Radial pulsation instability in massive RSGs during carbon burning and implications to H-rich SNe

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Abstract

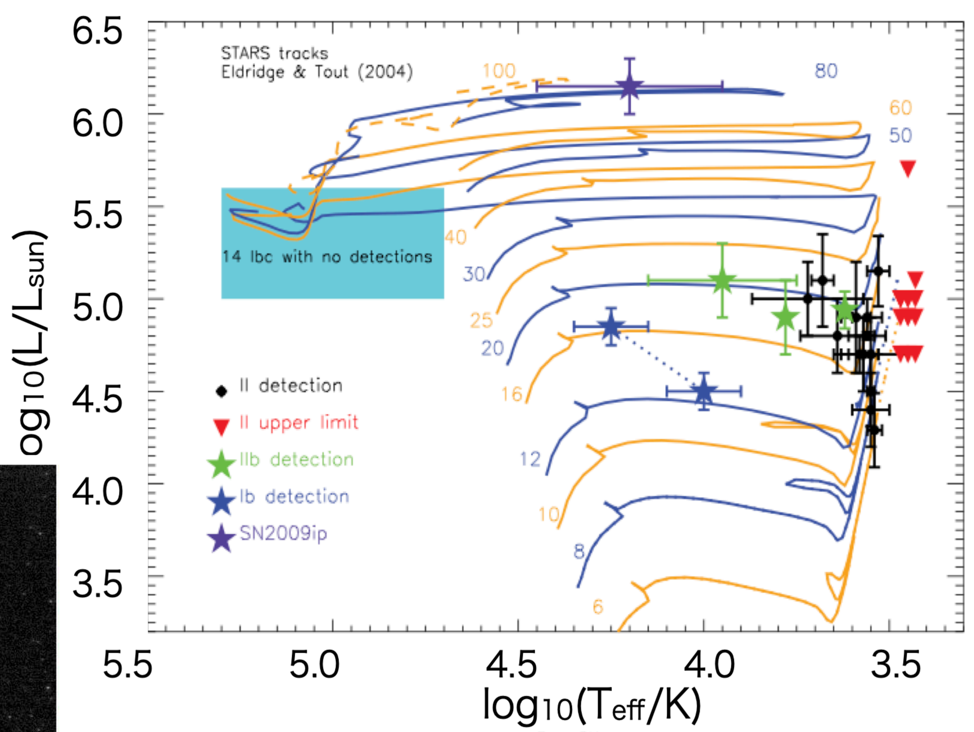
Performing a series of hydrodynamic stellar evolutionary simulations with MESA (Module for Experiments in Stellar Astrophysics), we investigate radial pulsations of massive red supergiants (RSGs) with the initial mass range of M_{ini}=13-18M_{sun}. We examine strong radial pulsations developing in the hydrogen-rich envelope during carbon burning. For higher-mass models, pulsations eventually grow to supersonic with surface velocities comparable to or faster than the escape velocity of the star. On the other hand, lower-mass models exhibit limit cycles with slower surface velocities. While the latter group ends up as a familiar transient population of exploding RSGs, i.e., type IIP supernovae (SNe), the former group may expel a part of their envelopes and explode as transients showing strong interaction features with hydrogen-rich circum-stellar materials, type IIn SNe.

