Dwarf Galaxies: From the Deep Universe to the Present
Proceedings IAU Symposium No. 344, 2019
K. B. W. McQuinn & S. Stierwalt, eds.

doi:10.1017/S1743921318006749

Evidence for discrete star formation events in the Small Magellanic Cloud based on 6.5m Magellan Telescope observations

A. Strantzalis[1], D. Hatzidimitriou[1,2], A. Zezas[3,4,5] and V. Antoniou[5]

[1]Department of Physics, National and Kapodistrian University of Athens, Panepistimioupolis
email: a_strantzalis@yahoo.gr

[2]IAASARS, National Observatory of Athens, Vas Pavlou and I. Metaxa, 15236 Penteli, Greece

[3]University of Crete, Physics Department & Institute of Theoretical & Computational Physics, 71003 Heraklion, Crete, Greece

[4]Foundation for Research and Technology-Hellas, 71110 Heraklion, Crete, Greece

[5]Harvard-Smithosian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

Abstract. The Small Magellanic Cloud (SMC) presents us with a unique opportunity to study in detail the effect of environmental processes (interaction with the LMC and the Milky Way) on its star formation history. With the 6.5m Magellan Telescope at the Las Campanas Observatory in Chile we have acquired deep B and I images in four 0.44 degree fields covering a large part of the main body of the SMC, yielding accurate photometry for 1,068,893 stars down to ∼24th magnitude, with a spatial resolution of 0.201 arcsec/pixel. Colour-magnitude diagrams and luminosity functions (corrected for completeness) have been constructed, yielding significant new results that indicate at least two discrete star formation events around 2.7 and 4-5 Gyr ago.

Keywords. Small Magellanic Cloud, Star formation events, Multiple populations

1. Introduction

At a distance of about 61 kpc (e.g. 61.09±1.47 kpc, Inno L.,*et al.* (2013), the Small Magellanic Cloud (SMC) is our closest late-type star-forming dwarf irregular galaxy. It interacts both with its neighbouring Large Magellanic Cloud (LMC) and with the Milky Way Galaxy (MW). Due to its relatively small mass, its star and cluster formation histories and overall dynamics are expected to be affected significantly by this interaction.

The star formation history (SFH) of the SMC has been the subject of numerous investigations over the past 4 decades. The first extensive sparially resolved study of the SFH of the SMC was conducted by Harris & Zaritsky (2004), over an area of $\simeq$ 18 deg^2 in the main body of the SMC. They identified three periods of enhanced star formation, at ages of 2.5, 0.4 and 0.06 Gyr. Several smaller area studies have been published since then, also identifying periods of enhanced SF usually in broad agreement with the Harris & Zaritsky results (e.g. McCumber & Garnett 2005; Chiosi *et al.* 2006; Noel *et al.* 2009; Cignoni *et al.* 2012). Very recently, Rubele *et al.* (2018) have produced a spatially resolved SFH map of the SMC over a 24 deg^2 area, based on near infrared VMC photometry. They concluded that the SMC has formed a total mass of $(5.31 \pm 0.05) \times 10^8 M_\odot$ in stars over its lifetime, with about half of this mass formed prior to an age of 6.3 Gyr, and 80 per cent between 8 and 3.5 Gyr ago.

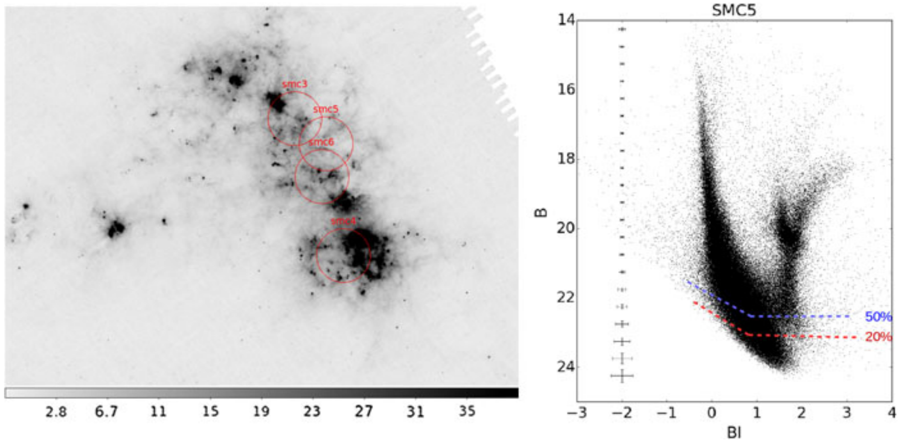

Figure 1. On the left panel, we show the location of the four fields studied, overlayed on an infrared image of SMC (Spitzer, MIPS, 24um). On the right panel we show the CMD for the entire SMC5 field.

