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Surface Imaging of Late-Type Contact Binaries II: Hα Emission in AE Phe and YY Eri †

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Abstract. We present and discuss the Hα (λ = 6563Å) observations of the contact (W UMa type) binaries AE Phoenicis and YY Eridani, obtained in 1989, 1990 and 1995 with the CAT/CES telescope of the Southern European Observatory (ESO). In particular, we compare the intrinsic equivalent widths of both components with the NextGen theoretical models and the saturation limit. We find that the average Hα equivalent widths are close to the saturation border and that the primary components have excess Hα-emission, indicating enhanced chromospheric activity. This is compatible with both theoretical and observational suggestions that the primary is the more magnetically active component and is filled with (mostly unresolvable) dark spots and associated chromospheric plages.

Keywords. binaries:close, binaries:eclipsing, stars:late-type, stars:activity, stars:chromospheres

1. Introduction

In contrast with theoretical predictions (Lucy 1968) the secondary (i.e. the less massive) components of late type contact binaries of W-subtype, in which the deeper light curve minimum corresponds to an occultation, are slightly hotter than the primaries. A possible explanation of this discrepancy is the presence of cool starspots on the primary (Mullan 1975, Rucinski 1985). Some evolutionary models predict shallower outer convective zones for the secondary, because of its physical status (out of thermal equilibrium), in particular the angular momentum loss via magnetic braking models (see, e.g., Vilhu 1982, Van't Veer & Maceroni 1988), and the Thermal Relaxation Oscillation models (e.g., Webbink 2003). Shallower convection would mean a less magnetically active secondary, because for a fixed rotation rate the dynamo action is stronger in a thicker convective zone. The strong tidal action could also help, decreasing more efficiently differential rotation in the secondaries (Barden 1985).

Observational confirmation of these predictions has remained mostly unexplored, as results for photometry are always rather ambiguous and high-resolution spectroscopy is quite challenging because of the short orbital periods and fast rotation. Nevertheless Maceroni *et al.* (1994), using both photometry and Ha spectroscopy of AE Phe and YY Eri, found the primaries slightly cooler than the secondary components and large photometric dark spots on the primary surface. Another (unpublished) series of observations of the same systems was obtained six years later with the same instrumentation (CAT/CES and ESO 50-cm at La Silla). Recently, Barnes *et al.* (2004), using high-resolution Doppler imaging techniques, found the primary of AE Phe spectroscopically

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† based on observations collected at the European Southern Observatory, La Silla, Chile

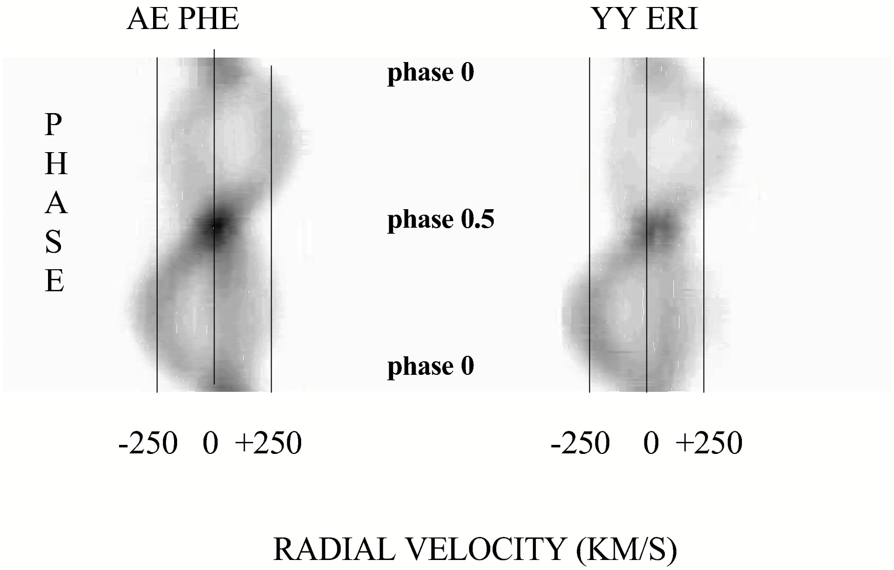

Figure 1. Hα 6563 Å dynamic spectra of AE Phe and YY Eri from the 1995 observations. The grey scale is linear, the white corresponding to the continuum and the darkest colour (at phase 0.5) to 60 % of the continuum level.

cooler, and provided further indication of unresolved dark spots. A similar result was obtained for VW Cep by Hendry & Mochnacki (2000). We present here the (re-)analysis of our full set of observations (1989, 1990, 1995) and a comparison with the predictions of up-to-date model atmospheres.

