Revista Mexicana de Astronomía y Astrofísica, **29**, 54-58 (1994)

THE CLUMPY ACCRETION IN HERBIG Ae/Be STARS

M. Pérez [1]
IUE Observatory/CSC, NASA-GSFC, U.S.A.
and
P.S. Thé
Astronomical Institute "Anton Pannekoek", University of Amsterdam,
The Netherlands

RESUMEN

En años recientes observaciones a varias longitudes de onda han sugerido que en los objetos de masa intermedia o estrellas Herbig Ae/Be, el gas se está acumulando hacia el objeto central a grandes velocidades. La prueba más directa de este fenómeno proviene del análisis de la forma de las líneas ultravioletas. Las observaciones aquí descritas proveen pruebas adicionales y complementarias a esta interpretación. Revisamos evidencias observacionales, derivadas de varios objetos, que indican que hay acumulación grumosa de masa en su vecindad circunestelar.

ABSTRACT

In the last few years much multiwavelength observational evidence has accumulated suggesting that in some of the intermediate-mass Herbig Ae/Be stars, gas is accreting toward the central source at large terminal velocities. The most direct proof of this phenomenon has come from the analysis of the ultraviolet lines. Concurrent and complementary support for this interpretation are provided by diverse observations described here. We review the strong observational evidence from several of these objects in support of the concept of clumpy mass accretion occurring in their circumstellar environments.

Key words: **STARS: EMISION-LINE — STARS: PRE-MAIN SEQUENCE — CIRCUMSTELLAR MATTER**

1. INTRODUCTION

Several new studies have suggested that Herbig Ae/Be (HAEBE) stars ($2 \leq M/M_{\odot} \leq 8$, Palla & Stahler 1993), are surrounded by viscously heated accretion disks which are the potential evolutionary precursors of more evolved systems like β Pic. Despite the prediction of stellar evolution that protostars exclusively generate their energy from gravitational contraction, the concept of mass accretion in pre-main sequence (PMS) stars was not initially considered as a mechanism to interpret the observations because it was thought not to be directly detectable. In this paper we concentrate on the observational evidence supporting accretion.

2. OBSERVATIONAL EVIDENCE

Since Herbig's (1960) observational definition of these objects, the interpretation of the activity, variability and related phenomena in these stars has been in terms of classical astrophysical schemes. For example, the most surprising discovery coming from UV spectroscopy was to find that there were several emission lines in

[1] Guest Observer with the *International Ultraviolet Explorer* at NASA-Goddard Space Flight Center.

their spectra, such as N V, C IV, O III, O I, C II, and Mg II. Traditionally, these emissions have been interpreted in terms of arising from ('thick' or 'thin') chromospheres and/or stellar winds (c. Catala 1989), in analogy to main sequence late- and early-type stars, respectively.

HAEBE stars are not as well-studied as the T Tauri stars, the latter identified as PMS objects already as early as the mid-1940's. The PMS nature of the HAEBE stars has been demonstrated only since the mid-1970's by Strom et al. (1972, 1975), who found that along with the presence of IR excesses many of these objects have surface gravities appropriate to PMS stars. In the ultraviolet, PMS solar-type stars present a high contrast effect in their spectra, which make them equally interesting; consequently the interpretation of their observations seems to be in a far more advanced stage when compared with HAEBE stars.

Nevertheless, in a recent blitz of publications on HAEBE stars, there is convincing and abundant evidence for the detection of accreting gas (e.g., R Cr A in Graham 1992; BF Ori in Welty et al. 1992; HR 5999 in Pérez et al. 1993; HD 176386 in Grady et al. 1993a; HD 45677 in Grady et al. 1993b; etc). Similarly, in a study including a larger sample of HAEBE stars, Hillebrand et al. (1992) analyzed the IR excesses of 47 objects and found that they can be classified into 3 main groups depending on their ages. In the younger group, 30 objects with large IR excesses, spectral energy distributions can be well fitted by assuming excess emission above the photospheric levels arising in a geometrically flat, optically thick circumstellar accretion disk. Likewise, from a detailed study of high-dispersion *IUE* SWP images, Blondel et al. (1993) detected broad and redshifted Lyman α emission in several systems, among which there were three HAEBE systems (HD 163296, HD 104237, and HR 5999); the Lyman α emission in these objects was interpreted as arising by recombination of infalling matter onto the central source. The derived accretion rates, based on this emission are, in general, lower than the ones calculated from the IR excesses by Hillebrand et al. (1992).

