

STAR FORMATION HISTORY AND DUST PRODUCTION: NGC 147 AND NGC 185

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ABSTRACT

NGC 147 and NGC 185, paired satellites of the Andromeda galaxy, possess the same order of mass and analogous structures, but they show different star formation and different amounts of interstellar gas and dust. Therefore, we present the first reconstruction of the star formation history of NGC 147 and NGC 185. Asymptotic Giant Branch stars are highly evolved stars that are brightest in K-band. This maximum K-band magnitude is related to the birth mass of stars. As a result, we have found a 9.9 Gyr old single star formation epoch for NGC 185 followed by relatively continuous star formation. NGC 147, however, has passed through two star formation episodes; one is as old as ~ 6 Gyr and the other is as recent as ~ 850 Myr. Asymptotic Giant Branch stars are also important dust factories; by fitting Spectral Energy Distributions to observed near and mid infrared data for each star, we were able to measure the dust production rates of individual stars; on order of $10^{-5} M_{\odot} \text{yr}^{-1}$. Hence, we estimate the total mass entering the interstellar medium to be $1.06 \times 10^{-4} M_{\odot} \text{yr}^{-1}$ and $2.89 \times 10^{-4} M_{\odot} \text{yr}^{-1}$ for NGC 147 and NGC 185.

Key words: galaxies: NGC 147, NGC 185 – galaxies: star formation – stars: AGB stars, LPV stars

1. INTRODUCTION

Asymptotic Giant Branch (AGB) stars are evolved stars with low to intermediate masses (0.8–8 solar masses). Since cool AGB stars emit most of their flux in near-infrared wavelengths the K-band is a good measure of the bolometric flux. On the other hand, the most evolved, dust-enshrouded AGB stars can only be detected at infrared wavelengths. Therefore, the K-band is an appropriate wavelength for observing Long Period Variable stars (LPVs).

NGC 147 and NGC 185, Andromeda's paired satellite galaxies, which have the same order of mass and analogous structures but different evolutionary tracks, offer a unique opportunity to consider star formation histories and evolution. Furthermore, NGC 147 and NGC 185 are categorized as dwarf spheroidal galaxies, and therefore are appropriate candidates to increase our insight about the evolution of dwarf spheroidal galaxies.

This paper aims to construct the birth mass function of Long Period Variable stars and derive star formation histories in the inner $6.4' \times 6.4'$ region of NGC 147 and NGC 185 in section 3. In section 4, we will state the amount of mass shed into Interstellar Medium (ISM).

2. DATA AND METHODOLOGY

NGC 147 and NGC 185 were observed on 38 nights between October 2003 and February 2006 in the Gunn-i-band with the 2.56 m Nordic Optical Telescope (NOT). Single-epoch K-band photometry for the target galaxies was obtained during two consecutive nights in September 2004. Finally, LPVs were detected by image subtraction method. Photometric data has been published in Lorenz et al. (2011) and we have made use of them.

A galaxy's Star Formation History (SFH) is the description of the amount of gas which has been converted to stars over a period of time, and can be described by the Star Formation Rate (SFR), ξ , as a function of time. Therefore, the mass of stars, dM , created during a time interval, dt , is:

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

Javadi et al. (2011) give the following form for ξ :

$$\xi(t) = \frac{dn'(t)}{\delta t} \frac{\int_{m_{min}}^{m_{max}} f_{IMF}(m)mdm}{\int_{m(t)}^{m(t+dt)} f_{IMF}(m)dm} \quad (2)$$

where f_{IMF} is the initial mass function. We have revised the theoretical models provided for stellar evolution by Padova group (Marigo et al. 2008) to construct the mass-luminosity relation for NGC 147 and NGC 185 related metallicities (Javadi et al. 2011). The theoretical models of the Padova group can also help us to

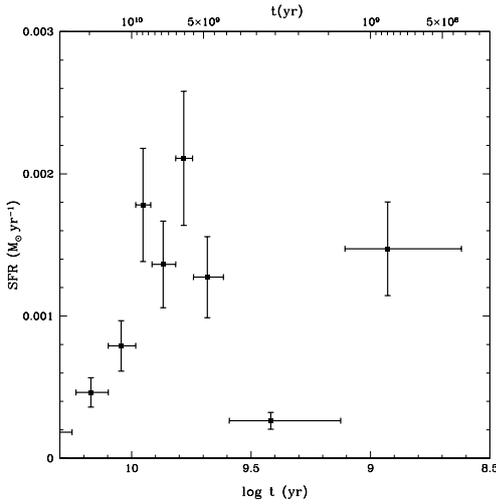


Figure 1. The Star Formation History of NGC 147 derived from near-IR Long Period Variable Stars

