

Binary-driven hypernovae as multimesseger astrophysical systems

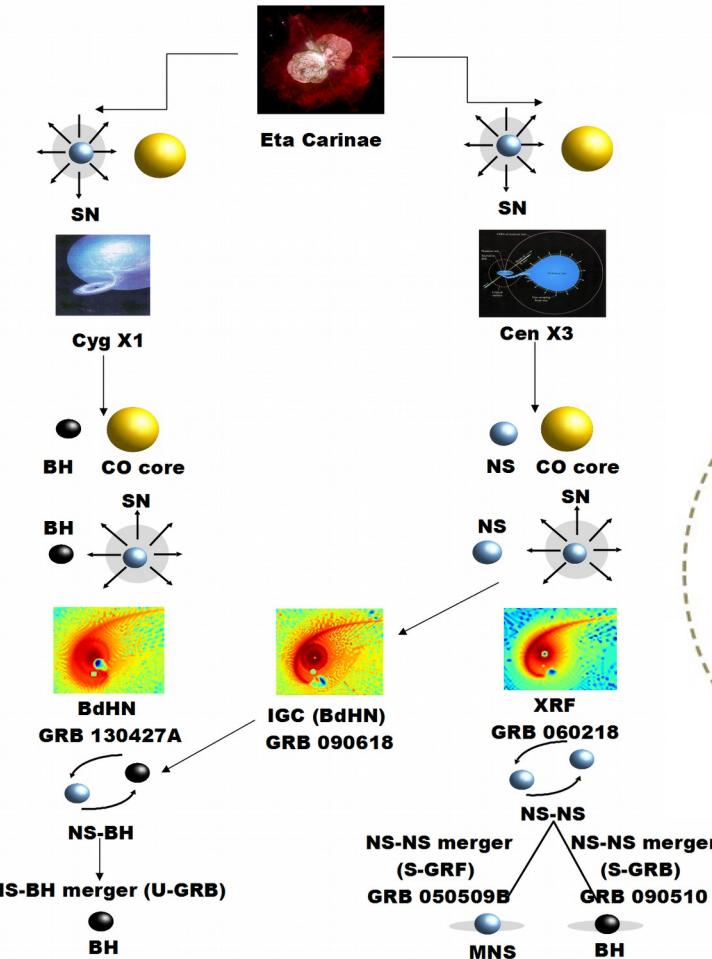
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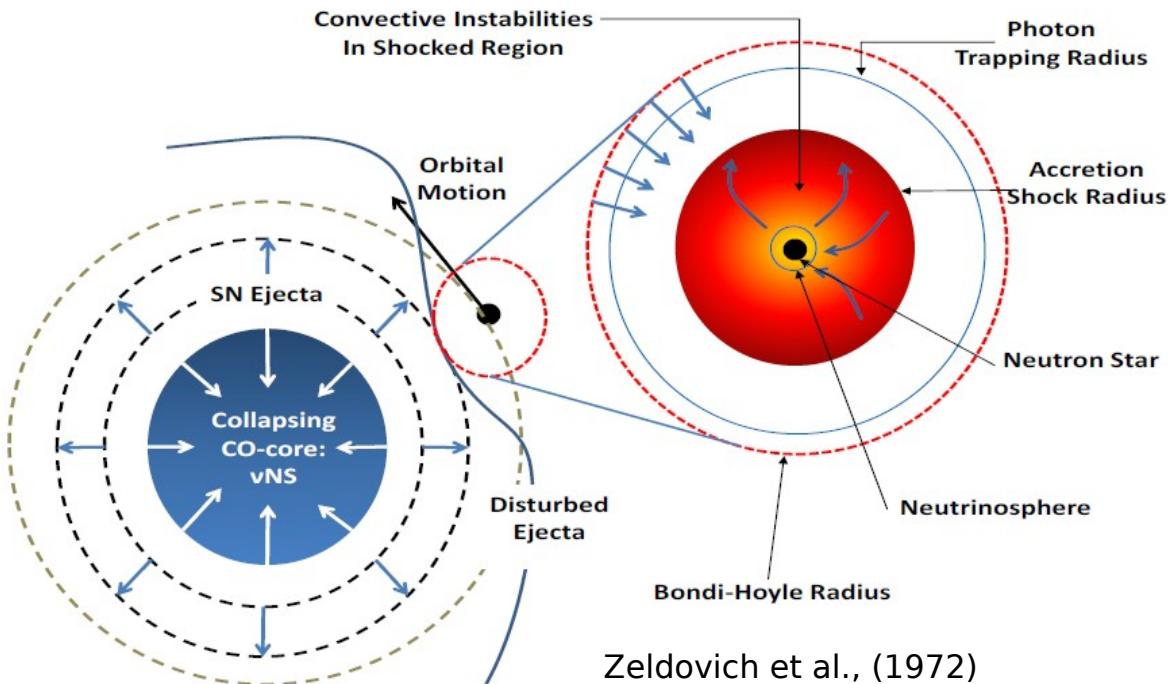
On behalf of a larger collaboration
(also present here: L. Becerra, R. Ruffini and Y. Wang)

THESEUS Workshop
October 5-6, Naples, Italy 2017

A common evolutionary scenario for short and long GRBs



Binary-driven hypernovae (BdHNe)



