J. Astron. Space Sci. 25(3), 249–254 (2008)

Near-IR TRGB Distance to Nearby Dwarf Irregular Galaxy NGC 6822

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(Received August 01, 2008; Accepted August 15, 2008)

Abstract

We report the distance modulus of nearby dwarf irregular galaxy NGC 6822 estimated from the so-called Tip of Red-giant Branch (TRGB) method. To detect the apparent magnitudes of the TRGB we use the color-magnitude diagrams (CMDs) and luminosity functions (LFs) in the near-infrared JHK bands. Foreground stars, main-sequence stars, and supergiant stars have been classified on the $(g - K, g)$ plane and removed on the near-infrared CMDs, from which only RGB and AGB stars are remained on the CMDs and LFs. By applying the Savitzky-Golay filter to the obtained LFs and detecting the peak in the second derivative of the observed LFs, we determined the apparent magnitudes of the TRGB. Theoretical absolute magnitudes of the TRGB are estimated from Yonsei-Yale isochrones with the age of 12 Gyr and the metallicity range of $-2.0 <$[Fe/H]< -0.5. The derived values of distance modulus to NGC 6822 are $(m - M) = 23.35 \pm 0.26, 23.20 \pm 0.42$, and 23.27 ± 0.50 for J, H, and K bands, respectively. Distance modulus in bolometric magnitude is also derived as $(m - M) = 23.41 \pm 0.17$. We compare the derived values of the TRGB distance modulus to NGC 6822 in the near-infrared bands with the previous results in other bands.

Keywords: TRGB, distance modulus, near-infrared, NGC 6822

1. Introduction

This is the third paper of series studying the distance determination of nearby dwarf galaxies from the TRGB magnitude on the near-infrared CMDs (Kang et al. 2007, Sohn et al. 2008). In the previous studies, we determined the distance modulus of nearby dwarf elliptical galaxies NGC 147 and NGC 185 from the TRGB method, and verified that the TRGB magnitude in the near-infrared bands is indeed a good distance indicator for nearby resolved galaxies.

The so-called TRGB is the evolution along the RGB ends with a helium ignition in the stellar core. At the point, the temperature of the degenerate quasi-isothermal core is mainly dependent on the properties of the thin hydrogen burning shell around it, and this varies very slightly with chemical abundance and surrounding mass (McConnachie et al. 2004). As the hydrogen burning shell increases the helium core mass on the RGB evolution, the core radius keeps the constant value and the core density increases. As a result, the core temperature is grown by the produced gravitational

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energy and the triple alpha reaction which depends on temperature occurs actively. However, the increased temperature doesn't directly connect the expansion because of the independence between the gas pressure and temperature. This causes an explosive helium burning in the core, i.e., a helium flash. At that time, the flux in the core increases significantly and reaches the maximum, this is the TRGB. The luminosity of TRGB depends on the value of helium core mass which is fairly constant over a large part of the low mass star range (Salaris et al. 2002), and then the TRGB has roughly constant brightness being related to age and metallicity.

Based on empirical data for nearby galaxies, Madore & Freedman (1995) suggested that the TRGB method can be successfully used to determine distance accurate to $\pm 10\%$ for galaxies out to 3 Mpc. Studies of the accuracy of TRGB method as the distance indicator indicate that the TRGB method is applicable to all morphological types of galaxies and successfully applied for calibration of the distances to several nearby galaxies (e.g., Salaris & Cassisi 1998). In the TRGB method, the determination of the accurate TRGB location is a key point. Until 1990s, most astronomers had found the TRGB positions in the color-magnitude diagram (CMD) by eyes. However, the qualities of those are not ideal and not reproducible (e.g., McConnachie et al. 2004). Lee et al. (1993a) applied a technique for distance determination using an edge detection with the Sobel filter to the luminosity functions (LFs) of resolved galaxies. This TRGB method was successfully confirmed thorough numerical simulations by Madore & Freedman (1995). Sakai et al. (1996) revised the method in order to reduce the dependency on bin size of the LF by Gaussian smoothing.

