Dragon III simulations

modelling million-body globular and nuclear star clusters over cosmic time

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ZENTRUM FÜR ASTRONOMIE

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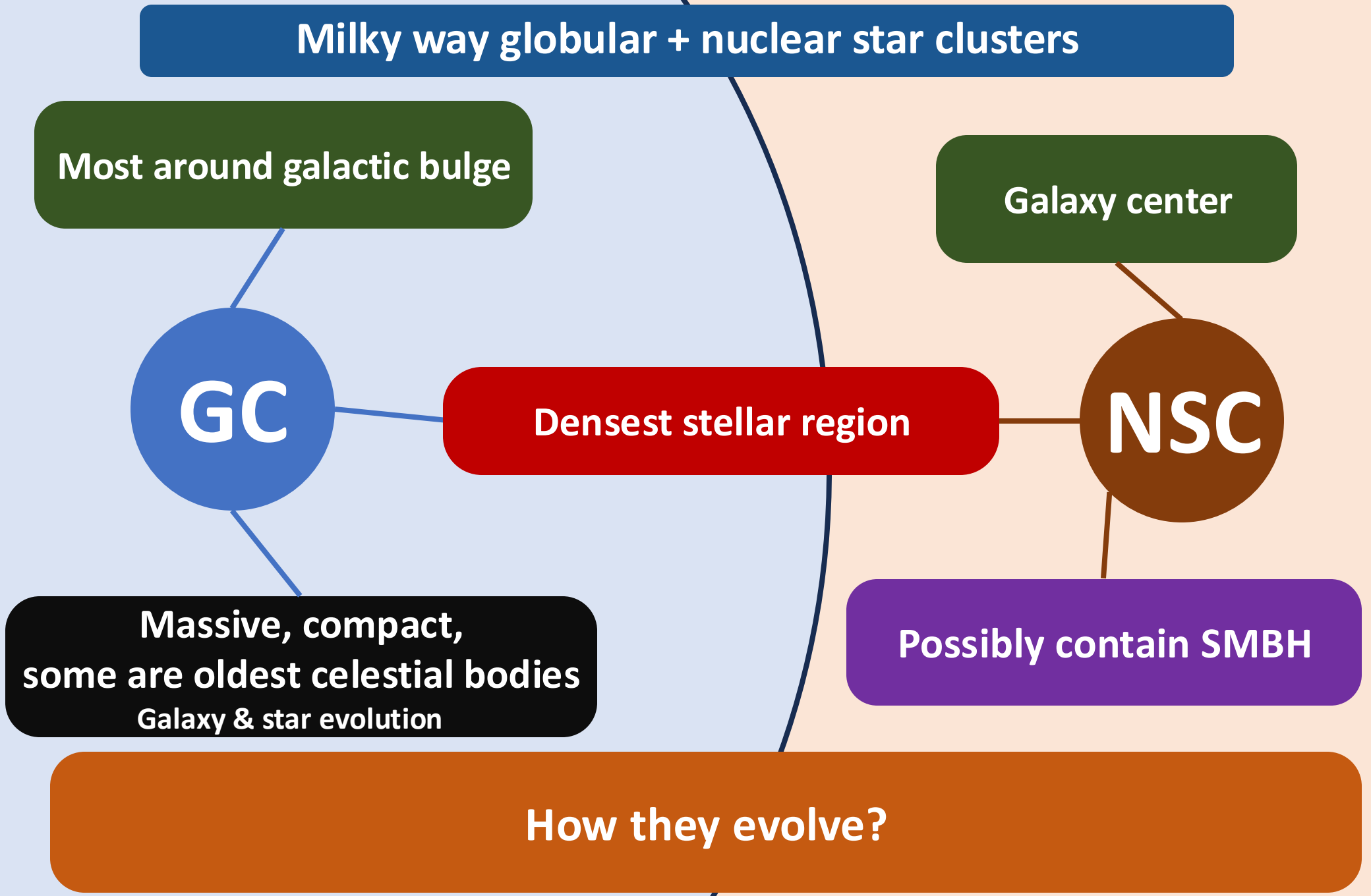
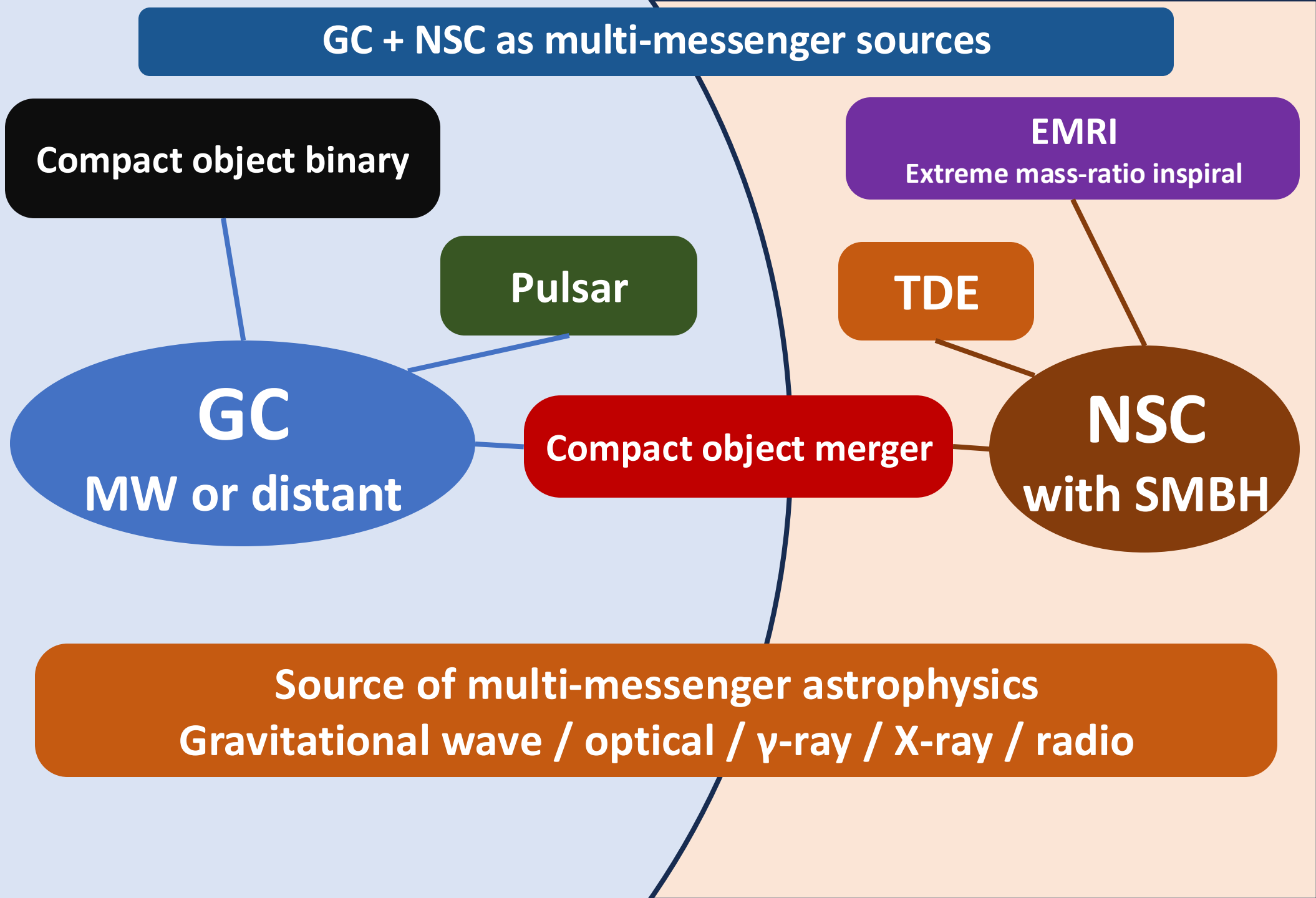




