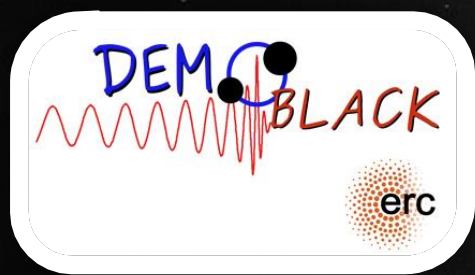


CHEMICALLY HOMOGENEOUS EVOLUTION:

IMPACT ON STELLAR POPULATION & COMPACT BINARY MERGERS

Marco Dall'Amico

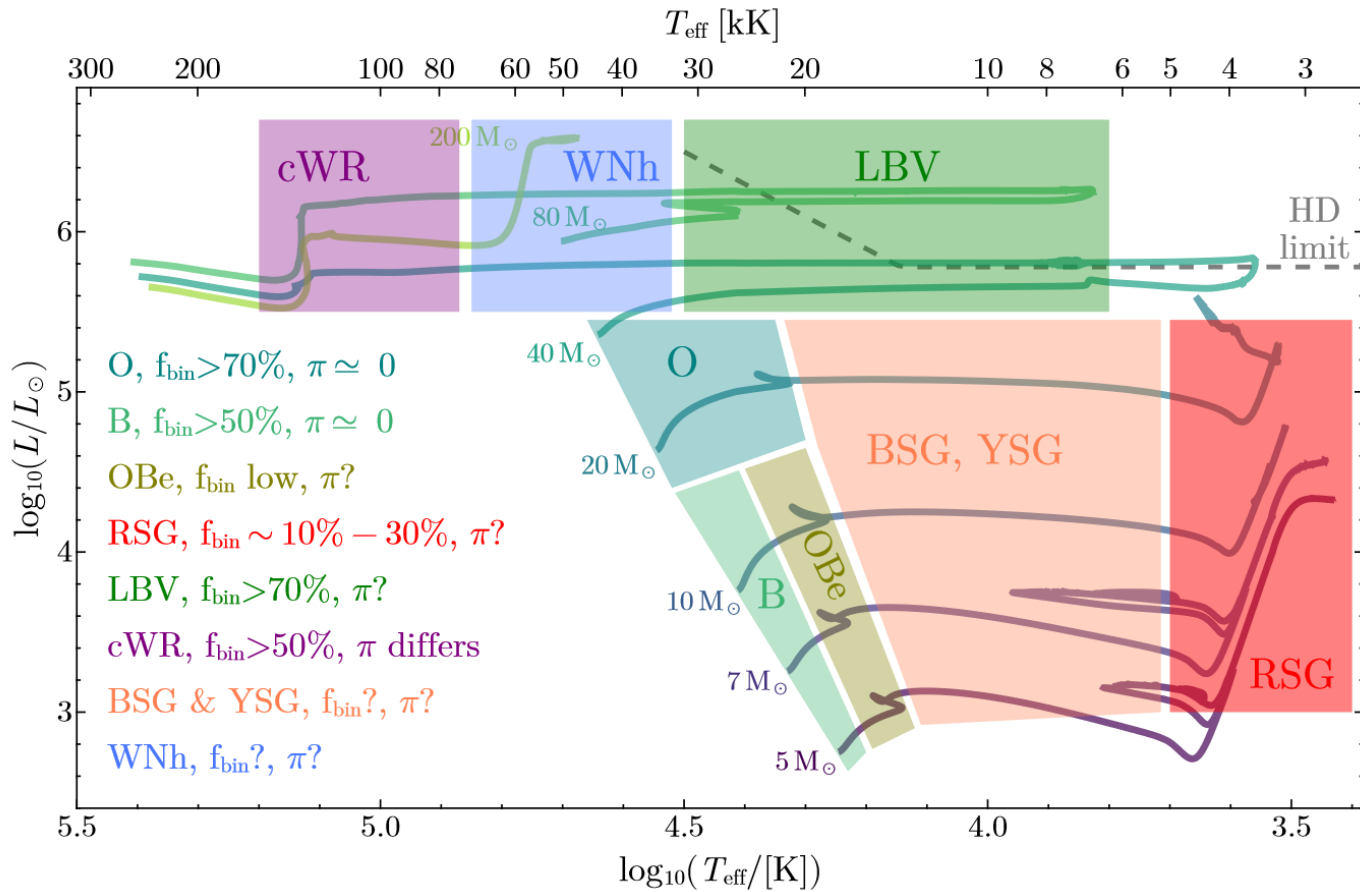


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DEGLI STUDI
DI PADOVA

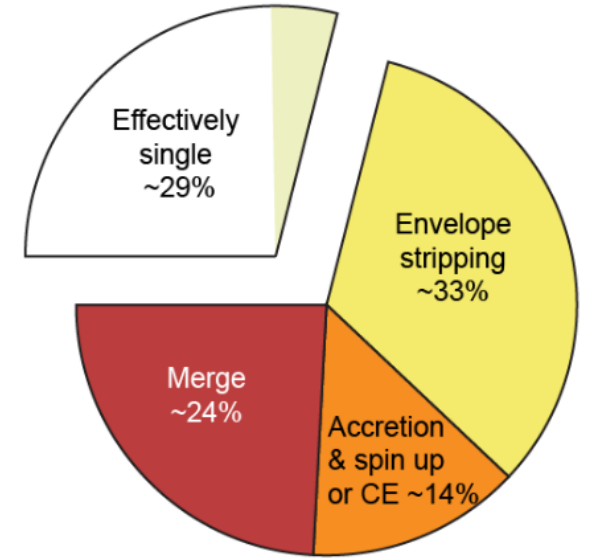


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HEIDELBERG
ZUKUNFT
SEIT 1386

MASSIVE STARS: BETTER TOGETHER

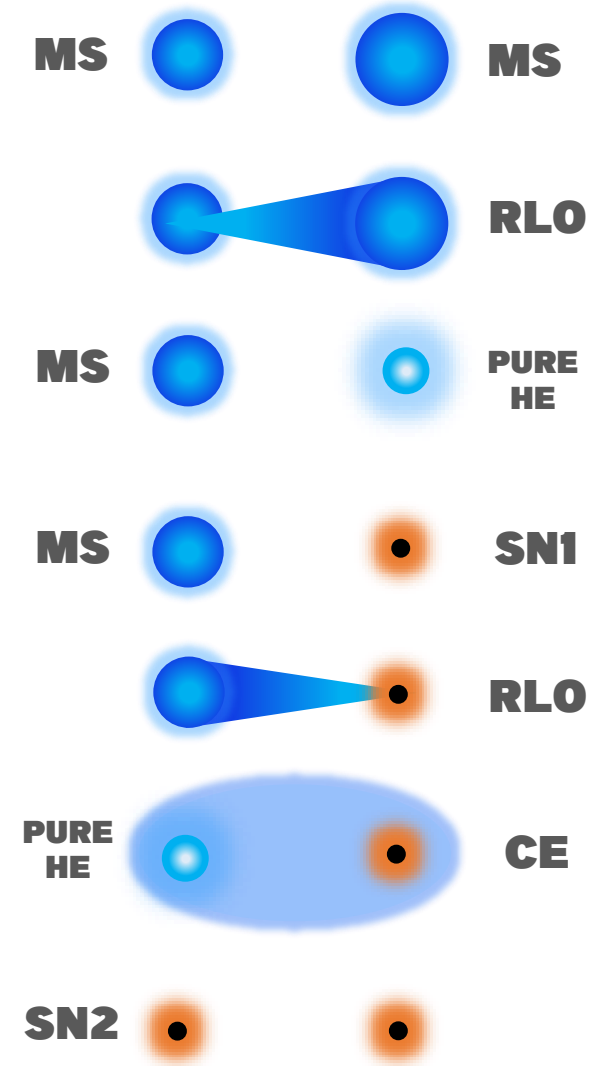


From Marchant & Bodensteiner 2024



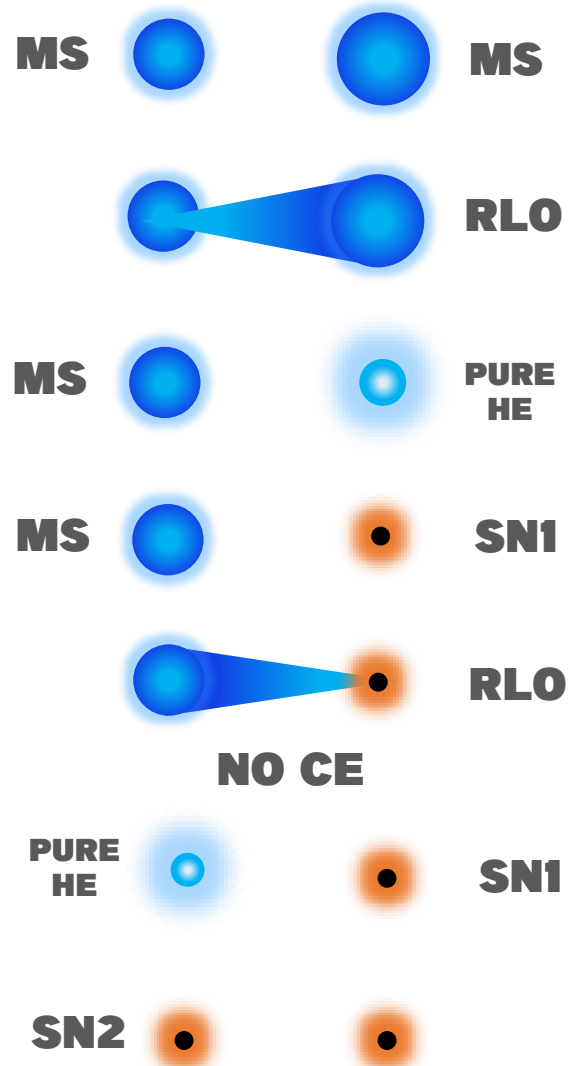
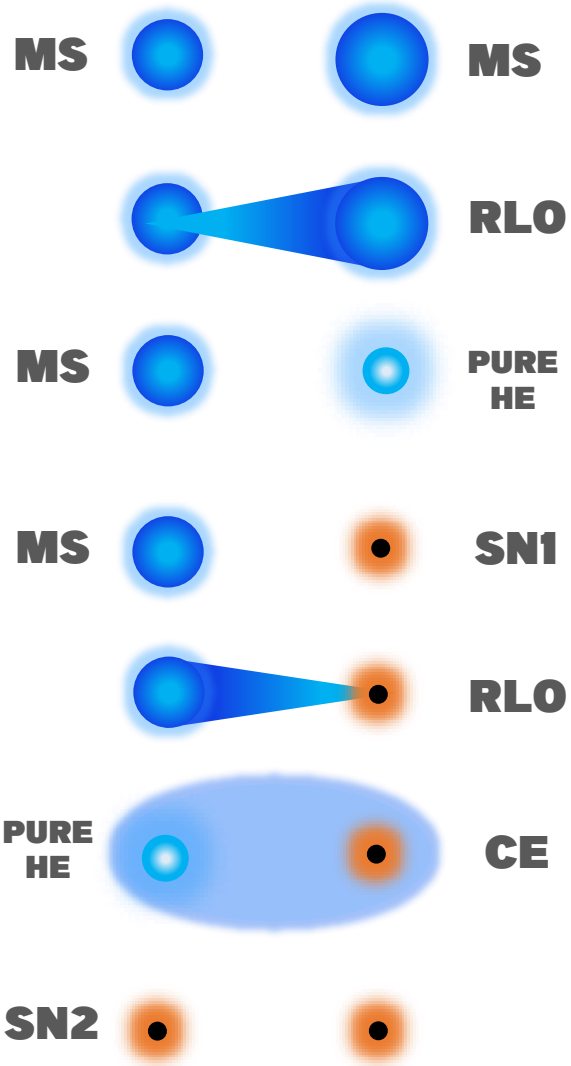
From Sana et al. 2012

CHANNEL 1



CHANNEL 1

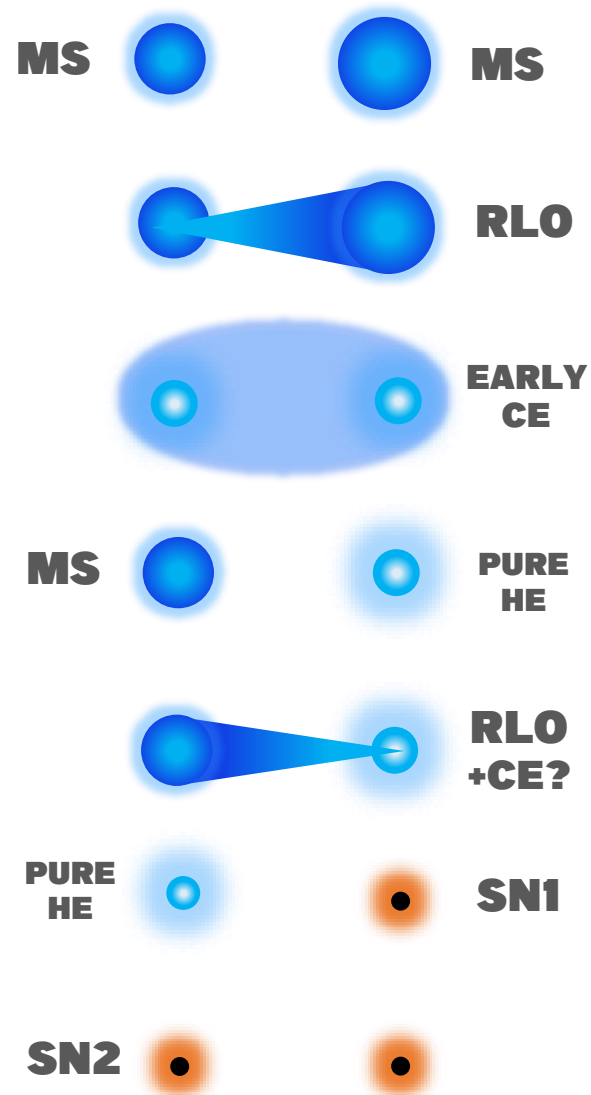
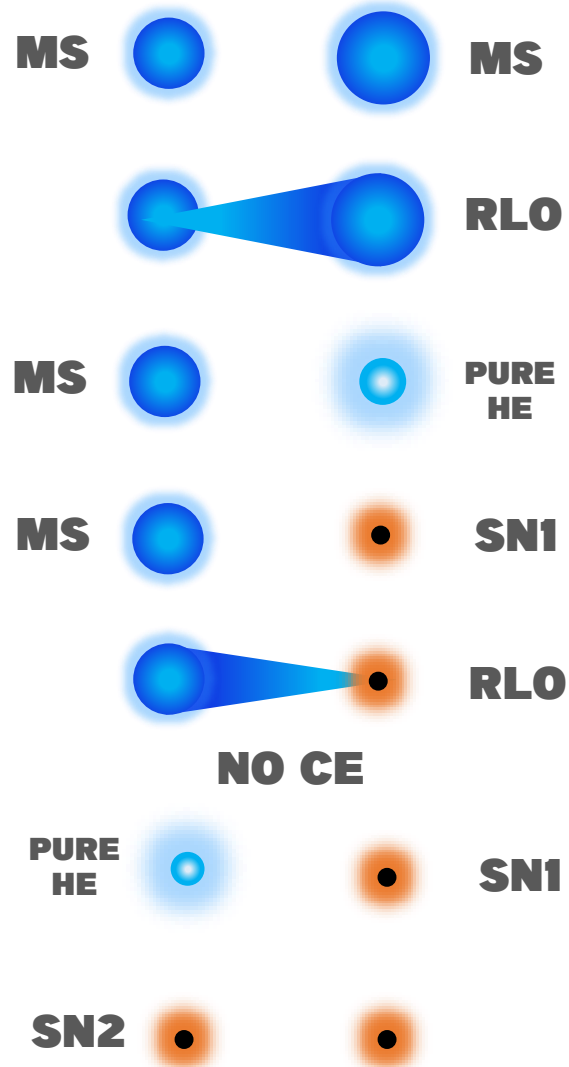
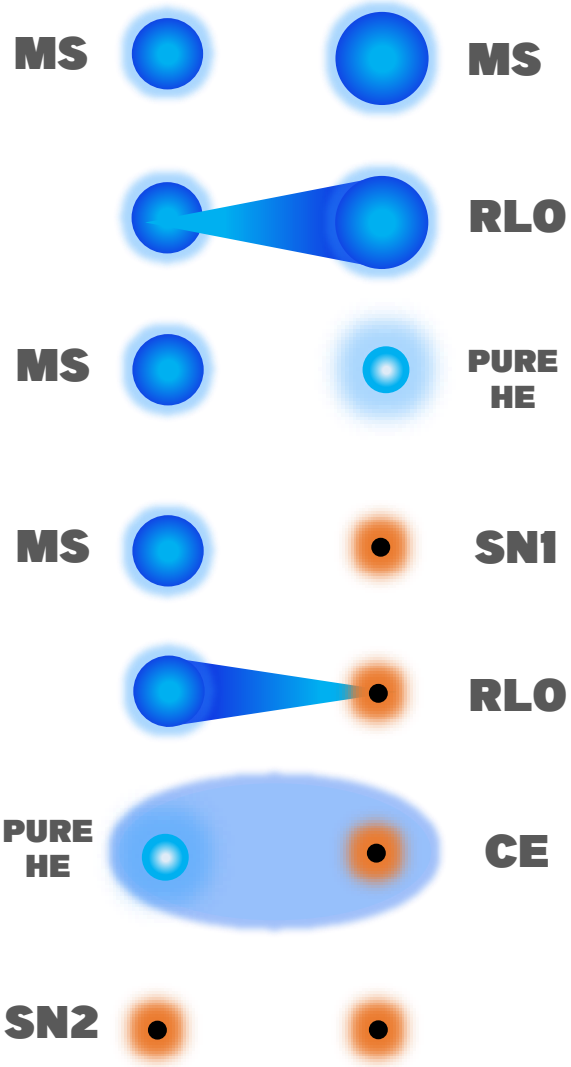
CHANNEL 2



