering the short gamma-ray burst.

Subject headings: gamma rays: bursts — accretion, accretion disks — gravitational waves — stars: black holes



Modeling the Afterglow of GW150914-GBM

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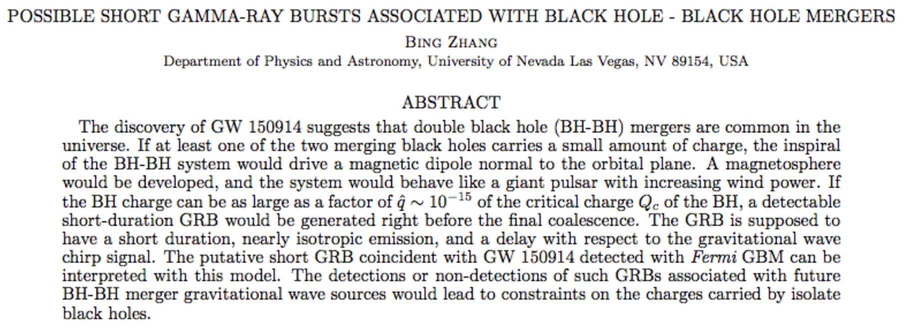
18 February 2016

ABSTRACT

We model the afterglow of the *Fermi* GBM event associated with LIGO detection GW150914, under the assumption that the gamma-ray are produced by a short GRB-like relativistic outflow. We model GW150914-GBM as both a weak, on-axis short GRB and normal short GRB seen far off axis. Given the large uncertainty in the position of GW150914, we determine that the best chance of finding the afterglow is with the MWA, with the flux from an off-axis short GRB reaching 0.1 - 10 mJy at 150 MHz by 1 - 12 months after the initial event. At low frequencies, the source would evolve from a hard to soft spectrum over several months. The radio afterglow would be detectable for several months to years after it peaks, meaning the afterglow may still be detectable and increasing in brightness **NOW**. With a localization from the MWA, the afterglow would be detectable at higher radio frequencies with the ATCA and in X-rays *Chandra* or XMM.



POSSIBLE SHORT GAMMA-RAY BURSTS ASSOCIATED WITH BLACK HOLE - BLACK HOLE MERGERS

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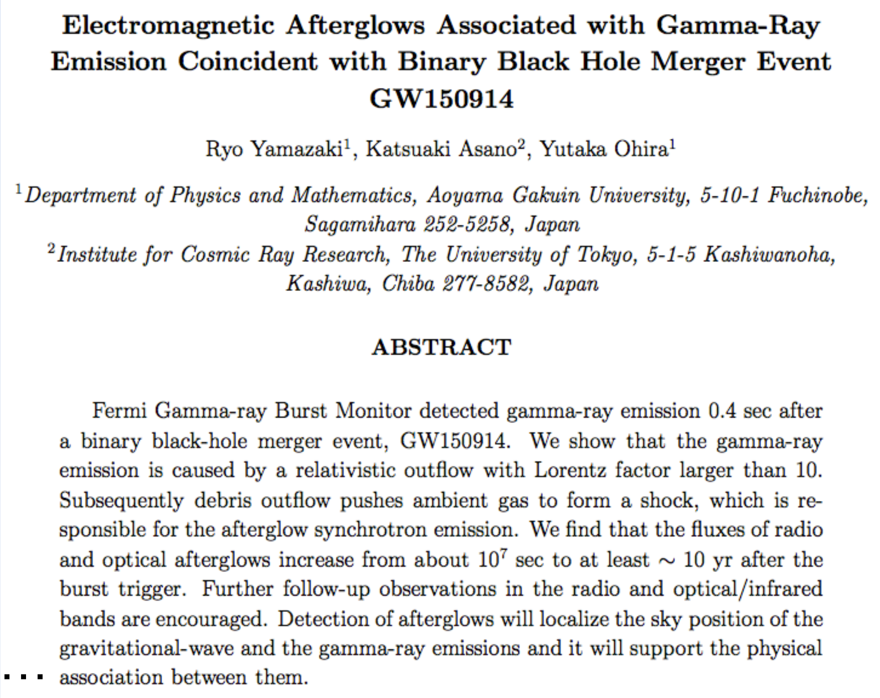
ABSTRACT

The discovery of GW 150914 suggests that double black hole (BH-BH) mergers are common in the universe. If at least one of the two merging black holes carries a small amount of charge, the inspiral of the BH-BH system would drive a magnetic dipole normal to the orbital plane. A magnetosphere would be developed, and the system would behave like a giant pulsar with increasing wind power. If the BH charge can be as large as a factor of $\hat{q} \sim 10^{-15}$ of the critical charge Q_c of the BH, a detectable short-duration GRB would be generated right before the final coalescence. The GRB is supposed to have a short duration, nearly isotropic emission, and a delay with respect to the gravitational wave chirp signal. The putative short GRB coincident with GW 150914 detected with *Fermi* GBM can be interpreted with this model. The detections or non-detections of such GRBs associated with future BH-BH merger gravitational wave sources would lead to constraints on the charges carried by isolate black holes.



