Wolf-Rayet –compact object binaries: the road to gravitational wave mergers

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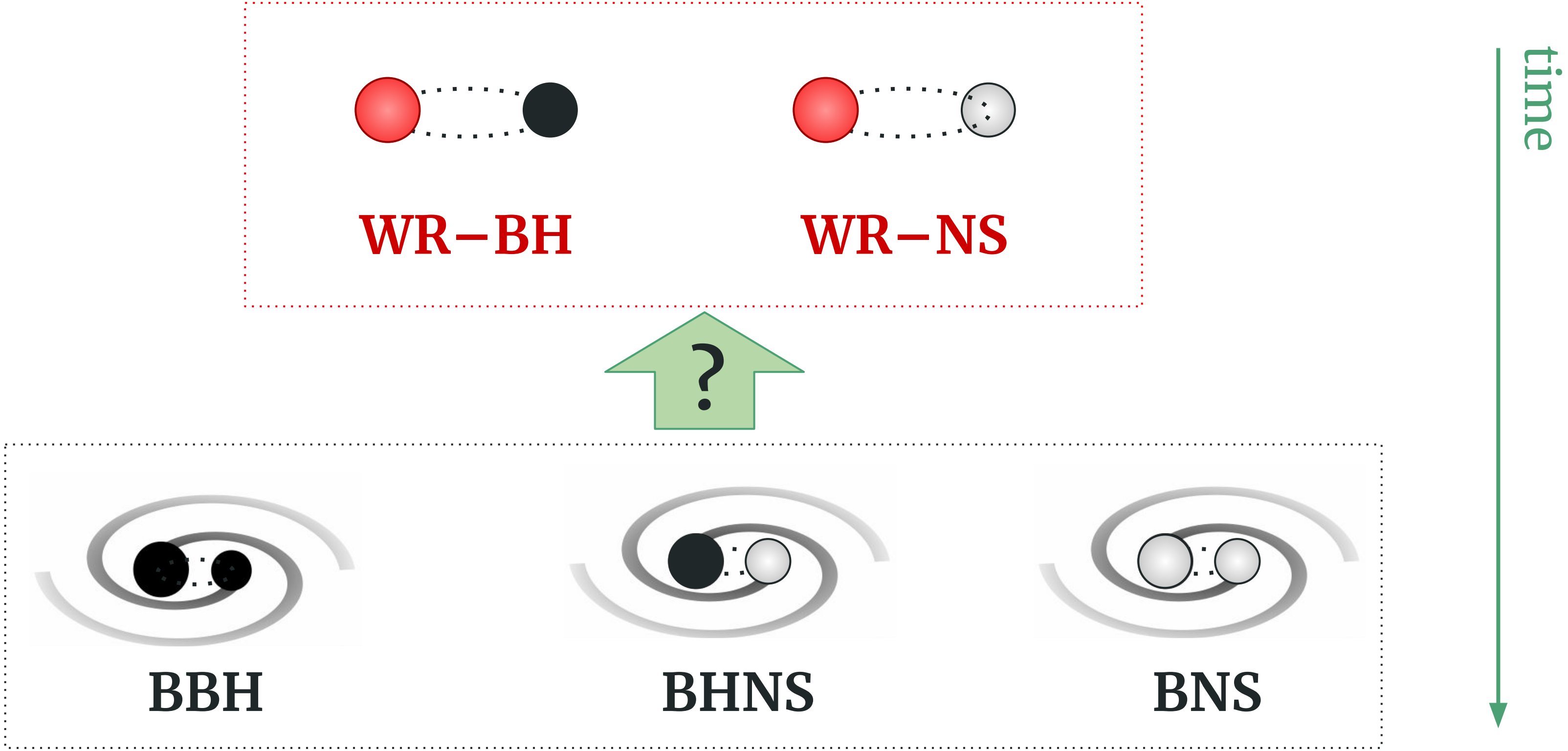
Main Collaborators:

Michela Mapelli, Giuliano Iorio, Guglielmo Costa + the DEMOBLACK group

The problem

Could WR-COs be the progenitors of GW-merging BCOs ?



Why WR–COs?

Wolf -Rayet

Black hole / Neutron star

✔ WR: BH/NS progenitor

✔ BH/NS already present

Crowther+2010, Belczynski+2013, Esposito+2013, 2015 Liu+2013, Maccarone+2014, Laycock+2015, Koljonen+2017, Binder+2021, Veledina+2024

Why WR–COs?

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- ✔ WR: proxy of mass transfer?
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Why WR–COs?

Wolf -Rayet

Black hole /
Neutron star

- ✔ WR: BH/NS progenitor
- ✔ WR: proxy of mass transfer?

- ✔ BH/NS already present
- ❌ Mass measurement: is a BH or a NS?

✔ ❌ **Only 7 WR–CO candidates so far!**

Crowther+2010, Belczynski+2013, Esposito+2013, 2015 Liu+2013, Maccarone+2014, Laycock+2015, Koljonen+2017, Binder+2021, Veledina+2024

The method

Population synthesis code + **Parameter exploration (96 combinations)**

Iorio+2023

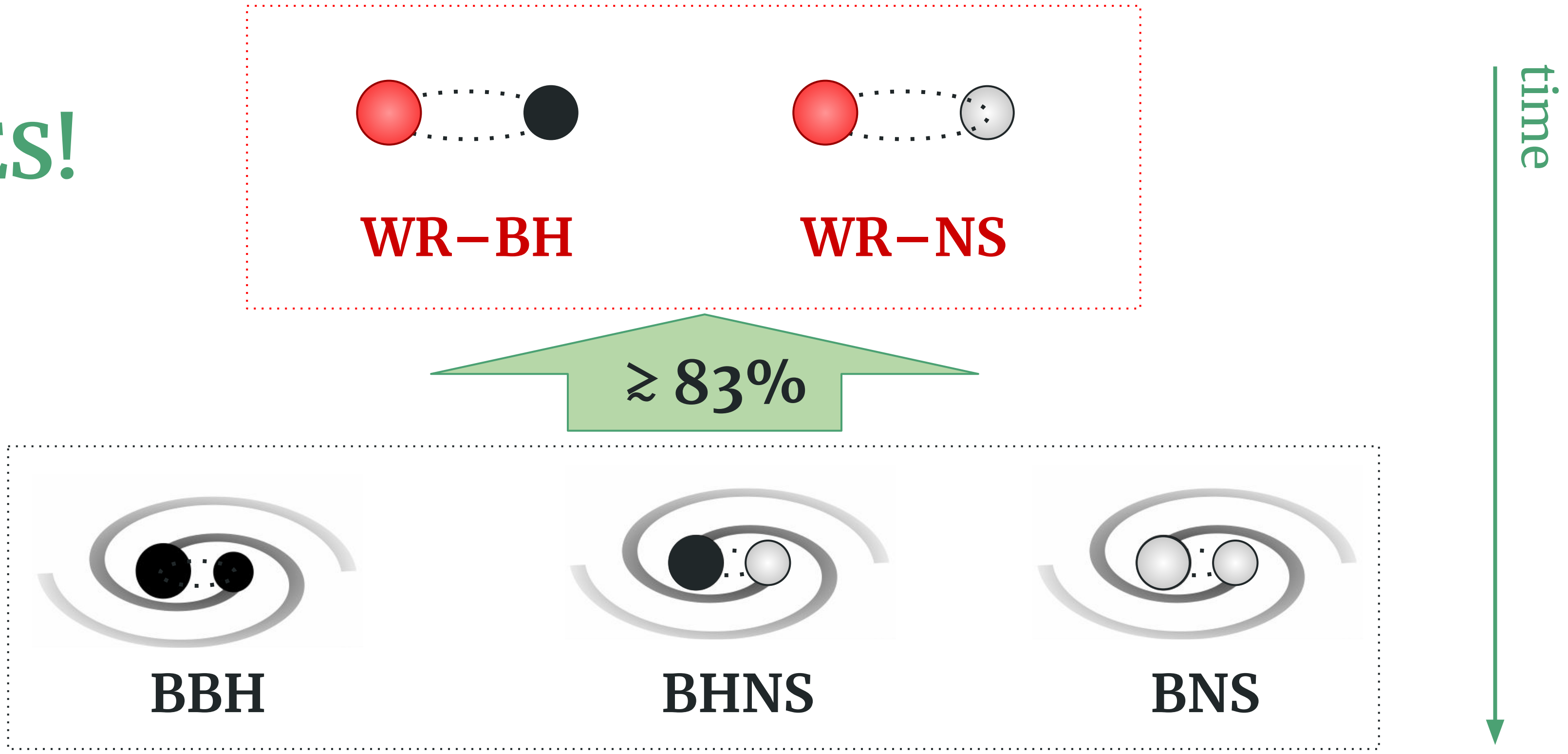
https://gitlab.com/sevncodes/sevn

α_{CE}	Z	CCSN	Natal kicks
1	2.0×10^{-2}	2-5 $M_\odot$ mass gap	Maxw. (σ=265 km/s)
3	1.4×10^{-2}	no 2-5 $M_\odot$ mass gap	Maxw. (σ=70 km/s)
	1.4×10^{-3}	compactness param.	Maxw. (+ fallback)
	1.4×10^{-4}		Maxw. (+ ejecta mass)
		O'Connor&Ott 2011, Fryer+2012, Mapelli+2020	*Hobbs+2005, Fryer+2012, Atri+2019, Giacobbo&Mapelli 2020*

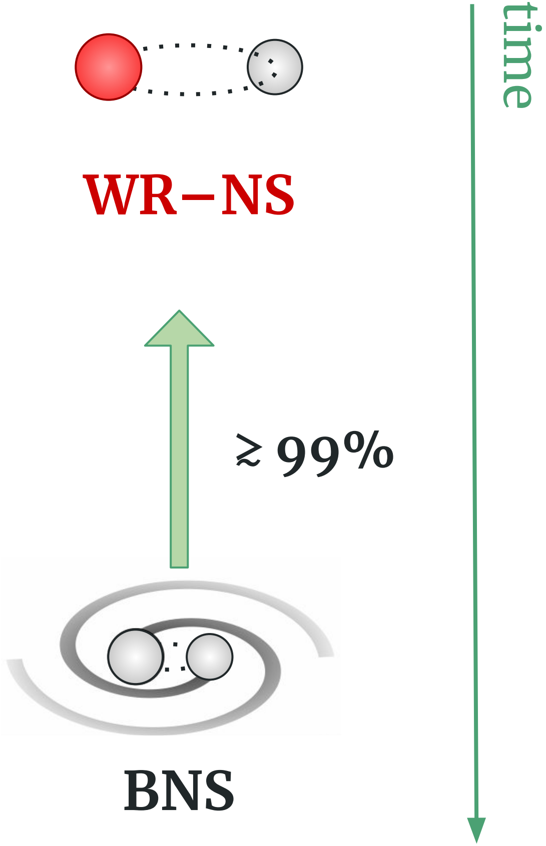
The results

Could WR-COs be the progenitors of GW-merging BCOs ?

YES!



The results: BCO progenitors



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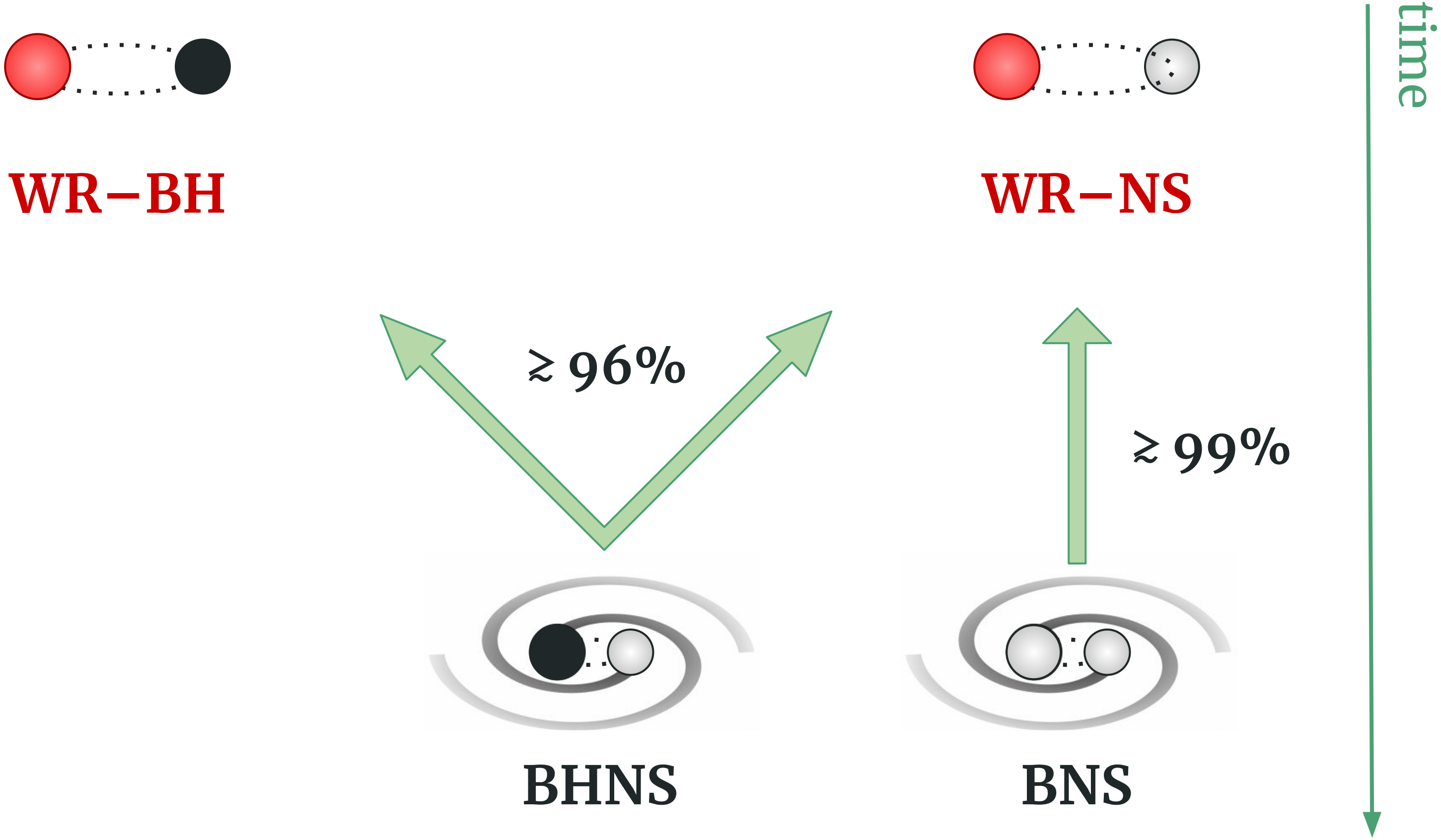

