Do Herbig Ae/Be stars have discs?

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Abstract. Hα spectropolarimetry on Herbig Ae/Be stars shows that the innermost regions of intermediate mass (2 – 15 M\textsubscript{\textodot}) Pre-Main Sequence stars are flattened. This may be the best evidence to date that the higher mass Herbig Be stars are embedded in circumstellar discs. A second outcome of our study is that the spectropolarimetric signatures for the lower mass Herbig Ae stars differ from those of the higher mass Herbig Be stars. Depolarisations across Hα are observed in the Herbig Be group, whereas line polarisations are common amongst the Herbig Ae stars in our sample. These line polarisation effects can be understood in terms of a compact Hα source that is polarised by a rotating disc-like configuration. The difference we detect between the Herbig Be and Ae stars may be the first indication that there is a transition in the Hertzsprung-Russell Diagram from magnetic accretion at spectral type A to disc accretion at spectral type B. However, it is also possible that the compact polarised line component, present in the Herbig Ae stars, is masked in the Herbig Be stars due to their higher levels of Hα emission.

1. Introduction

Herbig Ae/Be stars are intermediate mass (2 – 15 M\textsubscript{\textodot}) Pre-Main Sequence stars. They are the most massive counterparts of the lower mass T Tauri stars that are visible in the optical. Therefore, Herbig stars are ideal objects to determine whether key aspects of the T Tauri phase, such as discs and magnetic fields, are also of physical relevance to higher mass star formation. Yet, even the most basic question of whether Herbig Ae/Be stars are embedded in accretion discs has not been answered. Ideally, one would like to image the environments around Herbig Ae/Be stars directly, but these attempts have so far resulted in contradictory results. For instance, CO observations by Mannings & Sargent (2000) in the sub-millimetre regime show flattened structures on large scales (up to 1000 AU), but Millan-Gabet et al. (2001), who conducted a 2-telescope interferometric study at near-infrared wavelengths, concluded that accretion disc models can be ruled out on scales between 0.5 – 5 AU, with spherical models reproducing the visibility data much better. It is obvious from the above that
there is a need for an independent approach to answer this problem, providing a diagnostic that can resolve circumstellar structures in the innermost regions around young stars. Spectropolarimetry across emission lines is just such a tool, as it can probe spatial scales on the order of stellar radii (i.e. 1/100s AUs) rather than AUs.

2. The tool of linear spectropolarimetry

The application of linear spectropolarimetry was first established in studies of classical Be stars. The method is based on the expectation that the Hα photons – formed over a large volume in a circumstellar medium – undergo less electron scatterings off a disc than the stellar continuum photons do. Consequently, the line flux will be much less polarised than the continuum, and a change in the polarisation across the line occurs. We refer to this depolarisation as the classical line-effect because of its first appearance in observations of classical Be stars. The high incidence of these depolarisations among such objects (26 out of 44 in Poeckert & Marlborough 1976) indicated that Be star envelopes are not spherically symmetric. In its time, this evidence was taken as showing that classical Be stars possess discs – a result later confirmed by interferometric imaging. We use the tool of Hα spectropolarimetry on a large sample of bright Herbig stars. The sample needs to be large to make a proper distinction between intrinsic geometrical effects and our viewing angle. When viewed face-on, one would not expect to detect a line effect, due to the symmetry projected on the sky. When viewed edge-on, the line effect is maximal. Our sample so far consists of 12 Herbig Be stars and 11 Herbig Ae stars (see Vink et al. 2002).

3. The Herbig Be stars

A typical observation of the Herbig Be star BD+40 4124 is shown in Fig. 1. Note the presence of the classical line-effect, This directly implies that for this object the electron-scattering region is not spherically symmetric, i.e. it is flattened.

The frequency of depolarisations detected in the HBe star sample (7/12; Oudmaijer & Drew 1999 + Vink et al. 2002) is particularly interesting because it is essentially the same as was found for classical Be stars (Poeckert & Marlborough 1976). Continuing the analogy with classical Be stars, our Hα spectropolarimetry indicates that the higher mass Herbig Be stars are embedded in flattened structures. Note however, that just the presence of these flattened structures is not evidence for continuing accretion.

4. The Herbig Ae stars

At later spectral type we detect spectropolarimetry characteristics differing from the earlier type Herbig Be (HBe) stars. A switch in phenomenology may be expected to occur at some point working down the stellar mass range, as different physical mechanisms might play a more prominent role at different spectral types. For instance, radiation pressure forces are likely to play a role for the higher luminosity stars at the early B types, whereas magnetic fields may become
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Figure 1. The Herbig Be star BD+40 4124. The normal (intensity) spectrum is shown in the lower panel, the polarisation percentage is indicated in the middle panel, and the position angle (PA) is plotted in the upper panel. The data are binned to an error (1 $\sigma$) of 0.05 %. Note the depolarisation across the H$\alpha$ emission line.
Figure 2. The Herbig Ae star XY Per. The panels are as in Fig. 1. The data are binned to an error of 0.12%. Note the rotation in the Position Angle which can be explained with a compact Hα source in a rotating circumstellar disc.
more dynamically prominent at the later A types. The magnetically-channelled accretion model that is commonly applied to the lowest mass Pre-Main Sequence T Tauri stars may also be a suitable model as early as spectral type A. If it does operate, the inner accretion disc around the star is truncated by the magnetic field, and the depolarisation effect may then be absent because the inner hole will necessarily lead to reduced intrinsic continuum polarisation. Alternatively, the channelled accretion may produce a relatively bright and compact source of Hα emission that may be scattered either within the accretion column itself or within the disrupted disc. This in turn may yield a polarisation signature at Hα that is more complex than the simple depolarisation effect.

A typical Herbig Ae star (XY Per) is shown in Figure 2. Note first that the polarisation signature is more complicated than in Fig. 1, and that the data are clearly at variance with the depolarisation picture described above. The observed “flip” in the Position Angle can be understood by the presence of a compact Hα source, located within a rotating distribution of scatterers (see also Pontefract et al. 2000). The data for 9/11 Herbig stars in our sample imply the presence of a compact Hα source. This could arise from continuous accretion on the stellar surface, perhaps magnetically-controlled, producing hot spots on the stellar surface. Future spectropolarimetric monitoring campaigns in conjunction with radiative transfer modelling (using TORUS; Harries 2000) should be able to test this.

5. Difference between Herbig Be and Ae stars?

The spectropolarimetric differences between the Herbig Be and Ae stars (as seen in Figures 1 and 2) may be the first indication that there is a transition in the Hertzsprung-Russell Diagram from magnetic accretion at spectral type A to disc accretion at spectral type B. However, there are other differences between Herbig Ae and Be stars. Most notable, the Hα emission in Herbig Be stars is much more extended in volume and optical depth. It is therefore possible that the compact spectropolarimetric signature seen in the Ae stars may be produced in the Herbig Be stars also, but is completely masked there by Hα emission.

To conclude, our data indicate that flattened structures around Herbig Ae/Be stars are common on the smallest scales, suggesting that the higher mass Pre-Main Sequence stars may well be embedded in accretion discs.

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