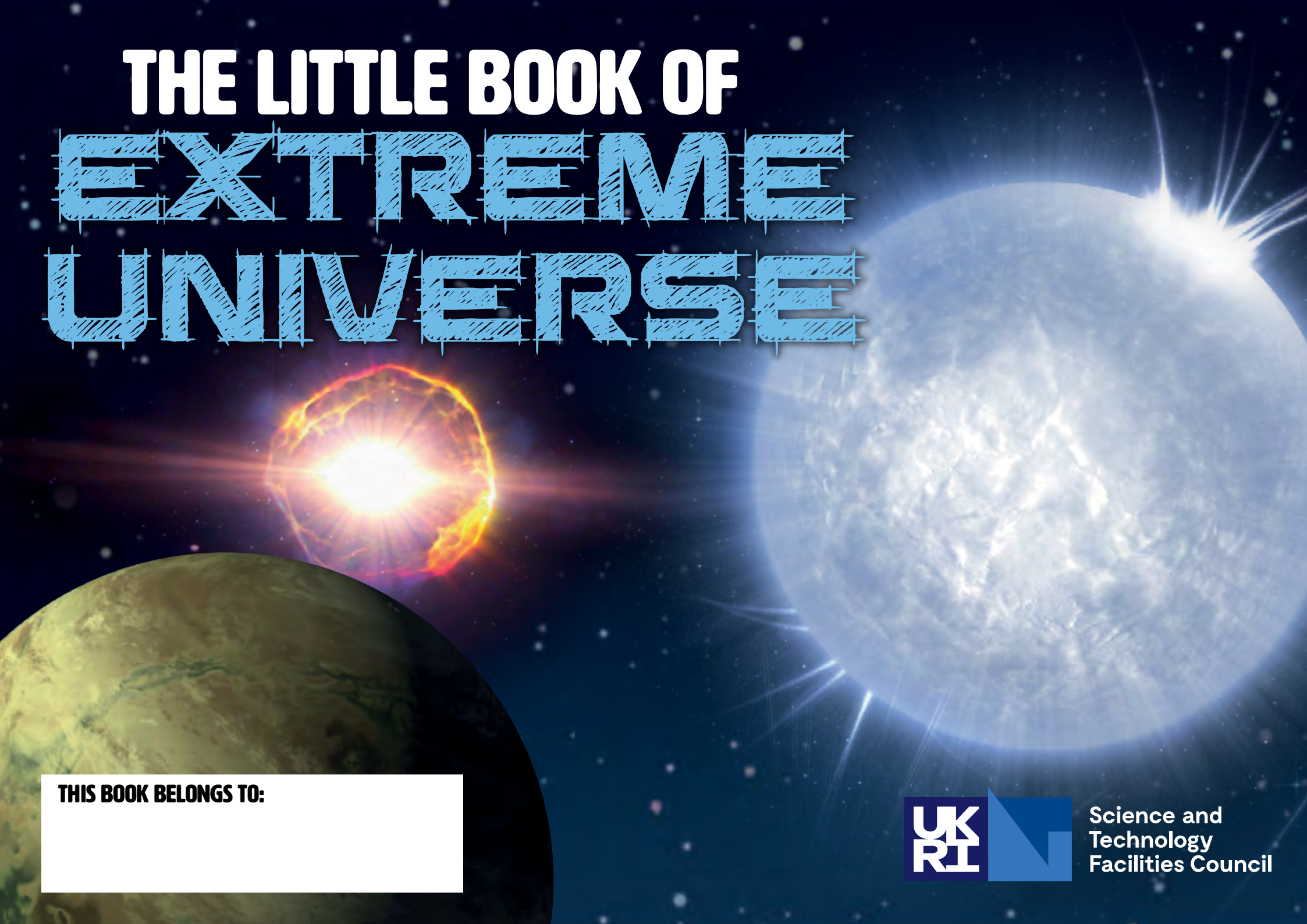
THE LITTLE BOOK OF EXTREME UNIVERSE



THIS BOOK BELONGS TO:

Science and Technology Facilities Council

What is the hottest object in the Universe, or the coldest, or the biggest?

Is the Sun the brightest object in the Universe?

How heavy is cubic centimetre of neutron star?

How can the biggest something also be the biggest nothing?

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

THE LITTLE BOOK OF EXTREME UNIVERSE

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UKRI Science and Technology Facilities Council

1 THE HOTTEST

What do you think the hottest object in the Universe is? Lava from a volcano? The Earth's core? The centre of the Sun? True, the Sun is very very hot indeed but, compared to the hottest objects in the cosmos, the Sun's temperature is really quite tame!

KELVIN OR CELSIUS

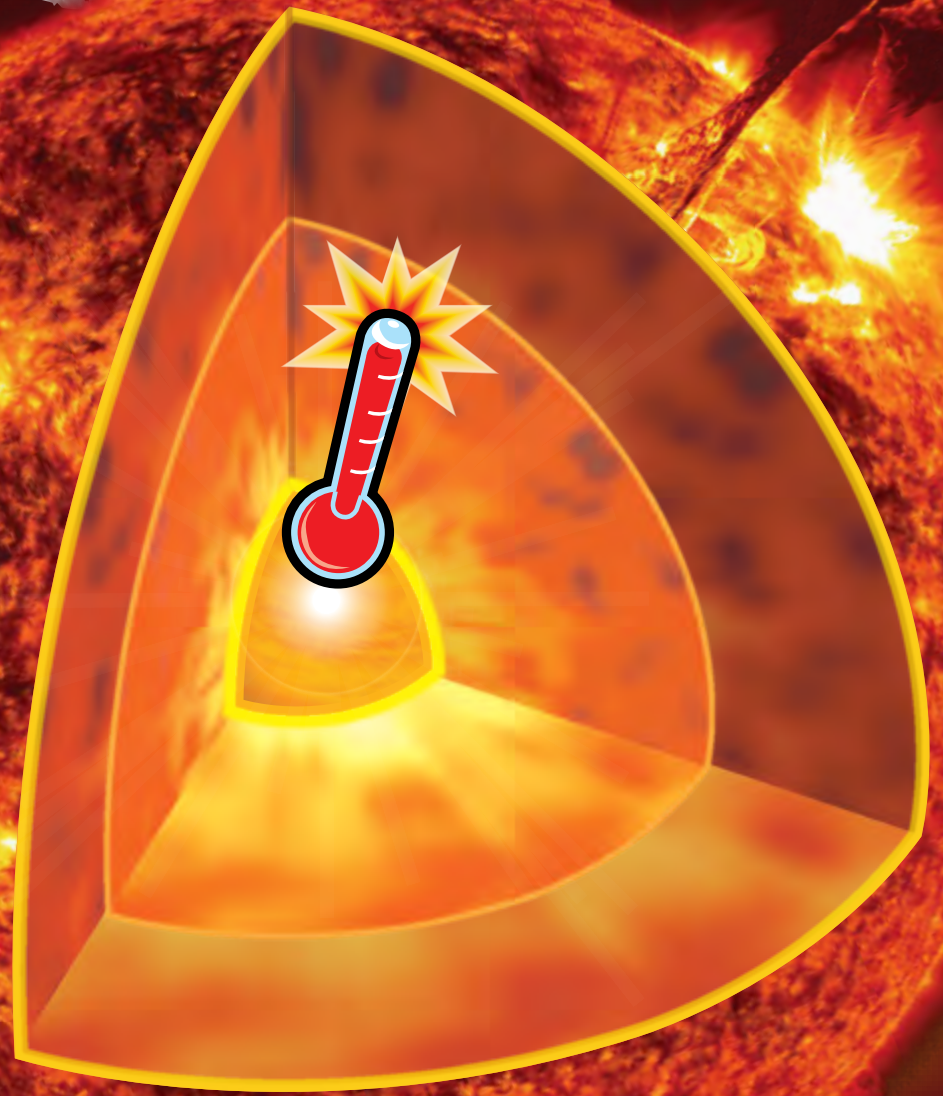
When scientists discuss really hot or really cold things, they use something called the Kelvin scale. Zero Kelvin is also called absolute zero, which (spoiler alert) is as cold as anything can get.... but we'll get to that later.
For this book we'll use the Celsius scale because that is scale we are used to using in everyday life – for reference, absolute zero in Celsius is minus 273.15 °C.

