Dwarf Galaxies: From the Deep Universe to the Present
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The Local Group Dwarf Galaxies. The Star Formation Histories derived using the Long Period Variable Stars

Elham Saremi[1], Atefeh Javadi[1], Jacco Th. van Loon[2], Habib Khosroshahi[1], Sara Rezaei kh[3], Roya Hamedani Golshan[4] and Seyed A. Hashemi[5,1]

[1]School of Astronomy, Institute for Research in Fundamental Sciences (IPM), Tehran, 19395-5531, Iran
email: saremi@ipm.ir

[2]Lennard-Jones Laboratories, Keele University, ST5 5BG, UK

[3]Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

[4]Physikalisches Institut der Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

[5]Physics Department, Sharif University of Technology, Tehran 1458889694, Iran

Abstract. Dwarf galaxies in the Local Group (LG) represent a distinct as well as diverse family of tracers of the earliest phases of galaxy assembly and the processing resulting from galactic harrassment. Their stellar populations can be resolved and used as probes of the evolution of their host galaxy. In this regard, we present the first reconstruction of the star formation history (SFH) of them using the most evolved AGB stars that are long period variable (LPV). LPV stars trace stellar populations as young as $\sim$ 30 Myr to as old as the oldest globular clusters. For the nearby, relatively massive and interacting gas-rich dwarf galaxies, the Magellanic Clouds, we found that the bulk of the stars formed $\sim$ 10 Gyr ago for the LMC, while the strongest episode of star formation in the SMC occurred a few Gyr later. A peak in star formation around 0.7 Gyr ago in both Clouds is likely linked to their recent interaction. The Andromeda satellite pair NGC147/185 show different histories; the main epoch of star formation for NGC 185 occurred 8.3 Gyr ago, followed by a much lower, but relatively constant star formation rate (SFR). In the case of NGC 147, the SFR peaked only 6.9 Gyr ago, staying intense until $\sim$ 3 Gyr ago. Star formation in the isolated gas-rich dwarf galaxy IC 1613 has proceeded at a steady rate over the past 5 Gyr, without any particular dominant epoch. Due to lack of sufficient data, we have conducted an optical monitoring survey at the Isaac Newton Telescope (INT) of 55 dwarf galaxies in the LG to reconstruct the SFH of them uniformly. The observations are made over ten epochs, spaced approximately three months apart, as the luminosity of LPV stars varies on timescales of months to years. The system of galactic satellites of the large Andromeda spiral galaxy (M31) forms one of the key targets of our monitoring survey. We present the first results in the And I dwarf galaxy, where we discovered 116 LPVs among over 10,000 stars.

Keywords. stars: formation, stars: AGB, stars: variables: LPV, Galaxy: stellar content, (galaxies:) Local Group, galaxies: dwarf.

1. Introduction

One of the best ways for finding out more about the structure and evolution of galaxies is to study the star formation history (SFH) of the LG dwarf galaxies, due to their proximity, high number and variety. To investigate the SFH, we have developed a method based on employing LPV stars (Javadi *et al.* 2011a; Rezaeikh *et al.* 2014; Golshan *et al.* 2017; Javadi *et al.* 2017), which are mostly AGB stars at their very late stage of evolution.

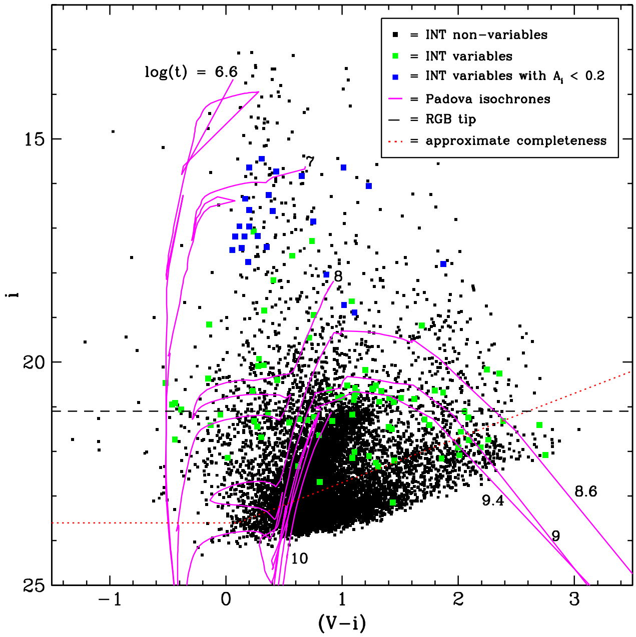

Figure 1. The colour–magnitude diagram of $(V - i)$ for And I, with variable stars highlighted in green. The variable stars with $A_{\rm i} < 0.2$ mag are highlighted in blue. Overplotted are isochrones from Marigo et al. (2008) with a distance modulus of 24.49 mag.

