The phase-dependent Ca II K emission of ζ Aur K-type supergiants: *chromospheric heating versus irradiation-induced emission*

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Abstract

ζ Aur systems, wide eclipsing binaries with K supergiants, have been given special attention in stellar astrophysics over the past 80 years, since their hot companions serve as probing light sources during chromospheric eclipse phases and provide us with unique information. On the other hand, at the same time their hot irradiation raises the question as to how representative the physical conditions found in ζ Aur type K supergiant chromospheres are for this class of objects.

We here present, using high quality (20,000 resolution, s/n = 120 to 160) TIGRE-spectra, the Ca II K emission of the K4 II supergiants of ζ Aur, 32 Cyg, and 31 Cyg in different orbital phases, representing different degrees of irradiation by the hot companion. To isolate the K giant spectra from each composite spectrum, we subtract each secondary's contribution by using a matching PHOENIX model spectrum as template. By the variation of the Ca II K emission with orbital phase, and by comparison with eclipse spectra of the K supergiants, we find that the additional (irradiation induced) contribution is in the range of 0.7 to at least 2.3 times that of the intrinsic chromospheric emission seen in eclipse (being caused by chromospheric heating processes common to all K supergiants).

ζ Aur K supergiants: how much can the observer really deduce from them?

Since long it is known that the hot companion in such binary systems acts as a unique light-probe to the chromospheres before and after any eclipse, see Ake and Griffin (2015) for a recent summary of the rich observational evidence, and orbital parameters are very well determined.

But there is not only benefit from the hot secondary star (regardless, whether it undergoes eclipses or not, actually): Its radiation also has some side-effects on the giant chromosphere, and so what is been observed may not be representative for a single K supergiant. This was already noted a long time ago (see Batten 1973, Wright 1970, and references therein). This may well apply to the Ca II K emission outside eclipse, and in fact we here show that a large fraction of it is irradiation-induced rather than intrinsic chromospheric emission – not dissimilar from the unique emission line formation of the Si I 3905 line (Harper et al. 2016).

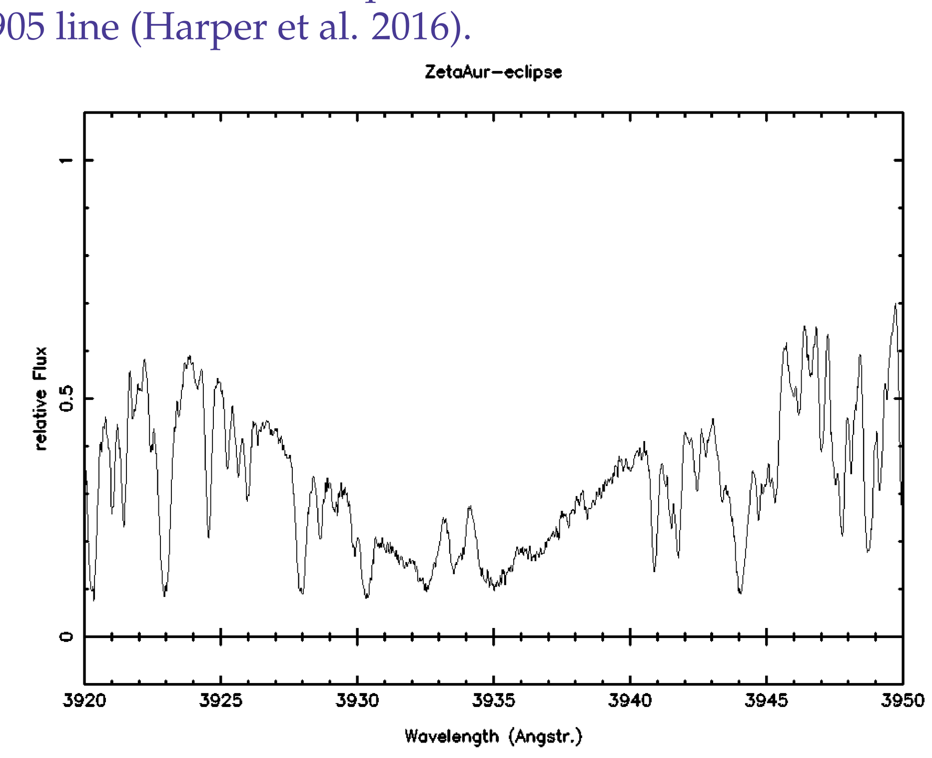

Fig. 1: The intrinsic Ca II K chromospheric emission of the ζ Aur K giant during the 2009-eclipse of the hot companion, when only the non-irradiated side is seen - spectrum obtained with the DAO 1.8m telescope and coude spectrograph with a spectral resolution of 40,000, and kindly communicated by R.E.M. Griffin.