CHANNEL 1

CHANNEL 2

CHANNEL 3

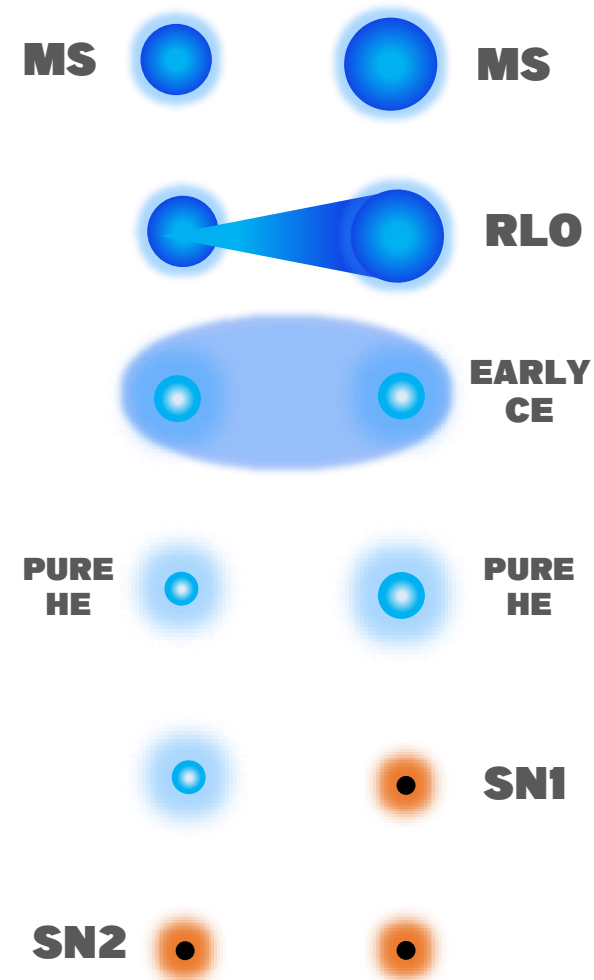
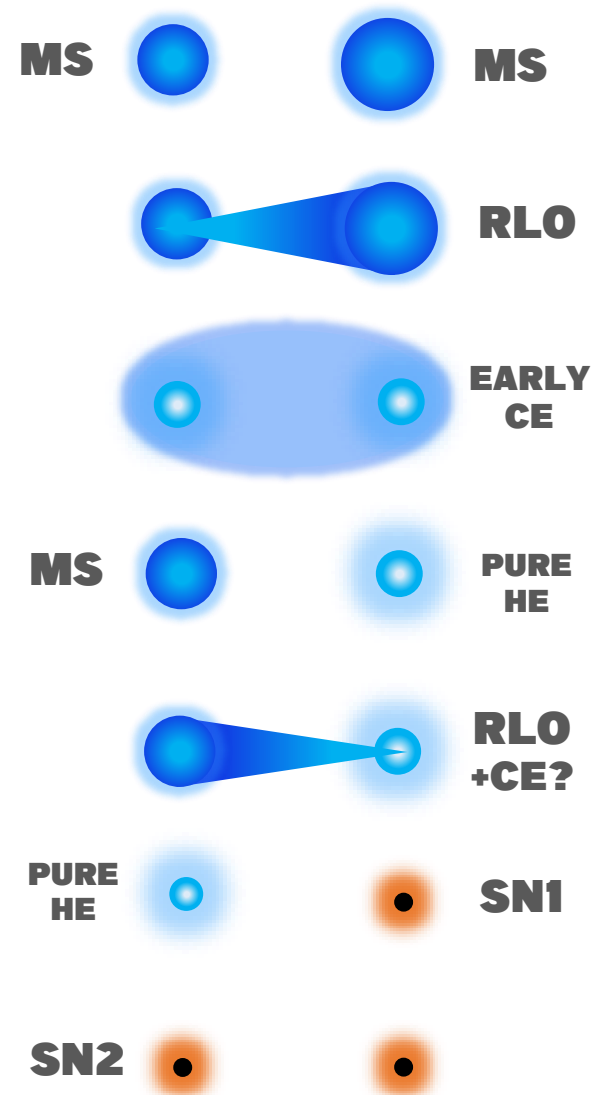
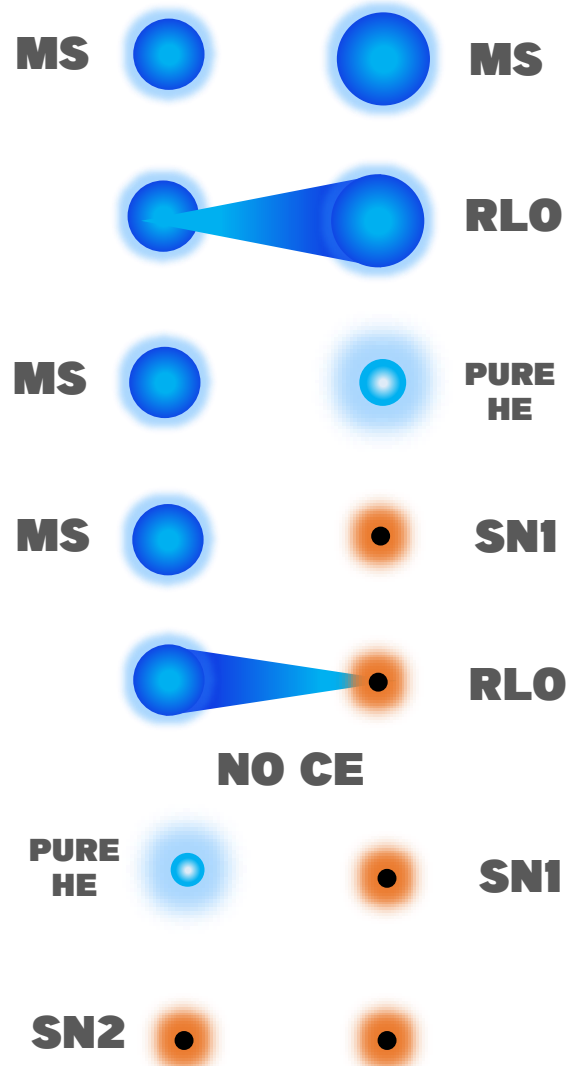
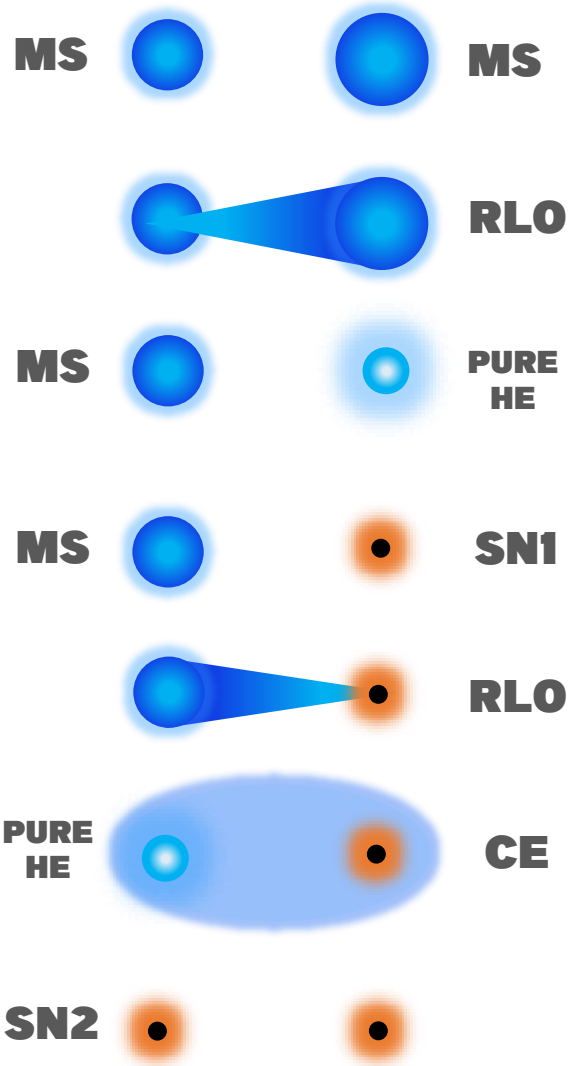


CHANNEL 1

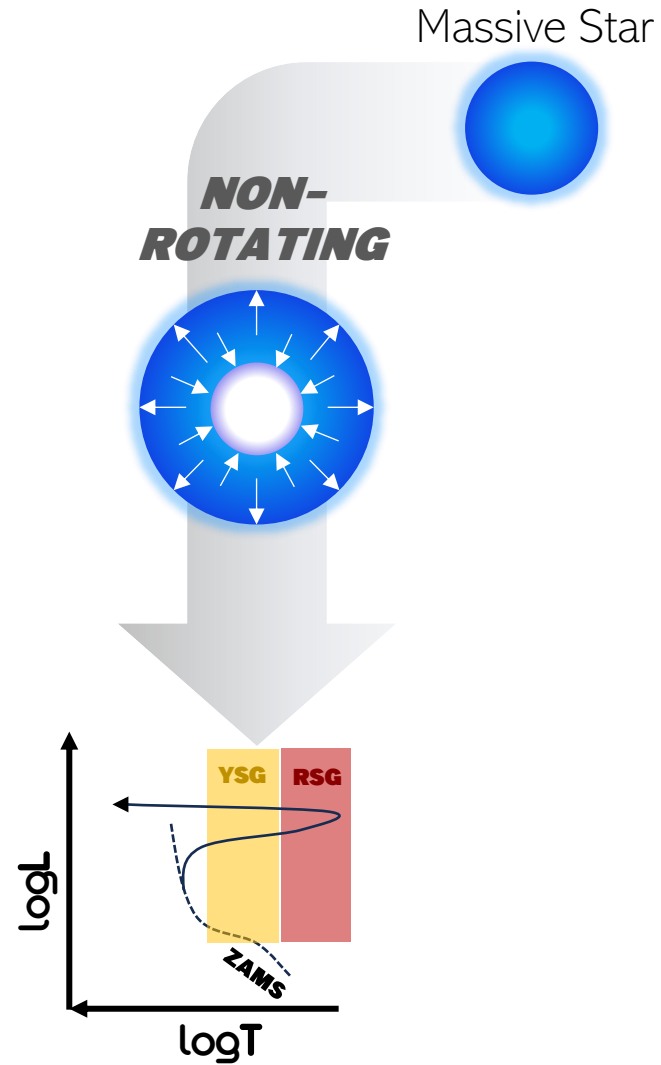
CHANNEL 2

CHANNEL 3

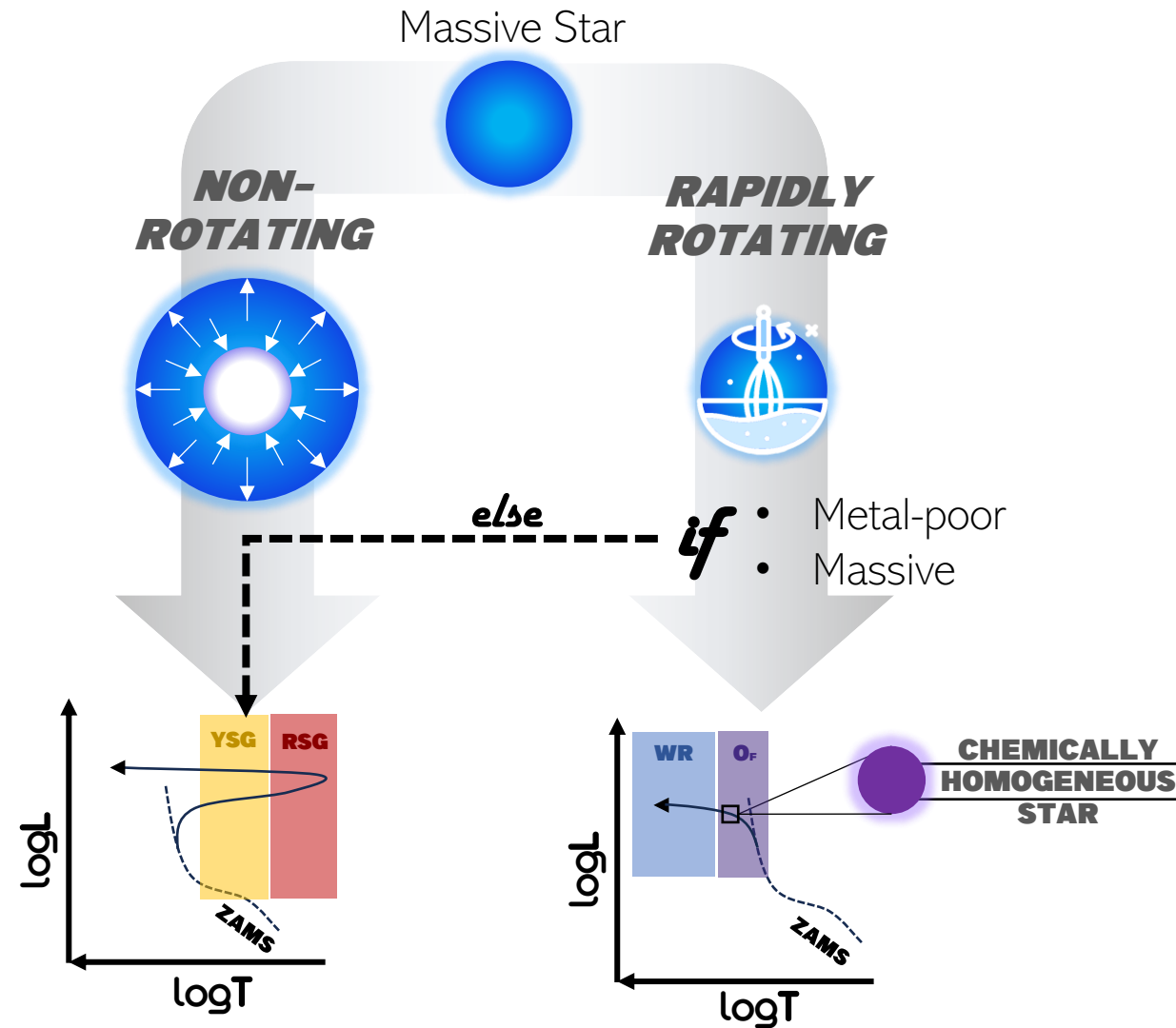
CHANNEL 4



CHEMICALLY HOMOGENEOUS EVOLUTION



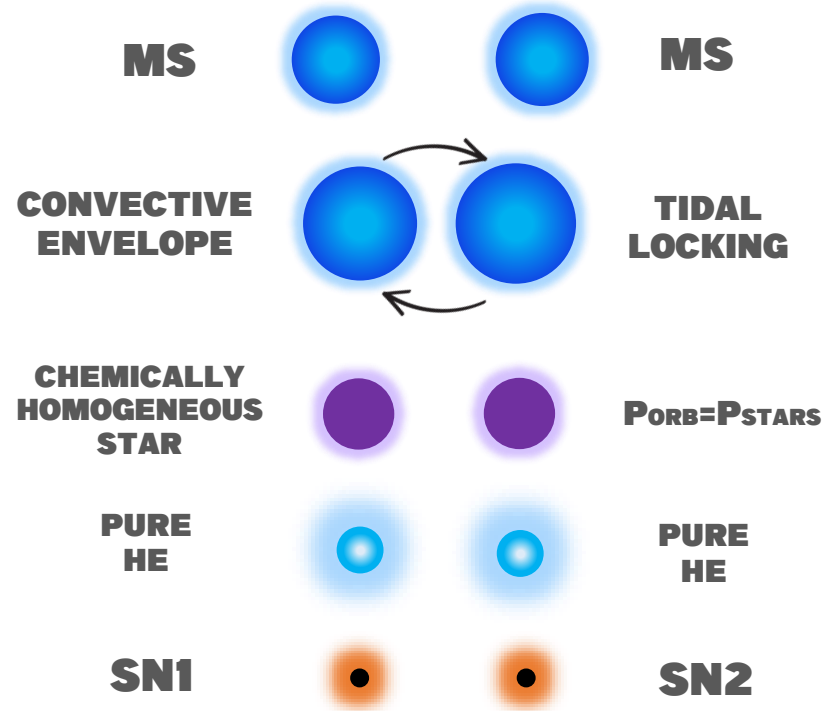
CHEMICALLY HOMOGENEOUS EVOLUTION



CHEMICALLY HOMOGENEOUS EVOLUTION

TIDAL - INDUCED MIXING

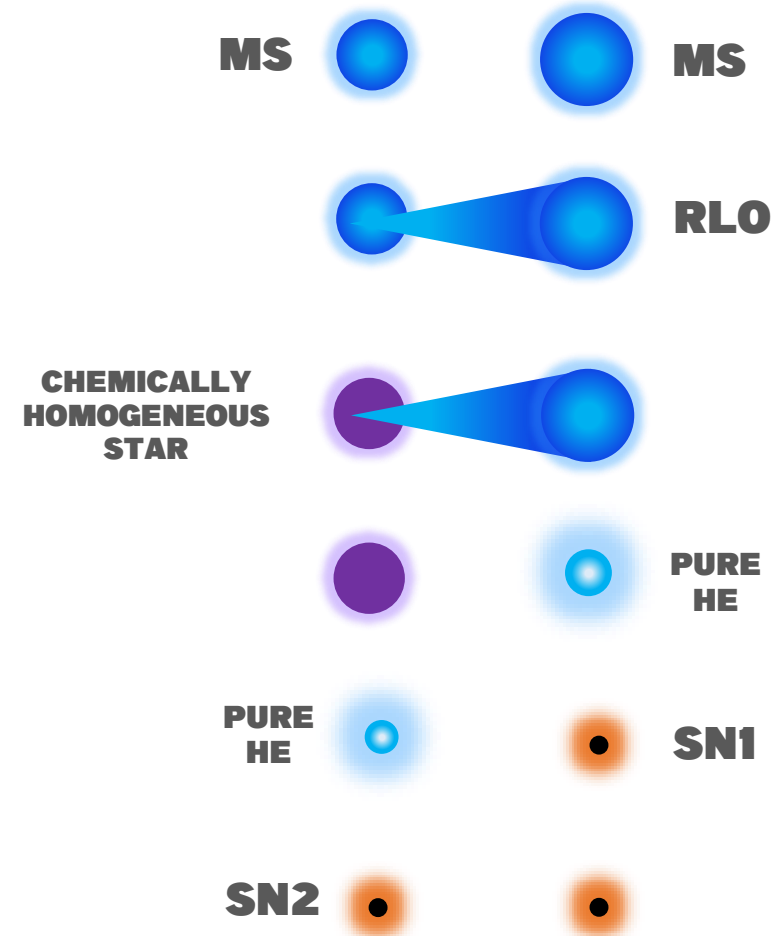
(e.g. De Mink 2009, Song et al. 2016)



- **Nearly equal-mass stars**
- **Short orbital period**

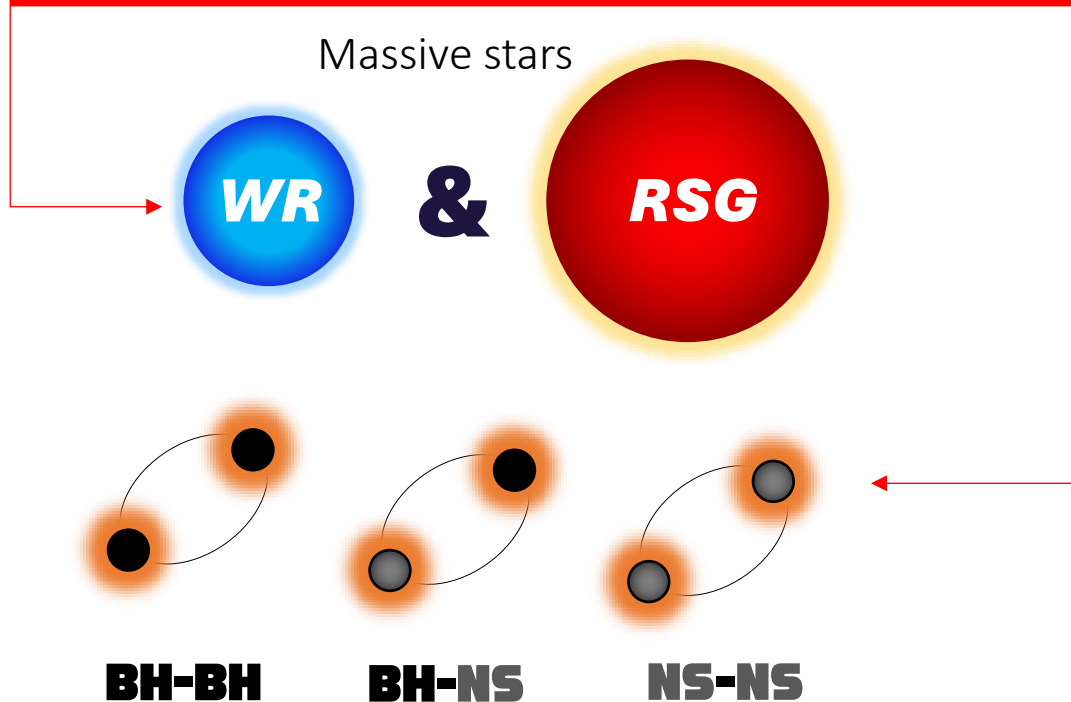
ACCRETION-INDUCED MIXING

(e.g. Pols et al. 1991, Eldridge et al. 2011)