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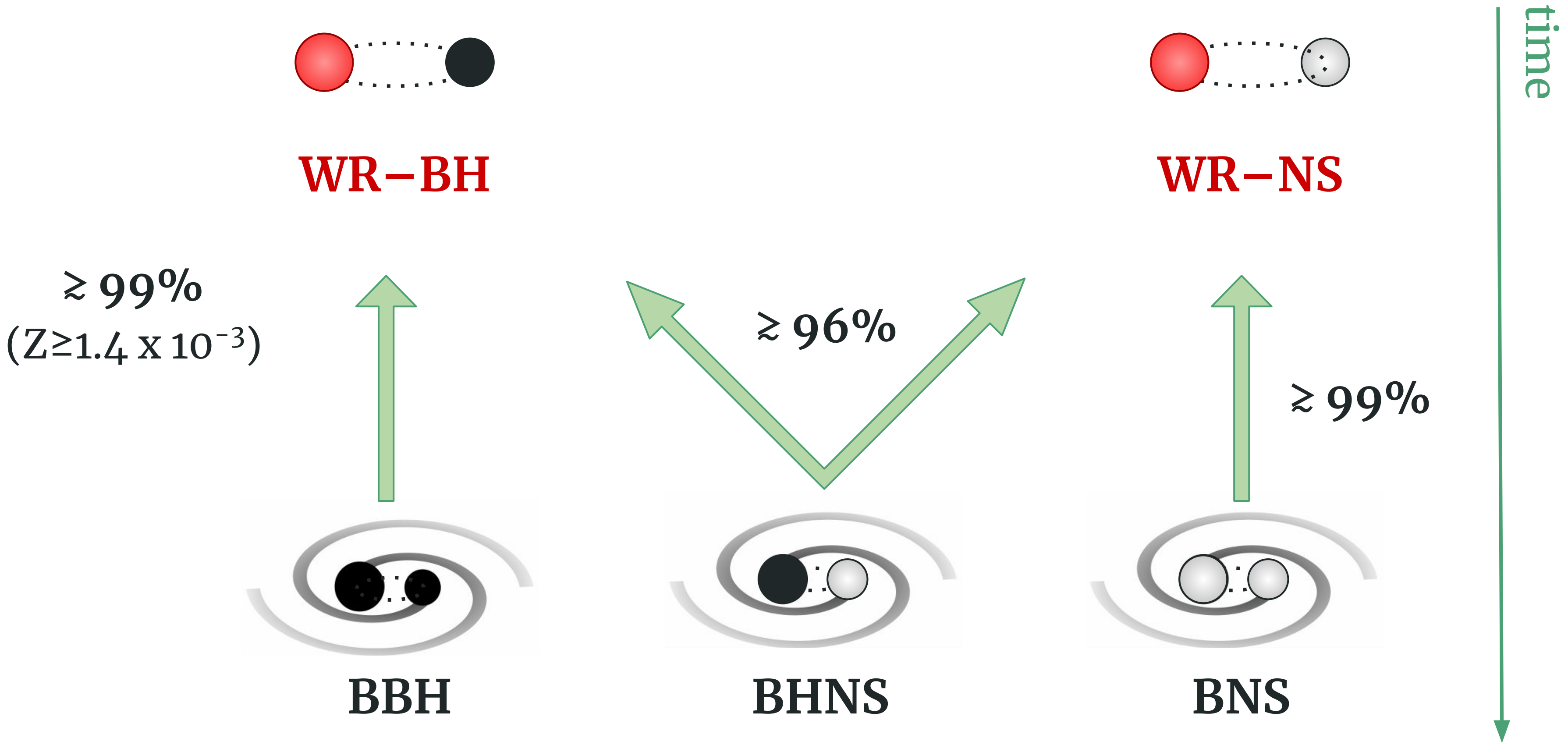

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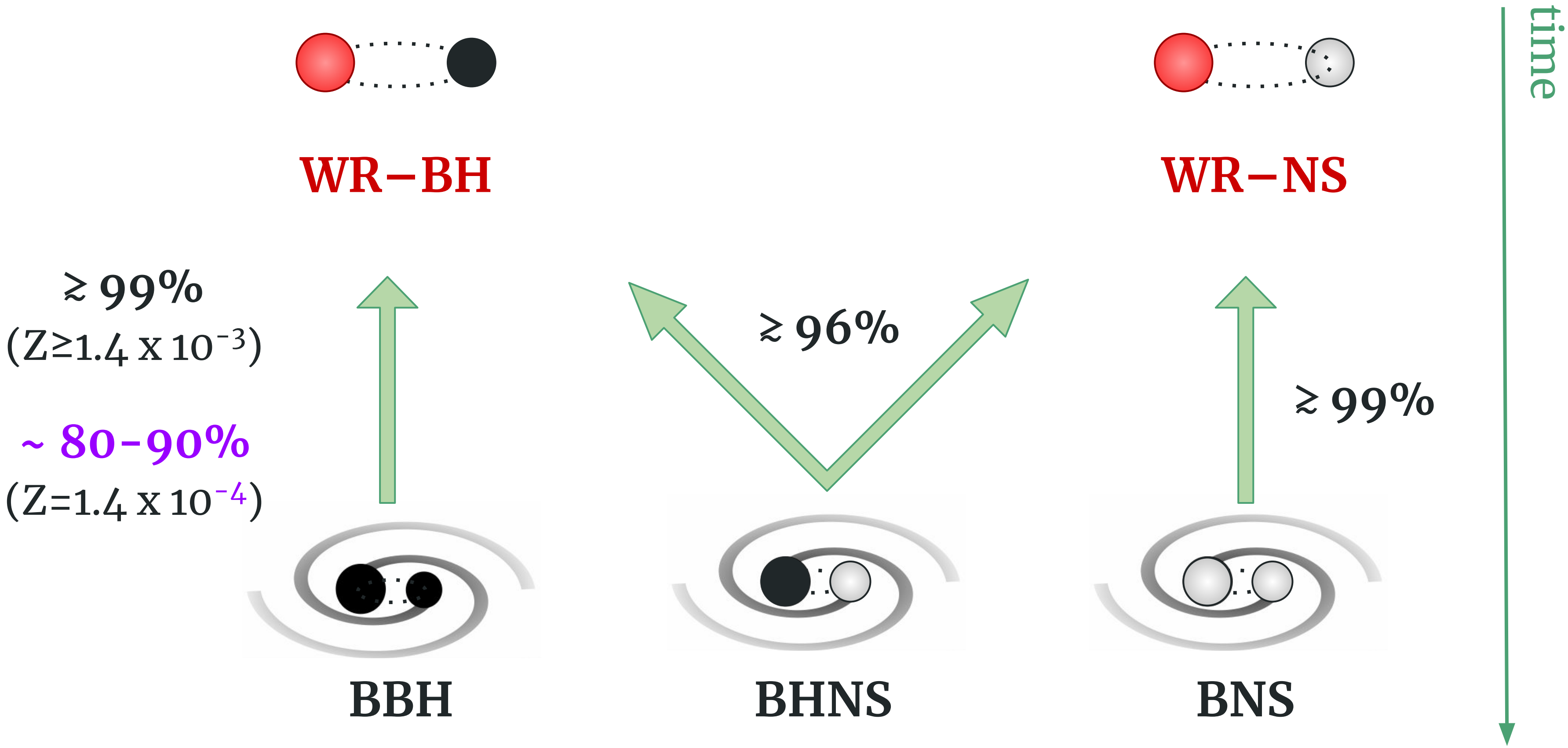
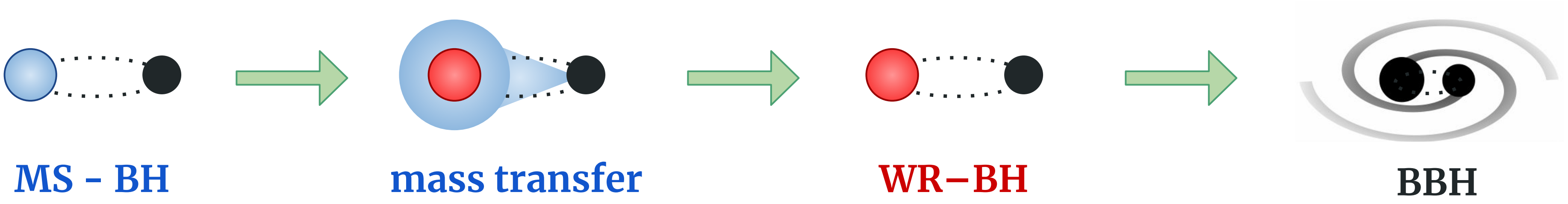


The results: BBHs at Z=1.4 x 10^{-4}



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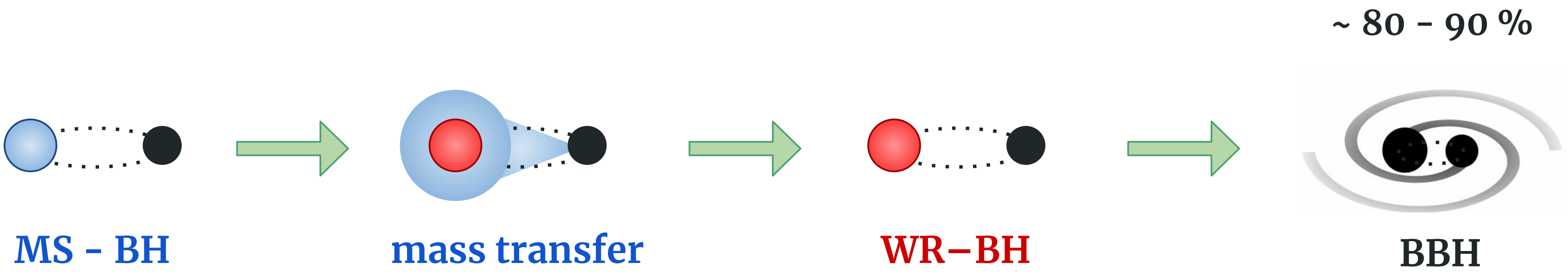

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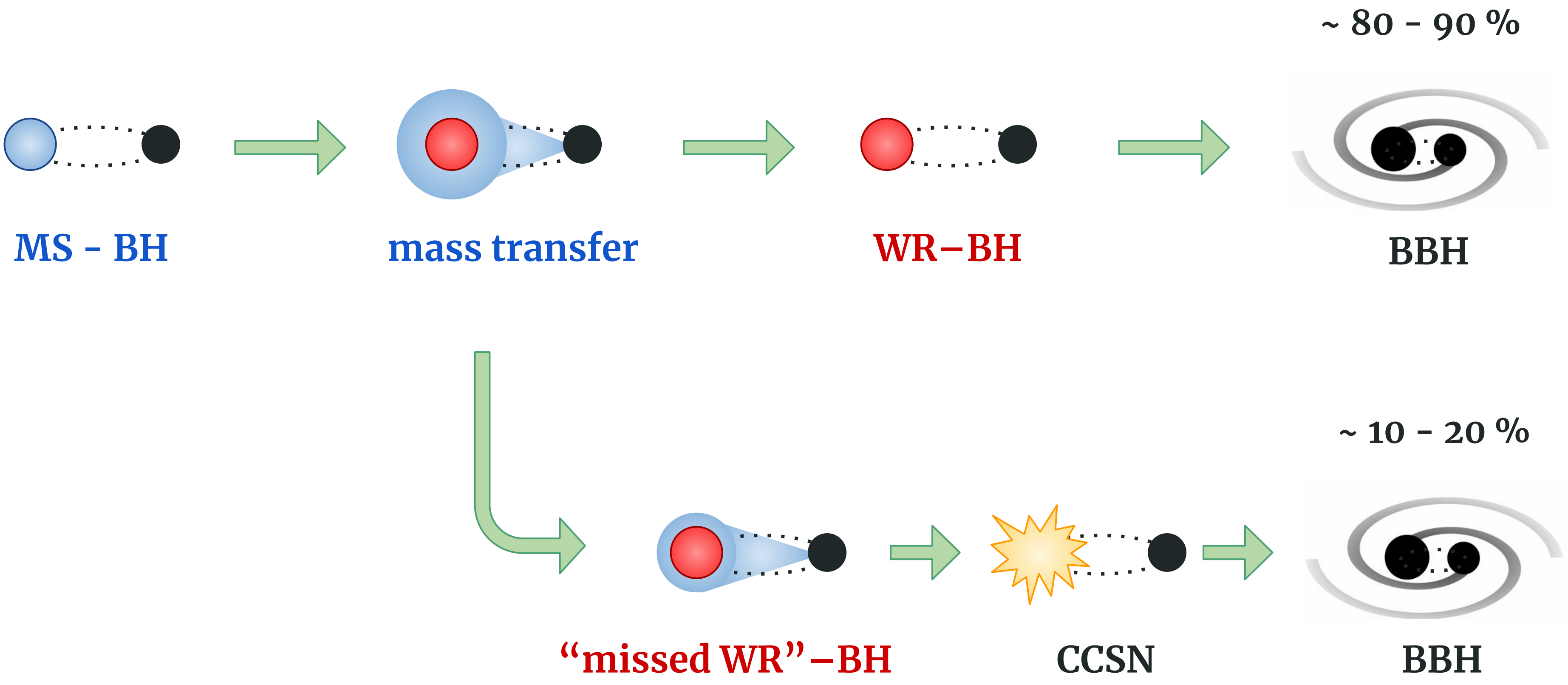

