Three SN rebrightenings in GRB afterglow light curves in the context of the full GRB-SN sample

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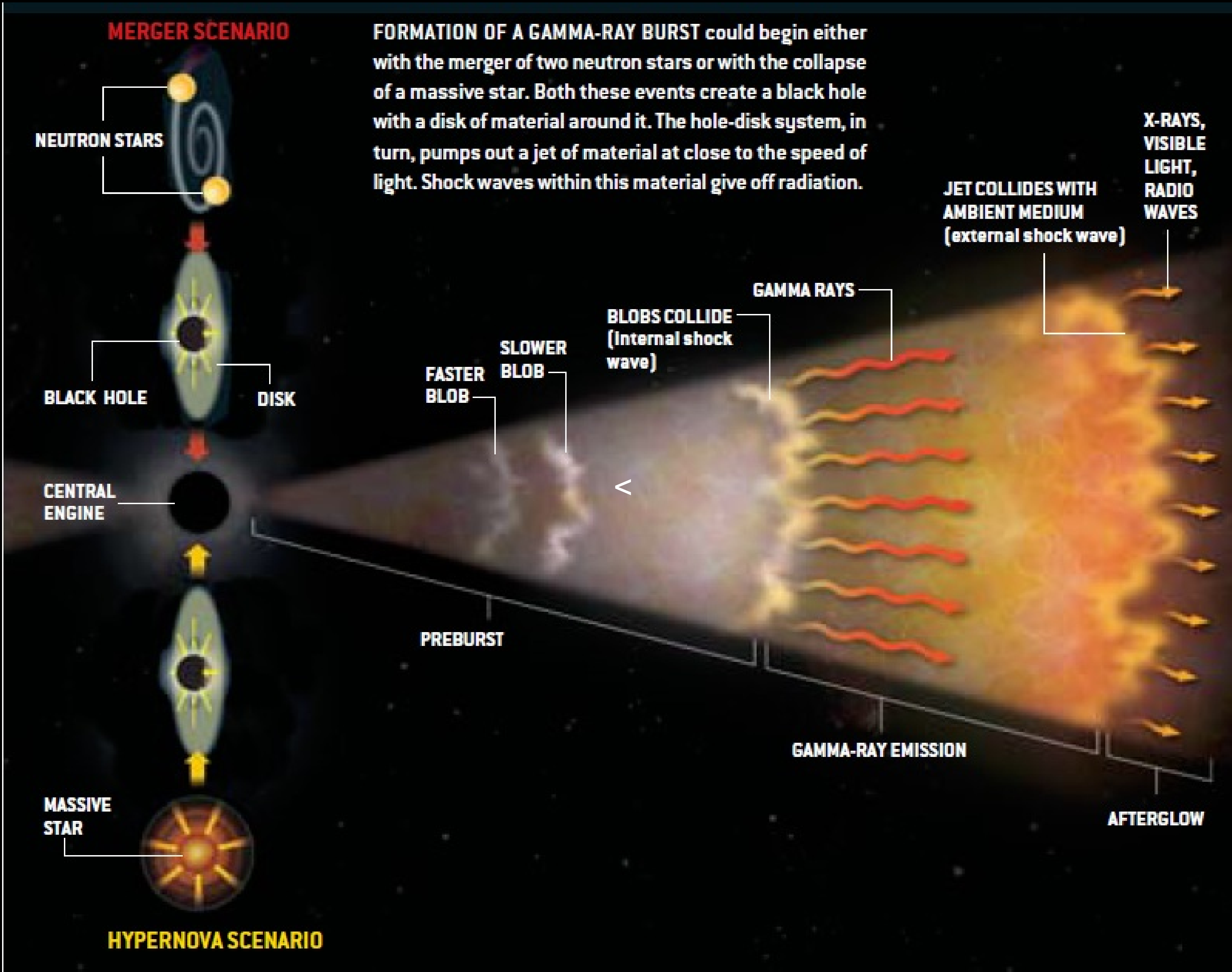
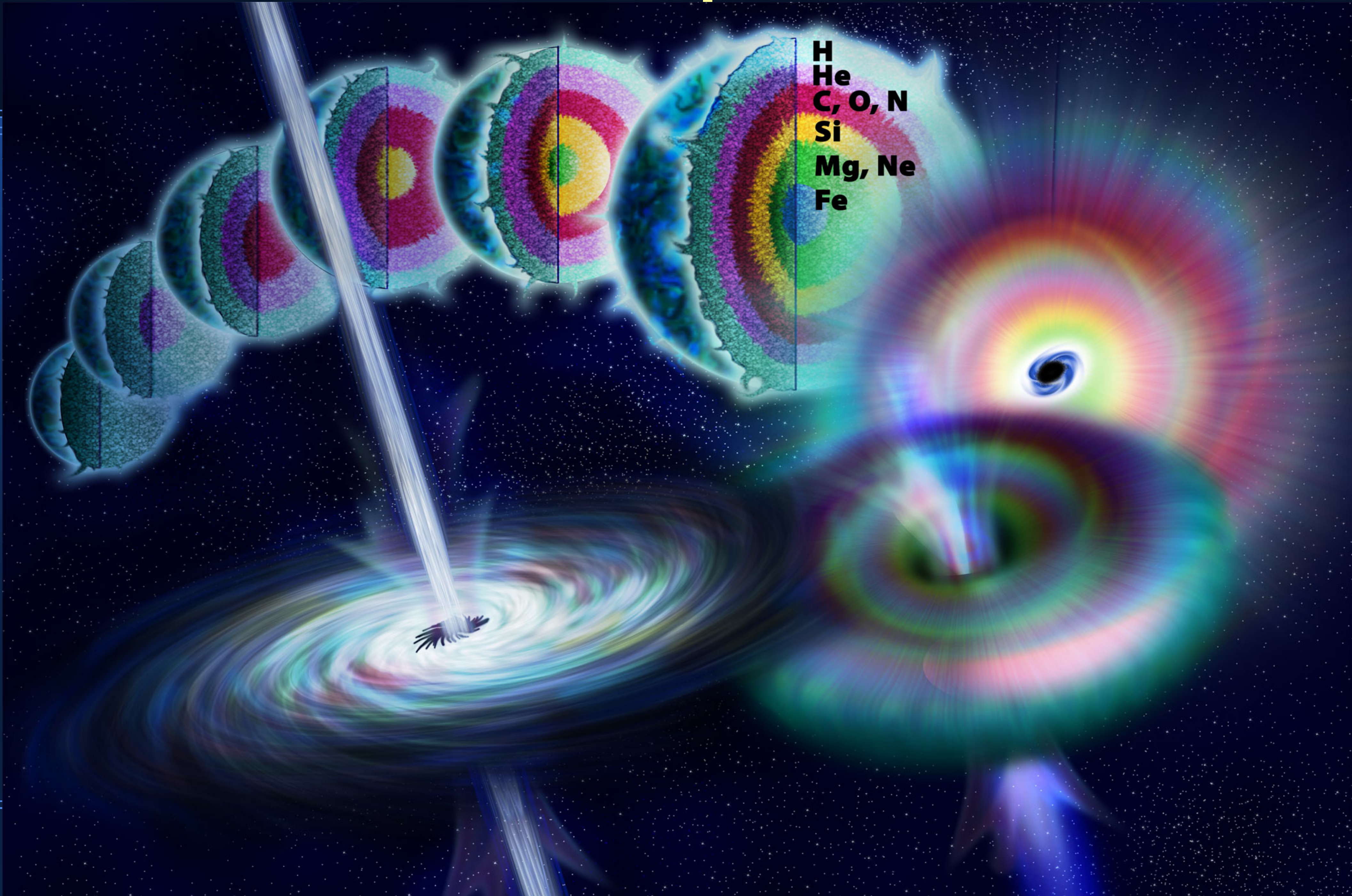
Kyoto on bike! Know more in less time.

- If you don't want to travel underground
- Bike 4 Rent shop: ROJI – YA
  Close to Nijojo-mae station
  500 Yen per day ; cheapest fare in Kyoto!

