Boletim da Sociedade Astronômica Brasileira, **30**, no. 1, 113-114

The Be star α Col: a laboratory for the physics of circunstellar disks

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Abstract. Be stars have been the target of several multi-technique and multi-spectral modelling works in the past years, in the framework of the Viscous Decretion Disk model (VDD). Although those results are very satisfying, there is a clear need to make multi-technique modelling, which fits one observable at a time, more robust. In this work we show the first results for a simultaneous fitting of all disk and stellar observables to a grid of HDUST models, using a Monte Carlo Markov Chain method, for the stable Be star α Col.

Resumo. Estrelas Be foram alvo de diversos trabalhos de modelagem multi-técnicas e multi-espectrais nos últimos anos, dentro do contexto do modelo do Disco de Decréscimo Viscoso (VDD). Apesar de satisfatórios, há uma clara necessidade de tornar a modelage multi-tecnica, que foca em um observável por vez, mais robusta. Nesse trabalho apresentamos os primeiros resultados para um ajuste simultâneo de observáveis tanto estelar quanto do disco à uma grade de modelos HDUST, utilizando um método de Monte Carlo em Cadeias de Markov, para a estrela Be estável α Col.

Keywords. Stars: individual: α Col – Stars: emission-line, Be

1. Introduction

Be stars are fast rotating, main sequence B stars that present a Keplerian decretion disk that causes excess emission of neutral hydrogen, among other changes in the spectrum. The model that best describes the physics of Be disks is the Viscous Decretion Disk model (VDD). In the VDD model, some mechanism accelerates stellar material so that it leaves the star and enters orbit. From this point onwards, turbulent viscosity redistributes the material, building the Be disk (see Rivinius et al. 2013 for a recent review on Be stars and the VDD). In order to test the VDD, multi-technique and multi-spectral modelling of stable Be stars have been made in the past decade, all with positive results (e.g., ζ Tauri – Carciofi et al. 2009, 48 Lib – Silaj et al. 2016 and β CMi – Klement et al. 2015). These works model stellar and disk parameters separately for each type of observation. In this work, we take the test one step further, simultaneously fitting all observables to a grid of HDUST models, using a Monte Carlo Markov Chain method. We present here our results for the stable Be star α Col.

2. Methodology

Analysis of polarimetric data indicate that α Col's disk has been relatively stable for the past couple of decades, a feature quite rare in Be stars, but that greatly simplifies the modelling procedure. An extensive data collection was the first step in the process. Next, we calculated a grid of models using the HDUST radiative transfer code (see Carciofi & Bjorkman 2006 and Carciofi & Bjorkman 2008). The preliminary grid consisted of 324 models, and the newest expanded grid consists of 1296 models, varying the parameters according to table 1. The stellar parameters varied were the mass, the oblatness and the fraction of hydrogen present in the nucleus, which corresponds to the time of life over the Main Sequence; the disk parameters were the base number density n_0, the radial density exponent n and the size of the disk, R_d. With the grid in hands, the analysis itself could begin.

Table 1. Disk and stellar parameters used to create the grid.

Stellar parameters	Values
$M[M_\odot]$	4.4, 4.9, 5, 6
R_{eq}/R_{pole}	1.07,1.33,1.51
H fraction	0.3,0.5,0.6
Disk parameters	Values
log n_0 $[cm^{-3}]$	12, 12.5, 13
n	2.0, 2.5, 3.0
R_d $[R_{eq}]$	10, 20, 30, 40

3. Markov chain Monte Carlo method

Our ultimate goal is to infer all disk and stellar parameters by finding the model that best fits all types of observations, but this cannot be accomplished in a straightforward way right from the start. The most reasonable method is to analyse a single observable first and add others continuously until the end goal is reached. We therefore began by studying the behaviour of the calculated grid of models with our observational SED data, from 0.115 μm to 6.3 cm. The great difficulty lies in determining how well the models fit the observational data and from that analysis, infer the most likely and best fit Be star parameters. Nowadays, the most practical and intelligent way to obtain probability density functions and correlations between many parameters in a sample with large dimensions is to use Bayesian inference methods, such as the Markov chain Monte Carlo (MCMC). To this end, we use the Python implementation of an MCMC method, the `emcee` code (Foreman-Mackey et al. 2013). The return of the `emcee` code is a corner plot where the PDFs of each parameter is presented on the main diagonal, while the intersection between a column and a row parameter gives their respective correlation map.

