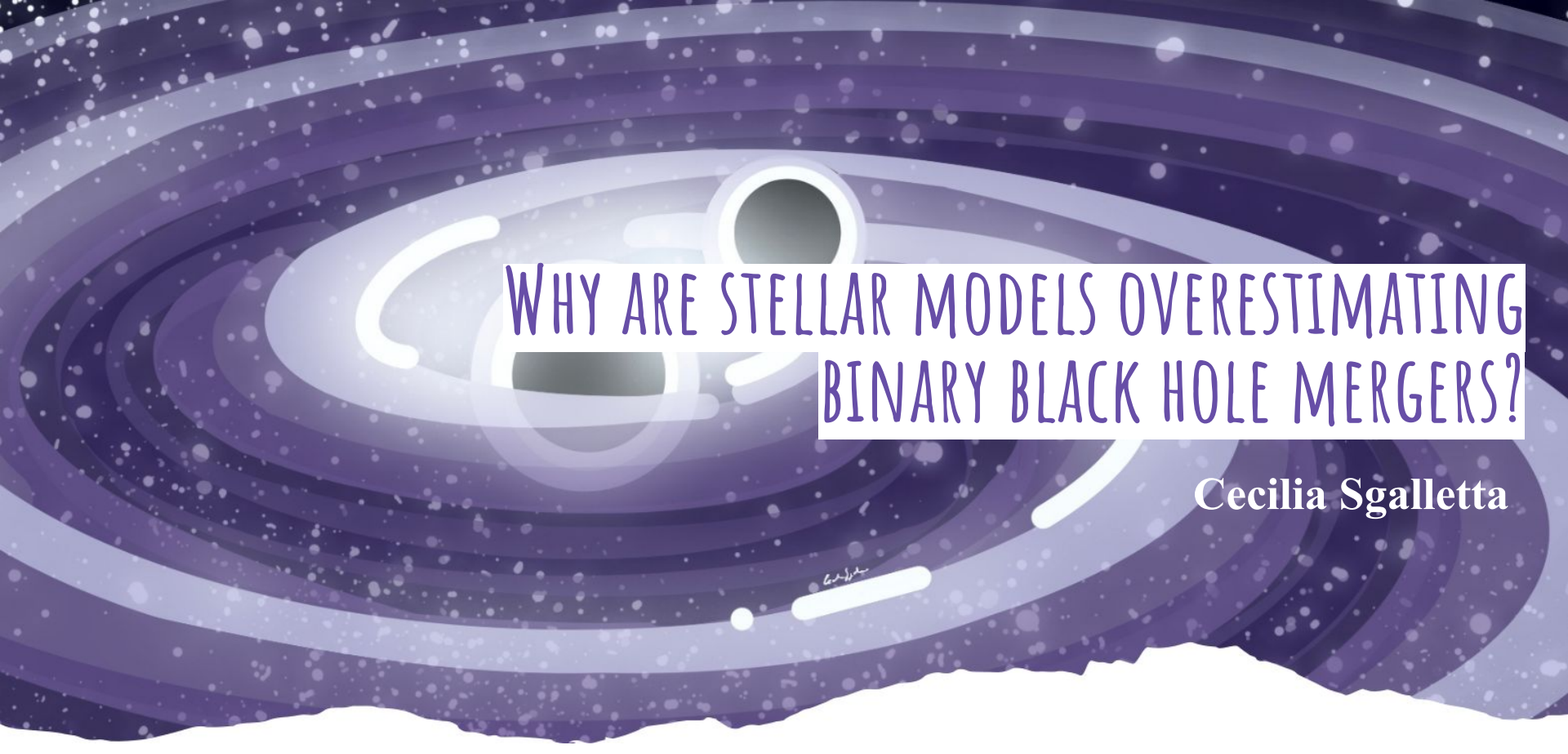


Why are stellar models overestimating binary black hole mergers?

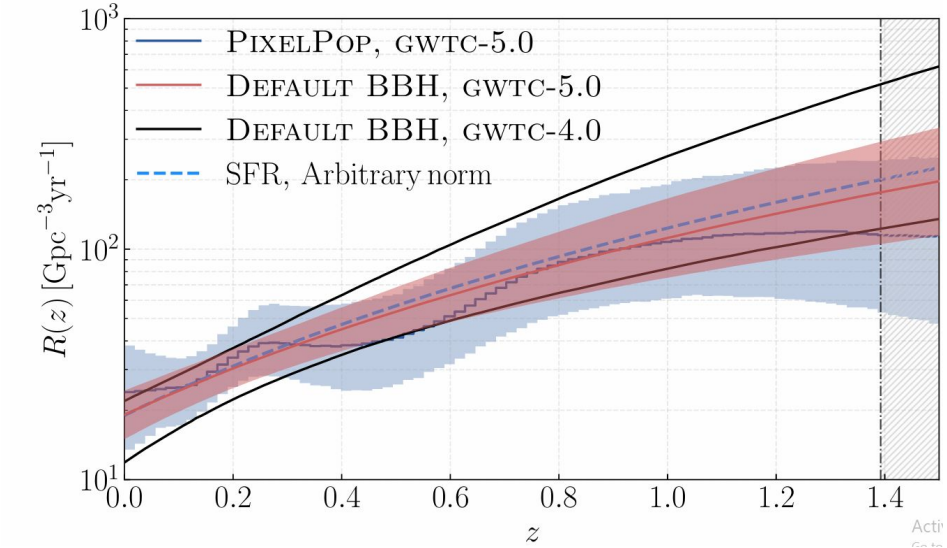
Cecilia Sgalletta

21 September 2026, Graz

75th Annual Meeting of the Austrian Physical Society

UNTERSTÜTZT VON / SUPPORTED BY
Alexander von HUMBOLDT STIFTUNG
STRUCTURES CLUSTER OF EXCELLENCE
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386
EINSTEIN TELESCOPE

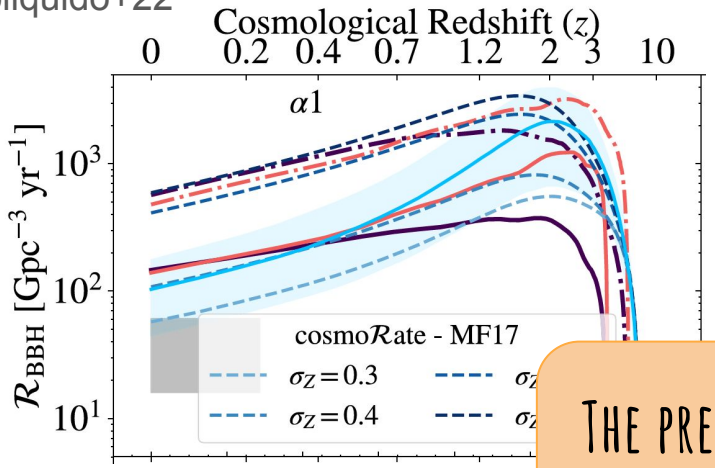
GW observations: rates

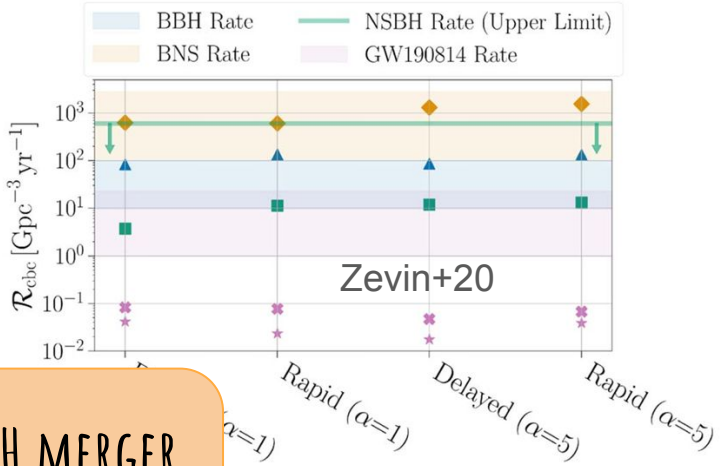


LVK collaboration 2026, GWTC-5 population paper

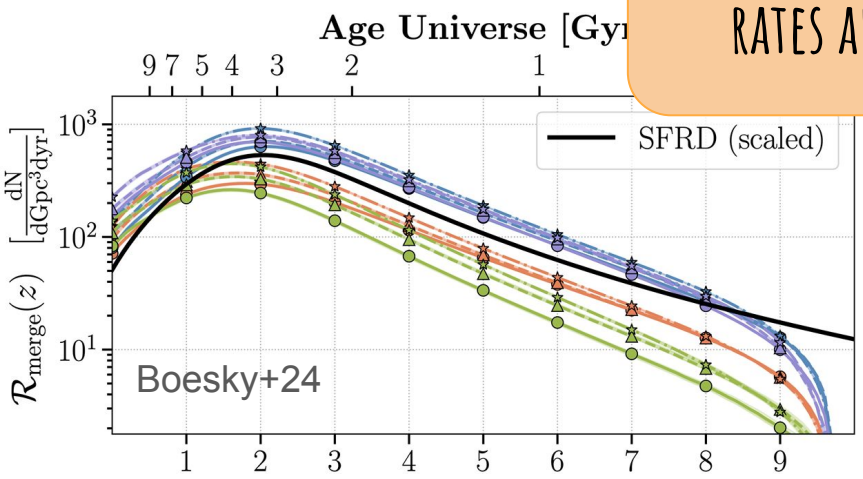
- Formation channels of binary black holes
- Evolution within a cosmological context

