Advancing the Physics of Cosmic Distances
Proceedings IAU Symposium No. 289, 2012
Richard de Grijs, ed.

doi:10.1017/S1743921312021801

Determination of the fundamental properties of an M31 globular cluster from main-sequence photometry

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Abstract. We determined the age of the M31 globular cluster B379 using isochrones of the Padova stellar evolutionary models. At the same time, the cluster's metal abundance, its distance modulus, and reddening value were also obtained. The results obtained in this paper are consistent with previous determinations, including the age. Brown *et al.* constrained the age of B379 by comparing its color–magnitude diagram with isochrones of the 2006 VandenBerg models. Therefore, this paper confirms the consistency of the age scale of B379 between the Padova isochrones and the 2006 VandenBerg isochrones. The results of B379 obtained in this paper are: metallicity [M/H] $= \log(Z/Z_\odot) = -0.325$ dex, age $\tau = 11.0 \pm 1.5$ Gyr, reddening $E(B-V) = 0.08$ mag, and distance modulus $(m-M)_0 = 24.44 \pm 0.10$ mag. Using the metallicity, the reddening value and the distance modulus obtained in this paper, we constrained the age of B379 by comparing its multicolor photometry with theoretical stellar population synthesis models. The age of B379 obtained is $10.6^{+0.92}_{-0.76}$ Gyr, which is in very good agreement with the determination from main-sequence photometry.

Keywords. galaxies: individual (M31), galaxies: stellar content

1. Introduction

Galactic globular clusters (GCs), which are thought to be among the oldest stellar objects in the Universe, provide vitally important information regarding the minimum age of the Universe and the early formation history of our Galaxy. The most direct method for determining the age of a star cluster is through main-sequence photometry, in which the isochrone that minimizes the discrepancies between the observed and calculated sequences can exactly yield the estimated cluster age. However, this method has only been applied to Galactic GCs and to GCs in the Milky Way's satellites (e.g., Rich *et al.* 2001) before Brown *et al.* (2004) used this method to constrain the age of an M31 GC, B379,† based on a color–magnitude diagram (CMD) reaching more than 1.5 mag below the main-sequence turn-off. The CMD of B379 was constructed from extremely deep images obtained with the Advanced Camera for Surveys (ACS) on the *Hubble Space Telescope (HST)*. Generally, extragalactic GC ages are inferred from composite colors and/or spectroscopy. B379 was first detected by Sharov (1973) (No. 19), then by Sargent *et al.* (1977) (No. 312 = S312) and Battistini *et al.* (1987) (No. 379 = B379). Brown *et al.* (2004) estimated an age of 10 Gyr for B379 by quantitative comparison to isochrones of VandenBerg *et al.* (2006).

† In Brown *et al.* (2004), SKHB 312 is used. In this paper, B379 is used following the nomenclature of the Revised Bologna Catalog (RBC) of M31 GCs and candidates (Galleti *et al.* 2004), which is the main catalog used in studies of M31 GCs.

Since the pioneering work of Tinsley (1968) and Searle (1973), evolutionary population synthesis modeling has become a powerful tool to interpret integrated spectrophotometric observations of galaxies and their components, such as star clusters (Anders *et al.* 2004). The evolution of star clusters is usually modeled by means of a simple stellar population (SSP) approximation. An SSP is defined as a single generation of coeval stars formed from the same progenitor molecular cloud (thus implying a single metallicity), and governed by a given initial mass function (IMF). GCs, which are bright and easily identifiable, are typically characterized by homogeneous abundance and age distributions. For example, Barmby & Huchra (2001) compared the predicted SSP colors of three stellar population synthesis models to the intrinsic broad-band $UBVIRJHK$ colors of Galactic and M31 GCs, and found that the best-fitting models match the spectral-energy distributions (SEDs) of clusters very well indeed.

In general, ages of extragalactic star clusters are obtained by comparing integrated photometry with models of SSPs. For example, de Grijs *et al.* (2003) determined ages and masses of star clusters in the fossil starburst region B of M82 by comparing their observed SEDs with the model predictions for an instantaneous burst of star formation. Bik *et al.* (2003) and Bastian *et al.* (2005) derived ages, initial masses, and extinctions for M51 star cluster candidates by fitting Starburst99 SSP models (Leitherer *et al.* 1999) to their observed SEDs in six broad-band and two narrow-band filters from the Wide-Field and Planetary Camera-2 (WFPC2) onboard the *HST*. Ma *et al.* (2006) derived the age and reddening value of the M31 GC 037-B327 based on photometric measurements in a large number of broad- and intermediate-band filters from the optical to the near-infrared regimes and SSPs of Bruzual & Charlot (2003).

