AUTOMATED INFORMATION RETRIEVAL AND INTERFACING SYSTEM (AIRIS) (FORMATION OF TRANSIENT EVENTS DATABASE FROM LIGHT CURVES)

Submitted in partial fulfillment of the Requirement for the award of the degree of

Master of Science in Physics of the Mahatma Gandhi University, Kottayam

By

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2017- 2019

CERTIFICATE OF EVALUATION

This is to certify that the work **AUTOMATED INFORMATION RETRIEVAL AND INTERFACING SYSTEM (AIRIS)** is a bonafide work done and submitted by Robin Thomas (170011003175) in partial fulfillment for the award of M. Sc Degree in Physics during the academic year 2017-2019 of **Mahatma Gandhi University, Kottayam**.

Examiners

1.

2.

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CERTIFICATE

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CERTIFICATE

This is to certify that **Robin Thomas**(170011003175) has successfully completed his project work on **"Automated Information Retrieval and Interfacing System (AIRIS)"** under my guidance and supervision.

KOZHENCHERRY NINAN SAJEETH PHILIP

DECLARATION

I, **Robin Thomas,** here by declare that this project work entitled "**Automated Information Retrieval and Interfacing System (AIRIS)**" is entirely original work and has been carried out by me independently under the supervision and guidance of Dr. Ninan Sajeeth Philip, during the academic year 2017-2019 in the partial fulfillment of the requirement for the award of the degree of Master of Science in Physics and this work has not been submitted for any other degree.

Kozhencherry
Date:

ROBIN THOMAS

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Gratitude cannot be seen or expressed; it can only be felt deep down in the heart and is beyond description .Although words are poor expressions of the depth of gratitude, I would like to express my gratitude in a few words. First of all, I humbly and whole heartedly bow my head before Lord Almighty for blessing me with all his grace to successfully complete my project.

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It is with deep pleasure ,I cherish the days with my classmates, who were always beside me with constant care and support.

I thankfully dedicate this project to my ever loving parents for their immense love and support towards me.

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CHAPTER ONE: INTRODUCTION

The sky has always been a source of constant awe and wonder for the humankind since time immemorial. When modern navigation tools like the GPS or maps were not available, sky with all its multiple tiny dots served as landmarks for the travelers. Using only a few crude tools and geometry, the visible sky had been mapped to facilitate accurate travel paths. This helped begin the ancient branch of science- Astronomy.

Over time, the study of astronomy has developed more than just navigation. Every information received from the outer space is an opportunity to look back into what the universe around must have been in the past. With better optical instruments, astronomical objects are no longer obscure tiny dots. The tiny dots are now resolved to provide images, in addition to the emission and absorption spectra, of different astronomical objects. Thus, a lot of answers to the origin of the world we know today lies in the field of astronomy.

1.1 ASTRONOMY

Star-gazing was likely a common evening pastime in ancient time. Some keen observers soon realized that there were a number of stars that wandered across the background of other stars in the sky. We do not know when such observations were first made, but it is likely that it was made long before the invention of writings. Those stars were called planets – a name which implied wanderer in Greek. Later, systematic observations and records of the movement of planets of ancient astrology revealed that there were fixed patterns governing each planet's movement. The fifteenth and sixteenth centuries were the time of the Renaissance (or rebirth) of learning. This occurred mainly in Italy. It established the scholastic ground work for modern astronomy. This was a time when ancient writings of a thousand years before found their way back into books of Western Europe. (Some) of what was relearned turned out to be false. But other knowledge, including advanced math and the rational thought, were used as the skills needed to allow modern western culture to expand The Catholic Church accepted the ancient philosophies of the Universe, including Ptolemy's theory that the sun orbited the earth and that the earth was the center of the universe. This was challenged by two men and one instrument.

The act of open-mindedness to accept the existence of bodies and phenomena beyond the grasp of mankind led to unbelievable rewards. This revolution in the scientific world started with the acceptance of the Heliocentric theory, that was proposed by Nicolaus Copernicus. The theory, in contrast to the classical Geocentric theory, proposed a model of the Universe where the Earth, the planets and the stars all revolved around the Sun. In so doing, he resolved the mathematical problems and inconsistencies arising out of the classic geocentric model and laid the foundations for modern astronomy.

Over time, the same theory was modified and it was accepted that sun wasn't the center of anything, save our solar system. We now accept that we orbit the Sun, whose physical properties are quite common, similar to the nearly 100 billion Sun-like stars within our galaxy, the Milky Way. It was subsequently discovered that the Milky Way was not, in fact, the entire Universe; the observable Universe is of order many billions of light years across, and there are of order 100 billion galaxies like our own floating around within it. In the center of these galaxies, there exists super-massive black holes whose masses can be up to 10 billion times the mass of the Sun. When these enormous black holes are built up by gases, they are called quasars. These produce light equivalent of 100 trillion Suns within a volume comparable to our solar system. The greater the separation between any two galaxies or quasars, the greater the rate at which they move apart or, in other words, the Universe is expanding. Thus by methods to measure the parallax method, as will be discussed later, a transcending conclusion was attained: The universe is expanding with time. Another very important analysis we reached was that the Universe is primarily made up of stuff that can't be seen or felt, dark energy and dark matter.

The term 'dark energy' and 'dark matter' is rather confusing. Einstein predicted that "empty space" can possess its own energy. This energy is a property of space itself and so, it would not be diluted as space expands, which is in contrast to the physical forces we know. As more space comes into existence, more of this energy-of-space would appear. As a result, this form of energy would cause the universe to expand faster and faster.

Another explanation for dark energy is that it is a new kind of dynamical energy fluid or field, something that fills all of space but something whose effect on the expansion of the universe is the opposite of that of matter and normal energy, similar to the repulsive Coulomb force between like charges. By fitting a theoretical model of the composition of the universe to the combined set of cosmological observations, an approximate composition of the known universe was reached, ~68% dark energy, ~27% dark matter, ~5% normal matter. Though we do not know what dark matter is, we have many indications if what dark matter is not. First, it is dark, that is, it cannot be observed, similar to the form of stars and planets that we see. Second, dark matter is not composed of dark clouds of normal matter, matter made up of particles called baryons. We know this because we would be able to detect baryonic clouds by their absorption of radiation passing through them. Third, dark matter is not antimatter, as the characteristic gamma rays that are produced as a result of annihilation reaction between matter and antimatter. Finally, we can rule out large galaxy-sized black holes on the basis of the high resolution telescopes that are employed to observe such phenomena.

fig 1.1: One of the most complicated and dramatic collisions between galaxy clusters ever seen is captured in this new composite image of Abell 2744. The blue shows a map of the total mass concentration (mostly dark matter). (Courtesy: www.science.nasa.gov)

The strategy of building bigger and more sensitive telescopes, meanwhile, has produced a growing number of “smaller” results that continue to employ regiments of astronomers: gamma-ray bursts, pulsars, X-ray emitting binary stars, clusters of galaxies, cosmic microwave background radiation, and the list goes on.

1.2 CELESTIAL OBJECTS

The universe consists of a huge range of celestial objects. Though most of the observable universe is bare empty space, this cold, dark and, more often than not, empty space consists of several objects that are spaced at far. It is known by astronomers by different names, such as celestial objects, celestial bodies, astronomical objects, and astronomical bodies. It is these bodies that fill the empty space of the universe. The list of celestial objects consists of the following:

1. **Stars**: Stars are the most abundant objects in the visible universe. They are the source of all the light and energy that fuels a solar system. They also create the heavy elements which are absolutely necessary to form and sustain life. A star is similar to a gigantic nuclear furnace. The nuclear reactions inside a star convert hydrogen into helium by means of nuclear fusion. This reaction gives a star its energy. When the star's hydrogen supply is consumed, it begins to convert helium into oxygen and carbon. If the star is massive, it continue until it converts carbon and oxygen into neon, sodium, magnesium, sulfur and silicon. Eventually, these elements will be transformed into calcium, iron, nickel, chromium, copper and others until iron is formed. When the core becomes primarily iron, the star's nuclear reaction can no longer continue. This is because the temperature required to fuse iron is very high. Consequently, the inward pressure of gravity becomes stronger than the outward pressure of the nuclear reaction. The star collapses in on itself.

2. **Planets**: The International Astronomical Union (IAU) defines a planet as a celestial body orbiting a star or stellar remnant which is

a. massive enough to be rounded by its gravity,

b. is not massive enough to cause thermonuclear fusion, and

c. has cleared its neighboring region of planetesimals.

Planetesimals are small objects formed from dust and gas when a new planetary system develops. There are three types of planets, based on the composition- Terrestrial, Gas giants and Dwarf planets.

3. **Nebulae**: Nebula is a cosmic cloud of gas and dust floating in space. Nebulae are the building blocks of the universe. They contain the elements from which stars and solar systems can be built, given the surrounding is conducive. Most nebulae are composed of about 90% hydrogen, 10% helium, and 0.1% heavy elements such as carbon, nitrogen, magnesium, and other heavy elements. Nebulae have been divided into five major categories. They are emission nebulae, reflection nebulae, dark nebulae, planetary nebulae, and supernova remnants. Emission and reflection nebulae tend to be fuzzy in appearance and do not possess any noticeable shape or structure. They are also called diffuse nebulae.

4. **Quasars**: The exact form, type and origin of a quasar is unknown. However, a recent study suggests quasars are produced by super massive black holes consuming matter in the accretion disk. As the matter spins faster, it heats up. The friction between all of the particles would give off enormous amounts of light and other forms of radiation such as x-rays. The black hole would be devouring the one solar mass per year. As this matter is sucked in by the black hole, enormous amounts of energy would be ejected along the black hole's north and south poles. These formations are known as cosmic jets. Another possible explanation for quasars is that they are, actually, very young galaxies. Since little is known about the evolutionary process of galaxies, it is possible that quasars represent a very early stage in the formation of galaxies. The energy we see may be ejected from the cores of the very young and very active galaxies.

5. **Pulsars and Neutron stars**: A pulsar is a rapidly spinning neutron star. A neutron star is highly compacted core of a dead star, left behind by a supernova

explosion. This neutron star has a very powerful magnetic field. Comparing the magnitudes, this magnetic field is about one trillion times as powerful as the magnetic field of the Earth. The magnetic field causes the neutron star to emit strong radio waves and radioactive particles from the north and south poles. These particles include a variety of radiation, including visible light. Pulsars that can emit powerful gamma rays are known as gamma ray pulsars. If the neutron star happens to be aligned so that the poles face the Earth, we see the radio waves when one of the poles rotates into our line of sight. It is a similar effect as in the case of a lighthouse. When the lighthouse rotates, its light appears to a stationary observer to blink on and off. In the same way, the pulsar appears to blink as its rotating poles sweep past the Earth. Different pulsars pulse at different rates, depending on the size and mass of the concerned neutron star. Sometimes a pulsar may have a binary companion also. In some cases, the pulsar may begin to draw in matter from its binary companion. Which can cause the pulsar to rotate even faster. The fastest pulsars can pulse at over a hundred times a second.