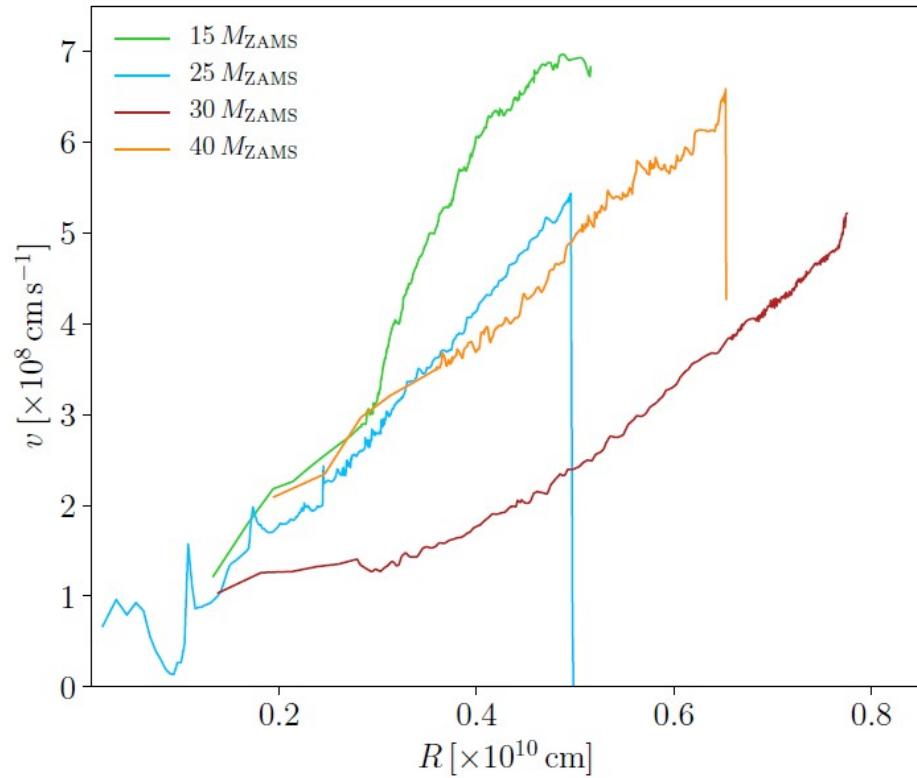
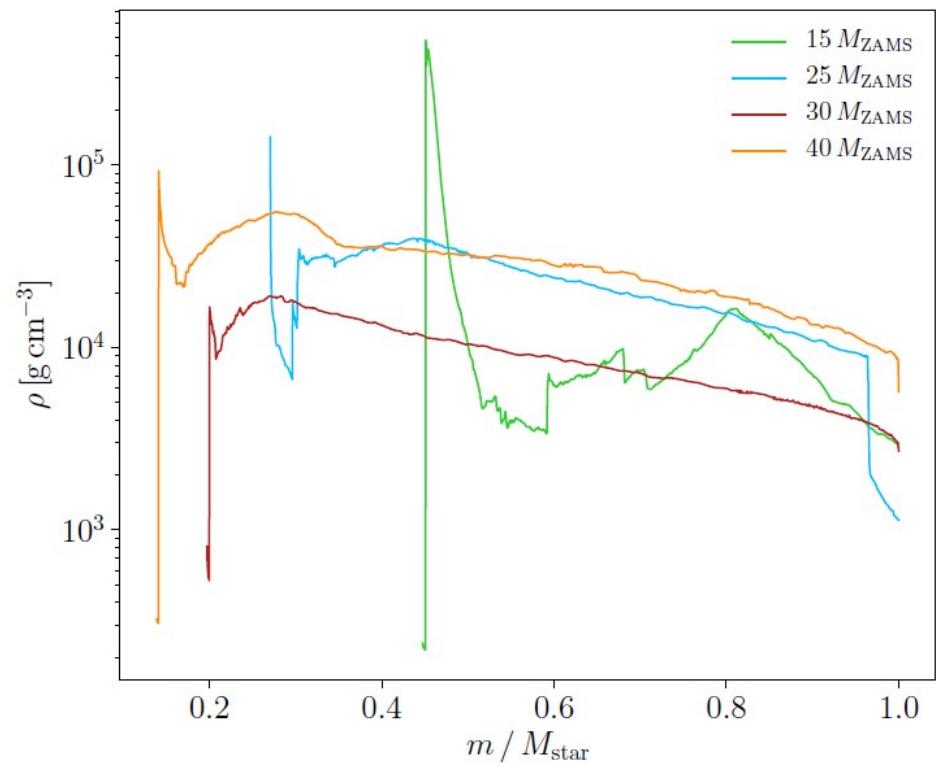
Zeldovich et al., (1972)
 Ruffini & Wilson (1973)
 Rueda & Ruffini, (2012)
 Fryer, Rueda, Ruffini, ApJL (2014)

Short and long GRB sub-classes

Table 1. Summary of the astrophysical aspects of the different GRB sub-classes and of their observational properties. In the first four columns we indicate the GRB sub-classes and their corresponding *in-states* and the *out-states*. In columns 5–8 we list the ranges of $E_{\text{p},i}$ and E_{iso} (rest-frame 1– 10^4 keV), $E_{\text{iso,X}}$ (rest-frame 0.3–10 keV), and $E_{\text{iso,GeV}}$ (rest-frame 0.1–100 GeV). Columns 9 and 10 list, for each GRB sub-class, the maximum observed redshift and the local observed rate ρ_{GRB} obtained in Ruffini et al. (2016b).

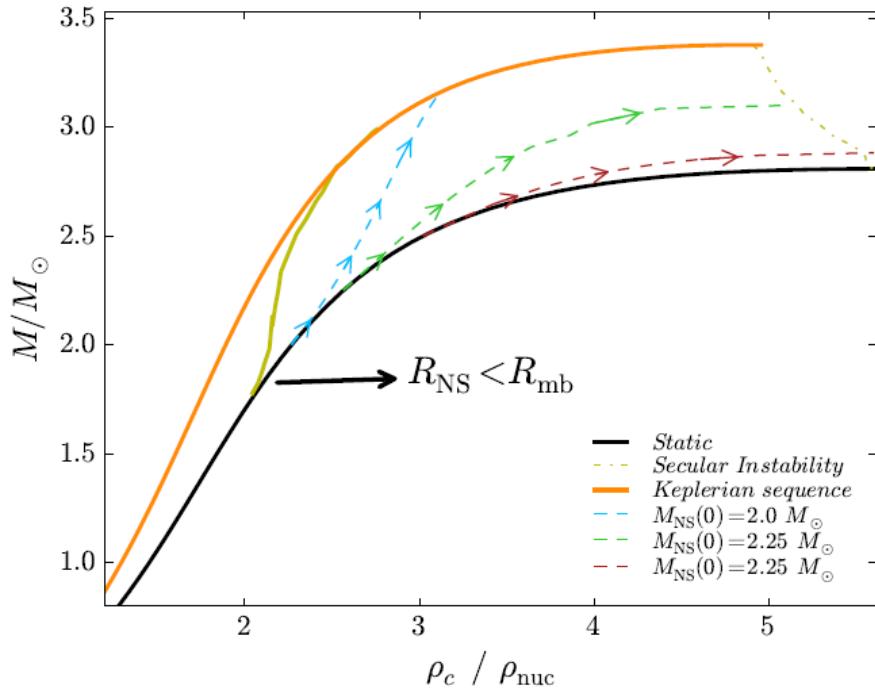
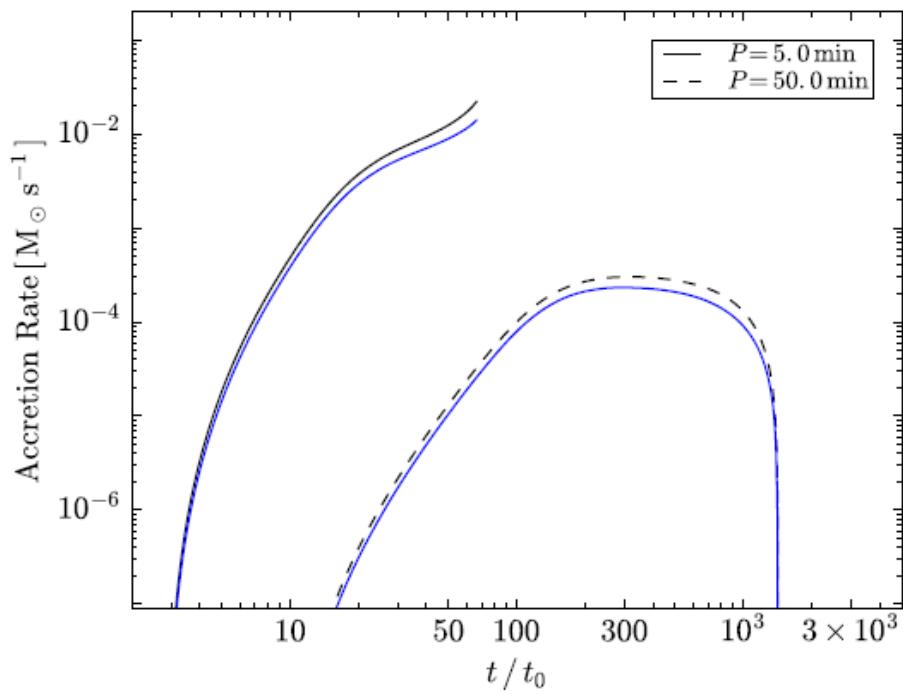
	Sub-class	<i>In-state</i>	<i>Out-state</i>	$E_{\text{p},i}$ (MeV)	E_{iso} (erg)	$E_{\text{iso,X}}$ (erg)	$E_{\text{iso,GeV}}$ (erg)	z_{max}	ρ_{GRB} (Gpc $^{-3}$ yr $^{-1}$)
I	XRFs	CO _{core} -NS	ν NS-NS	$\lesssim 0.2$	$\sim 10^{48}\text{--}10^{52}$	$\sim 10^{48}\text{--}10^{51}$	—	1.096	100^{+45}_{-34}
II	BdHNe	CO _{core} -NS	ν NS-BH	$\sim 0.2\text{--}2$	$\sim 10^{52}\text{--}10^{54}$	$\sim 10^{51}\text{--}10^{52}$	$\lesssim 10^{53}$	9.3	$0.77^{+0.09}_{-0.08}$
III	BH-SN	CO _{core} -BH	ν NS-BH	$\gtrsim 2$	$> 10^{54}$	$\sim 10^{51}\text{--}10^{52}$	$\gtrsim 10^{53}$	9.3	$\lesssim 0.77^{+0.09}_{-0.08}$
IV	S-GRFs	NS-NS	MNS	$\lesssim 2$	$\sim 10^{49}\text{--}10^{52}$	$\sim 10^{49}\text{--}10^{51}$	—	2.609	$3.6^{+1.4}_{-1.0}$
V	S-GRBs	NS-NS	BH	$\gtrsim 2$	$\sim 10^{52}\text{--}10^{53}$	$\lesssim 10^{51}$	$\sim 10^{52}\text{--}10^{53}$	5.52	$(1.9^{+1.8}_{-1.1}) \times 10^{-3}$
VI	U-GRBs	ν NS-BH	BH	$\gtrsim 2$	$> 10^{52}$	—	—	—	$\gtrsim 0.77^{+0.09}_{-0.08}$
VII	GRFs	NS-WD	MNS	$\sim 0.2\text{--}2$	$\sim 10^{51}\text{--}10^{52}$	$\sim 10^{49}\text{--}10^{50}$	—	2.31	$1.02^{+0.71}_{-0.46}$

