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DETECTION OF ACCRETING GAS TOWARD HD 45677: A NEWLY RECOGNIZED, HERBIG Be PROTO-PLANETARY SYSTEM

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Abstract

We report detection of high velocity, accreting gas toward the B[e] star with IR excess and bipolar nebula, HD 45677. High velocity (+200 to +400 km s^{-1}), variable column density gas, is visible in all IUE spectra from 1979-1992 in transitions of Si II, C II, Al III, Fe III, Si IV, and C IV. Low-velocity absorption profiles from low oscillator-strength transitions of Si II, Fe II, and Zn II exhibit double-peaked absorption profiles similar to those previously reported in optical spectra of FU Orionis objects. The UV absorption data, together with previously reported analyses of the IR excess and polarization of this object suggest that HD 45677 is a massive, Herbig Be star with an actively accreting circumstellar, proto-planetary

disk.

Subject Headings: Stars: Emission-line, Be, – Stars:Individual:HD 45677 Circumstellar Matter – Accretion – Stars: Pre-Main Sequence– ultraviolet: Stars

1. INTRODUCTION

The evolutionary state of galactic B[e] stars has been a topic of lively discussion with suggestions ranging from pre-main sequence Herbig Ae/Be (HAEBE) stars to evolved, post-Asymptotic Giant Branch (AGB) objects. While both classes of stars have circumstellar dust which may be distributed in disks, post-AGB stars tend to exhibit bipolar nebulosity and high velocity outflows which are most prominent at optical minimum (Kwok, 1990). Accreting material has not been reported for these stars as a group. In contrast, recent studies suggest that many of the IR - UV features of HAEBE stars are associated with accretion disks (Lada and Adams 1992; Hillenbrand et al. 1992). Accreting gas has been observed in a number of these systems (Pérez et al. 1993; Graham 1992; Chavarria-K. et al. 1989; Hamann and Persson 1992; Welty et al. 1992). All of the HAEBE stars with accreting gas exhibit large amplitude, aperiodic light and color changes (Bibo and Thé 1991). A number of these have polarimetric data suggesting that we view circumstellar disks edge-on (Grinin et al. 1991).

Since the most distinctive difference between the evolved and young objects is the presence or absence of accreting material, moderate resolution spectra sampling a range of ionization stages and elements can constrain the evolutionary state of B[e] stars viewed through their circumstellar dust disks. We present a discussion of recent and archival IUE high dispersion spectra of one of the brightest B[e] stars, HD 45677.

2. HD 45677

The star, HD 45677 (B2 IV: [e], Burnichon et al. 1967; v sin i~200 km s^{-1}, Swings and Allen 1971) is an isolated star lacking nebulosity (Swings 1973). The complex optical spectrum includes emission from the Balmer series of hydrogen, Fe II, and a number of forbidden transitions. From 2000-3000 Åfluorescent Fe II emission (Stalio and Selvelli 1980), which is most prominent at optical minimum (Pérez et al. 1993b), dominates the spectrum. Photometric variability with $8.58 \leq V \leq 7.55$ (Mendoza 1958; Feinstein 1976; Halbedel 1989, 1992) has prompted Coyne and Vrba (1976), and more recently Halbedel (1992) to suggest

that the star is intermittently obscured by dust clouds.

The presence of an IR excess indicating circumstellar dust has been discussed by a number of authors (Low et al. 1970; Swings and Allen 1971; Allen 1973; Sitko 1980; Sorrell 1989). The IRAS two-color diagram (Figure 1), with regions as defined by van der Veen and Habing (1988), has proven useful in the classification of evolved stars with dust. As shown in Figure 1, Ae (open symbols) and Be (filled) stars from the Hillenbrand et al. (1992) survey are not limited to a specific region in the diagram. Nyman et al. (1992) note that region IIIa, where HD 45677 is located contains both somewhat evolved and comparatively young objects with warm circumstellar dust. The similarity in color of HD 45677 to known Herbig Be stars extends to the (J-H) vs. (H-K) two-color diagram (Lada and Adams 1992). Although the location of HD 45677 in these diagrams is not proof that it is a young star, its colors are consistent with those for a young, dusty star.

