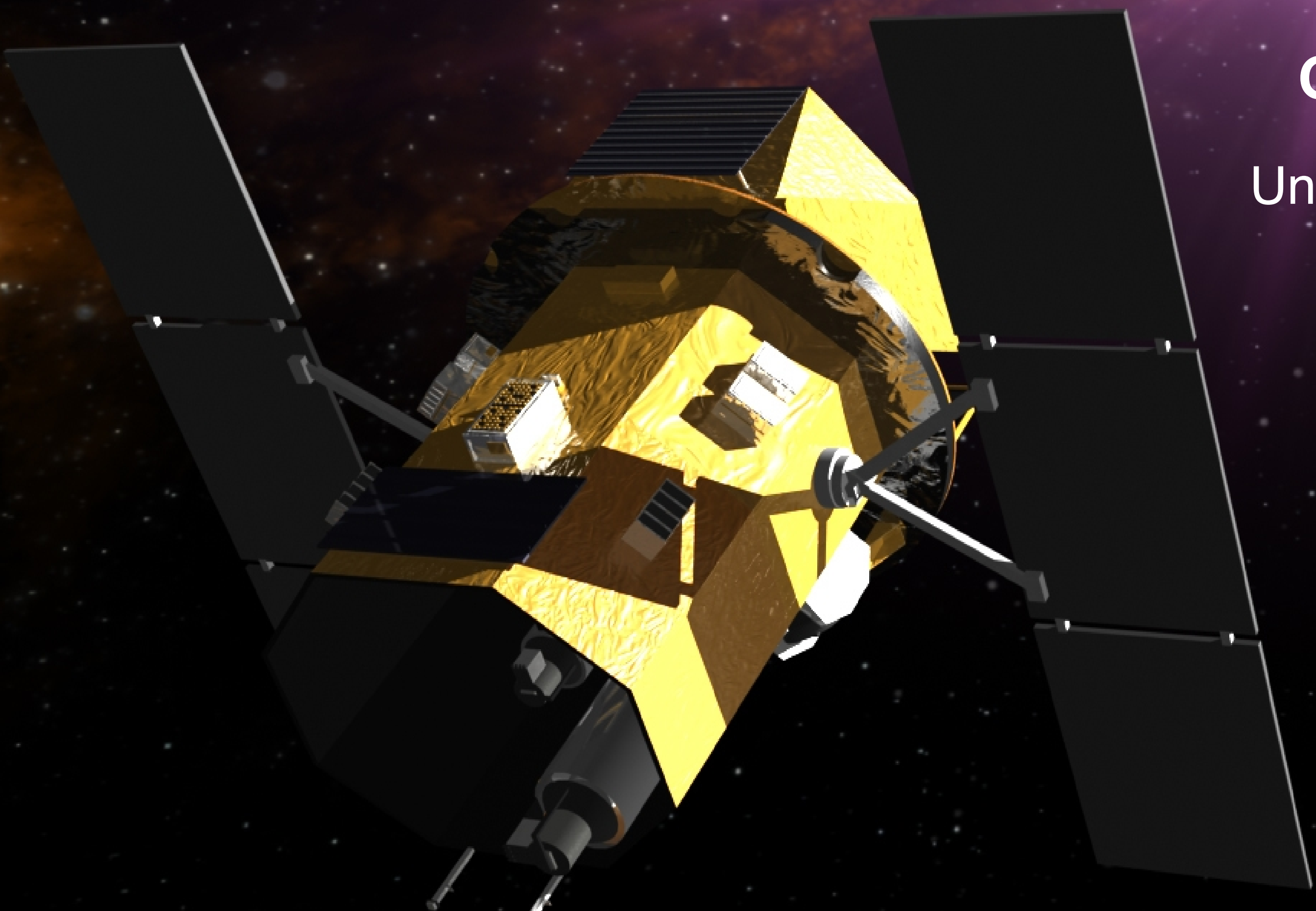
XIII International Conference on Gravitation, Astrophysics & Cosmology

15th Italian-Korean Symposium on Relativistic Astrophysics

The 1st ICRANet Catalog of Binary-driven HyperNovae



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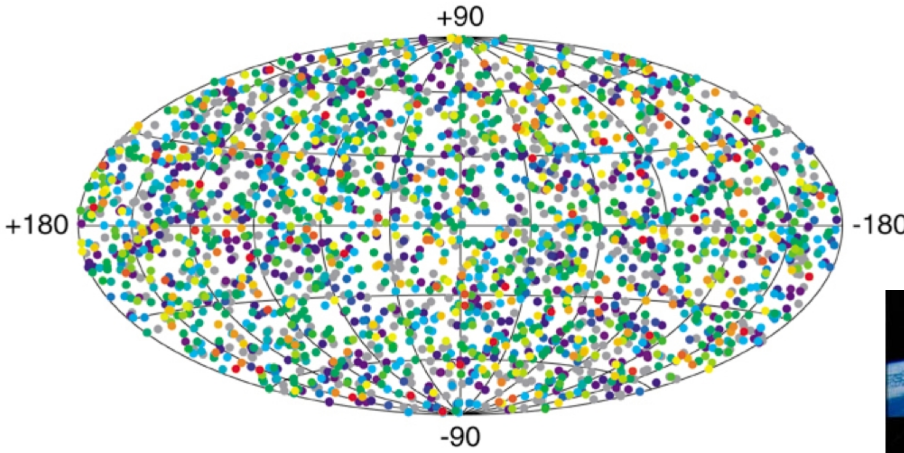
J.A. Rueda
Y. Wang

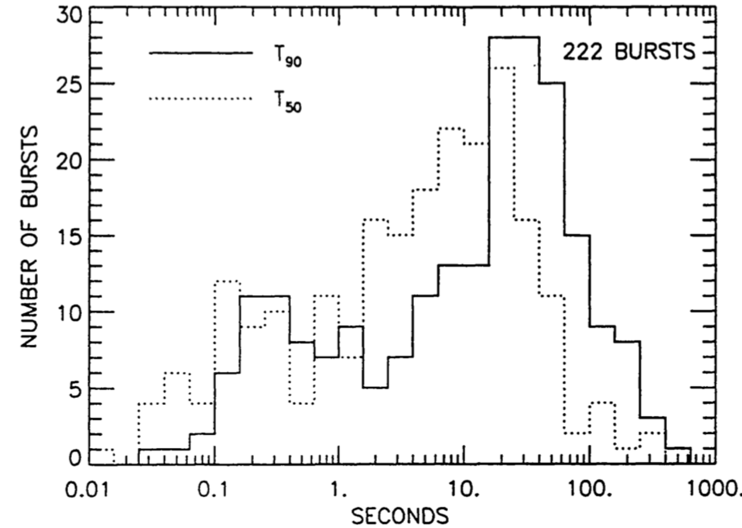
Seoul, Korea

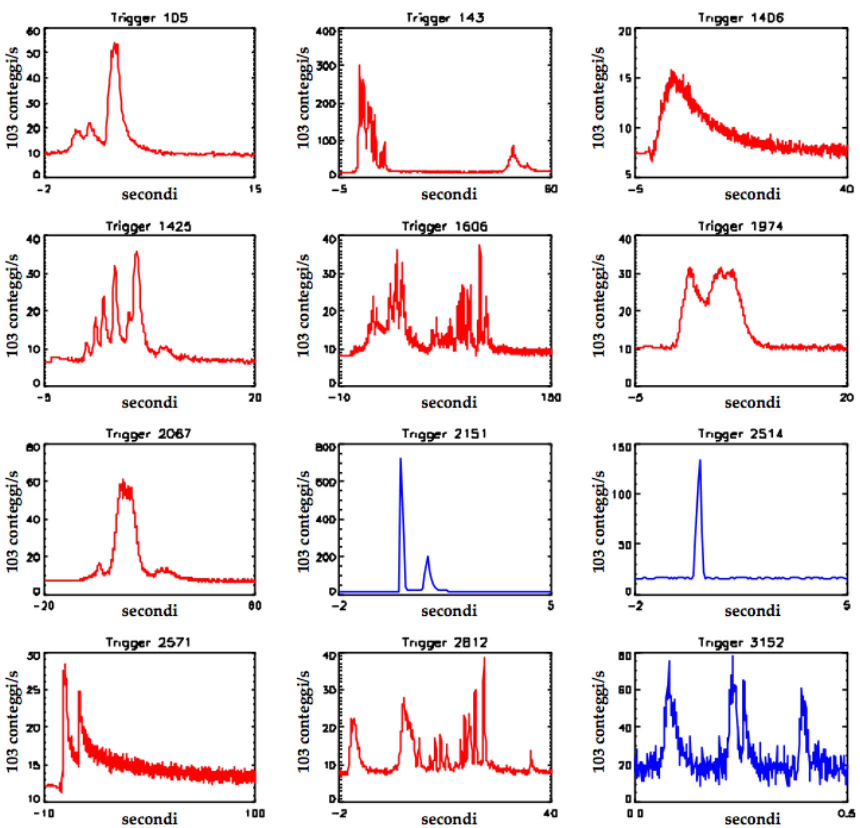
4th July 2017

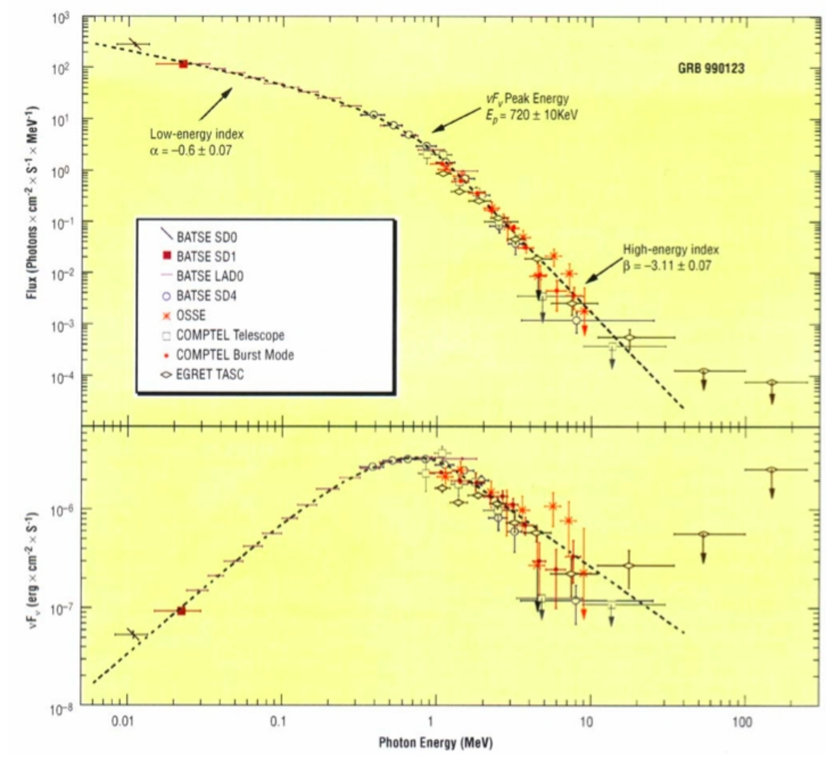
2704 BATSE Gamma-Ray Bursts



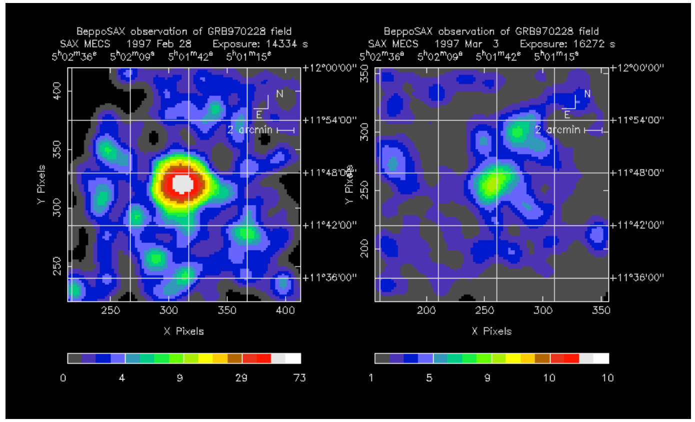
CGRO







Beppo-SAX



X-ray afterglow
refined position and redshift measurement thanks to the ground-based optical telescopes repointing

z ~ 0.01 ÷ 10

E_{iso} ~ 10^{48} ÷ 10^{55} erg

Swift

Fast repointing: 60 - 100 s

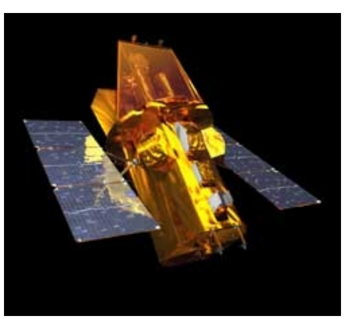
Early optical data

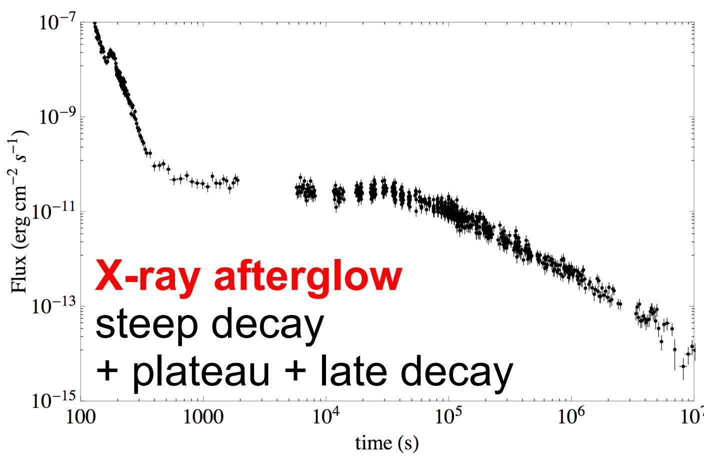
~1400 GRB detected

480 with measured redshift

Higher sensitivity (GRB 090423 at z=8.2)

Short GRBs + Extended Emission

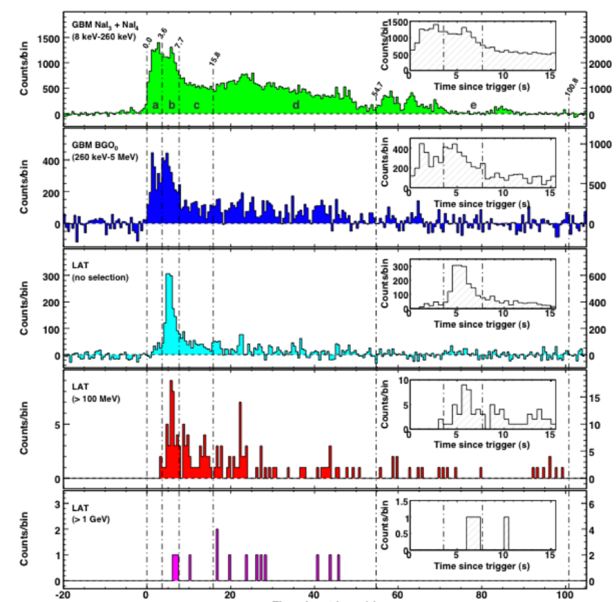




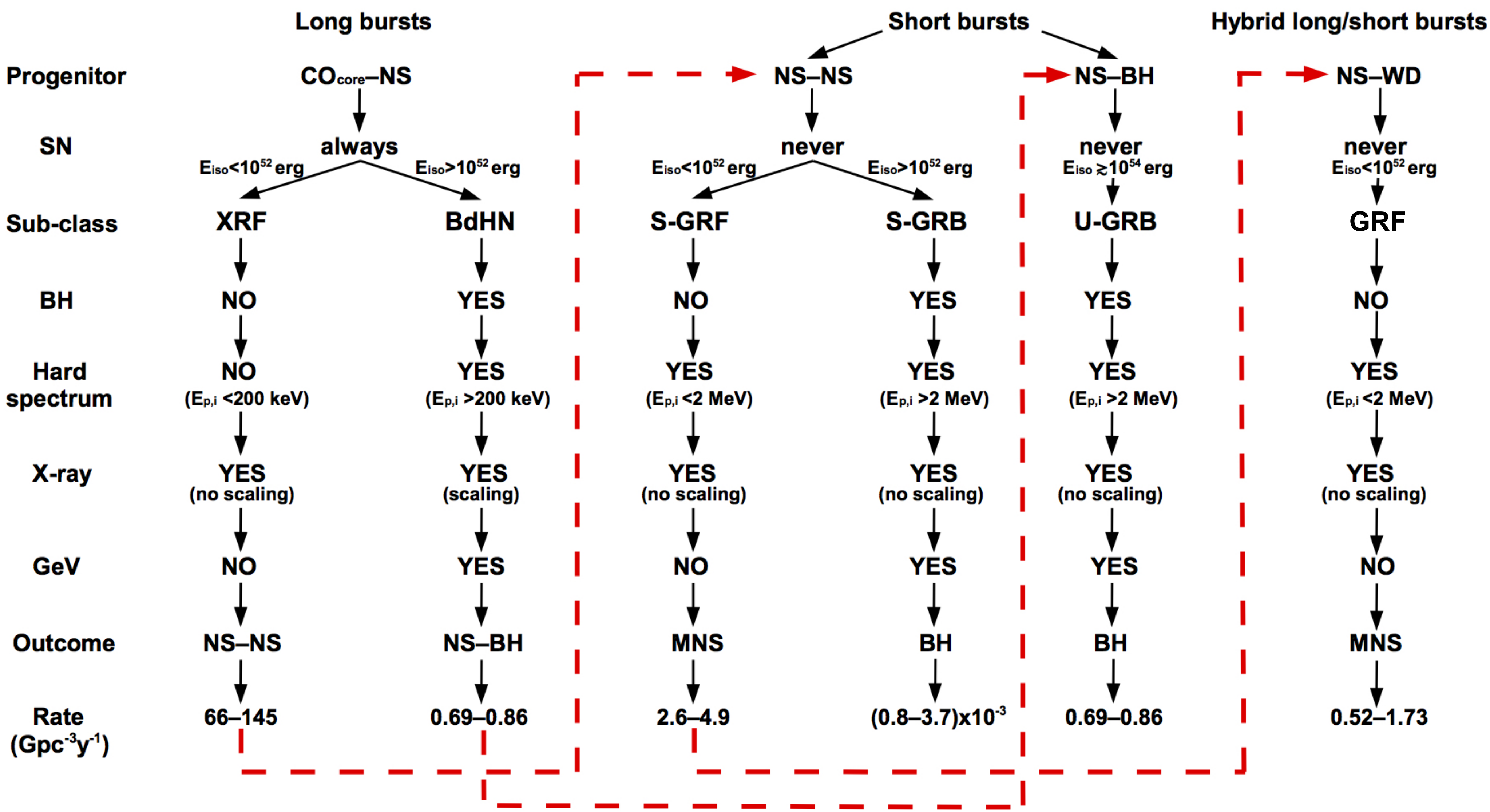
Fermi

Thermal component

GeV counterpart



All GRBs originate from binary systems



Ruffini et al. 2016, ApJ

Ruffini et al. submitted to ApJ

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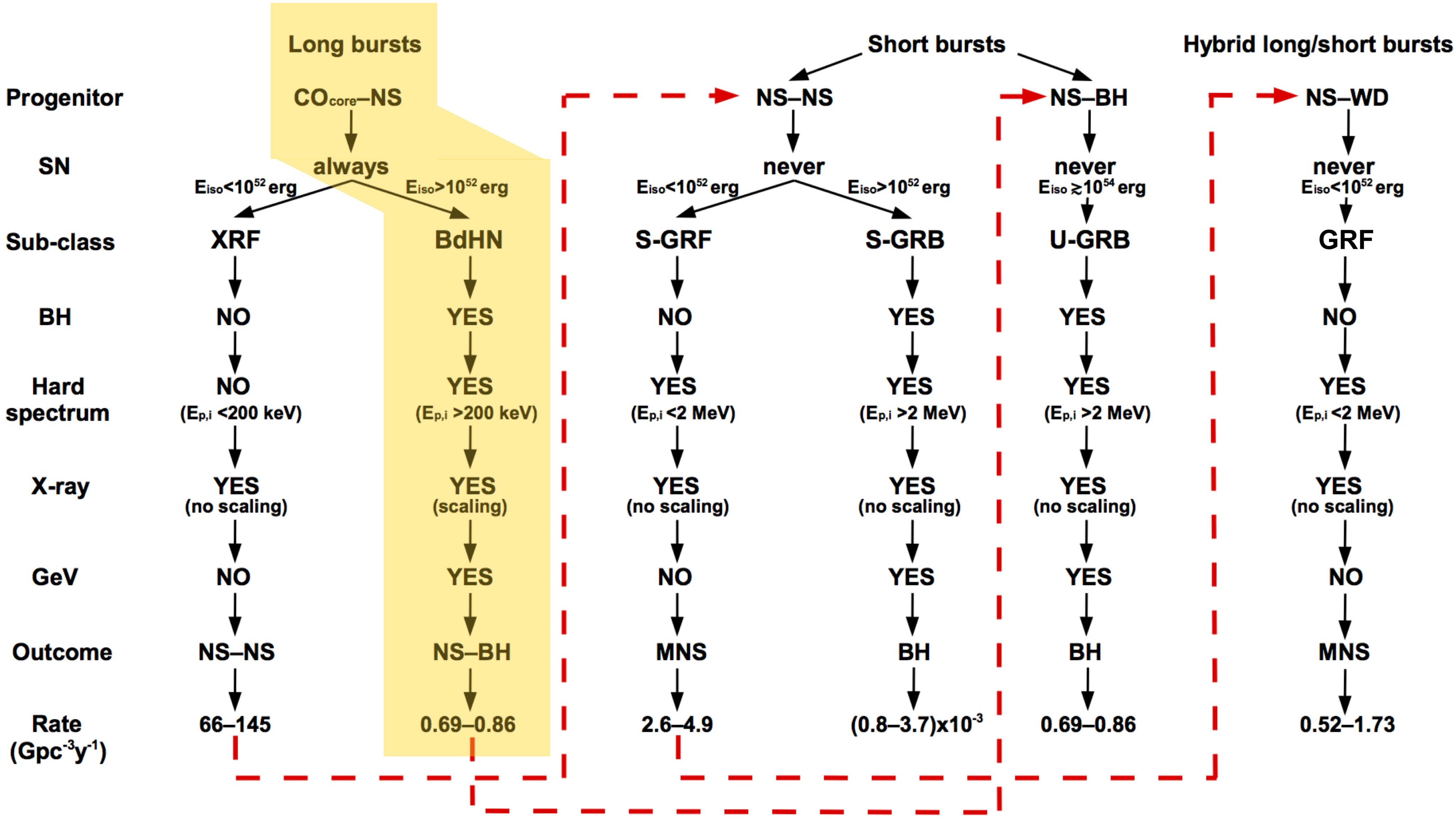


Ruffini et al. 2016, ApJ

Ruffini et al. submitted to ApJ

ICRANet Newsletter

3. The 1st ICRANet Catalog of Binary-driven Hypernovae and the BSDC

The director of ICRANet, Professor Remo Ruffini, announces the publication of the first ICRANet catalog of binary-driven hypernovae (IBdHNe), counting 175 sources observed up to the end of 2016 [1-3].

