Istituto Nazionale di Astrofisica

Osservatorio Astronomico di Brera

Short Gamma-Ray Bursts

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Short-Duration Gamma-Ray Bursts

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Key Words

gamma rays: observations, theory; gravitational waves; radiation mechanisms: non-thermal; relativistic processes; stars: neutron

Abstract

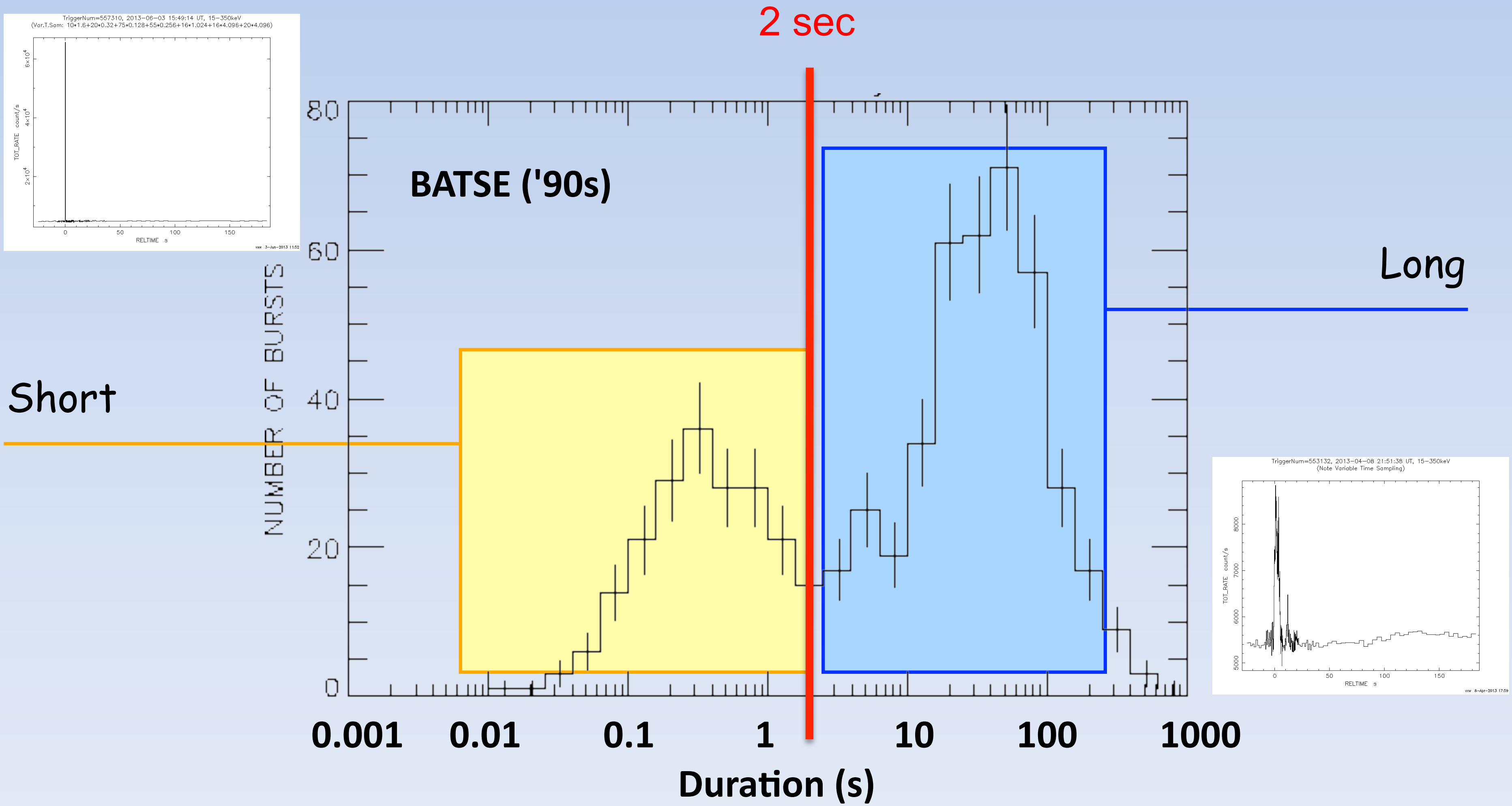
Gamma-ray bursts (GRBs) display a bimodal duration distribution, with a separation between the short- and long-duration bursts at about 2 sec. The progenitors of long GRBs have been identified as massive stars based on their association with Type Ic core-collapse supernovae, their exclusive location in star-forming galaxies, and their strong correlation with bright ultraviolet regions within their host galaxies. Short GRBs have long been suspected on theoretical grounds to arise from compact object binary mergers (NS-NS or NS-BH). The discovery of short GRB afterglows in 2005, provided the first insight into their energy scale and environments, established a cosmological origin, a mix of host galaxy types, and an absence of associated supernovae. In this review I summarize nearly a decade of short GRB afterglow and host galaxy observations, and use this information to shed light on the nature and properties of their progenitors, the energy scale and collimation of the relativistic outflow, and the properties of the circumburst environments. The preponderance of the evidence points to compact object binary progenitors, although some open questions remain. Based on this association, observations of short GRBs and their afterglows can shed light on the on- and off-axis electromagnetic counterparts of gravitational wave sources from the Advanced LIGO/Virgo experiments.

To appear in Annual review of Astronomy and Astrophysics, vol 51, (2014)

Hereafter: Berger 2014

Two flavors of GRBs

GRBs are short flashes of gamma rays
How much short?



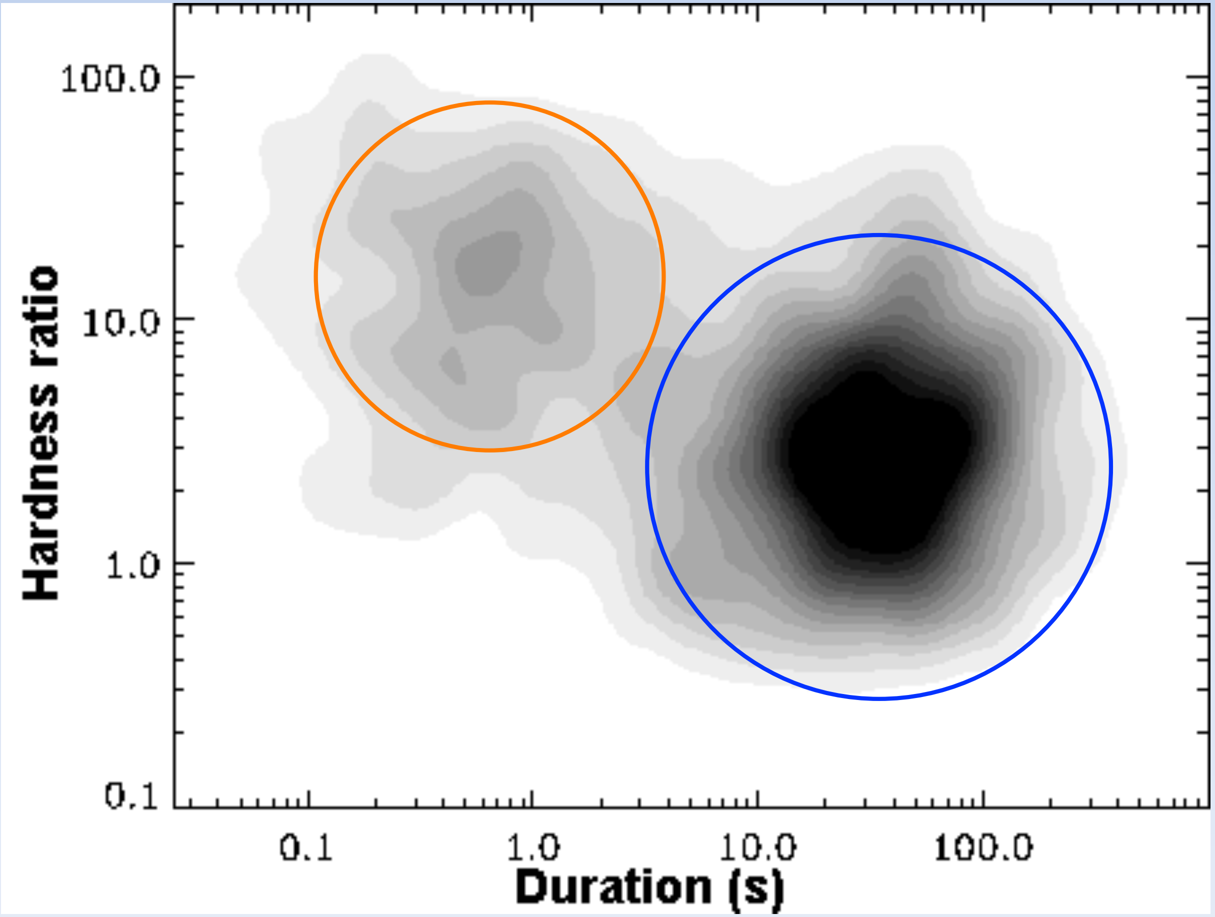
Kouveliotou et al. 1993

Another angle

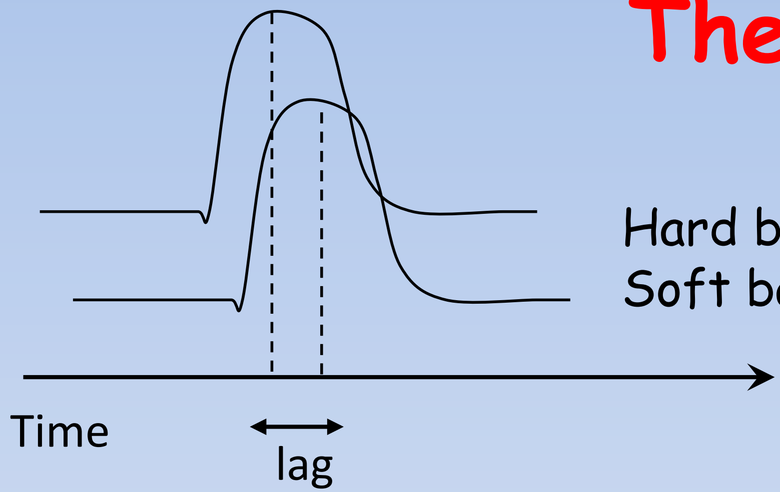
Hardness ratio: $HR = \frac{\text{countrate(hard)}}{\text{countrate(soft)}}$

Paradigm:

