= Star =

A star is a luminous sphere of plasma held together by its own gravity . The nearest star to Earth is the Sun . Many other stars are visible to the naked eye from Earth during the night , appearing as a multitude of fixed luminous points in the sky due to their immense distance from Earth . Historically , the most prominent stars were grouped into constellations and asterisms , the brightest of which gained proper names . Astronomers have assembled star catalogues that identify the known stars and provide standardized stellar designations . However , most of the stars in the Universe , including all stars outside our galaxy , the Milky Way , are invisible to the naked eye from Earth . Indeed , most are invisible from Earth even through the most powerful telescopes .

For at least a portion of its life , a star shines due to thermonuclear fusion of hydrogen into helium in its core , releasing energy that traverses the star 's interior and then radiates into outer space . Almost all naturally occurring elements heavier than helium are created by stellar nucleosynthesis during the star 's lifetime , and for some stars by supernova nucleosynthesis when it explodes . Near the end of its life , a star can also contain degenerate matter . Astronomers can determine the mass , age , metallicity (chemical composition) , and many other properties of a star by observing its motion through space , its luminosity , and spectrum respectively . The total mass of a star is the main factor that determines its evolution and eventual fate . Other characteristics of a star , including diameter and temperature , change over its life , while the star 's environment affects its rotation and movement . A plot of the temperature of many stars against their luminosities produces a plot known as a Hertzsprung ? Russell diagram (H ? R diagram) . Plotting a particular star on that diagram allows the age and evolutionary state of that star to be determined .

A star 's life begins with the gravitational collapse of a gaseous nebula of material composed primarily of hydrogen , along with helium and trace amounts of heavier elements . When the stellar core is sufficiently dense , hydrogen becomes steadily converted into helium through nuclear fusion , releasing energy in the process . The remainder of the star 's interior carries energy away from the core through a combination of radiative and convective heat transfer processes . The star 's internal pressure prevents it from collapsing further under its own gravity . When the hydrogen fuel at the core is exhausted , a star of mass 0 @.@ 4 times greater than the Sun 's will expand to become a red giant . In some cases , it will fuse heavier elements at the core or in shells around the core . As the star expands it throws a part of its mass , enriched with those heavier elements , into the interstellar environment , to be recycled later as new stars . Meanwhile , the core becomes a stellar remnant : a white dwarf , a neutron star , or if it is sufficiently massive a black hole .

Binary and multi @-@ star systems consist of two or more stars that are gravitationally bound and generally move around each other in stable orbits . When two such stars have a relatively close orbit , their gravitational interaction can have a significant impact on their evolution . Stars can form part of a much larger gravitationally bound structure , such as a star cluster or a galaxy .

= = Observation history = =

Historically , stars have been important to civilizations throughout the world . They have been part of religious practices and used for celestial navigation and orientation . Many ancient astronomers believed that stars were permanently affixed to a heavenly sphere and that they were immutable . By convention , astronomers grouped stars into constellations and used them to track the motions of the planets and the inferred position of the Sun . The motion of the Sun against the background stars (and the horizon) was used to create calendars , which could be used to regulate agricultural practices . The Gregorian calendar , currently used nearly everywhere in the world , is a solar calendar based on the angle of the Earth 's rotational axis relative to its local star , the Sun .

The oldest accurately dated star chart was the result of ancient Egyptian astronomy in 1534 BC . The earliest known star catalogues were compiled by the ancient Babylonian astronomers of Mesopotamia in the late 2nd millennium BC , during the Kassite Period (ca . 1531 ? 1155 BC) .

The first star catalogue in Greek astronomy was created by Aristillus in approximately 300 BC , with the help of Timocharis . The star catalog of Hipparchus (2nd century BC) included 1020 stars , and

was used to assemble Ptolemy 's star catalogue . Hipparchus is known for the discovery of the first recorded nova (new star) . Many of the constellations and star names in use today derive from Greek astronomy .

In spite of the apparent immutability of the heavens , Chinese astronomers were aware that new stars could appear . In 185 AD , they were the first to observe and write about a supernova , now known as the SN 185 . The brightest stellar event in recorded history was the SN 1006 supernova , which was observed in 1006 and written about by the Egyptian astronomer Ali ibn Ridwan and several Chinese astronomers . The SN 1054 supernova , which gave birth to the Crab Nebula , was also observed by Chinese and Islamic astronomers .

Medieval Islamic astronomers gave Arabic names to many stars that are still used today and they invented numerous astronomical instruments that could compute the positions of the stars . They built the first large observatory research institutes , mainly for the purpose of producing Zij star catalogues . Among these , the Book of Fixed Stars (964) was written by the Persian astronomer Abd al @-@ Rahman al @-@ Sufi , who observed a number of stars , star clusters (including the Omicron Velorum and Brocchi 's Clusters) and galaxies (including the Andromeda Galaxy) . According to A. Zahoor , in the 11th century , the Persian polymath scholar Abu Rayhan Biruni described the Milky Way galaxy as a multitude of fragments having the properties of nebulous stars , and also gave the latitudes of various stars during a lunar eclipse in 1019 .

According to Josep Puig , the Andalusian astronomer Ibn Bajjah proposed that the Milky Way was made up of many stars that almost touched one another and appeared to be a continuous image due to the effect of refraction from sublunary material , citing his observation of the conjunction of Jupiter and Mars on 500 AH (1106 / 1107 AD) as evidence . Early European astronomers such as Tycho Brahe identified new stars in the night sky (later termed novae) , suggesting that the heavens were not immutable . In 1584 Giordano Bruno suggested that the stars were like the Sun , and may have other planets , possibly even Earth @-@ like , in orbit around them , an idea that had been suggested earlier by the ancient Greek philosophers , Democritus and Epicurus , and by medieval Islamic cosmologists such as Fakhr al @-@ Din al @-@ Razi . By the following century , the idea of the stars being the same as the Sun was reaching a consensus among astronomers . To explain why these stars exerted no net gravitational pull on the Solar System , Isaac Newton suggested that the stars were equally distributed in every direction , an idea prompted by the theologian Richard Bentley .

The Italian astronomer Geminiano Montanari recorded observing variations in luminosity of the star Algol in 1667 . Edmond Halley published the first measurements of the proper motion of a pair of nearby " fixed " stars , demonstrating that they had changed positions since the time of the ancient Greek astronomers Ptolemy and Hipparchus .

