AG Meeting 2026, Munich, 11 September 2026

Astronomische Gesellschaft
German Astronomical Society

Black hole mergers:
insights from hundreds of gravitational wave data

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Heidelberg University

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

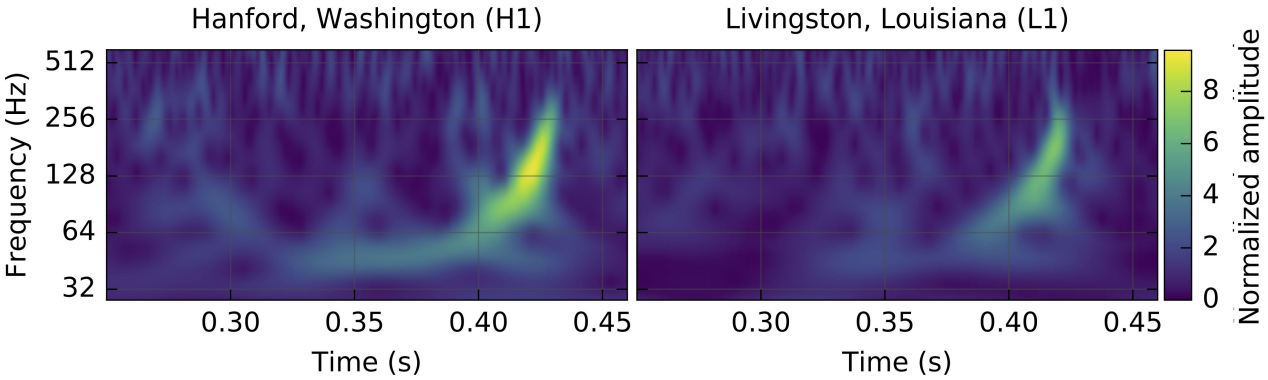
STRUCTURES CLUSTER OF EXCELLENCE

Main collaborators: Lumen Boco, Christian Burt, Lukas Fluegel, Giuliano Iorio, Boyuan Liu, Daniel Marin-Pina, Johanna Mueller-Horn, Irene Paulus, Stefano Rinaldi, Cecilia Sgalletta, Maria Paola Vaccaro, & the LIGO-Virgo-KAGRA collaboration

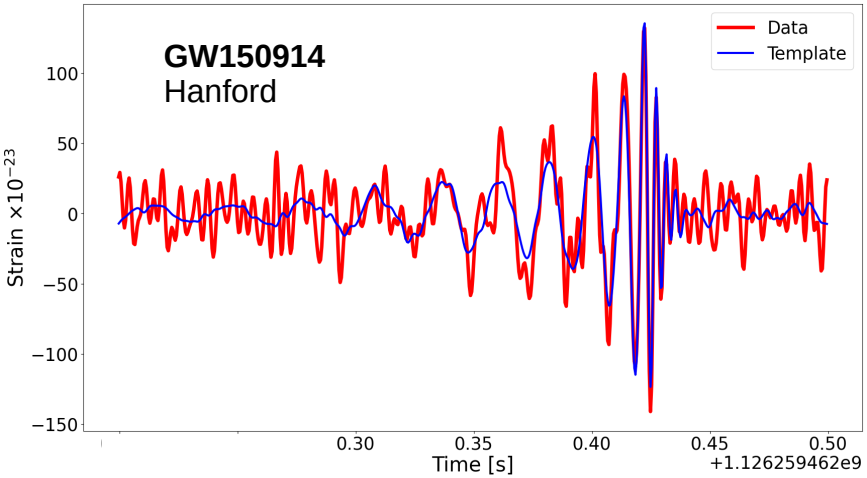
OUTLINE:

1. The Gravitational Wave Transient Catalog
2. The mass function
3. The merger rate density and natal kicks
4. Summary and outlook

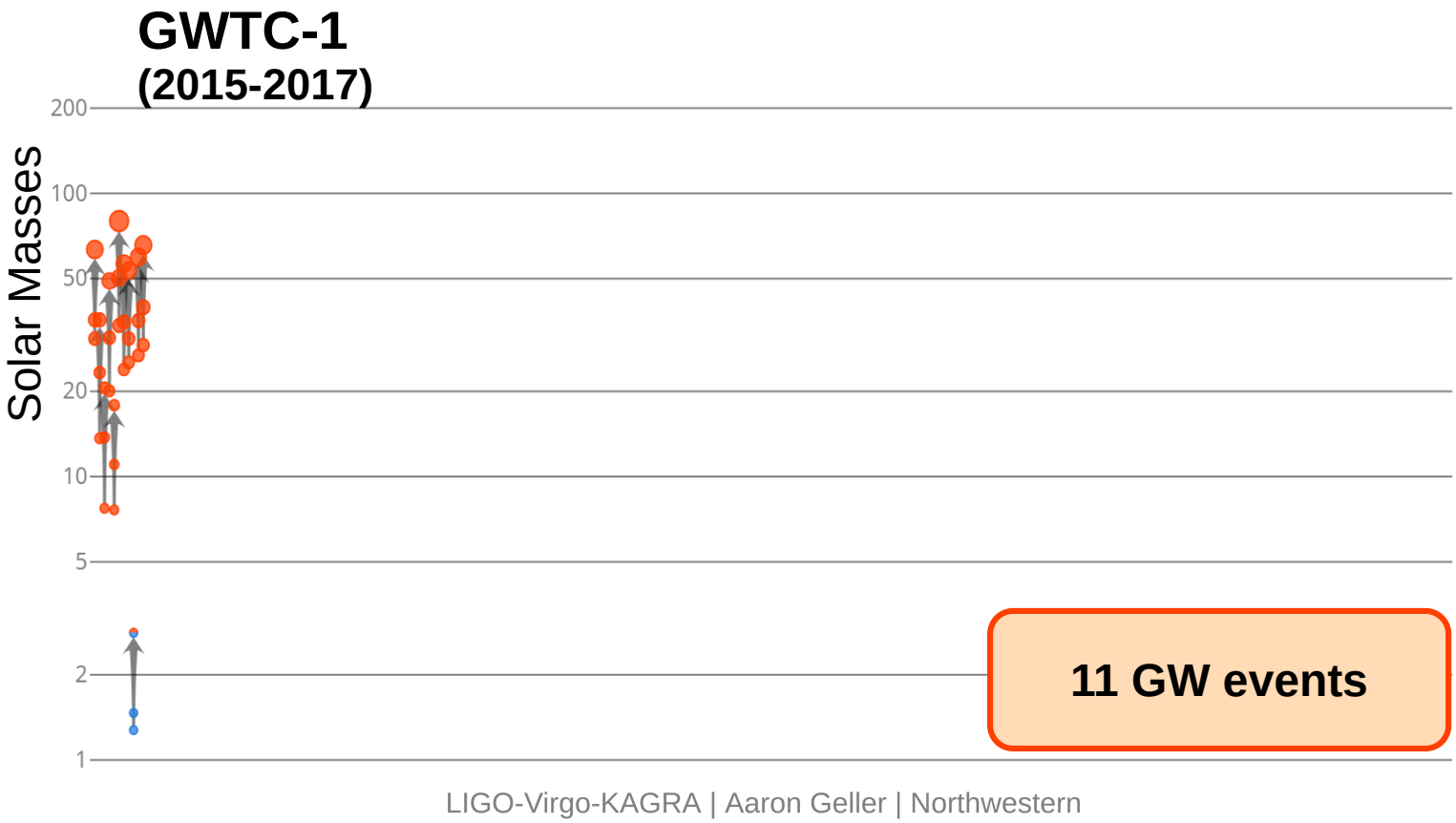
1. Almost exactly 11 years ago..



* First detection of gravitational waves
* First binary black hole
* First stellar-origin black hole masses > 20 Msun

