# Could population III binary stars be the progenitors of massive stellar black hole binaries?

Istituto Nazionale di Fisica Nucleare

SAPIENZA UNIVERSITÀ DI ROMA

EuroHPC Joint Undertaking


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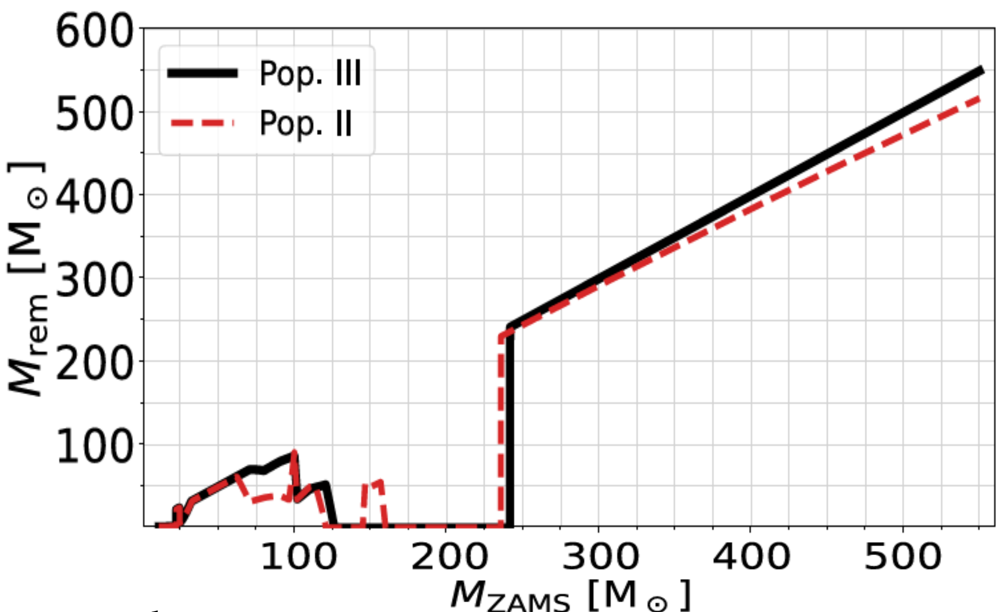


Costa et al. MNRAS, 2023

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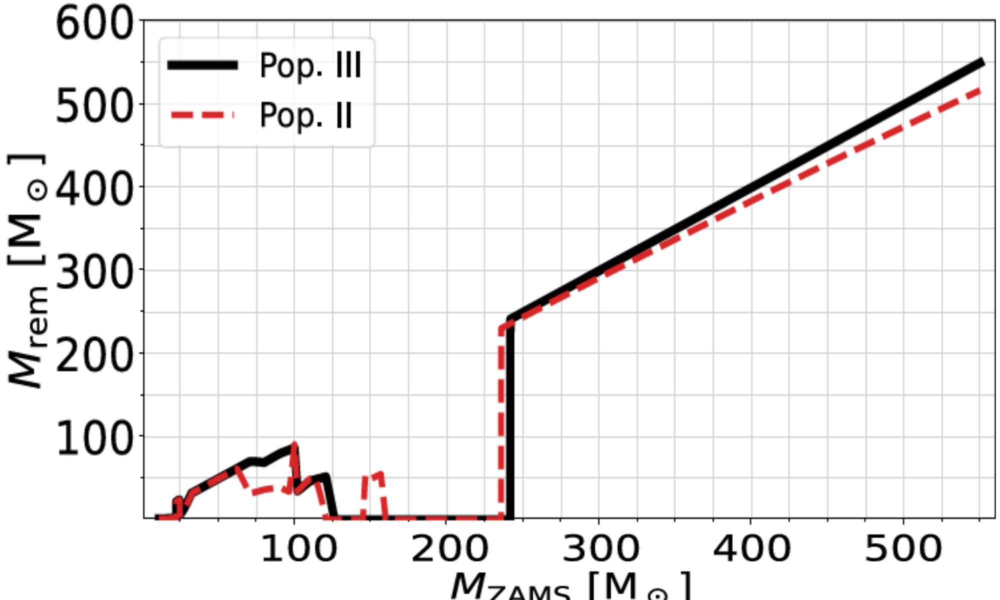
- Delay time $\gtrsim Gyrs$ → Merger redshift within $z \sim 1$.

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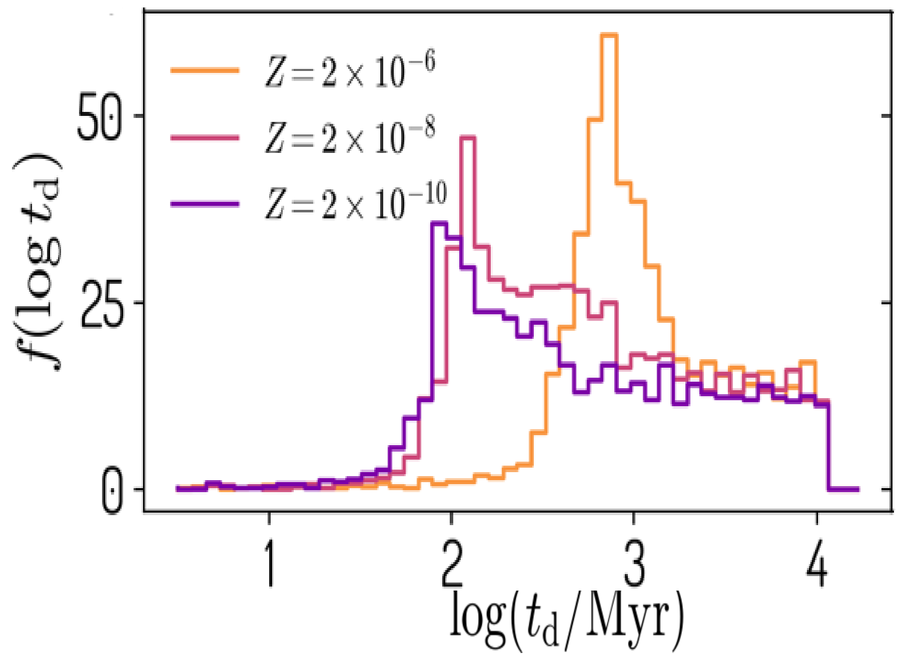


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- 60 % O3 events contains

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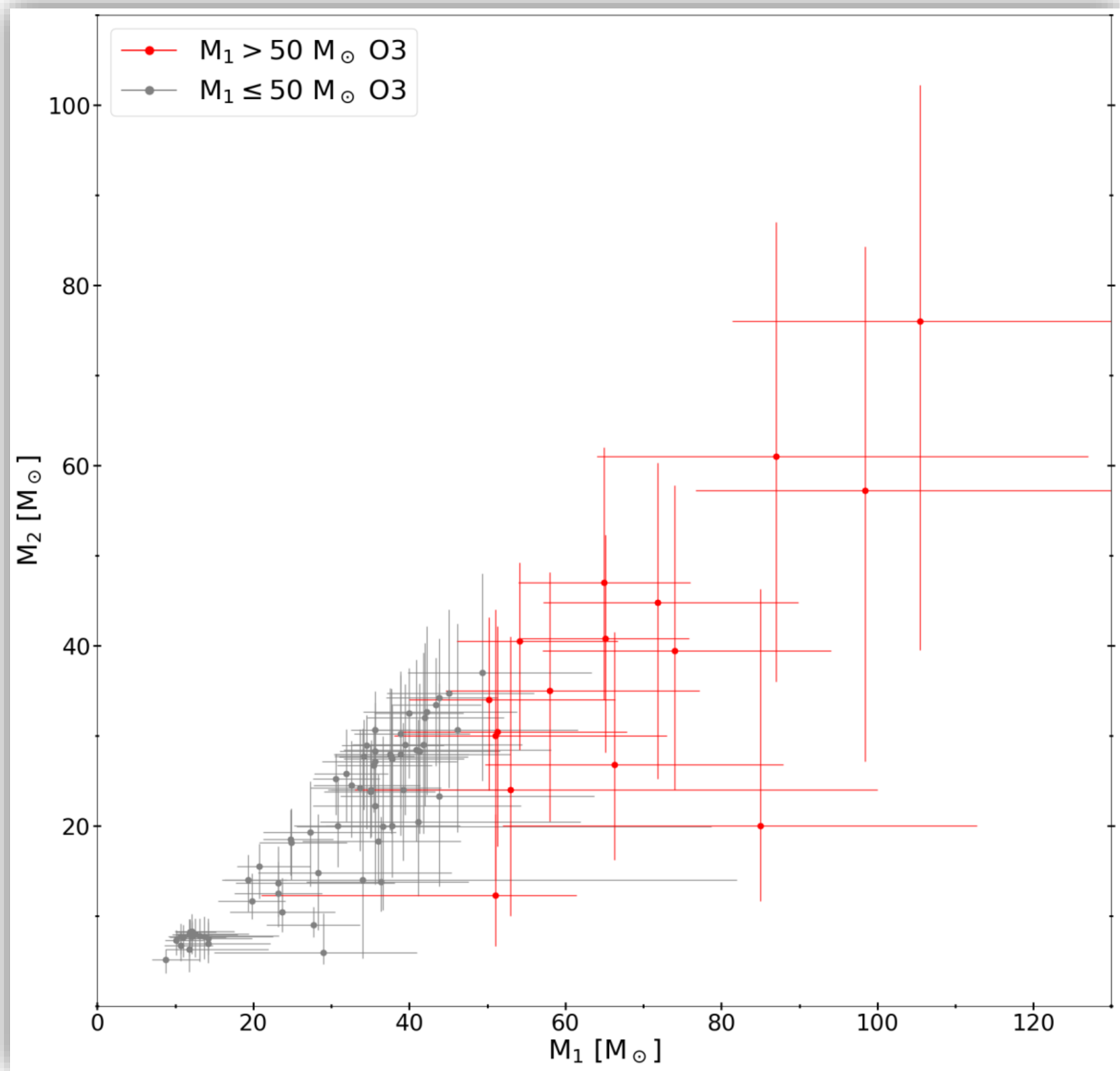

