Characterizing Variability in Classical Cepheid U Sagitarii with Differential Vc - Ic Photometry

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PHY 440 F25

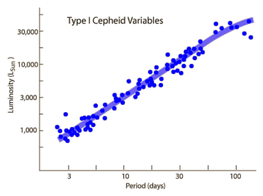
Abstract

U Sagitarii is a Classical Cepheid variable star located in the Messier 25 cluster. 11 observations were made in Cousins V and I bands from 2025-10-14 to 2025-11-15 using the Slooh Chile 2 Telescope. Photometric comparison stars were selected based on angular separation, SNR, and SIMBAD magnitude. Sinusoidal light curves with the established period of 6.74 days were fit for Cousins V and I band data, with R^2 values of 0.9301 and 0.7034 respectively. A strong correlation (r = 0.8450) was found between Vc - Ic color index and Vc magnitude, supporting the existence of the Kappa-mechanism. Distance calculation using Leavitt’s law were accurate for Ic but inaccurate for Vc (δ = 40.77%). Future studies can further explore the Kappa-mechanism after adjusting for dust extinction.

Introduction

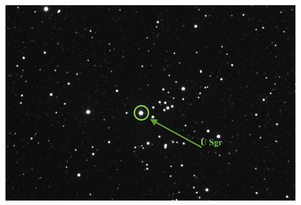
Cepheid variables are pulsating supergiant stars traversing the instability strip as they evolve. They cyclically expand and contract due to a helium- opacity-driven feedback loop known as the Kappa-mechanism.

Leavitt’s law describes a linear relationship between the period of a Cepheid star and its luminosity. This relationship is useful because we can use them as standard candles to measure inter-galactic distances.



U Sagitarii is a Classical Cepheid variable in the Messier 25 Cluster which has been used to calibrate cosmic distances. Further study of its properties can further refine cosmic distance.

M25 Cluster with Labeled U Sgr

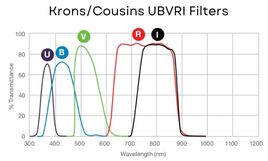


RA: 18:31:53.3323107600
DEC: -19:07:30.261459540

Methodology

U Sgr was identified and observed using the Slooh Chile Two Wide-Field telescope, which is a 432 mm, f/6.8 corrected Dall–Kirkham (CDK17) with a 2.938 m focal length, mounted at the Santa Martina Observatory in Santiago, Chile. Its FLI PL16803 CCD camera (Kodak KAF-16803) has a plate scale of 0.63″/pixel, producing a 43′×43′ field of view (1×1 binning) with a 4096×4096 resolution. From 2025-10–14 to 2025-11-15, images were taken of M25 in the Vc, Rc, and Ic bands with 4-second exposure and converted to FITS files.

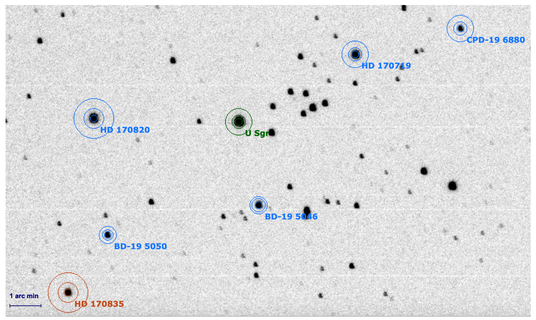
FITS files were calibrated by Slooh and platesolved with astrometry.net. Using the AAVSO tool VPhot, a sequence with 5 comparison stars and 1 check star (HD170835) was plotted based on angular proximity to U Sgr, SNR, and available SIMBAD magnitude in Vc, Rc, and/or Ic bands. Potential Rc band comp stars did not satisfy the criteria, so Rc data was not analyzed further.



Comp Star Inclusion Criteria

Name	Mean SNR	Radial distance	SIMBAD Mag
BD-19 5046	227 (V), 135 (I)	2.748`	9.004±0.024 (V), 8.559±0.031 (I)
BD-19 5050	104 (V)	5.578`	10.196±0.069 (V)
CPD-19 6880	74(V) 46(I)	7.739`	10.45 (V), 10.021±0.05 (I)
HD 170719	373(V)	4.322`	8.080±0.010 (V)
HD 170820	536(V), 618(I)	4.672`	7.372±0.011 (V), 5.742±0.015 (I)
HD 170835	254 (V)	7.766`	8.826±0.007 (V)

U Sgr and Comparison Stars in M25 Cluster



Images were visually screened for instrumental error, cloud cover, and proper 5 x 5 pixel peak finding. Saturated observations were removed from the sample, and images taken within a 3 minute period were mean-stacked. The final sample size including stacks was ($n_V = 11$ $n_I = 11$). Multi-aperture differential photometry was performed on Vc and Ic band data using the TimeSeries tool in VPhot.

