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RECURRENT SHELL INFALL EVENTS IN A B0.5e STAR, HD 58978 1979-1988

C.A. Grady
Astronomy Programs, Computer Sciences Corporation,
and IUE Observatory, Goddard Space Flight Center

G.J. Peters
Space Sciences Center,
University of Southern California

K.S. Bjorkman
Center for Astrophysics and Space Astronomy,
University of Colorado

H.F. Henrichs
Astronomical Institute, University of Amsterdam

ABSTRACT

We present a study of infall from the circumstellar envelope onto the bright B0.5 IVe star, HD 58978. The available IUE data indicate that the star has been surrounded by a low and moderately ionized circumstellar shell at least 12 times between 1979 and 1988. During six of these episodes, the signatures of cool circumstellar material were redshifted with respect to the photosphere by 20 to 80 km sec^{-1}. The available data indicate that the transition from infall to minimal shell absorption can occur in $\leq$10 days, and are consistent either with infall phases lasting up to 6 months, or with infall episodes shorter than 10 to 15 days. The long term behavior of the shell episodes is compared with variability in the stellar wind.

Keywords: Be Stars, outer atmospheres; circumstellar material, mass infall

1 INTRODUCTION

HD 58978 (FY CMa, HR 2855, B0.5IVe, $v \sin i$ =280 km sec^{-1} (Ref. 1)) is a comparatively early-type, bright Be star, which has been the subject of sporadic IUE observations from 1979 and into 1986. More frequent observations began in 1986 and will continue into 1989. Peters (Ref. 2) first noted the presence of multiple, low velocity discrete absorption components in C IV and N V. Subsequent IUE spectra have shown that this star has a strong and dramatically variable stellar wind with complex absorption profiles. The wind profiles in this star are characterized by variable high velocity absorption seen in N V, and C IV. Multiple low velocity (0 to -400 km sec^{-1}) discrete absorption components are present in all of the IUE spectra, although the absorption depth ranges from essentially saturated features to 20 percent below the continuum level. This star is unusual among the early-type Be stars surveyed by Grady, Bjorkman, and Snow (Ref. 3) in showing variable emission in N V, and possibly also C IV. Unlike most of the B0.5e stars observed with IUE, low ionization material is frequently present in outflow, and is particularly easily detected in Si III λ1206 at velocities up to -600 km sec^{-1}.

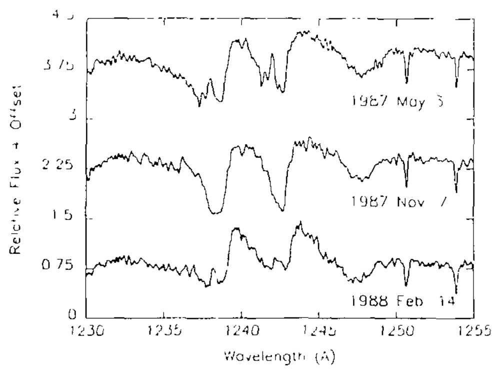

Figure 1 N V resonance profiles in HD 58978 for three dates in 1987 to 1988. Note the variations in the emission line strength, the amount of absorption in the low velocity discrete absorption components, and in the amount of high velocity wind absorption.

2. LOW IONIZATION INFALL

In an effort to better understand the complex wind profiles, and dramatic resonance profile variations, regular monitoring of this star was begun in 1986. Red shifted absorption features in lines of low and moderately ionized species were first noted in an IUE SWP observation made on 1987 May 3, which showed unusually strong absorption in the vicinity of the S III lines at 1202 Å . Further inspection of the spectrum showed that similar absorption features were present in all lines of S III (1)λ 1200, Si III (4)λ 1300, C II, Al IIIλλ1854, 1862, and several Fe III multiplets, especially multiplet 34. Comparison with the IUE spectrum obtained on 1987 March 6 (SWP 30443) showed that the low ionization features had not been present in March (Figure 2). Sharp absorption features in these ions, particularly the excited state lines, are normally not seen in the UV spectra of stars as hot as HD 58978 (Ref. 3), and indicate the presence of a moderately ionized circumstellar envelope.

The shell features observed on 1987 May 3 have radial velocities corresponding to the absorption maximum ranging from +85 to +110 km sec^{-1}. This range of absorption maxima is a real feature of the stellar spectrum, since interstellar lines observed in both that spectrum, and in the

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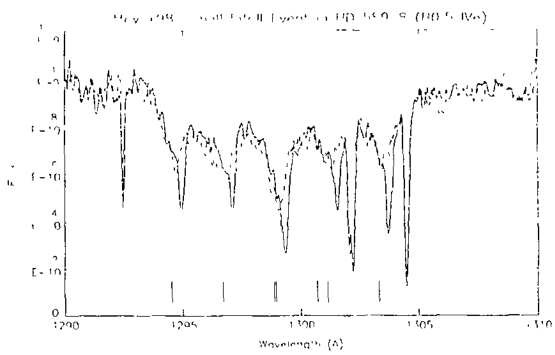

Figure 2: 1987 May 3 Si III (UV 4) line profiles for HD 59878 (solid) and 1987 March 6 (dashed) showing the redshifted absorption present in the May spectrum. Leader lines indicate the heliocentric wavelengths of the Si III transitions. The unmarked sharp absorption features in the spectrum are interstellar.

