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STUDYING THE PHYSICAL CONDITIONS IN BE STAR DISKS USING NON-LTE RADIATIVE TRANSFER CODES

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RESUMEN

Las estrellas Be Clasicas son rotadores rápidos, estrellas masivas que exhiben varias características observacionales distintas debido a la presencia de discos delgados de gas concentrados en el plano ecuatorial de la estrella. Para entender el mecanismo que gobierna el desarrollo de estos discos circunestelares, utilizamos códigos computacionales para crear modelos teóricos para estos objetos y su entorno y los comparamos con las observaciones de estrellas Be. El primer objetivo de este trabajo es la comparación de diferentes acercamientos usados en la creación de modelos teóricos de estrellas Be. Examinamos desarrollos independientes de códigos de equilibrio termodinámico no-local (N-ETL) diseñados para modelar ambientes circunestelares que resuelven simultáneamente los problemas de transporte radiativo, equilibrio térmico y equilibrio estadístico. Un análisis detallado de las diferencias y similitudes entre diferentes técnicas de transferencia radiativa puede proporcionar una valiosa comprensión acerca de los fenómenos físicos que gobiernan el desarrollo de los discos circunestelares de estrellas Be.

ABSTRACT

Classical Be stars are rapidly rotating, massive stars that exhibit several distinct observational characteristics due to the presence of thin disks of gas concentrated in the stars equatorial plane. In order to understand the mechanisms that govern the development of these circumstellar disks, we use computational codes to create theoretical models of these objects and their environments and we compare the predicted observables to observations of Be stars. The primary focus of this work is the comparison of different approaches used in the creation of theoretical Be star models. We examine independently developed non-local thermodynamic equilibrium (NLTE) codes designed to model circumstellar environments by simultaneously solving the problems of radiative transfer, thermal equilibrium and statistical equilibrium. A detailed analysis of the differences and similarities between different radiative transfer techniques may provide valuable insight into the physical processes which govern the development of Be star circumstellar disks.

Key Words: radiative transfer — stars: circumstellar matter — stars: emission-line, Be

1. GENERAL

Some important detectable characteristics of Be stars and their circumstellar disks include a prominent emission line spectrum, a partial polarization of radiated light, and a continuum excess in the infrared spectrum. These characteristics of Be stars are variable on timescales of days to decades due mainly to changing physical conditions in the circumstellar disk. While these interesting stars have been observed for some time, there remains significant uncertainty regarding the physical mechanisms involved in the evolution of these systems. In particular, the physical processes that govern the formation of the gaseous circumstellar disks are not well understood.

In order to develop a better understanding of Be stars and their circumstellar environments, we construct theoretical models of the star and its surrounding material. To accomplish this, we employ BEDISK, a non-LTE radiative transfer code. The principal features of this code are discussed in detail in Sigut & Jones (2007), with a basic overview of the code presented here. We begin by assuming that the circumstellar disk is axisymmetric about the rotation axis of the star, and symmetric about the disk's midplane. Furthermore, we assume that the radial density distribution of the disk falls off as a power law in the equatorial plane of the star, which we describe as:

$$\rho(R) = \rho_o(R/R_*)^{-n} , \tag{1}$$

where ρ_0 is the density of the circumstellar material at the stellar surface. Perpendicular to the plane of the disk, the circumstellar gas is in approximate vertical isothermal equilibrium. Using BEDISK, we are capable of constructing models with realistic chemi-

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cal compositions in the disk. The code incorporates 425 energy levels and over 1000 radiative and collisional transitions for the atoms and ions included in the disk model.

The code formally solves the radiative transfer equation from every part of the visible stellar surface to each disk location. For the calculated photoionizing radiation field at each location in the circumstellar disk, the computational code solves the equations of statistical equilibrium for the level populations of each atom and ion included in the computation. The heating and cooling rates are then computed and the temperature at each grid location is calculated by balancing the rates of energy gain and energy loss, thereby enforcing radiative equilibrium. Hence, BEDISK determines a self-consistent solution for the thermal structure of the circumstellar disk around a Be star.

We are currently comparing our computational technique to the radiative transfer code HDUST developed by Carciofi & Bjorkman (2006). This alternative to BEDISK for constructing theoretical Be disk models is a Monte Carlo simulation that executes a full spectral synthesis by emitting individual photons from the central star. While the two independently developed approaches employ contrasting techniques for solving the coupled problems of radiative transfer, statistical equilibrium and radiative equilibrium in the circumstellar region, in the end, both methods generate self-consistent solutions for the electron temperature and the gas density distribution throughout the disk.

The comparisons between the codes will highlight the importance of the different physical processes included in the construction of the theoretical models. We will examine the role of these mechanisms in the evolution of Be stellar systems. In addition, this study will enable us to evaluate the accuracy of the approximations used in either approach and to determine which code performs best for a particular scenario. Finally, these comparisons will also us to develop a set of benchmarks that can be used in modeling Be stars. In summary, this investigation should improve our understanding of the physical conditions in the gaseous regions surrounding hot massive stars and our knowledge of stellar evolution in rapidly rotating stars.

DISCUSSION

D. Baade: *Are your disk models truncated at some outer radius?* — We can truncate the disk models at some specific outer radius or we can run them out to very large distances from the star.

G. Meynet: *Such a code is a fantastic tool to give a good model of the disk at a given time. Are there attempts to look at its evolution as a function of time?* — Each model produced by BEDISK represents a static solution to the disk temperature stucture. However, it is possible to use construct models in series to simulate the evolution of the disk over time. Jones, Sigut, & Porter (2008) employed a hydrodynamical code in order to investigate the outflowing viscous disk model for Be stars. Future work involving hydrodynamics will study the long-term evolution of the Be star disks.

D. Gies: *Have you compared model disk sizes for Hα versus Brγ?* — Yes, the circumstellar disk is smaller in the infrared continuum for the models that we have considered to date.

O. Chesneau: *You have shown fits of your γ Cas model to various observables. This is an excellent internal consistency check. Do the parameters of the model vary significantly for each fit?* — Sigut & Jones (2007) examined the thermal structure of the circumstellar disk of γ Cas using BEDISK. They found a narrow range for the power-law equatorial gas density that could reproduce several observed disk properties, including the energy loss due to Hα emission and the near-infrared continuum excess. A similar procedure was followed for the Be Star δ Sco by Halonen et al. (2008).

M. Curé: *Do you plan to incorporate the oblateness of the star?* — Our models can include the effects of potential gravitational darkening and geometric distortion of the central star by rapid rotation. Work detailing the effect of these phenomena on the circumstellar disk is currently in progress (McGill, Sigut, & Jones, in preparation).

W. J. de Wit: *How does your disk structure change with metallicity?* — The metallicity of the disk noticeably affects its thermal structure via line cooling, which in turn, affects the vertical density distribution.

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