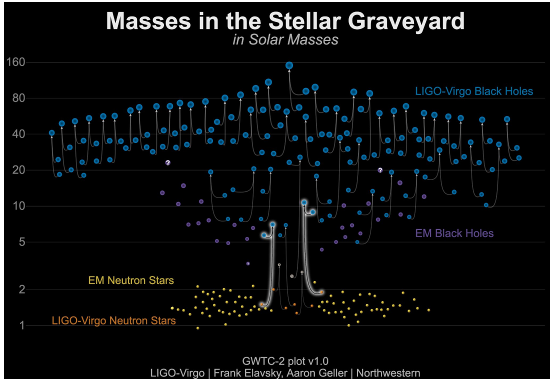
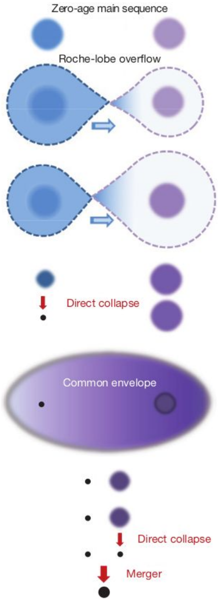
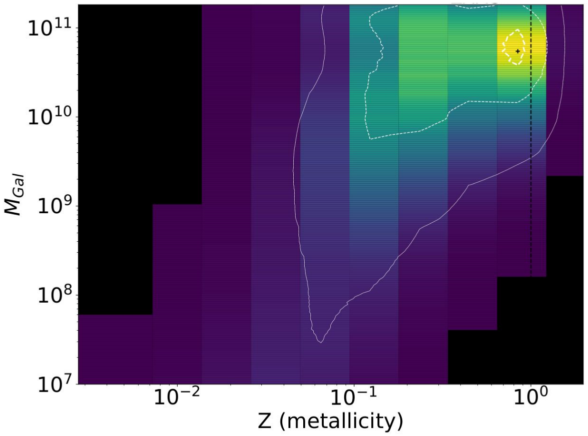
Understanding the stellar progenitors of binary black holes

Since Nov 2020





Belczinski et al 2016



Rahul Srinivasan

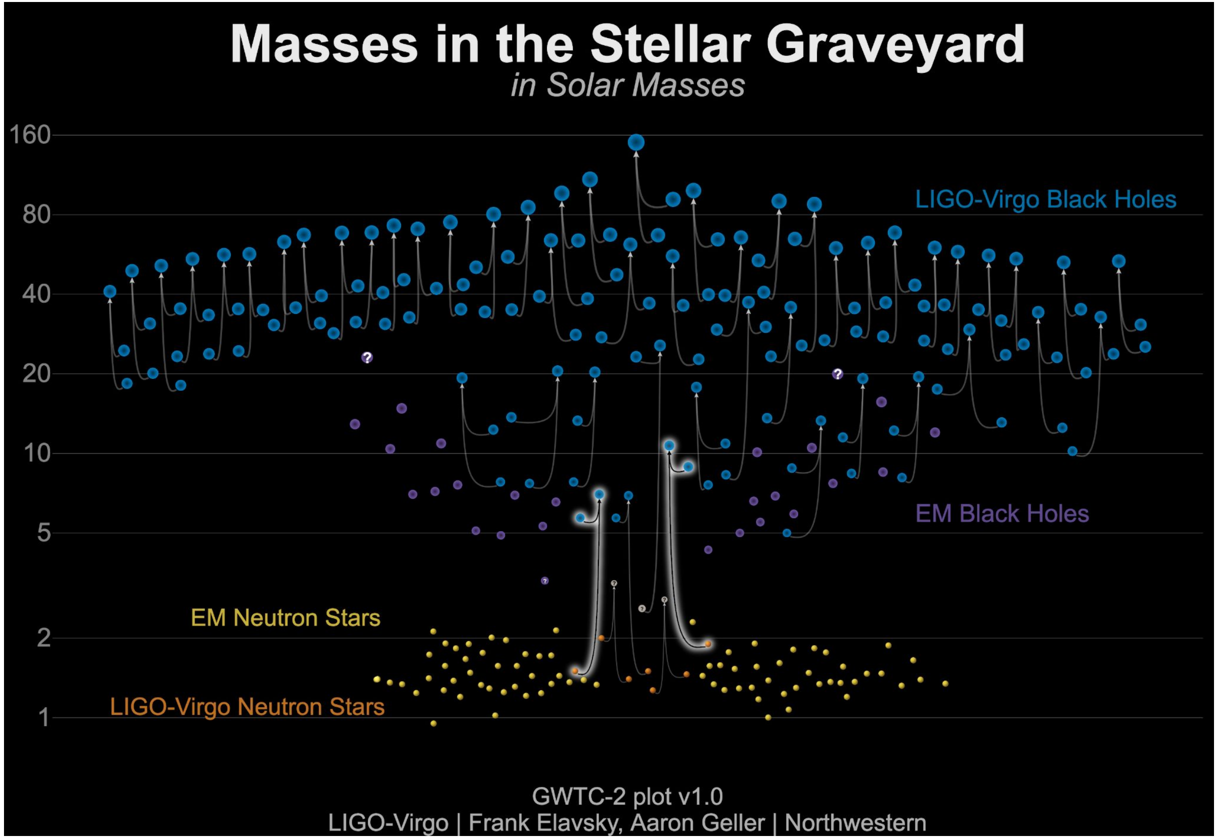
Under the supervision of **Astrid Lamberts, Marie-Anne Bizouard**

