Heavy Double Neutron Stars: birth, midlife and death

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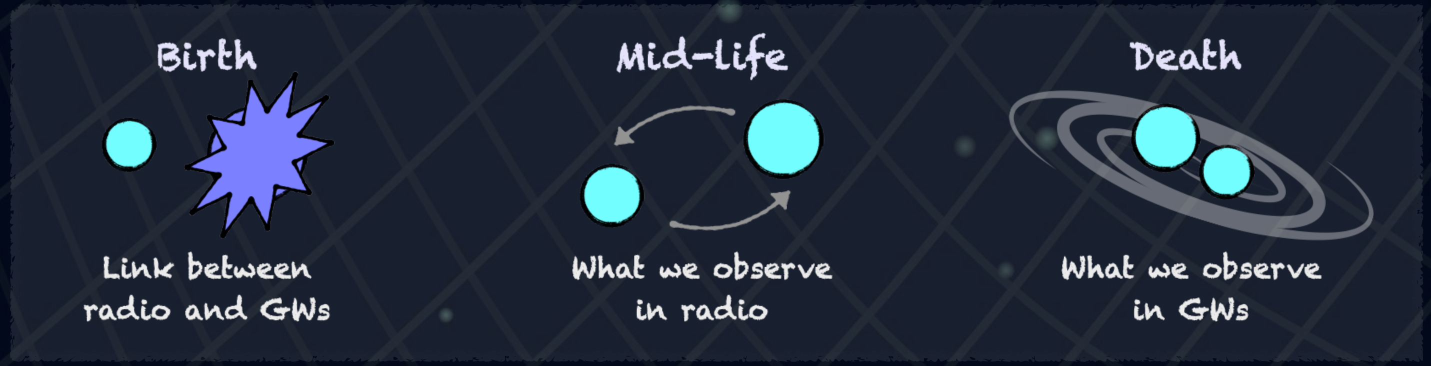
INTRODUCTION

We develop a model to determine the birth mass distribution of double neutron stars (DNS); the connection between radio and gravitational-wave (GW) populations. We also consider how to account for the unusual mass of GW190425.



Standard formation scenario DNS:

- first-born recycled neutron star sped up from accretion
- second-born slow neutron star.

Possible explanation for lack of high mass DNS in radio is that high mass DNS are fast-merging via unstable case-BB mass transfer (see Fig. 1).