In a series of recent publications, scientists from ICRANet led by professor Remo Ruffini have reached a novel comprehensive picture of gamma-ray bursts (GRBs) thanks to their development of a series of new theoretical approaches. Among those, the induced gravitational collapse (IGC) paradigm explains a class of energetic, long-duration GRBs associated with Ib/c supernovae (SN), recently named BdHNe (see Figure 1 and 2, and [4-7]).

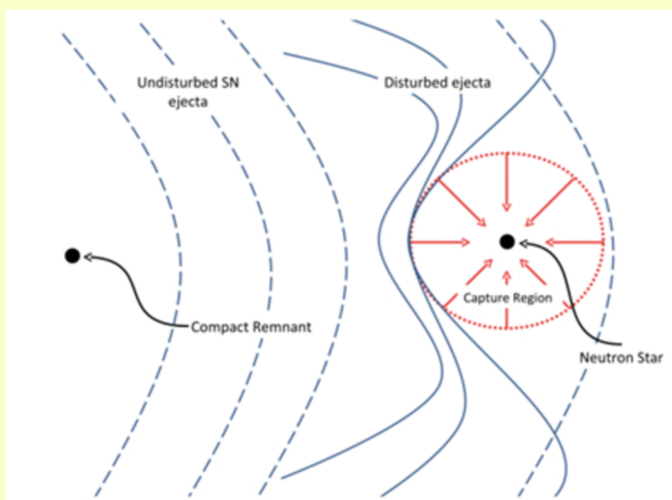


Fig. 1: Graphic representation of the IGC scenario. The Ns companion accretes material from the expanding outer layers of the SN which just exploded. If the binary system is tight enough, the accretion process becomes hypercritical, and the NS eventually collapse to a black hole, emitting a GRB.

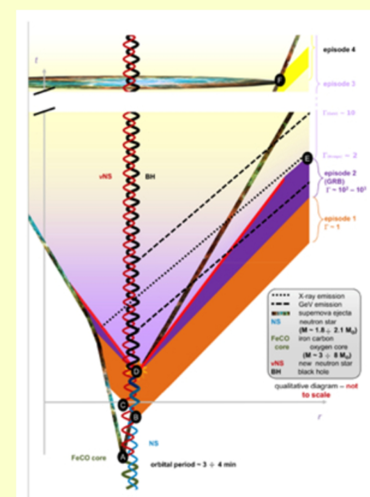
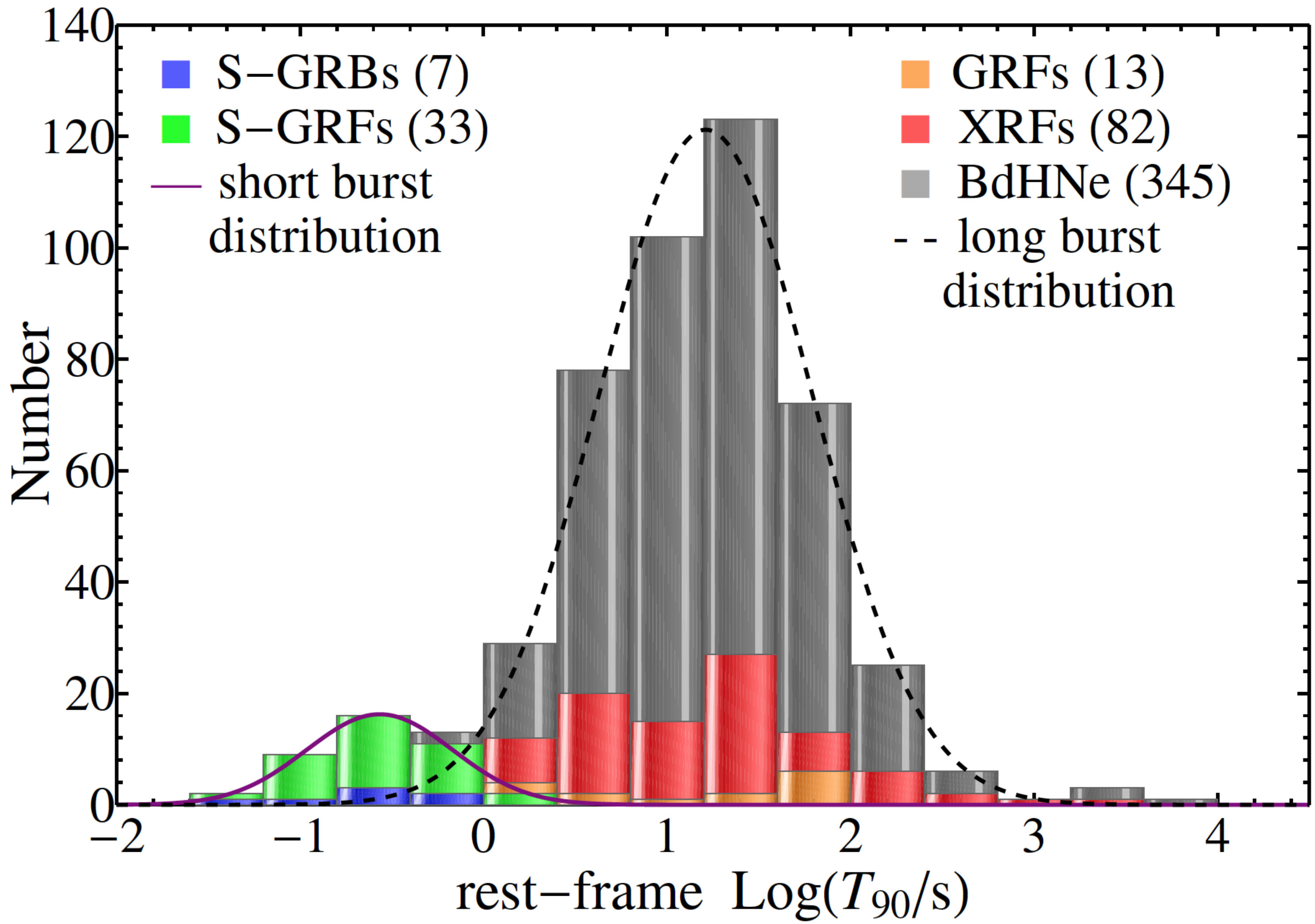


Fig. 2: This space-time diagram shows all the different physical processes and relative emissions occurring in a BdHN phenomenon.

Name	z	r-f T_{90} (s)	E_{iso} (erg)	t_{start} (s)	t_{end} (s)	slope	E_{LT} (erg)
1. IBdHN 090618A	0.54	73.5065	2.9×10^{53}	7000.	1.84513×10^{6}	1.48791	1.43605×10^{51}
2. IBdHN 060729A	0.54	75.3247	1.6×10^{52}	20000.	6.62361×10^{6}	1.31323	3.3637×10^{51}
3. IBdHN 061007A	1.261	33.1712	8.8×10^{53}	30.	510467.	1.68247	4.76995×10^{50}
4. IBdHN 080319B	0.94	25.7732	1.2×10^{54}	30.	1.35741×10^{6}	1.58526	1.9892×10^{51}
5. IBdHN 091127A	0.49	4.7651	1.8×10^{52}	2000.	2.70322×10^{6}	1.32196	1.35585×10^{51}
6. IBdHN 111228A	0.716	58.9744	4.1×10^{52}	4000.	1.49877×10^{6}	1.22734	1.24379×10^{51}
7. IBdHN 130427A	0.338	121.674	1.1×10^{54}	300.	1.17788×10^{7}	1.25685	4.17388×10^{51}
8. IBdHN 050315A	1.95	32.5424	8.3×10^{52}	30000.	302657.	0.838208	1.56063×10^{52}
9. IBdHN 050318A	1.44	13.1148	3.7×10^{52}	3000.	24035.6	1.73692	4.4151×10^{50}
10. IBdHN 050319A	3.24	3.53774	2.0×10^{53}	10000.	327517.	1.27211	1.23407×10^{52}
11. IBdHN 050401A	2.9	9.74359	9.2×10^{53}	3000.	140629.	1.5899	3.81786×10^{51}
12. IBdHN 050408A	1.24	15.1786	1.1×10^{53}	10000.	1.13675×10^{6}	1.13536	2.19411×10^{51}
13. IBdHN 050505A	4.27	11.3852	4.5×10^{53}	1100.	213860.	1.40808	8.66053×10^{51}
14. IBdHN 050525A	0.606	6.22665	2.3×10^{52}	3000.	869622.	1.4689	2.43182×10^{50}
15. IBdHN 050730A	3.97	31.1871	4.3×10^{53}	2000.	82133.2	2.41559	1.74003×10^{51}
16. IBdHN 050802A	1.71	4.79705	7.5×10^{52}	2000.	306202.	1.54827	1.23792×10^{51}
17. IBdHN 050814A	5.3	10.3175	2.7×10^{53}	12000.	130462.	2.22574	2.89741×10^{51}
18. IBdHN 050820A	2.61	7.20222	3.9×10^{53}	2000.	1.01284×10^{6}	1.23144	2.20632×10^{52}
19. IBdHN 050922C	2.2	1.5625	2.0×10^{53}	1500.	112067.	1.56565	9.74246×10^{50}
20. IBdHN 051109A	2.35	7.46269	1.8×10^{53}	1000.	452314.	1.20291	9.08963×10^{51}

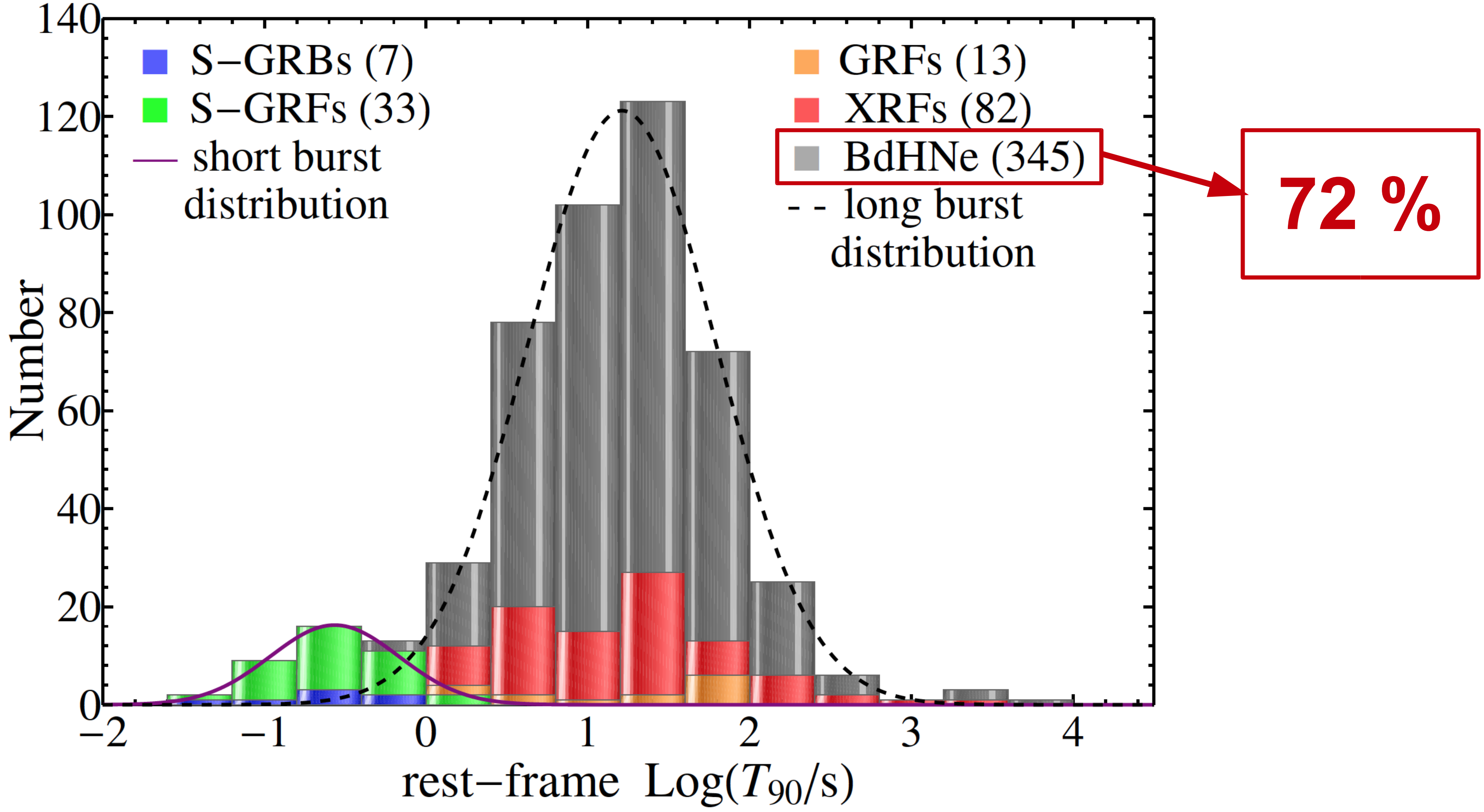
Fig. 3: The first 20 rows of the 1st IBdHN Catalog showing some of the significant observed quantities. The first seven BdHNe form the so called Golden Sample, the first source which have been identified as BdHNe

How many Binary-driven HyperNovae ?



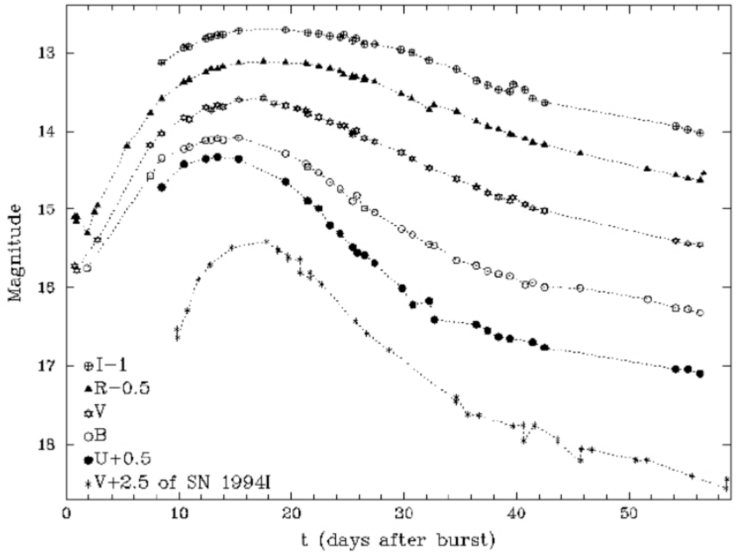
Ruffini et al. submitted to ApJ

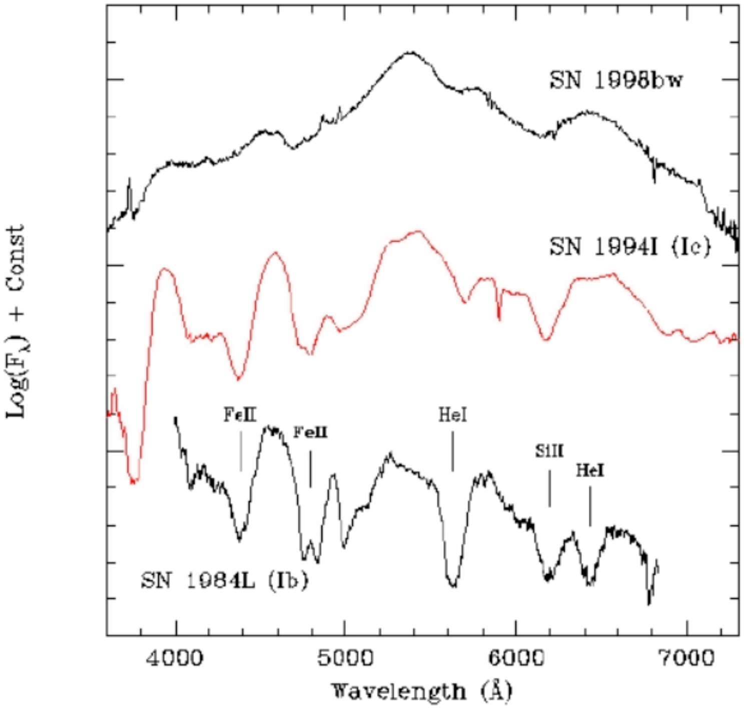
How many Binary-driven HyperNovae ?



Ruffini et al. submitted to ApJ

GRBs - SNe connection





GRB 980425 / SN 1998bw (Type Ic)

