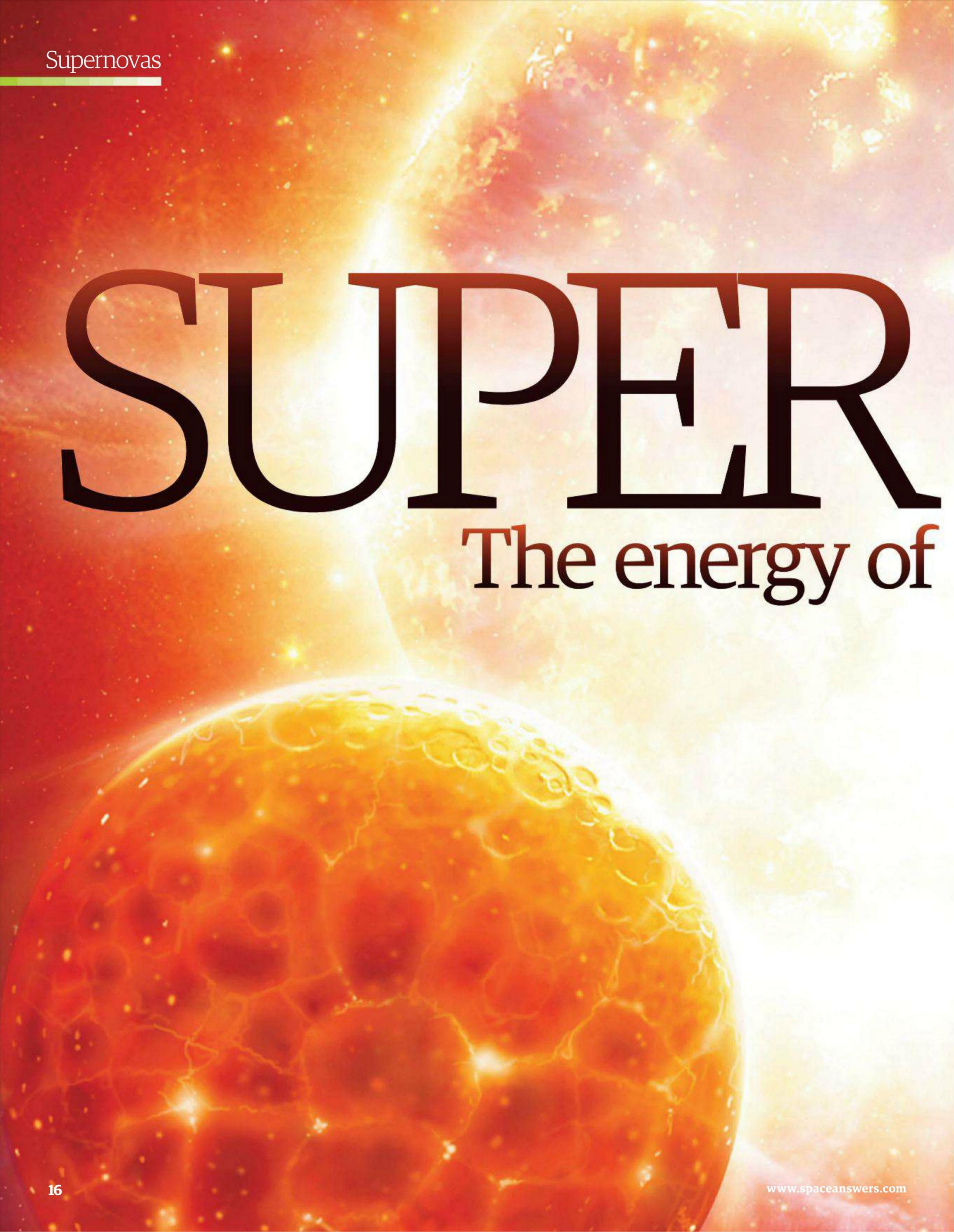


SUPER

The energy of

NOVAS
a billion suns

Written by Jonathan O'Callaghan

The massive stellar explosions capable of sending cosmic shockwaves across entire galaxies

Stars are large and volatile masses of energy, finely balanced to allow their existence to continue while also emitting large amounts of energy into their surroundings. Their very presence is one of the wonders of the universe, with these giant hot and dense balls of gas able to survive the harsh reality of space. But when the finely-tuned balance of gravity and pressure within a star is altered, something rather remarkable often happens. Try to imagine an explosion more powerful than a billion suns, and you might start to understand how stars can meet their explosive end when they go supernova.

