A Study of Stellar Evolution Using Hertzsprung - Russell Diagram

BHARATA MATA COLLEGE

TRHIKKAKARA

CERTIFICATE

This is to certify that the project report entitled **"A Study of Stellar Evolution Using Hertzsprung - Russell Diagram"** is a bonafide work carried out by **MILAN JOHN**, for the partial fulfilment of the requirement for the award of degree BACHELOR OF SCIENCE IN PHYSICS through the Department of Physics, Bharata Mata College, Thrikkakara, affiliated to Mahatma Gandhi University, Kottayam, Kerala.

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Thrikkakara

DECLARATION

I **MILAN JOHN**, hereby declare that this project report entitled **"A Study of Stellar Evolution Using Hertzsprung - Russell Diagram"** is an authentic work carried out during my course of study under the guidance of Dr. MANESH MICHAEL, Assistant Professor, Department of Physics, Bharata Mata College, Thrikkakara.

MILAN JOHN

DATE:
PLACE: TRIKKAKARA

Acknowledgement

I would like to take this opportunity to thank God Almighty for showering his blessings on me for the successful completion of the review work undertaken by me.

I express my sincere thanks to Dr. Shiny Palatty, Principal, Bharata Mata College, Thrikkakara for her constant encouragement for the completion of this work.

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I feel to acknowledge my indebtedness and deep sense of gratitude to Dr.Manesh Michael, Assistant Professor, Department of Physics and my project guide for immense help and guidance during this review work.

I am also thankful to my team members who had been there with me throughout this review work.

I also acknowledge with a deep sense of reverence, my gratitude towards my family, who has always supported me morally as well as economically.

Contents

1

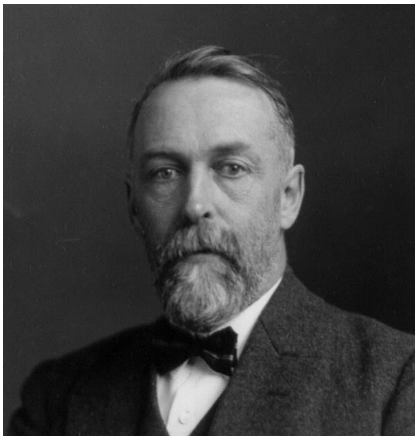
Introduction

One of the key concepts in astronomy is that stars change over time - they're born from clouds of interstellar gas and dust, they shine by their own light created through nuclear fusion of hydrogen in their cores, and eventually they run out of fuel and die, returning some of their mass back to interstellar space. Their remains can then be taken up into new generations of stars, starting the process over again. The process of change that a star undergoes during its lifetime is called stellar evolution. But this process can take millions or billions of years for a star, much longer than we can hope to observe directly. Since we can't observe stellar evolution over long timescales, how do we know it occurs?

There are many pieces of evidence that point toward our current understanding of stellar evolution. One was the understanding of the nuclear physics responsible for why stars shine, and the subsequent realization that stars have a large but finite source of fuel to create heat. Another piece of evidence was the observational study of star clusters - groups of stars all born at the same time and place - and the eventual realization that the properties of star clusters differ depending upon how old they are. Evidence about the physical properties of stars has also come from the study of variable stars.

Every time someone observes a variable star, they're collecting evidence of how the star is behaving. We can build hypotheses of why stars vary, and we can then test these hypotheses with all of the data that has been collected. Each piece of evidence provides a different test, and each test allows us to refine our hypotheses, and make a more accurate description of why stars vary. If we can learn enough about individual stars, we can then begin to learn about classes of variable stars. Eventually we can learn about all stars, variable or not, by putting together all of our models and descriptions of different kinds of stars, and then building a better understanding of what stars are and how they evolve in general.

When we classify stars, we try to use quantitative measurements of their properties, so that we can better understand how stars differ from one another, and why those differences occur. There are a number of physical characteristics of stars that provide important information on the lives of stars. Two quantities, mass and age, are probably most fundamental. The progress of a star's life is predestined by its mass, because ultimately the mass determines how much energy the star can produce and how quickly it will do so. The age of a star tells you how far along it is in its evolution. However, both of these quantities are hard to measure directly. You can sometimes measure the mass if the star is in a binary system, using the straightforward physics of Newton's laws of motion. But there's no scale that you can rest a star on and measure its mass. Likewise you can't tell a star's age directly just by looking at it. Again, you need some roundabout way of finding this out. Two other parameters are a star's luminosity and temperature, and both of these are related to mass and age in a way that we now understand, but like mass and age, deriving these physical parameters requires some extra work to derive.



