Holes
Binary Black ~~Boles~~ from First stars: Dependence on Initial Conditions and Stellar Models

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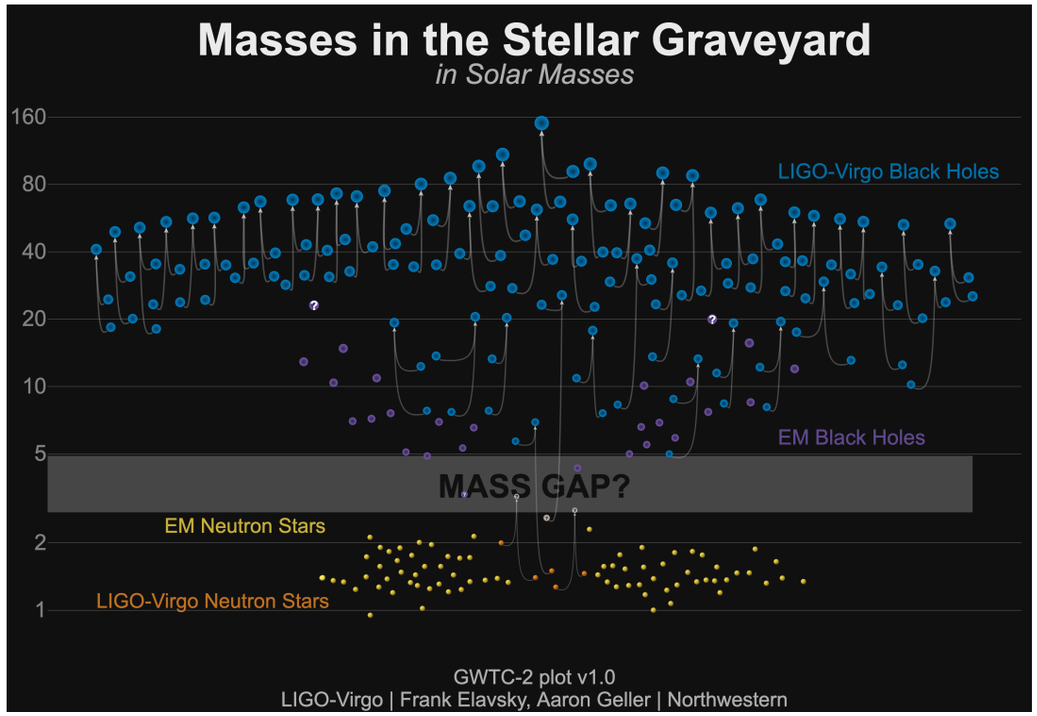
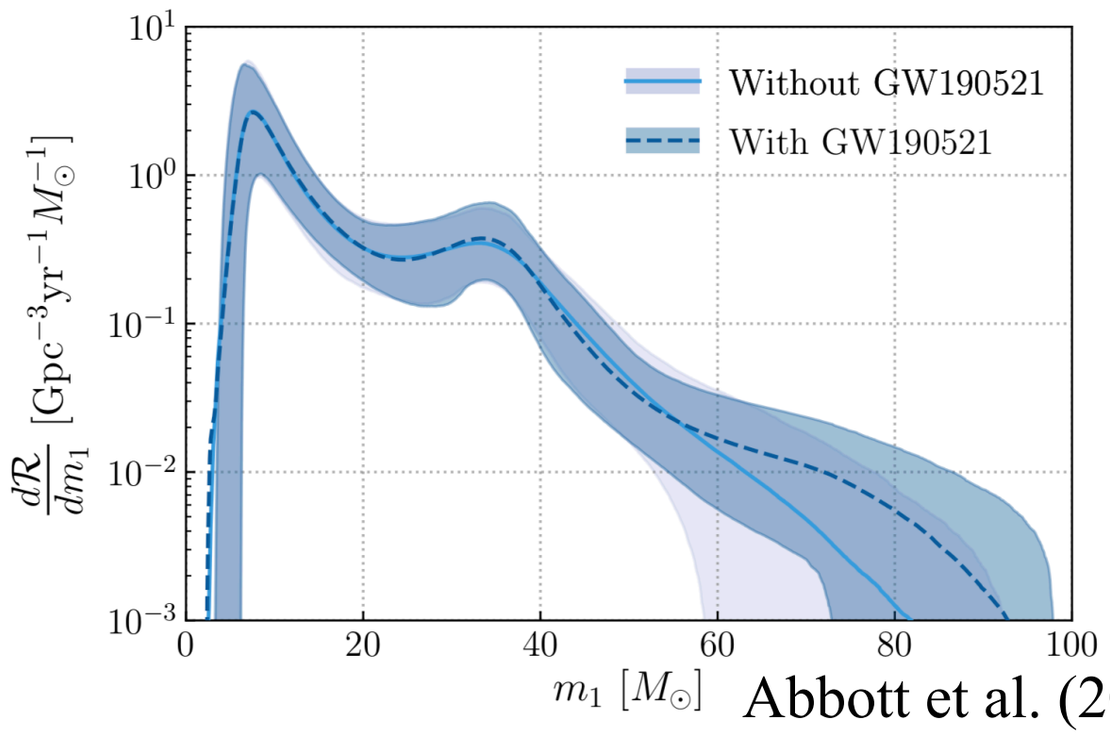
- Tanikawa et al. (2020, arXiv:2008.01890, accepted for ApJ)
- Tanikawa et al. (2020, arXiv:2010.07616)

