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The JHK_S Magnitudes of the Red Giant Branch Tip and the Distance Moduli of Nearby Dwarf Galaxy NGC 205

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Abstract

We have used the near-infrared JHK_S photometric data of resolved stars in a nearby dwarf elliptical galaxy NGC 205 to determine the magnitudes of the red giant branch tip (TRGB). By applying Savitzky-Golay filter to the observed luminosity functions (LFs) in each band, we derived the second derivatives of the LFs so as to determine the magnitudes of the TRGB. Absolute magnitudes of the TRGB in JHK_S bands were measured from the Yonsei-Yale isochrones. By comparing the determined apparent magnitudes and the theoretical absolute magnitudes of the TRGB, we estimated the distance moduli of NGC 205 to be $(m - M) = 24.10 \pm 0.08, 24.08 \pm 0.12$ and 24.14 ± 0.14 in J, H, and K_S bands, respectively.

Keywords: TRGB, distance modulus, near-infrared, NGC 205

1. Introduction

This is the fourth paper of a series estimating the distance moduli of nearby dwarf galaxies from the magnitude of the TRGB on the near-infrared LFs (Kang et al. 2007, Sohn et al. 2008a,b). The magnitude level of the TRGB on the LFs of resolved stars in a galaxy contains a crucial astrophysicacl significance of the low-mass stellar evolution and the cosmic distance scale of nearby galaxies. In a sequence of low-mass stellar evolution, the TRGB marks the helium ignition in the degenerated helium core. At the moment, the temperature of the degenerated core is generally dependent on the properties of the thin H-burning shell around it, and this varies very slightly with chemical abundance and surrounding mass (McConnachie et al. 2004). The intrinsic brightness of the TRGB is thus roughly constant, forming a discontinuity in the LF of the resolved stars in a galaxy. Indeed, the sharp cut-off occurring at the bright end of the LFs of RGB stars is the observable of the TRGB for nearby galaxies. This leads that the magnitude of the TRGB in the LF of the resolved stars could be a candidate of distance indicator for nearby dwarf galaxies.

The TRGB method as a distance indicator has been generally used in I-band observation, because I magnitude of the TRGB is weakly sensitive to metallicity than the other passbands (e.g., Da Costa & Armandroff 1990, Lee et al. 1993, Salaris & Cassisi 1998). Meanwhile, several studies have investigated the TRGB in near-infrared bands to measure the distances of the resolved nearby galaxies (e.g., Cioni et al. 2000, Cioni & Habing 2005) and those of the Galactic globular clusters

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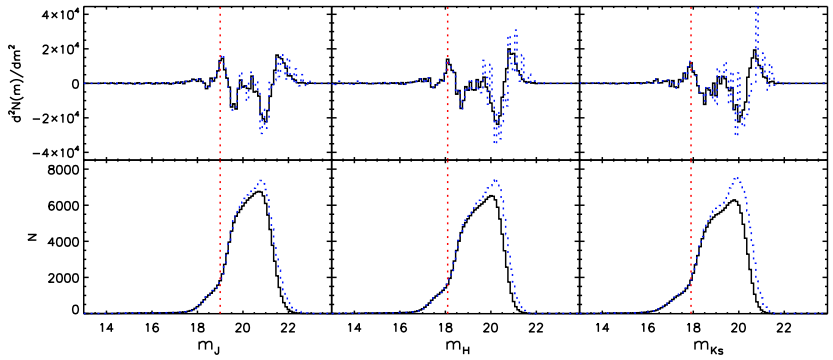

Figure 1. Lower: The near-infrared JHK_S band luminosity functions of the resolved stars in NGC 205. Solid lines are the LFs for the measured stars, and the dotted lines are those for the completeness corrected number of stars. Upper: The second derivatives of the observed LFs and the completeness corrected LFs. Vertical long-dashed lines in each panel indicate the determined magnitudes of the TRGB.

(e.g., Montegriffo et al. 1995, Bellazzini et al. 2004). Indeed, the near-infrared photometry offers an advantage in studying the RGB population, because of its high sensitivity to low temperature. In our previous papers (Kang et al. 2007, Sohn et al. 2008a,b), we measured the JHK magnitudes of the TRGB for two nearby dwarf elliptical galaxies (NGC 147 and NGC 185) and a dwarf irregular galaxy (NGC 6822), and determined the distance moduli of the galaxies. In this paper, we determine the distance modulus of the nearby dwarf elliptical galaxy NGC 205 by using the Savitzky-Golay filter to measure the brightness of the TRGB in the near-infrared LFs of resolved stars. In Sect. 2, we describe the photometric data in JHK_S bands for resolved stars in NGC 205. Sect. 3 presents the method to determine the observational and theoretical TRGB magnitudes. In Sect. 4, we present the determined distance moduli of NGC 205, comparing with the previous results.

