Contents

1 Introduction

"We are made of star-stuff. Our bodies are made of star-stuff. There are pieces of star within us all"
- Carl Sagan

People have wondered about the twinkling little stars since they have started looking at the night sky. Stars have been a source of inspiration and wonder for people throughout history. They have been used to navigate, to tell stories, and to inspire art and poetry. The study of stars has a long history, dating back to ancient civilizations. The Babylonians, for example, made systematic astronomical observations as early as 1000 BCE.

Stars are the most widely recognised astronomical objects and represent the most fundamental building blocks of galaxies. The age, distribution, and composition of the stars in a galaxy trace the history, dynamics, and evolution of that galaxy. Consequently, the study of the birth, life, and death of stars is central to the field of astronomy. From understanding that our sun is also a star to understanding the stellar properties of various stars, we have come a long way in astronomical research. The telescopes, now, allow us to look farther into the night sky and find more and more interesting celestial bodies.

In this project, we first look at the basic principles of astronomy like the astronomical coordinate systems and types of telescopes. We learn about the life cycle of stars ; how the stars are born, how different types of stars transform as they reach their end, and how they finally die. It is interesting to know that the death of a star depends on its mass. This also gives an insight on how our sun might die in the future.

In science, research reports are very important for any study. They provide the gist of the he study while also shedding light on the findings in the research. To have an idea on how that is done, we also did research on a topic of interest in astronomy, gave talks on them and submitted a report in LATEX. Coming back to the stars, we learn their stellar properties and how they are classified based on them. There are different mathematical and technical tools that we use in the studies of science. A such useful tool is Matlab. Hence, the basics of Matlab are learnt and used to plot HR diagrams, which is luminosity vs temperature, of various stars.

We then turn to the instruments used to scour the sky – telescopes. We learn the workings of telescope as we visited the OAAR and we set up a telescope and observed the moon through it. Then, we chose a planet – Kepler-452b and a star – Betelgeuse as case studies. We present those two case studies here.

2 Astronomical Coordinate System

Astronomical coordinate systems are organised arrangements for specifying positions of various celestial objects relative to physical reference points available to a situated observer. In the case of an observer on earth's surface, the reference points are the true horizon and the north pole. Astronomical coordinate systems are, generally, spherical coordinate systems, projected on the celestial sphere. These are analogous to the geographical coordinate system used on the surface of the earth.

2.1 Equatorial coordinate system

The equatorial coordinate system is expressed in spherical coordinates with the origin as the centre of the earth. The coordinate system is aligned with the earth's equator and pole. It does not rotate with the earth, but remains relatively fixed against the background stars. Hence, the coordinates are known to be geocentric. The Celestial equator is the projection of earth's equator onto the celestial sphere. The two coordinates that are used in this coordinate system are right ascension and declination.

- Right Ascension : the angular distance of a celestial body eastward along the celestial equator. It is measured from the Sun at the March equinox. March equinox is the place on the celestial sphere where the sun crosses the celestial equator from south to north at the March equinox. It is denoted by the symbol "alpha". It is analogous to longitude in earth's coordinate system.
- Declination : the angular distance of a celestial body perpendicular to the celestial equator, positive to the north and negative to the south. It is analogous to the latitude in the earth's coordinate system. Celestial equator has a declination of zero degrees while the north celestial pole and south celestial pole have +90 degrees and -90 degrees, respectively. It is denoted by the symbol, delta.

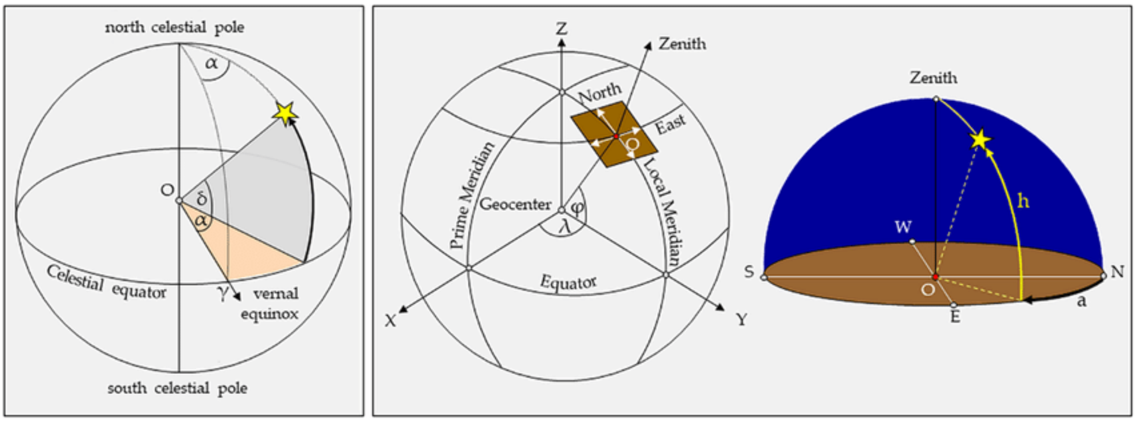

Figure 1: (a) Equatorial coordinate system: right ascension α and declination δ as seen from outside the celestial sphere; (b) horizontal system: the coordinates of a celestial body are expressed in terms of the elevation angle h and azimuth a, which depend on the position of the observer O on Earth.

2.2 Alt-az coordinate system

Alt-Az coordinate system, also known as the horizontal coordinate system, is a coordinate system that uses the observer's local horizon as the fundamental plane. Altitude and azimuth are the two celestial coordinates used in this system. The coordinate system is fixed to a location on earth, not the stars. Therefore, the altitude and azimuth of a celestial body change with the observation place and time.

- Altitude/elevation : The angle between the celestial body and the observer's local horizon is known as altitude. It ranges from 0 degrees to 90 degrees.
- Azimuth : the angle of the object around the horizon, measured from true north and increasing eastward is known as azimuth. It is measured either in the positive range 0 to 360 degrees or in the range -180 to +180 degrees.

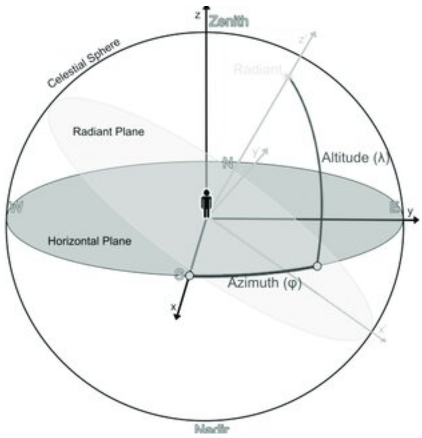

Figure 2: The Radiant, or Alt-Az Coordinate System, which is obtained from two successive rotations of the Horizontal Coordinate System.

3 Telescopes

The optical instruments used to obtain images of distant objects.
Components of telescopes:

1. Telescope – to collect light
2. An instrument to sort incoming radiation by wavelength as per need.
3. A detector to record the observations.

Parts of a telescope:

1. Minimum 2 lenses/mirrors.
2. Eyepieces of varying sizes are used.

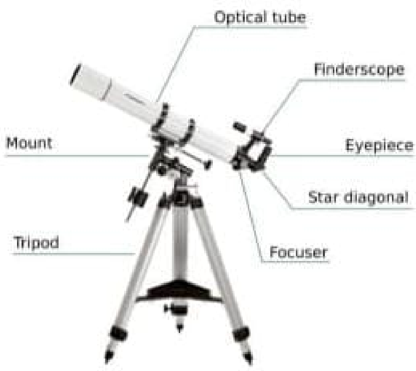

Figure 3: Parts of Telescope

Types of telescopes:

1. Refracting telescopes – using lenses
2. Reflecting telescopes – using mirrors
3. Catadioptric telescopes – combination of mirror and lenses
4. Radio telescopes – consists of a concave metal reflector (called a dish), analogous to a telescope mirror. Radio waves collected by the dish are reflected to a focus, where they can be directed to a receiver and analysed.

4 Cycle of stars

The life cycle of stars can be broadly divided into several stages, which vary based on the mass of the star. Here's a summary of the life cycle of stars:

I. **Nebula:** Stars are born in vast clouds of gas and dust called nebulae. These nebulae can be triggered to collapse under gravity by shockwaves from nearby supernovae or other disturbances.

II. **Protostar:** As the nebula contracts, it forms a dense core called a protostar. This protostar is not yet undergoing nuclear fusion but is gradually heating up and growing more massive.