(a) Ejnar Hertzsprung

(b) Henry Russel

Figure 1.1: Scientists Behind H-R Diagram

Two astronomers of the early 20th Century, Ejnar Hertzsprung and Henry Norris Russell, discovered an important observational means of comparing different stars with one another. In 1911, the Danish astronomer Hertzsprung plotted the absolute magnitude of stars (a measure of their luminosity) against their colours(measure of temperature).Later in 1913,the American astronomer Russel independently plotted spectral types against absolute magnitudes. If we plot these quantities for many individual stars in a diagram , the result is not a random scatter of points, but most stars fall into distinct groups. It is referred to as Hertzsprung-Russel diagam or color magnitude diagram. More observational and theoretical research showed that the Hertzsprung-Russell diagram was a snapshot of the evolutionary states of the stars plotted within the diagram.

2

Stellar Evolution

Stellar evolution is the process by which a star undergoes a sequence of radical changes during its lifetime. Depending on the mass of the star, this lifetime ranges from only a few million years for the most massive to trillions of years for the least massive, which is considerably longer than the age of the universe. The table shows the lifetimes of stars as a function of their masses. All stars are born from collapsing clouds of gas and dust, often called nebulae or molecular clouds. Over the course of millions of years, these protostars settle down into a state of equilibrium, becoming what is known as a main-sequence star.

Nuclear fusion powers a star for most of its life. Initially the energy is generated by the fusion of hydrogen atoms at the core of the main-sequence star. Later, as the preponderance of atoms at the core becomes helium, stars like the Sun begin to fuse hydrogen along a spherical shell surrounding the core. This process causes the star to gradually grow in size, passing through the subgiant stage until it reaches the red giant phase. Stars with at least half the mass of the Sun can also begin to generate energy through the fusion of helium at their core, whereas more massive stars can fuse heavier elements along a series of concentric shells. Once a star like the Sun has exhausted its nuclear fuel, its core collapses into a dense white dwarf and the outer layers are expelled as a planetary nebula. Stars with around ten or more times the mass of the Sun can explode in a supernova as their inert iron cores collapse into an extremely dense neutron star or black hole. Although the universe is not old enough for any of the smallest red dwarfs to have reached the end of their lives, stellar models suggest they will slowly become brighter and hotter before running out of hydrogen fuel and becoming low-mass white dwarfs.

BIRTH OF A STAR

Protostar:

Stellar evolution begins with the gravitational collapse of a giant molecular cloud. Typical giant molecular clouds are roughly 100 light-years (9.5×1014 km) across and contain up to 6,000,000 solar masses (1.2×1037 kg). As it collapses, a giant molecular cloud breaks into smaller and smaller pieces. In each of these fragments, the collapsing gas releases gravitational potential energy as heat. As its temperature and pressure increase, a fragment condenses into a rotating sphere of superhot gas known as a protostar. Brown dwarfs and sub-stellar objects.

Protostars with masses less than roughly 0.08 M (1.6×1029 kg) never reach temperatures high enough for nuclear fusion of hydrogen to begin. These are known as brown dwarfs. The International Astronomical Union defines brown dwarfs as stars massive enough to fuse deuterium at some point in their lives (13 Jupiter masses, 2.5 × 1028 kg, or 0.0125 solar masses). Objects smaller than 13 Jupiter masses are classified as sub-brown dwarfs (but if they orbit around another stellar object they are classified as planets).Both types, deuterium-burning and not, shine dimly and die away slowly, cooling gradually over hundreds of millions of years.

Hydrogen fusion:

Figure 2.1: A dense starfield in Sagittarius

For a more massive protostar, the core temperature will eventually reach 10 million kelvin, initiating the proton-proton chain reaction and allowing hydrogen to fuse, first to deuterium and then to helium. In stars of slightly over 1 M (2.0×1030 kg), the carbon–nitrogen–oxygen fusion reaction (CNO cycle) contributes a large portion of the energy generation. The onset of nuclear fusion leads relatively quickly to a hydrostatic equilibrium in which energy released by the core exerts a "radiation pressure" balancing the weight of the star's matter, preventing further gravitational collapse. The star thus evolves rapidly to a stable state, beginning the main-sequence phase of its evolution.

