Merger rate of black hole binaries from globular clusters:
theoretical error bars and comparison to GWTC-2

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Fabio Antonini
Cardiff/LIGO

11th Iberian GW meeting
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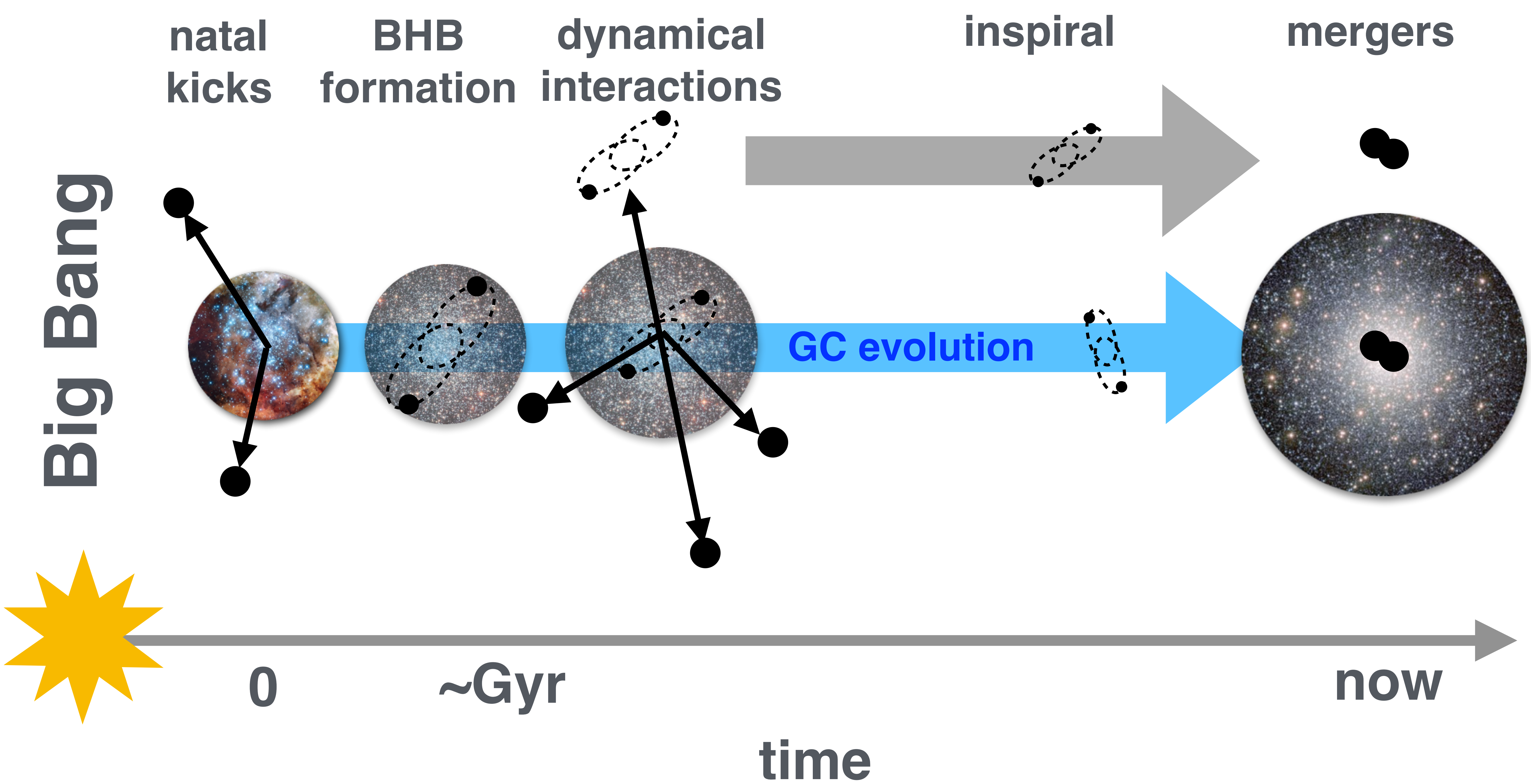
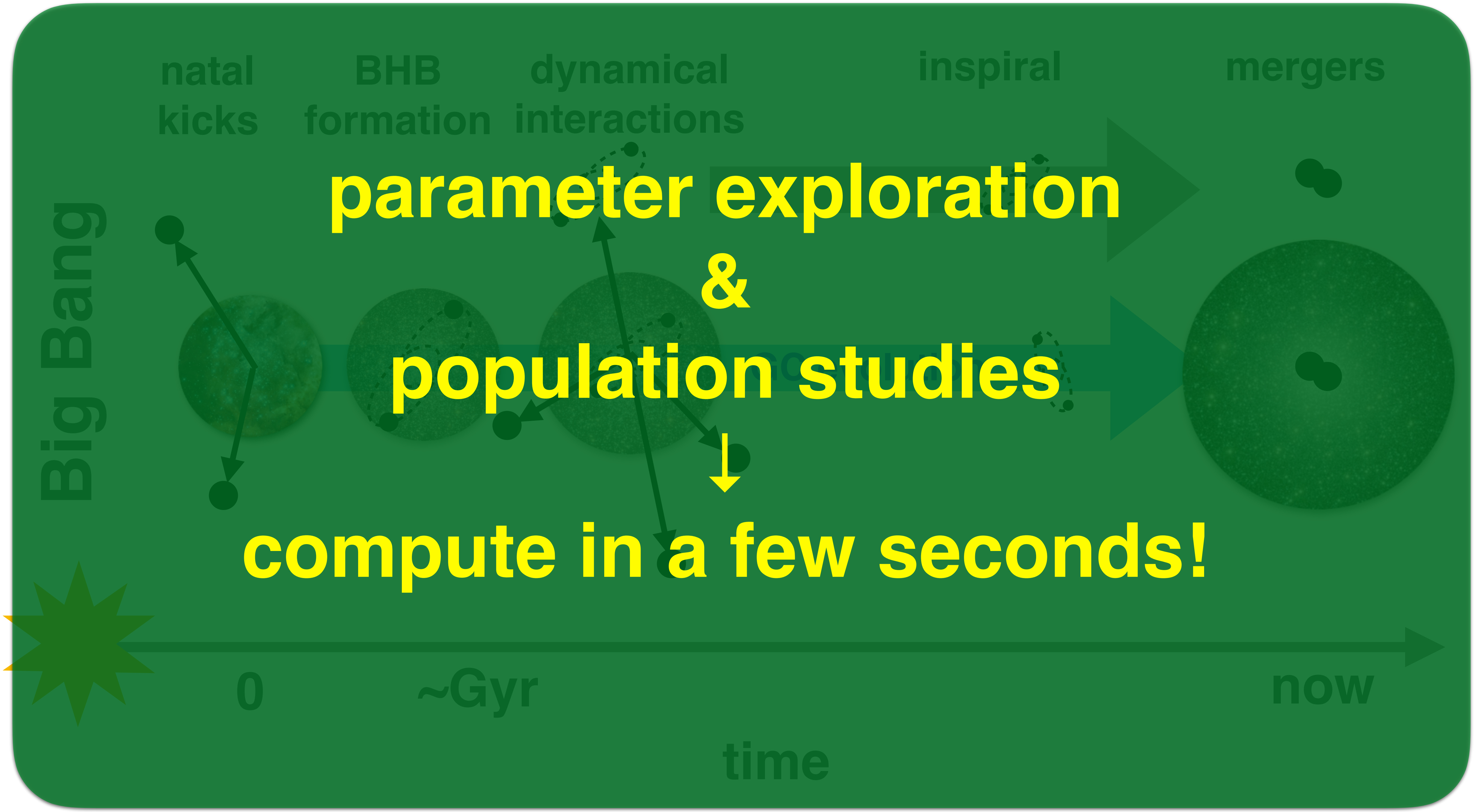
The dynamical formation of BHB mergers



