cl light-blue)

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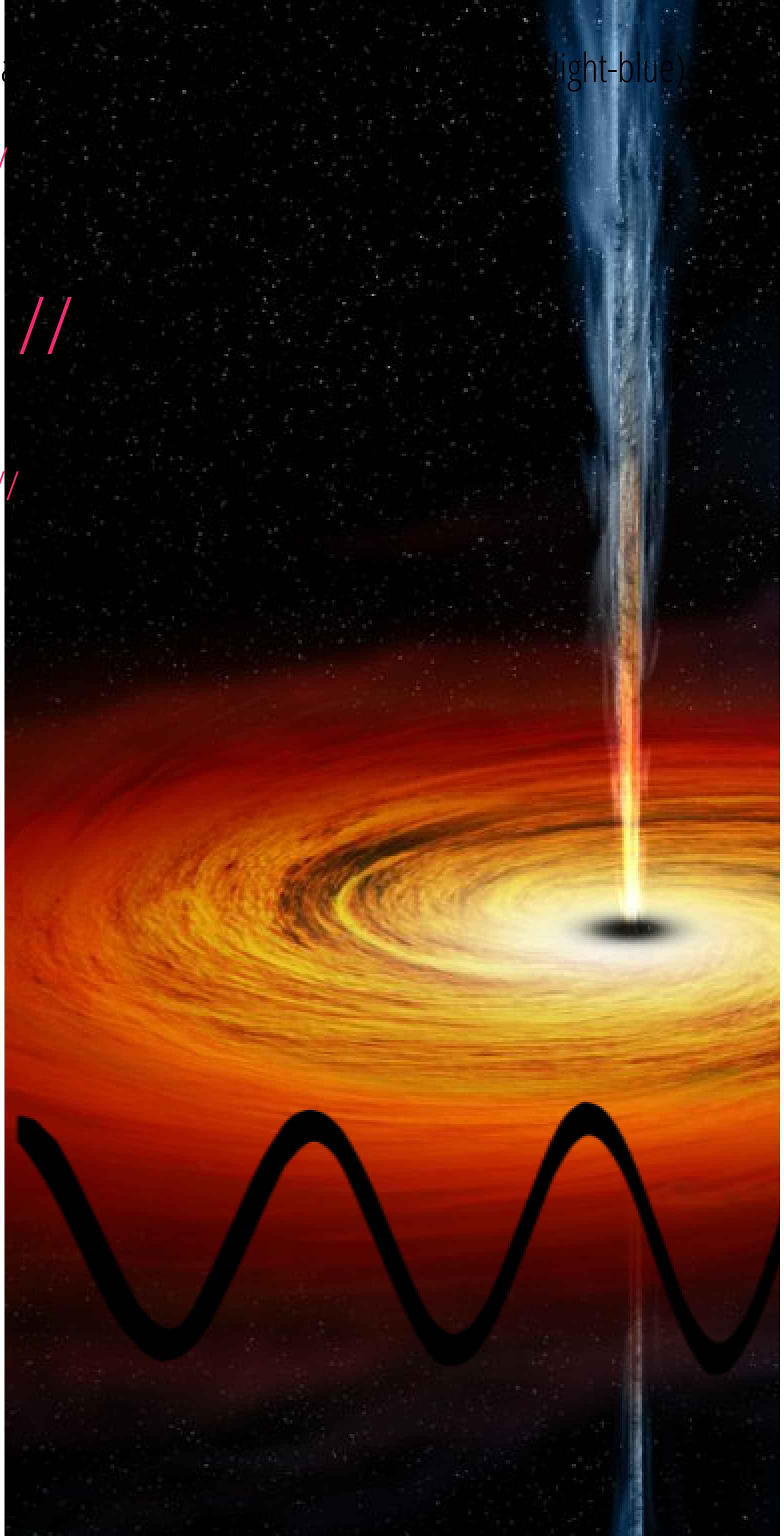


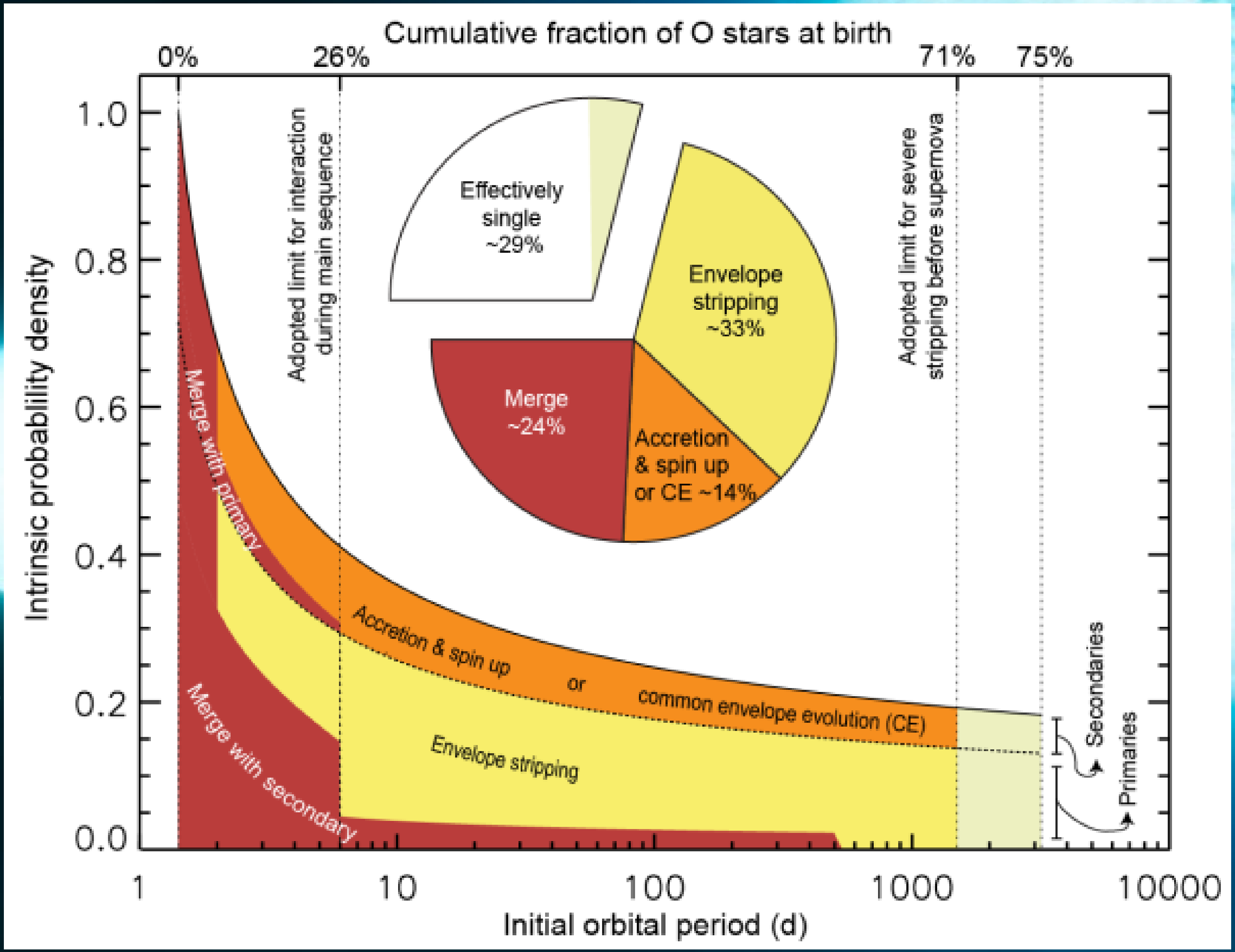
Progenitors of low-mass binary black hole mergers

Adolfo Simaz Bunzel, Federico García,
Sylvain Chaty, Edward Porter & Eric Chassande-Mottin

IAR - FCAGLP, La Plata, Argentina

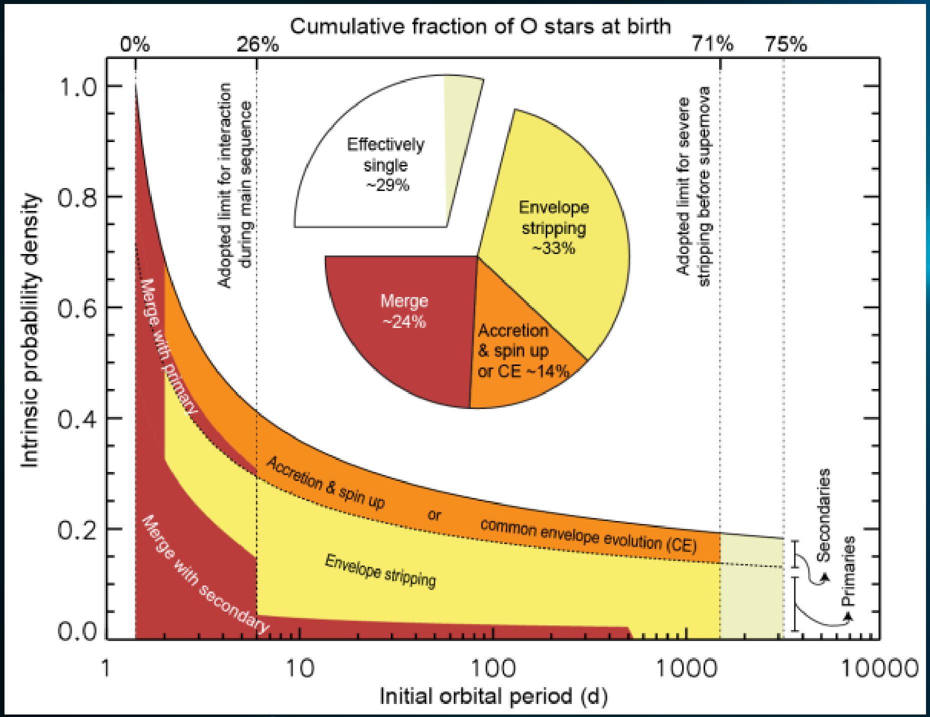
AIM - APC, Université Paris Diderot, France

Very common!

