SN models in binary population synthesis

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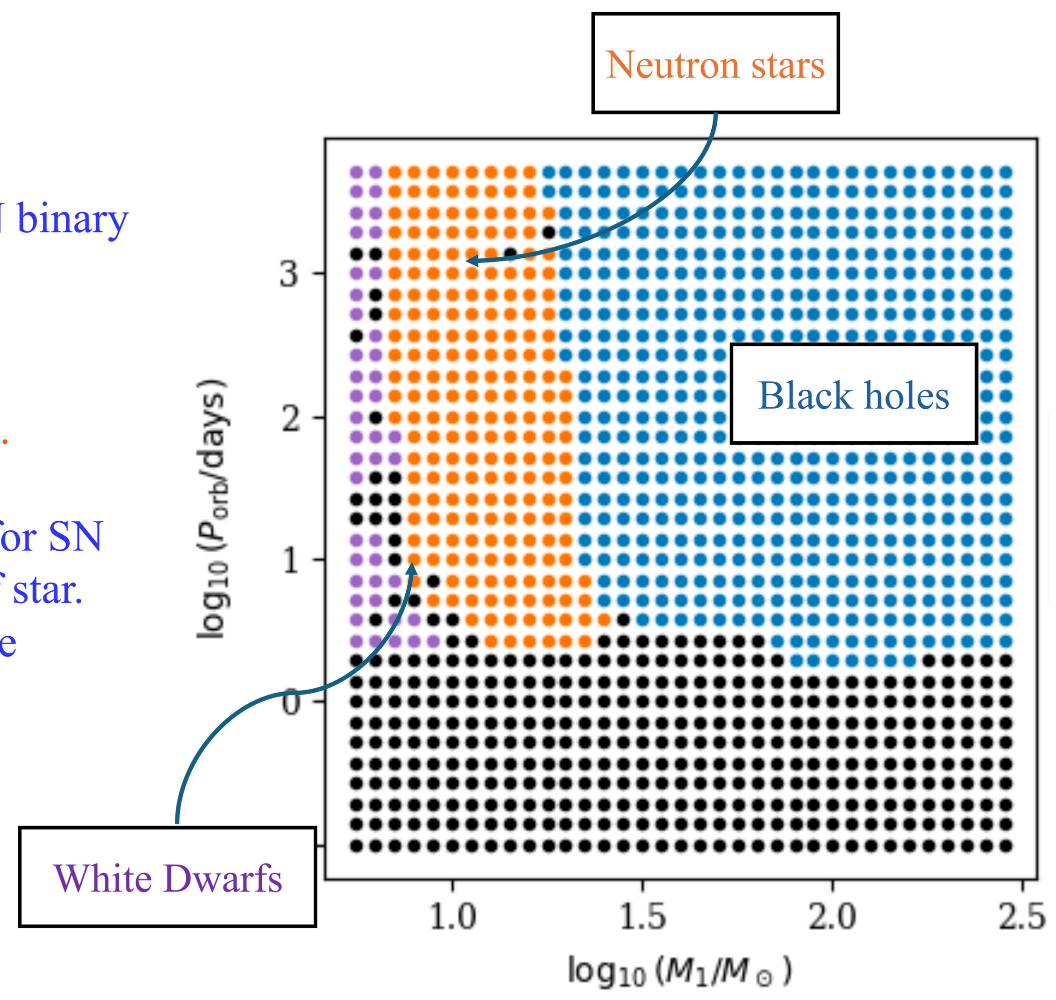
Introduction

