Observational aspects of Herbig Ae/Be stars and of candidate young A/B stars

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SUMMARY AND CONCLUDING REMARKS

1. The scientific aims of this thesis

The original goal of my thesis was to study the variabilities of Herbig Ae/Be (HAeBe) stars. As the photometric behaviour of many HAeBe objects are well known, mostly irregular variations, in some cases up to several magnitudes and occurring on different timescales (see the case of UX Ori in Chapter A4), it was intended to study possible spectroscopic variations and to learn if any co-variation exists along with the photometric changes. In order to study the variations in the line profiles of HAeBe stars by intensive monitoring, it is necessary to select relatively bright objects that exhibit photometric activity. Studying the existing lists of possible HAeBe candidates available at that time (1991), we noticed that the sample of bright HAeBes was small and heterogeneous. This conclusion was drawn by examining the observational properties of the listed objects. Besides searching for new bright HAeBe candidates, presented in Chapter A2, it was also important to obtain a more comprehensive picture about HAeBe stars, i.e. how are they defined and what is known about their observational properties? The results of this investigation are described in Chapter A1.

Another issue discussed in Chapter A1 is the importance in the study of HAeBes to consider different evolutionary phases of these young stars. In fact it is interesting to know how typical HAeBe properties, such as the infrared excess, photometric variability and the emission lines, gradually disappear as the young object evolves towards the main sequence; in other words, by what mechanism and how the circumstellar material will be dissolved. Major questions here are, whether or not there is a simple cleaning mechanism by the central hot star and its wind, in case the wind itself is (partly) induced by accretion effects (see Chapters A3 and A4), and/or if there is a mechanism in which clumpy material clean up the circumstellar matter, in which the collisionally grown bodies, the planetesimals, will finally form planets by coalescing. To my opinion, answers to these questions must fit in a more general evolutionary scenario. This view is supported by one of the presented highlights, the discovery of two very young objects, UX Ori and BF Ori, both revealing the existence of accreting bodies in their circumstellar environment. In the past, comet-like bodies were found near just one possible young object: β Pic.

In order to start the above described investigations, we have to rely on what is available in the literature. At the start of this project, the literature did however provide only in some individual cases a complete set of data which met the properties indicating the Herbig Ae/Be qualification. Usually, the presence of a star forming region is taken into consideration.

A large observational programme has been started to obtain the complete datasets which are needed for a more detailed study on the properties of HAeBe stars with respect to their evolutionary status. Low resolution spectroscopy and photometric observations were made for many objects of list I in the new Herbig Ae/Be catalogue (Chapter A1). Although only Southern hemisphere objects were included in the programme, the amount of data to be gathered is extremely large. The project is still in progress and nearly finished for the Southern stars. Parts of this study are presented in this thesis. In Chapter A5, the IR-excess of HAeBe is studied. Although the results are promising, this study has not yet been completed. For several objects, reliable spectral type and the distance, is lacking, for some objects the latter will be available from Hipparcos results.

2. Why is it important to have a large sample of genuine HAeBes?

The broad study described above is to collect a large homogeneous sample of genuine HAeBe stars. This is important because HAeBe stars are of a wide variety of spectral types, from early B to late A. It should be noted here that such a group comprises a large mass interval: from 2 up to 10 solar masses. The spectral and temperature ranges are dramatic: B0 to A8 comparable to a temperature interval from 30,000 down to 7,500 K. The consequence is, that to achieve the above described goals, one needs a large sample of genuine HAeBe objects. As indicated above, such a large sample was not available at the start of this project. Furthermore, one might wonder why just a few (about 110) good HAeBe candidates are known. This will shortly be discussed in Sect. 4.

3. Is the HAeBe class well defined?

Two very important conclusions which can be drawn from the catalogue, presented as Chapter A1, and from the HAeBe IR-excess study (Chapter A5) are, (a) the properties of the hotter Herbig Be stars are incompatible with the less luminous HAeBe, and (b) a broad sample of F-type young stars is absent.

Examining the pre-main sequence (PMS) evolution of the more massive stars, Palla & Stahler (1993) show that the PMS evolutionary times are typically of the order of 10^7 yrs, or even less. Objects of spectral type earlier than B2 can not be observed in their PMS phase; only as infrared accreting protostars. Although this PMS phase depends on the accretion onto the protostar and on the metallicity (Lamers et al. 1996), this phase is relatively short. Therefore, detecting early Be stars as Herbig Be objects (that is, massive stars in their pre-zero-age-main sequence phase) is very difficult. Note that their IR properties and their position in the HRD (see Chapter A5) suggest that these early type Herbig Be stars are probably post-main sequence objects. It must be remarked that these objects can also still be relatively young, several 10^7 yrs (Maeder & Meynet 1988). Therefore, it is not striking that several Be objects do show HAeBe characteristics as has been observed for a number of peculiar Be stars, for instance the B[e] stars. Examples are the embedded luminous B[e] sources CD-42°11721 and HD 87643, which both can be found in lists of HAeBe stars. Another possible B[e]/Herbig Be star, HD 45677, is discussed in Chapter B4. Again the difficulty to disentangle young Be stars from true PMS stars is illustrated in that chapter.

For the F-type stars, it is remarkable that their presence in lists of possible PMS objects, both T Tauri and HAeBe stars, is
low. This is certainly due to the following. Many astronomers study only T Tauri stars, solar and usually cooler than the sun, while only a few colleagues study HAEBe candidates. In the search for planetary systems and their formation this "ignored" group of PMS stars might be the key sources. In my future work I will certainly study these objects intensively as a possible link between T Tauri and HAEBe stars.

4. Young stars in clusters

As stated in several parts of this thesis, homogeneous samples of young stars are available in young open clusters, in which the distances are approximately the same. A study of the well known "Eagle Nebula", is presented in Chapters C1 and C2.