William Herschel was the first astronomer to attempt to determine the distribution of stars in the sky . During the 1780s he established a series of gauges in 600 directions and counted the stars observed along each line of sight . From this he deduced that the number of stars steadily increased toward one side of the sky , in the direction of the Milky Way core . His son John Herschel repeated this study in the southern hemisphere and found a corresponding increase in the same direction . In addition to his other accomplishments , William Herschel is also noted for his discovery that some stars do not merely lie along the same line of sight , but are also physical companions that form binary star systems .

The science of stellar spectroscopy was pioneered by Joseph von Fraunhofer and Angelo Secchi . By comparing the spectra of stars such as Sirius to the Sun , they found differences in the strength and number of their absorption lines ? the dark lines in a stellar spectra caused by the atmosphere 's absorption of specific frequencies . In 1865 Secchi began classifying stars into spectral types . However , the modern version of the stellar classification scheme was developed by Annie J. Cannon during the 1900s .

The first direct measurement of the distance to a star (61 Cygni at 11 @.@ 4 light @-@ years) was made in 1838 by Friedrich Bessel using the parallax technique . Parallax measurements demonstrated the vast separation of the stars in the heavens . Observation of double stars gained increasing importance during the 19th century . In 1834 , Friedrich Bessel observed changes in the

proper motion of the star Sirius and inferred a hidden companion . Edward Pickering discovered the first spectroscopic binary in 1899 when he observed the periodic splitting of the spectral lines of the star Mizar in a 104 @-@ day period . Detailed observations of many binary star systems were collected by astronomers such as William Struve and S. W. Burnham , allowing the masses of stars to be determined from computation of orbital elements . The first solution to the problem of deriving an orbit of binary stars from telescope observations was made by Felix Savary in 1827 . The twentieth century saw increasingly rapid advances in the scientific study of stars . The photograph became a valuable astronomical tool . Karl Schwarzschild discovered that the color of a star and , hence , its temperature , could be determined by comparing the visual magnitude against the photographic magnitude . The development of the photoelectric photometer allowed precise measurements of magnitude at multiple wavelength intervals . In 1921 Albert A. Michelson made the first measurements of a stellar diameter using an interferometer on the Hooker telescope at Mount Wilson Observatory .

Important theoretical work on the physical structure of stars occurred during the first decades of the twentieth century . In 1913 , the Hertzsprung @-@ Russell diagram was developed , propelling the astrophysical study of stars . Successful models were developed to explain the interiors of stars and stellar evolution . Cecilia Payne @-@ Gaposchkin first proposed that stars were made primarily of hydrogen and helium in her 1925 PhD thesis . The spectra of stars were further understood through advances in quantum physics . This allowed the chemical composition of the stellar atmosphere to be determined .

With the exception of supernovae , individual stars have primarily been observed in the Local Group , and especially in the visible part of the Milky Way (as demonstrated by the detailed star catalogues available for our galaxy) . But some stars have been observed in the M100 galaxy of the Virgo Cluster , about 100 million light years from the Earth . In the Local Supercluster it is possible to see star clusters , and current telescopes could in principle observe faint individual stars in the Local Group (see Cepheids) . However , outside the Local Supercluster of galaxies , neither individual stars nor clusters of stars have been observed . The only exception is a faint image of a large star cluster containing hundreds of thousands of stars located at a distance of one billion light years ? ten times further than the most distant star cluster previously observed .

= = Designations = =

The concept of a constellation was known to exist during the Babylonian period . Ancient sky watchers imagined that prominent arrangements of stars formed patterns , and they associated these with particular aspects of nature or their myths . Twelve of these formations lay along the band of the ecliptic and these became the basis of astrology . Many of the more prominent individual stars were also given names , particularly with Arabic or Latin designations .

As well as certain constellations and the Sun itself , individual stars have their own myths . To the Ancient Greeks , some " stars " , known as planets (Greek ???????? (plan?t?s) , meaning " wanderer ") , represented various important deities , from which the names of the planets Mercury , Venus , Mars , Jupiter and Saturn were taken . (Uranus and Neptune were also Greek and Roman gods , but neither planet was known in Antiquity because of their low brightness . Their names were assigned by later astronomers .)

Circa 1600 , the names of the constellations were used to name the stars in the corresponding regions of the sky . The German astronomer Johann Bayer created a series of star maps and applied Greek letters as designations to the stars in each constellation . Later a numbering system based on the star 's right ascension was invented and added to John Flamsteed 's star catalogue in his book " Historia coelestis Britannica " (the 1712 edition) , whereby this numbering system came to be called Flamsteed designation or Flamsteed numbering .

The only internationally recognized authority for naming celestial bodies is the International Astronomical Union (IAU) . A number of private companies sell names of stars , which the British Library calls an unregulated commercial enterprise . The IAU has disassociated itself from this commercial practice , and these names are neither recognized by the IAU nor used by them . One

such star @-@ naming company is the International Star Registry , which , during the 1980s , was accused of deceptive practice for making it appear that the assigned name was official . This now @-@ discontinued ISR practice was informally labeled a scam and a fraud , and the New York City Department of Consumer Affairs issued a violation against ISR for engaging in a deceptive trade practice .

Units of measurement

Although stellar parameters can be expressed in SI units or CGS units , it is often most convenient to express mass , luminosity , and radii in solar units , based on the characteristics of the Sun :
Large lengths , such as the radius of a giant star or the semi @-@ major axis of a binary star system , are often expressed in terms of the astronomical unit ? approximately equal to the mean distance between the Earth and the Sun (150 million km or 93 million miles) .