CHEMICALLY HOMOGENEOUS EVOLUTION EFFECTS ON

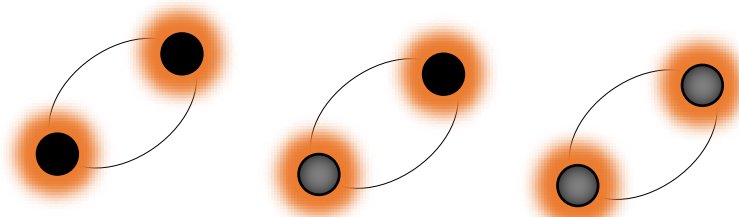
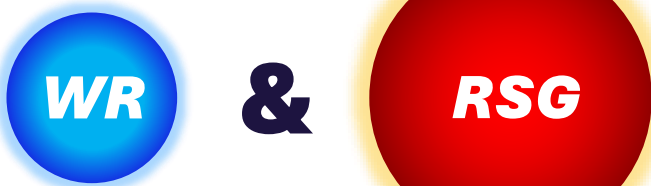
- ***Stellar population***
- ***Compact binary systems***



CHEMICALLY HOMOGENEOUS EVOLUTION EFFECTS ON

- **Stellar population**
- **Compact binary systems**

Massive stars



BH-BH

BH-NS

NS-NS

10⁸ BINARY - 10⁷ SINGLE SIMULATIONS WITH



PARSEC

PAdova TRIeste Stellar Evolutionary Code

Bressan+2012; Chen+2015;
Costa+2019,2021

lorio+2023

CHE: Accretion spin up as in Eldridge+2011

if

- **LOW METALLICITY**
($Z \leq 0.004$)
- **LARGE ACCRETED MASS**
($> 5\%$ of initial mass)
- **MASSIVE STAR**
($M > 15 M_{\odot}$)

MODEL W/O
CHE

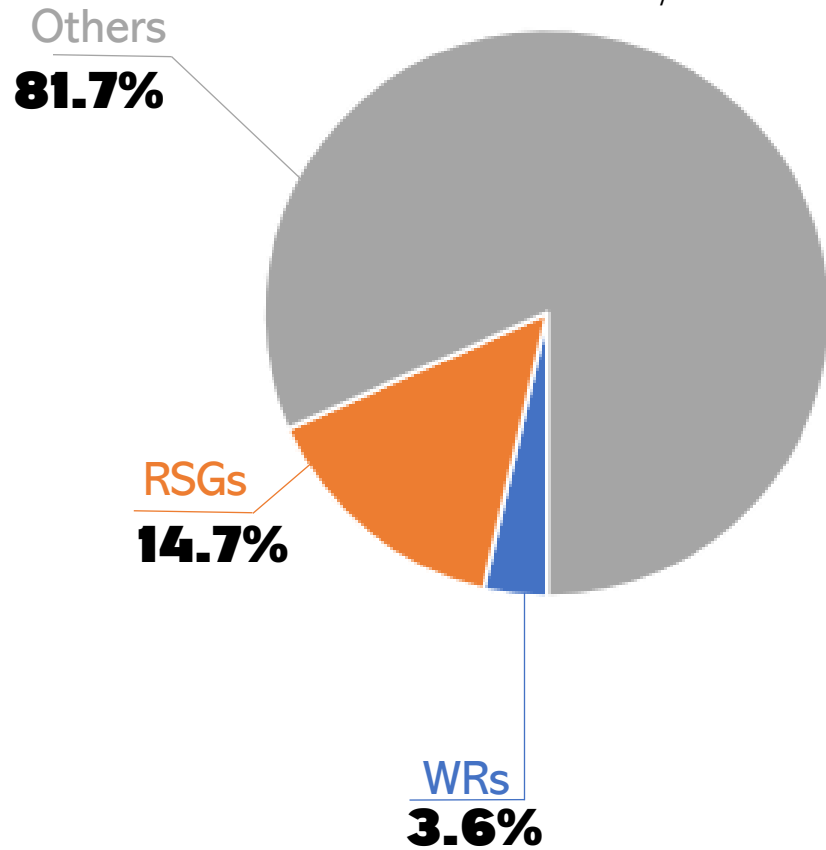
MODEL WITH
CHE

MODEL W/O
CHE

MODEL WITH
CHE **BINARIES EXP. CHE**
15% $Z=0.001$

MODEL W/O CHE

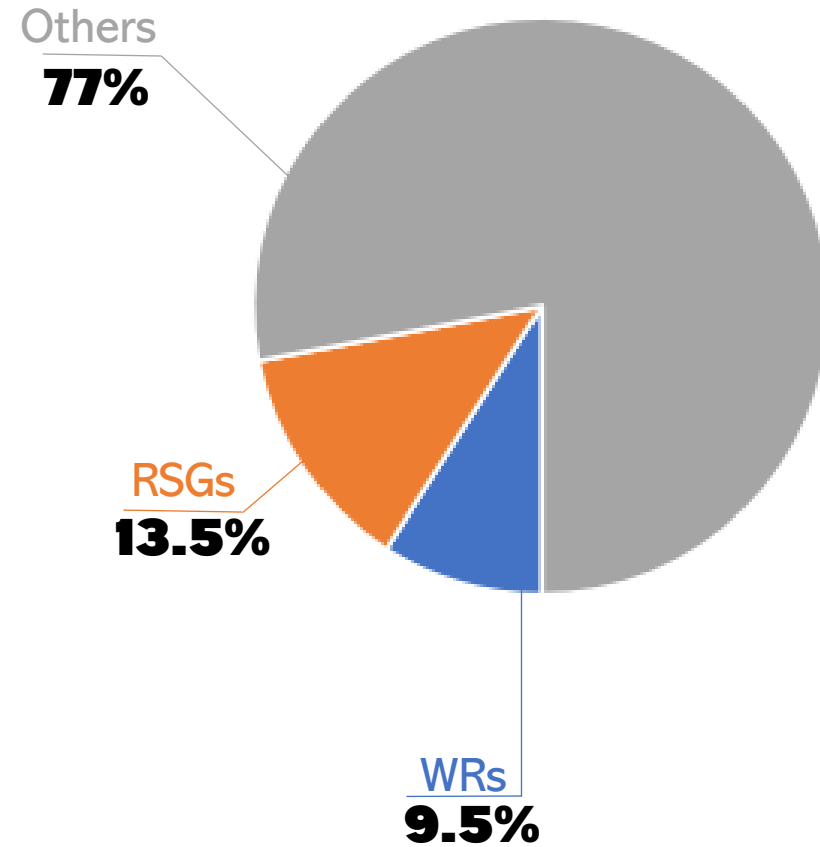
Fractions of stellar phases:



MODEL WITH CHE

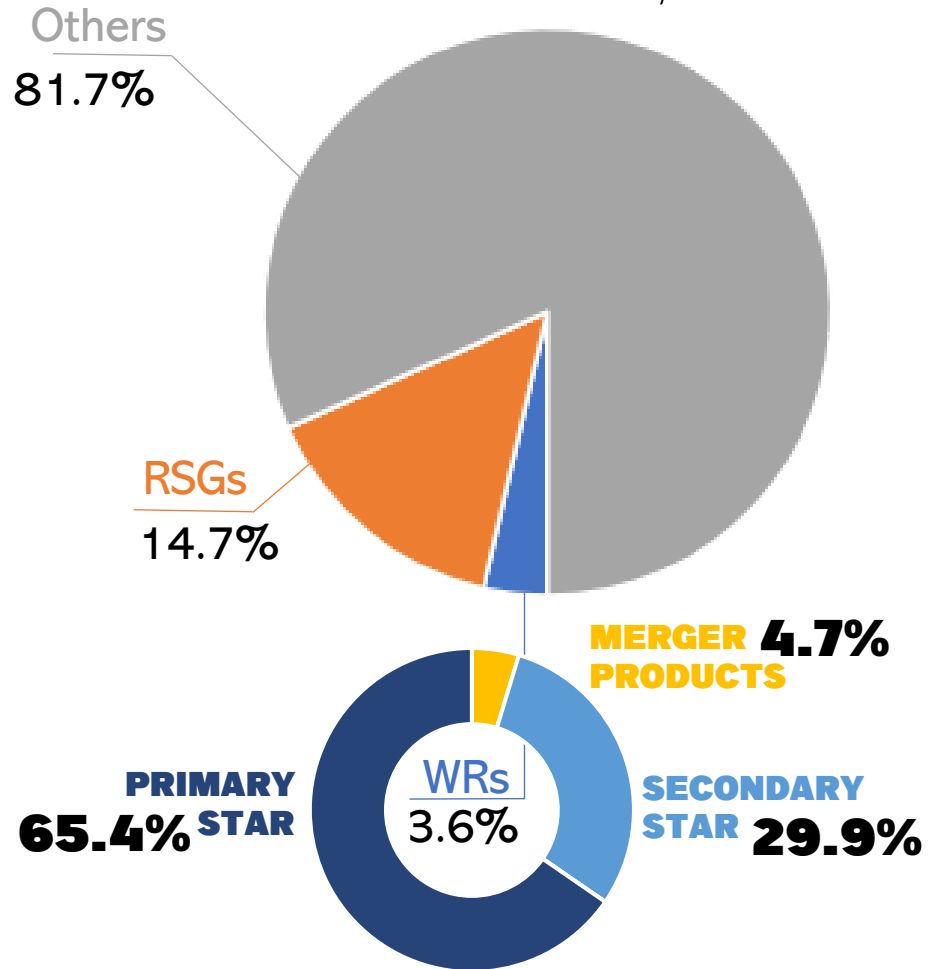
BINARIES EXP. CHE
15% Z=0.001

Fractions of stellar phases:



MODEL W/O CHE

Fractions of stellar phases:

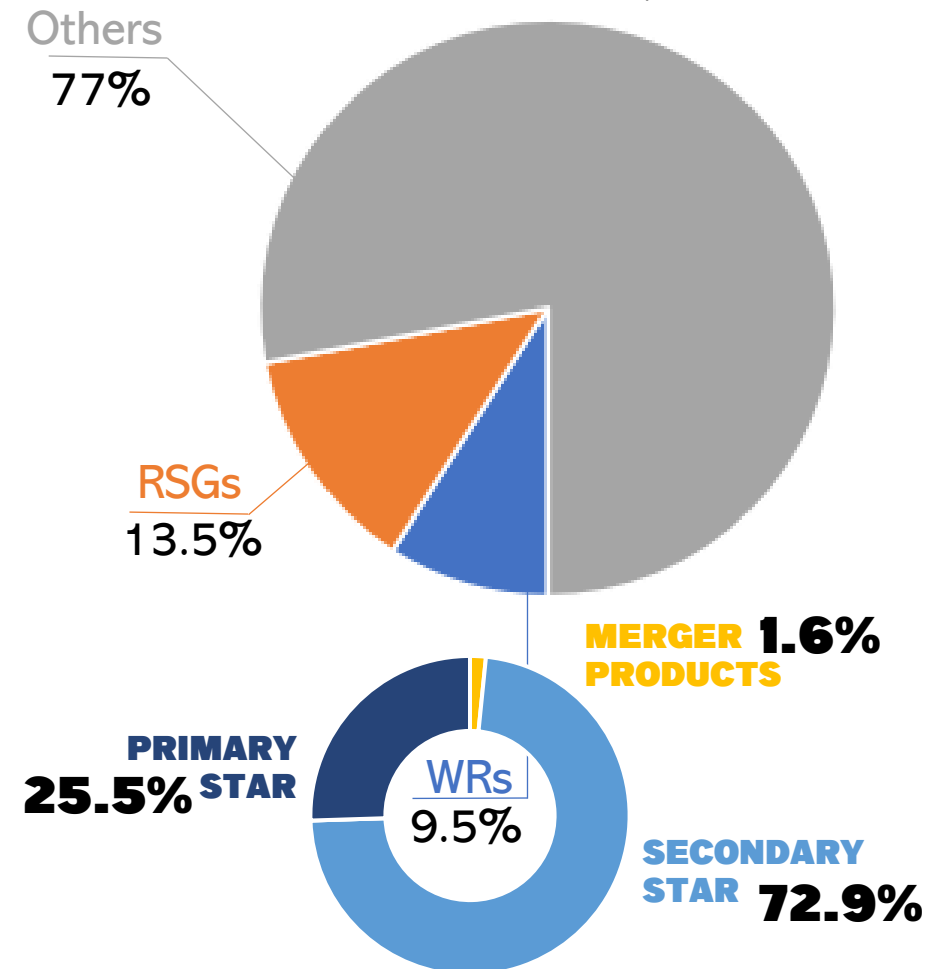


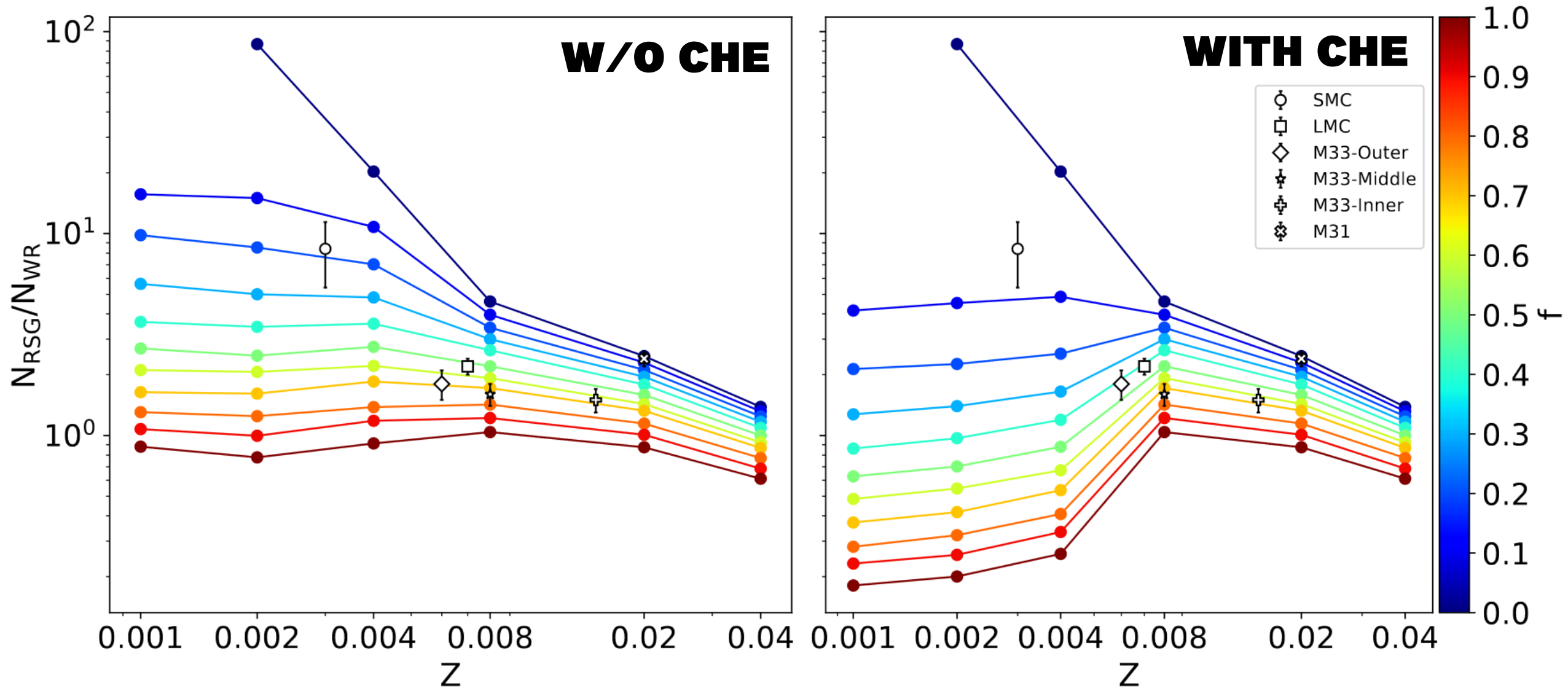
MODEL WITH CHE

BINARIES EXP. CHE

15% $Z=0.001$

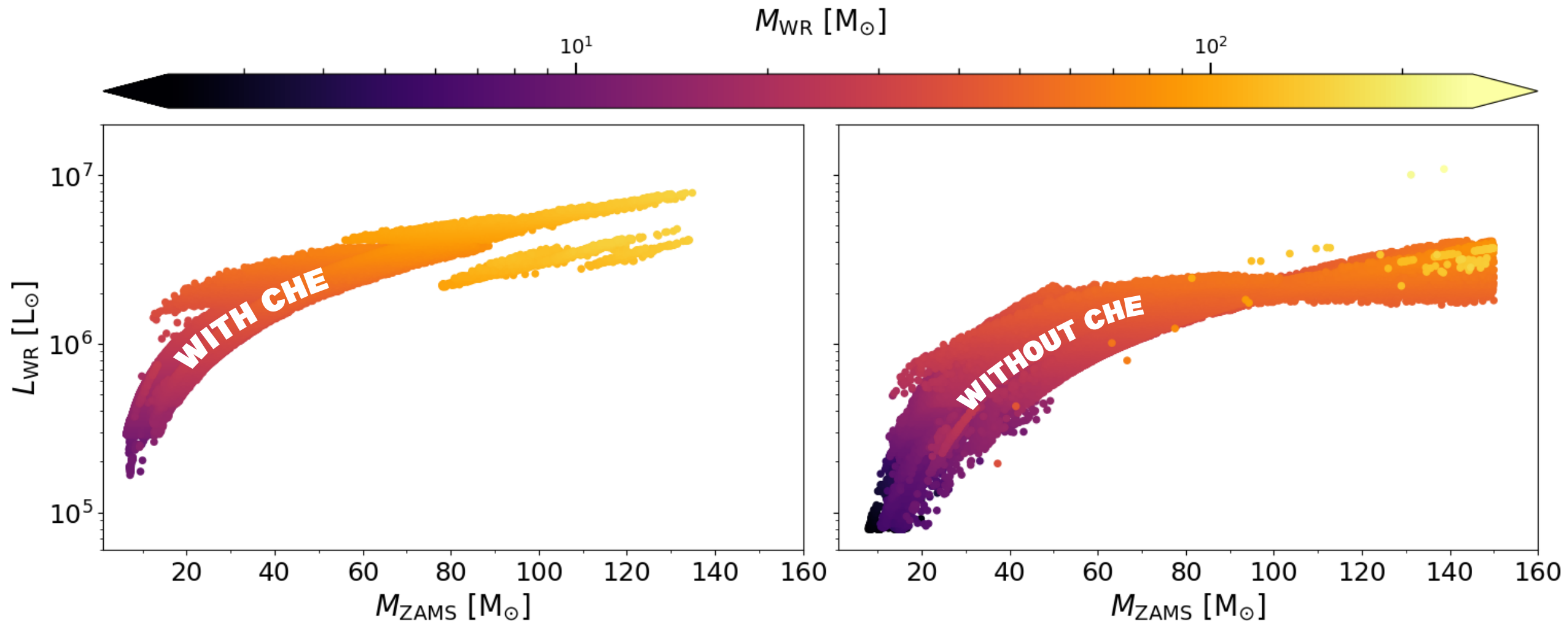
Fractions of stellar phases:



