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Distance and Extinction Effects on the LPV-Based Star Formation History of M31

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Abstract

We investigate how the adopted distance and extinction affect the star formation history (SFH) of M31 derived from long-period variable stars (LPVs). Using a sample of 1,149 LPVs, we test three distance moduli ($\mu_0 = 24.40$, 24.47, and 24.54 mag) and three additional visual extinction values ($\Delta A_V =$ 0.0, 0.1, and 0.2 mag). Changes in the distance modulus affect the inferred star formation rate more strongly, particularly for young stellar populations, whereas the tested extinction variations produce smaller changes. Nevertheless, the overall shape and main features of the reconstructed SFH remain broadly similar across all cases. These results emphasize the importance of adopting consistent distance and extinction corrections when comparing LPV-based SFHs.

Keywords: *stars: variables — stars: AGB and post-AGB — galaxies: individual (M31) — galaxies: star formation — galaxies: stellar content — dust, extinction*

1. Introduction

Long-period variables (LPVs), primarily asymptotic giant branch (AGB) stars, provide valuable tracers of past star formation in nearby galaxies (Javadi & van Loon, 2019, Rezaeikh et al., 2014). These variables span a range of pulsation periods and infrared excesses, reflecting differences in their luminosities, metallicities, and circumstellar dust production (Abdollahi et al., 2026, Alizadeh et al., 2026, Boyer et al., 2025, Gavetti et al., 2026, Goldman et al., 2019, Javadi & van Loon, 2022, Mahani et al., 2025, Saremi et al., 2020, Yuan et al., 2018). Their infrared luminosities are strongly correlated with initial mass and age, allowing these properties to be estimated from their observed brightness. By combining the observed number of LPVs with their relatively short evolutionary lifetimes, the star formation rate (SFR) can be estimated, providing a means of reconstructing the star formation history (SFH) of a galaxy (Abdollahi et al., 2023a,b, Hashemi et al., 2019a,b, Javadi et al., 2011a,b, 2017, Khatamsaz et al., 2026, Mahani et al., 2023, Navabi et al., 2021, Saremi et al., 2019, 2021, Torki et al., 2019, Torki et al., 2020). The reliability of this method depends on the adopted stellar luminosities, which depend on the assumed distance and interstellar extinction. Changes in the adopted distance modulus or extinction therefore propagate into the derived stellar masses, ages, and SFR estimates. In this study, we investigate the sensitivity of the reconstructed SFH of M31 to variations in these two parameters, using the same LPV sample and stellar evolutionary models throughout the analysis.

2. Method

We use a selected sample of 1,149 LPVs from the M31 catalogue of Mould et al. (2004). Adopting a reference distance modulus of $\mu_0 = 24.47$ mag, we first examine three distance moduli: $\mu_0 = 24.40$, 24.47, and 24.54 mag. We then fix the distance modulus at its reference value and investigate the effects of additional visual extinction values of $\Delta A_V = 0.0$, 0.1, and 0.2 mag. These values represent additional extinction increments rather than the total dust extinction. All cases use the same observed area of 105 kpc^2 and 16 logarithmically spaced age bins.

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We estimate stellar masses, ages, and LPV evolutionary lifetimes using the PARSEC–COLIBRI isochrones of Marigo et al. (2017), following the LPV-based method described by Javadi et al. (2011a). The SFR is calculated using their formulation:

$$\xi(t) = \frac{\int_{m_{\rm min}}^{m_{\rm max}} f_{\rm IMF}(m)\, m\, {\rm d}m}{\int_{m(t)}^{m(t+{\rm d}t)} f_{\rm IMF}(m)\, {\rm d}m} \frac{{\rm d}n'(t)}{\delta t}. \tag{1}$$

Here, $\mathrm{d}n'(t)$ represents the number of observed LPVs in an age bin, δt is the duration of the LPV phase, and $f_{\rm IMF}(m)$ is the initial mass function adopted from Kroupa (2001). Individual LPV lifetimes are taken into account when calculating the SFR. We divide the resulting SFR by the surveyed area of 105 kpc^2 to obtain the SFR per unit area. This quantity is not normalized by the total stellar mass formed.