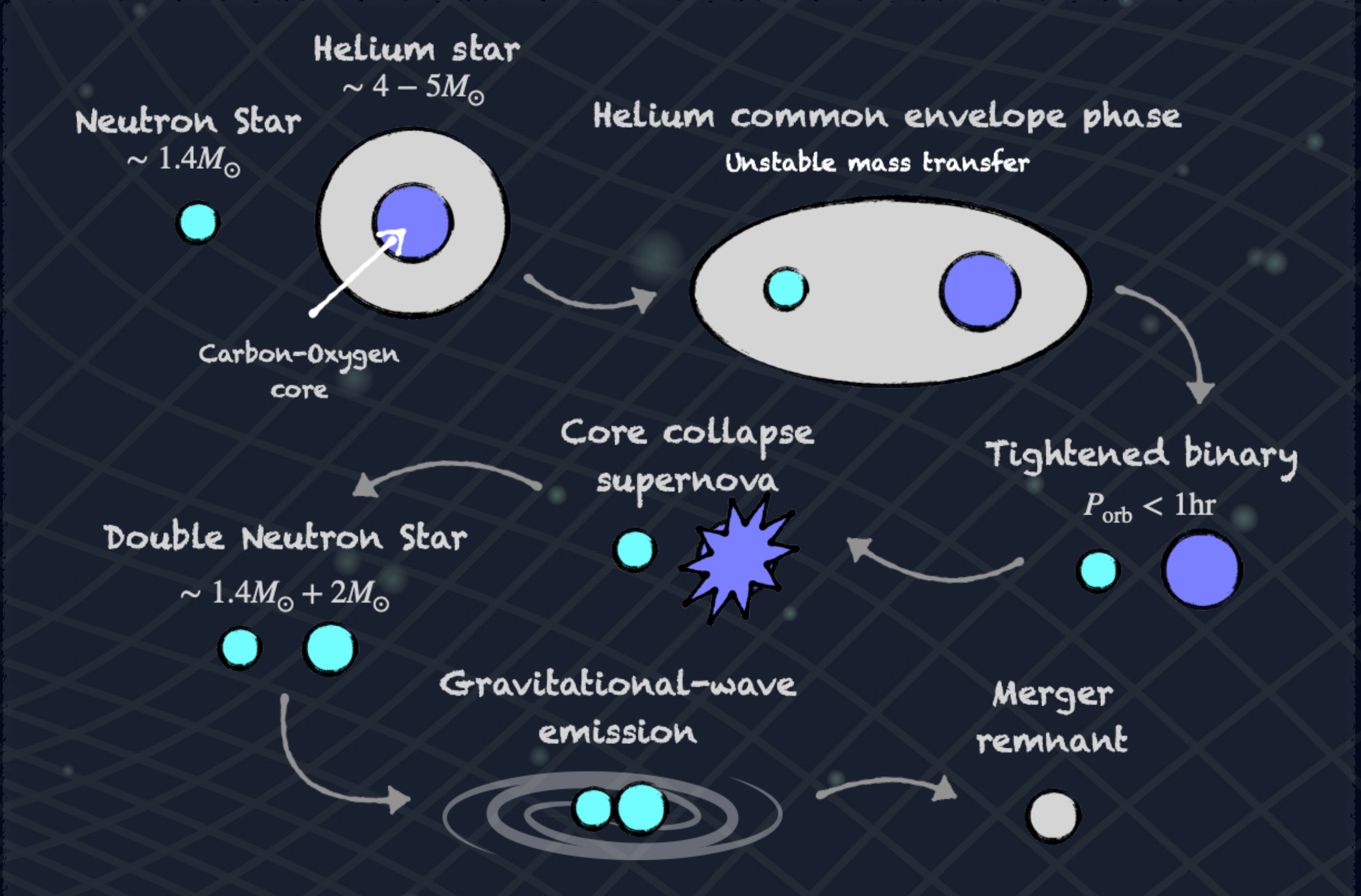


Fig. 1: Diagram illustrating the Case BB evolution process of a DNS system from formation to merger.

METHOD

We create a model for the birth distribution assuming some mass and rate density of the population at birth.

Birth mass distribution: Double Gaussian for **recycled** neutron star distribution (Farrow et al. 2019). For **slow**, we consider a double Gaussian where high-mass peak is motivated by fast-merging DNS (see Fig 2).

Birth formation rate densities: Milky Way - uniform over cosmic time; For extra-galactic Madau-Dickinson star formation rate density.

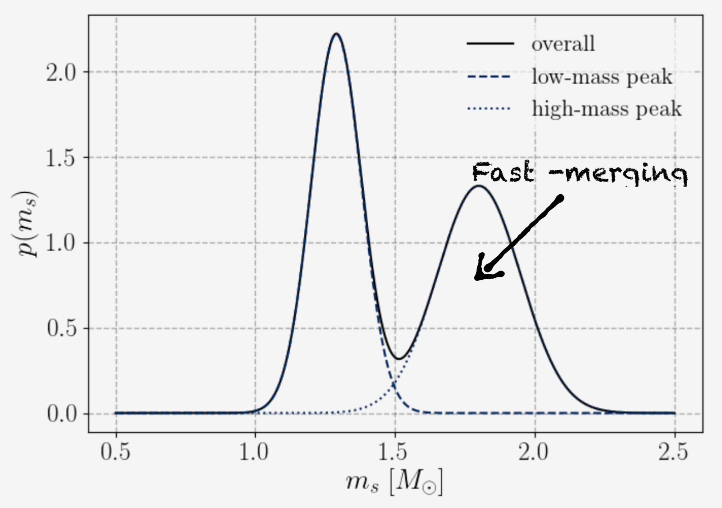
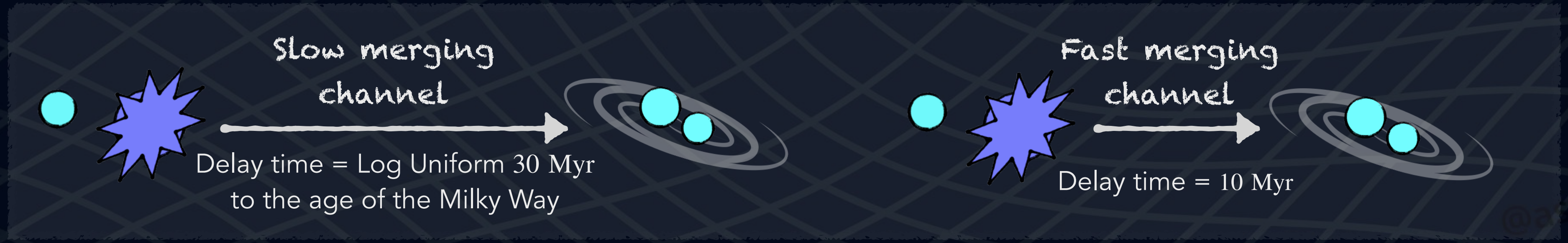