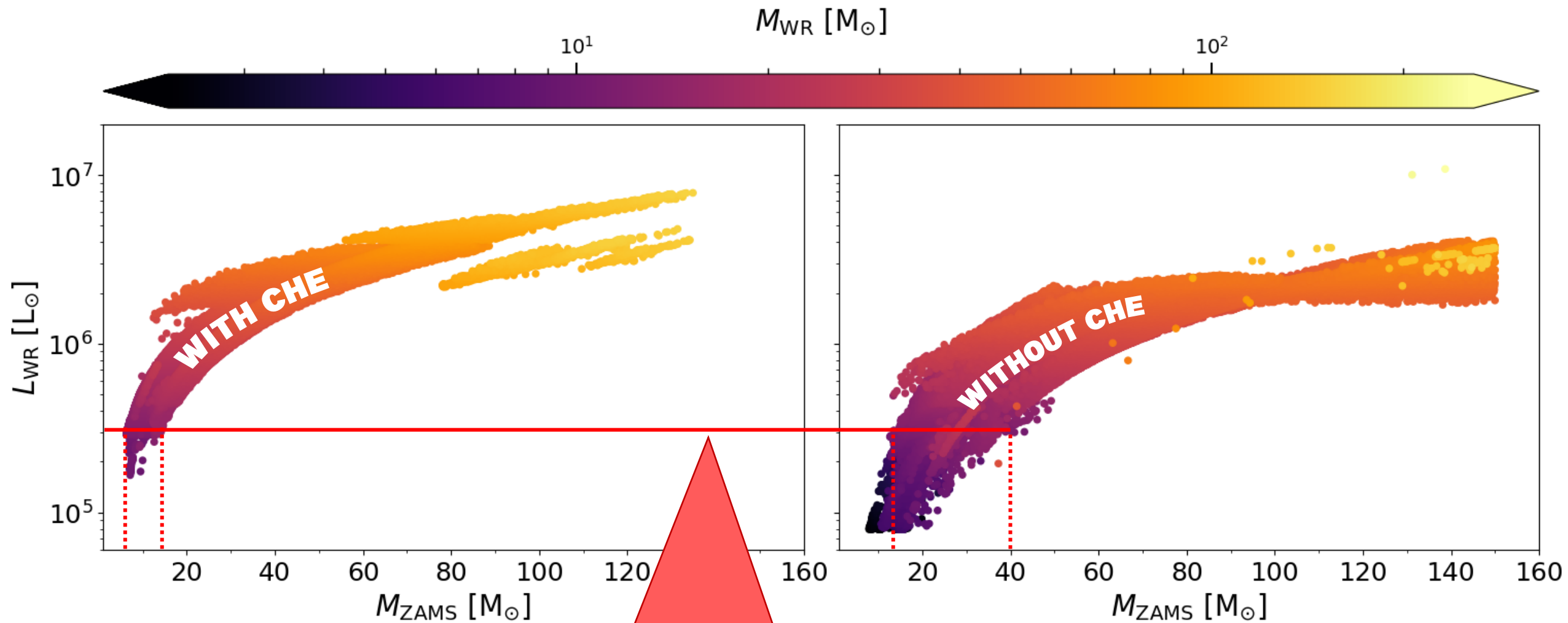


CHE PRODUCES ALMOST 3 TIMES MORE WR STARS THAN STANDARD BINARY EVOLUTION AT LOW METALLICITY

WR & PROGENITOR STAR (AT $z=0.001$)

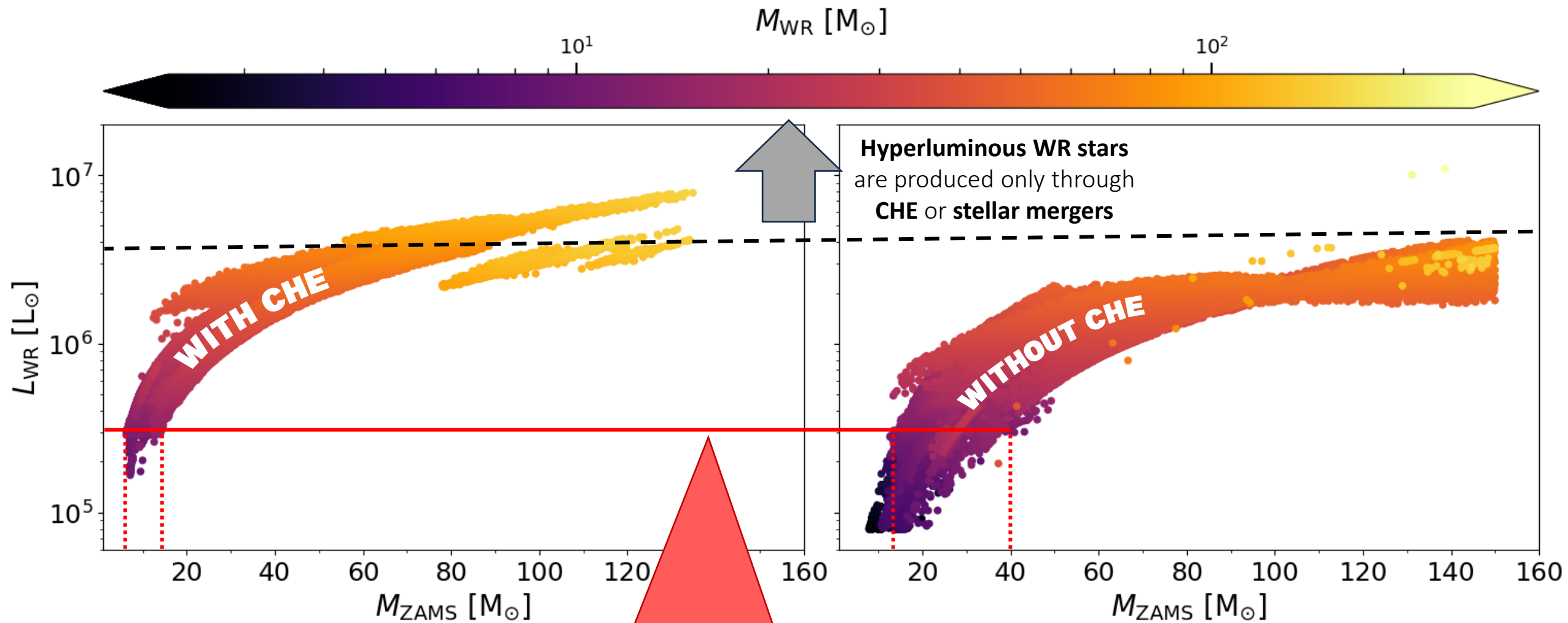


WR & PROGENITOR STAR (AT $z=0.001$)



WR produced by a $6-15 M_{\odot}$ star through CHE has the same **Luminosity** of a WR produced by a $15-40 M_{\odot}$ star through **standard binary evolution**

WR & PROGENITOR STAR (AT $z=0.001$)



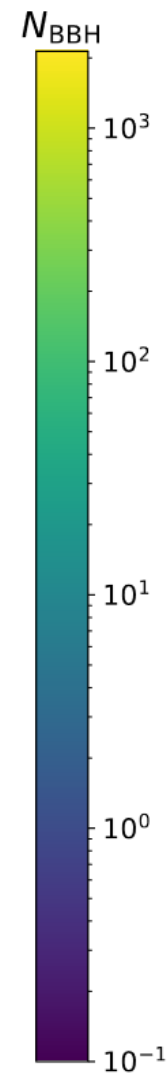
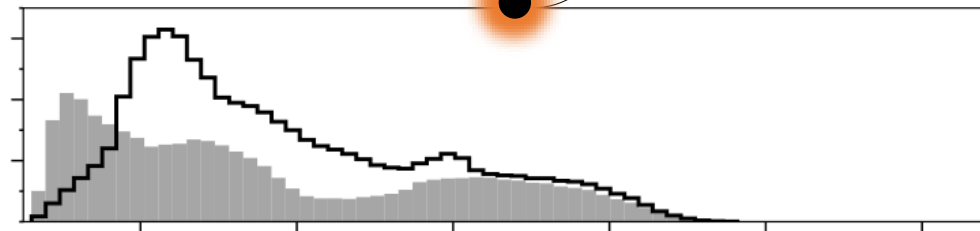
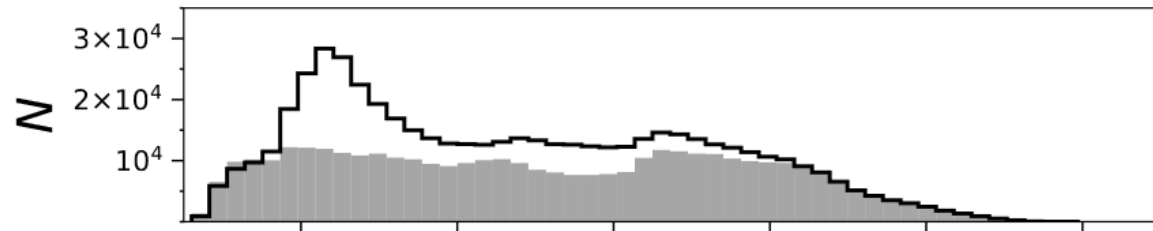
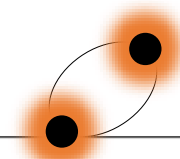
Hyperluminous WR stars
are produced only through
CHE or **stellar mergers**

WITH CHE

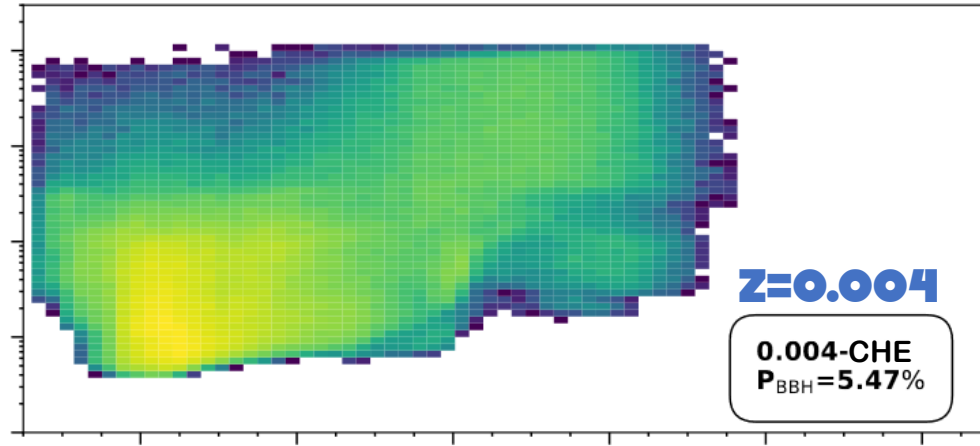
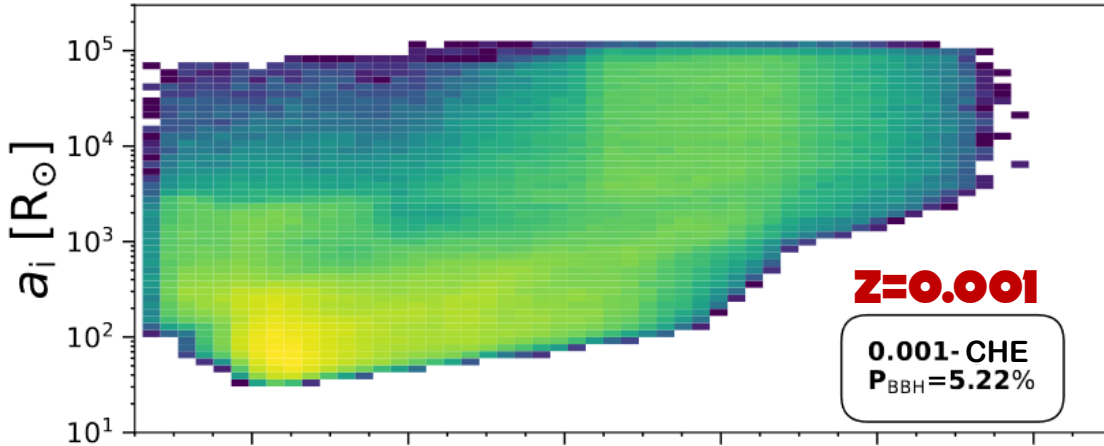
WITHOUT CHE

WR produced by a **6-15 M_{\odot}** star through **CHE** has
the same **Luminosity** of a WR produced by a **15-40
 M_{\odot}** star through **standard binary evolution**

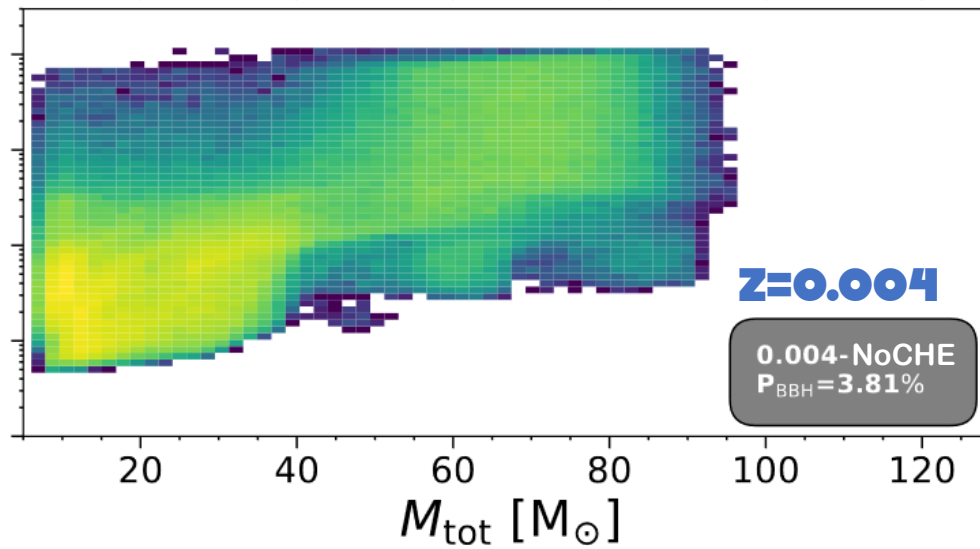
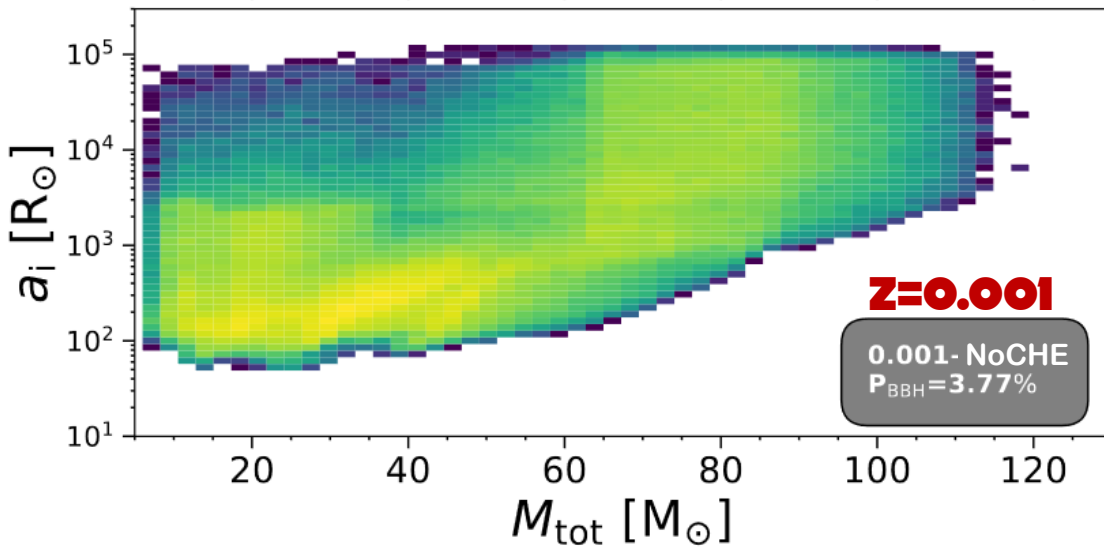
BINARY BLACK HOLES



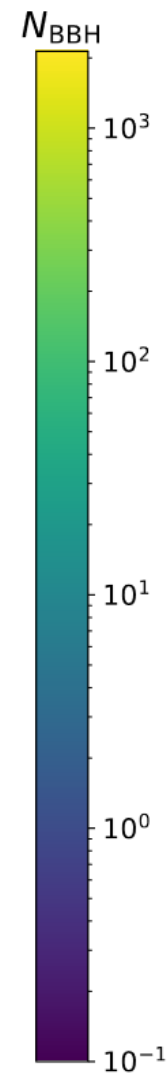
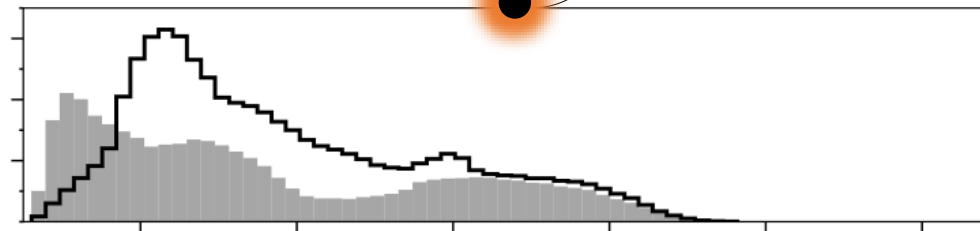
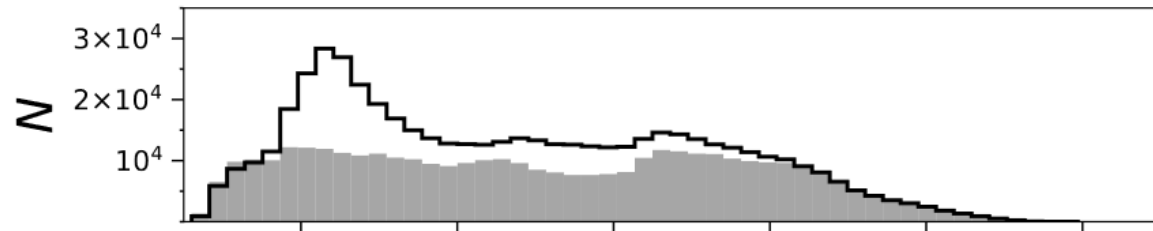
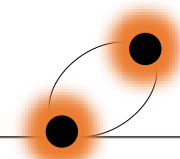
WITH
CHE



