CHEMICALLY HOMOGENEOUS EVOLUTION:

IMPACT ON STELLAR POPULATION & COMPACT BINARY MERGERS

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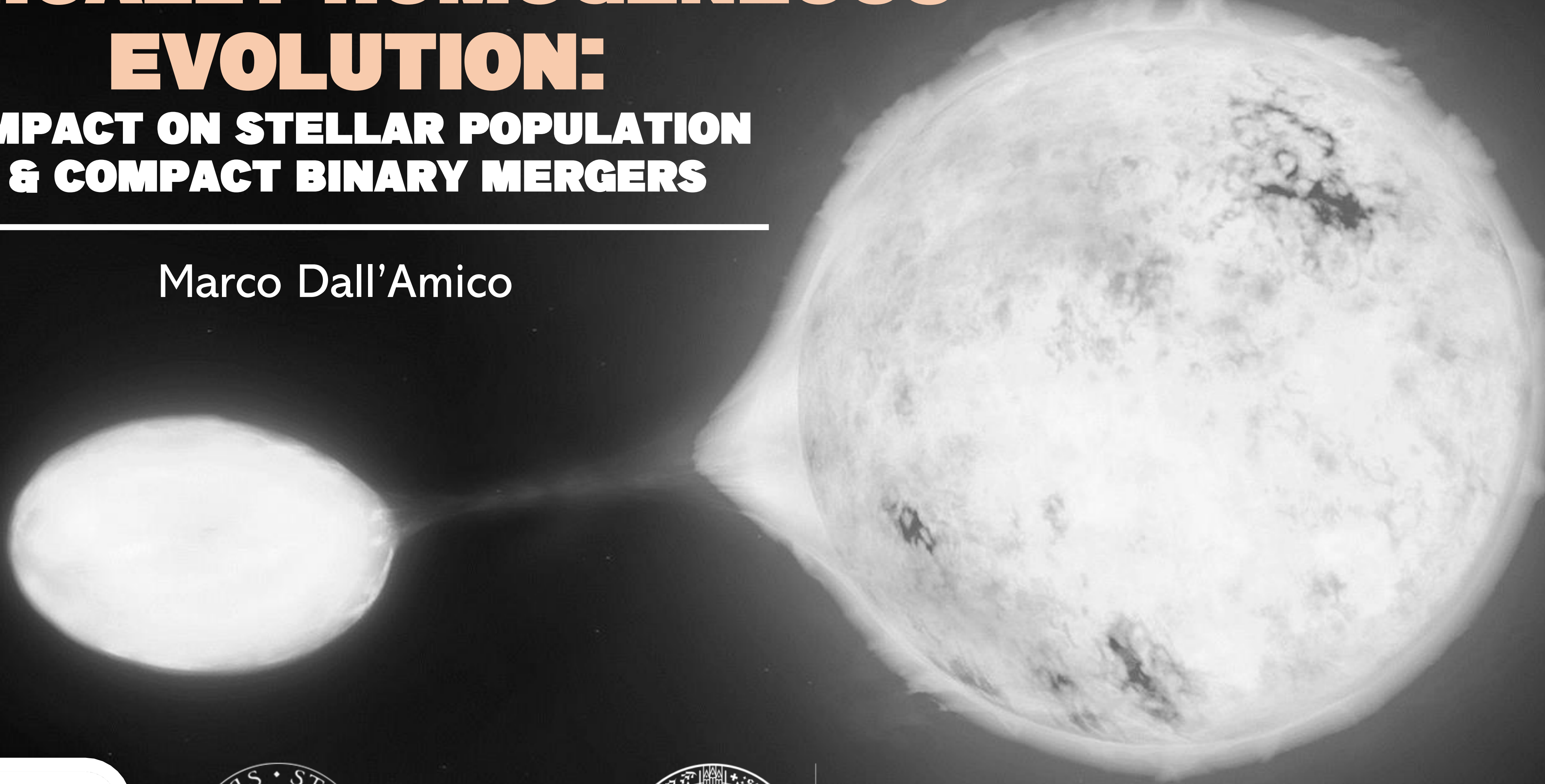
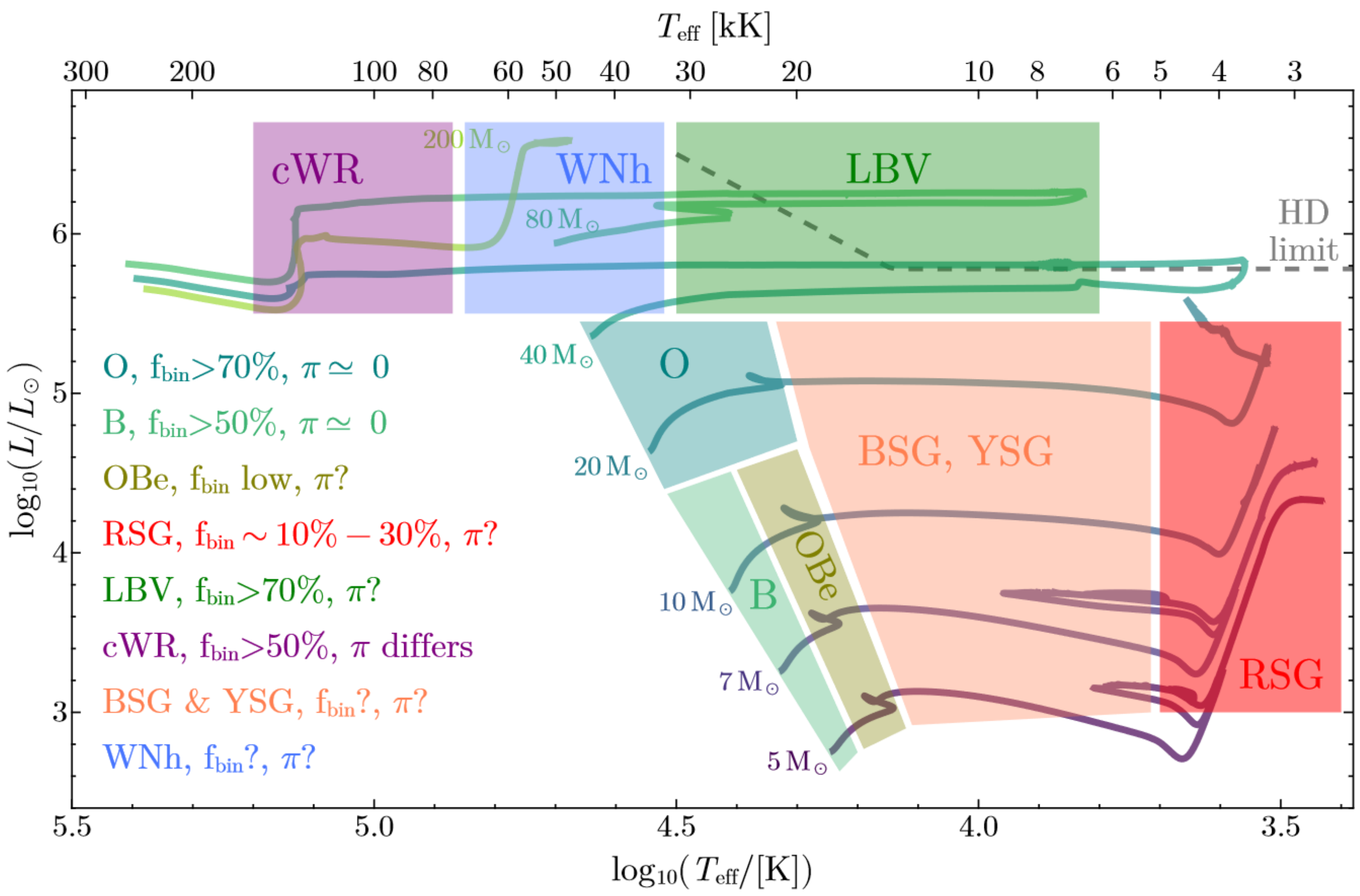
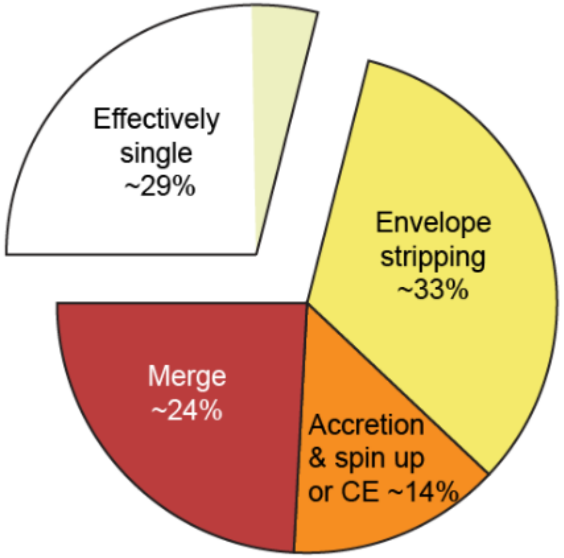
INFN