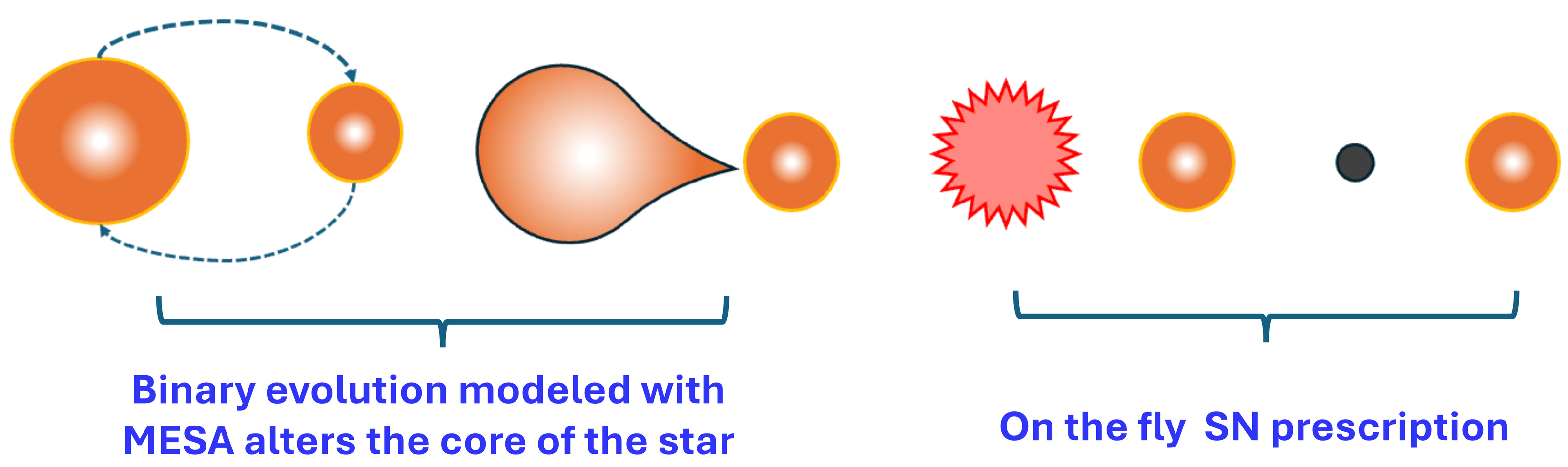
Most massive stars form and evolve in binary systems, which undergo interactions, fundamentally changing both stars' structures. The statistics of supernova demographics therefore intimately depends upon binary population synthesis models. Multiple codes (e.g., `cosmic`) have been developed to rapidly simulate the fate of millions of stellar binaries. However, these codes must all make approximations to achieve the necessary computational efficiency. Alternatively, stellar structure codes like MESA can accurately evolve individual binaries by simultaneously solving both stars' structures along with the binary. These codes are quite computationally expensive. POSYDON addresses this problem, offering a solution in a flexible and computation efficient way, by pre-computing ~10^5 separate binary models then training machine learning models to interpolate between these grids (Fragos et al. 2023).

Because POSYDON evolves the stellar structure equations, we know the structure of each star at core collapse. We have developed a model to calculate the fate of collapsing stars using their structures provided by POSYDON. Our model is loosely based on Herant et al. (1994) which argues the growth of convective instabilities drives supernova explosions. Since SN fundamentally change the characteristics of a binary due to their enormous mass loss and natal kicks, our models will improve our knowledge of which binaries become gravitational wave sources.

The POSYDON code

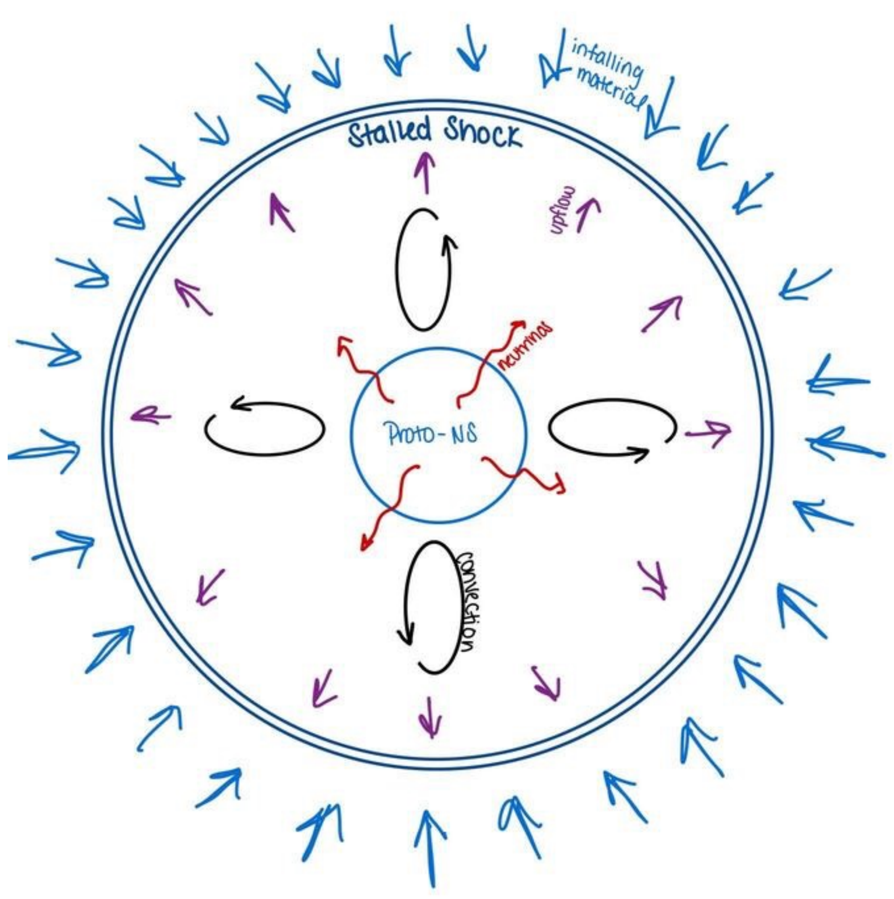
- ∗ Each marker represents a POSYDON binary evolved with MESA.
- ∗ The stars are evolved to core carbon depletion, very close to their collapse.
- ∗ We can apply different prescription for SN based on the pre-collapse structure of star. Marker colors represent the fate of the remnant.





