Data Reduction and Photometric Study of M57 (NGC 6720) Using the Kottamia Faint Imaging Spectro-Polarimeter (KFISP)

Cairo University

Ali Elsisi, Islam Fathallah, Mahmoud Mosleh

Astronomy, Space Science, and Metrology Department

Abstract

We present a photometric analysis of M57 (NGC 6720) based on observations taken with the 1.88-m Kottamia Telescope (KAO), focusing on its central star and nebular structure. Our primary objective is to provide precise apparent magnitude measurements for the central star in four Johnson filters (B, V, R, and I) and to examine the nebula's appearance across these filters, as well as in [Hα] and [O III] filters. To achieve this, we developed a Python code for data reduction to systematically process and calibrate the observations, incorporating astrometric calibration for accurate spatial alignment and positional measurements. Our findings reveal wavelength-dependent morphological variations, providing insights into the complex structures of M57. This study highlights the importance of ground-based observations in uncovering key astrophysical properties of planetary nebulae and demonstrates the value of photometric techniques in ensuring reliable data and meaningful scientific interpretations

Introduction

Planetary nebulae (PNe), like M57 (NGC 6720), are key to understanding stellar evolution, forming when intermediate-mass stars shed their outer layers (Kwok, 2000; Kaler, 1989). At the center of M57 lies a hot white dwarf, the remnant of the progenitor star, which emits intense ultraviolet radiation that ionizes and illuminates the surrounding nebular shell (Napiwotzki, 1999; O'Dell et al., 2007). Their distinct morphology aids studies of ionization and nebular dynamics (Kwok, 2024; Martin et al., 2016). This work presents a photometric analysis of M57 using the 1.88-m Kottamia Telescope, focusing on its central star, nebular structure, and a reliable methodology for photometric data reduction (O'Dell et al., 2002).

Data Collection

Observations were conducted using the **1.88-m Kottamia Telescope** and its advanced CCD system, as part of the **Kottamia Faint Imaging Spectro-Polarimeter (KFISP).** Table 1 provides an overview of the telescope's key capabilities, which were instrumental in obtaining high-quality data for this study (Azzam, et al., 2022)

Table 1: Capabilities of the 1.88-m Kottamia Telescope (KAO) and its CCD system

Telescope	1.88-m KAO (Note: 1.88-m Telescope at the Kottamia Astronomical Observatory (KAO), Egypt)
CCD Model	$E2V\ 42-40\ 2k$ CCD
Chip Size $(pixels)$	2048×2048
Scale $(\mathrm{arcsec}/pixel)$	0.24
Field $(arcmin^2)$	8.2×8.2
Gain (e^-/ADU)	2.14
Read-out Noise $(e^- rms)$	3.92
Typical Seeing (arcsec)	$1.25\ -\ 2.5$
Filters	Johnson (UBVRI) + SDSS-ugriz + Narrow Band (Hα, O III)

Data Reduction and Astrometric Calibration

To obtain accurate photometric measurements, we applied standard CCD reduction techniques, including bias subtraction, flat field correction, and cosmic ray removal (Howell, 2006). These steps mitigate instrumental noise and systematic errors, ensuring reliable data for analysis. The reduction pipeline, implemented in Python, utilized the ***ccdproc*** module, an ***Astropy-coordinated*** package for basic CCD data reduction (Craig et al., 2017), for calibration and ***L.A.Cosmic*** (van Dokkum, 2001; McCully et al., 2014) for artifact removal. Figure 1 presents the master bias and flat frames used in the calibration process. The effectiveness of data reduction is demonstrated in Figure 2.

