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PHOTOCENTRIC VARIABILITY OF RED SUPERGIANT STARS AND CONSEQUENCES ON GAIA MEASUREMENTS

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Abstract. Red supergiant stars are characterized by large convection-related surface structures that cause surface inhomogeneities and shock waves. We explore the impact of granulation on the photocentric motion using 3D simulations of convection with CO5BOLD and post-processing radiative transfer code Optim3D to compute spectra and intensity maps in the Gaia G band [325 – 1030 nm]. We found that the Gaia parallax for Betelgeuse-like supergiants are characterized by a systematic error of a few percents.

Keywords: supergiants, astrometry, parallaxes, hydrodynamics

1 Introduction

The aim of the Gaia mission is to determine high-precision astrometric parameters that, together with multi-band and multi-epoch photometric and spectrocopic data, will be used to reconstruct the formation, history and evolution of the Galaxy.
Red supergiant (RSG) stars are characterized by vigorous convection which imprints a pronounced granulation pattern on the stellar surface (Chiavassa et al. 2010). As a consequence, the granulation-related variability must be quantified in order to better characterize any resulting systematic error on the parallax determination.

2 RHD simulations of red supergiant stars

We employed detailed radiation-hydrodynamics (RHD) simulation of RSGs (Freytag et al. 2002; Freytag & Höfner 2008). The model has a mass of 12 $M_\odot$, employs an equidistant numerical mesh with 235^3 grid points with a resolution of 8.6 $R_\odot$ (or 0.040 AU), a luminosity average over time (i.e., over 5 years) of $L = 93\,000 \pm 1300\ L_\odot$, an effective temperature of $T_{\rm eff} = 3490 \pm 13$ K, a radius of $R = 832 \pm 0.7\ R_\odot$, and a surface gravity $\log g = -0.337 \pm 0.001$. This is our most successful RHD simulation so far because it has stellar parameters closest to Betelgeuse (Chiavassa et al. 2009). We computed spectra and intensity maps based on snapshots from the RHD simulations (Fig. 1, left), using the code Optim3D (Chiavassa et al. 2009) and a solar composition (Asplund et al. 2005).

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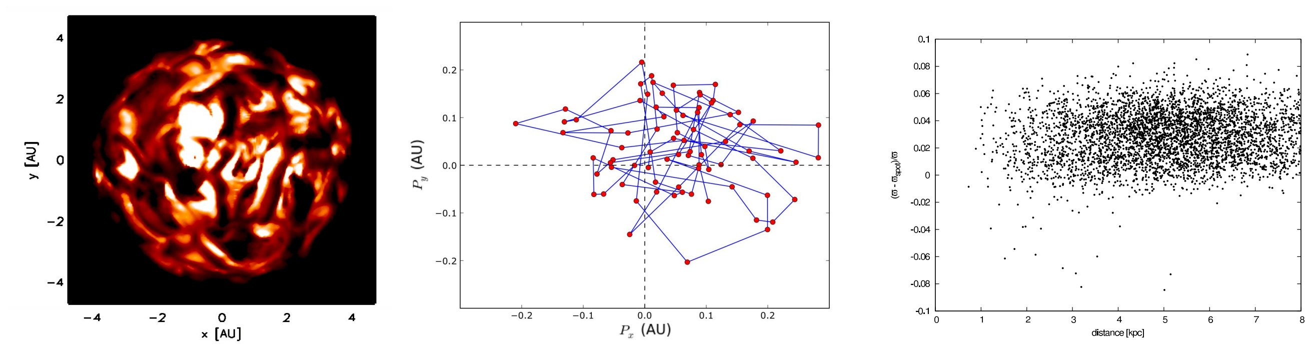

Fig. 1. *Left panel:* map of the linear intensity (the range is [0 – 230000] erg/s/cm^2/Å) in the Gaia G band photometric filter (Jordi & Carrasco 2007). *Central panel:* photocenter displacement as a function of time. Each point is a snapshot 23 days apart for a total of 5 years of simulation (comparable to the duration of the Gaia mission). *Right panel:* Relative difference between the parallaxes computed with and without the photocentric motion of the central panel, as a function of the distance.

3 Predictions

The simulated surface of RSGs (Fig. 1, left) displays high-contrast structures with spots up to 50 times brighter than the dark ones with strong changes over some weeks. This aspect is connected with the underlying granulation pattern, but also with dynamical effects such as shocks and waves which dominate at optical depths smaller than 1. We computed the position of the photocenter for all the synthetic maps (Fig. 1, center) and found that the photocenter excursion goes from 0.005 to 0.3 AU over 5 years of simulation (the stellar radius is $\approx$ 4 AU, left panel of the Figure).

4 Conclusions

We found that the convection-related structures on the surface of RGSs affect the position of the photocenter of Betelgeuse-like supergiants. In fact, Fig. 1 (right) shows that the Gaia parallax computed with ($\varpi_{\rm spot}$, calculated using a photocentric motion deduced from Fig. 1 and using Gaia Object Generator v7.0, GOG* Isasi et al. 2010, central panel) and without (ϖ) surface brightness asymmetries may be affected by a systematic error of a few percents. It might be of interest to monitor the photocentric deviations for a few well selected RSGs during the Gaia mission. Monitoring their phase closure on three different base lines would provide valuable information on the size of the inhomogeneities present on the stellar surface (see Sacuto et al., in preparation). However, there is a little hope to be able to correct the Gaia parallaxes of RSGs from this parallax error, without knowing the run of the photocentric shift for each considered star. More details and predictions can be found in Chiavassa, Pasquato, Jorissen et al. (submitted to A&A).

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