Magnetospheric accretion modelling of Hα & NaID lines in Herbig Ae stars

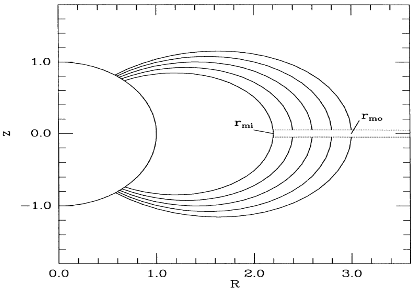
Mendigutía, I.[1] ; Muzerolle, J.[2] ; Montesinos, B.[1] ; Eiroa, C.[3] ; Mora, A.[4]

[1]Centro de Astrobiología, Dpto de Astrofísica. INTA/CSIC. Madrid, Spain
[2]Space Telescope Science Institute. Baltimore, MD. USA
[3]Universidad Autónoma de Madrid, Facultad de Ciencias. Madrid, Spain.
[4]GAIA Science Operations Centre, European Space Astronomy Centre. Madrid, Spain.

Scientific rationale:

The mass accretion rate (M_{acc}) is a main parameter constraining timescales for circumstellar (CS) gas dissipation and for giant planet formation in protoplanetary disks. Magnetospheric accretion (MA) is the current paradigm for explaining disk-to-star accretion in classical T-Tauri stars (e.g. Shu et al. 1994). According to that, matter is channeled through the magnetic field lines connecting the inner disk with the stellar surface, generating hot accretion shocks. Temperature differences with the stellar photosphere explain the optical continuum excess and the spectroscopic veilling found in T-Tauris (Calvet & Gullbring 1998). Emission and absorption features, such as Hα and NaID lines, were also reproduced from MA models (e.g. Muzerolle et al. 2001). Herbig Ae/Be (HAeBe) objects are the massive (1-10$M_\odot$) counterparts of T-Tauri stars. How CS matter accretes on those objects is still object of debate: HAeBes are not expected to have convective sub-photospheric zones generating the necessary magnetic fields, moreover, they do not tend to show optical continuum excess or veiling, making difficult a direct M_{acc} estimation. However, magnetic fields strong enough to sustain MA have been detected in several HAeBe objects (e.g. Wade et al. 2007), and line profiles of UX Ori -a prototypical HAe star- have been succesfully reproduced using MA models (Muzerolle et al. 2004). These authors explained that the absence of veiling results from the similar temperature characterizing the stellar photosphere and the accretion shocks (~ 9000 K). In addition, several other spectropolarimetric and spectroscopic observations are consistent with MA also operating in HAe objects (but not in HBes, see Vink et al. 2002, Mottram et al. 2007, Mendigutía et al. 2010). Aiming to gain insights into accretion in HAe stars, we made a grid of Hα and NaID line profiles from MA models. In the following we describe the grid and show several up-to-date results from the comparison with observational data.

The synthetic grid

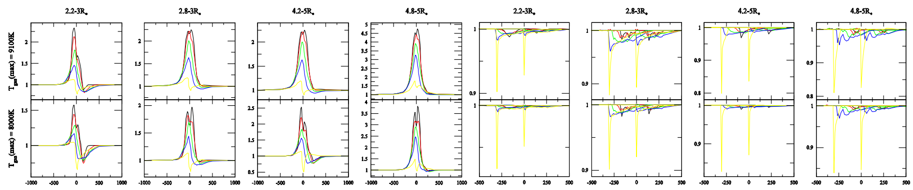


1) The model: It is fully described in Muzerolle et al. (2001). It calculates the atomic level populations for free-falling gas constrained along dipolar axisymmetric magnetic field lines. The panel (from Hartmann et al. 1994) shows a poloidal slice including the star, the disk and the magnetic lines. The size of the magnetosphere is delimited by r_{mi} and r_{mo}.

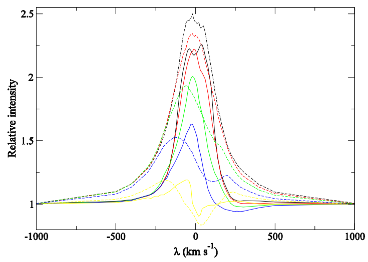
INPUT PARAMETERS:

M_* ($M_\odot$)	2.5
R_* ($R_\odot$)	2.5
T_e (K)	9000
$T_{accretion-shock}$ (K)	9000
M_{acc} ($M_\odot$/yr)	10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}
T_{gas}(max) (K)	12000-10000, 9100-8000, 7500-7200, 6500-5750
r_{mi} - r_{mo} (R_*)	2.2 - 3, 2.8 - 3, 4.2 - 5, 4.8 - 5
i (deg)	5, 25, 45, 60, 85

2) The input: Consists of parameters characterizing the central star (typical values for an HAe object), the accretion shock (modelled by a black-body ring), the mass accretion rate, the gas temperature, the magnetosphere size and the inclination to the line of sight

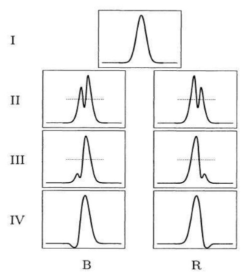


3) The output: We derive a grid with 240 Hα and NaID synthetic profiles. The panel shows the case for M_{acc} = 10^{-8} $M_\odot$/yr, maximum gas temperatures indicated on the left, magnetosphere sizes on the top, and inclinations 5, 25, 45, 60 and 85 deg (in black, red, green, blue and yellow, respectively.).

