BH-BH merger rates as probes of the massive star formation

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Dan Holz

Warsaw

1: moving to Radboud, Nijmegen

stable transfer

(hopefully)

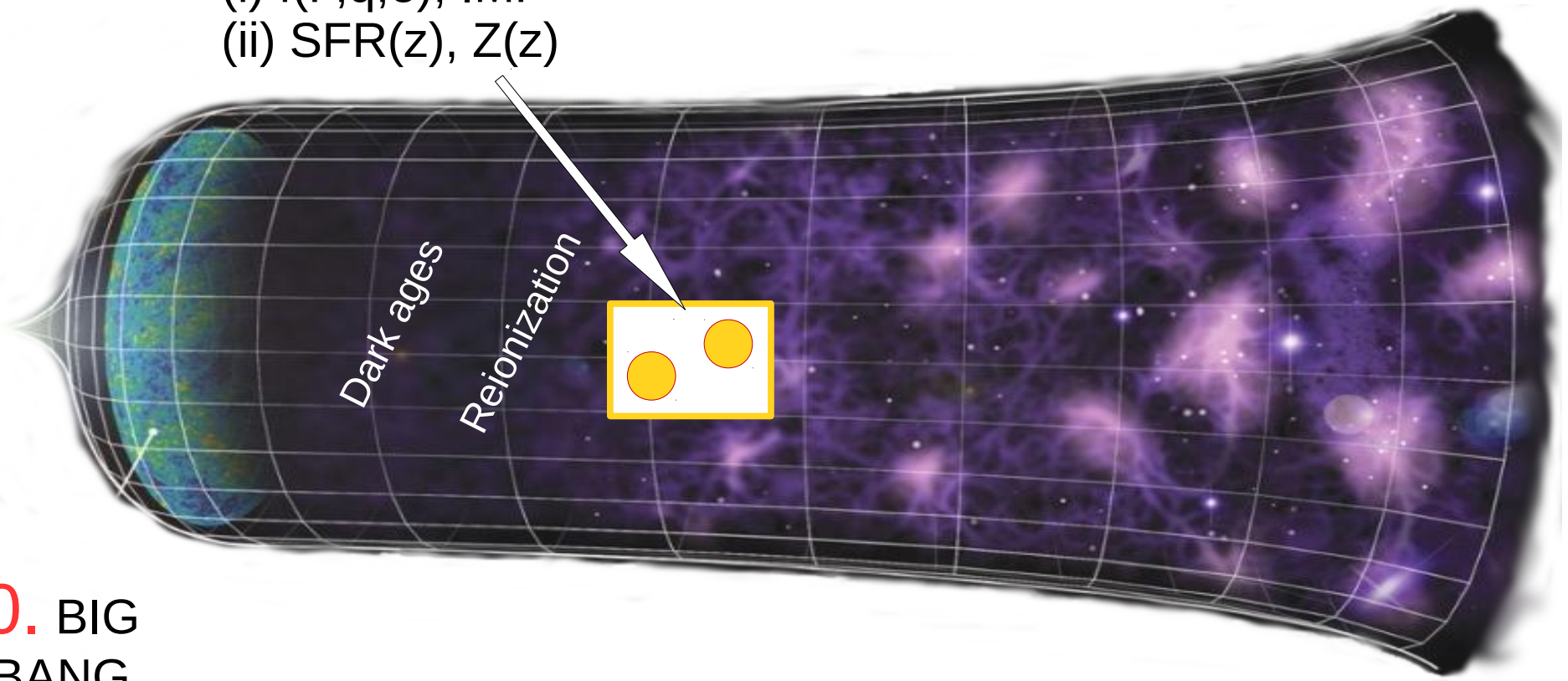
Nijmegen

Making predictions for LIGO

0. BIG BANG (primordial BH-BHs?)

Making predictions for LIGO

1. MS-MS binary formation
(i) f(P,q,e), IMF
(ii) SFR(z), Z(z)



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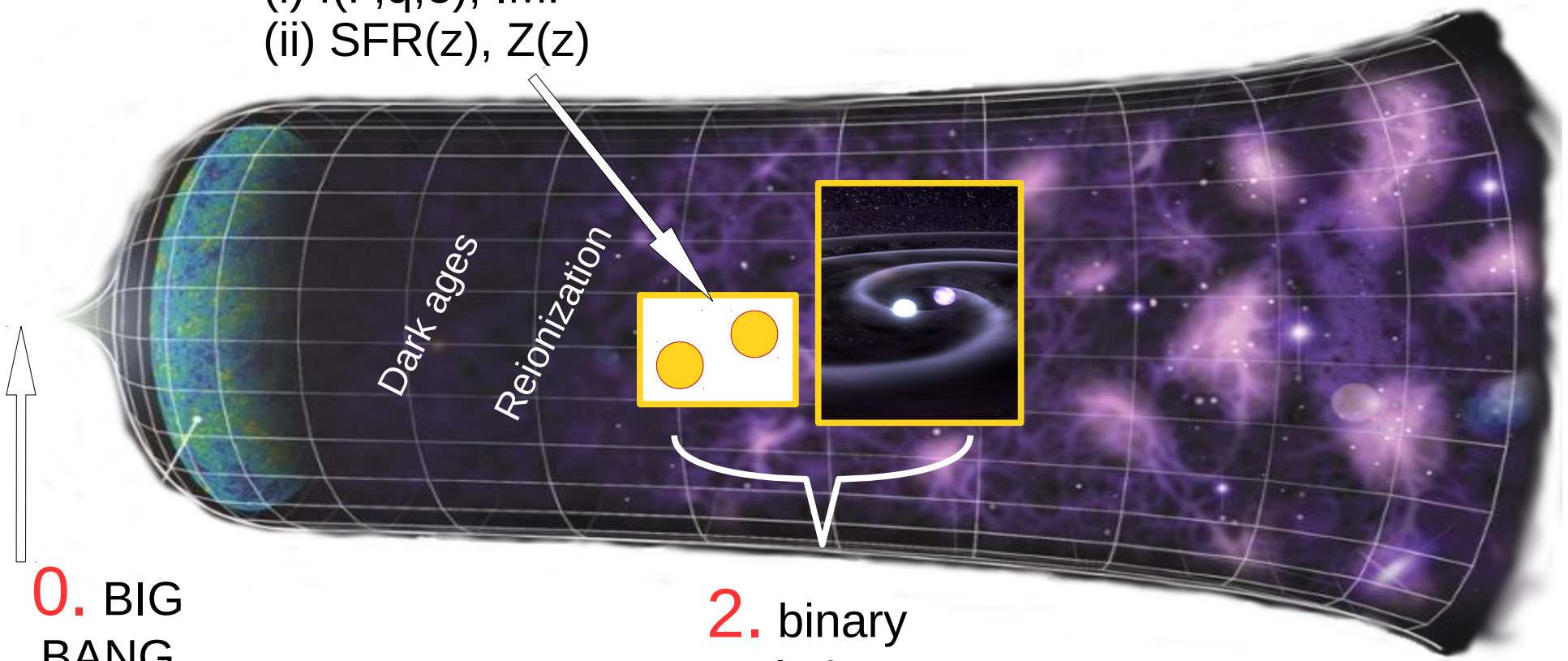