Fig. 2: Example of a slow neutron star mass distribution.



Gravitational-wave population: Using the DNS formation rate density and delay-time distribution we can calculate the merger rate density for the slow and fast merging channels

$$R_m(t) = \int_0^t dt_b R_b(t_b)\, \pi(t - t_b) \quad \text{Eq. 1}$$

Radio-visible population: Considering the population that has not merged we can determine the number of radio-visible population using the birth rate, merger rate and the fraction of radio binaries beamed towards Earth.

$$N_r(t) = \int_0^t dt' \left(R_b(t') - R_m(t')\right) \epsilon(t') \quad \text{Eq. 2}$$

We can evaluate Eq. 1 and 2 for our two channels and take the ratio between these two channels:

- merger rate densities: $\zeta_{\rm GW} = R_m({\rm slow})/R_m({\rm fast})$
- number of radio binaries: $\zeta_{\rm radio} = N_r({\rm slow})/N_r({\rm fast})$
- assume $\epsilon(t) \approx \epsilon$ (i.e. does not vary across cosmic time).

These ratios determine how the relative fraction of DNS evolving in each channel (e.g. $\zeta_{\rm radio} = 196$ means the fast-merging channel suppressed by a factor of 196 compared to slow-merging channel; see.Fig 3 for example).

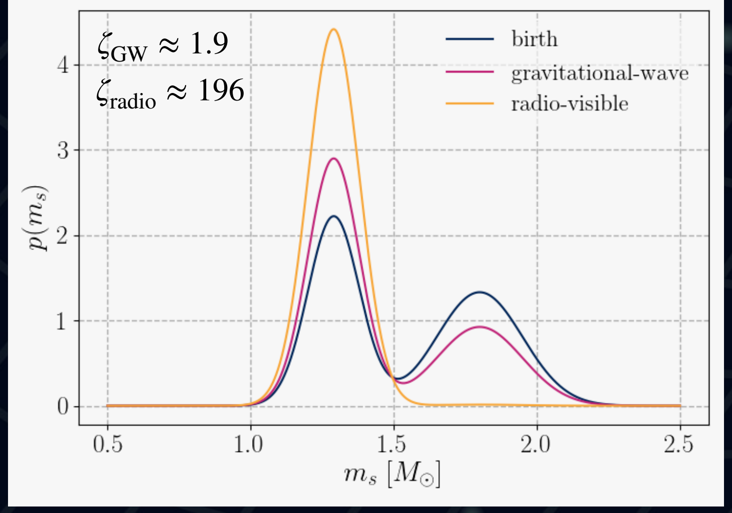


Fig. 3: Slow neutron star mass distribution for birth (navy) radio-visible (yellow) and GW (pink) populations

ANALYSIS

Using a hierarchical inference package, GWPopulation, we performed an analysis with gravitational-wave and radio observations:

- Radio dataset: 12 DNS from Farrow et al. 2019
- GW dataset: GW170817 and GW190425

Difference from toy model was that we allowed the fast-merging distribution to vary (delta function varies from 5 – 500 Myr) rather than being fixed at 10 Myr.

