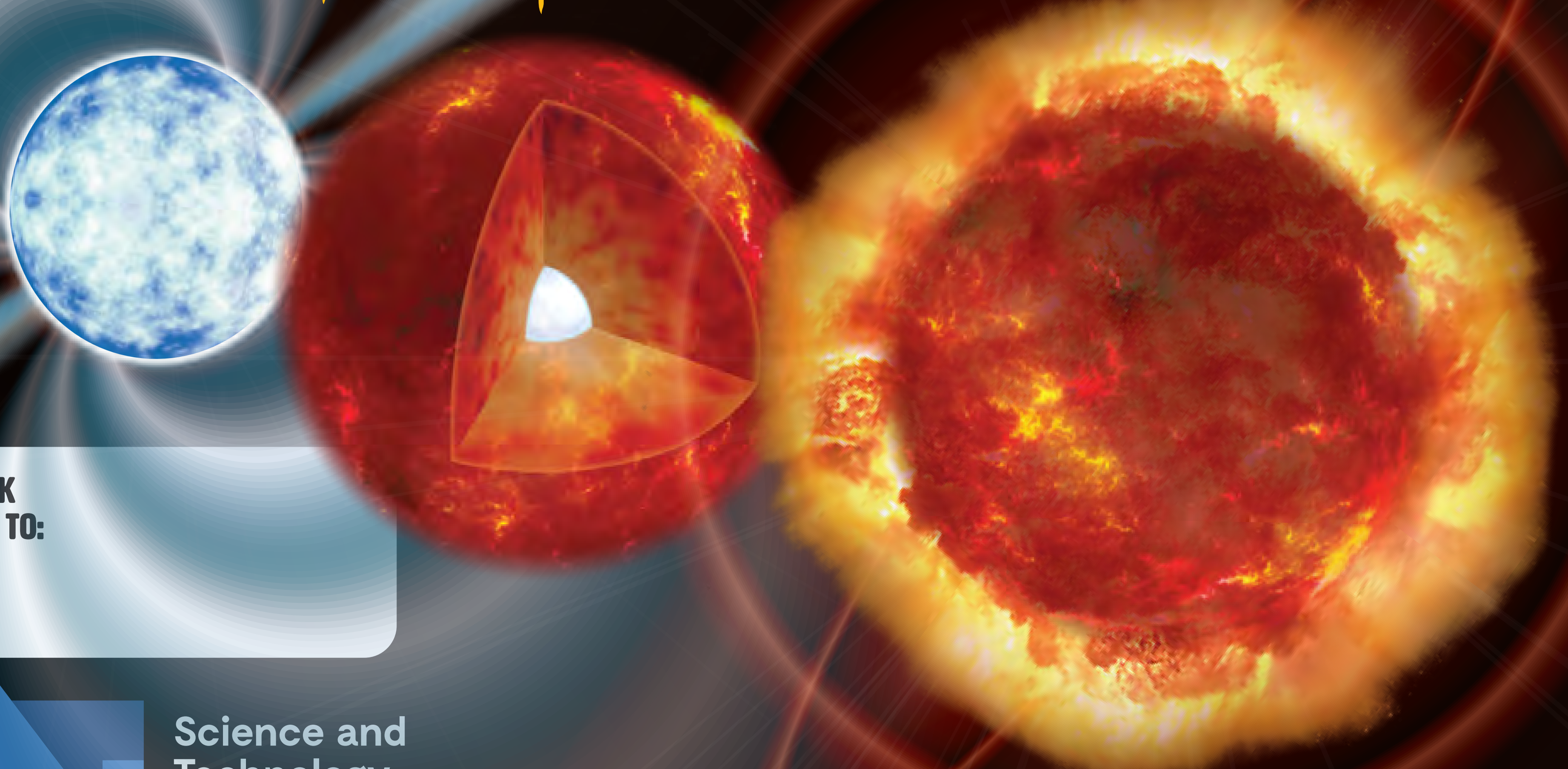
THE LITTLE BOOK OF THE STARS

A LITTLE BOOK OF THE SUN BOOSTER PACK



THIS BOOK BELONGS TO:

UKRI Science and Technology Facilities Council

How does a star like the Sun become a white dwarf star?

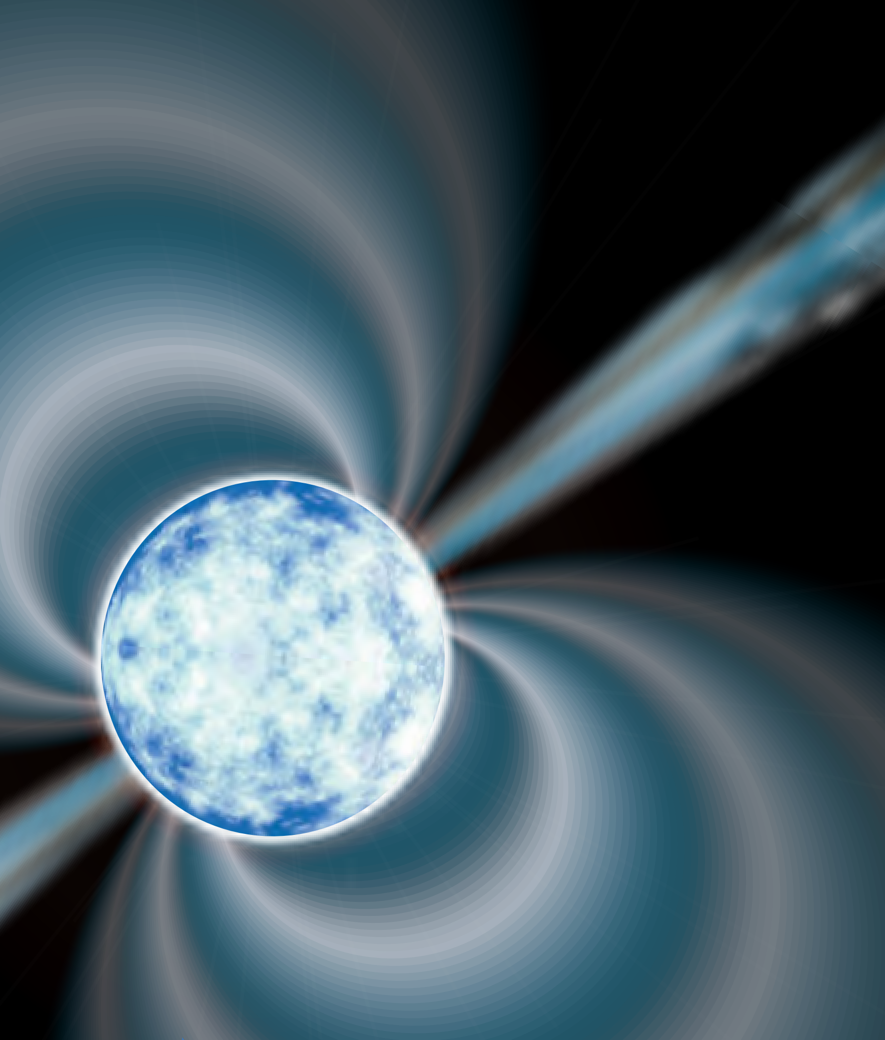
Why do stars expand before they die?

