The induced gravitational collapse model vs. the fireball collapsar model

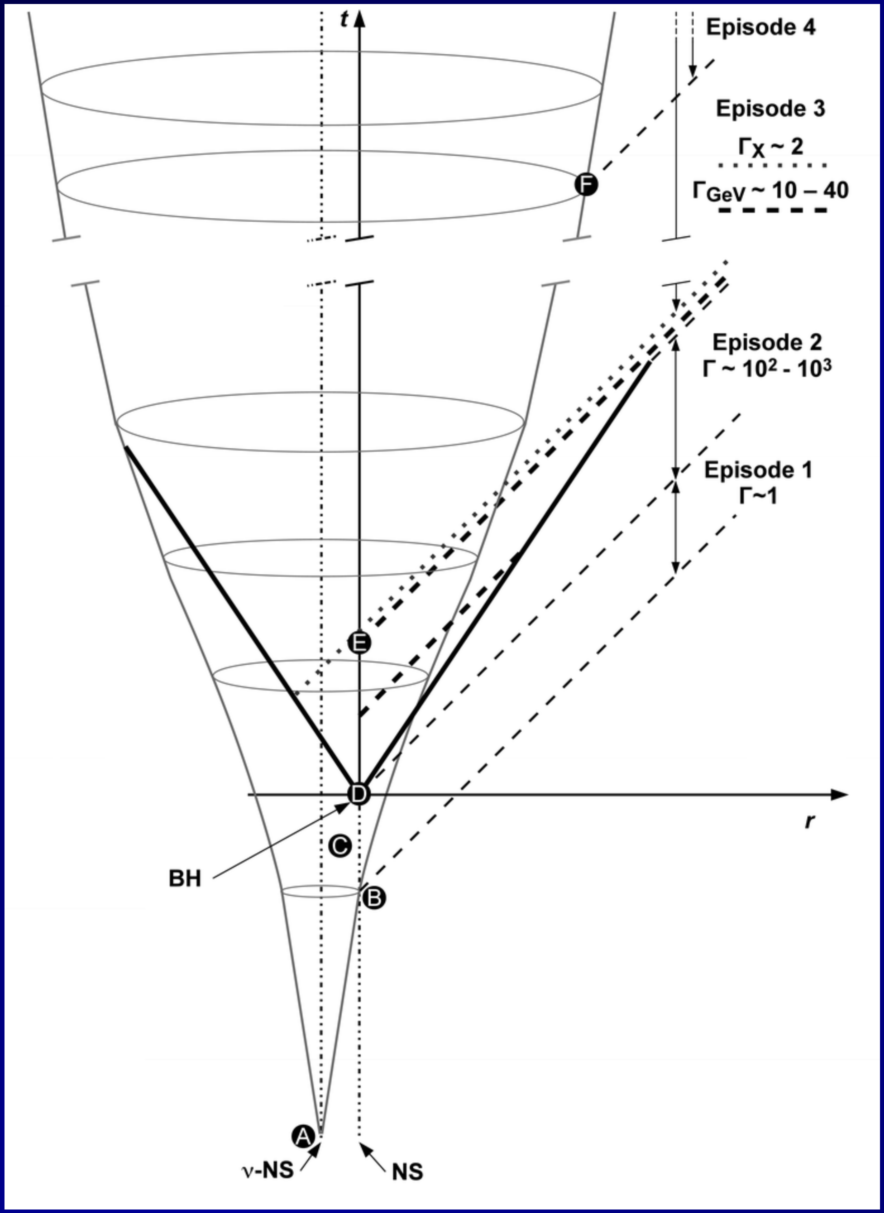
Remo Ruffini

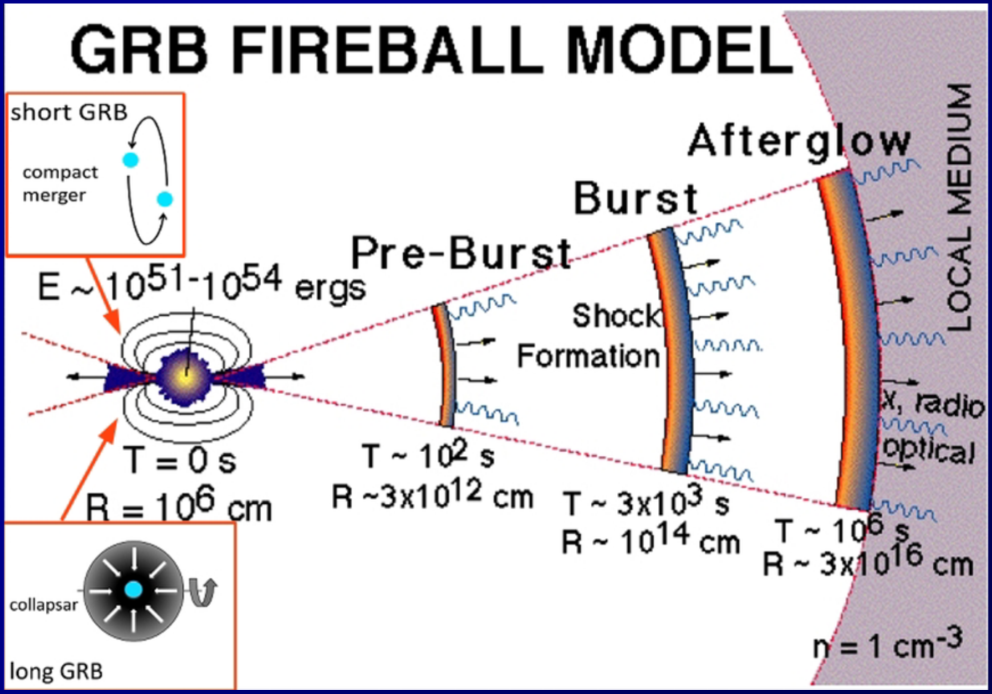
ICRANet

Swift – 10 years of discovery

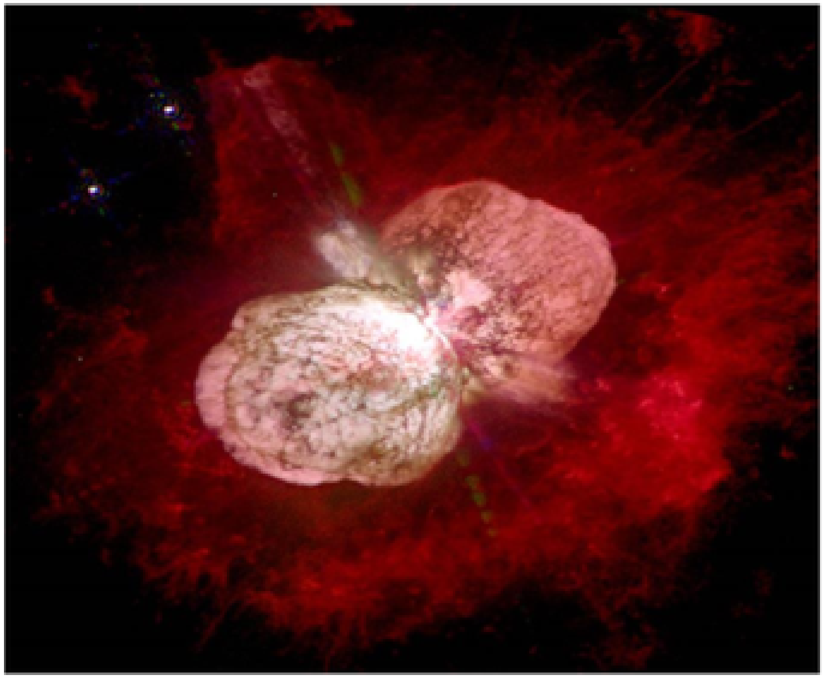
Roma – La Sapienza – December 2-5, 2014

Fireshell vs. Fireball

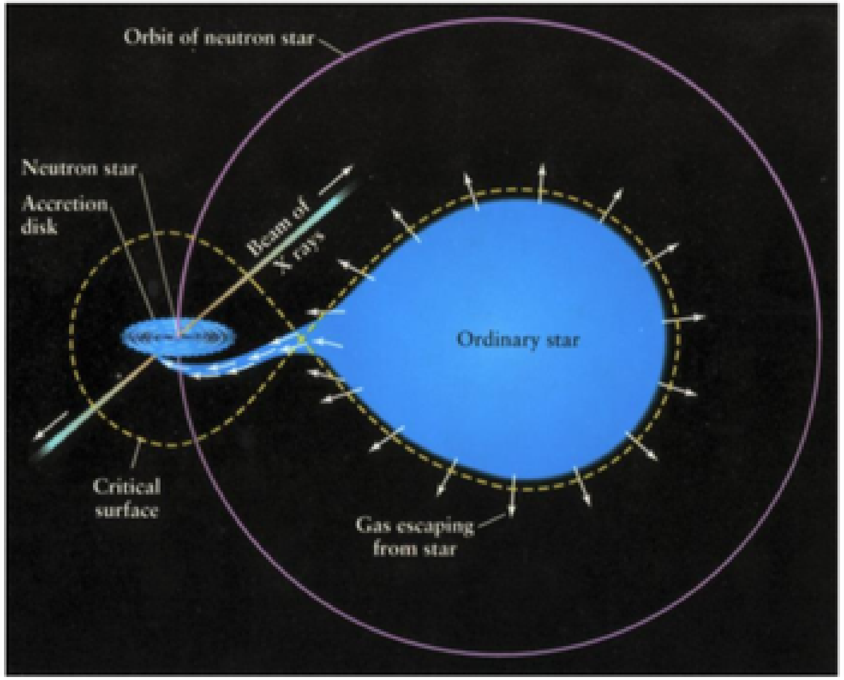




From the progenitor to the IGC sequence: the case of long GRBs related to SNe



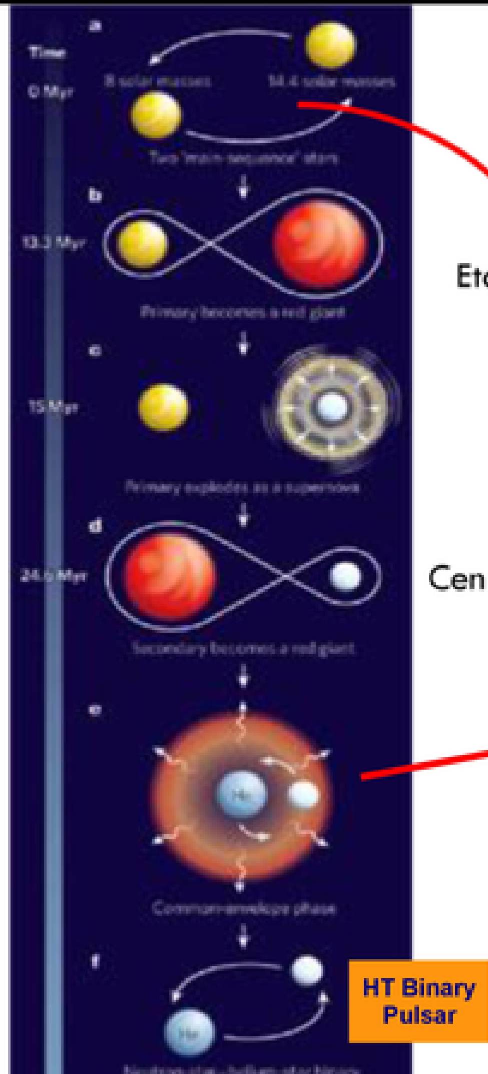
Massive Binary
