Satellite Absorption Components (SACs) of the UV spectral lines NV, CIV, NIV and SiIV in the atmosphere of the Oe star HD 66811 (ζPup)

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Introduction

The hottest of the bright Of stars is ζ Puppis, for which Walborn (1972) gave the spectral type O4I(n)f. Conti and Leep (1974) classified it as O4ef, while Lesh (1972) retained the historic type of O5f.

The main parameters of the star were summarized by Lamers and Morton (1976). The determination of the effective temperature yields large problems. The value derived from the angular diameter and the UV flux distributions is T_e= 32510 ± 1930 °K according to Code et al. (1976) or 31900 ± 1800 °K according to Brune et al. (1979). These values are similar to those of the later type stars ζ Oph (O9.5V) and τ Sco (B0V) and seem, therefore, much too low. A higher T_e value (50000 °K) and log(g)=4.0 was found from a study of COPERNICUS observations of the helium spectrum by Snijders and Underhill (1975), who compared observations of HeII lines with non-LTE predictions obtained for assumed non-LTE-plane-parallel model atmospheres by Auer and Mihalas (1972).

Lamers and Morton (1976) gave a detailed description of P Cygni profiles in ζ Puppis using high resolution spectral scans obtained with the COPERNICUS satellite. Rocket-UV spectra of ζ Puppis has been described by Carruthers (1968), Morton et al. (1969), Stecher (1970), Smith (1970) and Burton et al. (1973,1975). An absolutely calibrated rocket spectrum (12 to 15 Å resolution) was obtained by Brune et al. (1979). These investigations revealed strong P Cygni lines of C IV, N IV N V, O IV, Si IV, S IV and S VI in the far ultraviolet. Additionally, Snijders and Underhill (1975) analyzed the He II observed by the COPERNICUS satellite along with those available from ground-based spectra. Finally, Franco et al. (1983) found line profile variability in ζ Puppis and suggested that two different mechanisms could produce the observed ionization stages.

In this paper we apply the model proposed by Danezis et al. (1984, 1991, 2000, 2003), for the outer atmosphere of Oe and Be stars to the star HD 66811 (ζ Puppis) and we present some first results deriving from this application. This model allows the existence of many absorption shells or many independent density regions, considers that the expanding outer atmosphere consists of some absorbing and some emitting regions and concludes to a function for the spectral line, able to reproduce the profiles of all the spectral lines with great accuracy.

Method of spectral analysis

In order to study the physical structure and the existence of SACs phenomena in the regions where these lines are created we used the model proposed by Danezis et al. 2003a). This model presupposes the existence of independent density layers of matter in these regions. With this method we can calculate the apparent rotation (V_{rot}) and expansion/contraction radial velocities (V_{exp}) of these density regions, as well as their ξ value, which is an expression of the optical depth. The final function which reproduces the complex line profile is:

$$I = I_0 \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{e}\left(1-\exp\{-L_{ej}\xi_{eej}\}\right)\exp\{-L_g \xi_g\}$$

L_i, L_e, L_g: are the distribution functions of the absorption coefficients $k_{\lambda i}$, $k_{\lambda e}$, $k_{\lambda g}$ respectively. Each L depends on the values of the apparent rotation velocity as well as of the apparent expansion/contraction radial velocity of the density shell, which forms the spectral line (V_{rot}, V_{exp}) and

ξ: is an expression of the optical depth.

Observational Data

This project is based on three different spectra of ζ Pup (HD 66811), which are listed below:

- SWP 05963 (27-7-1979)
- SWP 33538 (16-5-1988)
- SWP 53460 (17-1-1995)

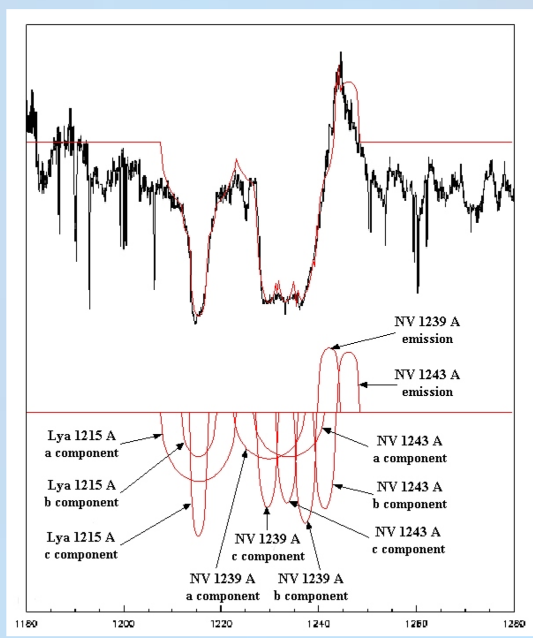
These spectra have been taken with the IUE satellite with the Short Wavelength range Prime camera (SWP) at high resolution (0.1 to 0.3 Å).

