Modelling the host galaxies of binary compact object mergers with observational scaling relations

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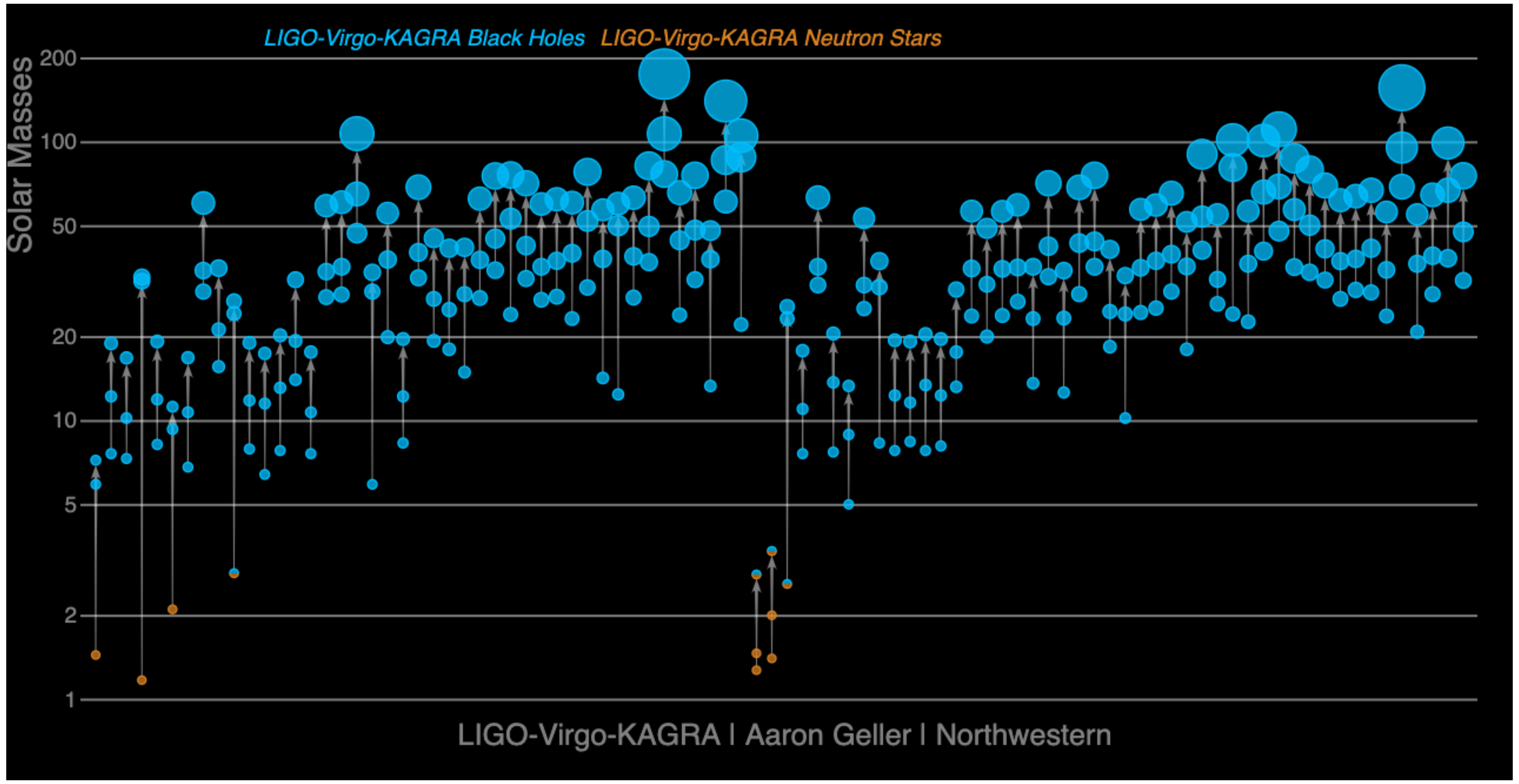
Quick introduction

- **Break the title down:** *"Modelling the host galaxies of binary compact object mergers with observational scaling relation"*
- **Goal**: link the properties of compact objects (different astrophysical models) to the properties of galaxies (huge parameter space)
- Host galaxies through cosmological simulations
- Take advantage of **observational properties of galaxies**
- This hybrid modelling of host galaxies will provide us *for free* also the cosmic **merger rate density** (aka **redshift distribution** of compact object mergers)

From GW detections to merger rate density



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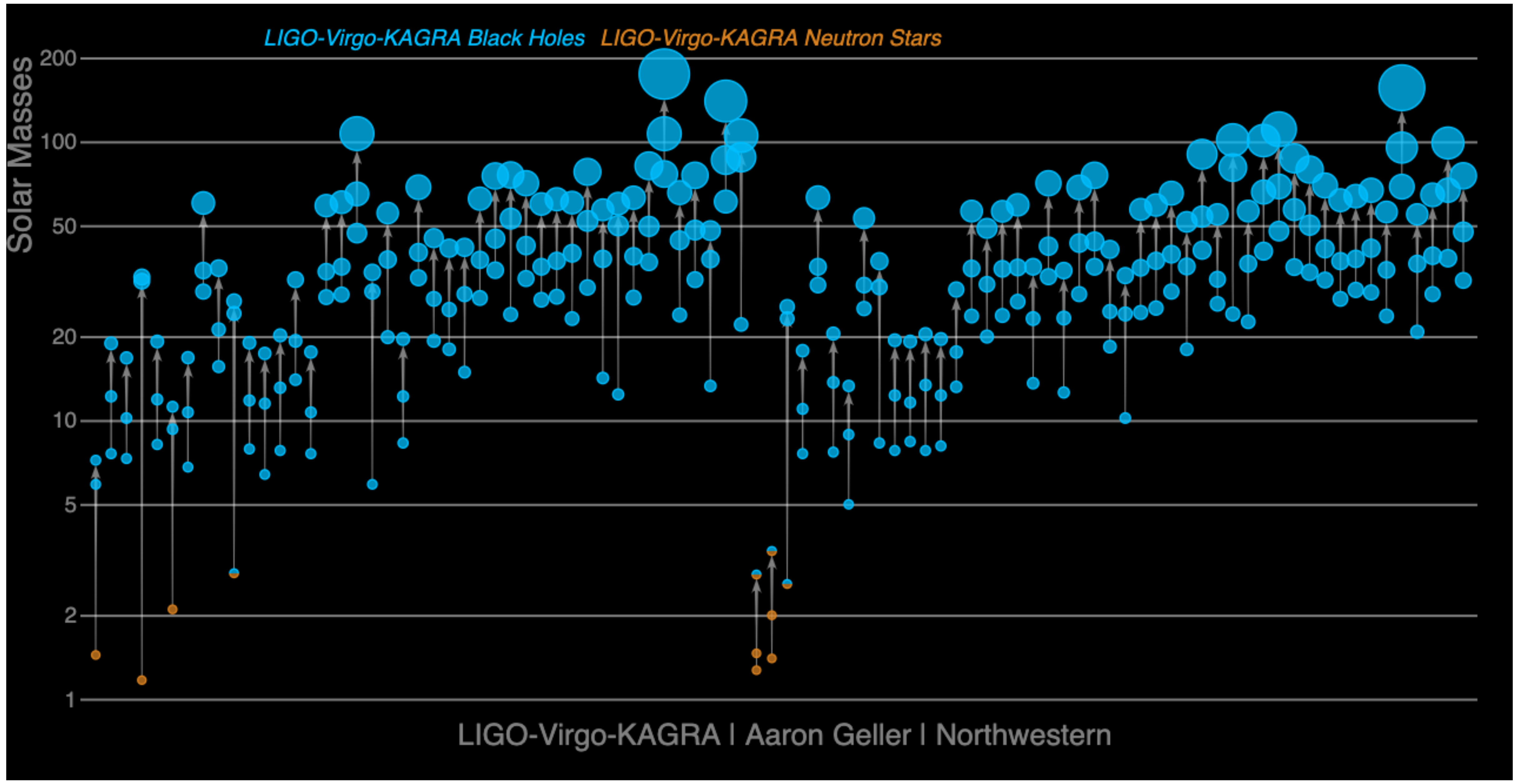
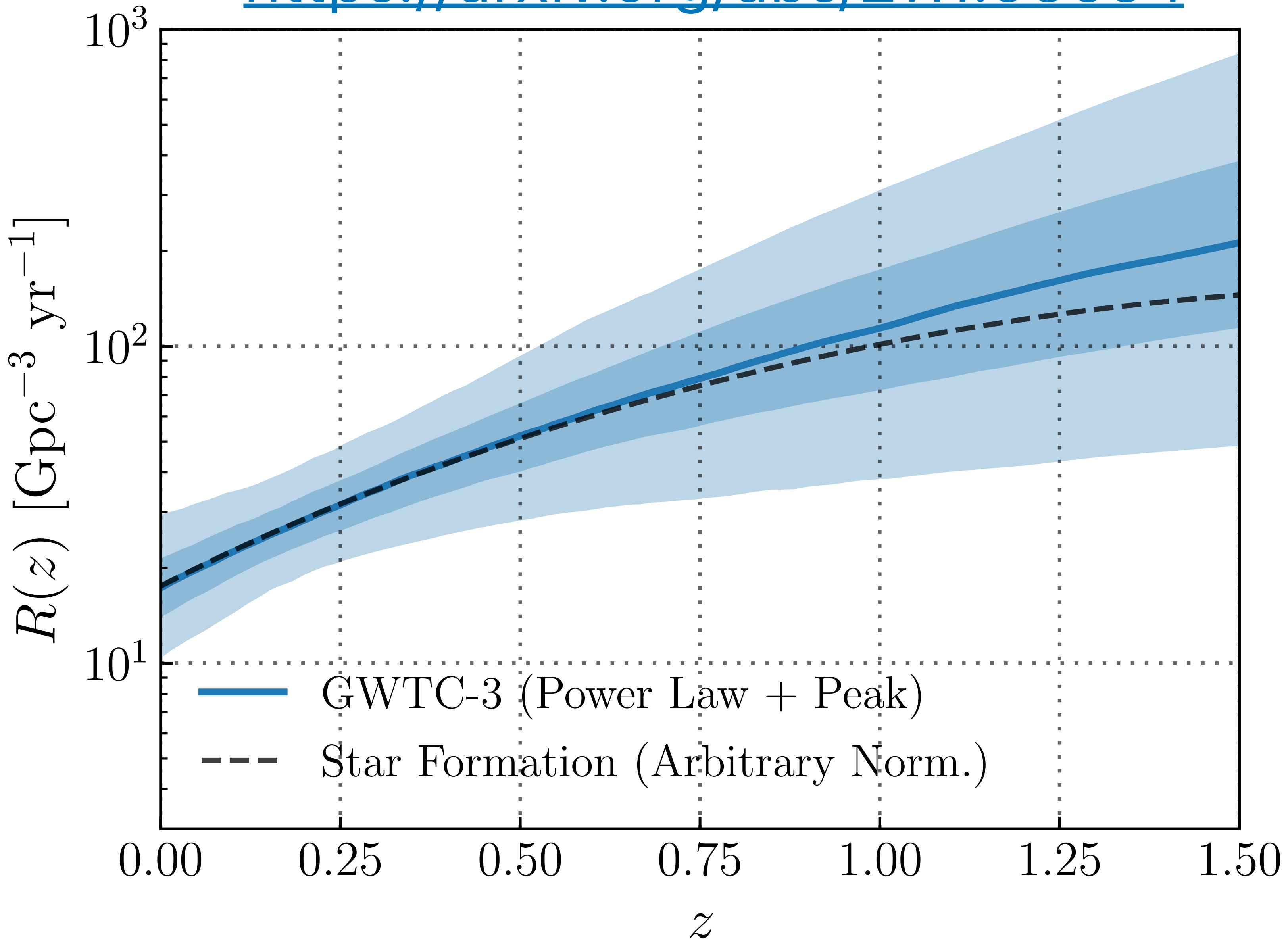


