Near-Field Cosmology with Dwarf Elliptical Galaxies
Proceedings IAU Colloquium No. 198, 2005
H. Jerjen and B. Binggeli, eds.

doi:10.1017/S1743921305004023

Optimizing the tip of the red giant branch distance estimator

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Abstract. Until very recently, our knowledge of the local peculiar velocity field has been severely hampered by the lack of reliable distance measurements. HST has dramatically changed this situation, allowing astronomers to obtain accurate distances to more than 150 nearby galaxies. This number could easily reach 400 if enough observing time would be dedicated to snapshot observation of the objects in the catalog of Karachentsev *et al.* (2004). Such a dense grid of objects correctly placed in their 3D position would provide key information on the amplitude of peculiar motions, the radial domain of bound groups, the clustering and morphological segregation properties of galaxies, and the incidence of extreme dwarfs galaxies. The key instrument to measure distances with HST is the Tip of the Red Giant Branch technique. The full exploitation of this powerful distance estimator requires a deeper understanding of the possible sources of errors and biases, such as the absolute calibration of the I-band magnitude of the tip and its dependency on age and metallicity of the underlying population, the possible contamination by AGB stars, the breakdown of the methodology in sparsely populated colour-magnitude diagrams and when the tip is close to the photometric limit.

Keywords. galaxies: distances and redshifts, stars: distances

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1. Introduction

Until the year 2000 very little data had been available to map the peculiar velocity field of galaxies in the vicinity of the Local Group. Noticeably, this was due to the lack of information on distances, while extensive compilations of radial velocities do exist that include information for thousands of galaxies. The knowledge of the peculiar velocity field plays a key role in putting reliable constraints on the current cosmological models. The Local Group itself is in a highly nonlinear collapse regime, and in a larger volume deviations from the Hubble flow can be expected due to the gravitational influence of nearby groups as well as by Virgo-centric and Great Attractor flow. Earlier hints that local expansion flow is very quiet (Tamman & Kraan 1978,Tully 1982) have been recently confirmed (Karachentsev *et al.* 2002). It is now appreciated that this cold flow is the signature of the Dark Energy (Baryshev *et al.* 2001) and that the earlier the transition from Dark Matter to Dark Energy dominance, the lower the amplitude of local peculiar velocities.

HST has dramatically improved our knowledge of the local peculiar velocity field thanks to its superior angular resolution. Using the Tip of the Red Giant Branch (TRGB) distance estimator, it's now possible to measure distances out to 5 to 7 Mpc with a single orbit, thus making an extremely efficient use of telescope time. For this reason, our group has started a long-term observational campaign aimed at collecting single-orbit images of the largest possible number of galaxies of the local universe. The project consists of two major parts. The first is an archive proposal aimed at collecting all the useful observations already obtained in the past with WFPC2 . All these observations will be reduced again using a uniform recipe. The second part of the project is based on several snapshot proposal submitted and accepted from 1999 to now, to get both WFPC2 and ACS images of the additional galaxies. An important step of this project is the optimization of the TRGB distance estimator. Indeed, it's important to understand what is the best method to identify the tip, to assess the uncertainties related to the absolute calibration of the tip, to measure the possible errors related to the presence of an AGB population, and to understand what happens when we reach the photometric limit. In this contribution, I will focus mainly on the different methods for detecting the tip, and I will discuss the possible biases related to AGB contamination, poorly populated Color-Magnitude Diagrams (CMD), and the detection of the tip near the photometric limit.

2. Testing the TRGB detection methods

2.1. *Crowding, Photometric Errors, AGB contamination*

Several different methods have been developed to detect the level of the RGB tip. With few exceptions, they can be grouped in two main categories, the first based on edge detector (ED) algorithms, and the second based on maximum-likelihood (ML) analysis. The ED algorithm we tested is the Sobel filter with the kernel $[-1, 0, +1]$ (Lee, Freedman, & Madore 1993). We tested this method applying it to both the linear and the logarithmic I-band luminosity function of our objects. We also tested two different ML algorithms. The first was presented by Méndez *et al.* (2002). The second has been recently developed by Makarov *et al.* (2005) and it is derived from the previous one, with the additional possibility to take into account the asymmetric distribution of photometric errors known as *bias* and the completeness function, both measured directly on artificial stars experiments.