Canonically, the TRGB method as the distance indicator has been used in $I-$band observation, because I magnitude of TRGB is weakly sensitive to the metallicity of the stellar population than the other magnitudes (e.g., Da Costa & Armandroff 1990; Lee et al. 1993a, Salaris & Cassisi 1998). Lee et al. (1993b) suggested that I magnitude of TRGB stars in globular clusters for metallicity range of $-2.2 < [Fe/H] < -0.7$ shows only small difference within 0.1 mag. Many authors investigated the study of TRGB in optical observations, while observations of infrared bands have rarely been studied until now. Recently, this method in infrared wavelength are noticed and carried out from infrared observations such as 2MASS and DENIS projects. Montegriffo et al. (1995) estimated the distance using TRGB in J and K bands for 47 Tucanae. Cioni et al. (2000) estimated the distances of LMC and SMC using TRGB in the I, J, and K_S bands from the data of DENIS catalogue towards the Magellanic Clouds. Also, Cioni & Habing (2005) obtained a distance modulus of NGC 6822 from the position of TRGB in IJK_S bands using the Issac Newton Group Red Imaging Device (INGRID) on the William Herschel Telescope. Valenti et al. (2004) measured TRGB in the J, H, and K bands for 24 Galactic globular clusters using the ESO-MPI 2.2 m telescope with the near infrard camera IRAC-2. Bellazzini et al. (2004) estimated the TRGB as distance indicator in I, J, H, and K bands for ω Centauri and 47 Tucanae from 2MASS data. We note that a large number of observations included the detection of TRGB in infrared bands is performed by many astronomers using ground-based large telescopes and space telescopes, and a great number of data is already accumulated. In addition, the JWST as next generation space telescope of the HST will conduct infrared observations of nearby galaxies in the future.

In this paper, we measure the distance modulus of the nearby dwarf irregular galaxy NGC 6822 using the Savitzky-Golay filter to measure the brightness of the TRGB in the near-infrared JHK and optical gi CMDs and LFs. In Sect. 2, we describe the data for the near-infrared and optical CMDs with JHK and gi bands. Sect. 3 describes the method to estimate the observational apparent and theoretical absolute magnitudes of the TRGB. In Sect. 4, we present the determined distance modulus of NGC 6822, and compare with the previous results.

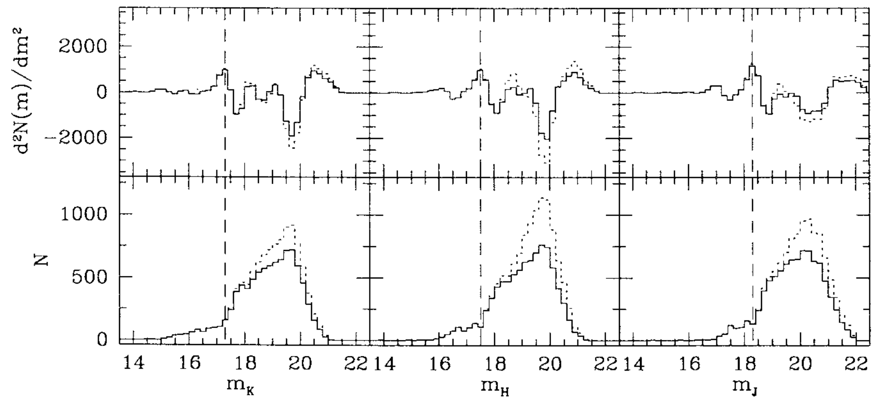

Figure 1. Lower: Luminosity functions in near-infrared JHK bands of NGC 6822. The LFs with solid and dotted lines are for only detected stars and for completeness corrected number of stars, respectively. Upper: The second derivative of LF and completeness corrected LF. Vertical long-dashed lines in each panel indicate the TRGB magnitudes.

2. The CMD Data of Near-infrared and Optical Bands

NGC 6822 is a nearby dwarf irregular galaxy isolated from any of subgroups of nearby galaxies. Near-infrared image data were obtained on June 5, 2004 using the CFHTIR infrared imager of the CFHT 3.6m telescope. The detailed information about the near-infrared observations and the process of data reduction could be found in our previous paper (Kang et al. 2006). Also the MegaPrime imager mounted on the prime focus of the CFHT was used to observe in optical gi bands on Aug. 24, 2003. The details of the gi observations are described in Hwang et al. (2005) and Kang et al. (2006). To classify populations and analyze the foreground star contamination, we use $(g-K, g)$ CMD for 12611 stars detected in all five $giJHK$ bands. ¿From the $(g-K, g)$ CMD, we classify populations of Galactic foreground stars, sub-giant branch stars, supergiant stars, RGB stars, AGB stars, and finally obtained $(J-K, K)$ CMD for 8830 AGB and RGB stars (see Figure 1 of Kang et al. 2006). The completeness tests indicate that the resolved stars with a magnitude of the TRGB are not seriously affected by the crowding effect in the observed images (Kang et al. 2006).