2. Observations and Hα equivalent widths

Our program stars, AE Phoenicis , (G0V, $P_{orb} = 0^d.362$) and YY Eridani (G5V, $P_{orb} = 0^d.312$) are late-type contact binaries (W UMa stars) of W-subtype. They were observed with the Coudé Auxiliary Telescope (CAT) of the European Southern Observatory (ESO at La Silla, Chile) during November 20-25, 1989, November 17-23, 1990, and October 26-31, 1995. The Coudé Echelle Spectrometer (CES), with the short camera in the red and resolution of 60 000 (5 km s^{-1}) at Hα 6563 Å was used. The exposure times were 15 and 20 minutes for AE Phe ($m_V = 7.9$) and YY Eri ($m_V = 8.4$), respectively. This guaranteed orbital smearing of less than 0.05 in phase for both stars. The ESO 50-cm telescope provided complementary photometric observations in B, V, and I filters which, though of low quality because of weather conditions, were useful to check the correct orbital phasing of the spectra.

A sample of line profiles for the years 1989 and 1990 were shown in Maceroni *et al.* (1994) and are not repeated here for the sake of brevity. In Figure 1 the grey-scale dynamic light curves (phase vs. λ) for the year 1995 are shown. The grey-scale is linear, the white corresponding to the continuum and the darkest colour (at phase 0.5) to 60% of the continuum level. The radial velocity curves of the broad Hα-absorption in both

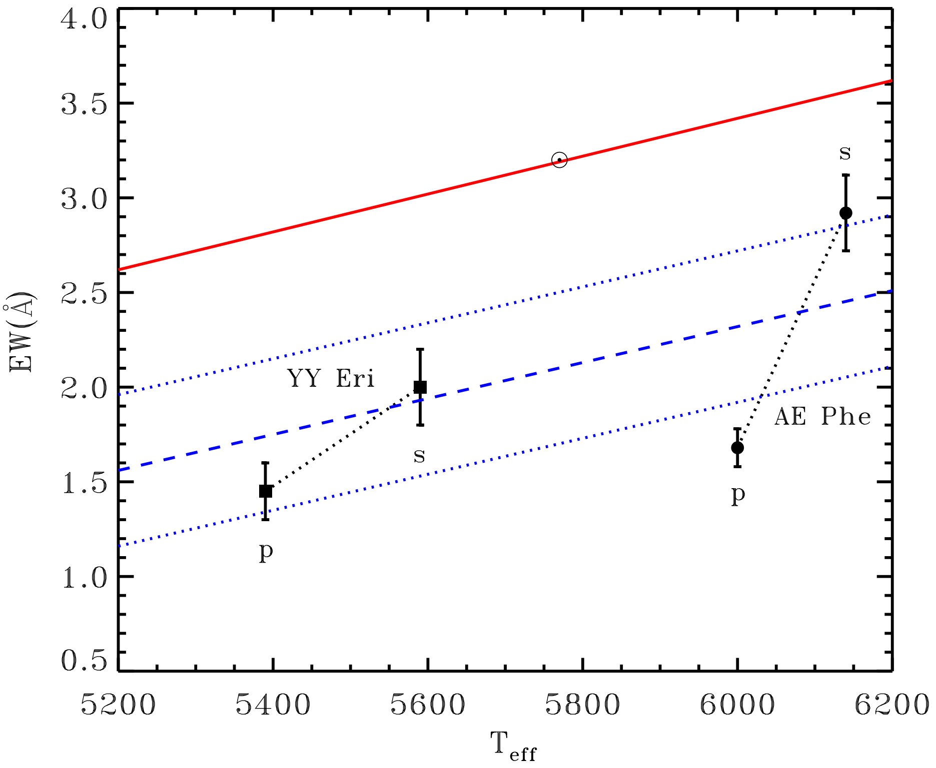

Figure 2. Mean Hα equivalent widths for the primary and secondary components of AE Phe and YY Eri (from Table 1). The values from theoretical NextGen-models (Hauschildt et al. 1999) are also shown (solid line) together with the saturation limit found by Herbst & Miller (1989) (dashed line, the dotted lines express the uncertainty in the relation).

components are clearly seen, the curves with larger amplitudes corresponding to the secondary (less massive) component.

The equivalent widths (relative to the total continuum) were measured at elongations, as mean values between phases $\varphi = 0.15 - 0.35$ and $\varphi = 0.65 - 0.85$. Intrinsic widths were obtained by scaling with the component luminosities according to: $L_p = L/a$ and $L_s = L(a-1)/a$, where L, L_p and L_s are the total, primary and secondary luminosities and $a = 1 + q^{0.92}(T_s/T_p)^4$ directly follows from the contact condition and the effective temperatures (by the way, the corresponding luminosity ratios are in very good agreement with the results from the light curve solutions of paper I).