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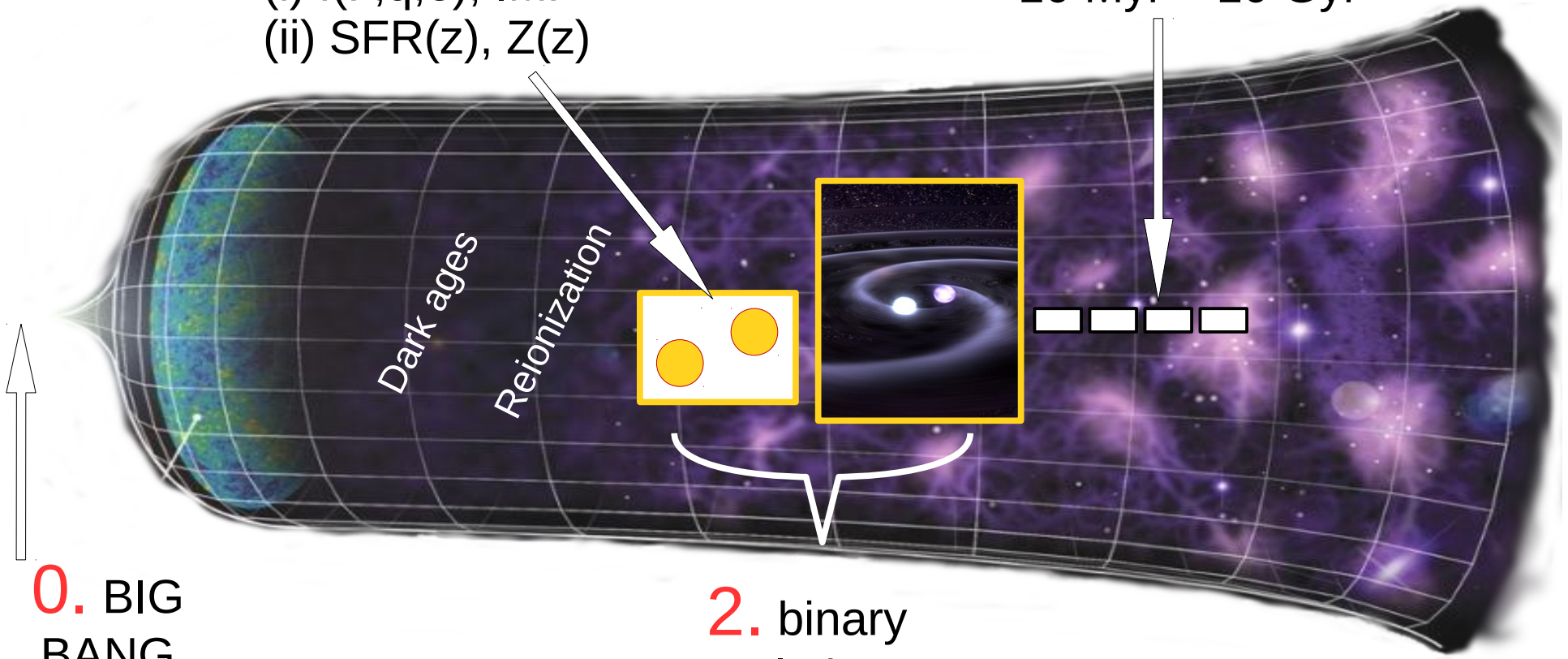
~ 10 Myr – 10 Gyr



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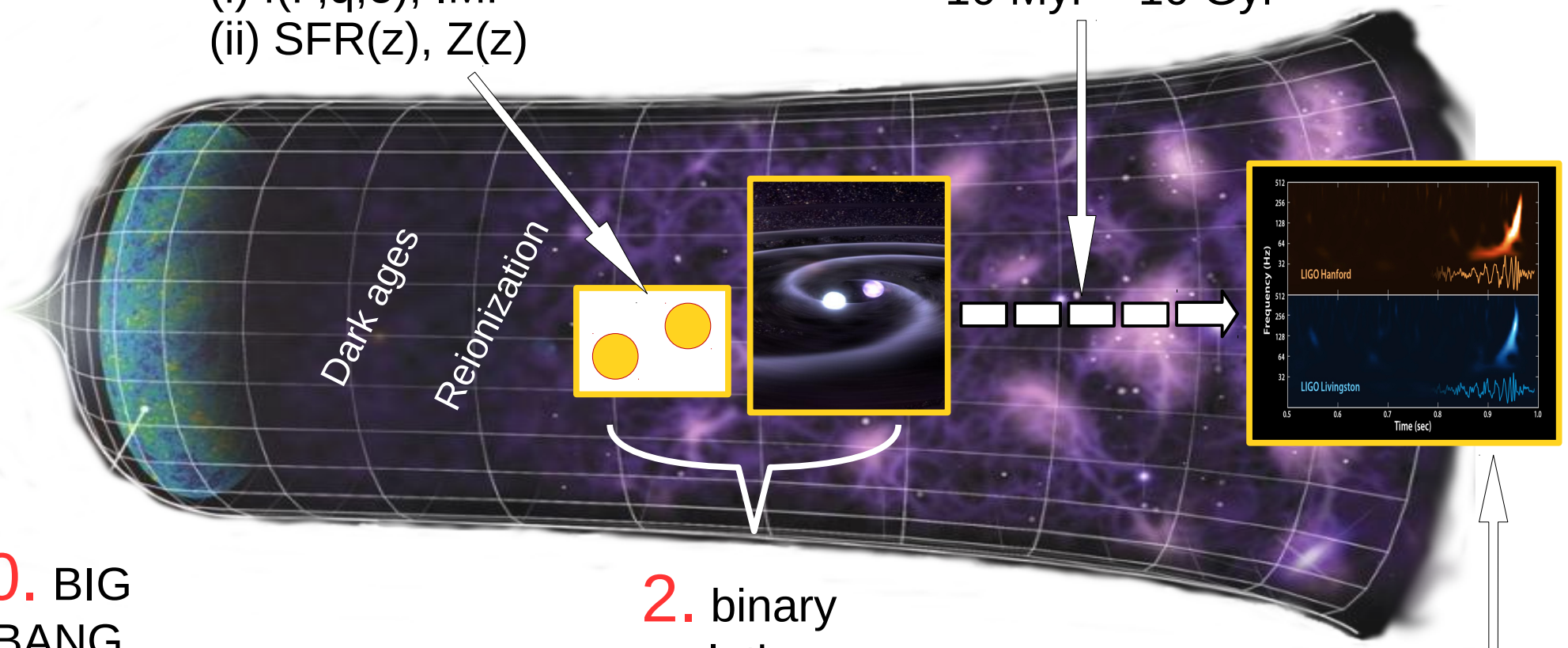

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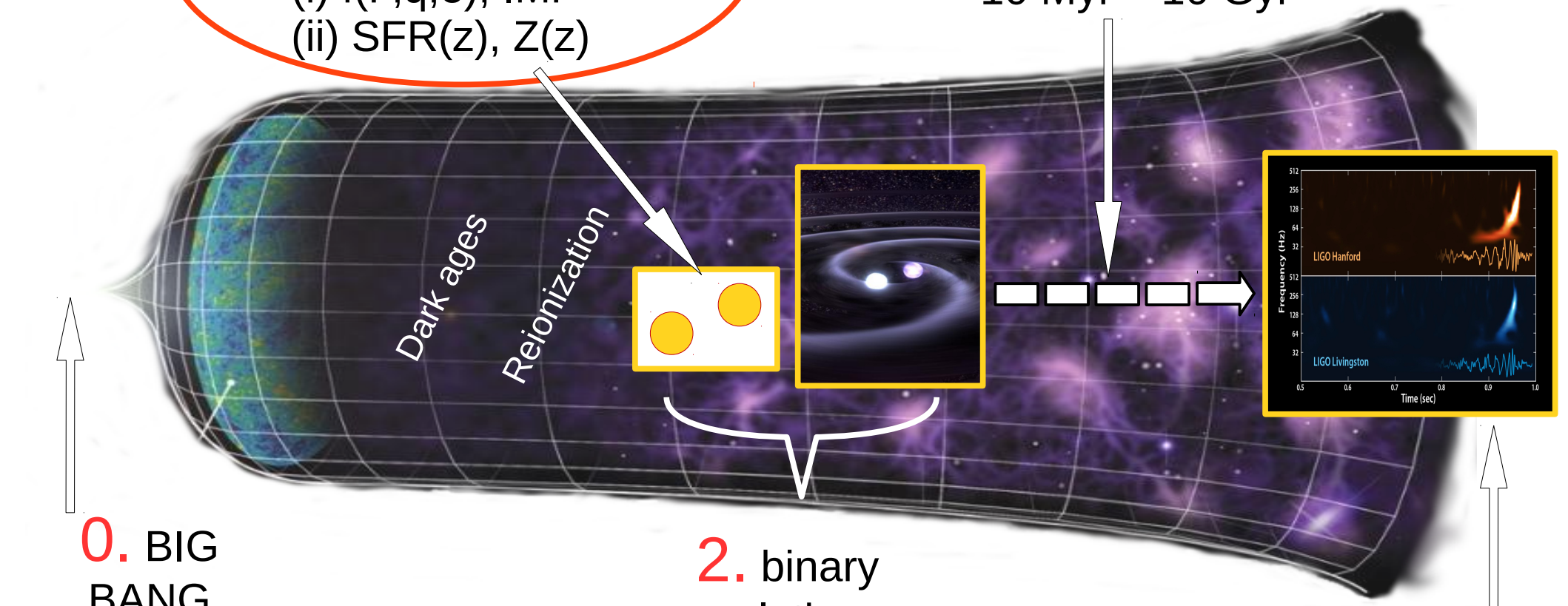

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Sana et al. 2012 ⟶ Moe & Di Stefano 2017