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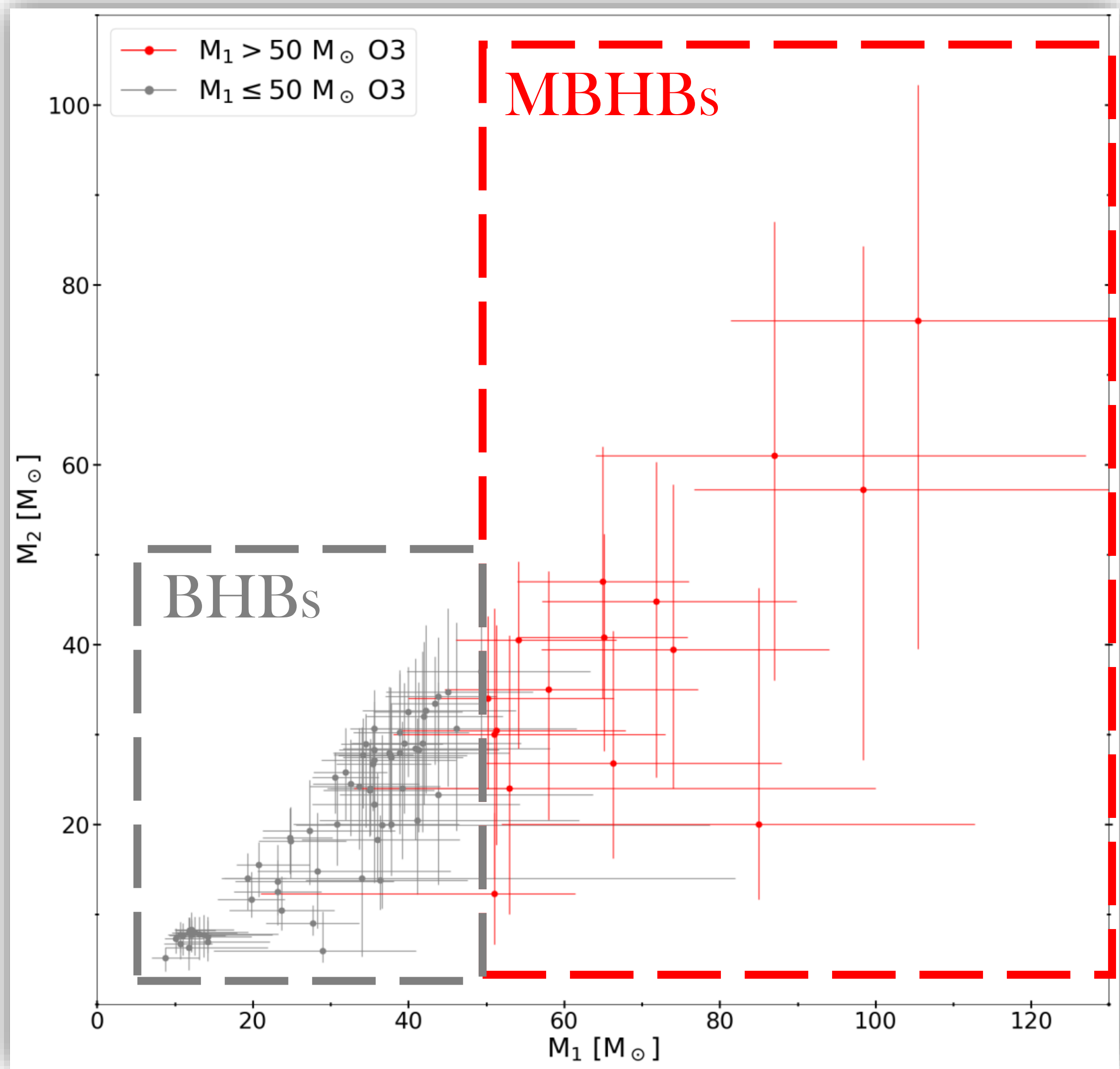

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- Possible formation path:

  Isolated binaries

  vs

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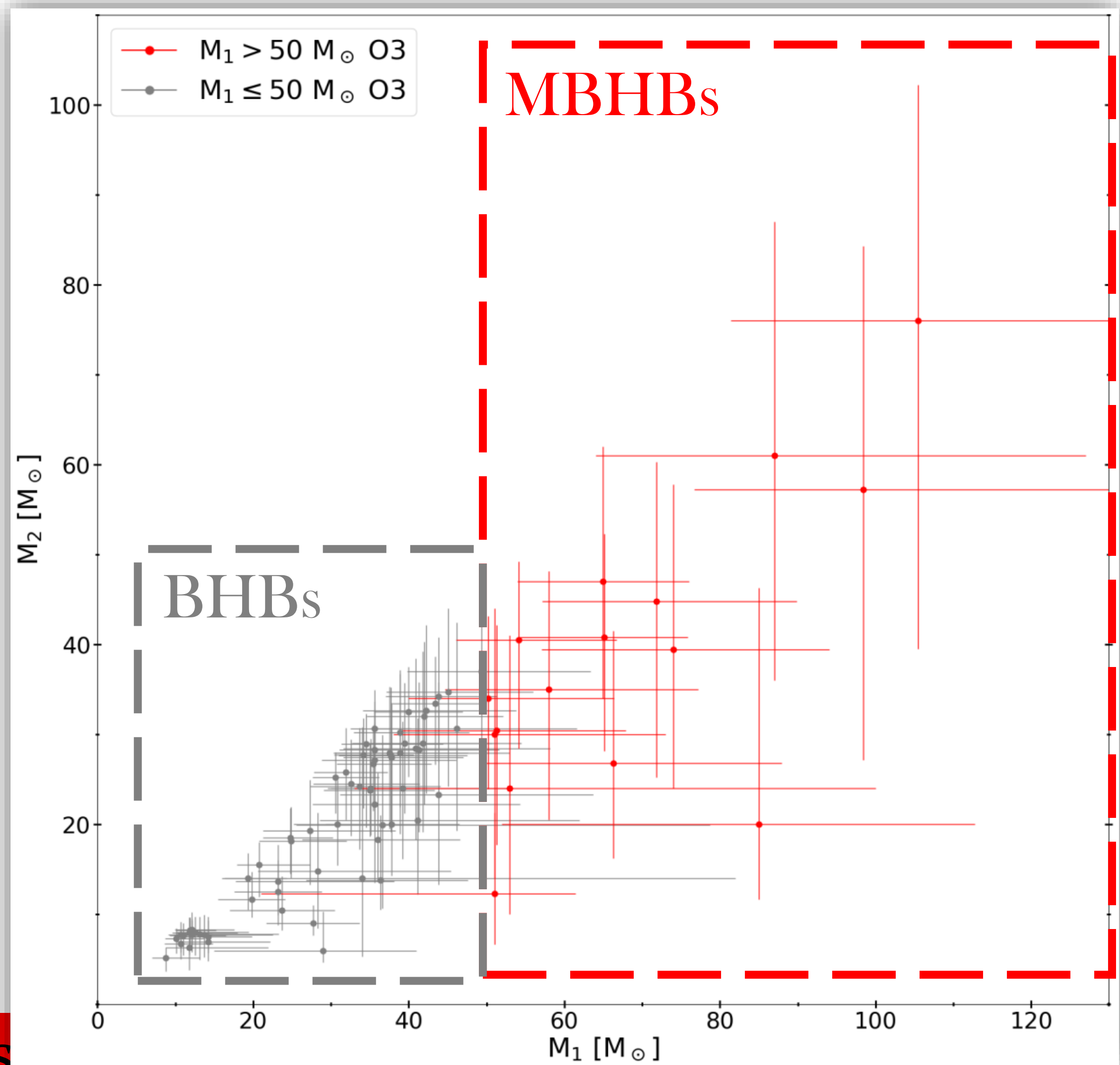

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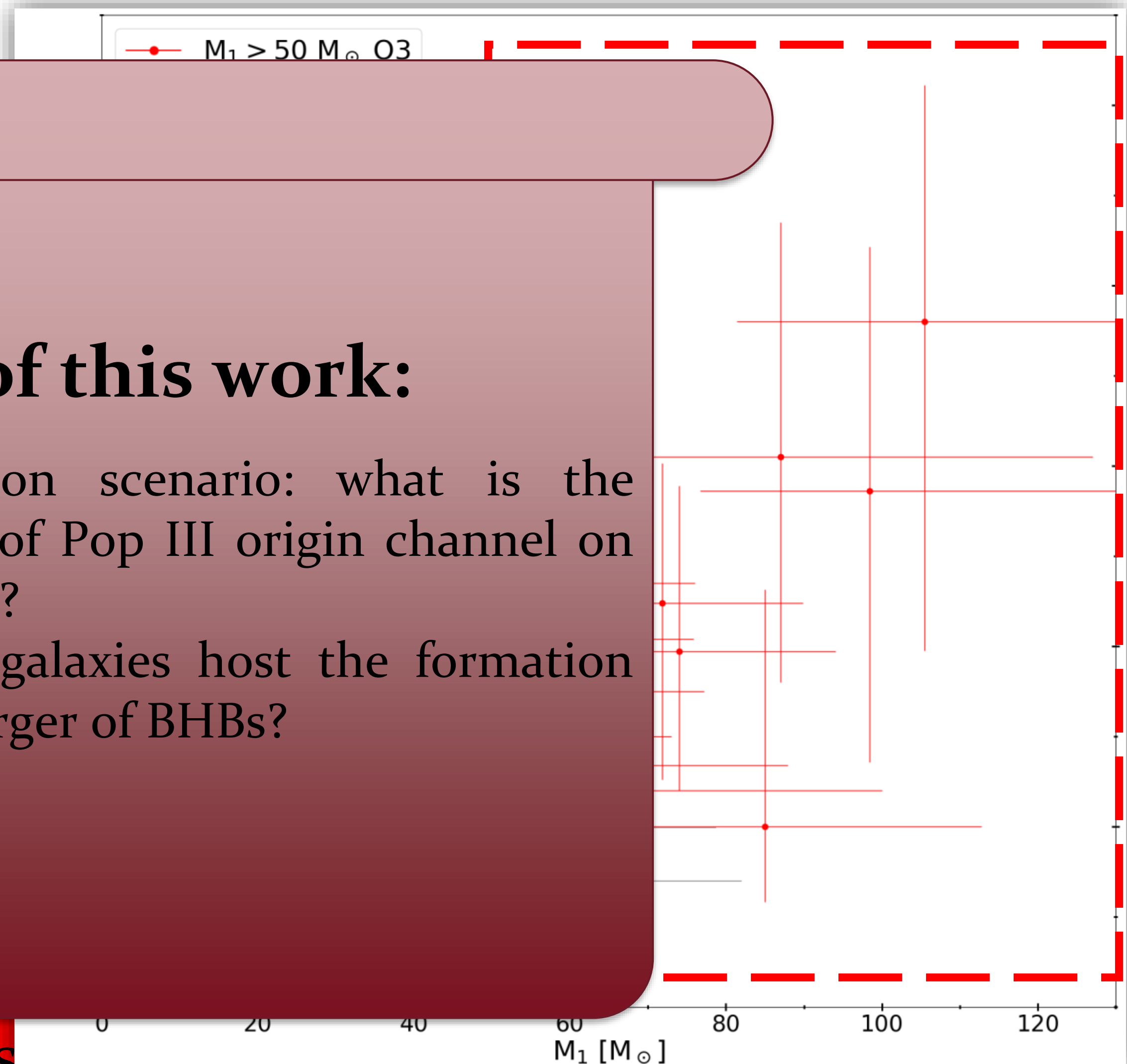


## Goals of this work:

1) Formation scenario: what is the impact of Pop III origin channel on O3 data?
2) Which galaxies host the formation and merger of BHBs?

