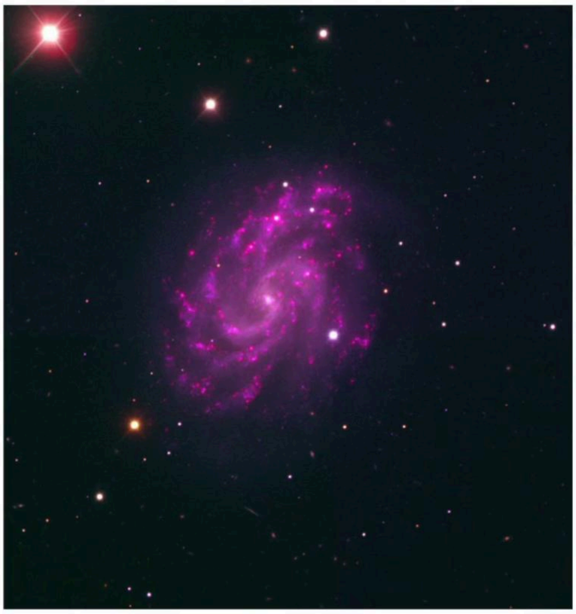
Supernovae and Supernovae Remnants (part 2)

Kim McAlpine



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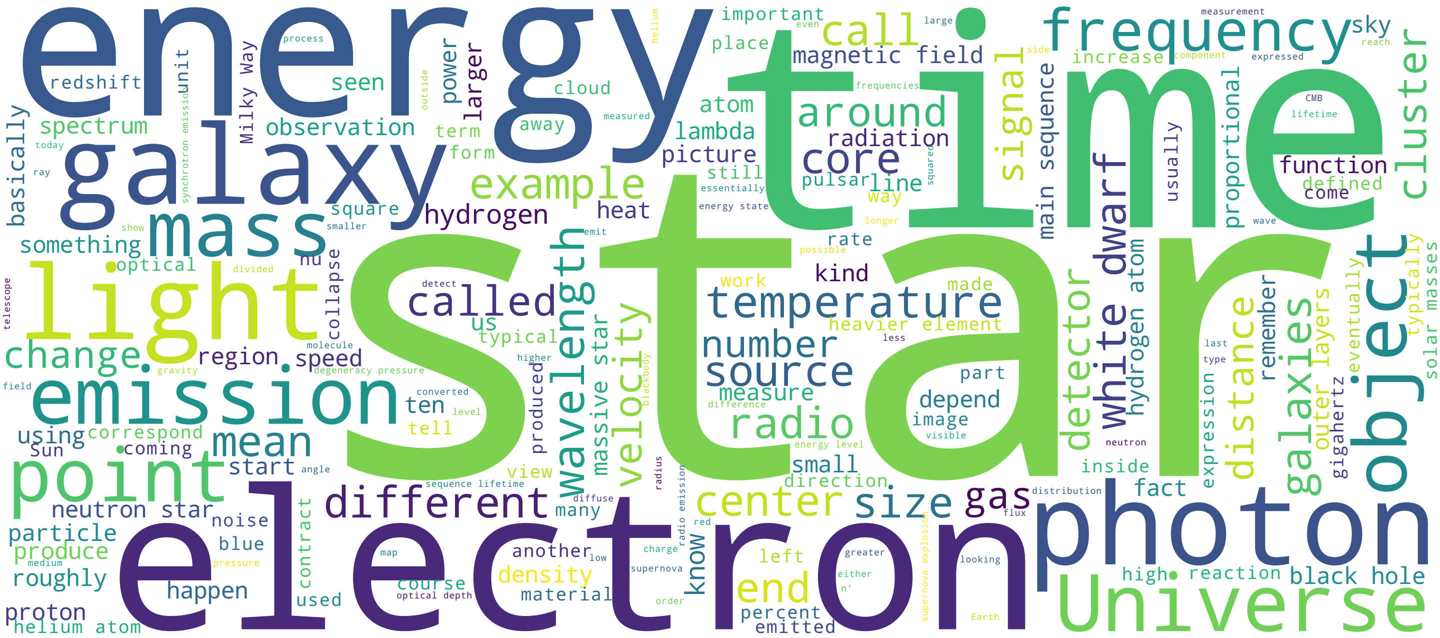

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Video

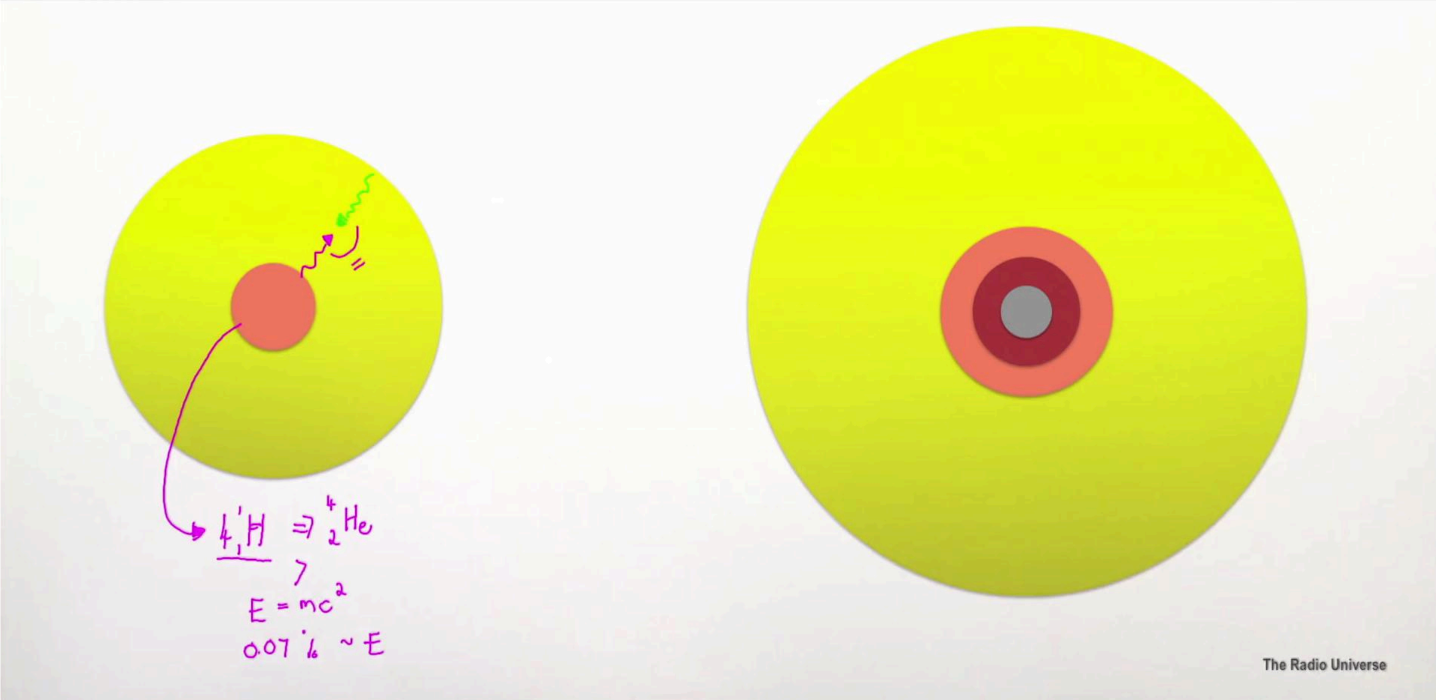
Earlier, we learned about the overall life cycle of stars and in this lecture we'll focus on the detailed processes that take place within a star during his lifetime and how those processes lead to a supernova explosion.