Formation and evolution

Stars condense from regions of space of higher density , yet those regions are less dense than within a vacuum chamber . These regions - known as molecular clouds - consist mostly of hydrogen , with about 23 to 28 percent helium and a few percent heavier elements . One example of such a star @-@ forming region is the Orion Nebula . Most stars form in groups of dozens to hundreds of thousands of stars . Massive stars in these groups may powerfully illuminate those clouds , ionizing the hydrogen , and creating H II regions . Such feedback effects , from star formation , may ultimately disrupt the cloud and prevent further star formation .
All stars spend the majority of their existence as main sequence stars , fueled primarily by the nuclear fusion of hydrogen into helium within their cores . However , stars of different masses have markedly different properties at various stages of their development . The ultimate fate of more massive stars differs from that of less massive stars , as do their luminosities and the impact they have on their environment . Accordingly , astronomers often group stars by their mass :
Very low mass stars , with masses below 0 @.@ 5 M ? , are fully convective and distribute helium evenly throughout the whole star while on the main sequence . Therefore , they never undergo shell burning , never become red giants , which cease fusing and become helium white dwarfs and slowly cool after exhausting their hydrogen . However , as the lifetime of 0 @.@ 5 M ? stars is longer than the age of the universe , no such star has yet reached the white dwarf stage .
Low mass stars (including the Sun) , with a mass between 0 @.@ 5 M ? and 1 @.@ 8 ? 2 @.@ 5 M ? depending on composition , do become red giants as their core hydrogen is depleted and they begin to burn helium in core in a helium flash ; they develop a degenerate carbon @-@ oxygen core later on the asymptotic giant branch ; they finally blow off their outer shell as a planetary nebula and leave behind their core in the form of a white dwarf .
Intermediate @-@ mass stars , between 1 @.@ 8 ? 2 @.@ 5 M ? and 5 ? 10 M ? , pass through evolutionary stages similar to low mass stars , but after a relatively short period on the RGB they ignite helium without a flash and spend an extended period in the red clump before forming a degenerate carbon @-@ oxygen core .
Massive stars generally have a minimum mass of 7 ? 10 M ? (possibly as low as 5 ? 6 M ?) . After exhausting the hydrogen at the core these stars become supergiants and go on to fuse elements heavier than helium . They end their lives when their cores collapse and they explode as supernovae .

Star formation

The formation of a star begins with gravitational instability within a molecular cloud , caused by regions of higher density - often triggered by compression of clouds by radiation from massive stars , expanding bubbles in the interstellar medium , the collision of different molecular clouds , or the collision of galaxies (as in a starburst galaxy) . When a region reaches a sufficient density of matter

to satisfy the criteria for Jeans instability , it begins to collapse under its own gravitational force .

As the cloud collapses , individual conglomerations of dense dust and gas form " Bok globules " . As a globule collapses and the density increases , the gravitational energy converts into heat and the temperature rises . When the protostellar cloud has approximately reached the stable condition of hydrostatic equilibrium , a protostar forms at the core . These pre ? main sequence stars are often surrounded by a protoplanetary disk and powered mainly by the conversion of gravitational energy . The period of gravitational contraction lasts about 10 to 15 million years .

Early stars of less than 2 M ? are called T Tauri stars , while those with greater mass are Herbig Ae / Be stars . These newly formed stars emit jets of gas along their axis of rotation , which may reduce the angular momentum of the collapsing star and result in small patches of nebulosity known as Herbig ? Haro objects . These jets , in combination with radiation from nearby massive stars , may help to drive away the surrounding cloud from which the star was formed .

Early in their development , T Tauri stars follow the Hayashi track ? they contract and decrease in luminosity while remaining at roughly the same temperature . Less massive T Tauri stars follow this track to the main sequence , while more massive stars turn onto the Henyey track .

Most stars are observed to be members of binary star systems , and the properties of those binaries are the result of the conditions in which they formed . A gas cloud must lose its angular momentum in order to collapse and form a star . The fragmentation of the cloud into multiple stars distributes some of that angular momentum . The primordial binaries transfer some angular momentum by gravitational interactions during close encounters with other stars in young stellar clusters . These interactions tend to split apart more widely separated (soft) binaries while causing hard binaries to become more tightly bound . This produces the separation of binaries into their two observed populations distributions .

= = = Main sequence = = =

Stars spend about 90 % of their existence fusing hydrogen into helium in high @-@ temperature and high @-@ pressure reactions near the core . Such stars are said to be on the main sequence , and are called dwarf stars . Starting at zero @-@ age main sequence , the proportion of helium in a star 's core will steadily increase , the rate of nuclear fusion at the core will slowly increase , as will the star 's temperature and luminosity . The Sun , for example , is estimated to have increased in luminosity by about 40 % since it reached the main sequence 4 @.@ 6 billion (4 @.@ 6 × 109) years ago .

Every star generates a stellar wind of particles that causes a continual outflow of gas into space . For most stars , the mass lost is negligible . The Sun loses 10 ? 14 M ? every year , or about 0 @.@ 01 % of its total mass over its entire lifespan . However , very massive stars can lose 10 ? 7 to 10 ? 5 M ? each year , significantly affecting their evolution . Stars that begin with more than 50 M ? can lose over half their total mass while on the main sequence .

The time a star spends on the main sequence depends primarily on the amount of fuel it has and the rate at which it fuses it . The Sun 's is expected to live 10 billion (1010) years . Massive stars consume their fuel very rapidly and are short @-@ lived . Low mass stars consume their fuel very slowly . Stars less massive than 0 @.@ 25 M ? , called red dwarfs , are able to fuse nearly all of their mass while stars of about 1 M ? can only fuse about 10 % of their mass . The combination of their slow fuel @-@ consumption and relatively large usable fuel supply allows low mass stars to last about one trillion (1012) years ; the most extreme of 0 @.@ 08 M ?) will last for about 12 trillion years . Red dwarfs become hotter and more luminous as they accumulate helium . When they eventually run out of hydrogen , they contract into a white dwarf and decline in temperature . However , since the lifespan of such stars is greater than the current age of the universe (13 @.@ 8 billion years) , no stars under about 0 @.@ 85 M ? are expected to have moved off the main sequence .

Besides mass , the elements heavier than helium can play a significant role in the evolution of stars . Astronomers label all elements heavier than helium " metals " , and call the chemical concentration of these elements in a star , its metallicity . A star 's metallicity can influence the time the star takes

to burn its fuel , and controls the formation of its magnetic fields , which affects the strength of its stellar wind . Older , population II stars have substantially less metallicity than the younger , population I stars due to the composition of the molecular clouds from which they formed . Over time , such clouds become increasingly enriched in heavier elements as older stars die and shed portions of their atmospheres .