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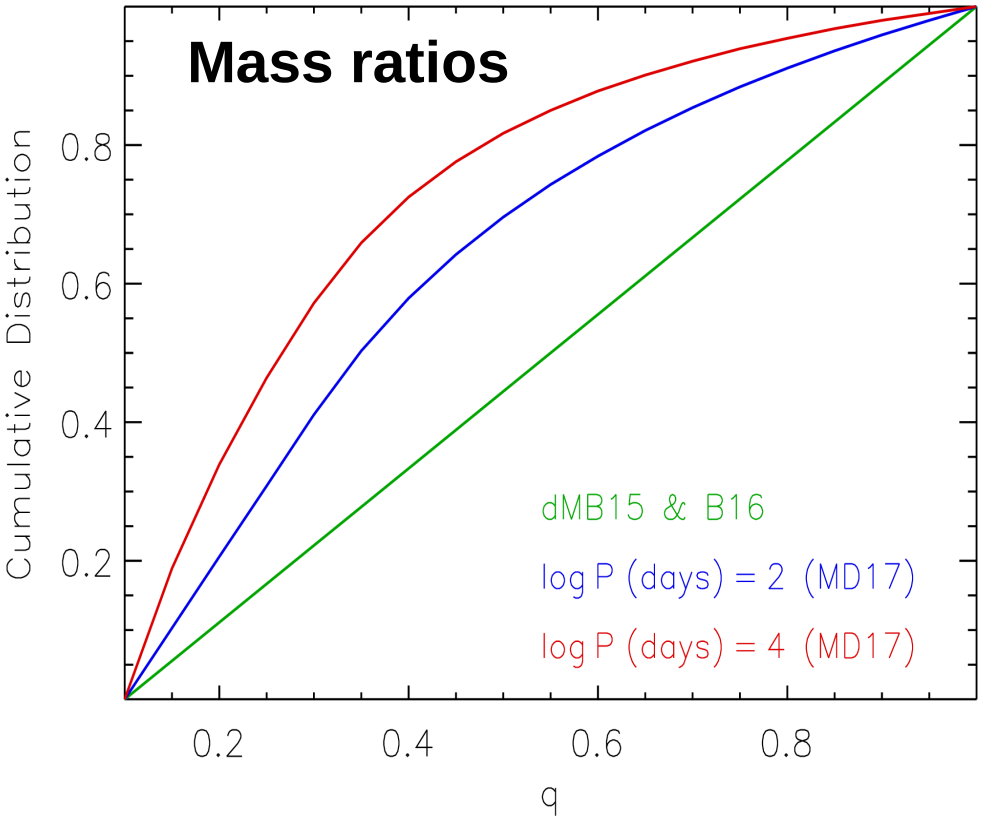

~2.5 less mass ratios q > 0.5

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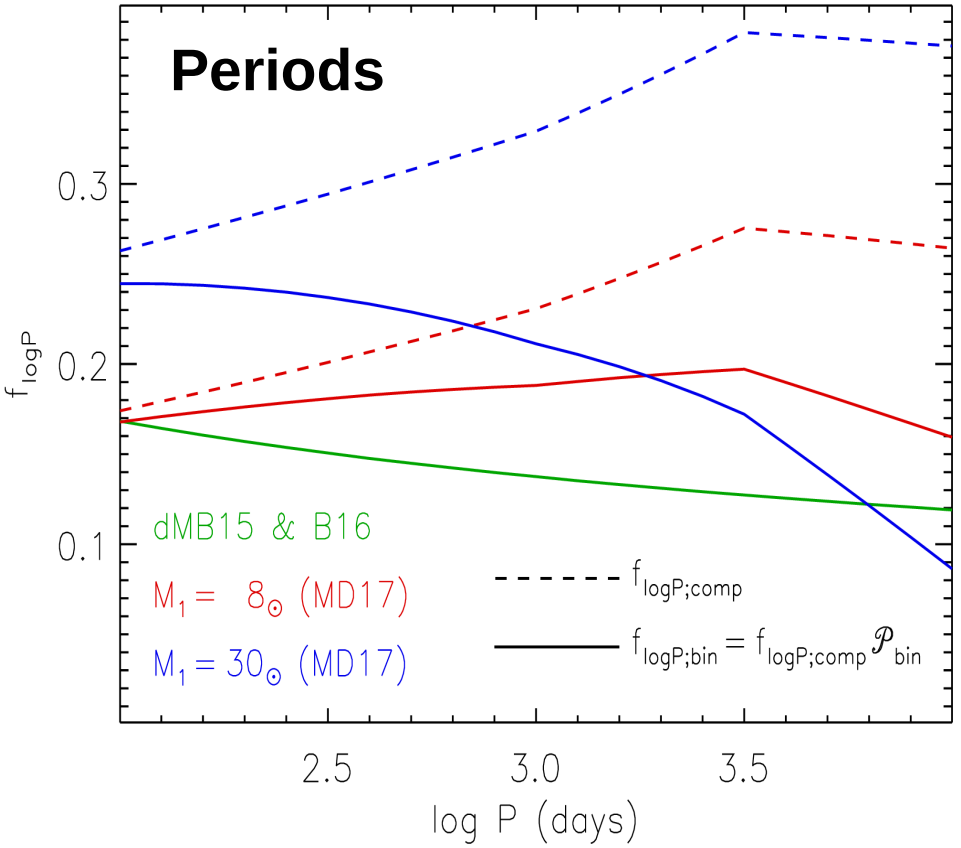
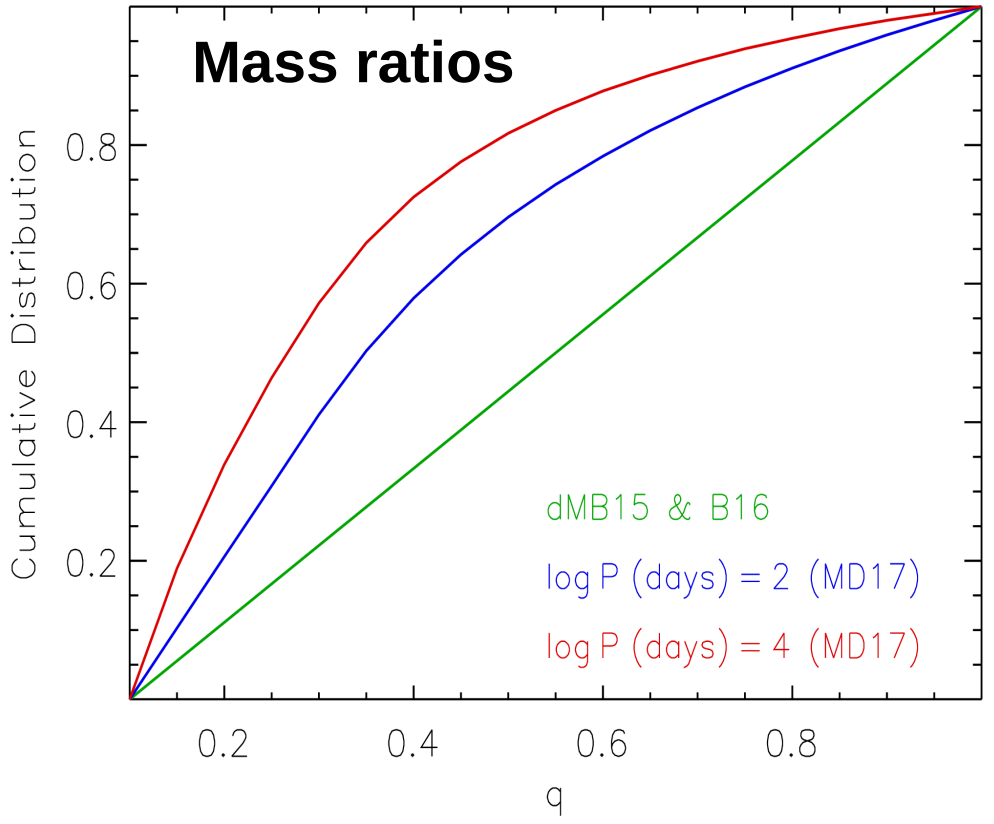