GRB fireball model

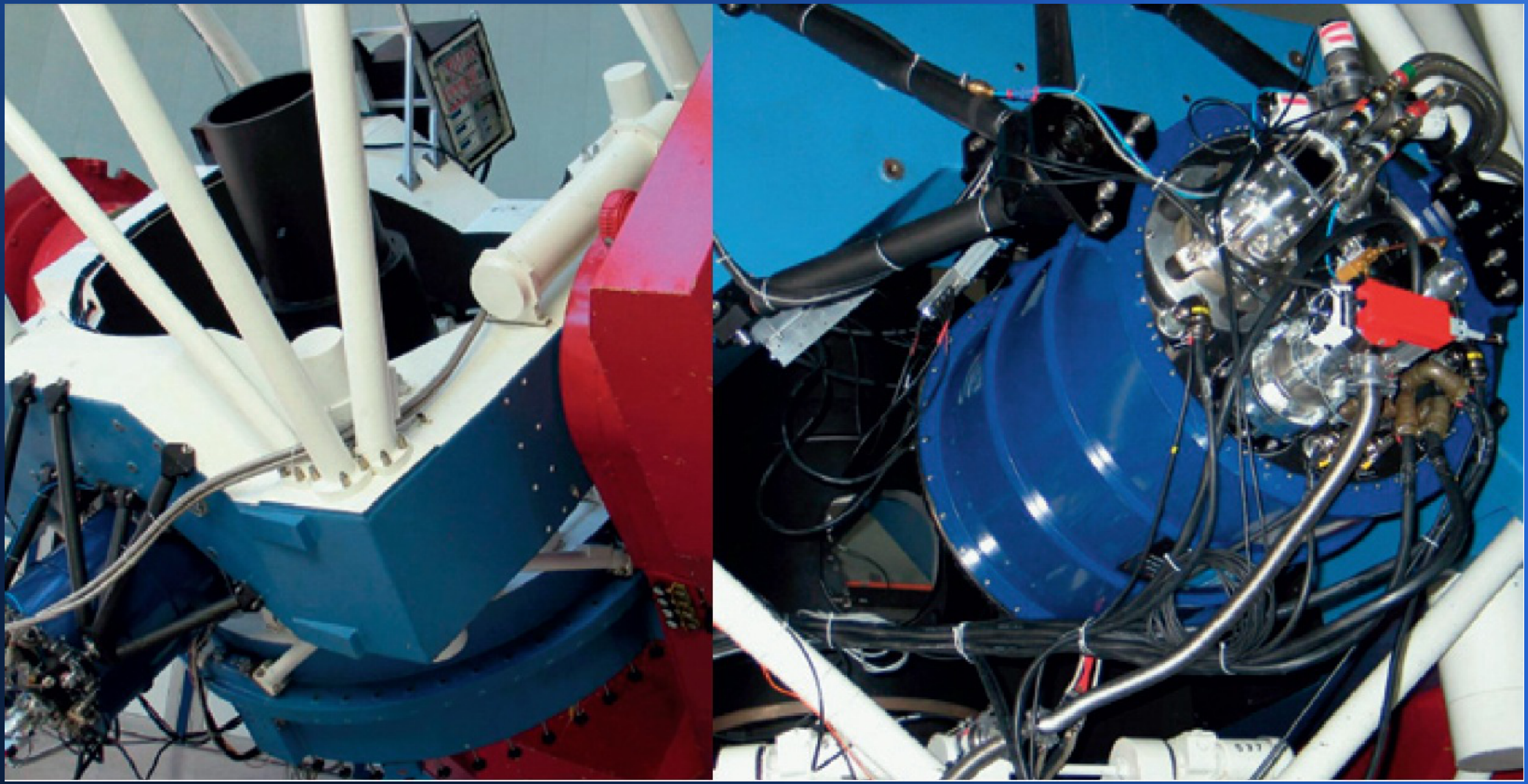


The SN collapsar model



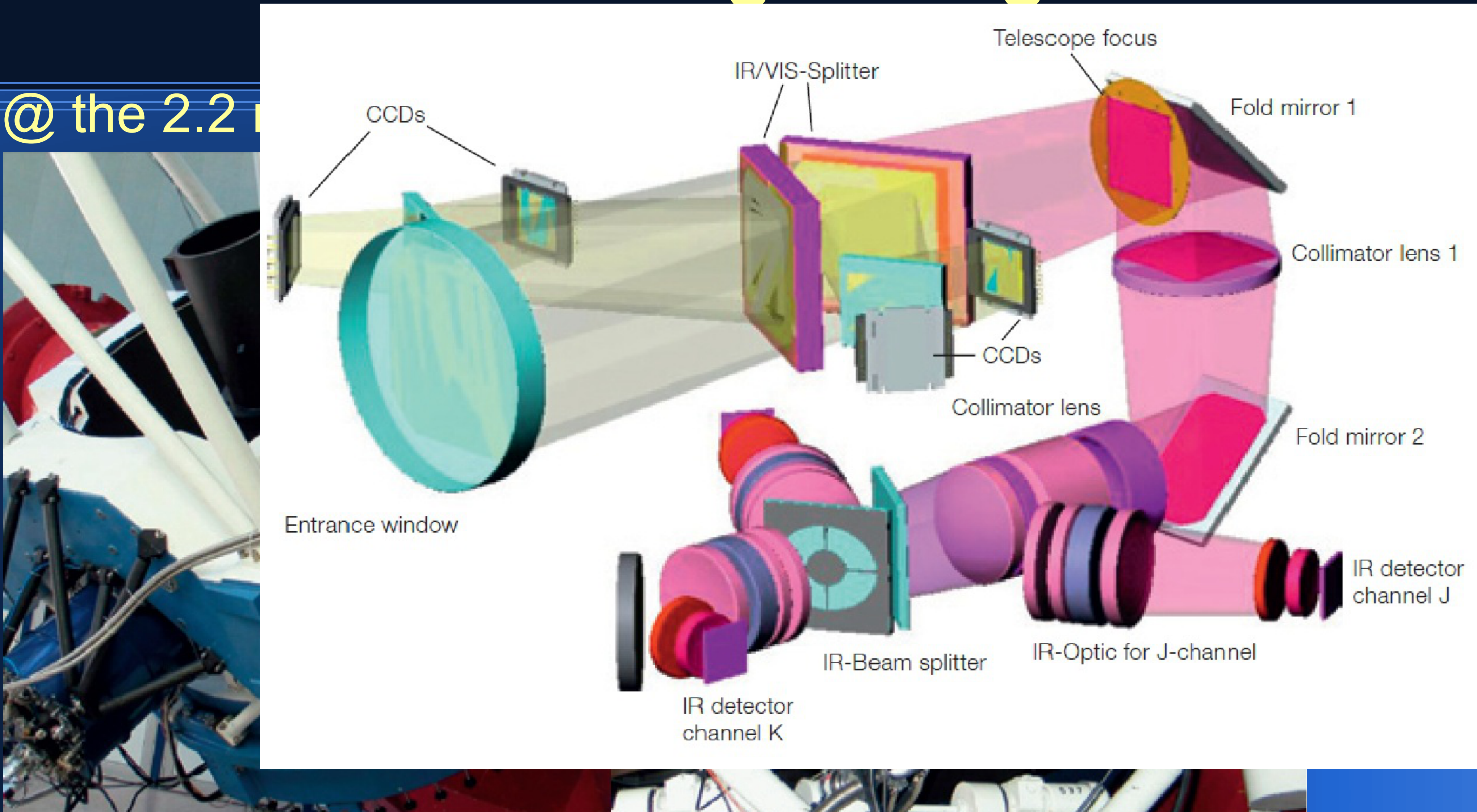
The multi-wavelength imager GROND

@ the 2.2 m MPG teslescope in La Silla



The multi-wavelength imager GROND

@ the 2.2



The multi-wavelength imager GROND

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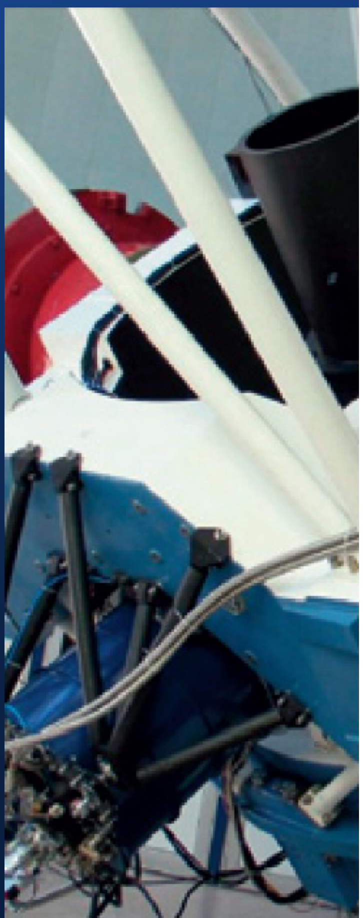
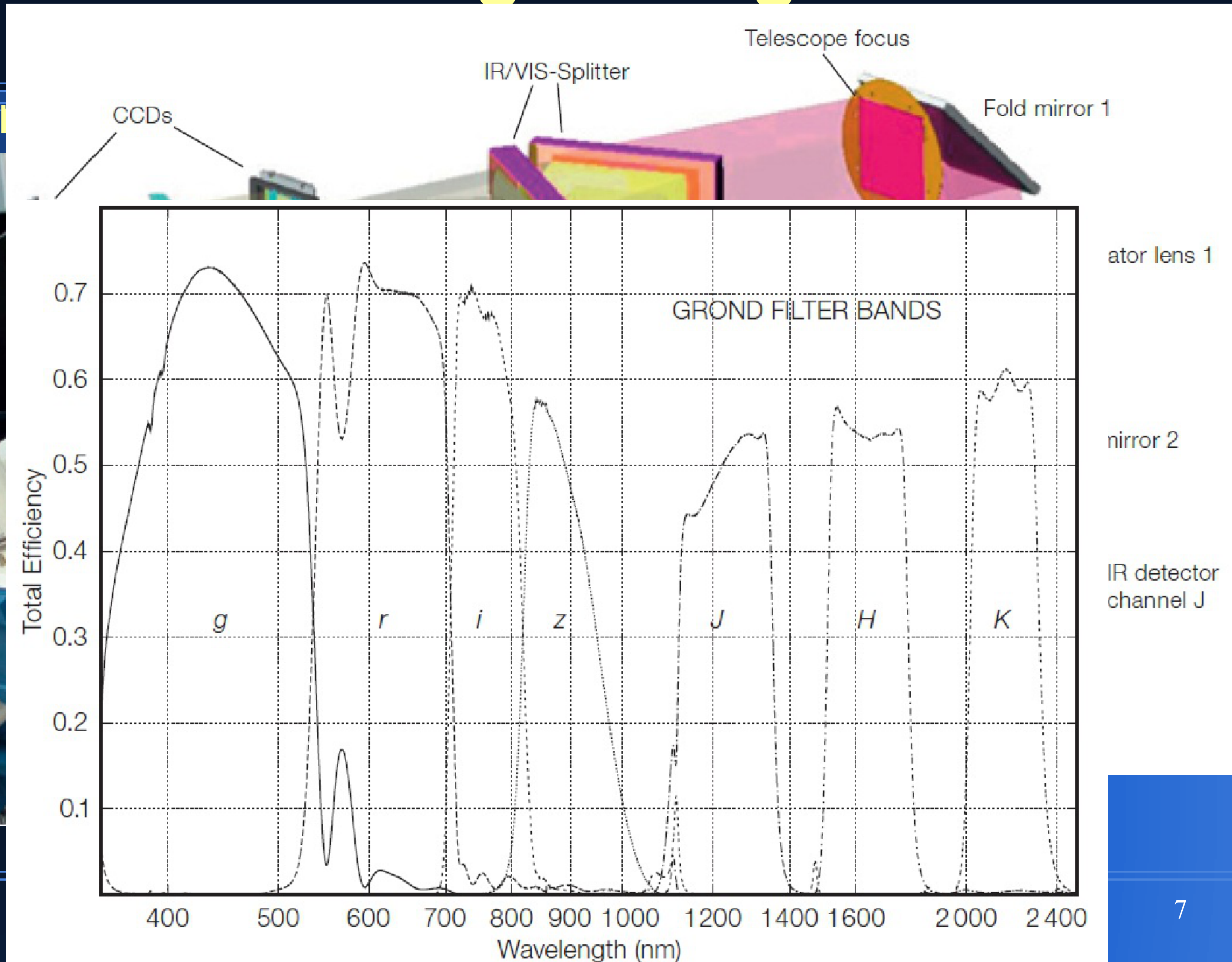
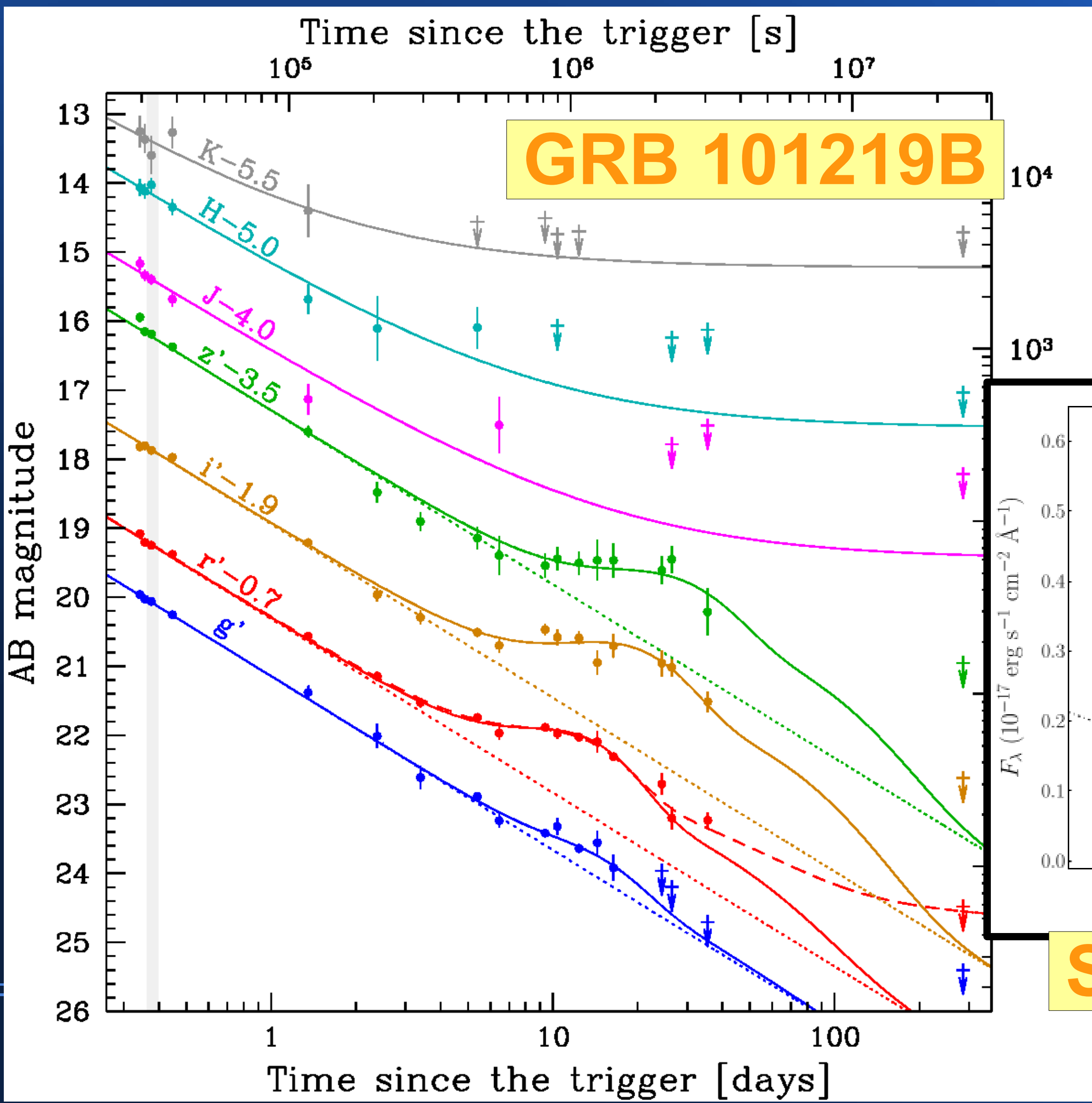




