

Binary compact objects populations: From LVK Results to Deci-Hz Prospects

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“La Caixa” Junior Leader fellow
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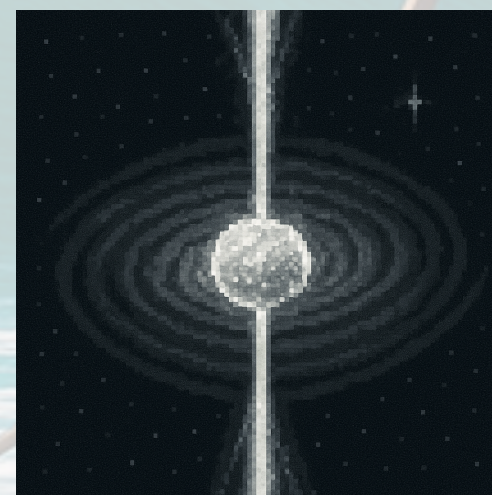
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From Massive stars ($>8 M_{\text{sun}}$)

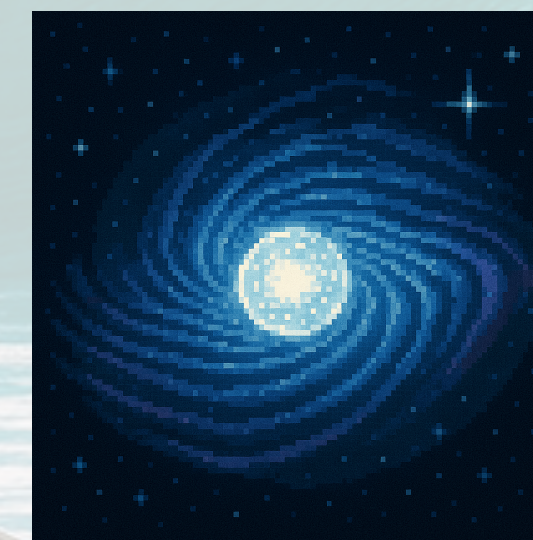
Low mass stars ($<8 M_{\text{sun}}$)



Black Holes

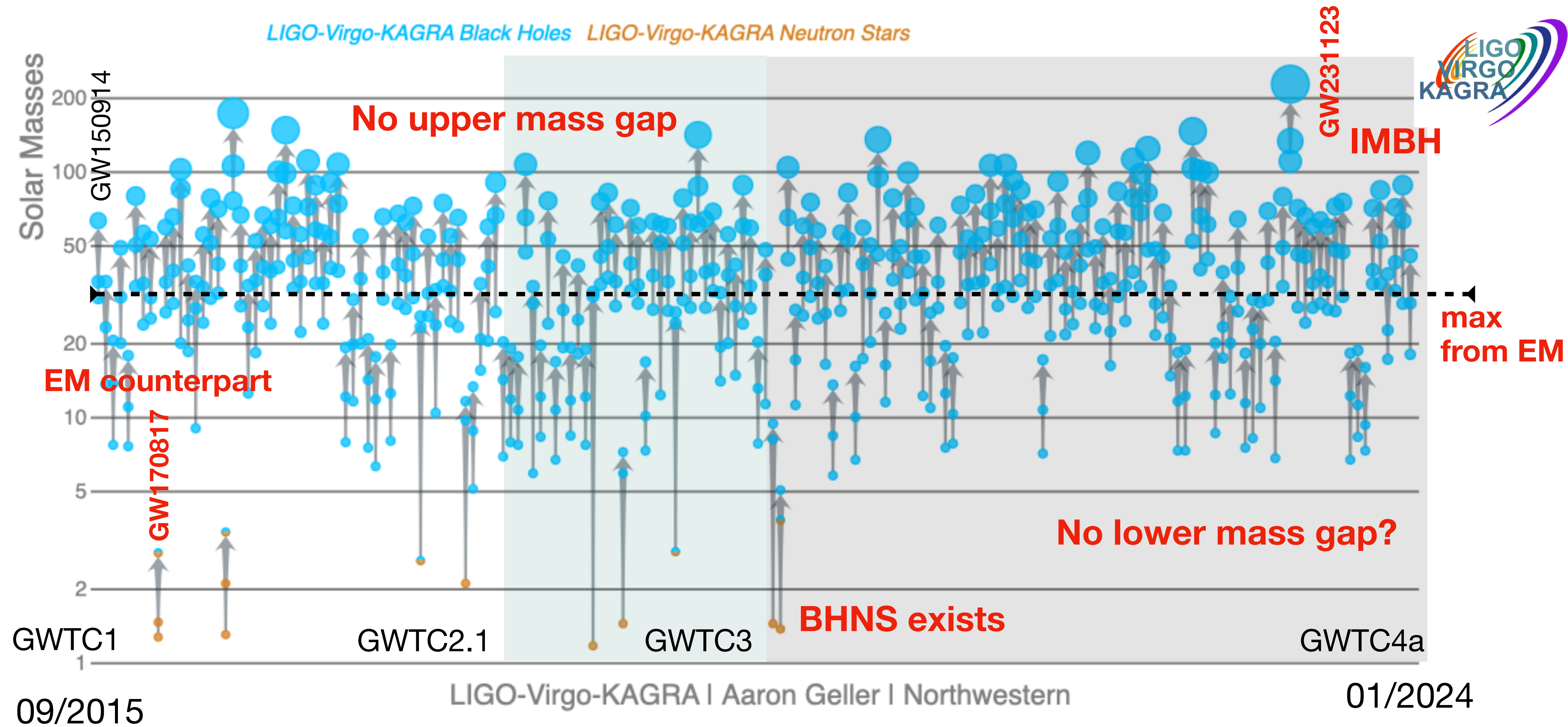


Neutron stars



White dwarfs

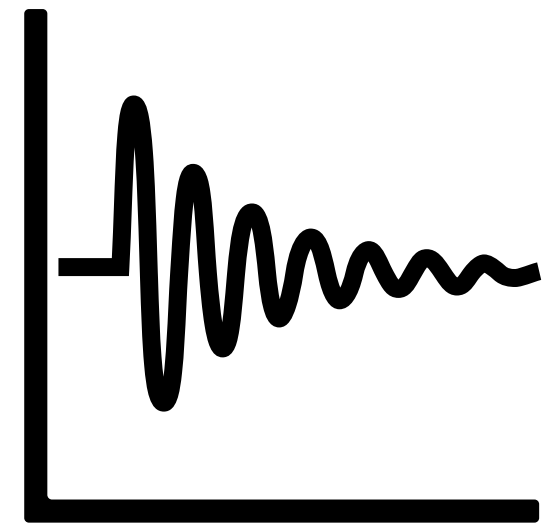
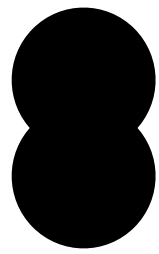
How do we observe BCOs?



219 events (158 with high confidence) (Abac+25)

Astrophysical relevance

Merger



Detection

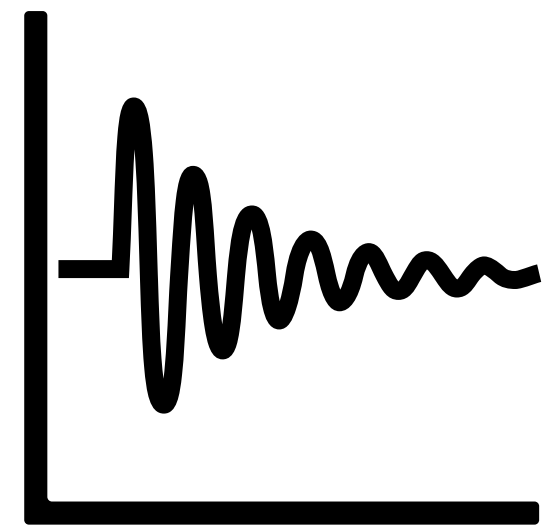
Masses

Spins

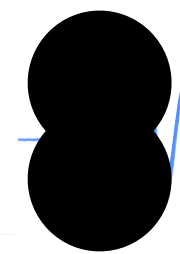
Distance

Location

Astrophysical relevance



Merger



$$t_{\text{delay}} \sim 10^6 - 10^{10} \text{ yr}$$

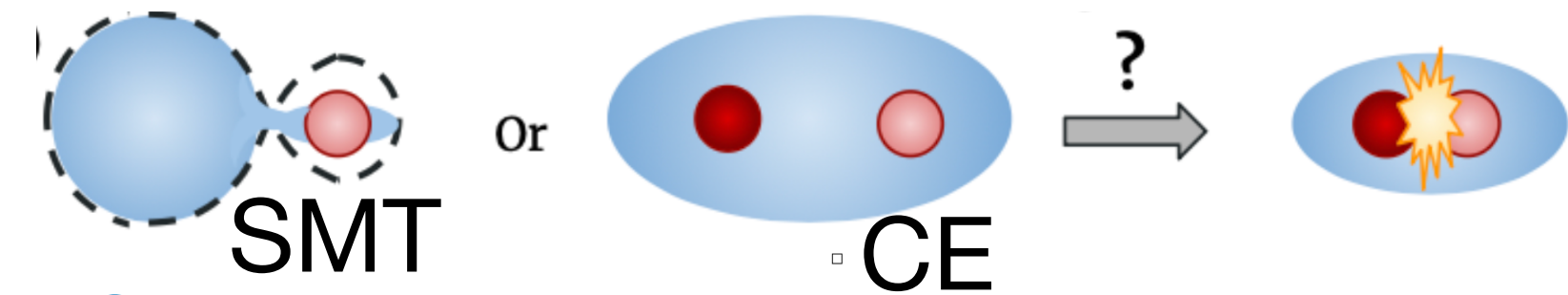


Isolated
Channel

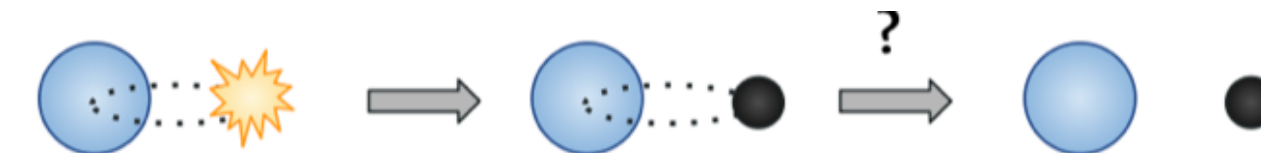
- **Stellar evolution**
(metallicity, winds, internal structure)



- **Binary processes**
(mass transfer, stability, common envelope)

