*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/S1743921318006324

# Recovering the Star Formation History of IC1613 Dwarf Galaxy Using Evolved Stars

**Seyed Azim Hashemi**[1,2], **Atefeh Javadi**[2] **and Jacco Th. van Loon**[3]

[1]Department of Physics, Sharif University of Technology, Tehran, 11155-9161, Iran
email: hashemi_seyedazim@physics.sharif.edu

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

[3]Lennard-Jones Laboratories, Keele University, ST5 5BG, UK
email: j.t.van.loon@keele.ac.uk

**Abstract.** Determining the star formation history (SFH) is key to understand the formation and evolution of dwarf galaxies. Recovering the SFH in resolved galaxies is mostly based on deep colour–magnitude diagrams (CMDs), which trace the signatures of multiple evolutionary stages of their stellar populations. In distant and unresolved galaxies, the integrated light of the galaxy can be decomposed, albeit made difficult by an age–metallicity degeneracy. Another solution to determine the SFH of resolved galaxies is based on evolved stars; these luminous stars are the most accessible tracers of the underlying stellar populations and can trace the entire SFH. Here we present a novel method based on long period variable (LPV) evolved asymptotic giant branch (AGB) stars and red supergiants (RSGs). We applied this method to reconstruct the SFH for IC1613, an irregular dwarf galaxy at a distance of 750 kpc. Our results provide an independent confirmation that no major episode of star formation occurred in IC1613 over the past 5 Gyr.

**Keywords.** stars: variables: general, stars: AGB and post-AGB, stars: supergiants, galaxies: dwarf, galaxies: irregular, galaxies: individual: IC 1613

---

## 1. Introduction

Because of observational constraints, different methods have been developed to find the star formation history (SFH) of galaxies. Recovering the SFH in resolved galaxies is mostly based on color–magnitude diagrams (CMDs), where we can trace the signatures of most of the stellar population using high resolution observations (e.g., Tosi, Greggio & Focardi 1989; Gallart *et al.* 1996; Dolphin 1997, 2002). As a matter of fact, because of the limited spatial resolution, this kind of analysis will limit us to a few dozen galaxies, mostly in our group (within ∼2 Mpc, Ruiz-Lara *et al.* 2015). In the distant and unresolved galaxies, analysis based on the individual stars is unfeasible, except possibly for the very brightest. Therefore, we are limited to the integrated light of galaxies (Ganda *et al.* 2009; Pérez & Sánchez-Blázquez 2011). The integrated light of the galaxy can be decomposed, albeit made difficult by an age–metallicity degeneracy (e.g., Pickles 1985; Bica 1988; MacArthur *et al.* 2004). This method is relatively successful in deriving the SFHs of simple systems, but still have some limitations to give the detailed SFHs of galaxies with complex stellar compositions (Ruiz-Lara *et al.* 2015).

Another solution to determine the SFH of resolved galaxies is based on evolved stars; these luminous stars are the most accessible tracers of the underlying stellar populations and can trace the entire SFH. In this paper we are going to apply a method recently developed in Javadi, van Loon & Mirtorabi (2011a,b), in which we use long period variables

(LPVs) to find the SFH. LPVs are mostly evolved asymptotic giant branch (AGB) stars (e.g., Fraser *et al.* 2005; Fraser, Hawley & Cook 2008; Soszyński *et al.* 2009), and in addition to their luminosity, their variability also helps us to identify them. This method already has been used successfully to derive SFHs of some nearby galaxies (Javadi, van Loon & Mirtorabi 2011a,b; Javadi et al. 2017; Rezaei Kh *et al.* 2014; Golshan *et al.* 2017; Hashemi *et al.* 2017). In the following, we will apply this technique to find the SFH of IC 1613 dwarf galaxy.

## 2. Data and Method

IC 1613 is an isolated, irregular dwarf galaxy within the Local Group at distance of 750 kpc (Menzies, Whitelock & Feast 2015). Its vicinity, inclination angle (Lake & Skillman 1989), and low foreground reddening (Schlegel, Finkbeiner & Davis 1998), makes it a target of choice for the study of its stellar populations. Our sample to find the SFH of IC 1613 contains 53 evolved stars in the field of view of about 200 arcmin square in the central part of the galaxy. These 53 stars have been obtained using a combination of data, that were published by Menzies, Whitelock & Feast (2015), Boyer *et al.* (2015). Previous application of our method (Javadi, van Loon & Mirtorabi 2011a,b; Javadi et al. 2017; Rezaei Kh *et al.* 2014; Golshan *et al.* 2017) was based on confirmed LPVs. In the case at hand, though, the limited cadency of the DUSTiNGS survey (Boyer *et al.* 2015) and the limited depth of the Menzies, Whitelock & Feast (2015) survey will have led to LPVs being missed. Therefore, we combine confirmed LPVs (Menzies, Whitelock & Feast 2015) with those AGB and red supergiant (RSG) candidate stars that are also expected to be LPVs. These candidates are:

1-Extreme-AGB (x-AGB) stars (from Boyer *et al.* 2015) and large amplitude variable (LAV) stars (Menzies, Whitelock & Feast 2015) without determined period that are expected to be LPVs in the end of AGB phase (e.g., Schröder *et al.* 1999; Fraser, Hawley & Cook 2008; Soszyński *et al.* 2009).