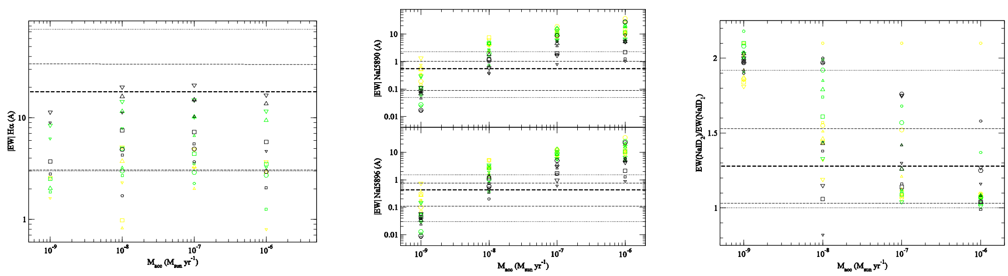


4) Rotation: The grid is being extended including several stellar rotation velocities (Muzerolle et al. 2001). The panel shows the case M_{acc} = 10^{-8} $M_\odot$/yr, T_{gas}(max) = 9100 K, and magnetosphere size 2.8 – 3 R_* (solid lines), modified with v = 80 km s^{-1} (dashed lines). Inclinations as in the left panel.

Comparison with observational data

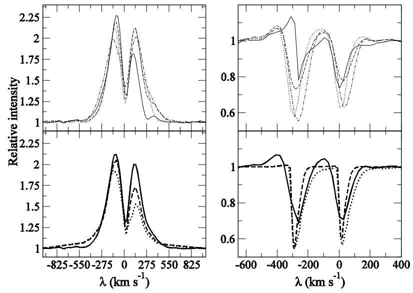


Line profiles: The grid reproduces all observed Hα profiles in HAeBe spectra, summarized above (from Reipurth et al. 1996). The exceptions are IIIB and IVB profiles: models do not include winds. However, B-profiles are more common in HBe spectra than in HAe stars (Finkenzeller & Mundt 1984, Mendigutía et al. 2010).



Line strengths: Hα and NaID EWs, and NaID EW ratios (indicative of the optical thickness of the medium), versus M_{acc} as derived from the grid. Large and small symbols are for the highest and lowest T_{gas}(max) used per M_{acc} value. Different symbol shapes indicate the magnetosphere sizes. Inclinations to the line of sight are in black, green and yellow (for i = 5, 45 and 85 deg, respectively). Horizontal dotted lines indicate upper and lower observational limits and horizontal dashed lines bracket the range of the most observed values, being the bold dashed line the mean observed value. Values from the grid profiles are mostly included in the observed range. Note that rotation introduces an additional EW enhancement. Observed ranges and line variability (Mendigutía et al. 2010) can be reproduced at different leves from changes in M_{acc} , the magnetosphere size and/or the gas temperature.

Fitting the profiles for BF Ori



BEST FIT PARAMETERS:

M_* ($M_\odot$)	2.5
R_* ($R_\odot$)	2.5
T_e (K)	9000
$T_{accretion-shock}$ (K)	9000
M_{acc} ($M_\odot$/yr)	10^{-8}, dashed line (10^{-7}, dotted line)
T_{gas}(max) (K)	9100, (7500)
r_{mi} - r_{mo} (R_*)	4.2 - 5
i (deg)	75, (70)

Observed multi-epoch Hα and NaID lines of BF Ori are shown at the top left panels. Despite of the variations, it shows a constant accretion rate between 10^{-7} and 10^{-8} $M_\odot$ /yr, depending on the tracer used (Mendigutía et al. 2010). Bottom left panels show the mean profiles (solid lines). They are best reproduced using M_{acc} = 10^{-8} $M_\odot$/yr (dashed lines), although M_{acc} = 10^{-7} $M_\odot$ /yr (dotted lines) also provides a good fit, especially for the NaID lines. Modelling parameters are in the right panel, which are in agreement with the stellar properties and possible inclination reported for this HAe star (Mora et al. 2001, Oudmaijer et al. 2001, Wade et al. 2007, Montesinos et al. 2009). Synthetic profiles were modified using v sini = 37 km/s (Mora et al. 2001).

Conclusions and future work

A simple geometrical MA model is able to reproduce the overall shape and strength of the Hα and NaID lines shown by HAe stars. Line profiles of specific HAe objects, such as BF Ori (and UX Ori, Muzerolle et al. 2004), are consistent with MA operating on them.

High projected rotational velocities characterize HAe stars. We will extend the grid including several rotation rates to study how they affect the line profiles. We will try to fit several other observed Hα and NaID lines from the models.

The final grid will be a useful tool to study accretion and line variability in HAe stars, and to derive M_{acc} values for these objects

References:

- Calvet & Gullbring, 1998, ApJ, 509, 802
- Finkenzeller & Mundt, 1984, A&AS, 55, 109
- Hartmann et al. 1994, ApJ, 426, 669
- Mendigutía et al. 2010, A&A, submitted.
- Montesinos et al. 2009, A&A, 495, 901
- Mora et al. 2001, A&A, 378, 116
- Mottram et al. 2007, MNRAS, 377, 1363
- Muzerolle et al. 2001, ApJ, 550, 944
- Muzerolle et al. 2004, ApJ, 617, 406
- Oudmaijer et al. 2001, A&A, 379, 564
- Reipurth et al. 1996, A&AS, 120, 229
- Shu et al. 1994, ApJ, 429, 781
- Vink et al. 2002, MNRAS, 337, 356
- Wade et al. 2007, MNRAS, 376, 1145

Contact e-mail: Ignacio.Mendigutia@cab.inta-csic.es