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The overlooked role of stellar variability in LMC intermediate-age clusters

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Abstract. Broad, extended main sequence turnoffs seen in the majority of the intermediate-age (1–3 Gyr) LMC star clusters, have been interpreted as the result of an extended star formation history and/or the effect of extreme stellar rotation. A more fundamental explanation may be given by stellar variability. For clusters in these age range, the instability strip crosses the upper main sequence producing a number of variable stars (known as Delta Scuti) which, if nor properly taken into account, could appear as an extended turnoff. First results of a variability program in the LMC cluster NGC 1846 reveals a sizeable number of this type of variables, although still too low to produce a meaningful broadening, with the caveat that the true variable content of the center of this and other clusters in the LMC will only be revealed with a dedicated *HST* program.

Key words. Magellanic Clouds – globular clusters: individual (NGC 1846) – stars: variables: delta Scuti

1. Introduction

The large range of ages found for the star cluster population in the Magellanic Clouds give us the chance to study stellar evolutionary stages and environments not available in our Galaxy.

One of the most striking observations is the extension of the main-sequence turn-offs (MSTOs) beyond the canonical expectation for single stellar populations that a large number of intermediate-age ($\sim$1–3 Gyr) star clusters in the Large Magellanic Cloud (LMC) present (e.g. Mackey & Broby Nielsen 2007; Milone et al. 2009). This extension might be explained by an extended star formation history (e.g. Goudfrooij et al. 2009; Milone et al. 2009) or as a signature of stellar rotation (e.g. Bastian & de Mink 2009; Brandt & Huang 2015).

2. The role of stellar variability

Even though both scenarios have been shown to have advantages and shortcomings when explaining the morphology of the color-magnitude diagrams (CMDs) of LMC intermediate-age clusters (e.g. Bastian et al. 2016; Goudfrooij et al. 2017), a more fundamental ingredient has been commonly overlooked: stellar variability. The lower instability strip crosses the upper main sequence and MSTO for stellar populations of ages between 1 and 3 Gyr, therefore producing pulsations in a number of stars. These pulsating main-sequence stars are known as Delta Scuti (hereatfer δ Sct , see e.g. Breger 2000 for a review).

When images of a star cluster are then obtained only a couple of times per filter, enough to construct a CMD, δ Sct will be observed at

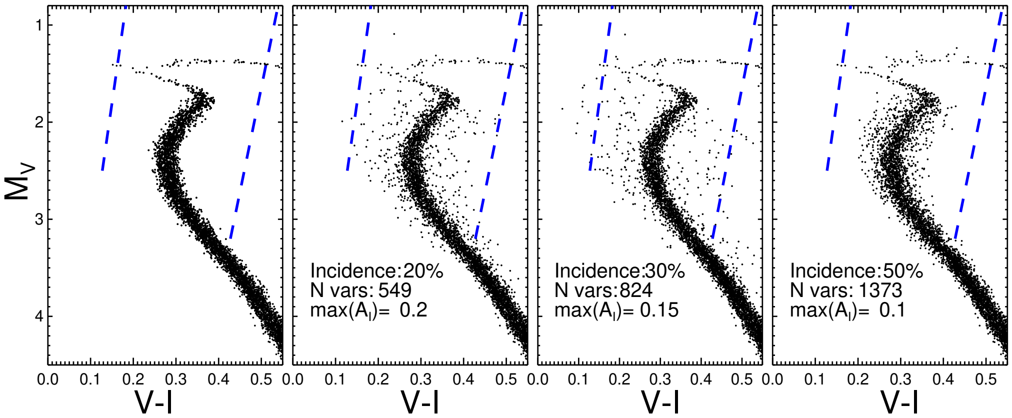

Fig. 1. A model of the influence of δ Sct based on BaSTi synthetic CMDs (Pietrinferni et al. 2004). In each panel, the dashed blue lines indicate the instability strip. Each panel indicates the assumed incidence, the maximum amplitude for the light curve amplitude distribution and the total number of δ Sct for each model. Figure adapted from Salinas et al. (2016b).

random phases, away from their "static" colors and luminosities, and therefore introducing a spurious spread which could be mistaken for a genuine extended MSTO (Salinas et al. 2016b).

