Star formation histories in NGC 147 and NGC 185

You may also be interested in:

Star formation histories in NGC 147 and NGC 185

R Hamedani Golshan[1,2], A Javadi[1] and J Th van Loon[3]

[1]School of Astronomy, Institute for Research in Fundamental Sciences (IPM), Tehran, 19395-5531, Iran
[2]Department of Physics, Isfahan University of Technology, Isfahan, 84156-83111, Iran
[3]Lennard-Jones Laboratories, Keele University, Staffordshire, ST5 5BG, UK

E-mail: `rhgolshan@ipm.ir`

Abstract.   NGC 147 and NGC 185 are two of the most massive satellites of the Andromeda galaxy (M 31). With similar mass and morphological type dE, they possess different amounts of interstellar gas and tidal distortion. The question therefore is, how do their histories compare? We present the first reconstruction of the star formation histories of NGC 147 and NGC 185 using long-period variable stars (LPVs). LPVs are low- to intermediate-mass stars at the asymptotic giant branch, which their luminosity is related to their birth mass. Combining near-infrared photometry with stellar evolution models, we construct the mass function and hence the star formation history. For NGC 185 we found that the main epoch of star formation occurred 8.3 Gyr ago, followed by a much lower, but relatively constant star formation rate. In the case of NGC 147, the star formation rate peaked only 7 Gyr ago, staying intense until ~ 3 Gyr ago, but no star formation has occurred for at least 300 Myr. Despite their similar masses, NGC 147 has evolved more slowly than NGC 185 initially, but more dramatically in more recent times.

1. Introduction

Dwarf galaxies are the most abundant type of galaxies in the universe; since they come in two main flavors: dwarf Irregulars (dIrrs) and dwarf Spheroidal/Ellipticals (dSph/dEs). Principally they are distinguished by the significant interstellar medium in dIrrs and almost complete lack thereof in dSphs/dEs, but their star formation histories also differ, with dIrrs being "younger" [1].

NGC 147 and NGC 185, dEs, are satellites of Andromeda (M 31). They share fundamental properties such as luminosity ($M_V \sim 16$) and velocity dispersion (25 km s^{-1}), but differ in many other aspects. NGC 185 contains some gas, dust and shows evidence for recent star formation in its central regions, while NGC 147 is destitute of gas and dust and shows no sign of recent star formation activity [2,3].

The Star Formation History (SFH) is of the most important tracers of the galaxies' evolution. We have developed a novel method to use Long-Period Variable stars (LPVs) to reconstruct the SFH [4–7]. LPVs are the most evolved stars with low to intermediate mass, at the tip of the Asymptotic Giant Branch (AGB). They represent the most luminous phase in their evolution, ~ 3000–60,000 L$_\odot$, and reach their maximum brightness at near-infrared wavelengths. Since the maximum luminosity on the AGB relates to the star's birth mass, we are able to use the brightness distribution function of LPVs to construct the birth mass function and hence the Star Formation Rate (SFR) as a function of time. We present the results from application of this method to the Local Group dEs NGC 147 and NGC 185.

2. Data and Method

2.1. Data

We take advantage of a number of published photometric catalogues; the optical V and i band magnitude of AGBs in [8], infrared K- band magnitude of LPVs in [9] and the J, H and K- band magnitude of carbon stars in NGC 147 and NGC 185 [10, 11].