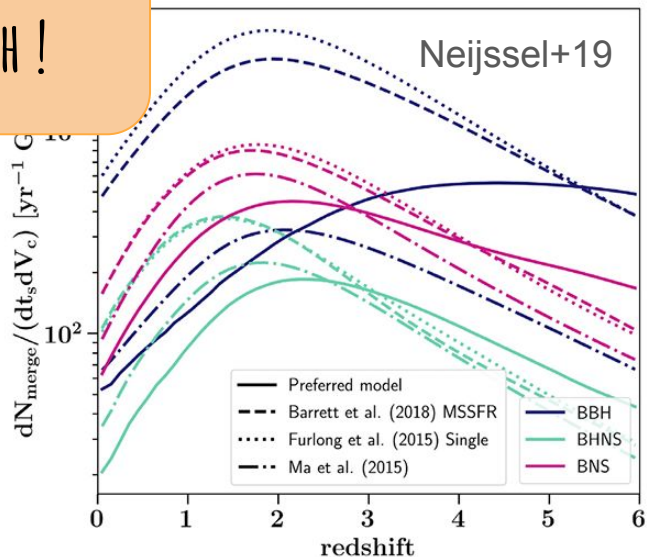
Santoliquido+22



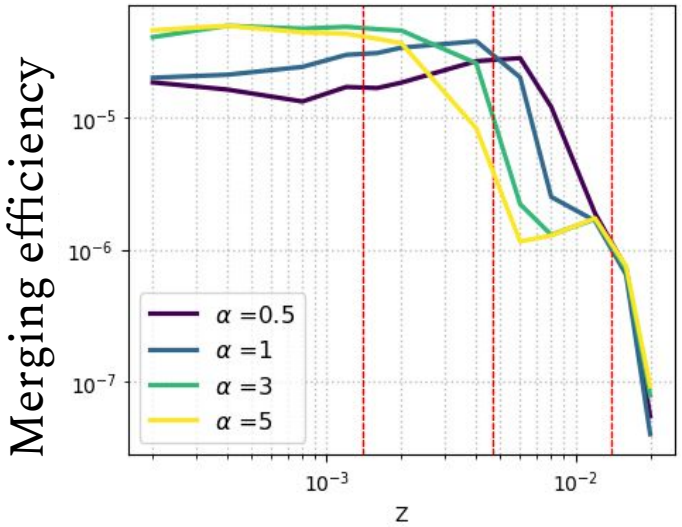


THE PREDICTED BBH MERGER RATES ARE TOO HIGH !





Binary evolution



\+ delay time distribution

Spera+17, Spera+19, Iorio+23

SEvN

\+

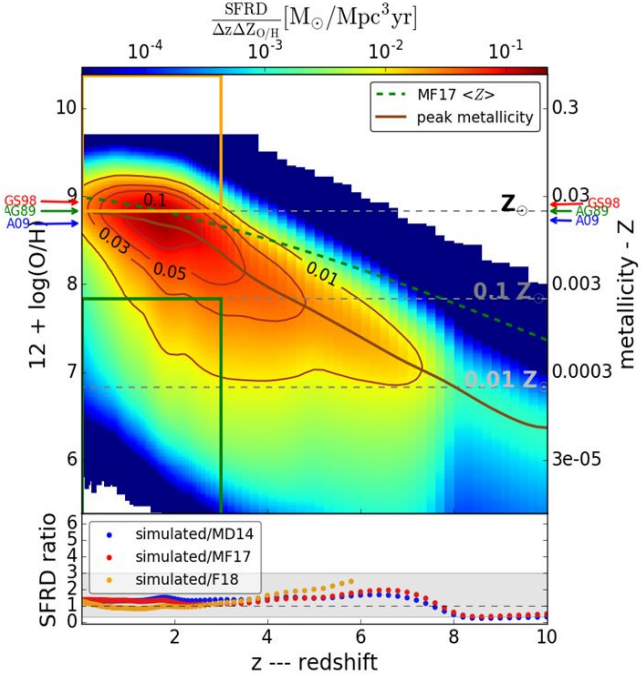
PARSEC

PAdova T**R**ieste **S**tellar **E**volution **C**ode

Costa+25

https://stev.oapd.inaf.it/PARSEC/

Cosmological context



Chruslinska+19

Can we solve the tension by improving the modelling of the metal-dependent star formation rate density?

galaxy Rate Santoliquido+22

https://gitlab.com/Filippo.santoliquido/galaxy_rate_open

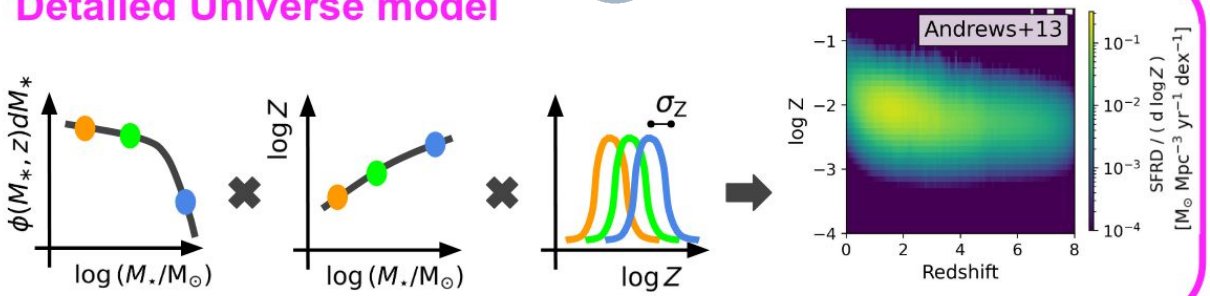
Data-driven **observational scaling relations**

⇩

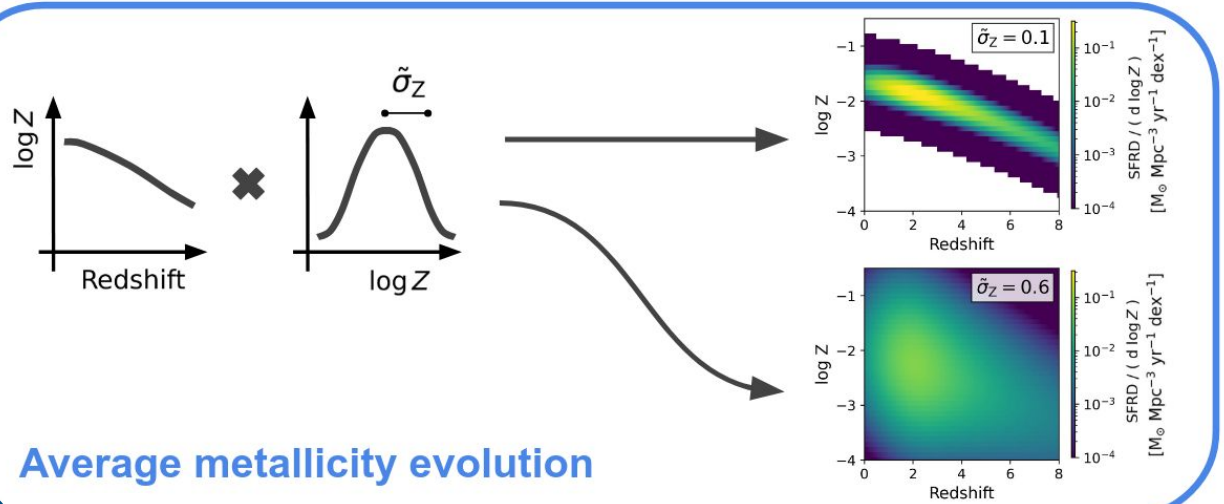
- Galaxy stellar mass function
- Galaxy SFR - mass
- Galaxy mass - Z

