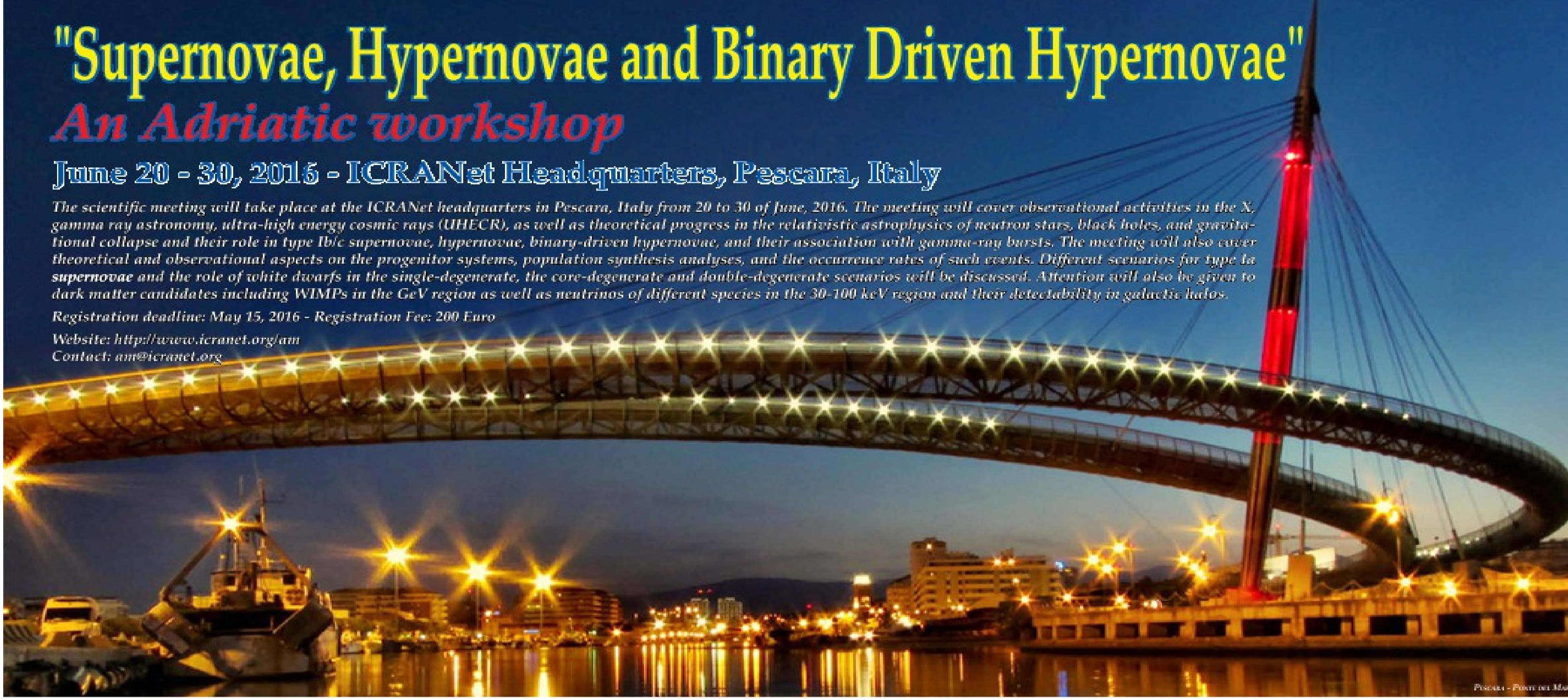


"GRB 090510: a S-GRB from a binary neutron star coalescing into a Kerr black hole"

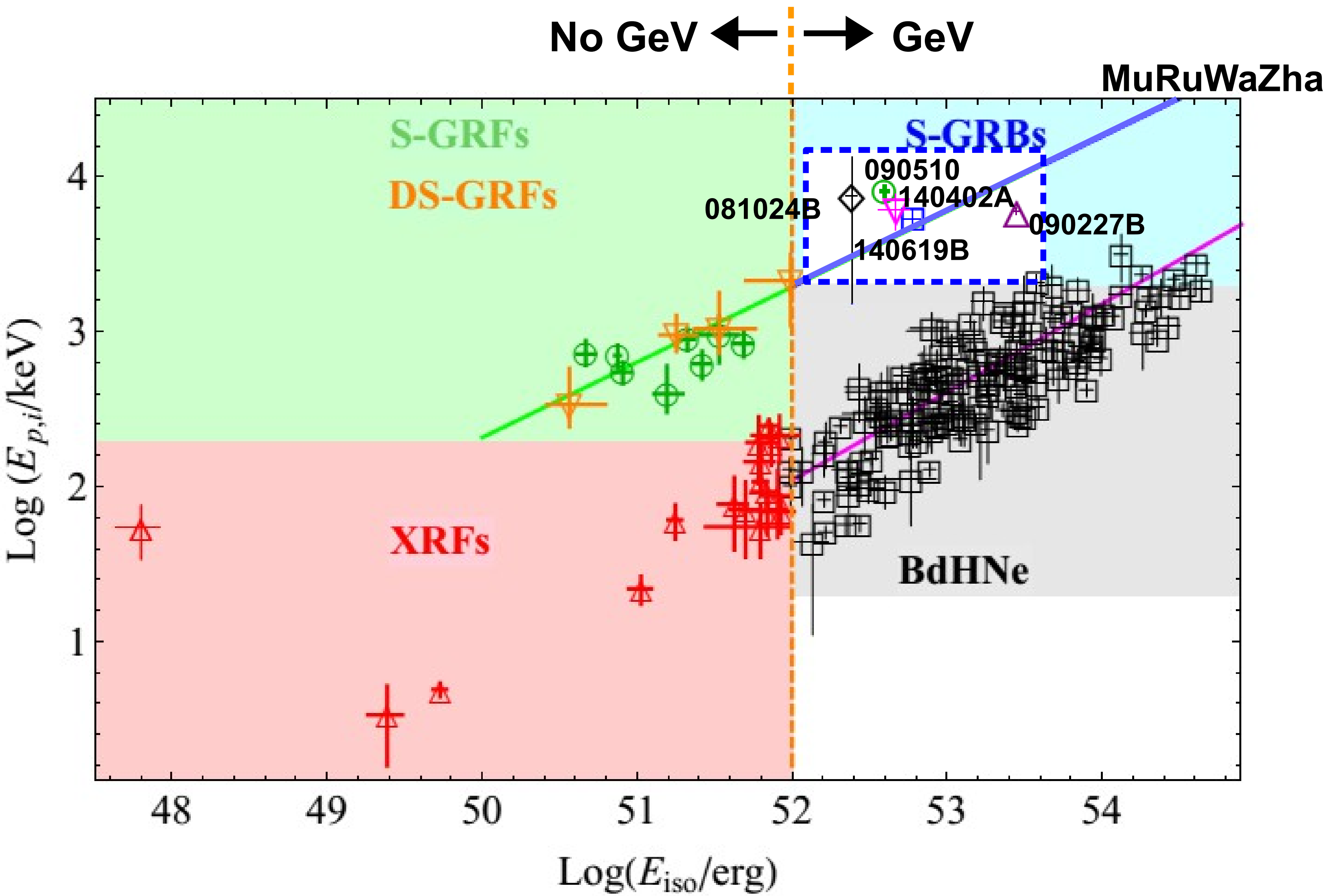
Marco Muccino

University of Rome "Sapienza" & ICRANet, Italy

On behalf of a large collaboration

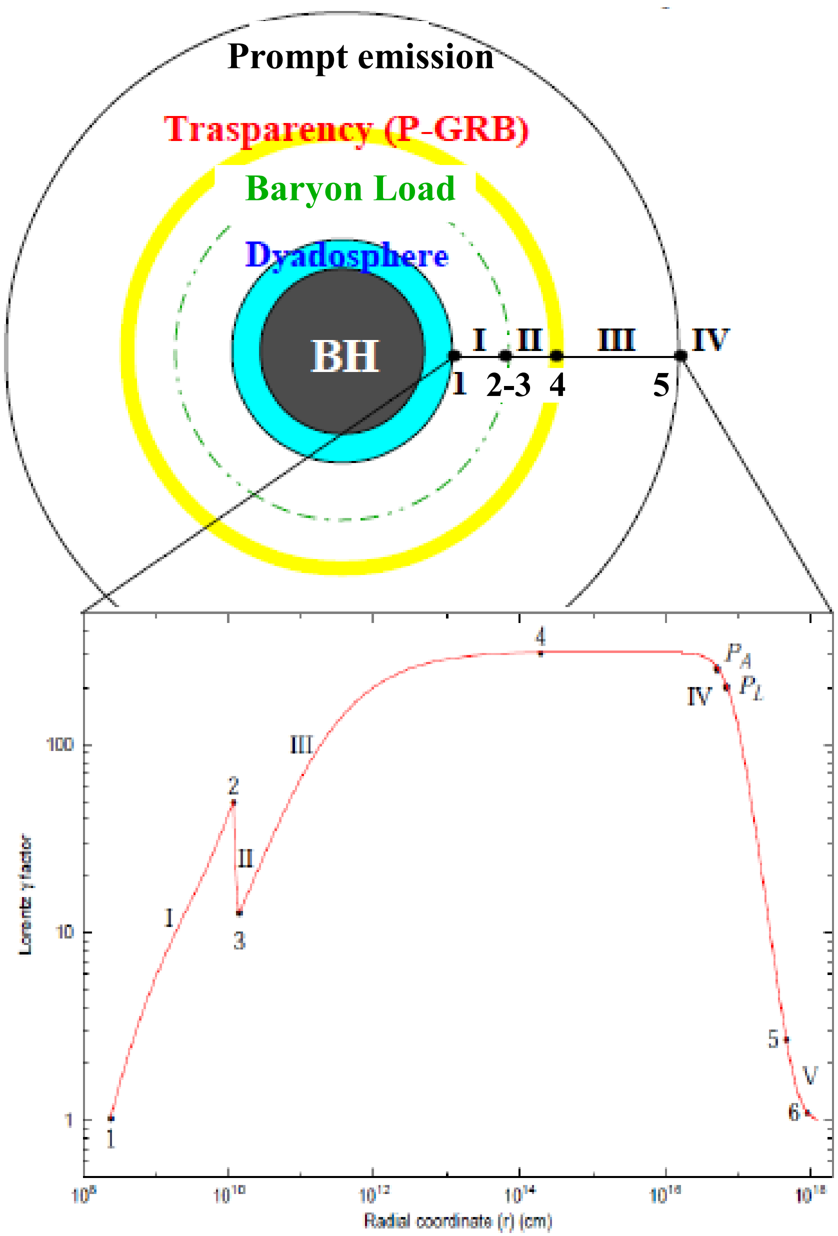
R. Ruffini, Y. Aimuratov, L.M. Becerra, C.L. Bianco, M. Enderli, M. Karlica, M. Kovacevic, R. Moradi, A.V. Penacchioni, G.B. Pisani, D. Primorac, J.A. Rueda and Y. Wang

