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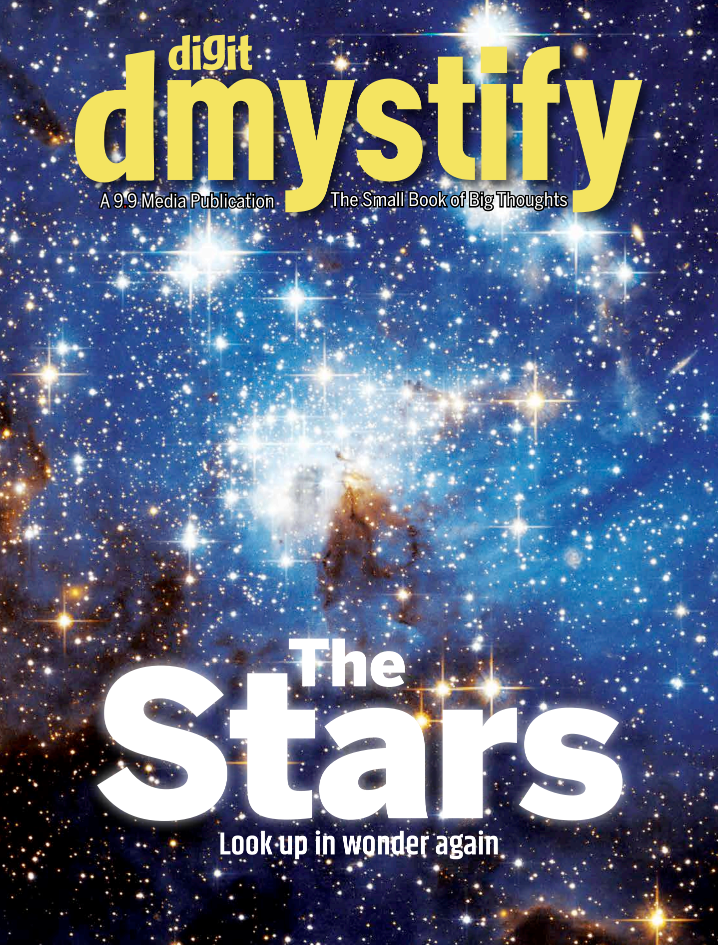
The Small Book of Big Thoughts



The Stars

Look up in wonder again

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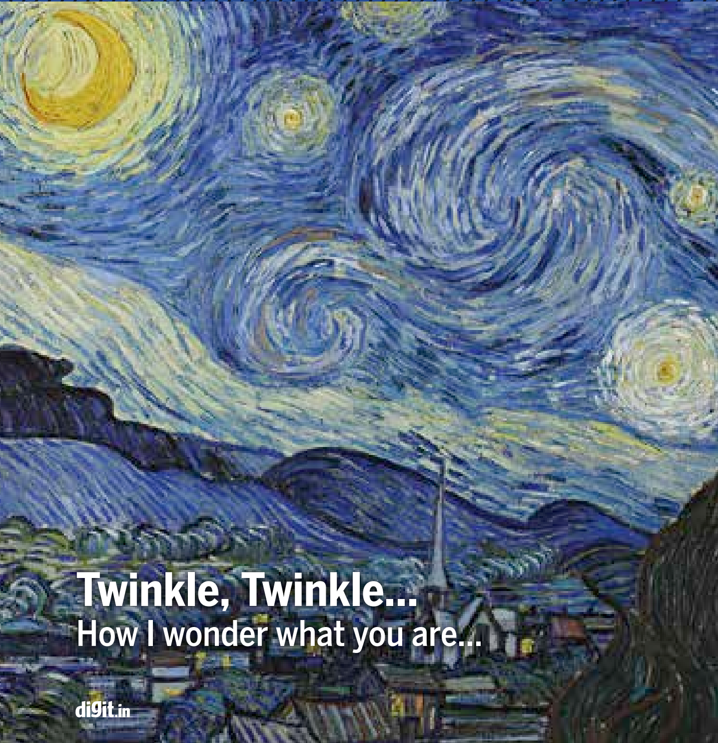
February 2017



Twinkle, Twinkle...

How I wonder what you are...

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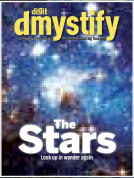
INSIDE



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We are star guts

Anyone who is interested in science, and our dmystify books, is probably also a star junkie. You have probably watched videos of space, read about it, and daydreamed at some point in your life about travelling amongst the stars. Although that's not really possible right now, we hope this book will give you a chance to daydream a little again.

Stars died so you could live! All hail the stars; praise be to the stars! This is true, because all that we see that isn't Hydrogen in the universe is made by stars, by a process that we will explain later in this book. For billions of years the stars have shone in space, and only now in the last few hundred years has our species truly been able to understand them. From thinking that there were only a few thousand stars just a few hundred years ago to a million, then a billion, and then to the current estimation of 1,000,000,000,000 ,000,000,000,000. The easiest way to say that is a trillion, trillion stars. Now that's just a number, so let's compare that with ALL the grains of sands on planet earth. Rough estimates put that at about 7,000,000,000,000,000,000 grains of sand total on Earth. So the ratio of stars in the universe to grains of sand on earth is about 1,000,000:7, or, the amount of grains of sands on 142,857 Earths! So what do we know about a trillion trillion stars? Read on... ■

The history of the stars

Well, more like our history of understanding them

At no time in Earth's 4.4 billion year history have stars not shone down in the night sky. Thus, astronomy is our oldest science. The first living things capable of wonder, have, without doubt, looked up at the night sky and been awed. Over millions of years, all the species of hominids that we've descended from, used to look up at the stars and let their imaginations run wild. We are no different.

It's not just staring at stars that has been common, but noticing patterns, identifying them, tracking their movement, making star maps... mankind has been fascinated by the stars more than any other subject, and for much longer.

Prehistory

By its very nature, prehistory is nothing more than an educated speculation, because we really do not know anything about events that are prehistoric, especially involving how humans thought. Archaeological evidence gives us clues, but with no written history, it's impossible to be sure. A classic example are the monoliths found across the globe. Their positioning and placement, such as with Stonehenge in England, seem to suggest something to do with heavenly bodies – most often the sun.

Our best guess is that heavenly bodies were worshiped as gods or spirits by prehistoric man. Mankind has the habit of assigning divine explanations for things we do not understand, and this was obviously true in the past as well. We also have the desire to find patterns in everything, in order to find a reason, or an explanation that makes sense to us, and prehistoric priests were probably citing things such as solar or lunar eclipses as omens, and associating droughts, floods, and other weather phenomenon with celestial patterns (wrongly, of course).

Heck, we still haven't been able to get rid of astrology, which is exactly such superstitious pattern matching, which claims that the positions of the stars in the sky at the time of your birth (or conception), govern who you are and the characteristics of your personality. Not only that, astrologers claim to be able to read your future, and make predictions about it. Despite many scientific studies proving these claims false, it still exists and is a thriving business. Sadly, we

Stonehenge, constructed in 3000 BC is thought to be linked to the sun and moon

Indians are especially exposed to such magicians, in some form or the other through our lives – when changing jobs, getting married, etc. However, this isn't supposed to be a rant against superstitions such as astrology, it's supposed to be a history of astronomy, so back to the point...

Sun and moon

One of the most obvious patterns for even early, prehistoric human settlements would have been the seasons. The way the sun moves in the sky, following patterns of the moon, the length of day and night is always changing, but with a set pattern that repeats after a set time interval. This interval is what we call a year now, but back then it was only just being discovered. Soon they had enough data to be able to predict, "Winter is coming", and did so accurately. This would seem almost magical to the natives of the time, and it's no wonder that such things were considered mystical and left to the priests. Back then, science and religion were very intertwined, and some would say it was early science that gave religion the power it needed to rule over people.

More prehistory

There is a whole field of science called Archaeoastronomy, which looks through history to try and learn how prehistoric humans tried to look at the stars. Some of the interesting finds of archaeo-astronomy are listed below:

Alexander Marshack found bones and cave art (scratches) dating to 32,000 BC which have markings that track the cycle of the moon on them. These markings are carefully etched to be of different thicknesses to indicate a waxing or waning moon.

This is evidence of humans doing some basic astronomy at least 34,000 years ago!

An archaeological dig at Warren Field in Scotland stumbled upon the world's oldest calendar (this is covered in more detail in our *dmystify Time* book). This is a 10,000 year old (8,000 BC) structure that is made up 12 pits that are used to track the movement of the moon, and also correct for the winter solstice, thus adjusting the lunar calendar to also be in sync with the solar cycle.

