Active OB stars: structure, evolution, mass loss, and critical limits
Proceedings IAU Symposium No. 272, 2010
C. Neiner, G. Wade, G. Meynet & G. Peters, eds.

doi:10.1017/S1743921311010775

Activity of Herbig Be stars and their environment

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Abstract. The Herbig Ae/Be stars are the high-mass counterparts of the T Tauri stars, and are therefore considered as the pre-main sequence progenitors of the A/B stars. These stars are still contracting towards the main sequence, and are surrounded by dust and gas, remnants of their parental molecular cloud. In order to understand the formation processes at high mass, as well as the magnetic and rotation properties of the MS A/B stars, it is fundamental to understand the structure of the circumstellar matter of the Herbig Ae/Be stars, as well as the interaction of these PMS stars with their close environment. In this talk I will review our current knowledge about the properties of the circumstellar environment of the Herbig Ae/Be stars as well as the possible physical processes at the origin of their observed activities.

Keywords. stars: pre–main-sequence, stars: activity, stars: circumstellar matter, stars: early-type, stars: emission-line, stars: formation

1. Introduction

In this paper I will review the current knowledge of the environment and activity of Herbig Ae/Be (HAeBe) stars by focusing only on the observed common properties and phenomena among Herbig Ae (HAe) and Herbig Be (HBe) stars. More information on the activity and environment of HAe stars can be found in various reviews on HAeBe stars (e.g. Waters & Waelkens 1998, Dullemond & Monnier 2010). This review is certainly not exhaustive and might reflect the interest of the author.

The following sections introduce first the reader to the objects called the Herbig Ae/Be stars, then discuss the pre-main sequence evolution in the HR diagram for intermediate- and high-mass stars, in order to give the definition of the HAe and HBe stars that I will use all along the paper. Section 2 and 3 will describe the environments of these stars, while a summary is given in Section 4.

1.1. *The Herbig Ae/Be stars*

In order to find the higher mass counterparts to the T Tauri stars, pre-main sequence (PMS) stars of low-mass, Herbig (1960) defined a sub-class of objects with the following criteria: (*a*) the spectral-type is A or earlier, with emission lines, (*b*) the star lies in an obscured region, and (*c*) the star illuminates bright luminosity in its immediate vicinity. While the emission lines condition has been chosen by analogy with T Tauris stars, condition (*b*) has been defined to select young stars in close proximity with their birthplaces, which excludes more evolved objects (e.g. Wolf Rayet or Be stars), and condition (*c*) guarantees the physical association of the star with its surrounding dark cloud.

Since Herbig (1960), the selection criteria evolved, and the number of members of HAeBe stars increased. Finkenzeller & Mundt (1984) remarked that the HAeBe stars are characterised with a stronger IR excess. The most complete, and most recent, catalog of HAeBe stars has been compiled by Thé *et al.* (1994, TWP hereinafter), that listed

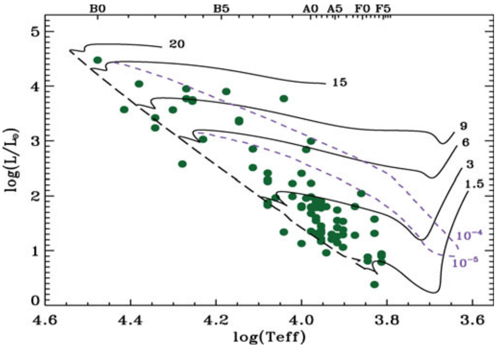

Figure 1. A sample of 80 HAeBe stars plotted in an HR diagram (Alecian *et al.* in prep.). The PMS evolutionary tracks has been computed using the code CESAM (Morel 1997).

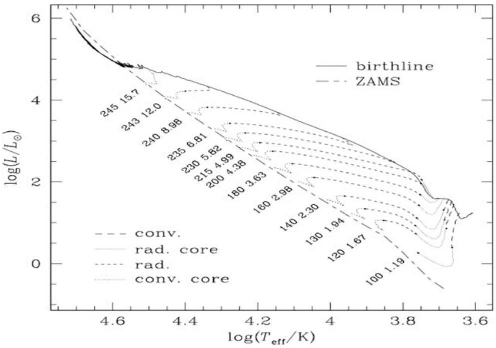

Figure 2. PMS evolutionary tracks calculated by Behrend & Maeder (2001). Couples of numbers represent the age of the stars on the ZAMS (in unit of 10^3 yr), and its mass.