MASSIVE STARS:
BETTER TOGETHER

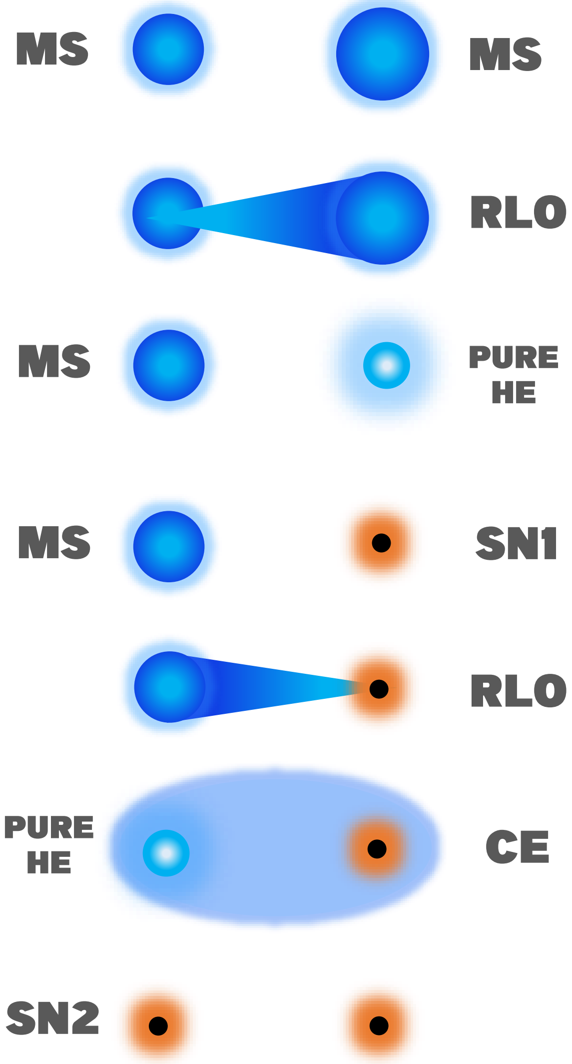


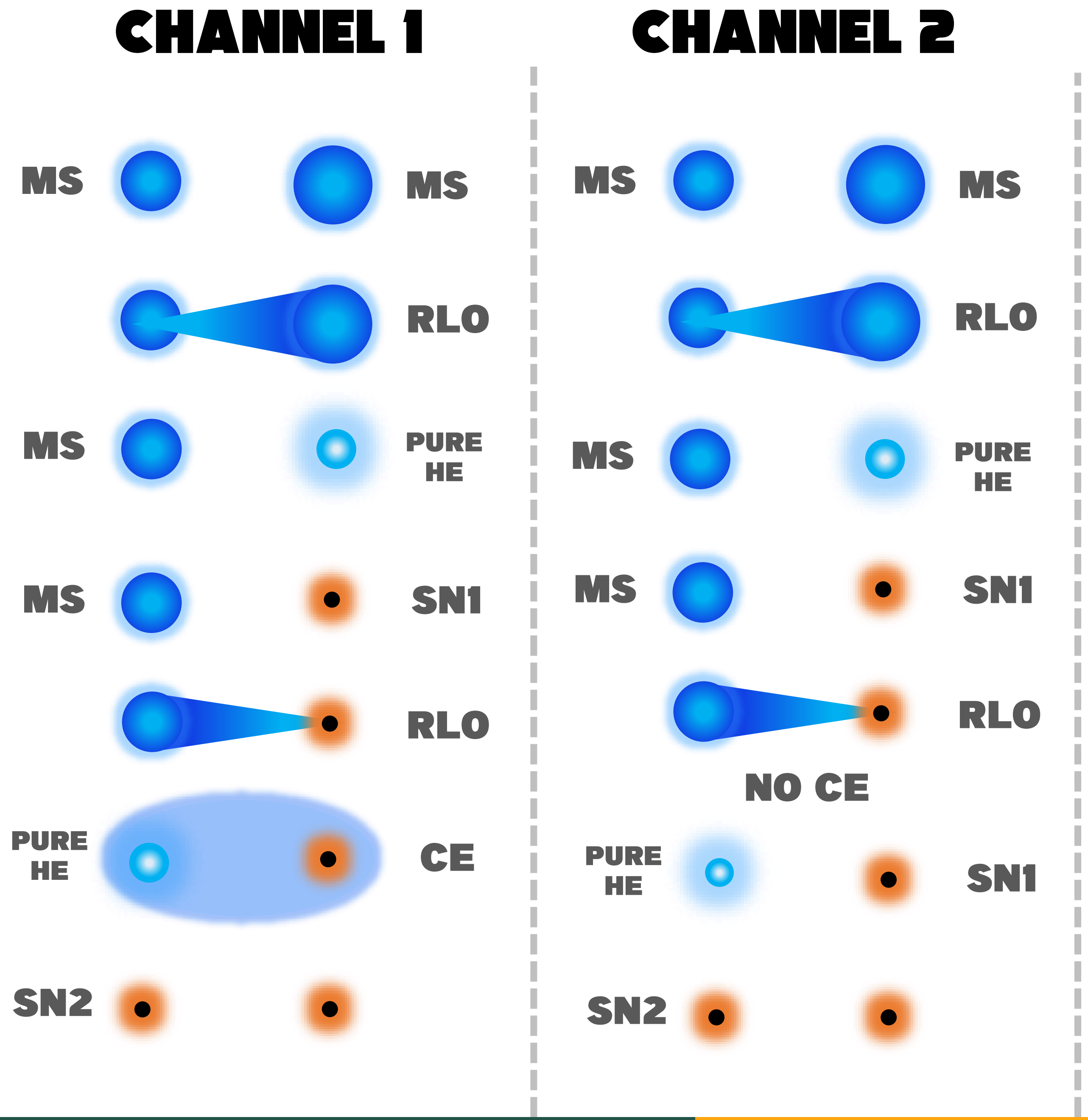
From Marchant & Bodensteiner 2024

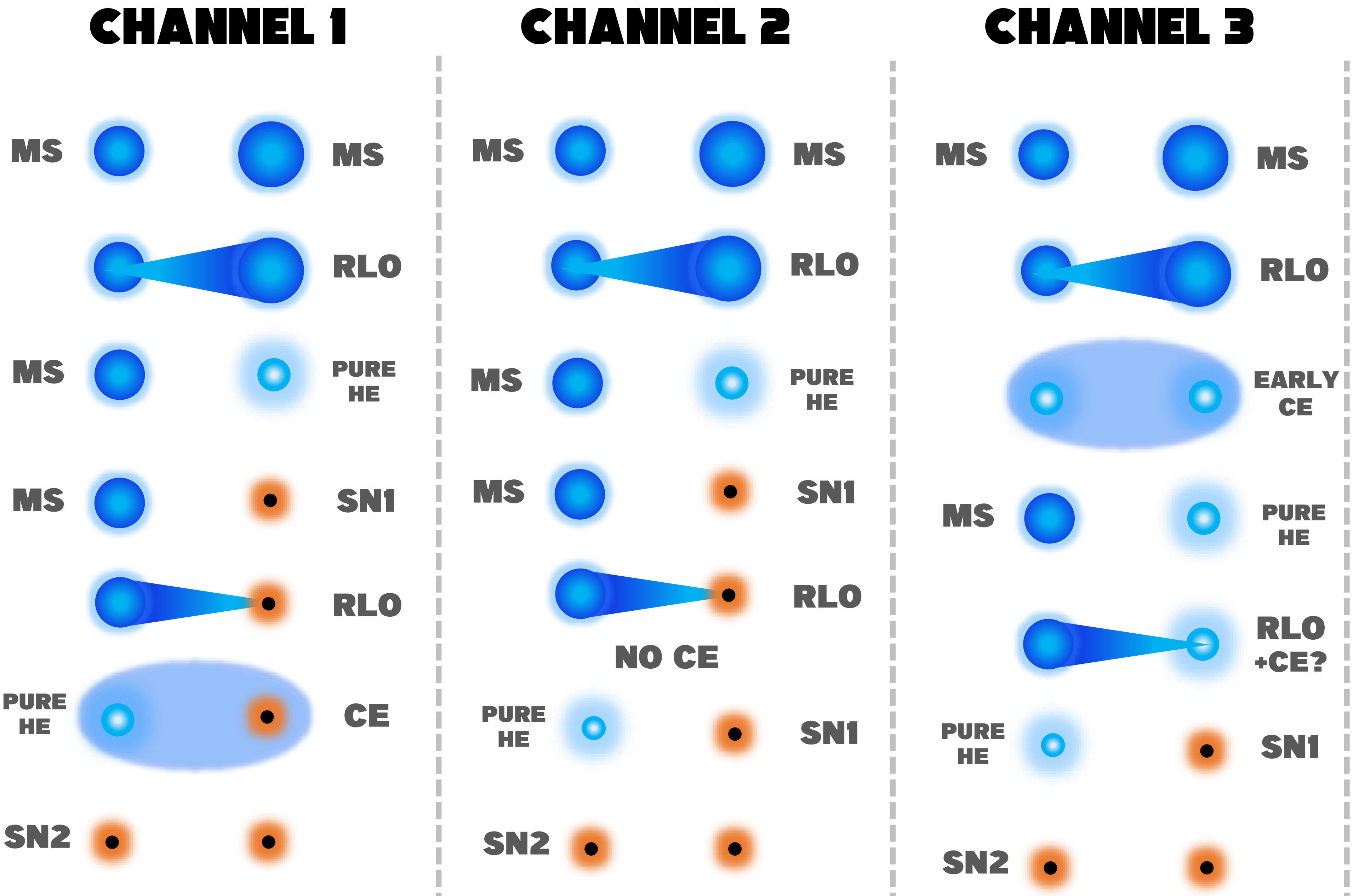


From Sana et al. 2012

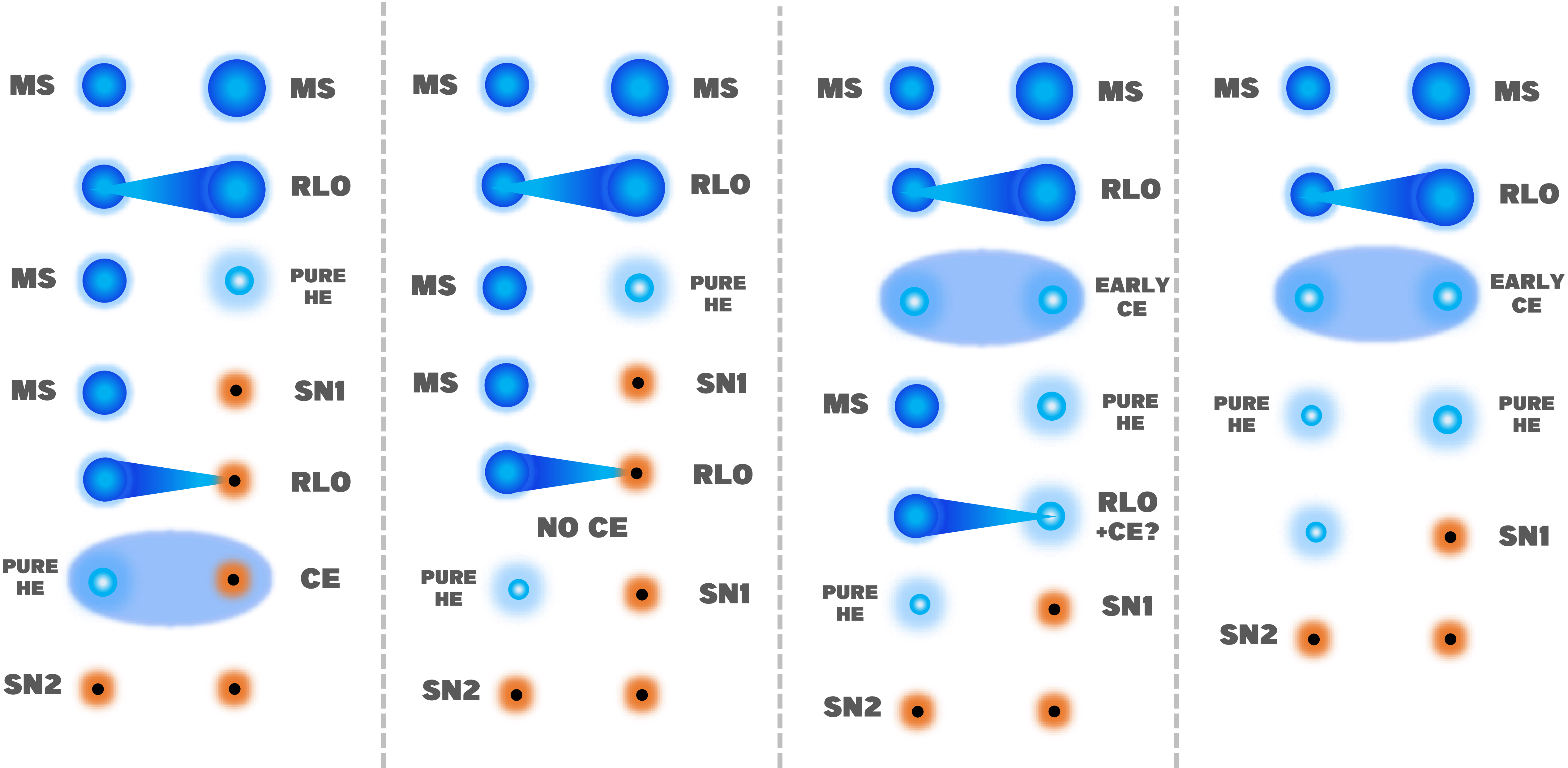
CHANNEL 1



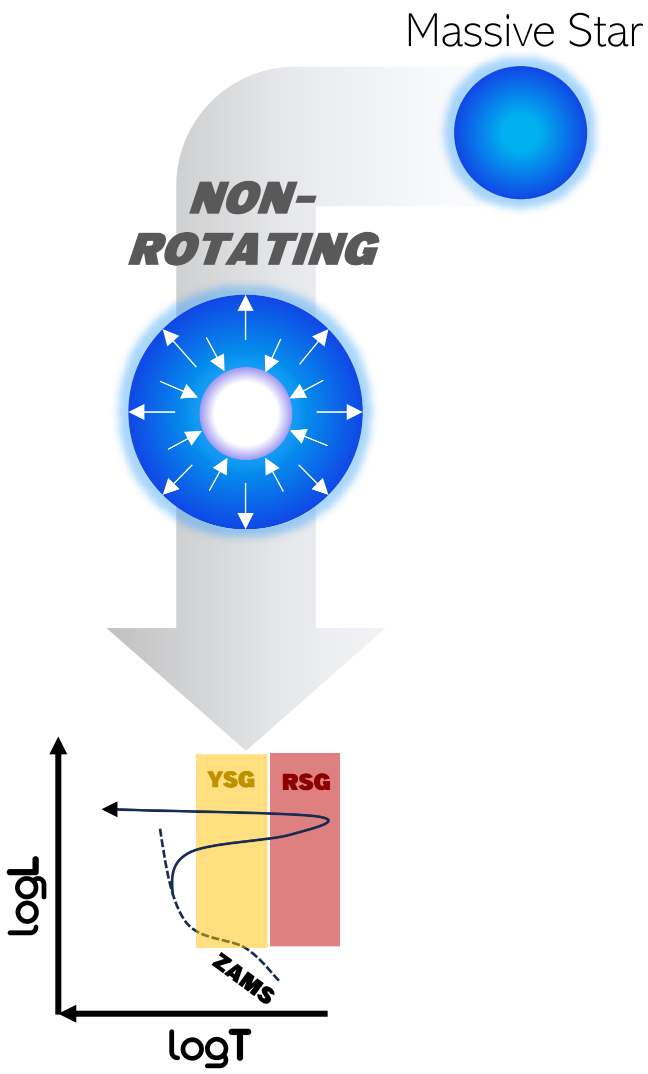

CHANNEL 1
CHANNEL 2
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
PURE HE
CE
SN2
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
NO CE
PURE HE
SN1
SN2


CHANNEL 1
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
PURE HE
CE
SN2
CHANNEL 2
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
NO CE
PURE HE
SN1
SN2
CHANNEL 3
MS
MS
RLO
EARLY CE
MS
PURE HE
RLO +CE?
PURE HE
SN1
SN2

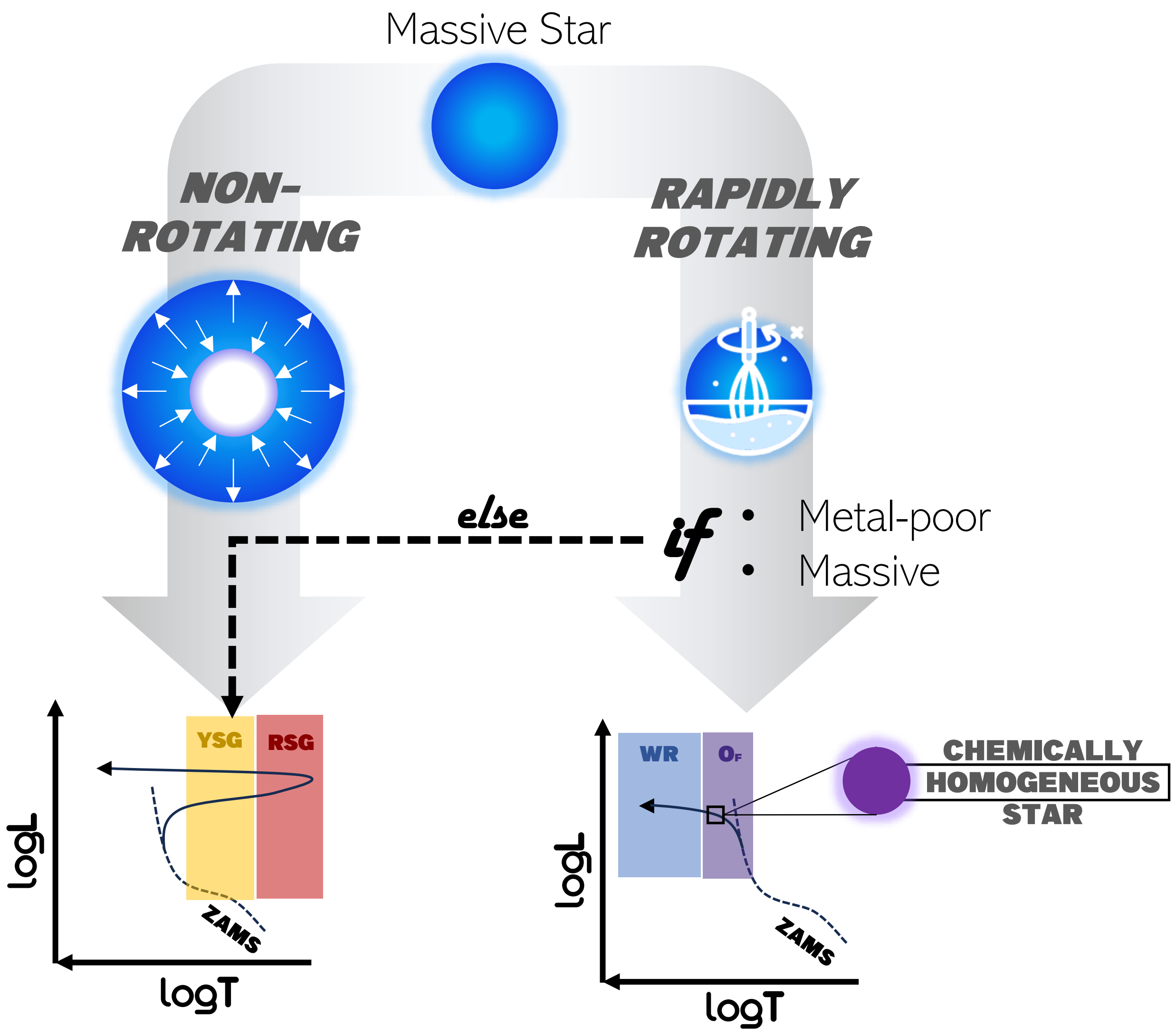
CHANNEL 1 | CHANNEL 2 | CHANNEL 3 | CHANNEL 4