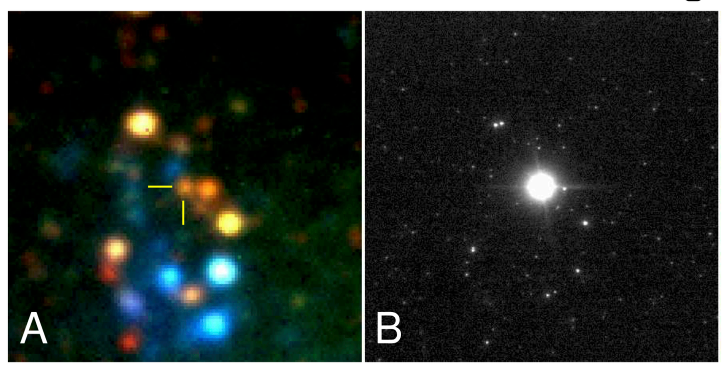
1.Introduction

Massive stars end their lives as **core-collapse supernovae (CCSNe)**. However, there is still a lot of debates on the relation between the initial mass and SN types, i.e., what kind of SNe are produced by massive stars in which initial mass range? Massive stars from M_{ini} ~10M_{sun} to 35-30M_{sun} are expected to evolve into **red supergiants (RSGs)**. and then explode as **type IIP SNe**. On the other hadnd, the direct progenitor detections of type IIP SNe imply an upper luminosity limit around $L/L_{sun}<10^{5.1}$. The correponding initial mass of 16-20M_{sun} disagrees with the initial mass range of RSGs (**RSG problem**; e.g, Smartt+2009).

RSG pulsations and associatrd mass-loss in late evlutionary stages are a promising way to make transition of an RSG into stripped stars. We examine the pulsation properties of RSGs.

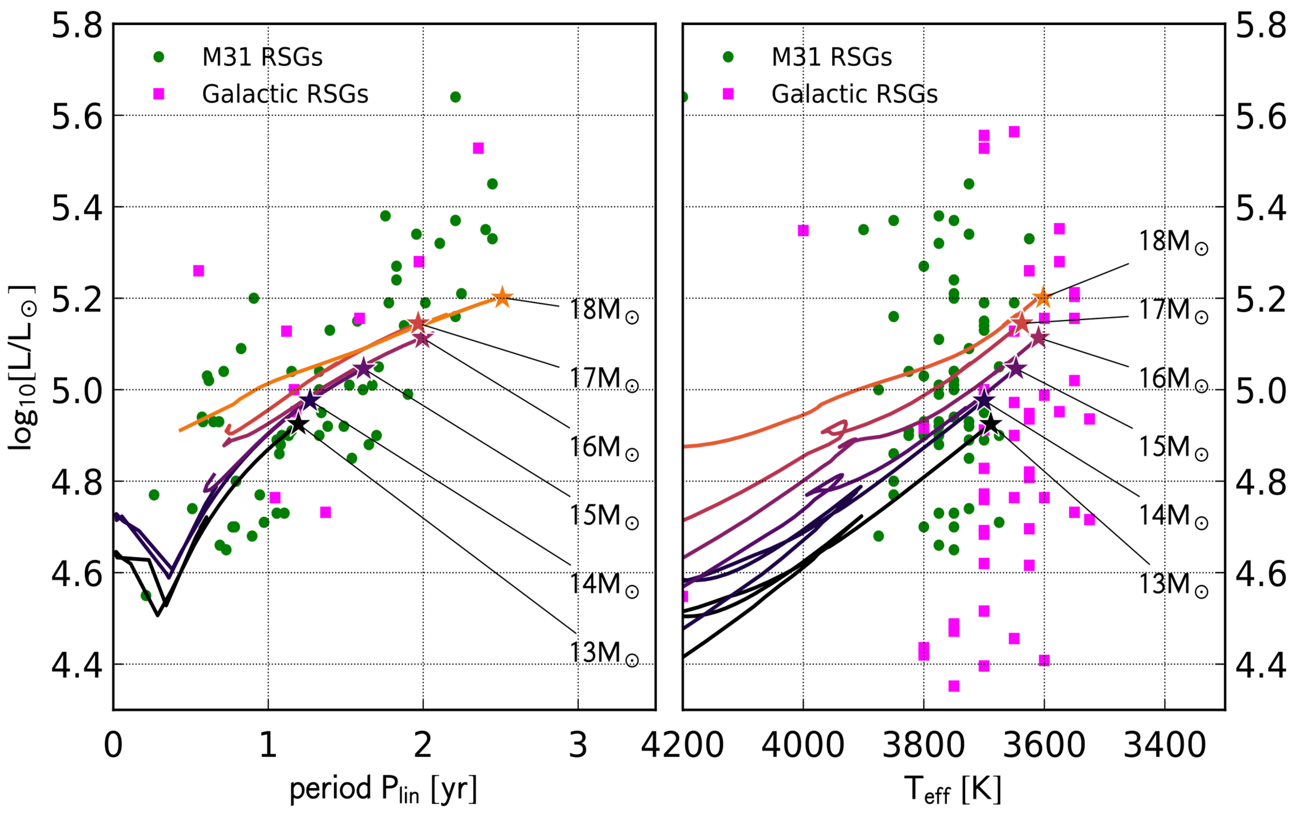
Smartt(2015)