2. The age, metallicity, reddening value, and distance modulus of B379

To determine the main characteristics (age and metallicity) of the population in B379, we fit isochrones to the Brown *et al.* (2004) CMD of B379. We used the Padova theoretical isochrones in the *HST*/ACS WFC STmag system (Marigo *et al.* 2008). We used the interactive Webtool (`http://stev.oapd.inaf.it/cmd`) to construct a fine grid of isochrones sampling the age range $8.0 \leqslant \tau \leqslant 13.5$ Gyr with intervals of 0.5 Gyr, and the metal-abundance range $0.00250 \leqslant Z \leqslant 0.00950$ in steps of 0.00025 dex. The overall metallicity $[\mathrm{M/H}] = \log(\mathrm{Z/Z_\odot})$, where $\mathrm{Z_\odot} \approx 0.019$, so this abundance range corresponds to $-0.88 \leqslant [\mathrm{M/H}] \leqslant -0.30$ dex. We followed the method of Mackey & Broby Nielsen (2007) of finding the best-fitting isochrone (see Ma *et al.* 2010 for details). The age, metallicity, reddening value, and distance modulus for B379 obtained in this paper are: 11.0 ± 1.5 Gyr, $Z = 0.009$ (or $[\mathrm{M/H}] = -0.325$ dex), $E(B-V) = 0.08$ mag, and $(m-M)_0 = 24.44 \pm 0.10$ mag, respectively, where the uncertainty is the standard error in the mean.

The best-fitting Padova isochrone is shown in Figure 1.

3. Stellar population of B379

We use a χ^2 minimization test to determine which galev SSP models (Anders & Fritze-v. Alvensleben 2003; and references therein) are most compatible with the observed SED. The SED consists of photometric data in the near-UV *GALEX* filters, nine *BATC* intermediate-band and 2mass near-infrared JHK_s filters obtained by Ma *et al.* (2007), and of the photometric data in five sdss filters obtained by Peacock *et al.* (2010). The best reduced $\chi^2_{\mathrm{min}}/\nu = 0.5$ is achieved for an age of $10.6^{+0.92}_{-0.76}$ Gyr (1σ uncertainties),

https://doi.org/10.1017/S1743921312021801 Published online by Cambridge University Press

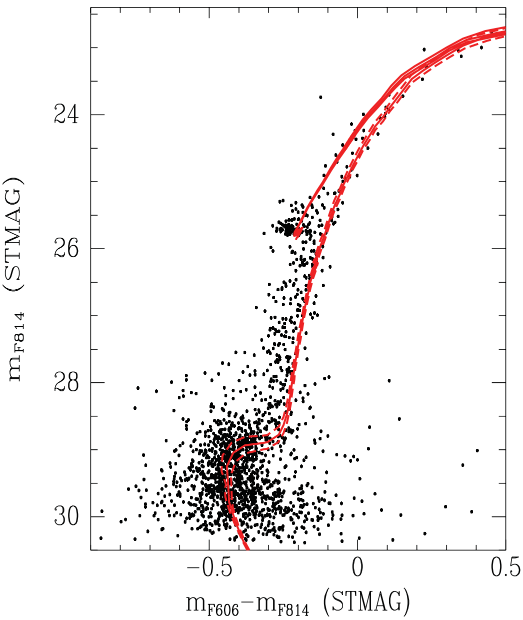

Figure 1. Best-fitting Padova isochrone overplotted on the CMD of B379. The isochrone has a metal abundance [M/H] = −0.325 dex and an age of 11.0 Gyr. The isocrone has been shifted by $E(B-V) = 0.08$ mag and $(m-M)_0 = 24.44$ mag. The two dashed lines represent ages of 9.5 and 12.5 Gyr, respectively.

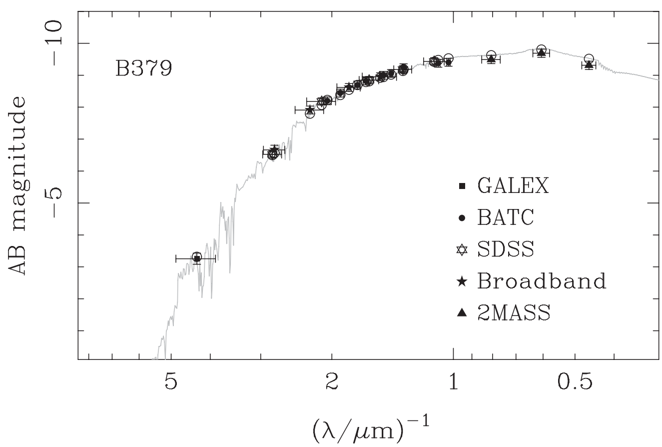

Figure 2. Best-fitting, integrated theoretical Bruzual & Charlot (2003) SEDs compared to the intrinsic SED of B379. The photometric measurements are shown as symbols with error bars. Open circles represent the calculated magnitudes of the model SED for each filter.

where $\nu = 21$ is the number of free parameters, i.e., the number of observational data points minus the number of parameters used in the theoretical model. The best fit to the SEDs of B379 is shown in Fig. 2, where we display the intrinsic cluster SEDs (symbols with error bars), as well as the integrated SEDs (open circles) and the spectrum of the best-fitting model.

https://doi.org/10.1017/S1743921312021801 Published online by Cambridge University Press

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