Non-radial pulsations (NRP) or co-rotating photospheric Helium clouds in ζ Tau?

Description of the phenomenon

Investigations of the HeI6678 line profile in ζ Tau show that it is quite different from a typical, rotationally broadened, photospheric profile. The core of the line is sharp, and the wings are extended. To demonstrate this, a comparison of the mean line profile with the best fitting rotationally broadened photospheric profile is shown in Fig.1 (from ApJ, 521,407-413).

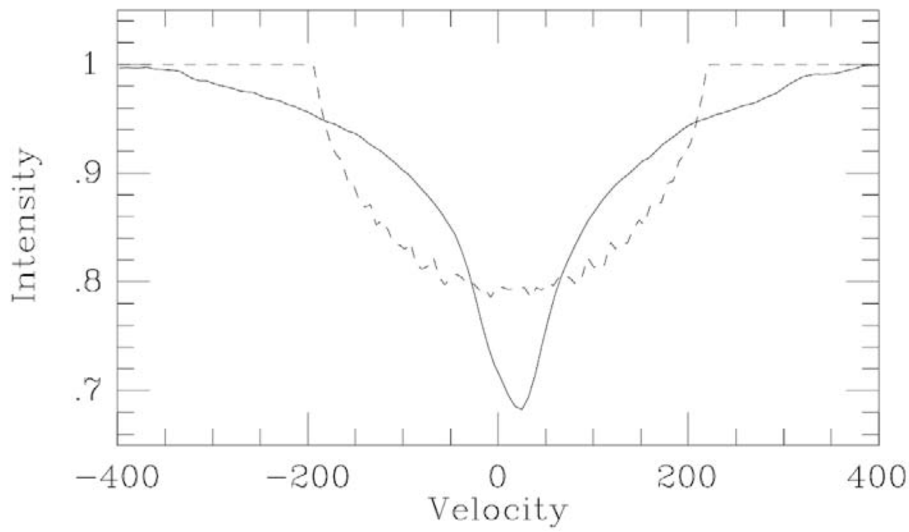

Fig. 1: Observed mean line profile of HeI6678 (solid line) and the best fit with a rotationally broadened profile (dashed line)

Balona & Kaye (1999) undertook a period analysis based on measurements of the position of minimum intensity of the HeI6678 line profile. They confirm the period derived from the analysis of Kaye & Gies (1997) 0.777± 0.002 days. They also confirm the result presented by Kaye & Gies (1997) in that there are no signs of the 0.683 or 0.095 day periodicities found by Yang et al. (1990), despite the fact that the two data sets are contemporaneous.

Kaye & Gies (1997) assert that the only plausible explanation for the periodicity and line profile variations of HeI6678 in this star is NRP. Instead of NRP, Balona & Kaye (1999) propose that what we see here closely resembles what is seen in 28 CMa and η Cen and may be attributed to co-rotating photospheric clouds. Smith, Robinson, & Hatzes (1998) have proposed the same model for the Be star γ Cas (Lynds 1959).

Balona & Kaye (1999) assume that the circumstellar material is spherically distributed and that there are “spots” or regions of smaller surface brightness, as would be the case for co-rotating density-enhanced areas suspended above the photosphere. A “patch” model, where the surface brightness is unchanged but the intrinsic line profile is different, will produce the same effect. If the clouds are located at approximately the same places on the photosphere, the same period (which is the period of rotation) will be observed from season to season.

Observations of η Cen over a 20 day period (Balona 1999) indicate that the clouds do not move significantly with respect to each other, which suggests that the mechanism that generates and/or maintains the density enhancements is long-lasting. Observations over a longer time interval are clearly needed to confirm this conclusion. The geometry of the circumstellar material in the immediate vicinity of the star is not known, although it is clear that a fattened, equatorial disk is present some distance away. It is possible that the whole photosphere, from pole to pole, may be covered with clouds; in other words, that the clouds form in effect a detached photosphere. Kaye & Gies (1997) also consider the possibility that the variation is due to two disk enhancements close to the photosphere. This they rule out because one might expect to see emission features outside the rotationally broadened line, and these are not seen. At present all in all, there are no sufficient data for modeling a more realistic scenario.

We decided to investigate the line profile variations through radial velocity measurements of the He6678 line how it was used also by Kaye & Gies (1997), Schrijvers & Telting (1997) and Aerts (1996). The spectra used in this study were taken over one night in 2012 and four nights in 2013 using the LHIRES III and the C14 Schmidt-Cassegrain telescope of the observatory of the Vereinigung der Sternfreunde Köln, Germany. The spectra record the wavelength region 6640-6725 Å and were made using a 2400 grooves/mm grating in first order blazed at 5500 Å. The spectra have a reciprocal dispersion of 0.028 Å/pixel and generally a S/N ratio better than 1000 (mostly better than 2000). The typical exposure time for these spectra was 960 sec.