How do stars make the chemical elements? Are we all made of star stuff?

When will our Sun die, and will it really swallow the Earth?

You'll find all this out (and lots more) in...

THE LITTLE BOOK OF STARS



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OTHER IMAGES: NASA, ESA, ESO

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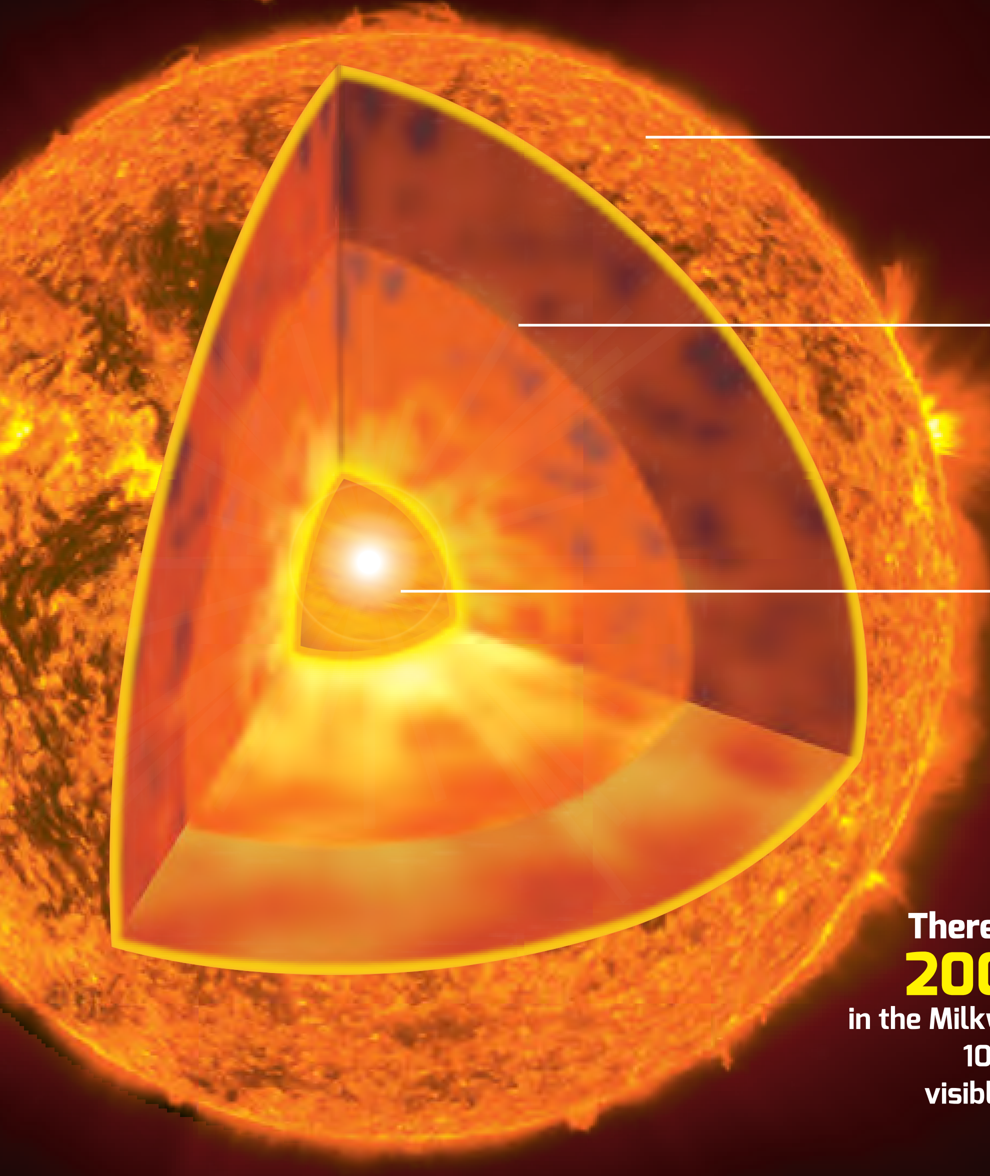
1 WHAT IS A STAR?

A star is an enormous ball of extremely hot gas that produces energy in its core and emits that energy as heat and light (and other forms of radiation) at its surface.



There are more than 200 billion stars in the Milky Way. Only about 10,000 of which are visible to the naked eye

We see all the stars in the night sky, apart from our Sun, as tiny, twinkling specks of light. Some of these specks are actually distant galaxies, but all of the individual stars we can see are actually part of our local galaxy, the Milky Way.

Even though these 'local' stars are quite close to us in cosmic terms, they are really a very long distance away. The closest is nearly 40 trillion kilometers away and most are much much further away.

Those twinkling specks of light might all look white to the naked eye but, if you were able to fly up and visit them, you'd see they come in all sorts of colours and in all sorts of sizes.

A star's colour is determined by how hot it is - really hot stars are blue, whereas cooler stars are yellow or even red. The spectrum of light emitted by a star can give us a lot of information about the star. Astronomers use seven main classifications for stars based on their colour spectrum.

