Stellar Spectroscopy

Horizon: The Physics and Astronomy Club
Centre for Innovation, IIT Madras

Pranav Satheesh
Madhav Lalwala, Mohit Kushwah, Vaibhavi Gawas

July 2019 - January 2020

Introduction

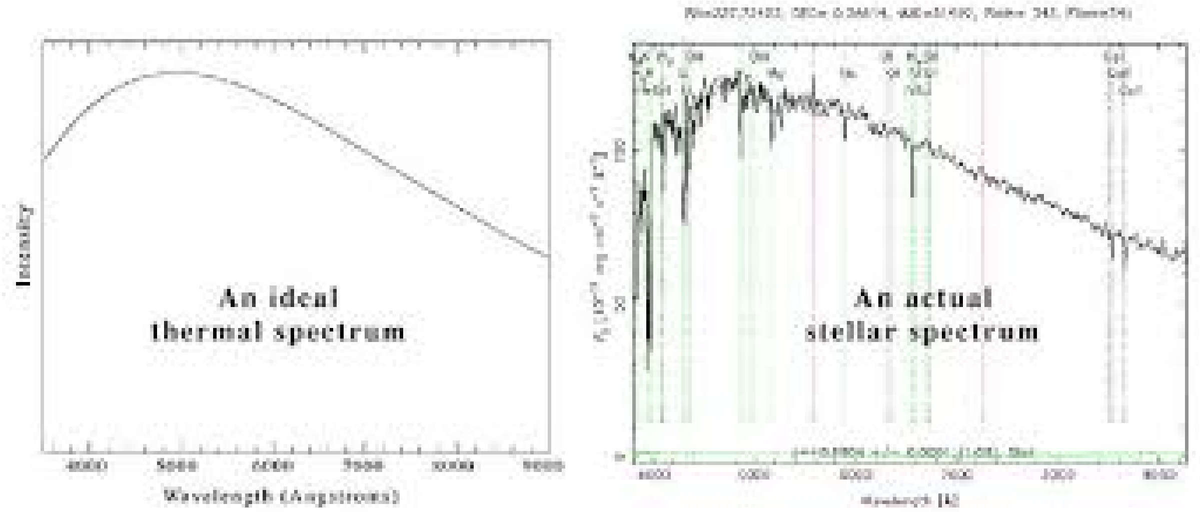
Spectroscopy is the technique of splitting electromagnetic waves into its constituents wavelengths; And this technique when applied to the light we receive from stars can reveal a lot about the stellar chemical compositions, surface temperatures of stars and their luminosities.

The project aimed at analysing the spectral data obtained from the Sloan Sky Digital Survey and plotting the color-color diagram and color-magnitude diagrams for stellar clusters.

Theory

Spectrum of a star:

In the first half of the 19th century the spectra of several different elements were studied and it was well established that each element had characteristics emission lines in its spectrum. During the same time Joseph Fraunhofer observed the dark line(now called the absorption lines) in the spectrum of sun. He went on to observe several other bright stars and discovered that spectra of stars had several similar features in general but certain characteristics were unique to a particular spectrum.



