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AGB stars as tracers to IC 1613 evolution

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Abstract. We are going to apply AGB stars to find star formation history for IC 1613 galaxy; this a new and simple method that works well for nearby galaxies. IC 1613 is a Local Group dwarf irregular galaxy that is located at distance of 750 kpc, a gas rich and isolated dwarf galaxy that has a low foreground extinction. We use the long period variable stars (LPVs) that represent the very final stage of evolution of stars with low and intermediate mass at the AGB phase and are very luminous and cool so that they emit maximum brightness in near–infrared bands. Thus near–infrared photometry with using stellar evolutionary models help us to convert brightness to birth mass and age and from this drive star formation history of the galaxy. We will use the luminosity distribution of the LPVs to reconstruct the star formation history–a method we have successfully applied in other Local Group galaxies. Our analysis shows that the IC 1613 has had a nearly constant star formation rate, without any dominant star formation episode.

Key words. Stars: AGB – Stars: X-AGB – Stars: LPV– Galaxy: dwarf – Galaxy: metallicity

1. Introduction

IC 1613 is an isolated irregular dwarf galaxy that is located in Local Group. We adopt the mean distance of 750 kpc ($(m - M)_0 = 24.37 \pm 0.08$ mag)) for this dwarf which is determined by Menzies et al. (2015) by fitting a period-luminosity relation to the C-rich Miras. Its proximity, low inclination angle (i = 38°) and low foreground reddening (E(B-V)= 0.025 mag; Menzies et al. 2015) make it very suitable target for studies of stellar population and evolution, interstellar medium and galaxy evolution.

Cool evolved stars are among the most accessible probes of stellar populations due to their immense luminosity, from 2000 $L_\odot$ for tip-RGB stars, $\sim 10^4$ $L_\odot$ for asymptotic giant branch (AGB) stars, up to a few 10^5 $L_\odot$ for red supergiants (Javadi et al. 2013). Their spectral energy distributions (SEDs) peak around 1μm, so they stand out in the I-band (and reddening is reduced at long wavelengths). They have low surface gravity causing them to pulsate radially on timescales of months to years. The most extreme examples among these long-period variables (LPVs) are Mira (AGB) variables, which can reach amplitudes of ten magnitudes at visual wavelengths. The variability helps identify these beacons; their luminosities can be used to reconstruct the star formation history; and their amplitudes pertain to the process by which they lose matter and ultimately terminate their evolution.

Resolved stellar populations within galaxies allow us to derive star formation histories on the basis of colour–magnitude diagram modelling, rather than from integrated light. They also allow us to determine distances based on the tip of the red giant branch (RGB), based on the period–luminosity relation of relatively young populations of Cepheid variable stars, or based on the luminosities of old populations of RR Lyrae variable stars. Distances to unresolved galaxies are highly uncertain, especially in the local Universe where the Hubble flow does not yet dominate the peculiar motions of galaxies due to local density enhancements in the cosmic web. However, stars can be resolved in all of the Local Group galaxies, down to luminosities < 1000 $L_\odot$ (Javadi et al. 2011a,b, 2015).

The Star Formation History (SFH) is one of the most important tracers of the galaxies evolution. We have developed a novel method to use LPVs to reconstruct the SFH (Javadi et al. 2011b,c, 2016, 2017; RezaeiKh et al. 2014; Golshan et al. 2017). In this paper we will use this new technique to represent the SFH of IC 1613.

2. Data

We benefit from a number of published data sets in near–IR and mid–IR wavelengths (see below).

2.1. The near-infrared data

Menzies et al. (2015) published JHKs photometry from three years survey of the central region of the IC 1613 galaxy. They used Japanese–South African Infrared Survey Facility (IRSF) equipped with SIRIUS camera. They identified all objects brighter than RGB–tip (K∼18 mag) as supergiants or AGB stars (not foreground stars or background galaxies). Other data source in near–IR is from Sibbons et al. (2015). They used WFCAM camera on UKIRT to obtain JHK photometry of an area of 0.8 degree squares centered on IC 1613 galaxy. This survey is wider and more complete than Menzies's work. From these data the iron abundance of $[Fe/H] = -1.26 \pm .08$ dex has been calculated and their presented catalogue contains 843 AGB stars within 4.5 kpc of the IC 1613 galactic center.