[LVK collaboration et al. 2021: https://arxiv.org/abs/2111.03634](https://arxiv.org/abs/2111.03634)



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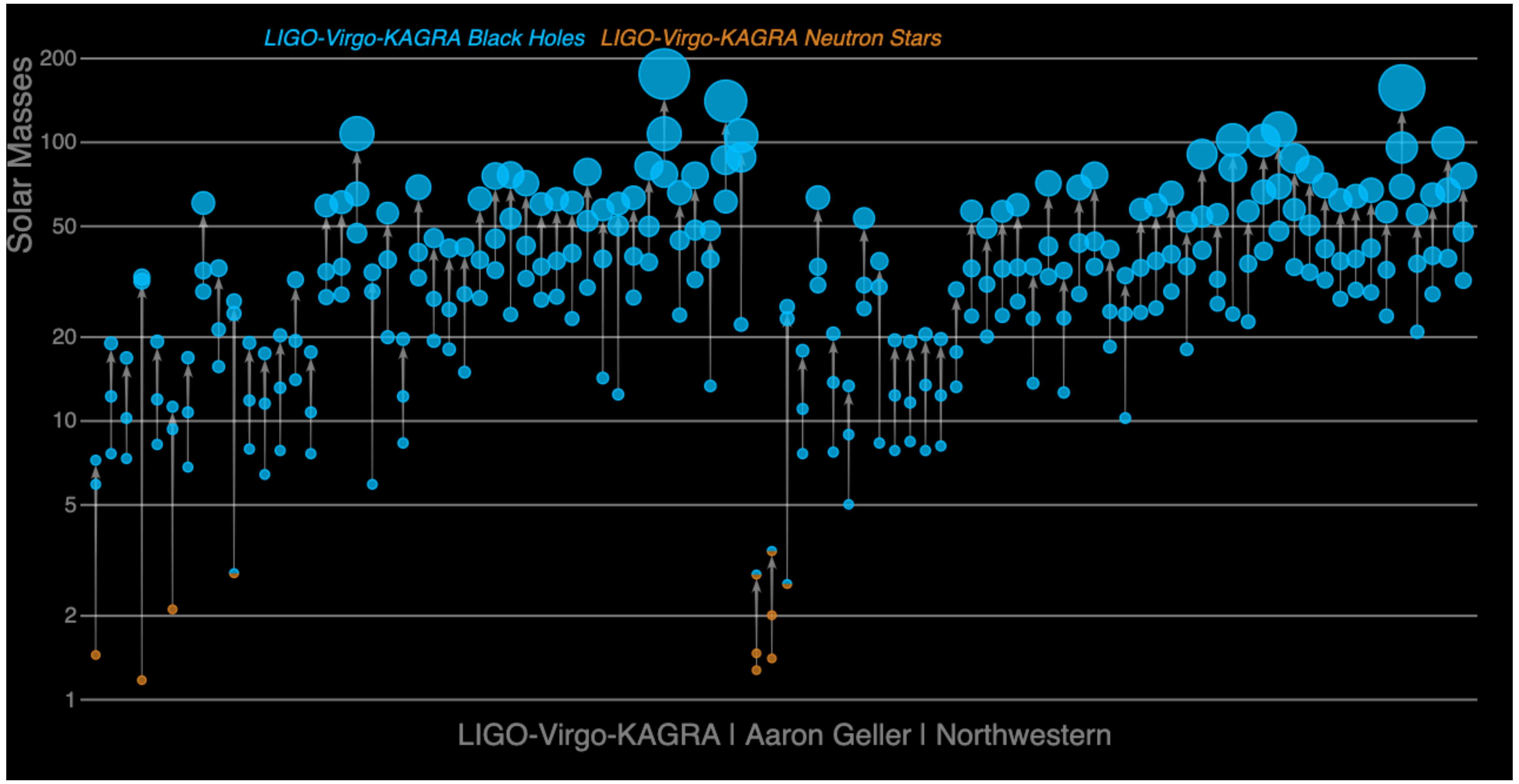

