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The Near-IR TRGB Magnitude and Distance Modulus to NGC 185

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Abstract

We determined values of distance modulus to nearby dwarf galaxy NGC 185 from the Tip of Red-Giant Branch (TRGB) method. Apparent magnitudes of the TRGB are estimated from the near-infrared JHK luminosity functions (LFs) of the resolved giant branch stars. Theoretical absolute magnitudes of the TRGB in near-infrared bands have been extracted from the Yonsei-Yale isochrones. The observed apparent and theoretical absolute magnitudes of the TRGB provide values of distance modulus to NGC 185 as $(m - M) = 23.39 \pm 0.14, 23.23 \pm 0.22$, and 23.27 ± 0.26 for J, H, and K bands, respectively. Distance modulus in bolometric magnitude is also derived as $(m - M) = 23.62 \pm 0.12$.

Keywords: TRGB, distance modulus, near-infrared, NGC 185

1. Introduction

This is the second paper of a series measuring the distance modulus of nearby dwarf galaxies from the brightness of the TRGB on the near-infrared LFs (Kang et al. 2007, Paper I). The so-called TRGB is the evolution along the RGB ends with helium ignition in the stellar core. The fact that the luminosity of the TRGB is fairly constant over a large part of low mass star range (Salaris et al. 2002) leads that the TRGB magnitude can be used as a distance indicator for nearby resolved galaxies (Lee et al. 1993a,b, Madore & Freedman 1995, Sakai et al. 1996).

While I band photometry has been generally used to determine the brightness of the TRGB because I magnitude of TRGB is weakly sensitive to the metallicity (e.g., Da Costa & Armandroff 1990, Lee et al. 1993a, Salaris & Cassisi 1998), near-infrared observations have rarely used to measure the TRGB of resolved galaxies (e.g., Cioni et al. 2000, Cioni & Habing 2005). In the Paper I, we used the TRGB in the near-infrared JHK bands and bolometric magnitudes to determine the distance modulus to nearby dwarf elliptical galaxy NGC 147. In this paper, we use the same method to measure the distance modulus of the nearby dwarf elliptical galaxy NGC 185, which is a dwarf elliptical satellite galaxy of the Andromeda galaxy. In Sect. 2, we describe the data for the near-infrared CMDs with J, H, and K bands. Sect. 3 describes the observational apparent and theoretical

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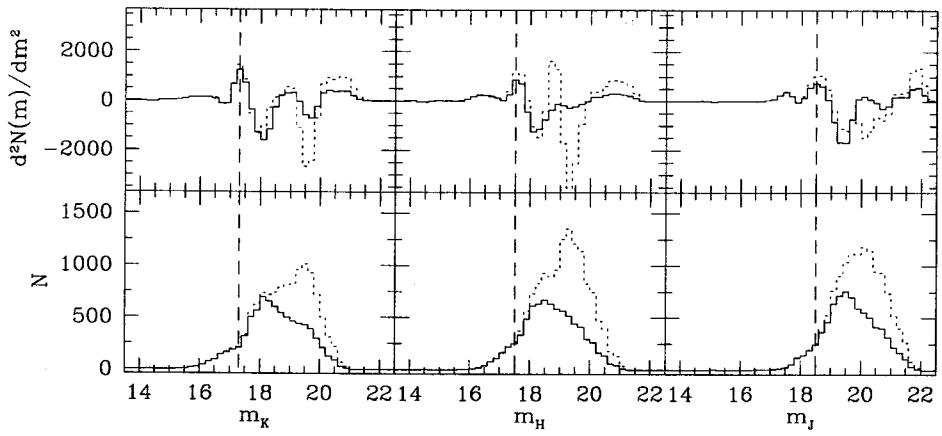

Figure 1. Lower: The observed luminosity functions in near-infrared JHK bands of resolved stars in NGC 185. The dotted lines are LFs in completeness corrected number of stars. Upper: The second derivative of the observed LF and the completeness corrected LF. Vertical long-dashed lines in each panel indicate the determined TRGB magnitudes.

absolute magnitudes of the TRGB for NGC 185. In Sect. 4, we present the determined distance modulus of NGC 185.

2. The data of near-infrared CMD

The near-infrared JHK images of NGC 185 were obtained during the night of UT June 3, 2004 using the CFHTIR imager mounted on the f/8 Cassegrain focus of the 3.6 m CFHT telescope. Each image covers a total $3'.6 \times 3'.6$ on the sky with an angular scale of $0''.211$/pixel. Seeings are $\sim 0''.7$ FWHM in JHK bands. The detailed information about observations and the process of data reduction could be found in our previous paper (Kang et al. 2005). After all pre-processing of the data and the point spread function photometry, we resolved 7804 stars in all three bands, as presented in the Figure 1 of Kang et al. (2005). The observed CMDs contain a AGB population and a bright part of RGB population. In the paper, we assumed the TRGB magnitude of NGC 185 as $K = 17.25$, for which we visually confirm that this value divide the boundary between AGB and RGB population in CMDs.