- SFR and Z - evolution with redshift (Madau & Fragos 2017)

Detailed Universe model



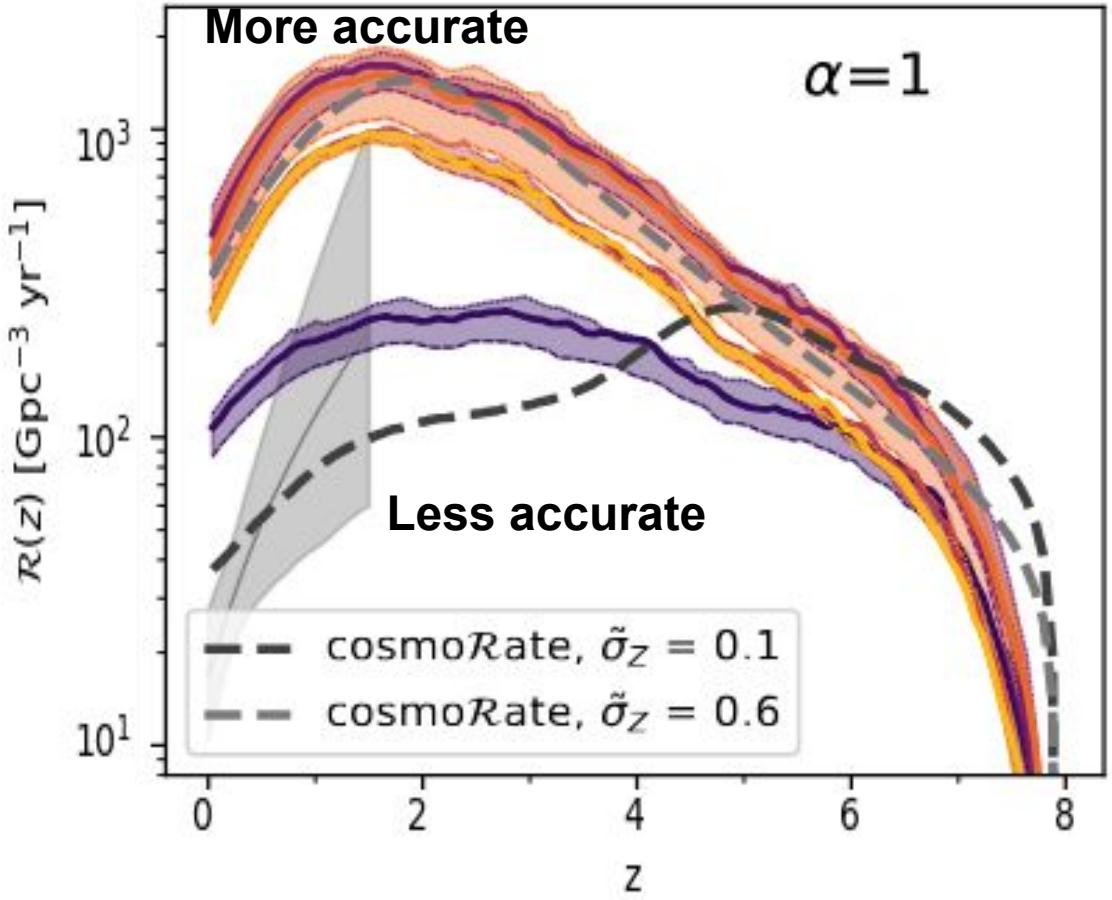
Average metallicity evolution



COSMO RATE Santoliquido+20

https://gitlab.com/Filippo.santoliquido/cosmo_rate_public

Sgalletta+25



galaxy Rate

Santoliquido+22

https://gitlab.com/Filippo.santoliquido/galaxy_rate_open

SFR-mass

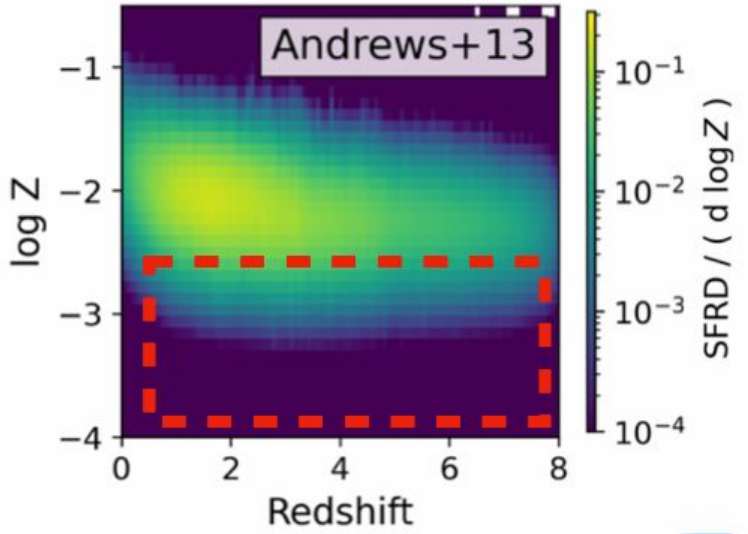
- Boogard+18
- Speagle+14
- **Popesso+23**
- P23+steep
- P23+shallow

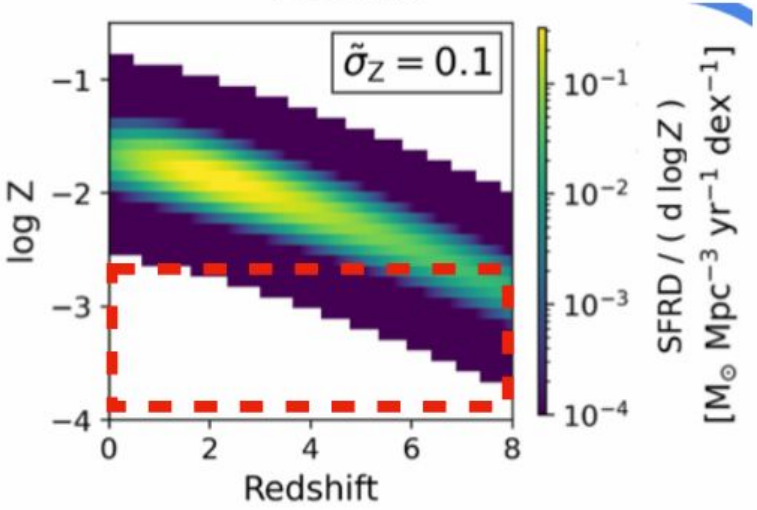
COSMO$\mathcal{R}$ATE

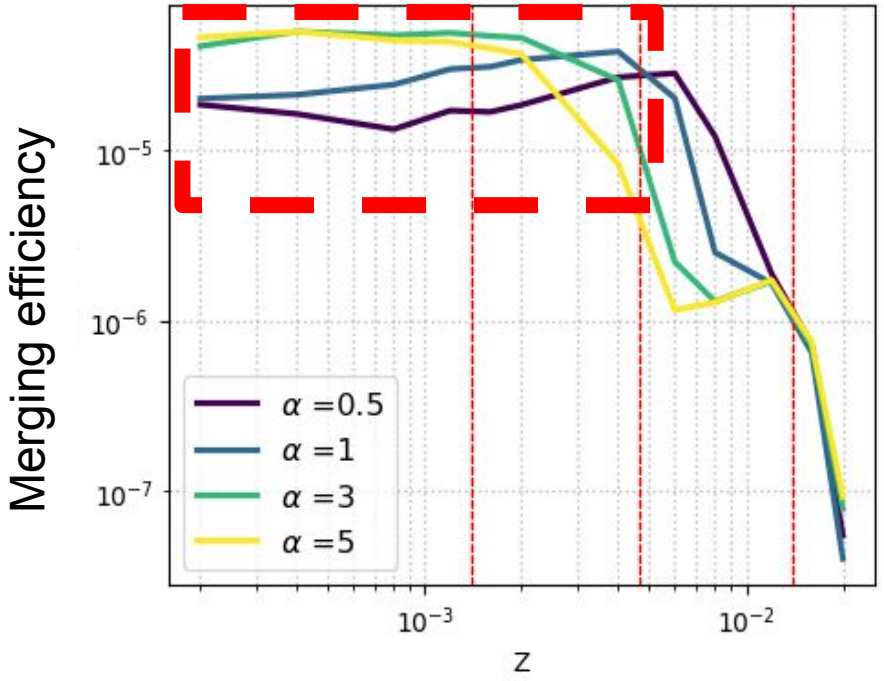
Santoliquido+20

https://gitlab.com/Filippo.santoliquido/cosmo_rate_public

Why?