The dynamical formation of BHB mergers



parameter exploration

&

population studies

↓

compute in a few seconds!

	initial conditions	**cluster evolution**	**BHB dynamics**
star-by-star models Portegies & Zwart & McMillan 2000; Rodriguez+ 2015, 2016, 2018; Hong+ 2018; Banerjee 2020	cluster mass cluster radius distribution function	solve equation of motion of N~10^6 stars	solve equation of motion BHB & perturbers, incl. pN

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cBHBd Antonini & Gieles 2020a	cluster mass cluster radius	$\dot{E}_{\rm cluster} \propto \frac{E_{\rm cluster}}{\tau_{\rm relax}}$ Hénon 1961	$\dot{E}_{\rm BHB} = -\dot{E}_{\rm cluster}$ + Peters' equations

computational effort: months-years

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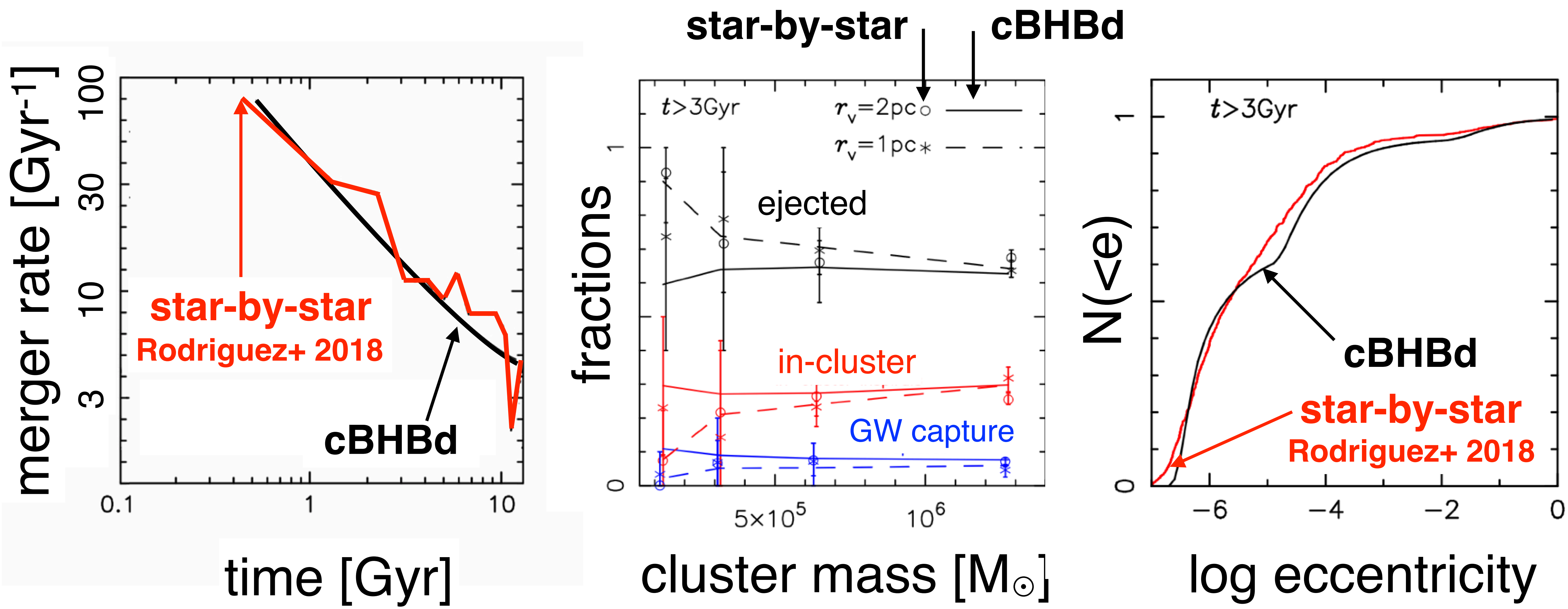
cBHBd Antonini & Gieles 2020a	cluster mass cluster radius	Hénon 1961	$-\dot{E}_{\rm cluster}$