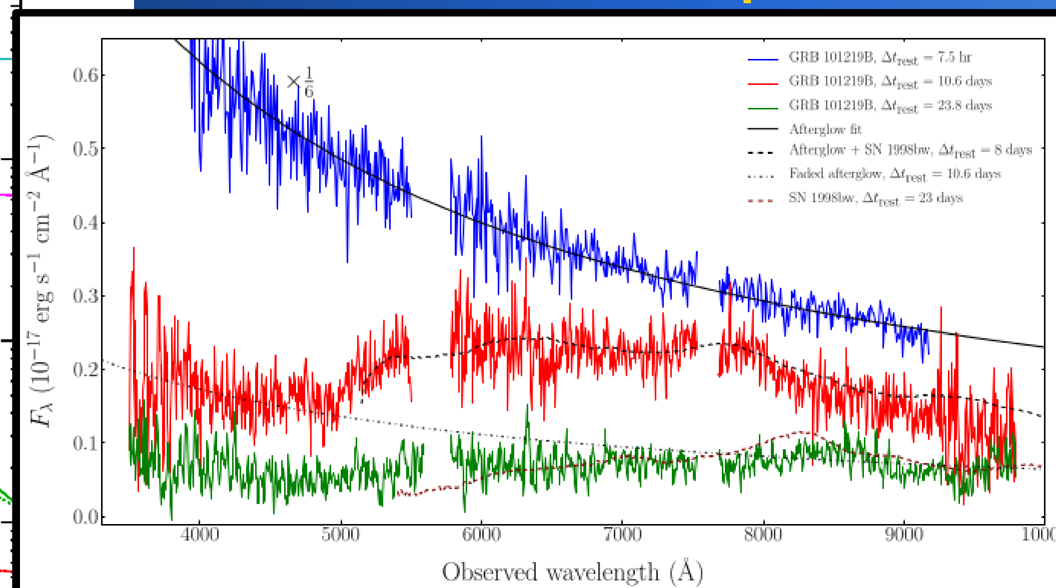
The Fantastic 3

GRB	SN	z	υ [km/s]	k	$E_{\gamma,iso}$ [10^{51} erg]	E_{peak} [keV]
081007	2008hw	0.530	- -	0.8	1.28	40
091127	2009nz	0.490	17 000	1.15	14.93	36
101219B	2010ma	0.552	- -	1.78	5.60	70

