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Evolution of massive stars

Mass-loss and red supergiants properties

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Abstract. In this work we use the stellar evolution code MESA to investigate whether the mass loss rates adopted in massive stars' evolution models are excessively high or not. To do so, we create models of massive stars with various initial masses and evolve them up to the red supergiant phase (if the model undergoes that phase). Then, we compare their properties with inferred properties of observed red supergiant stars.

Resumo. Neste trabalho, usamos o código de evolução estelar MESA para investigar se as taxas de perda de massa, comumente utilizadas em modelos de evolução de estrelas massivas, estariam ou não muito elevadas. Para isso, criamos modelos evolutivos com diferentes massas até a fase de supergigante vermelha (caso o modelo evolua para tal). Em seguida, comparamos parâmetros como massa e temperatura efetiva dos nossos modelos com de estrelas supergigantes observadas.

Keywords. Stars: evolution — mass-loss — supergiants

1. Introduction

Massive Stars are extremely luminous and hot objects. Because of that, they present powerful stellar winds which give momentum, energy and enrich the interstellar medium, thus having a strong impact on the intragalactic medium. Beyond that, they are well-known progenitors of stellar remnants, such as supernovae, neutron stars and black holes. Therefore, the understanding of several components of the Universe and its evolution since the first stars were born hinge upon our knowledge of the properties of the high-mass stars and how they evolve.

Our goal is to use MESA[1] as a tool to study the evolution of massive stars. To do so, (i) on the beginning of the project we have learned the basics of MESA by performing comparisons between it and other evolution codes (GENEC and STERN) and exploring the outcome results. Once this part has been finished, (ii) we applied MESA to investigate mass-loss rates commonly used on stellar evolution models by comparing our model's masses with inferred masses of red supergiants (RSGs) — our sample consists of 70 stars from Levesque et al. (2005).

2. Learning MESA as tool

MESA is a 1D stellar evolution code. We have chosen MESA because it is widely used on professional research, free, up-to-date, open source and has a very active community of users and developers.

In order to explore MESA outputs and learn it as a tool for research, following Keszthelhyi et al. (2016), we compared evolutionary tracks from MESA with results from GENEC (Ekstroem et al. 2012), without rotation, and with those from STERN (Brott et al. 2011), including rotation on the comparison this time.

As result, we obtained a good agreement between the evolutionary tracks from MESA and the other codes. However, the differences between MESA and STERN were greater than the other comparison. The main reason is the inclusion of rotation, which makes the numerical modeling more difficult and sensible to computational parameters (e.g. spatial resolution and timestep control); these are issues one needs to careful analyze when modeling stars.

[1] Modules for Experiments in Stellar Astrophysics, Paxton et al. (2015) and `http://mesa.sourceforge.net/`

Table 1. Models' initial conditions and physical parameters

<table>
<tr><th>M_{ZAMS}</th><th>Initial Rotation</th><th>Y</th><th>Z</th><th>α_{OV}[a]</th><th>α_{MLT}[b]</th></tr>
<tr><td>12 $M_\odot$</td><td>262 km/s</td><td rowspan="7">0.266</td><td rowspan="7">0.014</td><td rowspan="7">0.1</td><td rowspan="5">1.6</td></tr>
<tr><td>15 $M_\odot$</td><td>271 km/s</td></tr>
<tr><td>20 $M_\odot$</td><td>274 km/s</td></tr>
<tr><td>25 $M_\odot$</td><td>295 km/s</td></tr>
<tr><td>32 $M_\odot$</td><td>306 km/s</td></tr>
<tr><td>40 $M_\odot$</td><td>314 km/s</td><td rowspan="2">1.0</td></tr>
<tr><td>60 $M_\odot$</td><td>346 km/s</td></tr>
</table>

[a] Overshooting parameter.
The Schwarzchild instability criterion is used
[b] MLT parameter

3. Models input physics

We generated seven evolutionary tracks, covering the mass range at Zero-Age Main Sequence (ZAMS) from $12M_\odot$ to $60M_\odot$, which correspond to most of the massive stars initial masses. The physical ingredients, the mass-loss recipes and the definition of the RSG phase adopted in our models are based on the work of Meynet et al. (2015), which study the impacts of "boosting" the mass-loss rates during the RSG phase on pre-supernova models properties. The physical parameters are listed in table 1 and the mass-loss recipes in Figure 1.

