Study of physical characteristics and superhump – orbital period relationship of Su Ursae Majoris type stars

By

Pestheruwe Liyanaralalage Sujith Lakshan Cooray

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DECLARATION

The work described in this dissertation was carried out by me in collaboration with the Department of Physics, University of Sri Jayewardenepura, Sri Lanka under the guidance Dr. Shantha Gamage, senior lecturer, University of Sri Jayewardenepura, Sri Lanka and Mr. Indika Medagangoda, Research Scientist (Astronomy), Arthur C Clarke Institute for Modern Technologies, Sri Lanka and has not submitted elsewhere.

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Abstract

The photometric study of the main characteristics of the SU Ursae Majoris (SU UMa) stars is the main objective of this research. SU Ursae Majoris (SU UMa) stars belongs to the dwarf novae class of intrinsic cataclysmic variable (CV) stars. The relevant data obtained through Arthur C. Clarke Institute (ACCIMT) were analyzed from Image Reduction and Analysis Facility (IRAF), a professional astronomical data reduction and analysis software in Linux platform. During the period of the study raw image frames of four SU UMa stars such as SDSS0932, IY UMa, J0426 and J0711 were obtained. A set of time series raw images were analyzed by construction of light curves after reducing their dark, flat and bias noises. Since the obtained data samples were very faint, beyond 15 mag, a careful precise attention was made to reduce the noises of these frames. While Qphot and Phot packages in IRAF were mainly used for this data reduction and analysis the obtained results were compared with an IRAF script program (a program program that was written in iraf based programming method). Although it is found that there is a 0.5 magnification difference between IRAF Phot task and IRAF script the shapes of the features in their light curves were almost same. The main result of this research was obtained through the constructed light curve of the IY UMa system where it was observed normal bursts, one of the main characteristics of SU UMa systems, and an eclipse between normal star and the white dwarf the main components of a SU UMa system. The orbital period of the IY UMa was determined as 0.0743 days. The flux variation of the hotspot of the binary system was also clearly identified through the light curve

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List of Abbreviations

SU UMa……Su Ursae Majoris

ACCIMT……Arthur C Clarke Institute for Modern Technologies

IRAF……...Image Reduction and Analysis Facility

CCD……....Charge Coupled Device

DN……..Dwarf Novae

CV…….....Cataclysmic Variables

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Everything in the universe has a fate. Nothing is eternal. So stars have their own fate and the way of life. Every star born in a region of high density in a nebula. It is a cloud of gases. The center of the gas cloud will condense due to the gravity of its own. Then the region of condense matter will begin to heat up and start to glow forming Protostar. The Protostar have enough matter to make a millions of Kelvin temperature. This temperature produce energy via nuclear fusion which hydrogen atoms fuse to helium atoms. Now star begins to release its energy. It called as a **Main Sequence Star**.

A star of one solar mass (sun like) remains in a main sequence star for about 10 billion years, until hydrogen totally fuse to the helium. This helium core starts to contract due to the huge gravity and reaction begins the near the shell of the core due to the increase of the temperature. Now the temperature of the core enough to fuse helium into the carbon. And outer layer of the star begin to expand, cool and less shine. The expanding star called a **Red Giant**. When the helium runs out, the outer layer of the star drift away from its core as gaseous cloud called **Planetary Nebula**. The remaining core contains 80% of the star in its final stage. The core becomes to a **White Dwarf** which has huge gravity. There's no any fusion, cause to cool and dim. Eventually it comes to a **Black Dwarf**.

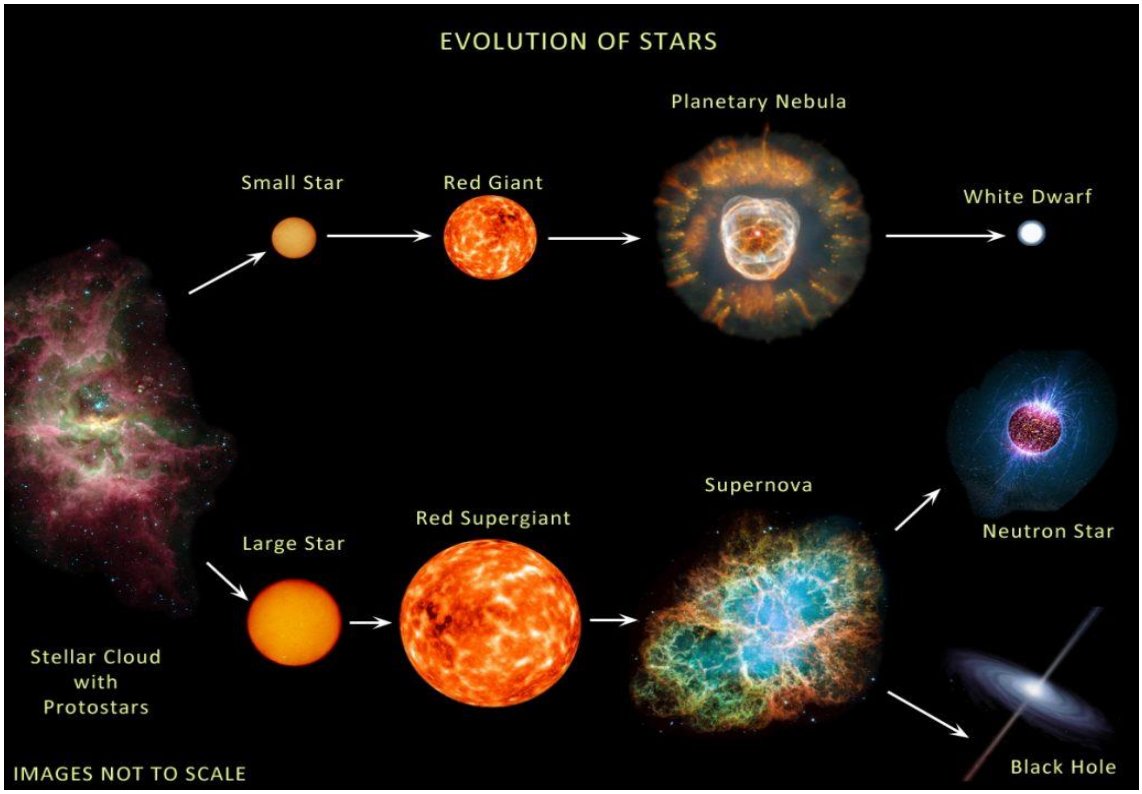

Figure 1-1 *Evolution of star; all stars born condensing a stellar cloud. Sun like stars follows the upper pathway and mass larger than three time solar mass follows the lower pathway*

Massive stars which has mass three time times or more greater than solar mass, evolve similar way in its early stages as small stars. Final stages are quite different for the massive stars. Massive star takes only millions of years to fuse its all hydrogen into helium when small star take billions of years. Then massive star become to **Red Supergiant** and shell around its helium core cooling and expanding gas. During next millions of years several fusion reaction occurs and forming several materials around the iron core. One day this core collapse in less than one second, makes an explosion called **Supernova** which shock wave blows the outer layer of the star. But sometimes core can survive after the explosion. The core with a 1.5-3 solar mass contract to become very tiny and dense **Neutron Star** and core has mass greater than three times solar mass cause to contracts to become **Black Hole**. (O'Brien & Windsor, 2017)

1.2 VARIABLE STARS

When we observing the stars by naked eye the brightness remains unchanged apart from twinkling due to the effect from our atmosphere. Careful observations shows that some stars do in fact appear to change in brightness over time. Some exhibit periodic behavior, brightening quickly then diminishing in brightness slowly only to repeat themselves. With some these changes take place over several days, others occur in a matter of hours or many months. So variable stars are the stars that change their brightness. There's two main types of variable stars. They are extrinsic variable stars and intrinsic variable stars.

Extrinsic variable stars change their brightness cause to the processes external to the star itself or due to the rotation of the star. Extrinsic star has two sub categories eclipsing binaries and rotating variables. Eclipsing binaries are binary star systems whose members eclipse each other, blocking one another's light, thereby causing the system to look fainter to observers on earth (Ex : Beta Persei (Algol)) **Figure 1-3**. The light curve of an eclipsing binary depends on the sizes and brightness of the stars, their separation from each other, and the geometry of view from earth. Our own sun is the example for the rotating variables. It shows extrinsic properties due to the sunspot on its surface. Rotating variables are rapidly rotating stars, often in binary systems, that undergo small-amplitude changes in light which may be due to dark or bright spots in the star's surface.

Intrinsic variable stars are star change their magnitude due to the internal physical changes that cause them to periodically brighten and fade. There's two sub categories of the intrinsic stars. They are pulsating variables and eruptive (cataclysmic) variables.

Radiation pressure occurs towards the surface of the surface due to the thermo nuclear process happen in inside of the star. Sometime there's some small imbalance between radiation pressure and gravitational force towards to the center of the earth that cause to pulsate the star. These stars name as a pulsating stars.

Eruptive or cataclysmic variable stars which undergo eruptions or explosions. Supernovae and Novae are the example for the eruption variable stars. Novae is the result of the stars in two different stages. One in sun like or giant star phase and other in white dwarf phase.

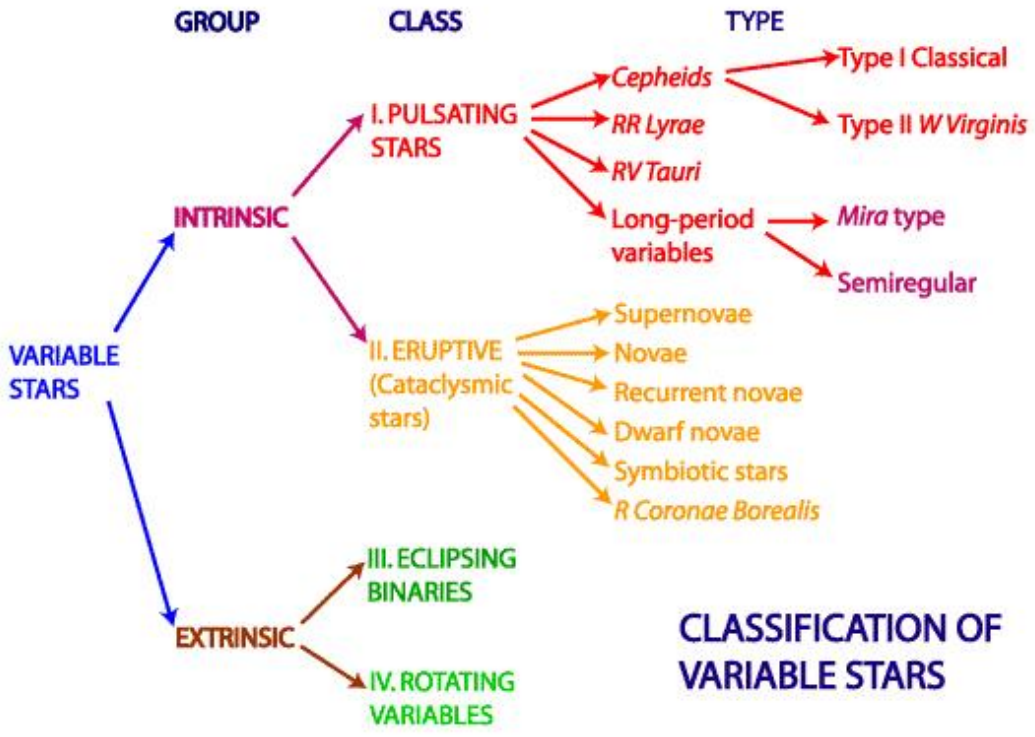

Figure 1-2 *Diagram for the summery of the variable stars classification*

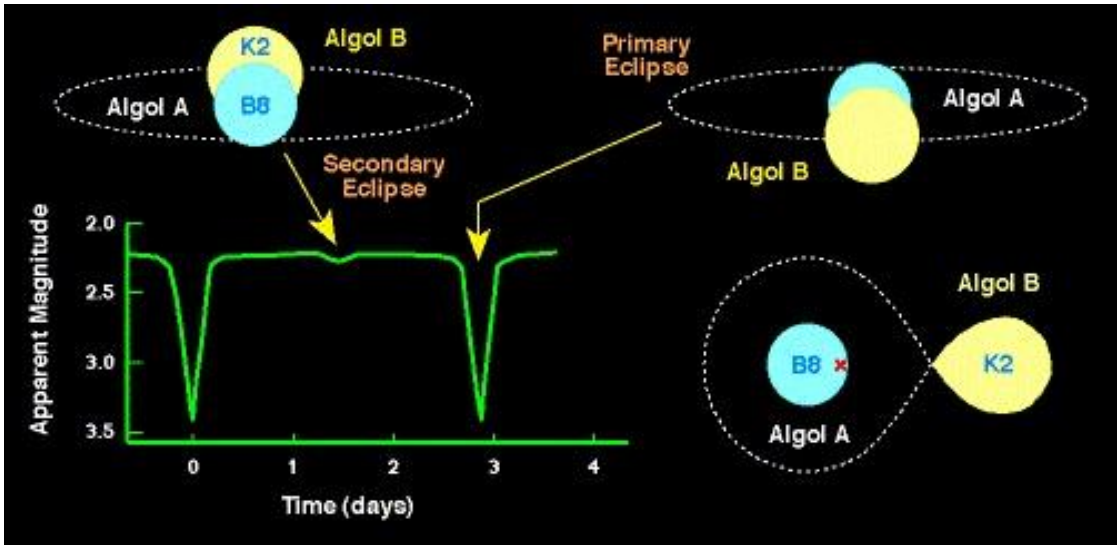

Figure 1-3 *the light variation of the eclipsing binary, Algol star. The light variation occurs due to the eclipses of the Algol A and Algol B. Algol A is brighter than Algol B. So brightness drop of primary eclipse which Algol A cover by Algol B, is greater than secondary eclipse which Algol B cover by Algol A*

1.2.1 CATACLYSMIC VARIABLE STARS

These are not one star systems, but two stars orbiting very close to each other, one of them a normal Sun-like or giant star, the other a white dwarf. White dwarf stars are very compressed: they may pack the mass of our entire Sun into a size no bigger than the Earth. Some of the outermost material from the larger is pulled away by the white dwarf's gravity, but this material does not fall directly onto the white dwarf. Instead, it builds up in a disk called accretion disk, which orbits the white dwarfs. The combination of normal or giant star, white dwarf and accretion disk can lead to some very spectacular celestial fireworks. That is why, instead of varying smoothly like most pulsating variables, eruptive variables exhibit outburst activity, usually brightening by a large amount. The changes in their light curves are usually very unpredictable, and tend to be sudden and dramatic; that is why these stars are also called "cataclysmic variables" (CV).

Novae explosions (eruptions) occur in a close binary systems consisting of a white dwarf orbiting a larger and cooler star. A layer of hydrogen rich material is slowly accreted from the cooler star onto the compact white dwarf. The accreted material provides the fuel for the nova explosion, a thermonuclear fusion reaction similar to the detonation of hydrogen bomb. The system increases in brightness by 7 to 16 magnitudes in a matter of one to its original brightness over several years or decades. Systems which have undergone two or more nova like eruptions during their recorded history are referred to as recurrent novae. Such recurrent eruptions have a slightly smaller amplitude than that which is observed in novae.

Another class of CV stars is called **Dwarf Novae** (DN). These are close binary systems made up of Sun like star, a white dwarf, and an accretion disk surrounding the white dwarf. As matter accumulates in the accretion disk, the disk becomes unstable. Eventually, matter from the unstable disk will fall onto the white dwarf, leading to an outburst. There are three sub classes of dwarf novae. (AAVSO, 2006)

1. *U Geminorum* sub class (also called SS Cygni sub class) – also in close binary systems, with orbital periods on the order of a few hours. After intervals of well-defined quiescence at minimum magnitude, they brighten suddenly within 1-2 days. Depending on the star, the eruptions occur at intervals of 30 to 500 days. The light amplitude of the outburst ranges from two to six magnitudes with a duration of 5 to 20 days. *Ex*: SS Cygni.
2. *Z Camelopardalis* – the second dwarf novae sub class, are physically similar to U Geminorum stars. Their eruptions occur at intervals of 10 to 30 days or more;

however, the quiescent level of Z Camelopardalis stars is not well defined. In addition, the cyclic variations are interrupted by intervals of constant brightness called standstills. The standstills last the equivalent of several cycles (sometimes years), with the star "stuck" at a brightness approximately a third of the way from maximum to minimum. In general, at the end of standstill, the star continues to fade its quiescent level.