The S-GRBs in the $E_{p,i}$-E_{iso} plane [1–5]

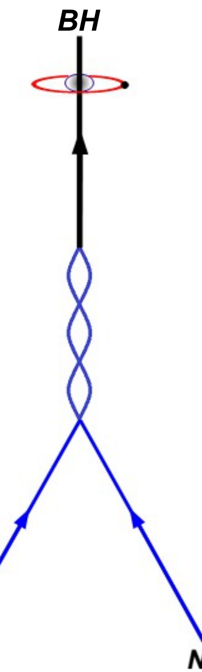


[1] Zhang, F.-W., Shao, L., Yan, J.-Z., & Wei, D.-M. 2012, ApJ, 750, 88.
[2] Calderone, G., Ghirlanda, G., Ghisellini, G., et al. 2015, MNRAS, 448, 403.
[3] Ruffini, R., Muccino, M., Kovacevic, M., et al. 2015, ApJ, 808, 190
[4] Amati, L., & Della Valle, M. 2013, International Journal of Modern Physics
[5] Ruffini, R., Rueda, J.A., Muccino, M., et al. 2016, arXiv:1602.02732

The fireshell model [6–8] and the S-GRBs [9]



– An optically thick $e^{\pm}$ plasma with energy $E^{tot}_{\pm}$ is formed in the merger of two neutron stars (NS) leading to the birth of a black hole (BH).



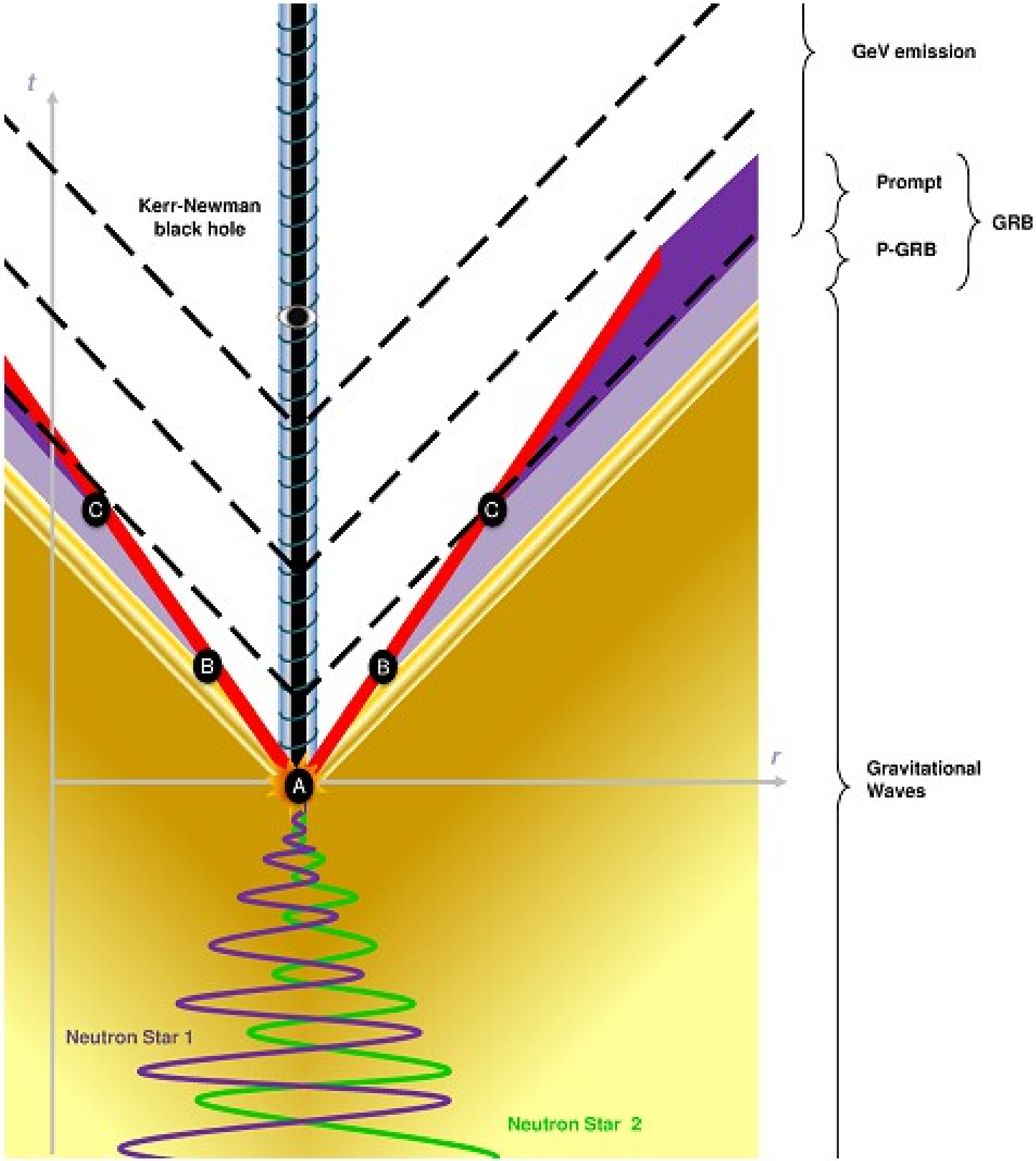
– The expanding $e^{\pm}$ *fireshell* engulfs the baryons left over in the collapse to BH, described by the baryon load $B=M_{B}c^2/E^{tot}_{\pm}$, and thermalizes with the baryons.

– The fireshell self-accelerates to ultra-relativistic velocities up to the transparency and the Proper-GRB (P-GRB), characterized by a thermal spectrum, is emitted.

– The optically thin shell of baryons collides with a Circum Burst Medium (CBM) of density n_{CBM} giving rise to the prompt emission. The CBM is modeled by the filling factor, which takes into account filamentary structures of the medium, $R=A_{eff}/A_{vis}$.

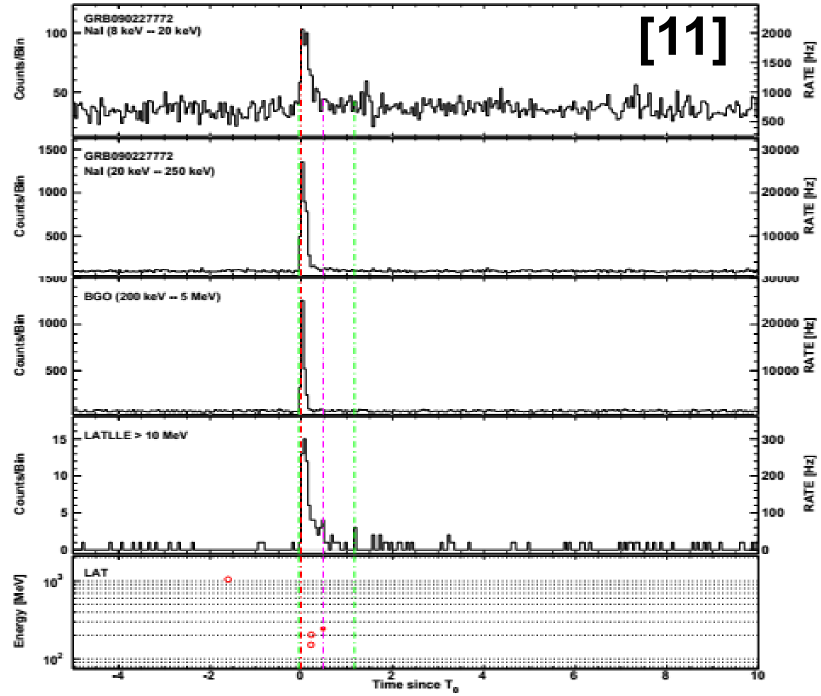
[6] Ruffini, R., Bianco, C. L., Fraschetti, F., Xue, S., & Chardonnet, P. 2001, ApJ, 555, L117
[7] Ruffini, R., Bianco, C. L., Fraschetti, F., Xue, S., & Chardonnet, P. 2001, ApJ, 555, L113
[8] Ruffini, R., Bianco, C. L., Fraschetti, F., Xue, S., & Chardonnet, P. 2001, ApJ, 555, L107
[9] Ruffini, R., Rueda, J. A., Muccino, M., et al. 2016, arXiv:1602.02732