Andrews+13
log Z
Redshift
SFRD / (d log Z)

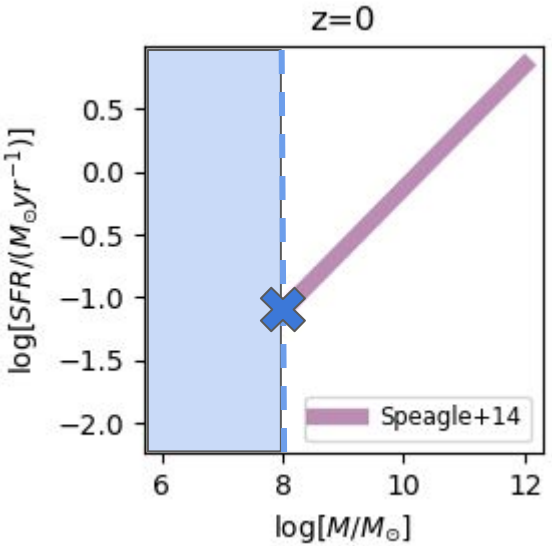

$\tilde{\sigma}_Z = 0.1$
log Z
Redshift
SFRD / (d log Z)
[$M_\odot$ Mpc^{-3} yr^{-1} dex^{-1}]

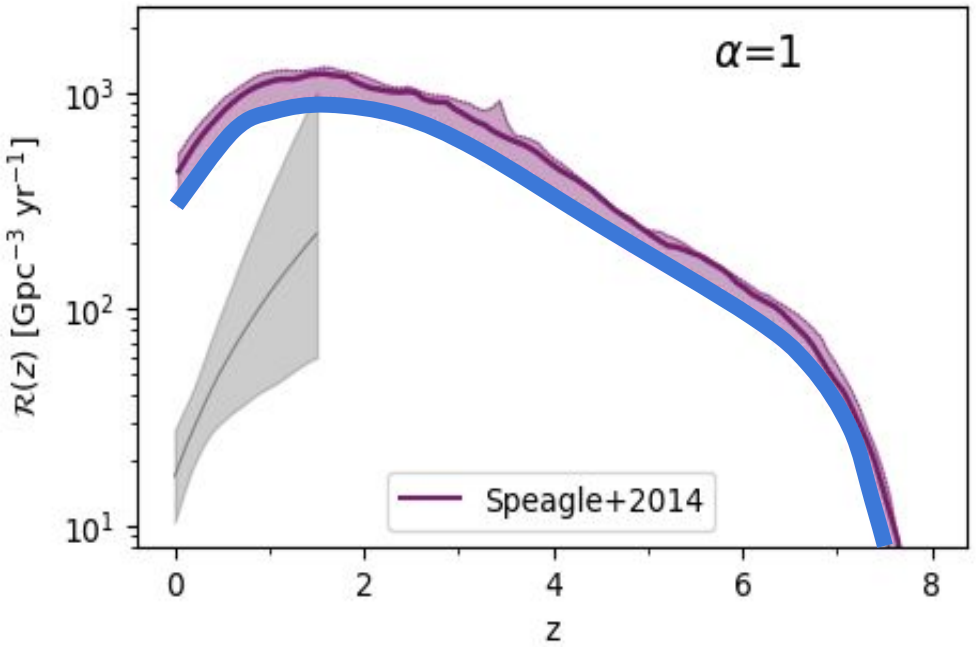

Merging efficiency
Z
α =0.5
α =1
α =3
α =5

What about low-mass galaxies?

Low-mass galaxies are the most metal-poor

Favorable environments for BBHs!





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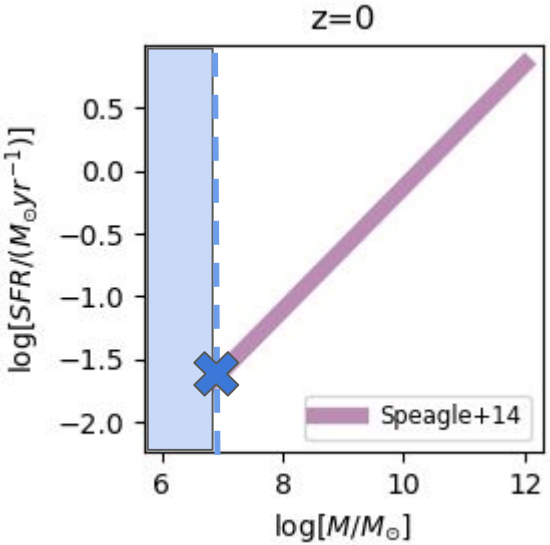