= = = Post ? main sequence = = =

As stars of at least 0 @.@ 4 M ? exhaust their supply of hydrogen at their core , they start to fuse hydrogen in a shell outside the helium core . Their outer layers expand and cool greatly as they form a red giant . In about 5 billion years , when the Sun enters the helium burning phase , it will expand to a maximum radius of roughly 1 astronomical unit (150 million kilometres) , 250 times its present size , and lose 30 % of its current mass .

As the hydrogen shell burning produces more helium , the core increases in mass and temperature . In a red giant of up to 2 @.@ 25 M ? , the mass of the helium core becomes degenerate prior to helium fusion . Finally , when the temperature increases sufficiently , helium fusion begins explosively in what is called a helium flash , and the star rapidly shrinks in radius , increases its surface temperature , and moves to the horizontal branch of the HR diagram . For more massive stars , helium core fusion starts before the core becomes degenerate , and the star spends some time in the red clump , slowly burning helium , before the outer convective envelope collapses and the star then moves to the horizontal branch .

After the star has fused the helium of its core , the carbon product fuses producing a hot core with an outer shell of fusing helium . The star then follows an evolutionary path called the asymptotic giant branch (AGB) that parallels the other described red giant phase , but with a higher luminosity . The more massive AGB stars may undergo a brief period of carbon fusion before the core becomes degenerate .

= = = = Massive stars = = = =

During their helium @-@ burning phase , stars of more than nine solar masses expand to form red supergiants . When this fuel is exhausted at the core , they continue to fuse elements heavier than helium .

The core contracts and the temperature and pressure rises enough to fuse carbon (see Carbon burning process) . This process continues , with the successive stages being fueled by neon (see neon burning process) , oxygen (see oxygen burning process) , and silicon (see silicon burning process) . Near the end of the star 's life , fusion continues along a series of onion @-@ layer shells within a massive star . Each shell fuses a different element , with the outermost shell fusing hydrogen ; the next shell fusing helium , and so forth .

The final stage occurs when a massive star begins producing iron . Since iron nuclei are more tightly bound than any heavier nuclei , any fusion beyond iron does not produce a net release of energy . To a very limited degree such a process proceeds , but it consumes energy . Likewise , since they are more tightly bound than all lighter nuclei , such energy cannot be released by fission . In relatively old , very massive stars , a large core of inert iron will accumulate in the center of the star . The heavier elements in these stars can work their way to the surface , forming evolved objects known as Wolf @-@ Rayet stars that have a dense stellar wind which sheds the outer atmosphere .

= = = = Collapse = = = =

As a star 's core shrinks , the intensity of radiation from that surface increases , creating such radiation pressure on the outer shell of gas that it will push those layers away , forming a planetary nebula . If what remains after the outer atmosphere has been shed is less than 1 @.@ 4 M ? , it shrinks to a relatively tiny object about the size of Earth , known as a white dwarf . White dwarfs lack

the mass for further gravitational compression to take place . The electron @-@ degenerate matter inside a white dwarf is no longer a plasma , even though stars are generally referred to as being spheres of plasma . Eventually , white dwarfs fade into black dwarfs over a very long period of time .

In larger stars , fusion continues until the iron core has grown so large (more than 1 @.@ 4 M ?) that it can no longer support its own mass . This core will suddenly collapse as its electrons are driven into its protons , forming neutrons , neutrinos , and gamma rays in a burst of electron capture and inverse beta decay . The shockwave formed by this sudden collapse causes the rest of the star to explode in a supernova . Supernovae become so bright that they may briefly outshine the star 's entire home galaxy . When they occur within the Milky Way , supernovae have historically been observed by naked @-@ eye observers as " new stars " where none seemingly existed before .

A supernova explosion blows away the star 's outer layers , leaving a remnant such as the Crab Nebula . The core is compressed into a neutron star , which sometimes manifests itself as a pulsar or X @-@ ray burster . In the case of the largest stars , the remnant is a black hole greater than 4 M ?) s . In a neutron star the matter is in a state known as neutron @-@ degenerate matter , with a more exotic form of degenerate matter , QCD matter , possibly present in the core . Within a black hole , the matter is in a state that is not currently understood .

The blown @-@ off outer layers of dying stars include heavy elements , which may be recycled during the formation of new stars . These heavy elements allow the formation of rocky planets . The outflow from supernovae and the stellar wind of large stars play an important part in shaping the interstellar medium .

==== Binary stars ====

The post ? main @-@ sequence evolution of binary stars may be significantly different from the evolution of single stars of the same mass . If stars in a binary system are sufficiently close , when one of the stars expands to become a red giant it may overflow its Roche lobe , the region around a star where material is gravitationally bound to that star , leading to transfer of material to the other . When the Roche lobe is violated , a variety of phenomena can result , including contact binaries , common @-@ envelope binaries , cataclysmic variables , and type Ia supernovae .

== Distribution ==

In addition to isolated stars , a multi @-@ star system can consist of two or more gravitationally bound stars that orbit each other . The simplest and most common multi @-@ star system is a binary star , but systems of three or more stars are also found . For reasons of orbital stability , such multi @-@ star systems are often organized into hierarchical sets of binary stars . Larger groups called star clusters also exist . These range from loose stellar associations with only a few stars , up to enormous globular clusters with hundreds of thousands of stars . Such systems orbit our Milky Way galaxy .

It has been a long @-@ held assumption that the majority of stars occur in gravitationally bound , multiple @-@ star systems . This is particularly true for very massive O and B class stars , where 80 % of the stars are believed to be part of multiple @-@ star systems . The proportion of single star systems increases with decreasing star mass , so that only 25 % of red dwarfs are known to have stellar companions . As 85 % of all stars are red dwarfs , most stars in the Milky Way are likely single from birth .

Stars are not spread uniformly across the universe , but are normally grouped into galaxies along with interstellar gas and dust . A typical galaxy contains hundreds of billions of stars , and there are more than 100 billion (1011) galaxies in the observable universe . In 2010 , one estimate of the number of stars in the observable universe was 300 sextillion (3 × 1023) . While it is often believed that stars only exist within galaxies , intergalactic stars have been discovered .

The nearest star to the Earth , apart from the Sun , is Proxima Centauri , which is 39 @.@ 9 trillion kilometres , or 4 @.@ 2 light @-@ years . Travelling at the orbital speed of the Space Shuttle (8

kilometres per second ? almost 30 @,@ 000 kilometres per hour) , it would take about 150 @,@ 000 years to arrive . This it typical of stellar separations in galactic discs . Stars can be much closer to each other in the centres of galaxies and in globular clusters , or much farther apart in galactic halos .