Supernova ejecta at t=0



Initial conditions from Los Alamos core-collapse SN code

NS evolution up to the instability point



Becerra, Cipolletta, Fryer, Rueda, Ruffini, ApJ 2015; arXiv: 1505.07580
ApJ 2016; arXiv:1606.02523

Some numbers related to the neutrino emission

Becerra, Guzzo, Rueda, Ruffini, Uribe, Torres, submitted

\dot{M} ($M_\odot \text{ s}^{-1}$)	ρ (g cm^{-3})	$k_B T$ (MeV)	η_{e^\mp}	$n_{e^-} - n_{e^+}$ (cm^{-3})	$k_B T_{\nu\bar{\nu}}$ (MeV)	$\langle E_\nu \rangle$ (MeV)	$F_{\nu_e, \bar{\nu}_e}^C$ ($\text{cm}^{-2} \text{s}^{-1}$)	$F_{\nu_x, \bar{\nu}_x}^C$ ($\text{cm}^{-2} \text{s}^{-1}$)	$n_{\nu_e \bar{\nu}_e}^C$ (cm^{-3})	$n_{\nu_x \bar{\nu}_x}^C$ (cm^{-3})	$\sum_i n_{\nu_i \bar{\nu}_i}^C$ (cm^{-3})
10^{-8}	1.46×10^6	1.56	∓ 0.325	4.41×10^{29}	1.78	6.39	4.17×10^{36}	1.79×10^{36}	2.78×10^{26}	1.19×10^{26}	3.97×10^{26}
10^{-7}	3.90×10^6	2.01	∓ 0.251	1.25×10^{30}	2.28	8.24	3.16×10^{37}	1.36×10^{37}	2.11×10^{27}	9.00×10^{26}	3.01×10^{27}
10^{-6}	1.12×10^7	2.59	∓ 0.193	3.38×10^{30}	2.93	10.61	2.40×10^{38}	1.03×10^{38}	1.60×10^{28}	6.90×10^{27}	2.29×10^{28}
10^{-5}	3.10×10^7	3.34	∓ 0.147	9.56×10^{30}	3.78	13.69	1.84×10^{39}	7.87×10^{38}	1.23×10^{29}	5.20×10^{28}	1.75×10^{29}
10^{-4}	8.66×10^7	4.30	∓ 0.111	2.61×10^{31}	4.87	17.62	1.39×10^{40}	5.94×10^{39}	9.24×10^{29}	3.96×10^{29}	1.32×10^{30}
10^{-3}	2.48×10^8	5.54	∓ 0.082	7.65×10^{31}	6.28	22.70	1.04×10^{41}	4.51×10^{40}	7.00×10^{30}	3.00×10^{30}	1.00×10^{31}
10^{-2}	7.54×10^8	7.13	∓ 0.057	2.27×10^{32}	8.08	29.22	7.92×10^{41}	3.39×10^{41}	5.28×10^{31}	2.26×10^{31}	7.54×10^{31}

$$T_{\text{acc}} \approx \left(\frac{3P_{\text{shock}}}{4\sigma/c} \right)^{1/4} = \left(\frac{7}{8} \frac{\dot{M}_{\text{acc}} v_{\text{acc}} c}{4\pi R_{\text{NS}}^2 \sigma} \right)^{1/4}$$

$$\epsilon_{e^- e^+} \approx 8.69 \times 10^{30} \left(\frac{k_B T}{1 \text{ MeV}} \right)^9 \text{ MeV cm}^{-3} \text{ s}^{-1}$$

$$\Delta r_\nu = \frac{\epsilon_{e^- e^+}}{\nabla \epsilon_{e^- e^+}} = \frac{\Delta r_{\text{ER}}}{9} \approx 0.08 R_{\text{NS}}$$

