A Deep Dive into Stellar Populations in M33's Central Region: Near-Infrared Observations and Analysis

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Abstract

Data collection was conducted using three cameras on the UK Infrared Telescope (UKIRT) from 2003 to 2007. Throughout three nights in August 2005, the UKIRT Fast-Track Imager (UFTI) made K-band observations. The J and H bands Wide Field Camera (WFCAM) data were gathered from 2005 to 2007. Furthermore, from 2003 to 2007, UIST data for the central region of M33 were collected in the K-band. Since luminosity is more closely correlated with birth mass in the latter stages of a star's evolution, we concentrated on these stars. We will combine all the PSF photometry catalogs of the UIST, the UFTI, and the WFCAM to present a novel master catalog of the central square kiloparsec to re-identify the LPV populations. By having more data points for each point source, the probability of detecting more LPVs goes up; also, a period might be derived for some. In addition to that, the SFH will be estimated more accurately by having a larger sample of variable stars.

Keywords: *stars: evolution – stars: long-period variables – stars: luminosity function – stars: mass-loss – galaxies: individual: M 33 – galaxies: central regions – photometry: near-infrared – telescopes: UKIRT*

1. Introduction

Spiral galaxies are among the universe's most significant and expansive structures. With their rotating, gaseous discs and spiral arms, these galaxies are the best targets to understand the galactic structure and stellar population dynamics. In the central region, they contain various stellar components, such as nuclear star clusters, bulges, and bars. However, the factors behind the presence and formation of these structures and spiral arms are not yet fully understood (Javadi et al., 2011a). M33 is one of the three spiral galaxies within the Local Group. Located in the Triangulum constellation, M33 spans approximately a degree across the sky. The inclination angle of 56 ° makes it an excellent candidate for examination of the intricate structure and stellar composition of a spiral galaxy similar to our own (Javadi et al., 2011b). However, compared to our own Milky Way, where the central regions are heavily obscured by the intervening dusty disc, M33 provides a unique opportunity to study a spiral galaxy up close and gain insight into the structure and evolutionary processes of the central regions (Benjamin et al., 2005, van Loon et al., 2003). Galactic evolution is heavily influenced by the final stages of stellar evolution. During these stages, evolved stars lose mass, in which they return enriched and sometimes dusty matter to the interstellar medium (ISM) in addition to energy and momentum (Javadi et al., 2013). These evolved stars, particularly in their later stages, are highly luminous and often among the coolest, which makes them prominently visible at infrared (IR) wavelengths (Javadi et al., 2017). Asymptotic giant branch (AGB) stars and red supergiants have main-sequence masses of up to 30 $M_\odot$. In their cooler atmospheres, they have strong radial pulsations. These pulsations make them

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identifiable as long-period variables (LPVs) in photometric monitoring campaigns that span months to years (Ita et al., 2004a,b, Whitelock et al., 1991, Wood, 2000). Long-period variable (LPV) stars achieve their maximum luminosity during the final stages of their evolution. This peak luminosity has a direct relationship with their birth mass (Navabi et al., 2021). Consequently, LPV stars allow us to derive the star formation history (SFH) across a broad age range, spanning approximately 30 Myr to 10 Gyr (Marigo et al., 2008). Therefore, star formation history can be derived from the mass function of LPVs, for which, in this work, we check the SFH in the inner square kpc of M33. We can also correlate spatial distributions of LPVs of different masses with galactic structures (spheroid, disc, and spiral arm components) (Javadi et al., 2015, 2017).

Many variability surveys of M33 have been conducted, mostly at optical wavelengths. However, observation cadences have generally been too short to adequately identify LPVs (Javadi et al., 2010). However, in our M33 monitoring project, we attempted to solve this problem by using longer observation periods at different times. We used three cameras at the UK InfraRed Telescope (UKIRT) between 2003 and 2007 to look for LPVs in the central parts of M33. We know that the birth mass of a star is directly related to its brightness when it is nearing the end of its evolution. This region's observations were obtained in three different bands: J, H, and K. Data for the J, H and K bands were collected by the Wide Field Camera (WFCAM) between 2005 and 2007. Additionally, UIST data from 2003 to 2007 were gathered to reach K-band data for M33's central region (Alizadeh et al., 2024).