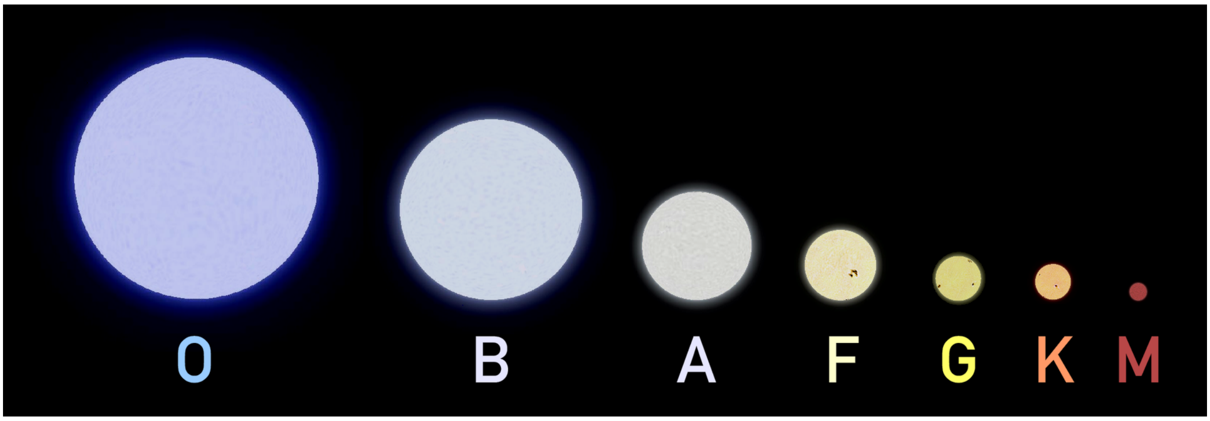
The spectrum of any star contains the information of

- Amount of energy(flux or intensity) it emits at given wavelength or in given wavelength band. The intensity v/s wavelength curve (Thermal Radiation curve) gives the direct estimate of the temperature of the star through Wien's Law ($\lambda_{peak} * T$=constant).
- The absorption and emission lines; The absorption lines in stellar spectrum reveals the chemical composition of any star and can be indirectly applied to infer the spectral type(OBAFGKM) of the star. All the absoption lines corresponds to unique transition of states of electrons in an element and thus indicates the presence of an element.

Spectral types:

Stellar classification is based on the observed surface temperature and the elements present in a star. O,B,A,F,G,K,M are the seven major classes(spectral types) where O type are stars with maximum temperature and M with minimum. L,T classes were also added with recent discoveries.

Each spectral type is further classified into 10 subclasses(A0,A1,A2....). The sequence has been expanded with classes for other stars and star-like objects that do not fit in the classical system, such as class D for white dwarfs and classes S and C for carbon stars. Type C stars, or carbon stars, are unusually rich in carbon. They have a beautiful, deep red color when viewed through a telescope. They appear red because a variety of carbon compounds on their surface absorb most of their blue light.Type L and type T stars are cooler, smaller, and dimmer than type M stars. They are usually very faint and difficult to find, and it's difficult to obtain spectra from them. Type W stars, also known as Wolf-Rayet stars, are as hot as the type O stars, but they have strong emission lines due to clouds of gas surrounding the star. Type S stars are very rare. They are similar to type M stars except with zirconium oxide and lanthanum oxide instead of titanium oxide. Every star's spectrum is unique, much like a human fingerprints.



Characteristics of the spectral types are given below in the figure.