The Nebra Sky Disk, and the Goseck Circle are German finds from 1600 BC and 5000 BC respectively. These were used to measure the solstices, and tracked the solar cycle. The Nebra sky disk is assumed to be a portable instrument to measure solstices. The Goseck circle is the opposite of portable; it's a set of concentric ditches with a radius of about 75 metres, with gaps in the circles that are exactly in line with the direction of the sunrise and sunset on solstice days. Radioactive dating of the site has set a date of 4900 BC, and pottery has been found at the site dating to as late as 4700 BC, which means people lived next to it and used it for at least 200 years.

There are many more such finds, and we could fill up the whole book with them, but that would be an injustice to the topic. If your interest in archaeology and archaeoastronomy has been whetted by this little introduction, we recommend the book *Archaeoastronomy: Introduction to the Science of Stars and Stones,* by Giulio Magli.

Ancient Indians

As usual, we are always left wishing that ancient Indians would have chosen to write instead of pass down information orally. Because oral accounts can easily be faked, or can be polluted with newer learnings being tacked on all the time, it's impossible to assign a specific date. What this means is that all the Indians who lived before the Indus Valley Civilisation are considered to be prehistory, as there is no proof of their contributions. Sad, but understandable, because the written word is the only real proof of ancient knowledge that can be accurately dated.

Many historians believe that the Vedas were not merely passed on orally, as the texts that have survived across the country and in Nepal are way too consistent and nearly identical. This, many historians feel, is proof that the Vedas share a written and oral tradition, with perhaps commoners only hearing the oral versions, while learned scholars would have written copies written on sheets made of bark or on palm leaves. The nature of the "paper" (palm leaves and bark) mean that no copies of the vedas are found that are more than a few hundred years old. The oldest in India is from the 14th century, and in Nepal dates to the 11th century (no more than 1000 years old). However, historians are pretty sure the Vedas originated sometime between 1500 and 1000 BC.

Coming back to astronomy, the Vedas contain references to the motion of the stars over the course of a year. Almost all of the astronomy done in ancient India was because of religious reasons, however. We are all aware of our national obsession of doing things at auspicious times, even today, and many of us who know this to be mere superstition will still partake, because what harm can it do, right?

The Vedanga Jyotisha is perhaps the oldest Indian astronomical text, which describes a winter solstice that occurred in (roughly) 1180 BCE. This leads historians to believe it to be approximately from 1200 BCE. The details it contains include the calculation of a lunar year, including a leap lunar month, the 12 zodiac signs, seven planets, and also knowledge and calculations of lunar and solar eclipses.

Next, we have to fast forward all the way to Aryabhata (476-550 CE), to get a look at the next big push forward for Indian astronomy. And what a push it was! Aryabhata's writing, titled Āryabhatīya is the most famous work of astronomy to ever come out of India. It deeply influenced a lot of later Indian mathematicians, such as Bhaskara I and Bhramagupta. It is perhaps the first astronomical publication across all civilisations to start the day at midnight (as we do even today), and noted that the Earth spins on its axis, which causes the stars to look as if they are in motion, when they are actually fixed. He calculated that the circumference of the Earth was 39,967 km (just 108 km off the modern value of 40,075 km). He wrote about how the moon only shines because it reflects sunlight, and also made many

Artist's impression of a triple star sunset from the moon of a large planet

more claims that we now know to be pretty accurate. So good was this work that the Islamic invaders took copies of it with them, and it kickstarted the Islamic astronomy movement.

The Stars

While many ancient people (as mentioned above) were obsessed with the sun and the moon, eventually humans shifted their focus to the background stars instead. Yes, the sun may be the closest star to us, but ancient people didn't know that. To them, the stars were something else, and were studied in great detail eventually.

It is in Egypt where the oldest star chart has been found (so far). It has been accurately dated to about 1530 BC. After that, the Babylonians started compiling star catalogues between 1500 and 1150 BC.

This continued with the Greeks creating even more comprehensive star catalogues in and around 300 BC. The Chinese also had star catalogues from around the same time, and in 185 AD they noted a supernova. We now know this event as SN 185, which happened on December 7, 185 AD. the Chinese noted it as a "guest star" because it appeared from nowhere and disappeared soon after (eight months later). This is the oldest known observation of a supernova.

Islamic astronomy catalogued and named many stars with Arabic names, many of which we use even today. Some examples are Betelgeuse (Ibṭ ul-Jawzā' – Armpit of the central one), Rigel (Rijl ul-Jabbār – Foot of the Giant), Fomalhaut (Fum al-Ḥūt – Mouth of the Whale) and Vega (an-Nisr ul-Wāqiʿ – the Falling Eagle).

Like the Sun

We all know today that the Sun is just one of the trillion trillion (septillion) stars out there, but it was an idea that was only played with every now and then in ancient history. Anaxogoras, a Greek astronomer first suggested it in 450 BC. He suggested that the stars and the sun were fiery stones that were hundreds of miles in size, and that other stars were just really far away, which is why their heat couldn't be felt. He was eventually imprisoned for his ideas.

Another Greek astronomer, Aristarchus (310-230 BC) later calculated the size of the sun and the earth, and the distances between them. Although his measurements were way off, he did calculate a much bigger sun than an Earth, and suggested that the earth revolved around the sun, instead of the other way around. He was also threatened for holding such ideas by the powers that were at the time, and was ignored.

Ptolomy came along in 140 AD with a geocentric (earth at the centre) model of the universe which suited the Church just fine, and thus his model was adopted for over 1400 years. It wasn't until Copernicus, in 1543, the same year that he died, proposed a heliocentric view of the solar system. He didn't say anything about the stars though.

It was Giordano Bruno, an Italian philosopher who first stated that the sun was just another star, and the Earth was just another planet orbiting the sun. He also said that the universe was infinitely large, and contained countless stars like the sun, and possibly countless planets like ours. He was burnt alive in 1600 for heresy.

Galileo was the first person to use the telescope to look at the stars. He concluded that since stars still remained a point of light even when seen through a telescope, they must be really far away. He promoted the heliocentric view of Copernicus. He was also accused and convicted of heresy in 1633, and was forced into publicly denying the heliocentric theory, and was kept under house arrest for the rest of his life.

Galileo's middle finger on display in Italy. We wonder if people get the message he's still sending out...

Johannes Kepler (1571-1630) studied the motion of the planets in great detail, and arrived at the conclusion that the sun was the centre of the solar system.

Newton (1642-1727) came along and formed "Newton's Law of Gravity" which explained in great detail the motion of the planets around the sun and the motion of moons around the planets, and finally it was accepted that the sun was the centre of the solar system, and that the Earth was not the centre of the universe after all.

Eventually in 1838, Friedrich Bessel, a German Astronomer (1784-1846) measured the distance of a distant star from our sun, and found the distances to be enormous – almost beyond comprehension at the time, and it was finally accepted by all that the stars were suns that were very far away indeed.

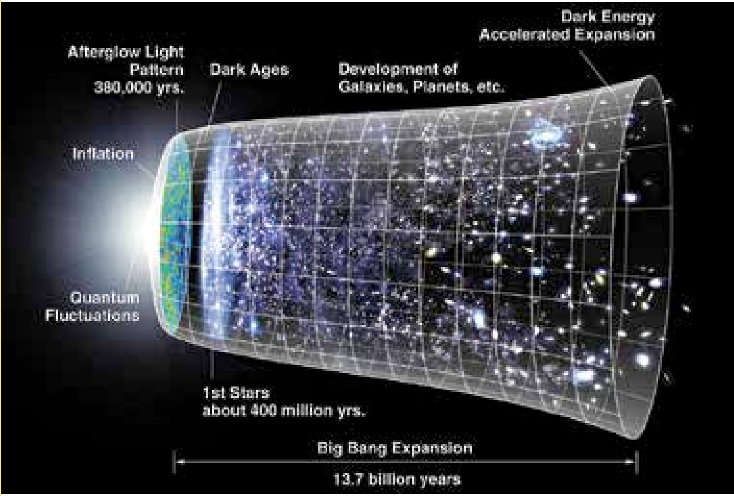
With Hubble discovering other galaxies, and kicking the Milky Way back from being the whole universe to just another galaxy amongst trillions, and Einstein coming up with relativity, we now have an understanding of how insignificant we really are in the grand scheme of things. ■

Evolution of stars

14 billion years in 14 minutes

Now that's a tough ask, but we will try to do it in a mere 14 minutes. So let's start at the start, which we currently call the Big Bang. It wasn't an explosion as such, but was more like a rapid expansion of space itself. Time and space came into existence at the Big Bang, but many people don't know any more than that about the theory, or in fact about the events that followed.