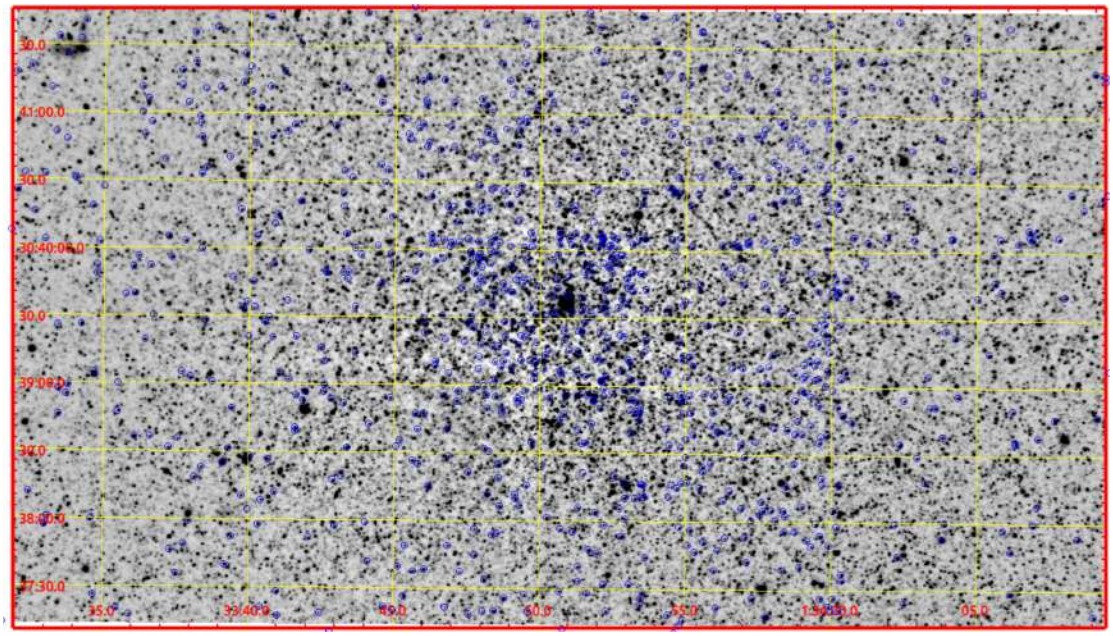

Figure 1. The central region of the M33 with the UIST instrument field of view. Blue circles indicate LPV stars.

2. Data

The data used in this investigation were gathered from three different instruments at the UK Infrared Telescope (UKIRT): the UKIRT Fast-Track Imager (UFTI), the Wide Field Camera (WFCAM), and the UKIRT Imager Spectrometer (UIST). The UFTI conducted K-band observations over three nights in August 2005, enabling high-resolution imaging of M33's center area. A more comprehensive view of star populations may be obtained from the WFCAM data, which were gathered in the J and H bands between 2005 and 2007. This view is further strengthened by the UIST data, which covers the K-band from 2003 to 2007.

Figure 1, shows the M33 galaxy's central region is studied using the UKIRT telescope. This is the field of view of the UIST instrument. Blue circles indicate LPV stars. These datasets work together to provide a thorough analysis of LPV stars, which are essential for comprehending the later phases of a star's life cycle. Previous research by Javadi et al. (2011b) and Saremi et al. (2019) stresses how important it is to combine data from different wavelengths to better understand how stars form in nearby galaxies. Because LPV stars are crucial for monitoring the SFH, we concentrate our inquiry on AGB and red supergiant (RSG) stars

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in particular. Point-spread function (PSF) techniques were used to thoroughly calibrate the observational data to ensure precision in photometric measurements. This technique is based on the methods described by Abdollahi et al. (2023) and Javadi et al. (2015), who showed how well infrared measurements work for locating and describing variable stars in the galactic central region. Our objective in using these datasets is to further our understanding of star populations in the center region of M33 and to contribute to broader discussions on galactic evolution.

The AGB stars, classified as LPV pulsating stars, encompass a diverse spectrum of ages, ranging from young stars to those that are significantly older. These stars serve as robust indicators of stellar populations due to their position in the final stages of stellar evolution, where there exists a direct relation between their luminosity and initial mass. As a result, an adequate population of LPVs is essential to derive the SFH of the M33 galaxy. Javadi et al. (2011a) and Saremi et al. (2020).

Owing to the concentration of stars in the M33 galactic central region, photometric technologies capable of determining the stars in this region with great resolution are of interest. Consequently, to enhance the precision of the task, we employed the PSF approach, previously utilized by Javadi et al. (2010). Figure 2 illustrates the differences in magnitude between the WSA (aperture) and DAOPHOT (PSF) photometry, plotted against the WSA magnitude which shows that the PSF photometry has been done with high accuracy.