CHEMICALLY HOMOGENEOUS EVOLUTION



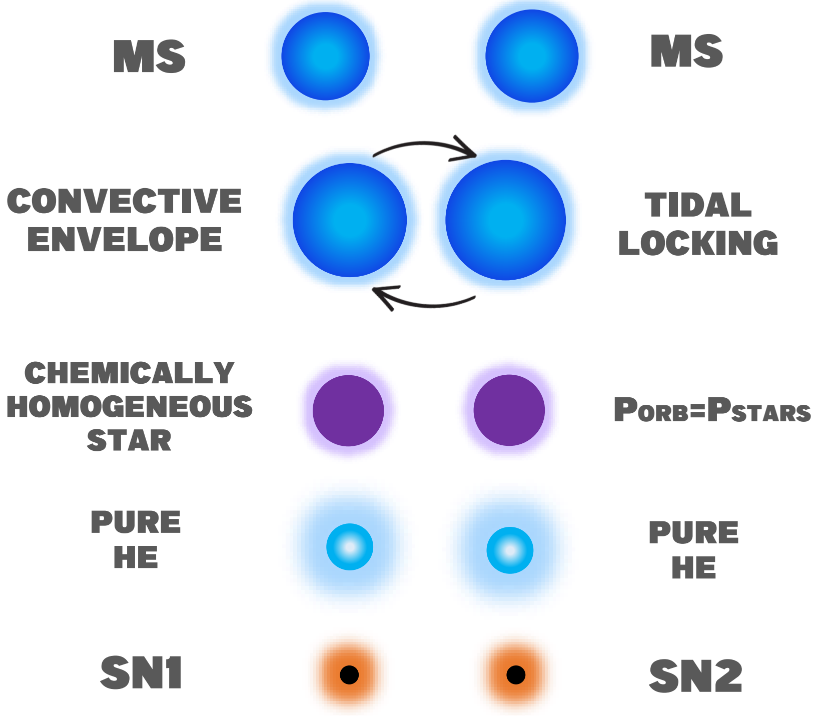
CHEMICALLY HOMOGENEOUS EVOLUTION



CHEMICALLY HOMOGENEOUS EVOLUTION

TIDAL - INDUCED MIXING

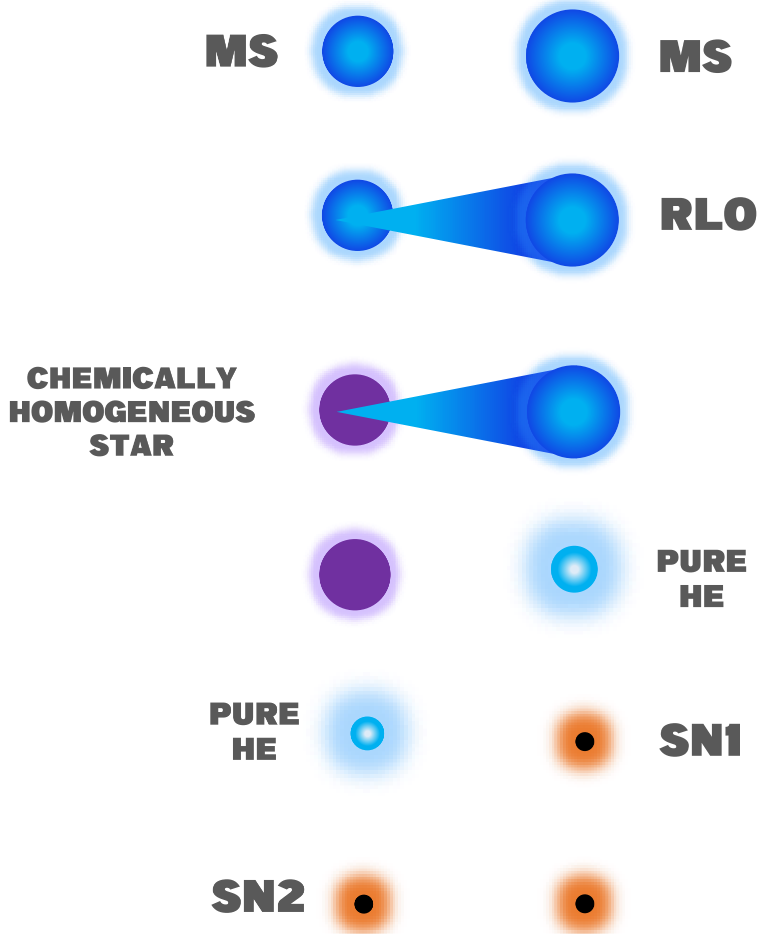
(e.g. De Mink 2009, Song et al. 2016)



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

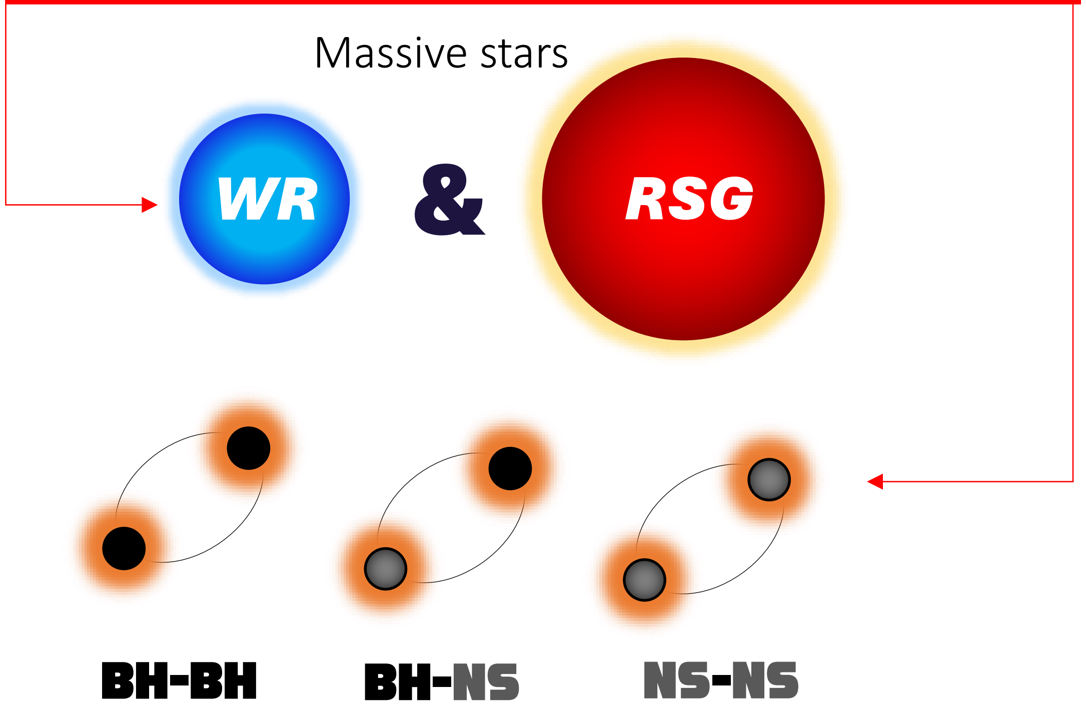
ACCRETION-INDUCED MIXING

(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

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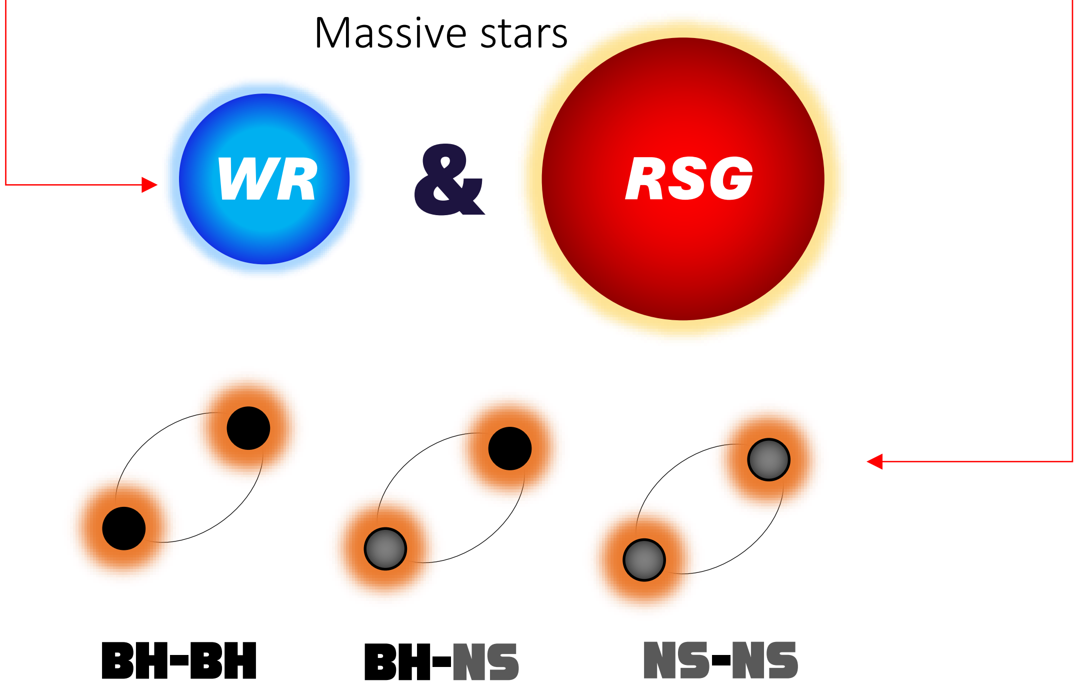


10^8 BINARY – 10^7 SINGLE SIMULATIONS WITH

SEVN + PARSEC

PAdova TRieste Stellar Evolutionary Code

Iorio+2023

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

CHE: Accretion spin up as in Eldridge+2011

if

- **LOW METALLICITY** (Z≤0.004)
- **LARGE ACCRETED MASS** (>5% of initial mass)
- **MASSIVE STAR** (M>15 M⊙)

MODEL W/O
CHE

MODEL WITH
CHE

MODEL W/O

CHE

MODEL WITH

CHE

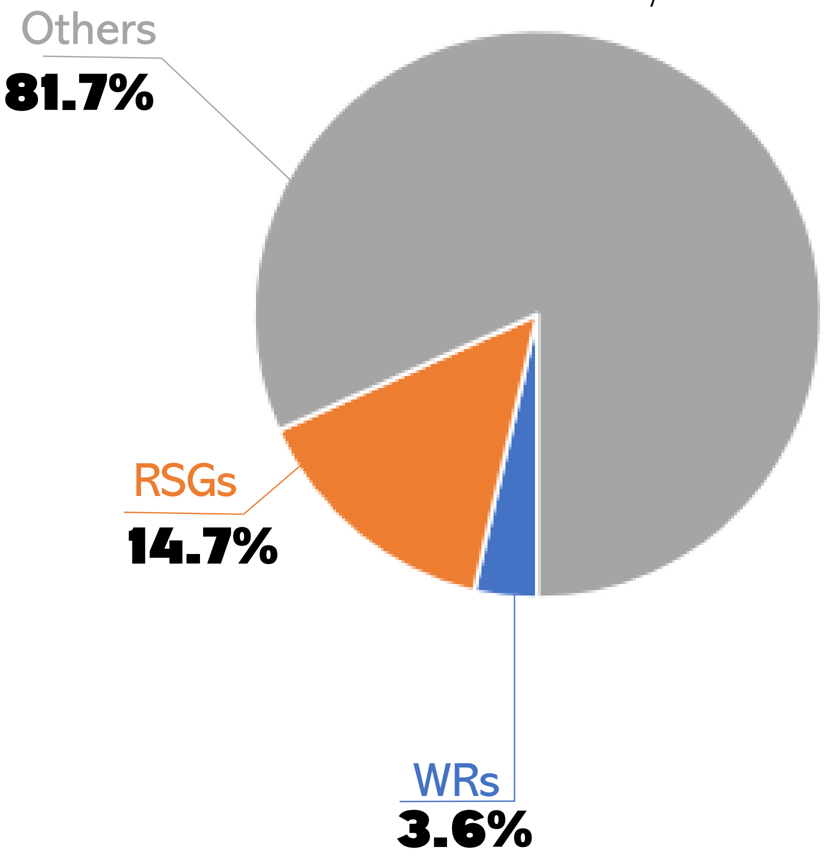
BINARIES EXP. CHE

15% Z=0.001

MODEL W/O

CHE

Fractions of stellar phases:



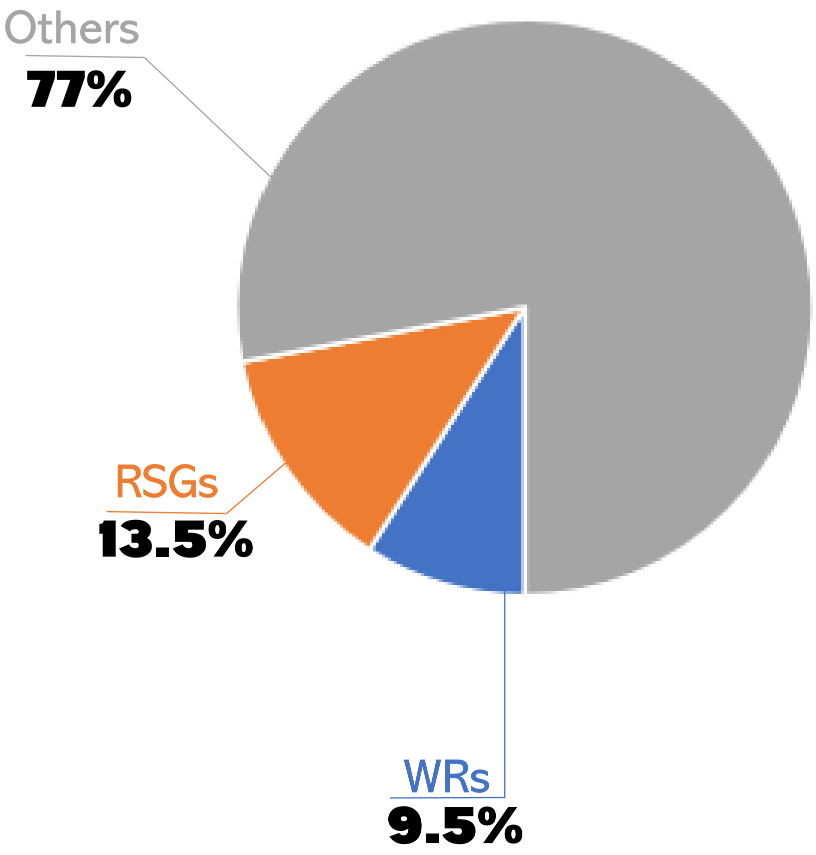
MODEL WITH

CHE

BINARIES EXP. CHE

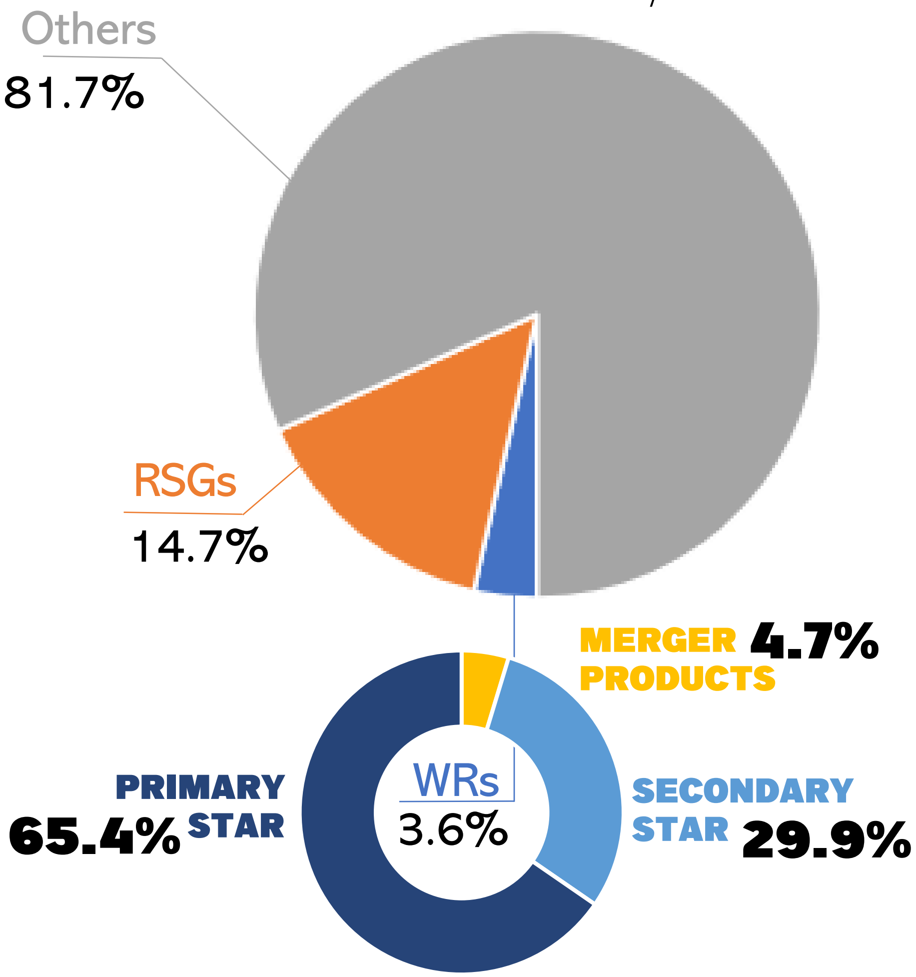
15% Z=0.001

Fractions of stellar phases:



MODEL W/O
CHE

Fractions of stellar phases:

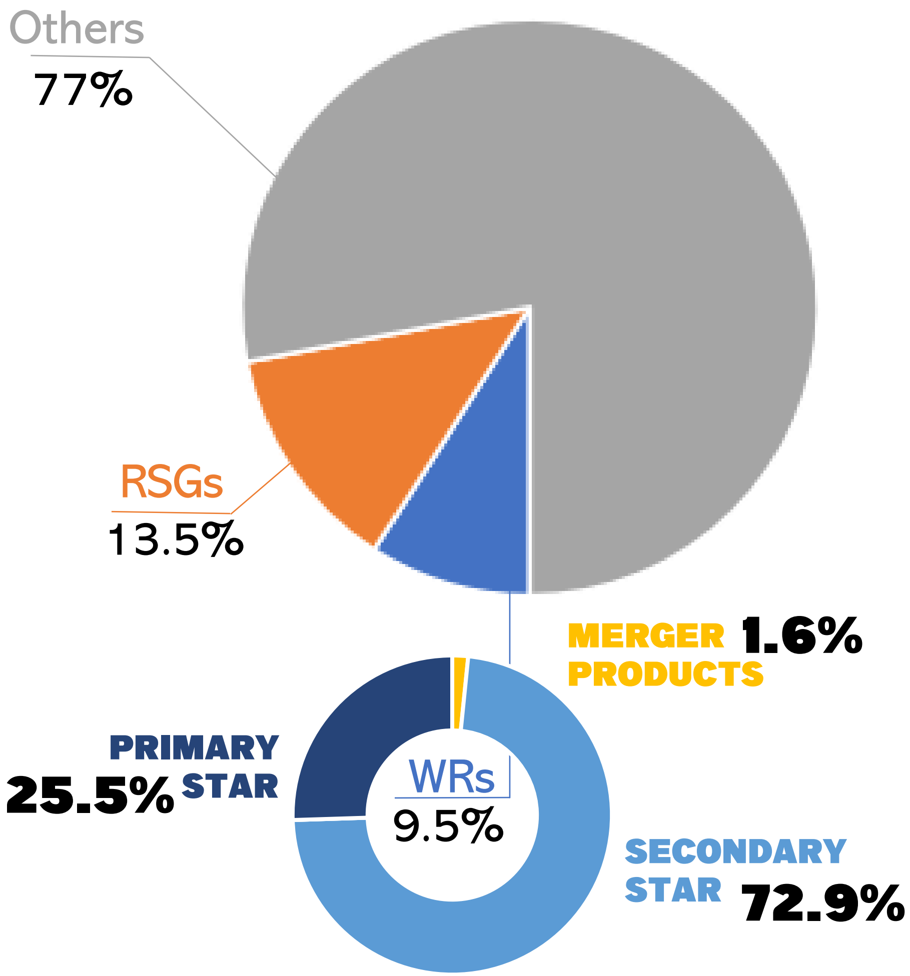


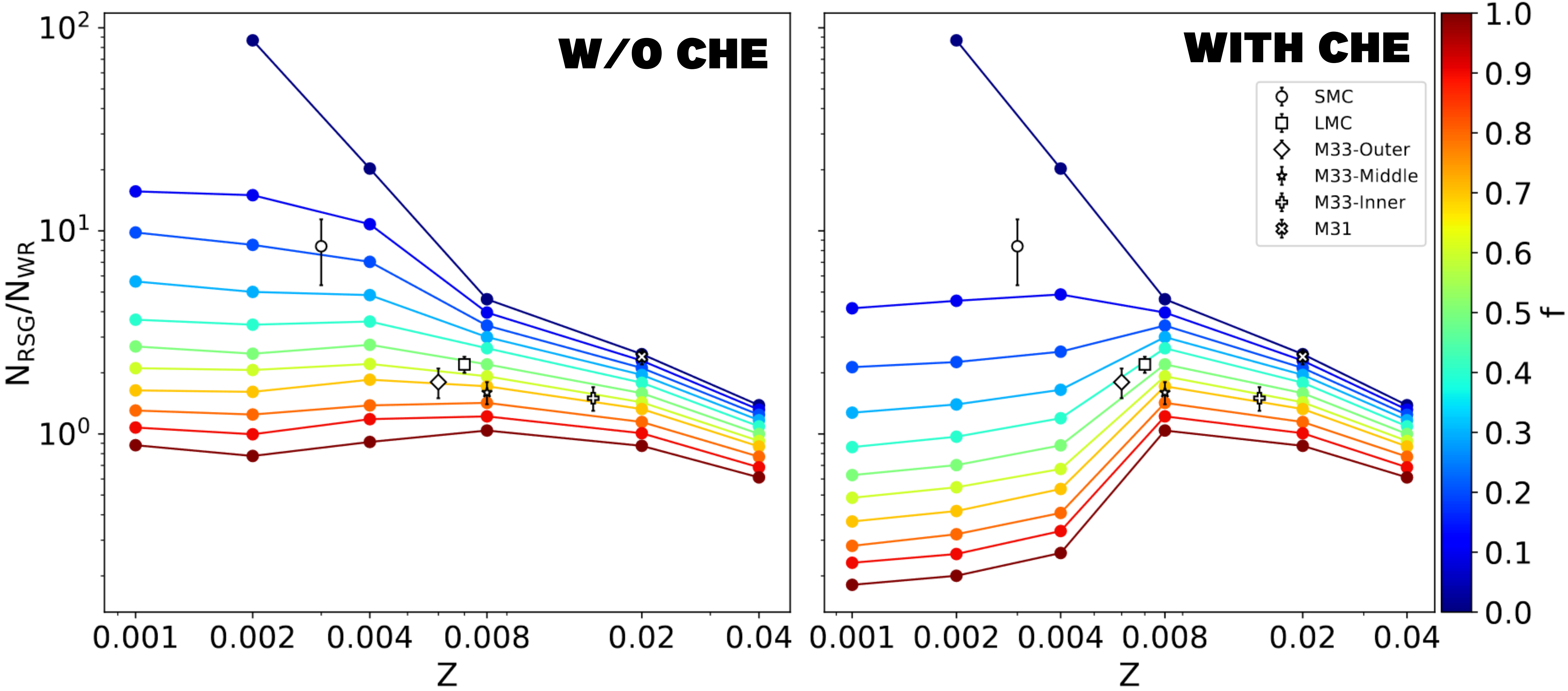
MODEL WITH
CHE

BINARIES EXP. CHE

15% Z=0.001

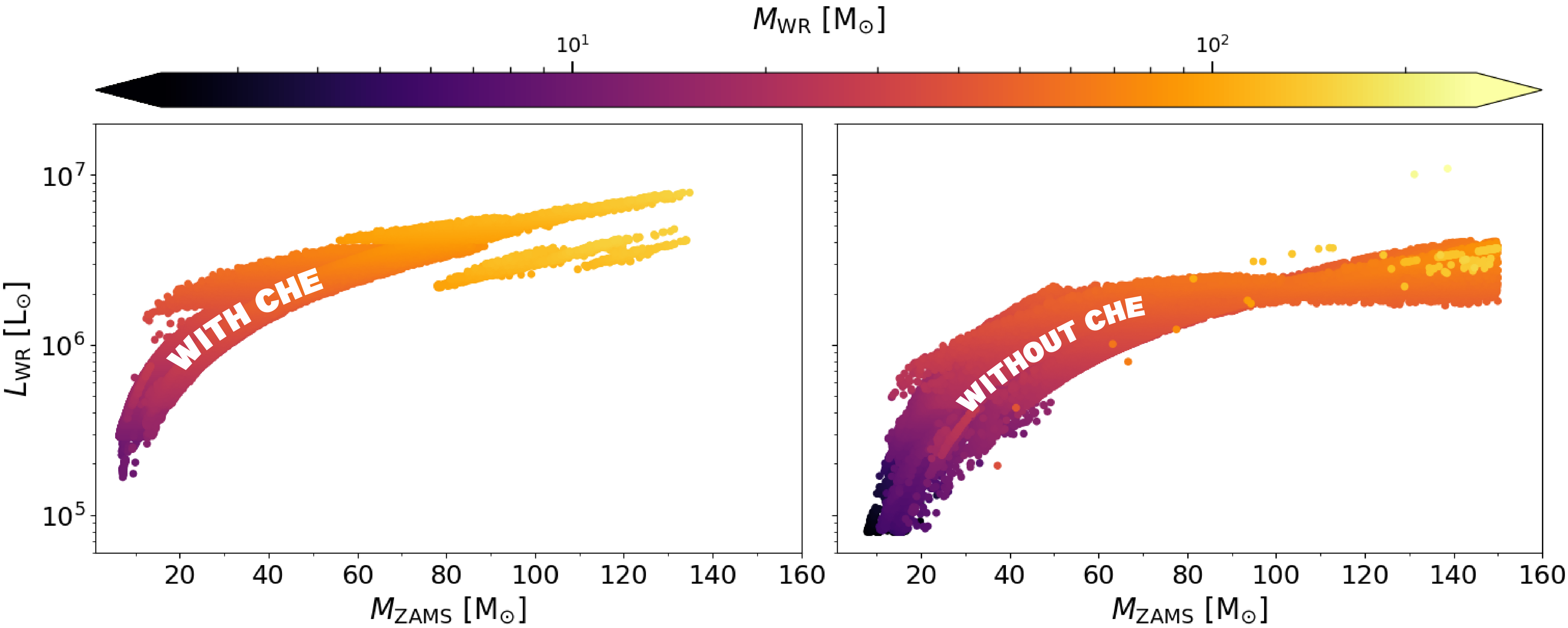
Fractions of stellar phases:



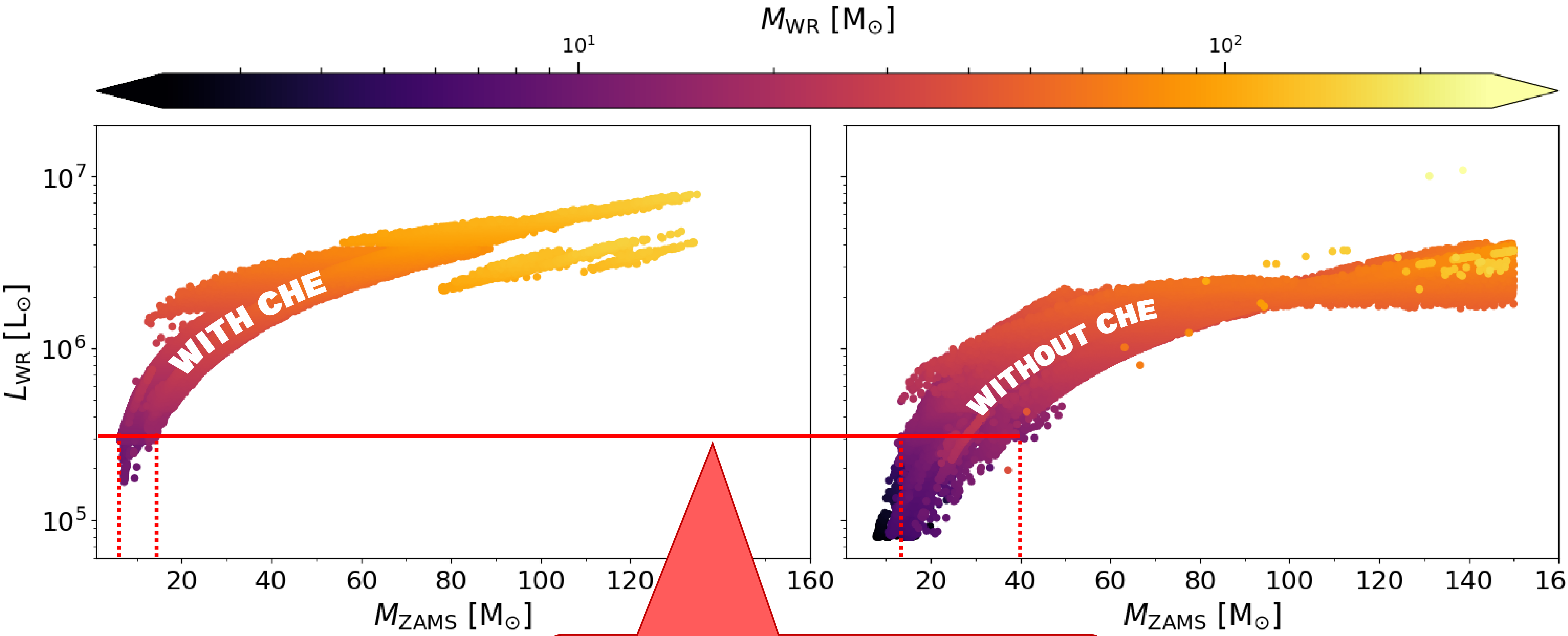


CHE PRODUCES ALMOST 3 TIMES MORE WR STARS THAN STANDARD BINARY EVOLUTION AT LOW METALLICITY

WR & PROGENITOR STAR (AT Z=0.001)