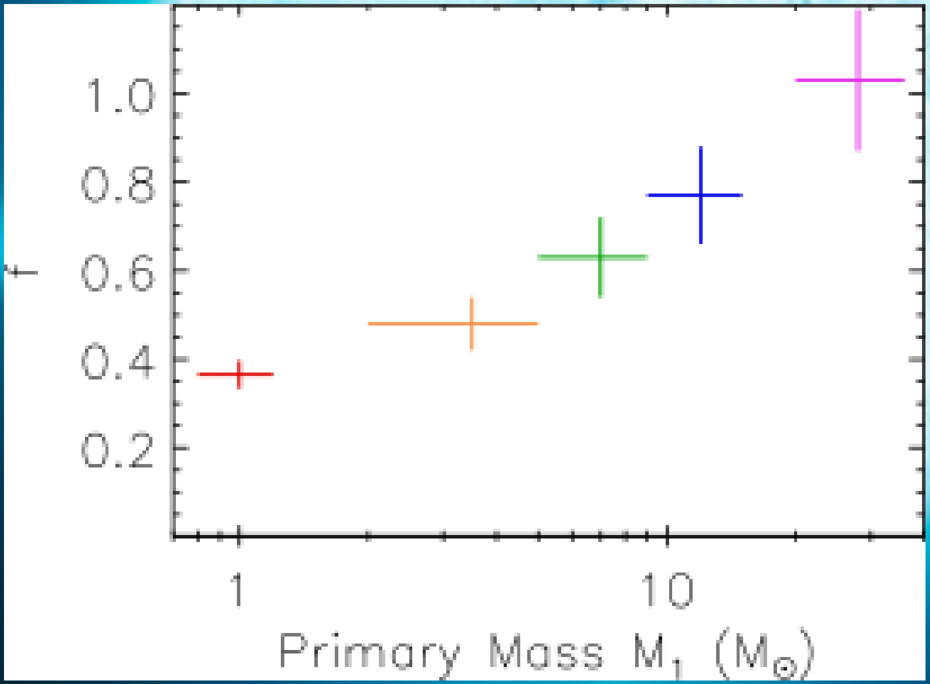


Fractions estimated for all stars with initial masses above 15 $M_\odot$ (Sana et al. 2012)

Indeed very common!

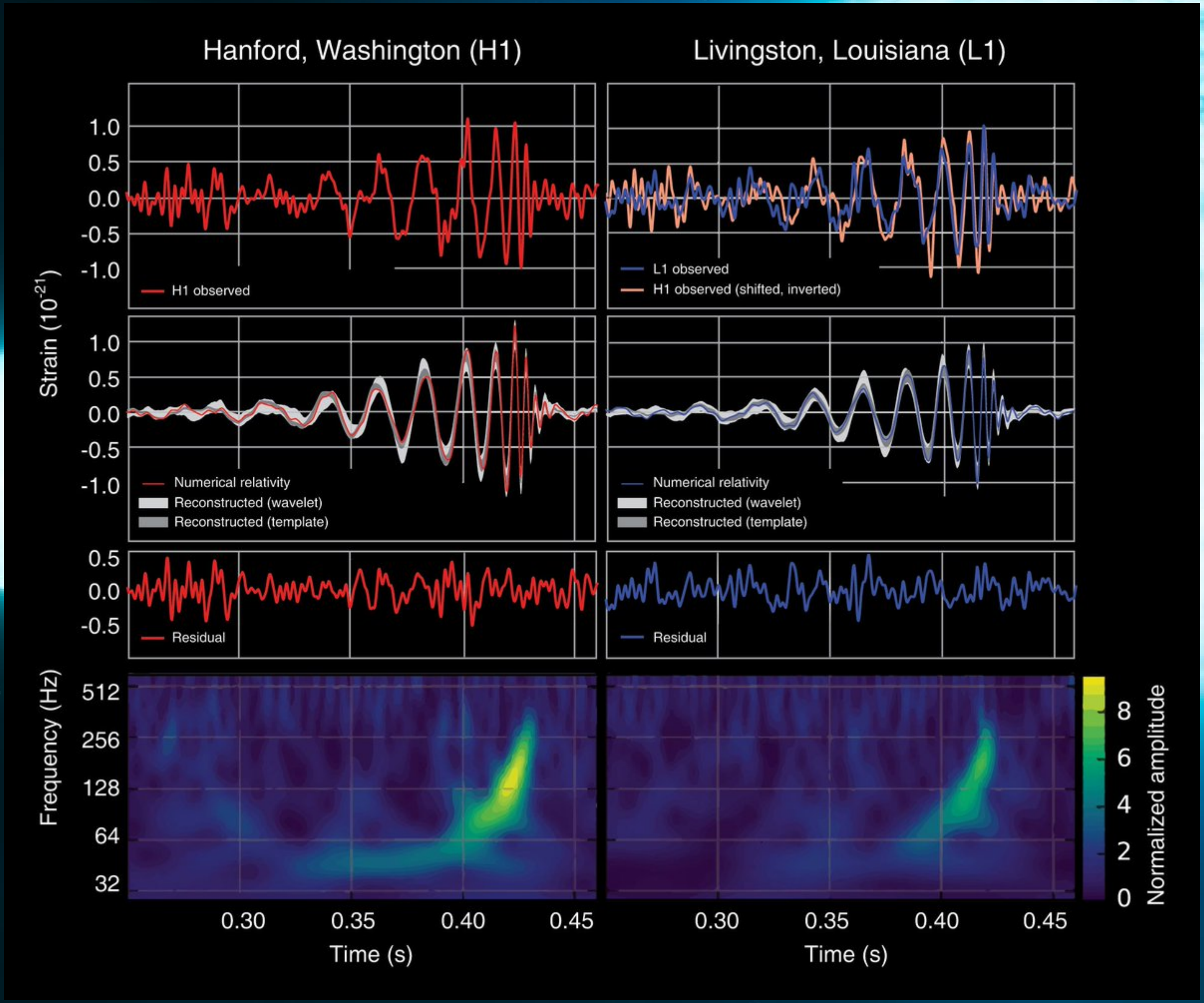


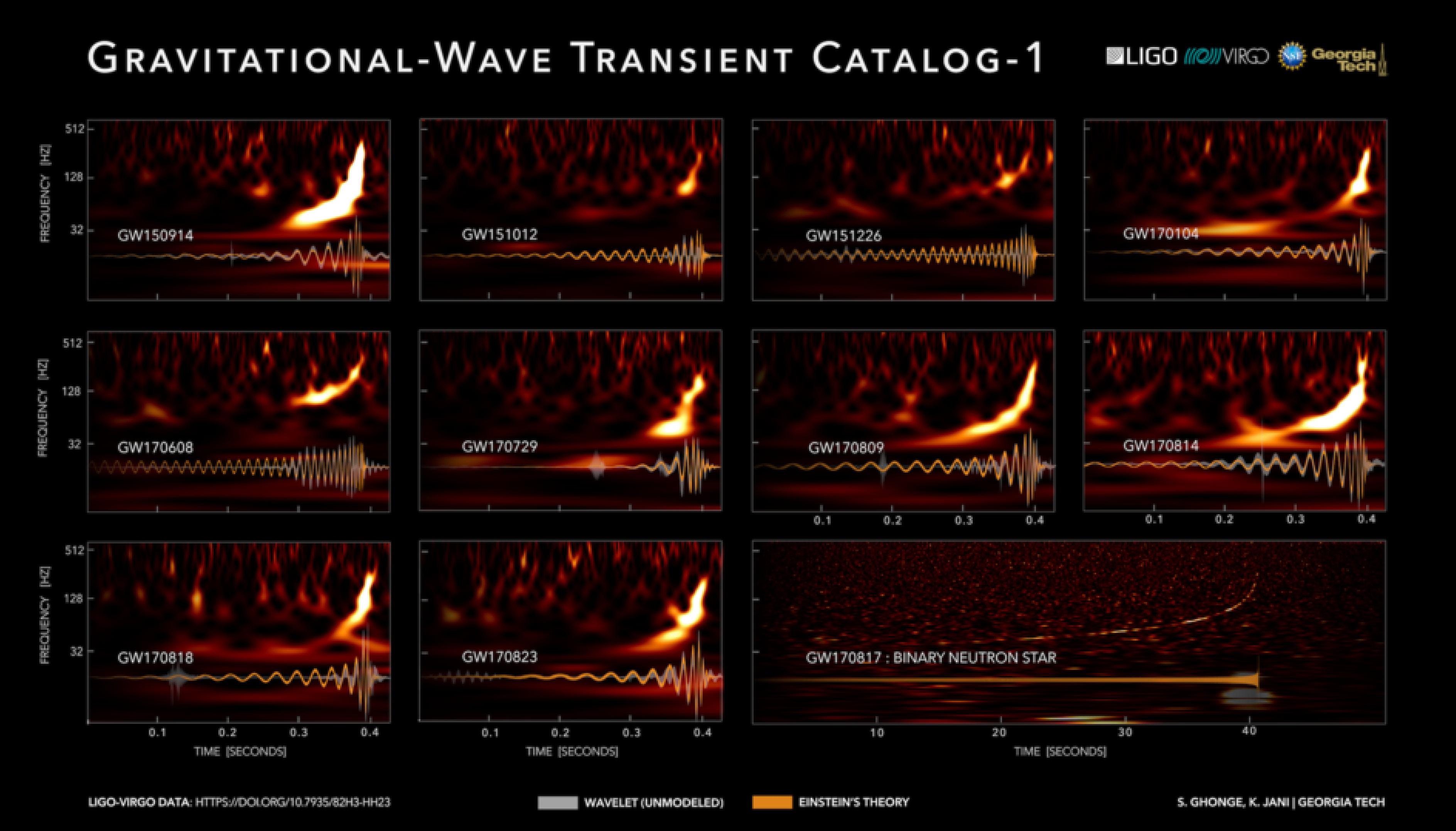
from Sana et al. 2012



from Moe & Di Stefano 2017

What about this?

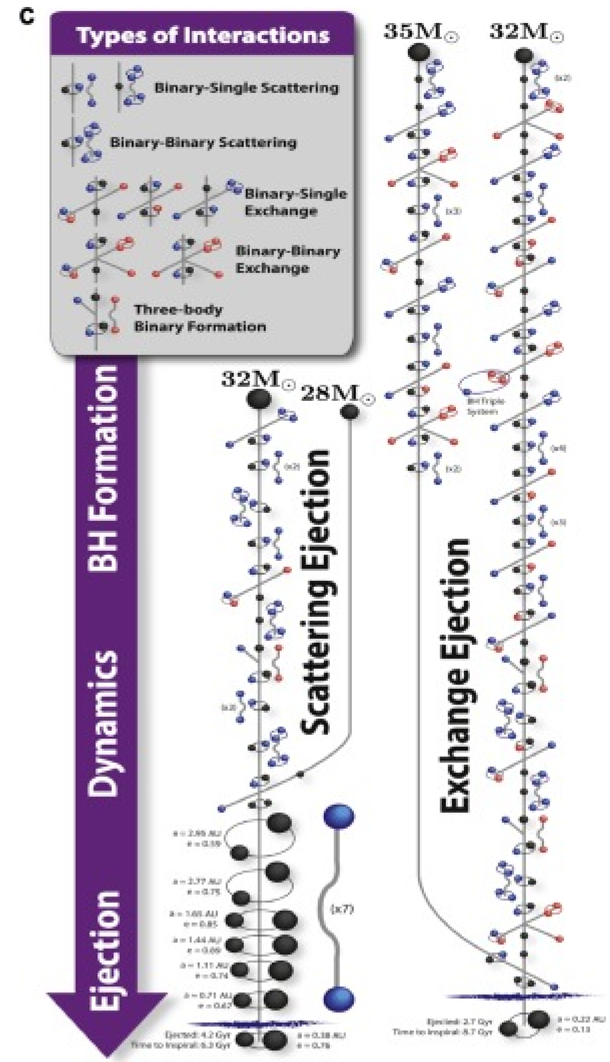



GRAVITATIONAL-WAVE TRANSIENT CATALOG-1
LIGO
VIRGO
NSF
Georgia Tech
FREQUENCY [HZ]
512
128
32
GW150914
GW151012
GW151226
GW170104
GW170608
GW170729
GW170809
GW170814
GW170818
GW170823
GW170817 : BINARY NEUTRON STAR
0.1
0.2
0.3
0.4
10
20
30
40
TIME [SECONDS]
LIGO-VIRGO DATA: HTTPS://DOI.ORG/10.7935/82H3-HH23
WAVELET (UNMODELED)
EINSTEIN'S THEORY
S. GHONGE, K. JANI | GEORGIA TECH

How do they formed?