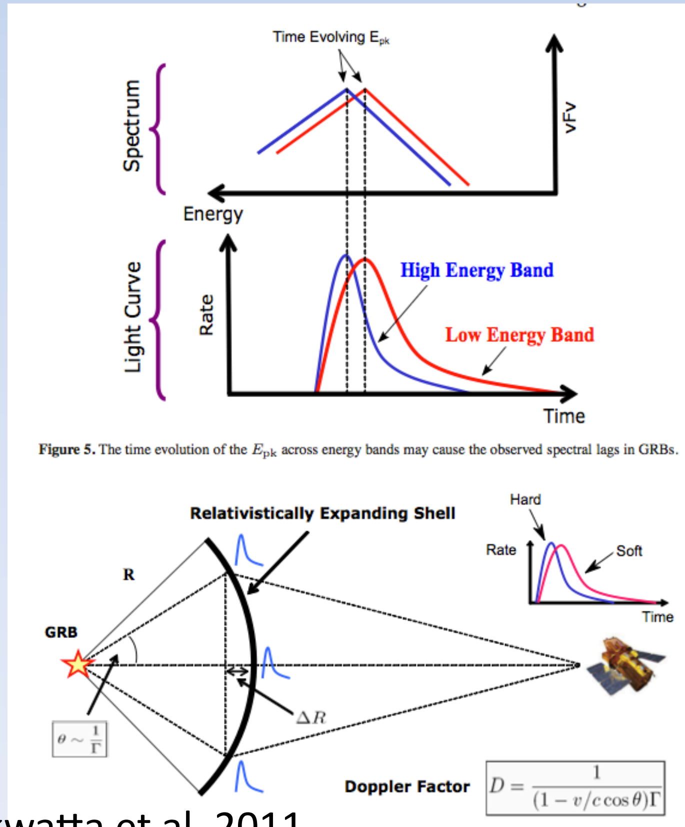
Long/soft
Short/hard



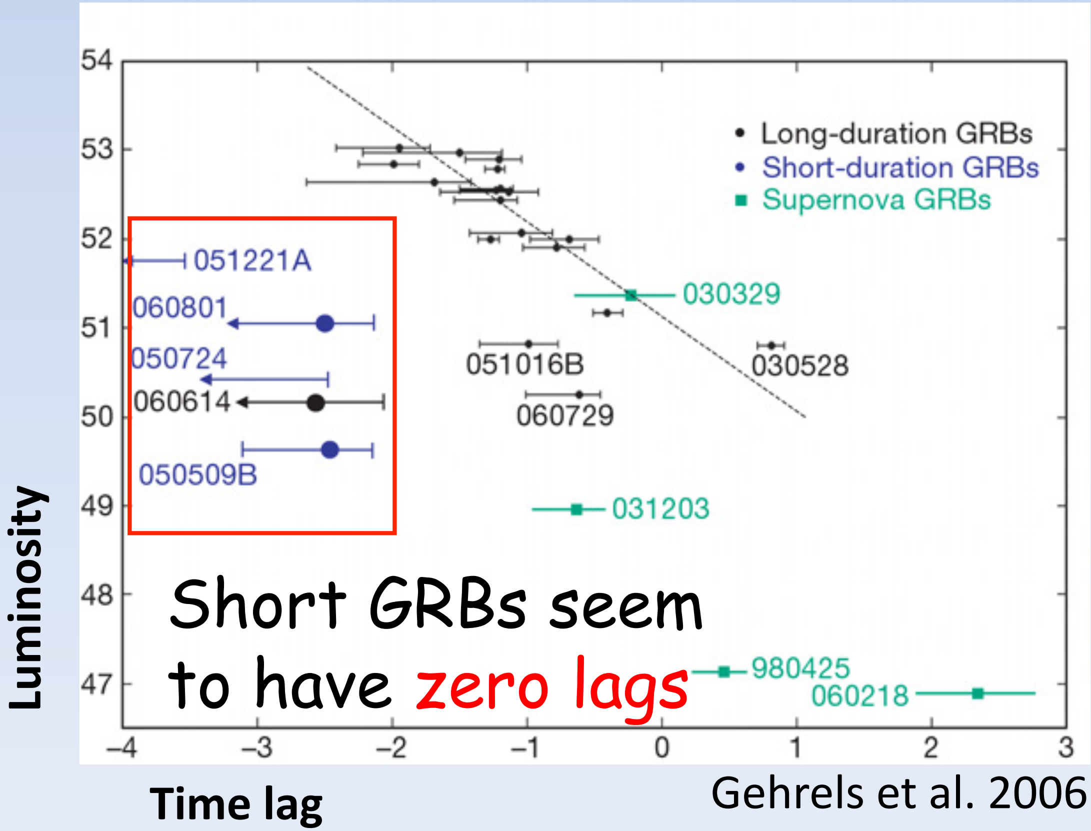
The third hint



The hard band leads the soft one



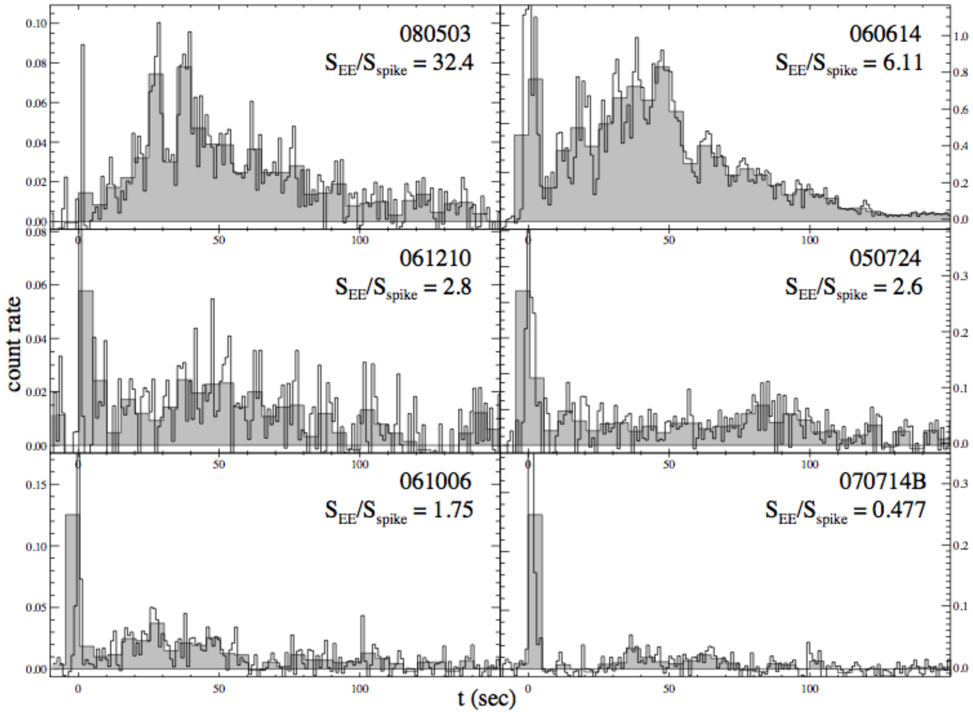
Ukwatta et al. 2011

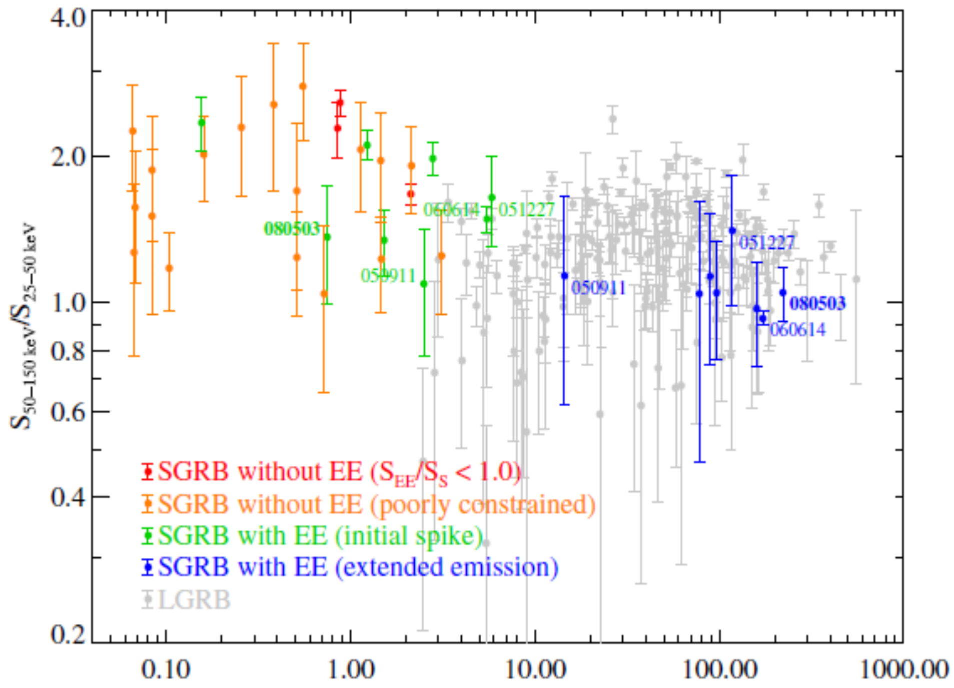


Short GRBs seem to have zero lags

Gehrels et al. 2006

Short GRBs: Extended Emission



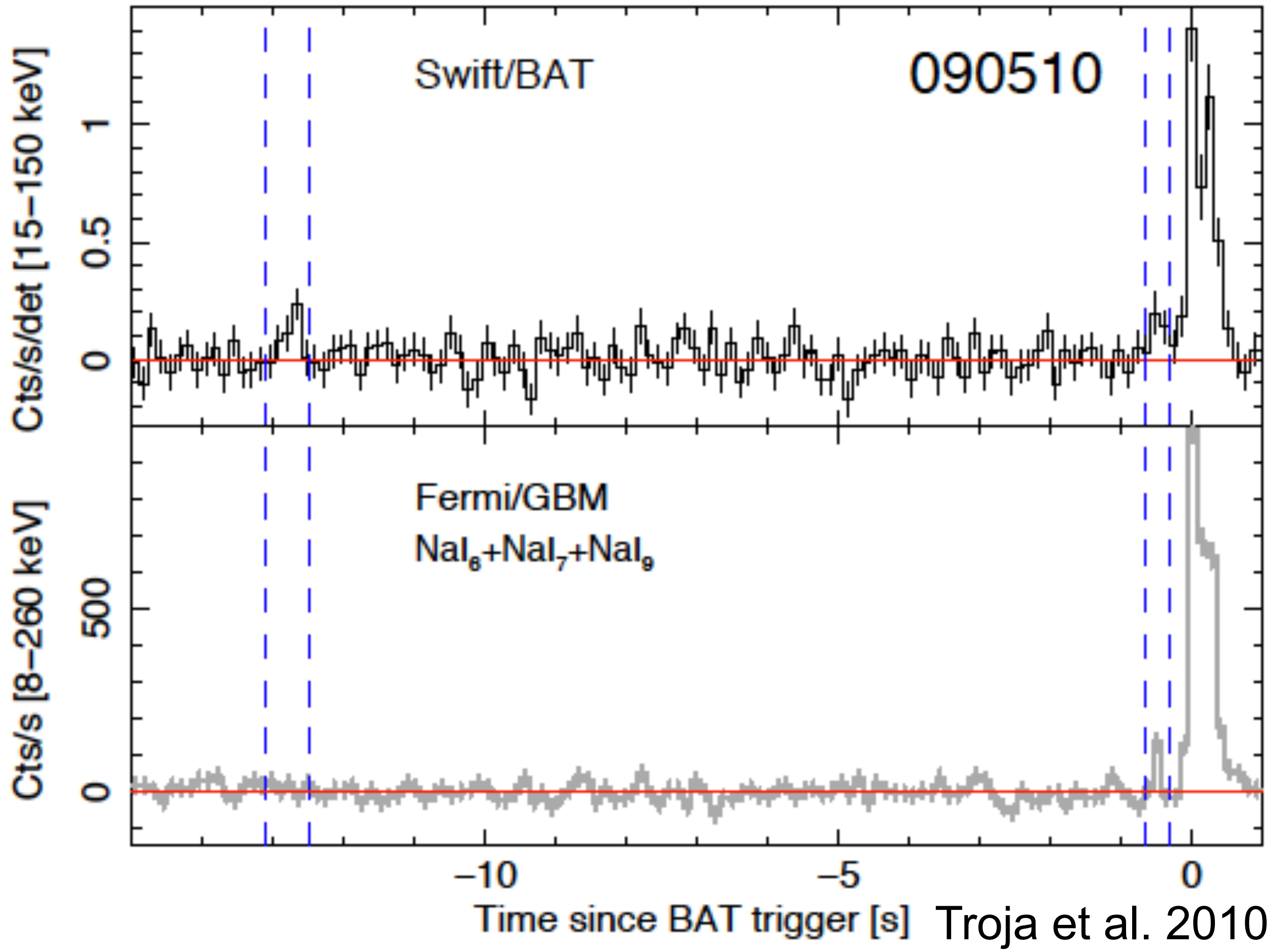


Perley et al. 2009

T_{90} >> 2 s

Short/hard spike
Long/soft tail

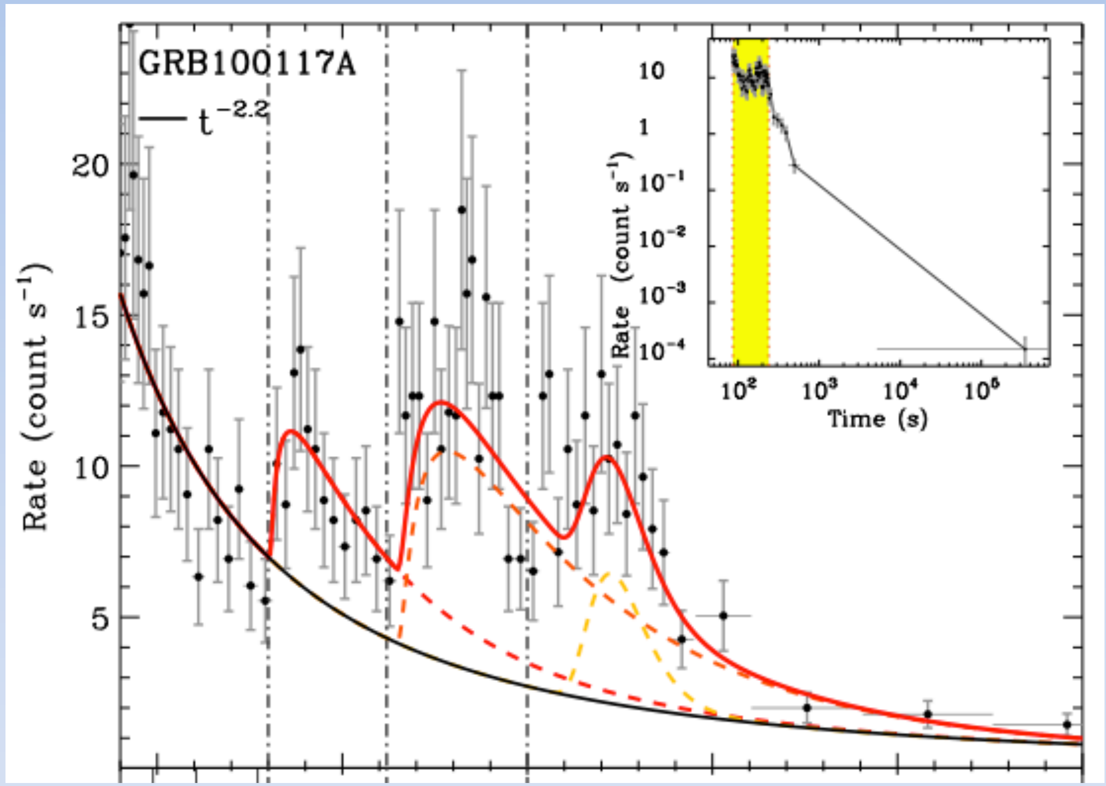
Precursors

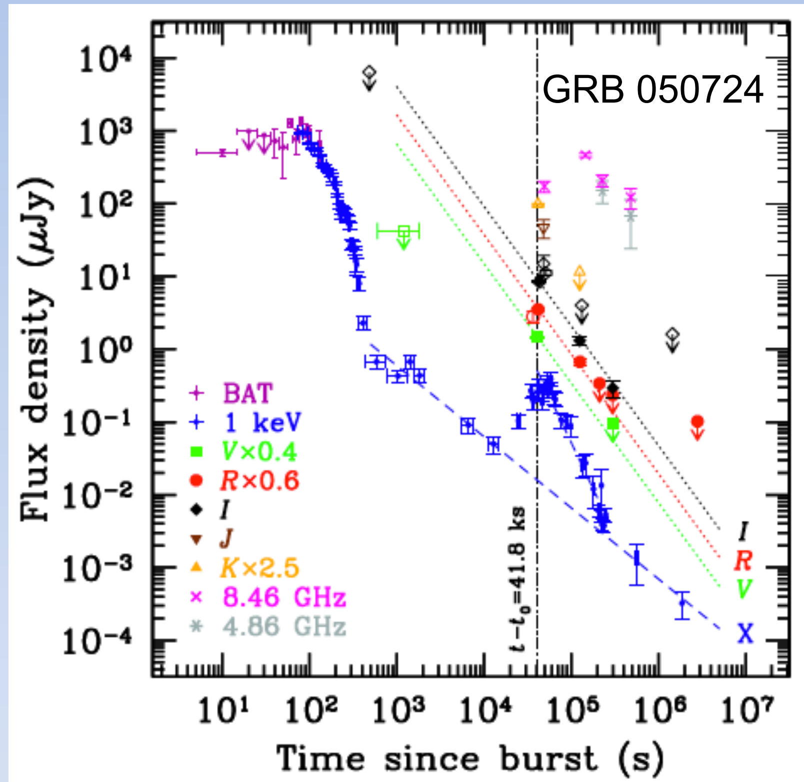


Troja et al. 2010

Precursors to the “main” prompt event are found in short and long GRBs

Flares

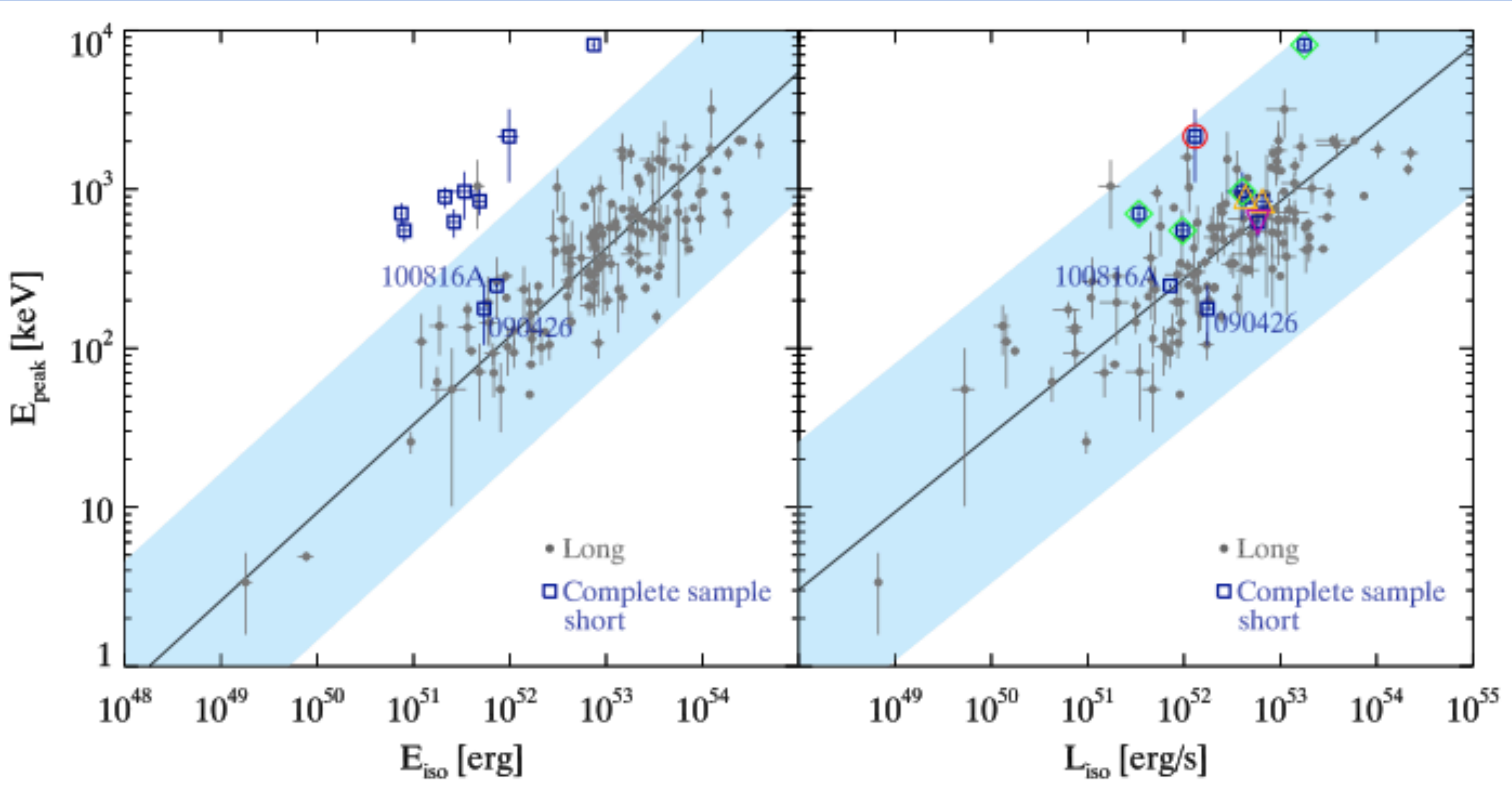




X-ray flares are found in short and long GRBs.
They are likely associated to the prompt emission (Margutti et al. 2010, 2011)
However, some late-time flares maybe associated to external shock (Bernardini et al. 2011)

Short vs. long GRBs: the prompt emission

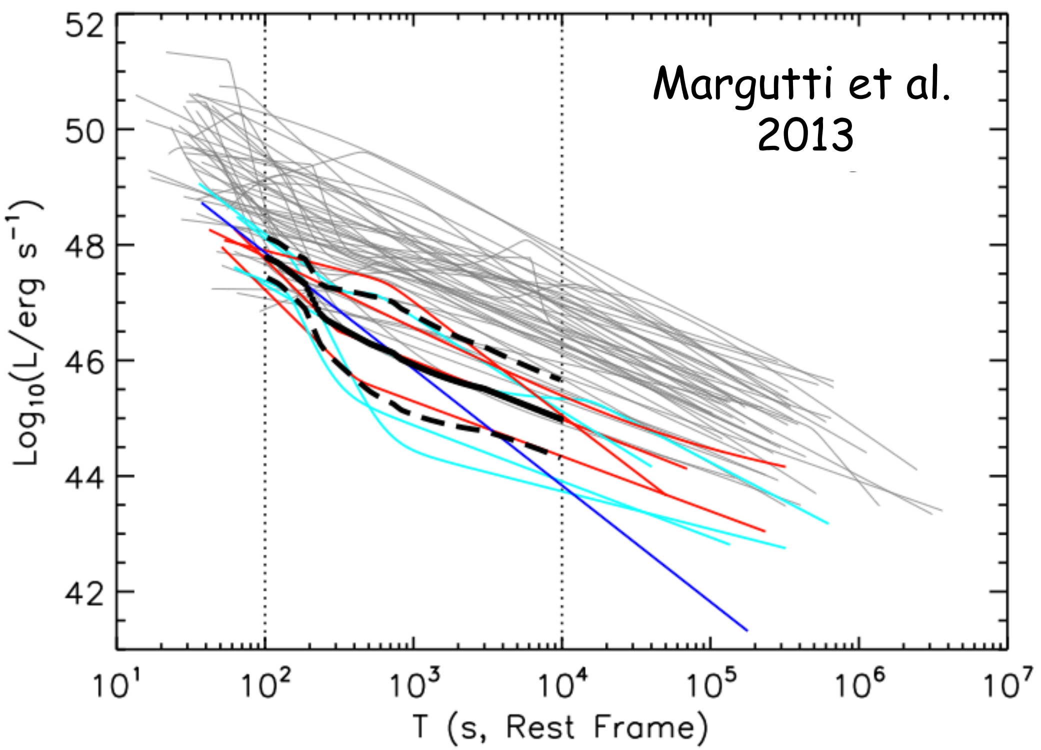
“Amati relation” “Yonetoku relation”



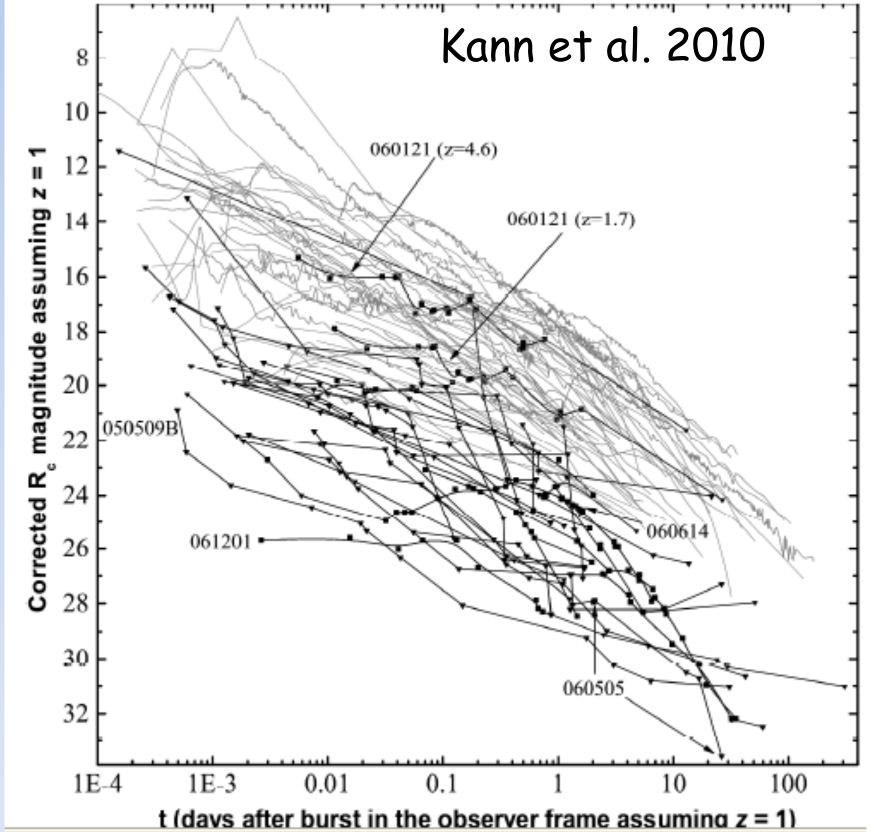
Amati et al. 2008
Younetoku et al. 2004
Ghirlanda et al. 2009
Zhang et al. 2012
D’Avanzo et al. in prep.

