Intermediate Report on January 2013 Campaign: Photometry and Spectroscopy of P Cygni

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Abstract In this campaign on the Luminous Blue Variable star P Cygni, we are trying for the first time, by way of contemporaneous measurements of photometric V brightness and Hα equivalent width (EW), to realize a long-term monitoring of the intrinsic Hα line flux. Photometric and spectroscopic observers started this campaign in November 2008 in order to continue former investigations whose results are based on multi-daily averaging of V and EW. The campaign results enable us to represent the quantitative behavior of the Hα line flux for the time span August 2005 to December 2011, which reflects variabilities in mass-loss rate, stellar wind density, and the ionization structure.

1. Introduction

The international observing campaign, Photometry and Spectroscopy of P Cygni, begun in 2008, is a cooperative project of the American Association of Variable Star Observers (AAVSO), Active-Spectroscopy-in-Astronomy (ASPA), and the Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne (BAV). One goal of the campaign is the monitoring of the behavior of the Hα-line equivalent width (EW) and the contemporaneous changes of the V-band magnitude of P Cyg. Another goal is to gather further information about the intrinsic flux of this spectral line.

P Cyg stars are characterized by very high luminosity, and belong to the spectral classes Ope to Fpe. Their irregular brightness variations, with time scales from weeks to months to years, cover amplitudes up to several V-magnitudes, connected with density inhomogeneity in their mostly spherical shell. P Cyg (Nova Cyg No. 1) was discovered on August 18, 1600, as its brightness suddenly had risen up to 3rd V-magnitude. Also, in the following century, the star showed remarkable changes of brightness from weeks to years, with occasional fadings to the limit of visual visibility. Since 1786 no strong changes of brightness have occurred. A slow brightness increase from 5.2 to 4.9 V took place in 1786 to 1879. Since then the variable has been a B1 supergiant of the "luminous blue variable" (LBV) class.

Typical for these stars are the profiles of individual lines. They consist in the simplest case as an emission line with a blueward-shifted absorption component. Such profiles point to mass-loss of the star in the form of a stellar wind. P Cygni stars are now believed to be in a development phase which lies temporally before the Wolf-Rayet stage of massive stars. De Groot and Lamers (1992) show that the theory of this phase of development is applicable, and in further spectroscopic investigations by Lamers *et al.* (1983), Markova and Puls (2008), Markova *et al.* (2001a, 2001b, 2005), and Richardson *et al.* (2011), the physical properties of P Cyg have been determined: Spectral type—B1 Ia; $T_{eff} = 19300 \pm 2000$ K; $R_{star}/R_{sun} = 76 \pm 14$; $L_{star}/L_{sun} = 5.86 \pm 0.3$.

2. Details

Our campaign assumed that the variability of the EW is caused by variations of the continuum flux and not by variations of the line flux (Markova *et al.* 2001b), which would indicate variations in the stellar wind density. Therefore, the variability of the continuum flux was our primary concern when the properties of the stellar winds and rate of mass loss were studied. To find correlations of photometric to spectroscopic data, an AAVSO call for observations was made at the beginning of the campaign for photoelectric photometry (PEP), and DSLR measurements, based on the Johnson-V system. To date, sixteen photometric observers are involved worldwide.

3. Photometric measurements

Figure 1 shows the comparison of PEP measurements (123) and DSLR measurements (141) through November 4, 2012. Except for occasional outliers (which occur in both) the observations on the 0.01-magnitude accuracy level are rather similar in both forms of measurement.

Photometric and spectroscopic changes in P Cyg seem to be weakly anti-correlated on short- and long-term scales. We observed a total change of 35Å in the equivalent width (EW) of the Hα line, and of ~0.25 magnitude in the V-band brightness. Our observations extend from JD 2454671 (July 23, 2008) through JD 2456244 (November 12, 2012).

4. Results

Figure 2 compares the time behavior of the V-brightness (upper) and the Hα EW (lower) in our campaign. In addition, the data from Richardson *et al.* (2011) have been plotted. As can be seen, the 20-day average V magnitude used does not recognize the quick variations, which were found very clearly in our monitoring.