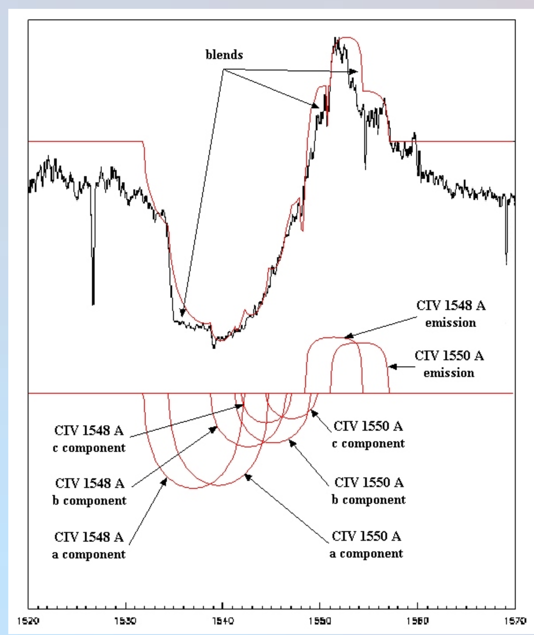
We study the structure of the spectral lines of:

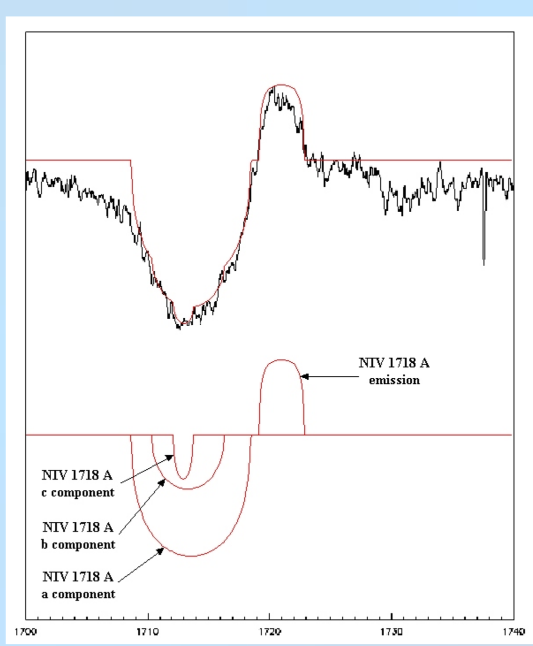
- N V λλ 1238,821, 1242,804 Å
- C IV λλ 1548,155, 1550,774 Å
- N IV λ 1718,80 Å
- Si IV λλ 1393,755, 1402,730 Å

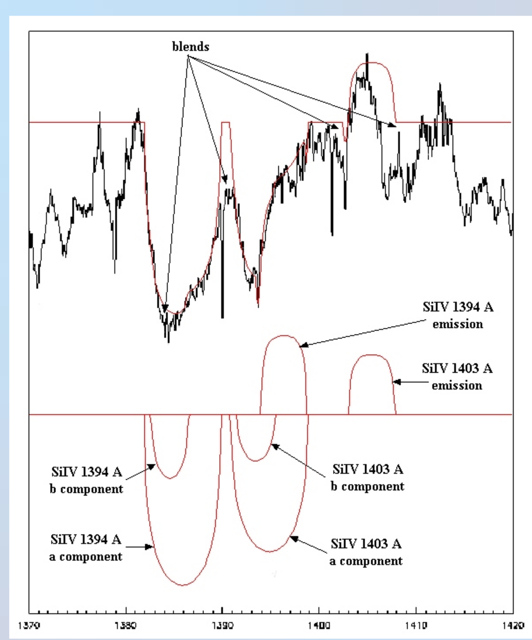
Figures

The best fit is not just the graphical composition of some components (line profiles). The reproduced feature is the result of the final function of the model. In these figures we present some best fits of the star HD 66811's spectra, which presents SACs. The black line presents the observed spectral line's profile and the red one the model's fit. We also present all the components which contribute to the observed features, separately.









