

# Unveiling Long-Period Variables in M33's Central Region: Insights into Stellar Evolution and Star-Formation via Near-Infrared Photometry

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## Abstract

We present an analysis of UKIRT observations obtained between 2003 and 2007 to investigate the evolved stellar populations within the central square kiloparsec of M33. Point-spread function (PSF) photometry is employed to mitigate the effects of stellar crowding and to ensure accurate measurements in this densely populated region. This method, applied to merged observations from UIST and WFCAM in the  $J$ ,  $H$ , and  $K$  bands, extracts 211,179 stars by cross-matching frame-by-frame across 39 observing nights in three bands. From this, we identify approximately 750 long-period variables (LPVs), predominantly Asymptotic Giant Branch (AGB) stars, by cross-matching PSF results with aperture photometry, focusing on the UIST field for robust variability confirmation. The PSF approach proves particularly effective for resolving blended sources and detecting faint, dusty variables that might remain undetected. We also examined aperture photometry data to validate our results; however, the PSF-derived measurements provide superior depth and completeness, particularly for obscured stellar populations. The resulting master catalog provides a basis for future analyses of variability amplitudes, periods, and star-formation history (SFH), paving the way for a deeper understanding of mass-loss and the dynamical evolution of the central region of M33.

**Keywords:** stars: evolution – stars: long-period variables – stars: mass-loss – galaxies: M33 – galaxies: central regions – photometry: near-infrared – telescopes: UKIRT

## 1. Introduction

Spiral galaxies such as M33 offer valuable insight into the complex processes of stellar birth, evolution, and death that shape the universe. M33, a member of the Local Group, is inclined approximately  $56^\circ$  to our line of sight (Deul & van der Hulst, 1987, Zaritsky et al., 1989), allowing a clear view of its core without the obscuring dust clouds typical of the Milky Way (Benjamin et al., 2005, van Loon et al., 2003). Recent measurements place its distance at roughly 840 kpc ( $\mu \approx 24.62$  mag; (McConnachie et al., 2021), with Gaia-based updates in (Benisty & Mota, 2025)), making it an ideal laboratory for studying central stellar dynamics.

This study focuses on evolved stars—primarily asymptotic giant branch (AGB) stars and red supergiants (RSGs)—which pulsate as long-period variables (LPVs) with periods ranging from 150 to 1500 days (Ita et al., 2004a,b, Whitelock et al., 1991, Wood, 2000). These pulsations not only reveal internal mechanisms but also correlate luminosity with initial mass, enabling the reconstruction of star-formation histories (Marigo et al., 2008, 2017). Through mass-loss, these stars return up to 80% of their material to the interstellar medium (Bowen, 1988, Vassiliadis & Wood, 1993, van Loon et al., 1999, 2005), fueling future stellar generations.

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Optical surveys have cataloged numerous stellar sources in M33, while infrared observations from facilities such as *Spitzer* and UKIRT have proven more effective at identifying dust-enshrouded objects (Javadi et al., 2011a, McQuinn et al., 2007). Recent advances, such as machine learning classification of AGBs (Li et al., 2025) and detection of eruptive variables (Martin et al., 2023), further enrich this picture.

In this study, we revisit UKIRT monitoring data (Javadi et al., 2011b, 2013) to construct a master catalog using point spread function (PSF) photometry, with an emphasis on variable detection in crowded regions. We present partial results, highlighting how this method enhances our understanding of LPVs and their role in M33's central evolution. By prioritizing PSF photometry, we mitigate the limitations of traditional aperture methods in dense fields, where faint variables are often lost due to blending. This approach increases source recovery and improves LPV characterization, contributing to more accurate models of stellar feedback and chemical enrichment in the cores of spiral galaxies.