In 185 AD, Chinese astronomers were astounded when a new star appeared in the night sky for eight months. The star appeared from nowhere and was stationary, ruling out the possibility of it being a comet. Although unknown at the time, those Chinese astronomers (and possibly Roman astronomers around the same period as well) unwittingly became the first people to record a supernova, which we know today as SN 185. In 2006, NASA's Chandra and XMM-Newton X-ray observatories imaged a remnant called RCW 86, a vast shell of gas seemingly ejected by SN 185. It might have taken 2,000 years, but we're gradually becoming able to observe and understand these massive events like never before.

When we deal with measures of time in this article, it is worth bearing in mind the limitations of the speed of light. When SN 185 was first observed in 185 AD, those Chinese astronomers were actually observing an event that happened 8,200 years prior, as SN 185 is 8,200 light years away. Of course, when the light finally reaches us we are able to observe the events in their entirety, but it is important to realise that these are cosmic occurrences that happened long in the past, from thousands of years to billions in some instances.

That doesn't take away from the scientific merit of observing them, however. They might be snapshots into the universe's past but they still hold key information into stellar life cycles and the regeneration of the cosmos. In fact, supernovas are thought to be among the most important events in the universe for a number of reasons. Before we tackle that, though, we need to understand the basics of how a supernova works.

At the heart of stars a process called fusion takes place, where light elements such as hydrogen and helium fuse together to form heavier elements, anything from carbon to iron to oxygen. The process of nuclear fusion releases a vast amount of energy in the form of many different types of radiation, including heat and visible light, both of which we directly observe and feel ourselves every day from the Sun. Stars are abundant in both hydrogen and helium, but their supplies are not endless. While it varies from star to star, eventually a star's source of fuel runs out. In most cases the predominant element left at the star's core is iron, which no star is able to fuse. What happens next is simply astounding.

Eventually, so much iron will build up that the star can no longer support its own weight. Until this point, and indeed for the majority of a star's lifetime, the force of gravity pulling the star inwards is delicately balanced by the pressure of the star's gases radiating outwards. Once the fuel is gone, however, this pressure suddenly dissipates. In just a millisecond, the core (which is now rich in iron and more massive than the Sun) collapses in on itself, shrinking in size by up to a thousand times from the size of the Earth to a ball only about 20 kilometres (12 miles) across.

Incredibly, though, the collapse is so quick that the layers of gas surrounding the core don't have time to react. Just a split second later, before these layers have even had a chance to begin collapsing as well, the now ultra-dense iron-rich core explodes with more energy than a quantity of TNT the size of Earth being instantly detonated. The energy output of a supernova is similarly astounding.

In most cases a supernova will shine as bright as 10 billion suns, and it will release 10^{44} joules, which is roughly the total output of the Sun in its entire 10 billion year lifetime. The resultant shockwave can travel at velocities approaching half the speed of light, and it will continue expanding into the surrounding interstellar space for thousands of years. The rate of expansion is such that a supernova's effects can be felt tens or even hundreds of light years away. If you think that all stars meet this same explosive end, however, you'd be wrong.

There are two main types of supernova: Type 1, or companion star supernovas, and Type II, or core collapse supernovas. The former typically occur in stars when their mass exceeds 1.4 solar masses, known as the Chandrasekhar limit, due to the accretion of matter in a binary star system with a white dwarf star, while the latter involve the collapse of stars between eight and 15 solar masses.