Stars: spectral types

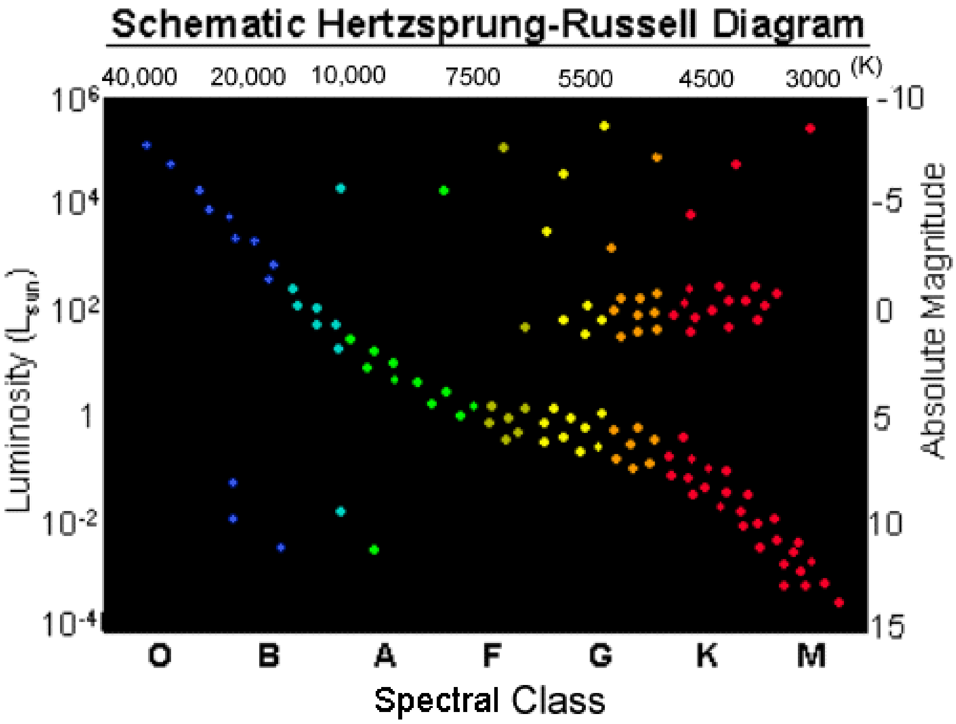
Spectral Type	Colour	Temperature (K) Surface / core	Spectral characteristics
M	Red	3000	Molecular lines (e.g. TiO, vanadium oxide), very strong neutral metal lines
K	Orange	4000	Strong Ca lines, strong neutral metal lines, ± TiO, extremely weak hydrogen lines
G	Yellow	6000	Ca^+ lines strong, ionised metal lines weakening, neutral metal lines weakening, CH strong, hydrogen lines very weak
F	White	8000	Ionised (e.g. Fe^+, Mg^+, Si^+) and neutral metal lines, hydrogen lines weakening
A	White/blue	10 000	Hydrogen lines strong, ionised metal lines strong, weak neutral metal lines
B	Blue/UV	25 000	Strong He lines, strong hydrogen lines, Mg^+ and Si^+ lines
O	Blue/UV	50 000	Strong He^+ lines, weak He and hydrogen Balmer lines, Si^{3+}, O^{2+}, N^{2+} and C^{2+} lines

Spectral Class	Colour	Mass	Radius	Luminosity	Temperature (K)
M	red	0.1	0.1	0.001	3 000
K	orange	0.5	0.3	0.03	4 500
G	yellow	1	1	1	5 500
F	white	1.5	1.2	5.0	7 000
A	white	2.5	2	50	9 000
B	blue	10	5	10 000	17 000
O	blue	40+	20	500 000	40 000

Mass, Radius and Luminosity are given reltive to those of the Sun, which is a yellow G class star. (Mass of the Sun ≡ 1 solar mass ≡ $1M_\odot = 1.99 \times 10^{30}$ kg; radius of the Sun ≡ one solar radius ≡ $1R_\odot = 6.96 \times 108$ m; luminosity of the Sun ≡ one solar luminosity ≡ $1L_\odot = 3.83 \times 10^{26}$ W, where 1 Watt ≡ 1W ≡ 1J/s ≡ $1Js^{-1}$).

Hertzsprung-Russel Diagram:

Very soon after its construction the HR diagram was used as powerful tool to study evolution of stars and hence classification. It represents star according to two observable, luminosity and temperature(or spectral type).