Dynamical interaction channel

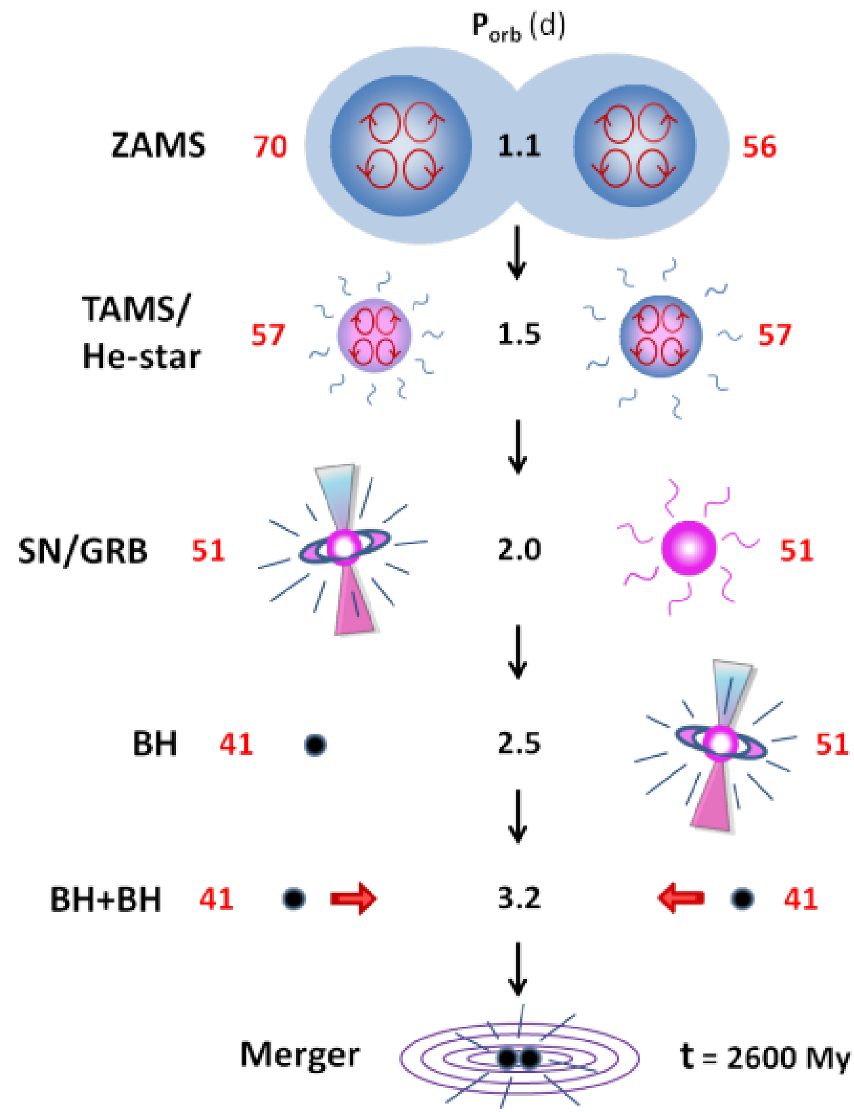
Key aspect: ***dense stellar cluster***. Several interactions before formation



from Rodriguez et al. 2016

Isolated binary evolutionary channel (I)

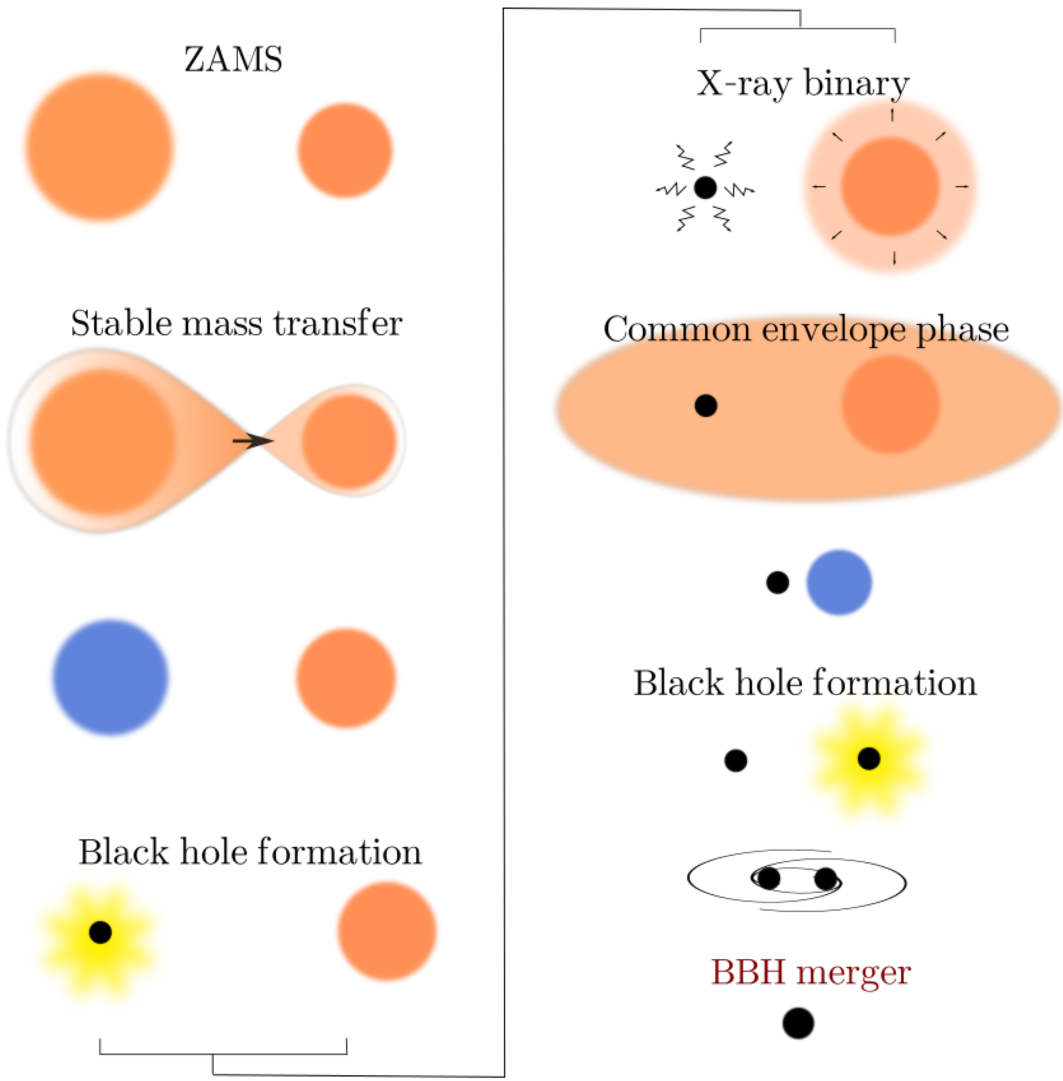
Key aspect: stars need to evolve ***chemical homogeneously*** their entire life



from Marchant et al. 2016

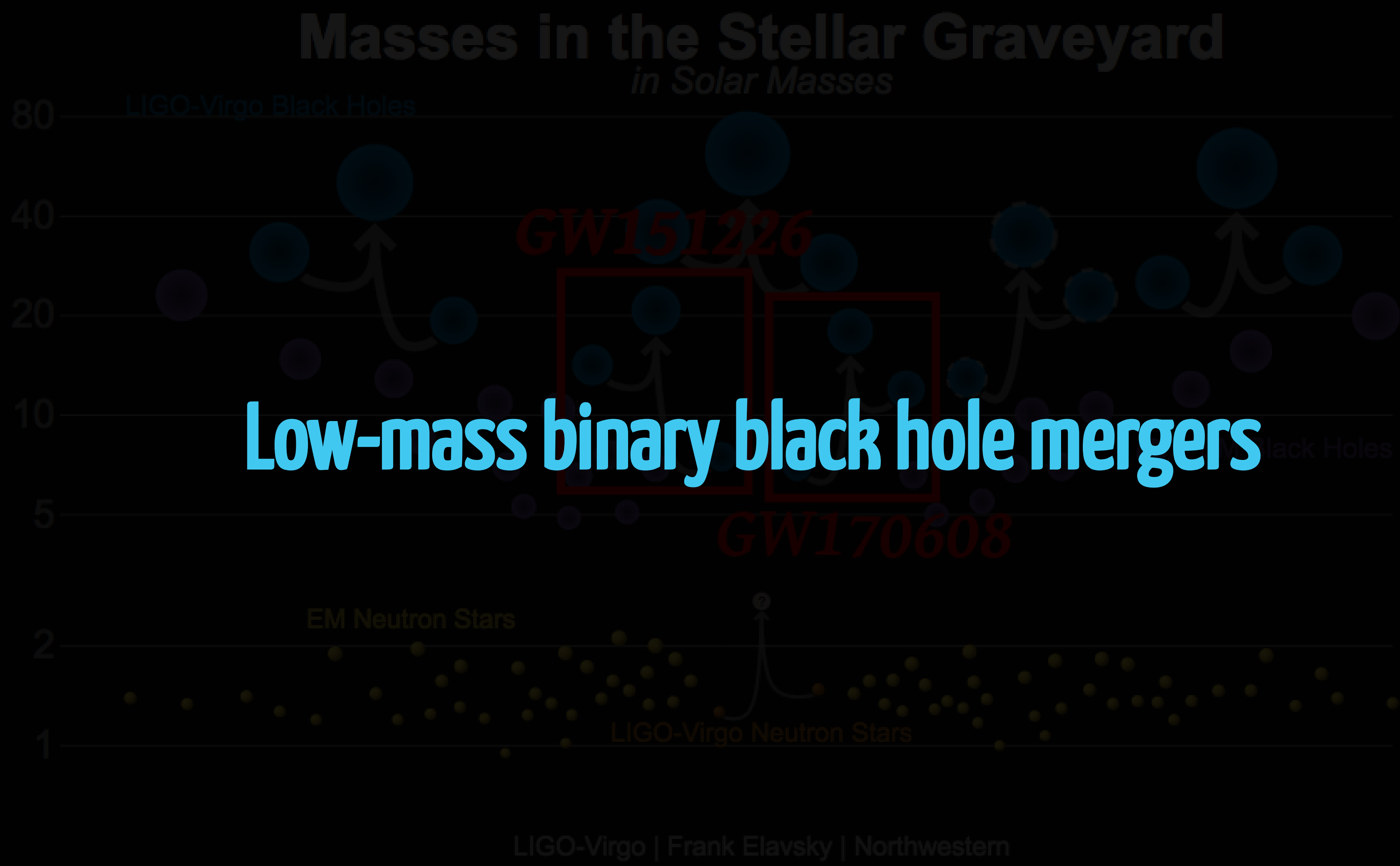
Isolated binary evolutionary channel (II)