Electromagnetic Afterglows Associated with Gamma-Ray Emission Coincident with Binary Black Hole Merger Event GW150914

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[1]*Department of Physics and Mathematics, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara 252-5258, Japan*
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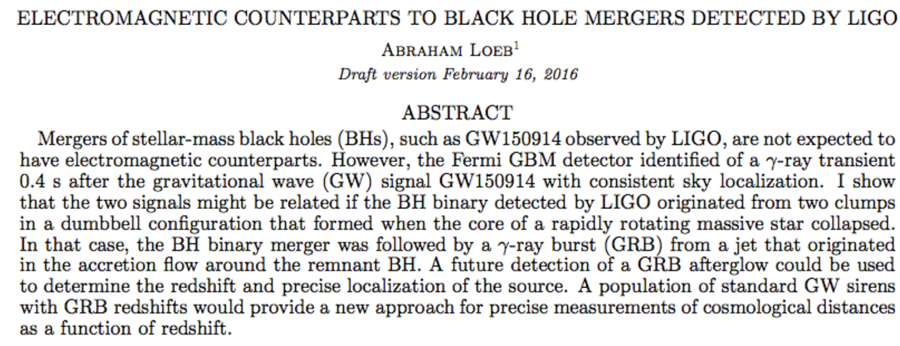
ABSTRACT

Fermi Gamma-ray Burst Monitor detected gamma-ray emission 0.4 sec after a binary black-hole merger event, GW150914. We show that the gamma-ray emission is caused by a relativistic outflow with Lorentz factor larger than 10. Subsequently debris outflow pushes ambient gas to form a shock, which is responsible for the afterglow synchrotron emission. We find that the fluxes of radio and optical afterglows increase from about 10^7 sec to at least ~ 10 yr after the burst trigger. Further follow-up observations in the radio and optical/infrared bands are encouraged. Detection of afterglows will localize the sky position of the gravitational-wave and the gamma-ray emissions and it will support the physical association between them.



