# The host galaxies of double compact objects across cosmic time

Mattia Toffano

1st Year PhD at University of Insubria

INAF- Brera Astronomical Observatory

Yokohama, Japan

November 1st 2019

# Host – Progenitors Link

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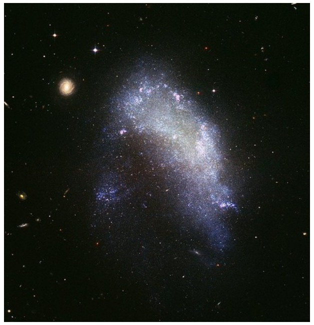
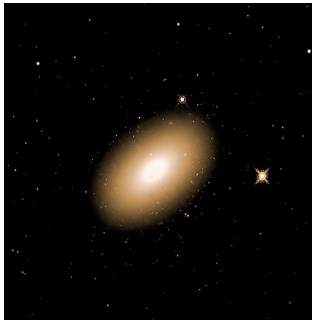
- Merger environment strictly related to host galaxy properties





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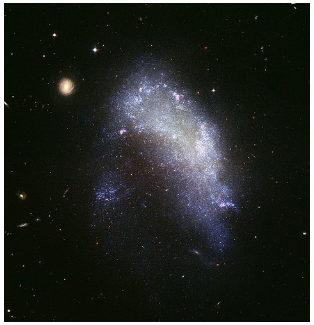
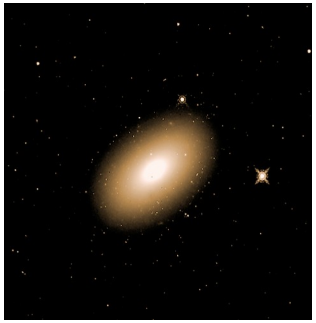
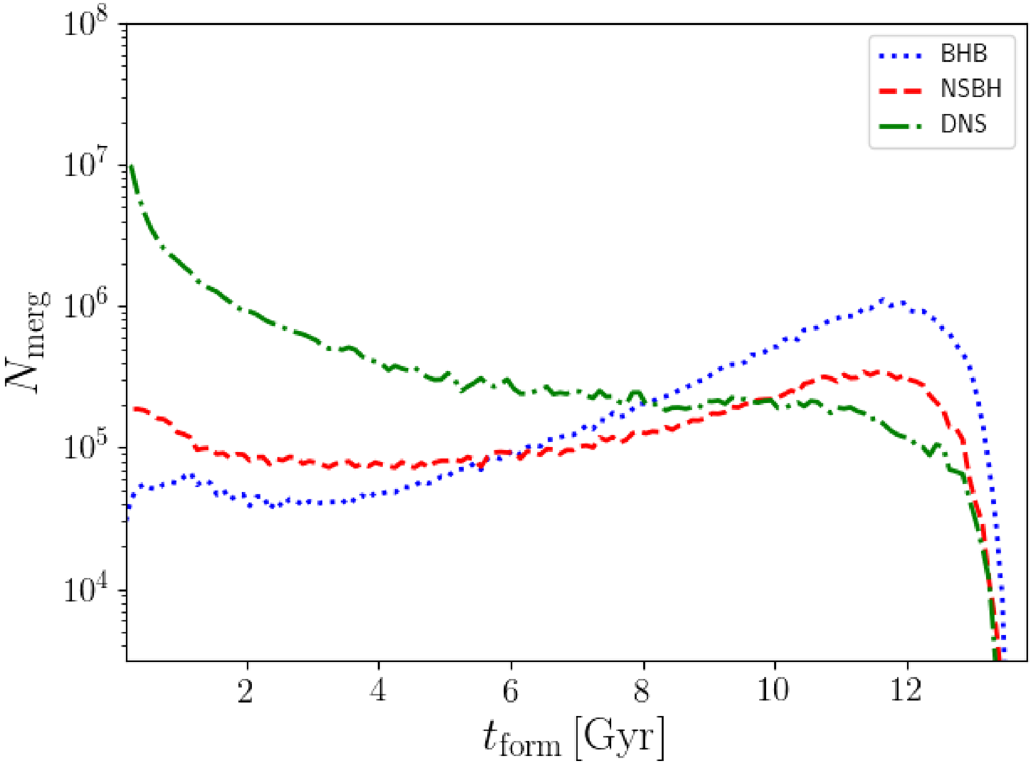




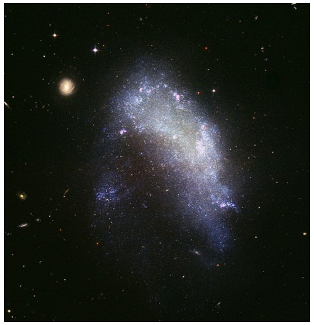
- Long delay time from formation of progenitors and merger → host galaxy evolves

