Introduction:
Good evening everyone. I am Aarya Patil, currently pursuing computer engineering at PICT. I am in the the third year, hoping to clear my 5th semester exams in this month, fingers crossed. I recently worked under the supervision of Dr. Kaustubh Vaghmare, Data Scientist at IUCAA, on a project due to which I stand here in front of you to share a little about my work, my experience and a little about the love we share for astronomy. Being a person who loves talking, I could go on for hours, but it'd rather not lose my breath in boring all of you, so please do interrupt me at any time for any questions and this talk would be way better if we interact so I know that you know what I know.

Introduction:

Picture of Night sky

"We each exist for but a short time, and in that time explore but a small part of the whole universe." But humans are a curious species. We wonder, we seek answers.
Now, I, personally, have always (let's try and use a nice word here) despised the fact that I do not have answers to the multitude of questions that exist. Where did this all come from? What is the nature of reality? Can we one day understand the world in which we find ourselves? Most of us do not spend most of our time worrying about these questions (we already have a bag full of things to worry about), but gazing at the immense heavens above, it does bother us some or the other time.
These questions are just why astronomy has been ever so enticing to me and probably to you all and the motive of this talk is for you to share in the very satisfaction of doing meaningful research.

So we are looking at the bigger picture, the theory of everything, but where did it all start?

Astronomical photometry:

Picture of Vega
Just another star of the night sky.
Now let me tell you something interesting.

Video

In the direction of the constellation Lyra, at a distance of 26 light years, there is a star called Vega. It's surface temperature is almost twice that of the sun. Twice. Each centimeter of its surface radiates over 175,000 watts in the visible portion of the spectrum. So what this really means is that, the power of all the electric lights in a typical home, multiply that by 100 and imagine that amount being radiated from a spot a little smaller than a postage stamp. Huge. After travelling for 26 years, the light from Vega reaches the neighbourhood of the sun diluted by a factor of 10^-39. Of this remaining light approximately 20 percent is lost by absorption in passing through the earth's atmosphere. Approximately 30 percent is lost by scattering and absorption in the optics of a telescope. So finally, after all these heavy calculations, a 25 cm diameter telescope pointed at Vega will collect only one half-billionth of a watt at its focus. Of this, only a fraction is actually detected by a modern photoelectric detector.

This was a lot heavy for me to take in, I hope it doesn't scare you. But to sum up, this incredibly small amount of energy corresponds to one of the brightest stars in the night sky. The amazing thing is that stars can be seen at all!
Perhaps even more amazing is that starlight can be accurately measured by a device which can be constructed at a cost of a few hundred dollars. Such is the nature of astronomical photometry and this is where it all started.

Ancients and us alike have been interested in this very night sky because it is visually exciting. However to do real science, we do need far more than pictures. Pictures are needed as a first step in classifying objects based on their appearance. To proceed this initial stage of investigation, we need quantitative information i.e. measurements of the properties of the objects. How far away is that object? How much energy does it emit? How hot it is?

Ask why would we want to know the properties of celestial objects?
Answer: to model the stellar structure, discover the origin…

To do so, we use the most basic information that we receive right at our doorstep, light. Photometry, photo means light, metry measurement. It’s the science of measuring light aka energy that we receive from celestial objects.

The ideal goal of modelling the stellar structure would be to obtain, how the energy from the object, i.e, light, which we all know is electromagnetic in nature, is distributed in wavelength. Thus we would want the spectrum, but this calls for spectroscopy which deals with narrow wavelength band measurements. Refer to the page.

Image
Imagine we want to know the flux of an object in the wavelength interval of 4000 nm

Photometry usually refers to measurements of flux over broad wavelength bands of radiation.

Now why did I choose Photometry:

Being the oldest research techniques in astronomy, what photometry differs from other modern sciences is that, you do not need vast commercial laboratories or university facilities to undertake important research. An amateur astronomer, just like me and you, with a modest telescope or people with access to it (don’t tell them I told you so) can make a valuable and needed contribution to science.
And who knows, you might start with a 25 cm telescope and end up working with the Hubble. Just saying.
The number of stars, galaxies, and nebulae vastly outnumber the professional astronomers today, needless to say they greatly outnumber the number of engineering pass outs every year, and there is still so much still left to unveil.