All the methods were applied to synthetic color-magnitude diagrams (CMD's), constructed using the ZVAR code (Bertelli *et al.* 1992). The photometric errors and the completeness effects were applied using a suitable set of artificial star experiments. To avoid biases, no attempt at modeling the errors or the completeness function was made, and the artificial stars table was actually used as a look-up table (see Rizzi *et al.* 2002 for details). Two different star formation histories were adopted, the first consisting of an old single episode about 14 Gyr ago (closely reproducing the case of a globular cluster), the second based on a continuous star formation activity from 14 Gyr ago until now. The model galaxies were put at distance moduli ranging from 27 to 30, the latter being the extreme case in which the TRGB is at the detection limit of the photometry.

The results of our simulations are shown in Figure 1. Left and right panels show the contribution to the total distance error due to the TRGB detection alone, for all the galaxies in the sample (distance moduli up to 30, or 10 Mpc). Results for globular cluster-like and continuous star formation histories are shown in the two panels, respectively. ED methods, applied both to linear and logarithmic luminosity function, and ML methods, both in the version of Méndez *et al.* (2002) and Makarov *et al.* (2005), are shown. Left and right panel of Figure 1 clearly show that is a significant difference in the behavior of the methods we tested. In particular, it is easily appreciated that for the nearest cases all the methods give very good results. Moving to more distant galaxies, ED methods seem

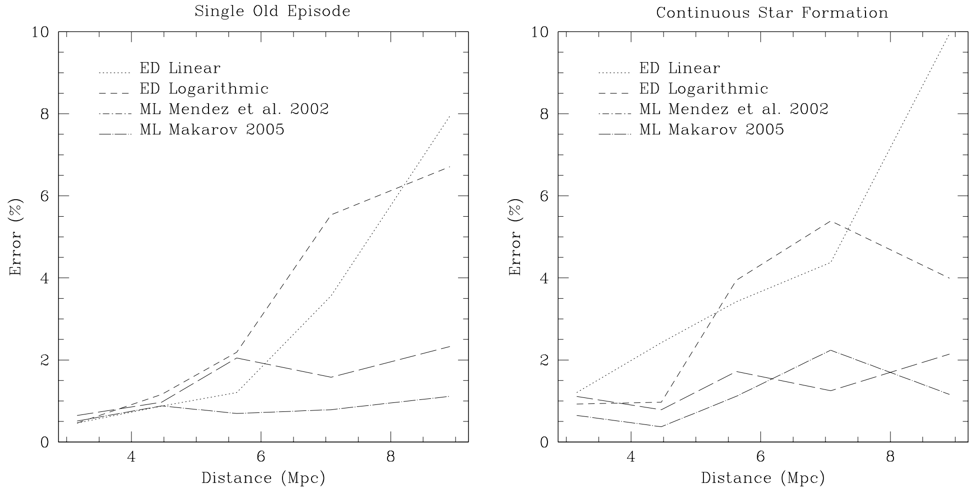

Figure 1. Contribution to the total distance error due to the TRGB detection alone. Left panel: Globular cluster-like galaxies. Right panel: Galaxies with continuous star formation.

to be more affected by the problems connected with the degraded photometric quality and by the increased crowding.

Right panel of Figure 1 shows what happens in a galaxy with a very strong AGB contamination, obtained by using a continuous star formation history. In this case, the RGBT is superimposed on an extended and bright AGB component. Comparison of left and right panel of this Figure clearly shows that ML methods are basically insensitive to the presence of AGB stars, while ED starts to produce significant errors as soon as the galaxies are more distant than 4 Mpc.