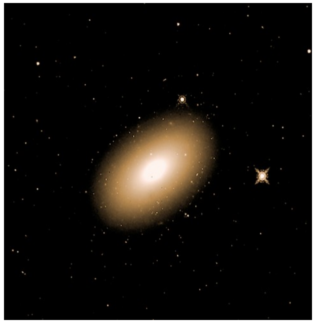


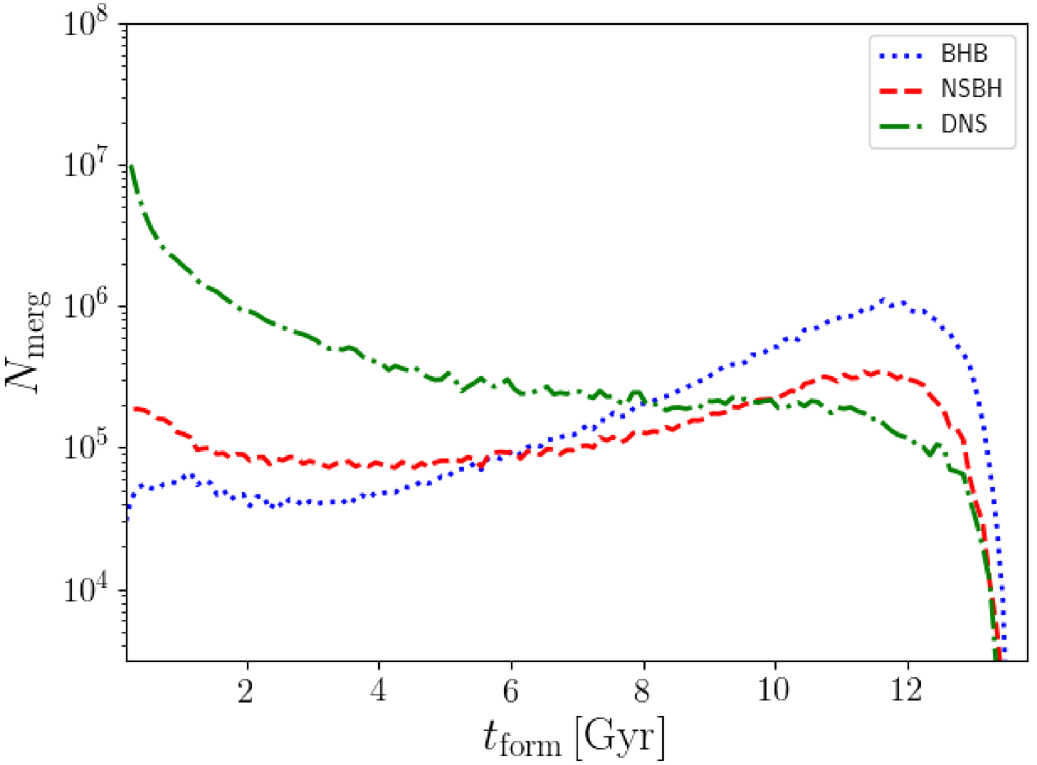

Adapted from Mapelli, Giacobbo, **Toffano** et al. 2018

# Host – Progenitors Link

- Merger environment strictly related to host galaxy properties
- Long delay time from formation of progenitors and merger → host galaxy evolves
- Environment evolution affects binary history








Adapted from Mapelli, Giacobbo, **Toffano** et al. 2018

# Practical Relevance of Studying Hosts

- Comprehension of host galaxy properties allow to **test and improve models of compact objects (CO) binary formation** (still affected by uncertainties) [Eldridge et al. 2019, Shao & Li 2018 and many others]
- Theoretical insights on the most likely properties of the host provide **criteria for electromagnetic counterpart search** [Mapelli et al. 2018, Del Pozzo et al. 2018]

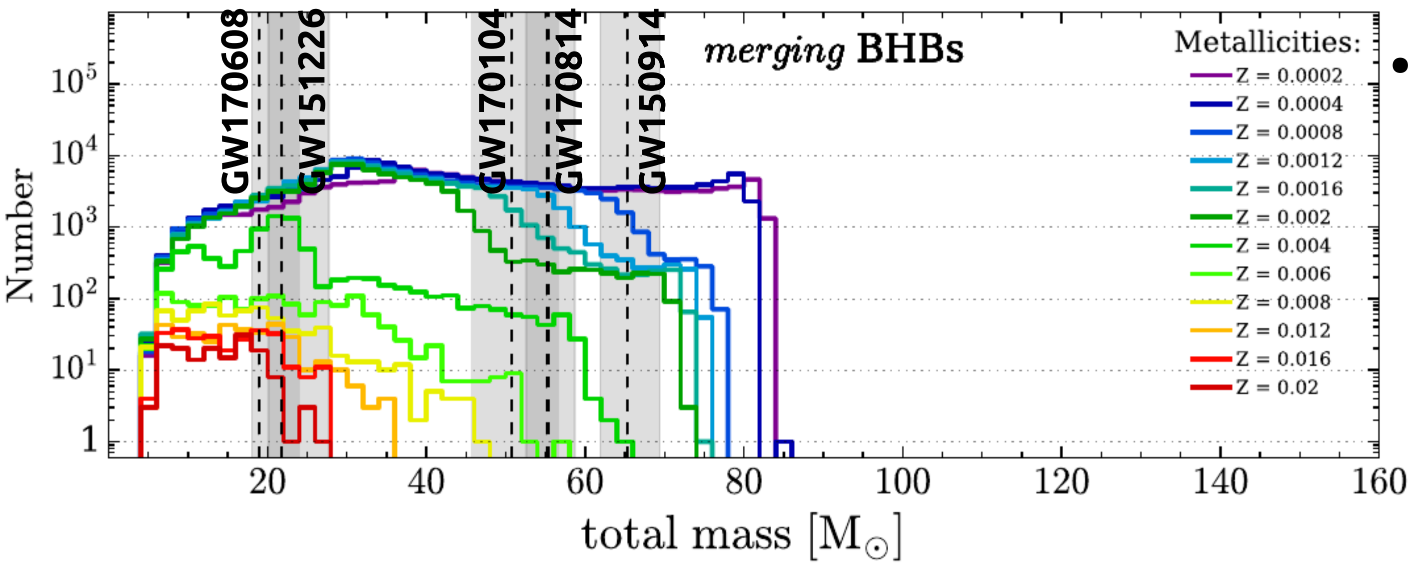
# Aim of the Work

**CO binaries** we see nowadays have formed in the past under different **environmental conditions.**

- Characterize the properties (**environment**) of the hosts in a cosmological framework.
- Relate them to binaries' formation and merger epochs, by combining a population synthesis model and a simulation of galaxy evolution.

