

Light curve analysis of SZ Lyn

By

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Declaration

This dissertation describes the internship training and industrial project work carried out between November 2017 and February 2018 as an intern at Arthur C. Clarke Institute for Modern Technologies (ACCIMT), Katubedda, Moratuwa under the supervision of Industrial and Academic supervisors.

This dissertation has not been submitted in whole or in part for any degree or diploma at this or any other university and is submitted to the Department of Physics in the university of Sri Jayewardenepura on

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I sincerely thank all the staff members of Space Application Division of ACCIMT

I thank my family members because I always receive good support from my family because none of this could have happened without them.

Last but not least, I would like to thank my all dearest friends, who contributed in many ways in my life.

Abstract

For three months from November 2017 to February 2018, I did an internship at Arthur C Clarke Institute for Modern Technologies, Katubedda, Moratuwa. This internship project is a part of my B. Sc. Special Degree in Physics offered by the Department of Physics, Faculty of Applied Sciences, University of Sri Jayewardenepura.

I worked on a short term industrial project on “Light curve analysis of SZ Lyn”. Through the project, I did not only gain a lot of knowledge but also had a great chance to sharpen my skills in a professional working environment in astronomy.

According to my short term industrial project, I was focused on SZ Lyn, most comprehensively studied high-amplitude δ -Scuti type star, discovered by Hoffmeister in 1949 with an ultra-short period of 0.120534 days. It was observed by using the 20-inch reflective telescope at the Mount Abu observatory, Rajasthan, India on 12th November 2016. This telescope facility has an Electron Multiplying Charged Coupled Device (CCD) with a filter wheel comprising visible (V), Blue (B), Red (R) and Infra-red (I) filters. 692 images were taken through V, 694 images in R and 1377 images were taken through I with short exposures.

The basic photometric reductions were done using the Image Reduction and Analysis Facility software package and the differential photometry was applied to reduce noise and eliminate the common atmospheric effects. The differential light curves were subjected to Fourier transform technique and frequencies were determined. To detect periodic signals in time-domain data of the SZ Lyn variable star, the multiband periodogram, a general extension of the well-known Lomb-Scargle was approached. The calculated fundamental pulsation periods for SZ Lyn for filters V, R and I are 0.11961082, 0.11971933 and 0.11889468 respectively. The second harmonic has twice the frequency of the fundamental and the third harmonic is three times the frequency of the fundamental. The Second and Third harmonic pulsation periods were calculated in each filter. These results were compared with those found in previous studies.

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List of Abbreviations

ACCIMT	Ather C. Clarke Institute for Modern Technologies
IRAF	Image Reduction and Analysis Facility
CCD	Charge Couple Device
JD	Julian Date

Chapter 01

Arthur C. Clarke Institute for Modern Technologies

This chapter deals with the information about Ather C. Clarke Institute for Modern Technologies in Katubedda, Moratuwa.¹

1.1 Introduction



Figure 1 Image of Arthur C Clarke Institute for Modern Technologies, Katubedda, Moratuwa.

ACCIMT is a state institution for research and development and training. The institute is a specialist in microelectronics, electronics, telecommunications, information technology, space technology, robotics, and the latest in technology and related areas. ACCIMT was established as Statutory Boards under the Act No 11 of 1994, it is currently in the form of the Ministry of Science, Technology, and Research in the institutional form. ACCIMT offers various technical services such as test and measurement services, equipment calibration, advanced electronic hardware recovery services and consultancy services. Especially advanced technology labs that offer these services to supervise special engineers and scientists.

¹ available at ACCIMT, http://www.accimt.ac.lk/accimt/?page_id=26

1.2 Vision of ACCIMT

“To be a leading innovation Centre for Modern Technologies in the region.”

1.3 Mission of ACCIMT

Become a premier institute for exploration, technology transfer, research & development and human resource enhancement, enabling solutions in applications of modern technology to improve the capabilities of industries and commercial establishments and thereby enhancing national wealth

1.4 Mandate of ACCIMT

- Accelerating the introduction of modern technologies such as Communication and related Sciences, Information Technology, Electronics, Micro-electronics, Space Technologies, Robotics, Photonics and New Materials to Sri Lanka by initiating, promoting and conducting research and development in the application of above technologies.
- Providing research and development support to the Government and private sector undertakings in the application of above technologies.
- Training of personnel in above technologies to meet the needs of the government and private sector undertakings.
- Promoting future studies.

1.5 History of ACCIMT

In 1984 The Arthur C Clarke Center for Modern Technologies (ACCMT) was established in the Act No. 30 of 1984 of Parliament to accelerate through the provision of new technology in the field of telecommunication, computer, energy, space technology and robotics, training and research facilities. In 1986, basic infrastructure was founded and technical work began in 1987. With the introduction of the new Science and Technology Act in 1998 center was renamed as the Arthur C Clarke Institute for Modern Technologies (ACCIMT).

1.6 Current Services

1.6.1 Research and Development

Existing research and development laboratories with advanced state-of-the-art equipment and computer systems assist in the organization of business research and product development related to electronics, telecommunications, and microprocessor-based hardware. At present, the institute has implemented various research and development projects with demand from government and private sector for the promotion of advanced technical products of local manufacturers. The research and development group is committed to competitive design and development activities internationally.

1.6.2 Continuing Professional Development Programmes

From time to time the Institute announces high technical training programs for local professionals and occasional senior managers. These short-term training programs have been developed to obtain more information on microelectronics, communications, remote sensing and GIS and computer systems fields. These short-term courses have a fair component of hands-on sessions.

1.6.3 Consultancy Services / Industrial Assistance

The professional staff of the Institute is dedicated to assisting in managing technical expertise and laboratory facilities for Advanced Technological Systems Management and Services. Local industries provide indigenous industries with the support of management of modern industrial systems, such as microprocessor-based machinery, telecom systems, information systems and computer networks etc. The technical services division also provides timing and calibration services for modern equipment.

1.6.4 Training Programme for Youth

Provides training programs on Electronic Engineering and other innovative topics to help the younger generation to develop their skills. These programs are conducted with other industrial agencies for domestic/foreign cooperation.

The institute commenced work at the 45 cm Cassegrain Reflecting Telescope Donated by the Government of Japan and launched a district level Astronomy Training

Program for school children. This program covers lectures and practical observational sessions on astronomy.

1.6.5 Library / Information Services

The institute has introduced Library Services (Membership) to meet the current demand for latest scientific and technical information by decision makers and technical and non-technical professionals in public and private sectors.

1.6.6 National and International Links

ACCIMT works closely with local universities, particularly the University of Moratuwa and other industrial institutions. It is closely tied to a number of cooperative programs that are currently under consideration, closely with foreign universities as well as UN agencies.

1.7 Founder Patron



Figure 2 Image of Sir Arthur C. Clarke

His father was a small farmer. Little Clarke was educated at the elementary school "Huysh" in the village before moving to public service. From childhood, he was influenced by little Clarke.

² Available at : <http://rudysbooks.com/arthurclarke.jpg>

Sir Arthur C. Clarke, popularly known as Sir Arthur, born at Minehead in the U.K., chose to live in Sri Lanka from 1956. Thus he enriched Sri Lanka with his vision, writings, and predictions and brought fame to this island for a period of over half a century.

Sir Arthur was known to many as a superb science fiction writer. His fiction had a specialty; they were based on some fundamental scientific elements and therefore many of the creations were not impossible. Similar events could actually materialize some day - in a few years or few centuries. Perhaps his early scientific background, experience at the Royal Air Force, U.K. during the Second World War as a RADAR technician and the Bachelors' degree he earned subsequently at Kings College, London in mathematics and physics enabled him to author realistic science fiction. He also wrote a number of popular nonfiction books and technical articles.

The most acknowledged of the technical articles which Sir Arthur published is the article titled "Extra-terrestrial Relays: Can Rocket Stations Give Worldwide Radio Coverage?" in the Journal "Wireless World" U.K. in October 1945. He calculated and showed that at 36,000 km above the equator, it was possible to have geostationary satellites and with three such satellites properly placed in orbit, global communication could be achieved. This was long before man-made satellites were launched. At ACCIMT, we are particularly grateful to him for this great work.

Sir Arthur C. Clarke loved and cared for nature. In Sri Lanka, he first settled down at Unawatuna on the south coast. He enjoyed scuba diving and was very interested in underwater exploration. Indeed, he was an explorer of underwater and above water, one could say covering the entire universe.

In the early part of the nineteen-eighties, the government was interested in setting up a Centre for Modern Technologies. A bill to bring in legislation through Parliament was prepared around 1983. The scientists and administrators associated with this preparation thought that it would be great to associate Arthur C. Clarke with this modern technologies institution. When contacted, Sir Arthur readily agreed to lend his name. Not only did he help by lending his name but also went on to donate the prize money he received from the prestigious Marconi Award. The initial equipment was obtained through a UN grant and the government undertook to bear the recurrent expenditure including salaries of staff. Thus, the Arthur C. Clarke Centre for Modern Technologies was born. Later, by another

Act of Parliament (Science & Technology Development Act No.11 of 1994), the center was renamed as the Arthur C. Clarke Institute for Modern Technologies. Sir Arthur C. Clarke was the Patron of this institute until he passed away in March 2008.

As the honorary Patron, Sir Arthur often graced the ceremonial functions of the Institution. He was a real inspiration and provided much guidance to the Institute and its staff. He was kind, humane and generous. Sir Arthur donated a large number of books to the library of the ACCIMT, including those authored by him and others. The Institute will continue to benefit from these valuable collections.

Sir Arthur C. Clarke also functioned as the Chancellor of the University of Moratuwa from 1972 to 2002. He was awarded an honorary doctorate by the University of Moratuwa in recognition of his achievements and services.

The staff at the Arthur C. Clarke Institute for Modern Technologies will fondly remember Sir Arthur. So will the public of Sri Lanka.

Sir Arthur C. Clarke was nominated for a Nobel Peace Prize and a Nobel Literature Prize in 1994 and 1999 respectively. In 2000, he was knighted by the United Kingdom in a ceremony held in Colombo. The 2001 Mars Odyssey orbiter is named in honor of his work. On the 14th of November, 2005, Sir Arthur C. Clarke was conferred Sri Lanka's highest civilian award, the 'Sri Lankabhimanya' (The Pride of Sri Lanka), for his contributions to science and technology and his commitment to his adopted country.

1.8 Governing Ministry

The ACCIMT, was under the purview of the Ministry of Higher Education in 1984 was brought under the purview of the Ministry of Industries, Science, and Technology in 1990. It came under the purview of the Ministry of Science and Technology in August 1994. With the establishment of the new Ministry for Economic Reform, Science and Technology, in December 2000 the ACCIMT too was transferred under its purview. In 2010, the institute came under the purview of the newly constituted Ministry of Technology and Research.

Chapter 02

Space Applications Division

This chapter deals with my experience and I described what I have learned in ACCIMT. Before that there is a small description of Space Applications Division, Staff members and the biggest telescope in Sri Lank.

2.1 Introduction

Space Applications Division is involved in the area of Astronomy and RS / GIS (Remote Sensing / Geographic Information Systems) and is responsible for the Sri Lankan largest optical telescope facility, GOTO 45cm Cassegrain telescope. Employees of space applications division collaborate closely with local universities, and telescopes are used to study basic research in astronomy. The Space Applications Division has launched various programs to popularize astronomy and space science among school children.

ACCIMT was named the National Focal Point (Center) for Space Applications in Sri Lanka at the Ministerial Conference for Space Applications for Development in Asia and the Pacific, held in Beijing in 1994.

Space Applications Division Has identified the need for a National Platform to exchange and exchange knowledge and experiences on GIS, Remote Sensing and Global Positioning Systems to address the socioeconomically issues pertaining to the management of spatially disbursed resources in the Island ACCIMT has organized several National Conferences.

2.2 Staff members of Space Applications Division

- **Mr. Saraj Gunasekara** –*Senior Research Scientist (Astronomy) / Acting Director (Space Technology & Application)*
- **Mr. Indika Medagangoda** – *Research Scientist (Astronomy)*
- **Mr. Janaka Adassuriya** – *Research Scientist (Astronomy)*
- **Mr. T. Chandana Peiris** – *Research Scientist (Astronomy)*
- **Mr. A. R. Mohamed Rila** – *Research Scientist*

- **Mr. Buddika Sampath Marasinghe** – *Research Scientist*
- **Mr. K. Mahindapala- Research Engineer** – *IT & Space Technology*
- **Ms. Nilushika Jayawardhana** – *Research Scientist*
- **Mr. V M I Chathuranga** – *Research Engineer*
- **Ms. Aruni Dissanayake** – *Management Assistant*
- **Mr. Kamal Shantha Perera** – *Lab Assistant*

2.3 The biggest telescope in Sri Lanka

In 1996, ACCIMT conducted the UN / ESA Workshop on Basic Space Astronomy as a result of the launch of the GOTO 45cm Cassegrain telescope donated by the Japanese Government. This is the largest telescope in Sri Lanka and is used to basic research studies in astronomy as well as for school and university students to teach astronomy.

This telescope has spectra, photos, and SBIG ST7 and ST9E CCD cameras. Spectrograph, photometer and SBIG ST7 and ST9E CCD cameras. SBIG ST7 CCD camera has been coupled to the spectrograph using a focusing mechanism which was designed and constructed locally. With this system, the wavelength range varies from 4000Å to 9000Å. The photometer of the telescope has RCA IP21 photomultiplier tube with pulse counting system and Johnson and Morgan UBV filters.



Figure 3 the image of largest telescope in Sri Lanka.

Table 1 Specifications of Telescope

Effective Aperture	45 cm
Effective Focal Length	5400mm
F Number	f/12
Theoretical Resolving Power	0.31 arcseconds
Maximum Visual Magnitude	15

2.4 Working experience

2.4.1 Solar Observations

Coronado SolarMax 60 filter is used to observe Sun in Hydrogen-alpha wavelength with a bandwidth of 0.7Å. Using this H Alpha filter solar chromospheric activities such as flares and prominences can be observed along the solar limb. Filaments, Spicula, and sunspots on the solar disk can also be viewed through the filter.

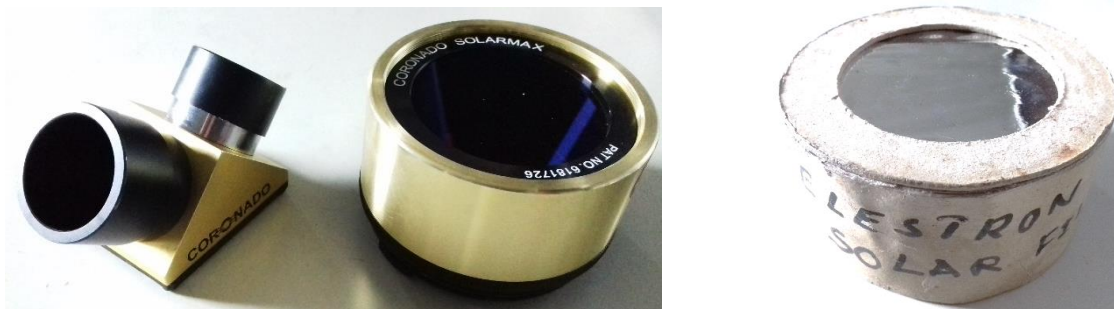


Figure 4 Left: The image of H Alpha Filter for solar observations, Right: The image of white Filter for solar observations



Figure 5 Doing solar observations.

2.4.2 Total Lunar Eclipse 2018.01.31

On January 31, 2018 the total lunar eclipse was observed at the Arthur C. Clarke Institute. The whole was not observable due to heavy cloud cover. However after the totality, the moon peeps out from clouds to show the partial coverage of the latter part of the eclipse.



Figure 6 the images of Total lunar eclipse on January 31, 2018

³ Available at : <http://www.accimt.ac.lk/accimt/?p=1941>

2.4.3 Night sky observations

I tried to get the data relating to my research done during the nighttime. But due to light pollution, I cannot do it successfully. Because of the Colombo city and harbor, light scattered all over the sky. Getting near the telescope, it can be monitored well [It shown in Figure 9 in page no.19]. In night observation sessions I learned how to operate the telescope, how to get data and how to get CCD image by using CCD Camera.

2.4.4 New telescope assembly

I was able to contribute to the assembling of the new telescope brought to the institute. It was the second largest telescope in Sri Lanka. I was able to identify the components of the telescope. Although the telescope was correctly fixed, data could not be obtained due to the bad weather conditions.



Figure 7 new telescope brought to the institute. It was the second largest telescope in Sri Lanka.

2.4.5 Telescope demonstrations for school children.

The basic concepts of astronomy are in the school curriculum. About 1500 students usually visit the ACCIMT each year and participate in astronomy lectures and telescopes depicting the staff of the Space Entry Division. I could demonstrate the school children about astronomy and how the telescope worked. In this demonstrations, I acted to show the sun, sunspots, solar flares etc.