The Sun is the hottest object in our Solar System. It's surface is a pretty scorching

5,500°c

but, like all stars, it is at its hottest deep in its centre where the core is an incredible

15 million °c



1.1 HOTTEST PLANET SURFACES

It makes sense that stars like the Sun will be among the hottest objects in the Universe, but there are some planets with surfaces hot enough to make you think twice about holidaying there.

VENUS

The second planet from the Sun has the hottest planetary surface in the Solar System. Thanks to its thick, heat-trapping atmosphere, Venus' surface is

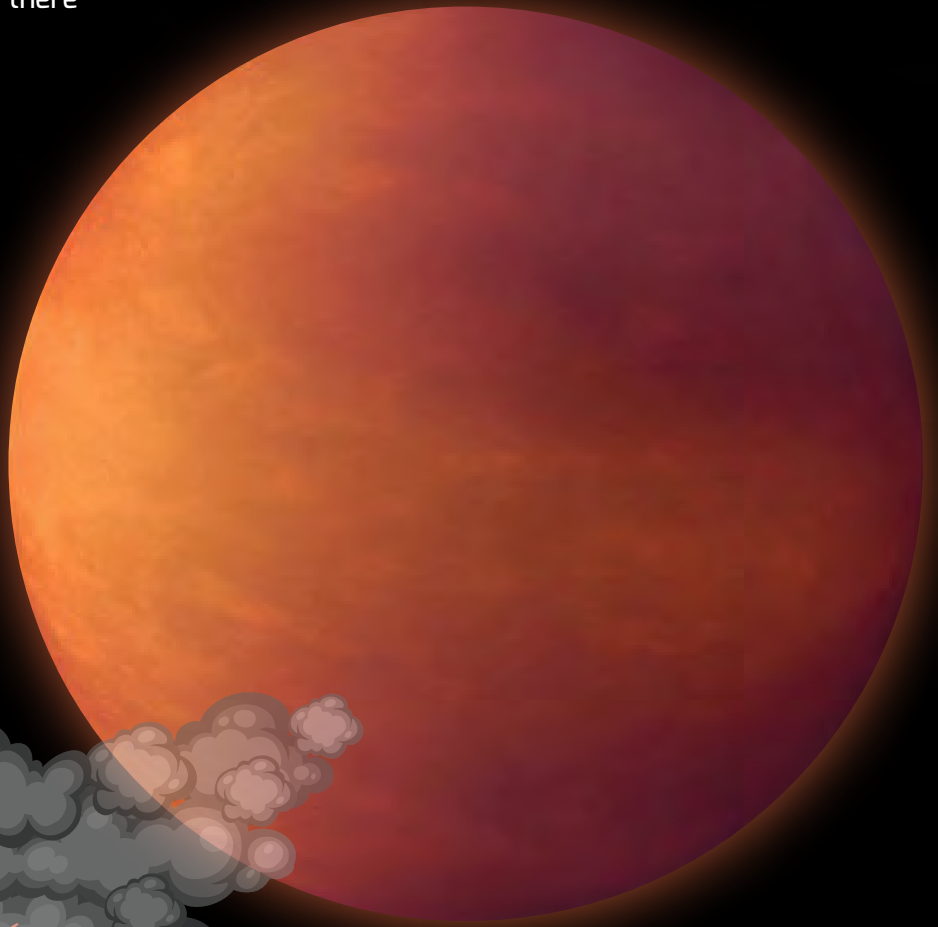
465°c

KELT-9B

This ultra-hot Jupiter-like gas giant orbits very close to a star 670 light years away from Earth. It holds the record as the hottest planet yet discovered with a surface temperature of

4,000°c

Kelt-9b is so hot that the heat tears apart hydrogen atoms in its atmosphere. It's only when they flow around to planet's night side that they cool enough to recombine, only to be torn apart again the next day.



THE FLOOR IS LAVA!

One of the hottest naturally-occurring things on Earth's surface is lava, which can reach temperatures as hot as

1,200°c

Lava is molten rock that has bubbled up from deep within the Earth. It is called lava only when it reaches the surface, while it is still underground it is called magma.

1.2 HOTTEST STARS

Kelt-9b is certainly a scorcher but it is positively chilly when compared with the surfaces of some of the hottest stars in the Universe! And those stellar surface temperatures are nothing when compared to the incredible heat generated deep within their cores.

BLUE SUPERGIANTS

Supergiants are stars that can be hundreds of times larger than the Sun and have many thousands of times more mass.

All that extra mass means that they burn very hot indeed and can have a surface temperature that exceeds

50,000°C

The core of a blue supergiant can get as hot as

100 million °C

DOESN'T BLUE MEAN COLD?