108 HAeBe members, all of spectral type Ae and Be, as well as 23 probable members with spectral type Fe. All these stars respect one of the HAeBe criteria chosen by TWP: a strong near- or far-IR excess. In addition, the members and probable members can fulfill one or more Herbig (1960) criteria, as well as many others such as: an anomalous extinction law, or the Mg II (2800 Å) doublet in emission.

Since the work of Thé *et al.* (1994), the selection of Herbig Ae/Be members has been mainly done with the presence of IR excess and/or emission lines (e.g. Hernández *et al.* 2004), and includes spectral types of F5 and higher. Not all HAeBe stars can be associated with an obscured region or a bright nebulosity, but most of them are (see Vieira *et al.* 2003). New HAeBe candidates have been identified by many authors, often associated with star forming regions, or young clusters or associations (e.g. Pauzen *et al.* 2007). Today the exact number of HAeBe stars is unknown, but from the works of Thé *et al.* (1994) and other authors previously cited, we can estimate the number of field HAeBe stars around 140.

1.2. *Evolutionary status of the Herbig Ae/Be stars*

The pre-main sequence nature of the HAeBe stars has been confirmed by Strom *et al.* (1972) who demonstrates that all the stars of their sample have surface gravities appropriate to pre-main sequence or zero-age main sequence stars. Alecian *et al.* (in prep.) made a spectropolarimetric suvey of about 80 stars, and plotted all the stars in the HR diagram (Fig. 1)superimposed with PMS evolutionary tracks at different masses and the zero-age main sequence (ZAMS), computed with CESAM 2K (Morel 1997), as well as the birthlines computed by Palla & Stahler (1992) using two mass accretion rates during the proto-stellar phase: 10^{-5} and 10^{-4} $M_\odot.yr^{-1}$. The birthlines are defined by the loci in the HR diagram where newly born stars become visible in the optical wavelength.

Palla & Stahler (1993, PS93 hereinafter) argue that the mass accretion rate during the proto-stellar phase should be identical at all masses and equal to 10^{-5} $M_\odot.yr^{-1}$, due to the lack of HBe stars more massive than about 6 $M_\odot$. Since their work, many massive HAeBe stars have nonetheless been identified (Fig. 1), and the question about the appropriate mass accretion rate is still unanswered. It seems reasonable to assume that the protostellar accretion rate could vary within a reasonable range depending on the mass of the core. Behrend & Maeder (2001, BM01 hereinafter) proposes that the mass accretion rate depends of the mass of the growing star. As a result, the mass accretion rate should therefore be larger for larger mass of the formed star. In Fig. 2 are plotted the birthline and the PMS evolutionary tracks calculated by BM01. While, with a unique accretion rate of 10^{-5} $M_{\odot}.yr^{-1}$ as proposed by PS93, the mass maximum of a PMS star is around 6 $M_{\odot}$, a modulated mass accretion rate, as proposed by BM01, allow the birthline to reach the ZAMS at much higher masses (around 20 $M_{\odot}$).

Massive Herbig Ae/Be stars are therefore theoretically predicted, and are observed. I will call the Herbig Be (HBe) stars, stars with masses larger than 5 $M_{\odot}$, and Herbig Ae (HBe), stars with masses comprised between 1.5 and 5 $M_{\odot}$. In Fig. 1, most of the Herbig Be stars have spectral types earlier than B4. For simplicity, I will consider in the following that B4 traces a reasonable limit between HAe and HBe stars. The following of this paper will justify the choice of this limit.

In Fig. 1, we observe easily that the number of HBe stars is much smaller than the number of HAe stars. Two main reasons can explain this: (i) the PMS evolution at high-mass is much faster than at intermediate-mass, and (ii) the confusion can very often be made between classical Be stars and Herbig Be stars. Furthermore, for long time it was assumed that massive Herbig Be stars couldn't exist. For all these reasons our knowledge of the environment of the Herbig Be stars is less developed than for the Herbig Ae stars, as will be shown in the following of this paper.

