The Extragalactic Distance Database: 
Color–Magnitude Diagrams

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ABSTRACT
The CMDs/TRGB (Color-Magnitude Diagrams/Tip of the Red Giant Branch) section of the Extragalactic Distance Database contains a compilation of observations of nearby galaxies from the Hubble Space Telescope. Approximately 250 (and increasing) galaxies in the Local Volume have CMDs and the stellar photometry tables used to produce them available through the web. Various stellar populations that make up a galaxy are visible in the CMDs, but our primary purpose for collecting and analyzing these galaxy images is to measure the TRGB in each. We can estimate the distance to a galaxy by using stars at the TRGB as standard candles. In this paper we describe the process of constructing the CMDs and make the results available to the public.

Subject headings: astronomical data base; catalogs; galaxies: stellar content; galaxies: photometry; galaxies: distances

1. Introduction

One of the most productive means of measuring distances to nearby galaxies over the last 10-15 years has been to use stars at the Tip of the Red Giant Branch (TRGB) as standard candles. As the name implies, this technique requires accurate photometry of RGB stars in other galaxies, and the facility most suited to this purpose is the Hubble Space Telescope (HST). We have compiled HST observations of ∼250 (and counting) nearby galaxies. These observations include imaging in two colors for each galaxy, and we present the resulting Color-Magnitude Diagrams (CMD) as part of the Extragalactic Distance Database1 (Tully et al. 2009).

The CMDs/TRGB index page of the database lists each galaxy’s PGC/LEDA number (Principal Galaxy Catalog/Lyon Meudon Extragalactic Database), common name, and a URL link to its CMD webpage. Each entry is indexed by its PGC/LEDA number rather than its common name in order to prevent a single galaxy from being listed twice in the database. The PGC/LEDA number also serves as a link to a DSS2 image of the galaxy provided by HyperLEDA2 (Paturel et al. 2003).

Though our primary purpose for producing these CMDs is to measure the apparent magnitude of each galaxy’s TRGB, there is a great deal of information about stellar populations that can be gleaned from the figures and photometry tables from which they are derived. For example, a galaxy’s metal abundance can be estimated by the color of the RGB (Da Costa & Armandroff 1990; Lee et al. 1993). Some of the HST observing programs from which we present our reductions were designed specifically for the purpose of measuring the TRGB in many galaxies, others came from case studies of a single galaxy, and we include observations from these and various other programs that happened to include observations in filters appropriate for locating the TRGB. The CMD database consists of as large a sample as available of galaxies within ∼10 Mpc, each analyzed in a consistent manner.

1Located at: http://edd.ifaa.hawaii.edu/ under the Miscellaneous Distances:CMDs/TRGB tab.

2Located at: http://leda.univ-lyon1.fr/
2. Data

The CMDs are produced by performing photometry on HST images taken with either the Wide Field-Planetary Camera 2 (WFPC2) or the Advanced Camera for Surveys (ACS). The HST flight filter most appropriate for locating the TRGB is $F_{814W}$, which can be described as ‘wide $I$.’ In order to discriminate between the RGB and other star types we require observations in another filter. Either of the $V$-equivalent filters: $F_{606W}$ and $F_{555W}$ most commonly serve this purpose, but it is possible to use one of the $B$-like filters such as $F_{475W}$ as well. All of the images from which we produce CMDs are available to the public through the HST Archive.3

3. Footprint Images

Below each galaxy’s CMD we display the footprint of the HST observations used. These images are obtained through the Hubble Legacy Archive.4 We present them in order to put the observations we use into context. Where there are multiple observations of galaxies of large angular extent we prefer those located towards the edge of the galaxy as seen in the footprint image (taken from Digitized Sky Survey-2), since it is this region where low-metallicity RGB stars most suitable for TRGB measurements are common and crowding is less of a problem than towards the core. Many galaxies in the sample have a small angular size that fits well within the field-of-view of ACS or WFPC2, and as such no attempt can be made to focus on the halo stars, see for example NGC4163 in Figure 1. The footprint of the observations used in our analysis is highlighted in yellow. The red boxes represent the footprint of another ACS observation of the galaxy. Footprints of observations other than those used for the production of the galaxy’s CMD often appear in these images, but those that are used are always highlighted in yellow. In order to reduce the clutter caused by the necessity of showing these unused observations we only show the footprints of one instrument on each image. So each CMD used with ACS data has one corresponding yellow ACS footprint, and any other ACS observations that happen to fall on the footprint image are shown in red, but no WFPC2 footprints are shown. The situation is similar for galaxies observed with WFPC2, except that non-used WFPC2 observations are shown in blue, and the ACS footprints are turned off. Each image in the database is set to a consistent zoom level corresponding to a field of view of $24' \times 24'$.

4. Analysis

We perform photometry on the WFPC2 images using the HSTPHOT (Dolphin 2000) software package, which was developed specifically for observations of resolved stellar populations using this instrument. Dolphin expanded HSTPHOT into a more general photometry software program called DOLPHOT.5 This release includes an ACS module, and we use this package for analysis of images taken with ACS. Each CMD webpage in the database contains a link to the photometry file out-

3Located at: http://archive.stsci.edu/hst/
4Located at: http://hla.stsci.edu/
5Available at: http://purcell.as.arizona.edu/dolphot/
put from HSTPHOT or DOLPHOT. These tables hold information about the measurement of a single star per row. There are, among others, columns that describe a star’s position on the image, and its apparent magnitude in both flight and ground-based filters, as well as several characterizations of the quality of the measurement. If there are several images per filter available then these values are displayed for each individual image as well as in combination. Hence it is not uncommon for the photometry table to contain more than fifty columns. Though the output is quite complex it breaks into simple sections that are described in detail be the HSTPHOT and DOLPHOT manuals.