computational effort: months-years

computational effort: seconds

independent of cluster mass and density

Orders of magnitude faster, acceptable loss of accuracy



population synthesis

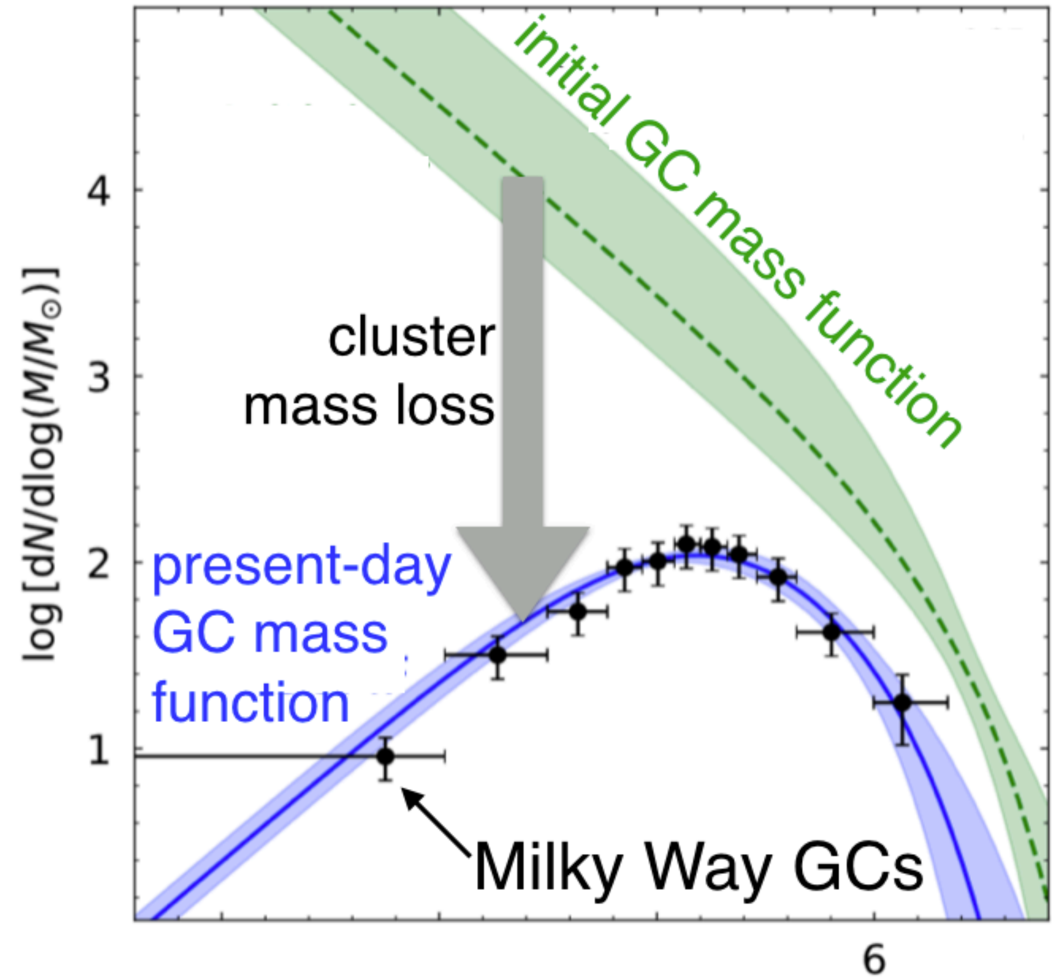
1. present-day GC density in Universe
$\rho_{\rm GC} \propto \rho_{\rm DM}$ Harris+ 2013, 2015, 2017
$= (7.3 \pm 2.6) \times 10^{14}\, M_\odot\, {\rm Gpc}^{-3}$

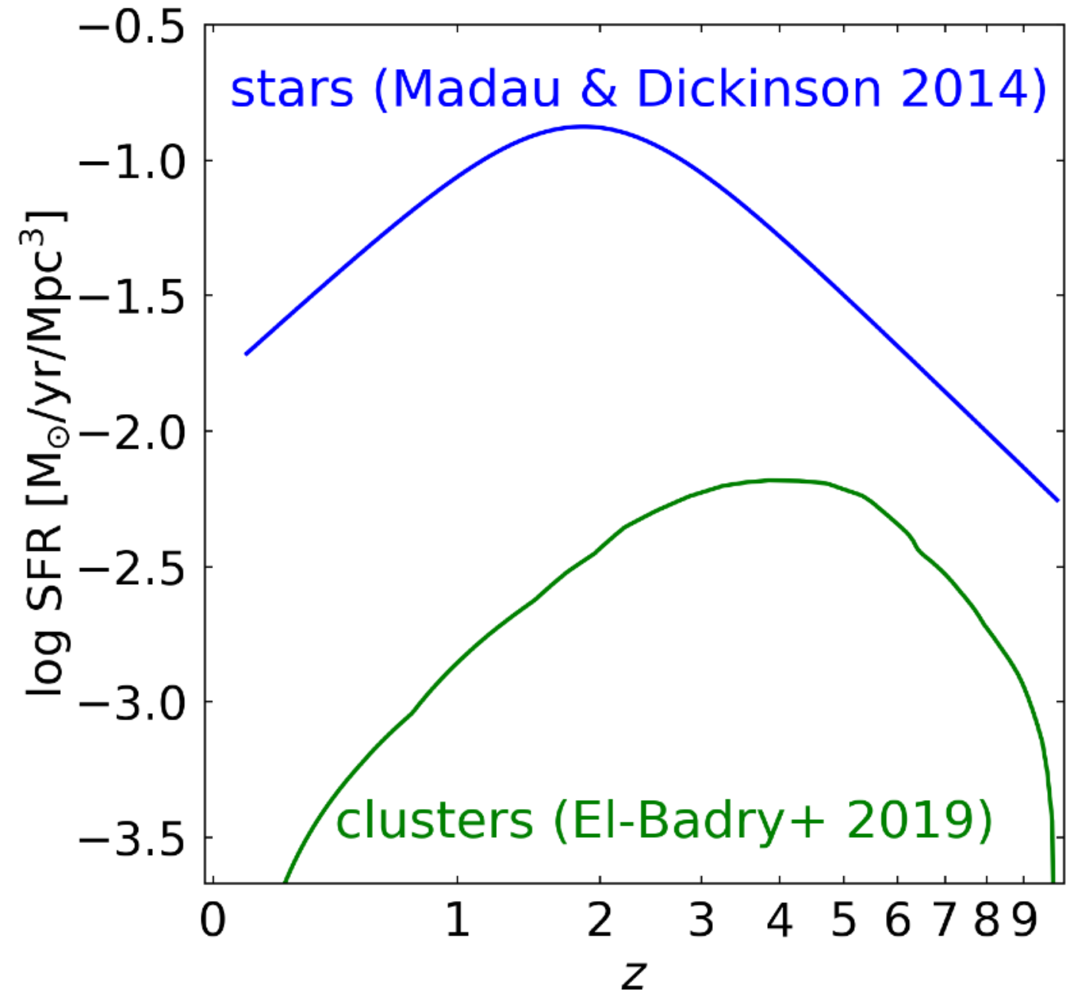
2. account for cluster mass loss
$\rho_{\rm GC,0} \simeq 33 \rho_{\rm GC}$