(Eta Carinae, Porb=5.5 yr)



Massive Star-Neutron Star X Ray Binary
(Centaurus X-3, Porb=2.1 days)

The IGC Binary Progenitor

Binary sequence

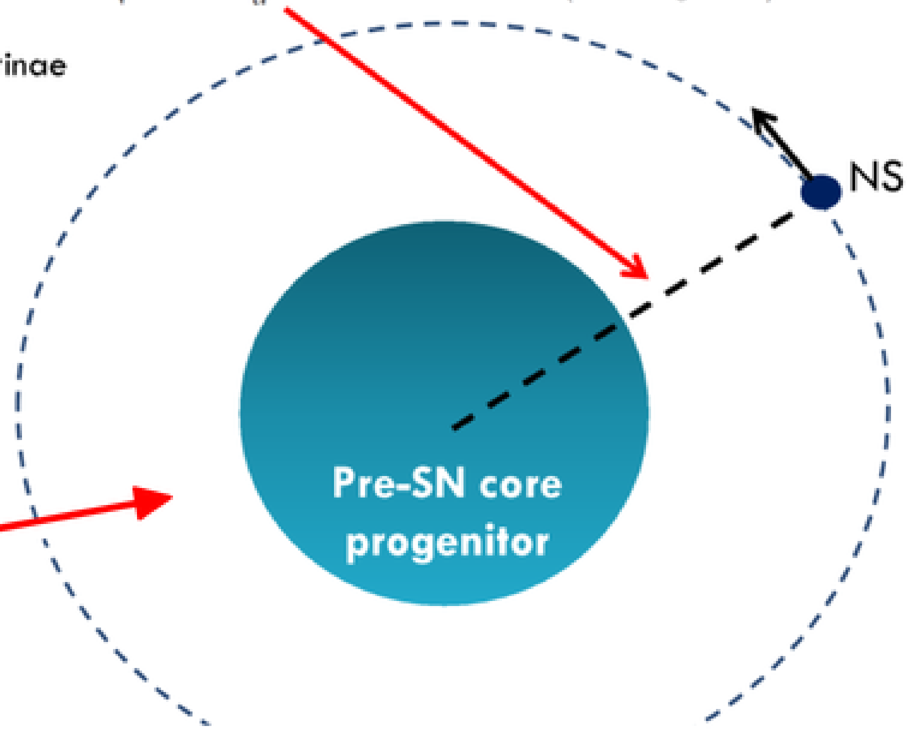


Eta Carinae

Cen X-3

Nomoto & Hashimoto (1988)
Nomoto et al. (1994)
Iwamoto et al. (1994)
and others…

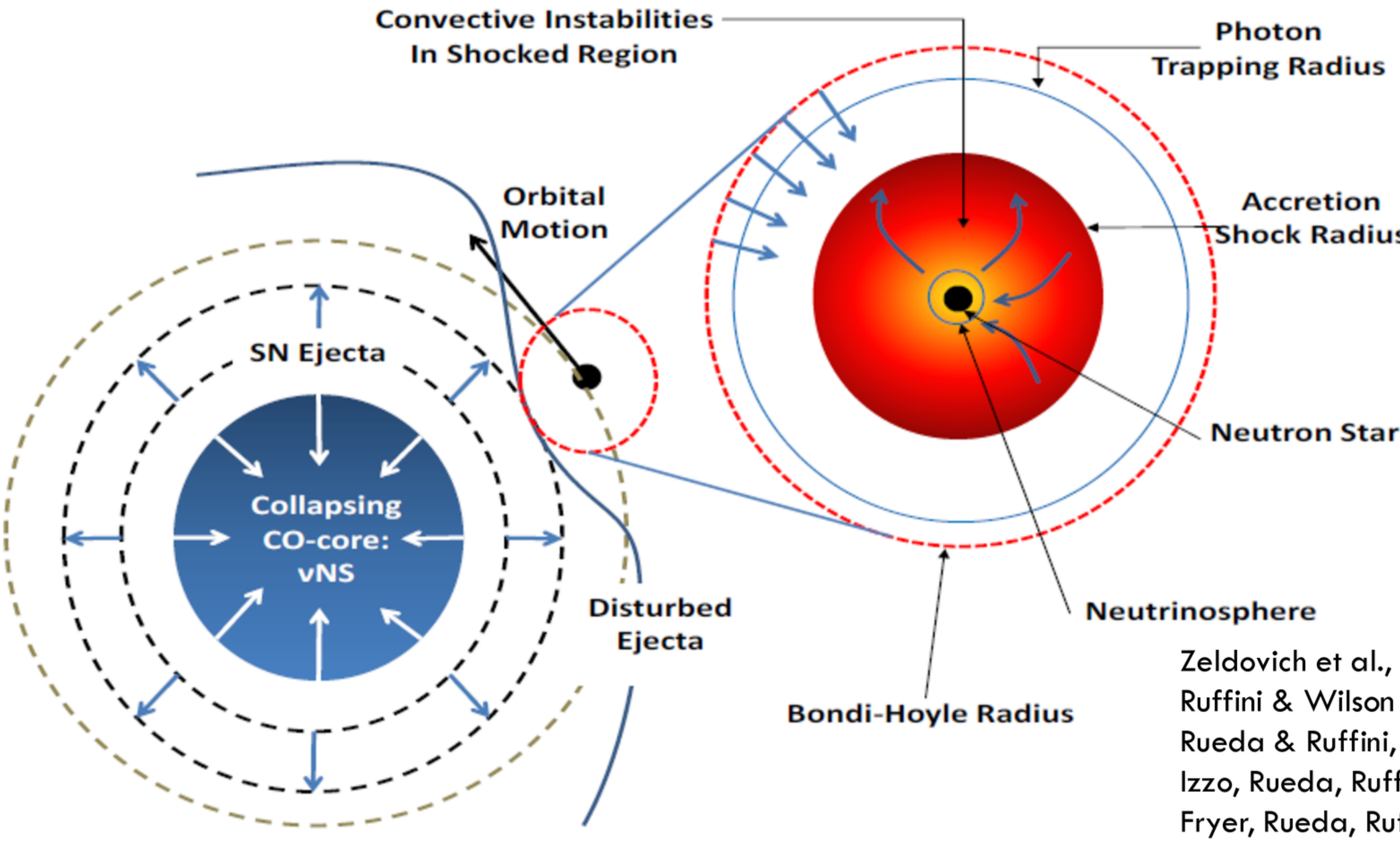
$$v_{\rm orb} = \sqrt{\frac{G(M_{\rm SN\text{-}prog} + M_{\rm NS})}{a}} = 1.15 \times 10^8 \left(\frac{M_{\rm SN\text{-}prog} + M_{\rm NS}}{M_\odot}\right)^{1/2} \text{ cm s}^{-1}$$



