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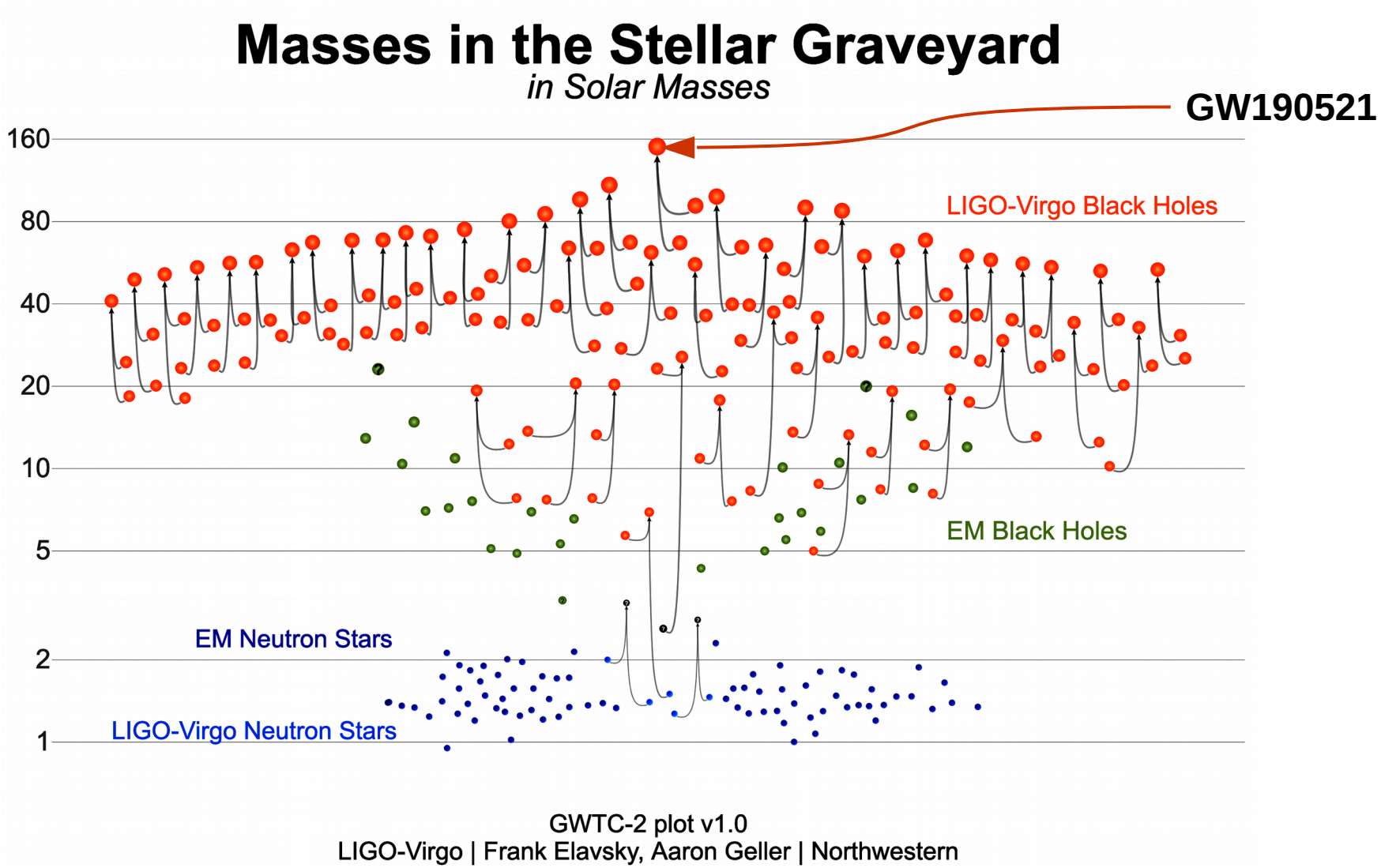
Few scattered ideas on GW190521

Main collaborators: M. Celeste Artale, Alessandro Ballone, Yann Bouffanais, Guglielmo Costa, Ugo N. Di Carlo, Nicola Giacobbo, Giuliano Iorio, Mario Pasquato, Sara Rastello, Filippo Santoliquido, Nadeen Sabha, Mario Spera, Stefano Torniamenti

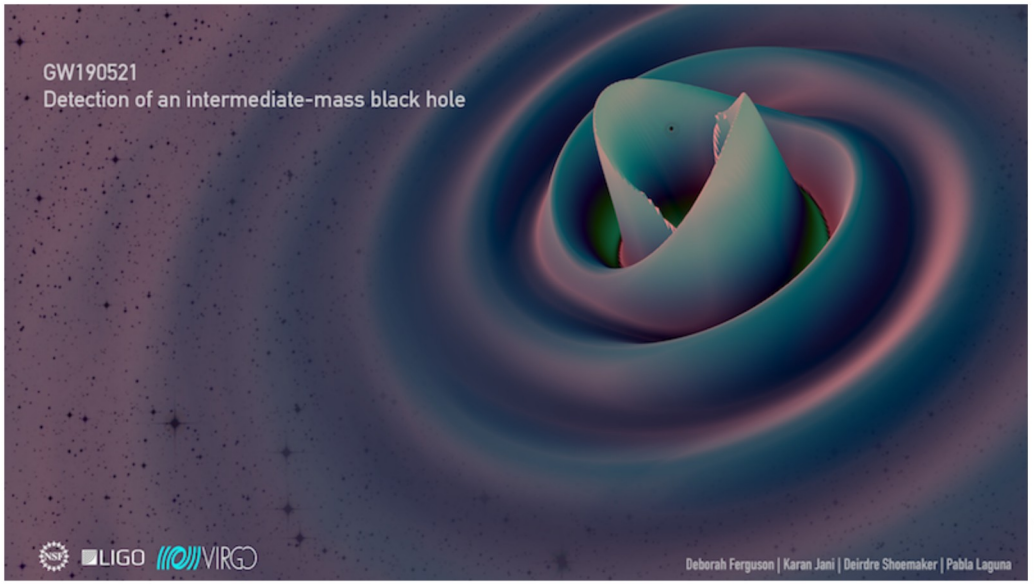
NBIA LIGO – Virgo Workshop, 18 November 2020