Notes

Summary

0m 05s

Stars on Main Sequence

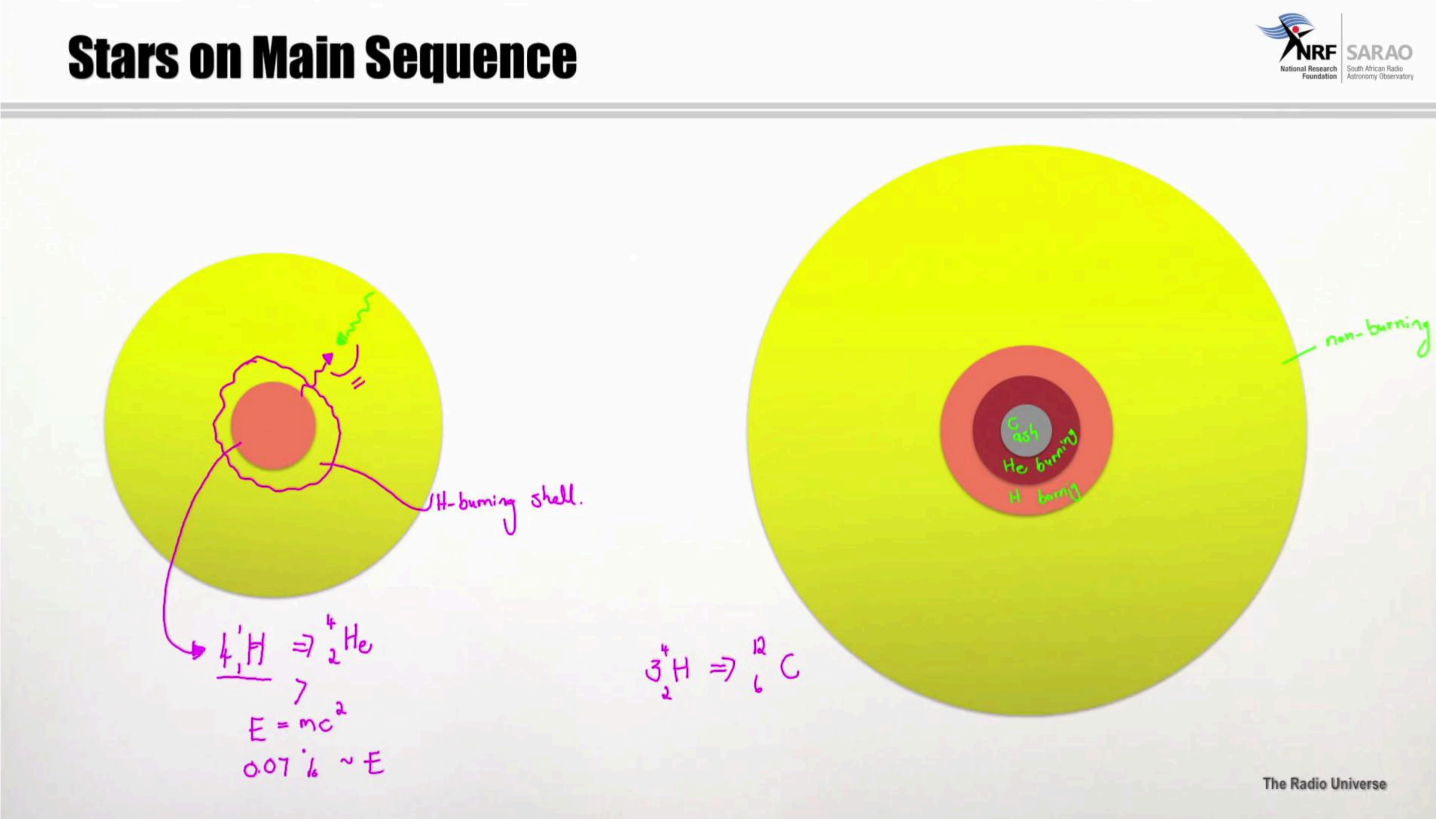


Stars on the main sequence are burning hydrogen to form helium in a small dense region at the center of the star known as the core of the star. In this region, we're converting four hydrogen atoms which each have one proton and one electron, to one helium atom with four nucleons, two protons and four electrons. The key thing to remember is that the mass of these four hydrogen atoms is actually slightly larger than the mass of the helium atom that's produced by this process and this missing mass is converted to energy by the famous equation from Einstein, 'E' equals 'mc' squared. The mass difference between the input hydrogen atoms and the final product is actually very small and so only around 0.07 percent of the mass of the hydrogen in the core is converted to energy. But this energy provides thermal pressure which is essential to keep the star stable against the force of gravity. The weight of the star is constantly pressing down on the core of the star trying to make the star collapse. And the star remains stable for most of its lifetime because these two forces remain fairly equal to each other.