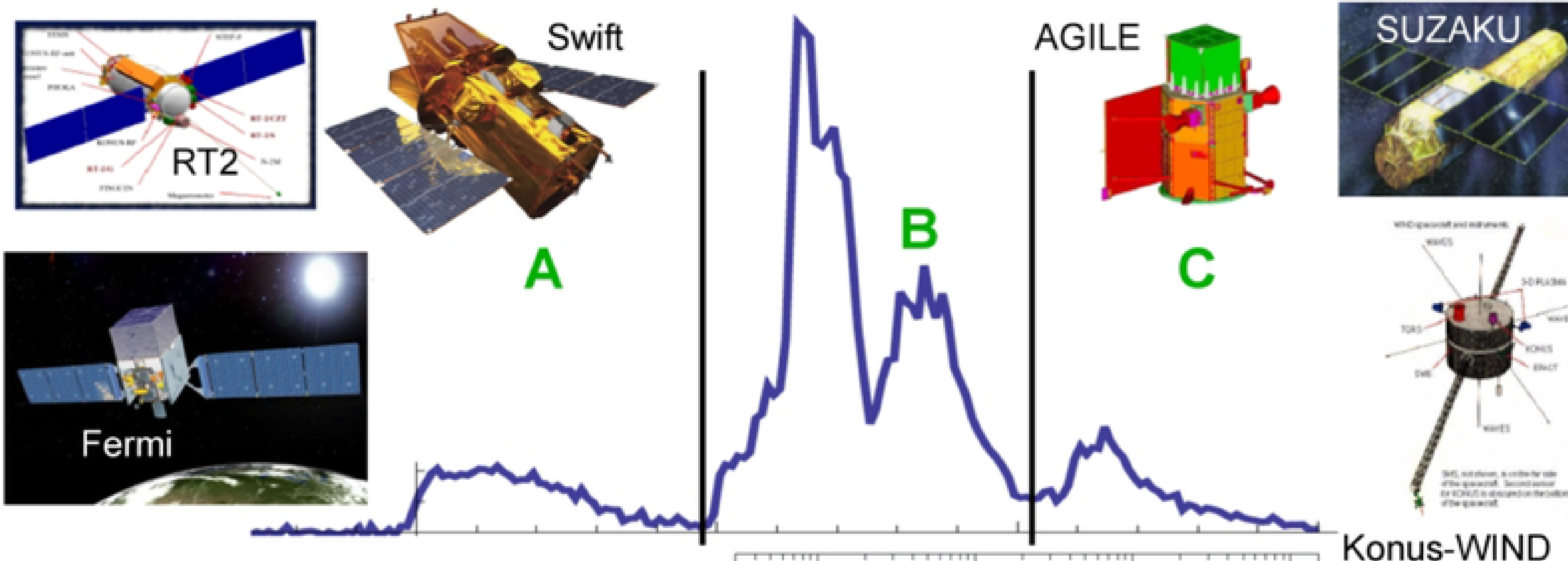
$$P = \sqrt{\frac{4\pi^2 a^3}{G(M_{\rm SN\text{-}prog} + M_{\rm NS})}} = 545 \left(\frac{M_{\rm SN\text{-}prog} + M_{\rm NS}}{M_\odot}\right)^{-1/2} \text{ s}$$

Rueda & Ruffini, ApJL (2012)
Izzo, Rueda, Ruffini, A&AL (2012)

Hypercritical Accretion, Binary-Driven HNe, and IGC



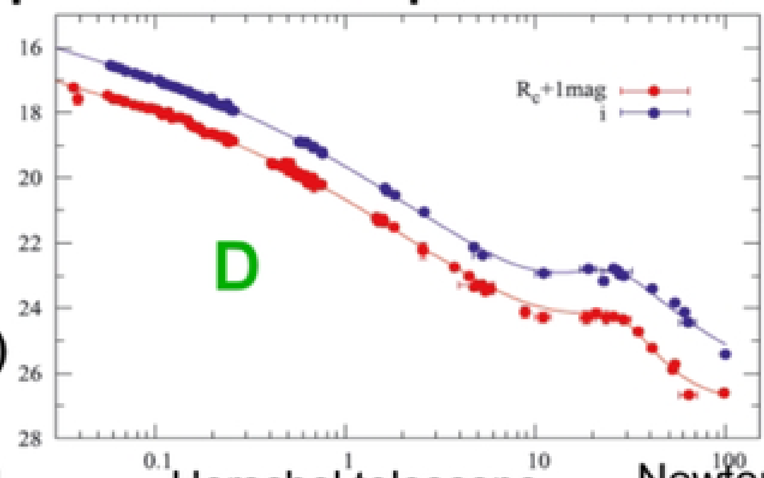
Zeldovich et al., Sov. Astron. (1972)
Ruffini & Wilson (1973)
Rueda & Ruffini, ApJL (2012)
Izzo, Rueda, Ruffini, A&AL (2012)
Fryer, Rueda, Ruffini, ApJL (2014)



GRB 090618

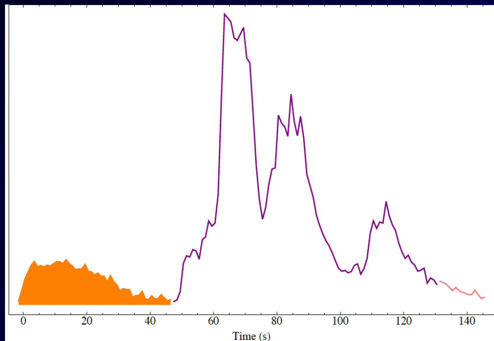
Eiso=2.8x10^{53} erg

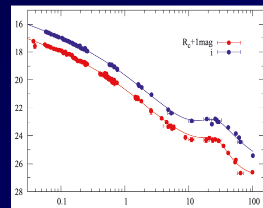
Z=0.54

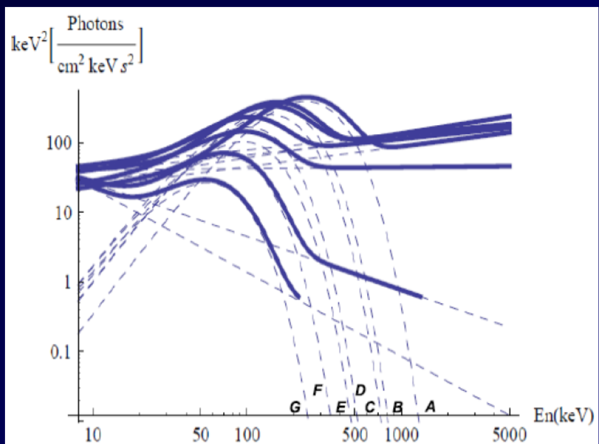


Ruffini et al. *PoS(Texas2010)*, 101 (2011)
Izzo et al., *A&A*, 543, A10 (2012)