Colour	*Class*	*Temperature*	*Colour*	*Class*	*Temperature*
	O	over 30,000 °C		G	5,300 °C
	B	20,000 °C		K	4,000 °C
	A	8,500 °C		M	3,000 °C
	F	5,300 °C			

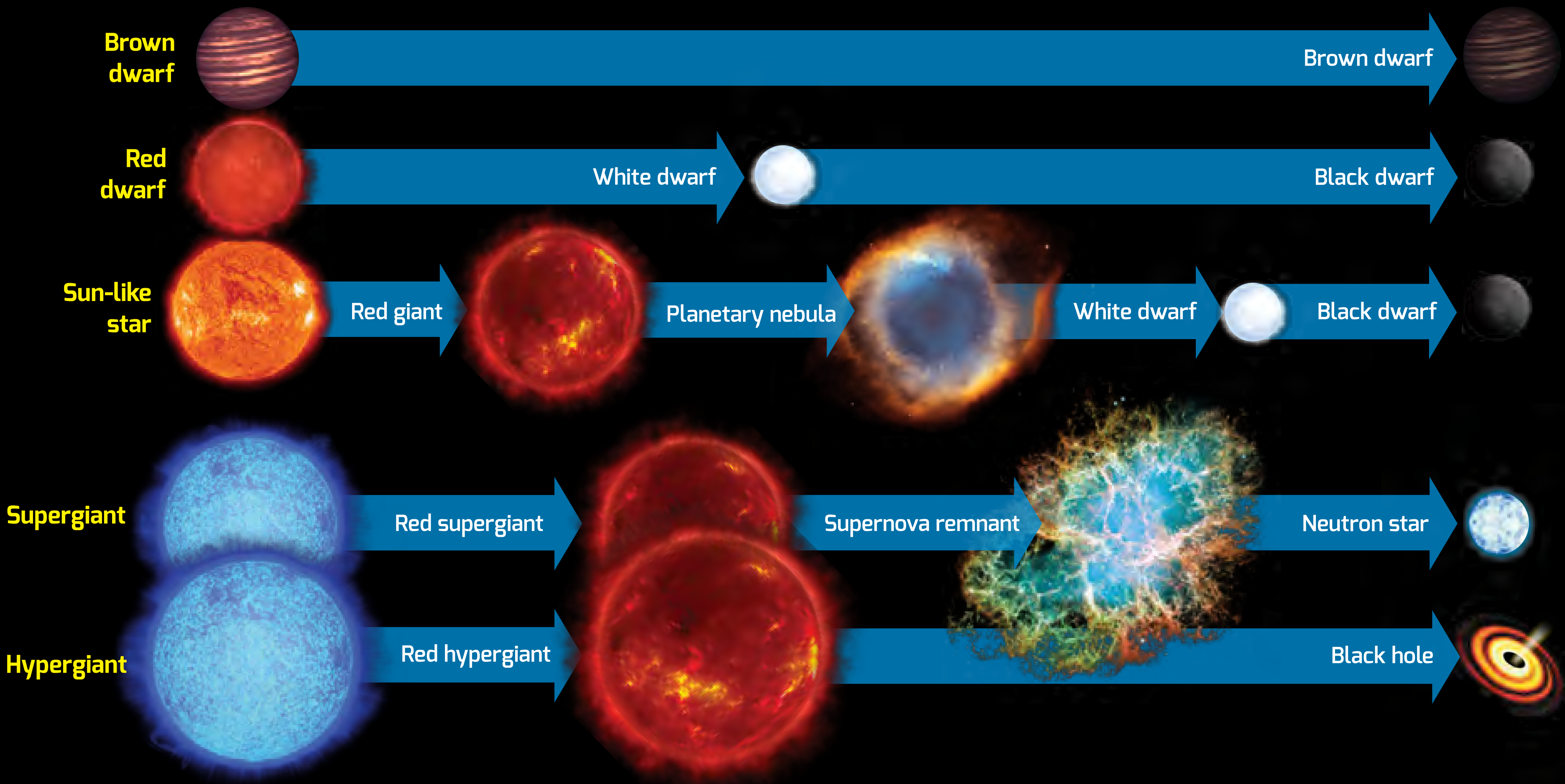
The Sun is a yellow G-class star

1.1 LIFECYLES OF THE STARS

A star's life cycle is determined by its mass and how hot it burns – supermassive stars can burn through their nuclear fuel in as little as a few tens of thousands of years, yet stars just a fraction of their size will burn for many time the current age of the Universe.

Brown dwarfs are often described as failed stars. They didn't have enough mass to ignite hydrogen fusion and are more like huge gas giant planets than stars. Their death is slow as they gently radiate their heat into space.

Red dwarfs are tiny but have just enough mass for hydrogen fusion. But they burn at such low temperatures that they'll be alive when the Universe is many times its current age. 75% of all stars in the Universe are red dwarfs.



Sun-like stars yellow dwarfs) have enough mass for hydrogen and helium fusion. When they run out of helium they expand to become red giants, shed their outer gas layers as planetary nebulae and leave behind a white dwarf star, which will slowly cool to become a black dwarf.

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Supergiants and hypergiants are so massive they burn through their fuel reserves in as little as few tens of thousands of years. They cool and swell to become red supergiants before finally exploding as supernovae. Less giant stars will become neutron stars or pulsars, but the most massive collapse to become black holes.