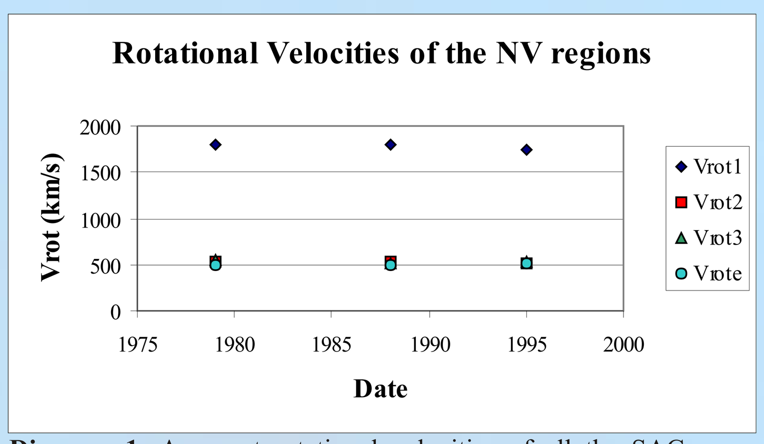


Diagram 1: Apparent rotational velocities of all the SACs as a function of time. The rotational velocity of the first SAC is about 1783 km/s. The second and third SACs' rotational velocities present the value of 533 km/s. The emission's rotational velocity is about 507 km/s.

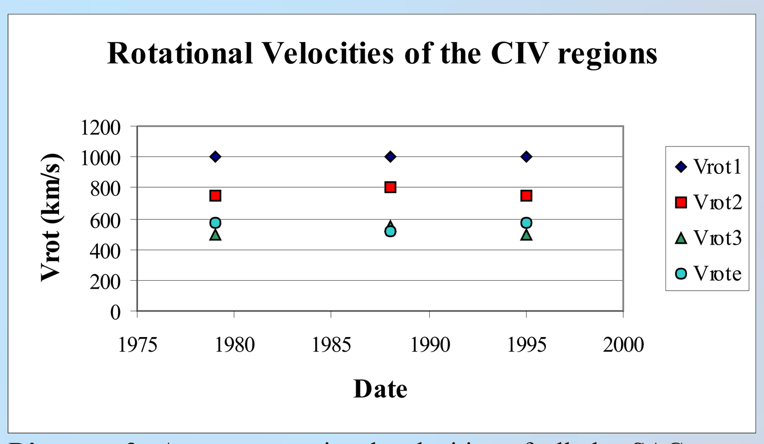


Diagram 3: Apparent rotational velocities of all the SACs as a function of time. The rotational velocity of the first, the second and the third SAC is about 1000 km/s, 767 km/s and 517 km/s, respectively. The emission's rotational velocitiy presents the value of 553km/s.

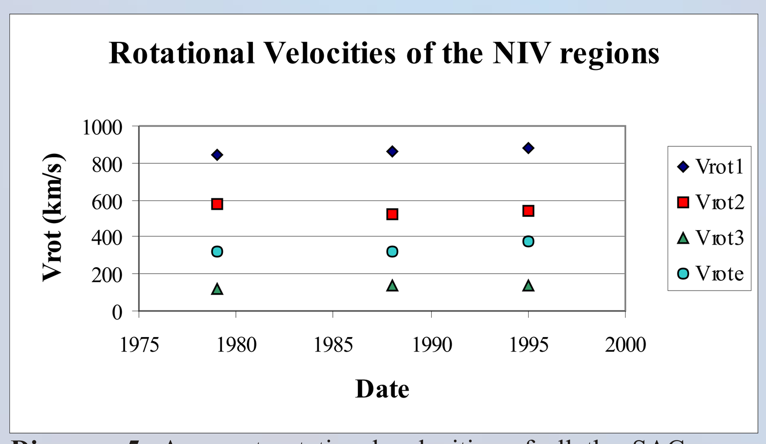


Diagram 5: Apparent rotational velocities of all the SACs as a function of time. The rotational velocity of the first, the second and the third SAC is about 860 km/s, 547 km/s and 133 km/s, respectively. The emission's rotational velocity present the value of 340 km/s.