2. Properties of the environment of the Herbig Ae/Be stars

2.1. *The gaseous environment*

2.1.1. *Large-scale molecular surroundings*

The physical association of Herbig Ae/Be stars with their associated dark clouds has been demonstrated by Finkenzeller & Jankovics (1984), by measuring no significant motion of a sample of 27 HAeBes relative to the clouds. The first radio surveys of these stars seem to show that they are located near the edges of their parent cores. The characteristic sizes were evaluated between 0.1 and 0.8 pc, and their masses between 150 and 2000 $M_{\odot}$. Large column density gradients, near the positions of the central stars, suggest a gas clearing, either by the interaction between the stars and the cores, or by internal molecular dissociation (e.g. Hillenbrand 1995).

Molecular outflows (Fig. 3) have also been detected in many Herbig Ae/Be stars (e.g. Levreault 1988, Matthews *et al.* 2007). Many of them appear bipolar. Their sizes are ranging from 0.07 to 5 pc, and the expansion velocities are estimated between 6 and 60 $km.s^{-1}$. While outflows are commonly observed in young stellar objects, the physical processes at the origin of these outflows are still highly debated, but seem to be strongly correlated with jets driven by the central young stars (e.g. Bachiller 1996).

2.1.2. *Gaseous structure of the environment at lower scales*

The interferometric millimeter and submillimeter observations of the environment of many HAeBe stars allowed to explore the gas and dust closer to the star, and revealed disk of cold gas in Keplerian rotation (Fig. 4), sometimes with a central gap (e.g. Mannings & Sargent 1997, 2000). Panić *et al.* (2010) have even measured a difference in temperature between one side and the other of the disk. The origin of this asymmetry is still not understood. The sizes of the disks have been estimated between $\sim$ 85 and $\sim$ 450 AU, while their masses range from $\sim$ 0.005 to $\sim$ 0.03 $M_{\odot}$. The work of Dent *et al.* (2005) revealed a decrease of the disk mass with time.

The inner gas structure (< 100 AU) of the environment of the Herbig Ae/Be stars can be probed using the IR and UV signatures of molecules. The first studies of the inner gas have used the infra-red (IR) spectral lines of CO and H^2O, which are consistent

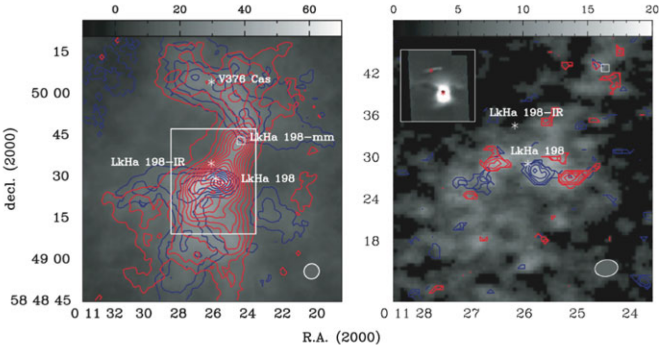

Figure 3. Gray scale showing the zeroth moment over the entire range of CO emission toward the region surrounding LkHα 198 (*left*), and centered on LkHα 198 (*right*). Optically visible HAeBe stars are marked as stars, while the embedded millimeter source is indicated by the square. Contours illustrate the emission toward us (blue) and opposite to us (red) (Matthews *et al.* 2007).

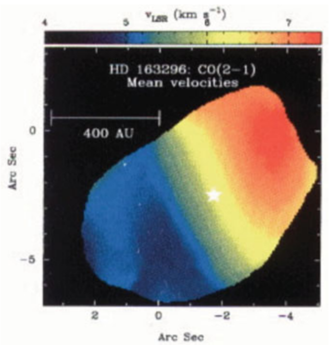

Figure 4. Intensity weighted-mean velocities of the CO radio emission observed around HD 163296. The star symbol represents the star position (Mannings & Sargent 1997).

with hot gas distributed in a disk (e.g. Najita *et al.* 2007). However the properties of the gaseous disk derived from these minor tracers must be considered with caution, as many assumptions used in the models are poorly known (see Deleuil *et al.* 2010).

H^2, the main gaseous constituent of the close environment of HAeBe stars, is difficult to detect in the IR, and can be easily contaminated with background extended emission (e.g. Thi *et al.* 2001, Sheret *et al.* 2003). While many attempts of H^2 detection have been made for HAeBe stars (Carmona *et al.* 2008), only two positive detections have been reported. The inner gas seem to be located in a disk within $\sim$ 35 AU or less, and its mass is estimated in a range of 10^{-2} to 1 $M_{\rm Jup}$ (e.g. Martin-Zaïdi *et al.* 2007).