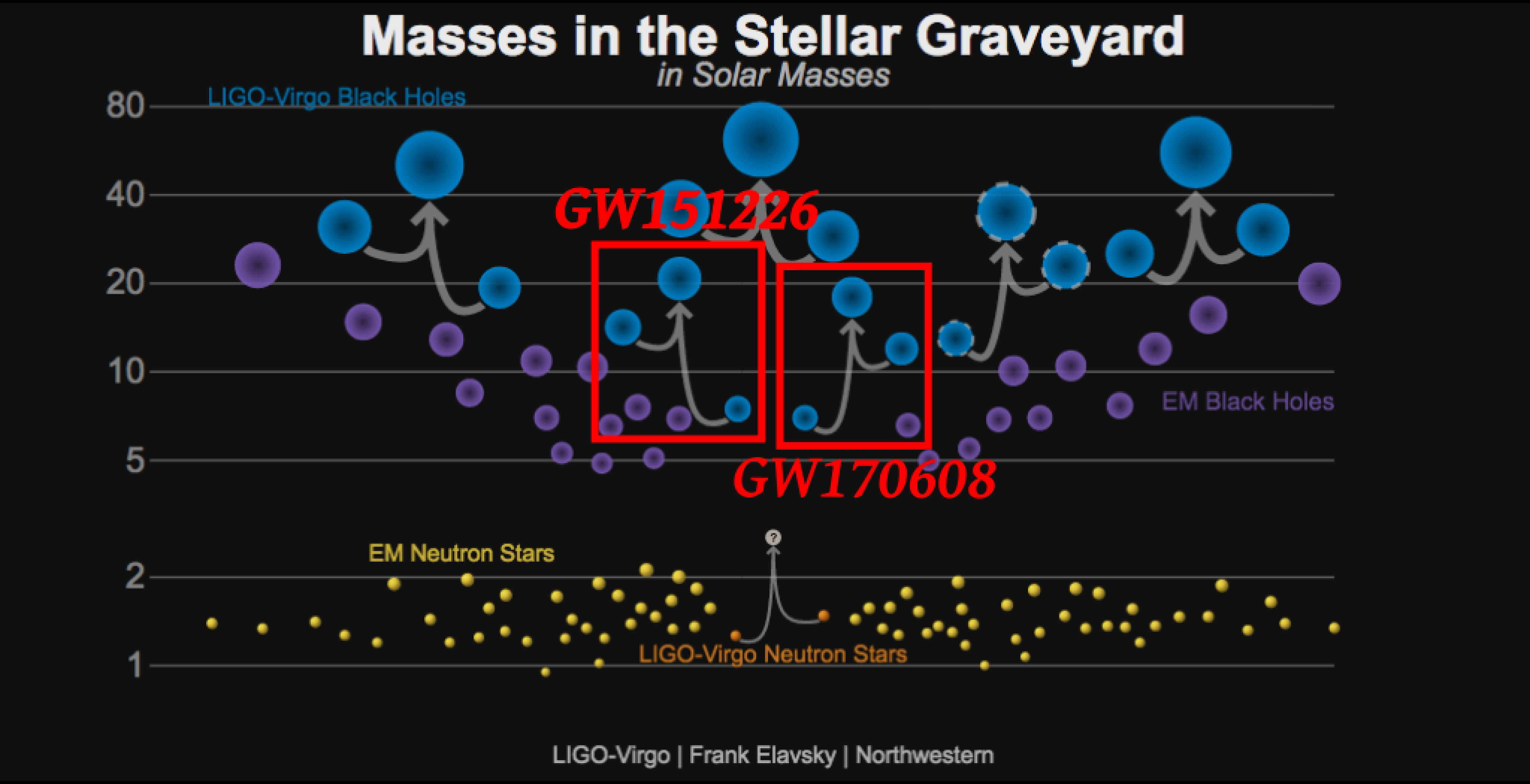
Key aspect: need a ***common-envelope phase*** (CE)



from Garcia et al. in prep

Low-mass binary black hole mergers

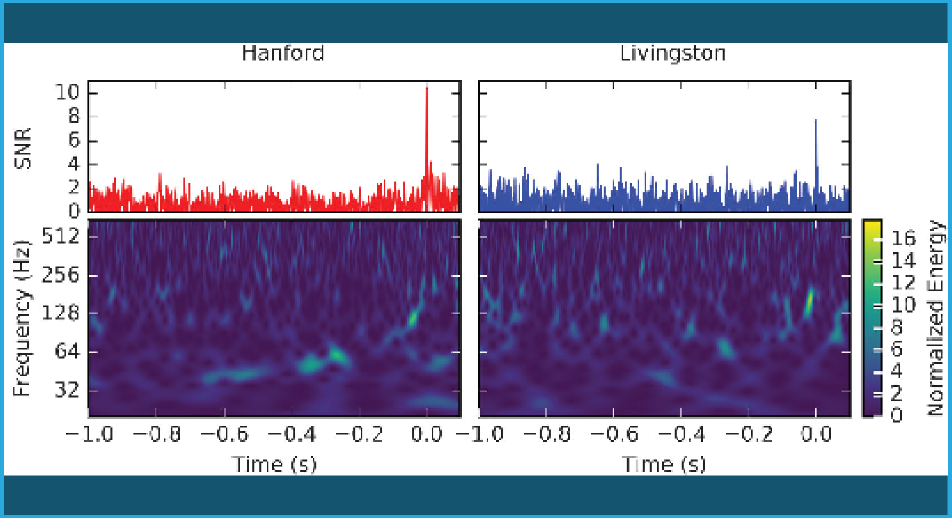




Masses in the Stellar Graveyard
in Solar Masses
LIGO-Virgo Black Holes
80
40
20
10
5
2
1
GW151226
GW170608
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
?
LIGO-Virgo | Frank Elavsky | Northwestern

GW151226

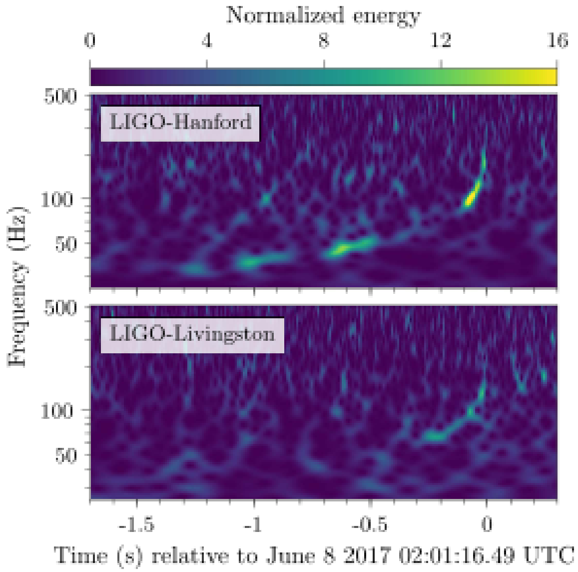
- Discovery date: December 26, 2015
- Hanford SNR of 10.5, Livingston SNR of 7.9
- Differences arising because of sensitivies



- Difficult signal visibility

GW170608

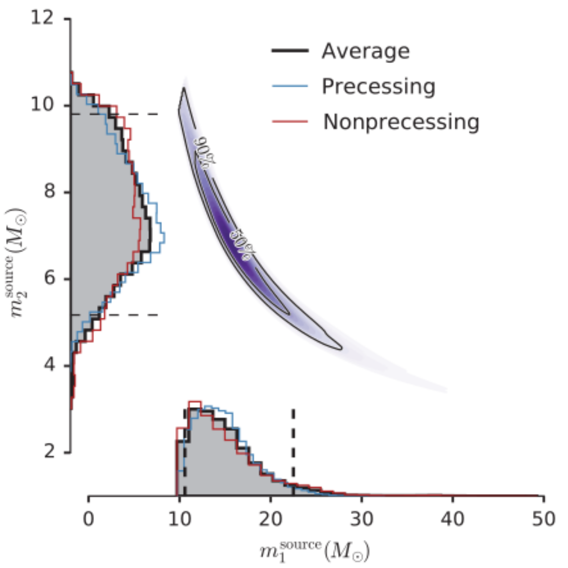
- Discovery date: June 8, 2017
- Livingston SNR of 9, Hanford data not reliable at first



- Different sensitivies and difficult signal visibility again!