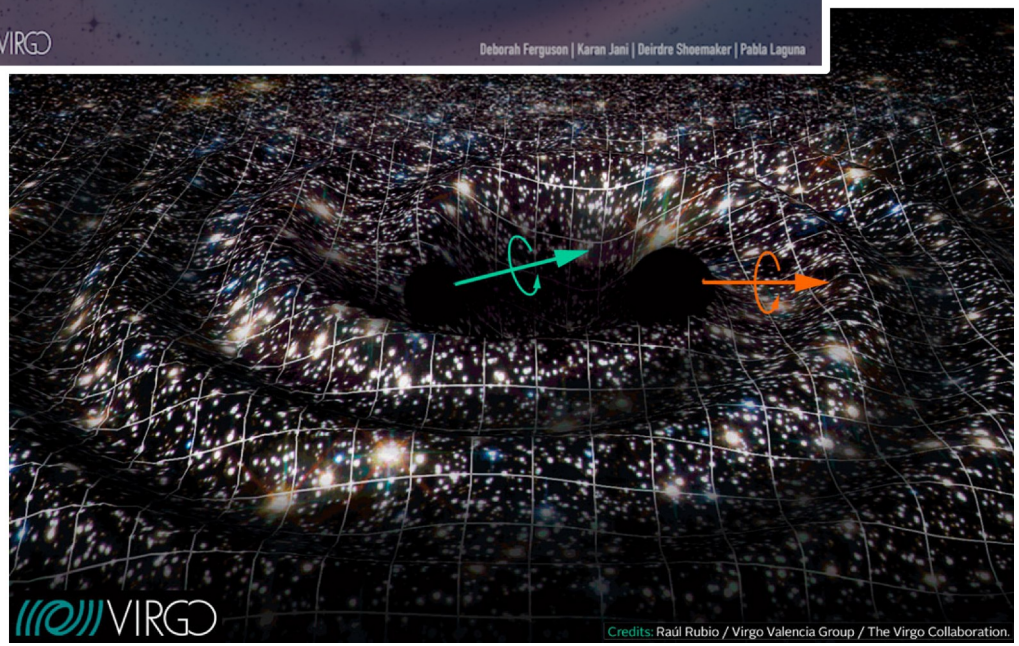
1. GW190521: the most massive event to date



Abbott et al. 2020, GWTC-2, 2020, https://arxiv.org/abs/2010.14527
Abbott et al. 2020, GW190521 discovery, https://arxiv.org/abs/2009.01075
Abbott et al. 2020, GW190521 implications, https://arxiv.org/abs/2009.01190

1. GW190521: the most massive event to date





GW190521

$$m_1 = 85^{+21}_{-14}\mathrm{M}_\odot$$
$$m_2 = 66^{+17}_{-18}\mathrm{M}_\odot$$
$$\chi_{\mathrm{eff}} = 0.08^{+0.27}_{-0.36}$$
$$\chi_{\mathrm{p}} = 0.68^{+0.25}_{-0.37}$$

1. most massive GW event to date: total mass ~ 150 M⊙

2. mild evidence for spin components in the orbital plane

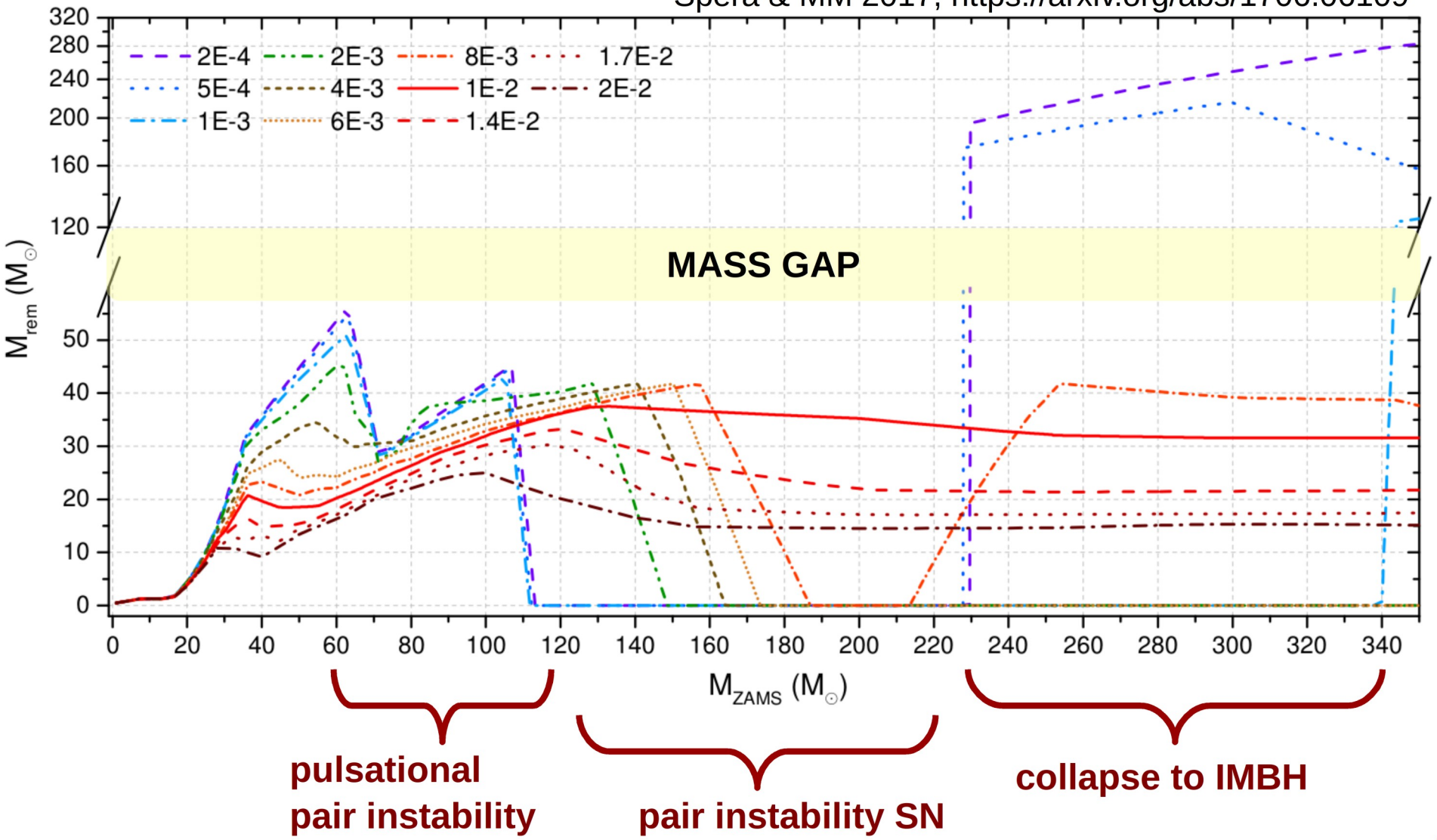
3. primary mass in the "pair instability mass gap"

Abbott et al. 2020, GW190521 discovery, https://arxiv.org/abs/2009.01075
Abbott et al. 2020, GW190521 implications, https://arxiv.org/abs/2009.01190