S-GRB space-time diagram [10]



[10] Enderli, M., Bianco, C. L., Izzo, L., et al. 2015, Proceedings of Swift: 10 years of discovery, PoS(SWIFT 10)073

Some canonical examples of S-GRBs

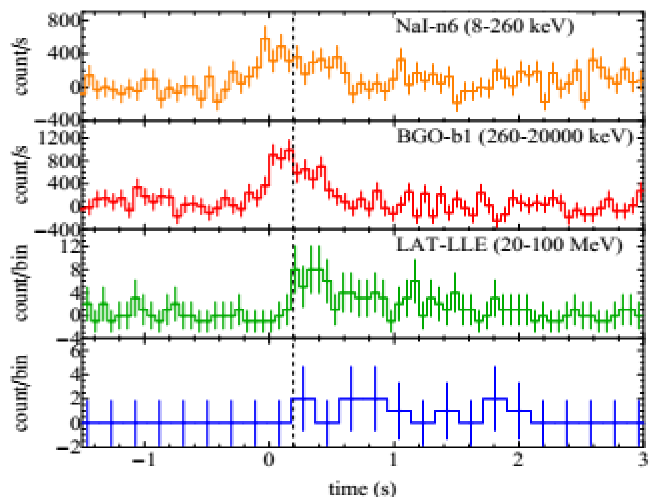


S-GRB 090227B

Muccino, M., Ruffini, R., Bianco, et al. 2013,ApJ, 763, 125

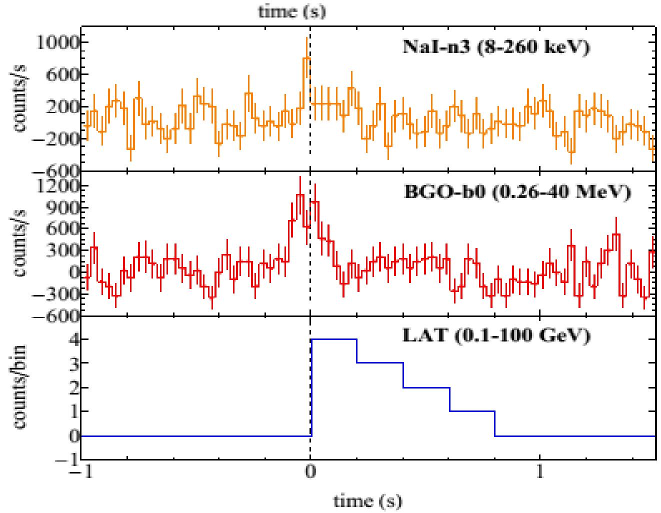
S-GRB 140619B

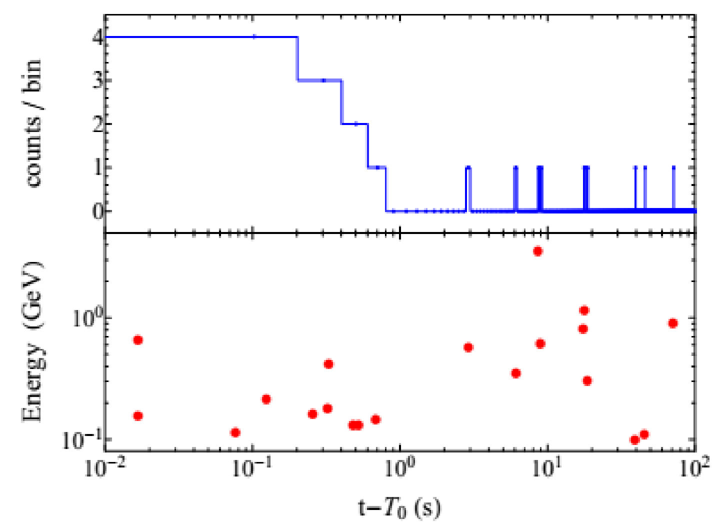
Ruffini, R., Muccino, M., Kovacevic, M., et al. 2015, ApJ, 808, 190



S-GRB 140402A

Aimuratov, Y., et al. in preparation





[11] Ackermann, M., Ajello, M., Asano, K., et al. 2013, ApJS, 209, 11

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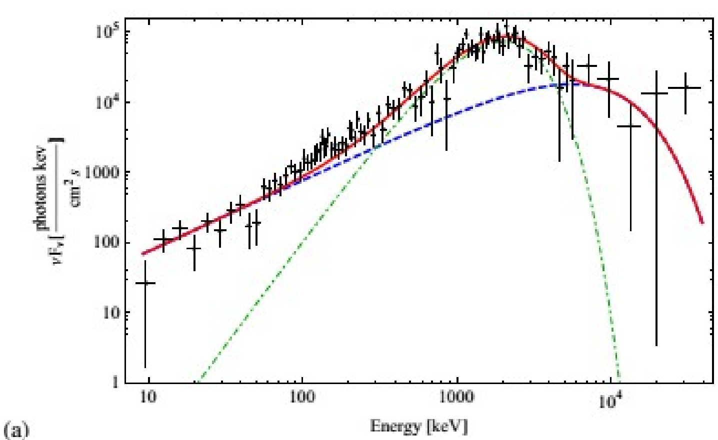

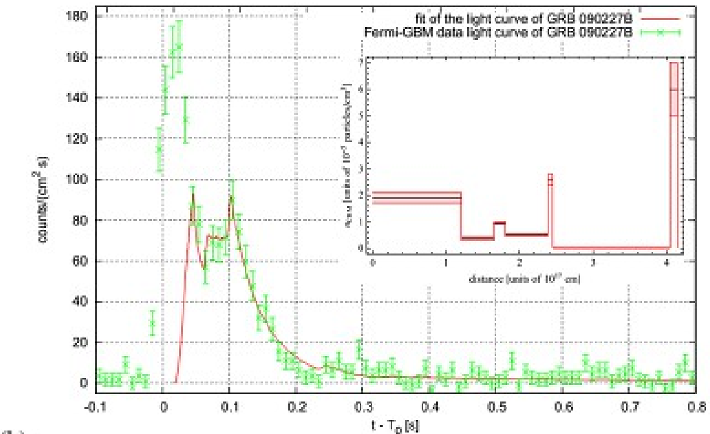

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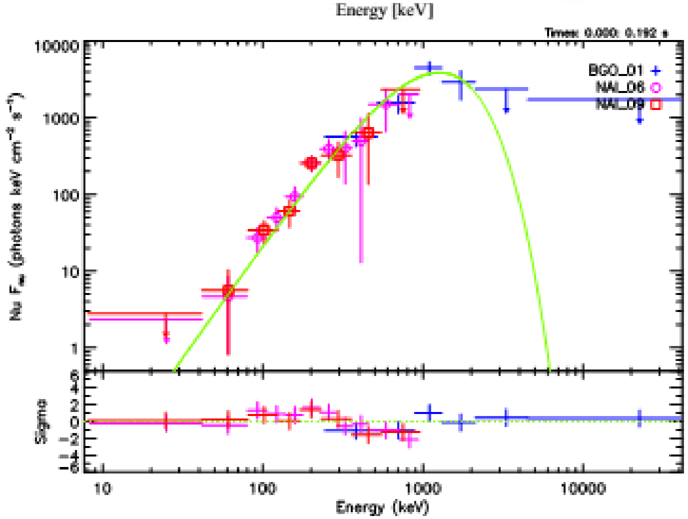