Contrary to the IR-domain, thousands of H^2 emission or absorption lines can be observed in ultraviolet (UV), and have been detected in many HAeBe stars (e.g. Bouret *et al.* 2003). The few studies of the UV H^2 lines, that can trace warm gas within 1 AU, revealed the presence of a flared-disk and warm and/or hot excited media very close to the HAe stars, while the observations of the HBe stars are more consistent with a photodissociation region (PDR), and therefore a large circumstellar envelope (e.g. Martin-Zaïdi *et al.* 2008). Martin-Zaïdi and collegues argue that the difference observed between HAe and HBe stars comes from the fastest evolution of the most massive stars, around which it is more likely to find molecular remnants.

Vink *et al.* (2002) propose to probe the structure of the innermost environment of HAeBe stars by studying the linear polarisation accross the emission profile Hα. Their work show that the regions emitting Hα are flattened on small scales. Based on differences in the signature of the linear polarisation between HAe and HBe stars, they argue that while in HBe the scenario of a classical accretion from the disk to the star is favoured, magnetospheric accretion is more likely to happen around the Herbig Ae stars.

2.2. *The dusty environment*

2.2.1. *The spectral energy distribution*

The IR-excesses of the HAeBe stars, are assumed to come from the dust in the close environment of the star, reprocessing the stellar light. Hillenbrand *et al.* (1992) analysed the spectral energy distribution (SED) of 47 HAeBe stars, and showed that 30 HAeBe stars of their sample display SED consistent with a model of disk with a central hole.

They derived disk masses in the range 0.01 to 6 $M_\odot$, the radii of the inner edges from 15 to 175 AU, as well as mass accretion rates, for which more realistic values (from 3.10^{-9} to 10^{-6} $M_\odot.yr^{-1}$) have been estimated by Garcia Lopez *et al.* (2006).

Malfait *et al.* (1998) proposed an evolutionary scenario, based on the various SED shapes of the HAeBe stars (Fig. 5): (a) first the star is still embedded in its molecular cloud, in which the SED is dominated by the IR excess ; (b) the environment is flattened, with a central hole between the star and its accretion disk, and the SED can now be reproduced by a single-dust temperature model ; (c) after some time a two-temperature model fit better the SED, indicating a gap inside the disk, that could be due to planet formation ; the two last steps describe β-Pictoris like (d) and Vega-like (e) stars, with only far-IR excess, that decreases with time as the dust disk vanishes.

Other authors (e.g. Meeus *et al.* 1998) propose that the differences observed in the SED can also be due to the line of sight inclination, the inner disk holes, and other physical parameters. Miroshnichenko *et al.* (1997) even proposes that the SED shapes can be reproduces with spherical envelopes. The modeling of the SED to probe the circumstellar dust of HAeBe stars should therefore be done with other restraining observations, such as interferometric data (e.g. Eisner *et al.* 2004).

2.2.2. *Direct detection*

Direct evidence of dust disks have first been obtained with continuum radio observations, showing disks of smaller size and much less massive ($\sim 10^{-4}$ $M_\odot$) than the gas disk (Mannings & Sargent 2000). Coronography and IR imagery allowed to detect the disk of few stars with sometimes the inner hole or a gap inside the disk (e.g. Augerau *et al.* 2001, Wisniewski *et al.* 2008). Adaptive optic have also been able to image the disc around few Herbig Ae/Be stars (e.g. Chen *et al.* 2006). The inner cavities appear optically thin in the HAe stars, while there is evidence that optically thick inner cavities are more often observed in HBe stars (Monnier *et al.* 2005, Kraus *et al.* 2008).

IR interferometric data of various HAeBe stars have been interpreted as flared disk with an inner puffed-up rim (e.g. Doucet *et al.* 2007, Eisner *et al.* 2007). The flared disk scenario have also found strong support with the work of Lagage *et al.* (2006), by observing an offset between the peak flux of the emission of the circumstellar material, and the geometrical center of the image of the emission (see also Okamoto *et al.* 2009). IR imaging polarimetry (e.g. Hales *et al.* 2006) and milimeter interferometry (Raman *et al.* 2006) bring also other evidence of flaring disks.