Isolating the giant spectrum

The TIGRE telescope and its 20,000 resolution refurbished, fibre-coupled HEROS spectrograph are located in central Mexico (near Guanajuato, alt. 2400m) and is mainly used for spectroscopic monitoring. Since there is a lack of spectral coverage of ζ Aur type systems outside eclipse, we included them for observation about once a month.

We obtained noisefree template spectra for the hot companions from non-LTE PHOENIX models of $T_{\rm eff}$ =14,000K (32 Cyg), 15,000K (ζ Aur) and 16,500K (31 Cyg), all $\log g = 4.0$. In the subtraction process (see Fig. 2) we adjust the scale of the observed composite spectrum to the latter by carefully comparing trial subtractions with TIGRE spectra of a similar bright, single K giants (e.g., ι Aur) and with a spectrum taken in total eclipse (see Fig. 1).

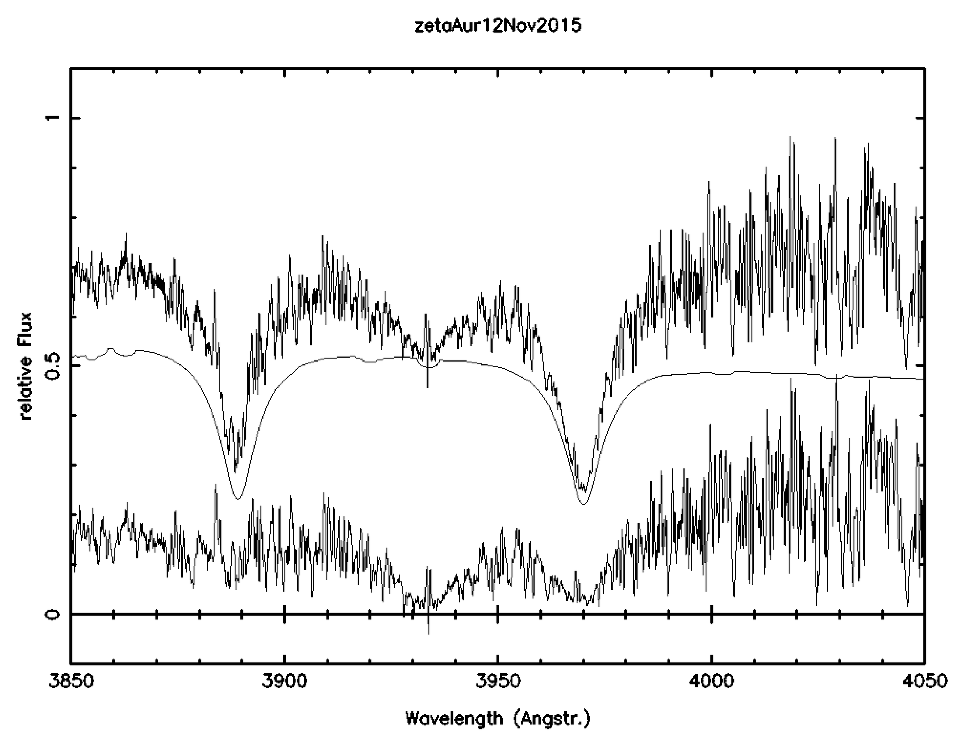

Fig. 2: Outside eclipse, here in Nov. 12, 2014, the giant spectrum has to be isolated from the composite spectrum. As a noise-free template for the hot companion, we use the spectrum of a 15.000K Phoenix model, broadened to 200 km/s.

Ca II K emission: more irradiation-induced than intrinsic?

We here present a small but characteristic selection of the Ca II K emission: at two very different phases of the ζ Aur orbit and one, each, for the 32 and 31 Cyg K supergiants (see Figs. 3 to 6). The chromospheric Ca II K emission is difficult to quantify, since a reasonable estimate of the photospheric Ca line bottom and of the central blanketing by the wind absorption has to be made. While a more thorough analysis must follow, we here already give estimates of the emission measures in relative terms.