As can be seen in Figure 2, when EW decreases, the contemporaneous stellar brightness increases, and vice versa. Strict anti-correlation is expected if the variation of the continuum flux is independent from variations of the EW. If the Hα line flux is constant over time, an increase of the continuum brightness will yield a smaller line flux from the measured EW and vice versa.

To find out if and how the flux obtained from the spectral line profiles varies, the EW measurements were corrected for continuum variations (Pollmann and Bauer 2012). It is important to consider the absolute flux of the line because its variations are caused by the effects of mass loss, stellar wind density, and changes of the ionization state of chemical elements in it. In the current campaign we have already obtained 170 nearly simultaneous measurements of the EW and the flux in the V band.

Figure 3 attempts to display if and to what extent the intrinsic line flux (as continuum-corrected EW) depends on V magnitude. From a statistical point of view one can say that the low (0.25) correlation coefficient (which should be zero after the continuum correction), with consideration of the measurement uncertainties, suggests the conclusion that the Hα line flux is independent of V magnitude.

Comparable investigations of this kind have been published by Richardson *et al.* (2011). The essential difference between these investigations (Figure 3 of Markova *et al.* 2001b) and our work is that they used non-contemporaneous EW and Vphot for their consideration of correlations. Their selected 20-daily average shows a weakly suggested positive correlation, whereas our correlation result in Figure 3 (this paper) delivers an extremely small correlation coefficient of only 0.25 from 170 spectra.

Thus, we have some doubts regarding the persuasive power of the positive correlation (which they found) of the relative flux with the interpolated magnitude. We would be very interested, together with the author of Markova *et al.* (2001a), to perform a new, comprehensive analysis with the data from both investigations to clarify these circumstances.

With consideration of the standard deviation and possibly other kinds of errors, the temporal variation of the line flux of Hα in the plot of Figure 4 will represent the result of variations in the mass loss rate, stellar wind density, and changes of the ionization from August 2005 through November 2012.

Although our data set of 170 spectra is of rather modest extent, we tried nevertheless to find a certain periodicity in the time behavior of the observed Hα line flux.

The usage of the period search program, AVE, did detect three dominant periods in the power spectrum, 242 days, 363 days, and 600 days (Figure 5). Although the 600-day period finds a certain confirmation in investigations about variability of the Hα EW in Markova (1993), our data set is, so far, still too limited to give these three periods a greater degree of confidence.

Variations of the mass-loss rate manifest themselves in P Cyg generally also in a varying absorption depth and proportionally to it in a varying emission strength of the HeI line at 6678Å, which is developed in the helium-forming zones closer to the star due to its higher excitation potential. While Markova preferentially investigated the correlations of velocity variations to variations of emission and absorption intensity in only 58 spectra at HeI λ3926, λ3867, λ4471, as well as NII λ4630 and SI IV λ4116 (Markova 1986a), our more extensive spectrum collection (> 160 spectra from 2003 to 2012 at HeI λ6678) clearly shows the variability of the emission and absorption intensity and their correlation to each other. Figure 6 shows "extreme" HeI 6678 spectra, taken between April 2003 and November 2012, for illustration of the variability of the absorption depth and the emission strength as a consequence of a variable mass-loss rate of the star (in units of the normalized continuum).

In Figure 7 it can be clearly seen that a portion of the profile at 6674.5 Å varies 2.8/1.5 times stronger than the variation of the emission intensity at 6678.138 Å.

The grey-scale diagram of the 100 spectra in Figure 8 clarifies that the absorption maximum around 6675Å is shifting with time towards shorter wavelengths, which could be due to increasing optical depth as a result of increasing mass-loss.

The plot of absorption depth versus emission strength in Figure 9 shows that both measured variables are related only with a correlation quality of ~0.44. Even if the emission comes by recombination, one would expect that a higher density (= higher mass loss) would produce both more absorption and more emission. The small coefficient of correlation could therefore be an expression for not implausible temperature variations in the stellar wind, whereby the absorption could increase also without change of mass loss, thereby without the emission increasing.