# Method: MOBSE

- MOBSE: Massive Objects Binary Stellar Evolution (Giacobbo et al. 2018)
- Updated and customized version of BSE (Hurley et al. 2002)
- Includes advanced theories on mass loss due to stellar winds, pre-SN and SN phases, evolution in a common envelope, natal kicks of compact objects

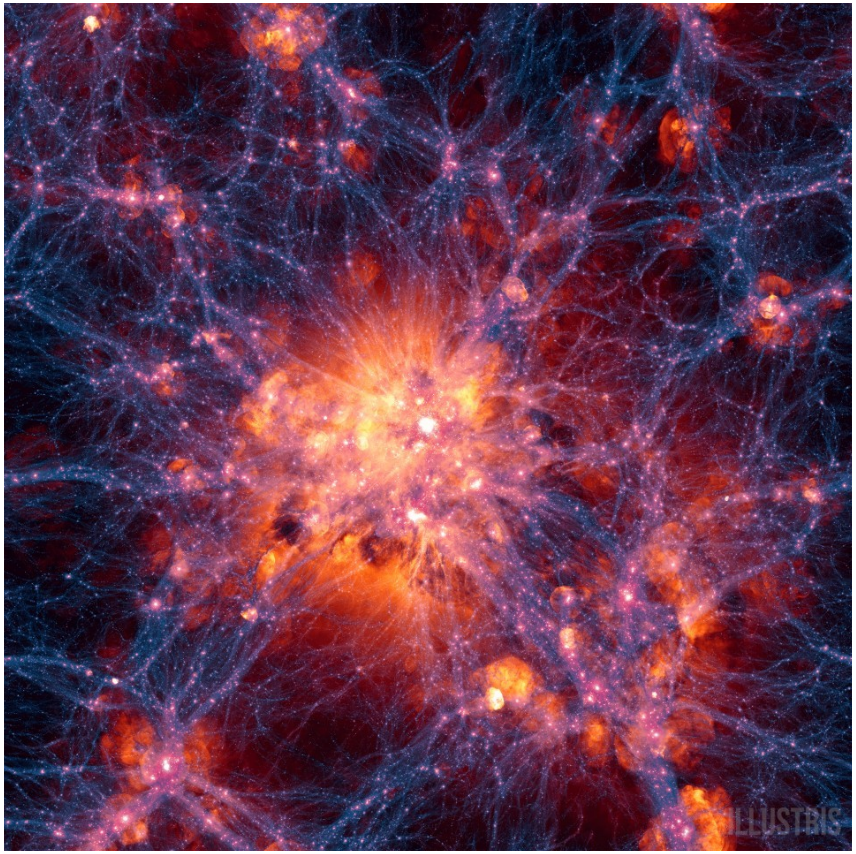



- Reproduces observed merging CO masses→ sub-solar *Z* of progenitors needed

Giacobbo et al. (2018)

# Method: Illustris

- Large-box state-of-art cosmological simulation of galaxy formation
- Reproduces evolution of dark and baryonic matter from z $\sim$ 46 till nowadays
- Cosmic star formation rate agrees with observational data by construction
- Physical models build an intrinsic Mass-Metallicity Relation (MZR)




- Box length: 106.5 Mpc
- Starting epoch: z=46
- Star particle mass: ~ $10^6 M_{sun}$

Credits: Illustris Project;
Vogelsberger et al. 2014;
Genel et al. 2014

# Method: Injecting MOBSE into Illustris

## Preliminary Adjustment

- Substitute intrinsic MZR with observational one

$$12+\log(O/H) = -0.0864(\log M - \log M_0)^2 + K_0$$

(Maiolino et al. 2008; Mannucci et al. 2009)

## Initial setup

- Initial mass $M_{Ill}$, metallicity $Z_{Ill}$ and formation redshift $z_{Ill}$ of Illustris particles
- MOBSE catalogue: population total initial mass $M_{BSE}$ (number of CO $N_{BSE}$), delay times $t_{delay}$, metallicity $Z_*$ of progenitors of CO

## Procedure

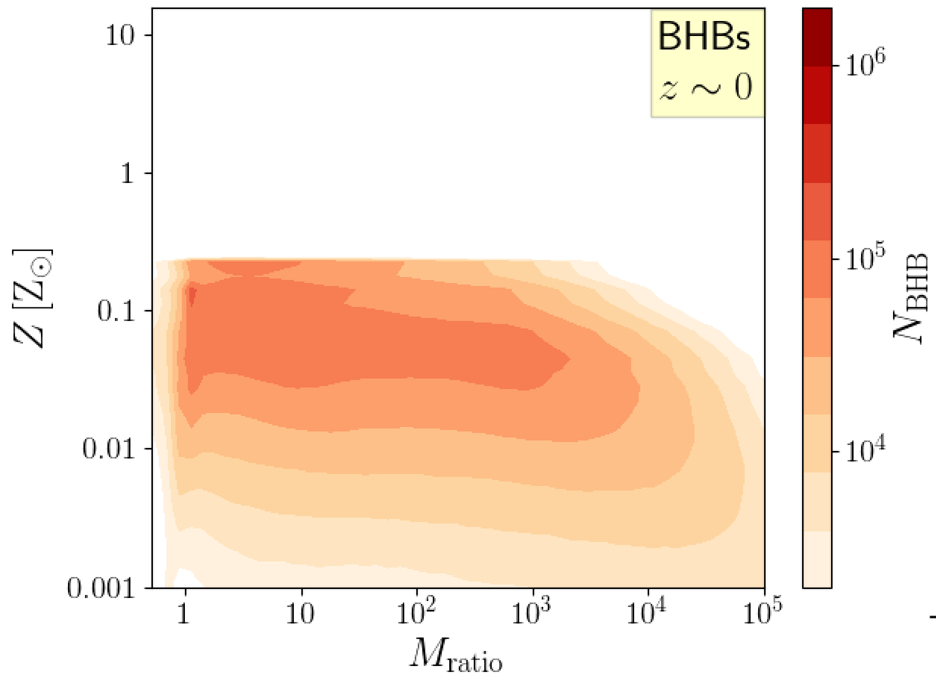
- Associate a number of CO to every Illustris particle