Magnitude system:

We’ve established that photometry deals with measurements.
Most ways of counting and measuring things work logically. When the thing that you're measuring increases, the number gets bigger. When you gain weight, after all, the scale doesn't

tell you a smaller number of pounds or kilograms. But things are not so sensible in astronomy — at least not when it comes to the brightnesses of stars.

Star magnitudes actually count backward, that is, the brighter the star, the smaller the magnitude. It was the result of an ancient fluke that seemed like a good idea at the time, and if you ask an astronomer now he/she would say, "you'll thank the magnitude scale to be backward once you are in PhD".

The story begins around 129 B.C., when the Greek astronomer Hipparchus produced the first well-known star catalog. Hipparchus ranked his stars in a simple way. He called the brightest ones "of the first magnitude," simply meaning "the biggest." Stars not so bright he called "of the second magnitude," or second biggest. The faintest stars he could see he called "of the sixth magnitude." It isn't surprising since we can easily see that stars vary greatly in brightness. Then came telescopes, we could see dimmer stars, the magnitudes kept getting added 7,8,9 to 31 magnitude seen by Hubble telescope.

By the middle of the 19th century, astronomers realised there was a pressing need to define the entire magnitude scale more precisely than by just eyeball judgment. Scientists really do love equations. They determined that a 1st-magnitude star shines with about 100 times the light of a 6th-magnitude star. Accordingly, Pogson proposed that a difference of five magnitudes be exactly defined as a brightness ratio of 100 to 1. This convenient rule was quickly adopted. One magnitude thus corresponds to a brightness difference of exactly the fifth root of 100, or very close to 2.512 , a value known as the Pogson ratio.They also found that some "1st-magnitude" stars were a whole lot brighter than others. The magnitude scale thus extended farther into negative numbers: Sirius shines at magnitude –1.5, Venus reaches –4.4, the full Moon is about –12.5, and the Sun blazes at magnitude –26.7.

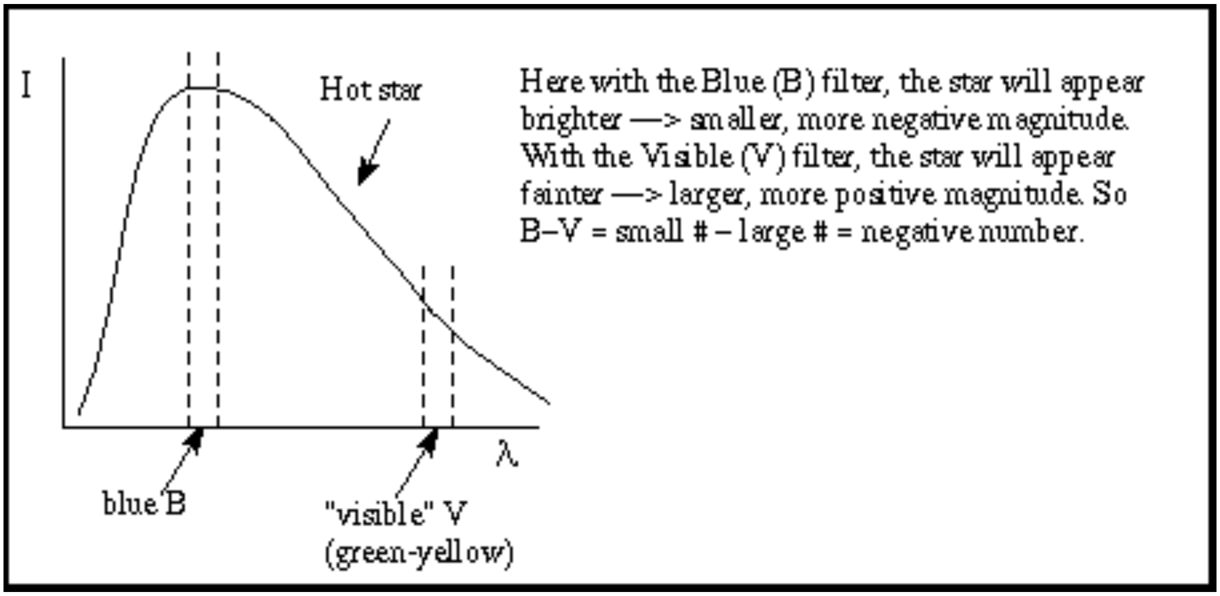
Up to now we've been dealing only with apparent magnitudes — how bright things look from Earth. We don't know how intrinsically bright an object is until we also take its distance into account. Thus astronomers created the absolute magnitude scale. An object's absolute magnitude is simply how bright it would appear if placed at a standard distance of 10 parsecs (32.6 light-years).