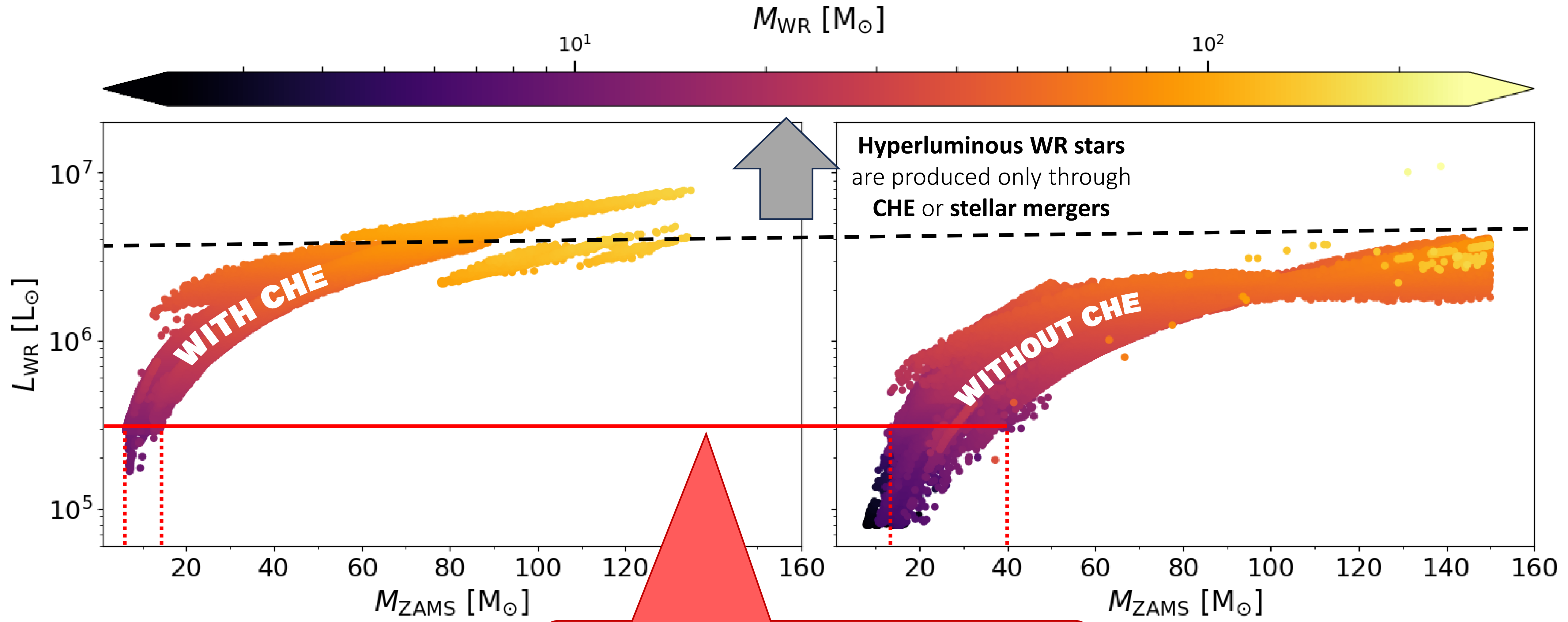


WR & PROGENITOR STAR (AT Z=0.001)



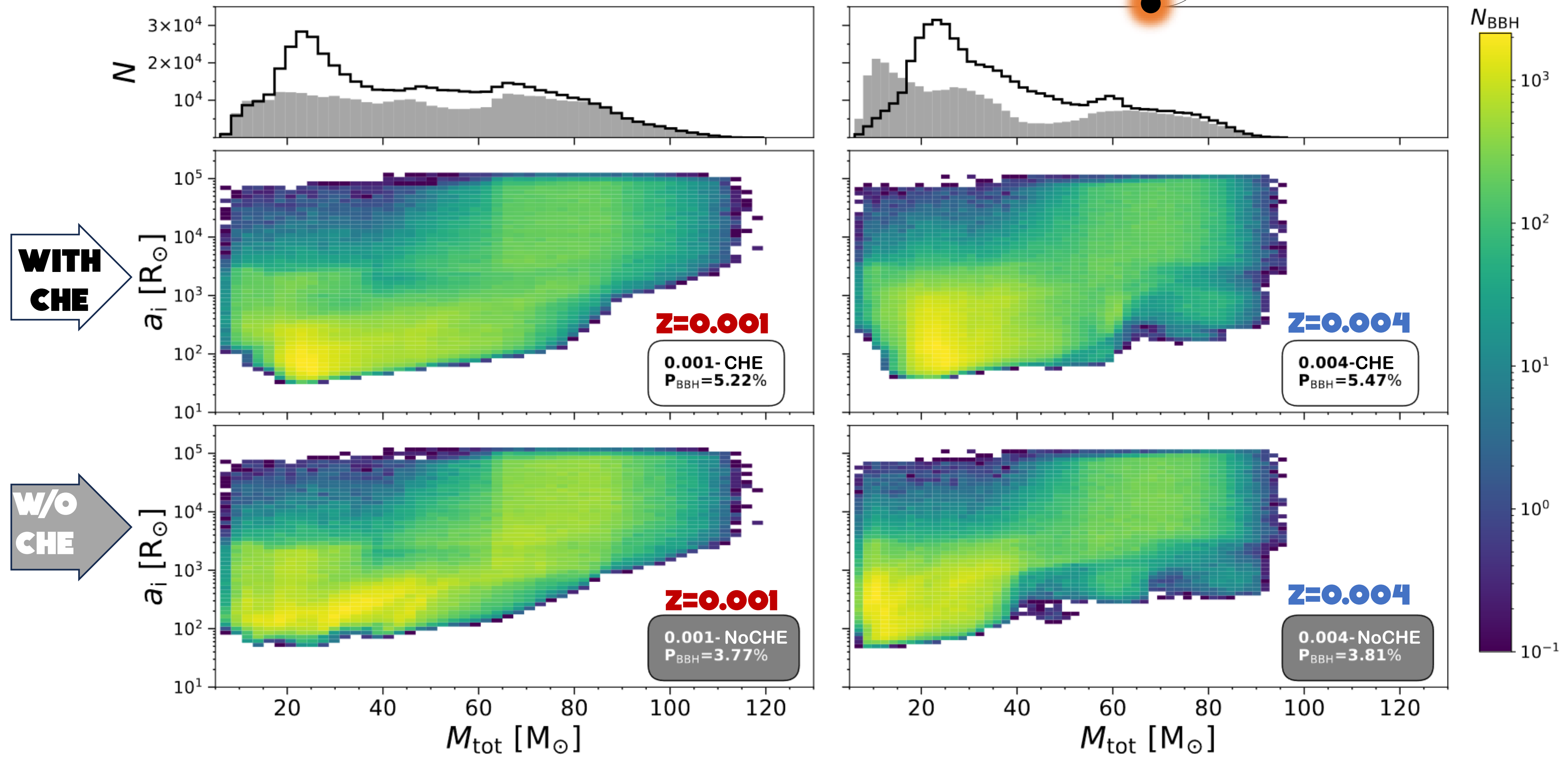
WR produced by a **6-15$M_\odot$** star through **CHE** has the same **Luminosity** of a **WR** produced by a **15-40 $M_\odot$** star through **standard binary evolution**

WR & PROGENITOR STAR (AT Z=0.001)

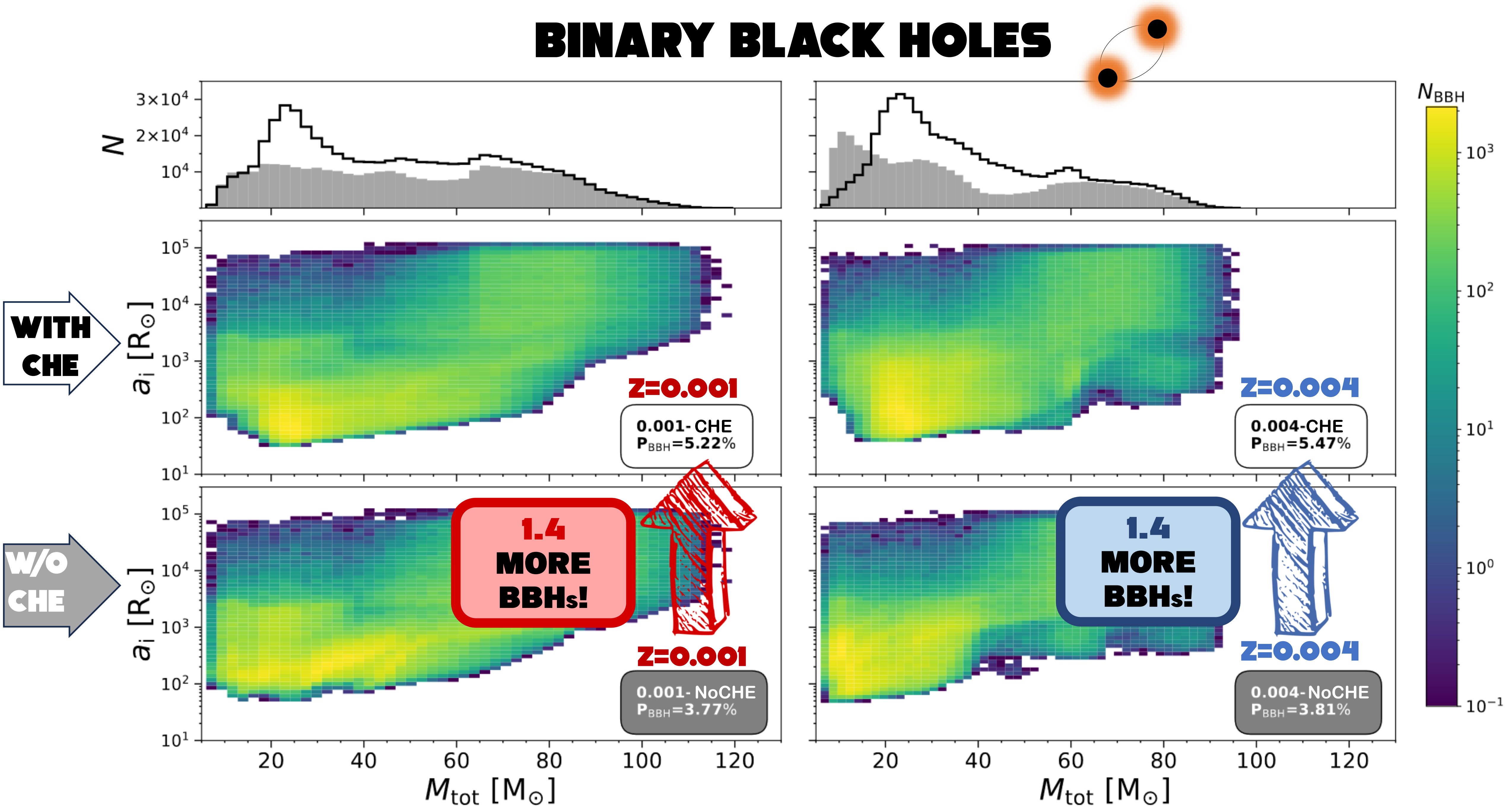


WR produced by a **6-15$M_\odot$** star through **CHE** has the same **Luminosity** of a **WR** produced by a **15-40 $M_\odot$** star through **standard binary evolution**