$$N_{CO,i} = N_{BSE,i}(Z \sim Z_{Ill}) \frac{M_{Ill}(Z_{Ill})}{M_{BSE}(Z \sim Z_{Ill})} f_{corr} f_{bin}$$

- Estimation of merger lookback time

$$t_{merg} = t_{form} - t_{delay}$$

# Results: BHBs – $M_{ratio}$ vs $Z_*$

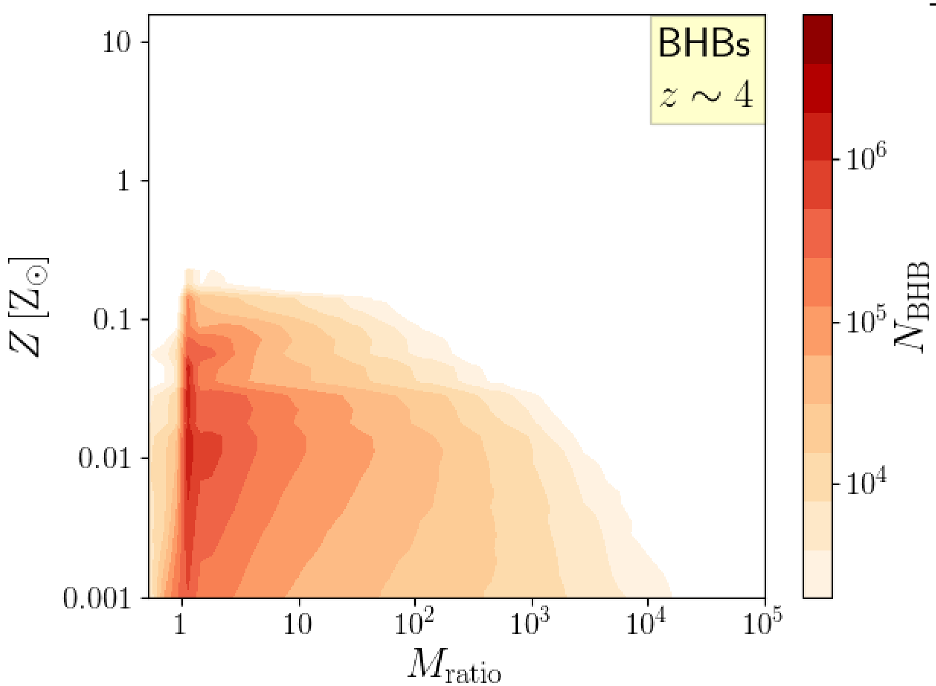



**Merging at z=0**

- Wide $M_{ratio}$ range → both long and short $t_{delay}$, strong tendency for $t_{delay}$ ~10-12 Gyr
- Metal-poor progenitors

50% of CO binaries $M_{ratio}$ interval

| | $z \sim 0$ | $z \sim 2$ | $z \sim 4$ | $z \sim 6$ |
|---|---|---|---|---|
| $M_{\rm ratio,BHB}$ | $6.1 - 7.2 \times 10^2$ | $1.3 - 24$ | $1 - 6.1$ | $1 - 5$ |




**Merging at z=4** ( $t_{lookback}$~12.17 Gyr)

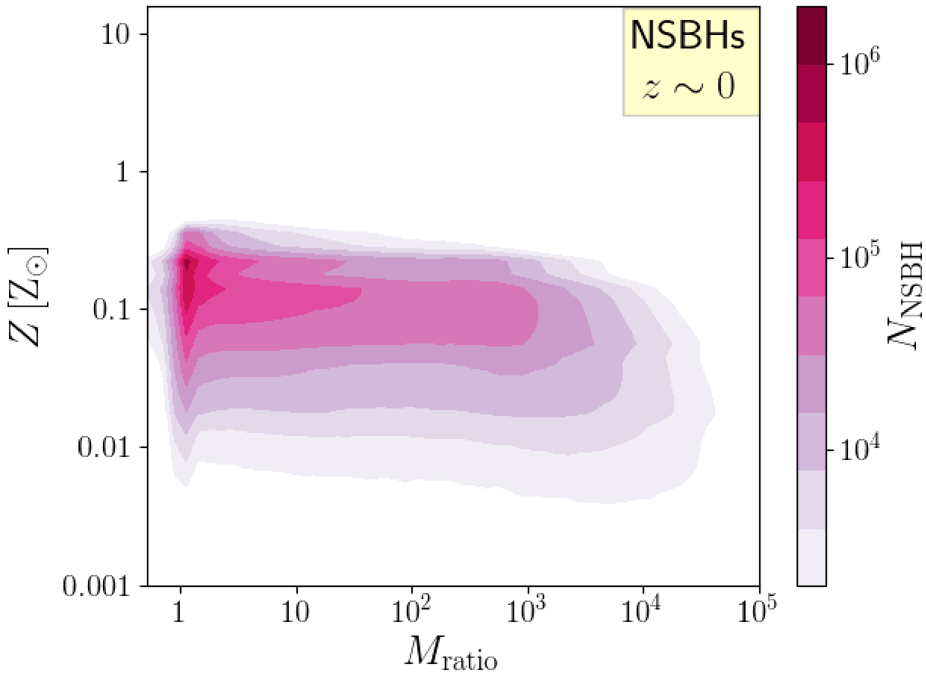
- Universe is younger→ narrower $M_{ratio}$ interval, more metal-poor progenitors (general trend)