2.2.3. *Disk properties*

The inferred disk scales from the various data vary from 0.3 to 1000 AU (e.g. Eisner *et al.* 2003, Okamoto *et al.* 2009). The work of Eisner *et al.* (2007) revealed a radial temperature gradient systematically steeper in HBe stars, than in HAe stars.

IR spectroscopy of many HAe/Be stars have revealed the presence of PAH (Polycyclic Aromatic Hydrocarbon) as well as silicate (e.g. Acke & van den Ancker 2004). No correlation is observed between PAH and silicate emission, however a clear correlation between PAH and the mid-IR excess is observed. Meeus *et al.* (2001) proposed a model to reproduce these observations (Fig.6): the disk around HAeBe stars is composed of 3 components: (I) an optically thick, geometrically thin disk causing the near and far-IR excess (observed in all the stars), (II) an optically thin/thick inner puffed-up rim causing the silicate emission (observed in all the stars), and (III) a geometrically thick, optically thin flared dust layer below and above the midplane of the optically thick, geometrically thin disk, responsible of the PAH emission and the strong mid-IR excess (only observed in stars displaying PAH emission). All stars possess components (I) and (II), while only

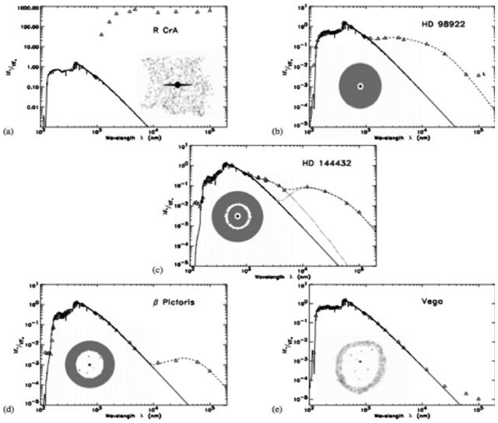

Figure 5. The evolutionary scenario proposed by Malfait *et al.* (1998).

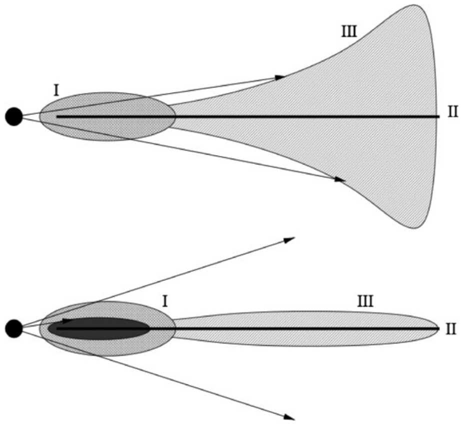

Figure 6. The model of HAeBe disks proposed by Meeus *et al.* (2001).

few of them possess the flared components. In the other stars an optically thin dust layer is still present but cannot be flared due to the optically thick puffed-up inner rim that block the UV radiation from the stars. This qualitative model have been developed quantitatively by Dullemond *et al.* (2001), and tested with success on many HAeBe star (Eisner *et al.* 2003, Acke & van den Ancker 2004).

According to Dullemond *et al.* (2001), the disk inner rim is heated due to the direct exposition to the stellar flux, and therefore is puffed-up. The assumption of a puffed-up inner rim is required to reproduce the near-IR and interferometric properties of HAeBe stars (e.g. Natta et al. 2001, Tatulli *et al.* 2007). Furthermore, a puffed-up rim can only appear if the inner part of the disk is optically thin. The observed inner holes in many HAeBe stars (e.g. Grady *et al.* 2005), as well as the low mass accretion rate derived by Garcia Lopez *et al.* (2006) are therefore additional arguments in favour of this model.

The origin of optically thin cavities observed between the stars and the innermost edge of the disk is still not well understood, and different theories exist. The presence of a magnetosphere, and the action of magnetospheric accretion could be one of the reasons of the clearance. Indication of magnetospheric accretion have ben observed in HAe stars (e.g. Muzerolle *et al.* 2004, Mottram *et al.* 2007). Another theory is the planet formation. Many clues of ongoing planet formation can be found in the literature, such as discret absorption component in the UV and optical spectra (e.g.Grady *et al.* 2006), or long-term photometric cyclicity (e.g. Shevchenko & Ezhkova, 2001).