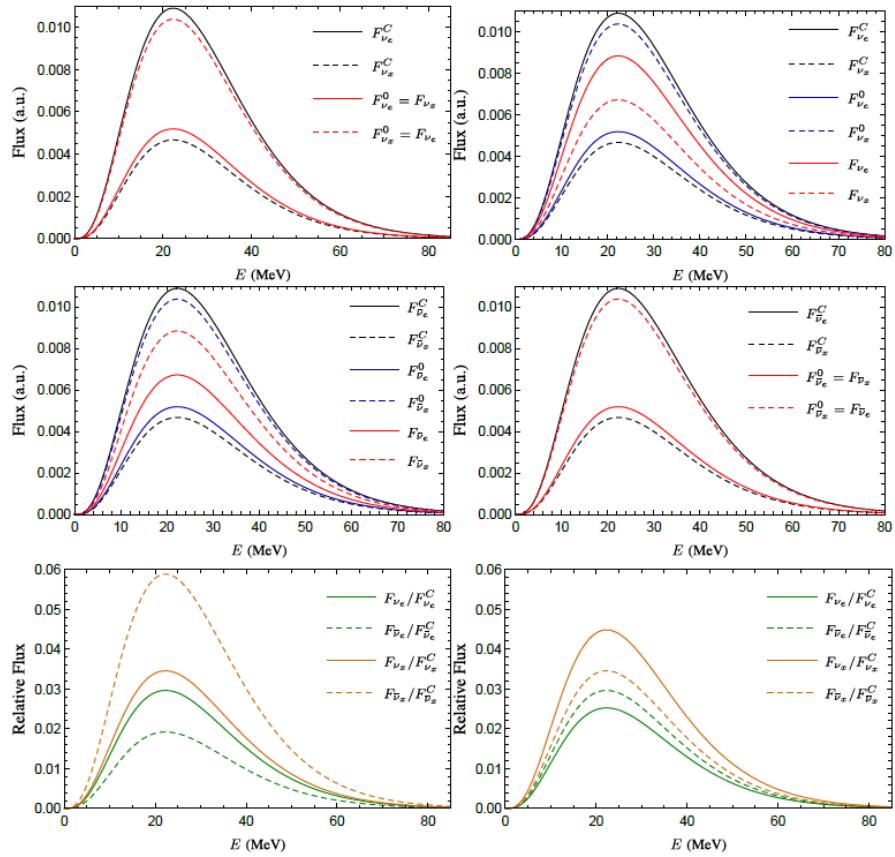
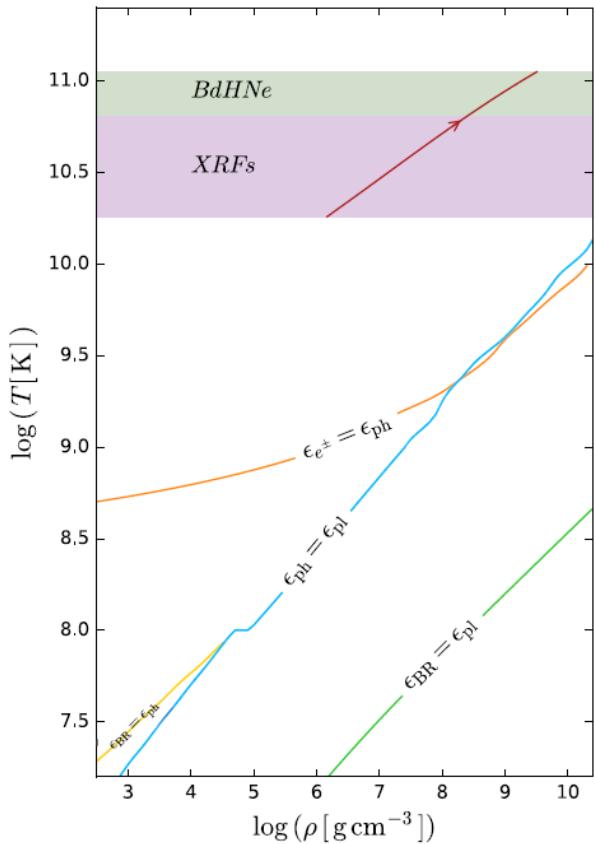
$$L_\nu \approx 4\pi R_{\text{NS}}^2 \Delta r_\nu \epsilon_{e^- e^+} \approx 10^{48} - 10^{57} \text{ MeV s}^{-1}$$

$$n_{\nu_i}^C = n_{\bar{\nu}_i}^C, \quad F_{\nu_i}^C = F_{\bar{\nu}_i}^C \quad \forall i \in \{e, \mu, \tau\}$$

$$\frac{n_{\nu_e}^C}{n_{\nu_x}^C} = \frac{n_{\bar{\nu}_e}^C}{n_{\bar{\nu}_x}^C} = \frac{F_{\nu_e}^C}{F_{\nu_x}^C} = \frac{F_{\bar{\nu}_e}^C}{F_{\bar{\nu}_x}^C} \approx \frac{7}{3}.$$

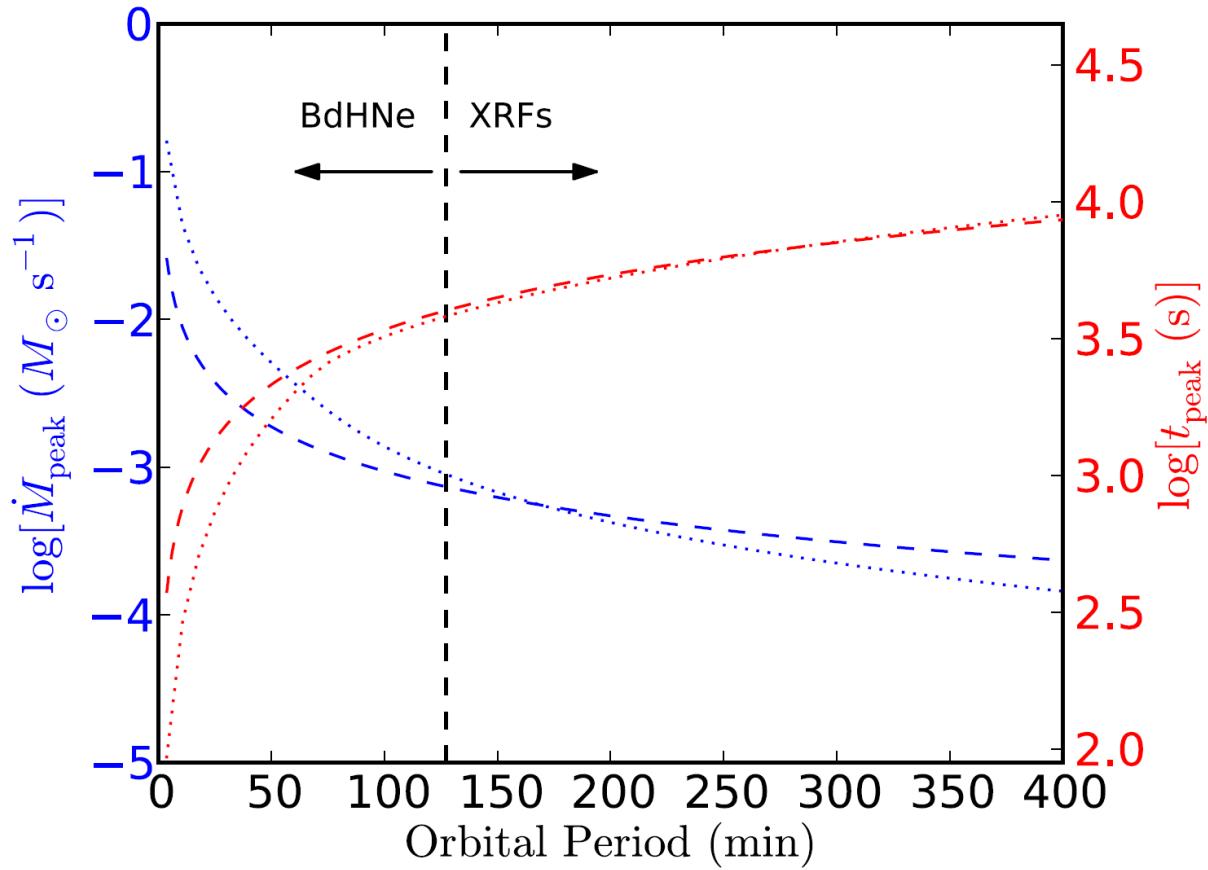
$$\frac{\varepsilon_e^0}{\varepsilon_x^0} = \frac{\varepsilon_e^0}{\varepsilon_\mu^0 + \varepsilon_\tau^0} = \frac{C_{+,e}^2}{C_{+,\mu}^2 + C_{+,\tau}^2} \approx \frac{7}{3}$$

