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Review on Photometric Study of Variable Stars

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Abstract: This literature review focuses on variable stars, which exhibit changes in brightness over time. This topic is vital in astronomical research, particularly due to the abundance of telescope data available in archives. The photometric study of variable stars is significant for understanding stellar evolution, classifying stars, and contributing to cosmological research. It enables precise distance measurements, examines exoplanetary systems, and identifies rare astronomical phenomena, thereby expanding our understanding of the universe. The study begins by outlining the fundamentals of variable stars and three methods for analyzing them: photometry, spectroscopy, and spectrophotometry. However, the focus of this study is solely on photometric studies. This work presents an overview of the photometric study of variable stars. Addressing research gaps in photometric studies of variable stars is crucial for improving our understanding of stellar behavior and evolution, with broader implications for astrophysics and cosmology. Future directions include conducting photometric studies on variable stars using machine learning to develop an automated variable star classification system utilizing online telescopic data archives.

Table of Contents

Acronyms/Abbreviations

ACCIMT - Arthur C. Clarke Institute of Modern Technologies
CCD - Charge Couple Devices
FT - Fourier Transformation
GCVS - General Catalogue of Variable Stars
HR diagram - Hertzsprung-Russell diagram
IRAF - Image Reduction and Analysis Facility
JD - Julian date
KASOC - Kepler Asteroseismic Science Operations Center
LCO - Las Cumbres Observatory
LS - Least Square

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1. Introduction

Let's start with the history of astronomy. Ancient peoples viewed the sun, moon, stars, and other celestial bodies as mysterious and divine. However, as they observed the periodicity in the motion of these bodies, they began to understand the science behind these phenomena. People used cosmic bodies for agriculture, timekeeping, weather forecasting, and navigation. This evolution marked the beginning of our understanding of celestial bodies. Among celestial bodies, stars play a crucial role in astronomy due to their significance in expanding our knowledge of the cosmos. Stars act as cosmic laboratories, carrying information about the universe in the form of photons. They are vital for establishing distances and the scale of the universe. Characteristics such as brightness, temperature, and chemical composition are used to classify stars and understand their evolutionary stages. By studying stars, astronomers can learn about the formation of star clusters and galaxies and investigate the early phases of the universe.

Ancient philosophers like Aristotle believed stars were static and emitted constant light. This view dominated cosmological thought until the 16th century. The first variable star, Omicron Ceti (later known as Mira), was discovered in the early 17th century. In 1596, David Fabricius described it as a nova, and later, in 1638, Johannes Holwards discovered its 11-month pulsation period. This discovery challenged the notion that stars were invariable. In 1669, Geminiano Montanari described the second variable star, Algol, as an eclipsing variable. John Goodricke accurately explained its variability in 1784. Later, G. Kirch recognized the Chi Cygni variable star in 1686, and G. D. Maraldi discovered the R Hydrae variable star in 1704. By 1786, eleven variable stars were known, with John Goodricke contributing discoveries such as Delta Cephei and Beta Lyrae. Since 1850, the number of recognized variable stars has grown significantly, especially after 1890, when photography enabled more efficient identification of variable stars.

Table-1 Discovery of Variable Starts [3]

Variable star	Discovery
Mira variables	Fabricius (1596)
Semiregular (SR) variables	Herschel (1782)
δ Cephei stars	1784, Pigott, Goodricke (1786)
RR Lyrae stars	Fleming (1899)
δ Scuti stars	Campbell & Wright (1900)
β Cephei stars	Frost (1902)
ZZ Ceti stars (DAV)	1964, Landolt (1968)
GW Virginis stars (DOV)	McGraw et al. (1979)
Rapidly oscillating Ap (roAp) stars	1978, Kurtz (1982)
V777 Herculis stars (DBV)	Winget et al. (1982)
Slowly Pulsating B (SPB) stars	Waelkens & Rufener (1985)
Solar-like oscillators	Kjeldsen et al. (1995)
V361 Hydrae stars (sdBVr)	1994, Kilkenny et al. (1997)

2. Variable Stars

A variable star is a star that undergoes changes in its apparent magnitude, meaning its brightness changes over time . These changes can occur over various timescales, from years to fractions of a second, with shifts in magnitude ranging from minor to significant. Even the sun is a variable star, experiencing a 0.1% change in energy output during its 11-year solar cycle. The latest edition of the General Catalogue of Variable Stars (GCVS-2023) lists a total of 59,102 named variable stars

Variable stars function as cosmic laboratories. Researching variable stars is important because it provides crucial information about various stellar properties such as mass, radius, luminosity, temperature, internal and external structure, composition, and evolutionary stages. These stars enable astronomers to examine dynamic processes such as pulsations, eruptions, and interactions in binary systems, offering a unique window into stellar evolution. Some variable stars, such as Cepheid variables, serve as distance indicators in the universe, allowing for precise measurements of cosmic distances. Moreover, the variability of stars offers an excellent testing ground for theoretical models of stellar structure and behavior. Often, the unique nature of a star's variability provides critical insights that lead to significant discoveries. This is why our literature review focuses on the study of variable stars.

