Occurrence of gravitational collapse of neutron star into a black hole in BdHNe leading to GRBs

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ICRANet Collaboration (International Center for Relativistic Astrophysics Network)

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Bogotá, Colombia

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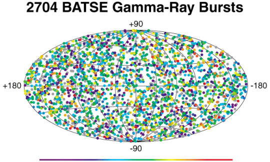
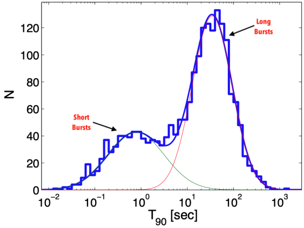
Gamma Ray Burst (GRBs)

The most energetic events



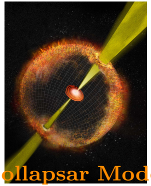


- Isotropic distribution
- Bimodal distribution
- Afterglow emission
- GRB-SNe Ic connection (The SNe show similar properties independent of the GRB)

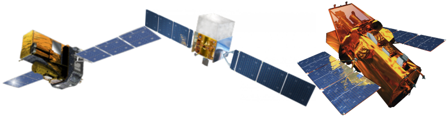
Short GRBs

GW170817

Long GRBs



Core-collapse of a single, massive, fast-rotating star



Binary Driven HyperNova Model (BdHNe)

Ruffini, et. al, ApJ 2001, Rueda & Ruffini, ApJ 2012, Ruffini et al, ApJ 2016

- GRB-SNe Ic connection (The SNe show similar properties independent of the GRB).
- GRB-SN events are related to massive star explosions, and most massive stars belong to binaries
- The models of SNe Ic show they are more plausibly explained via binary interactions to aid the pre-SN hydrogen and helium layers ejection.
- Direct formation of a BH may occur only in the evolved cores of zero-age main-sequence (ZAMS) stars above $25M_\odot$, and without an SN.

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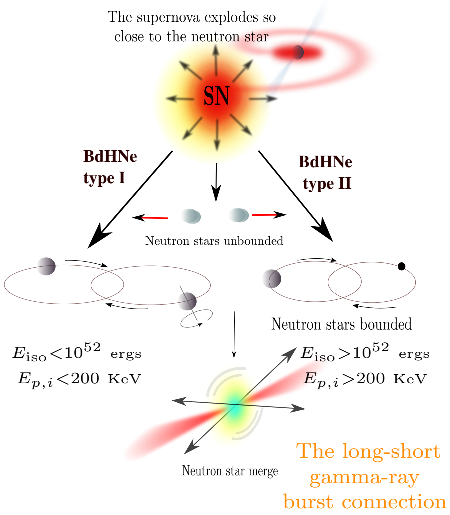

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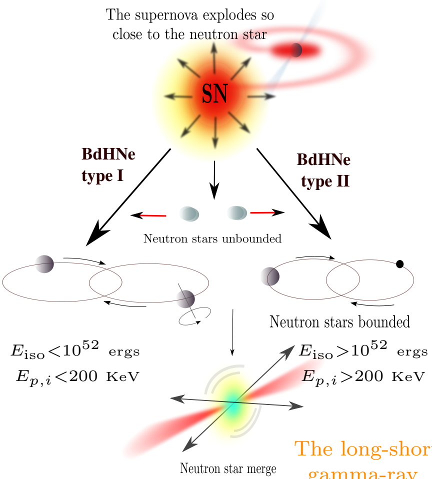
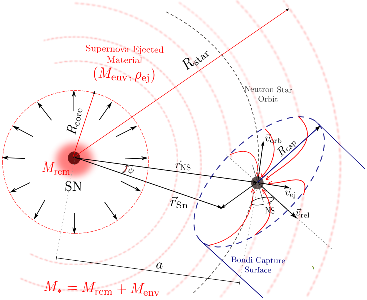