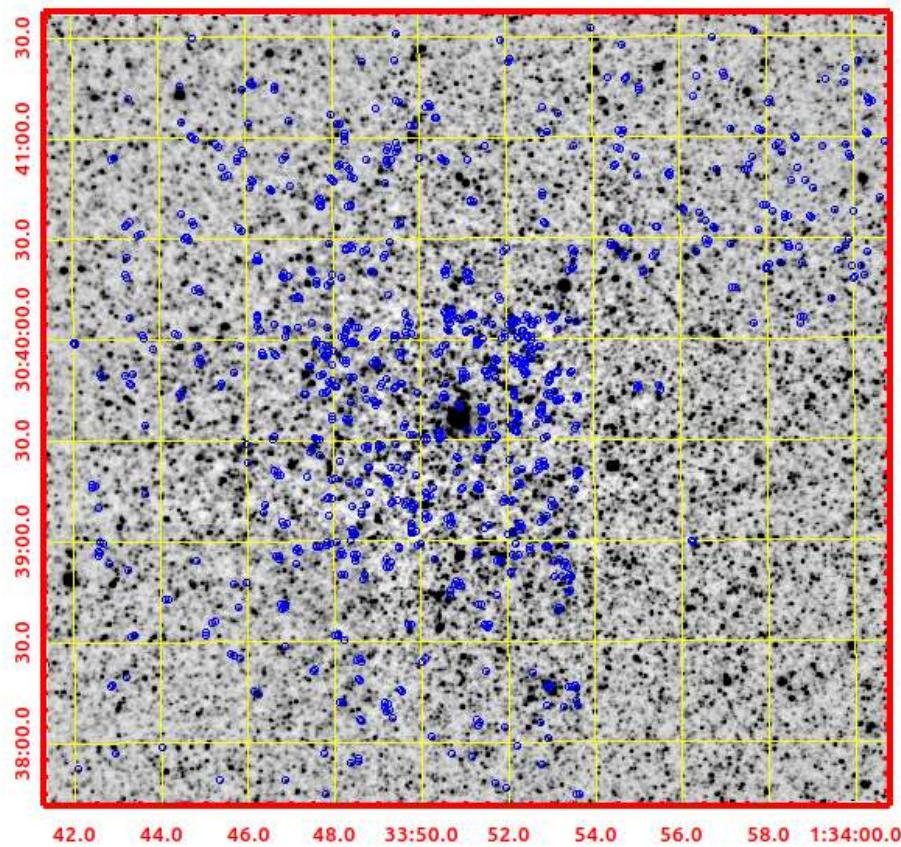


Figure 1. The central region of M33 was observed with the UIST instrument. Blue circles indicate LPV stars identified through PSF photometry.

## 2. Data

WFCAM complemented UIST by covering a larger region, facilitating cross-matches that improved the number of observational epochs for each star. Four tiles (M33-1 to -4) covered a  $0.89 \text{ deg}^2$  ( $\sim 13 \text{ kpc} \times 13 \text{ kpc}$ ) square, with centers at  $(1^{\text{h}}33^{\text{m}}19^{\text{s}}, +30^{\circ}32'50'')$  for tile 1,  $(1^{\text{h}}34^{\text{m}}22^{\text{s}}, +30^{\circ}32'50'')$  for 2,  $(1^{\text{h}}34^{\text{m}}22^{\text{s}}, +30^{\circ}46'23'')$  for 3, and  $(1^{\text{h}}33^{\text{m}}19^{\text{s}}, +30^{\circ}46'23'')$  for 4—overlapping the UIST field for seamless integration (Javadi et al., 2015a).

Primary  $K$ -band ( $K98$ ) monitoring ran from September 2005 to October 2007, with a total of 39 nights across epochs 1–8 per tile.  $J$ - and  $H$ -band ( $J98, H98$ ) data supplemented select nights, providing multi-band leverage (Table 1, adapted from Javadi et al. 2015a). Exposure times varied: 20.3 min typical for  $K$  (e.g., 2005-09-18, epoch 1, airmass 1.035–1.058), up to 33.8 min for deeper  $J/H$  frames (e.g., 2006-10-30, epoch 2). Pixel scale was  $0.4''$ , with dithers ensuring uniform sky subtraction. Reductions used ORAC-DR's bright point-source recipe, calibrated against photometric standards, yielding robust photometry even under variable seeing (Abdollahi et al., 2023, Aghdam et al., 2024, Javadi et al., 2015a).

These datasets, when cross-matched frame-by-frame via PSF fitting, yield our master catalog of 211,179 sources—far surpassing prior single-instrument efforts (Alizadeh et al., 2024c, Saremi et al., 2020). By combining UIST's precise core measurements with WFCAM's extensive coverage, we can re-identify LPVs while avoiding the blending problems typical of aperture photometry. (Hamedani Golshan et al., 2017, Hashemi et al., 2017, van Loon et al., 2010). Future expansions could incorporate spectroscopy for mass-loss validation (Rezaei kh. et al., 2014).