2.1.1. Classification of Stars

The variable star's characteristic is defined by its variability. Star variability can be produced by fluctuations in radiated light or a partial eclipse due to external factors. Because of these factors, variable stars are typically classified as intrinsic or extrinsic variables (see Figure 1).

Intrinsic Variables: Intrinsic variable stars have luminosity changes due to the star periodically expanding and contracting. The primary types of intrinsic variable stars are:

I. Pulsating Variables: Pulsating variables are stars whose brightness and size change periodically as their outer layers expand and contract. This pulsation is a fundamental aspect of their natural evolutionary aging processes. Examples of pulsating variables include Cepheid variables, where the star's outer layers periodically expand and contract in a regular pattern.

II. Eruptive Variables: Eruptive variables are stars that experience sudden and short brightness increases, frequently accompanied by eruptions on their surfaces. These eruptions can take the form of flares, mass ejections, or other types of explosions. The variability of these stars is caused by dynamic processes occurring on or near their surfaces.

III. Cataclysmic Variables: Cataclysmic variables are stars that experience severe and often irreversible changes in their characteristics. This category includes novae and supernovae, which occur when a star's brightness suddenly and dramatically increases as a result of explosive events such as nuclear fusion or the collapse of a large star. These events cause significant changes in the star's structure and characteristics.

IV. X-ray Variables: X-ray variable stars are binary systems that usually consist of a compact object, such as a neutron star or a black hole, in close orbit with a companion star. The massive gravitational interaction between the compact object and its companion causes the emission of X-rays.

Extrinsic Variables: Extrinsic variables are stars that vary due to external factors such as rotation or eclipses. In such cases, the star's overall energy output remains relatively constant (or is not the primary cause of its variability), but the amount of light observed from Earth's perspective changes. The primary types of extrinsic variable stars are:

I. Eclipsing Variables: Eclipsing variables change because the orbital planes of the star and its companion overlap with our line of sight to the system. When one component passes in front of the other, as seen from our vantage point, the light output decreases significantly.

II. Rotating Variables: Rotating variables change for a variety of reasons. Star spots, which rotate in and out of view, can cause the star to fade and brighten. In closely rotating pairs with tidal locking, one star can superheat the side facing it, reflecting more energy into space and producing more apparent brightness when rotated into view. Some rotating variables involve stars orbiting near enough to be stretched into non-spherical shapes by gravity, changing the area of their surface visible to observers on Earth and impacting their brightness accordingly.

III. Microlensing Variables: Microlensing variables become brighter and then fade because a gravitational lensing object passes in front of the star from our perspective. This lensing effect magnifies light from a distant object.

The classification of variable stars has evolved over the last century, changing as our understanding develops and new celestial objects are discovered, leading to changes in classification criteria.

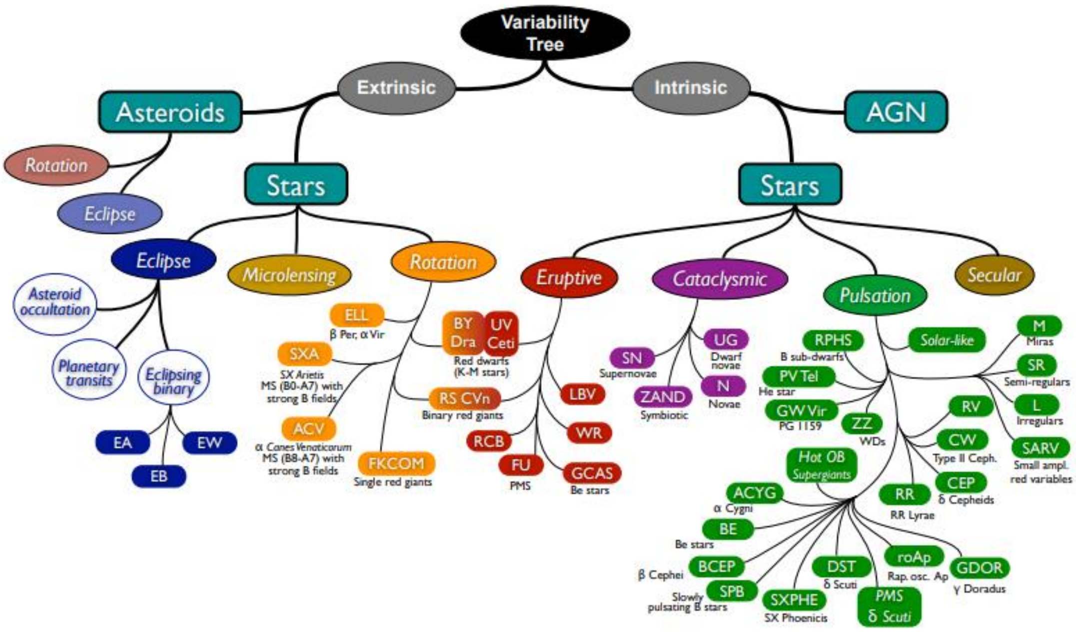

Figure-1 Variability of Star Tree [7]

3. H-R Diagram Distribution

The Hertzsprung-Russell diagram (HR diagram) is similar to the periodic table of elements but for stars. The HR diagram shows the mass, radius, lifetime, distance, temperature, spectral type, and luminosity of stars. The Instability Strip is a zone on this diagram that runs above and below the main sequence and includes the A, F, and occasionally G classes. Stars in this strip are capable of instability and pulsation, resulting in brightness variations.

