The Be Phenomenon in Early-Type Stars, IAU Colloquium 175
ASP Conference Series, Vol. 214, 2000
M. A. Smith, H. F. Henrichs, and J. Fabregat, eds.

Rapid Variations of Discrete Absorption Components in the spectrum of P Cygni

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Abstract.
The morphology and variability of spectral lines in the P Cygni high-resolution and high signal-to-noise near-UV spectra have been studied in detail over a period of few days. It is found that several Balmer lines have profiles with a complicated structure. All those lines which are well developed, but still not saturated, show two absorption components. A striking profile variability is discovered on a time-scale of from 1 to 3 days. The most dominant part of rapid variations is the drift of absorption components. It appears that there are two different kinds of components: long lived (with a characteristic time-scale of 200 days) and short-lived (time-scale of few days). The DAC phenomenon in the P Cygni stellar wind is a problems that still remains unsolved.

1. Observations

The observations of P Cygni were carried out on May 29–June 03 1999 with the SOFIN Echelle Spectrometer at the 2.5-m Nordic Optical Telescope of the Roque de los Muchachos Observatory (La Palma, Canary Islands, Spain). The spectra have a S/N$\geq$100 per resolution element, and a resolution of $R \sim 80\,000$ in the wavelength region 3600–4200 Å.

2. Morphology and Variability of Balmer-Line Profiles

It is generally accepted that many processes going on in the atmosphere/wind of P Cygni are unique and have not been observed in other hot supergiants (Israelian & de Groot 1999). The most remarkable feature in the spectrum of P Cygni is the existence of multi-component absorption profiles of H, He, Fe and many other elements. These components are wide and should *not be confused* with narrow absorption components (FWHM$<$ 15 km s^{-1}) widely observed in many other OB stars. The first extensive analysis of multiple absorption components was made by de Groot (1969), who observed three variable components in the hydrogen lines at -215, -160 and -95 km s^{-1} and two in the helium lines. He found that the first component at -215 km s^{-1} showed periodic radial-velocity variations of P=114 days and semi-amplitude 30 km s^{-1}. No periodic variations were found in other components. Luud et al. (1975) have argued that the second component at -130 km s^{-1} was also variable, but with P=57 days. They failed to detect any periodicity in the first component at -215 km s^{-1}.

https://doi.org/10.1017/S0252921100055688 Published online by Cambridge University Press

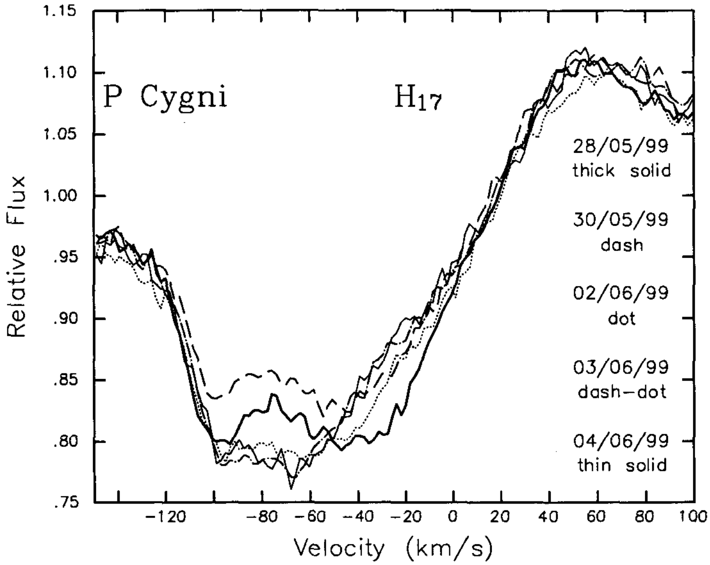

Figure 1. High-resolution profiles of P Cygni's Balmer line H_{17} obtained with NOT/SOFIN.

According to de Groot (1969) and Luud et al. (1975) the velocity of a given component increases and decreases with time. A different scenario was proposed by Kolka (1983) and Markova & Kolka (1984). These authors proposed that the variations of DACs are due to ejected shells with velocities increasing in time up to a constant value. Markova (1986a) has re-analysed the velocities of DACs of the Balmer lines published by de Groot (1969) and Luud et al. (1975) and has shown that the data seem more consistent with the recurrent shell-ejection scenario of Kolka (1983) over the period 1981 to 1983. She derived an ejection time of 200 days from the study of DACs observed in Balmer lines. This period was confirmed by Kolka (1998). Van Gent and Lamers (1986) have re-analysed published radial-velocity measurements of the shell components of P Cygni and found that the variations are not due to periodic oscillations but to shell ejections with a mean time-scale of 60–75 days. From the study of 13 helium lines over three years, Markova (1993b) has concluded that DACs appear every 4–5 months. DACs have been observed in hundreds of optical and at least 80 high-resolution *IUE* spectra. Note that all these detections were made using data with S/N$\leq$50. In another study, again based on the photographic observations with S/N$\sim$40, Markova & Kolka (1985) and Markova (1993a) concluded that virtually all absorption lines of H, He I, N II, O II, Si III and Si IV show complicated profile variations which can be explained in terms of fast-moving DACs superimposed on a slowly-varying underlying profile. These slow profile changes are most probably related to the variations detected by Stahl et al. (1994) and can be caused by non-radial pulsations.

3. DACs in the UV

There have been a number of detections (Cassatella et al. 1979; Luud and Sapar 1980) of DACs in the UV lines of Cr II, Ni II, Ni III, Si III, Mn II, etc. However, detailed studies have been performed only of those detected in Fe. Variable DACs in Fe II and Fe III have been studied in 33 high-resolution *IUE* spectra by Lamers et al. (1985). They found that Fe II lines have two absorption components, a stable and a variable one, and explained this phenomenon in terms of variable thick shells ejected from the star with a frequency of about once per year. The stable component at -210 km s^{-1} did not vary over 5 years. The second DAC varied from -112 to -174 km s^{-1} in 1978/79. They did not find a stable absorption component in the Fe III lines and concluded that the latter form in variable shells. With hindsight, it is now clear (Israelian et al. 1996) that this failure was due to their use of blended iron lines in their analysis. When one uses all available iron lines, two components are clearly seen in the Fe III lines. More recently, Israelian et al. (1996) have analysed 49 high-resolution *IUE* spectra obtained in the period 1985–1991 and found a repetition time between two successive shells of 200$\pm$11 days. This value agrees perfectly with those obtained from Balmer lines by Markova (1986a) and by Kolka (1998). It has been shown (Israelian et al. 1996) that the acceleration of DACs in the earliest phases when they appear at ~ -50 km s^{-1} can be as large as 0.6$\pm$0.3 km s^{-1} d^{-1}, while it is about 0.1$\pm$0.05 km s^{-1} d^{-1} at the end.

4. New observations of DACs

Absorption components (DACs) have been detected in the NOT/SOFIN as well (see Fig 1). Thus, *it is clear now that these components are not a result of the photographic noise.* The profiles of the higher members of the Balmer series (higher H_{10}) have split absorption cores and show complex variations. We did not find split cores in the He I lines. The most interesting result from these observations is a fast variability of these components on a time-scale of days. This is clearly demonstrated in Fig 1. This observational fact will obviously set strong constraints on the models of DACs. In fact, we found that the acceleration $\sim$ 10$\pm$2 km s^{-1} d^{-1} is exceptionally high and cannot be explained by any radiation pressure variations. This means that forces other than radiation are responsible for the fast variability of DACs. It is very important to start a new monitoring programme of these features with modern CCDs.

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