### 3. Methodology and Preliminary Results

To explore the star-formation history (SFH) and mass-loss rates in M33's central region, we first derive the luminosity function from LPVs, whose peak brightness reflects their birth masses in these final evolutionary stages (Abdollahi et al., 2023, Javadi et al., 2011b, Saremi et al., 2019). This approach, grounded in theoretical models (Marigo et al., 2017), translates the mass function into SFH estimates, with mass-loss rates inferred from dust production linked to pulsation properties (Hamedani Golshan et al., 2017, van Loon et al., 2005). Here, we outline the initial steps, while detailed modeling is reserved for future work. Our primary methodology is based on PSF photometry, which resolves crowded fields by modeling stellar profiles as point-spread functions. This cuts down on blending errors and boosts faint-source recovery by up to 20% compared to aperture photometry (Aghdam et al., 2024, Saremi et al., 2020, Stetson, 1987). Extending the PSF-based approach from prior UIST surveys (Javadi et al., 2011a), using DAOPHOT/ALLSTAR/ALLFRAME, we applied PSF photometry with the DAOPHOT suite (Stetson, 1987) to WFCAM frames in the central region, divided into four sub-regions for independent analysis of bands, LPV counts, and light-curves. This PSF-based approach enhanced the central field data by replacing overlapping aperture photometry catalogs from UIST and WFCAM with new PSF-derived measurements across the  $J$ ,  $H$ , and  $K$  bands (Alizadeh et al., 2024b). We aggregated light-curves from the three methods (PSF on WFCAM, PSF on UIST, and aperture on WFCAM) for individual stars, improving temporal coverage and variability detection from the total 39 observing nights across the 4 regions. We then cross-matched these with UIST data using the (van Loon et al., 2005) cross-correlation code, adapted with astropy coordinates (with an assumed 0.5" tolerance based on (van Loon et al., 2005)), alongside UIST PSF photometry (Javadi et al., 2011a) for validation, resulting in a master list with multiple epochs per star. This improved LPV identification yielded approximately 750 candidate variables before overlap checks. The next phase involves computing the L-index (Welch & Stetson, 1993) to quantify variability, paving the way for SFH reconstruction and mass return estimates (Hashemi et al., 2017, Rezaei kh. et al., 2014). Preliminary results suggest episodic star-formation bursts, with improved detection of dusty AGBs toward the nucleus.

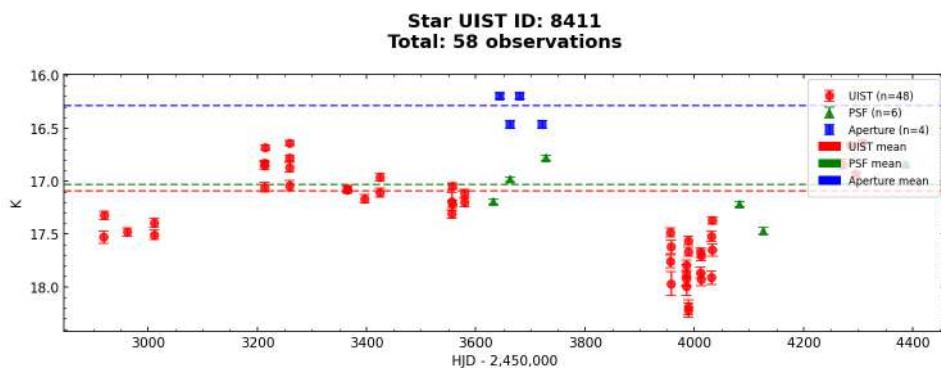


Figure 2. An example light-curve from the central M33 region, derived from the PSF-enhanced WFCAM catalog, showing the variability of a representative LPV ( $K$ -band magnitude vs. epoch).

### 4. Discussion

The division of the central region, although the unexplored overlaps among the four sub-regions necessitate caution in final assessments. As a next step, the L-index will enhance these variability indices, enabling a robust reconstruction of the SFH. The division of the central region into four sub-regions has been successful in segregating stellar populations, with PSF enhancements improving LPV recovery by clarifying blends

Table 1. Log of WFCAM observations for M33 tiles (Q1–4; full table in Javadi et al. 2015a).