Group Introduction

- Introduction
  - GC + NSC
  - Multi-messenger
- Method
- Dragon 1, 2, 3
- Dragon 3 ic
- Pre-results
  - Form compact obj.
  - Binary

Globular cluster simulations


Albrecht Kamlah

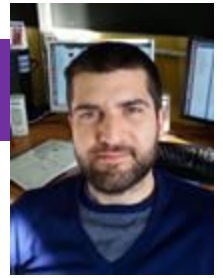

Kai Wu


Long Wang

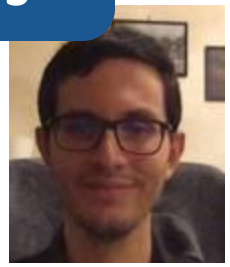

Peter Berczik


Mirek Giersz


Abbas Askar


Manuel Arca Sedda

Planetary systems in star clusters


Francesco Flammini Dotti


Rainer Spurzem

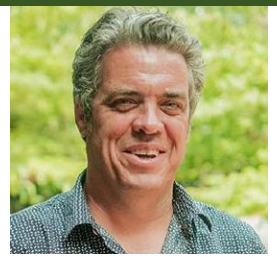
Rotating cluster

(a nice photo here)

Abylay Bissekenov
(talk on Mon.)


Vahid Amiri

Stellar evolution updates
(talk today and tomorrow)


Jarrod Hurley


Yuzhe Song (Robert)

Very massive star formation
(talk by Abbas on Mon.)


Marcelo Vergara

Nuclear cluster
(talk on Wed.)


Philip Cho

Method

Star-by-star, direct *N*-body simulation

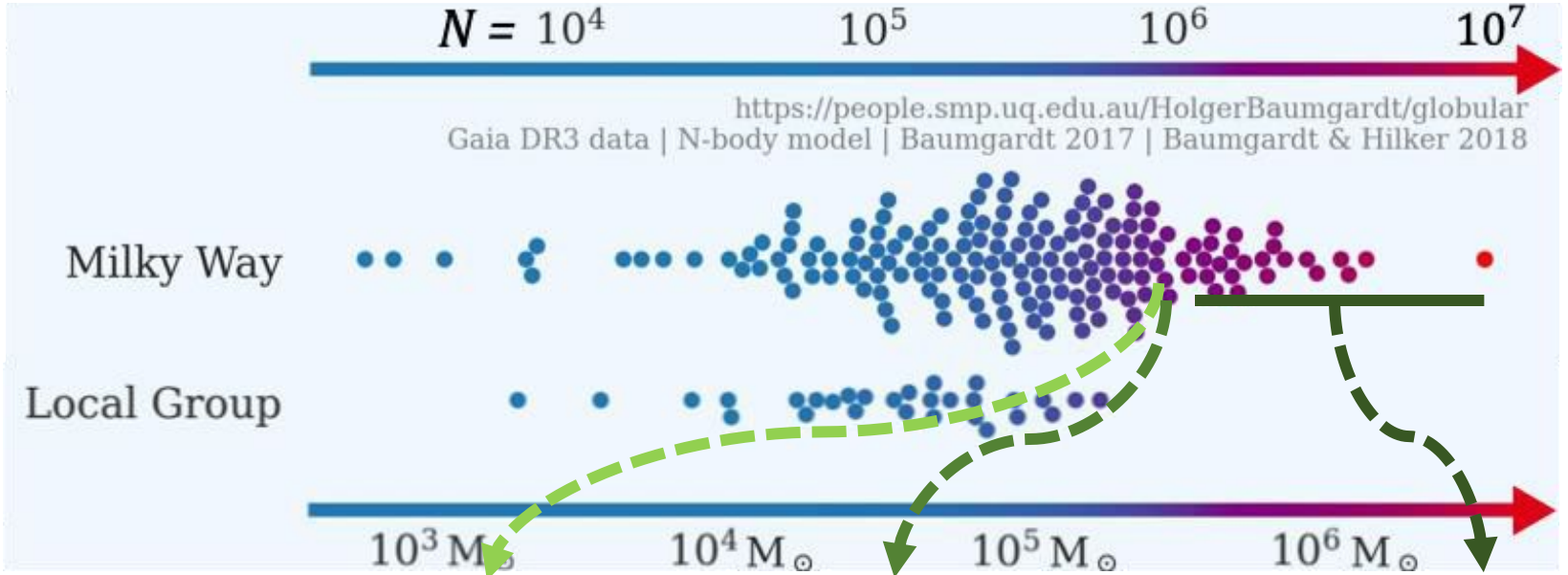
NBODY6++GPU
star cluster *N*-body simulator

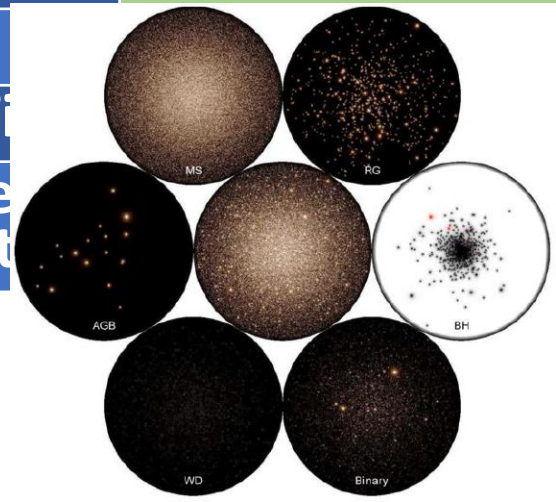
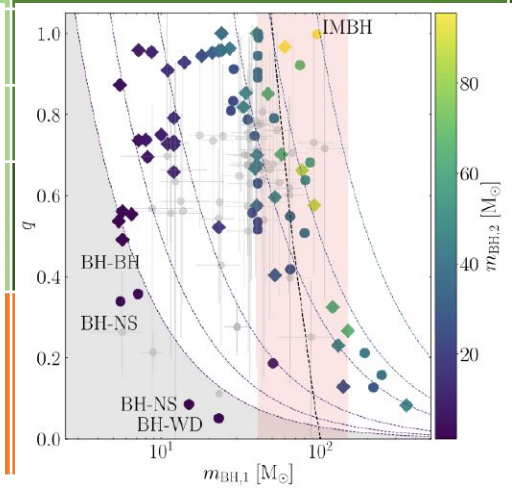
- 4th order Hermite integration
- Regularization; no softening
- Astrophysics (Stellar + Binary evo)
- External tidal field
- MPI, GPU, OpenMP, SIMD parallelization
- **Highly compatible with supercomputers**
- **Capable of million body × Gyr simulations**

https://github.com/nbody6ppgpu

Also with PeTar !