2.2. The mid–infrared data

The Dust in Nearby Galaxies by *Spitzer* (DUSTiNGS) is a *Spitzer* Cycle 8 program that imaged 50 nearby dwarf galaxies in 3.6 and 4.5 μm bands with a wide range in SFH and metallicity to detect dust–producing AGB stars (Boyer et al. 2015) . The survey discovered, 50 new variable AGB candidates in IC 1613, of which 34 are "extreme" (x–AGB) candidates. The red colors and variability of DUSTiNGS x–AGB candidates support the strong likelihood that these stars are true dust–producing AGB stars.

3. Star formation history

The SFH of a galaxy is a measure of the rate at which the gas mass was converted into stars over a time interval in the past. The most evolved stars with low to intermediate mass, at the tip of the Asymptotic Giant Branch (AGB) show brightness variations on timescales of ≈ 100 to > 1000 days due to radial pulsation. LPVs represent the most luminous phase in their evolution, ∼ 3000–60,000 $L_\odot$, and reach their maximum brightness at near-infrared wavelengths. Intermediate-mass AGB stars may become carbon stars as a result of the dredge up of carbon synthesized in the helium thermal pulses; the resulting change in opacity reddens their colours. Since the maximum luminosity attained on the AGB relates to the star's birth mass, we can use the brightness distribution function of LPVs to construct the birth mass function and hence derive the Star Formation Rate (SFR) as a function of time. In other words, the SFH is the SFR, ξ (in $M_\odot$ yr^{-1}), as a function of elapsed time, t. The amount of stellar mass, dM, created during a time interval, dt, is:

$$dM(t) = \xi(t)\, dt. \quad (1)$$

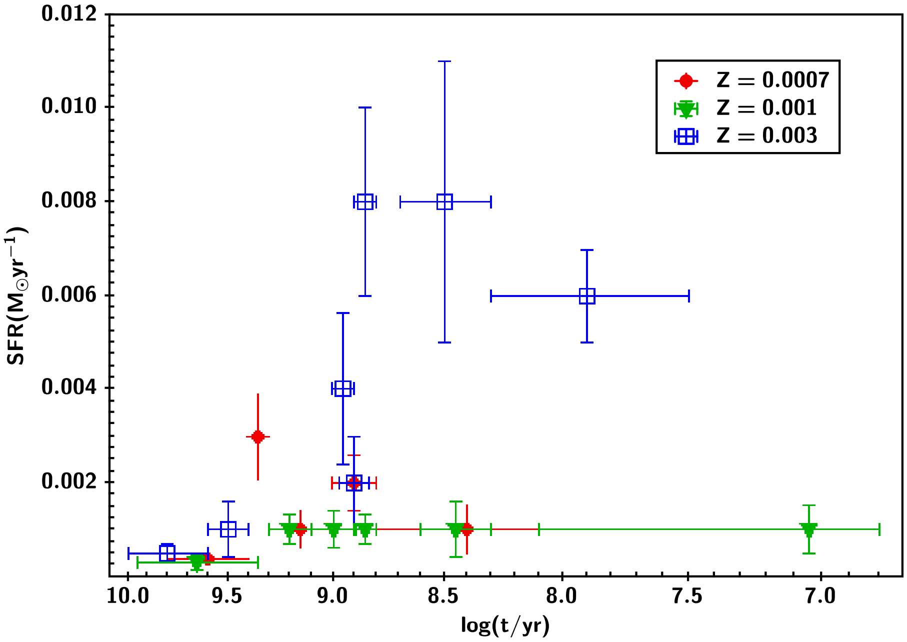

Fig. 1. SFR versus look–back time (t) for three choices of metallicity.