3. *SU Ursae Majoris* – the third dwarf novae sub class, are also physically similar to U Geminorum stars. They have short orbital periods of less than two hours. In addition, they have two distinct kinds of outburst: one is short, with a duration of one to several days, faint and more frequent; the other (superoutburst) is long, with a duration of 10 to 20 days, bright and less frequent. During superoutbursts, small amplitude, modulations (superhumps) appear with periods two to three percent longer than the orbital period of the system.

1.2.2 SU URSAE MAJORIS TYPE STARS

Discovered in 1908 by L. Ceraski of Moscow. The variable SU Ursae Majoris is located near the tip of the Great Bear constellation of Ursa Major, about 3 northwest of the bright star omicron Ursae Majoris. Variables of this sort are composed of a compact binary pair with a solar-type secondary star, a white dwarf primary star, and an accretion disk around the primary component. The observed outbursts are believed to be the result of interactions within the disk that circles the white dwarf. However, in addition to exhibiting normal dwarf nova outbursts which consist of a rise from quiescence of 2-6 magnitudes and 1-3 day durations.

Superoutbursts occur less frequently than normal outbursts (may occur every 3-10 cycles), last for 10-20 days, and may rise in brightness by at least an additional magnitude. Thus, as the name implies, superoutbursts are longer in duration and brighter in magnitude than the normal outburst. The rise to superoutburst cannot be distinguished from the rise to a normal outburst and while in superoutburst, a small periodic fluctuation of several tenths of a magnitude known as a superhump is observed at maximum. The unique aspect of superhumps is that the period of fluctuation is 2-3% longer than the orbital period of the system. Therefore, by observing the superhumps, one can obtain the orbital period of the system. SU UMa-type stars have been found (in almost all cases) to have orbital periods of less than 2 hours. (AAVSO, 2010)

1.3 SCOPE OF THE STUDY

The main purpose of this study is study the physical characteristics of SU UMa type stars by analyzing their light curve, using sufficient analysis method. SU UMa stars are hard to observe due to their faintness. So try to observe them using the Sri Lankan largest telescope at ACCIMT. And find the way to take the photometric data from online provided by foreign sites of telescopes and specially Kepler, space based telescope. Mainly, packages in the IRAF use to analyze the photometric images of the SU UMa stars. We had to reduce the dark, bias and flat noises of the photometric data. There were several steps that should follow for the analysis mainly using phot package, which took much time. All the analyzing procedure can include to the single programme using script based on the IRAF that can save the time. The light curve of the SU UMa stars could take using analyzing the photometric images. Light curve was the main feature that could use

to study the physical characteristic of the SU UMa stars in photometric aspects. These light curves was plotted and modelled using the MATLAB software.

The first chapter generally introduce the evolution of the star and classification of the variable stars. The second chapter will be covering the theory background of the cataclysmic variable stars. The third chapter involves the way of take SU UMA stars photometric data and analyzing methods. In forth chapter consist the result that took after the analysis. Finally fifth and sixth chapters include the discussion and conclusion of the study respectively.

CHAPTER 2

THEORETICAL BACKGROUND OF THE SU UMA STARS

2.1 INTRODUCTION

Physically arrive to the white dwarf system is impossible. Because these systems are far away from us. So things happen in the white dwarf system cannot observe, even via the telescopes. Electromagnetic radiations were the only source that could take information about the white dwarf system. Astronomers used electromagnetic radiation to analyze the Dwarf nova systems. Finally developed many models and theoretical predications for, that can be happen in the white dwarf system. These system consists two stars which are white dwarf and normal star. They rotate around themselves with having orbital period distribution. Huge gravity of the white dwarf star cause to attract the matter of the normal star. So matter of the normal star transfer to the white dwarf star. Theoretical phenomena of Roche lobe overflow, stream trajectory and bright spot are important when the mass transfer. The matter transfer cause to the light variation of the normal star. And exhibits normal outbursts, super outbursts and superhumps. Matter of the normal star isn't take directly. It takes matter via an accretion disk. Viscosity, Turbulence, Tidal limitation and disc precession are important when discuss about the accretion disk. Also angular momentum problem of the system is important.

2.2 ORBITAL PERIOD

The orbital period of a dwarf novae (DN) is the most precisely known parameter. But it is smaller than orbital period of a planets in a solar system. They rotate around their gravity point very quickly and there isn't large separation between these two stars. So orbital period of the DN system are less than 10 hours. The effect of tidal interaction on the secondary cause it to rotate synchronously. So except DNs to have circular orbits and synchronously rotating secondary. Then newton's generalization of Kepler's third law gives,

$$P^2{}_{orb} = \frac{4\pi^2 a^3}{G[M(1) + M(2)]} \rightarrow (2.1a)$$

Or

$$a = 3.53 * 10^{10} M_1^{\frac{1}{3}}(1)(1+q)^{\frac{1}{3}} P_{orb}^{\frac{2}{3}}(h)cm \rightarrow (2.1b)$$

Where

P_{orb} = Orbital period

a = Separation between the centers of mass of the binary components

M(1) = Mass of the primary

M(2) = Mass of the secondary

q = Mass ratio M(2)/M(1)

$M_1(1) = M(1)/M_\odot$

2.3 ROCHE LOBE GEOMETRY

The Roche lobe is the region around a star in a binary system within which orbiting material is gravitationally bound to that star. The secondary stars in most CVs are closely similar to single main scale stars or to giants, which the mass of the star is centrally condensed, So Roche approximation can be adopted.

Cartesian coordinates(x, y, z) of the rotating binary, with origin at the white dwarf star, where the x-axis lies along the line of the stars centers, the y axis is in the direction of the orbital period of the primary star and z axis is perpendicular to the orbital plane. The total potential of the system at any point is potentials of the two stars and the effective potential of the fictitious centrifugal force given by,

$$\phi_R = \frac{-GM(1)}{(x^2+y^2+z^2)^{\frac{1}{2}}} - \frac{GM(2)}{[(x-a)^2+y^2+z^2]^{\frac{1}{2}}} - \frac{1}{2}\Omega_{orb}^2[(x-\mu a)^2+y^2] \quad (2.2)$$

Where

$$\mu = \frac{M(2)}{[M(1)+M(2)]}$$

$$\Omega_{orb} = \frac{2\pi}{P_{orb}}$$

By equations 2.1a and 2.1b we can take

$$\phi_R = \frac{GM(1)}{a} F\left(\frac{x}{a}, \frac{y}{a}, \frac{z}{a}, q\right)$$

So then the shapes of the Roche equipotential, $\phi_R = const$, are functions only of **q** and their scale is determined by **a**

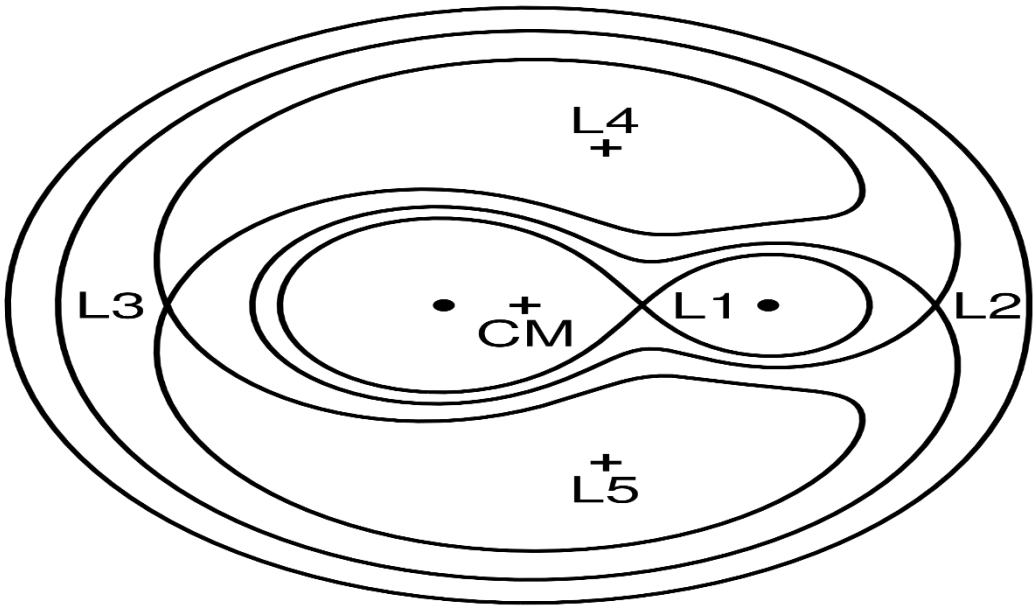

Figure 2-1 *Roche equipotential. The center of the primary is in big circle, secondary is in small circle and the center of gravity (CM). L1 and L2 are the inner and outer Lagrangian points respectively*

2.4 MASS TRANSFER

Mass transfer in CV makes thin disk called accretion disk. The system consists primary star, which is a white dwarf and secondary, which can fill the Roche lobe point that discussed in above section. This secondary star is a less massive star. This mass transfer is cause due to the huge gravity of the primary star. The mass flows off the secondary at the inner Lagrangian point L_1.

2.4.1 ROCHE LOBE OVERFLOW

When the secondary star exceeds its Roche lobe then its surface extend beyond the Roche lobe and mass that lies outside Roche lobe fall off into the other star Roche lobe via the inner Lagrangian point L_1, referred mass transfer via Roche lobe overflow.

The flow resembles the escape of gas through a nozzle into a vacuum; the velocity of the flow close to the thermal velocity of the atoms in the gas. The stream that leaving from the L_1 has a core that denser than the outer and its density profile should be close to the Gaussian.

The rate which mass lost from the secondary is

$$M'(2) = Q\rho'_{L_1} C_s \rightarrow (2.4)$$

Where,

Q = Effective cross-section of the stream

ρ_{L_1} = Density at L_1 averaged over the cross section

C_s = Averaged isothermal sound velocity

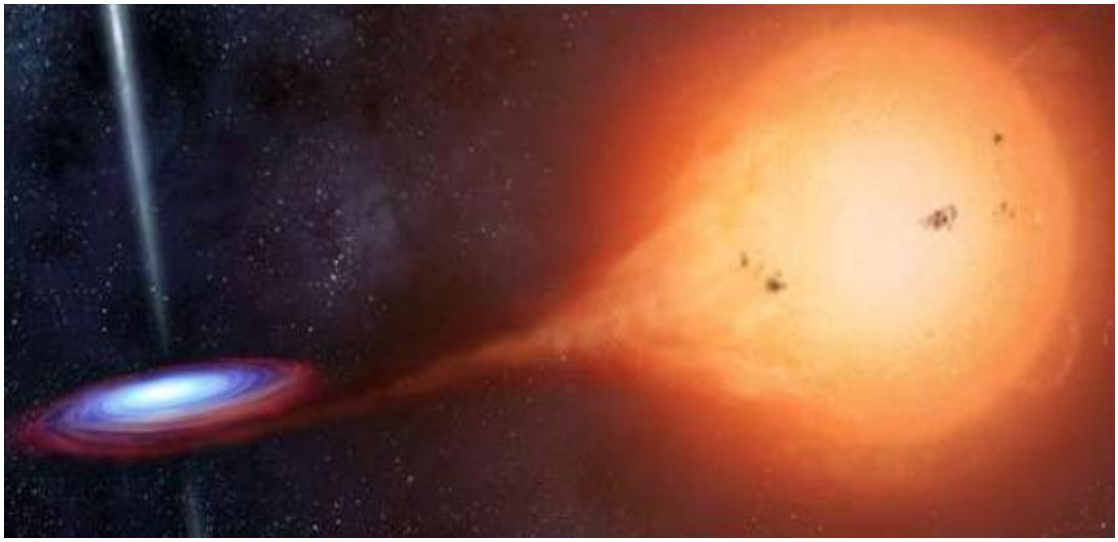

Figure 2-2 *Mass flow through the inner Lagrangian point*

2.4.2 STREAM TRAJECTORY

After Roche lobe overflow occur stream of gas flows away from the inner Lagrangian point L_1 the stream lines deflected by the Coriolis Effect. After leaving L_1 the gas particles fall towards the primary, which increases their original sonic velocities to highly supersonic. The stream expands transversely at the velocity of sound, so pressure forces are soon negligible and the stream trajectory is well described by the orbits of single particles ejected from L_1 in all directions at sonic velocities.

When a stream first begins to flow it passes by the primary and, the trajectory lying entirely in the orbital plane of the binary, collides with itself at a point well within the Roche lobe and relatively close to the primary. This collision at supersonic speed shocks the gas to high temperatures, thereby radiating away the relative kinetic energy of the impact. However, angular momentum is conserved and as a circular orbit has the least energy for a given angular momentum, the dissipation will tend to produce a ring of gas.

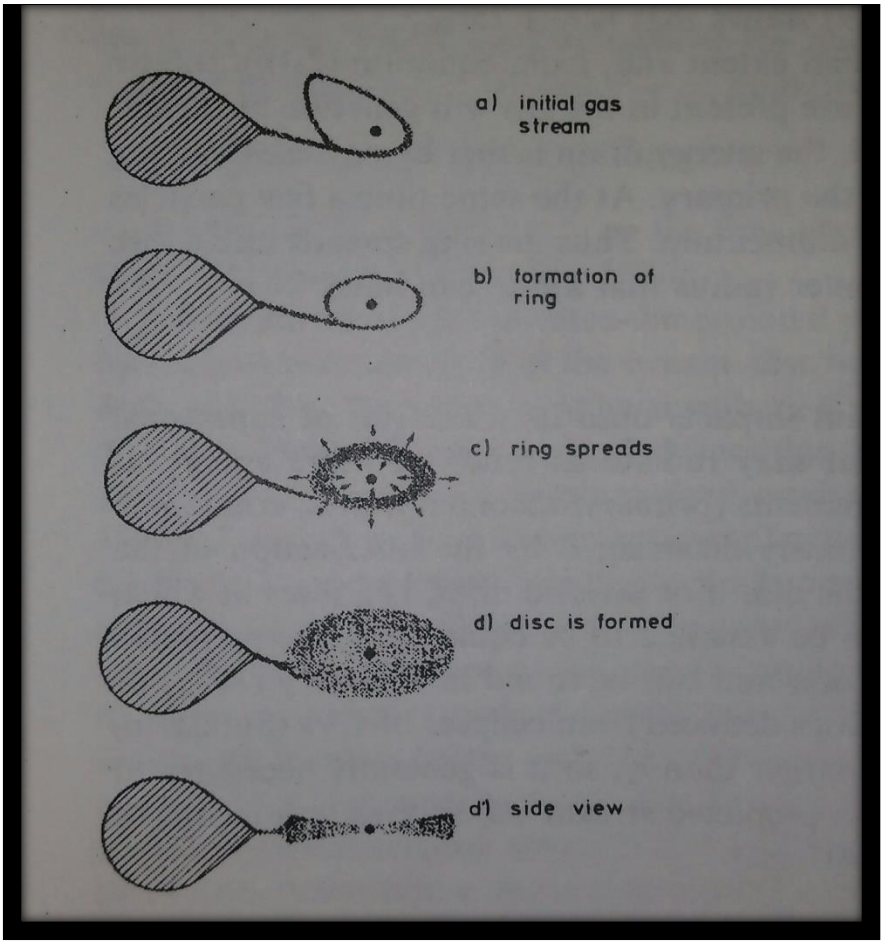

Figure 2-3 *Schematic illustration of the initial formation of a ring and its evolution into a dics.*

A rough estimate of the radius r_r of the ring, which form due to the stream trajectory can be obtained by assuming that after a particle leaves L_1 its angular momentum about the primary is conserved. A particle in a circular orbit at a distance r from the primary has a Keplerian velocity $v_K(r)$ given by,

$$v_K(r) = \left[\frac{GM(1)}{r}\right]^{\frac{1}{2}} \rightarrow (2.5)$$

and conservation of angular momentum requires that

$$r_r v_K(r_r) \approx \frac{2\pi}{P_{orb}} R_{L_1}^2 \rightarrow (2.6)$$

We have

$$\frac{r_r}{a} \approx \left(\frac{R_{L_1}}{a}\right)^4 (1+q) \rightarrow (2.7)$$

From single particle trajectories, in which angular momentum lost to the secondary is automatically allowed for, a more accurate value of r_r is obtained,

$$\frac{r_r}{a} = 0.0859 q^{-0.426} 0.05 \leq q < 1 \rightarrow (2.8)$$

The ring that is formed has a finite radial extent and, from equation (2.5) rotates differentially. Any viscous processes that are present in the gas will generate heat from this shearing flow. As the heat is radiated, the energy drain is met by particles moving deeper into the gravitational potential of the primary. At the same time a few particles must move outwards to conserve angular momentum. Thus the ring spreads into a disc. r_r is the minimum outer radius that a disc can have.