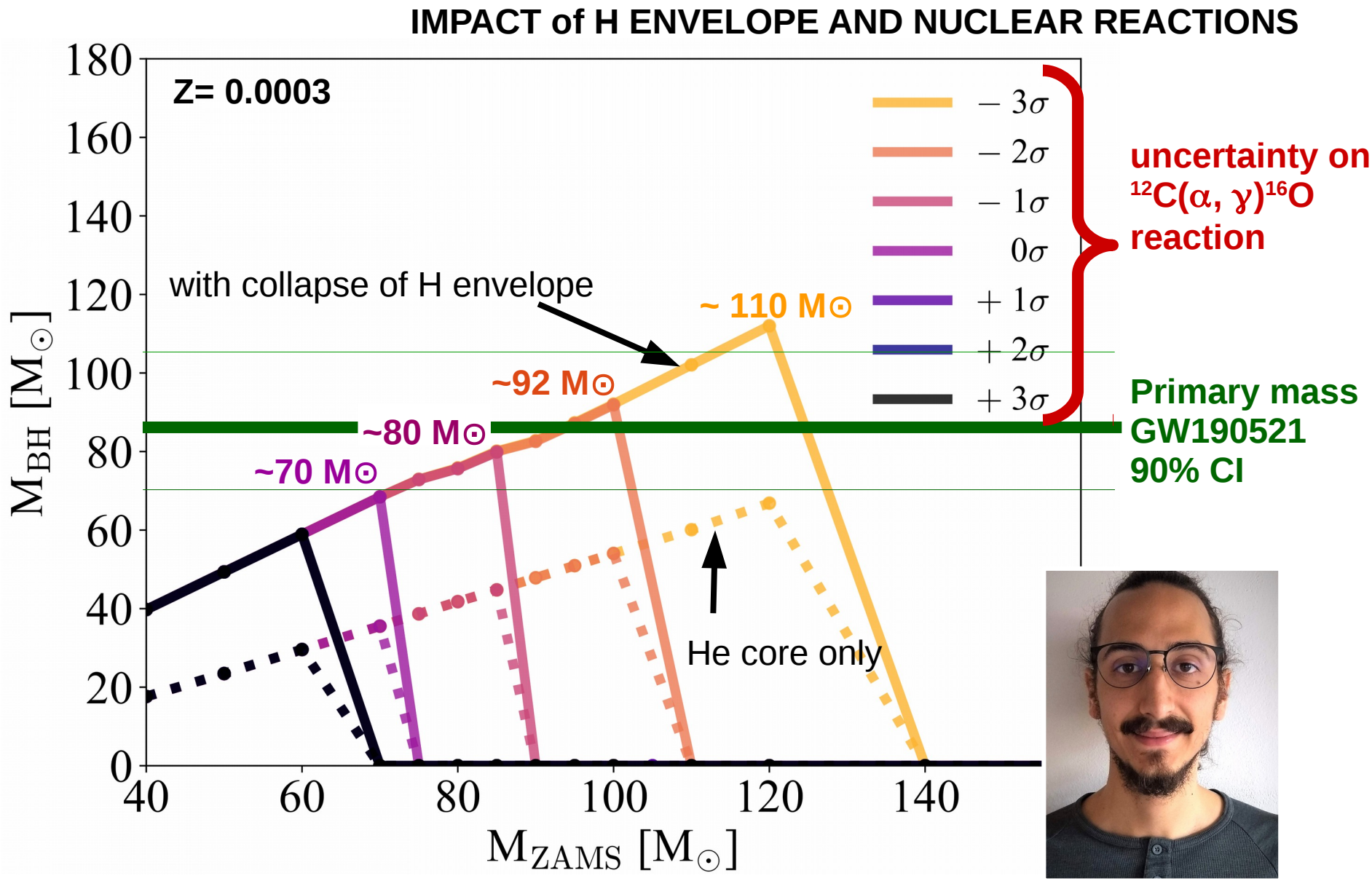
2. Pair instability mass gap

Impact of pulsational pair instability (if 32 < m_{He} / M⊙ < 64) and
pair instability supernovae (if 64 < m_{He} / M⊙ < 135)