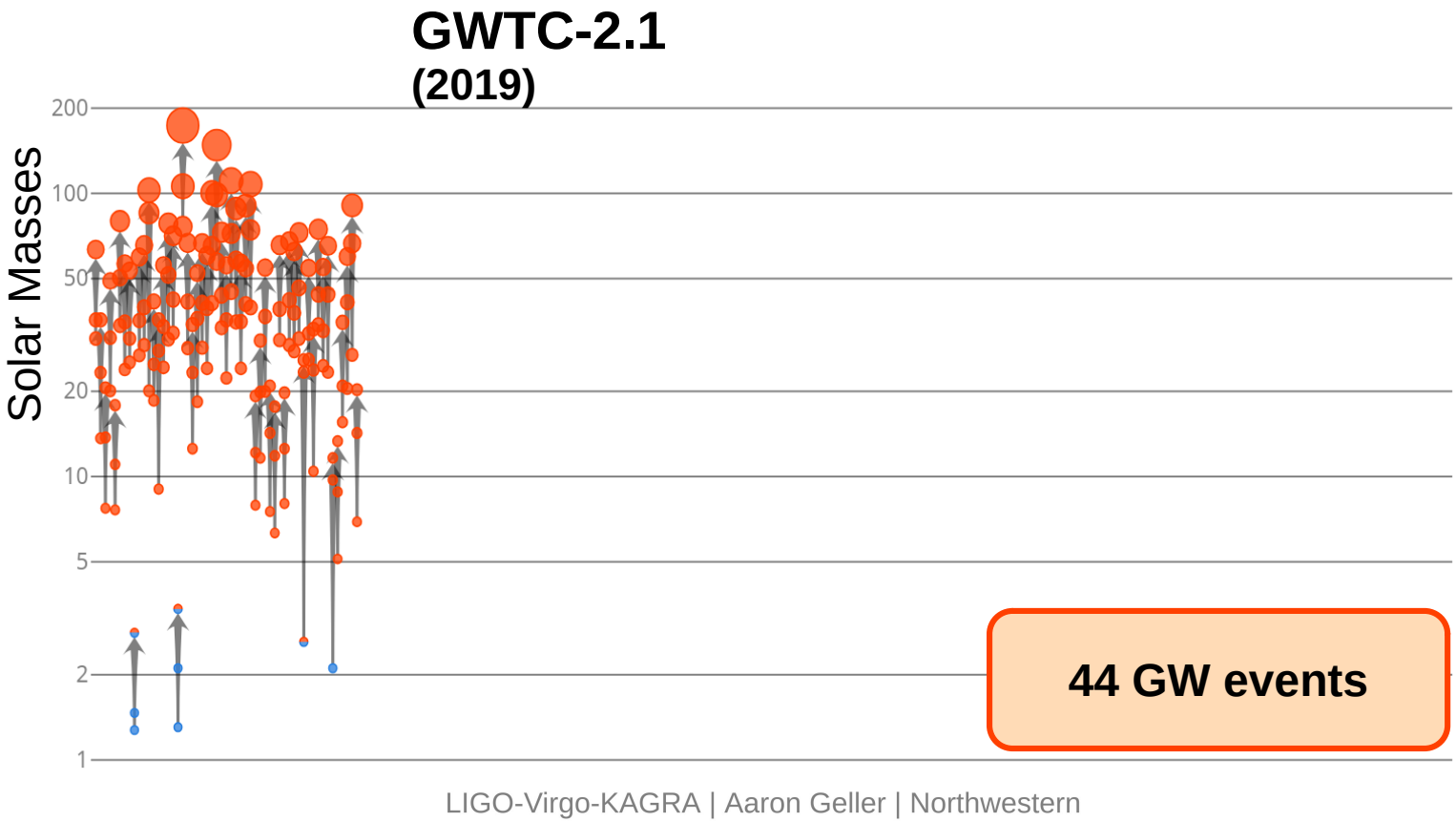


1. Black hole populations from GWTC-1: masses



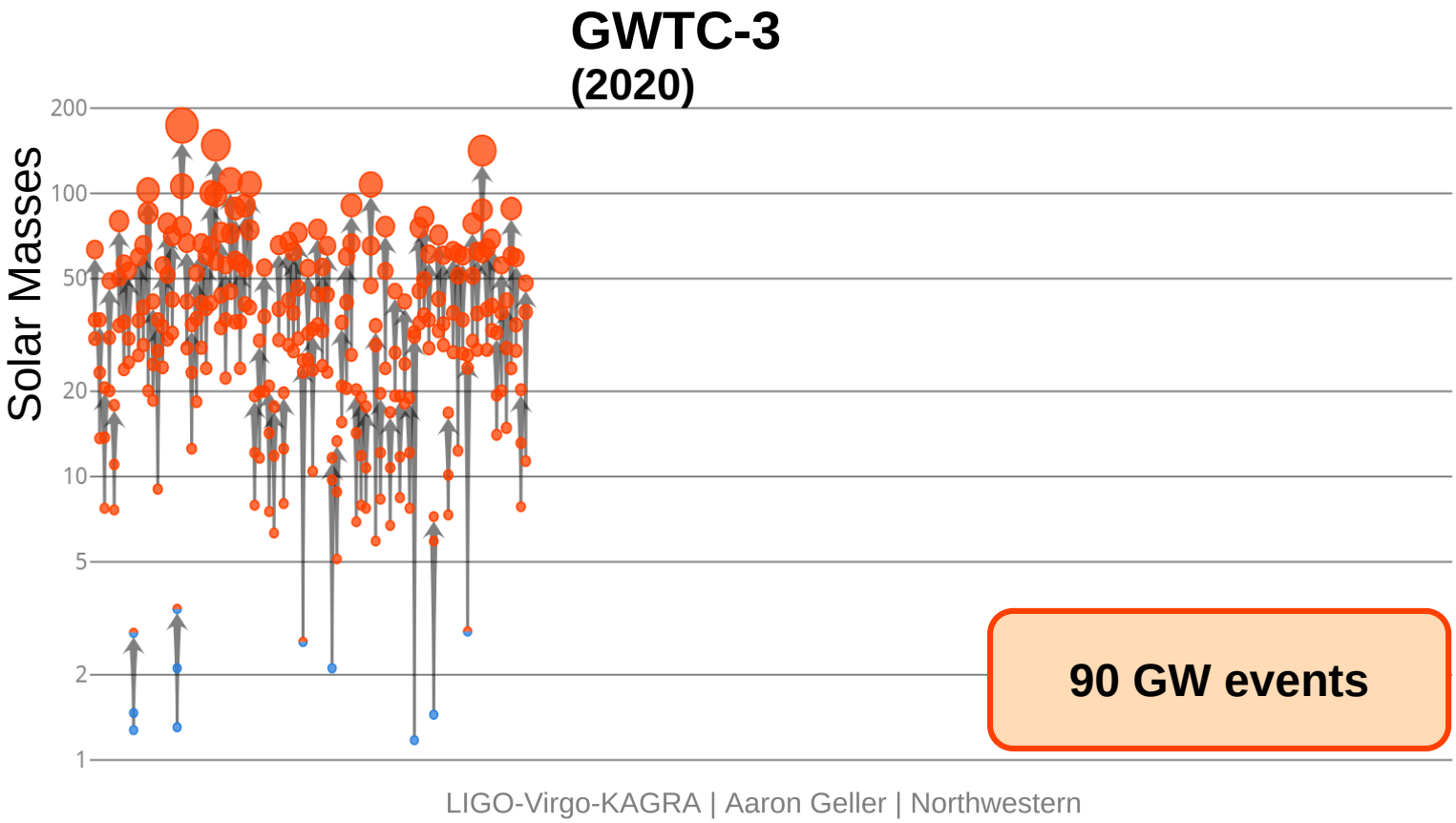
Abbott et al. 2019, GWTC-1

1. Black hole populations from GWTC-2: masses



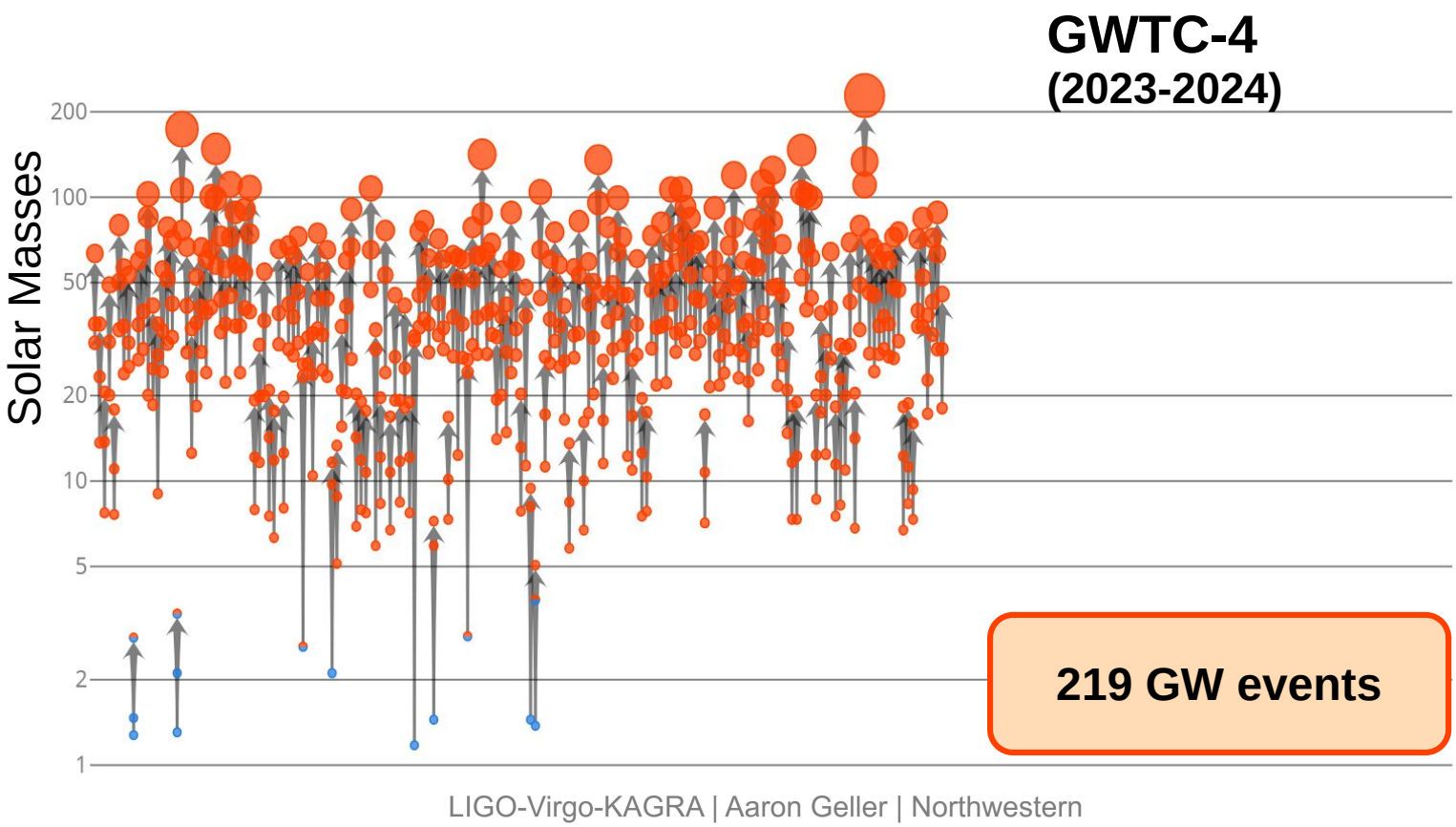
Abbott et al. 2024, GWTC-2.1

1. Black hole populations from GWTC-3: masses