2.4.3 BRIGHT SPOT

With the disc fully established, the stream impacts onto its outer rim at supersonic speeds, creating a shock-heated area that may radiate as much or more energy at optical wavelengths as all the other components combined. The location of this bright spot (Hot spot) is obviously determined by the intersection of the stream trajectory with the outer edge of the disc.

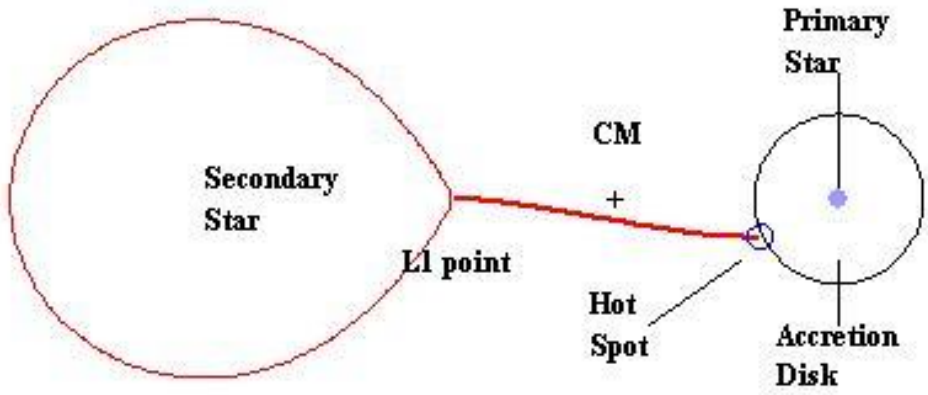

Figure 2-4 *Bright spot or hot spot at the outer edge of accretion dics of the primary star*.

Discs in which the viscosity is so low that their radii can be assumed to be equal to r_r ,the predicted geometry is a function only of mass ratio q. However, radii of discs deduced from eclipses of CVs are 2-3 times larger than r_r.

For a given CV, q is a constant, so variations in position of the bright spot can be derived from eclipse observations even if the absolute position may be somewhat uncertain. The results show that the spot can be relatively stable for some weeks, or can move significantly on the time scales of an hour.

More rapid variations in the structure and position of the bright spot which are result of the turbulence generated on impact. It is also possible that the stream itself is inhomogeneous as a result of turbulent flow through the L_1 nozzle.

Four important complications in the interaction of stream and disc,

a) If the impact region is optically thick, so that the energy of impact is not quickly radiated, then part of the stream bounces off the disc and is sprayed into the Roche lobe.
b) The denser core of the stream can penetrate into edge of the disc releasing its kinetic energy at optical depths greater than unity, thus locally heating the rim, increasing its scale height and causing a bulge that runs around the edge of the disc for typically half the perimeter.
c) Two shocks may form, with the stream material passing through one and the disc material through the other – these two shock faces form a triangular shaped region with an opening angle $M - 1$, where M is the Mach number of the converged of the downstream flow.
d) Part of the stream can flow over the rim of the disc and continue approximately along the single particle trajectory over the disc until impacts the disc at a later time.

2.5 ACCRETION DICS

Accretion disc is formed due to the mass transfer from secondary to primary. Both steady and non-equilibrium disc can found, often in the same object at different times. The light of many CVs in their steady state, and certainly of all DN at peak of outburst, is dominated by disc emission. Such objects behave almost like two dimensional stars, their thicknesses having only minor effects on observational properties.

The stream from the secondary lies in the orbital plane, and the turbulent impact at the bright spot is unlikely to raise a significant fraction of the stream material to large heights above the plane, the inflowing gas has momentum predominantly in the plane. The thickness of the disc is therefore determined by hydrostatic equilibrium.

Much of the disc is sufficiently close to the primary that the gravitational field of the secondary may be ignored – tidal interaction with the outer regions of the disc is, important in some circumstances. Throughout most of the disc the angular velocity Ω(r) of particles will differ negligibly from the Keplerian circular value.

$$\Omega(r) = \left[\frac{GM(1)}{r^3}\right]^{\frac{1}{2}} \rightarrow (2.9)$$

2.5.1 VISCOSITY

It is assumed that the disk behaves, in effect, like a fluid with a very high viscosity. Such an enhanced viscosity does indeed solve the angular momentum problem. As a thought experiment, start with a ring of gas orbiting at some distance from the source of the gravitational potential. Viscous stress between neighboring orbits rotating at slightly different velocity makes the ring spread both outward and inward, forming a disk. This spreading has a remarkable property: if sufficient time is available, almost all the mass accretes onto the central object. A small amount of mass in the outer parts of the disk expands indefinitely, carrying away almost all the angular momentum of the original ring. The time for spreading to a given distance is inversely proportional to the viscosity.

A characteristic velocity in the disk is the isothermal sound speed $c_s = (RT)^{\frac{1}{2}}$, where T is the temperature at the mid plane of the disk. A characteristic frequency is the orbital frequency Ω. The unknown disk viscosity **v** can then measure in terms of a dimensionless viscosity α, defined by

$$v = \frac{\alpha c_s^2}{\Omega} \rightarrow (2.10)$$

Where observational indications, such as the decay time of an outburst are available, they indicate viscosities in the range $\alpha = 10^{-3} - 1$.

2.5.2 BOUNDARY LAYER

The boundary layer (BL) is the region over which gas moving at Keplerian velocities in the disc decelerated to match the surface velocity of the primary. As a result radial support of the accreting gas is given largely by the pressure gradient instead of the centrifugal effect.

2.5.3 TIDAL LIMITATION

For discs that approach $R_L(1)$ in radius the outer parts will be significantly distorted by the gravitational influence of the secondary star. If pressure and viscosity effects can be neglected, streamlines of the disc flow are closely the same as simple periodic orbits in the restricted three body problem. There will be a largest orbit that does not intersect any other orbit; at larger radii intersecting orbits, which are equivalent to tidal shear, will produce dissipation and prevent the disc from growing any larger.

2.5.4 DISC PRECESSION

Several mechanisms have been proposed for generating a banking to an accretion disc. Of these, only that involving a disc freely precessing under the influence of the gravitational field of the secondary is probably relevant to CVs.

Two major theoretical problems associated with precessing discs are,

a) That each annulus will precess with a different period(unless the viscosity is very high), producing a twisted disc with no single precession period

b) A mechanism is required to feed gas to the tilted disc in a way that maintains the tilt.

CHAPTER 3

METHODOLOGY

3.1 OBSERVING STARS

Mainly we use telescopes to observe the space. Varies ranges in electro-magnetic spectrum; X-ray, Ultra-Violet, Visible, Infrared and Radio are used to observe. So different apparatus has to be mount to telescope for observe the different ranges. Very ranges have their own specification which gives important features in observing the space. Visible range was used to observe the stars. We used ground base telescope for space observation. But these telescope had many noises and observation was depended on the weather. So nowadays space-based telescope are used for space observation. The errors could reduce.

Charge Coupled Device (CCD) camera was used to take the photometric images of the stars. SU UMa stars are very faint. So sky supposed to be much clear. Otherwise we cannot observe it due to the background noises. Exposure time of the camera should be large enough to capture the light of the SU UMa stars.

3.1.1 SRI LANKAN LARGEST TELESCOPE IN ARTHUR C CLARKE INSTITUTE FOR MODERN TECHNOLOGIES (ACCIMT)

Sri Lankan largest telescope (**Figure 3-1**) situated at Arthur C Clarke institute for Modern Technologies, Katubadda, Moratuwa. It was GOTO 45 cm cassagrain telescope consist

with a spectrometer, photon counter and CCD cameras. This telescope could operate manually and automatically.

The specification of the cassagrain telescope is in APPENDIX 01**.** Telescope room roof was movable and had to open before the observation. Then the cover of the objective mirror had to remove. The CCD camera was mounted to the telescope eyepiece and telescope connected to the computer. Telescope could focused to star by giving the time of the location and coordinates of the star to telescope computer system. If it wasn't focused precisely then should focus manually. After that photometric images of the stars could be taken.

3.1.2 ONLINE OBSERVATION

Most of the telescope sites and space based telescopes provide their facilities via the internet. Internet users can access their facilities through the online. It is helpful to take the data who hasn't any good site for an observation.

Apache is one of the telescope site that provide online observation. SU UMa stars was tried to observe via online apache facility. Training sessions and require software for the online observation was provided by them. Time slot had reserved before the online observation. All the requirement and details was in their website. (**noc.apo.nmsu.edu**)

3.1.3 KEPLER TELESCOPE DATA

There's some space based telescopes use to take data about stars. The images taken from the space based telescopes has noises much less than ground base telescopes. Kepler is the one of the space based telescope (**Figure 3-2**).

There were several Kepler mission that conducted covering the specific regions of the space. Mission data was provide after a sometime via their data archives. Anyone can take this data and analyze them. They provide an analyzing tools to analyze the data.

The catalogue of the SU UMa star was created including their RA, DEC, classified category, suspect orbital period and magnitude. This catalogue was used to find the SU UMa stars in Kepler field.

The python version in operating system was upgraded. Because searching tools of the Kepler data were based on python. There were two task called K2fov and K2onSilicon that used find whether particular star was observe or not. The data searching procedure was in their website (https://keplerscience.arc.nasa.gov/software.html#k2fov).

Ten SU UMa stars were in their observed field (APPENDIX 02). The photometric data of this stars could take from their data archives by searching from the RA and DEC of the star. The Kepler package in the PYRAF, the python version of the IRAF can use analyze this data.

3.2 IMAGE REDUCTION AND ANALYSIS FACILITY (IRAF)

IRAF (**Figure 3-3**) is a collection of software written at the National Optical Astronomy Observatory (NOAO) geared towards the reduction of astronomical images in pixel array form. This is primarily data taken from imaging array detectors such as CCDs. It is available for all major operating systems for mainframes and desktop computers. Although written for UNIX-like operating systems. It is primarily used on Linux distributions.

IRAF commands are organized into package structures. Additional packages may be added to IRAF. Packages may contain other packages. There are many packages available by NOAO and external developers often focusing on a particular branch of research or facility. Of particular note are the STSDAS and TABLES packages by the STScI.

Just a few examples of functionality available in IRAF would be calibration of the fluxes and positions of astronomical objects within an image, sensitivity variations of the pixels & combine the multiple images.

There was software called Ureka which had the IRAF and its python version PYRAF. Which could install easily and quickly than IRAF of NOAO. The installation procedure and materials could found in http://ssb.stsci.edu/ureka/1.0/docs/index.html .

3.3 FIELD CORRECTIONS

The photometric data of the SU UMa star was taken using the CCD camera. These images are called raw images or object frames (**Figure 3-4**). The raw image contains everything that a CCD can generate both good and bad. We had record of the light that hits each photosite in CCD. Unfortunately, the record of light was mixed with other signals from the CCD that were, in a single frame indistinguishable from the signal made by light.

On the bad side, the thermal signal has added a scattering of hot pixels and a random background that obscures the weaker parts of the image. Noise and the voltage offset of the on chip amplifier overlay another layer of non-celestial signal. Furthermore, every pixel has registered brighter or darker than it ideally might have because the sensitivity of the photosite that generated that pixel differed from that of every other photosite.

Following errors can be occur when taking the raw images.

- An image of a celestial object, but it looks it looks weak or washed out. The celestial signal is sometimes considerably weaker than the sum of the noise sources, and therefore may be nearly lost in the raw image.
- The dark parts of the image do not have a pixel value of zero. Indeed, the lowest pixel value is often 100 or more. This is caused by amplifier bias and thermal signal; both effects increase the background even in the absence of light.
- Salt and pepper brightness variations in the background sky, with considerably more unusually bright pixels than there are unusually dark pixels. This effect is a

blend of random variation in the bias level caused by the on-chip amplifier and the random variation in the thermal signal each photosite generates.

- A random scatter of abnormally bright pixels, or “hot” pixels. Hot pixels come from photosites that generate much more thermal noise than most of the photosites on the chip.
- A circular glow from one corner of the image. This glow occurs because, in some cameras, the on-chip amplifier glows life a light-emitting diode.

All these effects can be removed or greatly reduced when we calibrate the raw image (**Figure 3-5**). Calibration produces an almost excellent improvement, not only for very faint objects, but also for bright ones.

There were several task in IRAF we had to use for the field correction. The every step that follow for the field correction in the APPENDIX 03. Normally did three types of corrections which were bias, dark and flat correction. So special frames were used for this correction which took during the observation of the object star.

We took the images of the bias, dark and flat. Each of them had several number of images. So we made masters for bias, dark and flat using *zerocombine*, *darkcombine* and *flatcombine* task in the IRAF respectively for each category. Finally reduced all raw images using these master frame.

3.3.1 BIAS CORRECTION

A bias frame is an image obtained from an optic-electronic image sensor, with no actual exposure time. The image so obtained only contains unwanted signal due to the electronics that elaborate the sensor data, and not unwanted signal from charge accumulation (ex. from dark current) within the sensor itself.

There were many frames of the bias. So single bias master frame (**Figure 3-6**) was created by using the task in IRAF. The followed procedure is in APPENDIX 03.

3.3.2 DARK CORRECTION

A dark frame was an image captured with the sensor in the dark, essentially just an image of noise in an image sensor. A dark frame, or an average of several dark frames (**Figure 3-7**), could then be subtracted from subsequent images to correct for fixed-pattern noise such as that caused by dark current.

3.3.3 FLAT CORRECTION

All the pixels making the CCD surface are almost similar; however, they present some variations of sensitivity: some of them will convert the light photons more efficiently into electrons than others. Also, the filters and lenses that are between the sky and the CCD can accumulate some dust particle that will cast a shadow on the CCD. The result of all these effects is that the image of a uniformly illuminated target will not appear uniform

on the CCD. To correct this effect, took several images of a flat field (uniformly illuminated), average them (**Figure 3-8**), and used them to map the sensitivity variations across the CCD.

3.4 PHOTOMETRY

Photometry is a technique of astronomy concerned with measuring the flux, or intensity of an astronomical object's electromagnetic radiation. At its most basic, photometry is conducted by gathering light in a telescope. An instrument that measured the light intensity of a single object by directing its light onto a photosensitive cell. These have largely been replaced with CCD cameras that can simultaneously image multiple objects.

In this research photometry was done for the four SU UMa stars by using IRAF Qphot, Phot task and IRAF script. Noise reduced raw images (**Figure 3-9**, **Figure 3-10**, **Figure 3-11** and **Figure 3-12**) were used for the photometry. There were many raw images which had constant exposure time that taken in the single observation as shown in below. But the same stars on the different frames were in different position. So stars were centroid before doing the photometry by using imcentroid or immatch task in the IRAF.

	IYUMA	SDSS092	J0426	J0711
Exposure	60	10	60	10
Number of frames	192	499	191	575

Table 3-1 *Exposure time and number of raw images of the star that use for the photometric analysis.*

Qphot used to do the quick photometry. The step that followed for Qphot in APPENDIX 04. Several steps had to follow for Phot task, referred (Massey & Davis, 1992). We had to use the datapars, centerpars, fitskypars and photopars task in the IRAF before using the Phot task.

3.5 IRAF SCRIPT

An IRAF script is a tool that allows to put together any number of IRAF Command Language (CL) statements to be executed as a group (Anderson). There were two types of modes which were command mode and program mode.

Sometime we repeated the photometric analysis by changing the some of the parameters of the task. So each of every step wanted to do again that took much time. We wrote an IRAF script for the Qphot and Phot (APPENDIX 05). And we used an advanced IRAF script for the data analysis.