Colour

Any object with temperature above absolute 0 K emits light of all wavelengths with varying degrees of efficiency. When an object is hot enough, you can see the radiation it emits as visible light. For example, when a stovetop burner reaches 1,000 Kelvin (K) — 726° Celsius (C) or 1,340° Fahrenheit (F) — it will glow red.

The description of the radiation leaving a star is an enormously complex problem, and there is no simple mathematical equation that accurately describes the intensity of a star.
Stars are basically dense hot balls of gas, so their spectra is similar to that of a perfect thermal radiator, which produces a smooth continuous spectrum.

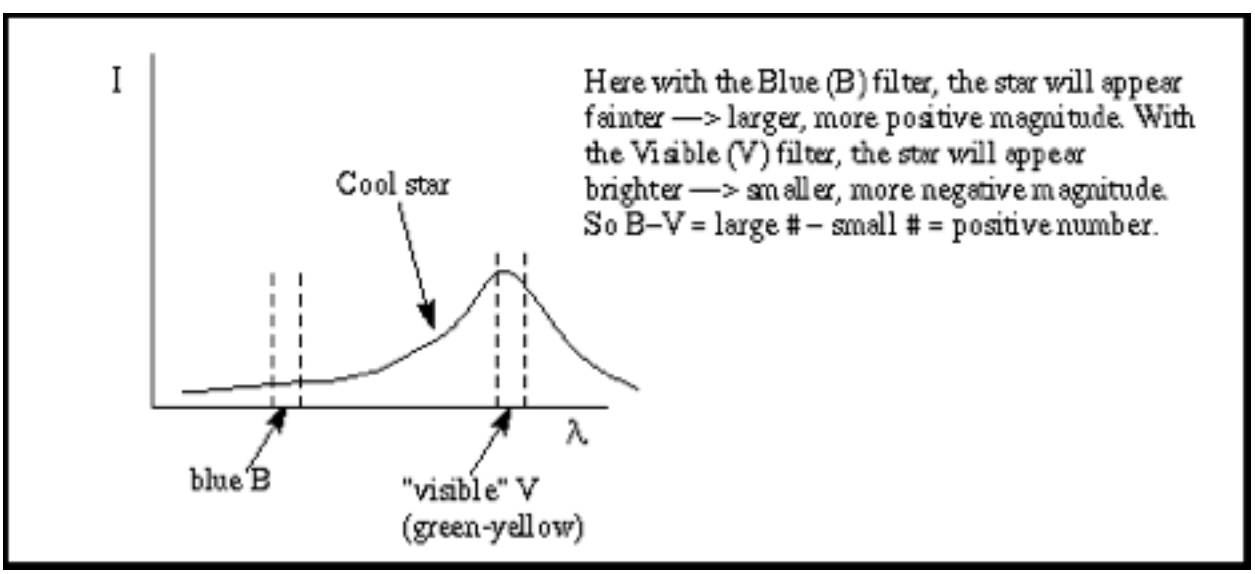
A blackbody or a perfect thermal radiator is an object that absorbs all radiation falling upon it. This object also emits as much energy as it receives and is therefore is in equilibrium at some temperature. Therefore, the colour of stars depends on their temperature---hotter stars are bluer



and cooler stars are redder.