Up to ~ 1.4 more periods between 100 and 10,000 days



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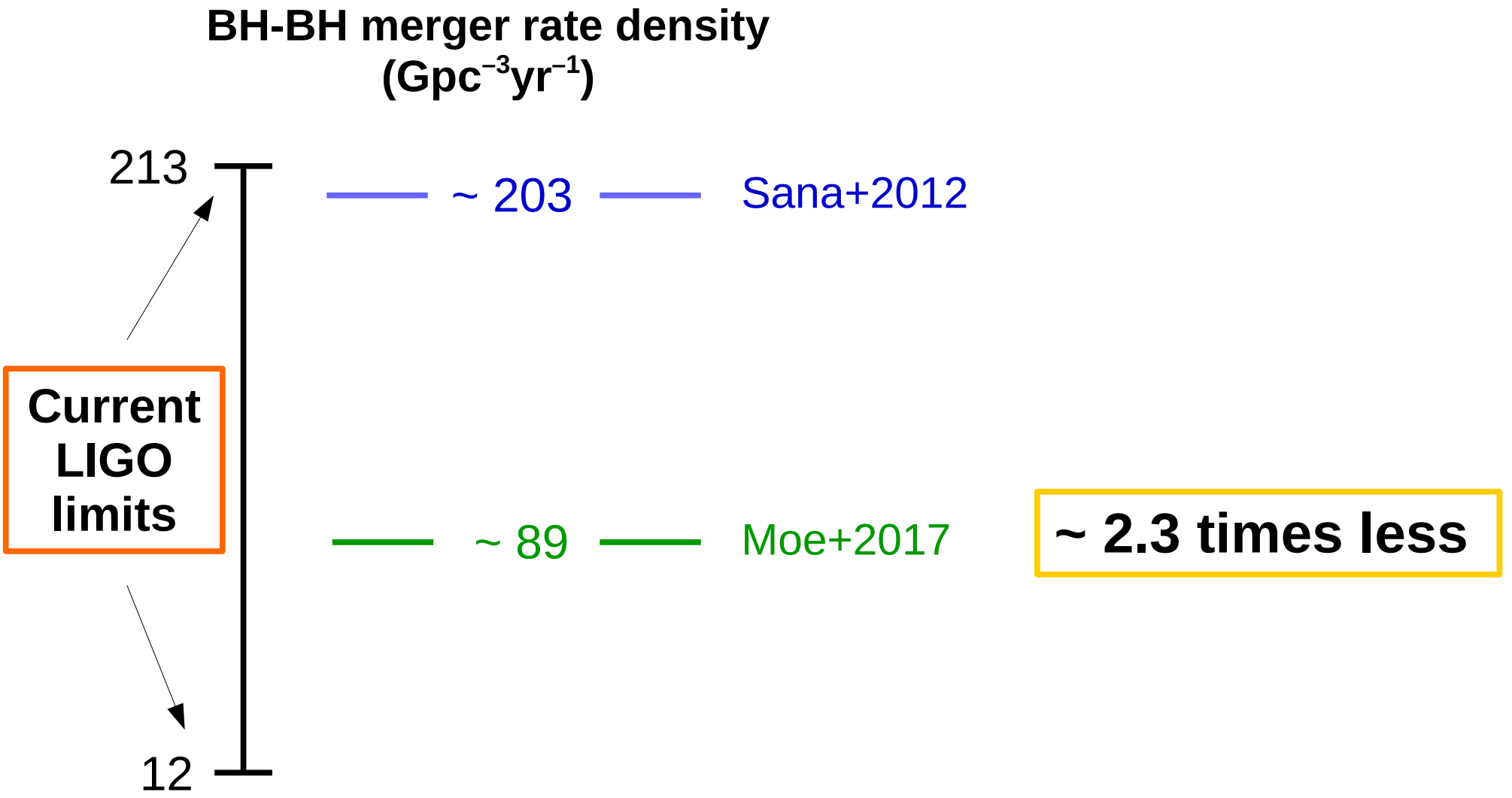
1) Sana vs Moe comparison



2) IMF

- de Mink & Belczynski (2015): $\alpha_3 = 2.7 \pm 0.5$

  biggest variations (x6) due to uncertainty in the IMF

- $\alpha_3 = 2.3 \pm 0.7$ (Kroupa 2001)
- New observations, Tarantula Nebula – $\alpha_3 \approx 1.9$?? (Selma de Mink, Paris talk)

$$\mathbf{dN/dM \sim M^{-\alpha}}$$

$\alpha_1 = 1.3$ for $0.08 < M < 0.5$

$\alpha_2 = 2.2$ for $0.5 < M < 1.0$

$\alpha_3 = \ldots ?$ for $1.0 < M$

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Problem:

obervations → **Local Group** ($z = 0$; [Fe/H] > -0.7; $Z > 0.004$)

vs

when did BH-BH mergers form?

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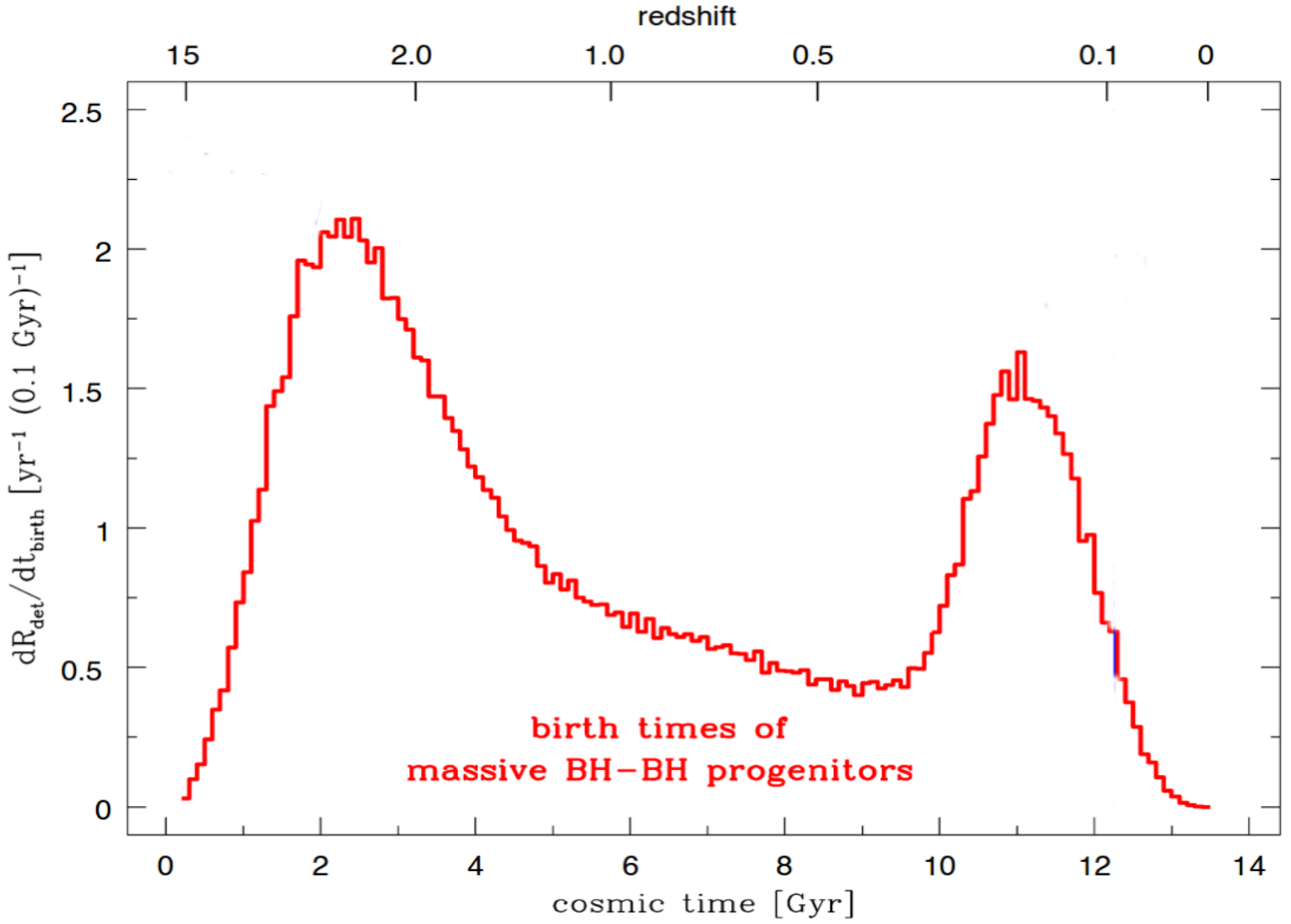

