

**LONG-TERM MONITORING OF H $\alpha$  EMISSION STRENGTH  
AND PHOTOMETRIC  $V$  MAGNITUDE OF  $\gamma$  Cas**

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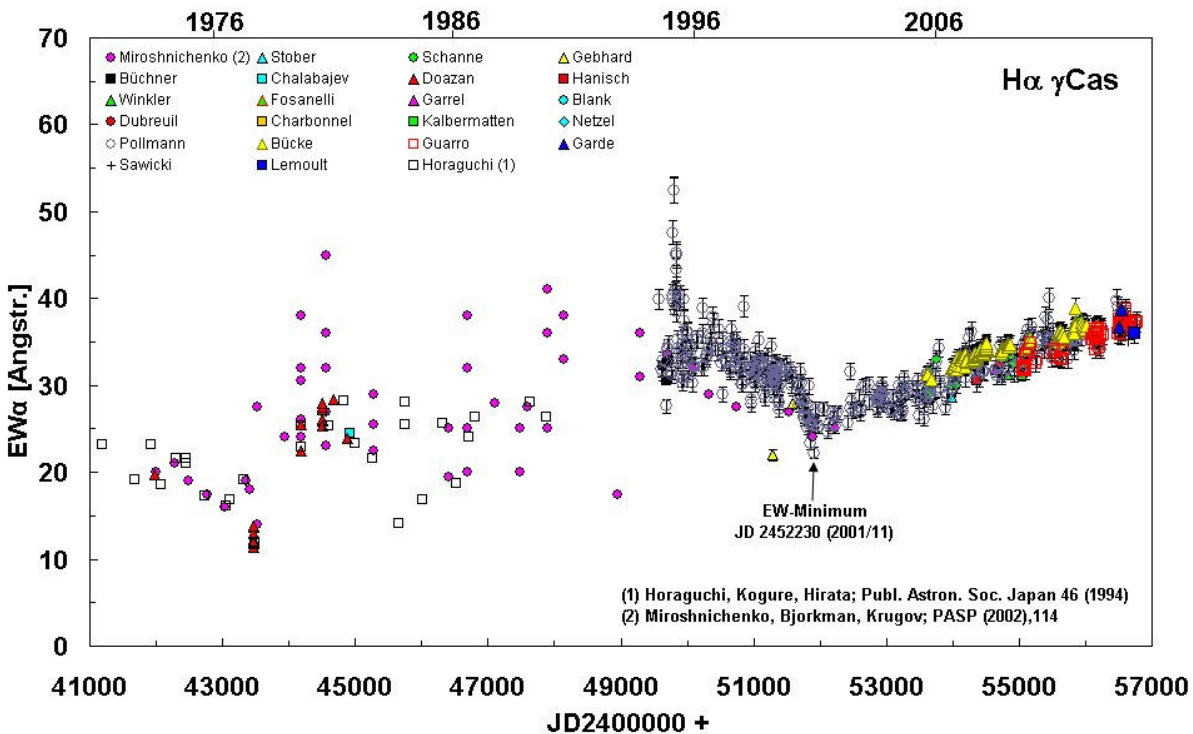
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After the discovery of Be stars (Secchi 1867) these stars were systematically monitored in long-term observing programs. Today we know that their spectra vary on time scales of a few days up to several decades. The H $\alpha$  and H $\beta$  emission lines in particular can sometimes vary unpredictably and dramatically in strength and appearance. An international group consisting mainly of members of the ARAS spectroscopy group (<http://www.astrosurf.com/aras/>) has been observing the H $\alpha$  emission line strength of the disk of the Be star  $\gamma$  Cas from the year 1994 up to now (2014) (Smith et al. 2012). They continue the professional observations carried out from August 1971 to October 1989 (Horaguchi et al. 1994 and Miroshnichenko et al. 2002) and together cover more than 40 years of data (Fig. 1).

The idea to investigate a possible correlation between the visual magnitude and the spectroscopic H $\alpha$  equivalent width (EW) emerged from the study of the relationship between  $\gamma$  Cassiopeia's X-ray emission and its circumstellar environment (Smith et al. 2012). The results of the investigation of the X-ray production of the star and its relationship to the intensity of the H $\alpha$  emission of the disk (Smith et al. 1998) were an additional incentive for our study. Essential to our study was the availability of high precision  $V$  magnitudes for a comparable time frame with the spectroscopic H $\alpha$  EW measures. Fortunately we were able to use the photometric  $V$  measures of G. Henry for the time period JD 2451085 to JD 2456702. They are complemented by the 263 DSLR measures by W. Vollmann for the time period JD 2455154 to JD 2456671. The  $V$  magnitude measures by G. Henry were already used in the study Rotational and cyclical variability in  $\gamma$  Cas (Smith, Henry, Vishniac 2006; Henry & Smith 2012). The observations were carried out for 15 years with the Automated Photometric Telescope (APT) in Arizona. The accuracy of the DSLR magnitude measures is  $\pm 0.02$  mag while the photoelectric APT measures are accurate to  $\pm 0.005$  mag.