H
Binary Black Boles

- $\sim$ 50 BH-BH discovered in these 5 years
- Heavy ($\sim 10 - 90 M_\odot$), low-spinning (~ 0) BHs
  - $\Longleftrightarrow$ Light ($\sim 10 M_\odot$), high-spinning (~ 1) BHs in X-ray binaries
- What makes them different?
  - Metallicity (Pop. II/III $\Longleftrightarrow$ Pop. I)
  - Formation site (Globular clusters $\Longleftrightarrow$ Binary)

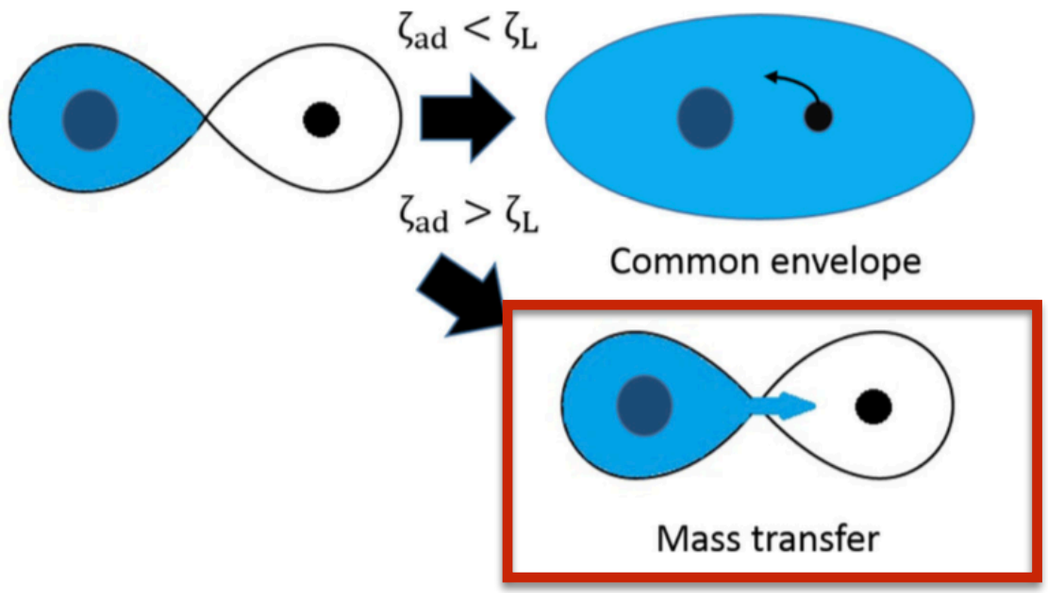


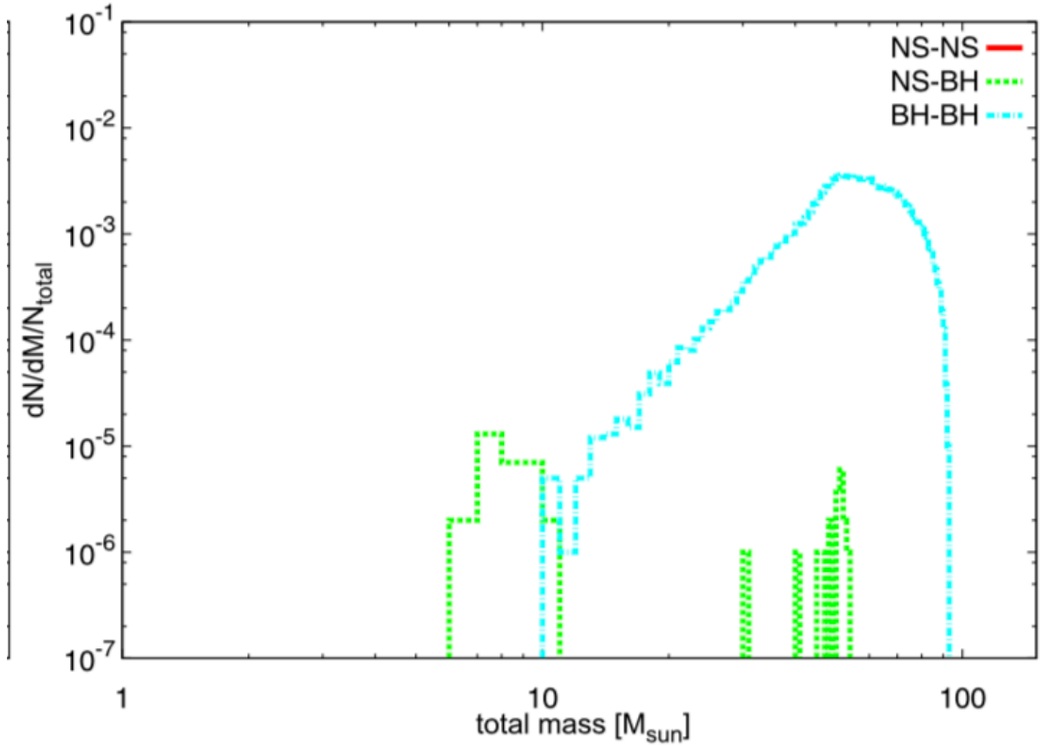


Abbott et al. (2020)

First stars (Pop. III stars)

- Typically $\sim 30 M_\odot$ BHs
  - Weak stellar winds
  - Stable mass transfer
- Our aims
  - Various initial conditions
  - Various stellar models
- Rate? Mass distribution? etc.

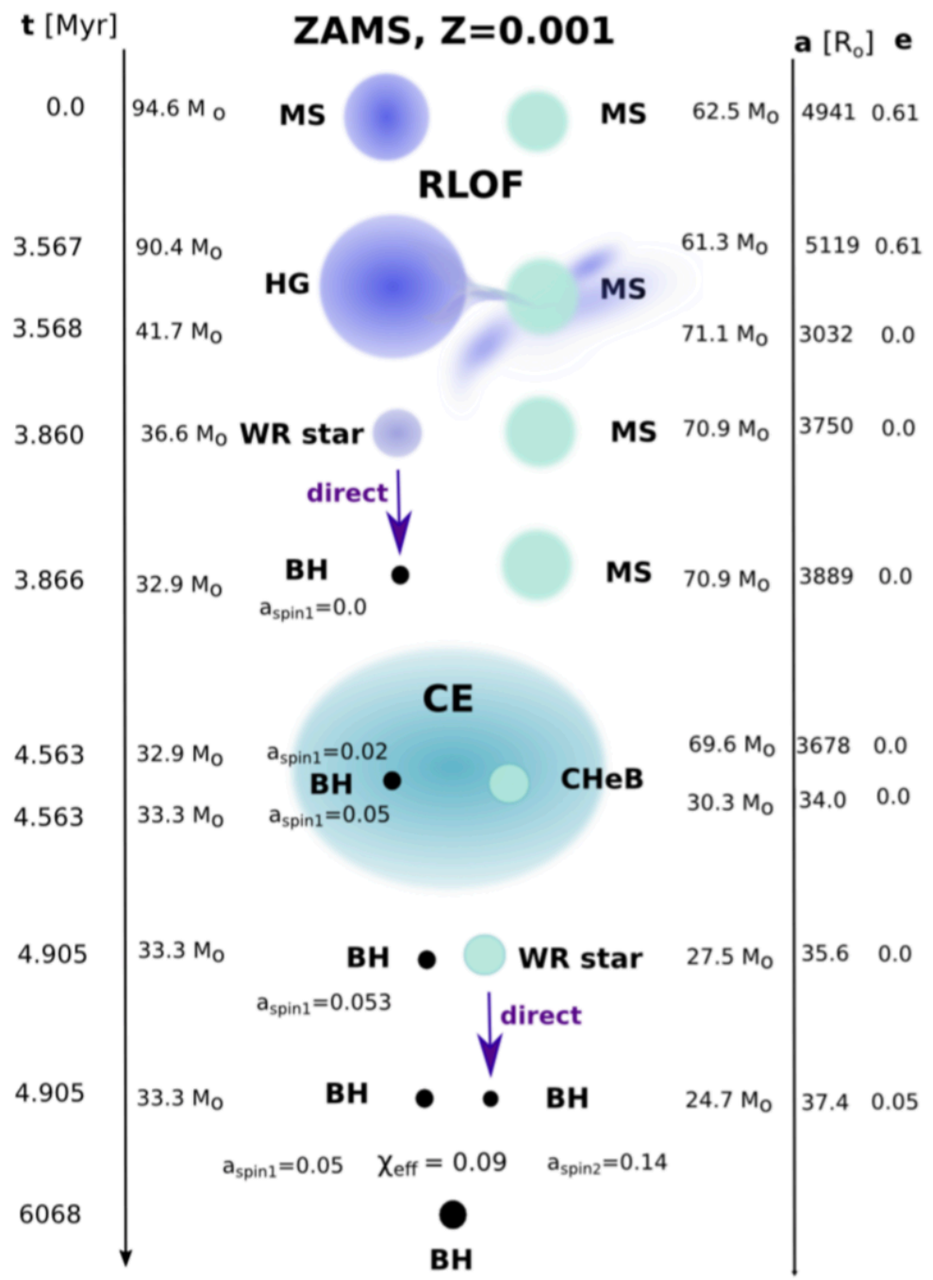




Kinugawa et al. (2014)