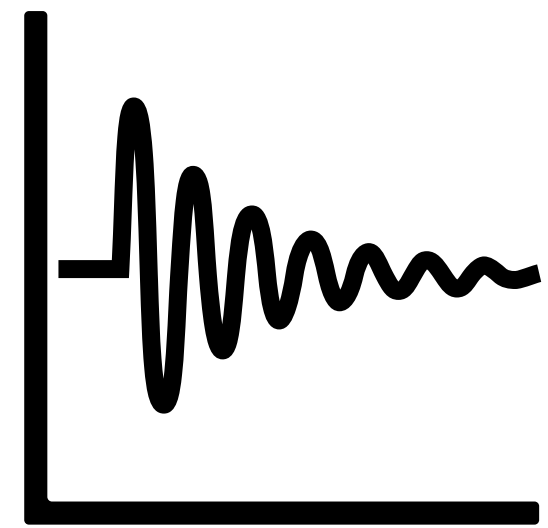


- **Supernovae**
(remnant type, remnant mass, kicks)

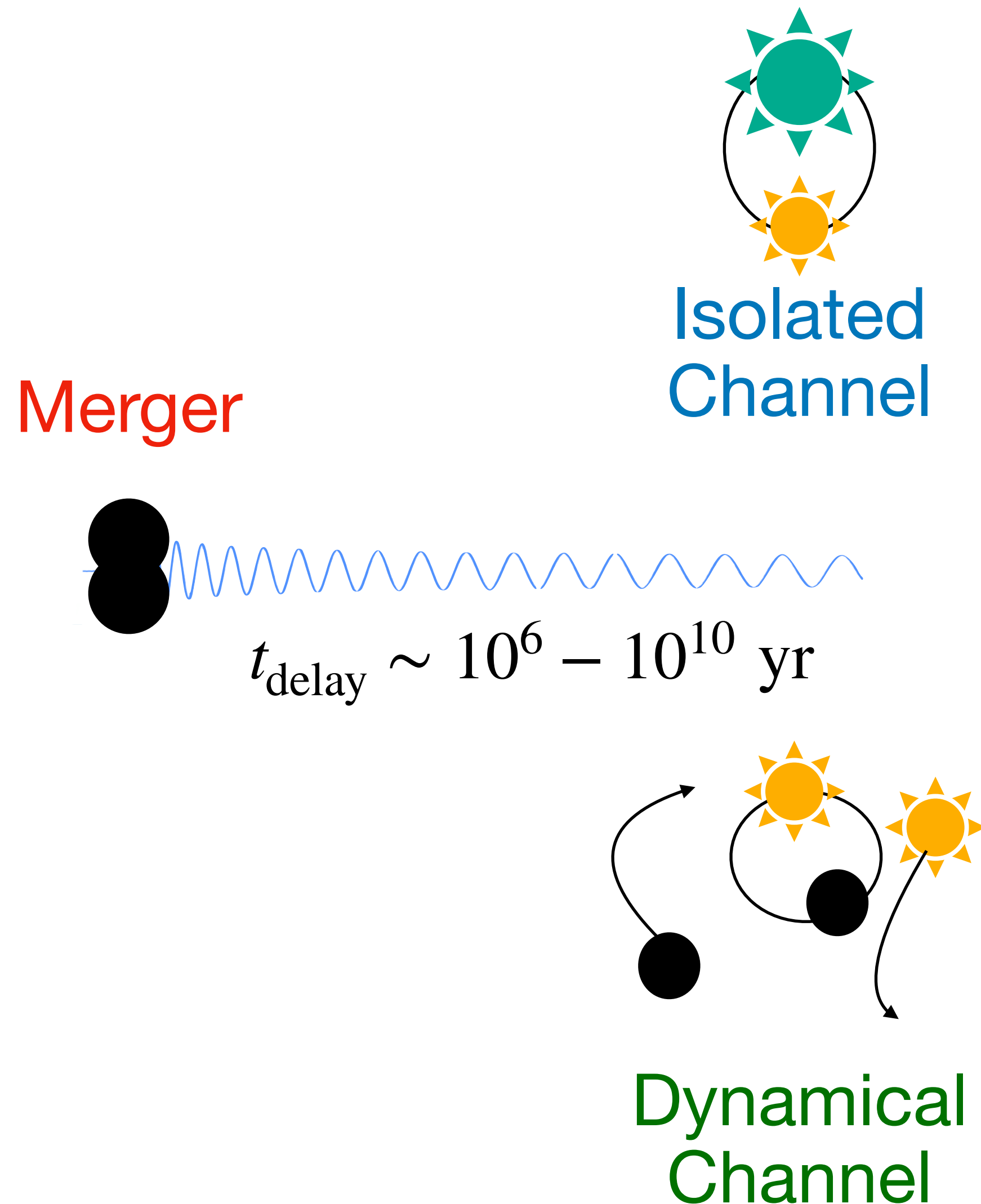


How/Channels

Astrophysical relevance

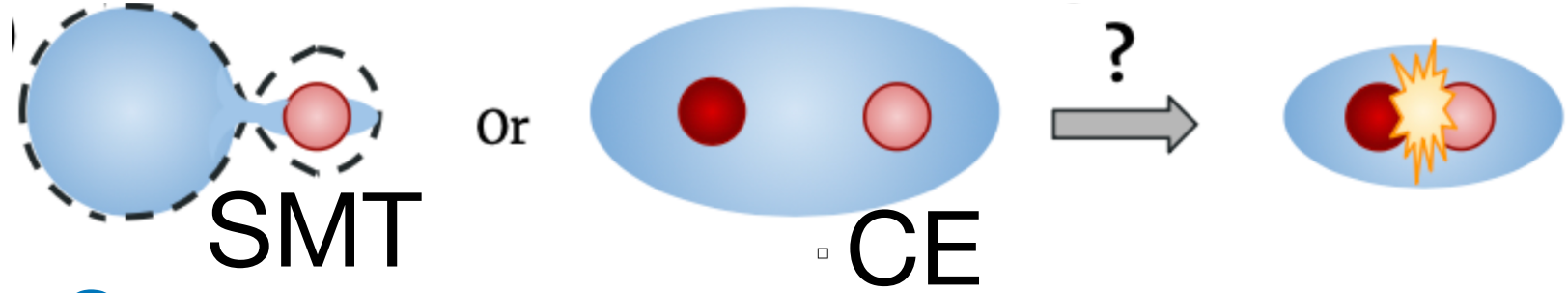
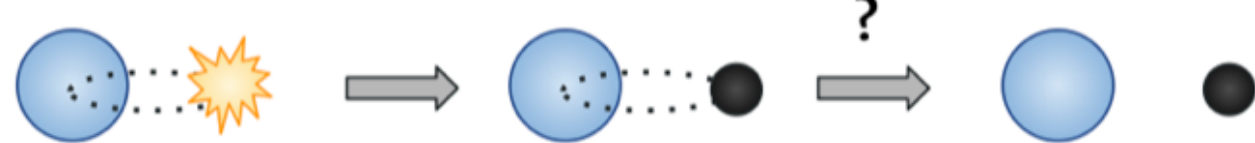


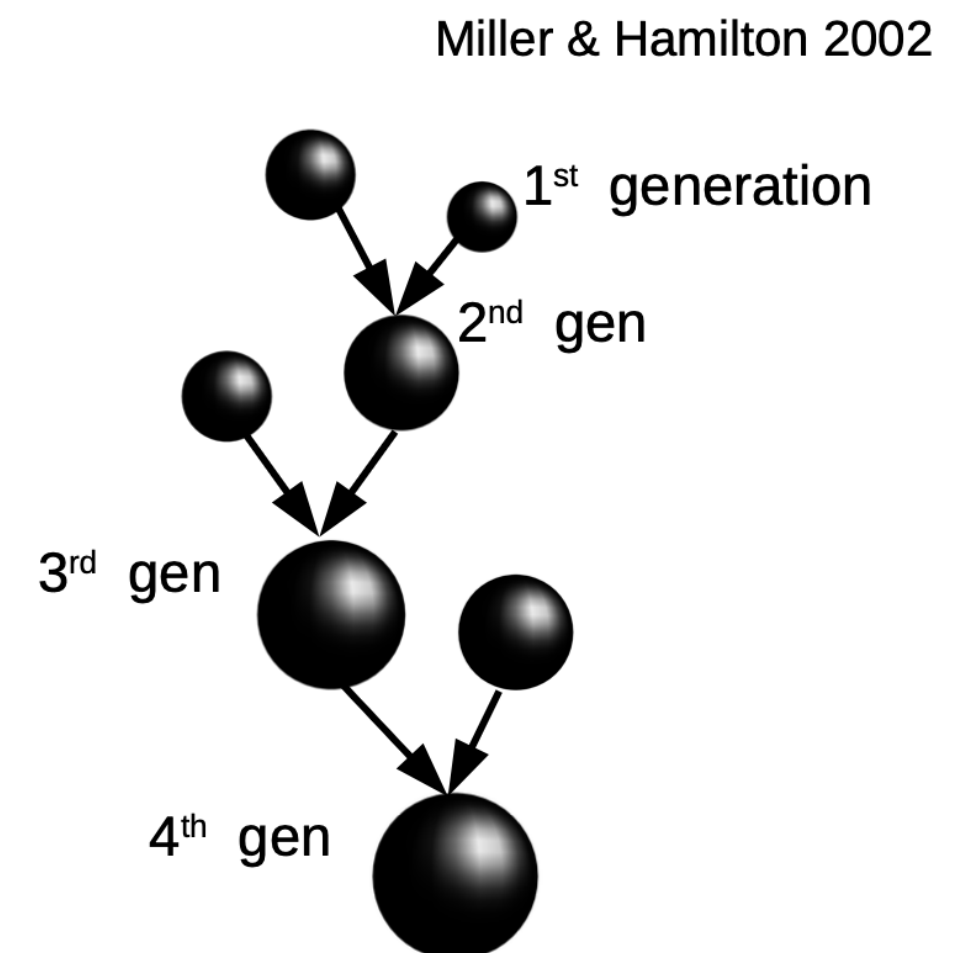
Detection
Masses
Spins
Distance
Location



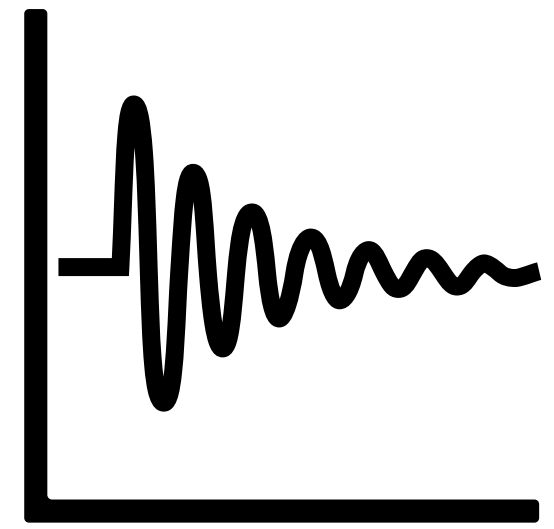
How/Channels

- **Stellar evolution**
(metallicity, winds, internal structure)