12 Oct 2021

Observatoire de la CÔTE d'AZUR
Membre de UNIVERSITÉ CÔTE D'AZUR

LAGRANGE

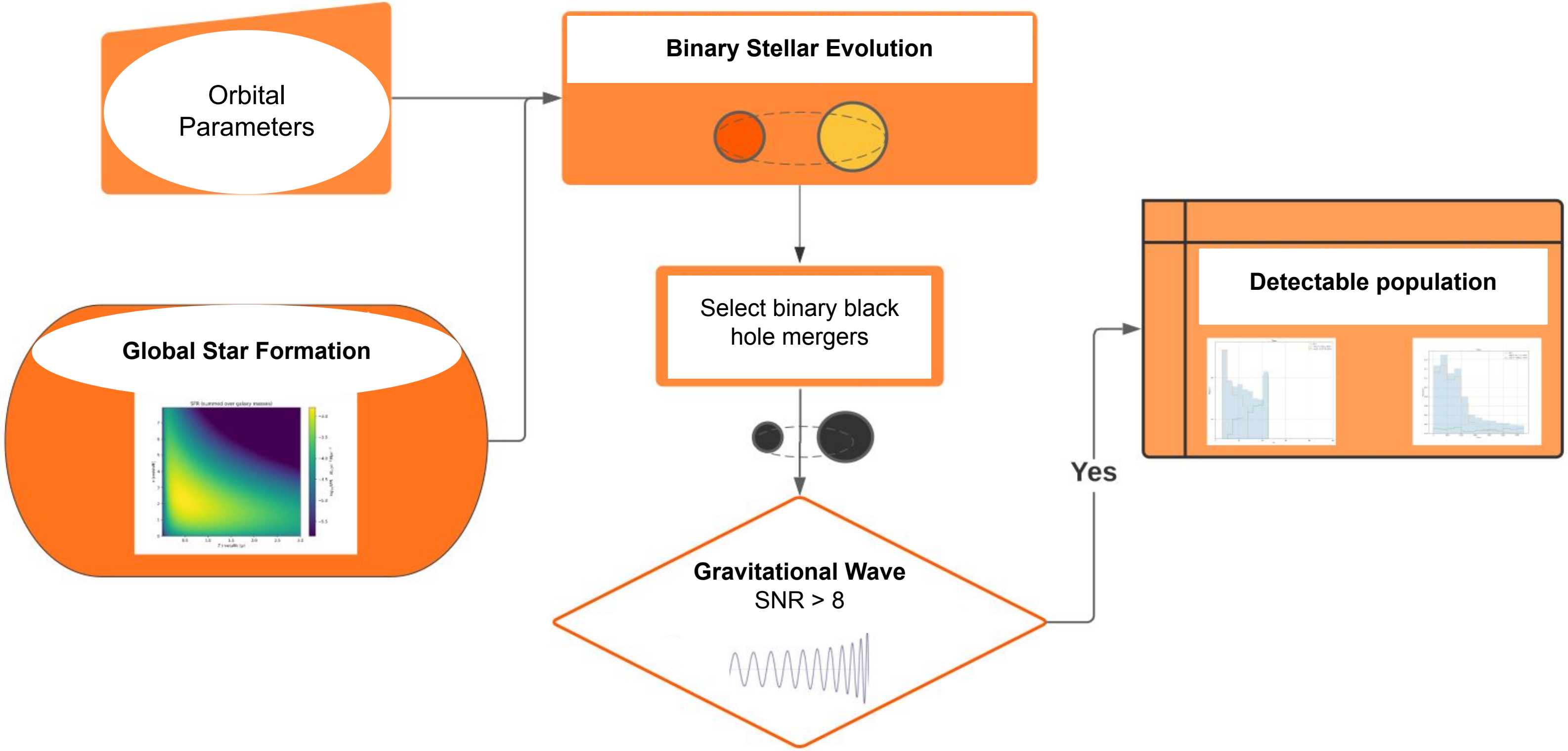
ARTEMIS

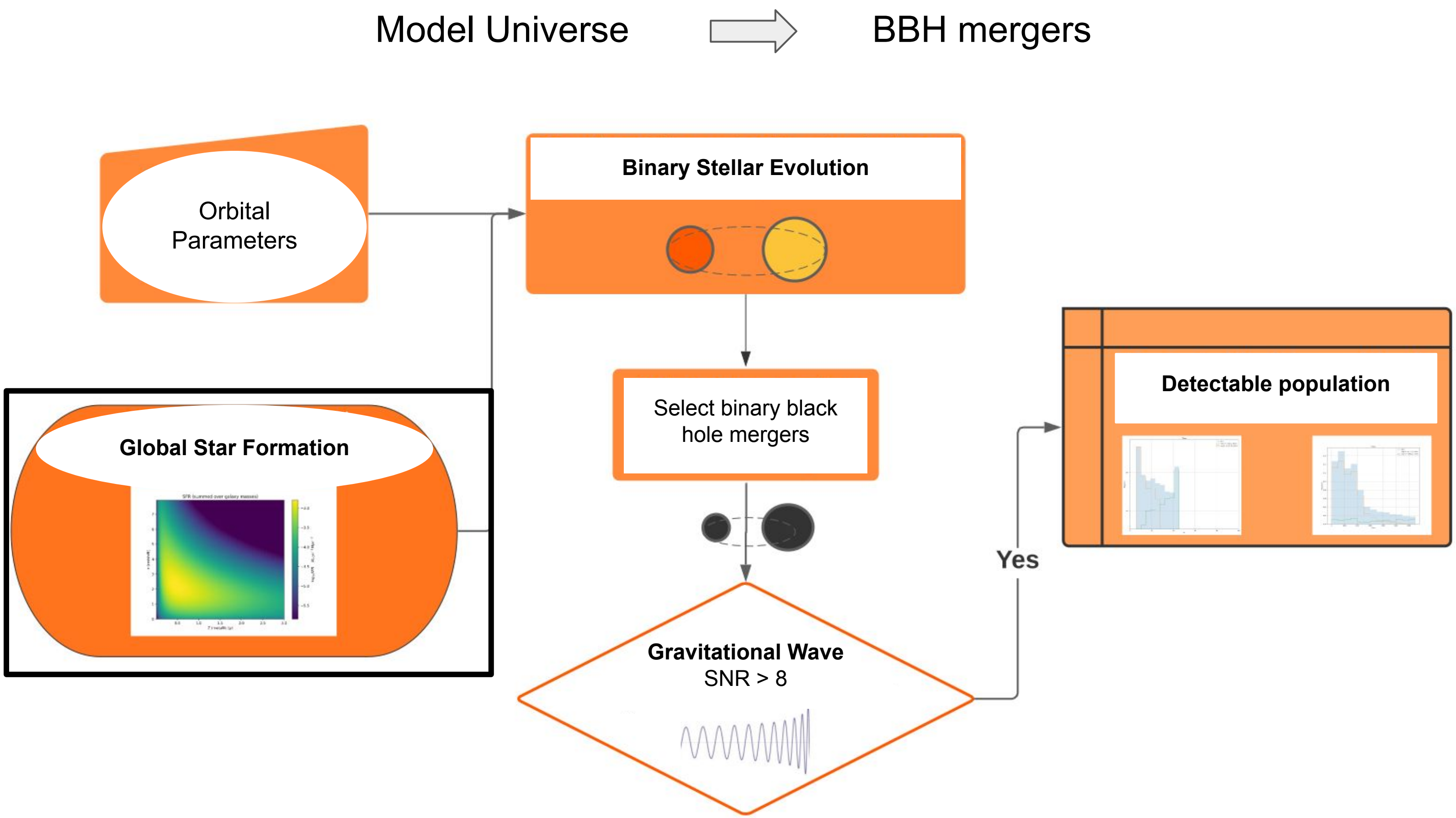


Gravitational wave **black holes** have mass 20-50 $M_\odot$ >> X-ray binaries have **black holes** with mass 5-15 $M_\odot$

Different progenitor stellar environments?