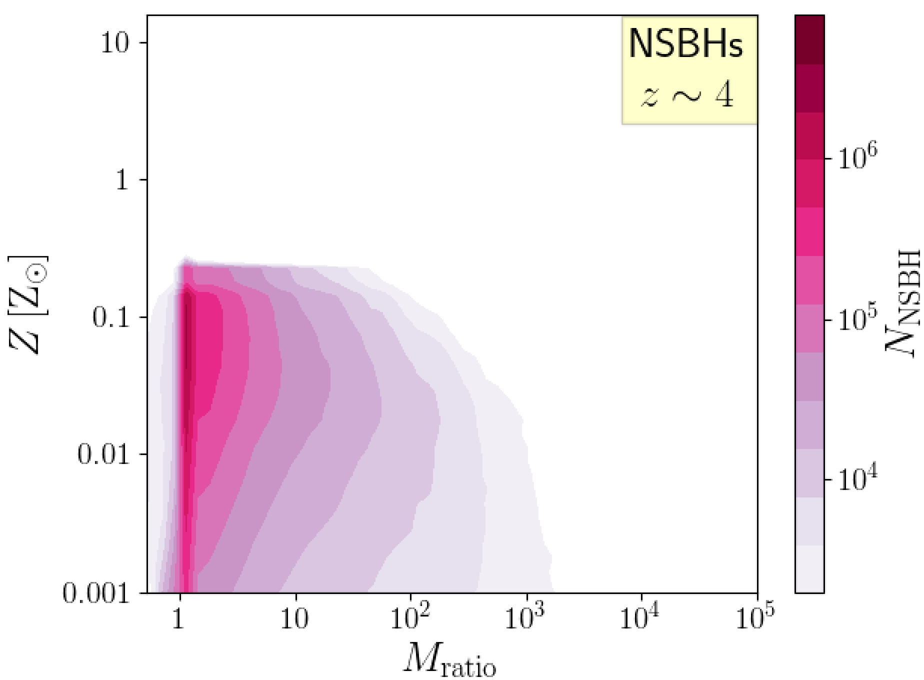
**Legend**

$M_{ratio}=M_{host,merg}/M_{host,form}$

$Z_*$=metallicity of progenitors

# Results: NSBHs – $M_{ratio}$ vs $Z_*$




## Merging at z=0

- Wide $M_{ratio}$ range, many binaries in $M_{ratio}$~1-10 → large $t_{delay}$ range, tendency for $t_{delay} \leq$ 4 Gyr
- $Z_*$ within ~0.01 and ~0.5 $Z_{sun}$

50% of CO binaries $M_{ratio}$ interval

| | $z \sim 0$ | $z \sim 2$ | $z \sim 4$ | $z \sim 6$ |
|---|---|---|---|---|
| $M_{\rm ratio,NSBH}$ | $1.5 - 1.6 \times 10^2$ | $1 - 5.8$ | $1 - 2.4$ | $0.9 - 1.9$ |

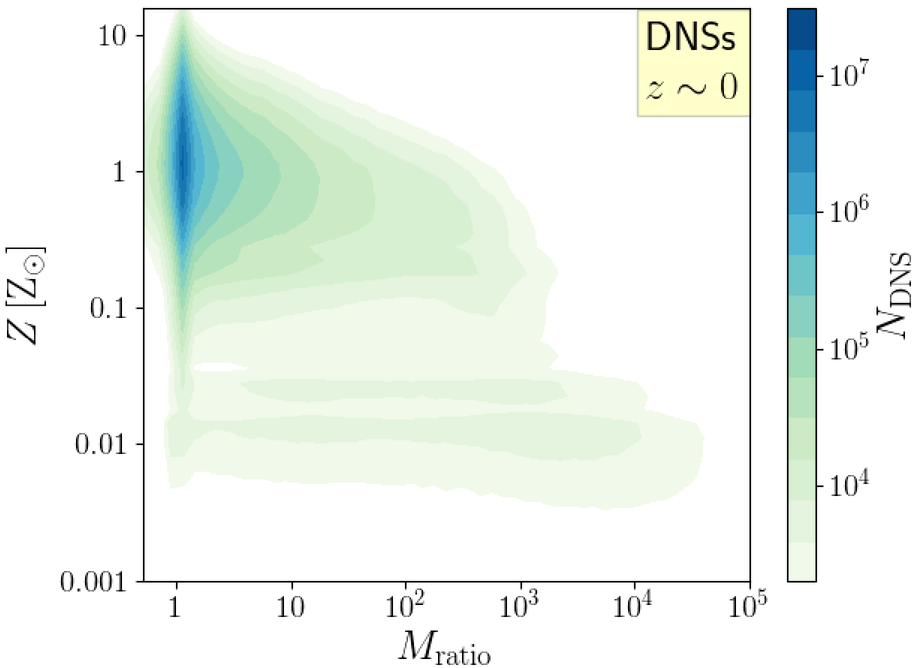
## Merging at z=4 ( $t_{lookback}$~12.17 Gyr)

