CIRCUMSTELLAR LINES IN BETA PICTORIS

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1. INTRODUCTION

Beta Pictoris has attracted special attention since the detection of circumstellar (CS) dust emission by the Infrared Astronomy Satellite (Aumann et al 1984) and subsequent imaging of an extended disk (Smith & Terrile 1984). A central cavity in the dust disk (Telesco et al. 1988) and episodes of infalling high-density gas (Kondo & Bruhweiler 1985) have also been found. The infalling gas is highly variable in infall velocity and mass rate (Bruhweiler, Kondo & Grady 1991). Sporadic mass outflow events have also occurred, implying that some of the CS gas may be stellar ejecta.

These observations of the gas around β Pic by the Goddard High-Resolution Spectrograph (GHRS) represent a significant enhancement in velocity resolution and S/N over previous UV studies of this star and permit for the first time a simultaneous probe of the density and velocity structure of the CS gas.

2. OBSERVATIONS

Beta Pictoris was observed with the GHRS on January 12 and February 4 of 1991. The data include moderate resolution spectra spanning the wavelength range 2579-2626 Å, covering the UV (1) multiplet of Fe II, and 2726-2772 Å covering the Fe II multiplets UV(62) and UV(63) with a resolution of ≈ 15 km/sec. Echelle spectra covering 2595-2608 Å and 2733-2745 Å, with a resolution of 3 km/sec, were also obtained. The operation of the GHRS instrument is described by Duncan & Ebbets (1989).

The UV spectrum of β Pic is dominated by rotationally broadened photospheric features with superposed absorption cores due to interstellar and CS gas (Slettebak & Carpenter 1983). The echelle spectra have S/N ≥ 25 adjacent to the absorption cores and the wavelength scales are accurate to ≈ 0.6 km/s. The combination of high S/N ratios, accurate radial velocities and accurate line profiles permits a clean separation of the CS absorption from the photospheric spectrum and confident detection of weak discrete features.

J. Bergeron (ed.), Highlights of Astronomy, Vol. 9, 481–483.

3. THE LINE PROFILES

I will describe the absorption cores of three spectral lines which are typical of other lines in their multiplets: Fe II (UV1) λ2599.396, λ2598.37 and Fe II (UV63) λ2739.546. The λ2598.37 and λ2739.546 lines are sensitive only to densities greatly in excess of those typical of the Local Interstellar Medium, whereas the λ2599.396 line is insensitive to density. Comparison of the absorption profiles in these lines allows a probe of the density structure of gas in the line of sight to β Pic, and the superior velocity resolution of the GHRS enables one to map the distribution of gas as a function of radial velocity. Only a qualitative discussion of the spectra is given here.

The Fe II λ2599.396 line arises from the zero V level of the ground configuration and thus has both interstellar and CS contributions. In the echelle spectra the line is resolved into at least four components. The January 12 spectrum has a narrow component with a velocity of 10.3 km/s, a broader feature with saturated absorption extending from 18-29 km/s, and a longward-asymmetric wing extending to ≈ 50 km/s. There is a suggestion of an extremely weak absorption near 70 km/s. On February 4 the sharp 10.3 km/s and saturated absorption were unchanged, but the longward- asymmetric wing was much stronger and extended to 220 km/s. Two new features were found: a sharp component (FWHM=3 km/s) at 33 km/s, and a broader feature (FWHM=24 km/s) at 52 km/s.

The λ2598.37 line, also a member of the UV1 resonance multiplet, comes from an excited J-level some 385 cm^{-1} above ground. A minimum density of ≈ 10^3 cm^{-3} is needed to produce appreciable absorption in this line, which thus provides a probe of the intermediate-density CS gas. The λ2598.37 profiles differ from the λ2599.396 profiles in the absence of both the 10.3 and 28 km/s features. The saturated absorption present in the λ2599.396 line is reduced to a feature centered at 20.4 km/s. The variations from 11 January to 4 February mirror the behavior of the λ2599.396 line.

The λ2739.546 line arises from the metastable 4D level ≈1.05 eV above ground, which is populated only if $n \geq 10^{8-9}$ cm^{-3} (Bruhweiler et al 1991). The velocity structure visible in this and other lines of UV(62) and UV(63) is similar to the λ2598.37 line. On February 4 the longward-asymmetric profile wing is visible to ≈190 km/s.

High-dispersion IUE long-wavelength spectra of β Pic were obtained on January 11 and February 9, 1991 for comparison with the GHRS data, allowing these data to be related to IUE archival spectra. The IUE profiles of the λ2599.396 feature agree well with heavily smoothed GHRS data. It appears that more gas was in the line of sight toward β Pic on the GHRS observation dates than occurs in the minimum absorption state, with additional absorption present shortward of the CS feature. Thus the low-density absorption may vary on time scales longer than ≈ 3 weeks.

4. DISCUSSION

The data indicate the presence of two features with $n < 10^3$ cm^{-3} in the line of sight. Applying Crutcher's (1982) relation to predict the interstellar wind velocity, one would expect a component at 16.6 km/s for β Pic, in

https://doi.org/10.1017/S1539299600009606 Published online by Cambridge University Press

disagreement with the velocity of either low-density component. The excess absorption noted in the IUE data suggests that the 10.3 km/s feature is variable, and hence circumstellar. The high-density CS gas around β Pic may be embedded in an extended, low-density gaseous halo.

The numerous prior detections of absorption features with large positive velocities have been interpreted as evidence for gas falling toward the star (Lagrange-Henri, et al 1988). The GHRS spectra show evidence for infall at times when the gaseous envelope is comparatively quiescent. Thus infall features, particularly those involving small column densities, may be common. The persistence of the +52 km/s feature from Feb. 4 to Feb. 9, when it was detected by IUE, together with the variability in the high-velocity components, suggests that features at ≈ 50 km/s may be visible for approximately one week. The detection of 2-3 infalling components per observation implies ≈ 100-150 infalling events per year.

A speculative model that would be consistent with the current observations would place most of the high-density CS gas in a ring well within the inner boundary of the dust disk and in Keplerian orbit about the star. How the gas in this ring would be maintained is unclear. Possibilities include steady erosion of the surrounding dust disk (Smith & Terrile 1984), by cometary bodies passing near the star (Lagrange-Henri et al 1988), or even by mass ejection events from the star itself (Bruhweiler et al 1991). Viscous forces or instabilities in the ring presumably trigger further infall, either as prolonged, uniform, steady flows, or in surges. Steady infall could produce the longward-asymmetric wings to the Fe II profiles. The surges produce denser streams, resulting in discrete features which develop wider velocity dispersions as they fall down the stellar gravitational well, manifested as a systematic broadening of the discrete components with increasing velocity. The location of the low-density gas is uncertain. Since the IUE data suggest that the 10.3 km/s feature is more likely to be CS, this component might be ascribed to the expanding halo inferred from IUE spectra (Bruhweiler et al 1991).

The research summarized here has resulted from the work of numerous individuals, most notably F. C. Bruhweiler and C. A. Grady. The results have been described more fully in Boggess et al (1991).

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https://doi.org/10.1017/S1539299600009606 Published online by Cambridge University Press