Hot stars appear bluer than cooler stars. Cooler stars are redder than hotter stars. The ``B-V color index'' is a way of quantifying this using two different filters; one a blue (B) filter that only lets a narrow range of colors or wavelengths through, centered on the blue colors, and a ``visual'' (V) filter that only lets the wavelengths close to the green-yellow band through.
A hot star has a B-V color index close to 0 or negative, while a cool star has a B-V color index close to 2.0. Other stars are somewhere in between. Here are the steps to determine the B-V color index:

Measure the apparent brightness (flux) with two different filters (B, V).
The flux of energy passing through the filter tells you the magnitude (brightness) at the wavelength of the filter.
Compute the magnitude difference of the two filters, B - V.



Photometry

Input: CCD images in fits format, in B and V filter.

A CCD (Charged couple device) is a a grid (2D array) of pixels which converts the incident photons into electron charges and finally a digital value can be read for each pixel.

FITS (flexible image transport) format is a lossless image format ranging from 2.1 MB to 1GB of memory for each file. More bits used pixel, more precise measurements, hence size is more. Also there's something called a FITS header which stores all the relevant information about the image. Used for a lot of purposes in processing the raw CCD image data as well as in data reduction from the image.

First step was to convert the raw instrumental image data into a reduced CCD image to remove errors due to the CCD device.

Why is the image of a star a blob?
Refer to pages

In aperture photometry, one defines one aperture (usually circular) enclosing the source, and another (usually a ring outside the first) that contains only sky. Why do we measure sky value?

Even when the sun disappears beneath the horizon, our world is filled with light. It may be fainter than daylight or present in the infrared and therefore undetectable by the eye, but is a major contributor to the errors of photometric observations.
Background light from faint stars and galaxies, Zodiacal light, twilight emission lines, night airglow, aurora.

One obtains the mean counts per pixel from the sky aperture, subtracts that mean from each pixel in the source aperture, and sums the remaining counts to find the total in the stellar image. The advantage of this technique is that it is simple.
Aperture photometry assumes that the background varies in a linear fashion in the aperture's vicinity. However, in a dense star cluster the background is usually nonlinear. Therefore, one may use point spread function (PSF) photometry in order to meaningfully measure the brightnesses of the sources. In the latter approach, a single model is fitted to each object allowing one to determine, with subpixel precision, their position, amplitude, and width.

SExtractor pipeline:
The complete analysis of an image is done in two passes through the data. During the first pass, a model of the sky background is built, and a couple of global statistics are estimated. During the second pass, the image is background-subtracted, filtered and thresholded "on-the-fly". Detections are then deblended, pruned ("CLEANed"), photometered, classified and finally written to the output catalog.

Convert to standard magnitude correct for airmass (since all the stars are in the same image, extinction correction will get absorbed in zero point value) and standard stars : query Aladin (In order to avoid the complication of using absolute photometry and be less weather-dependent we will select clusters with secondary standards, that is, constant stars with reliable values of the B and V magnitudes. As these "secondary standards" will be in the same image, all stars are observed at the same airmass, hence, the derivation of the atmospheric extinction can be omitted. The transformation of the instrumental magnitudes into absolute magnitudes is simplified as the product of the extinction coefficient times the airmass is a constant that will be absorbed by the coefficients in the transformation equations.)

What is a star cluster in layman terms and the types of cluster.
We could proceed with this definition, but I always like to question everything, so why do you think stars are born this way?
How clusters are born?

Theories accumulated over years, observations were made calculations done, sheets crumbled up and thrown in the dustbin, this is purely my say okay. But it does seem like a bit of a hassle. But finally we could tell the life cycle of a star.

Stars live, evolve and die just like humans. No heredity or lifestyle, only mass. Explain in short the life cycle.

How was all of this found, I mean we can't really look inside a star and see what governs its life and death? That is where HR diagram came to the rescue.

HR diagram

Graphing or plotting can reveal a correlation between properties of an object.

In the early 1900's, Ejnar Herstzprung and Henry Norris Russell independently made the discovery that the luminosity of a star is related to its surface temperature. Luminosity is a measure of how much energy a star gives off. So, essentially, the HR diagram graphed how much energy a star gives off as a function of the star's temperature.

We know that the colour of a star is related to the temperature of that star. Also the spectral classification gives an indication of the temperature of the star. The current system of naming spectral class was adopted in 1910 and consists of a letter and a number from 0 to 9, for example the spectral class of the Sun is G2. The letters used are in decreasing order of temperature.