Spera & MM 2017, https://arxiv.org/abs/1706.06109



3. GW190521 from stellar evolution?

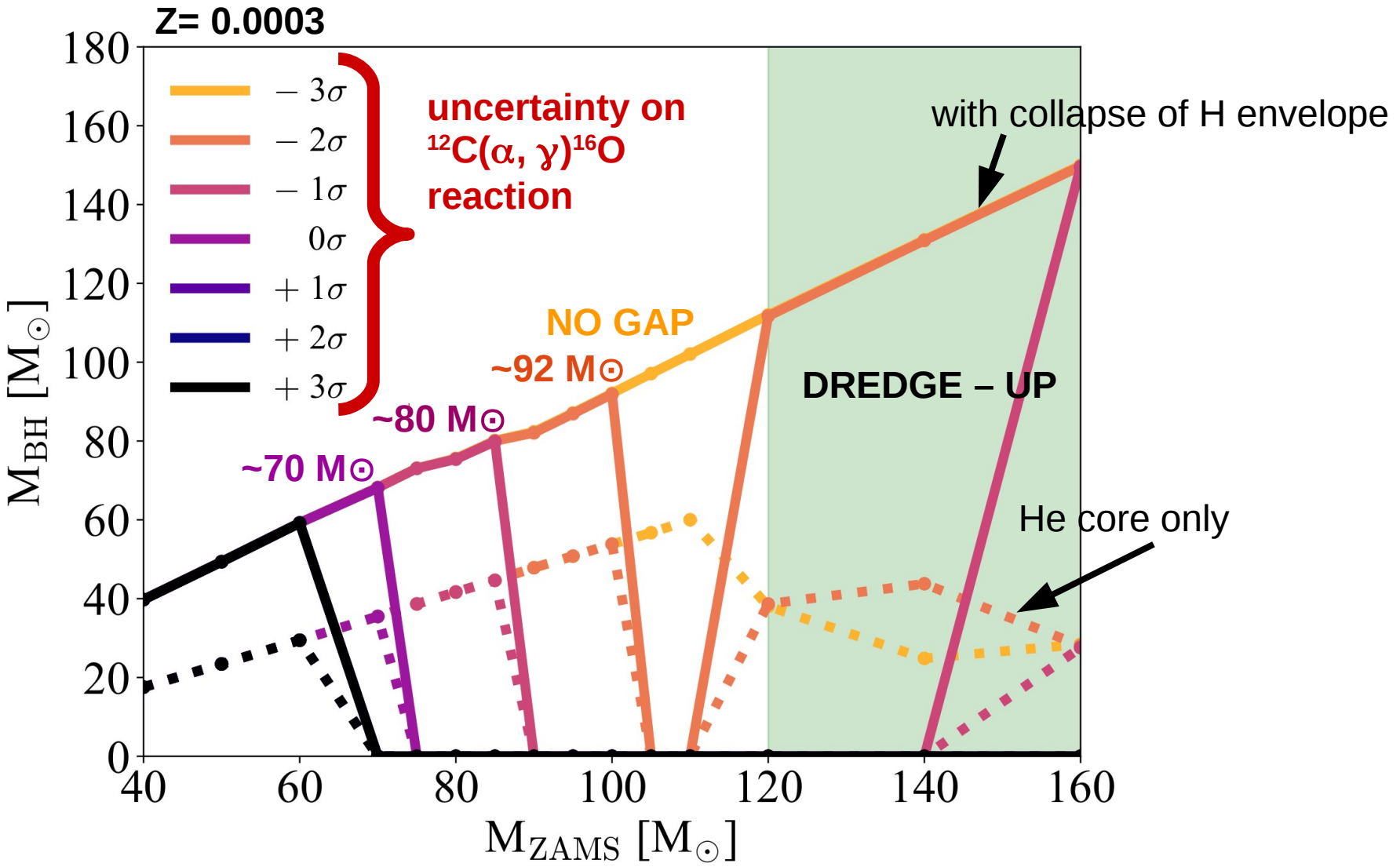


Guglielmo Costa
postdoc

Costa et al. 2020, https://arxiv.org/abs/2010.02242

3. GW190521 from stellar evolution?

ALLOWING FOR ENVELOPE OVERSHOOTING



Costa et al. 2020, https://arxiv.org/abs/2010.02242

3. GW190521 from stellar evolution?

Take – home message from stellar evolution:

* Uncertainties on boundaries of mass gap from stellar evolution are LARGE:
  - collapse of hydrogen envelope
  - $^{12}C(\alpha, \gamma)^{16}O$ reaction rate
  - core / envelope overshooting
  - rotation

* We cannot exclude formation of a black hole with mass similar to primary mass of GW190521

* but collapse of residual hydrogen envelope is important:

  only a single star or a star in a loose binary system can retain a fraction of its H envelope

* Strongly misaligned spins are difficult to reconcile with binary evolution

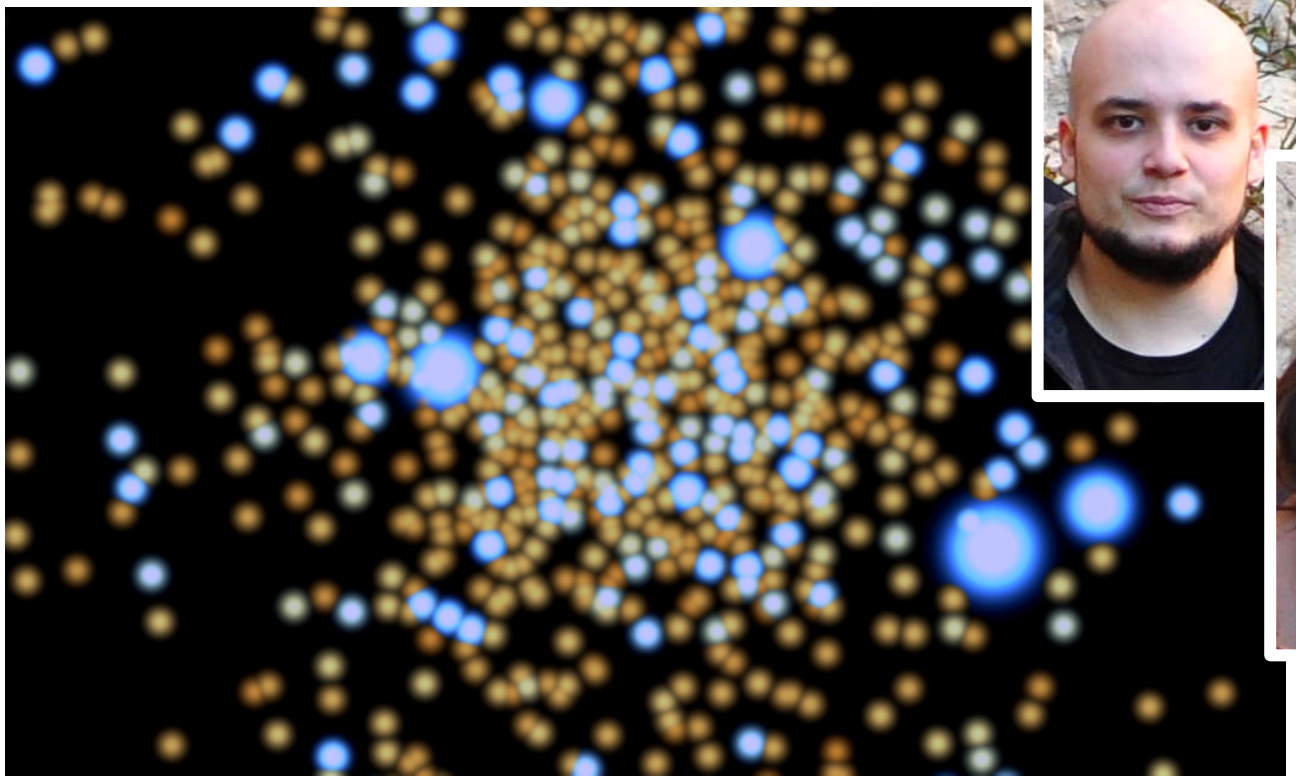
* How can we explain a GW190521 – like event?

  Let's consider dynamics

Costa et al. 2020; see also Takahashi 2018; Farmer et al. 2019, 2020; Marchant et al. 2019, 2020; Tanikawa et al. 2020; Farrell et al. 2020; van Son et al. 2020; Liu & Bromm 2020; Safarzadeh & Haiman 2020; Belczynski 2020; Kinugawa et al. 2020; Umeda et al. 2020;..

4. GW190521 from dynamics?

MOBSE (MM et al. 2017; Giacobbo+ 2018) & Nbody6++GPU (Wang et al. 2015, 2016)



Ugo Di Carlo
PhD student

Sara Rastello
postdoc

> 100’000 YOUNG STAR CLUSTERS (300 – 30’000 M⊙)
with fractal initial conditions
& initial binary fraction ~ 100% (for massive stars)