Notes

Summary

0m 18s

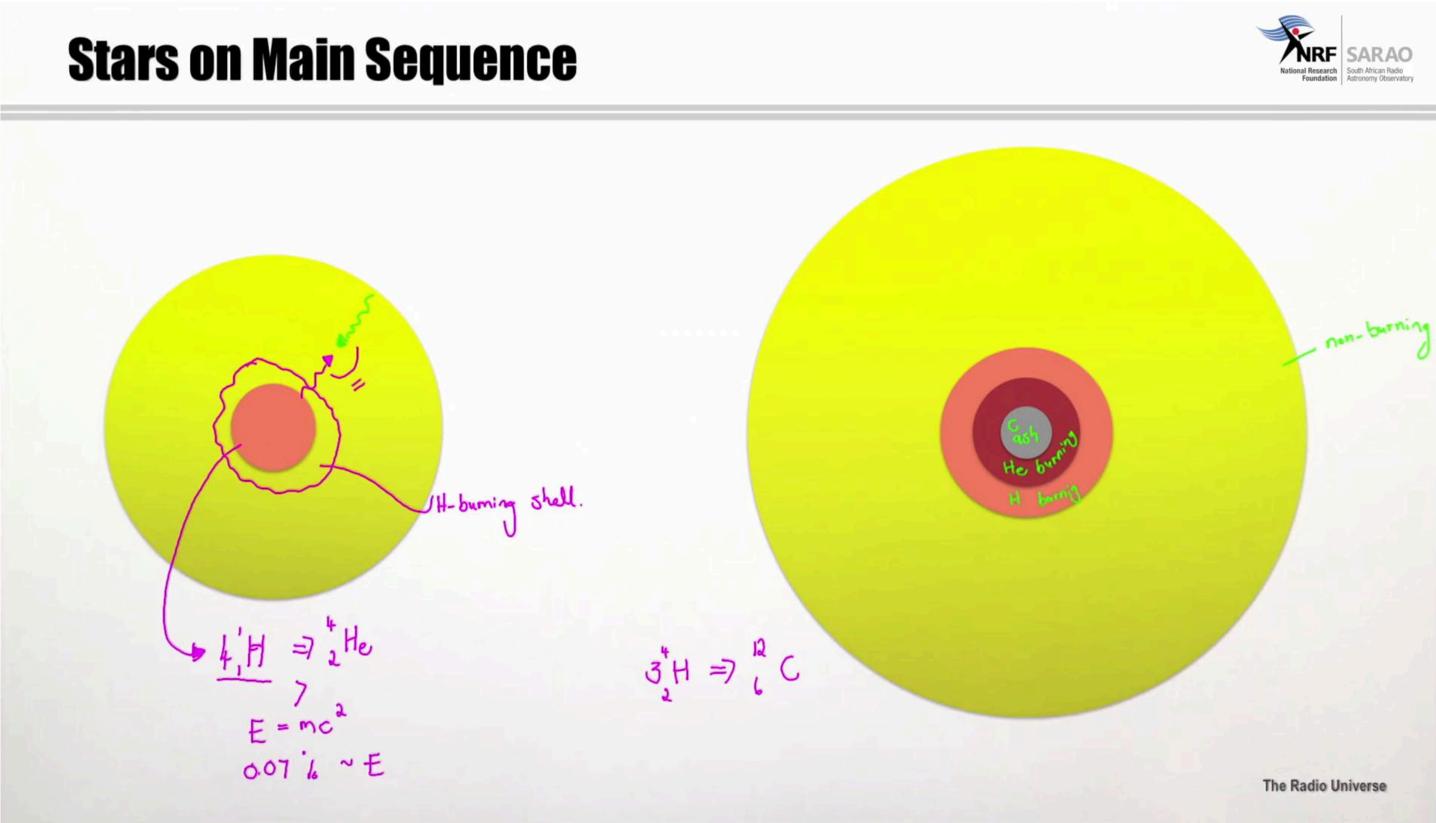


Eventually, the star exhausts all of the hydrogen that's available to it in the core and at this point it can no longer fuse hydrogen to form helium and temporarily gravity starts to win, the thermal pressure disappears and the core starts to contract under the weight of the star around it. As it's contracting, it starts to heat up under the pressure and as it heats up, the outer layers of the star get heated up and start to expand because of this extra temperature that's being put in. As it contracts, eventually it will reach a point where it can actually start to fuse hydrogen in a small shell around the core. It will form a hydrogen burning shell. This outer envelope is not burning or fusing any helium. It's merely glowing because it's being heated by the the interior reactions in the core. Eventually it will become hot enough then to actually fuse helium into carbon so at this point you'll be fusing three helium atoms to one carbon atom. And the inner structure of the star inside the core will be one where you have a carbon ash layer in the center, a helium burning layer around that and a hydrogen burning layer around that and once again you'll have a non-burning envelope on the outside which will now be much much larger than it was during the star's main sequence lifetime.

Notes

Summary

1m 45s

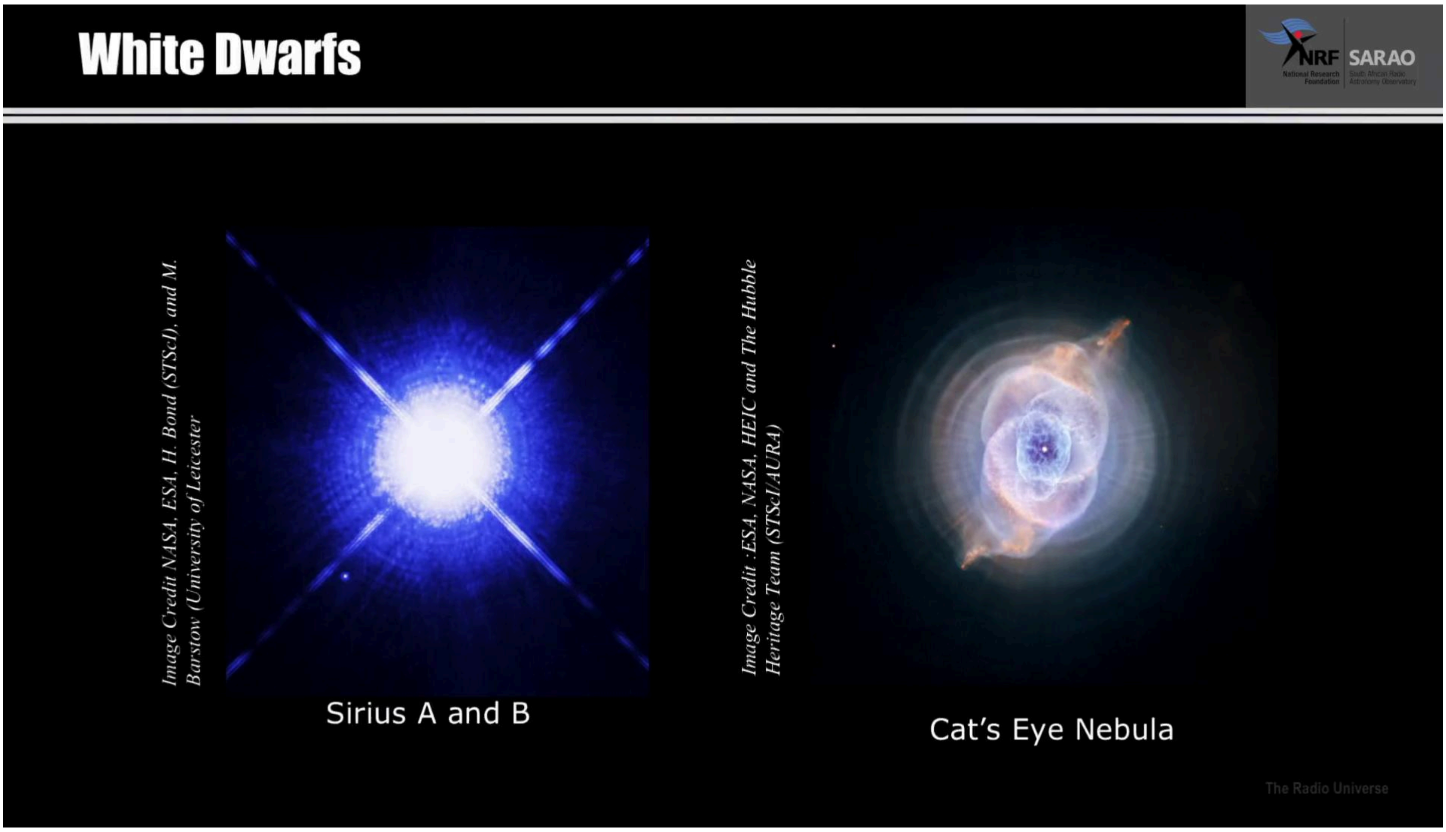


So the main sequence lifetime is associated with the conversion of hydrogen to helium and once that process stops and all these other processes start to take place, the star migrates into the giant phase of its life. For most low to intermediate mass stars they never become hot enough to convert carbon into heavier elements and so what happens is that fusion stops at the end of this process when you run out of helium to convert to carbon and most of the outer layers get blown away by stellar wind. So that in the end all you're left with is this carbon core which is now very much smaller and denser than the original star was and the outer layers are completely blown away into a gaseous nebula and as we said before, this carbon core is called a white dwarf.

Notes

Summary

3m 29s



I have some examples of what a white dwarf looks like. Here is a very famous example of a white dwarf, the Sirius B star which is a binary star orbiting Sirius A and you can see what a small star it is in comparison to a normal main sequence star. Here at the center of the Cat's Eye Nebula, we have a little white dwarf as well, the small white dot in the center and all of this lit up gas around it is what was originally the star's outer envelope which has now been blown away and is being lit up by the hot white dwarf in the center.

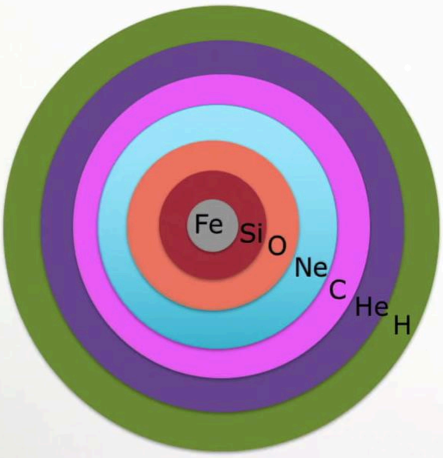
Notes

Summary

4m 21s

Massive Stars

- Cycle continues
- Fe
- Fusing Fe requires energy input



Stage	Timescale
H burning	7 Million yrs
He burning	0.5 Million yrs
C Burning	600 yrs
Ne Burning	1 yr
O Burning	6 months
Si Burning	1 day