2- RSG stars (Menzies, Whitelock & Feast 2015) that do not have determined period, but must be good candidates for being LPVs. We have to note that any meaningful period determination of RSGs may need decades of observations (e.g., Kiss *et al.* 2006; Pierce *et al.* 2000).

Using Padova evolutionary models and assuming constant metallicities, we can find mass, age and pulsation duration (duration that stars are in LPV phase) of LPVs, and then we sort the LPVs according to their ages and divided them into several bins. For different bins, with specified intervals in age and mass, we can find the star formation rate (SFR) as follows:

$$\xi(t) = \frac{\int_{\min}^{\max} f_{\mathrm{IMF}}(m) m \, dm}{\int_{m(t)}^{m(t+dt)} f_{\mathrm{IMF}}(m) \, dm} \, \frac{dn'(t)}{\delta t}, \tag{2.1}$$

where the m is mass, $f_{\mathrm{IMF}}(m)$ is Kroupa initial mass function (IMF) (Kroupa 2001), $dn'$ is the observed LPVs in each bins, and $\delta t$ is pulsation duration.

The statistical error bar for each bin can be derived from Poisson distribution:

$$\sigma_{\xi(t)} = \frac{\sqrt{N}}{N} \xi(t), \tag{2.2}$$

where N is the number of stars in each age bin.

## 3. Results and Discussion

Using our sample of evolved stars and applying our method, we estimate SFRs in IC 1613 over the broad time interval from 30 Myr to $\sim$ 5 Gyr ago. Because the metallicity is expected to increase over time as a result of the chemical evolution driven by

https://doi.org/10.1017/S1743921318006324 Published online by Cambridge University Press

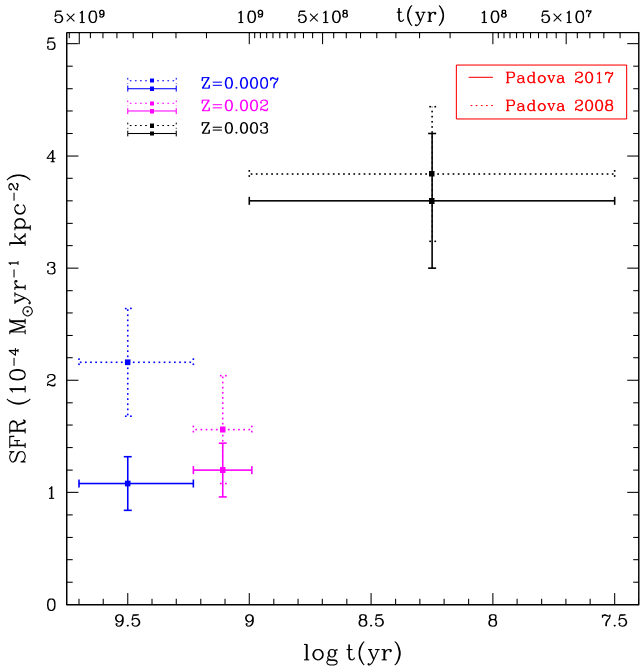


**Figure 1.** The SFH in IC 1613 with the adoption of an AMR akin that derived by Skillman *et al.* (2014), using the pulsation durations from Marigo *et al.* (2017) (solid) and Marigo *et al.* (2008) (dotted).

nucleosynthesis and mass loss, we adopt the linear age–metallicity relation (AMR) from Skillman *et al.* (2014) for values $4 \times 10^{-4} < Z < 4 \times 10^{-3}$ (corresponding to 13 Gyr ago $< t <$ now). Therefore, we applied $Z = 0.003$ for the last Gyr ($\log t(\mathrm{yr}) < 9$), $Z = 0.002$ for 1 Gyr $< t <$ 2 Gyr ($9 < \log t(\mathrm{yr}) < 9.3$) and $Z = 0.0007$ for $t >$ 2 Gyr ($\log t(\mathrm{yr}) > 9.3$). Considering these metallicities, our result is shown in Fig. 1. We obtained a mean value of the SFR across IC 1613 over the last Gyr of $\xi = (3.0 \pm 0.5) \times 10^{-4}$ M$_\odot$ yr$^{-1}$ kpc$^{-2}$, in excellent agreement with Skillman *et al.* (2014), who found $\xi \sim 3.4 \times 10^{-4}$ M$_\odot$ yr$^{-1}$ kpc$^{-2}$.