Chapter 03

Introduction of industrial project

This chapter deals with the project background and purpose of the study, introduction to photometry, fundamentals of variable stars and natural limitations in optical astronomy such as light pollution and clouds.

3.1 Background and purpose of the study

Sri Lanka is a country where very less astronomical activities are carried out. This is mainly due to inadequate instrumental facilities and awful weather conditions that the country experience. Although the situation is so terrible still there are some institutions, universities and very much interesting in astronomical activities. Study of characteristics of stars using photometry is an interesting area of study which has not yet been done by a local body. Therefore this project is carried out under the guidance of at Arthur C Clarke Institute for Modern Technologies (ACCIMT), Katubedda, Moratuwa and under the supervision of Mr.Janaka Adassuriya, the research scientist at ACCIMT.

The primary objective of this research project is to analyze data from images taken by CCD camera and generate the light curve for a selected variable star and a reference star and to calculate primary and secondary frequencies of “SZ Lyn” variable star by using photometry.

Due to the unpredictable sky conditions, it is very difficult to carry out an astronomical project in the Moratuwa area where the required instruments are located. Therefore used Mount Abu Observatory data set taken on 12th November 2016 was used.

3.2 The Stars

3.2.1 Introduction to Stars

Star is a luminous ball of very hot, glowing gas. Mostly hydrogen and helium contained in the stars. By a nuclear fusion process, stars generate their own light as well as energy. Sophisticated instruments such as spectrographs, photometers, satellites as well as radio telescopes can be used to measure the brightness of the stars.

3.2.2 Variable stars

Variable stars are stars that change brightness. The brightness changes of these stars can range from a thousandth of a magnitude to as much as twenty magnitudes over periods of a fraction of a second to years, depending on the type of variable star.

In fact, these stars vary not only in brightness but may also vary in size or in other respects as well. These variations are the outcome of physical processes going on in the interior of the star and therefore provide valuable information about the structure and properties of stars and about stellar evolution. As an instance, the timing of the brightness variation can tell the luminosities of certain types of variable stars, which is of great importance in distance determination.

With the development of new techniques of astronomical observation, the number of variables began to grow. In particular, with the advent of the photo-electric photometer, astronomers could measure the brightness variation of a star with great accuracy. As a result minute variations of brightness have been detected in many stars which were previously known to be of constant brightness.

3.2.3 Classification of variable stars

The classification of variable stars can be thought of as existing in a layer. In first the layer we can divide all variable stars into just two types:

01. Intrinsic variable stars: their brightness varies due to some internal cause and in which variation is due to physical changes in the star or stellar system,

02. Extrinsic variable stars: their brightness varied due to some external agency and in which variability is due to the eclipse of one star by another or the effect of stellar rotation.

In the next layer, we can divide the same stars this time into five groups. Pulsating variable stars, Cataclysmic variable stars, Eruptive variable stars, Eclipsing binary systems, Rotating variable stars. I choose these five groups but some authorities would insist that the entire population of variable stars divided in different ways.

For instance, they can also be divided up into groups based on the way their brightnesses vary with time. So some authorities speak of irregular variable stars and semi-regular stars, long-period variable stars, novae, dwarf novae and recurrent novae, and flare stars.

So, all variable stars can be classified into groups according to their scheme.

3.2.4 Summary Chart for Variable Star Classification

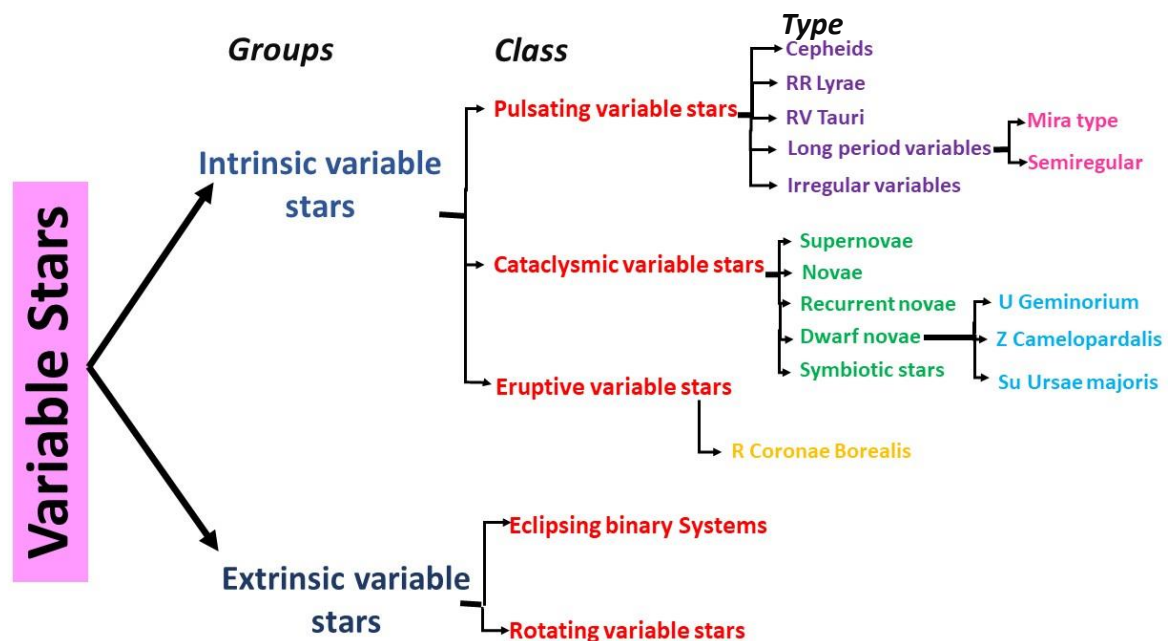


Figure 8 Classification of Variable Stars

3.3 Photometry

Word of photometry comes from the collection of two words as 'photo' and 'metron'. In this, the meaning of the photo is light and the meaning of the metron is measure. So, the process of measure the intensity or brightness of astronomical objects such as stars, planets, etc. is known as photometry. By determining the total output of light which emitted from the astronomical object can be measured the intensity or brightness. The incoming light which emitted from a star collects by telescope and tiny microchip is contained in the charge coupled device (CCD) which is a device for the transition of the electrical charge. The light comes from the star is focused on to that microchip. The large grid which is light sensing, as well as picture element, is included in the microchip and this is also known as a pixel. The atoms which are in the pixel is released electrons after the light comes to the pixel. Because of the release of the electrons pixel becomes charges and this process is known as photoionization. There has a relationship in between a number of electrons which released by a pixel and number of photons which incoming from a star as the number of electrons is proportional to the number of photons. With the completion of the exposure, a number of electrons which are in each pixel are counted. This results can be read by the computer and the results are named as counts otherwise intensity. Using this value of count can be determined the apparent magnitude of the astronomical objects. The more electrons are emitted from the pixel if the brightness of the star is high. Because of more electron emission, the count otherwise intensity of the star is high.

The star is displayed as a little point of the light in the night sky. But the position of the star can be slightly changed due to the confusion in the Earth's atmosphere at over time. Because of this reasons stars look like twinkle. Ten of seconds as well as minutes of exposure for the collection of more light in the image which taken from the telescope. The stars which twinkling causes to smear of their light during the time of exposure. According to that phenomenon each star display as a fuzzy disk instead of the point due to the image.

3.3.1 History of photometric studies

Earliest studies to determine the brightness of a star were done by naked eye. Hipparchos in 250 BC. Classified all the stars in the sky that he could see according to their brightnesses. When the telescope was invented many centuries later, astronomers realized that they could measure more exact brightnesses by examining how large a star appeared through the telescope.

There were nightly differences in atmospheric conditions, temperature, and the telescope itself which caused the relationship to vary somewhat. The early astronomers used the diaphragm to measure the star of interest plus at least one comparison star so that they could calibrate the diameter-brightness relation on every night, no matter what kind of conditions existed. The introduction of photography to the field of photometry leads to a much more accurate and reproducible result.

In 1961, Peter Fellgett proposed a fully automated plate measuring machine which would give both positions and magnitudes of stars without any human intervention. The first successful realization of his idea came in 1969, with the Edinburg GALAXY machine. The designed a flying laser beam guided two computer-controlled mirrors with orthogonal axes. The new set-up allowed for the measurement of 10 stars during each second, or 36,000 stars during each hour.

During the 1970s and 1980s, further developments took place to make measurements much more accurate. Scanning beam have narrowed and their intensities have been made much more constant, the light detector has become more sensitive to even minute differences in brightness, and the motion of the plate and chart has been synchronized further. Additionally, the density data collected in the newer machine can be automatically converted to brightness data and then sent to a computer for reduction and analysis. Furthermore, recent developments have included the use of television cameras, electronic cameras, and charged coupled devices (CCD) for which there is no intermediate step between photograph and computer, as photographs are almost literally taken on computers.

3.3.2 Uses of Photometry

Investigation of the stars which exhibit variations of the star's brightness called as variable stars are the most important application of the photometry. As well as the photometry can be used to extract light curves which are characterized the variation of the star's light with the time. For the study of the exoplanets which are the planets contained in the outside of the solar system can be also used photometry. So, several users can be achieved with the photometry.

3.3.3 Natural limitations in optical astronomy: Light pollution and cloud clarity

Light pollution occurs through skyglow. Sky glow happens because of poorly designed and improperly aimed light fixtures called luminaires. Luminaires that do not offer adequate shielding usually spill wasted light into the sky, it reflects off of tiny airborne dust and moisture particles. This happens even on very clear evenings, too. The skyglow phenomenon directly affects the scientific research of astronomers. Skyglow is a curable condition, and still adequate and safe illumination in the outdoor environment can be used with less harm.

Another form of Light pollution is when illumination crosses property lines. This is called Light Trespass. Light trespass can prevent from using property outdoors at night when wishing to gaze at the stars while lying on a blanket or viewing through a telescope.

Light pollution also occurs when too much illumination is applied to an area and a condition called glare results. Glare is defined as a visible source of illumination that causes a reduction in visual performance or an irritation.

Apart from the above-mentioned man-made light pollution forms, there are some other natural sources of night sky light which contributes error to the photometric observations.

Background light from faint stars and galaxies is probably the limiting factor in photometry of faint sources. This will not be much important in cases of fairly bright star observations. Since this is static the effects can be eliminated by always offsetting to the same locations to measure sky.

Night airglow is another terrestrial contributor which causes large errors in photometric measurements. It is the fluorescence of the atoms and molecules in the air from

photochemical excitation occurs about 100 km above the earth and is variable depending on sky conditions, local time, latitude, season and solar activity.

The cloudless sky is ideal for astronomical observations. But most of the time clouds act as a coat restricting the starlight to come to the earth. Although clouds can be classified into various groups, they always affect the data regardless of its kind. Most of the situations heavy clouds prevented observations. [1]



Figure 9 Light pollution occurs near the institute. This was an image of the direction of Colombo City.

Chapter 04

Theory

This chapter deals with the theoretical background of this study. It described some basic principles of CCD Camera and it's operation, CCD image types and Noises and their reduction process. It also described the important of Light Curve in astronomy.

4.1 From photography to CCD

The first observations of the sky relied on the naked eye. In this way, we can observe celestial objects to the 6th magnitude, with an angular resolution in the order of an arcminute. At the beginning of the 17th century, Galileo showed us that, with the use of an optical instrument, we can observe much fainter objects with a better resolution. Hence, a modest 20 cm telescope allows observation, visually, of 12th-magnitude stars with a resolution in the order of an arcsecond.

At the end of the 19th century, the appearance of the photographic film turned our vision of the cosmos upside down. Photography, coupled with large telescopes, allowed the observation of objects of the 20th magnitude thanks to the possibility of integrating light. The general public was thus able to see for themselves superb images from the celestial world. And is this not the usual starting point for amateur astronomers?

The quality of specialized photographic films for astronomy has continued to improve, especially during the 1970s, thanks to the hypersensitization of fine grain films. Bear in mind that the grains, whose average size is about 5 micrometers (5 thousandths of a millimeter), are the elementary points that form the photographic image.

The 1980s saw the rise of CCD cameras, which replaced photography in astronomy. CCD stands for the charge-coupled device. A CCD camera takes the form of a box equipped with a transparent window inside which is located in the CCD chip.

4.2 Some basic principles of CCD astrocameras

A CCD consists of an array of light-collecting units, called pixels. Each pixel on the CCD has the same size as its neighbors. That size can range from about 7 μm to 25 μm square. Professional astronomers mostly use large CCDs, typically 2048x2048 or more pixels around 25 μm square.

The array of CCDs pixels is mounted on an 'integrated circuit' or 'silicon chip' type base which has about 20 individual electrical connections to its supporting electronics. The way it works is that photons of light falling on particular pixels liberate electrical charges within each of them. The more light (and so more photons) falling on a given pixel, the more electrical charge is created within it. If an image is focused on the picture receiving area of the CCD the pixels corresponding to the brightness parts of the image have the greatest amount of charge liberated in them. The dimmest part of the image generates the smallest amount of charges in the corresponding pixels.

Charge continue to build up all the while the light is falling, until each and every pixel is full, or saturated. Well before this stage is reached, the process, known as integration, has to be stopped. Ideally an integration time (equivalent to the photographic 'exposure length') is selected so that at the end of it the pixels associated with the dimmest part of the image have only a small charge while those associated with the brightest parts of the image have lots of charges, though less than the amount necessary for saturation.

When the integration is completed the Array of charges is sequentially read off the chip and sent as a representative data stream to a computer.

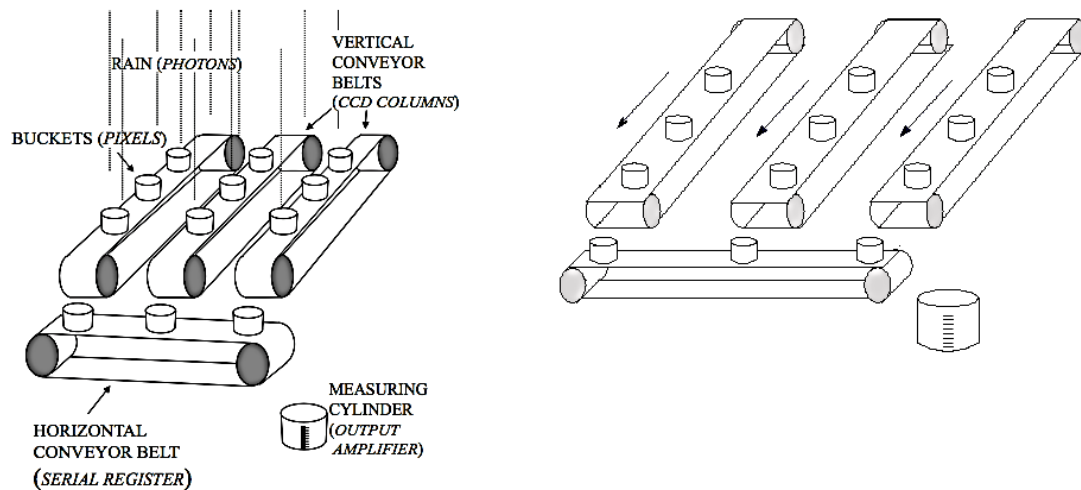


Figure 10 : Left schematic showing how charge coupling moves the photo-electrons from each pixel to the readout electronics, by way of the rain-bucket analogy. Right schematic showing an animation showing the same process.

Figure 10 shows that CCDs can be likened to an array of buckets that are placed in a field and collect water during a rainstorm (incoming photons). After the storm, each bucket is moved along conveyor belts until it reaches a metering station. The water collected in each field bucket is then emptied into the metering bucket within which it can be measured.

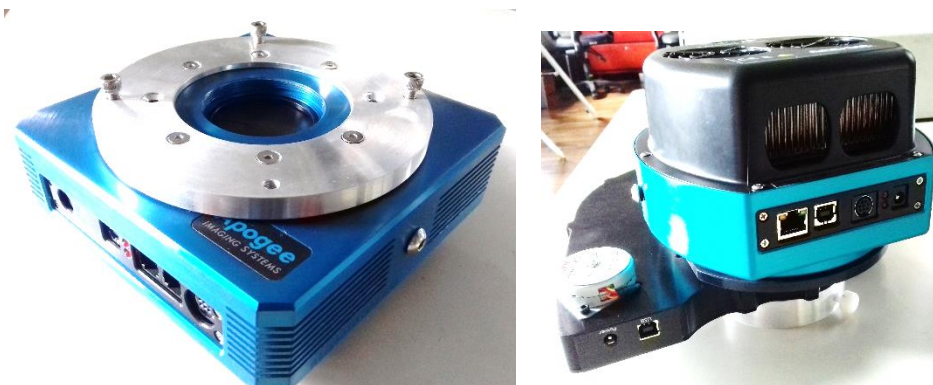


Figure 11 images of CCD Camera and filter wheel.

4.3 CCD Image Types

Astronomical imaging have six types of CCD Image such as raw images, bias images, thermal images, dark images, flat field images and calibrated images.