SN bumps in GRB AG light curves

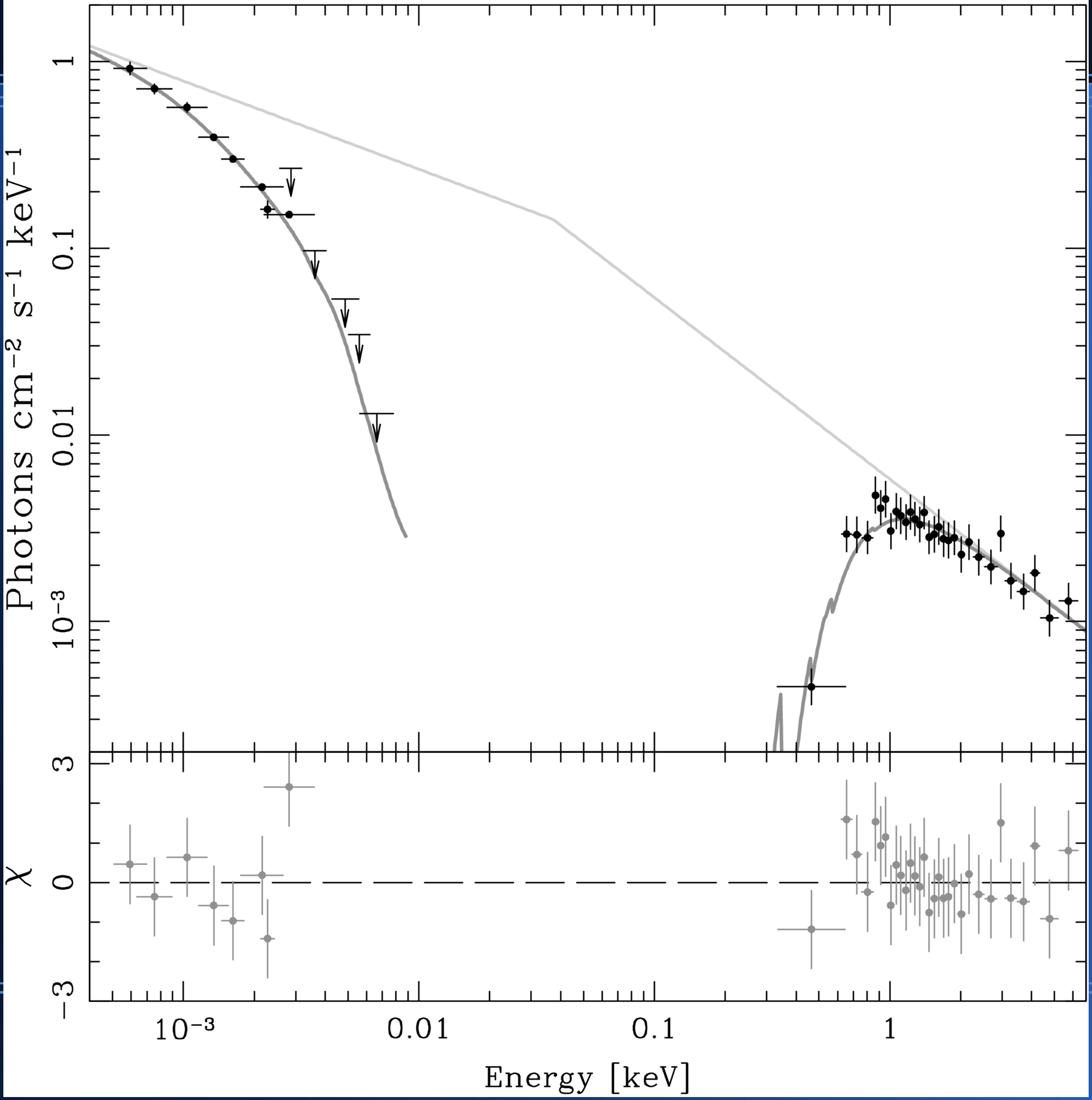


Sparre+11

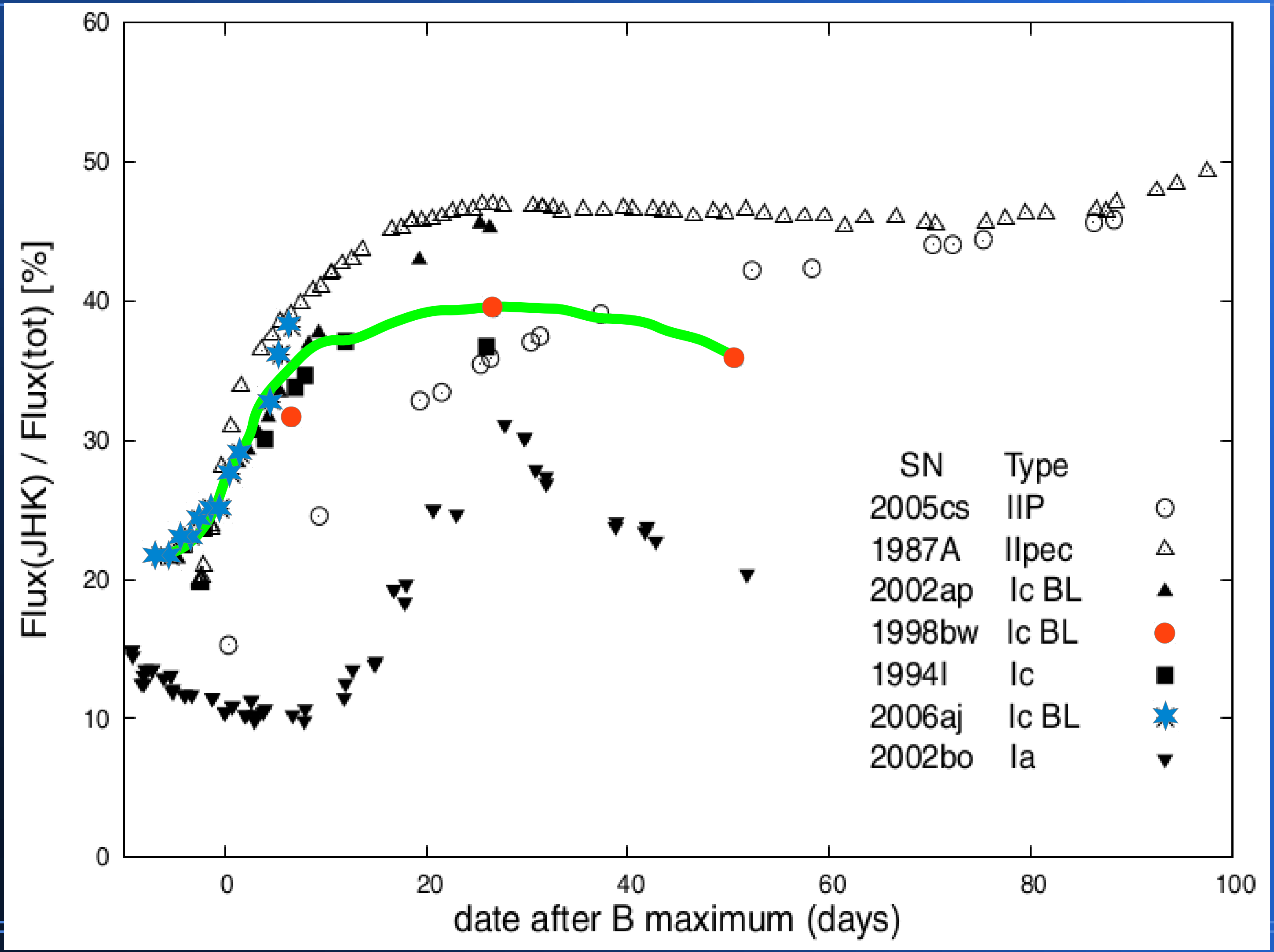


SN 2010ma

SED for GRB 081007



JHK Bolometric correction



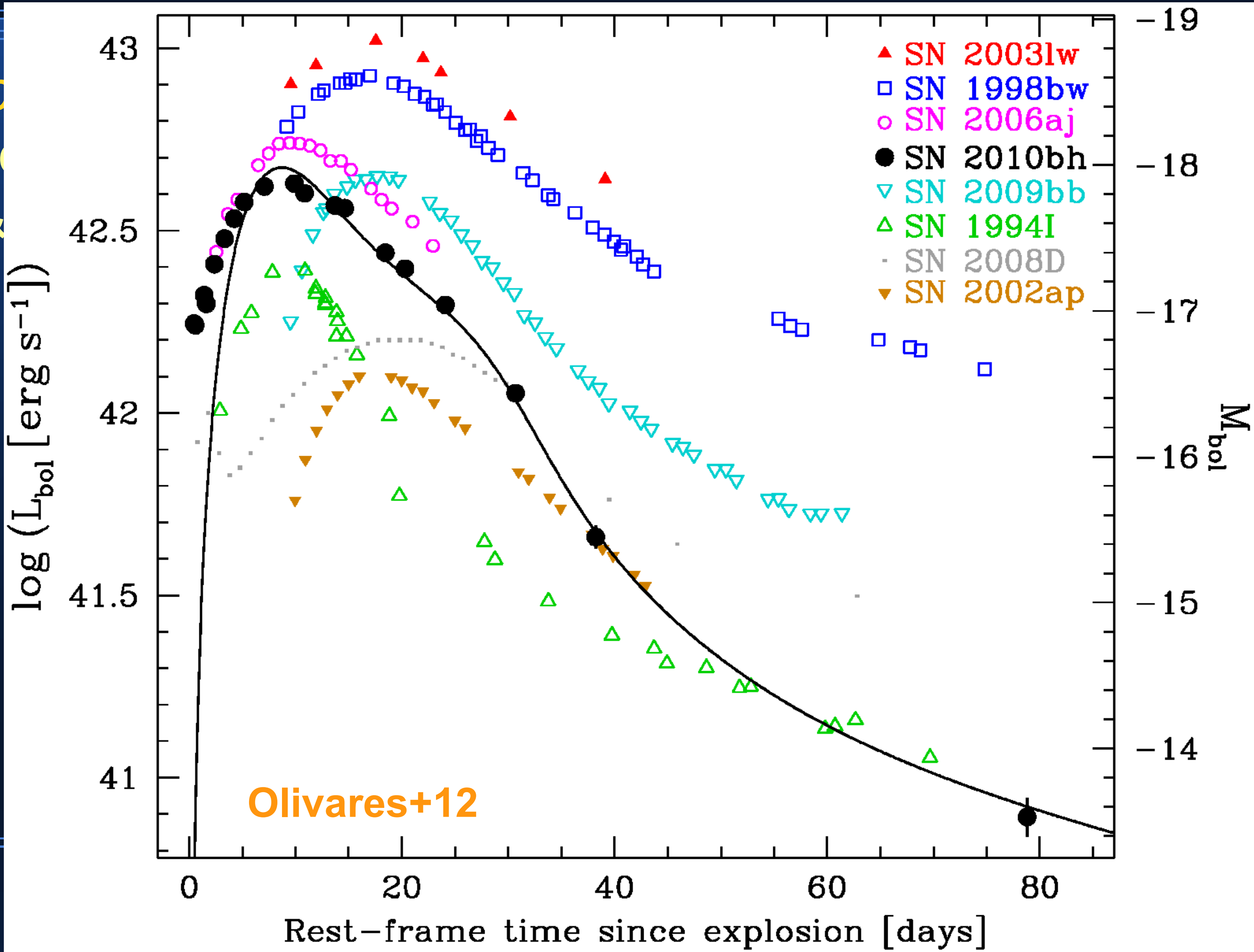
Bolometric Light Curves of GRB-SNe

Corrected for :

- host extinction (afterglow SED)
- UV & NIR contributions

Bolometric Light Curves of GRB-SNe

Correc
- host
- UV &



Bolometric Light Curves of GRB-SNe

Correc
- host
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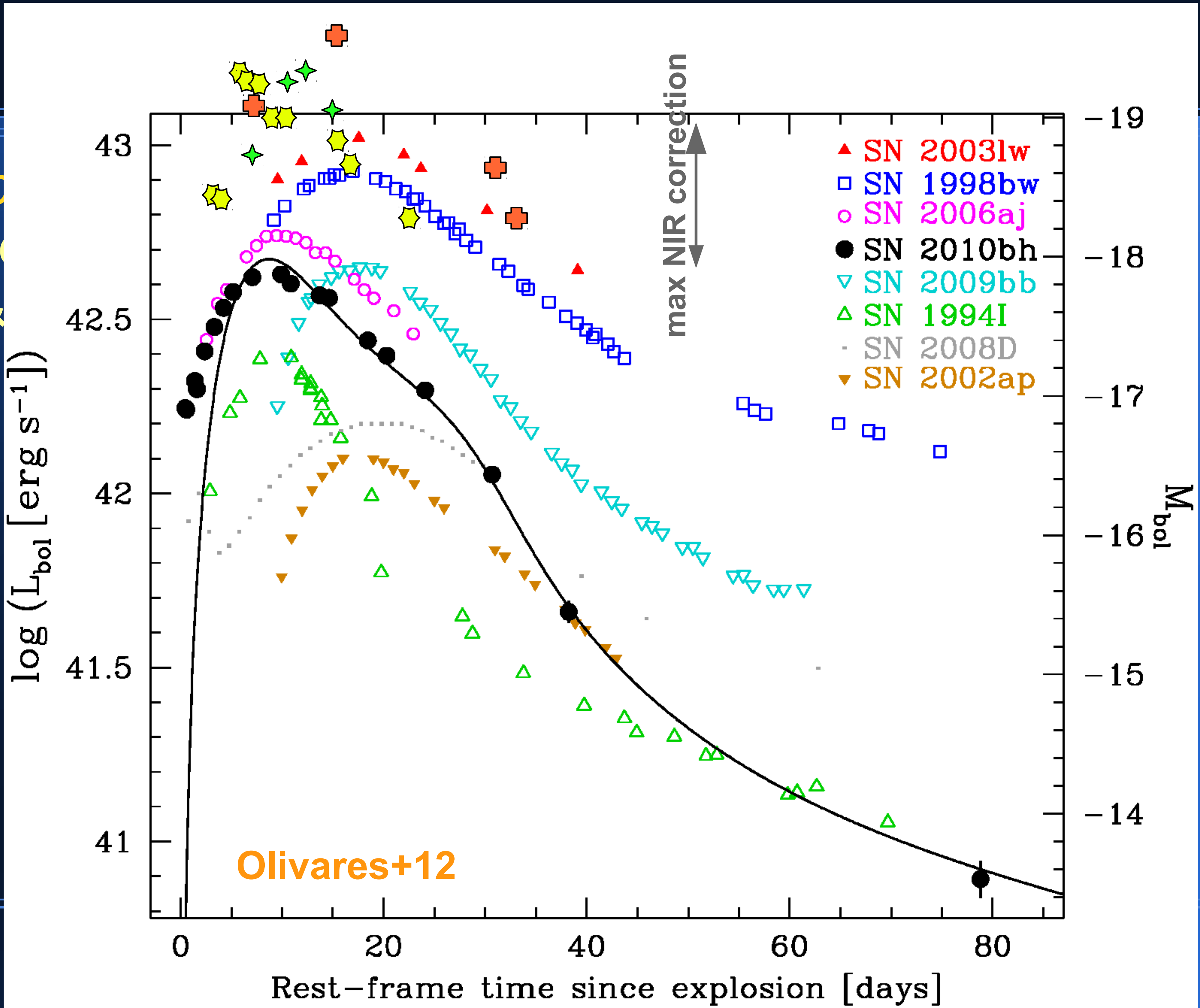
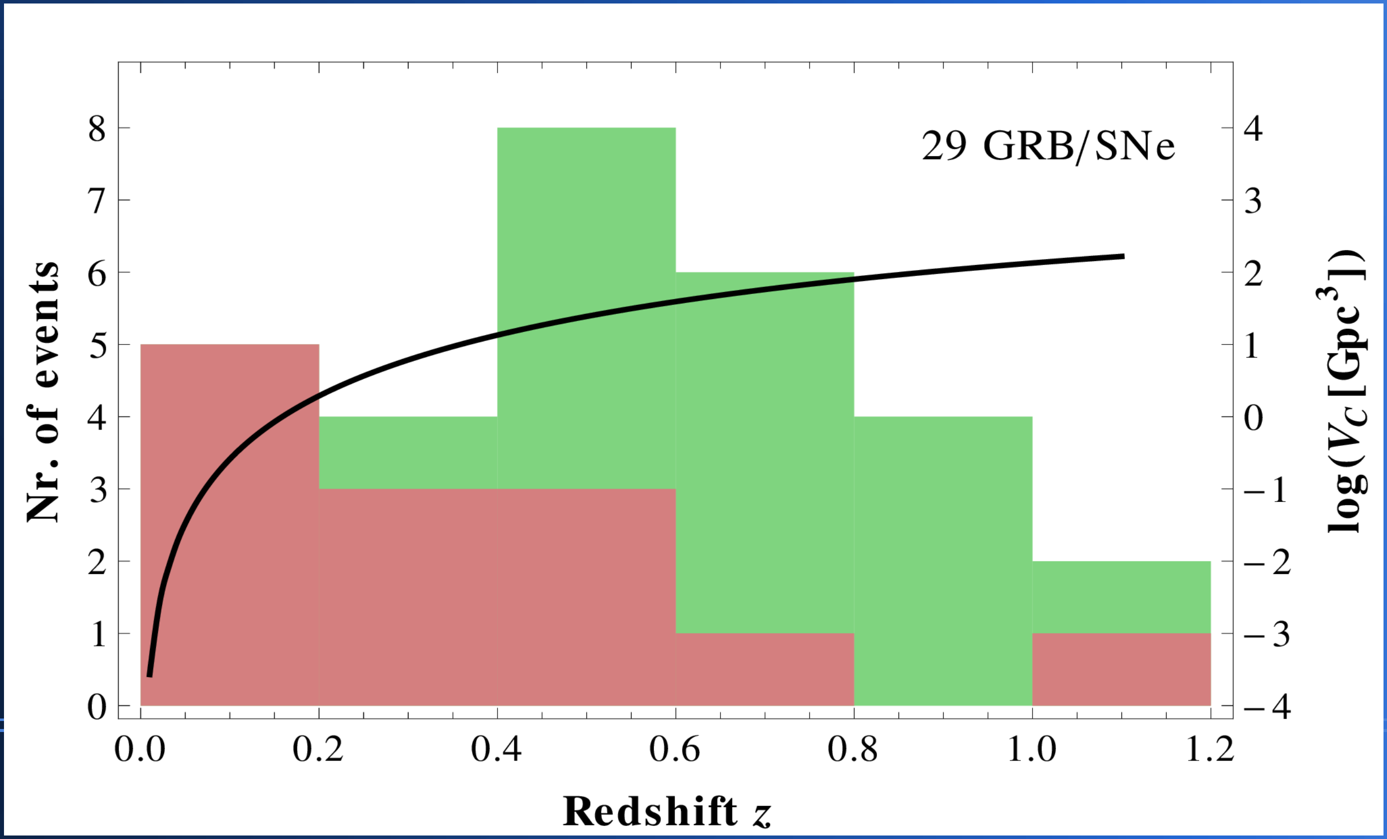
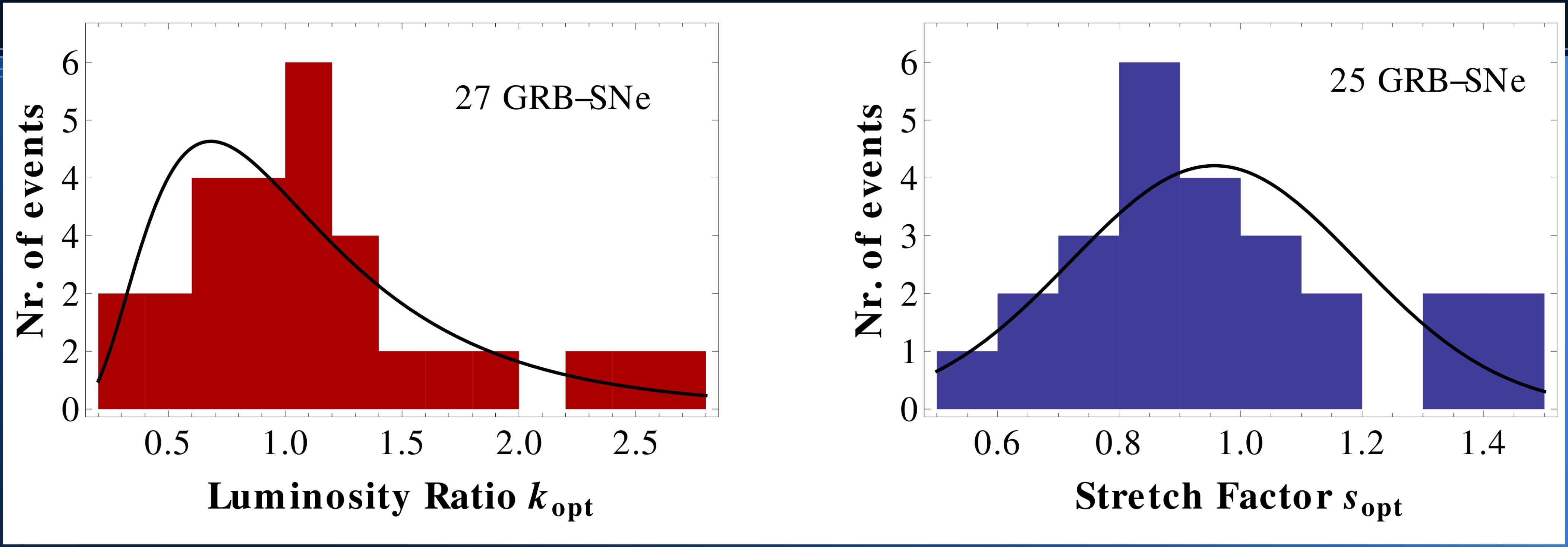