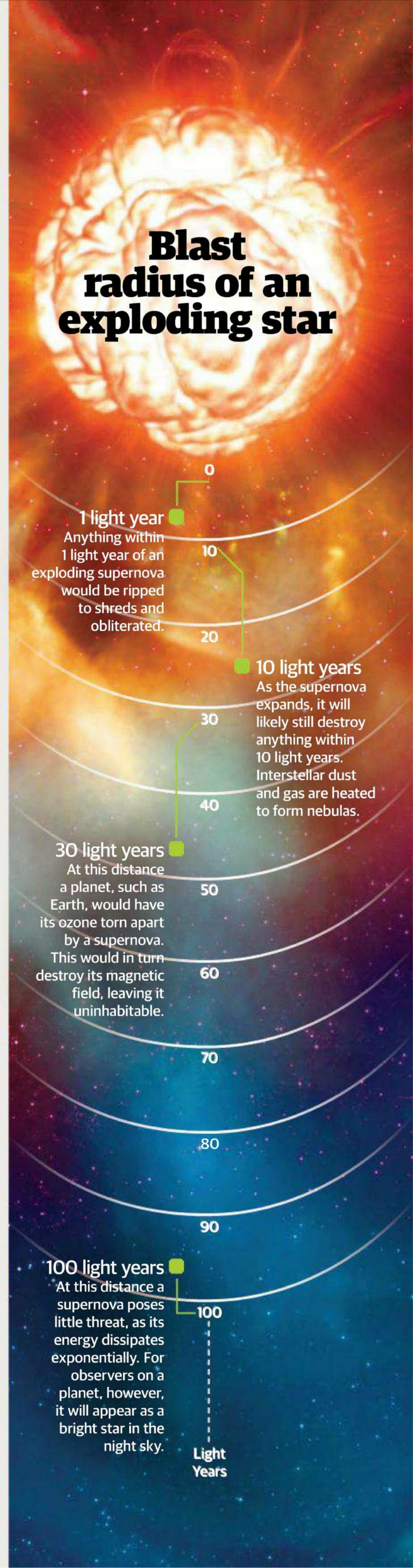
Both types are further sub-categorised to denote the particular characteristics of the supernova. The light of Type II-L supernovas steadily decreases after the explosion, whereas Type II-P supernovas emit light much more steadily. Type 1a supernovas involve a white dwarf and a larger star in a binary system, whereas Type 1b and 1c supernovas are more similar to the core collapse scenario, but they will have already lost most of their outer layers before the explosion.

One of the few supernovas to be observed was SN 2008D in the spiral galaxy NGC 2770 back in early 2008. By chance, researchers using NASA's orbiting Swift telescope noticed an increase in X-rays from the star, and immediately alerted eight other ground and space telescopes to the event. The resulting blast lasted just five minutes, but the research will surely last a lifetime. The expansion rate was estimated at 10,000 kilometres (6,000 miles) per second, although one side of the star expanded faster than the other, suggesting that the explosion was off-centred.

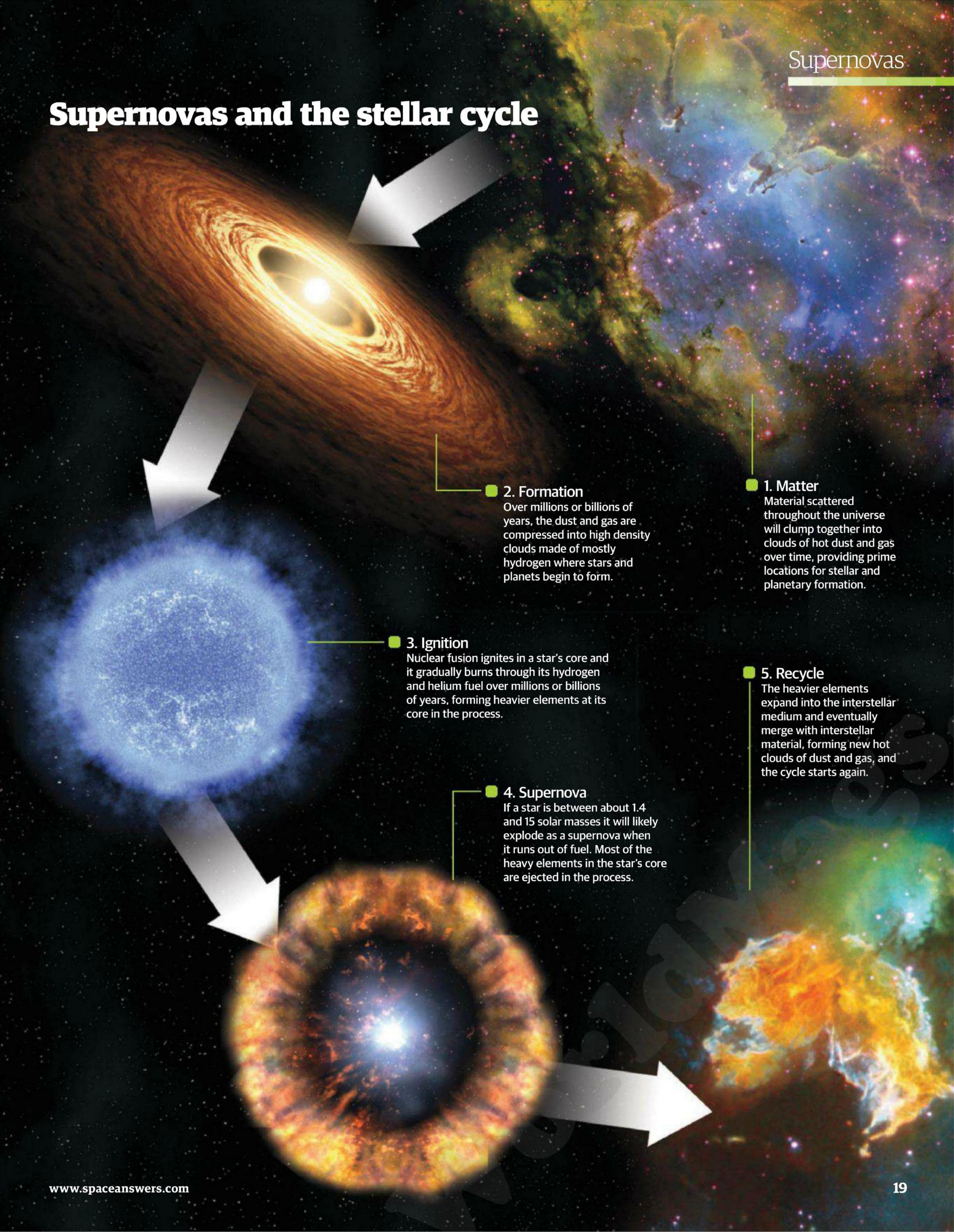
The universe is abundant in hydrogen and helium but not so much in heavier elements such as carbon and oxygen, life-essential elements without which planets like Earth could not become habitable. The only place where these heavier elements are known to be made is in the very heart of stars, where they are stored until the star explodes as a supernova and scatters them into the surrounding space. Without supernovas, these elements would remain locked away, unable to contribute to the formation of metal-rich objects like planets and asteroids. It's very likely that planetary systems, like our own Solar System, were born in this way, from a cloud of dust and gas left behind after a star went supernova.