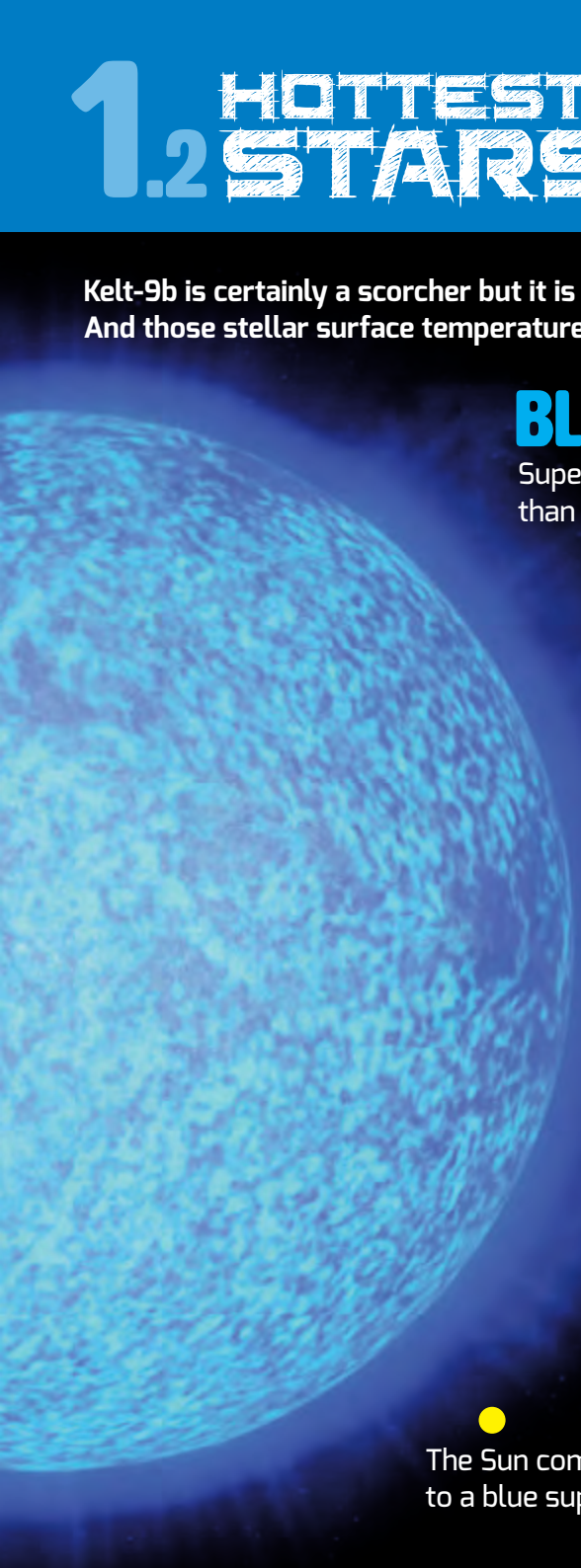
Blue stars are blue because they're very hot. This sounds wrong, because in the everyday world red means hot and blue means cold. But blue light carries more energy than red light, which means it needs a hotter source to produce it. This is why hot stars are blue and why iron goes from red hot to blue/white hot as you heat it.

It is possible that the largest supergiants may have core temperatures of more than **1 billion °C (1,000,000,000 °C)**

WHITE DWARF STARS

White dwarfs might be tiny stars but they pack a big punch when it comes to their surface temperatures. Although they are not much bigger than the planet Earth, they are so dense that their surfaces can be as hot as

200,000°C



The Sun compared to a blue supergiant

A white dwarf is what stars like the Sun become after they have exhausted all their nuclear fuel and lost their outer layers - leaving behind only the core.

1.3 HOTTEST PHENOMENA

If you thought a supergiant star with a million degree core was as hot as you can get, think again – the Universe has a few super-hot surprises left in store for you!

SUPERNOVA EXPLOSIONS

Some of the most violent (and hottest) events in the Universe happen when a dying star explodes as a supernova. During a supernova, the exploding star can reach more than

6 billion °c

SN 1987A

In 1987, astronomers witnessed a star exploding more than 160,000 light years away in the Large Magellanic Cloud (a galaxy outside of our Milky Way galaxy). This supernova briefly reached temperatures of about

200 billion °c

(200,000,000,000 °c)

QUASAR 3C273

Quasars are the blazing centres of active galaxies and are powered by a supermassive black hole that feeds on huge amounts of gas and then spews incredible amounts of energy back into space.

Quasar 3c273 was the first quasar ever found and is one of the brightest ever seen. It earned the award as hottest object every recorded when its centre was measured at astonishing

10 trillion °c

(10,000,000,000,000 °c)

2 THE COLDEST

Space is famous for being really cold but, in reality, empty space itself is neither hot nor cold because, well, it's empty. But there are plenty of really cold things in space!

Temperature is a funny thing because, while there is no real limit for how hot something can get, there is a limit to how cold anything can get. This is called 'absolute zero', which is **-273.15°C**

COLDEST PLACE ON EARTH

The East Antarctica Plateau in Antarctica is the coldest place on Earth. The area regularly reaches a rather chilly **-93°C**

COLDEST PLANET

Distant Uranus holds the record for the coldest planet in the Solar System with an average temperature of **-224°C**

WHAT IS HEAT?

All matter is made of tiny particles called atoms, molecules and ions. These tiny particles are always in motion – either bumping into each other or vibrating back and forth. It is the motion of particles that is the result of a form of energy called heat (or thermal) energy that is present in all matter.