2. The Near-Infrared Photometric Data

Our target for this study is a dwarf elliptical galaxy NGC 205 which is a companion of M31. The near-infrared imaging data were obtained with the WIRCam in Queued Service Observing (QSO) of the 3.6m CFHT on July 19, 2007. The WIRCam images cover $\sim 21'.5 \times 21'.5$ total field of view on the sky with a pixel scale of 0.304 arcsec/pixel. Since details of the observations and data reductions are appeared in Jung (2009), we briefly describe here the photometric data. The total exposure times were $600s$ in J, $300s$ in H and $500s$ in K_S. The data reduction followed the standard processing including dark subtraction, flat fielding, and sky subtraction. Also, TERAPIX program was used to correct the distortion and chip-to-chip variation and to coadds the frames. DAOPHOT II and ALLSTAR (Stetson 1987, Stetson & Harris 1988) were used to do point-spread-function (PSF) photometry on the stacked images. The standardization correlation were derived by comparing the 2MASS data in the target field. Finally, we detected 145 243 stars in the field of NGC 205 after all pre-processing and photometry. The observed stars contain populations of the AGB and the RGB in brighter parts, and those of the main-sequence and the field stars. We also note that the photometric completeness at the level of the determined TRGB magnitude of NGC 205 is above $\sim 90\%$.

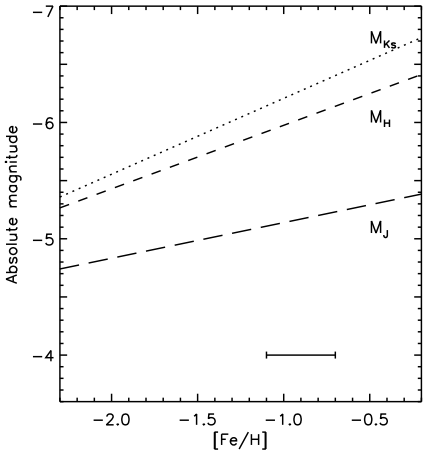

Figure 2. The relationships between the theoretical TRGB magnitude and [Fe/H] by Yonsei-Yale isochrones. The long-dashed, short-dashed, and dotted lines are those in JHK_S bands. Horizontal bar represents the adopted metallicity range of NGC 205.

3. The Apparent and Absolute TRGB Magnitudes

To determine the apparent TRGB magnitude of NGC 205, we applied the procedure of Cioni et al. (2000) to the LFs of resolved stars in the observed field. Indeed, the TRGB discontinuity causes a peak in the second derivative of the observed LF, which is derived by using a Savitzky-Golay filter. The filter yields for bin number i, $[d^2N/dm^2]_i = \sum_{j=-J}^{J} c_j N(m)_{i+j}$, where $N(m)$ is number of stars with m magnitude and the c_j are Savitzky-Golay coefficients for the chosen value of J and the desired derivative order $L = 2$. The filter fits a polynomial of order M to the data points $N(m)_j$ with $j = i - J, ..., i + J$, and then evaluate the Lth derivative of the polynomial at bin i to estimate d^2N/dm^2.

In Figure 1, the lower panels show the observed LFs in JHK_S bands of resolved stars in NGC 205, while the upper panels show the second derivatives of the observed LFs after applying a Savitzky-Golay filter to observed LFs. The dotted lines of each box indicate the completeness corrected LFs. We detected the peak of the second derivatives of the LFs as the apparent magnitudes of the TRGB, which are indicated by vertical dashed lines in each panel. The values of the brightnesses of the TRGB in near-infrared bands are $m_J = 19.0$, $m_H = 18.1$, and $m_{Ks} = 17.9$, respectively. After applying the reddening values $E(B - V) = 0.083$ estimated from the extinction map of Schlegel et al. (1998), we obtained the absorption corrected TRGB magnitudes of $m_{J_0} = 18.925$, $m_{H_0} = 18.052$, and $m_{Ks_0} = 17.870$.

In Figure 2, we show the relationship between metallicity and the absolute magnitudes of the TRGB in the near-infrared bands measured in the Yonsei-Yale isochrones (Kim et al. 2002, Yi et al. 2003) with the age of 12 Gyr. The thick long-dashed, short-dashed, and dotted lines represent the near-infrared J, H, and K magnitudes of the TRGB with respect to metallicities. The metallicity range of NGC 205 is $-1.1 <$ [Fe/H] < -0.7, as shown in Jung (2009). Applying the metallicity range and the age of 12 Gyr to Figure 2, we estimate the theoretical TRGB magnitudes for NGC 205 to be $M_J = -5.170 \pm 0.061$, $M_H = -6.030 \pm 0.109$, and $M_{Ks} = -6.272 \pm 0.131$. Note that the errors of the determined absolute magnitudes are simply occurred by the range of the metallicity.

4. The TRGB Distance to NGC 205

We have measured the apparent magnitudes and the theoretical absolute magnitudes of the TRGB for NGC 205 from near-infrared JHK_S photometric data of the resolved stars. The magnitudes of the TRGB give distance moduli of $(m-M)_J = 24.10 \pm 0.08$, $(m-M)_H = 24.08 \pm 0.12$, and $(m-M)_{Ks} = 24.14 \pm 0.14$. Error estimation considered only the propagation of errors for the bins size of LF in each band and metallicity range.

There have been several distance determinations for NGC 205. Ciardullo et al. (1989) determined the distance modulus of NGC 205 as $(m-M)_0 = 24.68 \pm 0.35$, from the observations of 12 planetary nebulae in the galaxy. Saha et al. (1992) found 30 RR Lyrae stars in NGC 205, from which they obtained a distance modulus of $(m-M)_0 = 24.65 \pm 0.25$. Using the I magnitude of the TRGB, it was estimated to be 24.3 ± 0.2 by Mould et al. (1984), 24.54 by Salaris & Cassisi (1998), and 24.76 ± 0.1 by Butler & Martinez-Delgado (2005). Consequently, distance moduli of NGC 205 estimated from the near-infrared TRGB magnitudes are comparable with values from the previous studies.

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