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Résumé

Les supergéantes rouges (RSG) sont des étoiles massives ($> 10 M_{\odot}$) qui, grâce à leur haute luminosité infrarouge, sont des indicateurs des distances intergalactiques et des sondes de la structure galactique. La compréhension de leurs propriétés est cruciale et elle touche à différents thèmes astrophysiques.

Les simulations numériques 3D d'hydrodynamique radiative (RHD), obtenues avec le code CO⁵BOLD (Freytag, Steffen, Ludwig et al.), aident à trouver la réponse aux principales questions concernant les RSGs.

J'ai conçu un code de transfert radiatif en 3D qui calcule des spectres et des cartes d'intensité à partir des simulations RHD. Grâce à cet outil, j'étudie en détail les principales caractéristiques des modèles RHD à différentes longueurs d'onde. J'examine ensuite l'impact de la convection sur les raies spectrales en terme d'asymétries et de décalages, et je prédis les variations de bissecteurs et du photocentre en vue de futures observations.

Par la suite, je cherche les vitesses caractéristiques de l'atmosphère des RSGs, et je constate que les simulations sont en accord avec les observations même si l'amplitude des vitesses est plus petite que celle observée.

Les structures convectives affectent les courbes de visibilité et les clôtures de phases, qui montrent clairement une nette déviation de la symétrie circulaire. Tout en les analysant, je cherche des contraintes pour les simulations RHD et je montre que l'interférométrie est le moyen observationnel privilégié pour caractériser la convection dans les RSGs. Le problème majeur des simulations RHD est le traitement gris des opacités. J'explore les effets du passage au non-gris sur les observables en utilisant un premier modèle de test non-gris.

Mots-clés: supergéantes rouges, modèles d'atmosphère, hydrodynamique radiative, spectroscopie, interférométrie

Abstract

Thanks to their high-peak infrared luminosity, red supergiant (RSG) stars are fundamental tracers of galactic structure, efficiently probing regions of high interstellar extinction. To understand their properties is crucial and impacts a broad segment of Astrophysics.

In this thesis, the answer to the principal questions about RSGs is addressed with three-dimensional radiation hydrodynamic (RHD) models. The computer code CO⁵BOLD, developed by Freytag, Steffen, Ludwig and collaborators, is used.

First, I have developed a three-dimensional radiative transfer code that computes spectra and intensity maps from RHD simulations. With this tool at hand, I characterize the granulation pattern of the RHD models at different wavelengths and I study the impact of the convection on spectral line in term of line shifts and asymmetries, prospecting line bisectors and photocenter variations for future observations.

Then, I measure the characteristic atmospheric velocities. From the comparison with the observations I find that the simulations are in agreement with the observations even if the velocity amplitudes are smaller than what is observed.

Furthermore, the convection-related surface structures show an evident departure from the circular symmetry on the visibility curves and closure phases. I seek constraints of the atmospheric movements analysing these observables and I show where and how the convection pattern can be detected and measured. I conclude that today interferometers are the best way for the characterization of the convection on RSG strars.

Finally, I highlight that the principal problem of RHD simulations is the grey treatment of opacities and I explore the effects on the observables using a first non-grey testing model.

Keywords: red supergiants, stellar atmospheres, radiation hydrodynamics, spectroscopy, interferometry