The theories suggest that very, very soon (usually measured in Planck time 5.4 x 10^{-44} seconds) after the Big Bang many different things happened in the very hot early universe. Most notably dark matter started clumping, inflation happened, gravity would have been the first to split from the unified force, matter won over antimatter, at about 10^{-12} seconds the universe was filled with a plasma of quarks and gluons, temperatures fell and things stabilised a bit. At 10^{-6} seconds (after the Big Bang) matter started forming, and just one second after the Big Bang neutrinos form.



The Big Bang that didn't go boom!

10 seconds after the Big Bang Hydrogen and Helium ions form, but it takes until about 380,000 years from the Big Bang for stable atoms of Hydrogen and Helium to form, which thin out the opacity of the universe, and finally photons are able to travel through space. These photons will eventually be the cosmic background radiation

that we detect today, because they red shift so much in 13.6 billion years that they become microwave radiation. This is the first point in time that we are actually able to look back at and directly measure. If we could build a neutrino telescope, we would be able to look back to 1 second after the Big Bang, but we haven't been able to build one yet.

This is where things are still murky, because the universe was a very dark place indeed for many millions of years. Exactly how many millions of years is a matter of debate at the moment and new discoveries keep changing that number... a rather broad range of 150 million to 800 million years after the Big Bang (ABB) is a safe bet. Recent discoveries suggest that it might be 400 or 500 million years ABB.

Whenever it happened, eventually, stars started forming, and this is where we get interested for the purposes of this book.

Early stars

The theory is that with all of that hydrogen available in the early universe, and the effects of dark matter clumping because of gravity, clouds of hydrogen started to form. This phenomenon happens even today in space, and if you chucked a handful of salt into space, eventually gravity would pull them all together into a sphere. However, the clouds of hydrogen we're talking of here would have spanned light years in diameter. Over millions of years the clouds would pack together in ever increasing density, and soon a core would form. This very dense core with a cloud of hydrogen around it being pulled in because of gravity would eventually raise the density of the core to such an extent that it would start heating up, and eventually spark fusion at the core. A star would burst into life, and that's how stars are born (even today).

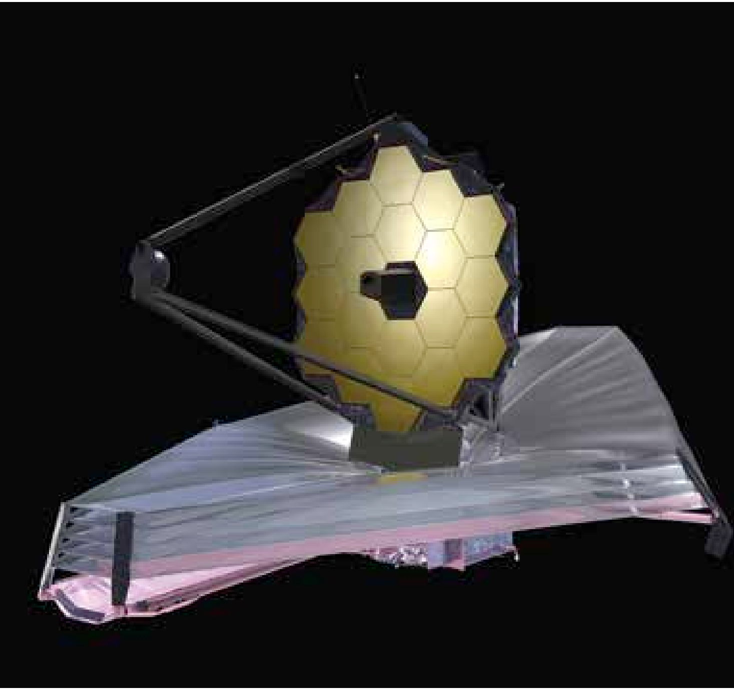
Early stars would be short-lived and meet violent ends rather quickly. Some theories based on supercomputer simulations suggest that the first stars could have formed in the murky dark universe as early as 50 million years ABB, but we'd never see them or be able to detect them. They would forever be shrouded in darkness in the dense early years of the universe, but that's not to say they didn't exist. We can only detect star formation that happened after the universe stopped being opaque. This transparent universe (about 550 million years ABB) would have been bathed in ultraviolet light from the early stars. Today of course, because of red-shifting we see these stars only in the infrared spectrum. Sadly, humanity doesn't have very good infrared telescopes up in space to look at the early stars and galaxies. In 2018, when the James Webb telescope is launched by NASA it will change that. Much more powerful than Hubble, and built to look specifically for highly redshifted radiation, there are some very exciting times in astronomy ahead.

For now, suffice to say that we just don't know enough about the very first stars to make any concrete claims until the data from the James Webb comes flowing in.

Theories and simulations suggest that the first stars started off much smaller than our own Sun, but grew rapidly as they gorged on the abundant hydrogen around them to become supermassive. Starting off as a tiny object, about a hundredth the mass of our sun, these stars would grow quickly to become 100 times the mass of our sun. How quickly? In a mere 10,000 years, which is just the blink of an eye in terms of current star lifetimes.

Stars which have almost no metal content, and are almost purely hydrogen and helium (which is all the earliest stars could have had) are known as Population III stars. Thus, the early universe gave birth to pretty much exclusively Population III stars, because there just wasn't anything but hydrogen and helium at that time.

Galaxies were thought to have formed close to a billion years after the Big Bang, but a 2016 discovery of a galaxy called GN-z11 shook up the astronomy world. The galaxy was found to have a red-shift of 11.1, which dates it at about 13.4 billion years old, or basically a mere 400 million years after the Big Bang. GN-z11 is a lot smaller than our Milky Way galaxy (25 times smaller), but it is still a lot larger than scientists ever thought a clump of stars could be 400 million years after the big bang. It has a mass of about a billion times our



What the James Webb telescope will look like sun (a billion solar masses), and is growing rapidly – much faster than the Milky Way.

Note: when we use the present tense ("is" growing rapidly), we obviously mean that the light reaching us now shows this. Since the galaxy is 13.4 billion light years away, we are now seeing the state it was in 13.4 billion years ago… it probably doesn't even exist anymore. Interestingly, if there was an observer in GN-z11 13.4 billion years ago, they wouldn't be able to see the Milky Way, because our galaxy only started forming 13.2 billion years ago! This is one of those oddities of space, the speed of light and galactic distances, where we can peer back in time to see a galaxy, when our own galaxy didn't even exist! I see you, but you can't see me!

What next?

After we understand the early formation of stars and galaxies, it's merely a question of watching stars and galaxies form, live, die and then make raw material for all new stars and galaxies.

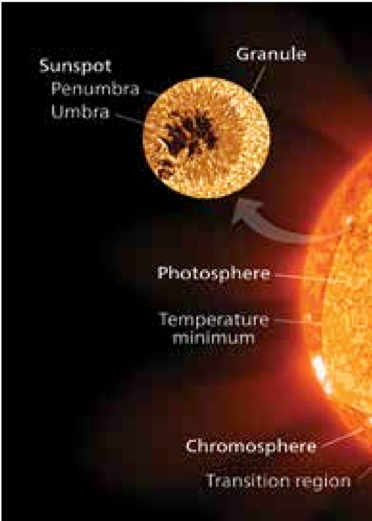
In the early universe, there were most certainly no planets, because there was only hydrogen and helium. At the very centre of the early, large and fast lived population iii stars, mostly hydrogen would fuse to form helium. However, due to the intense heat and pressure and density of the core of large stars, helium could also fuse to form heavier elements. When the star eventually died, usually by going supernova and blowing its guts out into space, these heavier elements were sent off like bullets heading in all directions. They would be absorbed by baby stars in the making, and then some of those heavier elements would fuse to form even heavier elements at the core of the new star, which would eventually blow up and seed even heavier elements into space, and so on, until you arrive at the abundance of water, rock, metals, etc., that we all take for granted here on Earth. All of us, all of the matter we see around us, everything was made in the bellies of stars, and the stars died billions of years ago so that we could live today… In essence, we are all made up of star stuff!

Stellar evolution

We've touched upon how stars form already. A giant cloud collapses under it's own gravity. A molecular cloud is usually about 100 light years across (yes, we did say they were big, remember?) and contain a mass of gas that's equivalent to 6 million solar masses (6 million times the mass of our sun). Our sun weighs about 2×10^{30} kg – 2 followed by 30 zeroes!