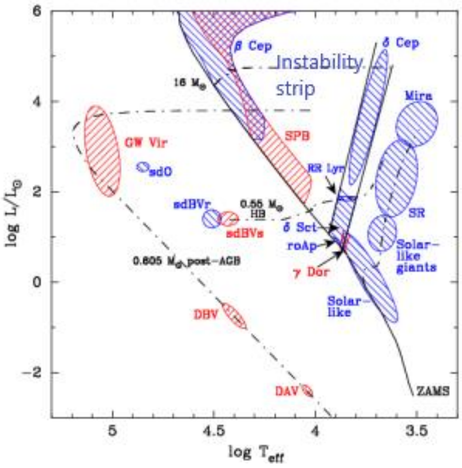

Figure-2 Instability Strip of variable stars in HR Diagram [8]

4. Observation

Variability in stars is primarily noticed as changes in brightness, which is the most common type of variability. However, stars show different types of fluctuation, especially changes in their spectrum. Spectral variations are changes in the distribution of a star's radiated light at various wavelengths. This range of variability provides astronomers with various kinds of observational data to study. By combining information from light curves, which illustrate how brightness changes over time, with an investigation of observed spectrum shifts, astronomers can typically determine the fundamental causes of a star's variability. Variable stars are usually researched using photometry, spectrophotometry, and spectroscopy:

I. Photometry: Photometry is the analysis of a variable star's brightness over time. Astronomers can produce a light curve, or graph, by taking images of the star at various intervals. Photometry examines periodic changes in a variable star, providing insights into its intrinsic characteristics and the fundamental mechanisms that cause the variability.

II. Spectroscopy: Spectroscopy is the study of a variable star's light using a spectrometer, which separates the light into its constituent wavelengths. By observing its spectrum, astronomers can identify the characteristics of a star, including the elements present, radial velocities, and physical properties. Spectroscopy is essential for understanding the physical processes that cause the variability of variable stars, such as pulsations, mass transfer in binary systems, and the presence of circumstellar material.

III. Spectrophotometry: Spectrophotometry combines the principles of spectroscopy with photometry. It involves determining the brightness of a variable star across several wavelengths. This technique provides extensive information on the star's spectral energy distribution, allowing astronomers to better understand how brightness varies across the spectrum. Spectrophotometry is very useful in examining the temperature, composition, and atmospheric aspects of variable stars.

Variable star photometry examines how a star's brightness changes over time; spectrophotometry expands this to several wavelengths; and spectroscopy examines a star's spectrum in detail, offering significant information about its composition, velocity, and physical features [9].

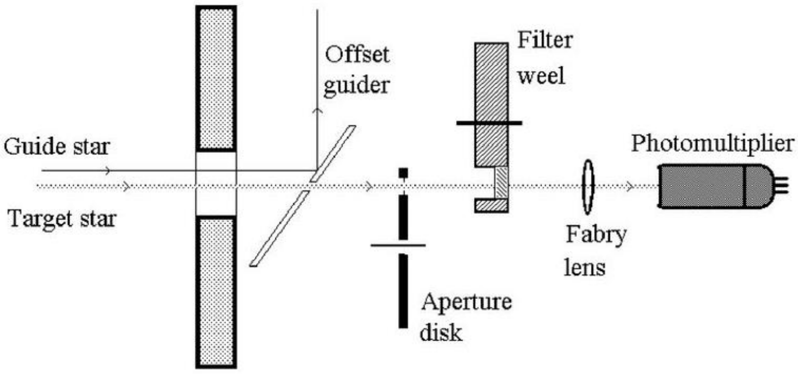

Figure-3 Classical - One Channel Photometer

Apparent magnitude of a celestial object is given by the following equation.

$$m = -2.5log\left(\frac{F}{F_0}\right) + C \tag{1.1}$$

Where,
m - Apperant magnitude of celestial object
F - Measured irradiance using spectral filter
F_0 - Reference flux (zero-point) for that photometric filter.

Photometry is used to study variable stars using techniques such as relative photometry, which compares the brightness of a target object to stars with known fixed magnitudes, and differential photometry, which measures the brightness of a target object while also measuring nearby stars in the starfield. Differential photometry is an effective technique for investigating variable stars. It involves observing the target star and a comparison star with the same photometric instrument and filters. By analyzing the brightness difference between the target and comparison stars, it can quickly eliminate the need for certain calibrations during observations. This approach is also useful for reducing the effect of air extinction on magnitude.