# Binary population synthesis codes

- BPS codes study the time evolution of binary systems;
- Based on analytic formulas for binary and stellar physics;
- Statistical predictions of *large* binary population (e.g. $10^7$) in a reasonable amount of time (e.g. 48 h);

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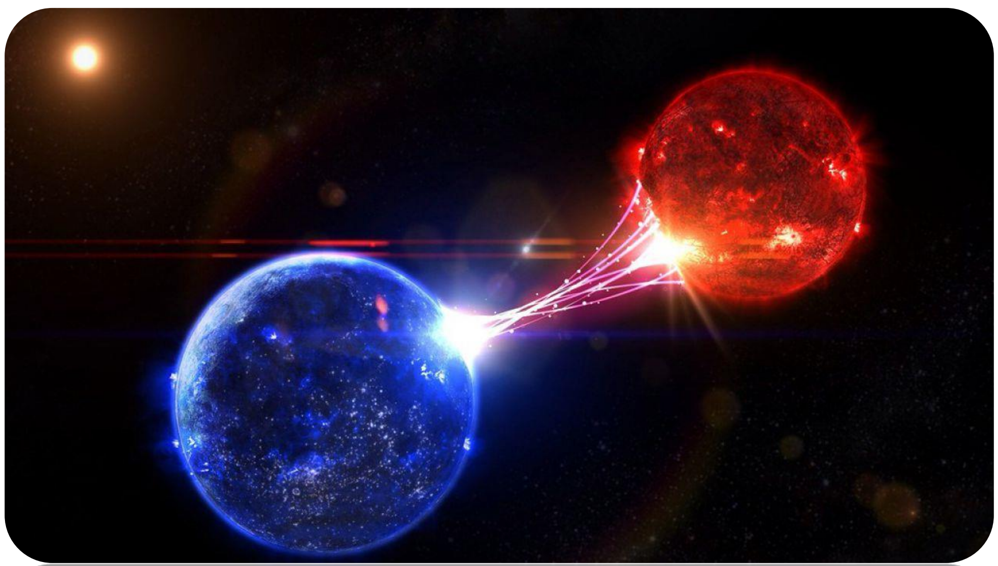
BSEEMP
(Tanikawa et al. MNRAS, 2021)



SEVN
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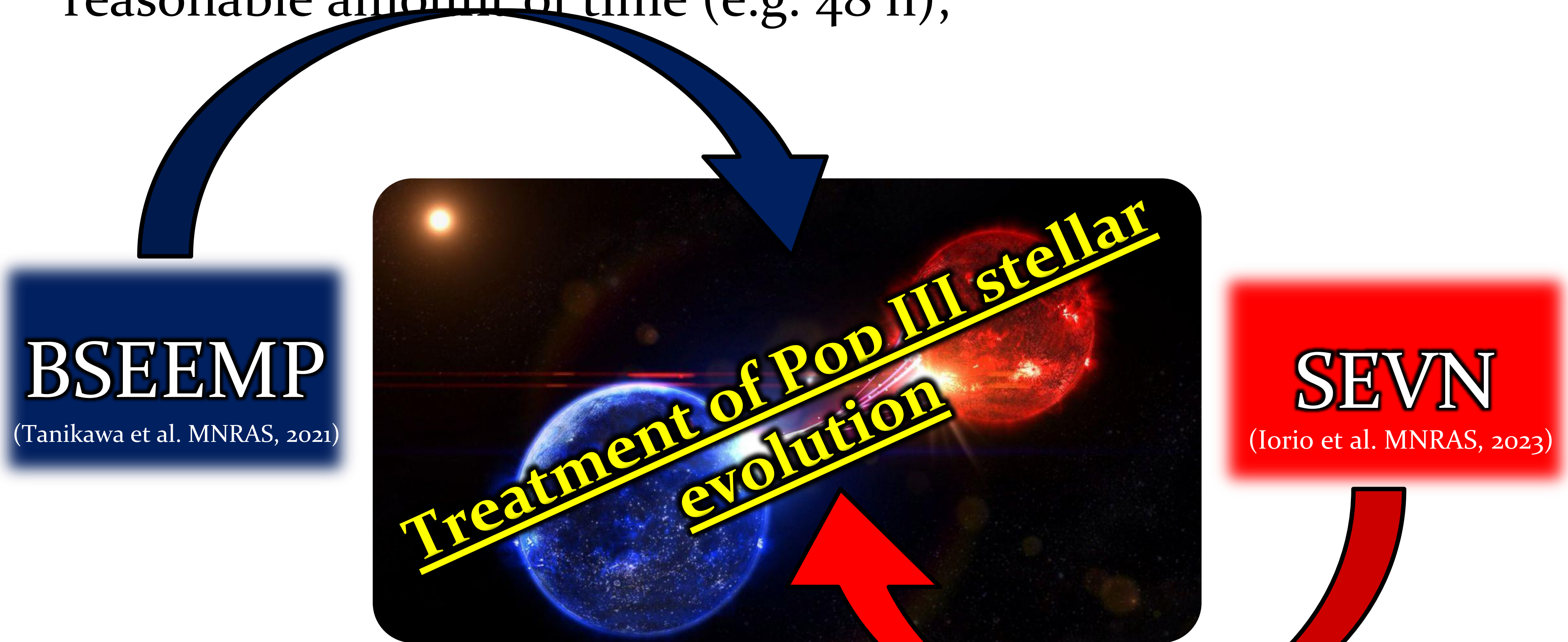

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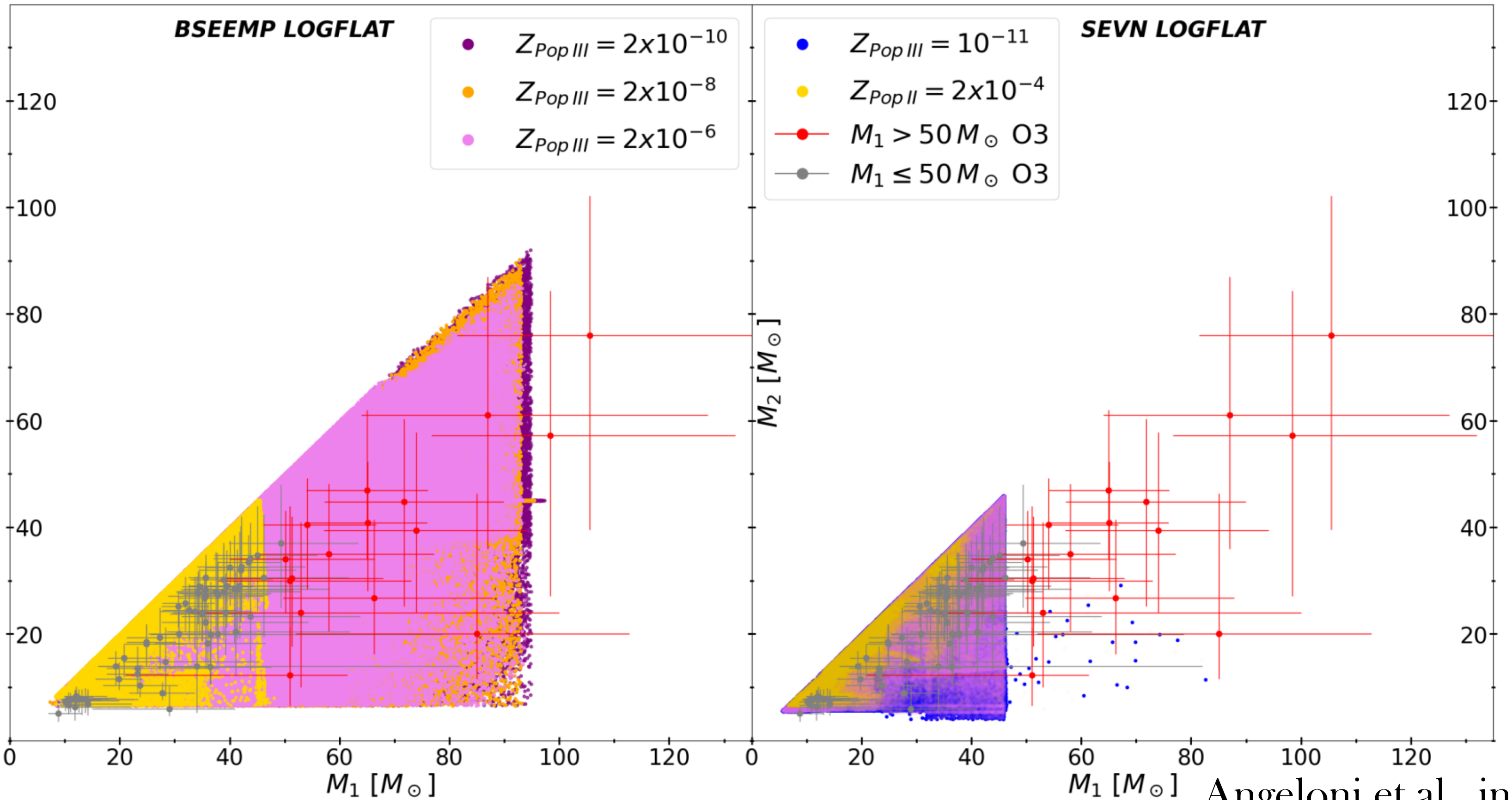


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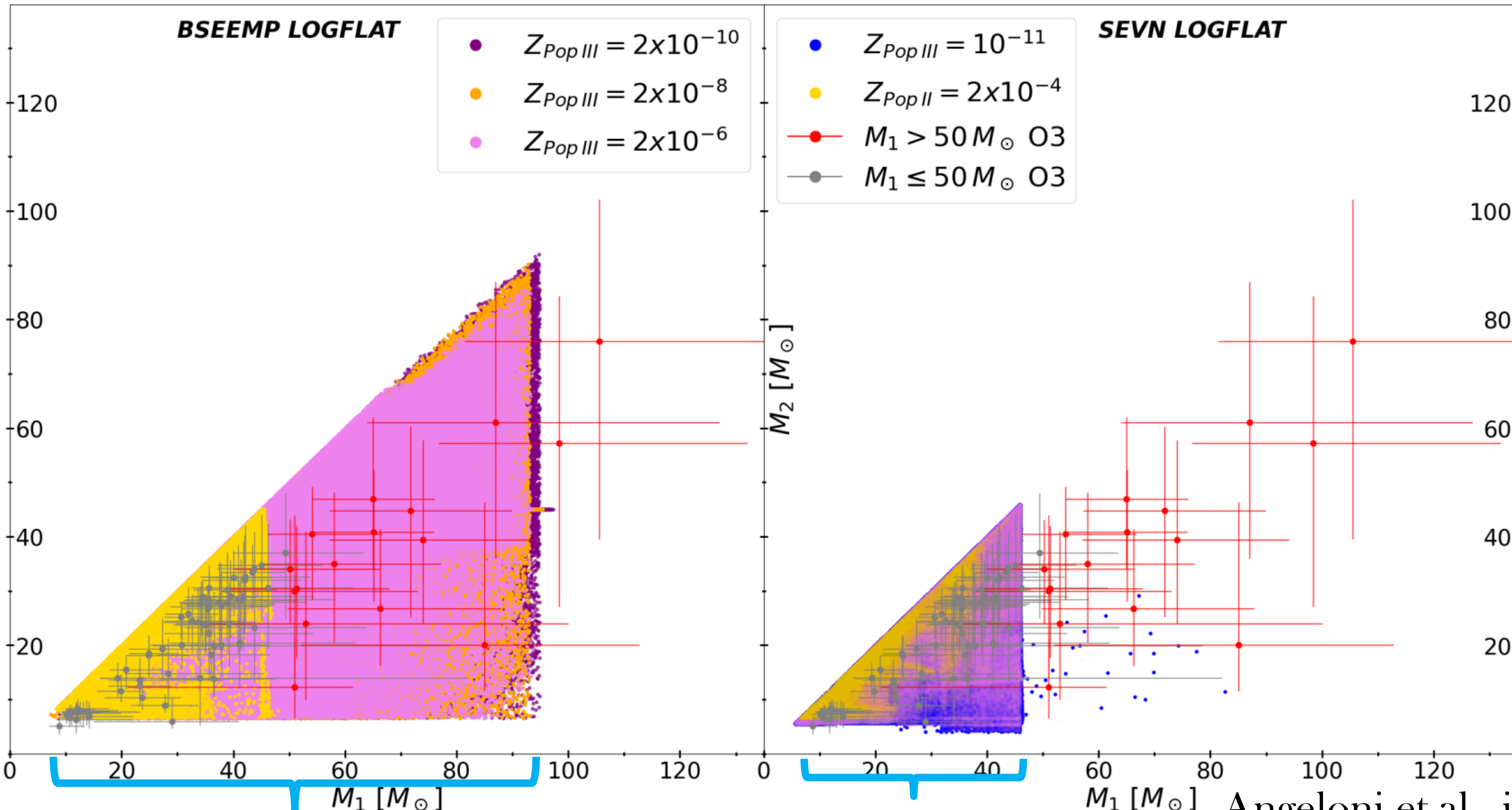