Another important consequence of supernovas is the formation of new stars. One of the oldest stars

Supernovas often leave behind their dense cores



Supernovas and the stellar cycle



1. Matter
Material scattered throughout the universe will clump together into clouds of hot dust and gas over time, providing prime locations for stellar and planetary formation.

2. Formation
Over millions or billions of years, the dust and gas are compressed into high density clouds made of mostly hydrogen where stars and planets begin to form.

3. Ignition
Nuclear fusion ignites in a star's core and it gradually burns through its hydrogen and helium fuel over millions or billions of years, forming heavier elements at its core in the process.

4. Supernova
If a star is between about 1.4 and 15 solar masses it will likely explode as a supernova when it runs out of fuel. Most of the heavy elements in the star's core are ejected in the process.

5. Recycle
The heavier elements expand into the interstellar medium and eventually merge with interstellar material, forming new hot clouds of dust and gas, and the cycle starts again.

that we know of is HE 1523-0901, a red giant star 7,500 light years from Earth. It was thought to have formed about 13.2 billion years ago, 500 million years after the estimated beginning of the universe. Clearly this means that most stars that we know of were formed after the Big Bang, in some cases (such as our own Sun) many billions of years after. The only way new stars could have been born was if older stars that survived from the birth of the universe eventually went supernova, releasing their various elements and eventually leading the way to the formation of new stars.

The final major contribution of supernovas to the universe is the continued addition of heavy elements to the interstellar medium. The gradual growth in abundance of these heavier elements, ones that were only found in traces before, has had an odd effect on some stars. Those like our own Sun undergo a somewhat different fusion process to those stars born nearer the start of the universe, as the former are moderated more by the presence of carbon. It is likely that future stars will continue to be altered by the presence of more heavy elements, further altering the fusion process within stars.

