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Accretion processes in Herbig Ae/Be stars: the case of HD 261941

T. Moura, A. P. Sousa, & S. H. P. Alencar

[1] Universidade Federal de Minas Gerais. e-mail: tatiana@fisica.ufmg.br

Abstract. Young stars are born with circumstellar disks and the star-disk interaction is an important factor to understand the early evolution of such systems. The morphology and variability of emission lines that are formed in the circumstellar environment of young stellar objects can be used as tools to understand the physics of accretion/ejection processes. These processes are not well described in intermediate mass young stellar systems, called Herbig Ae/Be stars. Our goal is to identify signatures of magnetospheric accretion and ejection in the spectra of the Herbig Ae star HD 261941. This star is member of the young (~ 3 Myr) open cluster NGC 2264 and was observed with the high resolution (R ~ 47000) UVES/ESO spectrograph (4800 – 6800 Å) over 20 non-consecutive nights. We determined stellar parameters comparing the average observed spectra with synthetic spectra. We also analyzed Hα, Hβ, He I λ5875.7 emission line variability and modelled the Hα mean line profile, using the MHD model described by Lima et al. (2010). The disk-wind presents a strong contribution to the Hα profile in this star and we found signatures of magnetospheric accretion in the observed spectra.

Resumo. Estrelas jovens formam-se com discos circunstelares e a interação estrela-disco é um fator importante para entendermos a evolução desses sistemas. A morfologia e a variabilidade das linhas de emissão que se formam no ambiente circunstelar de objetos estelares jovens podem ser usadas como ferramentas para compreender a física dos processos de acreção/ejeção. Esses processos não são bem descritos em sistemas estelares jovens de massa intermediária, denominados estrelas Ae/Be de Herbig. Nosso objetivo é identificar sinais de acreção magnetosférica e ejeções na estrela Ae de Herbig HD 261941. Esta estrela é membro do aglomerado aberto jovem (~ 3 Myr) NGC 2264 e foi observada com o espectrógrafo UVES/ESO de alta resolução (R ~ 47000; 4800 – 6800 Å) por 20 noites não consecutivas. Determinamos os parâmetros estelares comparando os espectros observados médios com espectros sintéticos. Analisamos a variabilidade das linhas de emissão Hα, Hβ, He I λ 5875.7 e modelamos o perfil médio da linha Hα, usando o modelo MHD descrito por Lima et al. (2010). O vento de disco apresenta uma forte contribuição para o perfil Hα nesta estrela e encontramos características de acreção magnetosférica nos perfis observados.

Keywords. Herbig Ae/Be stars – accretion disk – magnetospheric accretion – disk winds – line profiles

1. Introduction

Herbig Ae/Be (HAeBe) stars are optically visible Pre-Main-Sequence (PMS) stars with masses ranging from 2 e 10 $M_\odot$. They present F2 to B0 spectral types, which correspond to effetive temperature between 7000-30000 K (Pogodin et al. 2015). HAeBe stars show both characteristics of high-mass systems (Testi et al. 1999), like the absence of a convective envelope, as well as characteristics of young low mass stars (Vink et al. 2002), such as emission lines with similar features. One of the main open issues in star formation is the difference between the formation mechanisms of low and high mass stars. Although it is well established that low mass stars accrete matter from the circumstellar disk through a magnetic field, the mechanism that leads to this accretion in stars of larger masses is still uncertain. The study of HAeBe stars is extremely important for the understanding of these mechanisms, since it is a bridge between the star formation of low and high mass stars. Despite the absence of convective envelopes in the HAeBe stars, a globally organized magnetic field has been measured in some of these systems (Hubrig et al. 2013). The magnetospheric accretion model should therefore be applicable to some HAeBe stars.

2. Circumstellar lines

We analyze spectra of the HD 261941 star that was observed during 20 nights between 04 December 2011 e 24 February 2012 with the UVES (VLT/ESO) spectrograph in the spectral range 4800-6800 Å with resolution of ~ 47000.

Table 1. Parameters of the Mon-000631 system with their respective determination method.

Parameters	Value	Standard deviation	Methods/Code
T_{eff} (K)	8500	119	SME
$\log g$	3.5	0.2	SME
$[Fe/H]$	0.0	0.07	SME
v_{rad} (km/s)	22	0.7	SME
$v \sin i$ (km/s)	120	2	BinMag4
Period (day)	3.3	1.7	width 10% Hα
$\dot{M}_{ac}$ ($M_\odot$/yr)	5.3 x 10^{-6}	2.2 x 10^{-6}	Flux Hα
mass ($M_\odot$)	2.03	0.04	ATON 2.0
Radius ($R_\odot$)	4.4	1.2	ATON 2.0
Age (Myr)	5.99	0.17	ATON 2.0

Synthetic photospheric spectra were computed using the SME (Valenti el al. 1998) and BinMag4 (Kochukhov 2007) codes, with the ATLAS9 atmosphere models (Kurucz 1993) and a spectral line list from the *Vienna Atomic Line Database* (*VALD*) (Kupka el al. 1999) to determine stellar parameters.