4.3.1 Raw Image

Raw image records a celestial object. The raw image is an image of a target object with the other signal comes from the other possible sources. It means it can be caused by the light comes from the celestial object as well as it contains thermal as well as bias signals. And also raw image consists with a variation of the sensitivity of one photosite to another one. Raw image generated from the CCD can be good or bad because of the several phenomena. Have a record of the light which struck each photosite in the CCD according to the good side of the raw images. But sometimes other signals can be mixed with the light which recorded. Considering bad side of the raw image it contains a thermal signals, bias signals, as well as sensitivity variation of the photosite to photosite.

4.3.2 Bias Frame images

Bias images comes because of an exposure of zero duration. CCD cameras contain for scientific imaging usually include the ability to read out a bias frame. All of the CCD cameras include this feature. The bias frame is a snapshot of electronic noise in CCD camera. Constant voltage offsets is recorded by the bias frame. And also noise in the CCD's on-chip amplifier is recorded. As well as bias frame records noise generated which in the camera electronics.

4.3.3 Dark Frame

An exposure without light comes to the CCD is known as dark frame. And also it is a combination of the bias noise as well as thermal noise under specific CCD temperature as well as exposure time. Image of dark frame should be taken after or before immediately taking a raw image. Can be recorded the information which necessary to subtract bias as well as thermal noise from the raw image easily by taking a dark frame image. Can be taken the dark frame by capping the telescope for take an exposure which is same as the exposure time of the raw image.

4.3.4 Thermal Frame

Thermal signals in the CCD images can be removed by using the thermal frames. Simply, thermal frame is a subtraction of bias frame from the dark frame. In the thermal image contains the thermal signal which generated by every photosite on the CCD. This is results from the thermal signal of the image.

4.3.5 Flat-Field Frame

Flat-field frames are constitutes a map to calibrate the sensitivity variations of photosite-to-photosite. The flat field is an image of a uniform subject. It mean as the twilight sky or a sheet of white cardboard attached to the inside of then observatory dome. Sensitivity difference between one photosite to another photosite can be corrected by this operation. And also dust shadows as well as vignetting from images can be removed by using flat field frames. Flat field frame image can be made by exposing the CCD in to the light which is comes with uniform field.

4.3.6 Calibrated Image

Final goal of the CCD data reduction is the made of calibrated image. It mean it is a corrected records of the light which comes to the CCD during the exposure of the raw images. And also it is a image which having uniform sensitivity throughout the every point of the image and free from the thermal and bias signals. By using process of bias frame, thermal frame and flat field frame information can be made calibrated image using the raw image.

4.4 Noises in the CCD images

CCD stands for “charge coupled device”. And also CCDs are solid state light detectors and light comes from the stars detect at thousands of photosites which is consists with silicon chip.

The variations consists in the measured quantity is known as Noise. The measure of amount of light comes to the CCD is can’t be determined accurately, it mean random variations are initiated. So, random variations occur in the signal from the individual photosites which is in the CCD is known as image noise or in other word, the uncertainty comes with the random variations in the determination of the amount of light comes to the

appropriate pixel. There are several sources of noise in CCD images. Can be named as photon noise, thermal noise, readout noise, and quantization noise and sensitivity variation noise.

4.4.1 Photon Noise

During the time period of the exposure varies randomly, the number of photons comes from the star reach the CCD, just as we would expect the number of raindrops hitting a given patch of ground to vary during a rainstorm. Photon noise is produced with the random fluctuations occur in the photon signal of the source. It means the rate of the photon receive does not remain constant. According to the environmental effects photon noises can be generated and the production of photons may itself fluctuate.

4.4.2 Thermal noise

The generation of a signal by the light-sensing photosites in the CCD chip can be occurred whether light falls on to the photosites or not. Because of that reason thermal noise is occurred. If the CCD is warmer, the lot of non-light signals are initiated. And otherwise signal due to the non-light is drop when CCD is cool. Thermal effects are not constant, it means thermal signals varies with randomly.

4.4.3 Readout noise.

With the less accurate results which read out from the CCD another noises can be initiated and it is names as readout noise. It means, the number of electrons which comes from the each photosites cannot determine precisely on-chip amplifier. So, according to the random variations of the number of the electrons is specified as readout noise by the camera manufactures.

4.4.4 Quantized noise

The price which pay for having digital data is called as quantized noise. The output signal from the CCD chip divides in to digital steps after the camera digitized. For example, the 8 bit camera divides the signal in to 256 steps, the 12 bit camera divides in to 4096 steps as well as 16 bit camera divides in to the 65536 steps. If quantization step is 256 otherwise have an 8 bit camera may be coarser than the uncertainties introduce by all other types of

noises which discussed above. The quantization noise is limited how accurately capture an image using the camera.

4.5 Basic CCD Data Reduction

The removal of any effects due to the nature of the detector and the telescope is known as CCD data reduction. The basic set of images which form the core of the calibration and also data reduction process is made by the standard CCD image reduction process. There are three calibration frames consists in the basic set of images such as bias frame, dark frame and the flat field as well as data frames of the objects of interest. The basic set of images which want to calibrate can be used in the reduction of the CCD object frames is defined as follows. First, mean bias frame or if needed, dark frame is subtracted from the object frame. And then, the resulting image otherwise image which bias subtracted is divide by a mean flat field image. That's all about the reduction of the CCD images. By using these two simple steps can be corrected the object frame for bias level dark current as well as ununiformity arise in the each image pixel.

4.6 Light-curves and Julian Day numbers

Light curve can be used to plot observations of the variable stars. It mean light curve is a graph of apparent brightness versus time in Julian date. In this apparent magnitude is amount of energy coming from the star, as observed by the observer. Studying the Light curves are fundamental tools for variable star astronomy. They are relatively simple and easy to grasp. When we have collected enough points (magnitude determinations) for any chosen variable star we can draw up our own light-curves.

Light curves can used to several purposes such as to determine the basic information of the periodic behavior, the orbital period of the eclipsing binaries, to calculate masses, sizes of the stars, to show nature of the star's variations. Many variable stars show periodic behavior. And also by plotting and analyzing the light curves can be determined the periodicity.

The units given on the time axis are "JD". JD stands for Julian Day (or Julian Date). On this artificial system Julian Day 1 began at noon (Universal Time) on 4713 January 1

BC. Thus each new Julian Day begins at noon. Noon on 2003 January 1 marks Julian Day number (JD) 2452641.0. Midnight on the same day is JD 2452641.5. The reason for expressing times as JD numbers is to make the subsequent analysis of an astrophysical variable's behavior easier. It avoids having to reckon with year, month, and differing numbers of days in any one month (30 and 31), also February's 28 but 29 in a leap year). The system was devised with the 'day' beginning at noon in order to avoid a day change occurring during a night-time observing session.

4.7 Differential Photometry

Differential Photometry involves determining the magnitude difference between one star (the variable star) and another star (the comparison star) very close to it in the sky. The comparison star is selected so that, when determining the magnitude differences, most of the crucial effects which all-sky photometry must deal with simply "cancel out."

There are so many advantages of differential photometry.

1. If the variable and its comparison are close together in the sky, then atmospheric extinction affects both by about the same amount and only a quite small correction is needed to correct for the small differential atmospheric extinction.
2. If the variable and its comparison have very nearly the same color, then the difference in wavelength response between the instrumental system and the standard system affects both by about the same amount and only a quite small correction is needed to correct for the small differential transformation.
3. Variations in background flux and sky brightness can be minimized by differential photometry if sampled more quickly than the sky variations
4. When chopping can be applied, the noise at frequencies other than the chopping frequency can be minimized.

4.8 FITS Files

By using phone as well as camera which like a telescope camera and also having CCDs in them can be take photographs. And the photographs taken from the phone as well as camera are formatted as jpeg type images. But according to the photometry, the the images are typically formatted as FITS files. Meaning of FITS is as Flexible Image Transport System. In this digital format is used.

With work of astronomy, images are commonly used as FITS files. It is because of the goodness of the capacity to store data in FITS format. It mean in the FITS format images can be stored more data than the other image formats such as jpeg. And also this format is created especially for the scientific data.

Chapter 05

Methodology

This chapter deals with the CCD data reduction and how to doing aperture photometry by using IRAF software. And also Extracted the magnitude values of the star, Plotted Light curves and detecting oscillation periods of the SZ Lyn variable star were described.

5.1 Software installation

IRAF (Image Reduction and Analysis Facility) software was installed. It is based entirely on the command line, which can be installed only on Unix-based Operating Systems, such as Linux. After installing IRAF and familiarize it by doing some basic exercises.[2]

Then installed VARTOOLS package. The VARTOOLS program was a command line utility that provides tools for processing and analyzing astronomical time series data (light curves). It includes methods for calculating variability/periodicity statistics of light curves; for filtering, transforming, and otherwise modifying light curves; and for modeling light curves.[3]

After that install Period04 software. Period04 was a computer program especially dedicated to the statistical analysis of large astronomical time series containing gaps. The program offers tools to extract the individual frequencies from the multiperiodic content of time series and provides a flexible interface to perform multiple-frequency fits. [4]

5.2 CCD Data Reduction and Basic image processing

I used IRAF for CCD photometric data reduction process. This was a procedure essentially meant for cleaning the images that will be used for scientific analysis. The result of the reduction process will be a set of corrected images that will be used for analysis, which will be cleared of noise from many various sources. [5, 6, 7]

In the 12th November 2017 dataset, I have three data folders. They were bias, flats, and SZLYN. All the bias frames are in the “bias” folder, all the flat field images were taken by various filters were in the “Flat” folder and all the raw images were taken by various filters (V, B, I, R) were in “SZLYN” folder.

5.2.1 Making a master bias by using “Zerocombine” task.

Log in to “bias” folder and all the bias Imagers taken by a CCD camera were listed by using the commands given below

files *.fits >> bias.list

After that combined, all the bias images into one image called a master bias. This was an average of all of all bias images. Master bias frame was obtained by using “zerocombine” task which was in noao.imred.ccdred package. With all of the parameters properly set and execute the task. The result was master bias (master bias.fits) [7]

```

                                I R A F
                        Image Reduction and Analysis Facility

PACKAGE = ccdred
TASK = zerocombine

input      =      @bias.list  List of zero level images to combine
(output =    master_bias.fits) Output zero level name
(combine=      median) Type of combine operation
(reject =      minmax) Type of rejection
(ccdtype=      ) CCD image type to combine
(process=      no) Process images before combining?
(delete =      no) Delete input images after combining?
(clobber=      no) Clobber existing output image?
(scale =      none) Image scaling
(statsec=      ) Image section for computing statistics
(nlow =      0) minmax: Number of low pixels to reject
(nhigh =      1) minmax: Number of high pixels to reject
(nkeep =      1) Minimum to keep (pos) or maximum to reject (neg)
(mclip =      yes) Use median in sigma clipping algorithms?
(lsigma =      3.) Lower sigma clipping factor
(hsigma =      3.) Upper sigma clipping factor
(rdnoise=      0) ccdclip: CCD readout noise (electrons)
More

```

ESC-? for HELP

Figure 12 parameters of “zerocombine” task

5.2.2 Eliminate lesser quality imagers and grouped raw imagers

Then log in to “SZLYN” folder and all the imagers taken by a CCD camera were listed by using the following command

files *.fits >> star.list

The result of running above cord was “star.list”. It contains all the names of the star in SZLyn folder. Then all the images were observed one by one to find and eliminate lesser quality images by using the following script.

```
> list = "star.list "
> while(fscan(list,s1)!=EOF)
>>> {
>>> display(s1)
>>> }
```

Then images were categorized into four groups by creating a text file for each filter used by compiling the following cord.

```
list= "star.list"
while(fscan(list,s1)!=EOF)
{
imgets((s1),"FILT")
s2=(imgets.value)
print((s1),>>(s2)//".list")
print(s2)
}
```

After the running this code I get separate text files called V.list, B.list, I.list & R.list. In V.list text file, it contains only the names of images which were taken by V filter.

Then All images were grouped in separate folders (called V, B, I and R) by using above text files.

5.2.3 Removing bias from the flats by using “ccdproc” task

Copy the “master bias.fits” image into the flats folder. Then removing bias from the flats (the removal of instrument generated an error in the flat frames) using the master bias. For removing bias from the flat using the "ccdproc" task. Again, the parameters must be set

correctly and executed the task.

Then all the flat images taken by a CCD camera were listed by using the above cord. Flat images were categorized into four separate text files, like above method. All images were moved V, B, I & R folders by using “epar move” command. [7]

```

                                I R A F
                                Image Reduction and Analysis Facility

PACKAGE = ccdred
TASK = ccdproc

images =      @flat.list  List of CCD images to correct
(output =    ) List of output CCD images
(ccdtype=    ) CCD image type to correct
(max_cac=    0) Maximum image caching memory (in Mbytes)
(noproc =    no) List processing steps only?

(fixpix =    no) Fix bad CCD lines and columns?
(oversca=    no) Apply overscan strip correction?
(trim =      yes) Trim the image?
(zero=       yes) Apply zero level correction?
(darkcor=    no) Apply dark count correction?
(flatcor=    yes) Apply flat field correction?
(illumco=    no) Apply illumination correction?
(fringec=    no) Apply fringe correction?
(readcor=    no) Convert zero level image to readout correction?
(scancor=    no) Convert flat field image to scan correction?
(readaxi=    line) Read out axis (column|line)
(fixfile=    ) File describing the bad lines and columns
(biassec=    image) Overscan strip image section
(trimsec=    image) Trim data section
(zero =      master_bias.fits) Zero level calibration image
(dark =      ) Dark count calibration image
(flat =      ) Flat field images
(illum =     ) Illumination correction images
(fringe =    ) Fringe correction images
(minrepl=    1.) Minimum flat field value
(scantyp=    shortscan) Scan type (shortscan|longscan)
(nscan =     1) Number of short scan lines
(interac=    yes) Fit overscan interactively?
(funcio=     chebyshev) Fitting function
(order =     1) Number of polynomial terms or spline pieces
(sample =    *) Sample points to fit
(naverag=    1) Number of sample points to combine
(niterat=    1) Number of rejection iterations
(low_rej=    3.) Low sigma rejection factor
(high_re=    3.) High sigma rejection factor
(grow =      0.) Rejection growing radius
(mode =      ql)

```

Figure 13 parameters of “ccdproc” task

5.2.4 Making a master flat by using “flatcombine” task and normalized the flats

Once the flat frame images have been corrected with the master bias, they must then be combined to make a master flat. This is done in IRAF with the use of the "flatcombine" task. The parameters of "flatcombine" are very similar to those of zerocombine. This should be done for each filter separately. [7]

```

                                I R A F
                        Image Reduction and Analysis Facility
PACKAGE = ccdred
TASK = flatcombine

input      =      @R.list  List of flat field images to combine
(output =      master_flat_r ) Output flat field root name
(combine=      median) Type of combine operation
(reject =      minmax) Type of rejection
(ccdtype=      ) CCD image type to combine
(process=      no) Process images before combining?
(subsets=      no) Combine images by subset parameter?
(delete =      no) Delete input images after combining?
(clobber=      no) Clobber existing output image?
(scale =      mode) Image scaling
(statsec=      ) Image section for computing statistics
(nlow =      0) minmax: Number of low pixels to reject
(nhigh =      1) minmax: Number of high pixels to reject
(nkeep =      1) Minimum to keep (pos) or maximum to reject (neg)
(mclip =      yes) Use median in sigma clipping algorithms?
(lsigma =      3.) Lower sigma clipping factor
(hsigma =      3.) Upper sigma clipping factor
(rdnoise=      rdnoise) ccdclip: CCD readout noise (electrons)
(gain =      gain) ccdclip: CCD gain (electrons/DN)
(snoise =      0.) ccdclip: Sensitivity noise (fraction)
(pclip =      -0.5) pclip: Percentile clipping parameter
(blank =      1.) Value if there are no pixels
(mode =      ql)

```

Figure 14 parameters of “flatcombine” task

Then normalized the flats by getting the mode from “imstat” task:

imstat master_flat_b.fits

```

#      IMAGE      NPIX      MEAN      STDDEV      MIN      MAX
master_flat_b.fits 1048576 3669.  92.86  764.8  4638.

```

Then divided the flat by the mean

ccdred> imarith master_flat_b.fits / 3669 master_flat_b.fits

Then we had a normalized flat in which most pixels are near to a value of one.