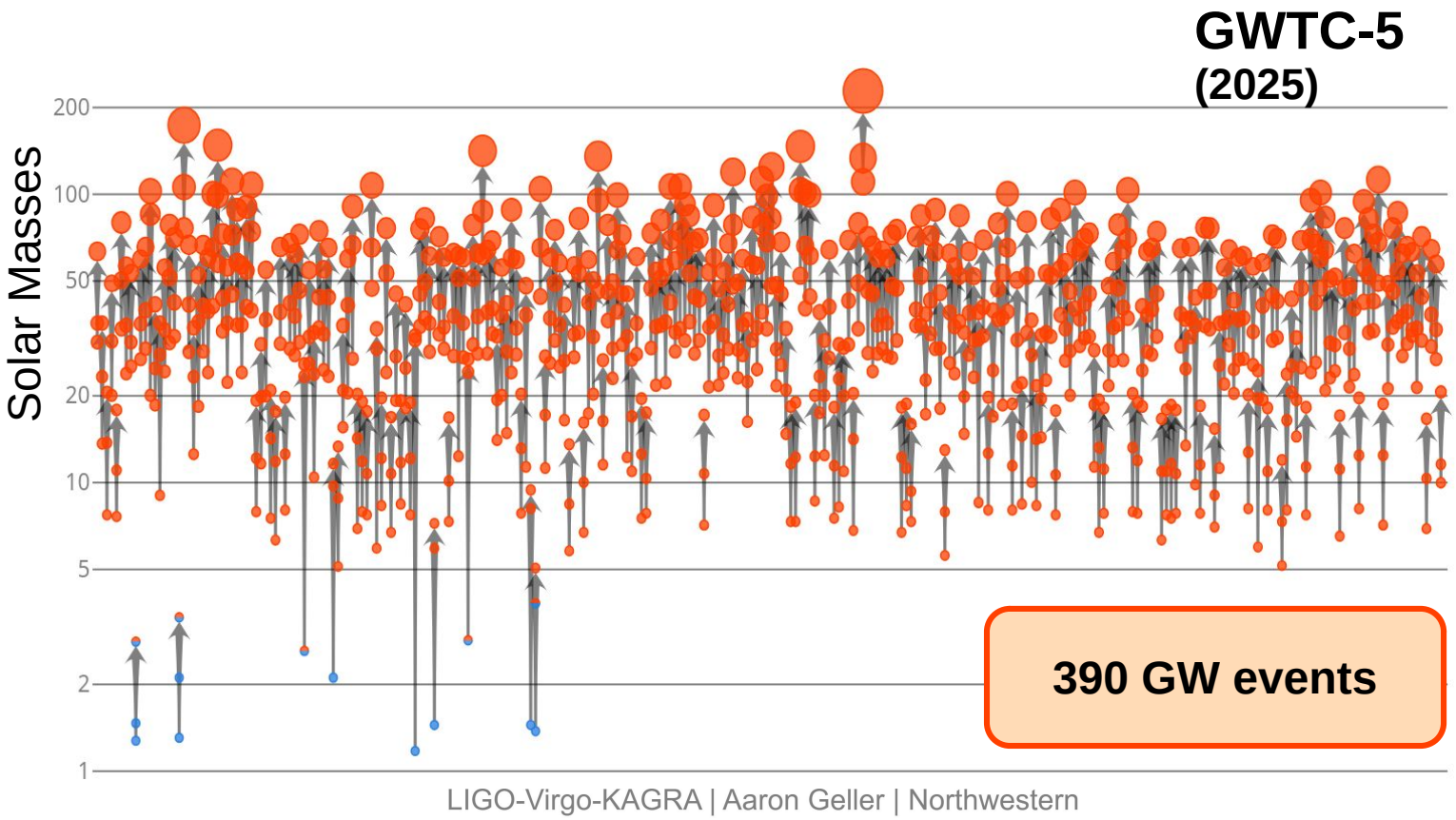
Abbott et al. 2023, GWTC-3

1. Black hole populations from GWTC-4: masses



GWTC-4 population paper, 2025

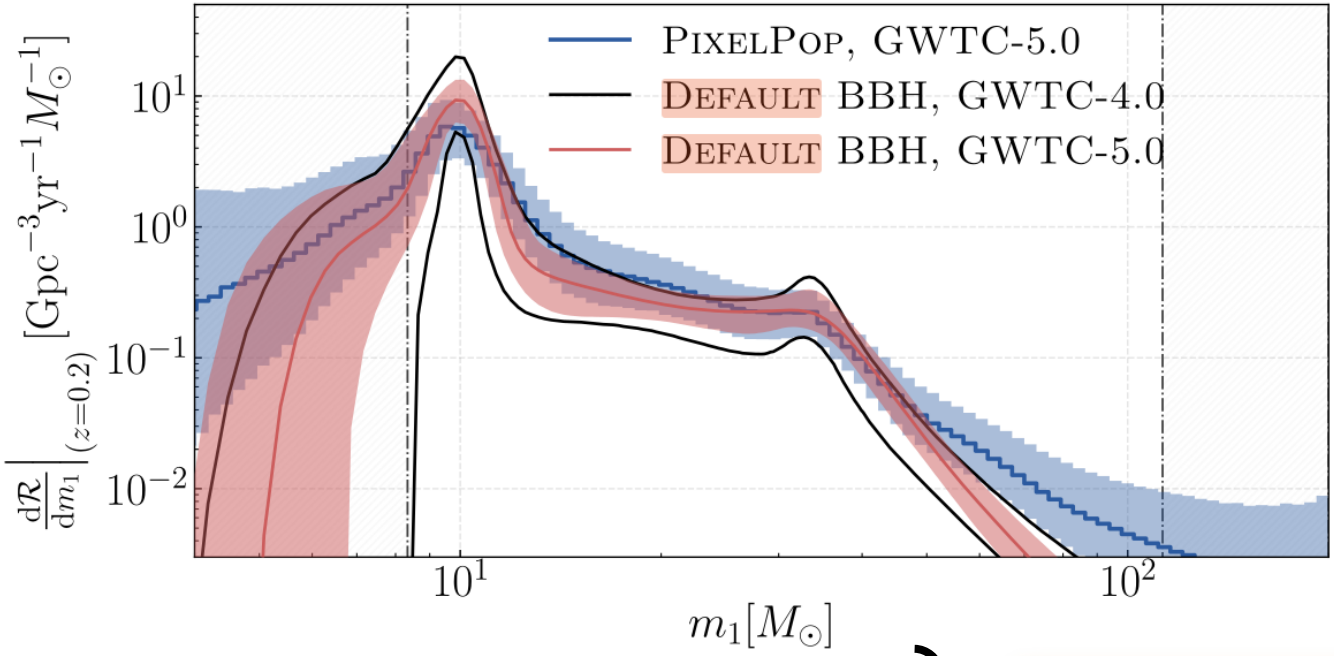
1. Black hole populations from GWTC-5: masses



New GWTC-5 population paper (https://arxiv.org/abs/2605.27226)