MM 2016
Di Carlo et al. 2019, 2020a, 2020b
Rastello et al. 2020

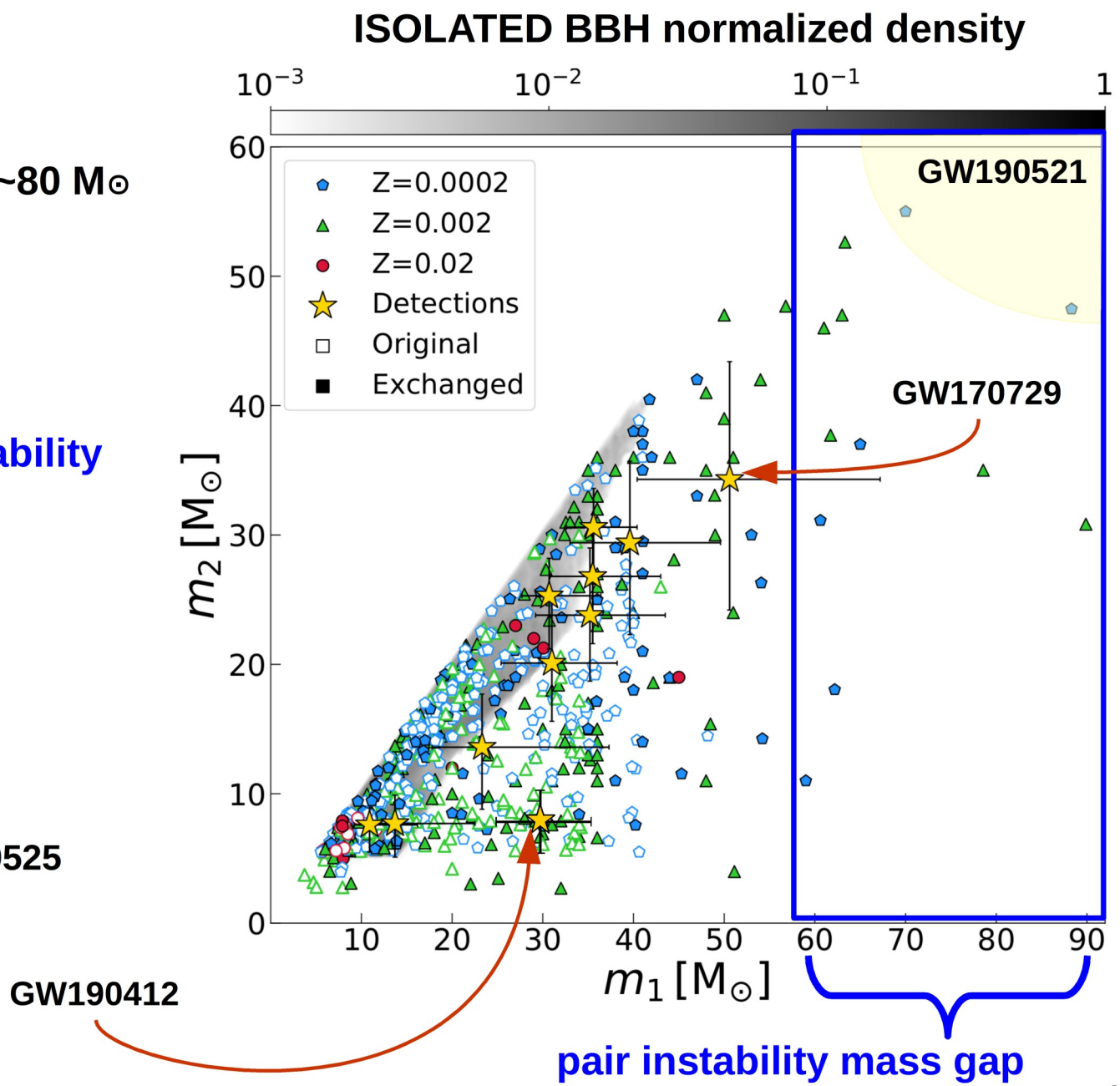
4. GW190521 from dynamics?

Isolated BBHs only up to ~80 M⊙

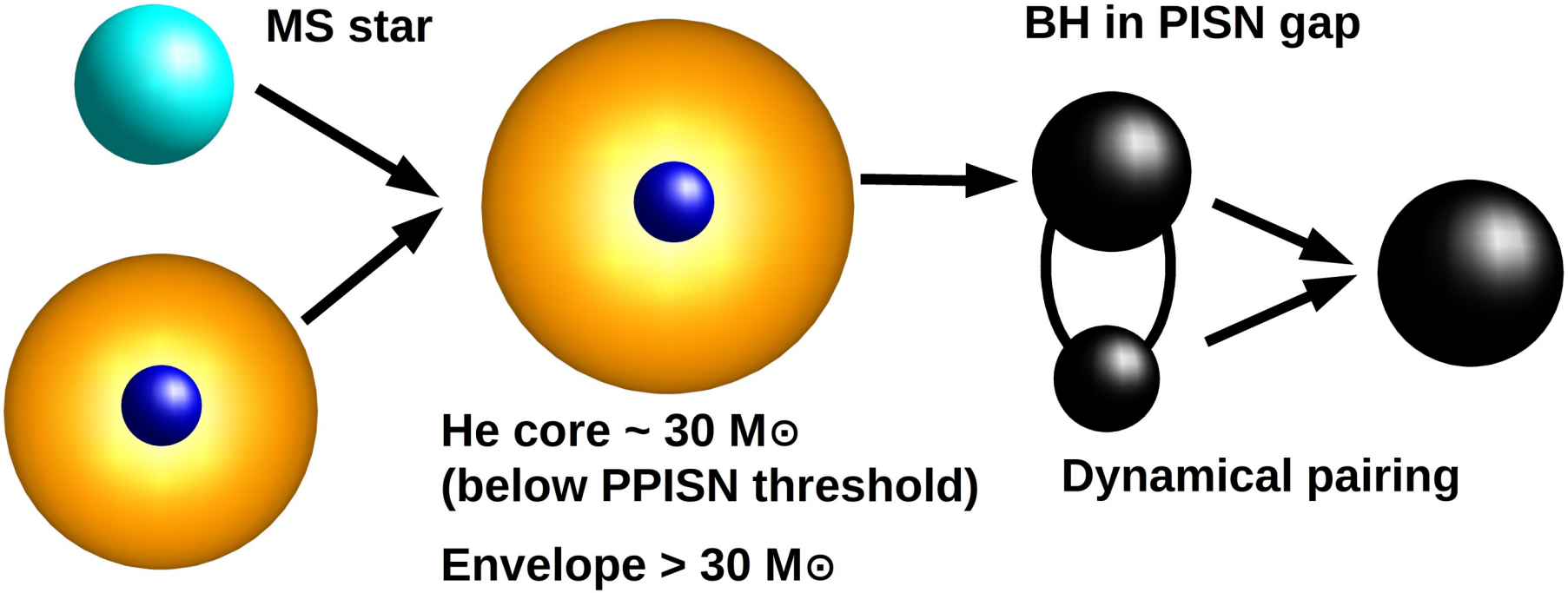
Dynamical BBHs with total mass > 80 M⊙

~0.5% BBH mergers with mass in the pair instability mass gap, corresponding to ~ 5% of detectable events

Di Carlo, MM et al. 2020b, https://arxiv.org/abs/2004.09525



4. GW190521 from dynamics?



My preferred scenario for GW190521 :)

Di Carlo et al. 2019, https://arxiv.org/abs/1901.00863

Di Carlo, MM et al. 2020a, https://arxiv.org/abs/1911.01434

See also Kremer et al. 2020, https://arxiv.org/abs/2006.10771
Renzo et al. 2020, https://arxiv.org/abs/2010.00705