Episode 1

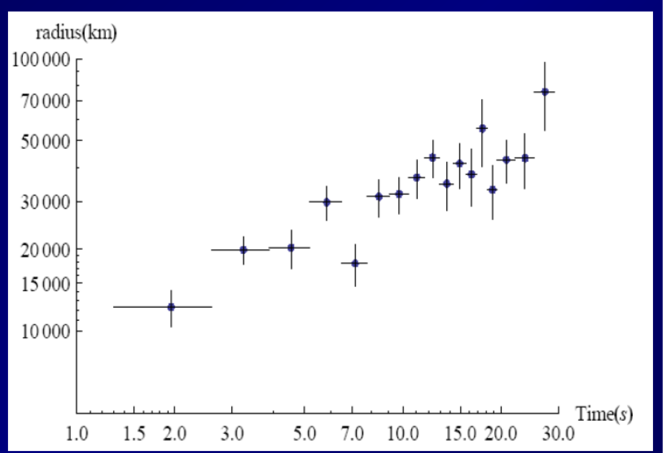




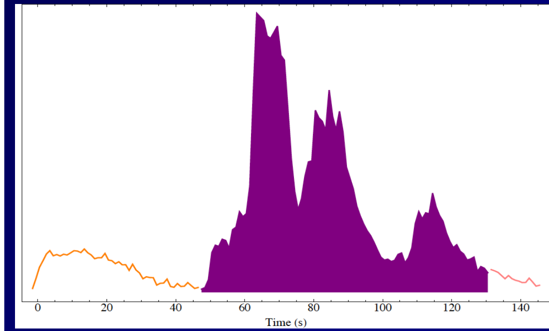


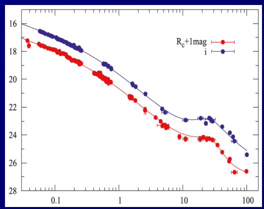
BB evolution
+
Non-thermal
emission

Evolution
Radius
Thermal
emitter

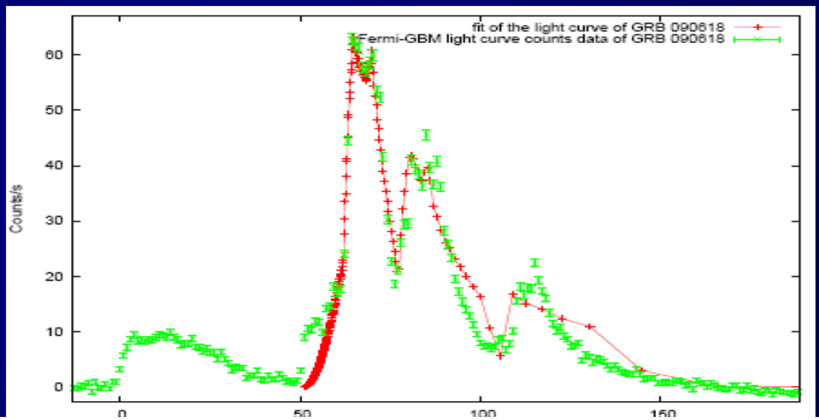


Episode 2





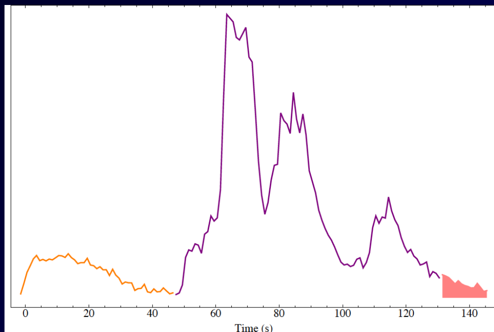
GRB simulation and results

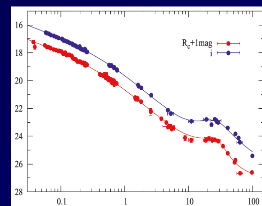


Parameter	Value
$E_{tot}^{e^+e^-}$	$2.49 \pm 0.02 \times 10^{53}$ ergs
B	$1.98 \pm 0.15 \times 10^{-3}$
Γ_0	495 ± 40
kT_{th}	29.22 ± 2.21 keV
$E_{P-GRB,th}$	$4.33 \pm 0.28 \times 10^{51}$ ergs
$< n >$	$0.6\ part/cm^3$
$< \delta n/n >$	$2\ part/cm^3$

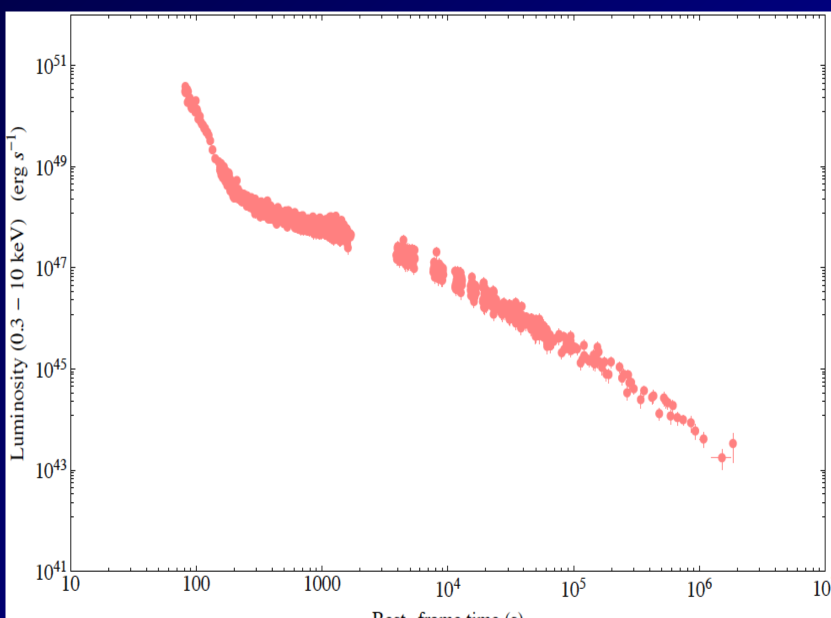
Ruffini et al. 2011; Rueda&Ruffini 2012; Fryer et al. 2014; Izzo et al. 2012

Episode 3

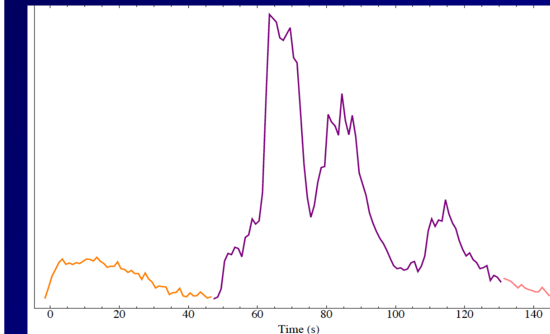


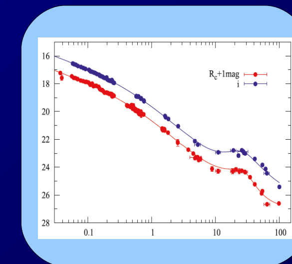


Swift-XRT afterglow light curve

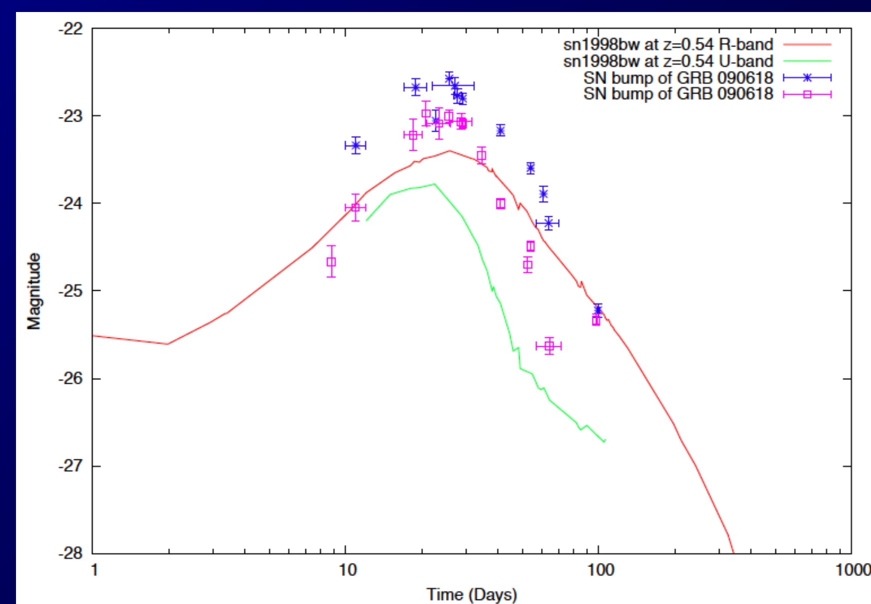


Episode 4

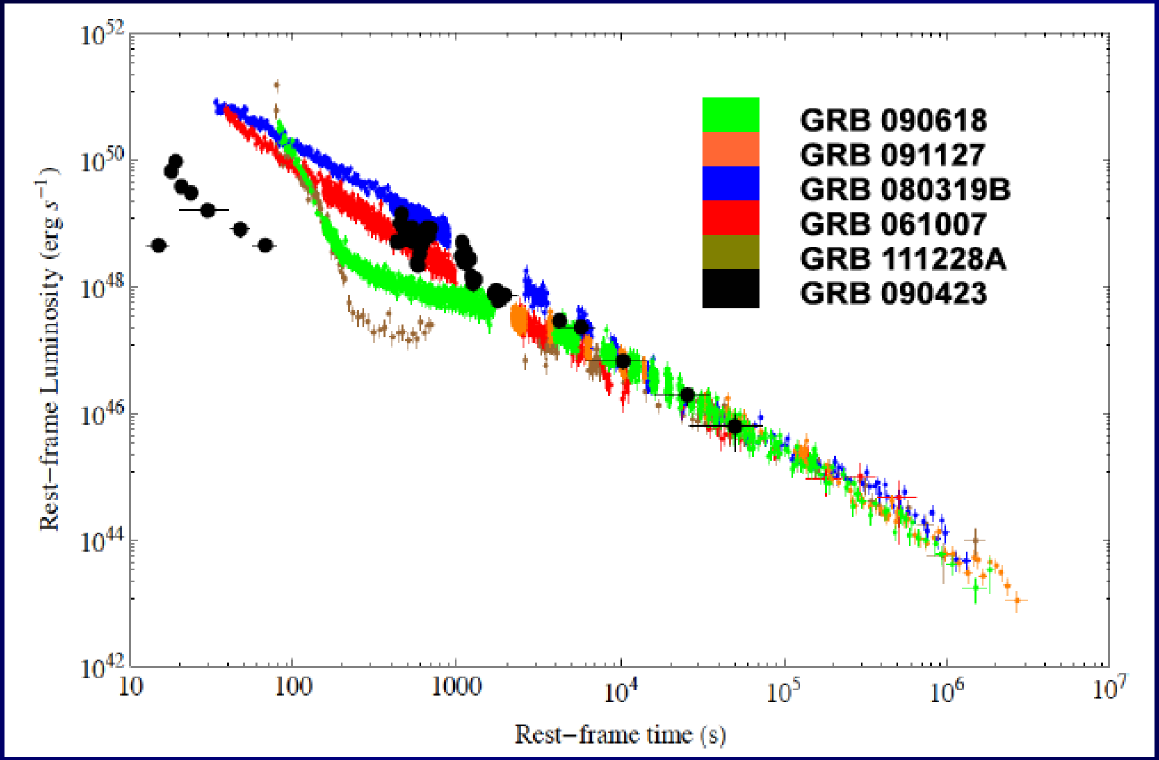




SN bump compared with sn 1998bw



Episode 3 scaling [1]



[1] Pisani, G.B., Izzo, L, Ruffini R., et al., 2013, A&A, 552, L5.