5.2.5 Correcting the row data by using “ccdproc” task

The final step in data reduction makes use again of the IRAF task "ccdproc" to correct the raw science frames, using both the master bias and the master flat acquired in previous steps. This also should be done for each filter separately. With these parameters set correctly execute the final task. The output was the final data. [7]

```

                                I R A F
                        Image Reduction and Analysis Facility

PACKAGE = ccdred
TASK = ccdproc

images =          @R.list  List of CCD images to correct
(output =          ) List of output CCD images
(ccdtype=          ) CCD image type to correct
(max_cac=          0) Maximum image caching memory (in Mbytes)
(noproc =          no) List processing steps only?

(fixpix =          no) Fix bad CCD lines and columns?
(oversca=          no) Apply overscan strip correction?
(trim =           yes) Trim the image?
(zero =           yes) Apply zero level correction?
(darkcor=          no) Apply dark count correction?
(flatcor=          yes) Apply flat field correction?
(illumco=          no) Apply illumination correction?
(fringec=          no) Apply fringe correction?
(readcor=          no) Convert zero level image to readout correction?
(scancor=          no) Convert flat field image to scan correction?

(readaxi=          line) Read out axis (column|line)
(fixfile=          ) File describing the bad lines and columns
(biassec=          image) Overscan strip image section
(trimsec=          image) Trim data section
(zero =           master_bias.fits) Zero level calibration image
(dark =           ) Dark count calibration image
(flat =           master_flat_r.fits) Flat field images
(illum =          ) Illumination correction images
(fringe =         ) Fringe correction images
(minrepl=          1.) Minimum flat field value
(scantyp=          shortscan) Scan type (shortscan|longscan)
(nscan =          1) Number of short scan lines

(interac=          yes) Fit overscan interactively?
(funcio=          chebyshev) Fitting function
(order =          1) Number of polynomial terms or spline pieces
(sample =         *) Sample points to fit
(naverag=          1) Number of sample points to combine
(niterat=          1) Number of rejection iterations
(low_rej=          3.) Low sigma rejection factor
(high_re=          3.) High sigma rejection factor
(grow =           0.) Rejection growing radius
(mode =           ql)

```

Figure 15 parameters of “ccdproc” task

5.2.6 Aligning raw Images

Three reference stars were selected for one reference image from each filter list (I have selected the first image in each list as my reference image)

Then used the “imexamine” task to extract the coordinates of the centers of various

reference stars. This task was very useful to do aperture photometry. Reference image was displayed image in ds9 and pointing the mouse cursor over a star (the cursor has become a circle) and press the “a” key. The information about the star was displayed in xgterminal. The coordinates of the stars were copied to separate text files.

By using “imcentroid” function measured the X and Y coordinates of a list of images and finds the mean X and Y shifts between the input images and a reference image. [7]

```

                                I R A F
                        Image Reduction and Analysis Facility

PACKAGE = immatch
TASK = imcentroid

input      =          @V.list  List of input images
referenc= 20161113195501-928-RA.fits  Reference image
coords     =          v_reff_coords  Reference coordinates file
(shifts =          ) Initial shifts file
(boxsize=          7) Size of the fine centering box
(bigbox =          199) Size of the coarse centering box
(negativ=          no) Are the features negative ?
(backgro=          INDEF) Reference background level
(lower   =          INDEF) Lower threshold for data
(upper  =          INDEF) Upper threshold for data
(niterat=          10) Maximum number of iterations
(toleran=          0) Tolerance for convergence
(maxshif=          INDEF) Maximum acceptable pixel shift
(verbose=          no) Print the centroids for every source ?
(mode   =          ql)

```

Figure 16 parameters of “imcentroid” task

Deviations in each image relative to the reference image and the reference coordinate file were copied in the text file by using the following command

imcentroid input=@I.list >> shift

The created ‘shift’ file contains so many parameters and deletes all the other parameters except ‘x shift’ and ‘y shift’. Using the “imshift” function and all the images were aligned. (The name of the text file containing the shifts for each input image was given to the ‘shift file’ parameter and list of images to be transformed as the ‘input’ parameter then “imshift” function shifts set of images in x and y)

I R A F
Image Reduction and Analysis Facility

```

PACKAGE = immatch
TASK = imshift

input    =          @V.list  Input images to be fit
output   =          @V.list  Output images
xshift   =          Fractional pixel shift in x
yshift   =          Fractional pixel shift in y
(shifts_ =          v_shift) Text file containing shifts for each image
(interp_ =          linear) Interpolant (nearest,linear,poly3,poly5,spline3,
(boundar=          constant) Boundary (constant,nearest,reflect,wrap)
(constan=          0.) Constant for boundary extension
(mode    =          ql)

```

Figure 17 parameters of "imshift" task

After doing alignment images were displayed and checked by using the following command.

```

> list = "V.list "
> while(fscan(list,s1)!=EOF)
>>> {
>>> display(s1)
>>> }

```

5.3 Aperture Photometry

The basic goal of photometry is to deduce the flux of objects in an image. [9]

5.3.1 Photometry with “imexamine” function

Imexamine⁴ is the most useful task when getting started with photometry. After Entered imexamine [image name] the cursor jumped to the image on displayed in DS9, and the arrow changed a blinking circle. Imexamine displayed information about the area under the cursor when press certain keys.

Before running aperture photometry parameters, first need to get an idea of the width of the stellar images and need to take some preliminary measurements with imexamine. To do this,

⁴ More details Available at imexamine function : <http://stsdas.stsci.edu/cgi-bin/gethelp.cgi?imexamine>

Entered imexamine and placed the cursor over a star. Pressed 'r' to see the radial profile for the star. At the base of the radial plot window, looked the number in the far right (The last value of the lower yellow line) was recorded. That was the full width at half-maximum (FWHM) in pixels, i.e., the width of the stars image where the intensity is one half of the central value or greater.

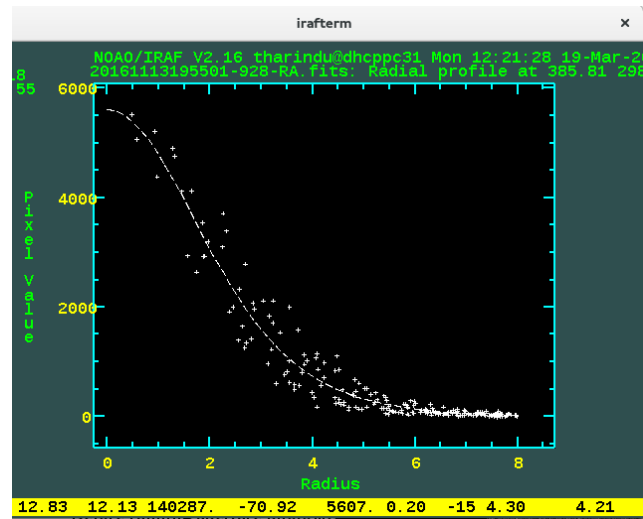


Figure 18 radial profile for the star

Then Enter imexamine, and placed the cursor over random spots in the sky and pressed 'm' to print statistics about the area under the cursor. Noted the standard deviation value (Sigma) for the sky. Do this several times and decided an appropriate.

Then pushing "h" button, a histogram was obtained. Pixel bin value corresponding to peak was recorded as the sky value.

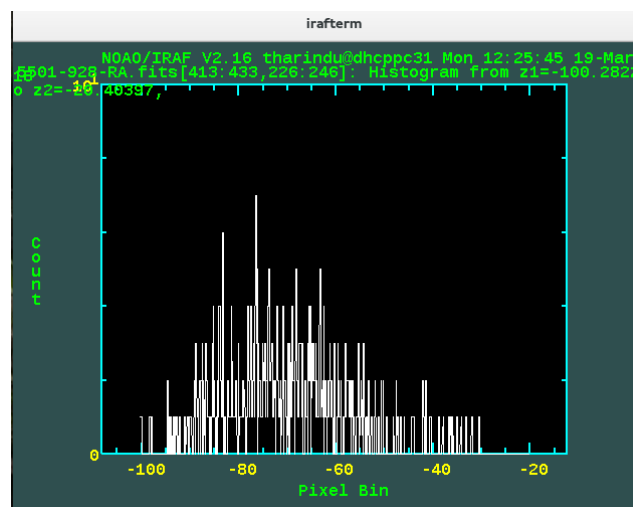


Figure 19 Histogram of the star

5.3.2 Photometry with "daofind" function

Daofind⁵ was a useful task for examining star clusters because IRAF can automatically find stars using an algorithm and do photometry on them. First data were input for photpar and datapar functions. In photpars edited the photometry parameters and in datapars edited the data dependent parameters.

The critical parameters fwhmpsf and sigma are located in datapars function. Radius for photpar was selected as it equal to 3 to 4 times of FWHM.

```

                                I R A F
                        Image Reduction and Analysis Facility PACKAGE = apphot

TASK = daofind

image = 20161113195515-166-RA.fits Input image(s)
(output = default) The output coordinates list(s) (default: image.coo.?)
(starmap=      ) The output density enhancement image(s)
(skymap =      ) The output sky image(s)
(datapar=      ) Data dependent parameters
(findpar=      ) Object detection parameters
(boundar= nearest) Boundary extension (constant, nearest, reflect,
(constan= 0.) Constant for constant boundary extension
(interac= no) Interactive mode ?
(icomman=      ) Image cursor: [x y wcs] key [cmd]
(gcomman=      ) Graphics cursor: [x y wcs] key [cmd]
(wcsout = )_.wcsout) The output coordinate system (logical,tv,physical)
(cache = )_.cache) Cache the image pixels ?
(verify = yes) Verify critical parameters in non-interactive mode
(update = no) Update critical parameters in non-interactive mode
(verbose= yes) Print messages in non-interactive mode ?
(graphic= stdgraph) Graphics device
(display= stdimage) Display device
(mode = ql)
```

Figure 20 parameters of "daofind" task

When daofind was done examining the image, it created a coordinate file with the same name as the image, but with a .coo tag. The .coo file contained information about the parameters chosen, some statistics, and photometric data. In the last column, each star was numbered. Looked first two columns for the stars' coordinates, and check to see which actual stars are and which were false.

⁵The parameters of daofind is Available at <http://stdas.stsci.edu/cgi-bin/gethelp.cgi?daofind>

5.3.3 Checking Stars Found with tvmark

Tvmark was an incredibly useful command that allows to see and edit the stars found by daofind. Edited the parameters by entering **epar tvmark** to mark the stars in a variety of ways.

Then until clear 3 stars including the variable star get marked on the display,

```

                                I R A F
                        Image Reduction and Analysis Facility

PACKAGE = tv
TASK = tvmark

frame = 1 Default frame number for display
coords = 20161113195515-166-RA.fits.coo.1 Input coordinate list
(logfile= ) Output log file
(autolog= no) Automatically log each marking command
(outimag= ) Output snapped image
(deletio= ) Output coordinate deletions list
(command= ) Image cursor: [x y wcs] key [cmd]
(mark = point) The mark type
(radii = 0) Radii in image pixels of concentric circles
(lengths= 0) Lengths and width in image pixels of concentric
(font = raster) Default font
(color = 204) Gray level of marks to be drawn
(label = no) Label the marked coordinates
(number = yes) Number the marked coordinates
(nxoffse= 0) X offset in display pixels of number
(nyoffse= 0) Y offset in display pixels of number
(pointsi= 5) Size of mark type point in display pixels
(txsize = 1) Size of text and numbers in font units
(toleran= 1.5) Tolerance for deleting coordinates in image pixe
(interac= no) Mode of use
(mode = ql)

```

Figure 21 parameters of “tvmark” task

5.3.4 Using Phot

Phot is the task that performs the aperture photometry. The parameter files within phot are⁶: Datapars⁷, Centerpars, Fitskypars⁸, Photpars⁹

⁶ The parameters of phot is Available at http://www.astro.gsu.edu/~bentz/a4100.6100/iraf_phot.pdf

⁷The parameters of Datapars is Available at <http://stsdas.stsci.edu/cgi-bin/gethelp.cgi?datapars>

⁸The parameters of Fitskypars is Available at <http://stsdas.stsci.edu/cgi-bin/gethelp.cgi?fitskypars>

⁹ The parameters of Photpars is Available at <http://stsdas.stsci.edu/cgi-bin/gethelp.cgi?photpars>

```

                                I R A F
                        Image Reduction and Analysis Facility

PACKAGE = apphot
TASK = phot

image =          @I.list  The input image(s)
skyfile =          The input sky file(s)
(coords = 20161113195515-166-RA.fits.coo.1) The input coordinate files(s) (defau
(output =          default) The output photometry file(s) (default: image.ma
(plotfil=          ) The output plots metacode file
(datapar=          ) Data dependent parameters
(centerp=          ) Centering parameters
(fitskyp=          ) Sky fitting parameters
(photpar=          ) Photometry parameters
(interac=          no) Interactive mode ?
(radplot=          no) Plot the radial profiles in interactive mode ?
(icomman=          ) Image cursor: [x y wcs] key [cmd]
(gcomman=          ) Graphics cursor: [x y wcs] key [cmd]
(wcsin =          )_.wcsin) The input coordinate system (logical,tv,physical
(wcsout =          )_.wcsout) The output coordinate system (logical,tv,physica
(cache =          )_.cache) Cache the input image pixels in memory ?
(verify =          yes) Verify critical parameters in non-interactive mo
(update =          yes) Update critical parameters in non-interactive mo
(verbose=          yes) Print messages in non-interactive mode ?
(graphic=          stdgraph) Graphics device
(display=          stdimage) Display device
(mode =           ql)

```

Figure 22 parameters of “phot” task

Full-Width Half-Maximum was assumed constant among star although their apparent radius was a variable. This was a reasonable assumption since most of the stars weren’t deformed in shape. The radius of the phot function in IRAF was chosen such that the background noise to be minimum and grasping all of the pixels from the star. The sky radius was chosen 5 pixels greater than the inner radius computed for phot function in order to define the background of the star.

5.3.5 Extracted the magnitude values

Using “pdump” commands, magnitudes of the wanted star and background reference stars were printed on separate text files.

Pdump *.mag.1 “ID,MAG,MERR” >> Bmag

Boolean expression (yes)

(ID – Image ID, MAG- a magnitude of the star which is in that ID, MERR- magnitude error which is in that ID)

5.4 Deferential photometry

After the executing above command it creates the one magnitude file in star1, star2 and star 3 with respect to the JD. Separate these values (star 1, star 2, star 3 magnitude) in separate files and get the magnitude difference between star 1(the variable star) and star 2 (the comparison star). When determining the magnitude differences can plotted light curves.

5.5 Plotted Light curves and detecting periods.

This photometric analysis begins by identifying the correct period for SZ LYN variable stars by using Magnitude values and their JDs. I calculated the time period using three methods.

Method 01: Fourier analysis and fitted Light curve

Method 02: Using the period04 software package to extract frequency

Method 03: Lomb-Scargle approach for detecting periodic

5.5.1 Fourier analysis and fitted Light curve

Fitting a Fourier series to a light curve provides a way to quantify the shape of the curve. In the Fourier series equation.

$$f(x) = a_0 + \sum_{n=1}^8 (a_n \cos n\omega + b_n \sin n\omega)$$

The constants a_0 , a_n and b_n , $n=1,2,3,\dots,8$, are called the coefficients of $f(x)$. By using Matlab 2017 software we can determine these Fourier coefficients. , in this case, ω is the frequency and for this work, I fitted an 8th order Fourier series. And calculated ω

5.5.2 Using the period04 software package to extract frequency

In this method, I used Perio04 software to examine a data set and determine the frequencies by using Fourier analyses to give to rough values of the frequencies and the fit module to refine these frequencies. It was the statistical analysis of large astronomical datasets containing gaps. It offers tools to extract the individual frequencies from the multiperiodic content of time series. [11, 12]

First load the data file in period04 then click on 'Display Graph' at the bottom right (see figure) then the new window was open with the light curves of all data. After that Perform a Fourier analysis of the data to calculate the main frequencies. In this case, light curve covers only one cycle and only one main frequency was displayed. In this case, I used Period04 software's help to learn how to perform a Fourier analysis.

