THE DETECTION OF A CIRCUMSTELLAR SHELL AROUND P CYGNI BY DIRECT CCD IMAGING

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The star P Cygni (=HD 193237) is the proto-type of a class of stars with peculiar spectra, the so-called P-Cygni-stars (or Luminous Blue Variables). They are characterized by extreme mass-loss characteristics and wind densities surpassed only by the winds of Wolf-Rayet stars.

The high wind densities in these objects and the resulting high surface brightness in certain nebular emission lines even at large (>10^3 R_*) stellar distances led to the direct discovery of circumstellar shells on deep H_α-images around several objects (e. g. AG Carinae and R 127). We report on direct narrow-band H_α-images of P Cygni obtained in an attempt to find evidence for circumstellar matter in the immediate surroundings of P Cygni.

The observations were performed at the 1.23-m telescope of the Spanish-German Astronomy Center on Calar Alto (Spain) using a CCD camera on October 12, 1985. The image scale was 0"46 pixel^{-1}. The CCD camera was equipped with a set of three interference filters: H_α (λ_0 = 6553 Å, $\Delta\lambda$ = 36 Å), [N II] (λ_0 = 6587 Å, $\Delta\lambda$ = 22 Å), continuum (λ_0 = 4784 Å, $\Delta\lambda$ = 118 Å). The observational technique was as follows: We chose a nearby comparison star of similar magnitude and spectral type (55 Cyg; V = 4^m84, B3Ia) and exposed P Cyg and 55 Cyg alternatively in each filter. The exposure time was 0.75 sec in each filter and for the two stars. The zenith distance was less than $\simeq 5^o$ and seeing was better than 0"7 in a photometric night. The observations were organized in several exposure sequences: We obtained CCD frames in H_α, [N II], and the continuum of 55 Cyg and immediately afterwards of P Cyg. The optimum focus had been determined for each filter at the beginning of the first sequence and was adjusted for each exposure. The sequence for 55 Cyg and P Cyg was repeated three times resulting in a total of 24 CCD frames for the two stars.

We analyzed the brightness profiles of P Cyg and 55 Cyg in H_α, [N II], and the continuum: In order to determine the

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centers of light we fitted 2-dimensional Gaussian profiles to the observed light distribution. The radial brightness profile was then derived by averaging the counts per pixel in concentric annular segments around the light center. The resulting profiles generally have a full width at half maximum of 0"6. Subsequently we multiplied the four best-fit profiles of each filter for 55 Cyg and P Cyg by constant factors in order to normalize the peak intensity to a common value. The normalization factor was chosen as to give best agreement for the count rates of the (radially) three innermost pixels of the profiles. After normalization the four respective profiles of H_α, [N II], and the continuum were superposed leading to seeing-disk profiles for P Cyg and 55 Cyg in H_α, [N II], and the continuum, respectively. The light distribution of P Cyg is more extended in $H\alpha$ and [N II] than the seeing disk of 55 Cyg. In contrast, P Cyg and 55 Cyg have identical seeing disk in continuum light. The agreement of the radial brightness profiles of P Cyg and 55 Cyg in continuum light and the extended structure of P Cyg in $H\alpha$ and [N II] can be interpreted in terms of a shell surrounding P Cyg. This shell can be most readily seen in nebular emission lines such as $H\alpha$ and [N II]. On the other hand, in continuum light the shell is essentially transparent and P Cyg's and 55 Cyg's light distributions are identical.

After conversion to absolute intensity units the intensity profile in $H\alpha$ and [N II] of the circumstellar shell around P Cyg is obtained from the difference of P Cyg's brightness profile and a point-spread function represented by 55 Cyg. In both cases the intensity as a function of central angular distance behaves as $\sim\alpha^{-3}$. An α^{-3} behavior is theoretically expected for the intensity of an expanding, spherically symmetric shell. The intensity in H_α is given by

$$I_O(H_\alpha) = \int \frac{1}{4\pi} N_P N_E a_{32} (T_E, N_E) h\nu_{32} dl \quad [\mathrm{erg\ cm^{-2}\ sec^{-1}\ sterad^{-1}}]$$

with

N_P, N_E: proton and electron number density, respectively (here: $N_P = N_E$)
a_{32}: recombination coefficient for H_α
$h\nu_{32}$: energy of Balmer photon
dl: path length along line of sight.

Using the equation of continuity together with the stellar parameters of P Cygni from Lamers (Astron. Astrophys. 159, 90 [1986]) the intensity can be expressed as a function of P Cyg's mass-loss rate $\dot{M}$ and α (after correction for reddenning):

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$$I(H_\alpha) = 1.66 \cdot 10^{-20} \frac{(\dot{M}[M_\odot yr^{-1}])^2}{(\tan\alpha[''])^3} [\mathrm{erg\ cm^{-2}\ sec^{-1}\ arc\ sec^{-2}}]$$

If $\dot{M} \sim 4.2 \cdot 10^{-4}\ M_\odot yr^{-1}$ is inserted in this equation the theoretical intensity profile is in good agreement with the observed one. A mass-loss rate of $\dot{M} \sim 4 \cdot 10^{-4}\ M_\odot yr^{-1}$ is not unreasonable for P Cygni. Its present-day mass-loss rate is $2 \cdot 10^{-5}\ M_\odot yr^{-1}$ (Lamers 1986) but Luminous Blue Variables are known to show outbursts exceeding $\dot{M} = 10^{-4}$ $M_\odot yr^{-1}$. Interestingly, P Cygni has shown a major outburst in the 17th century. The flow time-scale $t \sim a/v_\infty$ (accidentally?!) turns out to be ~300 yr. One may speculate that the extended structure found in P Cyg's light distribution is associated with the above outburst.

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