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Near-IR TRGB Distance Modulus of Dwarf Irregular Galaxy IC 1613

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Abstract

The JHK_S magnitudes of the red giant branch tip (TRGB) and the distance moduli of the nearby dwarf irregular galaxy IC 1613 have been determined from the near-infrared luminosity functions (LFs) of the resolved stars in the galaxy. Applying a Savitzky-Golay filtering, we derived the second derivatives of the LFs, and estimated the apparent magnitudes of the TRGB as $m_J = 19.1,\ m_H = 18.4$, and $m_{Ks} = 18.0$. The mean values of the theoretical absolute magnitudes of the TRGB were measured by using the Yonsei-Yale isochrones with a metallicity range of $-2.1 <$ [Fe/H] < -0.5 and age of 12 Gyr. The derived values of near-infrared TRGB distance moduli for IC 1613 are $(m - M) = 24.12 \pm 0.25,\ 24.20 \pm 0.44$, and 24.00 ± 0.52 for J, H, and K_S bands, respectively.

Keywords: TRGB, distance modulus, near-infrared, IC 1613

1. Introduction

The measurement of the TRGB is now a technique widely used to estimate the distance to nearby resolved galaxies of any morphological type (e.g., Lee et al. 1993, Madore & Freedman 1995). The TRGB in a color-magnitude diagram represents stars in the evolutionary stage of the He-flash with an electron-degenerate core. The luminosity of the TRGB depends on the value of the He-core mass which is considerably constant over the range of the low mass star (Salaris et al. 2002). As a result, the brightnesses of the TRGB are roughly uniform, and the LFs of these stars in a galaxy show a discontinuity at the TRGB (e.g., Lee et al. 1993, Madore & Freedman 1995, Sakai et al. 1996). In general, the I band photometric data have been used to determine the magnitude of the TRGB, because of the weak sensitivity to the metallicity of the stellar population in the band (e.g., Da Costa & Armandroff 1990, Lee et al. 1993, Salaris & Cassisi 1998). While the near-infrared magnitudes of the TRGB are more dependent on the metallicity than the I band magnitude, recent studies have successfully identified the TRGB discontinuity in near-infrared photometric data of nearby dwarf galaxies and globular clusters so as to determine the distances of the objects (e.g., Cioni et al. 2000, Cioni & Habing 2005, Valenti et al. 2004, Bellazzini et al. 2004).

This is the fifth paper of a series determing the distance moduli of nearby dwarf galaxies from the magnitude of the TRGB on the near-infrared LFs. In the previous papers (Kang et al. 2007, Sohn et al. 2008a,b, Jung et al. 2009), we have shown that the near-infrared magnitudes of the TRGB

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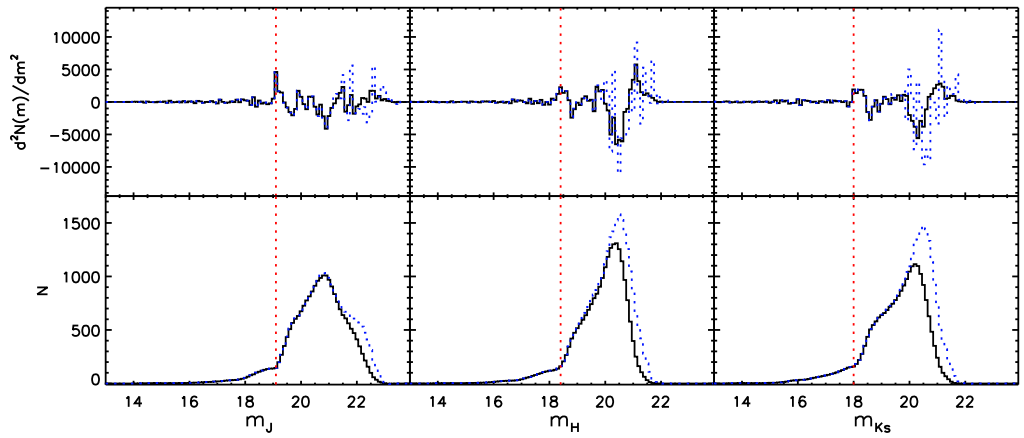

Figure 1. Lower: The near-infrared JHK_S band luminosity functions of the resolved stars in IC 1613. Solid lines are the LFs for the measured stars, and the dotted lines are those for the completeness corrected number of stars. Upper: The second derivatives of the observed LFs and the completeness corrected LFs. Vertical long-dashed lines in each panel indicate the determined magnitudes of the TRGB.

could also be an excellent distance indicator for nearby resolved dwarf galaxies, such as NGC 147, NGC 185, NGC 205, and NGC 6822. In this paper, we measure the TRGB magnitudes in the near-infrared JHK_S bands to estimate the distance moduli to the nearby dwarf irregular galaxy IC 1613. In Sect. 2, we describe the near-infrared JHK_S photometric data for IC 1613. In Sect. 3, we present the measured apparent magnitudes and the theoretical magnitudes of the TRGB in the near-infrared bands. In Sect. 4, we compare the determined distance moduli of NGC 205 with those of the other results.

2. The Near-Infrared Photometric Data

The nearby dwarf irregular galaxy IC 1613 is the prototype for DDO type Ir V. Near-infrared photometric data were secured from the Queued Service Observing (QSO) observations with the WIRCam attached at the 3.6m Canada-France-Hawaii Telescope (CFHT). Each image covers a total $21'.5 \times 21'.5$ field of view on the sky with an angular scale of 0.304 arcsec/pixel. The information in detail about the observations, data reduction, and the photometric measurements could be found in Jung (2009). In brief, the data reduction followed the standard processing for the near-infrared imaging data, and accurate point spread function (PSF) photometry detected 22 643 stars in JHK_S bands. The near-infrared color magnitude diagrams contained populations of main-sequence stars, massive supergiants, RGB stars, AGB stars, and the field stars. The photometric completeness at the level of the TRGB magnitude of IC 1613 is above ~ 90 %.

