Dust Production by AGB stars in the NGC 6822 Galaxy

N. Rostami [1] and H. Mahani [2]

[1]Department of Physics, Faculty of Physics, Alzahra University, Vanak, 1993891176, Tehran, Iran
[2]School of Astronomy, Institute for Research in Fundamental Sciences (IPM), PO Box 19395-5531, Tehran, Iran

Abstract

Asymptotic Giant Branch (AGB) stars and Long-Period Variables (LPVs) represent the final evolutionary stages of low- to intermediate-mass (0.8–8 M⊙) stars and play a crucial role in enriching the interstellar medium (ISM) with metals and dust, thereby influencing the chemical evolution of galaxies. In this study, AGB stars and LPVs in the dwarf irregular galaxy NGC 6822 were investigated using publicly available multi-wavelength photometric data spanning the near- to mid-infrared regime, including observations from JWST, Spitzer, and UKIRT. Candidate AGBs and LPVs were identified through cross-matching with available online catalogs, and a consolidated catalog of their multi-band photometry was compiled. The spectral energy distributions (SEDs) of these sources were modeled using the `DUSTY` and `SEDust` codes to derive mass-loss rates and other dust-related parameters. Both oxygen-rich (O-type) and carbon-rich (C-type) AGB and LPV populations were analyzed, and their combined contribution to the chemical enrichment of NGC 6822 was quantified, yielding a total mass-loss rate of 2.4×10^{-4} M⊙ yr^{-1} for the modeled sample. Correlations between key parameters, such as optical depth and bolometric correction, were further examined to estimate mass-loss rates for AGBs and LPVs not modeled due to incomplete photometric coverage.

Keywords: *AGB stars; NGC 6822; Mass-loss rates; Dust production*

1 Introduction

NGC 6822, also known as Barnard's Galaxy, is an isolated dwarf irregular galaxy in the Local Group (LG). It is located about 490 ± 40 kpc from the Milky Way (MW) (Sibbons et al. (2012)), making it the closest undisturbed dwarf irregular (dIr) galaxy beyond the Magellanic Clouds. Due to its position in the sky (R.A.(J2000) = $19^h44^m58.56^s$, DEC(J2000) = $-14°47'34.8''$;Tantalo et al. (2022)), it can be observed from both the northern and southern hemispheres. This accessibility has made NGC 6822 one of the most extensively studied dwarf galaxies. NGC 6822 has experienced a nearly constant rate of star formation for most of the past ∼11 billion years (Clementini et al. (2003)), but during the last 100–200 million years its activity has increased (Gallart et al. (1996)). The mixture of old, intermediate-age, and young stellar populations makes this galaxy an excellent laboratory for studying how galaxies evolve chemically and dynamically over time. Because of its low metallicity ([Fe/H] ≈ −1.2; ∼30% $Z_\odot$;Gallart et al. (1996); Lee et al. (2006)), isolated location, and recent star formation, NGC 6822 also provides valuable clues about the processes of star and galaxy formation in the early universe.

Asymptotic Giant Branch (AGB) stars, along with their pulsating sub-class known as Long-Period Variables (LPVs), represent the final evolutionary stage of low- to intermediate-mass stars (∼0.8–8 $M_\odot$; Hirschauer et al. 2020; Javadi et al. 2011b,c). They are cool, luminous, and short-lived compared to their main-sequence lifetimes. These stars trace the old and intermediate-age stellar populations of galaxies (Abdollahi et al. (2023b); Navabi et al. (2021); Hashemi et al. (2019); Blum et al. (2006)). Because they are among the brightest stellar objects, they are readily detected in the near-infrared (NIR)(Javadi et al. (2015, 2011a)).