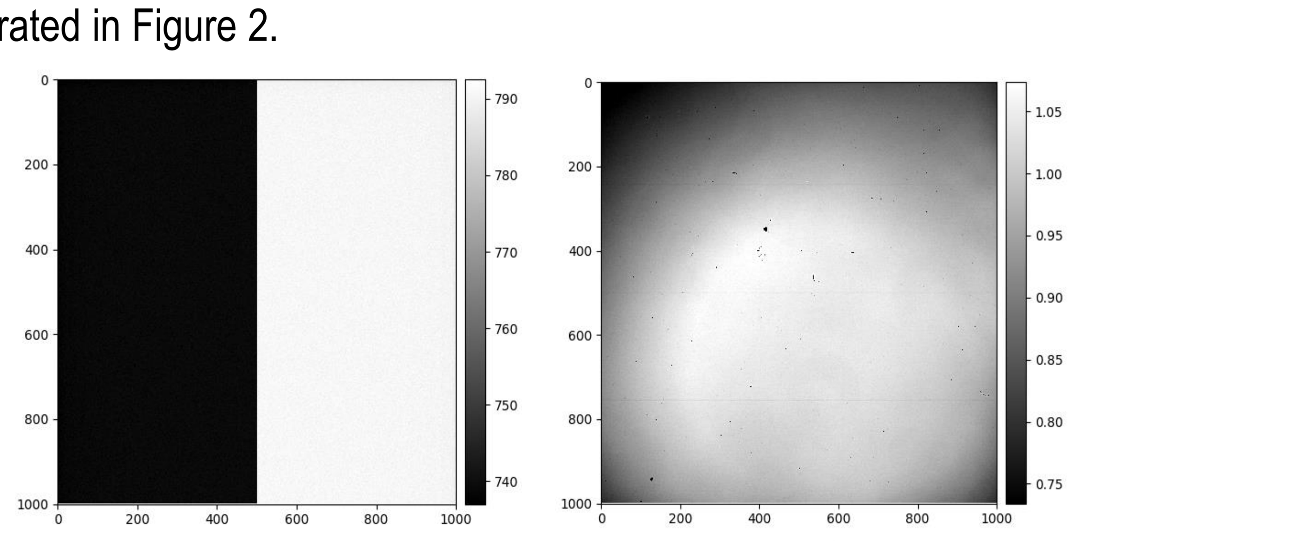

Figure 1: *(a) Master bias frame, used to remove electronic noise from CCD images. (b) Master flat frame in the V filter, used to correct for sensitivity variations and uneven illumination.*

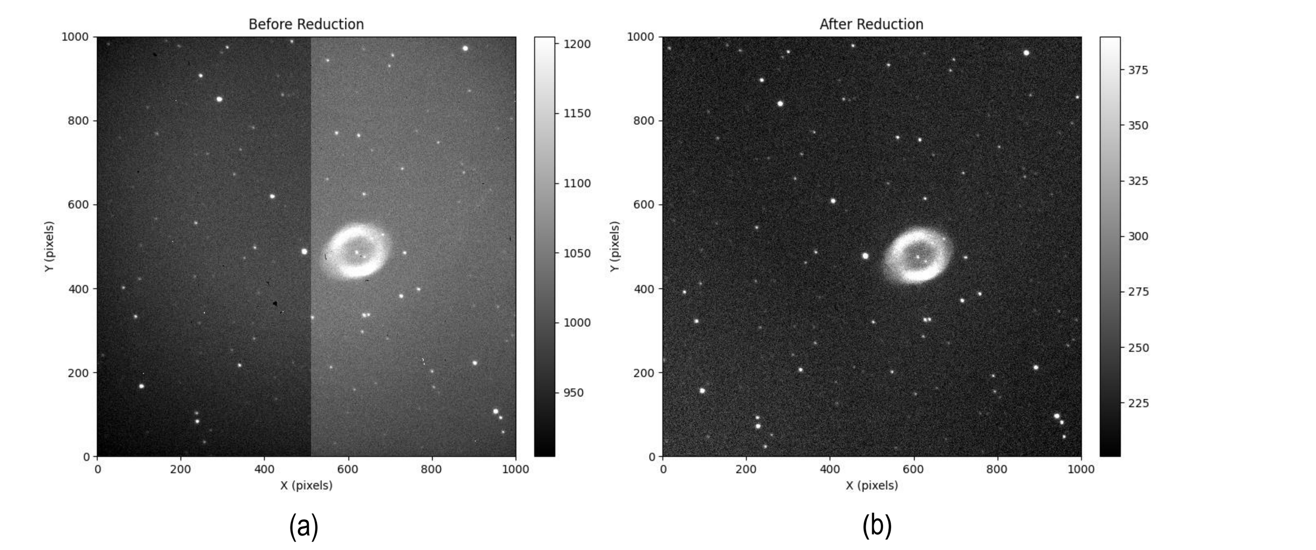

Figure 2: *Example of a V filter frame of M57 **(a)** shows the raw frame before data reduction **(b)** displays the same frame after reduction and cosmic rays removed*

Astrometric calibration was performed using ***astrometry.net*** (Lang et al. 2010), transforming pixel coordinates to the World Coordinate System (WCS) for precise celestial positioning, as illustrated in Figure 3.