III. **Main Sequence:** When the core temperature of the protostar reaches about 15 million degrees Celsius and nuclear fusion ignites.Here, hydrogen nuclei fuse to form helium in the star's core, releasing massive amounts of energy and creating an outward force and this is balanced by the inward force of gravity. This phase is called the main sequence phase and a star stays in this phase for most of its lifetime.

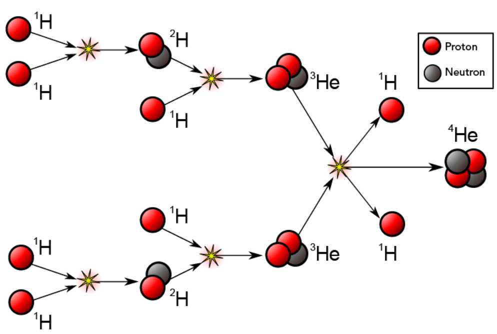

Figure 4: PP Chain stands, or Proton-Proton chain. In this reaction, 4 hydrogen nuclei combine to form 1 helium nucleus.

Once the Hydrogen runs out, Helium starts to fuse to make Beryllium and this makes the star swell in size. In this phase, low to intermediate-mass stars($0.6 - 10\,\mathrm{M}_{\odot}$) become **Red Giants**. High-mass stars($10\mathrm{M}_{\odot}$)can become even larger, becoming **Red Supergiants**. These stars start fusing helium and other heavier elements in their cores.

After this the fate of the star depends on its mass.

- Low to Intermediate Mass Stars($< 8\mathrm{M}_{\odot}$)-

Here the fusion of elements stops at Carbon as the heat and pressure is not enough for carbon to undergo furhte fusion.

IV. **Planetary Nebula :** The outer layers of the red giant are ejected into space, forming an expanding shell of gas and dust known as a planetary nebula. The core left behind is a white dwarf, a dense and hot remnant of the star's core.

V. **White Dwarf:** A low to intermediate-mass star's core becomes a white dwarf after shedding its outer layers. White dwarfs are very dense and no longer undergo nuclear fusion. Since there is no internal pressure to prevent the collapse, the atoms in this body come so close together that all the energy levels gets filled up with electrons and any further collapse must violate **Pauli's Exclusion Principle**. This type of matter is said to be "degenerate" and the internal pressure supporting the core is known as "Electron Degeneracy Pressure".

The maximum mass of a remnant core becoming White Dwarf can be $1.4M_{\odot}$. This is called as the **Chandrashekhar Limit**.

- High Mass Stars($> 8M_{\odot}$) -

The fusion of elements stops at Iron. This is because of the highest binding energy of its nucleons making its fusion to heavier elements an endothermic process.

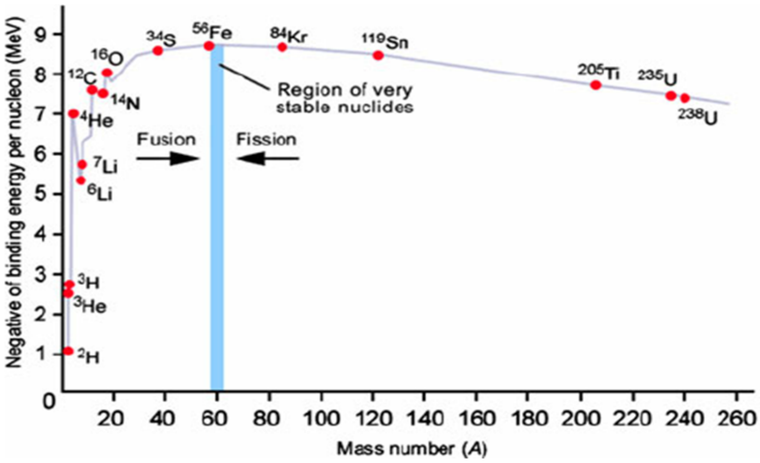

Figure 5: Binding energy Curve

VI. **Supernova :** High-mass stars eventually exhaust their nuclear fuel and undergo a catastrophic explosion called a supernova. During this explosion, elements heavier than iron are formed and scattered into space.

Depending on the remaining mass after the supernova explosion, the core may become a neutron star or a blackhole.

VIII. **Neutron Star:** A Neutron star is one of the densest objects in the universe. The high mass of the remnant core enables the contracting force to overcome "Electron Degeneracy pressure" and the electrons and protons combine via "Electron capture" to form a body almost entirely made up of neutrons. it retains most of its angular momentum. But, because it has only a tiny fraction of its parent's radius (sharply reducing its moment of inertia), a neutron star is formed with very high rotation speed.

Some neutron stars spin rapidly producing powerful magnetic fields. These are called Pulsars.

XI. **Blackholes:** Blackholes are formed when a star of mass greater than 8 solar mass collapses due to its own gravity after the completion of its nuclear fuel. They are so dense that even light cannot escape once it enters.

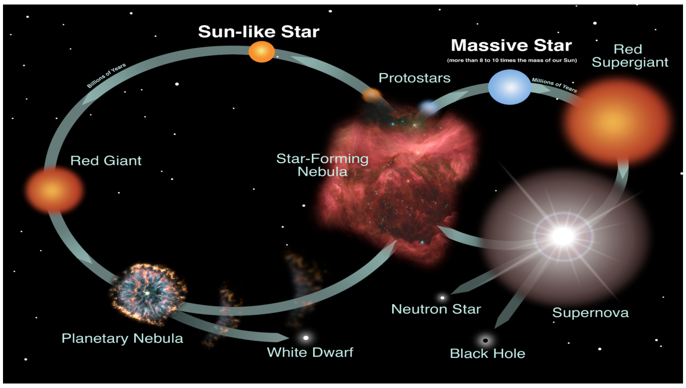

Figure 6: Diagram showing the lifecycles of Sun-like and massive stars.(Credit: NASA and the Night Sky Network)

5 MATLAB tutorial course

1. Overview of MATLAB's capabilities and applications in engineering, science, and data analysis.
2. MATLAB environment, including the Command Window, Editor, and Workspace.
3. Basic arithmetic operations and mathematical functions.
4. Variables, data types, and how to assign values to variables.
5. Working with arrays and matrices.
6. Importing and exporting data from/to different file formats.
7. Indexing and slicing arrays to access specific elements or subsets of data.
8. Creating 2D and 3D plots to visualise data using functions like plot, scatter, bar, surf, etc.
9. Customising plot appearance with labels, titles, colours, and styles.
10. Using conditional statements (if, else) to make decisions in code.
11. Employing loops (for, while) to repeat actions or iterate through data.
12. Writing custom functions to encapsulate reusable code.
13. Basic image processing operations like reading images, adjusting contrast, filtering, and edge detection.
14. Introduction to symbolic variables and expressions for algebraic manipulations.
15. Access to MATLAB documentation and online resources for further learning.

6 Talks and reports

6.1 Amar Sathwik – Olber's paradox:-

When Isaac Newton published his famous work, Philosophia Naturalis Principia Mathematica, in 1687, many scientists challenged it with different hypothetical situations and paradoxes. One such scientist was Heinrich Wilhelm Olbers. Newton's universe suggested an infinite and eternal, static universe, which means that there are infinite stars. The paradox is that the infinite stars must light up the whole sky and the night sky must be really bright.

A solution to the paradox proposed was that the universe was actually finite. But that would make the universe unstable. Another proposal was that there were dust clouds obstructing the stars. But that would mean the clouds absorb the radiation and would ultimately emit it back. The true solution was proposed by a poet, Edgar Allen Poe. It states that the universe is finitely old and the speed of light is finite. Hence there was just not enough time for the light from the farther stars to reach us and hence we are unable to see them. This is the solution to the Olber's paradox. This also fits well with the big bang theory, which states that the expansion of space caused the energy of the emitted light to be reduced via redshift. This is the reason why the night sky is dark.

6.2 Suyash – Quantum tunnelling in stars:-

Stars burn bright with the fusion engine in their core, but even the extreme temperature and pressure conditions can't overcome the electrostatic repulsions between the positively charged protons, at least classically. Quantum mechanics, in particular quantum tunnelling, helps overcome this barrier and sustain their energy output and stability.

According to quantum tunnelling, a key concept in quantum mechanics, particles exhibiting both particle and wave-like behaviour, can exist in regions prohibited by classical physics, enabling them to "tunnel" through the energy barrier. This tunnelling initiates the fusion process, where protons convert into helium nuclei, releasing immense energy in the form of gamma rays.

