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Exploring the properties of dust grains in supergiants stars envelopes

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Abstract. Red supergiant stars (RSGs) are massive stars that have the largest physical size of any star, with a radius between 100 and 2000 times the solar radius. Due to their colossal size, they have very cold surface temperatures, between 3500 K and 4500 K, and low surface gravity. These characteristics lead to the formation of a circumstellar envelope of molecules and dust grains around the star. The spectral energy distribution (SED) carries information about how much ultraviolet and visible radiation from the star is reprocessed into the infrared domain. Our goal is to understand how the SED of the red supergiant WOH G64 can be used to infer properties of the surrounding envelope, in particular its dust (composition, grain size distribution, etc.). The methodology combines the radiative transfer code HDUST, with a Bayesian inference based on Markov Chain Monte Carlo (MCMC) techniques. The Bayesian inference allows for the many parameters involved in the modeling to be put in a seamless perspective, where the relative role of each one on shaping the SED, as well their cross-correlations, is apparent from the posterior probabilities provided by the MCMC method. Preliminary results indicate that the dust layer surrounding WOH G64 has a external radius of $R_{ext} \geq 10^4 R_\star$ composed of grains with small sizes ($0.001\,\mu m \leq a \leq 0.01\,\mu m$). Furthermore, we found that the envelope is optically thick, with $\tau_V \approx 11.82$

Resumo. Estrelas supergigantes vermelhas (RSGs) são estrelas massivas que têm o maior tamanho físico de qualquer estrela, com um raio entre 100 e 2000 vezes o solar raio. Devido ao seu tamanho colossal, possuem temperaturas superficiais muito frias, entre 3500 K e 4500 K, e baixa gravidade superficial. Essas características levam à formação de um envelope circunstelar de moléculas e grãos de poeira ao redor da estrela. A distribuição de energia espectral (SED) carrega informações sobre quanta radiação ultravioleta e visível da estrela é reprocessada no domínio do infravermelho. Nosso objetivo é entender como o SED da supergigante vermelha WOH G64 pode ser usado para inferir propriedades do envelope circundante, em particular sua poeira (composição, distribuição de tamanho de grão, etc.). A metodologia combina o código de transferência radiativa HDUST, com uma inferência Bayesiana baseada em técnicas de Markov Chain Monte Carlo (MCMC). A inferência bayesiana permite que os vários parâmetros envolvidos na modelagem sejam colocados em uma perspectiva contínua, onde o papel relativo de cada um na formação do SED, bem como suas correlações cruzadas, é aparente a partir das probabilidades posteriores fornecidas pelo método MCMC . Resultados preliminares indicam que a camada de poeira ao redor de WOH G64 possui um raio externo de $R_{ext} \geq 10^4 R_\star$ composta por grãos com tamanhos pequenos ($0.001\,\mu m \leq a \leq 0.01\,\mu m$). Além disso, descobrimos que o envelope é opticamente espesso, com $\tau_V \approx 11.82$.

Keywords. Radiative transfer – supergiants – circumstellar matter

1. Introduction

A special type of supergiant star are red supergiant stars (RSGs). They have the largest physical size of all stars, with radii between 100 and 2000 $R_\odot$. Due to their colossal size, they have very cold temperatures, between 3500 K and 4500 K and high luminosities, from 100,000 to 500,000 $L_\odot$, in addition to extensive atmospheres that present spectra dominated by molecular absorption lines (Levesque 2009).

In the RSG phase, the surface of the star a small surface gravity, due to its large radius, and thus small perturbations can result in large mass losses. As a consequence of this phenomenon, we observe the formation of dust grains that condense in the ejected material as it cools away from the star.

The dust grains absorb radiation from the star at short wavelengths (ultraviolet and visible) and re-emit that energy in the infrared region of the spectrum. This process is known as reprocessing, and it causes the characteristic infrared excess observed in RSGs, that alter the observed spectral energy distribution (SED).

In this project, our goal is to understand how the SED can be used to infer the envelope properties, in particular its dust (composition, grain size distribution, etc.). The object chosen was the red supergiant star WOH G64, which is located in the Large Magellanic Cloud. It has a radius of $1540 R_\odot$, making it one of the largest stars known (Levesque 2009).

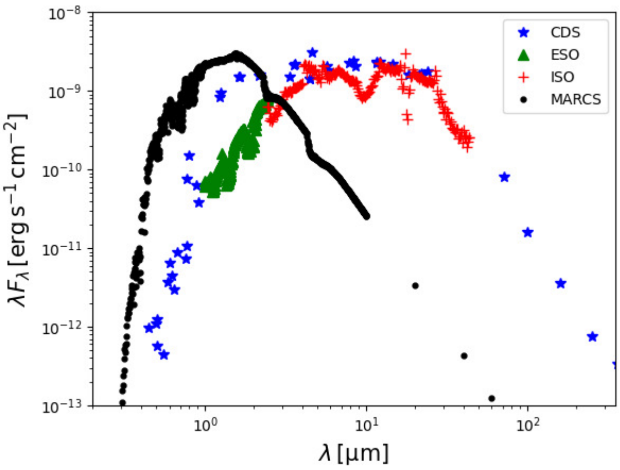

Figure 1. Observed SED of the star WOH G64. In red, data from *Infrared Space Observatory* (ISO), in blue, data from the CDS portal and in green, data from *European Southern Observatory*. This figure also shows a theoretical model for the star's atmosphere, computed using the MARCS code. By comparing the theoretical model and the observed SED, the effect of dust reprocessing becomes visible.