Thus, the horizontal axis in a HR diagram can be effective temperature, colour indices or spectral class, while the vertical axis can be luminosity with respect to that of the Sun or the absolute magnitude M_V.

When luminosity is plotted as a function of the temperature for a large number of stars, stars do not fall randomly on the graph; rather they are confined to specific regions. This tells you that there is some physical relationship between the luminosity and temperature of a star. From the figure one sees that most stars fall along a diagonal

strip from high temperature, high luminosity stars to low temperature, low luminosity stars. These are the **main sequence** stars.
Most nearby stars (85%), including the Sun, lie along a diagonal band in the H-R Diagram called the **Main Sequence.**

So you can see the main sequence, the supergiants, giants, sub giants, white dwarfs. These are all the stages that we discussed.

Why the main sequence is so important is that the size of a star does not change much during main sequence phase as the two opposing forces, gravity which tries to compress the star and the thermal pressure of the nuclear energy balance each other and it remains in this phase till its fuel dies which is almost 90% of its lifetime.

This band can be explained very simply if you remember the luminosity / temperature relationship for blackbodies:

The simplest version of this relationship (ignoring the radius), is that the hotter a star is, the brighter it will be, so the hottest stars are the brightest stars. The upper left corner of an HR diagram includes the hot, bright, blue stars. The coolest stars are much fainter than the hot stars, and they lie at the lower right. The band connecting the hot, bright stars at the upper left to the cool, faint stars at the lower right is called the MAIN SEQUENCE, and it includes stars from 3,000K up to 30,000K or so.

There are a few stars that are not in this diagonal strip. There are some low temperature, high luminosity stars - these are called **giants** and **supergiants**. The reason they are so luminous while being relatively cool is because they are so big (50 times more massive than our Sun). Another group of stars are in the high temperature, low luminosity corner of the diagram. Since these stars are hot, but not very luminous, they must be very small, so they're called **white dwarfs**.

Now we know what is an HR diagram and the significance of main sequence. Let's see how to find distance to a cluster using HR diagram.

These stars are gravitationally bound, all located at the same distance, and formed at the same time from the same cloud of gas and dust. It is assumed that the members of a cluster will be found at the same locations as stars in general on the HR diagram.
Explain by showing sun and irrespective of the cluster.
Show the cluster HR diagram vs Colour-Magnitude diagram. Ask them why they have the same pattern.

Main sequence fitting compares 1) the location of the main sequence for the cluster stars placed on the HR Diagram where apparent magnitude is used as the y-axis variable to 2) the location of the main sequence for nearby stars whose distances are well-known from parallax where absolute magnitude is used as the y-axis variable. Any difference in position between the main sequences must be due to the distance of the cluster, as all the **stars in the cluster** are effectively at the same distance away from us. The vertical position of the cluster main sequence is adjusted vertically that it lines up with the main sequence of nearby stars. The amount of vertical adjustment gives the distance modulus which in turn gives the distance.

m-M=-2.5log(10^2/d^2)
m-M=-5+ 5 log d

Thus, there will be some stars on the main sequence.
Show ageing.

Fit the main sequence with a least squares simple linear model.
Not so simple as there is a definite amount of stars of this main sequence.

There are some complications with main sequence fitting. When cluster stars run out of hydrogen fuel in their cores, they will leave the main sequence and evolve towards the upper right. Thus, these stars are really a distraction to the fitting process and the older a cluster is, the less of the main sequence you have to work with. The third problem is that one is not always confident regarding membership in the cluster – a few non-member stars are likely to be found in the same direction in the sky and end up included in the cluster photometry. Foreground main sequence stars will appear brighter and above the cluster main sequence stars, similar in appearance to stars becoming red giants. Background main sequence stars appear fainter and below the cluster main sequence stars.

Hence we use unsupervised learning to cluster the HR diagram into main sequence stars and the other.

I do dream of a day where I'll be sipping a cup of tea talking about the intertwining of space and time and reminiscing in the beauty of it's relativity.
My journey: Amateur to professional astronomy, hardships, things to learn. Encourage.