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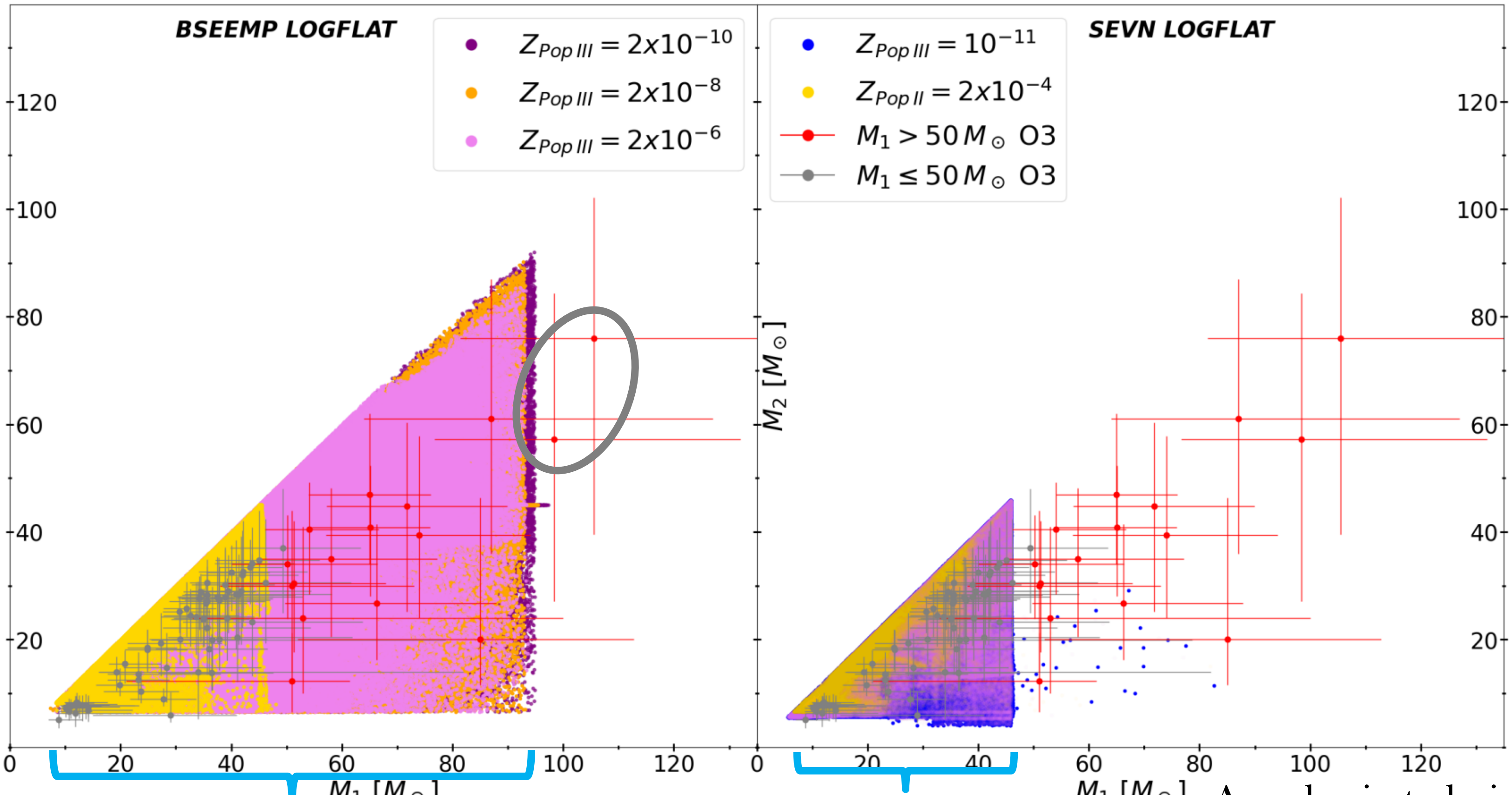


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- Different primary BH mass range on varying initial stellar metallicity;
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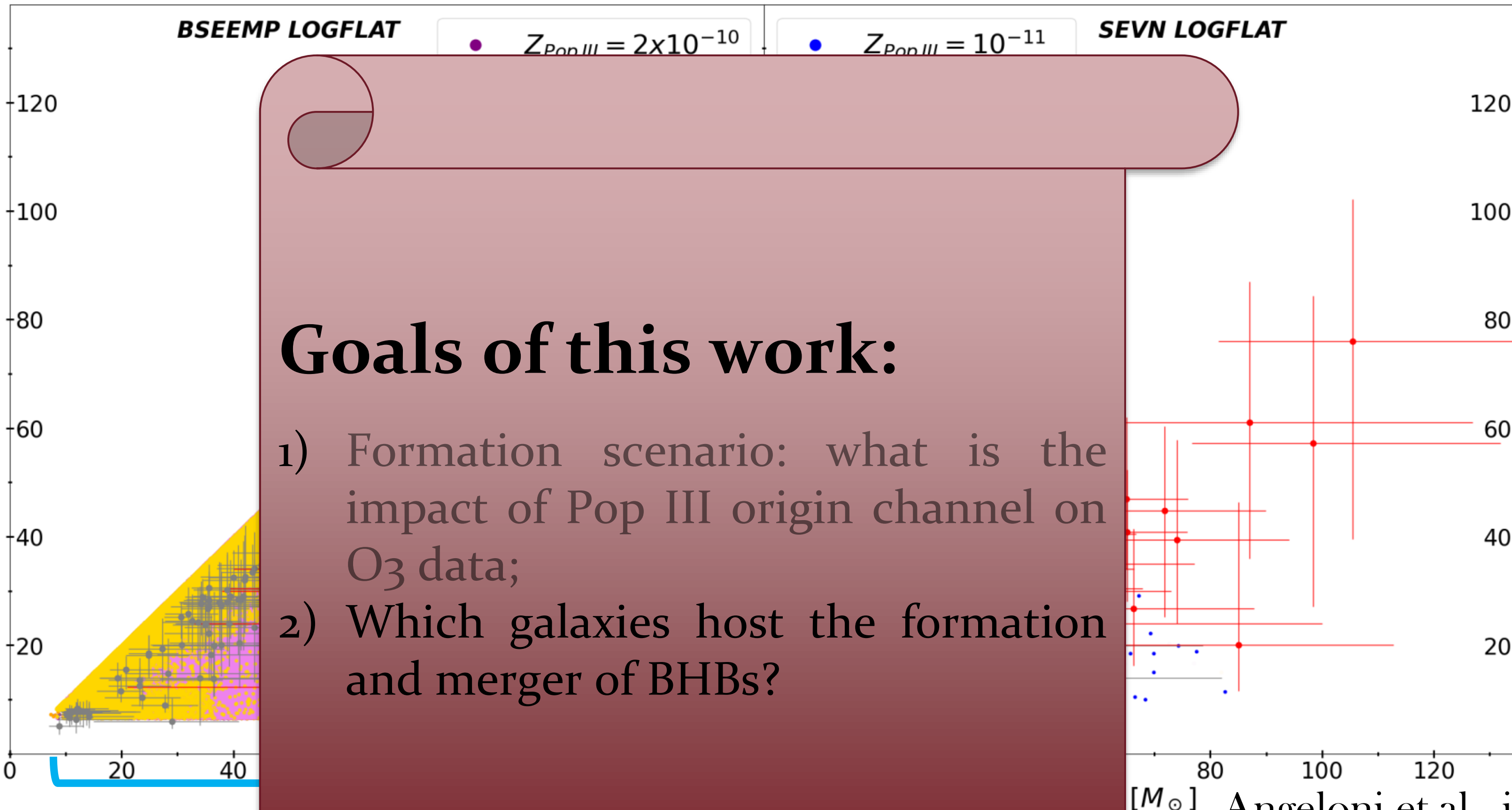