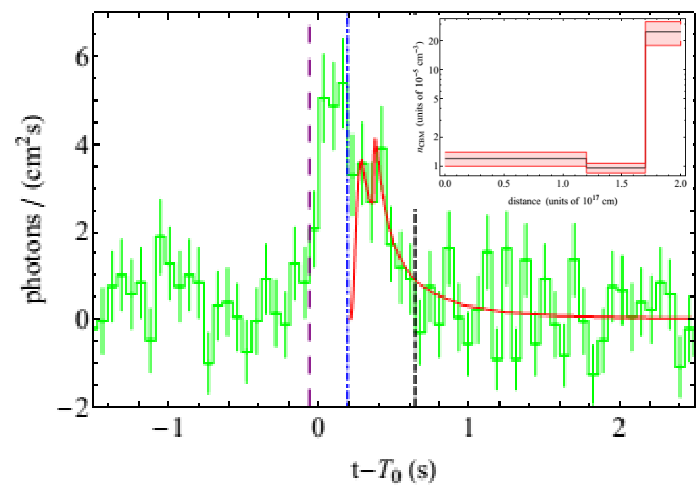

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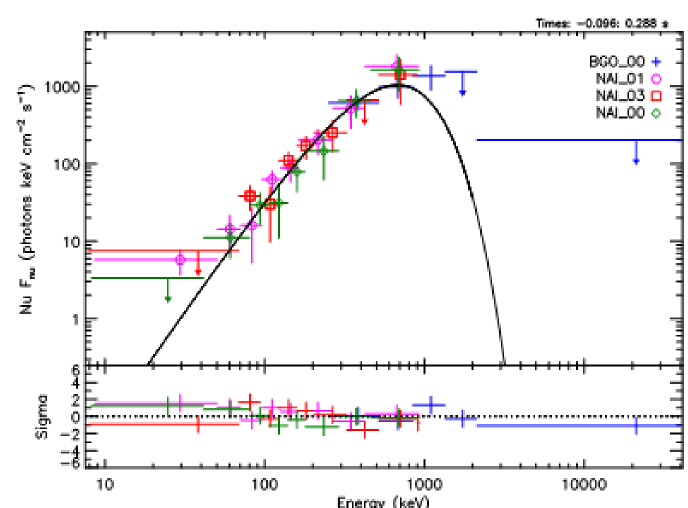
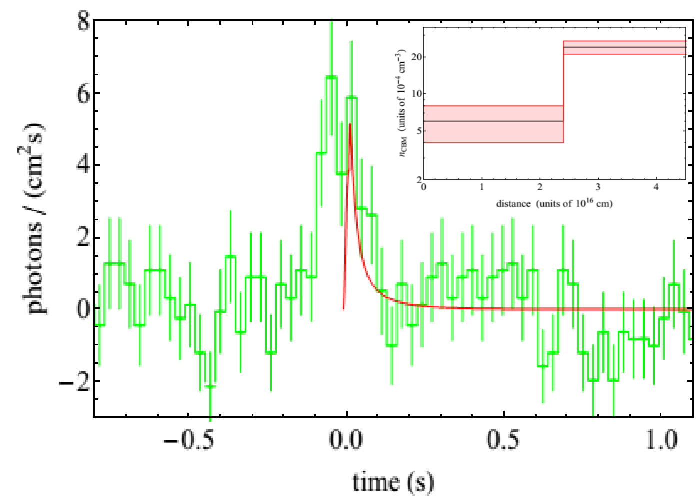
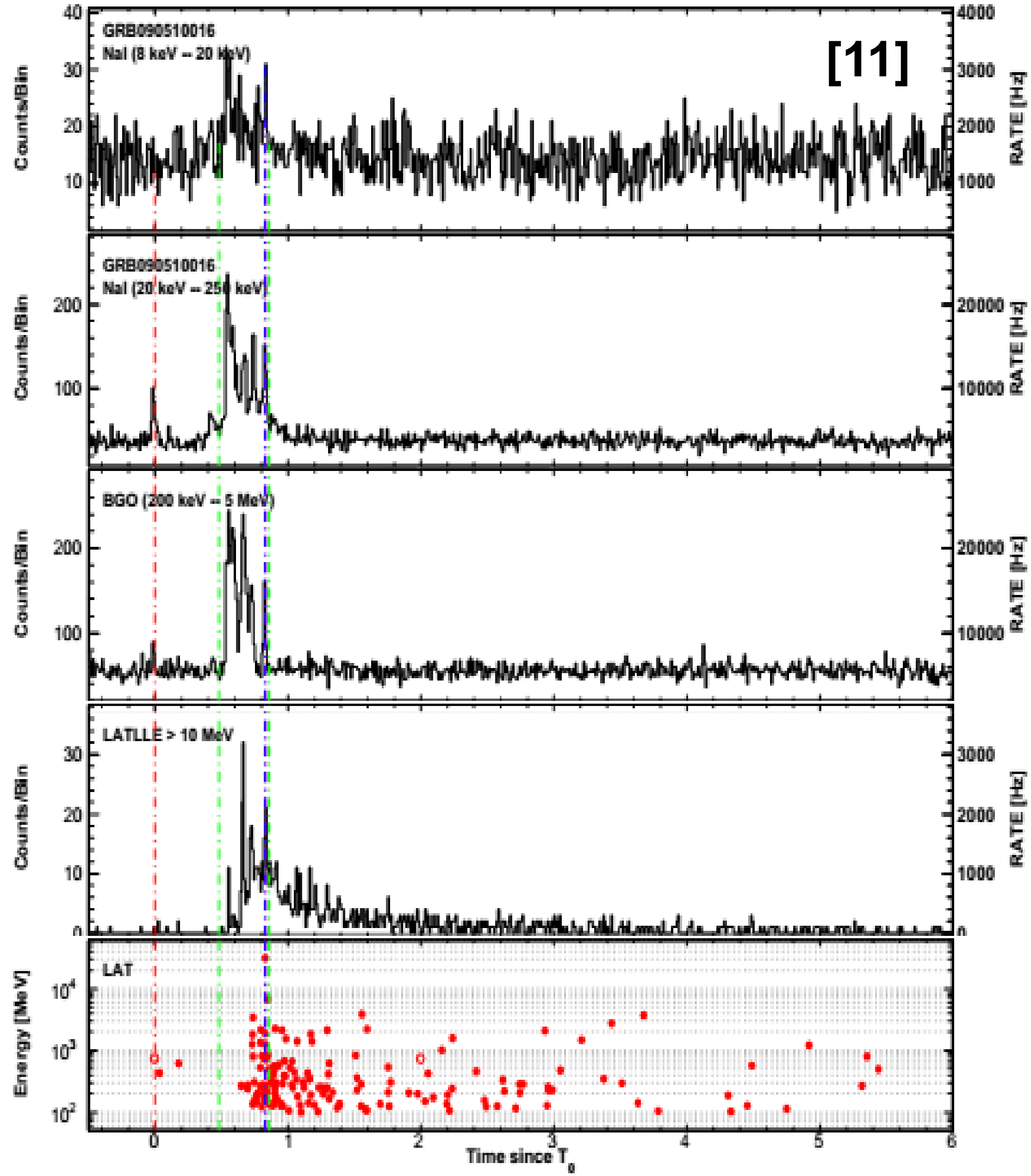




An unusual(?) example of S-GRBs

S-GRB 090510

Enderli, M., et al. ApJ submitted



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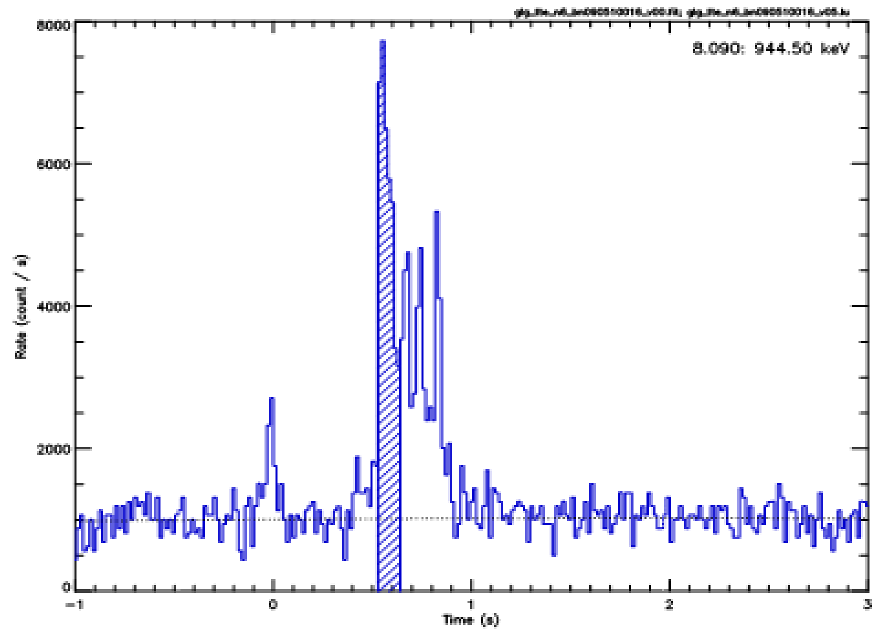
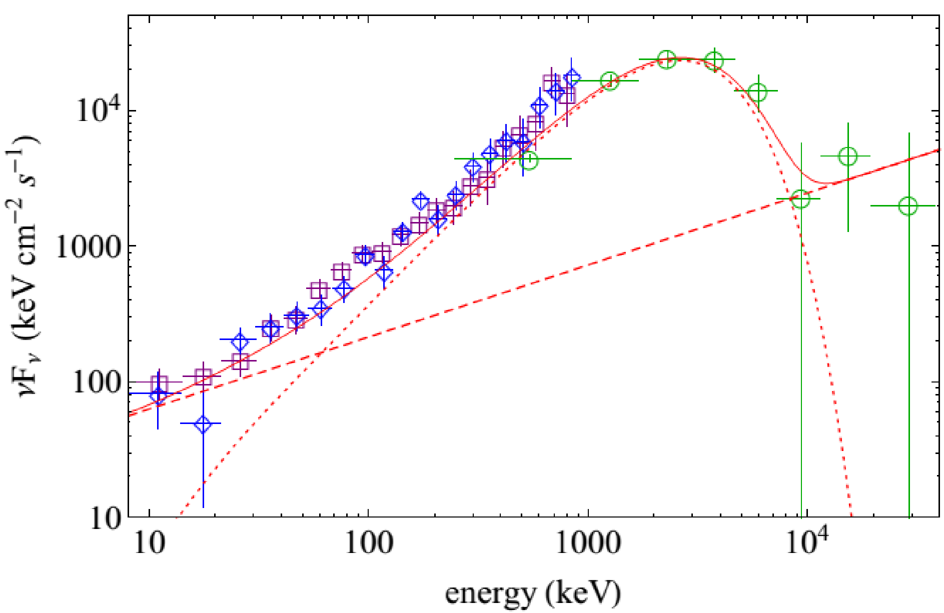


