International Observing Campaign: Photometry and Spectroscopy of P Cygni

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Abstract In this combined 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 longterm monitoring of the intrinsic Hα-line flux. The photometric observers of AAVSO and BAV (Germany) and a spectroscopic observer group (Japan, France, Spain, Germany) started observing for this campaign in November 2008 at the request of Bernd Hanisch and one of us (EP) in order to continue former investigations whose results were based on multi-daily averaging of V and EW. Additional data from literature enable us to represent the quantitative behavior of the Hα-line flux for the timespan August 2005 to December 2011, which behavior reflects variabilities in mass-loss rate, stellar wind density, and ionization structure.

1. Introduction

The international observing campaign, Photometry and Spectroscopy of P Cygni, begun in 2008 by Bernd Hanisch and one of us (EP) (Templeton 2008a, 2008b), is a cooperative project of the American Association of Variable Star Observers (AAVSO), Active-Spectroscopy-in-Astronomy (ASPA), and 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.

As background it should be mentioned that a lot of different investigations during the last decades have been carried out to clarify the causes of brightness and emission strength variation and possible links between them, the extensions of the Hα-emitting wind, and line structures in different spectral areas. One of the earliest interesting investigations of the Hα emission was performed by Scuderi *et al.* (1992) in order to determine properties of the mass-loss.

Five years later, Najarro *et al.* (1997) carried out a detailed parameter study of the line strength, line shape, and energy distribution for the H and HeI spectrum, in order to understand the nature of P Cygni and its wind. de Jager (2001) described photospheric models to explain outward motions in the atmosphere in context of luminosity and brightness variations. The investigation of the long-term spectral and quasi-simultaneous photometric behavior of P Cygni of Markova *et al.* (2001a, 2001b) was the main impetus to start our campaign.

The (for us) important question of the quantitative evaluation of the Hα emission and its reference to the radial distribution of the emitting regions around P Cyg was investigated in a comprehensive interferometric study by Balan *et al.* (2010). Relative to our investigation, it seems to give certain parallels in the current study of Richardson *et al.* (2011). They are showing in long-term studies the correlation behavior of the continuum flux and (not contemporaneous) photometric V-data, and they conclude that they vary in different manner in context of long-term and short-term timescales (the non-contemporaneous nature of their data is one of the substantial differences from campaign).

In our campaign it is assumed that the variability of the EW is caused by variations of the continuum flux and not by variations of the line flux, which would indicate variations in the stellar wind density. Therefore, the variability of the continuum flux shall be our primary concern when the properties of the stellar winds and rate of mass loss are studied.

Photometric and spectroscopic changes in P Cygni are shown to be anti-correlated on short- and long-term scales. We observed a total change of 35 Å 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 (23 July 2008) through JD 2455880 (14 November 2011).

2. Results

Figures 1 and 2 illustrate our observations. Figure 1 compares of the behavior of the V magnitude (top) and the Hα-EW (below) during our campaign. Figure 2 is a plot of the Hα-EW (black points) as a function of photometric V magnitude (open circles) of P Cyg from Markova *et al.* (2001b).

As can be seen in Figure 1, when the EW decreases, the contemporaneous stellar brightness increases and vice versa. So far, our own results in Figure 1 agree well with the results of Markova *et al.* (2001b), which are shown in Figure 2 for comparison. 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 are corrected for the effect mentioned in the previous section. From the definitions of

$$\mathrm{EW} = \int \frac{l_o - l_\lambda}{l_o}\, d\lambda \qquad (1)$$

and the relation between stellar magnitudes and continuum flux variations $F2 / F1 = 10^{-0.4\,(m2-m1)}$, it follows that the line flux is $F = C\ EW / 10^{(0.4\ Vphot)}$.

Here C is a constant factor. In practice, we correct EW with a simple division by $10^{(0.4*Vphot)}$. The derived quantity is then not the line flux in physical units, but a quantity proportional to the physical line flux, corrected for continuum variations. 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 122 nearly simultaneous measurements of the EW and the flux in the V-band (Figure 3). Strictly applied, the continuum flux at 6563 Å should be used. But here ΔV is a good approximation since the color indices of P Cygni do not vary greatly (Markova *et al.* 2001b, p. 903).

Figure 3 attempts to display if and to what extent the intrinsic line flux (a 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. With consideration of standard deviation and possibly other kinds of errors, the temporal variation of the line flux of Hα in the plot in Figure 4 will represent the result of variations in the mass loss rate, stellar wind density, and changes of the ionization.The 122 EW and contemporaneous V-measurements of the current campaign are, of course, from a statistical point of view, still not sufficient to make firm statements regarding the simultaneous temporal behavior of V and the intrinsic line flux. In order to achieve this aim, further multiyear, simultaneous spectroscopic and photometric measurements will be continued in this campaign. Maybe then we will have a opportunity to report here again about the state of the results.

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G. Horne, Mike Durkin, Desmond Loughney, Wolfgang Vollmann; Spectroscopy (Hα-EW)—Mitsugu Fuji, Benjamin Mauclaire, Joan Guarro, Bernd Hanisch, Ernst Pollmann, Thierry Garrel, Valerie Desnaux, Olivier Thizy, Jean Noel Terry, Christian Buil, Stephane Charbonnel, Pierre Dubreul, Alain Lopez (from Balan *et al.* (2010)).