2.2. *Poorly populated CM diagrams*

To simulate the effect of poorly populated CM diagrams, we investigated the case of a globular cluster-like galaxy, and an intermediate distance of $(m-M)_0 = 28$. A rather common way to quantify the star population in a CM diagram is the number of stars in the first magnitude bin after the tip (hereafter, $N^{(-1)}$). We generated galaxies with $N^{(-1)}$ between 300 and 30 and applied the detection methods to all of them. Results are shown in Figure 2

Left panel of Figure 2 shows that there is a general trend for a large scatter in the TRGB detection when $N^{(-1)}$ falls below 100. This is consistent with previous similar studies (e.g., Freedman & Madore 1995). Careful scrutiny of the this plot also shows that the average dispersion of measurements is significantly lower at any $N^{(-1)}$ for ML methods, compared to ED methods. This is further demonstrated by the right panel of Figure 2, that shows the r.m.s. of TRGB detections against $N^{(-1)}$. Not only the r.m.s. of ED methods is always higher, but ED methods also tend to break down at a $N^{(-1)}$ of about 100 stars, while ML methods seems to be able to produce reasonable results at least down to 50 stars. Incidentally, we also note that we don't find in our simulations the large systematic deviations pointed out by Madore & Freedman (1995). The difference is most likely due to the different type of simulated galaxies used for the simulations. Madore & Freedman (1995), indeed, use fiducial lines from globular clusters populated with power-laws distributions, so they don't have stars brighter than the TRGB. Removing stars from these simulated galaxies can only produce fainter TRGB detection, while the use of

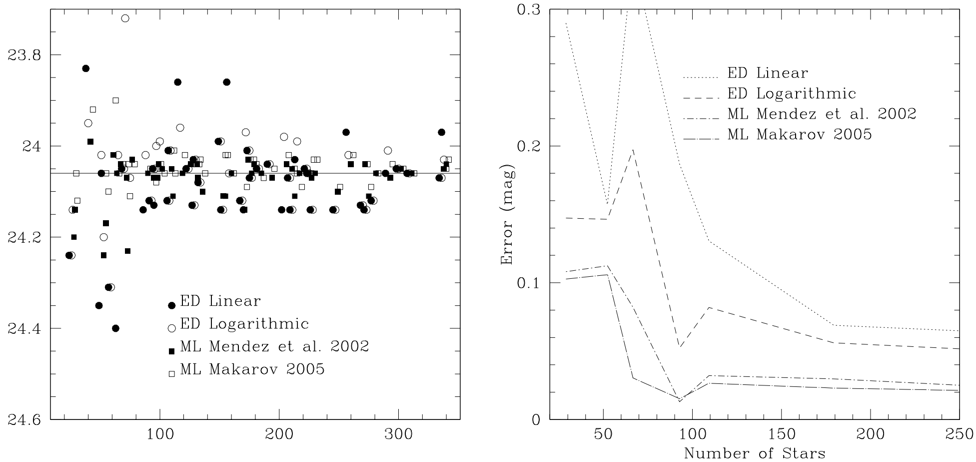

Figure 2. TRGB detection against the number of stars in the first magnitude bin. Left panel: Deviations from the expected TRGB position at 24.06. Right panel: R.m.s. of the different methods against number of stars in the first magnitude bin.

synthetic stellar populations produced with stellar models results in deviations in both directions.

3. Conclusions

We applied different TRGB detection methods to a set of simulated galaxy. We verified that ML methods are less sensitive to crowding and photometric errors than ED methods. We also verified that even a prominent AGB component does not significantly affect the detection. Finally, we applied the methods to poorly populated diagrams, and found that ED methods produce significantly higher errors for each level of $N^{(-1)}$. ML methods seem to be able to detect TRGB down to a level of only $N^{-1} = 50$.

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https://doi.org/10.1017/S1743921305004023 Published online by Cambridge University Press