IUE spectrum of the same star obtained on 1987 March 6 agreed to within 4 to 5 km s^{-1}, an accuracy typical of IUE's pointing (Ref. 4). Inspection of the absorption components revealed that the absorption was not distributed in the form of a single approximately gaussian component, but showed considerable red-asymmetry (Figure 3).

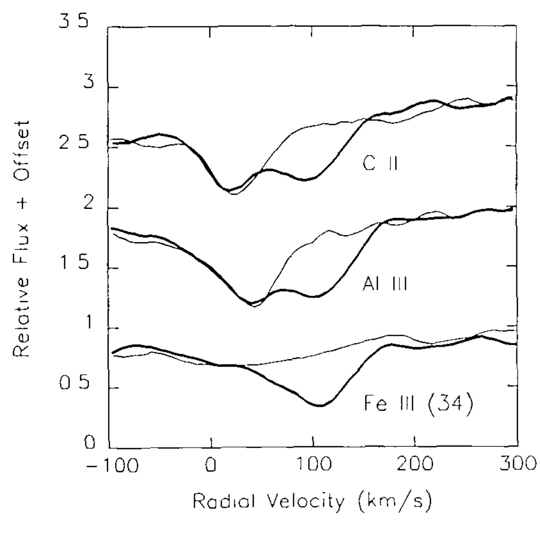

Figure 3: Distribution of infalling material as a function of radial velocity on 1987. The 1987 May 3 spectrum is shown in bold. A comparison spectrum taken in 1987 November (SWP 32317) was obtained at a time when the low ionization infall was minimal. The strong absorption feature centered at +29 km sec^{-1} is interstellar.

Since the discovery of low ionization infall in the spectrum of this star, we have continued to monitor the low ionization lines in this star, and have extended our analysis to the previously acquired IUE data. As shown in Figure 3, the Fe III (34) line at 1895.456 Å is particularly suitable for monitoring the strength and velocity characteristics of the cool circumstellar envelope, since this line does not have a strong photospheric component, lies in a portion of the IUE spectrum with good signal to noise, and is not blended with other circumstellar or interstellar lines.

The cool circumstellar absorption is present over a wide range of radial velocity in this star. Inspection of the profiles has shown that the radial velocity corresponding to the absorption maximum is variable, and is frequently displaced redward of both the heliocentric line center, and the stellar radial velocity of 29 km sec^{-1} (Ref. 5). Of the 23 spectra with appreciable Fe III absorption, 9 had Fe III circumstellar absorption centroid radial velocities displaced more than 20 km sec^{-1} redward of the photospheric radial velocity, and thus unambiguously indicate the presence of infalling circumstellar material. The remaining spectra showed comparatively undisplaced absorption, which following the optical terminology for Be stars is termed "shell" absorption. Eleven spectra showed no significant circumstellar Fe III absorption.

Figure 4a shows the circumstellar Fe III λ 1895.456 equivalent widths as a function of time. Radial velocities of the absorption maximum as a function of time are shown in Figure 4b. The 1987 data show that several successive spectra can show infall signatures. As a result, we define infall episodes to be time intervals where all IUE spectra show infall signatures and separated by IUE spectra without infall signatures, or where the interval between observations is more than approximately 2 months. Shell episodes are defined as intervals where the IUE spectra indicate the presence of cool undisplaced circumstellar material. By these criteria, the available IUE spectra correspond to 12 shell and infall episodes, six of which are infall events. Our data are consistent either with infall episodes shorter than 10 to 15 days, the characteristic separation of the 1987 and 1988 data, or at least as long as 41 days, and possibly as long as six months. The IUE spectra obtained in 1987 November indicate that the signatures of low ionization infall can vanish quickly, in as little as 7 days.

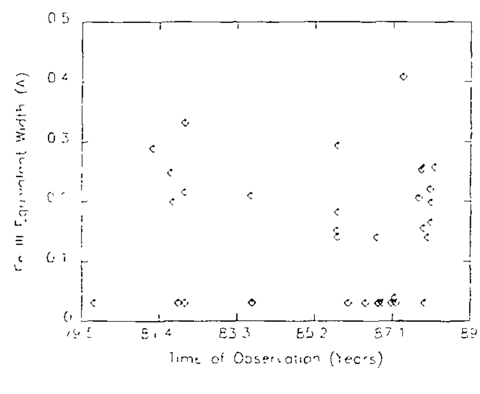

Figure 4a: Fe III (34) λ 1895.456 absorption equivalent widths as a function of time.