3. Results

As shown in Fig. 1, variations in the adopted distance modulus have a larger effect on the reconstructed SFR than the additional extinction values tested here. Near $\log_{10}(t/\mathrm{yr}) \approx 8$ (~ 100 Myr), the SFR surface density ranges from 3.49×10^{-4} to $5.69\times10^{-4}\, M_\odot\,\mathrm{yr}^{-1}\,\mathrm{kpc}^{-2}$ across the tested distance range, with a reference value of $4.46 \times 10^{-4}\, M_\odot\,\mathrm{yr}^{-1}\,\mathrm{kpc}^{-2}$. By comparison, additional visual extinction values of $\Delta A_V = 0.1$ and 0.2 mag yield SFR surface densities of 4.65×10^{-4} and $4.72 \times 10^{-4}\, M_\odot\,\mathrm{yr}^{-1}\,\mathrm{kpc}^{-2}$, respectively.

This difference arises because changes in the adopted distance modulus affect the inferred absolute magnitudes of all stars, thereby changing the stellar masses and ages derived from the evolutionary models. In contrast, the additional extinction values considered here produce relatively small changes in the inferred near-infrared magnitudes. These variations arise from the sensitivity of the inferred stellar masses, ages, and LPV lifetimes to the adopted distance and extinction, rather than from real changes in the past star formation of M31.

A similar trend is found in the estimated fraction of stellar mass formed over the last 1 Gyr. Across the tested distance range, this fraction varies from approximately 9.7% to 15.4%, whereas across the tested additional extinction range, it changes from 12.1% to 13.2%. Despite these quantitative differences, the overall age distribution and main features of the reconstructed SFH remain broadly similar across all tested cases.

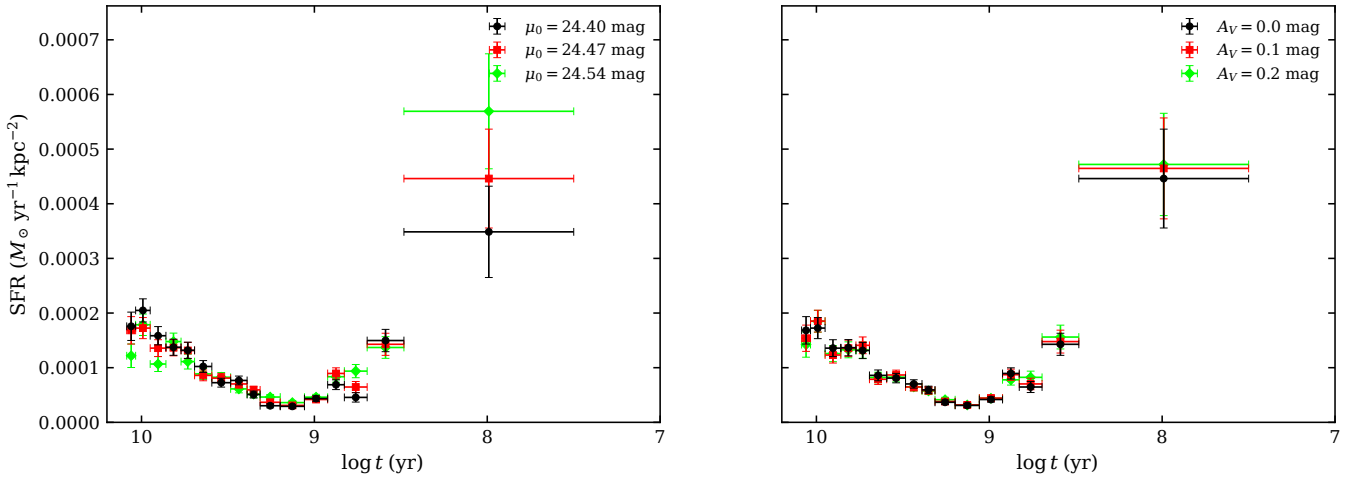

Figure 1: Effects of the adopted distance modulus (left) and additional visual extinction (right) on the reconstructed LPV-based SFR surface density of M31. The horizontal axis shows logarithmic age, decreasing from left to right. The left panel shows the effect of varying the distance modulus, while the right panel shows the effect of additional visual extinction.

4. Conclusion

The reconstructed SFR of M31 based on LPVs is more sensitive to the adopted distance modulus than to the additional visual extinction, particularly at younger ages. While changes in distance modulus produce noticeable variations in the derived SFR, small increases in visual extinction ($\Delta A_V \leq 0.2$ mag) have a comparatively minor effect. Nevertheless, the main features of the reconstructed SFH remain unchanged. These results highlight the importance of adopting consistent distance and extinction corrections when deriving and comparing LPV-based SFHs.

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