Resolving the Rise and Fall of Star Formation in Galaxies
Proceedings IAU Symposium No. 373, 2023
T. Wong & W.-T. Kim, eds.
doi:10.1017/S1743921322004951

From evolved stars to the formation and evolution of galaxies

Hamidreza Mahani[1], Atefeh Javadi[1], Jacco Th. van Loon[2], Habib Khosroshahi[1], Elham Saremi[3,4], Roya Hamedani Golshan[5], Mahdieh Navabi[1], Seyed Azim Hashemi[6], Mahtab Gholami[1] and Sima Taefi Aghdam[1]

[1]School of Astronomy, Institute for Research in Fundamental Sciences (IPM), Tehran, 19568-36613, Iran
email: mahani@ipm.ir

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

[3]Instituto de Astrof'ısica de Canarias, C/ V'ıa L'actea s/n, 38205 La Laguna, Tenerife, Spain

[4]Departamento de Astrof'?sica, Universidad de La Laguna, 38205 La Laguna, Tenerife, Spain

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

[6]Department of Physics and Astronomy, University of California Riverside, CA 92521, The USA

Abstract. Due to observational constraints, our detailed knowledge of stellar populations, formation, and evolution of galaxies is limited to a few dozen galaxies located in the Local Group. The Local Group of galaxies offers a unique opportunity to construct the formation histories and probe the structure and dynamics of many dwarf galaxies surrounding the Milky Way and Andromeda and of isolated dwarf galaxies. In this regard, we monitored the majority of galaxies in the Local Group, including the M33 galaxy and satellites galaxies surrounding the Milky Way and Andromeda galaxy, as well as isolated dwarf galaxies. We identified stellar populations and based on light curve analysis, the cool evolved stars pulsating in the fundamental mode were identified. In this paper, first, we will present the results we obtained for SFH and dust production rate in individual galaxies separately to answer how different types of galaxies have been formed and evolved over cosmic time. Then, we will discuss whether the mass return from dusty evolved stars can provide enough gas reservoirs to sustain the star formation or even rejuvenate the dwarf galaxy, as some seem to harbor relatively young stars.

Keywords. stars: AGB and post-AGB – stars: carbon – stars: mass-loss – supergiants – galaxies: evolution

1. Introduction

The Local Group members provide us with a unique opportunity to study and learn more about the structure and history of galaxies. One method to calculate the star formation rate (SFR) and star formation history (SFH) of these composite stellar populations is to use stars that have left the main sequence (Javadi et al. 2011). Highly evolved stars with low to intermediate initial masses that have moved through the helium-core burning phase are known as asymptotic giant branch (AGB) stars.

Finding variable AGB stars in the last stages of their evolution is an effective mechanism for retracing the history of star formation in a galaxy. Since they have undergone more evolution than less evolved AGB stars, their luminosity is more closely tied to their birth mass. The term long-period variables (LPVs) refers to variable stars that typically exhibit periodic variations in brightness with periods of a month to a few thousand days and amplitudes ranging from a few tenths to around ten magnitudes in the visual bands (Whitelock, Feast, & Catchpole 1991; Wood 2000). Another application of variable stars is studying the dust they spew into the interstellar medium (ISM). When investigating the structure and evolution of galaxies and the entire universe, ISM and star formation are inextricably linked and follow one another (van Loon, Marshall, & Zijlstra 2005). The ISM is further energized and accelerated by the stellar winds of evolved stars and the violent deaths of the most massive stars, which cause turbulence and galactic fountains as superbubbles explode as they approach the 'surface' of the galactic disc.

We studied a variety of galaxies, including dwarf spheroidals and irregulars, dwarf transition galaxies, and globular clusters, using the UK Infrared and Isaac Newton Telescope monitoring survey of Local Group members (Javadi et al. 2011; Parto et al. 2021). The primary goals of this study are as follows: locating every LPV in the LG dwarf galaxies that can be seen in the northern hemisphere; producing the SFHs from the present-day luminosity function of the LPVs; Modeling their SEDs and examining the relationship between stellar characteristics including mass, luminosity, metallicity, and pulsation amplitude and mass-loss (Saremi et al. 2020).

2. Methodology

In order to calculate the SFH by employing LPVs, we take use of the fact that LPVs are at the very last phases of evolution and that their brightness can be converted into their birth mass by using theoretical evolutionary tracks or by isochrones (Marigo et al. 2008; Javadi et al. 2011). The SFR behaves as a function of elapsed time to describe the SFH. The amount of gas transformed into stars per year is measured by this function. Javadi et al. 2017 showed that SFR, $\xi(t)$, could be derived from the following equation.