The spectroscopic observations are done by members of the international amateur spectroscopic community. They have been carried out since 1994 with CCDs and telescopes of 20 to 40 cm aperture, first with prism spectrographs then with slit spectrographs with a resolution  $R$  between 5000 and 17000. The measurement of the H $\alpha$  EW was done generally in the wavelength range 6530 to 6610 Å with an accuracy of  $\pm 3\%$  for the measures of a night (reproducibility of evaluation of two to three sum spectra per night). Today it

is well known that most Be stars are photometric long-term variables, and that at least two characteristic behaviours can be recognized when simultaneous photometry and optical spectroscopy are available: positive and inverse (negative) correlation between the Balmer emission strengths and the stellar brightness (Harmanec, 1983). Indeed, a positive correlation has been observed in several Be stars (e.g. 28 Tau: Pollmann et al. 2012;  $\kappa$  Dra: Juza et al. 1994; 4 Her: Koubsky et al. 1997) as their  $H\alpha$  emission gets stronger when their photometric  $V$  magnitude increases.



**Figure 1.**  $H\alpha$  EW long-term monitoring by professional and amateur observers from August 1971 up to now.  $EW\alpha$  is the  $H\alpha$  equivalent width – for its definition refer to Pollmann & Rivinius (2010).

These stars are not only seen pole-on but also from different viewing angles. Our study builds on the work by Pollmann et al. (2012) which used visual magnitude estimates superseded now by the significantly more accurate photoelectric measures with the APT. Fig. 2 shows the light curve of  $\gamma$  Cas based on the APT measures by G. Henry, complemented by the DSLR measures by W. Vollmann in 14 observing seasons.

Fig. 3 shows the variable intensity of the  $H\alpha$  EW for the same time span as Fig. 2. To make the visual hints for a correlation between the spectroscopic and photometric time series in these figures and already noted in the studies by Pollmann et al. (2012), Juza et al. (1994) and Koubsky et al. (1997) more concrete, we averaged the data for every observing season (see table in Fig. 4) and plotted them in a correlation diagram (Fig. 4). Hence, a correlation coefficient of 0.86 could be derived for the correlation between the  $H\alpha$  EW and  $V$  magnitude.

The diagram in Fig. 4 shows conspicuously that the high correlation coefficient of 0.86 is based primarily on the precision photometric APT measures. The physical cause for