This idea is exemplified in Fig. 1. Starting from a synthetic CMD based on BaSTi models (Pietrinferni et al. 2004) (leftmost panel), we select a percentage of stars within the instability strip (represented with dashed blue lines) which will be variables. This percentage is commonly known as the incidence of δ Sct . For each selected star we model a δ Sct light curve, which is then "observed" at a given fixed time. Details can be seen in Salinas et al. (2016b). Fig. 1 shows how the MSTO is broadened as a function of incidence and the amplitude distribution of the light curves, without a significant broadening of either the upper MS or the sub-giant branch, in close resemblance to the effect observed in *HST* CMDs.

3. A test case: NGC 1846

In order to the test the hypothesis of Salinas et al. (2016b), we obtained time series photometry of the LMC cluster NGC 1846 using the Gemini South telescope equipped with GMOS used as an imager (Gemini program ID GS-2015B-FT-7). Sixty six 120 second frames were obtained with the SDSS *r* filter, within the time span of 3.2 hours. After image reduction with the Gemini/IRAF package, variable stars were searched and its light variations were measured using a combination of ISIS (Alard 2000) and DAOPHOT (Stetson 1987), following the procedure described in Salinas et al. (2016a).

Our search revealed the presence of 55 δ Sct in the NGC 1846 field covered by GMOS, plus 18 variables of other types (Salinas et al. 2017 submitted). Considering the effect of radial completeness and background contamination, and using the cluster structural parameters from Goudfrooij et al. (2009), we estimate the total number of δ Sct in the cluster between 45 and 60 members.

If we compare with the hundreds or even thousands that are necessary to produce a significant broadening of the MSTO according to the Salinas et al. (2016b) models, then it seems the contribution of δ Sct to the extended MSTO phenomenon would be negligible, although in the Gemini data, given the extreme crowding, basically we found no δ Sct within the half-light radius of the cluster and therefore an unreliable extrapolation is ensued. Even though the ground-based Gemini photometry is too coarse to reveal a broadening of the MSTO, some insight on the effect of these variables

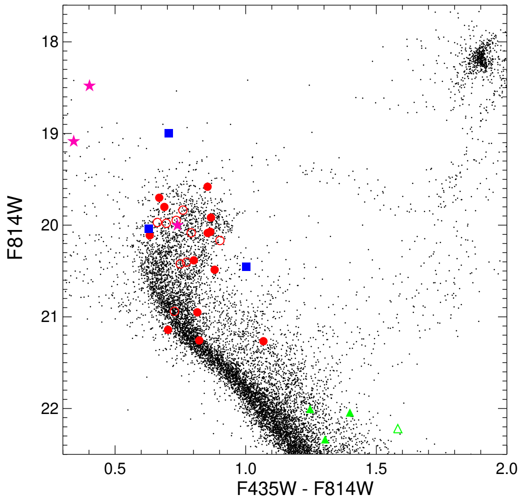

Fig. 2. *HST* photometry of NGC 1846 from Milone et al. (2009). Filled symbols indicate variable stars for which no signs of variability were found by Milone et al. (2009). Figure adapted from Salinas et al. (2017, submitted).

on a CMD morphology can be done cross-matching the variable star catalogue with the *HST* photometry of Milone et al. (2009). Fig. 2 shows 33 variables found in the Gemini data that are within the ACS field of view. δ Sct are depicted with red symbols, and as expected, they are concentrated at the upper MS and MSTO. The most revealing result from this plot comes from the quality flag assigned by Milone et al. (2009) to each star in their photometry, where one of the criteria is based on the rms of the magnitudes measured in different frames. Filled symbols in Fig. 2 are those stars labeled as "good quality", that is, 24 out 33 of these variable stars, despite a rejection based on rms, are considered with good quality.

Since rms was not the only criterion used by Milone et al. (2009) to discard stars, it is possible to say that at least a 70% of variables will not be found with current archival data of LMC clusters. Not even RR Lyrae stars, which have much larger amplitudes than δ Sct, will be detected (blue filled symbols).

4. Conclusions

Extended MSTOs in intermediate-age clusters of the LMC may be the product of extended star formation, stellar rotation and/or stellar variability. A first test of the influence of variability in the morphology of the MSTO has been attempted using Gemini photometry of the LMC cluster NGC 1846, revealing a large but insufficient amount of variability at the MSTO level, albeit with great uncertainty on the true variable star content within its half light radius. New observations scheduled with the Gemini South and SOAR telescopes will shed new light into the role of variability in lower mass LMC clusters, and for the first time, in SMC clusters.

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