DRAGON simulation family



	DRAGON-I	DRAGON-II	DRAGON-III
Paper	*Wang+2016*	*Arca Sedda+ 2023(a,b,c)*	
			1M, 4M, 10M
Ti			1 – 10 Gyr
Ste evolut			nlah+23 ee+19,20,21
			Largest *N* + latest stellar evo.

Initial conditions

Aim

Use *N*-body codes to their **limits**

Simulate
- Biggest
- Realistic
- Lifetime

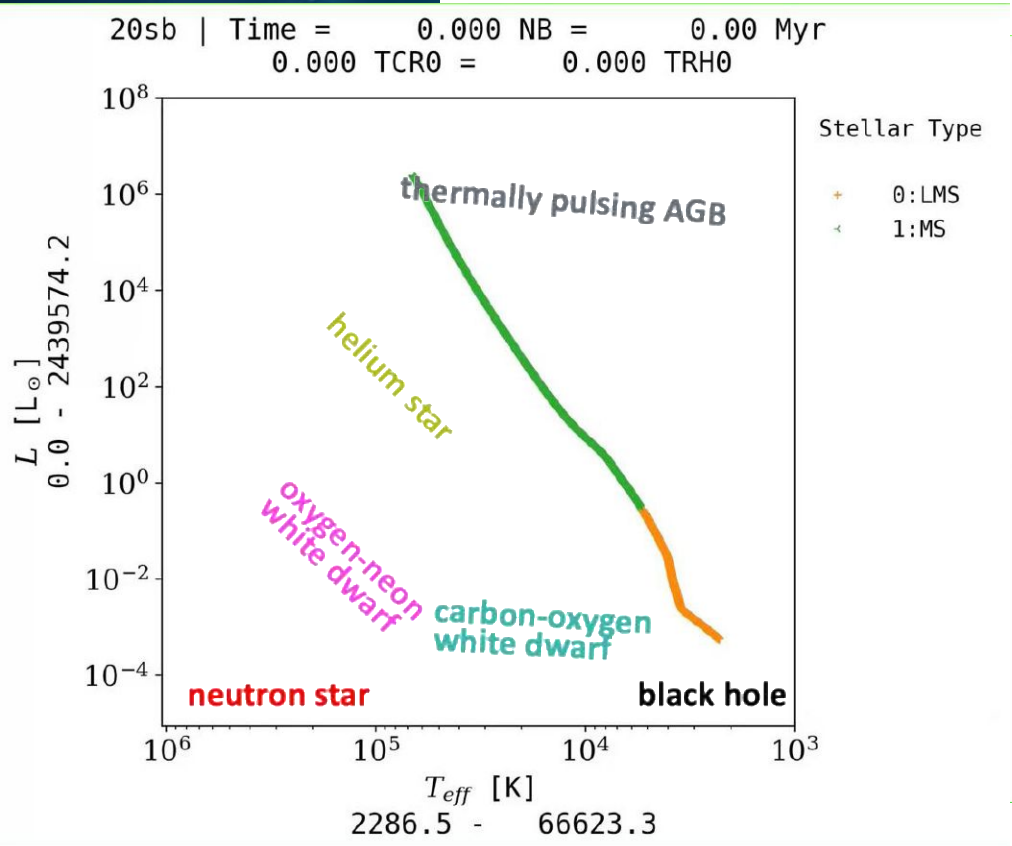
globular clusters

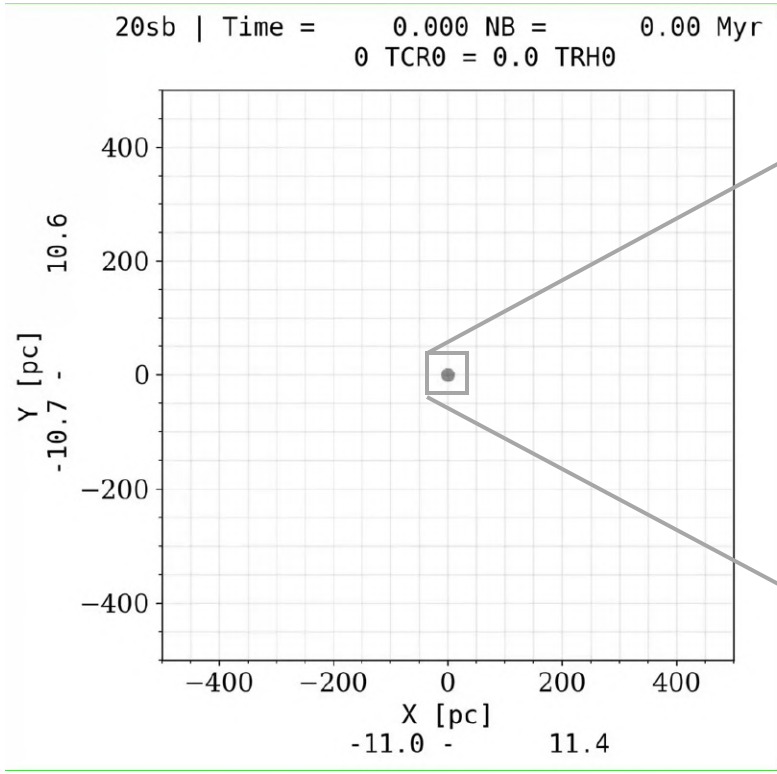
	DRAGON-III Globular SC	DRAGON-III Nuclear SC
		
N	1M, 4M, 10M	1M
Time	1 – 10 Gyr	~ Gyr
Binary	hard: 5% soft: 0% / 20% / 60%	
Stellar evolution	Kamlah+23 Banerjee+19,20,21	
Tidal field	Galpy MWPotential2014 representative value of MW GC	
IMF & profile	Kroupa 0.08 – 150 & King	
Additional Physics		Accreting CMBH
Computer	GPU-based Supercomputers in Germany, China, Finland	