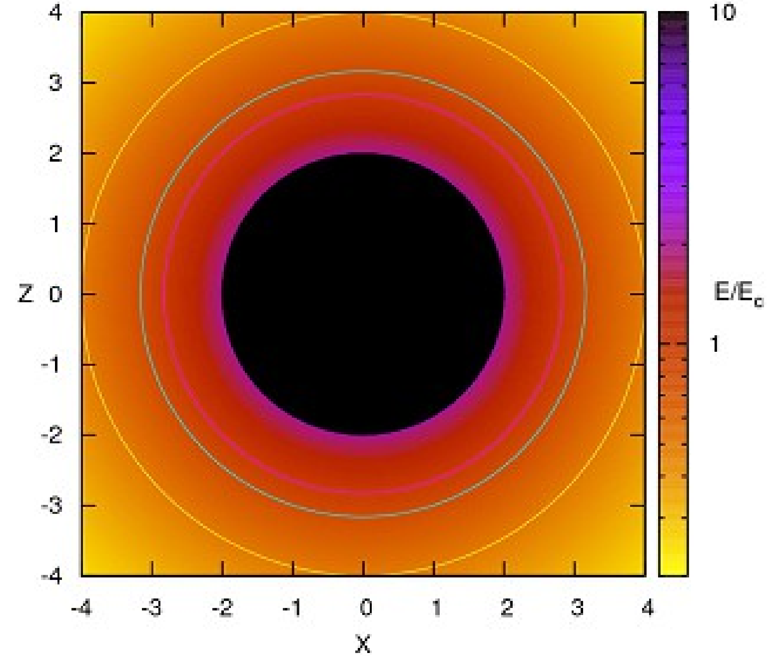
The P-GRB, occurring before the on-set of the GeV emission does not exhibit the typical thermal spectral component...

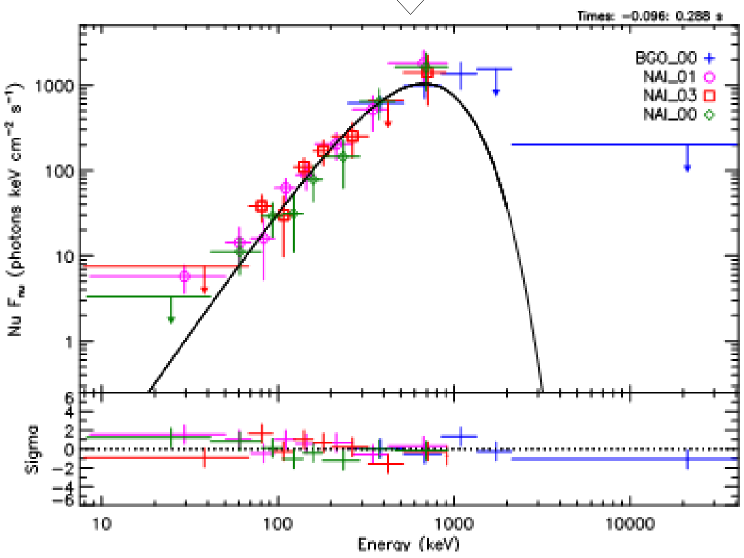
...WHY?



A spinning BH for the S-GRB 090510?

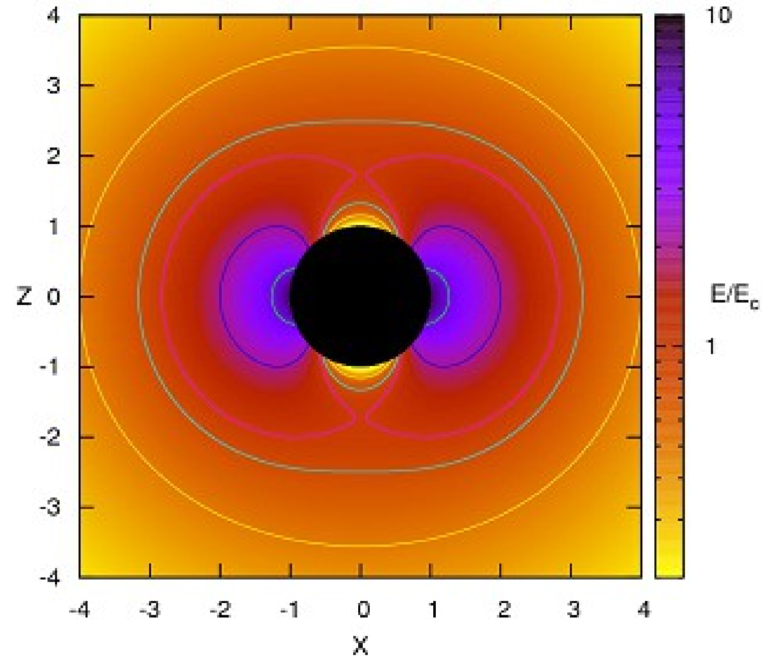
The dyadosphere for a Reissner-Nordström BH

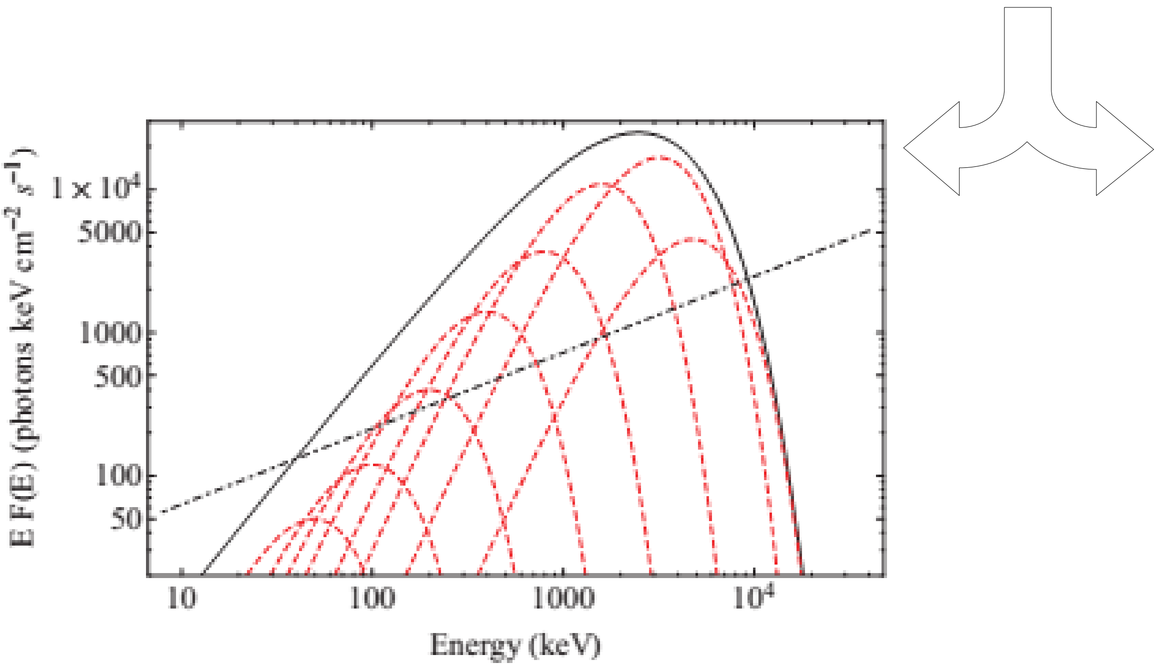


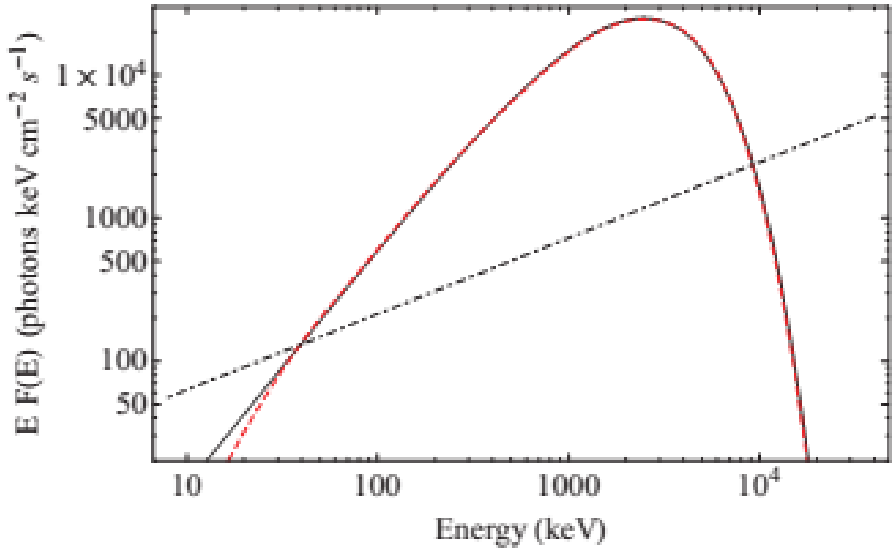


A spinning BH for the S-GRB 090510?