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

In equation 2.1, f_{imf} represents an initial mass function (e.g., canonical IMF proposed by Kroupa 2001), δt is the pulsation duration, and $dn'(t)$ is the number of LPVs observed in the age interval.

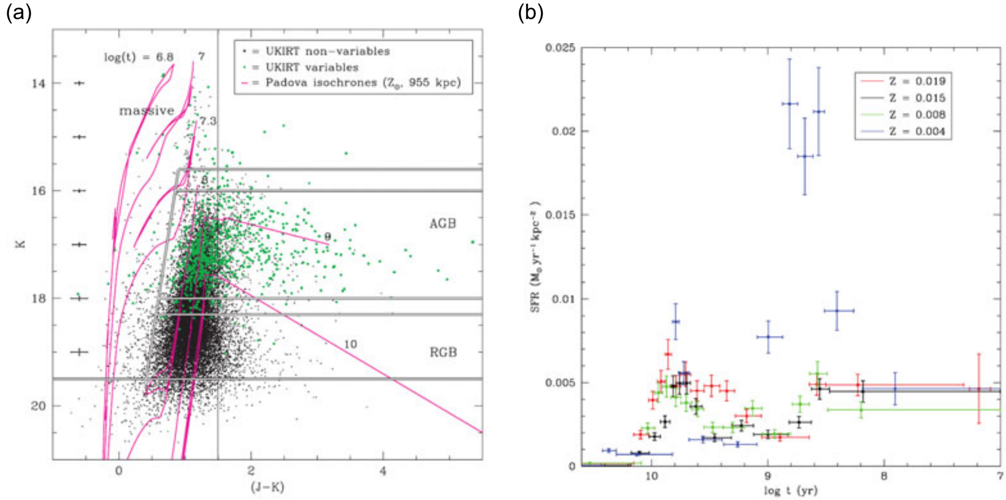
Investigating the mass-loss, we used `DUSTY`, the publicly available code (Ivezic & Elitzur 1997), to model the SEDs of all variable stars having observations in at least two near-IR and two mid-IR (Spitzer Space Telescope) bands. Simulations demonstrated that the mass-loss of the stars could be determined using the existing correlations between the color of the stars and their optical depth (Javadi et al. 2013).

3. Conclusion

We have utilized the novel method of Javadi et al. 2011 to determine the SFH and dust production in nearby galaxies and local group objects using long-period variable AGB stars. Following, we refer to the data acquired for a few of these galaxies.

• **M33:** Javadi et al. 2011 discovered that the disc of M33 was formed around 6 Gyr ago when more than 80% of this galaxy's previous star formation occurred. Since then, shorter epochs of star formation may have taken place; the most recent significant instance of such an occurrence was 250 Myr ago and contributed less than 6% to the star formation of the galaxy. They developed a two-dimensional map of the mass-return rate, which reveals a radial decrease in the rate and local increases caused by clusters of massive stars. They predict a total mass-loss rate of $0.004 - 0.005\, \mathrm{M}_{\odot} yr^{-1} kpc^{-2}$, which rises

https://doi.org/10.1017/S1743921322004951 Published online by Cambridge University Press



Colour–magnitude diagram of UKIRT catalogue

SFH compared for four choices of metallicity

Figure 1. As seen in subplot (a), the isochrones designated by their logarithmic ages, appear as significant trends towards red colors; carbonaceous dust has a distinct reddening slope at log t = 9 than oxygeneous dust does at log t = 10. Subplot (b) shows the SFH in M33's center that was generated by a near-IR AGB star and red-supergiant variable. Plots are adopted from Javadi et al. (2011).

to 0.006 $M_{\odot} yr^{-1} kpc^{-2}$ when eruptive mass-loss (such as supernovae) is taken into consideration. Comparing this to the present rate of star formation, they conclude that the center area of M33 can only support star formation if gas is accreted from circumgalactic regions or further out in the disc.

• **NGC 147 and NGC 185:** Regarding two of the most massive satellites of the Andromeda galaxy, Hamedani Golshan et al. 2017 showed that star formation began sooner in NGC 185 than in NGC 147, reaching its peak in NGC 185, 8.3 Gyr, and in NGC 147, 7 Gyr ago. In NGC 185, star formation persisted for the previous 6 Gyr, albeit at a much slower rate, in the center until 200 Myr ago, whereas it stopped much earlier in the edge. However, While star formation was prominent in NGC 147 between 3-6 Gyr ago, no star formation has been observed for the last 300 Myr.

• **And I:** Saremi et al. 2021 indicated that, in And I, a significant phase of star formation peaked around 6.6 Gyr ago, reached about 0.0035 $M_{\odot} yr^{-1}$, and only gradually declined until 1-2 Gyr ago. This galaxy's presence of a few dusty LPVs is consistent with a slight rise in recent star formation that peaked around 800 Myr ago. They estimated that And I is a late-quenching dSph and that the quenching period was around 4 Gyr ago.