3. initial density individual clusters
$\rho_0 = 10^{4\pm1}\, M_\odot\, {\rm pc}^{-3}$

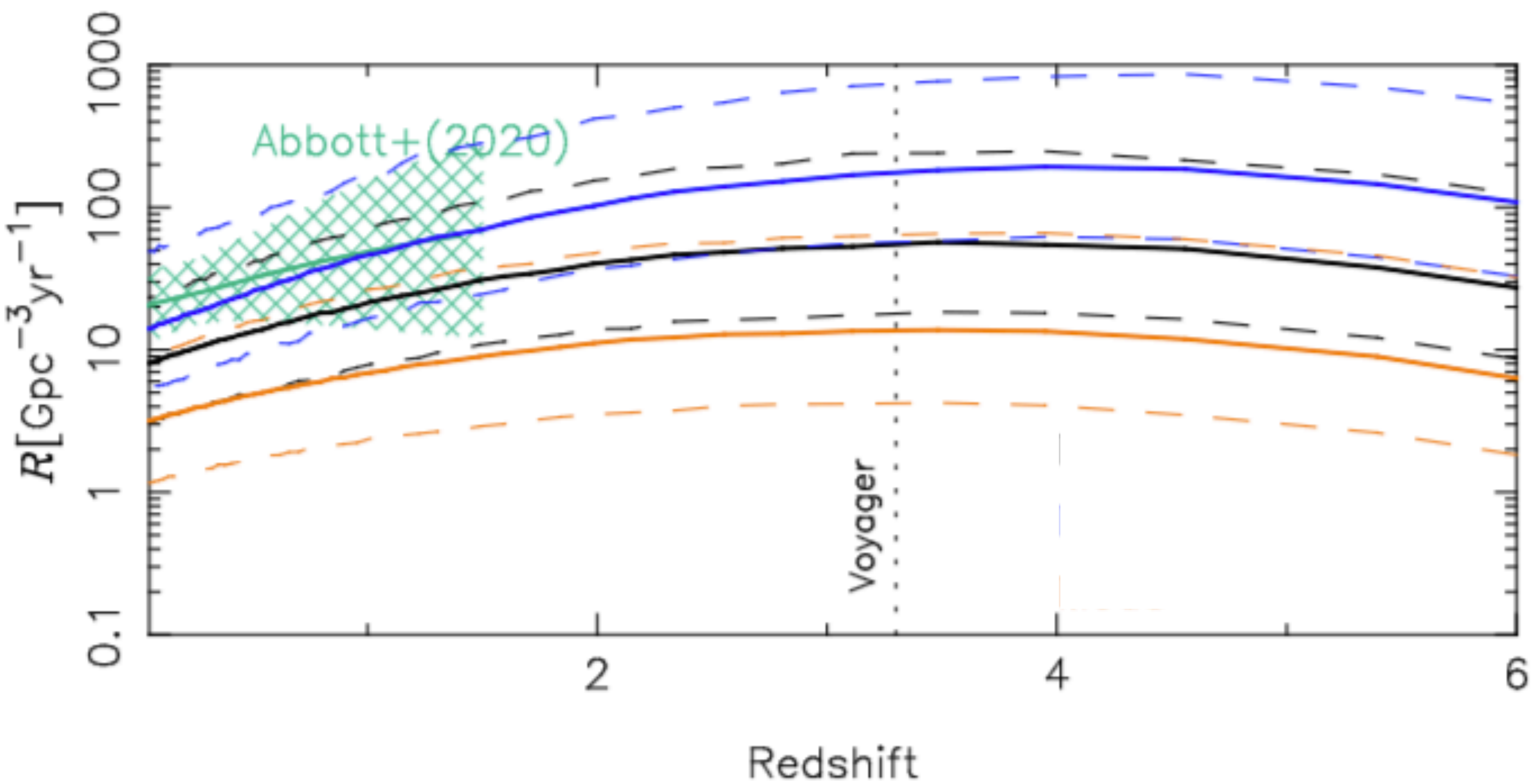
4. cluster formation history
El-Badry+ 2019

5. evolve!
Monte Carlo
(20 million clusters)





merger rates: compare to GWTC-2



cluster density:

$10^5\,M_\odot\,\mathrm{pc}^{-3}$

$10^4\,M_\odot\,\mathrm{pc}^{-3}$

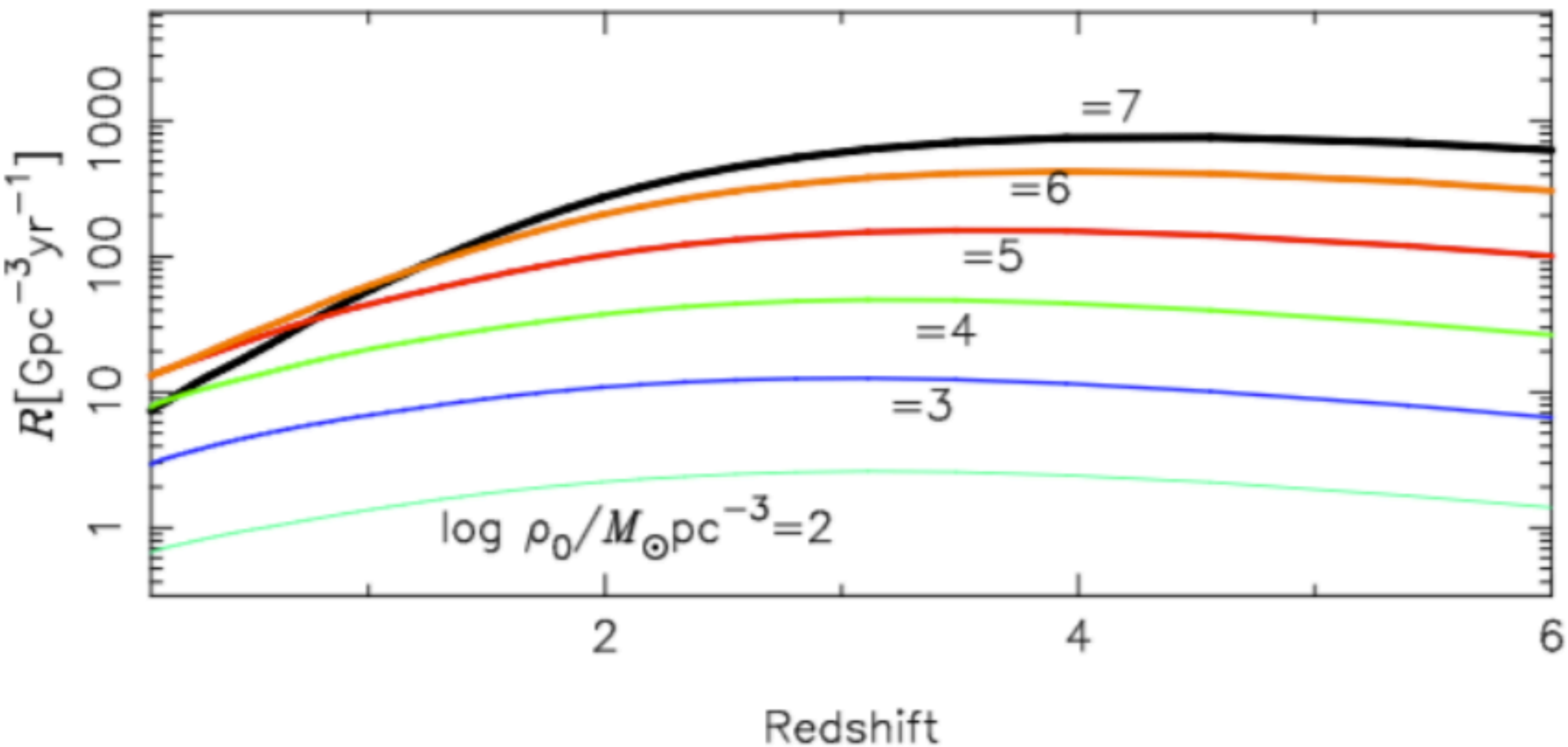
$10^3\,M_\odot\,\mathrm{pc}^{-3}$

$$\mathcal{R}_0 = 7.2^{+21.5}_{-5.5}\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$$

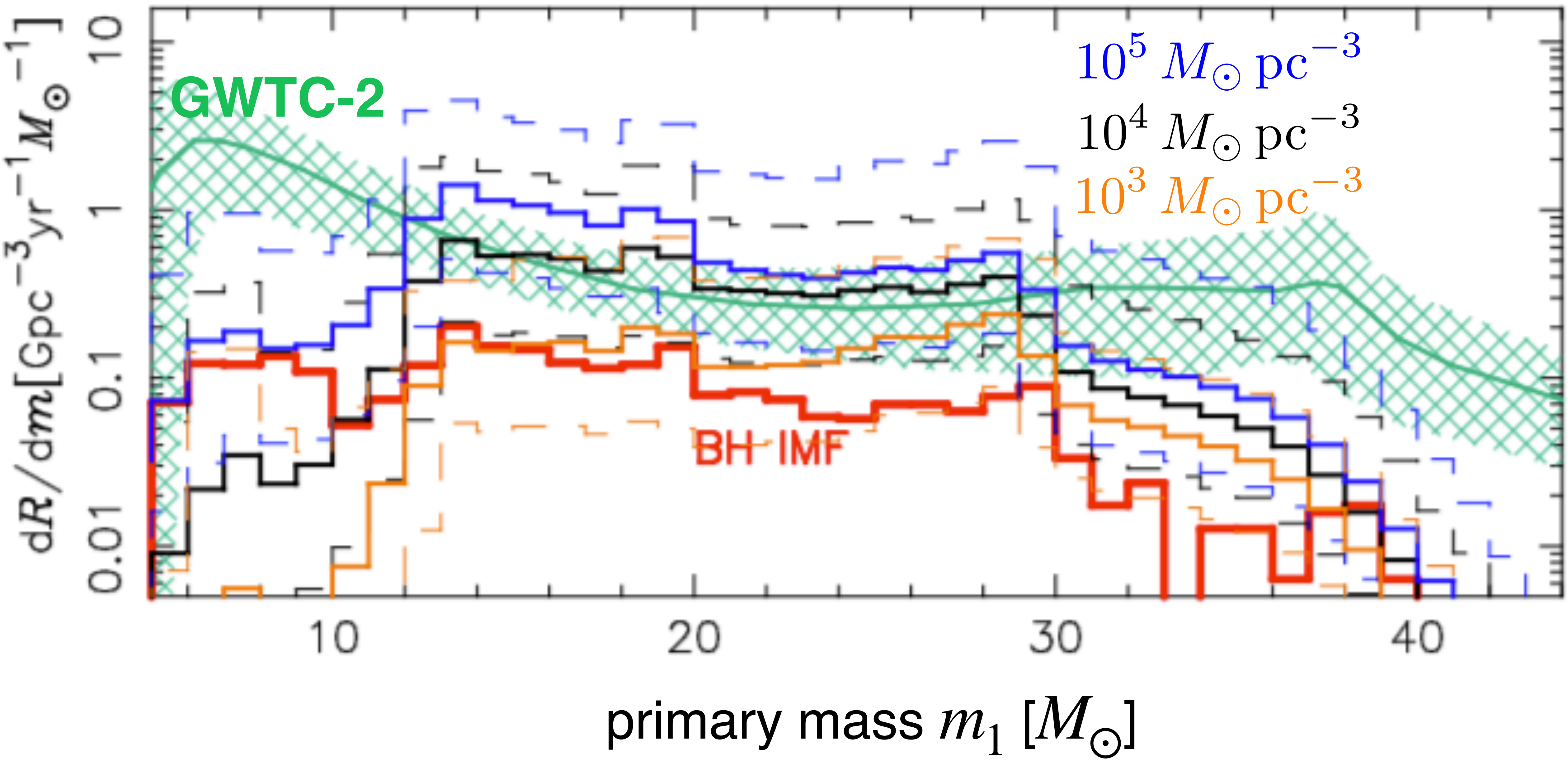
LIGO-Virgo: $19.1^{+16.2}_{-9.0}\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$

