DETECTION OF ACCRETING CIRCUMSTELLAR GAS AROUND WEAK EMISSION-LINE HERBIG Ae/Be STARS

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Abstract.

We present archival and recent IUE high dispersion spectra of late B stars which reveal the presence of accreting gas with velocities as high as 350 km s^{-1}, collisional ionization of the accreting gas to temperatures above the stellar T_{eff}, and column densities intermediate between those observed toward classical Herbig Ae/Be stars and the nearby proto-planetary system β Pictoris. One of the stars, HD 176386, while lacking obvious optical signatures of youth, is a member of the R CrA star formation region, and with an inferred age of 2.8 Myr has not yet arrived on the zero-age main sequence (ZAMS). The other object, an isolated, field B star with pronounced IR excess due to warm, circumstellar dust, 51 Oph, exhibits only modest Hα emission. The combination of high velocity, accreting gas in systems with IR excesses due to circumstellar dust suggests that not only are these objects candidate proto-planetary systems, but that they may represent an extension to higher stellar masses of the weak-emission pre-main sequence (PMS) stars.

Key words: stars: early-type – circumstellar gas – proto-planetary systems – UV: spectroscopy

1. Introduction

Since the discovery of a large circumstellar disk surrounding the nearby A star, β Pictoris, some of the most important questions raised have been the age of the system, its relation to phenomena seen in pre-main sequence objects (PMS), and the time scale for the evolution of the circumstellar envelope to something resembling the β Pic system. Recent advances in the study of 2-10 $M_{\odot}$ PMS stars, the Herbig Ae/Be stars, suggest that these objects are surrounded by large, optically thick, viscously heated accretion disks (Hillenbrand *et al.* 1992), which apparently become optically thin on time scales of a few $\times 10^5$ years (early B stars) to 1.5 Myr (late A stars) (Strom and Edwards 1992).

Detailed studies of 2 Herbig Ae/Be systems, HR 5999 (Pérez *et al.* 1993a,b) and HD 45677 (Grady *et al.* 1992, 1993b), which are fortuitously oriented with the disk edge-on to our line of sight, demonstrate that the inner, optically thin cavities needed to fit the IR data are filled by optically thick, accreting gas with behavior similar to β Pic, although with substantially higher column densities in both the high velocity gas, and in the material seen near the system radial velocity. These data suggest that the β Pic system is comparatively young.

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TABLE I
HD 176386 and 51 Oph

Star	Spectral Type	v sin i	V_{max}
HD 176386	B9.5 IV	180	300
51 Oph	B9.5 IVe	220	100-150:

Due to the lack of stellar age indicators for mid-A stars, the suggestion of comparative youth for the β Pic system cannot be directly tested with additional observations of that object. Thus, it becomes important to explore the evolution of proto-planetary systems as the mass accretion rates begin to decline and the star approaches the ZAMS, with stars of similar orientation to β Pic, and known ages. A natural place to search for such systems is in areas of on-going or comparatively recent star formation with known distances, permitting accurate estimation of the stellar luminosity, and hence its location in the HR diagram and thence the age of the star.

One such star, which from its luminosity is still slightly above the ZAMS, and is lacking in obvious optical indicators of a high accretion rate such as strong ($W_{H\alpha} \geq$ 5Å) Hα emission, is HD 176386 (B9.5 IV, Grady *et al.* 1993a; $v \sin i$=180 km s^{-1}, Bibo, Thé, and Dawanas 1992, see Table 1). With its location in the R CrA star formation region and its inferred age of 2.8 Myr, this object may be the higher mass analog of the weak-emission line T Tau stars (Walter 1986), or if we adopt a parallel nomenclature, a weak-emission line Herbig Ae star. A very similar, but isolated, object of unknown age is 51 Oph (B9.5 Ve, $v \sin i$=220 km s^{-1}, Slettebak 1982) which IR (Waters, Coté, and Geballe 1988; Dougherty *et al.* 1991; Farjado-Acosta *et al.* 1992) and UV studies (Grady *et al.* 1991; Grady and Silvis 1993) have strongly suggested is another field, proto-planetary system similar to β Pic.

2. Detection of Accreting Gas

Both HD 176386 and 51 Oph are sufficiently bright to permit high dispersion (R=20,000) UV spectral observations with the IUE. As the brighter object, 51 Oph has been more extensively studied (Grady *et al.* 1990; Grady and Silvis 1993) and is known to exhibit variable column densities of accreting gas, similar to β Pic. The more recently identified system, HD 176386, has been observed on 3 dates spanning 5 years, most recently in 1992 September (see Grady, Pérez, and Thé 1993a for a more detailed discussion). The UV spectra of these proto-planetary system candidates share a number of features.

2.1. High Velocity, Accreting Gas

Only modest indicators of accreting gas are visible in the lower oscillator strength transitions of singly ionized species such as Fe II, Si II, Al II, and C II. The Mg II