The balance between gravitational forces trying to collapse the star and the energy released from fusion reactions sustains a star's equilibrium. Without quantum tunnelling, stars would not have sufficient energy to counteract gravitational collapse, leading to catastrophic outcomes.

The rate of quantum tunnelling is influenced by temperature and pressure, varying between stars of different masses and ages. High-mass stars with hotter cores experience faster fusion rates, leading to shorter lifespans and more explosive ends. In contrast, low-mass stars like our Sun have slower fusion rates, resulting in longer lifespans and stable energy production.

Understanding quantum tunnelling in stars is crucial for comprehending stellar astrophysics, as it shapes a star's life cycle, determines its size, brightness, and ultimate fate. This knowledge deepens our understanding of the cosmos and the fundamental processes driving the dynamics of celestial bodies.

6.3 Chayyank – Astronomical distances:-

The methods used by astronomers to measure astronomical distances, known as the cosmic distance ladder. The cosmic distance ladder is a series of techniques to determine distances to celestial objects. Direct distance measurement is only possible for objects relatively close to Earth, while more distant objects require indirect methods based on correlations between different measurement techniques.

The methods discussed include:

- Radar: Using radio waves, radar measures distances within our solar system with great precision.
- Parallax: This trigonometric method measures the apparent shift in a star's position when observed from opposite sides of Earth's orbit, allowing astronomers to calculate the star's distance.
- Cepheid Variable Stars: These stars pulsate with a stable period and brightness, making them standard candles for measuring distances to nearby galaxies.
- Supernovae: These powerful explosions can be used as standard candles for measuring distances to other galaxies, although they occur unpredictably.

  Each method in the cosmic distance ladder builds upon the previous one, providing a way to measure distances at different scales in the universe. The Hubble Law, based on redshift, is particularly important for measuring distances to very distant objects.

6.4 Samarth – Gravitational lensing:-

Gravitational lensing is a remarkable phenomenon in astrophysics, which is based on the principle that when light from a distant source passes close to a massive foreground object, like a galaxy or a cluster of galaxies, the light's path is altered due to the curvature of spacetime around the massive object. As a result, the distant source's image is distorted, magnified, and sometimes even split into multiple images. This effect was first predicted by Albert Einstein in his general theory of relativity.

There are two primary types of gravitational lensing: strong lensing and weak lensing. Strong lensing occurs when the foreground mass is highly concentrated, leading to significant image distortion and the formation of multiple images. On the other hand, weak lensing happens when the foreground mass is more spread out, causing subtle distortions in the background source's shape.

Gravitational lensing has numerous applications in astrophysics and cosmology. One of its key roles is in the study of dark matter and dark energy, as the bending of light provides a way to map the distribution of dark matter in the universe. By comparing the observed lensing effects with theoretical models, scientists can infer the mass distribution of the lensing object and its surroundings. It acts as a cosmic telescope, magnifying and brightening distant sources, such as high-redshift galaxies, which aids in their study and understanding.

In conclusion, gravitational lensing is a captivating and powerful phenomenon that plays a crucial role in modern astrophysics and cosmology. Its ability to bend and magnify light from distant sources provides astronomers with unique opportunities to explore and unravel the mysteries of the universe.

6.5 Garv - Terraforming:-

In simpler words, Terraforming means artificially transforming an inhospitable planetary body into an Earth-like planet. Humanity needs to be a spacefaring species to survive and thrive forever and not become extinct in an apocalyptic event. To be an interplanetary species, we need to be able to terraform any planet we want. We have done the opposite of terraforming and are still doing it. We are destroying our own planet. But there is a hope here too, if we can damage our planet then we repair it too. Coming back to the topic of terraforming of other planets, this is possible and our best candidate for terraforming is our red neighbour Mars". Terraforming Mars or any other planet may seem like an impossible task, but it is not. It is an achievable task and there are many promising theories on how to do it. Nowadays, companies like SpaceX and Blue Origin are preparing to do so. One day we will surely be an interplanetary species!!

6.6 Anirudh – Space probes:-

Space probes are unmanned robotic spacecraft sent to explore and conduct research in our vast Solar System. Due to the high cost and risks associated with sending humans to space, space probes serve as valuable alternatives. These probes are either programmed or remotely controlled from Earth to perform various tasks, including photography, data collection, and sample analysis. The several types of space probes include:

- Flyby probes: These probes approach celestial objects closely for a brief time, gathering valuable information.
- Orbital probes: These probes enter and maintain orbits around celestial bodies for extended periods, allowing long-term observations.
- Landers: Lander probes descend and perform soft landings on a celestial body's surface, studying its soil and taking pictures.
- Rovers: Rovers go a step further by having wheels, enabling them to move and explore different areas after landing. They are remotely controlled from Earth and may have excavation tools for analysing rocks.
- Miscellaneous probes: Other probes serve specific purposes such as sample return probes and impact probes.

6.7 Abhishek Kumar – Novae and their types:-

Novae, supernovae, and hypernovae are all extraordinary astronomical events, each representing different stages in the life cycle of stars.

Novae occur in binary star systems, where a white dwarf accretes material from its companion star. When the accreted material reaches a critical mass, nuclear fusion is ignited on the white dwarf's surface, causing a temporary increase in brightness. Unlike supernovae, novae do not lead to the complete destruction of the white dwarf, and the star can go through multiple nova events over time.

Supernovae, on the other hand, are cataclysmic explosions that occur when massive stars exhaust their nuclear fuel and undergo gravitational collapse. These intense events release an enormous amount of energy, outshining entire galaxies for a brief period. Supernovae play a crucial role in dispersing heavy elements into space, enriching the interstellar medium and enabling the formation of new stars and planets.

Hypernovae are a subclass of supernovae characterised by even more extreme energies and brightness. They are associated with the collapse of exceptionally massive stars, typically those with masses significantly greater than that of our Sun. Hypernovae are rare but have a profound impact on the universe, potentially leading to the formation of black holes or other exotic remnants.

Overall, these celestial phenomena, novae, supernovae, and hypernovae, provide valuable insights into stellar evolution, the chemical enrichment of the cosmos, and the incredible forces shaping the universe on both small and grand scales.

6.8 Diwakar – Quantum gravity:-

Quantum Gravity is a captivating frontier in physics that seeks to merge gravity, described classically as a continuous force shaping spacetime, with quantum mechanics, which governs the microscopic world. However, finding a unified theory that reconciles these two frameworks remains one of the most significant challenges in physics. Various theoretical frameworks, such as String Theory, Loop Quantum Gravity, Causal Dynamical Triangulation, and Asymptotic Safety, are being explored to address this issue. Despite ongoing research, there is currently no working theory that unifies gravity with the other fundamental forces, but the field continues to expand with new experiments and theoretical insights. The potential applications of Quantum Gravity in astrophysics are vast, with promising avenues to explore phenomena like black holes, gravitational waves, the Big Bang, cosmology, and the mysterious dark matter and dark energy that dominate our universe. Developing a unified theory necessitates a breakthrough in our understanding of physics, and while challenging, Quantum Gravity offers a fascinating journey into the fundamental nature of our universe and reality.

6.9 Arjit – Galaxies:-

The evolution and formation of galaxies is a fascinating journey that spans billions of years, dating back to the early universe. It all began shortly after the Big Bang when tiny fluctuations in the primordial matter began to grow due to gravity, eventually leading to the formation of cosmic structures. These building blocks, known as dark matter halos, provided the gravitational scaffolding for the accumulation of gas and dust. As these clouds collapsed, stars ignited, and galaxies started to take shape. There are various types of galaxies, including elliptical, spiral, and irregular, each with unique characteristics. Galaxies can also interact and merge, leading to the creation of new structures and influencing their evolution. The life cycle of galaxies involves an interplay of processes, from star formation and active galactic nuclei to stellar ageing and supernovae explosions. Over time, galaxies will continue to evolve, with some growing larger through mergers, while others may gradually fade away or transform into other types of structures, perpetuating the ever-changing cosmic tapestry

6.10 Harshit - Fermi paradox and the great filter:-

The Great Filter theory suggests that a critical point exists in the evolution of life, hindering the growth of advanced civilizations. Despite the vastness of the universe, the absence of advanced alien civilizations may serve as a warning sign. Encountering extraterrestrial life could lead to disastrous consequences for humanity if they have surpassed the filter and face challenges we cannot overcome. Additionally, interaction with technologically superior civilizations poses risks, potentially resulting in our annihilation. The excitement of discovering alien life must be balanced with the careful consideration of the potential hazards involved.