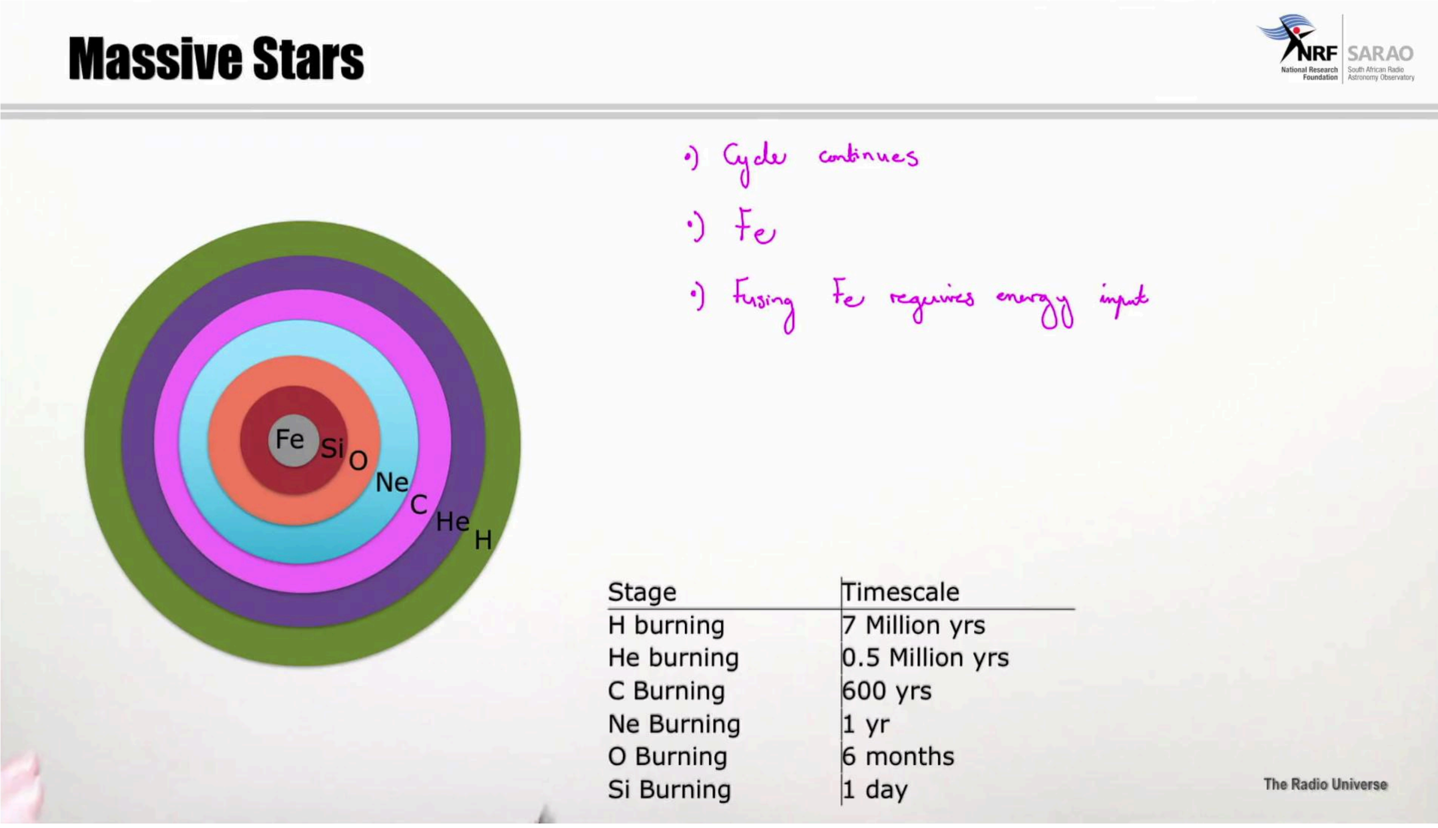
The Radio Universe

For massive stars, the cycle of fusing heavier and heavier elements continues. So just like at the end of the main sequence lifetime of the star at the end of the helium burning phase, the star's core will once again contract because there won't be energy to balance the gravitational pressure against it. As it contracts, it will heat up and then it will heat up sufficiently to allow carbon to fuse to a heavier element and this will happen repeatedly until you reach the point where you've managed to produce iron. So the inside of a massive star has this kind of onion layered structure, a structure where each of them has a heavier and heavier subsequently heavier and heavier element. Remember that the core is still only a very small part of the overall star. The outer envelope of the star is very much larger than this. Once you reach the point where you have produced iron ash, you have this problem that fusing iron to produce a heavier element does not release energy and in fact, it's endothermic. It requires energy. So fusing iron requires an energy input and so at this point, you will no longer be able to fuse iron to produce thermal energy to counteract the gravitational collapse of the star.

Notes

Summary

4m 55s

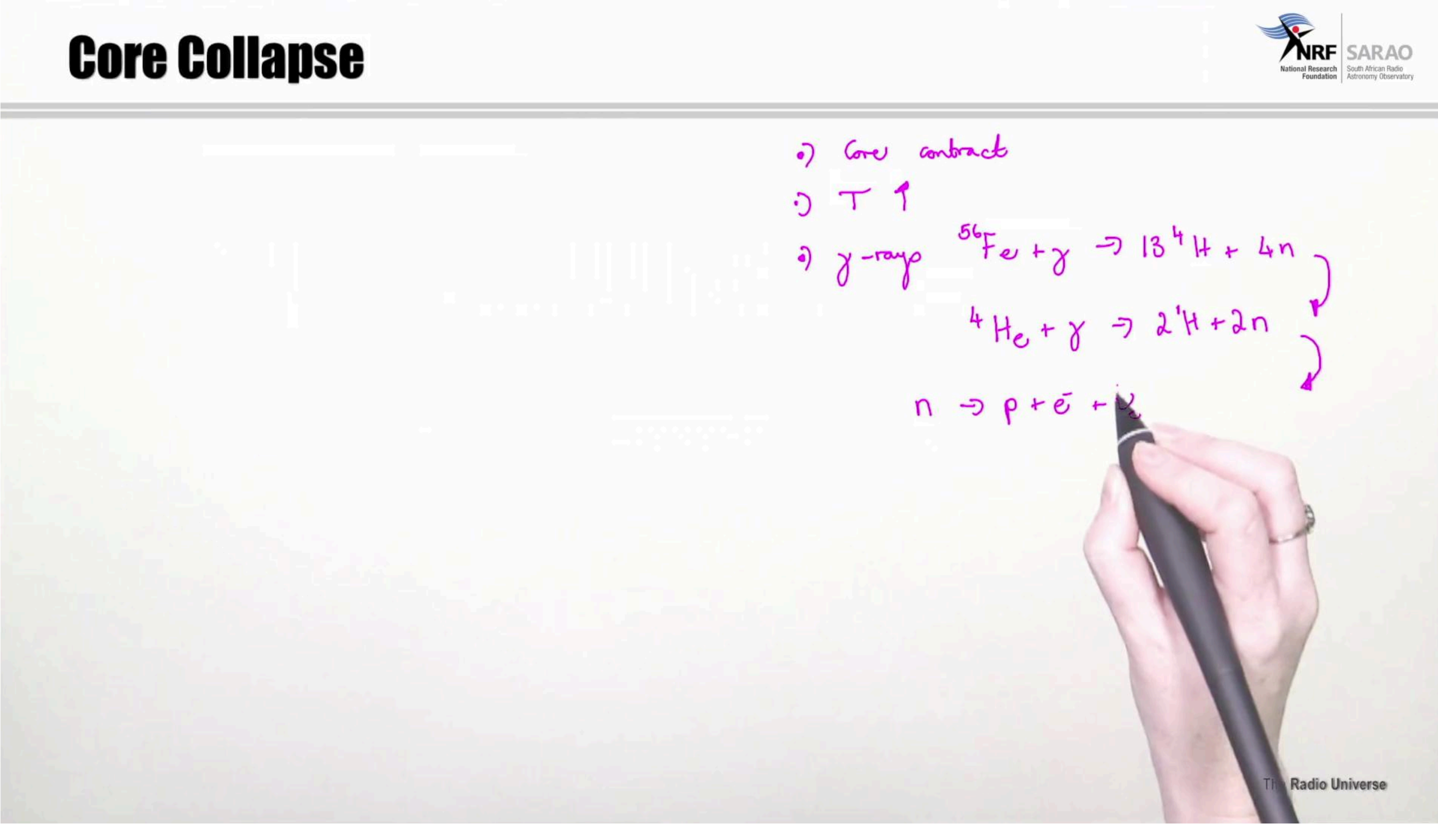


Something interesting to note is that as each of these reactions to fuse heavier and heavier elements take place at higher temperatures and higher pressures, the reactions tend to occur at a faster and faster rate and so the star burns through its fuel faster and faster as it goes through these subsequent stages and so each of these stages lasts a shorter and shorter amount of time and here's an example of this accelerating rate of change. So here you can see that the hydrogen burning phase with the main sequence lifetime can last say, 7 million years for a massive star whereas the silicon burning phase only lasts one day. Once you've reached this point where you no longer have thermal energy to counteract the gravitational force of the outer layers of the star, there will be an enormous collapse.