Observation results

In the following we present the individual results of observations. Fig 2a shows at first the width of variations in wavelength (and hence in radial velocity RV) for 45 spectra from March 2010-2013. Fig. 2b shows salient "bumps" (caused by NRP or clouds as mentioned in the previous text) on the blue flank of the profile during observations on 2013-12-02.

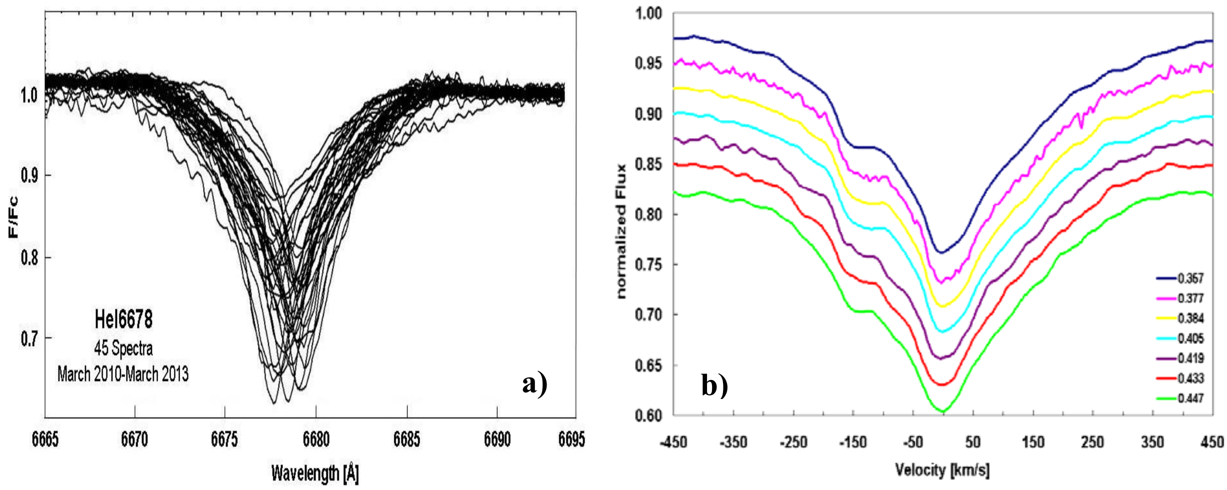

Fig. 2a & 2b: Impression of the variability in
profile size (right) and radial velocity RV (left) of the HeI6678 absorption line