1. Black hole populations from GWTC-5: masses

GWTC-5 population paper

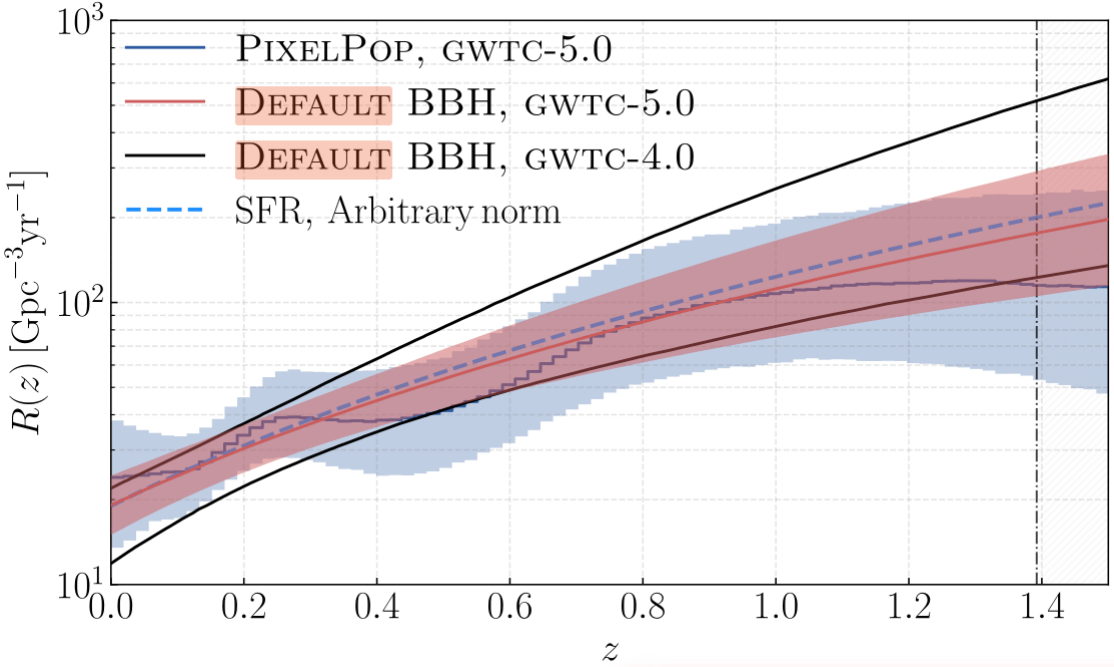


* Primary black hole mass 10 Msun peak
* Secondary feature: 35 Msun **edge**
* Long tail extending up to ~100 Msun → inside mass gap

Encode key information about the origin of black holes from their progenitor stars

1. The merger rate density from GWTC-5

GWTC-5 population paper



MERGER RATE DENSITY

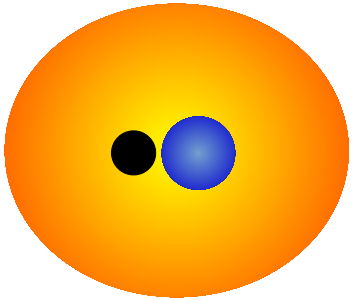
27.5–49.4 Gpc^{-3} yr^{-1} at redshift z = 0.2

for binary black holes
(90% credible interval)

Black hole rate is problematic for the models

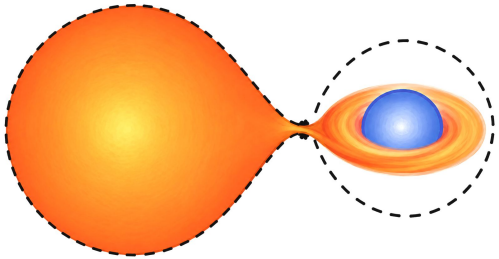
2. The zoo of binary black hole (BBH) formation channels

Binary evolution:
Common envelope
Bethe & Brown 1998;
Dominik et al. 2012

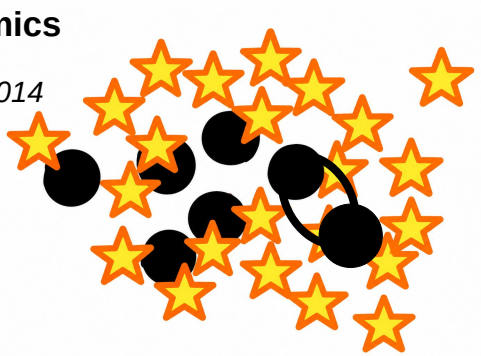


Triple evolution
Antonini, Toonen & Hamers 2017

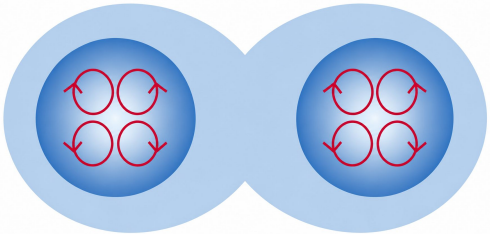




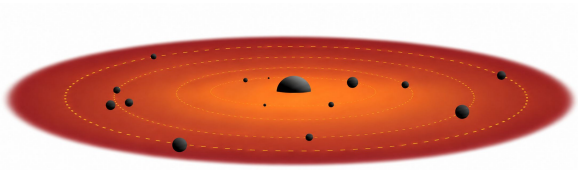
Dense Star Clusters' Dynamics
Portegies Zwart & McMillan 2000;
Tanikawa et al. 2013; Ziosi et al. 2014



Binary evolution:
stable mass transfer
Giacobbo et al. 2018;
Bavera et al. 2021



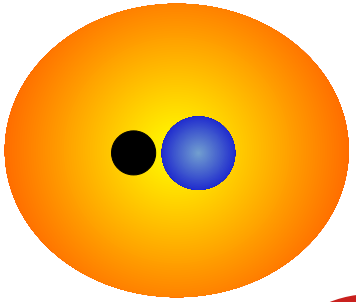
Chemically homogeneous binary evolution
Marchant et al. 2016;
Mandel & de Mink 2016



AGN disk scenario
McKernan et al. 2012; Bartos et al. 2017

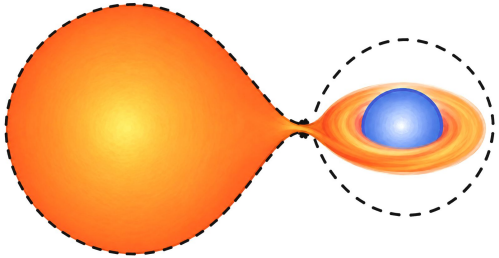
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Binary evolution:
Common envelope
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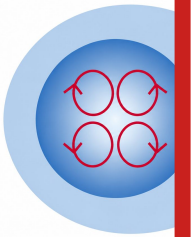