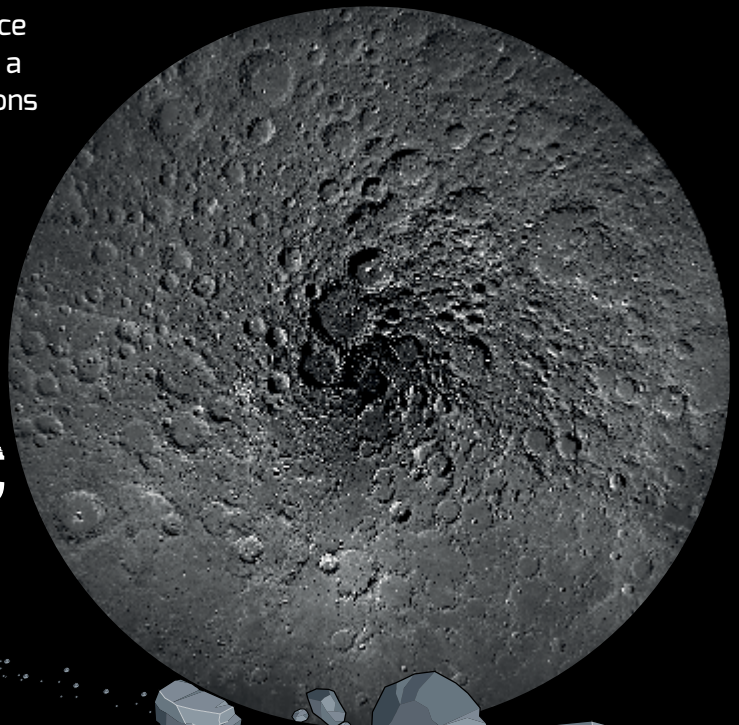
In a solid, like a metal, the particles can't move about so they vibrate – the more energy they have, the more they vibrate and the hotter the metal gets.

If you cool an object down, the particles have less and less energy and their movement slows down. The point at which they run out of energy completely and stop moving is called absolute zero.

COLDEST IN THE SOLAR SYSTEM

You'd expect the coldest place in the Solar System to be on a distant planet or moon millions of miles away from the Sun, such as Uranus. But the title actually goes to a crater near the Moon's north pole where the temperature was recorded at a super cool

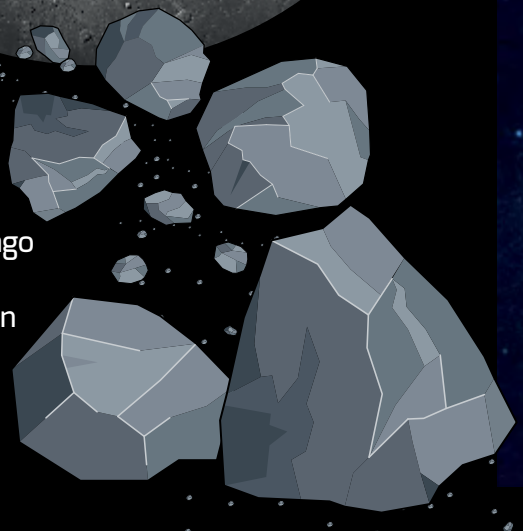
-246°C



COLDEST SPACE ROCKS

With nothing to heat them up the left over heat from the Big Bang – more than 13.7 billion years ago – any comet or space rock wandering through intergalactic space are likely to be no warmer than

-270.15°C



BOOMERANG NEBULA

This rapidly expanding nebula is even colder than the leftover background temperature of BIg Bang – reaching a temperature just a whisker above absolute zero – at

-272.15°C

The nebula's rapid expansion actively cools the gases within it (just as expansion chills the coolant in a refrigerator).

3 THE BIGGEST

If there's one thing everyone knows about space is that space is really really big. It's so big that boring old measurements like miles and kilometres are just too small and astronomers like to use the distance light can travel in a year (a light year) as their unit of choice!

Space might be the biggest thing of all but it is also full of really big objects such as planets, stars and galaxies. Some are so big that they boggle the mind...

BIGGEST SOLAR SYSTEM PLANET

There is no contest for the title of biggest planet in the Solar System. Jupiter is not only the biggest but is also the most massive – having more than twice the mass of all the other Solar System planets combined! The gas giant has a diameter of

142,700 km

Jupiter's size compared to KOI-2513 b

BIG DOESN'T MEAN MASSIVE

In science, describing something as 'massive' doesn't necessarily mean something is big. Instead it refers to how much mass an object has (how much matter it is made of). For example, a bath sponge is bigger than a marble, but the marble contain more matter (which makes it heavier) and so the marble can be described as being more massive than sponge even though it is smaller!

BIGGEST EXOPLANET

Jupiter is dwarfed by the biggest gas giant yet discovered outside of our Solar System. KOI-2513 b orbits a star 6,470 light years away and is just over nine times Jupiter's diameter – measuring in at an enourmous

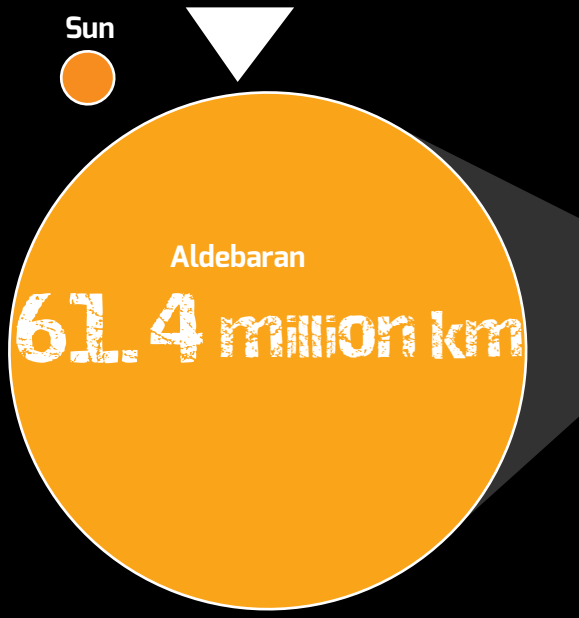
1,260,000 km

That's about the same a 100 Earth's lined up next to each other!

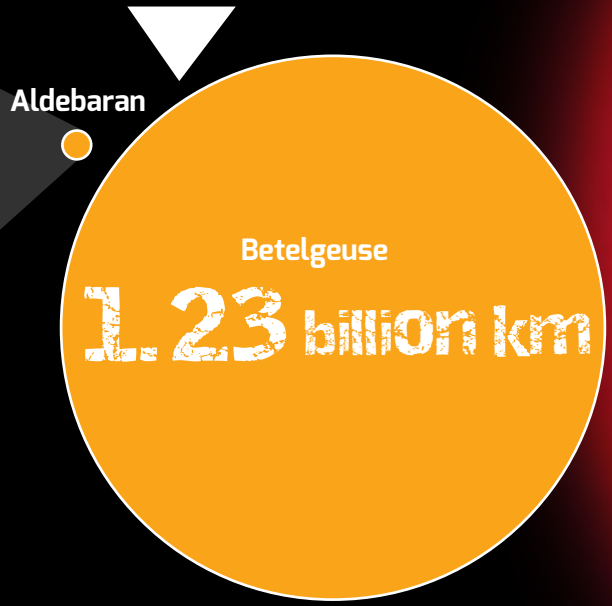
3.1 THE BIGGEST STARS

It's hard to imagine just how big things can be when it comes to space. We like to think of our local star, the Sun, as being really very big – and it is very big when compared to other objects in our Solar System – but, compared to the biggest stars, our Sun is almost insignificant!