The convection SN model

- The SN is triggered when **the star collapses** under its own gravity. The collapse halts when the nuclear forces in the newly formed proto-neutron star launch an outward spherical shock, **"the bounce"** .
- The shock stalls and behind it, it creates a convective unstable region where is going to start being dominated by **Rayleigh-Taylor instabilities**.
- The **convection** transfers energy from the inner to the outer layers of the convective region. At the same time transport mass from the stalled shock to the core depositing more energy.



The convection deposits energy continuously: $E_{exp}(t) = E_{ini} + \dot{E}_{inj}t$

$$P_{exp} \sim \frac{E_{exp}(t)}{R^3_{shock}}$$

The shock accretes material at free-fall time :

$$t_{ff} = \frac{\pi}{2}\sqrt{\frac{r^3}{2Gm}}$$

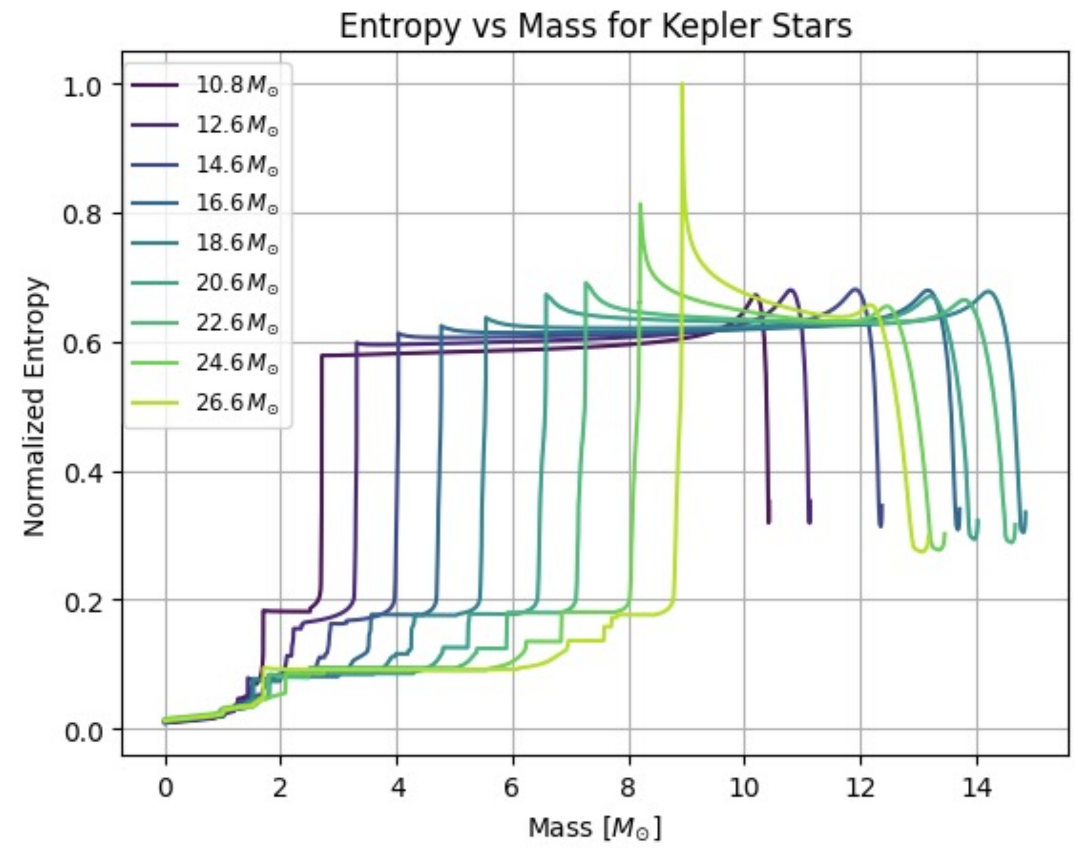
As time passes, convection grows, piling up material and increasing the shock pressure:

$$P_{shock} = \frac{\dot{M}\, u_{ff}}{4\pi r^2}$$

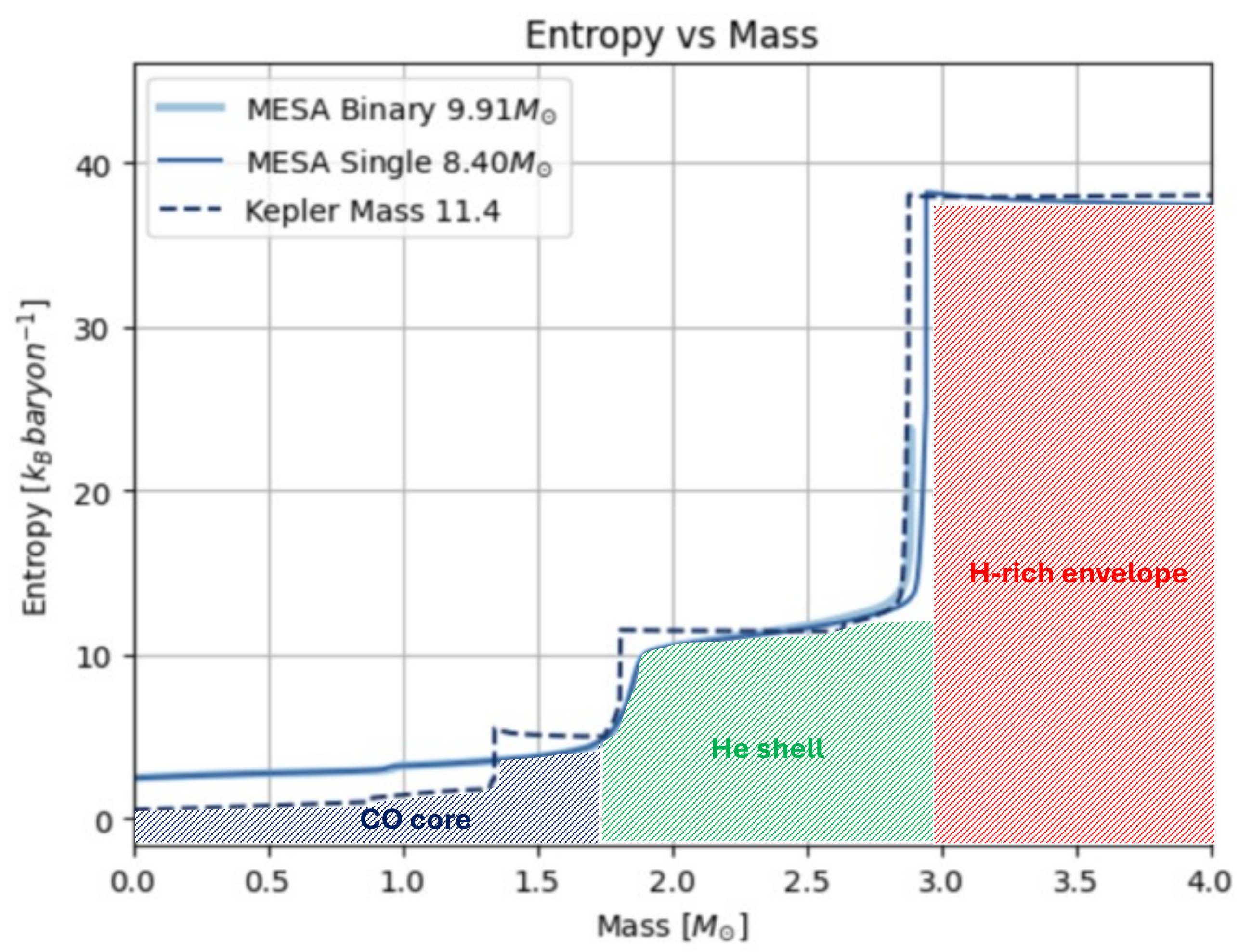
Once $P_{shock} < P_{exp}$ the bounce starts propagating, triggering the **explosion**

