From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Differential Rotation in Two RS CVn Systems: σ Gem and ζ And

Zsolt Kővári[1], János Bartus[1,2], Levente Kriskovics[1], Katalin Oláh[1], Krisztián Vida[1], Orsolya Ribárik[1], and Klaus G. Strassmeier[2]

[1]Konkoly Observatory, Konkoly Thege út 15-17., H-1121 Budapest, Hungary
email: kovari, kriskovics, olah, vida, wennot@konkoly.hu

[2]Leibniz Institute for Astrophysics Potsdam,
An der Sternwarte 16, 14482 Potsdam, Germany
email: jbartus, kstrassmeier@aip.de

Abstract. The differentially rotating convective envelope is an indispensable element of the magnetic dynamo working in RS CVn-systems. Tidal coupling is responsible for maintaining fast rotation, and also the observed high level of magnetic activity. In this work, we compare the physical properties of two well known RS CVn-type binaries, that is the long-period system σ Gem and the ellipsoidal variable ζ And. For the comparison, we use the results obtained from processing time-series Doppler images. We also aim at understanding how differential rotation could be affected by tidal forces in such close binaries.

Keywords. stars: activity, stars: imaging, stars: individual (σ Gem, ζ And), stars: spots, stars: late-type

1. Binarity and activity

The differential rotation (DR) is of utmost importance in understanding the magnetic activity, since it is a key element of the dynamo mechanism, which has a controlling influence over the strength of magnetic fields generated, thus that of the activity itself. DR on stars with convective envelopes puts constraints on the large scale topology of the magnetic field, therefore has important information on the working of the dynamo beneath the surface. It is well known that in close binaries tidal effects help maintain the fast rotation and also magnetic activity at higher levels. In this interaction, tidal coupling between the star with the differentially rotating envelope and its companion star is essential, cf. Scharlemann (1981, 1982), Schrijver & Zwaan (1991), Holzwarth & Schüssler (2000, 2002). Although, the theoretical background is still under development and earlier observational techniques gave only a poor chance for justification of this interaction, with Doppler imaging this can be observationally studied.

2. Method and results

Measuring DR by means of time-series Doppler imaging was introduced and demonstrated on different targets by Kővári *et al.* (e.g., in 2004, 2007a,b, etc.). The employed method called ACCORD (acronym from 'Average Cross-CORrelation of consecutive Doppler images') is based on averaging cross-correlation function (ccf) maps of subsequent Doppler images in a way to enhance the DR pattern in the ccf maps, while suppressing the unwanted effect of stochastic spot changes. For this study, the stellar and system parameters of our targets, σ Gem and ζ And, are adopted from Kővári *et al.* (2001, 2007a).

Distortion. From our extended DI code we determine the gravitational distortion (for the method see Kővári *et al.* 2007a). The star is approximated with a rotational ellipsoid, that is elongated towards the secondary, where $\epsilon = (1-(\frac{a}{b})^2)^{0.5}$ parameterizes the distortion (a and b are the long and short radii, respectively). Scanning through a meaningful part of the ($\epsilon - v \sin i$) parameter plane, while all other parameters are held constant in the imaging process, yields the likely best estimate when the χ^2 of the line-profile fits reaches a minimum. This way for σ Gem we get $\epsilon \leqslant 0.12$, while in the case of ζ And the formal O-C minimum suggests $\epsilon = 0.27 \pm 0.02$ (filling 82% of the Roche-volume).

Surface differential rotation. Our time-series data were obtained during a 70-night long observing run at NSO in 1996/97. From that we reconstruct 34 and 36 time-series Doppler images for σ Gem and for ζ And, respectively. Applying ACCORD for σ Gem yields equatorial deceleration, i.e. anti-solar-type DR with an average surface shear of $\alpha = -0.07 \pm 0.026$. In the case of ζ And, we get solar-type DR with a surface shear of $\alpha = +0.05 \pm 0.02$ (Kővári *et al.* 2007a). This value is consistent with our new result of $\alpha \approx +0.053$ derived from new ζ And data (see the forthcoming paper by Kővári *et al.*).

3. Discussion

From the scaled graphs of the two binaries (see Fig. 1 in Schrijver & Zwaan 1991), a striking difference is seen: i.e., the center of gravity of σ Gem is outside the limb of the giant component, while in the case of ζ And, the center of mass lies well within the star. This difference may reshape the DR inside the convective bulk, which can explain the observed differences. It is also interesting to compare the corotating latitudes ($\beta_{\rm cor}$, i.e. the latitude of the differentially rotating component that rotates synchronously with the system). Scharlemann's (1982) theoretical calculations showed that in a given close binary system the stellar and system parameters determine the developing corotation latitude. Using his assumption, we get $\beta_{\rm cor} \approx 20°$ for σ Gem, which is near the value of 22° derived from ACCORD. However, the more distorted ζ And with synchronized equatorial belt ($\beta_{\rm cor} \approx 10°$) performs a different subsurface scenario: Holzwarth & Schüssler (2000, 2002) showed that the tidal forces and the distortion of the active component in an RS CVn-type binary can explain the emergence of magnetic flux at preferred longitudes. Observations showed the existence of spots concentrating at quadrature positions in ζ And (e.g. Kővári *et al.* 2007a, Korhonen *et al.* 2010). Likewise, the deformation could also account for the disparate DR laws obtained for ζ And and for σ Gem.

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