This cloud doesn't collapse into one star, it collapses into many clumps, and each clump becomes a star. As it collapses, potential energy caused by gravitation is released as heat. Temperature and pressure increase, and the core starts spinning rapidly because of the forces it's experiencing. In this phase, it ceases to be a clump of gas, and is now called a protostar.

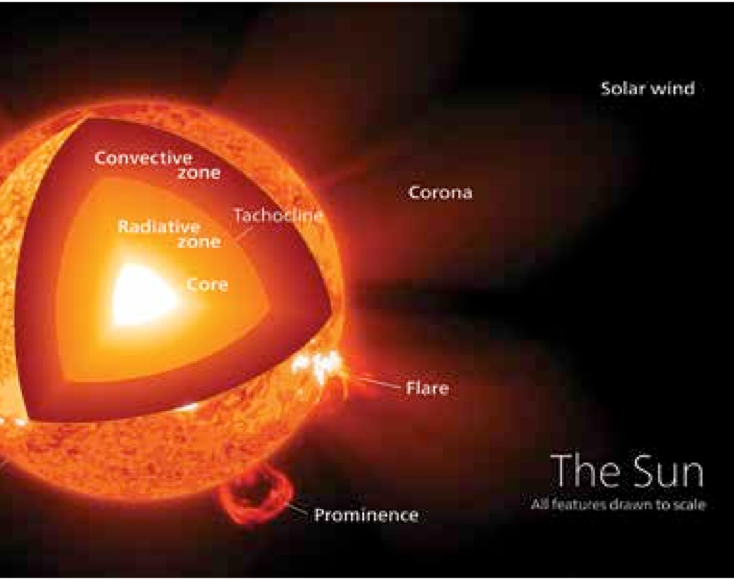
Since protostars don't have any fusion happening just yet, they continue to absorb more and more gas, and grow rapidly (in galactic terms). This protostar then becomes a pre-main-sequence star as it approaches its final mass – the final mass being the point at which fusion gets kick started. Once the fusion reaction gets kickstarted, a solar wind forms and blows away all the remaining gas or molecular clouds that surround it. If clumps have formed in the plane of the star's rotation, planets can form from these smaller clumps – only if enough mass and heavier elements have been gathered before the solar wind starts. What happens next depends solely on the type of star that has been formed.



Peering inside our sun

Structure of the Sun

There are as many different star structures as there are types of stars, so it's obvious that we can't walk you through all of them, however, we will break down the structure of one star (our sun)



which will give you an understanding of all the terminology that will be used ahead in this book.

At the very centre of our sun is the core. This extends from the centre to about one fourth of the radius of the sun, and although it's mostly made up of hydrogen and helium, it's about 150 times the density of liquid water on Earth. The core experiences temperatures of about 15.5 million kelvin, which is a lot hotter than the surface temperature of the sun (5,800 K). The core accounts for 99% of the sun's energy generation via fusion (1% happens just outside the core).

Between the 25% mark on the radius of the sun which is where the core ends, to the 70% mark is the Radiative zone of the sun. This is a non-energy producing zone (in fact it absorbs heat), and the temperature drops from about 7 million K at the start of the radiative zone near the core to 2 million K at the end of it closer to the surface. There are no significant convection currents in this zone, and it has a pretty uniform rotational speed and direction throughout this zone – it rotates slower than the core though.

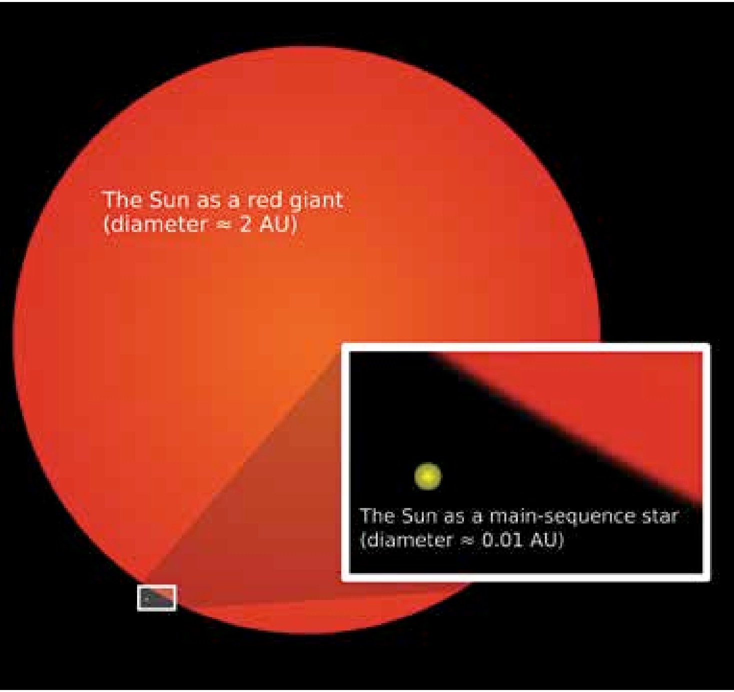
Next comes the Tachocline, which is basically a surface layer of the radiative zone that is affected because of the huge turmoil of the convection zone above. Although not confirmed, there is a theory that this thin layer is what generates the sun's magnetic field because of the friction between the layer above and below it. The Convection zone, as the name suggests is where convection occurs. It is a layer that starts at about 70% of the radius to almost near the surface. Think of the way water boils in a saucepan, the surface is bubbling because the water at the bottom is getting heated by the heat source and rising to the top, while cooler water at the surface is being pushed downwards. This is pretty much how convection works, and is exactly what this layer does – instead of water it's hydrogen plasma, but you get the picture.

The surface layer of the sun is called the photosphere, and this is the layer we see, and the layer that emits all of the light. Although stars don't really have a well defined surface (except the really dense neutron stars), they appear to have a surface like that of the sea, even though plasma is not like liquid. Basically, the photosphere is not only the part of the sun where light is given off and energy escapes the sun, but also the barrier which the photons themselves cannot penetrate. Thus, the photosphere ends where the sun becomes opaque to light.

If the photosphere is to be considered the visible surface, then the corona is the invisible surface of the sun. Think of it like the atmosphere on Earth. It's only visible during a total solar eclipse, and looks like an aura of plasma around the sun.

Sun death

Nothing is forever, and our sun is not nothing. Eventually, our sun will start running down as it uses up the hydrogen in the core. So what



How large our sun will grow before it finally dies happens then? The sun has been around for about 4.5 billion years, and will continue at least for another 5.5 billion years. The sun is also going to get hotter. It will increase brightness by 1% every 100 million years. Nothing that we have to worry about really, but whatever is left on Earth after another 4.5 billion years goes by will have to deal with a 30% brighter (and hotter) sun. Talk about global warming!

Thankfully the sun isn't massive enough to go boom in a supernova, but it will start to turn into a red giant. 5 billion years from now it will grow big enough to swallow up Mercury first, and then Venus, and probably Earth as well. Even if it doesn't it will boil away the oceans and bake the Earth much in the way it bakes Mercury right now.

After spending a billion years as a red giant, the sun is going to lose about 33% of its mass.Then suddenly there is going to be what is termed a Helium Flash. The sun is not massive enough to start a nice steady chain reaction of helium conversion, as a result, it's going to do it in a flash. About 40% of the sun's mass will be converted from helium to carbon in a matter of minutes! It will then start burning helium, and once that is done it will swell again, lose mass, and eventually become a white dwarf that will last trillions of years. There certainly won't be any inner planets left to witness this though. ■

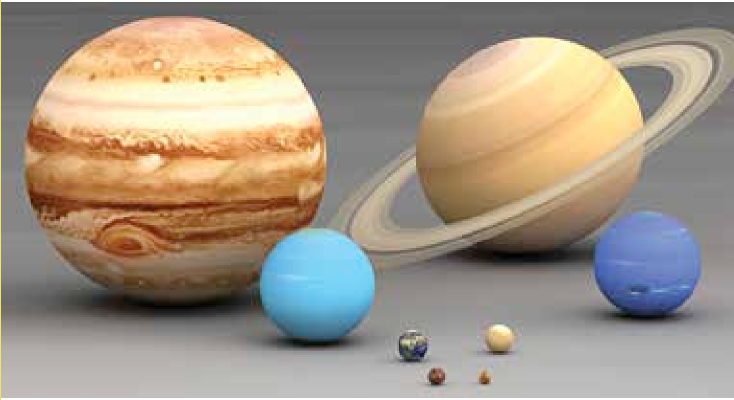
Types of stars

So what are the different types of stars?