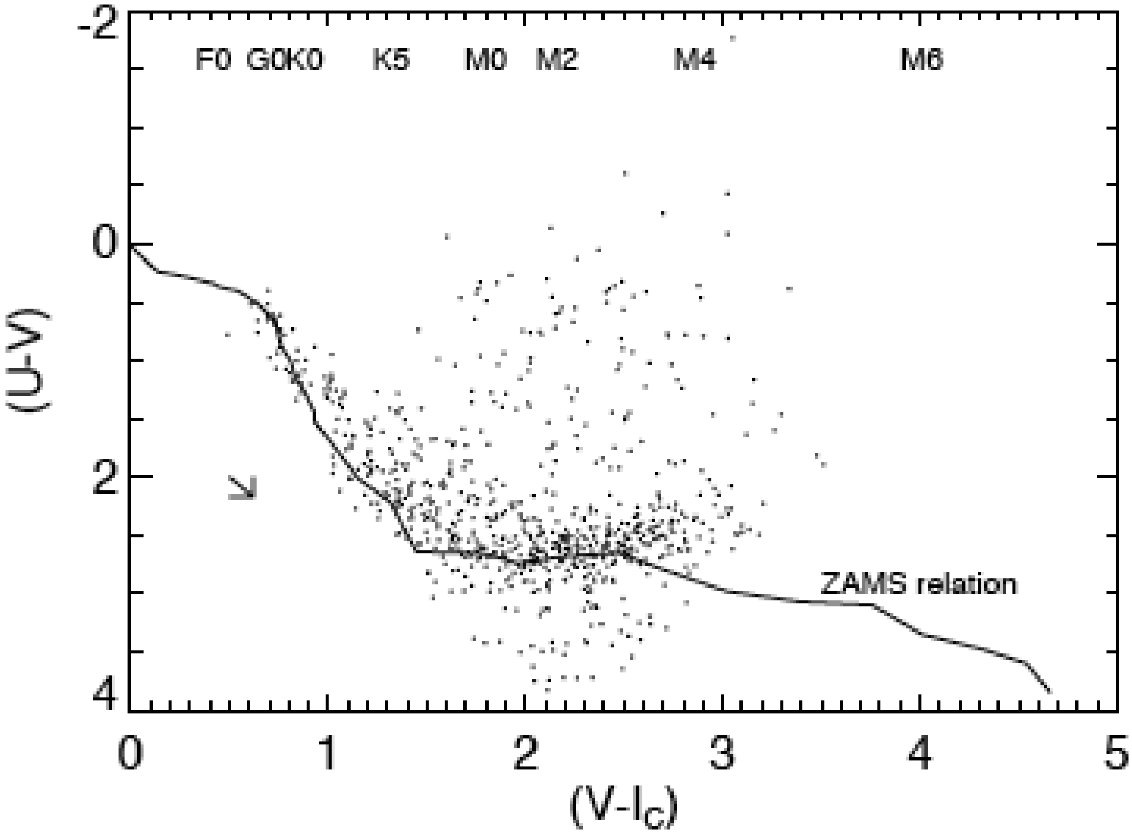
Thermal Radiation Curves:

All bodies above 0 kelvin emits thermal radiation. Spectrum of this radiation(i.e the intensity v/s wavelength distribution) follows the idealized black-body radiation curve. All stars can be approximated to be (non-ideal) black bodies and their radiation curves provide an estimate of the surface temperature.

Color-Color Diagram(CCD):

Color color diagram is a tool that can give you temperature of the star in the case when its spectrum is not available.