In the case of HBe stars, their UV radiation could be sufficient for photodissociating the innermost part of the disk. Many clues of photodissociation around HBe stars have been obtained recently: Okamoto *et al.* (2009) have detected photoevaporation tracers in the IR spectrum of HD 200775 ; the mass of the disks around HBe stars are usually 5 to 10 times smaller than those around lower mass stars (Alonso-Albi *et al.* 2009) ; and Berné *et al.* (2009) showed HBe IR spectra typical of photodissociated regions.

All these recent results show that the impact of the stellar radiation on the gas and matter surrounding HBe stars is relatively important in determining the structure of the close environment of these stars.

2.2.4. *Accretion diagnostics*

While many clues of magnetospheric accretion onto the T Tauri stars exist, it is not clear if accretion exists and how it operates onto HAeBe stars. Contrary to the T Tauri stars, there isn't any clear evidence of magnetospheric accretion, such as veiling, or the presence of blueshifted forbidden emission lines (e.g. [OI] 6300 Å). We observe, however, in some stars, Hα profiles similar to the T Tauri ones, which are therefore assumed to have the same origin. We also observe inverse P-Cygni profiles, or redshifted circumstellar absorption features. However these features can be well understood in terms of clumpy accretion, which is enforced by typical spectroscopic and photometric variability (e.g. Mora *et al.* 2004). While most of these clumpy accretion diagnostics are observed in HAe stars, we can observe them also in few HBe stars (e.g. Boley *et al.* 2009).

2.3. *Winds and jets*

Finkenzeller & Mundt (1984) have detected P Cygni profiles in the Hα and Mg II h & k lines, in a large number of HAeBe stars. The presence of P Cygni profiles definitely confirm that some Herbig Ae/Be stars possess a stellar wind. Böhm & Catala (1994) argue that the presence, in about half of their sample, of forbidden emission lines, such as [OI] (6300 Å), centered on the stellar radial velocity, indicates the presence of a stellar wind. Radio emission detected in HAeBe stars by Skinner *et al.* (1993) is predominantly thermal, and in many cases wind-related. Finally, spectro-interferometric observations, around the Brγ line, of few HAe/Be stars are better interpreted with the presence of an optically thick disk, and a stellar wind whose the apparent size is much larger than the disk extension (e.g. Malbet *et al.* 2007).

Beside the presence of large-scale molecular outflows driven by HAeBe stars, mentioned in Sec. 2.1, optical outflows, such as Herbig-Haro (HH) objects or jets, have been associated with many Herbig Ae/Be stars (e.g. Ray *et al.* 1990, Gomez *et al.* 1997). According to Mundt & Ray (1994) these outflows are 2 to 3 times faster than those driven by low-mass objects, and 70% of them are highly collimated. Recently, collimated bipolar microjets driven by HD 163296 and HD 104237, have been detected very close to the stars, at distances down to 7 AU (e.g. Grady *et al.* 2004).

The origin of the winds and jets associated with HAeBe stars is poorly understood. Corcoran & Ray (1997) propose the theory of accretion driven winds. They argue that the positive correlations observed between the forbidden emission lines [OI] and Hα, or the IR excess, imply a strong link between outflows and disk. However, in many HAeBe stars, the absence of high-mass disks (especially in HBe stars), as well as the evidence of low-mass accretion rates (e.g. Garcia Lopez *et al.* 2006), are indication of passive disk. In the HBe stars, that emit a strong radiation field, theories like radiation driven winds might be more appropriate (e.g. Babel & Montmerle 1997).

3. The activity of the Herbig Ae/Be stars

I will only expose below our knowledge on magnetic related activity of Herbig Ae/Be. The reason is that other activity types (photometric variability or pulsations) have only been reported in HAe stars (e.g. Herbst & Shevchenko 1999 ; Böhm *et al.* 2004).

3.1. *Evidence of magnetic fields in Herbig Ae/Be stars*

Many indirect evidence of magnetic fields are observed in Herbig Ae/Be stars. Highly-ionised species, such as N V or O VI, are observed in emission in the spectra of HAeBe stars (e.g. Roberge *et al.* 2001), and X-rays have also been reported in HAeBe stars (e.g. Hamaguchi *et al.* 2005). These emissions are believed to come from very high-temperature regions close to the stellar surface, such as hot corona or chromosphere (e.g. Bouret *et al.* 1997). Non-thermal radio observations of few HAeBe stars have also been reported by Skinner *et al.* (1993), suggesting a magnetic origin. Finally, rotational modulations of wind lines have been observed in few HAeBe stars, and are interpreted as being formed in winds structured by magnetic fields (e.g. Catala *et al.* 1991).