Thus far we've looked at some history of astronomy and then fast forwarded you through billions of years of star evolution. We've given you a rough idea of how stars form, and now it's time to get to the types of stars that can form, based on the density of the cloud that they formed from, the components of the cloud, and various other factors. Next, we will dive into the various types of stars that have been observed. Keep in mind that we classify stars using our sun as the norm. This may not be the best way to do things, but since we're only talking to people from earth (we hope), science just doesn't care to find a galactic norm just yet. Thus, all stars are measured in terms of solar masses (always compared to the mass of our sun), or solar luminosity (the luminosity of our sun), etc.

Substellar objects

Not all clouds are big enough or don't contain enough matter to form stars like our sun. Thus, a substellar object is simple an object that



Just some substellar objects taking a break after 4.5 billion years of running about

forms in space which is too small to start fusion at it's core. This critical mass is considered to be 0.08 solar masses – basically any star that has more than 8% of our sun's mass can get hydrogen fusion started at its core. Anything smaller, such as Jupiter (0.001 solar masses) becomes a substellar object.

Substellar objects are classified as solid, transitional or gaseous, and they may or may not revolve around another star. Mercury, Venus, Earth and Mars would be considered to be solid substellar objects (usually planets). Neptune and Uranus would be considered to be transitional (both solid and gaseous), and Jupiter and Saturn would be considered gaseous substellar objects. However, not all substellar objects are planets.

Brown Dwarfs

The smallest gaseous substellar objects are usually planets like Jupiter. Gaseous substellar objects larger than Jupiter could be considered Brown Dwarfs, based on how large they are (in mass). These gaseous substellar objects all form in exactly the same way as a star, but they have masses that range from the size of Saturn all the way to 0.08 times the mass of our Sun.

"Sub-brown dwarfs" lie somewhere in between the planet size of Jupiter and 13 times the mass of Jupiter. They can be found orbiting a larger star, but can also form outside of a star system. When they form independently, they are often referred to as free-floating planets, or "rogue planets". The reason why they're smaller than 13 times the mass of Jupiter is because if the mass is higher, they are classified as brown dwarfs.

Unlike sub-brown dwarfs, Brown Dwarfs are often capable of a limited amount of fusion. Although the brown dwarf isn't large enough to fuse hydrogen into helium, it is able to fuse normal hydrogen into deuterium. In case you don't know, normal or common hydrogen (protium) has just a proton and an electron, and no neutron. Deuterium is basically protium with a neutron added on. The threshold below which a Brown Dwarf will not be able to fuse deuterium is thought to be 13 Jupiter masses (or 0.013 solar masses). Beyond 65 jupiter masses until 90 Jupiter masses, it is thought that in addition to deuterium fusion, a brown dwarf might be able to also burn Lithium – a process where Lithium can be combined with a proton to produce two Helium-4 atoms.

Although they're called "brown" dwarfs, many brown dwarfs are not brown. To the human eye, in fact, most brown dwarfs would appear magenta. Others might appear more orangish-red, but all brown dwarfs would be barely visible to us, because of the very low amounts of visible light they emit.

The closest brown dwarf to us is Luhman 16, which is actually a binary system of two brown dwarfs orbiting each other. They were discovered as recently as 2013, and are 6.5 light years away from our sun. They were only discovered recently because they appear in the earth's night sky very close to the galactic plane, which is very bright and densely populated from our perspective. This meant that Luhman 16 was quite simply drowned out by much brighter stars. They're named after the astronomer who discovered them, Kevin Luhman, from Pennsylvania State University, by studying images taken by NASA's Wide-field Infrared Survey Explorer (WISE) satellite.

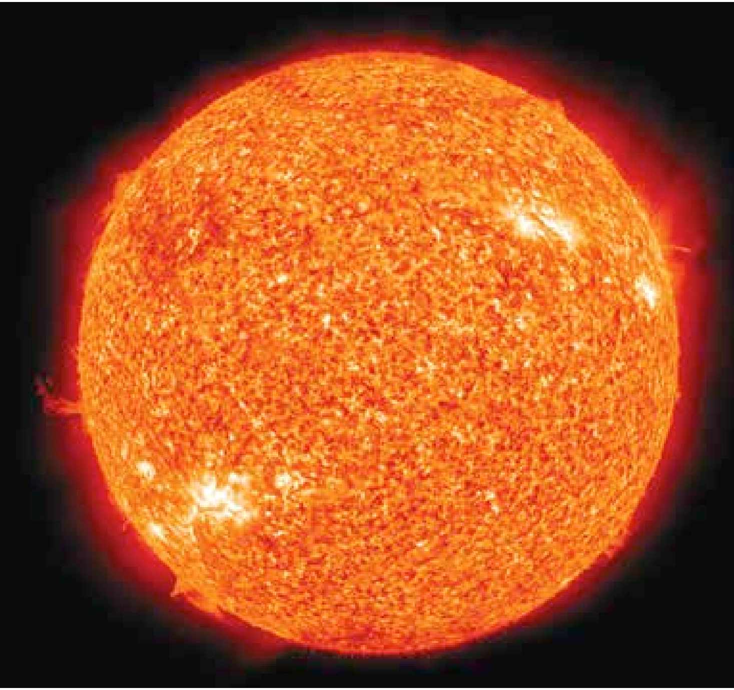
Brown dwarfs by definition have many times the mass of Jupiter (as we already mentioned, a minimum of 13 Jupiter masses), but they're far denser, and as a result, are often the same size as Jupiter (same radius/diameter). The largest brown dwarfs might only be twice the size of Jupiter.

Brown dwarfs are classified into four spectral classes – M, L, T and Y. More on this later. They can also have planetary systems, and this is actually easier to detect because even a Jupiter-sized planet orbiting a brown dwarf would make the system seem more like a binary star system, and the wobbles would be quite prominent.

Main sequence stars

As the name suggests these are the most common stars in the universe. The closest main sequence star to us is our sun. Using a graph method called a Hertzsprung–Russell diagram (named after Ejnar Hertzsprung and Henry Norris Russell), which is a plot of a star's luminosity (brightness) vs its temperature. When this graph is plotted, most stars clump together in the middle of the graph. This is why they are termed as main sequence stars.

Fusion occurs at the core of main sequence stars, and hydrogen is fused to form helium. Most main sequence stars are in hydrostatic



The closest main sequence star to us... the sun!

equilibrium – this means that the star experiences a pressure of gravity pulling it in on itself, but it is perfectly balanced by the pressure of the very hot core pushing outwards.

Stars don't live their entire life as Main Sequence stars, and might live through a phase of being main sequence, and then change into another type, which we will get to later.

Proton-proton chain

Stars below 1.3/1.5 times the mass of the sun are considered to be lower main sequence stars (yes, our sun is a lower main sequence star). These stars fuse hydrogen atoms to form helium (like all other stars), but they do it using a method we call a proton-proton chain reaction which starts off at temperatures of about 4 million kelvin. What this means is that inside our sun (and in others like it) the process by which hydrogen converts to helium is something like this:

Because the hydrogen in a star is in plasma form (the fourth state of matter) it is ionised. Which means that while normal hydrogen gas has one electron and one proton, in plasma state the electrons are separated, and thus you basically have protons and electrons existing freely without bonds being formed.

1. First two protons fuse to form a diproton (Helium-2). This is a very unstable Helium isotope that has two protons and no

neutrons. Normal, stable Helium (Helium-4) has two protons and two neutrons.

2. Then, one proton becomes a neutron, a positron is emitted (to get rid of the positive charge of the proton) and a neutrino is also given off. This makes the Helium-2 into Deuterium (an isotope of hydrogen that has a proton and a neutron).
3. Next, the Deuterium fuses with a proton to form Helium-3 (two protons and a neutron). Helium-3 is a pretty stable isotope of Helium.
4. After this, there are multiple ways in which this Helium-3 can be fused into Helium-4
   i. In the first way two Helium-3 atoms fuse to form Helium-4 by giving off 2 protons
   ii. The second way is where Helium-3 fuses with Helium-4 to form Berylium-7 (and a gamma ray is given off). Then Berylium-7 gains an electron and gives off an electron neutrino to form Lithium-7. Lithium-7 then fuses with a proton to output two Helium-4 atoms (this process is called Lithium burning).
   iii. The third is similar to the second way. Here also Helium-3 fuses with Helium-4 to form Berylium-7 (giving off a gamma ray). Berylium-7 then gains a proton to form Boron-8 (releasing another gamma ray). Boron-8 then decays into Berylium-8 by giving off an electron and an electron neutrino. This Berylium-8 then decays into two Helium-4 atoms.

iv. The last way (theoretical, not observed) is where Helium-3 fuses with a proton to output Helium-4, an antielectron (positron) and a high energy neutrino. Positrons or anti-electrons are antimatter, and they collide with electrons and both are annihilated, producing two or more gamma rays in the process.