2.Stellar evolutionary simulations

We first produce base models with M_{ini}=13-18M_{sun}. The computaions are carried out by using Module for Experiments in Stellar Astrophysics (MESA; Paxton+2011,…). The evolutionary tracks of these models in their RSG stages reproduce the regions occupied by Milky Way and M31 RSGs in HR diagram (right panel) and the observed period-luminosity relations (left panel).

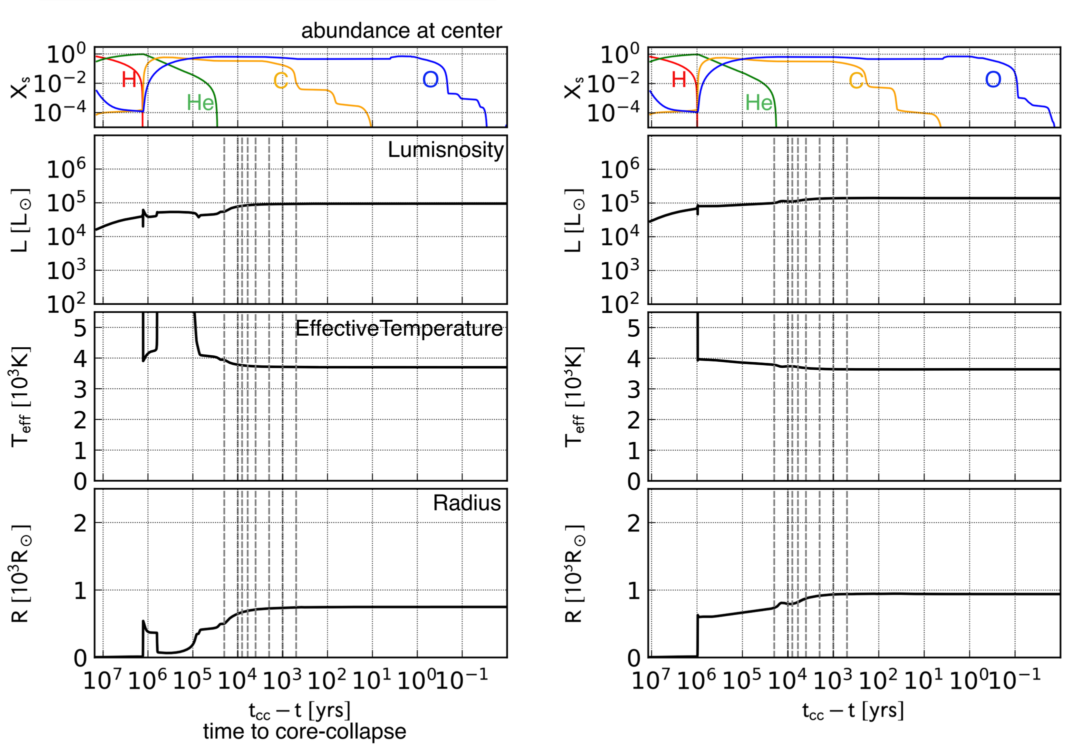


The evolution of the 14M_{sun} and 17M_{sun} models are presented below. They follow a standard evolutionary history of massive stars; core H depletion, envelope expansion, core He depletion, advanced burning stages, and so on. We pick up 8 epochs covering from core He depletion to C depeletion in order to examine the pulsation properties of the models.

t_{cc}-t ~ 2x10^4[yr] : **epoch 1**
1x10^4[yr] : **epoch 2**
8x10^3[yr] : **epoch 3**
6x10^3[yr] : **epoch 4**
4x10^3[yr] : **epoch 5**
2x10^3[yr] : **epoch 6**
1x10^3[yr] : **epoch 7**
5x10^2[yr] : **epoch 8**