Belczynski+16

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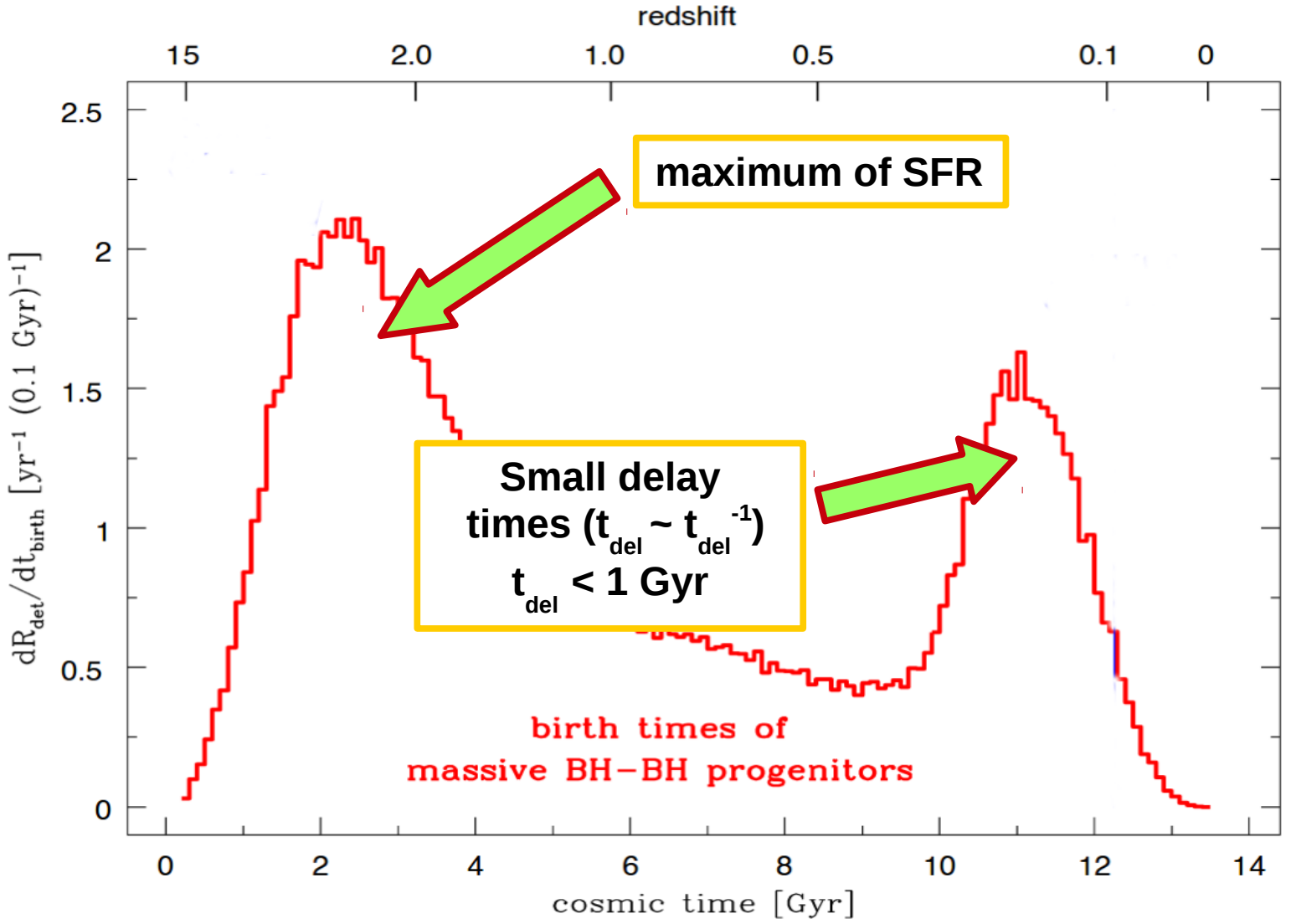

Belczynski+16

2) IMF – not so universal?

(Pavel Kroupa talk)

Theory,
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top-heavy IMF
in low metallicity!

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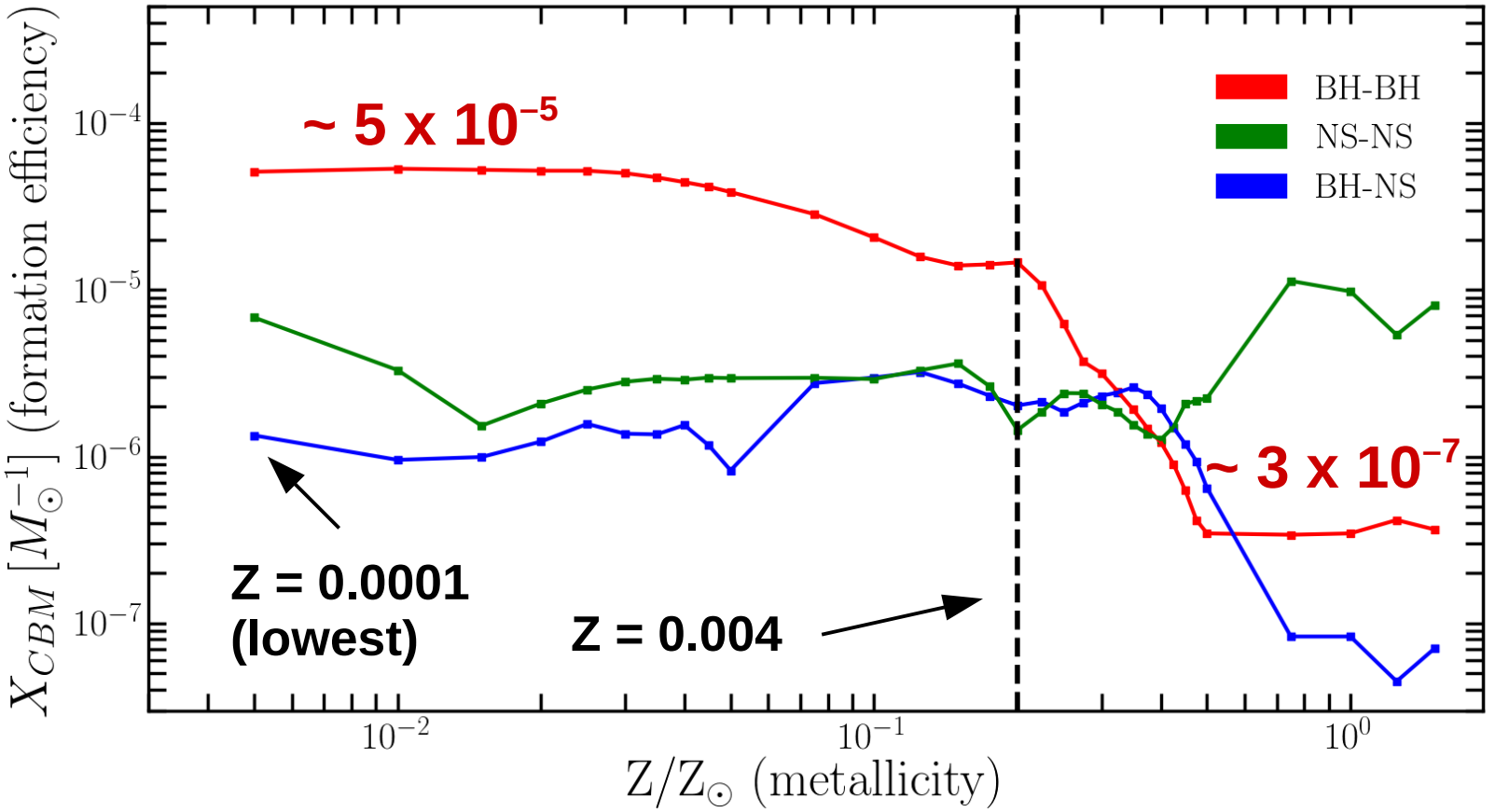