Short vs. long GRBs: the afterglow emission

X-ray



optical



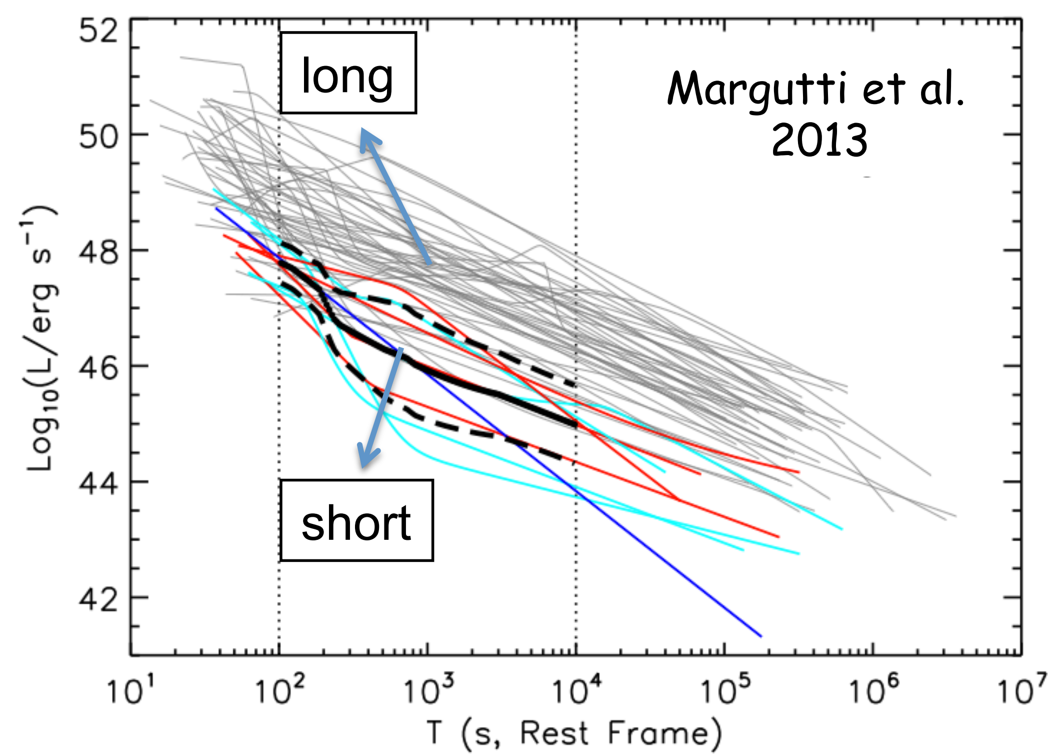
Short GRBs afterglows are fainter:

- less dense environment?

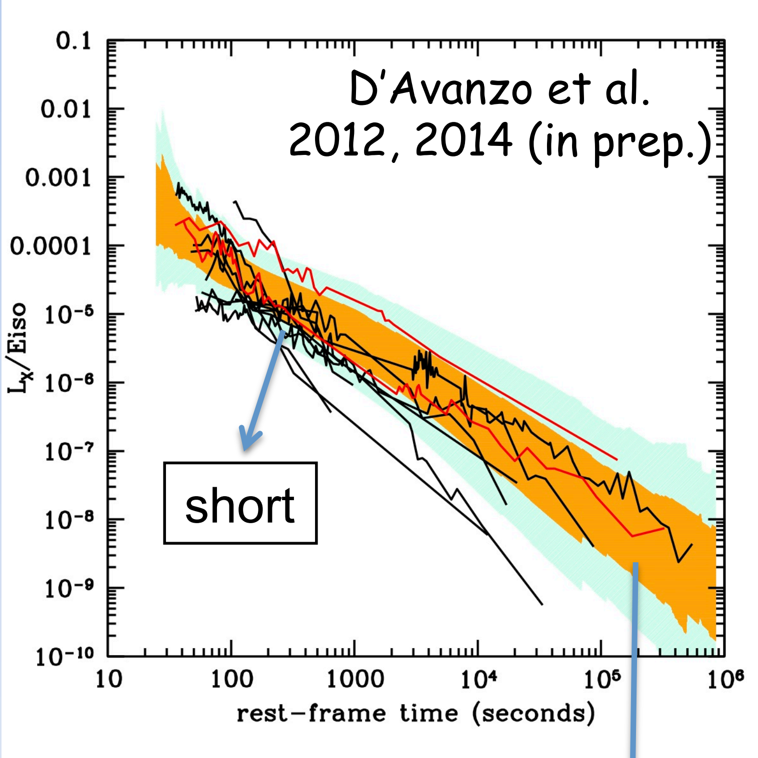
- less energetic?

Short vs. long GRBs: the afterglow emission

Rest frame X-ray luminosity



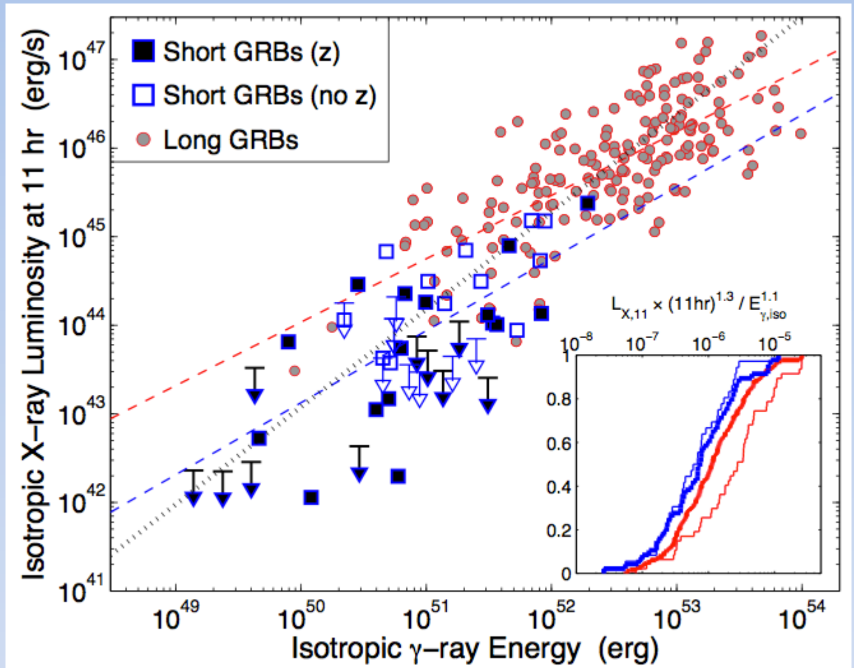
Rest frame X-ray luminosity normalized to Eiso

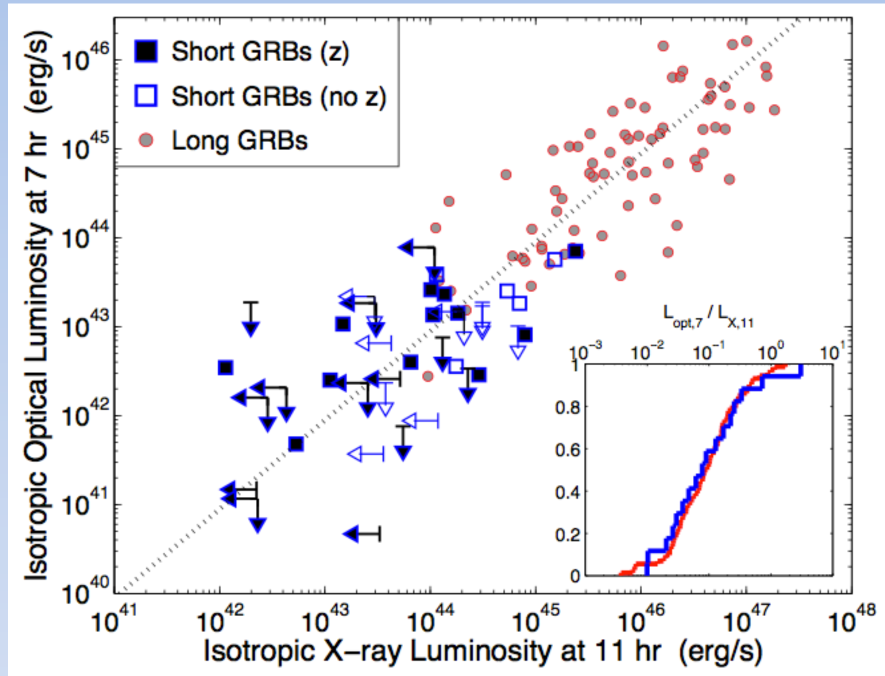


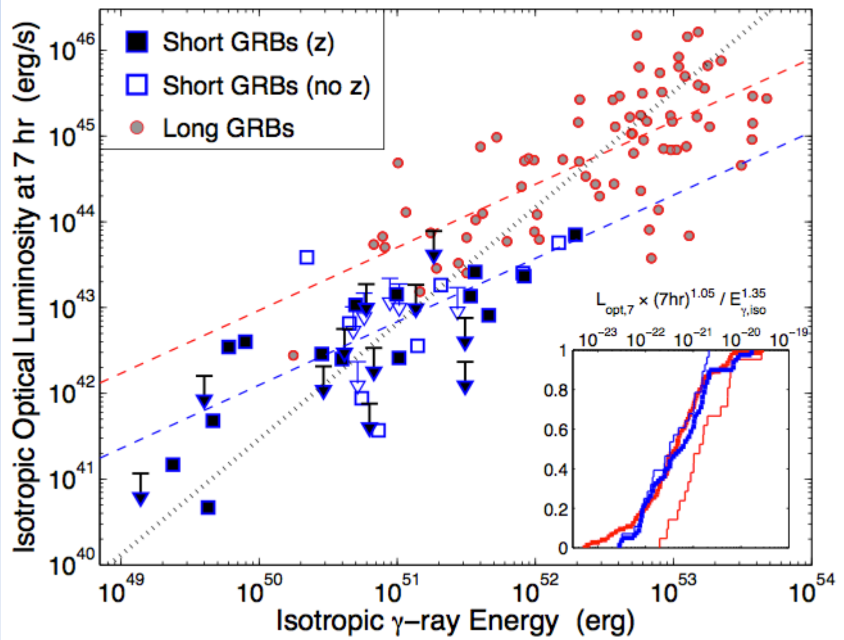
1sigma scatter for long GRBs

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

Short GRBs: prompt-afterglow correlations



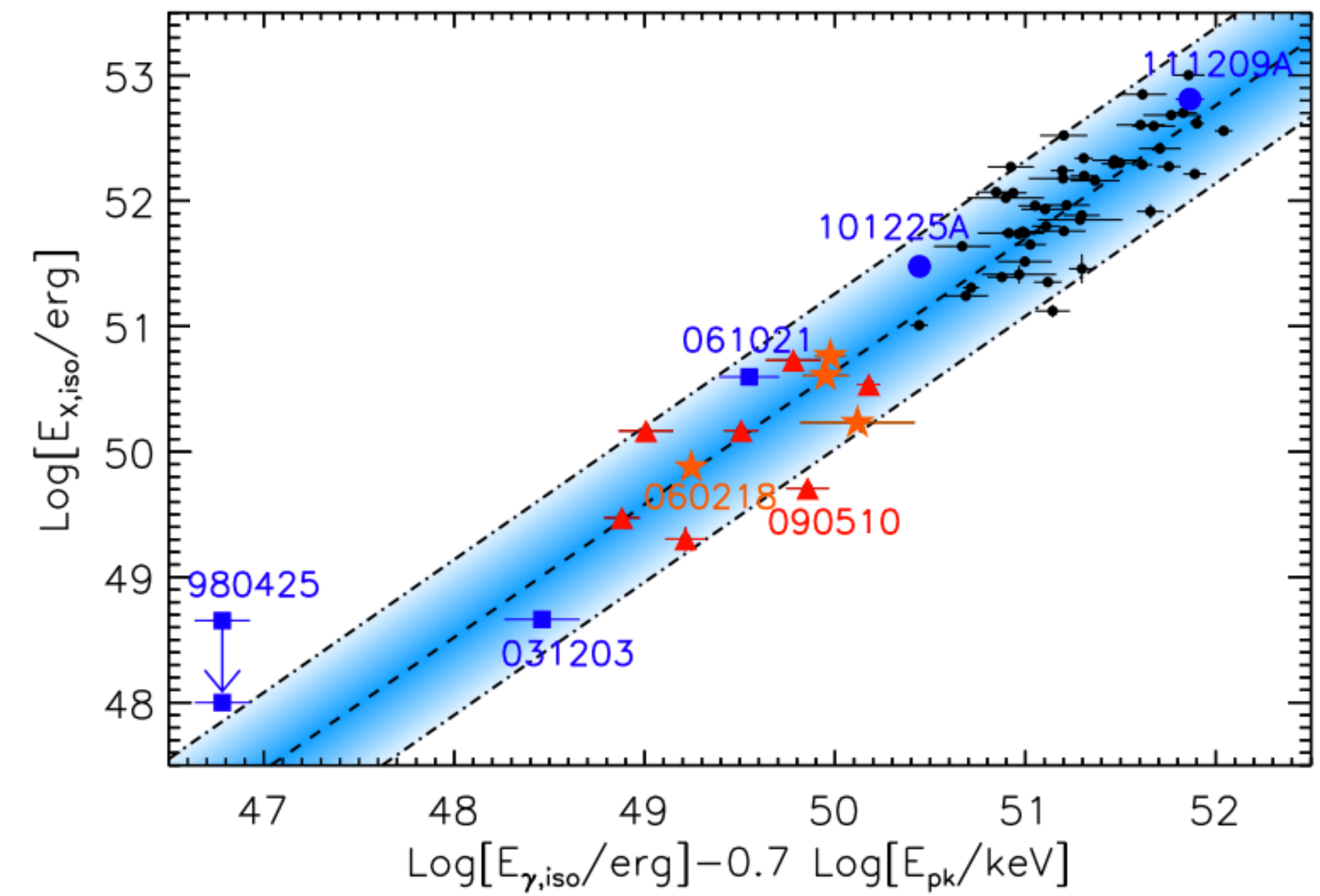




Berger et al. 2014

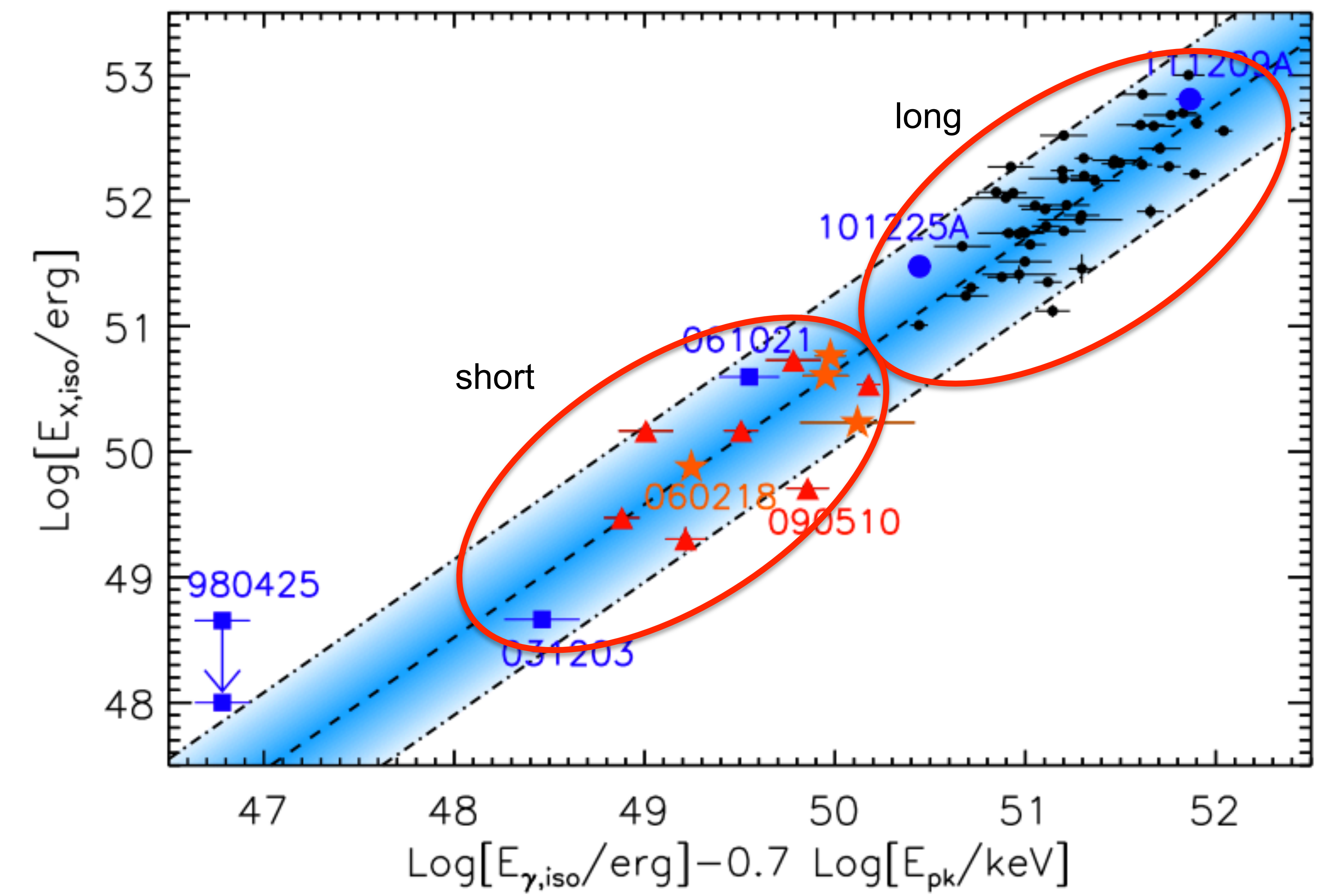
See also:
Nysewander et al. 2009
Margutti et al. 2013