The Sun has a diameter of 1.4 million km. This is the Sun compared to a star called Aldebaran. Aldebaran is huge compared to the Sun but...

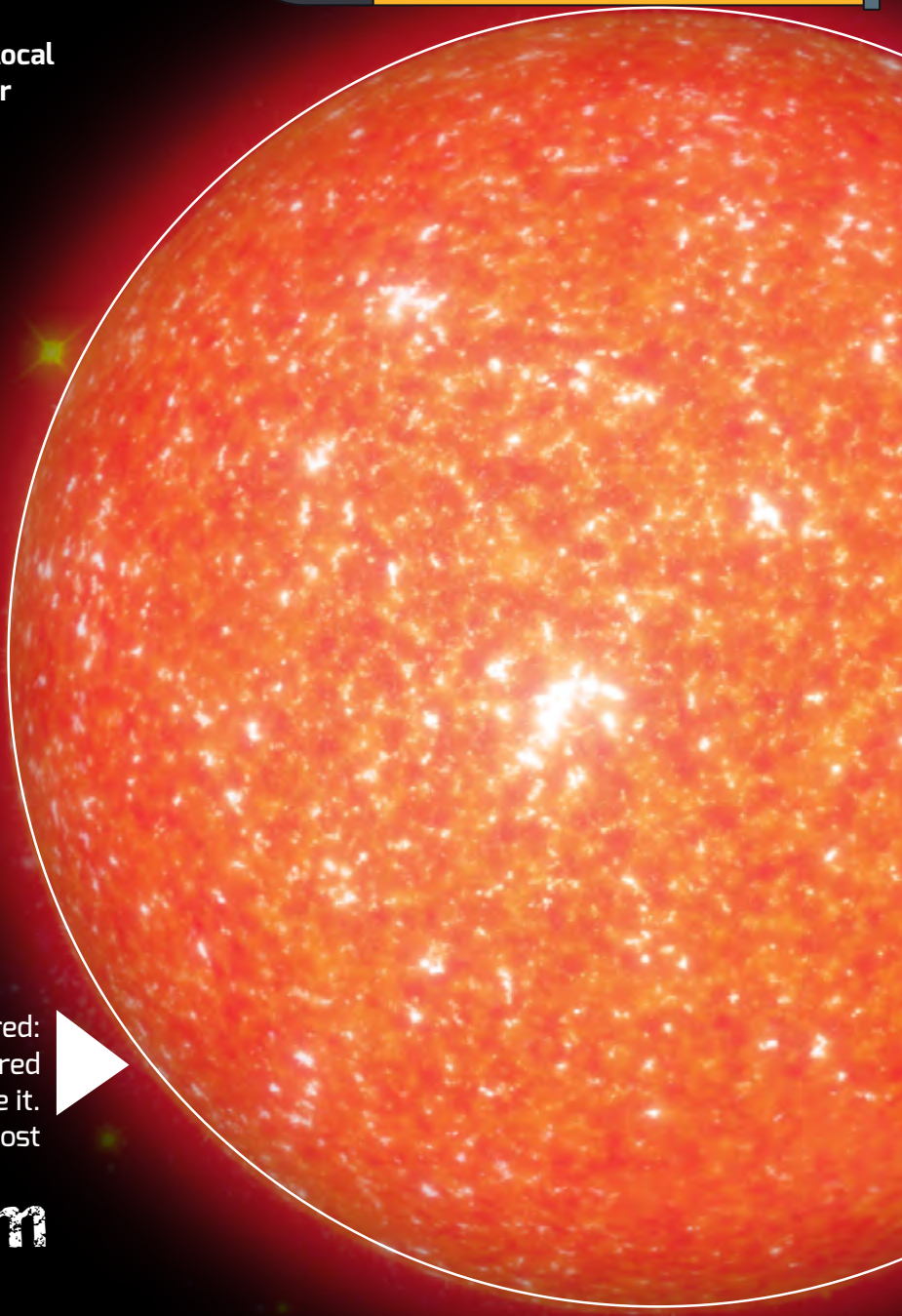


... this is Aldebaran compared to a star called Betelgeuse. Betelgeuse makes Aldebaran look tiny by comparison but...



... even Betelgeuse seems small when compared to one of the biggest star yet to be discovered: VY Canis Majoris (which means 'Big Dog'). This is one of only very few stars to earn the title 'red hypergiant' and is so large that you could fit the whole of our Solar System inside it. VY Canis Majoris has a diameter of almost

2 billion km



3.2 THE BIGGEST GALAXY

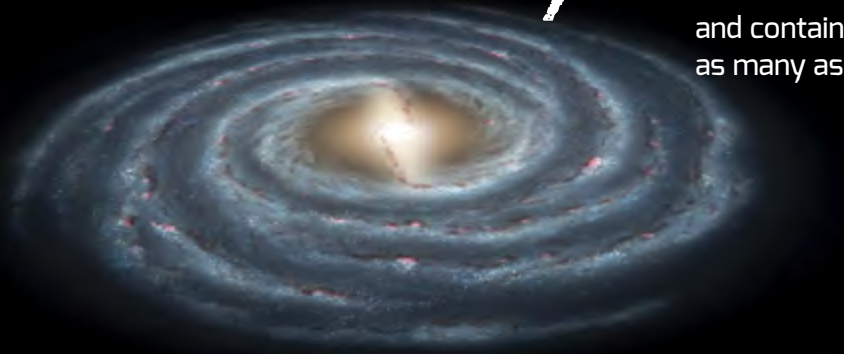
As we've seen, stars can get pretty enormous but what about those even more enormous things that contain lots of stars: galaxies? A galaxy like the Milky Way is home to about 100 billion stars and yet it is far from being one of the biggest galaxies in the Universe!