Triple evolution
Antonini, Toonen & Hamers 2017





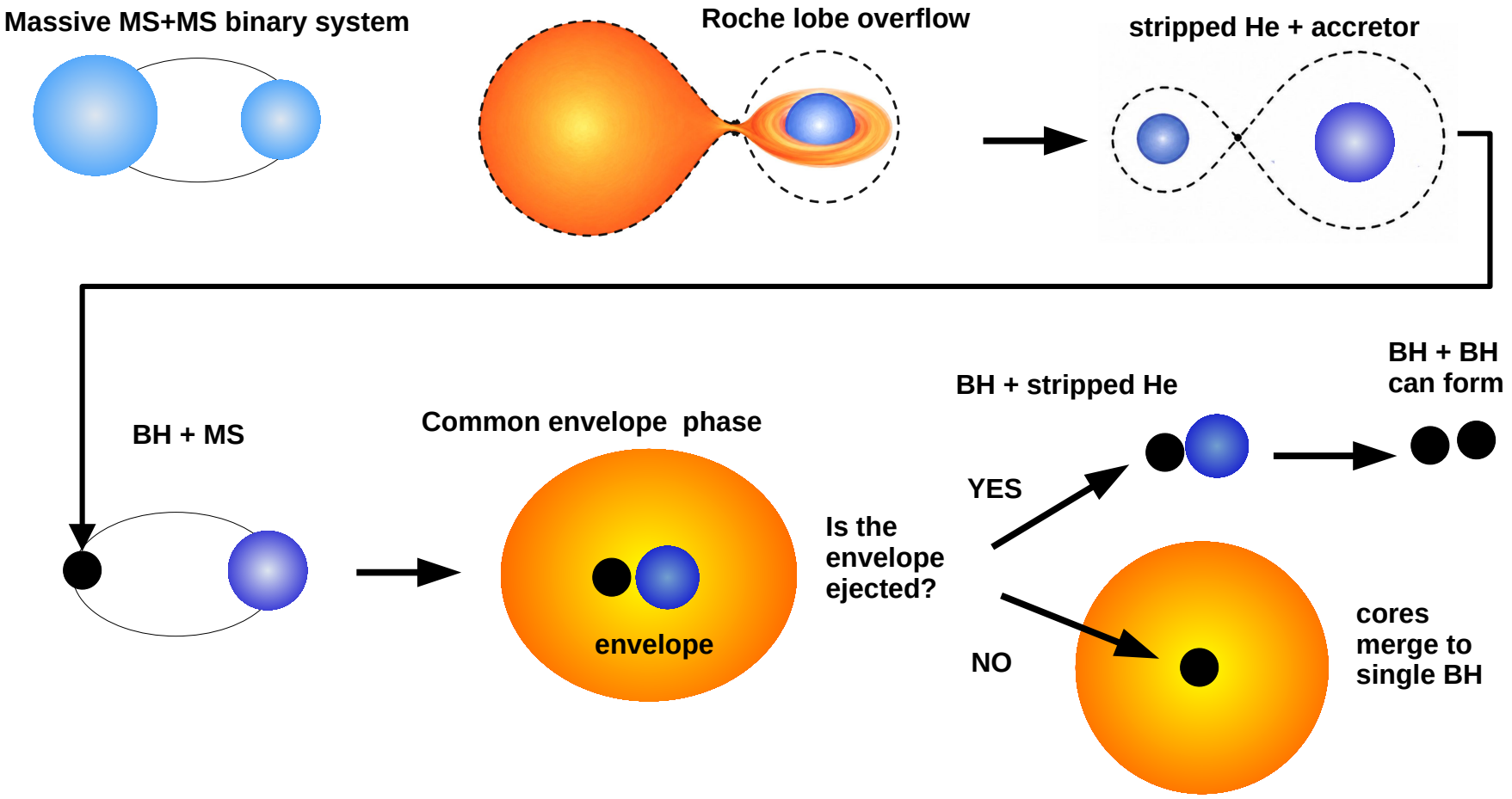
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Giacobbo et al. 2018;
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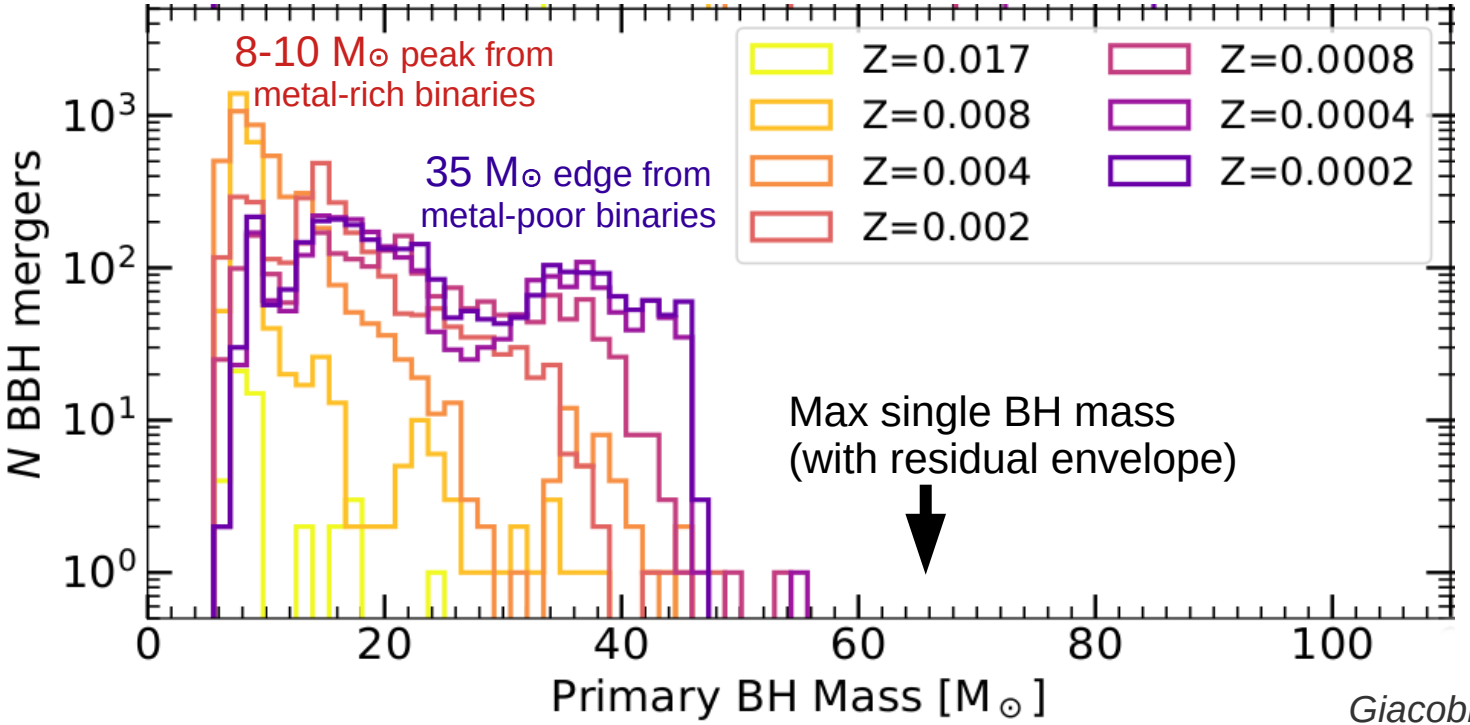
Chemically ho
binary evolutio
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Mandel & de Mink 2016

NO TIME to talk about DYNAMICS: ask me if interested!

2. Mass of binary black holes from isolated binary evolution



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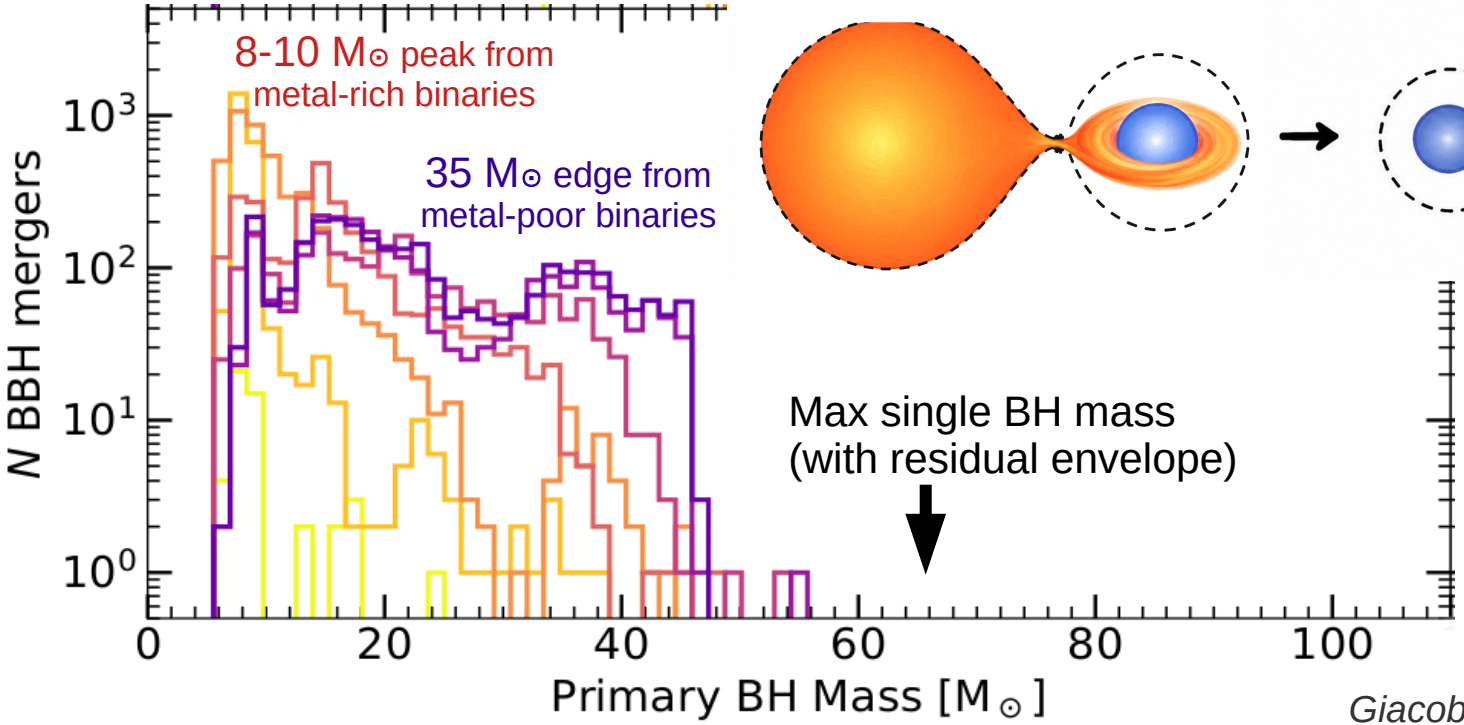


SEVN code
download link

Giacobbo & MM 2018
Iorio, MM, et al. 2023

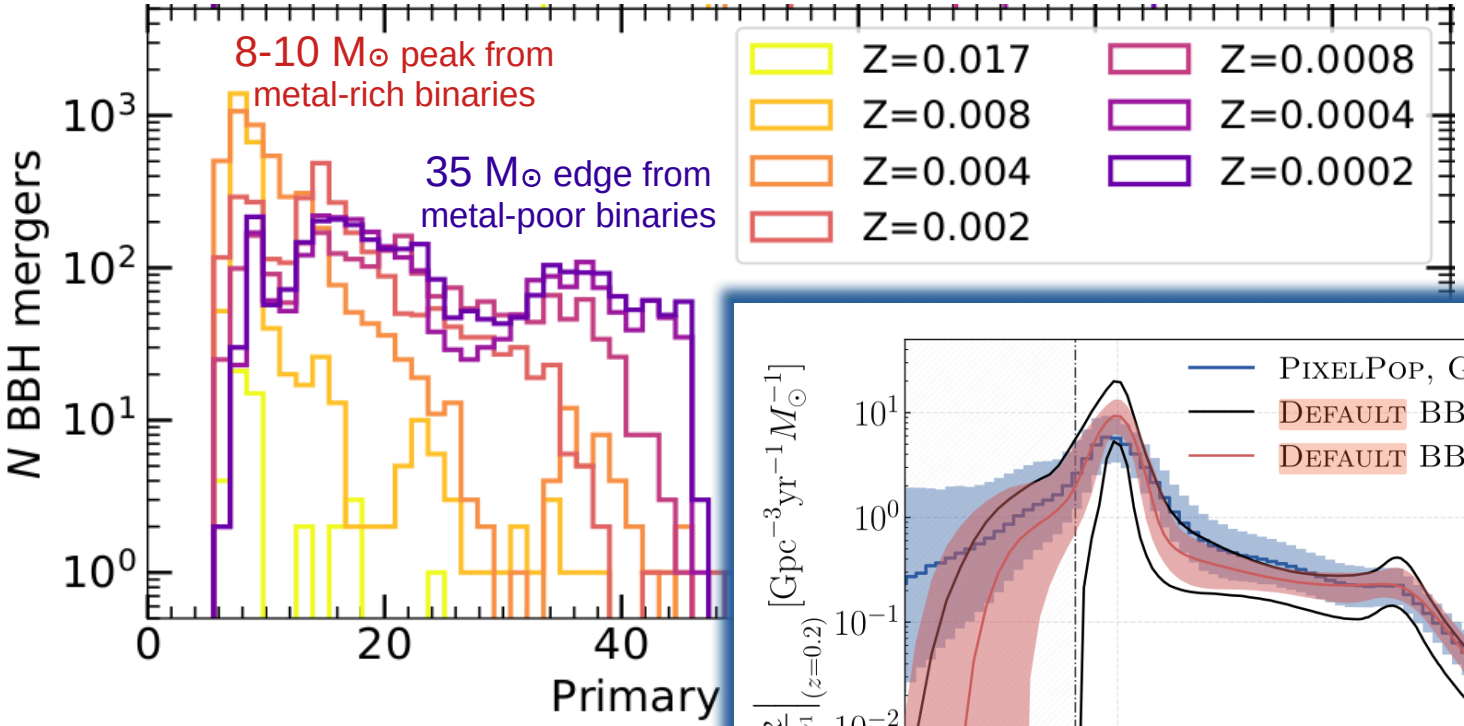
2. Mass of binary black holes from isolated binary evolution