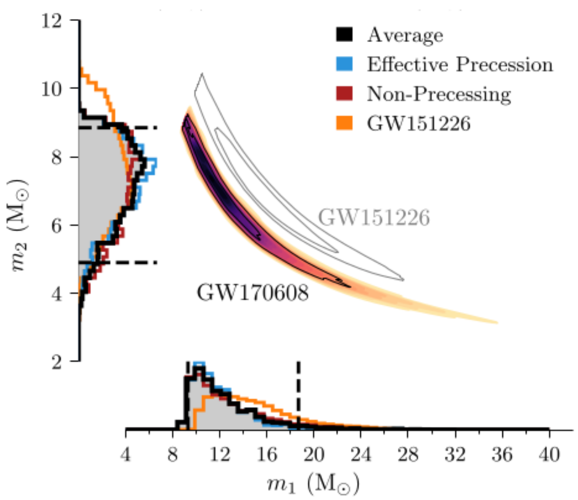
GW151226

- $M_{\mathrm{BH},1} = 14.2^{+8.3}_{-3.7}\,M_{\odot}$
- $M_{\mathrm{BH},2} = 7.5^{+2.3}_{-2.3}\,M_{\odot}$
- $M_{\mathrm{chirp}} = 8.9^{+0.3}_{-0.3}\,M_{\odot}$
- $M_{\mathrm{merged-BH}} = 20.8^{+6.1}_{-1.7}\,M_{\odot}$
- redshift: $z = 0.09^{+0.03}_{-0.04}$



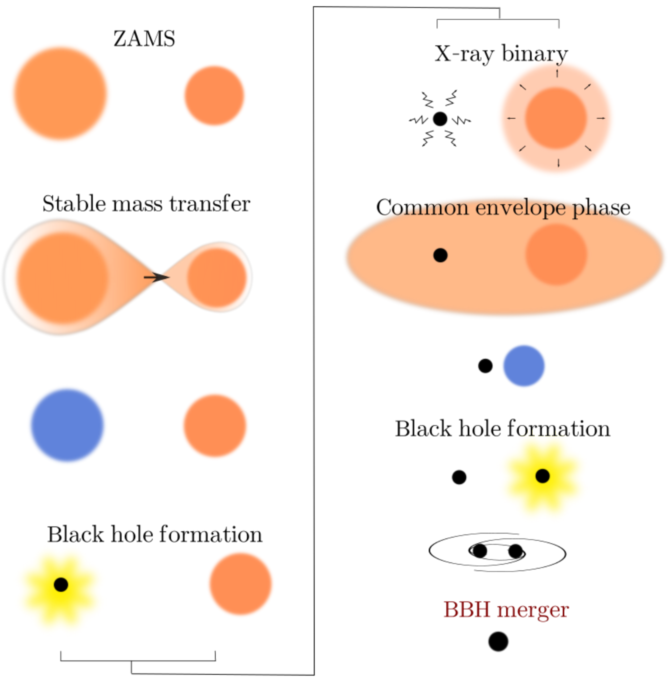
GW170608

- $M_{\mathrm{BH},1} = 12^{+7}_{-2}\,M_{\odot}$
- $M_{\mathrm{BH},2} = 7^{+2}_{-2}\,M_{\odot}$
- $M_{\mathrm{chirp}} = 7.9^{+0.2}_{-0.2}\,M_{\odot}$
- $M_{\mathrm{merged-BH}} = 18^{+4.8}_{-0.9}\,M_{\odot}$
- redshift: $z = 0.07^{+0.03}_{-0.03}$



Aims

1) Study the progenitor properties for these two GW events in the isolated binary evolutionary scenario going through a common-envelope phase



2) Obtain merger rates for them in O1, O2 and expected ones in O3

Methods:

First part

- Follow the complete evolution of the binary: from two non-degenerate stars up to the formation of two black holes
- Using a detailed stellar evolutionary code, publicly available, ***MESA***, modified to include the common-envelope phase

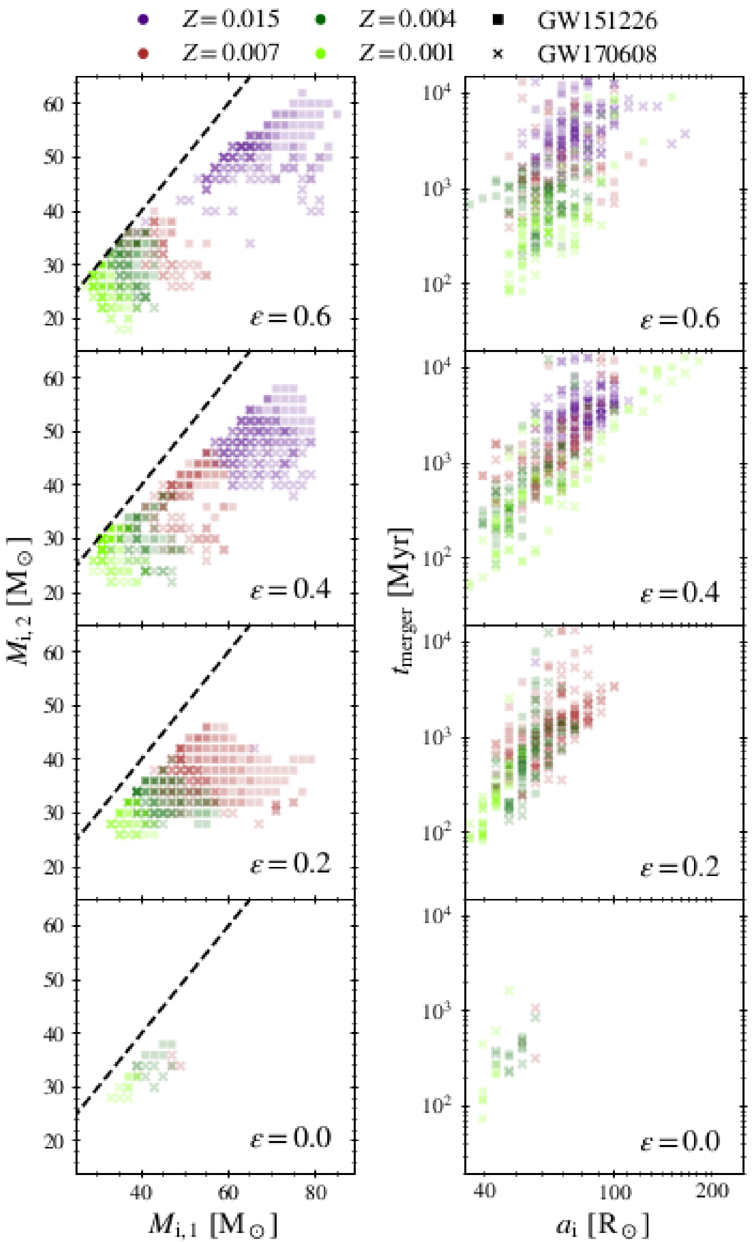
Methods:

First part

Free parameters in simulations
Metallicity of the population, (Z)
Accretion efficiency during the stable mass-transfer phase, (ϵ)
Efficiency for the removal of a star envelope during a common-envelope phase, ($\alpha_{\rm CE}$)

3D grids of initial masses and binary separations were created for each combination of the above parameters.

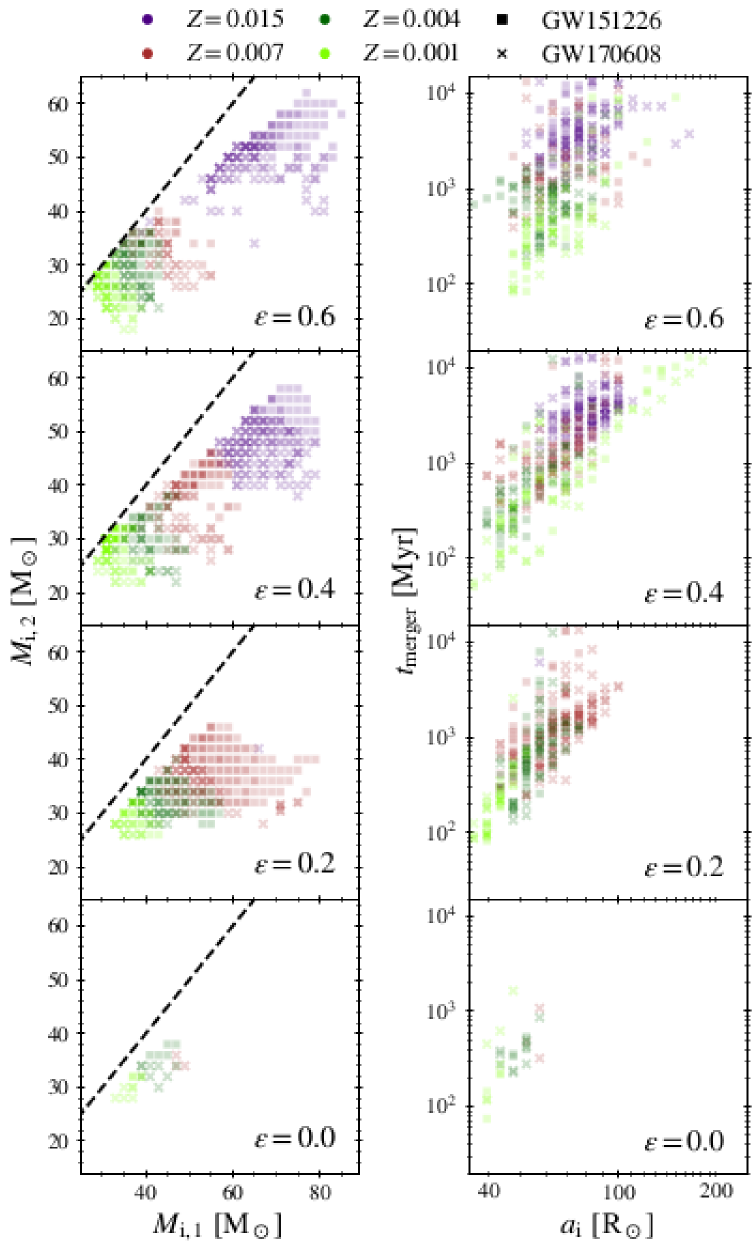
Total number of simulations above 50 000!