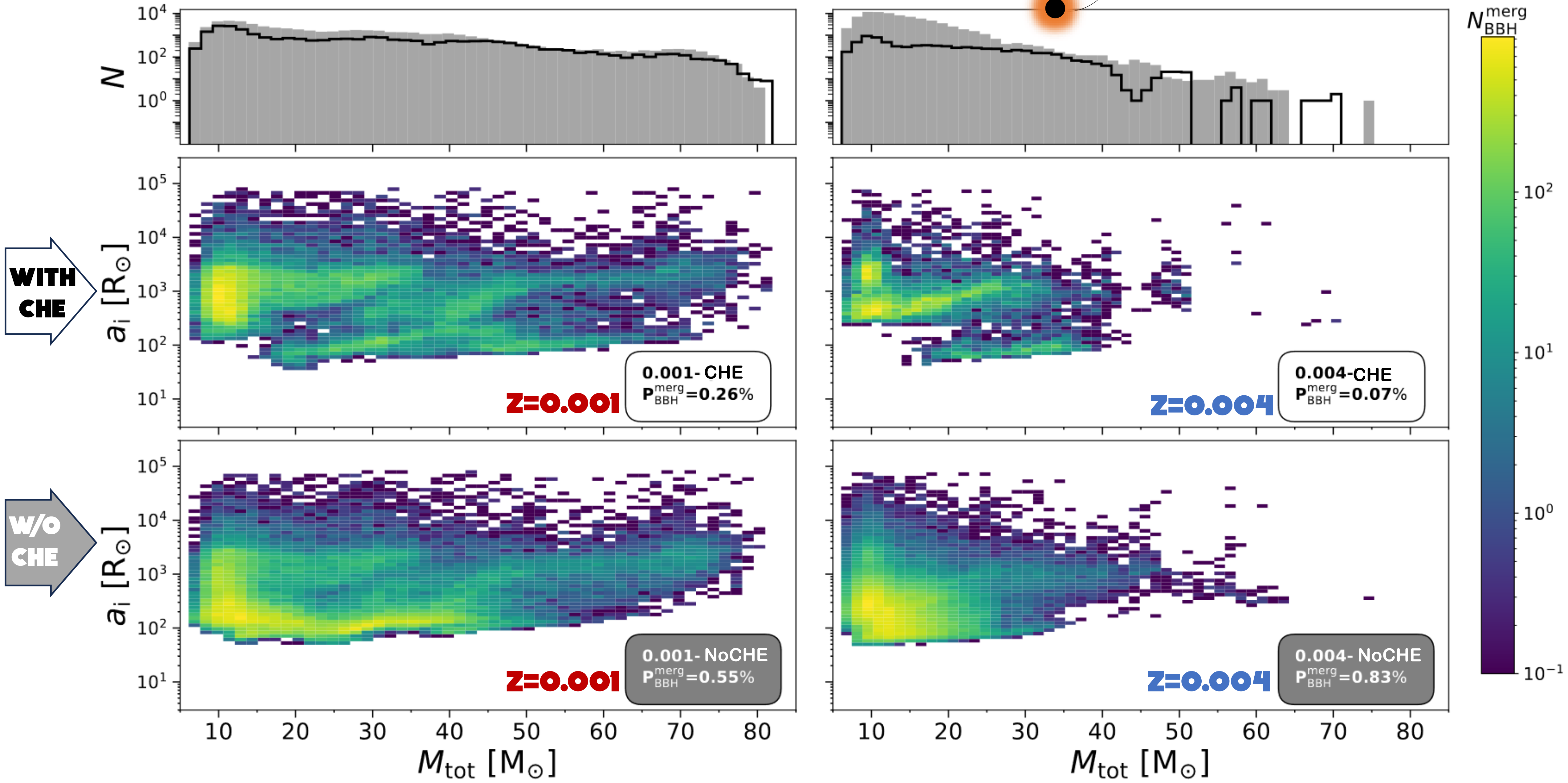
BINARY BLACK HOLES



BINARY BLACK HOLES

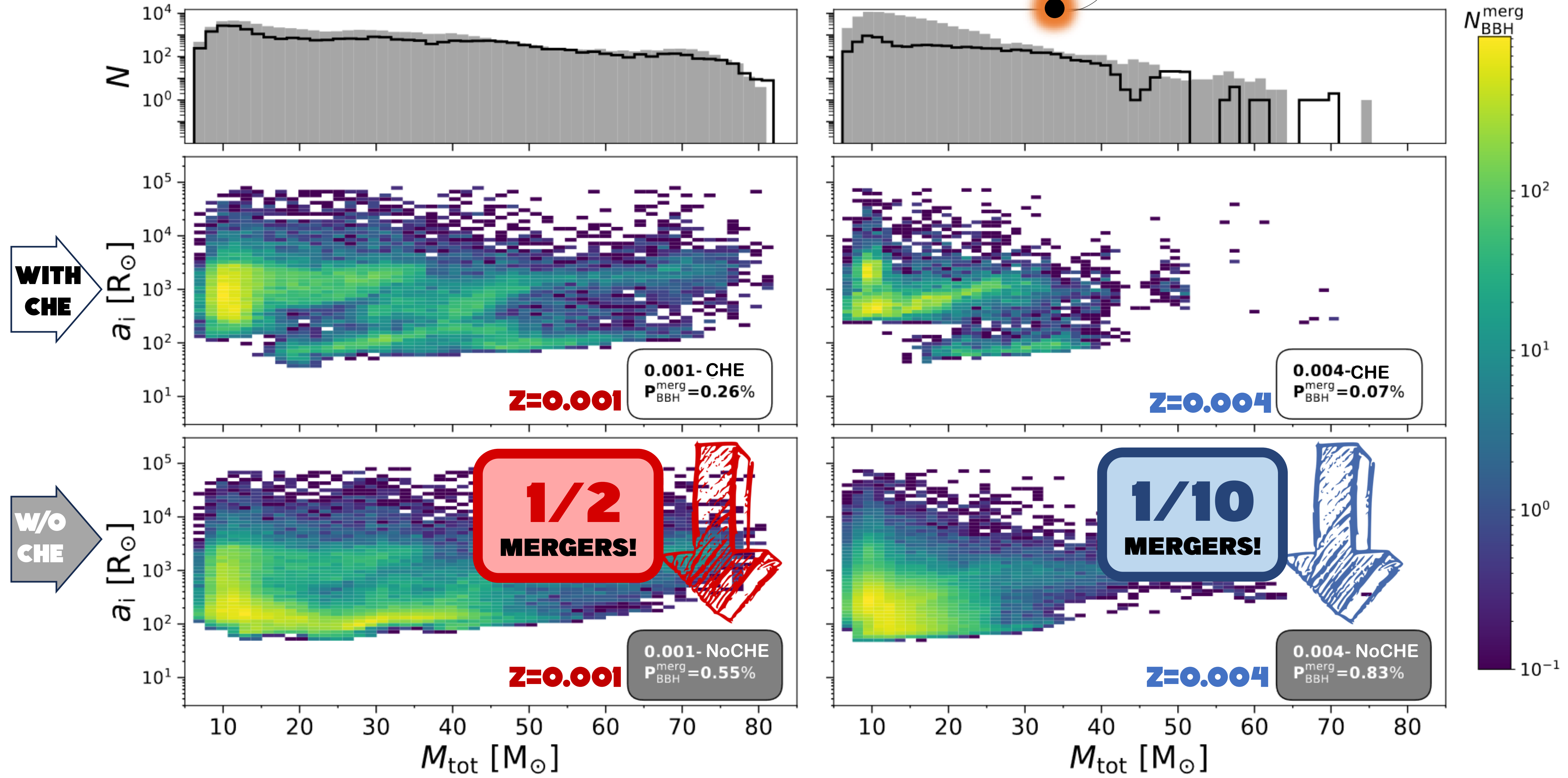


BBH MERGERS

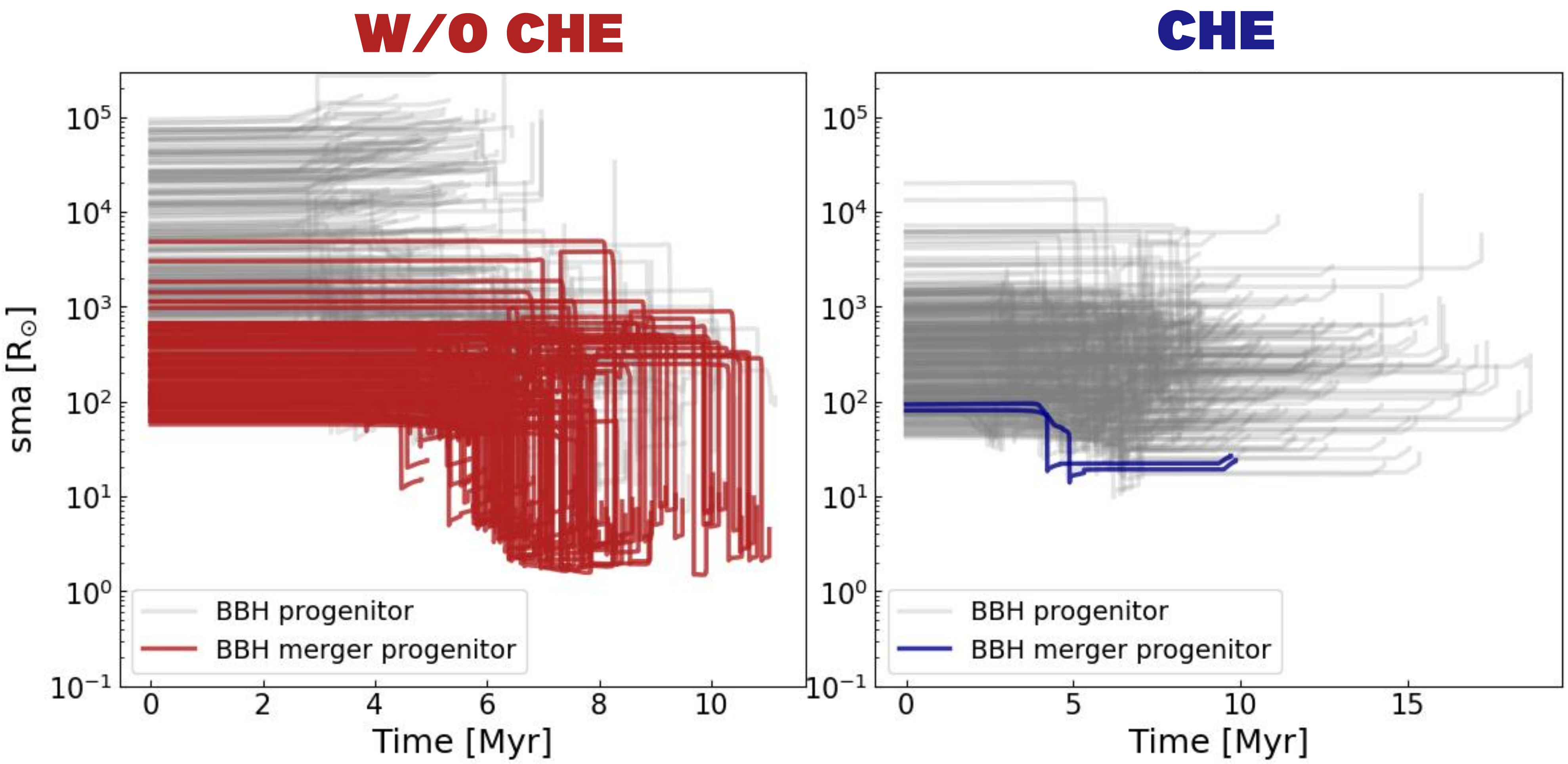


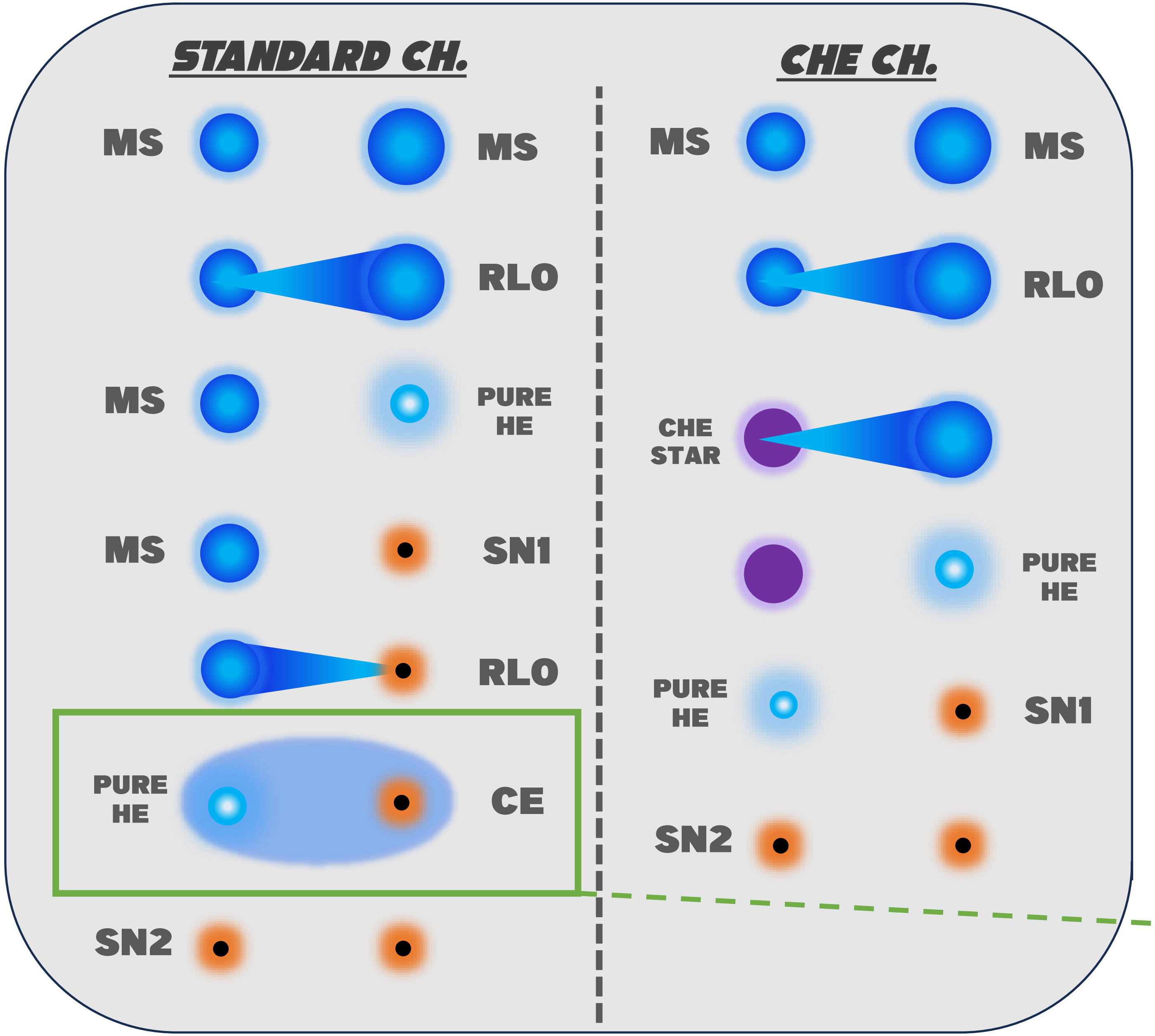
WITH CHE
W/O CHE
N
$a_i\ [R_\odot]$
$M_{tot}\ [M_\odot]$
N^{merg}_{BBH}
Z=0.001
Z=0.004
0.001- CHE
P^{merg}_{BBH}=0.26%
0.004-CHE
P^{merg}_{BBH}=0.07%
0.001- NoCHE
P^{merg}_{BBH}=0.55%
0.004- NoCHE
P^{merg}_{BBH}=0.83%