2. Methods

Our model consists of a central star with a given radius $R_\star$ and effective temperature, Teff, surrounded by a dust shell with an inner and outer radius R_{int} and R_{ext}, respectively. In Figure 1, we can see the effect of reprocessing on the WOH G64 star. To model this effect, and based on Carciofi (2004), we built a grid considering the grain temperature, the reprocessing optical depth (a measure of the amount of light absorbed), the grain size distribution, the density profile and dust envelope size as free parameters. The grain size distribution consists of a power law for spherical silicate grains (Mathis 1977). The slope of the grain, n , is define as

$$\rho = \rho_0 \left(\frac{R_\star}{r} \right)^n \tag{1}$$

where ρ_0 is the mass density at the inner radius of the dust shell.

The stellar parameters such as Teff = 3400 K and L≈ 280.000 $L_\odot$ were obtained from Levesque (2009). The SED models were generated by the HDUST code Carciofi (2004). The analysis of the results obtained was performed using the EMCEE Bayesian code Foreman-Mackey (2013).

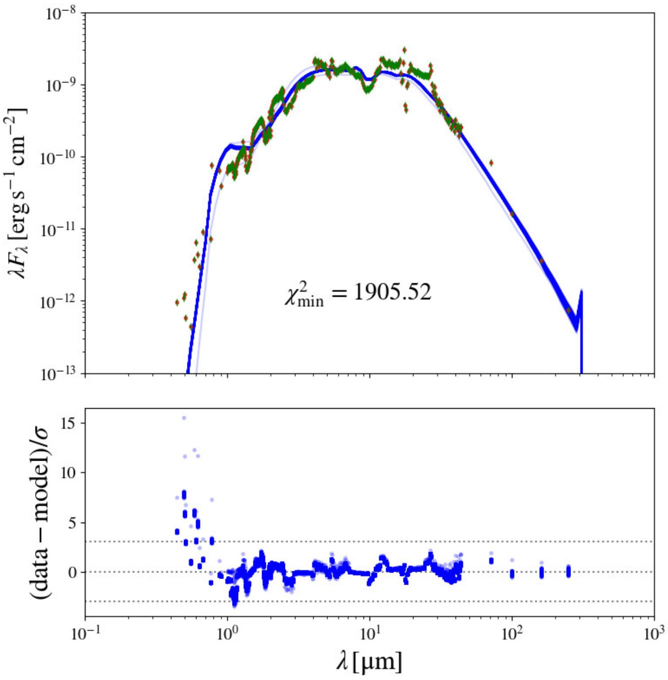

Figure 2. Observed SED from WOH G64 and in blue the best model obtained by EMCEE.

3. Results

The best-fit model is shown in Figure 2, and their associated probability density fucntions in Figure 3. We see that the models with small grains (0.001 μm ≤ a ≤ 0.01 μm) were able to reproduce the absorption band at 9.7m (Figure 2). The density profile obtained (n = 1.95) indicates that the envelope is formed by a wind that is likely expanding at a constant velocity. We also note that a good fit requires the existence of an extremely large dust envelope (3.2 pc). This value for the dust envelope radius tells us that we need very small and cool grains. The absorption band at 9.7 μm that we observe in the SED of the star (Figure 1) is an indication of these small grains, mainly composed of silicate, which satisfies the methodology used. Although some probability distributions obtained for certain parameters reached the grid limit (Figure 3), this last result shows us that with some adjustments in the parameters, the SED of this star should be well reproduced by our models.

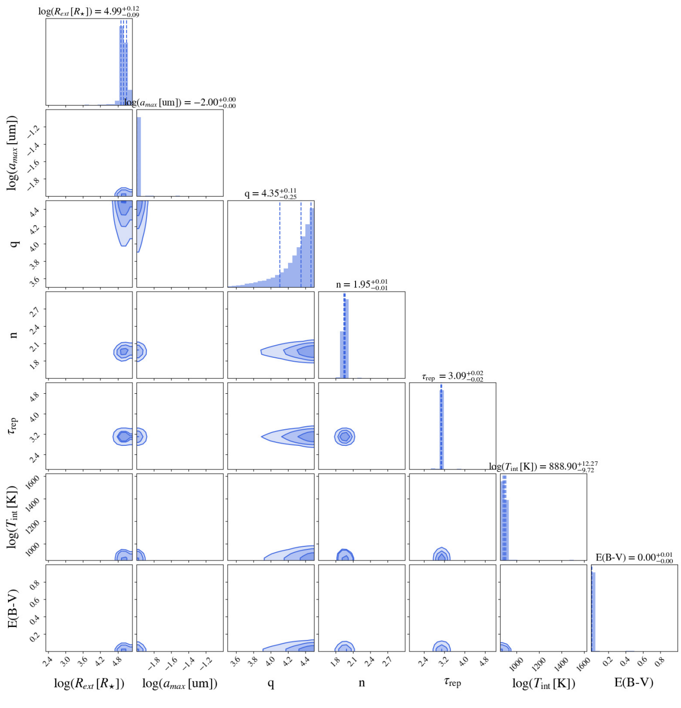

Figure 3. Best probability distributions obtained for the parameters.

4. Conclusions

We conclude that the methodology used in this project proved to be completely effective to represent the WOH G64 SED. With some modifications in the parameters of the model grid, expanding the parameter space for the parameters that reached the grid limit, it will be possible to represent the entire SED and infer different properties about the envelope of this star.

The future goal of this project is to repeat this technique in a number of RSGs in order to determine common characteristics.

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