Due to the relatively vast distances between stars outside the galactic nucleus , collisions between stars are thought to be rare . In denser regions such as the core of globular clusters or the galactic center , collisions can be more common . Such collisions can produce what are known as blue stragglers . These abnormal stars have a higher surface temperature than the other main sequence stars with the same luminosity of the cluster to which it belongs .

= = Characteristics = =

Almost everything about a star is determined by its initial mass , including such characteristics as luminosity , size , evolution , lifespan , and its eventual fate .

= = = Age = = =

Most stars are between 1 billion and 10 billion years old . Some stars may even be close to 13 @.@ 8 billion years old ? the observed age of the universe . The oldest star yet discovered , HD 140283 , nicknamed Methuselah star , is an estimated 14 @.@ 46 ± 0 @.@ 8 billion years old . (Due to the uncertainty in the value , this age for the star does not conflict with the age of the Universe , determined by the Planck satellite as 13 @.@ 799 ± 0 @.@ 021) .

The more massive the star , the shorter its lifespan , primarily because massive stars have greater pressure on their cores , causing them to burn hydrogen more rapidly . The most massive stars last an average of a few million years , while stars of minimum mass (red dwarfs) burn their fuel very slowly and can last tens to hundreds of billions of years .

= = = Chemical composition = = =

When stars form in the present Milky Way galaxy they are composed of about 71 % hydrogen and 27 % helium , as measured by mass , with a small fraction of heavier elements . Typically the portion of heavy elements is measured in terms of the iron content of the stellar atmosphere , as iron is a common element and its absorption lines are relatively easy to measure . The portion of heavier elements may be an indicator of the likelihood that the star has a planetary system .

The star with the lowest iron content ever measured is the dwarf HE1327 @-@ 2326 , with only 1 / 200,000th the iron content of the Sun . By contrast , the super @-@ metal @-@ rich star ? Leonis has nearly double the abundance of iron as the Sun , while the planet @-@ bearing star 14 Herculis has nearly triple the iron . There also exist chemically peculiar stars that show unusual abundances of certain elements in their spectrum ; especially chromium and rare earth elements . Stars with cooler outer atmospheres , including the Sun , can form various diatomic and polyatomic molecules .

= = = Diameter = = =

Due to their great distance from the Earth , all stars except the Sun appear to the unaided eye as shining points in the night sky that twinkle because of the effect of the Earth 's atmosphere . The Sun is also a star , but it is close enough to the Earth to appear as a disk instead , and to provide daylight . Other than the Sun , the star with the largest apparent size is R Doradus , with an angular diameter of only 0 @.@ 057 arcseconds .

The disks of most stars are much too small in angular size to be observed with current ground @-@ based optical telescopes , and so interferometer telescopes are required to produce images of these objects . Another technique for measuring the angular size of stars is through occultation . By precisely measuring the drop in brightness of a star as it is occulted by the Moon (or the rise in

brightness when it reappears) , the star 's angular diameter can be computed .

Stars range in size from neutron stars , which vary anywhere from 20 to 40 km (25 mi) in diameter , to supergiants like Betelgeuse in the Orion constellation , which has a diameter approximately 1 @,@ 070 times that of the Sun ? about 1 @,@ 490 @,@ 171 @,@ 880 km (925 @,@ 949 @,@ 878 mi) . Betelgeuse , however , has a much lower density than the Sun .

= = = Kinematics = = =

The motion of a star relative to the Sun can provide useful information about the origin and age of a star , as well as the structure and evolution of the surrounding galaxy . The components of motion of a star consist of the radial velocity toward or away from the Sun , and the traverse angular movement , which is called its proper motion .

Radial velocity is measured by the doppler shift of the star 's spectral lines , and is given in units of km / s . The proper motion of a star , its parallax , is determined by precise astrometric measurements in units of milli @-@ arc seconds (mas) per year . With knowledge of the star 's parallax and its distance , the proper motion velocity can be calculated . Together with the radial velocity , the total velocity can be calculated . Stars with high rates of proper motion are likely to be relatively close to the Sun , making them good candidates for parallax measurements .

When both rates of movement are known , the space velocity of the star relative to the Sun or the galaxy can be computed . Among nearby stars , it has been found that younger population I stars have generally lower velocities than older , population II stars . The latter have elliptical orbits that are inclined to the plane of the galaxy . A comparison of the kinematics of nearby stars has allowed astronomers to trace their origin to common points in giant molecular clouds , and are referred to as stellar associations .

= = = Magnetic field = = =

The magnetic field of a star is generated within regions of the interior where convective circulation occurs . This movement of conductive plasma functions like a dynamo , wherein the movement of elecrical charges induce magnetic fields , as does a mechanical dynamo . Those magnetic fields have a great range that extend throughout and beyond the star . The strength of the magnetic field varies with the mass and composition of the star , and the amount of magnetic surface activity depends upon the star 's rate of rotation . This surface activity produces starspots , which are regions of strong magnetic fields and lower than normal surface temperatures . Coronal loops are arching magnetic field flux lines that rise from a star 's surface into the star 's outer atmosphere , its corona . The coronal loops can be seen due to the plasma they conduct along their length . Stellar flares are bursts of high @-@ energy particles that are emitted due to the same magnetic activity .

Young , rapidly rotating stars tend to have high levels of surface activity because of their magnetic field . The magnetic field can act upon a star 's stellar wind , functioning as a brake to gradually slow the rate of rotation with time . Thus , older stars such as the Sun have a much slower rate of rotation and a lower level of surface activity . The activity levels of slowly rotating stars tend to vary in a cyclical manner and can shut down altogether for periods of time . During the Maunder minimum , for example , the Sun underwent a 70 @-@ year period with almost no sunspot activity .

= = = Mass = = =

One of the most massive stars known is Eta Carinae , which , with 100 ? 150 times as much mass as the Sun , will have a lifespan of only several million years . Studies of the most massive open clusters suggests 150 M ? as an upper limit for stars in the current era of the universe . This represents an empirical value for the theoretical limit on the mass of forming stars due to increasing radiation pressure on the accreting gas cloud . Several stars in the R136 cluster in the Large Magellanic Cloud have been measured with larger masses , but it has been determined that they could have been created through the collision and merger of massive stars in close binary systems ,

sidestepping the 150 M ? limit on massive star formation .