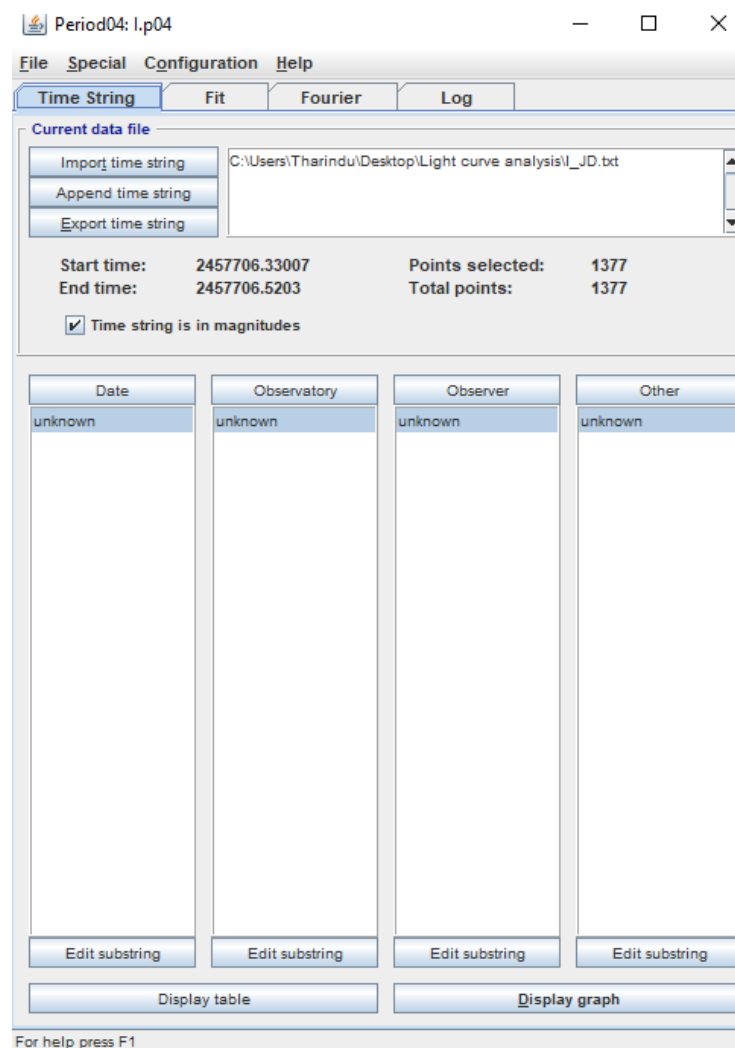


Figure 23 Graphical user interface of Period04 software

5.5.3 Lomb-Scargle approach for detecting periodicity

The Lomb-Scargle Periodogram is a commonly-used statistical tool designed to detect periodic signals in unevenly-spaced observations and has seen particularly wide use within the astronomy community. [13, 14, 15]

First Run the Lomb-Scargle period-finding algorithm on the light curve on my data located folder (EXAMPLES/V). In this case, I used following cord in VARTOOLS package.

```
./vartools -i EXAMPLES/V -online -ascii  
-LS 0.01 2. 0.1 5 1 EXAMPLES/OUTDIR1 whiten clip 5. 1
```

After executing this cord the results were displayed. By comparing the signal to noise ratio of the period value. In the above code Searched for periods between 0.01 and 2.0 days at a frequency resolution of $0.1/T$ (T is the time-span of the lc, 0.12 days in this case). Reported the top 5 peaks, and output the periodogram to EXAMPLES/OUTDIR1 (the filename will be EXAMPLES/OUTDIR1/V.ls, the -ASCII option causes the output to be in ASCII rather than the default binary format).

If the "whiten" keyword is given, then the light curve will be whitened at each peak period and the periodogram will be recomputed before searching for the next peak period. Then the RMS used in finding the signal-to-noise ratio is computed on the whitened periodogram. For each whiten cycle it displayed "Log10 of the false alarm probability" of the periodic finding.

After the calculation of false alarm probability, plot false alarm probability vs frequency function (power spectrum) we can get an idea of how the period values were distributed with frequency and how they exist.

Pre-whiten (If the "whiten" keyword is not given) the light curve and re-apply L-S before finding the next peak, and use a 5 sigma iterative clipping in determining the spectroscopic the signal-to-noise ratio. After that, the signal-to-noise ratio was compared with whiten method. The pre-whiten method was used to calculate the main period because Signal to noise ratios was low in other periods and Signal to noise ratio was lower than 'whiten' case. This method also should be done for each filter data (V, R and I)

Chapter 06

Results and Interpretation

This chapter deals with the results of this project, interpretations of plotted light curves and determinations of the pulsating period of SZ Lyn variable star.

6.1 Results

Table 2 Defferential magnitude values of observed stars with their corresponding Julian dates (V,R and I filters separately)

Time (JD)	Deffrential Magnitude for V Band	Time (JD)	Deffrential Magnitude for R Band	Time (JD)	Deffrential Magnitude for I Band
2457706.32987269	-1.785	2457706.3297801	-1.478	2457706.33006944	-1.123
2457706.33015046	-1.838	2457706.3299537	-1.47	2457706.33031250	-1.117
2457706.33042824	-1.812	2457706.3302315	-1.498	2457706.33033565	-1.202
2457706.33070602	-1.878	2457706.3305093	-1.496	2457706.33057870	-1.241
2457706.33098380	-1.805	2457706.3307870	-1.46	2457706.33061343	-1.21
2457706.33126157	-1.824	2457706.3310648	-1.476	2457706.33085648	-1.174
2457706.33153935	-1.818	2457706.3313426	-1.522	2457706.33089120	-1.216
2457706.33181713	-1.805	2457706.3316088	-1.444	2457706.33113426	-1.187
2457706.33209491	-1.798	2457706.3318866	-1.447	2457706.33116898	-1.207
2457706.33237268	-1.71	2457706.3321644	-1.465	2457706.33141204	-1.195
2457706.33263889	-1.784	2457706.3324421	-1.496	2457706.33144676	-1.215
2457706.33291667	-1.832	2457706.3327199	-1.517	2457706.33168982	-1.178
2457706.33319444	-1.763	2457706.3329977	-1.492	2457706.33172454	-1.124
2457706.33347222	-1.803	2457706.3332755	-1.451	2457706.33196759	-1.224
2457706.33375000	-1.805	2457706.3335532	-1.464	2457706.33200231	-1.174
2457706.33402778	-1.772	2457706.3338310	-1.489	2457706.33224537	-1.172
2457706.33430556	-1.727	2457706.3340972	-1.467	2457706.33228009	-1.18
2457706.33458333	-1.747	2457706.3343750	-1.453	2457706.33252315	-1.162
2457706.33486111	-1.787	2457706.3346528	-1.438	2457706.33255787	-1.225
2457706.33512732	-1.844	2457706.3349306	-1.519	2457706.33280093	-1.169
2457706.33540509	-1.809	2457706.3352083	-1.441	2457706.33283565	-1.17

(Like vice 692 data values in V filter, 694 data values in R filter, 1377 data values in I filter were used to plot the light curves. All data values are attached in **Appendix A**)

6.2 Method 01: Fourier analysis and fitted Light curve

In this method, the light curves were analyzed using Fourier analysis technique in Matlab 2017 software and determined the angular frequency and time period.

6.2.1 Light curves of observed stars with V, I & R filters (Magnitude vs JD)

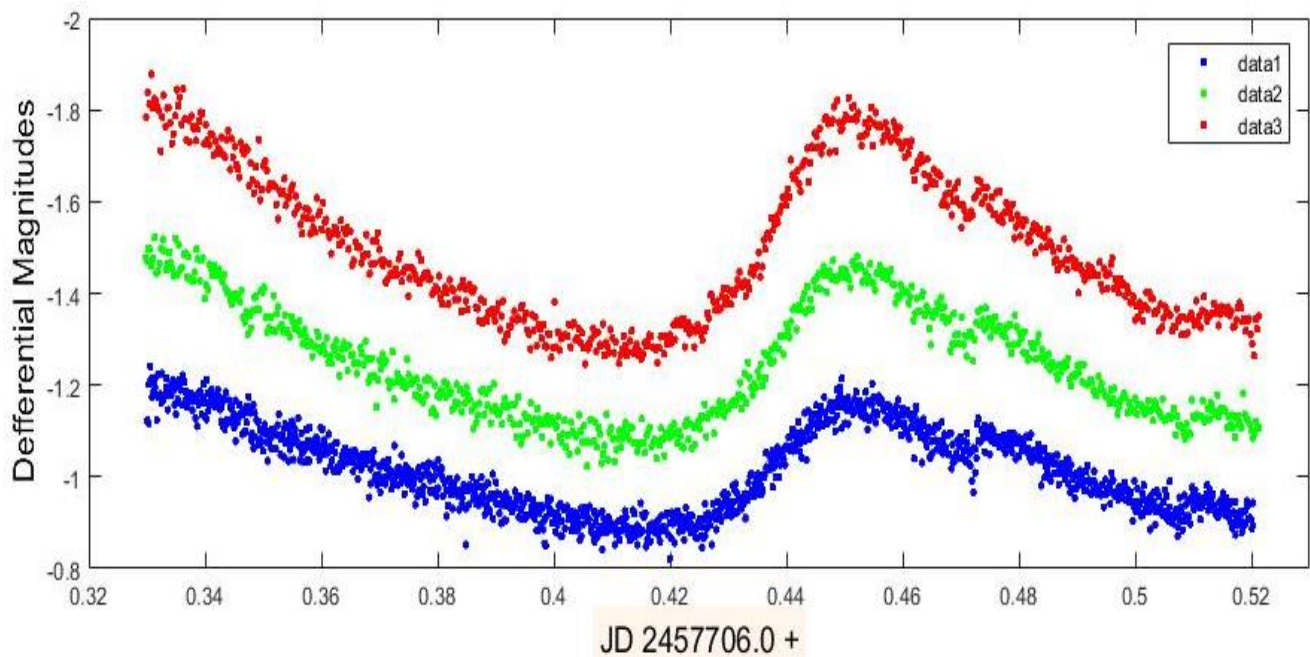


Figure 24 Light curves of observed stars with V (red color), R (Green color) & I (blue color) filters

The data consist of a time series of observations through V filter (red color light curve), R filter (Green color light curve) and I filter (blue color light curve). The time series was plotted in Figure 24. It is clear that the star is variable because the differential magnitudes vary with the function of time.

6.2.2 Light curve of observed stars in V filter (Magnitude vs JD)

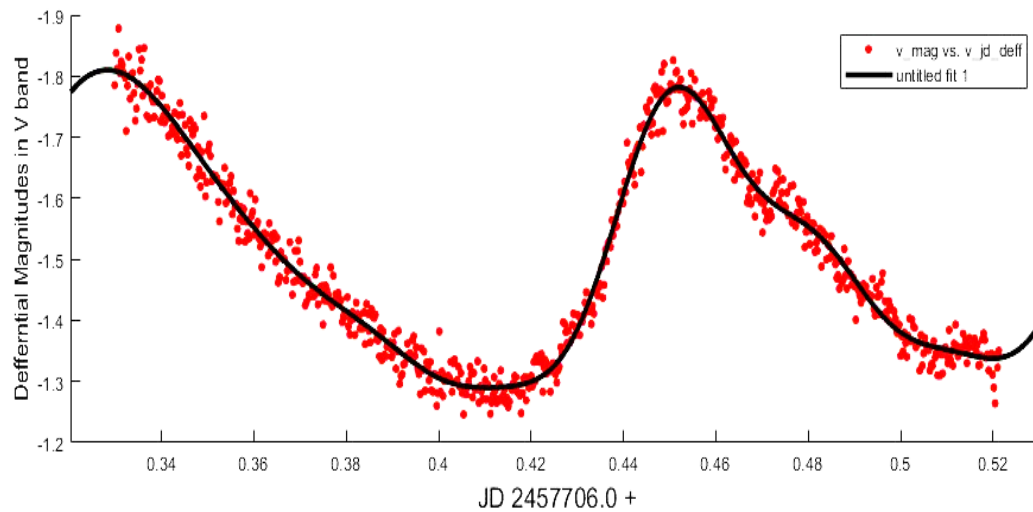


Figure 25 Differential Magnitude vs JD for frames taken with filter V

The data consist of a time series of observations through V filter. This light curve was an X-Y plot of a SZ-LYN variable star's differential magnitude (with respect to the reference star) versus time, with the time was plotted on the X-axis (covered the date range from Julian Date 2457706.32987 to 2457706.52125) and the differential magnitude was plotted on the Y-axis.

Fitting a Fourier series to a light curve provides a way to quantify the shape of the curve in V Filter.

Determination of Fourier coefficients

Equation for the fitted curve in figure

$$f(x) = a_0 + \sum_{n=1}^8 (a_n \cos nw + b_n \sin nw)$$

a0 = -1.516	a1 = 0.03118	b1 = -0.05769	a2 = -0.1826	b2 = 0.1121	a3 = -0.04705
b3 = -0.009027	a4 = 0.024	b4 = 0.04459	a5 = 0.003699	b5 = 0.02148	a6 = 0.01436
b6 = 0.0007364	a7 = 0.01626	b7 = -0.000576	a8 = 0.00607	b8 = -0.000194	

$$w = 26.99$$

$$\text{Primary frequency} = 2 \times w$$

$$\text{Pulsating period of V band} = 2\pi / (2 \times w) = 0.11644524 \text{ days}$$

6.2.3 Light curves of observed stars in R filter (Magnitude vs JD)

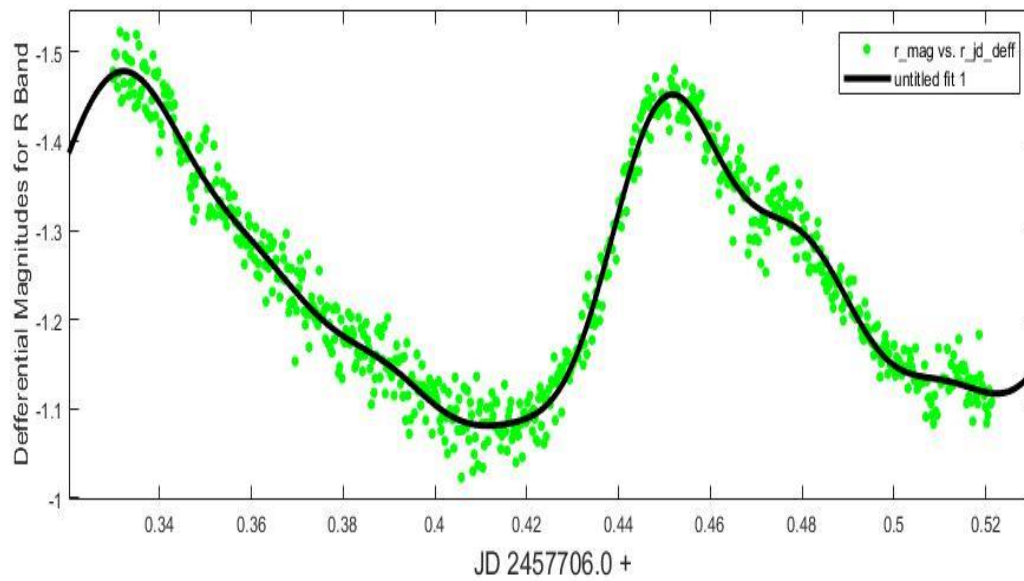


Figure 26 Differential Magnitude vs JD for frames taken with filter V

The data consist of a time series of observations through R filter. This light curve was a X-Y plot of a SZ-LYN variable star's differential magnitude (with respect to the reference star) versus time, with the time was plotted on the X-axis (covered the date range from Julian Date 2457706.32978009 to 2457706.52133102) and the differential magnitude was plotted on the Y-axis.

Fitting a Fourier series to a light curve provides a way to quantify the shape of the curve in R Filter.

Equation for the fitted curve in figure

$$f(x) = a_0 + \sum_{n=1}^8 (a_n \cos nw + b_n \sin nw)$$

a0 = -1.249	a1 = 0.02221	b1 = -0.03013	a2 = -0.1598	b2 = 0.004447	a3 = 0.01546
b3 = -0.02626	a4 = -0.02036	b4 = 0.03914	a5 = -0.008347	b5 = 0.003486	a6 = 0.006791
b6 = 0.01628	a7 = -0.002794	b7 = 0.01126	a8 = 0.000386	b8 = 0.006673	

$$w = 27.49$$

$$\text{Primary frequency} = 2 \times w$$

$$\text{Pulsating period of R band} = 2\pi / (2 \times w) = 0.1143272878 \text{ days}$$

6.2.4 Light curves of observed stars in I filter (Magnitude vs JD)

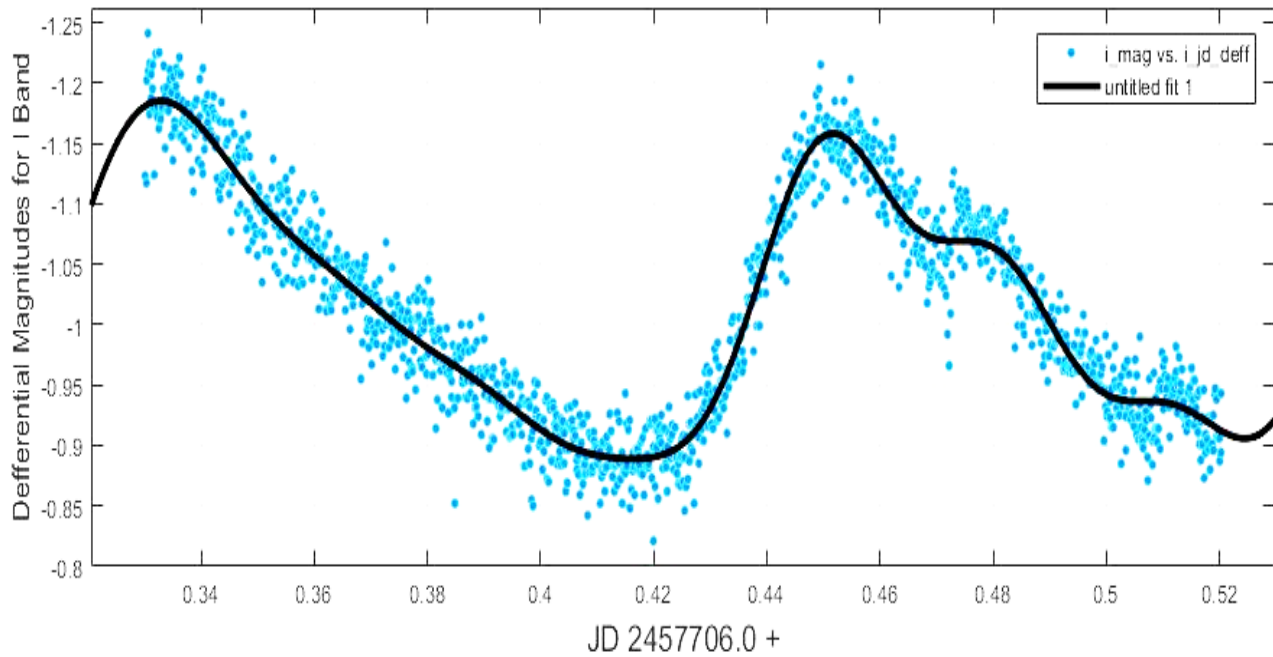


Figure 27 Differential Magnitude vs JD for frames taken with filter V

The data consist of a time series of observations through I filter. This light curve was a X-Y plot of a SZ-LYN variable star's differential magnitude (with respect to the reference star) versus time, with the time was plotted on the X-axis (covered the date range from Julian Date 2457706.33006944 to 2457706.52030093) and the differential magnitude was plotted on the Y-axis.