6.11 Priyanshu- Cosmic Rays:-

Cosmic rays are fascinating high-energy particles or clusters racing through space at nearly the speed of light. These enigmatic messengers originate from diverse sources, such as galactic cosmic rays from outside our solar system and solar energetic particles born during solar flares and coronal mass ejections.The composition of cosmic rays mainly comprises protons and atomic nuclei, but also includes other subatomic particles like electrons and positrons. Detecting cosmic rays involves both direct and indirect methods. Direct detection entails measuring their interactions with detectors, while indirect methods focus on observing the secondary particles they produce when colliding with the Earth's atmosphere.

One essential tool in cosmic ray research is the Cosmic Ray Isotope Spectrometer, enabling scientists to identify and measure the composition of these high-energy particles. The talk highlighted the advantages of cosmic rays in scientific research. They aid in distinguishing sources of high-energy phenomena, offering insights into cosmic objects and enabling the study of particle interactions at extreme energies. However, cosmic rays also present challenges, especially for space missions and astronauts. Their ability to penetrate spacecraft can potentially damage sensitive instruments and pose risks to human health.

In conclusion, cosmic rays remain a captivating area of scientific exploration, offering valuable opportunities to study the cosmos at extreme energies. By better understanding their origins, behaviour, and interactions, we can gain deeper insights into the universe's mysteries while ensuring the safety of space exploration. Continued research in this field promises to shed more light on the cosmic realm and further enrich our understanding of the cosmos.

6.12 Abhivardhan- Age of Universe:-

The age of the universe is a critical scientific measurement that has been refined over time through a combination of ancient observations and cutting-edge technology. From early beliefs in a static and eternal cosmos, the discovery of the universe's expansion through the work of astronomers like Edwin Hubble led to the development of the Big Bang theory, suggesting that the universe began around 13.8 billion years ago.

By studying the cosmic microwave background radiation, which is a faint remnant of the Big Bang, scientists have been able to further confirm the age of the universe. Advanced space telescopes and precise instruments, such as the Planck satellite, have provided crucial data to refine the estimate, leading to a remarkable consensus on the age of our universe.

The knowledge of the universe's age has profound implications for cosmology and our understanding of the cosmos. It serves as a fundamental parameter in various cosmological models, offering valuable insights into the universe's evolution, expansion rate, and the formation of galaxies and stars. The determination of the age of the universe represents a monumental achievement in humanity's quest to unravel the mysteries of the cosmos and our place within it.

7 Stellar properties

7.1 Stellar Temperature

7.1.1 Color and the Blackbody Curve:-

A blackbody is an object that absorbs all of the radiation that it receives (that is, it does not reflect any light, nor does it allow any light to pass through it and out the other side). The energy that the blackbody absorbs heats it up, and then it will emit its own radiation. The only parameter that determines how much light the blackbody gives off, and at what wavelengths, is its temperature. There is no object that is an ideal blackbody, but many objects (stars included) behave approximately like blackbodies. Other common examples are the filament in an incandescent light bulb or the burner element on an electric stove. As you increase the setting on the stove from low to high, you can observe it produce blackbody radiation; the element will go from nearly black to glowing red hot.

The temperature of an object is a measurement of the amount of random motion (the average speed) exhibited by the particles that make up the object; the faster the particles move, the higher the temperature we will measure. If you recall from the very beginning of this lesson, we learned that when charged particles are accelerated, they create electromagnetic radiation (light). Since some of the particles within an object are charged, any object with a temperature above absolute zero (0 K or −273 degrees Celsius) will contain moving charged particles, so it will emit light.

A blackbody, which is an “ideal” or “perfect” emitter (that means its emission properties do not vary based on location or the composition of the object), emits a spectrum of light with the following properties:

1. 1.The hotter the blackbody, the more light it gives off at all wavelengths. That is, if you were to compare two blackbodies, regardless of what wavelength of light you observe, the hotter blackbody will give off more light than the cooler one.

2. 2.The spectrum of a blackbody is continuous (it gives off some light at all wavelengths), and it has a peak at a specific wavelength. The peak of the blackbody curve in a spectrum moves to shorter wavelengths for hotter objects. If you think in terms of visible light, the hotter the blackbody, the bluer the wavelength of its peak emission. For example, the sun has a temperature of approximately 5800 Kelvin. A blackbody with this temperature has its peak at approximately 500 nanometers, which is the wavelength of the color yellow. A blackbody that is twice as hot as the sun (about 12000 K) would have the peak of its spectrum occur at about 250 nanometers, which is in the UV part of the spectrum.

The first of the two properties listed above (and seen in the image above) is usually referred to as the **Stefan-Boltzmann Law** and is stated mathematically as:

$$E = \sigma T^4$$

Where: E is the energy emitted per unit area, or intensity, σ is a constant, and T is the temperature (measured in Kelvins). The total luminosity of a blackbody, that is, how much energy the entire object gives off, is the energy per unit area (E) multiplied by the surface area. For a sphere, this is:

$$L = 4\pi R^2 \sigma T^4$$

Here, L is the luminosity (energy per unit time) and R is the radius of the sphere.

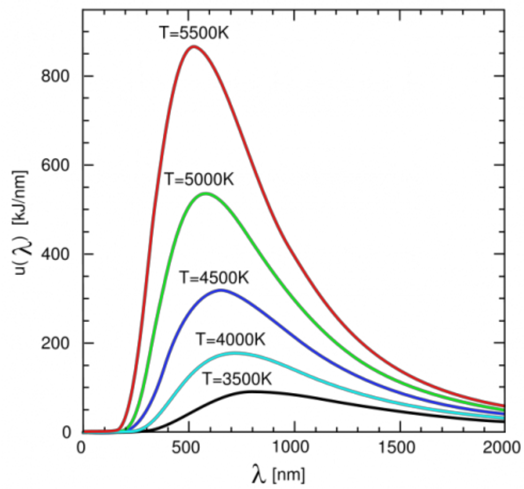

Figure 7: Variation of spectral energy density u(λ) with wavelength λ in nano-meters. The wavelength λ max at which u(λ) is maximum is observed to shift towards shorter wavelength as T increases.

The second of the two properties listed above is referred to as **Wien's Law**. To determine the peak wavelength of the spectrum of a blackbody, the equation is:

$$\lambda = \frac{0.29(cmK)}{T}$$

7.1.2 Stellar Spectra

All stellar spectra show absorption lines due to a variety of species.

For the Sun, these were first discovered by Joseph von Fraunhofer in the early 1800s. Stellar spectra are a fundamental aspect of astrophysics and refer to the range of electromagnetic radiation (light) emitted or absorbed by a star.When the light from a star is dispersed through a spectrograph, it creates a spectrum that contains information about the star's physical properties and composition.

The stellar spectrum is typically depicted as a graph with wavelength (or frequency) on the x-axis and intensity (or flux) on the y-axis. It shows how much light is present at different wavelengths. The spectrum may consist of continuous regions, where light intensity changes smoothly, and absorption or emission lines, where light intensity drops or increases sharply at specific wavelengths.

Spectra of stars having surface temperatures exceeding 25,000 K usually show strong absorption lines of singly ionised helium (i.e Helium atoms that have lost one orbiting electron) and multiply ionised heavier elements, such as oxygen, nitrogen, and silicon. Hydrogen lines are strongest in stars having intermediate surface temperatures of around 10,000 K. This temperature is just right for electrons to move frequently between hydrogen's second and higher orbitals, producing the characteristic visible hydrogen spectrum.

7.1.3 Stellar Classification

Stellar classification is a scheme for assigning stars to types according to their temperatures as estimated from their spectra. The generally accepted system of stellar classification is a combination of two classification schemes: the Harvard system, which is based on the star's surface temperature, and the MK system, which is based on the star's luminosity.

In the 1860s the Italian astronomer Angelo Secchi distinguished four main spectral types of stars. At the Harvard College Observatory in the 1880s, during the compilation of the Henry Draper Catalogue of stars, more types were distinguished and were designated by letter in alphabetic sequence according to the strength of their hydrogen spectral lines. Most of this work was done by three assistants, Williamina P. Fleming, Antonia C. Maury, and Annie Jump Cannon. As the work progressed, the types were rearranged in a non alphabetic sequence to put them in order by surface temperature. From hot stars to cool, the order of stellar types is: O, B, A, F, G, K, M. (A traditional mnemonic for this sequence is "Oh Be A Fine Girl [or Guy], Kiss Me.") Additional letters have been used to designate novas and less common types of stars. Numbers from 0 to 9 are used to subdivide the types, the higher numbers applying to cooler stars. The hotter stars are sometimes referred to as early and the cooler as late. With the discovery of brown dwarfs, objects that form like stars but do not shine through thermonuclear fusion, the system of stellar classification has been expanded to include spectral types L, T, and Y.