2. Observations

The observations used in the present study were obtained with the 6.5m Magellan Telescope at the Las Campanas Observatory in Chile on October 4th, 2004, using the Inamori Magellan Areal Camera and Spectrograph (IMACS). IMACS is a wide-field image and multi-object spectrograph with an eight CCD mosaic, a total field of view of 0.44 deg (in diameter) and a pixel size of 0.2 arcsec. The images were taken through B and I standard Johnson-Cousins filters. Each exposure was 120 s long in B and 30 s in I. Each image was constructed from a total of 6 dithered single exposures in B and 2 in I. Figure 1 shows the location of the observed fields, overlaid on an infrared image of the SMC obtained with Spitzer (MIPS, 24 μm).

3. Data Reduction

The images were bias subtracted and flat fielded using the IRAF procedure CCDPROC Tody, (1993). Astrometry was achieved using the 2MASS catalog (Skrutskie, *et al.* 2006) as reference. The absolute astrometric accuracy of the reference catalog is $\sim$0.1 arcsec. The final astrometric solutions had positional scatter less than 0.3 arcsec. The final mosaic image in each filter was constructed using the program SWarp (Bertin *et al.* 2002). PSF photometry was conducted using the DAOPHOT/ALLSTAR package in IRAF. Absolute photometry in B and I was achieved by employing a large sample of relatively bright ($B < 17.5$ mag and $I < 18$ mag) isolated stars common with the Zaritsky *et al.* (2002) photometric catalog as secondary standards. A set of B vs B-I colour-magnitude diagrams (CMD) were constructed over the entire region studied.

Extensive artificial star experiments were performed in order to estimate the level of completeness and photometric accuracy of the data. We used the ADDSTAR standard artificial star package in DAOPHOT. In this work we focused on fields SMC3 and SMC5 due to the low photometric errors and relatively low differential reddening (which strongly affects the stellar populations in the SMC4 field). The final CMD of field SMC5 is shown in Figure 1 with the photometric errors indicated on the left side of the CMD.

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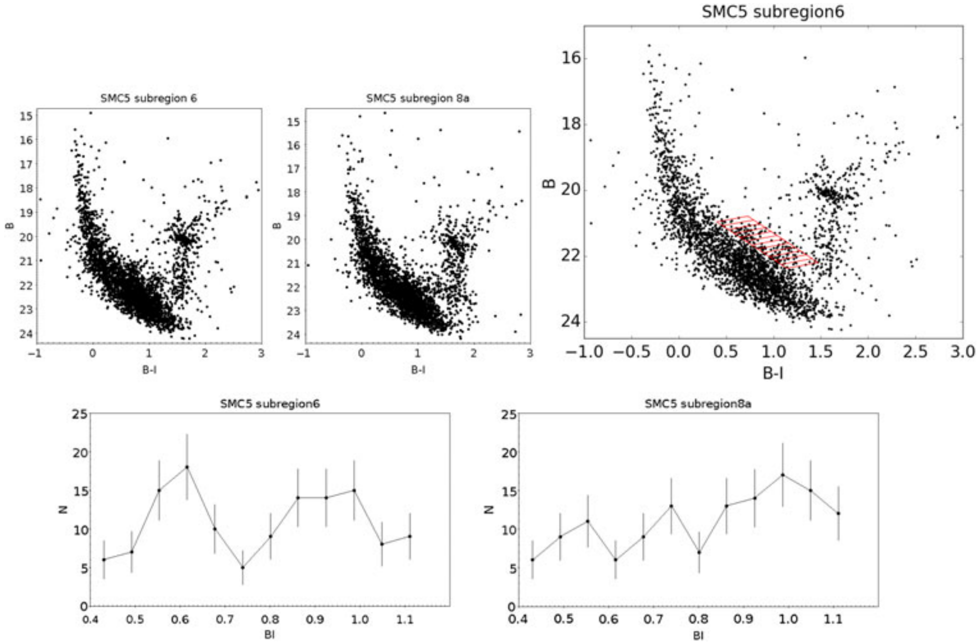