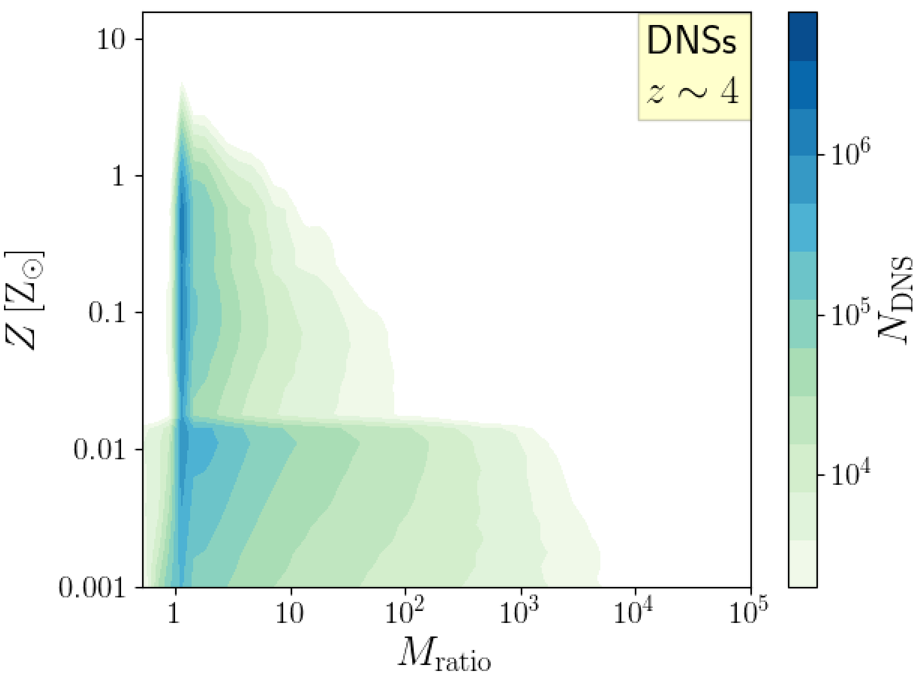
- Majority in $M_{ratio}$ ~ 1-5 → very short $t_{delay}$
- $Z_*$ extended to lower values

## Legend

$M_{ratio}=M_{host,merg}/M_{host,form}$
$Z_*$=metallicity of progenitors

# Results: DNSs – $M_{ratio}$ vs $Z_*$




**Merging at z=0**

- Mainly $M_{ratio}$~1→ short $t_{delay}$
- Tendency for solar – super-solar metallicity

50% of CO binaries $M_{ratio}$ interval

| | $z \sim 0$ | $z \sim 2$ | $z \sim 4$ | $z \sim 6$ |
|---|---|---|---|---|
| $M_{ratio,DNS}$ | $1 - 2.7$ | $0.9 - 1.5$ | $1 - 2.7$ | $1 - 3.5$ |

**Merging at z=4** ( $t_{lookback}$~12.17 Gyr)

- Metal-rich progenitor even at z=4
- appearing of a sub-population of metal-poor DNS progenitors, featuring a longer $t_{delay}$ (similarly to BHBs)

