Modelling the Core Collapse Supernova Explosion Mechanism in One Dimension

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Core collapse supernovae (CCSN) are the violent explosions occuring as the result of the deaths of massive stars. At the end of their lives, massive stars develop an onion like structure with an inert iron core and layers of burning elements with lower atomic number elements in each layer going outward. This iron core can reach the Chandrasekhar mass at which point it collapses because it can not be supported by electron degeneracy pressure. This collapse is then halted by a strong shock wave which leaves a proto neutron star as the inner core. This shock stalls slightly above the radius of the proto neutron star but is revived by the large number of neutrinos before the outer envelope is violently ejected. Although observations have been made of CCSN, the theoretical understanding of this explosion mechanism is still an open problem. The core collapse supernova explosion mechanism is fundamentally 3 dimensional, but running three dimensional simulations is computationally expensive. 1 dimensional simulations are easier to run but they do not explode as they are missing turbulence. In this project, we model turbulence in one dimensional simulations with diffusion. In the simulation, the hydrodynamic equations were solved using self similarity then diffusion was added to model the effect of turbulence in one dimension. The diffusion coefficient, with units of length times speed, is the length of the eddies times the thermal velocity. Newtonian point gravity of the proto-neutron star was then added to the model, and self similarity was maintained by changing the slope of the density profile to R^{-2}, where R is the distance to the proto-neutron star.

The shock radius was tracked from the hydrodynamic profiles of the simulation. The shock follows the trajectory given by equation 1 where R is the shock radius. In the case with uniform density, $\omega = 0$ and in the case with point gravity, $\omega = 2$.

$$R \propto t^{2/(5-\omega)} \tag{1}$$

The simulation was run with a range of diffusion strengths. The trajectories were then plotted and fit to the corresponding models to determine the trajectory prefactors, as shown in Fig. 1. The result was that increasing the diffusion strength increases the trajectory prefactor. This means that diffusion increases the speed of the shock wave, making it easier to explode. This is because diffusion brings more mass in closer to the centre before the shock front.

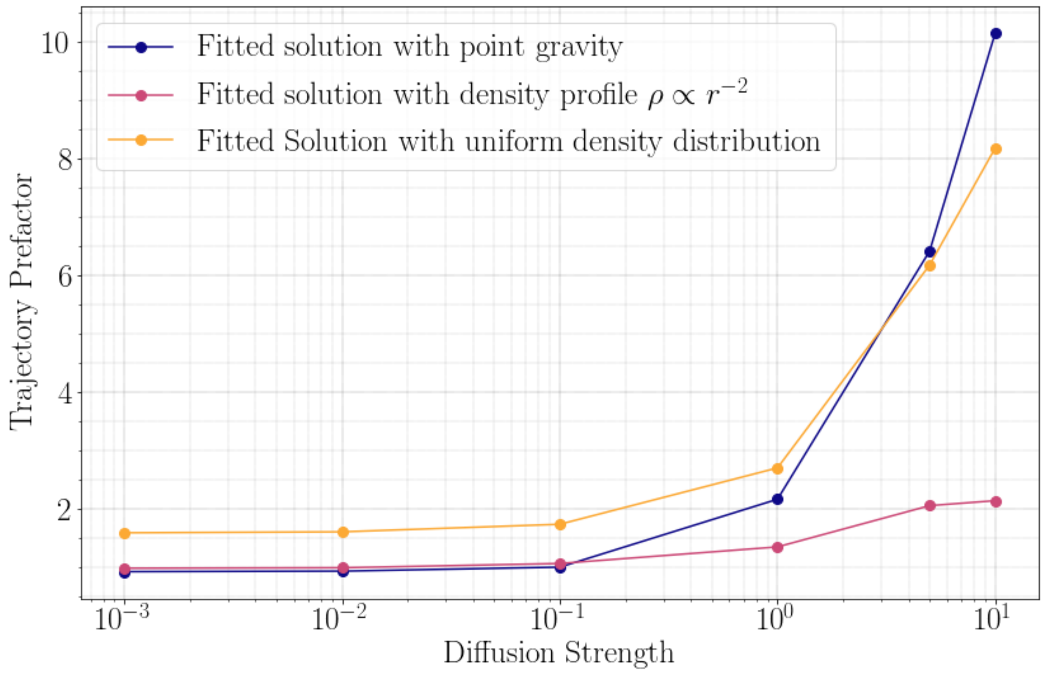

Figure 1: The trajectory prefactors of the trajectories with varied diffusion strengths. The pink and blue lines are the trajectory prefactors fit to the model given by equation 1 with $\omega = 2$. The orange line is the trajectory prefactors, fit to the model given by equation 1 with $\omega = 0$. The x axis in this plot is the values of the diffusion coefficient plotted with a log scale. For all simulations, the trajectory prefactor increases with the diffusion strength, indicating that diffusion increases the speed of the shock wave.

This model only looked at how diffusion affected the shock trajectories. The next step in this project would be to find the energy threshold for a successful explosion as a function of the diffusion coefficient in the case with point gravity. Below a certain energy, the gravity will be too strong, and collapse will ensue. Above a certain energy threshold the explosion will occur. It is predicted that with increased diffusion strength, this energy threshold will be lower. This research shows how diffusion, and thus turbulence, plays a key role in core collapse supernova explosions. Diffusion makes it easier to explode the star, allowing successful one dimensional explosions. By modelling turbulence in one dimension large parameter simulations can now be done in one dimensional, less computationally expensive simulations with successful explosions. This brings us one step closer to understanding the core collapse supernova explosion mechanism.