Figure 3-1 *Sri Lankan largest, GOTO 45 cm cassegrain telescope located at roof top in the ACCIMT, Katubadda, Moratuwa*

Figure 3-2 *Image of the Kepler space based telescope. The cylindrical part use to collect the light of the stars. And it has solar panel system to produce the power. The main objective of the Kepler telescope is find the exoplants and extraterrestrial life.*

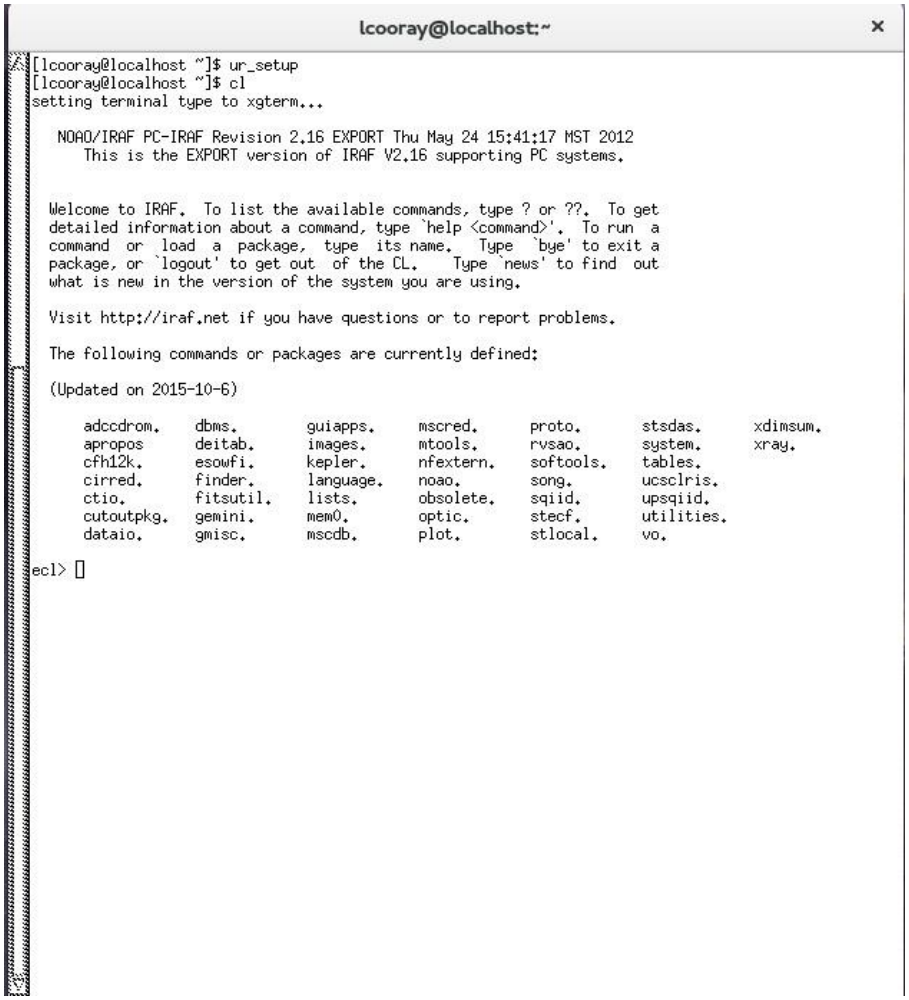

Figure 3-3 *First view of the IRAF in Ureka when open in the terminal called xgterm.*

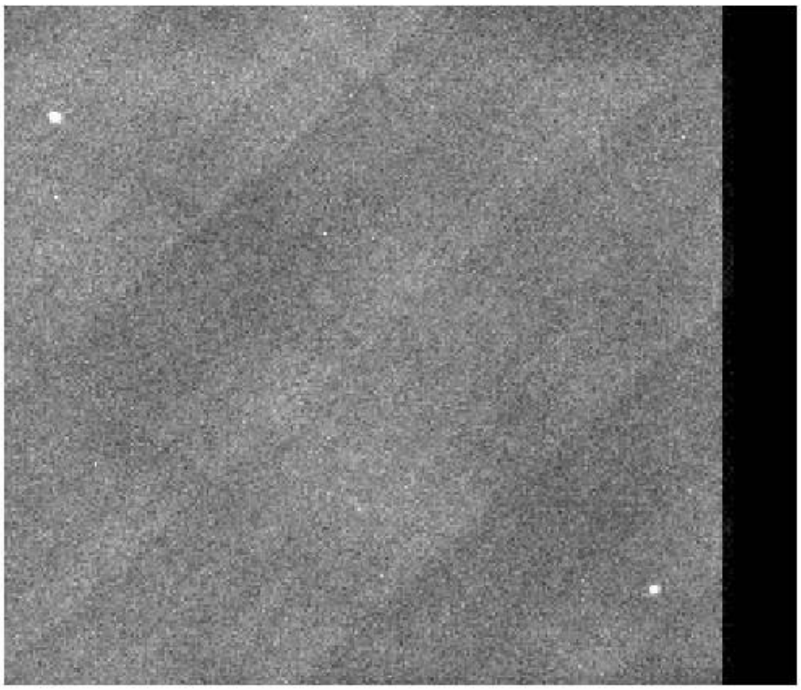

Figure 3-4 *Raw image of the SDSS0932 star. Two white dots are the object star and comparision star. This field has bias, flat and dark noises. Totally dark region is unwant part of the image.*

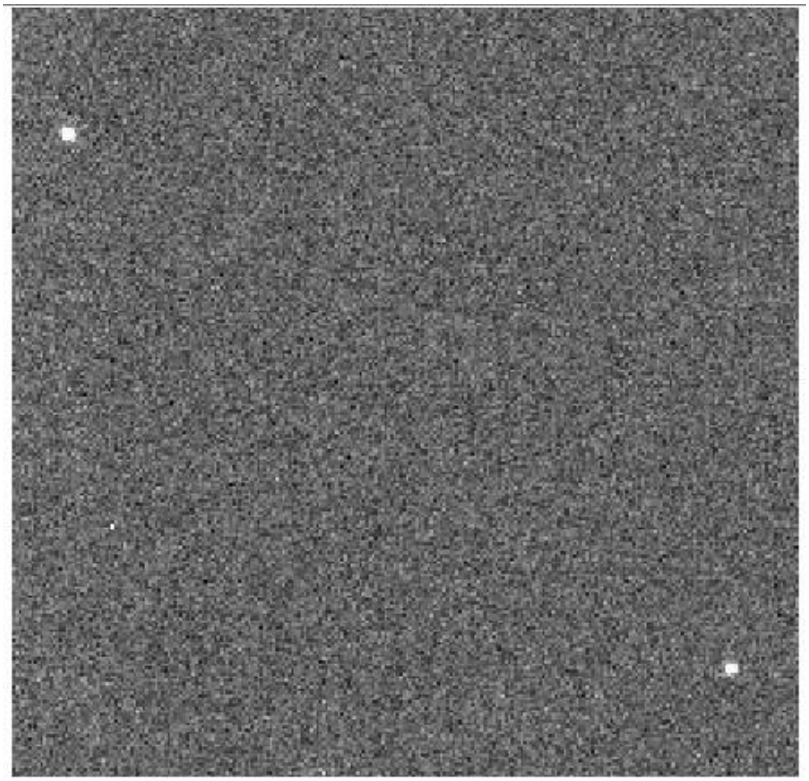

Figure 3-5 *Bias, dark and flat noises corrected raw image of the SDSS0932 star. So object and comparison can clearly identify.*

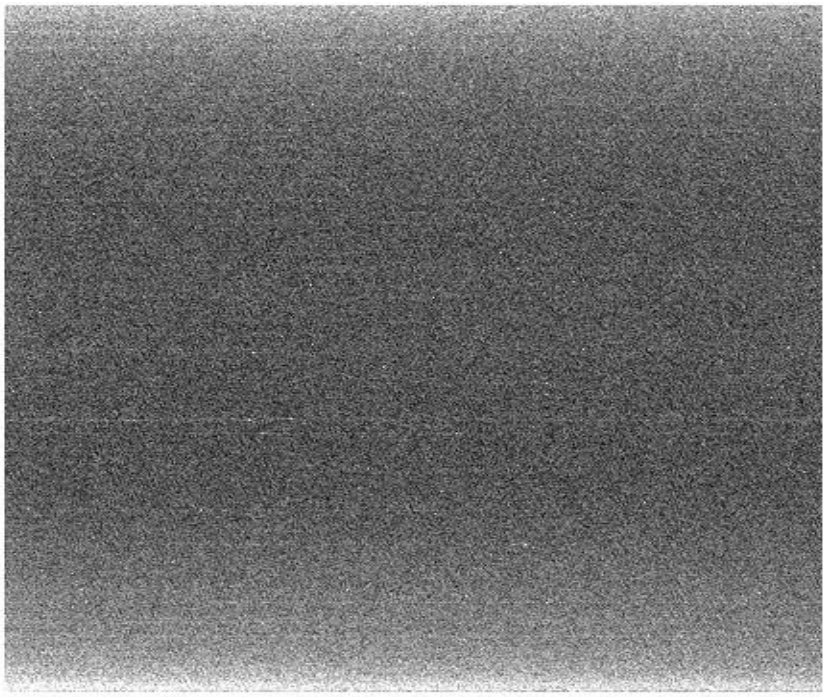

Figure 3-6 *Master bias frame image used for bias noise correction of the IY UMa star. There's no any star in this image, because looking only for the noises from the instrument. And there's no any .fix exposure time.*

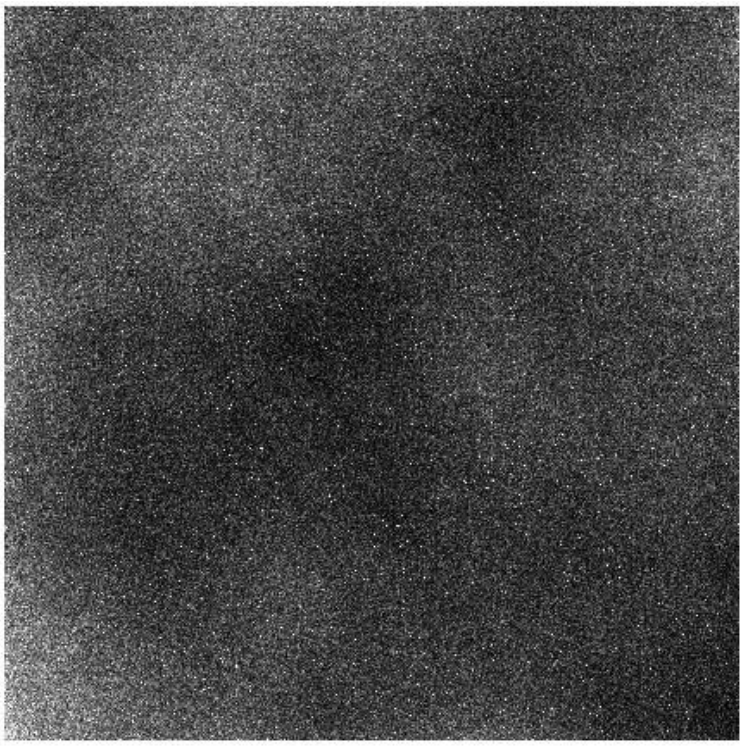

Figure 3-7 *Master dark frame used for dark correction of the IY UMa star. This image was created by combining the many dark images using IRAF darkcombine task.*

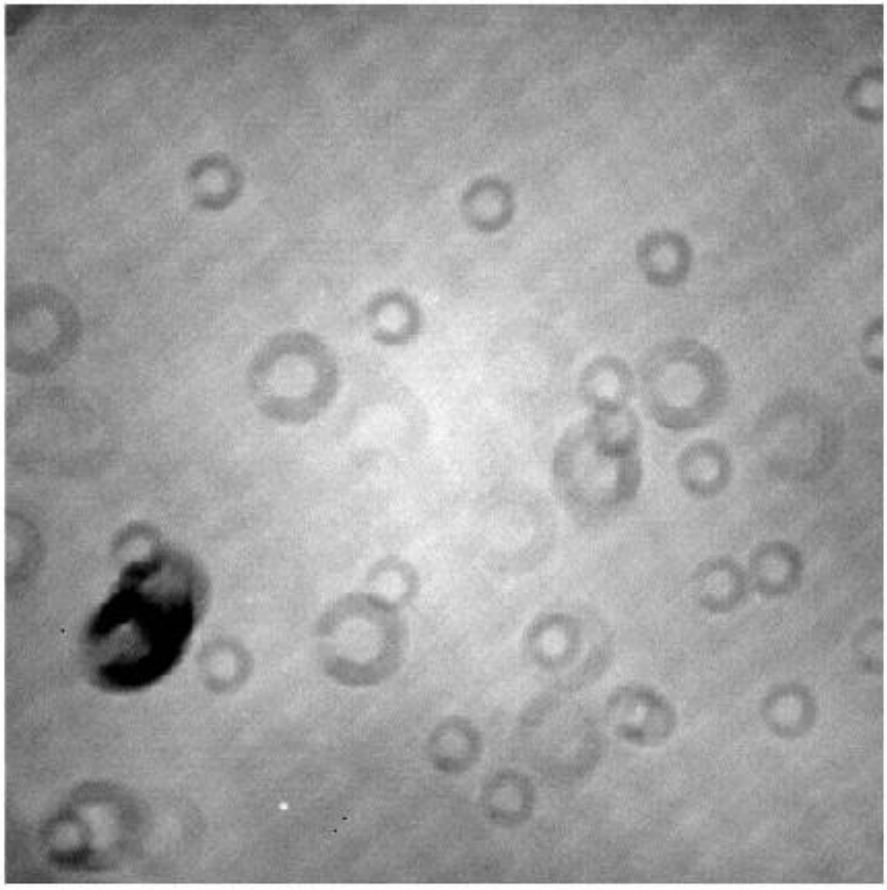

Figure 3-8 *Master flat image that used for flat correction in the IY UMa stars. There were many flat frames, so made master frame by combining all flat frames.*

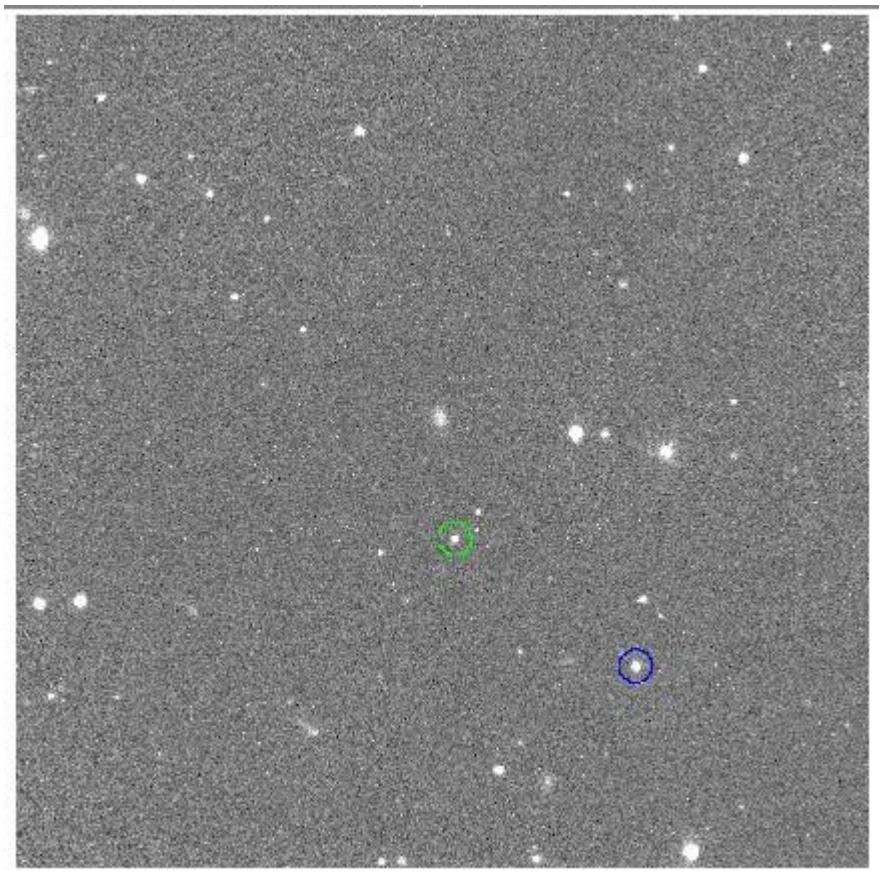

Figure 3-9 *Noise reduced object frame of the IY UMa. Green circled star is the object star. Blue circled star is the comparison star.*