HD 45677 also exhibits intrinsic linear polarization with a wavelength dependence expected for polarization by dust grains (Coyne and Vrba, 1976; Schulte-Ladbeck et al. 1992), and with constant polarization position angle in the optical. UV spectro-polarimetry shows a gradual rotation of the observed position angle and a 90 degree flip in the intrinsic polarization with decreasing wavelength (Schulte-Ladbeck et al. 1992). The polarization data are consistent with some of the UV light being scattered in a bipolar nebula oriented orthogonally to the dust disk.

In combination, these data suggest that we view HD 45677 through its disk. To date, all HAEBE systems viewed at this inclination exhibit accreting gas. The availability of IUE high dispersion data enables us to test the hypothesis that HD 45677 is a massive, Herbig Be star with its disk oriented edge-on to our line of sight.

3. THE UV ABSORPTION PROFILES

Most of the absorption profiles in the UV spectrum of HD 45677 are seen from 1150-1950 Å corresponding to the IUE SWP camera. High dispersion spectra were obtained on 6 dates

from 1979-1992, with 8.69< $V(FES)$ <8.16, as estimated from the IUE Fine Error Sensor (FES) data using the calibration of Pérez and Loomis (1991) and a mean (B-V)=0.07 (van den Ancker 1992).

A distinctive feature of the UV absorption line spectrum of HD 45677 is the absence of rotationally broadened profiles consistent with a rapidly rotating B2 IV-III star. Instead, the spectrum is dominated by a strong shell spectrum. In contrast to the stronger Fe II lines, which are filled in by emission, weak transitions of singly ionized species such as the lines of Fe II (8) and Si II (1), and Zn II (1) 2025 Å (figure 2), have double-peaked absorption profiles, which in the stronger Si II transitions are represented by rather blocky absorption troughs. These profile shapes are not seen in classical Be star or shell star spectra, but have been observed in the UV spectra of one bright Herbig Ae star, HR 5999 (Pérez et al. 1993a), and are reminiscent of optical line profiles of FU Orionis-type objects (Welty et al. 1992b). In most of the spectra the absorption troughs are centered shortward of the nominal stellar radial velocity of 21.6 km s^{-1} (GCRV) which appears to correspond (Swings 1973) to the velocity of the optical, forbidden emission lines. Strong absorption in this velocity range is also seen in Al III, Si IV, and C IV, as well as in the lines of Fe III (34). The IUE data suggest that small amounts of N V may also be present. Detection of N V indicates the presence of collisionally ionized gas in the envelope of a B2 star (Marlborough and Peters 1987). The other ionization stages are routinely seen in UV spectra of normal early B stars and in the spectra of HAEBE stars such as HD 200775 and HD 259431 (Grady et al. 1988). The IUE data, despite limited S/N and velocity resolution, suggest that the blocky components increase in FWHM with increasing ionization.

Enhanced absorption on the long wavelength wing of UV resonance lines usually associated with stellar winds, and in the stronger lines usually associated with circumstellar shell features, is seen in all IUE spectra. Low ionization species such as Si II and C II exhibit absorption extending to +150-200 km s^{-1}. Transitions from higher ionization species such as Al III (1), Fe III (34), Si IV (1), and C IV (1) show enhanced absorption to +300-400

km s^{-1}. As shown in Figure 3, the column density of the gas between +200 and +400 km s^{-1} is highly variable. The IUE data suggest, independent of the stellar radial velocity, that material is accreting onto HD 45677. Similar line profiles are observed toward the Herbig Ae star HR 5999 (Pérez et al. 1993a), and in the spectra of β Pic (Boggess et al. 1991). In contrast, the Herbig Be stars HD 200775 and HD 259431 as well as the bright Herbig Ae stars AB Aur, HD 163296, and HD 104237, which are not believed to be viewed through dense circumstellar disks, show strong stellar winds.