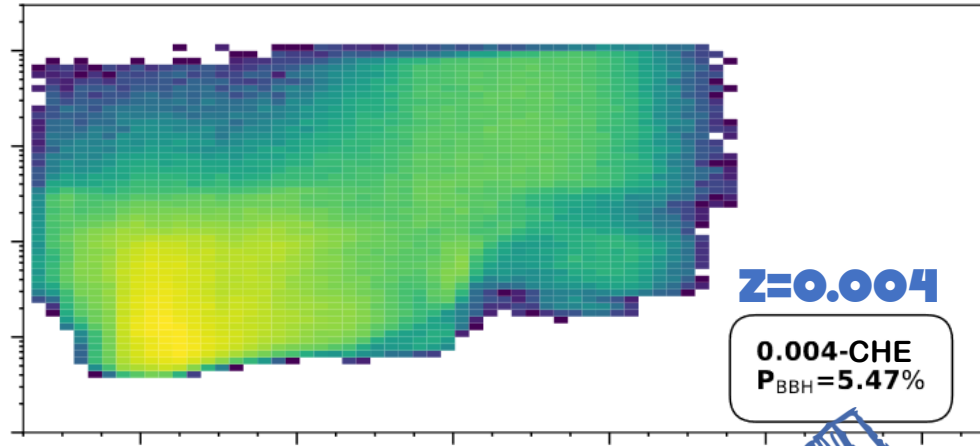
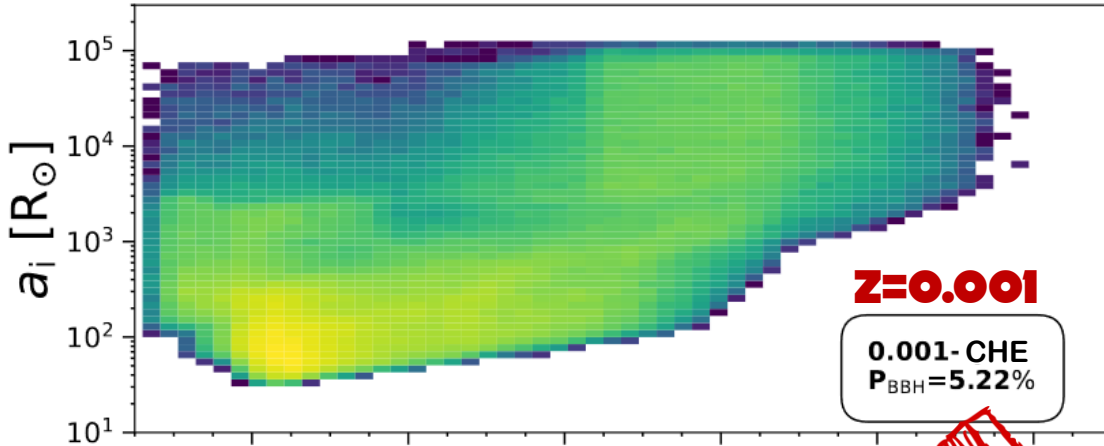
W/O
CHE



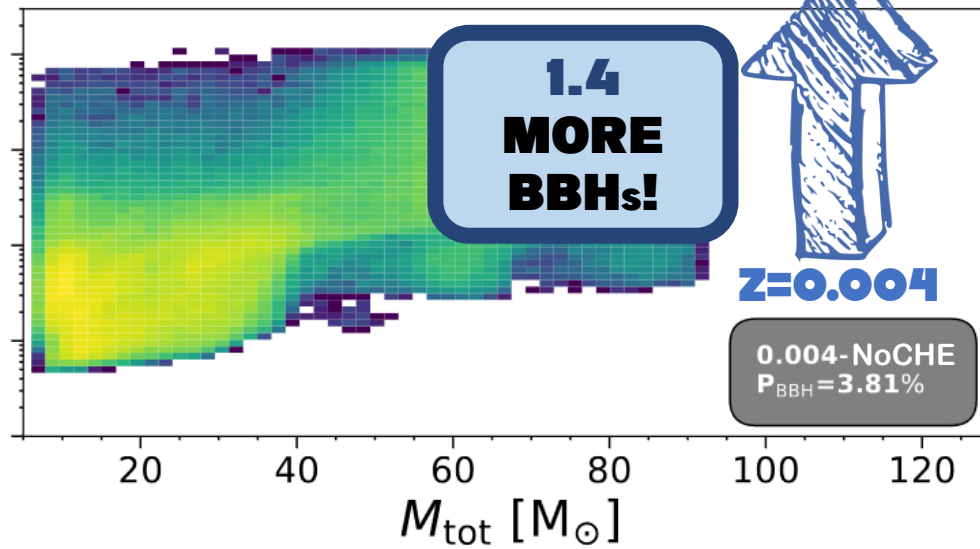
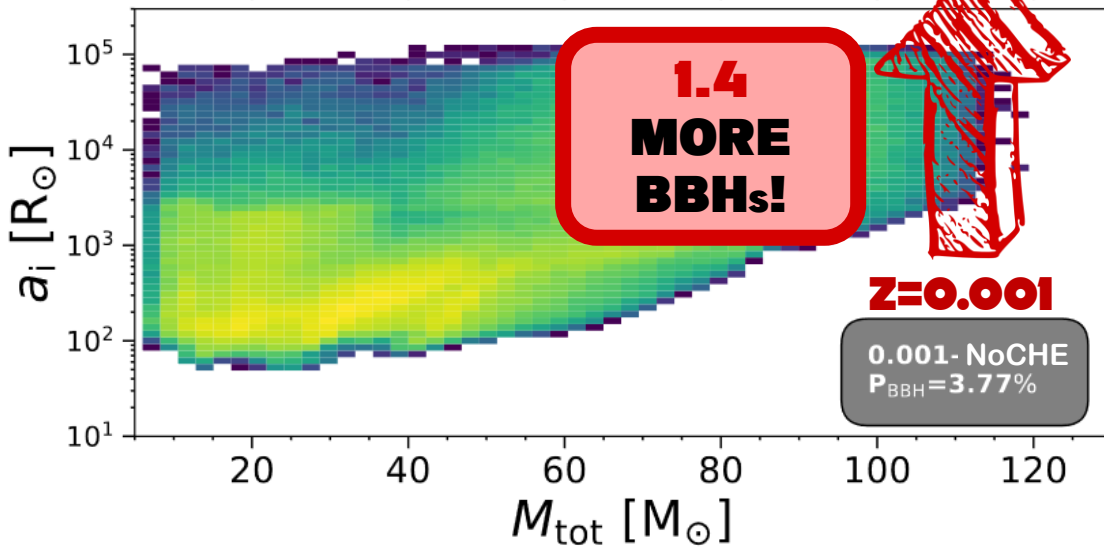
BINARY BLACK HOLES



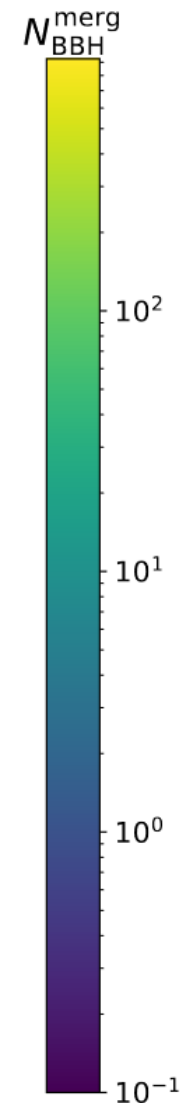
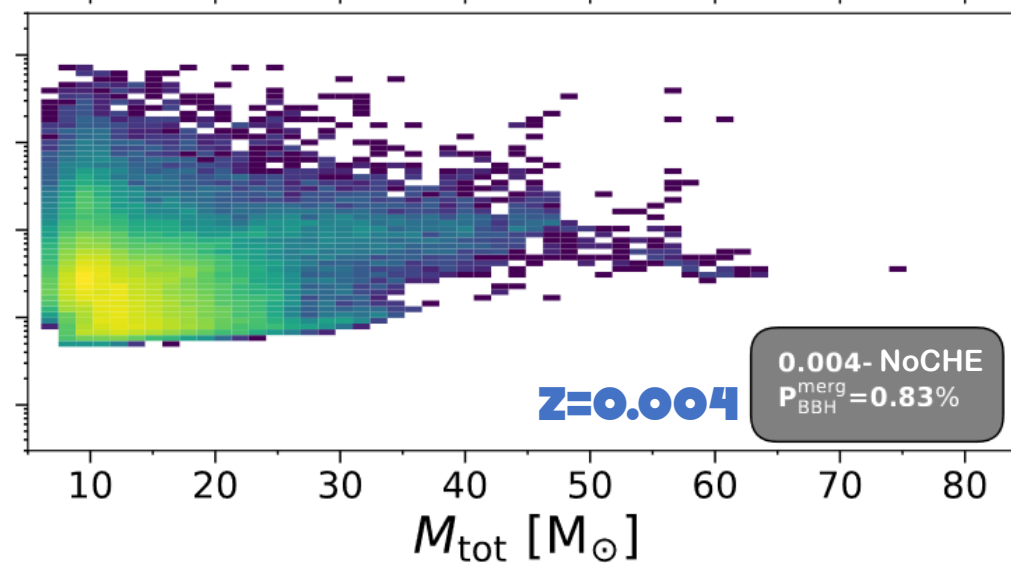
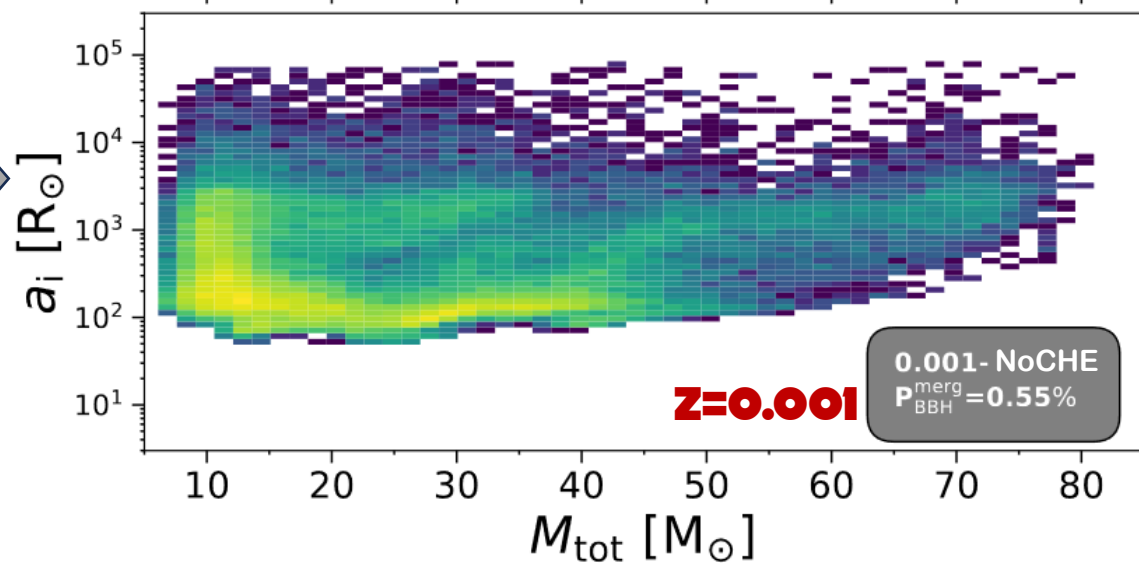
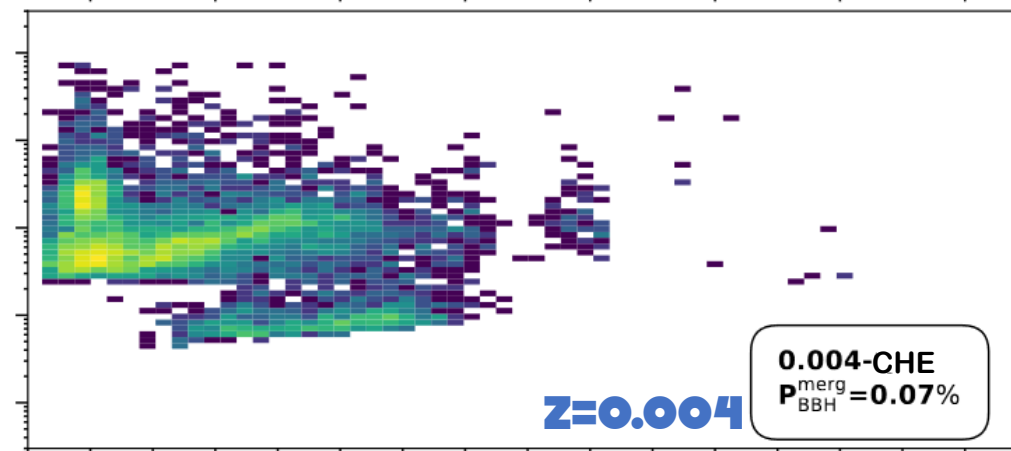
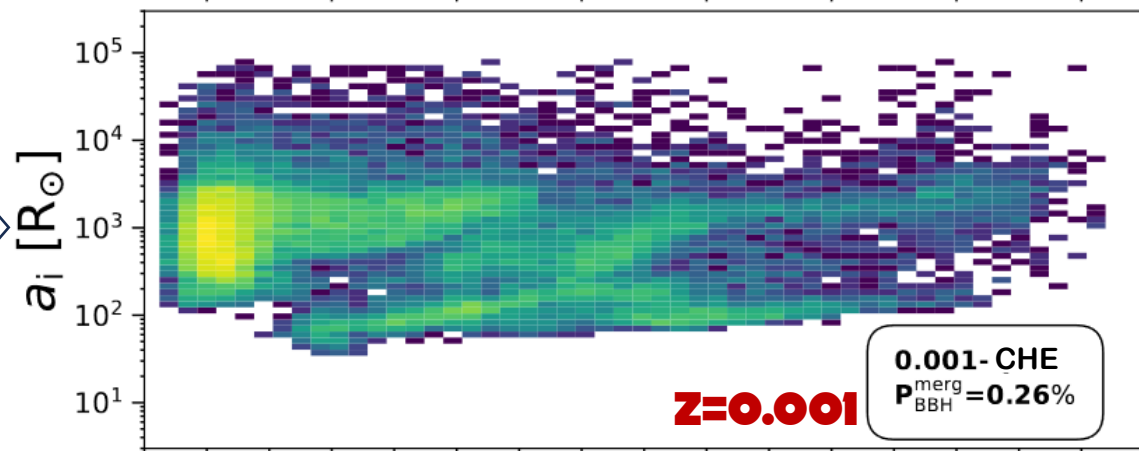
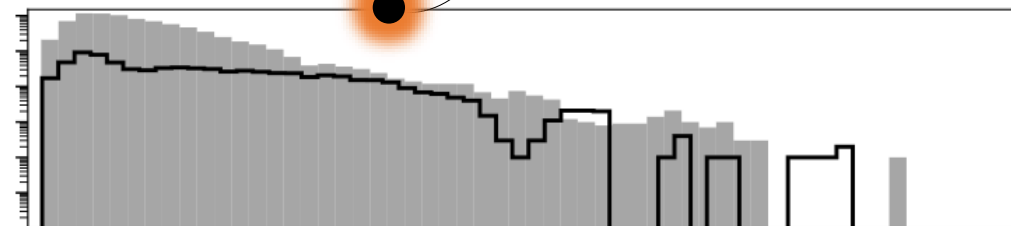
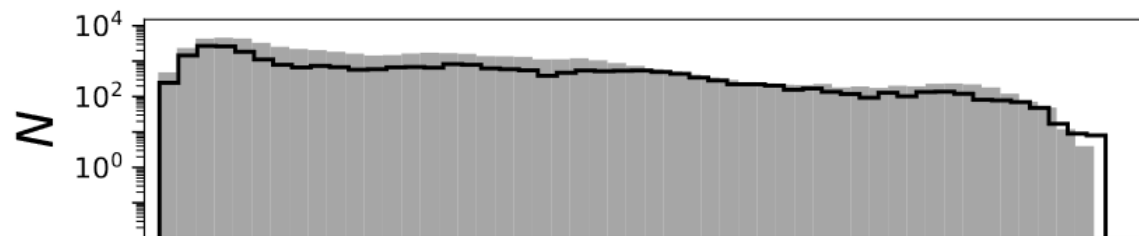
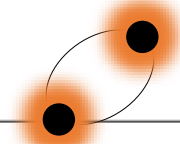
WITH
CHE