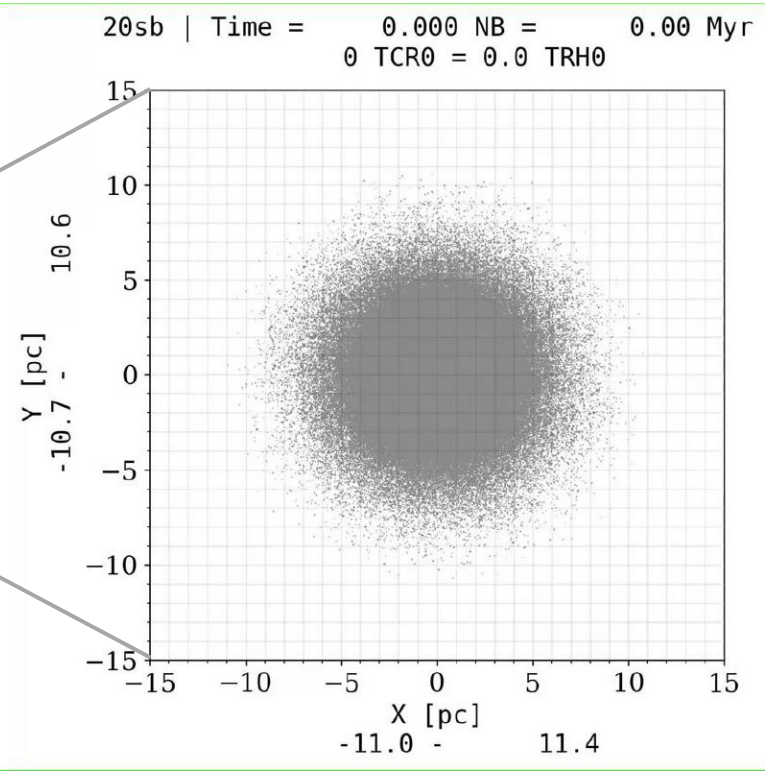
Other params follow DRAGON-II

JÜLICH Forschungszentrum

Stellar evo. → form compact objects







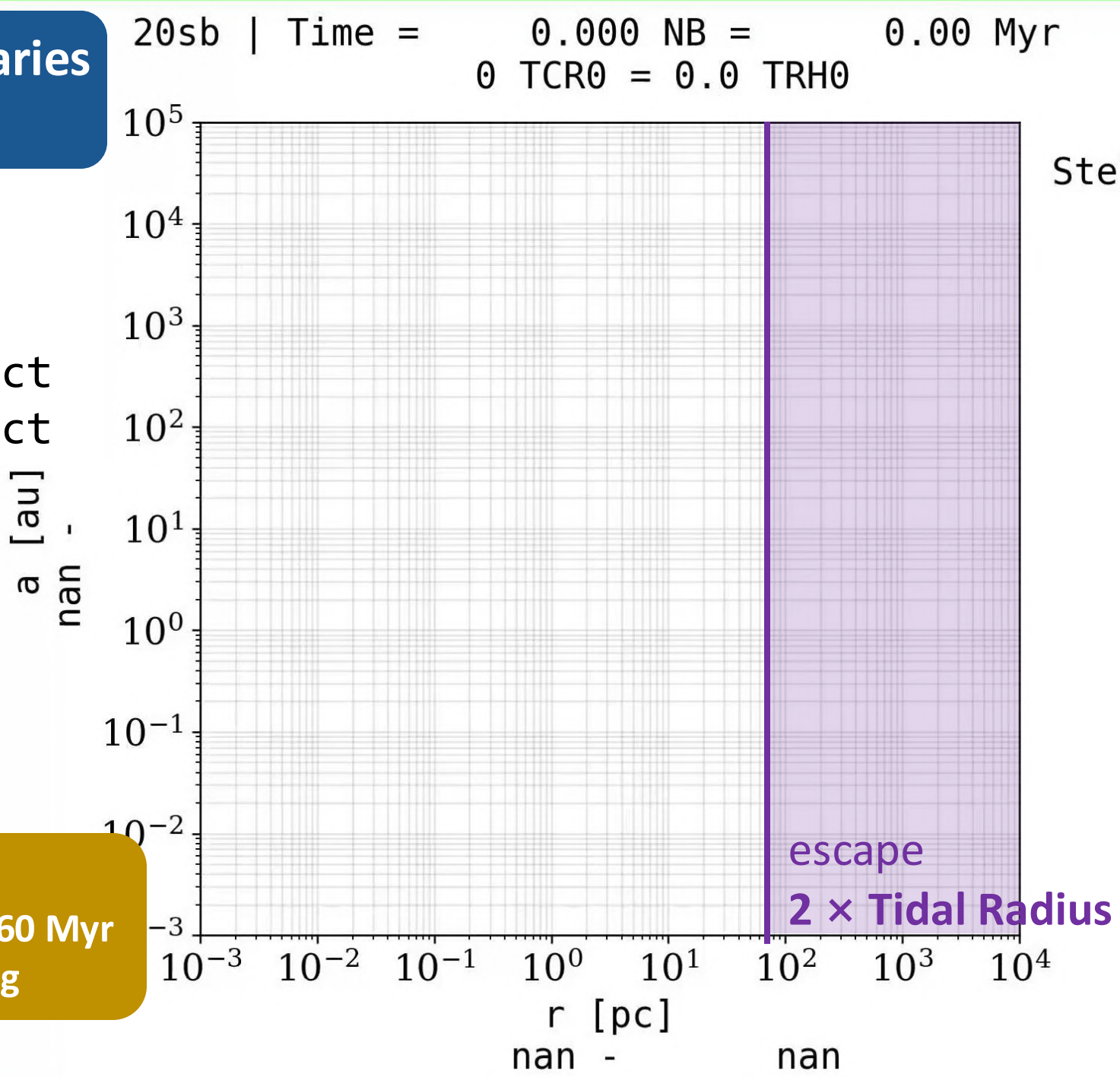
Summary

1. natal kicks
2. keep evolving escapers (+ compact obj. bin)
3. stellar evo. form wide range of stellar types
4. hierarchical BH/NS/WD subsystems?