The first stars to form after the Big Bang may have been larger , up to 300 M ? , due to the complete absence of elements heavier than lithium in their composition . This generation of supermassive population III stars is likely to have existed in the very early universe (i.e. , they are observed to have a high redshift) , and may have started the production of chemical elements heavier than hydrogen that are needed for the later formation of planets and life . In June 2015 , astronomers reported evidence for Population III stars in the Cosmos Redshift 7 galaxy at z = 6 @.@ 60 .

With a mass only 80 times that of Jupiter (MJ) , 2MASS J0523 @-@ 1403 is the smallest known star undergoing nuclear fusion in its core . For stars with metallicity similar to the Sun , the theoretical minimum mass the star can have and still undergo fusion at the core , is estimated to be about 75 MJ . When the metallicity is very low , however , the minimum star size seems to be about 8 @.@ 3 % of the solar mass , or about 87 MJ . Smaller bodies called brown dwarfs , occupy a poorly defined grey area between stars and gas giants .

The combination of the radius and the mass of a star determines its surface gravity . Giant stars have a much lower surface gravity than do main sequence stars , while the opposite is the case for degenerate , compact stars such as white dwarfs . The surface gravity can influence the appearance of a star 's spectrum , with higher gravity causing a broadening of the absorption lines .

= = = Rotation = = =

The rotation rate of stars can be determined through spectroscopic measurement , or more exactly determined by tracking their starspots . Young stars can have a rotation greater than 100 km / s at the equator . The B @-@ class star Achernar , for example , has an equatorial velocity of about 225 km / s or greater , causing its equator to be slung outward and giving it an equatorial diameter that is more than 50 % greater than between the poles . This rate of rotation is just below the critical velocity of 300 km / s at which speed the star would break apart . By contrast , the Sun rotates once every 25 ? 35 days , with an equatorial velocity of 1 @.@ 994 km / s . A main sequence star 's magnetic field and the stellar wind serve to slow its rotation by a significant amount as it evolves on the main sequence .

Degenerate stars have contracted into a compact mass , resulting in a rapid rate of rotation . However they have relatively low rates of rotation compared to what would be expected by conservation of angular momentum ? the tendency of a rotating body to compensate for a contraction in size by increasing its rate of spin . A large portion of the star 's angular momentum is dissipated as a result of mass loss through the stellar wind . In spite of this , the rate of rotation for a pulsar can be very rapid . The pulsar at the heart of the Crab nebula , for example , rotates 30 times per second . The rotation rate of the pulsar will gradually slow due to the emission of radiation .

= = = Temperature = = =

The surface temperature of a main sequence star is determined by the rate of energy production of its core and by its radius , and is often estimated from the star 's color index . The temperature is normally given in terms of an effective temperature , which is the temperature of an idealized black body that radiates its energy at the same luminosity per surface area as the star . Note that the effective temperature is only a representative of the surface , as the temperature increases toward the core . The temperature in the core region of a star is several million kelvins .

The stellar temperature will determine the rate of ionization of various elements , resulting in characteristic absorption lines in the spectrum . The surface temperature of a star , along with its visual absolute magnitude and absorption features , is used to classify a star (see classification below) .

Massive main sequence stars can have surface temperatures of 50 @,@ 000 K. Smaller stars such as the Sun have surface temperatures of a few thousand K. Red giants have relatively low surface temperatures of about 3 @,@ 600 K ; but they also have a high luminosity due to their large exterior

surface area .

Radiation

The energy produced by stars , a product of nuclear fusion , radiates to space as both electromagnetic radiation and particle radiation . The particle radiation emitted by a star is manifested as the stellar wind , which streams from the outer layers as electrically charged protons and alpha and beta particles . Although almost massless , there also exists a steady stream of neutrinos emanating from the star 's core .

The production of energy at the core is the reason stars shine so brightly : every time two or more atomic nuclei fuse together to form a single atomic nucleus of a new heavier element , gamma ray photons are released from the nuclear fusion product . This energy is converted to other forms of electromagnetic energy of lower frequency , such as visible light , by the time it reaches the star 's outer layers .

The color of a star , as determined by the most intense frequency of the visible light , depends on the temperature of the star 's outer layers , including its photosphere . Besides visible light , stars also emit forms of electromagnetic radiation that are invisible to the human eye . In fact , stellar electromagnetic radiation spans the entire electromagnetic spectrum , from the longest wavelengths of radio waves through infrared , visible light , ultraviolet , to the shortest of X @-@ rays , and gamma rays . From the standpoint of total energy emitted by a star , not all components of stellar electromagnetic radiation are significant , but all frequencies provide insight into the star 's physics .

Using the stellar spectrum , astronomers can also determine the surface temperature , surface gravity , metallicity and rotational velocity of a star . If the distance of the star is found , such as by measuring the parallax , then the luminosity of the star can be derived . The mass , radius , surface gravity , and rotation period can then be estimated based on stellar models . (Mass can be calculated for stars in binary systems by measuring their orbital velocities and distances . Gravitational microlensing has been used to measure the mass of a single star .) With these parameters , astronomers can also estimate the age of the star .

Luminosity

The luminosity of a star is the amount of light and other forms of radiant energy it radiates per unit of time . It has units of power . The luminosity of a star is determined by its radius and surface temperature . Many stars do not radiate uniformly across their entire surface . The rapidly rotating star Vega , for example , has a higher energy flux (power per unit area) at its poles than along its equator .

Patches of the star 's surface with a lower temperature and luminosity than average are known as starspots . Small , dwarf stars such as our Sun generally have essentially featureless disks with only small starspots . Giant stars have much larger , more obvious starspots , and they also exhibit strong stellar limb darkening . That is , the brightness decreases towards the edge of the stellar disk . Red dwarf flare stars such as UV Ceti may also possess prominent starspot features .

Magnitude

The apparent brightness of a star is expressed in terms of its apparent magnitude . It is a function of the star 's luminosity , its distance from Earth , and the altering of the star 's light as it passes through Earth 's atmosphere . Intrinsic or absolute magnitude is directly related to a star 's luminosity , and is what the apparent magnitude a star would be if the distance between the Earth and the star were 10 parsecs (32 @.@ 6 light @-@ years) .