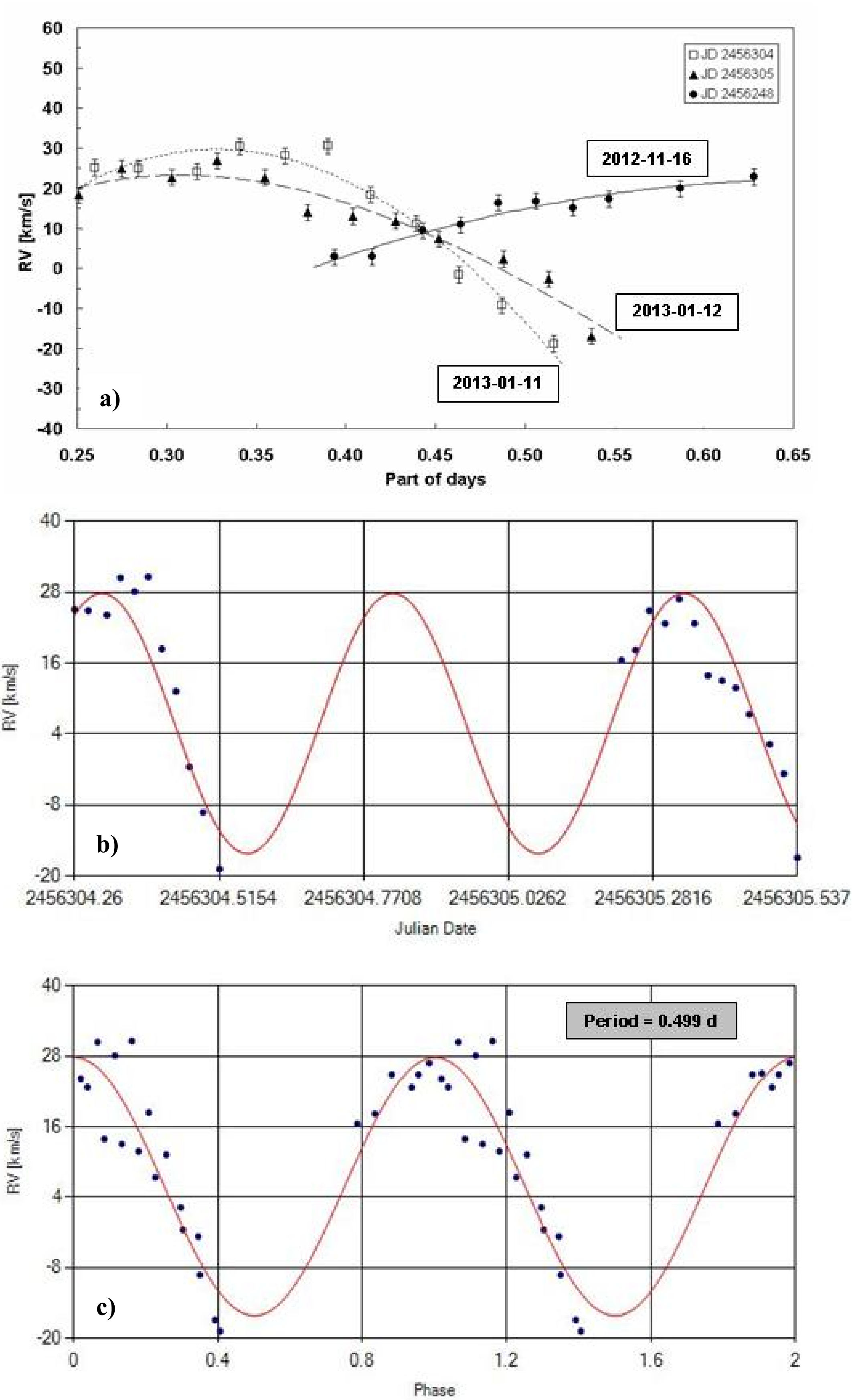

Fig. 3a shows the RV time behavior of the HeI6678 line of three nights: 2012-11-16, 2013-01-11 and 2013-01-12. Fig. 3b shows the period analysis of these RV´s as time series with a 0.499 day period and Fig. 3c shows the corresponding phase plot.