It is possible to determine whether a particular CMD was produced with WFPC2 or ACS data, and thus reduced with HSTPHOT or DOLPHOT respectively, by searching for the galaxy and observing program number at the HST Archive website. However, a simpler method for determining which camera was used is to look at the Footprint image situated below the CMD. This section of each galaxy’s webpage, described further below, shows the location and orientation of the field of view of the camera used in the observations. WFPC2 and ACS are easily distinguishable by the shape of their footprints. ACS’s looks like a somewhat distorted square, with a line through the center dividing it into to equally sized rectangles (denoting the two chips: WFC1 and WFC2). WFPC2’s now famous jagged shape consists of the three Wide-Field chips making an ‘L-shape’, with the smaller Planetary Camera situated at the vertex of the ‘L’. It is important to determine which camera is the source of the observations in order to interpret the photometry file because the columns definitions vary between HSTPHOT (for WFPC2) and DOLPHOT (for ACS).

The full photometry files are available through the CMD webpage, but we do not plot every star in those files on their respective CMDs. We use some of the data quality parameters to reject some measurements as unreliable. Each measurement has a $\chi$ value, Sharpness parameter, Object Type, and PSF parameter assigned to it. In order for the measurement to be accepted we require that it fall in the range of values recommended in the manuals, as well as have a Signal-to-Noise ratio: $S/N \geq 5$. Each star measurement that passes all these tests is plotted on the CMD shown on each galaxy’s webpage.

5. Color-Magnitude Diagrams

Figure 2 shows an example CMD from ACS observations of the galaxy NGC4163 in the $F814W$ and $F606W$ filters. The most prominent feature on the CMD of this galaxy (and of most other galaxies in the database) is the RGB, seen here as a solid wedge due to the high density of points. Other populations visible include the Main Sequence and Blue Loop stars that together form a vertical band seen between about $-0.4 < F606W - F814W < +0.4$. Above and redward of the TRGB centered around $F814W = 23$ and $F606W - F814W = +1.3$ are the Asymptotic Giant Branch stars. Each of these groups hold a wealth of information about the stellar content and history of the galaxy, but here we focus our attention on the RGB and its tip.
6. TRGB Distances

Red Giant stars burn hydrogen in shells around a degenerate helium core that has a temperature independent equation of state. While a star is in this phase the mass and temperature of the core continuously increase until the temperature reaches about $10^8$ K, at which point triple-$\alpha$ helium burning ignites and sends the star off the RGB to the Horizontal Branch. The helium falling on the core from the outer shell drives this increase in temperature, and hence the degeneracy is broken when the core mass crosses the threshold for helium burning. This mass threshold, therefore, determines an upper limit to the luminosity of Red Giants. The flux from these stars is least sensitive to age and metallicity in $I$-band (Rizzi et al. 2007), thus our requirement that galaxies be observed in $F814W$.

Early attempts to use the TRGB as a distance indicator simply used by-eye estimates to measure its apparent magnitude. Over the years TRGB measurement methods have become more sophisticated and reproducible (e.g. Lee et al. 1993; Mendez et al. 2002; Makarov et al. 2006; Mager et al. 2008). We employ a program called TRGBTOOL that uses a maximum-likelihood method described by Makarov et al. (2006). This program fits a power-law with a step to a finely binned histogram of the number of stars versus magnitude. This is done because, as seen in Figure 2, the TRGB is seen as a discontinuity in the density of stars at a particular magnitude, decreasing from the tip location to slightly brighter magnitudes. This method also incorporates the results of artificial star tests performed on the HST images using HSTPHOT or DOLPHOT. This fake photometry is used to account for how completeness, crowding, and color-spreading affect the reliability of the tip measurement.

Once we have determined the apparent magnitude of a particular galaxy’s TRGB we are then able to calculate a distance modulus. The absolute magnitude of stars at the TRGB is $M_I \approx -4.0$ with only a weak dependence on age and metallicity in this wavelength range. Rizzi et al. (2007) present a zero-point calibration that is adjusted for metallicity as well as for the details of HST observations. We use their calibration of the absolute magnitude and correct for foreground extinction using values derived from the dust maps by Schlegel et al. (1998) to produced a distance modulus. Extinction within the target galaxies cannot be estimated with these observations. However, we note that the stars most amenable to TRGB distance measurements are old and low-metallicity, those that are preferentially found in the outer halo where dust obscuration is minimal, so when possible we focus on these regions. The uncertainty of TRGB distances we measure from galaxies with well-sampled CMDs (those with a tip at least 1.5 mag above the limit of the observations) typically hover around a few percent.

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REFERENCES


Fig. 1.— HST Footprint of the galaxy NGC4163 from ACS observations. The footprint of observations from program 9771 is shown in yellow. The red boxes denote the footprint from another ACS observation of the field.

This 2-column preprint was prepared with the AAS LATEX macros v5.2.
Fig. 2.— CMD of the galaxy NGC4163 in $F606W - F814W$ versus $F814W$ constructed from ACS observations with HST observing program: 9771.