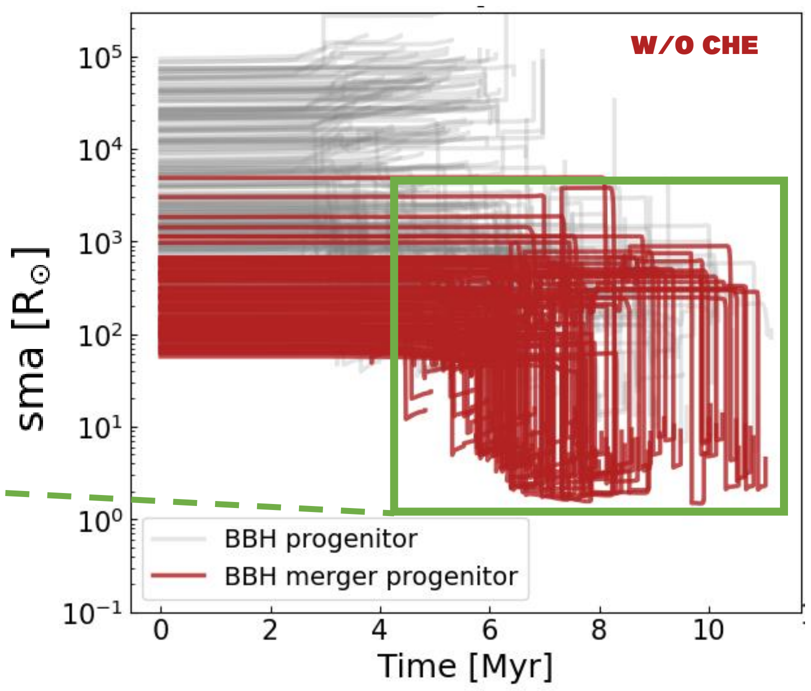
BBH MERGERS

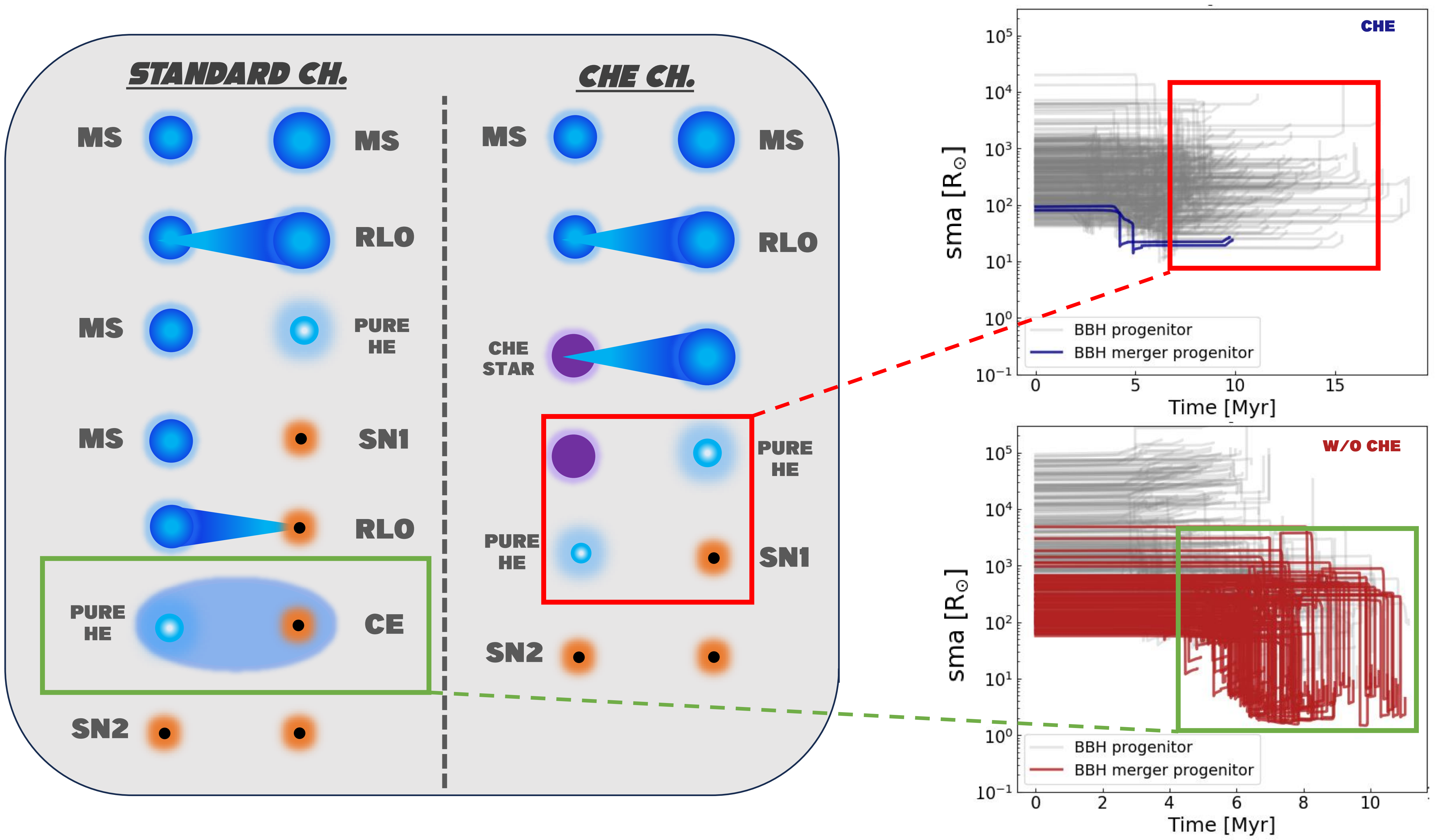

WITH CHE
W/O CHE
N
a_i [$R_\odot$]
M_{tot} [$M_\odot$]
N_{BBH}^{merg}
0.001- CHE
P_{BBH}^{merg}=0.26%
Z=0.001
0.004-CHE
P_{BBH}^{merg}=0.07%
Z=0.004
1/2
MERGERS!
0.001- NoCHE
P_{BBH}^{merg}=0.55%
Z=0.001
1/10
MERGERS!
0.004- NoCHE
P_{BBH}^{merg}=0.83%
Z=0.004

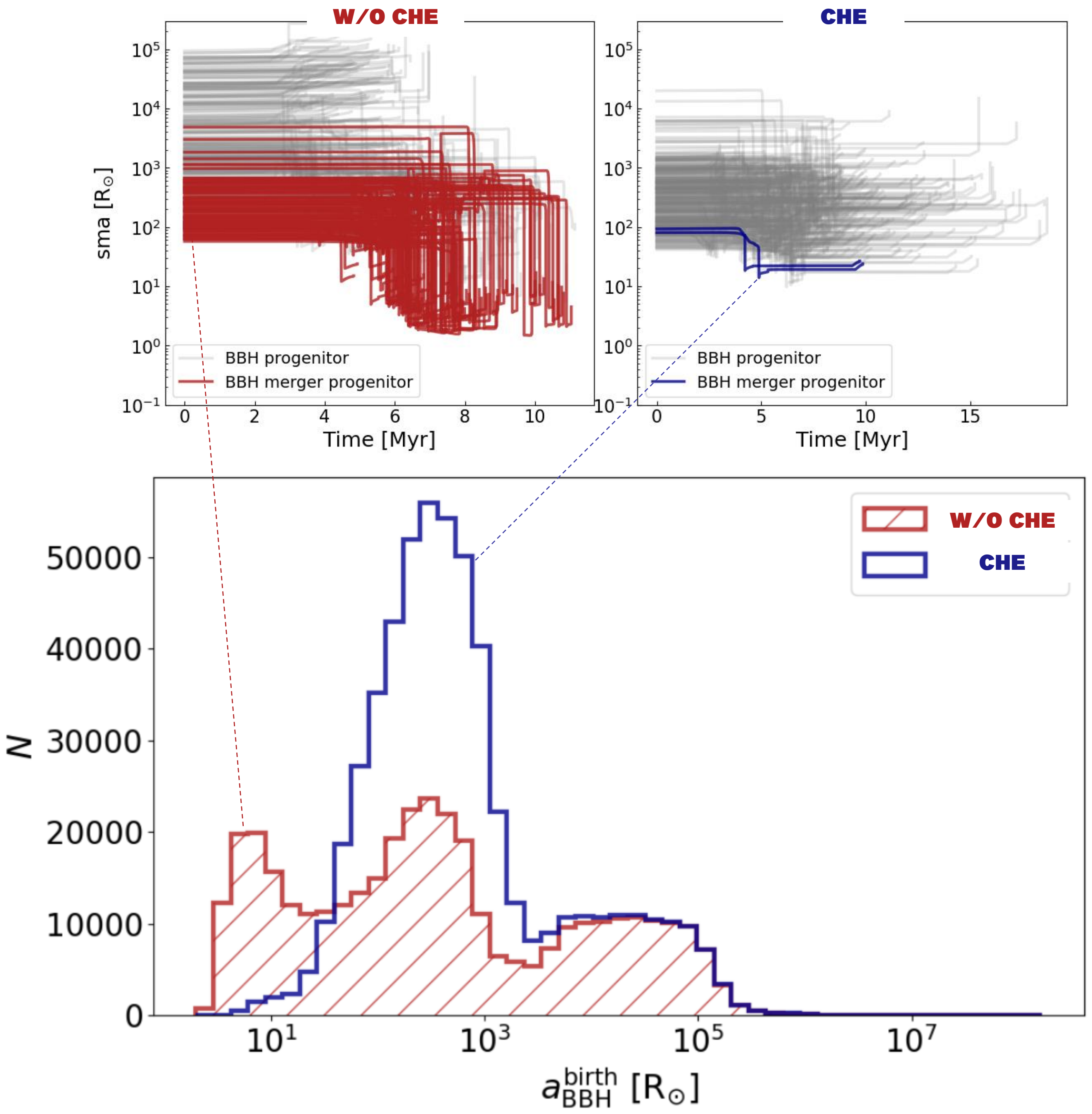
ORBITAL SEPARATION EVOLUTION (AT Z=0.004)




STANDARD CH.
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
PURE HE
CE
SN2
CHE CH.
MS
MS
RLO
CHE STAR
PURE HE
PURE HE
SN1
SN2


W/O CHE
sma [R⊙]
Time [Myr]
BBH progenitor
BBH merger progenitor


STANDARD CH.
MS
MS
RLO
MS
PURE HE
MS
SN1
RLO
PURE HE
CE
SN2
CHE CH.
MS
MS
RLO
CHE STAR
PURE HE
PURE HE
SN1
SN2
CHE
sma [R⊙]
Time [Myr]
BBH progenitor
BBH merger progenitor
W/O CHE
sma [R⊙]
Time [Myr]
BBH progenitor
BBH merger progenitor



BBH FORMED THROUGH CHE BORN WITH **LARGER ORBITAL SEPARATIONS**

SUMMARY

+ **BINARY EVOLUTION**

+ **CHEMICALLY HOMOGENEOUS EVOLUTION**

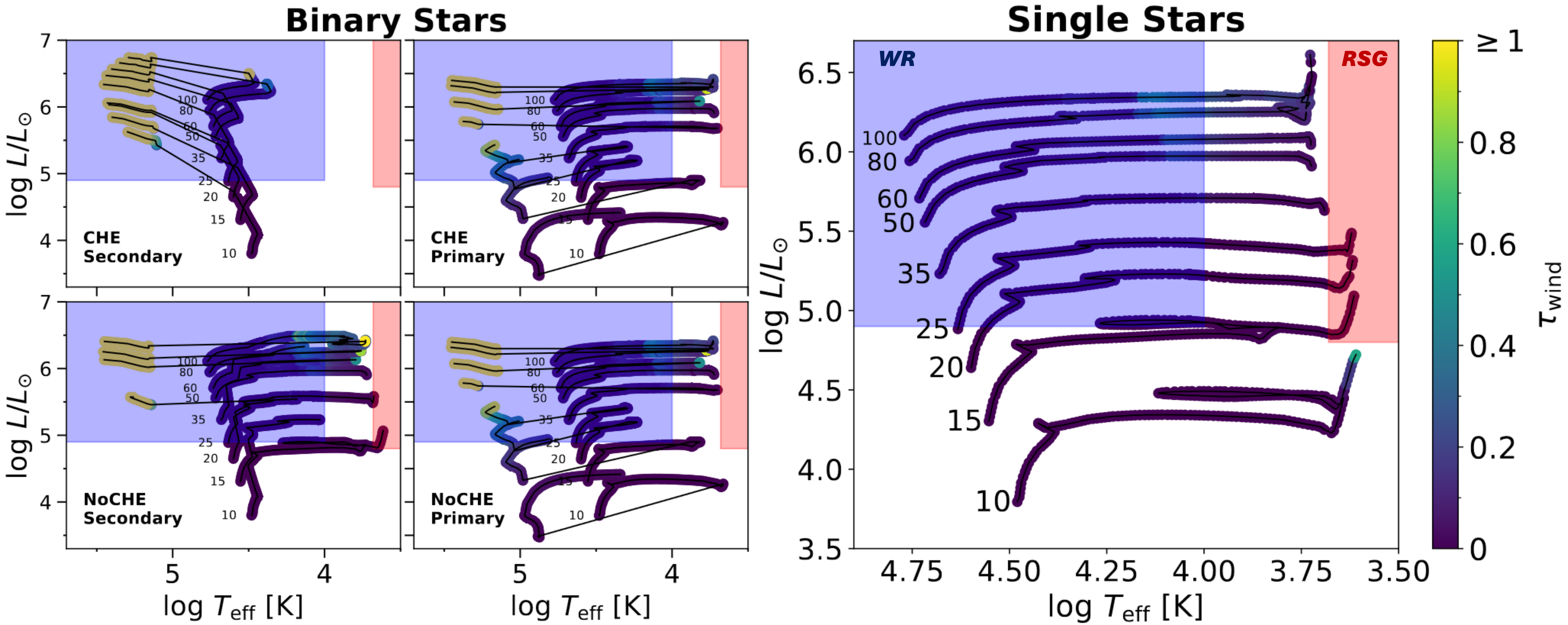
=
1. **MORE NUMEROUS WR**
   ↳ More massive BHs
2. **MORE MASSIVE WR**
   ↳ More luminous WRs from less massive progenitors
3. **LESS BBH & BHNS MERGERS**
   ↳ CHE quenches BBH & BHNS merger formation
4. **ASYMMETRIC BBH**
   ↳ BBH with Mass ratio 0.4-0.6