GRB 090618: Izzo, L., Ruffini, R., Penacchioni, A. V., et al. 2012, A&A, 543, A10
Izzo, L., Rueda, J. A., & Ruffini, R. 2012, A&A, 548, L5

GRB 091127: Wilson-Hodge, C. A. & Preece, R. D. 2009, GRB Coordinates Network, 10204, 1
Cobb, B. E., Bloom, J. S., Perley, D. A., et al. 2010, ApJ, 718, L150

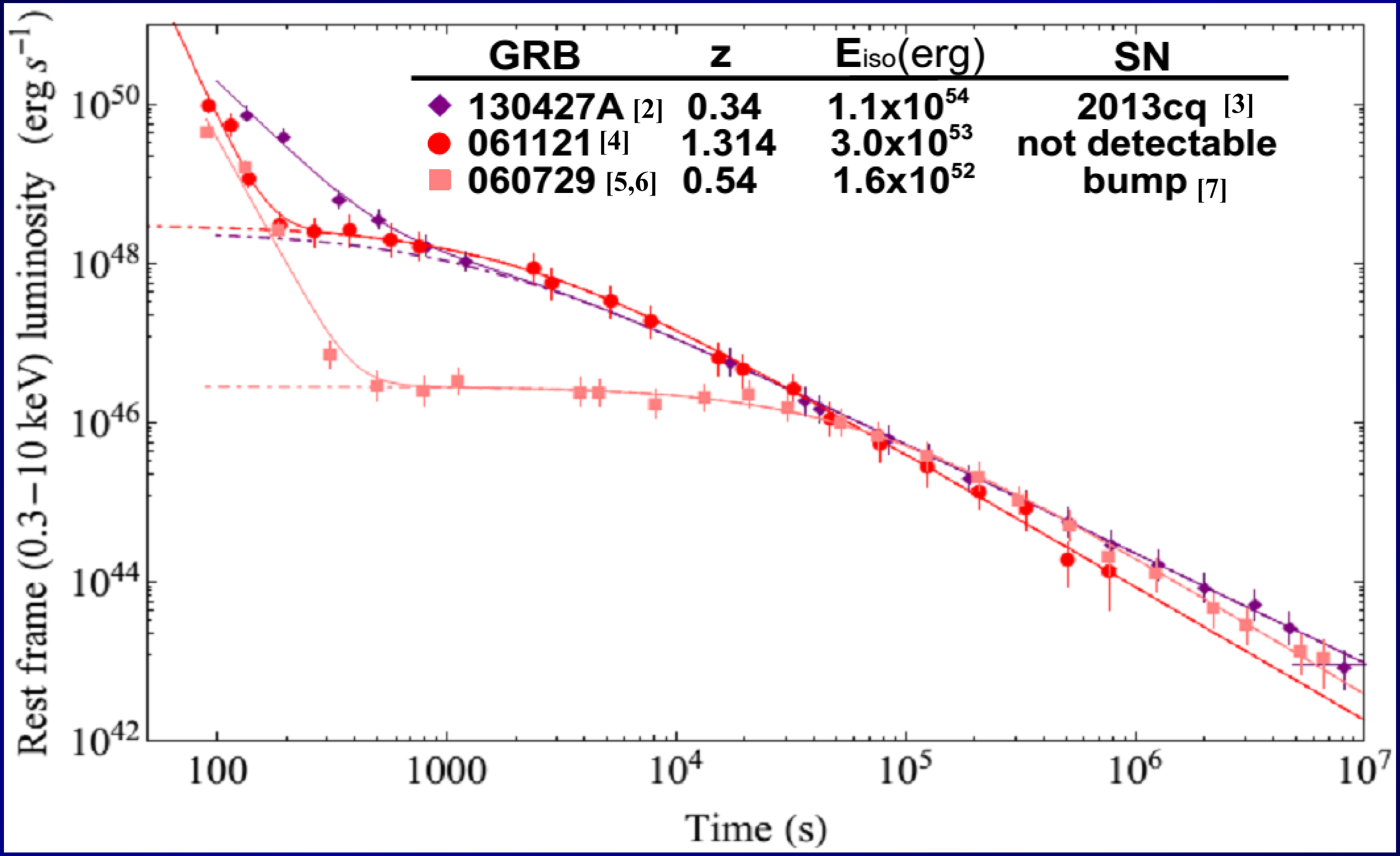
GRB 080319B: Golenetskii, S., Aptekar, R., Mazets, E., et al. 2008, GRB Coordinates Network, 7482, 1
Kann, D. A., Schulze, S., & Updike, A. C. 2008, GRB Coordinates Network, 7627, 1

GRB 0601007: Larsson, J., Ryde, F., Lundman, C., et al. 2011, MNRAS, 414, 2642
Golenetskii, S., Aptekar, R., Mazets, E., et al. 2006, GRB Coordinates Network, 5722, 1

GRB 111228A: Briggs, M. S. & Younes, G. 2011, GRB Coordinates Network, 12744, 1
D'Avanzo, P., Melandri, A., Palazzi, E., et al. 2012, GRB Coordinates Network, 13069, 1

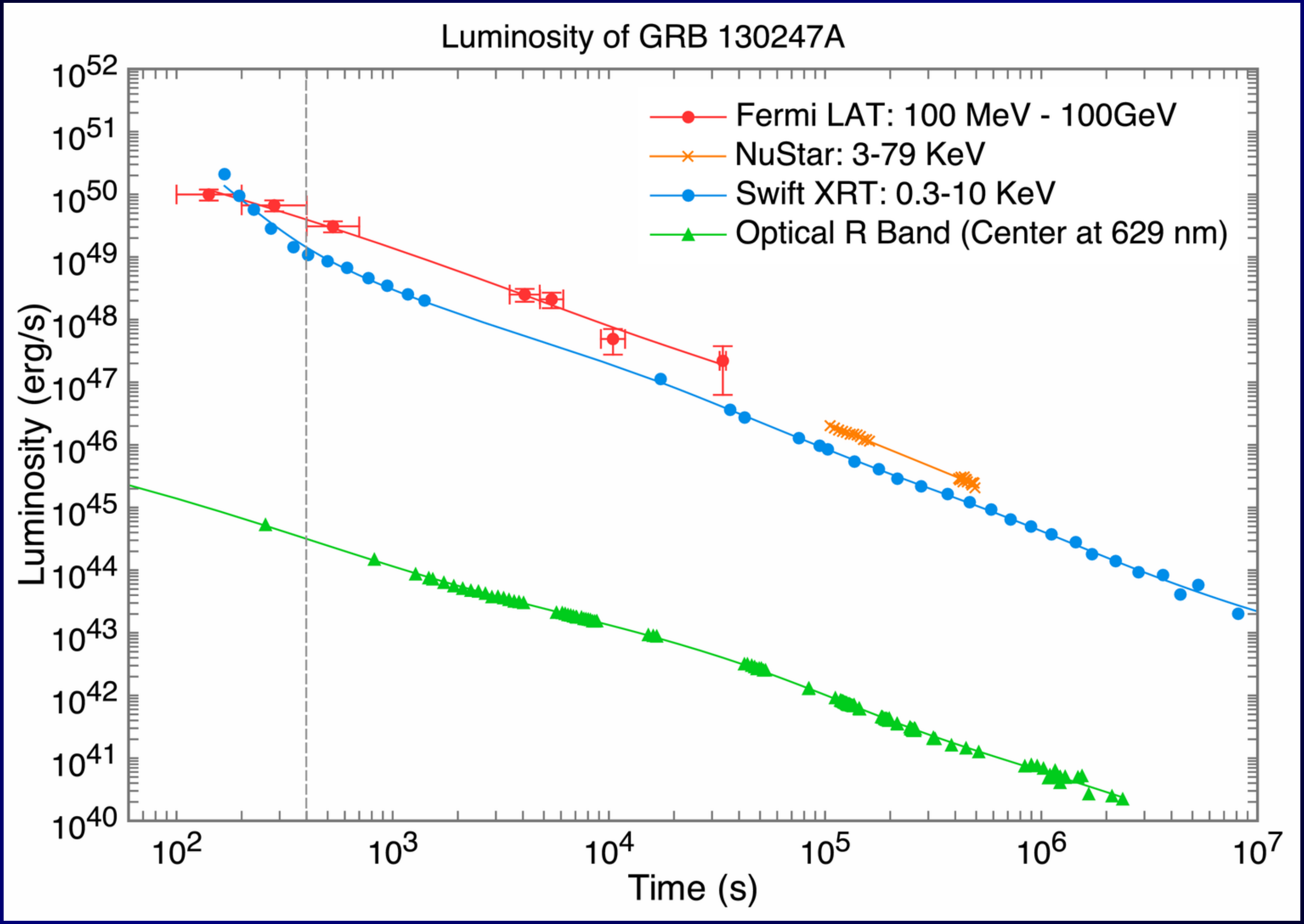
GRB 090423: Ruffini, R., Izzo, L., Muccino, M., et al. 2014, A&A, 569, A39