3. The Apparent and Absolute TRGB Magnitude

Applying the Savitzky-Golay filtering method to the observed LFs in JHK_S, we determined the peaks of the second derivative of the LFs, which are assigned as the JHK_S magnitudes of the TRGB of stars in IC 1613. Note that details of the applying Savizky-Golay filter method to the

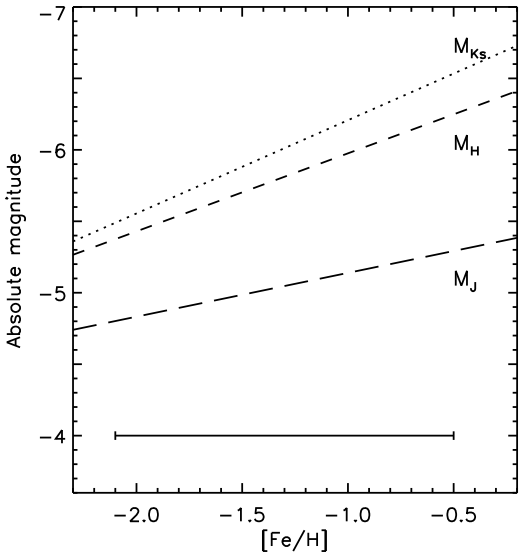

Figure 2. The relationship between the theoretical TRGB magnitude and [Fe/H] from Yonsei-Yale isochrones. The long-dashed, short-dashed, and dotted lines are the relations in JHK_S bands. Horizontal bar represents the adopted metallicity range of IC 1613.

observed LFs are presented in Cioni et al. (2000). In Figure 1, the solid lines in the lower panel indicate the observed near-infrared LFs of resolved stars in the field of IC 1613, and the solid lines in the upper panel are the second derivative of the LFs after applying a Savitzky-Golay filter. The dotted lines of each box represent the completeness corrected LFs for IC 1613. Vertical dashed lines are the estimated TRGB apparent magnitudes which are assigned to the peaks of the second derivative LFs. As appeared in Figure 1, the determined TRGB magnitudes in the apparent LFs are same as those in the completeness corrected LFs. Moreover, the peaks of the second derivative of the LFs are likely to reflect the change of the slopes of the observed LFs. Consequently, the brightnesses of TRGBs in near-infrared bands of IC 1613 are derived as $m_J = 19.1$, $m_H = 18.4$, and $m_{Ks} = 18.0$, respectively. Applying the reddening values of $E(B-V) = 0.03$ for IC 1613 adopted from Freedman (1988), we estimated the absorption corrected TRGB magnitudes of $m_{J_0} = 19.073$, $m_{H_0} = 18.383$, and $m_{Ks_0} = 17.989$.

The absolute JHK_S magnitudes of the TRGB are derived from the theoretical Yonsei-Yale isochrones (Kim et al. 2002, Yi et al. 2003). Figure 2 shows the relation between metallicity and the absolute magnitude of the TRGB in the near-infrared bands, which were extracted from the Yonsei-Yale isochrones with age of 12 Gyr. We note that the longer wavelength in near-infrared bands, the steeper slope of absolute magnitude to metallicity. The metallicity range of IC 1613 is $-2.1 < [\mathrm{Fe/H}] < -0.5$, as shown in Freedman (1988). Applying the metallicity range, we estimate the theoretical TRGB magnitudes for IC 1613 as $M_J = -5.047 \pm 0.245$, $M_H = -5.812 \pm 0.437$, and $M_{Ks} = -6.011 \pm 0.522$. The errors of the determined absolute magnitudes are mainly caused by the range of the metallicity.

4. The TRGB Distance to IC 1613

From the observed apparent magnitudes and the theoretical absolute magnitudes of the TRGB in near-infrared JHK_S, we calculate the distance modulus of IC 1613. The measured values are $(m-M)_J = 24.12 \pm 0.25$, $(m-M)_H = 24.20 \pm 0.44$, and $(m-M)_{Ks} = 24.00 \pm 0.52$. Errors are calculated from those in magnitudes for both of the bins size of LF and the matllicity range. Sandage (1971) estimated the distance modulus of IC 1613 as $(m-M)_0 = 24.43$ from the BV photometry of 24 Cephieds. McAlary et al. (1984) used the near-infrared H band observations of 10 Cepheids in IC 1613 to determine $(m-M)_H = 24.32 \pm 0.11$ and $(m-M)_0 = 24.31 \pm 0.12$. Subsequently, Freedman (1988) employed $BVRI$ CCD photometry to obtain $(m-M)_0 = 24.30 \pm 0.10$. Using the observations of RR Lyrae stars in IC 1613, Saha et al. (1992) derived $(m-M)_0 = 24.10 \pm 0.27$. From the apparent I band magnitude of the TRGB for IC 1613, Lee et al. (1993) found $(m-M)_0 = 24.27$. Recently, Pietrzynski et al. (2006) observed 29 Cepheids in IC 1613 at JK bands to measure $(m-M)_0 = 24.29 \pm 0.04$. Consequently, the distance moduli of IC 1613 estimated by the near-infrared JHK_S TRGB magnitudes in this paper are in consistent with those previously measured by various methods.

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