ELECTROMAGNETIC COUNTERPARTS TO BLACK HOLE MERGERS DETECTED BY LIGO

Abraham Loeb[1]
Draft version February 16, 2016

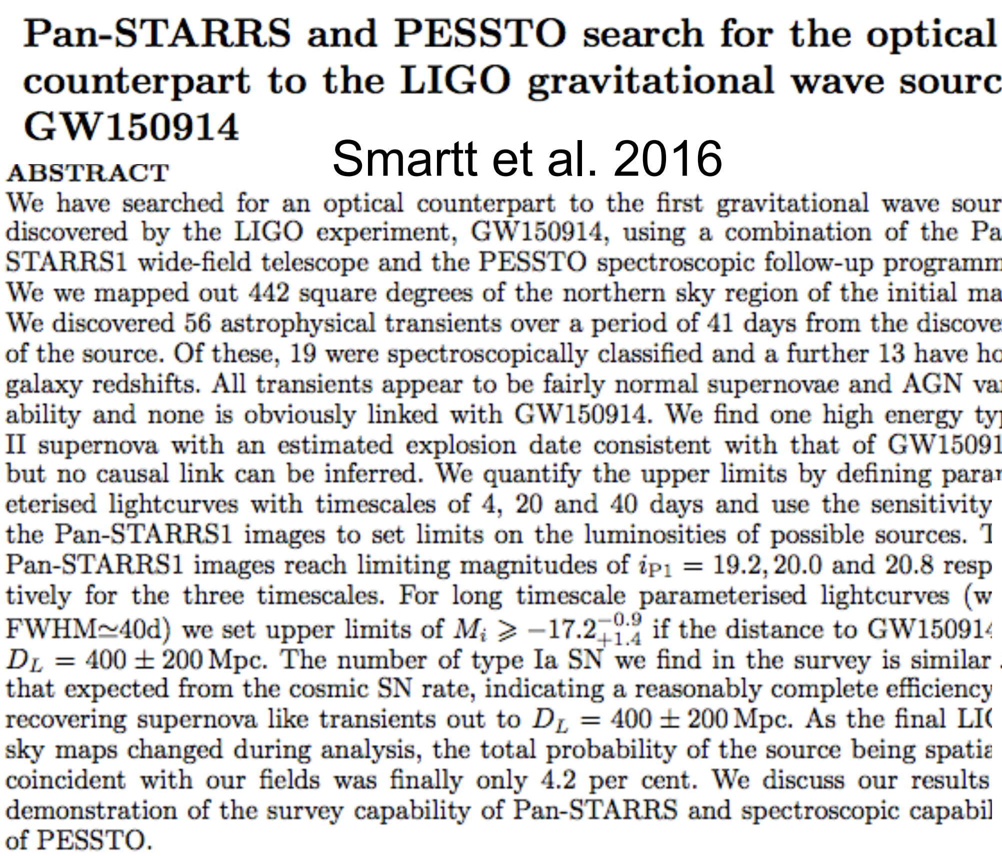
ABSTRACT

Mergers of stellar-mass black holes (BHs), such as GW150914 observed by LIGO, are not expected to have electromagnetic counterparts. However, the Fermi GBM detector identified of a γ-ray transient 0.4 s after the gravitational wave (GW) signal GW150914 with consistent sky localization. I show that the two signals might be related if the BH binary detected by LIGO originated from two clumps in a dumbbell configuration that formed when the core of a rapidly rotating massive star collapsed. In that case, the BH binary merger was followed by a γ-ray burst (GRB) from a jet that originated in the accretion flow around the remnant BH. A future detection of a GRB afterglow could be used to determine the redshift and precise localization of the source. A population of standard GW sirens with GRB redshifts would provide a new approach for precise measurements of cosmological distances as a function of redshift.

and more…

GW electromagnetic counterpart search: GW 150904

What if the GW source is a BH-BH binary???



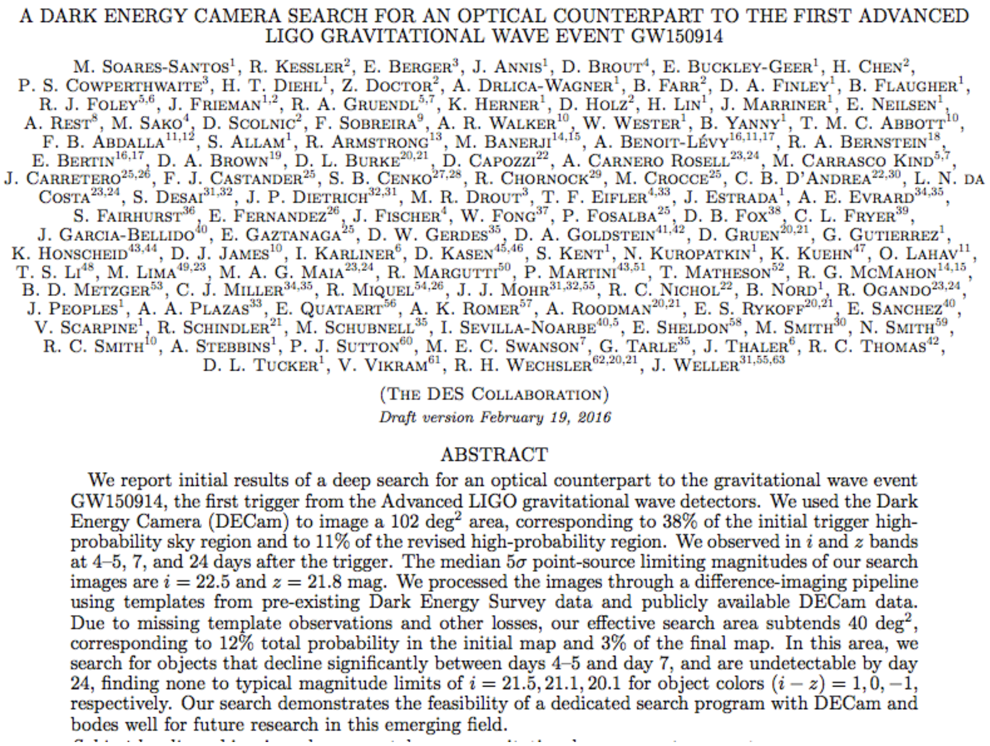
Pan-STARRS and PESSTO search for the optical counterpart to the LIGO gravitational wave source GW150914

Smartt et al. 2016

ABSTRACT

We have searched for an optical counterpart to the first gravitational wave source discovered by the LIGO experiment, GW150914, using a combination of the Pan-STARRS1 wide-field telescope and the PESSTO spectroscopic follow-up programme. We we mapped out 442 square degrees of the northern sky region of the initial map. We discovered 56 astrophysical transients over a period of 41 days from the discovery of the source. Of these, 19 were spectroscopically classified and a further 13 have host galaxy redshifts. All transients appear to be fairly normal supernovae and AGN variability and none is obviously linked with GW150914. We find one high energy type II supernova with an estimated explosion date consistent with that of GW150914, but no causal link can be inferred. We quantify the upper limits by defining parameterised lightcurves with timescales of 4, 20 and 40 days and use the sensitivity
the Pan-STARRS1 images to set limits on the luminosities of possible sources. T
Pan-STARRS1 images reach limiting magnitudes of $i_{\rm P1} = 19.2, 20.0$ and 20.8 resp
tively for the three timescales. For long timescale parameterised lightcurves (w
FWHM$\simeq$40d) we set upper limits of $M_i \geqslant -17.2^{-0.9}_{+1.4}$ if the distance to GW15091
$D_L = 400 \pm 200$ Mpc. The number of type Ia SN we find in the survey is similar
that expected from the cosmic SN rate, indicating a reasonably complete efficiency
recovering supernova like transients out to $D_L = 400 \pm 200$ Mpc. As the final LI
sky maps changed during analysis, the total probability of the source being spatia
coincident with our fields was finally only 4.2 per cent. We discuss our results
demonstration of the survey capability of Pan-STARRS and spectroscopic capabil
of PESSTO.