Thank you

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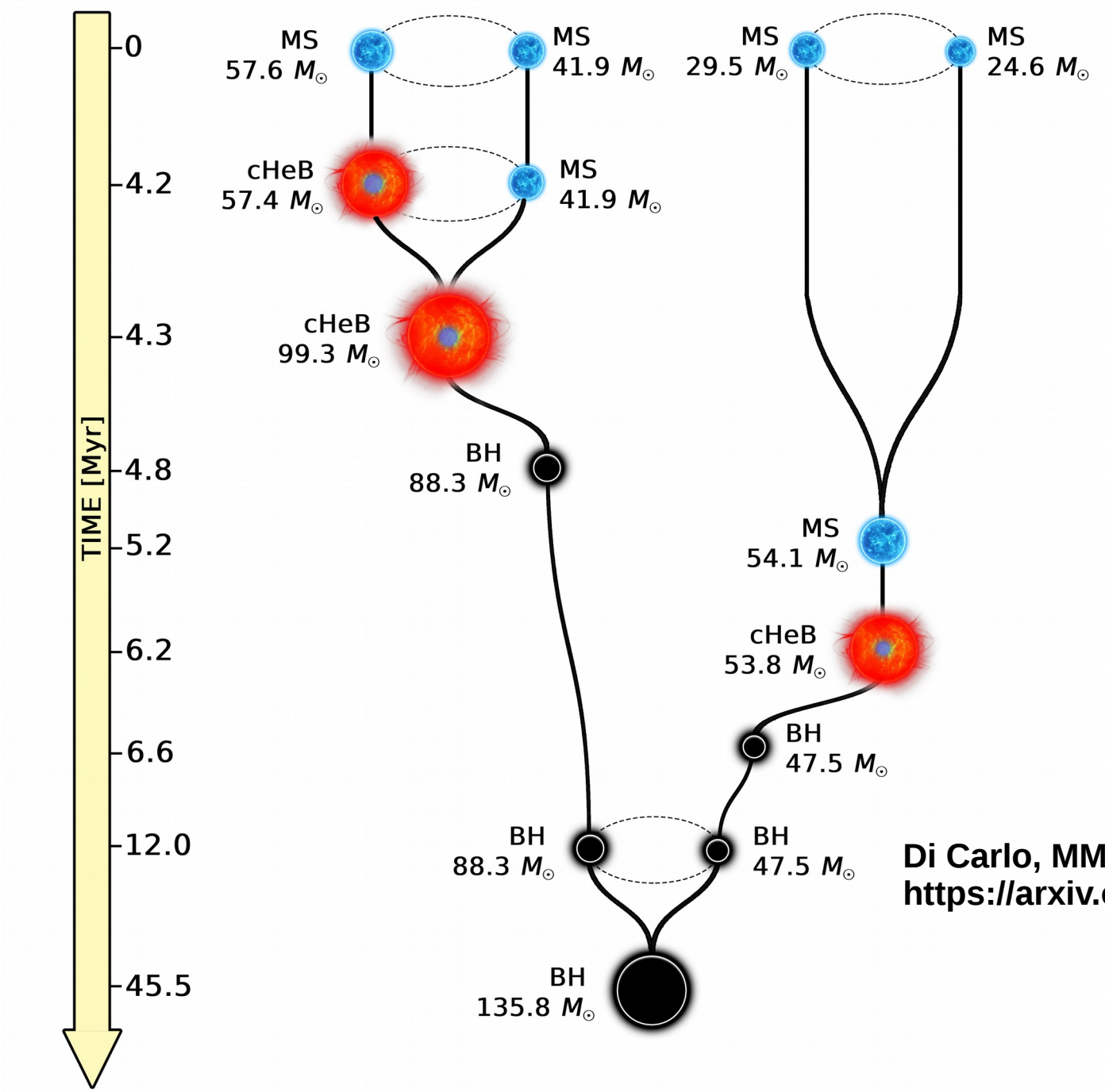
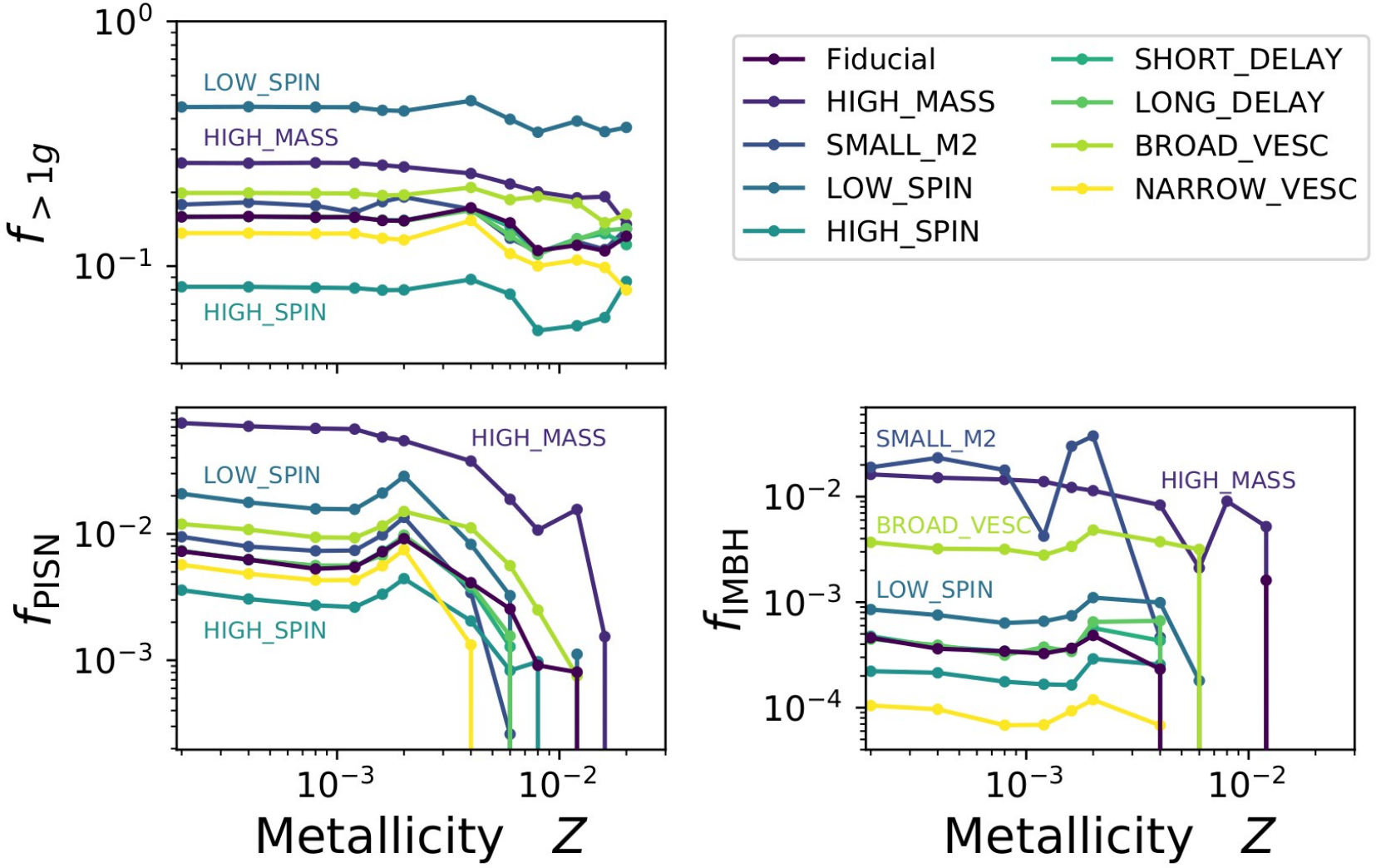
GW190521 from dynamics? Stellar merger