Interpretation of the 35 Msun edge: maximum stripped core mass to lead to a binary black hole (BBH) merger

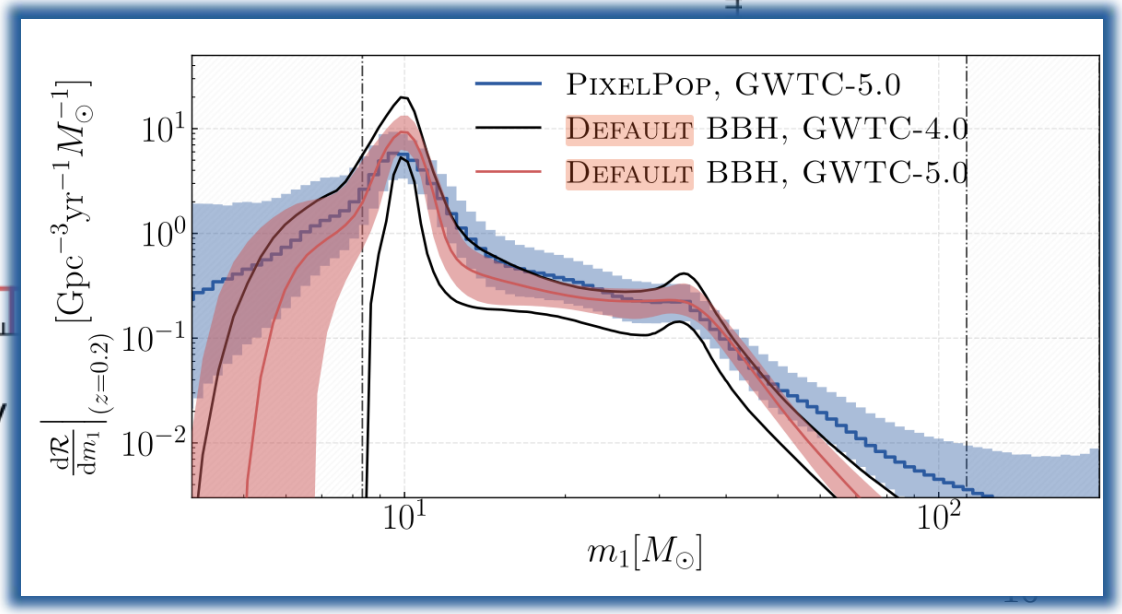


Giacobbo & MM 2018
Iorio, MM, et al. 2023

2. Mass of binary black holes from isolated binary evolution



SEVN code
download link



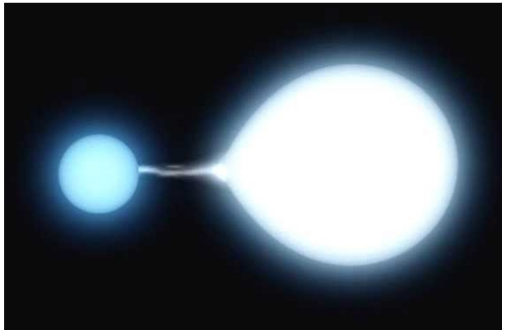
3. How to calculate the rate?