CNO Cycles

Upper main sequence stars (stars with mass of 1.3/1.5 times the sun or higher) use a process called CNO to fuse hydrogen into Helium. Here, CNO stands for Carbon-Nitrogen-Oxygen. This is because the stars use the three elements in various stages of the fusion process.

The CNO process uses the heavier elements as catalysts in the fusion chain reaction. What's interesting is that the process was proposed independently by two German physicists – Carl Weizsäcker and Hans Bethe as a way to explain how the sun created energy. It was a mistaken belief that the sun had a high concentration of Nitrogen at the time (1930s), and both physicists explained a process of hydrogen fusion using Nitrogen or Carbon as catalysts. Back then it was assumed that as much as 10% of the sun was made of Nitrogen, which we now know to be less than half a percent. It does explain the composition and much higher temperatures of bigger stars perfectly though, so it turned out to be pretty good science in the end!

There are two ways in which the CNO cycle works, and they have been termed the Cold and Hot CNO cycles, even though there's nothing "cold" about a star. We're talking millions of degrees kelvin here. The CNO cycle itself is not the major process in our sun because it is too cold. Our Sun has a temperature of roughly 16 million kelvin, and the CNO cycle needs a minimum of 15 million kelvin to even get started. Only at 17 million kelvin does the CNO cycle start to become more dominant than the proton-proton chain.

Supernova: When stars go boom, the whole universe sees them

The Cold CNO cycle is what interests us because it is the process that powers large stars. The Hot CNO cycle occurs only in special cases – such as when a white dwarf "eats" a nearby star in a binary system. A runaway chain reaction occurs on the surface of the white dwarf because of the sudden addition of fresh fuel (Hydrogen). This event is also called a nova (plural: novae), and is detected when a white dwarf suddenly gets a lot brighter in a very short period of time. This is not to be confused with other stellar events such as a supernova (plural: supernovae), which is the exploding death of a large star. To us viewers of space, a supernova outshines the entire galaxy that it is a part of when it explodes.

Here's how the cold CNO cycle works:

1. The most common CNO cycle is CNO I
    i. Carbon-12 fuses with a proton to produce Nitrogen-13, giving off a gamma ray.
    ii. Then, Nitrogen-13 decays to form Carbon-13, a positron and an electron neutrino.
    iii. Carbon-13 fuses with another proton to form Nitrogen-14 and a gamma ray.
    iv. Nitrogen-14 fuses with a proton to form Oxygen-15 and a gamma ray
    v. Oxygen-15 decays to give Nitrogen-15, a positron and an electron neutrino

vi. Nitrogen-15 fuses with a proton to form Carbon-12 and Helium-4
vii. The process repeats with Carbon-12 all over again

2. CNO II takes off from step vi mentioned above
    i. Nitrogen-15 fuses with a proton to give Oxygen-16 and a gamma ray
    ii. Oxygen-16 fuses with a proton to give Fluorine-17 and a gamma ray
    iii. Fluorine-17 decays to Oxygen-17, a positron and an electron neutron
    iv. Oxygen-17 fuses with a proton to form Nitrogen-14 and Helium-4
    v. Nitrogen-14 fuses with a proton to form Oxygen-15 and a gamma ray
    vi. Oxygen-15 decays to form Nitrogen-15 a positron and an electron neutrino
    vii. The Nitrogen-15 starts the process all over again
3. CNO III starts off from step iv above
    i. Oxygen-17 fuses with a proton to Fluorine-18 and a gamma ray
    ii. Fluorine-18 decays to form Oxygen-18, a positron and an electron neutrino
    iii. Oxygen-18 fuses with a proton to form Nitrogen-15 and Helium-4

   iv. Nitrogen-15 fuses with a proton to form Oxygen-16 and a gamma ray
   v. Oxygen 16 fuses with a proton to form Nitrogen-17
   vi. Nitrogen-17 decays to form Oxygen-17 a positron and an electron neutrino.
   vii. The process repeats
4. CNO IV is a different process that happens in large stars
   i. Fluorine-19 fuses with a proton to form Oxygen-16 and Helium-4
   ii. Oxygen-16 fuses with a proton to give us Fluorine-17 and a gamma ray
   iii. Fluorine-17 decays to Oxygen-17, a positron and an electron neutrino
   iv. Oxygen-17 fuses with a proton to give us Fluorine-18 and a gamma ray
   v. Fluorine-18 decays to Oxygen-18 a positron and an electron neutrino
   vi. Oxygen-18 fuses with a proton to form Fluorine-19 and a gamma ray
   vii. The process repeats

Inside our sun, all of these (except CNO IV) happen, but the whole CNO cycle accounts for a tiny fraction of the sun's energy.

Artist's impression: a white dwarf surrounded by debris

White dwarfs

A white dwarf, also called a degenerate dwarf, is basically the core of a star that's been exposed when the outer layers are blown away. Once fusion stops in a core, usually of a red giant, the outer layers blow away and all that's left is a very dense core of the star. How dense? A white dwarf the mass of our sun would be about as big as earth. Basically, imagine shoving all that makes up our sun into a ball the size of earth and you can imagine how dense a white dwarf is.

Despite no fusion, white dwarfs still radiate stored up energy from when the core was super hot. White dwarfs will eventually cool and release all energy, but because they release energy so slowly, it takes billions of years. The universe has not existed long enough for even the first white dwarfs to have totally cooled off. We don't really know for sure how long it would take them to totally lose all energy, but mathematically our best guess would be hundreds of billions of years (if not a trillion). Funnily enough, these aren't the longest lived stars either!

Red Dwarfs

Red dwarfs are relatively small and cool main sequence stars. They have a mass of between 0.075 to 0.5 solar masses, and are by far the most common stars in the Milky Way, especially in our solar neighbourhood. This leads us to believe that Red Dwarfs are perhaps the most common star in the universe, but we cannot be sure because they are not easy to observe at long distances. This is why almost all of the red dwarfs that we know of are really close to us.

They have a surface temperature of 4,000 kelvin or lower, which means they are very faint indeed – our sun has a surface temperature of a little under 5,800 kelvin. Proxima Centauri, the closest star to us is a red dwarf, but even that is not visible with the naked eye. In fact 20 of the 30 closest stars to us are red dwarfs, and astronomers suggest that as many as 75% of all stars in the Milky Way are red dwarfs. Since we don't believe our stellar neighbourhood or galaxy to be anything special or out of the ordinary, it stands to reason that the entire known universe could perhaps follow the same pattern, but it's not something we are going to be able to prove in a hurry, and so it stays a hypothesis.

The best way to study red dwarfs has actually been computer simulations, and these simulations tell us that all red dwarfs of solar mass 0.35 or lower are fully convective, which means they don't suffer from the fate of, say, normal main sequence stars, and their cores are not isolated. This also means that it will take a lot longer for a red dwarf to run out of fuel. How much longer? Red Dwarfs are expected to stay in main sequence for several trillions of years, never losing any luminosity or gaining size, or suffering any of the fates that other stars have to fear. Red dwarfs will be around when all the other stars have died, and if we're looking for a new home, one that orbits close to a red dwarf would be a good find.

Giants

This was a name coined for stars that appeared to have the same surface temperature of the sun, but were much larger and brighter than it. So how big do they get? Typically stars are considered giants if they have radii several times larger (up to a few hundred times larger) than the size of our sun. However, because they have the same surface temperature as the sun, but are larger in size, they can be anywhere from 10 to thousands of times more luminous than the sun. Your best pair of glares (sunglasses) would be useless if you had any of these bad boys in the sky above you. But then again, you wouldn't even exist if they were in the sky above, so no big deal.

Even if a star is much larger than the sun, but is in its main sequence (fusion in full flow), it is termed a dwarf, technically, in astronomy. Thus, the term "giant" is reserved for stars who have exited the main sequence, and is no longer fusing hydrogen at its core.

Red Giant

So what happens to a main sequence star when it runs down? It becomes a red giant. Red giants generally have low mass (0.3 to 8 times the mass of our sun), but are much larger. They have low surface temperatures of about 5,000 kelvin.