The best fit photospheric synthetic spectrum was subtracted from the observed spectra to obtain the circumstellar spectral contribution in this system. In Table 1 we list the stellar parameters determined from the spectral line synthesis and the mass accretion rate, obtained from modeling of the Hα circumstellar contribution.

We notice a strong variability in the intensity and morphology of the Hα, Hβ and He I lines (Figure 2). This variability is characteristic of young stars and can be used to analyse the dynamics of the accretion and outflow processes.

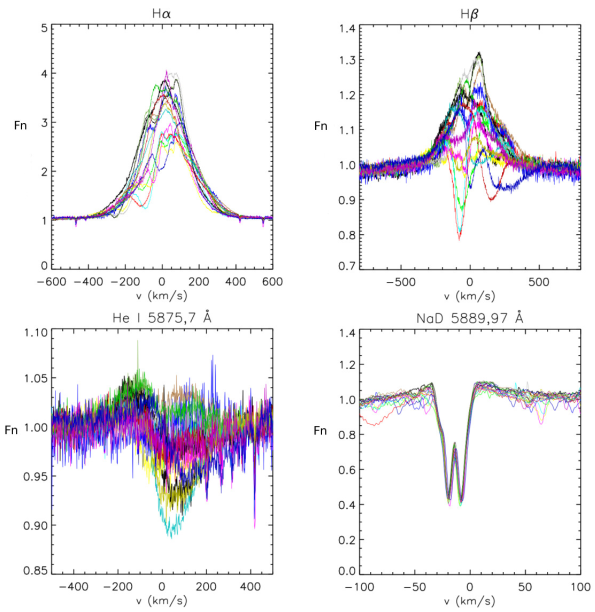

FIGURE 1. Circumstellar contributions of observed spectral lines. Fn represents the normalized flux.

The Hα line variability is most prominent in the blue, indicating variations due to winds (photons absorbed in regions where the gas has projected velocities on our line of sight traveling towards us). The Hβ line contains absorptions in the blue and red wings, thus indicating regions where the material is possibly being absorbed by the wind and the magnetosphere (redshifted absorptions correspond to photons absorbed in regions where the gas has projected velocities on our line of sight traveling away from us), respectively. The morphology of this line indicates that there is a possible magnetospheric accretion and outflow scenario. The He I λ5875,7 line presents a variable absorption throughout in the red wing, contributing to the magnetosphere accretion scenario.

3. Magnetospheric accretion and outflow model

The computational model used in this work was initially proposed by Hartmann et al. (1994) and complemented by Lima et al. (2010). The model allows the calculation of the Hα profile coming from an accreting magnetosphere radiatively coupled to a diskwind. Figure 3 shows results of the Hα line profile modeling and Table 2 summarizes the parameters of the best fit models.

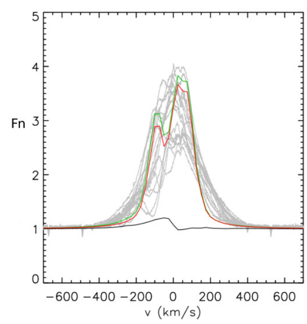

FIGURE 2. Computed models with only the magnetospheric accretion contribution (black), with only the diskwind contribution (red) and with both the magnetosphere and diskwind contributions (green). The parameters used in the three models are shown in Table 2. Fn represents the normalized flux.

Table 2. Parameters of the Mon-000631 system obtained from the best Hα line model: θ, lauching angle between the accretion disk and magnetic field lines; R_{do}, outer wind radius; R_{mi}, inner magnetosphere radius; R_{mo}, outer magnetosphere radius; T_{mag}, maximum magnetosphere temperature; T_{wind}, maximum disk wind temperature; and i, inclination of the system.

Parameters	Value
θ	33.42°
R_{do}	20 R_*
R_{mi}	2.0 R_*
R_{mo}	2.45 R_*
T_{mag}	7000 K
T_{wind}	7000 K
i	85°
B_* (*)	0.6 kG

(*) Dipole component of the magnetic field (B_*) was obtained from the best fits of $\dot{M}_{ac}$ e R_m ($R_m \propto [B_*^4/\dot{M}_{ac}^2]^{1/7}$; Bessolaz el al. 2008)

4. Conclusions

- The hybrid model of magneto-accretion plus disk wind can be applied to the Herbig Ae star HD 261941
- Main line formation sites: Hα - diskwind; Hβ - magnetosphere + disk wind; He I - hot spot + magnetosphere
- High mass accretion rate ($\sim$ 3,0 x 10^{-6} $M_\odot$/yr)

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