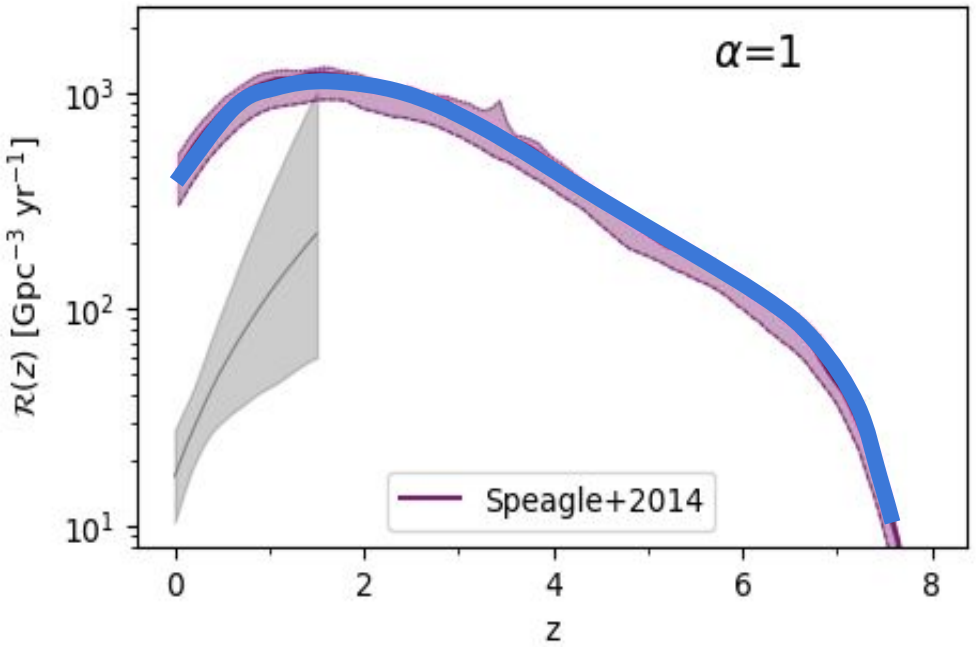

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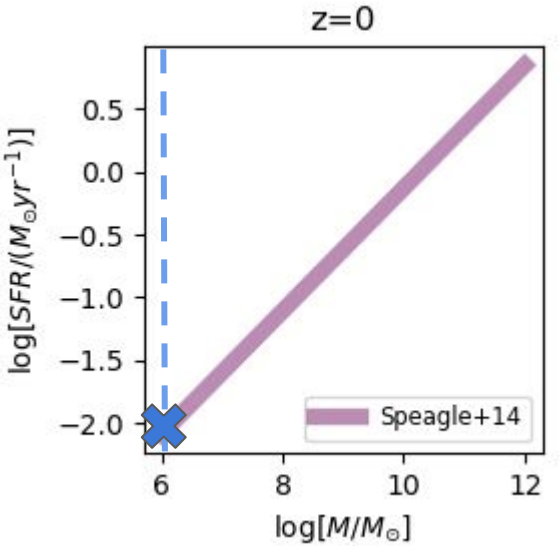
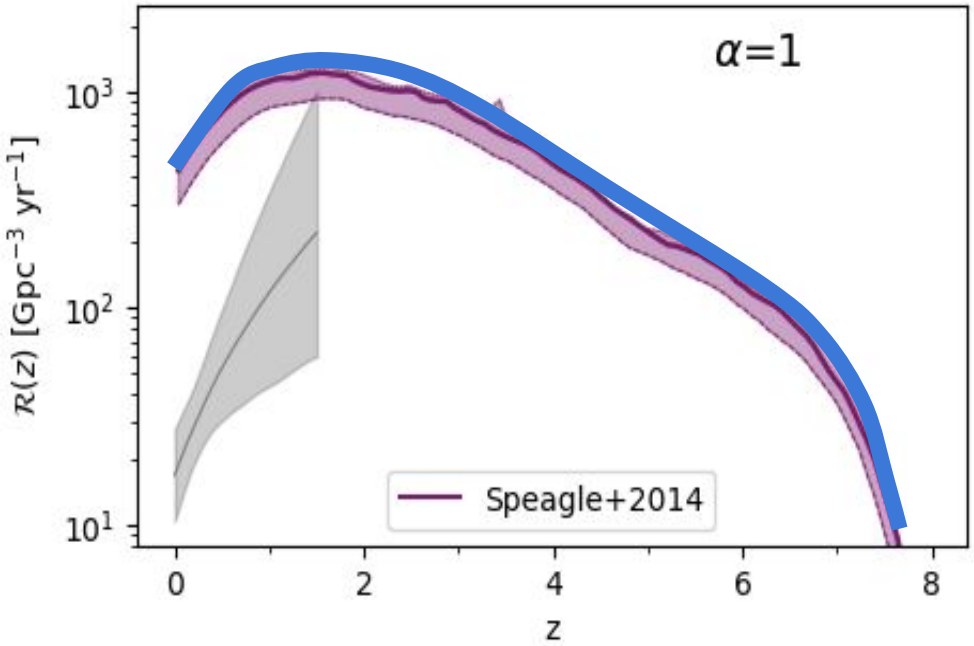




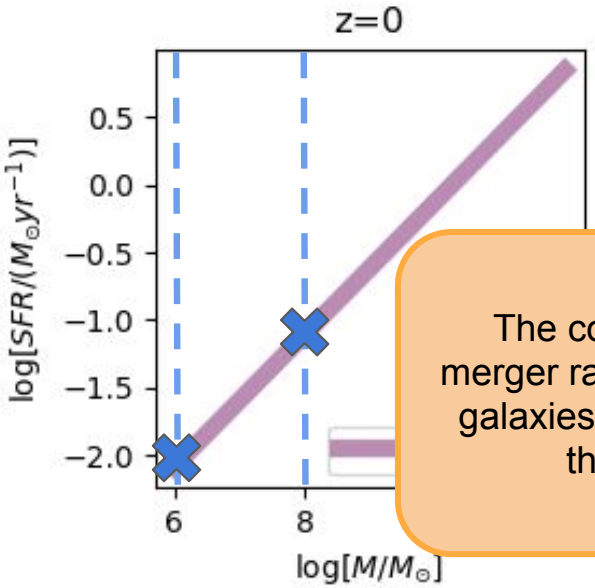
What about low-mass galaxies?

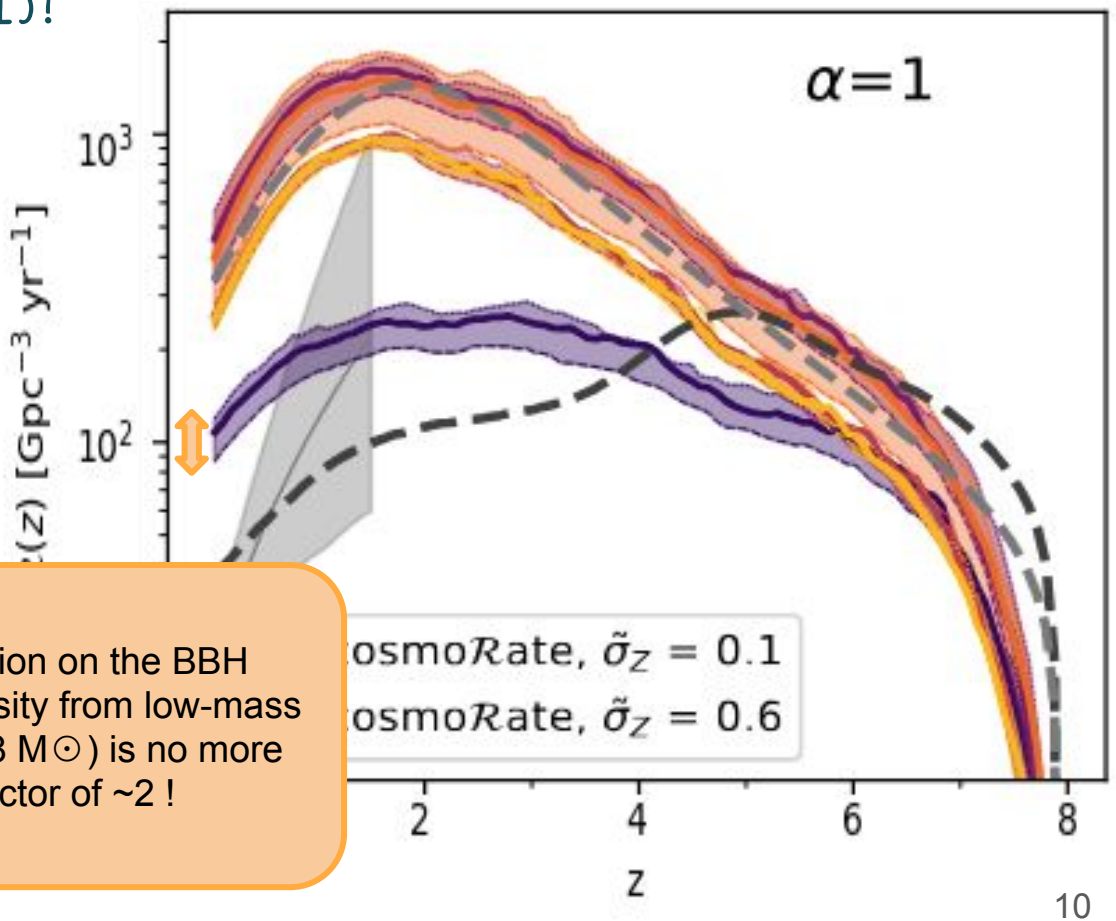
Sgalletta+25

Low-mass galaxies are the most metal-poor

⇩

Favorable environments for BBHs!