The long-short gamma-ray burst connection

Schematic Initial Conditions

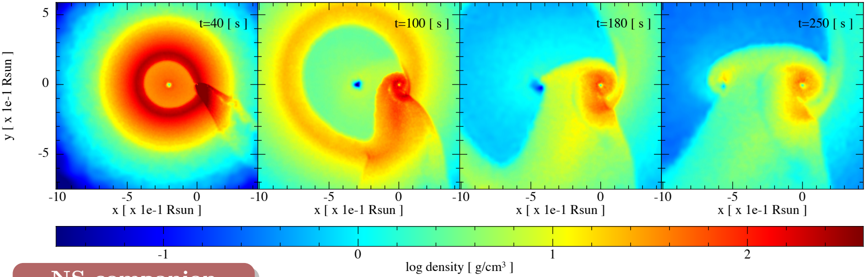
L. Becerra, et. al., ApJ 2015, 2016



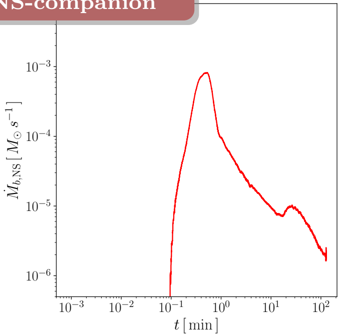
Parameter space:
(CO, $E_{\rm sn}$, $M_{\rm ns}$, $P_{\rm orb}$)

Smooth particle hydrodynamic (SPH) of the IGC scenario

L. Becerra, C. Ellinger, C. Fryer, R. Rueda and R. Ruffini, ApJ 871, 2019



NS-companion



Canonical Simulation

CO Progenitor ($M_{\rm zams}$):	25 $M_\odot$
Total energy:	1.57×10^{51} ergs
Ejected Mass:	5.0 $M_\odot$
ν-NS Mass:	1.85 $M_\odot$
NS Mass:	2.0 $M_\odot$
Orbital Period :	≈ 5 minutes
Orbital Separation:	1.35×10^{10} cm
Number of particles:	1 million

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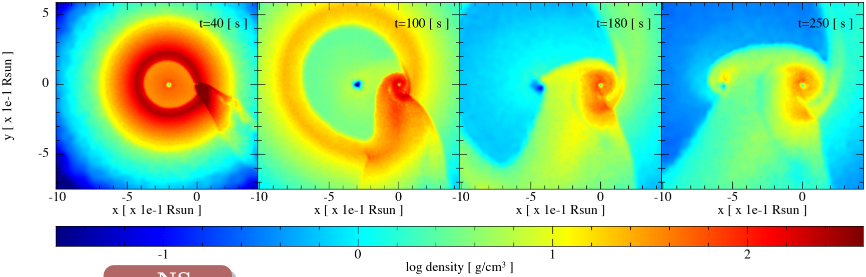