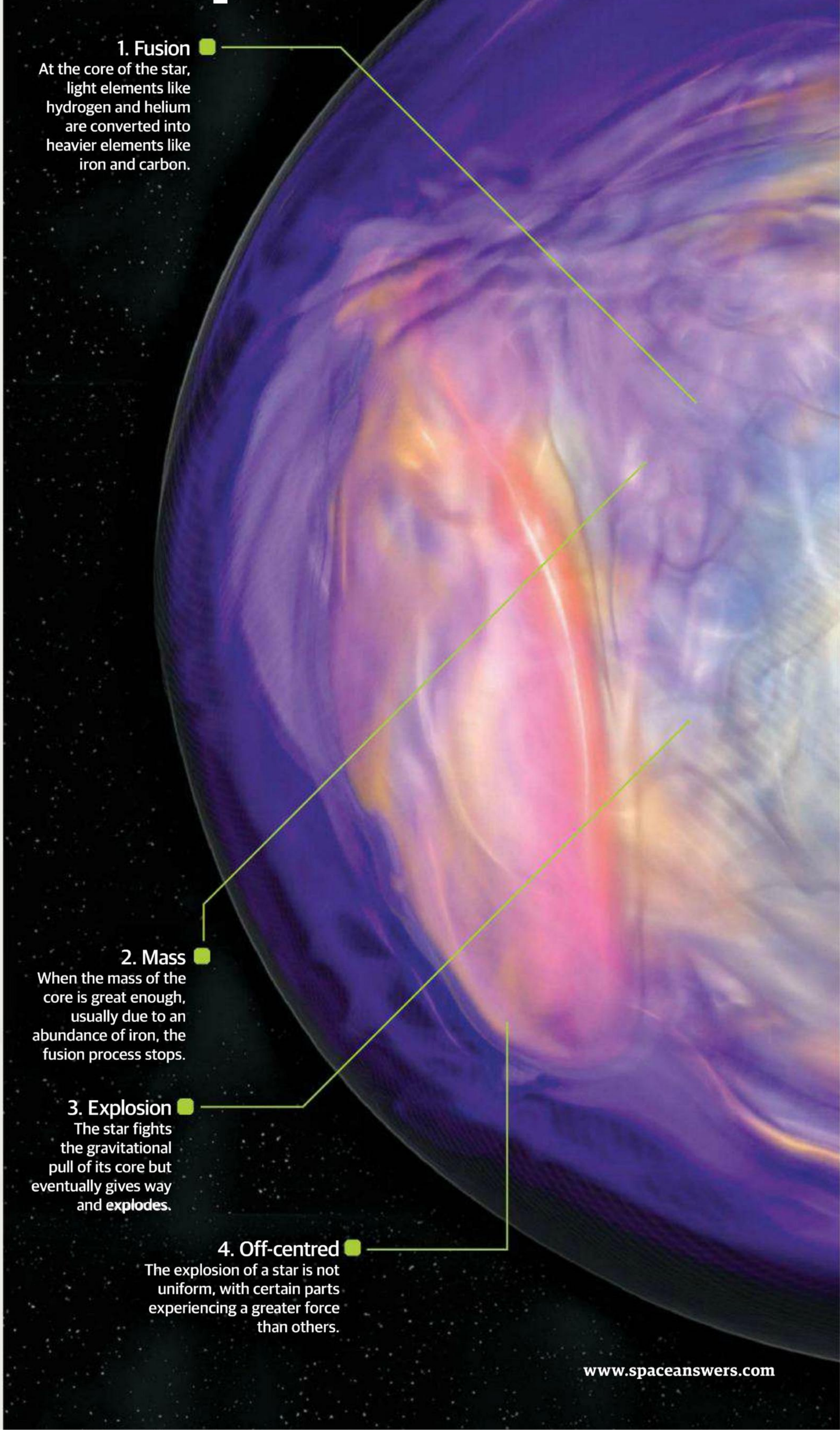
So, it's safe to say that supernovas are really quite important, but how do we know so much about them? After all, we've only observed very few, instead normally catching only the aftermath or the resultant remnant. Well, fortunately by observing the aftermath we're able to discern a lot about the explosion itself. For one thing, most Type 1a supernovas seem to undergo very similar final moments. If we see one explode we are able to calculate how far away it is thanks to something known as the "standard candle" method, where all Type 1a explosions explode with pretty much the same magnitude. In addition, using spectroscopy, we can analyse the resultant remnant and, by observing its size and composition, we can work out what the original star might have been like.

Supernovas will continue to be one of the most fascinating and exhilarating events in the universe, providing us with a view into stellar formation and the death of stars. It is thanks to these events that we know so much about the inner composition of stars, and by continuing to study them we will unearth more secrets of the universe.

What is a remnant?