A new star will sit at a specific point on the main sequence of the Hertzsprung–Russell diagram, with the main-sequence spectral type depending upon the mass of the star. Small, relatively cold, low-mass red dwarfs fuse hydrogen slowly and will remain on the main sequence for hundreds of billions of years or longer, whereas massive, hot supergiants will leave the main sequence after just a few million years. A mid-sized star like the Sun will remain on the main sequence for about 10 billion years. The Sun is thought to be in the middle of its lifespan; thus, it is currently on the main sequence.

The graph below illustrates the evolutionary tracks of stars with different initial masses

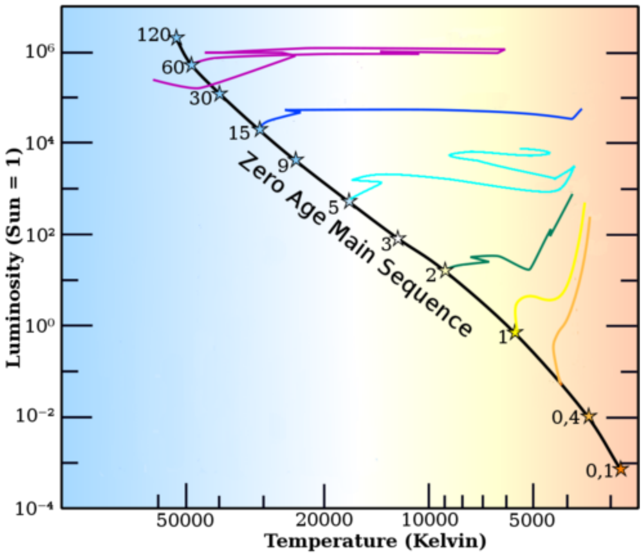


Figure 2.2: H-R Diagram

on the Hertzsprung–Russell diagram. The tracks start once the star has evolved to the main sequence and stop when fusion stops.

A yellow track is shown for the Sun, which will become a red giant after its main-sequence phase ends before expanding further along the asymptotic giant branch, which will be the last phase in which the Sun undergoes fusion.

Eventually the core exhausts its supply of hydrogen and the star begins to evolve off of the main sequence. Without the outward pressure generated by the fusion of hydrogen to counteract the force of gravity the core contracts until either electron degeneracy becomes sufficient to oppose gravity or the core becomes hot enough (around 100 MK) for helium fusion to begin. Which of these happens first depends upon the star's mass.

Low-mass stars:

What happens after a low-mass star ceases to produce energy through fusion has not been directly observed; the universe is thought to be around 13.8 billion years old, which is less time (by several orders of magnitude, in some cases) than it takes for fusion to cease in such stars.

Mid-sized stars:

Stars of roughly 0.5–10 solar masses become red giants, which are large non-main-sequence stars of stellar classification K or M. Red giants lie along the right edge of the Hertzsprung–Russell diagram due to their red color and large luminosity. Examples include Aldebaran in the constellation Taurus and Arcturus in the constellation of Boötes. Red giants all have inert cores with hydrogen-burning shells: concentric layers atop the core that are still fusing hydrogen into helium. Mid-sized stars are red giants during two different phases of their post-main-sequence evolution: red-giant-branch stars, whose inert cores are made of helium, and asymptotic-giant-branch stars, whose inert cores are made of carbon.

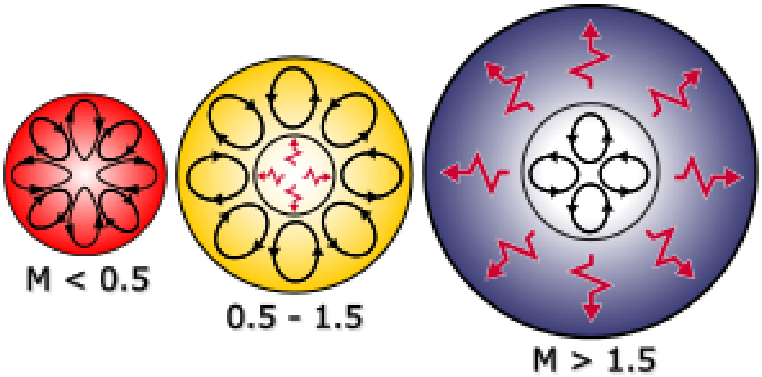


Figure 2.3

Internal structures of main-sequence stars, convection zones with arrowed cycles and radiative zones with red flashes. To the left a low-mass red dwarf, in the center a mid-sized yellow dwarf and at the right a massive blue-white main-sequence star.