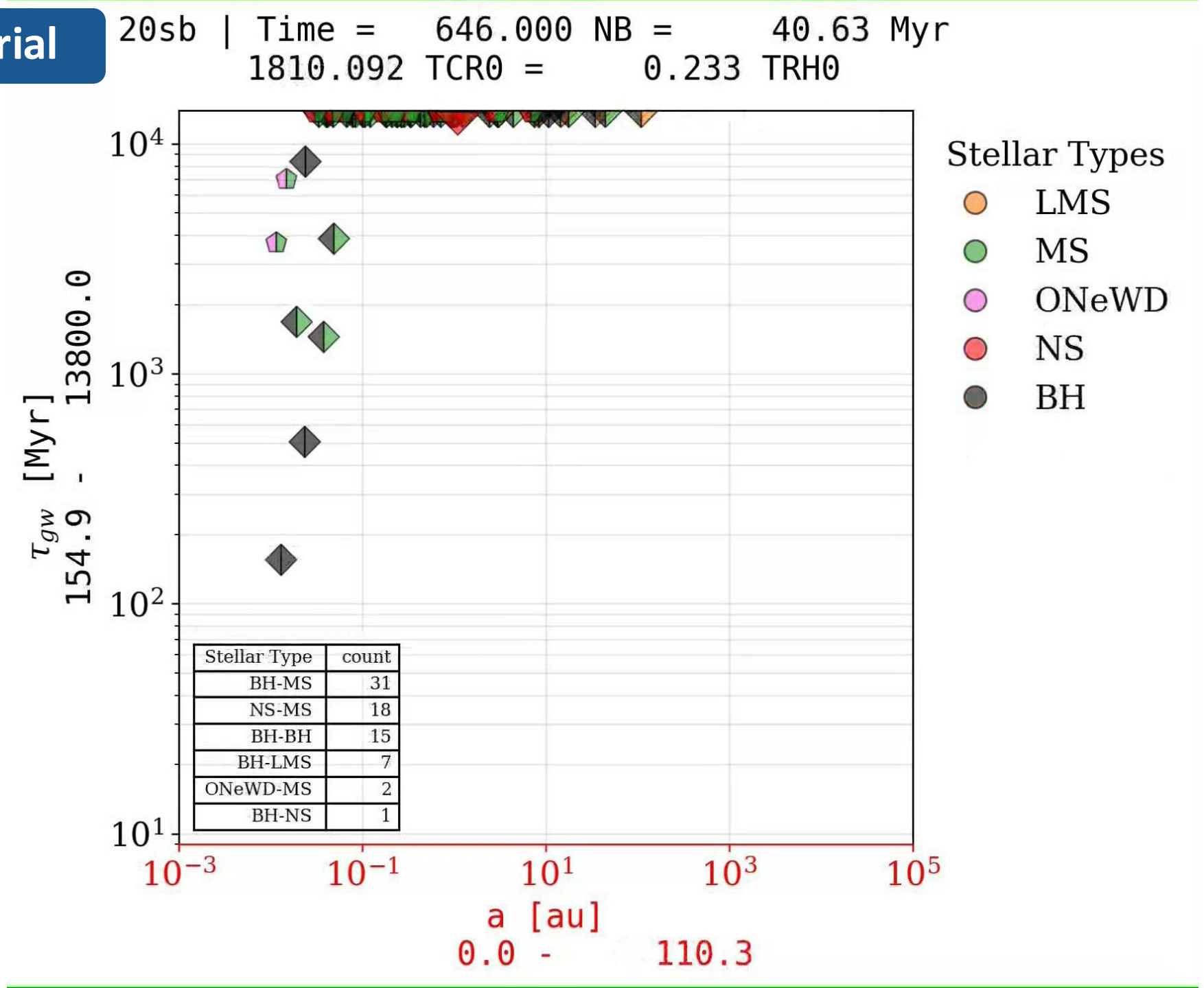
Compact object binaries form & escape

6 escaped BH-BH
1 escaped BH-NS
2 escaped NS-WD
5 escaped BH–non-compact
14 escaped NS–non-compact

1. "escapers" are not removed
2. NS-MS *baby-boom* at 15 Myr & 60 Myr
3. we also have "Gaia BH", escaping



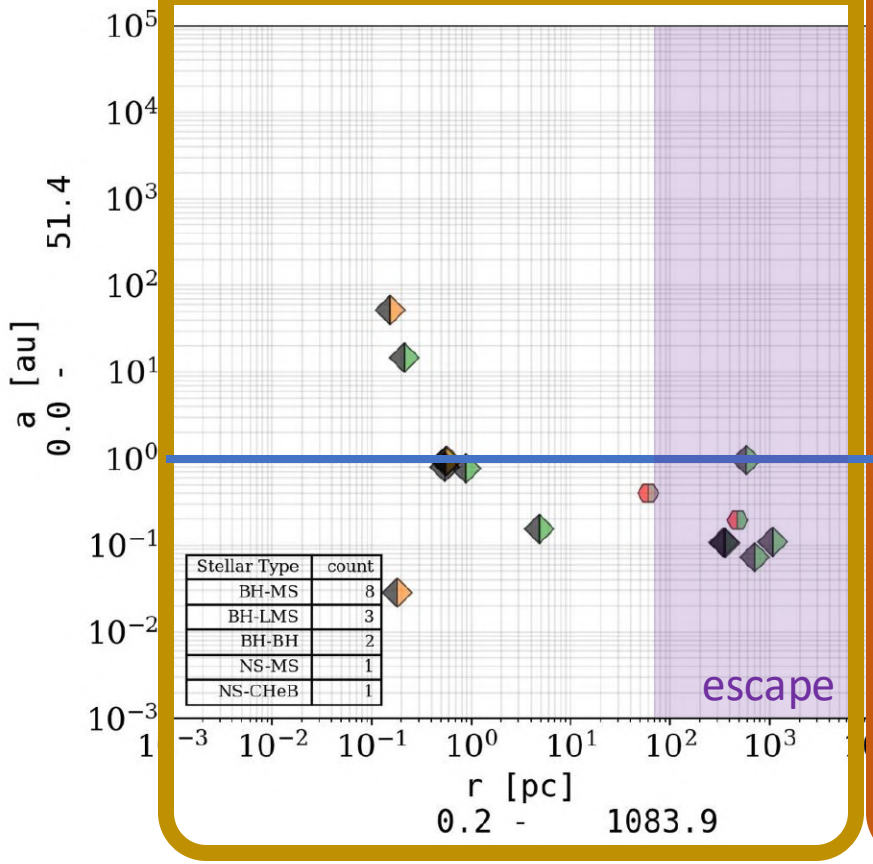
GW inspirial



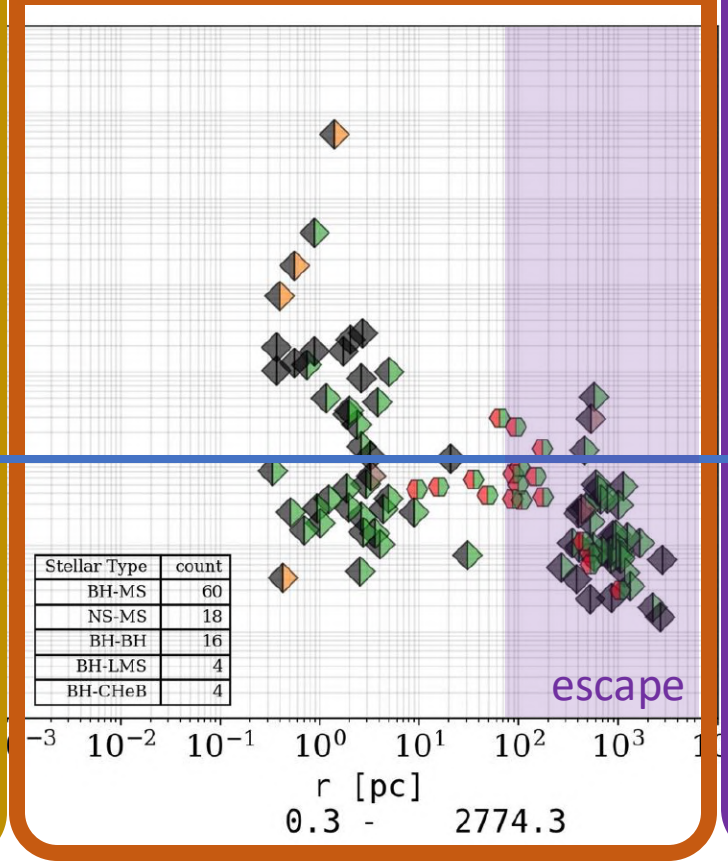
The “soft power”

