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Is the magnetospheric accretion active in the Herbig Ae/Be stars?

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Abstract. This contribution is based on the work published by (Pinzón et al. 2021) in which we computed rotation rates for a sample of 79 young stars (∼3 Myr) in a wide range of stellar masses (from T Tauri Stars to Herbig Ae/Be stars) in in the Orion Star Formation Complex (OSFC). We study whether the magnetospheric accretion scenario (MA), valid for young low mass stars, may be applied over a wide range of stellar masses of not. Under the assumption that stellar winds powered by stellar accretion are the main source for the stellar spin down, the hypothesis of an extension of MA toward higher masses seems plausible. A comparison with Ap/Bp stars suggest that HAeBes should suffer a loss of angular momentum by a factor between 12 and 80 during the first 10 Myr in order to match the magnetic Ap/Bp zone in HR diagram.

Keywords. stars, formation, rotation.

1. Overview

Herbig Ae/Be stars (HAeBes) are young stellar objects with similar properties to their lower mass counterparts, the T Tauri stars (TTs). They both have comparable ages, infrared and ultraviolet excess levels associated with the presence of an accreting circumstellar disk, p-cygni line profiles in the most prominent emission lines, and forbidden line emission that confirms the existence of stellar winds in such systems (Hubrig et al. 2014). Although, the internal structure of HAeBes differs from that of TTs; while the former is mainly radiative, TTs are fully-convective stars. Consequently, there are a low number of magnetic HAeBes, less than 10% in the majority of studied star formation regions. The origin of magnetism in the few magnetic HAeBes is uncertain. In the merging scenario of Ferrario (2009), the magnetic field in HAeBes is the consequence of merging two magnetic TTs when at least one of them has reached the end of its radiative track in the HRD.

In the MA framework, TTs generate their own magnetic field that is able to truncate the disk at a few stellar radii from the stellar surface. From such location, gas in the disk with higher angular momentum falls onto the stellar surface along the magnetic field lines. The energy released during accretion process excites large fluxes of Alfvén waves along open field lines in the magnetosphere, that is, stellar winds, which play an important role in the outward transfer of angular momentum (Boehm et al. 1994; Matt et al. 2008). While this scenario describes angular momentum in TTs, its extrapolation toward magnetic HAeBes is not straightforward. High resolution spectral analysis of the region between the star and the inner disk, suggest that accretion process in HAeBes differs from that in TTs. Futhermore, the simultaneous presence of redshifted and blushifted

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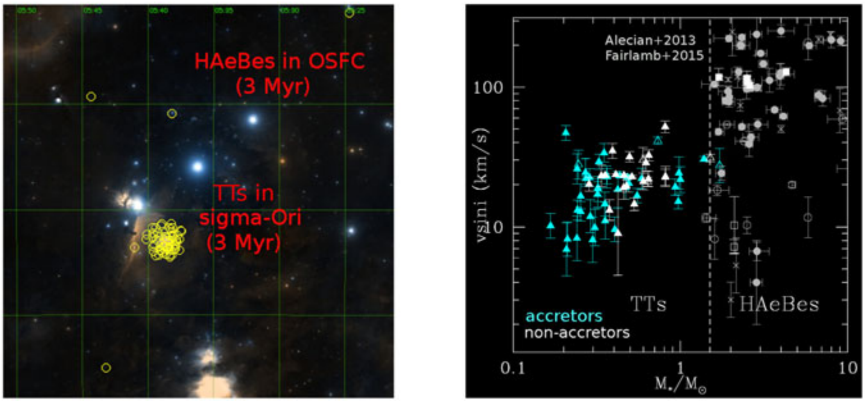

Figure 1. Left. Sample of TTs and HAeBes in OSFC. **Right.** Snapshot of the projected rotational velocities for the same objects. TTs (triangles) and HAeBes (rectangles). TTs with active accretion are indicated with bigger triangles in blue. Complementary data of HAeBes taken from (Alecian 2013) and (Fairlamb 2015) have been included in gray. Binaries are indicated with open circles and upper limit values with crosses.

absorption features in Balmer lines is a characteristic present in TTs spectra. In contrast, most promiment emission lines HAeBes generally lack such simultaneous absorption features(Cauley 2015).