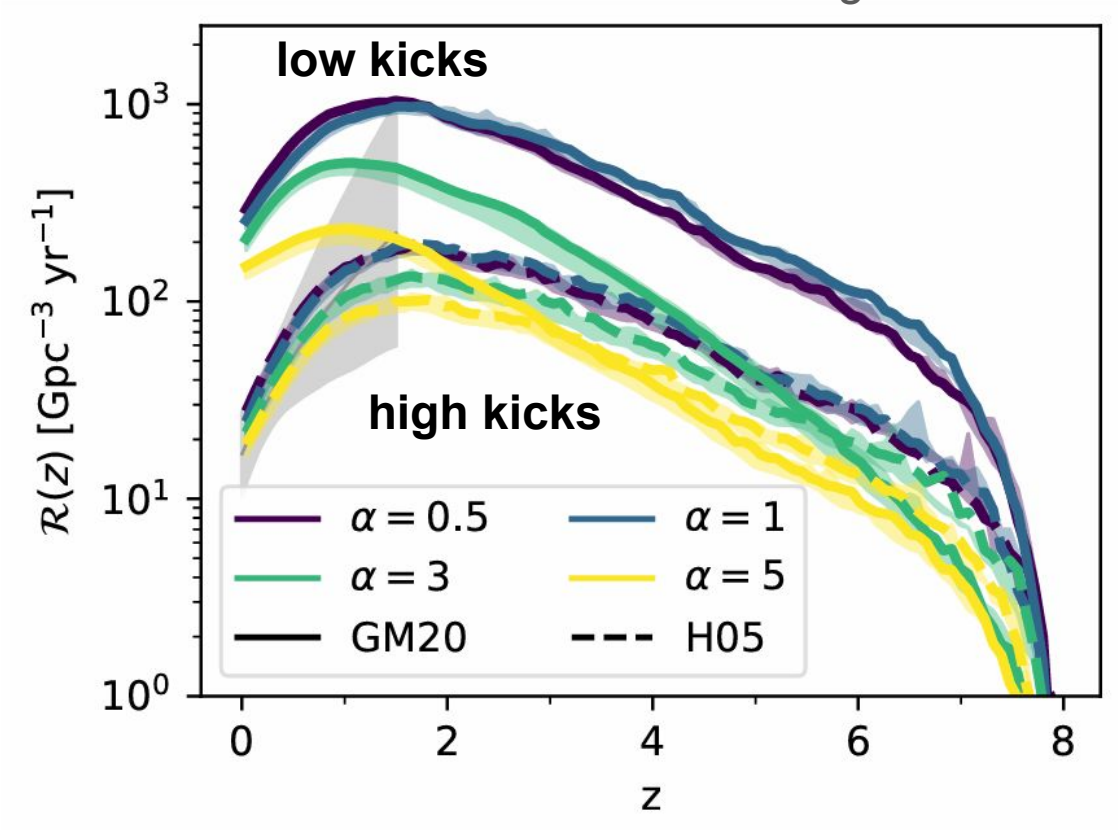


The contribution on the BBH merger rate density from low-mass galaxies (<10^8 M⊙) is no more than a factor of ~2 !

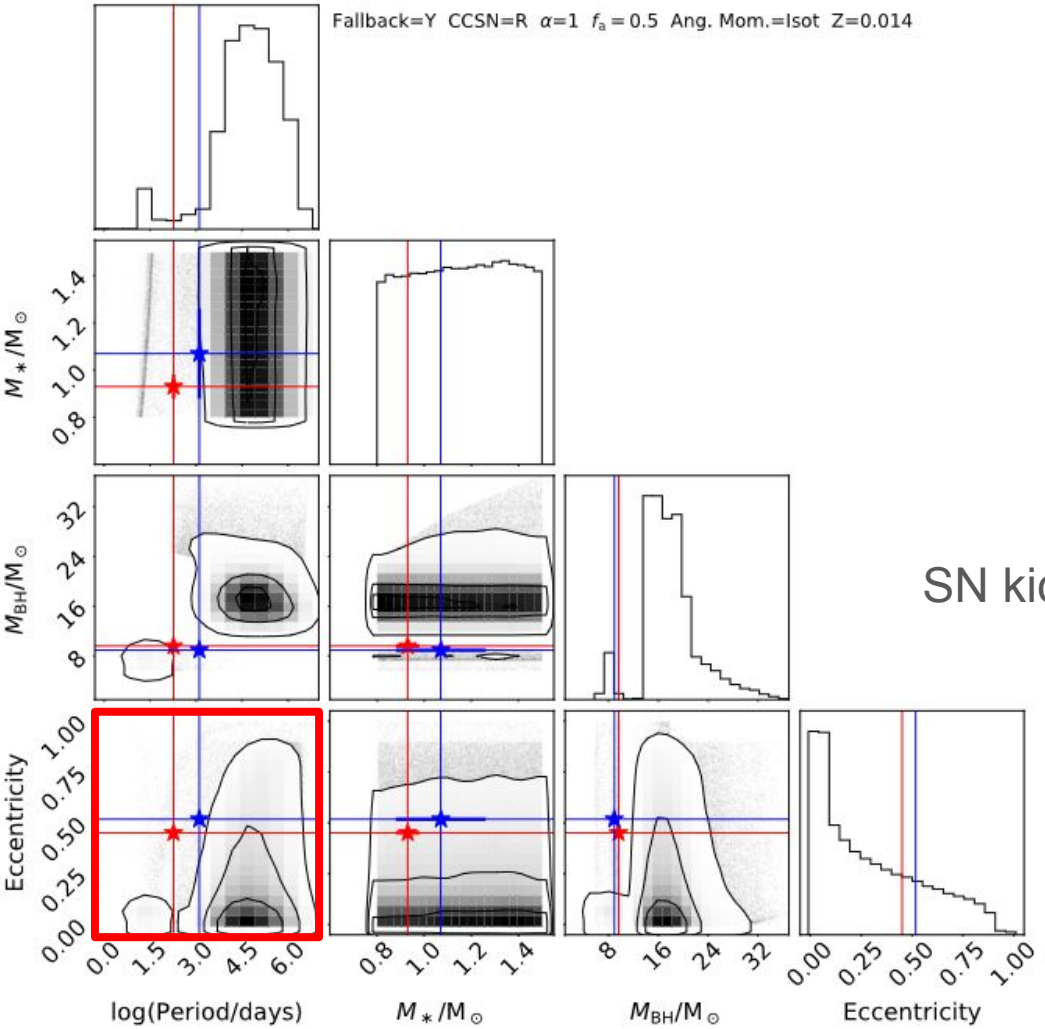
How can we reconcile the theoretical models with the data?