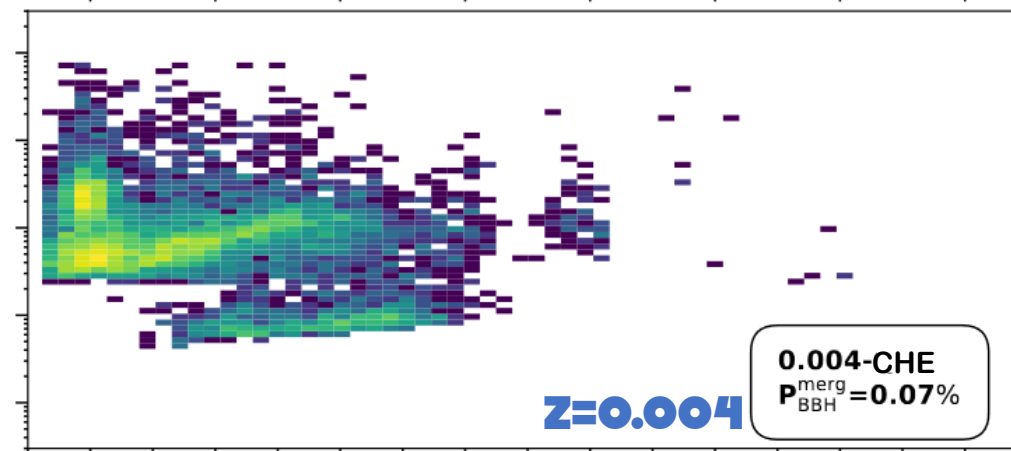
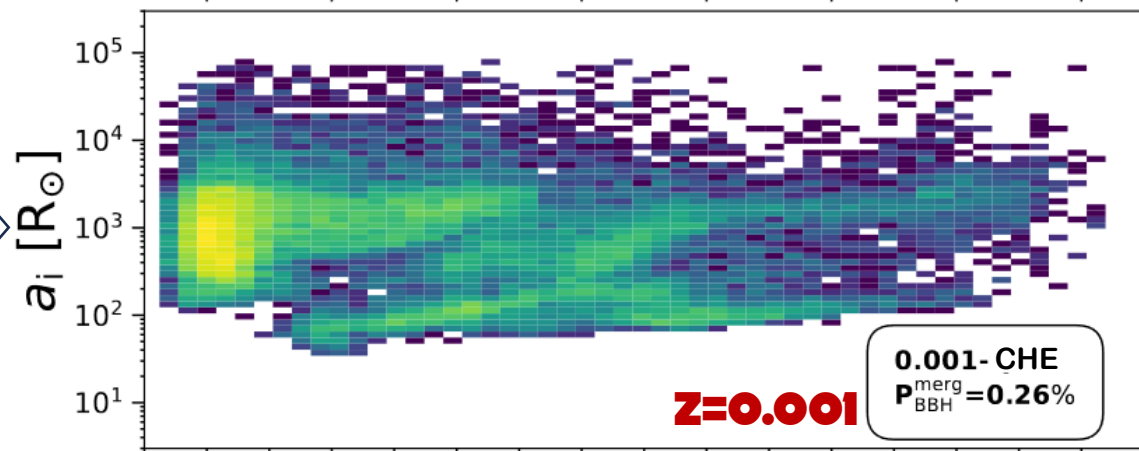
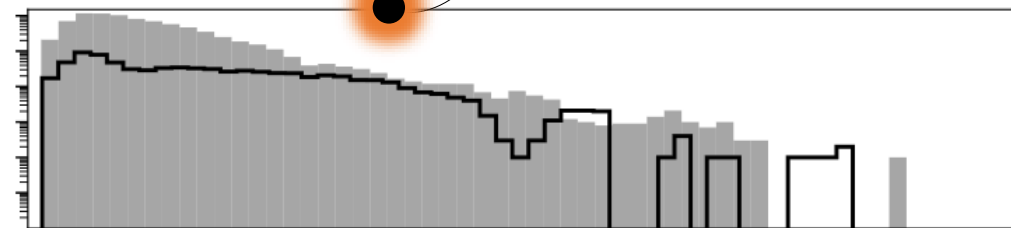
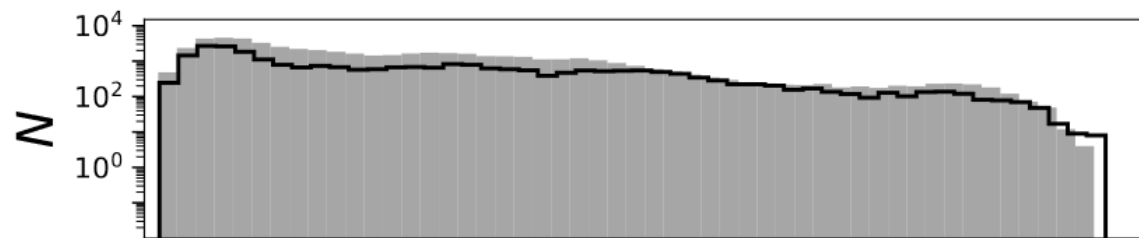
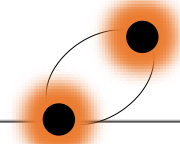
W/O
CHE



BBH MERGERS

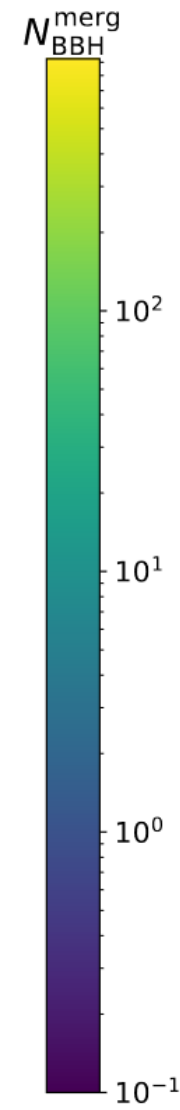
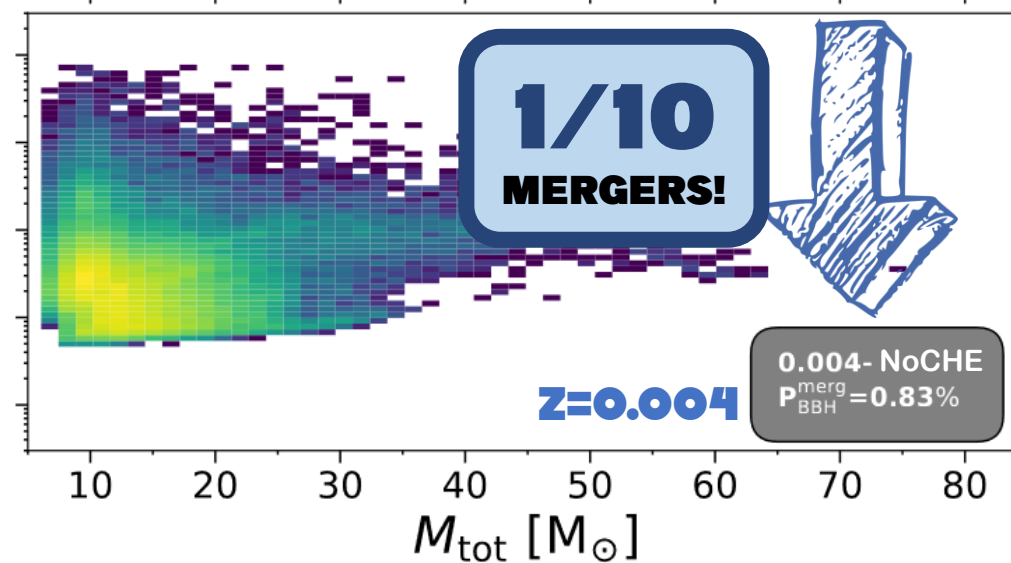
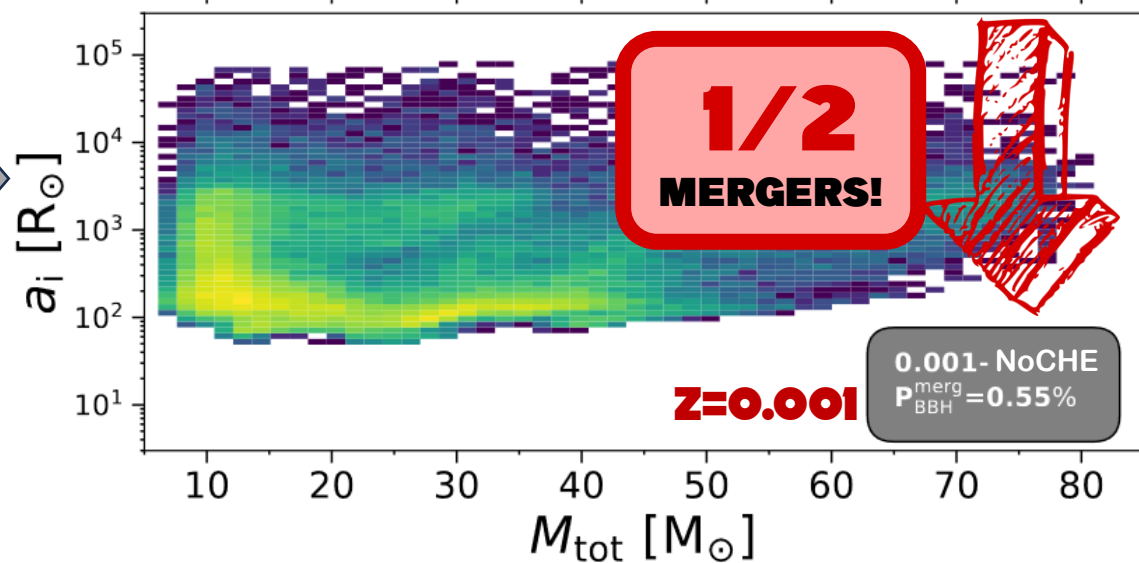


BBH MERGERS



WITH
CHE

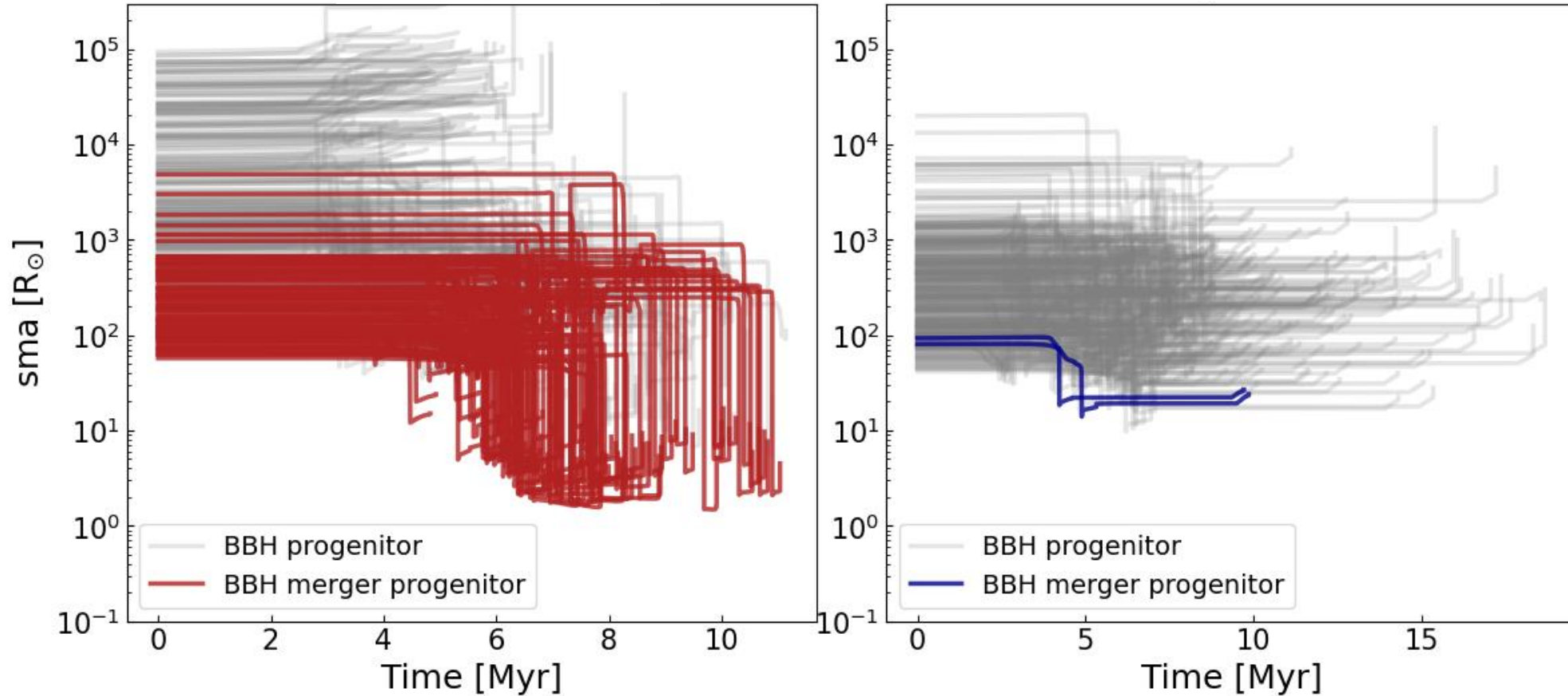
W/O
CHE

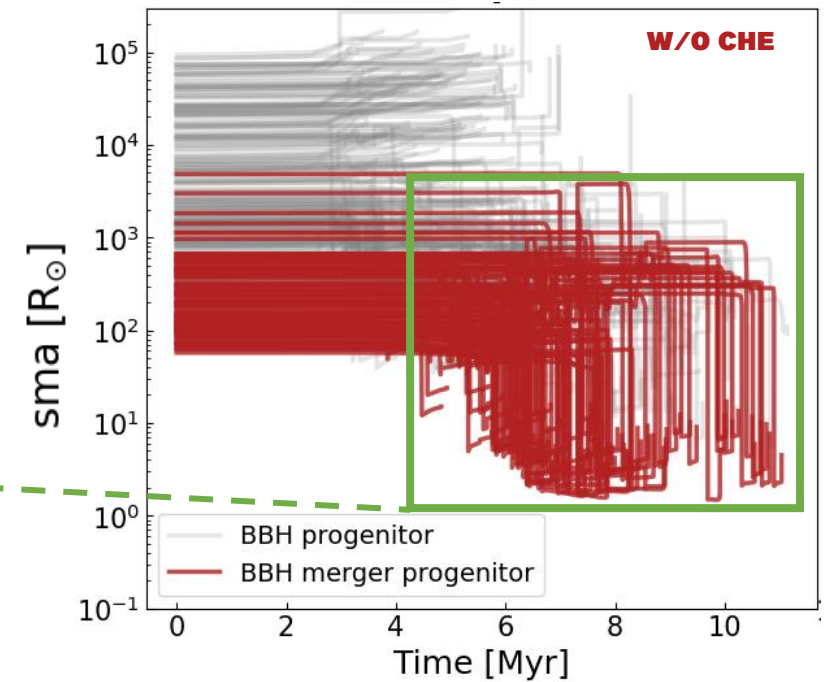
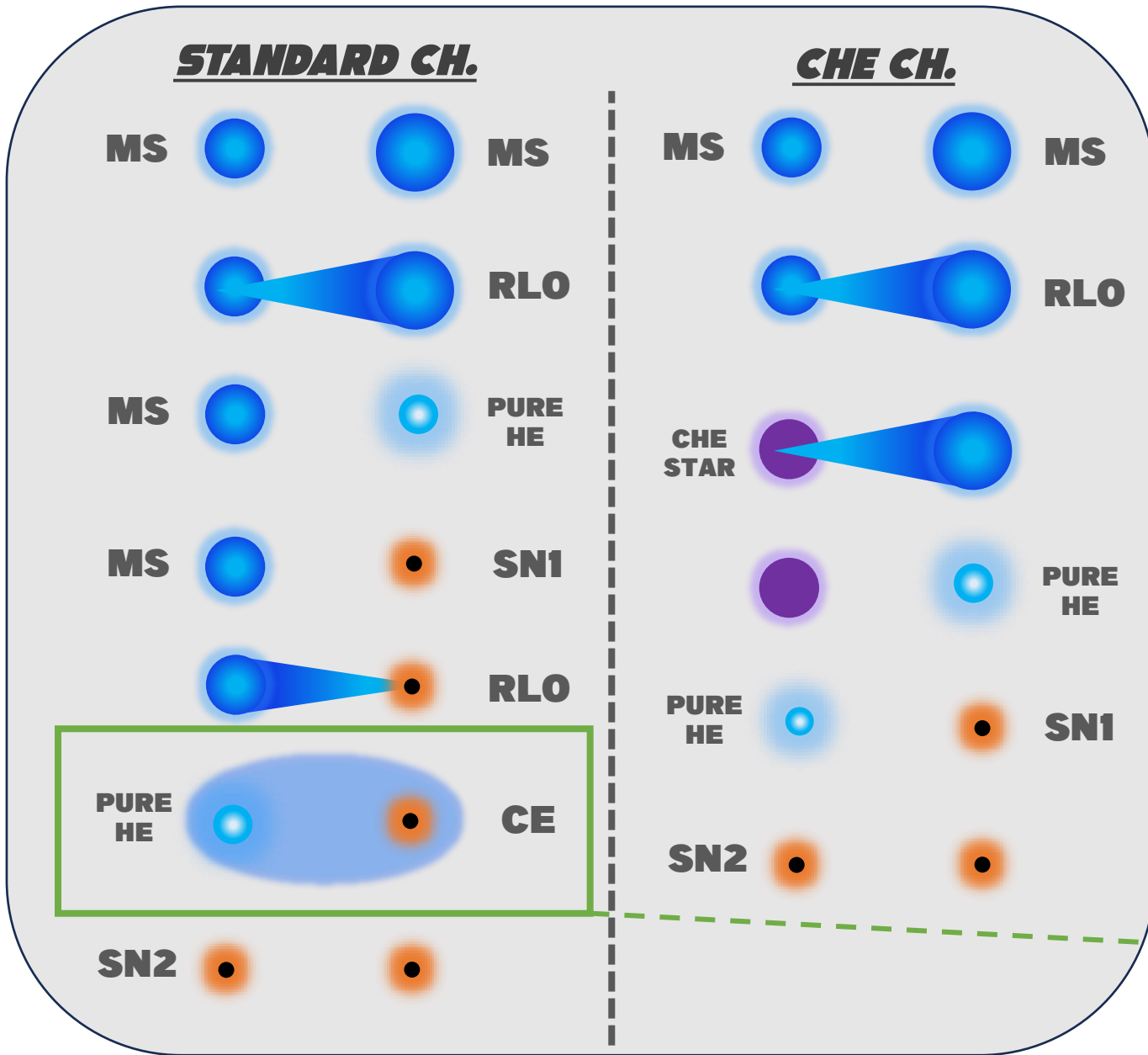