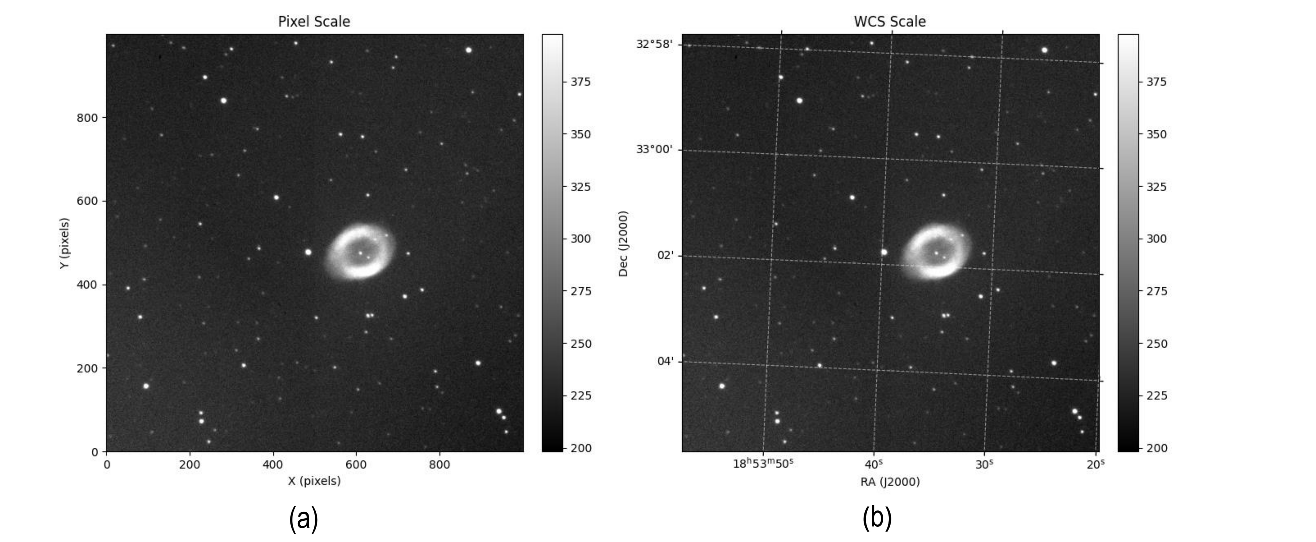

Figure 3: *Reduced M57 frames in V filter presented in two coordinate systems. **(a)** The frame is shown in the pixel scale **(b)** The same frame is calibrated to the World Coordinate System (WCS) using astrometry.*

Photometric Analysis

Aperture photometry was performed using ***Photutils***, an Astropy-affiliated package for detecting and performing photometry of astronomical sources (Bradley et al. 2022). A mask was applied to exclude bright field stars before source detection, and the net flux was calculated after background subtraction. The instrumental magnitudes were derived as:

$$m_{inst} = -2.5\ log_{10}\left(\frac{F}{t_{exp}}\right)$$

The process is illustrated in Figure 4, which shows the initial and refined star detection steps, as well as the aperture photometry setup.