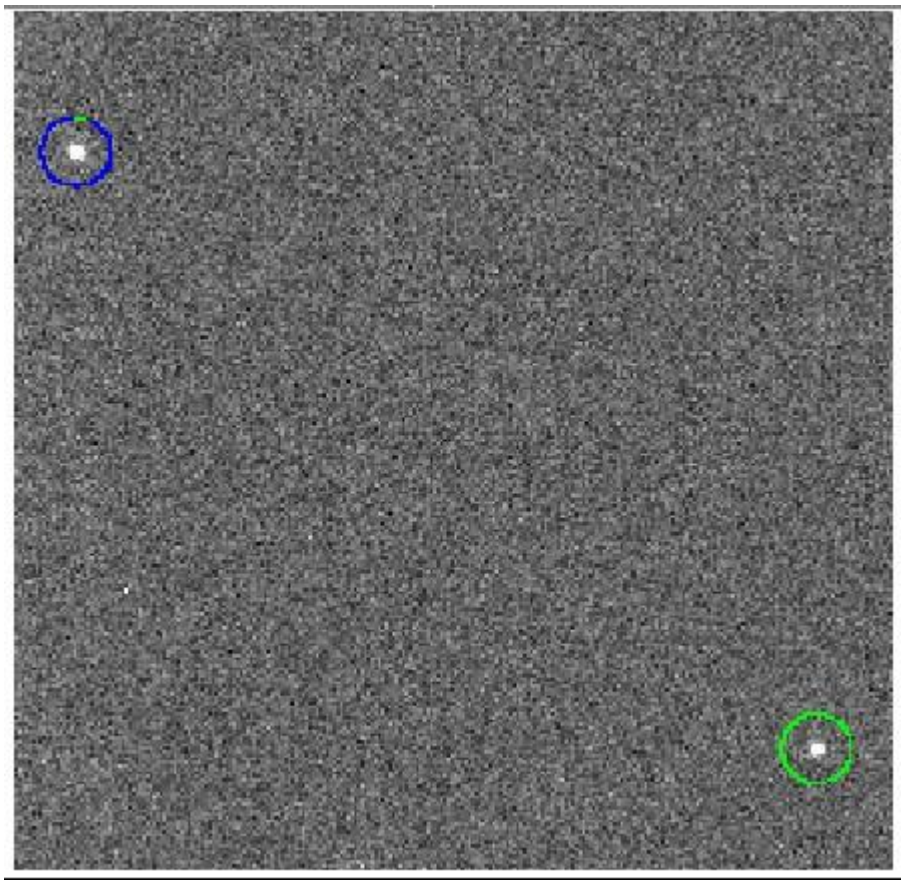

Figure 3-10 *Noise reduced object frame of the SDSS0932. Green circled star is the object star. Blue circled star is the comparison star.*

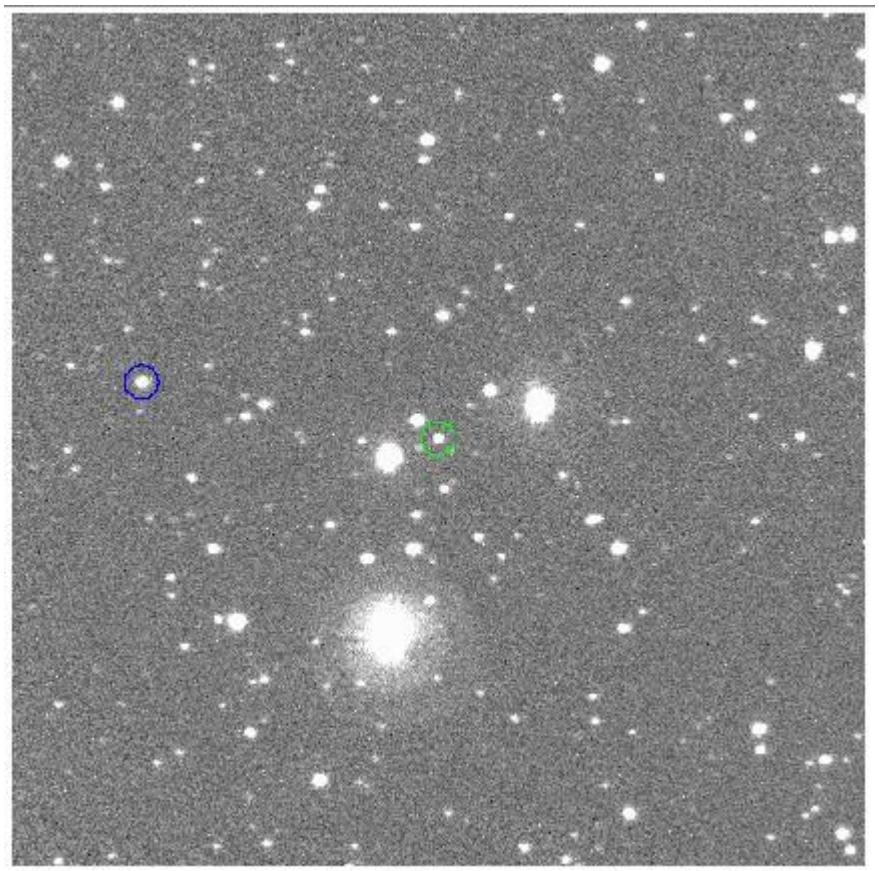

Figure 3-11 *Noise reduced object frame of the J0426. Green circled star is the object star. Blue circled star is the comparison star.*

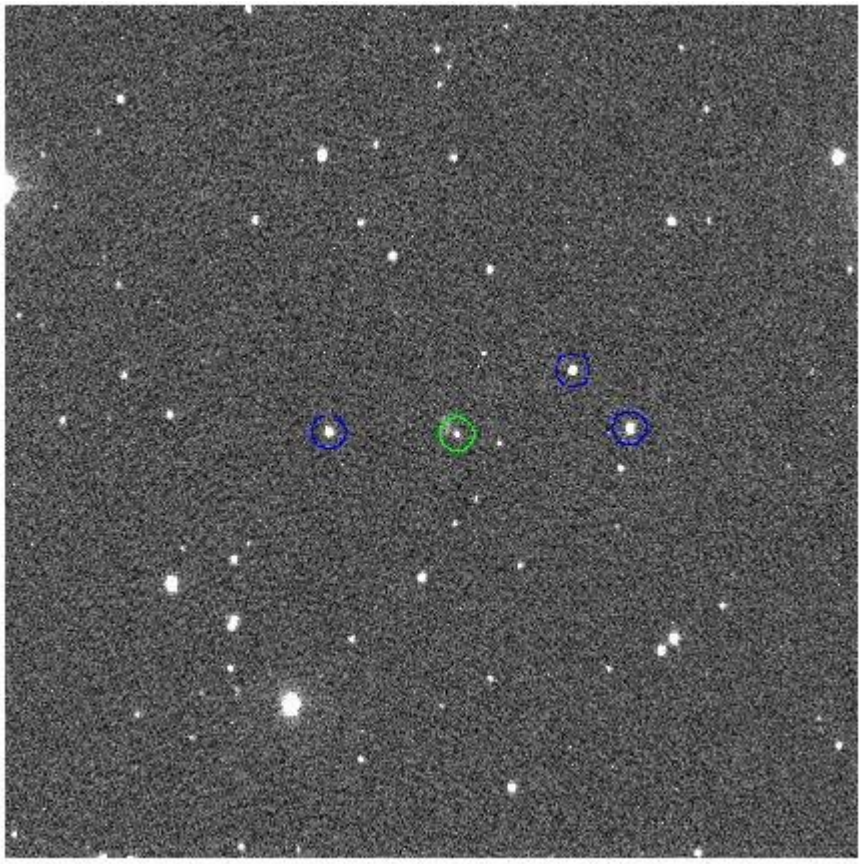

Figure 3-12 *Noise reduced object frame of the J0711. Green circled star is the object star. Blue circled stars are the comparison stars and check stars..*

CHAPTER 4

RESULTS

4.1 INTRODUCTION

Photometric analysis was done for the four SU UMa stars as following,

- IY UMa
- SDSS0932
- J0426
- J0711

Different time frames were obtained in a single observation run for above each stars to identify the light variations due to their internal characteristics. Two non-variable stars were selected as a comparison star and a check star to confirm any atmospheric effects.

The analysis mainly obtained on IRAF NOAO phot package. A developed IRAF script in order to minimize the series of steps in IRAF phot package were also tested and compared with the obtained phot results

The final outcome of this analysis was to obtain the magnitude variation of the objective (SU UMa) star during the considered observational run. The obtained light variation commonly known as light curves of above SU UMa systems were plotted in MATLAB. The shape and features of the light curve are used to interpret the physical properties of the considered star.

4.2 IY UMa

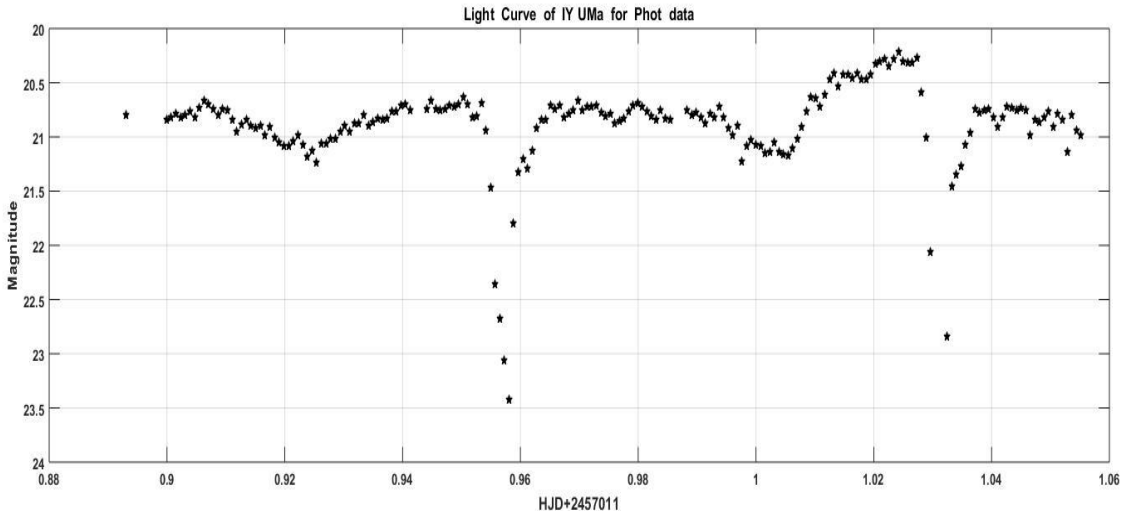

Figure 4-1 *Light curve of the IY UMa, the magnitude taken by using the phot task in IRAF noao package. The light curve was drawn by using MATLAB.*

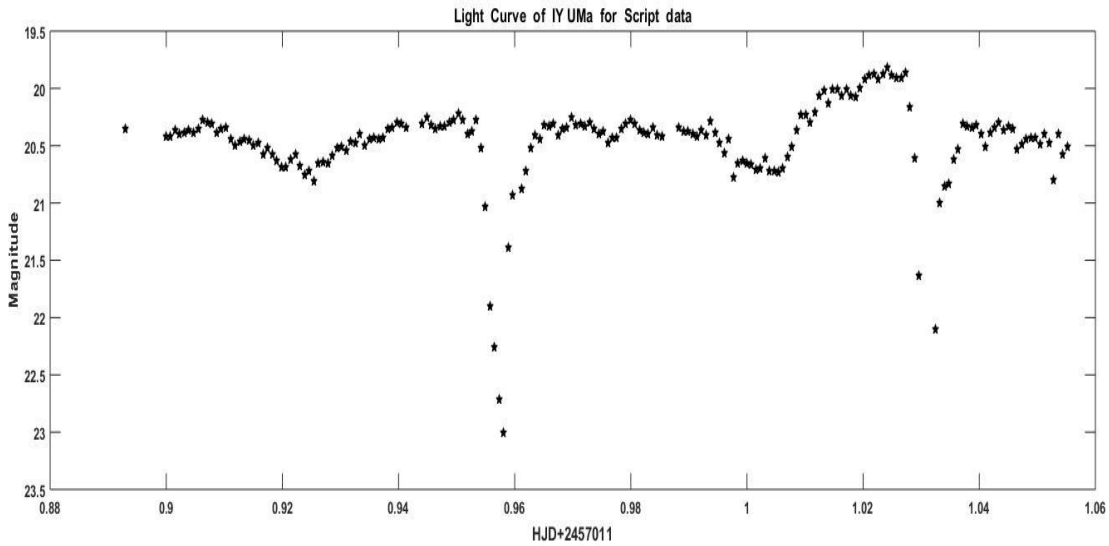

Figure 4-2 *Light curve of the IY UMa, the magnitude taken by using the IRAF script. The light curve was drawn using MATLAB*

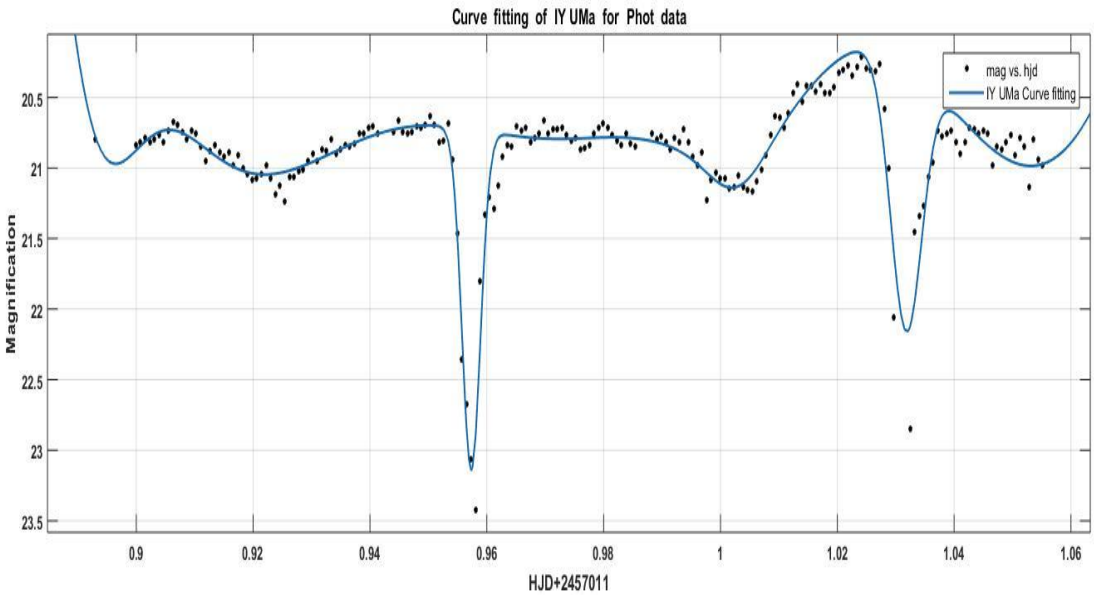

Figure 4-3 *Fitting Gaussian function to the light curve of the IY UMa, by using MATLAB. Magnitude of the star was taken by the IRAF noao phot package.*

The Gaussian function given by MATLAB that fitted to the light curve of the IY UMa

General model Gauss8:

$$f(x) = a1 * exp(-((x-b1)/c1)\text{^}2) + a2 * exp(-((x-b2)/c2)\text{^}2) + a3 * exp(-((x-b3)/c3)\text{^}2) + a4 * exp(-((x-b4)/c4)\text{^}2) + a5 * exp(-((x-b5)/c5)\text{^}2) + a6 * exp(-((x-b6)/c6)\text{^}2) + a7 * exp(-((x-b7)/c7)\text{^}2) + a8 * exp(-((x-b8)/c8)\text{^}2)$$

Coefficients (with 95% confidence bounds):