Model Universe → BBH mergers




Model Universe
BBH mergers
Orbital Parameters
Binary Stellar Evolution
Global Star Formation
Select binary black hole mergers
Detectable population
Yes
Gravitational Wave
SNR > 8

Realistic Star Formation Rate (SFR)

The SFR strongly depends on:

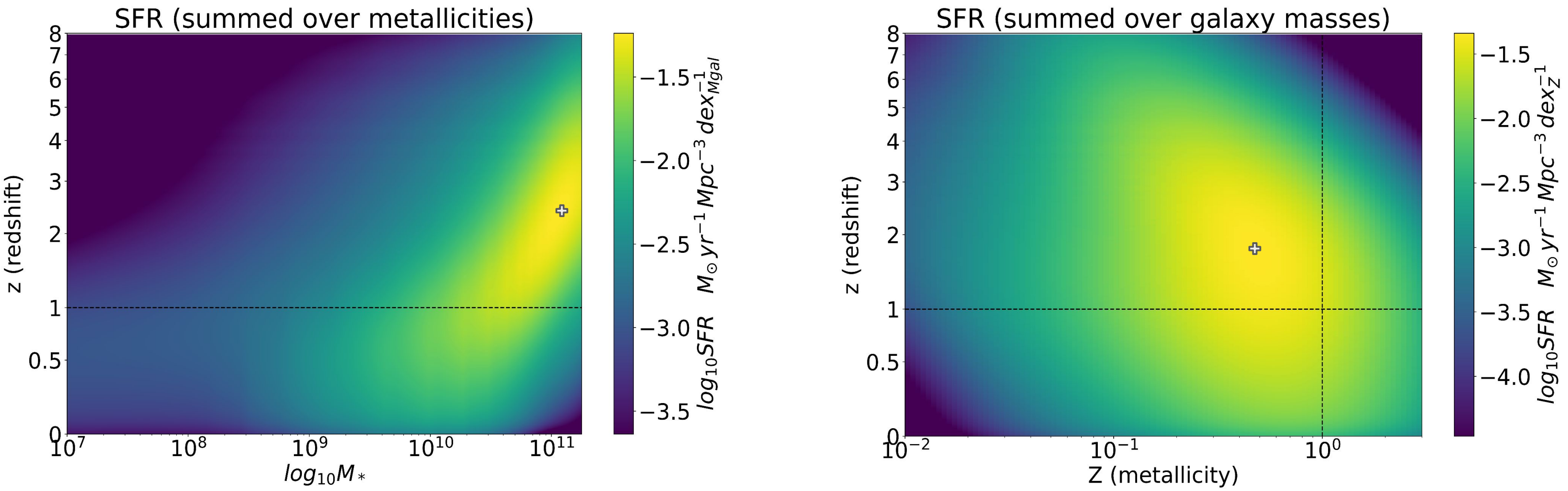
- Metallicity (Z)
- Galaxy mass (Mgal)
- Redshift (z)

Model Universe is modelled based on **observed** statistics of {Z, Mgal, z}.

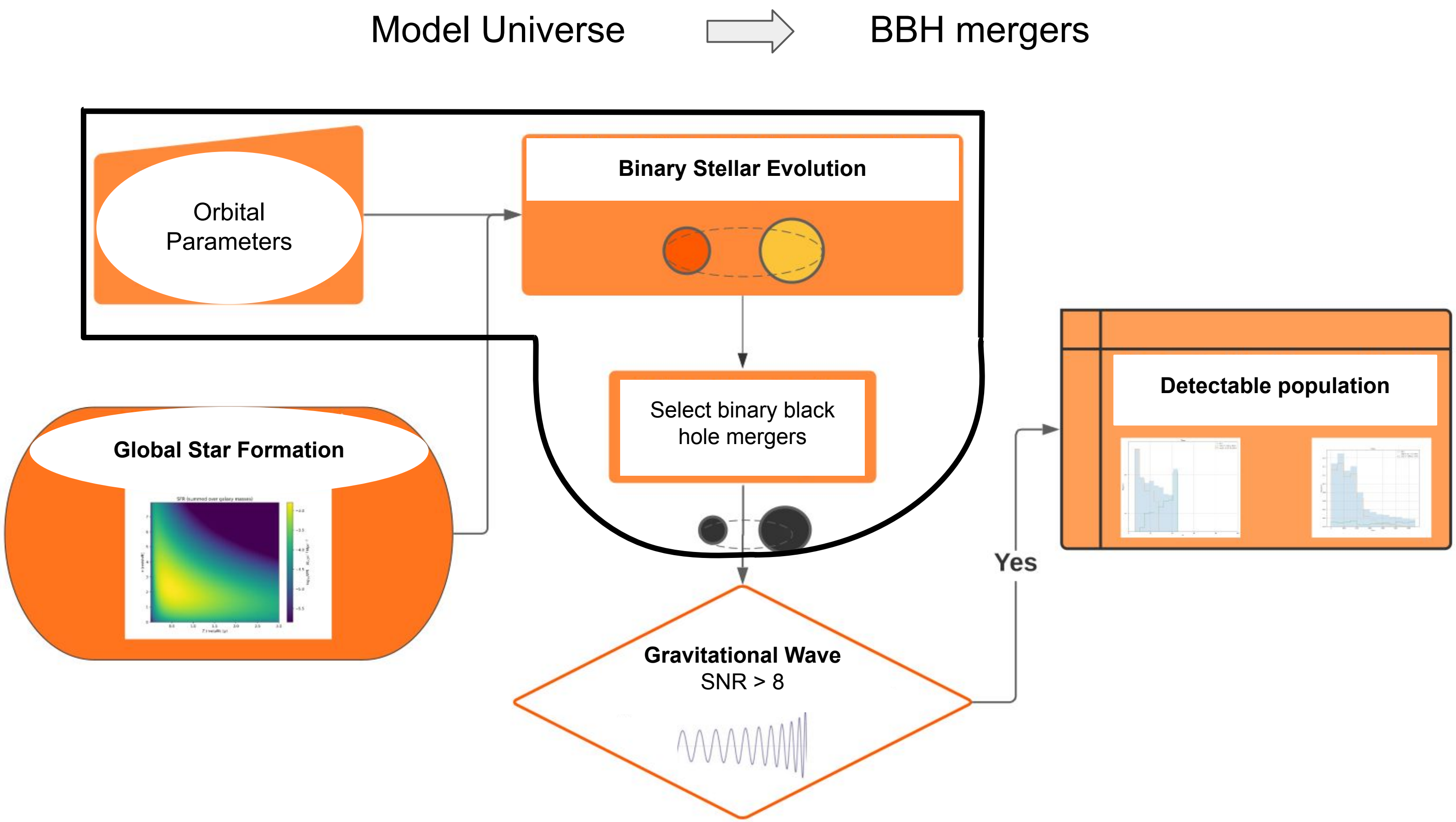
Realistic Star Formation Rate (SFR)