Short and long GRBs: a unified view



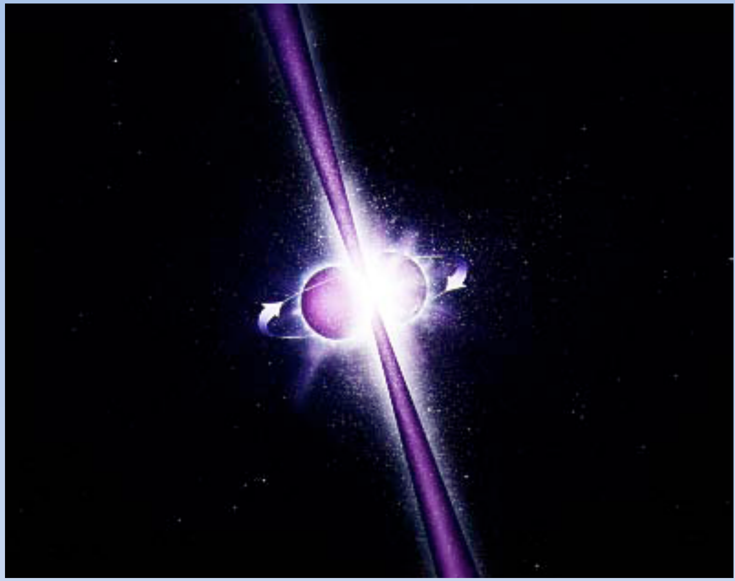
Bernardini et al. 2012; Margutti et al. 2013

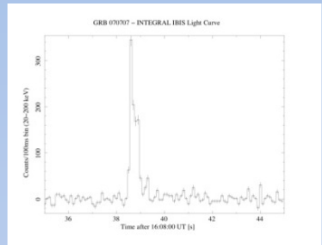
Short and long GRBs: a unified view



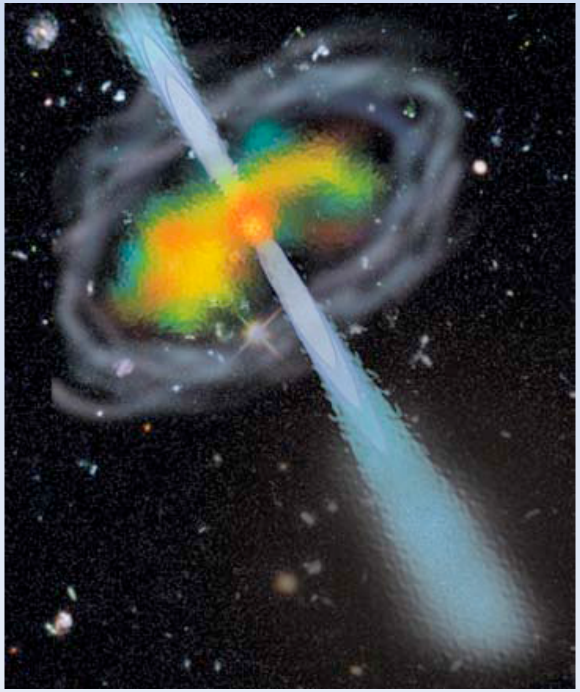
Bernardini et al. 2012; Margutti et al. 2013

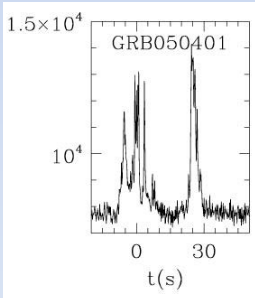
Progenitors





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

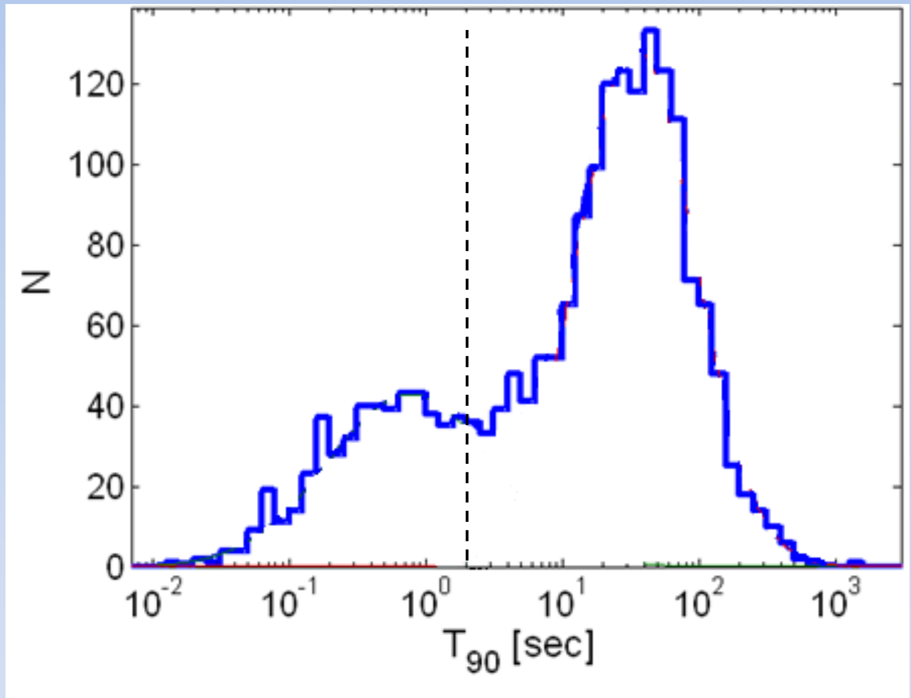




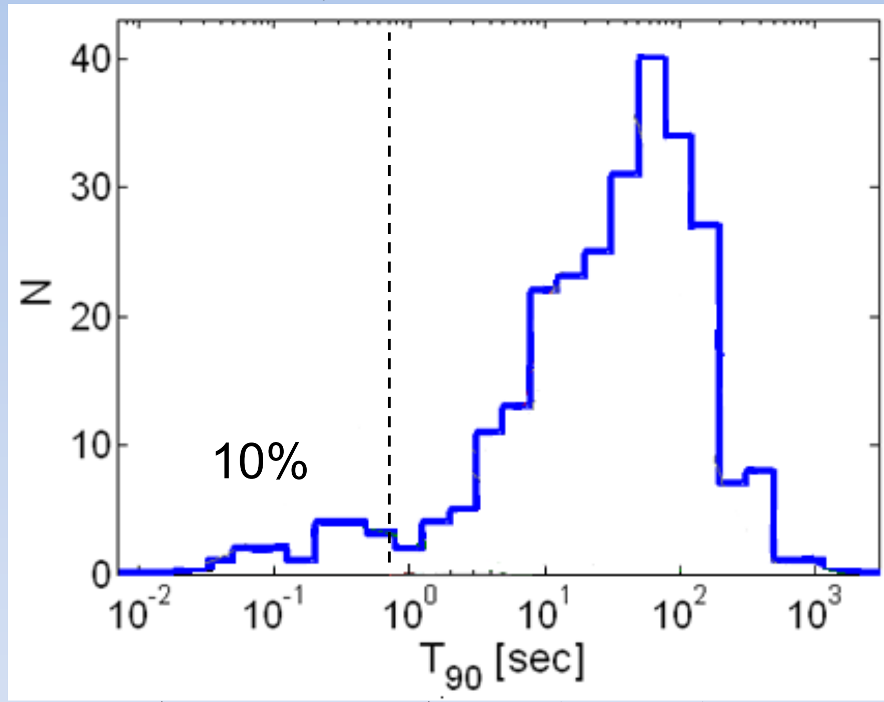
Long/soft GRBs
• spectral lag
• in SF galaxies
• younger stellar population
• many with associated SN
• collapsar progenitor model

How much short?

BATSE T_{90}



Swift T_{90}

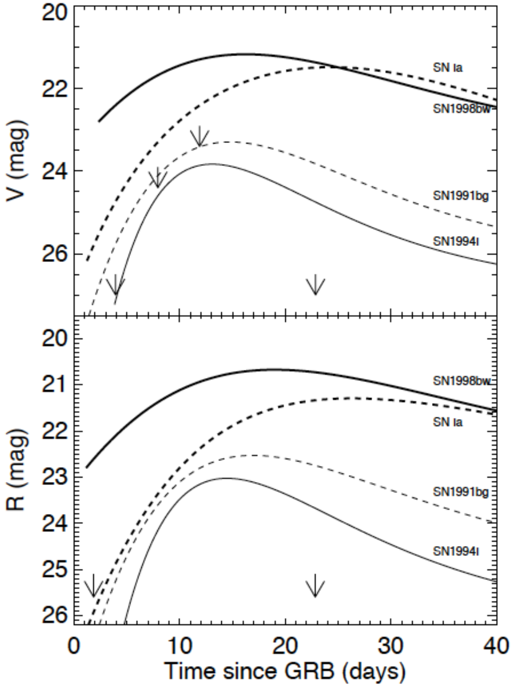


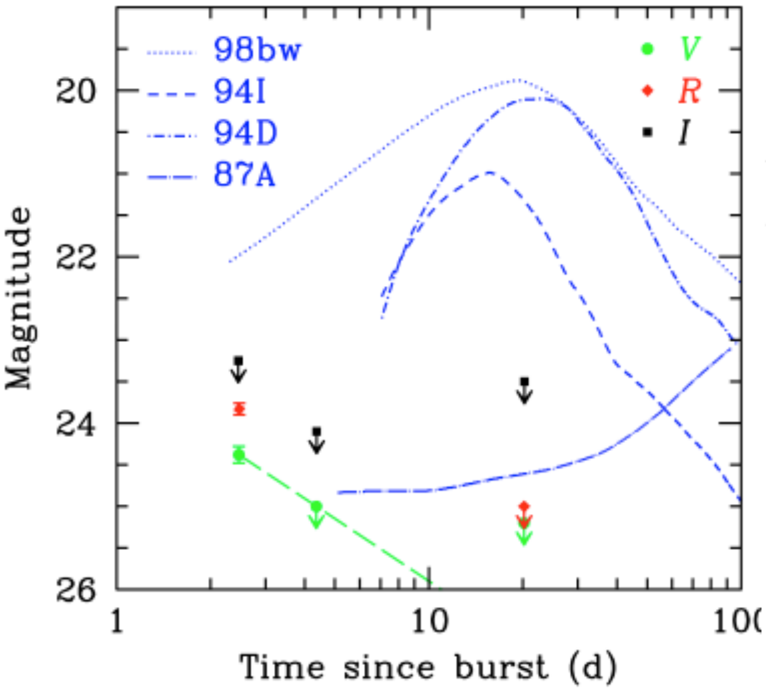
Credits: http://www.astro.ljmu.ac.uk/grb2012/presentations/presentations/nakar_liverpool2012.ppt

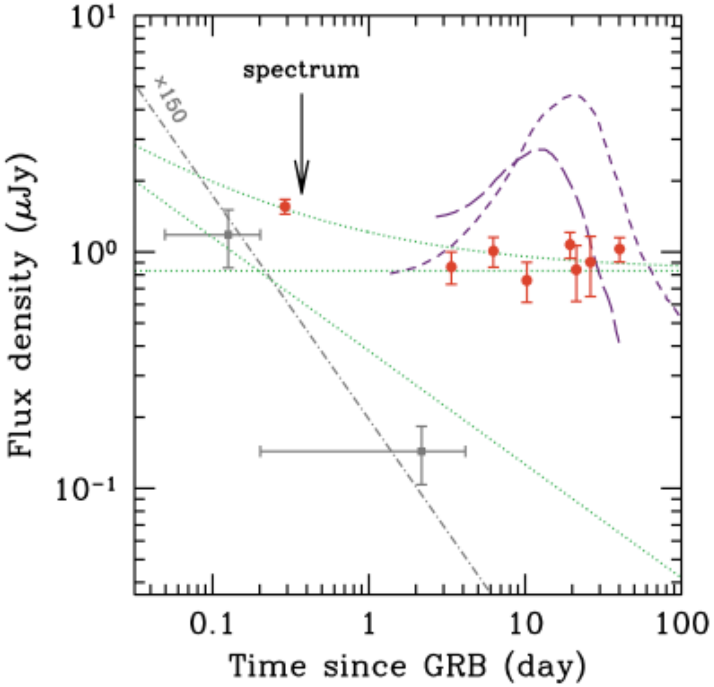
Bromberg et al. (2012) propose that the threshold duration for the Swift sample should be shorter than for the BATSE sample (0.6-0.7 s)

Swift GRBs with 1s $< T_{90} <$ 2s can be (>50%) collapsars

Short GRBs & (no) SNe







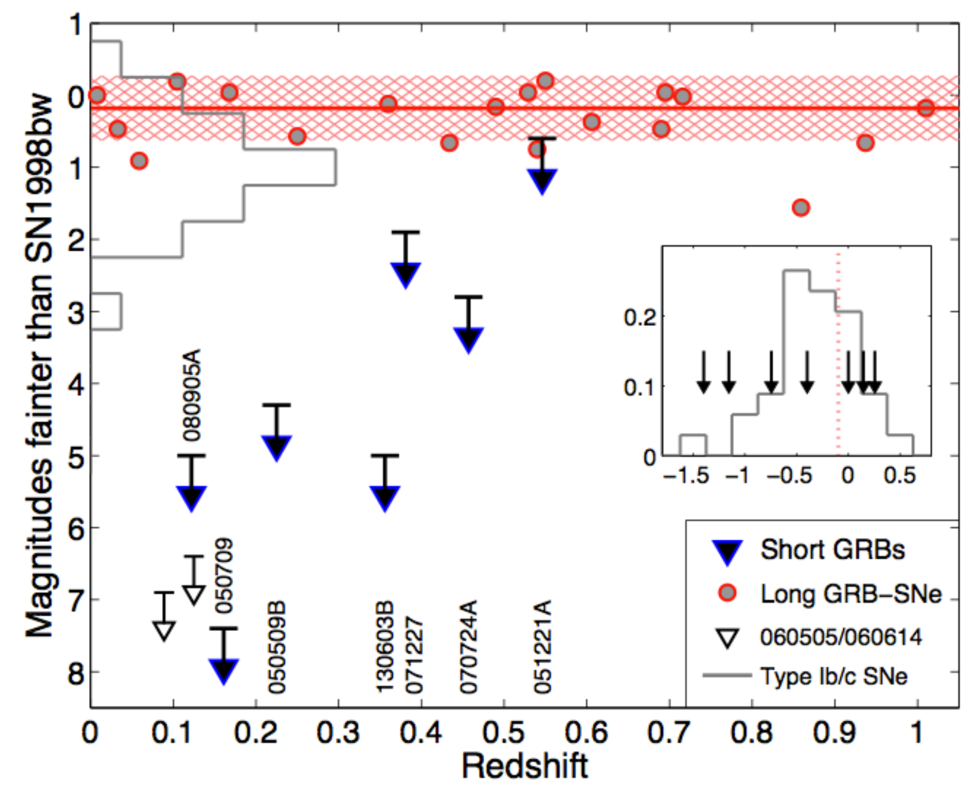
GRB 050509B
(z=0.225)

GRB 050709
(z=0.161)

GRB 071227
(z=0.381)

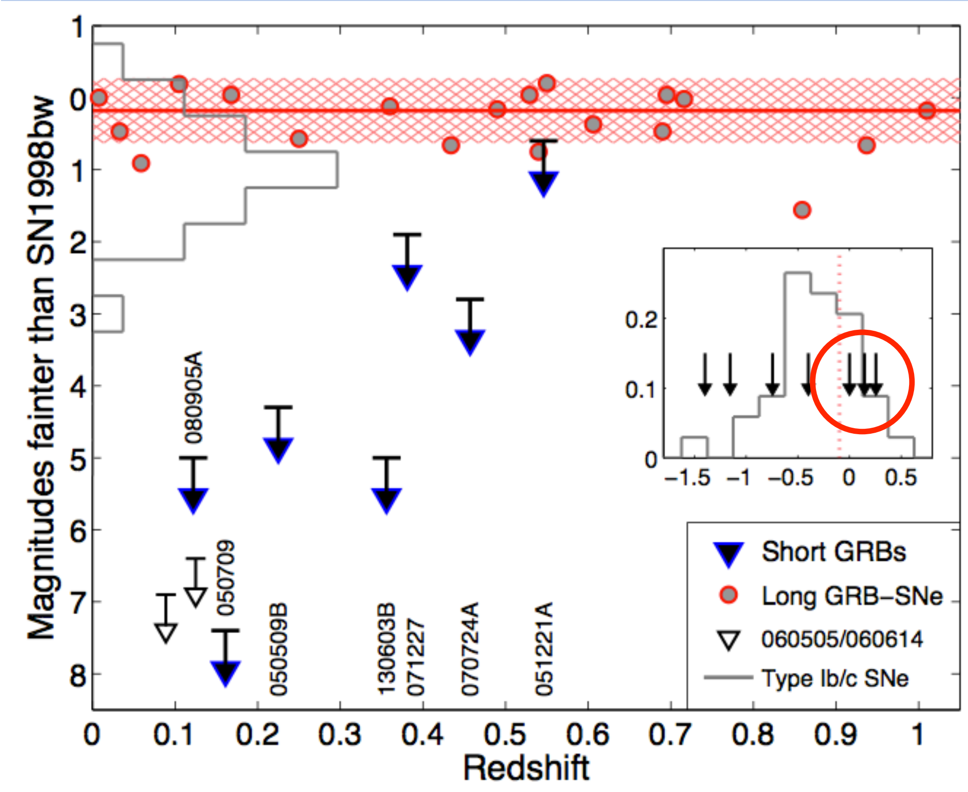
Hjorth et al. 2005
Covino et al. 2006
D'Avanzo et al. 2009