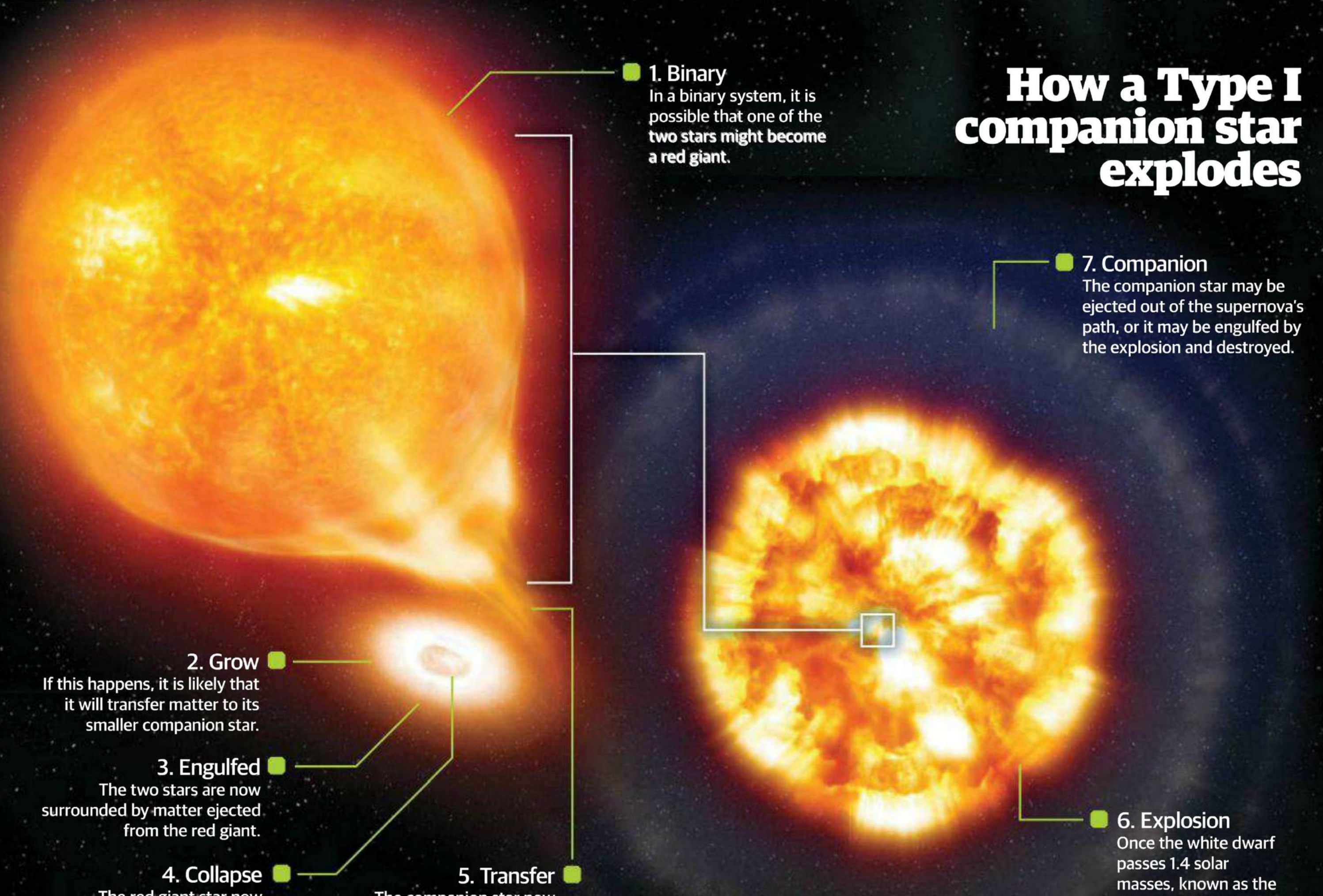
A supernova remnant is the expansion of the blast wave from the supernova as it moves through space, pushing material out along with it that we can observe in different wavelengths from Earth. The expansion rate of a remnant can be up to several thousand kilometres per second, approaching 1% the speed of light, and it may continue for hundreds or thousands of years. Many nebulas we can see from earth are the result of the expansion of supernova remnants, and they can often measure several hundred light years across.

What happens when a star explodes?



"Using spectroscopy we can analyse the resultant remnant and we can work out what the original star might have been like"