$a1 = 2.42 \ (2.225, 2.615)$

$b1 = 0.9573 \ (0.9572, 0.9575)$

$c1 = 0.002237 \ (0.002013, 0.00246)$

$a2 = 1.916 \ (1.652, 2.18)$

$b2 = 1.032 \ (1.031, 1.032)$

$c2 = 0.003792 \ (0.003214, 0.004369)$

$a3 = 18.07 \ (-81.96, 118.1)$

$b3 = 0.9041 \ (0.6777, 1.13)$

$c3 = 0.05182 \ (-0.2201, 0.3238)$

$a4 = 0.265 \ (-0.3119, 0.842)$

$b4 = 1.003 \ (0.9992, 1.006)$

$c4 = 0.006568 \ (-0.001911, 0.01505)$

$a5 = 16.04 \ (-154.8, 186.9)$

$b5 = 0.9775 \ (0.9123, 1.043)$

$c5 = 0.05123 \ (-0.3713, 0.4738)$

$a6 = 19.65 \ (-35.01, 74.31)$

$b6 = 1.062 \ (0.872, 1.252)$

$c6 = 0.05735 \ (-0.2249, 0.3396)$

$a7 = 2.558 \ (-8.996, 14.11)$

$b7 = 0.8908 \ (0.8701, 0.9116)$

$c7 = 0.01105 \ (-0.006921, 0.02903)$

$a8 = 1.129 \ (-5.609, 7.867)$

$b8 = 1.006 \ (0.9965, 1.015)$

$c8 = 0.01815 \ (-0.01715, 0.05346)$

4.3 SDSS0932

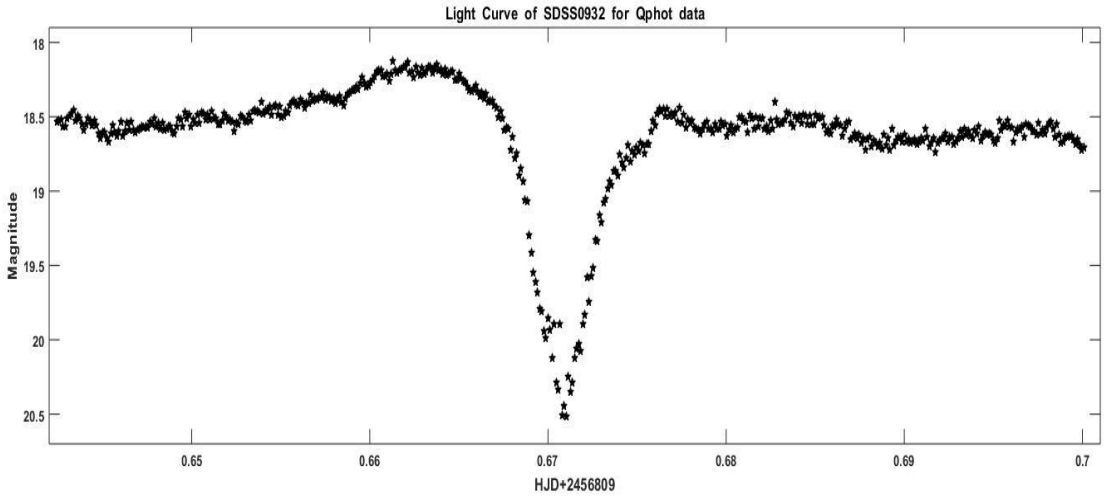

Figure 4-4 *Light curve of the SDSS0932, the magnitude taken by using the qphot task in IRAF noao package. The light curve was drawn by using MATLAB*

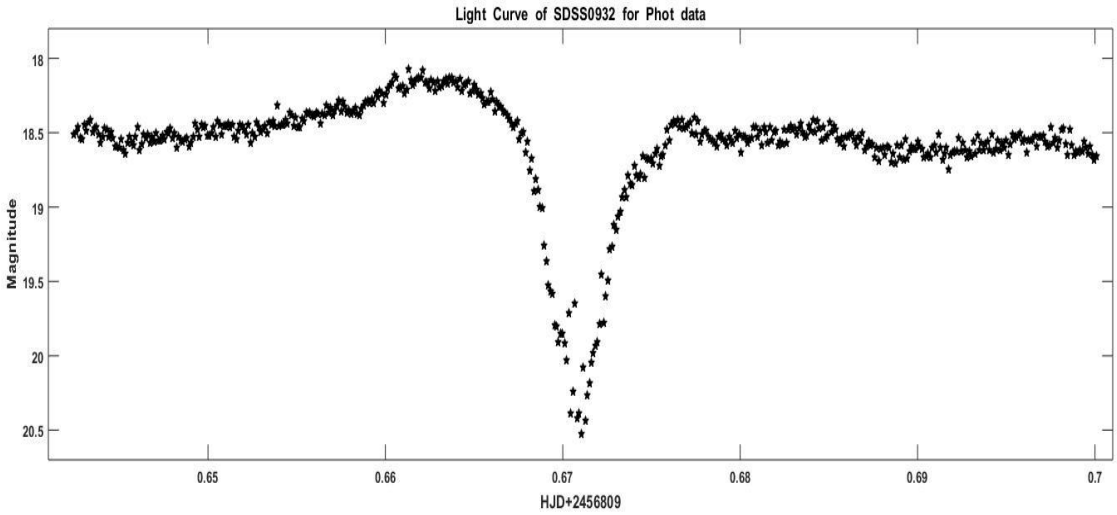

Figure 4-5 *Light curve of the SDSS0932, the magnitude taken by using the phot task in IRAF noao package. The light curve was drawn by using MATLAB*

4.4 J0426

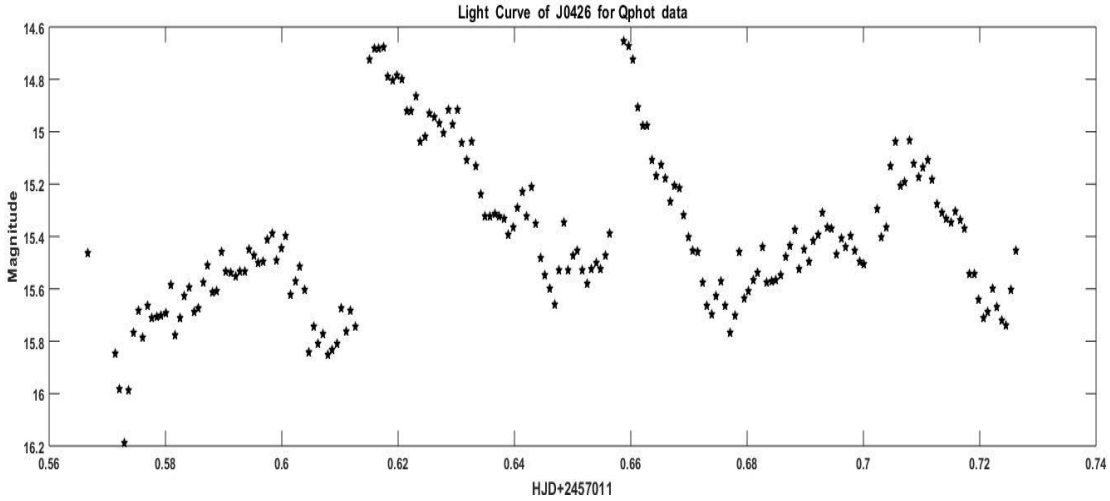

Figure 4-6 *Light curve of the J0426, the magnitude taken by using the qphot task in IRAF noao package. The light curve was drawn by using MATLAB*

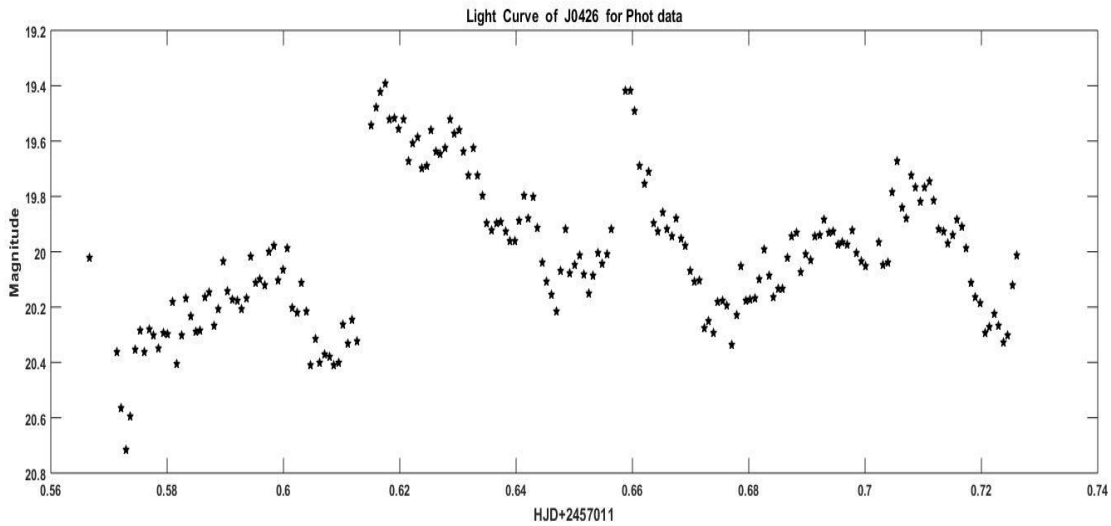

Figure 4-7 *Light curve of the J0426, the magnitude taken by using the phot task in IRAF noao package. The light curve was drawn by using MATLAB*

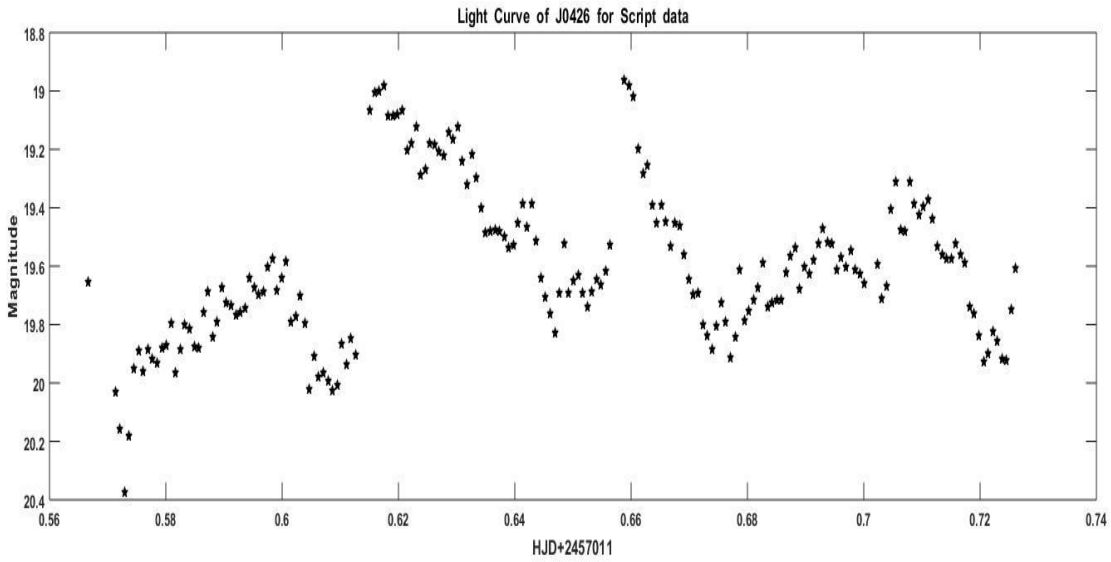

Figure 4-8 *Light curve of the J0426, the magnitude taken by using the IRAF script. The light curve was drawn using MATLAB*

4.5 J0711

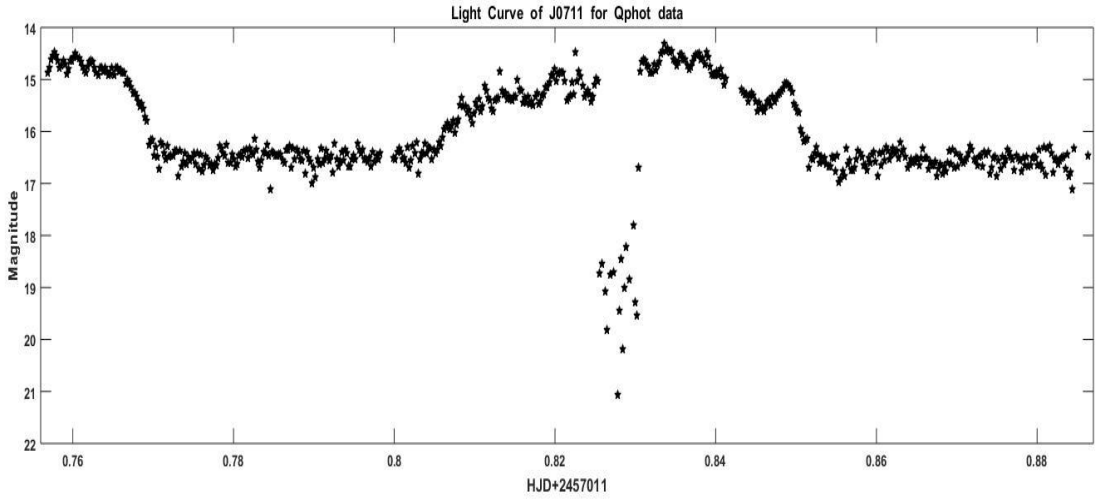

Figure 4-9 *Light curve of the J0711, the magnitude taken by using the qphot task in IRAF noao package. The light curve was drawn by using MATLAB*

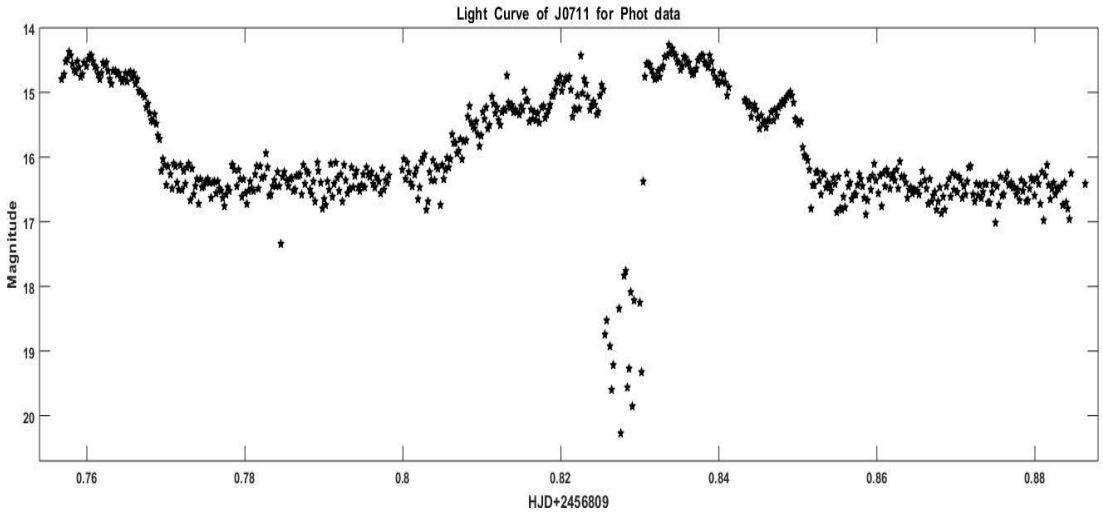

Figure 4-10 *Light curve of the J0711, the magnitude taken by using the phot task in IRAF noao package. The light curve was drawn by using MATLAB*

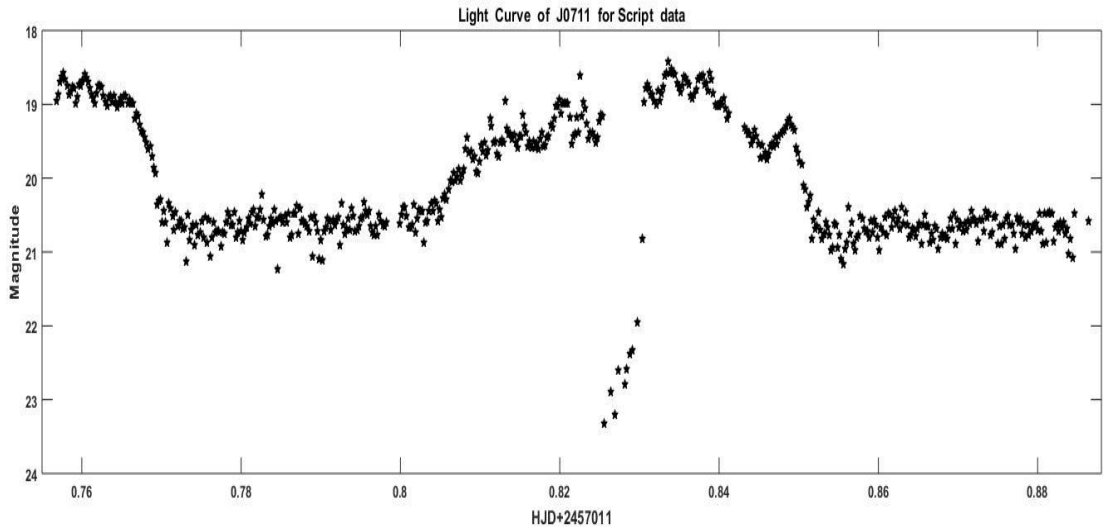

Figure 4-11 *Light curve of the J0711, the magnitude taken by using the IRAF script. The light curve was drawn using MATLAB*

CHAPTER 5

DISCUSSION

In this research two tasks in IRAF such as Qphot and Phot in IRAF noao package were used to obtain the instrumental magnitudes from the raw photometric data of the SU UMa stars.