MILKY WAY

There's no denying that the spiral galaxy we call home is enormous. Our Sun is just one tiny speck among more than 100 billion other stars and it measures more than

100,000 light years

and contains as many as **400 billion stars**



BUZZING ABOUT LIGHT YEARS

Many things in space are too big to measure using miles and kilometres so astronomers use something called a light year as a unit of measure. A light year is the distance light can travel through a vacuum in one year. As light travels at a speed of 300,000 km per second, one light year is more than

9 trillion km

(9,000,000,000,000 km)

ESO 383-76

The biggest galaxy that has been discovered is ESO 383-76. This supergiant elliptical galaxy looks very different to the Milky Way. At the centre of ESO 383-76 , there is a supermassive black hole, which also happens to be one of the largest black hole ever discovered. ESO 383-76 has an estimated diameter of

1,760,000 light years

and contains **trillions of stars**

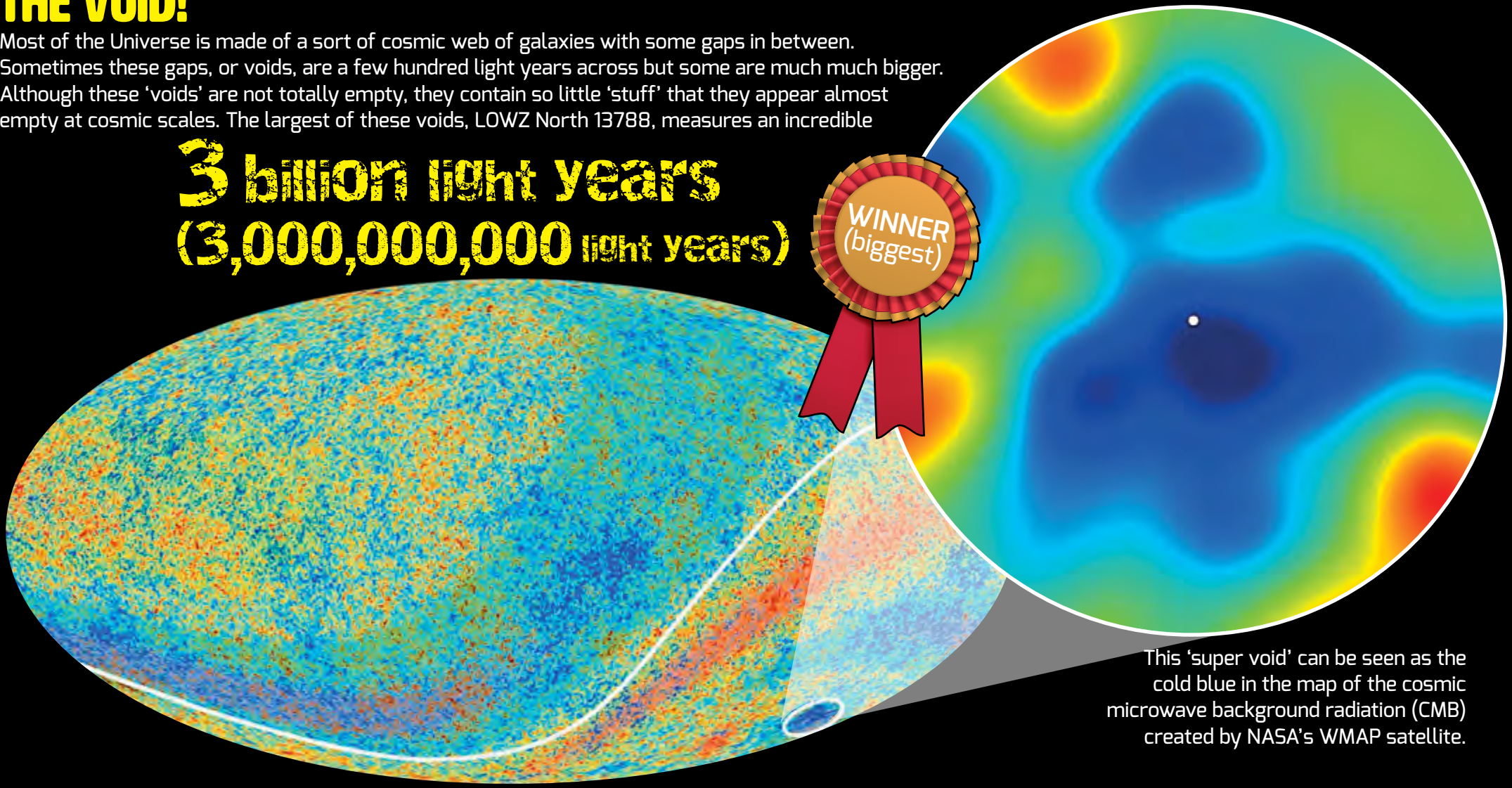
3.3 THE BIGGEST SOMETHING IS NOTHING OF ALL

It's hard to top a galaxy that measures more than 1.7 million light years in diameter... so we are going to cheat a bit and make the biggest something in the Universe actually the biggest nothing in the Universe.

THE VOID!

Most of the Universe is made of a sort of cosmic web of galaxies with some gaps in between. Sometimes these gaps, or voids, are a few hundred light years across but some are much much bigger. Although these 'voids' are not totally empty, they contain so little 'stuff' that they appear almost empty at cosmic scales. The largest of these voids, LOWZ North 13788, measures an incredible

3 billion light years (3,000,000,000 light years)



This 'super void' can be seen as the cold blue in the map of the cosmic microwave background radiation (CMB) created by NASA's WMAP satellite.

4 THE DENSEST

How dense an object is determines how heavy it feels in your hand and it is another way of saying how much mass an object has. A dense object like a metal ball bearing is a lot heavier than a bath sponge – even though the sponge is much larger in size. This is because the ball bearing packs a lot more mass into a much smaller area than the sponge – the metal is more dense than the sponge.

DENSEST MATERIAL ON EARTH

Osmium is the densest known naturally occurring material on Earth. Osmium is a metallic element that is twice as dense as lead.

0.22kg per cubic cm

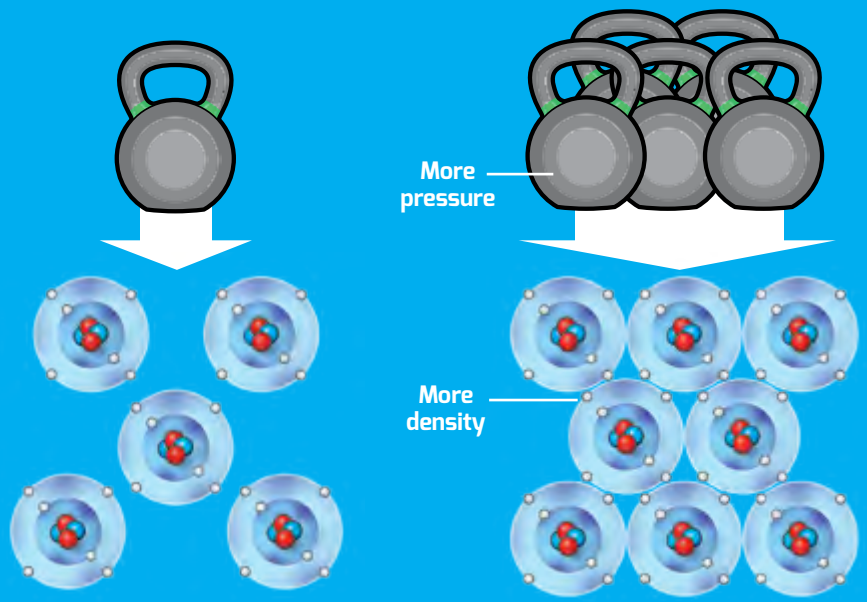
A cubic centimetre is about the same size as a small sugar cube. A 22g sugar cube is pretty heavy... but you haven't seen anything yet!