2. Methodology

To describe the SFH, we identify the LPV stars in a galaxy and use their brightness distribution function, $f(mag)$, to construct the birth mass function and hence the Star Formation Rate (SFR), ξ, as a function of look-back time ("age"), t:

$$\xi(t) = \frac{f(mag(M(t)))}{\Delta(M(t)) f_{\rm IMF}(M(t))}, \tag{2.1}$$

where Δ is the duration of the evolutionary phase during which LPV stars display strong radial pulsation, and $f_{\rm IMF}$ is the Initial Mass Function describing the relative contribution to star formation by stars of different mass. Each of these functions depends on the stellar mass, M, and the mass of a pulsating star at the end of its evolution is directly related to its age (Javadi *et al.* 2011b).

3. Data and Results

We are presenting the SFH of the dwarf galaxies in the LG uniformly based on identifying their LPV stars. In this regard, an optical long-term monitoring survey, with the Isaac Newton Telescope (INT), of the majority of dwarf galaxies in the LG are conducted (Saremi *et al.* 2017a), except those have sufficient data and/or are not visible in the Northern hemisphere survey such as NGC 147, NGC 185, IC 1613 and Magellanic Clouds (the LMC and SMC).

The first results of this survey in the And I dwarf galaxy show 116 LPVs among over 10,000 identified stars. Fig. 1 presents the colour–magnitude diagram of $(V - i)$ for And I, with LPV stars highlighted in green. The variable stars with $A_{\rm i} < 0.2$ mag are highlighted in blue. Overplotted are isochrones from Marigo et al. (2008) with a distance modulus of 24.49 mag and Z = 0.00069 (Kalirai *et al.* 2010). The 10 Gyr isochrone defines the

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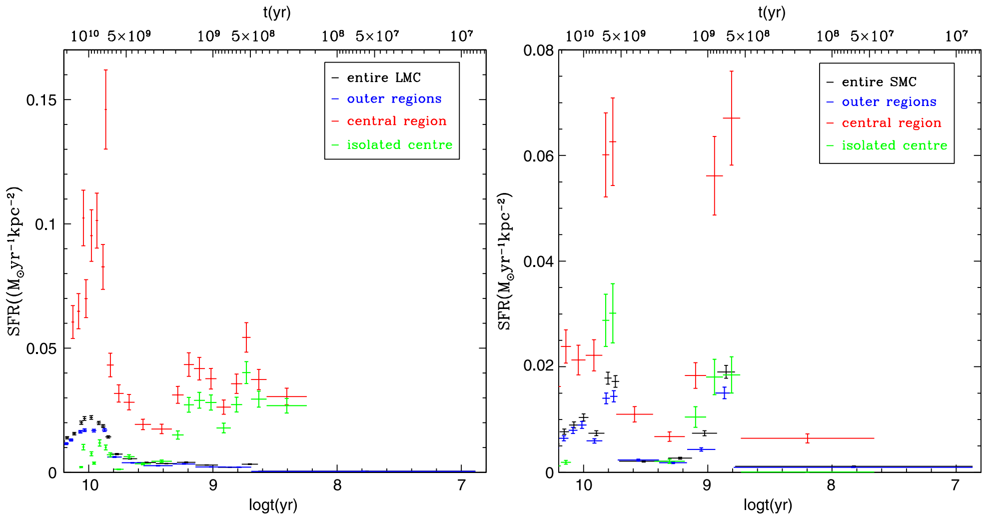

Figure 2. SFHs in the different regions of the LMC (*left*) and the SMC (*right*). Black symbols: global star formation; blue symbols: star formation in the outskirt of the galaxies; red symbols: bar (for the LMC) and central (for the SMC) star formation; and green symbols: isolated star formation for the central regions derived by subtracting the SFH of the surrounding parts; The vertical lines show statistical error bars and the horizontal lines represent the age bins (Rezaeikh *et al.* 2014).