Binary population synthesis

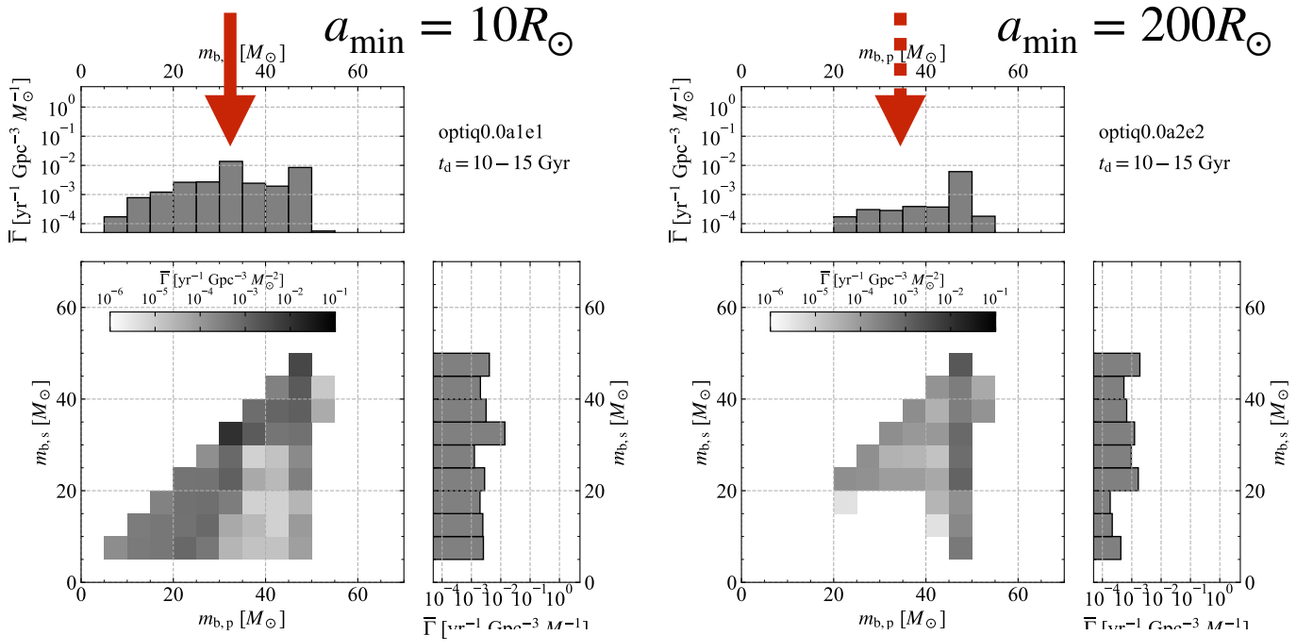
- Approximate binary model → 10^6 binaries
  - Star evolution, stellar wind, …
  - Mass transfer, common envelope, tidal interaction, …
- Initial conditions
  - Minimum separation: $a_{\min} = 10{,}200 R_\odot$
  - Minimum mass ratio: $q_{\min} = 0{,}0.9$
- Star model
  - Rotational enhanced stellar wind: on/off
  - BH natal kick: on/off