The K-band photometry is the best suited for calculating the SFR; since not only spectral energy distributions of stars peak at near-infrared wavelengths but also interstellar and circumstellar extinction are much less important at infrared wavelengths than optical. Carbon stars also can be used to trace (part of) the AGB, therefore we have cross matched the LPV and carbon stars catalogues, using the average of K-band magnitudes for stars in common. We can thus examine the location of the AGB stars in a colour–magnitude diagram (CMD), in comparison with isochrones from the stellar evolution models from the Padova group [12], which we use later in our technique to derive the SFH. The CMDs of NGC 47 and NGC 185 are presented in figure 1.
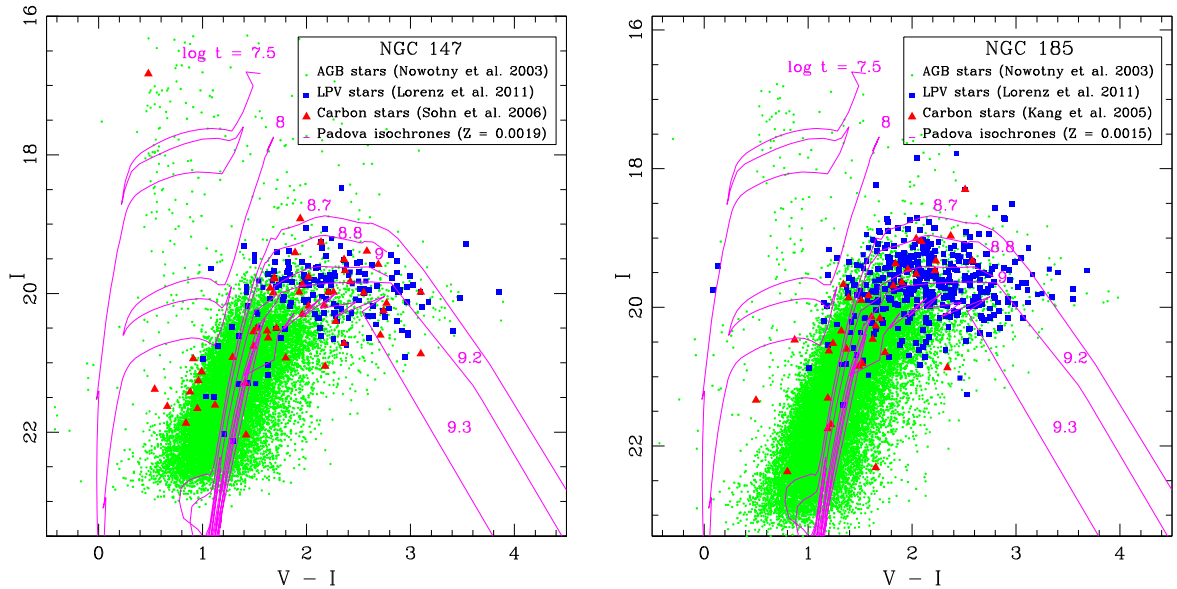
Figure 1. CMD of NGC 147 (*left panel*) and NGC 185 (*right panel*). Isochrones from [12] are labelled with logarithmic ages.

2.2. Method: star formation history

The SFH of a galaxy is a measure of the rate at which gas mass was converted into stars over a time interval in the past. Or in other words, it is the SFR, ξ (in $M_\odot$ yr^{-1}), as a function of time. We used the following relation to calculate the SFR based on LPV counts

$$\xi(t) = \frac{\int_{\min}^{\max} f_{\mathrm{IMF}}(m)m \ dm}{\int_{m(t)}^{m(t+dt)} f_{\mathrm{IMF}}(m) \ dm} \ \frac{dn'(t)}{\delta t}, \tag{1}$$

where f_{IMF} is the initial mass function, $dn'(t)$ and δt are a statement of numbers of LPVs and pulsation duration respectively. Detailed procedure to obtain above relation can be found in [4–7].

LPVs reach their maximum luminosity that relate their birth mass. Theoretical models of Padova [12] are appropriate tools to transform this maximum luminosity to birth mass. We have

applied Padova models to construct mass K-band magnitude relation. The left panel in figure 2 represents this relation for the mean metallicity of NGC 147; $Z = 0.0019$ (more information for NGC 185 can be found in [7]).

Mass-age relation, like the ones in the second panel of figure 2 are obtained from isochron tables of Padova model too. These graphs relate the birth mass of variable stars that are observable at present time to the time spent from their birth.