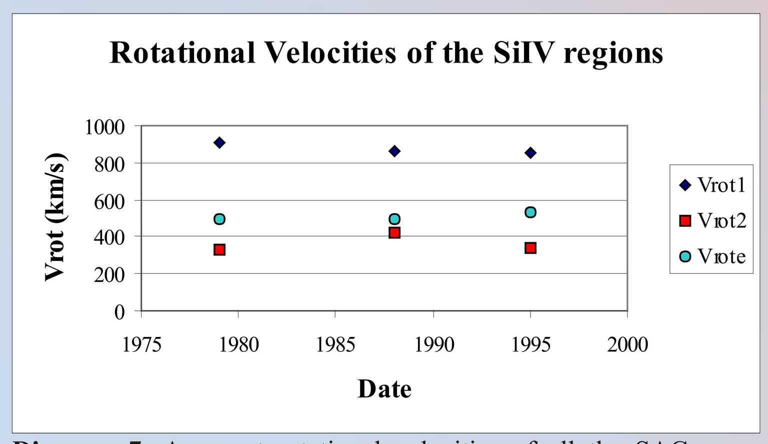


Diagram 7: Apparent rotational velocities of all the SACs as a function of time. The rotational velocity of the first and the second SAC is about 873 km/s and 363 km/s, respectively. The emission's rotational velocity presents the value of 510 km/s.

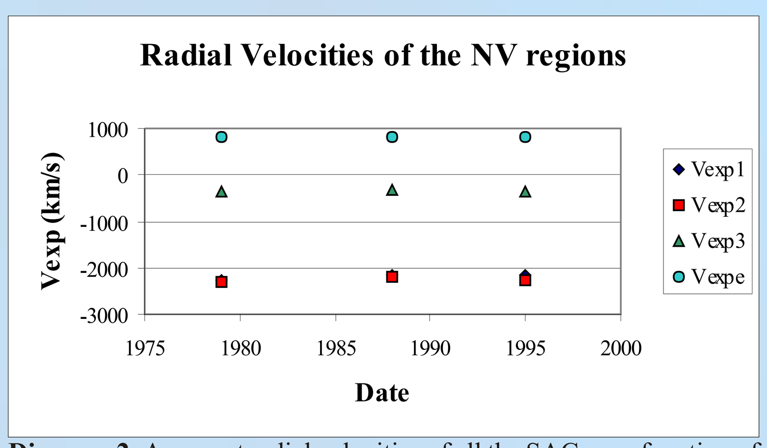


Diagram 2: Apparent radial velocities of all the SACs as a function of time. The radial velocity of the first, the second and the third SAC is about -2190 km/s, -2250 km/s and -347 km/s, respectively. The emission's radial velocity presents the value of 822 km/s.

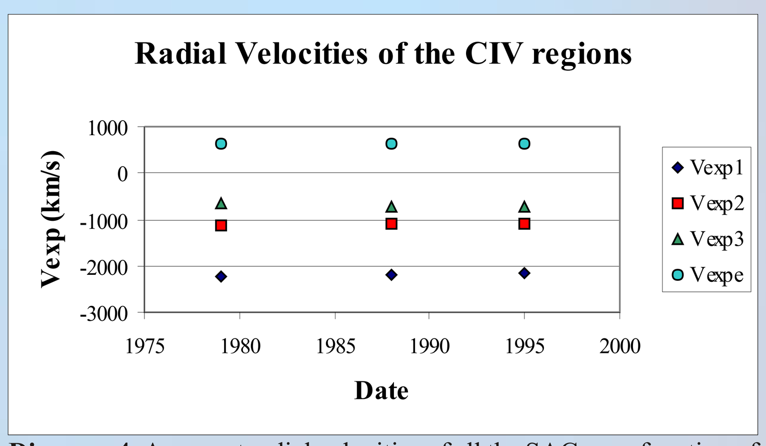


Diagram 4: Apparent radial velocities of all the SACs as a function of time. The radial velocity of the first, the second and the third SAC is about -2195 km/s, -1100 km/s and -690 km/s, respectively. The emission's radial velocity presents the value of 633 km/s.