5. Acknowledgements

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The EW, V(phot), and line flux data are available at the following website: http://astrospectroscopy.de/Data_PCyg_Campaign/Campaign_data_2013.txt

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Richardson, N. D., Morrison, N. D., Gies, D. R., Markova, N., Hesselbach, E. N., and Percy, J. R. 2011, *Astron. J.*, **141**, 120.

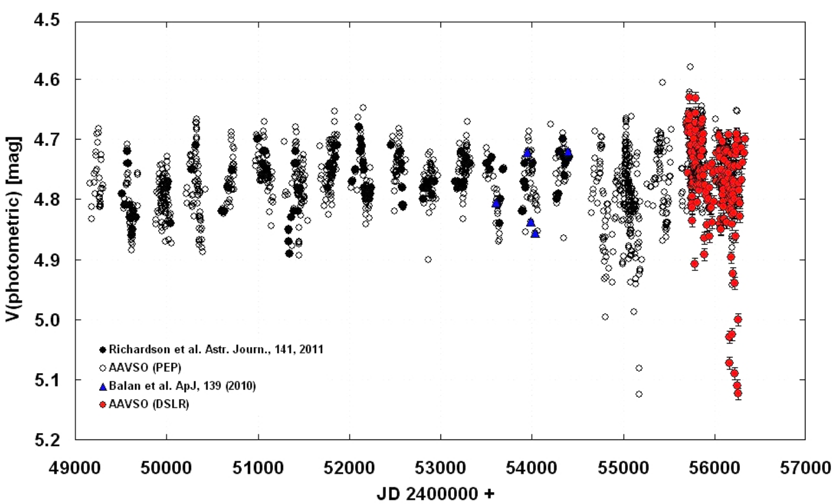

Figure 1. Comparison of AAVSO PEP observations with AAVSO DSLR observations of P Cyg.