Results

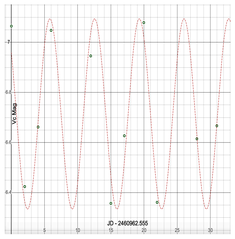
Vc Band Time Series Photometric Measurements from 10-14 to 11-11

	Filter	Average	Min	Max	Std
Targets					
U Sgr	V	6.751	6.357	7.079	0.292
Check stars					
HD 170835 (8.826)	V	8.786	8.723	8.872	0.038
Comparison stars					
BD-19 5046 (9.004)	V	8.992	8.959	9.015	0.017
BD-19 5050 (10.196)	V	10.214	10.179	10.246	0.021
CPD-19 6880 (10.450)	V	10.434	10.380	10.468	0.030
HD 170719 (8.080)	V	8.086	8.061	8.117	0.018
HD 170820 (7.372)	V	7.372	7.346	7.416	0.019

Ic Band Time Series Photometric Measurements from 10-14 to 11-11

	Filter	Average	Min	Max	Std
Targets					
U Sgr	I	5.416	5.230	5.711	0.174
Comparison stars					
BD-19 5046 (8.559)	I	8.534	8.487	8.570	0.037
CPD-19 6880 (10.021)	I	10.110	10.062	10.180	0.047
HD 170820 (5.742)	I	5.678	5.653	5.700	0.021

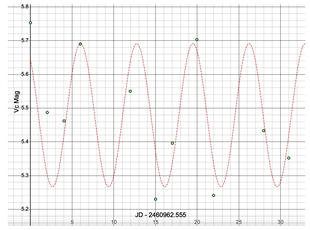
Vc-Band Light Curve



Using the established period of 6.74 days, $R^2 = 0.9301$ was achieved with the curve

$$y \approx -0.379757 \sin\left(\frac{2\pi}{6.74}x - 0.701031\right) + 6.71431$$

Ic-Band Light Curve



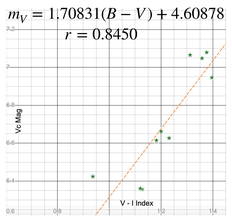
Using the established period of 6.74 days, $R^2 = 0.7034$ was achieved with the curve

$$y \approx -0.212399 \sin\left(\frac{2\pi}{6.74}x - 0.888031\right) + 5.47878$$

During the ~ 1-month observation period, skyglow increased because M25’s peak altitude decreased and the moon’s altitude increased.

Using the Vc & Ic band Leavitt coefficients from Lanoix et al. 1999, the distance to U Sagitarii was estimated as follows.

Relationship between Vc Mag and Vc - Ic Index



$$M_{Vc} \approx -2.77\ log(P) - 1.44 \pm 0.05 \approx -3.735 \pm 0.05$$
$$M_{Ic} \approx -3.05\ log(P) - 1.81 \pm 0.09 \approx -4.337 \pm 0.09$$

$$d = 10^{\frac{m-M+5}{5}} \quad , \quad d_{\text{Cepheid}} \approx 10^{\frac{\overline{m}-(a\log_{10}P+b)+5}{5}}$$

Values of $d = 886.85 \pm 17.83\ pc$ and $d = 641.94 \pm 23.39\ pc$ are attained using $m_{Vc} = 6.761 \pm 0.005$ and $m_{Ic} = 5.429 \pm 0.014$

Discussion

The relationship between Vc - Ic color index and Vc magnitude was first analyzed to confirm the existence of pulsations via the Kappa–mechanism. Vc - Ic reddening was strongly correlated with increases in magnitude (r = 0.8748), suggesting expansions and contractions in line with Stefan-Boltzmann’s law.

$$L = 4\pi R^2 \sigma T_{eff}^4, \text{ where } (V_c - I_c) \textit{ depends on } T_{eff}$$

Light curve determination was first attempted using Monte Carlo simulated harmonic analysis to account for characteristic Cepheid asymmetry, but low sample size precluded suitable fits. Consequently, a low-frequency ($P = 6.74d$) sinusoidal fit was achieved with $R^2 = 0.9301,\ 0.7304$, for Vc and Ic, confirming the existence of Berdnikov et al’s period. Lower R^2 for Ic is likely due to noise from higher Std comp stars.

The distance calculated using Leavitt’s law differs from the accepted value of 630 ± 25 pc by 40.77% and 1.895% for Vc and Ic, respectively. This discrepancy is only significant in Vc band results, which aligns with the relatively larger effect of dust extinction on Vc than Ic band light due to grain size, implying that interstellar reddening has a consequential impact on the apparent magnitudes obtained from differential photometry. While this error is minimized by the interstellar reddening that also impacts the comparison stars in the unadjusted zero-point calculations, the angular separation range of 2-8 arcminutes between U Sgr and the comp stars allows for much variation in interstellar medium concentrations along the telescope’s line of sight, which is compounded by radial velocities suggesting varied comp star cluster membership. While the dust extinction coefficient could not be calculated due to a lack of Bc observations and Vc - Ic calibration standards, future studies can collect more robust data exploring U Sagitarii’s Kappa-mechanism while accounting for variabilities in dust extinction.

Acknowledgements and References

This project would not have been possible without the help of free online databases, such as SIMBAD, and free online tools, including VPhot, AstroImageJ, and Astrometry.net. I’m extremely grateful for the advice and mentorship of Dr. José Manuel Zorrilla Matilla.

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