4. DISCUSSION

Accreting gas has not previously been reported in spectra of evolved objects, for which evolutionary models predict a slow, dense wind component produced during the red giant phase, and a hot, fast, and comparatively tenuous component produced during periods when the star is blue. Accreting gas, however, has now been observed in optical spectra of HAEBE stars (Welty et al. 1992a; Graham 1992; Chavarria-K. et al. 1988; Hamann and Persson 1993) with velocities similar to those observed toward HD 45677. In contrast to the bright, unobscured HAEBE stars with the most extensive UV data, the optical photometric and polarimetric data for these objects suggest that we view the stars through their circumstellar disks, with the same geometry as inferred for HD 45677 (Schulte-Ladbeck et al. 1992). The combination of IR, photometric, polarimetric data and our detection of accreting material are all consistent with HD 45677 being a Herbig Be star.

Our detection of accreting gas toward HD 45677, together with the UV continuum and emission line analysis of Pérez et al. (1993b) suggests an evolution of the geometric model proposed by Schulte-Ladbeck et al. (1992). The correlation of the Fe II emission line visibility with increasing A_V, noted by Pérez et al. (1993b), suggests that the permitted emission lines originate in the bipolar nebula inferred by Schulte-Ladbeck et al. (1992). The IUE data suggest that the clumpy dust disk (Coyne and Vrba 1976) is not simply a passive disk, but is actively accreting (Plate 1). If the geometry of HD 45677 is typical of other HAEBE stars, the data for this object and the less heavily obscured objects suggest that the

bipolar emission line region may in fact be a dense, collimated stellar wind of the kind seen toward well-studied HAEBE stars such as AB Aur (Praderie et al. 1991).

Objects originally classified as HAEBE stars (Herbig 1959) were chosen on the basis of location in star formation regions and association with nebulosity to exclude classical Be stars. This criterion was not intended to serve as a rigorous identification criterion for young objects. However, the lack of extended nebulosity surrounding HD 45677 has prompted a number of observers to suggest that, rather than being a comparatively young object, HD 45677 might be an evolved star. Several HAEBE stars such as UX Ori (Grinin et al. 1991) and HD 163269 (Thé et al. 1985) are also isolated, as are other other bright, galactic B[e] stars with pronounced IR excesses due to circumstellar dust. Some of these B[e] stars, many of which have UV spectra similar to known HAEBE stars, are likely to represent previously unrecognized PMS stars. Collectively, these objects suggest that, as for low mass stars (Strom et al. 1993; de la Reza et al. 1989), star formation for 2-10 $M_{\odot}$ objects can occur in associations with a wider range in number of stars than has previously been considered. Production of intermediate mass PMS stars in very small associations which dissipate rapidly would naturally account for the presence of a large circumstellar disk around isolated stars such as β Pictoris.