5. Instrumentation

5.1. Telescope

Telescopes are fundamental instruments for astronomical observations, including variable star astronomy. They are crucial in photometry because they capture light from the object being examined. Telescopes are classified into two types based on how light behaves within them: refraction telescopes, which use lenses, and reflection telescopes, which use mirrors. Refraction telescopes, which use lenses to focus light, are subject to optical defects such as chromatic and spherical aberration. Modern reflection telescopes, which use parabolic mirrors, successfully reduce these aberrations, resulting in better performance in scientific observations than refraction telescopes.

Reflection telescopes are further classified into two basic types based on their configuration: Newtonian reflection telescopes, which use a flat mirror as their secondary mirror, and Cassegrain reflection telescopes, which use a hyperbolic mirror. While parabolic mirrors in reflection telescopes effectively minimize chromatic and spherical aberrations, they generate a new optical error called comatic aberration, which results in distorted images with a comet-like tail. Cassegrain reflection telescopes reduce comatic aberration by using a secondary hyperbolic mirror, resulting in higher image quality than Newtonian reflectors. The Arthur C. Clarke Institute of Modern Technologies in Sri Lanka has a GOTO 45 cm diameter Cassegrain reflection telescope dedicated to studying variable stars. This advanced telescope, located within the observatory, allows Sri Lankan astronomers and researchers to examine and analyze variable stars.

Figure-4 GOTO 45cm diameter Cassegrain reflection telescope at ACCIMT [10]

5.2. Online Observatories

Many telescope sites and space-based observatories offer their services to the public via the internet, allowing users to view their facilities remotely. This helps those who don't have access to observation sites by enabling them to collect relevant data from a distance. They provide training sessions and the software required for online observation. The time slots must be reserved in advance, and all the requirements and specifics are listed on their websites. Some telescopes in space collect information about stars, and the images they record have significantly less background noise than telescopes on the ground. Kepler is an example of a space telescope.

In addition to the physical telescope, various telescopic datasets are accessible to everyone for variable star astronomy. For example, the Kepler Asteroseismic Science Operations Center (KASOC) provides astronomers with asteroseismological data from NASA's Kepler and K2 spacecraft. This data repository contains essential information that can help with the understanding and study of variable stars. Currently, many astronomers can access these essential datasets via KASOC at https://kasoc.phys.au.dk. KASOC serves as a centralized hub, enabling efficient and orderly access to asteroseismological data collected by NASA's Kepler and K2 missions. This platform allows for the exploration and analysis of stellar variability, assisting astronomers in their studies on variable stars. The Kepler mission covered specific regions of space, and the mission data became available via their data archives after some time. Anyone can gather and analyze this data using the tools provided, enabling academics to conduct research on variable star astronomy **[11]**.

5.3. Filters

Filters are optical devices used in astronomy to isolate specific regions of the electromagnetic spectrum while conducting observations. These filters play a crucial role in photometry by allowing astronomers to examine the intensity of light in specific wavelength ranges, providing valuable information about the characteristics of celestial objects. In variable astronomy, filters are used to monitor changes in brightness across different wavelengths, enabling astronomers to investigate variations in the spectral energy distribution of variable stars. By focusing on specific regions of the spectrum, astronomers can track the brightness of a variable star over time.

To obtain precise photometric observations with imaging equipment, it is important to choose the right photometric filter or filter set. There are two common types of filter sets: Johnson/Bessel and Kron/Cousins. The Johnson/Bessel type is suitable for use with a photomultiplier tube, providing effective performance in specific configurations. The Kron/Cousins type, on the other hand, is more suitable for applications that require a Silicon CCD, offering optimal performance with this particular detector technology. Selecting the appropriate filter type is important, depending on the characteristics of the measuring system.

The UBVRI filter system is the most widely used system, consisting of filters for the ultraviolet (U), blue (B), visual (V), red (R), and infrared (I) ranges, providing a broad spectrum of optical wavelengths. Both Johnson/Bessel and Kron/Cousins filter sets use the U, B, and V filters but differ in their use of the R and I filters. These variations are important because the R and I filters are built specifically to match the response of the detector being used, ensuring accurate and reliable photometric measurements [12].

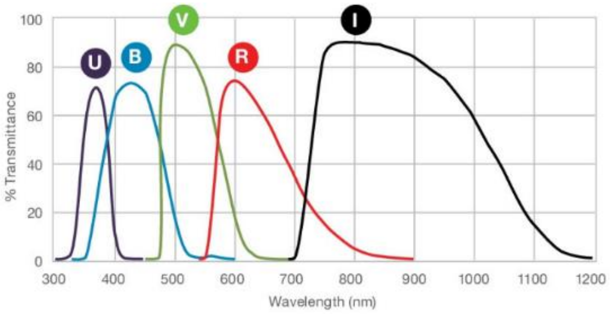

Figure-5 Johnson/Bessel UBVRI Filters transmittance versus wavelength graph [12]

5.4. CCD Camera

A CCD camera acts like a grid of photometers, capturing and recording photons from all sources in its field of view. Charge-coupled devices (CCDs) are sensitive photon detectors used in telescopes to generate images, replacing traditional film or photographic plates. CCDs were invented in the late 1960s and have recently found use in digital cameras, photocopiers, and various other devices. The inventors of CCDs, Willard Boyle and George E. Smith, received the Nobel Prize in Physics in 2009 for their revolutionary achievement. A CCD is a small microchip that captures the focused light gathered by the telescope. The microchip has a large number of individual light-sensitive components known as pixels. Each pixel is significantly small, measuring around 10 micrometers square, and is printed on a silicon piece that is around 50 micrometers thick, similar to the thickness of tissue paper. The preceding photographs show astronomical CCDs from one of LCO's telescopes, including both the front and back viewpoints [13].