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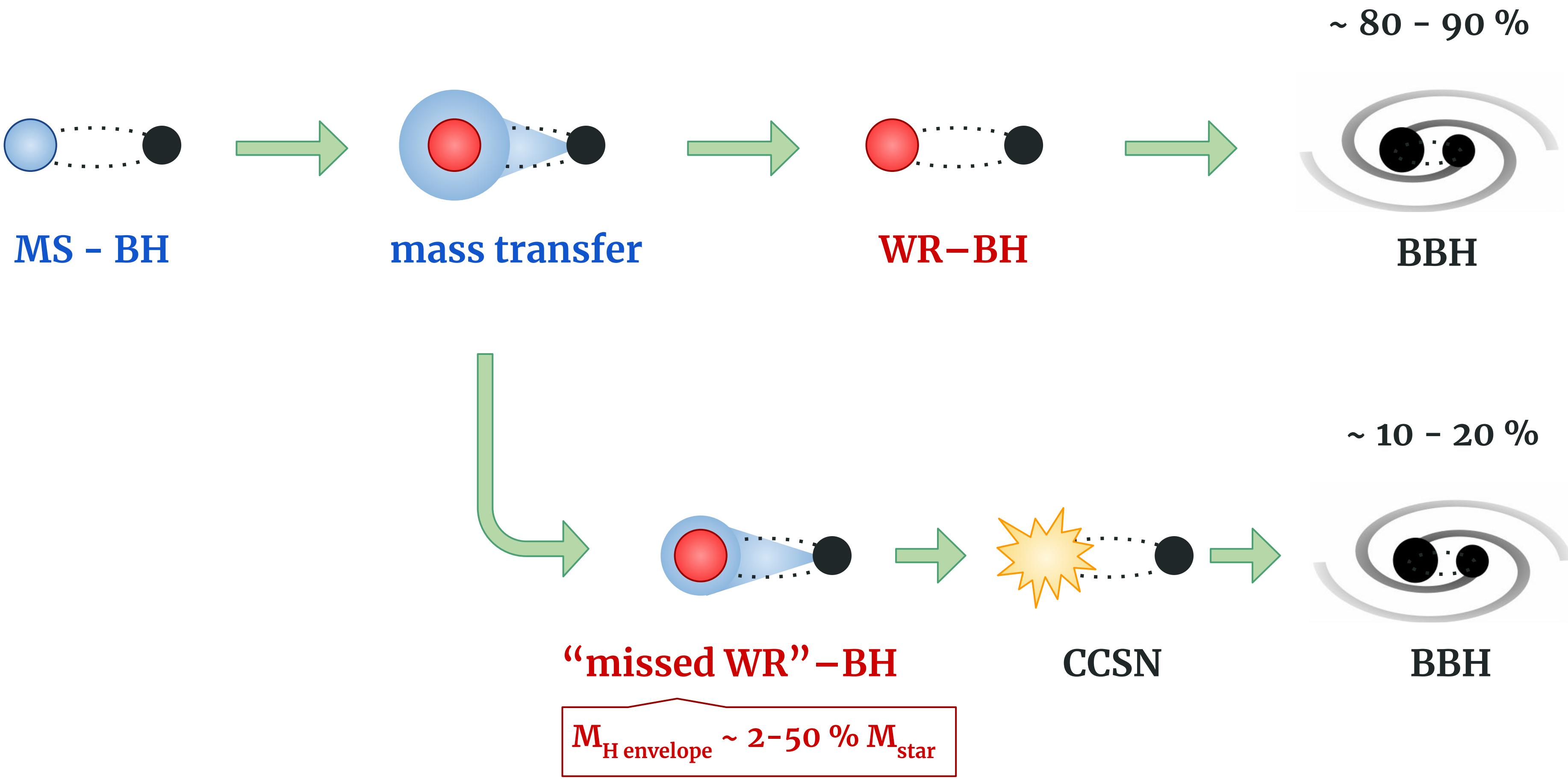
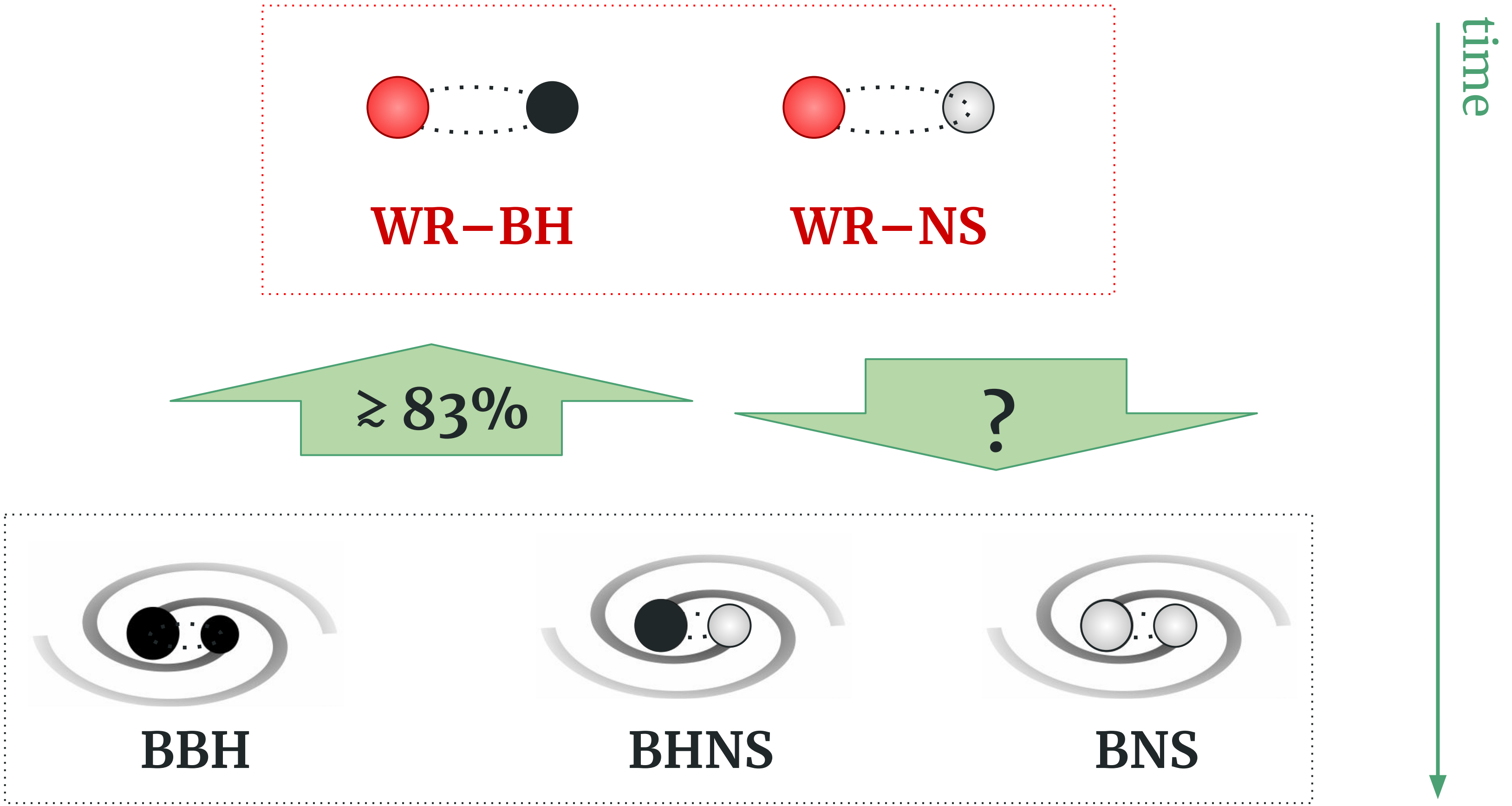
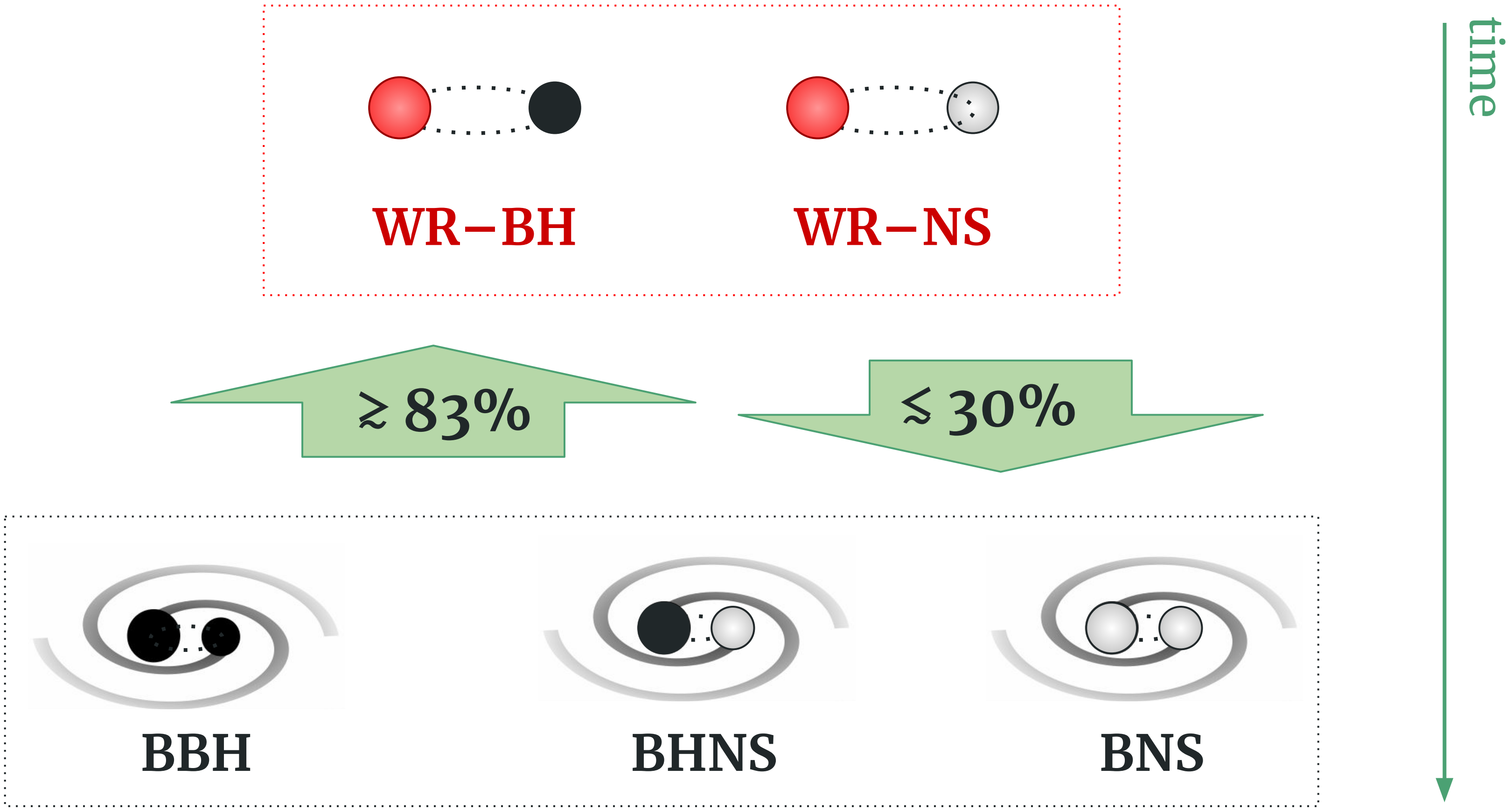


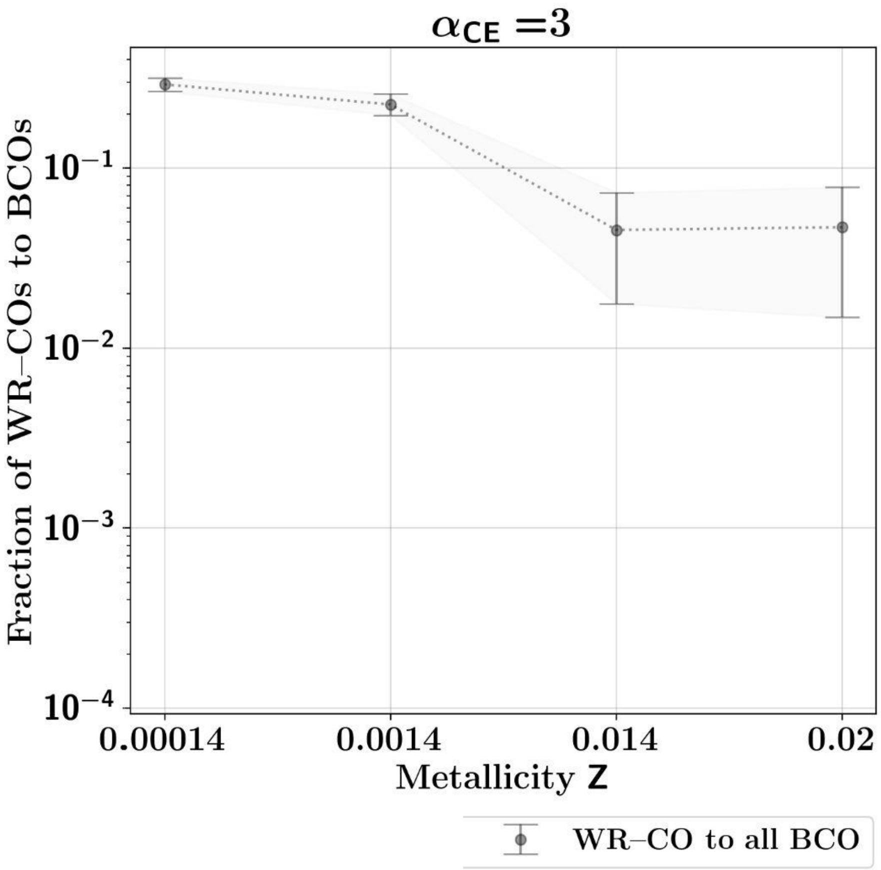
The results: do most WR–COs produce BCOs?



The results: do most WR–COs produce BCOs? Not really...