Antonini & Gieles 2020b

maximum $\mathcal{R}_0(\rho_0)$



mass function

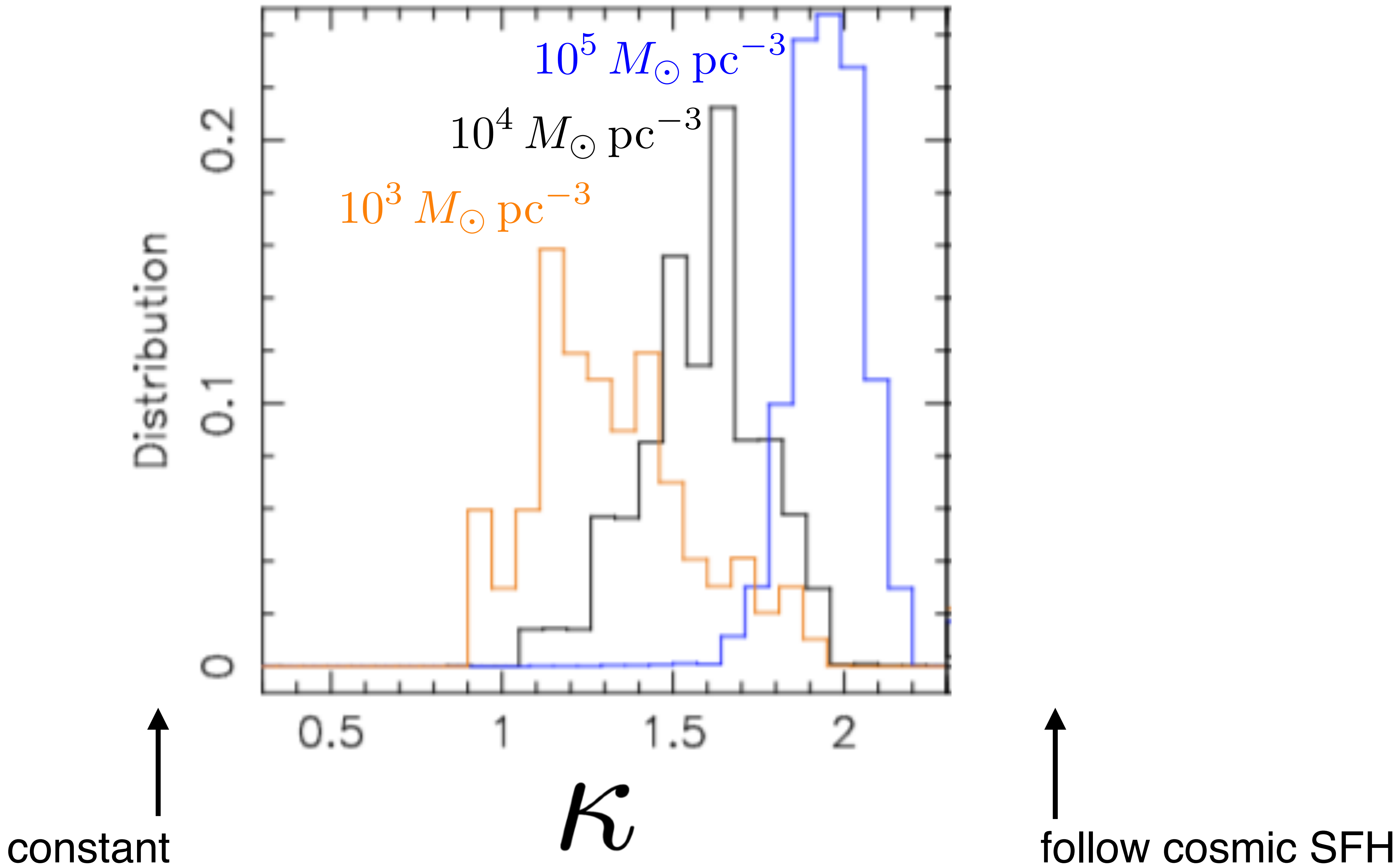


$\rho_0 = 10^5\ M_\odot\,\mathrm{pc}^{-3}$ reproduces the total rate

$\rho_0 = 10^4\ M_\odot\,\mathrm{pc}^{-3}$ reproduces the ***mass-dependent*** rates between 13-30 $M_\odot$