See also Evans et al. 2016



A DARK ENERGY CAMERA SEARCH FOR AN OPTICAL COUNTERPART TO THE FIRST ADVANCED LIGO GRAVITATIONAL WAVE EVENT GW150914

M. Soares-Santos[1], R. Kessler[2], E. Berger[3], J. Annis[1], D. Brout[4], E. Buckley-Geer[1], H. Chen[2], P. S. Cowperthwaite[3], H. T. Diehl[1], Z. Doctor[2], A. Drlica-Wagner[1], B. Farr[2], D. A. Finley[1], B. Flaugher[1], R. J. Foley[5,6], J. Frieman[1,2], R. A. Gruendl[5,7], K. Herner[1], D. Holz[2], H. Lin[1], J. Marriner[1], E. Neilsen[1], A. Rest[8], M. Sako[4], D. Scolnic[2], F. Sobreira[9], A. R. Walker[10], W. Wester[1], B. Yanny[1], T. M. C. Abbott[10], F. B. Abdalla[11,12], S. Allam[1], R. Armstrong[13], M. Banerji[14,15], A. Benoit-Lévy[16,11,17], R. A. Bernstein[18], E. Bertin[16,17], D. A. Brown[19], D. L. Burke[20,21], D. Capozzi[22], A. Carnero Rosell[23,24], M. Carrasco Kind[5,7], J. Carretero[25,26], F. J. Castander[25], S. B. Cenko[27,28], R. Chornock[29], M. Crocce[25], C. B. D'Andrea[22,30], L. N. da Costa[23,24], S. Desai[31,32], J. P. Dietrich[32,31], M. R. Drout[3], T. F. Eifler[4,33], J. Estrada[1], A. E. Evrard[34,35], S. Fairhurst[36], E. Fernandez[26], J. Fischer[4], W. Fong[37], P. Fosalba[25], D. B. Fox[38], C. L. Fryer[39], J. Garcia-Bellido[40], E. Gaztanaga[25], D. W. Gerdes[35], D. A. Goldstein[41,42], D. Gruen[20,21], G. Gutierrez[1], K. Honscheid[43,44], D. J. James[10], I. Karliner[6], D. Kasen[45,46], S. Kent[1], N. Kuropatkin[1], K. Kuehn[47], O. Lahav[11], T. S. Li[48], M. Lima[49,23], M. A. G. Maia[23,24], R. Margutti[50], P. Martini[43,51], T. Matheson[52], R. G. McMahon[14,15], B. D. Metzger[53], C. J. Miller[34,35], R. Miquel[54,26], J. J. Mohr[31,32,55], R. C. Nichol[22], B. Nord[1], R. Ogando[23,24], J. Peoples[1], A. A. Plazas[33], E. Quataert[56], A. K. Romer[57], A. Roodman[20,21], E. S. Rykoff[20,21], E. Sanchez[40], V. Scarpine[1], R. Schindler[21], M. Schubnell[35], I. Sevilla-Noarbe[40,5], E. Sheldon[58], M. Smith[30], N. Smith[59], R. C. Smith[10], A. Stebbins[1], P. J. Sutton[60], M. E. C. Swanson[7], G. Tarle[35], J. Thaler[6], R. C. Thomas[42], D. L. Tucker[1], V. Vikram[61], R. H. Wechsler[62,20,21], J. Weller[31,55,63]