Class O includes bluish white stars with surface temperatures typically of 25,000–50,000 K (although a few O-type stars with vastly greater temperatures have been described); lines of ionized helium appear in the spectra. Class B stars typically range from 10,000 K to 25,000 K and are also bluish white but show neutral helium lines. The surface temperatures of A-type stars range from 7,400 K to about 10,000 K; lines of hydrogen are prominent, and these stars are white. F-type stars are yellow-white, reach 6,000–7,400 K, and display many spectral lines caused by metals. The Sun

Spectral Class	Temperature (K)	Prominent Absorption Lines	Familiar Examples
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	Mintaka (O9)
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2)
			Barnard's Star (M5)

Figure 8: Main properties of each stellar spectral class for the stars

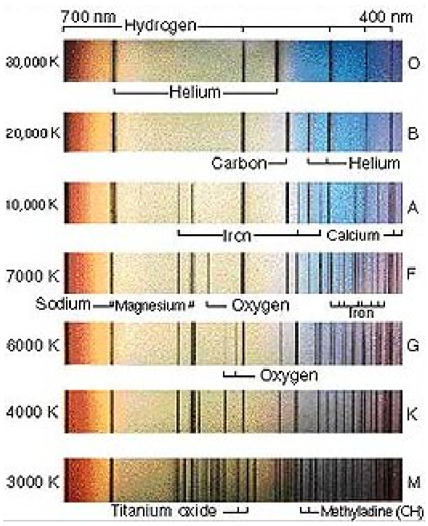

Figure 9: Comparison of spectra observed for seven different stars having a range of surface temperatures. The spectra of the hottest stars, at the top, show lines of helium and multiply ionized heavy elements. In the coolest stars, at the bottom, helium lines are absent, but lines of neutral atoms and molecules are plentiful. At intermediate temperatures, hydrogen lines are strongest.

is a class G star; these are yellow, with surface temperatures of 5,000–6,000 K. Class K stars are yellow to orange, at about 3,500–5,000 K, and M stars are red, at about 3,000 K, with titanium oxide prominent in their spectra. L brown dwarfs have temperatures between about 1,500 and 2,500 K and have spectral lines caused by alkali metals such as rubidium and sodium and metallic compounds like iron hydride. T brown dwarfs have prominent methane absorption in their spectra and temperatures between about 800 and 1,500 K. Class Y brown dwarfs are cooler than 800 K and have spectral lines from ammonia and water.

Supplementary classes of cool stars include R and N (often called C-type, or carbon stars: less than 3,000 K), and S, which resemble class M stars but have spectral bands of zirconium oxide prominent instead of those of titanium oxide.

The MK, or Yerkes, system is the work of the American astronomers W.W. Morgan, P.C. Keenan, and others. It is based on two sets of parameters: a refined version of the Harvard O-M scale, and a luminosity scale of grades I (for supergiants), II (bright giants), III (normal giants), IV (subgiants), and V (main sequence, or dwarf, stars); further specifications may be used, such as a grade Ia for bright supergiants and grades VI and VII for subdwarfs and white dwarfs, respectively. Thus the Sun, a yellow dwarf star of some 5,800 K, is designated G2 V; while Barnard's star, a red dwarf of some 3,100 K, is classified M5 V; and the bright supergiant Rigel is classified B8 Ia.

7.2 Luminosity

Luminosity is the amount of radiation leaving a star per unit time. It is an intrinsic stellar property and does not depend in any way on the location or motion of the observer. It is sometimes referred to as the star's absolute brightness. However, when we observe a star, we see not its luminosity but rather its apparent brightness which is the amount of energy striking unit area of some light sensitive surface or device, such as a human eye, per unit time.

The apparent brightness of a star is directly proportional to the star 's luminosity and inversely proportional to the square of its distance:

$$Apparent\ brightness \propto \frac{luminosity}{distance^2}$$

This means that two different stars with different luminosity can have the same apparent brightness if they are located at different distances from the observer.

7.2.1 Magnitude Scale

Instead of measuring apparent brightness in SI units (for example, watts per square meter, W/m^2) optical astronomers find it more convenient to work in terms of a construct called the magnitude scale —a system of ranking stars by their apparent brightness. The modern apparent magnitude scale is logarithmic, where a change of 5 magnitudes corresponds to a factor of 100 in apparent brightness. For example:

- The Sun, when seen from Earth, has an apparent magnitude of approximately -26.8, making it extremely bright in our sky.
- The faintest objects detectable by powerful telescopes, like the Hubble or Keck, have apparent magnitudes around +30, which are incredibly faint.

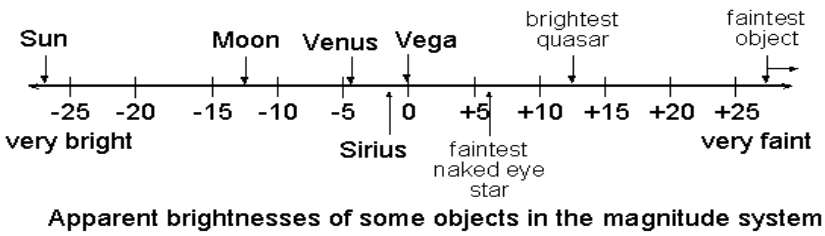

Figure 10:

Absolute Magnitude

To compare intrinsic, or absolute, properties of stars, however, astronomers imagine looking at all stars from a standard distance of 10 pc. A star's absolute magnitude is its apparent magnitude when viewed from 10 pc. Because distance is fixed in this definition, absolute magnitude is a measure of a star's absolute brightness, or luminosity. Despite the Suns large negative (that is, very bright) apparent magnitude, our star's absolute magnitude is 4.8. In other words, if the Sun were moved to a distance of 10 pc from Earth, it would be only a little brighter than the faintest stars visible in the night sky.

$$\textit{apparent magnitude} - \textit{absolute magnitude} = 5\log_{10}\left(\frac{\text{distance}}{10\text{ pc}}\right)$$

8 Hertzsprung Russell Diagrams(or H.R Diagrams)

The Hertzsprung-Russell diagram, or H-R diagram, is the periodic table of the stars – an analogue of the periodic table of the elements. It was discovered that when the luminosity (absolute magnitude or brightness) of stars, expressed in units of solar luminosity ($3.9 * 10^{26} W$), is plotted against their temperature (stellar classification); although in the unconventional sense of temperature increasing to the left, so that the spectral sequence O, B, A, . . . reads left to right.

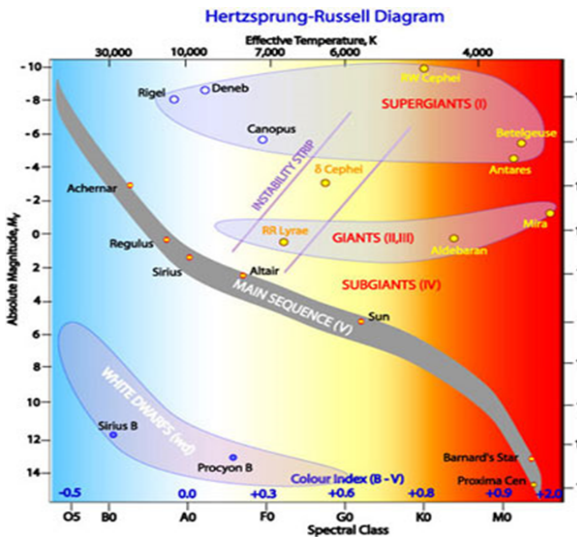

Figure 11:

The stars are not randomly distributed on the graph but are mostly restricted to a few well-defined regions. The stars within the same regions share a common set of characteristics, just like the groups, periods, and blocks of elements in the periodic table. Unlike the periodic table however, the physical characteristics of stars change over time, and therefore their positions on the H-R diagram change also – so the H-R diagram can be thought of as a visual plot of stellar evolution. It is a graphical tool that astronomers use to classify stars. From the location of a star on the graph, the luminosity, spectral type, colour, temperature, mass, chemical composition, age, and evolutionary history are known.