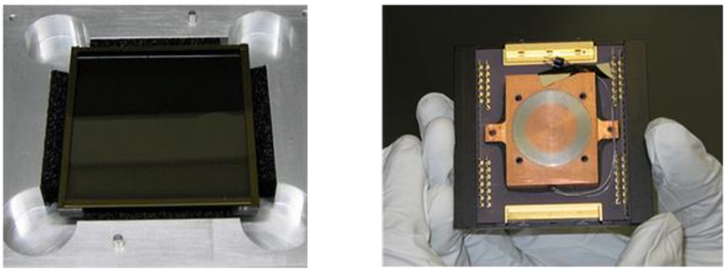

Figure-6 Front and Back View of a CCD [13]

When light strikes a pixel, electrons are released from atoms within it. To calculate the amount of light on each pixel, the number of electrons released must be counted. This involves measuring the charge on the pixel located at the end of the grid's final row. After measuring this charge, it is eliminated, and all other charges in the row are shifted to that same corner pixel. The process is then repeated for the next charge in line, and so on until all charges in that row have been processed. The charges in the remaining rows are then pushed over one row, and the cycle is repeated. Remarkably, the entire chip can be "read" in less than ten seconds. This reading mechanism distinguishes CCDs from other devices, such as photodiodes and CMOS devices, which also convert photons into electrons **[14]**.

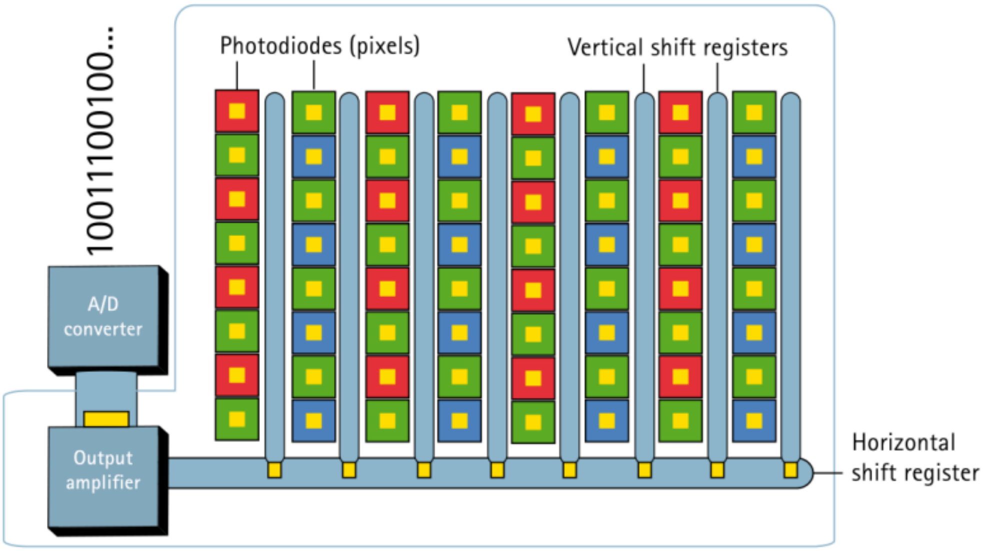

Figure-7 Architecture of a Charge Coupled Devices semiconductor image sensor [14]

As the telescope's movement is synchronized with the Earth's rotation, the camera can maintain a constant focus on a given spot in space for extended periods. When the CCD is exposed to the sky for a long duration, it collects a greater number of photons, enabling it to detect fainter and more distant celestial objects. In astronomical applications, CCD exposures can take seconds, minutes, or even longer, in contrast to digital cameras' shorter exposure times (usually a fraction of a second). To reduce the impact of thermal noise, CCDs in telescopes are normally kept at very low temperatures, ranging from -50°C to -100°C. Maintaining a low temperature reduces the thermal energy of electrons within CCD atoms, preventing them from escaping on their own and contributing to thermal noise. This enables precise photon counting from astronomical objects.

6. Data Reduction

The following raw CCD images were taken for the purpose of the data reduction procedure. Data reduction in astronomy requires the use of a number of software and tools, including IRAF (Image Reduction and Analysis Facility), FTOOLS, CASApy, DRO, Visual Spec, and Gild. Analyze the data obtained from images captured by a CCD camera using any of the data reduction applications, construct light curves for a chosen variable star and a reference star, then calculate the phase of the resulting curve. In the procedure, take into account the use of IRAF software **[15]**. IRAF carries out the following main tasks:

- Reducing noise in CCD-captured images.
- Calibrating stellar spectra.
- Conducting photometric studies.