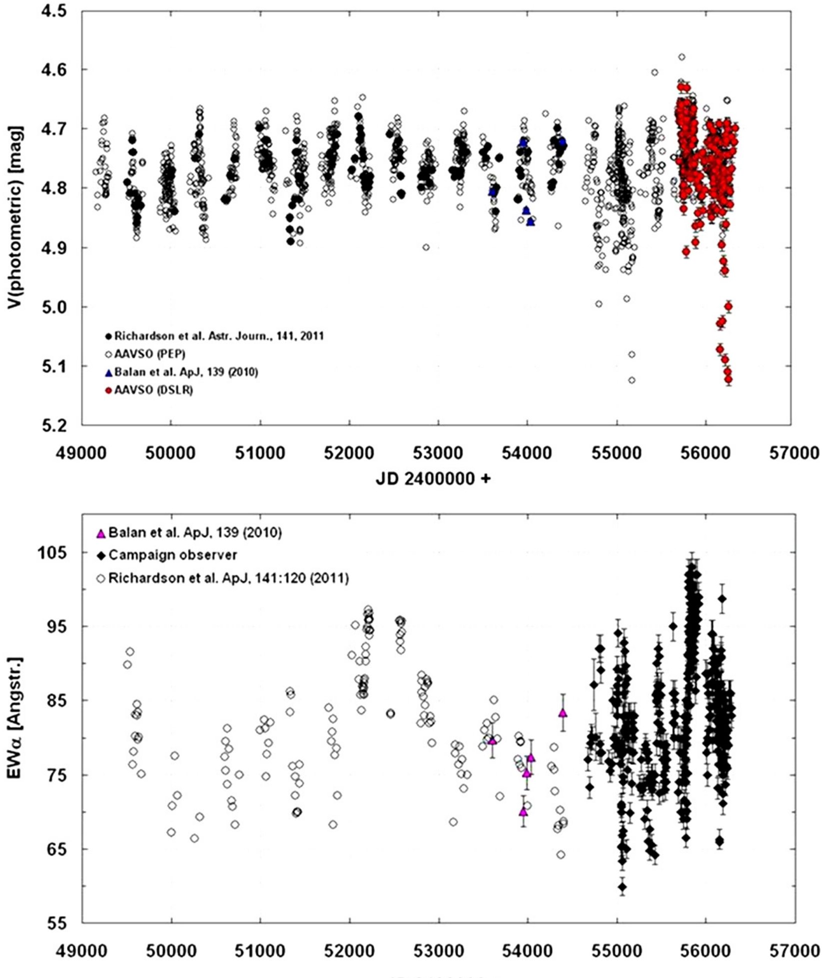

Figure 2. Our V magnitude photometric and spectroscopic observations (upper) and Hα-EW (lower) during the P Cyg campaign (including data of Balan *et al.* 2010 and Richardson *et al.* 2011).

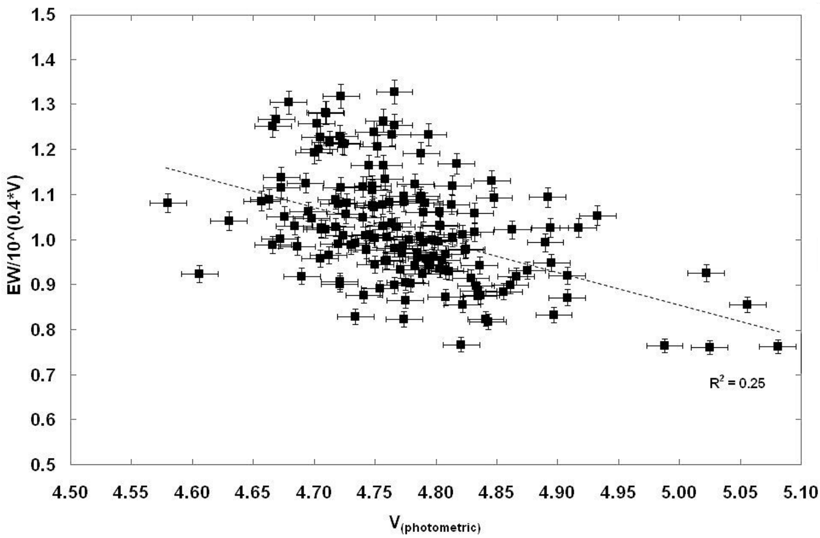

Figure 3. Hα-line flux versus photometric V brightness for P Cyg (170 contemporaneous measurements).

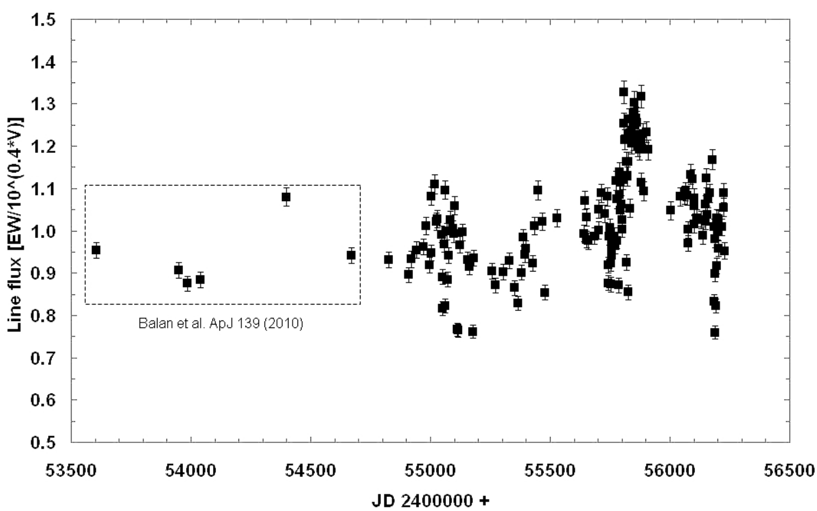

Figure 4. The intrinsic Hα-line flux for P Cyg from JD 2453605 (August 22, 2005) to JD 2455911 (November 12, 2012).