Synthetic galaxies

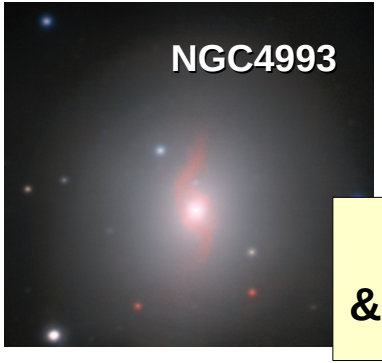


star formation
and metallicity

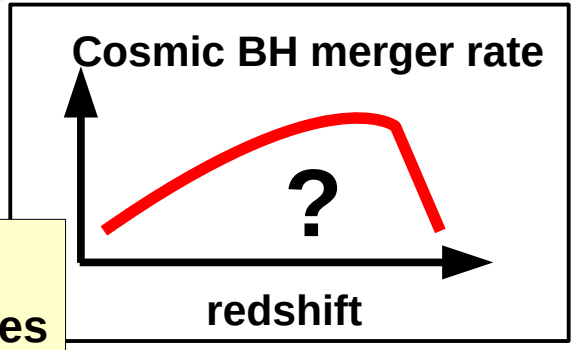
Binary compact object catalogs



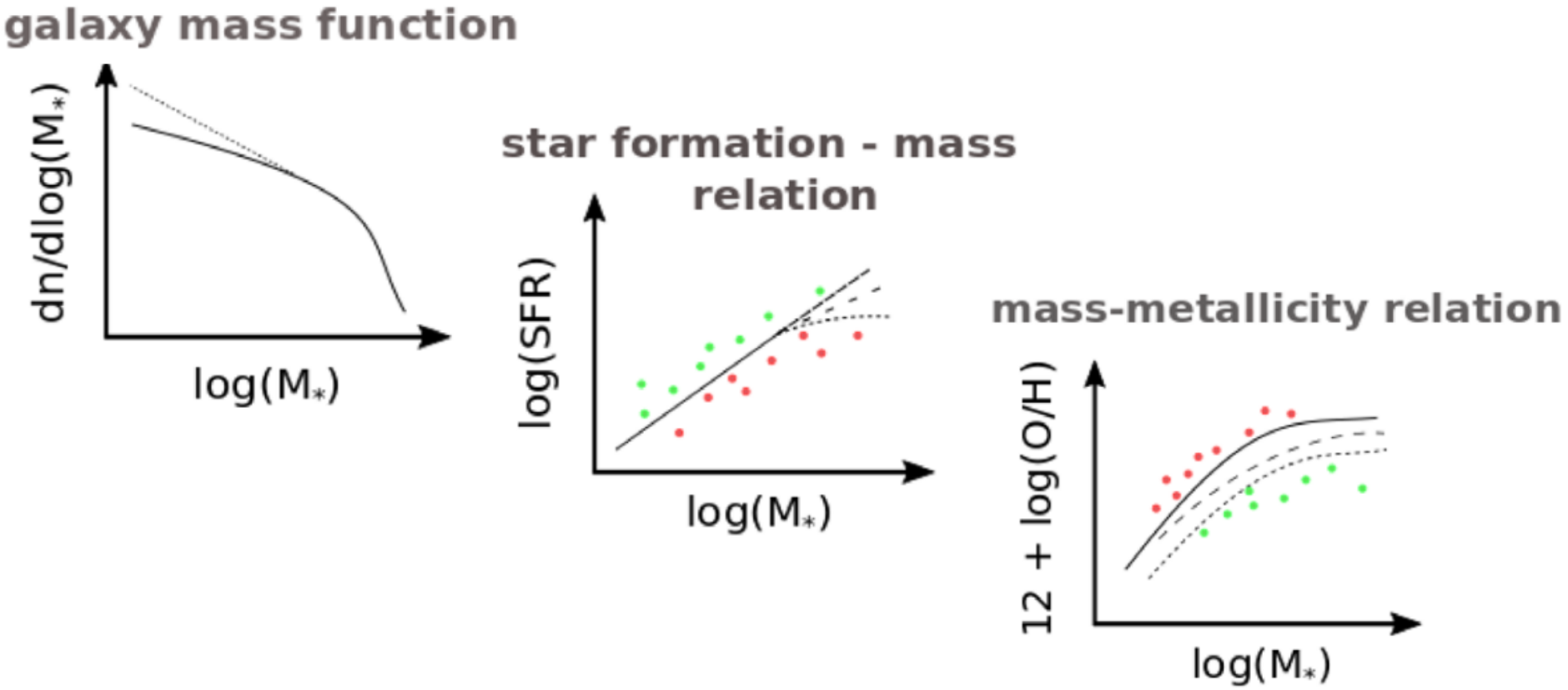
semi-analytic model



Cosmic merger rate
& host galaxy properties



3. How to calculate the rate? Mass – Metallicity – SFR relation



Chruslinska et al. 2019

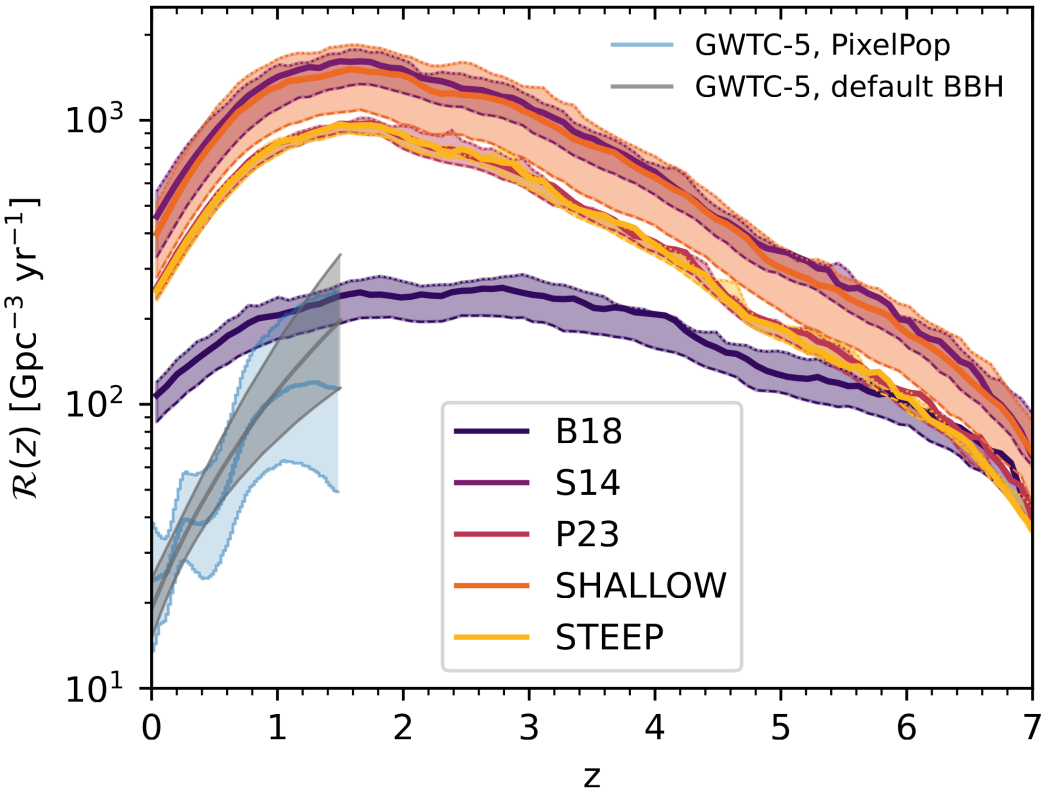
3. The merger rate density from GWTC-4: tension with the models

Isolated binary evolution

Excess of simulated BBH mergers compared to LVK rate

cannot be explained with metal-dependent cosmic SFR

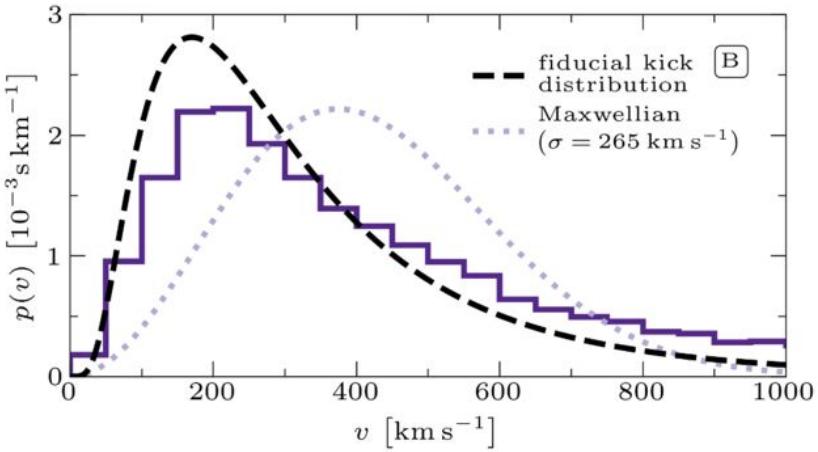
Problem with progenitor star's evolution? Natal kicks?



Sgalletta, MM, et al. 2025
https://arxiv.org/abs/2410.21401

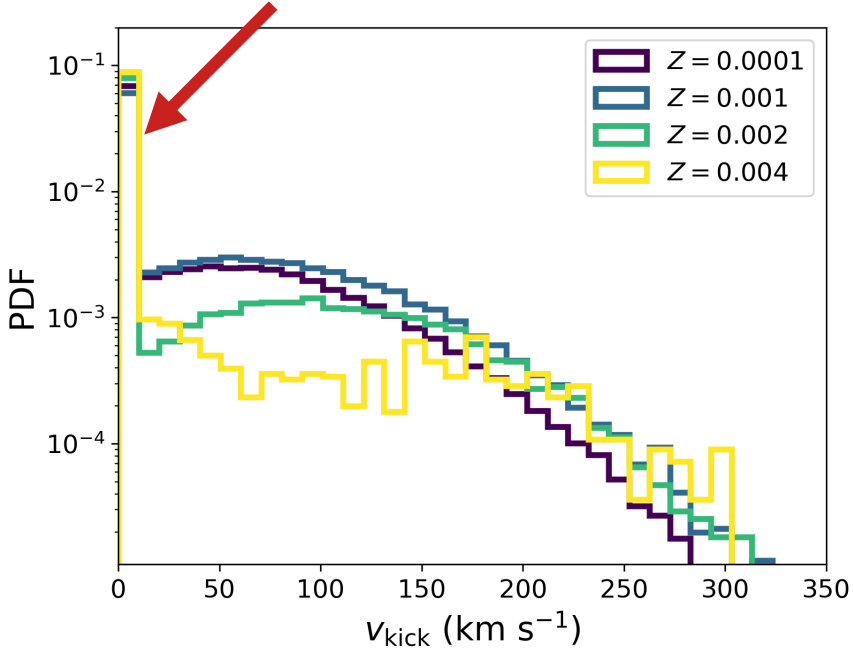
3. BBH merger rate density with high kicks