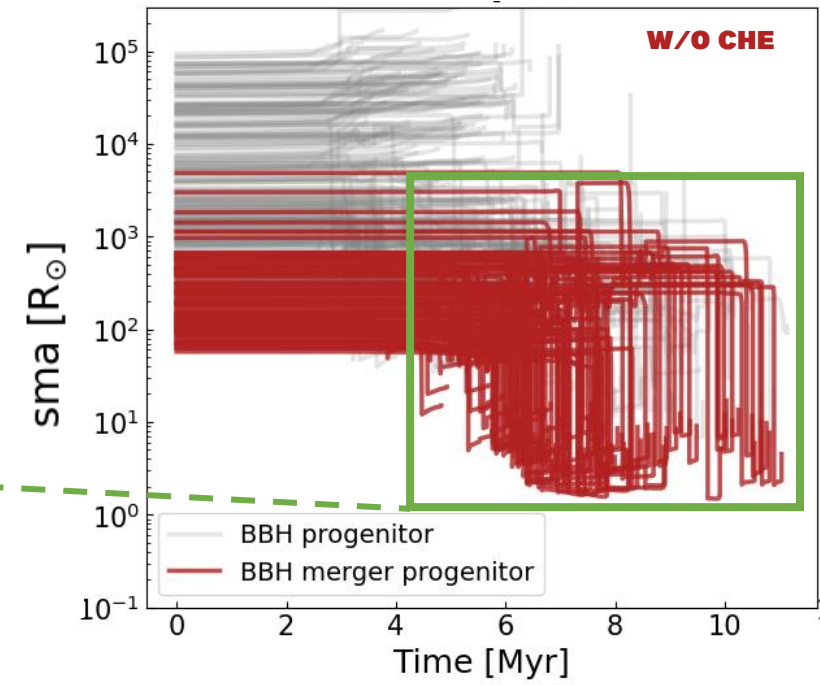
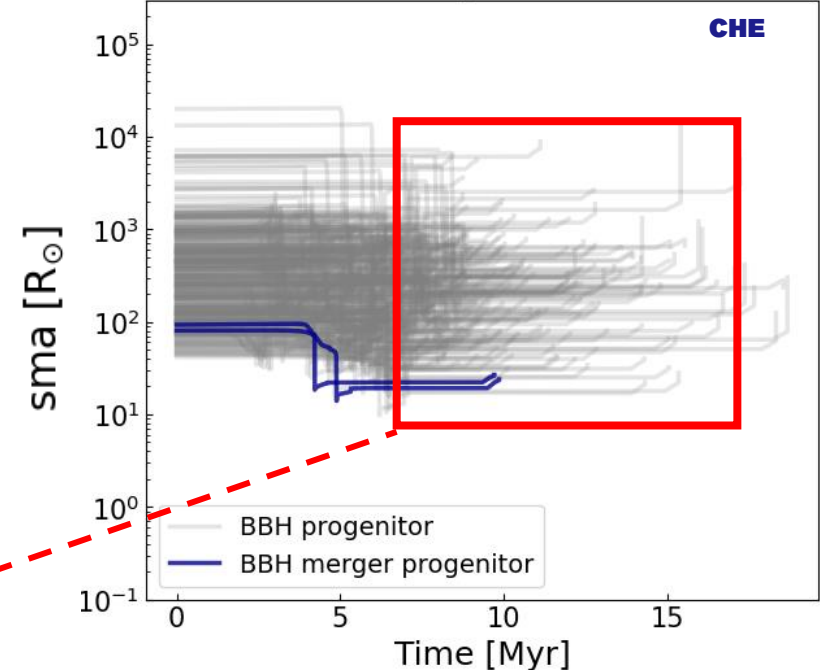
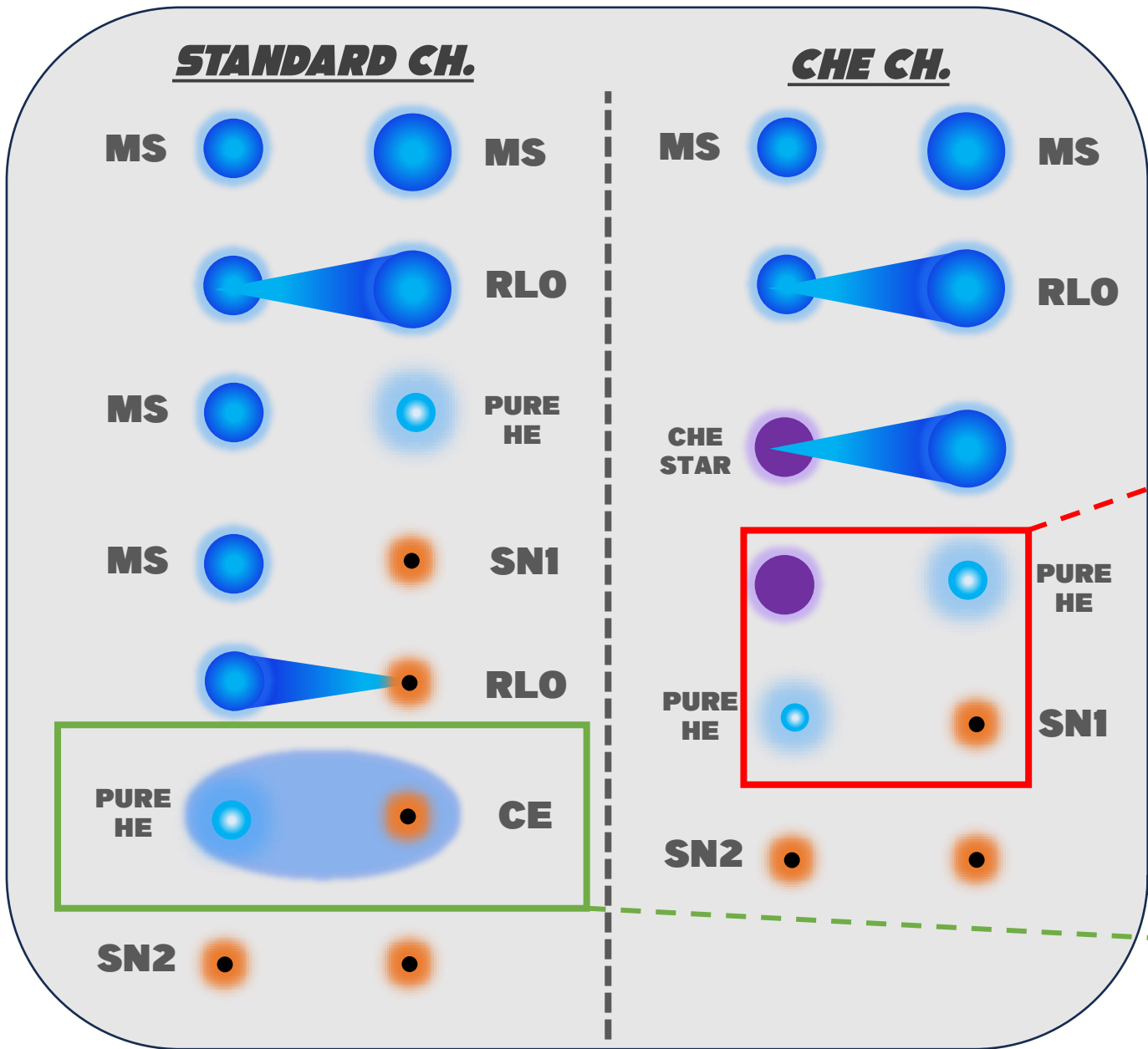
ORBITAL SEPARATION EVOLUTION (AT $z=0.004$)

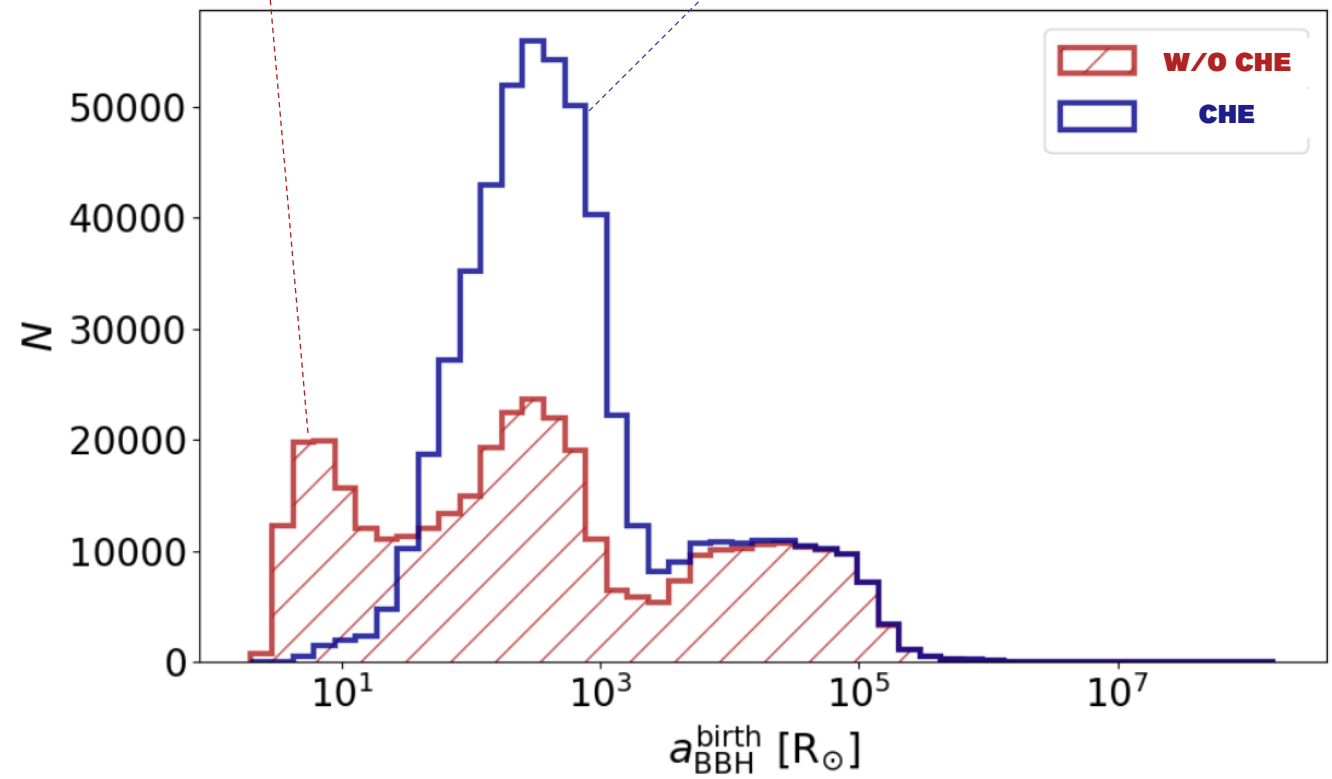
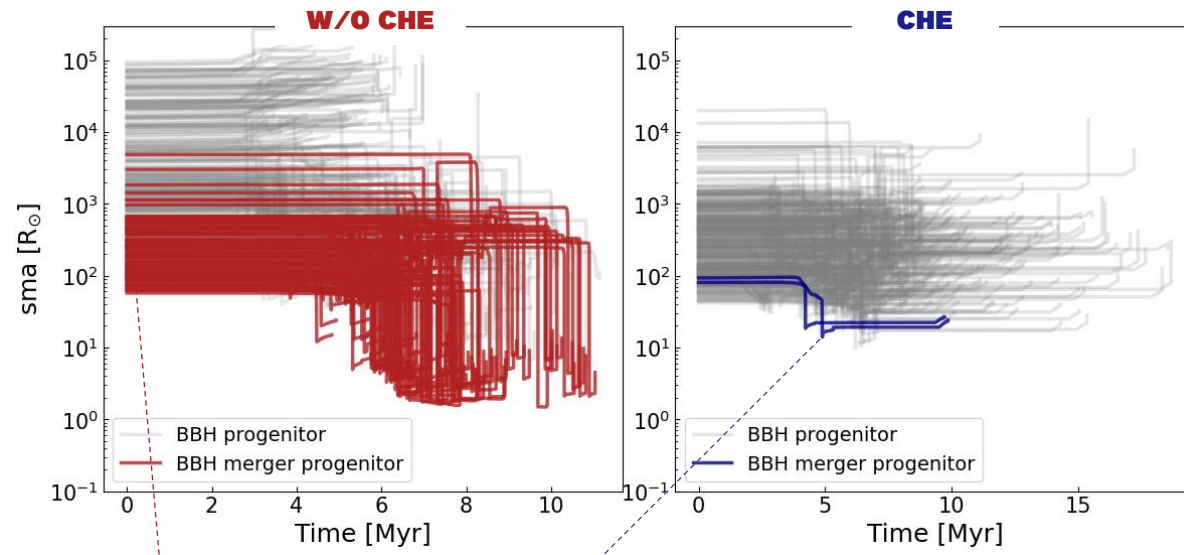
W/O CHE

CHE









BBH FORMED THROUGH CHE BORN WITH LARGER ORBITAL SEPARATIONS



SUMMARY

+ **BINARY EVOLUTION**

+ **CHEMICALLY HOMOGENEOUS EVOLUTION**

= **1. MORE NUMEROUS WR**

↳ More massive BHs

2. MORE MASSIVE WR

↳ More luminous WRs from less massive progenitors

3. LESS BBH & BHNS MERGERS

↳ CHE quenches BBH & BHNS merger formation

4. ASYMMETRIC BBH MERGERS

↳ BBH with Mass ratio 0.4-0.6

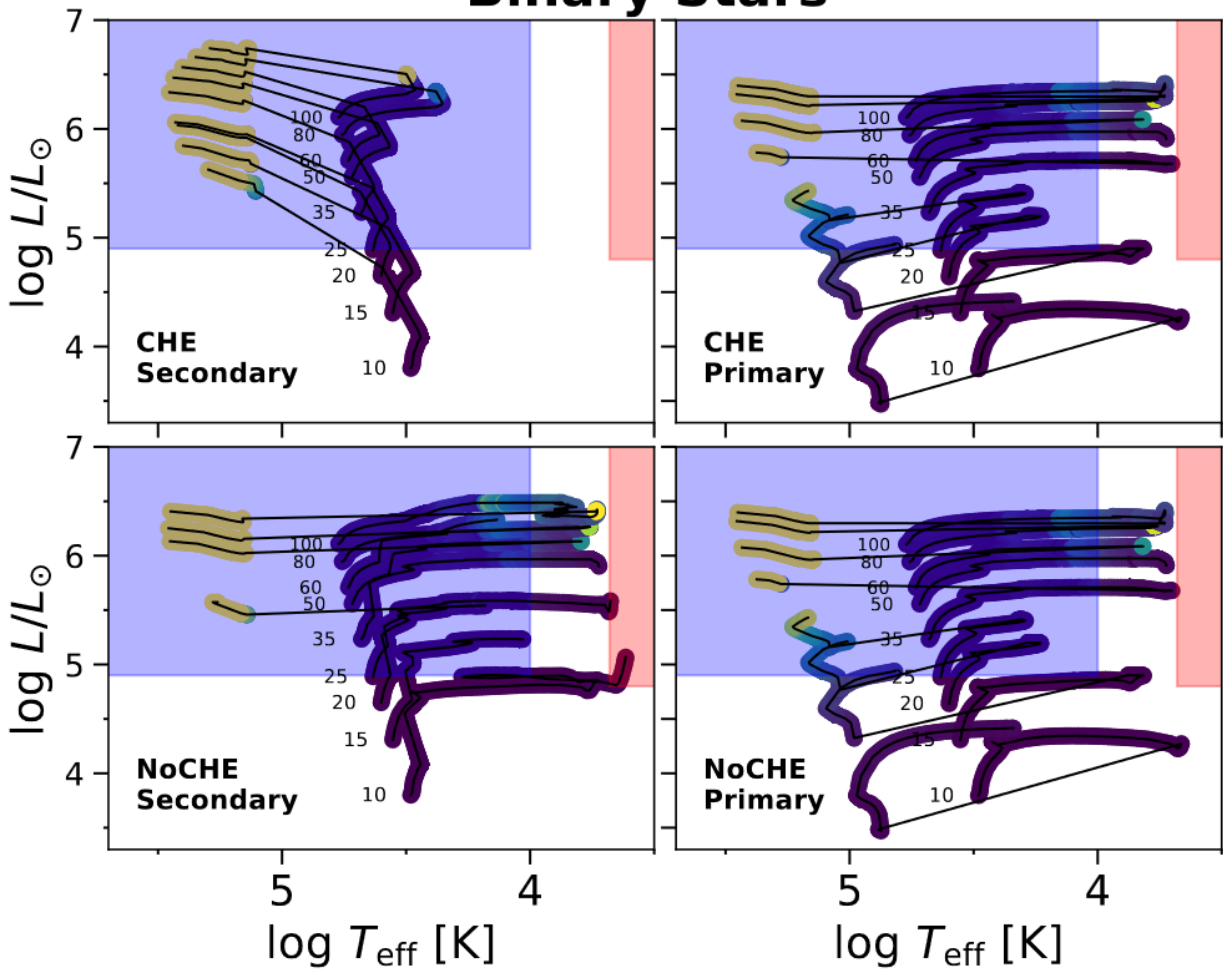
Langer1989

$$\tau_{\text{wind}} = \frac{\kappa_e |\dot{M}|}{4\pi R(v_\infty - v_0)} \ln \left[\frac{v_\infty}{v_0} \right]$$