Short GRBs & (no) SNe

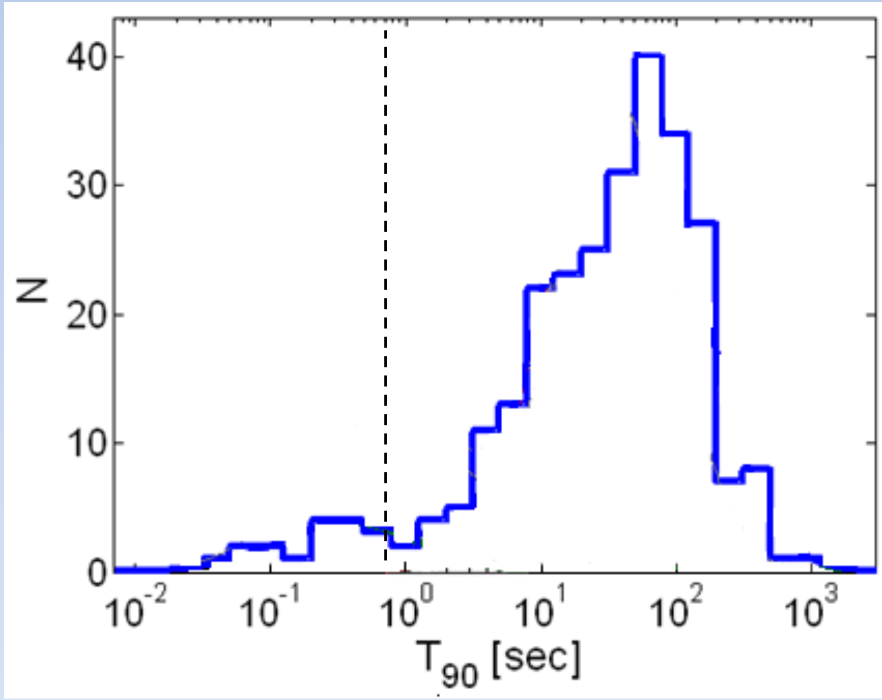


Berger et al. 2014

Short GRBs & (no) SNe



Berger et al. 2014

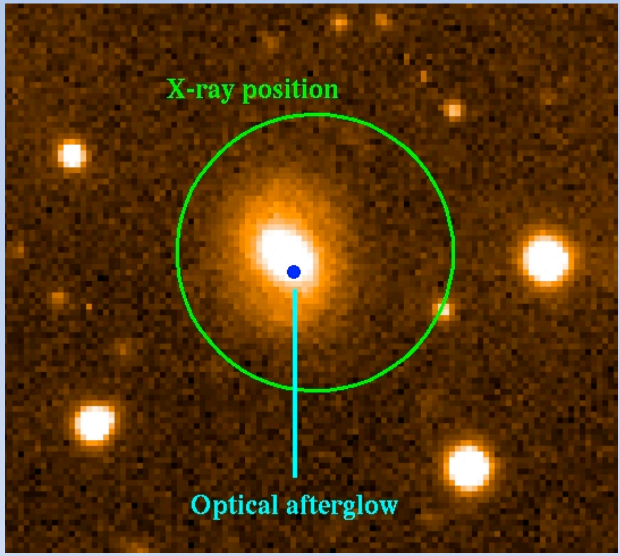


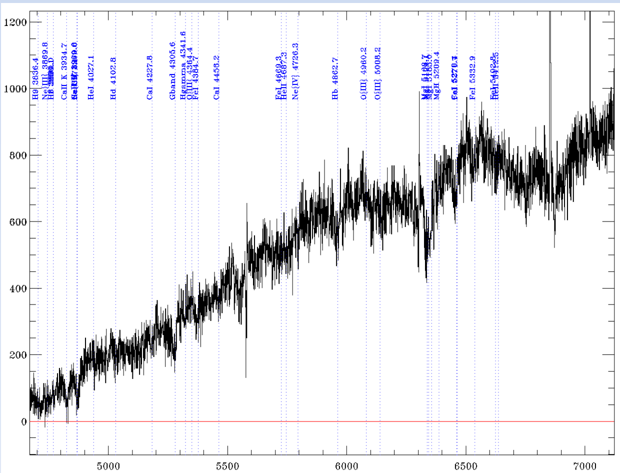
Bromberg et al. 2012

At least 3 short GRB with duration > 1 s
have no SN associated

Short GRB hosts

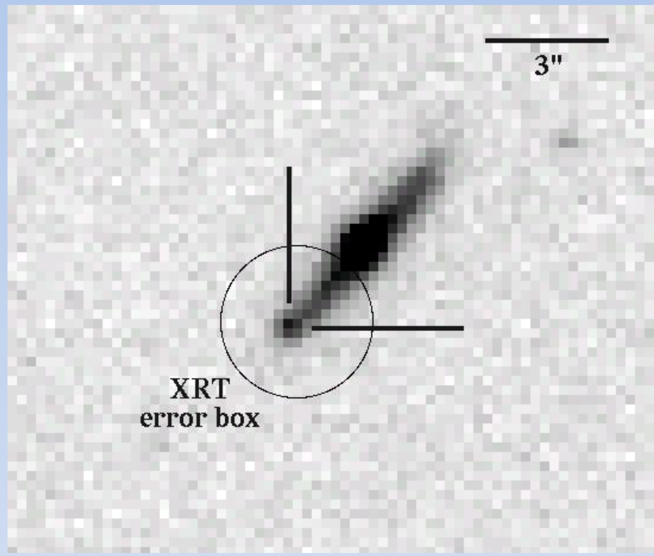
Early-type

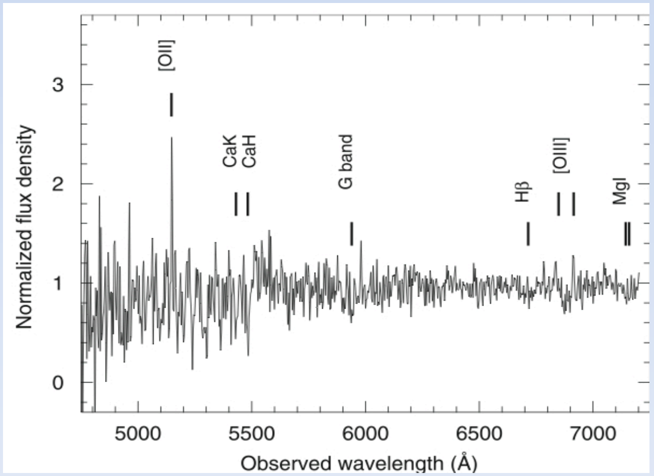




GRB 050724
Barthelmy et al. 2005;
Malesani et al. 2007

Late-type





GRB 071227
D'Avanzo et al. 2009

Host-less

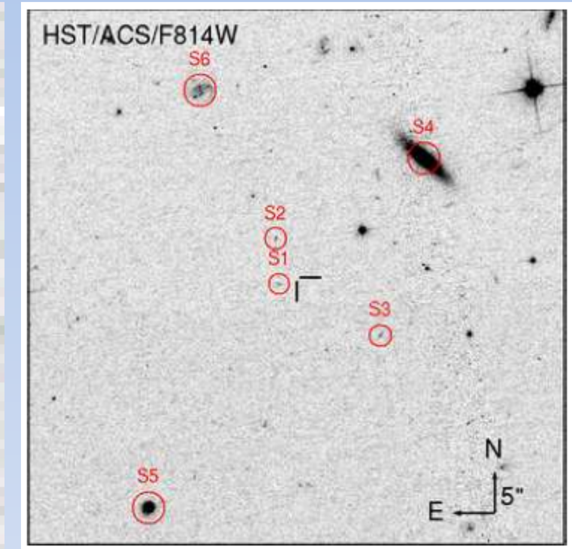


TABLE 2
Observations of Short GRBs with Optical Afterglows and no Coincident Host Galaxies
(*Sample 2*)

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.

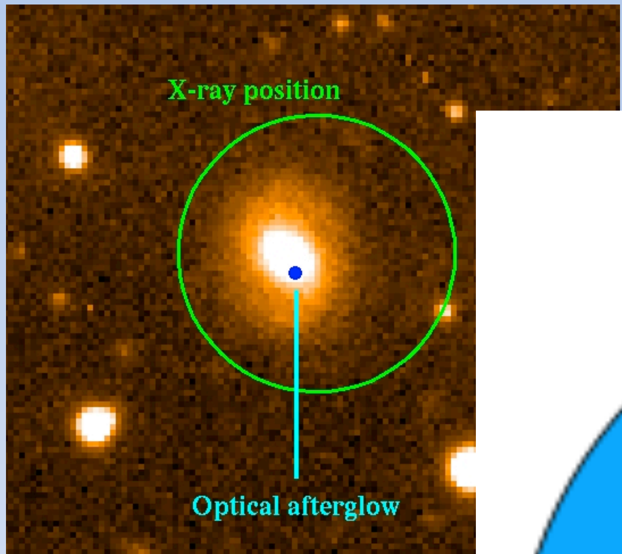
- High-z?
- (very-)low lum HG?
- kicked progenitor?

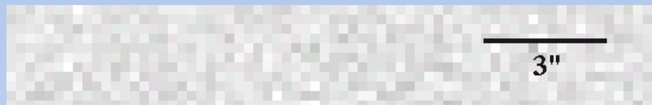
Short GRB hosts

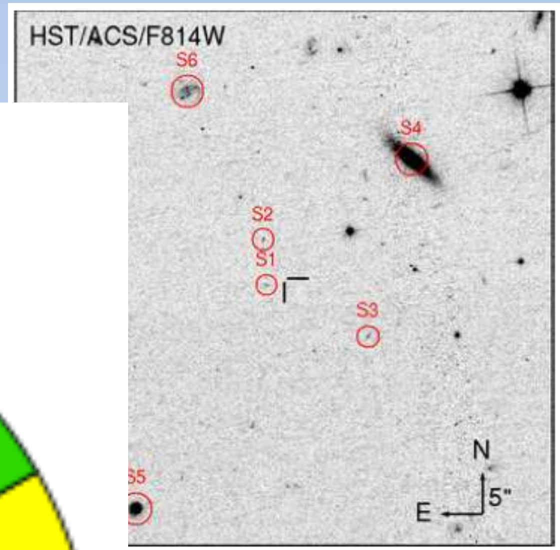
Early-type

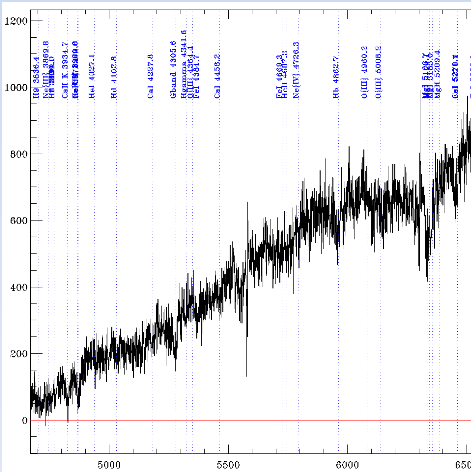
Late-type

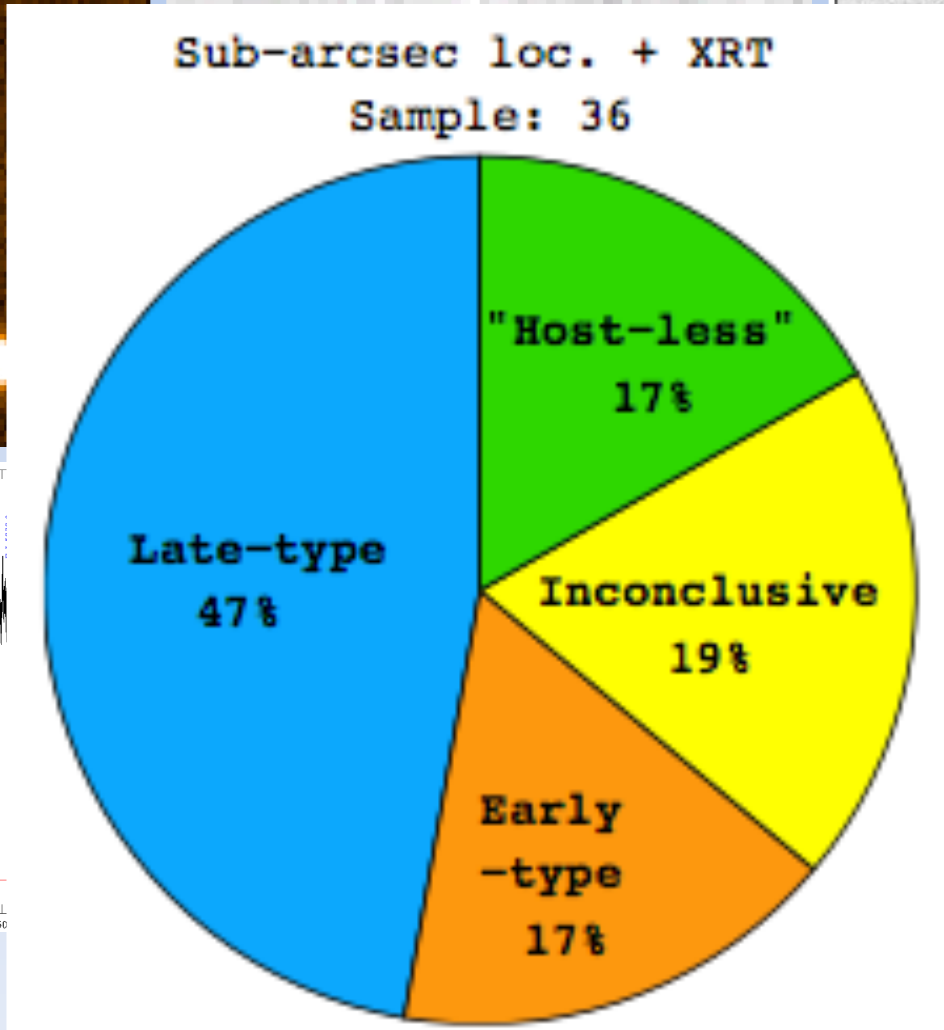
Host-less











Berger 2014

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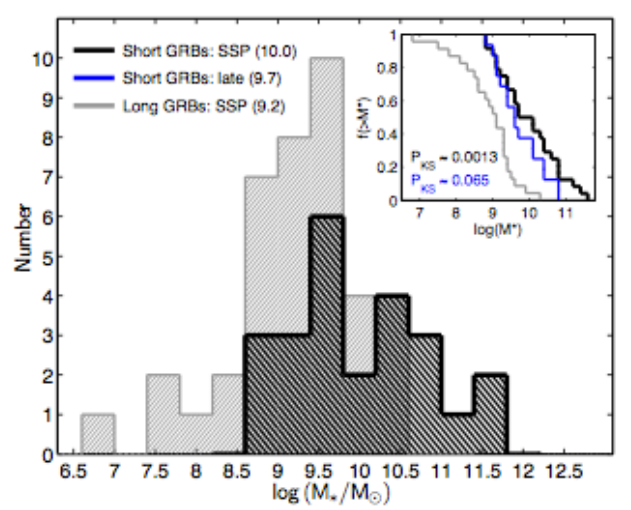
[a] Limits are 3σ.

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

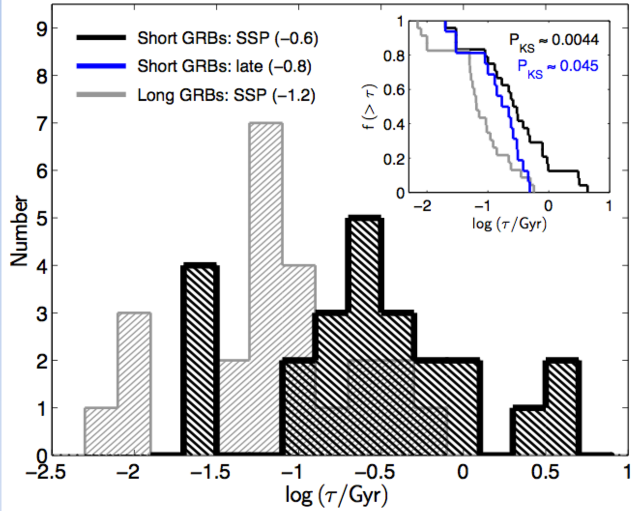
igh-z?
ery-)low lum HG?
cked progenitor?