A correction factor is appeared in equation 1, this factor is a statement of the duration in which star pulsates with large amplitude. For an LPV to be detected in the observations, pulsation duration is an important factor. Massive stars spend less time in this phase than lower mass stars. By using isochrons table and fitting a multiple Gaussian function, we are able to achieve pulsation duration as a function of Mass as shown in the third panel of figure 2.
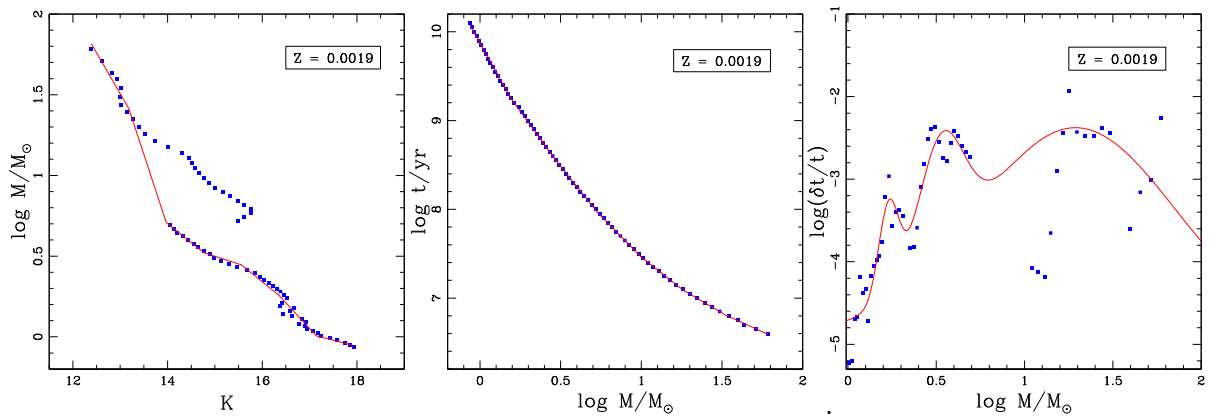

Figure 2. Mass–luminosity relation for $Z = 0.0019$ (*left panel*), mass–age relation (*middle panel*)m and mass–pulsation duration relation (*right panel*). The squares refer to models from [12].

Being in hand the coefficients of fitted lines and curves on dots - resulting from Padova models - and using equation 1, we are able to calculate SFR of different time bins and achieve SFH of galaxies based on LPVs count (The tables of coefficients are presented in [7]) for different metallicities.

3. Results and Conclusions

We have applied a novel method of [4] using long-period variable AGB stars to derive the SFH in NGC 147 and NGC 185 (see figure 3). Our main findings are:

- Star formation started earlier in NGC 185 than in NGC 147, peaking around 8.3 Gyr ago in NGC 185 and 7 Gyr ago in NGC 147.

- Star formation continued in NGC 185 over the past 6 Gyr, albeit at a much lower rate, until as recent as 200 Myr ago in the centre; in NGC 147, on the other hand, while star formation was significant between 3–6 Gyr ago, no star formation is seen for the past 300 Myr.

- The total stellar mass is $> 2.42 \times 10^8 \, M_\odot$ for NGC 185 and $> 1.16 \times 10^8 \, M_\odot$ for NGC 147; the true values are unlikely to be higher by more than a factor of a few.

- Of the total stellar mass, 70% (90%) was in place by $\log t = 9.90$ (9.56) in NGC 185 and by $\log t = 9.71$ (9.55) in NGC 147 (see figure 4).