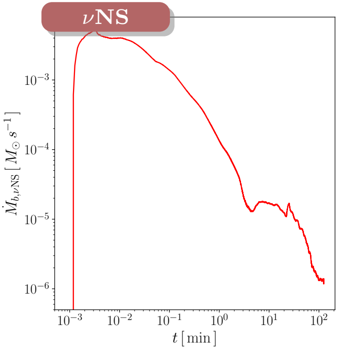

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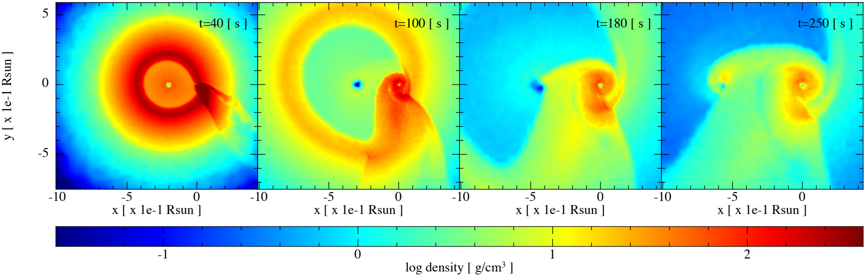
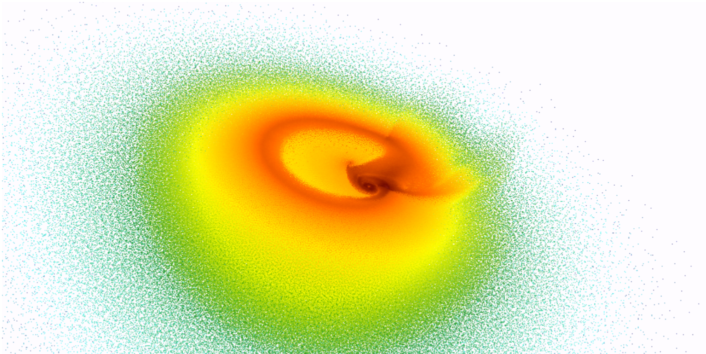
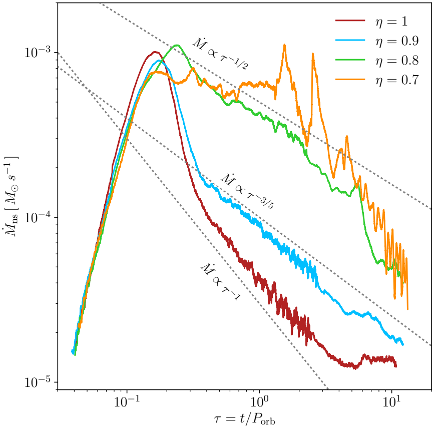




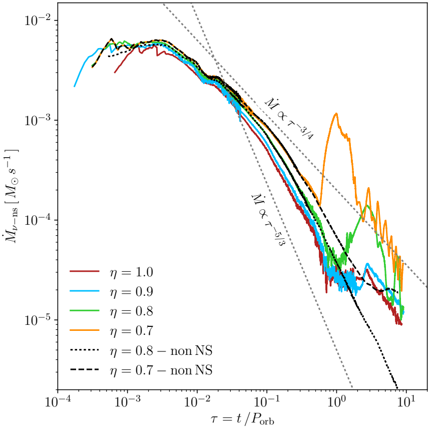
Mass Accretion Rate on the νNS and the NS companion

SN Energy and Initial Binary Period (L. Becerra et al, ApJ 871,2019)

NS-companion



νNS



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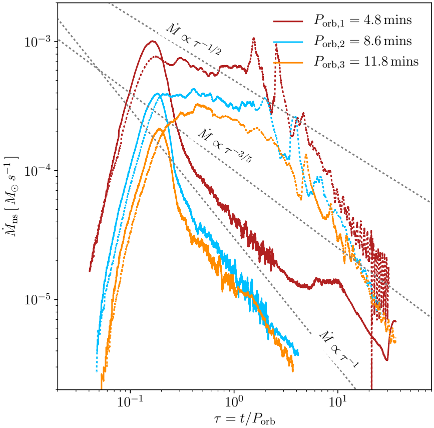

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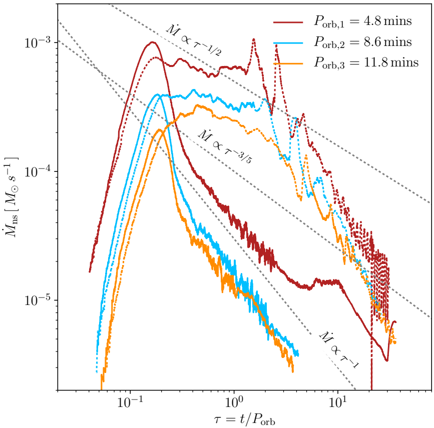
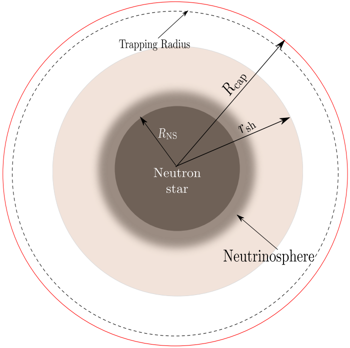


The gravitational energy gain is mostly taken away by the emission of **MeV-neutrinos**