There are 3 main regions (or evolutionary stages) of the HR diagram:

1. The Main Sequence stretching from the upper left (hot, luminous stars) to the bottom right (cool, faint stars) dominates the HR diagram. It is here that stars spend about 90

   Main sequence stars have a Morgan-Keenan luminosity class labelled V. The surface temperatures of main-sequence stars range from about 3000 K (spectral class M) to more than 30,000 K (spectral class O). This temperature range is relatively small—only a factor of 10. In contrast, the observed range in luminosity is very large, covering eight orders of magnitude (that is, a factor of 100 million), from 10 -4 to 10 4 the luminosity of the Sun.

2. Red giant and Supergiant stars (luminosity classes I through III) occupy the region above the main sequence. They have low surface temperatures and high luminosity which, according to the Stefan-Boltzmann law, means they also have large radii. Stars enter this evolutionary stage once they have exhausted the hydrogen fuel in their cores and have started to burn helium and other heavier elements.

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 HR diagram. These stars are very hot but have low luminosity due to their small size.

Astronomers generally use the HR diagram to either summarise the evolution of stars, or to investigate the properties of a collection of stars. By plotting a HR diagram for either a globular or open cluster of stars, astronomers can estimate the age of the cluster from where stars appear to turn off the main sequence (see the entry on main sequence for how this works.

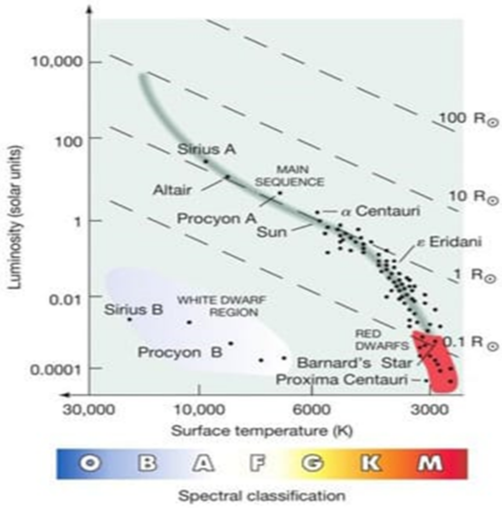

Figure 12: H-R diagram for stars lying within 5 pc of the Sun. Note that most stars in the solar neighbor¬ hood lie on the main sequence.

Using the radius-luminosity-temperature relationship, astronomers find that stellar radii also vary along the main sequence. The faint, red M-type stars in the bottom right of the H-R diagram are only about 1/10 the size of the Sun, whereas the bright, blue O-type stars in the upper left are about 10 times larger than the Sun. The dashed lines in Figure-12 represent constant stellar radius, meaning that any star lying on a given line has the same radius, regardless of its luminosity or temperature. Along a constant-radius line, the radius-luminosity- temperature relationship implies:

$$luminosity \propto temperature^4$$

By including such lines on our H-R diagrams, we can indicate stellar temperatures, luminosities, and radii on a single plot.

9 Tour to observatory

The IITK observatory is a facility dedicated to astronomical research and observation. It is equipped with advanced telescopes and instruments that allow astronomers, researchers, and students to study celestial phenomena and conduct cutting-edge research in the field of astrophysics. The observatory plays a crucial role in fostering interest and expertise in astronomy among the academic community and promotes scientific exploration beyond the classroom.

Figure 13: Observatory made by students at IITK

The observatory at IITK is likely involved in various research projects and collaborations with other national and international astronomical organisations. Researchers and students at the institution have the opportunity to engage in observational astronomy, data analysis, and theoretical astrophysics, gaining valuable insights into the mysteries of the universe.

The telescope is a Cassegrain telescope with an automated equatorial mount. It is installed with a PHD2 guiding software used in locating objects and rendering images.

The PHD2 software lets you type in the coordinates of the observing area, date, time and name of the object and it automatically points towards the object you are looking for. You can also move the telescope manually in any direction.

It has 3 scopes. The finder scope, the main eyepiece and one for taking photos.

For taking pictures of the night sky, one should adjust the exposure time of the camera. Keeping more exposure time lets the light in for longer periods, resulting in an image with more clarity.

Once taken the software compares the picture with an actual pic of the night sky from the same coordinates and makes changes to give us an even more accurate image. This software also allows you to take images through clouds.

The instructions for using the telescope are as follows:-

1. Understand your telescope and read the user manual.
2. Set up the telescope in a stable and dark location.
3. Leave the telescope for about 20 minutes so that the lenses have minimal temperature difference with the surroundings.
4. Align the telescope with the celestial poles for tracking (equatorial mount).
5. Calibrate the finder scope to aid in locating objects.
6. Choose the right eyepiece for your observing goals. Start with a lower magnification eyepiece.

7. Focus the telescope carefully on bright, distant objects.
8. Observe objects patiently and avoid touching the telescope during use.
9. Store the telescope properly and clean it regularly.
10. Never observe the Sun directly without proper filters.

10 Case Study of KEPLER-452b

Kepler-452b is an exoplanet orbiting within the inner edge of the habitable zone of the star Kepler-452. It is the only planet in the system discovered by kepler.

· Designation : KOI-7016.01
· Distance from earth : 1800 light years (550 pc)
· Constellation : Cygnus
· Discovered on : 23rd July 2015
· Mean radius : (1.5-0.22 to 1.5 +0.32)R ; R = radius of the Earth
· Mass : (5-2 to 5+2)M ; M=mass of the earth
· Surface gravity : (1.9-1.0 to 1.9+1.5)g
· Planetary equilibrium Temperature : 265K
It is also known as Earth 2.0 or Earth's cousin as it shares many similarities with our earth.
· Radius : 50
· Orbital radius around its star : 1.04 AU (1AU = Earth's orbital radius)
· Orbit : circular orbit and not tidally locked
· Surface gravity : nearly twice as much as Earth's
· Equilibrium temperature : Its eq. temp. is a little warmer than Earth
· If it is a terrestrial planet, it most likely has many active volcanoes due to its high mass and density
· Similar to Earth, the planet takes 385 Earth days to orbit its star
· It also lies in the habitable zone of its parent star.
The host star Kepler-452
· Type : G-type
· Mass : 3.7 % more massive than the sun
· Radius : 11 % larger than the sun
· Surface temperature : It has temp of 5757K, nearly same as the sun (5778K)
· Luminosity : 20 % more luminous than the Sun
· Age : It is 6 billion years old, about 1.5 billion years older than the sun.
· Apparent magnitude (how bright the star is from the Earth's surface) : 13.426 (which is too dim to be seen with naked eye)

10.1 Physical Characteristics of KEPLER-452b

Kepler-452b is 50 percent larger in diameter than Earth and is considered a super-Earth-size planet. While its mass and composition are not yet determined, previous research suggests that planets the size of Kepler-452b have a good chance of being rocky.

NASA's Kepler mission has confirmed the first near-Earth-size planet in the "habitable zone" around a sun-like star. This discovery and the introduction of 11 other new small habitable zone candidate planets mark another milestone in the journey to finding another "Earth."

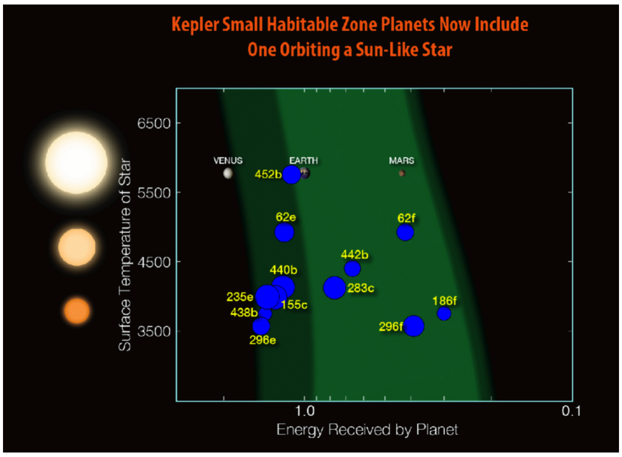

Figure 14: Highlighted are 12 new planet candidates from the seventh Kepler planet candidate catalogue that are less than twice the size of Earth and orbit in the stars' habitable zone Credits: NASA Ames/W. Stenzel

Highlighted are 12 new planet candidates from the seventh Kepler planet candidate catalogue that are less than twice the size of Earth and orbit in the stars' habitable zone

While Kepler-452b is larger than Earth, its 385-day orbit is only 5 percent longer. The planet is 5 percent farther from its parent star Kepler-452 than Earth is from the Sun. Kepler-452 is 6 billion years old, 1.5 billion years older than our sun, has the same temperature, and is 20 percent brighter and has a diameter 10 percent larger.