Figure 2.4: The Cat's Eye Nebula, a planetary nebula formed by the death of a star with about the same mass as the Sun

Red-giant-branch phase:

The red-giant-branch phase of a star's life follows the main sequence. Initially, the cores of red-giant-branch stars collapse, as the internal pressure of the core is insufficient to balance gravity. This gravitational collapse releases energy, heating concentric shells immediately outside the inert helium core so that hydrogen fusion continues in these shells. The core of a red-giant-branch star of up to a few solar masses stops collapsing when it is dense enough to be supported by electron degeneracy pressure. Once this occurs, the core reaches hydrostatic equilibrium: the electron degeneracy pressure is sufficient to balance gravitational pressure.The core's gravity compresses the hydrogen in the layer immediately above it, causing it to fuse faster than hydrogen would fuse in a main-sequence star of the same mass. This in turn causes the star to become more luminous (from 1,000–10,000 times brighter) and expand; the degree of expansion outstrips the increase in luminosity, causing the effective temperature to decrease.

Asymptotic-giant-branch phase:

After a star has consumed the helium at the core, fusion continues in a shell around a hot core of carbon and oxygen. The star follows the asymptotic giant branch on the Hertzsprung–Russell diagram, paralleling the original red giant evolution, but with even faster energy generation (which lasts for a shorter time).Although helium is being burnt in a shell, the majority of the energy is produced by hydrogen burning in a shell closer to the surface of the star. Helium from these hydrogen burning shells drops towards the center of the star and periodically the energy output from the helium shell increases dramatically. This is known as a thermal pulse and they occur towards the end of the asymptotic-giant-branch phase, sometimes even into the post-asymptotic-giant-branch phase. Depending on mass and composition, there may be several to hundreds of thermal pulses.

Massive stars:

In massive stars, the core is already large enough at the onset of the hydrogen burning shell that helium ignition will occur before electron degeneracy pressure has a chance to become prevalent. Thus, when these stars expand and cool, they do not brighten as much as lower-mass stars; however, they were much brighter than lower-mass stars to begin with, and are thus still brighter than the red giants formed from less massive stars. These stars are unlikely to survive as red supergiants; instead they will destroy themselves as type II supernovas.

Supernova:

Once the nucleosynthesis process arrives at iron-56, the continuation of this process consumes energy (the addition of fragments to nuclei releases less energy than required to break them off the parent nuclei). If the mass of the core exceeds the Chandrasekhar limit, electron degeneracy pressure will be unable to support its weight against the force of gravity, and the core will undergo sudden, catastrophic collapse to form a neutron star or (in the case of cores that exceed the Tolman-Oppenheimer-Volkoff limit), a black hole. Through a process that is not completely understood, some of the gravitational potential energy released by this core collapse is converted into a Type Ib, Type Ic, or Type II supernova. It is known that the core collapse produces a massive surge of neutrinos, as observed with supernova SN 1987A. The extremely energetic neutrinos fragment some nuclei; some of their energy is consumed in

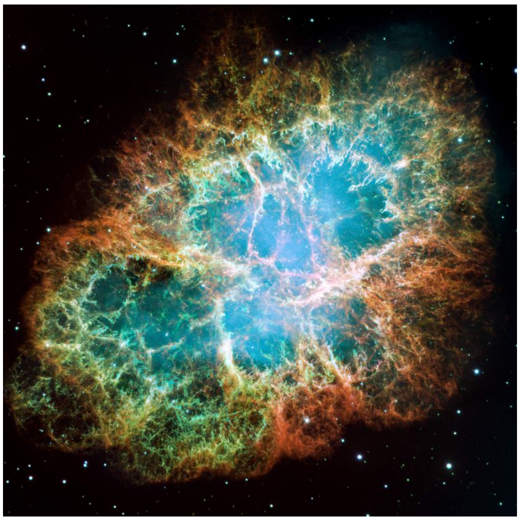


Figure 2.5: The Crab Nebula, the shattered remnants of a star which exploded as a supernova, the light of which reached Earth in 1054 AD

releasing nucleons, including neutrons, and some of their energy is transformed into heat and kinetic energy, thus augmenting the shock wave started by rebound of some of the infalling material from the collapse of the core.