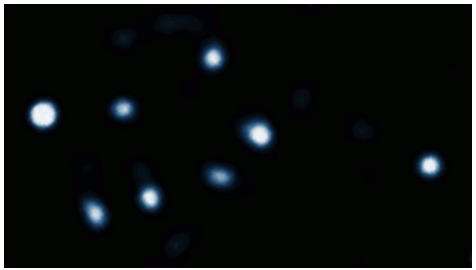
The impact of Supernova kicks

Sgalletta+25



GAIA BHs

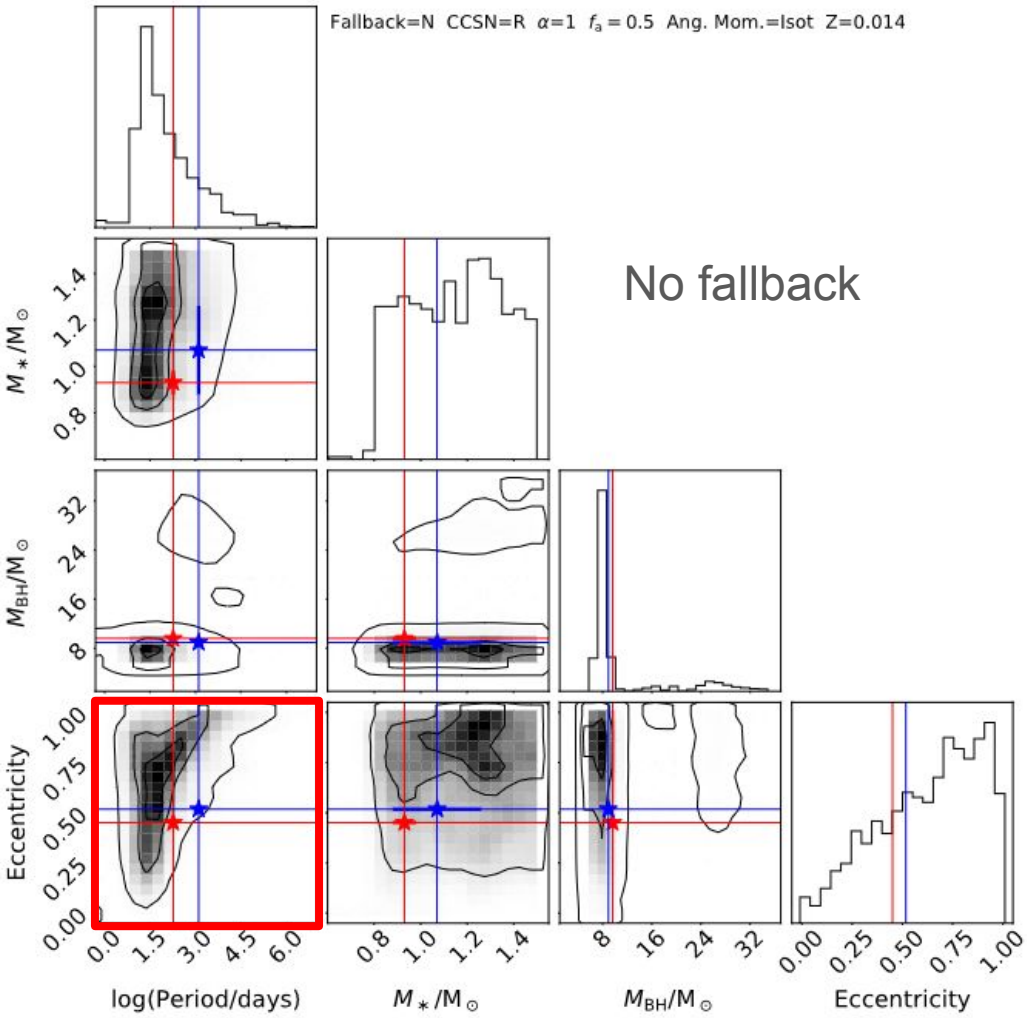


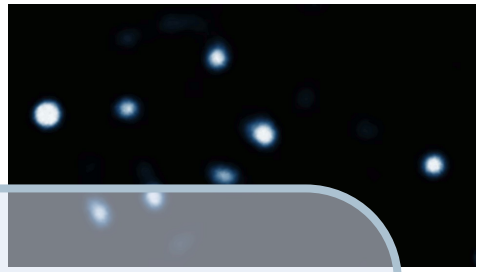


SN kicks + fallback

Mapelli+26

GAIA BHs

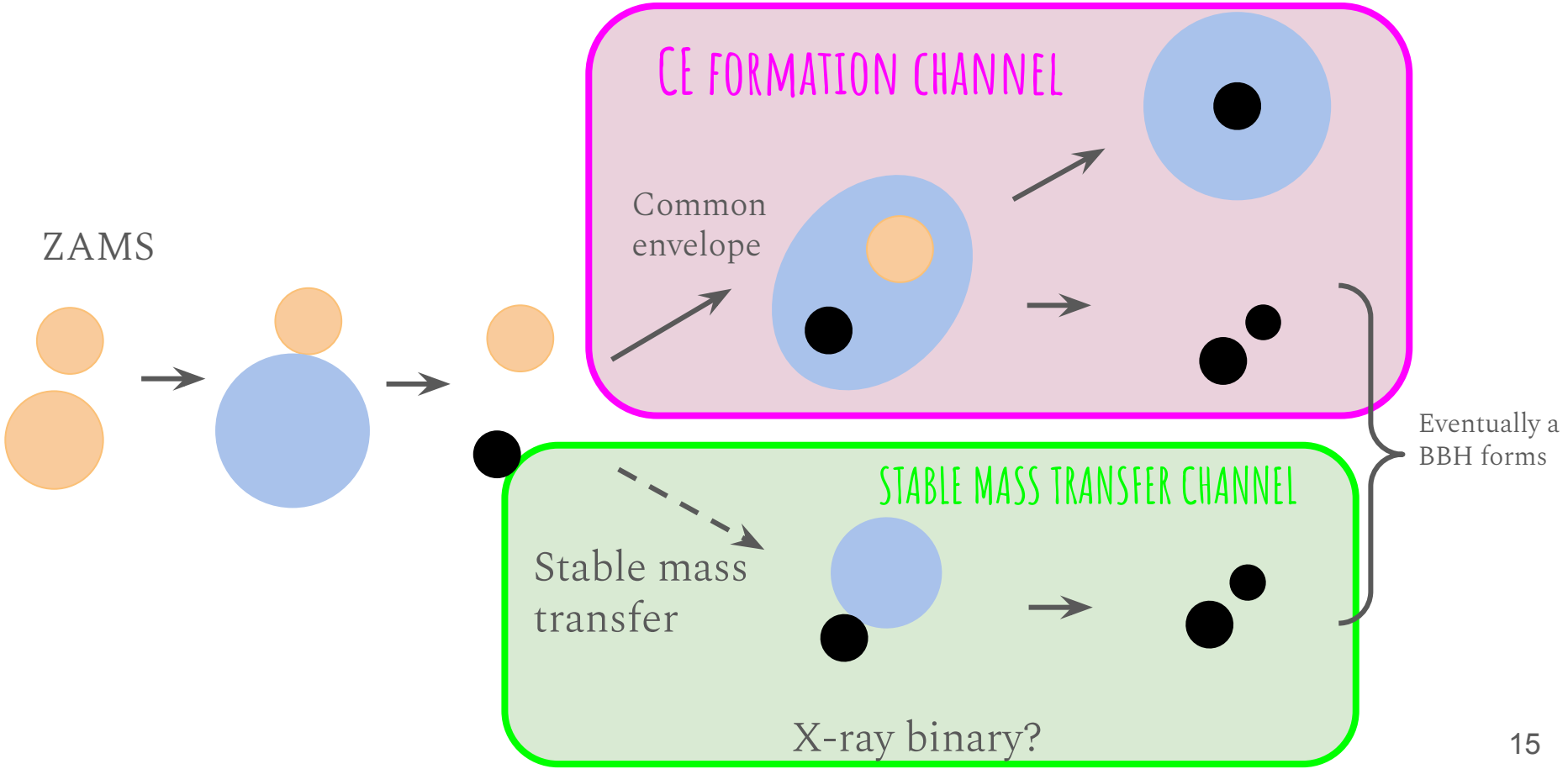




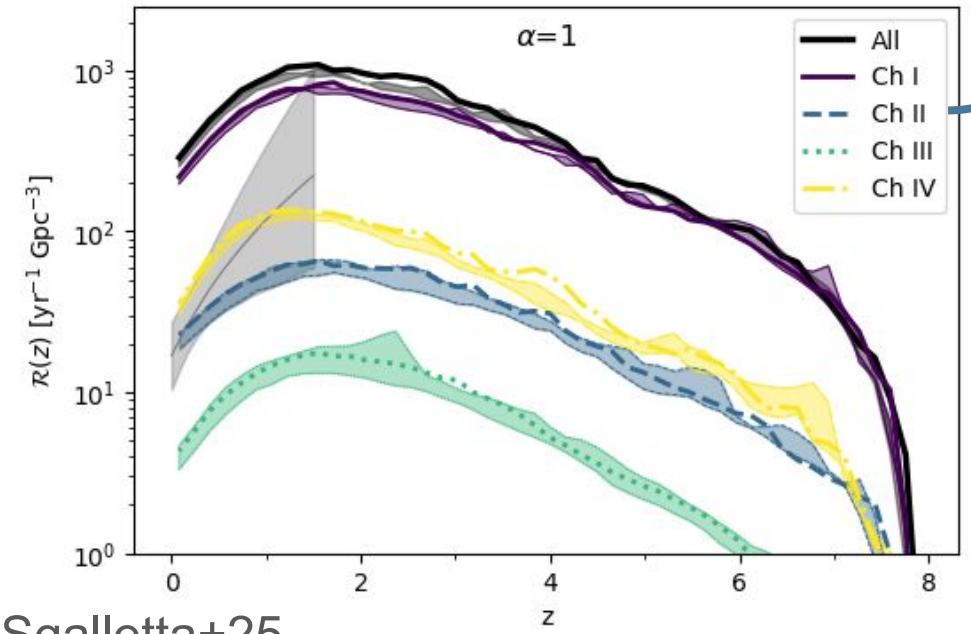
- Large kicks disrupt the long period binaries
- The kick sets the final eccentricity of the system

Gaia DR4 will tell us more!

Mapelli+26


ZAMS
CE FORMATION CHANNEL
Common envelope
STABLE MASS TRANSFER CHANNEL
Stable mass transfer
X-ray binary?
Eventually a BBH forms

Stable vs common envelope channels



Sgalletta+25

Ch II → only stable mass transfer

State-of-the-art binary population synthesis codes tend to predict too high BBH merger rates

Improving the modelling of the metal-dependent SFR does not reduce the BBH merger rates!

How to reconcile with the data ?