Now that we know about about the different kind of celestial objects present, the next question would be how does one decide what a distant object is, based on the image one receives, sitting light years away. The answer lies in stellar properties.

1.3 STELLAR PROPERTIES

From the light one receives from a celestial object, a lot of properties can be deduced. Some of these properties of star have been discussed below,

1.3.1 BRIGHTNESS

Brightness is a measure of the observed stellar light. It is the amount of energy per second per unit area that falls on a detector such as photographic plate or CCD. Brightness depends upon the distance as well as the amount of light the star is actually producing. The brightness of a star is called its magnitude. Usually, star's brightness is measured in terms of apparent and absolute magnitude.

Apparent magnitude refers to the brightness as seen by the observer. It depends on the location of the observer. Absolute magnitude measures the intrinsic brightness of the object. Absolute magnitude is defined as the apparent magnitude the object would have if it were at a fixed distance (10 parsec away) from the observer.

Another measurement of brightness is called luminosity. Absolute magnitude is a measure of the luminosity of the star. It is the amount of energy that a star emits from its surface every second. The luminosity of a star is independent of the distance and hence it is a measure of the intrinsic brightness of the star. Luminosity of a star is usually measured in terms of luminosity of the sun $L_\odot$ where $L_\odot = 3.846\times10^{26}$ W.

1.3.2 COLOR OF THE STAR

Color of a star is a function of its effective temperature. From the color of a star one can understand how young or old it is and in which stage of its life cycle the star is living. Color of a star depends on its surface temperature and size. It is an additive combination of emissions from different wavelengths. Stars vary in color ranging from red to blue. The coldest stars are red which have surface temperature of about 2500k while the hottest stars are blue which have surface temperature of about 5000k.

This sequence of color is divided into 7 main spectral types, indicated by the letters O, B, A , F, G, K, M. Each of the class is further subdivided into 10 subclasses indicated by number from 1 to 9. The approximate color and temperature range of stars are given below. Table 1.1 shows the approximate color and temperature range of stars.

Color	Temperature	Spectral Type
blue	30000-60000k	O
Blue-white	10000-30000k	B
white	7500-10000k	A
White-yellow	6000-7500k	F
yellow	5000-6000k	G
orange	3500-5000k	K
red	2000-3500k	M

1.3.3 TEMPERATURE

A Star's temperature is measured in a unit known as the Kelvin, with a temperature of zero K equaling minus 273.15 degree Celsius or minus 459.67 degree Fahrenheit. A dark red star has a surface temperature of about 2500 K, a bright red star about 3500K, the sun and other yellow stars at about 5500K, blue stars may have temperatures ranging from 10,000K to 50,000K. The surface temperature of a star depends on its mass and affects its brightness and colour. Specifically, the luminosity of a star is proportional to its temperature raised to the fourth power. For instance, if two stars are of the same size but one is twice as hot as the other, the former would be 16 times as luminous as the latter.

1.3.4 SIZE

Size of star is measured in terms of the radius of sun. For instance, Alpha Centauri has a radius of 1.05 solar radii. Stars range in size from neutron stars, which can be only 12 miles wide to super-giants roughly 1000 times the diameter of the sun. The size of a star affects its brightness. Specifically, luminosity is proportional to radius squared.

We've discussed about certain stellar properties. It is, now, necessary to discuss about two very important graphical methods that is repeatedly used throughout in the field of astronomy.

1.4 HERTZSPRUNG-RUSSELL DIAGRAM(H-R DIAGRAM)

The Hertzsprung-Russell diagram(HR diagram) is a very important tool in the study of stellar evolution. It was developed independently in the early 1900s by two great astronomers, Ejnar Hertzsprung and Henry Norris Russell, it plots the temperature of stars against their luminosity(theoretical HR diagram), or the color of stars against their absolute magnitude(the observational HR diagram). Depending on its initial mass, every star goes through specific evolutionary stages dictated by its internal structure and its production of energy. Each of these stages corresponds to a change in the temperature and luminosity of the star, which is seen to move to different regions on the HR diagram as the star evolves. Thus, astronomers can know a star's internal structure and evolutionary stage simply by determining its position in the diagram.

Hertzsprung-Russell diagram shows a group of stars in various stages of the evolution cycle. The most prominent feature is the main sequence, that runs from the upper left (hot, luminous stars) to the bottom right (cool, faint stars) in the diagram. The giant branch is also well populated and includes many white dwarfs. Morgan-Keenan luminosity classes are also plotted that distinguish between stars of the same temperature but different luminosity. A close observation of the H-R diagram points towards three main regions (or evolutionary stages) of the HR diagram:

1.The main sequence which stretches from the upper left (hot, luminous stars) to the bottom right (cool, faint stars). This sequence dominates the H-R diagram. It is here that stars spend about 90% of their lives burning hydrogen into helium in their cores, as part of the fusion reaction. Main sequence stars have a Morgan-Keenan luminosity class of V.

2.Red giant and super-giant stars (luminosity classes I through III) occupy the area above the main sequence. These have low surface temperatures and high luminosities which, in accordance with the Stefan-Boltzmann law, means they also have large radii. Stars enter this evolutionary stage once they exhaust the hydrogen fuel in their cores and start burning helium and other heavier elements as fuel.

3.White dwarf stars (luminosity class D) are the final evolutionary stage of low to intermediate mass stars, and are found in the bottom left of the H-R diagram. These stars are very hot but have low luminosities due to their small size.

The Sun is on the main sequence with a luminosity of 1 and a temperature of around 5,400 Kelvin.

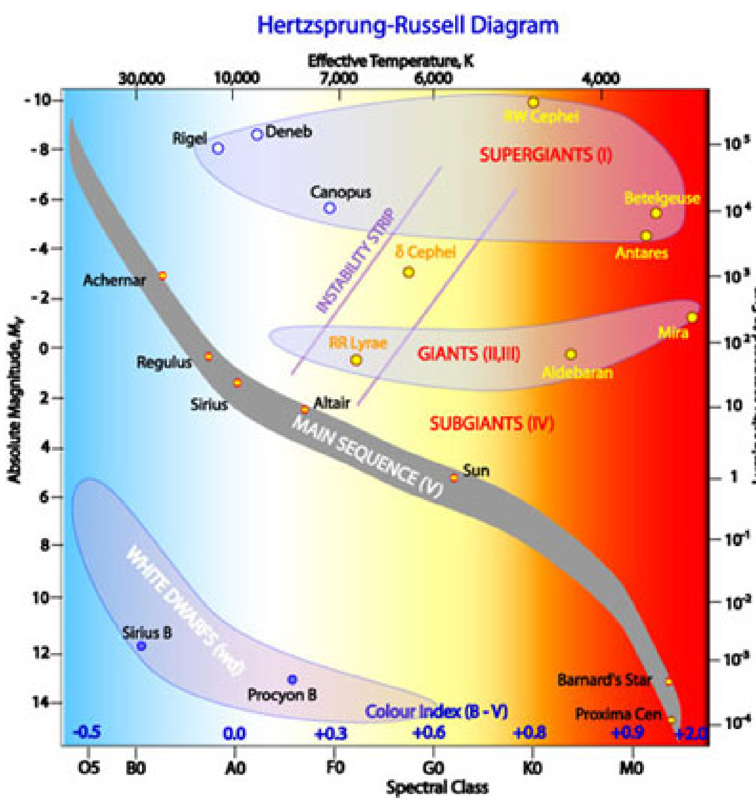
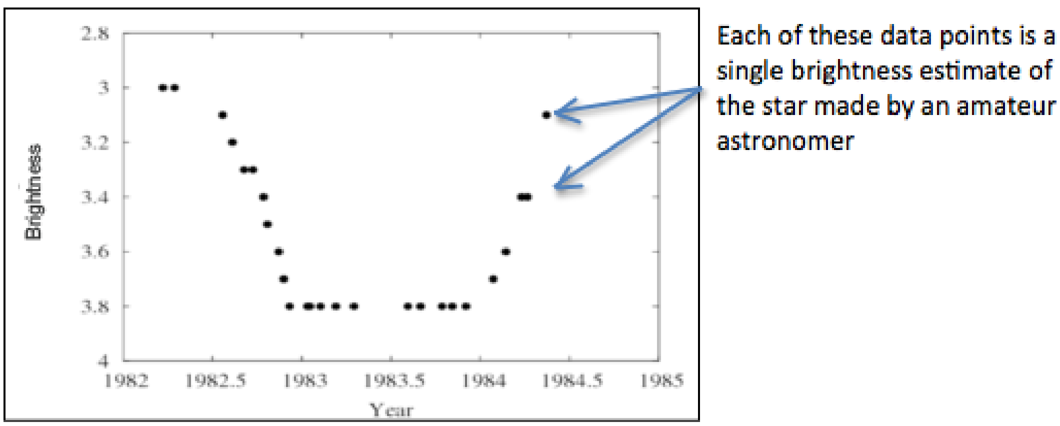


Fig 1.2: The Hertzsprung-Russell diagram the various stages of stellar evolution. By far the most prominent feature is the main sequence (grey), which runs from the upper left (hot, luminous stars) to the bottom right (cool, faint stars) of the diagram. The giant branch and supergiant stars lie above the main sequence, and white dwarfs are found below it. (Courtesy: R. Hollow, CSIRO)

1.5 LIGHT CURVE

Light curves are the most fundamental tools in variable star astronomy. They are graphs of brightness (Y axis) vs. time (X axis). Brightness increases as we go up the graph and time advances as we move to the right.
It is an important and valuable tool in the study of objects such as variable star, supernova, nova etc. which change their brightness over time. Information about their periodic behavior, orbital period, regularity of stellar eruptions etc can be directly obtained from the light curve. The study of light curve together with any other observation gives information about physical process that produces this variation. The brightness increases when we go up the graph and time advances towards the left.



This light curve shows that the star began at a brightness of magnitude 3 in 1982. Around mid-year it began to rapidly dim until it reached brightness of magnitude 3.8 by the end of the year. It remained there until the beginning of 1984 when it began a slower climb back to normal brightness. By the middle of 1984, it was almost back to normal brightness. Thus, light curves are very much helpful in understanding the nature of a star.

In this first chapter, we discussed the basics of astronomy and the several tools we use for making sensible observations, which on being processed gives valuable data. An introduction to time-domain astronomy and variable stars is given in the next chapter.

CHAPTER 2: TIME DOMAIN ASTRONOMY AND VARIABLE STARS

INTRODUCTION

The time-scales associated with stellar and galactic evolution are generally so large that the Universe has been traditionally viewed as a static phenomenon. However, we have long known of short-human-timescale events, such as Solar System events, eclipsing binaries, and stellar explosions. But only within the last decade of 1990's or so, with the advent of robotically controlled telescopes, and high cadence near-all sky monitoring, the study of astronomical events on ever shorter time-scale has literally exploded. With access to this new stream of data, our understanding of many phenomena has increased significantly, but also, the number of unanswered questions have increased, multiple times. One such question addressed the dilemma why many celestial bodies varied in their brightness. This led to the study in the field of Time Domain Astronomy.