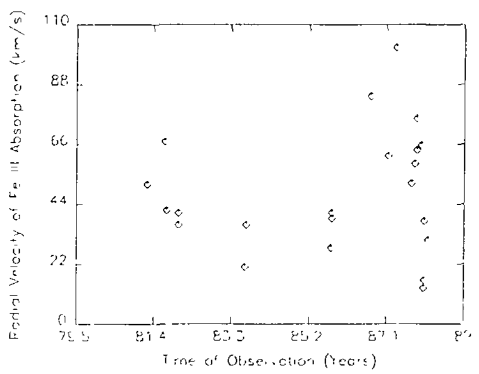

Figure 4b: Fe III (34) λ 1895.456 absorption centroid radial velocities as a function of time

3. HIGH IONIZATION INFALL

Four IUE spectra, SWP 6963 (1979 day 296), SWP 28457 (1986 day 159), SWP 30392 (1987 day 57) and SWP 32317 (1987 day 318), show no significant low ionization infall. Instead, these spectra show strong absorption components in N V with centroid velocities of +50, +7 with a strong asymmetric tail extending to +113 km sec^{-1}, +150 and +50 km sec^{-1} respectively. In the 1987 February spectrum, infalling material is visible out to at least +260 km sec^{-1} (Figure 5). The three more recent spectra showing the high ionization infall are separated by multiples of approximately 260 days from observation to observation. The available IUE data are too sparse to currently determine whether this interval represents a periodic phenomenon in the stellar envelope, although IUE observations planned for the remainder of the tenth and the eleventh episode may be able to address this question.

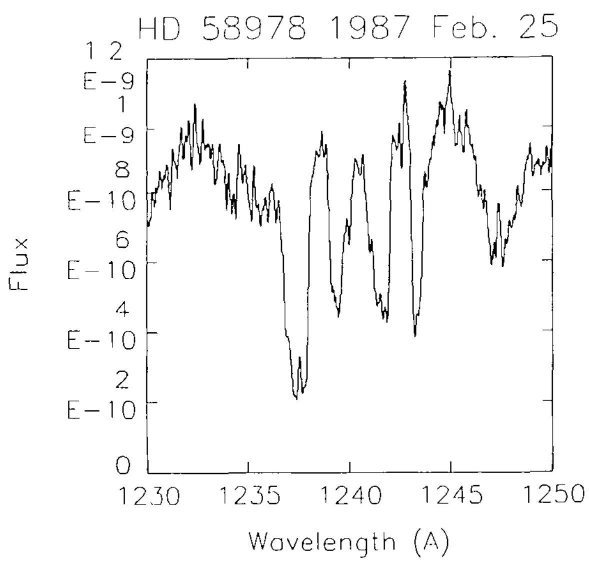

Figure 5: N V profile for HD 58978 obtained on 1987 February 25 showing the highly redshifted absorption feature in addition to the more typical low velocity (outflow) discrete absorption components.

4. CORRELATION OF INFALL EVENTS WITH WIND VARIATIONS

Correlating the behavior of the cool circumstellar envelope with the stellar wind is complicated by the complexity of the wind profiles, and by the dramatic variability of all portions of the stellar wind profiles. Of the resonance lines, the N V doublet is the most promising for analysis since the resonance lines are infrequently saturated, and the signal to noise in that part of the spectrum is good. The absorption portion of the C IV profile tends to be saturated at low radial velocities in outflow, precluding reliable measurement. The Si IV profiles are dominated by the strong photospheric absorption profiles, making evaluation of the wind absorption more difficult. All of the available IUE spectra show absorption from low velocity (outflow) discrete absorption components which are particularly pronounced in N V. No weak wind episodes, characterized by the absence of discrete absorption components have been observed in the nearly nine years of IUE observations, in contrast to the behavior of many other early-type Be stars.

The discrete components are the most obviously variable portion of the N V profile. Figure 6 shows the total equivalent width for the low velocity discrete absorption features. This measurement includes the low velocity (outflow) components, any undisplaced circumstellar absorption features, and any red-shifted absorption features. The continuum level for the measurements was determined using the local photospheric continuum outside the resonance profile. Due to the uncertain, and variable number of absorption components the equivalent widths are not easily translated into column densities. Figure 7 shows the Fe III λ 1895.456 circumstellar material equivalent width plotted against the summed N V discrete component equivalent widths. Despite the scatter in the N V data, the larger N V equivalent widths tend to be associated with the smaller circumstellar Fe III equivalent widths. This is also supported by the detection of red-shifted N V absorption features only in spectra with no detectable Fe III absorption. These results suggest that the ionization balance in the vicinity of the star is variable, perhaps indicating the presence of transient shocks. At present the data are consistent either with temporal variations, or with variability as a result of orbital motion. A more reliable estimate of the periodicity of the N V red-shifted absorption feature will be required to separate temporal variations, which are not uncommon in Be stellar winds, from any orbital effects.