The basic new idea in the study of the open cluster NGC 6611 is to treat members individually. For each programme star a complete dataset, consisting of low resolution spectroscopy and multi-wavelength photometry, is necessary in order to obtain astrophysical parameters and information on the extinction law in the direction of the object. In previous open cluster studies, one obtains only averaged cluster properties based on the assumption of a general extinction law. Employing the presented method, we have found only a small number of stars to have HAEBe characteristics. Although NGC 6611 contains many very young A- and B-type members, of which the ages must be similar to that of HAEBe stars, i.e. they are in their PMS phase, they do not show the typical HAEBe properties. Their spectroscopic and IR properties reveal the absence of strong emission lines in several cases and/or combined with the absence of a near-IR excess in most of them. Not much can be said about their photometric behaviour since no extensive photometric data are available.

These results indicate strongly that in NGC 6611 the very young A and B type stars do not have (enough) circumstellar material. In fact such objects resemble "classical" Be stars. A possible explanation is the strong radiative influence of the luminous hot OB-type members of the cluster. This is supported by the recent discovery of evaporating gaseous globules (EGGs) in NGC 6611 (Hester & Scowen 1995).

In Chapter C2, it was also suggested that in crowded fields where OB-type objects are present, the circumstellar envelope of a young star close to those hot stars can not survive long enough to form of a flattened circumstellar structure (and ultimately planets?) which is the basic ingredient for having HAEBe properties. Support for this idea is that in other young open clusters, having a number of hot OB-type members, a lack of typical HAEBe stars also occur (Pérez et al. 1996, in preparation). This important conclusion can also help to explain why so few HAEBe stars have been identified. When simultaneous massive and intermediate-mass star formation occurs in a relative short time, circumstellar disks around PMS stars will therefore be rare.

5. Binarity among young stars

In stellar evolution binarity is an interesting and intriguing phenomenon, which can not be ignored. However, the difficulty is to know whether or not an object is part of a multiple system. Some stars are known to have optically or spectroscopically detected counterparts. In the catalogue of Chapter A1 of HAEBe stars, only less than 10% are reported to be members of a multiple system, whereas it is generally accepted that two third of the stars are "born" in multiple systems. This suggests that many of the HAEBe stars in the lists might have a companion. Recent and on-going studies to detect companions of HAEBes (Leinert et al., 1994) indicate a much higher number (up to about 30%) of binaries among HAEBe stars.

In this thesis, a possible detection of a T Tauri companion around the probable young star, HR 6000, is reported (see Chapter B6). HR 6000 itself has as proper motion companion HR 5999, a well known HAEBe star. As they are therefore probably of the same age, it should be questioned why HR 6000 has not been observed as a typical Herbig Be star. An explanation might be its higher mass compared to that of HR 5999, which again indicates that it is difficult to trap a young B star as a HAEBe object in its short PMS phase.

Another example of differences in observational properties which occur in neighbouring young objects are TY CrA and HD 176386. Both are located in the same reflection nebula, both have the same spectral type and might therefore be considered as being of the same age. TY CrA has typical HAEBe characteristics: photometric variability, IR-excess and emission lines, HD 176386 is in all its observed properties a normal B9 main sequence star. TY CrA is found to have an eclipsing companion, which means that we see its circumstellar disk about edge-on. It is still an open question whether this is the cause of the different behaviour of TY CrA with respect to HD 176386 of which the disk might be orientated pole-on. It then remains still not yet clear why no emission lines are seen and why only a little IR-excess is present at HD 176386.

Above examples show that it is interesting, maybe fundamental, to study the consequences of the presence of a companion on the observable HAEBe characteristics, and the influence of this object on the evolution of the circumstellar material.

6. The UXOR group

Several well known HAEBe stars are located in relatively empty regions. Examples are given in list I of Chapter A1. A number of these objects belongs to the so-called UXOR group, consisting of HAEBe stars such as UX Ori, BF Ori, WW Vul and CQ Tau, as discussed in Chapters A3 and A4. This sample of HAEBe stars shows a remarkable photometric behaviour and from simultaneous polarimetric and photometric studies we know that a circumstellar flattened disk is present around these objects. The photometric and polarimetric changes can be understood by the obscuration of revolving bodies in the circumstellar disk. Since it was one of the original aims of this thesis to investigate this enigmatic field, several objects within the UXOR group were studied by high resolution spectroscopy.

As a first result, we have detected a spectacular new phenomenon. Redshifted lines of cool gas probably indicate infall of material from the outer parts of the circumstellar disk of these stars. A follow up study supports these observations and put some constraints on the minimum size of the infalling bodies and on the distance at which they might evaporate. Furthermore, the observations suggest that there might be large orbiting bodies around these objects. The observations, combined with other preliminary results indicate that this phenomenon can be observed for all members of the UXOR group.
The importance of detecting accreting and orbiting bodies around young stars is that circumstellar disk planetesimals may exist, which can lead to larger collisionally grown bodies, and that circumstellar disk material is replenished by cool material accreting from the outer parts of this disk. This will generate a higher value of the refractory to volatile gas ratio; this change in abundances is extremely important for the formation of (inner) planets.

This study should be extended to some older objects, i.e. young main sequence stars of about the same mass. For the selection of such stars, we need to know the evolutionary status of young A- and B-type objects. Therefore, a fundamental study of the astrophysical properties of a selection of candidate young stars (see Sect. 1) is necessary. The results of high resolution spectroscopic studies of this sample may answer the question whether or not ξ Pic is unique in its properties or not (the latter seems to be the case).

Extending this study further to lower mass stars, will lead us to the understanding of the origin of the sun, planets and life.

References