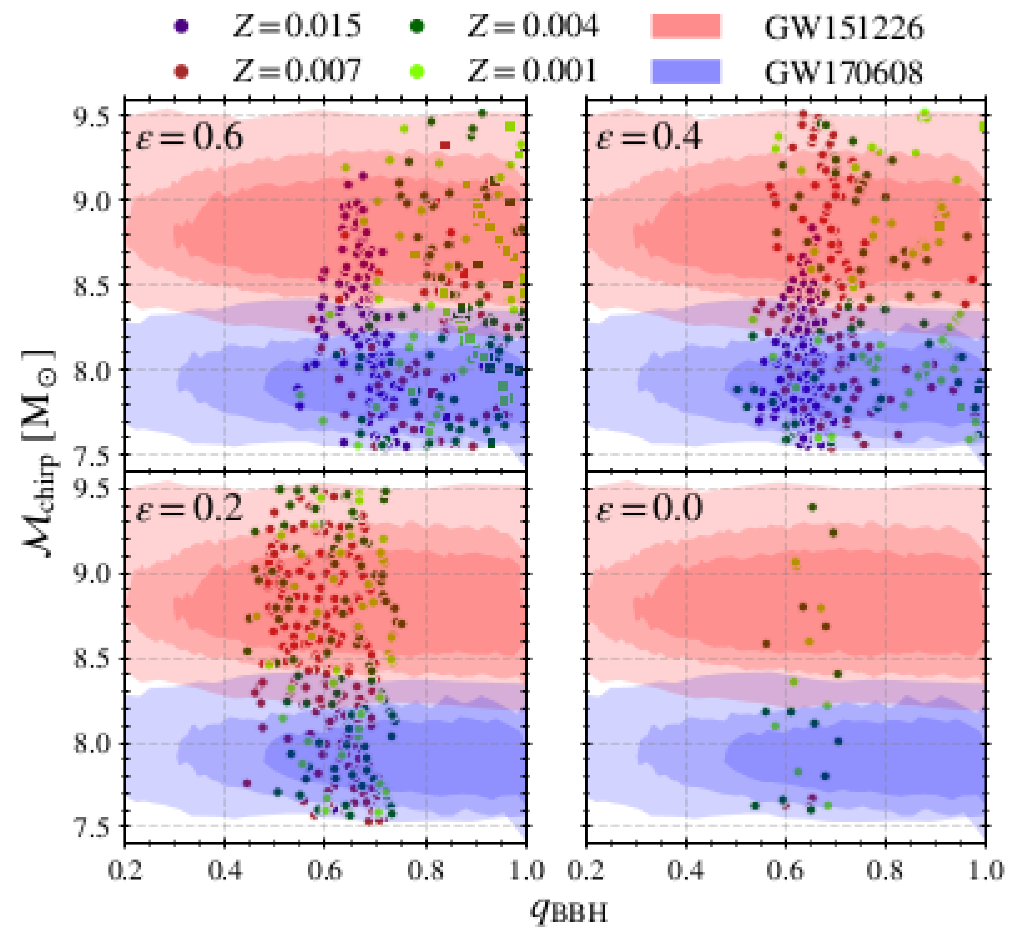


Initial binary parameters for $\alpha_{\mathrm{CE}} = 2$

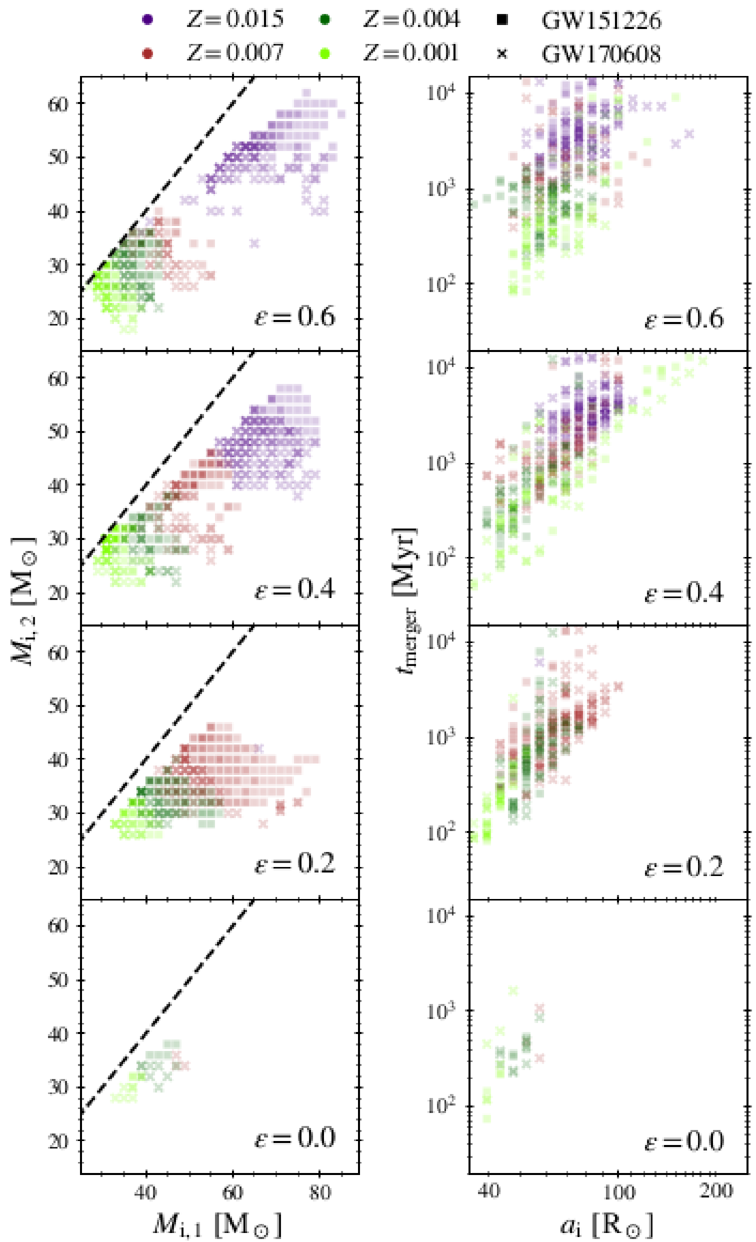
- Higher metallicities requires increasingly massive stars: directly related with winds
- In the low mass-accretion regime, only low metallicity binaries are progenitors. High metallicity ones produce low chirp masses.
- For $\epsilon > 0.2$ binaries with similar initial masses are also progenitors.

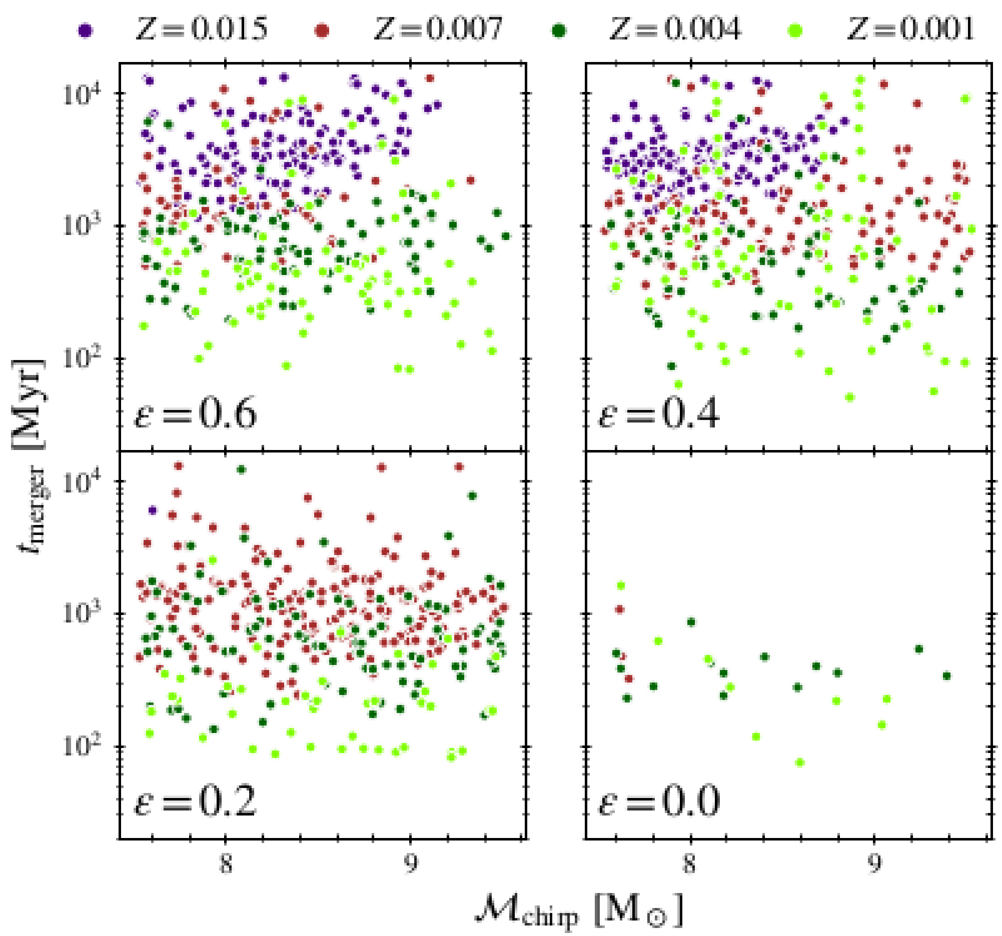
Map of initial parameters for α_{CE} = 2 with BBH properties