"We can think of Kepler-452b as an older, bigger cousin to Earth, providing an opportunity to understand and reflect upon Earth's evolving environment," said Jon Jenkins, Kepler data analysis lead at NASA's Ames Research Center in Moffett Field, California, who led the team that discovered Kepler-452b. *"It's awe-inspiring to consider that this planet has spent 6 billion years in the habitable zone of its star; longer than Earth. That's a substantial opportunity for life to arise, should all the necessary ingredients and conditions for life exist on this planet."*

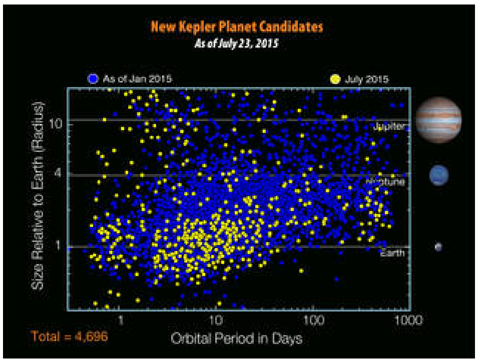

Figure 15: There are 4,696 planet candidates now known with the release of the seventh Kepler planet candidate catalogue - an increase of 521 since the release of the previous catalogue in January 2015. Credits: NASA/W. Stenzel

10.2 Habitability Of KEPLER-452b

For a planet to be classified as habitable, multiple factors need to be considered. The most important of these is availability of liquid water on the surface and an atmosphere (especially a magnetosphere) that protects from meteoroids harmful radiation (together, these also limit the allowed range of surface temperatures). Strength of surface gravity and availability of essential elements like carbon, oxygen, hydrogen, nitrogen and phosphorus are also important. For these conditions to be satisfied, the planet must have a radius between 0.5 and 1.5 earth radii and a mass between 0.1 and 5.0 earth masses. This ensures that the surface gravity is strong enough to hold together an atmosphere and have geological activity under the surface but is still able to have tolerable surface gravity. If the atmosphere is too thick and the greenhouse effect is stronger, the habitable zone shifts away from the star. Planetary orbits with high eccentricity are also unfavourable to life as they cause extreme temperature fluctuations. In the outer regions of the habitable zone, the risk of transitioning into a globally frozen "snowball" state poses a threat to the habitability of planets with the capacity to host water-based life. For a constant semi major axis, the annual mean stellar irradiation scales with $(1 - e^2)^{-1/2}$, one might expect the greatest habitable semimajor axis (for fixed atmospheric composition) to scale as $(1 - e^2)^{-1/4}$. This provides a reasonable lower bound on the outer boundary of the habitable zone.

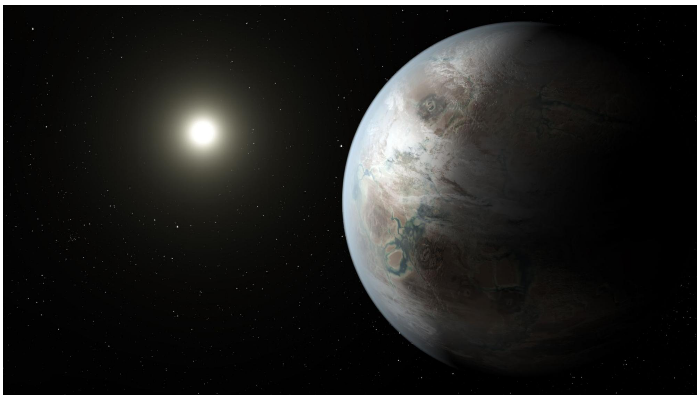

Figure 16: An artist's impression of KEPLER-452b

Note that not fulfilling these requirements may not rule out extremophilic life. Complex life, however, is thought to be unlikely to evolve in such environments. As seen from the data, Kepler-452b fulfils most of the requirements for being a habitable planet, but it's important to remember that these conditions are necessary but not sufficient for a planet to harbour life. It is unknown if it is entirely habitable, as its gravity is nearly twice that of earth and it is receiving slightly more energy than Earth and could be subjected to a runaway greenhouse effect.

But It's awe-inspiring to consider that this planet has spent 6 billion years in the habitable zone of its star; longer than Earth. That's a substantial opportunity for life to arise, should all the necessary ingredients and conditions for life exist on this planet.

Scientists with the SETI (Search for Extraterrestrial Intelligence Institute) have already begun targeting Kepler-452b, the first near-Earth-size world found in the habitable zone of a Sun-like star. SETI Institute researchers are using the Allen Telescope Array, a collection of 6-meter (20 feet) telescopes in the Cascade Mountains of California, to scan for radio transmissions from Kepler-452b. As of July 2015, the array has scanned the exoplanet on over 2 billion frequency bands, with no result. The telescopes will continue to scan over a total of 9 billion channels, searching for alien radio analysis.

10.3 Conclusion

In conclusion, the study of Kepler-452b has yielded significant insights. Researchers have identified Kepler-452b as the most Earth-like exoplanet discovered to date, with similar characteristics such as size and orbit. Its potential for sustaining liquid water raises the possibility of supporting life, making it a prime candidate for further investigation and a potential target for future space missions. However, challenges remain in confirming the planet's habitability and understanding its atmospheric composition. Despite these uncertainties, Kepler-452b stands as a crucial milestone in humanity's quest to understand the cosmos and discover habitable worlds beyond our solar system.

11 Case Study of Betelguese

11.1 Introduction

Betelgeuse is a red supergiant star of spectral type M1-2 and one of the largest visible to the naked eye. It is usually the tenth-brightest star in the night sky and, after Rigel, the second-brightest in the constellation of Orion. It is a distinctly reddish, semiregular variable star whose apparent magnitude, varying between +0.0 and 1.6.

Betelgeuse has been classified as a "semiregular variable star," which is a type of variable star that periodically waxes and wanes in brightness and occasionally undergoes irregular light changes. Betelgeuse, typically, has a 400-day cycle as well as a longer cycle that stretches about 5 years.

11.2 Location

As a result of its distinctive orange-red color and position within Orion, Betelgeuse is easy to find with the naked eye. It is one of three stars that make up the Winter Triangle asterism, and it marks the center of the Winter Hexagon.

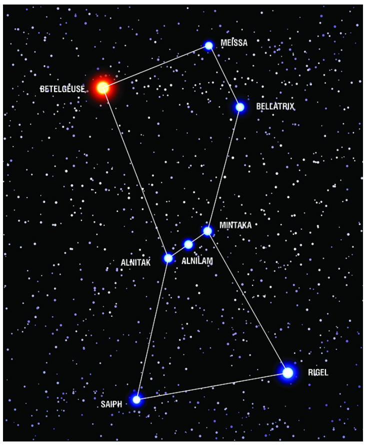

Figure 17: Betelguese in the orion constellation.

At the beginning of January of each year, it can be seen rising in the east just after sunset. Between mid-September to mid-March (best in mid-December), it is visible to virtually every inhabited region of the globe, except in Antarctica at latitudes south of 82°. In May (moderate northern latitudes) or June (southern latitudes), the red supergiant can be seen briefly on the western horizon after sunset, reappearing again a few months later on the eastern horizon before sunrise. In the intermediate period (June–July, centered around mid June), it is invisible to the naked eye (visible only with a telescope in daylight), except around midday low in the north in Antarctic regions between 70° and 80° south latitude (during midday twilight in polar night, when the Sun is below the horizon).

11.3 Stellar Characteristics

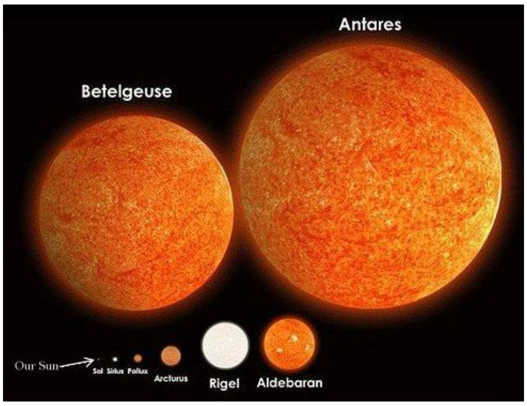

Figure 18: Comparison between size of Betelguese and some well-known stars

It is an enormous star with a diameter that ranges from approximately 700 to 1000 times that of our Sun. If it were at the center of our Solar System, its surface would lie beyond the asteroid belt and it would engulf the orbits of Mercury, Venus, Earth, and Mars. Calculations of Betelgeuse's mass range from slightly under ten to a little over twenty times that of the Sun.