redshift dependence

$$\mathcal{R} = \mathcal{R}_0(1+z)^{\kappa}$$



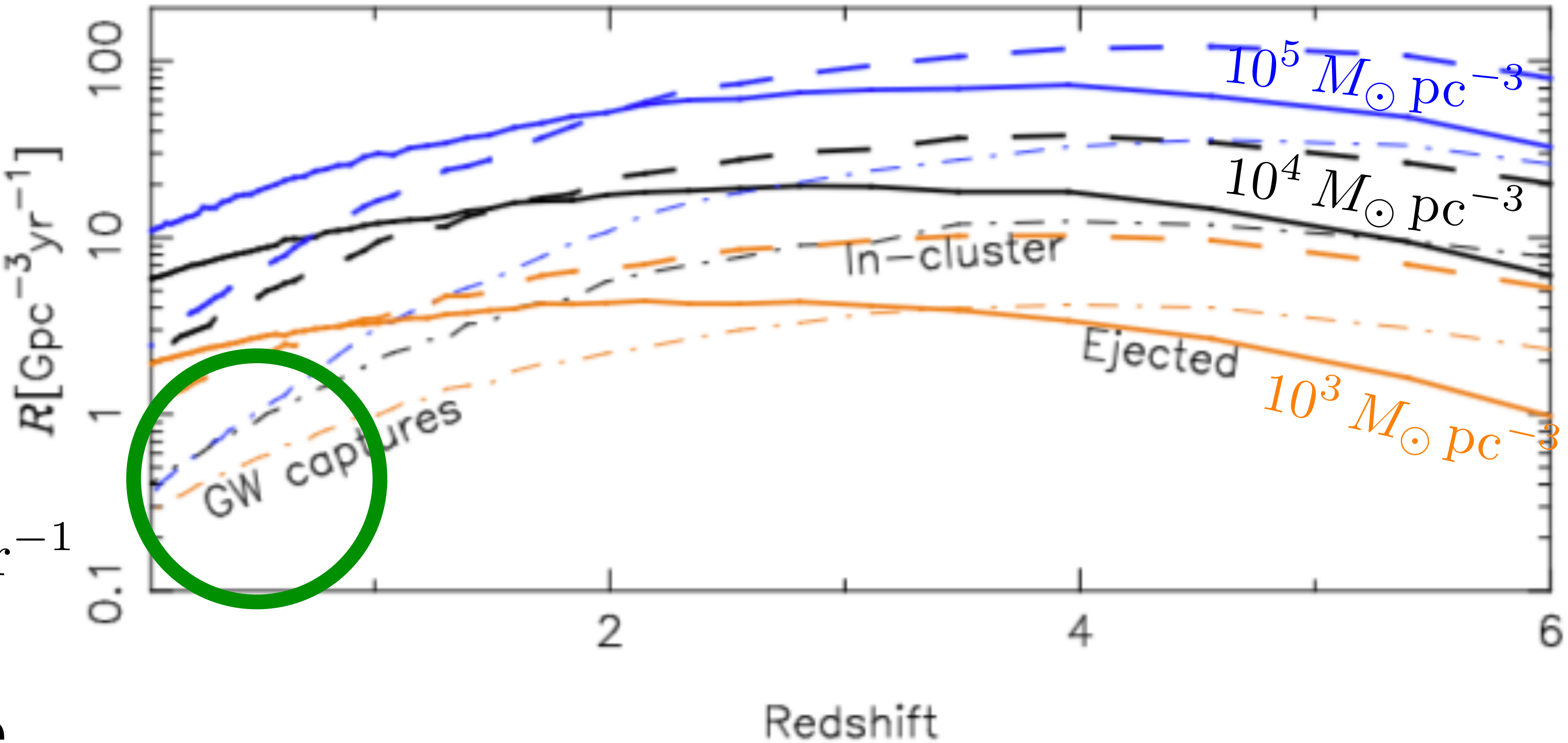
Madau & Dickinson 2014

in-cluster / ejected / GW captures

After O1+2:

$\mathcal{R}(e > 0.1) < 100\ \mathrm{Gpc^{-3} yr^{-1}}$

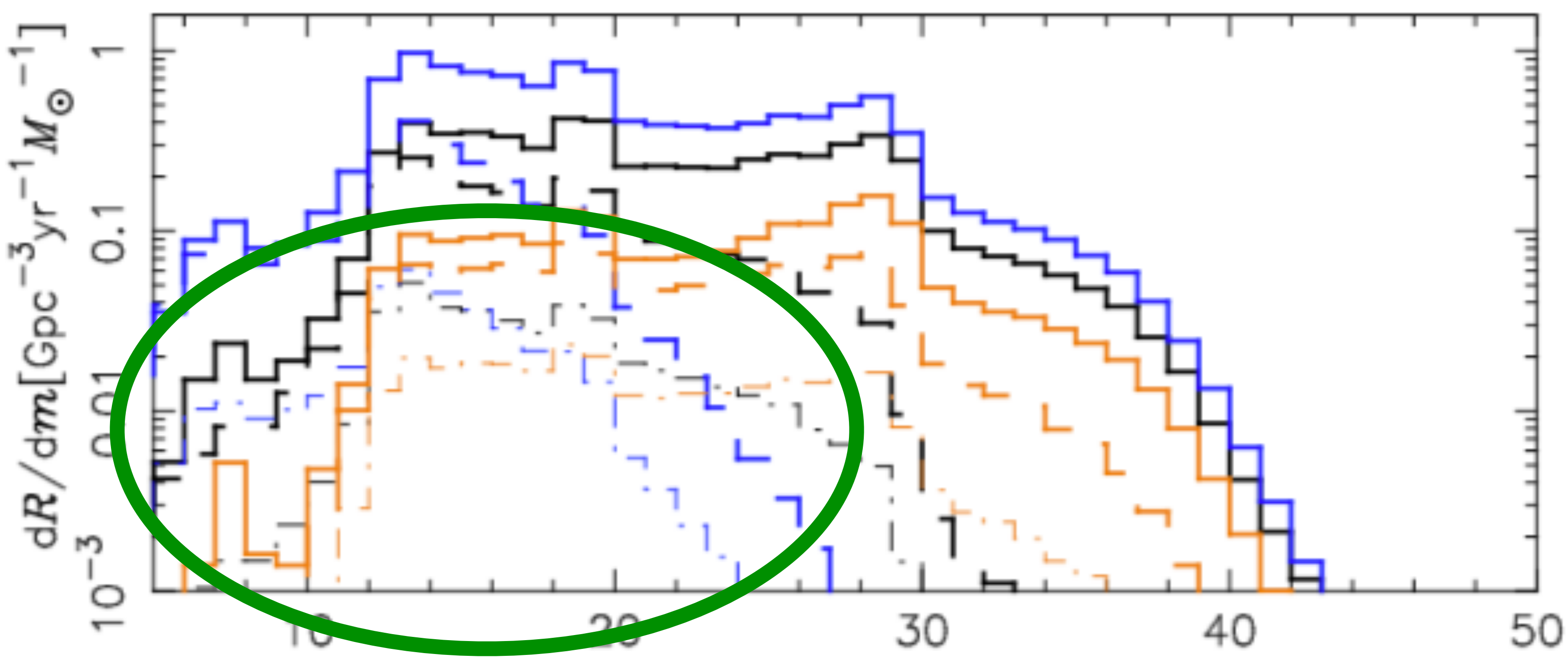
Abbott+ 2019, ApJ, 883, 149
Romero-Shaw+ 2019