The intrinsic EWs of Table 1 are compared in Figure 2 with the NextGen models† of solar abundance and log g= 4.5 (Hauschildt *et al.* 1999, Short & Hauschildt 2005). Also shown is the saturation limit (by chromospheric emission filling) found by Herbst & Miller (1989) for a large sample of K-M stars: $\log L_{\mathrm{H}\alpha}/L_{\mathrm{bol}} = 3.9 \pm 0.2$.

The theoretical models match quite well with the solar value marked in Figure 2 (EW = 3.2 Å), as observed with the CAT/CES telescope by exposing the twilight sky before the observations.

The (absorption) equivalent widths of AE Phe and YY Eri are clearly below the theoretical predictions. An explanation (which we adopt here) for this deficiency is that

† The NextGen uses the model atmosphere PHOENIX code. The code is available from `http://dilbert.physast.uga.edu/yeti`

Table 1. Hα equivalent widths (EW, in units of Ångströms) of the more massive (p, primary) and the secondary (s) components of AE Phe and YY Eri. The values are average values from the observations of 1989, 1990 and 1995. The observed values are direct measurements, with the total luminosity as continuum, over the orbital phases 0.15–0.35 (marked as 0.25) and 0.65–0.85 (0.75). The intrinsic values are scaled with the components' individual luminosities (see text).These intrinsic values are shown in Figure 2. The errors include the differences from epoch to epoch.

comp	EW(0.25)	EW(0.75)	EW mean	EW intrinsic
AE Phe p	1.25 ±0.1	1.05 ±0.05	1.15 ±0.07	1.68 ±0.10
AE Phe s	0.90 ±0.07	0.95 ±0.07	0.92 ±0.07	2.92 ±0.20
YY Eri p	1.00 ±0.10	0.90 ±0.07	0.95 ±0.10	1.45 ±0.15
YY Eri s	0.70 ±0.07	0.75 ±0.07	0.74 ±0.07	2.00 ±0.20

chromospheric emission fills in the photospheric absorption, thus lowering the measured equivalent widths. Herbst & Miller (1989) have estimated this emission for a large sample of K-M stars. They found an upper bound (the saturation limit) to the fraction of star's bolometric luminosity that can appear as Hα emission: $L_{\mathrm{H}\alpha}/L_{\mathrm{bol}} = 10^{-3.9}$. Using $F_{\mathrm{H}\alpha}/F_{\mathrm{bol}}$ values at different effective temperatures, as computed from the NextGen models, this relation can be easily converted to the saturation line in Figure 2.

3. Discussion and conclusions

Both AE Phe and YY Eri clearly have equivalent widths of the Hα-absorption smaller than the Sun and smaller as well than those predicted by NextGen-models for normal main-sequence stars of similar effective temperatures. This can be interpreted as being due to extra chromospheric Hα emission that partly fills the photospheric absorption. The average values of both stars lie close to the saturation limit. This behaviour is similar to other chromospheric emission diagnostics (see, e.g., Vilhu 1987), giving additional support for this interpretation.

The components of YY Eri are not very different from each other, but in AE Phe the primary has clearly much more Hα-emission than the secondary. This is presumably due to a weaker dynamo-generated magnetic activity of the secondary. Since both components rotate with the same rate and have almost the same spectral types (effective temperatures) they probably differ with respect to another crucial parameter of dynamo theories, the thickness of the convective zone; the shallower this zone, the weaker dynamo action (see, e.g., Vilhu 1987). Theoretical contact binary models predict shallower convective zones for the secondaries as well, due to their thermal non-equilibrium condition (AML or TRO models; see, e.g., Vilhu 1982, Webbink 2003).

The equivalent widths remained practically the same over all our observing runs, from 1989 to 1990 and 1995. In particular, the 1989 and 1990 observations showed that the larger photometric spots are found on the primary star (Maceroni *et al.* 1994), as well as weaker Hα-absorption, compatible with the present results. Barnes *et al.* (2004) interpreted their spectroscopic observations (analysed by Doppler imaging) by introducing unresolved dark spots on the primary. Since the appearance of active chromospheres (plages) and cool spots correlate and are the results of the same physical phenomenon, our interpretation sounds valid.

The phase 0.75 side of the AE Phe primary is chromospherically more active than the 0.25 side (see Table 1). This is compatible with the larger spots found on this side during the first two observing runs by Maceroni *et al.* (1994) (paper I).

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