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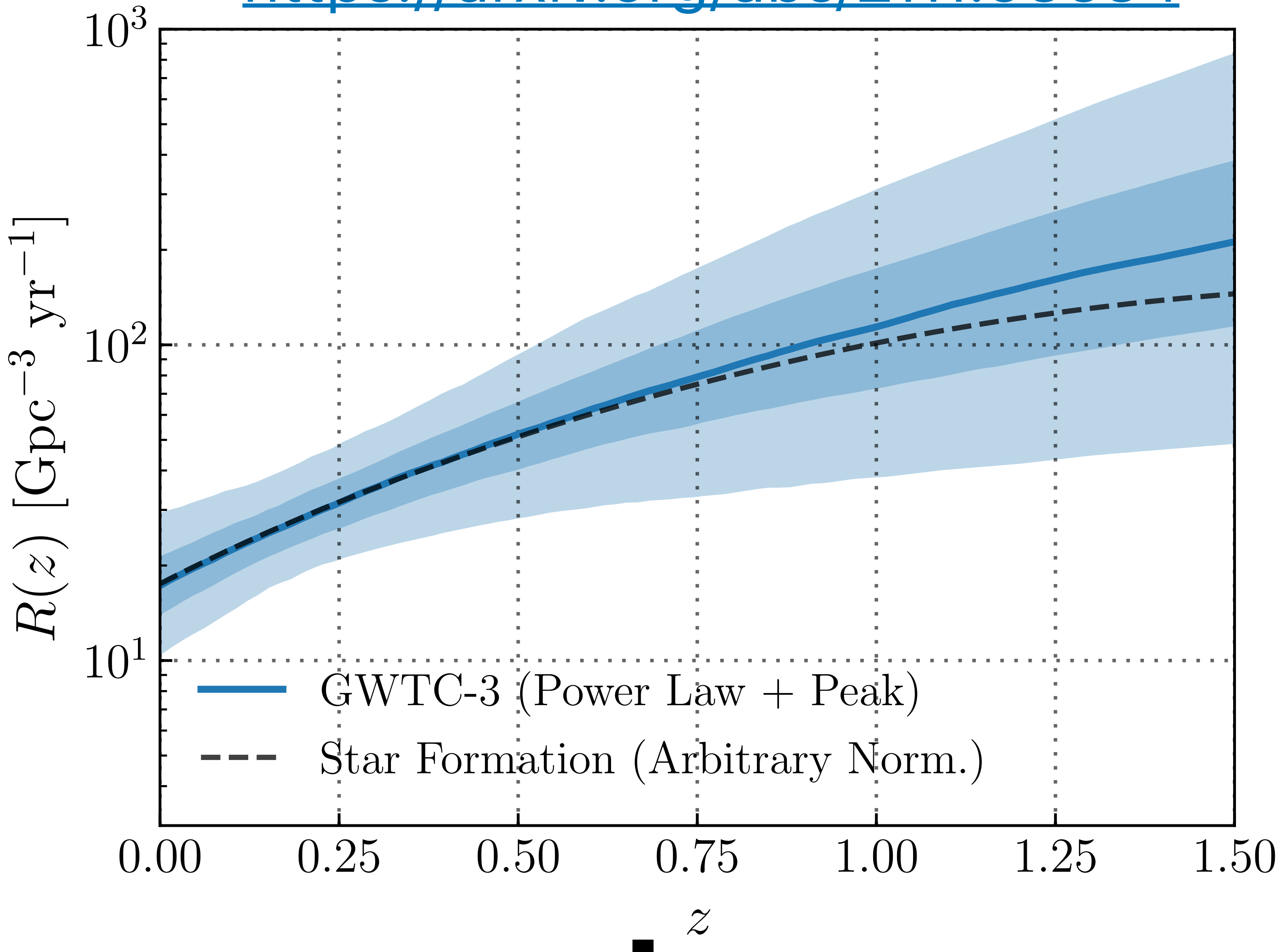
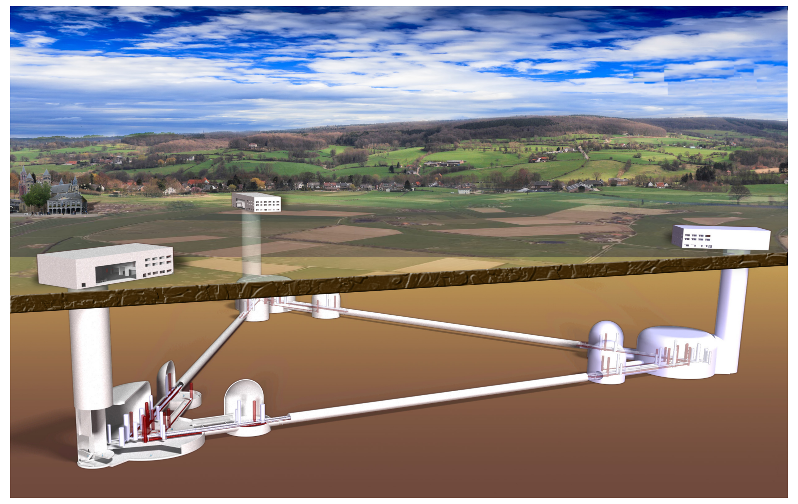
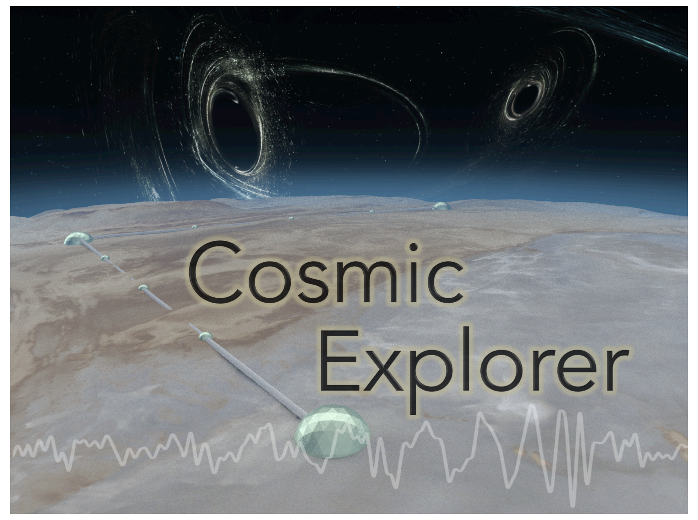


Third-generation detectors



Credits: Ego Collaboration



https://cosmicexplorer.org/

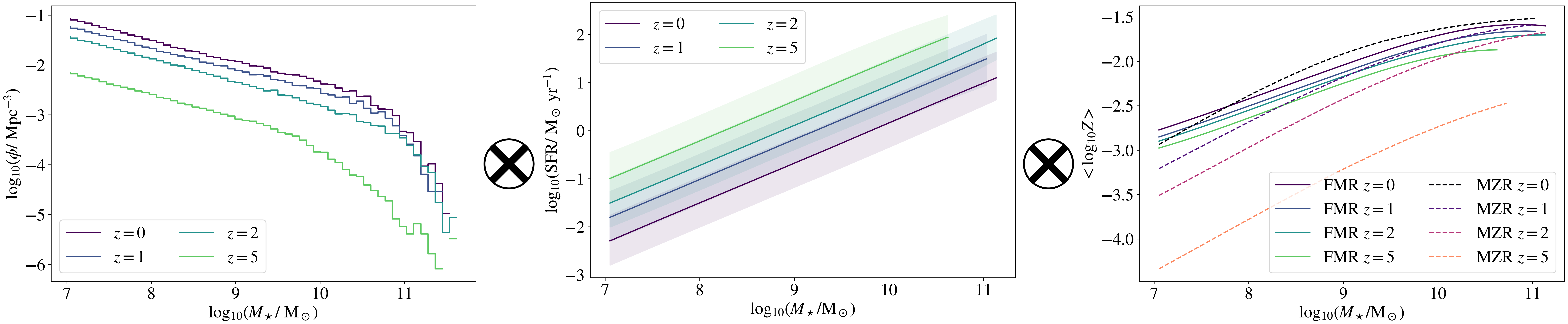
General scheme of `galaxyRate`

General scheme of galaxyRate

Formation galaxies → Merging compact objects → Host galaxies

↑

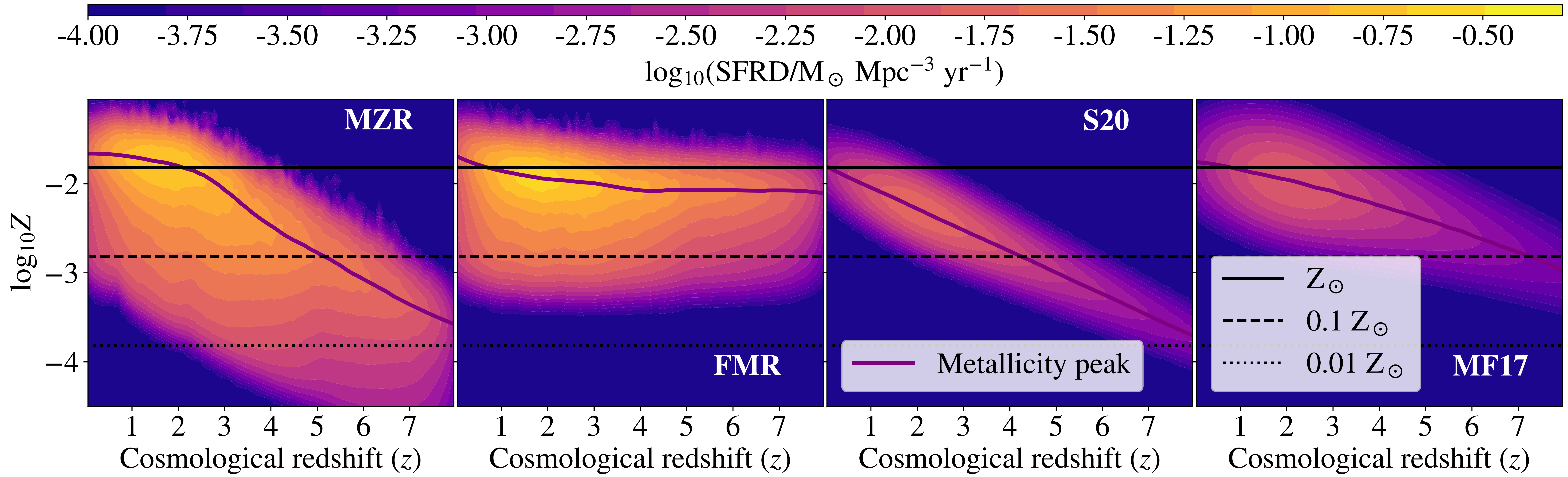
We create a population of star-forming galaxies, each of them defined by its **stellar mass**, its **star-formation rate** and its **metallicity**.