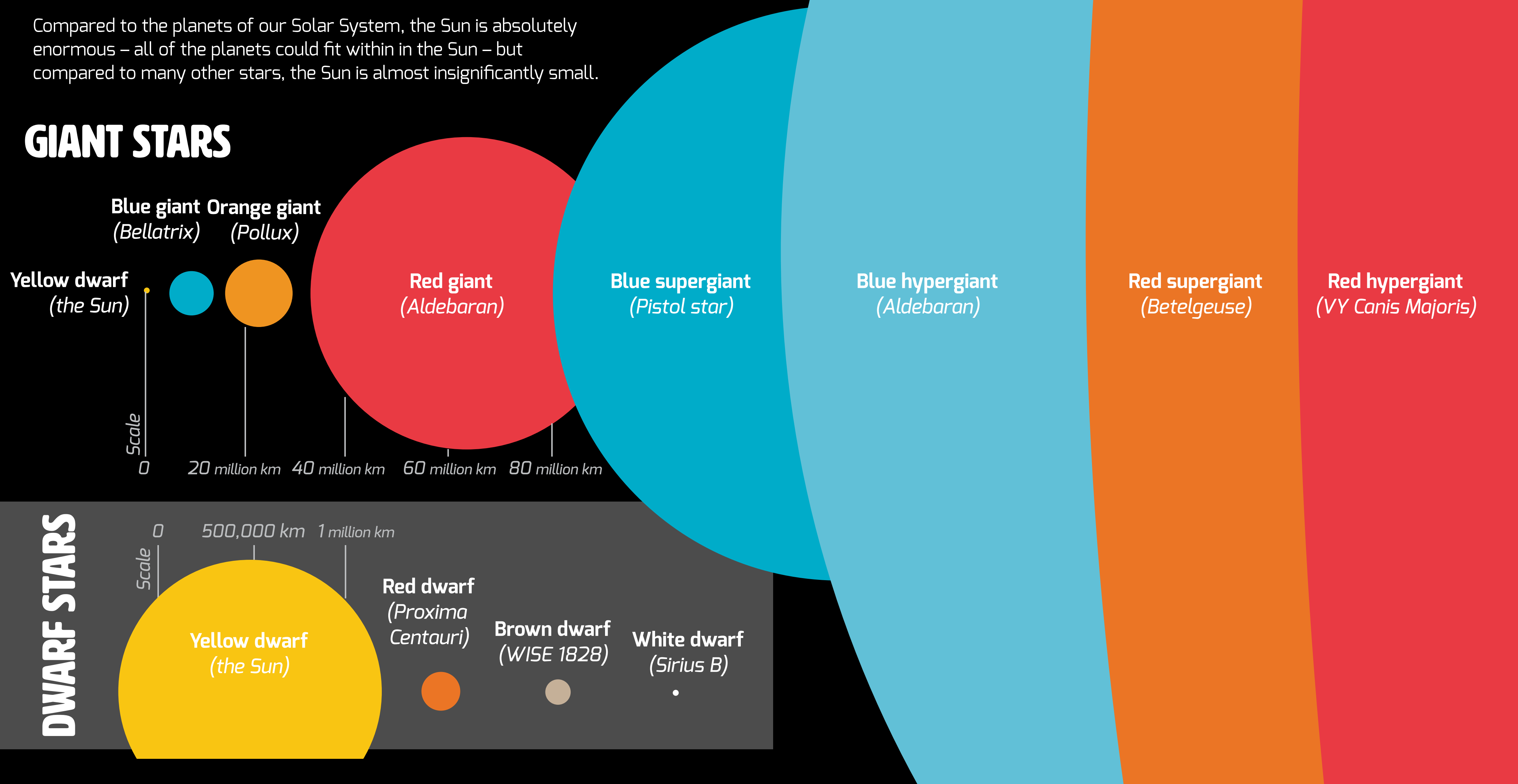
1.2 SO YOU THINK THE SUN IS BIG?

They might all look the same to the naked eye, but stars actually come in all sorts of sizes. The smallest neutron star might be only 25 km wide. A super or hypergiants can be as much as 8 billion times greater in volume than the Sun while a red dwarf can be not much bigger than a planet.

Compared to the planets of our Solar System, the Sun is absolutely enormous – all of the planets could fit within in the Sun – but compared to many other stars, the Sun is almost insignificantly small.

GIANT STARS

DWARF STARS



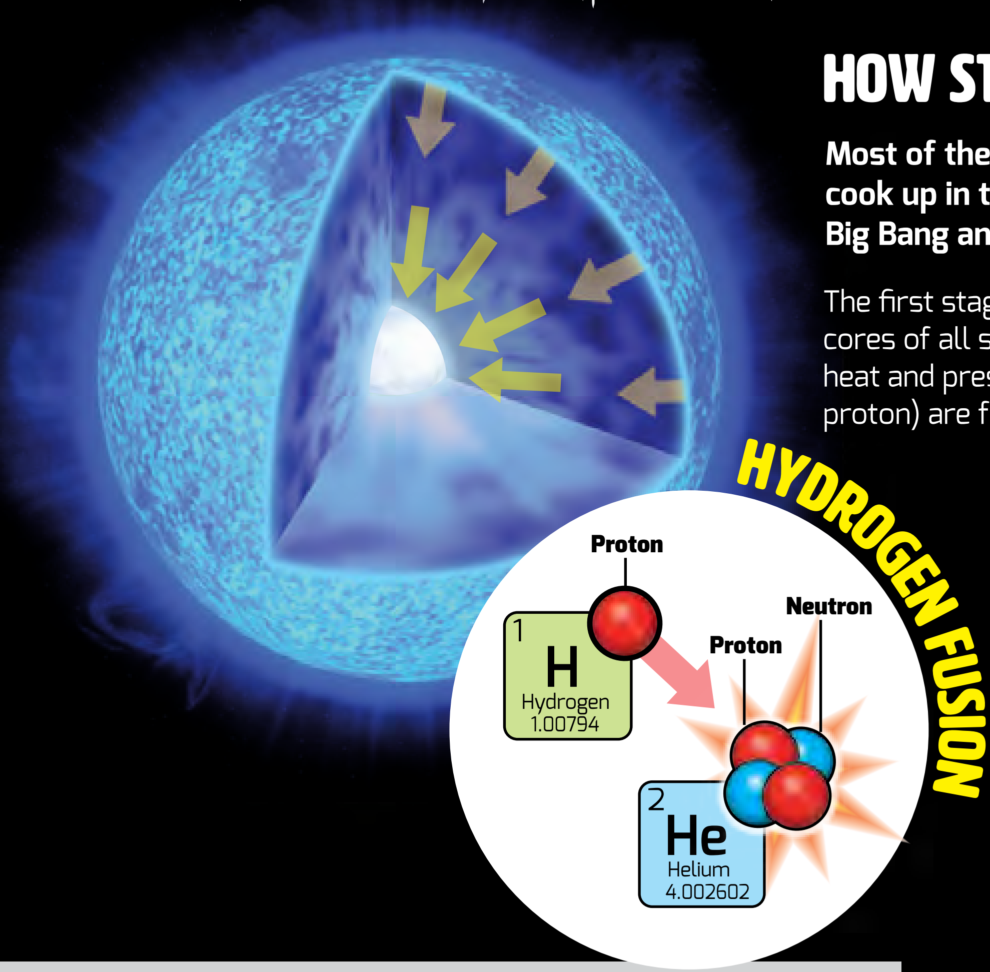
2 WE ARE ALL STAR STUFF

HOW STARS COOK UP THE CHEMICAL ELEMENTS

Most of the chemical elements that make up you and me and the world around us were actually cook up in the cores of giant stars. These nuclear furnaces took the hydrogen gas created in the Big Bang and fused the atoms together to create increasingly heavy chemical elements.