Therefore, the number of formed stars are related to this mass by the following equation:

$$dN(t) = \frac{\int_{\min}^{\max} f_{\rm IMF}(m)\, dm}{\int_{\min}^{\max} f_{\rm IMF}(m) m\, dm}\, dM(t), \qquad (2)$$

where $f_{\rm IMF}$ is the Initial Mass Function (IMF). We use the IMF defined in Kroupa (2001). We need to relate this to the number of stars, N, which are variable at the present time. If stars with mass between $m(t)$ and $m(t+dt)$ are LPVs at the present time, then the number of LPVs created between times t and $t+dt$ is:

$$dn(t) = \frac{\int_{m(t)}^{m(t+dt)} f_{\rm IMF}(m)\, dm}{\int_{\min}^{\max} f_{\rm IMF}(m)\, dm}\, dN(t). \qquad (3)$$

Substituting equation 1 and 2 in equation 3 gives:

$$dn(t) = \frac{\int_{m(t)}^{m(t+dt)} f_{\rm IMF}(m)\, dm}{\int_{\min}^{\max} f_{\rm IMF}(m) m\, dm}\, \xi(t)\, dt. \qquad (4)$$

We are considering an age bin of dt, to determine $\xi(t)$. The number of LPVs observed in this age bin, dn', depends on the duration of the evolutionary stage during which the long period variability occurs:

$$dn'(t) = \frac{\delta t}{dt}\, dn(t). \qquad (5)$$

Finally, by combining the above equations we obtain a relation to calculate the SFR based on LPVs counts:

$$\xi(t) = \frac{\int_{\min}^{\max} f_{\rm IMF}(m) m\, dm}{\int_{m(t)}^{m(t+dt)} f_{\rm IMF}(m)\, dm}\, \frac{dn'(t)}{\delta t}. \qquad (6)$$

To obtain the SFR we need to determine the individual stars' masses, ages (t) and duration of pulsation (δt). For this we rely on theoretical models. The most appropriate theoretical models for our purpose are the Padova models (Marigo et al. 2017)

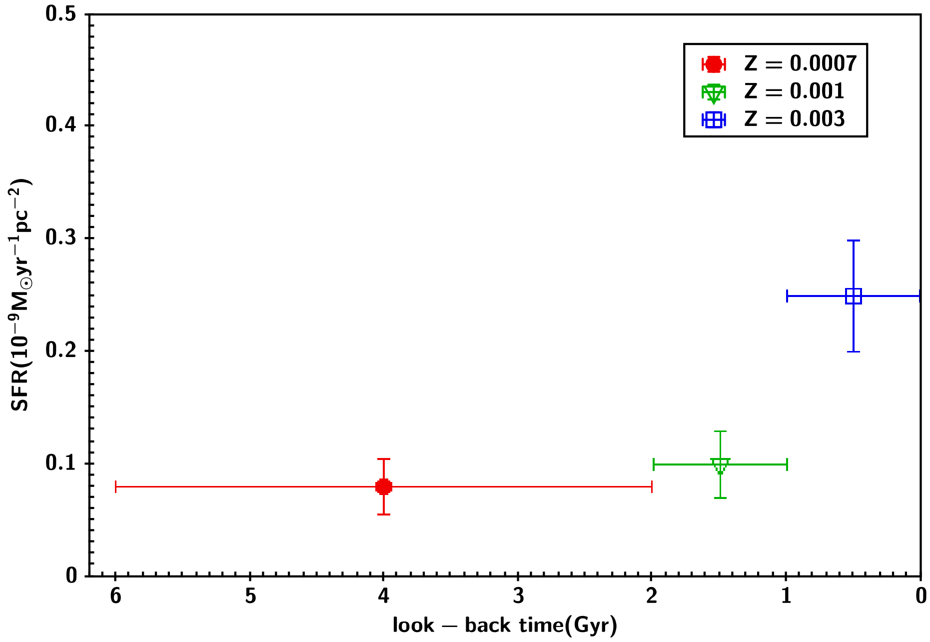

Fig. 2. SFH with considering the metallicity evolution of the galaxy

4. Results

The SFR as a function of look-back time (t) in IC 1613 is shown in Fig. 1 for different metallicites. The horizontal errorbars represent the age bins.

As a galaxy ages, the metallicity of the ISM and hence that of new generations of stars changes as a result of nucleosynthesis and feedback from dying stars. So we expect older stars to have formed in more metal poor environments than younger stars have. Fig. 2 shows the SFH when we consider the effect of chemical evolution of the galaxy.

5. Conclusions

Our analysis shows that the SFH of the observed field in IC 1613 is consistent with being almost constant over the lifetime of the galaxy.

Our results were obtained completely independently, using different data and a different method, and yet they are corroborated by previous work (Skillman et al. 2014).

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