Chruslinska et al. 2019 | Speagle et al. 2014, Boogaard et al. 2018 | Mannucci et al. 2009, Mannucci et al. 2011

Result: SFRD distribution

Formation galaxies → Merging compact objects → Host galaxies



galaxyRate cosmoRate

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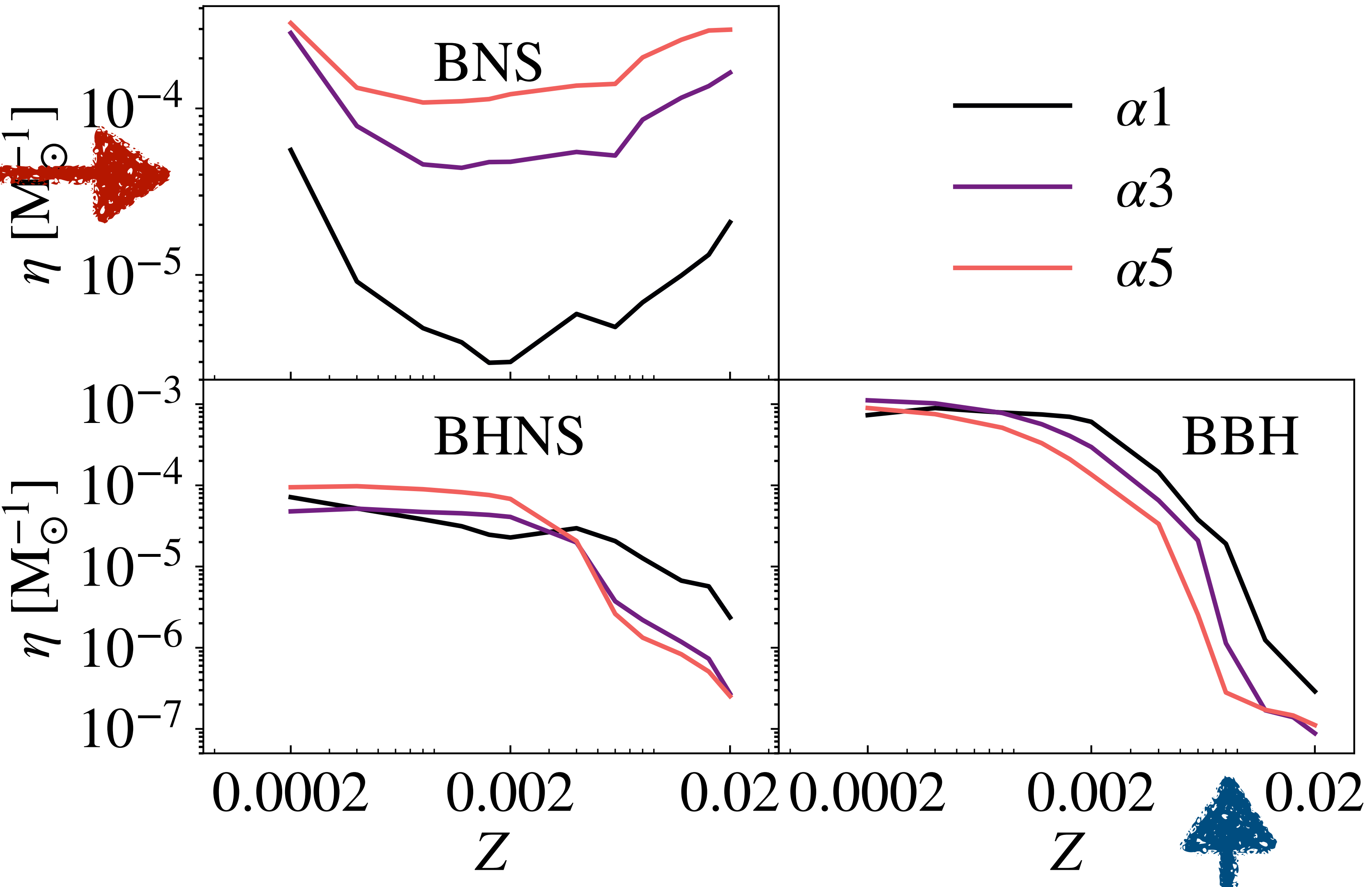
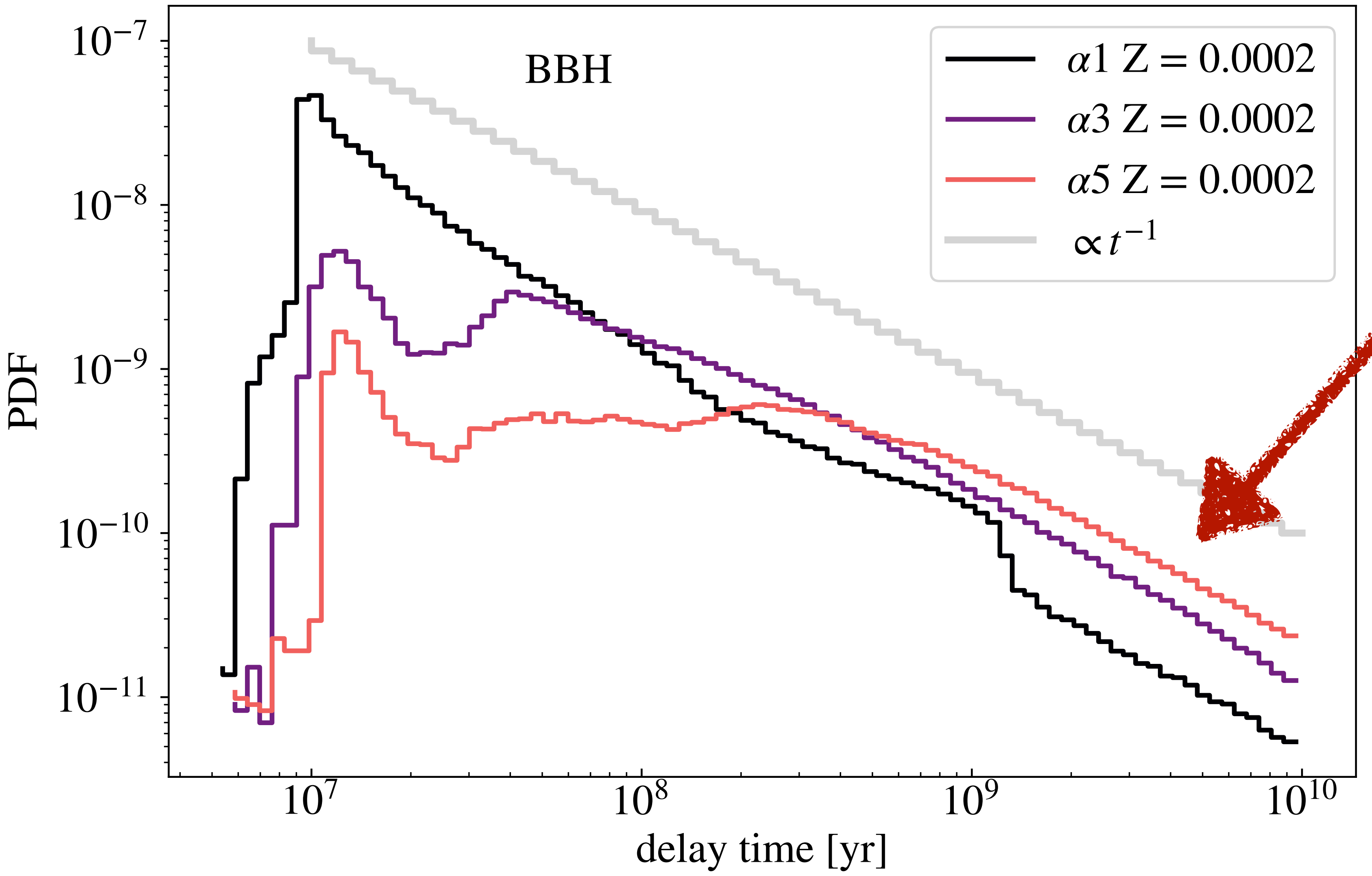
General scheme of galaxyRate