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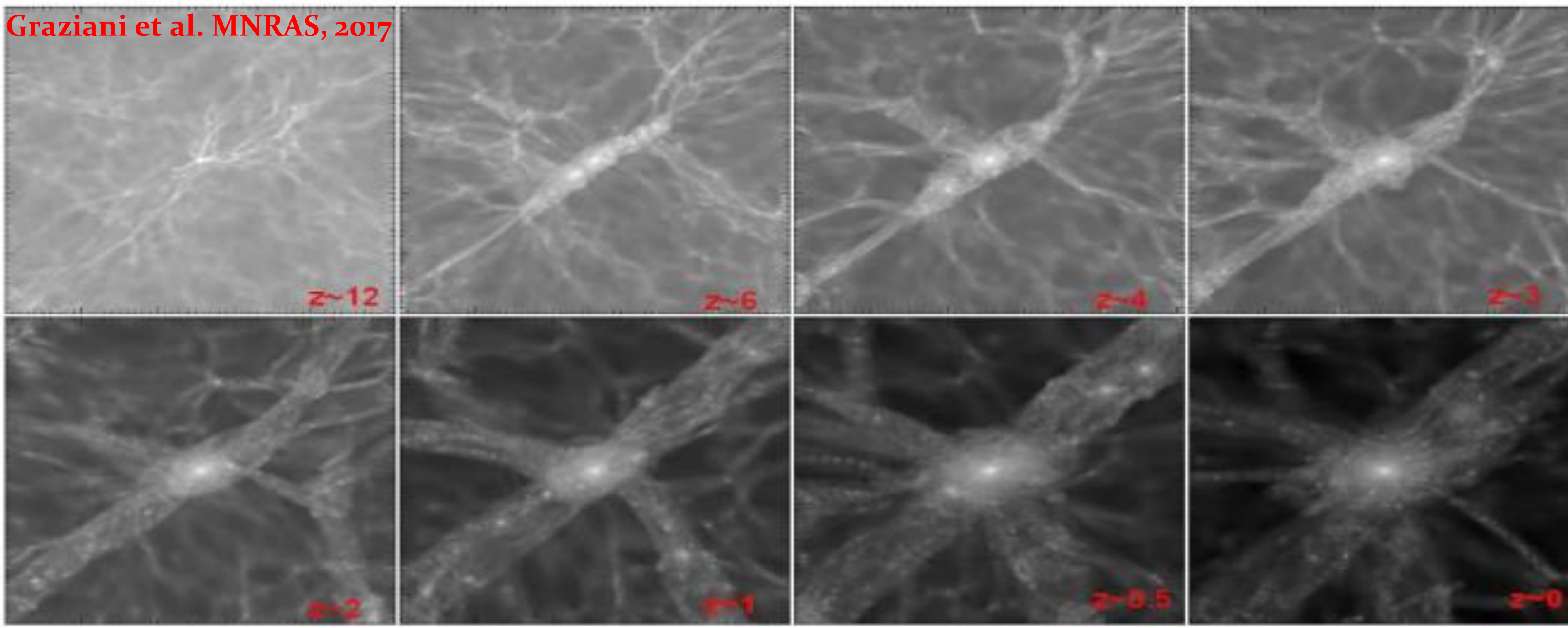
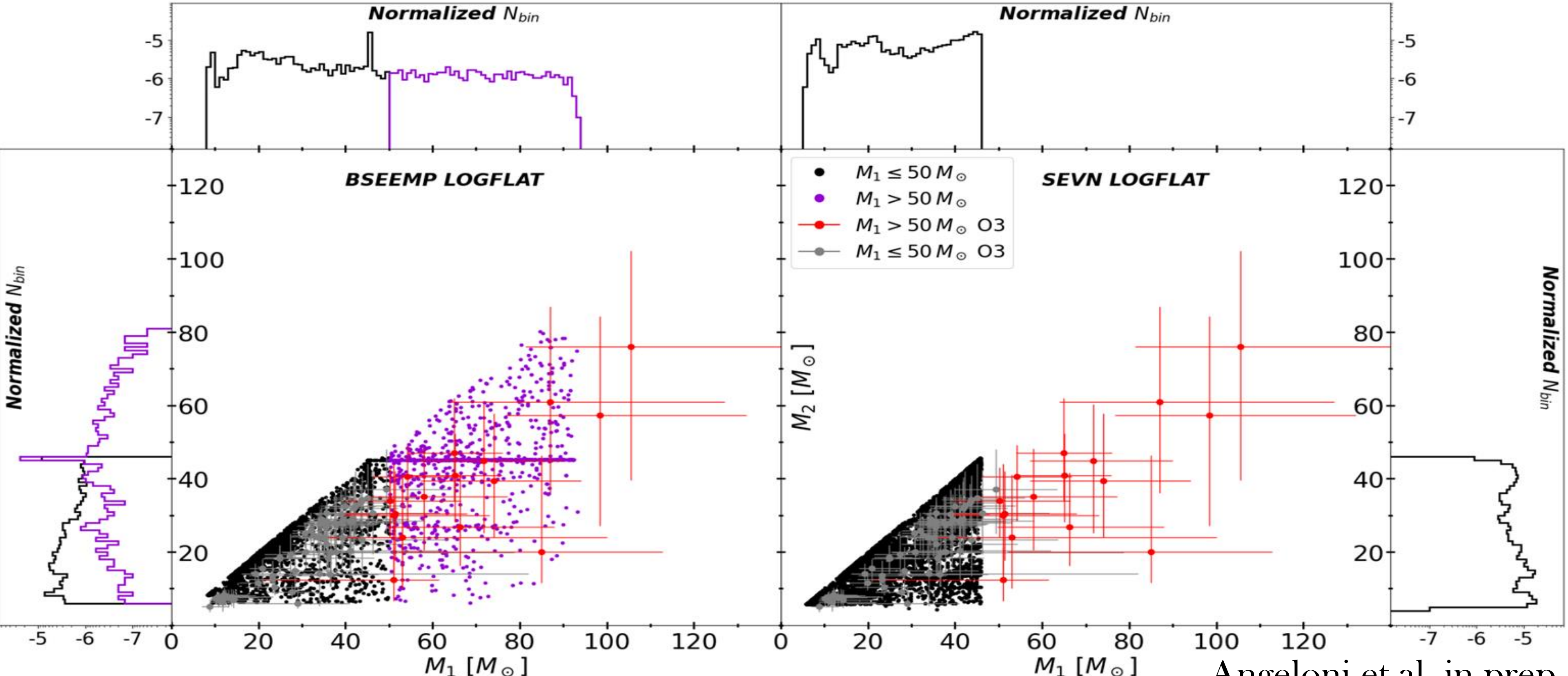
# Model of galaxy formation: GAMESH

- Semi-numeric model: N-body + semi-analytic model for baryons;
- Simulated volume: $5^3\ cMpc^3$ (Local Group-like) with the Milky Way at centre and resolved mini-halos;
- Fast and flexible runs coupled with BPS still require HPC.



# Coupling GAMESH with BPS codes: BHB mass distribution

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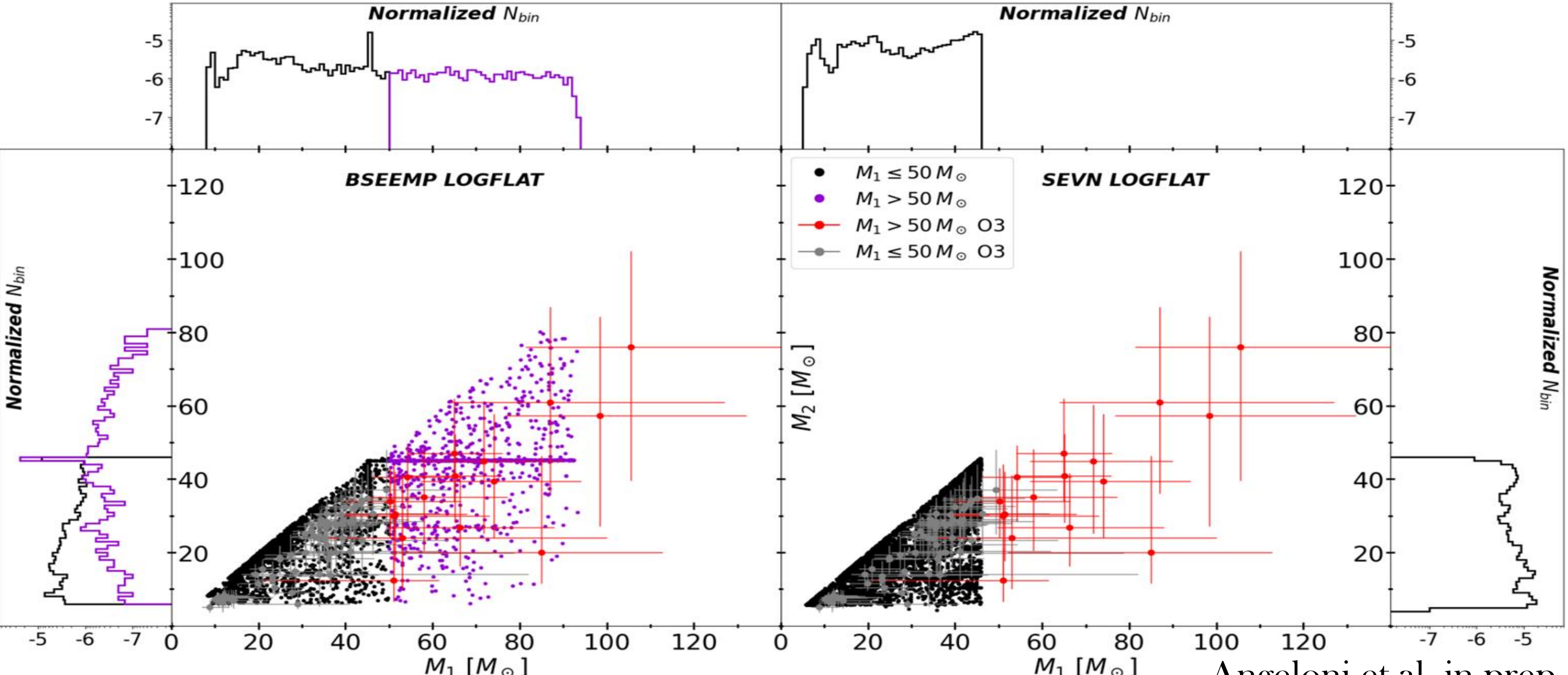


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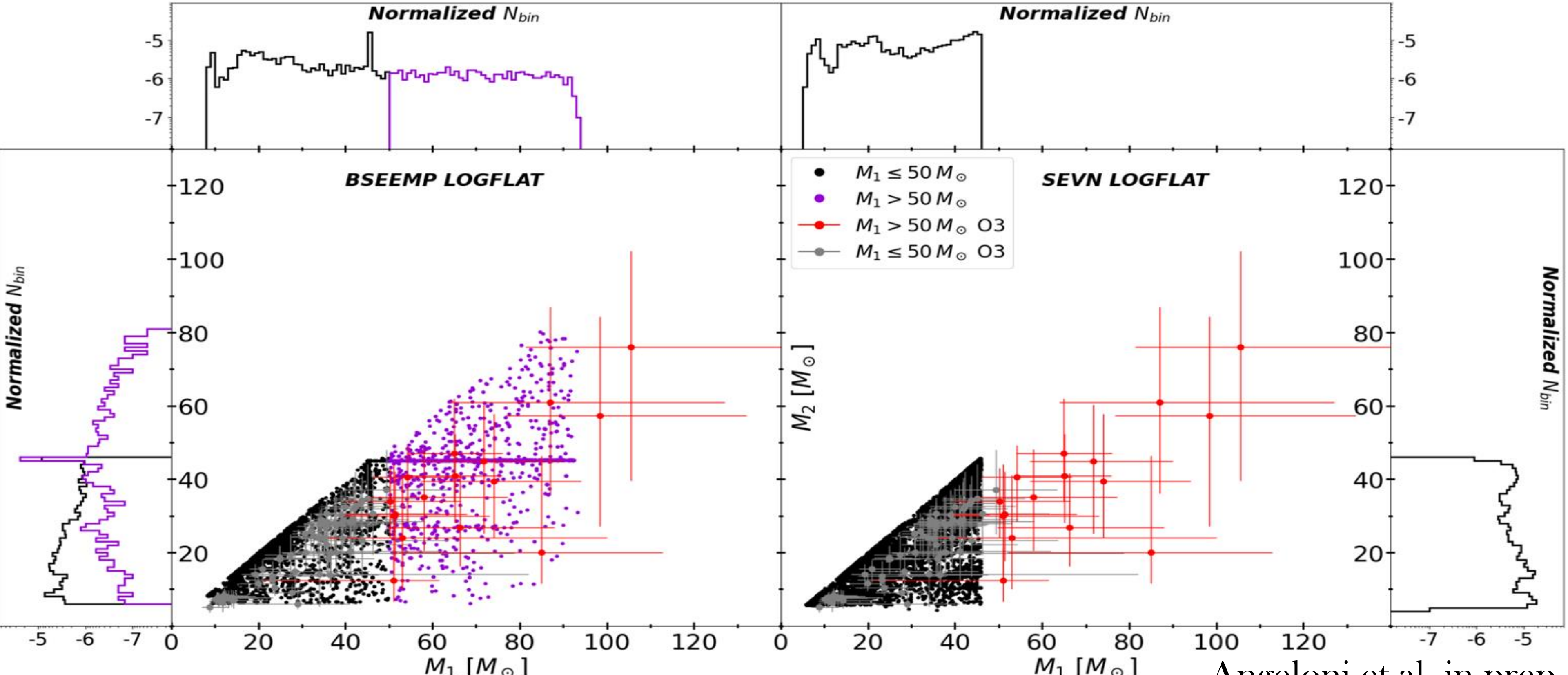


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  - ➢ Less selected binary systems due to rapid metal-enrichment;
- Detectable MBHBs still be present after the coupling with GAMESH!

# Statistics of coalescing BHBs from Pop III binary stars in a Local Group-like Volume

| | GAMESH+BSEEMP | | | GAMESH+SEVN | | |
|---|---|---|---|---|---|---|
| | Total | % coal. | % Pop III | Total | % coal. | % Pop III |
| $M_1 \leq 20\ M_\odot$ | $\sim 2.1 \times 10^3$ | 33% | 10% | $\sim 1.8 \times 10^4$ | 7.4% | 29% |
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- Star formation with $Z_\star < 2 \times 10^{-6}$ quenched rapidly by metal-enrichment.