The full sample of GRB-SNe

GRB and SN parameters for:
- 4 GRB-SNe analysed (addition of 10bh, Olivares E.+12)
- 25 objects from the literature (Olivares E.+14, in prep)



Optical Light Curve Parameters



med(kopt) = 0.95 ± 0.71

med(Mv) = -19.27 ± 0.81

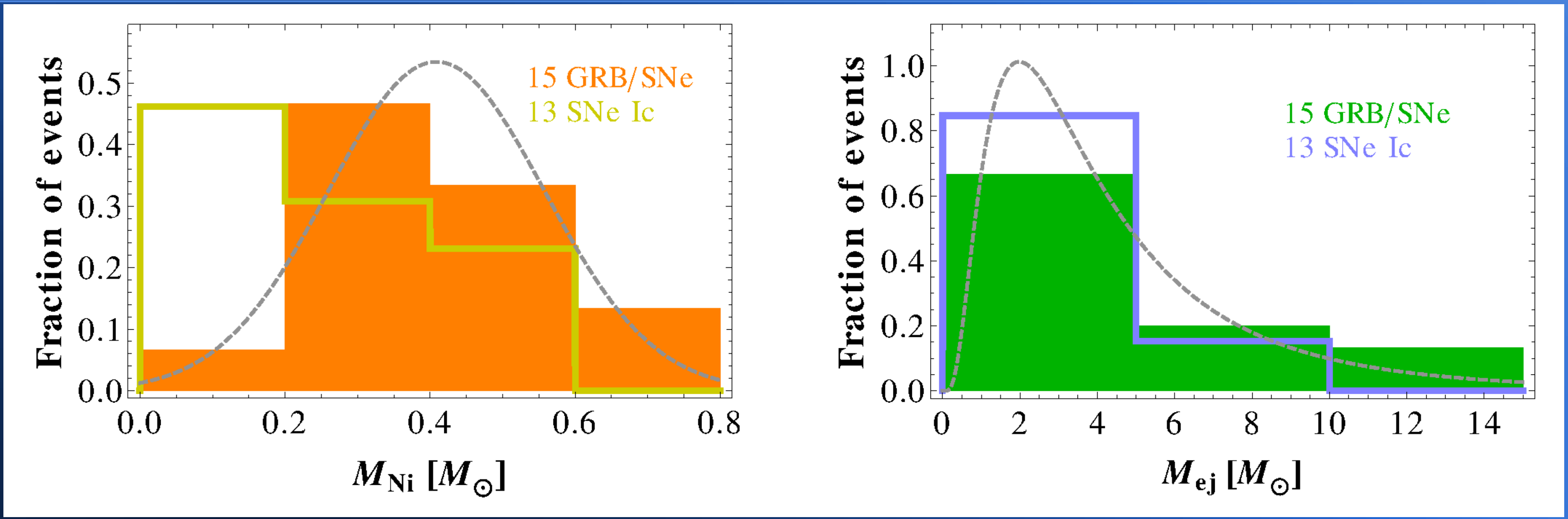
kopt KS P-value = 0.97

< sopt > = 0.96 ± 0.24

sopt KS P-value = 0.62

Only 2 objects (7%) are significantly brighter than SN 98bw

Masses of the SN explosion

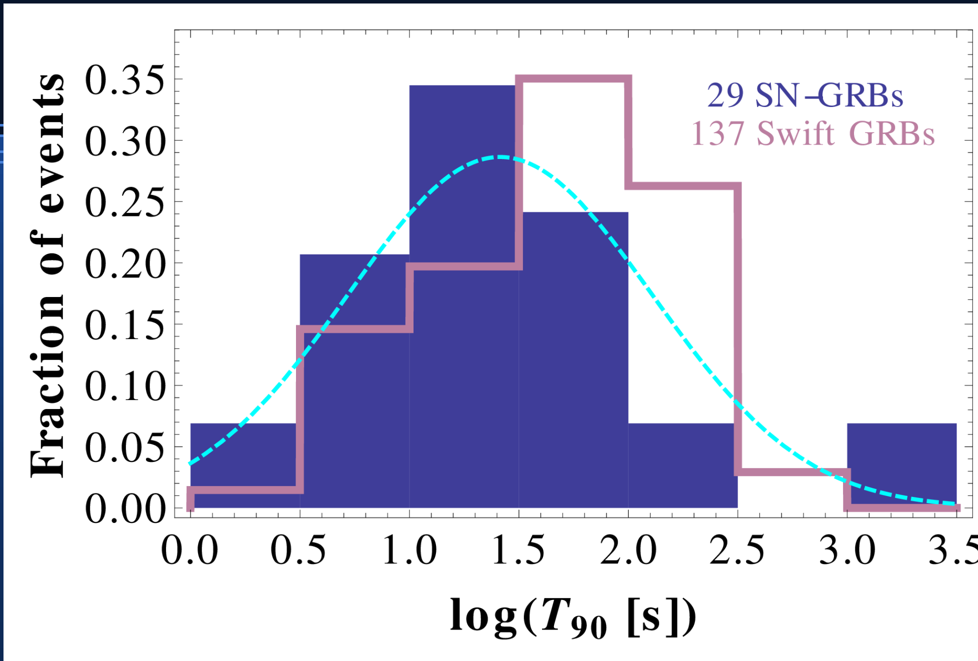


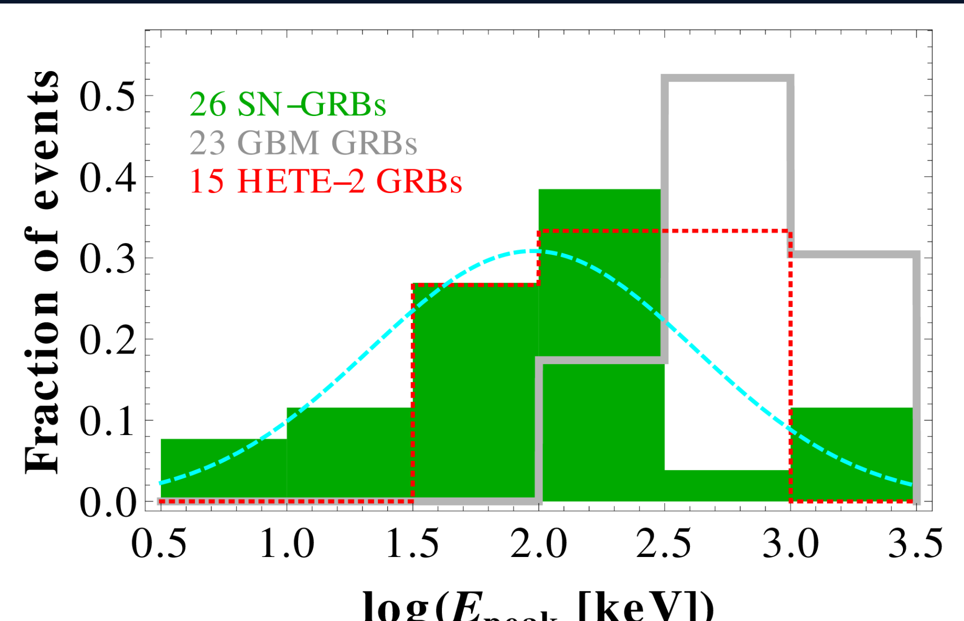
$< M_{Ni} > = 0.41 \pm 0.15\ M_{\odot}$ med(M_{ej}) = $3.5 \pm 4.0\ M_{\odot}$

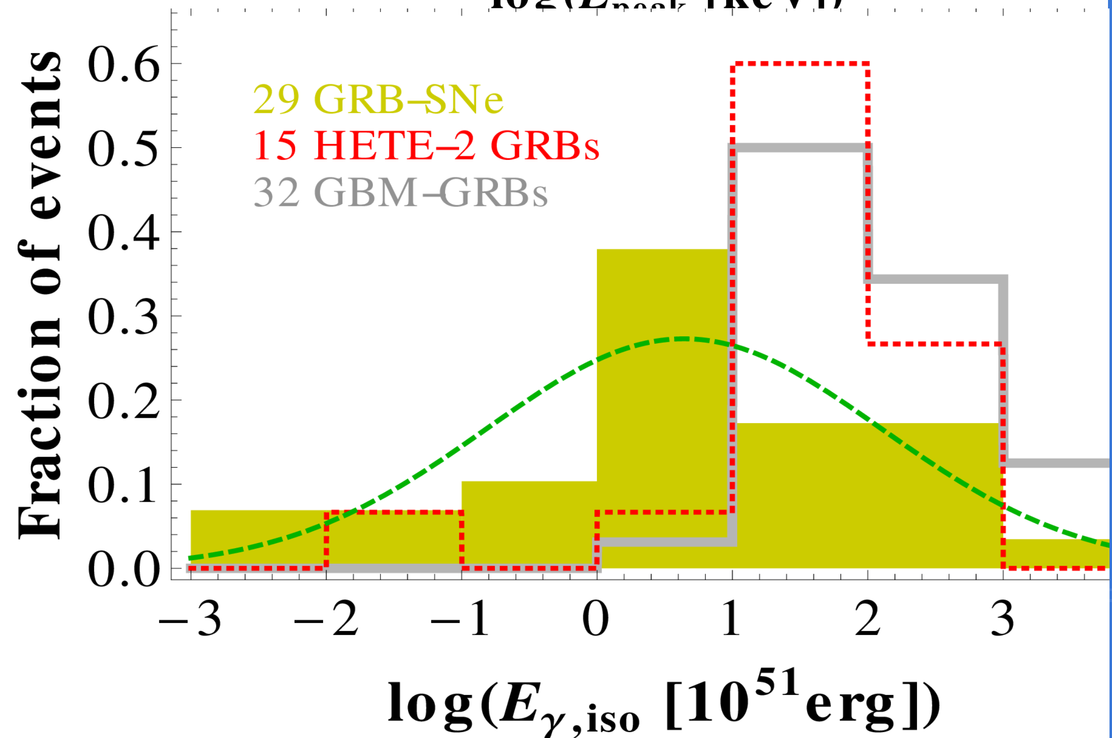
Compared to "normal" type Ic SNe (**Drout+11**):

M_{Ni} KS P-value = 0.03 M_{ej} KS P-value = 0.43

Properties of SN-associated GRBs







KS Comparisons:

T_{90} vs Swift: P = 0.02

E_{peak} vs HETE-2: P = 0.03

$E_{\gamma,iso}$ vs HETE-2: P = 0.004

To Be Done & Conclusions

- NIR correction
- Arnett modelling for all GRB-SNe
- Explore correlations between GRB and SN
- Only 7% of GRB-associated SNe are brighter than SN 1998bw
- But the median luminosity of GRB-SNe is about that of SN 1998bw

- **Short Quiz:**
  1 How do you pronounce (“su”) in Japanese?
  2 Which city is more expensive, Tokyo or Kyoto?
  3 Remember the location of the bike4rent shop.
  4 What Japanese city has been the capital the longest?
- **Question:** Does anyone have a micro-SD to SD adapter that I can borrow?