The EW, V(phot), and line flux data are available at the following website: http://astrospectroscopy.de/Data_PCyg_Campaign/Data%20table%20of%20the%20campaign.txt

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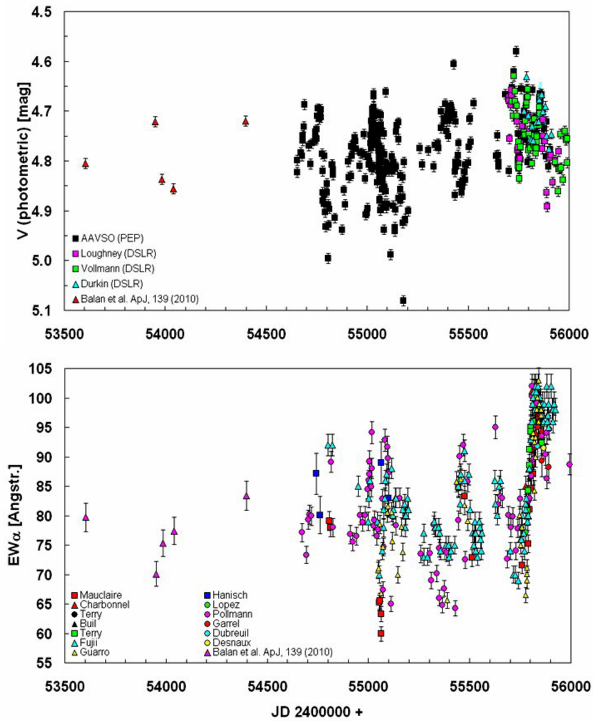

Figure 1. Photometric and spectroscopic observations: V-magnitude (top) and the Hα-EW (bottom) of P Cyg during the campaign (including data of Balan *et al.* 2010).

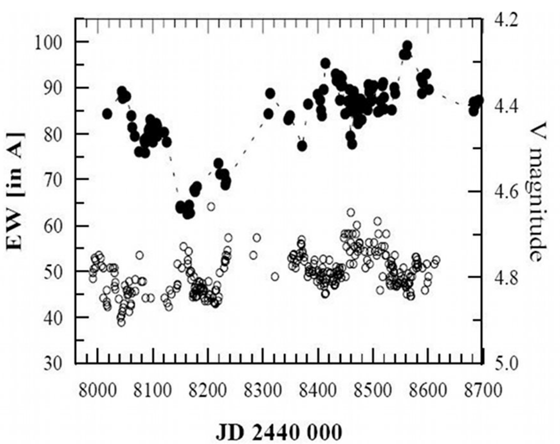

Figure 2. Plot of the Hα-EW (black points) as a function of photometric V-magnitude (open circles) of P Cyg (from Markova *et al.*2001b).

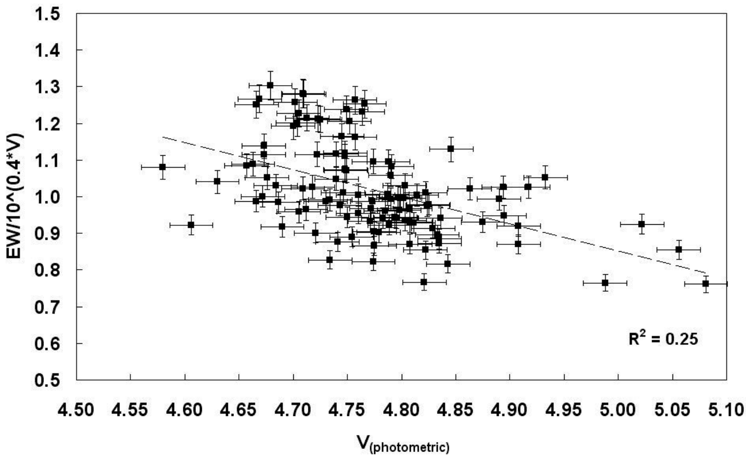

Figure 3. The relationship between line flux and V-magnitude of P Cyg.

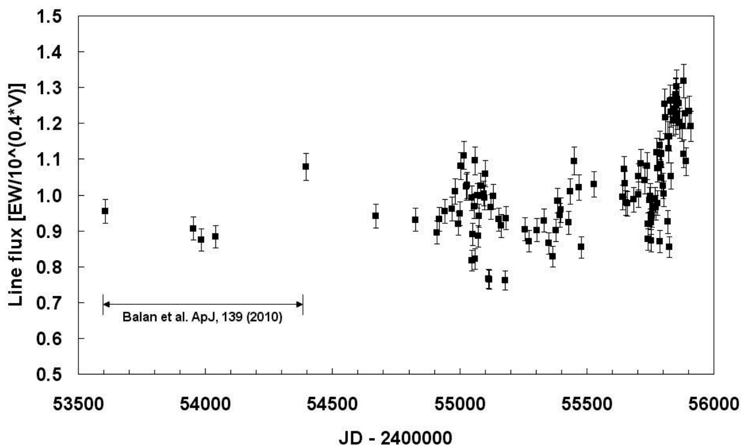

Figure 4. Intrinsic flux of the Hα line of P Cyg, 22 August (JD 2453605) to 15 December 2011 (JD 2455911).