The first stage of cooking up heavy elements takes place in the cores of all stars that achieve nuclear fusion. Under the extreme heat and pressure, two hydrogen gas nuclei (made up of a single proton) are fused together to create the heavier element, Helium.

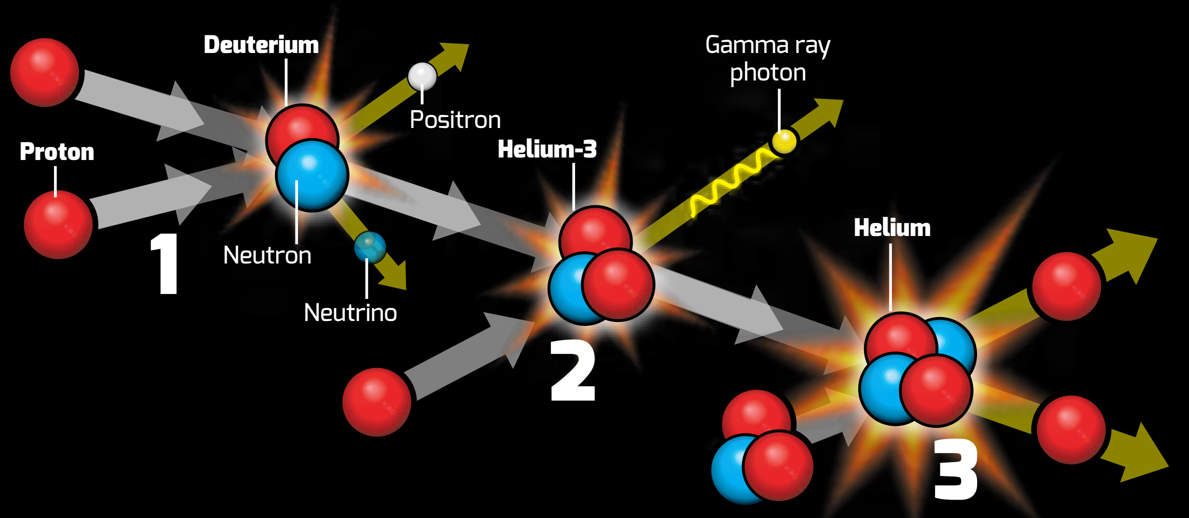
But wait, helium also contains two neutrons... where did they come from?

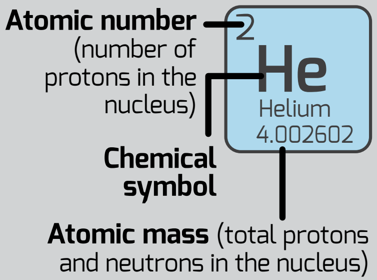


1. When two hydrogen nuclei are forced together. One of the protons decays into a neutron, emitting a positron and a high-energy neutrino – creating a deuterium, or heavy hydrogen, nucleus.

2. Another proton fuses with the deuterium nucleus, emitting a high-energy gamma ray photon – creating a helium-3 (light helium) nucleus.

3. Finally, two helium-3 nuclei fuse to create a helium (helium-4) nucleus. Two protons are ejected along with lots of energy.





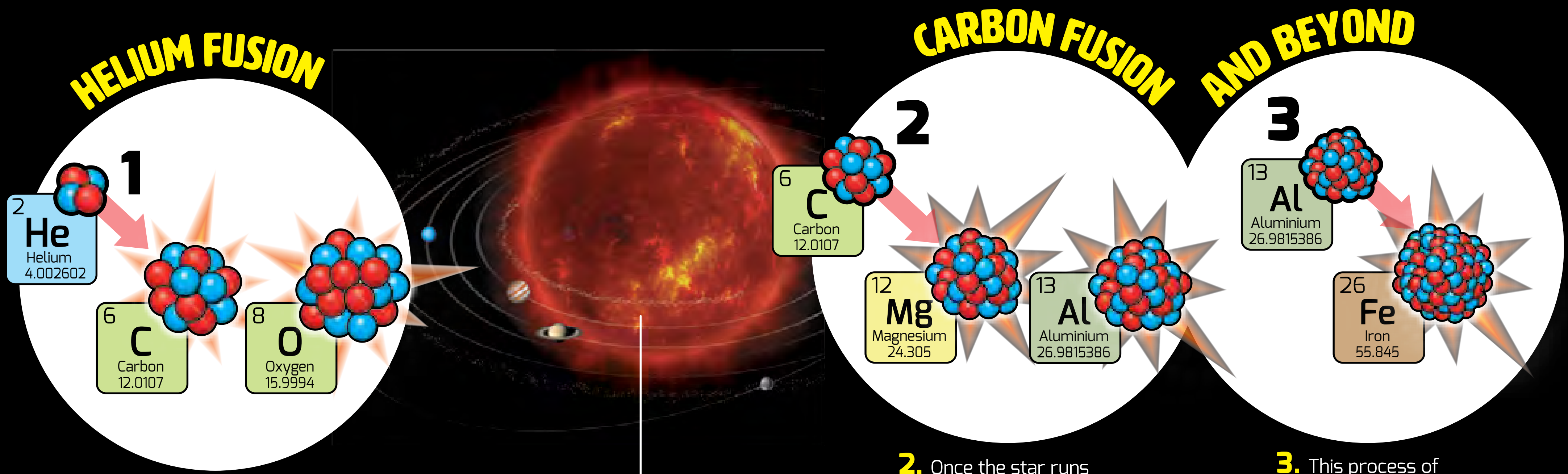
Each element has a particular number of protons and electrons, but the number of neutrons can vary. Those with greater of fewer neutrons are called isotopes.

2.1 HOW MASSIVE STARS MAKE ELEMENTS

Hydrogen fusion is the just the first step on the way to making the chemical elements. Unfortunately, the heavier a chemical element is, the more heat and pressure a star needs to force them to fuse together. When a star runs out of its supply of hydrogen fuel, fusion actually shuts down.

The inside of a star is delicate balance between the heat being created in the core pushing outwards and the mass of the star wanting to collapse inwards. When fusion shuts down, there is nothing to push against the star's mass and the core gets crushed.

But, as the core gets crushed, this increases the pressure and temperature in the core and fusion can start again.



1. The next stage after hydrogen fusion is helium fusion. All the helium the star made is fused together to make elements like oxygen and carbon.