How a Type I companion star explodes



1. Binary
In a binary system, it is possible that one of the two stars might become a red giant.

2. Grow
If this happens, it is likely that it will transfer matter to its smaller companion star.

3. Engulfed
The two stars are now surrounded by matter ejected from the red giant.

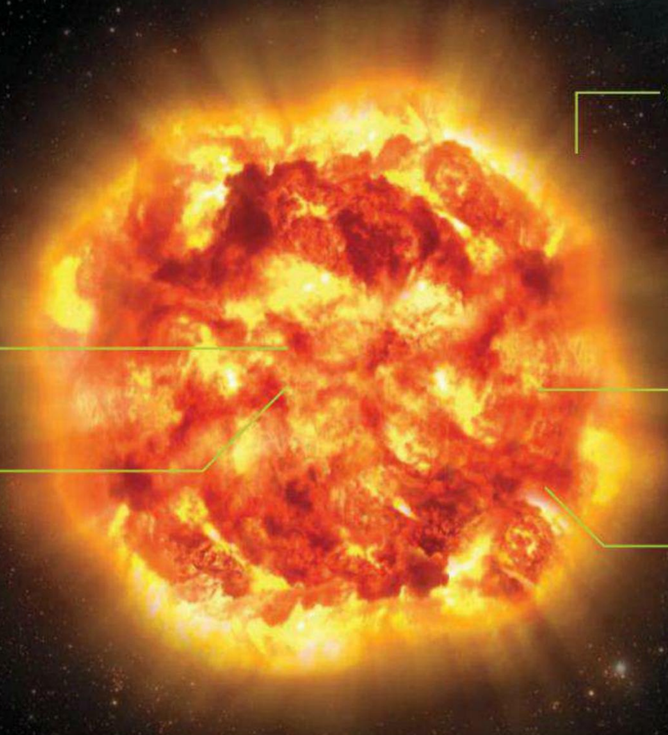
4. Collapse
The red giant star now collapses, leaving only its core behind as a white dwarf.

5. Transfer
The companion star now transfers matter to the white dwarf, increasing its mass.

6. Explosion
Once the white dwarf passes 1.4 solar masses, known as the Chandrasekhar limit, it can no longer support itself and explodes.

7. Companion
The companion star may be ejected out of the supernova's path, or it may be engulfed by the explosion and destroyed.

What happens in a Type II core collapse



1. Core
A star's iron core collapses under the force of gravity as it runs out of fuel.

2. Density
When the density of the core exceeds that of the surrounding matter, the core starts sending out waves of pressure.

3. Shock waves
The pressure waves rebound off material falling towards the core, sending shockwaves back into the centre of the star.

4. Energy
At first, the waves are unable to overcome the force of the outgoing pressure waves and thus cannot reach the surface of the core.

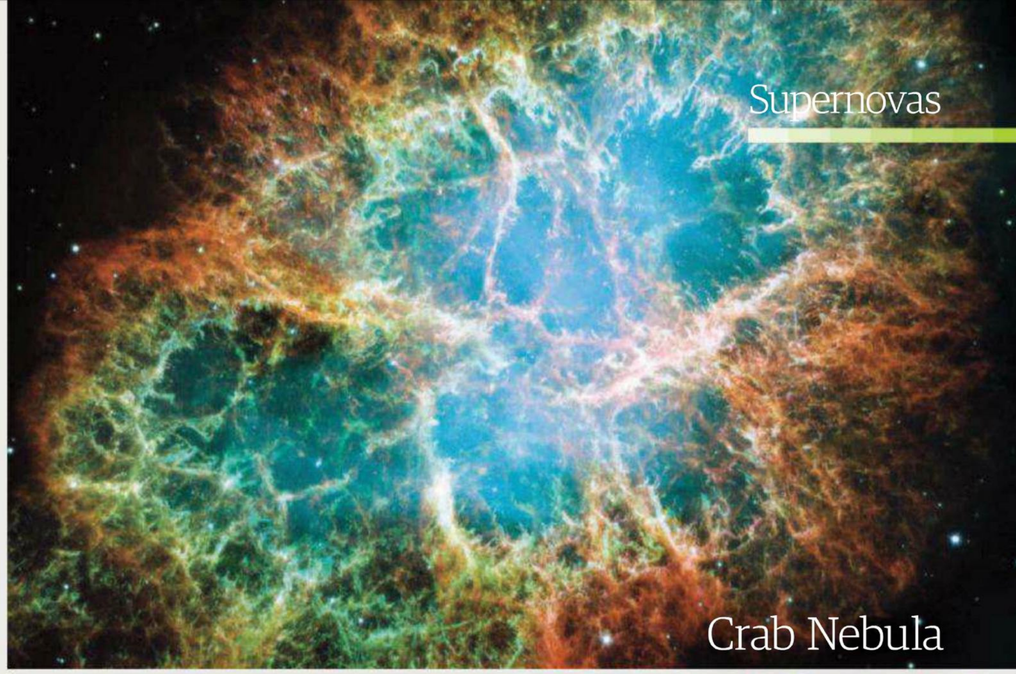
5. Explosion
Eventually, the build-up of shockwaves overcomes the pressure waves, and the surface of the core is impacted and, subsequently, explodes.