2.1 TIME DOMAIN ASTRONOMY

Time-domain astrophysics is a field of observational astronomy that studies the universe on all timescales from less than milliseconds to more than decades, and at all wavelengths. Became possible due to the availability of remarkable detectors and computing advances over the past decades. The idea of observations and analysis have now moved beyond the one-off photographic surveys in the past. Beginning from the 1990s, the MACHO(massive astrophysical compact halo object), OGLE(Optical Gravitational Lensing Experiment) and SuperWASP projects used large field-of-view, highly sensitive cameras on manual or robotic optical or near-infrared telescopes, depending on the spectrum under observation, obtained deep digital images of large swathes of the sky. These scans were repeated to build up huge databases of time-resolved images.

If we were to describe the elementary ideas of time-domain astronomy, we could explain it in the following manner. Observe a particular section of the sky. Note the physical limits visible in that section. After some time t, observe the section under consideration. If any of the physical quantities have changed from what was earlier, we tag the particular body in the database for future study. The time it takes for the instrument to re-observe the same patch of sky is referred to as the "cadence." By using the old strategy of looking deep and far into the Universe, sources of a given brightness are methodically mapped out in a three-dimensional volume. In time-domain astronomy, sources that vary by some brightness with a rate equal to the inverse of the instrument cadence can be steadily mapped out. In a way, the time-domain adds another dimension, given by the frequency equal to the inverse cadence, to the properties of observed phenomena. The study of variable stars is an important section of time-domain astronomy.

2.2 VARIABLE STARS

Variable stars change in brightness overtime. These changes can vary from as small as few parts in a million or by a huge factor. The changes observed can also range from a few milliseconds to a few years or decades for that matter. Since a spectrum of astronomical bodies can qualify as a "variable star", an array of techniques are devised to discover, measure and analyze the possibility of a variable star. The next obvious question is why the study of a variable star is important. The study is of importance as the variations provide and unique insights about the nature, the origins, evolution and often the future trajectory of the star under observance. This information helps us deduce more fundamental knowledge about our universe.

The variations may be due to the rotational motion executed by a spotted star, or due to of a star being eclipsed by its companion star, or even by an unseen planet.

The variations may also be due to the vibrations of a star. If these vibrations are complex, we might be able to get a rough picture of the internal structure and composition of this star. The variations may be due to eruptions on a star (flares), or an accretion disc (dwarf novae) or major explosions on a star (novae), or to the total disruption of a star in a supernova. Supernovae are the most violent incidents in the known universe. However, the existence of life is an indirect result of supernovae. They help to recycle the atoms created in stars into space. Some of these atoms became part of the Sun, others into planets, and for that matter, even biosphere. It is deduced that the elements heavier than iron were mostly created in the supernova explosion. Supernovae may be dramatic and extreme, but they represent only one of the many roles that variable stars play in modern astrophysics, and in our understanding of the universe and the processes which govern it. The organized study and recording of observations led to the establishment of the Variable Star Section of the British Astronomical Association (BAAVSS) in 1890, followed soon after by the establishment of variable star studies at Harvard College Observatory which eventually led to the founding of the American Association of Variable Star Observers (AAVSO) in 1911.

2.3 IDENTIFICATION AND MEASUREMENT OF VARIABLES

Different methods can be employed to be quantize, catalogue and conduct in-depth studies about a variable star (*or variable*). We'll be discussing about three commonly used methods.

1. Photometry
2. Spectroscopy
3. Polarimetry

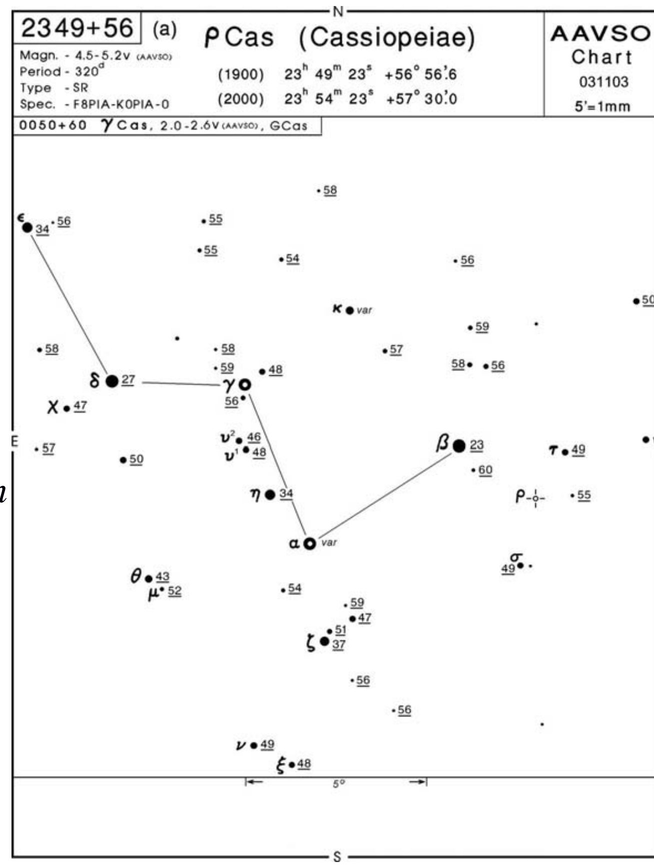
2.3.1 PHOTOMETRY

Astronomers measured the brightness of a variable star, relative to one or more constant stars of known or assumed magnitude, by interpolation (or by extrapolation). This method is often called standard candle method, where the brightness of the variable is compared in respect with a known constant star. Figure 2.2 shows a visual chart used by the AAVSO. The observer estimates the magnitude of the variable star, relative to the standard stars. The magnitude of the variable star may be the same as that of one of the comparison stars. If not, it is estimated relative to the magnitudes of two or more comparison stars, which bracket it in brightness. For instance, if it is half way between the magnitudes of two comparison stars, then it is the average of those two magnitudes. The eye is reasonably good at making these comparisons between the brightness of light sources involved. However, the quality and accuracy of measurement is only as good as the eye that made it. There are a lot of possible sources of systematic error when we undertake such a method to determine the brightness of a variable star, especially if the colors of the variable star and the comparison stars are different. The Purkinje effect (named after Jan Purkinje (1787-1869)) is a change in the color sensitivity of the eye at low light levels. The overall sensitivity of the eye increases. However, the peak sensitivity moves towards the blue side of the spectrum becomes less sensitive to red light. This is because the cone cells that function perfectly only at higher light levels are red-sensitive compared to the rod cells. The color sensitivity varies from person to person, and so an eye cannot be taken as a dependable instrument for photometry. There are also small effects connected with the orientation of the variable star, relative to the comparison stars in the sky, which occur because of the uneven distribution of the rod cells on the retina. Another drawback is that magnitudes of the comparison stars must be known to approximate the brightness of the variable star.

Figure 2.2 A chart for making visual observations of a variable star,

ρ *Cassiopeiae.*

The underlined numbers are the magnitudes of non-variable comparison stars, with the decimal points removed, in order not to confuse them with stars. (Courtesy: www.aavso.org)



With the discovery of photoelectric effect by Einstein in the 1908, a new generation of photometers were made available. We know, in photoelectric effect, if a beam of photons is made to shine on certain kinds of materials, the photons would liberate electrons from the material with the number of electrons liberated being proportional to the number of photons. This effect is employed to create a current of electrons-DC photometry-or, with sufficiently sensitive and complex photomultiplier tubes, individual electrons could be counted through photon-counting photometry. Photomultiplier tubes have a series of diodes. Each one multiplies the electrons which fall on it until there is a measurable pulse of electrons; the pulses are then counted, to determine the number of incident photons. The observer uses a chart similar to the above figure, except that the magnitudes of the comparison stars are given with an error range of ±0.01 magnitude. The observer measures the current of photons from the variable star (including the sky around it), then from an equivalent region of blank sky; the sky current is subtracted from the (star+sky current), and the result is converted into a magnitude. The same is done for a non-variable comparison and check star. The magnitude of the variable star is then expressed relative to that of the comparison star. This is called differential photometry.

The magnitude of the check star is also expressed relative to that of the comparison star. Finally, the differential magnitudes must be corrected for the small effect of differential extinction or dimming, if the stars are observed at slightly different altitudes above the horizon.

Differential photometry has better accuracy than absolute photometry, where the stars being observed are situated all over the sky. This is because the variable, comparison, and check stars being observed are close in time and position in the sky.

Panoramic photoelectric detectors, or electronic cameras are commonly used for photometric purposes were developed. Charge-coupled devices or CCDs are the most popular type of electronic cameras used. These consist of an array of typically 1000*1000 microscopic light-sensitive pixels. The camera is exposed to the sky. When light is made incident on the camera, the electrons produced in each pixel are read out, and the number stored in a computer. The numbers corresponding to each pixel must be corrected for the particular sensitivity and other characteristics of each pixel. These processes are referred to as subtracting the bias and dark frames, and flat-fielding. Then the total number of electrons corresponding to each star must be added up and corrected in the same way as for single-star photoelectric photometry. CCD photometry is especially powerful if there are hundreds, thousands, or more variable stars on a single image or frame.

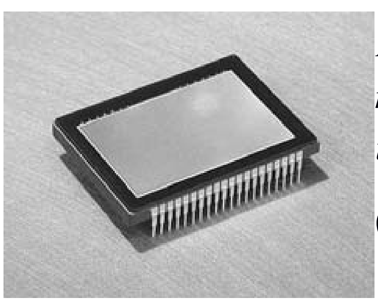


Figure 2.3 A CCD chip. The chip has large numbers of microscopic detectors which form the pixels of the image.

(Courtesy: AAVSO CCD documentation file)

2.3.2 SPECTROSCOPY

Spectroscopy is a very important tool for understanding variable stars. The complete information about the observed variables can be obtained from the full spectrum of wavelengths. However, high light intensity is required to gain credible information. Thus, the need for larger telescopes, longer time exposures and/or brighter stars grew stronger. The absorption lines provide information about the composition and properties of the stars. Through the Doppler effect, the apparent wavelength provides information about the dynamics of the variable-about pulsation, about the motion of binary and rotating stars, about expansion of eruptive variables such as supernovas, and about the presence and properties of faint companion stars and planets. The spectrum is imaged on a detector such as a CCD.

2.3.3 POLARIMETRY

The concept of starlight being unpolarized comes naturally to us. But it often is polarized, especially if the star has a disc or wind or other non-spherical distribution of matter around it. If the starlight passes through interstellar material, then the dust particles produce polarization. Due to their non-spherical shape, the polarized light are partly aligned by the weak magnetic field of our galaxy. This component of the polarization tells us about the nature of the interstellar matter, but not about the star itself. A very few observatories are engaged in astronomical polarimetry, and this technique can provide useful information about the stars and their immediate surroundings. In a polarimeter, a polarizing filter is placed in the light path, to measure the amount and the orientation of the polarization.