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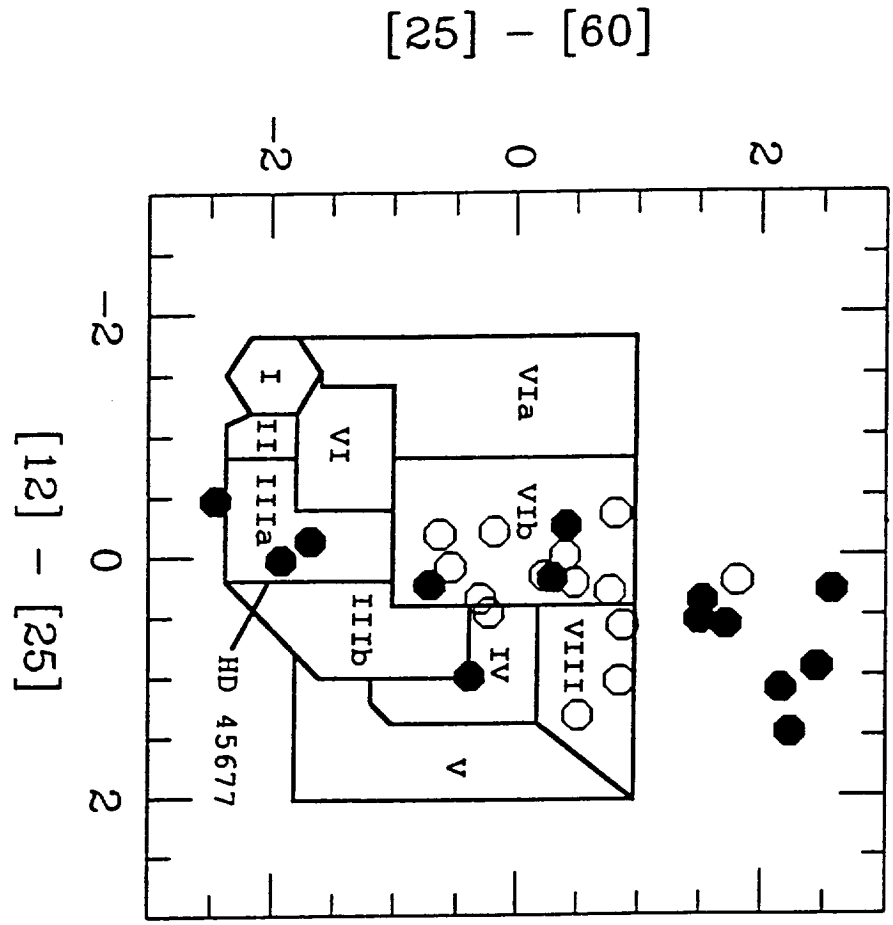
Figure Captions

Figure 1: The location of HD 45677 in the IRAS two-color diagram. Specific regions have been defined by van der Veen and Habing (1988). Herbig Ae (open symbols) and Be (filled symbols) stars from the Hillenbrand et al. (1992) survey together with 51 Oph, HD 50138 and β Pic are shown.

Figure 2: Absorption profiles from low oscillator strength transitions of Si II (1), Fe II (8), and Zn II 2025 Å as a function of heliocentric radial velocity. Transitions to the χ=0 eV level of the ground configuration are shown as light lines, while transitions to excited J-levels in the ground configuration, which should have minimal foreground interstellar contamination, are shown in bold.

Figure 3: High velocity, accreting gas toward HD 45677 in C IVλ 1548.2, Si IVλ1393.7, Al III (1)λ 1854.7, and Fe III (34)λ 1895.456. The left hand panel shows the spectra obtained on 1979 February 22 (SWP 4340, V=8.67, bold), and 1980 Nov. 21 (SWP 10652, V=8.63, light) at optical minimum. The right hand panel shows the data for 1990 Dec. 5 (SWP 40272, V=8.25, bold; in conjunction with the ASTRO-1 observation by WUPPE and HUT), and 1992 Dec. 21-22 (SWP 46548, V=8.16).

