Mem. S.A.It. Vol. 88, 605

Memorie della

The formation and evolution of Herbig Ae/Be stars

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Abstract. Herbig Ae/Be stars are intermediate mass pre-Main Sequence stars whose masses lie between those of the solar mass T Tauri stars and the Massive Young Stellar Objects which have masses larger than 8-10 $M_{\odot}$. Given that the formation mechanisms of low and high mass stars are thought to be different, the Herbig Ae/Be stars can provide important clues to the respective formation scenarios. In addition, they span the mass range where the transition in formation scenario occurs. Here we present the results of two recently completed surveys; X-Shooter spectroscopy of 90 objects, and linear spectropolarimetry around Hα of 56 objects. We show that both the derived mass accretion rates and linear spectropolarimetry indicate a change in properties across the B7-B8 region.

Key words. Stars: formation – Stars: pre-main sequence – Stars: circumstellar matter – Stars: individual: Herbig Ae/Be

1. Introduction

Herbig Ae/Be (HAeBe) stars, first identified by Herbig (1960), are optically visible pre-main-sequence (PMS) stars with masses roughly between 2 and 10 $M_{\odot}$. Whereas lower mass stars are thought to form through magnetically controlled accretion (MA, e.g. Bouvier et al. 2007), the case is not yet understood for higher mass PMS stars for which magnetic fields have hardly been detected (e.g. Alecian et al. 2013).

Evidence has been accumulating that, observationally, Herbig Ae stars are more similar to the T Tauri stars than to Herbig Be stars. For example, Schöller et al. (2016) explain the spectroscopic variability of a Herbig Ae star as due to magnetically-controlled accretion. In contrast, Kurosawa et al. (2016) conclude that the magnetosphere in a Herbig Be star must be small, while Patel et al. (2017) do not need magnetic fields to explain the spectroscopic properties of early type Herbig Be stars. Vink et al. (2002, 2003) found similar linear spectropolarimetric properties of T Tauri and Herbig Ae stars, while the Herbig Be stars are different. Cauley & Johns-Krull (2015) found that the emission and absorption line properties of Herbig Be stars are significantly different from Herbig Ae stars. Here we present 2 recently completed studies focussing on the statistical properties of the class.

2. An X-Shooter survey - accretion rates of Herbig Ae/Be stars

Fairlamb et al. (2015; 2017) studied the X-Shooter spectra of a sample of 90 objects, and derived their astrophysical parameters in a homogeneous manner. These served as input to derive the mass accretion rates from the ob-

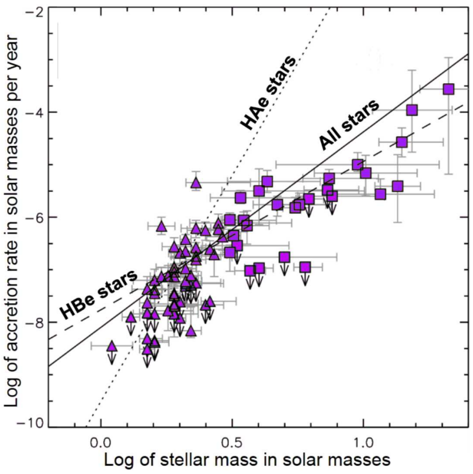

Fig. 1. The derived mass accretion rate as function of mass for the X-Shooter sample of Herbig Ae/Be stars (Fairlamb et al. 2015). The triangles denote the Herbig Ae stars, while the squares are the Herbig Be stars. Fits to the data have been made to, respectively, the Herbig Ae stars (dashed line), Herbig Be stars (long dashed) and the entire sample (solid). The mass dependency of the accretion rate is different for the Herbig Ae and Herbig Be stars respectively. Figure adapted from Fairlamb et al. (2015).

served UV-excesses determined from the same data (cf. e.g. Mendigutía et al. 2011).

Fig. 1 shows the resulting mass accretion rates as function of mass, which reveals a different behaviour between Herbig Ae and Be stars. It can be seen there is a break in the relationship between spectral types A and B. In addition, they found that Herbig Ae stars can be explained by MA, but that the earliest Herbig Be stars have too large UV-excesses to be explained by the usual accretion shock scenario.

3. Probing the disks – Linear spectropolarimetry across Hα

Linear spectropolarimetry has been long known to reveal the presence of very small scale disks around stars (e.g. Oudmaijer & Drew 1999). Subsequent studies of HAeBe stars showed that spectropolarimetric effects across the Hα emission fall into a small number of categories (e.g. Ababakr, Oudmaijer & Vink, 2016). In particular, Vink et al. (2002, 2003) found that the intrinsic line polarization of Hα predominately occurs for T Tauri and Herbig Ae stars and can be explained by compact Hα emission scattered off a circumstellar disk, while the Herbig Be stars typically display a line *de*-polarization that can be explained with a disk reaching onto the stellar surface (Vink, Harries & Drew 2005, Mottram et al. 2007).

