Precise and accurate distance determination to the LMC and SMC

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We present distance determinations to the LMC and SMC based on very scarce long period eclipsing binary systems composed of giants. Our LMC distance accurate to 2.2 %, currently sets the best zero point for the whole extragalactic distance scale, while the 1 % relative distance between the LMC and SMC offers unique opportunity to study populational effects on the stellar distance indicators. We also present recent results on eclipsing binary systems containing classical Cepheids. They provide a way to precisely calibrate Baade - Wesselink technique for distance measurement.

Apart from distances, analysis of our systems allowed us to measure with a very good accuracy basic stellar parameters (1-3 % radii, masses, effective temperature, etc) of relatively large sample of static giants (26) and also 5 classical Cepheids. This catalog provides unique opportunity to calibrate evolutionary models of giant stars and pulsating stars.

1 Introduction

The main goal of the Araucaria project is to significantly improve the calibration of the cosmic distance scale based on observations of several distance indicators in nearby galaxies (Gieren et al. 2005, Pietrzyński et al. 2006). A very important part of the Araucaria project is related to detailed studies of eclipsing binary systems, recently discovered by the OGLE project, which have very large potential for precise and accurate distance determination and also for improving our knowledge of basic physics of pulsating stars. During my talk I will focus on a few results obtained for some of these systems.

2 Distance to the LMC

We have analyzed 8 systems discovered by Graczyk et al. (2013) based on extensive monitoring of the LMC over some 18 years in the course of the OGLE project. Over some 10 years we collected high quality spectroscopic and near infrared data with Magellan+MIKE, 3.6m+HARPS, and NTT+SOFI telescopes / instruments (Pietrzyński et al. 2009, 2013).

For all LMC systems linear sizes of both components were measured with 1-2 % accuracy based on modelling of high-quality photometric light curves obtained by the OGLE project and radial velocity curves constructed by the Araucaria team. Having first ever discovered late-type eclipsing binaries (G-K type), we used a well calibrated relationship between angular diameter and V - K colour (Di Benedetto 2005, Kervella

et al. 2004) and measured corresponding angular sizes of the components of our systems with an accuracy of 2 %. As the result we obtained the most accurate and reliable LMC distance (2.2 %), which provides a strong basis for the determination of the Hubble constant with an accuracy of about 3 % (Pietrzyński et al. 2013). At present, we are working on improving the surface brightness-colour calibration and measuring the LMC distance with an accuracy of 1 %.

3 Distance to the SMC

Based on analysis of five late type systems we measured distance to the SMC of 18.95 $\pm$ 0.07 mag (Graczyk et al. 2012, 2013). The individual distances to studied systems clearly show that there is very small depth of view in the main body of the SMC. Indeed the measured dispersion of distances is of 0.05 mag only, and is very similar to the corresponding dispresion of distances measured for our LMC systems (Pietrzyński et al. 2013). Errors on both distance determinations to the LMC and SMC are dominated by systematic error related to the precision of the surface brihtness - colour relation (about 2 %). However this error does not affect the relative distance between the Magellanic Clouds, which we measured with an unprecedented accuracy of about 1 %. Such precise and accurate relative distance provide an excellent tool to study influence of the population effects on brightness of several distance indicators extensively observed in both Clouds (e.g. Soszyński et al. 2010, 2011, 2013). In particular the metallicity dependence of the Period - Luminosity relation for classical Cepheids could be calibrated completely independently and with a very good accuracy.

4 Cepheids in binary systems

The OGLE project provided also very good candidates for classical Cepheids in eclipsing systems (e.g. Soszynski et al. 2008). Such systems provide a unique opportunity to measure precisely and accurately stellar parameters of Cepheids. In consequence, they provide very strong constraints on stellar evolutionary and pulsation models. One can also measure distances to such targets using three independent techniques: P-L relation, Baade-Wesselink method, and eclipsing binaries described above. Comparing the independent distances, the potential systematic errors associated with each of these methods can be precisely traced out. Because of the huge potential of these systems for improving our capability of measuring distances with classical Cepheids and to better understand basic physics of these stars, as a part of the Araucaria project we started a long-term program to characterize them. In 2010 we confirmed that one of the OGLE candidates - OGLE-LMC-CEP-227 - is indeed a physical system containing a Cepheid. Based on high-quality data, we measured the dynamical mass of the Cepheid with an accuracy of 1 % (Pietrzyński et al. 2010). Recently, we significantly improved the accuracy of determination of the physical parameters of this system and measured directly the p factor for the Cepheid (Pilecki et al. 2013). This analysis complements our previous study on the calibration of the p factor (Gieren et al. 2005, Nardetto et al. 2011, Storm et al. 2011). Pietrzyński et al. (2011) measured the dynamical mass of another Cepheid in an eclipsing system with similar accuracy. These results already triggered several theoretical investigations (Cassisi & Salaris 2011, Neilson et al. 2011, Prada Moroni et al. 2012, Marconi et al. 2013). Unfortunately, there are no Cepheids in eclipsing binary systems known so far in the Milky Way. However, some of the Cepheids in binary systems are sufficiently close to

observe them interferometrically (Gallenne et al. 2013). Combining spectroscopic and interferometric data one should be also able to precisely measure distances, masses and other physical parameters for several Cepheids in the Milky Way (Gallenne et al. 2013).

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