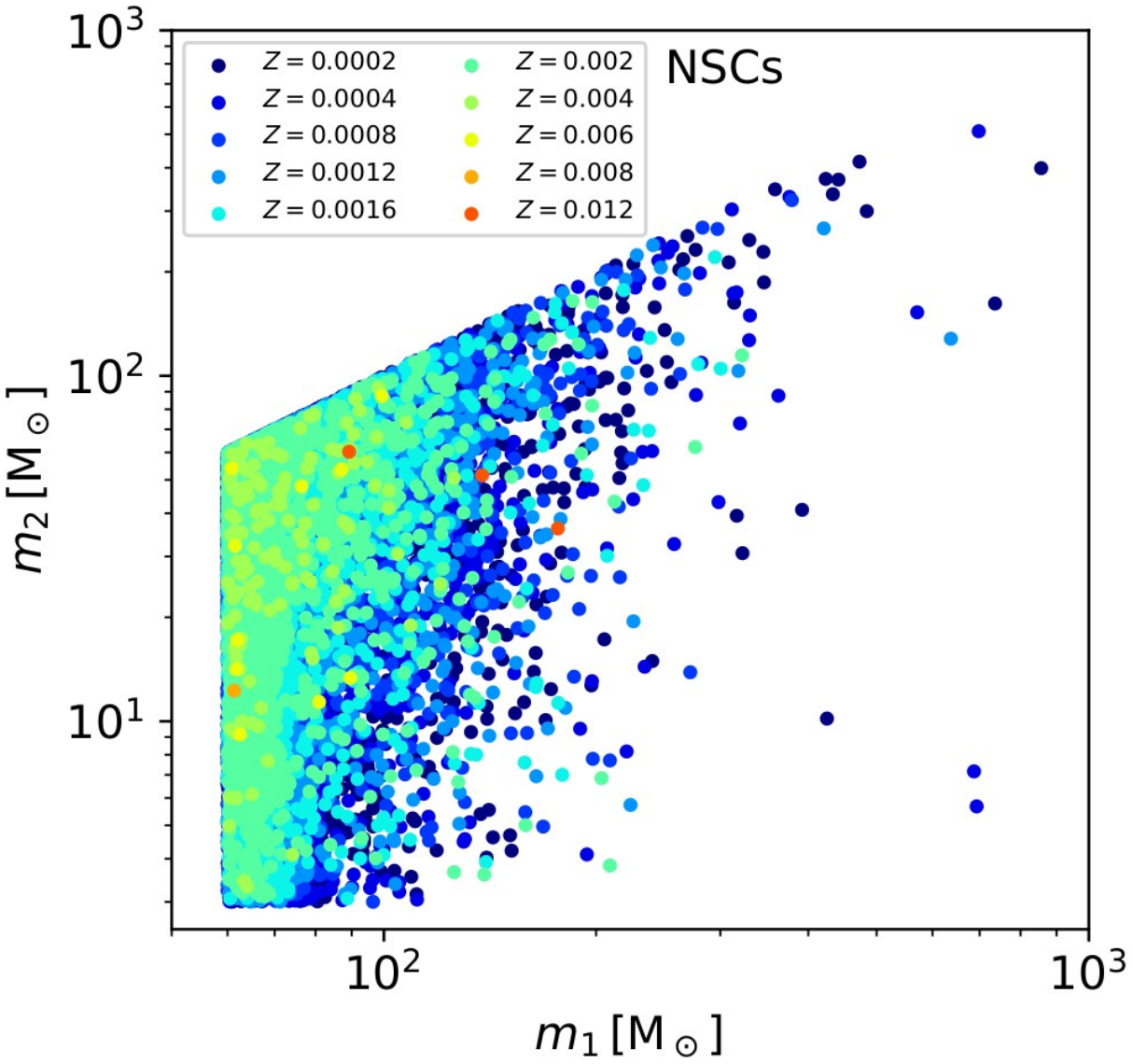
Di Carlo, MM et al. 2020b, https://arxiv.org/abs/2004.09525