Less massive stars, like our Sun, don't have enough mass to create the pressure needed for carbon fusion, so this is where they die. Only the giants and supergiants are big enough make heavier elements.

When the Sun starts to run out of hydrogen fuel in about five billion years, it will slowly expand by 259 times to become a red giant star. It will swallow the inner rocky planets and, in about 7.5 billion years from now, the Earth will also be incinerated.

2. Once the star runs out helium to burn, fusion stops again. If the star is massive enough, the core will be crushed again and it will get hot enough again for carbon fusion to begin. This creates heavier elements like magnesium, aluminium and sodium.

3. This process of fusion, running out of fuel, fusion stopping, core collapse and fusion restarting are repeated until, finally, iron is created. No star has enough mass to fuse iron nuclei together. So this where even the biggest stars die.

2.2 HOW EXPLODING STARS MAKE ELEMENTS

So, if all the chemical elements are made in stars, and no star can make anything heavier than iron, where did all the elements heavier than iron come from? Well, do make them you need a star to explode as a supernova!

1. So, to make the heaviest elements a supergiant star needs to reach the point where it has fused everything it has into iron.

2. The star expands to become a red supergiant. Deep inside, the star's core now has a iron inner core covered in layers of other elements that weren't fused into iron – a bit like an onion.

3. Now that fusion has stopped and there is no heat pushing outwards, the core collapses violently creating a shockwave. At the same time, the rest of the star also collapses and the two shockwaves meet.

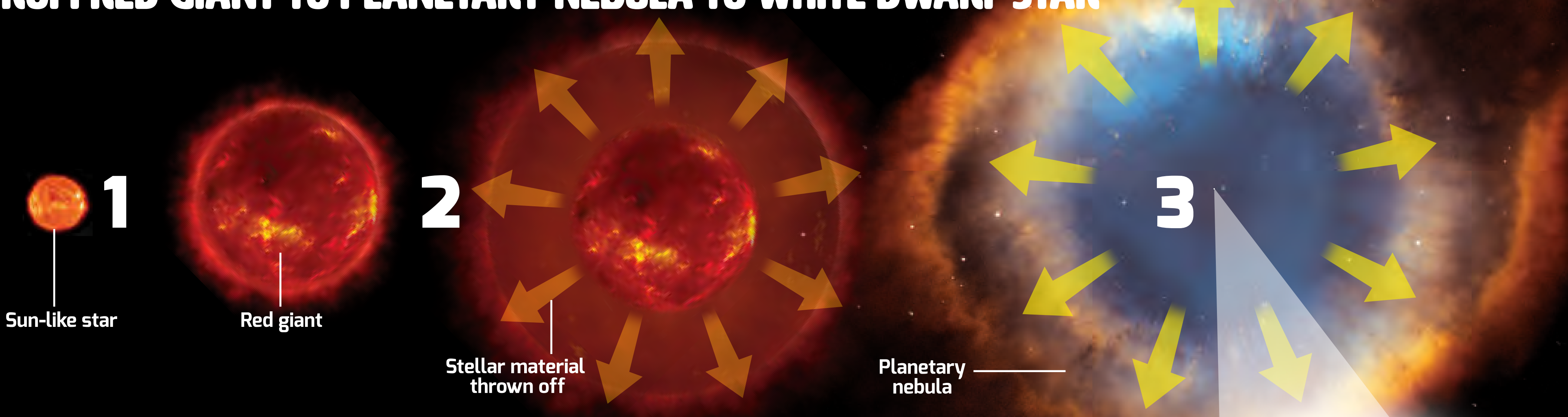
All that iron and other elements are suddenly compressed and super-heated.
This triggers one last wave of fusion that creates heavy elements like gold, lead, mercury, titanium and uranium

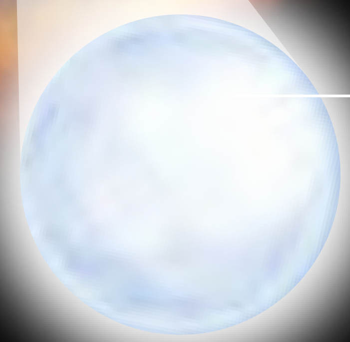
4. The shock wave tears through the remaining stellar material and the star explodes in a powerful supernova explosion that throws everything the star has made during its lifetime out into space.

3 LIFE AFTER DEATH

Just because a star has run our fuel to burn, or exploded as a supernova, it doesn't its story is over. Smaller stars can be transformed into white dwarf stars, while larger stars that went supernova might become a neutron star or a black hole. Also, that supernova will have thrown their heavy elements out into the cosmos to one day become a moon or a planet or a weird alien creature like you and me.

FROM RED GIANT TO PLANETARY NEBULA TO WHITE DWARF STAR





1. When a star about the size of the Sun runs of hydrogen fuel, it expands to become a red dwarf

2. When it starts to run out of helium to fuse, the energy produced in fusion reactions can vary – causing the star's core to pulse as the energy increases and decreases. This pulsing starts to push away the star's outer layers and blow the material into space.

3. Eventually, all of the star's gases are blown away to form a cloud of gas called a 'planetary nebula'. At the centre of this nebula, the star's still super hot core is left behind. This object is called a white dwarf.

As you'd expect for the collapsed remains of a star's core, white dwarf material is very hot and dense – a teaspoon of it would weight several tonnes. Because there is no fusion going on in white dwarf, they slowly cool and fade.

3.1 FROM SUPERGIANT TO NEUTRON STAR

We've seen that the leftover core of a Sun-like star can become a white dwarf, but what about the cores of much more massive stars like supergiants.

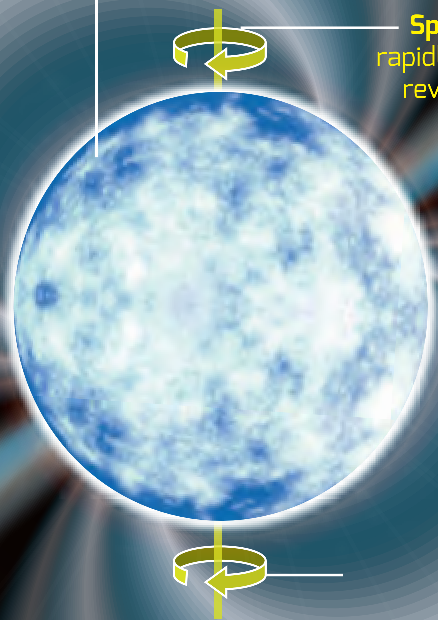
For a star with four to eight times the Sun's mass, once it perishes in a supernova explosion, it leaves behind a core with enough mass that it will collapse to become a neutron star.