4. Results

We present here the resulting corner plot for the fitting of a grid of HDUST models to our observational SED data in the UV re-

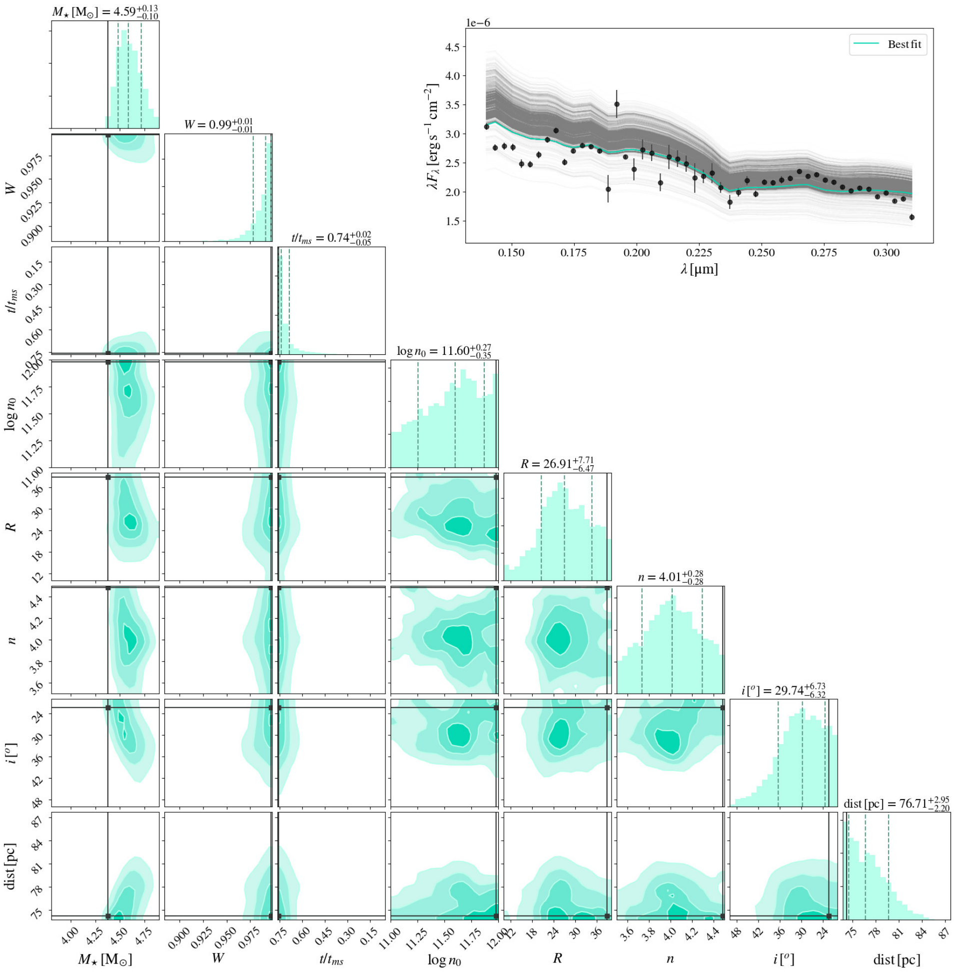

Figure 1. Corner plot for the UV part of the SED, from from 0.115 to 0.3 μm. The plot on the upper right is the observational `IUE` data (black dots) and a fraction of our models; the darker the line, the smaller the associated χ^2 of the fit to the data.

gion (from 0.115 to 0.3 μm), in Fig. 1. The sharpness of the PDFs are indicative of a good convergence of the results. Besides the parameters varied to build the grid, we also consider the inclination angle of the disk i and the distance of the Be star d in parsecs. In this case, since the grid is still under construction, we are probing a very small part of the SED, and most of the excess in the UV region comes from the central star, not the disk ((Vieira et al. 2015)). Therefore, the disk parameters n, n_0 and R are not as well defined as the stellar parameters, and neither is the disk inclination i. We can see in the PDF for t/t_{ms} that smaller values of H fraction in the nucleus need to be included in the grid, since the result forces the PDF very clearly towards the left. That is most likely forcing the distance parameter to smaller distances as well, to compensate the effect. It should be noted that result shown in Fig. 1 is not very well sampled yet, since the MCMC calculations take much longer once the number of steps and walkers are increased (see Foreman-Mackey et al. 2013 for more information on how these values impact results). More MCMC calculations and further grid expansion are already under way.

5. Final remarks

Multi-technique analysis of Be stars have been done in the past, always analysing each observable separately. Using Bayesian statistics, a grid of HDUST radiative transfer models, and taking advantage of years of observations by various missions, we intend to take the analysis further, by simultaneously probing both disk and stellar parameters using all observables for the stable Be star α Col. Inferring all parameters at once would be an even greater test for the VDD model and would positively cement it as the definitive model for describing the physics of a Be star disk. Preliminary results show the multi-technique analysis potential, being able to define well stellar parameters from just the UV region of the SED. Expansion of the grid to smaller values of H fraction is under way, as well as to the other regions of the SED and polarimetry. Better sampled MCMC calculations are also being worked on.

Acknowledgements. ACR acknowledges support from FAPESP grant 2017/08001-7.

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