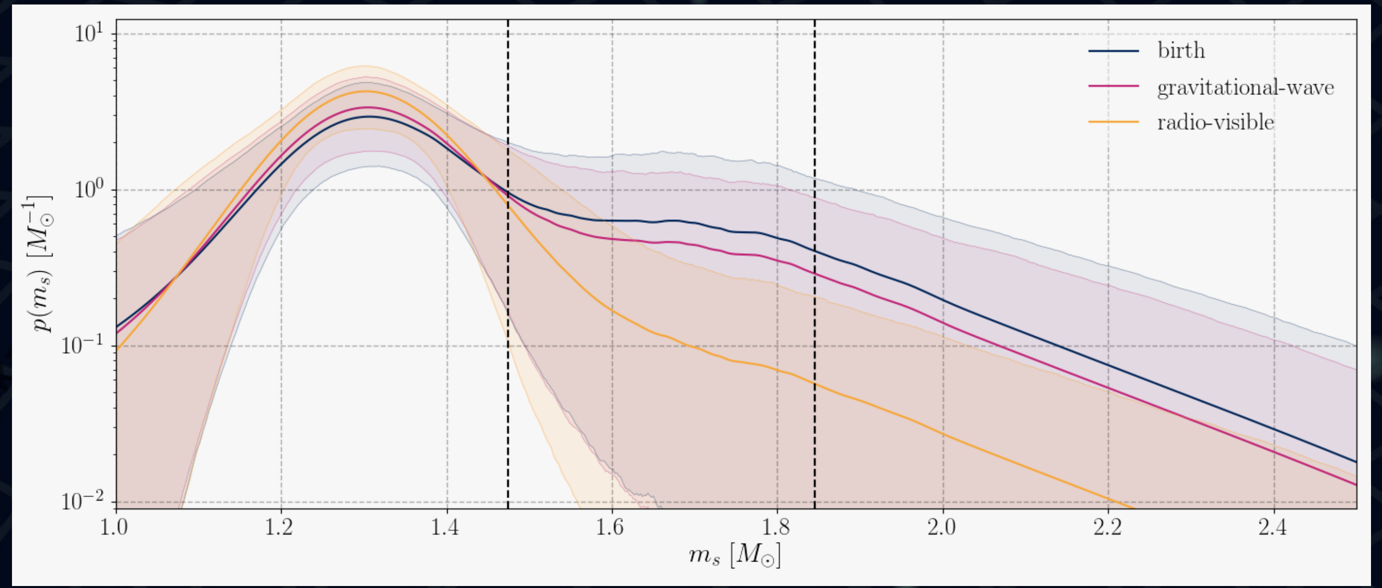


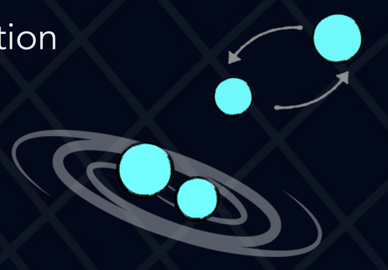
Fig. 4: Slow NS mass distribution for birth (navy) radio-visible (yellow) and gravitational-wave (pink) populations for hierarchical inference study including 2 binary neutron stars and 12 radio DNS

The birth, radio and GW mass distributions of the DNS population are shown in Fig. 4. We find that the radio distribution is suppressed by a factor of $\approx 4-74$ at 90% credibility.

CONCLUSION

In this work we proposed a framework for linking the distribution of DNS at birth, mid-life (radio), and death (GWs) and model the mass distribution of slow and recycled neutron stars.

- Mild evidence to support the fast-merging channel hypothesis
- GW190425 is not a clear outlier from the Galactic population
- $8-79\,\%$ of DNS born are fast-merging
- typical fast-merging delay-time is $5-401$ Myr.



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