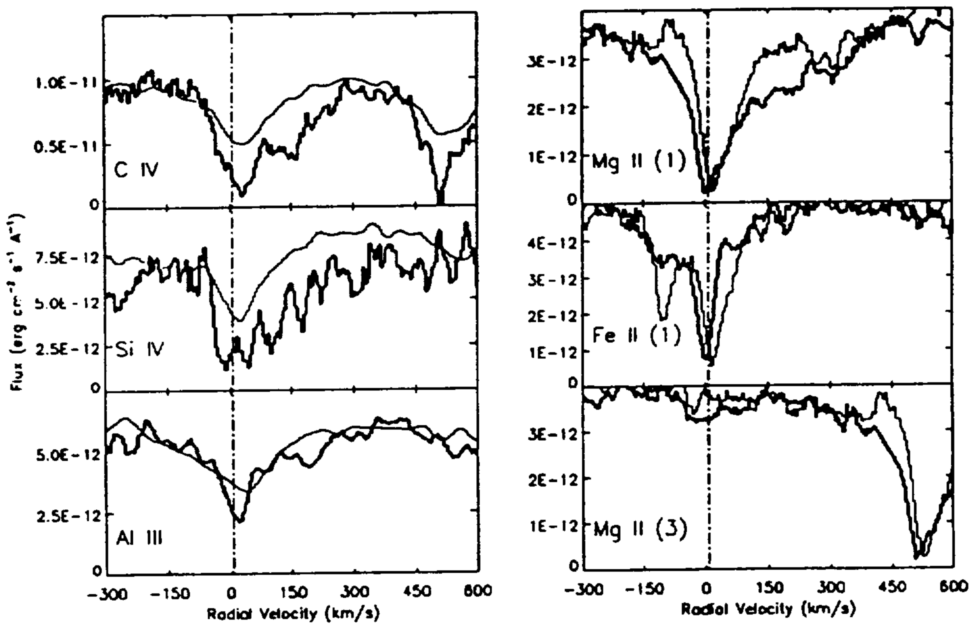

Fig. 1. Accreting gas toward HD 176386 (bold) and 51 Oph (light), in C IV 1548, Si IV 1393, Al III 1854, Mg II (1) 2795, Fe II (1) 2599, and Mg II (3) 2791 Å. The HD 176386 data are from 1992 September 23. The 51 Oph spectra have been chosen to exhibit the highest line-of-sight accretion and are from 1987 May 4 for C IV-Al III and 1989 March 12 for Mg II and Fe II).

(1) lines in both stars provide unambiguous evidence for the presence of excess absorption on the long wavelength side of the transitions extending to 90-100 and 220 km s^{-1} for 51 Oph and HD 176386, respectively. In the case of 51 Oph (Grady and Silvis 1993) the larger number of IUE observations demonstrate that the accreting gas is variable in column density, much as has been observed for β Pic. Transitions of higher ionization stages, such as the resonance doublets of Al III, Si IV, and C IV show much more pronounced profile asymmetries to positive radial velocities, with absorption in 51 Oph followed to +100-150 km s^{-1} and for HD 176386 to 300-350 km s^{-1} (Figure 1). For HD 176386, the 1992 September data show the C IV column density, which traces the highest ionization plasma observed toward this star, peaking at +30 km s^{-1}, and there is a suggestion of a secondary maximum in the column density at 150 km s^{-1}.

2.2. Collisional Ionization of the Accreting Gas

Detection of C IV and Si IV absorption in the spectra of very late B stars is unexpected, as is detection of absorption with the observed equivalent widths. At B9.5, no photospheric contribution to either species is expected, nor are main sequence stars of this spectral type expected to have sufficient FUV/ EUV fluxes to photoionize carbon or silicon to these stages anywhere in the vicinity of the star (Bruhweiler *et al.* 1989). Thus, detection of these species suggests that the circumstellar envelope of both stars is collisionally ionized to temperatures in excess of those expected from equilibrium with the stellar radiation field. The positive displacement of the largest apparent column densities of both species relative to the stellar velocities suggests that the collisional ionization occurs as the gas accretes onto the star.

2.3. Comparison with β Pic

The circumstellar envelope of β Pic displays similar signatures of collisional ionization, with the detection of Al III extending to +300-400 km s^{-1}, and the Al III apparent column density typically peaking near 60-80 km s^{-1} (heliocentric), a displacement of 40-60 km s^{-1} relative to the stellar radial velocity (Lagrange-Henri *et al.* 1987). Collisional ionization of accreting gas toward the two edge-on Herbig Ae/Be stars studied in detail to date is also observed, again with the accreting gas being visible to progressively higher velocities as the ionization potential of the species increases. The available data suggest that collisional ionization of the accreting gas may be a characteristic feature of all massive, proto-planetary systems beginning at comparatively young ages (1-5$\times10^5$ years), and continuing for at least several Myr.

2.4. The Low Velocity Gas

The stars HD 176386, 51 Oph, and β Pic, as well as the classical Herbig Ae/Be stars have UV and optical spectra with strong low velocity absorption features which are present in all available IUE observations, independent of the column density of high velocity gas. These features are present not only in the lower ionization species, but also in species indicating collisional ionization of the gas. Detection of such species at these velocities suggests that this material, like the high velocity gas is produced comparatively close to the star. In the case of the Herbig Ae/Be stars, particularly, HD 45677, the absorption is well-resolved in the IUE high dispersion data. Optically thin transitions from Fe II and Si II in that system exhibit the double-absorption profile previously seen in FUORs, and interpreted by Hartmann and Kenyon (1985) as detection of rotationally broadened absorption produced by gas in Keplerian orbit in an optically thick disk-photosphere, rather than in the more conventional spheroidal stellar atmosphere. In such a model, progressive broadening of the profile or increasing separation of the absorption peaks, if the ion is confined to a comparatively thin annulus, with increasing ionization of the gas is expected, and in fact, observed in HD 45677 (Grady *et al.* 1992, 1993b).

Neither 51 Oph nor β Pic exhibit such resolved profiles at the resolution of the IUE in the singly ionized gas. However, higher resolution (R=100,000) optical spectra have revealed a trend of progressively increasing profile width in the low velocity Na I and Ca II absorption (Hobbs *et al.* 1985; Vidal-Madjar *et al.* 1986) for β Pic. HST/GHRS observations of Mg I, Fe I, Mn II, and Fe II confirm this observation and suggest that the circumstellar disk is marginally spectrally resolved with a resolution R=100,000 (Bruhweiler *et al.* 1993).

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