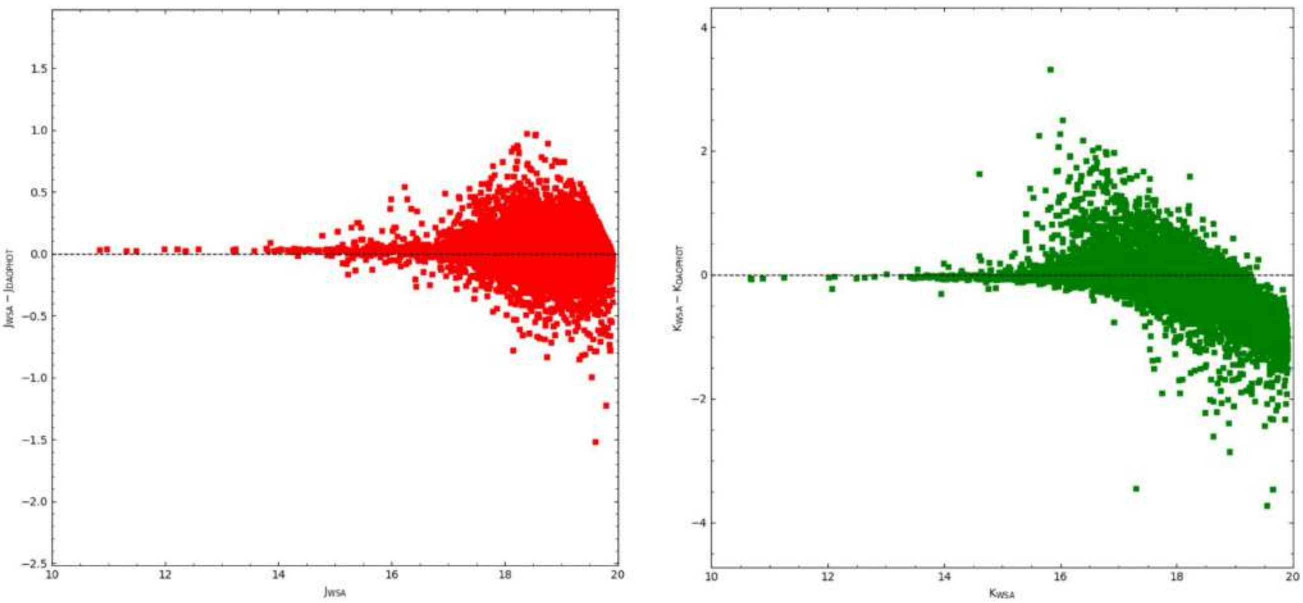

Figure 2. Differences in magnitude between WSA (aperture) and DAOPHOT (PSF) photometry, plotted against WSA magnitude.

3. Methodology

Our approach to studying star formation via isochrone fitting is based on the well-established method described by Javadi et al. (2011b) that has been used to study many galaxies Hamedani Golshan et al. (2017), Abdollahi et al. (2023), Aghdam et al. (2024), Rezai Kh et al. (2014) and Hashemi et al. (2017). To learn more about the SFH of galaxies like M33, we look at LPV stars, especially AGB and RSG stars, which are crucial for finding their paths. We can estimate star formation rates (SFRs) and determine stellar ages by fitting theoretical isochrones from the Padova group (Marigo et al., 2017).

As shown in the work of Saremi et al. (2019, 2020), this method enables us to link the measured luminosities and colors of LPV stars with their evolutionary phases, thus offering insight into the temporal distribution

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of star formation activities in the center area of the galaxy. We use an approach that incorporates Kroupa (2001) Initial Mass Function (IMF) to help determine the mass distribution of stars in our sample, ensuring robust findings.

In this investigation, we analyze the mass-loss rates and dust production from evolved stars located within the central square kiloparsec of the galaxy M33. We combine near-infrared (NIR) and mid-infrared (MIR) photometric data using the spectral energy distribution (SED) fitting method to investigate how evolved stars, particularly AGBs and RSGs, contribute to the enrichment of the interstellar medium (ISM). This occurs through their intense mass-loss processes and the subsequent formation of dust production, including carbonaceous and silicate compounds, which are ejected into the ISM via stellar winds. These expelled materials provide essential building blocks for future star and planet formation, highlighting their pivotal role in the chemical and physical evolution of galaxies Javadi et al. (2011b). Some of the UKIRT data that we use to study the SEDs of long-period variable stars are UFTI, WFCAM, and UIST. This plan is based on the work of Javadi et al. (2013), which shows how important dust feedback is in the formation of galaxies.

4. Discussion and On-going Work

In this study, we performed PSF photometry on data collected from the central region of the M33 galaxy using the WFCAM camera. By combining data across different wavelengths, we aim to improve the cadence of observations and accurately identify LPVs. These variables are pivotal for reconstructing the star formation history of the central region of M33, providing insights into the galaxy's evolutionary processes.

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