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# THE ARAUCARIA PROJECT. IMPROVING THE COSMIC DISTANCE SCALE

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RESUMEN

En el transcurso del Proyecto Araucaria hemos recolectado una gran cantidad de datos espectroscópicos, ópticos y del cercano infrarrojo para varios indicadores de distancia en unas 30 galaxias cercanas. El principal objetivo de nuestro proyecto es mejorar los 3 pasos más débiles en la calibración de los indicadores de distancia estelares primarios (Cefeidas, estrellas RR Lyrae, TRGB, estrellas de la acumulación roja y supergigantes azules): el punto cero, dependencia con el ambiente y un apropiado tratamiento de la extinción interna. Aquí resumimos los resultados obtenidos y discutimos los planes a futuro.

ABSTRACT

In the course of the Araucaria Project we have collected a huge amount of accurate near-infrared, optical and spectroscopic data for several major distance indicators in some 30 nearby galaxies. The main goal of our project is to improve the three weakest steps in the calibration of primary stellar distance indicators (Cepheids, RR Lyrae stars, TRGB, red clump stars and blue supergiants): the zero point, environmental dependences and proper treatment of the internal extinction. We resume obtained results and discuss the future plans.

*Key Words:* binaries: eclipsing — Cepheids — distance scale — stars: variable: other



## 1. INTRODUCTION

Over the past decade, the HST Key Project on the Extragalactic Distance Scale (Kennicutt et al. 1995) has been an extraordinary effort to solve a long-standing problem in astrophysics, viz. to achieve the calibration of the extragalactic distance scale and in consequence of the Hubble constant, with the an accuracy of 10%. As discussed by Freedman et al. (2001) in their final paper on the HST Key Project results, there are, however, a number of systematic uncertainties attached to their method of distance determination which have so far prevented to achieve a truly accurate calibration of the distance scale. Among these uncertainties, the most important ones are: the accurate determination of the reddening, the dependence of the major distance indicators on the environmental properties, and the distance to the LMC, which provides the fiducial Cepheid PL relation.

Recently our group has started the Araucaria Project with the main goal of improving the distance scale calibrations based on observations of major distance indicators in several nearby galaxies. In this contribution I will present our recent results and will shortly discuss the future plans.

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## 2. OPTICAL AND NEAR INFRARED OBSERVATIONS OF MAJOR DISTANCE INDICATORS

As a first step of our project we have performed a wide-field multi-epoch optical monitoring of seven nearby galaxies containing Cepheids. In the case of the Local Group galaxies (WLM, NGC 6822, NGC 3109) and NGC 300 the samples of Cepheids were very significantly extended (tripled on average) while for NGC 55, NGC 7793 and NGC 247 we have discovered rich populations of Cepheids for the first time (Pietrzynski et al. 2002, 2004, 2006a,b, 2007; Gieren et al. 2005). Then subsamples of discovered Cepheids were subjects of the near infrared follow-up imaging with 4 and 8 m class telescopes. The resulting period-luminosity (P-L) relations constructed for the V, I, J, and K bands were carefully examined and the corresponding relative distance moduli for each of our target galaxies with respect o the LMC were derived. Based on our results we can conclude that the slope of the Cepheid P-L relations in I, J and K bands do not depend on metallicity in a very wide range of metallicities ($-1 <$ [Fe/H] $< 0$). The dependence of the zero point of the Cepheid I band P-L relation is $0.15 \pm 0.04$ mag/dex. In the near infrared domain this dependence seems to be even smaller. Combining optical and near infrared data we have calculated accurate total reddenings and true distance moduli for our target galaxies (Gieren et al.

2004, 2006, 2008; Pietrzynski et al. 2006; Soszynski et al. 2006). We have shown that in all cases the obtained total reddening is significantly larger than the corresponding foreground reddening estimated from the Galactic extinction maps of Schlegel et al. (1998). Therefore in order to derive precise distance it is obligatory to carefully account for the internal reddening related to the interstellar matter of the host galaxy.

In the course of the Araucaria project we have also derived precise distances from TRGB method for about 30 nearby (closer than 4 Mpc) galaxies and RR Lyrae and red clump stars for some 9 Local Group galaxies (Pietrzynski & Gieren 2002; Pietrzynski et al. 2003; Pietrzynski et al., in prep.). We have just started a detailed analysis of the accurate relative distances derived from all different distance indicators for all galaxies, spanning now a very wide range of environmental properties, which should lead to an accurate determination of the population dependence of all studied standard candles and the consistent set of distances to our studied galaxies. It is worthwhile noticing that working in the infrared domain where the extinction is ten times smaller as compared to the optical region, we can practically get rid of the very important systematic error associated with distances, the reddening. What is even more important, combining our IR data with the optical ones, we will be able to accurately determine the total reddening for some of our galaxies, and investigate for the first time the influence of the internal reddening, which was by now neglected, assumed or very roughly derived from the optical data alone, on the whole distance scale. The extinctions (as well as the homogeneous metallicities) will be also independently derived from the analysis of the spectra and optical and infrared photometry of blue supergiants (e.g. Bresolin et al. 2007; Evans et al. 2007).

In order to improve the zero point of the cosmic distance scale we are securing accurate radial velocities and precise K band photometric measurements for 10 (7 from the LMC and 3 from the SMC, respectively) very rare eclipsing systems very carefully selected from the OGLE databases consisting of late type (G,K) giants, which are extremely interesting for distance determination. They are bright enough (V=16–17.5 mag) to obtain precise radial velocity measurements with a modern 8 meter class telescopes. For these systems an accurate surface brightness-color calibration can be used, and the full potential of eclipsing binaries as distance indicators can be exploited for the first time. The accuracy of our distance determination will be affected by the following factors. Using high resolution spectra and having S/N=10, we will determine radial velocities accurate to 0.5 km s$^{-1}$. This means an 1.3% error in the Vr amplitude, and thus the distance. Relative radii can routinely be derived with an 1% accuracy. The zero point error of the OGLE data (0.01 mag) adds another 0.6% uncertainty. The zero point of the K-band photometry (0.02 mag) translates to about 0.8% in the distance determination. The error associated with the uncertainty of the reddening is only about 1%, due to working in the K band. The error associated with the calibration of the surface brightness-color relation is about 0.03 mag which corresponds to about 2% mag in distance. Adding all these errors quadratically together, one would reasonably expect to obtain the distance to each of our three systems with a 3% accuracy. We note that our targets are all located relatively close to the LMC or SMC center, and most probably are located in the bar of the LMC or SMC, respectively. Any geometrical correction resulting from the tilt of the LMC bar is smaller than 0.02 mag. Our distance determination to the LMC from the 7 late-type binaries, will set-up a precise zero point of the whole distance scale.

Addressing, very carefully all three major problems (reddening, population dependence of the main standard candles and the zero point) related to the distance determination we expect to calibrate the cosmic distance scale with an accuracy of about 4–5%, which is supposed to have a very big impact on the modern cosmology, which requires a precise value of the Hubble constant.

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