For all these reasons, Herbig Ae/Be stars have been assumed to host magnetic fields. Many attempt of direct magnetic detection have been made without much success (e.g. Catala *et al.* 1999, Wade *et al.* 2007). Until recently only one marginal detection in HD 104237 have been reported by Donati *et al.* (1997). It is only with the emergence of the new generation of spectropolarimeters ESPaDOnS and Narval, installed at the Canada-France-Hawaii Telescope (CFHT, HAwaii) and at the Telescope Bernard Lyot (TBL, France), respectively, that a large survey of HAeBe stars could be performed, leading to the detection of 8 magnetic stars, and an incidence of $\sim 6\%$ (e.g. Alecian *et al.* 2009).

The origin of the magnetic fields in Herbig Ae/Be stars and in their decedents, the main sequence A/B stars, is highly debated. These stars possess a small convective core surrounded by a large radiative envelope. Some very young HAeBe stars are even totally radiative. They therefore lack the convective envelope favourable to the generation of magnetic fields, as in the low-mass stars. It has been known for long time that about 5% of the main sequence A/B stars possess strong magnetic fields, organised on large-scales, and stable over many years (e.g. Donati & Landstreet 2009). None of the theories including a core dynamo have been able to reproduce the magnetic characteristics of these stars (Moss 2001).

Today, the favoured hypothesis is a fossil origin. This theory implies that the magnetic fields observed in the main sequence A/B stars are remnants of fields either present in molecular clouds from which these stars formed, or that they were generated by a dynamo during the early stages of star formation. The spectropolarimetric survey of HAeBe stars have brought very strong argument in favour of this hypothesis, by discovering that the progenitor of the magnetic A/B stars possess also strong magnetic fields organised on large scales, and that are stable on many years (Wade *et al.* in prep.). A fossil link has therefore been established between the PMS and the MS phases of intermediate- and high-mass stars.

3.2. *X-rays from Herbig Ae/Be stars*

The first large studies of X-ray emissions from HAeBe stars, using the satellites *Einstein* and *ROSAT* lead to an X-ray incidence close to 50% (e.g. Damiani *et al.* 1994). Thorough studies of binarity of HAeBe stars showed that most of the X-ray emission in the direction of HAeBe stars can be attributed to one or more close late-type companions (Stelzer *et al.* 2009). However in few cases, it is very unlikely that a late-type companion is responsible of the X-ray emission, and in 2 peculiar cases (AB Aur and HD 104237), based on detailed analyses of X-ray data, the companion theory has been totally rejected (e.g. Telleschi *et al.* 2007). Most interesting are the X-ray periodic variability of AB Aur and HD 104237 coinciding with the rotational periods of the stars (Telleschi *et al.* 2007, Testa *et al.* 2008), but also with the period of the modulations of non-photospheric lines formed in the winds (e.g. Catala *et al.* 1999). In addition, AB Aur and HD 104237 show the presence of emission lines of highly ionised species, confirming the existence of high-energy phenomena in their surroundings. Besides, Damiani *et al.* (1994) observed that the HBe stars are X-ray brighter than HAe stars. Such a correlation is not expected in the low-mass companion theory. Some HAeBe stars are therefore very likely X-ray emitters. Among them we find 2 HBe stars HD 259431 and HD 200775, that share some of the high-energy properties of AB Aur and HD 104237. These stars are therefore not unique and seem to describe a specific sub-class.

The most promising theories, capable of explaining the observed X-ray properties of this class of stars, involve magnetic fields: the Corotating Interaction Regions (CIR, Bouret *et al.* 1997) and the Magnetically Confined Winds Shocks (MCWS, Babel & Montmerle 1997). However, no correlation is observed between the presence of magnetic fields and the emission of X-rays in HAeBe stars : while HD 104237 and HD 200775 have been detected as magnetic, AB Aur and HD 259431 do not possess strong magnetic fields. On the other side, Bouret *et al.* (1997) argue that a surface magnetic field of only 100 G in the CIR theory would be sufficient to reproduce the UV and X-ray properties of AB Aur, which is below our limit of magnetic detection ($\sim$ 500 G, Wade *et al.* in prep.) Magnetic fields, too faint to be detected, could therefore exist in more HAeBe stars, and could be at the origin of the X-rays in HAeBe stars.