Stellar remnants:

After a star has burned out its fuel supply, its remnants can take one of three forms, depending on the mass during its lifetime.

White dwarfs:

For a star of 1 solar mass, the resulting white dwarf is of about 0.6 solar mass, compressed into approximately the volume of the Earth. White dwarfs are stable because the inward pull of gravity is balanced by the degeneracy pressure of the star's electrons, a consequence of the Pauli exclusion principle. Electron degeneracy pressure provides a rather soft limit against further compression; therefore, for a given chemical composition, white dwarfs of higher mass have a smaller volume. With no fuel left to burn, the star radiates its remaining heat into space for billions of years. A white dwarf is very hot when it first forms, more than 100,000 K at the surface and even hotter in its interior. It is so hot that a lot of its energy is lost in the form of neutrinos for the first 10 million years of its existence, but will have lost most of its energy after a billion years. The chemical composition of the white dwarf depends upon its mass. A star of a few solar masses will ignite carbon fusion to form magnesium, neon, and smaller amounts of other elements, resulting in a white dwarf composed chiefly of oxygen, neon, and magnesium, provided that it can lose enough mass to get below the Chandrasekhar limit (see below), and provided that the ignition of carbon is not so violent as to blow the star apart in a supernova.A star of mass on the order of magnitude of the Sun will be unable to ignite carbon fusion, and will produce a white dwarf composed chiefly of carbon and oxygen, and of mass too low to collapse unless matter is added to it later (see below). A star of less than about half the mass of the Sun will be unable to ignite helium fusion (as noted earlier), and will produce a white dwarf composed chiefly of helium. In the end, all that remains is a cold dark mass sometimes called a black dwarf. However, the universe is not old enough for any black dwarfs to exist yet.

Neutron stars:

Figure 2.6: Bubble-like shock wave still expanding from a supernova explosion 15,000 years ago.

When a stellar core collapses, the pressure causes electron capture, thus converting the great majority of the protons into neutrons. The electromagnetic forces keeping separate nuclei apart are gone (proportionally, if nuclei were the size of dust mites, atoms would be as large as football stadiums), and most of the core of the star becomes a dense ball of contiguous neutrons (in some ways like a giant atomic nucleus), with a thin overlying layer of degenerate matter (chiefly iron unless matter of different composition is added later). The neutrons resist further compression by the Pauli Exclusion Principle, in a way analogous to electron degeneracy pressure, but stronger. These stars, known as neutron stars, are extremely small—on the order of radius 10 km, no bigger than the size of a large city—and are phenomenally dense. Their period of rotation shortens dramatically as the stars shrink (due to conservation of angular momentum); observed rotational periods of neutron stars range from about 1.5 milliseconds (over 600 revolutions per second) to several seconds.When these rapidly rotating stars' magnetic poles are aligned with the Earth, we detect a pulse of radiation each revolution. Such neutron stars are called pulsars, and were the first neutron stars to be discovered. Though electromagnetic radiation detected from pulsars is most often in the form of radio waves, pulsars have also been detected at visible, X-ray, and gamma ray wavelengths.

Black holes:

Figure 2.7: First ever picture of a black hole

If the mass of the stellar remnant is high enough, the neutron degeneracy pressure will be insufficient to prevent collapse below the Schwarzschild radius. The stellar remnant thus becomes a black hole. The mass at which this occurs is not known with certainty, but is currently estimated at between 2 and 3 solar masses. Black holes are predicted by the theory of general relativity. According to classical general relativity, no matter or information can flow from the interior of a black hole to an outside observer, although quantum effects may allow deviations from this strict rule. The existence of black holes in the universe is well supported, both theoretically and by astronomical observation.