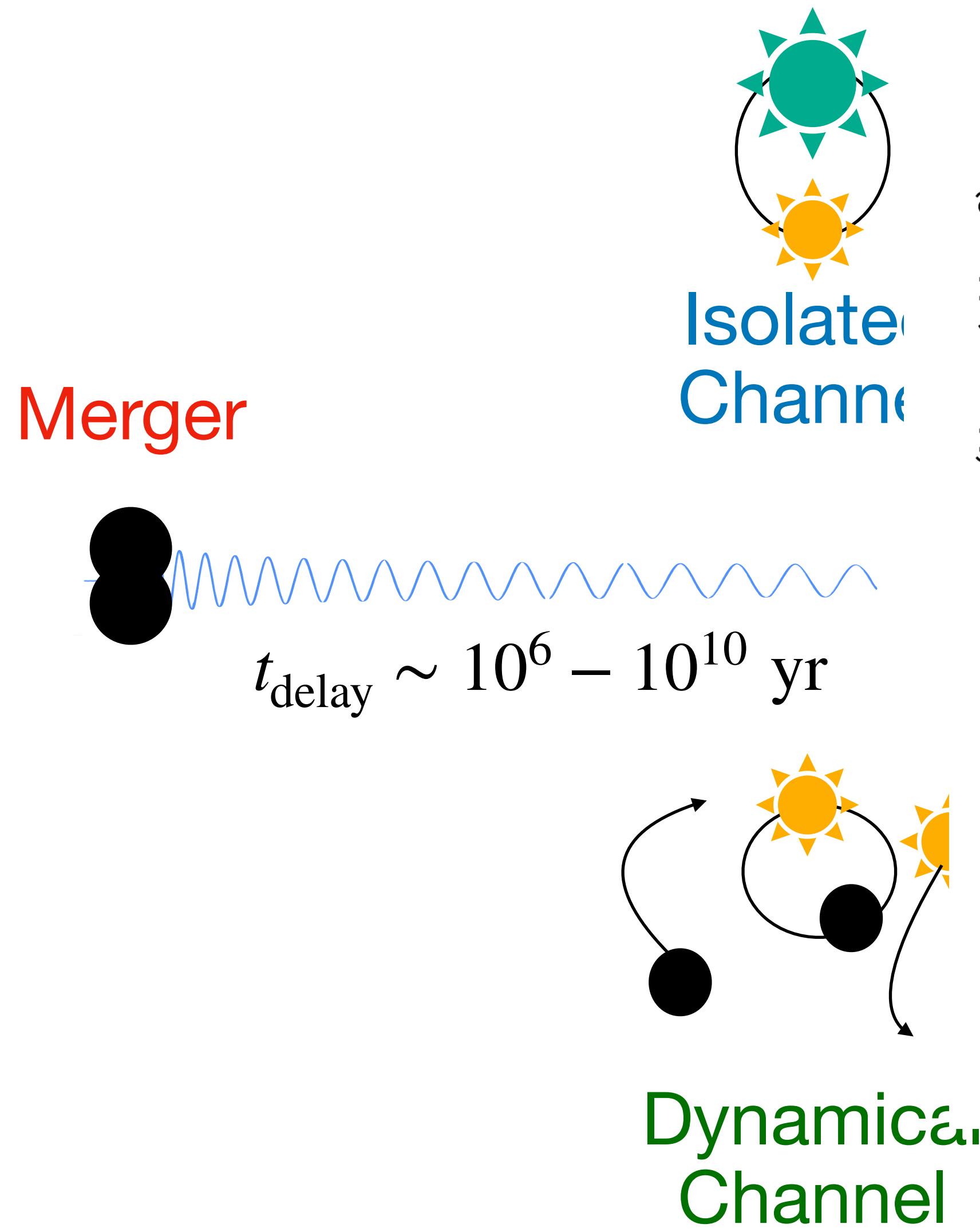
- **Binary processes**
(mass transfer, stability, common envelope)

- **Supernovae**
(remnant type, remnant mass, kicks)

- **Exchange**
- **Binary/Stellar disruption**
- **Binary hardening**
- **Runway mergers**
- **Hierarchial mergers**