With 56 objects, Ababakr, Oudmaijer & Vink (2017) presented the largest linear spectropolarimetric study of Herbig HAeBe stars. They found a break in the spectropolarimetric, and possibly accretion, properties of high and low mass objects to occur around the B7-B8 spectral type. This is found in both the detection statistics and, especially, the nature of the line effect (see Fig. 2).

The similarities in the spectropolarimetric properties between T Tauri stars - which are known to undergo magnetospheric accretion - and the late-type Herbig Be and Herbig Ae stars suggest this mechanism also acts on these intermediate mass stars (cf. Vink et al. 2002). Although magnetic fields have been detected towards few HAeBe stars (Alecian et al. 2013), they are weak ($\sim$ a few hundred G) and rare. It is therefore an open question whether HAe stars have sufficient magnetic fields to facilitate MA or not.

4. Final remarks

The main take away messages from the short overview above are that:

i) Herbig Ae/Be stars bridge the gap between low and high mass young stars and cover the mass where a change in accretion occurs.
ii) We determined temperatures and log g from stellar spectra and accretion rates directly from the simultaneously observed UV excess or line flux for a sample of 90 HAeBe objects.
iii) From linear spectropolarimetric observations of 56 objects, we find Herbig Ae stars are similar to T Tauri stars and that their line polarization can be explained by accretion shock emission scattered off a disk.

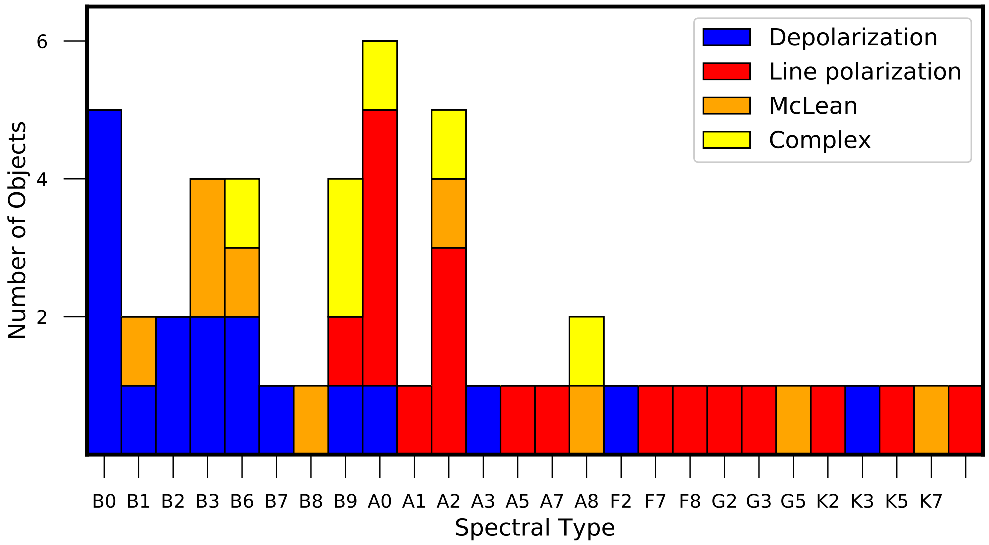

Fig. 2. The occurrence of the various line effects observed in the linear spectropolarimetry as a function of spectral type. The "line depolarization" and "line polarization" are the most common types. It can be seen that the line depolarization, probing disks reaching close to the star, predominately occurs for the hotter Heribg Be stars. In contrast, the line polarization, tracing line emission scattering off a circumstellar disk, mostly occurs for the cooler, lower mass, Herbig Ae and T Tauri stars. It appears that the change occurs roughly around spectral type B7-B8. Figure adapted from Ababakr et al. (2017).

iv) From both mass accretion rates and spectropolarimetry, there appears to be a change in properties, and therefore perhaps accretion mode, at around 3 $M_\odot$ (mid to late B-type).

Finally, we are now using GAIA to expand the set of known HAeBe stars to improve on the statistical findings presented here and, following the initial work by Testi, Palla & Natta (1999), aim to establish the presence or absence of clusters around these objects to study their clustering properties as function of mass (see Vioque et al. and Pérez-Blanco et al. in these proceedings).

Acknowledgements. The STARRY project has received funding from the European Union's Horizon 2020 research and innovation programme under MSCA ITN-EID grant agreement No 676036.

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