Data analysis process using default Qphot task was faster. But has limited user controllable parameters than the Phot. Consideration of sky background, frame alignments, instrumental parameters are used in IRAF Phot. Therefore the Phot is recommended for a serious, bulk, accurate data analysis. On the other hand the Qphot task is good enough for a simple faster data analysis.

Since Phot process takes considerable amount of time when analyzing a bulk data as used in this project. The professional alternative is to use an IRAF script which needs only few inputs to do the particular task. Apart from default Qphot and Phot tasks, in order to speed-up the process of these data reduction an incomplete (still developing) IRAF script was also tested. It has been identified that the obtained light curve features between default methods and script were same but the magnitudes values obtained from the script were little lower than the default tasks.

Having obtained the instrumental magnitudes variation from Phot against the observation time of the star IY UMa two types of eclipses were identified in its light curve (**Figure 4-1**). The eclipses identified by sudden decrease of the brightness of the light which

represent as sudden increase of magnitude in the light curve. The first eclipse happened when the normal star eclipses from accretion disk around the white dwarf along with hotspot. The light decrement in this eclipse is greater than second one. The second eclipse happens when normal star eclipses the accretion disk and hotspot.

These two eclipses imply that the IY UMa system which included an accretion disk around white dwarf and a normal star makes a complete rotation around its common center of gravity. So time gap between two eclipses or maximums of magnitude in the light curve was the orbital period of this system.

In order to verify these minimum points in the minima a mathematical function using MATLAB was fitted to the light curve. Since the obtained best fit curve was a higher order Gaussian function (**Figure 4-3**) first derivations of the minima were used to finding the minimum points.

Using the above fit the orbital period of the IYUMA was found as 0.074378 days. This value only deviates 0.63% from the value, 0.073913 days, determined for the same by Uemura, et al., 2000.

Through the previous researches on SU Uma systems examples Uemura, et al., 2000, Rolfe & Haswell, 2001 it has been observed that the periods of superhumps of SU Uma systems are 2-3% longer than their orbital periods. Although the reasons behind this correlation were still unclear the above calculated orbital period of this research for IYUMA is in the range of 2%-3% when compared with the previously determined

superhump period of IYUMA by Uemura et al 2000 i.e 0.07588 days.

The photometric data of IY UMa used for this research, was taken in 2014. Which was nearly take 14 years after it first observation. But still there wasn't such a change in period of the orbital or superhump. Only 0.011 hours difference in orbital period.

There was decrease of the magnitude or increase of the brightness before the second eclipse. Any literature wasn't found that explain this feature. So need a longer observation of the IY UMa. The matter of the normal star transfer to the accretion disk of the white dwarf. During this mass transfer brightness was increased. So this might be an event that matter entering to the accretion disk of the white dwarf.

There was 0.5 magnitude difference in IRAF phot and IRAF script (**Figure 4-1** and **Figure 4-2**). But the features were same. This magnitude difference wasn't affect when finding the characteristic. So both light curves could use to study the characteristic of the system. Feature study of script wants correct this magnitude difference. We took a comparison and check star for our analysis. Then differential magnitude could take away this difference.

It might be eclipse either white dwarf or normal in the light curve of the SDSS0932 star (**Figure 4-5**). Eclipse couldn't identify specifically because there was only one eclipse. Two successive eclipses wanted to identify the type of eclipse.

There was a brighter area in SDSS0932 before in its eclipse. This might be the hot spot feature of the accretion disk according to the literature of the SU UMa. But it wants to observe feature.

There were two peaks of the brightness in the light curve of the J0426 (**Figure 4-7**).This interesting feature might be a normal burst. But more data were need to identify and confirm the feature. There wasn't any eclipse to identify because when eclipse occurred magnitude would be increased by nearly 2. So the orbital period of the J0426 was larger than other three stars.

There might an eclipse in the J0711 star (**Figure 4-10**). But couldn't use it to find the orbital period of the system. There wasn't continuous light decreasing in the first half of the suspected eclipse. Sudden change of the brightness occurred in this suspected eclipse.

Sri Lankan largest telescope in ACCIMT is locate in Colombo region. Many artificial light sources use in current large development projects, harbor, airports, and sky towers in the Colombo region during the night time. There's air pollution occurs due the automobiles and factories in the city side. This artificial lights and air pollution were caused to artificial light pollution. The night sky was made brighter than under the normal condition.

Some of the SU UMa stars were tried to observe which had magnitude less than 15, using the cassagrain telescope in the ACCIMT. But couldn't observed them due to the artificial light pollution in the telescope site. When the telescope was focused to our SU UMa stars

it seemed only dark. If magnification power of the telescope increased using a different eyepieces then the image was fully white. So couldn’t take the clear images of the SU UMa stars using the cassagrain telescope that could use to analyze.

We have to pay to reverse a time slot for online observation via apache telescope. We didn’t have fund for pay their cost. Then online observation opportunity was missed

The observed photometric data of 10 SU UMa stars could take via the Kepler space telescope website. This data facility was important which hadn’t good site to observe the SU UMa stars. But feather study wanted to analyze this Kepler data using provided software facility.

CHAPTER 6

CONCLUSION

In this study we used three analyzing methods to take the magnitude variation of the objectives stars. The most precise and accurate method is default phot task in the IRAF noao package. Use of Qphot is fast but less user controllable parameters. If a thoroughly and accurately developed IRAF script may be useful when handling bulk data set

Photometry data of four SU Uma stars were analyzed to study their characteristics. Although all of them showed various features in their light curves but only some can be interpreted. Among these stars IYUMA was special where orbital period and the correlation between orbital and superhump period were determined. On the other hand one of the main difficulties we found is lack of previous researches outcomes of this star in order to predict or compare our values. The faintness of the star and the recent confirmation as SU UMa may be the reasons for the lacking of literature of this system. Therefore more future observations are recommended to get more interesting results.

SDSS0932 star showed only one eclipse due to either of white dwarf or normal star. The brightness increase before the eclipse of SDSS0932 might be due to the matter transfer via hot spot on to the accretion disk. Couple of humps (sudden increments of brightness) in the light curve of J0426 were interesting but cannot be confirmed as normal burst due to the lack of data. No distinguishable features were shown by the data set of J0711 SU UMa star.

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APPENDIX 01

SPECIFICATION OF THE SRI LANKAN LARGEST TELESCOPE

Specifications of Telescope

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

Photometer specifications

Filters	Johnson and Morgan UBV filters
Photon counting system	RCA IP21 photomultiplier tube with pulse counting

Spectrograph Specifications

Spectrograph configuration	Monk-Gillieson type spectrograph
Plane reflective gratings	150, 900 and 1200 grooves/mm
Camera	SBIG ST 7 CCD

APPENDIX 02

SU UMA STARS IN KEPLER OBSERVE FIELD

Campaign	Line_No	Object_name		RA			DEC	
1	28	J1125-0016	11	25	55.7	0	16	38
1	71	QZ Vir	11	38	27	3	22	8
1	181	RZ Leo	11	37	22.3	1	48	58
1	445	J1126+0846	11	26	19.4	8	46	51
5	186	J0812+1318	8	12	7.6	13	18	24
5	292	AK Cnc	8	55	21.2	11	18	15
6	172	HS Vir	13	43	38.4	-8	14	3
8	24	J0116+0922	1	16	13.8	9	22	16
9	504	J1756-2748	17	56	7.3	-27	48	48
9	525	V5627 Sgr	18	1	56.3	-27	22	56
9	541	J1805-2743	18	5	7.1	-27	43	9
10	61	V406 Vir	12	38	13.7	-3	39	33
10	519	J1220-1027	12	20	59.8	-10	27	35
11	656	J1714-2943	17	14	42.6	-29	43	45
12	183	EG Aqr	23	25	19.2	-8	18	19
12	442	J2305-0225	23	5	23.3	-2	25	49
13	19	J0501+203	5	1	24.1	20	38	18
15	624	J1519-2440	15	19	29.6	-24	40	1
15	640	J1537-2440	15	37	56.9	-24	40	14
15	687	GW Lib	15	19	55.5	-25	0	25
17	172	HS Vir	13	43	38.4	-8	14	3
18	186	J0812+1318	8	12	7.6	13	18	24
18	205	J0819+1915	8	19	36.1	19	15	40
18	292	AK Cnc	8	55	21.2	11	18	15
19	174	HY Psc	23	3	51.7	1	6	52
19	442	J2305-0225	23	5	23.3	-2	25	49

APPENDIX 03

FIELD CORRECTION OF THE RAW IMAGES

Date -18/05/2017
Author – Sujith Cooray (90412)

Open the **ds9**
Open the **xgterm**
Set the ureka enviroment by **ur_setup**
Start the iraf by typing **cl**

Go to the photometry working directory. Its good to make it inside iraf that in Ureka.
cl> cd /home/indika/Ureka/iraf/SuUma/sdss0932

First we have to make the master bias frame using the all bias frames. So we have to move into the bias frame directory.
cl> cd bias

we do this using ccdred package
cl> noao
cl> imred
cl> ccdred

Before making the master bias (zerocombine) we have to check the IMAGETYPE of the bias frames.
cl> dir
cl> imhead bias.0001.fits l+

If it's IMAGETYPE not in “zero” we must have to edit it as “zero”
cl> hedit bias*.fits IMAGETYPE “zero” add+

Now we can combine the all bias frames.
cl> epar zerocombine

```
      input = bias*.fits       List of zero level images to combine
   (output = "Zero")          Output zero level name
  (combine = "average")       Type of combine operation
   (reject = "minmax")        Type of rejection
  (ccdtype = "zero")          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)
    (gain = "1.")        ccdclip: CCD gain (electrons/DN)
  (snoise = "0.")        ccdclip: Sensitivity noise (fraction)
   (pclip = -0.5)        pclip: Percentile clipping parameter
   (blank = 0.)          Value if there are no pixels
    (mode = "ql")
```

Run the zerocombine.
:go

And it make the master bias as **Zero.fits** in current directory.
Running IMSTATISTICS on the raw biases and the combined bias will show that we have indeed improved our noise statistics.

cl> imstat bias.00??.fits, bias.0020,Zero
cl> display Zero 1 fill+
cl> implot Zero

Now we have to decide the overscan and trim region paramters. We can decide it by look the avalanche of the intensity that shows in the ximtool. The numerical pixel value can be took just press the space bar by put the cursor on the avalanche point. In my case overscan was [260:283,1:256] and trim was [1:260,1:256]. we take the whole pixels in lines.

Quit from ximtool press **q**

Now we want make the master flat, so we have to go to the directory that have the all flat field images.

cl> cd /home/indika/Ureka/iraf/SuUma/sdss0932/flat

Before making the master flat (flatcombine) we have to check the IMAGETYPE of the flat frames.
cl> dir
cl> imhead flat.0001.fits l+

If it's IMAGETYPE not in “flat” we must have to edit it as “flat”
cl> hedit flat*.fits IMAGETYPE “flat” add+

And now we have to look the oversacn and terim regions of the flat fields.
cl> implot flat.0001.fits
In my case it was same as bias fields.(but I forget to see the front side correction of the fields. I consider only last pixels.)

We have to copy master bias (Zero.fits) to the flat field directory.

```
cl>epar ccdproc
      images = "flat*.fits"       List of CCD images to correct
    (ccdtype = "flat")          CCD image type to correct
   (max_cache = 0)             Maximum image caching memory (in Mbytes)
     (noproc = no)            List processing steps only?\n
     (fixpix = no)            Fix bad CCD lines and columns?
   (overscan = yes)           Apply overscan strip correction?
       (trim = yes)           Trim the image?
    (zerocor = yes)           Apply zero level correction?
    (darkcor = no)            Apply dark count correction?
    (flatcor = no)            Apply flat field correction?
   (illumcor = no)            Apply illumination correction?
  (fringecor = no)            Apply fringe correction?
    (readcor = no)            Convert zero level image to readout correction?
    (scancor = no)            Convert flat field image to scan correction?\n
   (readaxis = "line")        Read out axis (column|line)
    (fixfile = "")            File describing the bad lines and columns
    (biassec = "[260:283,1:256]") Overscan strip image section
    (trimsec = "[1:255,1:256]") Trim data section
       (zero = "Zero")        Zero level calibration image
       (dark = "")            Dark count calibration image
       (flat = "")            Flat field images
      (illum = "")            Illumination correction images
     (fringe = "")            Fringe correction images
  (minreplace = 1.)           Minimum flat field value
   (scantype = "shortscan")   Scan type (shortscan|longscan)
      (nscan = 1)             Number of short scan lines\n
 (interactive = no)           Fit overscan interactively?
   (function = "chebyshev")   Fitting function
      (order = 1)             Number of polynomial terms or spline pieces
     (sample = "*")           Sample points to fit
   (naverage = 1)             Number of sample points to combine
   (niterate = 1)             Number of rejection iterations
  (low_reject = 3.)           Low sigma rejection factor
 (high_reject = 3.)           High sigma rejection factor
       (grow = 0.)            Rejection growing radius
       (mode = "ql")
```

run the ccdproc

:go

```
cl>epar flatcombine
input   =          flat*.fits)  List of flat field images to combine
(output =               Flat) Output flat field root name
```

```
(combine=          average) Type of combine operation
(reject =        crreject) Type of rejection
(ccdtype=             flat) CCD image type to combine
(process=             yes) 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   =              1) 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=           1.96) ccdclip: CCD readout noise (electrons)
(gain   =           3.66) 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)
```

Run the flatcombine.
:go

we got the mater flat (Flat.fits).
We can see the difference of flat field and master flat field by drawing the implot of each of these.