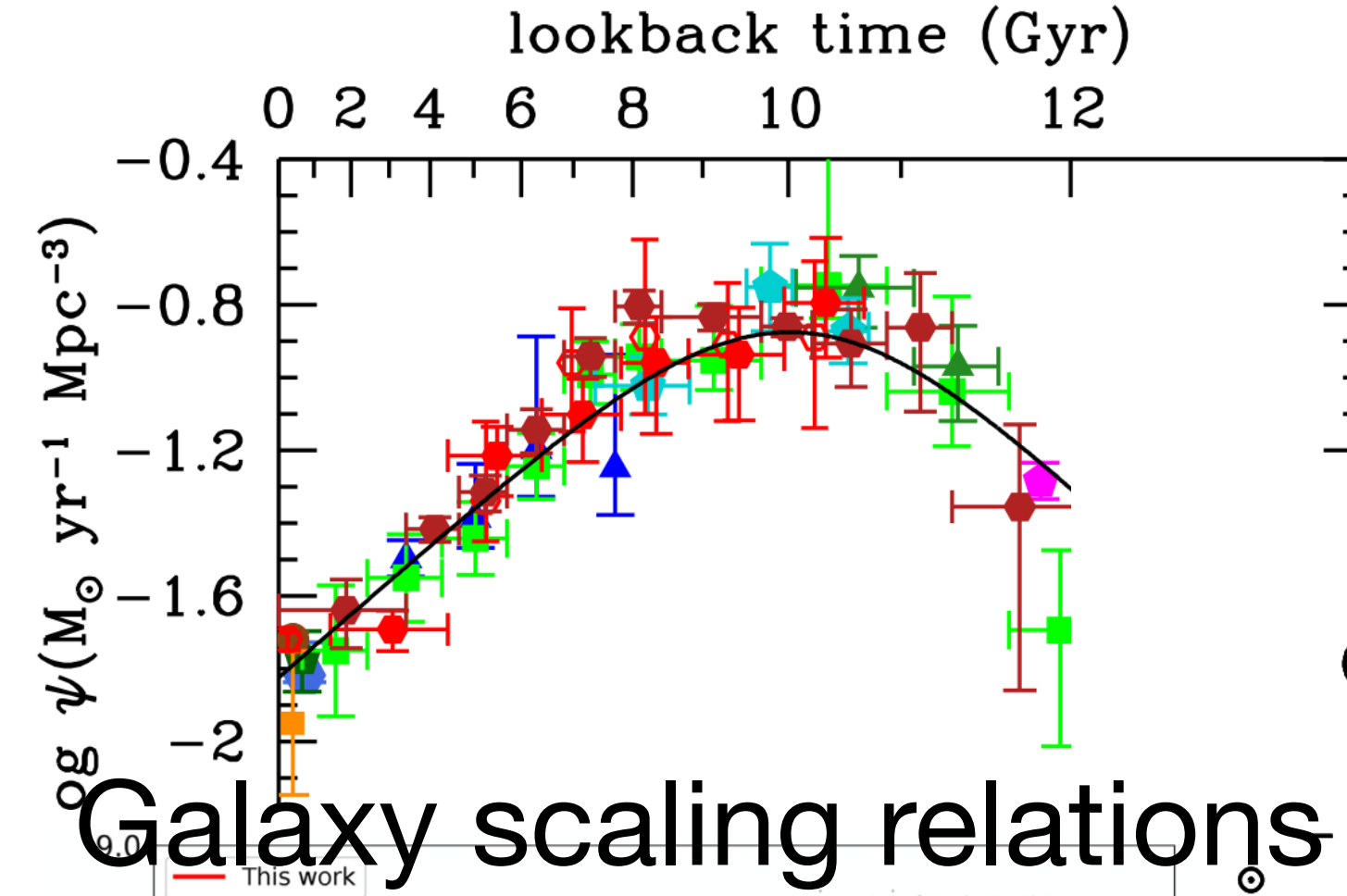
Astrophysical relevance



Detection
Masses
Spins
Distance
Location

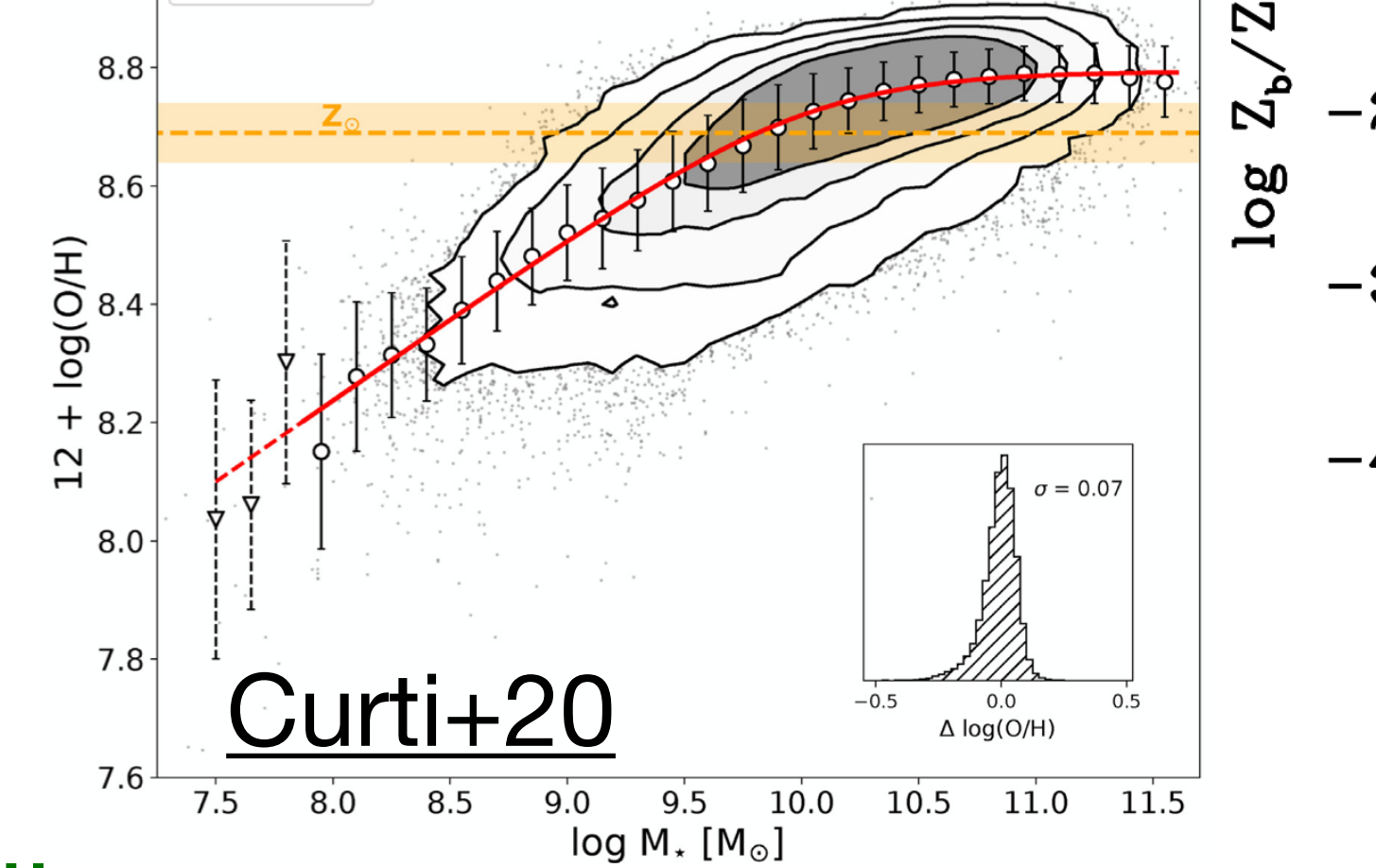
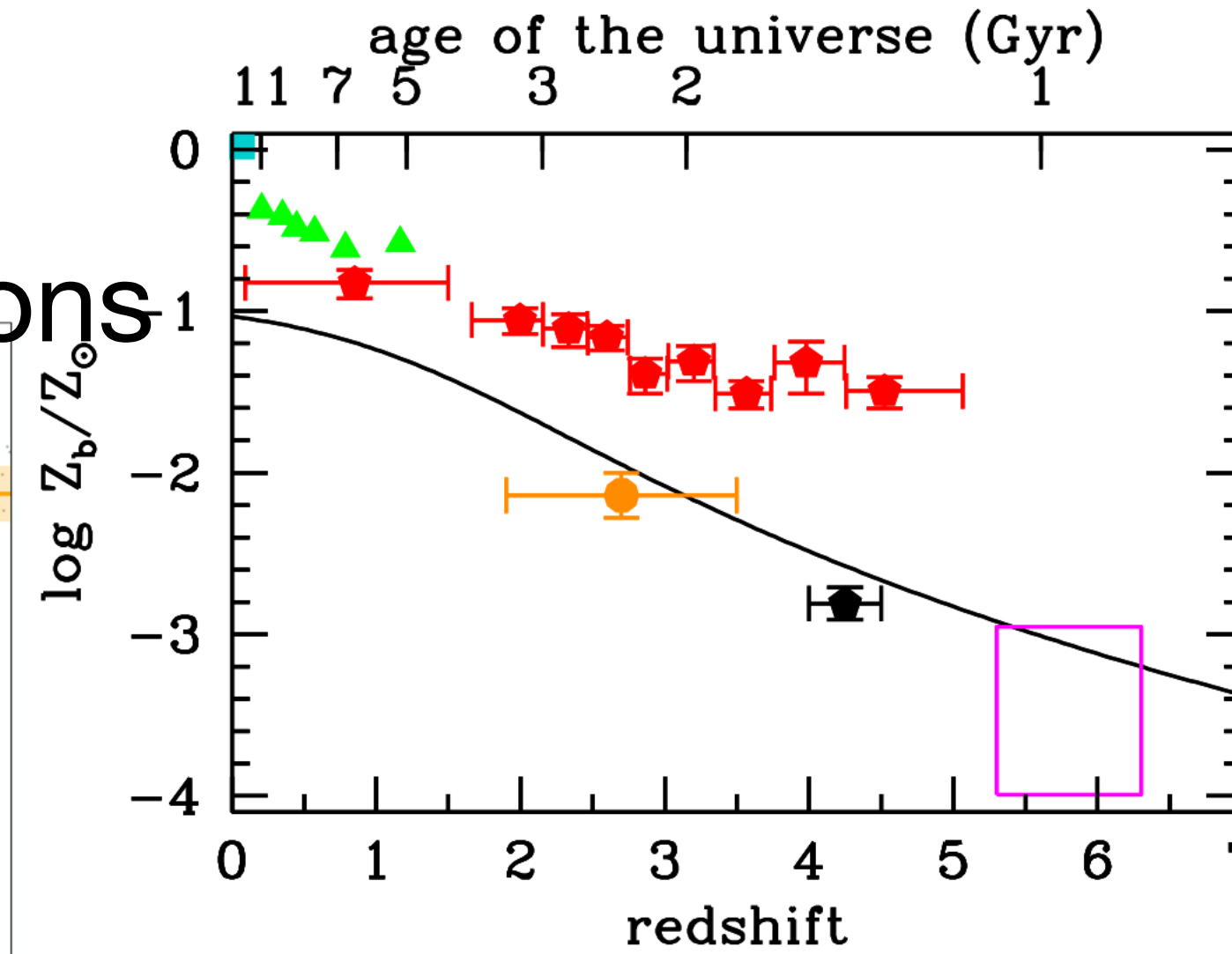


Star formation rate density



Madau&Dickinson14

Metallicity evolution

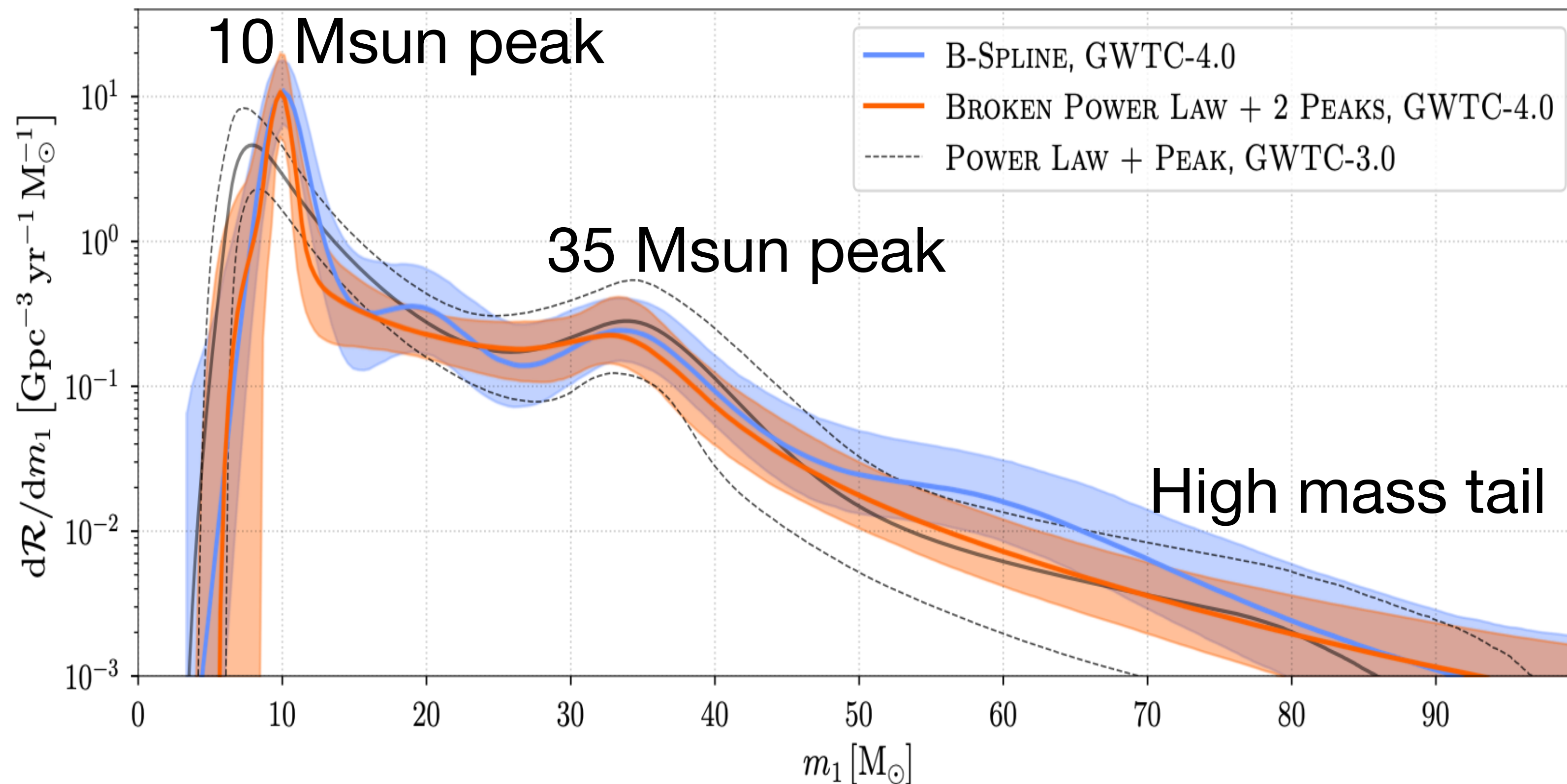


How/Channels

When/Where/Environments

Results from LVK

Mass spectrum



Rates

GWTC-4
(Abac+25)