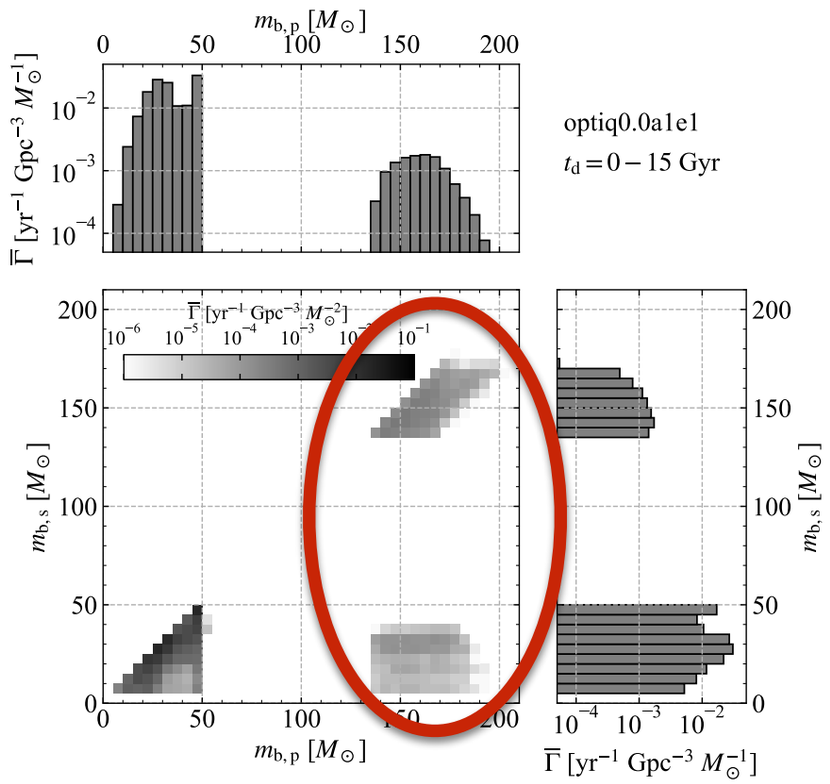


Belczynski et al. (2020)

Results

- The merger rate density is insensitive to initial conditions, $\sim 10^{-14}\mathrm{yr}^{-1}\mathrm{Gpc}^{-3}M_\odot^{-1}$.
- The $30M_\odot$ peak disappears without close ($\sim 10R_\odot$) Pop. III binaries.
- The sum of IMBH-BH and IMBH-IMBH merger rates is $\sim 1\ \mathrm{yr}^{-1}$ within $z \sim 0.82$ in a conservative Pop. III formation rate.



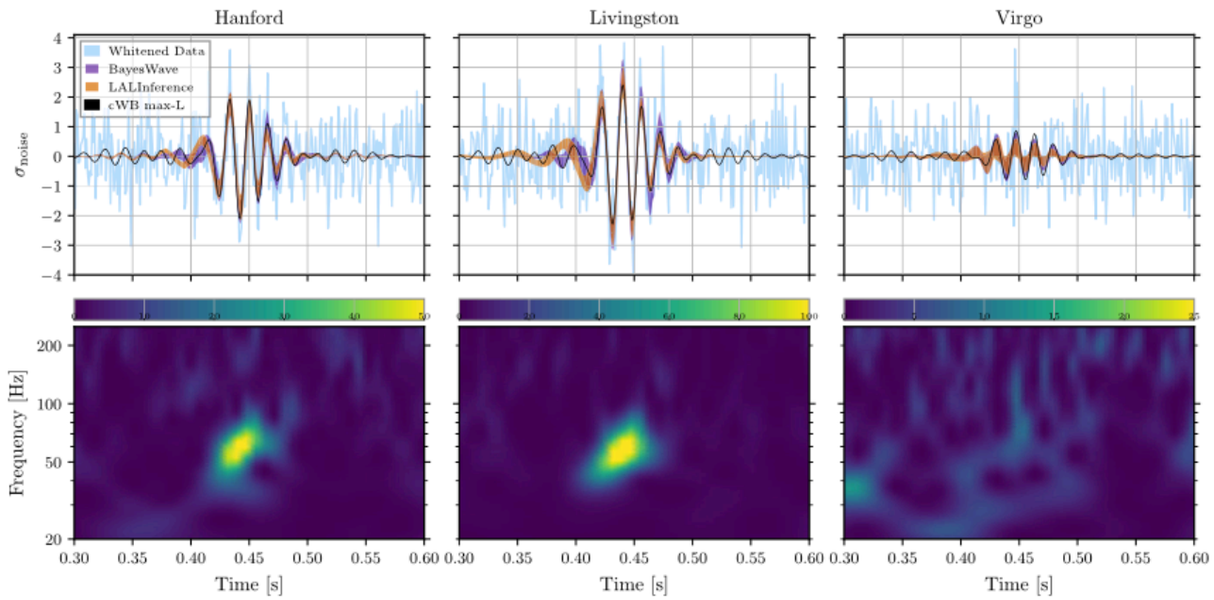


Tanikawa et al. (2021, arXiv: 2008.01890, ApJ accepted)