z = 0.0085

Galama et al. 1998, Nature

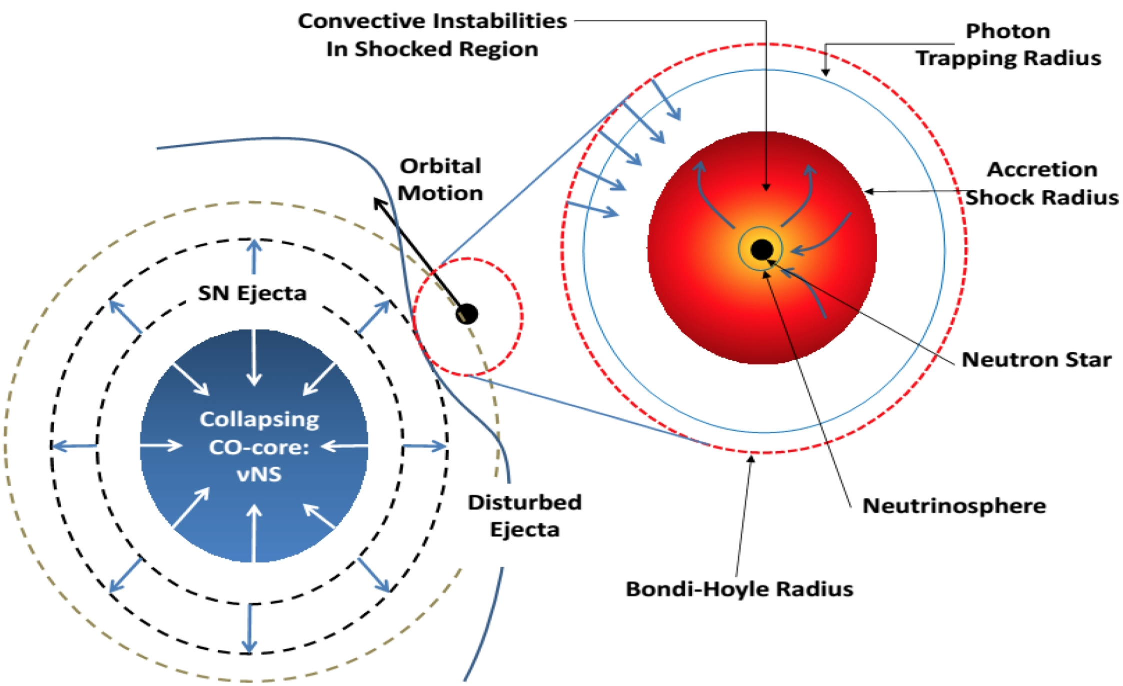
GRBs - SNe connection

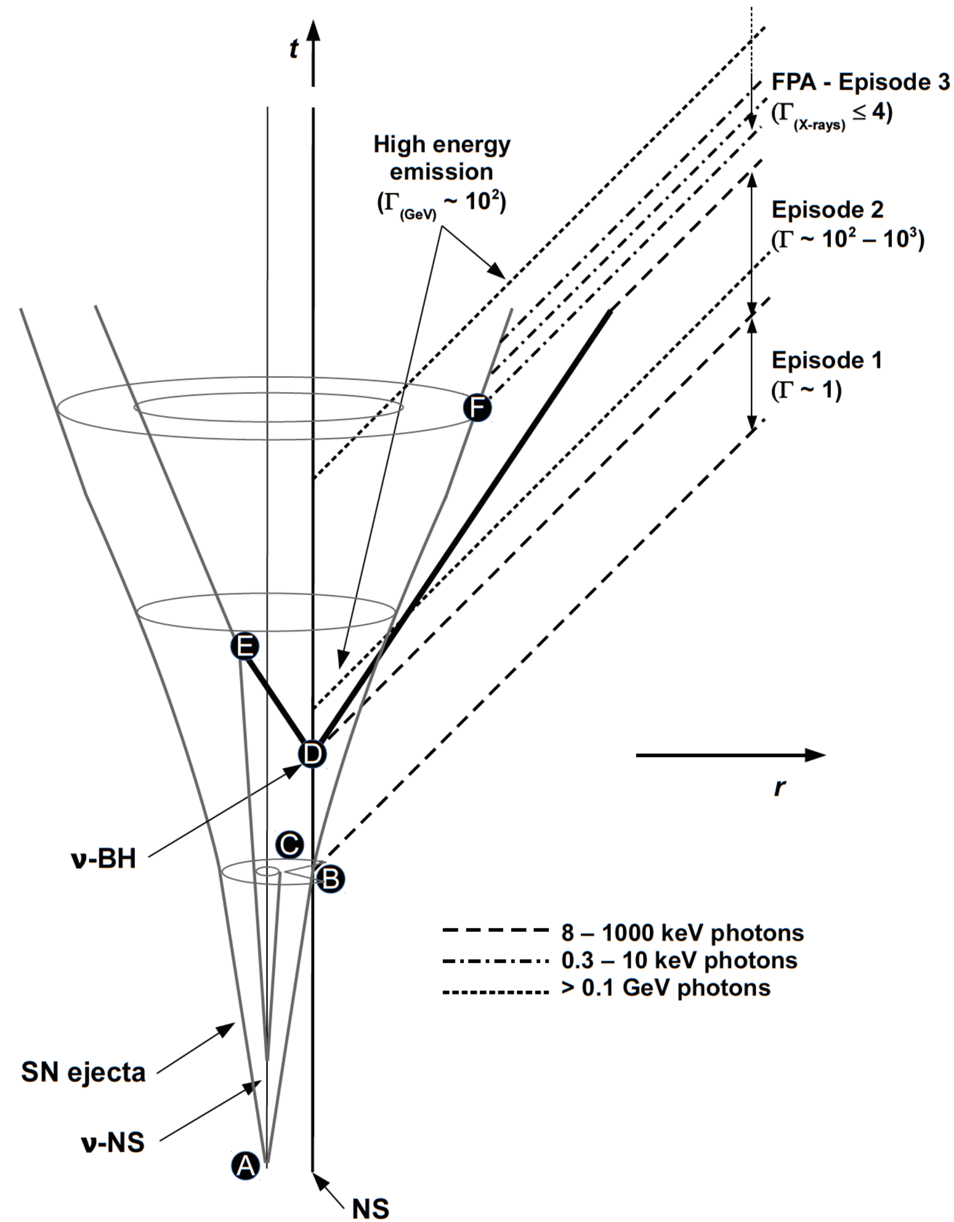
GRB	E_{iso} (erg)	Discovered by	z	SN identification	SN name	Refs.
970228	1.86×10^{52}	BATSE/SAX	0.695	bump		(Reichart 1997)
980326	5.60×10^{51}	BATSE/SAX	1(?)	bump		(Bloom et al. 1999)
980425	6.38×10^{47}	BATSE	0.0085	spec.	SN1998bw	(Galama et al. 1998)
990712	7.80×10^{51}	SAX	0.434	bump		(Frontera et al. 2009; Zeh et al. 2004)
991208	2.59×10^{53}	SAX	0.706	bump		(Frontera et al. 2009; Zeh et al. 2004)
000911	7.80×10^{53}	Konus-WIND	1.058	bump		(Lazzati et al. 2001; Hurley et al. 2000)
010921	1.10×10^{52}	HETE	0.45	bump		(Zeh et al. 2004)
011121	9.90×10^{52}	Ulysses	0.36	bump	SN 2001ke	(Bloom et al. 2002; Hurley et al. 2001; Greiner et al. 2003)
020305	$0.7\text{-}4.6 \times 10^{51}$	Ulysses	0.2-0.5	bump		(Gorosabel et al. 2005; Hurley et al. 2002b)
020405	1.28×10^{53}	Ulysses	0.695	bump		(Masetti et al. 2003; Hurley et al. 2002a)
020410	2.20×10^{52}	Konus-WIND	~ 0.5	bump		(Nicastro et al. 2004; Levan et al. 2005)
021211	1.30×10^{52}	HETE	1.006	spec.	SN 2002lt	(Della Valle et al. 2003; Vreeswijk et al. 2003; Crew et al. 2002)
030329	1.70×10^{52}	Konus-WIND	0.168	spec.	SN 2003dh	(Golenetskii et al. 2003; Kawabata et al. 2003; Stanek et al. 2003)
030723	$< 1.60 \times 10^{53}$	HETE	< 1	bump		(Fynbo et al. 2003)
031203	9.99×10^{49}	INTEGRAL	0.105	spec.	SN 2003lw	(Soderberg et al. 2003; Tagliaferri et al. 2004)
040924	1.10×10^{52}	HETE	0.86	bump		(Fenimore et al. 2004; Soderberg et al. 2006c)
041006	3.50×10^{52}	HETE	0.716	bump		(Galassi et al. 2004; Bikmaev et al. 2004; Soderberg et al. 2006c)
050525A	3.39×10^{52}	Konus-WIND	0.606	spec.	SN 2005nc	(Della Valle et al. 2006)
060218	1.66×10^{49}	Swift	0.033	spec.	SN 2006aj	(Campana et al. 2006; Soderberg et al. 2006a)
060729	1.60×10^{52}	Swift	0.54	bump		(Cano et al. 2011; Parsons et al. 2006)
070419	7.90×10^{51}	Swift	0.97	bump		(Hill et al. 2007)
080319B	1.30×10^{54}	Swift	0.937	bump		(Perley et al. 2008; Kann et al. 2008; Cummings et al. 2008)
081007	2.50×10^{51}	Swift	0.5295	bump	SN2008hw	(Soderberg et al. 2008; Markwardt et al. 2008)
090618	2.90×10^{53}	Fermi-GBM	0.54	bump		(Izzo et al. 2012; Cano et al. 2011; McBreen 2009)
091127	1.60×10^{52}	Fermi-GBM	0.49	bump	SN 2009nz	(Cobb et al. 2010; Wilson-Hodge & Preece 2009)
100316D	9.81×10^{48}	Swift	0.059	spec.	SN 2010bh	(Bufano et al. 2012; Chornock et al. 2010; Sakamoto et al. 2010)
101219B	4.39×10^{51}	Fermi-GBM	0.55	spec.	SN 2010ma	(Sparre et al. 2011; van der Horst 2010)
111228A	7.52×10^{52}	Fermi-GBM	0.714	bump		(D'Avanzo et al. 2012; Briggs & Younes 2011)
120422A	1.28×10^{51}	Swift	0.283	spec.	SN 2012bz	(Melandri et al. 2012; Barthelmy et al. 2012)
120714B	4.51×10^{51}	Swift	0.3984	spec.	SN 2012eb	(Cummings et al. 2012; Klose et al. 2012)
120729A	2.30×10^{52}	Swift	0.80	bump		(Cano et al. 2014; Ukwatta et al. 2012)
130215A	3.10×10^{52}	Fermi-GBM	0.597	spec.	SN 2013ez	(de Ugarte Postigo et al. 2013; Younes & Bhat 2013)
130427A	9.57×10^{53}	Fermi-GBM	0.3399	spec.	SN 2013cq	(Melandri et al. 2014; Xu et al. 2013; von Kienlin 2013)
130702A	7.80×10^{50}	Fermi-GBM	0.145	spec.	SN 2013dx	(Cenko et al. 2013; Collazzi & Connaughton 2013; Singer et al. 2013)
130831A	4.56×10^{51}	Konus-WIND	0.4791	spec.	SN 2013fu	(Klose et al. 2013; Golenetskii et al. 2013)

Table 1. The sample of the 35 confirmed GRB-SN connections updated to the 31 May 2014.

Induced Gravitational Collapse (IGC) scenario

Binary driven HyperNova (BdHN)





Ruffini et al. 2001, ApJL

Ruffini et al. 2007, ESASP

Rueda & Ruffini 2012, ApJL

Izzo, Rueda, Ruffini 2012, A&A

Fryer et al. 2014, ApJL

Ruffini et al. 2014, A&A

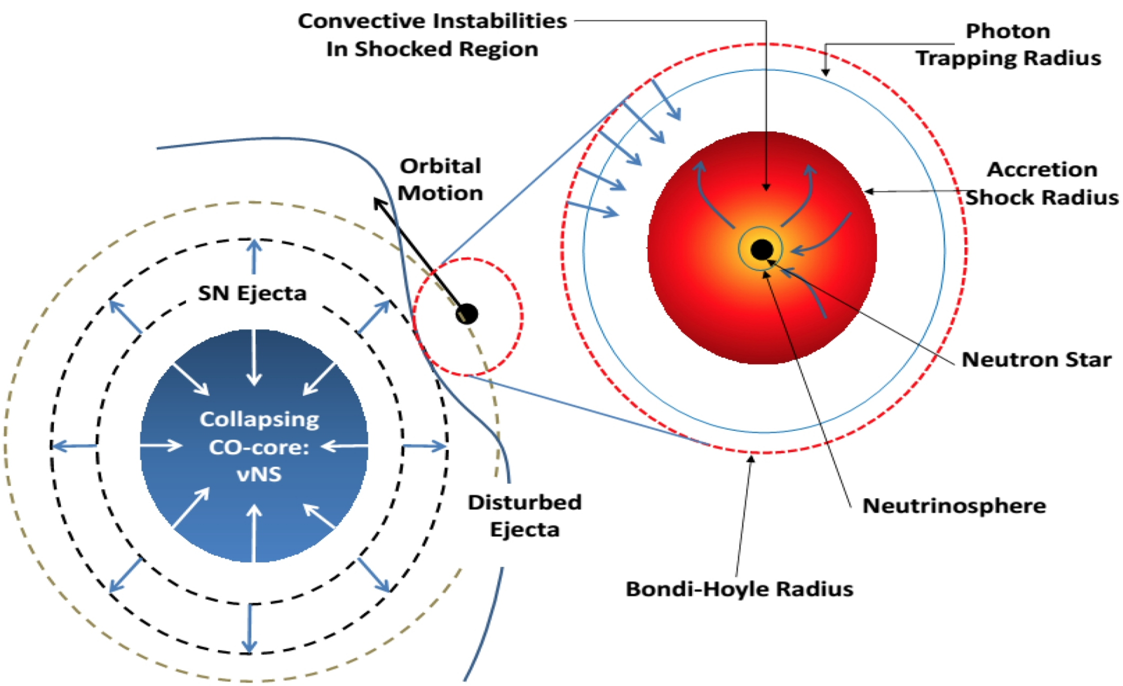
Ruffini et al. 2015, ApJ

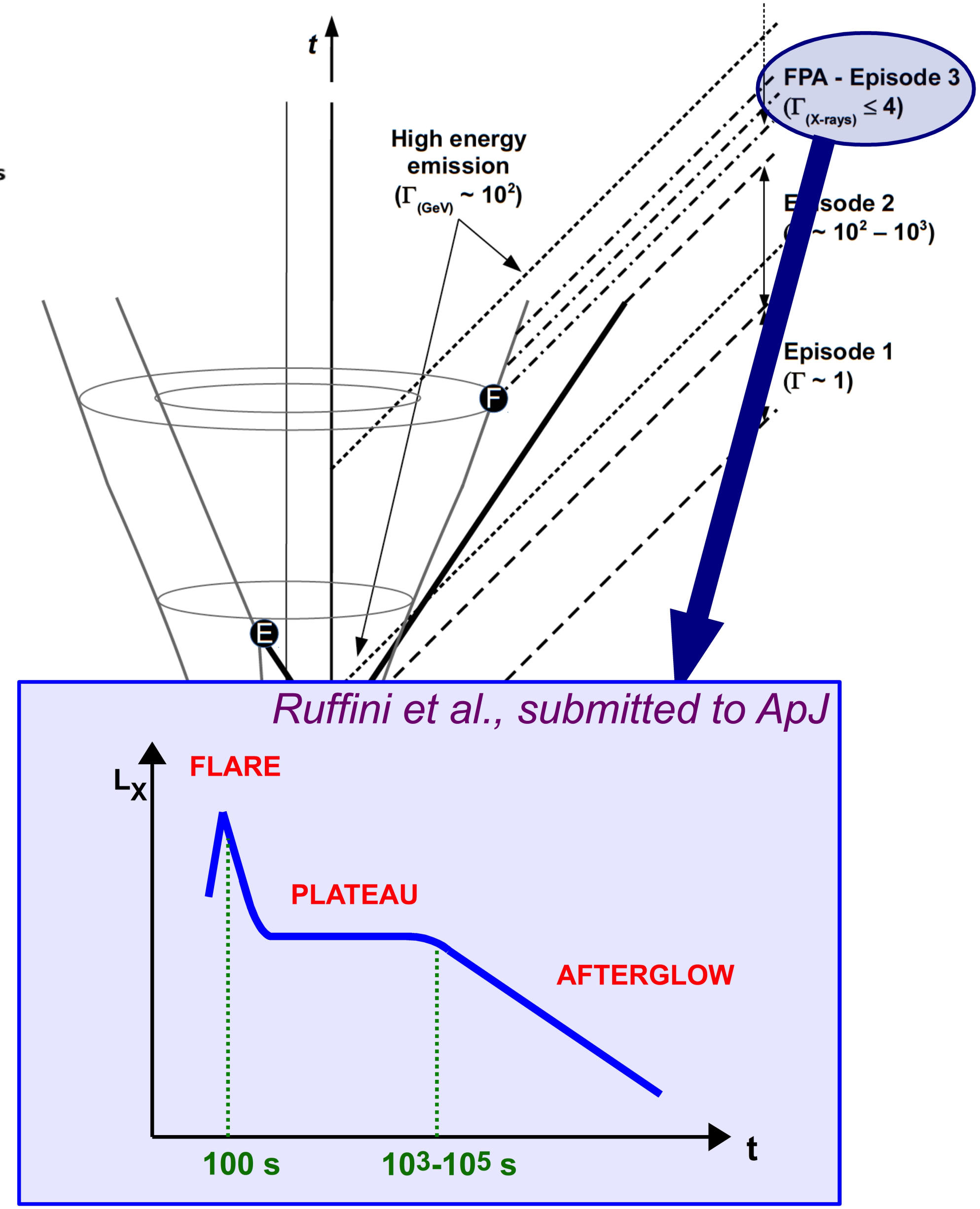
Becerra et al. 2015, ApJ

Ruffini et al. 2016, ApJ

Induced Gravitational Collapse (IGC) scenario

Binary driven HyperNova (BdHN)





Ruffini et al. 2001, ApJL

Ruffini et al. 2007, ESASP

Rueda & Ruffini 2012, ApJL

Izzo, Rueda, Ruffini 2012, A&A

Fryer et al. 2014, ApJL

Ruffini et al. 2014, A&A

Ruffini et al. 2015, ApJ

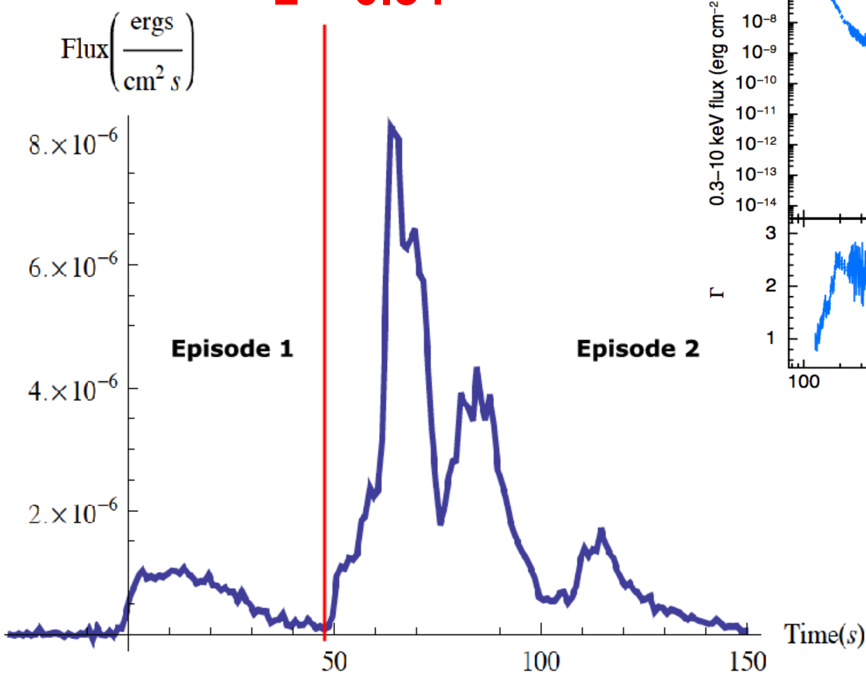
Becerra et al. 2015, ApJ

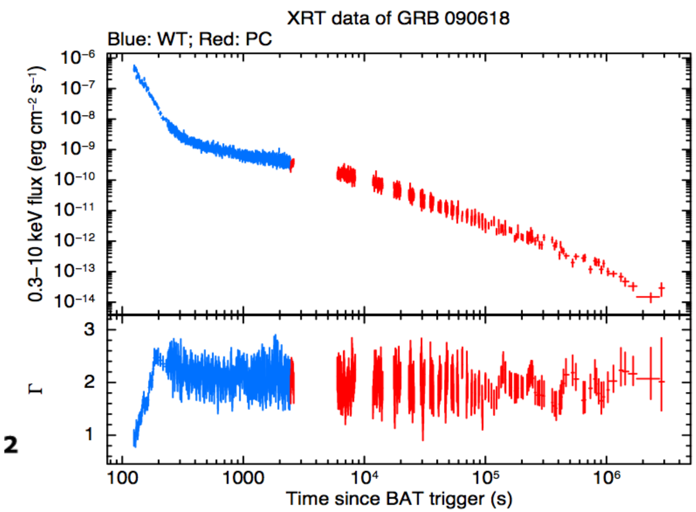
Ruffini et al. 2016, ApJ

The BdHN first prototype: GRB 090618

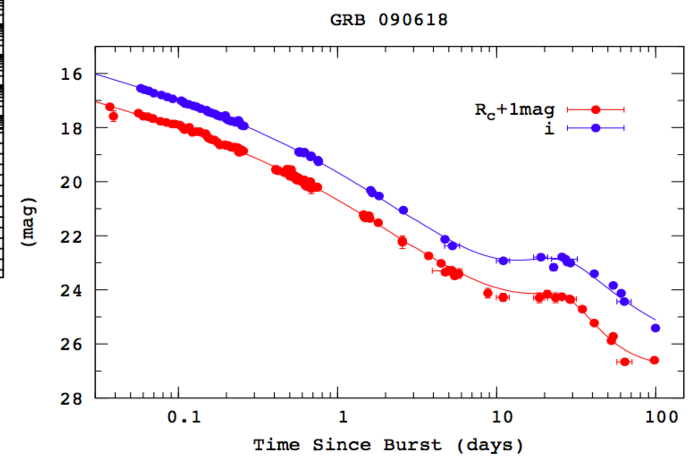
$E_{iso} = 2.8 \cdot 10^{53}$ erg

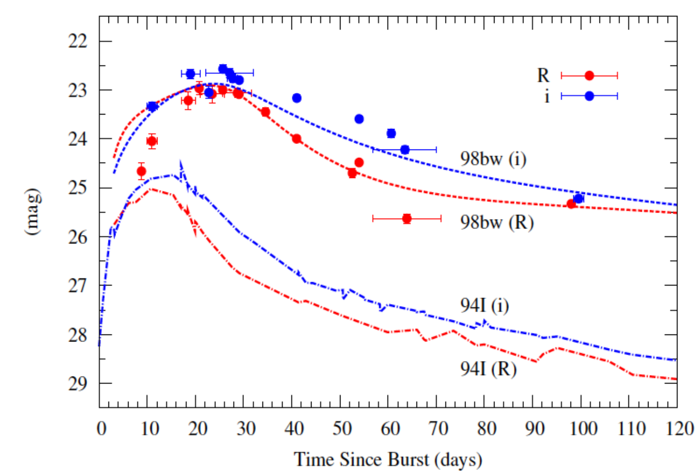
z = 0.54

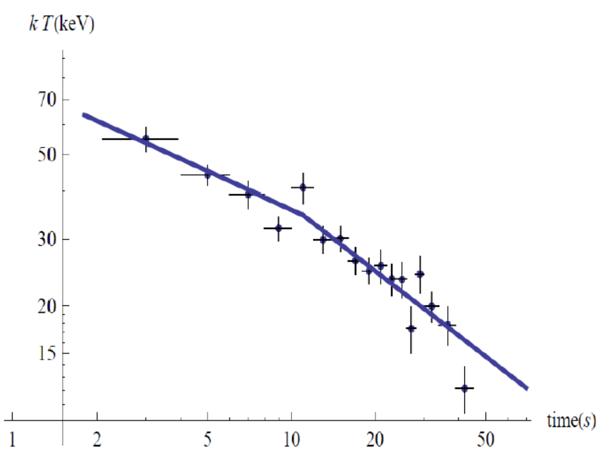


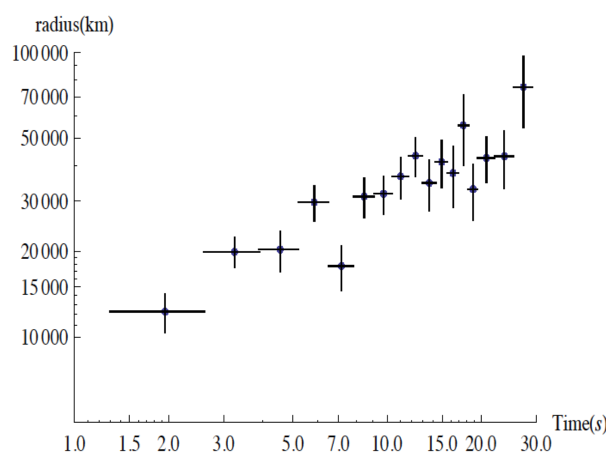


Cano et al. 2011, MNRAS









Izzo et al. 2012, A&A

1^{st} Sample of BdHNe: the Golden Sample

Pisani et al. 2013, A&A

1) Isotropic energy $E_{iso} > 10^{52}$ erg

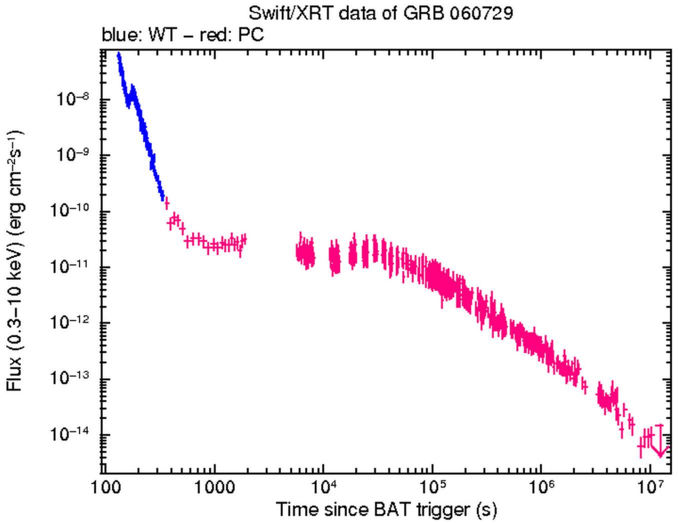
2) Evidence of a double emission in the gamma-rays: the first with a decaying thermal component (Episode 1), followed by a canonical GRB (Episode 2)

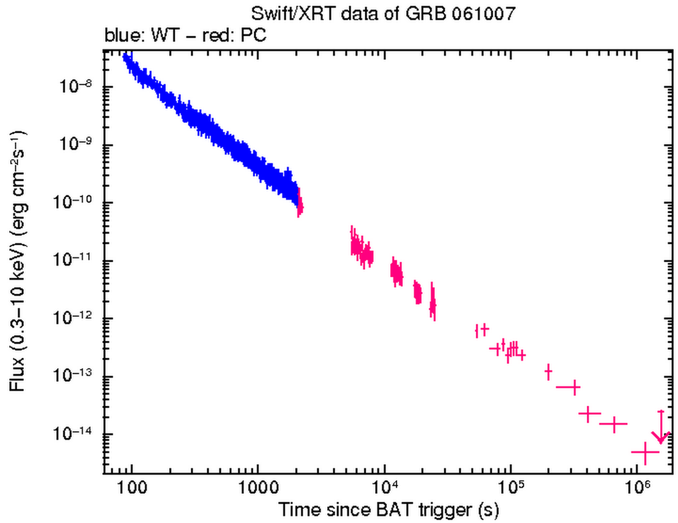
3) Presence of a shallow phase followed by a steeper power-law decay in the X-ray afterglow (Episode 3)

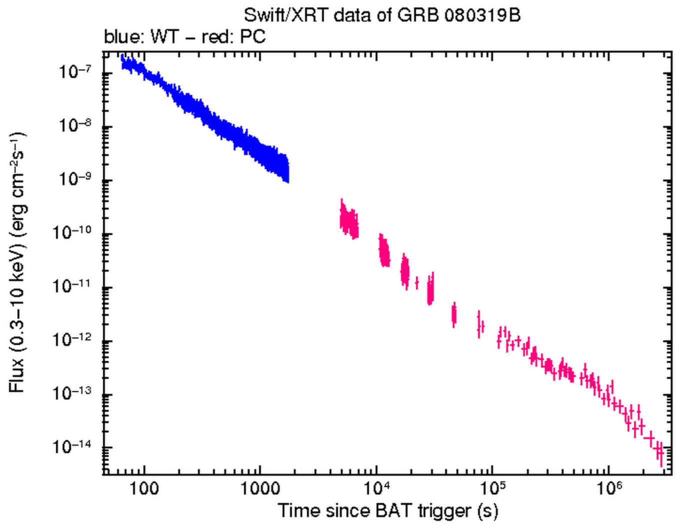
4) Evidence of an associated SN (Episode 4)