Formation galaxies → Merging compact objects → Host galaxies

Effect of common envelope





Effect of common envelope

Effect of progenitor metallicity

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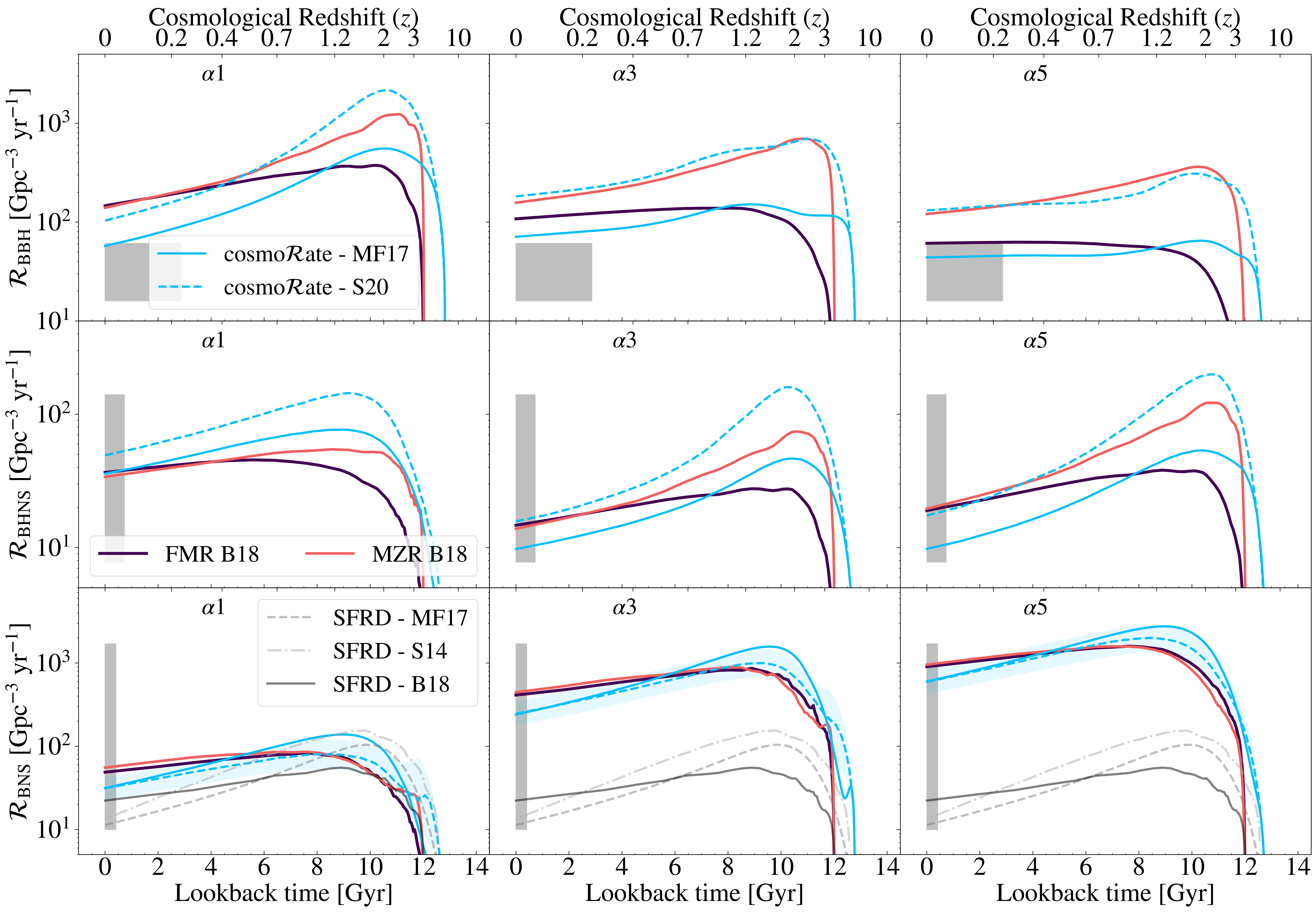
Result: Cosmic Merger Rate Density



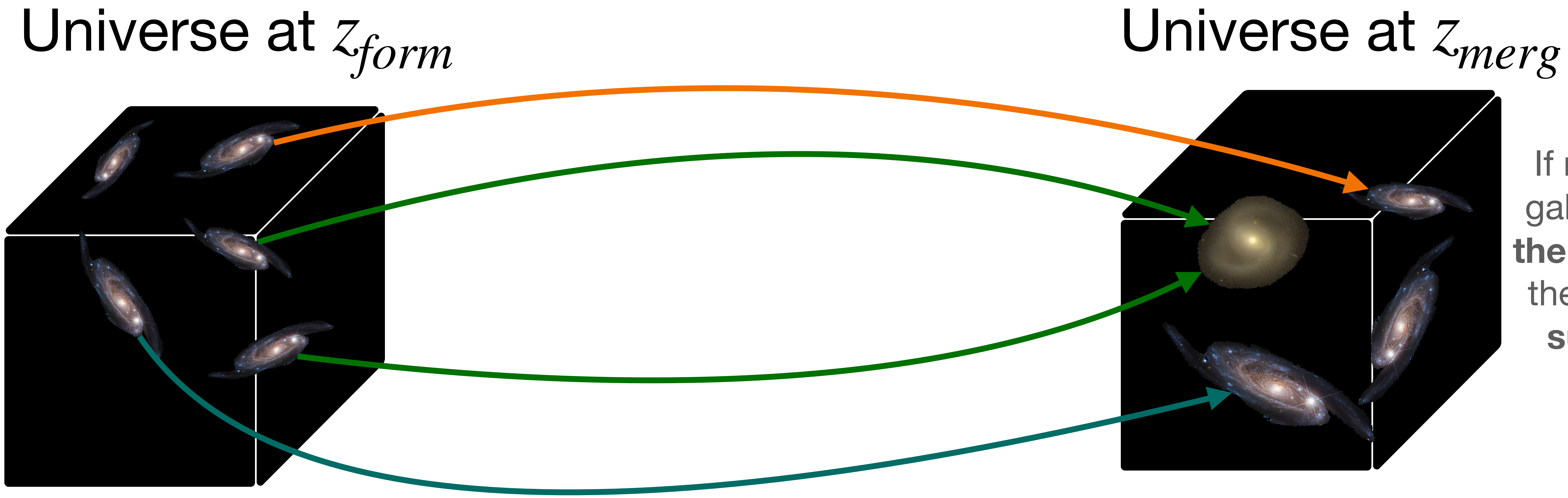
- `galaxyRate` models **overestimate the BBH merge rate density** in the local Universe with respect to `cosmoRate`.
- **different evolution** of BBH merger rate density with either **MZR or FMR.**
- The merger rate density of BHNS and BNS is inside the 90% credible interval inferred from O3b
- **BNS merger rate density** is dominated by **SFRD evolution** and it is extremely sensitive to the **Common Envelope** evolution

General scheme of galaxyRate

Formation galaxies → Merging compact objects → Host galaxies

From the **merger trees** of the EAGLE cosmological simulation we compute empirically

the following conditional probability $p(\mathrm{M}_{host}, \mathrm{SFR}_{host} \,|\, \mathrm{M}_{form}, \mathrm{SFR}_{form}, z_{form}, z_{merg})$.



If **multiple** formation galaxies are **linked to the same host galaxy**, their merger rates are **summed together**

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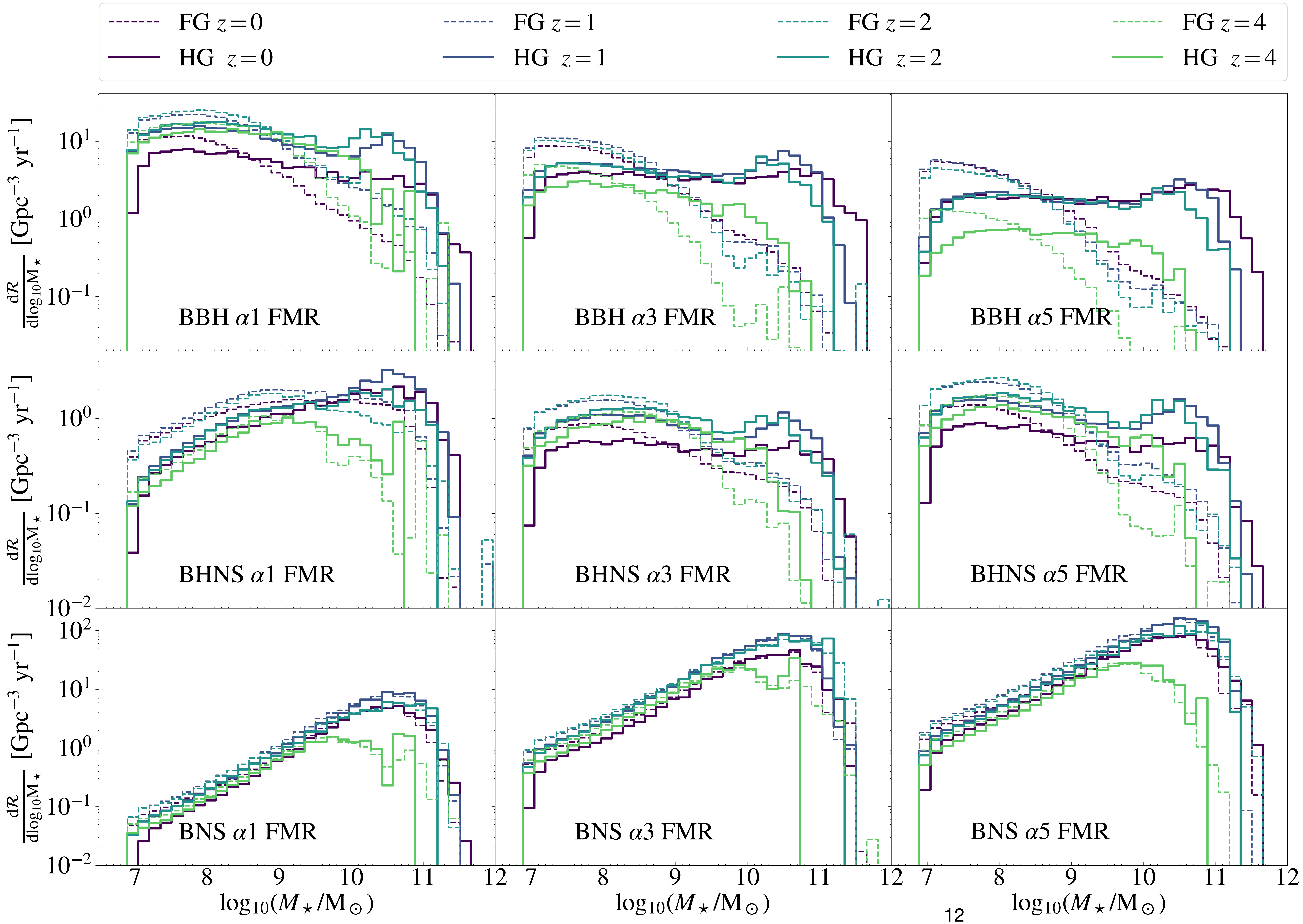
Host galaxies of merging compact objects