Fitting a Fourier series to a light curve provides a way to quantify the shape of the curve in I Filter.

Equation for the fitted curve in figure

$$f(x) = a_0 + \sum_{n=1}^8 (a_n \cos nw + b_n \sin nw)$$

a0 = -1.015	a1 = 0.02306	b1 = -0.01706	a2 = -0.09772	b2 = -0.06356	a3 = 0.009565
b3 = -0.02214	a4 = -0.03382	b4 = 0.005346	a5 = -0.003063	b5 = -0.008307	a6 = -0.01331
b6 = 0.008696	a7 = -0.01062	b7 = -0.006398	a8 = -0.002095	b8 = -0.002806	

$$w = 28.08$$

$$\text{Primary frequency} = 2 \times w$$

$$\text{Pulsating period of I band} = 2\pi / (2 \times w) = 0.1119251119 \text{ days}$$

6.3 Method 02: using the period04 software package to extract frequency

In this method the pulsating periods were derived with a Fourier transformation by using Period04 software. In the power spectrum we can identified the main frequencies for the SZ Lyn star as follows.

Filter	Frequency(cycles/day)	Magnitude	pulsating periods (days)
V	8.7087997 ± 0.0023969	0.222203976	0.1148263861
R	8.6138971 ± 0.0019350	0.167469306	0.1160914727
I	8.6736428 ± 0.0011262	0.121429565	0.1152918120

6.3.1 Light curve and power spectrum in V band

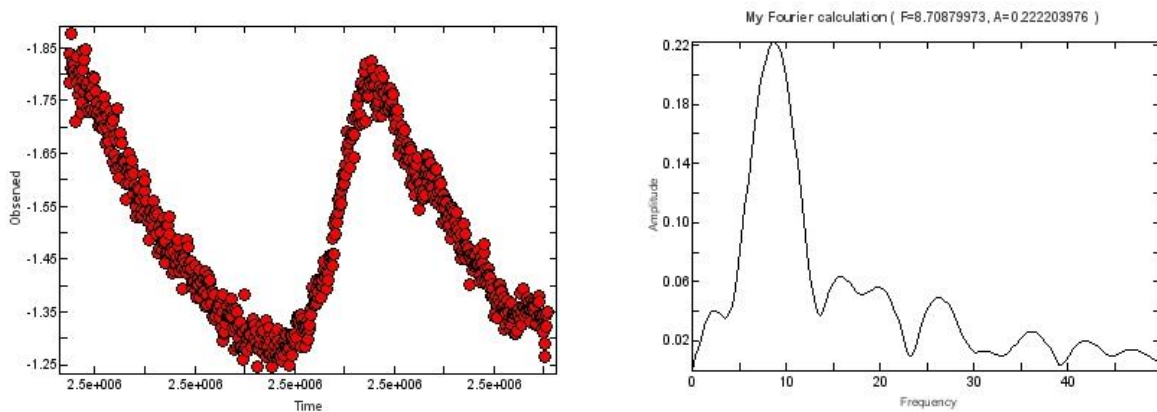


Figure 28 Left: Light curve in V band, Right: Power Spectrun in V band

6.3.2 Light curve and power spectrum in For R band

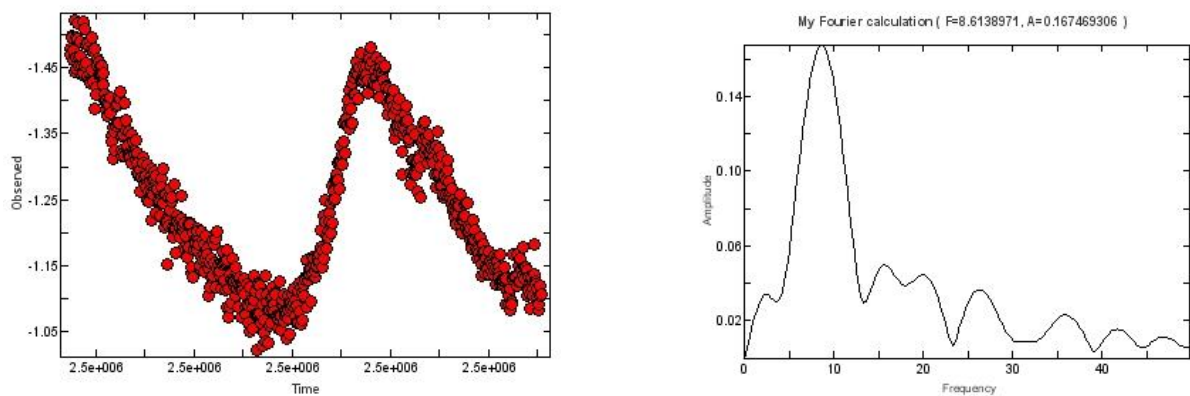


Figure 29 Left: Light curve in R band, Right: Power Spectrun in R band

6.3.3 Light curve and power spectrum in I Band

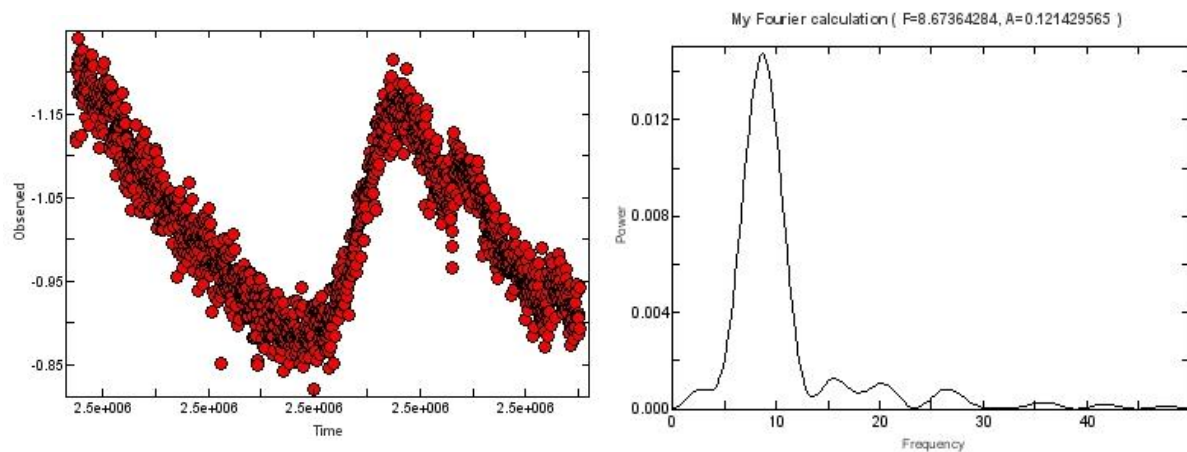


Figure 30 Light curve in I band, Right: Power Spectrun in I band

6.4 Method 03: Perform a Generalized Lomb-Scargle (L-S) search of the light curves in vartools package

6.4.1 LS approach in V band

If the "**whiten**" keyword was given, then the light curve will be whitened at each peak period and the periodogram will be recomputed before searching for the next peak period. In this case I used following cord in VARTOOLS package.

```
./vartools -i EXAMPLES/V -online -ascii  
-LS 0.01 2. 0.1 5 1 EXAMPLES/OUTDIR1 whiten clip 5. 1
```

After the execute this cord VARTOOLS Reported the top 5 peaks as follows.

Name = EXAMPLES/V
 LS_Period_1_0 = 0.11961082
 Log10_LS_Prob_1_0 = -217.58020
 LS_Periodogram_Value_1_0 = 0.76889
 LS_SNR_1_0 = 13.15471
 LS_Period_2_0 = 0.05980541
 Log10_LS_Prob_2_0 = -50.80927
 LS_Periodogram_Value_2_0 = 0.29544
 LS_SNR_2_0 = 20.20915
 LS_Period_3_0 = 0.03680333
 Log10_LS_Prob_3_0 = -8.81208
 LS_Periodogram_Value_3_0 = 0.06712
 LS_SNR_3_0 = 17.05579
 LS_Period_4_0 = 0.03086731
 Log10_LS_Prob_4_0 = -0.15223
 LS_Periodogram_Value_4_0 = 0.00965
 LS_SNR_4_0 = 2.09002
 LS_Period_5_0 = 0.01772012
 Log10_LS_Prob_5_0 = -0.00847
 LS_Periodogram_Value_5_0 = 0.00647
 LS_SNR_5_0 = 0.99087

According to the above results I can summarized the main period values and signal to noise ratio as follows.

Table 3 Top 5 periodic values in V filter by using VARTOOS package

	Time Period(days)	Signal to noise ratio	Selected or rejected
LS period 01	0.11961082	13.15471	Selected
LS period 02	0.05980541	20.20915	Selected
LS period 03	0.03680333	17.05579	Selected
LS period 04	0.03086731	2.09002	Rejected
LS period 05	0.01772012	0.99087	Rejected

By analyzed the power spectrum we can identified the main frequencies for the SZ Lyn star. In this case I used whited data set and plotted the power spectrum as follows.

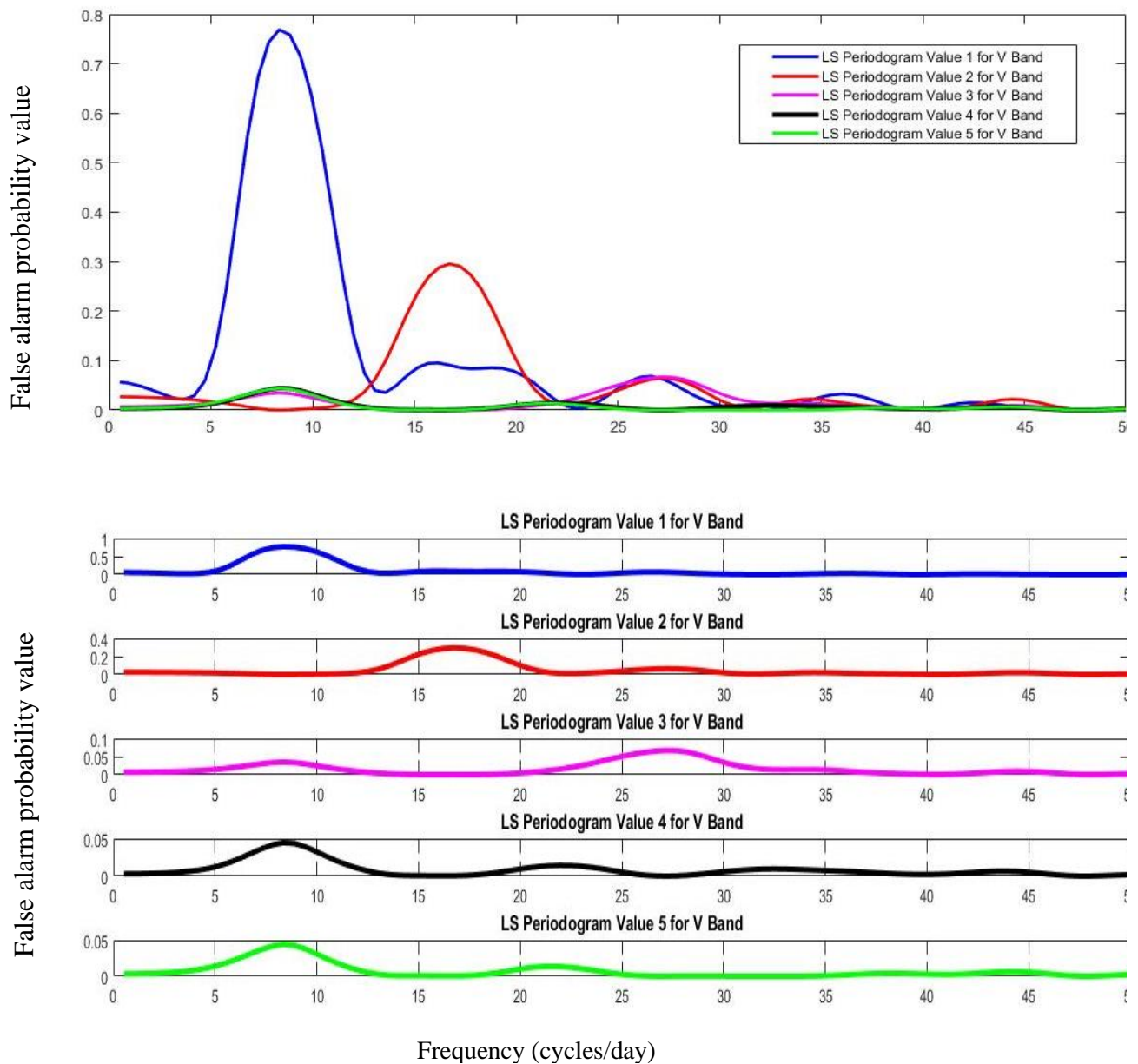


Figure 31 LS False alarm probability value vs frequency graph in V Band

False alarm probability value vs frequency graph was shown in the figure 31. Only Period 1, Period 2 and Period 3 are exist. And Period 04 and Period 05 were rejected because of lower probability and due to Low Signal to noise ratio.

6.4.2 LS approach in R Band

If the "**whiten**" keyword was given, then the light curve will be whitened at each peak period and the periodogram will be recomputed before searching for the next peak period.

In this case I used following cord in VARTOOLS package.

```
./vartools -i EXAMPLES/V -online -ascii
```

```
-LS 0.01 2. 0.1 5 1 EXAMPLES/OUTDIR1 whiten clip 5. 1
```

After the execute this cord VARTOOLS Reported the top 5 peaks as follows

```
Name = EXAMPLES/R
LS_Period_1_0 = 0.11971933
Log10_LS_Prob_1_0 = -278.43469
LS_Periodogram_Value_1_0 = 0.84529
LS_SNR_1_0 = 7.58057
LS_Period_2_0 = 0.05985967
Log10_LS_Prob_2_0 = -122.83823
LS_Periodogram_Value_2_0 = 0.56361
LS_SNR_2_0 = 9.51266
LS_Period_3_0 = 0.03831019
Log10_LS_Prob_3_0 = -48.48959
LS_Periodogram_Value_3_0 = 0.28374
LS_SNR_3_0 = 6.94258
LS_Period_4_0 = 0.02992983
Log10_LS_Prob_4_0 = -14.48823
LS_Periodogram_Value_4_0 = 0.09695
LS_SNR_4_0 = 2.02409
LS_Period_5_0 = 0.02424695
Log10_LS_Prob_5_0 = -1.28443
LS_Periodogram_Value_5_0 = 0.01621
LS_SNR_5_0 = -0.04814
```

According to the above results I can summarized the main period values and signal to noise ratio as follows.

Table 4 Top 5 periodic values in R filter by using VARTOOS package

	Time Period	Signal to noise ratio	Selected or rejected
LS period 01	0.11971933	7.58057	Selected
LS period 02	0.05985967	9.51266	Selected
LS period 03	0.03831019	6.94258	Selected
LS period 04	0.02992983	2.02409	Rejected
LS period 05	0.02424695	-0.04814	Rejected

By analyzing the power spectrum we can identify the main frequencies for the SZ Lyn star. In this case I used the whitened data set and plotted the power spectrum as follows.