In the case of T Tauri stars which were found soon after their discovery to be very young objects of low mass, the strength of the ultraviolet emission lines and continuum excesses were interpreted as an indication of chromospheric activity (cf. Calvet et al. 1984; Herbig & Goodrich 1986). However, after some difficulties with the chromospheric models, it became evident that the interplay of boundary layers and accretion disks can better explain the integrated spectra of T Tauri stars (e.g., Bertout et al. 1988, references therein). Most of the observed photometric and spectroscopic features in T Tauri stars can now be understood in terms of a model in which a low-mass PMS star is surrounded by a circumstellar accretion disk. This is the current view supported by most of the community regarding PMS low-mass stars.

3. THE INDECISIVE INFRARED

The clear evidence that many of the classical HAEBE stars present large near-IR and far-IR excesses has led to the interpretation of diverse mechanisms as capable of reproducing their spectral energy distributions. Near-IR, far-IR and mm observational evidence has been excluded from this review since it has led to contradictory results; for example, supporting the disk/accretion view are Hillebrand et al. (1992), Hammann & Persson (1992), and Lada & Adams (1992); supporting the spherical dust envelope view are Berrilli et al. (1992), and Hartmann et al. 1993); finally Skinner et al. (1993) provides warning that the accretion mass rates derived by Hillebrand et al. (1992) appear to be overestimated. Furthermore, Natta et al. (1993) argue that the IR excesses may come from material not intimately associated with the PMS star.

4. OBSERVATIONAL DIAGNOSTICS

We summarize here the observational signatures, aside from the IR arguments, that have indicated the presence of extended disks and clumpy accretion phenomena in HAEBE stars. We emphasize that most of the evidence for accretion is indirect since it is not possible to directly observe the drift of material from the outer disk toward the inner disk and onto the central source.

• **Ultraviolet accreting lines.** The variable column density of accreting gas in the line-of-sight can be detected by the dramatic changes in the red absorption wings of low-ionization species (Pérez et al. 1993). This phenomenon has been well-studied in more evolved stars such as β Pic (Boggess et al. 1991), 51 Oph (Grady & Silvis 1993) and HD 176386 (Grady et al. 1993a).

• **Lyman α emission.** The presence of highly redshifted Lyman α emission in several stellar systems was interpreted by Blondel et al. (1993) to be due to recombination of infalling matter onto the central source. Therefore, the relevant question is: Is Lyman α a diagnostic of accretion? Several on-going surveys seem to indicate that other systems with known accretion properties also show Lyman α redshifted emission (e.g., CH Cyg, four T Tauri stars, several interacting binaries - AE Aqr, 17 Lep). The survey of objects with Lyman

α emission is brightness limited since only objects brighter than V $\leq$ 10 can be observed with *IUE* in high-dispersion for a full detection of the emission. A strong reason to favor accretion over other mechanisms is the energy budget consideration which can be summarized in the following statement: the energy needed to produce Lyman α emission at the intensity and redshift that have been detected in several of these systems is *not* compatible with passive mechanisms such as chromosphere, magnetic fields and sunspots.

- **Mg II emission lines.** These P Cygni lines can be reinterpreted as arising in high latitude winds from accretion disks, based on the theoretical framework presented by Shlosman & Vitello (1993) which deals with the formation of ultraviolet lines from accretion disks (see Figure 5 in their paper), these models can clearly reproduce the Mg II detected in HAEBE stars.

- **Superionization regions.** The emission primarily of N V, C IV is produced in regions hotter than 10^5 K, which has been interpreted as arising from chromospheric activity, although the onset of chromosphere has been placed at spectral types later than A7. In classical models, emission coming from Mg II, O I, C IV and from other lines originated in a "chromosphere-like" or "super-ionization" region (T$\sim 8 \times 10^5$ K) of uncertain origin, since the photosphere for a massive star in this temperature range was expected to be radiative, rather than convective.

- **Shift toward earlier spectral types with decreasing wavelength.** A trend of inferred spectral type shifting to earlier types with decreasing wavelength, larger UV excesses during episodes of high optical luminosity, and a flux distribution which is not consistent with a single-temperature stellar model, has previously been observed in lower mass PMS stars, particularly in stars undergoing FU Orionis-type outbursts (Hartmann & Kenyon 1985). These phenomena have been interpreted as evidence for the presence of emission from an optically thick accretion disk and boundary layer. The case of HR 5999 is presented in Pérez et al. (1993).