Short GRB host galaxies

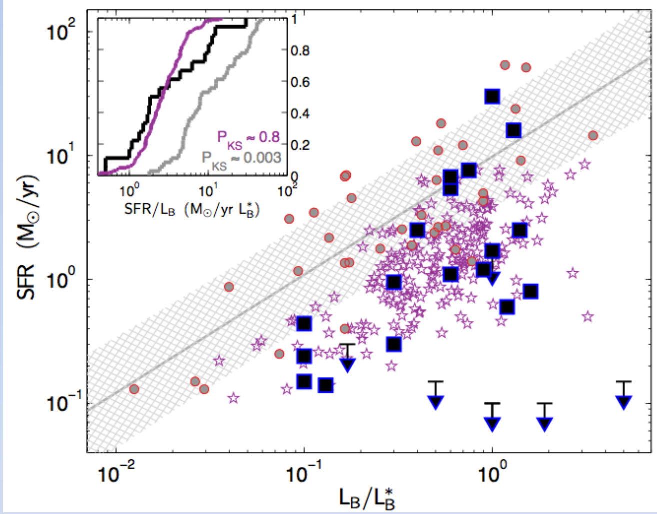
Mass



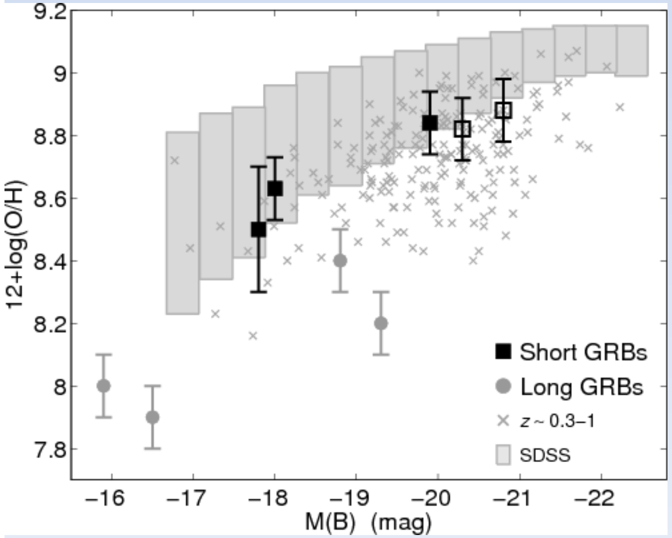
Age



SFR & Luminosity



Metallicity

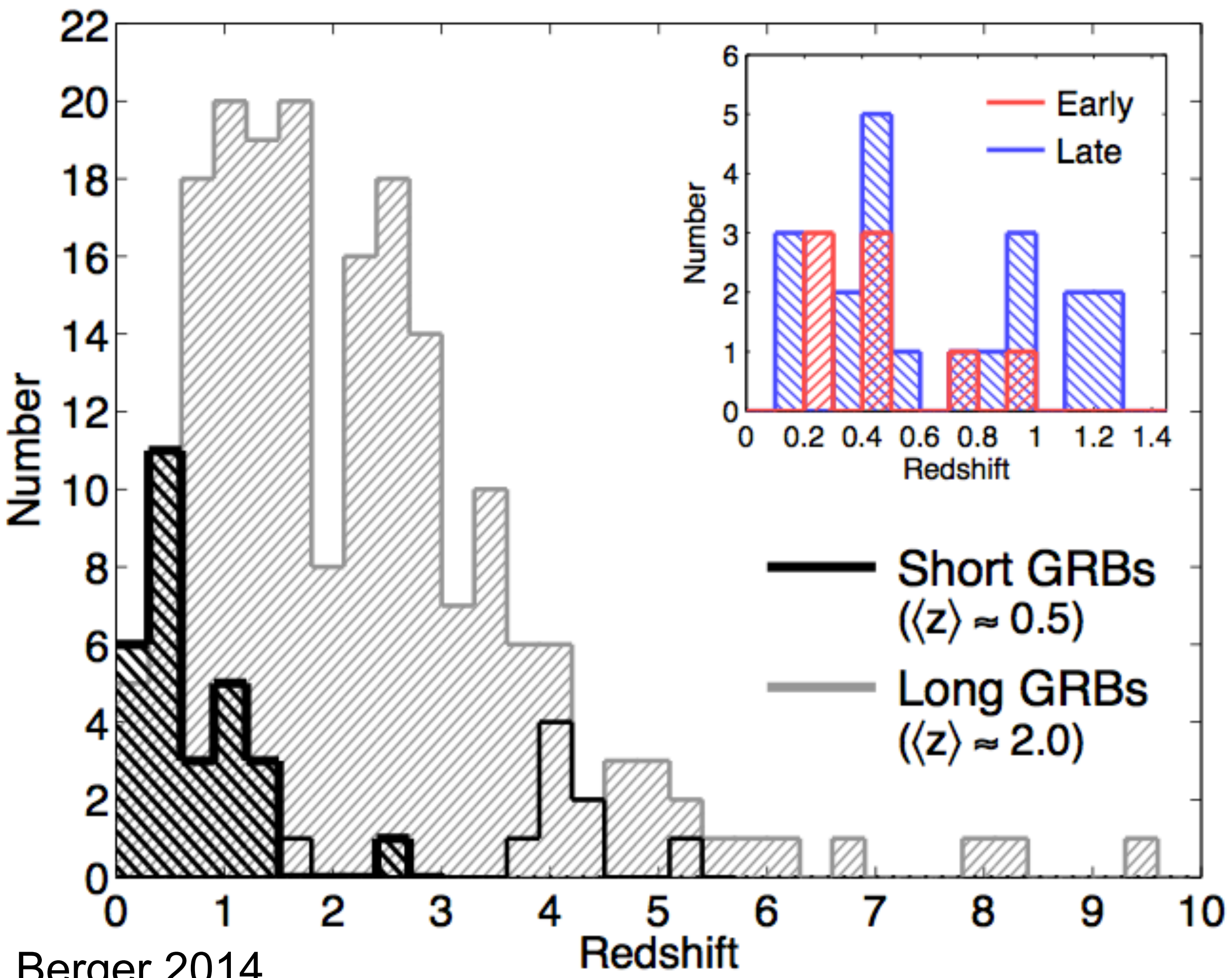


SGRBs are found in all type of galaxies
Properties similar to field (survey) galaxies

LGRBs are found in more peculiar hosts (with respect to field galaxies) mainly in terms of mass, SFR and metallicity

Berger 2009
Berger 2014

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. in prep.)

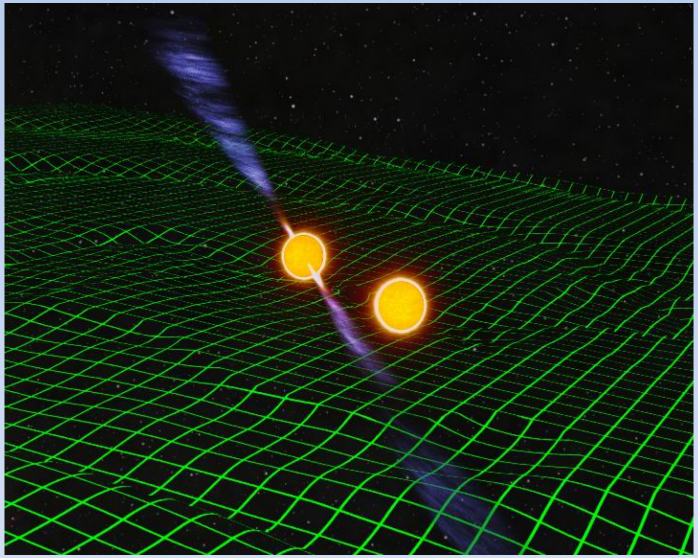
Hinting for a "primordial binary" progenitor, expected to have a z distribution peaking at z ≥ 0.8. (Salvaterra et al. 2008).

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:

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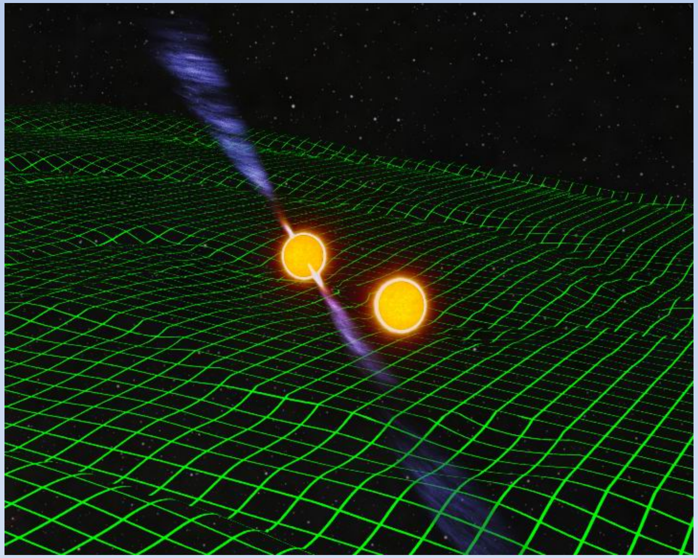

While orbiting, the two objects emit gravitational waves losing energy: MERGING

- 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

"primordial binaries"

- merging can occur in old and young stellar populations

- **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)

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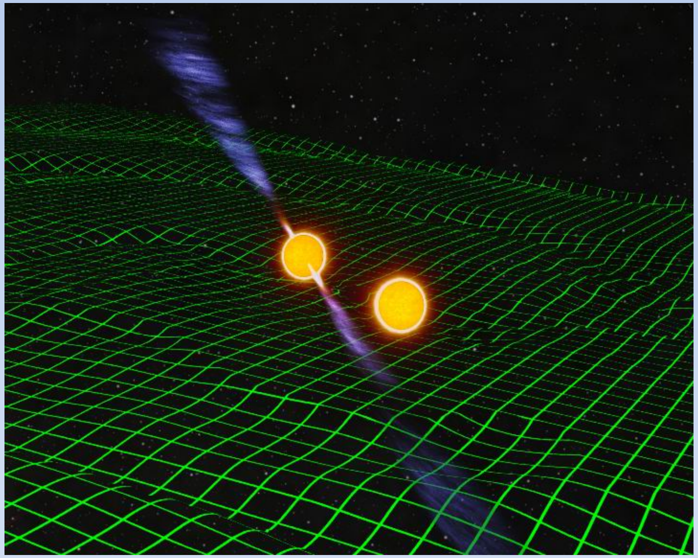
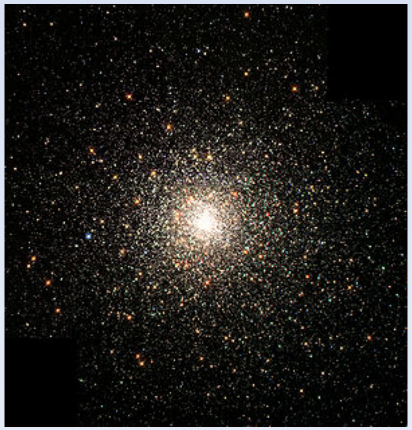
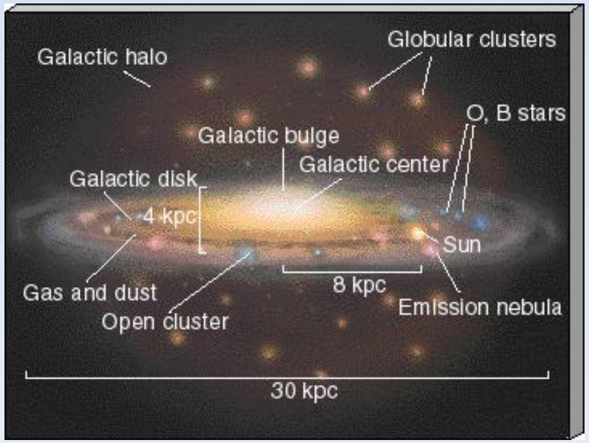


Another possibility: dynamical formation of a double compact object system (e.g. in globular clusters)

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



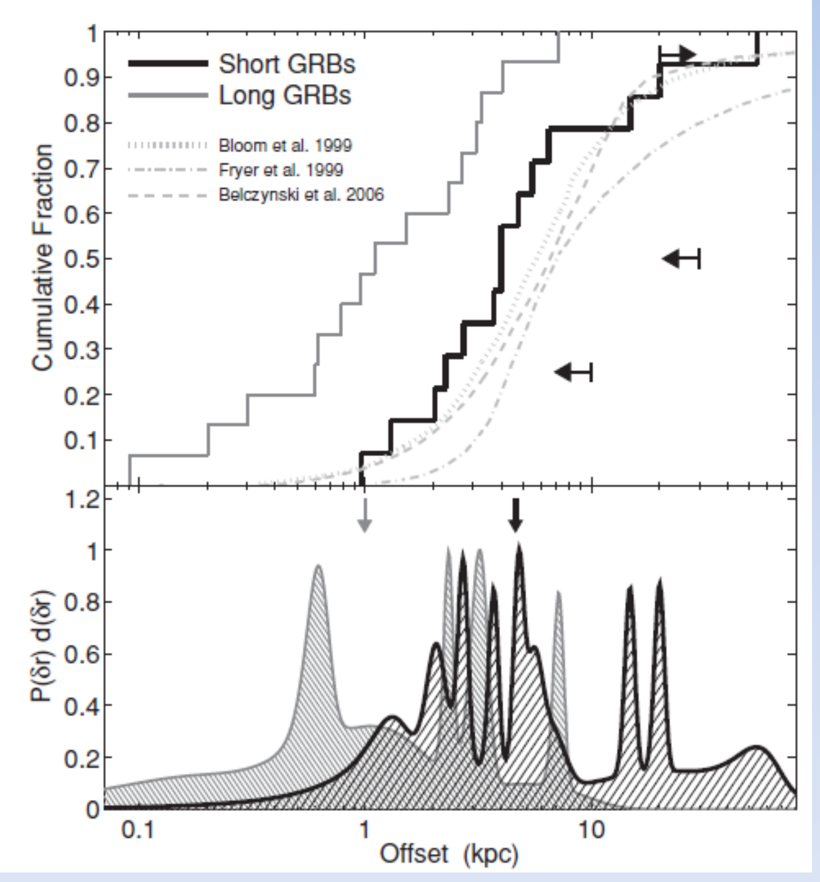


"dynamically formed binaries"