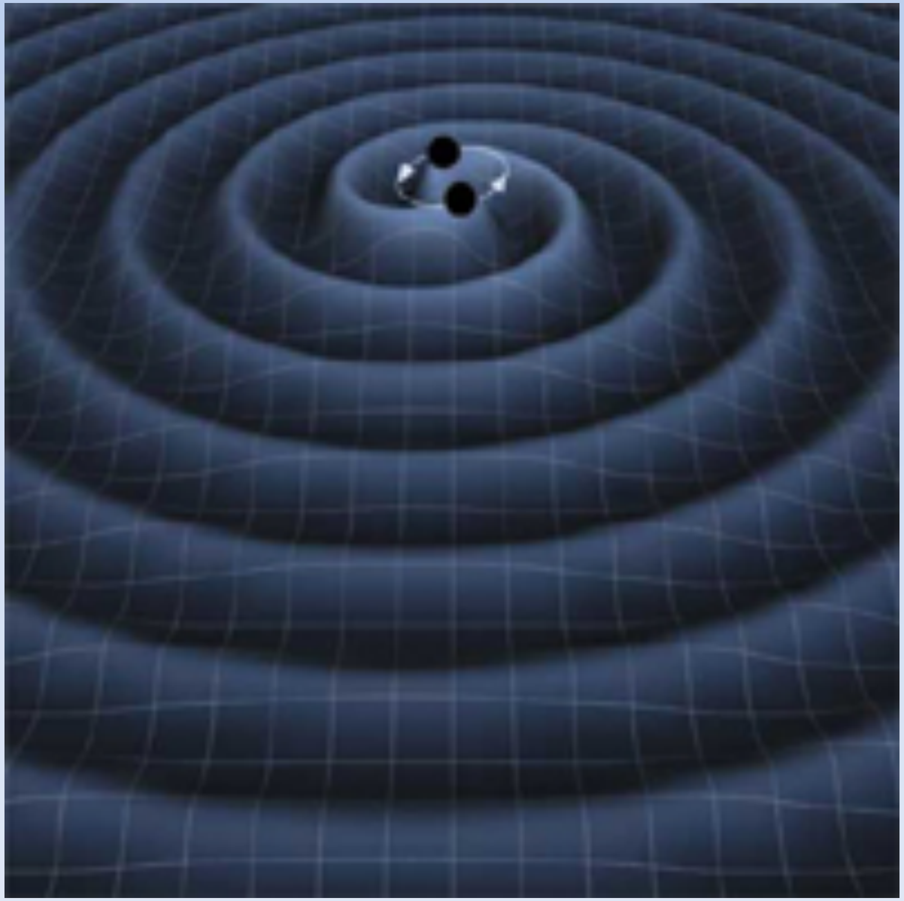
(The DES Collaboration)