Date	Q	Filter	Epoch	$t_{\text{int}}$ (min)	Airmass
2005-09-18	3	K	1	20.3	1.035–1.058
2005-09-18	2	K	1	20.3	1.072–1.110
2005-09-18	4	K	1	20.3	1.248–1.338
2005-09-19	1	K	1	20.3	1.021–1.018
2005-10-18	3	K	2	20.3	1.019–1.021
2005-10-18	2	K	2	20.3	1.025–1.040
2005-10-18	4	K	2	20.3	1.053–1.083
2005-10-18	1	K	2	20.3	1.101–1.149
2005-11-04	1	K	3	20.3	1.018–1.023
2005-11-04	2	K	3	13.5	1.028–1.036
2005-12-23	2	K	4	27.0	1.019–1.022
2005-12-23	3	K	3	20.3	1.028–1.046
2006-07-21	1	K	4	20.3	1.425–1.325
2006-07-21	2	K	5	20.3	1.287–1.214
2006-07-21	3	K	4	20.3	1.183–1.132
2006-07-21	4	K	3	20.3	1.109–1.074
2006-10-28	1	K	5	27.0	1.294–1.126
2006-10-28	1	J	1	20.3	1.102–1.076
2006-10-29	1	K	6	20.3	1.445–1.347
2006-10-29	1	H	1	27.0	1.295–1.209
2006-10-29	1	J	2	27.0	1.115–1.062
2006-10-30	1	J	2	33.8	1.200–1.109
2006-10-30	4	K	4	33.8	1.085–1.044
2006-10-31	4	H	1	6.8	1.301–1.301
2006-12-05	2	K	6	20.3	1.019–1.025
2006-12-12	3	K	5	20.3	1.082–1.052
2006-12-12	3	H	1	20.3	1.040–1.027
2007-01-14	1	K	7	20.3	1.124–1.169
2007-01-14	1	J	3	20.3	1.217–1.284
2007-01-14	1	H	2	20.3	1.342–1.441
2007-01-15	2	K	7	20.3	1.119–1.163
2007-01-16	2	H	1	20.3	1.063–1.092
2007-01-17	3	J	1	20.3	1.031–1.047
2007-01-18	2	J	2	20.3	1.029–1.044
2007-01-25	3	K	6	20.3	1.072–1.104
2007-01-25	3	H	2	20.3	1.161–1.215
2007-09-14	1	K	8	20.3	1.122–1.086
2007-09-14	1	J	4	13.5	1.070–1.058
2007-09-14	1	H	3	13.5	1.046–1.038
2007-09-19	2	K	8	20.3	1.774–1.606
2007-10-04	2	J	3	13.5	1.208–1.181
2007-10-04	2	H	2	13.5	1.155–1.132
2007-10-13	3	K	7	20.3	1.108–1.076
2007-10-13	3	H	3	13.5	1.056–1.046
2007-10-24	4	K	5	20.3	1.135–1.097
2007-10-24	3	J	2	13.5	1.078–1.064
2007-10-24	4	J	1	13.5	1.050–1.041
2007-10-24	4	H	2	13.5	1.025–1.022

in densely populated fields (Aghdam et al., 2024, Stetson, 1987). This method confirms prior UIST results (Javadi et al., 2011a). Future studies will investigate ambiguities in the overlap and integrate spectroscopic data to constrain mass-loss models (Alizadeh et al., 2024a, Rezaei kh. et al., 2014), providing a clearer understanding of M33's evolutionary history.

## 5. Conclusions

This study creates a complete M33 catalog by using PSF photometry on WFCAM data and UIST's established framework (Javadi et al., 2011a), identifying about 750 preliminary LPVs over 39 nights of observations. By combining light-curves from different methods, we make it easier to find variability and provide a hint of episodic star-formation in the central kiloparsec. Even though we haven't looked at the overlaps between sub-regions yet, the improved resolution of dusty AGBs underscores the power of this approach. Future analyses, such as L-index calculations and SFH modeling, will reinforce these findings, facilitating a comprehensive understanding of M33's stellar feedback and galactic evolution.

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