Binary evolution uncertainties (common envelope, stable mass transfer, supernovae …) likely are the source of the tension

- **SN kicks should be higher?**
- **too many systems survive CE?**

Backup

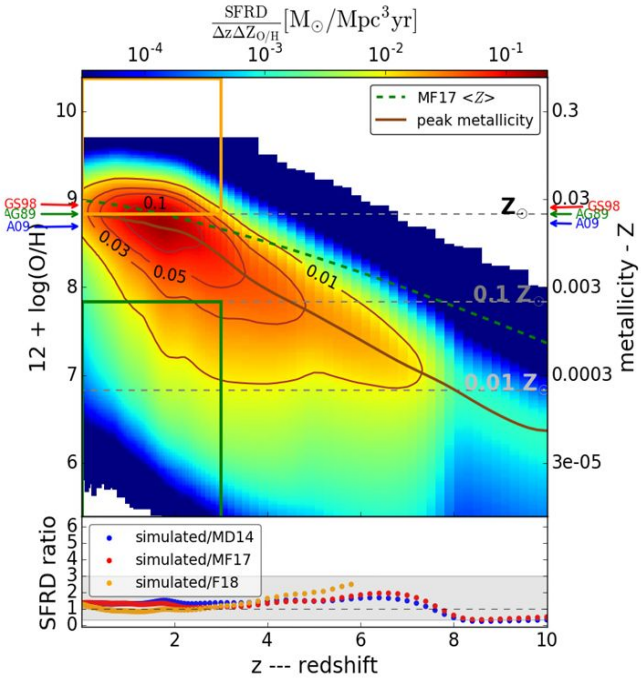
Cosmological context

Major issues:

1. Star-forming metallicities are poorly constrained at z>3
2. Low-mass galaxy properties are more difficult to observe and poorly constrained
3. Metallicity calibration issues

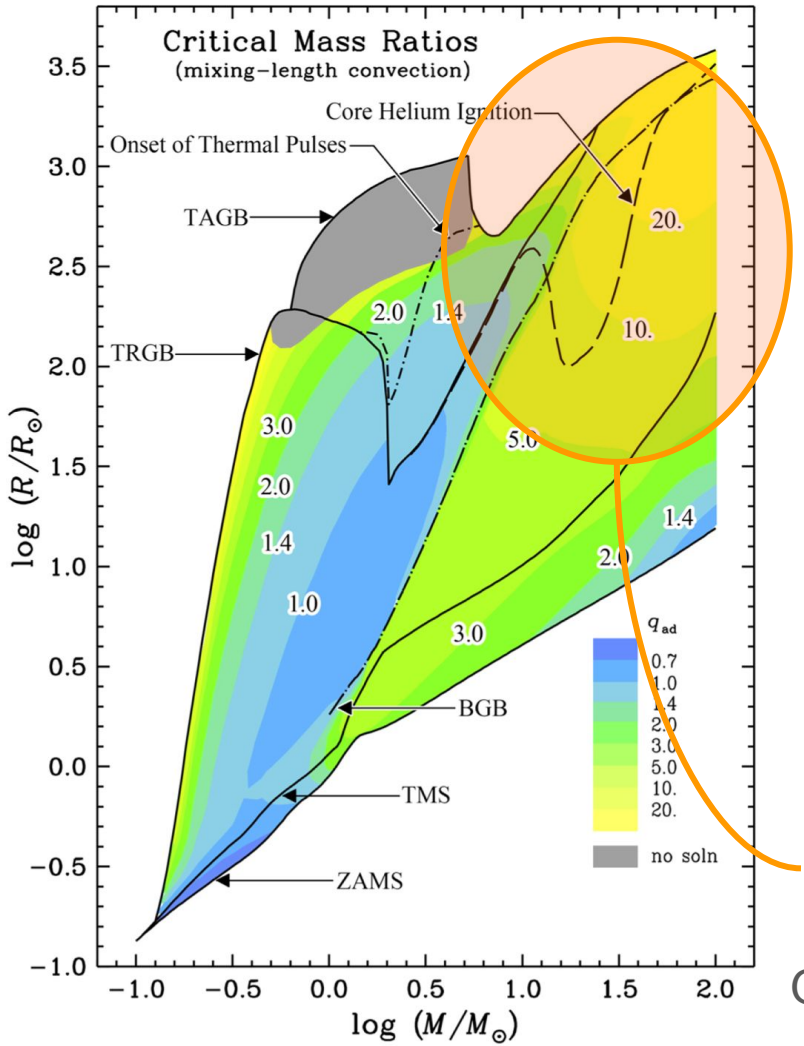
1. Low - mass galaxies impact
2. SFR - Galaxy mass relations

3. Fundamental metallicity relations



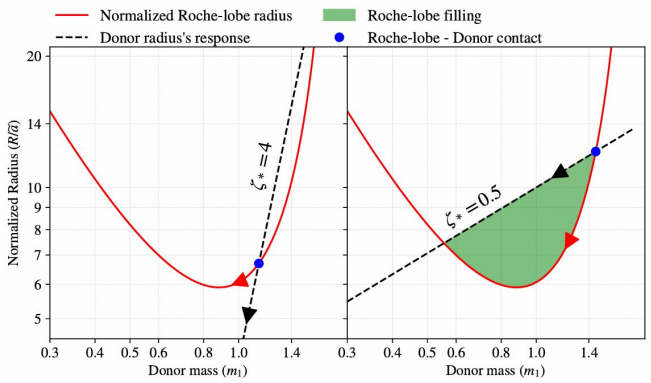
Chruslinska+19

Stability of mass transfer



Pop synth use simplified formalism based on critical mass ratios
q=Md/Ma

Typical critical values:
q=1 – 5



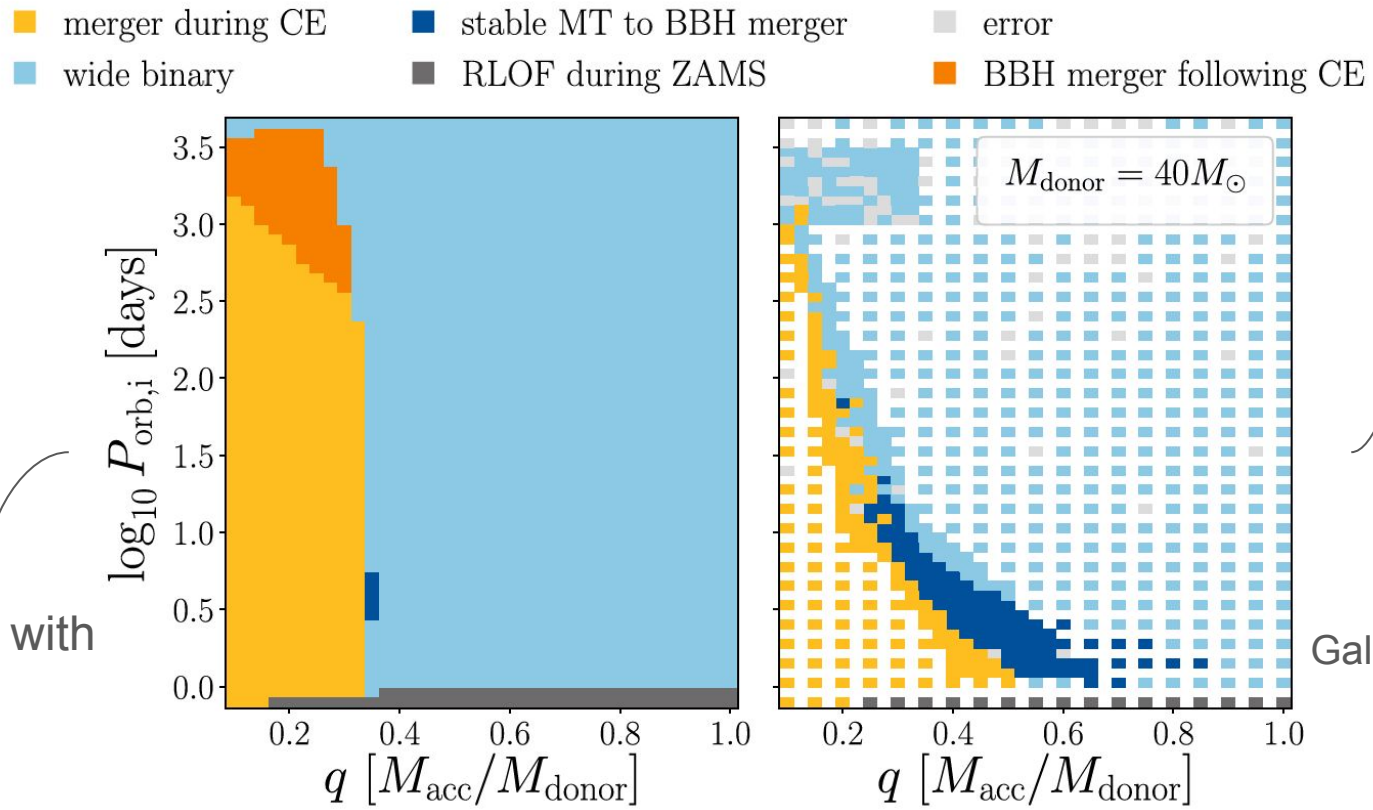
Spera+23

→ Massive donors might be responsible for **stable mass transfer episodes**

Ge+20

Stability of mass transfer

Detailed stellar evolution with MESA



Evolution with COSMIC

Gallegos-Garcia+21