T-rho at NS surface - neutrino production

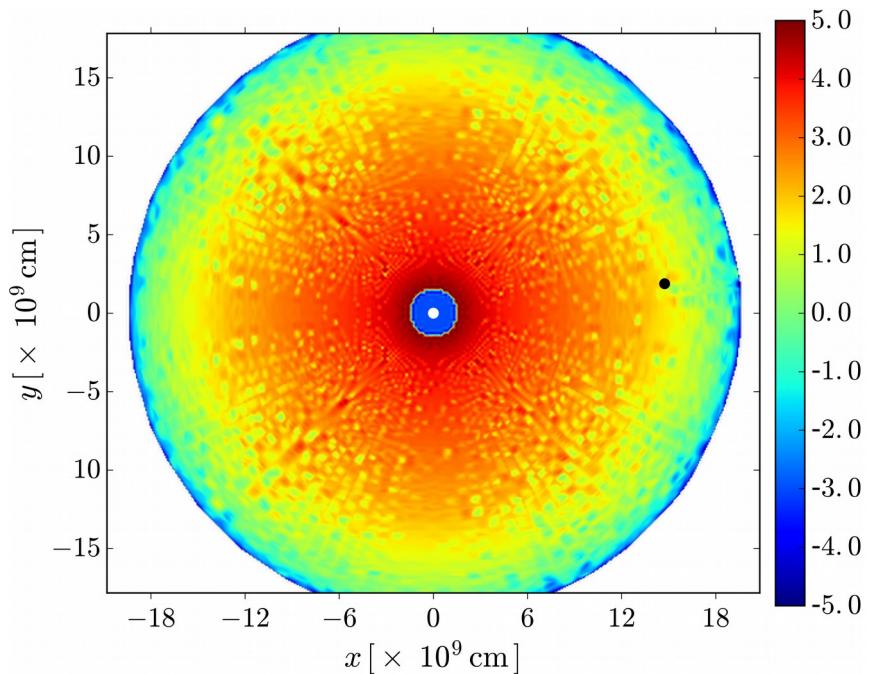
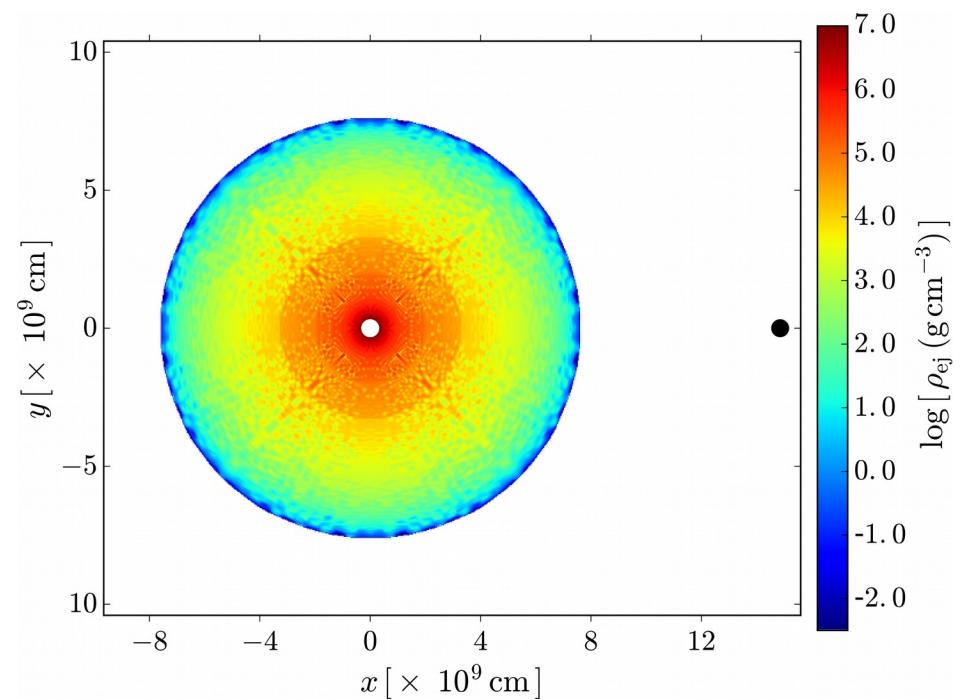


X-ray Flashes - BdHNe Separatrix

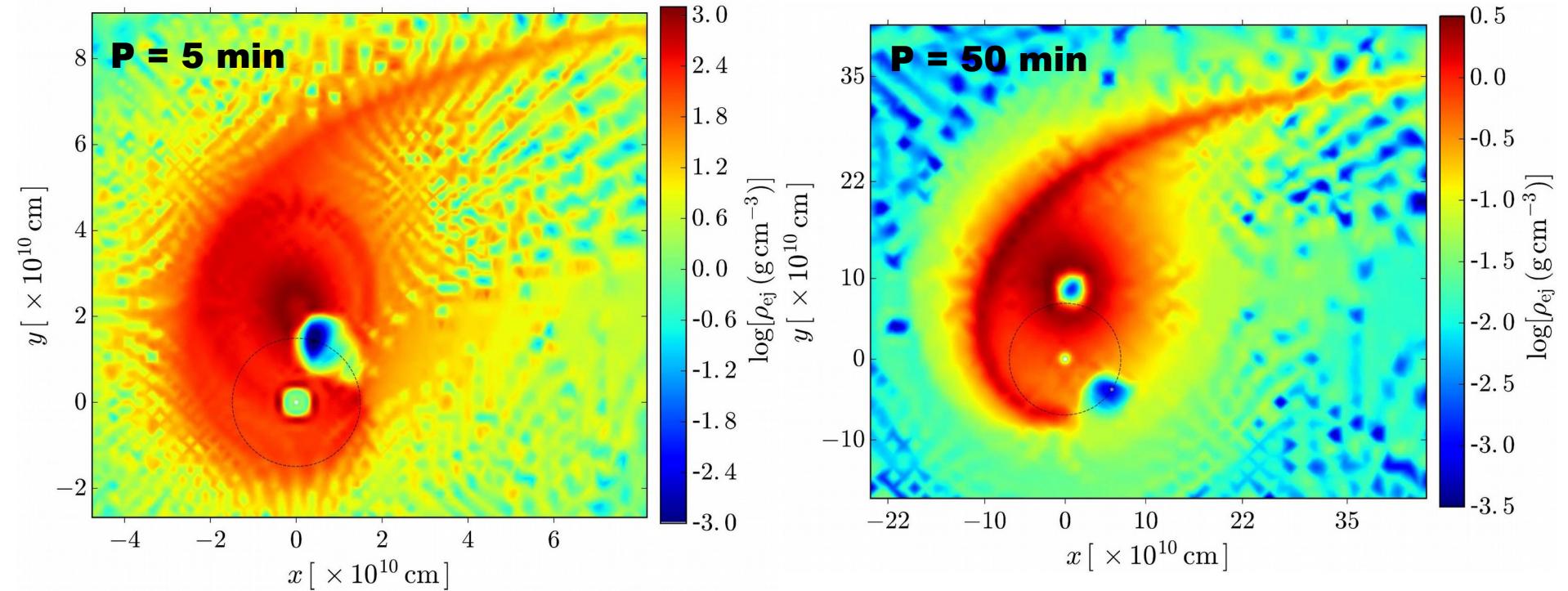
(Becerra, Bianco, Fryer, Rueda, Ruffini, ApJ 2016; arXiv:1606.02523)