3

H-R Diagram

One of the most useful and powerful plots in astrophysics is the Hertzsprung-Russell diagram (H-R diagram). It originated in 1911 when the Danish astronomer, Ejnar Hertzsprung, plotted the absolute magnitude of stars against their colour (hence effective temperature). Independently in 1913 the American astronomer Henry Norris Russell used spectral class (surface temperature) against absolute magnitude (stellar luminosity).The plot is with luminosity on the vertical axis and surface temperature on the horizontal axis . Their resultant plots showed that the relationship between temperature and luminosity of a star was not random but instead appeared to fall into distinct groups. More specifically saying it shows a group of stars in various stages of their evolution.

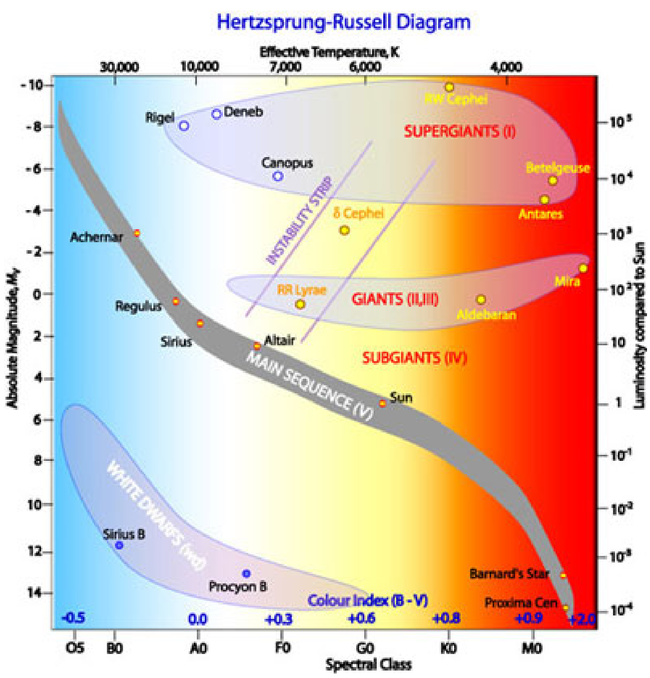


Figure 3.1: Hertzprung-Russell Diagram

The key features of H R diagram are:

- Because luminosity increases upward in the diagram and surface temperature increases leftward, stars near the upper left corner are hot and luminous. Similarly, stars near the upper right corner are cool and luminous; stars near the lower right corner are cool and dim; and stars near the lower left corner are hot and dim.

- Several regions of the HR diagram have been given names, although stars can occupy any portion. The brightest stars are called supergiants. Stars just off the main sequence called red giants. Main sequence stars are called dwarfs. The faint and hot stars are called white dwarfs.

Main Sequence : The band that stretches diagonally across the H-R diagram is called the main sequence.

- It extends from the top left corner of the diagram to the bottom right corner, with blue stars on the upper left corner of the sequence and red stars on the lower right corner.
- Stars that fall on this diagonal band are called main sequence stars. This is the longest lived stage in the life of any star. Stars spend 90% of their lifetime in this phase.
- Normal hydrogen burning stars reside on the main sequence of the H-R diagram.
- Sun is located in the main sequence(temperature 5400K).
- Stars in the upper right are called giants (named so because of their big size).
- At the extreme upper right corner are a few stars that are even bigger than the giants. These are the supergiants, which have radii up to 1000 Rsun. Examples : Antaresin Scorpius and Betelgeuse in Orion
- Stars between giants and the main sequence are called subgiants.
- Above and to the right of main sequence, stars with high luminosities are called red giants. They are called giant stars because they have expanded considerably from their original size and, in doing so, their surfaces have cooled and therefore changed in colour to slightly red.
- The blue giant stars lie above and to the right of the main sequence. They are rarer than red giants, because they develop from more massive and less common stars, and they have short lives in blue giant stage.
- At the lower left, stars of much smaller radius appear white. These are the white dwarf stars, They are hot stars with low luminosities; therefore, they must be small and hence the name dwarf stars. They are approximately the same size as the earth. White dwarfs account for about 9% of stars in the night sky. A well-known example is Sirius B, the companion of Sirius.