One of the most important characteristics of AGB and LPV stars is the substantial mass loss they experience during the final stages of their evolution. Strong stellar winds push out large amounts of material into the surrounding space, driven primarily by two mechanisms: pulsations in the stellar atmosphere and radiation pressure on dust grains. From a chemical standpoint, AGB stars are broadly classified into two main categories: oxygen-rich (C/O < 1, M-type) and carbon-rich (C/O > 1, C-type) stars. The ejected material is chemically enriched, with its dust composition depending on the stellar type; carbonaceous

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compounds, such as graphite, dominate in carbon-rich stars, while silicate and aluminum oxide grains are typical of oxygen-rich stars. Through this process, AGB stars play a crucial role in enriching the interstellar medium (ISM)(Boyer et al. (2025); Abdollahi et al. (2023a); Goldman et al. (2019)).

In this study, we present a quantitative analysis of the mass-loss rates of AGB stars in the NGC 6822 galaxy, along with an estimate of the total dust production in the system. To this end, we adopt the method proposed by Javadi & van Loon (2022) and Javadi et al. (2013) and model the spectral energy distributions (SEDs) of the AGB stars using near- and mid-infrared data. The mass-loss rates are then analyzed separately for carbon-rich and oxygen-rich stellar populations. Our results provide insights into the contribution of AGB stars to the enrichment of the ISM and their role in the evolution of dwarf irregular galaxies.

2 Data

Our primary catalog for studying AGB stars in NGC 6822 is based on Hirschauer et al. (2020), who identified evolved and dusty stars using a combination of near- and mid-infrared photometry. The dataset includes observations from the United Kingdom Infrared Telescope (UKIRT) in the J, H, and K bands (Sibbons et al. (2012)), as well as from the Spitzer Space Telescope in the IRAC 3.6, 4.5, 5.8, and 8.0 µm bands and the MIPS 24 µm band (Khan et al. (2015)). The catalog lists 1292 RSG candidates, 1050 oxygen-rich AGB stars, and 560 carbon-rich AGB stars, all identified with high confidence.

To obtain AGB star magnitudes across multiple wavelengths, we cross-matched our primary catalog with additional datasets. One of these catalogs is from Letarte et al. (2002), who observed NGC 6822 using the CFH12K camera. Using a four-band photometric technique (R, I, CN, and TiO filters), they identified 904 carbon stars in the region centered on the galaxy. In addition, NGC 6822's central bar was observed by the JWST with NIRCam in the F115W, F200W, F356W, and F444W filters, providing high-resolution near- and mid-infrared data. In our final catalog, we include a total of 1735 AGB stars from Hirschauer et al. (2020). Cross-matching with the aforementioned catalogs enabled us to compile photometric measurements across 14 wavelength bands. Figure 1 shows the distribution of AGB stars in the NGC 6822 galaxy from Hirschauer et al. (2020) and Letarte et al. (2002).

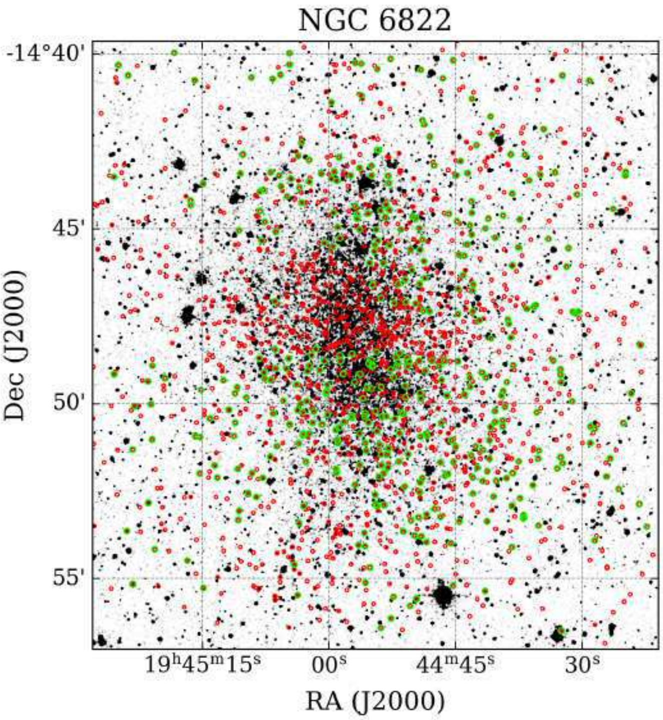

Figure 1: Distribution of AGB stars in NGC 6822. Red and green dots represent AGB stars from Hirschauer et al. (2020) and Letarte et al. (2002), respectively, with 576 sources found in common between the two catalogs.