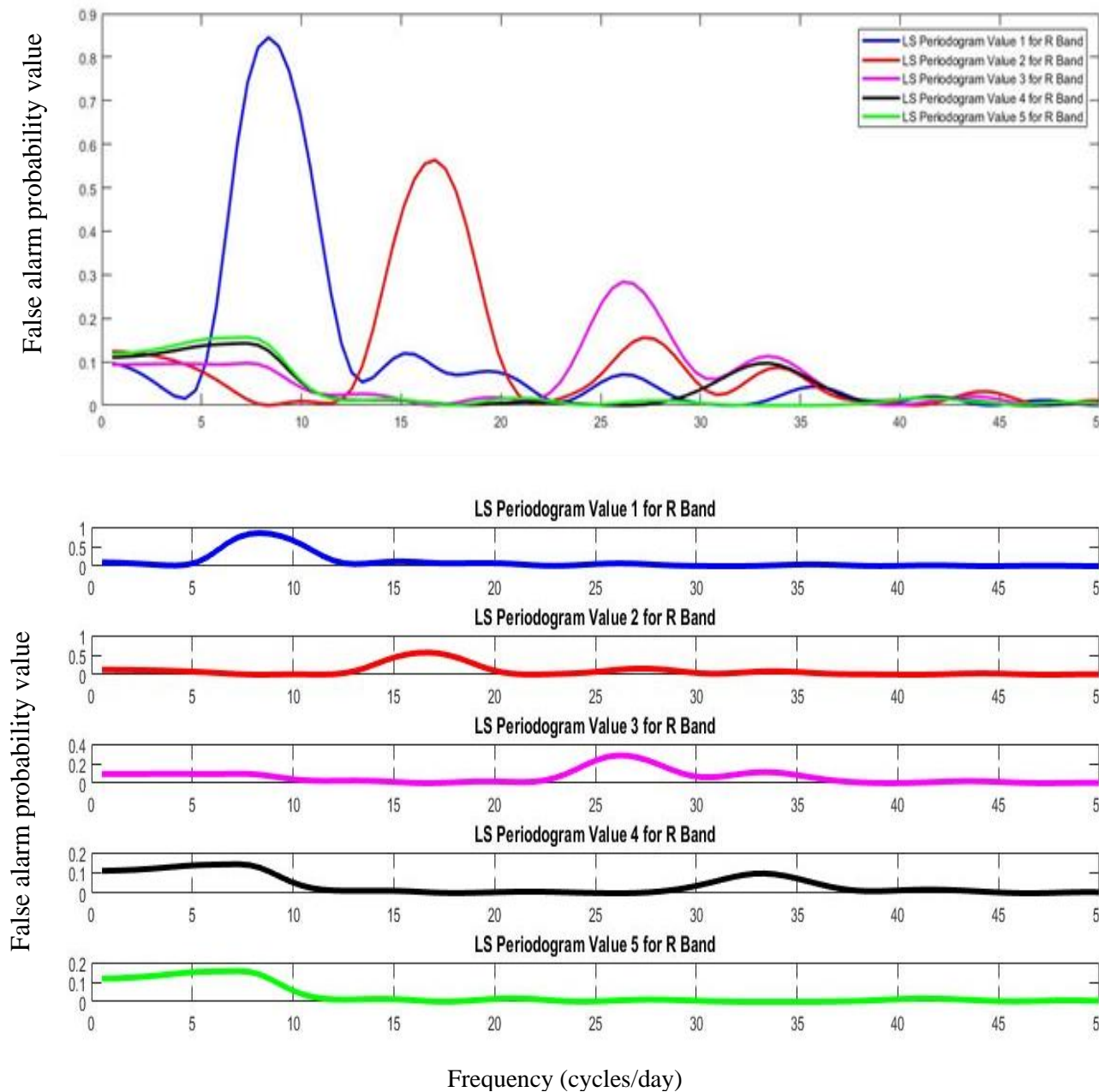


Figure 32 LS False alarm probability value vs frequency graph in R Band

False alarm probability value vs frequency graph was shown in the figure 32. Only Period 1, Period 2 and Period 3 are exist. And Period 04 and Period 05 were rejected because of lower probability and due to Low Signal to noise ratio.

6.4.3 LS approach in I Band

If the "**whiten**" keyword was given, then the light curve will be whitened at each peak period and the periodogram will be recomputed before searching for the next peak period.

In this case I used following cord in VARTOOLS package.

```
./vartools -i EXAMPLES/V -online -ascii  
-LS 0.01 2. 0.1 5 1 EXAMPLES/OUTDIR1 whiten clip 5. 1
```

After the execute this cord VARTOOLS Reported the top 5 peaks as follows

```
Name           = EXAMPLES/I  
LS_Period_1_0   = 0.11889468  
Log10_LS_Prob_1_0 = -514.59928  
LS_Periodogram_Value_1_0 = 0.82273  
LS_SNR_1_0      = 8.99149  
LS_Period_2_0   = 0.05944734  
Log10_LS_Prob_2_0 = -178.32066  
LS_Periodogram_Value_2_0 = 0.45281  
LS_SNR_2_0      = 9.14965  
LS_Period_3_0   = 0.03730029  
Log10_LS_Prob_3_0 = -80.52206  
LS_Periodogram_Value_3_0 = 0.24056  
LS_SNR_3_0      = 8.63655  
LS_Period_4_0   = 0.02972367  
Log10_LS_Prob_4_0 = -24.37236  
LS_Periodogram_Value_4_0 = 0.08227  
LS_SNR_4_0      = 2.61932  
LS_Period_5_0   = 0.01883480  
Log10_LS_Prob_5_0 = -2.28355  
LS_Periodogram_Value_5_0 = 0.01164  
LS_SNR_5_0      = -0.07143
```

According to the above results I can summarized the main period values and signal to noise ratio as follows.

Table 5 Top 5 periodic values in I filter by using VARTOOS package

	Time Period	Signal to noise ratio	Selected or rejected
LS period 01	0.11889468	8.99149	Selected
LS period 02	0.05944734	9.14965	Selected
LS period 03	0.03730029	8.63655	Selected
LS period 04	0.02972367	2.61932	Rejected
LS period 05	0.01883480	-0.07143	Rejected

By analyzed the power spectrum we can identified the main frequencies for the SZ Lyn star. In this case I used whited data set and plotted the power spectrum as follows.

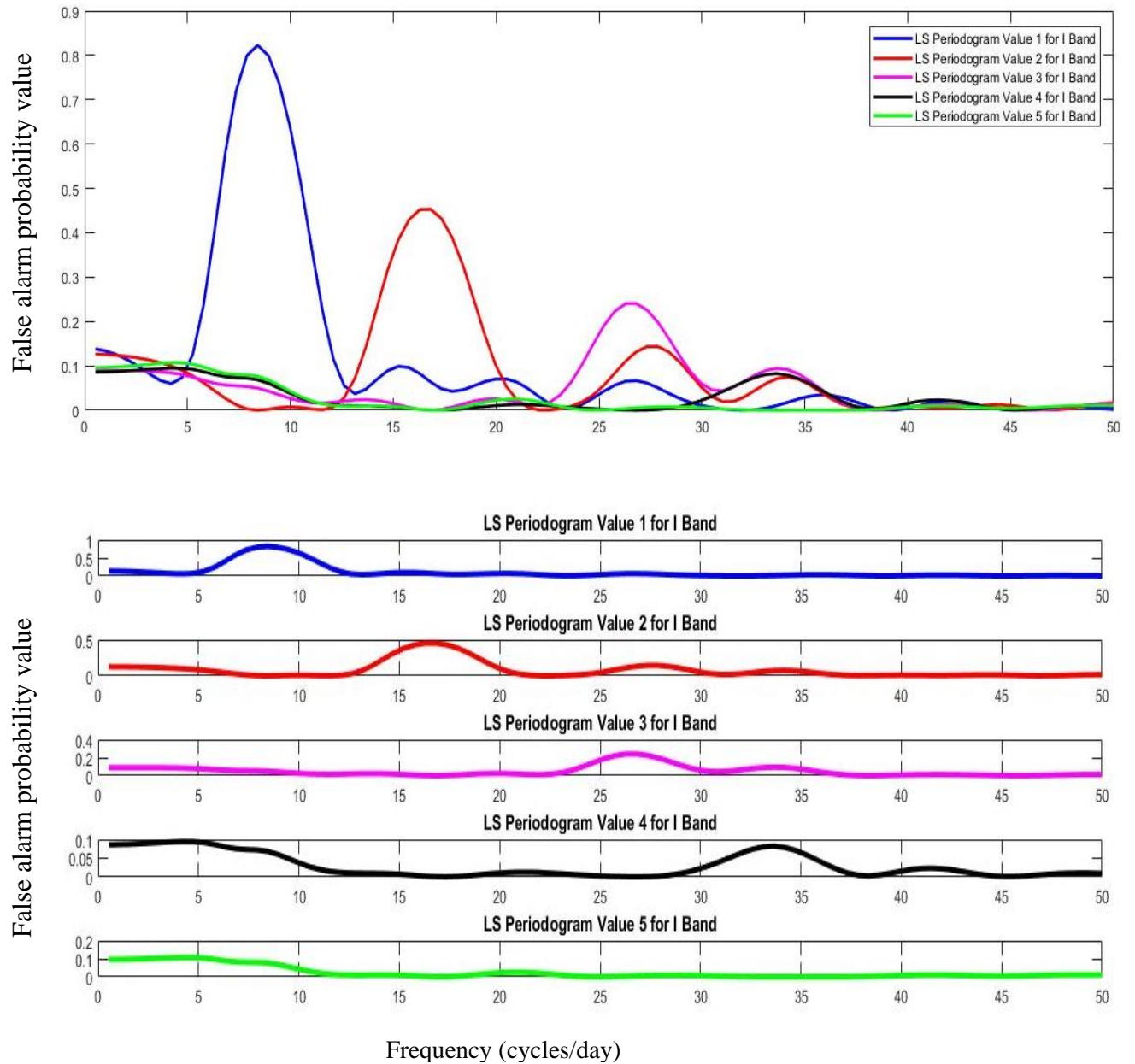


Figure 33 LS False alarm probability value vs frequency graph in I Band

False alarm probability value vs frequency graph was shown in the figure33. Only Period 1, Period 2 and Period 3 are exist. And Period 04 and Period 05 were rejected because of lower probability and due to Low Signal to noise ratio.

Chapter 07

Conclusion and Discussion

Determined the pulsating period of the SZ Lyn in three methods and they can compared as follows.

The photometric reduction was done by using the IRAF software. In order to calculate the pulsational period, I applied three methods. They are Fourier analysis method, period04 software package, and Generalized Lomb-Scargle (LS) approach.

Method 01: Fourier analysis method

The frequency analysis of the plotted data can be done using Fourier analysis method in Matlab 2017 software. The observed primary pulsating periods of SZ Lyn from V, R and I filters are

Filter	pulsating periods (days)
V	0.1164452 ± 0.0255100
R	0.1143272 ± 0.0236300
I	0.1119251 ± 0.023400

These values are approximately equal to that of previous studies. In this method the values depend on the goodness of the fitted curve, particularly the values of the coefficients.

Method 02: Using period04 software package

The frequency analysis of the plotted data can be done using the Period04 software. The observed primary pulsating periods of SZ Lyn from V, R and I filters are

Filter	pulsating periods (days)
V	0.1148263 ± 0.0023969
R	0.1160914 ± 0.0019350
I	0.1152918 ± 0.0011262

As the above values are approximately equal with previous studies. In this case Identified only one pulsating period. More data on SZ Lyn is needed for identify other modes in the star.

Method 01 and 02 used Fourier analysis technique. The Lomb-Scargle periodogram was better optimized to minimize the coefficients as opposed to the Fourier curve fit.

Method 03: Perform a Generalized Lomb-Scargle (LS) approach.

The frequency analysis of the plotted data can be done using Lomb-Scargle Periodogram since the time distribution is non-uniform. In this case

Band	First mode of vibration(fundamental)	Second mode of vibration(1 st Overtone)	Third mode of vibration (2 nd Overtone)
V	0.11961082	0.05980541	0.03680333
R	0.11971933	0.05985967	0.03831019
I	0.11889468	0.05944734	0.02972367

As the above values agree very well with results reported by the previous researchers on this star and these observations can also be considered to be of international standards. LS method is more accurately and precise than the Fourier analysis method because It used least square estimate approach to detecting periods.

LS method can only detect fundamental, second and third mode of vibration. The second harmonic has twice the frequency of the fundamental and the third harmonic is three times the frequency of the fundamental.

From the results found in this research and in previous studies on this star, we can conclude that the star SZ Lyn is a binary and short period δ -Scuti type variable star. I recommended further spectroscopic observations on this star to confirm binary nature of the system.

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Appendices

Appendix A: Differential magnitude values of observed stars with their corresponding Julian dates (V,B and I filters separately)

This document is related to table 2 in page 43

Time (JD)	Deffrential Magnitude for V Band	Time (JD)	Deffrential Magnitude for R Band	Time (JD)	Deffrential Magnitude for I Band
2457706.32987269	-1.785	2457706.3297801	-1.478	2457706.33006944	-1.123
2457706.33015046	-1.838	2457706.3299537	-1.47	2457706.33031250	-1.117
2457706.33042824	-1.812	2457706.3302315	-1.498	2457706.33033565	-1.202
2457706.33070602	-1.878	2457706.3305093	-1.496	2457706.33057870	-1.241
2457706.33098380	-1.805	2457706.3307870	-1.46	2457706.33061343	-1.21
2457706.33126157	-1.824	2457706.3310648	-1.476	2457706.33085648	-1.174
2457706.33153935	-1.818	2457706.3313426	-1.522	2457706.33089120	-1.216
2457706.33181713	-1.805	2457706.3316088	-1.444	2457706.33113426	-1.187
2457706.33209491	-1.798	2457706.3318866	-1.447	2457706.33116898	-1.207
2457706.33237268	-1.71	2457706.3321644	-1.465	2457706.33141204	-1.195
2457706.33263889	-1.784	2457706.3324421	-1.496	2457706.33144676	-1.215
2457706.33291667	-1.832	2457706.3327199	-1.517	2457706.33168982	-1.178
2457706.33319444	-1.763	2457706.3329977	-1.492	2457706.33172454	-1.124
2457706.33347222	-1.803	2457706.3332755	-1.451	2457706.33196759	-1.224
2457706.33375000	-1.805	2457706.3335532	-1.464	2457706.33200231	-1.174
2457706.33402778	-1.772	2457706.3338310	-1.489	2457706.33224537	-1.172
2457706.33430556	-1.727	2457706.3340972	-1.467	2457706.33228009	-1.18
2457706.33458333	-1.747	2457706.3343750	-1.453	2457706.33252315	-1.162
2457706.33486111	-1.787	2457706.3346528	-1.438	2457706.33255787	-1.225
2457706.33512732	-1.844	2457706.3349306	-1.519	2457706.33280093	-1.169
2457706.33540509	-1.809	2457706.3352083	-1.441	2457706.33283565	-1.17
2457706.33568287	-1.827	2457706.3354861	-1.507	2457706.33307870	-1.178
2457706.33596065	-1.768	2457706.3357639	-1.451	2457706.33310185	-1.18
2457706.33623843	-1.846	2457706.3360417	-1.457	2457706.33334491	-1.195
2457706.33651620	-1.781	2457706.3363194	-1.484	2457706.33337963	-1.214
2457706.33679398	-1.735	2457706.3365972	-1.487	2457706.33362269	-1.146
2457706.33707176	-1.778	2457706.3368634	-1.436	2457706.33365741	-1.189
2457706.33734954	-1.73	2457706.3371412	-1.48	2457706.33390046	-1.196
2457706.33762731	-1.786	2457706.3374190	-1.43	2457706.33393519	-1.178
2457706.33789352	-1.764	2457706.3376968	-1.429	2457706.33417824	-1.186
2457706.33817130	-1.758	2457706.3379745	-1.426	2457706.33421296	-1.177
2457706.33844907	-1.733	2457706.3382523	-1.446	2457706.33445602	-1.203
2457706.33872685	-1.758	2457706.3385301	-1.496	2457706.33449074	-1.211
2457706.33900463	-1.776	2457706.3388079	-1.475	2457706.33473380	-1.192
2457706.33928241	-1.794	2457706.3390857	-1.428	2457706.33476852	-1.156
2457706.33956019	-1.792	2457706.3393634	-1.473	2457706.33501157	-1.136
2457706.33983796	-1.726	2457706.3396296	-1.477	2457706.33504630	-1.205
2457706.34011574	-1.768	2457706.3399074	-1.388	2457706.33528935	-1.168