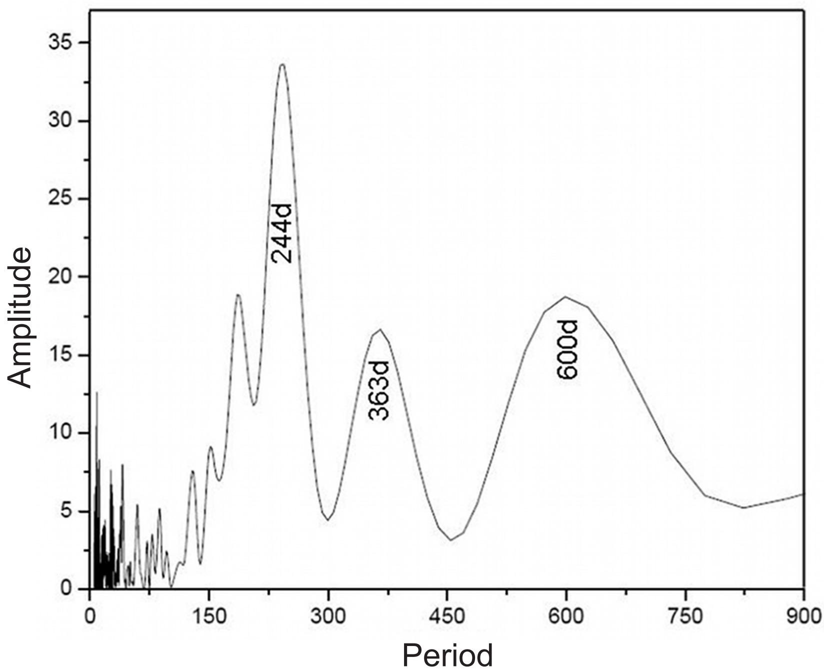

Figure 5. Scargle periodogram with data from Figure 4.

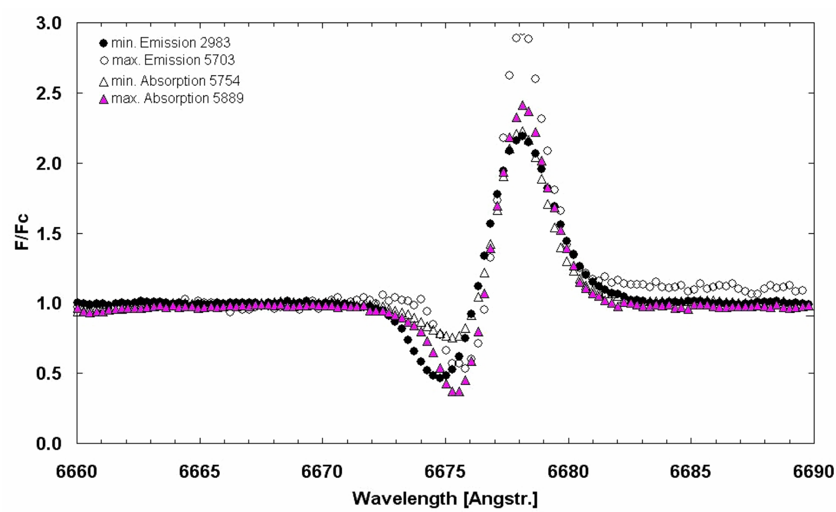

Figure 6. Variability of the absorption depth and emission strength in extreme-profile-spectra of P Cyg (JD 2452983, 2455703, 2455754, 2455889).