- Our conclusions were obtained completely independently, using different data and a different method, yet they are corroborated by previous work.
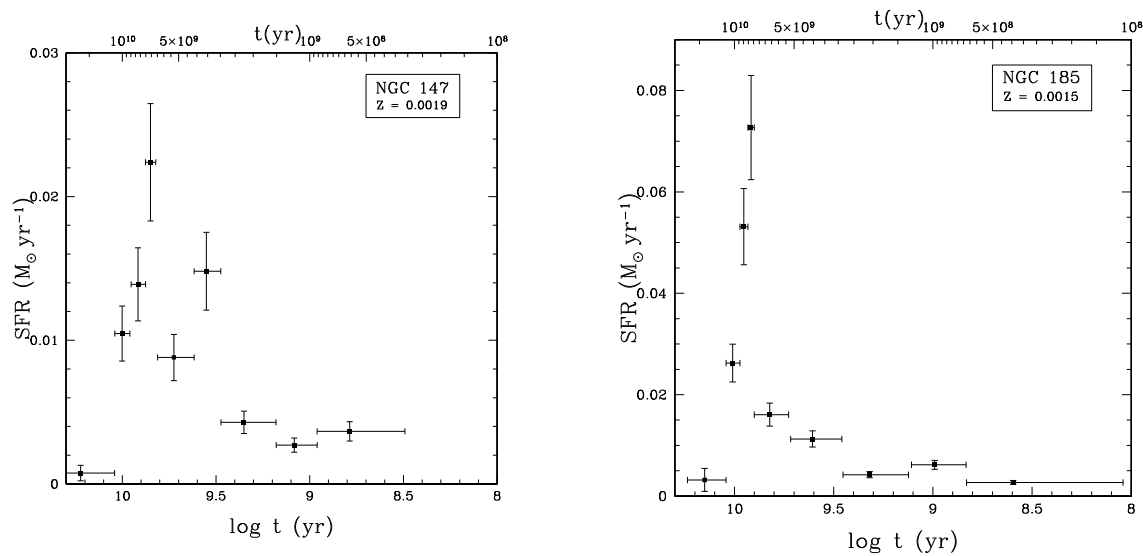
Figure 3. SFHs in the central $6'.5 \times 6'.5$ regions of NGC 147 (*left*) and NGC 185 (*right*), from LPV counts assuming a constant metallicity.
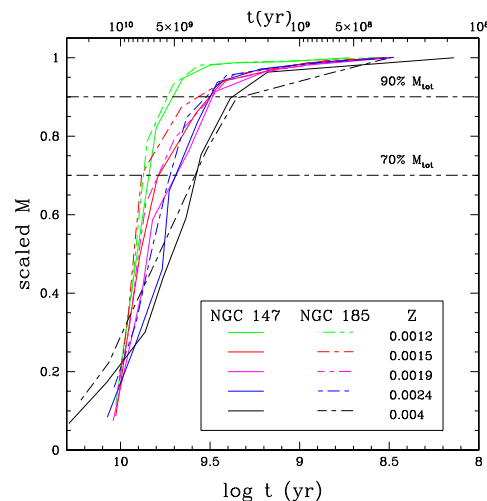
Figure 4. Cumulative SFH in NGC 147 and NGC 185 assuming different mean metallicity.

References

[1] Battinelli P and Demers S 2006 *A&A* **447** 473
[2] Young L M and Lo K Y 1997 *ApJ* **476** 127
[3] De Looze I *et al.* 2016 *MNRAS in press*
[4] Javadi A, van Loon J Th and Mirtorabi M T 2011 *MNRAS* **414** 3394
[5] Rezaeikh S, Javadi A, Khosroshahi H and van Loon J Th 2014 *MNRAS* **445** 2214
[6] Javadi A, van Loon J Th, Khosroshahi H G, Tabatabaei F and Hamedani Golshan R 2017 *MNRAS* **464** 2103
[7] Hamedani Golshan R, Javadi A, van Loon J Th, Khosroshahi H and Saremi E 2017 *MNRAS* **466** 1764
[8] Nowotny W, Kerschbaum F, Olofsson H and Schwarz H E 2003 *A&A* **403** 93
[9] Lorenz D, Lebzelter T, Nowotny W, Telting J, Kerschbaum F, Olofsson H and Schwarz H E 2011 *A&A* **532** 78
[10] Sohn Y J, Kang A, Rhee J, Shin M, Chun M S and Kim H I 2006 *A&A* **445** 69
[11] Kang A, Sohn Y J, Rhee J, Shin M, Chun M S and Kim H I 2005 *A&A* **437** 61
[12] Marigo P, Girardi L, Bressan A, Groenewegen M A T, Silva L and Granato G L 2008 *A&A* **482** 883