The results: fates of WR–COs



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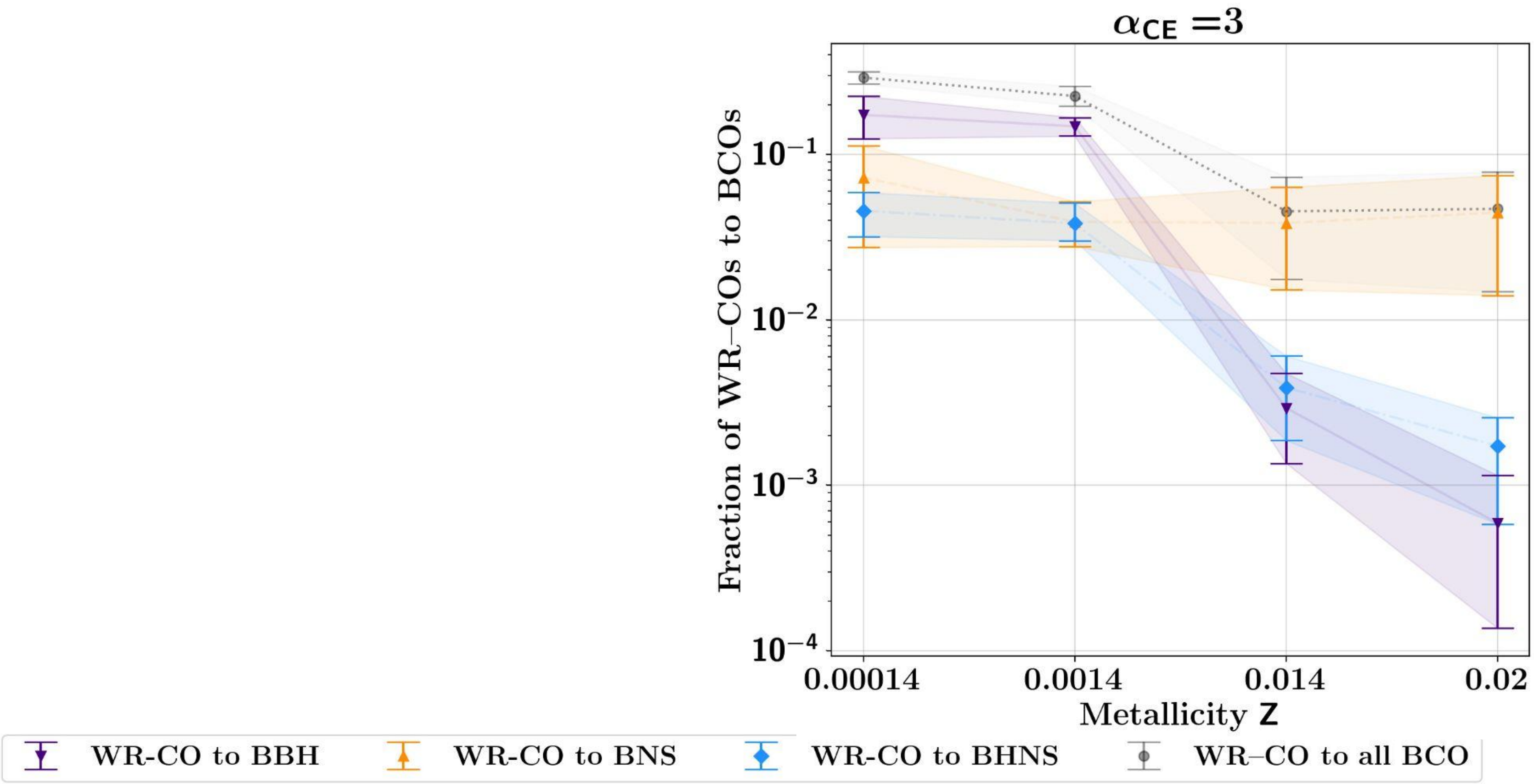
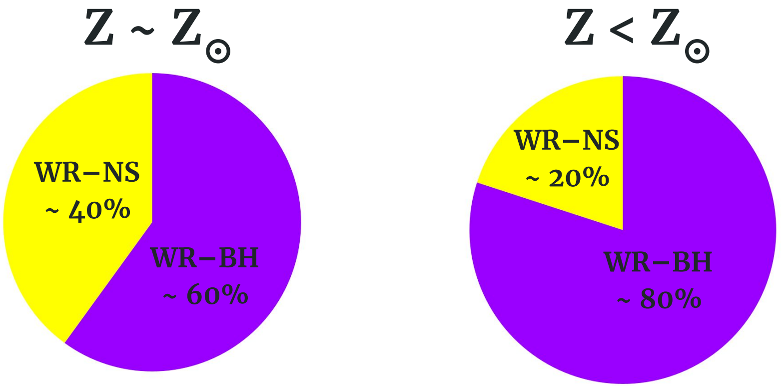
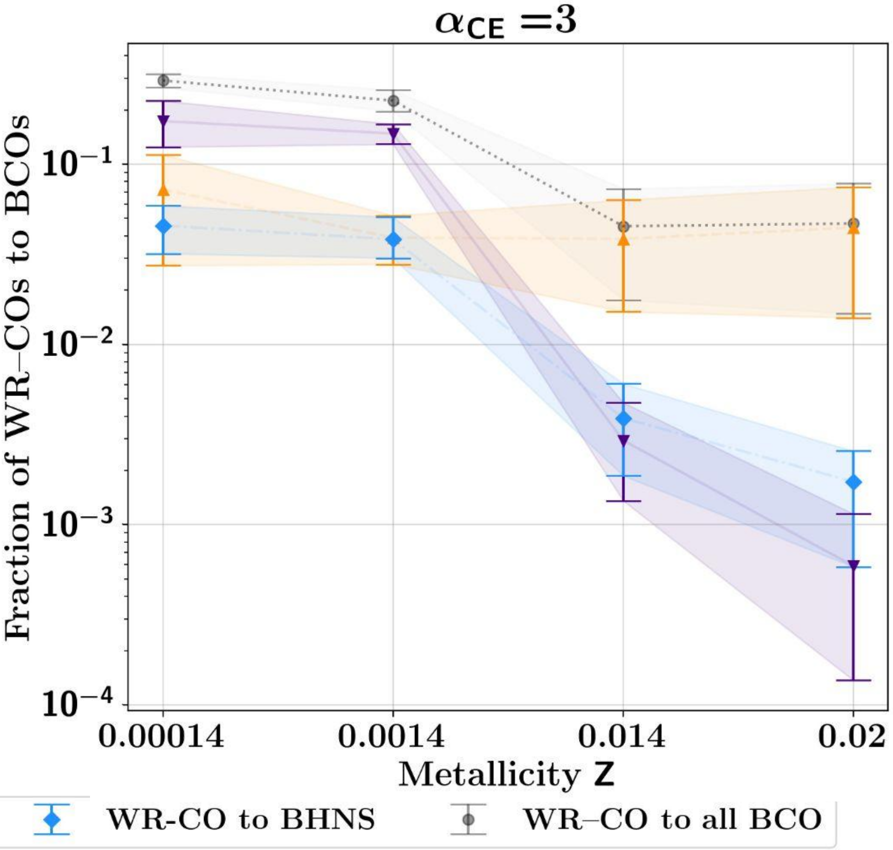


The results: fates of WR−COs

WR−COs:
~3% of the initial binary population

(within all the explored parameter space)





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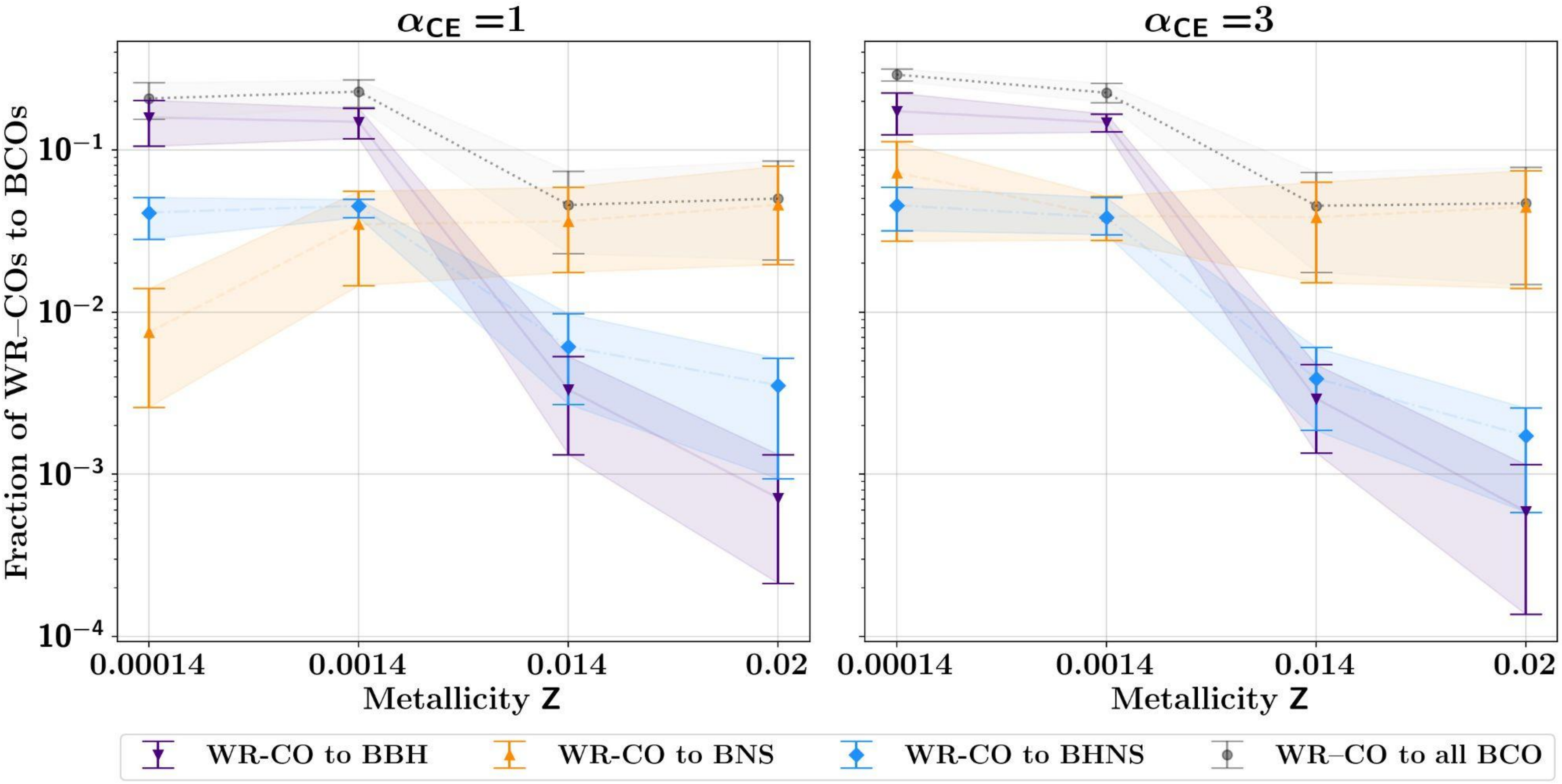
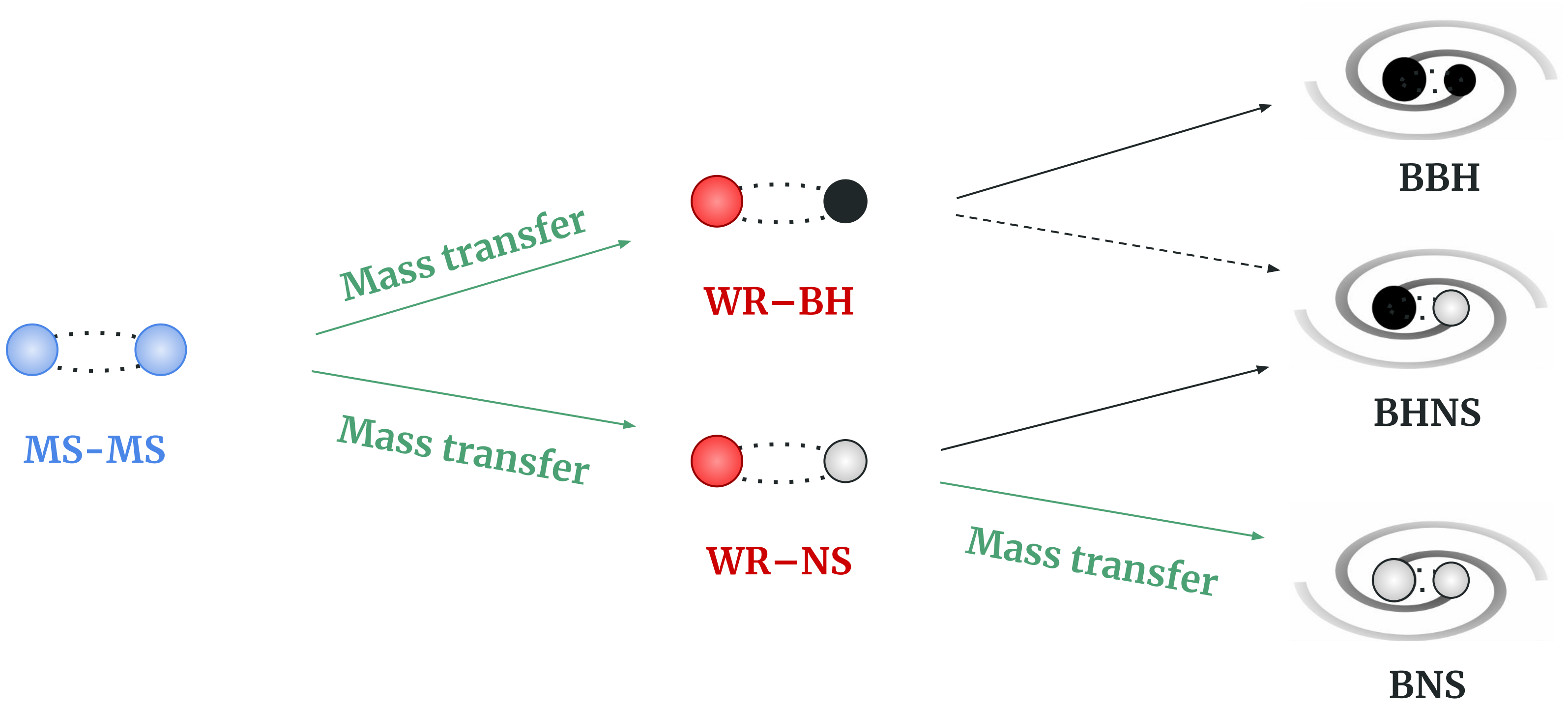
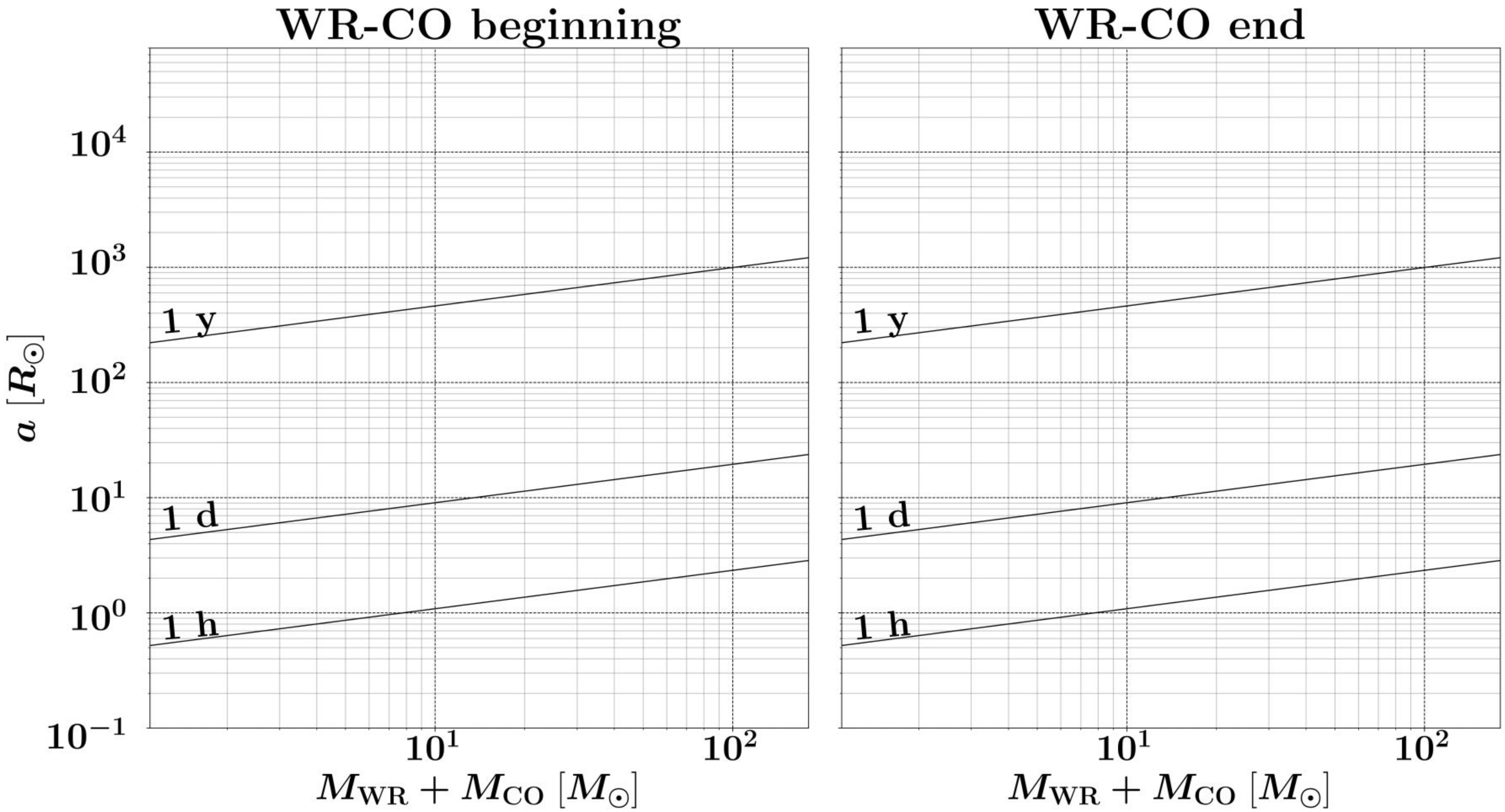