Now we are going the make the master dark. So we to go the directory that dark fields had.

cl> cd /home/indika/Ureka/iraf/SuUma/sdss0932/dark.10

Before making the master dark (darkcombine) we have to check the IMAGETYPE of the dark frames.
cl> dir
cl> imhead dark.0001.fits l+cl> cd
/home/indika/Ureka/iraf/SuUma/sdss0932/dark.10

If it's IMAGETYPE not in “dark” we must have to edit it as “dark”
cl> hedit dark*.fits IMAGETYPE “dark” add+

We have to copy mater bias (Zero.fits) to the dark field directory.

```
cl>epar ccdproc
     images = "dark*.fits"      List of CCD images to correct
    (ccdtype = "dark")         CCD image type to correct
```

```
   (max_cache = 0)            Maximum image caching memory (in Mbytes)
     (noproc = no)            List processing steps only?\n
     (fixpix = no)            Fix bad CCD lines and columns?
   (overscan = yes)           Apply overscan strip correction?
       (trim = yes)           Trim the image?
    (zerocor = yes)           Apply zero level correction?
    (darkcor = no)            Apply dark count correction?
    (flatcor = no)            Apply flat field correction?
   (illumcor = no)            Apply illumination correction?
  (fringecor = no)            Apply fringe correction?
    (readcor = no)            Convert zero level image to readout correction?
    (scancor = no)            Convert flat field image to scan correction?\n
   (readaxis = "line")        Read out axis (column|line)
    (fixfile = "")            File describing the bad lines and columns
    (biassec = "[260:283,1:256]") Overscan strip image section
    (trimsec = "[1:255,1:256]") Trim data section
       (zero = "Zero")        Zero level calibration image
       (dark = "")            Dark count calibration image
       (flat = "")            Flat field images
      (illum = "")            Illumination correction images
     (fringe = "")            Fringe correction images
  (minreplace = 1.)           Minimum flat field value
   (scantype = "shortscan")   Scan type (shortscan|longscan)
      (nscan = 1)             Number of short scan lines\n
 (interactive = no)           Fit overscan interactively?
   (function = "chebyshev")   Fitting function
      (order = 1)             Number of polynomial terms or spline pieces
     (sample = "*")           Sample points to fit
   (naverage = 1)             Number of sample points to combine
   (niterate = 1)             Number of rejection iterations
  (low_reject = 3.)           Low sigma rejection factor
 (high_reject = 3.)           High sigma rejection factor
       (grow = 0.)            Rejection growing radius
       (mode = "ql")
```

run ccdproc **:go**

```
cl> epar darkcombine
       input = "dark*.fits"    List of dark images to combine
     (output = "Dark")         Output dark image root name
    (combine = "average")      Type of combine operation
     (reject = "minmax")       Type of rejection
    (ccdtype = "dark")         CCD image type to combine
    (process = yes)            Process images before combining?
     (delete = no)             Delete input images after combining?
    (clobber = no)             Clobber existing output image?
      (scale = "exposure")     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)
     (gain = "1.")          ccdclip: CCD gain (electrons/DN)
   (snoise = "0.")          ccdclip: Sensitivity noise (fraction)
    (pclip = -0.5)          pclip: Percentile clipping parameter
    (blank = 0.)            Value if there are no pixels
     (mode = "ql")
```

Now we have the masters of bias, flat and dark fields. So now we looking for do the corrections for the object fields. So we move on to the directory that have the object fields. And check the it's image type was correct.

```
cl> cd /home/indika/Ureka/iraf/SuUma/sdss0932/sdss0932
```

We have 500 object fields. So we have to make a object list.

```
cl> files sdss*.fits > plist
cl> imhead @plist
cl> ccdlist @plist

cl> epar ccdproc
     images = "@plist"       List of CCD images to correct
    (output = " ")           List of output CCD images
   (ccdtype = "object")      CCD image type to correct
  (max_cache = 0)            Maximum image caching memory (in Mbytes)
    (noproc = no)            List processing steps only?\n
    (fixpix = no)            Fix bad CCD lines and columns?
  (overscan = yes)           Apply overscan strip correction?
     (trim = yes)            Trim the image?
   (zerocor = yes)           Apply zero level correction?
   (darkcor = yes)           Apply dark count correction?
   (flatcor = yes)           Apply flat field correction?
  (illumcor = no)            Apply illumination correction?
  (fringecor = no)           Apply fringe correction?
   (readcor = no)            Convert zero level image to readout correction?
   (scancor = no)            Convert flat field image to scan correction?\n
  (readaxis = "line")        Read out axis (column|line)
   (fixfile = "")            File describing the bad lines and columns
   (biassec = "[261:283,1:256]") Overscan strip image section
   (trimsec = "[1:254,1:256]") Trim data section
     (zero = "Zero")         Zero level calibration image
```

```
      (dark = "Dark")        Dark count calibration image
      (flat = "Flat")        Flat field images
     (illum = "")            Illumination correction images
    (fringe = "")            Fringe correction images
 (minreplace = 1.)           Minimum flat field value
   (scantype = "shortscan")    Scan type (shortscan|longscan)
     (nscan = 1)             Number of short scan lines\n
(interactive = no)           Fit overscan interactively?
   (function = "chebyshev")    Fitting function
     (order = 1)             Number of polynomial terms or spline pieces
    (sample = "*")           Sample points to fit
   (naverage = 1)            Number of sample points to combine
   (niterate = 1)            Number of rejection iterations
 (low_reject = 3.)           Low sigma rejection factor
(high_reject = 3.)           High sigma rejection factor
      (grow = 0.)            Rejection growing radius
      (mode = "ql")
```

run the ccdproc

:go

Now object images will replace from the field corrected images.
To see the difference implot and view the field corrected ones and original ones.

APPENDIX 04

PHOTOMTRIC ANALYSIS USING QPHOT TASK

Date – 19/06/2017
Author – Sujith Cooray (90412)

Photometry

Open ds9 image window
Open xgterm
Set up the Ureka enviroment by **ur_setup**
login into the iraf by **cl**

Now we are in iraf….

We have to do the photometry in the directory that have the field corrected images.
It's good to put your image folder inside the iraf that was in Ureka folder.

cl> cd /home/indika/Ureka/iraf/SuUma/sdss0932/sdss0932
cl> dir

We will need the exposure time, the filter identification, and the airmass. On closer inspection of one of our headers. In my case it was as follows,

EXPTIME = 10.
FILTER = sdss g
AIRMASS was different for each images, we can look the all airmass values by creating a objectlist and filter the airmass from the imahe header.

cl> files *.fits > darklist

```
cl> list = "darklist"
cl> While(fscan(list,s1)!=EOF){
imgets((s1),"ZMAG")
s2 = (imgets.value)
print ((s2), >>  "zmag.list" )
print (s2)
}
```

We have to set the airmass if it doesn't have in image header. We can use setairmass in astutil package. At that time we have to enter the iraf observetory that that mention in the imheader of the image. In my case all airmass was set.

We have to centroid the star before doing the photometry.

Then centroid the star compared to any reference frame. Mostly we take it as a first frame of the image set. We have to take the x center and y center of the star in a reference image. For that open the reference image in a de 9 tool

cl> display sdss0932.4.m.0001.fits 1
cl> imexamine

Now the it become to the cursor mode and noew ds 9 is the active window. Point the star that want to centroid and press the 'a'. Then it's give the x and y center values of the star.

Create gedit file that including this coordinates called center_coords as folllows

```
#Object_star
#x              y
#255.90                 257.01
```

cl>epar imcentroid

```
input   = J0426_sdss_g_20141220_0*.fits  List of input images
referenc= J0426_sdss_g_20141220_012808.fits  Reference image
coords  =       center_coords  Reference coordinates file
(shifts =                    ) Initial shifts file
(boxsize=                     5) Size of the fine centering box
(bigbox =                    11) 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=                    15) Maximum number of iterations
(toleran=                     0) Tolerance for convergence
(maxshif=                 INDEF) Maximum acceptable pixel shift
(verbose=                   yes) Print the centroids for every source ?
(mode   =                    ql)
```

:go

Then the all x and y shift were displayed in the xgterminal (In here better to use the system terminal that easy to copy the all data.)

Copy the output of the imcentroid to the excel sheet and take the x and y shifts only to the gedit file called “centroid”

Now we are ready to proceed with the aperture photometry measurements.

cl> digiphot
cl> apphot

We need to decide the size of our aperture radius for doing the photometry. This radius will depend on the FWHM of the stars. But here I look the few of them and take the average value for FWHM. We can measure the FWHM with IMEXAMINE.

cl> display sdss0932.4.m.0050.fits 2
cl> imexamine

put the cursor on a upper star and then press

r

three values of the FWHM are printed at the end of the status line on the bottom of the plot - each value was computed using a slightly different algorithm. And do the same for lower star.

A good rule of thumb is that the aperture radius should be 4 or 5 times the size of the FWHM, to insure that we measure all of the light. Since our FWHM is about 3.0 pixels that would indicate that we should use ~15 pixels for our aperture radius. But since our stars are relatively faint we may want to consider using an aperture radius of 10 pixels. Since we want to simplify things and use the same radius for all frames, let's verify that the FWHM is about the same for the other frames and that we will get all of the light through the 10 pixel aperture, continuing with our use of IMEXAMINE.

```
d                    # display  sdss0932.4.m.0100
r                    # measure a two of stars
d                    # display sdss0932.4.m.0200
r                    # measure a two of stars
d                    # display sdss0932.4.m.0300
r                    # measure a two of stars
d                    # display  sdss0932.4.m.0400
r                    # measure a two of stars
d                    # display  sdss0932.4.m.0450
r                    # measure a two of stars
d                    # display  sdss0932.4.m.0500
r                    # measure a two of stars
q                    # quit
```

I got the average value for the FWHM is 1.53. so when take the 5 times it was 9.2. so I take the appeture size as a 10.

We will use the task QPHOT, in interactive mode, to measure some stars in the first field. Run EPAR on the task and edit the parameters until they look like those below

```
cl> epar qphot
      image = "sdss0932.4.m.0050.fits"    The input image(s)
       cbox = 5.            The centering box width in pixels
    annulus = 11.           The inner radius of sky annulus in pixels
   dannulus = 9.            The width of the sky annulus in pixels
```

```
   apertures = "7"          The list of photometry apertures
     (coords = "")      The input coordinate file(s) (default: *.coo.?)
     (output = "default")     The output photometry file(s) (default: *.mag.?)
   (plotfile = "")           The output plot metacode file
       (zmag = 25.)          The zero point of the magnitude scale
   (exposure = "exptime")     The exposure time image header keyword
    (airmass = "airmass")     The airmass image header keyword
     (filter = "filter")      The filter image header keyword
    (obstime = "hjd")     The time of observation image header keyword
      (epadu = 1.96)           The instrument gain in e-/ADU
 (interactive = yes)           Interactive mode ?
   (radplots = no)           Plot the radial profiles in interactive mode ?
  (icommands = "")           Image cursor: [x y wcs] key [cmd]
  (gcommands = "")           Graphics cursor: [x y wcs] key [cmd]
 wcsin = )_.wcsin)      The input coordinate system (logical,tv,physical,world)
     (wcsout = )_.wcsout)     The output coordinate system (logical,tv,physical)
      (cache = )_.cache)      Cache input image pixels in memory ?
    (verbose = no)           Print messages in non-interactive mode ?
   (graphics = )_.graphics)    Graphics device
    (display = )_.display)     Display device
       (mode = "ql")
```

:go

i # point at star 6 - image window

set the extraction box to 25 - plot window

then type "**v**" to select interactive setup mode - plot window

mark the centering box – 5
press : let's round it to 5.

mark the inner sky radius – 15
press : now round to 15

mark the outer sky radius – 10
press : then round the width to 10

mark our aperture radius – 10
press : hen round to the 10

q # to exit this mode and return to image window

notice that photometric information is printed on your screen for this star - center (x and y), sky, magnitude, error (if any)

w # save the parameters that we just computed - image window

now we will measure our stars looking at the radial profile plot for each star as we do the measurement

:radplot yes # turn on the radial profile option - notice that after you type the : you may need to move the cursor from the image window to the text window to finish typing the command - move back to the image window to continue

Mesure in order upper and lower star – point the cursor and press space bar.

q (in image window and in text window)

All of your measurements should have been saved in a file - the image nameplus .mag.1 appended. Look at that file. We can pull out selected information from this file with the TXDUMP command. We can also plot the errors in the magnitudes against the magnitudes themselves to see if there is any trend.

cl> dir
cl> page sdss0932.4.m.0050.fits.mag.1
cl> txdump sdss0932.4.m.0050.fits.mag.1 image,xcenter,ycenter,mag,msky,stdev, otime yes
cl> txdump sdss0932.4.m.0050.fits.mag.1 mag,merr yes | graph point+

look at upper and lower star in other images and compare the coordinate readout in ds9 with the position of the star in our TXDUMP list - there is roughly a 5.5 pixel shift in x ok.

Using TXDUMP let's create a coordinate list for our stars. Notice that we could apply a shift to this list with the task LINTRAN in the LISTS package, if we needed to. Let's plot the coordinates back up on the image to verify our identifications.

cl> txdump sdss0932.4.m.0050.fits.mag.1 xcenter,ycenter yes > coords1
cl> type coords1
cl> display sdss0932.4.m.0002.fits 1
cl> tvmark 1 coords1 mark=circle radii=10 color=205

Now we do the qphot for the other every images

cl>epar qphot
image = "sdss0932.4.m.00*.fits" The input image(s)
cbox = 5. The centering box width in pixels
annulus = 11. The inner radius of sky annulus in pixels

```
    dannulus = 9.            The width of the sky annulus in pixels
   apertures = "7"           The list of photometry apertures
     (coords = "coords1")       The input coordinate file(s) (default: *.coo.?)
     (output = "default")     The output photometry file(s) (default: *.mag.?)
   (plotfile = "")            The output plot metacode file
       (zmag = 25.)           The zero point of the magnitude scale
   (exposure = "exptime")     The exposure time image header keyword
    (airmass = "airmass")     The airmass image header keyword
     (filter = "filter")      The filter image header keyword
    (obstime = "hjd")     The time of observation image header keyword
      (epadu = 1.96)            The instrument gain in e-/ADU
(interactive = no)            Interactive mode ?
   (radplots = no)            Plot the radial profiles in interactive mode ?
  (icommands = "")            Image cursor: [x y wcs] key [cmd]
  (gcommands = "")            Graphics cursor: [x y wcs] key [cmd]
      (wcsin = )_.wcsin)       The input coordinate system (logical,tv,physical,world)
     (wcsout = )_.wcsout)      The output coordinate system (logical,tv,physical)
      (cache = )_.cache)       Cache input image pixels in memory ?
    (verbose = no)            Print messages in non-interactive mode ?
   (graphics = )_.graphics)    Graphics device
    (display = )_.display)     Display device
       (mode = "ql")

:go

cl> dir *.mag*
```

there should be a mag file for each image

```
cl> txdump sdss*.mag.1 otime,mag yes | graph point+
cl> txdump sdss*.mag.1 otime,mag yes > text2
cl> txdump *.mag* otime,mag,merr yes
```

O

APPENDIX 05

IRAF SCRIPT FOR THE QPHOT

```
procedure myqphot(file_name,coords)

string file_name
string coords
struct *flist
struct *image

begin

struct line

flist = file_name
image = coords

#print(image)

qphot.annulus = 4
qphot.dannulus = 5
qphot.apertures = 3
qphot.coords = image
qphot.zmag = 20.4772
qphot.exposure = "EXPTIME"
qphot.airmass = "AIRMASS"
qphot.filter = "FILTER"
qphot.obstime = "HJD"
qphot.epadu = 1.25
qphot.interactive = no
qphot.verbose = no
#qphot

while(fscan ( flist, line) != EOF){
      qphot.image = line
      qphot
}

end
```

IRAF SCRIPT FOR THE PHOT

```
#load the packages noao, digiphot, daophot, images, imutil,
imstatistics

procedure
myphot(file_name,readnoise,epadu,exposure,airmass,filter,obstime
,itime)

file file_name {prompt = 'list of File'}
real readnoise {prompt = ' CCD readout noise in electrons 11.8'}
real epadu {prompt = 'Gain in electrons per count 1.25'}
char exposure {prompt = 'Exposure time image header keyword'}
char airmass {prompt = 'Airmass image header keyword'}
char filter {prompt = 'Filter image header keyword'}
char obstime {prompt = 'Time of observation image header
keyword'}
int itime {prompt = 'Exposure time'}
struct *flist

begin

real zmag
real totzmag = 0
real totfwhm = 0
file stddev
real sd=0
int number = 0
real avgzmag
real avgfwhm
real rdnoise
real gain
char expo
char amass
char fil
char obtime
int etime
struct line,line1


flist = file_name
rdnoise = readnoise
gain = epadu
expo = exposure
amass = airmass
fil = filter
obtime = obstime
etime = itime

unlearn imstatistics
```

```
imstatistics.fields = "stddev"
imstatistics.format = no

while(fscan(flist,line)!=EOF){

      imgets((line),"ZMAG")
      zmag = real(imgets.value)
      totzmag = totzmag + zmag

      imgets((line),"FWHM")
      fwhm = real(imgets.value)
      totfwhm = totfwhm + fwhm

      imstatistics.images = line
      imstatistics


      #while(fscan(stddev,line1)!=EOF){
      #     sd = sd+real(line1)
      #     print(line1)
      #}

      number = number +1
}

avgzmag = totzmag/number
avgfwhm = totfwhm/number
print("Average zeroth level of the star field -> ",avgzmag)
print("Average fwhm vale -> ",avgfwhm)

unlearn datapars
unlearn centerpars
unlearn fitskypars
unlearn photpars
unlearn phot

datapars.fwhmpsf = avgfwhm
datapars.sigma = 105.0983
datapars.readnoise = rdnoise
datapars.epadu = gain
datapars.exposure = expo
datapars.airmass = amass
datapars.filter = fil
datapars.obstime = obtime
datapars.itime = etime

centerpars.cbox = 5

fitskypars.annulus = 4
fitskypars.dannulus = 5

photpars.apertures = 3
photpars.zmag = zmag
```

```
flist = file_name
phot.coords = "coords.coo.1"

#while(fscan ( flist, line) != EOF){
#     phot.image = line
#     phot(verify=no)
#}

print("end of the program")

end
```