2.4 ANALYSIS OF VARIABLE STAR DATA

A number of physical parameters need to be measured to document and understand the absorption spectra of a variable star accurately. The parameters that are measured consist of values of magnitude, color, radial velocity, or some other property, along with the Julian Date-the time at which they were made.

Consider the following example. When a new ‘species’ of frogs is discovered, the first step is to cross-check whether the said new species is not an already discovered type. Similarly, the analysis of a variable star beings with the question whether the variable star is actually variable. If its range of variation is much larger than the allowed error range, then object is a variable star. If the variability is based on a small number of measurements which differ from the others, there is a possibility of mis-identification of the variable, or to clouds.

We know, photometric measurements are normally expressed as magnitudes, and these are a logarithmic function of the physical quantity, flux. For instance:

1. The output of theoretical models of variable stars is given as flux.

2. The average observed magnitude or color is calculated by taking flux-average of the light or color curve, especially if the amplitude is large.

3. The addition of two sinusoidal components should be carried out by considering the components as fluxes. Fourier analysis of light curves should be done on flux curves, if valid amplitudes are to be obtained.

4. Some variable stars (such as Mira) have an unresolved companion of constant brightness; the decomposition of the combined light curve should be done as flux, to allow for the constant contribution of flux from the companion.

5. A linearly declining light curve represents an exponential decrease in flux; this is seen in the declining phases of the light curves of supernovae which are being powered by exponential radioactive decay.

2.4.1 LIGHT CURVES

The simplest form of variable star analysis is inspection of the shape of the light curve (figure 2.4), and the time and magnitude of maximum and minimum. The term range is usually used to denote the difference between maximum and minimum. Each point on a light curve denotes a data set that was recorded by the variable star at the photometer.

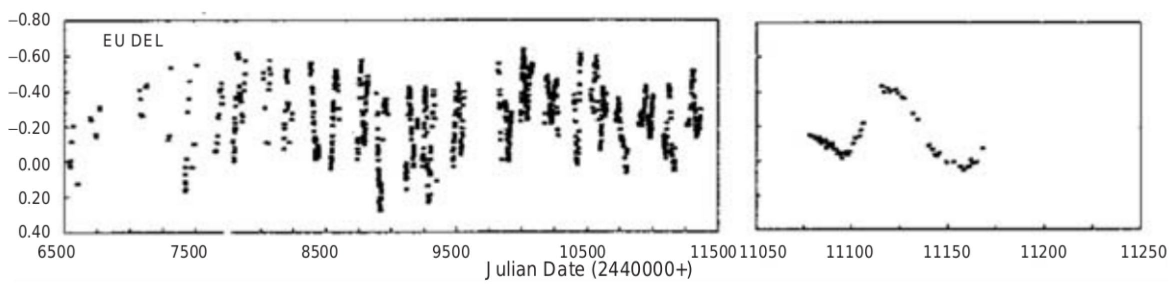


Figure 2.4 The light curve of the pulsating red giant EU Delphini on a 5000-day scale (left) showing the slow variability of the star, and on a 200-day scale (right) showing the 63-day period of the star. Light curves, on time scales of hours to decades, can provide a visual impression of the star's variability on a range of time scales. (Courtesy: Percy, Wilson, and Henry, 2001).

Note: A number of other methods available to facilitate the study of variability of a particular star. However, discussion of such methods will be outside the scope of this project report and is a matter of further reading.

2.5 CLASSIFICATION OF VARIABLE STARS

The General Catalogue of Variable Stars (GCVS) recommends an official classification system of variable stars based on:

1. Light Curve

2. Temperature

3. Luminosity

4. Population type

Based on this system, a family tree of variable stars can be constructed. Such a tree is called a Variability Tree. A simplified version of the variability tree is given below.

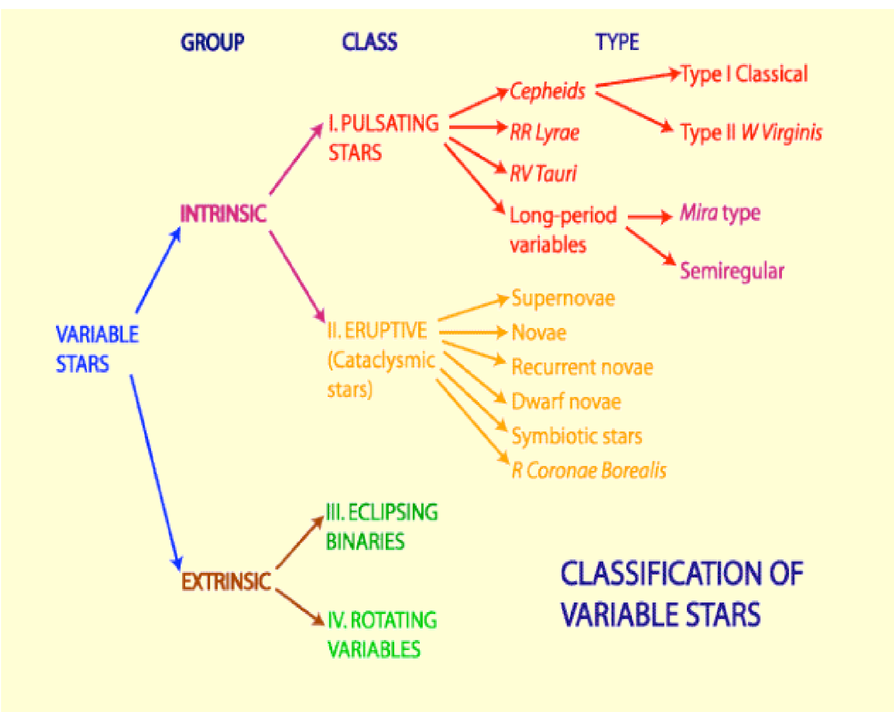


Fig 2.5: Classification of variable stars (*Courtesy:* [*www.atnf.csiro.au*](http://www.atnf.csiro.au))

2.5.1 INTRINSIC VARIABLE STARS

Intrinsic variable stars vary their light output, hence their brightness, due to the physical variation in the star or stellar system. This type of star provides a large amount of information about the internal structure of the star that helps astronomers to model the stellar evolution. Pulsating stars and eruptive or cataclysmic variable stars belong to this category.

2.5.1.1 PULSATING VARIABLE STARS

Pulsating variables are the stars that show periodic expansion and contraction of their surface layers. The change in brightness occurs due to the change in their size or shape. Most of the pulsating stars simply expand and contract repeatedly in a continuing cycle of size changes and this is known as the fundamental mode of pulsation. Some of them changes not only in their size, but also in their internal arrangement of material. Some others vibrate in more than one way at the same time and this makes the system complex. Like most vibrating systems, pulsating variables repeat their changes and they tend to be periodic. Depending on the period, on the mass and evolutionary status of the star, pulsating variables are classified into many categories. Following sections describes briefly about the pulsating variables.

2.5.1.1.1 CEPHEID VARIABLE STARS

Cepheid variables form an important class of pulsating variables. These are large yellow stars pulsate with periods from 1 to 70 days, with an amplitude of light variation from 0.1 to 2 magnitudes. They are very bright objects and have periodic oscillations. Brighter Cepheids have longer period and they follow a period -

luminosity relationship. Period luminosity relationship states that ‘more luminous cepheids pulsated more slowly’. This concept was put forward by Henrietta Leavitt in 1912. The period of Cepheid can be calculated from its light curve which can be used to estimate the Cepheid’s luminosity. Knowing its magnitude and luminosity we can calculate the distance using the relation

$$\mathbf{m - M = 5 \log (d/10)}$$

where **m** is the apparent magnitude, **M** is the absolute magnitude and **d** is the distance.

Cepheid light curves are distinctive and show a rapid rise in brightness followed by a more gradual decline that is shaped like a shark fin. The spectral class of Cepheid actually changes as it pulsates, being about an F type at maximum luminosity and down to G or K at minimum. The light curve of a Cepheid variable is shown in figure 2.2. In the figure each dot represents one observation.

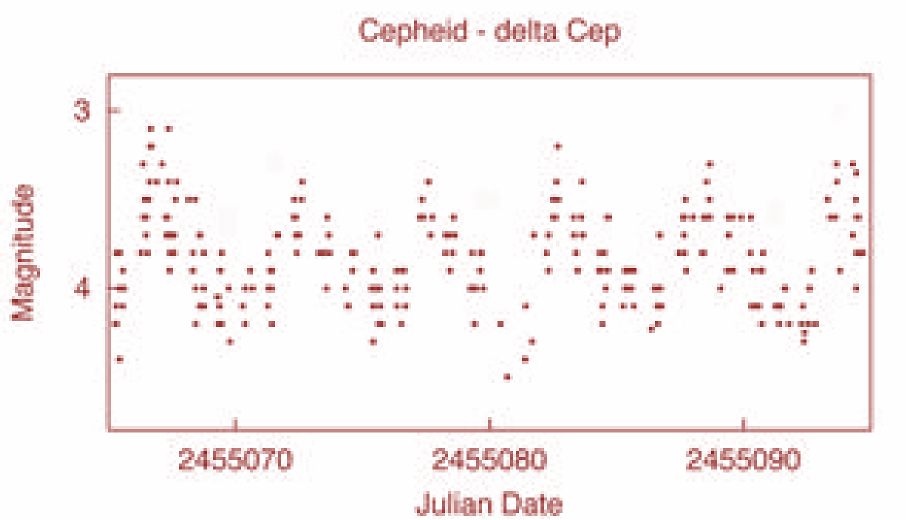


Figure 2.6: Light curve of cepheid variables (Courtesy: www.aavso.org)

2.5.1.1.2 LONG PERIOD VARIABLES

One of the largest population of pulsating variables are the long period variables (LPVS). They are pulsating red giants or supergiants with periods ranging from 30 - 1000 days. Long period variables are further subdivided into two major subclasses, the Mira type and the semi-regular variables.

(i) Mira Variable :

These are periodic red giant variables that vary with periods of 80 to 1000 days in magnitudes as high as 2.5 in the visible bands. Mira type variables are red giant stars, often of enormous size. Their high luminosity means that they can be detected at large distances. Many of them are slowly ejecting a steady stream of matter into the surrounding space and this mass loss has dramatic consequences on their future evolution. They have weak outer layers in their atmosphere which gets heated from regular pulsations. This can give rise to emission lines in their spectra. Figure 2.3 shows an example light curve of Mira variable observed during the year 1950 – 2010.