Peak SFR:

Z = 50% of $Z_\odot$ Mgal = $10^{11} M_\odot$ z = {2 - 2.5}



Reproduced from A. Lamberts et al 2016, based on P. Behroozi et al 2013


Model Universe
BBH mergers
Orbital Parameters
Binary Stellar Evolution
Select binary black hole mergers
Global Star Formation
Gravitational Wave
SNR > 8
Yes
Detectable population

Binary Stellar Evolution

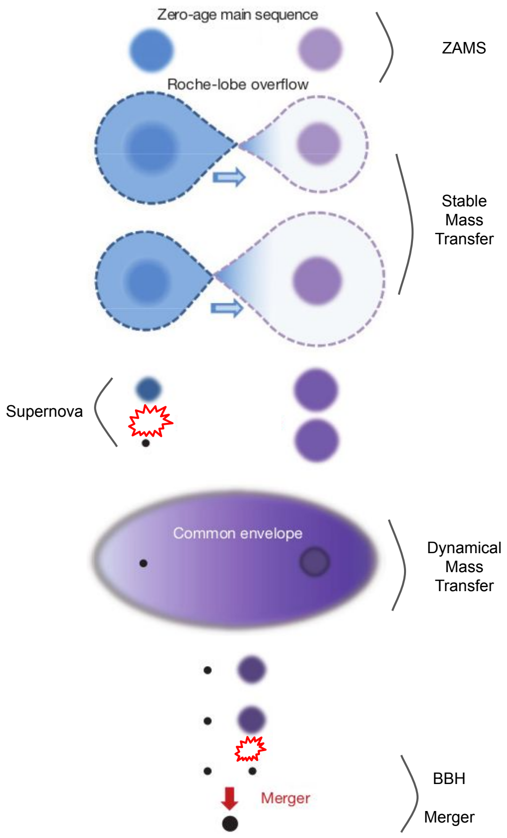
Rapid binary population synthesis model

- **COSMIC** (Compact Object Synthesis and Monte Carlo Investigation Code, Breivik et al. 2020)

The binary evolution is modelled after physical parameters:

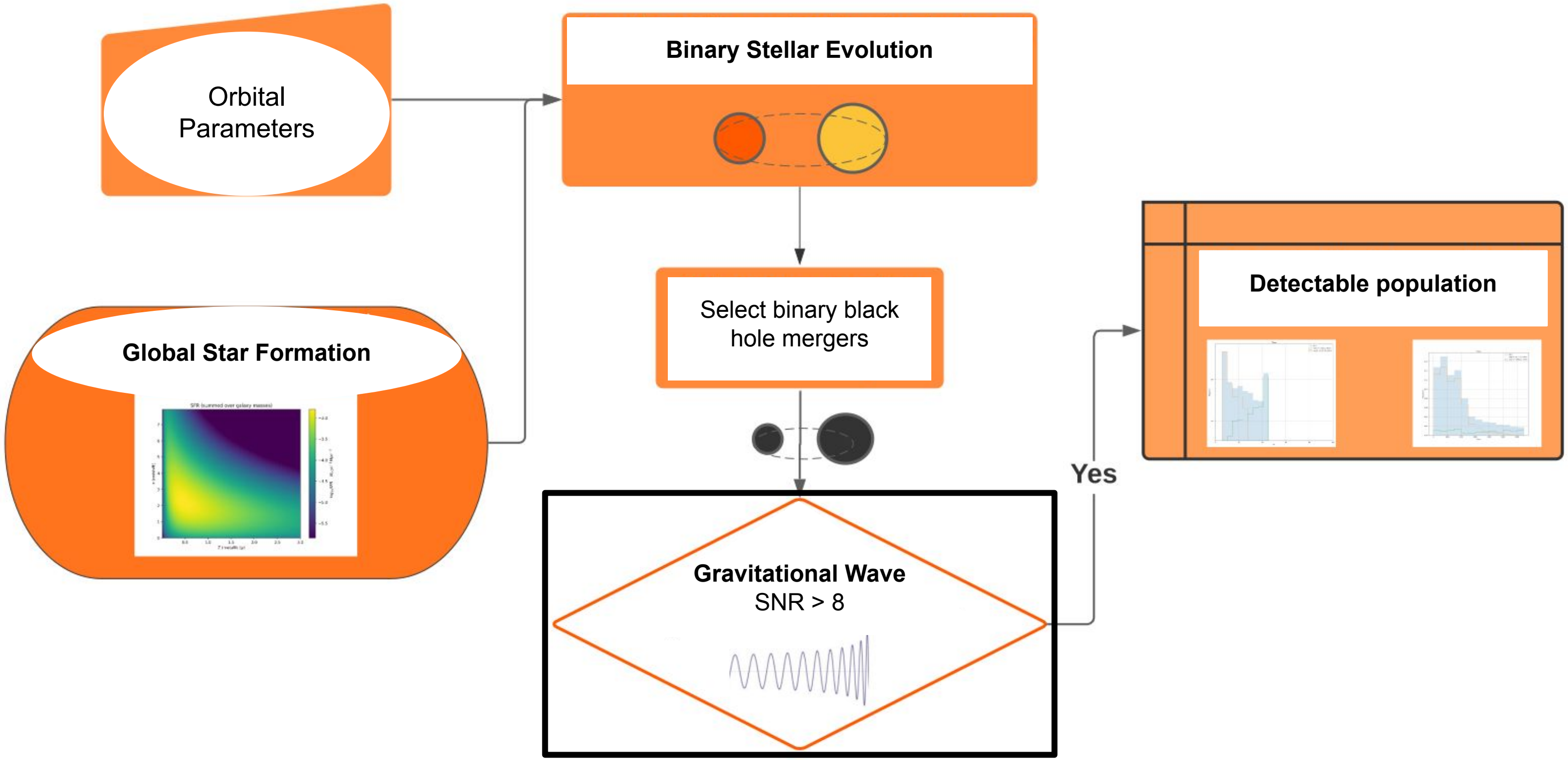
- Stellar winds
- Supernova kicks
- Mass-transfers
- Remnant Mass (NS/BH mass gap)
- Tide
- Compact Star
- Magnetic Braking