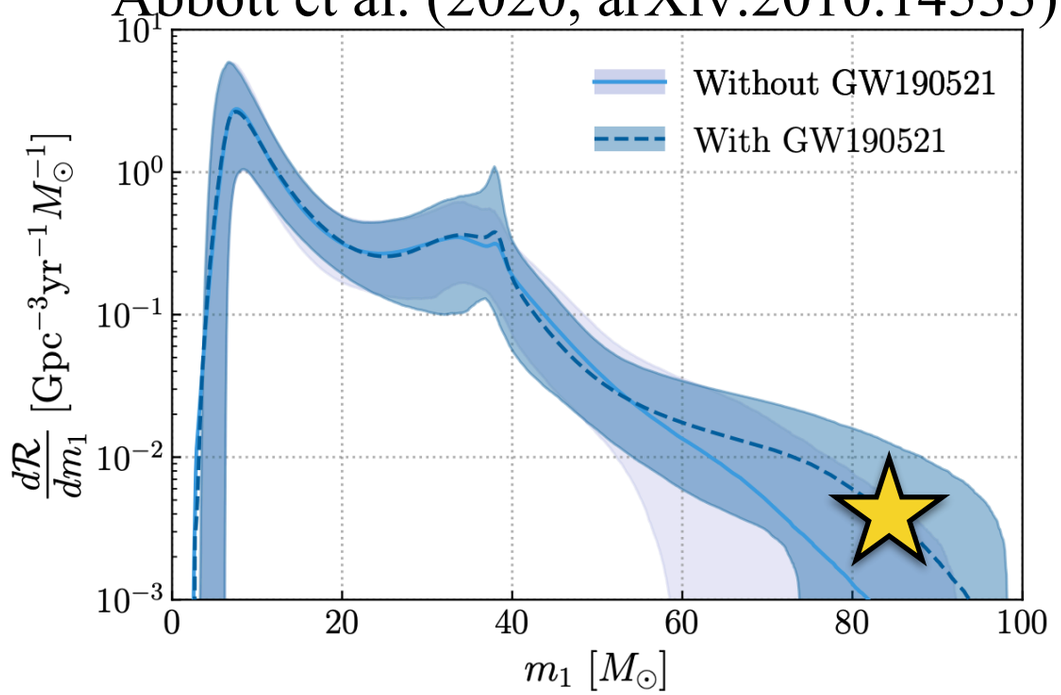
Mass gap event: GW190521

- $85^{+21}_{-14}M_{\odot}$BH - $66^{+17}_{-18}M_{\odot}$ BH
- So-called mass gap BHs because of pair instability
- Can binary evolution form such mass gap events?

Abbott et al. (2020, PRL, 125, 101102)

