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The circumstellar environment of the FS CMa star IRAS 00470+6429

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Abstract. FS CMa type stars are a recently described group of objects with the B[e] phenomenon that exhibit strong emission-line spectra and strong IR excesses. In this paper we report the first attempt for a detailed modeling of IRAS 00470+6429, for which we have the best set of observations. Our modeling is based on two key assumptions: the star has a main-sequence luminosity for its spectral type (B2) and that the circumstellar (CS) envelope is bimodal, composed of a slowly outflowing disk-like wind and a fast polar wind. Both outflows are assumed to be purely radial. We adopt a novel approach to describe the dust formation site in the wind that employs timescale arguments for grain condensation and a self-consistent solution for the dust destruction surface. With the above assumptions we were able to reproduce satisfactorily many observational properties of IRAS 00470+6429, including the HI line profiles and the overall shape of the spectral energy distribution.

Keywords. circumstellar matter, stars: emission-line, Be, stars: winds, outflows, stars: activity

1. Introduction

This series of papers is devoted to studying objects from the Galactic FS CMa type group. The group comprises about 40 objects with the B[e] phenomenon, which refers to the simultaneous presence of forbidden lines in the spectra and strong excesses of IR radiation (Miroshnichenko 2007, Lamers *et al.* 1998). Its members show properties of B-type stars with typical main-sequence luminosities [$\log(L/L_{\rm sol}) \sim 2.5 - 4.5$]. On the other hand, they exhibit extremely strong emission-line spectra that are on average more than an order of magnitude stronger than those of Be stars of similar spectral types.

One of the main problems in understanding those objects has to do with the presence of significant amounts of hot dust in their circumstellar region that cannot be left from the time of the stars' formation. It is also hard to explain the dust formation using typical mass loss rates from single stars of an appropriate mass range ($\sim 5 - 20\ M_{\rm sol}$). Our observations show that over 30% of the group objects show signs of secondary companions in the spectra (e.g., Li I 6708 Å absorption line). Therefore, one might assume that the large amounts of circumstellar matter near FS CMa type objects may be a consequence of the binary evolution, although direct evidence of the mass transfer between the stellar companions is not observed.

The observed properties of the first object for which we collected a good wealth of data, IRAS 00470+6429, were presented by Miroshnichenko *et al.* (2009). In the present paper we make use of the Monte Carlo code HDUST (Carciofi & Bjorkman 2006) to determine the physical parameters of this intricate system.

2. Results

In this paper we adopted an ad hoc model for IRAS 00470+6429 which is physically motivated by the current knowledge of the CS envelopes of sgB[e]. The model consists of a 6 $R_{\rm sol}$ central star with $T_{\rm eff} = 20\,000$ K and $L = 5\,100$ $L_{\rm sol}$, surrounded by a bimodal CS envelope composed of a dense, slowly outflowing disk-like wind and a fast polar wind. In the model the underlying physical reason for the bimodal envelope is that the mass loss is, somehow, enhanced around the equator. From the analysis of the observed SED and H I line profiles, it was found that the equatorial outflow is at least 200 times denser than the fast polar wind and about 10 times slower. In addition, the opening angle of this slowly outflowing disk (defined as the co-latitude for which the mass loss rate drops to half of its value at the equator) is about 7°.

We determined that the integrated stellar mass loss rate is $\dot{M} = 2.5 — 2.9\times10^{-7}$ $M_{\rm sol}$ yr^{-1}. The two extremes correspond to fits to observations made in December 2006, but separated by an interval of two weeks. This gives a quantitative measure of how the mass loss varies in short timescales. The above value of $\dot{M}$, while much smaller than that of sgB[e], which is of the order of 10^{-6} — 10^{-5} $M_{\rm sol}$ yr^{-1}, is at least 100 times larger than that of main-sequence stars of spectral type B. We adopted a prescription for dust formation based on two complementary criteria. In order to form dust at a given point in the CS envelope, the equilibrium temperature of the dust grains must be smaller than a given grain destruction temperature, $T_{\rm destruction}$, and the gas density must be larger than a critical value. Several important radiative transfer effects are considered in our calculations, such as the shielding of the dust by the optically thick inner CS material and the fact that differently sized grains have different equilibrium temperatures.

To investigate the properties of the dusty content of IRAS 00470+6429 we studied dust models with three different grain size distributions, one with the standard MRN distribution (a = 0.05—0.25 μm), one with both small and large grains (a = 0.05—10 μm), and one with only large grains (a = 1—50 μm). The dust was assumed to be oxygen-based (silicates), an assumption supported by evolutionary arguments and our Spitzer observations of FS CMa stars. The only model capable of reproducing the observed IR excess in the entire 2 — 13 μm range was the model with only large grains ($a_{\rm min} = 1$ μm), because the presence of small grains always results in a strong 9.7 μm silicate emission, which is not observed. One consequence of the prevalence of large grains around IRAS 00470+6429 is that the bulk density of the grain material must be very small ($\rho_{\rm dust} \sim 0.1$ g cm^{-3}). Therefore, the observed shape of the IR excess seems to firmly indicate that the CS dust grains of IRAS 00470+6429 are both very large and fluffy. This work is described in detail in a recently accepted paper to the Astrophysical Journal (Carciofi, Miroshnichenko & Bjorkman 2010).

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