Binary Stellar Evolution

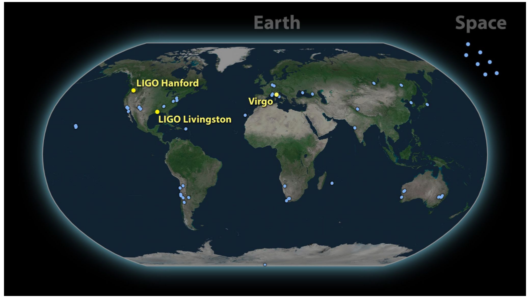


Belczinski et al 2016

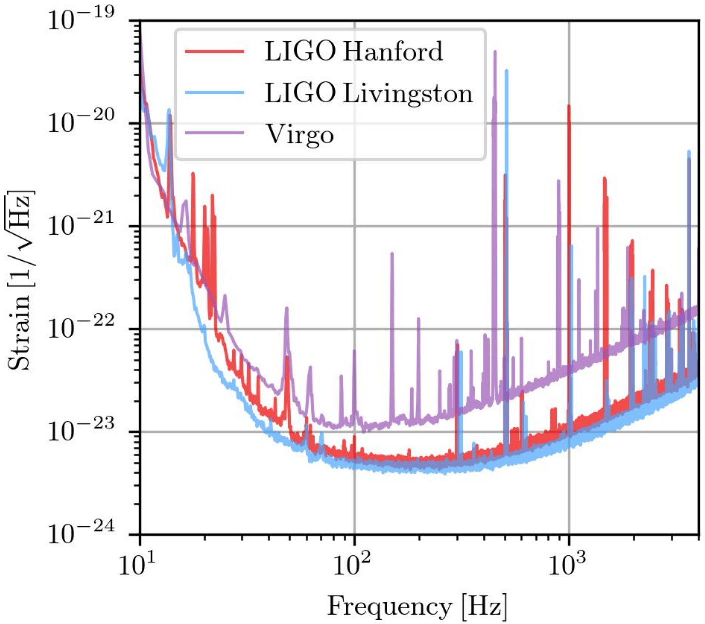
Model Universe → BBH mergers



GW Detection - SNR Calculation



MIT News



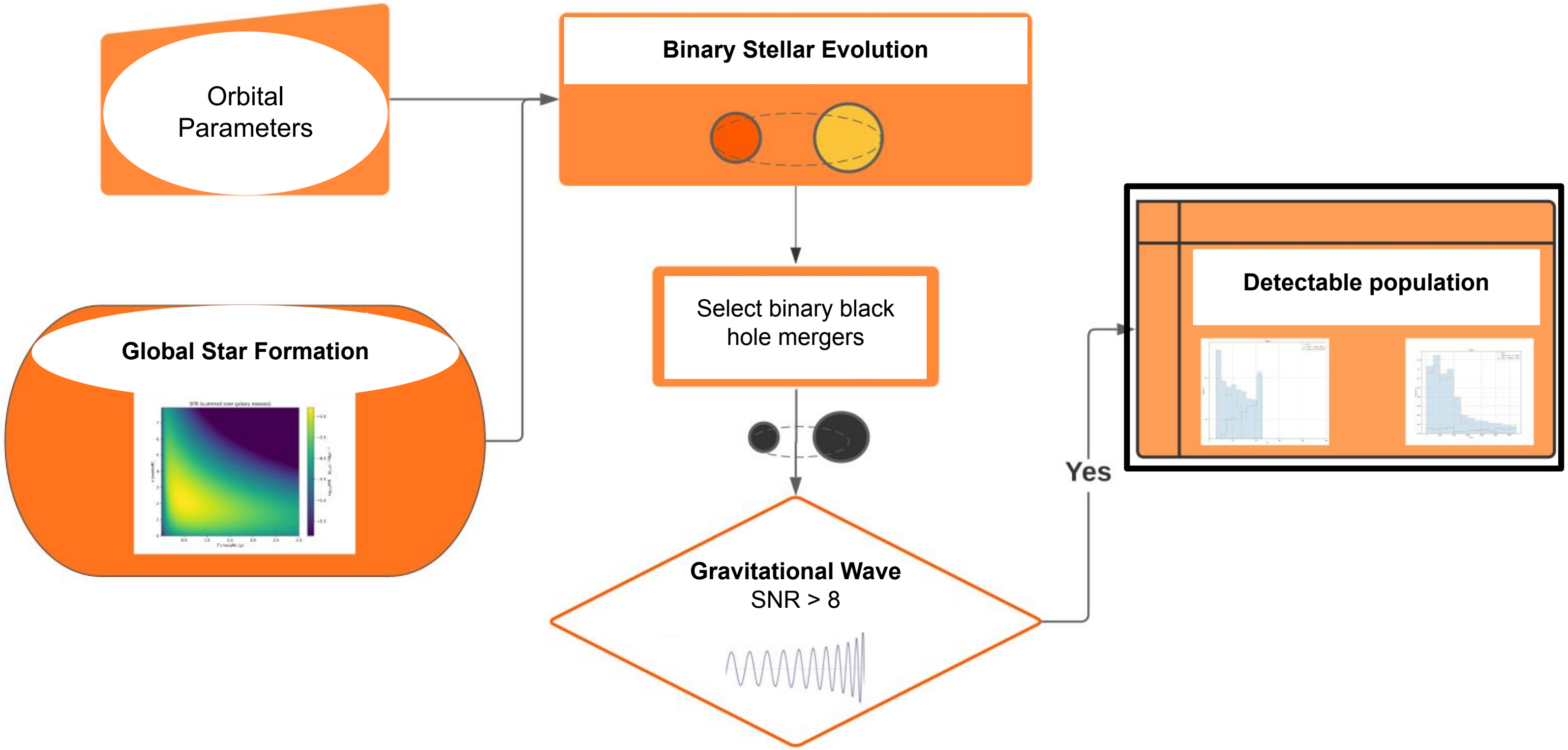
GWOSC

The gravitational waveform (IMRPhenomD) depends on:

- $M_{1\ BH}$
- $M_{2\ BH}$
- Luminosity distance
- Redshift (reweights mass)

O3 L1, H1 and V1 sensitivity curves were used to mimic LVC's O3 run.