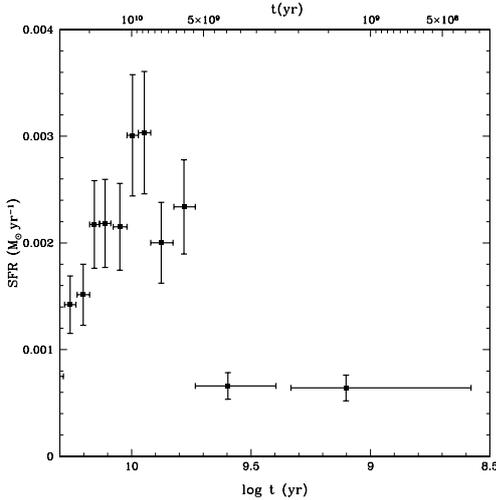


Figure 2. The Star Formation History of NGC 185 derived from near-IR Long Period Variable Stars

determine mass-age relations and mass-pulsation duration.

As we mentioned above, AGB stars experience copious mass loss. The “Dusty” code is an appropriate tool to use to determine the total amount of mass that each star loses during the late stages of evolution. Furthermore, we have used WISE mid-IR photometric data.

3. STAR FORMATION HISTORY

The SFR as a function of elapsed time is depicted in Fig. 1 and Fig. 2 for NGC 147 and NGC 185, respectively. NGC 185 went through a 9.9 Gyr old star formation epoch that produced 79.02% of the total mass of stars. It was followed by a relatively continuous SFR of $6.5 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$. However, we found two star formation epochs in NGC 147; one ~ 6 Gyr ago at the rate

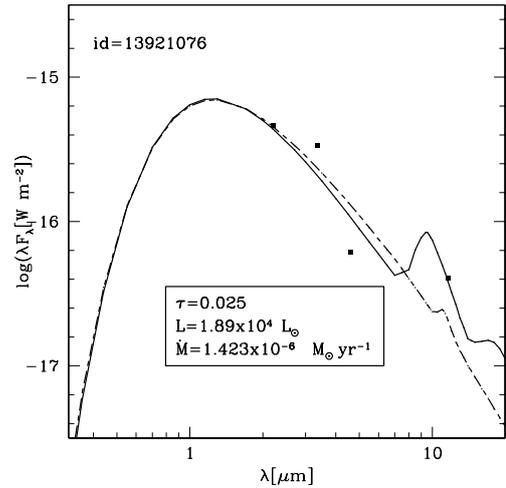


Figure 3. Dots: Photometric data in the near and mid-IR from Lorenz et al. (2011) and WISE. Curves: The best SEDs of dusty models matched to photometric data; M-type star (solid curve), C-type star (dotted curve)

of $\sim 2.1 \times 10^{-3} M_{\odot} \text{ yr}^{-1}$ and another one only 850 Myr ago at the rate of $1.5 \times 10^{-3} M_{\odot} \text{ yr}^{-1}$. During these two epochs 76.96% and 7.6% of total mass of stars were formed.

4. DUST PRODUCTION

We have modeled the dust of AGB stars by combining near and mid-IR photometry data and the fitted SED of the Dusty code (Fig. 3). The optical depth, luminosity and mass loss of the sample star were then determined; the mass loss is $1.423 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$. We have repeated this process for a sample of 91 carbon stars in NGC 147 (Sohn et al. 2006) and 73 carbon stars in NGC 185 (Kang et al. 2005). We achieve the complete mass loss rate as follows; $1.06 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$ for NGC 147 and $2.89 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$ for NGC 185.

5. DISCUSSION

The total mass of stars created in NGC 185 is $3.8 \times 10^8 M_{\odot}$. Davidg (2005) proposed a value of $2 \times 10^8 M_{\odot}$. In NGC 147 total mass of stars is $1.7 \times 10^8 M_{\odot}$.

Modeling the dust of carbon stars gives an estimate of the total mass enters the ISM. For NGC 147 and NGC 185, this amount is $1.06 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$ and $2.89 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$, respectively. Welch et al. (1996) predicted a $1.8 \times 10^{-4} M_{\odot} \text{ yr}^{-1}$ mass loss rate for NGC 185. Gallagher et al. (1981) derive a mass return rate of $1-2 \times 10^{-3} M_{\odot} \text{ yr}^{-1}$ for NGC 185.

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