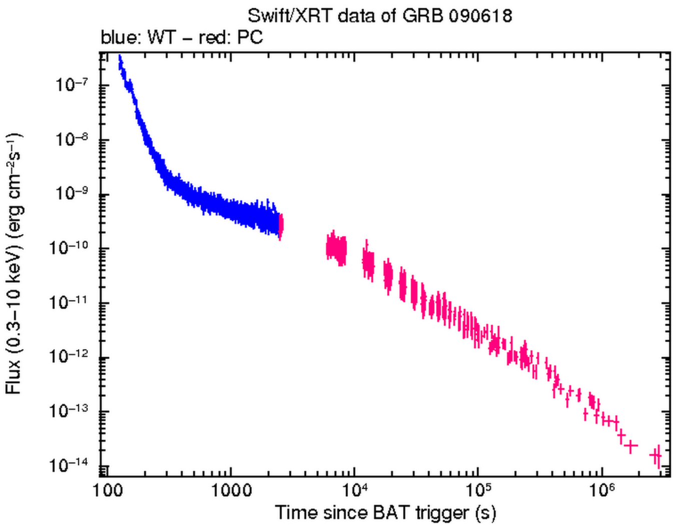
GRB	z	E_{iso} (erg)	SN	Episode 1
060729	0.54	$1.6 \cdot 10^{52}$	photometric	possible
061007	1.261	$1.2 \cdot 10^{54}$	too far	yes
080319B	0.937	$1.4 \cdot 10^{54}$	photometric	possible
090618	0.54	$2.8 \cdot 10^{53}$	photometric	yes
091127	0.49	$1.4 \cdot 10^{52}$	SN 2009nz	possible
111228	0.713	$2.3 \cdot 10^{52}$	photometric	yes

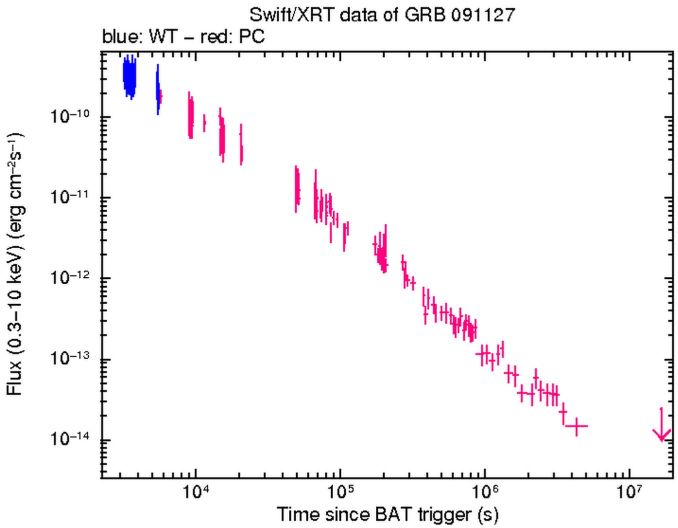
1st Sample of BdHNe: the Golden Sample

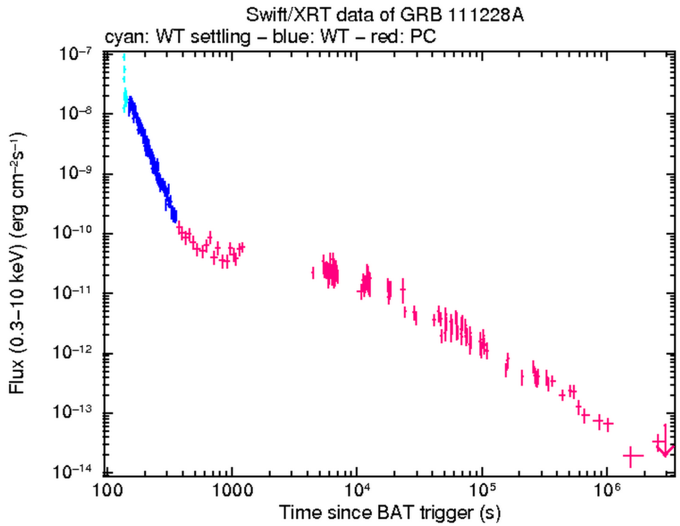




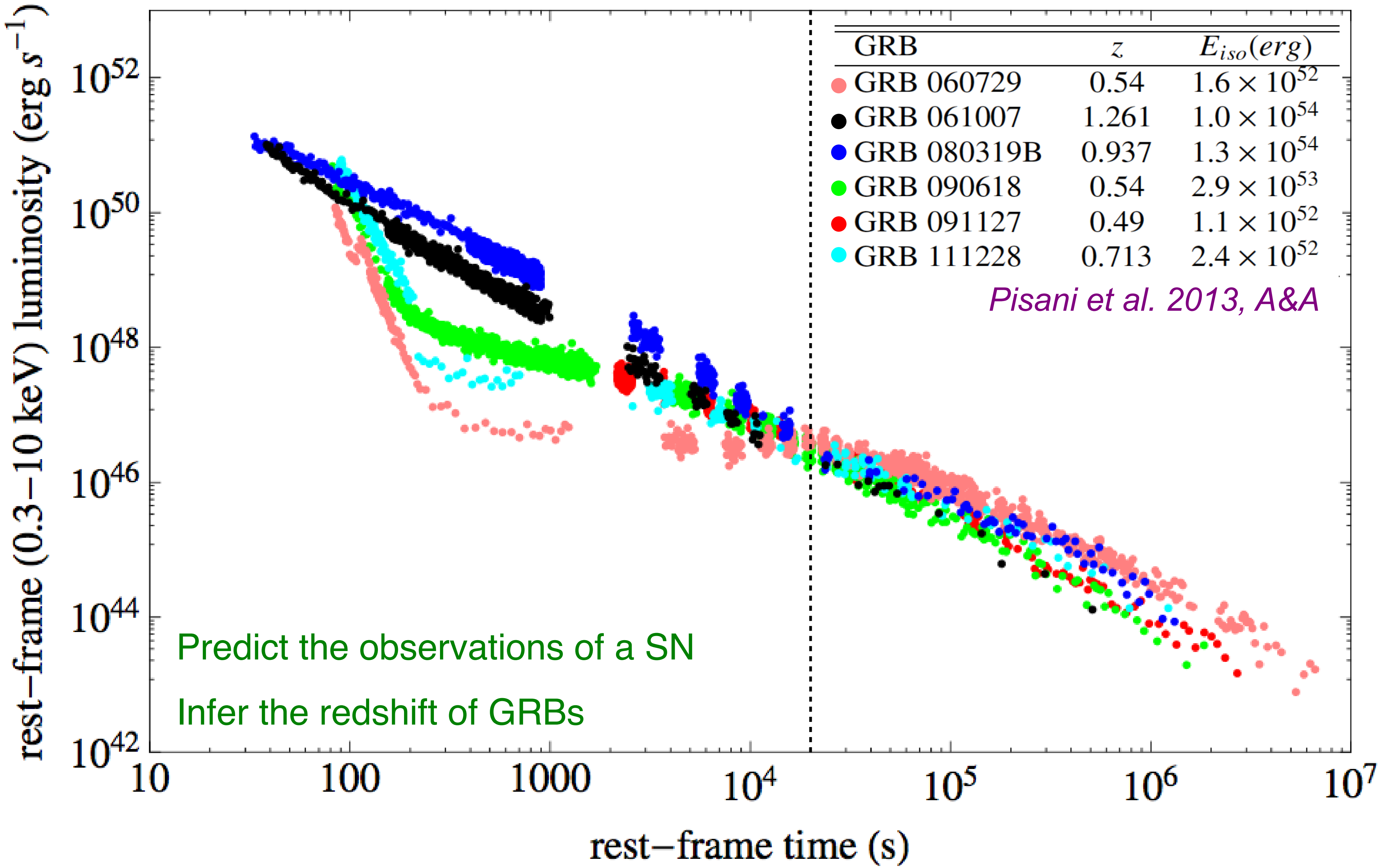








1st Sample of BdHNe: the Golden Sample



Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ

1) Long GRB

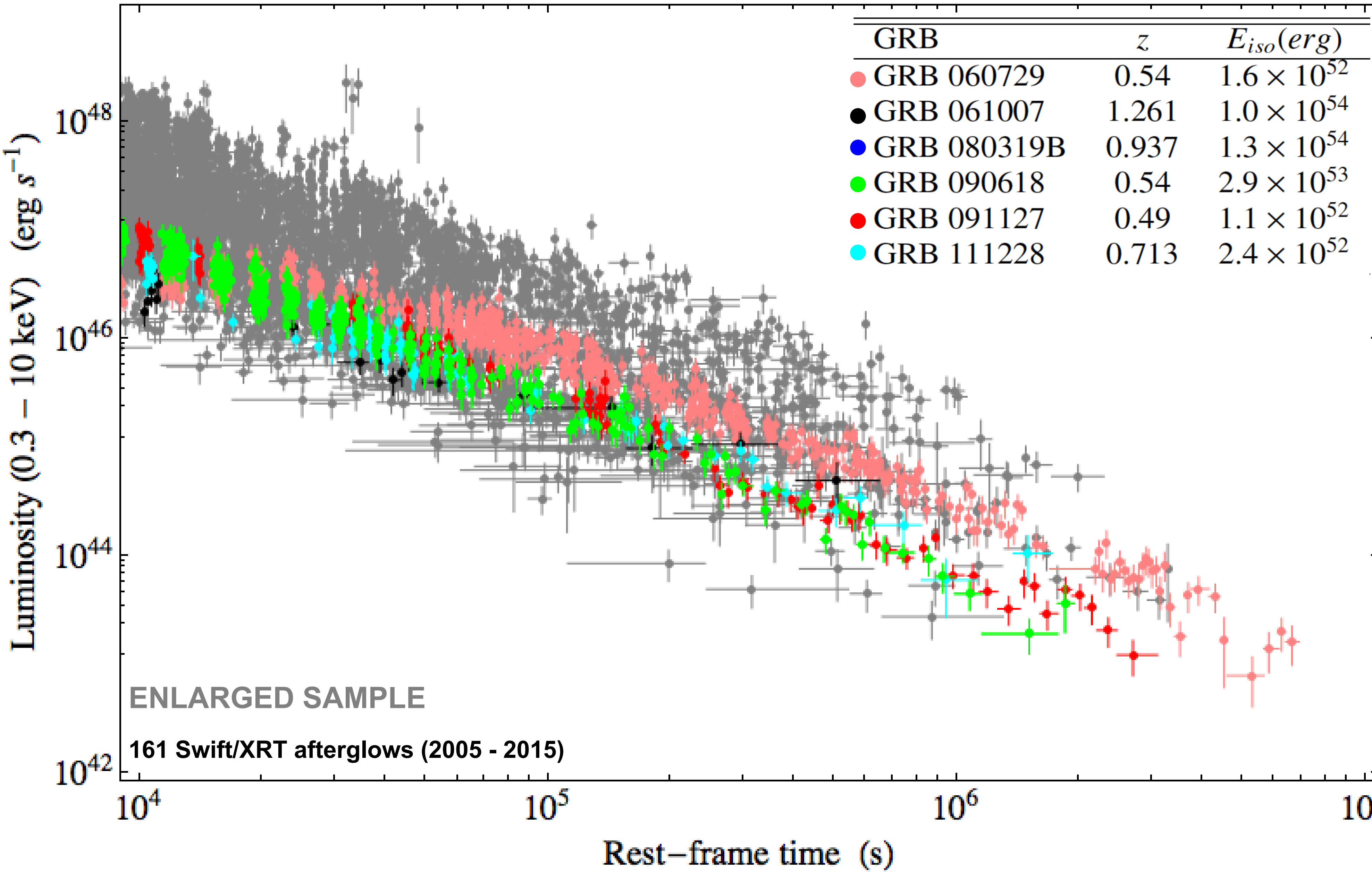
2) Measured redshift z

3) Isotropic energy E_{iso} larger than 10^{52} erg

4) Presence of associated Swift/XRT data lasting up to at least 10^4 s in the rest-frame after the initial GRB explosion

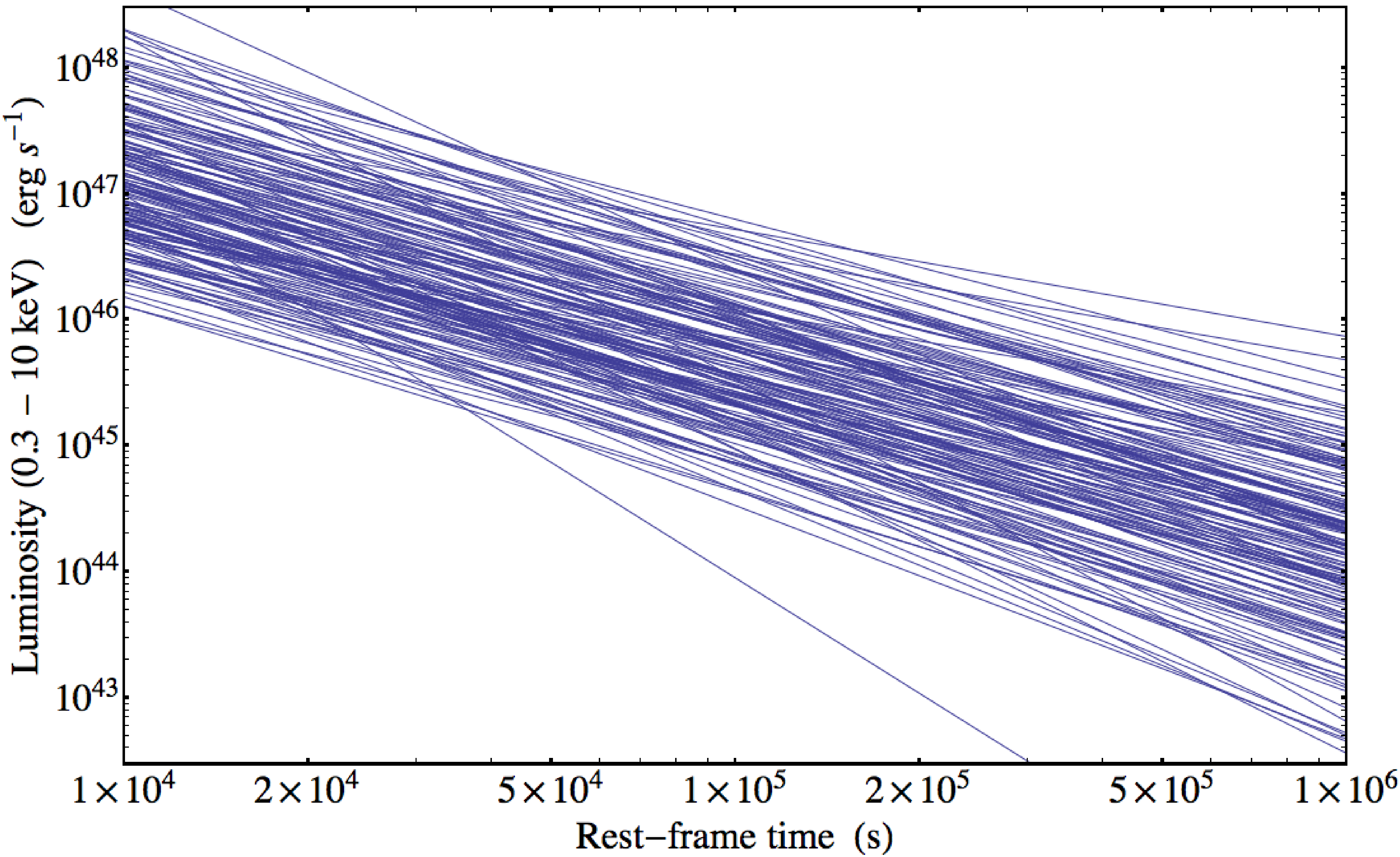
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



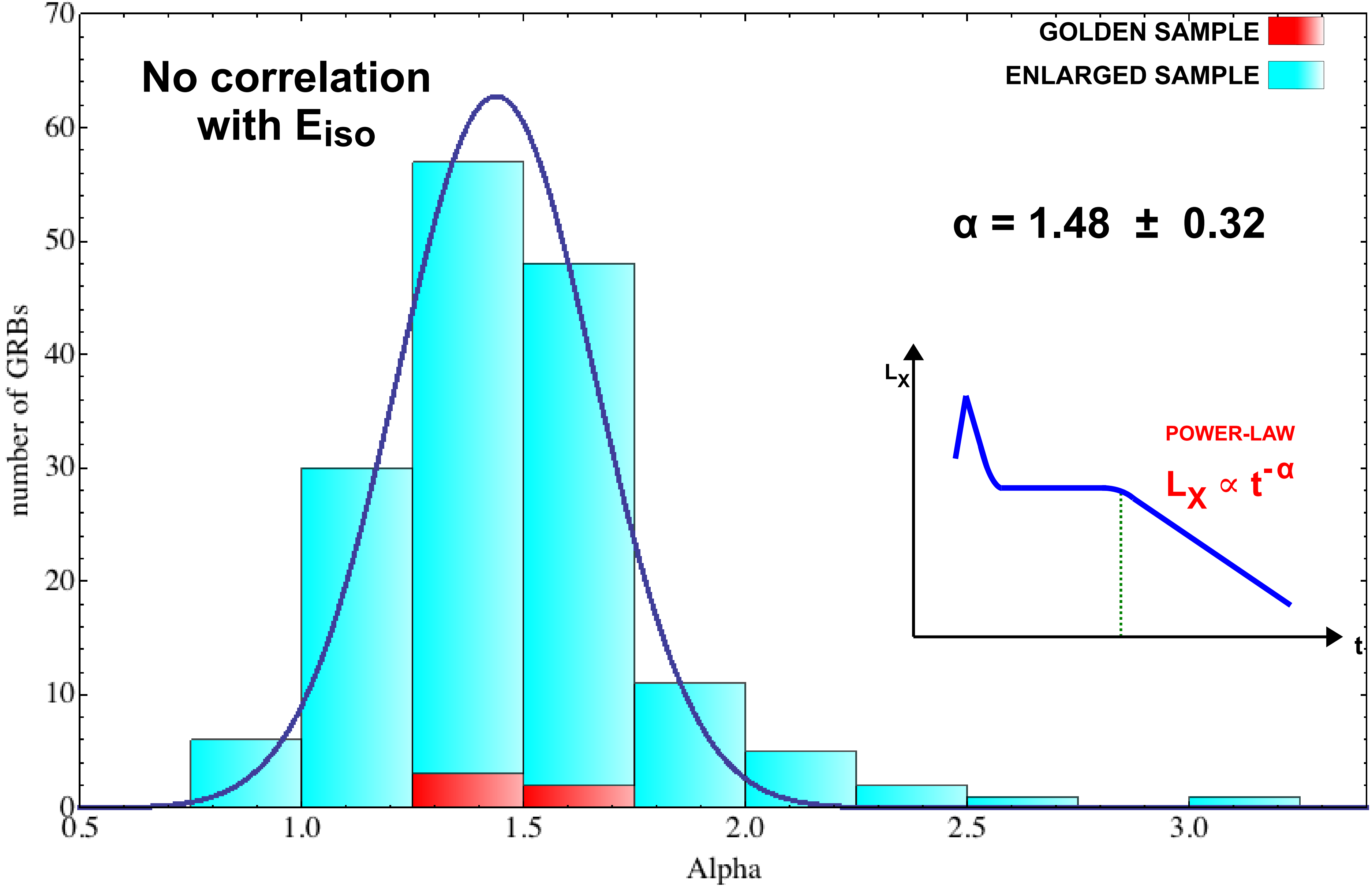
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



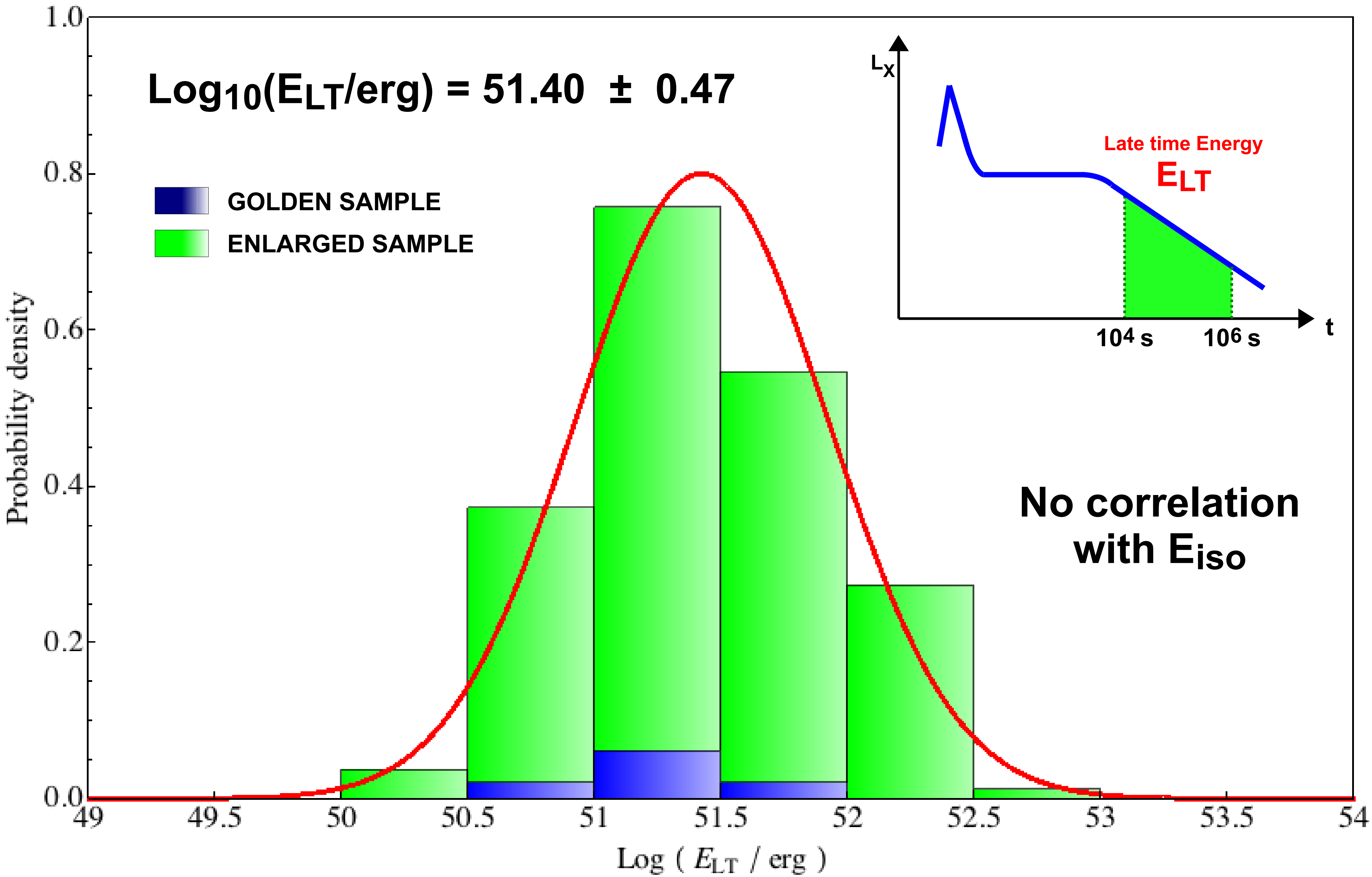
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