The results: evolution



The results: WR−CO properties



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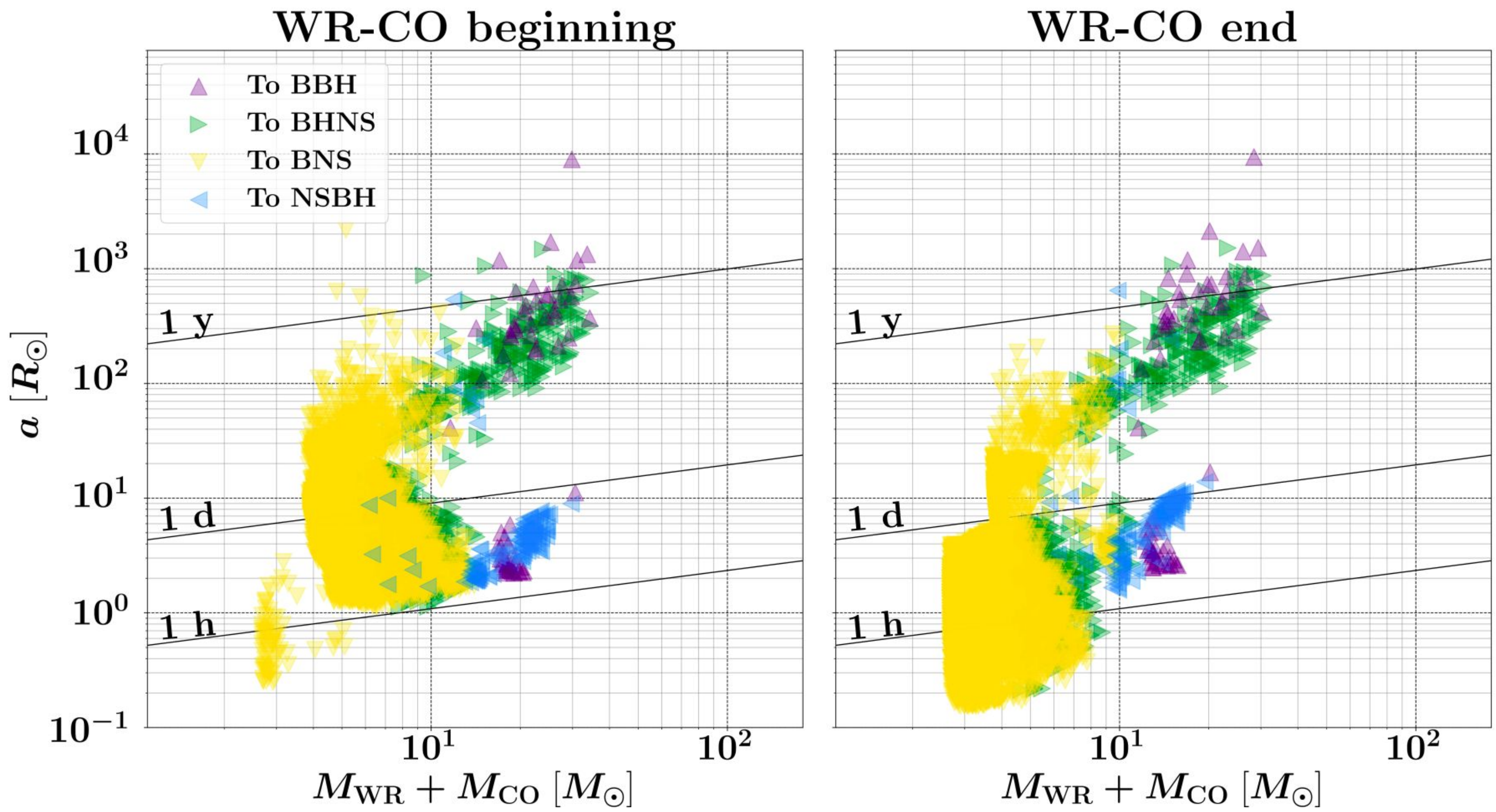

The results: Cyg X-3 candidates

Cyg X-3:

- the only WR-CO candidate in the Milky Way — Esposito+2015
- proposed as BCO progenitor — Belczynski+2013
- *probably* hosts a BH — Zdziarski+2013

P = 4.8 hours — *Singh+2002*

M_{WR} = 8-14 $M_\odot$ — *Koljonen & Maccarone 2017*

M_{CO} < 10 $M_\odot$ — *Koljonen & Maccarone 2017*

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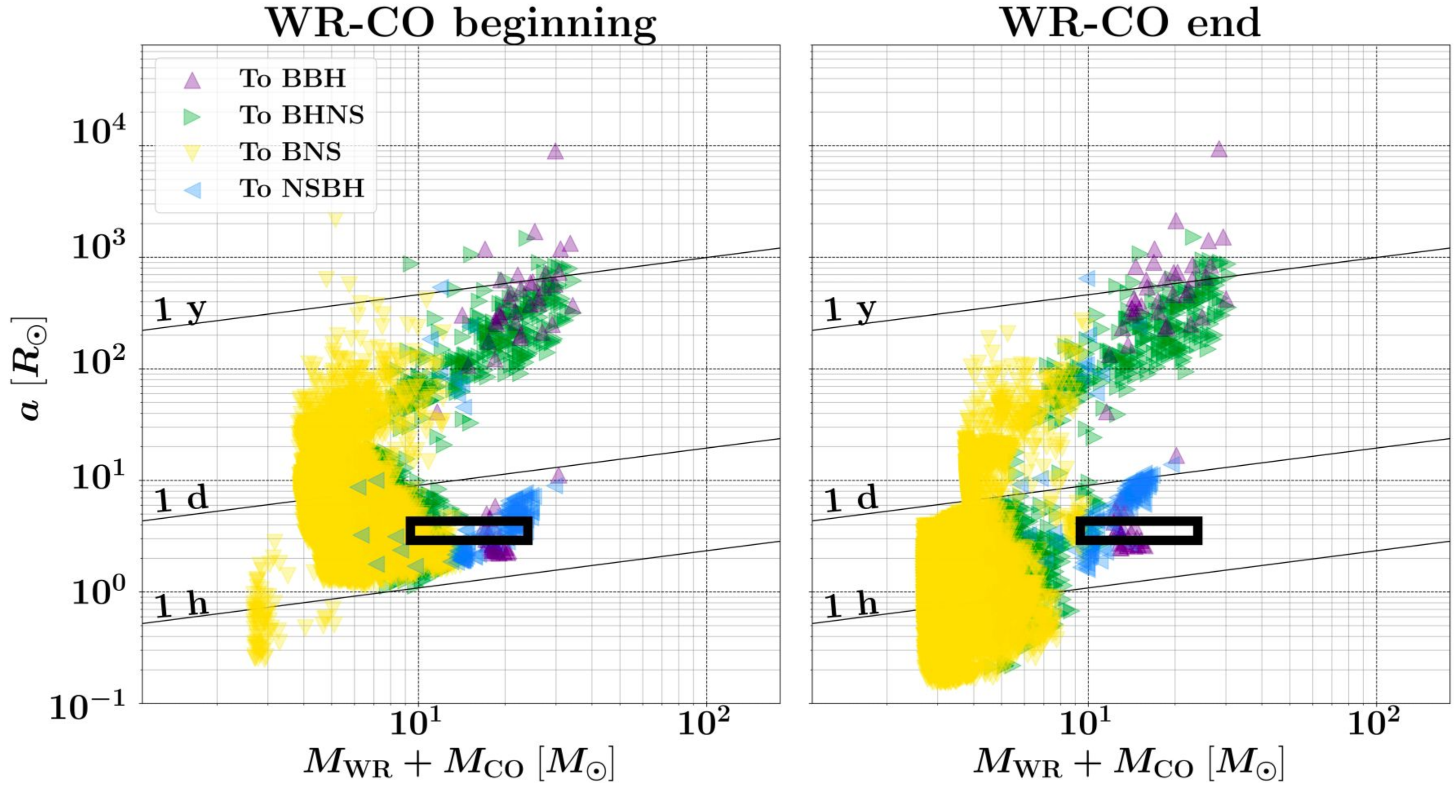

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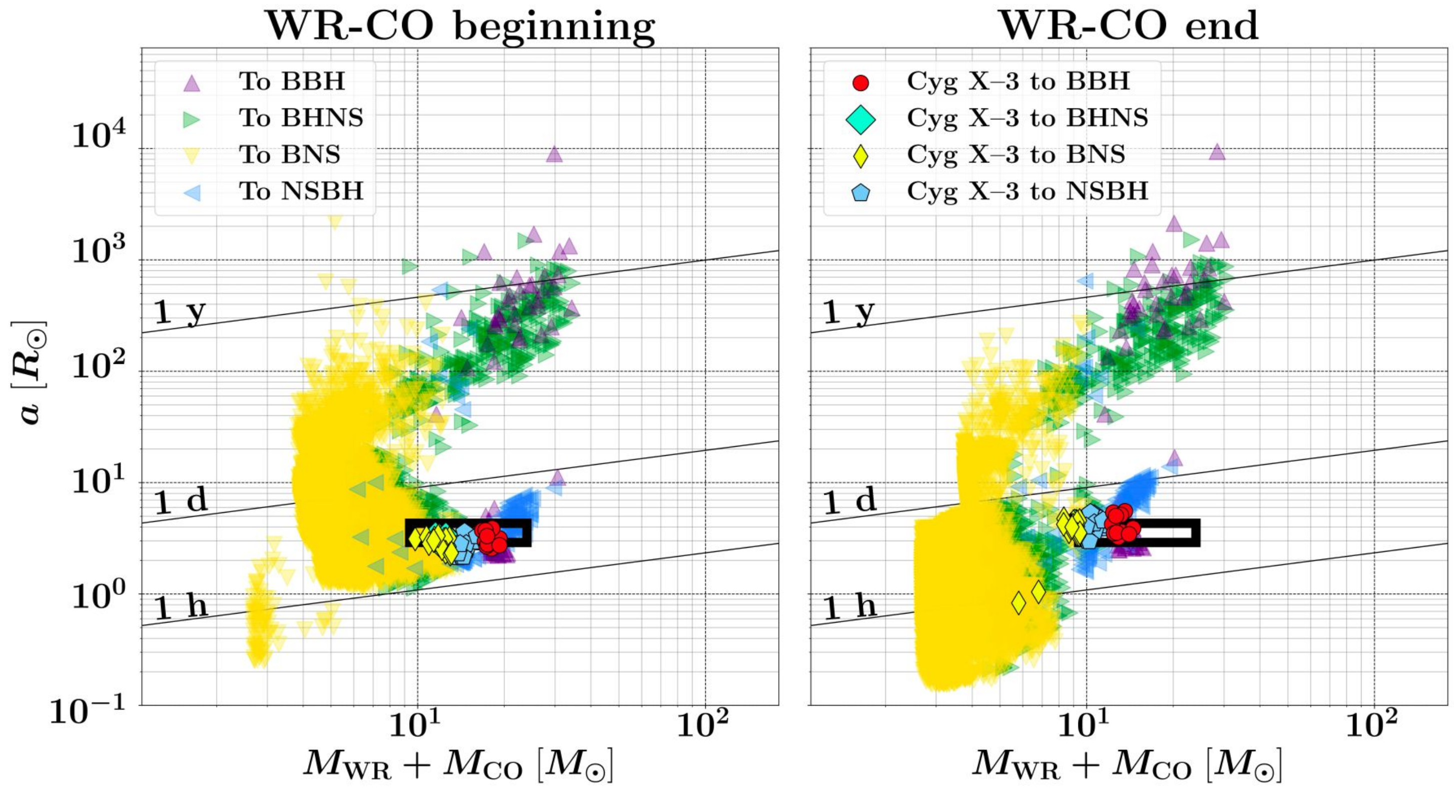