Figure 2. On the top left panels are shown the CMDs of subregions 6 and 8a of field SMC5. On the upper right panel the red grid indicates the region used to measure the star counts. The bottom diagrams show the number distribution along the main sequence turnoff region of subregions 6 and 8a, respectively.

4. Results

The CMDs over relatively extended regions suffer from differential interstellar absorption, small but non-negligible residual systematic photometric errors, and possible distance variations, which limit our ability to identify possible distinct star formation events. In order to overcome some of these limitations, we focus on smaller regions (with still enough stars to allow statistical analysis) with sizes between 0.9 and 1.1 arcmin in radius. We take care to avoid regions affected by extended dust absorption and since we are interested in field populations we also avoid star clusters. Our results show clear indications of distinct main-sequence turnoffs on the CMDs, suggesting isolated relatively short-lasting enhanced star formation events, as indicated by the two examples shown in Figure 2 (CMDs of subregions 6 and 8a in SMC5, top panels). On the lower panels of Figure 2 we show the number distribution along the main sequence turnoff region (star counts are made in cells parallel to the zero-age MS; top right panel of Figure 2). The identified main sequence turnoffs appear as peaks in these number count distributions.

Several other subregions were identified in the higher photometric quality fields SMC3 and SMC5, showing similar behaviour to the two reference regions shown in Figure 2. In Figure 3 we present a composite of the number distribution along the main sequence turnoff area from all these regions. At least two peaks can be seen, one better defined at $B-I \simeq 0.6$ mag and one less well defined at $B-I \simeq 0.9$ mag. The second broad peak seems to be universal in all regions. The first peak is only seen in subregion 6 - type areas. As a first approximation, we estimate that the two peaks correspond to about 2.7 and 4 Gyr, using the PARSEC isochrones and a metallicity of Z = 0.0009, which is

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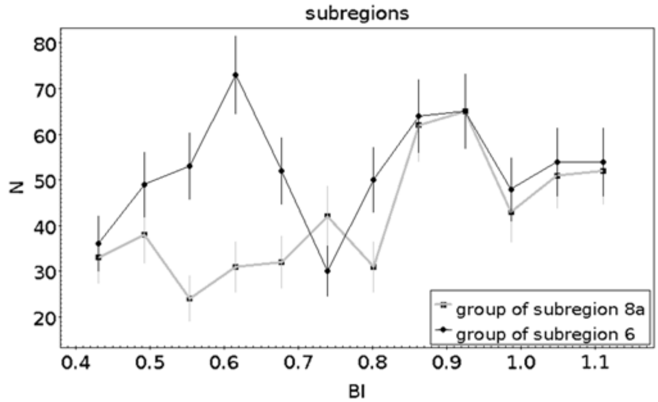

Figure 3. Two composites of the number distribution along the main sequence turnoff area from other similar subregions that were identified in fields SMC3 and SMC5 and which present similar behaviour to the two reference regions of Figure 2.

consistent with the mean metallicity of the intermediate age and old populations in the SMC. The 2.7 Gyr peak is coincident with the 2.5 Gyr SF enhancement identified by Harris & Zaritsky (2004). Interestingly, they also found that this star formation event is not smoothly distributed but rather located within a ring structure. The relatively small extent of our study cannot confirm the ring geometry, but we have found indications of non-uniformity in the spatial distribution of this population (contrary to the conclusion of Rubele *et al.* 2018). Regarding the second peak, several studies have shown enhanced star formation at 4-5 Gyr ago (e.g. Cignoni *et al.* 2012; Noel *et al.* 2009 and (McCumber & Garnett 2005). What is new in the present study is that we could actually identify distinct main sequence turnoffs that allow a better estimate of the duration of the SF events. A full SF history study using the IMACS data in SMC3 and SMC5 is in progress.

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