- The approximate relationship between luminosity L and mass M for main sequence stars is described by the following equation:

$$L \propto M^{3.5}$$

USE OF H-R DIAGRAMS

- The H-R diagram directly provides important information about the radius of stars, because the luminosity of a star depends on both its surface temperature and surface area or radius.
- They quickly tell us which kind of a star is (giant or dwarf).
- They also reveal the mass, age and life-span of the star.
- The distance to a star using H-R diagram can be calculated using the following relation :

$$d = \sqrt{L}/4\pi b$$

where L is the luminosity and b brightness of a star.

4

Plotting of H-R Diagram

Hertzsprung-Russell diagram can be visualised by plotting Absolute magnitude against Tenperature or Color. The following H-R Diagram includes data from 2720 stars. The dataset include HIP number, Absolute Magnitude (Vmag), Right Ascension (RE), Declination (DE), Parallactic Angle (plx), Proper Motion Right Ascension (pmRE), Proper Motion Declination (pmDE) and B-V Color Index. H-R Diagram is obtained by plotting Vmag against B-V from the following dataset.

Stars Dataset:

	HIP	Vmag	RA	DE	Plx	pmRA	pmDE	e_Plx	B-V
1	2	9.27	0.003797	-19.498837	21.9	181.21	-0.93	3.1	0.999
2	38	8.65	0.111047	-79.061831	23.84	162.3	-62.4	0.78	0.778
3	47	10.78	0.135192	-56.835248	24.45	-44.21	-145.9	1.97	1.15
4	54	10.57	0.151656	17.968956	20.97	367.14	-19.49	1.71	1.03
5	74	9.93	0.221873	35.752722	24.22	157.73	-40.31	1.36	1.068
6	81	8.57	0.243864	-4.932115	23.43	-184.7	-172.67	1.28	0.642
7	110	8.61	0.348708	39.610818	20.42	-29.92	-41.34	1.91	0.787
8	135	8.64	0.426746	-0.217499	20.1	20.73	-114.08	1.22	0.62
9	143	10.35	0.455182	21.462138	20.05	177.97	150.19	1.64	1.033
10	149	11.26	0.478685	26.005577	22.92	-309.64	-628.61	2.17	0.932
11	191	12.43	0.612287	-46.028841	22.98	192.39	-22.43	4.38	1.49
12	223	7.17	0.696411	2.130376	21.58	62.25	-91.23	1.65	0.617
13	305	7.66	0.972063	-28.393769	20.44	88.62	-17.68	0.96	0.741
14	350	10.37	1.099309	-57.322875	21.14	-36.89	74.23	1.62	1.1
15	351	9.8	1.102623	-47.06813	22.52	293.22	33.72	1.48	0.855
16	407	8.13	1.244275	-70.212207	22.09	52.32	-97.72	0.71	0.71
17	420	7.53	1.281668	-52.151423	23.9	-110.55	-130.74	0.85	0.577
18	460	9.13	1.369764	22.224675	22.2	169.54	-75.17	1.14	0.735
19	475	8.22	1.423333	58.313656	21.03	65.98	-162.94	1.06	0.636