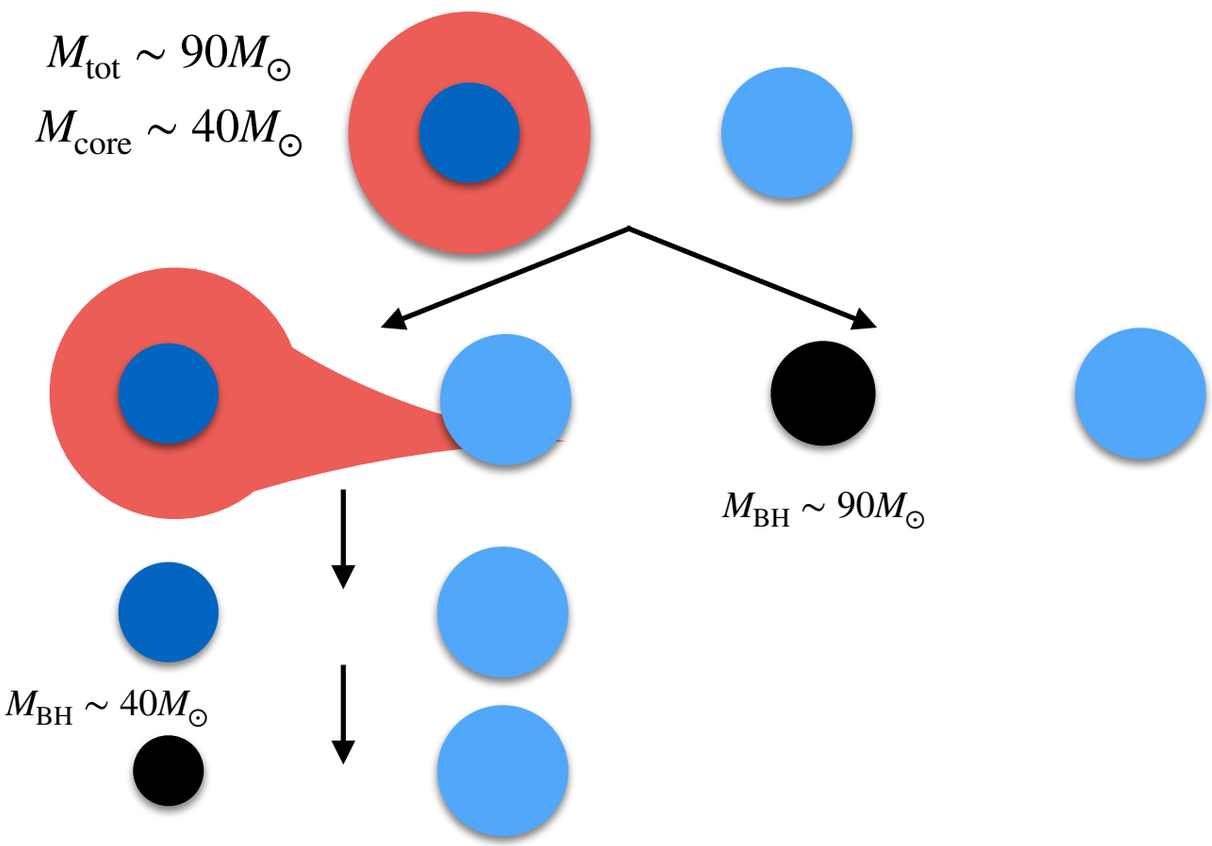


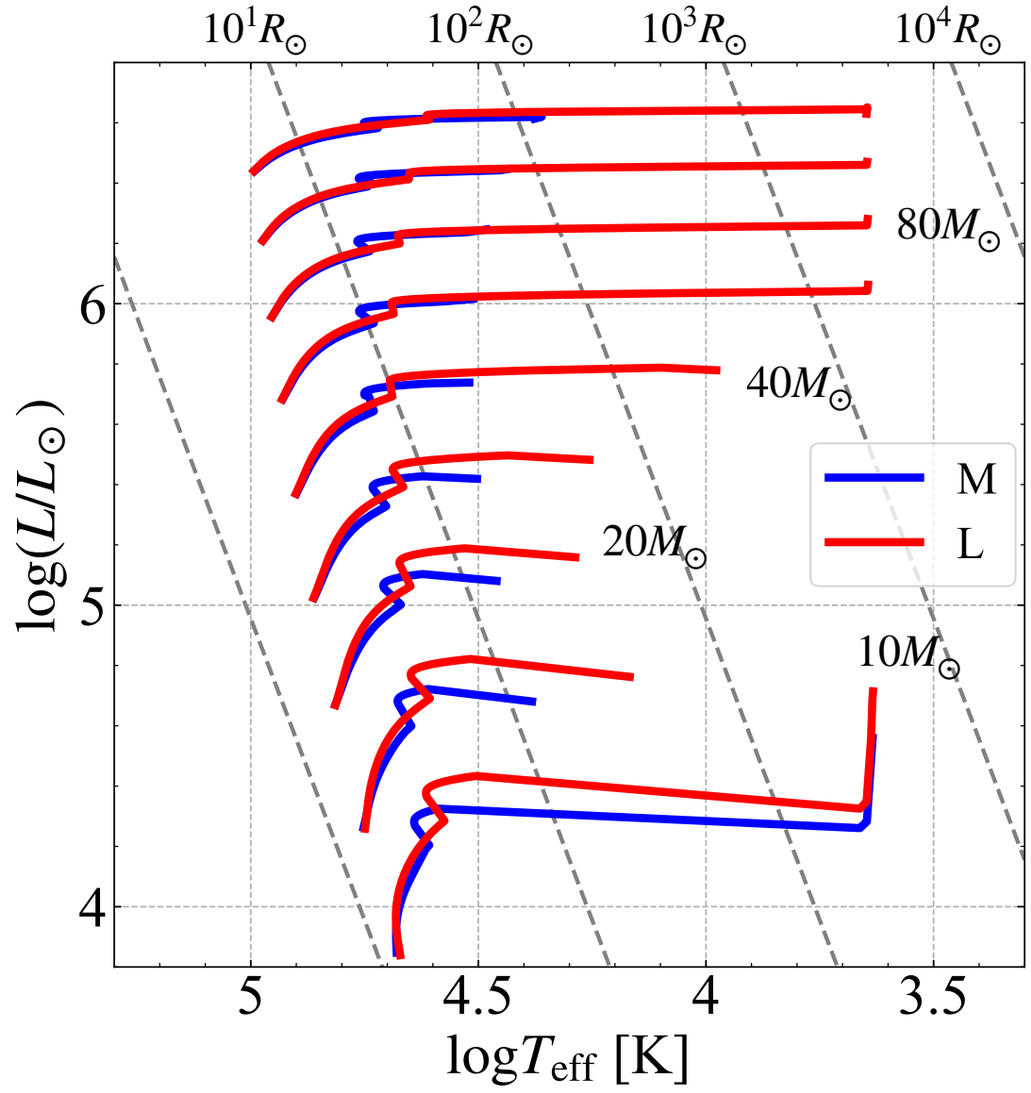
Abbott et al. (2020, arXiv:2010.14533)



Mass gap event (GW190521)