- Here is the **distribution** of merger rate density per **galaxy mass.** We compare the formation galaxy (FG) with the host galaxy (HG)
- Large fraction of **BBHs is hosted** in **low-mass** galaxies
- Contribution of **high-mass** galaxies increases with **increasing** α

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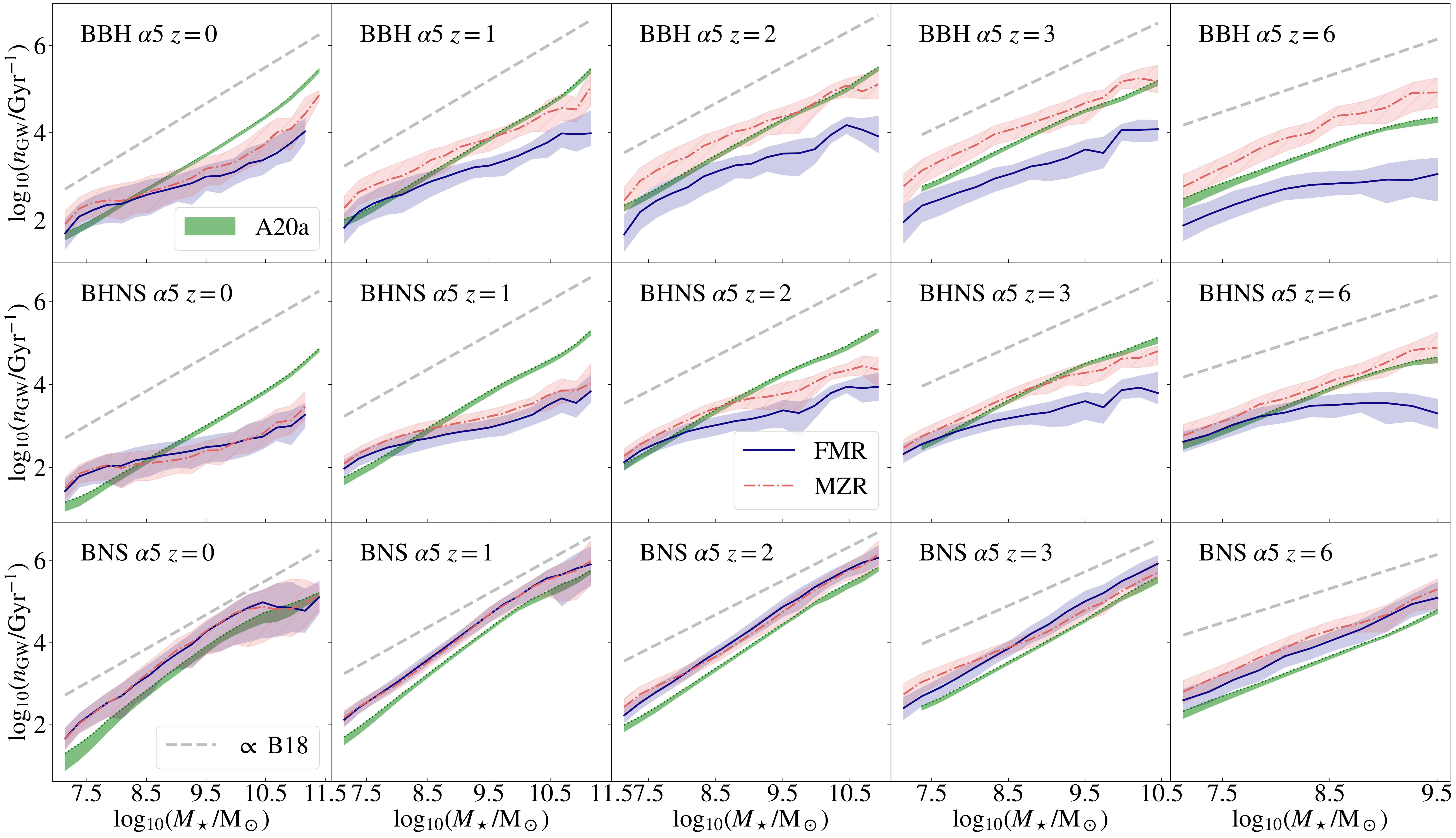
Merger rate per galaxy

- Here we are showing the **merger rate per galaxy** as function of **stellar mass**
- We compare it with results obtained in *Artale et al. 2020* considering EAGLE **cosmological simulation**
- Slope of the correlation of n_{GW} with stellar mass depends on **redshift** and **metallicity evolution** model for BBHs



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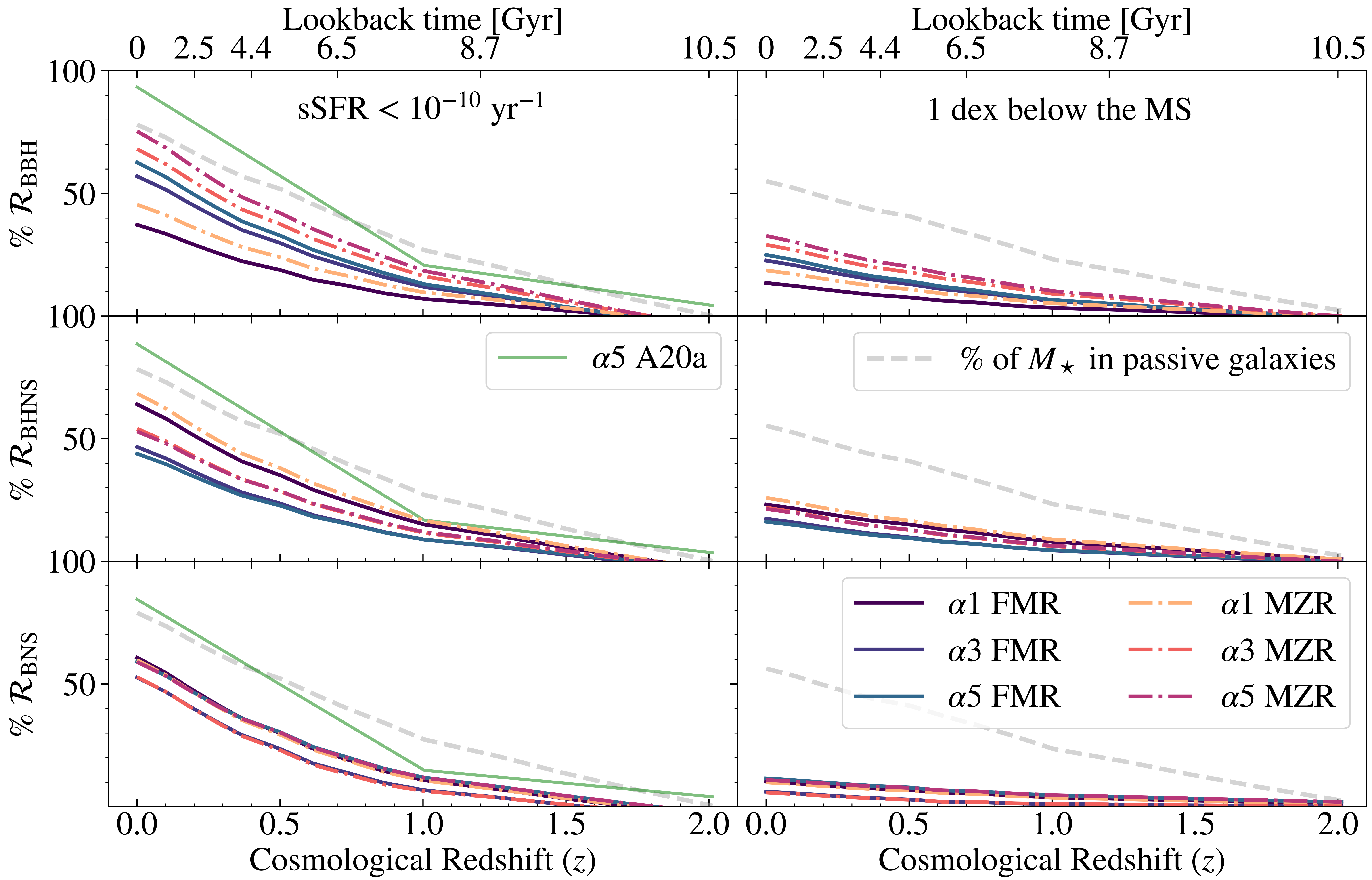
Passive galaxies