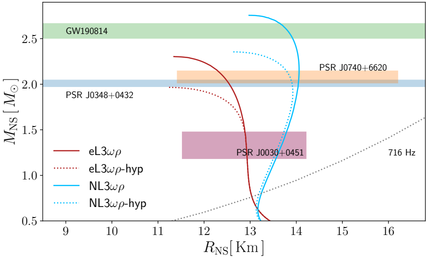
NS critical mass and gravitational collapse

Rotating NS configurations - RNS Code (L. Becerra et al., ApJ 871, 2018, L. Becerra et al., arXiv:2409.05767)

The evolution of the NS gravitational mass and angular momentum is:

$$\frac{dJ_{\rm NS}}{dt} = \chi\, l(R_{\rm in})\frac{dM_{\rm b}}{dt} + \tau_{\rm mag}$$

$$l(R_{\rm in} = \begin{cases} l_{\rm isco}, & \text{if } R_{\rm in} \geq R_{\rm ns} \\ \Omega\ R_{\rm ns}^2, & \text{if } R_{\rm in} < R_{\rm ns} \end{cases}$$



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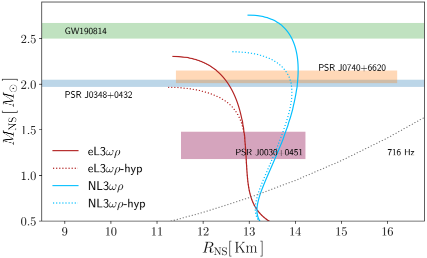

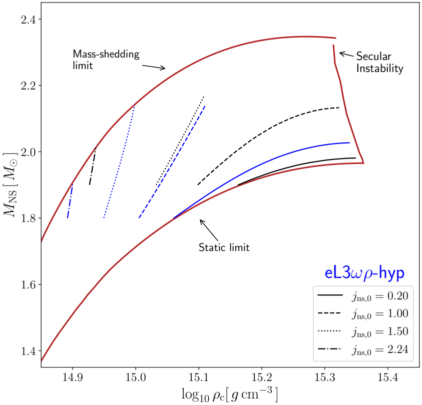

The NSs could have different fates.

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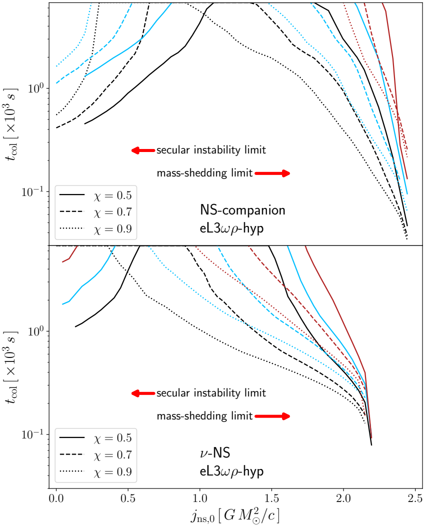

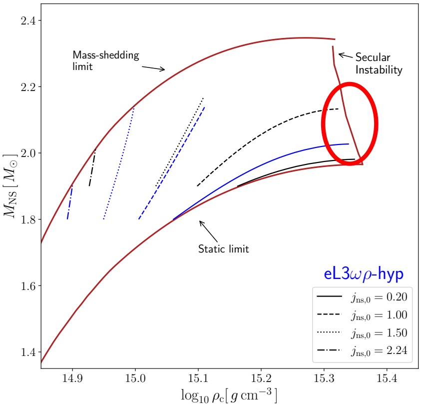

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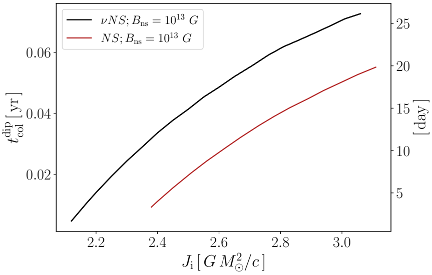
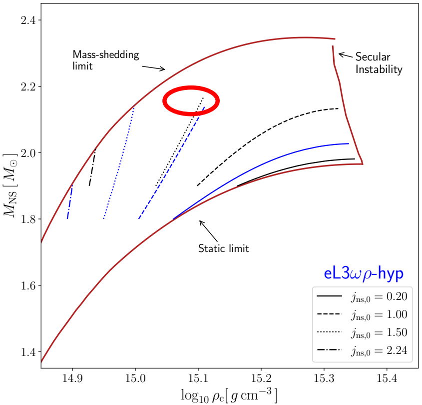


The star does not collapse during the accretion process, but it collapses in a shorter time than the merger time.