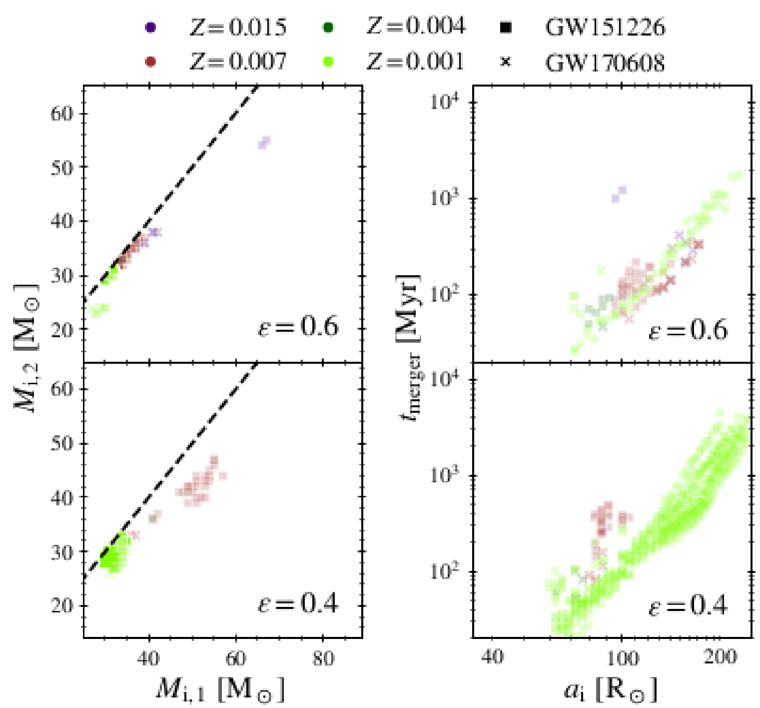




Map of initial parameters for $\alpha_{\rm CE}$ = 2 with BBH properties



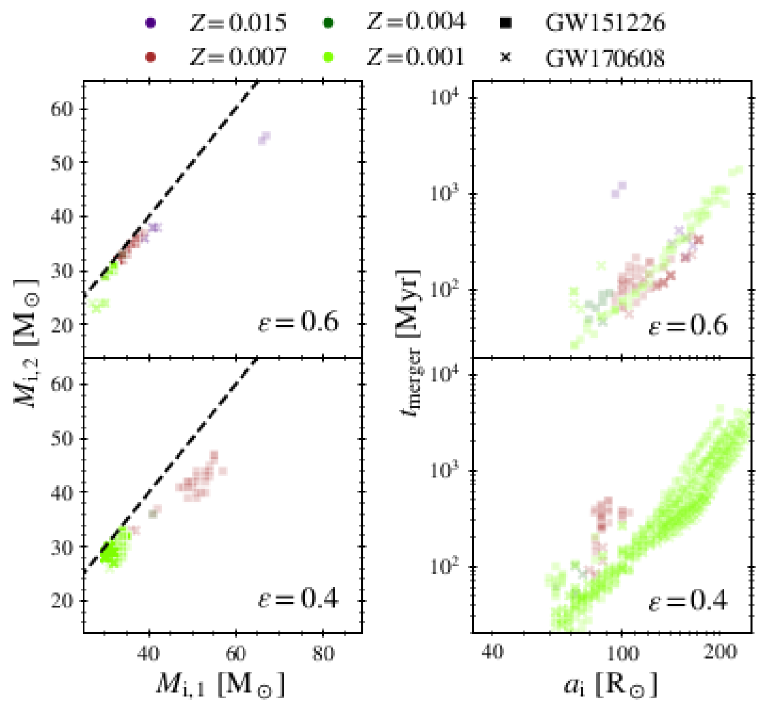


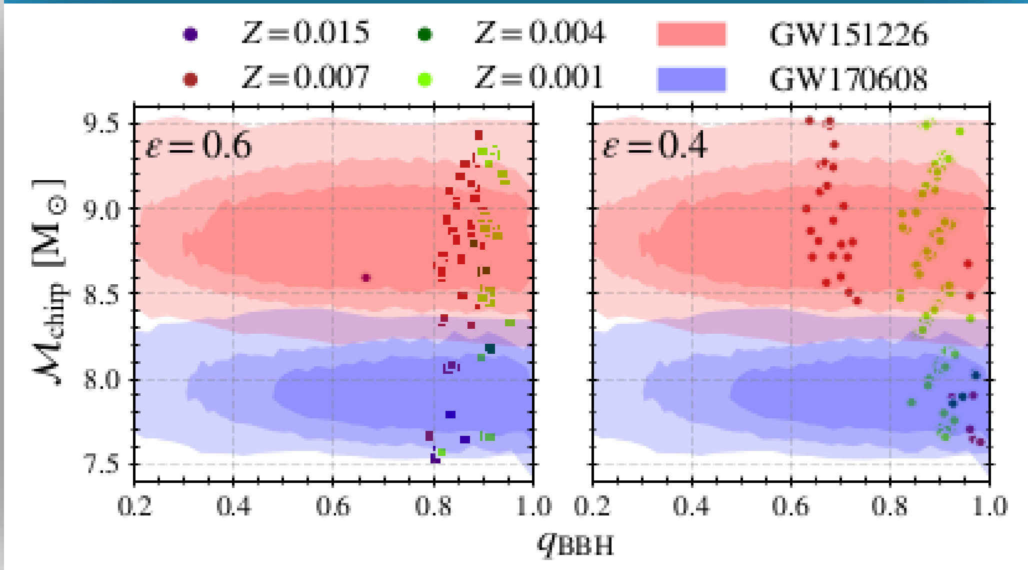


Initial binary parameters for $\alpha_{CE} = 1$

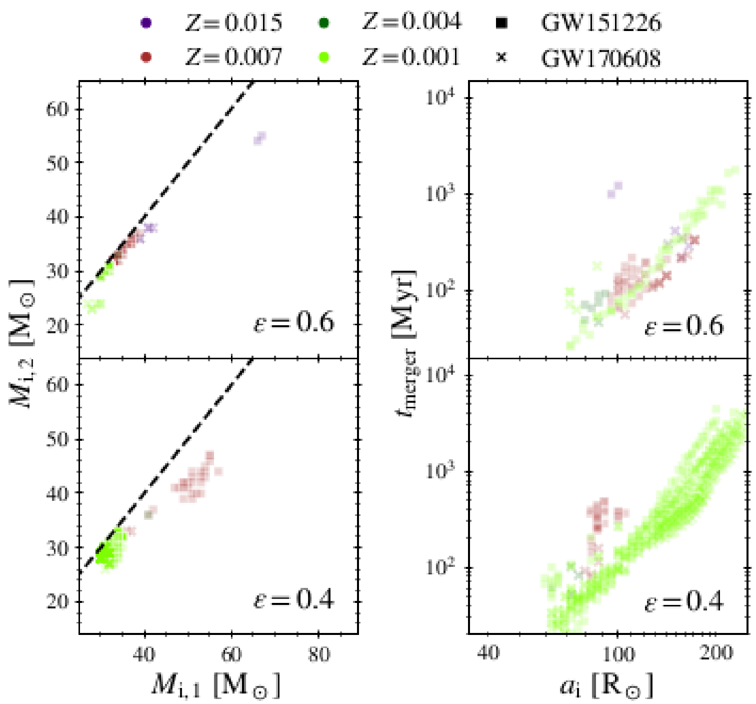
- Initial mass ratios are closer to unity.
- No solutions were found for mass-accretion efficiencies that are below $\epsilon < 0.2$
- Also, binaries with separations lower than 60 merge during a CE phase as a consequence of having a lower efficiency for the CE ejection
- Merger times are also lowered.

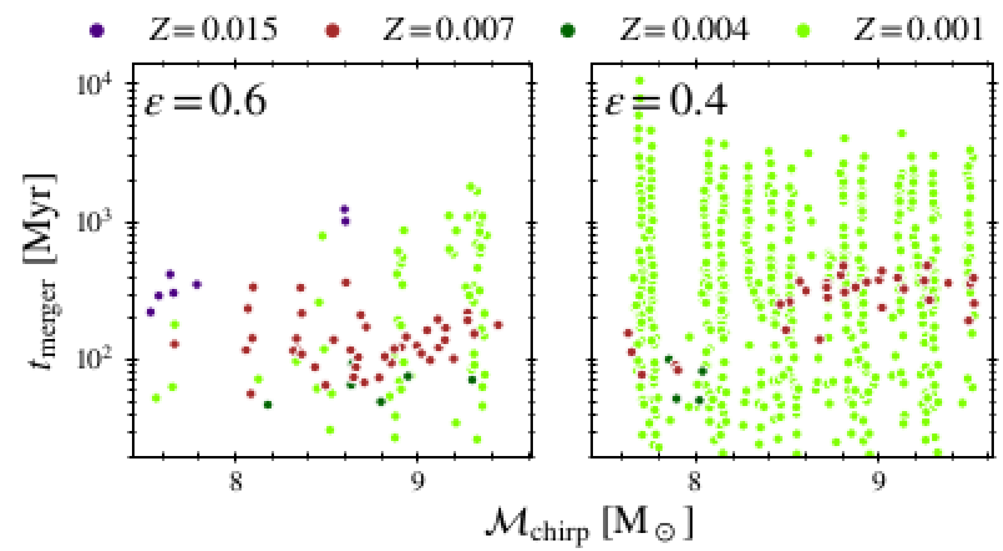
Map of initial parameters for $\alpha_{\rm CE} = 1$ with BBH properties





Map of initial parameters for α_{CE} = 1 with BBH properties





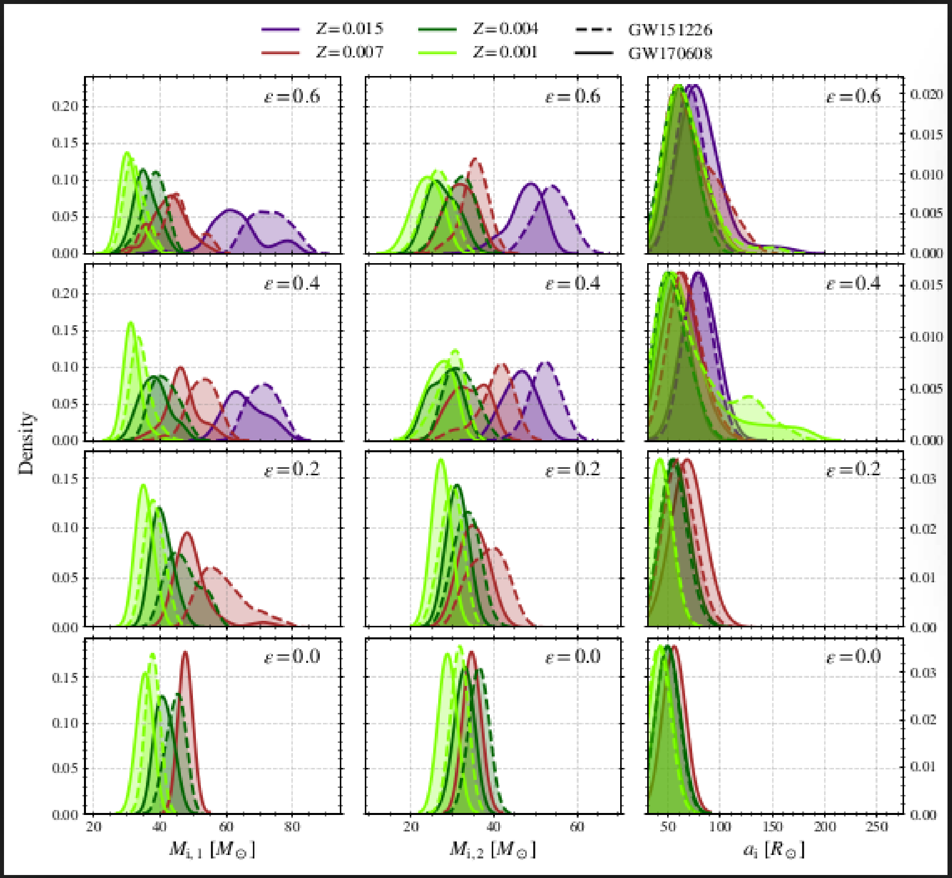
Methods:

Second part

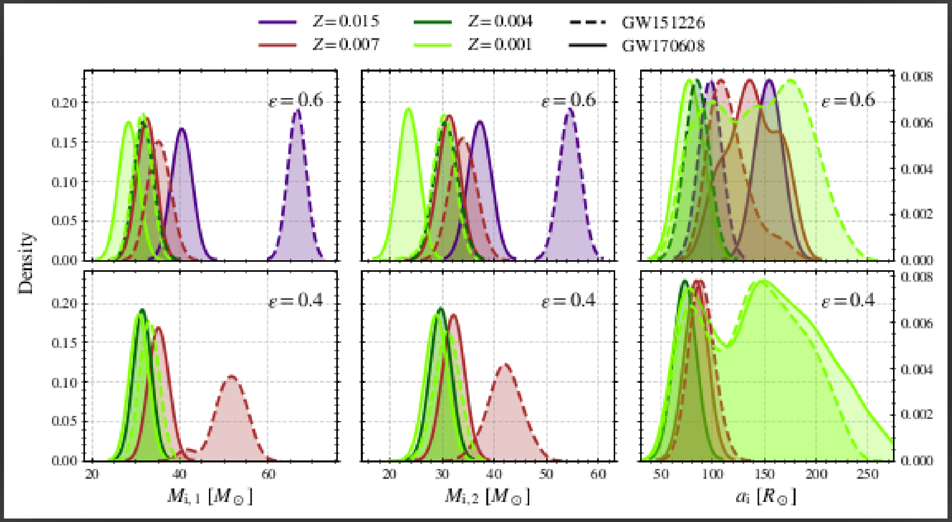
To estimate expected properties, detailed stellar models were rescaled by empirical **initial mass functions** (IMF) for the primary and secondary stars and by an **initial separation distribution** from the observed binary orbital period distribution