Spectroscopic GRB-SN associations

GRB	SN	z	υ [km/s]	k	$E_{\gamma,iso}$ [10^{51} erg]	E_{peak} [keV]
980425	1998bw	0.009	14 000	1	0.001	148
030329	2003dh	0.169	17 000	1.5	5.34	68
031203	2003lw	0.106	24 000	1.28	0.003	5.3
060218	2006aj	0.033	18 000	0.67	0.003	41
100316D	2010bh	0.059	28 000	0.65	0.142	19.6

All type Ic SNe

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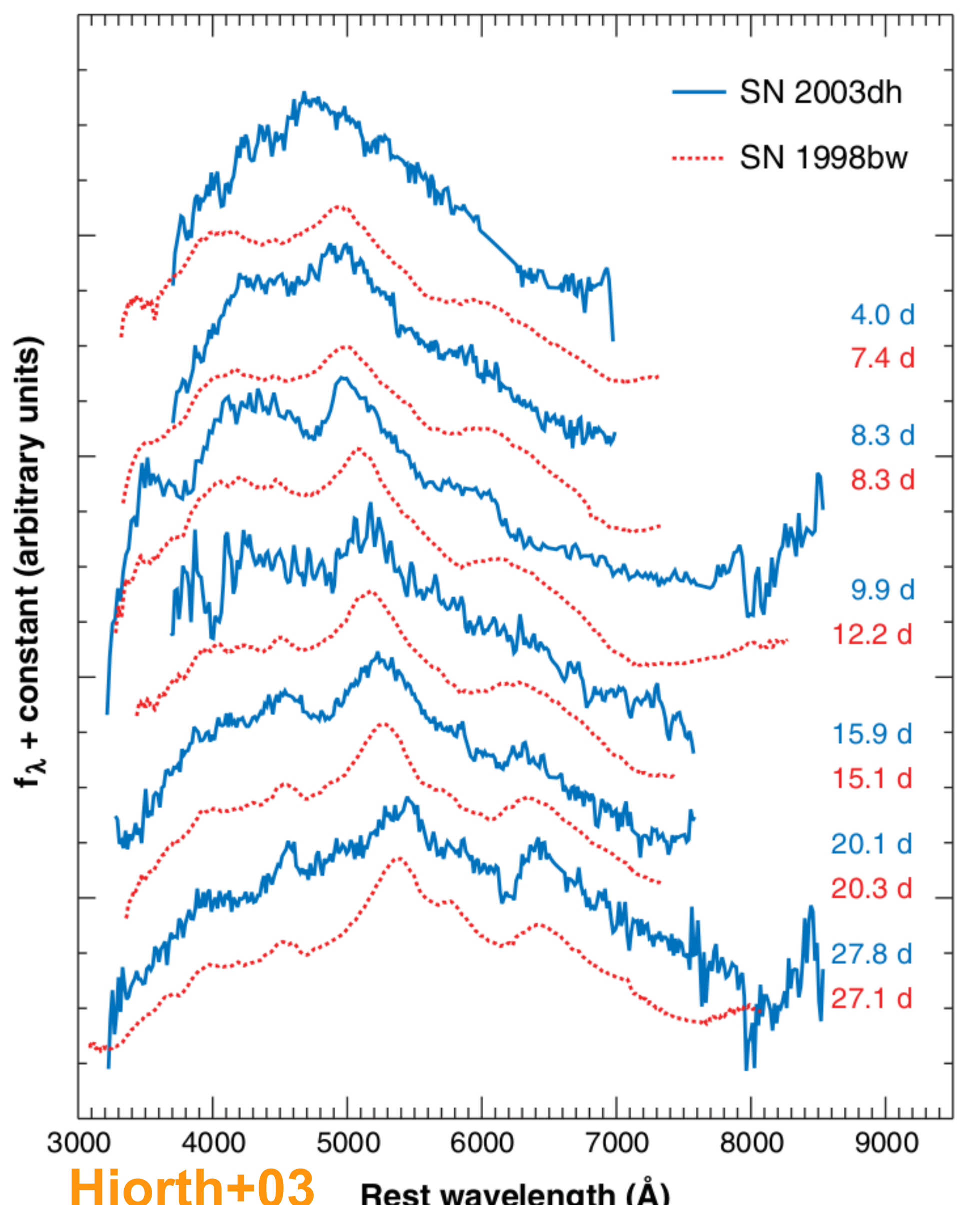
100316D	**2010**	**0.142**	**19.6**



Hjorth+03

All type Ic SNe

GRB neutrinos

$$p^{+} + \gamma \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

SN neutrinos

$$p^{+} + e^{-} \rightarrow n + \nu_{e}$$

Bolometric Light-Curve Modelling

Optically thick regime:

$$L_{\rm ph} = M_{\rm Ni}\, e^{-x} \left[(\epsilon_{\rm Ni} - \epsilon_{\rm Co}) \int_0^x A(z)\, dz + \epsilon_{\rm Co} \int_0^x B(z)\, dz \right]$$

with $A(z) = 2z\, e^{-2zy + z^2}$ and $B(z) = 2z\, e^{-2zy + 2zs + z^2}$

where $x \equiv t/\tau_m$, $s \equiv \tau_m (\tau_{\rm Co} - \tau_{\rm Ni})/(2\, \tau_{\rm Co}\, \tau_{\rm Ni})$

For homogeneous density $\tau_m = \left(\frac{\kappa_{\rm opt}}{\beta c} \right)^{1/2} \left(\frac{10\, M_{\rm ej}^3}{3\, E_{\rm k}} \right)^{1/4}$ and $\upsilon_{\rm ph}{}^2 = \frac{6\, E_{\rm k}}{5\, M_{\rm ej}}$

Optically thin (nebular) regime:

$$L_{\rm neb} = [\text{Ni decay}] + [\text{Co Decay}] + [e^+ \text{ Annihilation}] + [e^+ \text{ Kinetic Energy}]$$