2. Rotation of TTs and HAeBes

Using Hectochelle ($R\sim 32000$) and FIES ($R\sim 68000$) high resolution spectra we computed the projected rotational velocities (vsin$i$) for the sample of 79 TTs and HAeBes with confirmed membership (Hernández 2014) indicated in Figure 1. We obtained vsin$i$ applying two methods: (1) analysis of the cross correlation function of the object spectrum against a rotational template (Tonry & Davis 1979) and (2) Fourier Transform (FT) of selected line profiles in the object spectrum (Serna 2021). Results shown in Figure 1 confirm similar vsin$i$ values for accretors and non-accretors as expected for TTs. While HAeBes rotate on average, to one third of their break-up limit ($\sim$300 km/s for $3M_{\odot}$), TTs rotation remains below of 10% of this limit as expected from MA scenario.

3. Stellar winds in HAeBes

Stellar wind indicators such as p-cygni line profiles are observed in the FIES spectra of HAeBes. In Figure 2 we can a see a dip in the flux at -200 km/s in the residual emission of $H\beta$ 4861Å. In addition to this, the presence of the [OI]λ6300, which is originated in outermost regions of magnetosphere is a clear indicator of stellar winds. On the other hand, the significant Balmer excess observed in the most of the HAeBes spectra when compared with the expected flux of reference main-sequence stars, suggest that accretion and winds could be related in someway. The interplay among accretion and mass loss in the winds, regulates the angular momentum evolution during the first Myr of stellar evolution.

We used a stellar spin evolution model that includes accretion powered stellar winds in the context of MA framework, as the main source of angular momentum loss from the stellar surfaces in both, TTs and HAeBes. Briefly, the model assumes that stars are contracting and that posses a dipolar magnetic field with strenghts in the range 0.5 to 3 kG. Star-disk interaction is included through the net torque onto the star, which has two main contributions: (1) magnetic braking with the disk and (2) stellar wind

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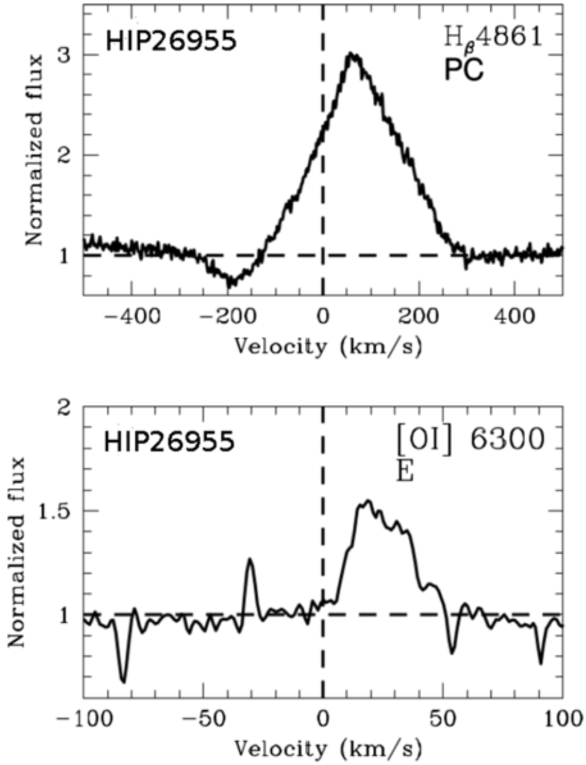

Figure 2. Residual emission for the $H\beta$ 4861Å and [OI] 6300.31Å lines in FIES spectrum of the Herbig Ae/Be star HIP26955. The continuum, normalized to 1.0 is marked with a horizontal dashed line while the stellar rest velocity is labeled with a vertical dashed line.