Model Universe → BBH mergers



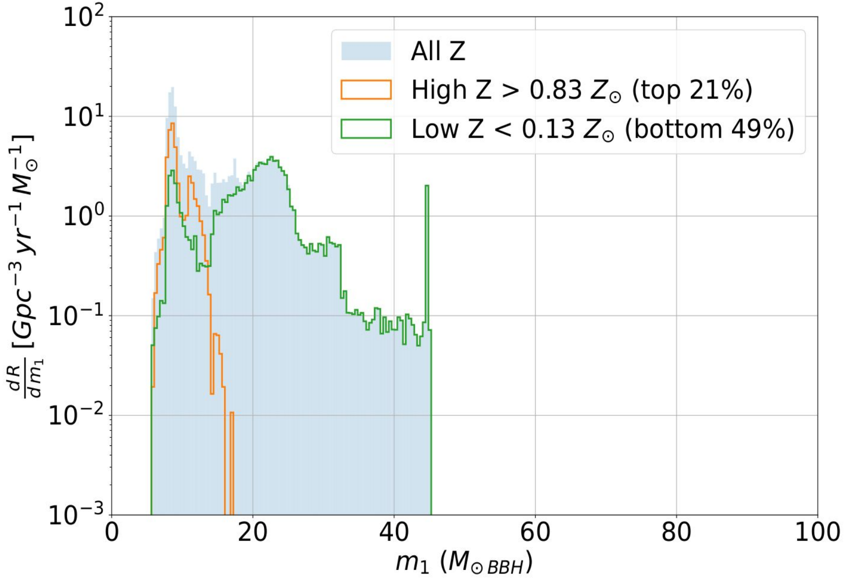
Simulations

We simulated 3×10^8 binary star systems across:

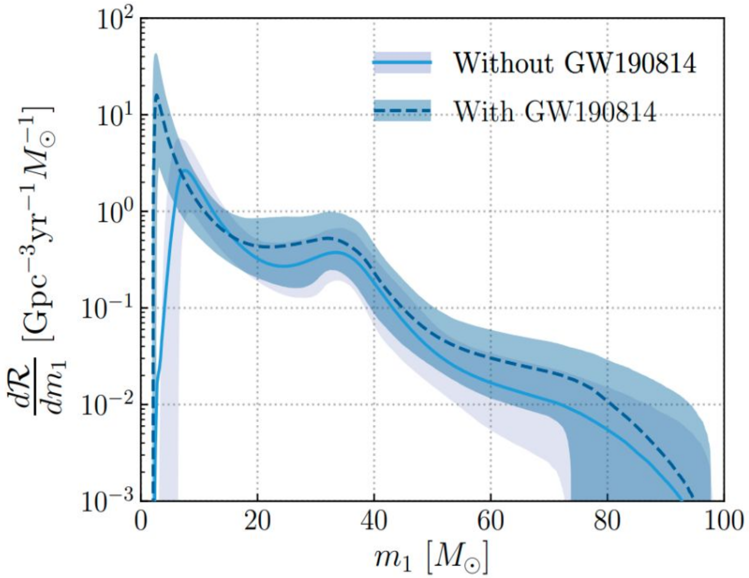
- z : **0 - 8**,
- Mgal: **10^7**$M_\odot$ **- $10^{11.25}$**$M_\odot$
- Z : **0.01** $Z_\odot$ - **1.2** $Z_\odot$
- Binary Evolution Models: **32** sets

The following slide shows the results for the "***default***" binary evolution model.

Results: Consistency with LVC rates

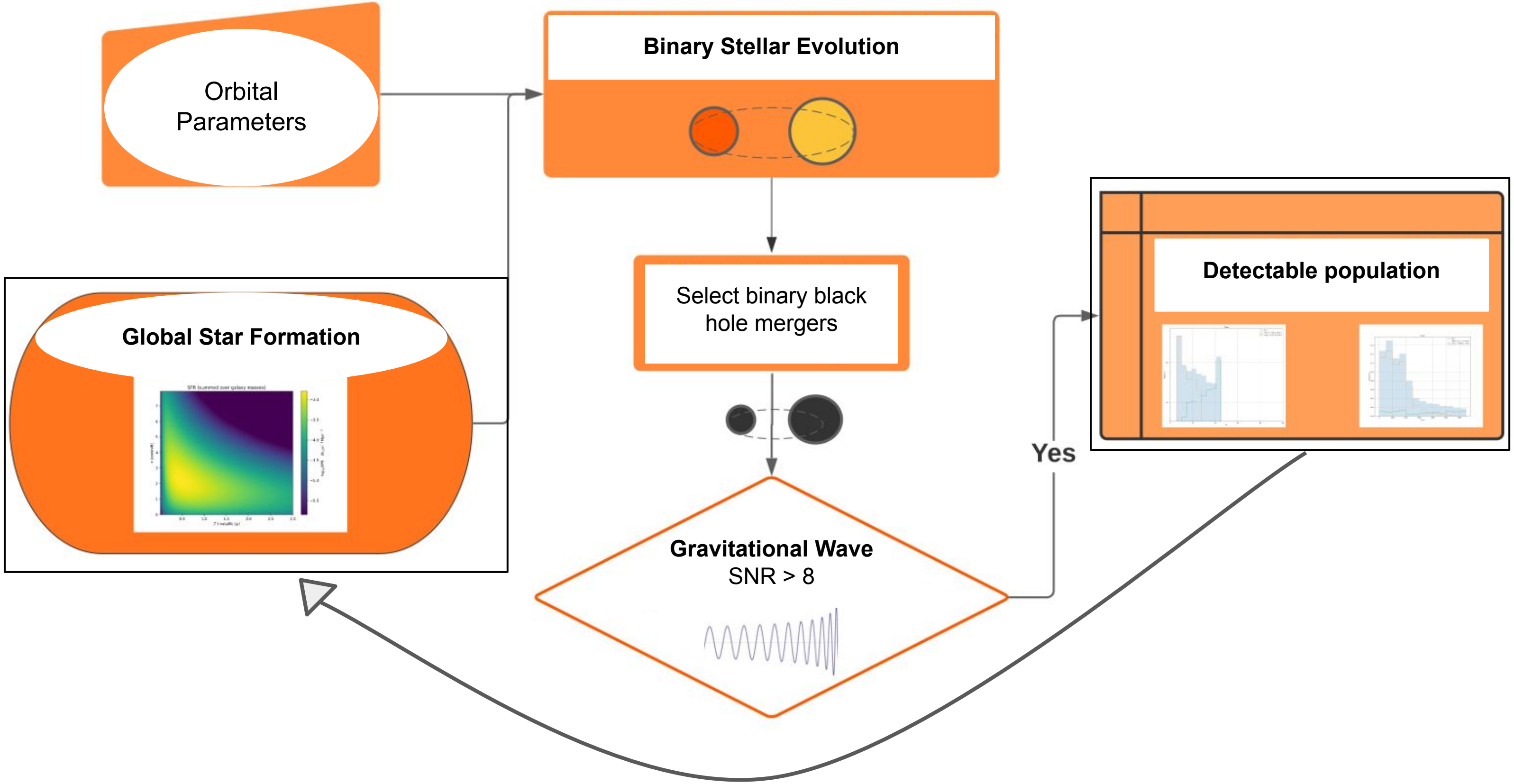


(a) Simulation



(b) LVC (Abbott et al, 2021)