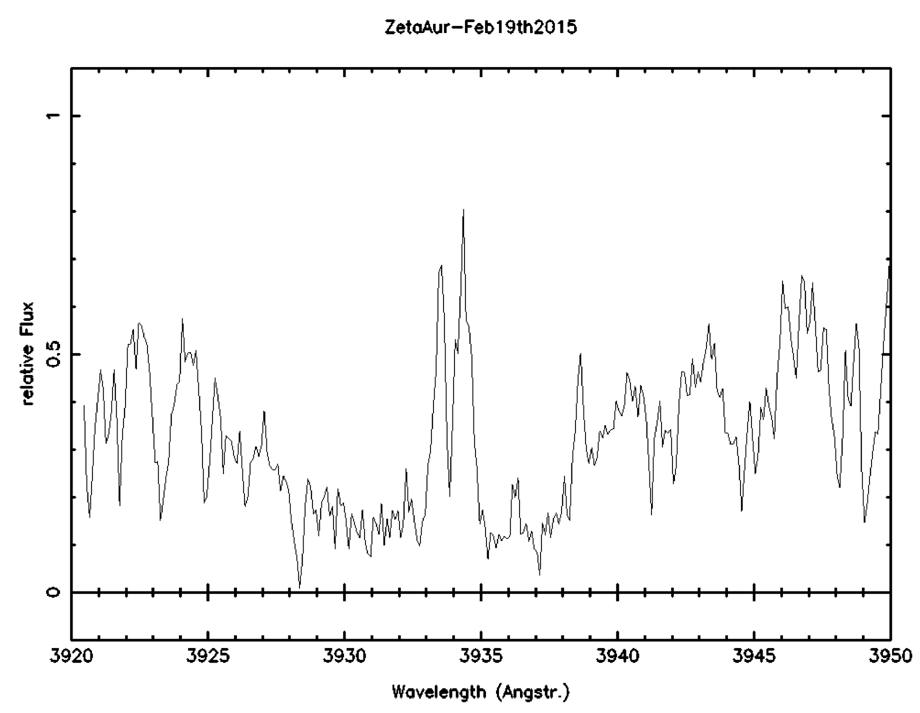

Fig. 3: About half a year after eclipse, here on Febr. 19, 2015, about 4 months after periastron passage and already showing us a good part of the irradiated ζ Aur giant chromosphere, the Ca II K emission is very strong. Similar to the emission seen in November 2014, it is about 3.3 times larger than the intrinsic chromospheric emission observed in eclipse (see Fig. 1).

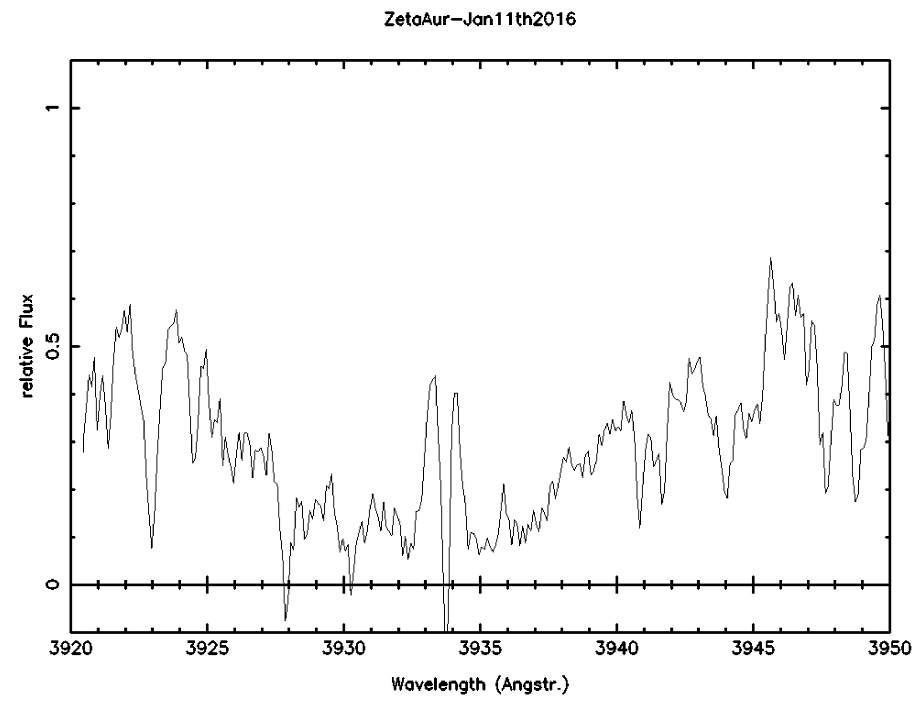

Fig. 4: About half a period after eclipse, here on Jan. 11, 2016, the out-of-eclipse Ca II K emission is only 1.7 times the eclipse emission measure. Nearing apastron, the distance to the hot companion is much larger now (compare with Fig. 3).