BBHs: 16-24 $\text{Gpc}^{-3} \text{yr}^{-1}$

BNSs: 7.6-260 $\text{Gpc}^{-3} \text{yr}^{-1}$

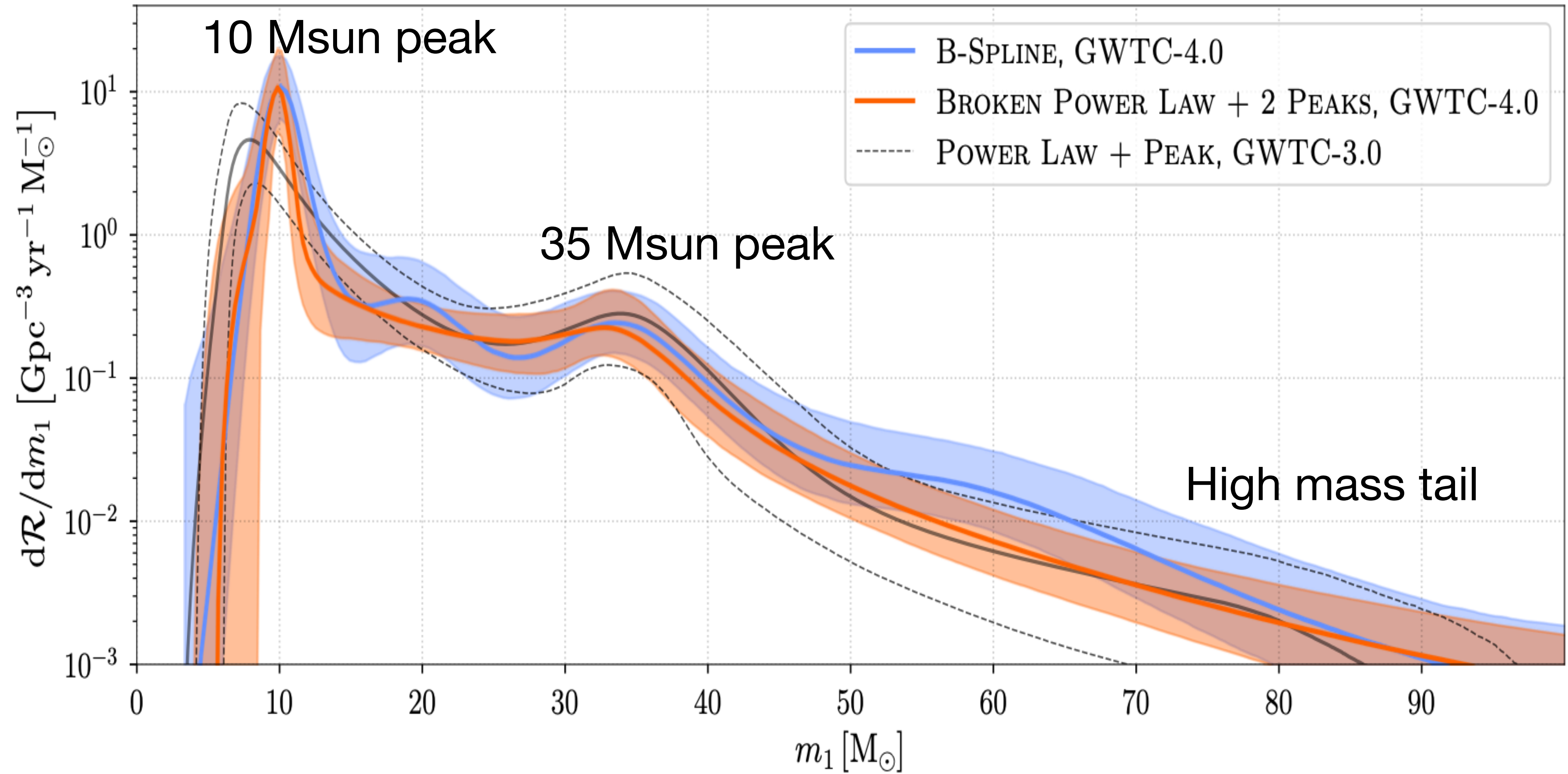
BHNSs: 9.1-84 $\text{Gpc}^{-3} \text{yr}^{-1}$



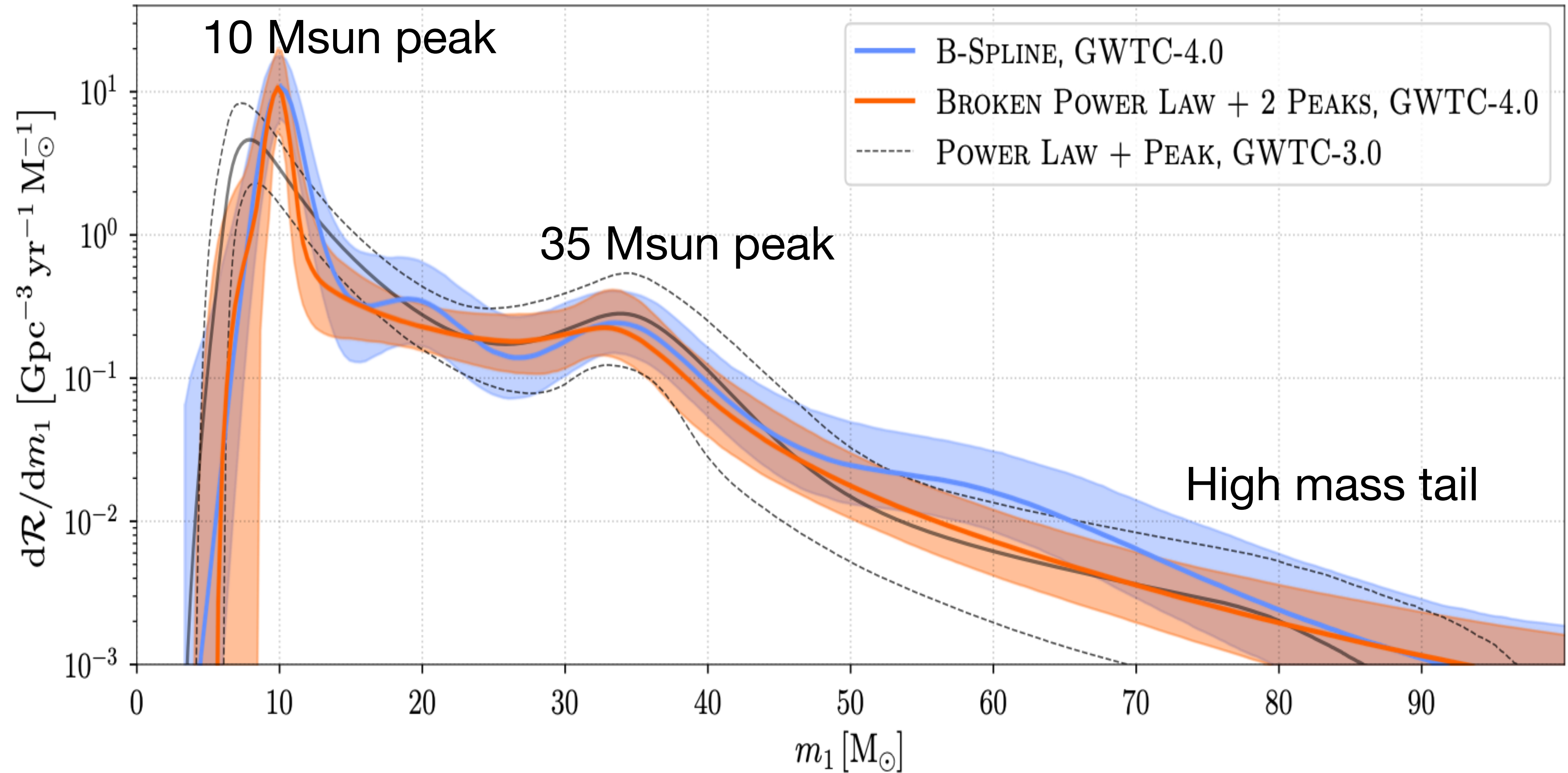
What is causing the features on the mass spectrum?

What population models fit the observed rates?