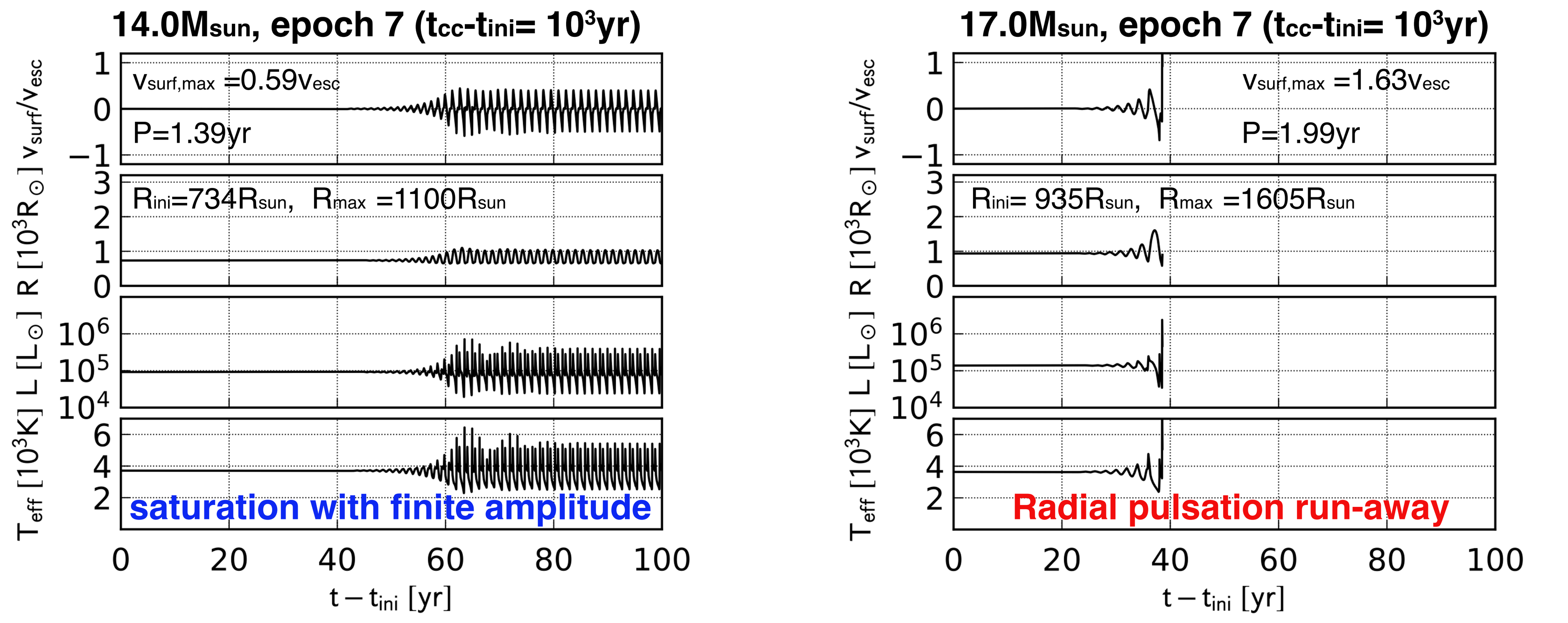
We restart simulations from these epochs with much smaller timestep (Δt_{max}=5x10^{-4}yr)