Typically, red giants form when the core of a main sequence star is completely converted from hydrogen to helium. With an inert core, the fusion process then starts in a layer around the core, which causes them to expand (in diameter) significantly. Because the core is inert, it shrinks under its own gravity with no fusion to push outwards. This sucks in hydrogen from outer layers into areas where fusion can start again (albeit at a much smaller scale than a core chain reaction).

They can grow to be hundreds of times larger than our sun, and even though they are much cooler, their larger size means they are often hundreds of times more luminous than our sun.

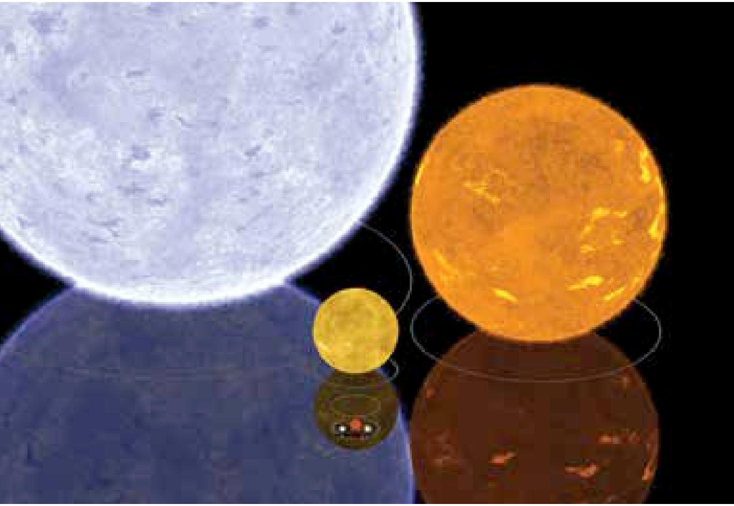
Red giants eventually start helium fusion in their cores. At this point they will contract again, and stop being a red giant. Once the helium in the core has been exhausted and turned into carbon, they will expand again, once again becoming a red giant. Under 8 solar masses, carbon fusion will not happen, so they will just eventually shed their outer layer, expose their core and become white dwarfs.

Yellow Giant

Yellow giants form from main sequence stars with much higher solar masses than those that eventually become red giants. They are not very common in the Milky Way, perhaps because the yellow giant phase is very short lived, and also because main sequence stars with solar mass greater than 8 are much rarer.

Blue giant

These are hot stars, and we're not talking about good-looking celebs, we're talking about stars with temperatures that would melt a celeb in an instant from a million miles away. They're far brighter than the sun.



Blue giant Bellatrix compared to Algol B, the Sun, a red dwarf, and some planets.

Some blue giants can be red giants that have entered the Helium-fusion stage, and thus heat up and appear blue (hotter and brighter). They are pretty much always stars that have evolved past the hydrogen fusion stage. It would be wrong to consider hotter main sequence stars that appear blue because of the high surface temperature to be blue giants.

Supergiant

Supergiants were discovered soon after giants and it was basically a term made up to distinguish the new stars from giants, because they were much bigger. Supergiants have masses of between 8 and 12 times the sun, but they are about 1000 to a million times more luminous than the sun. They are also about 30 to 1,000 times the size of the sun (radius/diameter). These stars are so massive that they just begin fusing Helium towards the end of the star's main sequence – so they're fusing both Hydrogen and Helium simultaneously at the end of their main sequence life. They will then go on to fuse carbon, and only end fusion in the core when it turns into iron! In the end though, they just end up exploding as supernovae, and giving the rest of the universe quite the show.

There are red and blue supergiants, and they are classified based on the temperature of the surface, which is what makes them appear red or blue – obviously blue supergiants have a higher surface temperature (they're hotter).

If a red supergiant and a blue supergiant have the same luminosity, it is obvious that the red supergiant is much bigger. Supergiants aren't the biggest stars in the galaxy though.

Hypergiant

These are very rare, and very large stars indeed. They live fast, die young, and are like the rock stars of the universe. They shine brighter than any other stars, but for much shorter.

When the astronomy world had just got used to supergiants, in 1956 astronomers used the term super-supergiant. This was to signify stars that were much brighter than even the supergiants that had been studied. The name was soon modified to hypergiant, but it wasn't a well defined classification. It was only in 1971 when Philip C Keenan suggested that the term be used only for supergiant stars that have a large atmosphere (and as a result a large rate of mass loss). When Keenan said it, that's what astronomy did… more on him later.

Hypergiants are typically stars who have a luminosity that is very close to the Eddington Limit. The Eddington limit, named after the British astronomer Sir Arthur Stanley Eddington, is the maximum luminosity a star can reach before the force of radiation (which is what determines luminosity) matches or exceeds the force of gravity at the surface layers. If you cross the Eddington limit, the outer layers of the star will get blown away, it loses mass and then shines less brightly. Thus, the Eddington limit cannot be exceeded by stable stars, not even by hypergiants. In the next chapter we will look at some of the famous stars in our galaxy (and others) and this will illustrate how big supergiants and hypergiants really are.

Neutron star

When a large star collapses (stars of 10 to 29 solar masses), it forms a neutron star. Neutron stars are the smallest and densest stars known to us as of now. We told you about white dwarfs being dense and occupying the volume of the Earth but having the mass of our sun? A neutron star would be a ball just 10 km in radius (20 km diameter) and have double the mass of our sun. Neutron stars are formed when large stars explode in a supernova, and then the core collapses due to gravitation. They are thought to be made up of mostly neutrons (thus the name), and cannot be more than two or three times the sun's mass. It is theorised that a neutron star more massive than 3 solar masses would collapse in on itself and form a black hole. The smallest observed black hole has 5 times the mass of our sun, however. A newly formed neutron star can have core temperatures of over a trillion degrees K, but they soon lose energy in the form of neutrinos and their stable temperature is closer to a million degrees K. They mostly only output x-rays, and not too much visible light. They are packed so dense that each neutron is almost touching one another. In fact, if you had one teaspoon of a neutron star, it would weigh about a billion tons on Earth. Which makes it obvious that you'd never get close enough to get a sample, and even if you did overcome the gravity and deadly x-rays, you would still need the universe's strongest teaspoon to collect that sample!

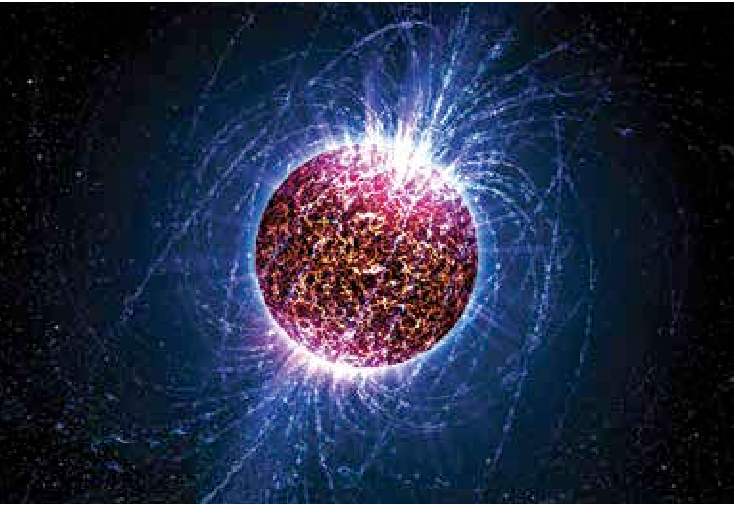


Illustration of a neutron star

Black hole

It is possible (or even probable) that black holes started their life off as massive stars, which collapsed and were too dense to form neutron stars. Whatever they are, we can only describe them as regions of spacetime where the gravitational effects are so strong that even light cannot escape from inside it. We are not going to dwell too much on this because we could theoretically write an entire dmystify on black holes. Suffice to say that although black holes may very well have started out as stars, they are anything but when they become a black hole, and thus our interest in them for this book ends right there.

Pulsar

Short form for pulsating radio star, a pulsar is nothing more than a fast rotating and highly magnetised neutron star. It emits a very focussed beam of electromagnetic radiation, and is essentially the strobe light in the party that is the universe! It is only detected when the beam is pointed directly at us (towards Earth), but it has regular rotational periods. Interestingly, when the first pulsar was discovered in 1967, the scientists who first noticed the regular 1.33 second pulse felt a chill go up their spine. Of course astronomers aren't likely to jump to the conclusion that they've just received a signals from aliens, but it's something that's always at the back of the mind when looking at the stars.