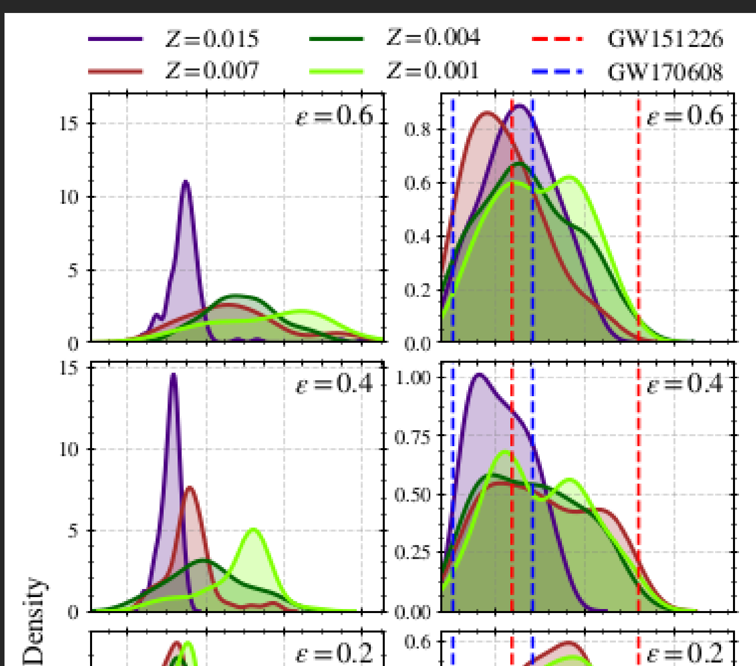
Weighted initial binary parameters

$\alpha_{\mathrm{CE}} = 2$

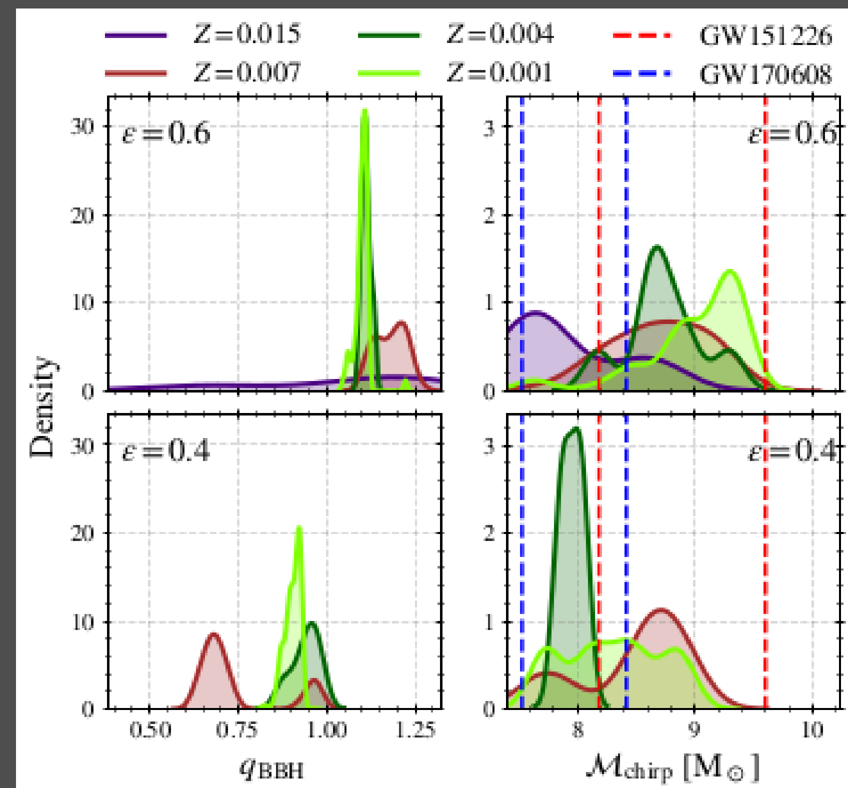


$\alpha_{\mathrm{CE}} = 1$





$\alpha_{\mathrm{CE}} = 1$

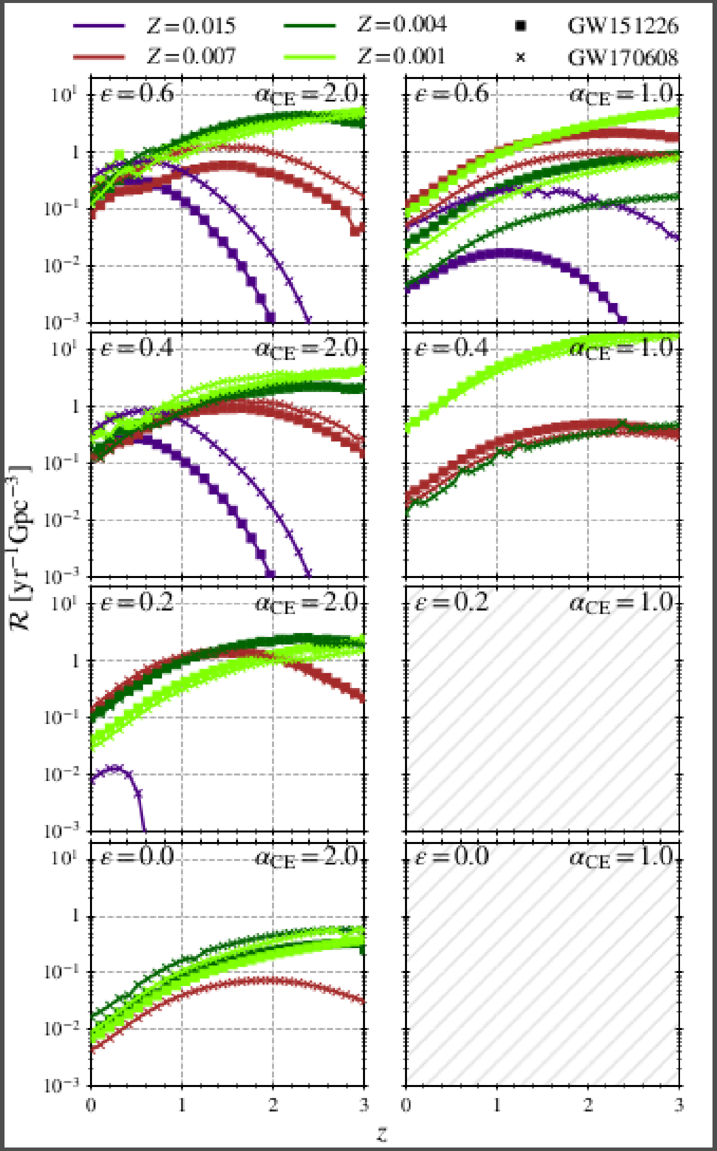


Methods:

Second part

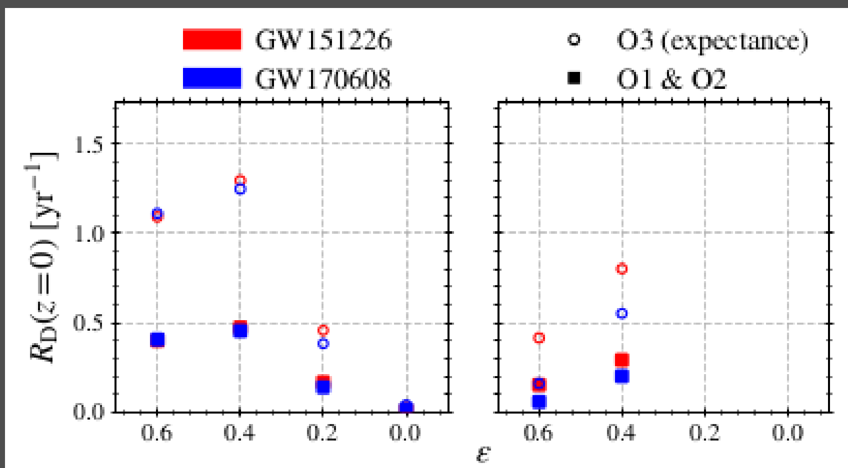
Intrinsic merger rate for a GW event is:

$$\mathcal{R}(Z, z(t)) = \mathcal{N}_{\mathrm{corr}} \int_0^{t(z)} \int_{M_{\mathrm{i},1}} \int_{M_{\mathrm{i},2}} \int_{a_{\mathrm{i}}} \int_0^{t(z)} \frac{\mathrm{d}N}{\mathrm{d}M_{\mathrm{i},1}\,\mathrm{d}M_{\mathrm{i},2}\,\mathrm{d}a_{\mathrm{i}}\,\mathrm{d}t_{\mathrm{m}}} \widehat{\mathrm{SFR}}(t';Z)\delta\left[t(z) - (t_{\mathrm{m}} + t')\right] \mathrm{d}t_{\mathrm{m}}\mathrm{d}a_{\mathrm{i}}\,\mathrm{d}M_{\mathrm{i},2}\,\mathrm{d}M_{\mathrm{i},1}\,\mathrm{d}t'$$



Merger rate density history

- The expected local merger rate densities are all larger for the highest value of CE removal efficiency. Related to 'size' of parameter space
- For high metallicties, rates decay with redshift because of the chemical evolution
- For the low CE efficiency, rates are largely dominated by low metallicities



$$R_\mathrm{D} = \frac{4\pi}{3} D_\mathrm{h}^3 \langle w^3 \rangle \langle (\mathcal{M}_c \,/\, 1.2\, M_\odot)^{15/6} \rangle \mathcal{R}(z=0)$$

Detectable merger rate at zero redshift

- The highest rate is obtained at $\epsilon = 0.4$ for both CE efficiencies
- However, expected rates obtained are within a factor of 2, thus we are not able to distinguish a preferred value for the mass-accretion efficiency

Conclusions

With current and future campaings of observing GW, more we will now about their progenitors

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Giving the rising power of computers, having a large grid of detailed binary calculations is possible. Even to calculate complete populations of progenitors

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Giving the rising power of computers, having a large grid of detailed binary calculations is possible. Even to calculate complete populations of progenitors

Several uncertainties are still present in nowadays calculations, so estimates like rates can vary by order of magnitude when changing input physical parameters

THANK YOU!