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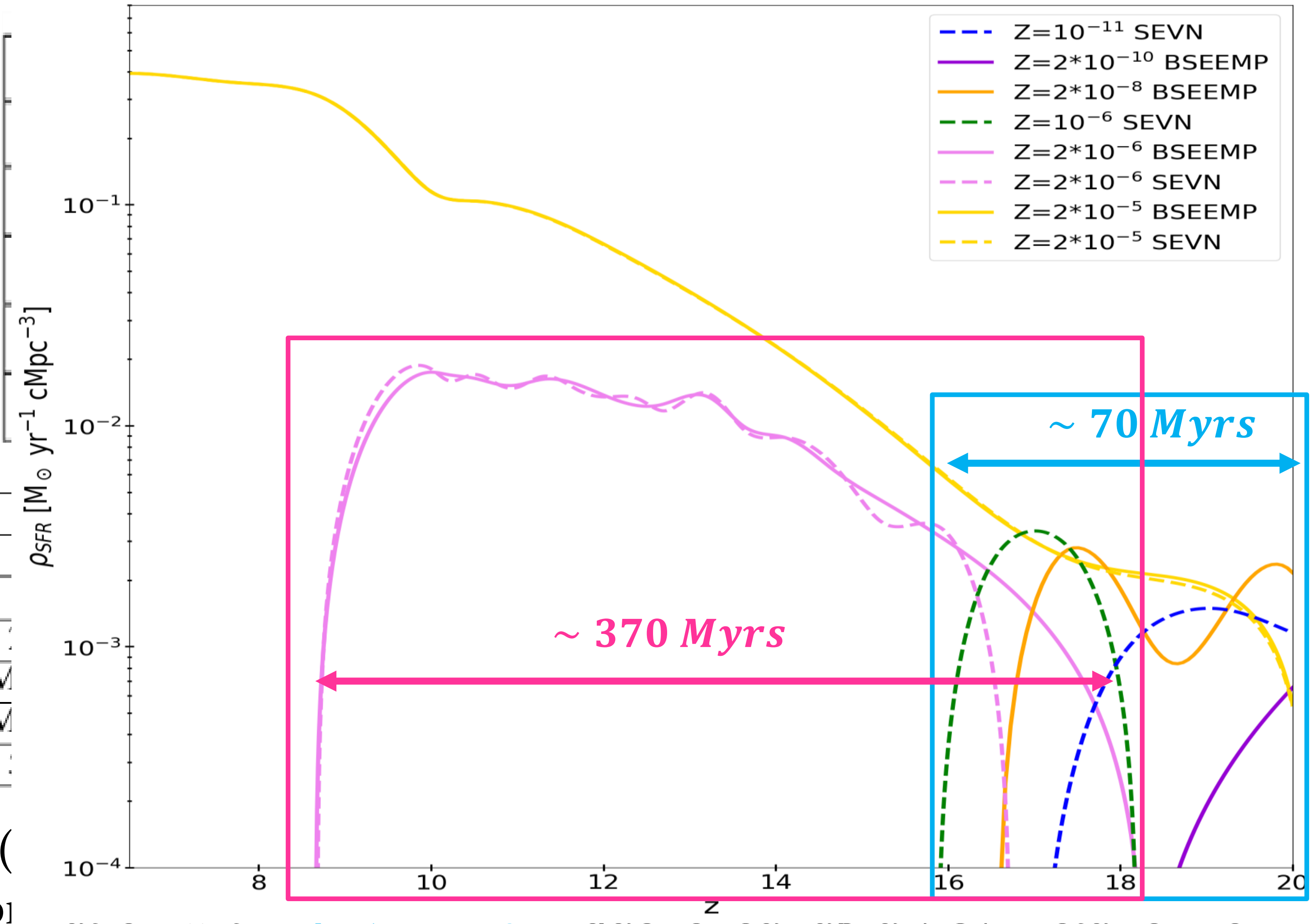
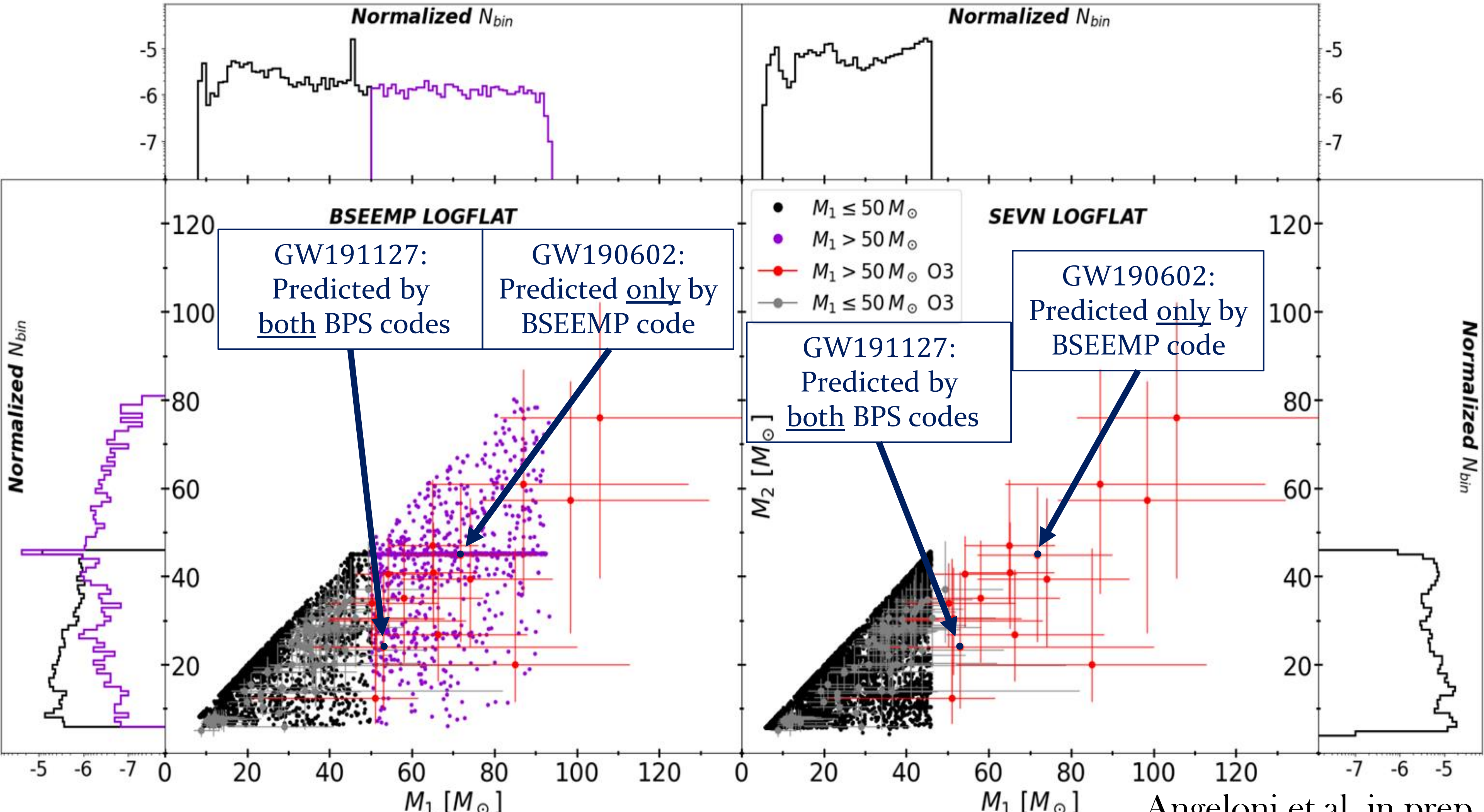



| | |
|---|---|
| | |
| | Pop II |
| | $\geq 2 * 10^{-5}$ |
| $M_1 \leq$ … | 72% |
| $20\ M_\odot < M$ … | 25% |
| $35\ M_\odot < M$ … | 3.8% |
| $M_1 >$ … | 0% |

- BHBs ( … ·6;
- Star fo… ent.

# Contribution to O3 candidates: GW191127 & GW190602

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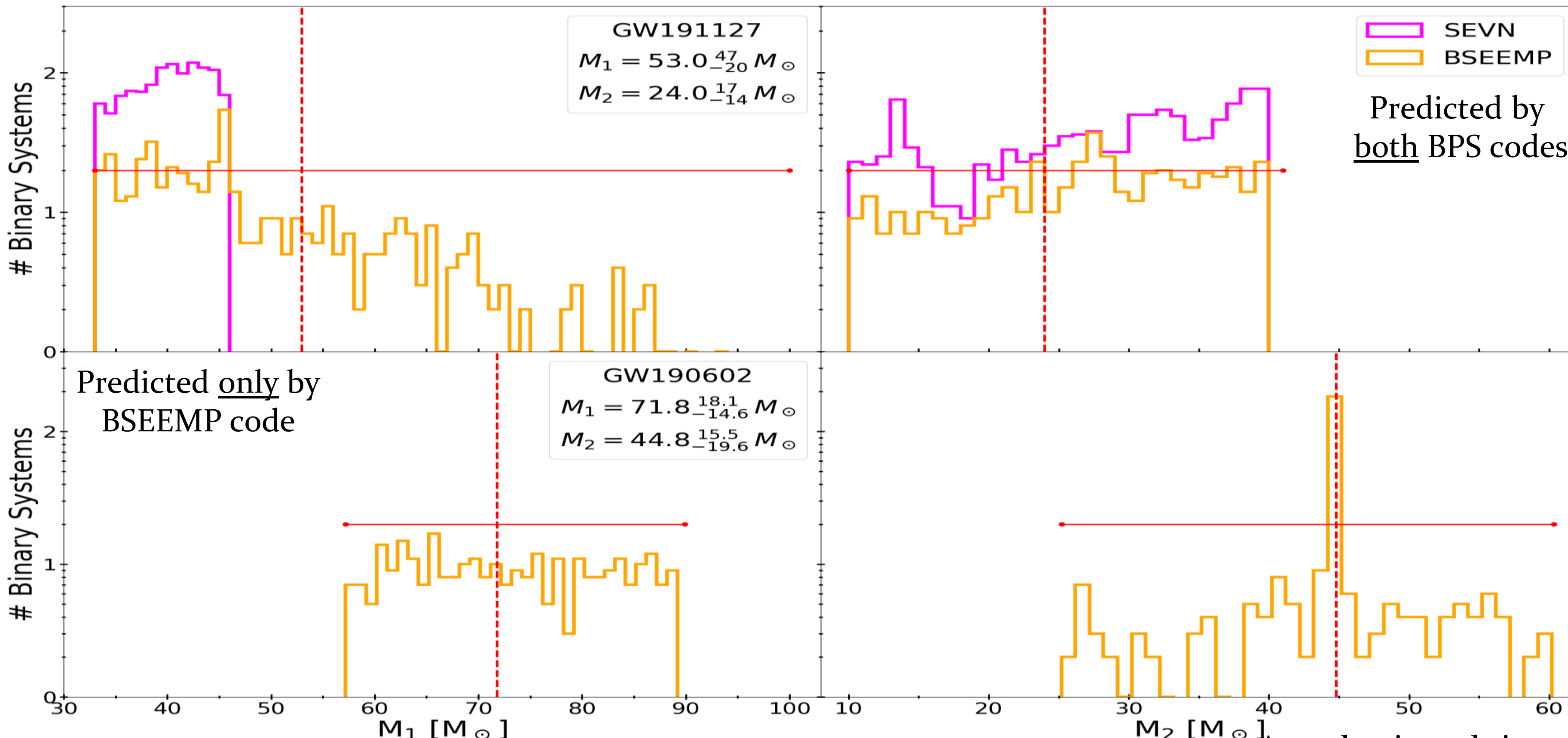


