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Supplying angular momentum to the jittering jets explosion mechanism using convection in inner star layers

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Abstract. The jittering jets explosion mechanism of core collapse supernovae proposes that stochastic convective motion, amplified by instabilities, results in intermittent accretion disk that launches jittering jets that explode the star. We conduct one-dimensional simulations of a wide range of stellar masses and show that the convective motion in the pre-collapse stellar core, when scaled to corresponding three-dimensional simulations, supply sufficient angular momentum fluctuation to form the intermittent accretion disk the launches the jittering jets. The resulting neutron star masses are consistent with observations.

Keywords. supernovae: general

1. Introduction

In the jittering jets explosion mechanism of core collapse supernovae (CCSNe), perturbations in the pre-collapsing core serve as the source of stochastic angular momentum fluctuations (Soker 2019) that are then further amplified by instabilities. The main relevant instability is the spiral standing accretion shock instability (spiral SASI). According to the jittering jets explosion mechanism, the amplified perturbations lead to the formation of intermittent accretion disks (or belts, Schreier & Soker 2016), which in turn launch the jittering jets (e.g., Papish & Soker 2011, Gilkis & Soker 2014). Supplying large enough perturbation seeds to the spiral SASI such that the final angular momentum fluctuations form the intermittent accretion disks is the key challenge of the jittering jets explosion mechanism.

In (Shishkin & Soker 2021) we followed the evolution of stars to core collapse velocities of $v_{\rm fall} > 1000$ km s^{-1}. We argued that the convective specific angular momentum fluctuations in the core are sufficiently large seed-perturbations to SASI for the formation of intermittent accretion disks around the newly born neutron star (NS). In (Shishkin & Soker 2022) we connect the properties of the pre-collapse core with the expected final remnant mass in the frame of the jittering jets explosion mechanism.

2. Results

We simulated stellar evolution up to core-collapse using MESA $r10398$. In Figure 1 we show a $M_{\rm ZAMS} = 15 M_\odot$ model and the appearance of a vigorous inner convective zone at the edge of the iron core at the onset of collapse, with a convective velocity of $v_{conv} \sim 350$ km s^{-1}. Defining the minimal specific angular momentum fluctuations to explode the star as $j_{\rm jje}$ and the average value of specific angular momentum over a shell of at least $0.1 M_\odot$ as $\bar{j}_{\rm conv,0.1}$, we extract the inner most convective zone to satisfy $M_{\rm rem,B} = m(\bar{j}_{\rm conv,0.1} > j_{\rm jje})$ which is our condition to create an accretion disk/belt. In

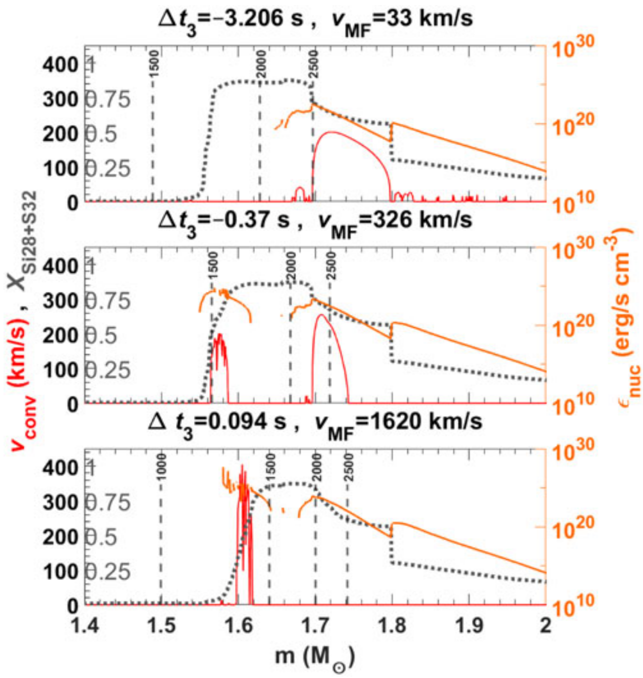

Figure 1. Evolution of the mass layer $m = 1.4 - 2M_\odot$ of a stellar model with $M_{\rm ZAMS} = 15M_\odot$ at three times from early to late core collapse. The time Δt_3 is measured relative to the time when the maximum infall velocity is $v_{\rm MF} = 1000$ km s^{-1}. We present the convective velocity (red solid line; scale on the left outside), the relative mass fraction of the ^{28}Si and ^{32}S combined (dotted gray line; scale on the left inside), and the nuclear power in erg s^{-1}cm^{-3} (solid orange line; scaled on the right). Vertical dashed lines indicate 4 radii as we mark in km. The $r = 1000$km line appears only in the last panel. Note the disappearance of the outer convective zone where oxygen burns and the appearance of a vigorous convective zone at the inner layer where silicon burns. Figure 1 from (Shishkin & Soker 2021).

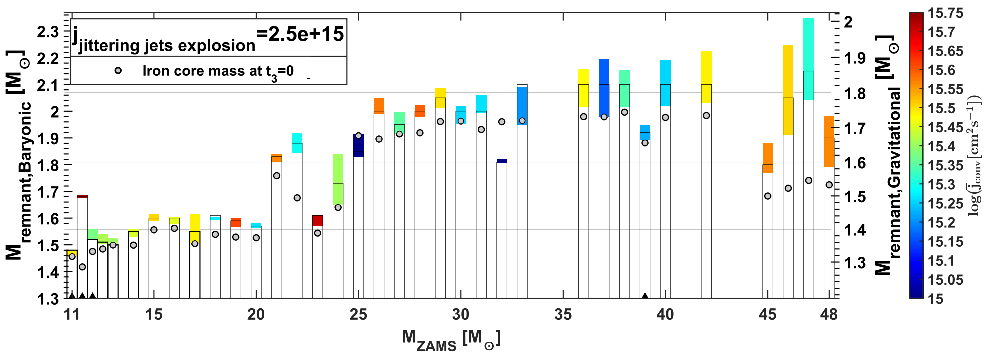

Figure 2. The expected remnant masses in the frame of the jittering jets explosion mechanism for a minimal specific angular momentum fluctuations to cause explosion value of $j_{\rm jje} = 2.5 \times 10^{15}{\rm cm^2 s^{-1}}$. The final remnant mass given by the height of the each column. The colored region depicts the $\bar{j}_{\rm conv}$ of the inner most convective zone that obeys our conditions to seed explosion. Figure 1 from (Shishkin & Soker 2022).

Figure 2 we display the expected remnant masses and the respective convective regions with sufficient angular momentum fluctuations to explode the star according to the jittering jets explosion mechanism, for many masses in the range of $M_{\rm ZAMS} = 11 - 48M_\odot$.

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3. Conclusion

We find vigorous convective regions at core collapse to have sufficient angular momentum fluctuations to explode the star according to the jittering jets explosion mechanism.

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