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3 Method

In this study, we calculated the mass-loss rates of 1735 AGB stars from our catalog by modeling their SEDs using the `DUSTY` code Ivezic & Elitzur (1997). `DUSTY` solves the problem of radiation transport in a dusty environment. The key input parameters for the code include stellar temperature, dust temperature, optical depth, chemical composition, and the dust grain size distribution. The photometric magnitudes were first converted into fluxes, which were subsequently used by the `SEDust` pipeline, developed by Mahani et al. (2025) and Mahani & Javadi (2025), to derive the best-fitting SED models for each source. `SEDust` is a pipeline that identifies optimal SED models by employing a χ^2 minimization scheme to compare `DUSTY` model outputs with observational data. The pipeline incorporates a grid of 24000 models, enabling reliable fitting for both carbon-rich and oxygen-rich AGB stars. It provides key physical parameters, including luminosity, optical depth, and mass-loss rate, and produces the corresponding best-fit SED plots (Mahani & Javadi (2025)) (Figure 2).

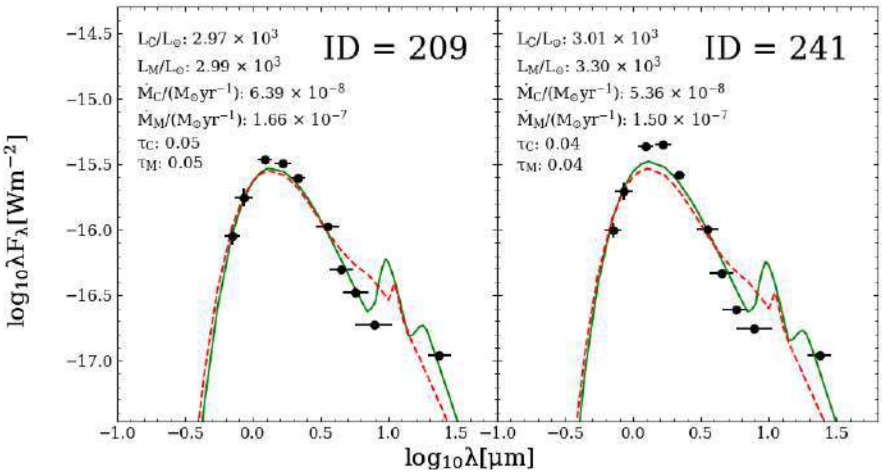

Figure 2: Examples of best-fit SEDs for AGB stars. The solid green and dashed red lines represent the models for M-type and C-type AGB stars, respectively. Error bars indicate the photometric uncertainties in each band.

4 Results

The mass-loss rates of all oxygen-rich and carbon-rich AGB stars were derived by modeling their spectral energy distributions. A total mass-loss rate of 2.4×10^{-4} $M_\odot$ yr^{-1} was obtained for the sample. Figure 3 presents the relation between mass-loss rate and luminosity for the subclass of LPVs in NGC 6822. The diagonal dashed line represents the classical limit of the mass-loss rate for dust-driven winds due to single scattering, as defined by Javadi et al. (2013). The mass-loss rates of our sample stars are generally in good agreement with this theoretical limit.

Figure 4 shows the relationship between optical depth and the color index of LPV stars. As the optical depth increases, the color index also becomes redder. This trend is expected, as a higher optical depth reduces the number of photons reaching the outer layers of the star. Consequently, the temperature gradient between these layers increases, causing the stellar surface to appear redder and resulting in a higher color index.