Episode 3 Nesting [1]



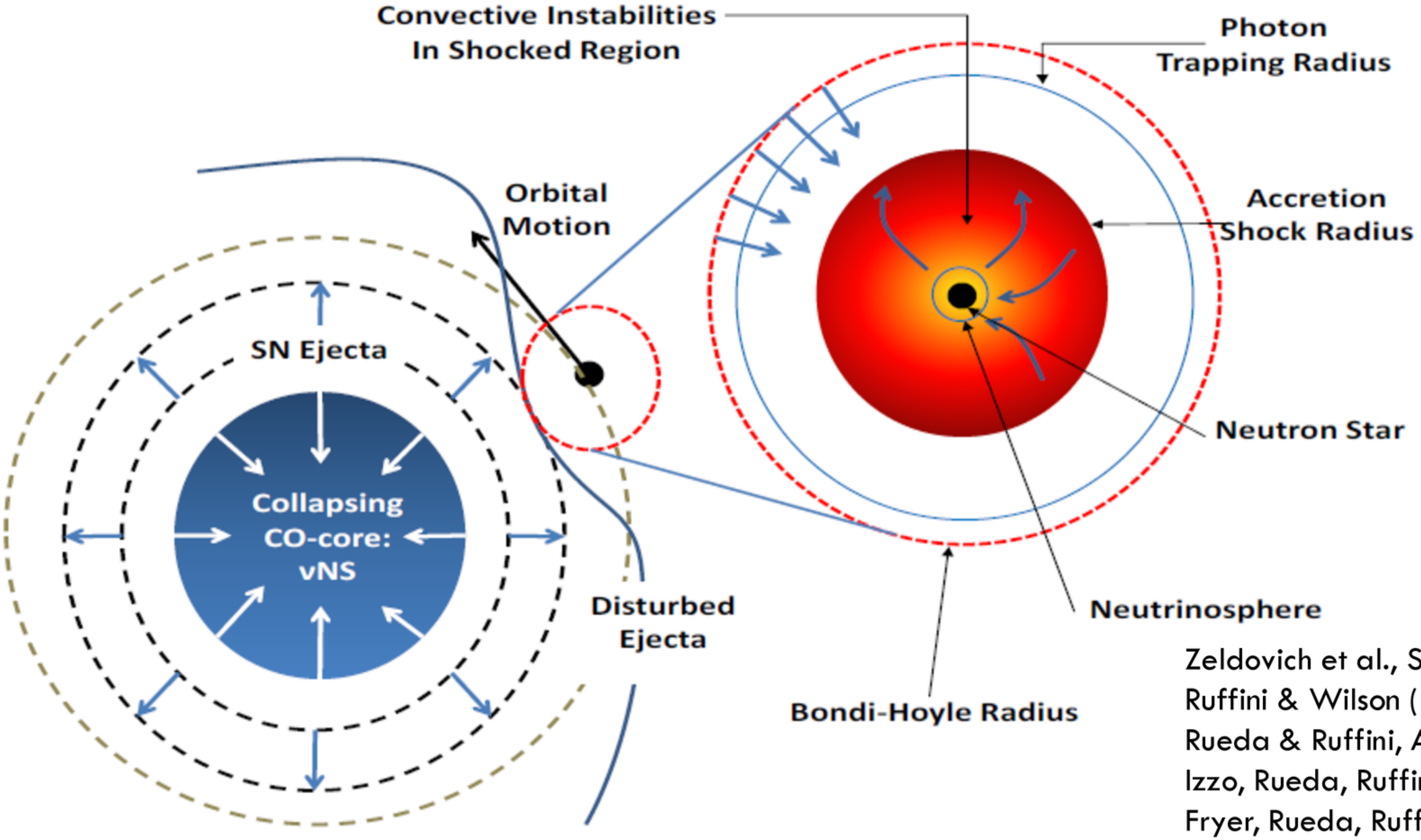
[1] Ruffini, R., Muccino, M., Bianco, C. L., et al. 2014, A&A, 565, L10
[2] Ruffini, R., Wang, Y., Kovacevic, M., et al. 2014, ArXiv e-prints
[3] Xu, D., de Ugarte Postigo, A., Leloudas, G., et al. 2013, ApJ, 776, 98
[4] Bloom, J. S., Perley, D. A., & Chen, H. W. 2006, 5826, 1
[5] Pisani, G. B., Izzo, L., Ruffini, R., et al. 2013, A&A, 552, L5
[6] Grupe, D., Gronwall, C., Wang, X.-Y., et al. 2007, ApJ, 662, 443
[7] Cano, Z., Bersier, D., Guidorzi, C., et al. 2011, MNRAS, 413, 669

Episode 3 of GRB 130427A



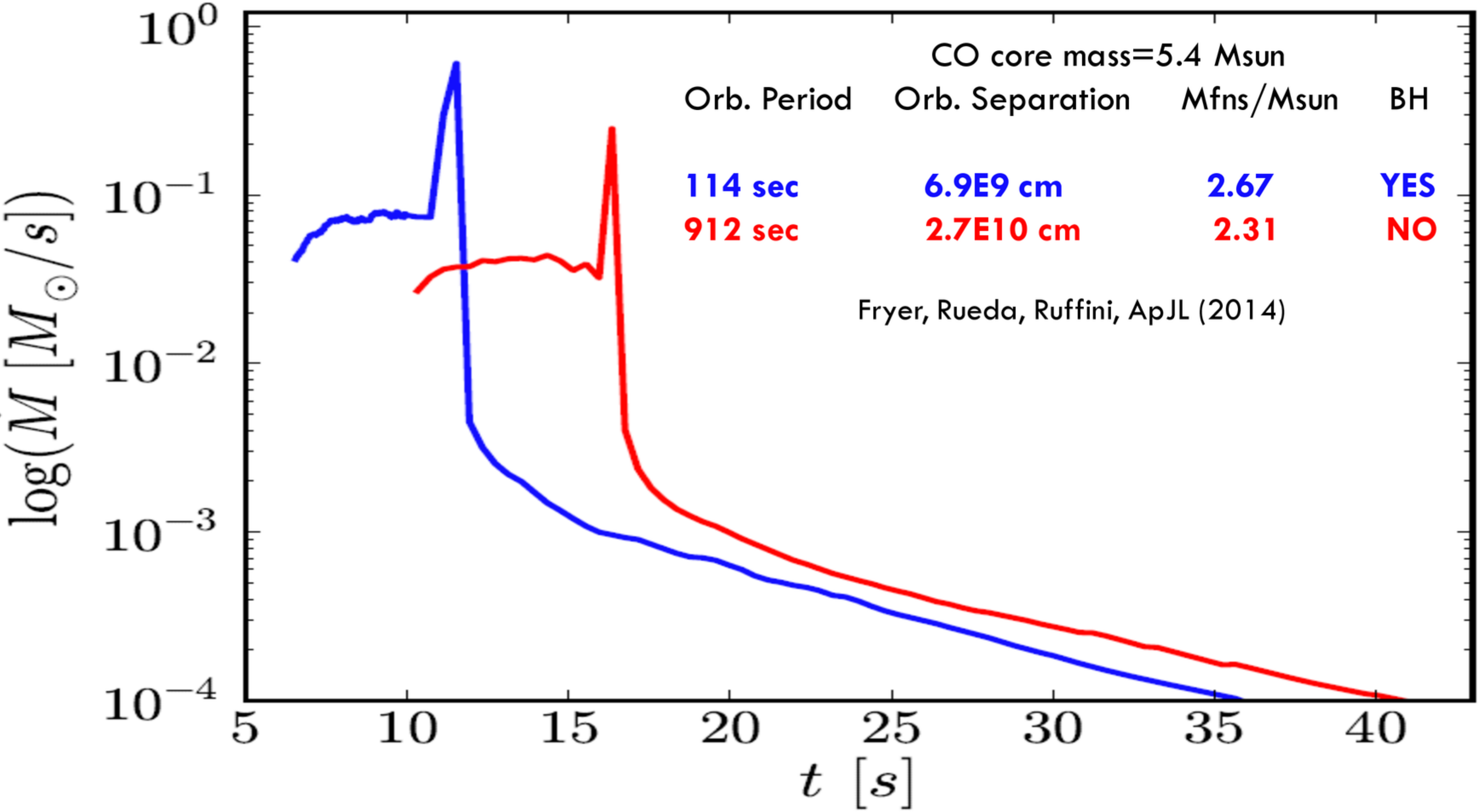
Ruffini, R., Wang, Y., Enderli, M., et al., ApJ, in press.