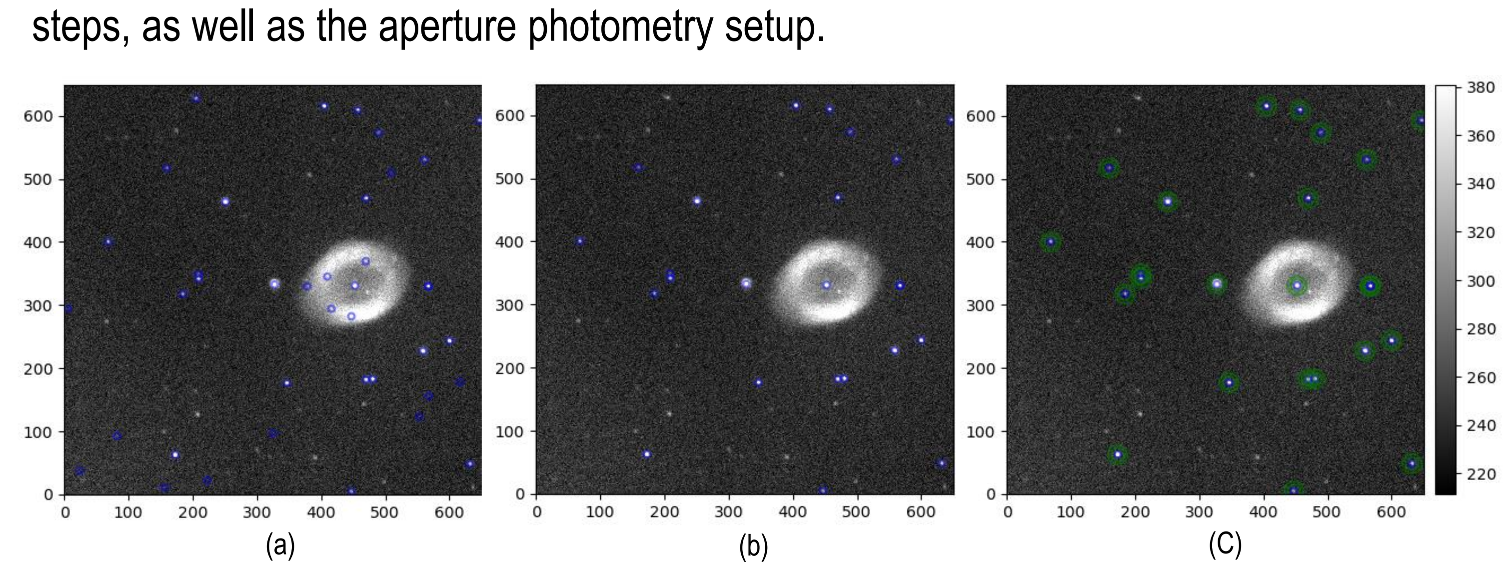

Figure 4: *(a) Initial detection of stars (b) Refined star detection after excluding bright regions and unresolved (c) Aperture photometry setup displaying annular apertures (green) for background estimation around detected sources (blue).*

Photometric calibration, as shown in Figure 5, was performed using matched stars from the **APASS DR9** catalog (Henden et al. 2016), providing Johnson magnitudes, and cross-matched with **Gaia DR3** (Gaia Collaboration 2022) to confirm non-variability. The matching, done in **TOPCAT** (Taylor 2005). The final calibrated magnitudes were computed as:

$$m_{cal} = m_{inst} + ZP$$

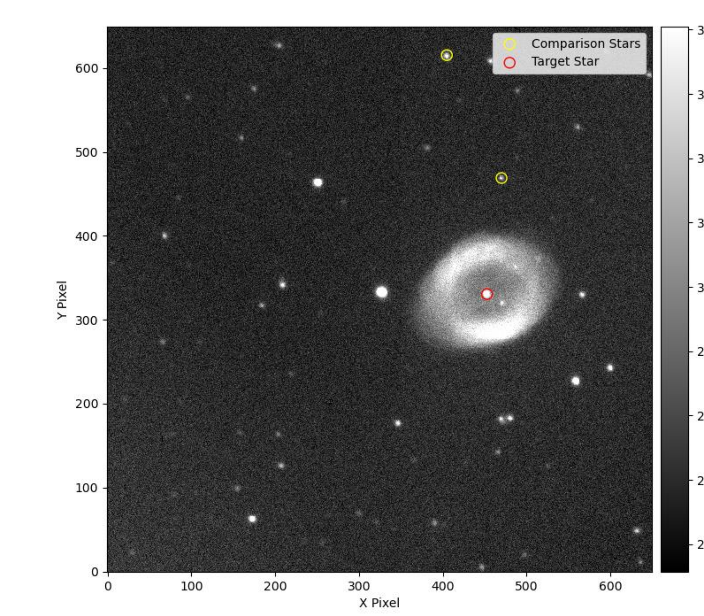

Figure 5: *Photometric Calibration. The central star -target star- (red) and comparison stars (yellow)*

Results

Table 2: Photometric Results for the Central Star of M57 in Johnson Filters.