The dyadotorus for a Kerr(-Newman) BH

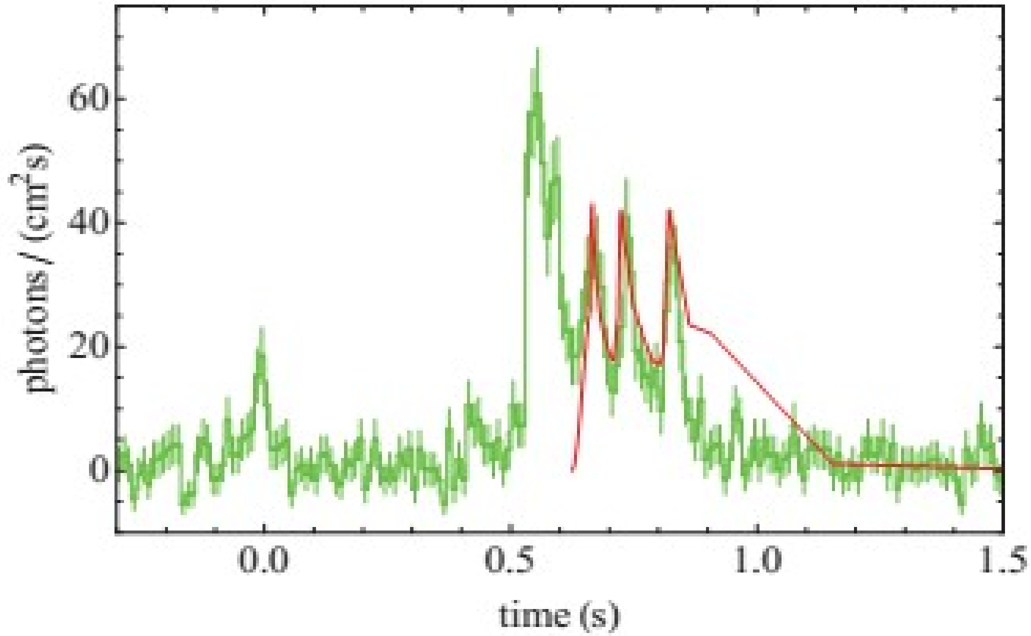


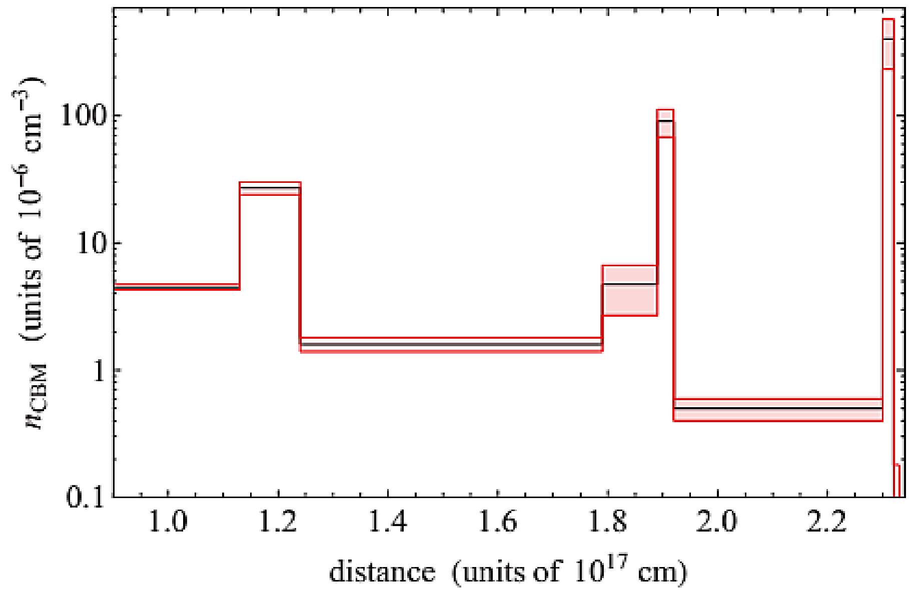


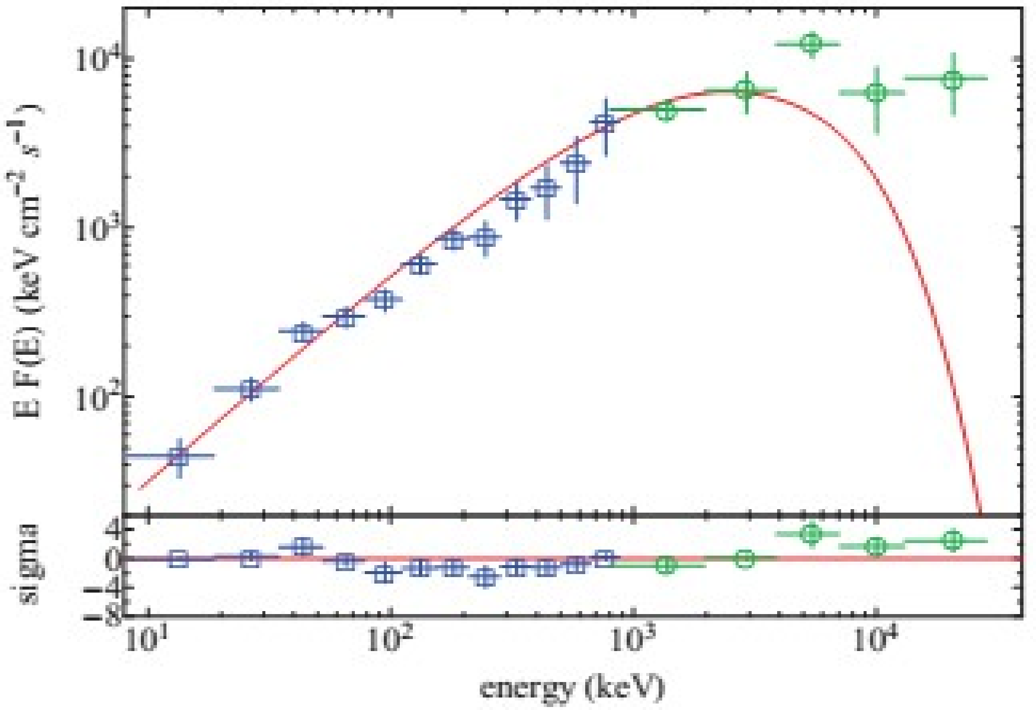


The γ-ray emission in the fireshell model [12]

Parameter	Value
B	$(5.54 \pm 0.70) \times 10^{-5}$
$\gamma_{\rm tr}$	$(1.04 \pm 0.07) \times 10^{4}$
$r_{\rm tr}$	$(7.60 \pm 0.50) \times 10^{12}$ cm
$E^{\rm tot}_{e^+e^-}$	$(3.95 \pm 0.21) \times 10^{52}$ erg
$kT_{\rm blue}$	$(1.20 \pm 0.11) \times 10^{3}$ keV
$\langle n \rangle$	$(8.7 \pm 2.1) \times 10^{-6}$ cm^{-3}