$\mathcal{R}(e > 0.1) \simeq 0.4\, \mathrm{Gpc^{-3}\, yr^{-1}}$

1. insensitive to ρ_0
2. steep z dependence

3. low mass



primary mass $[M_\odot]$

eccentric mergers

model predictions

Globular clusters:

$$\mathcal{R}(e > 0.1) \simeq 0.4\,\mathrm{Gpc}^{-3}\,\mathrm{yr}^{-1}$$

Antonini & Gieles 2021b

Young massive clusters:

$$\mathcal{R}(e > 0.1) \simeq 5\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$$

Banerjee 2021

observations

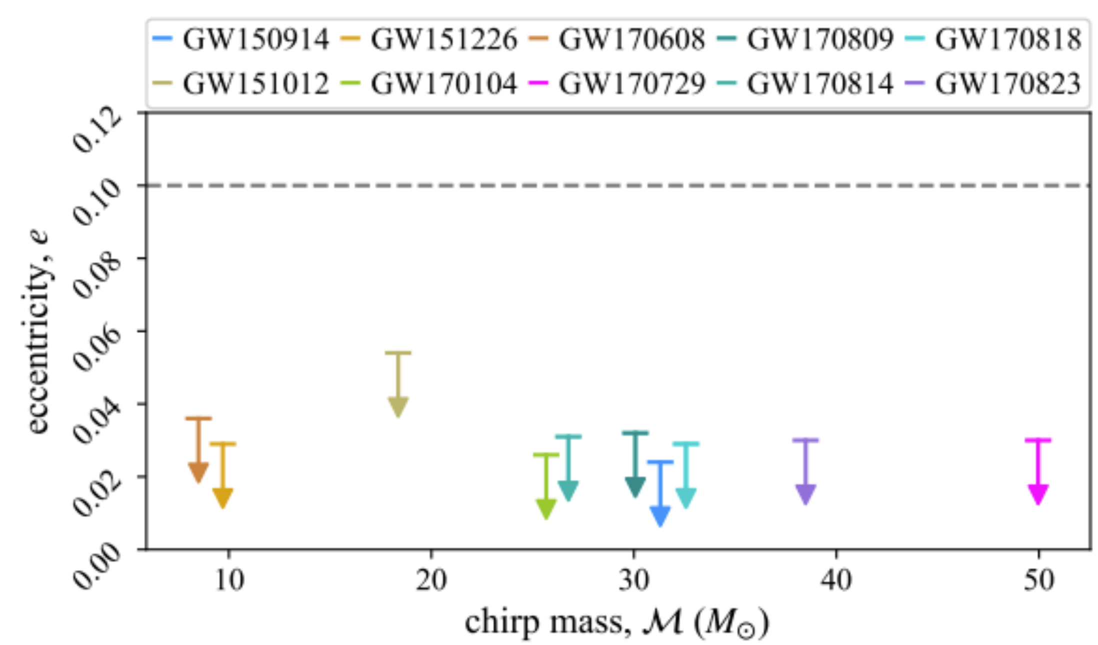
After O1+O2:

$$\mathcal{R}(e > 0.1) < 100\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$$

Abbott+ 2019

GW190521?

Abbott+ 2020; Gayathri+ 2020; Calderón Bustillo+ 2021



Romero-Shaw+ 2019

Conclusions

1. Scenario in which most mergers have a dynamical origin is consistent with the data, ***if*** $\rho_{\rm GC}(0) \gtrsim 10^4\, M_\odot/{\rm pc}^3$
2. Uncertainty of model rates most ***sensitive*** to: uncertainties in initial GC mass function & densities and ***insensitive*** to: natal kicks, [Fe/H], BH mass function
3. Our models underpredict rates $m_1 \lesssim 12\ M_\odot$ and $m_1 \gtrsim 30\, M_\odot$

Predictions

1. Rate of eccentric mergers from ***old*** GCs: $R(e > 0.1) \lesssim 0.4\ {\rm Gpc}^{-3}\,{\rm yr}^{-1}$
2. Correlations between rate, redshift dependence and eccentricity distribution

Ongoing/future work

1. Contrain model predictions with observations of Milky Way GCs
2. Mass ratios!
3. Lower mass, young star clusters (Daniel Pina, PhD student)
4. Contribute to development eccentric waveforms and searches (O4) (Tomas Andrade, with Valencia)