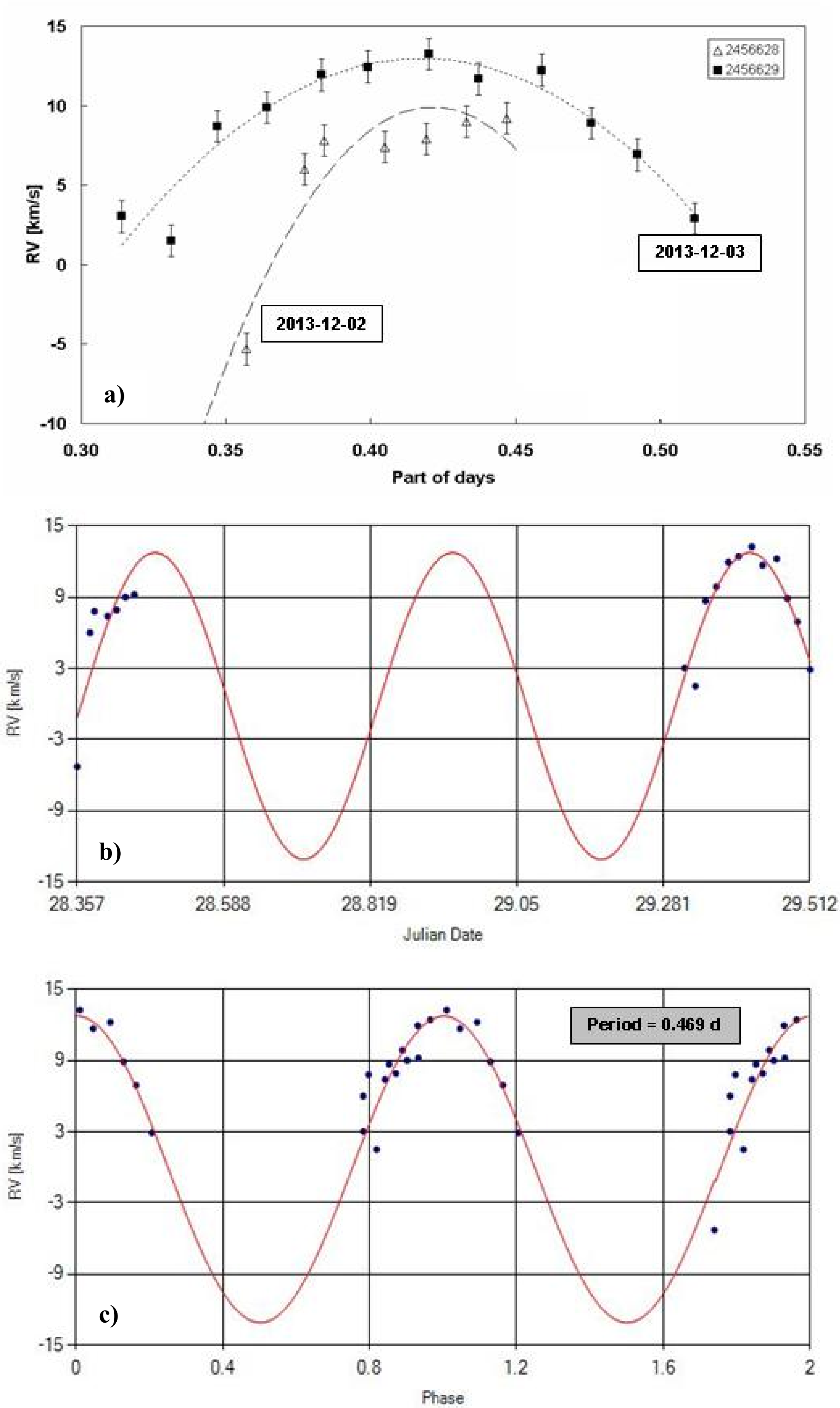

Fig. 4a shows the RV time behavior of the HeI6678 line of two nights: 2013-12-02 and 2013-12-03. Fig. 4b shows the period analysis of these RV´s as time series with a 0.469 day period and Fig. 4c shows the corresponding phase plot.

Before the background of these results, the question has to be clarified whether, for example "flexure" of the spectrograph at the telescope can be excluded. RV measurements of Aldebaran of a similar hour angle can be used to check this.

These RV comparison measurements (Hα) with Aldebaran for comparable hour angles (as with ζ Tau) are shown in Fig. 5. The spectra were likewise evaluated with the mirror method. As can be seen, there is a small RV trend with increasing hour angle, however with 1km/s in an order of magnitude, which is negligibly small, compared with the RV variability in ζ Tau. The error bar indicates the reproducibility accuracy of repetitive evaluations (3 times).

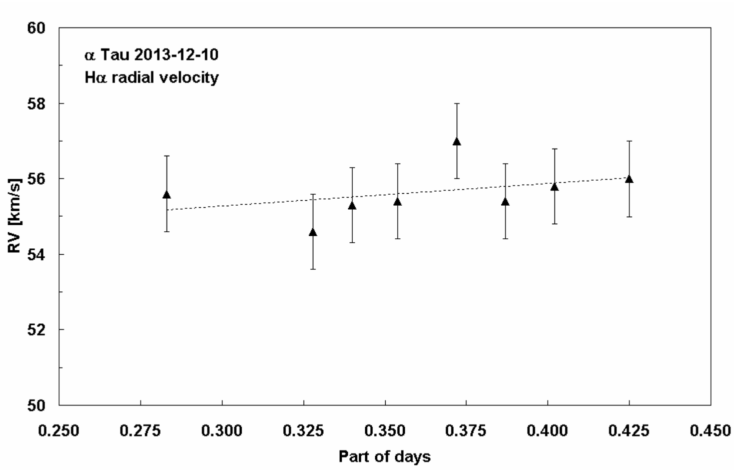

Fig. 5: Check measurements of the RV stability at Aldebaran for comparable hour angles as it has been in ζ Tau

Comment of the referee (results only) Dr. Thomas Rivinius (ESO-Chile):

Because in a shell star like ζ Tau within the HeI6678 absorption line some (many) effects are mixed, it is difficult to say, what the real causes for such a short-term radial velocities could be. Next to something photospheric, it could indeed be localized density enhancements orbiting the star before they get smoothed out by viscosity. However, neither NRP nor such a thing shift the profile, but affect only part of it. If the entire profile is shifted, there might be other reasons. At present the disk is in its historically smallest size, where small effects, which are otherwise hardly to be recognized, now show a better contrast in relation to the "rest".

References
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