3. The Apparent and Absolute Magnitudes of the TRGB

To calculate the distance to galaxies using the TRGB brightness, we need values for the apparent and absolute magnitudes of the TRGB in the near-infrared CMDs. For the apparent magnitude of the TRGB on the observed CMDs, we use the method of Cioni et al. (2000). The absolute magnitude of the TRGB are determined by using the theoretical Yonsei-Yale isochrones (Kim et al. 2002, Yi et al. 2003).

The TRGB which marks the violent onset of core helium burning in low-mass stars causes a distinct and abrupt termination of the bright end of the RGB LF (Makarov et al. 2006). Cioni et al. (2000) indicated that the TRGB discontinuity causes a peak in the second derivative of the observed stellar LF, and found that the set of the second derivatives of the LFs provides a better handle on the brightness of TRGB. For the estimation of the second derivative, they used a Savitzky-Golay

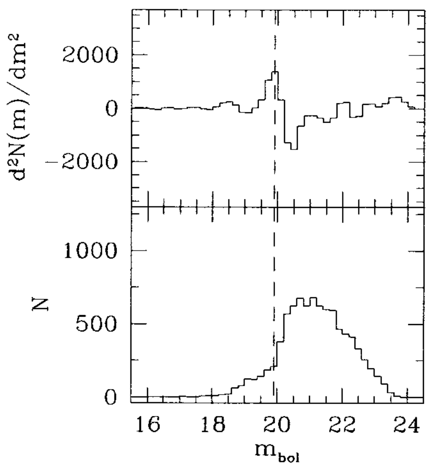

Figure 2. Lower: Luminosity function in bolometric magnitude for resolved stars in NGC 6822. Upper: The second derivative of bolometric LF.The long-dashed line shows the TRGB magnitudes.

filter to the observed LFs. 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. We applied the method to the LFs of resolved AGB and RGB stars in NGC 6822 to determine the apparent magnitudes of the TRGB.

Figure 1 shows near-infrared LFs of NGC 6822 in J, H, and K bands (lower) and the second derivative of the LFs (upper) after applying a Savitzky-Golay filter. The dotted lines are the completeness corrected LFs and the second derivatives of the LFs. Indeed. we easily detected the apparent TRGB magnitudes at the peaks of the second derivatives of the LFs as shown in Figure 1. We note that the TRGB magnitudes in the apparent LFs are same as those in the completeness corrected LFs. This indicates again the detected magnitude of the TRGB are not seriously affected by the crowding effect. Finally, the brightnesses of TRGBs in near-infrared bands of NGC 6822 are derived as $m_J = 18.3$, $m_H = 17.5$, and $m_K = 17.3$, respectively. After applying the reddening values to NGC 6822 (i.e., Schlegel et al. 1998), we obtained the absorption corrected TRGB magnitudes of resolved stars in NGC 6822 as $m_{J_0} = 18.284$, $m_{H_0} = 17.362$, and $m_{K_0} = 17.212$.

To obtain the bolometric LF of the resolved AGB and RGB stars in NGC 6822, Kang et al. (2006) calculated the bolometric m_{bol} magnitudes of the stars by using the empirical relation between BC_K and $(J - K)$ by Bessell & Wood (1984) and Costa & Frogel (1996). The lower panel of Figure 2 presents the LF in bolometric magnitude for resolved stars in NGC 6822. We also applied the Savitzky-Golay filter to the LF in bolometric magnitude, and determined the bolometric magnitude of the TRGB as $m_{bol} = 19.9$ by detecting the peak of the second derivative of the bolometric LF (upper panel of Figure 2). We note that the bolometric magnitude is less affected by metallicity and age as well as dust extinction (Cioni et al. 2000), and that we can obtain more accurate distance to the galaxy by using the bolometric magnitudes of resolved stars.