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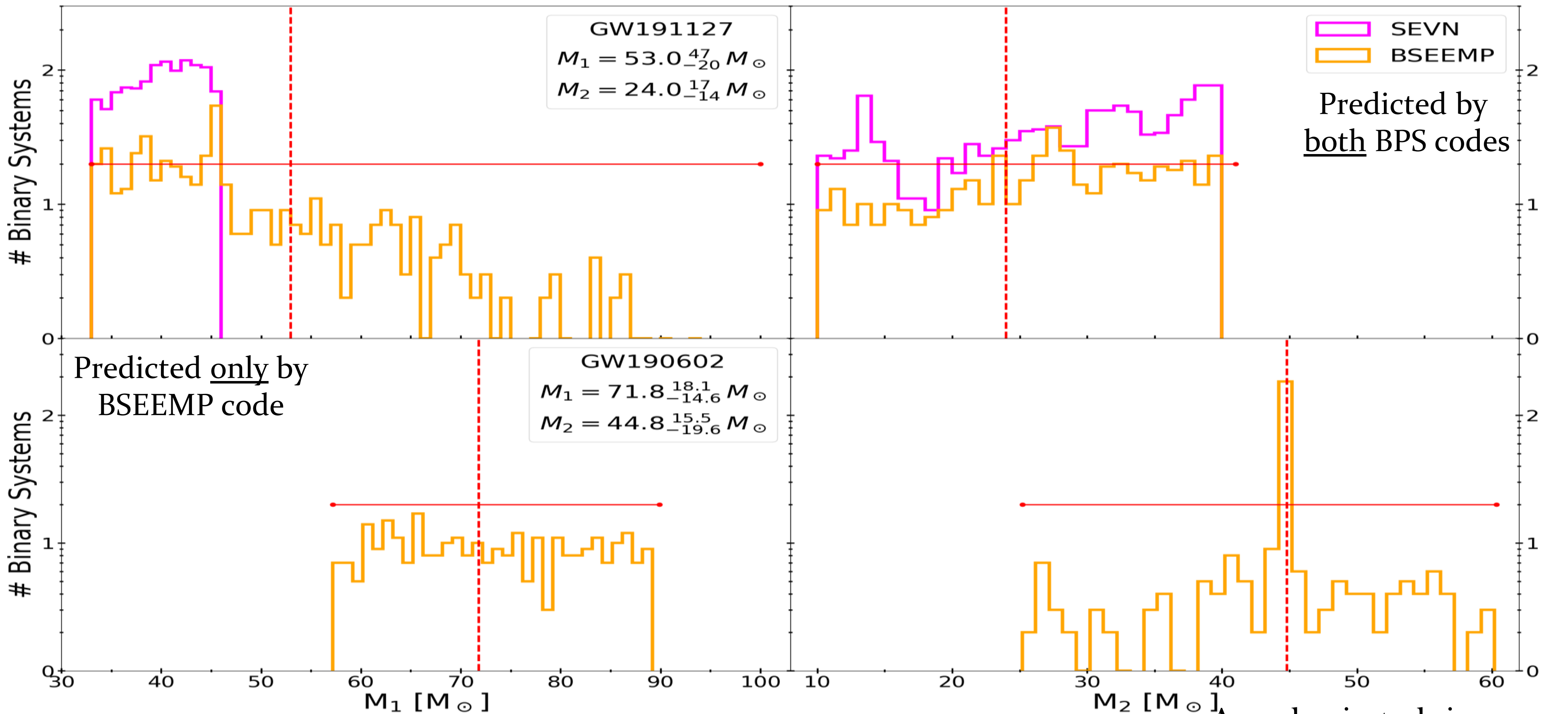


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- Strong observative constraints on BH masses and merger time → candidates still be present within error bars!
- Predictions for O4: hundreds of new GW events detectable by LVK!

# Conclusions

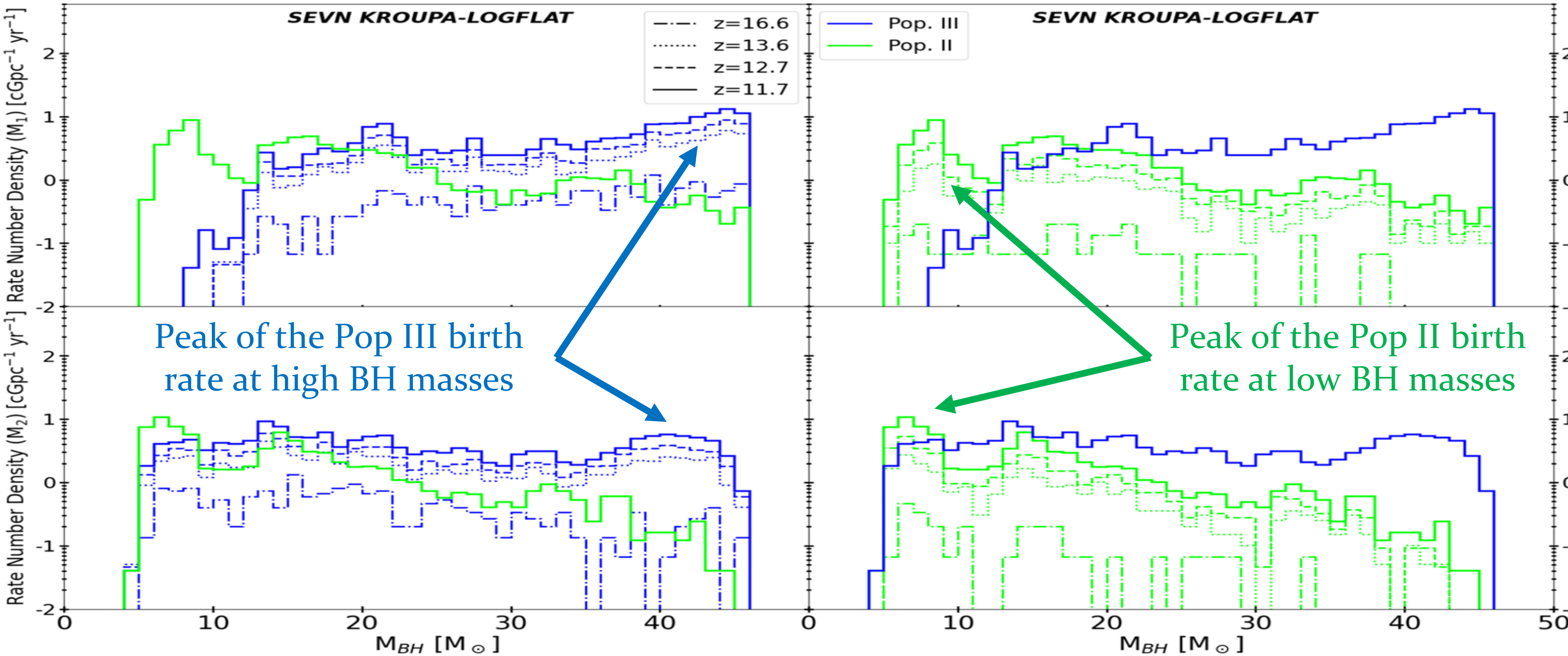
1) GW190426 and GW190521 certanly not from isolated binaries;
2) More than 50% of massive GW events with $35\ M_\odot < M_1 \leq 50\ M_\odot$ from Pop III stars according to both BPS;
3) More than 65% of BHBs with $M_1 > 35\ M_\odot$ formed at metallicity $Z_\star \sim 10^{-6}$;
4) Hundreds of new detectable GW events predicted by our coupling simulations → our large statistics ready to interpret O4

# Next steps and future prospectives

1) Characterize the BHB birth and coalescence sites with all populations: BH-BH, NS-NS and BH-NS;
2) Predictions for the future interferometers ET, CE and LISA;
3) Cosmological prediction of merger and birth rate density of all populations by the coupling with the cosmological fully hydrodynamic zoom-in simulation dustyGadget (**Graziani et al. MNRAS, 2020**);
4) Impact of dynamical formation channel on the O3 events.


Thank you for the
attention!!

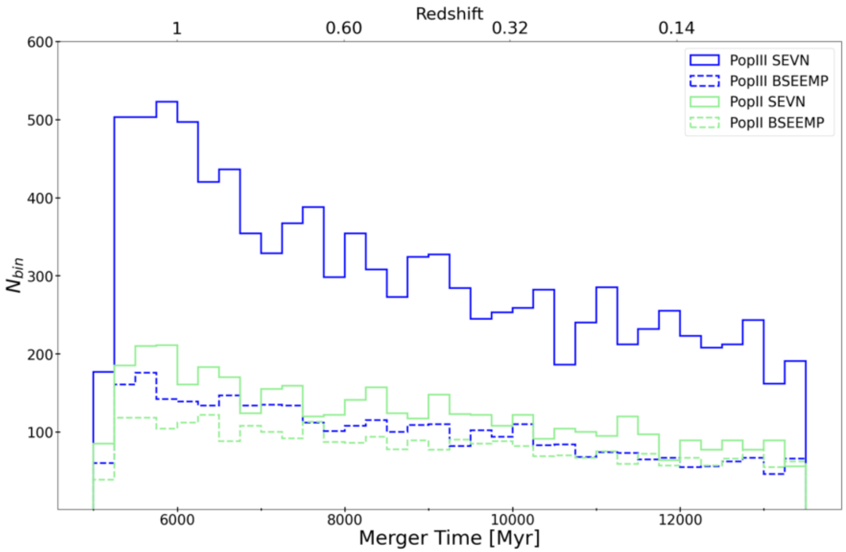
# Redshift evolution BHB formation rate from Pop III and II binary stars

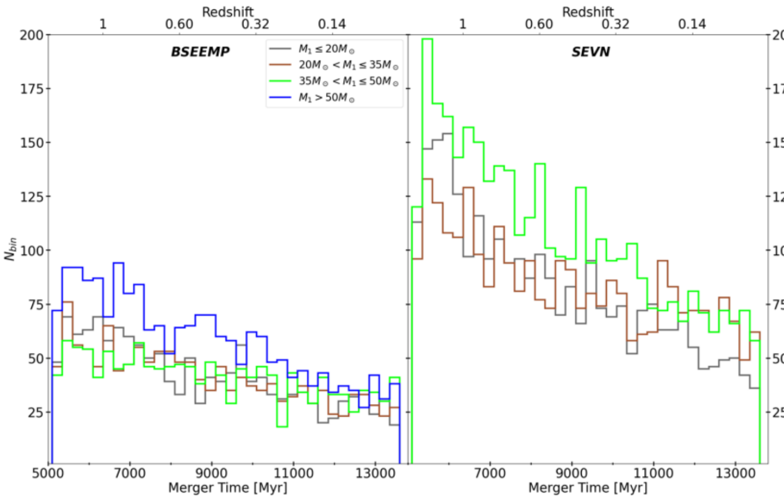


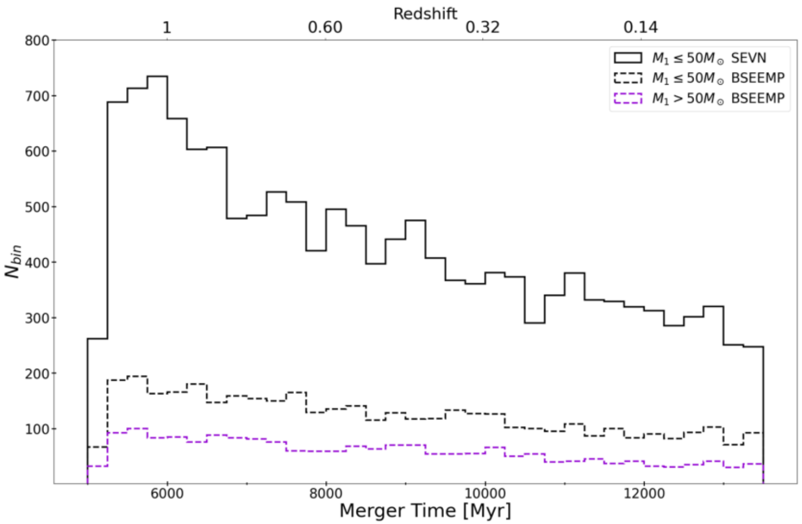

Angeloni et al. in prep.