- This plots shows the **mergers hosted by passive galaxies**, showing here two definition of passive galaxies (Artale et al. 2019, Donnari et al. 2021)
- Percentage of mergers hosted by passive galaxies **increases at decreasing redshift**
- For **BBHs** the percentage of mergers hosted in passive galaxies can changed by a **factor of ~2 depending on the considered model**



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Conclusions

- We evaluated the merger rate density of **compact objects** and **explored the properties** of **host galaxies** for a set of models, varying both the star formation rate density and the binary evolution

- **BBH** merger rate density is highly **depended** on star-formation rate at **sub-solar metallicity**. **BNS** are mostly **affected** by binary evolution (**common envelope** evolution)
- A **large fraction** of **BBHs** can merge **in low-mass host galaxies** and this depends on the delay time distribution.
- Strong correlation between the **BNS merger rate per galaxy** ($n_{\rm GW}$) and stellar mass of the host galaxy
- All compact objects have more chances to be hosted in **passive galaxies** if their **delay time distribution is longer**

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Thank you!

I'm happy to take your questions!

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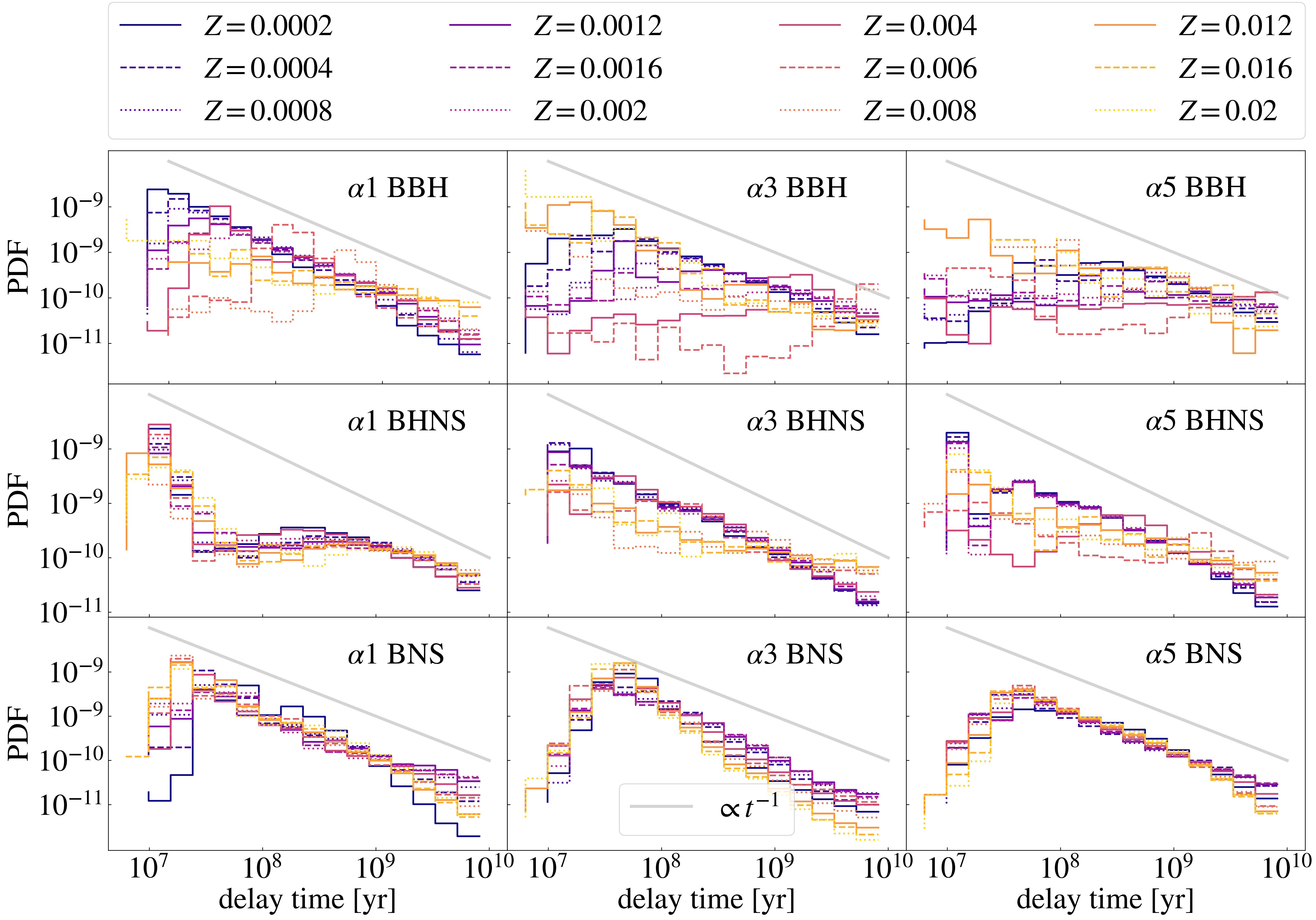
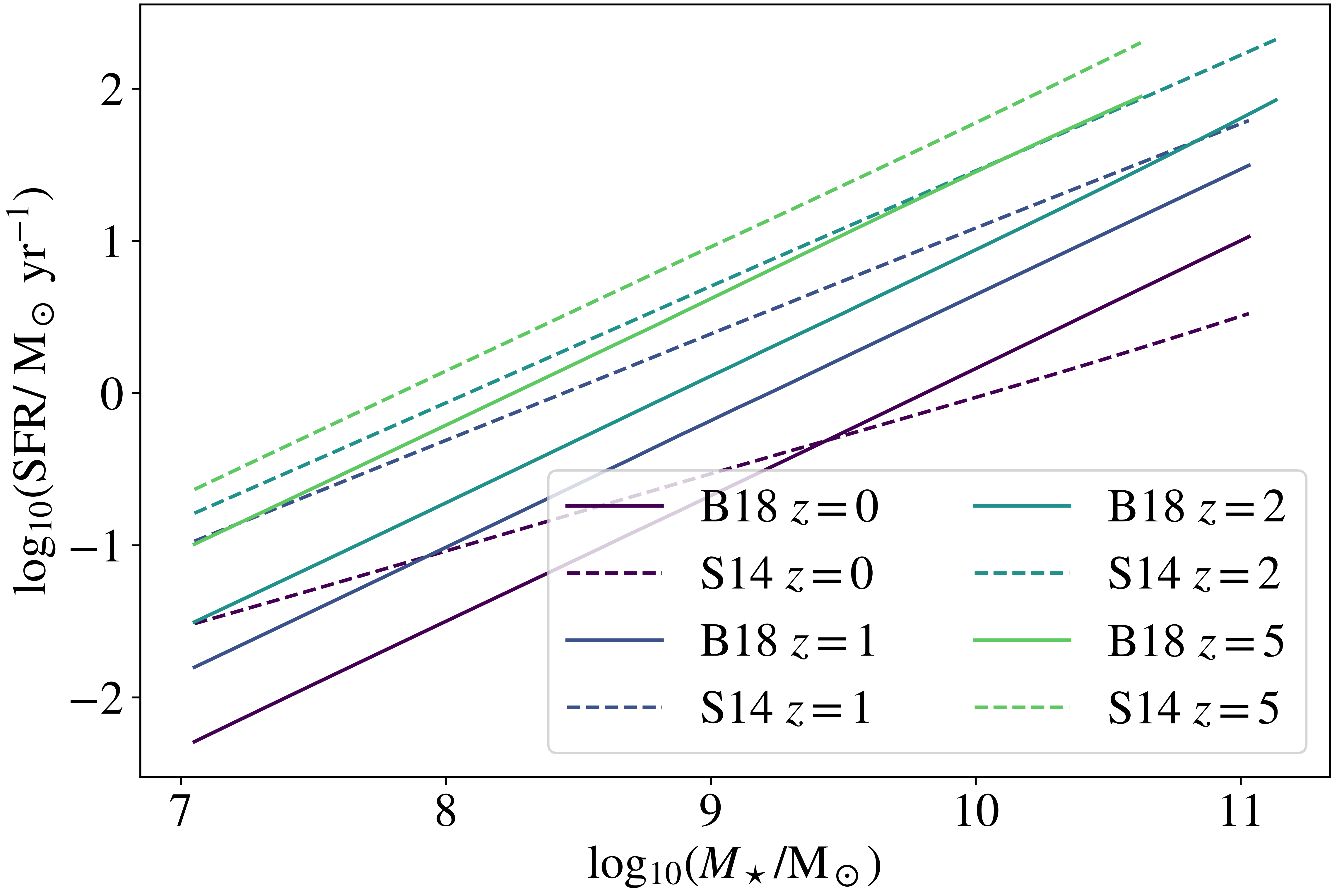
Backup slides