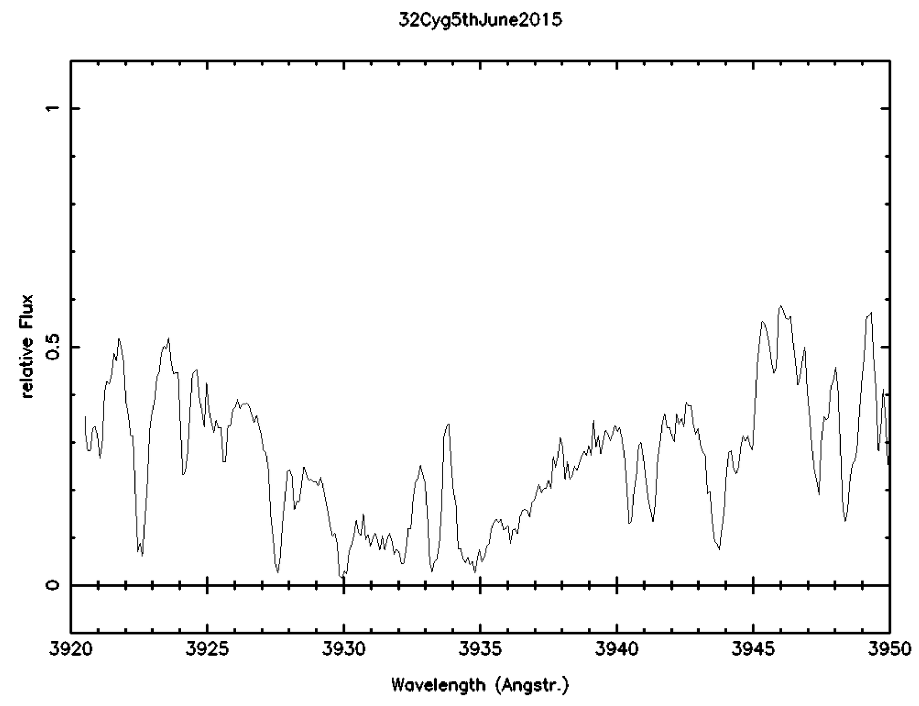

Fig. 5: The effect is similar in 32 Cyg, where the distance to the hot companion is similar to ζ Aur in early 2016 (compare with Fig. 4). Here (June 5, 2015) still in the remote half of its orbit, we expect to see more emission in other phases.

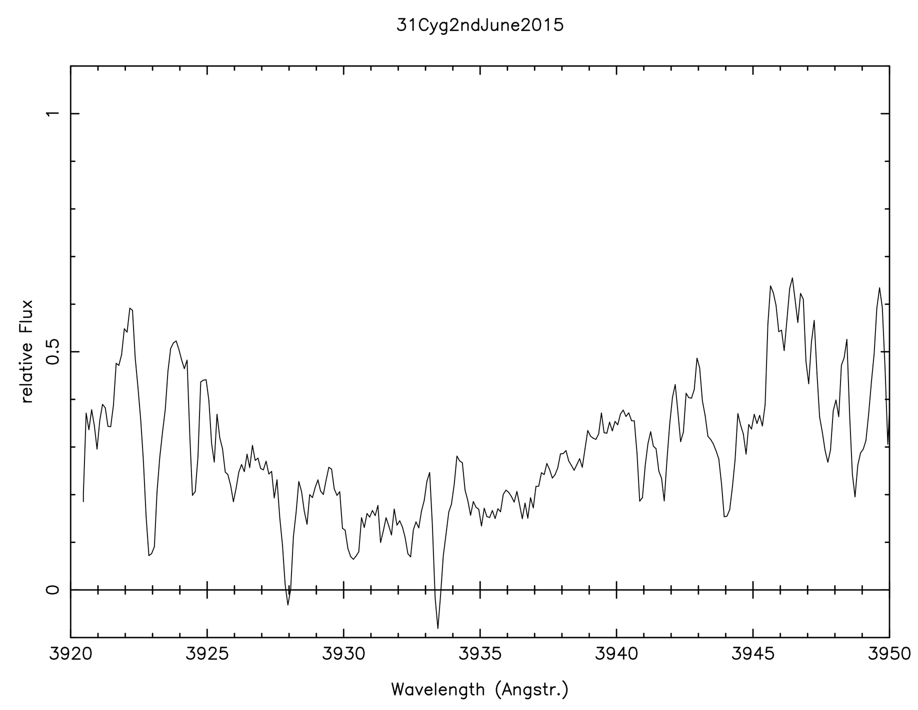

Fig. 6: By contrast, the wider orbit of 31 Cyg leaves a smaller irradiation-induced Ca II K emission, despite a more UV-luminous companion (compare with Figs. 4, 5). Since the companion is here (2nd of June, 2015) in the remote half of the orbit, some residual CS and IS absorption in its spectrum artificially reach below the zero-line of the subtraction result because we used a CS-absorption-free template.

We find that (i) there is a significant phase-variation of the Ca II K emission in ζ Aur, (ii) a much smaller effect in 31 Cyg, having a much wider orbit, and (iii) a similar effect in 32 Cyg with an orbit comparable to ζ Aur. All this is observational evidence entirely consistent with an irradiation-induced effect. The emission in excess of the intrinsic amount observed in total eclipse of ζ Aur lies in the range of 0.7 to at least 2.3 times the intrinsic chromospheric emission of this K supergiant. However, only a consistent longterm monitoring campaign will show the long-term variation of the Ca II K emission in all three systems, which seems so evident from existing observations with a variety of instrumentation.

References:

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