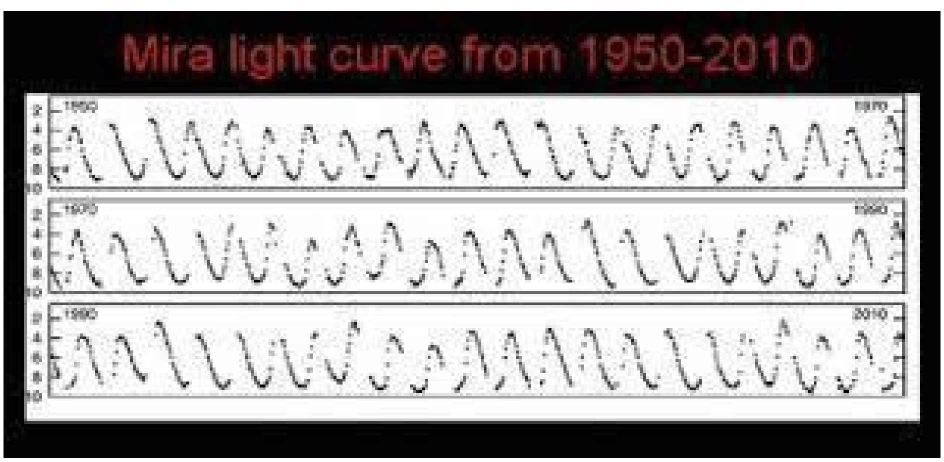


Figure 2.7: Mira light curve from 1950-2010 (Courtesy: www.astrbob.areavoice.com)

(ii) Semi-regular Variable:

Semi-regular variables are giants or supergiants which show appreciable periodicity accompanied by semi-regular or irregular light variation. Their periods range from 30 to 1000 days, generally with amplitude variation of less than 2.5 magnitudes. The light curve of semi-regulars have a variety of shapes. Light curve of Z UMa, a semiregular variable star, is as shown in figure 2.4.

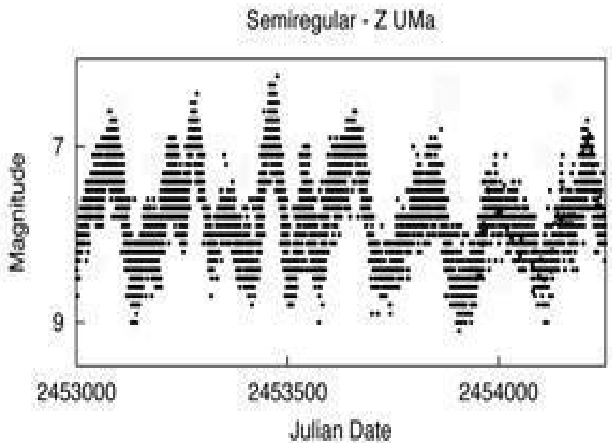


Figure 2.8: Light curve of Z-UMa(courtesy- www.aavso.com)

2.5.1.1.3 RR LYRAE

RR lyrae stars are short period (.05 to 1.2 days), pulsating white giant stars, usually of spectral class A. They are older and less massive than Cepheids. The amplitude of variation of RR Lyrae is generally from .3 to 2 magnitudes. They are of second importance to the cepheids as distance markers. Figure 2.5 shows the light curve of RR Lyrae variable star.

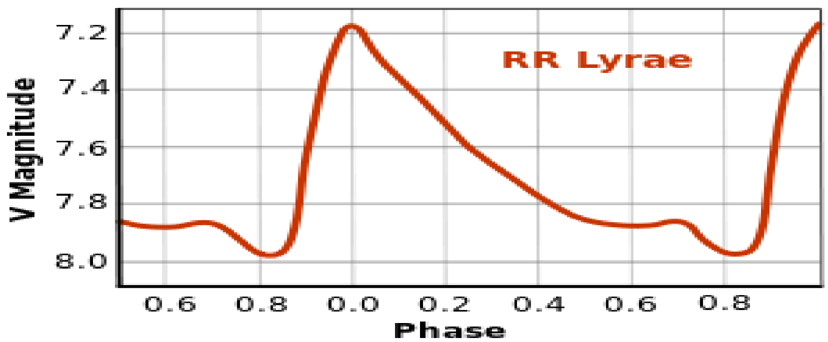


Figure 2.9: Light curve of RR Lyrae (Courtesy: www.en.wikipedia.org/wiki/RR_Lyrae)

2.5.1.1.4 RV TAURI STAR

RV Tauri stars are yellow supergiants having a characteristic light variation with deep and shallow minima. Their periods, defined as the interval between two deep minima ranges from 30 to 150 days. They show brightness variations of up to 3 magnitudes. Some of these stars show long term cyclic variations from hundreds of thousands of day. Generally, their spectral class ranges from G to K. Light curve of RV Tauri star is shown in figure 2.6.

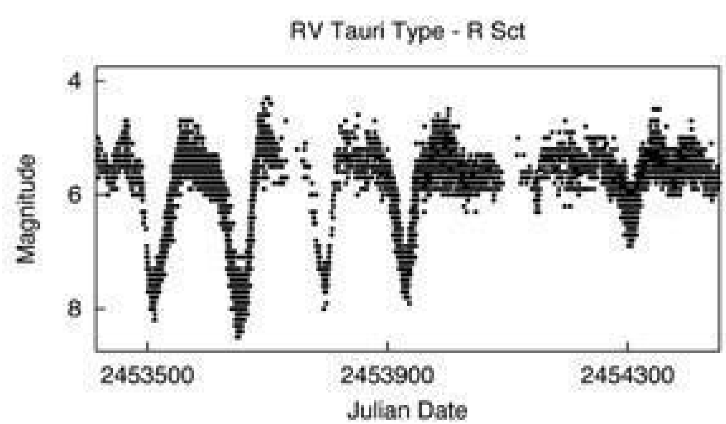


Figure 2.10: Light curve of RV tauri star (Courtesy: www.aavso.org)

2.5.1.2 ERUPTIVE OR CATACLYSMIC VARIABLE STAR

Eruptive variables are stars varying in brightness because of violent outburst caused by thermonuclear processes either in their surface layers or deep within their interiors. They exhibit significant and rapid changes in their luminosity which is usually accompanied by mass outflow in the form of stellar winds of variable intensity. These are a system of two stars (binary system) orbiting very close to each other. One of them is a normal sun-like or giant star, while the other is a white dwarf. Some of the outermost material from the larger star 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 dwarf. Thus, the eruptive variable star is a combination of normal or giant star, white dwarf and accretion disk as shown in figure 2.7.

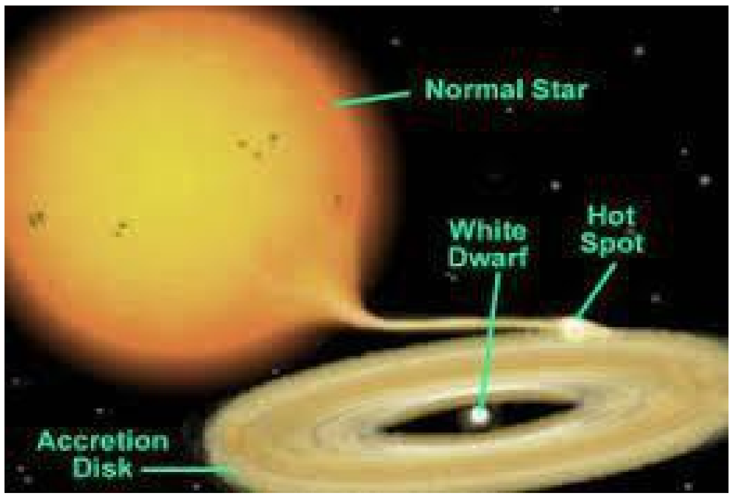


Figure 2.11: Eruptive variable star (Courtesy- www.astrosurf.com)

The combination of normal or giant star, white dwarf and accretion disk lead to celestial fireworks. So, instead of varying smoothly like pulsating variables, eruptive variables exhibit outbursts of activity. Some events may result in the destruction of the star while others can re-occur one or more times. The changes in their light curves are usually very unpredictable, and tend to be sudden and dramatic. There are wide varieties of eruptive or cataclysmic variables. They are described briefly in the following sections.

2.5.1.2.1 SUPERNOVAE

Supernovae are massive stars which are characterized by a sudden and dramatic rise in brightness. When a massive star has reached the end of its nuclear fuel, it can become a supernova. A supernova arises when the core of a star collapses under its own gravitational attraction, releasing energy which causes the outer envelope to explode. Thus, the inner part undergoes an implosion, while the outer part undergoes an explosion. The imploding core may form a white dwarf or neutron star. The exploding envelope carries an enormous quantity of energy outwards in the form of fast moving electrons, protons, and nuclei, as well as the electromagnetic radiation. The star implodes and then explodes with a catastrophic release of energy that exceeds any other known explosion in the universe. Supernovae are subdivided into type 1 and type 2 supernovae. Type 1 supernovae exhibit no hydrogen lines in spectra while type 2 supernovae show hydrogen lines in their early spectra. A supernova within a few hundred light years of Earth may destroy most life on the planet. Sample light curve of a supernovae is shown in figure 2.8.

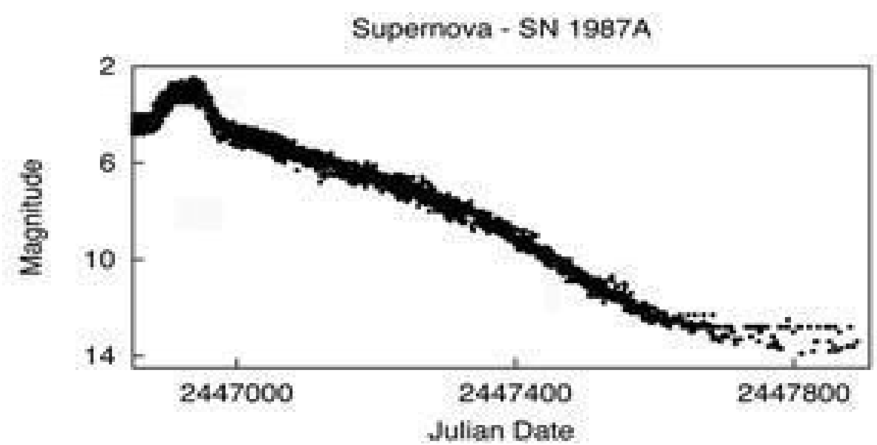


Figure 2.12: Light curve of supernovae (Courtesy- www.aavso.org)

2.5.1.2.2 NOVAE

A nova occurs in a close binary system and is characterized by a rapid and unpredictable rise in brightness. This binary system consist of a white dwarf as a primary and a low mass star as the secondary star. Explosive nuclear burning of the surface of the white dwarf causes the system to brighten 7 to 16 magnitudes in one to several hundred days. After the outburst, the star fades slowly to the initial brightness over several years or decades. This suggests that the event causing the nova does not destroy the original star. Figure 2.9 shows the light curve of a typical nova.