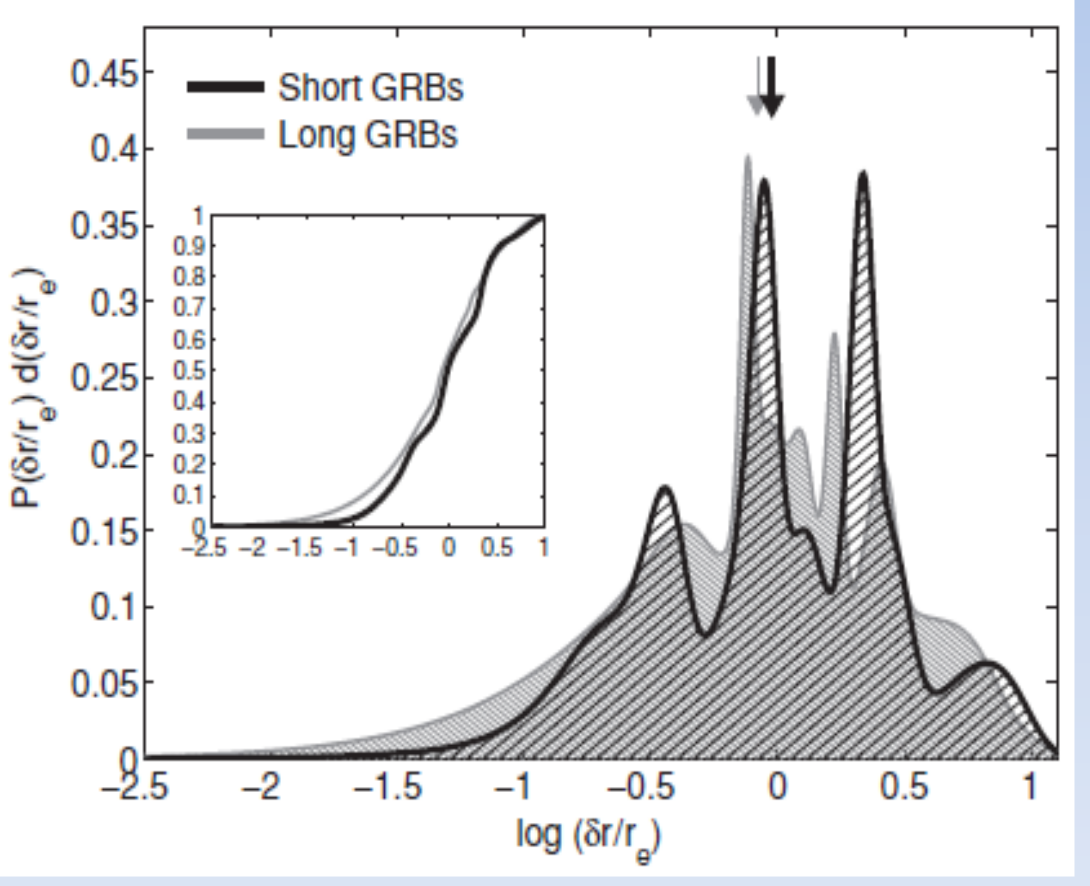
OFFSET/low density CBM

Short GRBs: Offsets

Offset from HG centre



Offset normalized to HG eff. radius

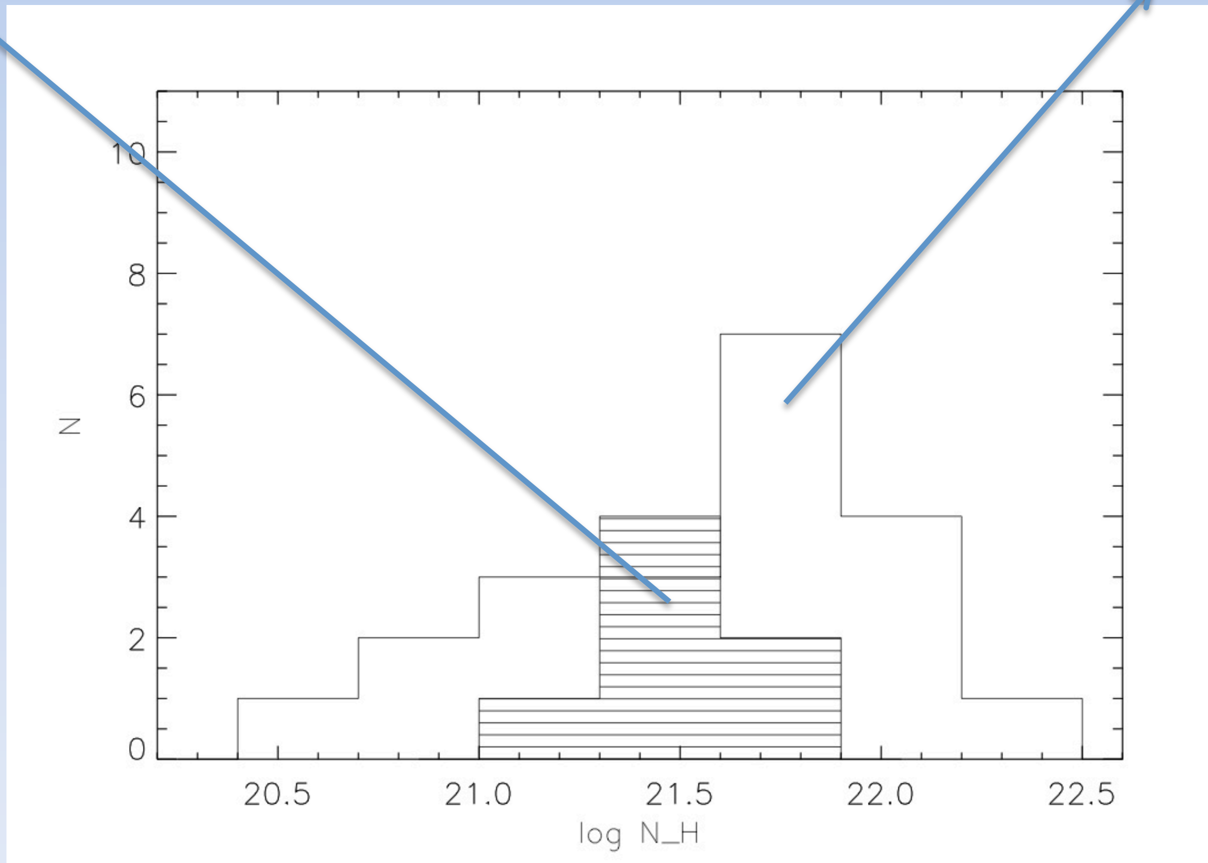


Fong et al. 2010

The X-ray absorbing column densities of SGRBs

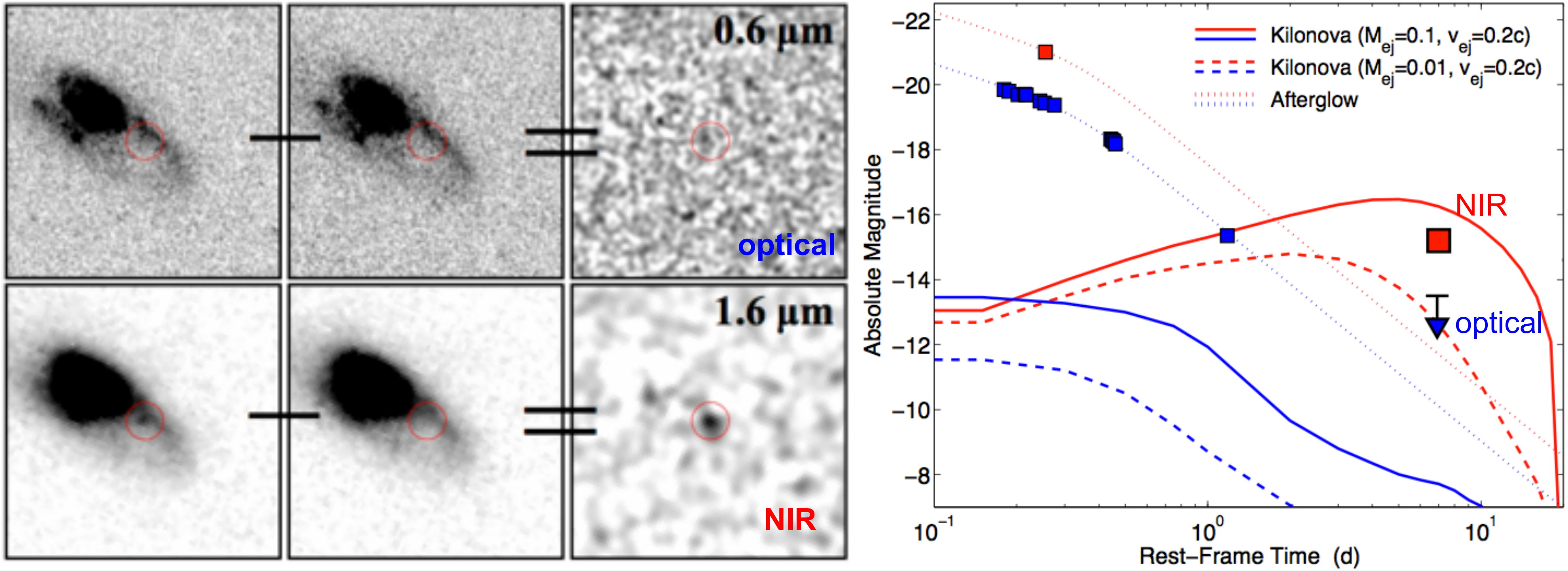
Intrinsic X-ray N_H for a complete (flux-limited) sample of bright SGRBs with $0.1 < z < 1.3$ (D'Avanzo et al. in prep.)

Intrinsic X-ray N_H for a complete (flux-limited) sample of bright LGRBs with $0.1 < z < 1.3$ (Campana et al. 2012)



See also: Kopac et al. 2012; Margutti et al. 2012

A Kilonova associated to GRB 130603B?

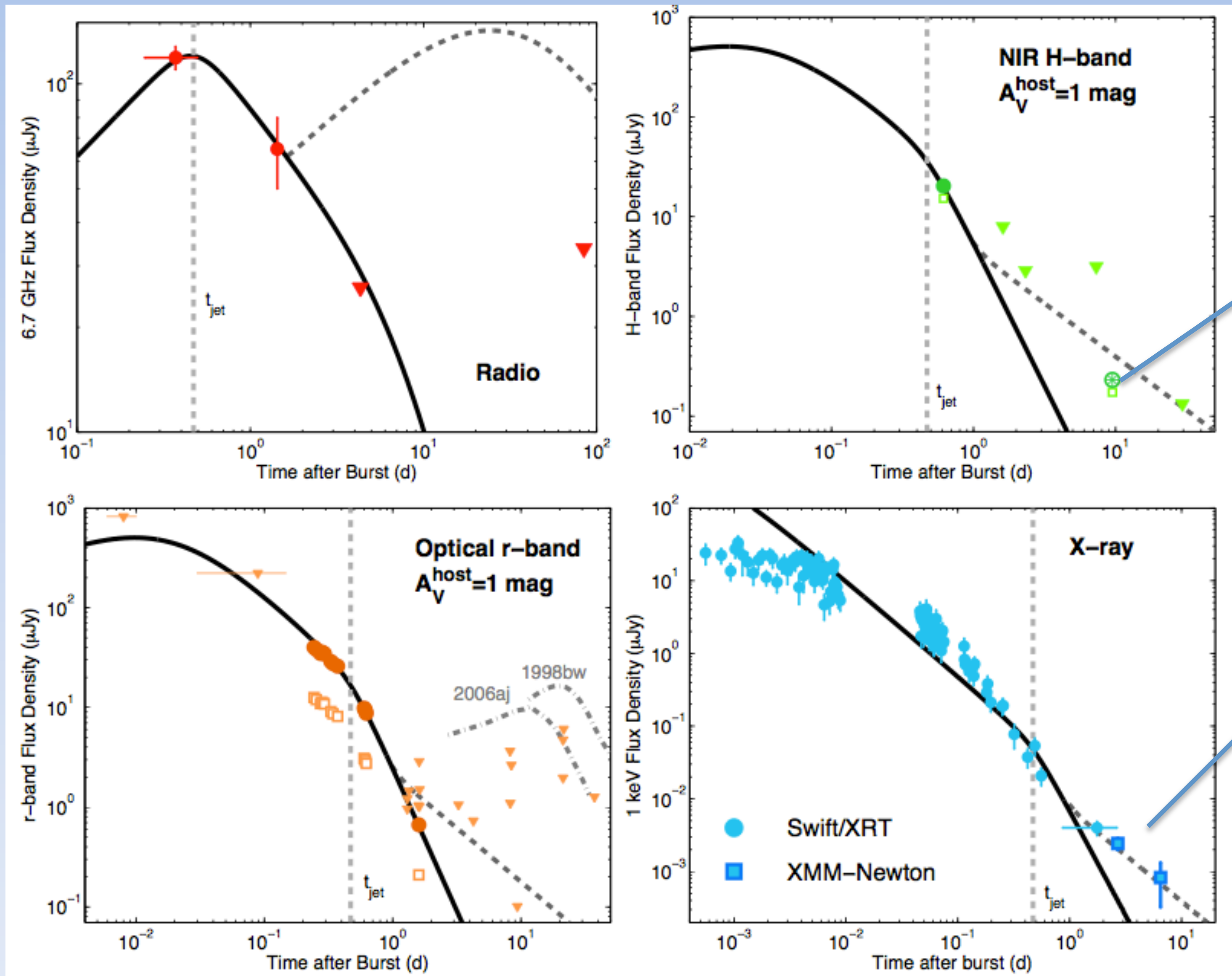


Tanvir et al. 2013

Berger et al. 2013

A "flux excess" is seen in the X-ray light curve too. Suggested to be due to fall-back accretion or to magnetar spin-down (Fong et al. 2014)

A Kilonova associated to GRB 130603B?



Kilonova
NIR excess

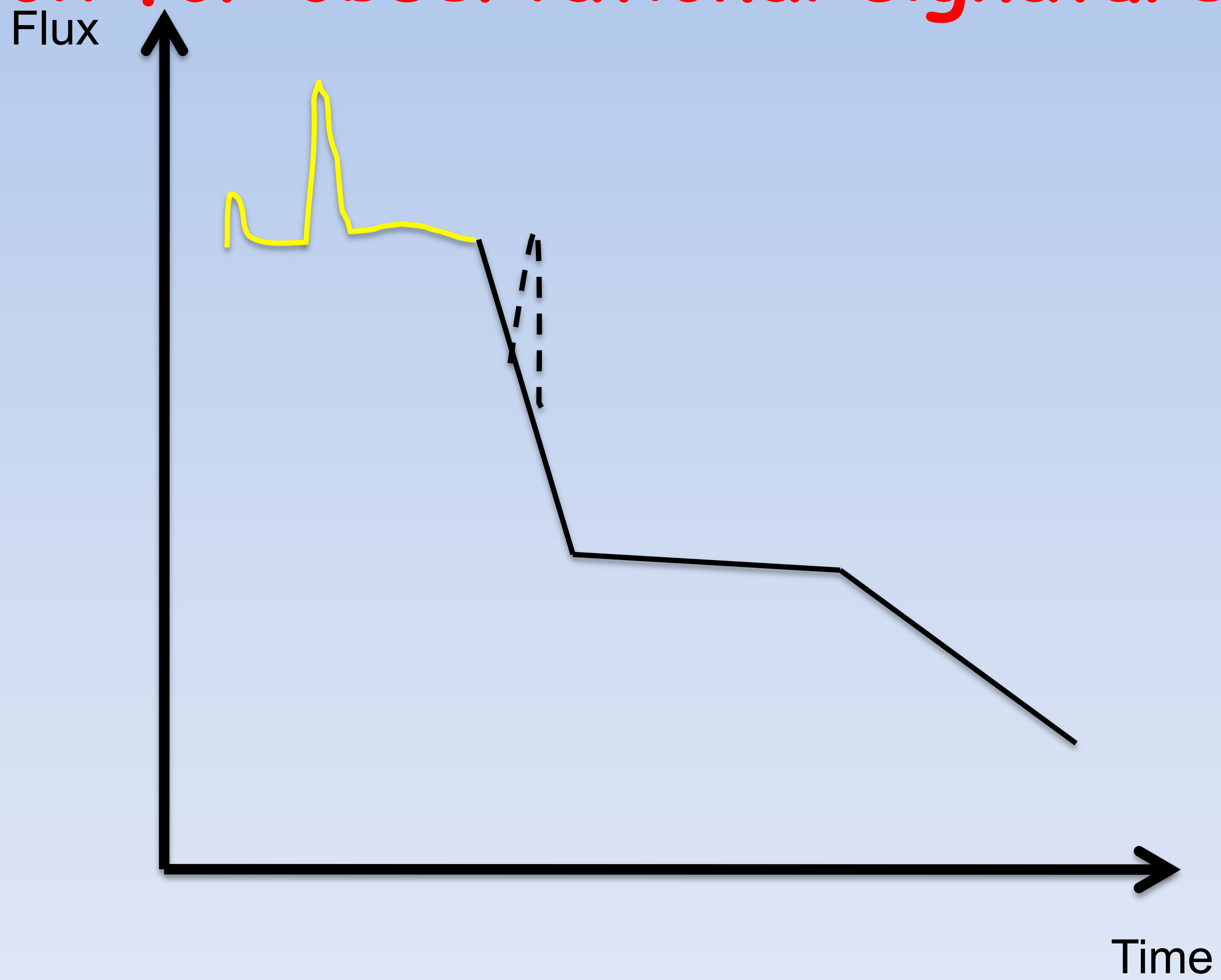
Fall-back
Accretion

or

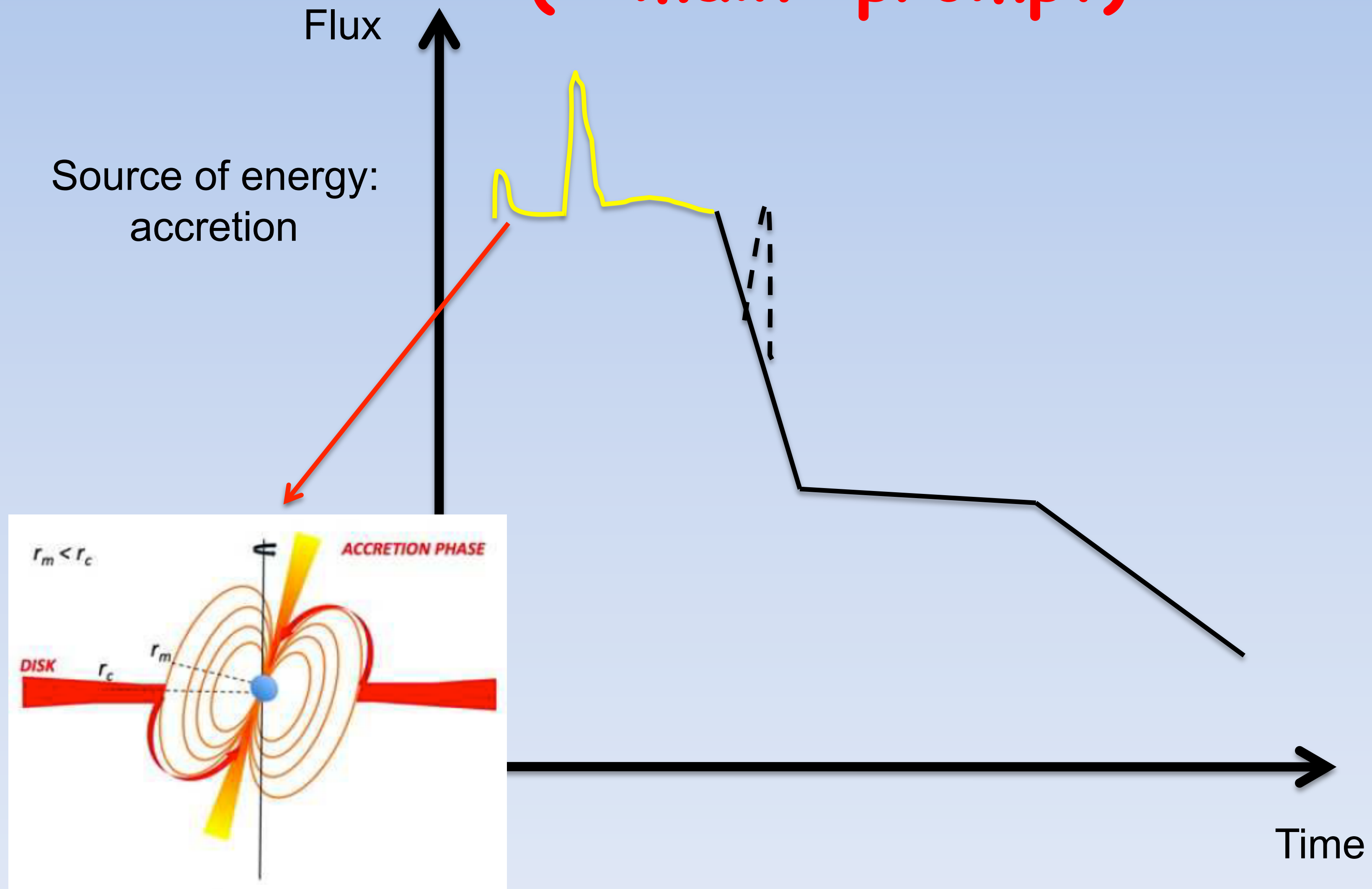
magnetar
spin-down

Fong et al. 2014

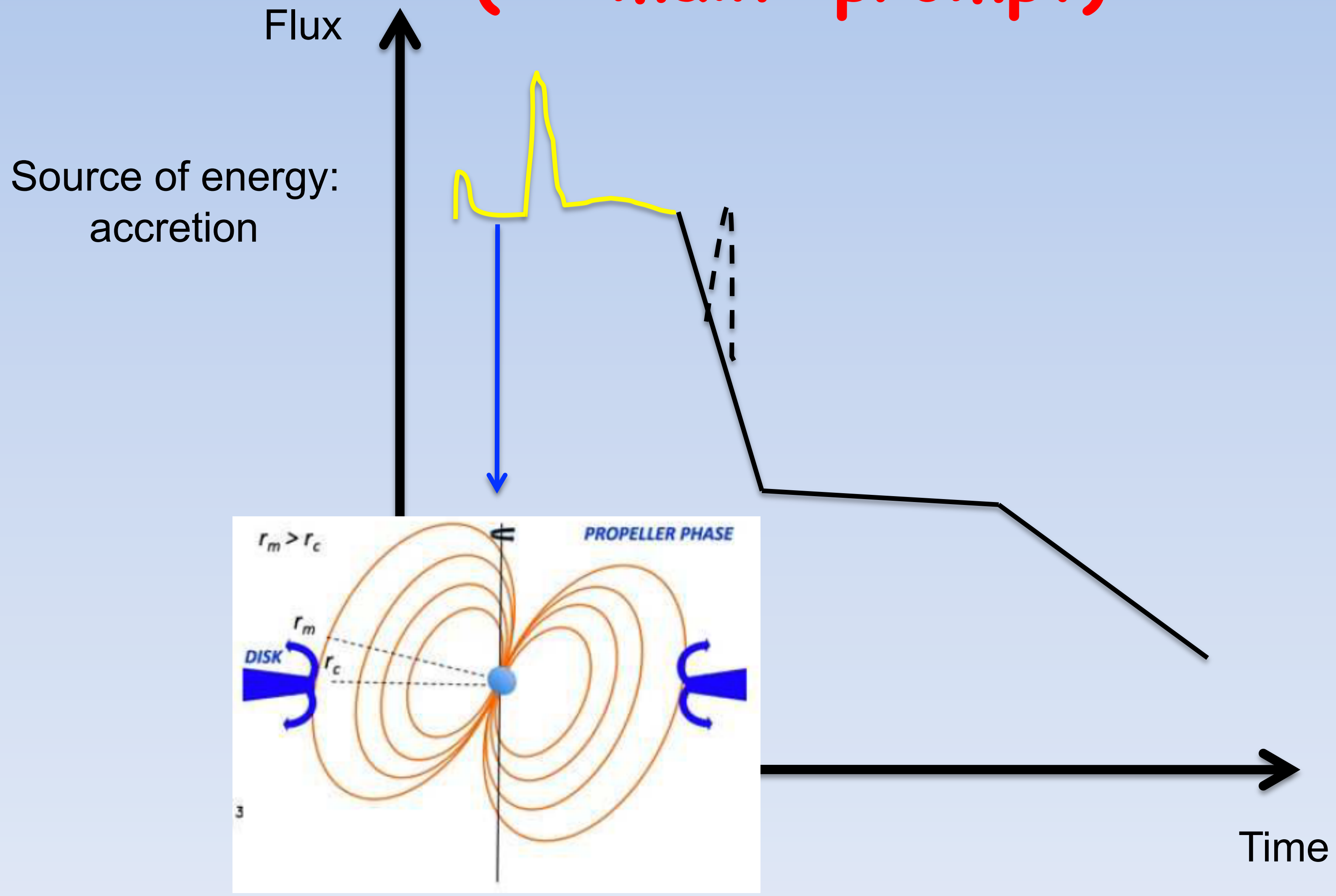
Magnetars as SGRBs progenitors: where to look for observational signatures