Mass spectrum features



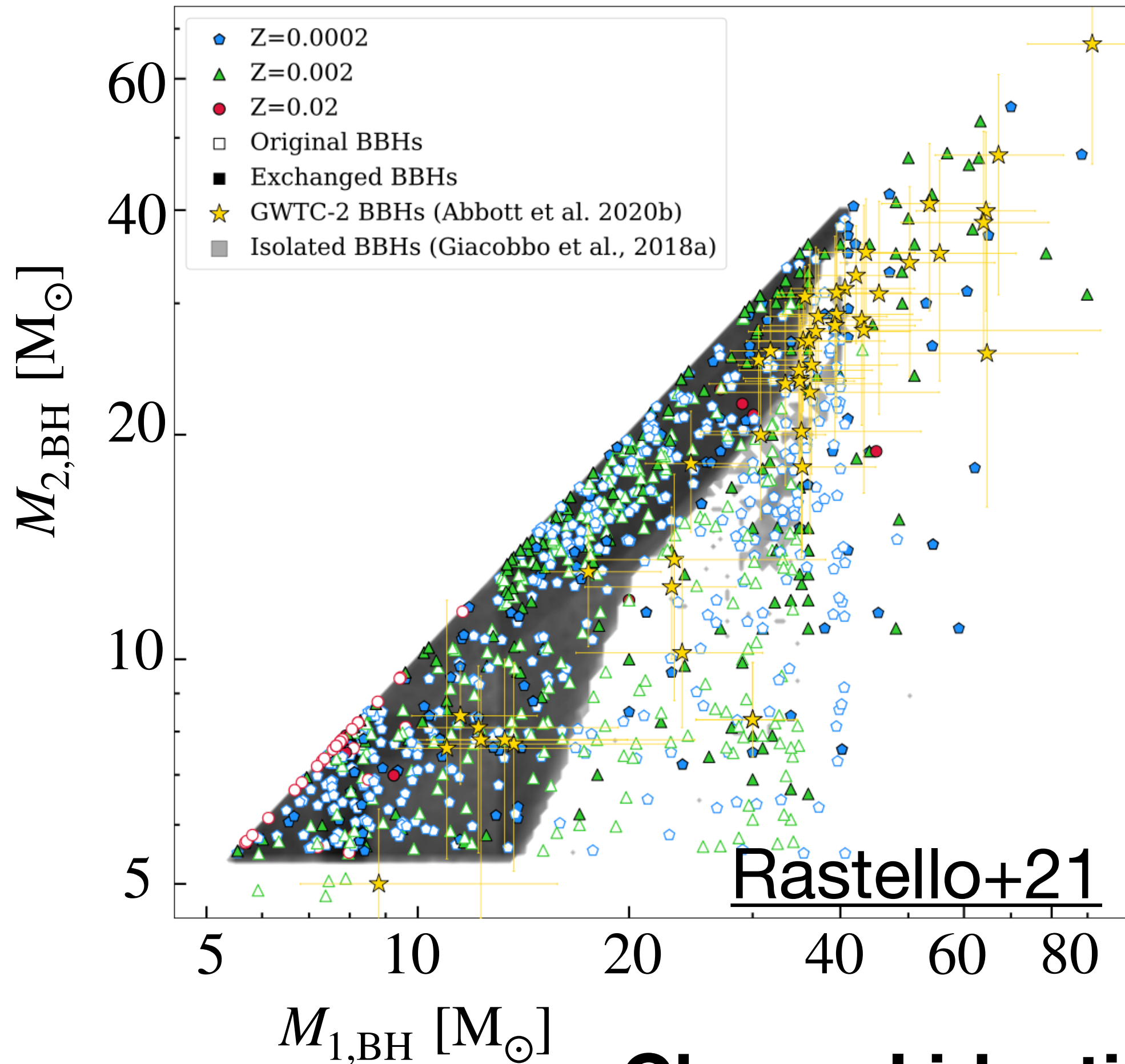
Mass spectrum features



SN vs metallicity vs Binary processes vs Channel

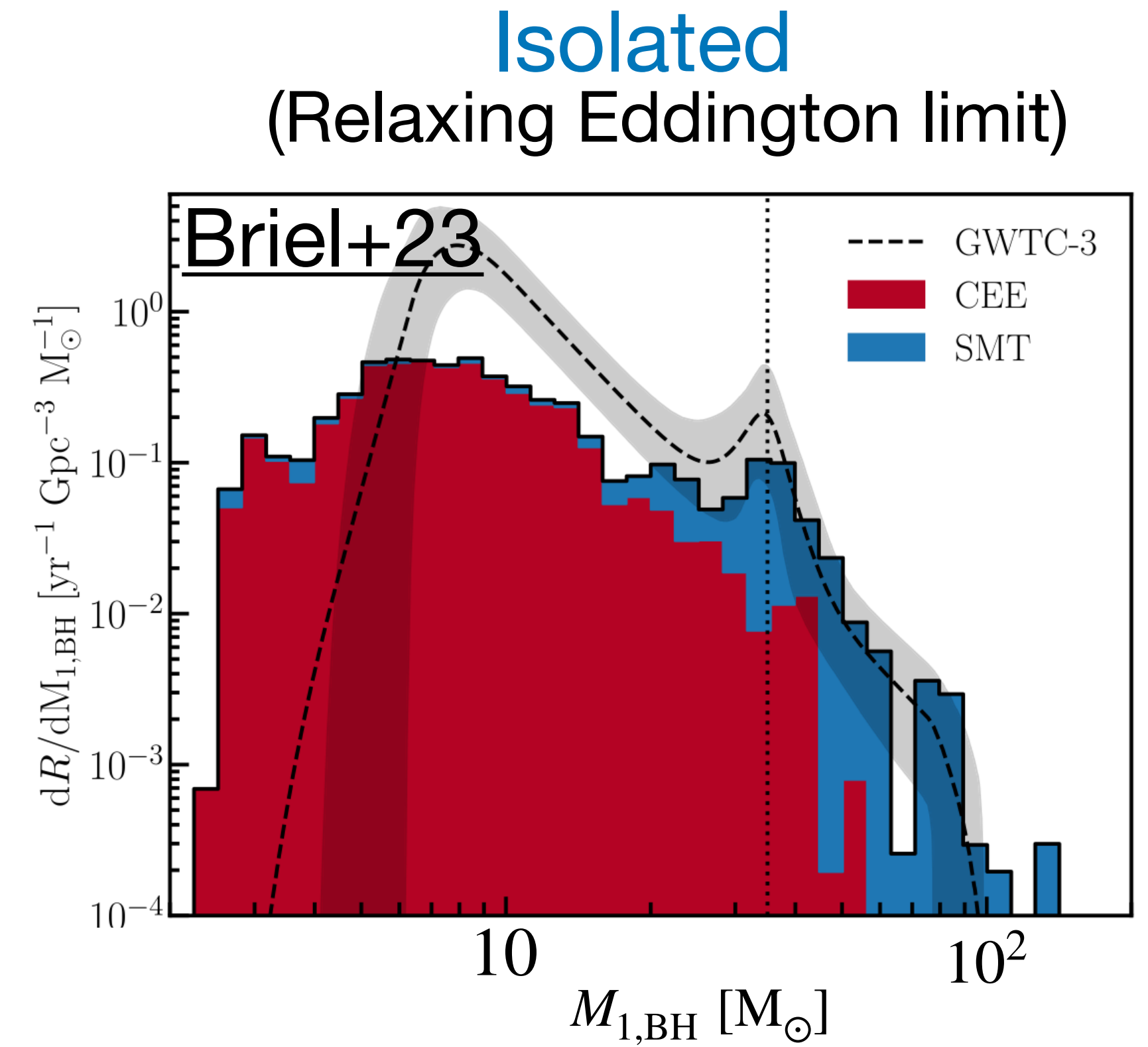
Formation channel of high mass black holes

High mass tail ?



Dynamics

- High BH mass
- High eccentricity
- Isotropic Spin distribution

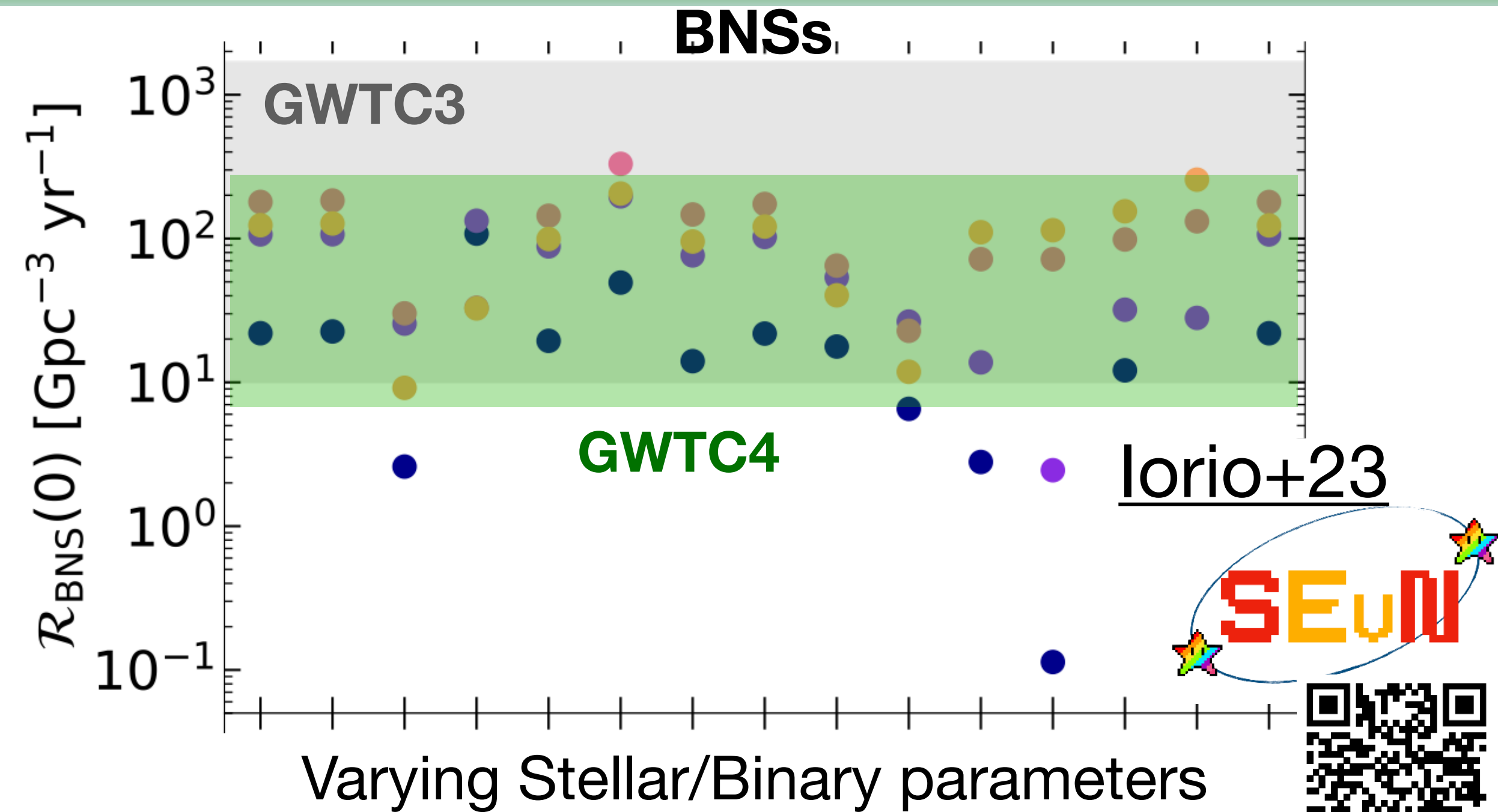
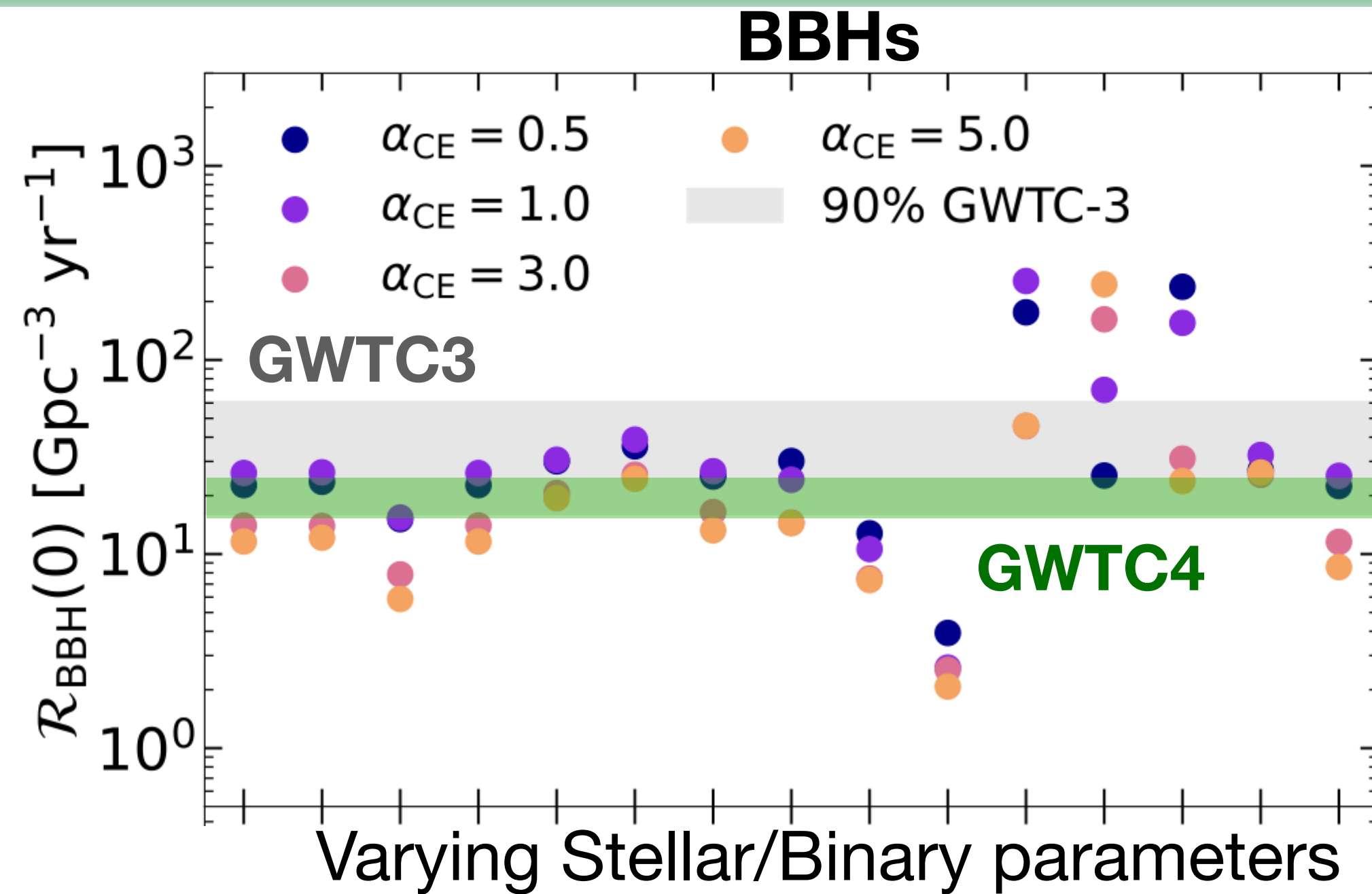