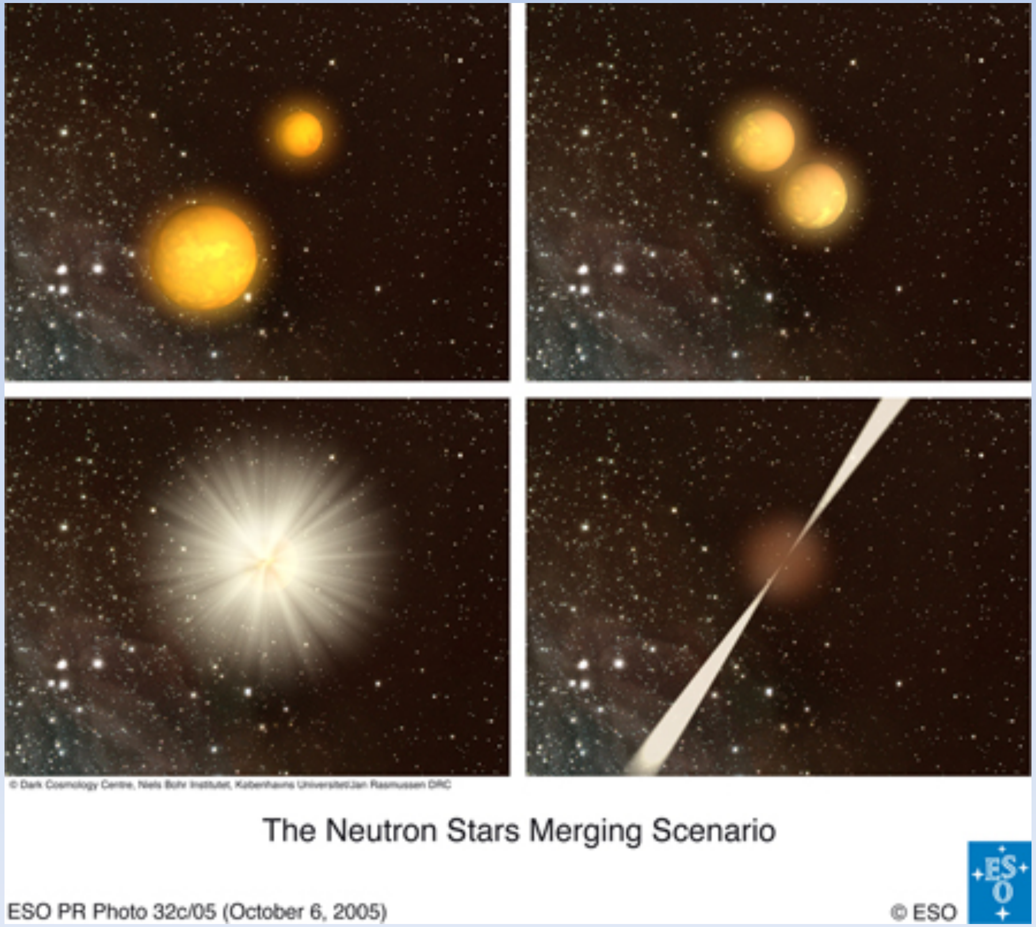
Draft version February 19, 2016

ABSTRACT

We report initial results of a deep search for an optical counterpart to the gravitational wave event GW150914, the first trigger from the Advanced LIGO gravitational wave detectors. We used the Dark Energy Camera (DECam) to image a 102 deg^2 area, corresponding to 38% of the initial trigger high-probability sky region and to 11% of the revised high-probability region. We observed in i and z bands at 4–5, 7, and 24 days after the trigger. The median 5σ point-source limiting magnitudes of our search images are $i = 22.5$ and $z = 21.8$ mag. We processed the images through a difference-imaging pipeline using templates from pre-existing Dark Energy Survey data and publicly available DECam data. Due to missing template observations and other losses, our