The results: Cyg X-3 candidates

- not a frequent WR–CO configuration (< 1/ 1 000, most optimistic)
- more likely BCO progenitors with respect to WR–COs (that are ~5% at $Z_\odot$)

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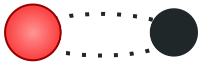
~40-60 % of Cyg X-3 candidates are BCO progenitors

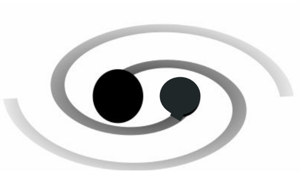
WR–BH



≳ 70-100 %

WR–NS

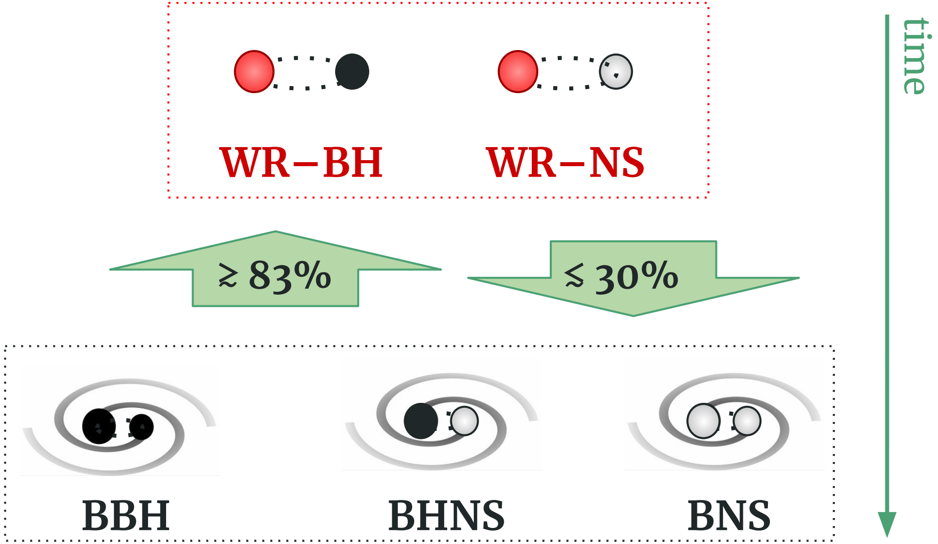
≲ 10-60 %



The conclusions

Most BCOs evolve from WR–COs …

but few WR–COs become BCOs



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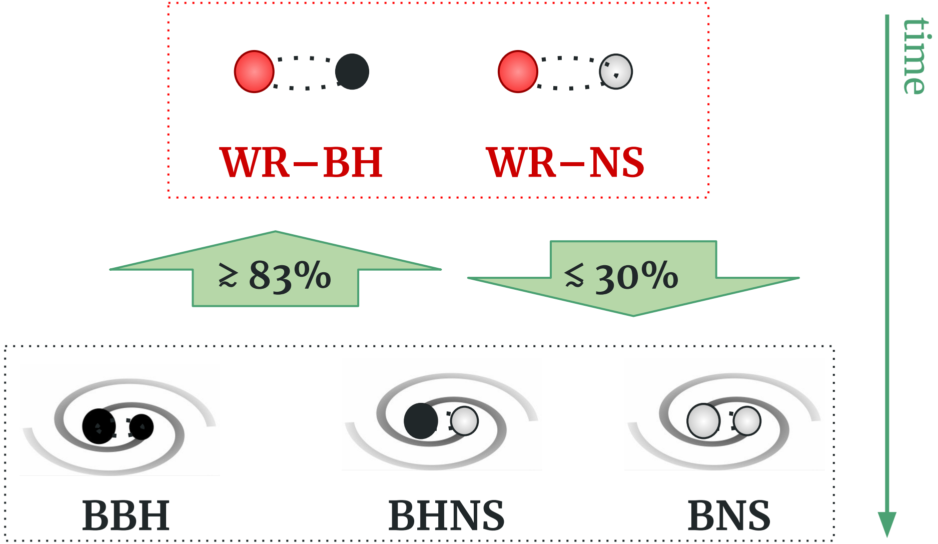
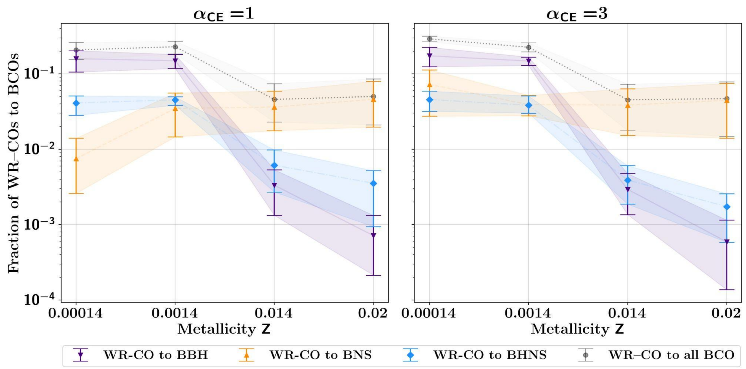


Parameter exploration



The conclusions

Most BCOs evolve from WR–COs ...

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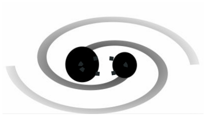
WR–BH

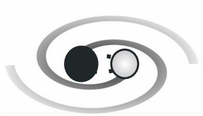
WR–NS

≳ 83%

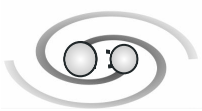
≲ 30%



BBH



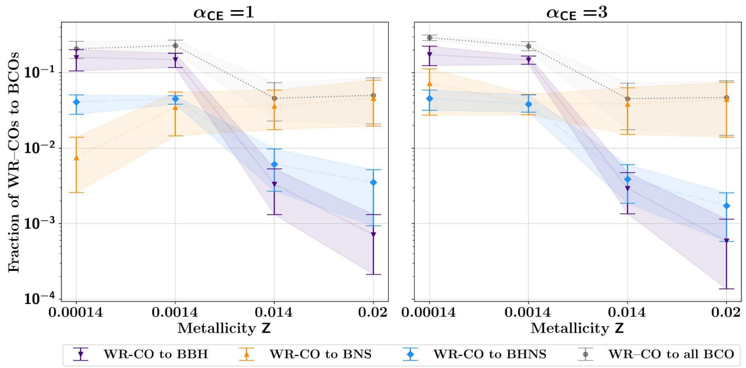
BHNS



BNS

time

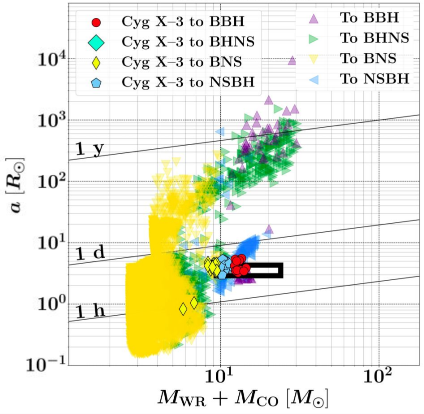
Parameter exploration



Cyg X-3

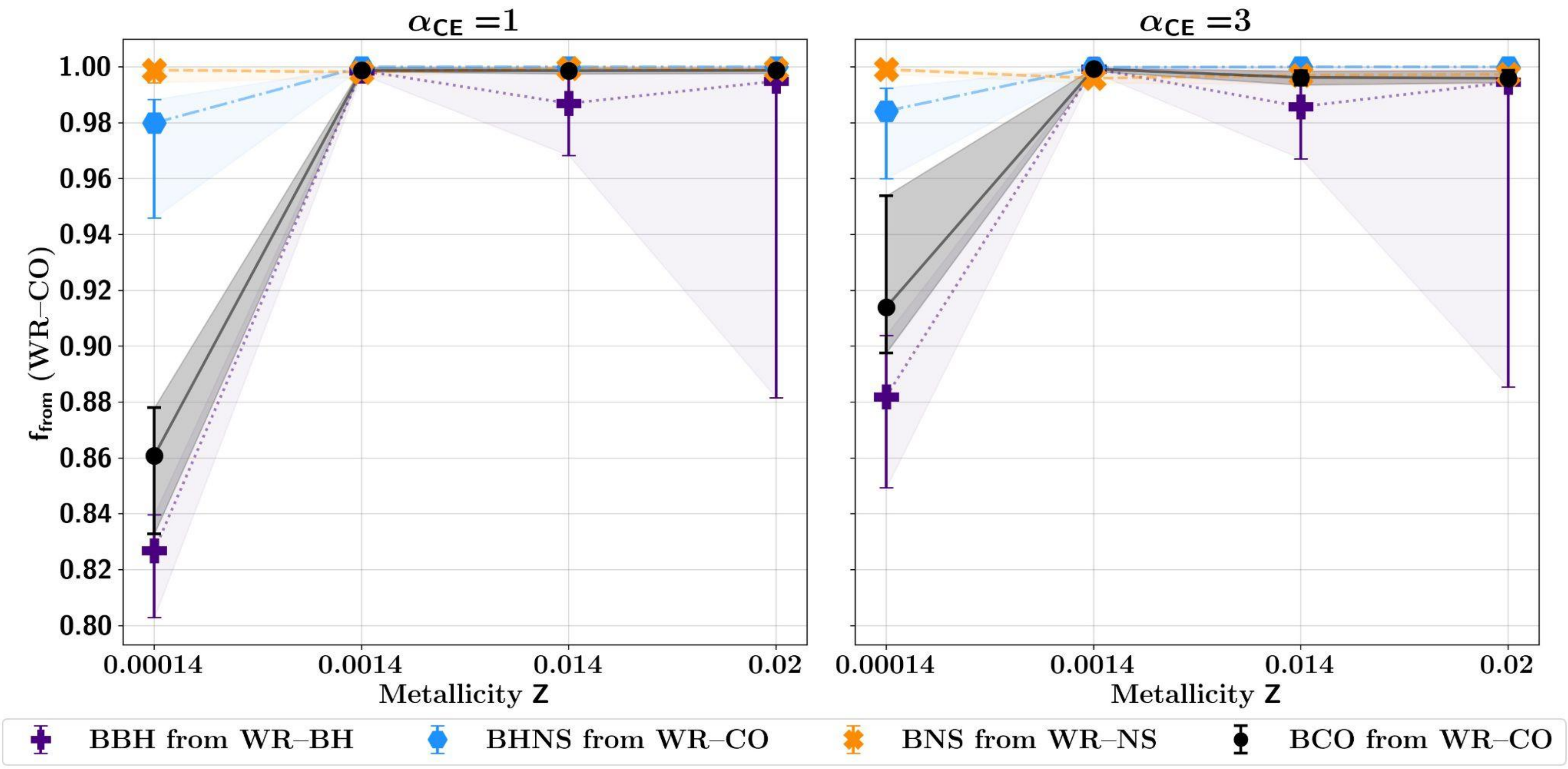
probable BCO progenitor

(especially if it is a WR–BH)