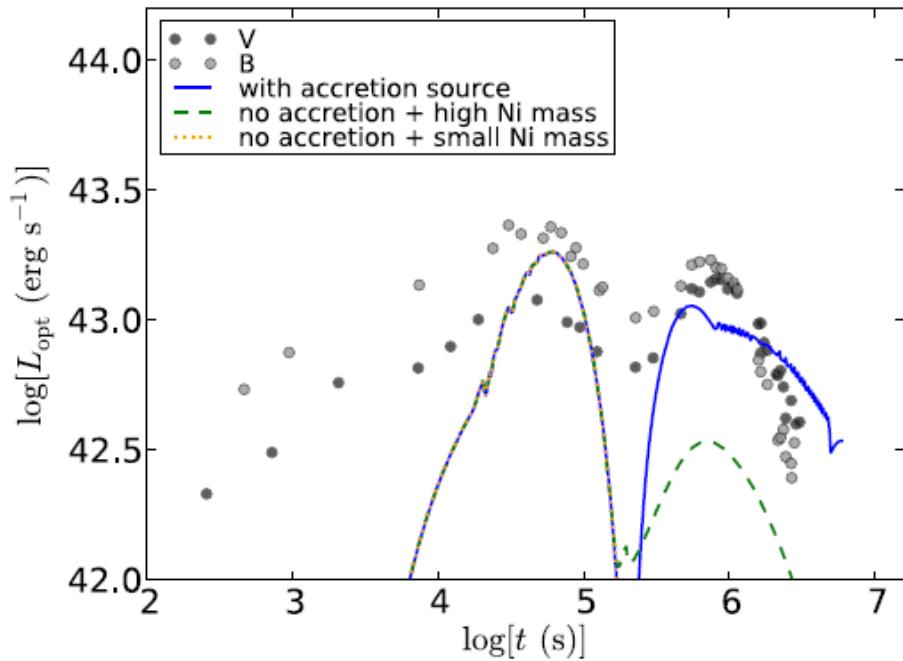
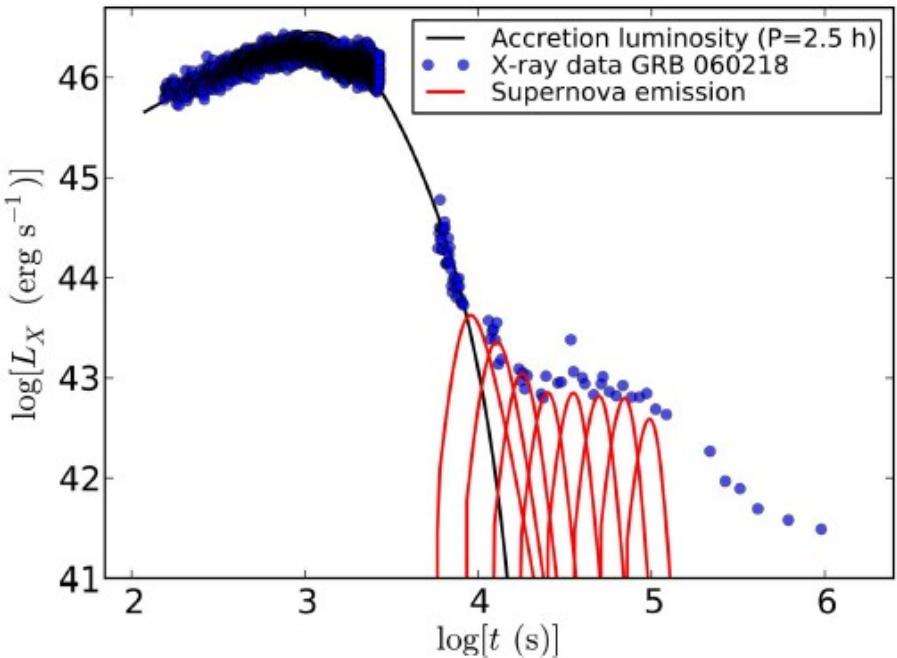
Visualizing the IGC process



X-ray Flashes and BdHNe

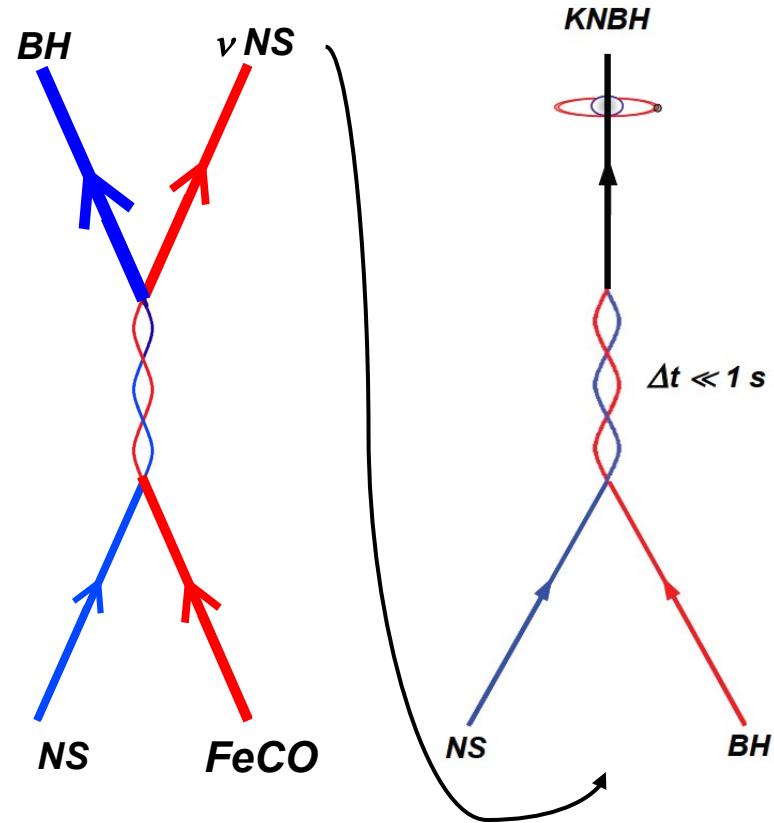
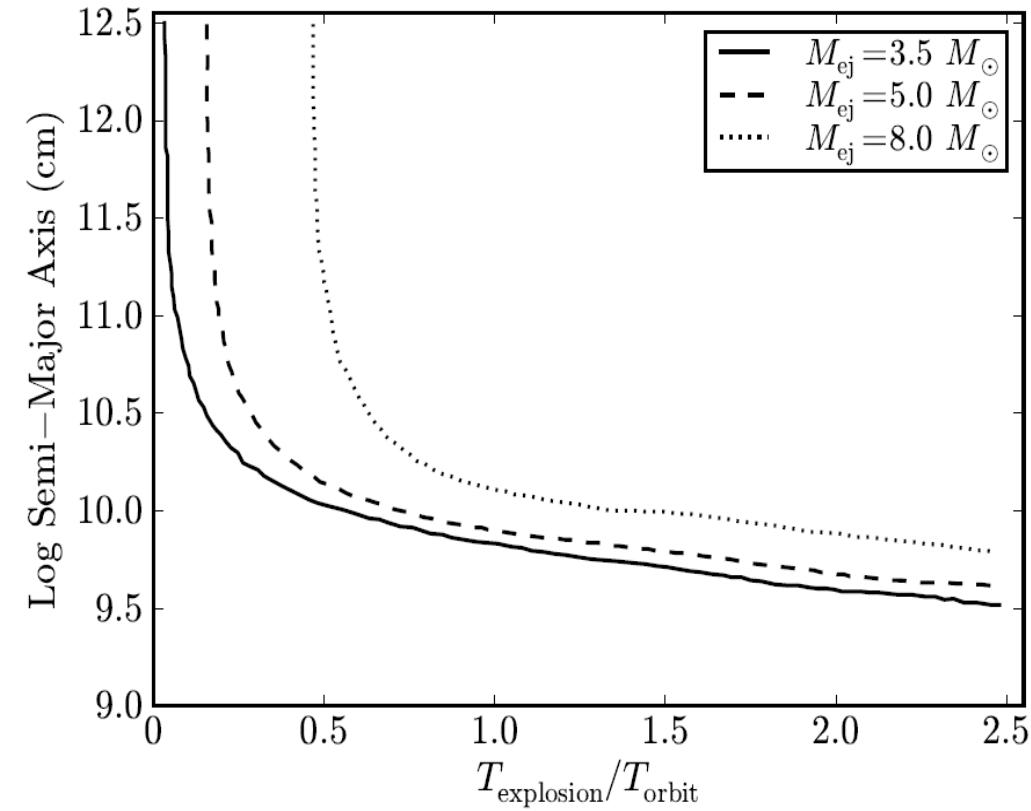