Notes

Summary

6m 23s

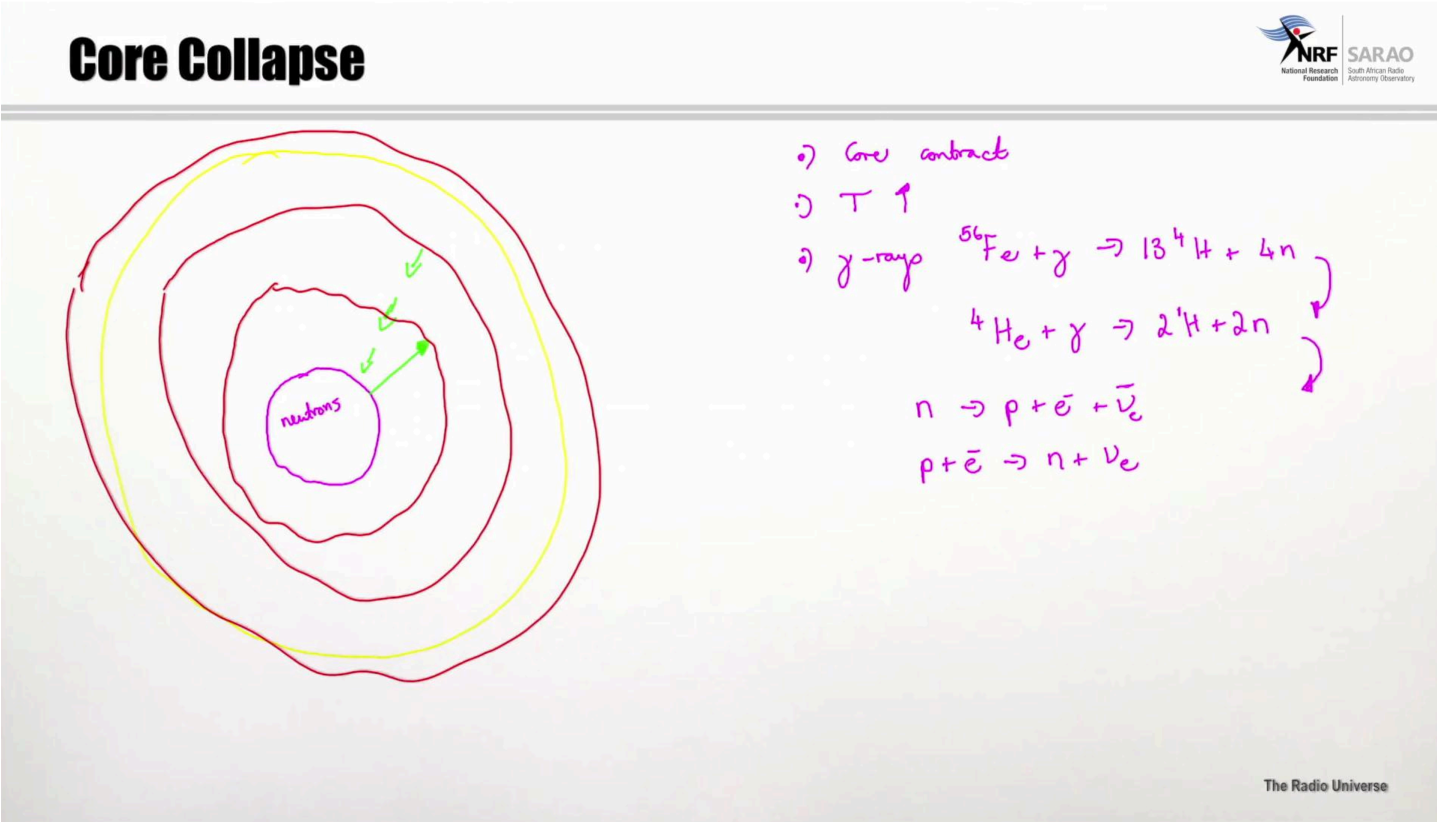


When the star runs out of material to fuse into iron, the usual process will take place where you will run out of energy to counteract gravity so the core will contract and so the temperature of the core will increase but at this point no further fusion reactions will take place because as we mentioned, iron requires energy to fuse. Instead, the gamma rays that are produced by this very high temperature core are able to further disintegrate the iron into its constituent parts so that you have the reaction that iron plus a gamma ray breaks down into thirteen helium atoms plus four neutrons. But this reaction is also an endothermic reaction so it's using up energy inside the star and that tends to work to speed up the collapse because you have less energy available to counteract gravity. So as the collapse speeds up and the temperature increases further, you have another reaction which takes place which is the breaking up of the helium atoms into hydrogen atoms plus two neutrons and again this uses up energy and the core contracts further. Now normally free neutrons would decay into a proton plus an electron plus an antineutrino.