**Legend**

$M_{ratio}=M_{host,merg}/M_{host,form}$
$Z_*$=metallicity of progenitors

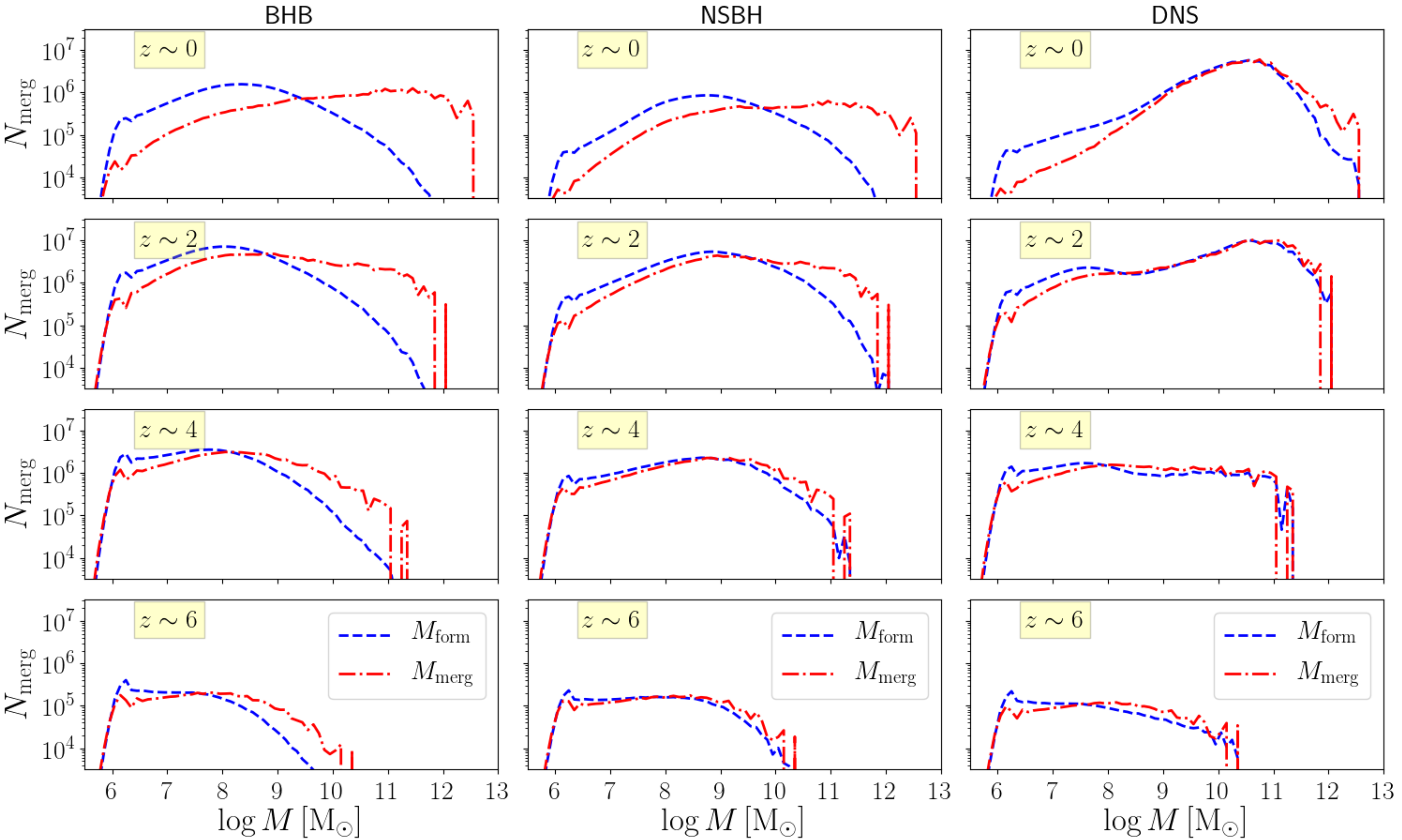
# Conclusions

- **BHBs**: mainly long $t_{delay}$~10-12 Gyr, formed in small hosts and merge at present time in more massive ones uniformly in the whole considered range ($10^7 – 10^{13}$ $M_{sun}$); metal-poor progenitors at all epochs.
- **NSBHs**: foresee to observe them merging at present in the whole considered mass range; both short and long $t_{delay}$ at low z, very short $t_{delay}$ at higher z; metal-poor progenitors at all epochs.
- **DNSs**: mainly short $t_{delay}$<4 Gyr; foresee to observe them in $10^9$-$10^{11}$ $M_{sun}$ hosts (**consistent with short GRBs range!**); metal-rich progenitors at low z, both metal-rich and -poor at higher z.

Article: **Toffano**, Mapelli, Giacobbo, Artale & Ghirlanda, *The host galaxies of double compact objects across cosmic time;*
MNRAS: https://academic.oup.com/mnras/article/489/4/4622/5558258