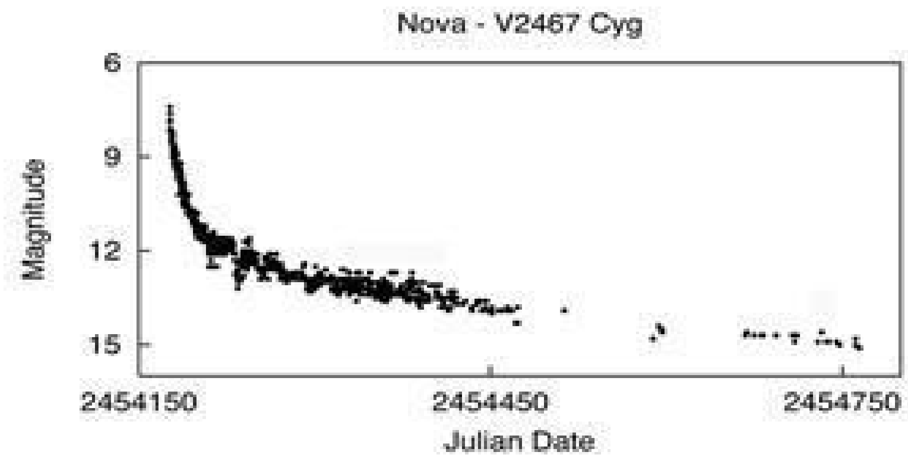


Figure 2.13: Light curve of nova (Courtesy- www.aavso.com)

2.5.1.2.3 RECURRENT NOVAE

Systems which undergone two or more nova-like eruptions during their recorded history is referred to as recurrent nova. Such recurrent eruptions have slightly smaller amplitude than that of typical novae. In all other respects they are identical to novae. Light curve of recurrent novae is given in figure 2.10.

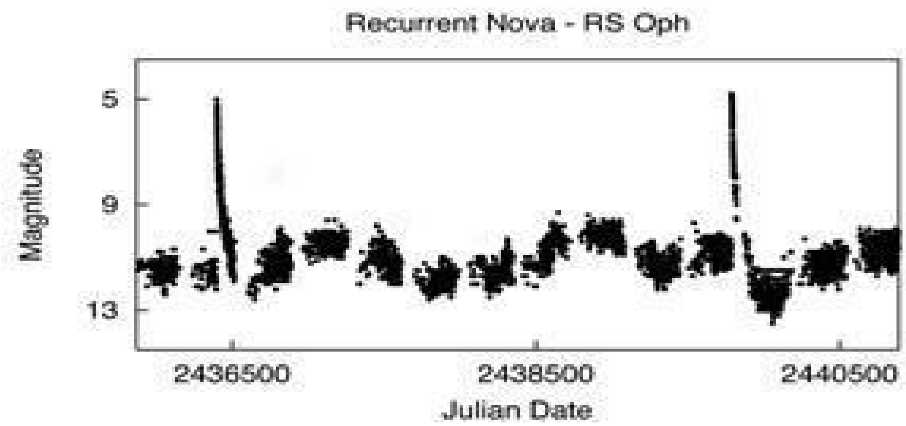


Figure 2.14: Light curve of recurrent nova (Courtesy: www.aavso.org)

2.5.1.2.4 DWARF NOVAE

They are faint stars that exhibit a sudden increase in brightness of 2 to 5 magnitudes over a few days. This type of stars have intervals of weeks or months between the outbursts. They are closed binaries with a white dwarf as one of the component stars. The brightening by 2 to 5 magnitudes is due to instability in the disk which forces the disk material to go down onto the white dwarf. There are three main subclasses of dwarf nova. They are U geminorum, Z camelopardalis and SU stars.

2.5.1.2.5 SYMBIOTIC STARS

Symbiotic stars display semi-periodic nova-like outburst up to four magnitudes. These are close binary systems with one red giant component and the other a hot blue star. In the case of recurrent nova, the material is being accreted by gravitational attraction while in the case of symbiotic systems materials are ejected from the surface of the red giant due to stellar wind. Also, the ejected materials are less regular and smaller than in other eruptive variables.

2.5.2 EXTRINSIC VARIABLE STAR

Extrinsic variable stars are those in which the light output changes due to some process external to the star itself. The two main classes of extrinsic stars are the eclipsing binaries and rotating variables.

2.5.2.1 ECLIPSING BINARIES

Eclipsing binaries are binary star systems whose members eclipse each other, blocking one another's light. As a result, the system looks occasionally fainter to observers on earth. 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 the earth. The process of eclipsing and corresponding light curve of an eclipsing system is shown in figure 2.11.

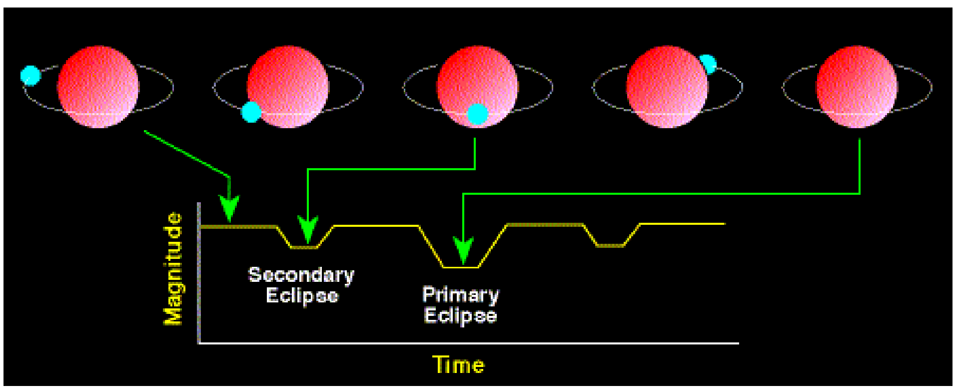


Figure 2.15: Eclipsing binary star (courtesy-www.csep10.uk.edu)

Here, the first star is larger and totally eclipse the second, while the second only partially eclipses the first. Thus, the light output is dimmed most when the blue star is eclipsed (this is called primary eclipse) and it is dimmed less when the red star is eclipsed (this is called secondary eclipse). The time between primary eclipses is taken as the orbital period of the binary system. Detailed analysis of the light curve shape yields much information about the size, mass and shape of the star and shape of their orbits. Algol (beta Persei) is an example for eclipsing binary.

2.5.2.2 ROTATING STAR

Rotating variables are rapidly rotating stars, often in binary systems, that undergo small amplitude changes in light due to dark or bright spots on the star's surface which is much similar to sunspots on the sun. Stars with sizeable sunspots show significant variations in brightness as they rotate. Stars which have ellipsoidal shape also exhibit variation in brightness when they present varying areas of surface to the observer.

CHAPTER 3: METHODOLOGY

INTRODUCTION

A transient astronomical event (transient) is an astronomical object or phenomenon whose duration varies from seconds to several years. We know that galaxies and their component stars in the universe evolve in a timescale of the millions or billions of years. It is a general term used for violent deep-sky events, such as supernovae, novae, dwarf nova outbursts, gamma-ray bursts.

Transient events were visible to the naked eye from within or near the Milky Way Galaxy were very rare, before the invention of high resolution telescopes. Such events were recorded in literature, such as the supernova in 1054 observed by Chinese, Japanese and Arab astronomers, and the event in 1572 known as "Tycho's Supernova" after Tycho Brahe, who studied it until it faded after two years. Though telescopes enable us to see more distant events, the small fields of view, typically less than 1 square degree, meant that the probability of viewing a particular place at the particular time were low. Schmidt cameras with wide field were invented in the 20th century, but was used to observe the unchanging heaven.

The interest in transients has increased as studying them helps astrophysicists to understand the mechanisms which kick-started the universe. As telescopes with larger fields of view were invented, such as the Palomar Transient Factory, the spacecraft Gaia and the LSST, it spotted many more occurrences. The ability of such instruments to observe wavelengths that are invisible to the human eye(radio waves, infrared, ultraviolet, X-ray) increases the amount of information that are available and may be obtained when a transient is studied. The upcoming satellites shall observe a field of more than 200 square degrees continuously in the UV range. This wavelength is important to detect supernovae within minutes of their occurrence.

Two major facilities are employed in studying the transient events across the heavens. We shall attempt to discuss them in short.

3.1 PALOMAR TRANSIENT FACTORY

The Palomar Transient Factory (PTF) is a comprehensive transient detection system which includes a wide-field survey camera, an automated real-time data reduction pipeline, a dedicated photometric follow-up telescope, and a full archive of all detected sources. The survey camera observed first light in December 2008 and the project completed commissioning in 2009 June.

The transient detection component of PTF is carried out at the automated Palomar Samuel Oschin 48 inch telescope (P48). Candidate transients are then photometrically followed up at the automated Palomar 60 inch telescope (P60). This dual-telescope method allows high survey throughput, in addition to a very flexible follow-up program.

Data taken with the camera is transferred to two automated reduction pipelines (Fig.3.1). A near–real-time image subtraction pipeline is run by the Lawrence Berkeley National Laboratory (LBNL) and identifies optical transients within minutes of images being captured. The output of this pipeline is then sent to UC Berkeley, where a source classifier determines the probability of the reduced image being part of a particular scientific class set, based on all available time-series and context data. In a few days time, the images are included into a database at the Infrared Processing and Analysis Center (IPAC). Each incoming frame is then calibrated and searched for objects, before the detections being merged into a database. This database is then made public.

Follow up of detected transients is the most important component of a successful transient surveys The P60 photometric follow-up telescope that is employed automatically generates colors and light curves for interesting transients detected using the P48 telescope. The PTF collaboration also has a further 15 telescopes for photometric and spectroscopic follow up. An automated system collates detections from the Berkeley classification engine, then, make them available to the various follow-up facilities, coordinate the observations, and finally report on the results.

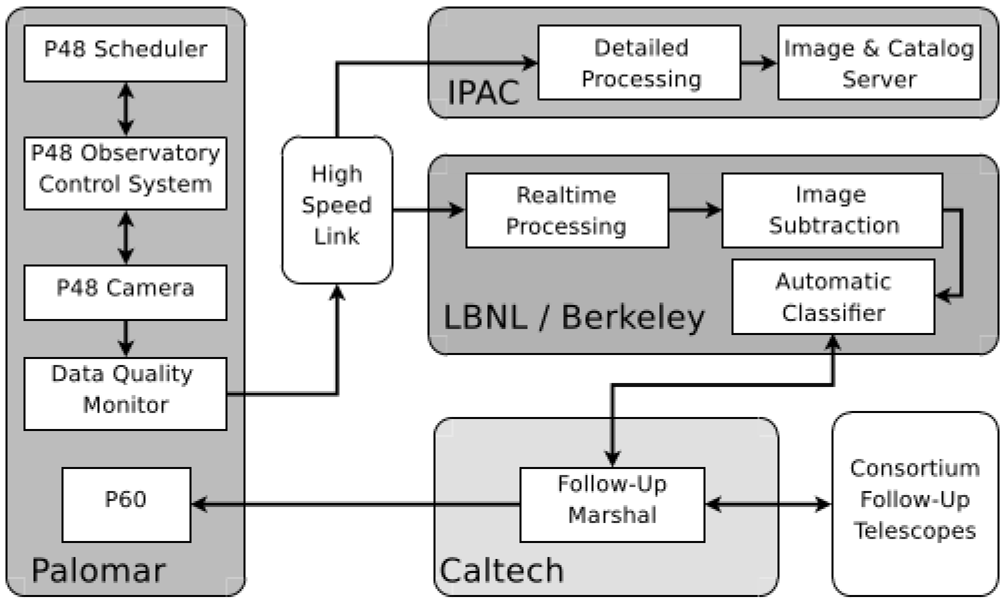


Fig 3.1 : Overview of the PTF project data flow.