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Observables in the GRB data

Y. Wang, et al 2019, R. Morandi et. al. 2021, Rueda, et. al. 2022, L. Becerra et al., 2022

Physical phenomenon	BdHN	GRB observable				
		νNS-rise (soft-hard X-rays)	UPE (MeV)	GeV emission	SXFs HXFs	Afterglow (X/optical/ radio)
Early SN emission	I, II, III	$\otimes$				
Hypercritical accretion onto νNS	I, II, III	$\otimes$				
Hypercritical accretion onto NS	I, II	$\otimes$				
BH formation from NS collapse	I			$\otimes$		
Transparency of e^+e^- (from vacuum polarization) with low baryon load region	I		$\otimes$			
Synchrotron radiation *inner engine*: BH + B-field+SN ejecta	I			$\otimes$		
Transparency of e^+e^- (from vacuum polarization) with high baryon load	I				$\otimes$	
Synchrotron emission from SN ejecta with energy injection from νNS	I, II, III					$\otimes$
Pulsar-like emission from νNS	I, II, III					$\otimes$

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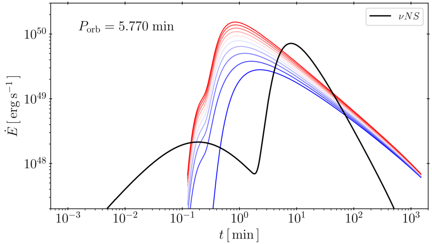
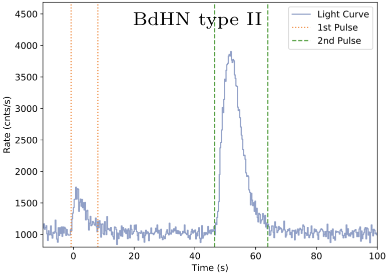
Accretion: $\dot{E} = \Omega \dot{J}$



GRB 190829A



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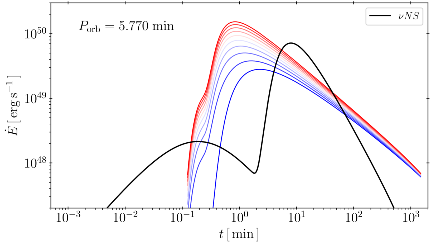

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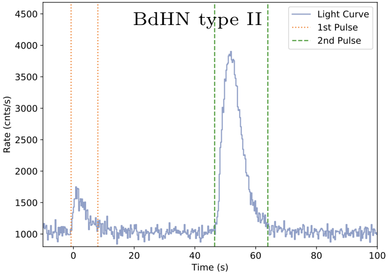
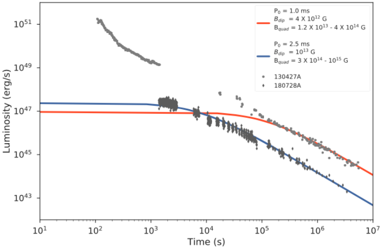


Afterglow



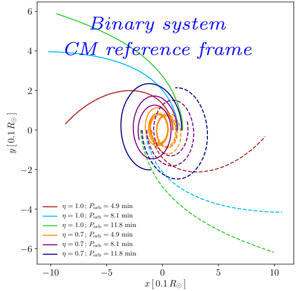
Pulsar-like emision: *GRB 130427A - GRB 180728A*