Neutron stars are tiny – only about 10 to 15 km across. They are so dense that they are not made of normal matter. In normal matter, an atom is actually made up of 99.9999% empty space. In a neutron star, all of that empty space has been squeezed out - leaving behind only densely packed neutrons.

This makes them so dense that a piece of neutron star the size of a grain of rice would weigh the same as large passenger jet here on Earth. If you were able to land on a neutron star you would weigh 100 billion more than you do on Earth.

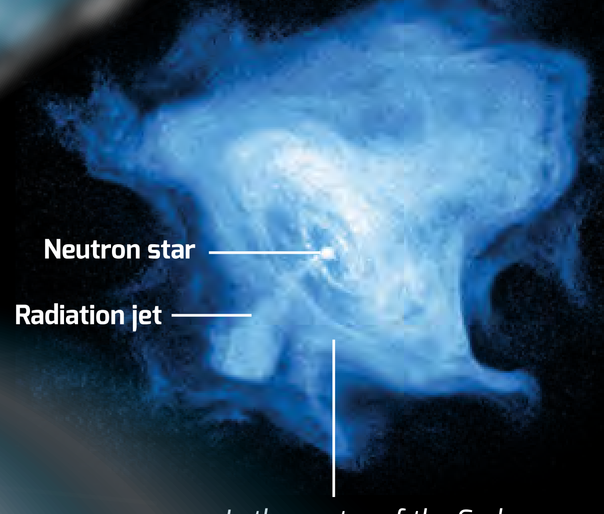
Surface: Atoms are so densely packed that the surface is stronger than steel. It is almost perfectly smooth with 'mountains' that are only a few millimetres high

Spin: Neutron stars spin rapidly – some as fast as 700 revolutions every second



Radiation jet: Powerful beams of radiation are funneled by the star's magnetic field

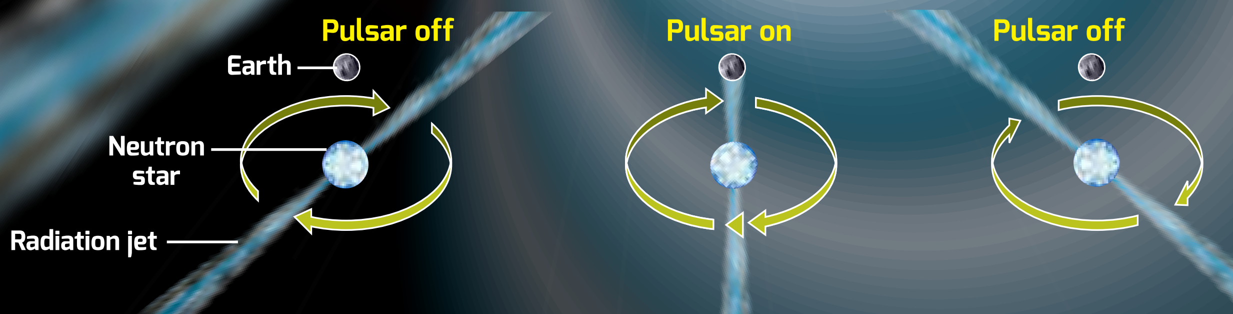
Magnetic field: Neutron stars have extremely powerful magnetic fields that rotate at the same speed as the star



In the centre of the Crab Nebula there is a neutron star that spins at a rate of 30 revolutions per second. The ring-like shapes you can see are shockwaves produced by the star's radiation jets.

WHEN IS A NEUTRON STAR A PULSAR?

When the radiation jet from a neutron star is detectable from Earth, we call it a pulsar.

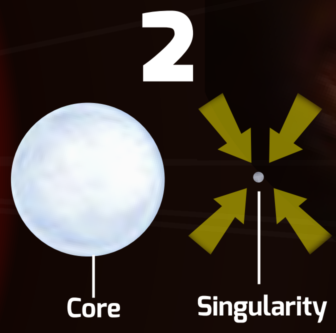


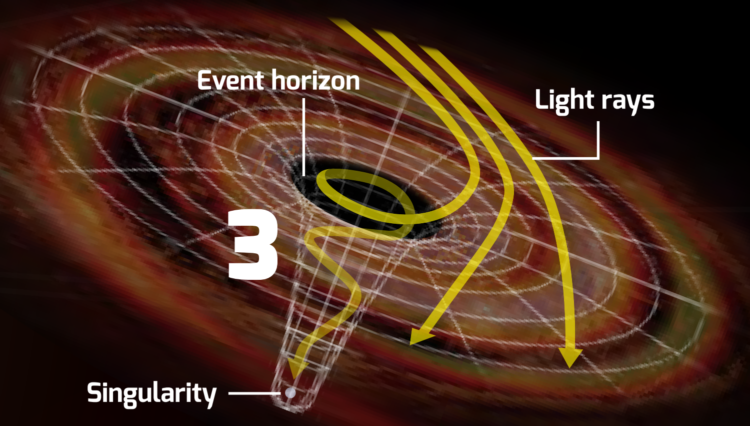
As the pulsar spins, its radiation beams sweep though space. When the beam points at the Earth, we can see it. This sweeping motion makes it look like the pulsar is turning off and on.

3.2 FROM HYPERGIANT TO BLACK HOLE

The ultimate extreme ending for a star's life is to become a black hole or, as they were known when their existence was first imagined, a 'dark star'.