14.0M_{sun} model: **17.0M_{sun} model:**

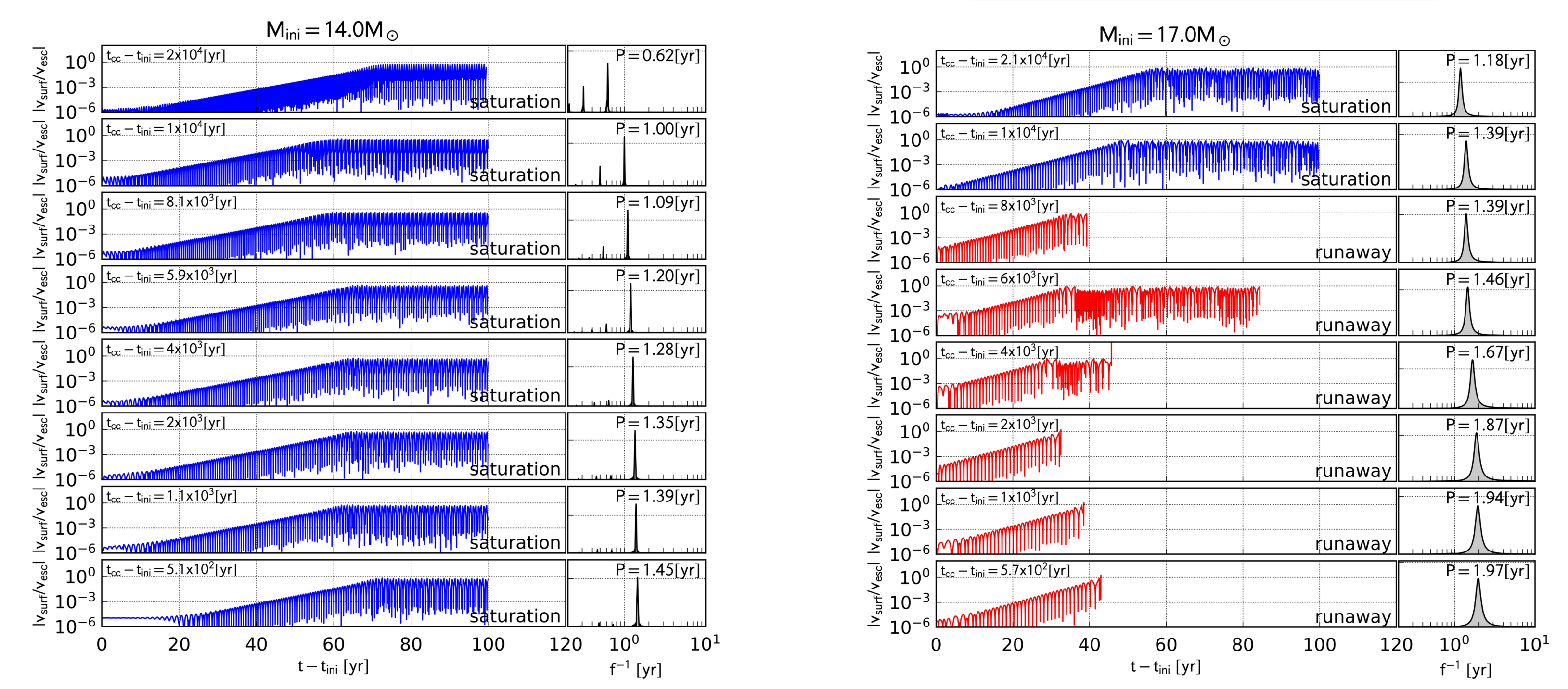


3.Pulsation properties

In general, massive RSGs are unstable to radial pulsations. Therefore, with sufficiently short timesteps, the radial pulsation grows exponentially with time. The non-linear properteis of RSG pulations are, however, different for lower and higher mass models. While lower mass models show limit cycles with $|v_{surf}|<v_{esc}$ in the non-linear stage, the radial pulsation leads to **"run-away"** with $|v_{surf}|>v_{esc}$ in higher mass models



14.0M_{sun} models: **17.0M_{sun} models:**



4.Discussion

The pulsation runaway more likely happens for more massive RSGs in later evolutionary stages, which may imply eruptive mass-loss episodes in their last moments before the core-collapse. Indeed, the velocity profile (bottom right) exhibits ~0.01M_{sun} layers at velocities exceeding the escape veocity $v>v_{esc}$.

The HR diagram below shows the evolutionary tracks of 13-18M_{sun} models explored in this study. Models with pulsation runaway(■) and with saturation with finite amplitudes(●) are separated at L/L_{sun} ~10^5. This may explain the RSG problem.