(Courtesy: THE ASTRONOMICAL SOCIETY OF THE PACIFIC)

By 2013, the Palomar Transient Factory transitioned into an upgraded facility, the intermediate Palomar Transient Factory.

The intermediate Palomar Transient Factory (iPTF) is a completely automated, wide-field survey for a systematic exploration of the optical transient sky. With improved software for data reduction and source classification, the project has achieved significant successes in the early discovery and rapid follow-up studies of transient sources.

This project uses a large field camera subtending 7.8 square degrees on the sky.

The iPTF used the 48 inch Oschin telescope for transient candidate discoveries. Any interesting candidates are then followed up with many other facilities, including Palomar 60 and 200 inch telescopes for both photometry and spectroscopy. Palomar 48 inch telescope has an advanced robotic control system.

By the end of 2017, the iPTF had transitioned into the Zwicky Transient Facility(ZTF), by bringing about a lot of changes and upgrades in the method of observation and detection.

3.2 ZWICKY TRANSIENT FACILITY

The Zwicky Transient Facility (ZTF) is a next-generation optical time-domain survey currently in operation. This includes near-Earth asteroids (NEAs); rare and fast-evolving flux transients and all classes of Galactic variable sources.

The PTF camera only used a small fraction (7.3 square degrees) of the available 47 square degree focal plane of the Palomar 48-inch Samuel Oschin Schmidt telescope. A new camera with 16 6k x 6k CCDs fills the focal plane, providing a sixfold increase in the sky captured in each image.

This camera has the world's widest field of view on a telescope larger than a half meter with each image being able to cover 235 times the area of the full moon.

3.2.1 OVERVIEW OF PROCESSING UNDERTAKEN

1. Raw data ingestion and pre-processing
    1. Raw data ingest, archival of raw CCD image files and storage of metadata in database;
        1. Raw CCD images
        2. Archive
        3. Real-time
    2. Raw-image decompression, splitting of CCD images into readout-quadrant images, floating bias corrections;

1. Internal, real-time
2. Calibration generation

3. Bias-image derivation from stacking calibration images acquired in afternoon
   1. Image file per readout-quadrant
   2. Made before on-sky operation during day

4. Instrumental calibration of readout-quadrant images: astrometric and photometric calibration

3. Real-time science-data processing:

5. Image subtraction and transient extraction (point-sources and streaks for "fast" moving asteroids)

4. **Ensemble-based processing (combining epochal science products)**

6. Reference-image generation

7. Source-matching across epochal source catalogs with relative photometric refinement for lightcurves

8. Moving Object Discovery Engine (ZMODE): construction of moving-object tracks from linking machine-learned vetted point source transients at the end of each observing night using all data from the previous three nights at most if available, otherwise use the most recent one or two night(s).

3.2.2 LIST OF CONTENTS IN A ZTF ALERT TABLE

The following is a section of the transient alert table, containing details of all the transients as observed by the ZTF, during the course of time.

Prev Next Results: 39925980 Pages: 399260 Latest Alert: 2019-06-15 05:50:35 UTC

id	objectId	time	filter	ra	dec	magpsf	magap	distnr	Δmaglatest	Δmagref	rb
89703074	ZTF19aazqgbe	2019-06-15 05:50:35	r	225.76432	79.10400	18.43	18.98	13.094			0.353
89703078	ZTF19aazqgcg	2019-06-15 05:50:35	r	228.62546	73.15251	19.31	19.58	1.223		3.05	0.444
89703080	ZTF18aamtzmq	2019-06-15 05:50:35	r	235.90214	75.26148	16.96	16.98	0.179	-0.48	-1.47	0.924
89703082	ZTF18abawbha	2019-06-15 05:50:35	r	230.15580	75.53424	16.13	16.10	0.729	1.04	-2.49	0.349
89703084	ZTF18aaoeiax	2019-06-15 05:50:35	r	239.58005	76.58414	16.00	16.03	0.266	-0.35	-1.62	0.789
89703087	ZTF19aazqgep	2019-06-15 05:50:35	r	227.28724	78.14607	19.63	19.55	10.739			0.391
89703091	ZTF19aazqgfg	2019-06-15 05:50:35	r	217.19202	77.91661	18.61	18.92	9.244			0.296
89703092	ZTF19aazqgfw	2019-06-15 05:50:35	r	229.03263	78.60775	18.80	18.89	0.542		3.70	0.210
89703094	ZTF18aauyinp	2019-06-15 05:50:35	r	211.86246	78.43810	16.25	16.46	0.917	-0.12	-3.01	0.247
89703097	ZTF19aazqggx	2019-06-15 05:50:35	r	233.92979	75.30078	18.95	18.62	2.064			0.174
89703103	ZTF19aazqgok	2019-06-15 05:50:35	r	233.10315	79.05941	18.76	19.14	7.492			0.281
89703104	ZTF18aakqtfy	2019-06-15 05:50:35	r	239.60302	72.93336	18.19	18.30	0.066	0.44	-2.16	0.947
89703106	ZTF18aaoehqe	2019-06-15 05:50:35	r	243.59564	76.45515	18.03	17.91	0.338	-0.42	-1.84	0.731
89703107	ZTF19aazqgbu	2019-06-15 05:50:35	r	243.01977	76.61673	19.10	19.25	8.578			0.249
89703108	ZTF19aazqgcw	2019-06-15 05:50:35	r	219.16849	77.06725	17.19	17.48	6.132			0.133
89703109	ZTF19aazqgcx	2019-06-15 05:50:35	r	218.57487	77.08819	18.23	18.76	4.899			0.406

Fig3.2 ZTF alert table. (Courtesy- www.mars.lco.global)

Each column stands for a particular physical or optical observable from the transient. They are discussed as follows:

1. id: Id is only a means to point out the chronological order in which the alerts corresponding to different events were observed at the ZTF. This column gives no other special inference.

2. objectID: These represent alert packets, to show various observations as made at the facility. As is visible, different id's represent different transient events. An

algorithm is followed in naming the alerts. The algorithm has been discussed in the next section.

3. Time: This column denotes the time at which the observation was carried out.

4. Filter: This column specifies the type of filter that was used. Filters are used with telescopes and in CCD cameras to improve the observation of an object and to facilitate the measurement of photons with wavelengths in a particular range. Filters of varying wavelength bandpass can be achieved.

5. ra and dec: Right Ascension(ra) and Declination(dec) are analogous to what latitude and longitude is to surface of earth. RA is effectively measured in hours, minutes and seconds, while Dec is measured in degrees, arcminutes and arcseconds.

6. Magpsf: Observed magnitude from Point Spread Function (PSF) photometry. PSF describes the response of the telescope or CCD to the distant transient events, which act as point-sources.

7. Magap: Aperture magnitude using a 14 pixel diameter aperture. Aperture photometry is defined as the measurement of light which falls inside a particular aperture, in ZTF's case, a circular aperture of 14 pixel diameter.

8. Distnr: Distance to nearest source in reference image.

9. Deltamaglatest and deltamagref: Differnce in magnitude of the observation form the standard reference value

10. rb- RealBogus quality score - range is 0 to 1 where closer to 1 is more reliable.

3.2.3 ALERT NAMING PROCESS

Alert packets are assigned names (objectId) using the algorithm outlined in Figure 3.3

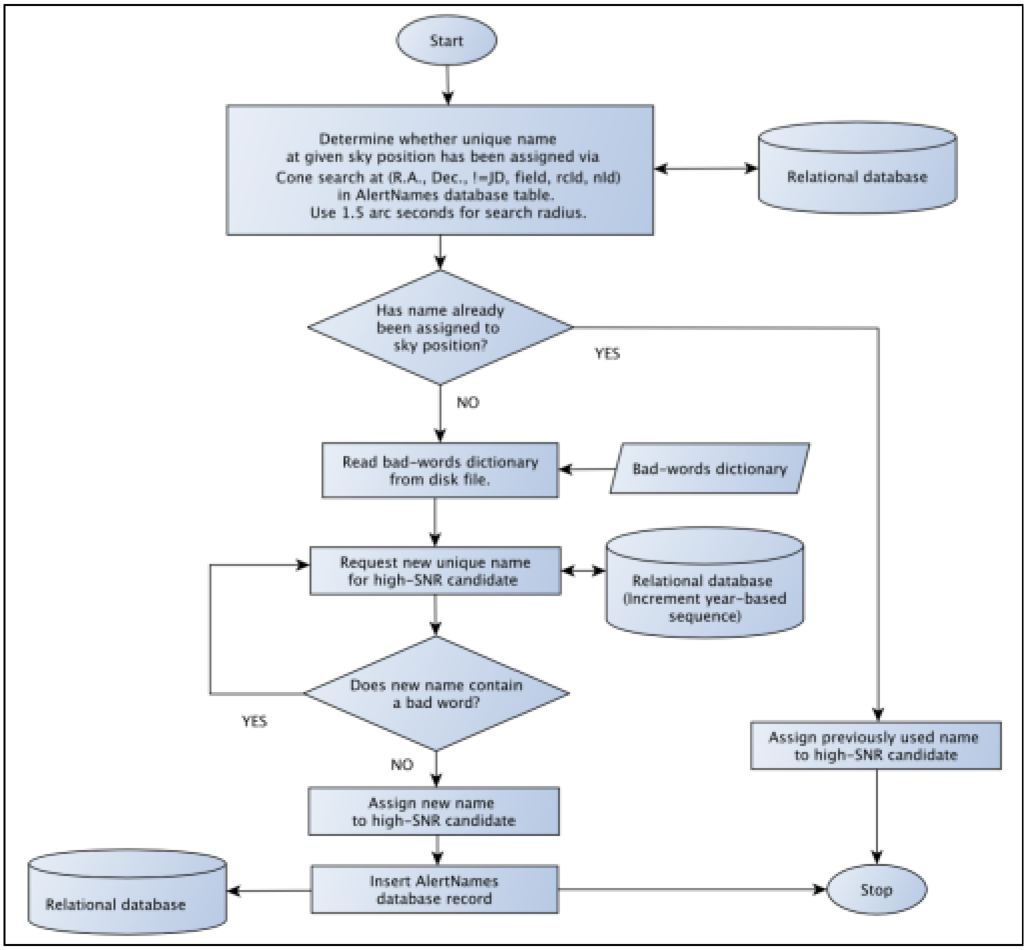


fig 3.3

The idea is "brand" each alert with a name to indicate its origin is from ZTF. Names (objectIds) are initially assigned to newly discovered alerts. Subsequent alerts that fall on/near a previously named alert (based on a positional search) going back to the beginning of commissioning (~ UT 2017-10-15) inherit that same name. The closest matching alert within the search radius (currently 1.5 arcsec) handles ambiguous cases. objectId has the following format, for example: ZTF18abcdefh. This consists of the fixed ZTF prefix followed by the year and a seven (alphabet-based) character string, with range a to z for each character. Seven characters allows for 26^7 = 8,031,810,176 possible unique names to be assigned over the course of a year. Estimates for the number of possible alerts per year are well under this limit. The assignment of objectId is sequential, beginning with ZTF18aaaaaaa. The naming process commenced during the early commissioning. Therefore, it's possible to obtain objectIds with prefix ZTF17, for example, for alerts that reoccur on a variable star. The AlertNames database table is used to book-keep and reassign objectIds from older alerts. This table will store one record for each objectId used, i.e., when it was first assigned. This includes associated metadata for the discovery epoch/position of the alert it was first assigned to.