4. Summary

At large-scale the molecular gas surrounding the Herbig Be stars seem to be concentrated in disks. Molecular outflows, such as jets and winds are also observed at very large-scales. Molecular gas has been detected down to few AU, and is very likely distributed in flared disks, but also in hot media very close to the star. Spectropolarimetric and UV observations seem to describe differences between HAe and HBe stars, the latter being surrounded with classical accretion disk and molecular remnants, while the former could experience magnetospheric accretion, and lack of molecular remnants.

Combined with other type of data (e.g. UV, optical, or IR spectroscopy), the analysis of the SED of HAeBe stars reached the conclusion that HBe stars are also surrounded with dusty disk, which have been directly detected using various instrumentation. The current favoured scenario consists of flared-disk with a puffed-up inner rim, heated by the radiation field of the star. The photometric and spectroscopic differences observed between HAe and HBe stars could be explain by the absence of flared-disk in HBe stars, either because the disk would have been photodissociated, or because the puffed-up inner rim is too opaque for allowing the external part of the disk to flare, or a combination of both. Many other clues have been recently obtained indicating photodissociation around HBe stars. This could therefore explain the presence of much less massive disk around HBe than around HAe stars. The strong radiation field of the HBe stars seem to have a largest impact on the structure of its environment, than in HAe stars.

While it sounds evident that PMS HBe stars are still accreting from their disk, there is no clear indication of accreting matter onto the stars. The nature and physical origin of this potential accretion is still an open question.

Strong clues of stellar winds have been reported from spectroscopic and interferometric observations. Optical jets and Herbig-Haro objects have also been associated with many HAeHBe stars. The physical processes at the origin of these outflows are not known. While accretion driven mechanisms could be active in HAe stars, the evidence of passive disks around HBe stars does not favoured this hypothesis.

While indirect magnetic proofs have been observed for long time in HAeBe stars, it is only recently that direct detections of magnetic fields in HAeBe stars have been obtained. Their characteristic strongly support a fossil link between PMS and MS A/B stars. However the detailed processes of this theory during the star formation are not known, and should be investigated in the future in order to validate it.

There are convincing arguments that a small number of HAeBe stars emit X-rays. While the favoured hypotheses for their origin include all magnetic fields, no clear observational link has been drawn between X-rays and magnetic fields. More investigation of these theories and of the X-ray and environment properties of these stars are required in order to understand the high-energy phenomena observed around them.

To conclude, many work has been done in order to understand the properties of the environment of the HAeBe stars. However most of them concern only HAe stars, which is due to a very small number of known HBe stars. In order to progress in this domain, it is crucial to increase this number. A very efficient way is to observe very young clusters and associations. It would increase the HBe number by factor of at least 10. However these clusters are far away and magnitude limited for the current ground instrumentation. In the future it would therefore be very helpful to increase the sensibility of our instrumentation and to be able to use it on bigger telescope (the 8m and 40m classes).

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Discussion

WISNIEWSKI: Recent coronographic imaging surveys which examine the radial surface brightness profiles show a wide range of power-laws for Group I vs Group II Meeus sources (see e.g. Grady *et al.*, Wisniewski *et al.*), which raises very serious doubts that there is an evolutionary sequence between Group I and Group II. Also, some Group II show jets (e.g. HD 163296) which shouldn't be present if they were older systems.

GAGNE: In the magnetically detected HAeBe stars, you have magnetic dipole geometries and field strengths that can be input into modified versions of existing magnetic/wind models (RRM, RFHD, MCWS, cf. the work of Towsend *et al.* and Owocki *et al.*).

MIROSHNICHENKO: We have just finished modelling of our results of high-resolution spectro-interferometry of the Herbig Be star MWC 297 in the Brackett-gamma line region. An accretion-powered disk-wind model was used. We were able to successfully reproduce the Br-gamma line profile as well as the line and nearby continuum visibilities. This may lead to a better understanding of the mentioned problem of the hydrogen emission origin in Herbig Ae/Be stars.