5 Summary

In this study, we investigated the mass-loss rates and dust production of AGB stars in the dwarf irregular galaxy NGC 6822. Using a combined dataset from UKIRT, Spitzer, and JWST observations, we modeled the SEDs of 1735 AGB stars with the `DUSTY` and `SEDust` codes. Our catalog includes 1099 M-type and 639 C-type AGB stars. From the best-fit SED models, we derived a total mass-loss rate of 2.4×10^{-4} $M_\odot$ yr^{-1} for the entire sample. The luminosity of M-type stars ranges approximately from 1.2×10^3 to 1.2×10^5 $L_\odot$, while that of C-type stars extends from 1.2×10^3 to 2.5×10^4 $L_\odot$. We also found that the mass-loss rate correlates positively with stellar luminosity, following the classical limit for dust-driven winds as proposed

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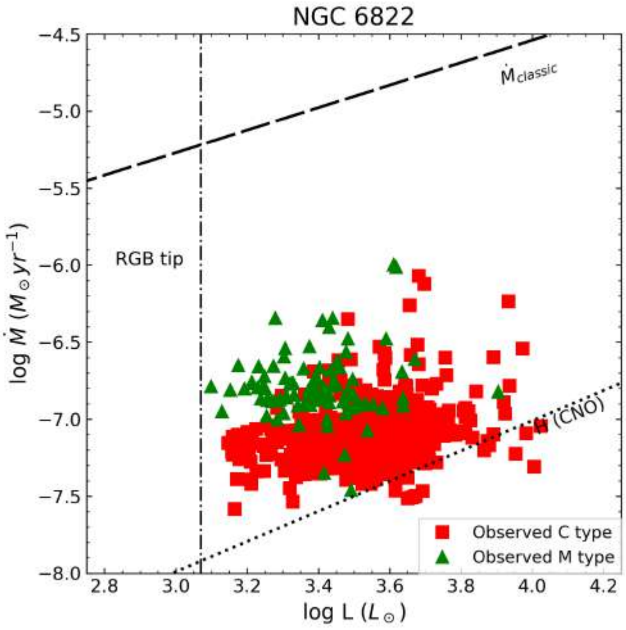

Figure 3: Mass-loss rates of LPV stars as a function of luminosity. The diagonal dashed line indicates the classical limit for dust-driven winds due to single scattering Javadi et al. (2013).

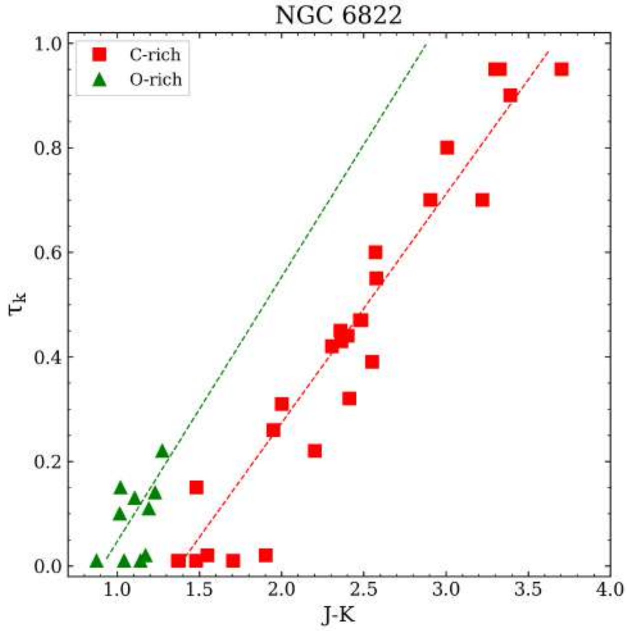

Figure 4: Relationship between optical depth (τ) and Near-Infrared (NIR) colors of Long period variable stars.

by Javadi et al. (2013). Furthermore, our analysis of optical depth and mid-infrared color indices indicates that stars with higher optical depths exhibit redder colors, consistent with stronger dust absorption and re-emission.

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