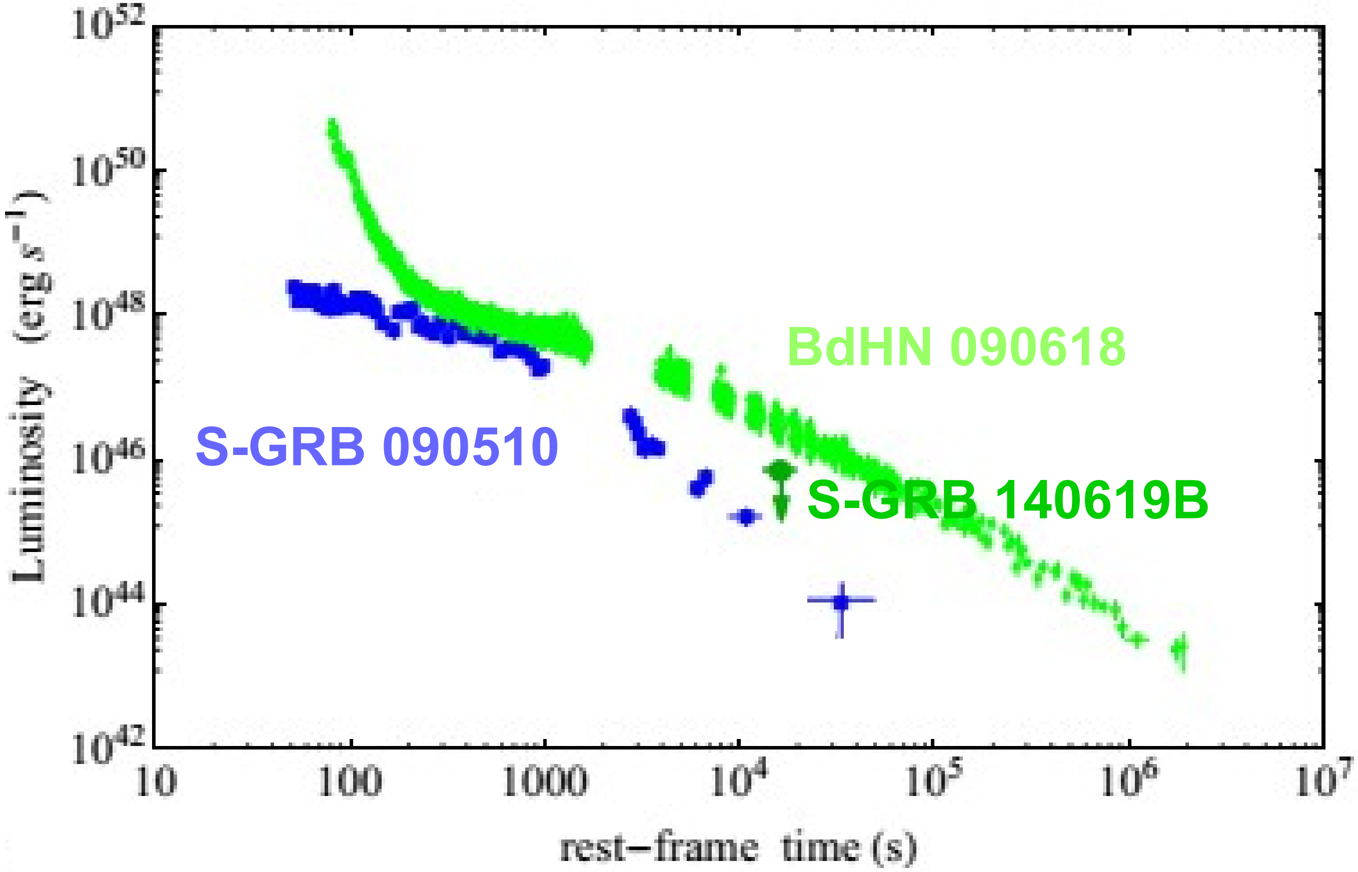






[12] Enderli, M., et al. ApJ submitted

Not a binary-driven hypernova (BdHN) [12]



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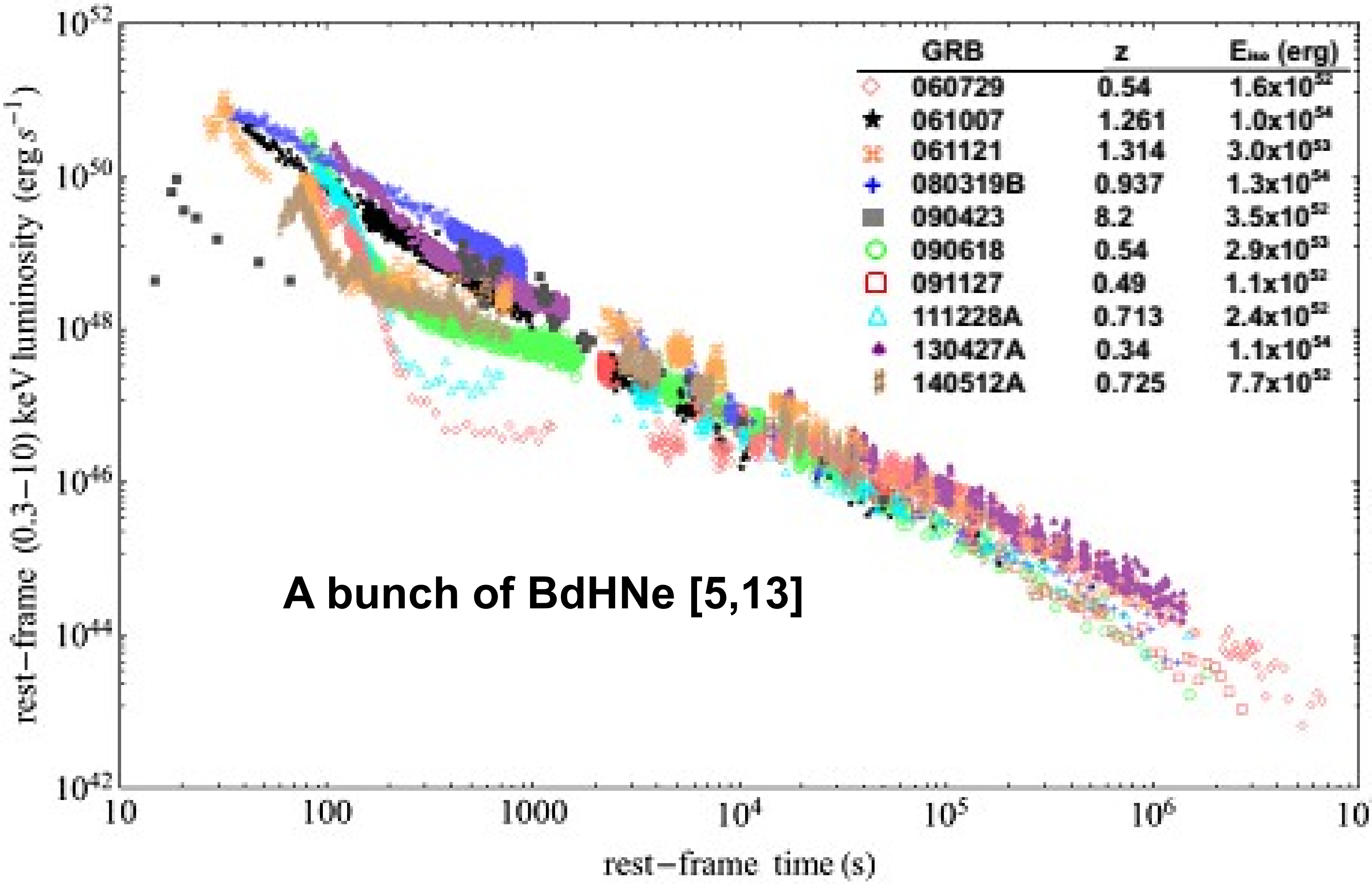
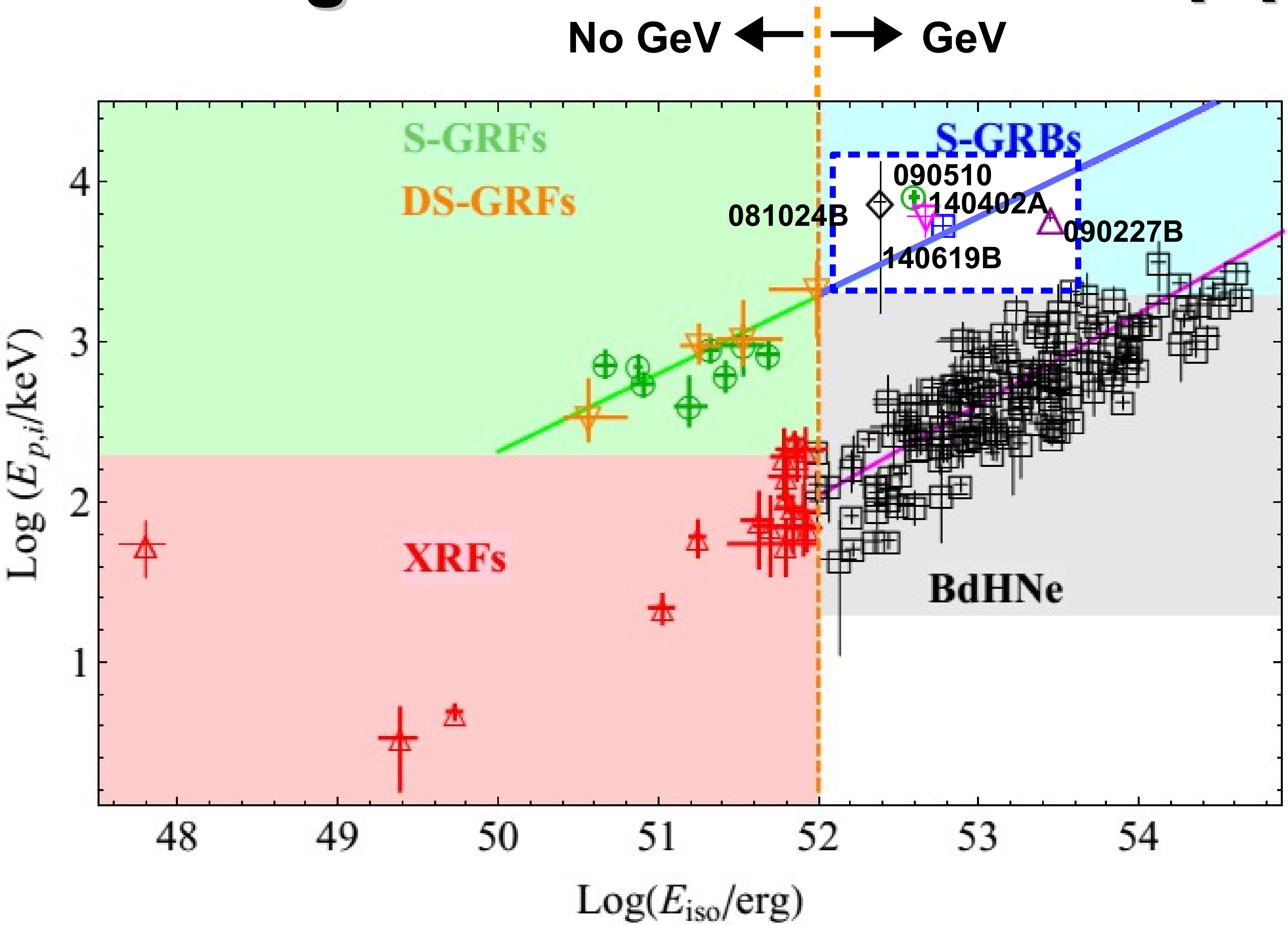