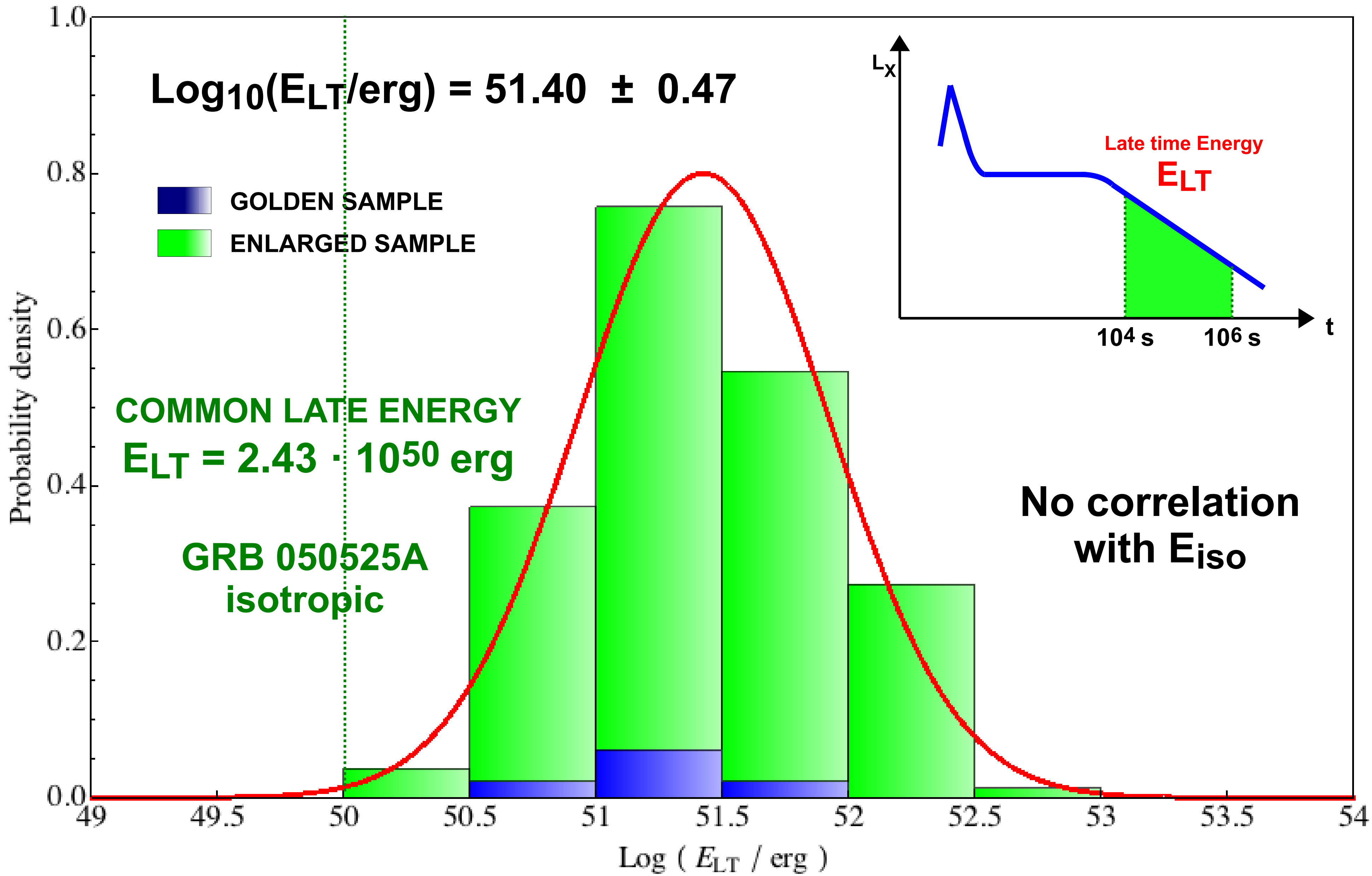
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



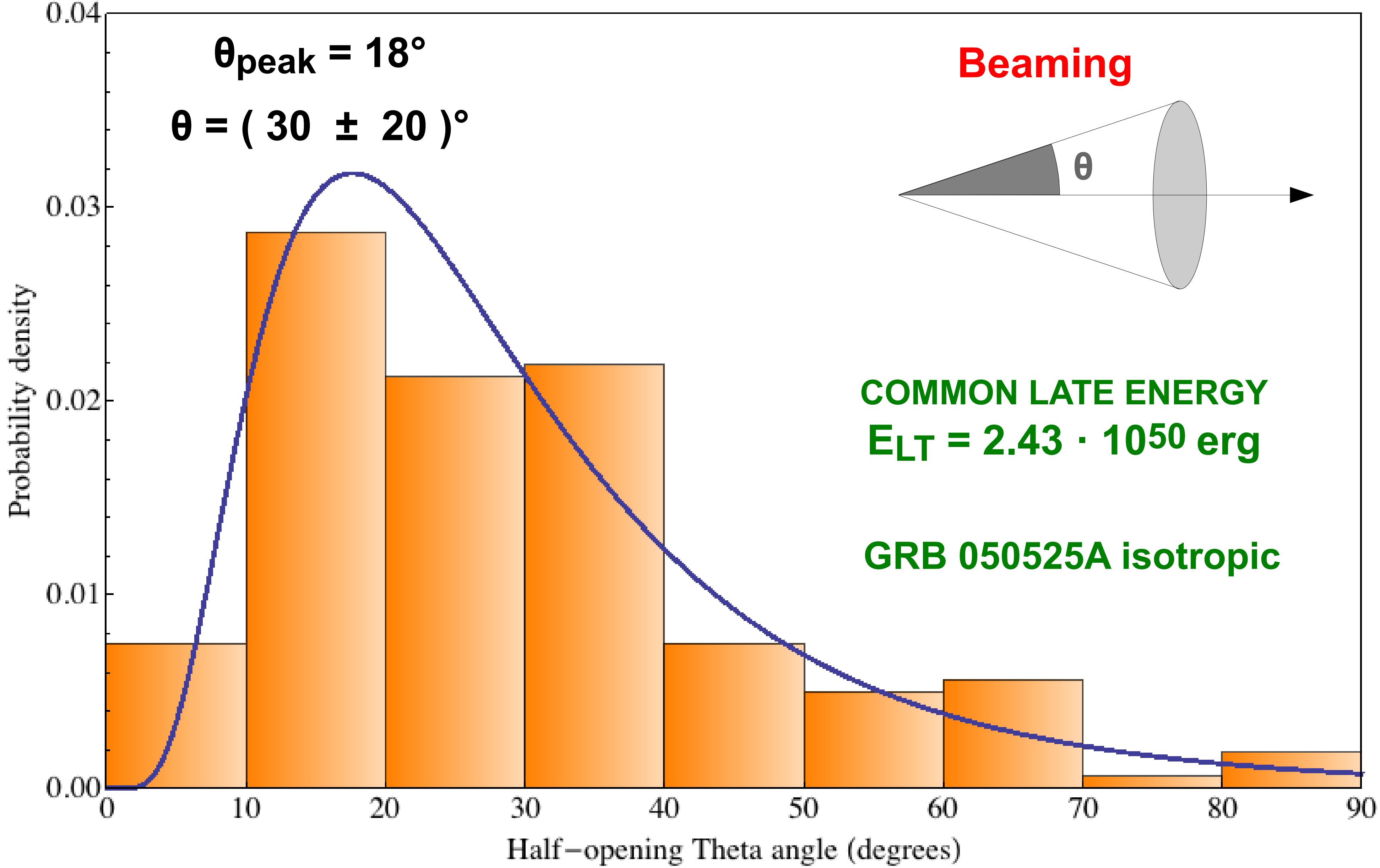
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



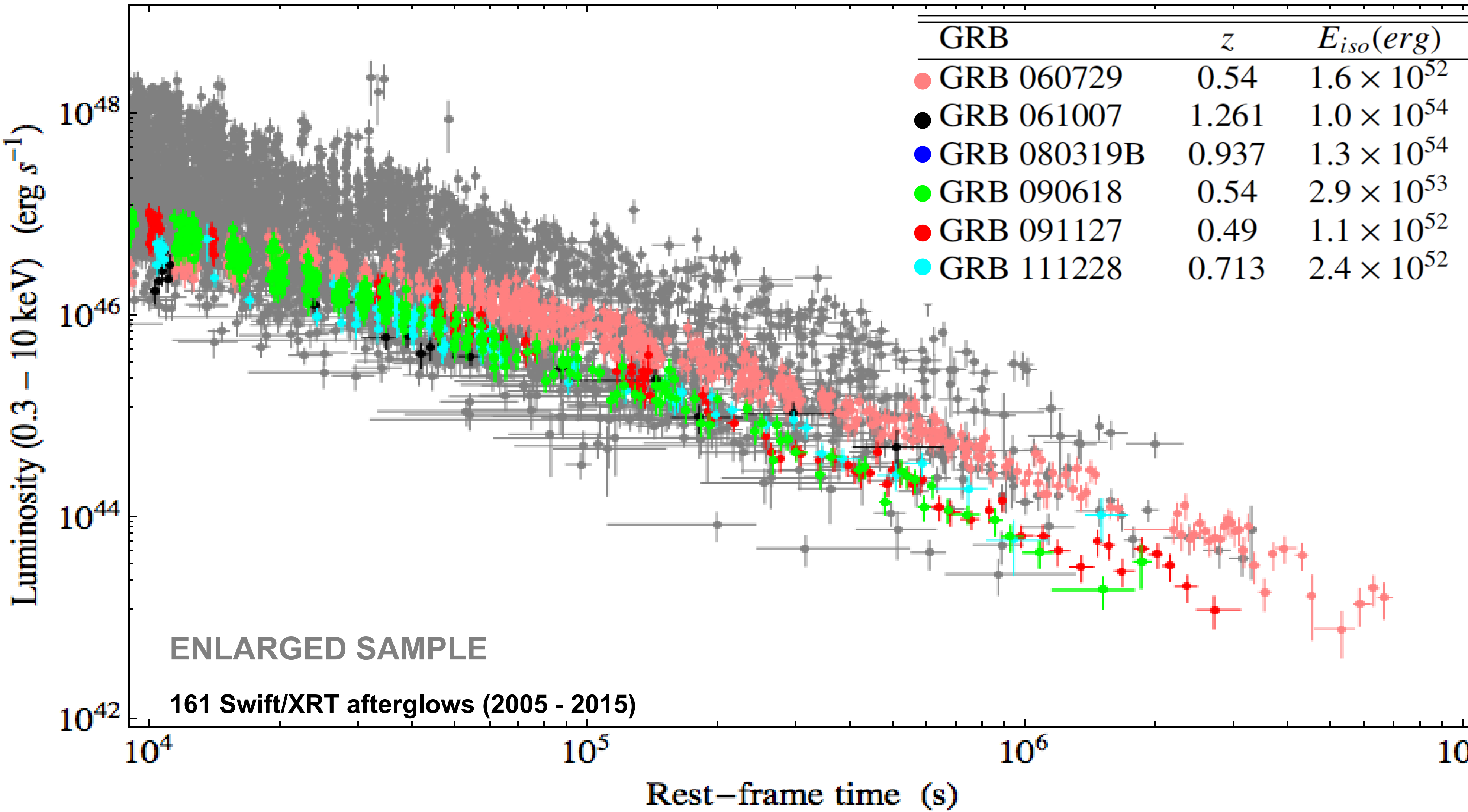
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



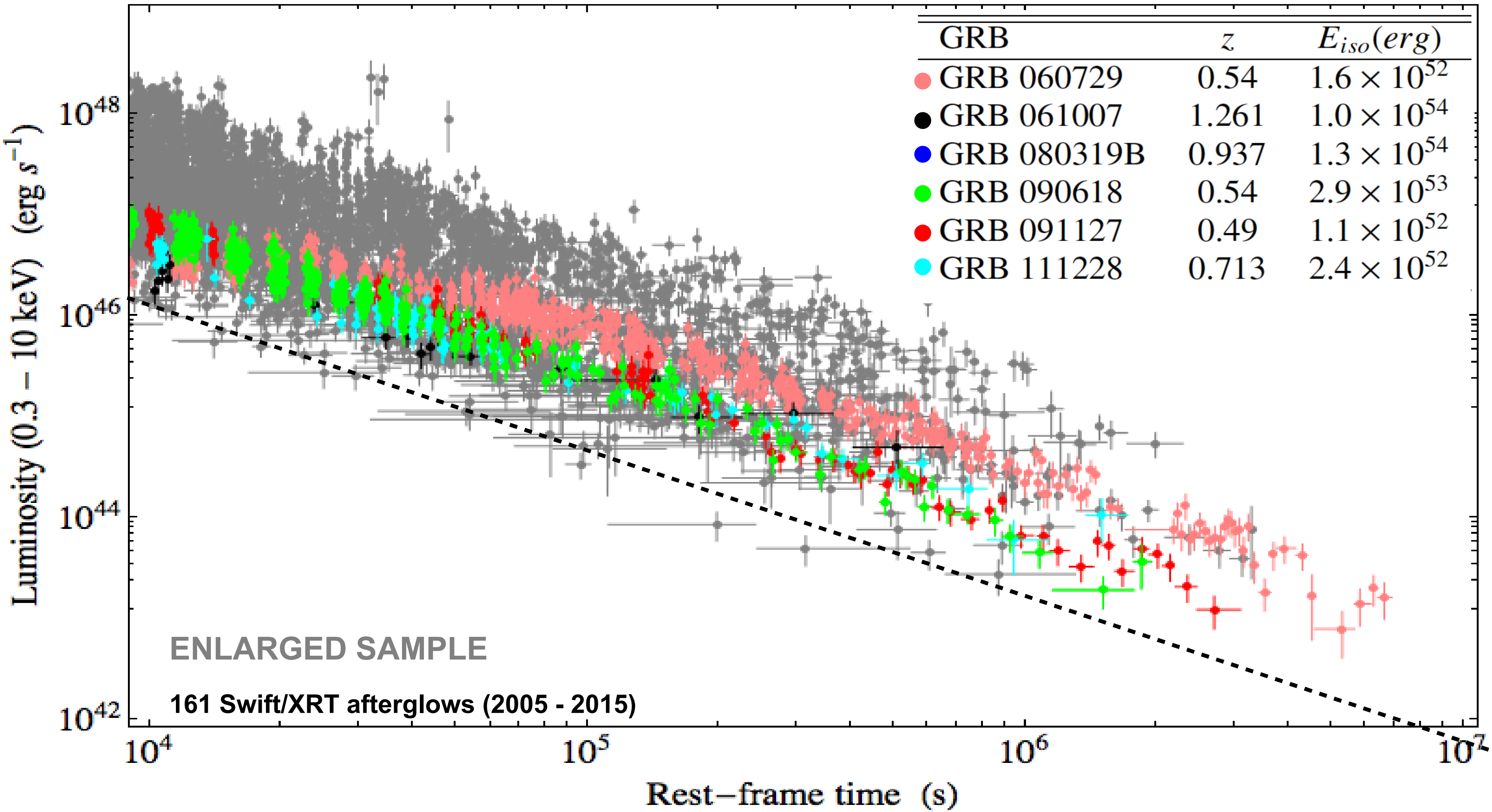
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ



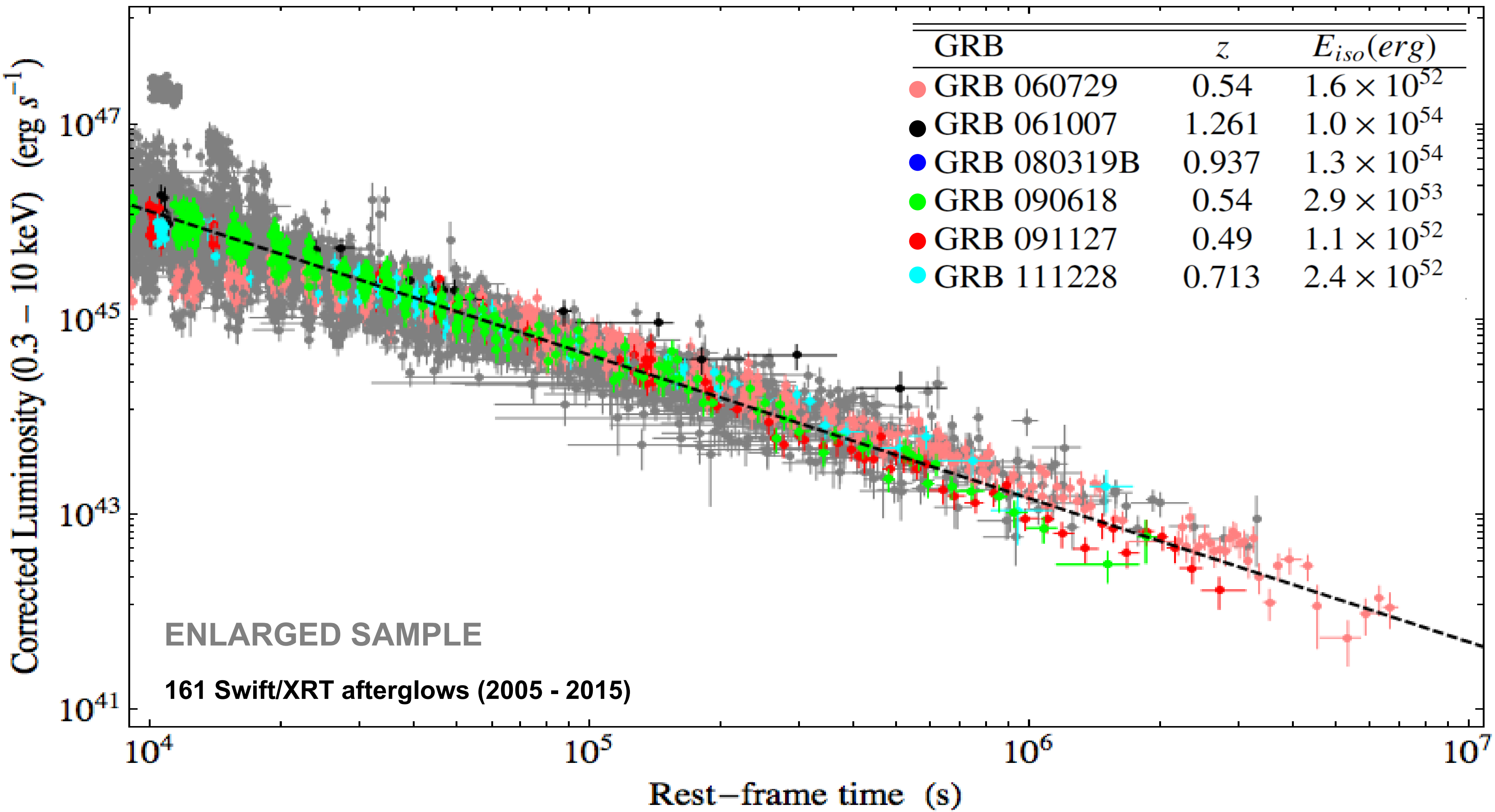
Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ

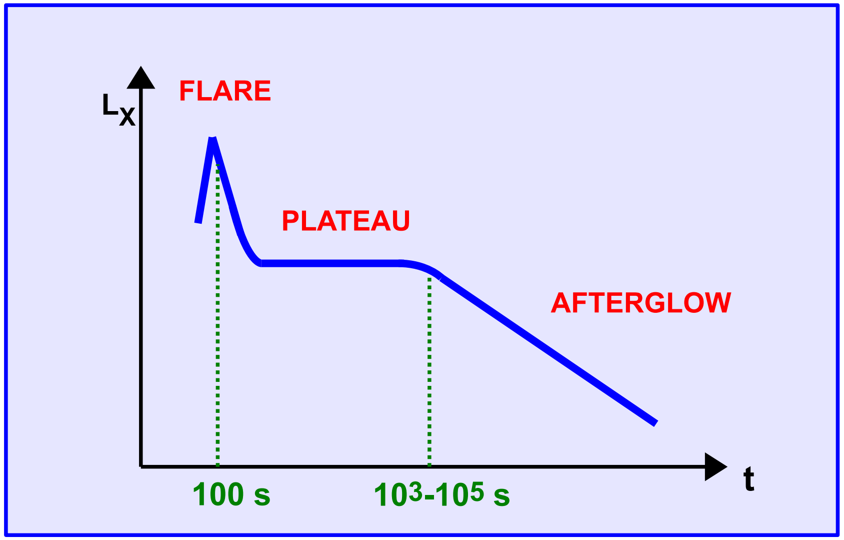


Enlarged Sample of BdHNe

Pisani et. al 2016, ApJ

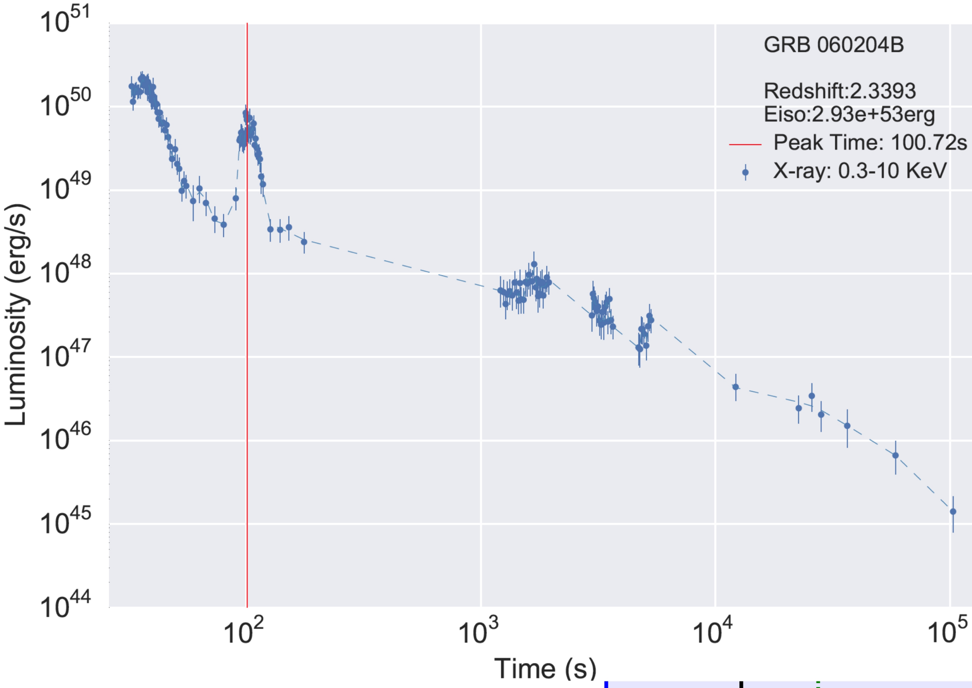


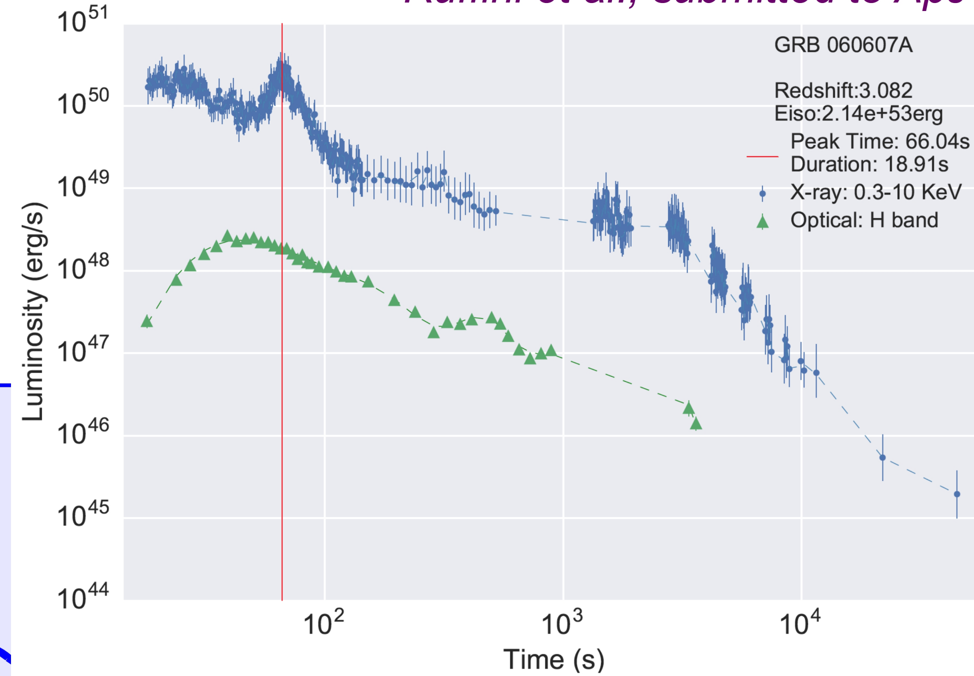
Early X-ray Flares

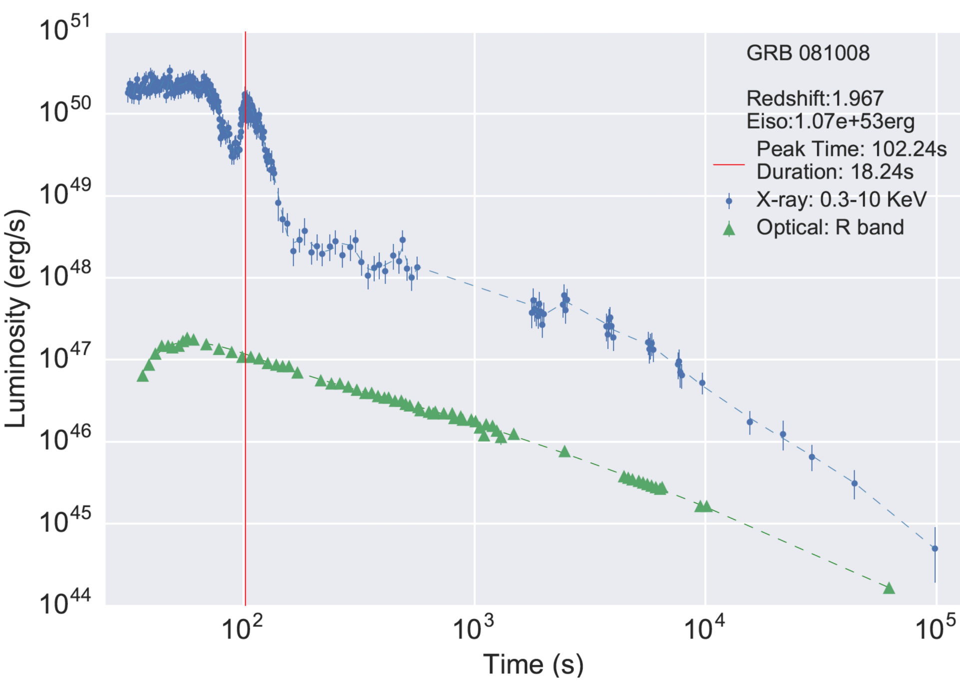


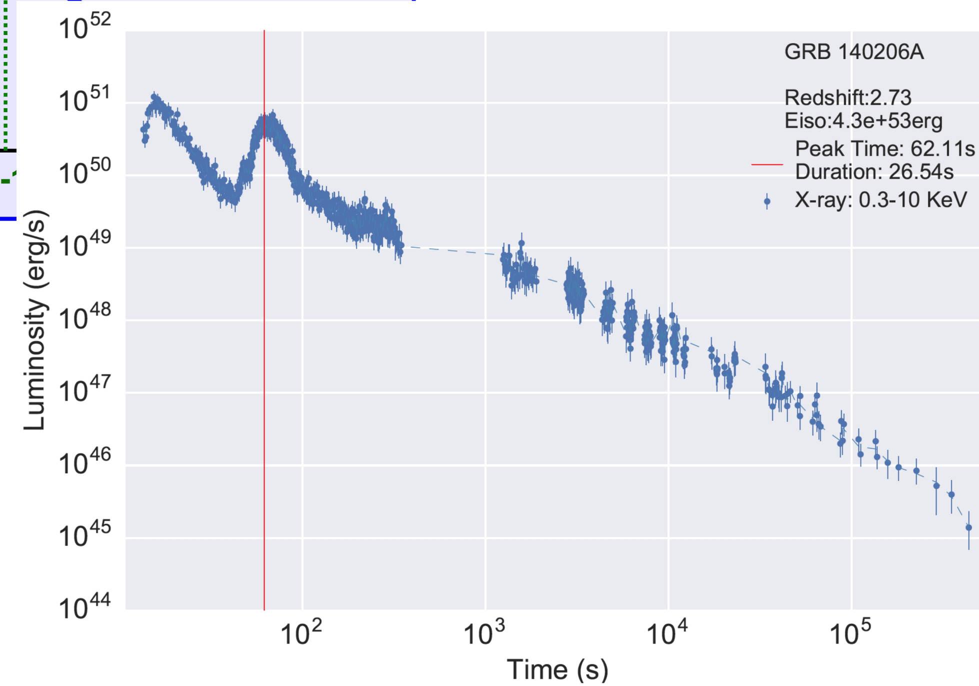
Early X-ray Flares

Ruffini et al., submitted to ApJ









Summary of the BdHNe Catalog up to the end of 2016

Ruffini et al., submitted to ApJ
www.icranet.org

Total sample

- Long GRBs
- Measured cosmological redshift z
- Isotropic energy $E_{iso} > 10^{52}$ erg

} **345**

Good Late X-ray Data ---> Cosmology

- Swift/XRT observations (12 years)
- X-ray data lasting up to at least 10^4 s in the rest-frame after the initial GRB explosion

} **182** **~53%** **~15/year**

X-ray Early Flare ---> IGC

- Presence of an flare in the X-rays around 100 s in the rest-frame

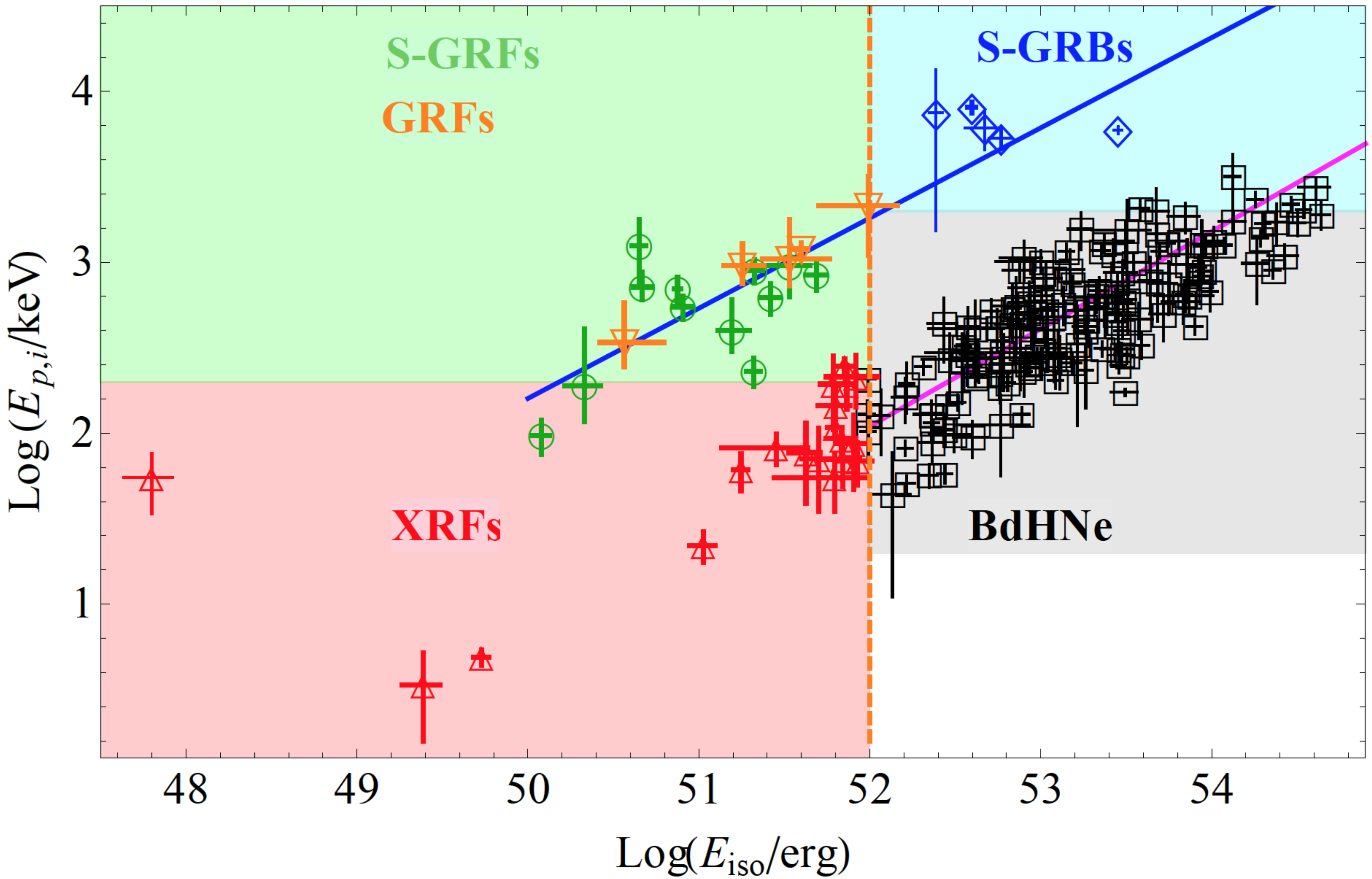
} **36** **~10%** **~3/year**

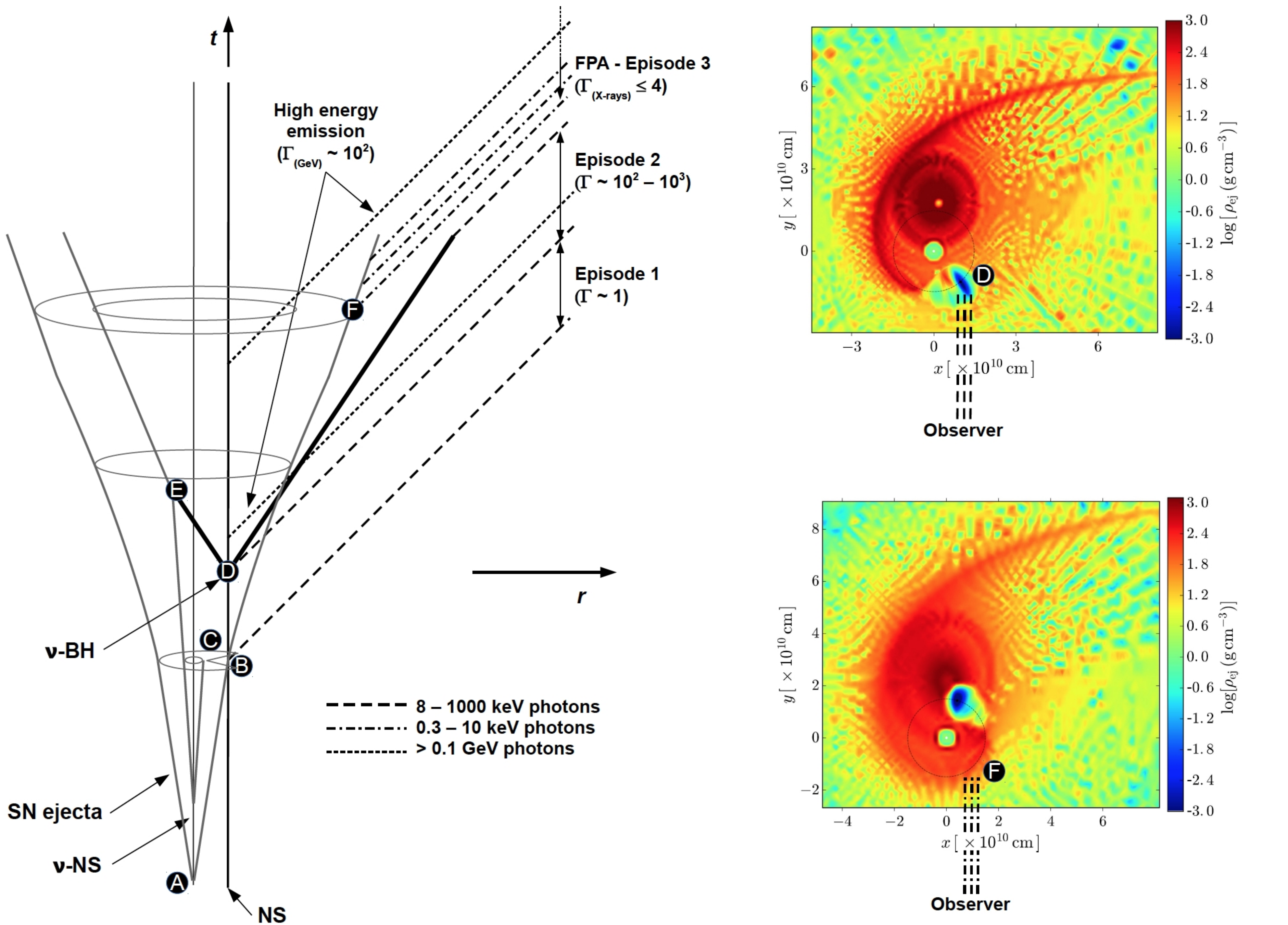
- Signal to noise ratio > 20
- No contamination by gamma-rays

} **16** **~5%** **1-2/year**

XIII International Conference on Gravitation, Astrophysics & Cosmology

15th Italian-Korean Symposium on Relativistic Astrophysics

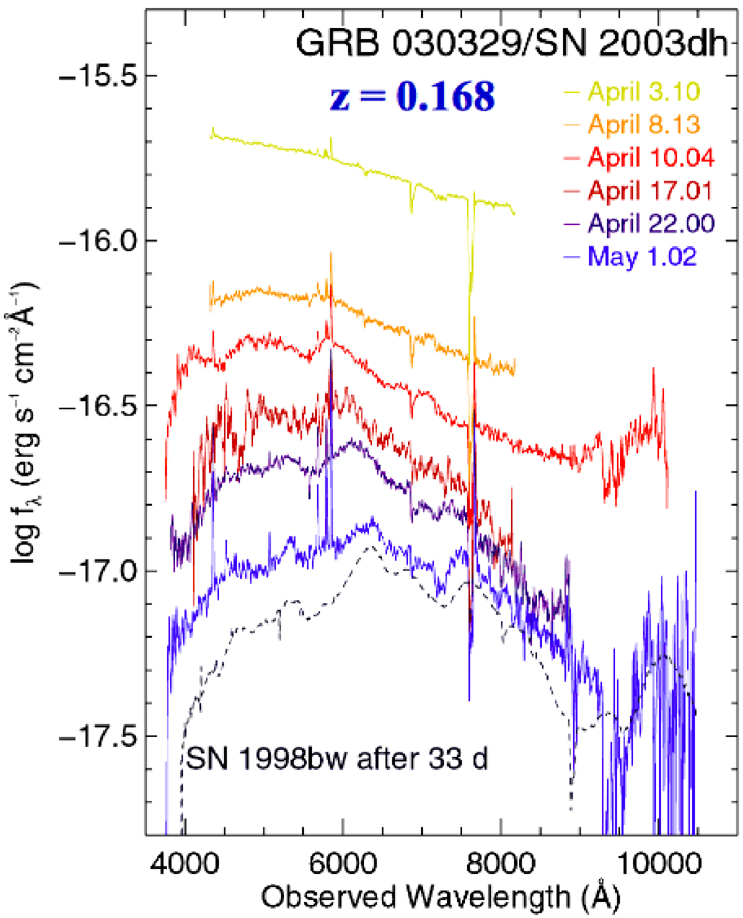

S-GRFs
GRFs
S-GRBs
XRFs
BdHNe
Log($E_{p,i}$/keV)
Log($E_{\rm iso}$/erg)
1
2
3
4
48
49
50
51
52
53
54



t
High energy emission
(Γ(GeV) ~ 10²)
FPA - Episode 3
(Γ(X-rays) ≤ 4)
Episode 2
(Γ ~ 10² – 10³)
Episode 1
(Γ ~ 1)
F
E
D
C
B
A
r
ν-BH
SN ejecta
ν-NS
NS
8 – 1000 keV photons
0.3 – 10 keV photons
> 0.1 GeV photons
D
Observer
F
Observer
x [× 10¹⁰ cm]
y [× 10¹⁰ cm]
log [ρej (g cm⁻³)]

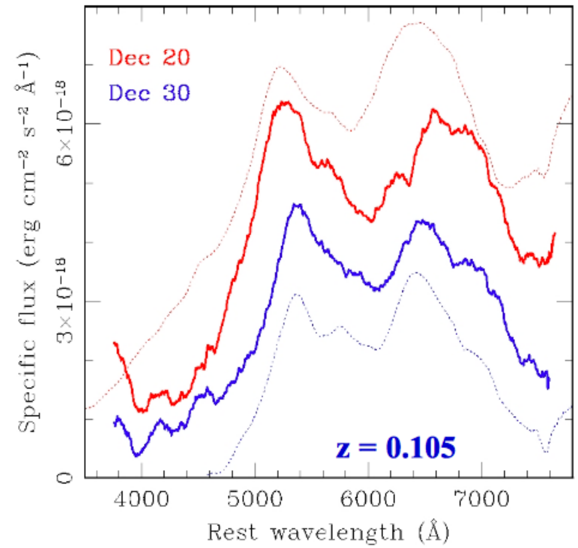
GRBs - SNe connection

“smoking-gun”



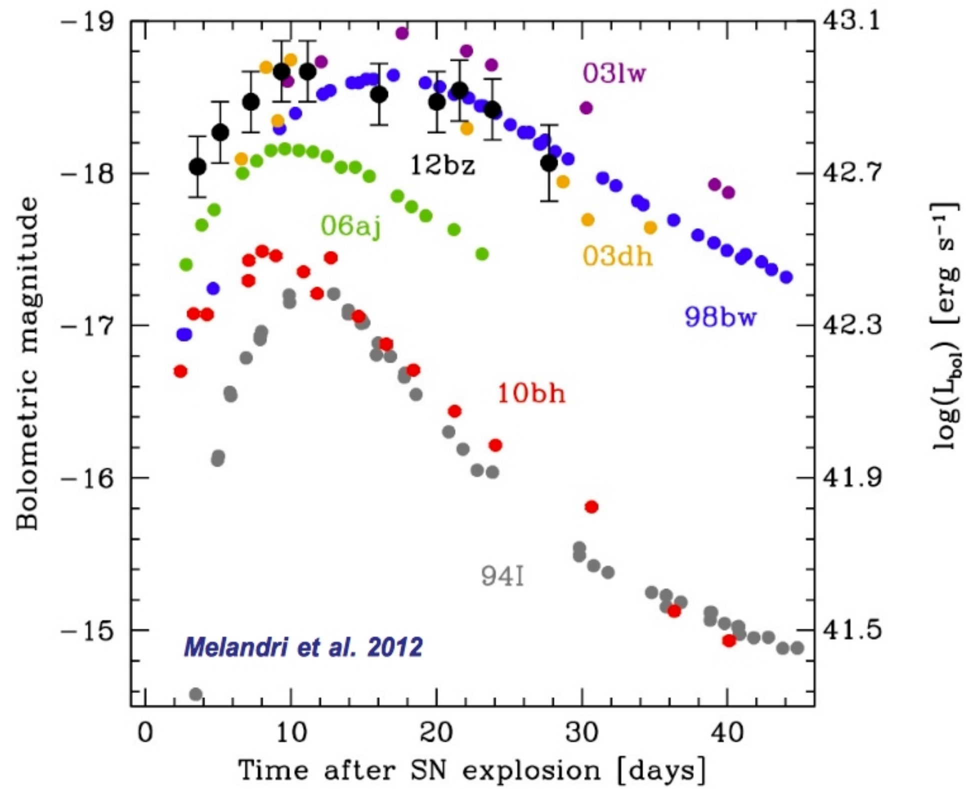
GRB 030329 / SN 2003dh

Matheson et al. 2003, ApJ
Stanek et al. 2003, ApJL
Hjorth et al. 2003, Nature
Kawabata et al. 2003, ApJL