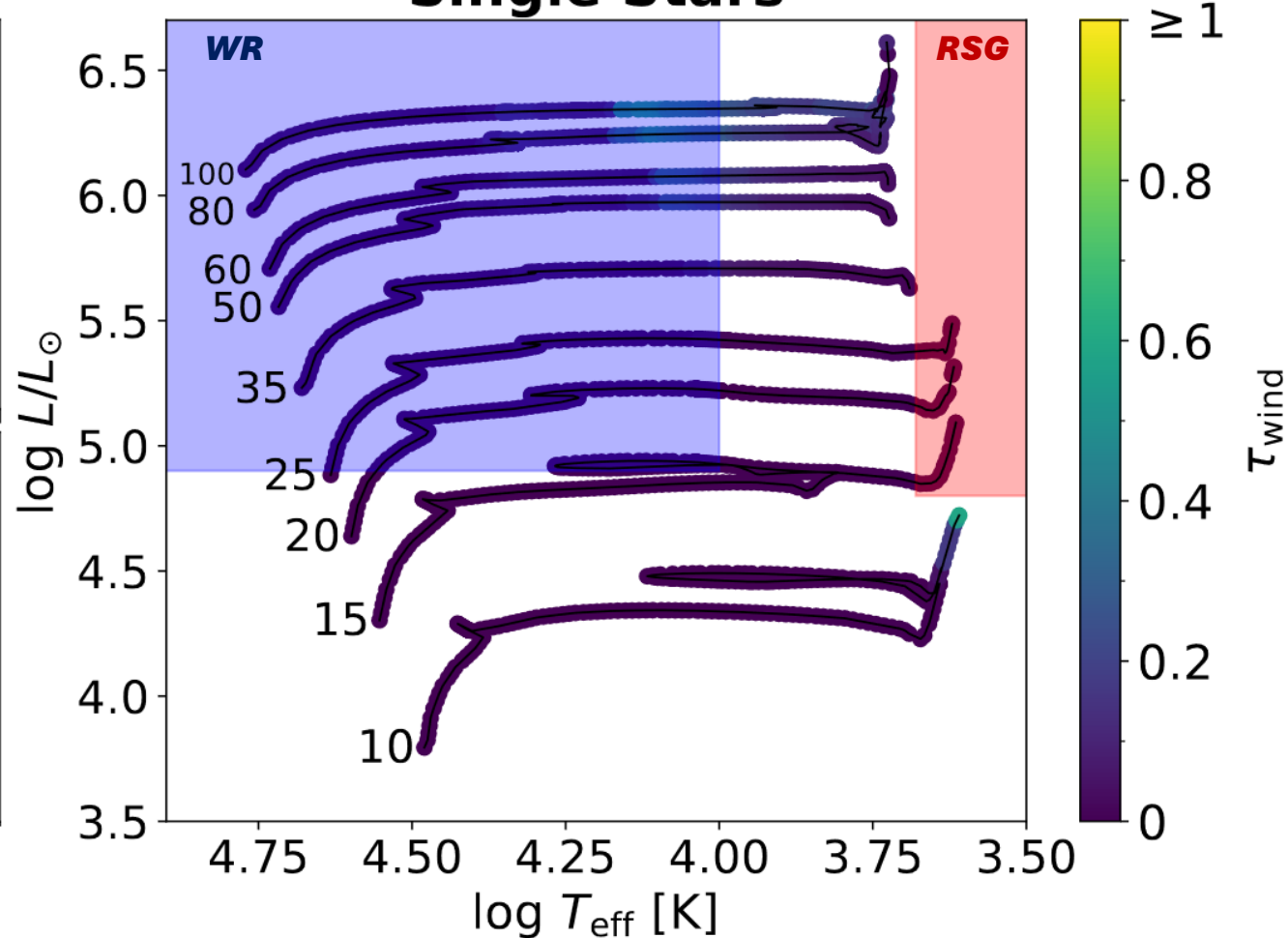
WR & RSG

Z=0.001

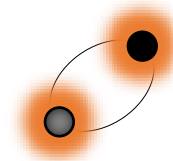
Binary Stars



Single Stars

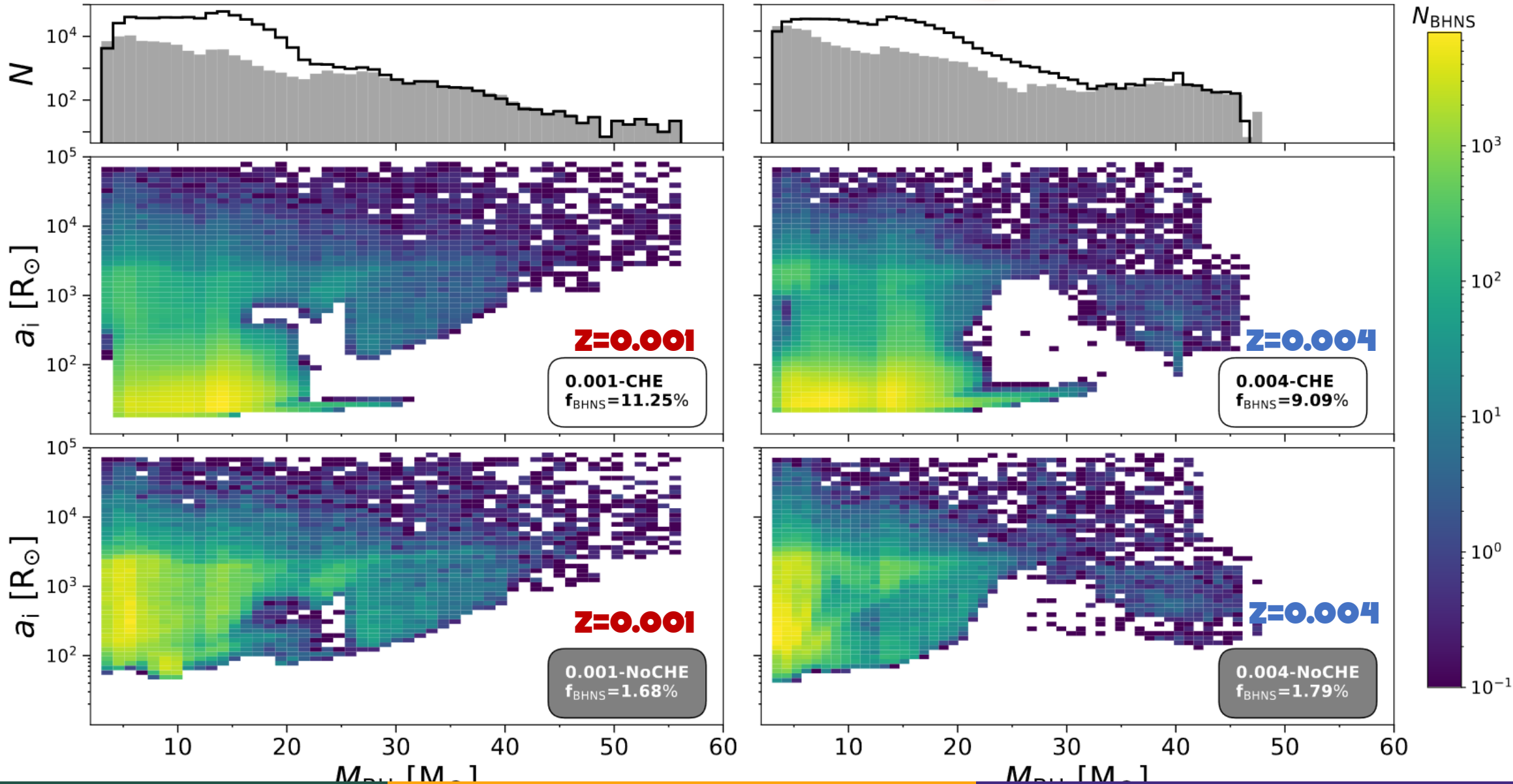


BH-NS SYSTEMS

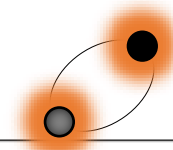


WITH
CHE

W/
CHE

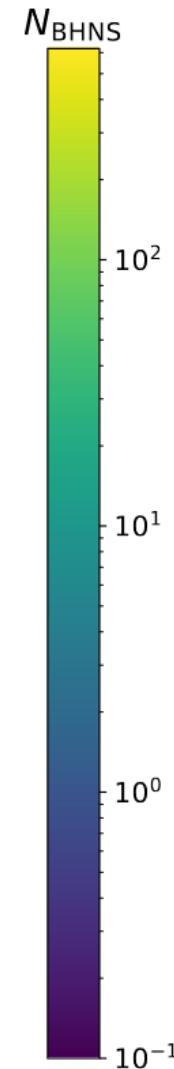
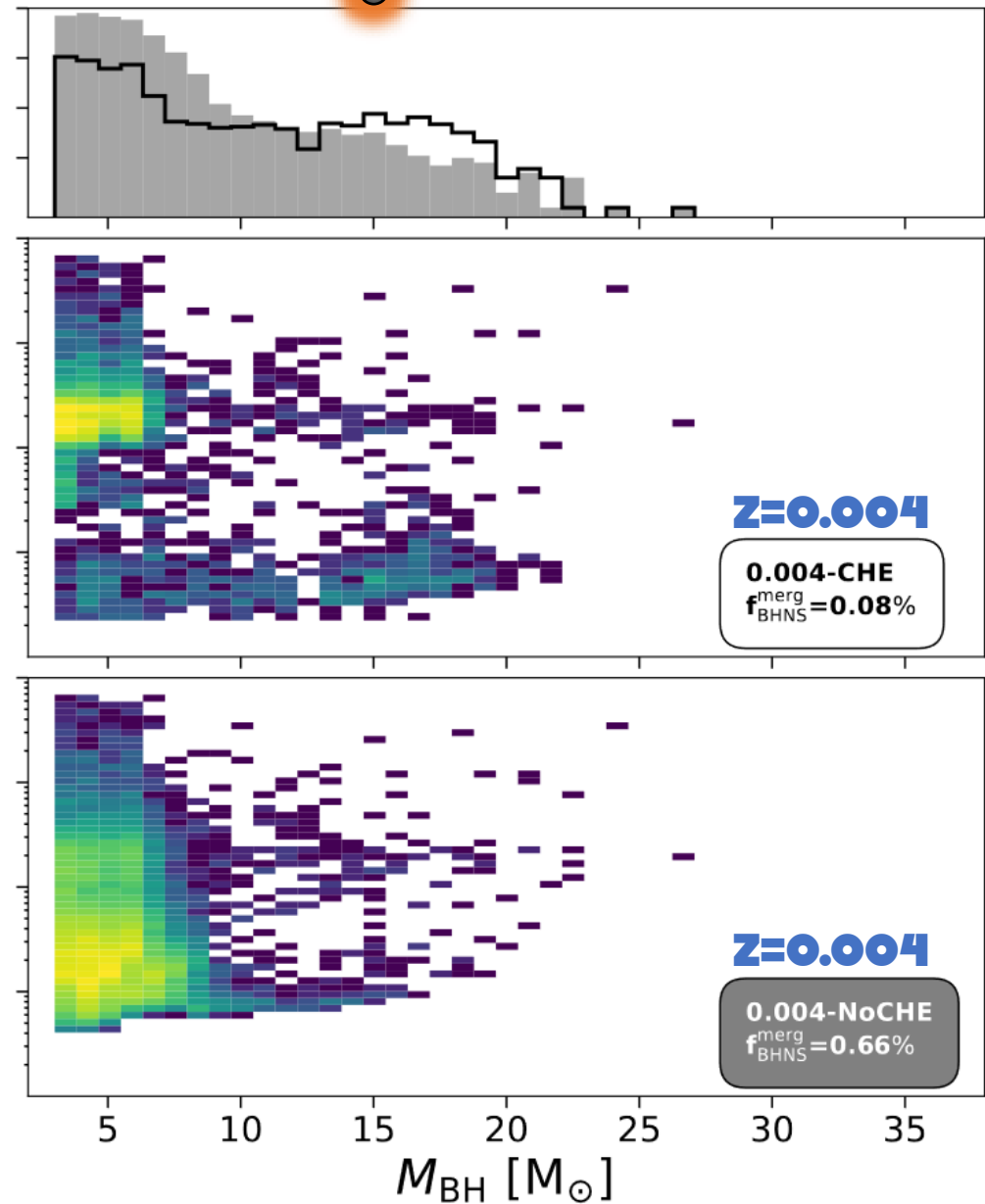
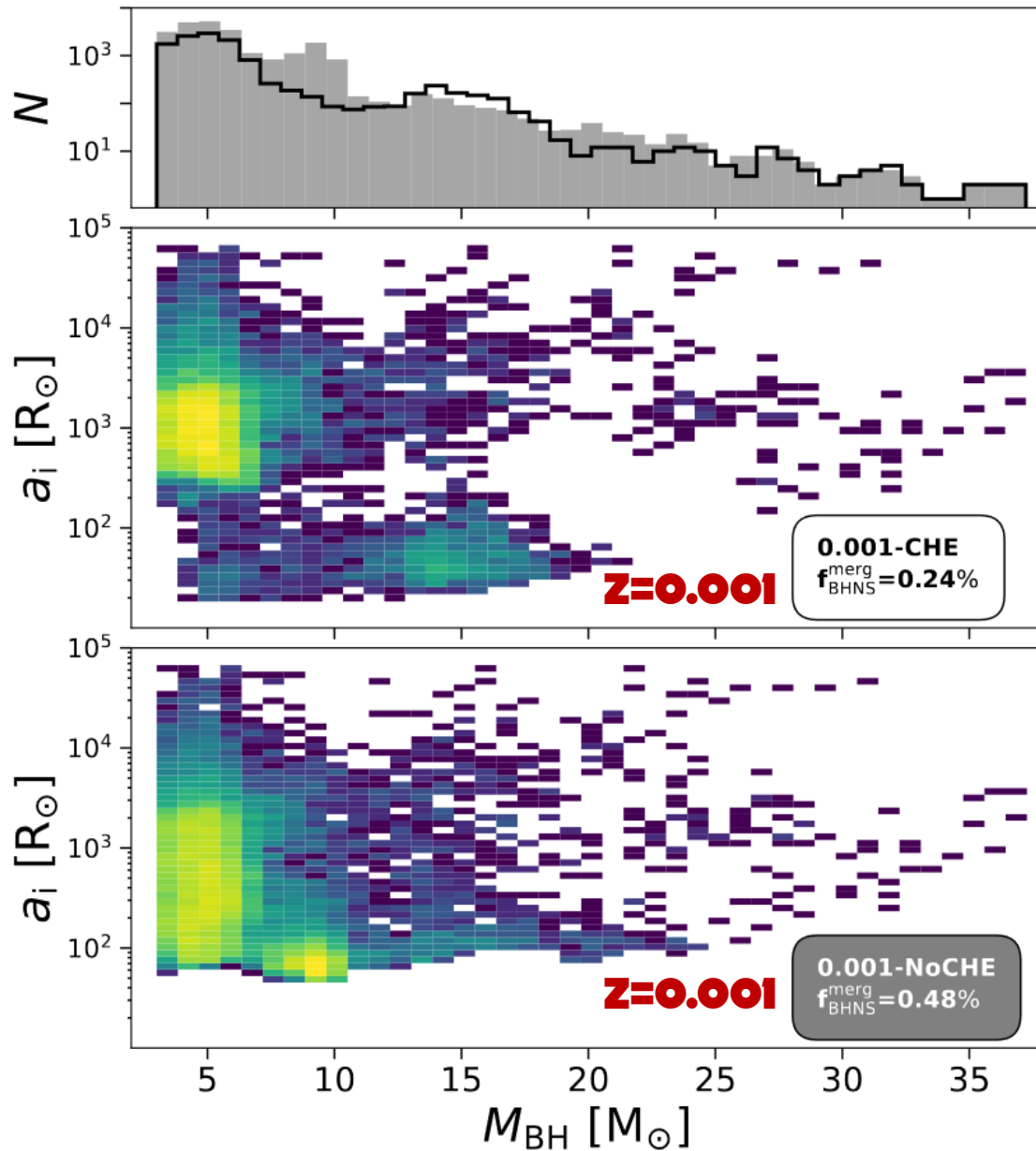


BH-NS MERGERS



WITH
CHE

W/
CHE



BINARY – SINGLE POP SYNTH SIMULATIONS WITH



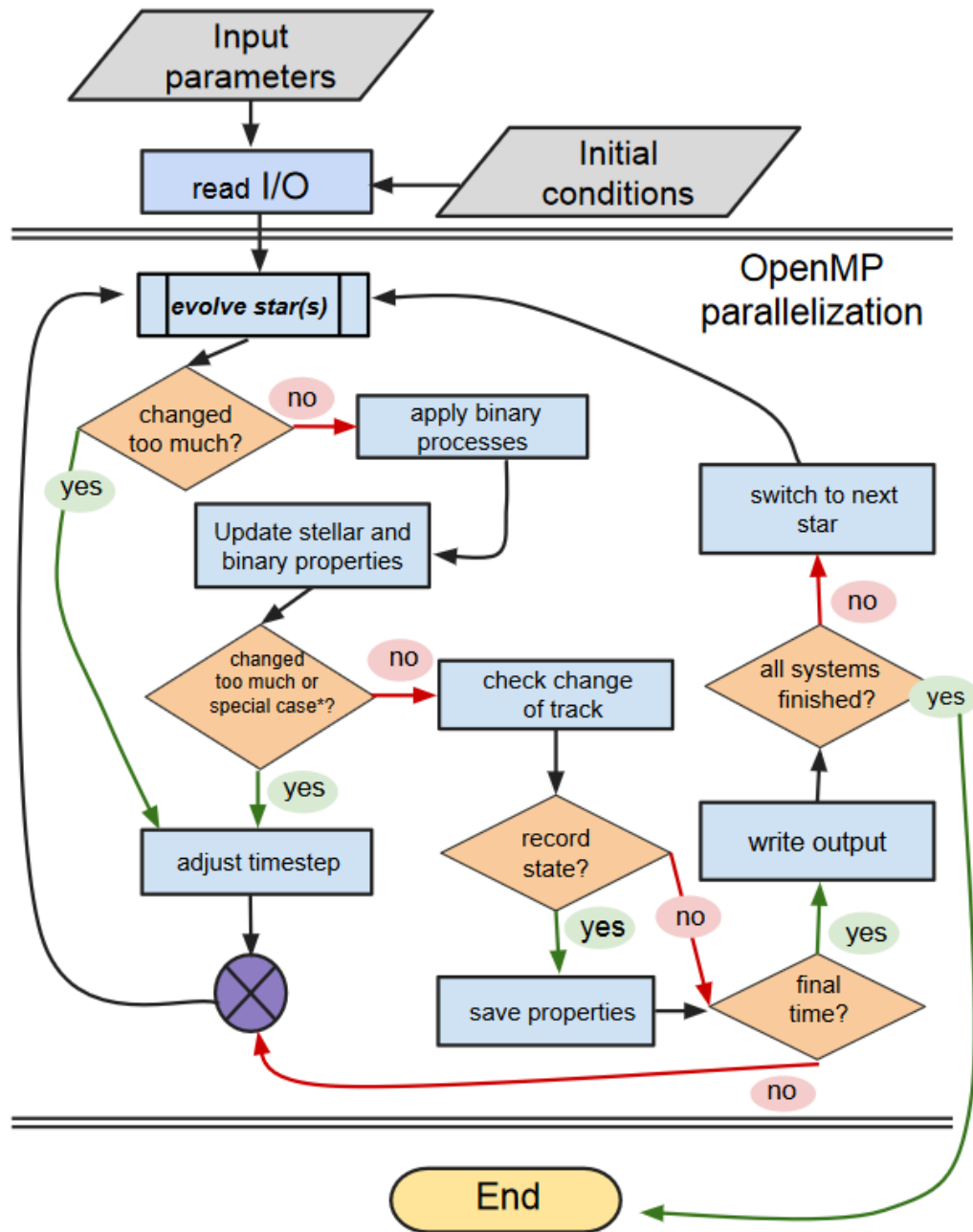
Iorio et al. 2023

SSE: pre-computed stellar tracks interpolation

BSE: analytic and semi-analytic prescriptions

STELLAR TRACKS: *PARSEC* stellar evolution code
(Bressan et al. 2012; Chen et al. 2015;
Costa et al. 2019,2021)

CHE: Accretion spin up as in Eldridge+2011



COMPACT OBJECT BINARIES

Z	name	P_{CHE}	BBH			BHNS			BNS		
			P_{cob}	P_{merg}	$P_{\text{merg}}^{\text{CHE}}$	P_{cob}	P_{merg}	$P_{\text{merg}}^{\text{CHE}}$	P_{cob}	P_{merg}	$P_{\text{merg}}^{\text{CHE}}$
0.001	NoCHEzams	0	4.28	0.92	0	0.97	0.23	0	0.66	0.42	0
	NoCHEpreMS	0	4.28	0.92	0	0.97	0.24	0	0.66	0.41	0
	CHE10zams	14.8	5.17	0.32	22.63	5.76	0.06	19.99	0.17	0.05	0
	CHE10preMS	14.69	5.18	0.31	23.42	5.68	0.06	20.01	0.17	0.05	0
	CHE20zams	4.25	4.69	0.28	13.8	1.38	0.07	3.63	0.62	0.39	0
	CHE20preMS	4.29	4.7	0.28	14.36	1.39	0.07	3.7	0.62	0.39	0
0.004	NoCHEzams	0	3.98	0.59	0	0.94	0.18	0	0.61	0.32	0
	NoCHEpreMS	0	3.98	0.59	0	0.94	0.18	0	0.60	0.32	0
	CHE10zams	14.93	5.43	0.05	37.7	4.72	0.02	32.94	0.20	0.09	0
	CHE10preMS	14.31	5.44	0.05	39.15	4.57	0.02	32.66	0.20	0.10	0
	CHE20zams	5.85	4.86	0.04	12.96	1.67	0.02	12.3	0.45	0.22	0
	CHE20preMS	5.9	4.86	0.04	13.51	1.69	0.02	11.83	0.45	0.22	0

WR & RSG STATS

	Z=0.001			Z=0.004			Z=0.008		Z=0.02		Z=0.04	
	CHE	NoCHE	Sing	CHE	NoCHE	Sing	NoCHE	Sing	NoCHE	Sing	NoCHE	Sing
P_{WR}	9.5	3.6	0	12.2	7.0	1.9	8.7	4.6	10.7	8.6	12.6	12.2
P_{WRbin}	15.9	5.4		18.4	10.6		13.6		17.1		19.8	
P_{WRprim}	25.5	65.4		34.6	57.4		55.0		53.5		47.0	
P_{WRsec}	72.9	29.9		56.6	26.6		23.0		22.5		25.0	
P_{WRmerg}	1.6	4.7		8.8	16.0		22.0		24.0		28.0	
P_{WR-WR}	0.3	0.2		0.7	0.5		1.2		1.8		2.8	
P_{RSG}	13.5	14.7	27.5	14.4	15.5	29.2	16.7	29.6	17.3	15.6	19.3	39.2
P_{RSGbin}	23.7	25.6		25.4	26.5		28.7		29.8		33.6	
$P_{RSGprim}$	48.4	44.5		45.1	42.1		43.0		43.5		39.5	
P_{RSGsec}	20.4	26.2		18.3	22.9		21.6		22.7		26.6	
$P_{RSGmerg}$	31.2	29.3		36.6	35.0		35.4		33.0		33.9	
$P_{RSG-RSG}$	0.03	0.03		0.2	0.2		0.3		0.4		0.3	

WR & PROGENITOR STAR (AT $z=0.004$)