Langer1989

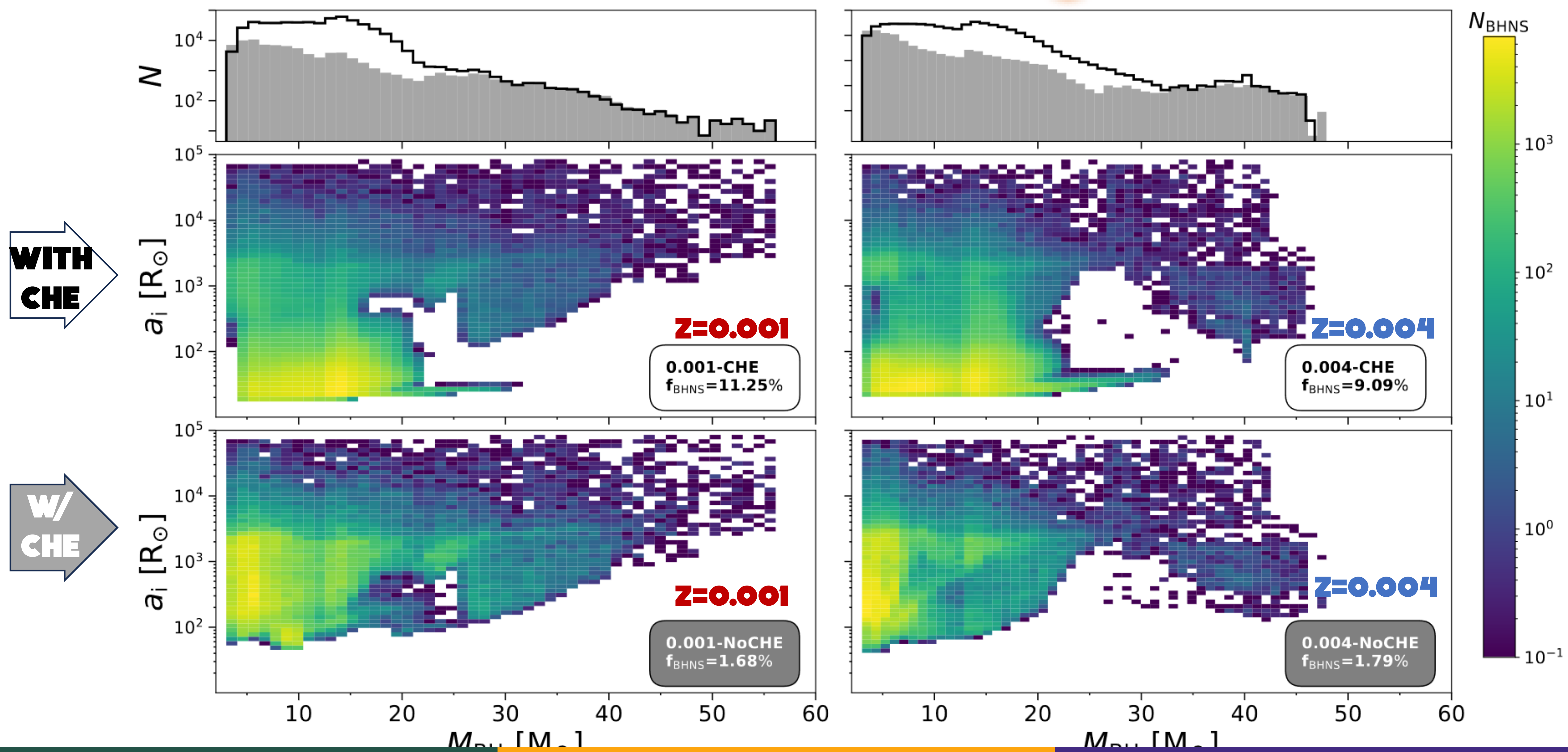
$$\tau_{\rm wind} = \frac{\kappa_{\rm e}\,|\dot{M}|}{4\,\pi\,R(v_\infty - v_0)}\,\ln\left[\frac{v_\infty}{v_0}\right]$$

WR & RSG

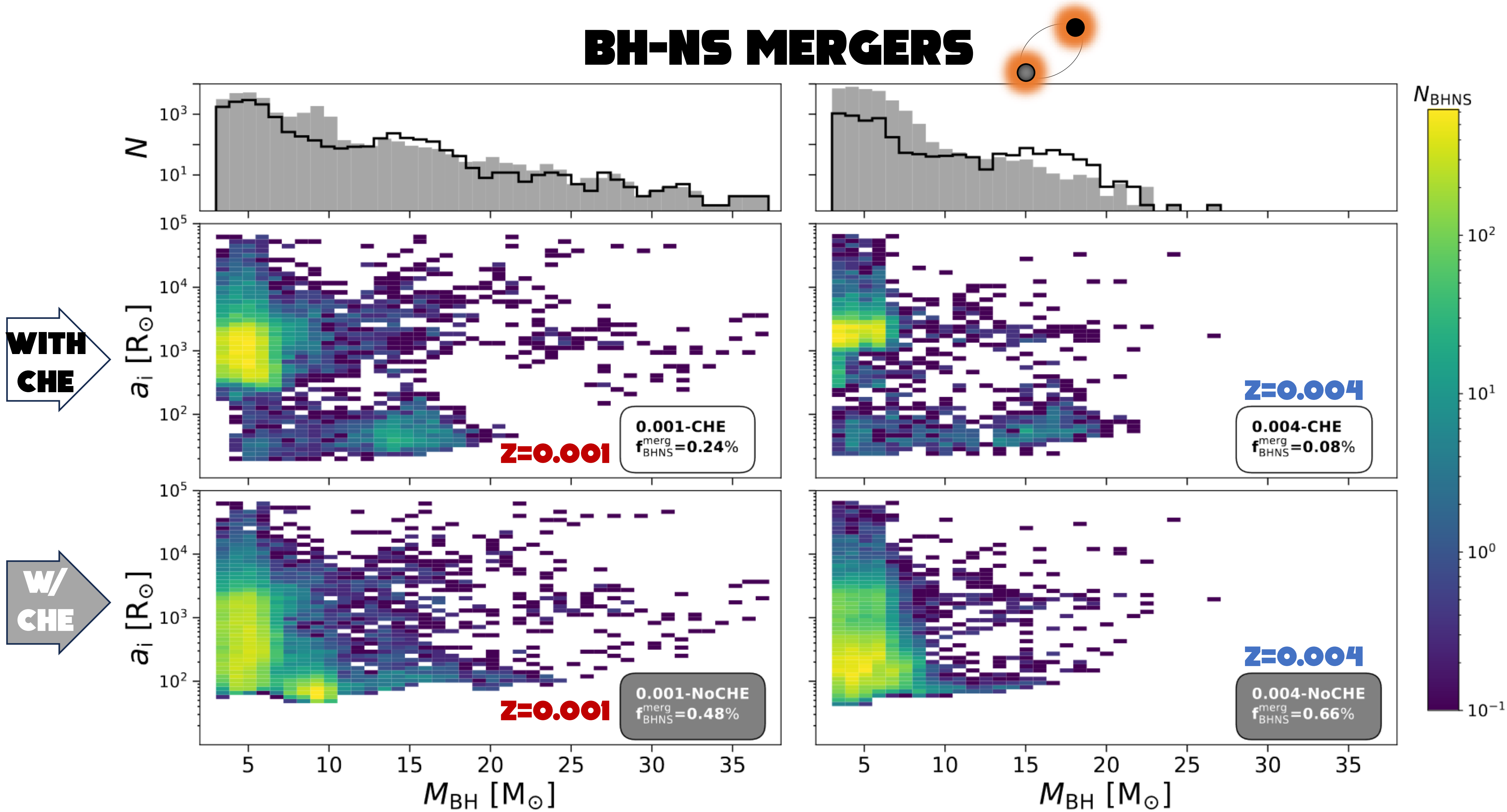
Z=0.001

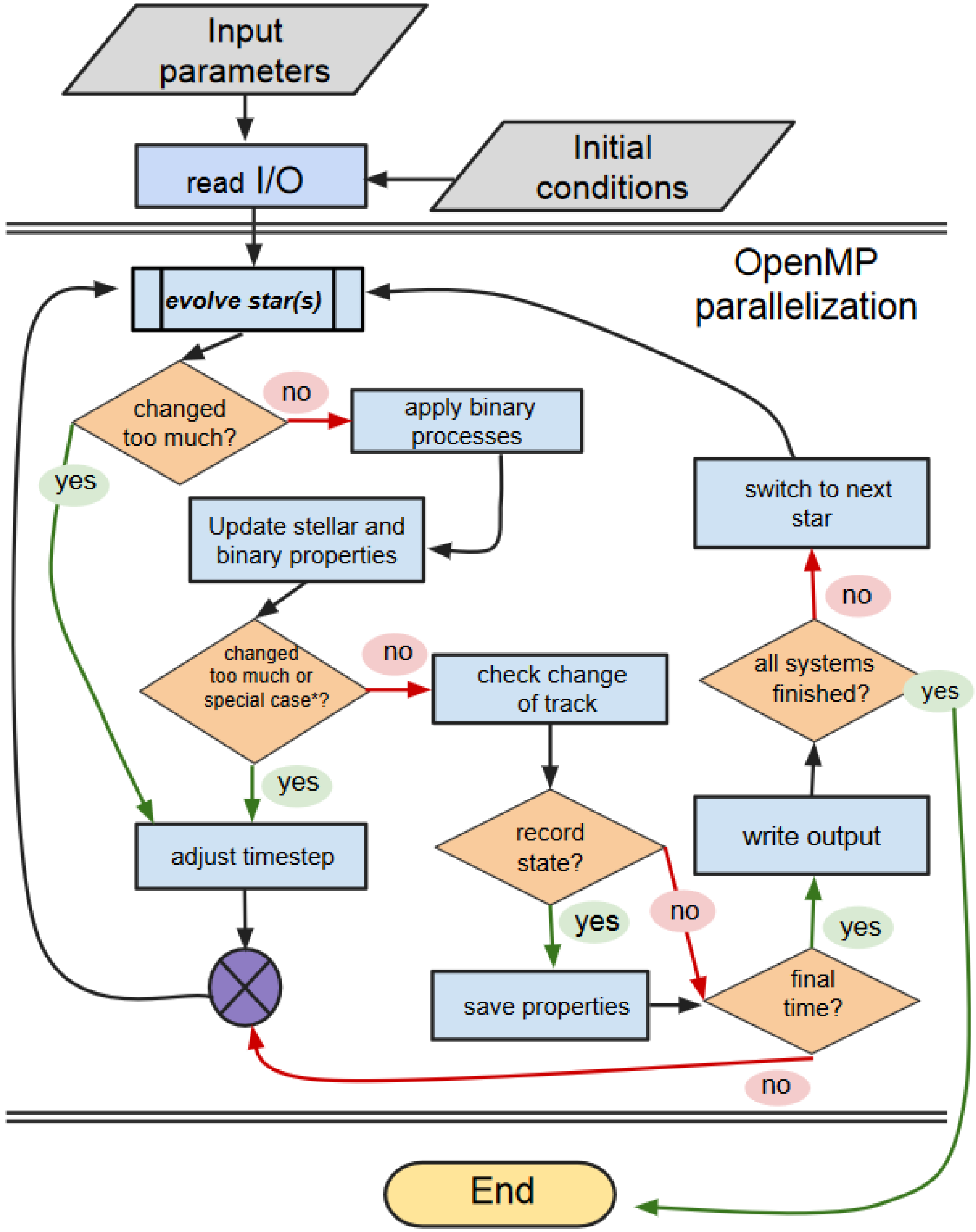


BH-NS SYSTEMS



BH-NS MERGERS





BINARY – SINGLE POP SYNTH SIMULATIONS WITH

SEVN

Iorio et al. 2023

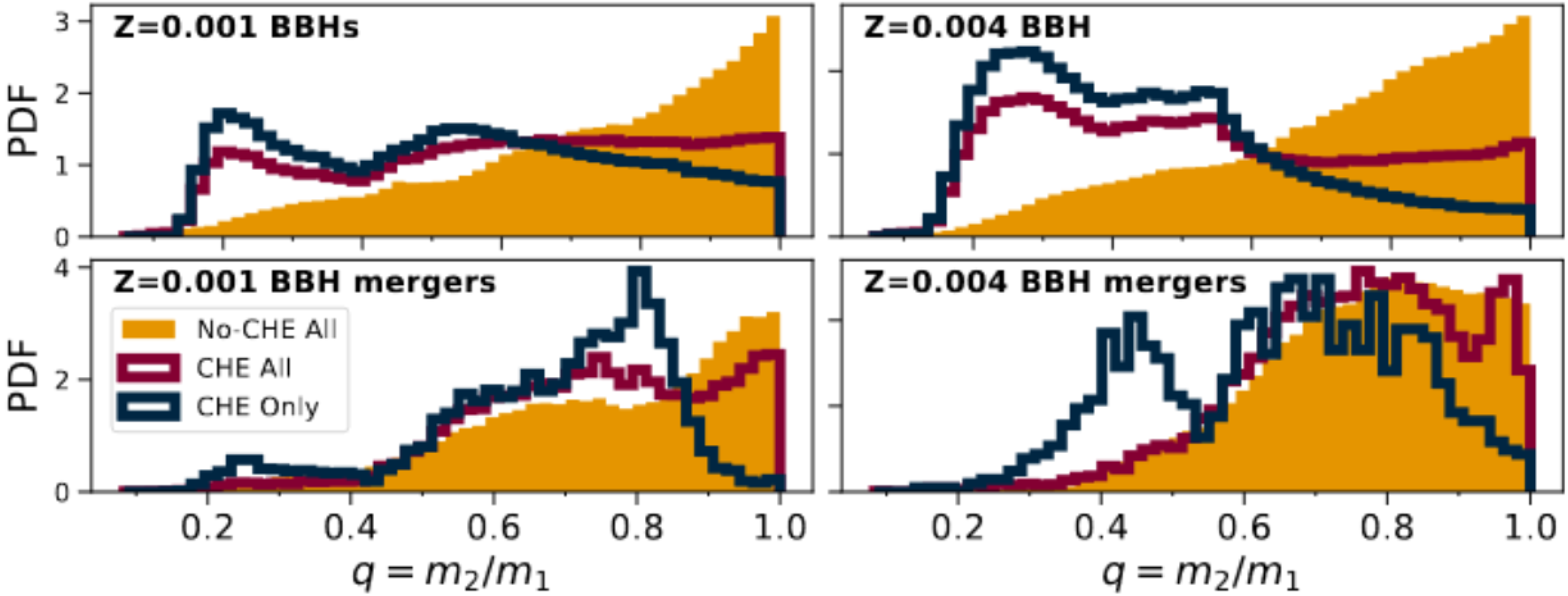
SSE: pre-computed stellar tracks interpolation

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

BBH MASS RATIO



COMPACT OBJECT BINARIES

Z	name	P_{CHE}	BBH P_{cob}	BBH P_{merg}	BBH P_{merg}^{CHE}	BHNS P_{cob}	BHNS P_{merg}	BHNS P_{merg}^{CHE}	BNS P_{cob}	BNS P_{merg}	BNS P_{merg}^{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)