5. DISCUSSION

Infalling material in main sequence stars with appreciable circumstellar material have been reported in interacting binary stars (Ref. 6), and in the protoplanetary disk/A shell star β Pic (Ref. 7, 8). Signatures of infalling material were present in IUE high dispersion spectra of β Pic from 1984 December through 1985, and were also visible in Ca II profiles (Ref. 8). The absorption profiles, and velocity range observed in these lines are similar to those seen in the majority of our spectra. High ionization infall has not been reported in β Pic, and would be unlikely from the erosion of a comparatively cool dust and gas disk, unless that mate-

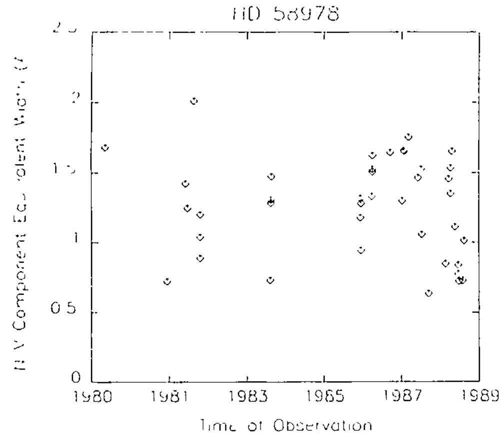

Figure 6: N V λ1238.821 discrete absorption component equivalent width as a function of time. This measurement includes both the low velocity material in outflow, and any redshifted absorption. The 1σ uncertainty in the measurements due to continuum placement in 0.3Å.

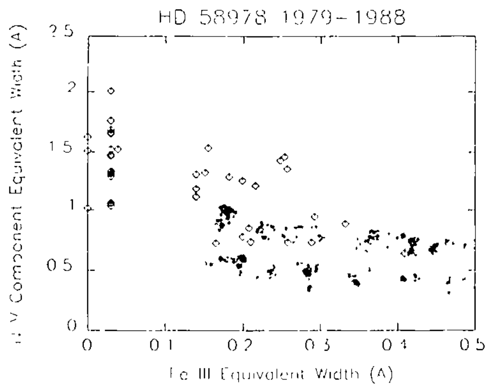

Figure 7: N V discrete component equivalent width plotted as a function of the Fe III circumstellar equivalent width.

rial were to encounter a high density stellar wind moving at sufficiently high velocity to produce x-rays in the collision The available infrared data on HD 58978 (Ref. 9) are consistent with an infrared excess produced by free-free emission from a gas disk, rather than the presence of a large dust disk, as is observed in β Pic. This result, together with the ionization variations in HD 58978's wind and circumstellar environment suggest that this star may be an interacting binary system.

Interpretation of this star as an interacting binary is supported by by the similarity of the resonance profiles to some known interacting Be-binary systems. Cool and moderately ionized infalling material is present in the UV spectrum of HD 41335 (HR 2142), where the infall is present at a limited number of phases, and outflow is present in the same lines at other times (Ref. 10). No high ionization infall has been detected in this star. The bright Be star ϕ Per (Ref. 11), which is somewhat cooler than HD 58978, has C IV profiles similar to the N V profiles seen in this star, complete with emission, and strong low velocity absorption in outflow. Redshifted absorption features are seen in some of the IUE spectra. Further confirmation of the binary interpretation for this star will require additional IUE spectra, in order to establish which portions of the complex circumstellar envelope show signs of periodic variability.

6. IMPLICATIONS FOR OTHER Be STARS

Grady, Bjorkman, and Snow (Ref. 3) found several Be tars, not known to be interacting binaries, which had wind (outflow) profiles similar to HD 58978. These stars had emission in at least one resonance profile which was more highly ionized than would be expected in a normal B star of comparable spectral type and luminosity class, and also had strong and extremely low velocity discrete absorption components. These stars also showed wind signatures over a wide ionization range, and in at least one case infalling material is present. The other stars have been insufficiently observed to determine whether infall is present at some times or phases. If all of these objects can be shown to be interacting binary stars, the wind peculiarities may reflect the presence of a hot and luminous secondary in the system, a hot spot caused by the collision of the stellar wind and the mass transfer stream, or the presence of an accretion disk.

The available IUE database on stellar winds in B stars is now sufficiently complete, that single observations of the C IV or N V resonance profiles can identify stars with peculiar winds. Since the integration times to acquire IUE spectra tend to be shorter than those required for x-ray observations, UV spectral surveys of early-type stars may prove to be an efficient way of identifying such interacting binary systems for future study.

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