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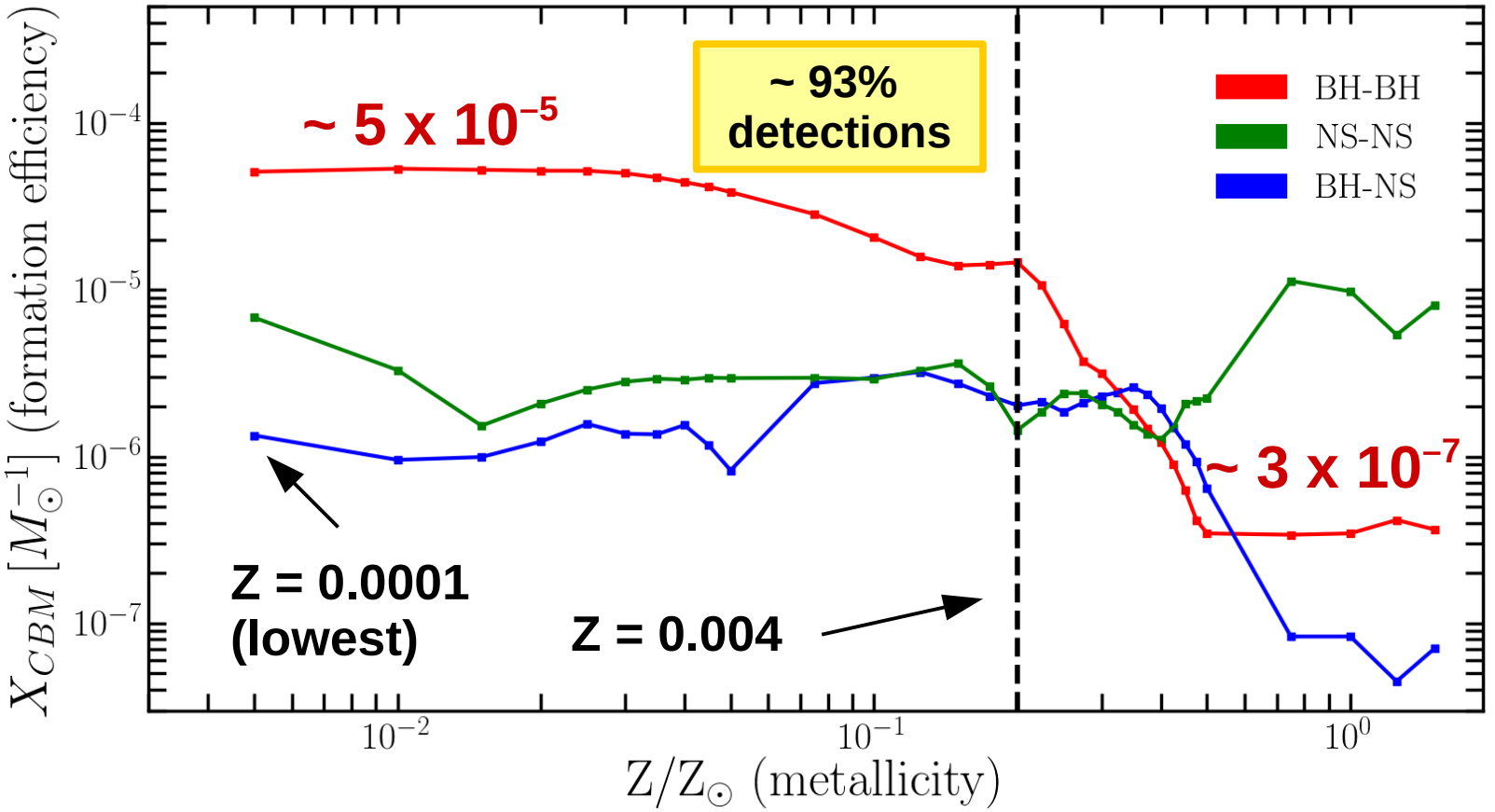
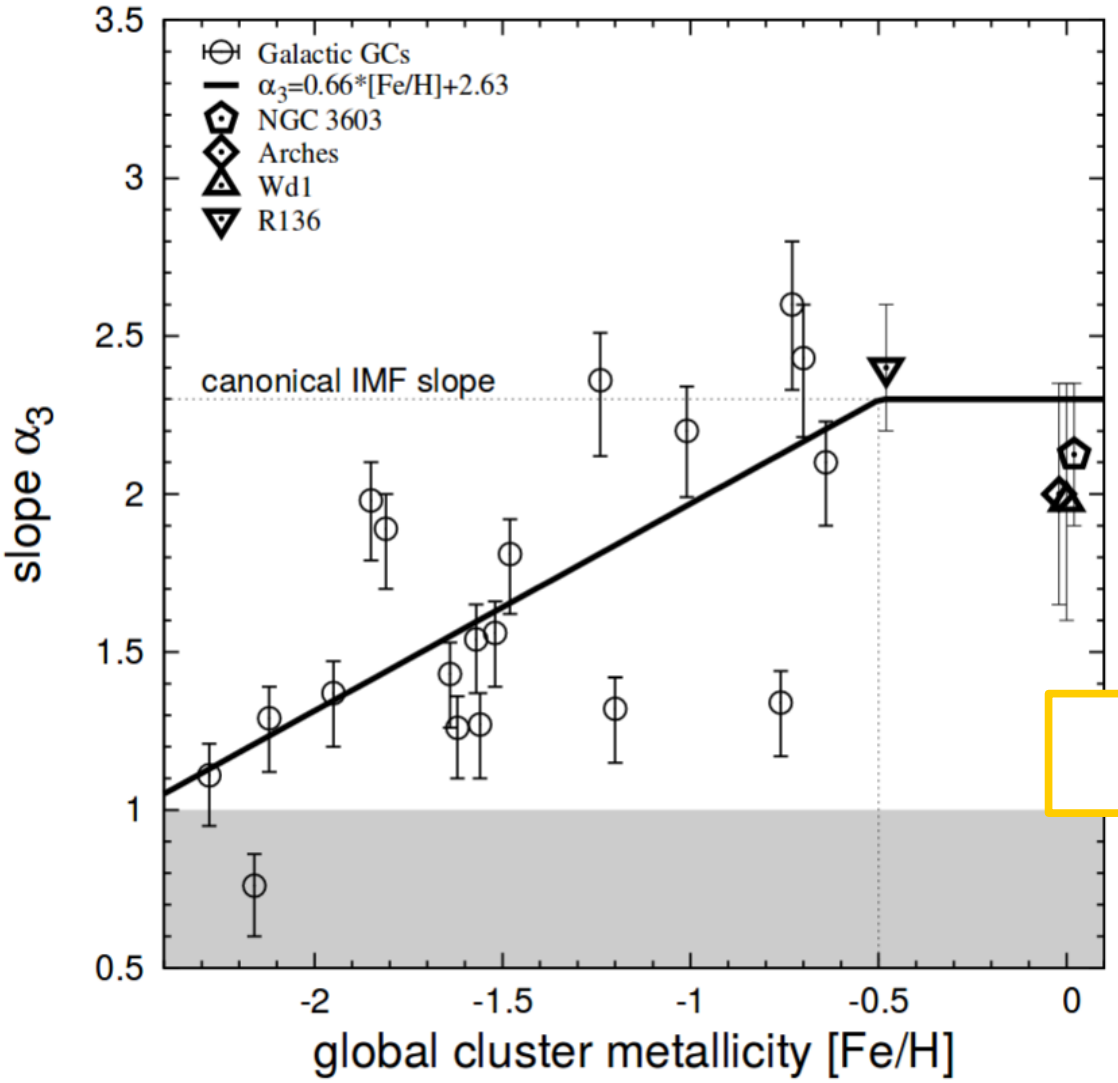


2) IMF (Z) – Marks+12 calibration



Marks+2012

Metallicity range:

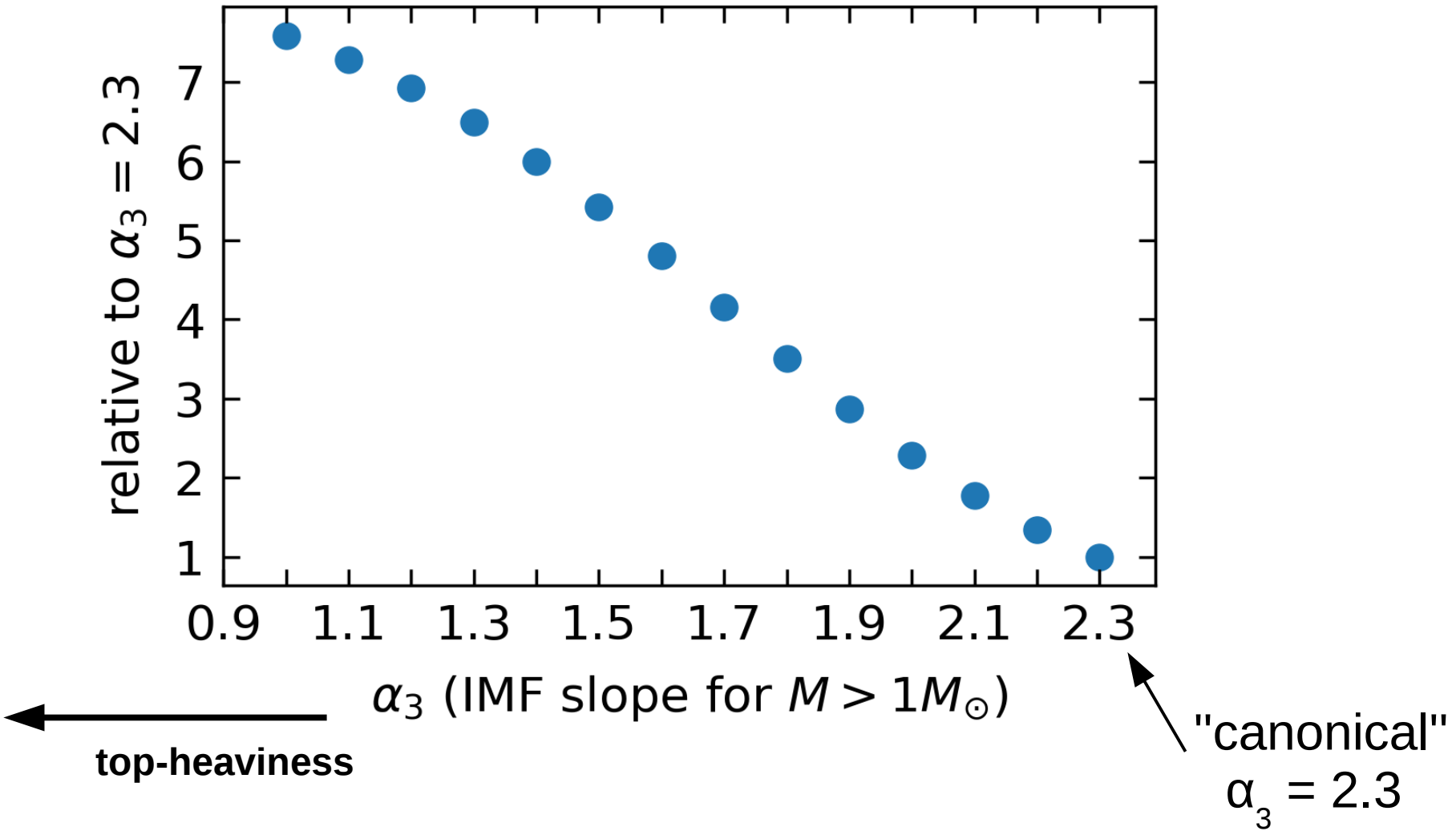
$0.0001 < Z < 0.004$

$-2.3 < [Fe/H] < -0.7$

$\alpha_3 = 2.3 + 0.76\ (\log Z + 2.4)$

α_3 down to ~1.1 at Z = 0.0001

Relative number of M > 40 Msun stars



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Massive stars, M > 5 Msun

Re-radiation of dust absorbed UV

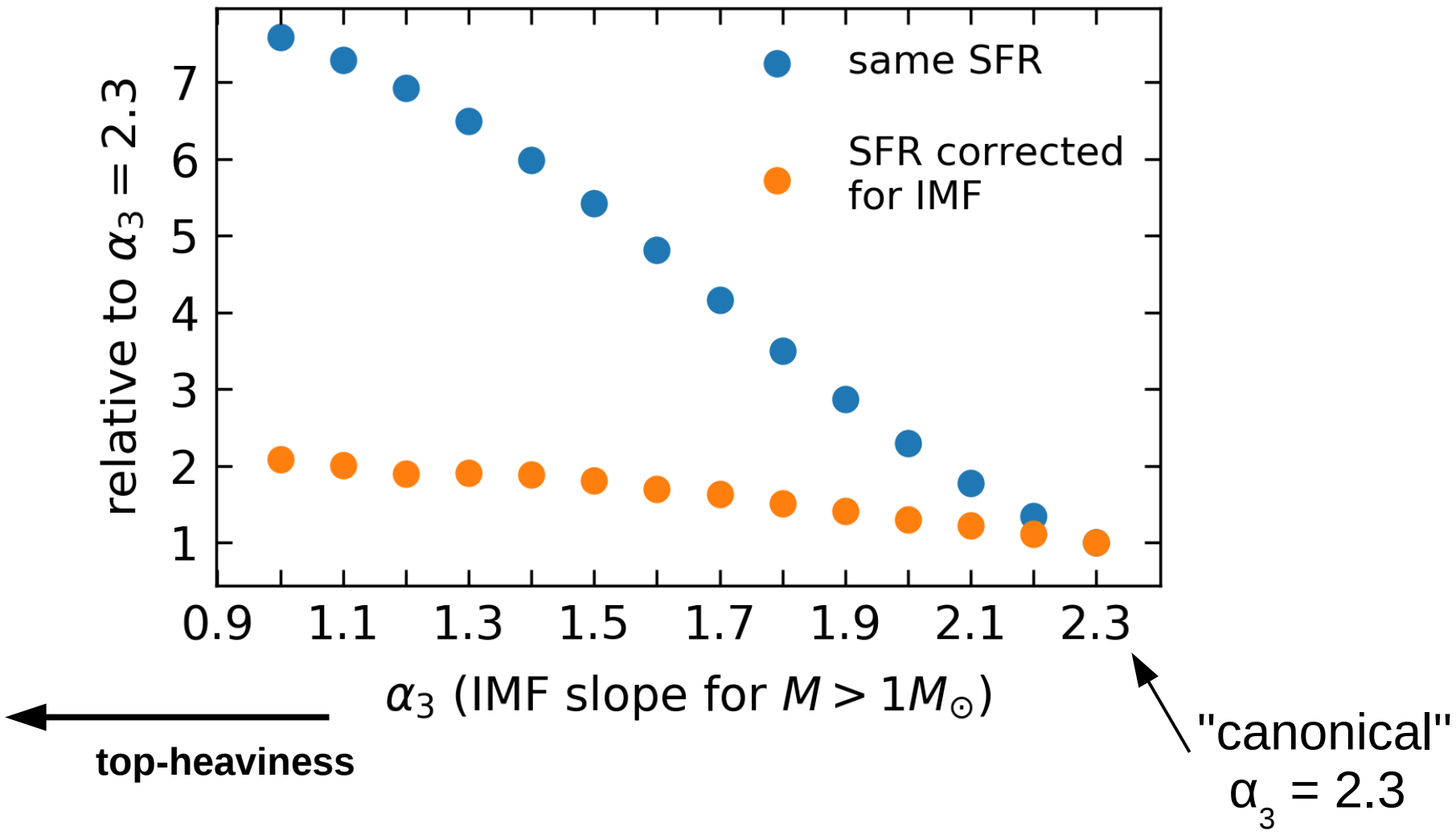
- Using IMF to extrapolate (MD14 used IMF of Salpeter)

$$\mathrm{SFR}_{\mathrm{IMF}}(z) = \mathcal{K}_{\mathrm{IMF}} \times \mathrm{SFR}_{\mathrm{Salpeter}}(z)$$

Correction is needed!!!

Starburst99
(Leitherer+ 99,05)

