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The Baade-Wesselink p-factor of Cepheids in the Gaia area

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Abstract. With the next *Gaia* release (expected in April 2018), the distance of about 300 Galactic Cepheids will be derived with a precision of better than 3%. These distances will be used first to constrain the Cepheid period-luminosity relation, but they will also bring strong constrains on the physics of Cepheids, through the projection factor, a physical quantity used in the inverse Baade-Wesselink (BW) method.

Keywords. Cepheids, projection factor, Gaia, distances

1. The astrophysics behind the projection factor

The BW method is used to determine the distance of Cepheids in the Milky Way and beyond, in the Magellanic Clouds, and consists in combining the angular size variations of the star with its linear size variation. The angular size variation can be determined using infrared surface-brightness relations (Storm *et al.* 2011, Storm *et al.* 2011b), interferometry (Kervella *et al.* 2004a) or even a full set of photometric and interferometric data (SPIPS approach; Merand *et al.* 2015). The linear size variation is deduced from spectroscopy. The radial velocity curve is first derived from a spectral line profile or a set of spectral line profiles (cross-correlation). The radial velocity curve is then multiplied by a projection factor, which is used to derive the true pulsation velocity curve of the star. Finally this pulsation velocity curve is time-integrated in order to derive the radius variation of the star. In this approach, the projection factor and the distance of the star are fully degenerate. Thus, if the distance is known, the p-factor can be derived. This has been done for several Cepheids already (Merand *et al.* 2005, Breitfelder *et al.* 2016, Kervella *et al.* 2017), but with *Gaia* parallaxes, it should be possible to derive the projection factor of about 300 Cepheids with a 3% precision. In this context, the p-factor decomposition into three sub-concepts proposed by Nardetto *et al.* 2007 will be useful in order to interpret the *Gaia* p-factors. For a Cepheid described simply by a uniform disk pulsating, the value of the projection factor is 1.5 (whatever the pulsation phase). But actually, the radial velocity of each surface element of the star is projected along the light of sight and weighted by the intensity distribution of the Cepheid. The limb-darkening of δ Cep reduces the p-factor significantly, and the so-called geometric projection factor (p_0, **step 1** in Fig. 1) is between 1.36 to 1.39, depending on the wavelength in the visible range. The time variation of the p-factor, due mainly to limb-darkening variation, is neglected as it has no impact on the distance (Nardetto *et al.* 2006b). However, a Cepheid is not simply a limb-darkened pulsating photosphere, it has also an extended atmosphere with various spectral lines (in absorption) forming at different levels from which we derive the radial velocity curve used in the BW method. Moreover, there is a velocity gradient in the atmosphere of the Cepheid, which can be measured from spectroscopic observations (**step 2**). Then, depending on the line considered, the amplitude of the radial velocity curve will not be the same and the resulting projection factor will

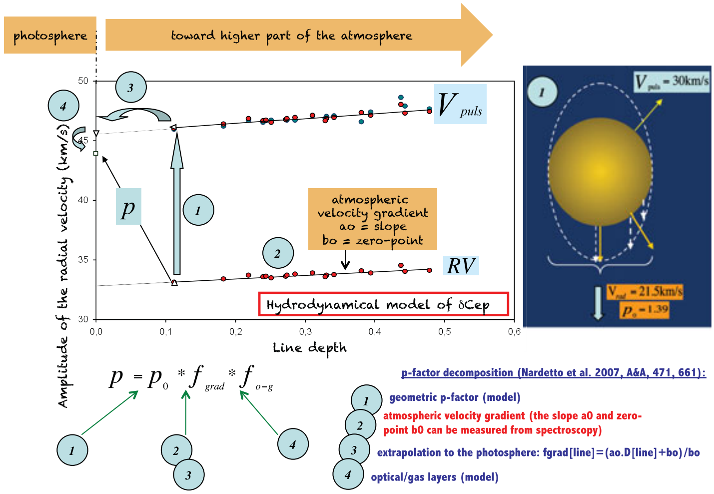

Figure 1. The p-factor decomposition is illustrated based on the model of δ Cep.

be different. In Fig. 1 ($f_{\rm grad}$, **step 3**), we show the impact of the atmospheric velocity gradient on the p-factor for a line forming rather close to the photosphere (line depth of about 0.1). The higher is the line forming region in the atmosphere, the lower is the projection factor (up to 3% compared to p_0 in the case of δ Cep). The last correction on the projection factor ($f_{\rm o-g}$, **step 4**) is more subtle. In spectroscopy, the radial velocity is actually a velocity associated with the moving *gas* in the line forming region, while in photometry or interferometry, we probe an *optical* layer corresponding to the black body continuum (i.e. the layer from which escape the photons). A correction on the projection factor of several percents (independent of the wavelength or the line considered) has to be considered. A relation between the period of Cepheids and the p-factor has been established using this approach for a specific line (Nardetto *et al.* 2007) or using the cross-correlation method (Nardetto *et al.* 2009). This decomposition of the projection into physical concepts has been recently validated in the case of δ Cep thanks to HARPS-N spectroscopic data (Nardetto *et al.* 2017). We thus have all the conceptual tools in hands in order to interpret the future Gaia p-factors.

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