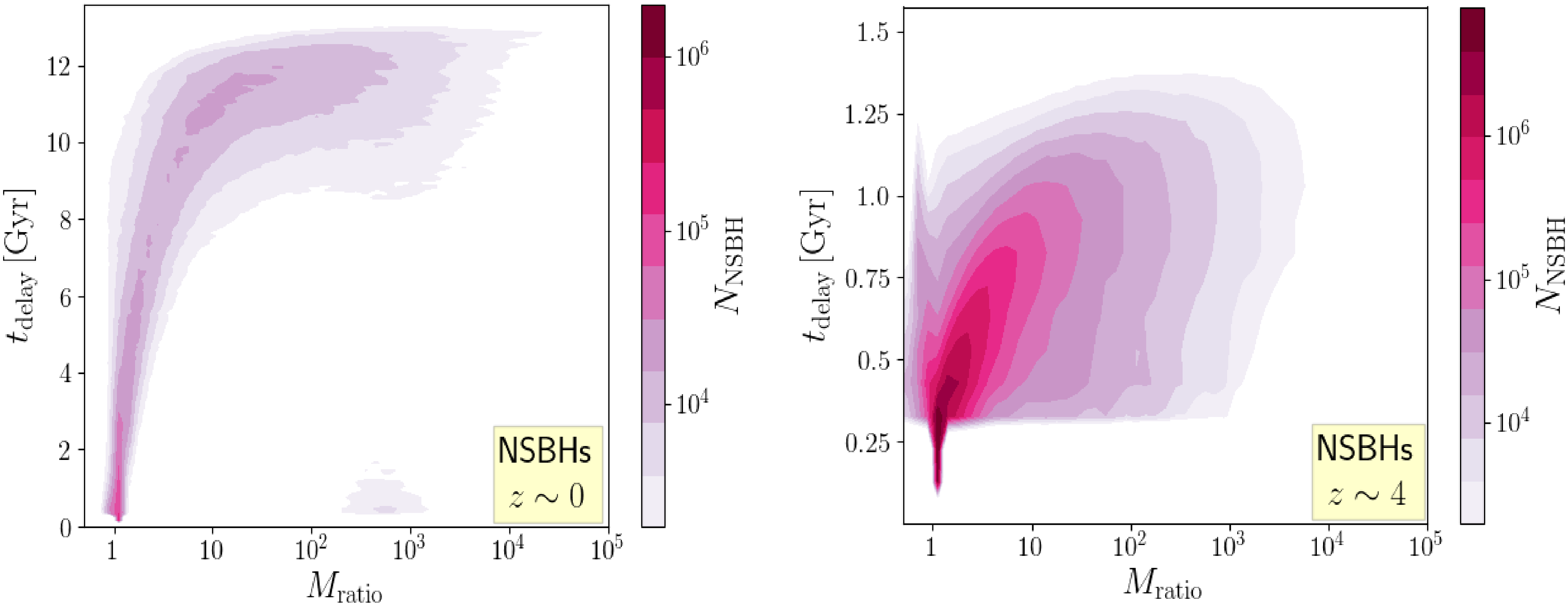
# Backup Slides

# $M_{form} - M_{merg}$

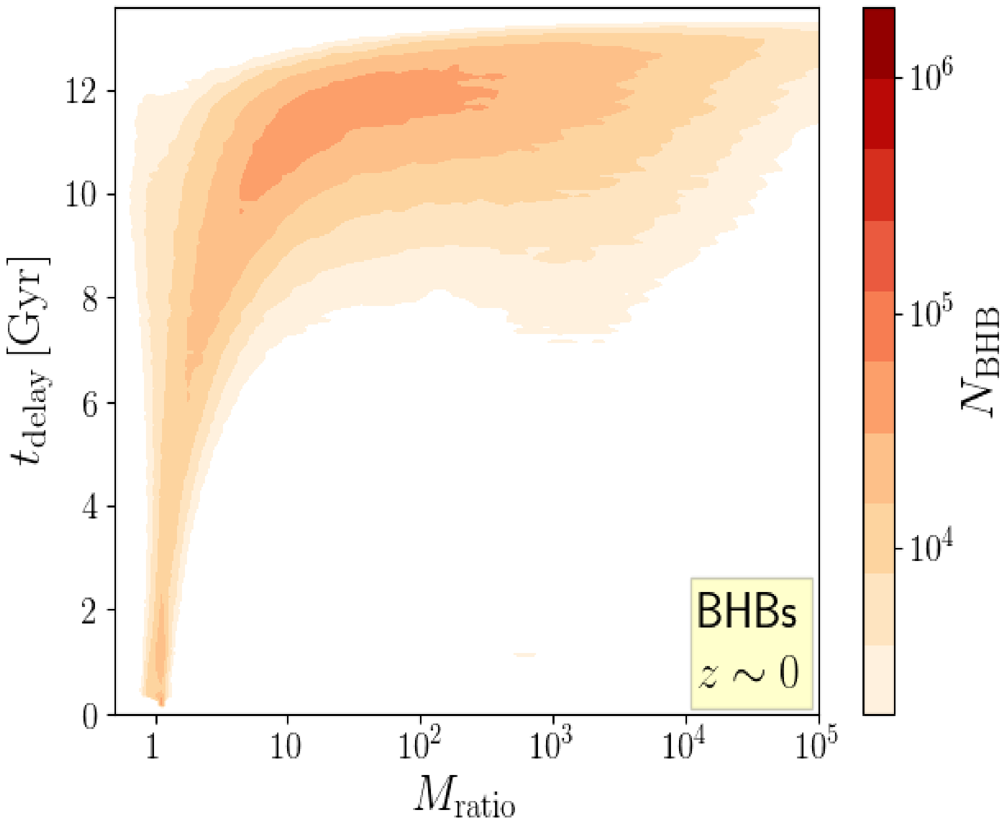


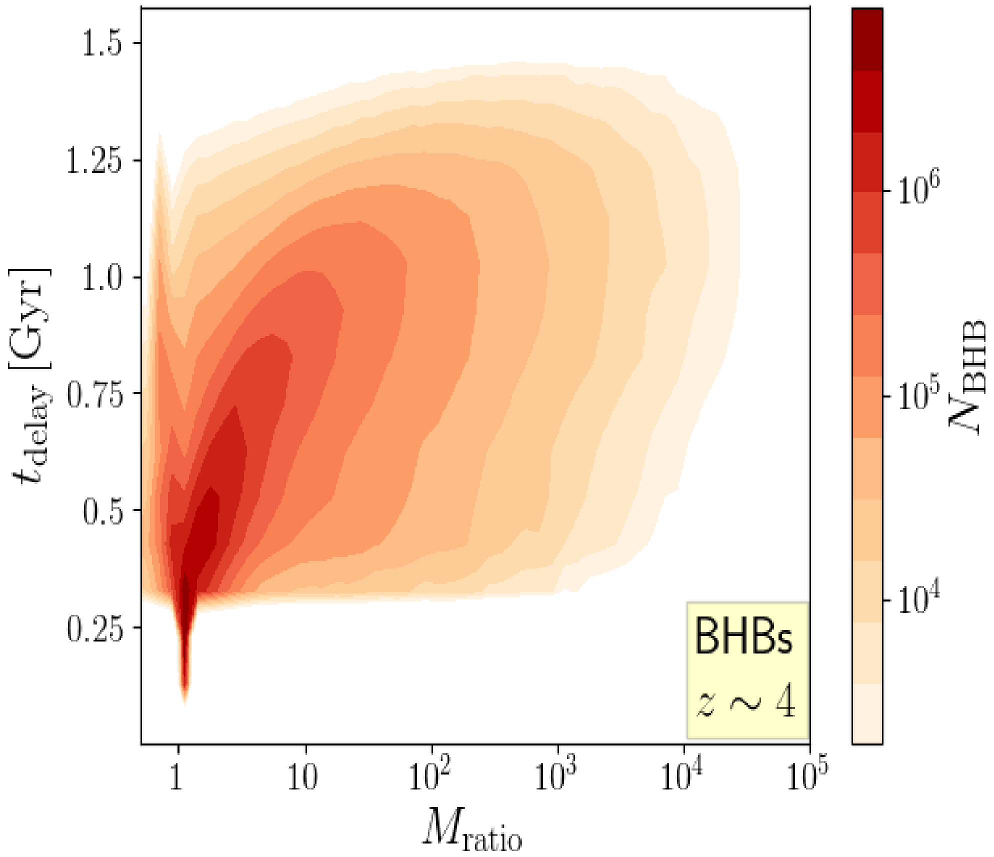
BHB
NSBH
DNS
$z \sim 0$
$z \sim 2$
$z \sim 4$
$z \sim 6$
$N_{merg}$
$M_{form}$
$M_{merg}$
$\log M$ [$M_\odot$]

# NSBH – $M_{ratio}$ vs $t_{delay}$



# BHB – $M_{ratio}$ vs $t_{delay}$



# DNS – $M_{ratio}$ vs $t_{delay}$