Backup slides

WR–COs: the key BCO progenitors



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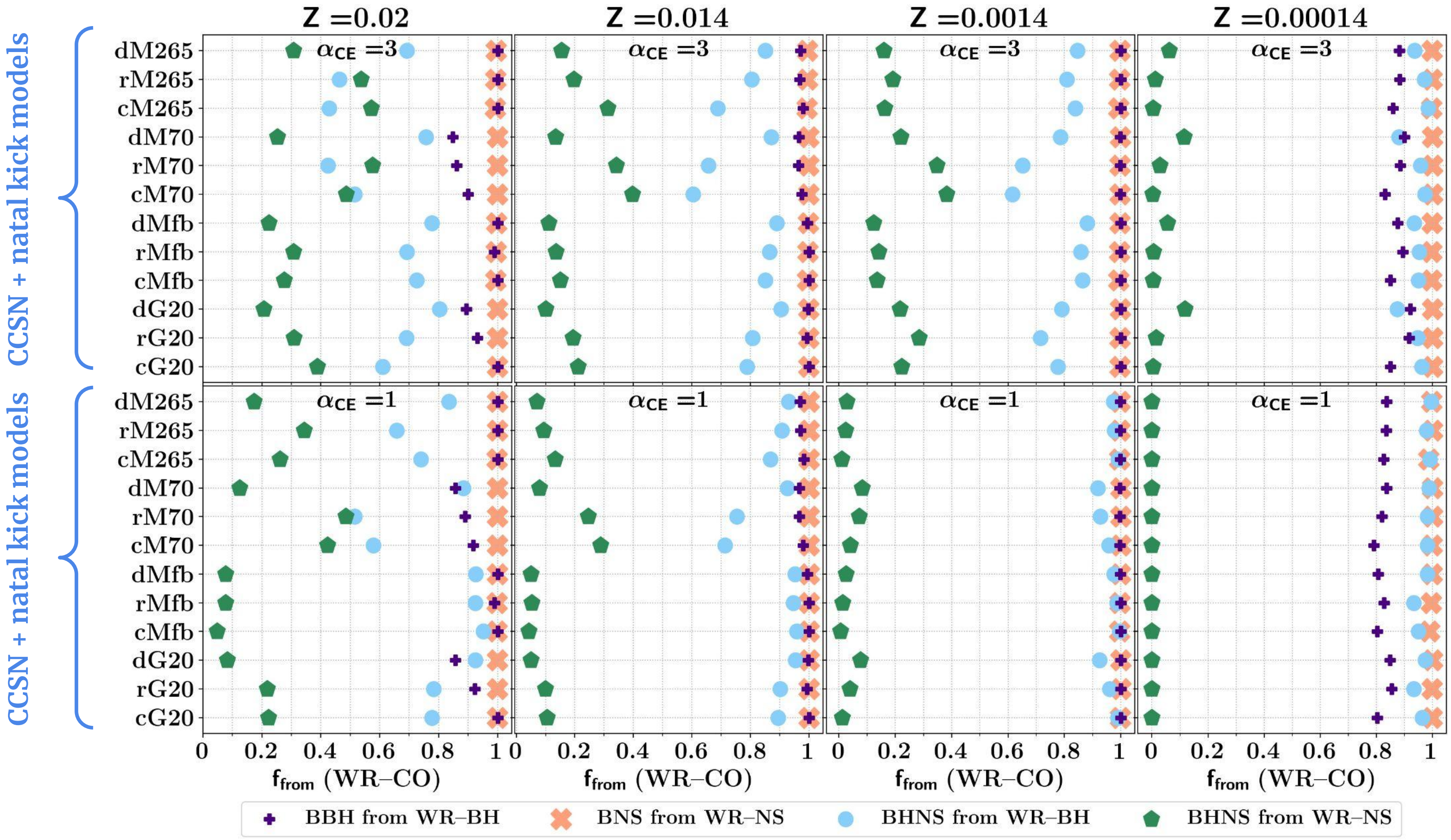
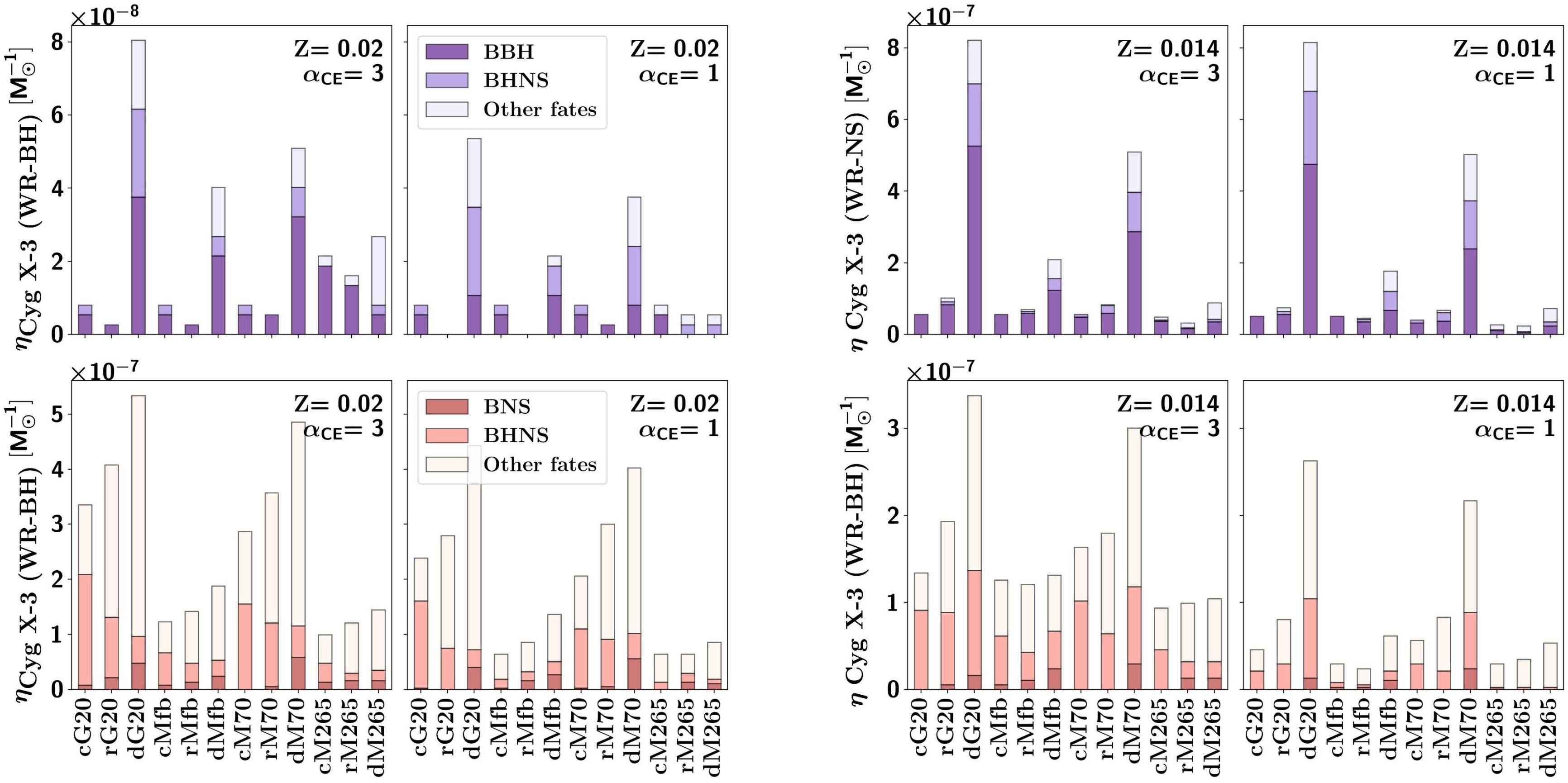
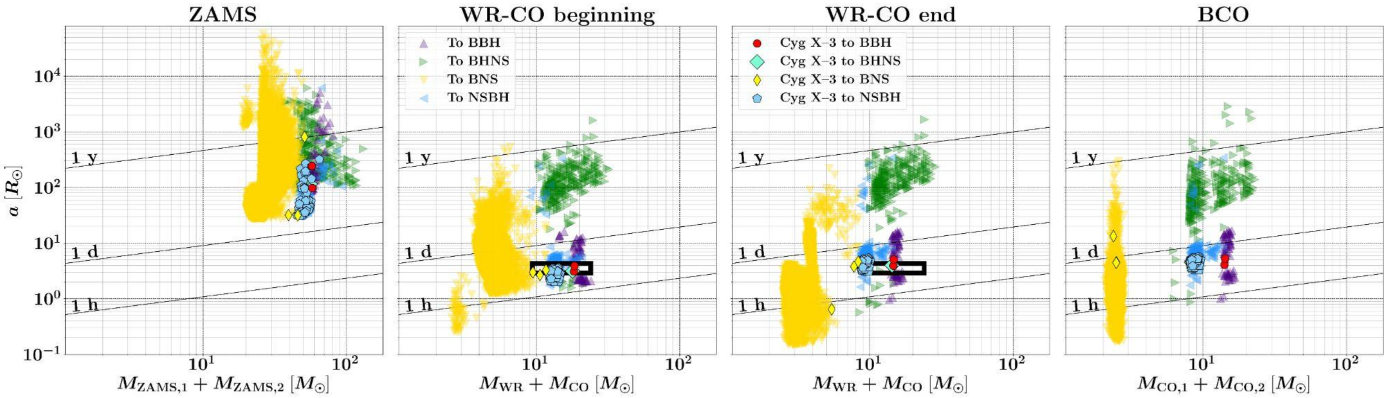


Cyg X-3: a promising BCO progenitor



Cyg X-3: changing the CCSN model

$\alpha_{CE} = 3$
Z=0.02

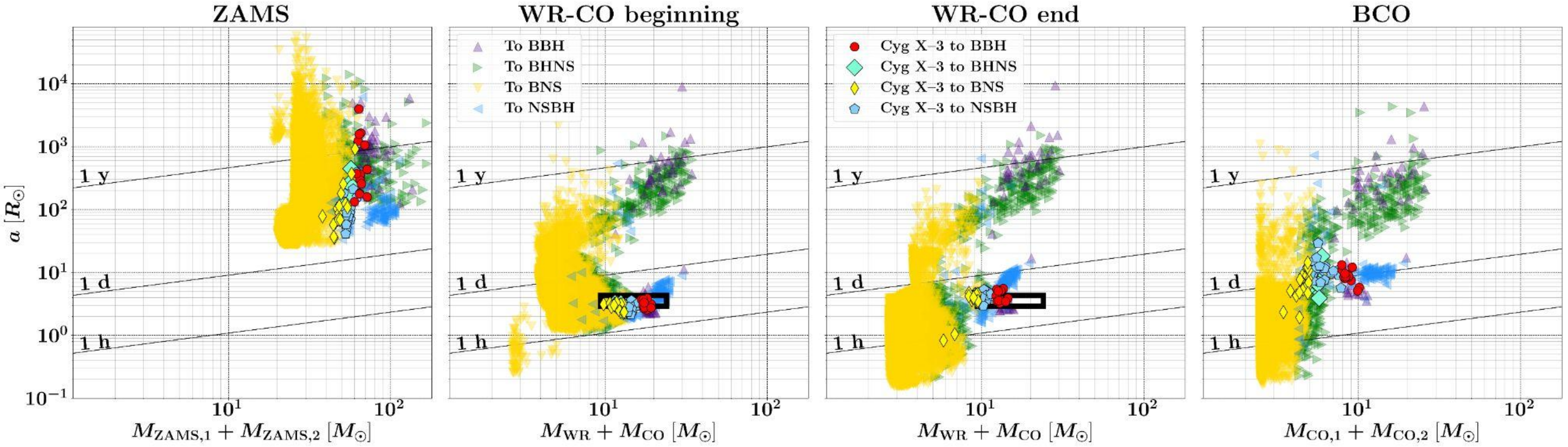


compactness

O'Connor&Ott 2011, Mapelli+2020

low-mass gap

"delayed", Fryer+2012



The 7 WR–CO candidates

Host galaxy	Name	M_{BH} [$M_\odot$]	M_{WR} [$M_\odot$]	P [hours]	t_{GW} [Gyr]	Z [$Z_\odot$]	d [Mpc]
Milky Way	Cyg X-3	3-10 [a]	8-14 [a]	4.8 [b]	0.02	0.92	0.00741
IC 10	IC10 X-1	- [c]	17-35 [d]	34.9 [e]	3.5	0.22	0.70
NGC 300	NGC300 X-1	13-21 [f]	15-26 [g]	32.8 [f]	2.9	0.19	2.02
NGC 253	CXOU J004732.0-251722.1	-	-	14.5 [h]	0.3	0.24	3.0
Circinus	CG X-1	-	-	7.2 [i]	0.05	0.10	4.2
M101	M101 ULX-1	8-46 [j]	17-19 [j]	196.8 [j]	348	0.17	6.9
NGC 4490	CXOU J123030.3+413853	-	-	6.4 [k]	0.04	0.23	8.55

[a] Koljonen et al. 2017 [b] Singh et al. 2002 [c] S. G. T. Laycock et al. 2015
[d] Clark et al. 2004 [e] Silverman et al. 2008 [f] Binder et al. 2021
[g] P. A. Crowther et al. 2010 [h] Maccarone et al. 2014
[i] Esposito et al. 2015 [j] Liu et al. 2013 [k] Esposito et al. 2013

Based on Esposito et al. 2015

Natal kicks

Hobbs+2005, Atri+2019

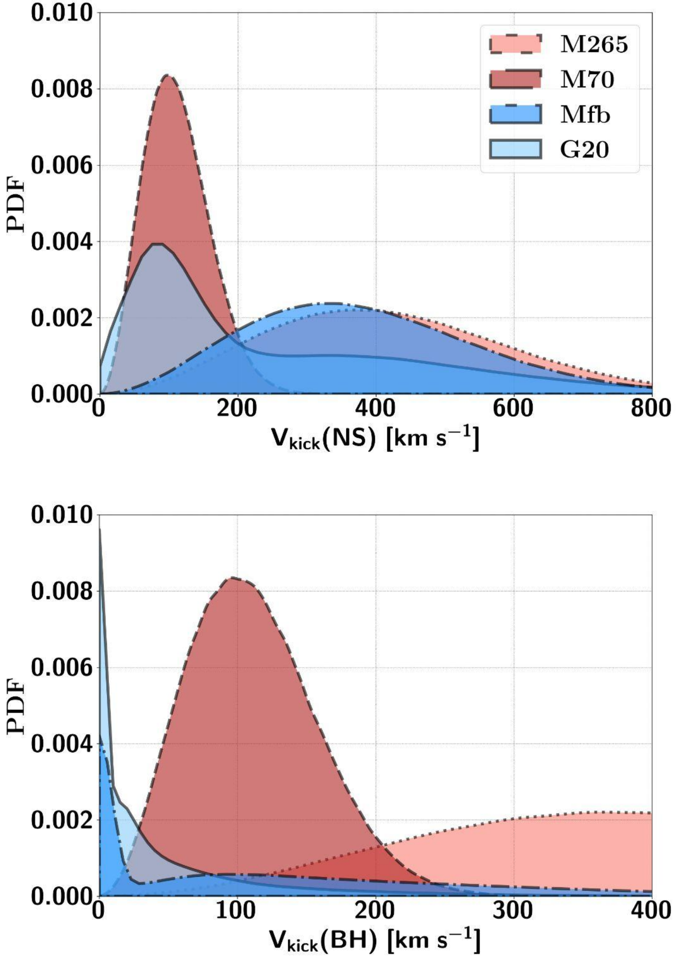
$$v_{kick} = f_{\sigma}$$

Fryer+2012

$$v_{kick} = f_{\sigma=265}\,(1 - f_{fb,CCSN})$$

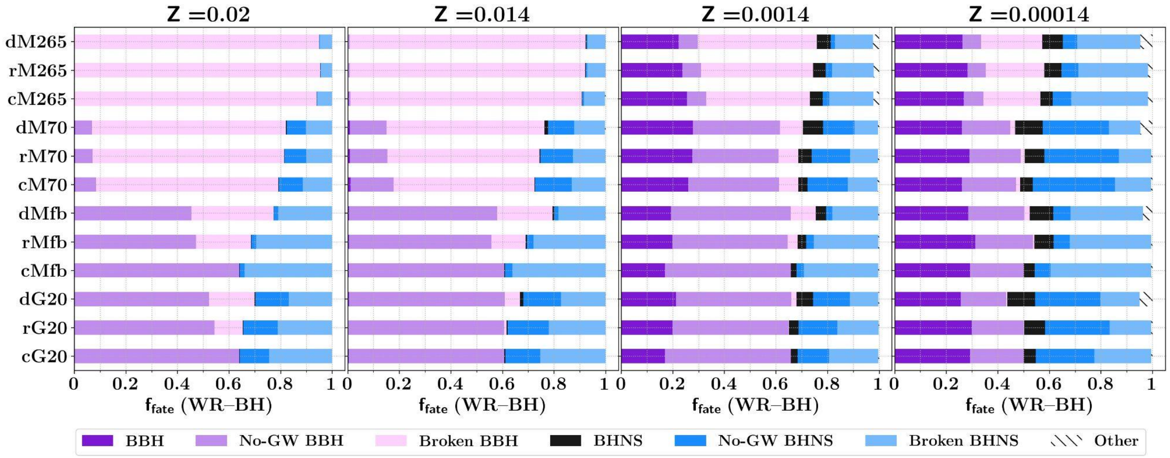
Giacobbo & Mapelli 2020

$$v_{kick} = f_{\sigma=265}\,\frac{\langle M_{NS}\rangle}{M_{rem}}\,\frac{M_{NS}}{\langle M_{ej}\rangle}$$