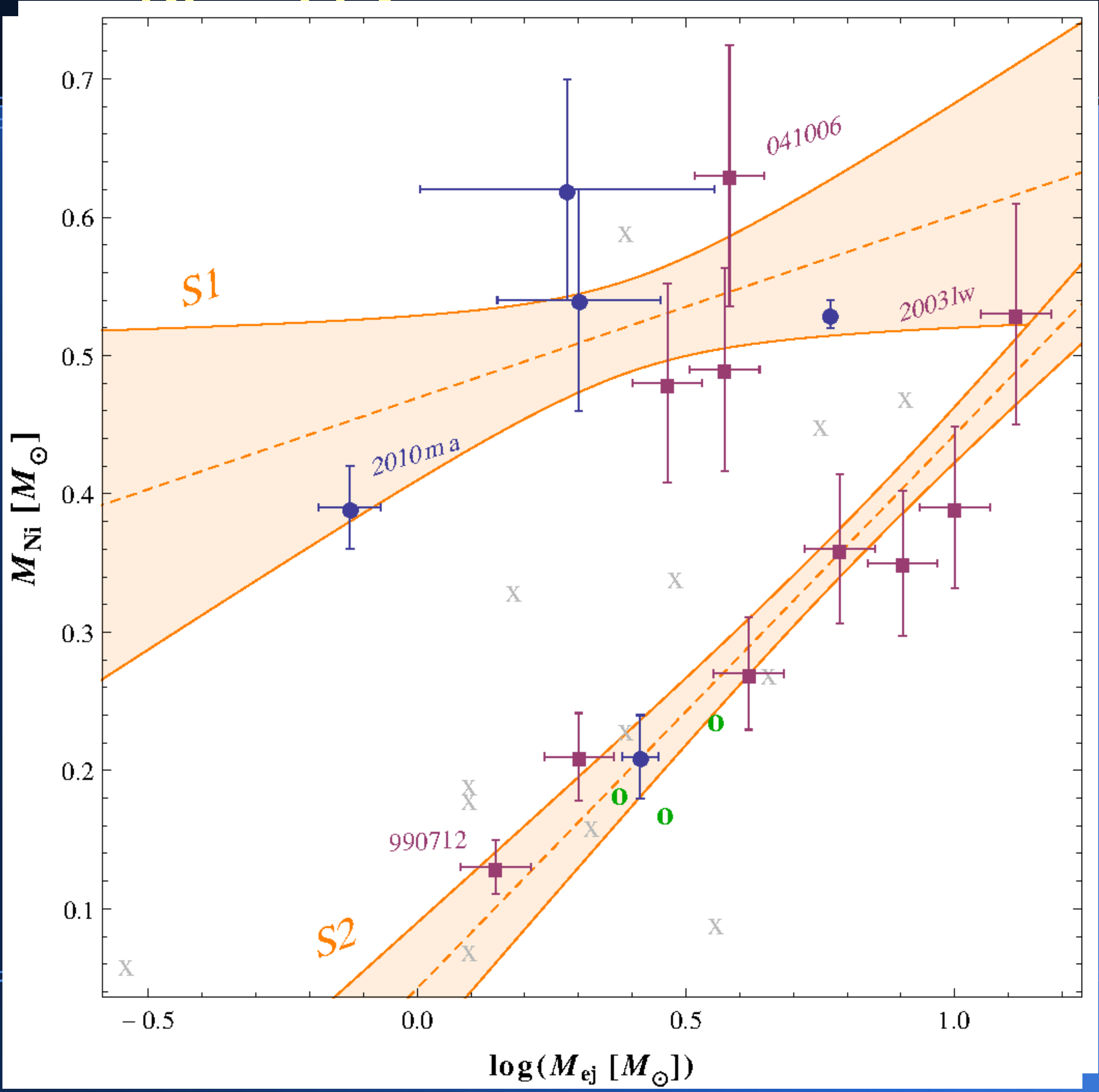
$$L_{\rm neb} \propto M_{\rm Ni}$$

Arnett82, Maeda+03, Tautenberger+06, Valenti+08, Olivares+12

The M_{Ni}-M_{ej} plane

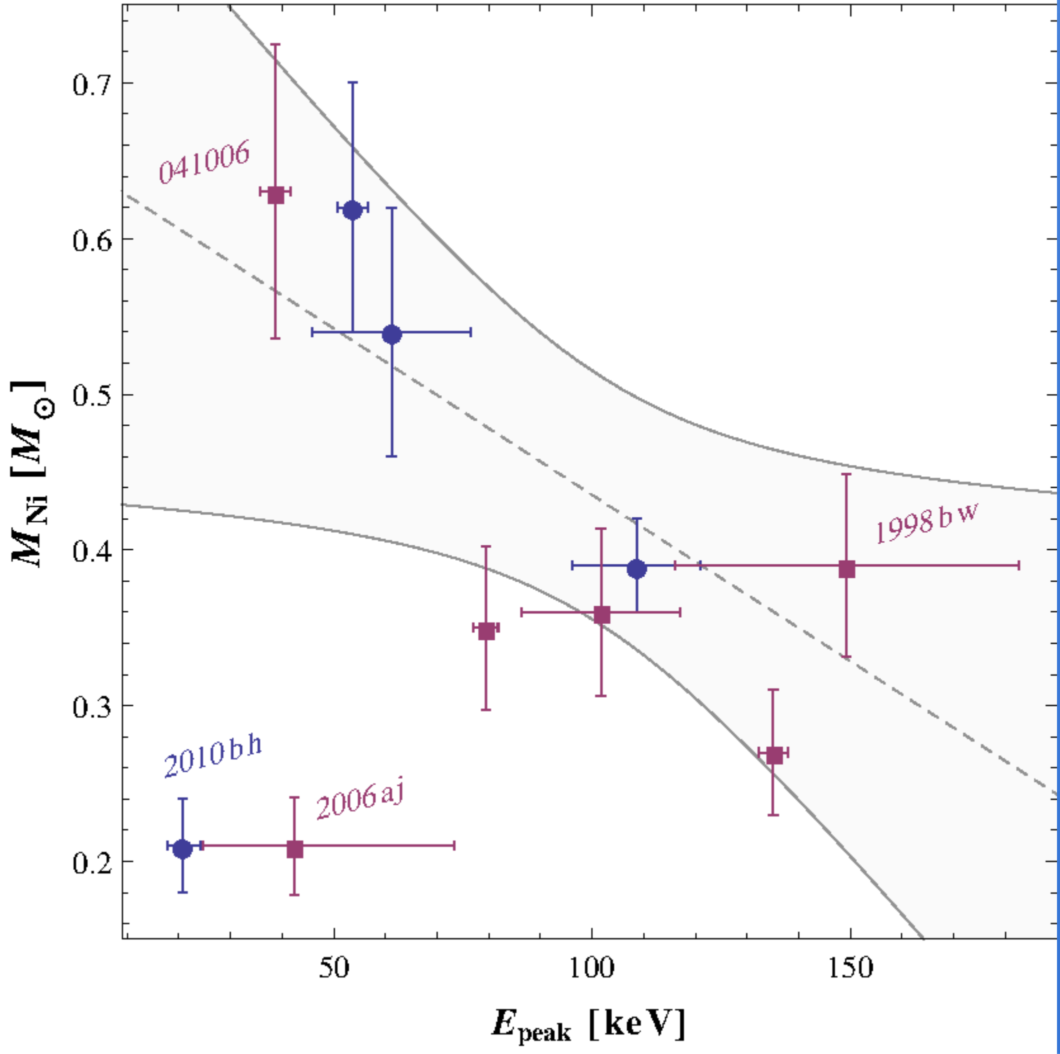
Group 1: high mass loss at the
end of their lives only, allowing
the core growth at earlier stages,
which translates into a larger Ni

Group 2: higher mass loss at early stages inhibited the core growth,
hence less Ni is synthesised

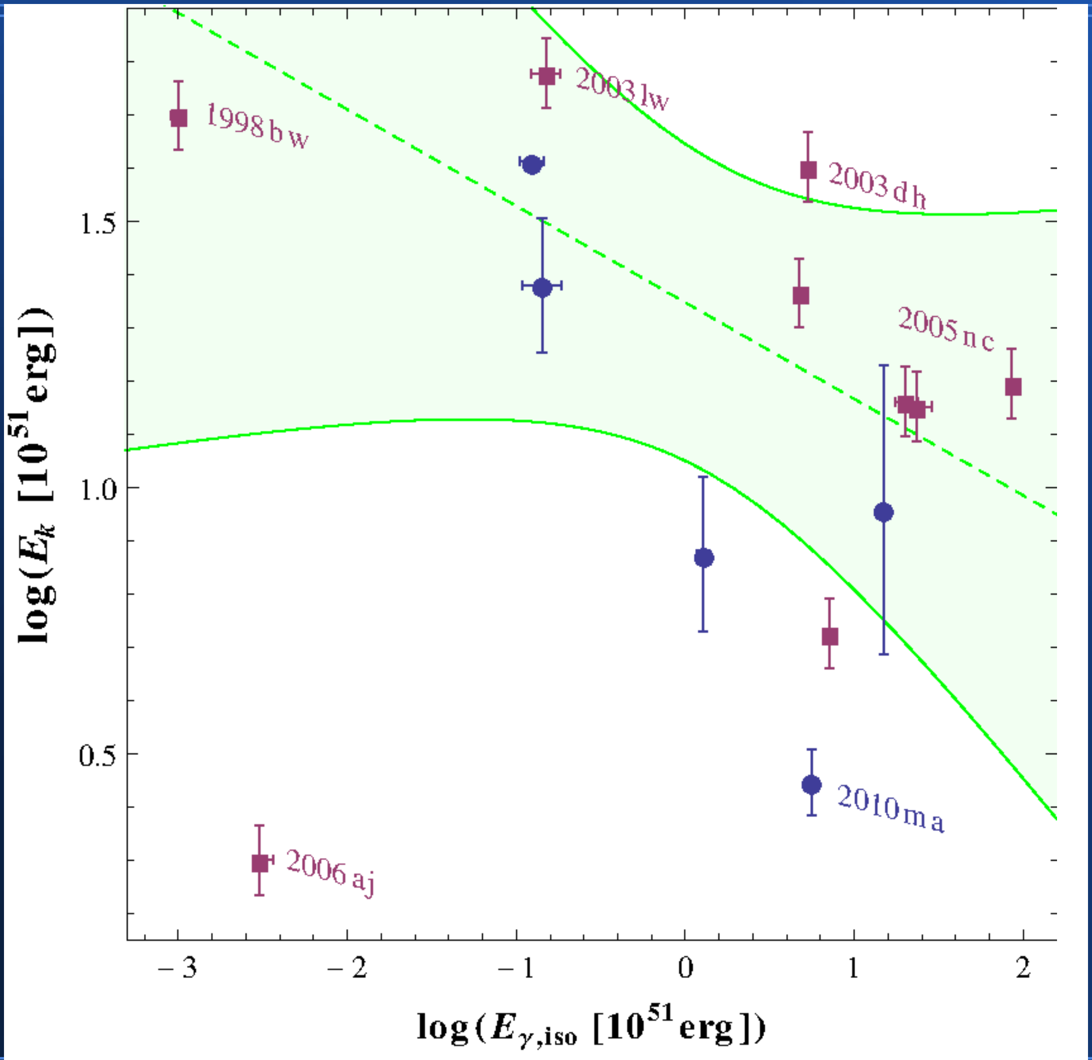


GRB-SN energy anti-correlations

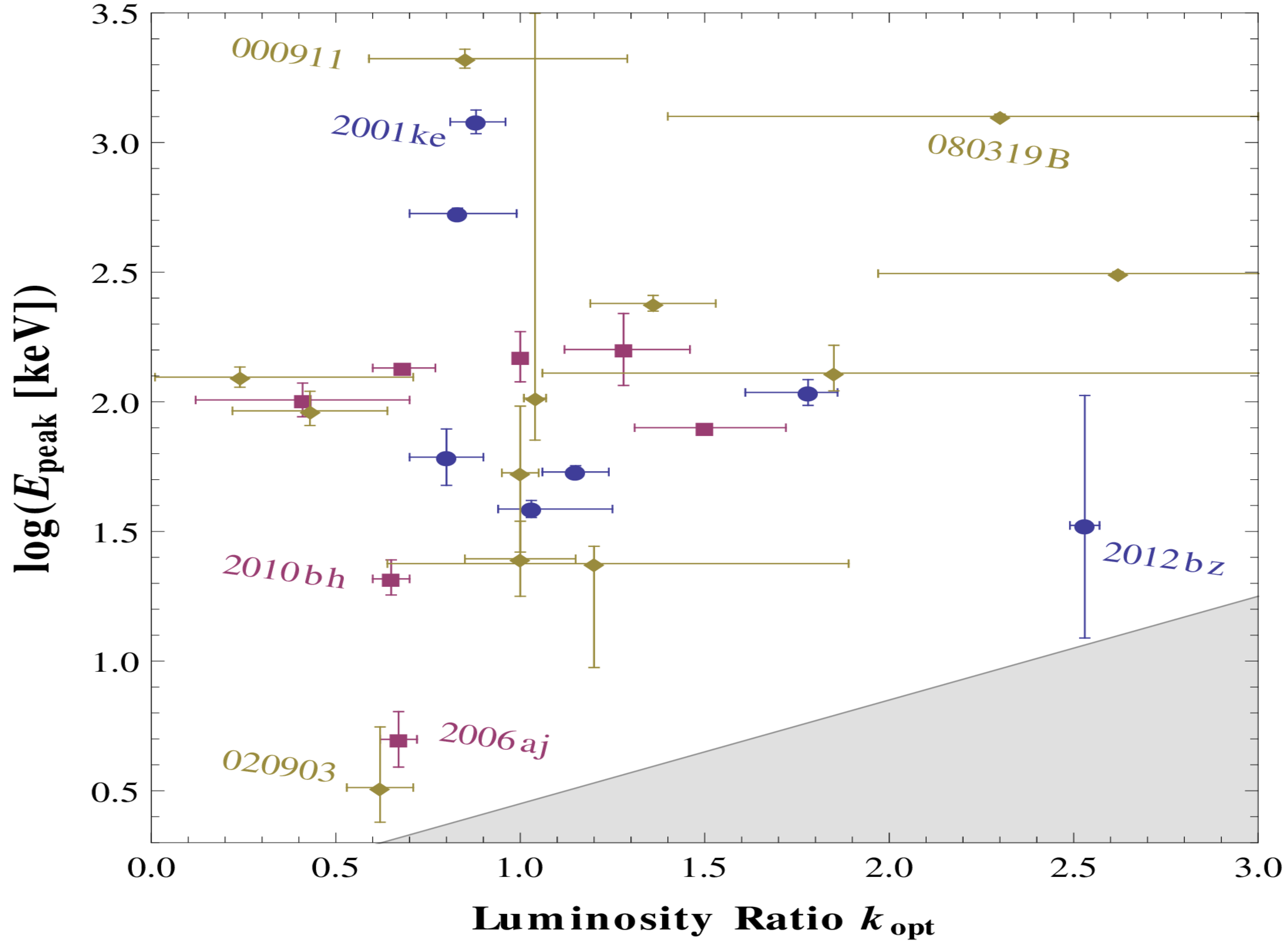
Moderate M_{Ni} -E_{peak} correlation:
z-statisics gives $R^2 = 0.97$ after excluding SNe 2010bh and 2006aj due to their peculiar high energy emission.