3.3 PYTHON AND PANDAS

3.3.1 PYTHON

Python is a high-level, interpreted, interactive and object-oriented scripting language. It is designed to be highly readable and uses English keywords extensively, where as other languages use punctuation. It has fewer syntactical constructions as compared to other high level programming languages. One of the main features of python is that it is interpreted. It is processed at runtime by the interpreter. One does not need to compile the program before executing it. This is similar to PERL and PHP.

Another advantage of python is that it is interactive. One can actually sit at a Python prompt and interact with the interpreter directly to write the programs. Python is Object-Oriented: Python supports Object-Oriented style or technique of programming that encapsulates code within objects. • Python is a Beginner's Language: Python is a great language for the beginner-level programmers and supports the development of a complete range of applications.

Python language was chosen to write the interfacing surface due to its user-friendliness and ease of use.

3.3.2 PANDAS PYTHON MODULE

Pandas is a Python library written for the Python programming language for data manipulation and analysis. In particular, it offers data structures and operations for manipulating numerical tables and time series.

Library features

•DataFrame object for data manipulation with integrated indexing.

•Tools for reading and writing data between in-memory data structures and different file formats.

•Data alignment and integrated handling of missing data.

•Reshaping and pivoting of data sets.

•Label-based slicing, fancy indexing, and subsetting of large data sets.

•Data structure column insertion and deletion.

•Group by engine allowing split-apply-combine operations on data sets.

•Data set merging and joining.

•Hierarchical axis indexing to work with high-dimensional data in a lower-dimensional data structure.

•Time series-functionality: Date range generation and frequency conversion, moving window statistics, moving window linear regressions, date shifting and lagging.

•Provides data filtration.

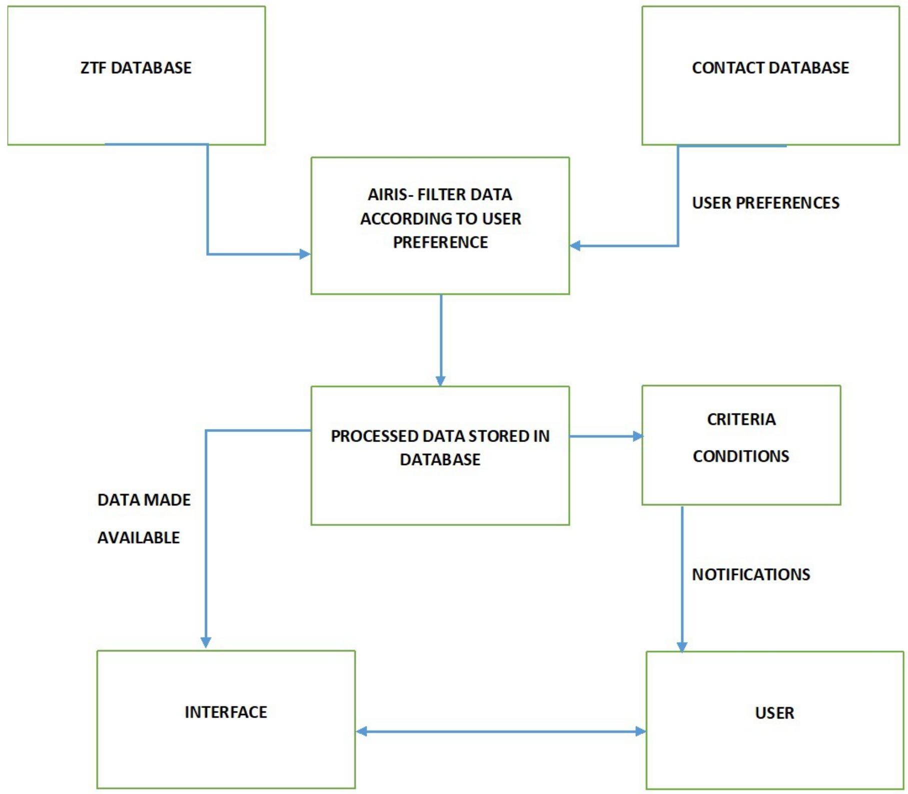
3.4 AIRIS- AUTOMATED INFORMATION RETRIEVAL AND INTERFACING SYSTEM

The ZTF database, at its time of inception, had made available only the light curves of individual transient events, in the general domain. For a researcher who wants to study about a particular transient event, it would be a very tedious process to sift through light curves, determine which transient event was being reported and then search for individual readings. This is a very time consuming job and forces an interested individual to actually spend more determining what transient event he was looking at than in actual research. Thus, the **main objective** of the project was to create a database, based on the daily report of light curves, as given out by the ZTF.

The **other objective** of this project was to design a platform that would cater to an individual interested in transient events. This platform would provide all alert packets that this individual is interested in only, from the ZTF database. Thus, an in-depth study was conducted about transient events, especially variant stars and their properties. This was followed by handling Python and all necessary modules that would help in data analysis and graphics. The algorithm and details of AIRIS is discussed in the following sections.

The first step was a study on transient events and their classification, based on parameters. The next step was the designing of the platform, algorithm of which is explained below.

3.4.1 ALGORITHM



3.5 STEPS TO BE FOLLOWED

The intended platform has two independent programs, both of which can access a common database. The first program is called Dataframe Formation, while the second is called Interfacing.

3.5.1 DATAFRAME FORMATION

The ZTF alerts are now accessible for the general public at www.mars.lco.global. The ZTF database has more than 40 million alerts (data entries) on transients as of date. So, the need is to acknowledge a particular individual's choice, somehow filter the data and store data-sets corresponding to this particular event only, in an intermediate database where further processing will be done. This part of the program is to be accessed only by the administrator.

The basic steps to be carried out are:

INFORMATION RETRIEVAL

1. Accept details from individuals who are interested to receive notifications. Ideally, the admin must get the following details: Name, Transient event that the individual is interested in, Email Address to send notifications to and Last Updated time. When a person signs up for our platform, he is provided with a password, using which the data will be accessed from the second program. Store this contact data into a csv file, name it contact.csv.

2. Using the area of interested transient events as a filter, we filter out alerts from the ZTF database. For example, if a particular individual wants data related to event A, our program should filter the ZTF database, download alerts that are relevant and save it to a csv file, say ztfdata.csv. During the first run, the entire ZTF database is checked and saved to our database. Store the date of first run**.**

3. Now, a provision must be made so that the program can run everyday at a designated time, to update the csv file with any new entries. Thus, in the subsequent runs, datasets appearing after the date of first run is filtered and saved.

PROCESSING OF DOWNLOADED DATA

4. Now, all data in the ztfdata file can't be presented to the user, as the chances of redundancy are very high. Thus there is a need for different verticals, based on which meaningful information regarding the transient events can be passed on to the end user. A temporary dataframe with alerts of objectId corresponding to one contact (from the contact database) is formed.

5. We select the following as verticals:

   a. The last updated time of the individual in the contact file is compared with the time of observation of the alert

   b. The value of Δmaglatest should be compared with a threshold value given by the user. Thus, we need to introduce a column 'THRESHOLD' which will define the minimum value of Δmaglatest. If there are alerts with values beyond the threshold, user must be notified.

6. Update the last updated time of the individual with the new time.

7. Send out notifications for alerts which satisfied all verticals that were set, via email addresses provided by the user.

8. The program is designed to run once a day at particular time.

3.5.2 INTERFACING

Now, the user has got a notification email that tells him of a new alert that satisfies the criteria. The second part of the program is designed as a front-end program. Here, the user can log-in to the interface by using the username and password that were allotted on sign-up. Once the user has logged in successfully, a light curve of the object of interest and the all data entries corresponding to that object is to be displayed. There should be, finally, a provision to change the threshold value, if the user wants.

3.7 DISCUSSIONS AND FUTURE SCOPE

The aim of this project was to create an intermediate step between a Transient Facility database that propagates gigabytes of information and an end user who is interested in a hundred megabytes of information. The study of variable stars and transient events helped the understanding of concepts a tad bit easier. Transient events are actually messages of violent deep-sky phenomena. The intensity that reaches us is very low. However, the quantity of information received has no connection with the importance of information received. It only underlines the importance of the same. In-depth studies and development of better tools in this fields surely will produce better answers to the question about Origin of the universe we know.

This project was motivated largely by the acute dearth and growing need for a real-time data analysis and exploitation in astronomy and space science. However, the challenges we are tackling are common to many other fields, and it is only imperative to envision applications in fields as diverse as environmental monitoring, security, etc. In many situations, when there are short time scales and large raw data volumes, combined with bandwidth limitations or signal latency, it implies a need for a highly automated system. The key to a better system lies in machine learning- decision making, and rapid and prioritized follow-up response, without any human intervention.

This should be as a dynamic process, incorporating the new data as they come in to make use of limited follow-up resources and constrained local processing capability (e.g., on a spacecraft, or in a field sensor).

FUTURE SCOPE

The interface developed under this project is a Python program and hence requires Python to be pre-installed in a user's workstation. As an attempt to achieve cross-platform recognition, attempts were made to use Flask, Kivy and PyQT to develop an app to facilitate the interfacing. Due to time constraints, that had to be left. Another huge opportunity lies in integrating machine learning with the project.

An automated, rapid classification of transient events detected in different sky surveys is essential for scientific utility and effective follow-up using scarce resources. This presents some unusual challenges: the data available is sparse, heterogeneous and incomplete; evolving in time. Using machine learning to auto-classify the transient events as and when they appear and then sending out the required alerts to individuals concerned is the way ahead for this project.

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