5% initial hard binary, AND

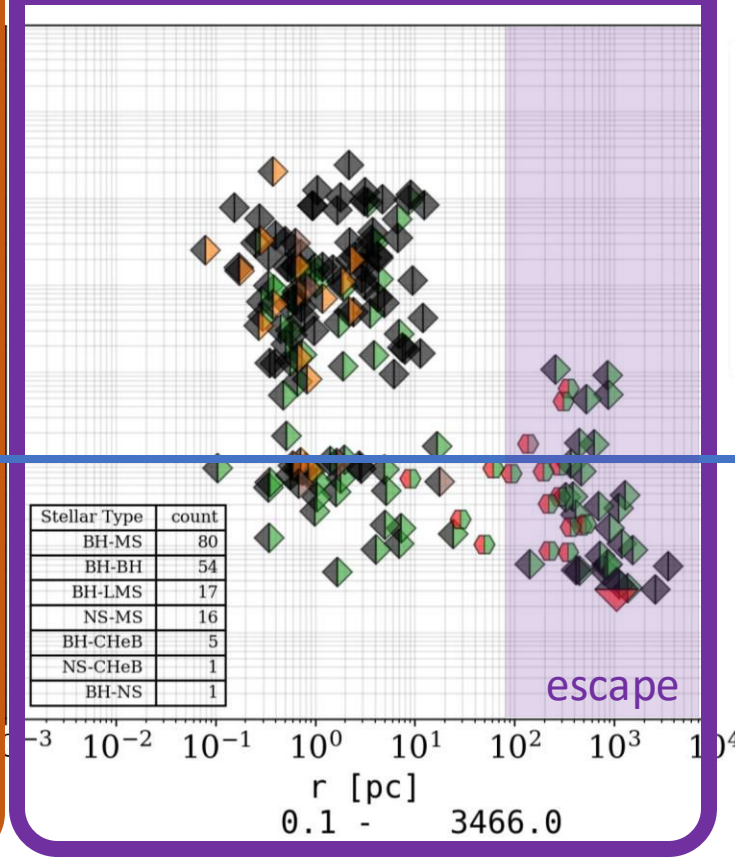
0 % initial soft binary

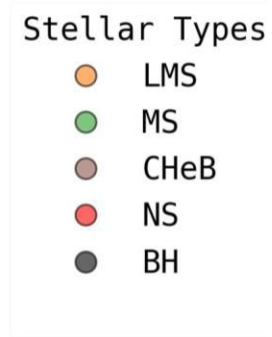


20 % initial soft binary



60% initial soft binary



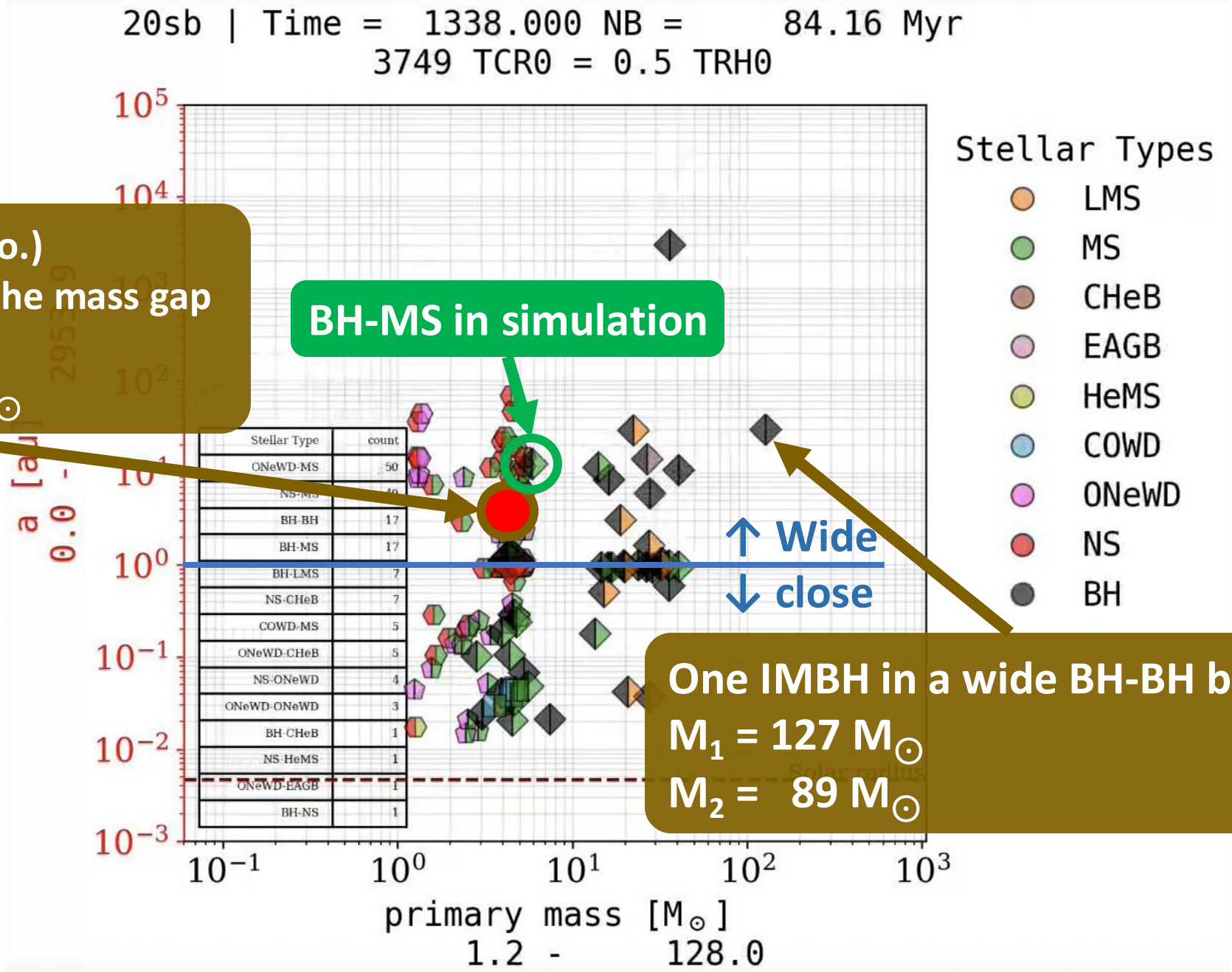


↑ Wide
↓ Close

age = 17 Myr

Wide compact object binaries

Song Wang+24 (Nat. Astro.)
Wide BH-giant binary in the mass gap
- 2.1 < a < 5.1 au
- 3.1 $M_\odot$ < M_{BH} < 4.1 $M_\odot$



One IMBH in a wide BH-BH binary!
M_1 = 127 $M_\odot$
M_2 = 89 $M_\odot$

up to

10,000,000

particles

up to

10 Giga-year

simulation

Globular

&

Nuclear

star cluster

stellar evolution

Latest

single + binary

× compact obj.