Hypercritical Accretion, Binary-Driven HNe, and IGC



Zeldovich et al., Sov. Astron. (1972)
Ruffini & Wilson (1973)
Rueda & Ruffini, ApJL (2012)
Izzo, Rueda, Ruffini, A&AL (2012)
Fryer, Rueda, Ruffini, ApJL (2014)

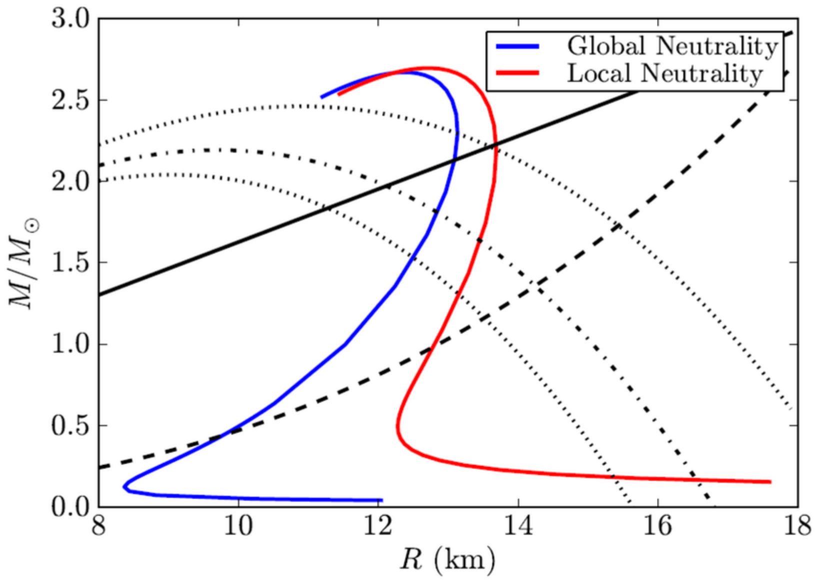
Hypercritical Accretion, Binary-Driven HNe, and IGC

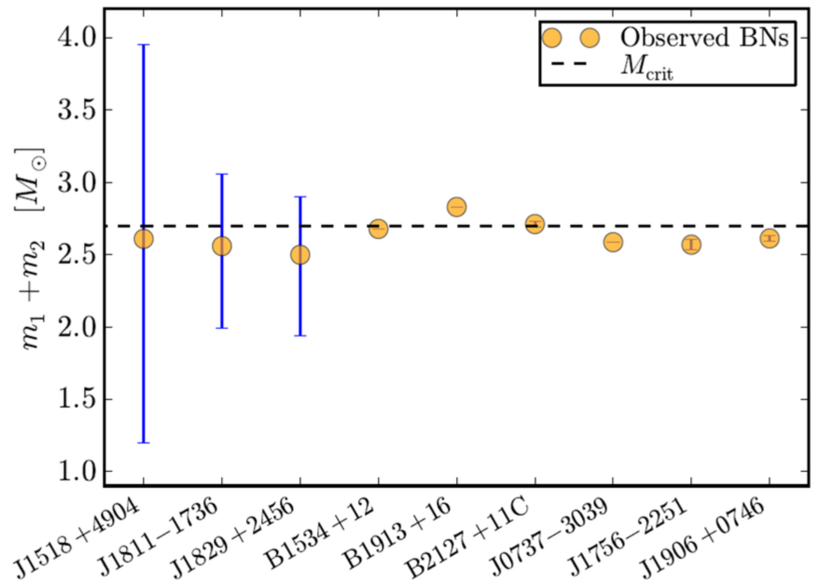


NS Critical Mass and Observed BNS Masses

NS mass ~1.3 Msun
BNS Mass ~ 2.6 Msun
NS critical mass ~ 2.7 Msun

Iff Mbns > Mcrit
BH





Belvedere, Boshkayev, Rueda, Ruffini, NPA (2014)
Belvedere, Pugliese, Rueda, Ruffini, NPA (2012)

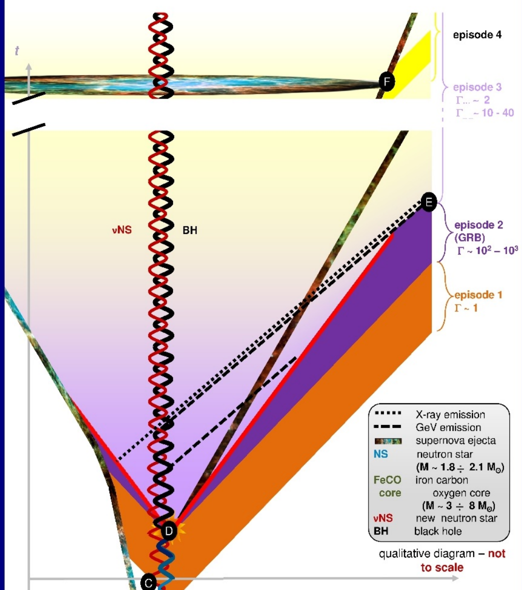
Masses taken from:
Zhang et al. PRC (2011)
Antoniadis, arXiv 2014

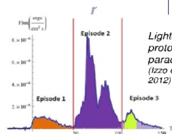
Long GRBs

$E_{iso} > 10^{52}$ erg

Binary driven hypernova (BdHN)

Signature Scaled X-ray afterglow / Supernova / Long-lived GeV component / Hard spectrum ($E_p > 100$ keV)



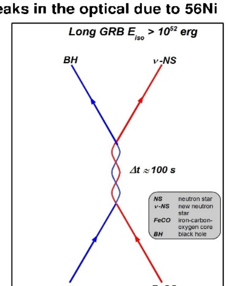


Lightcurve of GRB 090618, prototype of the IGC paradigm (Izzo et al. 2012, Rueda & Ruffini 2012)

Refs. *Ruffini et al. 2001, 2007, 2014b, Pisani et al. 2013, Fryer et al. 2014*

The initial configuration is composed of an evolved, likely FeCO stellar core and a companion neutron star.

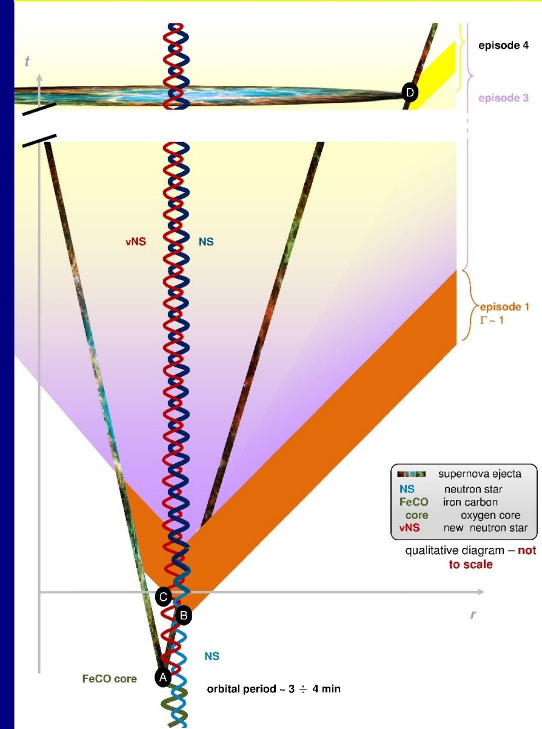
- **A** **The core undergoes a supernova and creates a new neutron star and its remnant.**
- **B** **Beginning of the accretion of the SN ejecta onto the companion neutron star, emitting episode 1.**
- **C** **The new neutron star interacts with emission from the episode 1.**
- **D** **Accretion of the SN ejecta on the companion neutron star induces the black hole formation and the emission of the e^+/e^- fireshell.**
- **E** **Transition point between Episode 2 (ultra-relativistic) and Episode 3 (mildly relativistic)**
- **F** **After t ~10 (1+z) days in observer frame, the supernova peaks in the optical due to 56Ni decay.**



$E_{iso} < 10^{52}$ erg

Hypernova

Signature X-ray afterglow / Supernova / Soft spectrum ($E_p < 100$ keV)