• **And VII:** Through multi-epoch imaging with the Isaac Newton Telescope in the i and V bands, Navabi et al. 2021 discovered 55 LPV candidates within two half-light radii. The star formation rate of And VII was calculated as a function of cosmic time based on their birth mass function. They showed that star formation began in its primary phase 6.2 Gyr ago, with an SFR of $0.006 \pm 0.002\, M_{\odot} yr^{-1}$. They discovered slow star formation throughout the previous 6 Gyr, $0.0005 \pm 0.0002\, M_{\odot} yr^{-1}$, which persisted until 500 Myr ago.

• **IC 1613:** In IC 1613, Hashemi, Javadi, & van Loon 2018 noticed 53 highly evolved stars, eight of which are supergiants. Using stellar evolution models, they determined these stars' age and birth mass to recreate the SFH and reported that during the previous

https://doi.org/10.1017/S1743921322004951 Published online by Cambridge University Press

Gyr, the average star formation rate was $\sim 0.0003\,\mathrm{M}_{\odot} yr^{-1} kpc^{-2}$. They demonstrated that the absence of a dominant era of star formation over the past 5 Gyr shows that IC 1613 has evolved in isolation for that prolonged, uninfluenced by other galaxies in the Local Group.

• **IC 10:** In order to calculate the luminosity function and rebuild the SFH for IC 10, Gholami et al. 2022 first discovered 430 LPVs within two half-light radii of the galaxy's center. After correcting for star extinction, they calculated the galaxy's current star formation rate, $\xi(0) = 0.32\,\mathrm{M}_{\odot} yr^{-1}$, for a constant metallicity Z = 0.0008, indicating that the galaxy is actively undergoing star formation.

• **NGC 5128:** According to Taefi Aghdam et al. 2022, NGC 5128 has three significant star formation episodes that occurred at 800 Myr, 3.2 Gyr, and 10 Gyr in the past. The star formation rate at about 800 Myr ago is consistent with earlier research suggesting the galaxy underwent a merger at that time. In addition, the galaxy has recently had a lower star formation rate, which may have been caused by jet-induction star formation, multiple AGN outbursts, a minor merger 400 Myr ago, and multiple AGN outbursts in this galaxy.

References

Gholami M., Javadi A., van Loon J. T., Khosroshahi H., Saremi E., 2022, Manuscript in preparation.
Hamedani Golshan R., Javadi A., van Loon J. T., Khosroshahi H., Saremi E., 2017, MNRAS, 466, 1764.
Hashemi S. A., Javadi A., van Loon J. T., 2019, MNRAS, 483, 4751.
Ivezic Z., Elitzur M., 1997, MNRAS, 287, 799.
Javadi A., van Loon J. T., Mirtorabi M. T., 2011, MNRAS, 411, 263.
Javadi A., van Loon J. T., Khosroshahi H., Mirtorabi M. T., 2013, MNRAS, 432, 2824.
Javadi A., van Loon J. T., Khosroshahi H. G., Tabatabaei F., Hamedani Golshan R., Rashidi M., 2017, MNRAS, 464, 2103.
Kroupa P., 2001, MNRAS, 322, 231.
Marigo P., Girardi L., Bressan A., Groenewegen M. A. T., Silva L., Granato G. L., 2008, A&A, 482, 883.
Navabi M., Saremi E., Javadi A., Noori M., van Loon J. T., Khosroshahi H. G., McDonald I., et al., 2021, ApJ, 910, 127.
Parto T., Dehghani S., Javadi A., Saremi E., van Loon J. T., Khosroshahi H., Taghi Mirtorabi M., et al., 2021, ApJ submitted.
Saremi E., Javadi A., Th. van Loon J., Khosroshahi H., Molaeinezhad A., McDonald I., Raouf M., et al., 2020, ApJ, 894, 135.
Saremi E., Javadi A., Navabi M., van Loon J. T., Khosroshahi H. G., Bojnordi Arbab B., McDonald I., 2021, ApJ, 923, 164.
Taefi Aghdam S., Javadi A., Hashemi S., van Loon J. T., Khosroshahi H., Hamedani Golshan R., Saremi E., Saberi M., 2022, Manuscript in preparation.
van Loon J. T., Marshall J. R., Zijlstra A. A., 2005, A&A, 442, 597.
Whitelock P., Feast M., Catchpole R., 1991, MNRAS, 248, 276.
Wilson C. D., Scoville N., Rice W., 1991, AJ, 101, 1293.
Wood P. R., 2000, PASA, 17, 18.