Photometry and Spectroscopy of P Cygni: Periodic Variation of the Intrinsic Hα-line Flux

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Received April 15, 2020; revised July 8, 31, 2020; accepted August 8, 2020

Abstract Simultaneous V-band photometry and high-resolution spectroscopy of P Cygni during the years 2005 to 2019 have been combined to yield a time series of the continuum-corrected line flux of Hα. For the first time, a clear dominant period, 318 ± 1.5 days, is derived.

1. Introduction

The international observation campaign "Photometry and Spectroscopy on P Cygni" started in November 2008 as a joint project among AAVSO, BAV, and the spectroscopy group ARAS. The aim of the campaign is, by the use of simultaneous photometric V brightness and Hα equivalent width (EW), to carry out a long-term monitoring of the intrinsic Hα-line flux, and thereby to extend the investigations by Markova *et al.* (2001a) and Markova *et al.* (2001b) on the anti-correlation between the Hα equivalent width and the photometric V brightness. To find out if and how the flux obtained from the spectral line profiles varies, the EW measurements are corrected for the effect of variation of the continuum flux. From these new data, there emerges a clear, dominant period of 318 days, to which future observations can be referred.

The current state of our campaign enables us, with all our collected data of the Hα equivalent width (shown in Figure 1) and the V-band measurements (shown in Figure 2), to try a period analysis of the intrinsic Hα-line flux, which is the primary aim of this campaign (http://astrospectroscopy.de/Projects). The intrinsic Hα-line flux (ordinate of Figure 3) was calculated by division of the Hα equivalent width EW by the flux derived from the simultaneous photometric V data of different observers.

2. Observations

The Hα spectra for the investigation presented here were obtained with 0.2-m to 0.5-m telescopes with a long-slit (in most cases) or an échelle spectrograph with resolutions of R ~ 10,000–20,000. All spectra included the 6400−6700 Å region, with S/N (at least) of ~100 for the continuum near 6605 Å, and exposure times ~1,200 sec. The spectra have been reduced with standard procedures (instrumental response, normalization, wavelength calibration) using the programs VisualSpec (Desnoux 2019) and the spectral classification software package xmk22 (Gray 2020). For V-band measurements the UBV photometric system UBV (Johnson-Morgan) was used. EW and V-band measurements have been obtained on the same night (time lag ~ 0.5–0.8 day at maximum).

From the definition of equivalent width,

$$EW_\lambda = \int_{\lambda 1}^{\lambda 2} \frac{F_c - F_\lambda}{F_c}\, d\lambda \qquad (1)$$

with F_λ the flux at wavelength λ and F_c the continuum flux, and from the relation between stellar magnitude and flux variations, $F_2 / F_1 = 10^{-0.4(m_2 - m_1)}$, it follows that the Hα-line flux is

$$F_{H\alpha} = C \times EW_{H\alpha(corr)} = C \times EW_{H\alpha(obs)} \times 10^{-0.4\,\Delta V}, \qquad (2)$$

where ΔV is the observed V magnitude minus a fiducial magnitude corresponding to a fiducial, wavelength-averaged, continuous flux that is included in the constant C.

The determination of the $EW_{H\alpha(obs)}$ has been performed as an integration over the wavelength range λ_1 = 6525 Å to λ_2 = 6605 Å in all spectra that had previously been cleared of telluric absorptions. The accuracy of the spectroscopic EW measurements are of the order ± 2–3% and the V measurements of the order ± 0.01–0.03 mag. 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.

Use of the period search program ave (Astrogea 2020) in Figure 4 enables carrying out the main aim of the campaign, to determine periodicities of the continuum-corrected Hα EW.

3. Results

The continuum-corrected Hα EW data shown in Figure 3 enable the period analysis shown in Figure 4. The Lomb-Scargle-diagram shows a clear dominant period of 318.3 (± 1.5) days. The phase diagram of that period is shown in Figure 5. However, the dispersion of the continuum-corrected Hα EW in Figure 5 is too large to be explained by observational errors. Rather, it results mainly from real variations in line or continuum flux as the result of variations in the mass loss rate, stellar wind density, and changes of the ionization from JD 2453605 (2005 August 22) through JD 2458782 (2019 October 25) on a time scale different from the identified period.

Earlier results of the investigation period 2008 to 2013 (170 spectra and V-band measurements) published by Pollmann and Vollmann (2013) show in the Lomb-Scargle power spectrum periods of 242 days, 363 days, and 600 days, with a dominant period at 242 days. The current data set with 340 spectra and V-band data represents a more extended investigation period from 2005 to 2019 and gives, with the dominant period of 318.3 (± 1.5) days, with a much greater degree of confidence.

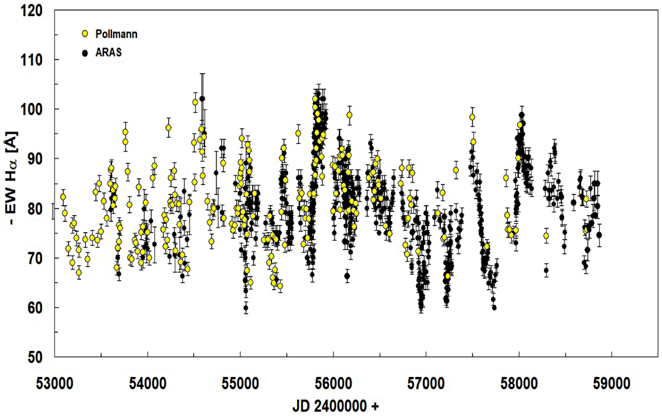

Figure 1. Long-term monitoring of the Hα equivalent width of P Cyg in collaboration with different observers of the ARAS group.