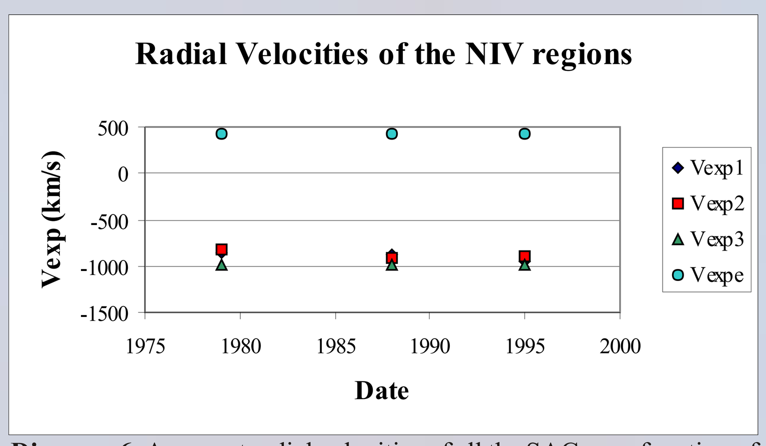


Diagram 6: Apparent radial velocities of all the SACs as a function of time. The radial velocity of the first, the second and the third SAC is about -890 km/s, -876 km/s and -986 km/s. The emission's radial velocity presents the value of 428 km/s.

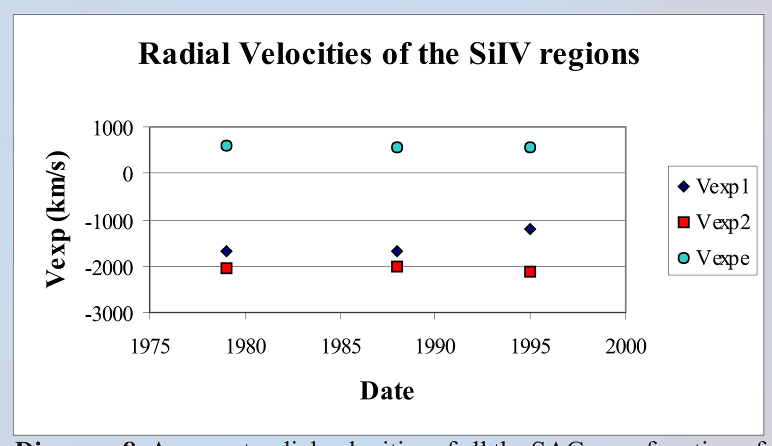


Diagram 8: Apparent radial velocities of all the SACs as a function of time. The radial velocity of the first and the second SAC is about -1525 km/s and -2060 km/s. The emission's radial velocitiy presents the value of 584 km/s.

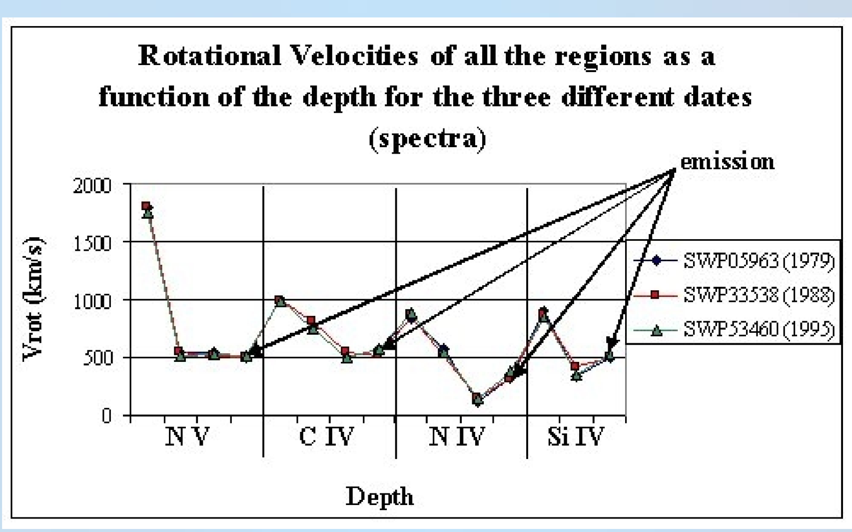


Diagram 9: Apparent rotational velocities of all the SACs as a function of the distance from the star.