7. Calibration

he first stage in minimizing noise in the raw CCD image involves addressing various sources of noise, including photon noise, thermal noise, readout noise, quantization noise, and sensitivity changes. Readout noise and quantization noise are inherent to the CCD camera's construction and cannot be improved by the user. However, thermal noise can be minimized through cooling, and if not, it can be quantified and subtracted from the image. Calibration frames are images taken with specific methods and settings to improve the quality of light frames. The purpose of calibration frames is to modify light frames, or actual photographs of the target, by removing various types of noise, vignetting, and imperfections such as dust in the optical setup. This smoothing procedure cleans up the light frames before stacking them together to form the final image.

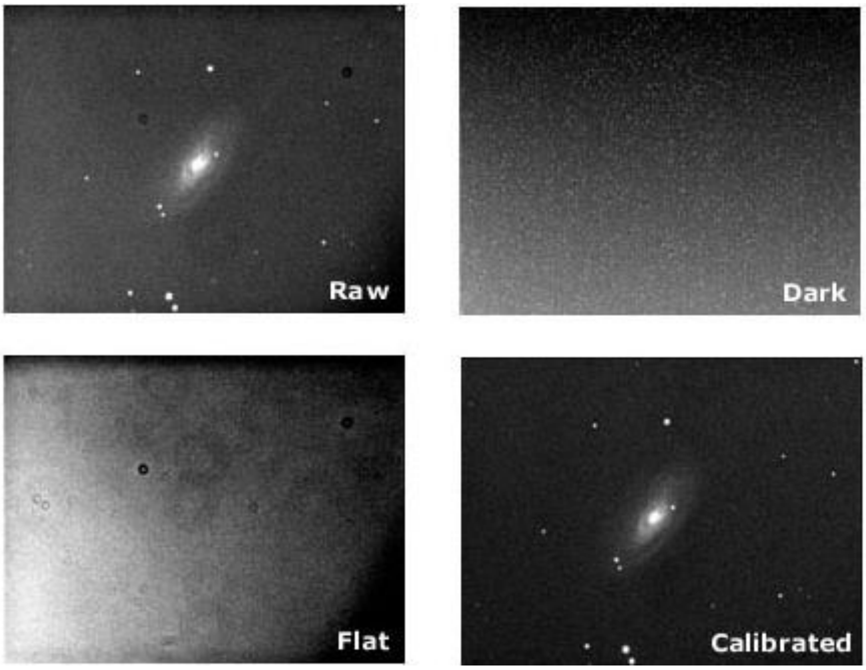

Figure-8 Calibrated Light Frame [16]

- ***Dark Frame:*** A dark frame is an image captured with no light reaching the CCD. Dark frames are used to remove dark current, sensor glow, and hot and dead pixels from the light (raw) frame.

- ***Bias Frame/Zero Frame:*** A bias frame is a zero-second exposure that corrects the electrical offset in the CCD.

- ***Flat Frame:*** Flat frames are designed to eliminate the vignetting and uneven image shining produced by dust or dirt in the optical system. Additionally, with uniform lighting during flat-frames, the processing software can determine how differently the pixels react to light.

The median method was used to combine the bias frames, resulting in a single master bias frame with minimum noise. The flat frames were combined using a median method which produced a single normalized master flat frame for each filter. The master bias frame was subtracted from the object frames (which are images of celestial objects). The object frame was subsequently divided by the master flat frame for each filter. [16]

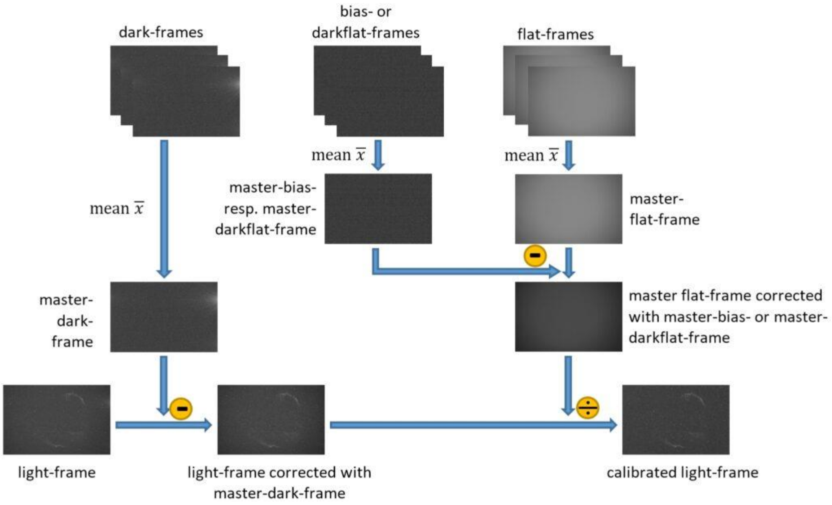

Figure-9 Schematic illustration of the use of the calibration images [17]

IRAF uses commands to combine dark frames into a master dark and subtract the dark from science frames. This also applies to the flat frames. This is how IRAF calibrates raw CCD images using a series of procedures that commonly include bias subtraction, dark current correction, and flat fielding. These processes improve the quality and accuracy of the final calibrated image.