Figure 3 shows the relationship between metallicity and the absolute magnitudes of TRGB in the

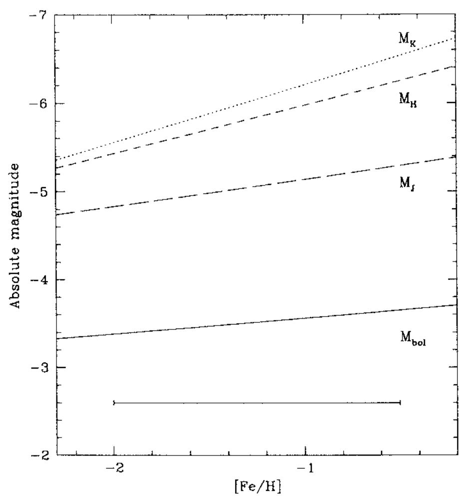

Figure 3. The relationship between the theoretical TRGB magnitude and [Fe/H] by Y^2 isochrones. The solid line shows the relationship in bolometric magnitude, and the long-dashed, short-dashed, and dotted lines are those of JHK bands. Horizontal bar represents the adopted metallicity range of NGC 6822.

near-infrared and bolometric magnitudes extracted from the Y^2 isochrones with the age of 12 Gyr (Kim et al. 2002, Yi et al. 2003). The absolute magnitude of the TRGB depends on the metallicity as shown in Figure 3. This causes the uncertainty of the absolute magnitudes of the TRGB for a galaxy. In this paper, we adopted the metallicity range of NGC 6822 as $-2.0 <$[Fe/H]< -0.5 (Kang et al. 2006) and the age of 12 Gyr, and then we finally estimate the theoretical absolute magnitudes of the TRGB for NGC 6822 to be $M_J = -5.061 \pm 0.240$, $M_H = -5.837 \pm 0.413$, $M_K = -6.053 \pm 0.486$, and $M_{bol} = -3.510 \pm 0.139$.

4. The TRGB Distance to NGC 6822

The observed apparent TRGB magnitudes of nearby dwarf irregular galaxy NGC 6822 are obtained from the CMDs and LFs in JHK and bolometric magnitudes of AGB and RGB stars. By applying Savitzky-Golay filter to the LFs, we obtained the second derivative of the LFs and detected the peak of the profile as magnitudes of the TRGB. Absolute magnitudes of the TRGB in JHK and bolometric magnitudes are also extracted from the theoretical Y^2 isochrones. Using the observed magnitudes in near-infrared bands and theoretical magnitudes of TRGBs, we calculate distance modulus for NGC 6822. The calculated values for each near-infrared band are $(m-M)_J = 23.35 \pm 0.26$, $(m-M)_H = 23.20 \pm 0.42$, $(m-M)_K = 23.27 \pm 0.50$, and $(m-M)_{bol} = 23.41 \pm 0.17$ for the bolometric magnitude. Errors are calculated from those in magnitudes for both of the bin size in LF and the metallicity range.

Using the Cepheids of NGC 6822, McAlary et al. (1983) estimated the distance modulus of 23.47 ± 0.11 in H band. With the same method, Gallart et al. (1996) determined the distance modulus of 23.49 ± 0.08. Using the I band magnitude of the TRGB, Gallart et al. (1996), Cioni & Habing (2005), and Lee et al. (1993a) measured the distance modulus of NGC 6822 to be 23.4 ± 0.1, 23.34 ± 0.12, and 23.46, respectively. From the reevaluation of the TRGB method, Salaris & Cassisi

(1998) obtained 23.61 ± 0.14 for the distance modulus of NGC 6822. Mateo (1998) summarized the study about dwarf galaxies in the Local Group and presented the distance to the NGC 6822 as 490±40 kpc. It is apparent that the estimated values of distance modulus for NGC 6822 in this paper are comparable with previous values from other studies. At the point that near-infrared observations are getting more important for the observational cosmology, we need more observational studies for the distance modulus measurements of resolved galaxies in the near-infrared bands.

Acknowledgements: This work has been supported by the Korea Research Foundation Grant funded by the Korea Government (KRF-2007-313-C00321), for which we are grateful.

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