THE ATOMIC SQUEEZE

There is a limit to how dense a material can get under the relatively weak gravity of Earth – this is because it is only subjected to very mild pressures and temperatures.

Put at its most simple, the density of a material is determined by how closely packed together the atoms that make it up are. Osmium is dense because it contains a lot more atoms squeezed into a small area than a lighter material.

But there is a limit to how close atoms can be squeezed together on Earth because each atom is surrounded by a cloud of negatively-charged electrons. These electron clouds repel each other so strongly that it takes a huge amount of pressure (and very high temperatures) to force the atoms to squeeze closer together.



4.1 THE DENSEST

As we've seen, it takes a lot of pressure (and heat) to force atoms to squeeze together. So to find the densest materials in the Universe we need to look at some of the most massive (remember massive means lots of mass) objects in the Universe. In fact, we need to look deep inside the most massive objects where the heat and pressure is at its most extreme...

WHITE DWARF STAR

We've already seen that a white dwarf is one of the hottest objects in the Universe, but they also have a lot of mass which can squeeze the material in its core to a density of

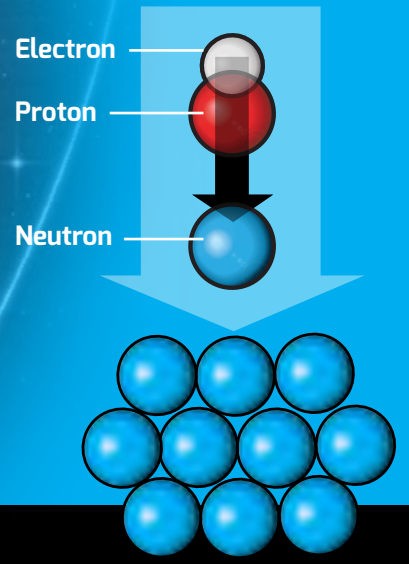
1,000,000,000kg per cubic cm

NEUTRON STAR

A neutron star is so dense that it makes a white dwarf look like a fluffy ball of cotton wool. A neutron star has so much mass that the atoms in its core are subjected to so much pressure all the empty space is squeezed out. This leaves a core with a colossal density of

100,000,000,000,000kg per cubic cm

In a neutron star, the negatively-charged electrons are literally squeezed into the positively-charged protons so that they cancel each other out and leave behind a neutron. This leaves behind nothing but neutrons all squeezed up next to each other, which is why they are called neutron stars.



BLACK HOLE SINGULARITY

It's no coincidence that the object with the most extreme density is the most extreme object in the Universe: a black hole.

At the centre of a black hole is something called a singularity. The singularity is a thing so dense that the we really don't understand what it actually is – in fact, it is so dense that the laws of physics as we know them just fall apart.

You can think of the singularity as being the core of a star many times the size of the Sun shrunk down to a point so small that it actually has a volume of zero (we did say that physics falls apart) – this gives a black hole singularity a denity of

INFINITY kg per cubic cm

If you think an infinite density squeezed down to zero volume is odd, it gets even stranger when you work out the density of the entire black hole! If you extend it to the point at which light can't escape (called the Schwarzchild radius) and imagine the black hole as a sort of black billiard ball, the density reduces from being infinite to, on average, only a little more dense than water!

5 THE BRIGHTEST

We think of outer space as being a pretty dark place but you just have to look up to see thousands of cosmic lamps shining away. Some of these are so bright that our everyday Earthly units of measurement are far too small. Instead, astronomers use the amount of light output by the Sun as a unit.

THE SUN

The Sun is actually an above average star when it comes to brightness. It has a light output equivalent to about 3.8 million billion billion 100 watt light bulbs. But when it comes down to it, it only outputs the same energy as

1 sun

ALNILAM

Alnilam, or Epsilon Orionis is a blue supergiant. You can find this blazing behemoth in the middle of Orion's Belt. Located 1,300 light years away, Epsilon Orionis shines with the light of

800,000 suns

Sun's size versus Alnilam

ETA CARINAE

Hiding at the centre of this cloud of star dust is the unstable star Eta Carinae. Eta Carinae is so unstable that it could explode as a supernova at any time – in fact, the giant cloud that surrounds it was created by an explosion about 150 years ago. With a mass of more than 100 times that of the Sun, Eta Carinae is as bright as

5 million suns

5.1 THE BRIGHTEST

SUPERNOVA

Supernova explosions are famously bright but some are so bright that they boggle the mind. One in particular, called SN2016aps, was spotted in 2016 in a galaxy 3.6 billion light years away. It might be the brightest stellar explosion ever recorded with its brightness peaking at

76 billion suns (76,000,000,000 suns)