- **SEVN:**
  - Almost the same BH mass range from Pop III and II stars;
  - Probability function distribution completely different.

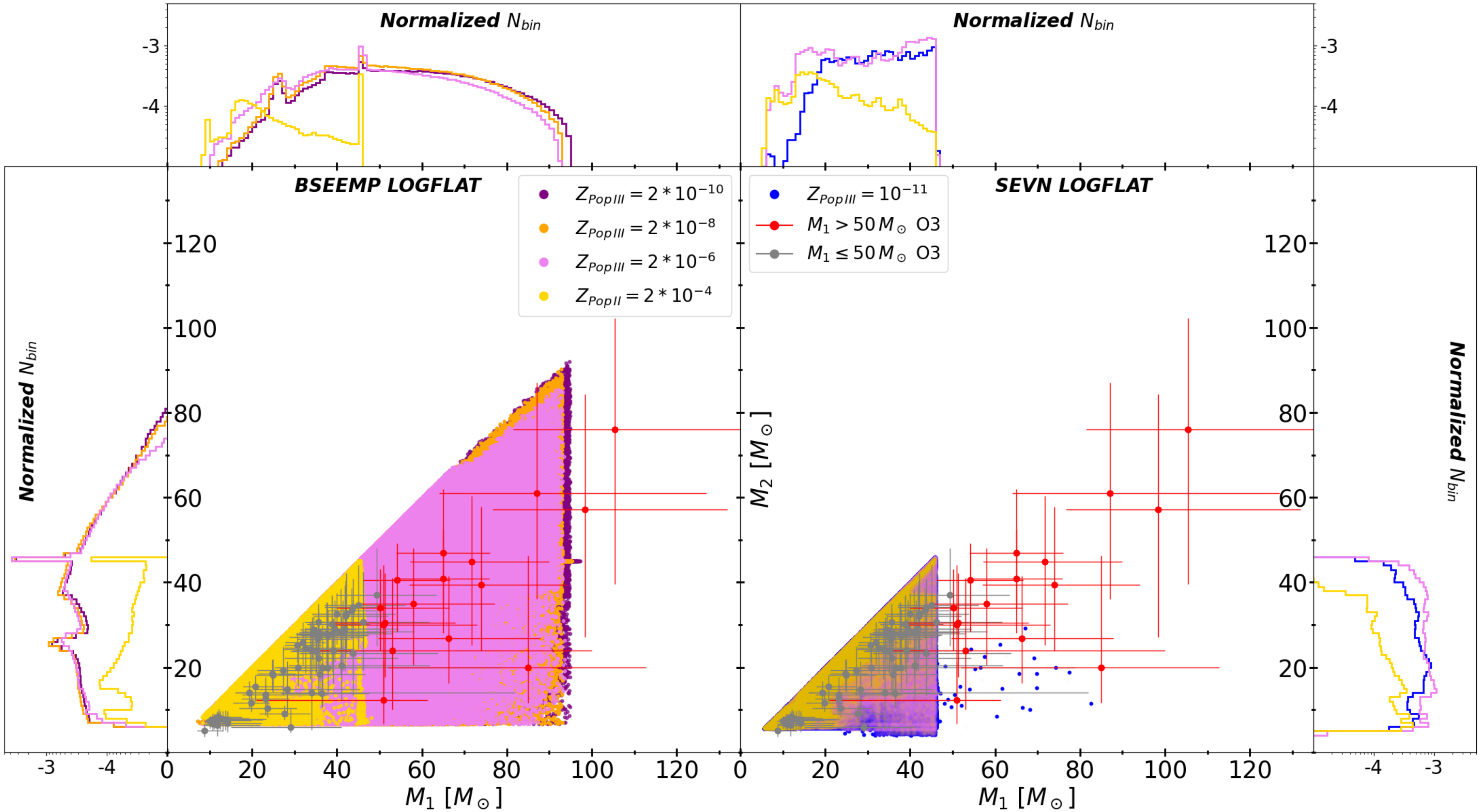
# Merger Time Distribution



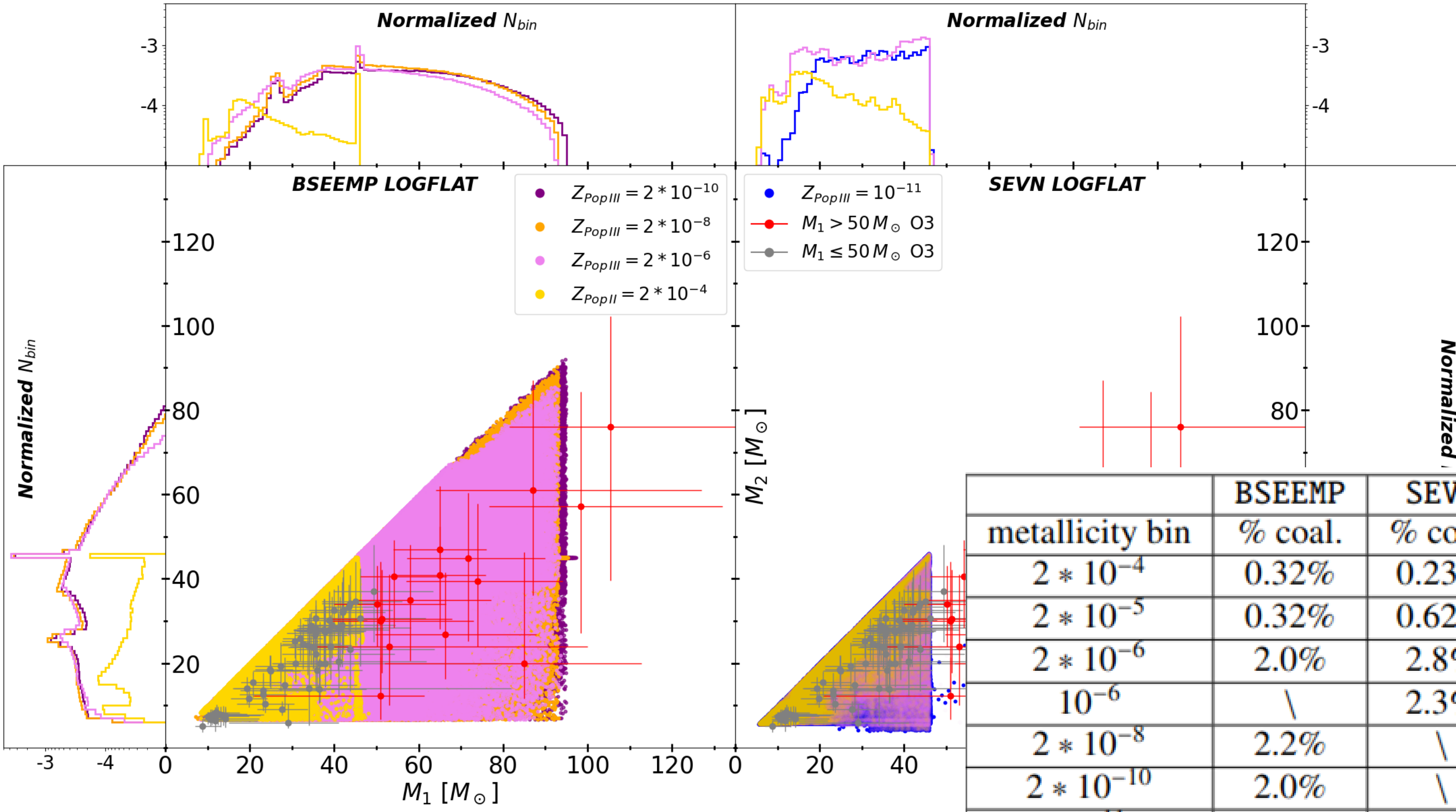



# Predictions of BPS codes at low metallicity: BSEEMP vs SEVN



# Predictions of BPS codes at low metallicity: BSEEMP vs SEVN



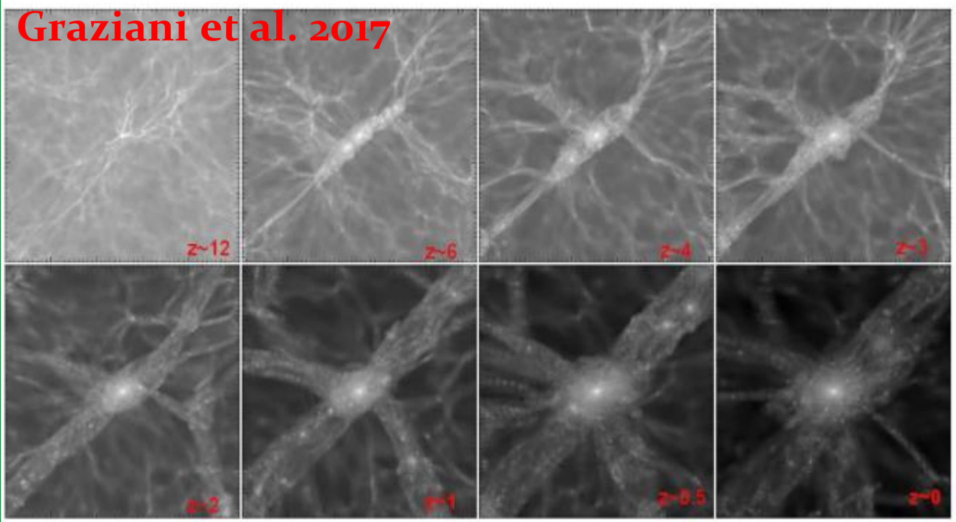

| | BSEEMP | SEVN |
|---|---|---|
| metallicity bin | % coal. | % coal. |
| $2*10^{-4}$ | 0.32% | 0.23% |
| $2*10^{-5}$ | 0.32% | 0.62% |
| $2*10^{-6}$ | 2.0% | 2.8% |
| $10^{-6}$ | \ | 2.3% |
| $2*10^{-8}$ | 2.2% | \ |
| $2*10^{-10}$ | 2.0% | \ |
| $10^{-11}$ | \ | 1.9% |

# Models of galaxy formation to predict birth and merger sites of BHBs

## GAMESH

Simulated volume: 5 cMpc

- Semi-numeric model: N-body + semi-analytic model for baryons;
- More Flexible;
- Fast simulation runs.




## dustyGadget

Simulated volume: 50 cMpc

- Fully hydrodynamic simulation: N-body + gas hydrodynamics;
- More accurate;
- More computationally expensive → HPC facilities.