Plotting HR-Diagram using Python Libraries

[1]:
```
#importing essential libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

[2]:
```
#importing data from a csv file
stardata = pd.read_csv('stardata.csv')
```

[3]:
```
#droping null values
stardata = stardata.dropna()
```

[4]:
```
#shape of the data
stardata.shape
```

[4]: (2678, 9)

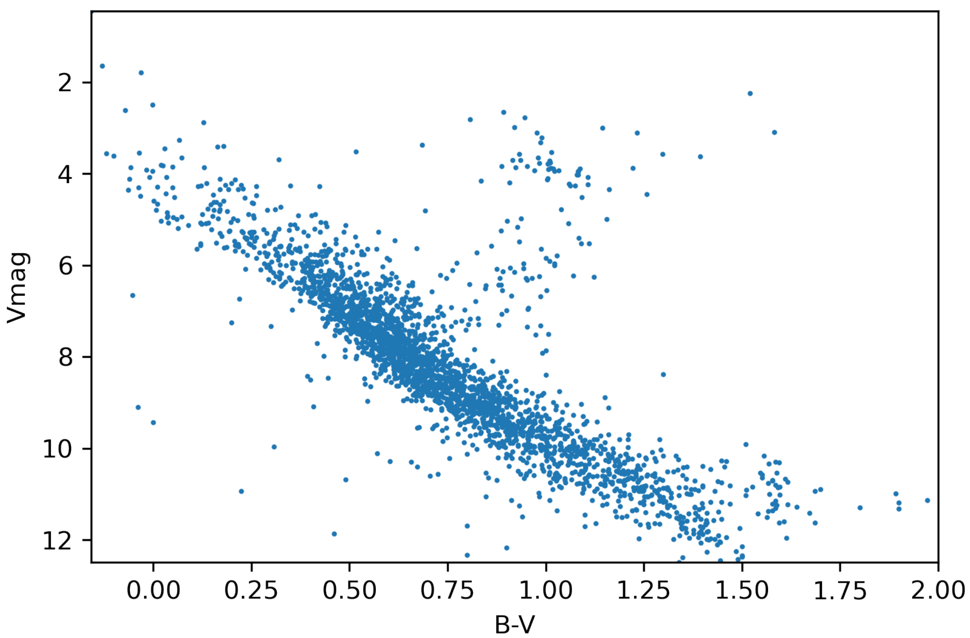
[5]:
```
#first 20 rows of data
stardata.head(20)
```

[5]:

	HIP	Vmag	RA	DE	Plx	pmRA	pmDE	e_Plx	B-V
0	2	9.27	0.003797	-19.498837	21.90	181.21	-0.93	3.10	0.999
1	38	8.65	0.111047	-79.061831	23.84	162.30	-62.40	0.78	0.778
2	47	10.78	0.135192	-56.835248	24.45	-44.21	-145.90	1.97	1.150
3	54	10.57	0.151656	17.968956	20.97	367.14	-19.49	1.71	1.030
4	74	9.93	0.221873	35.752722	24.22	157.73	-40.31	1.36	1.068
5	81	8.57	0.243864	-4.932115	23.43	-184.70	-172.67	1.28	0.642
6	110	8.61	0.348708	39.610818	20.42	-29.92	-41.34	1.91	0.787
7	135	8.64	0.426746	-0.217499	20.10	20.73	-114.08	1.22	0.620
8	143	10.35	0.455182	21.462138	20.05	177.97	150.19	1.64	1.033
9	149	11.26	0.478685	26.005577	22.92	-309.64	-628.61	2.17	0.932
10	191	12.43	0.612287	-46.028841	22.98	192.39	-22.43	4.38	1.490
11	223	7.17	0.696411	2.130376	21.58	62.25	-91.23	1.65	0.617
12	305	7.66	0.972063	-28.393769	20.44	88.62	-17.68	0.96	0.741
13	350	10.37	1.099309	-57.322875	21.14	-36.89	74.23	1.62	1.100

14	351	9.80	1.102623	-47.068130	22.52	293.22	33.72	1.48	0.855
15	407	8.13	1.244275	-70.212207	22.09	52.32	-97.72	0.71	0.710
16	420	7.53	1.281668	-52.151423	23.90	-110.55	-130.74	0.85	0.577
17	460	9.13	1.369764	22.224675	22.20	169.54	-75.17	1.14	0.735
18	475	8.22	1.423333	58.313656	21.03	65.98	-162.94	1.06	0.636
19	490	7.51	1.468617	-41.752882	24.85	97.62	-76.40	0.92	0.595

[6]:
```
#ploting graph using matplotlib library
x = stardata.iloc[:,8].values
y = stardata.iloc[:,1].values
fig = plt.figure()
ax = fig.add_subplot(111)
ax.set_xlabel('B-V')
ax.set_ylabel('Vmag')
plt.scatter(x,y,s=1) # marker size
plt.ylim([y.min(axis=0),y.max(axis=0)]) # x-axis range
plt.xlim([x.min(axis=0),2]) # x-axis range
plt.gca().invert_yaxis()  # y-axis reversed
plt.figure(dpi=300)
plt.show()
```



5

Conclusion

Through our theoretical study on stellar evolution, we have looked into the various stages of a star starting from its birth till it becomes a black hole. We have briefly explained the processes occurring in each stage of the evolution. In particular, we analysed the characteristics of different stars in detail and hence plotted the Hertzsprung- Russell diagram. The characteristic curve of the HR diagram was obtained using the data collected, thereby graphically illustrating the difference in characteristics of a star at various stages in its lifetime. We then discussed its key features and also its applications in astronomy and astrophysics.

6

References

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