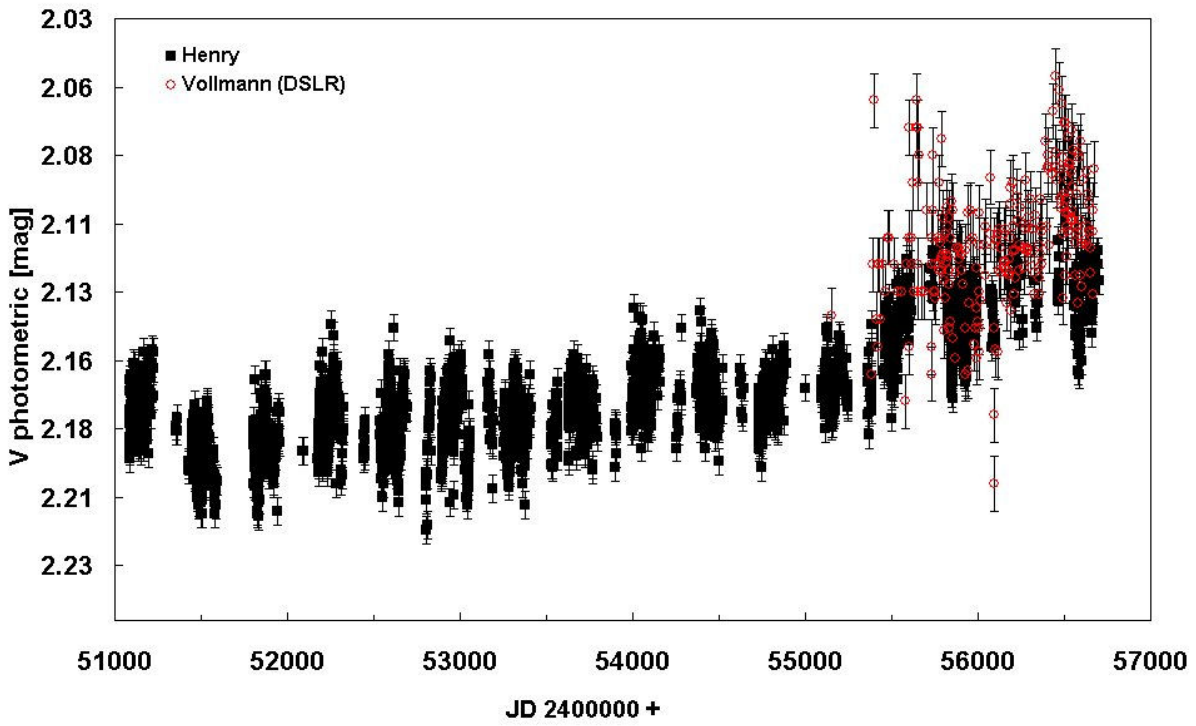


Figure 2. Johnson  $V$  magnitude of  $\gamma$  Cas, measured with the T3 40 cm APT at the Fairborn Observatory, Arizona (USA).

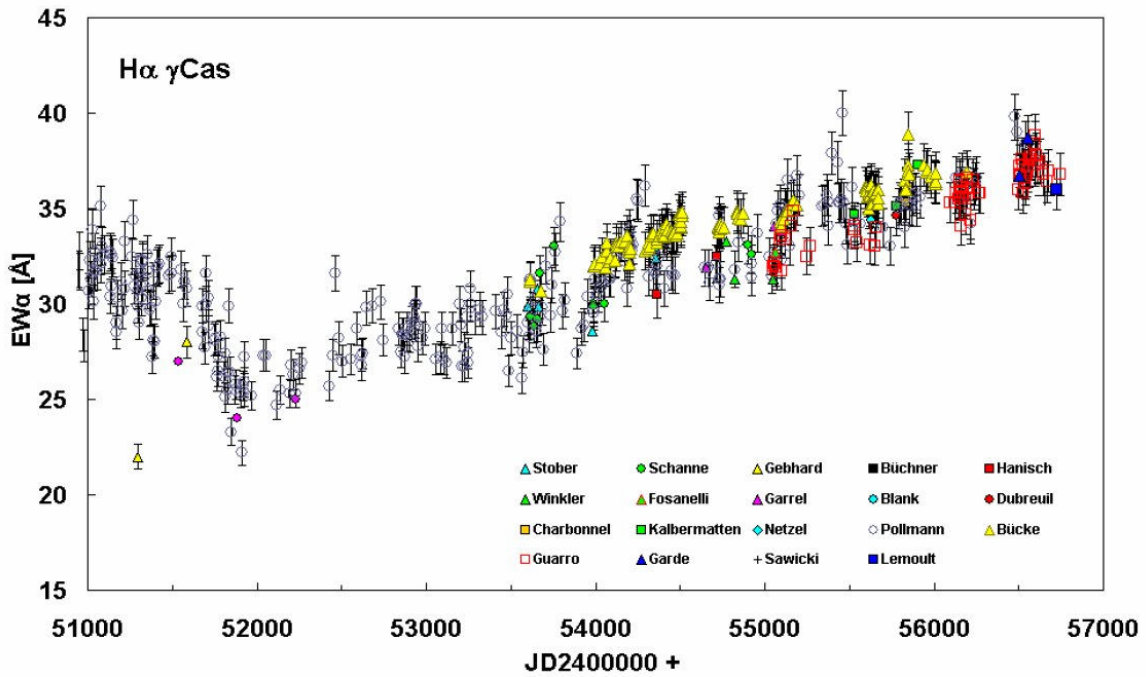
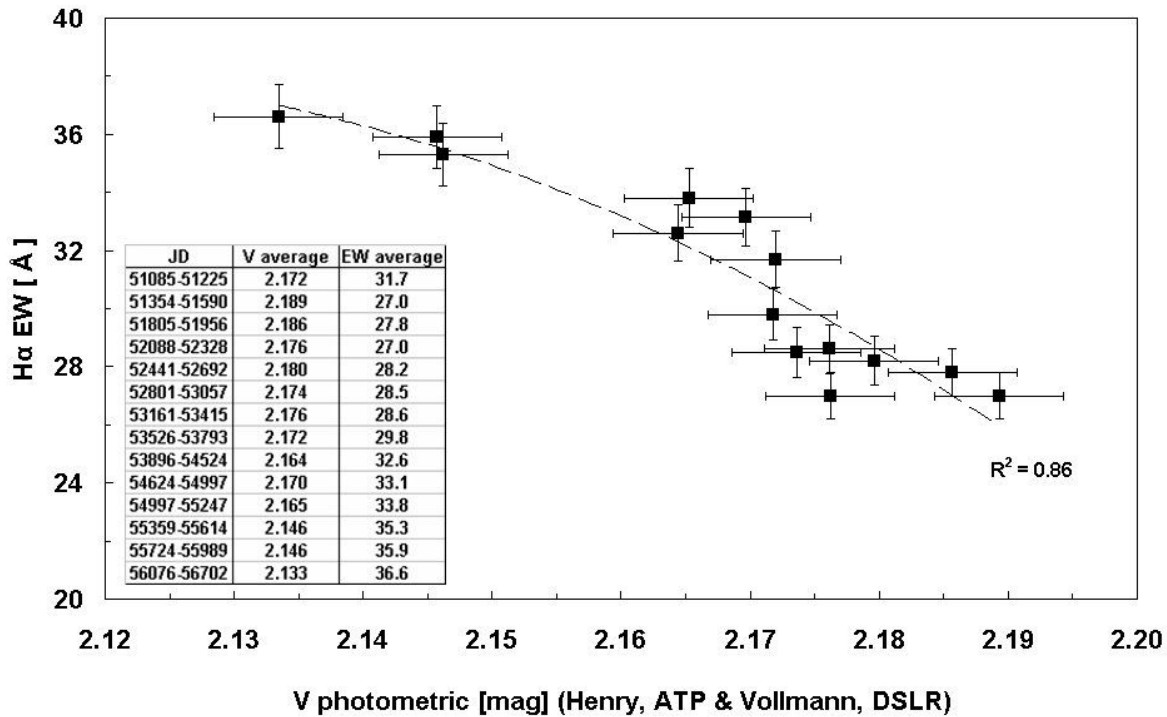