Natal kicks of neutron stars



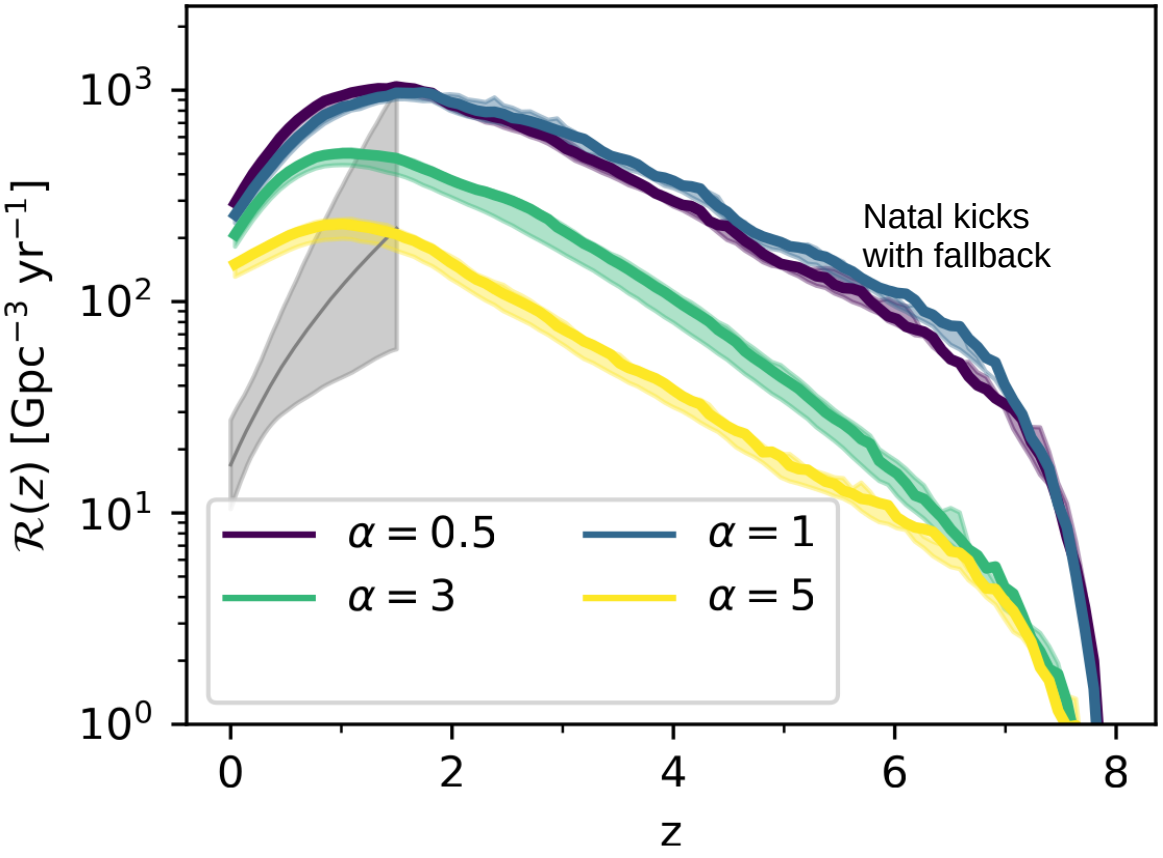
Disberg & Mandel 2025

Natal kicks of black holes with fallback assumption: **lower natal kicks**



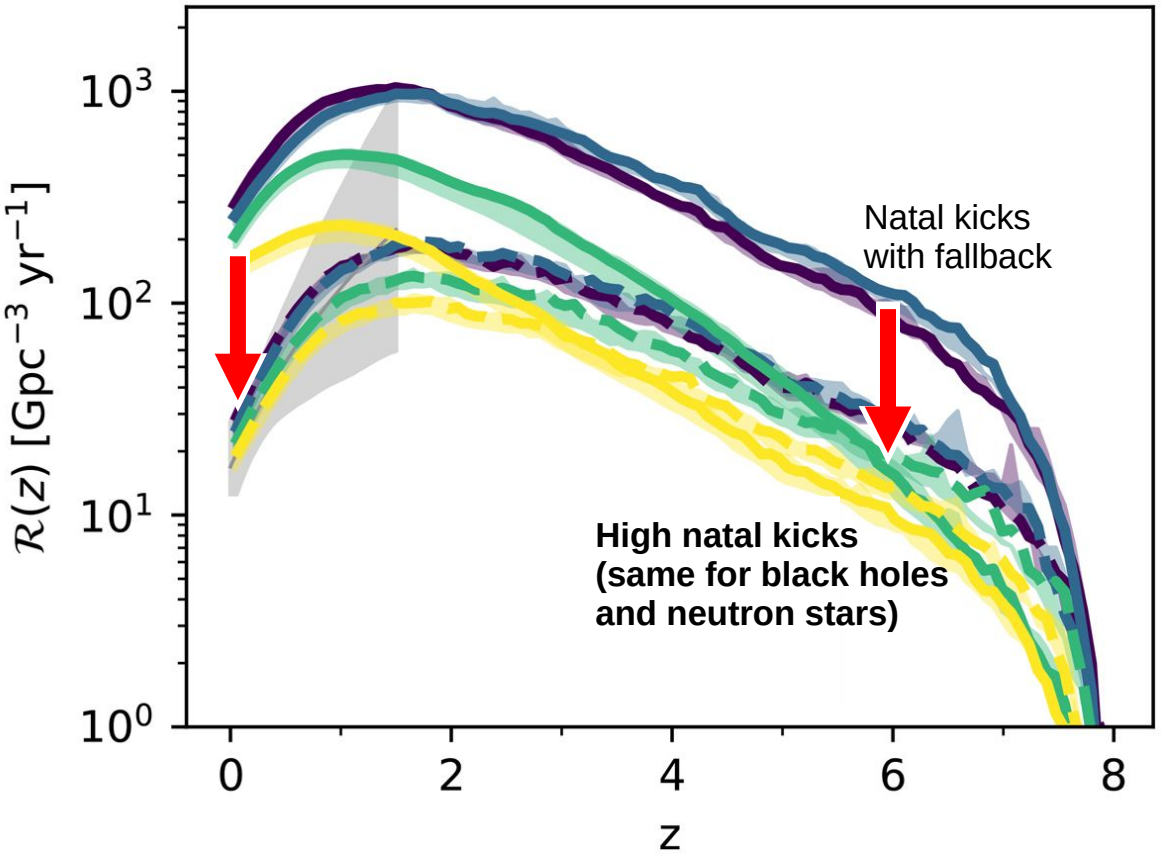
Fryer et al. 2012, Giacobbo & MM 2020

3. BBH merger rate density with high kicks



Sgalletta, MM et al. 2025
https://arxiv.org/abs/2410.21401

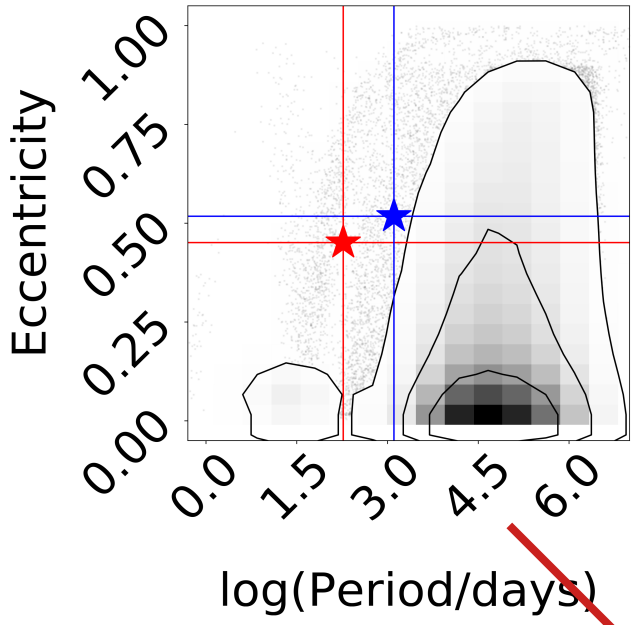
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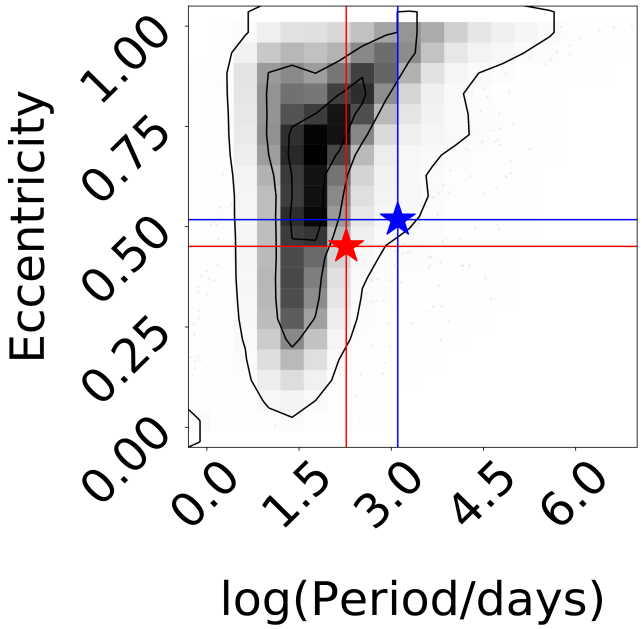
Sgalletta, MM et al. 2025
https://arxiv.org/abs/2410.21401

3. Some help from Gaia DR4 black hole binaries?

Gaia BHs with fallback kicks:
Long-period systems survive



Gaia BHs with high kicks:
Long-period systems split



Invisible in Gaia DR3 visible in DR4

MM et al. 2026,
https://arxiv.org/abs/2604.12839

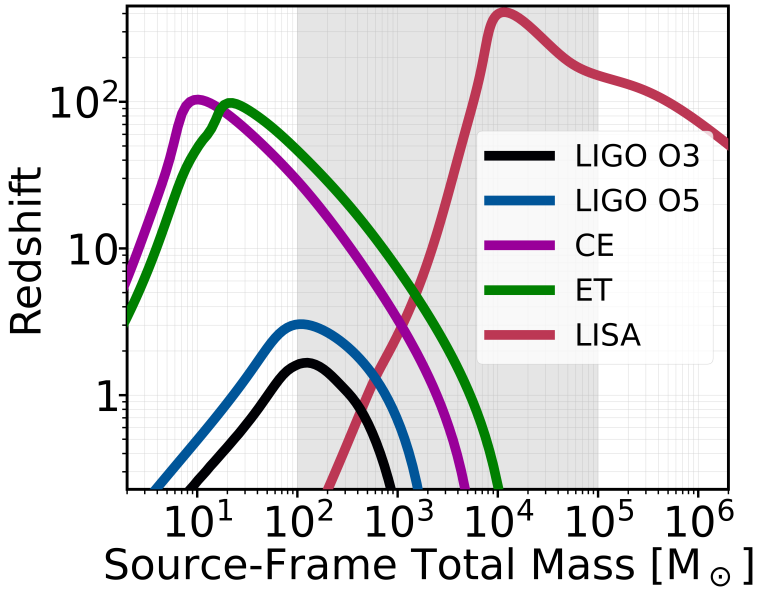
4. Summary and outlook

- Problem with the merger rate density of BBHs
- Accurate models of host galaxies cannot solve it
- BBH natal kicks might provide the solution
- Gaia DR4 coming by the end of year will provide complementary constraints

- **Next-gen gravitational-wave detectors**

  ~10^5 binary black hole detections / yr

  Mergers up to z = 100, 16 Myr after Big Bang



THANK YOU

See you in Heidelberg for the AG 2027!

UNIVERSITÄT HEIDELBERG
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