4. Results

As main result we found that our tracks do not explain about 37 % of the more massive RSGs in Mass and T_{eff}. We also found that the $25M_\odot$ $32M_\odot$ and $40M_\odot$ models become RSGs slightly

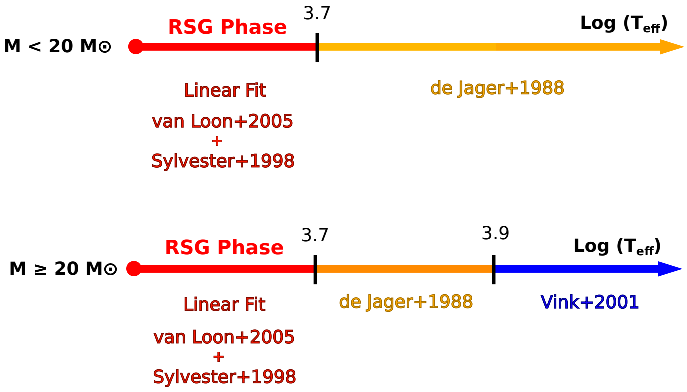

Figure 1. Mass-loss recipes of de Jager et al. (1988), Vink et al. (2001) and van Loon et al. (2005) combined with Sylvester et al. (1998), as used by Meynet et al. (2015).

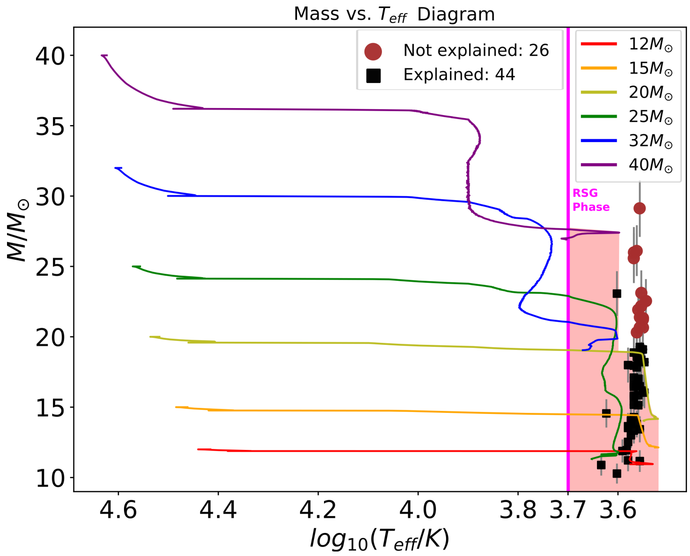

Figure 2. Evolutionary tracks along the Mass vs. T_{eff} plane. The fuchsia line ($T_{eff} = 10^{3.7}$) shows the RSG region border. Observed stars within the light pink region are explained by the models (black squares), and the opposite are the brown circles.

hotter than the sample, and the $60M_\odot$ model did not become RSG, as expected — see Figure 2.

As RSG, the $40M_\odot$ models agrees in mass with the heavier stars from the sample, but stays at this phase only for $\sim$ 6000 years — see Figure 4. Beyond that, according to most stellar formation models $12M_\odot$ stars are much rarer than less massive ones. Therefore, a possible interpretation is that it's very unlikely the heavier RSGs are due to the evolution of a single star from this kind.

Given these results, we conclude the mass-loss rates during the evolution might be excessively high. This is in resonance with the picture present by the most recent literature about mass-loss in high-mass stars.

5. Conclusions

During this project, due to MESA openness and active discussion forums, this stellar evolution code presented itself as a great tool to study and research the evolution of massive stars.

When investigating the chosen astrophysical problem, we were able to learn several aspects, the philosophy and deal with some difficulties of numerically modeling massive stars. The results obtained seems to indicate excessively high mass-loss rates during the models' evolution and RSG phase.

As possible future perspectives, some results might be deeper investigated, such as the fact the more massive model, which become RSGs, are hotter than the observed stars. Also, an interesting continuity of this work, is investigate the evolution of models with reduced mass-loss rates and include more recent observed red supergiants (e.g. with properties derived through interferometry).

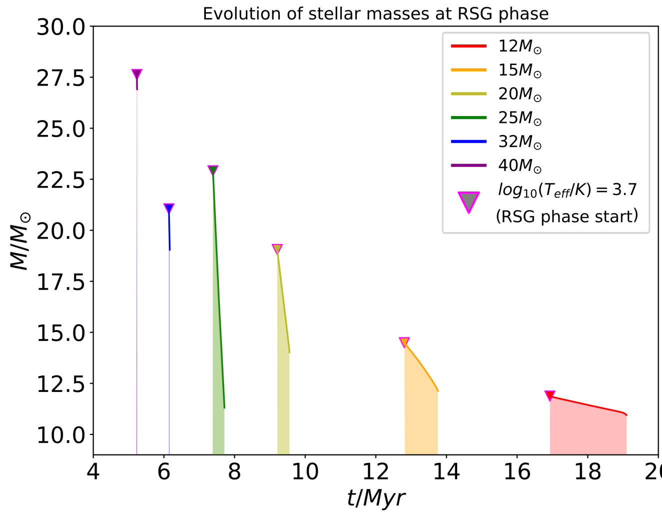

Figure 3. Evolution of the models' masses after they become RSG. The width of color shaded region below the curves indicates the amount of time spent from the start of RSG phase to the stopping condition (central temperature above 10^9K).

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