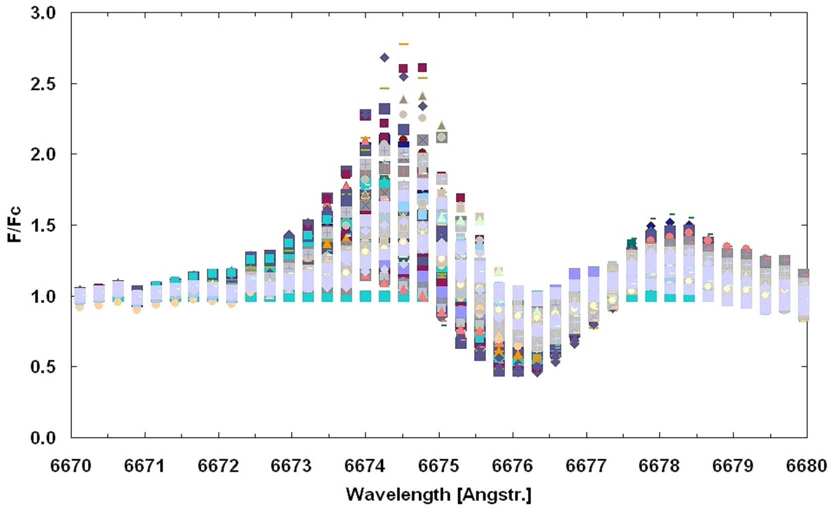

Figure 7. Division spectra with absorption maximum at 6674.5Å related to a maximum-intensity spectrum at JD 2455703 for P Cyg.

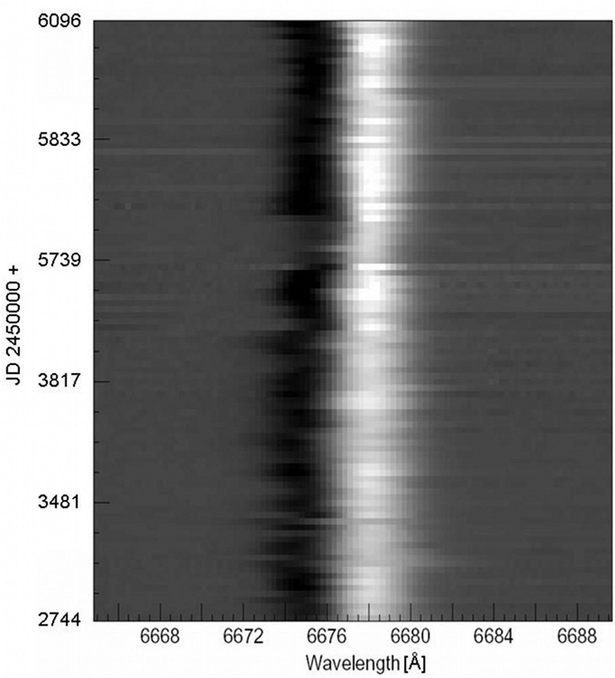

Figure 8. The moving absorption maximum (around 6675Å) of the He6678 line profile with time for P Cyg. 100 Spectra sorted by Julian Date.

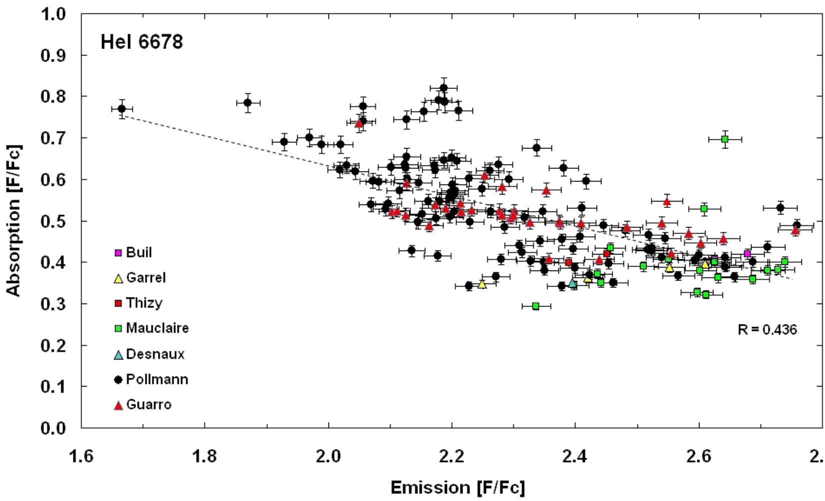

Figure 9. Variability of the absorption depth versus emission strength of the HeI 6678 line (April 2003 until November 2012) for P Cyg.