Notes

Summary

7m 19s

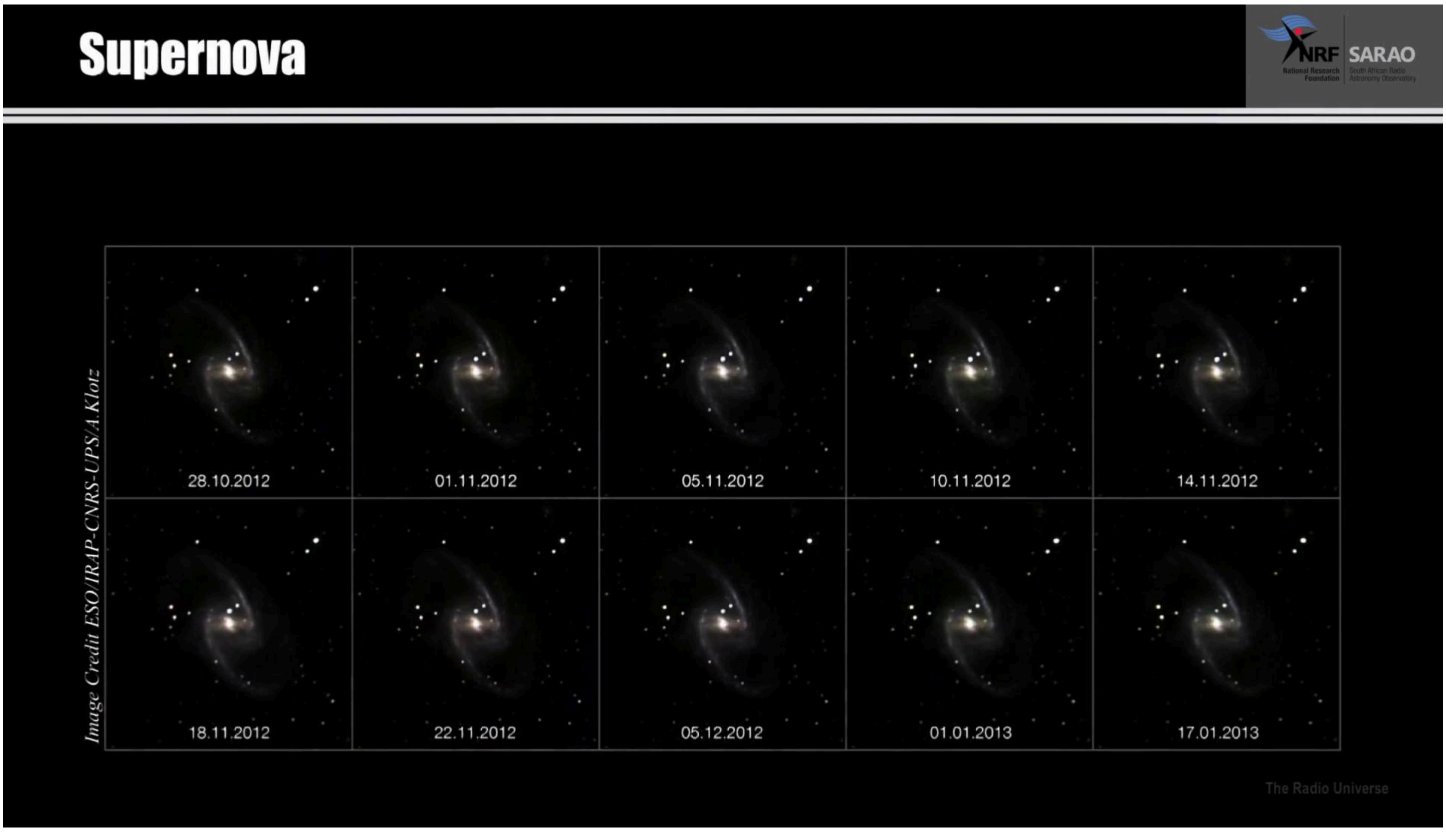


But because of the energetic conditions inside of the star, this is no longer possible and in fact, the opposite happens. The reverse happens. A proton plus an electron is converted to a neutron plus a neutrino. These neutrinos stream out of the star also taking with them a lot of energy and speeding up the collapse. And so what you're left with here is an object that is very dense and consists mostly of neutrons and at some point, the neutron degeneracy pressure will become important and no longer allow this object to continue to contract. So when this happens this neutron star in the center becomes completely incompressible. But this in the core happens on a much shorter timescale than it takes for the outer layers to collapse onto the star. So eventually these outer layers will collapse towards the center and they will hit this hard incompressible neutron star and then rebound off them creating a very fast shockwave ahead of them. From the outside of the star everything really looks normal at this point. You have no idea what's being all the chaos that's happening inside here but eventually this blast wave will punch through the star and be visible from the outer layers of the star and your supernova will have exploded.

Notes

Summary

8m 50s



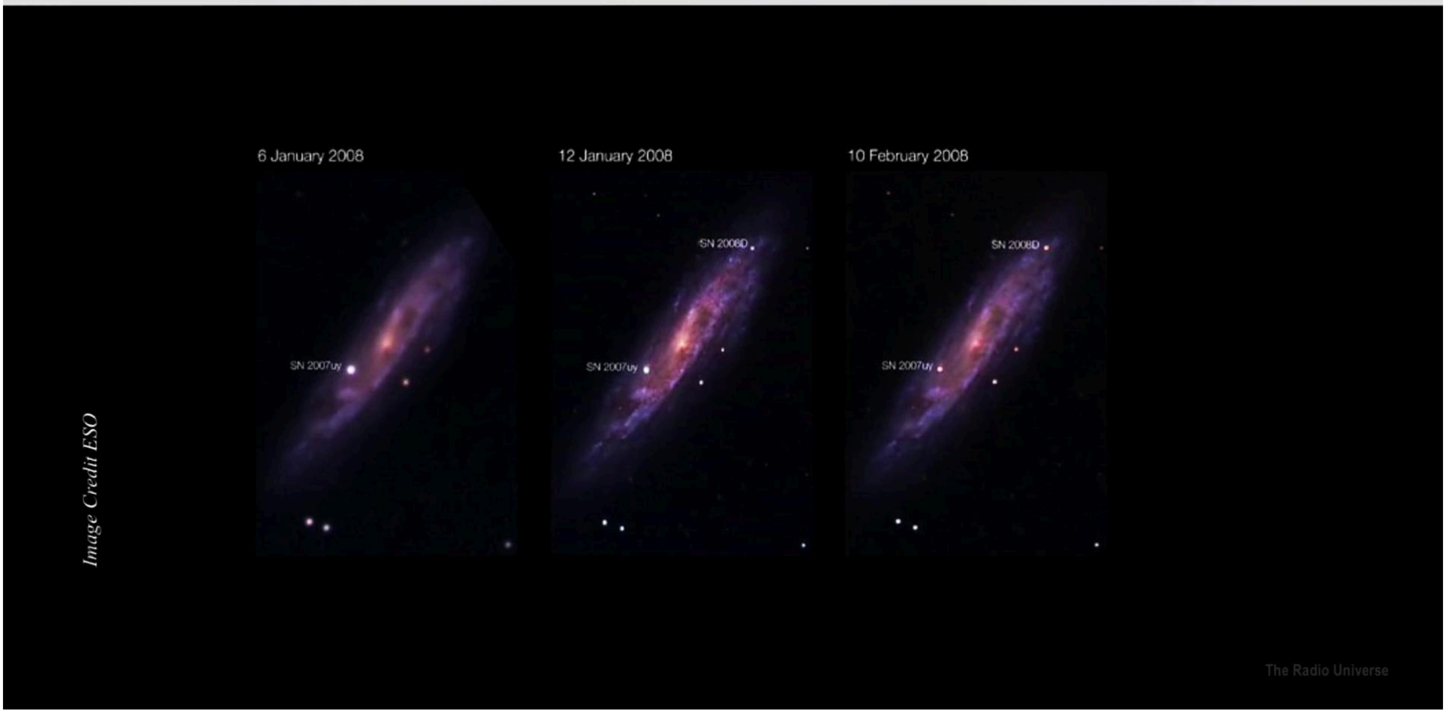
Here we have some examples of what a supernova looks like. Here you can see there is a small dim star here which is then systematically brightening as the star explodes and then dimming as the explosion comes to an end.