Quasar

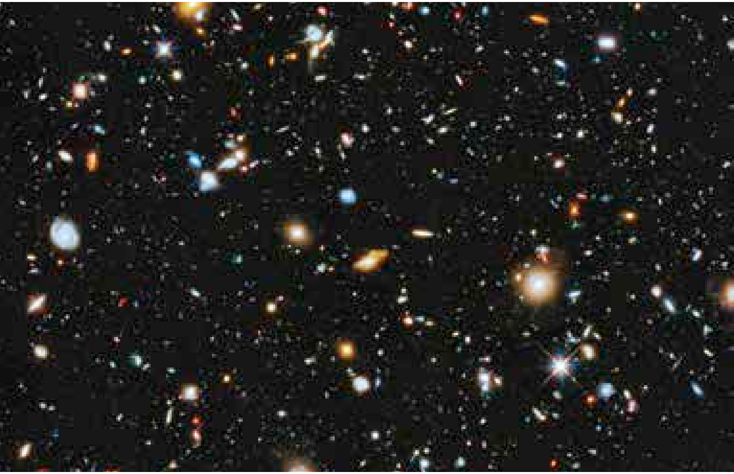
A quasar isn't a star, but it is brighter than anything else in the night sky. Often called the brightest objects in the universe, quasars often emit light that is 100 times the brightness of the entire Milky Way galaxy! They are found near supermassive black holes (black holes which have masses in the order of a billion times the mass of our sun). The word quasar is short for "quasi-stellar" radio source. When matter is sucked towards a black hole, most of it goes in, but a tiny amount escapes because of the speed and angle at which it approaches. Think of it as using a supermassive black hole as a gravitational slingshot. So how fast does a supermassive black hole slingshot you away? At pretty much just under the speed of light! Here is one way for matter (particles) to be accelerated to close to the speed of light, and all it takes is the power of a few billion of our suns! Quasars are thought to be the birth of galaxies around supermassive black holes, and it is theorised that the Milky Way once had a quasar at its center.

Naming stars

Let's be clear, this isn't about the silly schemes where people are fleeced out of money by being promised a name. Many companies are happy to take your money and send you a very official looking paper or certificate that shows you a picture of your star and the name you have paid for, but it's nothing more than a hoax. The International Astronomical Union (IAU) – the agency that officially gives stars the names that the world recognises – clearly states that it does not accept any amount of money to name a star. If you pay to buy a star and name it, you have been hoodwinked, and that same star has probably been sold by another company to someone else, and no astronomer is ever going to know that star by the name that's been paid for. It's like buying land on Mars or the Moon. No one owns Mars or the Moon to be able to sell it to you, so make sure you don't throw your money away. Instead, donate it to the local planetarium, or buy something from their gift shops.

With that rant over, there are actually quite a few ways in which stars are named. To start with, stars that were named from antiquity right until the 19th century already have many names depending on where in the world you are. The Greeks would have named a star something, and so would have Islamic scholars, as would the Chinese and the Russians, and so on.

With literally trillions and trillions of stars out there to look at, how are we supposed to ever catalogue them all? The simple answer is that we don't, not unless there is something of interest in a star system or a stellar neighbourhood. We still need to classify all the hundreds of thousands of stars that we do study, and this is why stellar classification is such a big deal in astronomy. The ancient astronomers had the luxury of using only their eyes to identify and romanticise stars. They even named them with interesting names, made out shapes and saw constellations. Today, however, with mil-



A Hubble image of distant galaxies, each with billions of stars like our Milky Way

lions of stars to study (over a billion, actually, at last count) – and those are just the interesting ones – most stars are just classified by type and given a number, unless they're super interesting to the point of the general public wanting to know about them. Then we name them.

Thus, there are star catalogues from all over the world, and the IAU has the task of sorting out the names of stars. The newer ones are easy, it's the older ones that are the challenge.

Thankfully only about 350 stars have proper names, though they have names in many languages, and most of them were named in Arabic. These also happen to be the brightest stars in the sky. Let's take Polaris, for example, and look at the amount of names it has. It's been called the North Star, Pole Star, Alruccabah, Lodestar, Star of Arcady, Yilduz, Tramonata, Phoenice, Navigatoria, Mismar, Cynosura, Angel Stern, 1 Ursae Minoris, HR 424, SAO 308, ADS 1477, etc. Confusing, no? And this is for one of the most famous stars in all of human history! This is why people prefer to use and mention the catalogue name of a star. But which catalogue?

One of the oldest catalogues still in use today is the Bayer catalogue – published in 1603 and named after famed German celestial cartographer Johann Bayer. The Bayer designation of a star contains a Greek letter, a possessive case of the parent constellation's Latin name. So Tauri is possessive (also called genitive) for Taurus, and Ori is possessive for Orion, etc. This resulted in a naming convention that resulted in names such as Alpha Tauri, or Alpha Ori – written as α Ori, β Ori (beta ori), γ Ori (gamma ori), etc.

Another classification used is the Flamsteed designation. Named after John Flamsteed, a 17th century English astronomer who catalogued over 3,000 stars that were visible from England. This is very similar to the Bayer method of cataloguing, except that it uses a number instead of a Greek alphabet – which makes it a lot easier to write. The numbering was not as easy though. For example, the star Aldebaran, which is denoted as α Tauri in the Bayer classification is 87 Tauri in the Flamsteed catalogue.

Most modern catalogues are computer generated, which is why we have a billion stars listed in them, as opposed to the life's work of one astronomical cartographer totalling 3,000 stars. Of course computers are anything but romantic or creative. A famous computer generated catalogue is the Guide Star Catalogue (also known as the Hubble Space Telescope Guide Catalogue – HSTGC). This results in names for stars that are in the format GSC FFFFF-NNNNN, where FFFFF are Hubble coordinates and NNNNN is a number.

There are many more catalogues in use even today, such as the Henry Draper catalogue, the Hipparcos catalogue, Gould designations, and more. Suffice to say, you'd need a degree in astronomy to really make sense of it all, and even then it's a huge mess. Thankfully, most of the stars you will want to know about already have names.

But all this was just about naming, what about the classifications used to describe stars? How can you understand what those numbers mean?

Star Classification

Most stars are classified even today using the Morgan-Keenan method, named after William WIlson Morgan and Philip Childs Keenan. Initially the classification method was called the MKK (Morgan-Keenan-Kellman) method, the extra K belonging to astronomer Edith Kellman. Their classification system was completed in 1943. Later, Morgan and Keenan reworked and updated the method, and it was rechristened the MK method.

The MK method basically used two parameters of a star to classify it – temperature and luminosity. The classification can be listed as follows:

Temperature

The surface temperature (in degrees Kelvin) of stars in the MK system are classified as below:

O Greater than 30,000 K
B 10,000 to 30,000 K
A 7,500 to 10,000 K
F 6,000 to 7,500 K
G 5,200 to 6,000 K
K 3,700 to 5,200 K
M 2,400 to 3,700 K

In addition to the letters, numbers from 0 to 9 are used to signify the differences between surface temperatures of stars of the same class. The sun has a surface temperature of 5,770 K, and is thus a G2 star in terms of temperature. The sun is actually a G2V star, and we will explain the "V" part next. A G1 star will be slightly more massive than the sun and slightly hotter, and a G3 star will be slightly less massive and cooler. Thus, when using the numbers 0 to 9 in the MK system remember that 0 means hottest, and 9 means coolest.

Luminosity

Luminosity of stars in the MK system are classified as follows:

Ia-O	Very luminous supergiants
Ia	Luminous supergiants
Ib	Less luminous supergiants
II	Bright giants
III	Normal giants
IV	Subgiants
V	Main sequence dwarf stars
VI (or SD)	Sub dwarfs
D	White dwarfs

The sun, as we know, is a main sequence dwarf star, and thus has a luminosity ranking of V. This is why the sun is classified as a G2V star. Note that the MK system is merely a classification that tells you about the temperature and luminosity, it says nothing about the location of the star. That's why naming is needed, and the computer naming we mentioned earlier is important, because the computer understands its own language, so when you command it to show you SDSSp J153259.96-003944.1, it will know which one you mean, and that's the only thing that matters. All you need to know is that SDSSp J153259.96-003944.1 is a high red-shifted quasar

We know that there is a lot about stars that has been missed because of space constraints, but we hope we have whetted your appetite. If you live away from a metro city and light pollution, buy a telescope, look up, and dream. If you live in big cities, you're going to have to settle for apps that show you the cosmos, sadly. Please send feedback about this book to *dmystify@digit.in* as usual. ■

The Hubble space telescope

http://dgit.in/HublImg