Our results, in the older time intervals ($9 < \log t(\mathrm{yr}) < 9.6$), are between 30% to 50% of the values derived by Skillman *et al.* (2014). We think that these lower rates are mainly because of incompleteness in our data (Menzies, Whitelock & Feast 2015), however, estimation of pulsation duration ($\delta t$) also can be a possible reason for that. In Fig. 1, solid lines and symbols show the results which are obtained using 2017 Padova models (based on Marigo *et al.* 2017) and dotted lines and symbols show the resulting SFRs when we use the pulsation duration estimated using 2008 Padova models (based on Marigo *et al.* 2008). In fact, using pulsation duration from 2008 Padova models leads to higher star formation rates, which are more compatible to rates that are presented by Skillman *et al.* (2014).

## 4. Conclusion

In this paper using only 53 evolved stars, we applied a novel method to find the SFH of IC 1613 dwarf galaxy. Our result show that the average star formation rate of the galaxy during the last Gyr is $\sim 3 \times 10^{-4}$ M$_\odot$ yr$^{-1}$ kpc$^{-2}$. Furthermore, the absence of a dominant epoch of star formation over the past 5 Gyr supports the notion that IC 1613 has evolved in isolation at least in the past 5 Gyr.

https://doi.org/10.1017/S1743921318006324 Published online by Cambridge University Press

## References

Bica, E. 1988, *A&A*, 195, 76
Boyer, M. L., *et al.* 2015, *ApJ*, 800, 17
Dolphin, A. E., 1997, *New Astron.*, 2, 397
Dolphin, A. E. 2002, *MNRAS*, 332, 91
Fraser, O. J., Hawley, S. L., Cook, K. H., & Keller, S. C. 2005, *AJ*, 129, 768
Fraser, O. J., Hawley, S. L., & Cook, K. H. 2008, *AJ*, 136, 1242
Ganda, K., Peletier, R. F., Balcells, M., & Falcón-Barroso, J. 2009, *MNRAS*, 395, 1669
Gallart, C., Aparicio, A., Bertelli, G., & Chiosi, C., 1996, *AJ*, 112, 1950
Golshan, R. H., Javadi, A., van Loon, J. Th., Khosroshahi, H., & Saremi, E. 2017, *MNRAS*, 466, 1764
Hashemi, S. A., Javadi, A. & van Loon, J. Th. 2017, *MemSAIt*, 88, 436
Javadi, A., van Loon, J. Th., & Mirtorabi, M. T. 2011a, *ASPC*, 445, 497
Javadi, A., van Loon, J. Th., & Mirtorabi, M. T. 2011b, *MNRAS*, 414, 3394
Javadi, A., van Loon, J. Th., Khosroshahi, H., & Mirtorabi, M. T. 2013, *MNRAS*, 432, 2824
Javadi, A., van Loon, J. Th., Khosroshahi, H., Tabatabaei, F., Golshan, R. H., & Rashidi, M. 2017, *MNRAS*, 464, 2103
Kiss, L. L., Szabó, G. M. & Bedding, T. R. 2006, *MNRAS*, 372, 1721
Kroupa, P. 2001, *MNRAS*, 322, 231
Lake, G., & Skillman, E. D. 1989, *AJ*, 98, 1274
MacArthur, L. A., Courteau, S., Bell, E., & Holtzman, J. A. 2004, *ApJS*, 152, 175
Marigo, P., Girardi, L., Bressan, A., Groenewegen, M. A. T., Silva, L., & Granato, G. L. 2008, *A&A*, 482, 883
Marigo, P., Girardi, L., Bressan, A., Rosenfield, P., Aringer, B., Chen, Y., & Trabucchi, M. 2017, *ApJ*, 835, 77
Menzies, J. W., Whitelock, P. A., & Feast, M. W. 2015, *MNRAS*, 452, 910
Pierce, M. J., Jurcevic, J. S. & Crabtree, D. 2000, *MNRAS*, 313, 271
Pickles, A. J. 1985, *ApJ*, 296, 340
Pérez, I. & Sánchez-Blázquez, P. 2011, *A&A*, 529, A64
Rezaei Kh, S., Javadi, A., Khosroshahi, H., & van Loon, J. Th. 2014, *MNRAS*, 445, 2214
Ruiz-Lara, T., *et al.*, 2015, *A&A*, 583, A60
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525
Schröder, K. P., Winters, J. M. & Sedlmayr, E. 1999, *A&A*, 349, 898
Skillman, E. D., *et al.* 2014, *ApJ*, 786, 44
Soszyński, I., *et al.* 2009, *AcA*, 59, 239
Tosi, M., Greggio, L., & Focardi, P., 1989, *Ap&SS*, 156, 295

https://doi.org/10.1017/S1743921318006324 Published online by Cambridge University Press