Type II-L and II-P supernovae from pulsating red-supergiants

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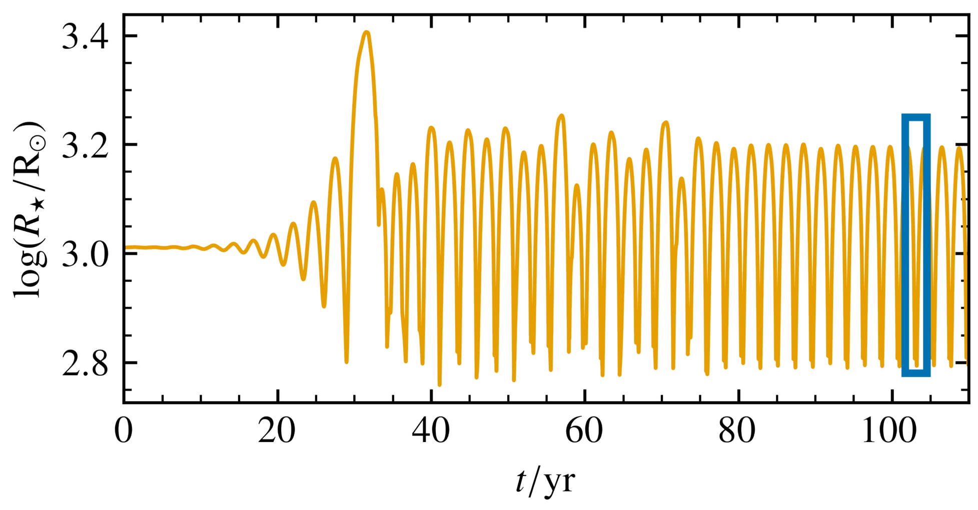
Motivation

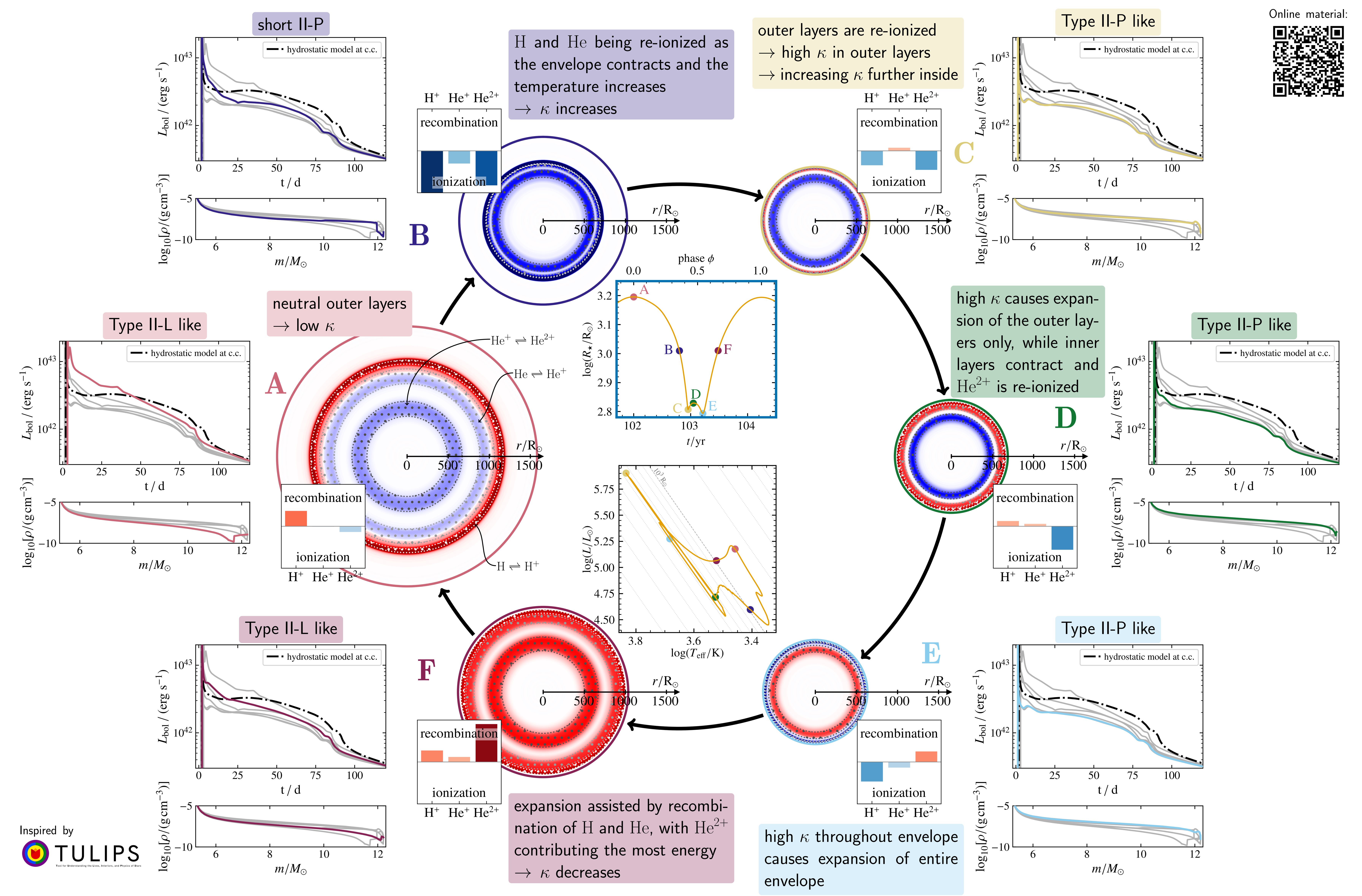
The origin of the different sub-types of hydrogen-rich (Type II) supernovae and their connection to stellar and binary physics remains uncertain. Type II-L supernovae are often believed to originate from stars that have lost parts of their hydrogen-rich envelopes through binary mass transfer or strong mass loss. However, such models tend to have difficulties reproducing all features of observed II-L light curves, in particular the early emission. Type II-P supernovae have been observed to originate from red supergiants (RSGs).
We propose that the observed diversity of type II supernovae can be explained by considering the naturally-induced pulsations of red supergiants towards the end of their evolution.