Plate 1: A cartoon for the HD 45677 system based on the accretion disk+ inner cavity model of Hillenbrand et al. (1992), the optical polarization data of Coyne and Vrba (1976), and the bipolar nebula of Schulte-Ladbeck et al. (1992). Our data suggest that the optically thin cavity in the dust disk is in fact filled with accreting gas, and in analogy to the known HAEBE stars viewed essentially normally to their dust disks, the bipolar nebula is likely to be a bipolar flow or disk wind.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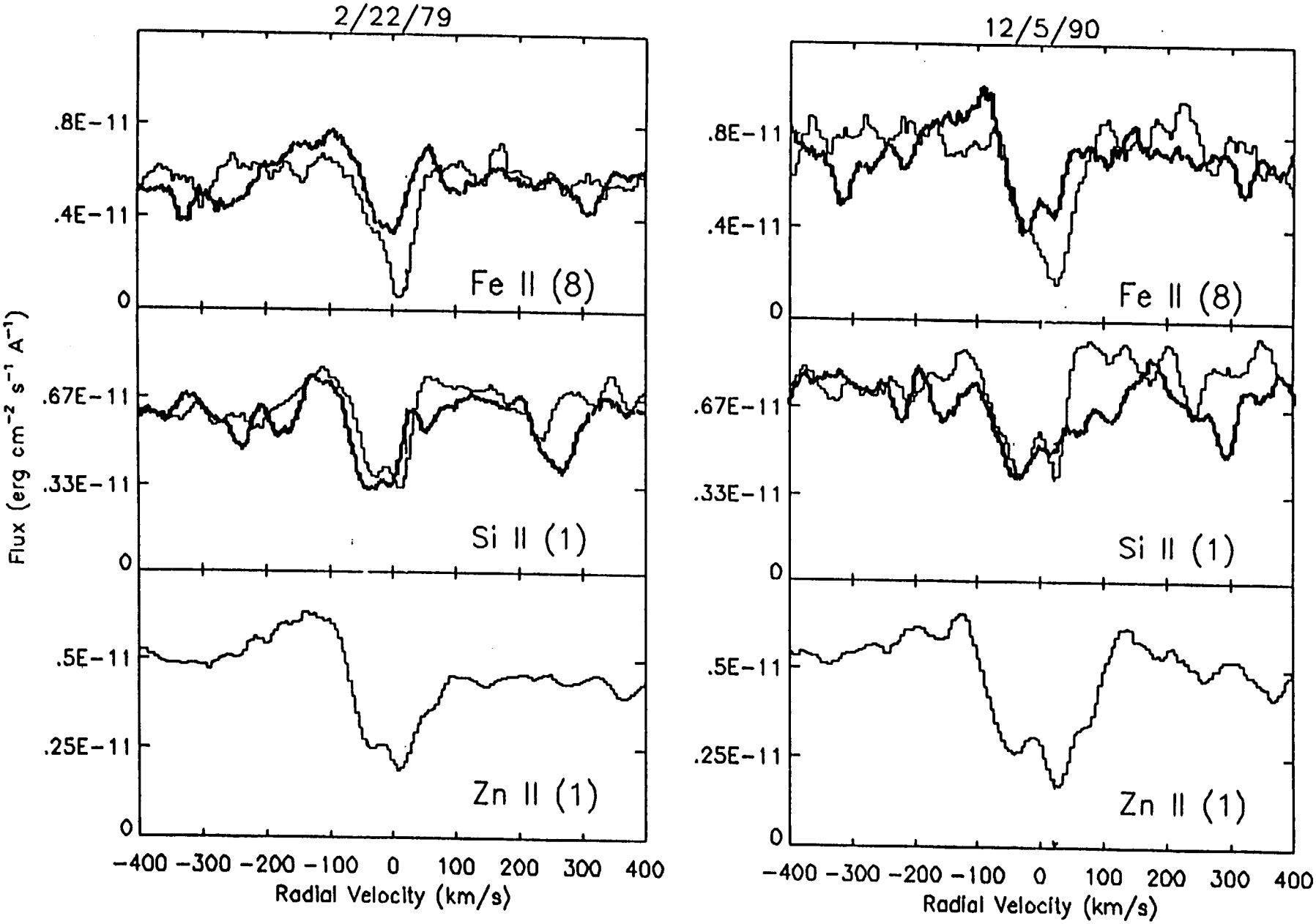
HD 45677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Zn II (1)
Flux (erg cm^{-2} s^{-1} A^{-1})