effective search area subtends 40 deg^2, corresponding to 12% total probability in the initial map and 3% of the final map. In this area, we search for objects that decline significantly between days 4–5 and day 7, and are undetectable by day 24, finding none to typical magnitude limits of $i = 21.5, 21.1, 20.1$ for object colors $(i - z) = 1, 0, -1$, respectively. Our search demonstrates the feasibility of a dedicated search program with DECam and bodes well for future research in this emerging field.

Short GRBs as GW sources





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The Neutron Stars Merging Scenario

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

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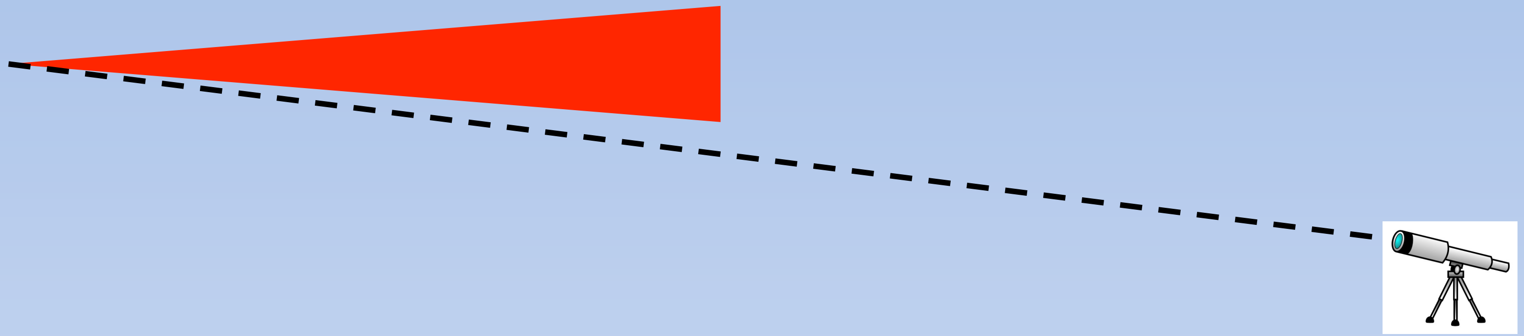
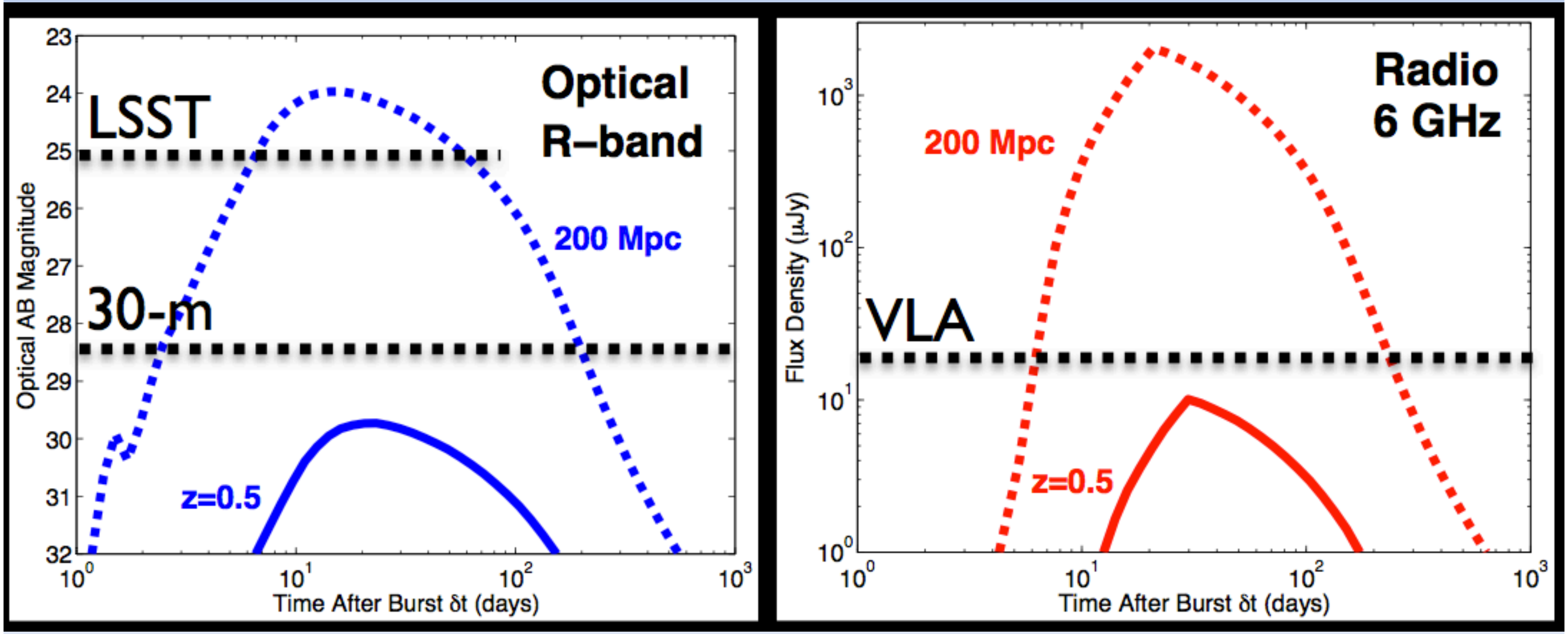
Off-axis SGRBs