QUASARS

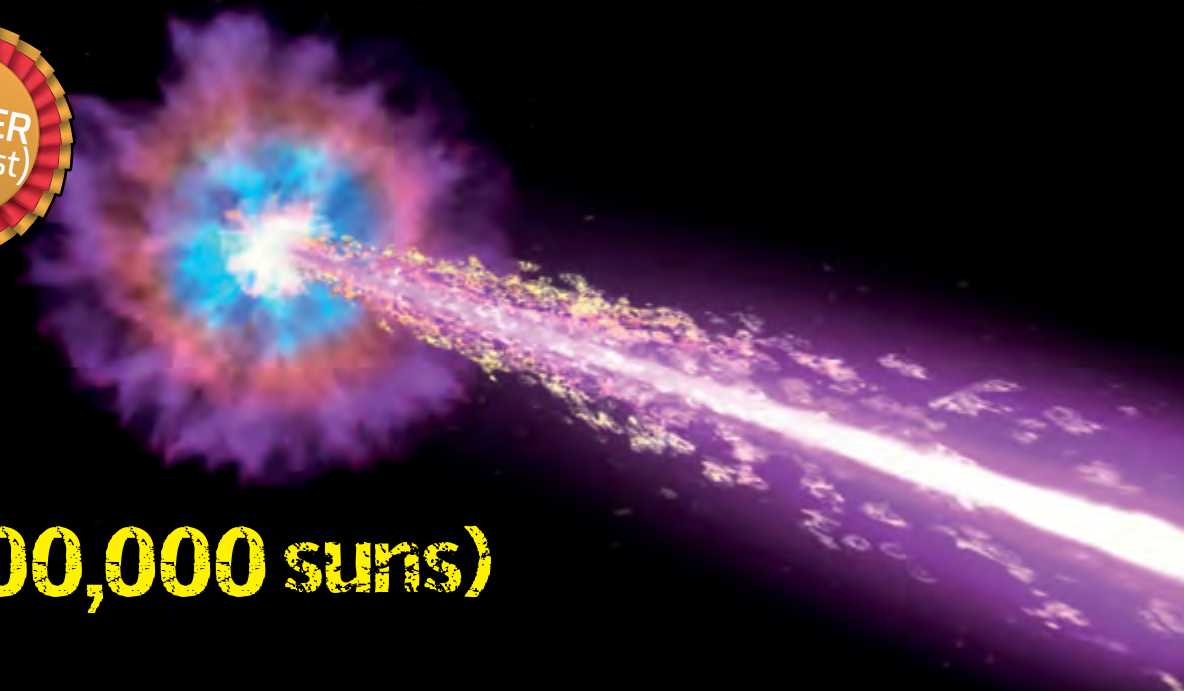
If supernova explosions, or gamma ray bursts don't last long enough for you, then the brightest steadily shining lights in the Universe belong to quasars. A quasar is a supermassive black hole that is feeding off nearby stars and gases. Identified in 2024, quasar J0529-4351 has a mass of 17 billion Suns and swallows the mass of one Sun every day. It is the brightest object ever discovered (that isn't a gamma ray burst) and shines as bright as

500 trillion suns (500,000,000,000,000 suns)

GAMMA RAY BURSTS

Gamma-ray bursts are the most powerful and violent explosions we know of. These brief flashes of high-energy light result from some of the Universe's most explosive events, including the birth of black holes and collisions between neutron stars. They only last a few milliseconds to, at most, a few minutes, but they can be as bright as

10 trillion trillion suns (10,000,000,000,000,000,000 suns)



NOTES

Need to make some notes or doodle some ideas?
This is the place to do it!

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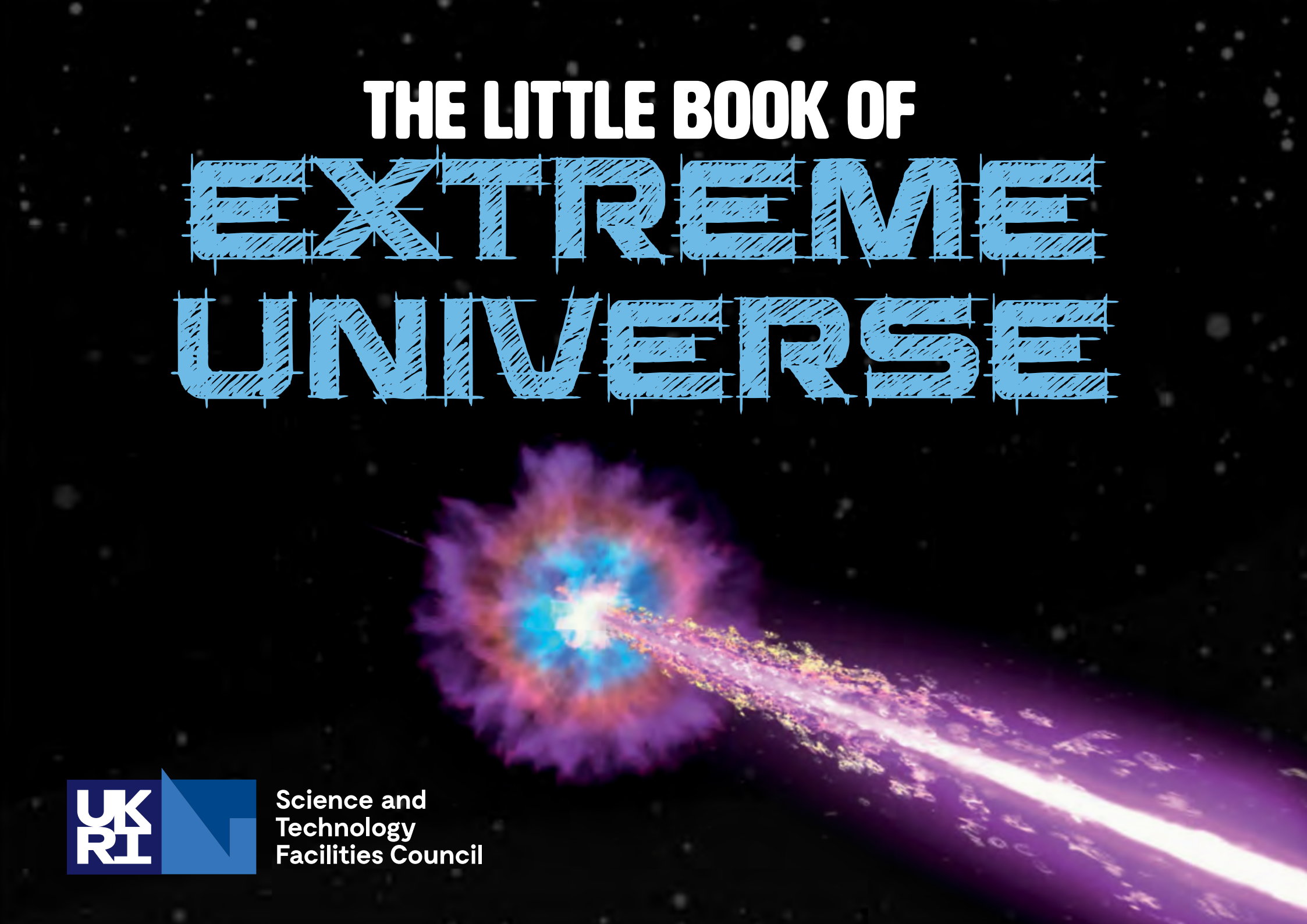

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