2457706.34038194	-1.734
2457706.34065972	-1.724
2457706.34093750	-1.748
2457706.34121528	-1.747
2457706.34149306	-1.702
2457706.34177083	-1.732
2457706.34204861	-1.705
2457706.34232639	-1.716
2457706.34260417	-1.712
2457706.34288194	-1.74
2457706.34314815	-1.703
2457706.34342593	-1.697
2457706.34370370	-1.736
2457706.34398148	-1.756
2457706.34425926	-1.67
2457706.34453704	-1.737
2457706.34481481	-1.697
2457706.34509259	-1.72
2457706.34537037	-1.681
2457706.34564815	-1.672
2457706.34591435	-1.653
2457706.34619213	-1.728
2457706.34646991	-1.713
2457706.34674769	-1.704
2457706.34702546	-1.719
2457706.34730324	-1.714
2457706.34758102	-1.634
2457706.34785880	-1.684
2457706.34813657	-1.647
2457706.34841435	-1.619
2457706.34868056	-1.676
2457706.34895833	-1.637
2457706.34923611	-1.735
2457706.34951389	-1.603
2457706.34979167	-1.626
2457706.35006944	-1.678
2457706.35034722	-1.688
2457706.35062500	-1.669
2457706.35090278	-1.628
2457706.35118056	-1.638
2457706.35144676	-1.634
2457706.35172454	-1.637
2457706.35200231	-1.633
2457706.35228009	-1.594
2457706.35255787	-1.562
2457706.35283565	-1.624
2457706.35311343	-1.618
2457706.35339120	-1.623
2457706.35365741	-1.65
2457706.35393519	-1.592
2457706.35421296	-1.611
2457706.35449074	-1.608
2457706.35476852	-1.625
2457706.35504630	-1.636
2457706.35532407	-1.574
2457706.35560185	-1.612
2457706.35586806	-1.586
2457706.35614583	-1.591
2457706.35642361	-1.55
2457706.35670139	-1.53
2457706.35697917	-1.566

2457706.3401852	-1.419
2457706.3404630	-1.408
2457706.3407407	-1.463
2457706.3410185	-1.453
2457706.3412963	-1.439
2457706.3415741	-1.459
2457706.3418519	-1.439
2457706.3421181	-1.451
2457706.3423958	-1.453
2457706.3426736	-1.439
2457706.3429514	-1.425
2457706.3432292	-1.441
2457706.3435069	-1.409
2457706.3437847	-1.401
2457706.3440625	-1.401
2457706.3443403	-1.386
2457706.3446181	-1.377
2457706.3448843	-1.397
2457706.3451620	-1.397
2457706.3454398	-1.391
2457706.3457176	-1.393
2457706.3459954	-1.381
2457706.3462732	-1.405
2457706.3465509	-1.347
2457706.3468287	-1.337
2457706.3471065	-1.359
2457706.3473843	-1.311
2457706.3476620	-1.352
2457706.3479282	-1.324
2457706.3482060	-1.362
2457706.3484838	-1.391
2457706.3487616	-1.393
2457706.3490394	-1.366
2457706.3493171	-1.365
2457706.3495949	-1.405
2457706.3498727	-1.402
2457706.3501505	-1.413
2457706.3504167	-1.347
2457706.3506944	-1.316
2457706.3509722	-1.325
2457706.3512500	-1.348
2457706.3515278	-1.32
2457706.3518056	-1.395
2457706.3520833	-1.317
2457706.3523611	-1.355
2457706.3526389	-1.371
2457706.3529167	-1.328
2457706.3531829	-1.332
2457706.3534607	-1.317
2457706.3537384	-1.353
2457706.3540162	-1.32
2457706.3542940	-1.314
2457706.3545718	-1.305
2457706.3548495	-1.348
2457706.3551157	-1.338
2457706.3553935	-1.324
2457706.3556713	-1.323
2457706.3559491	-1.319
2457706.3562269	-1.339
2457706.3565046	-1.309
2457706.3567824	-1.29

2457706.33532407	-1.163
2457706.33556713	-1.197
2457706.33559028	-1.212
2457706.33583333	-1.189
2457706.33586806	-1.208
2457706.33611111	-1.156
2457706.33614583	-1.221
2457706.33638889	-1.207
2457706.33642361	-1.156
2457706.33666667	-1.167
2457706.33670139	-1.185
2457706.33694444	-1.171
2457706.33697917	-1.152
2457706.33722222	-1.164
2457706.33725694	-1.174
2457706.33750000	-1.168
2457706.33753472	-1.182
2457706.33777778	-1.167
2457706.33781250	-1.146
2457706.33805556	-1.176
2457706.33809028	-1.175
2457706.33833333	-1.166
2457706.33835648	-1.127
2457706.33859954	-1.169
2457706.33863426	-1.11
2457706.33887731	-1.182
2457706.33891204	-1.157
2457706.33915509	-1.186
2457706.33918981	-1.161
2457706.33943287	-1.136
2457706.33946759	-1.161
2457706.33971065	-1.172
2457706.33974537	-1.203
2457706.33998843	-1.162
2457706.34002315	-1.132
2457706.34026620	-1.125
2457706.34030093	-1.212
2457706.34054398	-1.183
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2457706.34084491	-1.179
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2457706.34136574	-1.16
2457706.34140046	-1.175
2457706.34164352	-1.16
2457706.34167824	-1.154
2457706.34192130	-1.179
2457706.34195602	-1.156
2457706.34219907	-1.189
2457706.34223380	-1.175
2457706.34247685	-1.171
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2457706.34275463	-1.121
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2457706.34303241	-1.17
2457706.34306713	-1.11
2457706.34331019	-1.168
2457706.34334491	-1.104
2457706.34358796	-1.116
2457706.34361111	-1.184

2457706.35725694	-1.585
2457706.35753472	-1.563
2457706.35781250	-1.582
2457706.35809028	-1.529
2457706.35836806	-1.562
2457706.35863426	-1.543
2457706.35891204	-1.534
2457706.35918981	-1.608
2457706.35946759	-1.571
2457706.35974537	-1.578
2457706.36002315	-1.54
2457706.36030093	-1.598
2457706.36057870	-1.556
2457706.36085648	-1.561
2457706.36113426	-1.534
2457706.36140046	-1.521
2457706.36167824	-1.487
2457706.36195602	-1.53
2457706.36223380	-1.543
2457706.36251157	-1.541
2457706.36278935	-1.528
2457706.36306713	-1.506
2457706.36334491	-1.559
2457706.36362268	-1.512
2457706.36390046	-1.54
2457706.36416667	-1.532
2457706.36444444	-1.542
2457706.36472222	-1.496
2457706.36500000	-1.535
2457706.36527778	-1.462
2457706.36555556	-1.471
2457706.36583333	-1.512
2457706.36611111	-1.502
2457706.36638889	-1.5
2457706.36666667	-1.5
2457706.36693287	-1.466
2457706.36721065	-1.481
2457706.36748843	-1.484
2457706.36776620	-1.528
2457706.36804398	-1.484
2457706.36832176	-1.442
2457706.36859954	-1.463
2457706.36887731	-1.514
2457706.36915509	-1.465
2457706.36943287	-1.514
2457706.36969907	-1.531
2457706.36997685	-1.496
2457706.37025463	-1.471
2457706.37053241	-1.461
2457706.37081019	-1.471
2457706.37108796	-1.424
2457706.37136574	-1.43
2457706.37164352	-1.465
2457706.37192130	-1.442
2457706.37219907	-1.439
2457706.37246528	-1.443
2457706.37274306	-1.453
2457706.37302083	-1.44
2457706.37329861	-1.475
2457706.37357639	-1.486
2457706.37385417	-1.426

2457706.3570602	-1.321
2457706.3573380	-1.305
2457706.3576042	-1.285
2457706.3578819	-1.288
2457706.3581597	-1.294
2457706.3584375	-1.262
2457706.3587153	-1.284
2457706.3589931	-1.284
2457706.3592708	-1.315
2457706.3595486	-1.306
2457706.3598264	-1.273
2457706.3601042	-1.283
2457706.3603704	-1.285
2457706.3606482	-1.268
2457706.3609259	-1.303
2457706.3612037	-1.25
2457706.3614815	-1.263
2457706.3617593	-1.248
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		2457706.5213310	-1.108	2457706.42599537	-0.941

There are 1377 data values in I filter used to plot the light curve. In this case I include 694 data values only.

Appendix B: Internship Project Proposal

PHY 494 6.0 – Internship Project Proposal



LIGHT CURVE ANALYSIS OF SZ-LYN

By

P.T.L.V. Cooray
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Department Of Physics

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PHY 494 6.0 – Internship for B. Sc. Special Degree in Physics offered by the Department
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01. Introduction

Stars appear to shine with a constant light; however, thousands of stars vary in brightness. The brightness that a star appears to have (apparent magnitude) from our perspective here

on Earth depends upon its distance from Earth and its actual intrinsic brightness (absolute magnitude.) The behavior of stars that vary in magnitude (brightness) - known as variable stars - can be studied by measuring their changes in brightness over time and plotting the changes on a graph called a light curve.

SZ Lyn is a one of the variable star with high-amplitude δ -Scuti star and this project is based on Light curve Analysis of SZ Lyn variable star. Studying the Light curves are fundamental tools for variable star astronomy. They are relatively simple and easy to grasp. They show the brightness of an object over a period of time. In the study of objects which change their brightness over time, such as novae, supernovae, and variable stars, the light curve is a simple but valuable tool to a scientist.

In past, scientific data was hard to find and took a lot of time to analyze. In the late 20th century, most data collection (from both satellites and Earth-based telescopes) became computerized, but it required special software to analyze such as IRAF (the Image Reduction and Analysis Facility). IRAF is an astronomical software package that is widely used for almost anything an observational astronomy needs. Get an idea with IRAF's packages and how to handle IRAF Software to CCD Data reduction is the main object in this project.

02. Background and Significance

Research on **variable stars** is **important** because it provides information about stellar properties, such as mass, radius, luminosity, temperature, internal and external structure, composition, and evolution. Some of this information would be difficult or impossible to obtain any other way.

There are two basic types of variable stars such as **Intrinsic variables** and **Extrinsic variables**. **Intrinsic variables** are those in which the change in brightness is due to some change within the star itself such as in pulsating stars like the Cepheids.

Extrinsic variables are those in which the light output changes due to some process external to the star itself. The diagram below the main types of variable stars.

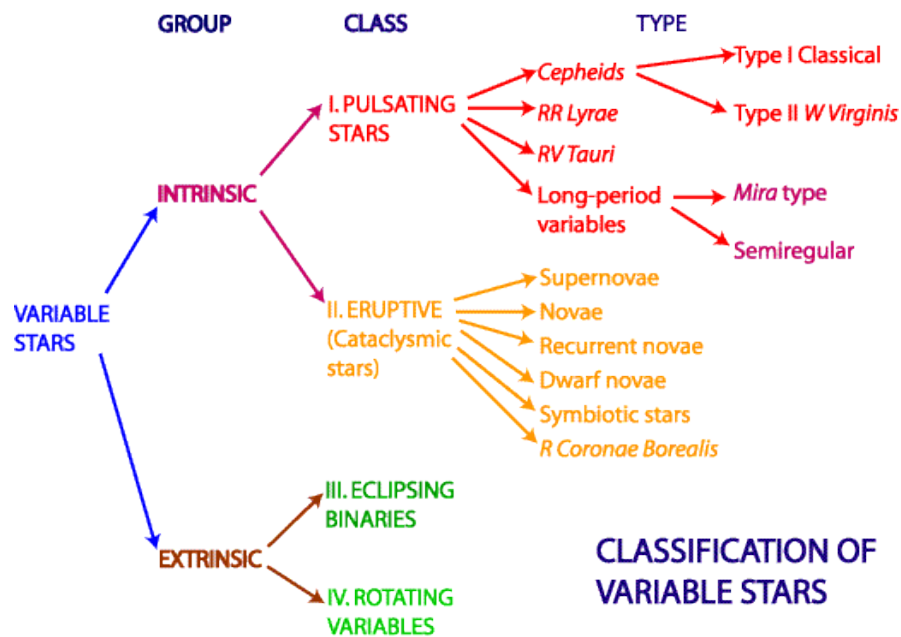


Figure 34 : Classification of Variable Stars

Some types of pulsating variable stars such as Cepheids exhibit a definite relationship between their period and their intrinsic luminosity. Such period-luminosity relationships are invaluable to astronomers as they are a vital method in calculating distances within and beyond our galaxy.

Most Research based on photometry is very important because it provides information about most of the stellar properties. Photometry is literally the measurement of light, how much, what colour and so on. Astronomically it is generally thought of in terms of measuring the colours and brightness of stars but it also includes the investigation of surface brightness in extended objects such as the moon, the planets, galaxies and, for example, arcs of emission nebulae in our own galaxy. The unit of brightness measurement, which is used on a regular basis by astronomers, is the ‘magnitude’.

Photometric data used to Calculating Distance and size of the variable stars. Photometric observations, be they naked-eye estimates, photographic plates, or photoelectric CCD images provide the apparent magnitude values for the Cepheid. Plotting apparent magnitude values from observations at different time results in a light curve. From the light curve and the photometric data, two values can be determined; the average apparent magnitude, m , of the star and its period in days. Knowing the period of the Cepheid we can now determine its mean absolute magnitude, M , by interpolating on the period-luminosity plot. Once both apparent magnitude, m , and absolute magnitude, M are known we can

simply substitute in to the distance-modulus formula and rework it to give a value for d , the distance to the Cepheid.

In this research by using photometric data set brightness changes over time. We will observe two naked-eye variable stars (Delta Cephei and Beta Lyrae) over a period of several weeks, then graph their light curves to verify their periods and ranges of brightness.

03. Objectives

- Installing and becoming familiar with IRAF Software.
- Get an idea with IRAF's packages, How to handle with IRAF Software to CCD Data reduction.
- Preliminary objectives of this research is Draw a Light Curve, Identify the period of the visual magnitude of the delta-Scuti star SZ Lyn and Identify the sub frequencies.
- Get an idea with physical change in SZ Lyn variable star size and surface temperature.

04. Methodology

- First of all get an idea about Linux Operating System is very important because Some of the computers in the Astronomy Lab use a version of Linux called Fedora as the Operating System. Some of the Linux based software such as IRAF used in astronomical analysis.
- The basic tool for scientific work on images from telescopes, which are in **fits** format, is the Image Reduction and Analysis Facility or in short: **IRAF**. Install IRAF 2.16 version in PC by using installation manuals in internet.
- Doing some short exercise that should help acquaint with the basics of IRAF. It helps to familiar with IRAF. IRAF Script writing is the essential thing to photometry. Then studying IRAF Script writing and familiar with IRAF Command language.
- After that Refer the Theoretical background of variable stars and CCD data reductions.

- My Supervisor Mr. Janaka Adassuriya (Research Scientist) provides me with data from SZ Lyn Variable star which was taken at 12th November 2016.
- The first step in this process was to identify the stars in the images. Before using data it has been calibrated and reduced the noises by using IRAF software. CCD photometric data reduction process is a procedure essentially meant for cleaning the images that will be used for scientific analysis. The result of the reduction process will be a set of corrected images that will be used for analysis, which will be cleared of noise from many various sources, external to the object(s) and our interest.
- The basic steps for analyzing the CCD images :-
 1. Copy the image files and set up the software IRAF and DS9.
 2. Learn how to display images.
 3. Construct a flat field calibration image and understand its purpose.
 4. Understand the purpose of the sky background image for each target and wavelength.
 5. Use the sky and flat field images to perform image reduction.
 6. Align and combine individual images to produce a final V and R image.
 7. Align the final V and R images.
- Before analyzing the CCD images they require several corrections by using IRAF packages and commands.

01. Making a master bias

The first step in CCD photometry data reduction is to combine the bias images into one image called a master bias. The IRAF task used to create the master bias image is called **zerocombine**. To properly use this task.

02. Removing bias from the flats

The next step in data reduction is the removal of instrument generated error in the flat frames using the master bias. For this we will use the "**ccdproc**" task.

03. Making a master flat

Once the flat frame images have been corrected with the master bias, they must then be combined to make a master flat. This is done in IRAF with the use of the "**flatcombine**" task.

04. Correcting the raw data

The final step in data reduction makes use again of the IRAF task "**ccdproc**" to correct the raw science frames, using both the master bias and the master flat acquired in previous steps.

05. Aligning Multiple Images for Stacking

Unlike darks and flats, there is an extra step in combining several science exposures: alignment. The images will be offset slightly from one another, so we need to shift them into alignment. To do this we use the **imalign** task.

06. Combining Multiple Images

Once the images are aligned using **imalign**. We combine them using **imcombine** similarly to what we did when combining flats.

- With the reduced data, analysis may finally be performed. The ultimate goal of most photometry data analysis is to acquire the magnitudes of the objects in the images. The object magnitudes are essentially the results of photometry, and may be used in many various ways.
- After CCD Data reduction and analyze, graph their light curves to verify their periods and ranges of brightness and Frequencies.

05. Time scale bar chart

	Week No											
	1	2	3	4	5	6	7	8	9	10	11	12
Theoretical Survey												
Software Installation : Fedora 22												
IRAF or UREKA												
DS9												
Doing IRAF Exercisers												
CCD Data reduction												
Analyzing the imagers												
Draw light curve												
Prepare a report												

06.Source of funding / Resources provider:

Arthur C Clarke center for modern technology.

07.Summary

SZ Lyn Variable star data set which was taken at 12th November 2016 will analyze by using IRAF software and then graph their light curves to verify their periods and ranges of brightness and Frequencies.

08.References

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A User's Guide to CCD Reductions with IRAF, by Phil Massey, February 1997.

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