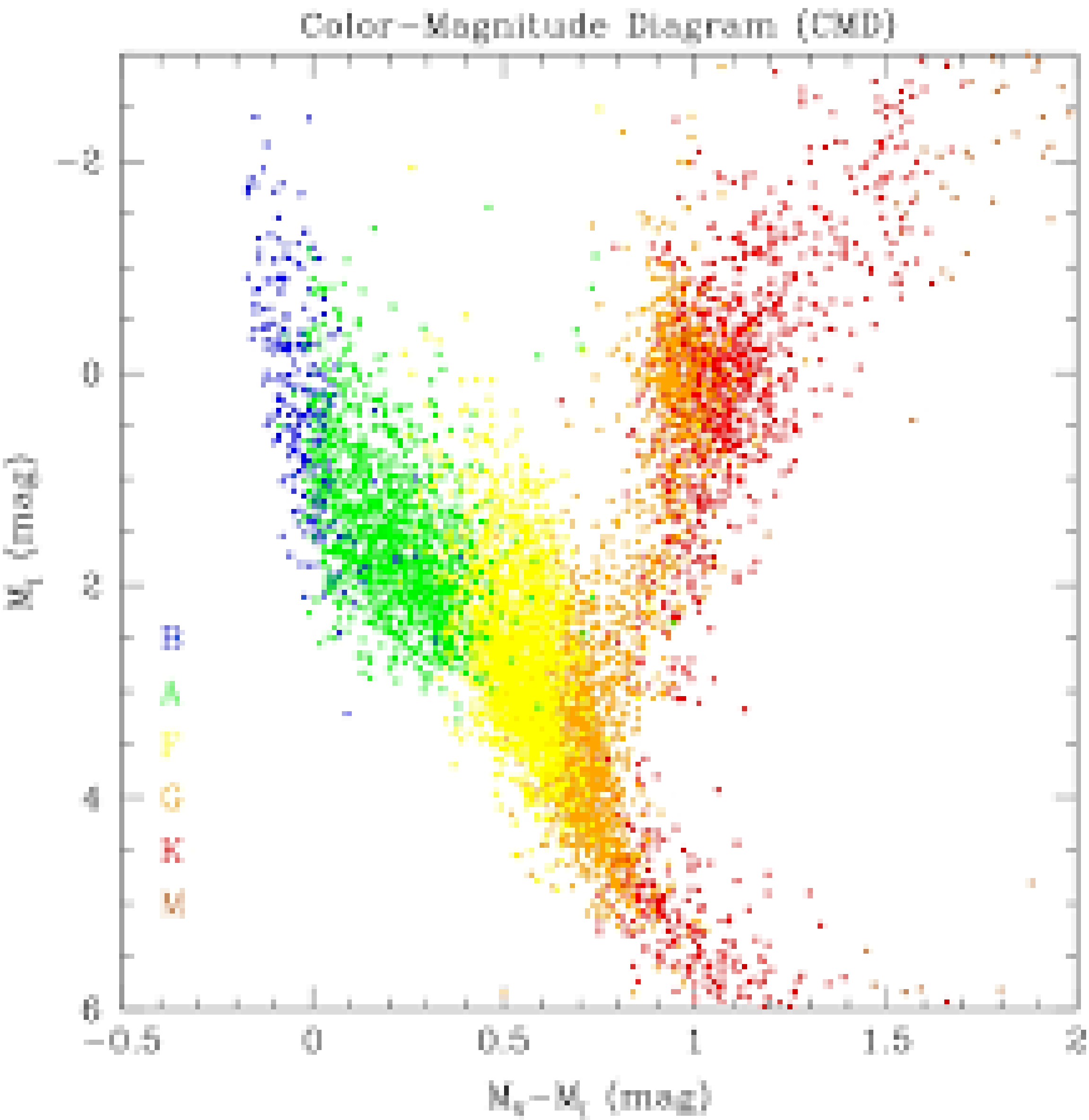
A color is determined by subtracting the magnitude of observed flux in one filter from another (for example if u(ultraviolet) and g(green) are two filters then color is u-g or g-r). The plot of one color against another(example u-g v/s g-r) is the color-color diagram.



The magnitude differences between each color is unique for given temperature, thus by comparing the magnitude of the star in multiple different color indices, the effective surface temperature of the star can be determined.

Color-Magnitude diagrams(CMD)

A color magnitude diagram is a variant of the Hertzsprung-Russell diagram. While the Hertzsprung-Russell (H-R) diagram is a summary of temperatures and magnitudes of individual stars, a color magnitude diagram (CMD) is dedicated to the study of star clusters. The two most common star clusters are globular and open. A globular cluster contains thousands of stars and is considered old in comparison to other clusters. They also tend to organize outside the main disk of a galaxy. Open clusters on the other hand are considered young, and exist within the main disk of a galaxy.The CMD is a plot of observational data which shows how a population of stars can be plotted in terms of their brightness (or luminosity) and colour (or surface temperature). With the help of CMD one can predict the type, temperature etc.



Future Plans:

We are planning to use a software called DS9 to analyze the stars and create an isochrones. Which will help us in the analysis of the temperature and the color of a star.

We are also planning to create our own data base of stars to get better understanding of HR diagrams.

GitHub Link:

To open the link Click here or go to the next url `https://github.com/lalwalamadhav/Spectroscopy`