Relative number of M > 40 Msun stars



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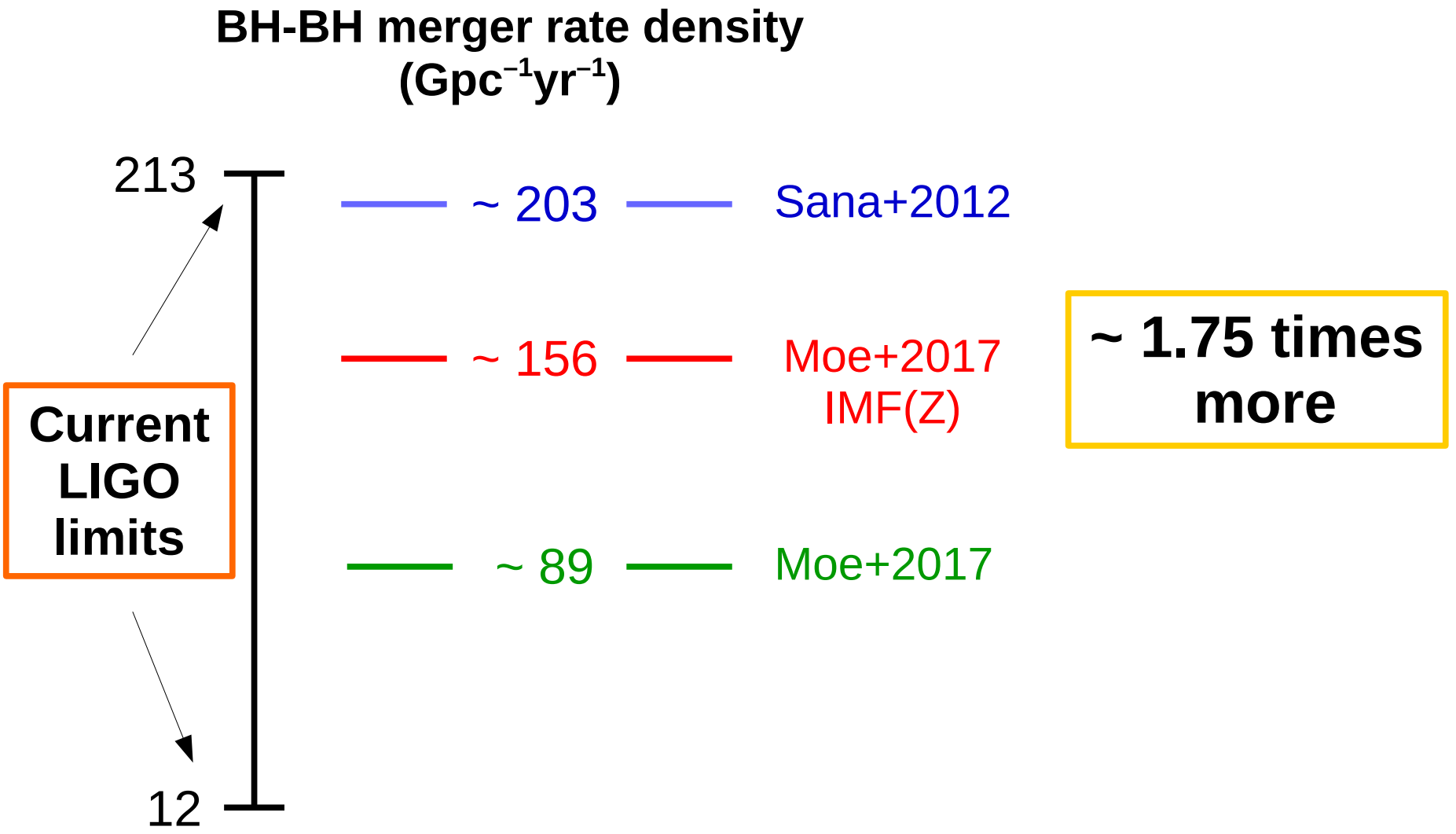
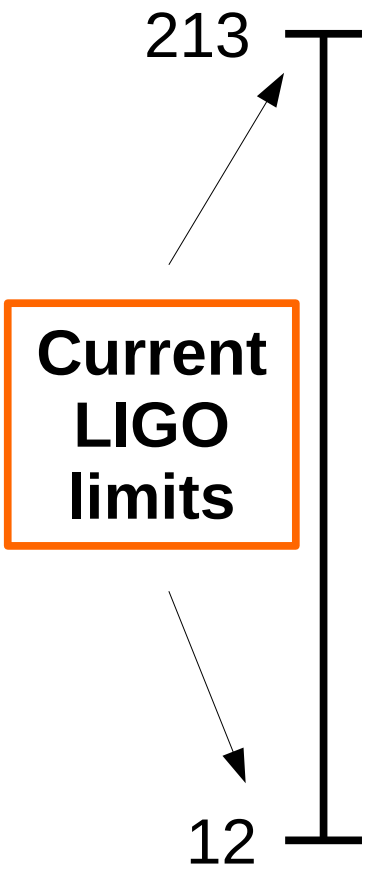

BH-BH merger rate density
(Gpc^{-1}yr^{-1})
213
12
Current LIGO limits
~ 203
Sana+2012
~ 156
Moe+2017
IMF(Z)
~ 89
Moe+2017
~ 1.75 times more

1) Sana vs Moe

BH-BH merger rate density ($Gpc^{-1}yr^{-1}$)

Detection rate O1/O2 LIGO



~ 203 — Sana+2012 — ~ 112 (yr^{-1})

~ 156 — Moe+2017 IMF(Z) — ~ 106 (yr^{-1})

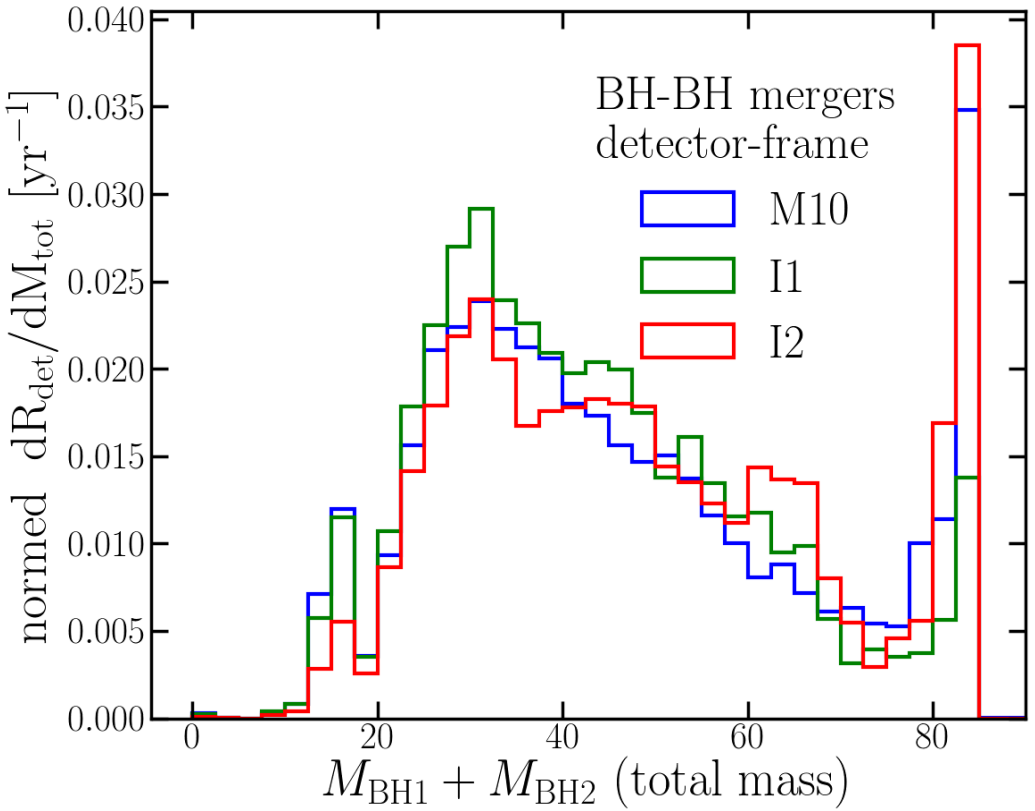
~ 89 — Moe+2017 — ~ 49 (yr^{-1})

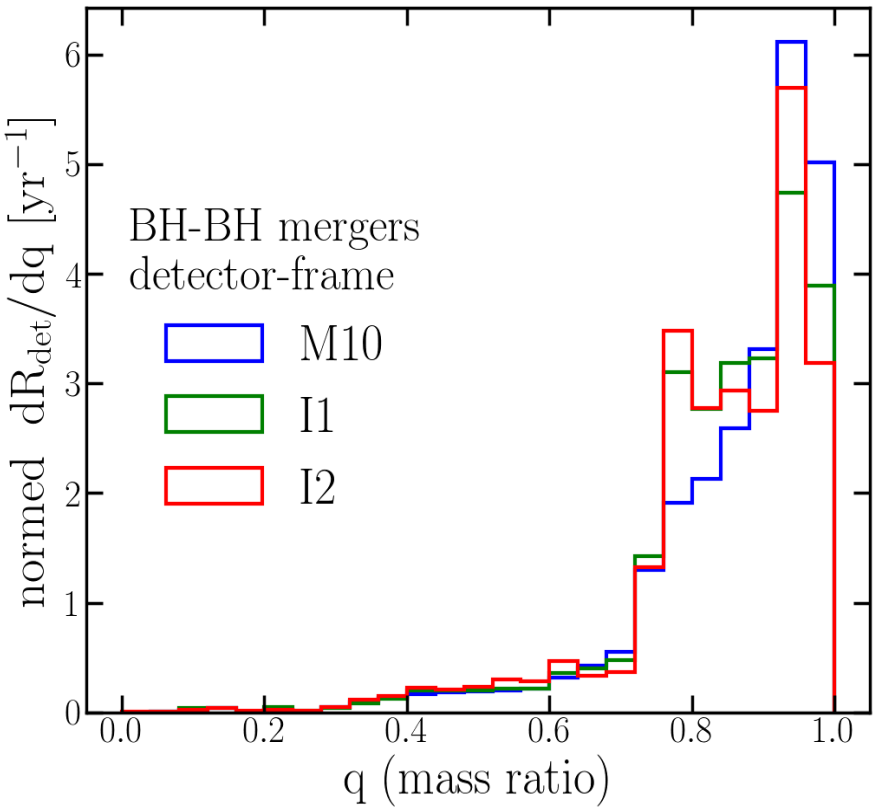
Take-home messages:

- Mind your Ps and **Qs** (factor ~ 2.5 for BH-BH and NS-NS)
- Correct SFR for the IMF you use! (x 0.51 lower for $\alpha_3 = 2.3$)
- IMF variations / uncertainties maybe not all that important

Thank you for your attention!

Masses and mass ratios





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