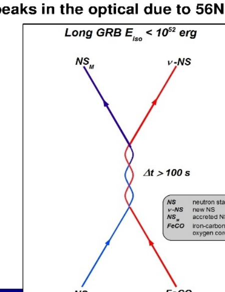
Refs. *Ruffini et al. 2014b*

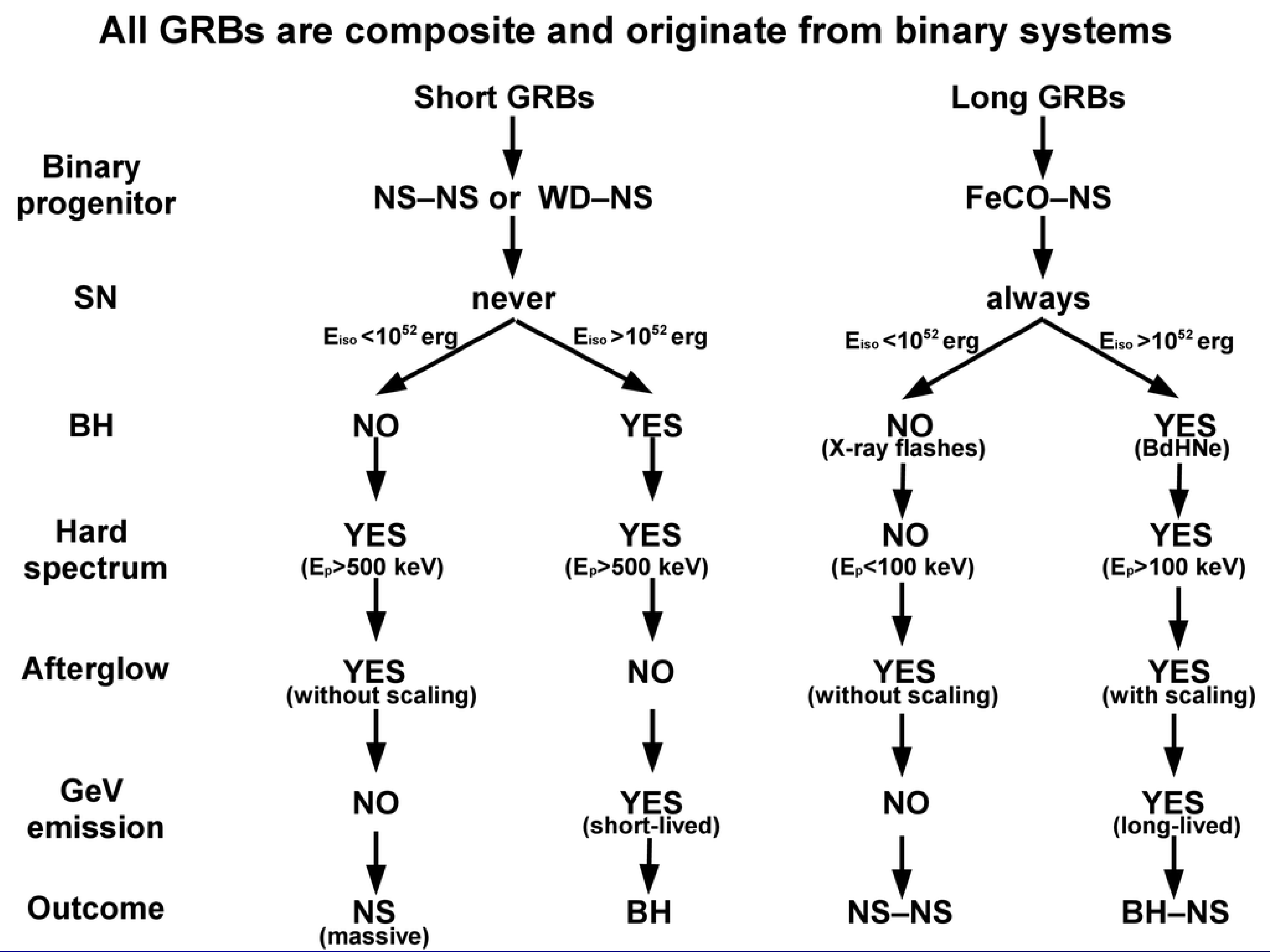
The initial configuration is composed of an evolved, likely FeCO stellar core and a companion neutron star.

- **A** **The core undergoes a supernova and creates a new neutron star and its remnant.**
- **B** **Beginning of the accretion of the SN ejecta onto the companion neutron star, emitting episode 1.**
- **C** **The new neutron star interacts with emission from the episode 1.**

The companion neutron star *does* not accrete enough matter to induce black hole formation: no episode 2 is emitted.

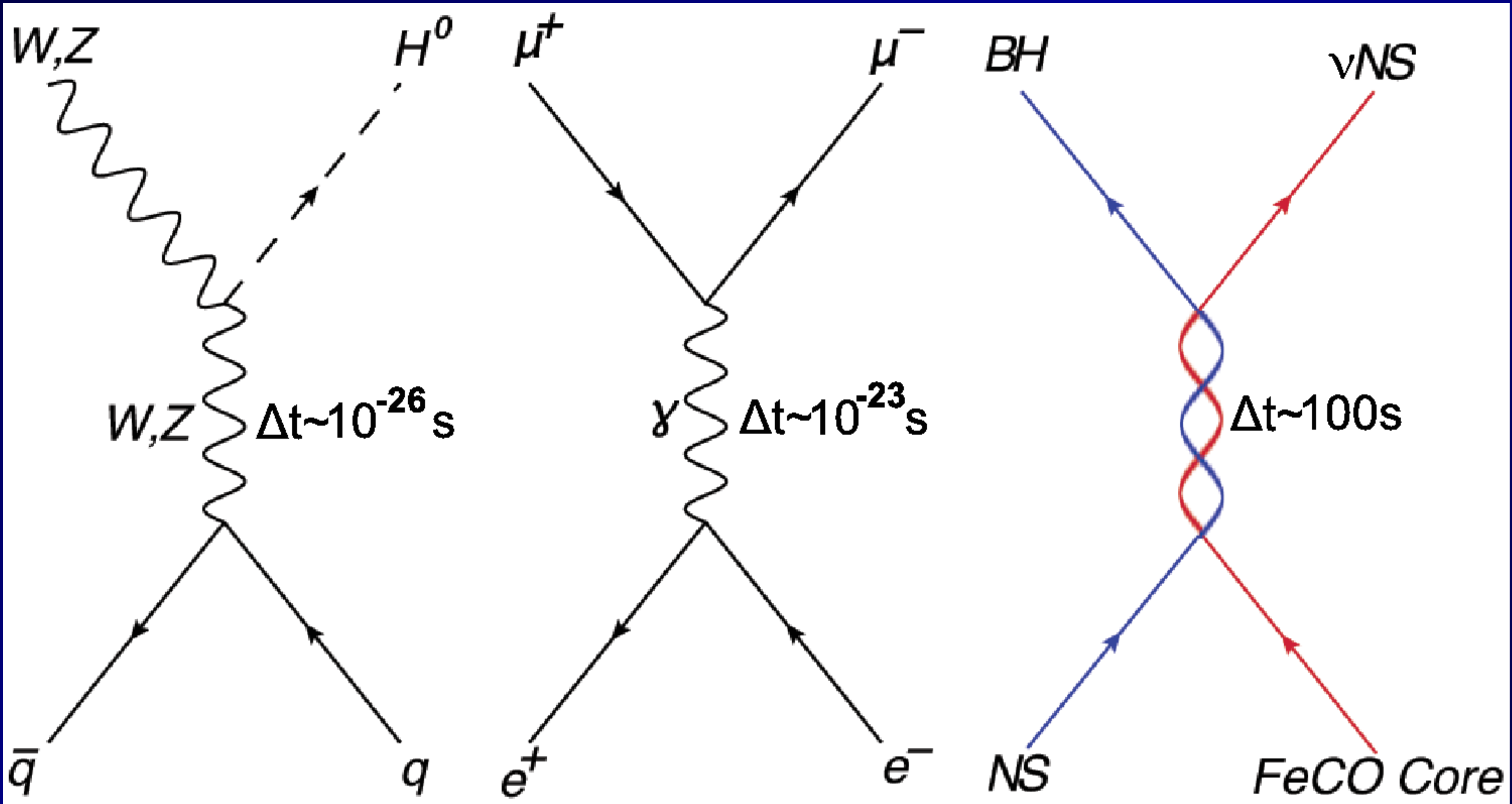
- **D** **After t ~10 (1+z) days in observer frame, the supernova peaks in the optical due to 56Ni decay.**





Muccino, et al., ApJ, submitted

Ruffini, R., Wang, Y., et al., ApJ, in press


W,Z
H0
W,Z
Δt~10-26s
q̄
q
μ+
μ−
γ
Δt~10-23s
e+
e−
BH
νNS
Δt~100s
NS
FeCO Core

The IGC paradigm for long and short GRBs

- **GRBs are composed by up to 4 different Episodes, each one characterized by specific astrophysical processes and Lorentz gamma factors (from gamma ~ 1 up to gamma ~ 10^3).**

- **Both short and long GRBs with $E_{iso} > 10^{52}$erg originate from a gravitational collapse to a black hole ($M > M_{crit} \sim 2.6M_{\odot}$) and can have GeV emission.**

  Long GRBs → BdHNe

  Short GRBs → Massive BNS mergers

- **Both short and long GRBs with $E_{iso} < 10^{52}$erg *do not* form black holes and have *no* GeV emission**

  Long GRBs → X-Ray Flashes - Hypernovae

  Short GRBs → Edo Berger's sources