Both the apparent and absolute magnitude scales are logarithmic units : one whole number difference in magnitude is equal to a brightness variation of about 2 @.@ 5 times (the 5th root of 100 or approximately 2 @.@ 512) . This means that a first magnitude star (+ 1 @.@ 00) is about 2 @.@ 5 times brighter than a second magnitude (+ 2 @.@ 00) star , and about 100 times brighter

than a sixth magnitude star (+ 6 @.@ 00) . The faintest stars visible to the naked eye under good seeing conditions are about magnitude + 6 .

On both apparent and absolute magnitude scales , the smaller the magnitude number , the brighter the star ; the larger the magnitude number , the fainter the star . The brightest stars , on either scale , have negative magnitude numbers . The variation in brightness (ΔL) between two stars is calculated by subtracting the magnitude number of the brighter star (m_b) from the magnitude number of the fainter star (m_f) , then using the difference as an exponent for the base number 2 @.@ 512 ; that is to say :

<formula>
<formula>

Relative to both luminosity and distance from Earth , a star 's absolute magnitude (M) and apparent magnitude (m) are not equivalent ; for example , the bright star Sirius has an apparent magnitude of ? 1 @.@ 44 , but it has an absolute magnitude of + 1 @.@ 41 .

The Sun has an apparent magnitude of ? 26 @.@ 7 , but its absolute magnitude is only + 4 @.@ 83 . Sirius , the brightest star in the night sky as seen from Earth , is approximately 23 times more luminous than the Sun , while Canopus , the second brightest star in the night sky with an absolute magnitude of ? 5 @.@ 53 , is approximately 14 @,@ 000 times more luminous than the Sun . Despite Canopus being vastly more luminous than Sirius , however , Sirius appears brighter than Canopus . This is because Sirius is merely 8 @.@ 6 light @-@ years from the Earth , while Canopus is much farther away at a distance of 310 light @-@ years .

As of 2006 , the star with the highest known absolute magnitude is LBV 1806 @-@ 20 , with a magnitude of ? 14 @.@ 2 . This star is at least 5 @,@ 000 @,@ 000 times more luminous than the Sun . The least luminous stars that are currently known are located in the NGC 6397 cluster . The faintest red dwarfs in the cluster were magnitude 26 , while a 28th magnitude white dwarf was also discovered . These faint stars are so dim that their light is as bright as a birthday candle on the Moon when viewed from the Earth .

= = Classification = =

The current stellar classification system originated in the early 20th century , when stars were classified from A to Q based on the strength of the hydrogen line . It thought that the hydrogen line strength was a simple linear function of temperature . Rather , it was more complicated ; it strengthened with increasing temperature , it peaked near 9000 K , and then declined at greater temperatures . When the classifications were reordered by temperature , it more closely resembled the modern scheme .

Stars are given a single @-@ letter classification according to their spectra , ranging from type O , which are very hot , to M , which are so cool that molecules may form in their atmospheres . The main classifications in order of decreasing surface temperature are : O , B , A , F , G , K , and M. A variety of rare spectral types are given special classifications . The most common of these are types L and T , which classify the coldest low @-@ mass stars and brown dwarfs . Each letter has 10 sub @-@ divisions , numbered from 0 to 9 , in order of decreasing temperature . However , this system breaks down at extreme high temperatures as classes O0 and O1 may not exist .

In addition , stars may be classified by the luminosity effects found in their spectral lines , which correspond to their spatial size and is determined by their surface gravity . These range from 0 (hypergiants) through III (giants) to V (main sequence dwarfs) ; some authors add VII (white dwarfs) . Most stars belong to the main sequence , which consists of ordinary hydrogen @-@ burning stars . These fall along a narrow , diagonal band when graphed according to their absolute magnitude and spectral type . The Sun is a main sequence G2V yellow dwarf of intermediate temperature and ordinary size .

Additional nomenclature , in the form of lower @-@ case letters added to the end of the spectral type to indicate peculiar features of the spectrum . For example , an " e " can indicate the presence of emission lines ; " m " represents unusually strong levels of metals , and " var " can mean variations in the spectral type .

White dwarf stars have their own class that begins with the letter D. This is further sub @-@ divided into the classes DA , DB , DC , DO , DZ , and DQ , depending on the types of prominent lines found in the spectrum . This is followed by a numerical value that indicates the temperature .

= = Variable stars = =

Variable stars have periodic or random changes in luminosity because of intrinsic or extrinsic properties . Of the intrinsically variable stars , the primary types can be subdivided into three principal groups .
During their stellar evolution , some stars pass through phases where they can become pulsating variables . Pulsating variable stars vary in radius and luminosity over time , expanding and contracting with periods ranging from minutes to years , depending on the size of the star . This category includes Cepheid and Cepheid @-@ like stars , and long @-@ period variables such as Mira .
Eruptive variables are stars that experience sudden increases in luminosity because of flares or mass ejection events . This group includes protostars , Wolf @-@ Rayet stars , and flare stars , as well as giant and supergiant stars .
Cataclysmic or explosive variable stars are those that undergo a dramatic change in their properties . This group includes novae and supernovae . A binary star system that includes a nearby white dwarf can produce certain types of these spectacular stellar explosions , including the nova and a Type 1a supernova . The explosion is created when the white dwarf accretes hydrogen from the companion star , building up mass until the hydrogen undergoes fusion . Some novae are also recurrent , having periodic outbursts of moderate amplitude .
Stars can also vary in luminosity because of extrinsic factors , such as eclipsing binaries , as well as rotating stars that produce extreme starspots . A notable example of an eclipsing binary is Algol , which regularly varies in magnitude from 2 @.@ 3 to 3 @.@ 5 over a period of 2 @.@ 87 days .