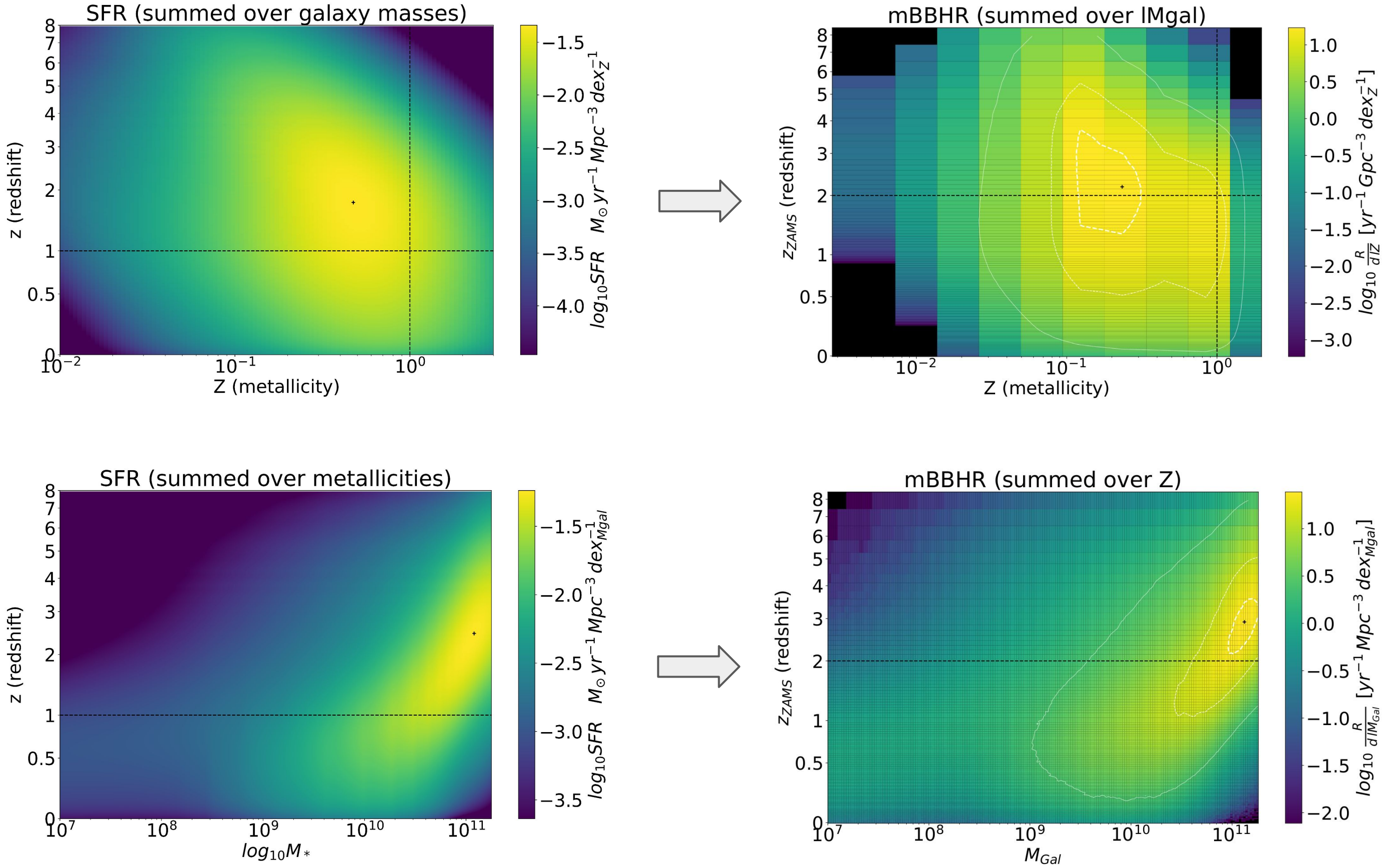
Model Universe ⇒ BBH mergers



Results: Progenitor Formation Rate

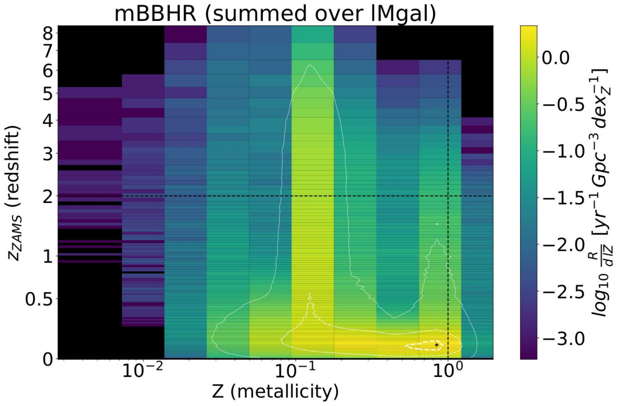
All Stars

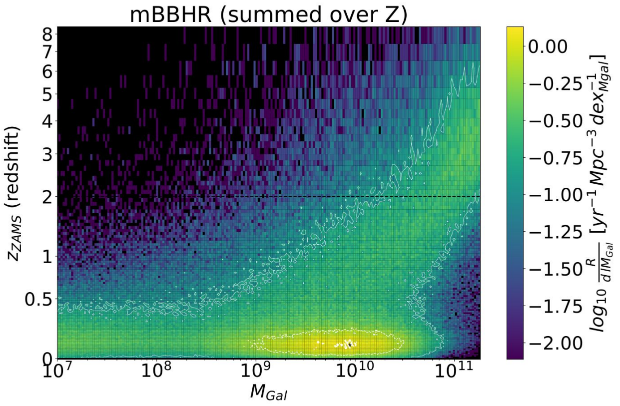
All Progenitor Stars



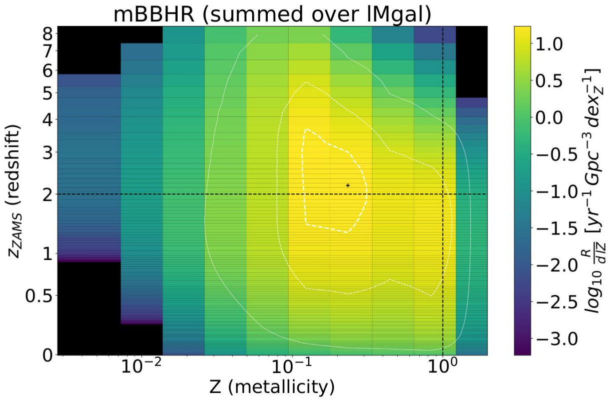
Results: Progenitor Formation Rate

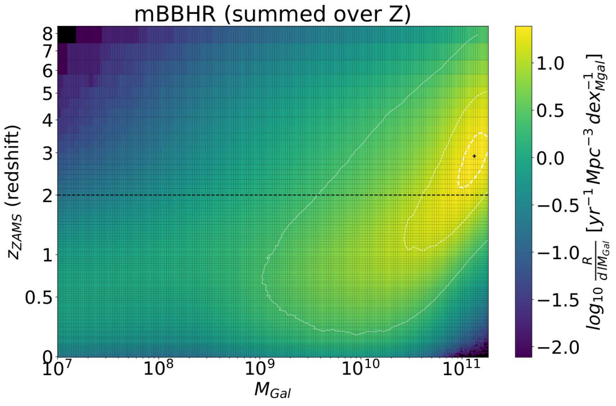
Progenitor Stars with Detectable BBHs





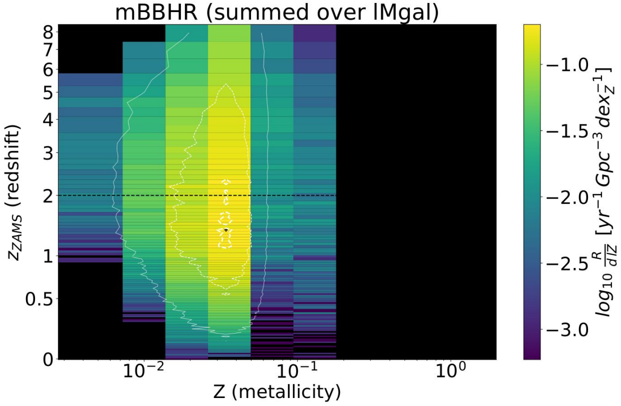
All Progenitor Stars

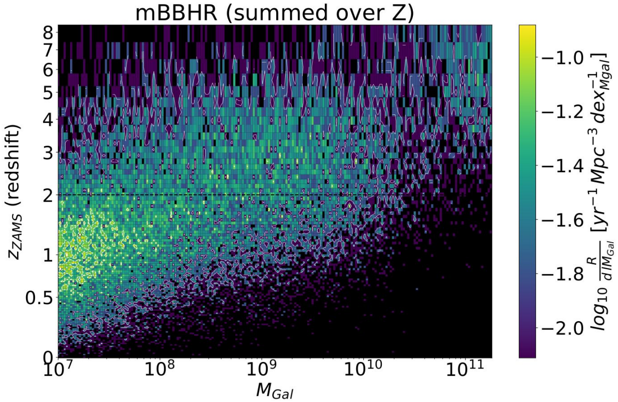




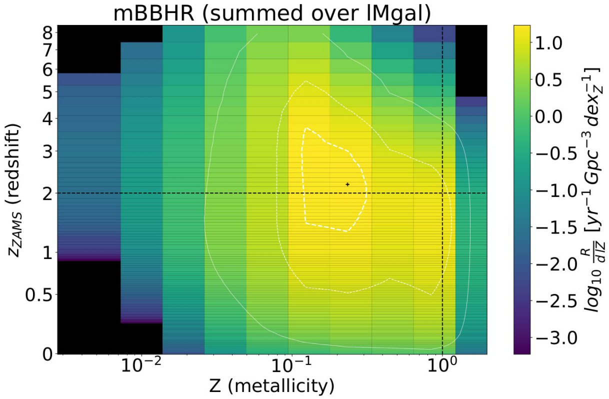
Results: Progenitors with $M_{1,BBH}$>30$M_\odot$

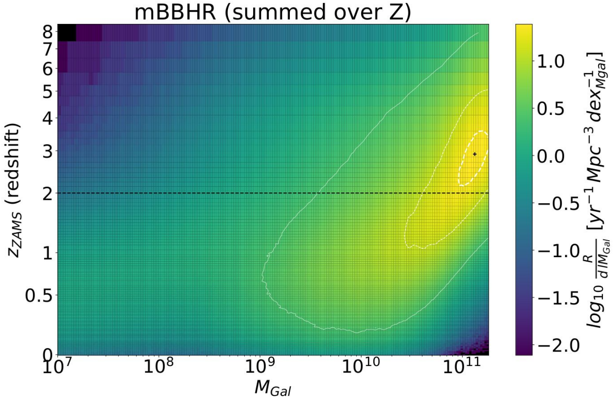
Progenitor Stars with $M_{1,BBH}$>30$M_\odot$





All Progenitor Stars





Conclusions

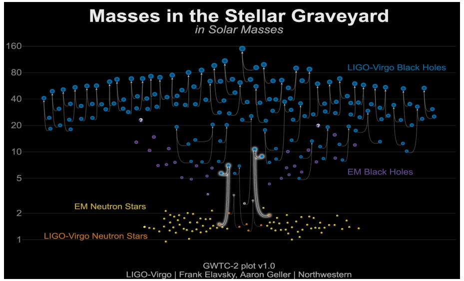
1) Gravitational wave detectors induce an observational bias towards detecting low redshift BBHs. Hence, their progenitors tend to form at low redshifts.

2) Large mass BH: dwarf galaxies in low metallicity (0.02 $Z_\odot$) environments at low redshifts (<1).
Few

3) Smaller mass BH: Milky-way galaxies in high metallicity (> 50% $Z_\odot$) environments at larger redshifts
Numerous

On-going Work

1) Repeat for other binary evolution models and identify those that are consistent with LVC rates.
2) Analyse the degeneracies in progenitor properties (Z, Mgal, z) across evolution models.



Q) Different progenitor stellar environments between GW and X-ray binaries?

- Repeat analysis for X-ray binaries in the Milky Way.