CALIBRATING THE CEPHEID PERIOD-LUMINOSITY RELATION WITH THE VLTI

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Abstract. The VLTI is the ideal instrument for measuring the distances of nearby Cepheids with the Baade-Wesselink method, allowing an accurate recalibration of the Cepheid Period-Luminosity relation. The high accuracy required by such measurement, however, can only be reached taking into account the effects of limb darkening, and its dependence on the Cepheid pulsations. We present here our new method to compute phase- and wavelength-dependent limb darkening profiles, based on hydrodynamic simulation of Classical Cepheid atmospheres.

1 Introduction

Since the discovery of their Period-Luminosity (P-L) relation, at the beginning of the century (Leavitt 1906), Classical Cepheids have played a central role as primary distance indicators. The reliability of this relation, however, depends on the accuracy of its calibration. This is done by using a handful of nearby Cepheids, whose distances can be independently determined. Due to the low-density distribution of the Cepheids in our galaxy, however, this is a difficult task to accomplish. Large errors still affect direct parallax measurements done with the Hipparcos satellite (see e.g. Madore & Freedman 1998), and even future space-based surveys appear to suffer from the same limitations.

Recent progresses in ground-based, long baseline interferometry, however, have finally opened the possibility of direct measurements of nearby Cepheids distances by using the so-called *geometric* Baade-Wesselink (BW) method (Baade 1926, Wesselink 1946). A detailed description of this method and its implications for the accuracy of the zero-point calibration of the Cepheid P-L relation is given in Sasselov & Karovska 1994 (SK94 hereafter).

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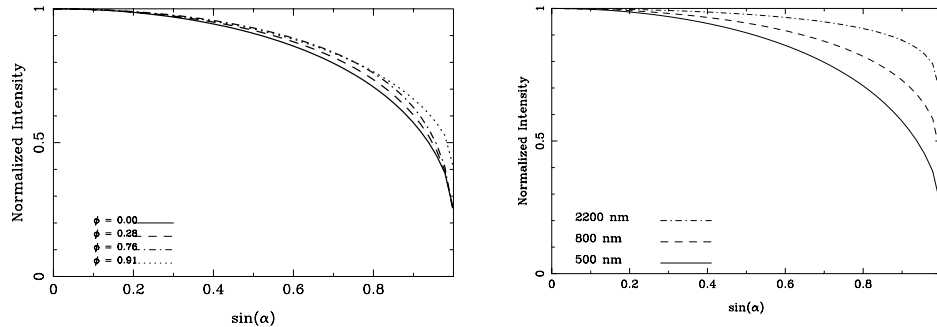
Fig. 1. Limb darkened profiles at different pulsational phases (*left*) and at different wavelengths (*right*) for our ζ Gem model. Left panel profiles are computed for $\lambda = 500$ nm; right panel profiles for minimum radius ($\phi = 0$). Adapted from MM02.

The BW method relies on the accurate measurement of the Cepheid diameter as the star pulsates. As such, it can only be carried on with high angular resolution interferometric measurements. The VLTI will be the ideal instrument for such measurements, given the available long baselines, and the large apertures allowing to reach fainter sources. However, to convert the measured VLTI visibilities into accurate diameters, it is critical to use appropriate limb darkening models for different pulsational phases.

2   Limb darkening models for pulsating Cepheids

As described in SK94, the feasibility of the geometric BW method depends on the availability of accurate hydrodynamic models for the Cepheid atmospheres, which are required to compute reliable time-dependent limb darkening profiles. In Marengo et al. 2002 (MM02 hereafter) we describe a new approach to compute detailed wavelength- and phase-dependent limb intensity profiles for pulsating Cepheids. Our profiles are based on time-dependent, non-LTE hydrodynamic computations which, starting from a model of the Cepheid pulsation, reproduce the dynamic structure of the stellar atmosphere as it pulsates (see Sasselov & Lester 1994). From these model atmospheres, we obtain the intensity emerging from the stellar photosphere (and thus the limb darkening), computed for each pulsational phase relevant to the interferometric observations. This procedure can be applied to all Cepheids for which a reliable pulsational model is available.

Figure 1 shows the effects of non-LTE hydrodynamics in the limb darkening of the Classical Cepheid ζ Gem. Limb darkening appears to change with the pulsational phase and wavelength. The change is not only in the amount of limb darkening, but also in the shape of the limb profile. This shows that a single parametrization of the limb profile is not adequate for all pulsational phases. Detailed time-dependent modeling is thus required for realistic limb darkening.

Our simulations show that the corrections introduced by the hydrodynamic effects and the wavelength dependence of the limb darkening in the diameter measurement, are of the order of a few percent at optical wavelengths. In the near-IR, which is the VLTI primary domain, the corrections are of the order of $\sim 2\%$, and are still sensitive to the effects of the pulsations.

3   Geometric BW method and the VLTI

The high accuracy of the VLTI visibilities, and the large spectral dispersion of the AMBER camera, will finally provide the high quality data necessary to apply the BW method. At the same time, VLTI will allow the first direct testing of the atmospheric model themselves, improving our knowledge of the stellar atmosphere dynamics. To reach the full potential of the VLTI, it is however necessary to take into account the corrections induced by limb darkening and its dependence from the pulsational hydrodynamics.

As the only long baseline interferometer below the equator, the VLTI offers a unique opportunity to apply the geometric BW method to southern sources. VLTI provides both the sensitivity and the angular resolution necessary to detect the radial variations of a sample of Classical Cepheids, to be used to calibrate the zero point of the P-L distance relation.

The sensitivity required is of the order of mag 2–4 in the K band, for stars which are of mag 5–7 in the optical. Such sensitivity can be easily achieved at the VLTI by the near-IR camera AMBER, using a setup with three Auxiliary Telescopes, and large spectral resolution to isolate individual spectral lines. The typical expected diameters are of the order of ~ 1 mas, with a variation due to the stellar pulsation of about 10% of the diameter. This angular resolution can be reached with the VLTI by using baselines of ~ 100m, or longer.

To-date, the angular diameter variations of Classical Cepheids have been measured only for two sources (ζ Gem and η Aql, see Lane et al. 2000; Lane et al. 2002). The VLTI will give a substantial contribution in extending this sample, providing the necessary statistical significance for the recalibration of the P-L relation zero point with the BW method.

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