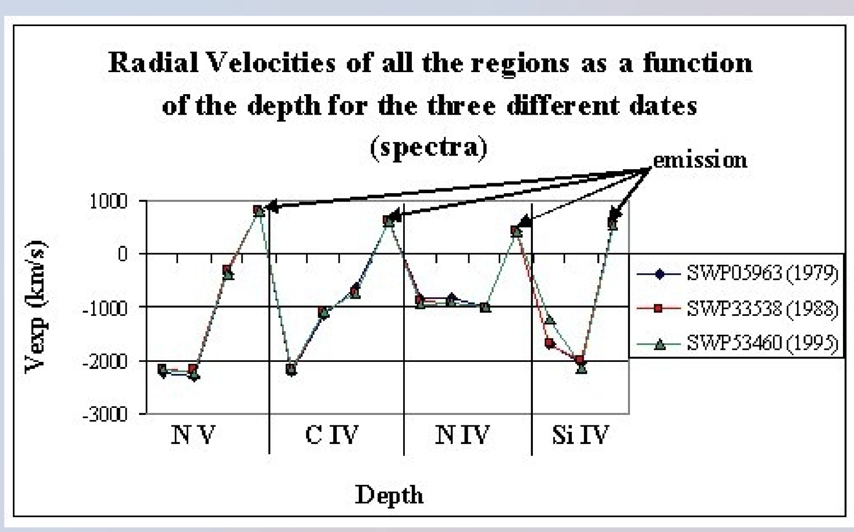


Diagram 10: Apparent radial velocities of all the SACs as a function of the distance from the star.

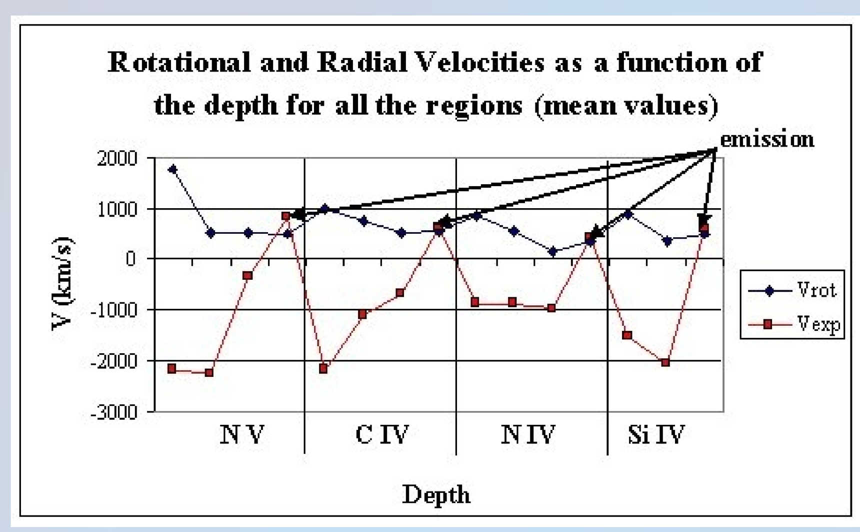


Diagram11: Mean values of the apparent rotational and radial velocities of all the SACs as a function of the distance from the star.

Conclusions

1. By applying the proposed by Danezis et al. (2003), model we are able to reproduce the profiles of all the spectral lines of the star HD 66811 (ζPuppis) with great accuracy. This means that the coronal model allowing the existence of successive, independent density shells of matter represents accurately the structure of the gaseous envelope of ζPuppis.
2. The best fit of all lines derived by the model we described leads to the conclusion that the layer of matter in the region we studied {33eV (Si IV)-78 eV(N V)} is structured as the model describes:
   i) An area of gas consisting of i independent absorbing layers of matter.
   ii) One emitting layer of matter.
   iii) Occasionally, an external absorption layer of matter.
3. It is interesting to point out that in the regions we study there exist successive shells which move radially with velocities between -2200 km/s and 822 km/s, and rotate with velocities between 133 km/s and 1783km/s.
4. Apparent rotational and radial velocities of each layer of matter show an insignificant variation between the three different spectra we used.

Acknowledgements

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