7.1.1. Alignment

When taking long-exposure images with telescopes, the images may show objects moving due to tracking issues. It is difficult to assign a precise location to objects (in this case, variable stars and comparison stars) in all photos. Furthermore, it is impossible to manually analyze the complete collection of images. The most suitable course of action is to modify and arrange the images so that each object in each photo may be allocated a single position, and then program IRAF to execute the analysis on these locations (objects).

Initially, the collected pictures were organized according to the filter used. The pictures were then separated into subgroups within each filter group, each of which had a specific number of images. These subgroups moved equally linearly over the star field. To deal with this, an IRAF script was written to compute the vertical and horizontal gradients of the linear motion. The script was then run to shift and align all photos in each subgroup. This alignment method was used consistently for all subgroups.

7.1.2. Computation

These procedures involve the use of specific commands within the IRAF software.[18]

- The images captured by a CCD camera were categorized based on filters using the provided commands, listing them separately.
- The images, sorted by filters (filter-wise), were displayed individually to identify and eliminate unclear frames.
- All clear and useful images were grouped together to simplify the shifting process.
- For shifting grouped images, a reference image is essential for generating a coordinate file.
- The entire set of grouped images was shifted collectively using the reference coordinate file.
- With IRAF, star magnitude values were extracted from the images.
- The corresponding Julian dates for all images were also extracted using an IRAF command.
- The mentioned steps were carried out individually for chosen filters and the shifted images.
- A light curve graph, plotting magnitude against Julian date, was created for the variable star and the reference star in the chosen filters.

The light curve obtained from the CCD images using IRAF.

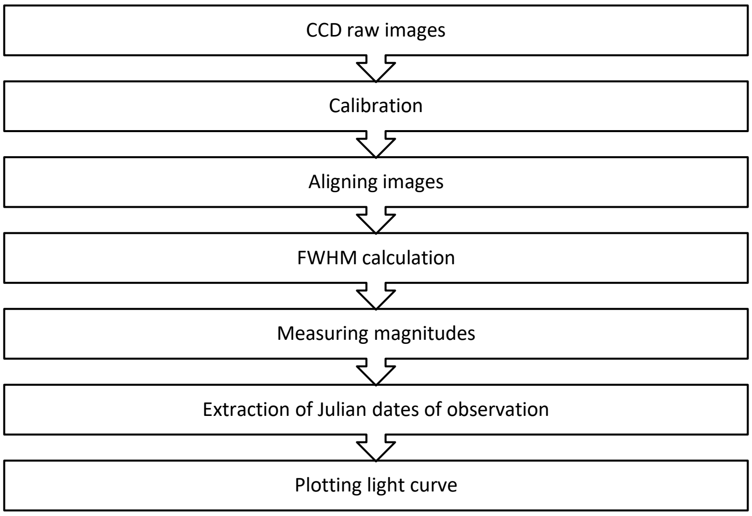

Figure-10 Data reduction and analysis procedure [19]

8. Analysis

In previous sections, the light curve has been constructed from the CCD images using IRAF.

8.1.1. Light Curve

A light curve of a variable star is a graph that shows its magnitude over time. Differential magnitude is commonly used for convenience. Time is typically measured in Julian dates, which are a continuous count of days starting at noon on January 1, 4713 BC. The Julian date includes a decimal portion indicating the hours, minutes, or seconds elapsed since the previous Julian date. This light curve is unique and offers significant insights into the star's internal structure, composition, and seismology. Extracting this information requires an in-depth analysis of the light curve.