Figure 3.  $H\alpha$  EW measures for the same time period as the photometric measures in Fig. 2 (section of Fig. 1).



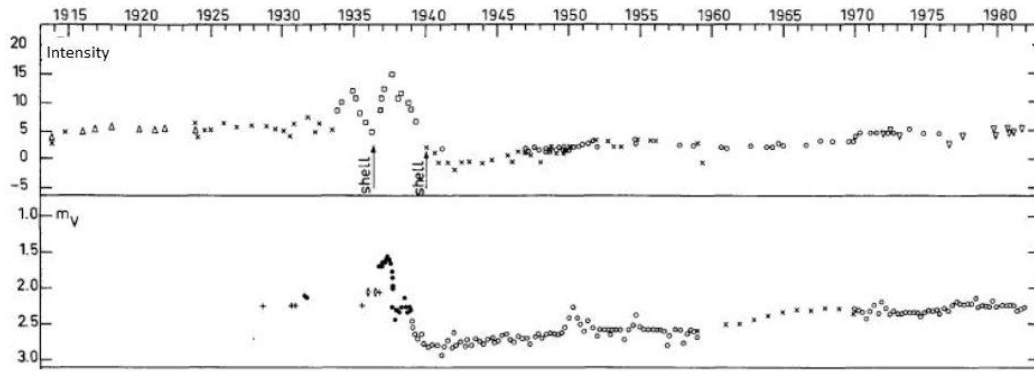
**Figure 4.** Correlation diagram of H $\alpha$  equivalent width versus  $V$  magnitude (explanation in the text).

the correlation results from the fact that H $\alpha$  EW is an indicator for the variability of the size, volume and density of the disk around the star, which also gives rise to brightness variations (cf. Pollmann et al. 2012, Juza et al. 1994, Koubsky et al. 1997).

Before our study, it was questionable if magnitude variations of  $\gamma$  Cas would be detectable since we see its disk from a viewing angle of about 45 degrees. However, our data show that the increase of the H $\alpha$  EW by ca. 10 Å observed during the last 15 years was accompanied by a slight magnitude increase of 0.06 mag. Our observations give evidence for a non-linear relationship between the H $\alpha$  EW and the  $V$  magnitude but it is unknown how long their increase will continue in the future.

The very first investigation of this kind was conducted by Doazan et al. (1983). Their investigations shows, that during and after the spectacular episode of the Be phase from 1932 to 1942, the Balmer lines and the brightness followed the same trend of variations (see H $\alpha$  in Fig. 5). New correlation model calculations of H $\alpha$  EW and  $UBV$  photometry for Be stars with increasing disk sizes and/or an increasing disk density of Sigut & Patel (2013) are able to explain the positive and negative correlations between long-term variations in H $\alpha$  EW and  $V$  brightness as observed for well known Be stars (Harmanec 1983). However, the need for real observations to examine and refine the model calculations was expressed explicitly. We provide it here.

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**Figure 5.** Long-term variations of  $\gamma$  Cas in the visual region: (top panel) intensity variations of the Balmer emission lines (squares:  $H\alpha$ ); (bottom panel) long term variations of the visual brightness (Doazan et al. 1980).

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