Growth of pulsations



Growth of radial pulsations in the envelope of a $12\,M_\odot$ RSG at core carbon depletion, induced by the κ-mechanism. After about $80\,\mathrm{yr}$, the star settles into steady and periodic pulsations. The blue box highlights one pulsation cycle and is shown in more detail below.

κ-mechanism driving pulsations of RSG and influencing SN light curves



Methods

We use the 1D stellar evolution code MESA to evolve a $15\,M_\odot$ star from the zero-age main-sequence to core carbon depletion, when it turned a RSG of about $12\,M_\odot$ and has a radius of about $1000\,R_\odot$. Then, we loosen the assumption of hydrostatic equilibrium for the stellar models and let the star evolve dynamically. Radial pulsations are naturally and self-consistently produced in our models through the κ-mechanism.
Once the RSG settles into steady and periodic pulsations of its envelope, we simulate the supernova explosion of the star at different phases of the pulsation cycle. The explosions are calculated using the SuperNova Explosion Code SNEC. For all light curves, we assume a fixed explosion energy of $1\,\mathrm{B}$, a nickel mass of $0.05\,M_\odot$ (nickel uniformly mixed until $3\,M_\odot$) and the formation of a compact object of $1.4\,M_\odot$. We then compare the resulting supernova light curves at the different phases of the pulsation cycle.

Results and outlook

We find that the envelope of the RSG starts to pulsate radially. The pulsations are driven by the κ-mechanism and are self-consistently excited in our models. The opacity κ is low in the expanded phase, because of the neutral outer layers. This lowers the support from radiation pressure and the envelope contracts. Then, the temperature in the envelope increases and causes re-ionization, which in turn increases κ. Radiation pressure builds up and the envelope starts to expand. During the expansion, the envelope cools down, the outer layers recombine and assist the expansion, while κ decreases. Then, everything repeats...
The resulting supernova light curves at different phases of the pulsation cycle show large variations. We find Type II-L like light curves when the star explodes during the expanded phase. In the contracted phase, the light curves resemble Type II-P supernovae. In between, we find light curves with a short plateau phase.

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