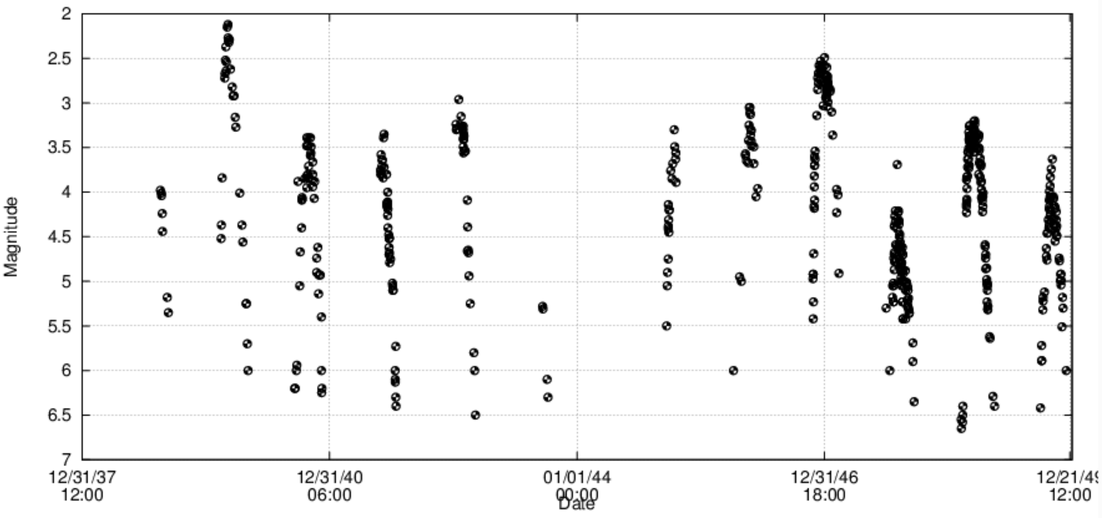

Figure-11 Light curve of Mira variable star [19]

Light curves are brightness profiles of variable stars over time, representing time series data. Analyzing light curves involves using time series analysis techniques to derive useful statistics and properties. Through time series analysis, one can determine the number of pulsations in a star, as well as their durations and amplitudes.

VARTOOLS, like IRAF, is a valuable tool for handling and analyzing astronomical time series data. It is a command-line application used by astronomers to study light curves, which illustrate how the brightness of astronomical objects changes over time. VARTOOLS offers a variety of commands for processing and analyzing light curves, including calculating variability and periodicity statistics, filtering and modifying light curves, and predicting patterns. It is designed to efficiently manage large volumes of light curves, executing each command sequentially and passing the results to subsequent commands. The statistics from each stage are stored in an easily readable format. VARTOOLS has proven useful in various astronomical research projects, including space astrometry missions such as Hipparchus, CoRoT, and Kepler. In this study, VARTOOLS was used to analyze light curves. This included normalizing light curves, converting them into phase amplitude diagrams, and performing advanced analyses such as least square spectrum analysis and discrete Fourier transformation [19].

Table-2 VARTOOLS Commands used for light curve analysis [19]

Task	**VARTOOLS Command**
Least Square spectral analysis	LS
Discrete Fourier transformation	dftclean
Conversion of light curves into Phase amplitude	phase

9. Estimations

Raw images of star fields are captured using a telescope system equipped with filters and CCDs. These photos are then calibrated using dark, flat, and bias frames to minimize noise and enhance image quality. The noise-reduced images are processed using computer programming, with a focus in this work mainly on IRAF software. The next step is to extract light curves from the processed images. Light curves are crucial for analyzing how the brightness of variable stars changes over time. IRAF software is used to analyze these light curves, providing information about the properties and characteristics of variable stars. Through the analysis of variable star light curves, several intrinsic properties can be derived, offering valuable insights into their nature and behavior, such as:

- **Periodicity:** The periodicity of a variable star, denoting the time taken to complete one cycle of brightness variation, can be inferred from its light curve. Determining the period enables astronomers to classify variable stars into distinct categories based on their variability mechanisms.
- **Amplitude:** The amplitude of brightness variation, quantifying the difference between the maximum and minimum luminosity levels, offers insights into the energy processes driving variability and the intrinsic properties of the star.
- **Evolutionary Stage:** The shape and characteristics of the light curve can provide clues about the evolutionary stage of the variable star, aiding in the classification and understanding of stellar evolution processes.
- **Variability Type:** Analysis of the light curve morphology enables classification of variable stars into various categories, such as pulsating variables, eclipsing binaries, or cataclysmic variables, each exhibiting distinct variability patterns.

The estimation and extraction of data from variable star light curves yield valuable insights into the intrinsic properties and dynamic behavior of these celestial entities. By discerning properties such as periodicity, amplitude, evolutionary stage, and variability type, astronomers can deepen their understanding of stellar astrophysics and contribute to broader cosmological inquiries. This study underscores the significance of robust methodologies for data extraction and highlights the rich scientific dividends derived from comprehensive analyses of variable star light curves.

10. Conclusion

In conclusion, this literature review has established a comprehensive foundation for understanding the background and characteristics of variable stars, as well as the methods used to study them. By examining the classification of variable stars and their distribution on the Hertzsprung-Russell (H-R) diagram, we gained valuable insights into their properties and evolutionary paths. The importance of photometry was emphasized through a detailed discussion of observational techniques and necessary instrumentation, including telescopes, filters, and CCD cameras. The review meticulously covered the data reduction process, underscoring the critical steps required to convert raw data into usable datasets with high accuracy. This was followed by an in-depth analysis of light curves, which are essential for uncovering the dynamic behaviors and fundamental physical processes of variable stars. Finally, the review delved into various parameters crucial for understanding variable stars, such as variability, brightness variation, contraction and expansion dynamics, pulsation times, and average density. Each of these aspects provides a unique perspective on the nature and characteristics of these fascinating celestial objects. Overall, this literature review serves as a robust platform for further research and exploration in the field of variable star studies.

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12. Conflict of Interest

The author declare no competing conflict of interest.

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