For various reasons, its distance has been quite difficult to measure; current best estimates are on the order of 500–600 light-years from the Sun. Its absolute magnitude is about −6. It is also surrounded by a complex, asymmetric envelope, roughly 250 times the size of the star, caused by mass loss from the star itself. The star's luminosity is around 100,000 times greater than that of the Sun, despite being cooler in temperature.

11.4 Variability

Betelgeuse is a variable star, meaning its brightness changes over time. The star exhibits both semi-regular pulsations and irregular variations in luminosity. Its brightness can fluctuate from magnitude 0.2 to 1.2 over periods ranging from a few months to years.

The exact cause of Betelgeuse's variability is not fully understood, but convection and star spots are thought to play a role.

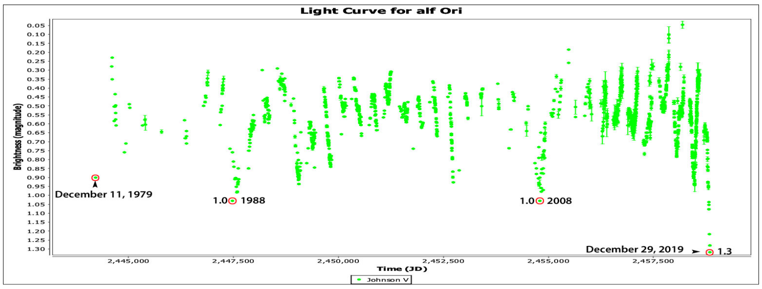

Figure 19:

11.5 Evolutionary Stage and Supernova

Betelgeuse is currently in the latter stages of its life cycle. Having exhausted its core's hydrogen fuel, it has expanded into a red supergiant phase. The star is now fusing helium into heavier elements in its core. Betelgeuse's fate is uncertain, but it is expected to undergo a supernova explosion in the future.

When Betelgeuse eventually goes supernova, it will shine as bright as the half-Moon— for more than three months and be visible even during the day. Life on Earth will be unharmed. The explosion will release an immense amount of energy and trigger the synthesis of heavy elements. The remnants of the supernova will expand into space, enriching the interstellar medium with newly formed elements and potentially seeding the birth of new stars.

11.6 Recent Observations and Dimming Event

Starting in October 2019, Betelgeuse began to dim noticeably, and by mid-February 2020 its brightness had dropped by a factor of approximately 3, from magnitude 0.5 to 1.7. It then returned to a more normal brightness range, reaching a peak of 0.0 visual and 0.1 V-band magnitude in April 2023. Infrared observations found no significant change in luminosity over the last 50 years, suggesting that the dimming was due to a change in extinction around the star rather than a more fundamental change.

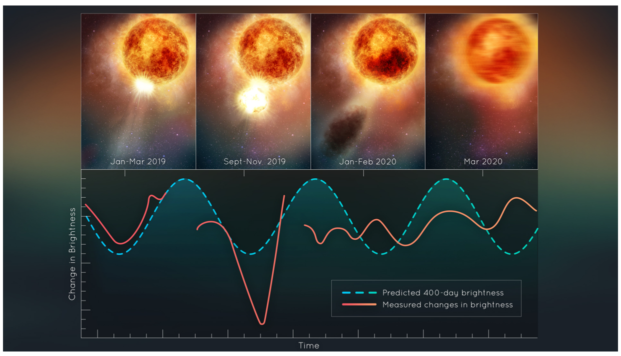

Figure 20: Artist's impression of the aftermath of the SME, with the mass cooling and forming a cloud of dust which dimmed the star for a short period of time. Credits: NASA, ESA, Elizabeth Wheatley (STScI).

A study using the Hubble Space Telescope suggests that occluding dust was created by a surface mass ejection. This cast material millions of miles from the star that then cooled to form the dust that caused the star's dimming.

11.7 Asymmetric Shells

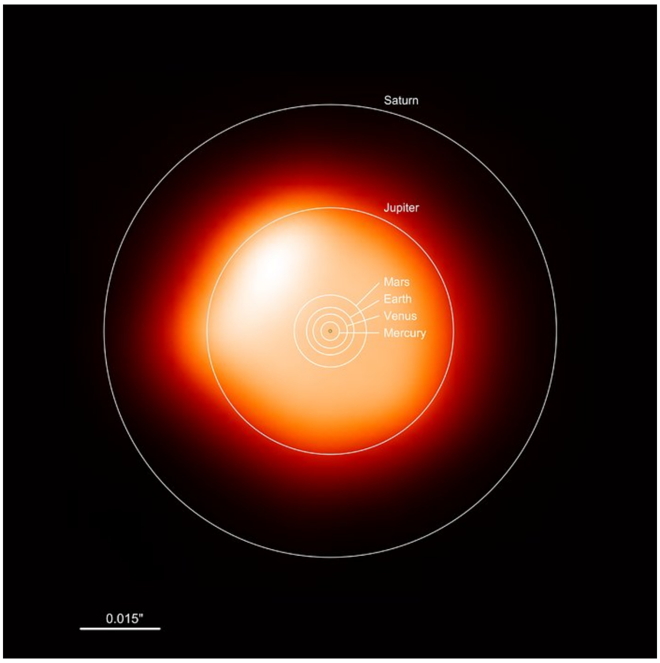

Figure 21: Asymmetric shells of Betelguese

A large plume of gas extending at least six times its stellar radius indicates that Betelgeuse is not shedding matter evenly in all directions. The plume's presence implies that the spherical symmetry of the star's photosphere, often observed in the infrared, is not preserved in its close environment. The asymmetric gaseous envelope, another cooler region, extends for several radii (∼10–40 AU) from the photosphere.

It is enriched in oxygen and especially in nitrogen relative to carbon. These composition anomalies are likely caused by contamination by CNO-pro in the later stages of their lives, having exhausted their core hydrogen fuel and begun fusing heavier elements. The dimming raised questions about whether Betelgeuse was on the brink of a supernova or if it had simply undergone a normal pulsation event.

11.8 Significance in Stellar Evolution Studies

Betelgeuse serves as a vital object of study in the field of stellar evolution. Its red supergiant phase and impending supernova provide a unique opportunity to understand the processes governing the later stages of massive star evolution. Observations and simulations of Betelgeuse's behavior can improve our knowledge of stellar interiors, mass loss mechanisms, and the effects of pulsations in red supergiants.

11.9 Future Observations and Predictions

Astronomical events occur on vast timescales, and predicting them requires a deep understanding of the complex processes happening within the star, along with careful observations and data analysis. The exact timing of a supernova event is difficult to predict, as it depends on several factors, including the star's mass, composition, and internal structure. While Betelgeuse's core is undergoing fusion of heavier elements, it is challenging to determine precisely how much nuclear fuel remains and when the core collapse will occur.

The notion of Betelgeuse going supernova anytime soon is somewhat speculative. The term "soon" in astronomical contexts can span thousands or even tens of thousands of years. It's important to understand that astronomical events are measured on vast timescales compared to human lifetimes.

It's worth noting that in late 2019 and early 2020, Betelgeuse exhibited an unprecedented dimming, leading to speculation about an imminent supernova. However, the dimming event turned out to be caused by a combination of stellar activity, dust obscuration, and convection-driven temperature changes on the star's surface. Betelgeuse has since returned to its typical brightness, indicating that a supernova event is not imminent.

Given the dynamic nature of Betelgeuse, continuous monitoring and future observations are crucial. The study discusses the importance of ongoing research and the potential for advanced telescopes and instruments to further unravel the mysteries surrounding Betelgeuse and similar stars.

11.10 Conclusion

Betelgeuse, with its colossal size and recent dimming event, remains a captivating subject of study for astronomers and astrophysicists. By combining observational data, theoretical models, and advanced technologies, this case study contributes to our understanding of massive star evolution, variability, and the complexities of the universe. Continued research on Betelgeuse and other celestial objects holds the promise of enriching our knowledge of the cosmos and the forces shaping its grand tapestry.

12 Conclusion

Through this project, new concepts and skills were learned. Talks were held, Evolution of a star from being a gas cloud to being a black hole or a neutron star or a white dwarf was briefly discussed, H-R diagram was made, Case studies for Betelguese and KEPLER-452b were done, Different celestial bodies were observed through stargazing and much more. In this project, a tour to the OAAR also happened where its basic working principles and various other things were discussed. It is very astounding to know how modern computing has made the lives of astronomers better.

It was an amazing learning experience for all of us.

13 References

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