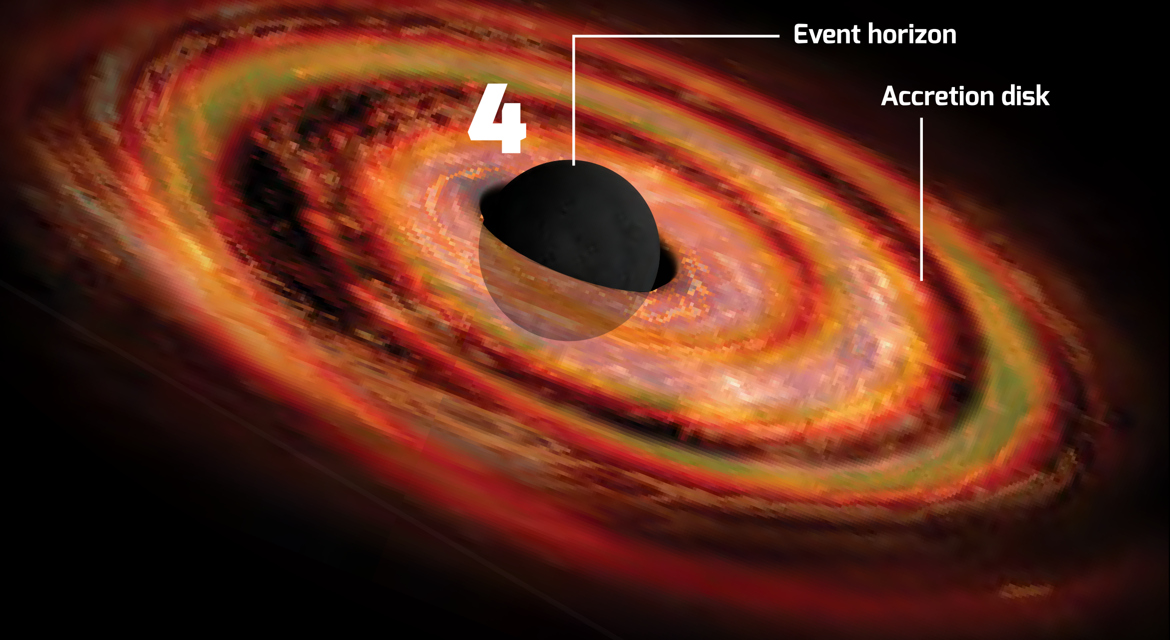
A black hole is a region of space where matter has been squeezed to a point where it has so much gravitational energy that anything that passes too close, even light, will fall into it.





3. It is so dense and so gravitationally strong that anything that strays too close to the singularity falls towards it. Even light, if it gets too close, can't escape.

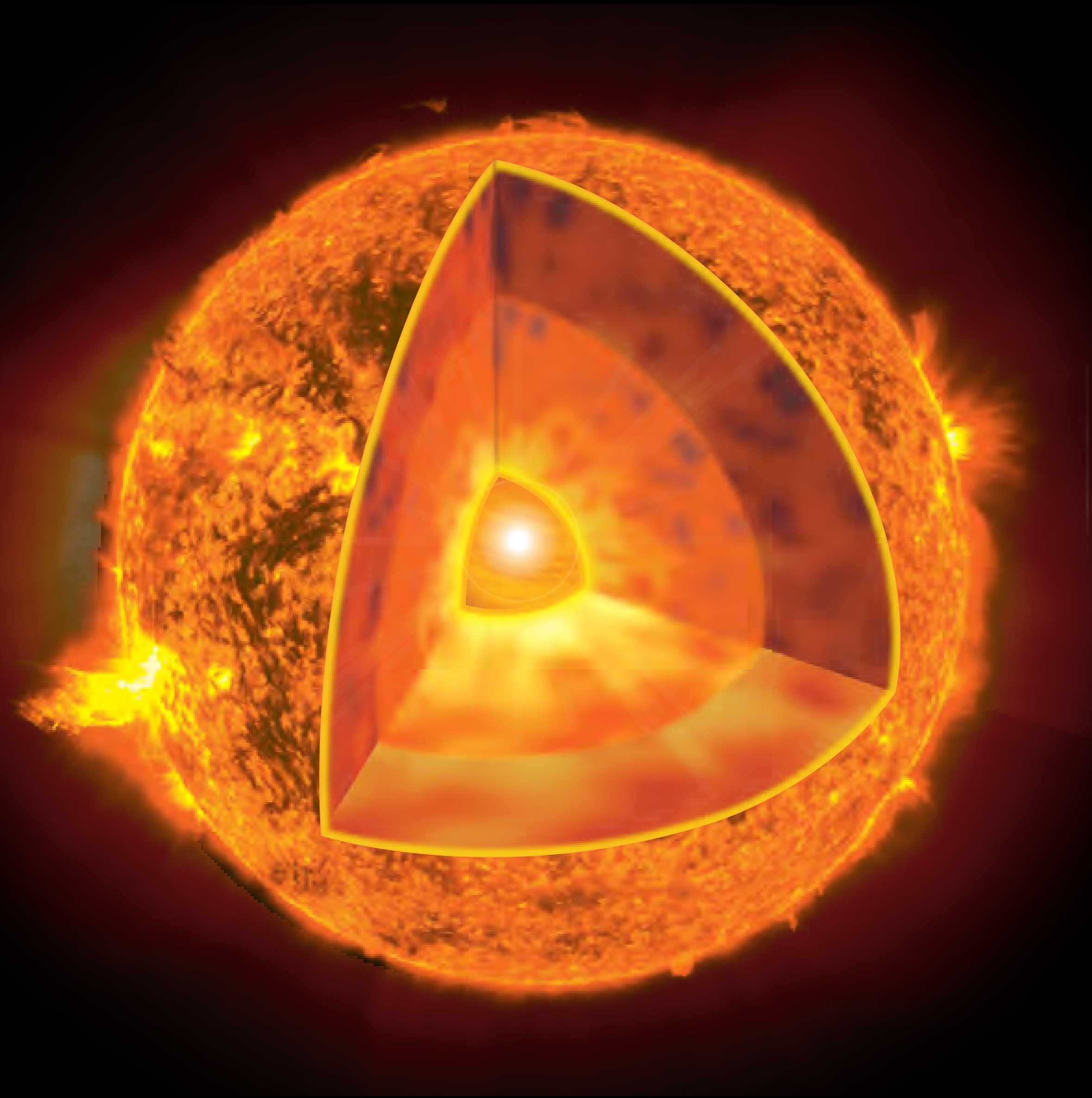
4. The boundary past which light can no longer escape is called the 'event horizon'. Some black holes are surrounded by disks of gas and matter that spirals into the black hole, this is called an accretion disk.



1. This hypergiant star has just exploded as a supernova. I has left behind a core that has the mass of many Sun's packed up inside it.

2. It has so much mass and so much gravity that, unlike the neutron star, it can collapse past the point of squeezing out all the space between atoms. It can collapse so far that it can become what is known as a singularity.

A singularity is where all the matter from the star's core has been squeezed to a minuscule point of infinite density.



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