- High BH mass

Channel identification uncertain if based solely on mass

(But interesting new results including spins, e.g. [Antonini+25](#))

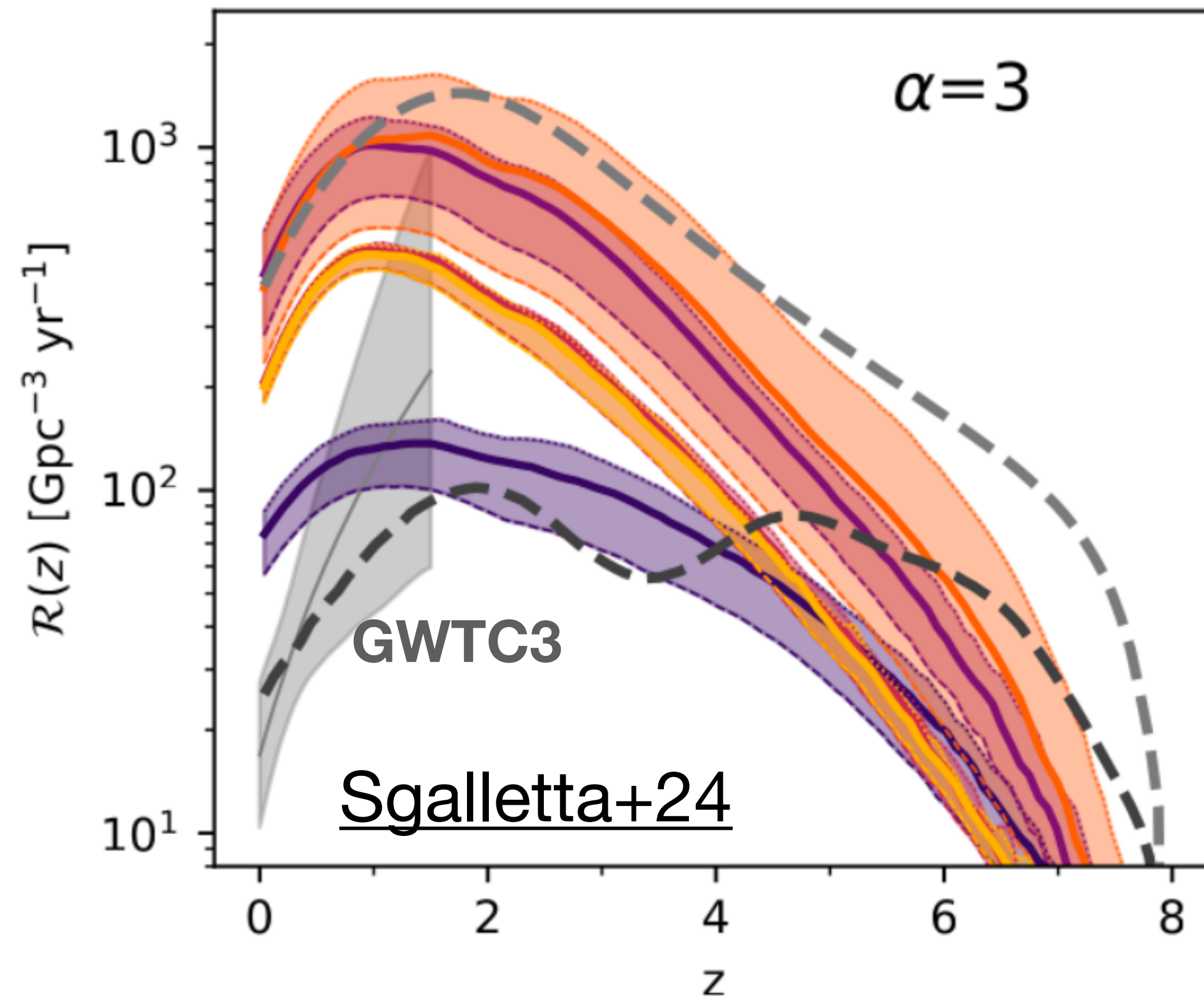
Rates from population models



+ many others (e.g. [Giacobbo&Mapelli18](#), [Broekgaarden+22](#), [Boesky+24](#))

- **Many models fit the GWTC-3 rates**
- **Degeneracy** between stellar evolution models, binary evolution parameters, and cosmological models
- **Hard to constrain parameters** regarding the evolution of massive stars and binaries

The more accurately the metal-dependent star formation rate is modeled,
the larger the predicted excess of black holes



Accurate:
Scaling relations in galaxies



Averaged:
Average + custom spread



What is wrong with the stellar and/or binary evolution models?

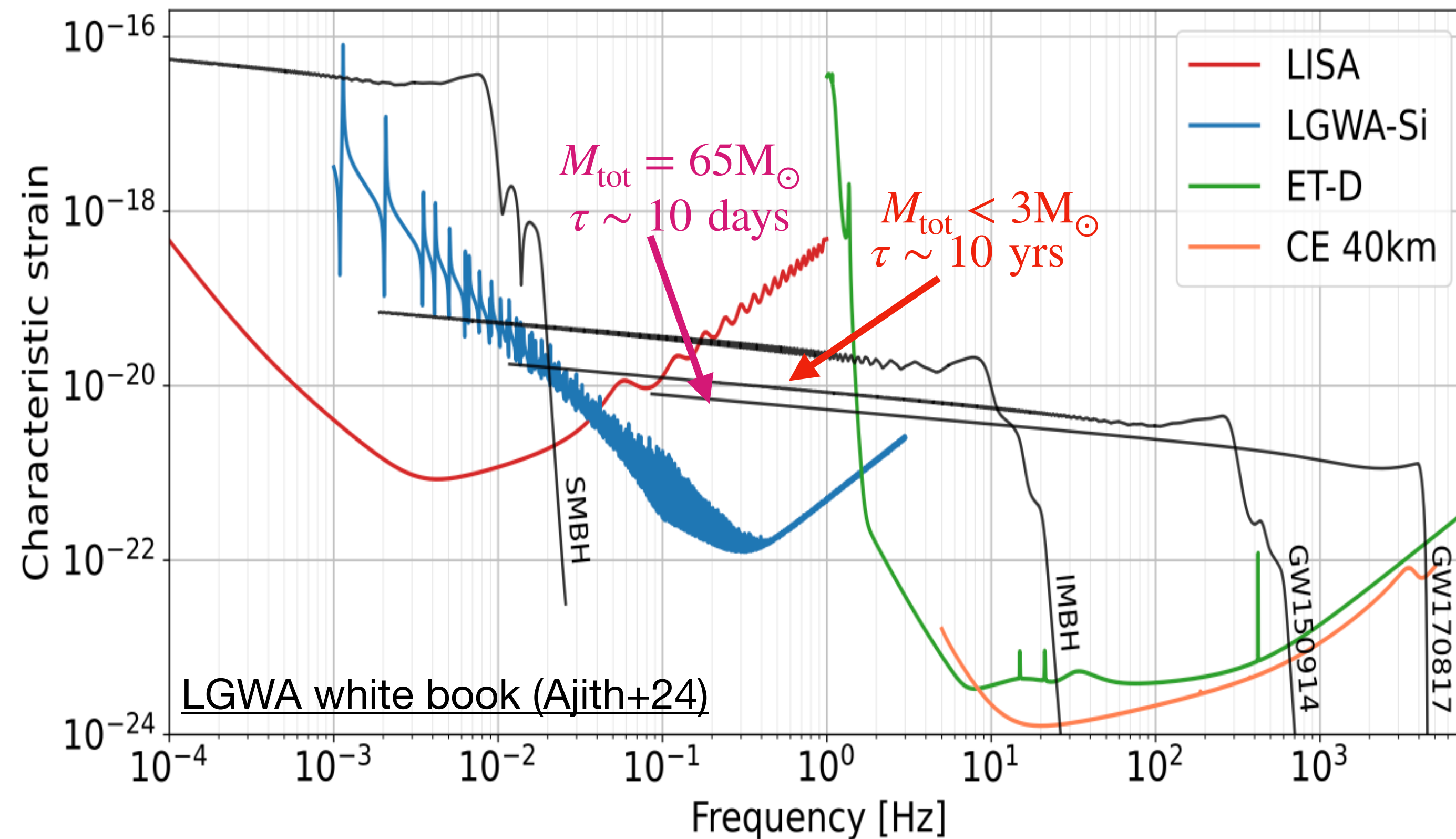
Essential summary

Some (**very relevant**) certainties,
Many open questions, Possible tensions



How observations in deci-Hz band can help?