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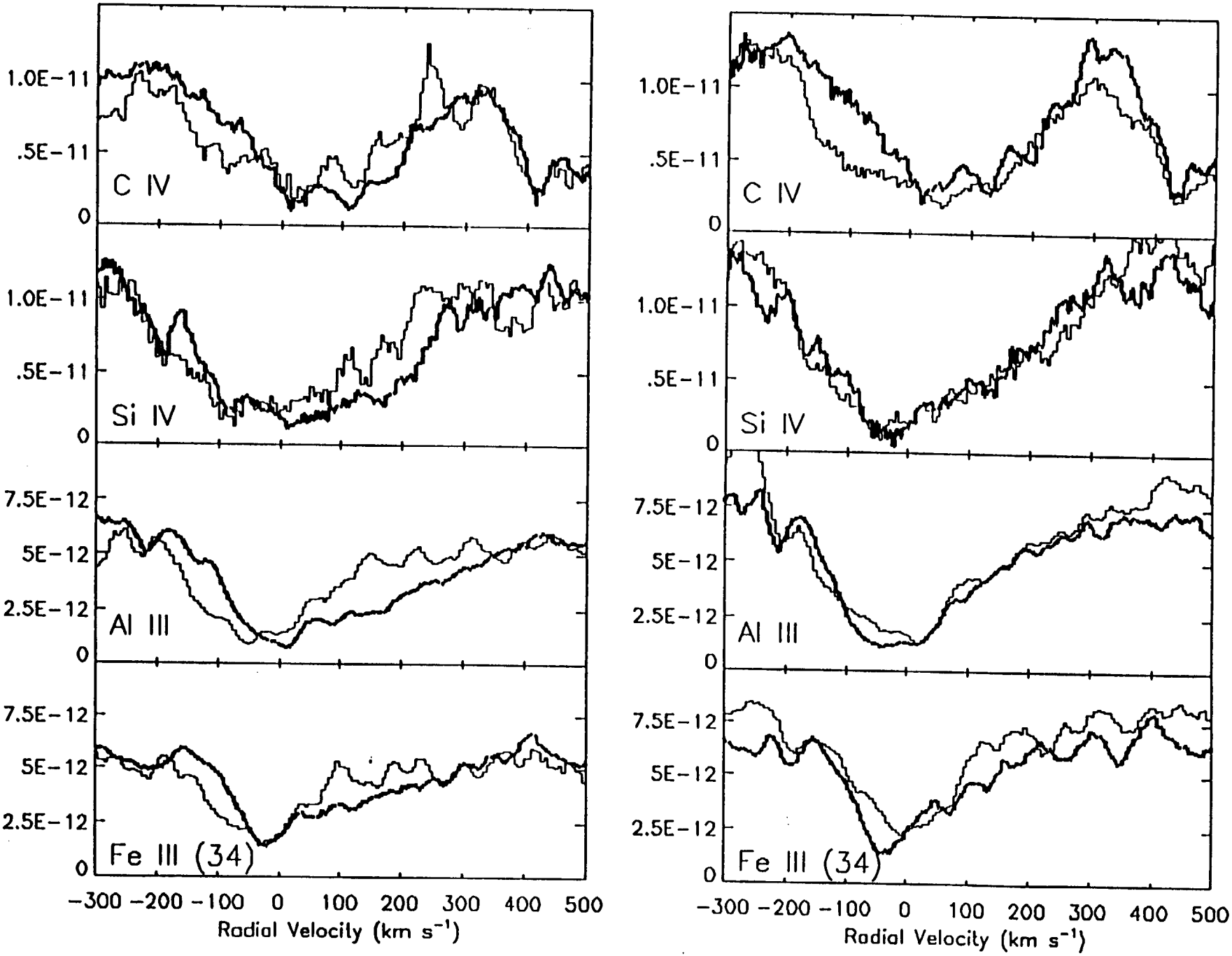
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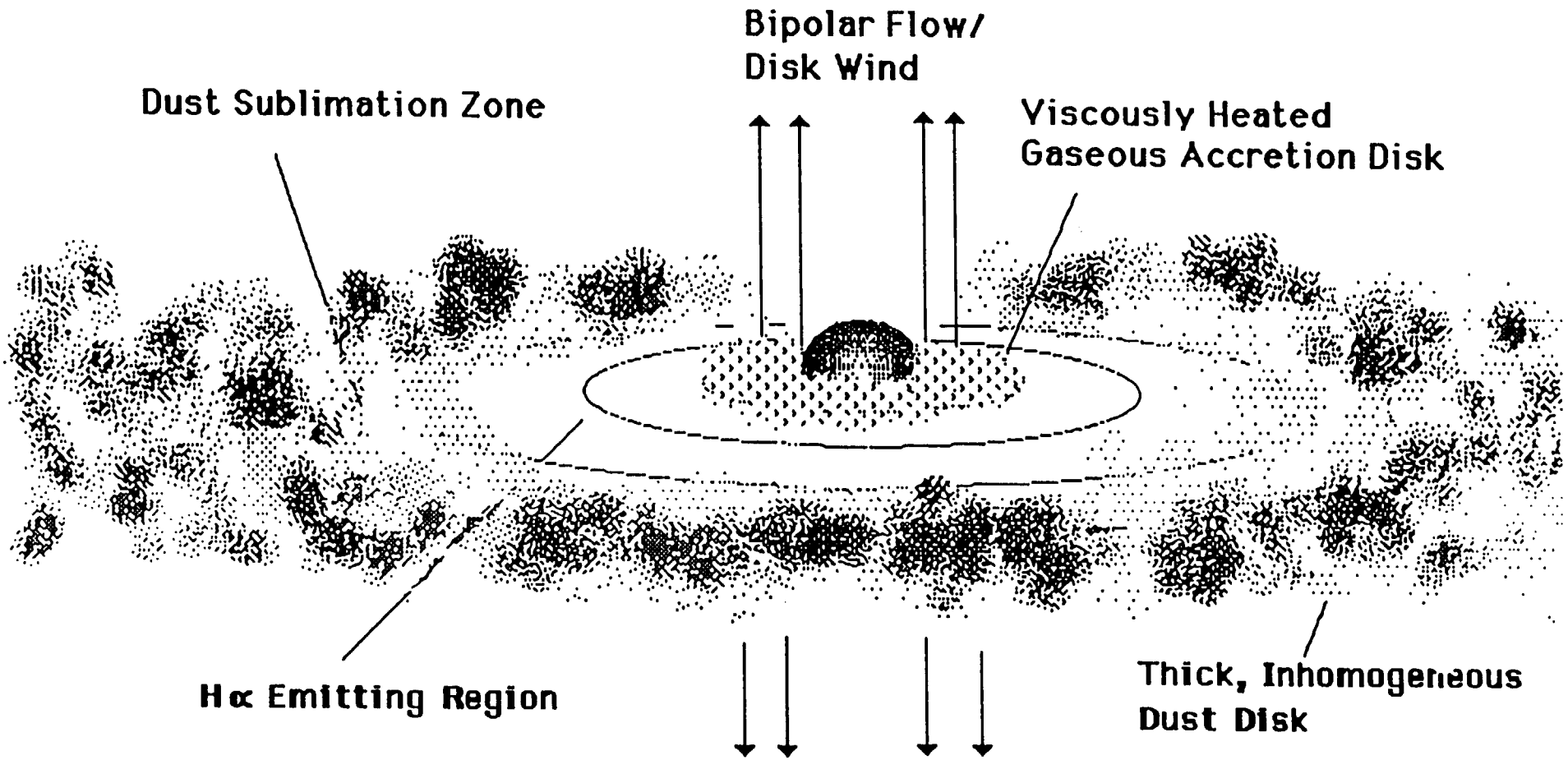
Radial Velocity (km s^{-1})


Bipolar Flow/
Disk Wind
Dust Sublimation Zone
Viscously Heated
Gaseous Accretion Disk
Hα Emitting Region
Thick, Inhomogeneous
Dust Disk