Object Name	Date	Johnson Filter	Apparent Magnitude (m ± σ)
Central Star of NGC 6720	20 April 2024 (2460420.5 JD)	B	13.38 ± 0.01
		V	13.94 ± 0.02
		R	14.67 ± 0.02
		I	15.12 ± 0.02

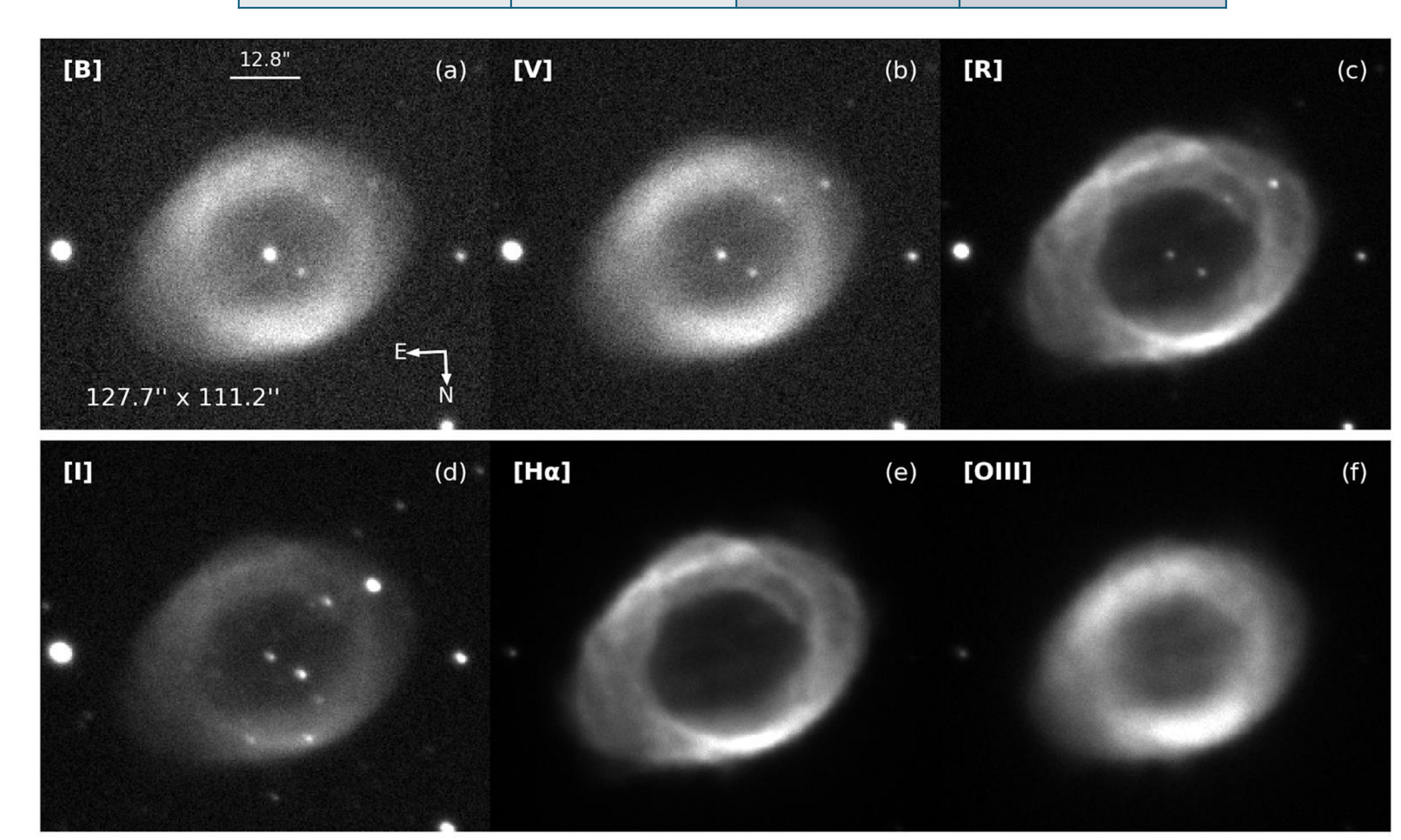

Figure 6: *Multiband Imaging of M57. The planetary nebula M57 is observed across multiple photometric bands: **(a)** [B], **(b)** [V], **(c)** [R], **(d)** [I], **(e)** [Hα], and **(f)** [OIII].*

Our analysis confirm the expected photometric characteristics of M57. The results contribute to a better understanding of the central star's brightness and the nebula's emission properties, supporting future studies on its evolution.

References

Scan the QR code to access the full list of references, source code, and observational data used in this study.