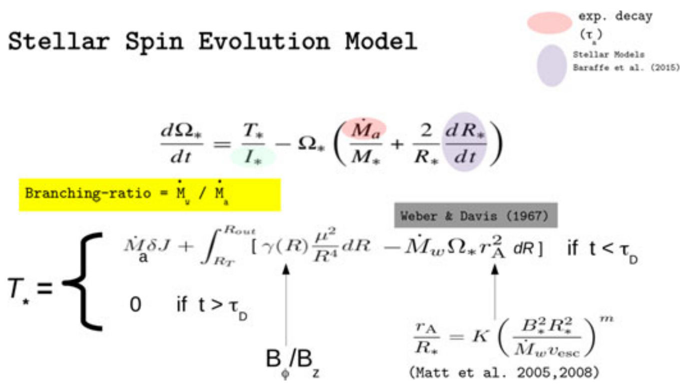

Figure 3. The stellar spin evolution model used for explaining the stellar rotation in our sample of TTs and HAeBes.

torque. At each instant the net torque onto star is computed and used to obtain the stellar angular frequency ($\Omega_* = vR_*$). Stellar radii and moment of inertia are obtained from evolutionary models of Baraffe et al. (2015). We suppose that cirmumstellar disk surrounding young star has a finite timelife $\tau_{disk} = 3$ Myr and that accretion and mass loss rate follow an exponential time decay as indicated in Figure 3.

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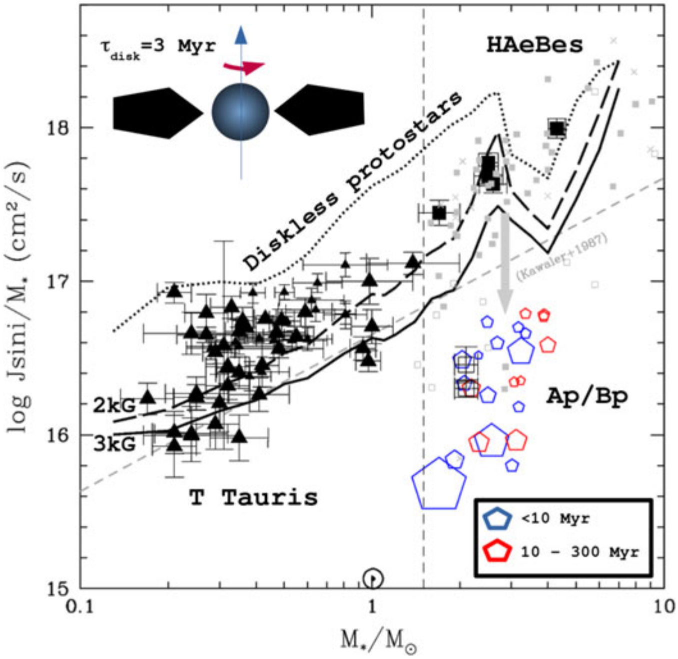

Figure 4. Specific angular momentum for TTs in the σ-Orionis cluster (triangles) and HAeBes (rectangles in black). The dashed grey line represents the main-sequence trend. Pentagons correspond to the sample of Ap/Bp stars of Aurière (2007) with size symbols are proportional to the dipolar field strength. Solid lines represent a snapshot of angular momentum at 3 Myr for two $B_* = 2$ and 3 kG.

4. Main Results

• Using stellar radii for our well characterized sample of TTs and HAeBes, we computed the specific angular momenta (per unit of mass J/M_*). For comparison purposes and under assumption that disks survive along the Hayashi track in the HR diagram, we calculated the synthetic $< J/M_* >$ values. Solid black lines in Figure 4 correspond for magnetic field strenghts of 2 and 3 kG under the following assumptions : (1) MA operates along the whole spectral types of our sample and (2) the mass loss rate behaves as the accretion rate but with one tenth of its intensity.

• The best fit to the data is obtained for $B_* = 2.0$ kG. For this particular case and through the use of the Kawaler law, we estimate that specific angular momentum is transferred outward during the contraction towards the main sequence by a factor of $\sim$3.2, equivalent to $\sim 3.2 \times 10^{17}\ cm^2\ s^{-1}$.

• We have included $< J/M_* >$ values for the sample of Ap/Bp stars of Aurière (2007) which are expected to be evolved HAeBes. We find that specific angular momentum must be lost by a factor between 12 and 80 from HAeBes to Ap/Bp stars, depending on the intensity of the dipolar field.

Although detailed phenomena of TTs and HAeBes are not considered, our approach result useful for testing the validiy of MA using stellar rotation as a proxy. However, the results obtained for the angular momentum in HAeBes do not explain the low rotation of Ap/Bp stars.

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