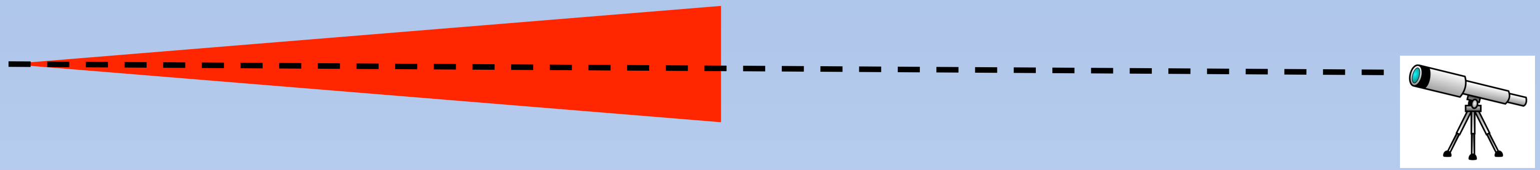


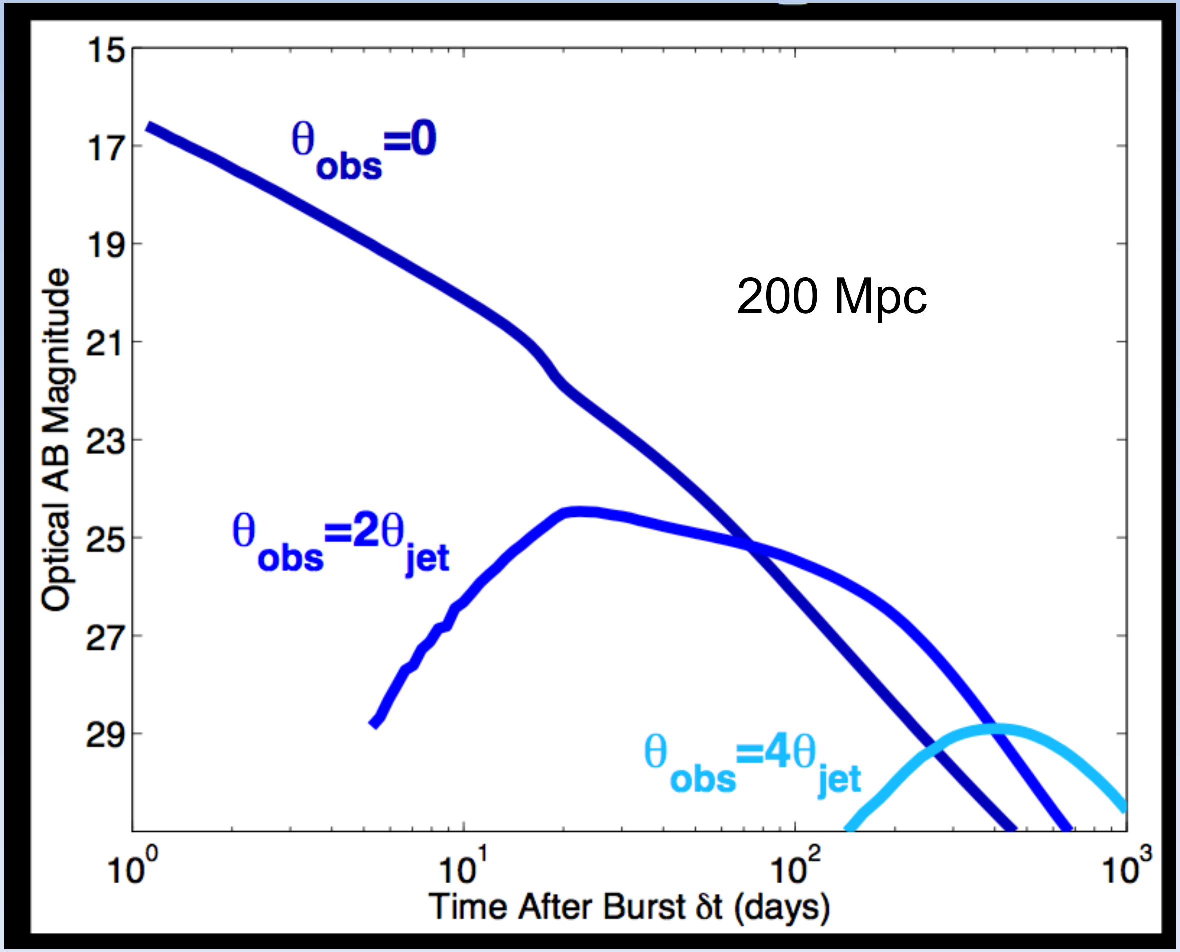


Assuming n~4x10^{-3} cm^{-3}, E~10^{49} erg, θ_{jet}~2 deg, θ_{obs}~20 deg

Fong et al. (http://www.brera.inaf.it/Swift10/Talks/Fong.pdf)

On-axis SGRBs





Assuming $n \sim 4\times10^{-3}$ cm^{-3}, $E \sim 10^{49}$ erg, $\theta_{jet} \sim 2$ deg, $\theta_{obs} \sim 20$ deg

Fong et al. (http://www.brera.inaf.it/Swift10/Talks/Fong.pdf)

Kilonovae as possible GW counterparts

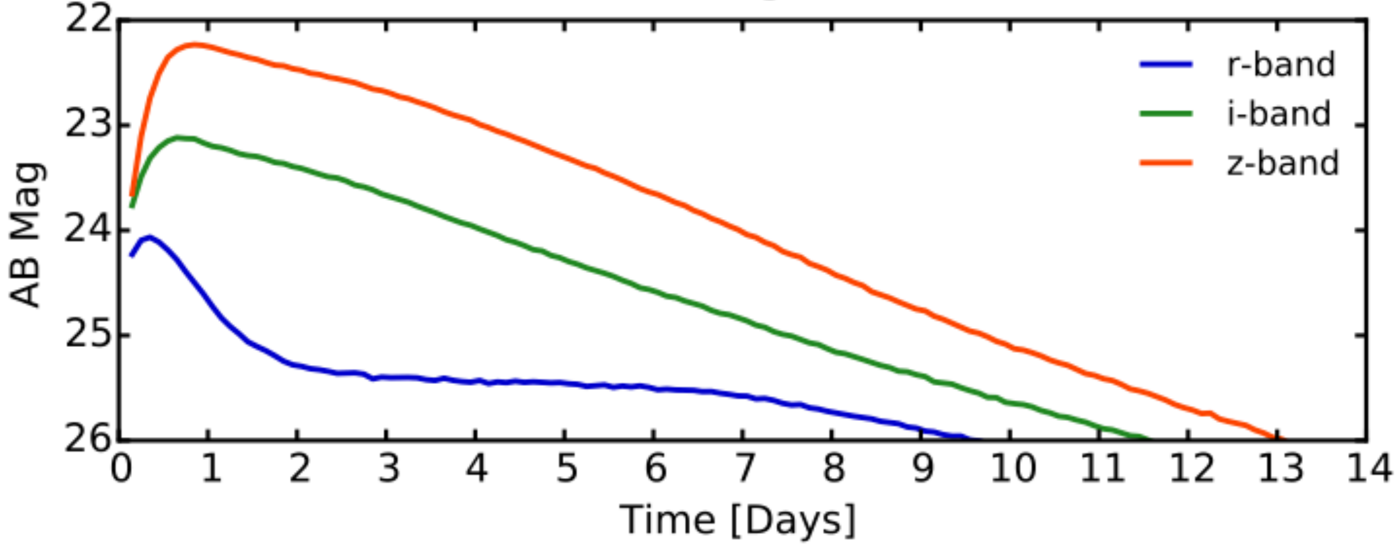


FIG. 1.— Top: Kilonova spectra from Barnes & Kasen (2013) at ~ 1 d and ~ 1 week with ejecta properties of $M_{\rm ej} = 10^{-2}\ M_\odot$ and $\beta_{\rm ej} = 0.2$. Bottom: Light curve for the same model parameters computed at a fiducial distance of 200 Mpc in the DECam r, i- and z-band filters.

Cowperthwaite & Berger 2015

Short GRBs: some conclusions

- Properties shared with long GRBs:
    - Flares
    - Plateaus
    - Similar scaling for prompt and afterglow emission
    - Same intrinsic N_H (on the same redshift bin)

- Evidences for compact binary merger progenitors:
    - No SNe
    - Different host galaxies (also early-type)
    - Associated to old stellar population
    - Hints for primordial, fast-merging, binary channel (z, offset, N_H)
    - No-host SGRBs (large offset? Dynamical channel?)
    - Possible Kilonova in some short GRB (smoking gun?)
    - Waiting for (more) GWs

- Perspectives:
    - systematic search for jet-breaks (true energetics and rate)
    - systematic search for associated kilonovae
    - GW EM counterparts

Observational reviews: Berger 2014, ARA&A, 52, 43; D'Avanzo, 2015, JHEAp, 7, 73