Magnetars as SGRBs progenitors: precursors (+"main" prompt)

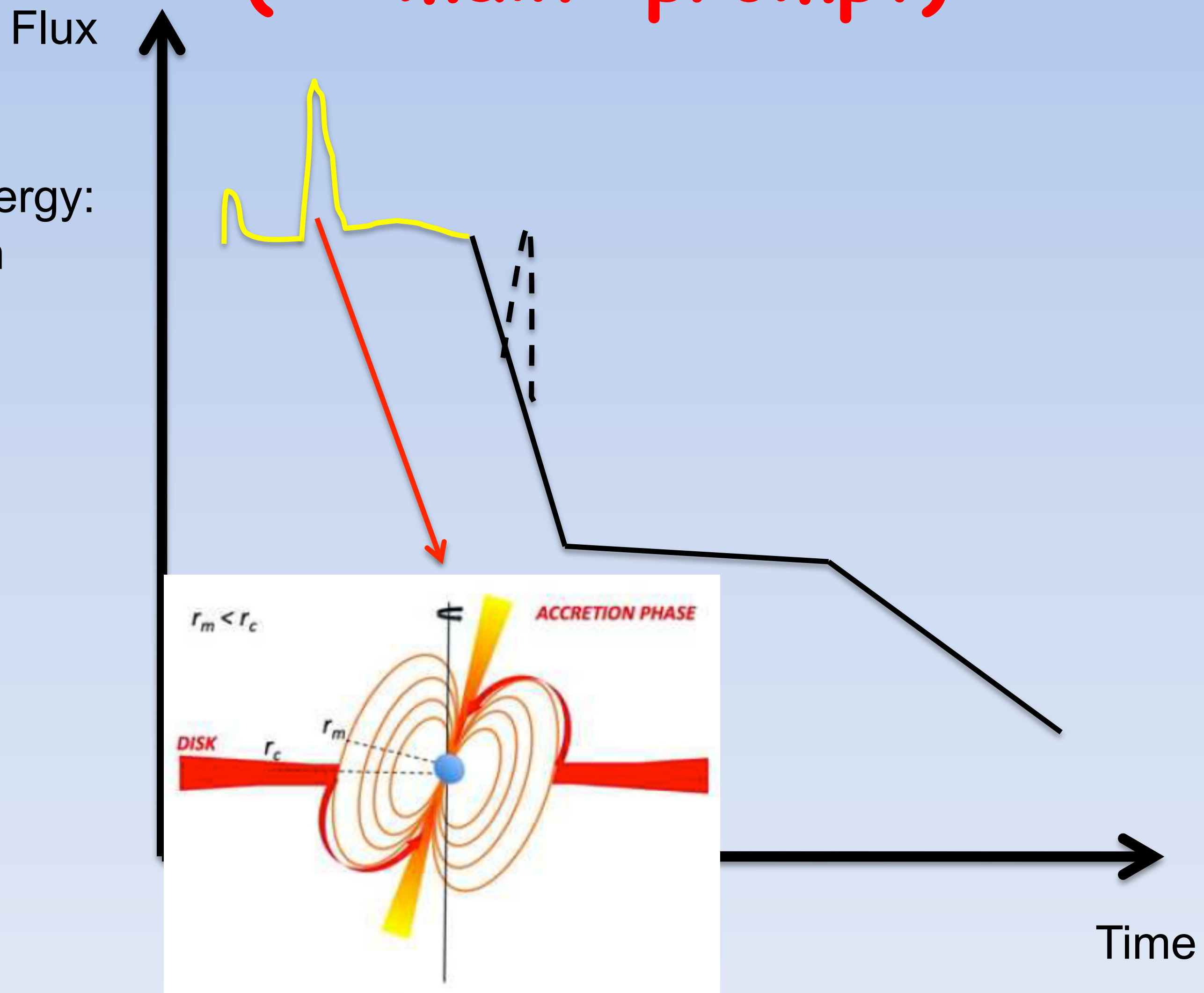


Magnetars as SGRBs progenitors: precursors (+ "main" prompt)



Magnetars as SGRBs progenitors: precursors (+ "main" prompt)

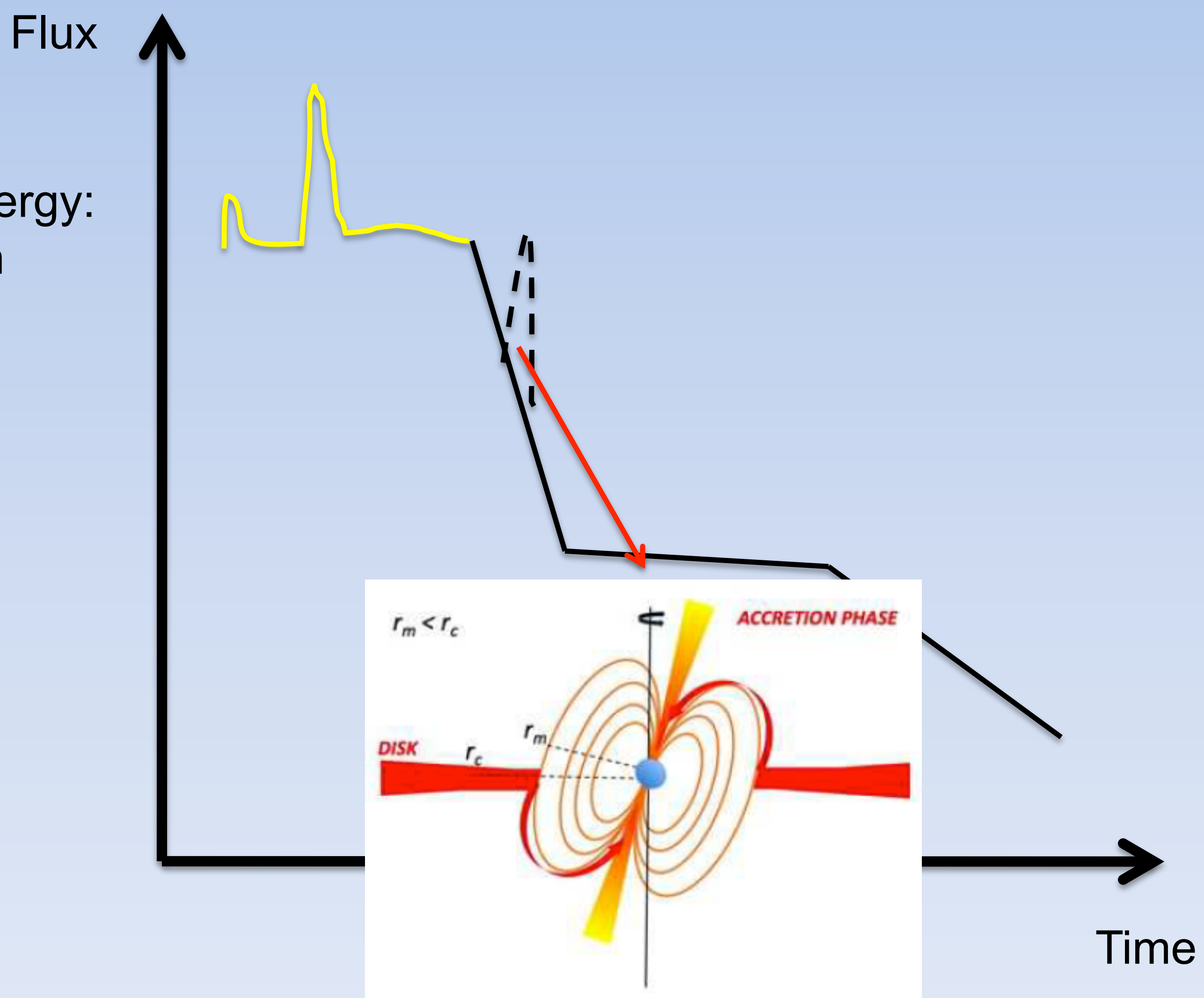
Source of energy: accretion



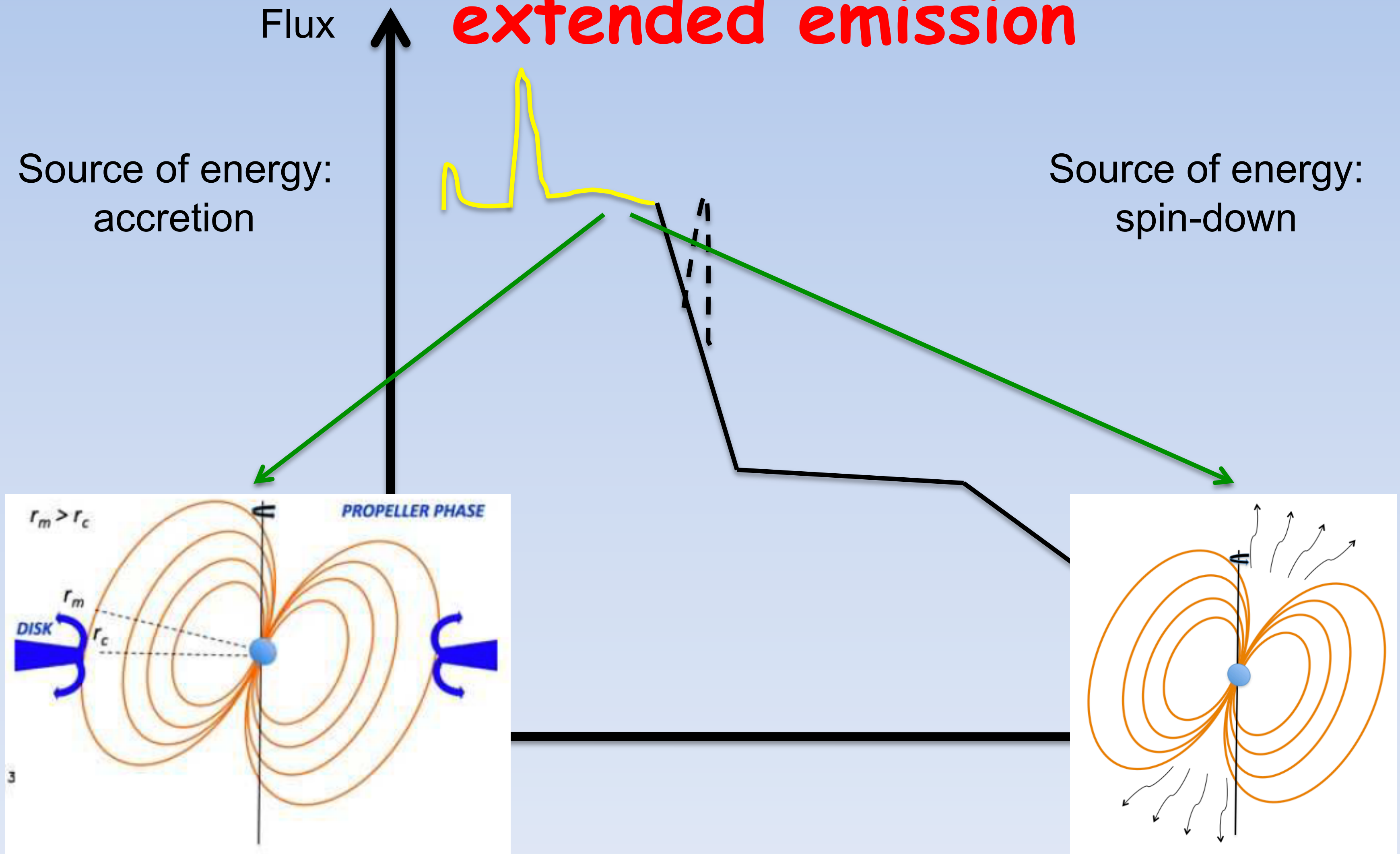
Bernardini et al. 2013

Magnetars as SGRBs progenitors: flares

Source of energy:
accretion



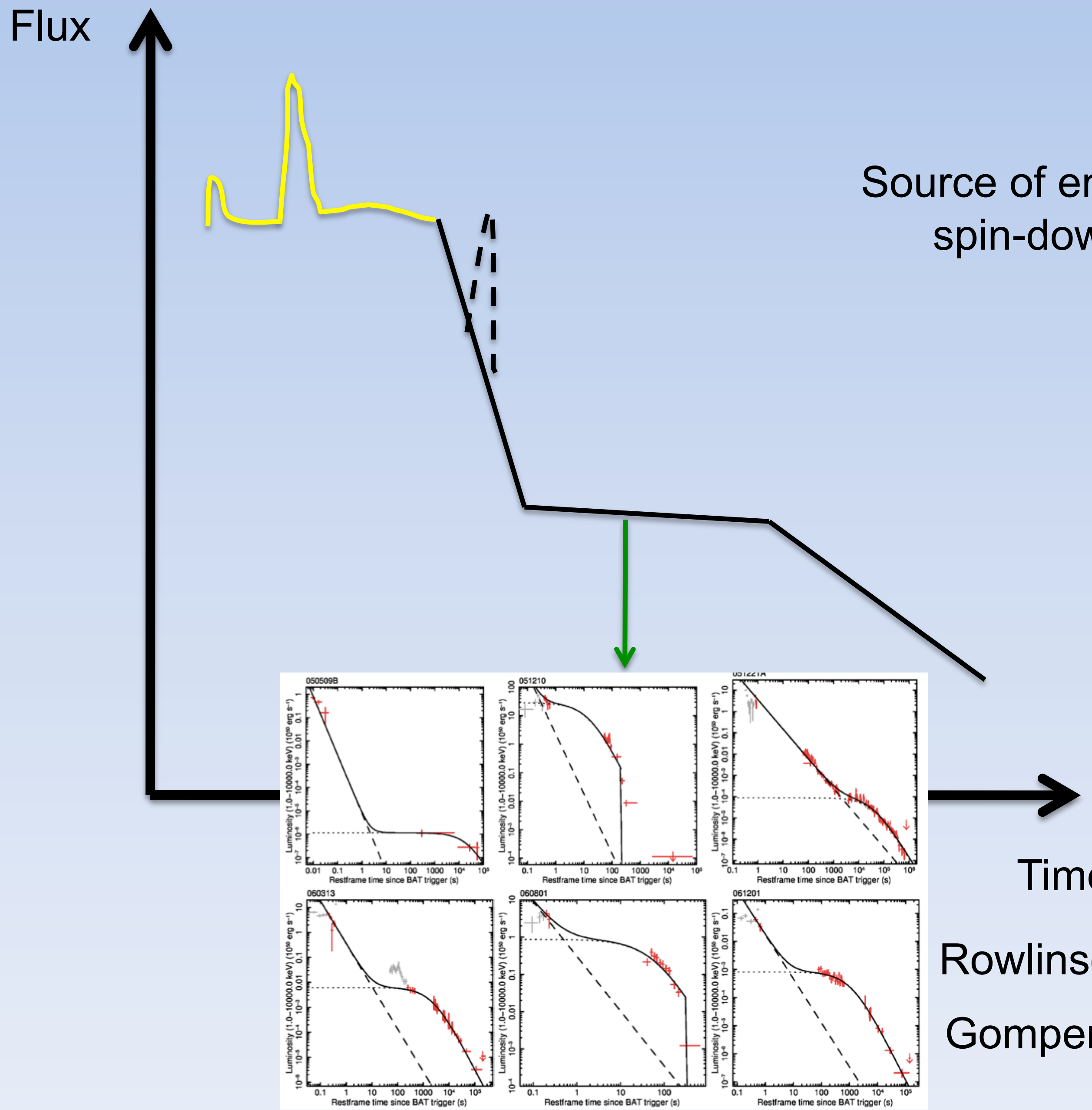
Magnetars as SGRBs progenitors:
extended emission



Gompertz et al. 2014

Metzger et al. 2008
Bucciantini et al. 2012

Magnetars as SGRBs progenitors: plateau



Source of energy:
spin-down

Rowlinson et al. 2013

Gompertz et al. 2014

Short GRBs: some conclusions

- Properties shared with long GRBs:
  - Precursors
  - 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 binary channel (z, offset, N_H)
  - No-host SGRBs (large offset? Dynamical channel?)
  - Possible Kilonova in GRB 130603B (smoking gun?)
  - Waiting for GWs
- Possible magnetar signatures:
  - Precursors and flares
  - Extended emission
  - Plateaus