A bunch of BdHNe [5,13]

[5] Ruffini, R., Rueda, J.A., Muccino, M., et al. 2016, arXiv:1602.02732
[13] Pisani, G. B., Izzo, L., Ruffini, R., et al. 2013, A&A, 552, L5

The origin of the LAT emission [12]

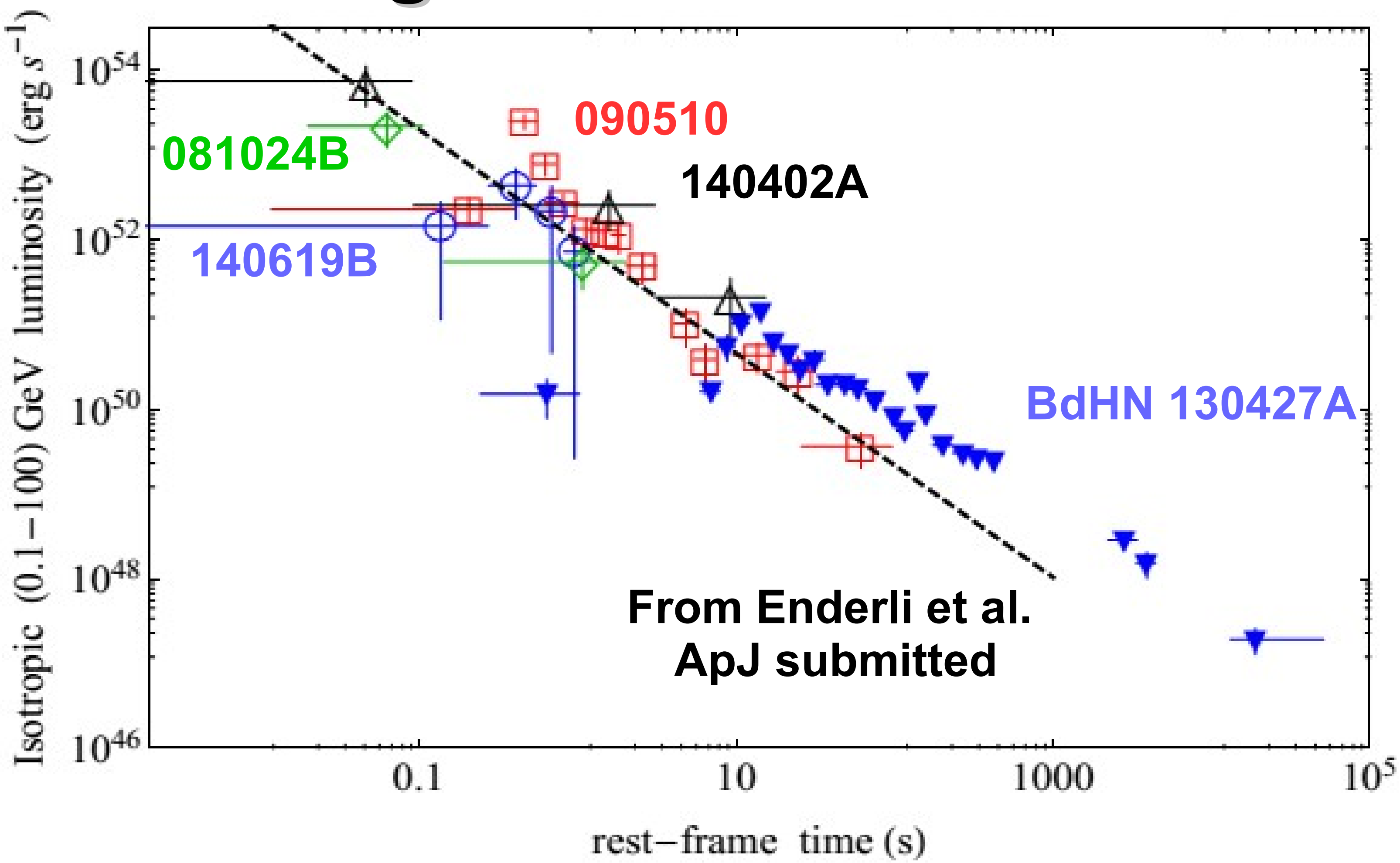


What do S-GRBs have in common that could give origin to the GeV emission (when LAT data are available), while S-GRFs do not?

An already formed BH!!

[12] Enderli, M., et al. ApJ submitted

The origin of the LAT emission



GRB	z	$E_{p,i}$ (MeV)	E_{iso} (10^{52} erg)	E_{LAT} (10^{52} erg)
081024B	2.6 ± 1.6	8.7 ± 4.9	1.83 ± 0.78	1.94 ± 0.67
090227B	1.61 ± 0.14	5.89 ± 0.30	28.3 ± 1.5	-
090510	0.903 ± 0.003	7.89 ± 0.76	3.95 ± 0.21	5.78 ± 0.60
140402A	5.52 ± 0.93	6.1 ± 1.6	4.7 ± 1.1	16.6 ± 5.3
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The accretion can explain in a simple way the GeV emission energy resevoir [12]

$$E_{\rm LAT} = f_b^{-1} \eta_\pm M_{\rm acc} c^2$$

where $f_b \equiv 1 - \cos\theta$ **and** $\eta_+ = 42.3\%$ **or** $\eta_- = 3.8\%$ **for a Kerr BH [13].**

Two cases can be studied, e.g., for the case of the S-GRB 090510:

1) Isotropic emission $f_b \equiv 1$ $\Longrightarrow M_{\rm acc} \gtrsim 0.08\ {\rm M}_\odot$ **for the co-rotating case**

$\Longrightarrow M_{\rm acc} \gtrsim 0.86\ {\rm M}_\odot$ **for the counter-rotating case**

[13] Ruffini & Wheeler in Landau, L. D. & Lifshitz, E. M. 2003 "The classical theory of fields", fourth revised edition, Butterworth-Heinemann (Oxford), 352

The origin of the LAT emission

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2) **Accretion from a 1.6+1.6 M⊙ NS–NS merger crustal mass. In the NL3 nuclear model each globally neutral NS has a crustal mass of** $M_c = 4.30 \times 10^{-5}\, {\rm M}_\odot$ **[14] and part of it goes into the baryon load,** $M_B \equiv E^{tot}_{e^+e^-} B/c^2 = 1.22\times 10^{-6}\, {\rm M}_\odot$**. So, the total available mass for accretion is** $M_{\rm acc} \equiv 2M_c - M_B = 8.48 \times 10^{-5}\, {\rm M}_\odot$**.**

Thus a beaming is necessary $\Longrightarrow\ \theta \gtrsim 2^{\rm o}.70$ **for the co-rotating case**
$\Longrightarrow\ \theta \gtrsim 0^{\rm o}.81$ **for the counter-rotating case**

[14] Belvedere, R., Pugliese, D., Rueda, J. A., et al. 2012, Nuclear Physics A, 883, 1

The origin of the LAT emission

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These beaming angles are larger than the relativistic beaming angle $\theta_r = \gamma_{\rm LAT}^{-1} \approx 0^{\rm o}.1$**, where the lower limit on the Lorentz factor** $\gamma_{\rm LAT} \approx 550$ **has been derived by applying the pair production optical depth formula [15] to the GeV luminosity light curve.**

[15] Lithwick, Y., & Sari, R., 2001, ApJ, 555, 540

Conclusions

⟹ The E_p and E_{iso} values of GRB 090510 fulfill the MuRuWaZha relation.

⟹ The P-GRB spectrum of GRB 090510 is best-fitted by a Comptonized model and it is interpreted as a convolution of thermal spectra originating in a dyadotorus.

⟹ The prompt emission occurs after the P-GRB. The analysis within the fireshell model leads to an average value of the CBM density of 8.7×10^{-6} cm^{-3}, typical of galactic halos where NS binaries are expected to migrate due to large natal kicks.

⟹ The GeV emission occurs after the P-GRB emission, in both S-GRBs and BdHNe, and originates from a Kerr(-Newman) BH dominated by its angular momentum, i.e., a Kerr BH, approximately. The energy of the GeV emission in GRB 090510 can be explained by matter accretion on co-rotating and counter-rotating orbits around an extreme Kerr BH. If the accretion involves the crustal mass from a 1.6+1.6 $M_\odot$ NS–NS binary, fulfilling global charge neutrality, geometrical beaming angles of 0°.81, for co-rotating case, and 2°.7, for the counter-rotating case, are necessary. These angles are larger than the relativistic beaming from the initial Lorentz factor of the jetted material, $\gamma \approx 550$.

⟹ Whe GeV emission can be jetted, no beaming appears to be present both in the P-GRB and in the prompt emission.

⟹ The late X-ray emission of GRB 090510 does not follow the characteristic patterns expected in BdHN events.

Thank you