GW190521 from dynamics? Hierarchical scenario



MM et al. 2020,
https://arxiv.org/abs/2007.15022

GW190521 from dynamics? Hierarchical scenario



MM et al. 2020,
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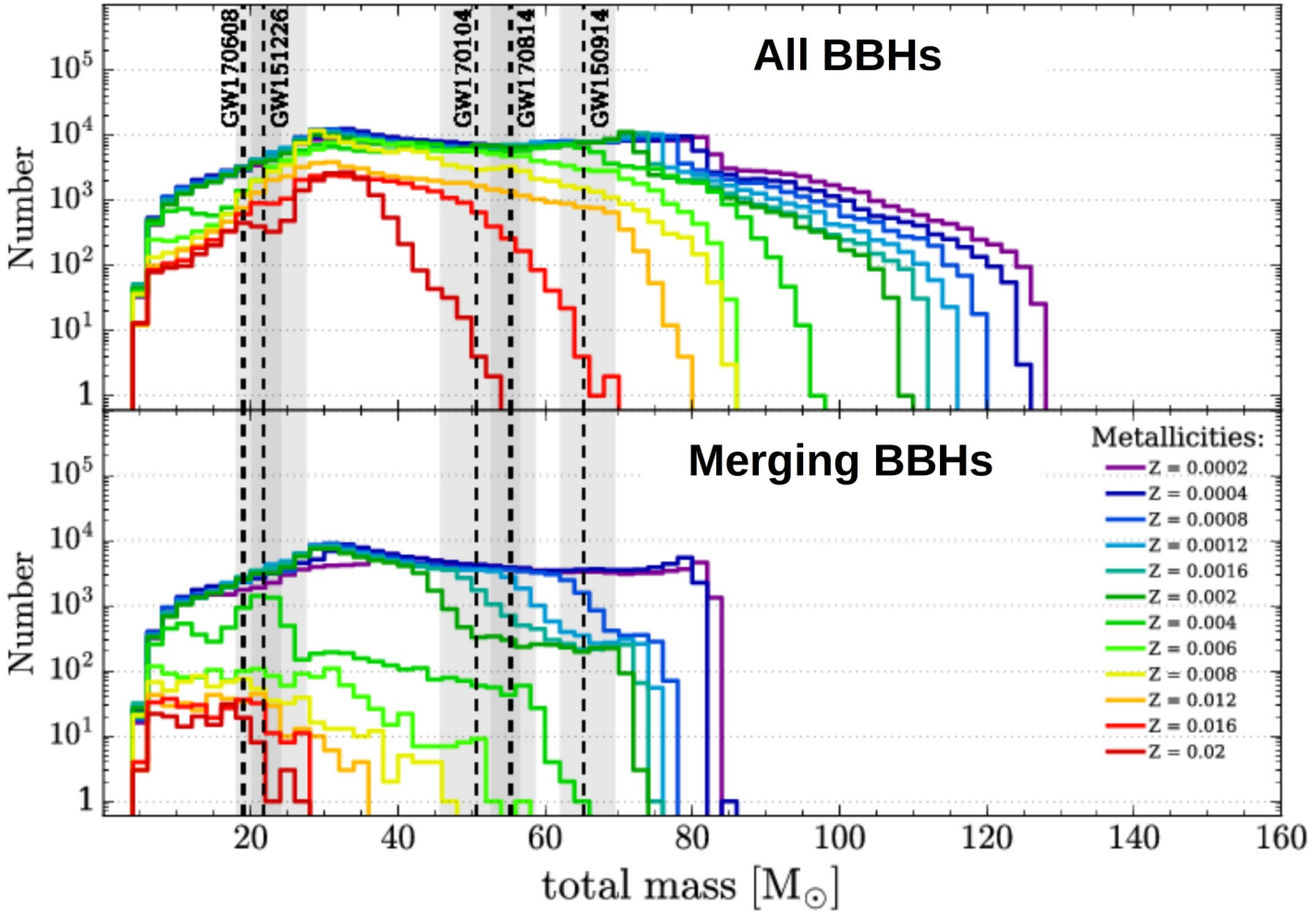
Formation channels of BBHs: isolated

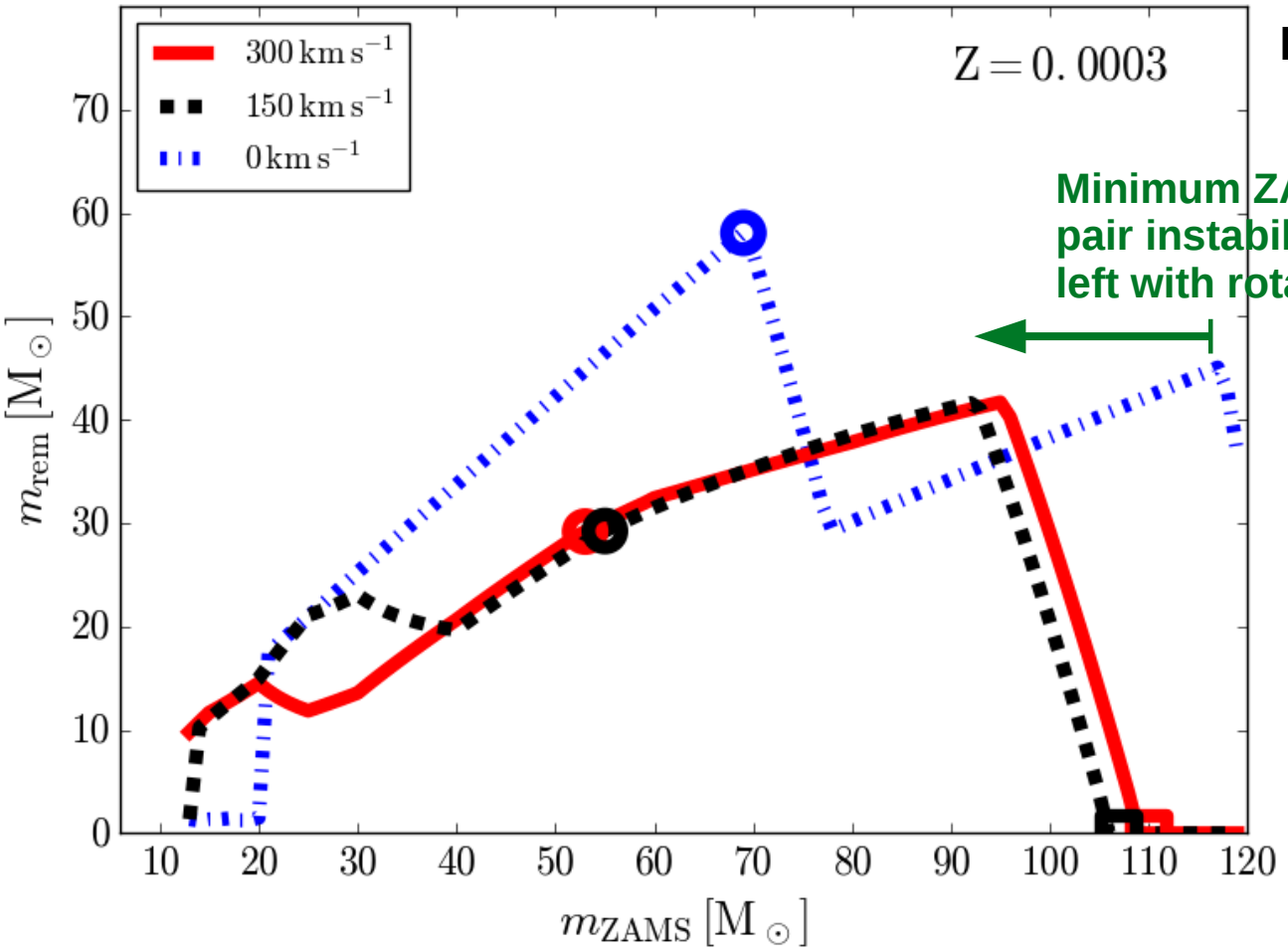


Giacobbo & MM 2018; Spera et al. 2019

*** Mass and number of BBHs depend on metallicity (Z)**

*** BHs with mass ≤ 65 $M_\odot$ form, but only BHs with mass ≤ 40 $M_\odot$ merge in isolation (wait for dynamics..)**

The mass of black holes: impact of ROTATION



MM et al. 2020

Minimum ZAMS mass for pair instability shifts to the left with rotation

Larger core → PISNe and PPISNe start at lower ZAMS

Higher mass loss → H envelope completely lost

Smaller BH mass in rotating stars

MM et al. 2020 using FRANEC models, Limongi & Chieffi 2018