- **Absence of photospheric lines or photospheric veiling.** The lack of photospheric lines consistent with the rotational velocities has been suggested as the hallmark of the presence of thick disks around stars. These systems also present indications of variability due to accretion phenomena. For example, for the star R CrA, Graham (1992) confirmed that the photosphere is not visible in the region of 5150–9100 A.

- **Blueing effect.** Many HAEBE stars vary in brightness sometimes up to 2 or 3 magnitudes in a relatively short time. When, during these brightness variations the magnitude is plotted against the color index (e.g., *B-V*), we observe that the star is becoming redder when the brightness is reduced. However, after a certain magnitude has been reached, several stars show a color-reversal; the stars become bluer again when they are dimmed further (see Bibo & Thé 1991 for a discussion). This effect has also been detected in accretion disks around black holes (e.g., see the case of LMC X-3 in Cowley et al. 1991).

- **Polarimetric data.** Optical and UV polarimetric data also reveal the strong evidence of disks around these objects. In the case of HD 45677 (irregular B[e] star) from optical and UV polarization measurements reported by Schulte-Ladbeck et al. (1992), it is noted that the angle between the optical and UV polarization vectors differ by 90°. The polarization of the emission lines in the UV is consistent with formation in a bipolar flow or disk-wind normal to the circumstellar disk.

- **Strong correlation between brightness decrease and increase of linear polarization.** This correlation seems to confirm that the obscuration is due to external agents to the central sources. This is particularly true for the so-called isolated HAEBE stars (e.g., Grinin et al. 1991).

- **Photometric flickering**. Large variabilities in the timescale of minutes and hours are classically interpreted due to the instabilities in accretion flows (Livio 1994). Likewise, the random "pulsed-shaped" optical variability in the timescale of several days (Pérez et al. 1992) has also led to arguments for the presence of large instabilities due to internal phenomena (as opposed to external phenomena such as binarity which is periodic).

- **Spectroscopic flickering**. Short-time spectral variability in low-ionization absorption lines have also been interpreted as arising from clumpy accretion. Graham (1992) for some high-mass stars in the Corona Australis star-forming region found spectral variability of R CrA and T CrA, which was interpreted as being due to variable accretion onto the central stars.

5. CURRENT VIEW

The spherical models of dust and gas may not be in total disagreement with the disk models since they appear to sample different regions, densities and physical conditions in the stars. The collapse of a primordial cloud with non-negligible angular momentum is not spherical; however, at large distances within the centrifugal radius, it appears spherical. Depending on the gas density and magnitude of the centrifugal radius, the presence of a disk near the star, recipient of the material falling into the star, may become detectable in the line of sight. In some HAEBE stars, the presence of accretion disks and a boundary layer, which mimic a photosphere, appear unavoidable. In these systems, the line of sight to the observer passes through different layers of optically thick and thin material yielding a multi-temperature spectra. It is possible that physical conditions can allow for the presence of pseudo-chromospheres in the atmosphere surrounding the boundary layer and accretion disk.

It is conceivable that bipolar flows are also present in these objects. The energetic Mg II winds found in the majority of these stars appear to be generated above the disks, since they do not present velocity shifts or large extinctions. Disks and protoplanetary clouds circulating in Keplerian orbits are suspected to be present at a large distance from the central source. The existence of these clouds explains the blueing effect by acting as a natural coronograph, as has been found when the stars are at minimum brightness. Arguments raised by Böhm & Catala (1994) on the absence of the well-known blueshift of forbidden lines present in T Tauri stars in HAEBE stars appear to be another indication of the disimilarity of HAEBEs rather than proof of the absence of disks and/or accretion in these objects.

We are grateful for the many discussions with a large number of colleagues, in particular, C. Grady, P. Blondel and D. de Winter.

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M.R. Pérez: IUE Observatory, Code 684.9, Goddard Space Flight Ctr., Greenbelt, MD 20815 U.S.A. e-mail perez@iuesoc.gsfc.nasa.gov.

P.S. Thé: Sterrenkundig Institute 'Anton Pannekoek', Kruislaan 409, NL-1098SJ, Amsterdam, The Netherlands