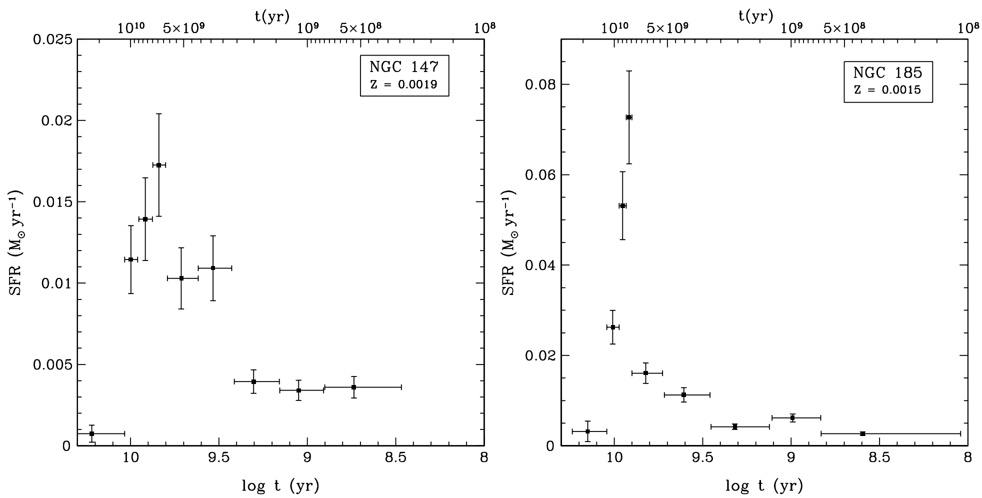

Figure 3. SFHs in the central 6.′5 × 6.′5 regions of NGC 147 (*left*) and NGC 185 (*right*), from LPV counts assuming a constant metallicity (Golshan *et al.* 2017).

location of tip of the RGB, that here is 21.1 mag for i band. The dotted line marks the 50% completeness limit (Saremi *et al.* 2017b).

Results for the Magellanic Clouds were obtained based on the variable star catalogues of Spano *et al.* (2011; LMC) and Soszyński *et al.* (2011; SMC) with 43,551 and 19,384 LPV stars, respectively. As is shown in Fig. 2, the bulk of the stars formed ~ 10 Gyr ago for the LMC, at a rate of 1.598 ± 0.054 $M_\odot$ yr^{-1}, while for the SMC, two formation epochs at ~ 6 Gyr, with SFR 0.282 ± 0.017 $M_\odot$ yr^{-1} and ~ 0.7 Gyr ago, with SFR 0.310 ± 0.019

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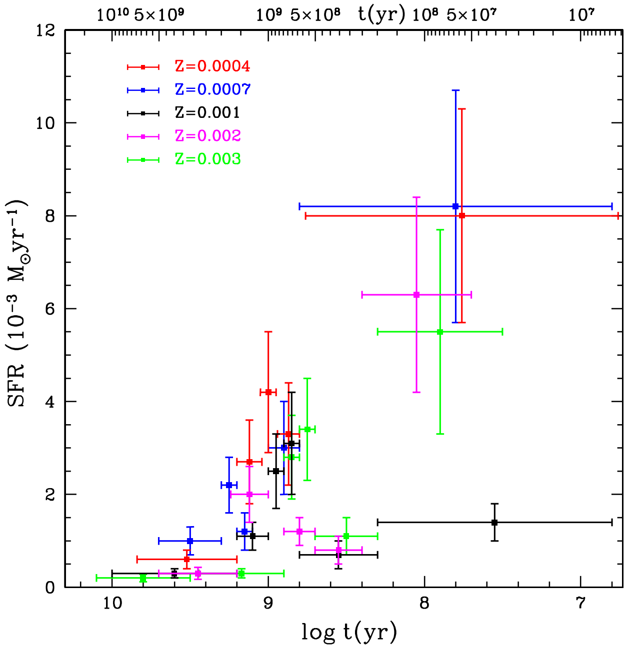

Figure 4. IC 1613 SFH for different metallicities (Hashemi *et al.* 2018; submitted).

M$_\odot$ yr^{-1}, are observed. We derived the total stellar mass produced, $\sim 2.2 \times 10^{10}$ M$_\odot$ for the LMC and $\sim 4.0 \times 10^8$ M$_\odot$ for the SMC (Rezaeikh *et al.* 2014).

NGC 147 and NGC 185 are two of the Andromeda satellites, which despite their similar mass and morphological type, show different SFHs. Using the catalogue of LPV stars from Lorenz *et al.* 2011 we estimated that the star formation started earlier in NGC 185 (8.3 Gyr ago) than in NGC 147 (6.9 Gyr ago) and continued over the past 6 Gyr until 100 Myr ago, albeit at a much lower rate, while no star formation is seen for the past 300 Myr in NGC 147 (Fig. 3). We calculated the total stellar masses of $M \approx 1.13 \times 10^8$ M$_\odot$ and $M \approx 2.3 \times 10^8$ M$_\odot$ in NGC 147 and NGC 185, respectively (Golshan *et al.* 2017).

Also, we studied the SFH of the isolated gas-rich dwarf galaxy IC 1613, based on identified LPV stars by Menzies *et al.* 2015 and Boyer *et al.* 2015. Fig. 4 shows the SFH of IC 1613 for different metallicities. With adopting the amount Z = 0.003 for last Gyr ($log\, t(yr) < 9$), Z = 0.002 for $1\, Gyr < t < 2\, Gyr$ ($9 < log\, t(yr) < 9.3$), and $Z = 0.0007$ for $t > 2\, Gyr$ ($log\, t(yr) > 9.3$), it can be concluded that there is not any dominant episode of star formation in IC 1613 over the past 5 Gyr (Hashemi *et al.* 2018; submitted).

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