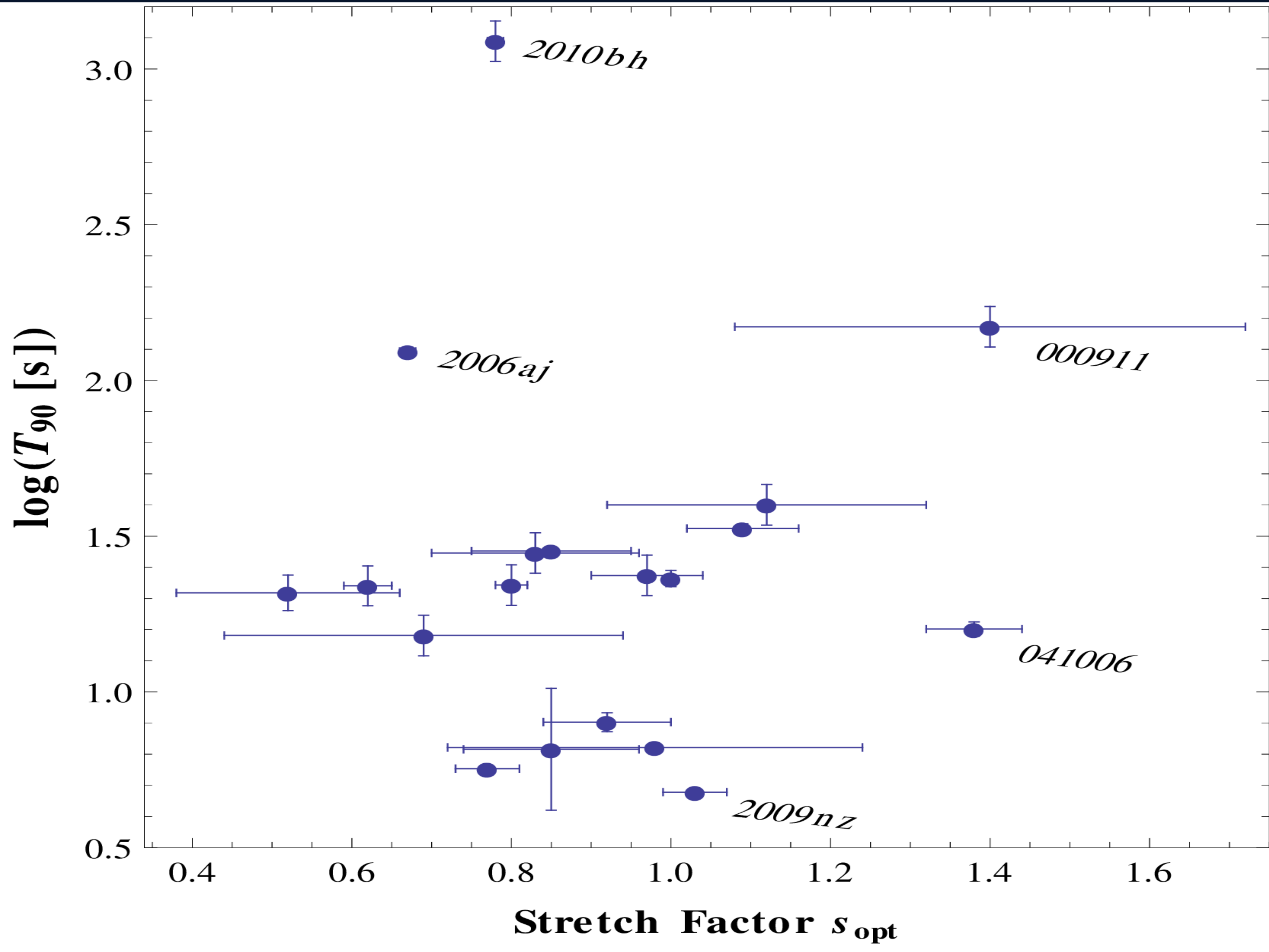
GRB-SN energy anti-correlations



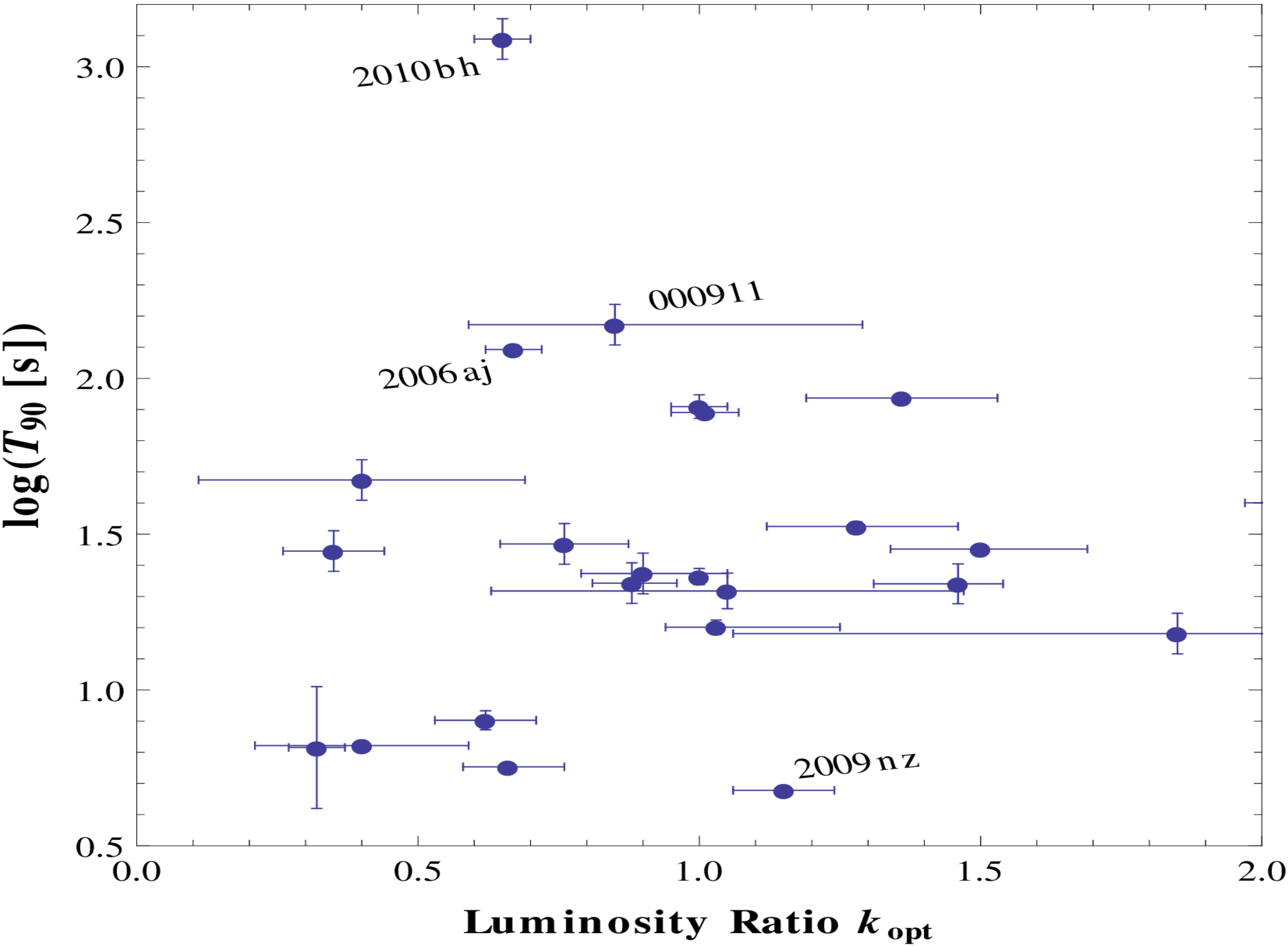
Moderate E_k -$E_{\gamma,iso}$ correlation:
z-statisics gives $R^2 = 0.93$ after excluding SN 2006aj due to their peculiar high energy emission.



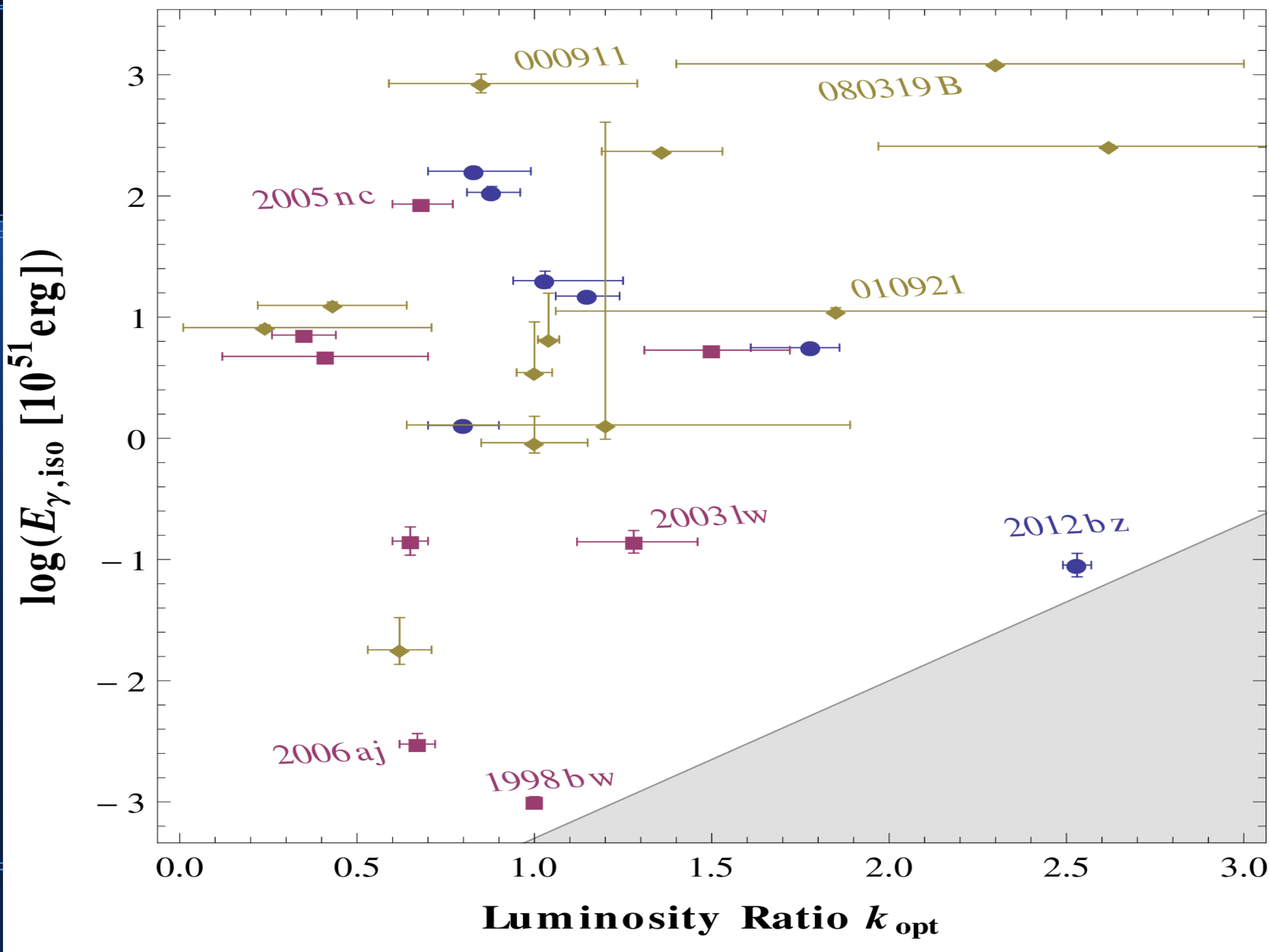
000911
2001ke
080319B
2010bh
2012bz
2006aj
020903
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
log($E_{\rm peak}$ [keV])
Luminosity Ratio $k_{\rm opt}$



2010bh
2006aj
000911
041006
2009nz
3.0
2.5
2.0
1.5
1.0
0.5
0.4
0.6
0.8
1.0
1.2
1.4
1.6
log(T_{90} [s])
Stretch Factor s_{opt}



2010bh
000911
2006aj
2009nz
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.5
1.0
1.5
2.0
log(T_{90} [s])
Luminosity Ratio k_{opt}


000911
080319B
2005nc
010921
2003lw
2012bz
2006aj
1998bw
3
2
1
0
−1
−2
−3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
log($E_{\gamma,\mathrm{iso}}$ [10^{51}erg])
Luminosity Ratio k_{opt}