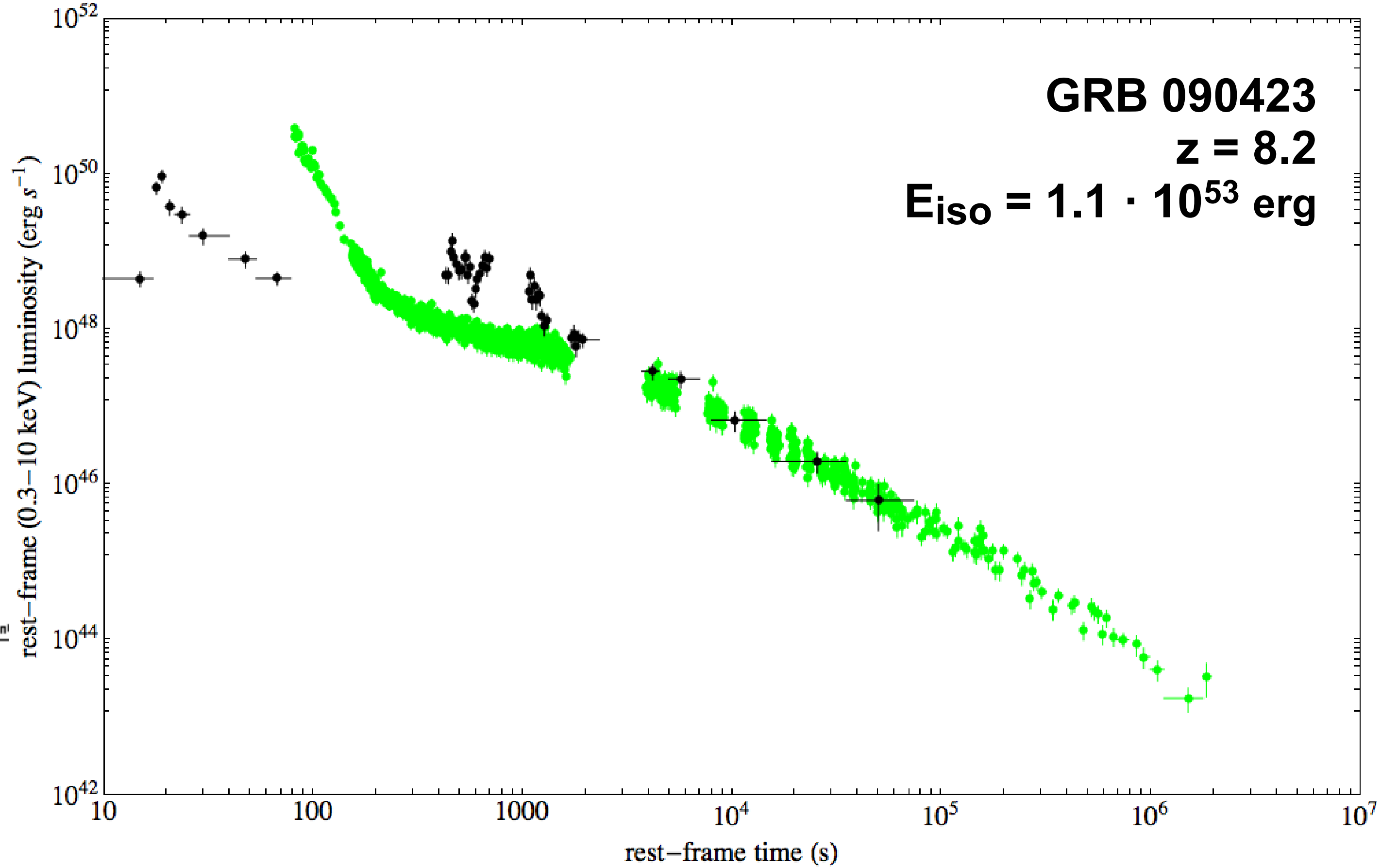
GRB 031203 / SN 2003lw

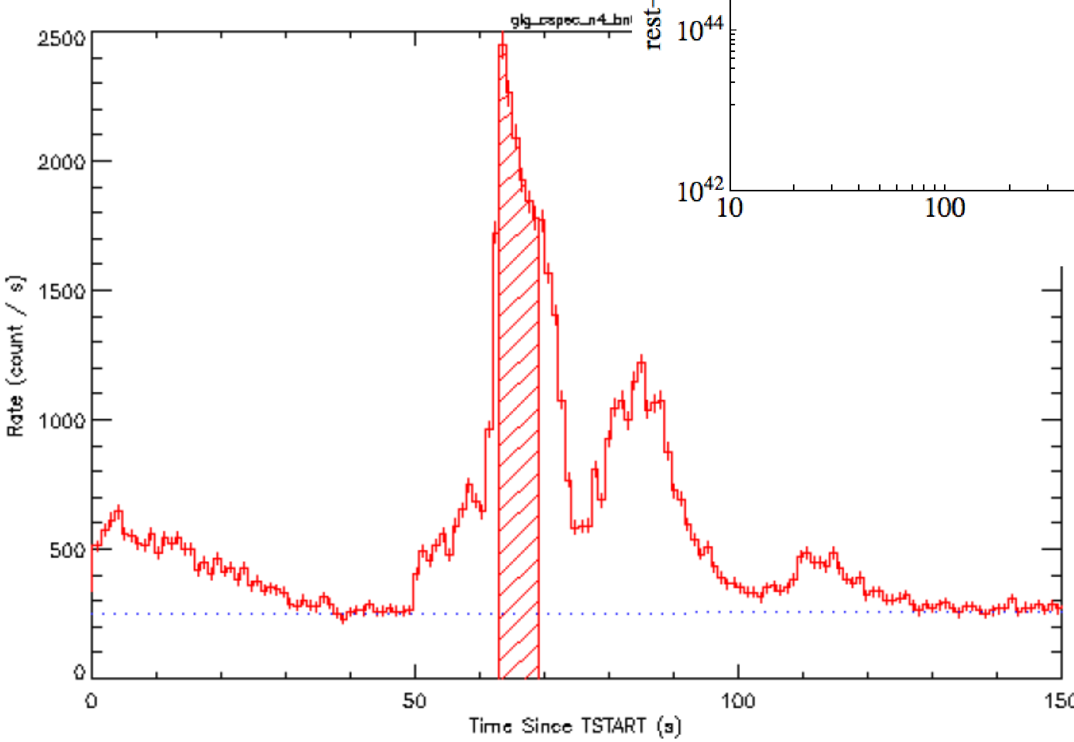
Thomsen et al. 2004, A&A
Cobb et al. 2004, ApJL
Gal-Yam et al. 2004, ApJL
Malesani et al. 2004, ApJL



A BdHN at the highest redshift: GRB 090423 at z = 8.2

Ruffini et al. 2014, A&A





Computation of the luminosity in the 0.3-10 keV rest frame energy band

1) We assume a simple power-law function as best-fit for the spectral energy distribution of the XRT data (we consider the data provided by the UK Swift-XRT Leicester group *http://www.swift.ac.uk/xrt curves/*):

$$\Phi(E) \propto E^{-\gamma}$$

2) We can write the flux light curve in the 0.3 – 10 keV rest frame energy range as:

$$f_{rf} = f_{obs} \frac{\int_{\frac{0.3\,keV}{1+z}}^{\frac{10\,keV}{1+z}} E\,\Phi(E)}{\int_{0.3\,keV}^{10\,keV} E\,\Phi(E)} = f_{obs}(1+z)^{\gamma-2}$$

3) Then, in order to obtain the luminosity, we have to multiply it by the spherical surface having the luminosity distance as radius (where we assume the standard cosmological model):

$$L_{rf} = 4\,\pi\,d_l^2(z) f_{rf}$$

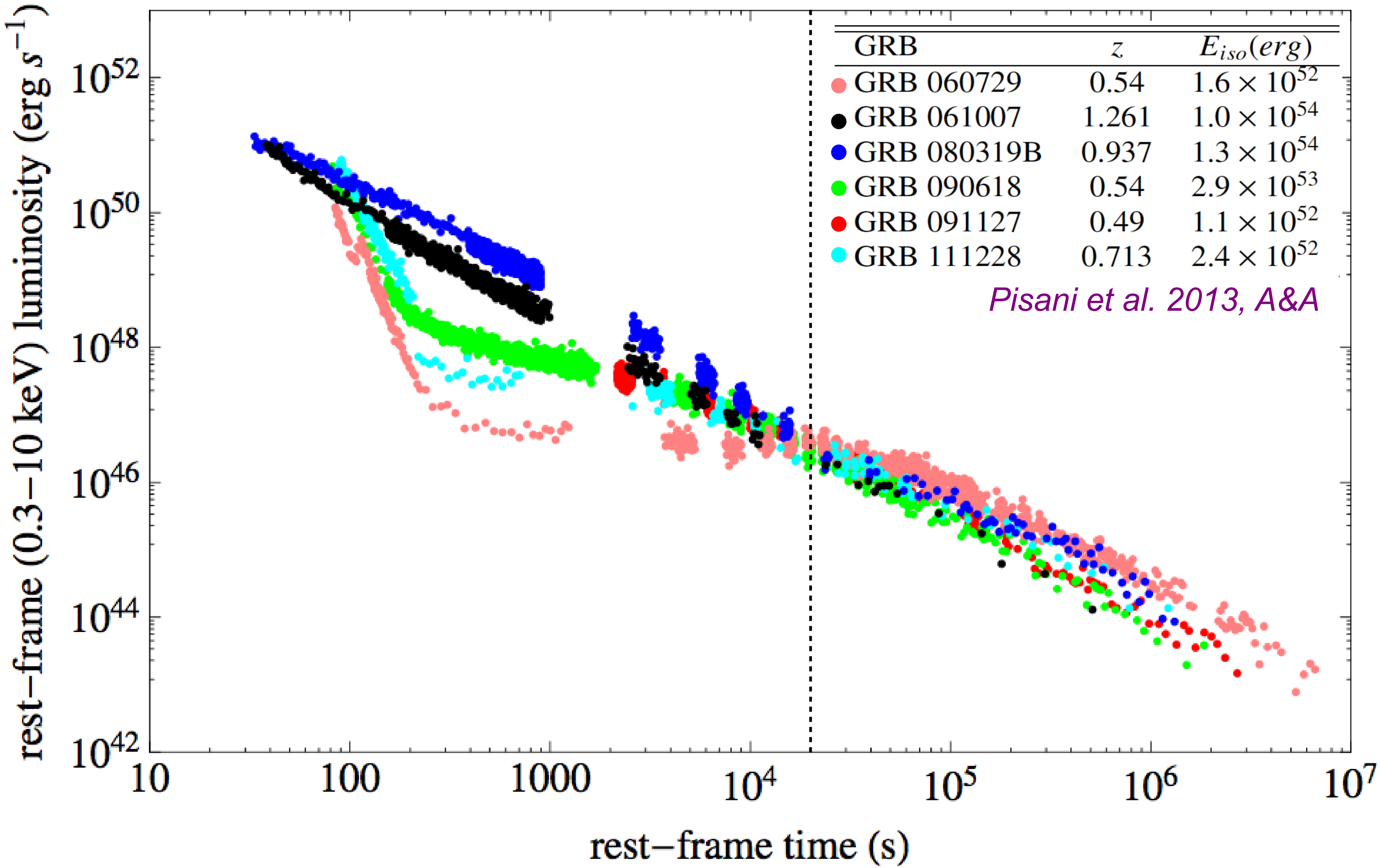
4) Finally, we need to transform the observer time to rest frame time:

$$t_{rf} = \frac{t_{obs}}{1+z}$$

Pisani et al. 2013, A&A

A common behavior of the rest-frame X-ray luminosity after 20 000 s

THE GOLDEN SAMPLE



Predictive power of this result:

1) GRBs at redshift $z > 1$

in this case we can predict the existence of a SN in such a system, expected to emerge after a time of $\sim 10\,(1 + z)$ days, the canonical time sequence of a SN explosion. This offers a new challenge to detect SNe at high redshift

2) GRBs at redshift $z < 1$

we can indicate in advance, from the X-ray luminosity light curve observed by XRT, the expected time for the observations of a SN and alert direct observations from on-ground and space telescopes

3) GRBs with no measured redshift

we can infer the redshift of the GRBs as done for GRB 110709B and GRB 101023A

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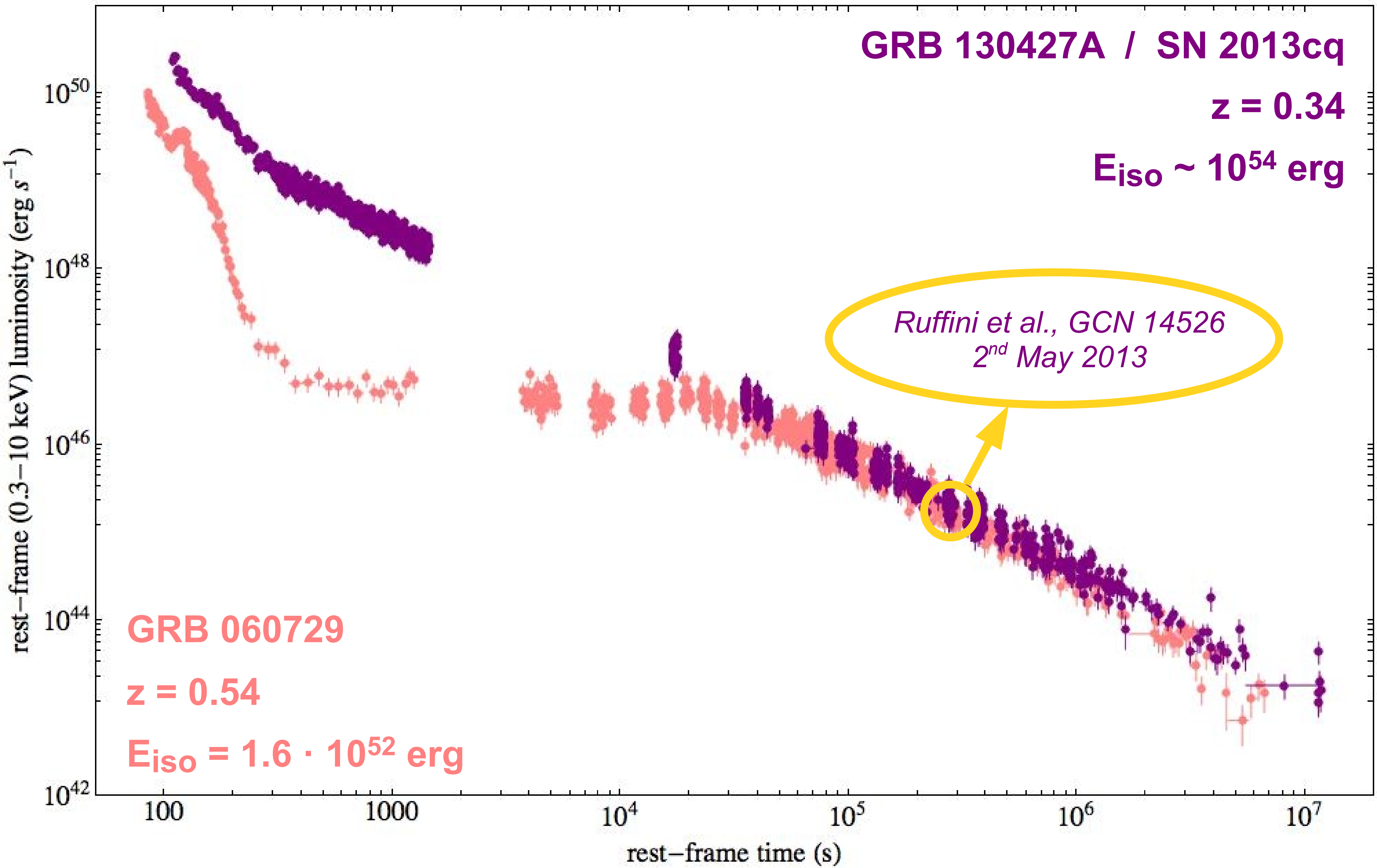
GRB 130427A: late X-ray luminosity overlap with GRB 060729



Ruffini et al. 2015, ApJ

GRB 130427A: associated supernova confirmation

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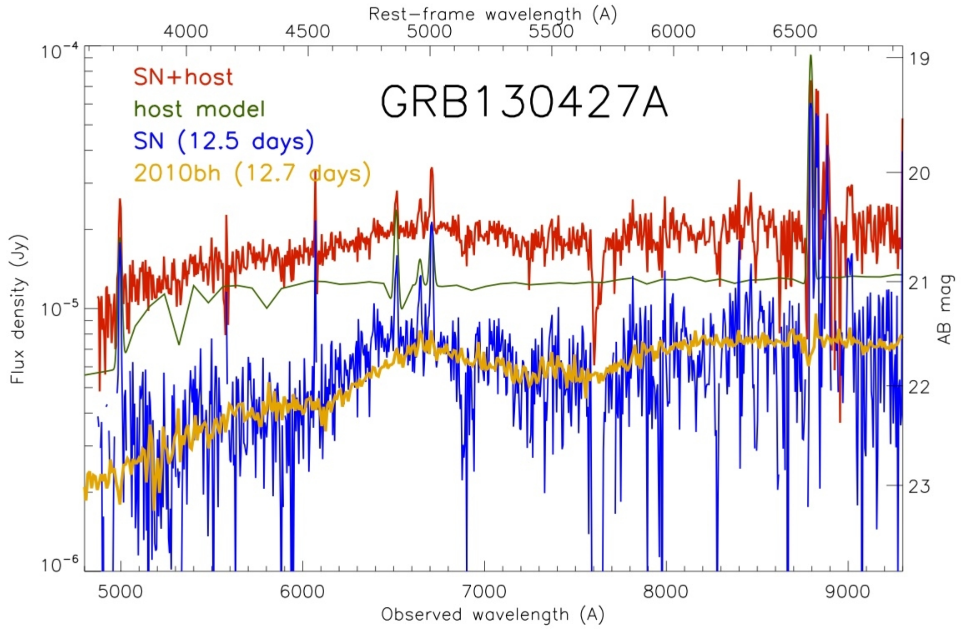
TITLE:   GCN CIRCULAR
NUMBER:  14646
SUBJECT: GRB 130427A: Spectroscopic detection of the SN from the 10.4m GTC
DATE:    13/05/14 21:21:33 GMT
FROM:    Antonio de Ugarte Postigo at IAA-CSIC  <deugarte@iaa.es>