Escaper trace

Dragon III simulations

€ 0.00

data reduction

on demand

Dragon DR1 & paper

Coming soon

this year

191

X-ray binaries

within 100 Myr

1

BH-BH merger

within 100 Myr

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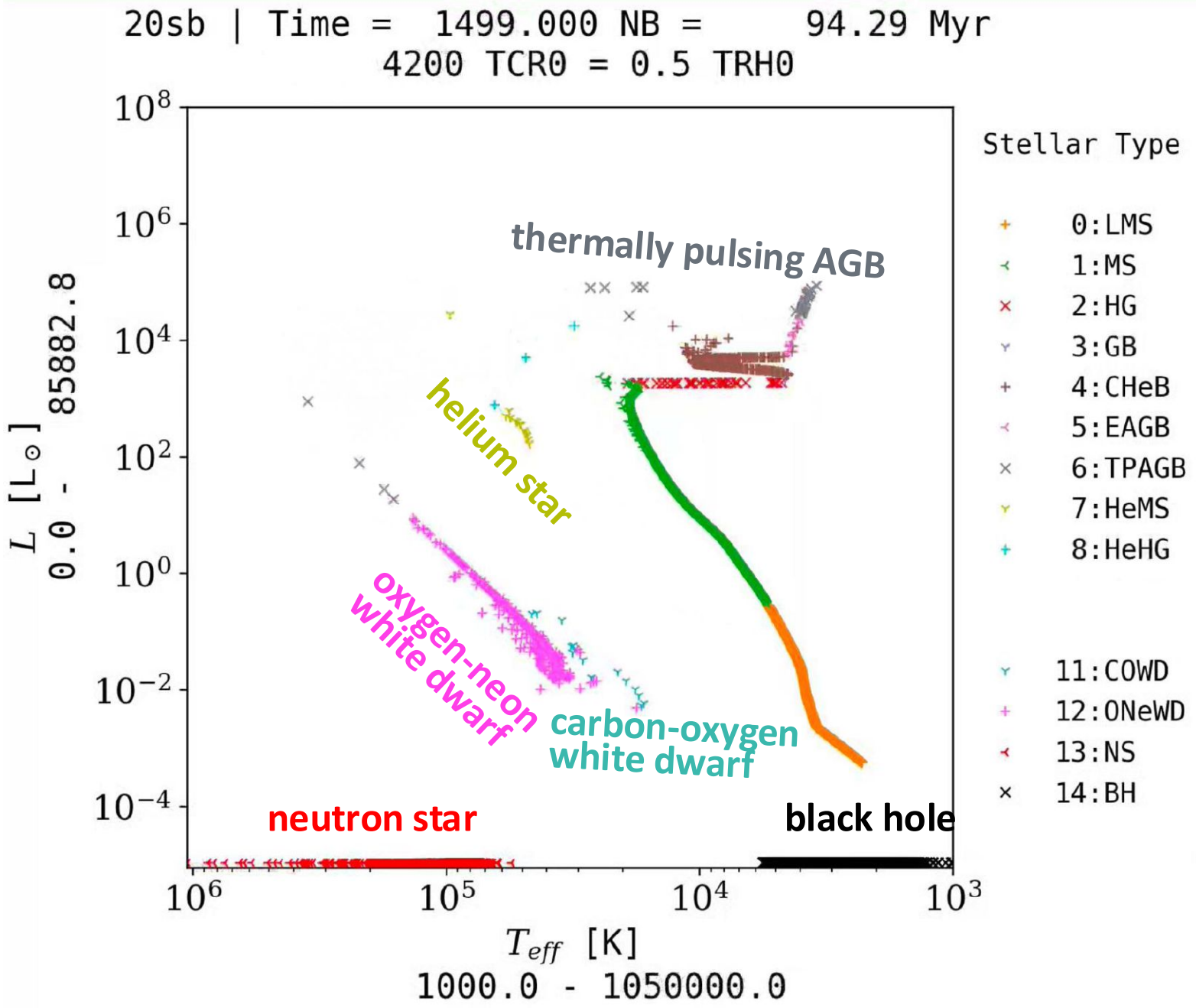
BACKUP SLIDES BELOW