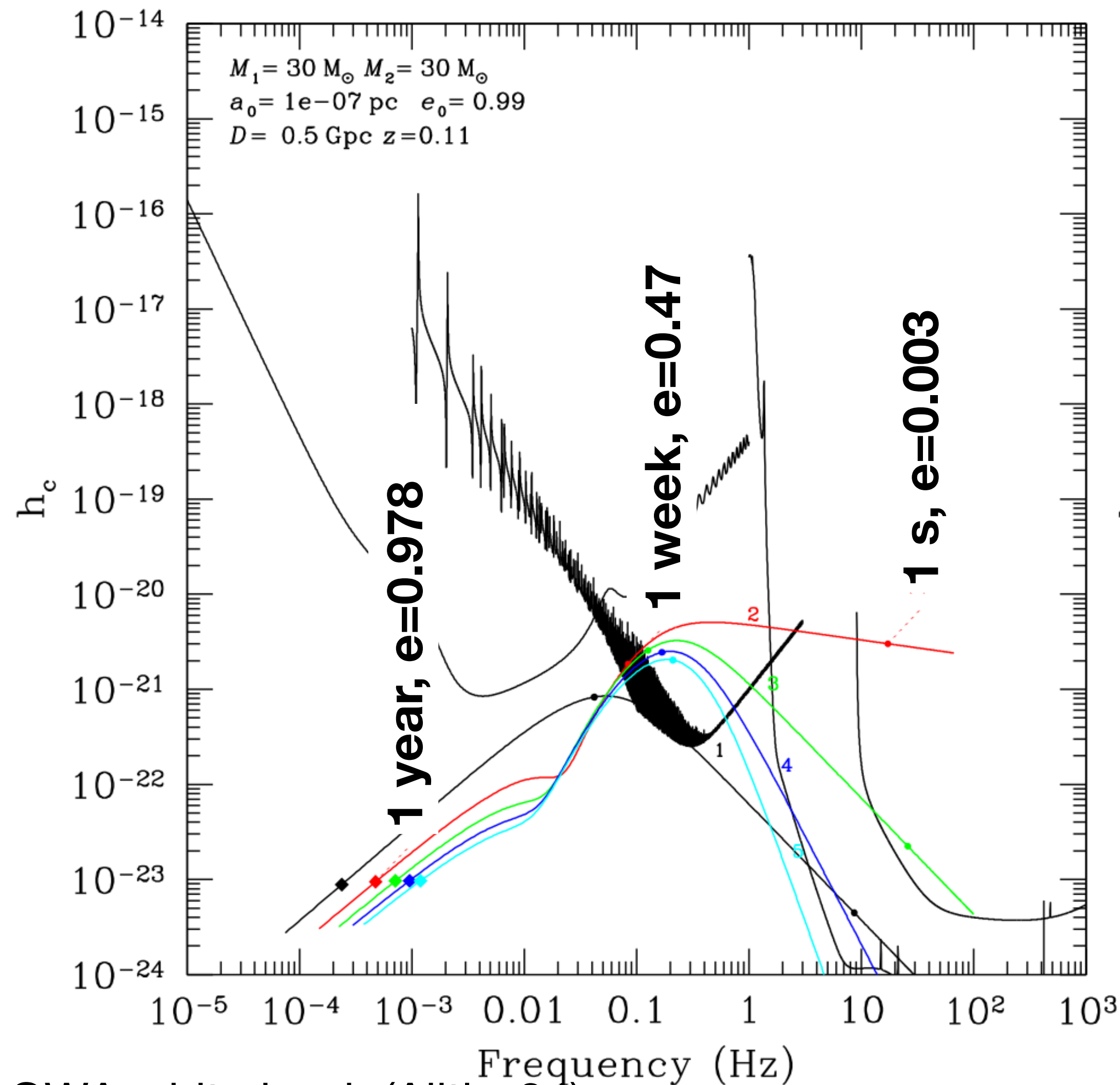
Complementary and multi-band detections



- **Multi-band detections**, especially for the BCOs in the high-mass tails
- **Days-years in band: improve characterisation**
- Days-years in band: **early alert** for EM counterpart

Complementary and multi-band detections: eccentricity and early

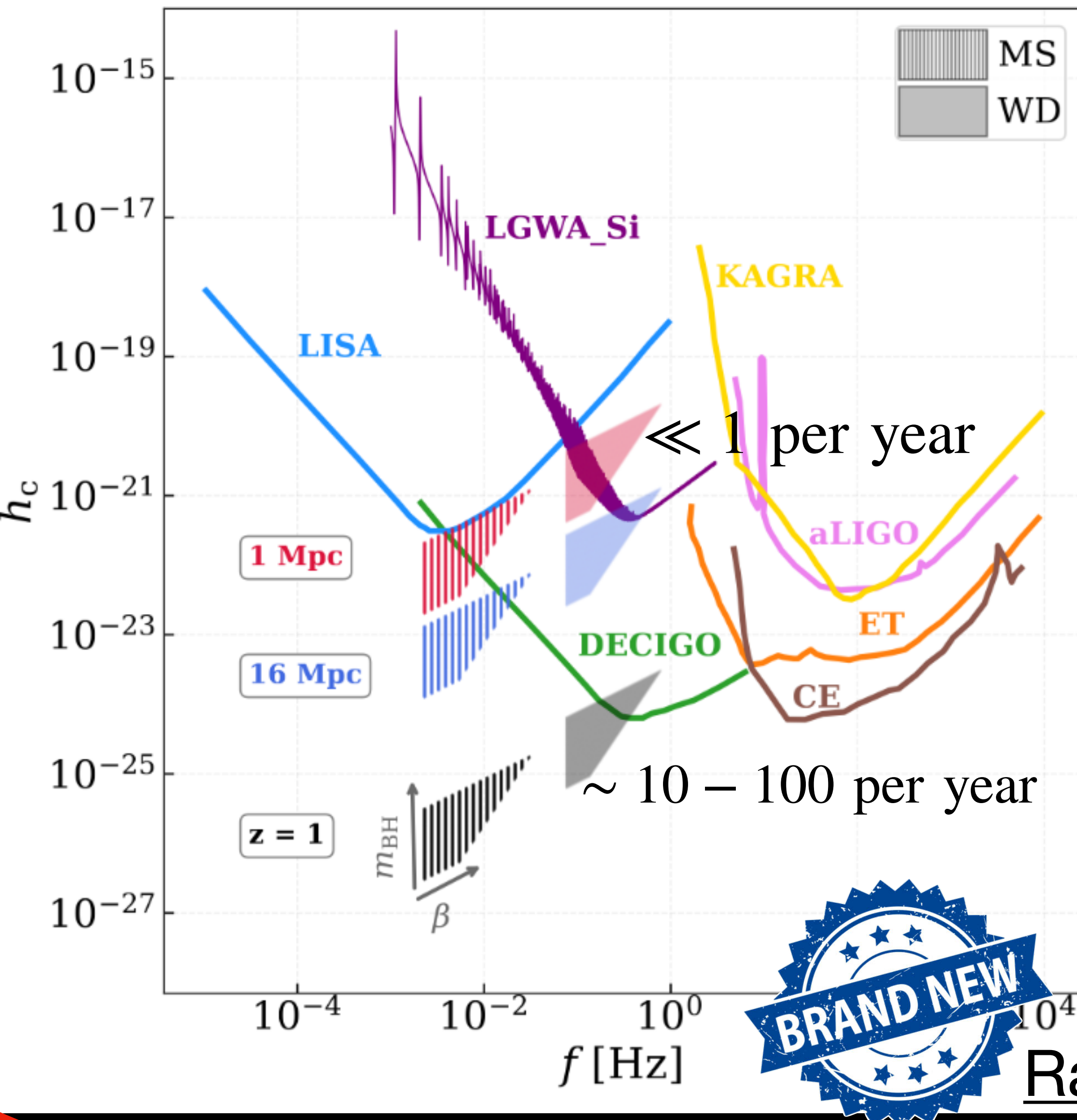
$$M_1 = M_2 = 30M_{\odot} \quad e_0 = 0.99 \quad z = 0.11$$



- Very eccentric systems will still have a **measurable residual eccentricity** in deci-Hz band
- “Smoking gun” for the dynamical formation channel

Micro-TDEs

(Stars destroyed by stellar mass black-holes)



- Micro-TDEs in star clusters could be a **complementary** way to reveal the properties of **BHs in dynamical environments**
- Micro-TDE rates / BCOs merger rates correlated in star clusters => additional constraints
- **Peak in deci-Hz band**, but the predicted rates are too low for LGWA, good science case for DECIGO

- Micro-TDE rates / BCOs merger rates correlated in star clusters => additional constraints

- **Peak in deci-Hz band**, but the predicted rates are too low for LGWA, good science case for DECIGO

Rastello, Iorio+25 (arXiv:2509.07067)

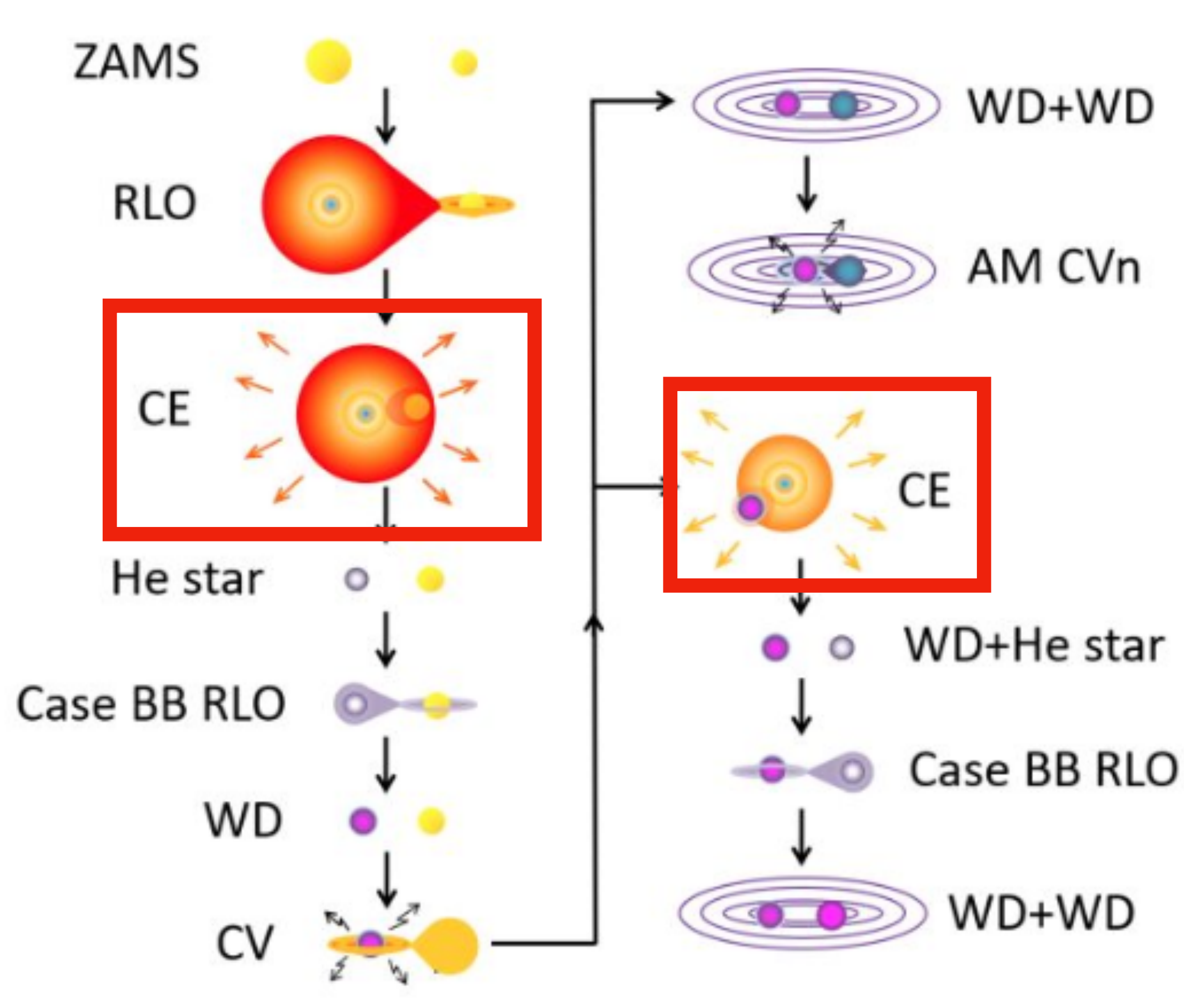


Complementary set of observations

Ultra compact binaries

- Neutron star-WD Binaries
- WD-WD Binaries

**Complementary constraints
on binary processes
(e.g. mass transfer and common
envelope)**



Tauris and van den Heuvel (2022), Amaro-Seoane et al. (2022)

Summary

- ▶ **BCO populations encode a wealth of astrophysical information**
- ▶ **GW and LVK starts the era of population studies of BCOs**
- ▶ **At moment: some (very relevant) certainties, many open questions, possible tensions**
- ▶ **Future synergy with deci-Hz and LGWA offers a complementary set of observations and observables that will help the astrophysical interpretation of BCO populations**

THANK YOU