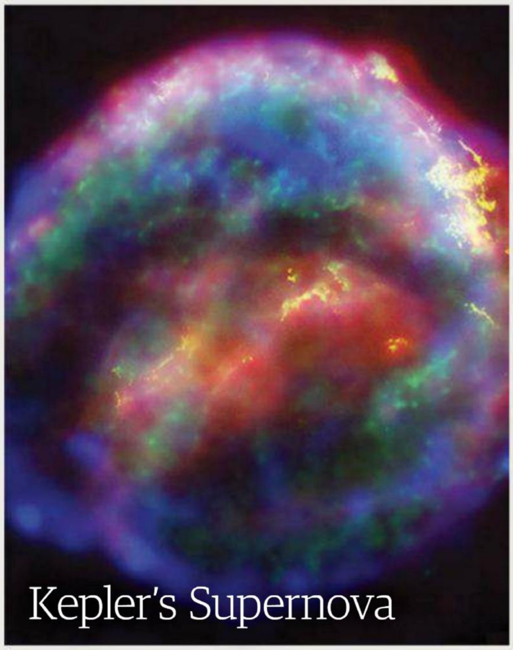
Most spectacular supernovas

Crab Nebula
Exploded: 7,500 years ago
Distance: 6,500 light years
This famous supernova remnant has a rapidly rotating star known as the Crab Pulsar at its centre, left behind after the original star exploded. This nebula is now 11 light years across but is still expanding at a rate of 1,500 km (930 miles) per second, 0.5% the speed of light. It is part of the Perseus Arm of the Milky Way Galaxy and the nebula is also referred to as Messier 1 or M1, being the first Messier Object catalogued in 1758. The explosion of the supernova that created this nebula, SN 1054, was recorded around the world in 1054 AD.

Kepler's Supernova
Exploded: 24,000 years ago
Distance: 20,000 light years
Observed by astronomer Johannes Kepler in October 1604, hence the name, Kepler's Supernova (SN 1604) is the most recent stellar explosion that was visible to the naked eye on Earth, although evidence exists for a Milky Way supernova whose signal would have reached earth around 1868, but was not visible to the unaided human eye. Kepler's Supernova was brighter in the night sky for three weeks than any other star or planet, except for the Sun and Venus, and could even be seen during the day.

RCW 86
Exploded: 11,000 years ago
Distance: 9,100 light years
This supernova remnant is thought to be that left behind after star SN 185 blew up in 185 AD. It was recorded by Chinese astronomers and remained visible for some eight weeks. Recent X-ray studies show a good match for this estimated age. As such, RCW 86 is the oldest recorded supernova, and was thought to be a companion star supernova. The remnant is bigger than scientists would expect from such a supernova, suggesting the initial dwarf star created a 'cavity' in space before it exploded into which ejected material could quickly traverse.

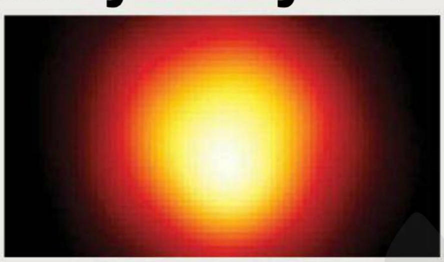

Crab Nebula


Kepler's Supernova

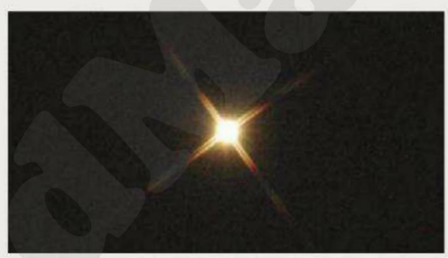

RCW 86

Coming soon to a galaxy near you...

IK Pegasi
Will explode: 5 million years from now
Distance: 150 light years
IK Pegasi A is expected to evolve into a red giant, which will transfer matter to the smaller IK Pegasi B white dwarf star and cause it to explode in a Type 1a supernova. IK Pegasi is moving away, so while it is currently the closest star to us that can go supernova, when it does in a few million years it will no longer be.



Betelgeuse
Will explode: 0 to 1 million years from now
Distance: 640 light years
Currently in the later stages of its life, it is expected to explode as a Type II supernova within the next million years, although it could explode at any minute. The star is a red supergiant and is less than ten million years old, a miniscule amount in astronomical terms, and thus it has passed through its life rapidly.



Antares
Will explode: 0 to 1 million years from now
Distance: 550 light years
The red supergiant Antares has a companion star, Antares B, that is thought will contribute to a Type 1a supernova event in the coming years. However, the exact timing of the supernova is unknown. Antares is more than 880 times bigger than our Sun and thus the explosion is expected to be quite an event.