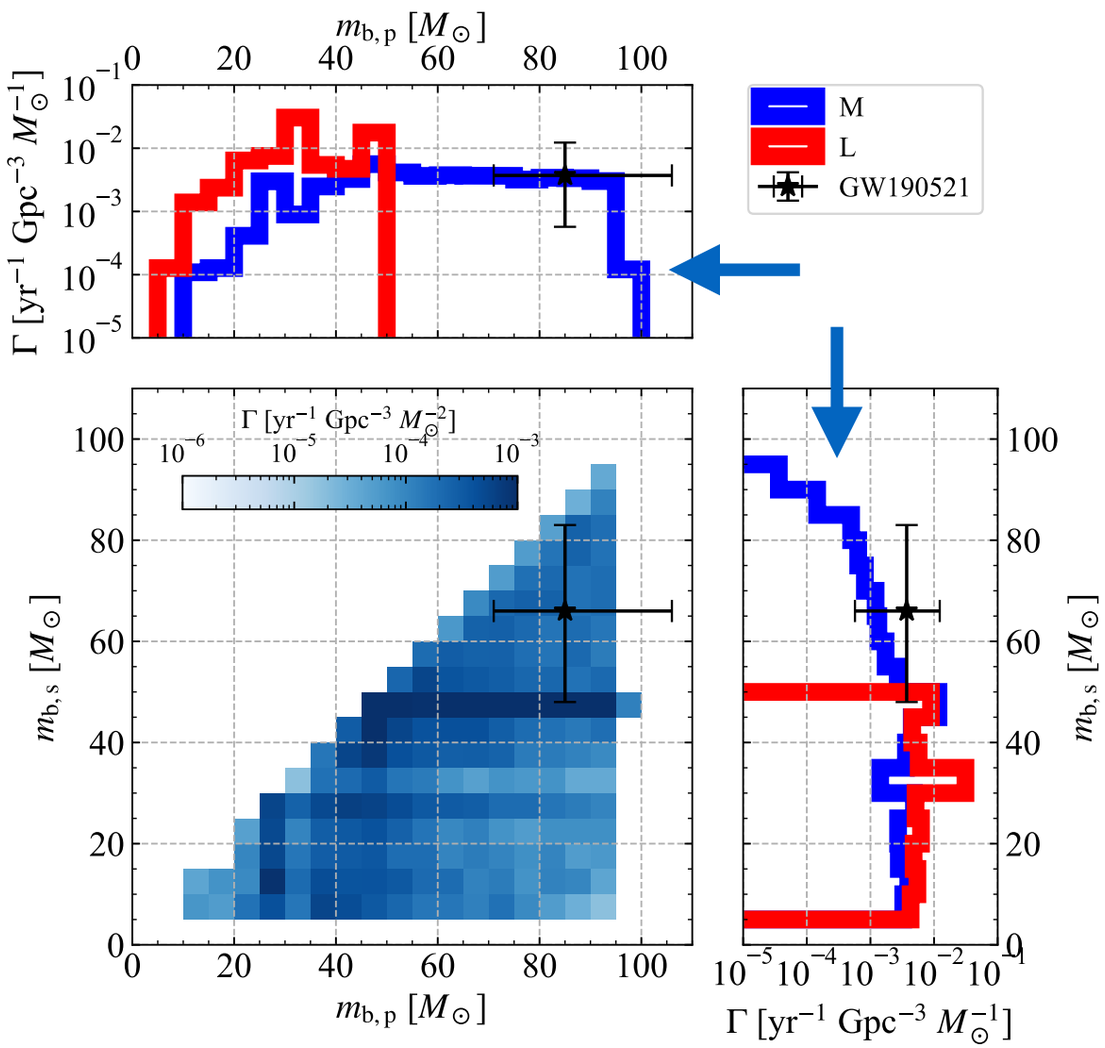
- Pop. III binaries can form the mass gap event if Pop. III stars with $\sim 90 M_\odot$ expand up to $\lesssim 100 R_\odot$.
  - It can be attained if convective overshoot is not effective.





Results

- Binary population synthesis
- Large overshoot model (large radii)
  - The maximum mass: $\sim 50 M_\odot$
  - Envelope loss through mass transfer
- Small overshoot model (small radii)
  - The maximum mass: $\sim 100 M_\odot$
  - No envelope loss
- The choice of overshoot parameters is very important



Tanikawa et al. (2020, arXiv: 2010.07616)

Summary

- Tanikawa et al. (2020, arXiv:2008.01890, ApJ accepted)
  - First star (Pop. III) BH-BHs may not have a peak at $\sim 30 M_\odot$, if first star binaries are not close ($\gtrsim 100 R_\odot$).
  - First stars can form IMBH binaries at a rate of $\sim 0.01\ \mathrm{yr}^{-1}\ \mathrm{Gpc}^{-3}$, which will be detected by the current GW observatories in the near future.
- Tanikawa et al. (2020, arXiv:2010.07616)
  - The mass gap event GW190521 can be formed through first star binaries if convective overshoot is not effective.