CMD



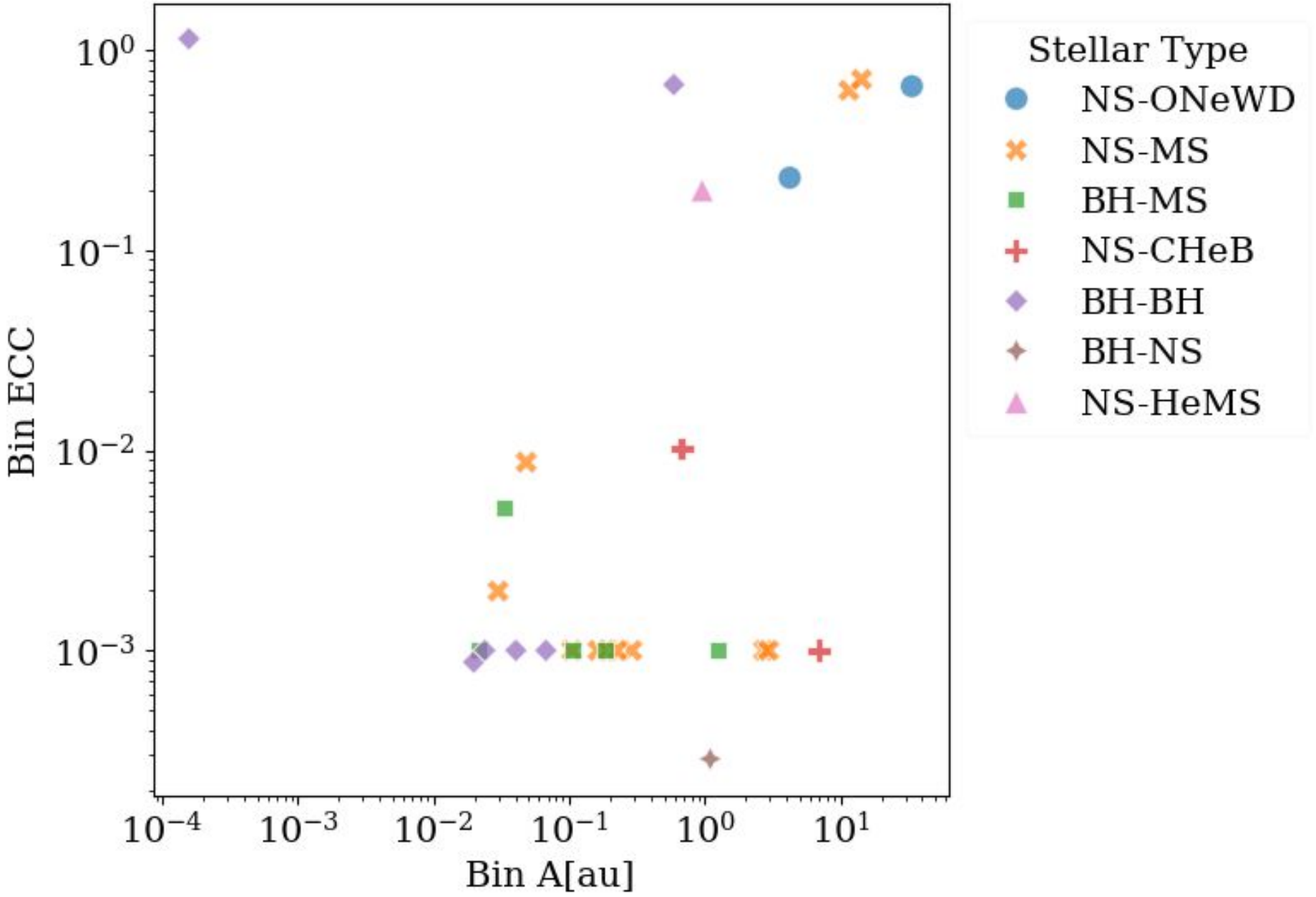
compact object binaries (1+) in 5% hard + 20% soft run

97 WD – non-compact, but no escaper within 100 Myr

Stellar Type	count
ONeWD-MS	46
NS-MS	26
COWD-MS	26
BH-MS	16
BH-BH	16
ONeWD-CHeB	14
BH-LMS	9
ONeWD-ONeWD	8
NS-ONeWD	7
NS-CHeB	6
ONeWD-HeMS	2
COWD-LMS	2
ONeWD-LMS	2
COWD-CHeB	2
NS-HG	1
BH-CHeB	1
BH-NS	1
NS-HeMS	1

Ejected compact object binary eccentricities

Stellar Type	
NS–MS	11
BH–BH	6
BH–MS	5
NS–ONeWD	2
NS–CHeB	2
BH–NS	1
NS–HeMS	1



BH-BH Merger

BH-BH merger in Dragon 3 by far

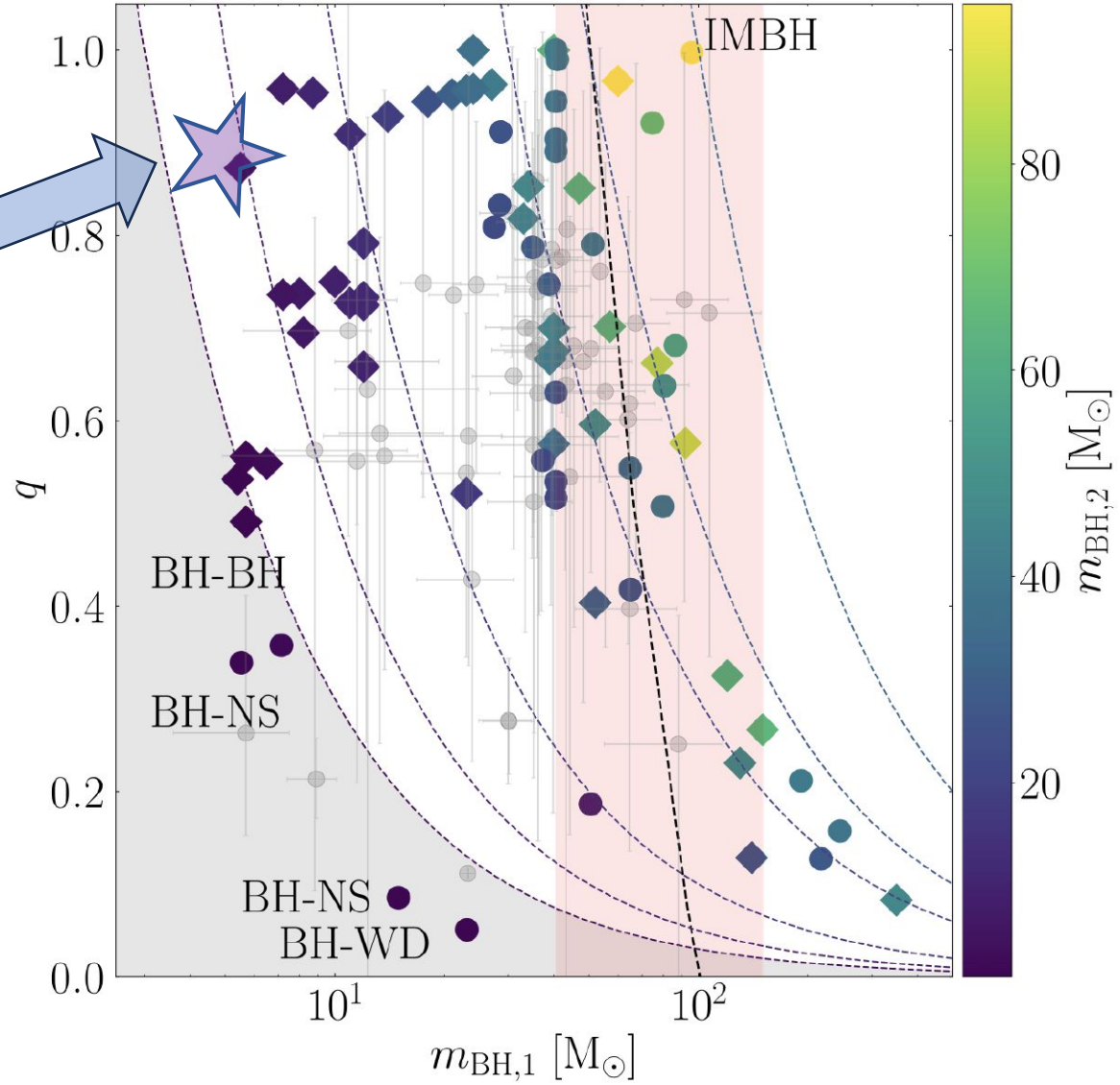


Fig. 2 of Arca Sedda+ 2023c

5% hard binary + 20% soft binary run lagrangian radii evolution