An XRF example (GRB 060218): X-rays and optical emission

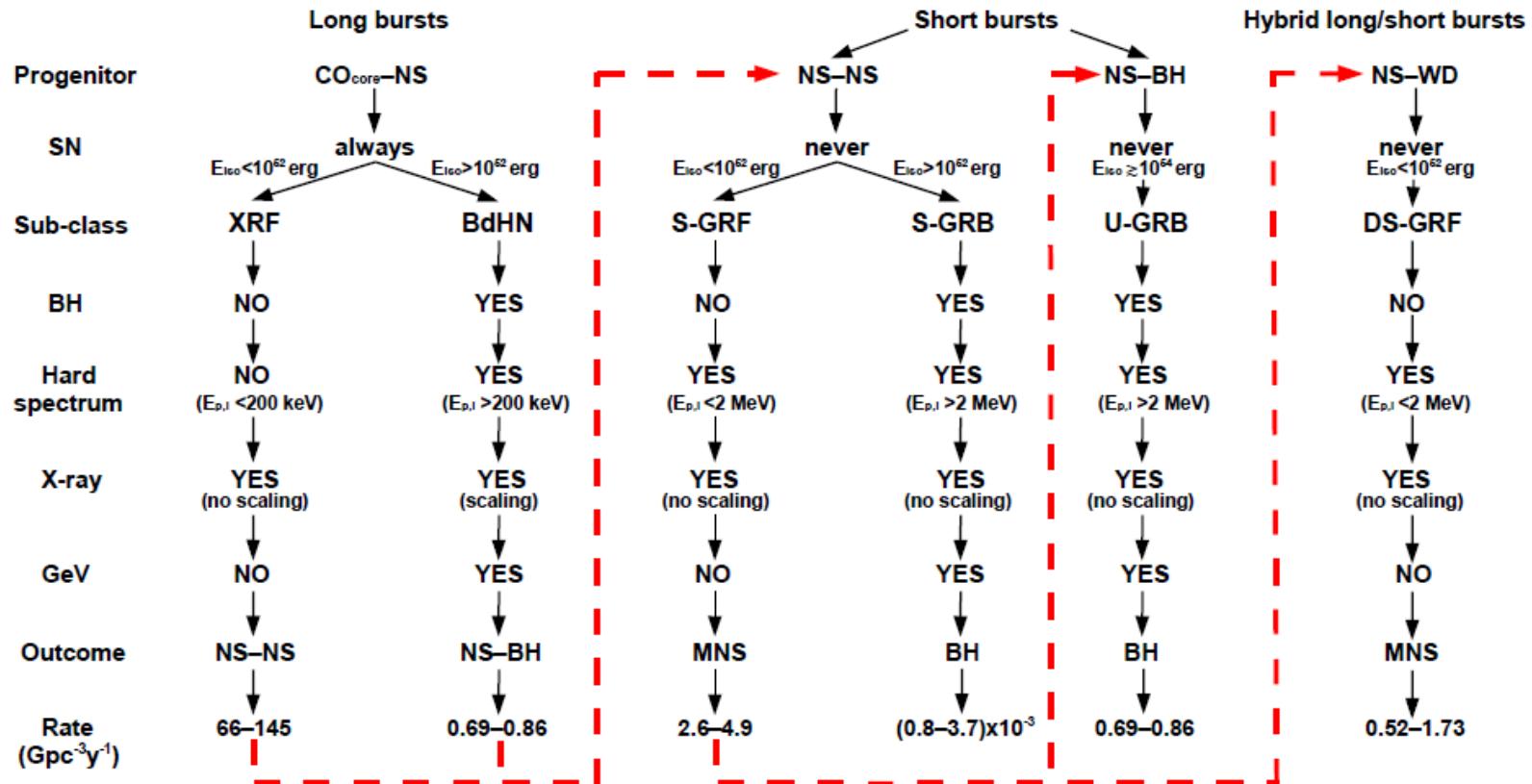


NS-BH binaries produced by BdHNe

(Fryer, Oliveira, Rueda, Ruffini, Phys. Rev. Lett 2015; arXiv:1505.02809)



Short and long GRB subclasses



GW detectability (aLIGO-eLISA-Bars)

Inspiral/merger

Solid/dots:

S-GRF: $1.4+1.4$

$f_{\text{mgr}} = 1.2 \text{ kHz}$

$z=0.11, d = 508 \text{ Mpc}$

$D_{\text{gw}} = 168 - 475 \text{ Mpc}$

Short-dashed/star :

S-GRB: $2.0+2.0$

$f_{\text{mgr}} = 1.43 \text{ kHz}$

$z=0.9, d = 5.8 \text{ Gpc}$

$D_{\text{gw}} = 227 - 640 \text{ Mpc}$

Dotted/triangle:

U-GRB: $1.5+3.0$

$f_{\text{mgr}} = 1 \text{ kHz}$

$z=0.17, d = 804 \text{ Mpc}$

$D_{\text{gw}} = 236 - 666 \text{ Mpc}$

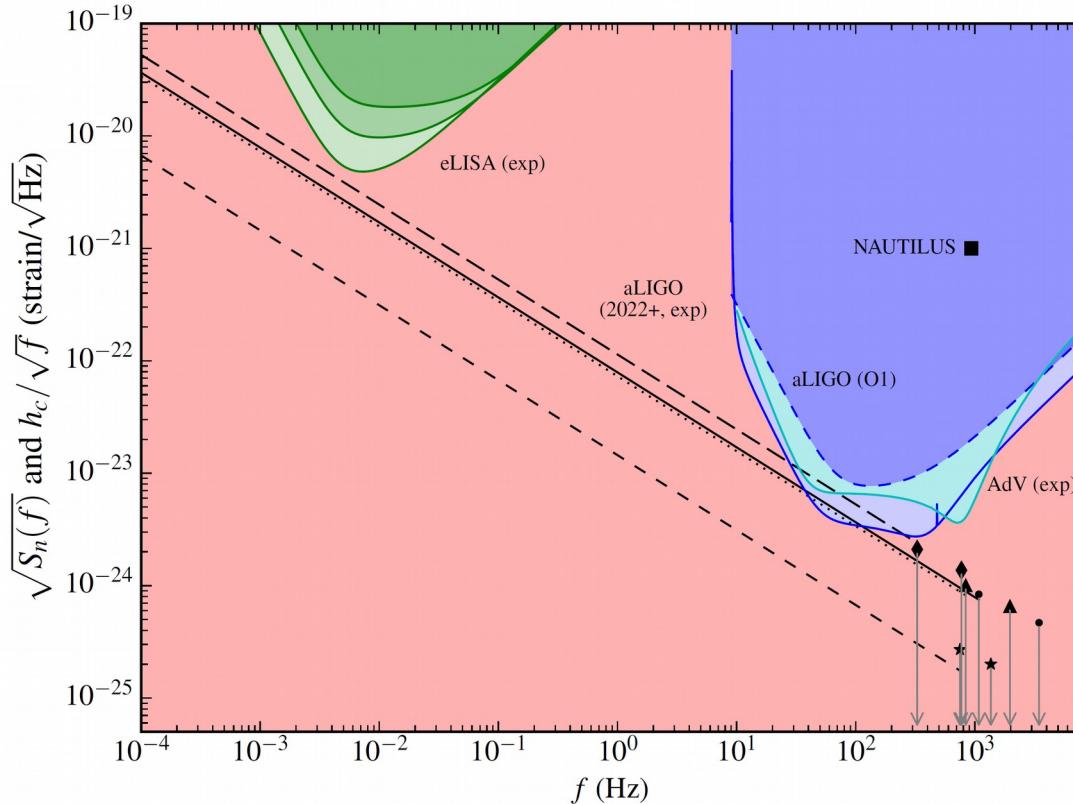
Long-dashed/diamond:

U-GRB: $1.5+10$

$f_{\text{mgr}} = 1 \text{ kHz}$

$z=0.17, d = 804 \text{ Mpc}$

$D_{\text{gw}} = 236 - 666 \text{ Mpc}$



Ruffini, Rodriguez, Muccino, Rueda et al., arXiv: 1602.03545

aLIGO sensitivity from Abbott et al., Liv. Rev. Rel. 19 (2016)

eLISA sensitivity from Klein et al. PRD 93, 024003 (2016)

NAUTILUS sensitivity from Astone et al., CQG 25, 114048 (2008)

GW CONCLUSION:

$$\dot{N}_{\text{GW}} = \rho_{\text{GRB}} V_{\text{max}}^{\text{GW}}$$

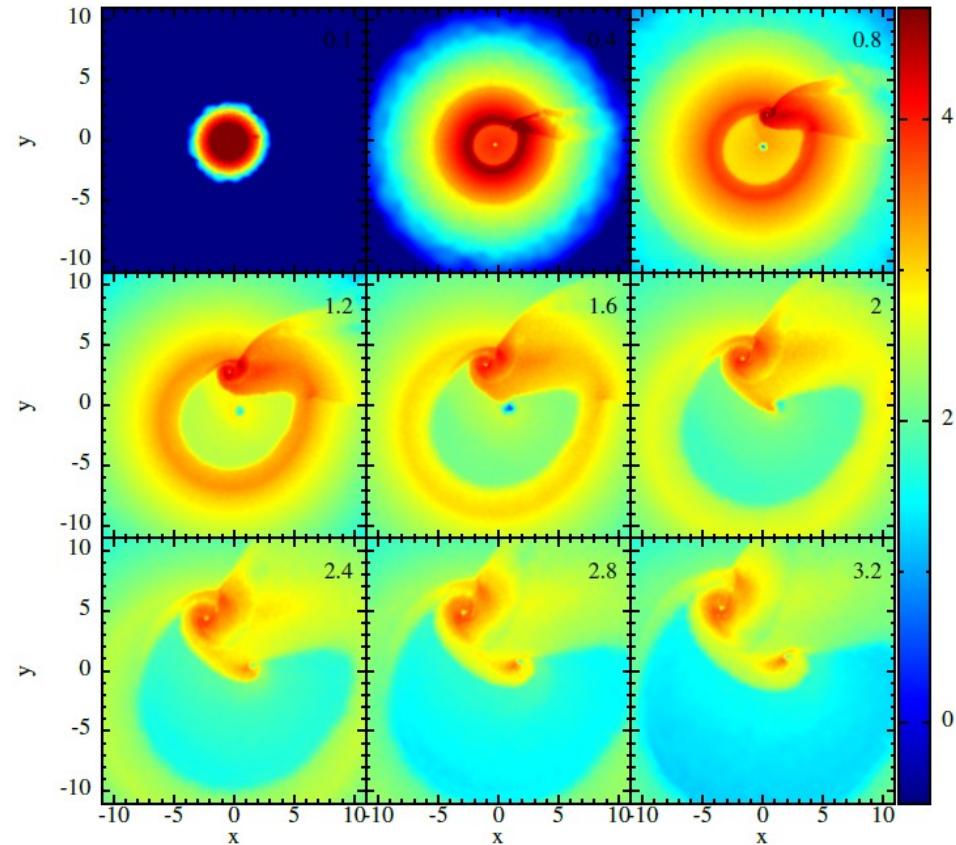
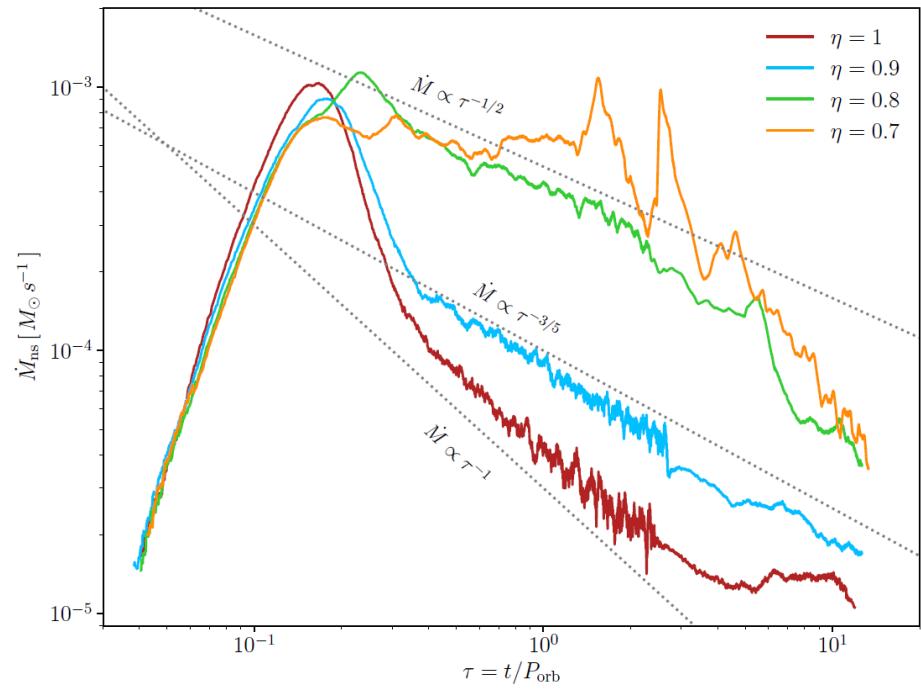
$$V_{\text{max}}^{\text{GW}} = (4\pi/3)\mathcal{R}^3$$

\mathcal{R} is the GW “range”; the values for aLIGO from:
 Abbott et al., Liv. Rev. Rel.
 19 (2016)

GRB sub-class	\dot{N}_{GRB} (yr^{-1})	$\dot{N}_{\text{GRB}}^{\text{obs}}$ (yr^{-1})	\dot{N}_{GW} (yr^{-1})
XRFs	144–733	1 (1997–2014)	undetectable
BdHNe	662–1120	14 (1997–2014)	undetectable
BH-SN	$\lesssim 662$ –1120	$\lesssim 14$ (1997–2014)	undetectable
S-GRFs	58–248	3 (2005–2014)	O1: $(0.4\text{--}8) \times 10^{-3}$ O3: 0.011–0.065 2022+: 0.1–0.2
S-GRBs	2–8	1 (2006–2014)	O1: $(0.4\text{--}8) \times 10^{-6}$ O3: $(0.08\text{--}1.2) \times 10^{-4}$ 2022+: $(0.8\text{--}3.6) \times 10^{-4}$
U-GRBs	662–1120	—	O1: $(0.36\text{--}3.6) \times 10^{-3}$ O3: 0.008–0.032 2022+: 0.076–0.095

For more details see: Ruffini, Rodriguez, Muccino, Rueda et al.; arXiv: 1602.03545

Coming soon: next ICRA-Net-LANL simulations



Becerra, Fryer, Rueda, Ruffini et al., in preparation