WR-COs to BCOs: role of metallicity and natal kicks

CCSN + natal kick models



$\alpha_{CE} = 3$

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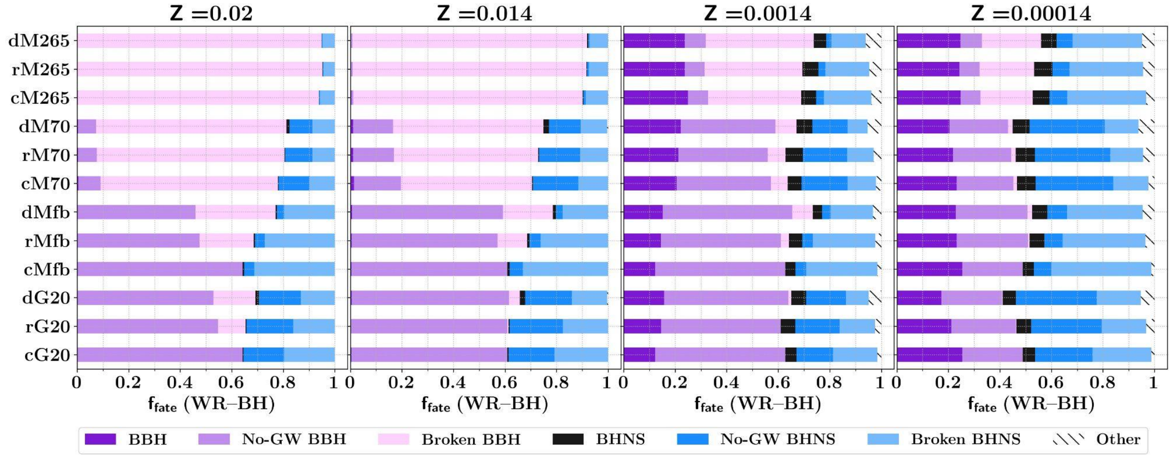
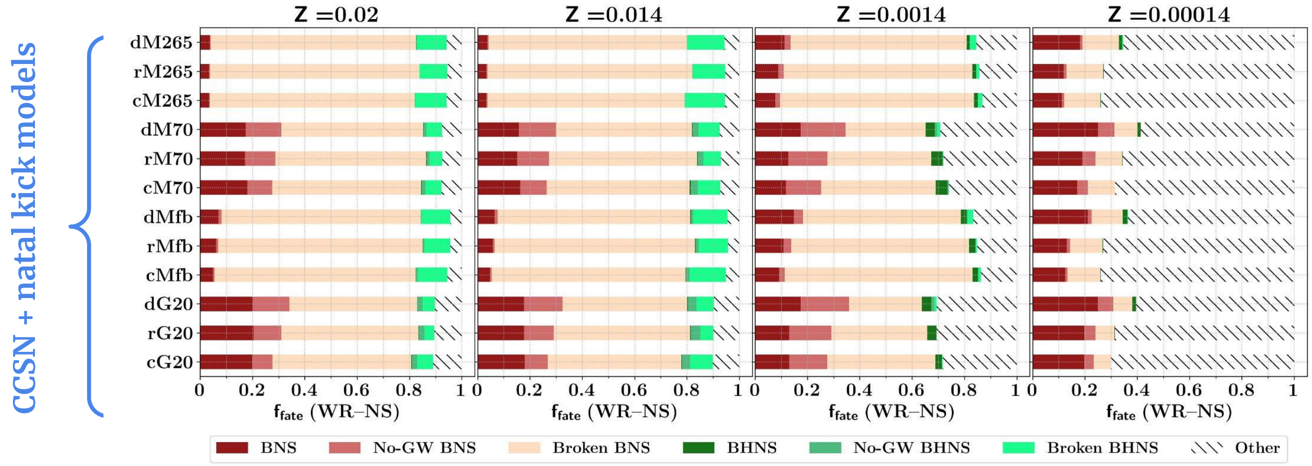


$\alpha_{CE} = 1$

WR–NSs to BCOs: role of metallicity and natal kicks



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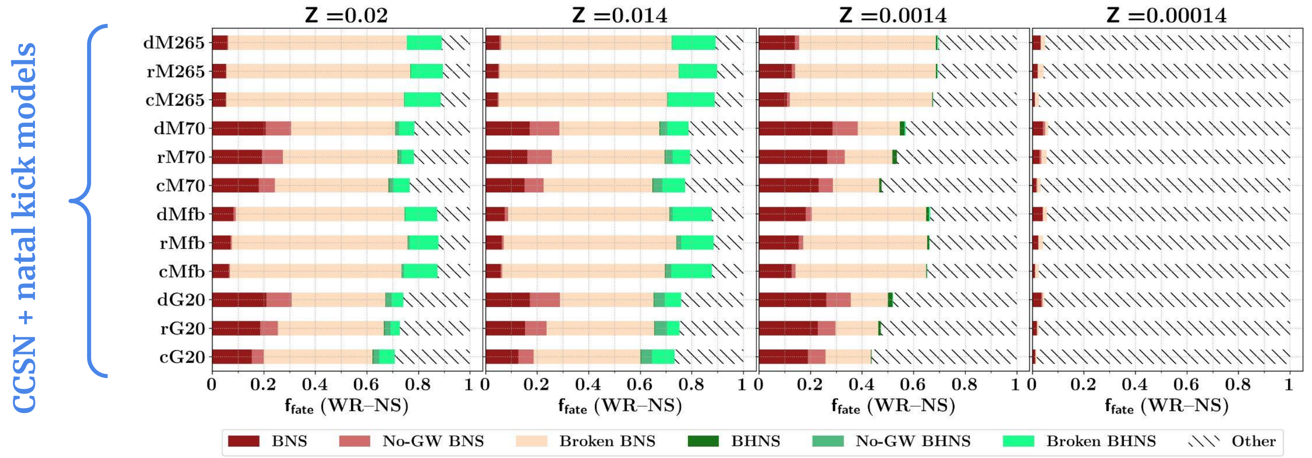
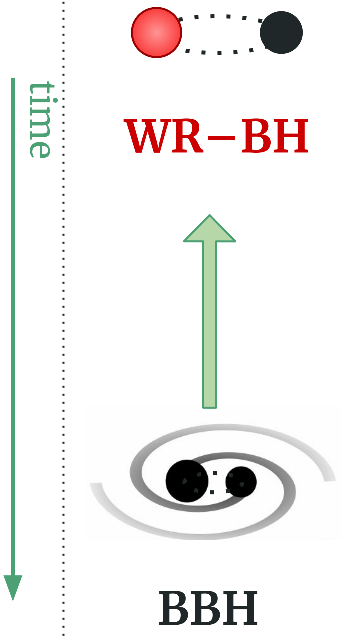


$\alpha_{CE} = 1$

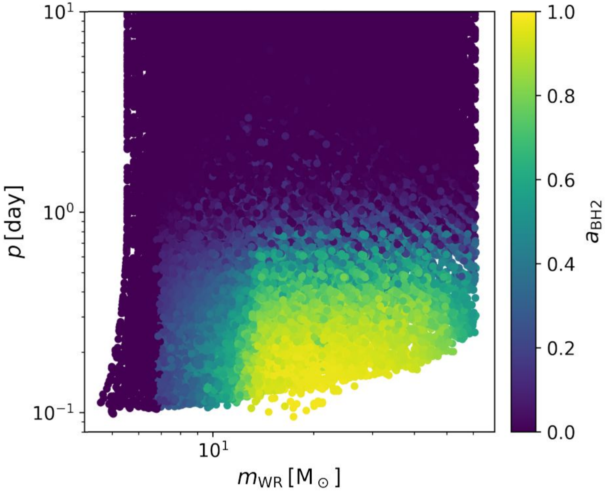
The results: Spins

Most BBHs from WR−BHs



+

Spin model for BBHs from WR−BHs

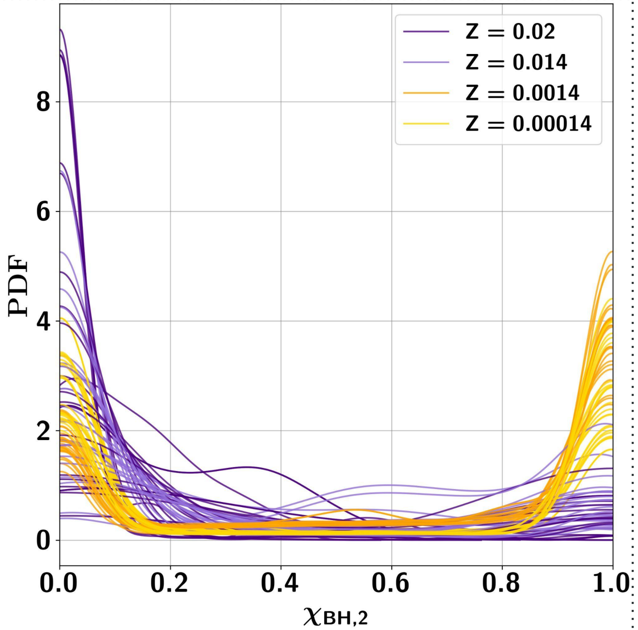


Bavera+2021

$$\chi_{BH} = \begin{cases} f(P, M_{WR}) & P \leq \ 1 \text{ day} \\ 0 & \text{otherwise} \end{cases}$$

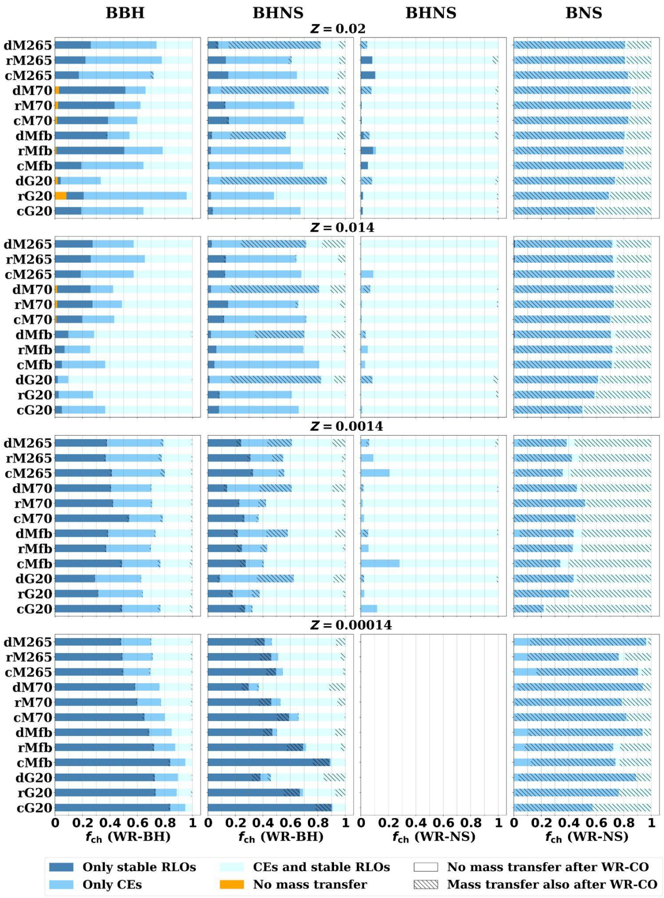
=

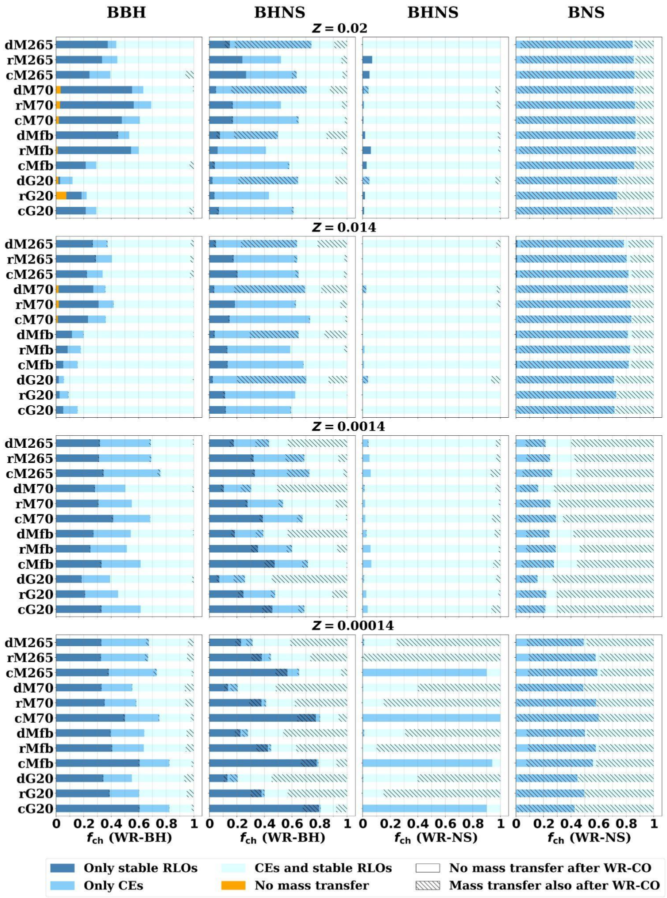
Prediction of BH spin distribution



Mass transfer: stable or unstable?

$\alpha_{CE} = 1$





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