Notes

Summary

10m 18s

Supernova

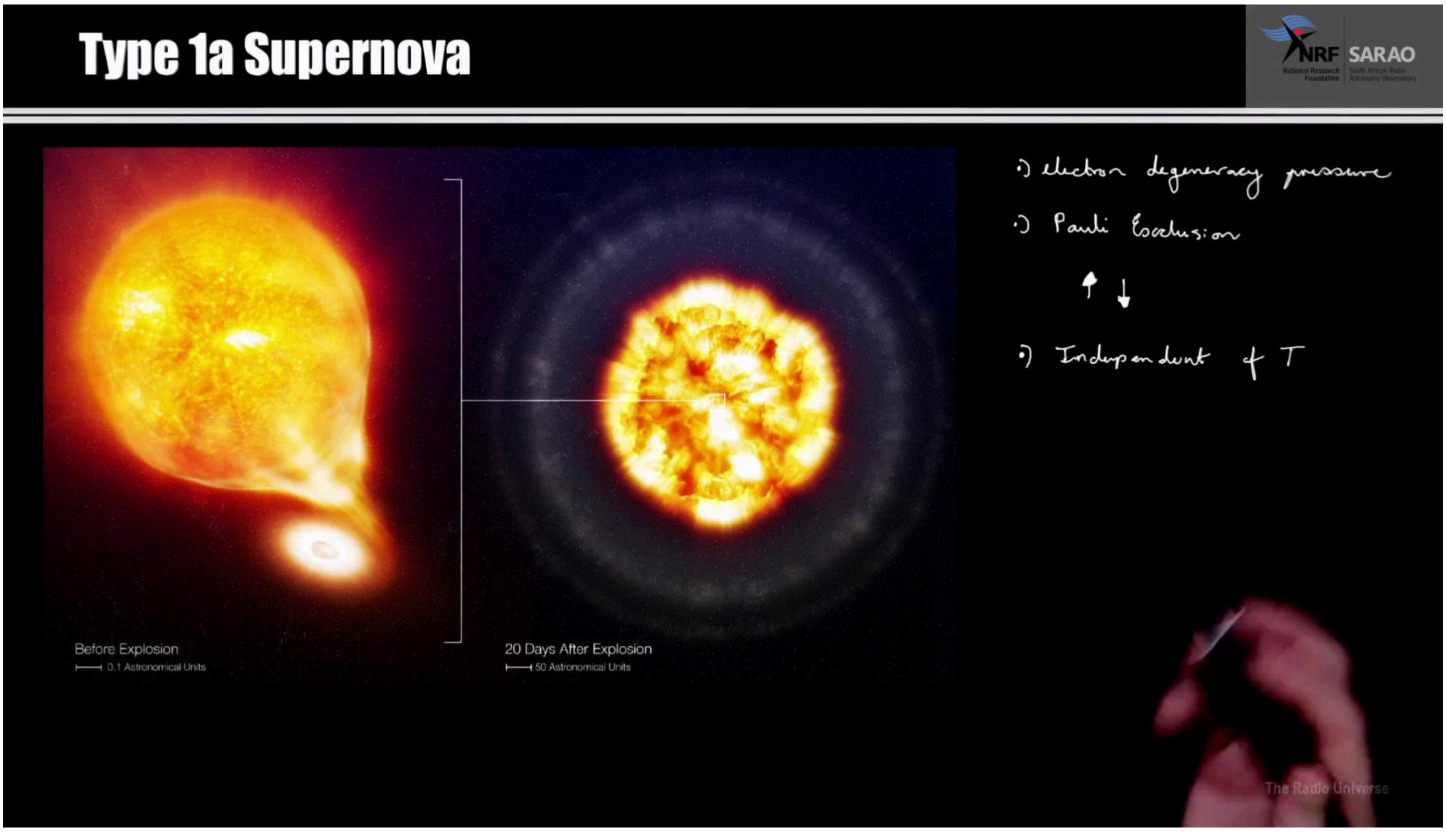


Here we have an example of two supernovae taking place within a galaxy within a very short period of each other which is very unusual. Here this very bright spot is one supernova and here is another bright spot which is another supernova explosion.

Notes

Summary

10m 39s

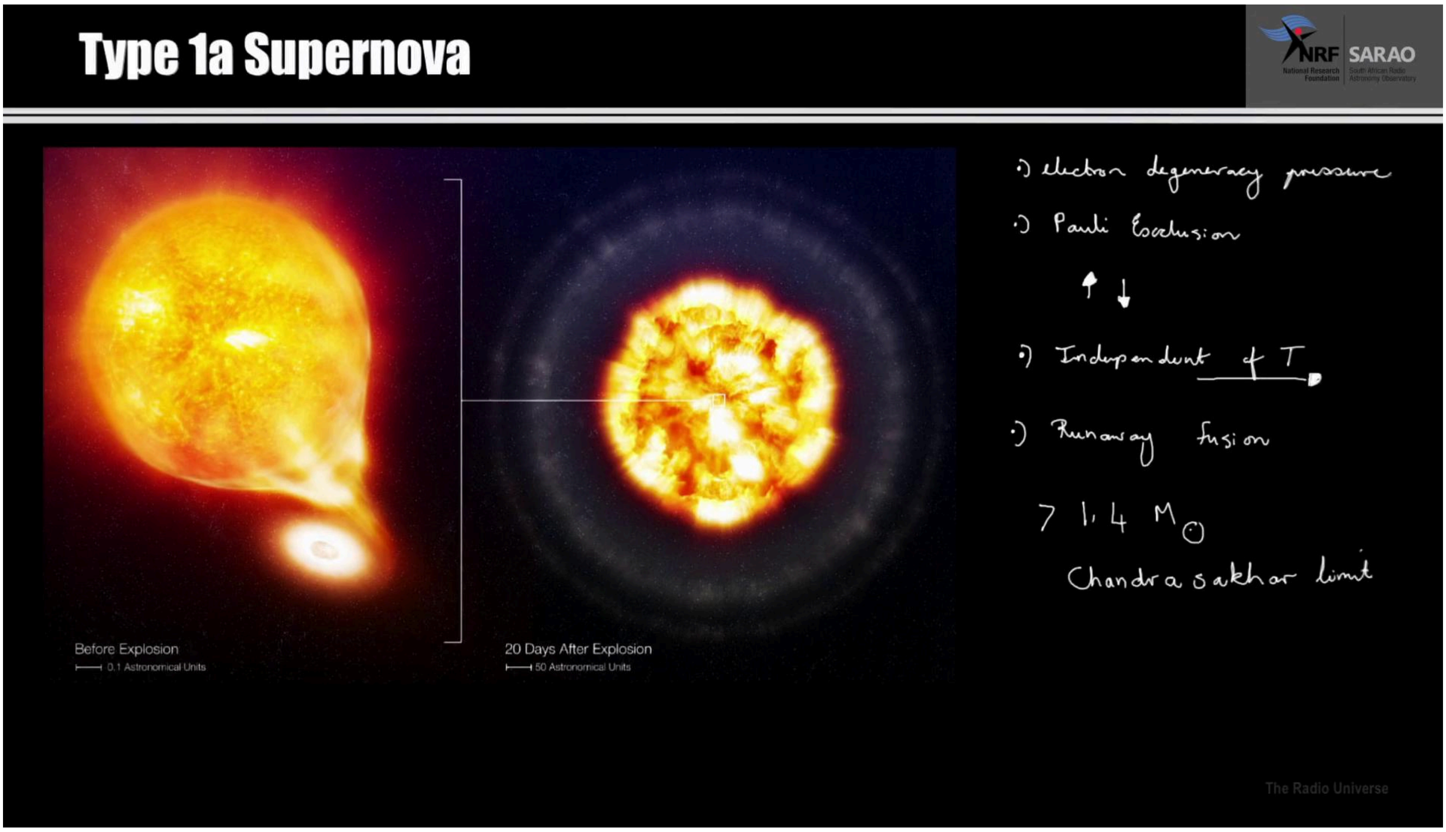


There's another part of having a supernova and that is when a white dwarf accretes mass from a companion star. So white dwarfs are kept stable by electron degeneracy pressure. This is a pressure that arises because electrons are not ever allowed to occupy the same energy state. Now remember from the Pauli Exclusion Principle when you studied quantum mechanics that in an atom no two electrons can have the same state so if they are in the same energy level, they have to have opposite spin. The electrons inside the white dwarf are not bound to the atoms. They're in a kind of sea of free electrons but they still have to have individual energy states which means that there is an extra source of pressure which keeps the white dwarf stable against its own gravity. But the key thing about the source of pressure is that it's independent of temperature and so in a normal star, the star remains stable because if the fusion reactions become very fast and are generating too much heat, the core expands slightly and then it cools and so the rate of the reaction then slows down. So it's able to self-regulate the rate of the reaction to remain stable.