Delay time distribution

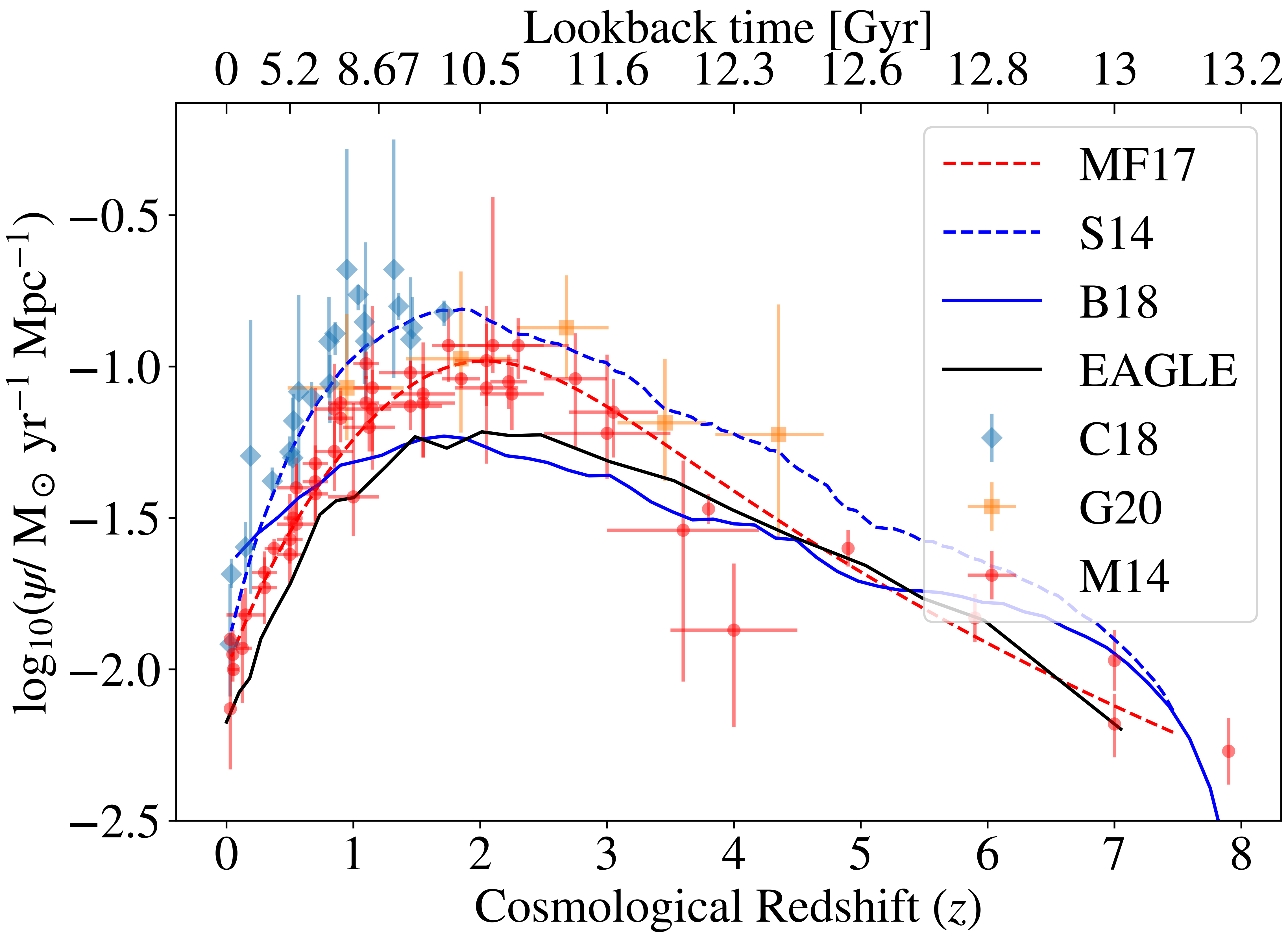
- The figure shows that if $\alpha = 1$ the delay time distribution peaks at shorter delay times than for larger values of α.
- A small value of α implies a more effective shrinking of the progenitor binary during common envelope.
- Figure shows that $\mathrm{d}N/\mathrm{d}t_{\mathrm{del}} \propto t_{\mathrm{del}}^{-1}$ for long delay times.



Different MS

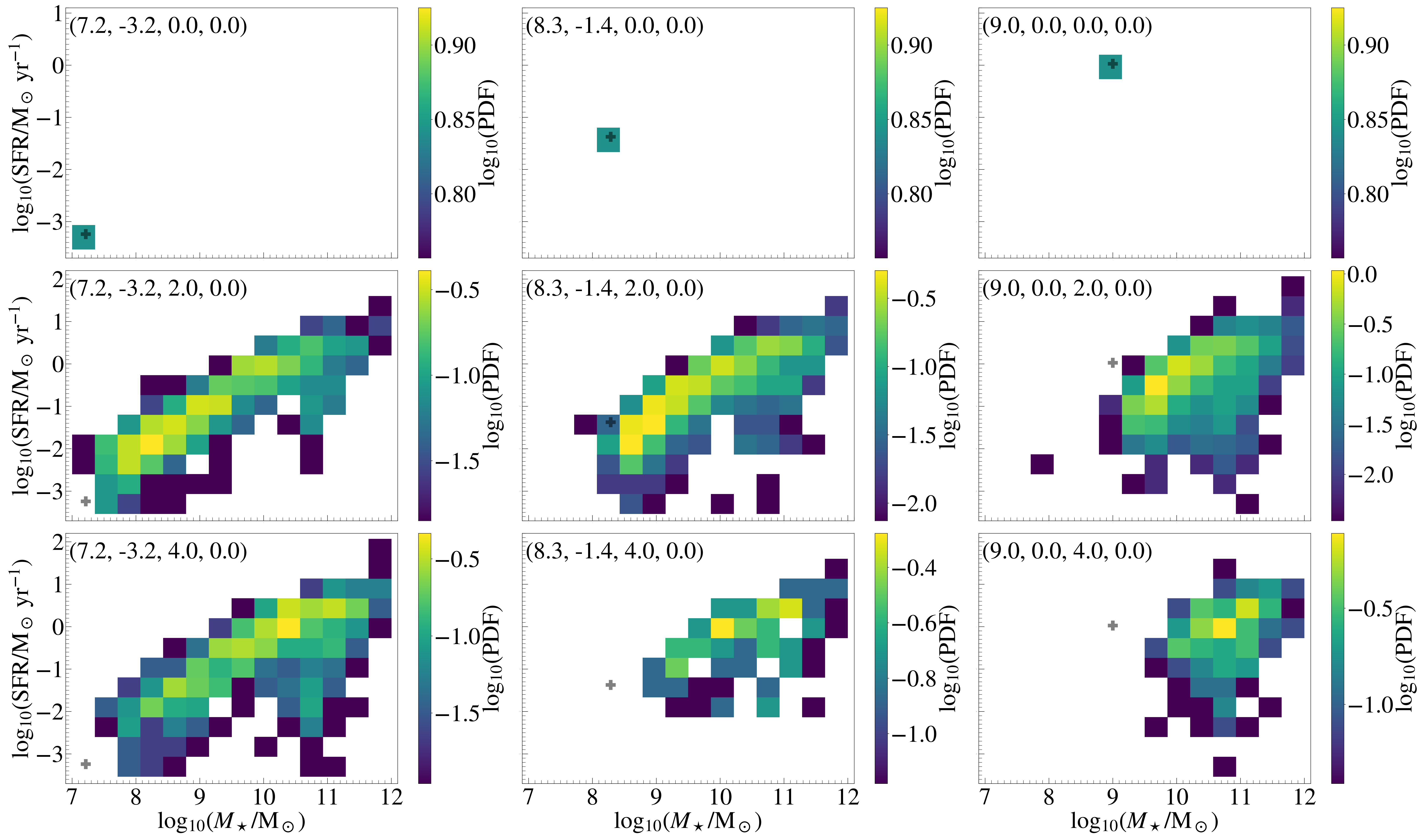


SFRD = GSMF x MS



Conditional Probability

The figure shows some examples of the conditional probability, for various properties of the formation galaxies, annotated at the top of each panel following the order $(\log_{10}(\mathrm{M_{form}}/\mathrm{M_\odot}),\ \log_{10}(\mathrm{SFR_{form}}/\mathrm{M_\odot yr^{-1}}),\ z_{\mathrm{form}})$



If the formation galaxy has no time to evolve (short delay time), the properties of the host galaxy remain the same (first row) as those of the formation galaxy, while if the formation galaxy has more time to evolve (long delay time) then the host galaxy can be very different from the formation galaxy.