= = Structure = =

The interior of a stable star is in a state of hydrostatic equilibrium : the forces on any small volume almost exactly counterbalance each other . The balanced forces are inward gravitational force and an outward force due to the pressure gradient within the star . The pressure gradient is established by the temperature gradient of the plasma ; the outer part of the star is cooler than the core . The temperature at the core of a main sequence or giant star is at least on the order of 107 K. The resulting temperature and pressure at the hydrogen @-@ burning core of a main sequence star are sufficient for nuclear fusion to occur and for sufficient energy to be produced to prevent further collapse of the star .
As atomic nuclei are fused in the core , they emit energy in the form of gamma rays . These photons interact with the surrounding plasma , adding to the thermal energy at the core . Stars on the main sequence convert hydrogen into helium , creating a slowly but steadily increasing proportion of helium in the core . Eventually the helium content becomes predominant , and energy production ceases at the core . Instead , for stars of more than 0 @.@ 4 M ? , fusion occurs in a slowly expanding shell around the degenerate helium core .
In addition to hydrostatic equilibrium , the interior of a stable star will also maintain an energy balance of thermal equilibrium . There is a radial temperature gradient throughout the interior that results in a flux of energy flowing toward the exterior . The outgoing flux of energy leaving any layer within the star will exactly match the incoming flux from below .
The radiation zone is the region of the stellar interior where the flux of energy outward is dependent on radiative heat transfer , since convective heat transfer is inefficient in that zone . In this region the plasma will not be perturbed , and any mass motions will die out . If this is not the case , however , then the plasma becomes unstable and convection will occur , forming a convection zone . This can occur , for example , in regions where very high energy fluxes occur , such as near the core or in areas with high opacity (making radiatative heat transfer inefficient) as in the outer envelope .

The occurrence of convection in the outer envelope of a main sequence star depends on the star 's mass . Stars with several times the mass of the Sun have a convection zone deep within the interior and a radiative zone in the outer layers . Smaller stars such as the Sun are just the opposite , with the convective zone located in the outer layers . Red dwarf stars with less than 0 @.@ 4 M ? are convective throughout , which prevents the accumulation of a helium core . For most stars the convective zones will also vary over time as the star ages and the constitution of the interior is modified .

The photosphere is that portion of a star that is visible to an observer . This is the layer at which the plasma of the star becomes transparent to photons of light . From here , the energy generated at the core becomes free to propagate into space . It is within the photosphere that sun spots , regions of lower than average temperature , appear .

Above the level of the photosphere is the stellar atmosphere . In a main sequence star such as the Sun , the lowest level of the atmosphere , just above the photosphere , is the thin chromosphere region , where spicules appear and stellar flares begin . Above this is the transition region , where the temperature rapidly increases within a distance of only 100 km (62 mi) . Beyond this is the corona , a volume of super @-@ heated plasma that can extend outward to several million kilometres . The existence of a corona appears to be dependent on a convective zone in the outer layers of the star . Despite its high temperature , and the corona emits very little light , due to its low gas density . The corona region of the Sun is normally only visible during a solar eclipse .
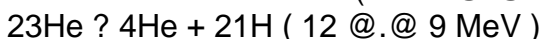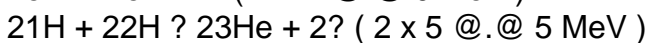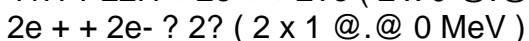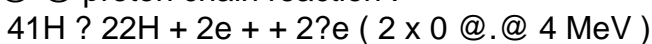
From the corona , a stellar wind of plasma particles expands outward from the star , until it interacts with the interstellar medium . For the Sun , the influence of its solar wind extends throughout a bubble @-@ shaped region called the heliosphere .

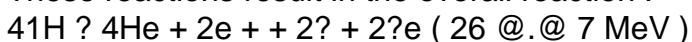= = Nuclear fusion reaction pathways = =

A variety of nuclear fusion reactions take place in the cores of stars , that depend upon their mass and composition . When nuclei fuse , the mass of the fused product is less than the mass of the original parts . This lost mass is converted to electromagnetic energy , according to the mass @-@ energy equivalence relationship $E = mc^2$.

The hydrogen fusion process is temperature @-@ sensitive , so a moderate increase in the core temperature will result in a significant increase in the fusion rate . As a result , the core temperature of main sequence stars only varies from 4 million kelvin for a small M @-@ class star to 40 million kelvin for a massive O @-@ class star .

In the Sun , with a 10 @-@ million @-@ kelvin core , hydrogen fuses to form helium in the proton @-@ proton chain reaction :

41H ? 22H + 2e + + 2?e (2 x 0 @.@ 4 MeV)
2e + + 2e- ? 2? (2 x 1 @.@ 0 MeV)
21H + 22H ? 23He + 2? (2 x 5 @.@ 5 MeV)
23He ? 4He + 21H (12 @.@ 9 MeV)

These reactions result in the overall reaction :

41H ? 4He + 2e + + 2? + 2?e (26 @.@ 7 MeV)

where e + is a positron , ? is a gamma ray photon , ?e is a neutrino , and H and He are isotopes of hydrogen and helium , respectively . The energy released by this reaction is in millions of electron volts , which is actually only a tiny amount of energy . However enormous numbers of these reactions occur constantly , producing all the energy necessary to sustain the star 's radiation output . In comparison , the combustion of two hydrogen gas molecules with one oxygen gas molecule releases only 5 @.@ 7 eV .

In more massive stars , helium is produced in a cycle of reactions catalyzed by carbon called the carbon @-@ nitrogen @-@ oxygen cycle .

In evolved stars with cores at 100 million kelvin and masses between 0 @.@ 5 and 10 M ? , helium can be transformed into carbon in the triple @-@ alpha process that uses the intermediate element beryllium :

4He + 4He + 92 keV ? 8 * Be
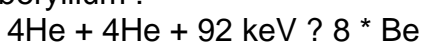
4He + 8 * Be + 67 keV ? 12 * C

12 * C ? 12C + ? + 7 @.@ 4 MeV

For an overall reaction of :

34He ? 12C + ? + 7 @.@ 2 MeV

In massive stars , heavier elements can also be burned in a contracting core through the neon burning process and oxygen burning process . The final stage in the stellar nucleosynthesis process is the silicon burning process that results in the production of the stable isotope iron @-@ 56 , an endothermic process that consumes energy , and so further energy can only be produced through gravitational collapse .

The example below shows the amount of time required for a star of 20 M ? to consume all of its nuclear fuel . As an O @-@ class main sequence star , it would be 8 times the solar radius and 62 @,@ 000 times the Sun 's luminosity .