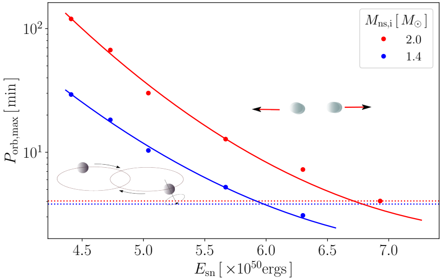
$$Lx = -\dot{E}_{\rm rot} = I\Omega\dot{\Omega}$$

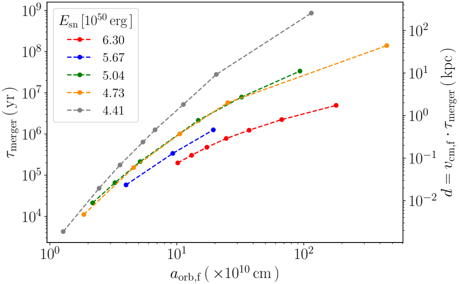
$$J_{\rm CO} = J_{\nu \rm NS} \qquad \rightarrow \qquad \frac{P_{II}}{P_I} = 2.5$$

Binary System fate: the long and short GRB connection

Motion of the binary stars (L. Becerra et al, Universe 9 2023, L. Becerra et al, arXiv:2401.15702)



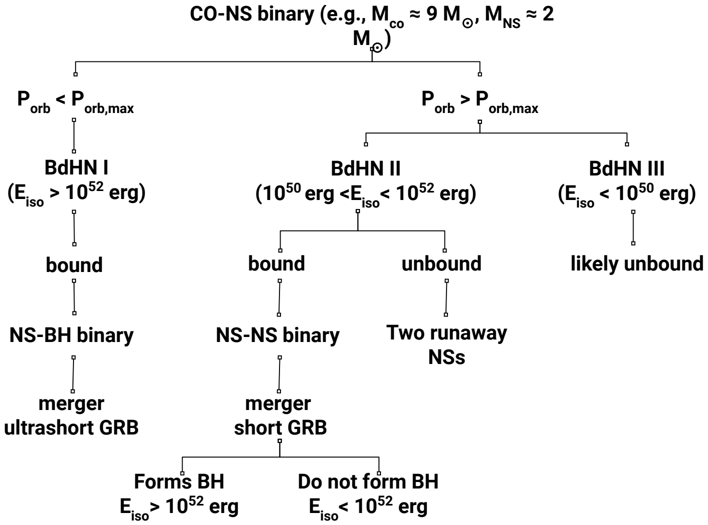




$\mathcal{R}_{\rm long} > \mathcal{R}_{\rm short}$

The short and long GRBs connection predicted by the BdHN scenario implies : $\mathcal{R}_{\rm short}/\mathcal{R}_{\rm long} \approx 2\%–8\%$.

Summary


CO-NS binary (e.g., $M_{co} \approx 9\,M_\odot$, $M_{NS} \approx 2\,M_\odot$)
$P_{orb} < P_{orb,max}$
$P_{orb} > P_{orb,max}$
BdHN I
($E_{iso} > 10^{52}$ erg)
BdHN II
(10^{50} erg $< E_{iso} < 10^{52}$ erg)
BdHN III
($E_{iso} < 10^{50}$ erg)
bound
bound
unbound
likely unbound
NS-BH binary
NS-NS binary
Two runaway NSs
merger
ultrashort GRB
merger
short GRB
Forms BH
$E_{iso} > 10^{52}$ erg
Do not form BH
$E_{iso} < 10^{52}$ erg

Summary

- The results of 3D-numerical simulations of the IGC model have opened new lines of research on the interpretation of long GRB data.
- Rotational energy acquired by the νNS and the NS companion, along with accretion power, can result in early emissions preceding the main prompt emission. This suggests the potential for detecting precursors with a double-peak structure in X-ray and/or gamma-ray observations.
- BdHNe events can result in BH-BH, BH-NS, and NS-NS binaries. These systems, driven by GW radiation, will merge and lead to short GRBs. The relative rates of BdHNe I and II offer vital insights into the nuclear EOS of NSs. This data also offers clues about the stellar evolution leading to CO-NS binaries in the BdHN scenario.

Thanks!