A. de Ugarte Postigo (IAA-CSIC, DARK/NBI), D. Xu (DARK/NBI),
G. Leloudas (OKC, Stockholm, DARK/NBI),  T. Kruehler,
D. Malesani (DARK/NBI), J. Gorosabel (IAA-CSIC, UPV/EHU), Z. Cano (U. Iceland),
C.C. Thoene, R. Sanchez-Ramirez (IAA-CSIC), S. Schulze (PUC and MCSS),
J.P.U. Fynbo, J. Hjorth (DARK/NBI), P. Jakobsson (U. Iceland) and
A. Cabrera-Lavers (IAC-ULL) report on behalf of a larger collaboration:
```



SPECTROSCOPIC DETECTION

Gran Telescopio Canarias
GCN 14646

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TITLE:   GCN CIRCULAR
NUMBER:  14686
SUBJECT: GRB 130427A / SN 2013cq: Hubble Space Telescope Observations
DATE:    13/05/20 23:08:33 GMT
FROM:    Andrew S. Fruchter at STScI  <fruchter@stsci.edu>

A.J. Levan (U. Warwick), A.S. Fruchter, J. Graham (STScI), N.R. Tanvir (U.
Leicester), Jens Hjorth, Johan Fynbo (Dark Cosmology Centre, Copenhagen), D.
Perley (Caltech), S.B. Cenko (U.C. Berkeley), E. Pian (Trieste), Z. Cano (U.
Iceland) A. Pe'er (Cork), R. Hounsell (STScI), K. Mishra (ARIES, India), C.
Kouveliotou (MSFC) report:
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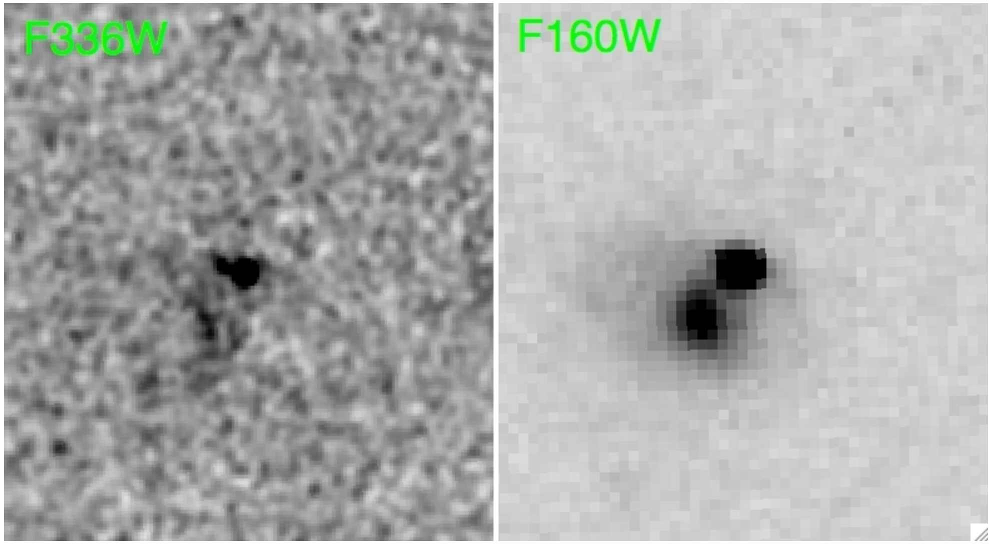

PHOTOMETRIC DETECTION

Hubble Space Telescope
GCN 14686

Predictive power of this result:

1) GRBs at redshift $z > 1$
in this case we can predict the existence of a SN in such a system, expected to emerge after a time of $\sim 10\,(1 + z)$ days, the canonical time sequence of a SN explosion. This offers a new challenge to detect SNe at high redshift

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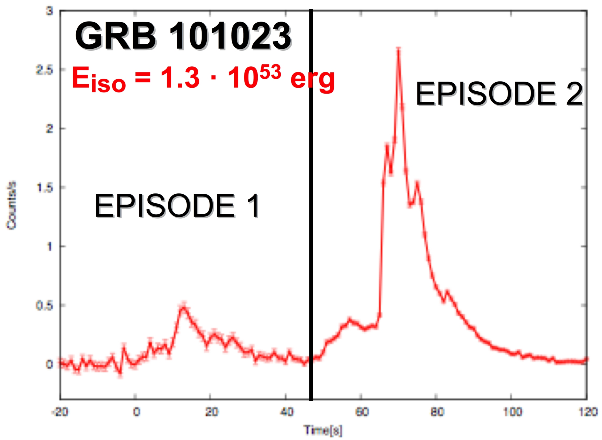
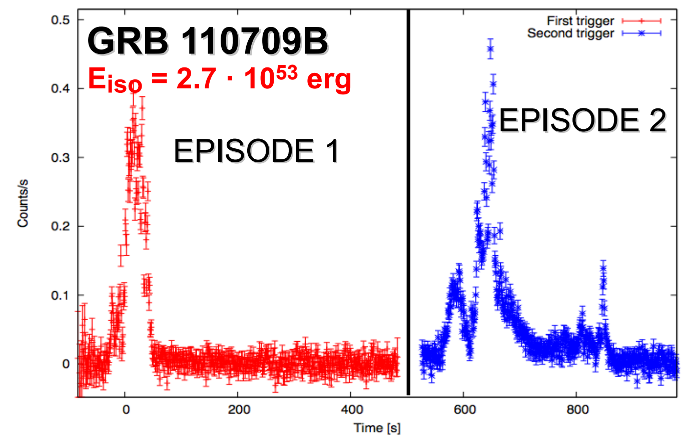
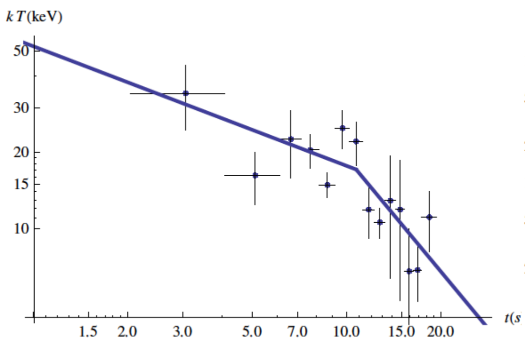
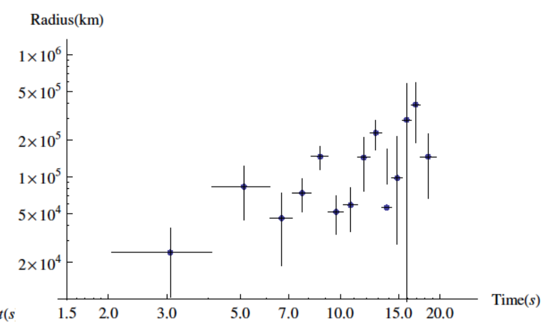
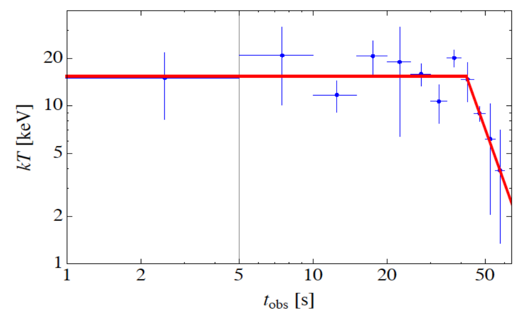
Prediction of the redshift: GRB 101023 and GRB 110709B

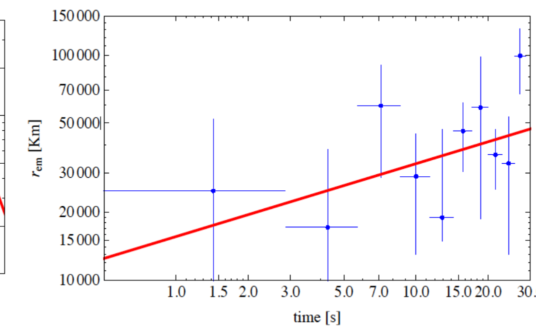


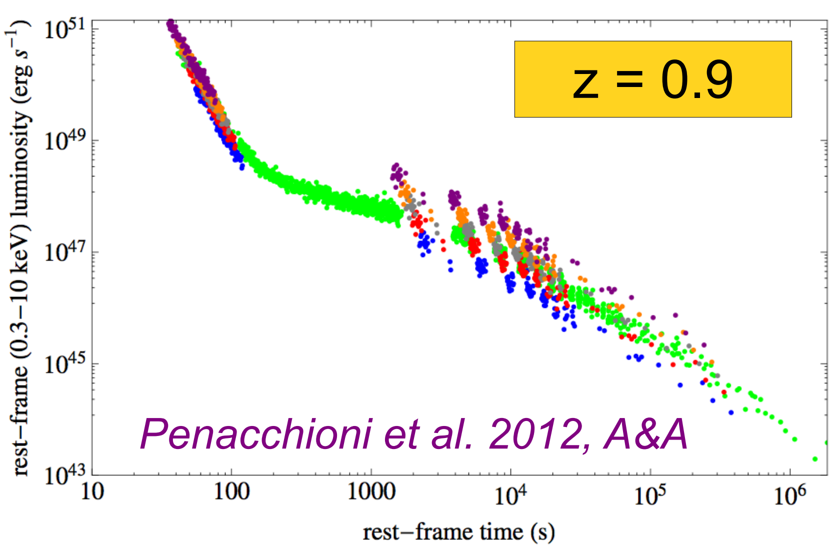


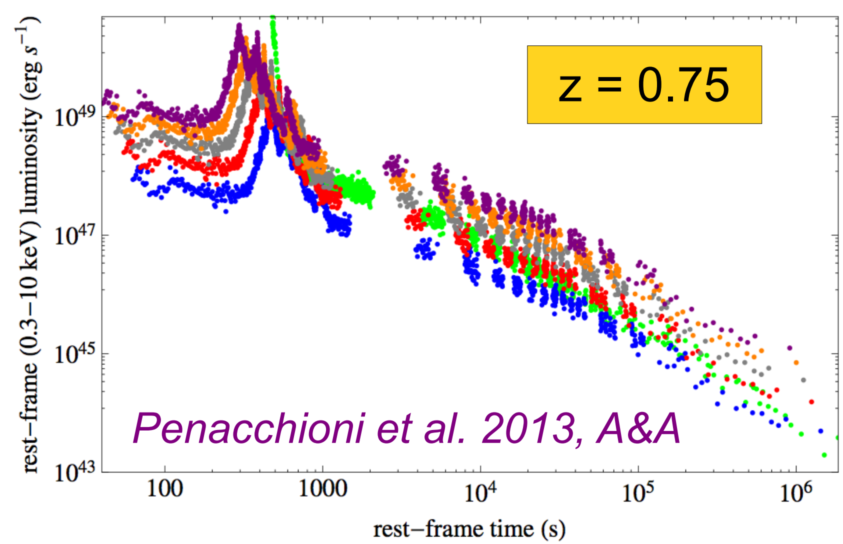






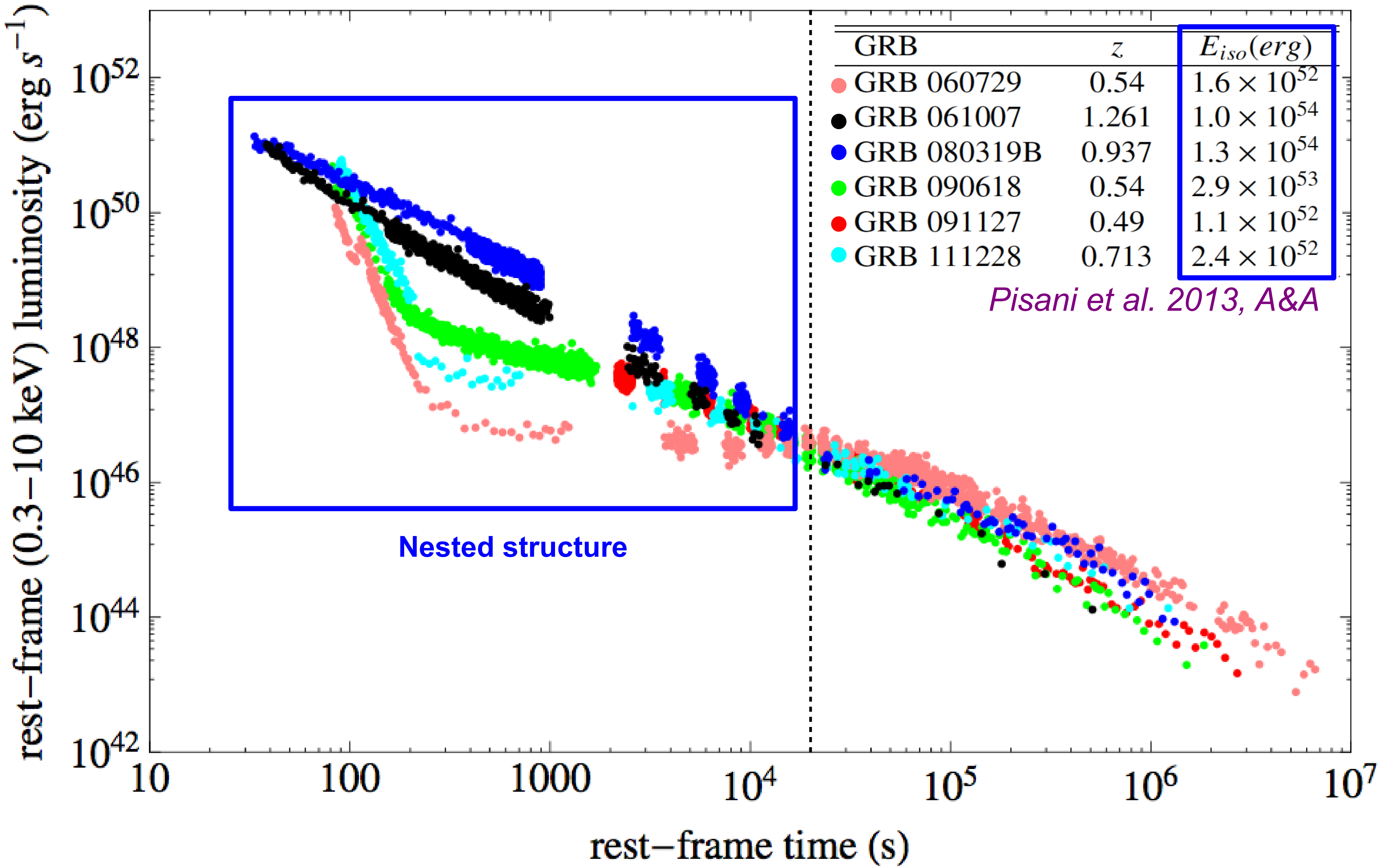






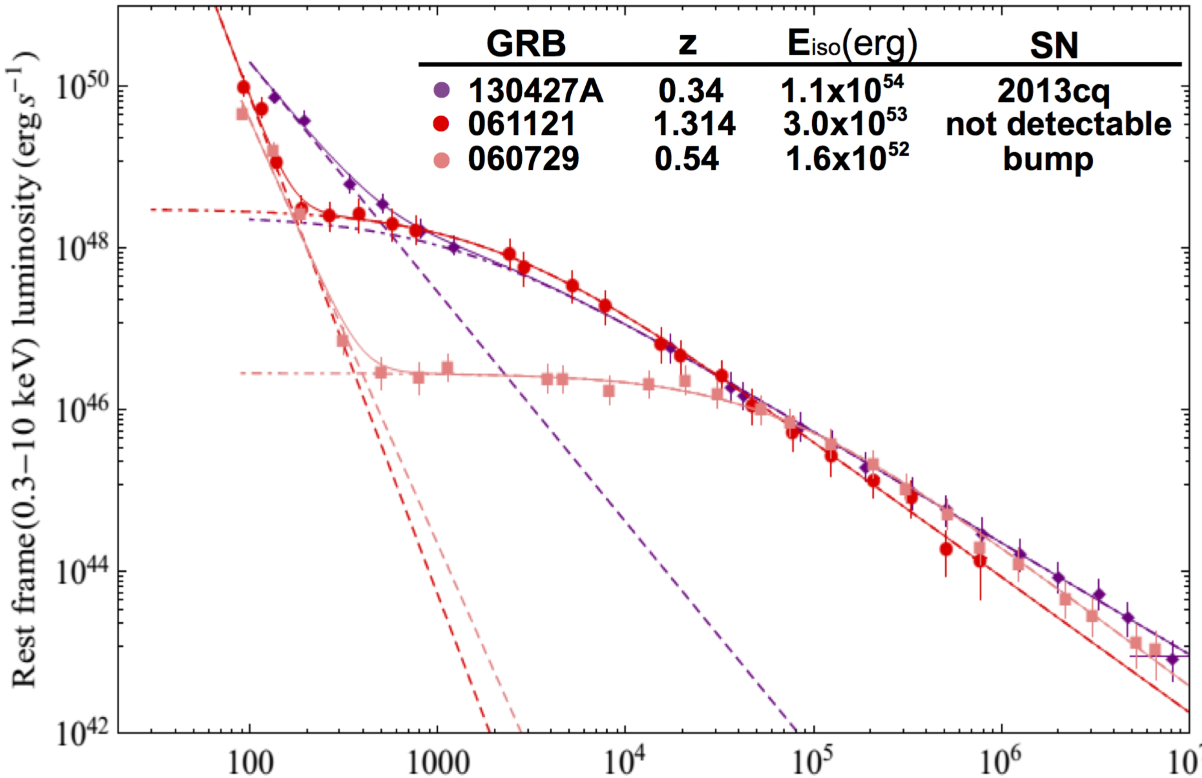
A common behavior of the rest-frame X-ray luminosity after 20 000 s

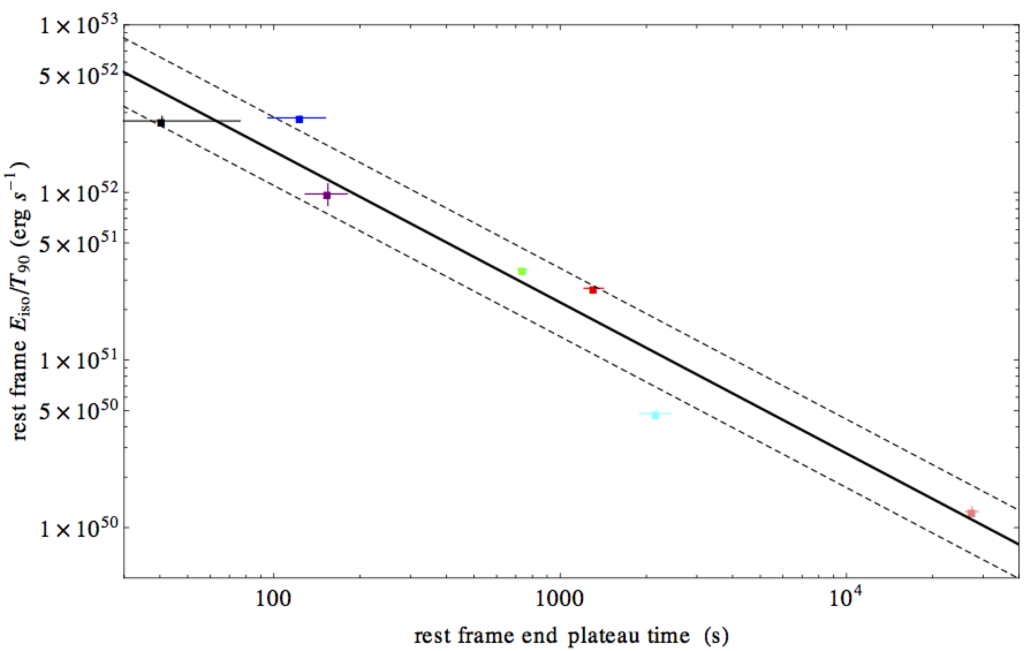
THE GOLDEN SAMPLE

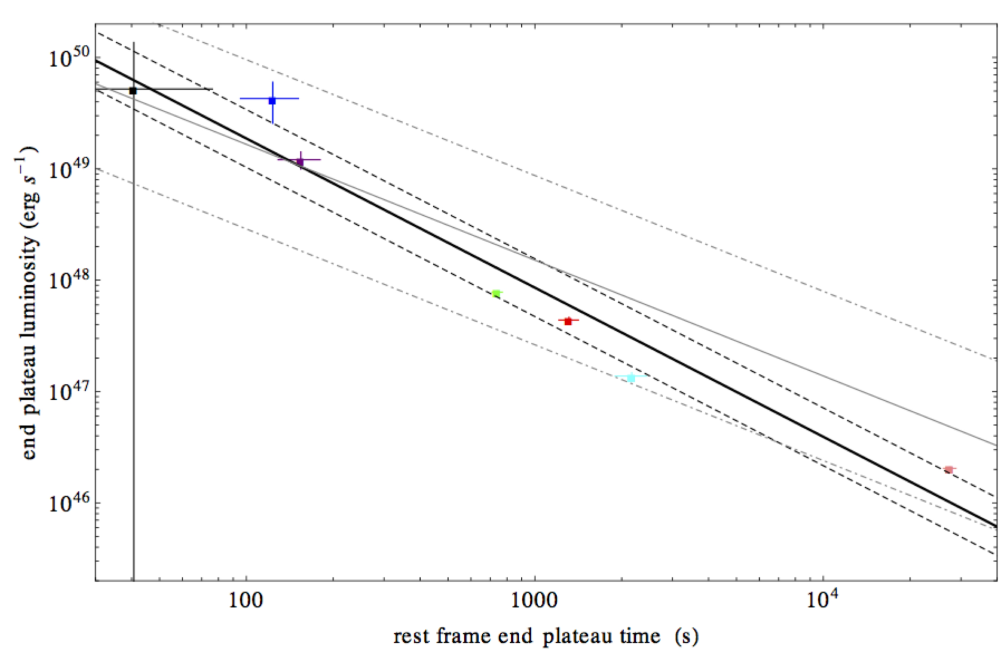


The nested structure of Episode 3

Ruffini et al. 2014, A&A



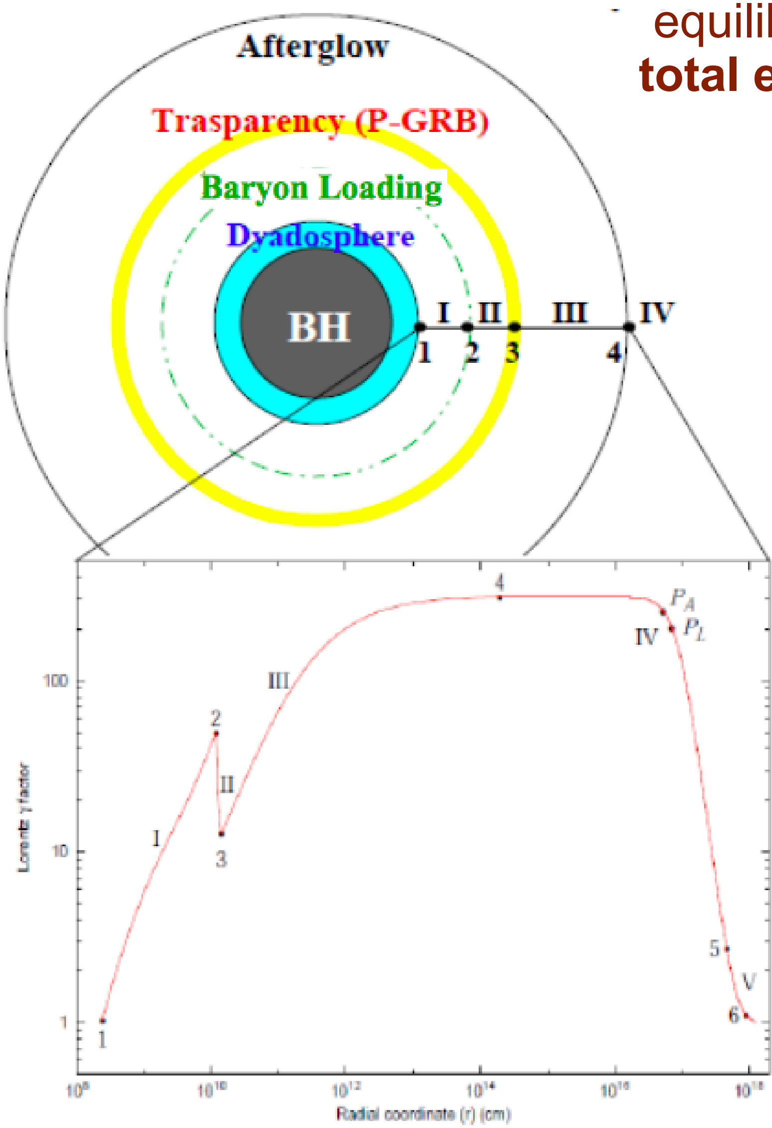




Fireshell model

gravitational collapse to a Black Hole

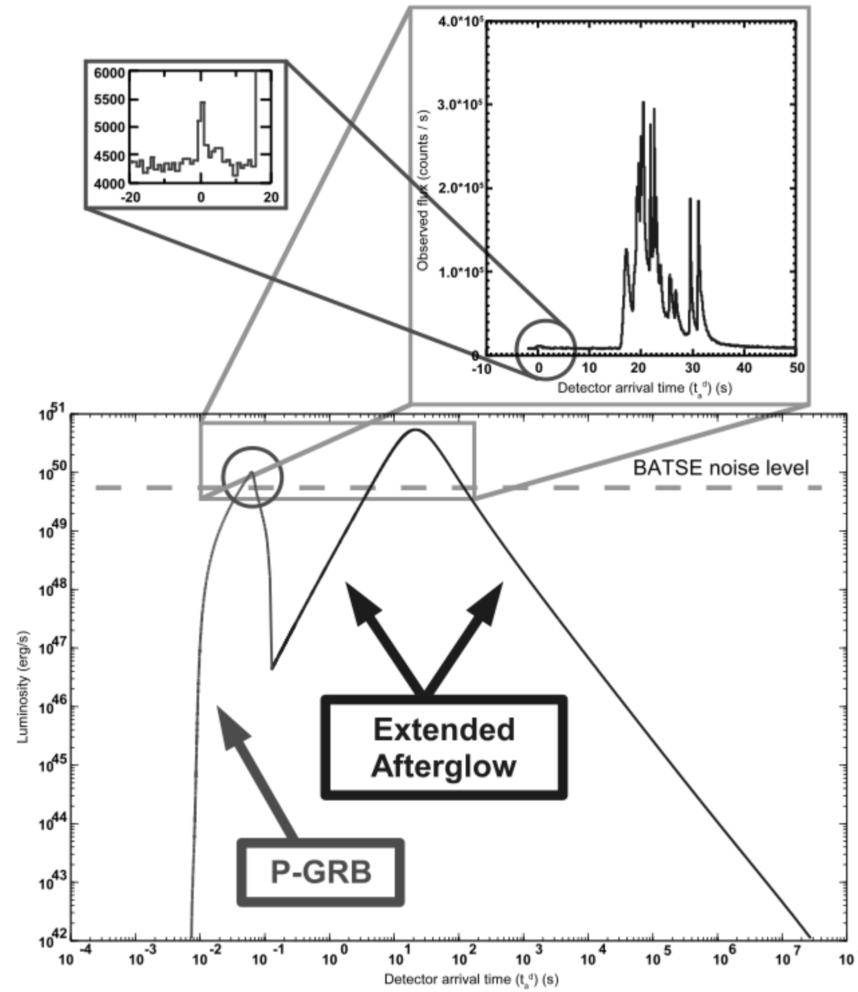
optically thick plasma of $e_{\pm}$ at thermal equilibrium with **total energy $E_{e\pm}$**



gradual annihilation confined in a relativistically expanding shell

engulfing of the left over barions
$B = M_b c^2 / E_{e\pm}$

at transparency **P-GRB** is emitted



accelerated barions interact with the circumburst medium giving rise to the **Extended Afterglow**

Fireshell model