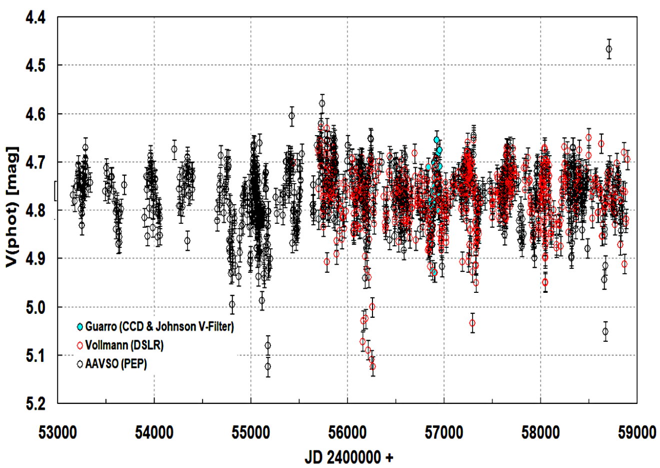

Figure 2. Long-term monitoring in V from the AAVSO International Database (photoelectric photometry (PEP) and DSLR) (Kafka 2019), and from J. Guarro (ARAS, CCD, and Johnson filter) (Balan *et al.* 2010).

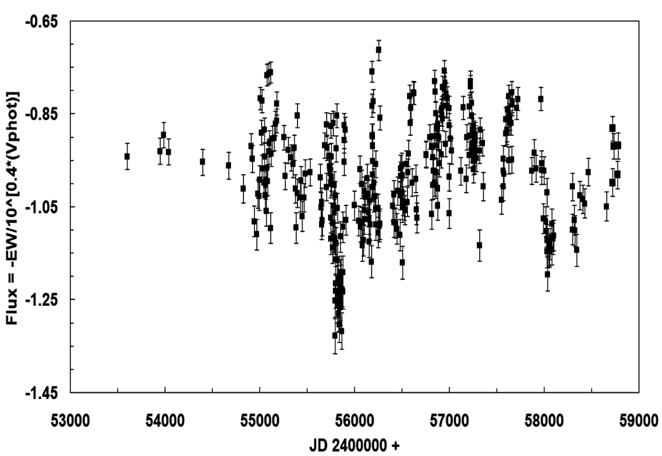

Figure 3. Long-term monitoring of the Hα EW, corrected for the variation in the underlying continuum.

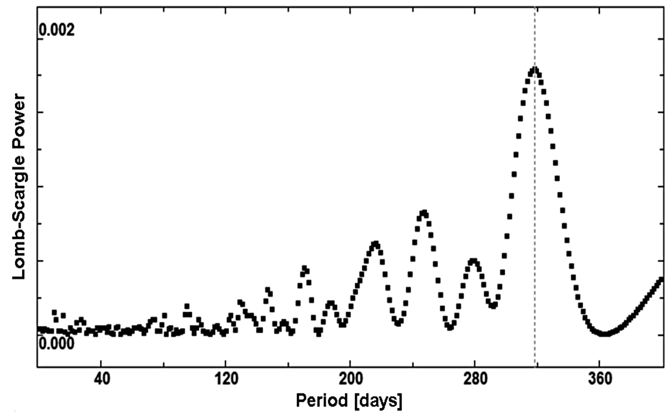

Figure 4. The Lomb-Scargle period analysis (period = 318.3 d (± 1.5)) of the Hα-line flux data in Figure 3, performed with the program AVE (Astrogea 2020).

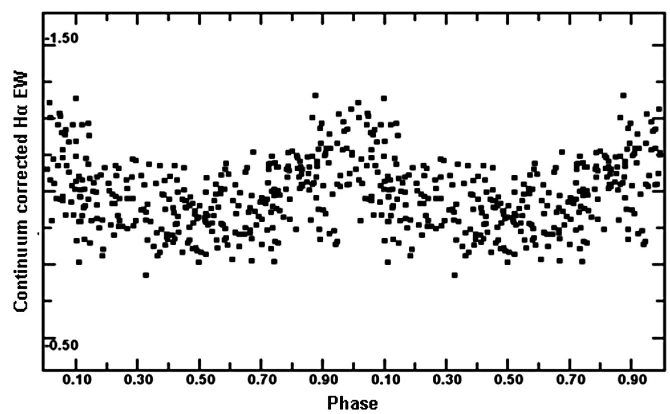

Figure 5. Phase diagram of the 318.3-day (± 1.5) period of Figure 4.

4. Conclusion

For the first time, through our data we have reliable evidence of the periodic character of the intrinsic flux of the Hα emission (see intermediate report 2014: http://www.astrospectroscopy.de/Projects). It will be of high interest to see how the found period can be improved with further data over the next years. It is planned to make the spectra used in Figure 3 for calculating the intrinsic Hα-line flux available on the author's website (Pollmann 2020).

5. Acknowledgements

I am grateful to the observers of the AAVSO (https://www.aavso.org), the BAV (http://www.bav-astro.eu/joomla/index.php/beobachtungspraxis/spektroskopie/kampagnen), and the ARAS group (http://www.astrosurf.com/aras)

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