Mapping to Kepler Models

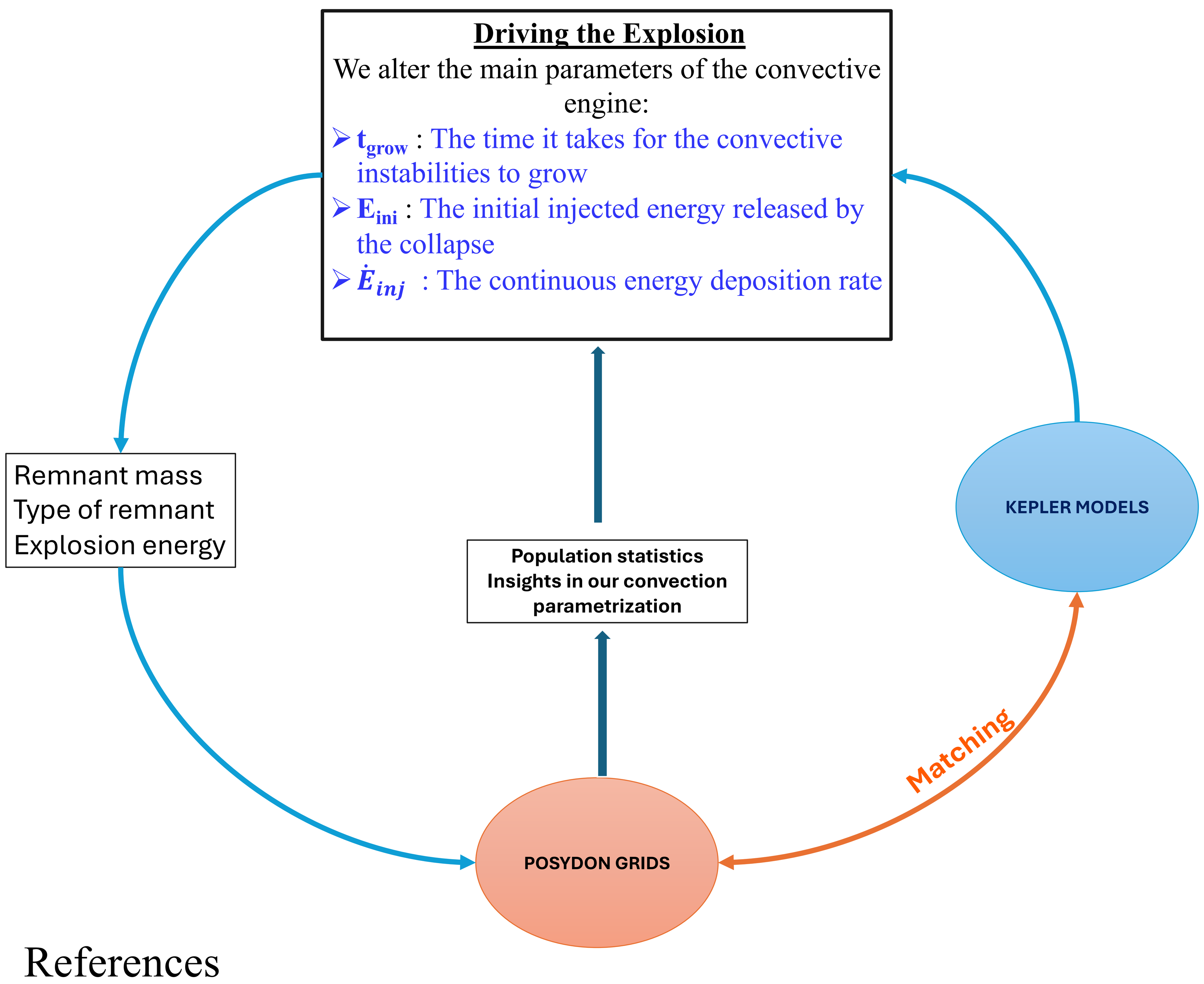
- The nature of the convection and how fast it will grow along with the accretion rate can make or break the SN.
- Our understanding of the convective-enhanced neutrino-driven engine is very limited due the immense computational expense that it would take to resolve them.
- We propose simple 1D convective engine paradigms were the knowledge of the 2D-3D simulations can be harvested.



- ➢ POSYDON stars are evolved to core carbon exhaustion, our model requires evolution to iron. We apply our model to previously evolved Kepler models of single stars (Heger et al. 2000).
- ➢ The outcomes of the explosion can be matched with the MESA grid models based on the CO core and entropy profiles of the progenitor stars.



Constraining SN Physics



References

[1] Fragos et. al 2023, ApJS, 264, 45
[2] Herant et al. 1994, ApJ, 435, 339
[3] Heger, Langer, & Woosley 2000, ApJ, 528, 368