3. The apparent and absolute TRGB magnitudes of NGC 185

To determine the apparent magnitude of the TRGB, we follow the method of Cioni et al. (2000) to the observed LFs of resolved stars in NGC 185. Applying the Savitzky-Golay filter to the observed LFs, we derive the second derivative of the LFs and detect a peak as a TRGB magnitude. Details of the Savitzky-Golay filter method to the observed LFs are described in Kang et al. (2007). The lower panels of Figure 1 show the observed near-infrared LFs of resolved stars in NGC 185, and the upper panels show the second derivative of the LFs after applying a Savitzky-Golay filter to the

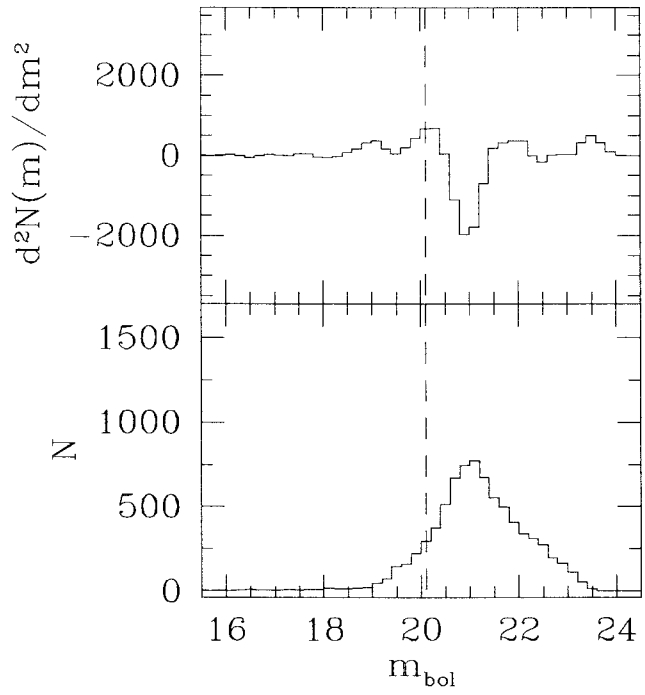

Figure 2. Lower: Bolometric luminosity function of resolved stars in NGC 185. Upper: The second derivative of bolometric LF. The long-dashed line shows the obtained bolometric magnitude of the TRGB.

observed LFs. The peaks of the second derivative LFs indicate the derived apparent magnitudes of the TRGB, i.e., $m_J = 18.5$, $m_H = 17.5$, and $m_K = 17.3$, respectively. The absorption corrected TRGB magnitudes of NGC 185 are estimated as $m_{J_0} = 18.335$, $m_{H_0} = 17.395$, and $m_{K_0} = 17.233$ by using reddening values to the direction of NGC 185 (Schlegel et al. 1998). Also, we used the estimated bolometric magnitudes of the resolved AGB and RGB stars in NGC 185 (Kang et al. 2005) to determine the bolometric magnitude of the TRGB from the bolometric LF. Figure 2 shows the bolometric LF and the second derivative of the LF for resolved stars in NGC 185. The peak of the second derivative of the bolometric LF for resolved stars in NGC 185 provides a observed bolometric magnitude of the TRGB as $m_{bol} = 20.1$.

To extract the absolute magnitudes of TRGBs for NGC 185, we use the theoretical Yonsei-Yale isochrones(Kim et al. 2002, Yi et al. 2003). As shown in Figure 3 of Kang et al. (2007), the relationship between metallicity and the theoretical absolute magnitude of TRGB in the near-infrared and bolometric magnitudes indicates that the brightness of TRGB in bolometric magnitude is less sensitive to metallicity than those in near-infrared bands. For absolute magnitude of the TRGB in near-infrared bands JHK, the longer wavelength, the more sensitive to the metallicity. These lead that errors of the absolute TRGB magnitudes mainly come from the adopted metallicity range of stars in the Galaxy. In this paper, we use the metallicity range of stars in NGC 185 as -1.6 <[Fe/H]< -0.9 (Kang et al. 2005). Finally, the theoretical absolute TRGB magnitudes are

estimated to be $M_J = -5.060 \pm 0.101$, $M_H = -5.833 \pm 0.196$, $M_K = -6.033 \pm 0.238$, and $M_{bol} = -3.519 \pm 0.062$ from the Yonsei-Yale isochrones with a age of 12 Gyr.

4. TRGB distance to NGC 185

From the observed apparent magnitudes and the theoretical absolute magnitudes of the TRGB in near-infrared JHK and bolometric magnitudes, we calculate the distance modulus of NGC 185. Errors in the distance modulus contain the magnitude errors for both of the bin size in LF and the metallicity range. The estimated values are $(m-M)_J = 23.39 \pm 0.14$, $(m-M)_H = 23.23 \pm 0.22$, $(m-M)_K = 23.27 \pm 0.26$, and $(m-M)_{bol} = 23.62 \pm 0.12$. There have been several distance determinations for NGC 185 by using the TRGB methods to the visible band LFs, i.e., 23.94 (Lee et al. 1993a), 23.96 ± 0.21 (Lee et al. 1993b), 23.95 ± 0.10 (Martinez-Delgado & Aparicio 1998), and 24.12 ± 0.32 (Salaris & Cassisi 1998). From the mean magnitude of the RR Lyrae stars Saha & Hoessel (1990) determined the distance modulus to NGC 185 as 23.79 ± 0.25. The fact that values of the distance modulus to NGC 147 in this paper are comparable with previous values from other studies indicates the near-infrared TRGB magnitude in near-infrared bands is a good distance indicator to nearby resolved galaxies.

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