Notes

Summary

10m 56s

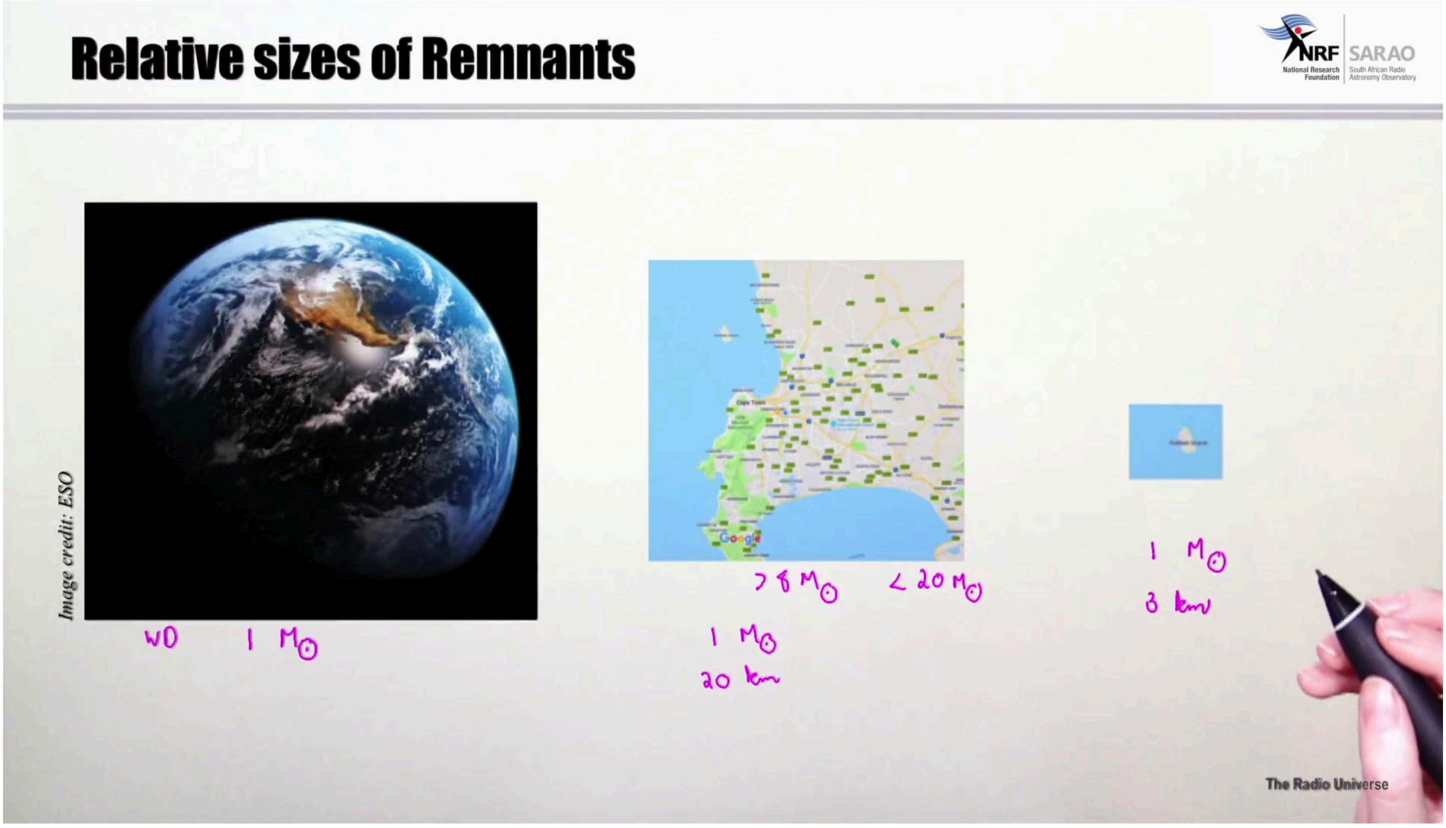


Because this electron degeneracy pressure is independent of temperature, when the reaction gets faster expanding doesn't actually slow down the rate of this reaction and so you end up with a runaway fusion reaction so you're fusing carbon atoms and they're releasing a huge amount of energy and it's happening at a faster and faster rate and so that triggers a thermonuclear explosion which is essentially what happens in an atomic bomb. The point at which this electron degeneracy pressure and runaway fusion happens is at a point where this white dwarf has a mass greater than around 1.4 solar masses and this is called the Chandrasekhar limit after the scientists who originally realized that the situation would occur.

Notes

Summary

12m 14s

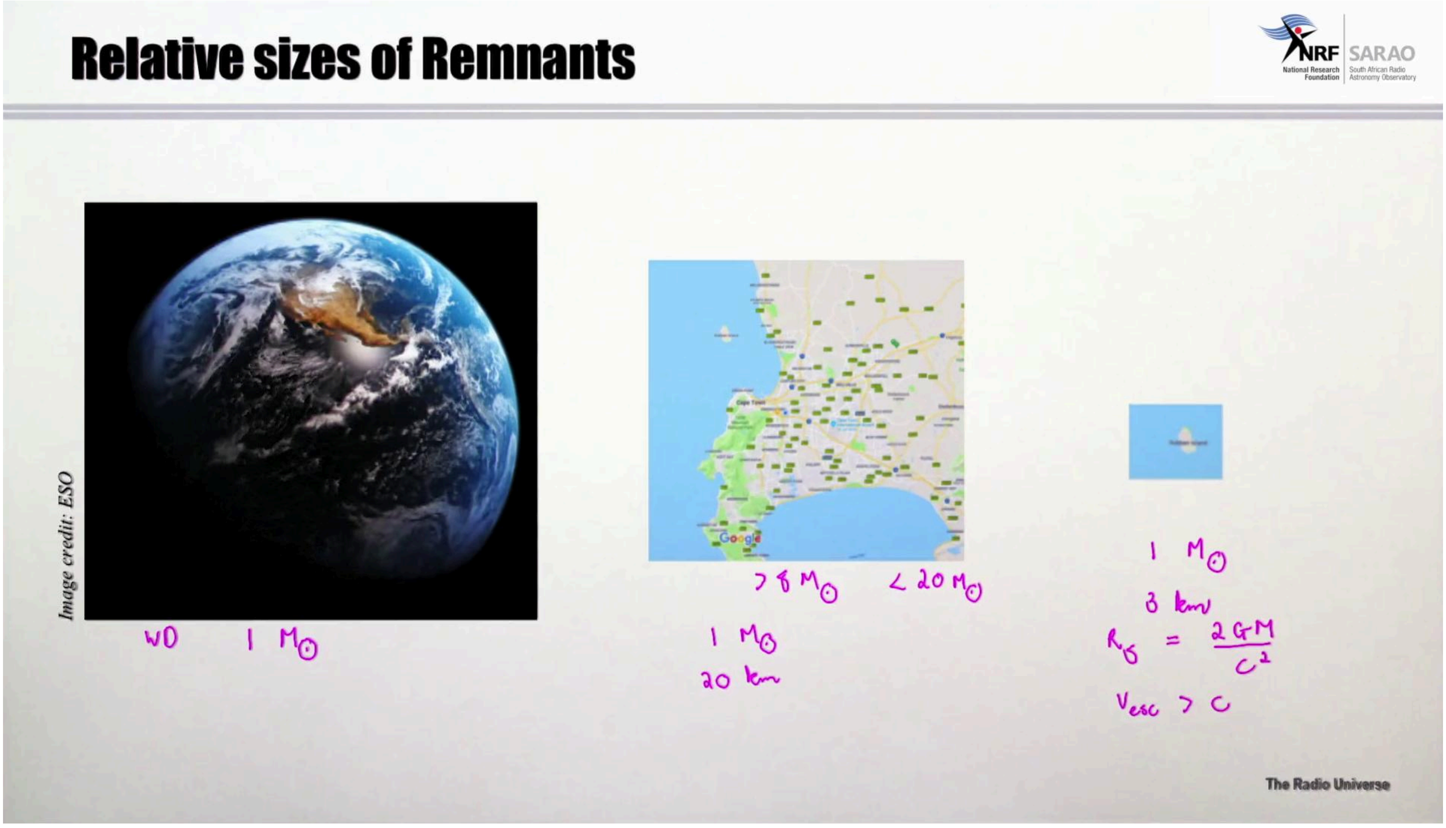


At the end of the star's life, you'll be left with several types of potential stellar remnants. So for an lower to intermediate mass star, you'll be left with the white dwarf. And to give you a comparison between the sizes and densities of the different remnants, I've drawn up this handy comparison. So a white dwarf is an object that has something like the radius of the earth as its size for one solar mass of material whereas a neutron star which is the result of a supernova explosion of a not as massive massive star so something that's greater than eight solar masses but probably less than 20 solar masses is roughly the size of the city. So for one solar mass of material, the neutron star would have the size of roughly 20 kilometers so roughly the size of the city like Cape Town, for example. Whereas for a black hole, all of the mass that's in our Sun, one solar masses worth of mass would be compressed into something that is only around three kilometers in diameter. So if a neutron star is roughly the size of Cape Town then a black hole is roughly the size of Robben Island here.

Notes

Summary

13m 06s



A black hole is defined as an object that's collapsed inside its Schwarzschild radius which is given by this equation, two times the gravitational constant times mass over 'C' squared and it's defined as an object where the escape velocity is going to be greater than the speed of light. So not even light can escape from the gravitational pull of a black hole.

Notes

Summary

14m 28s