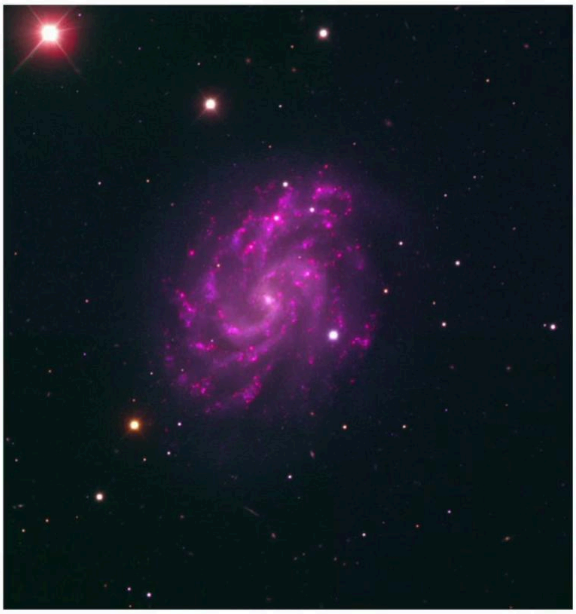
Supernovae and Supernovae Remnants (part 3)

Kim McAlpine



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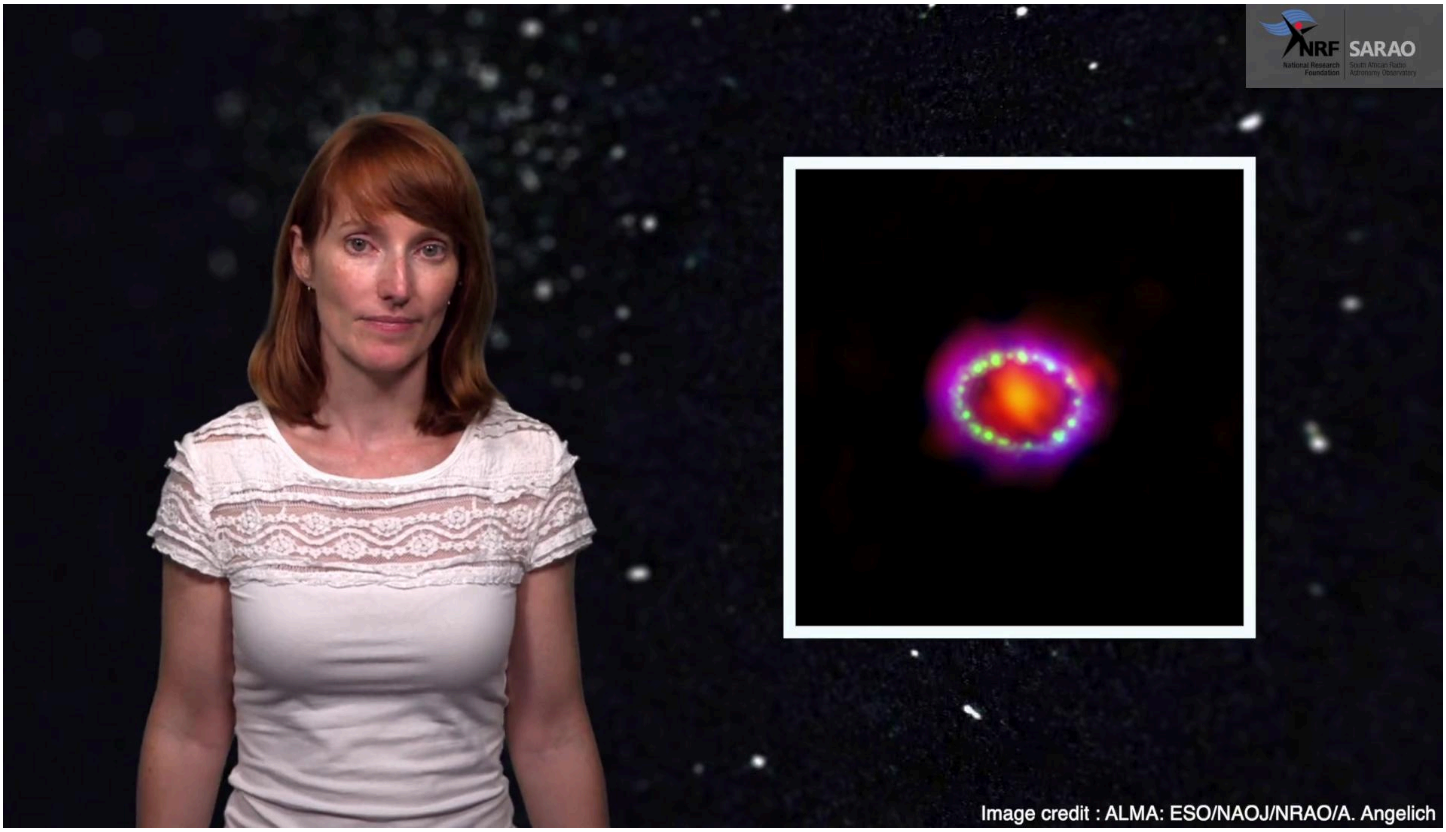
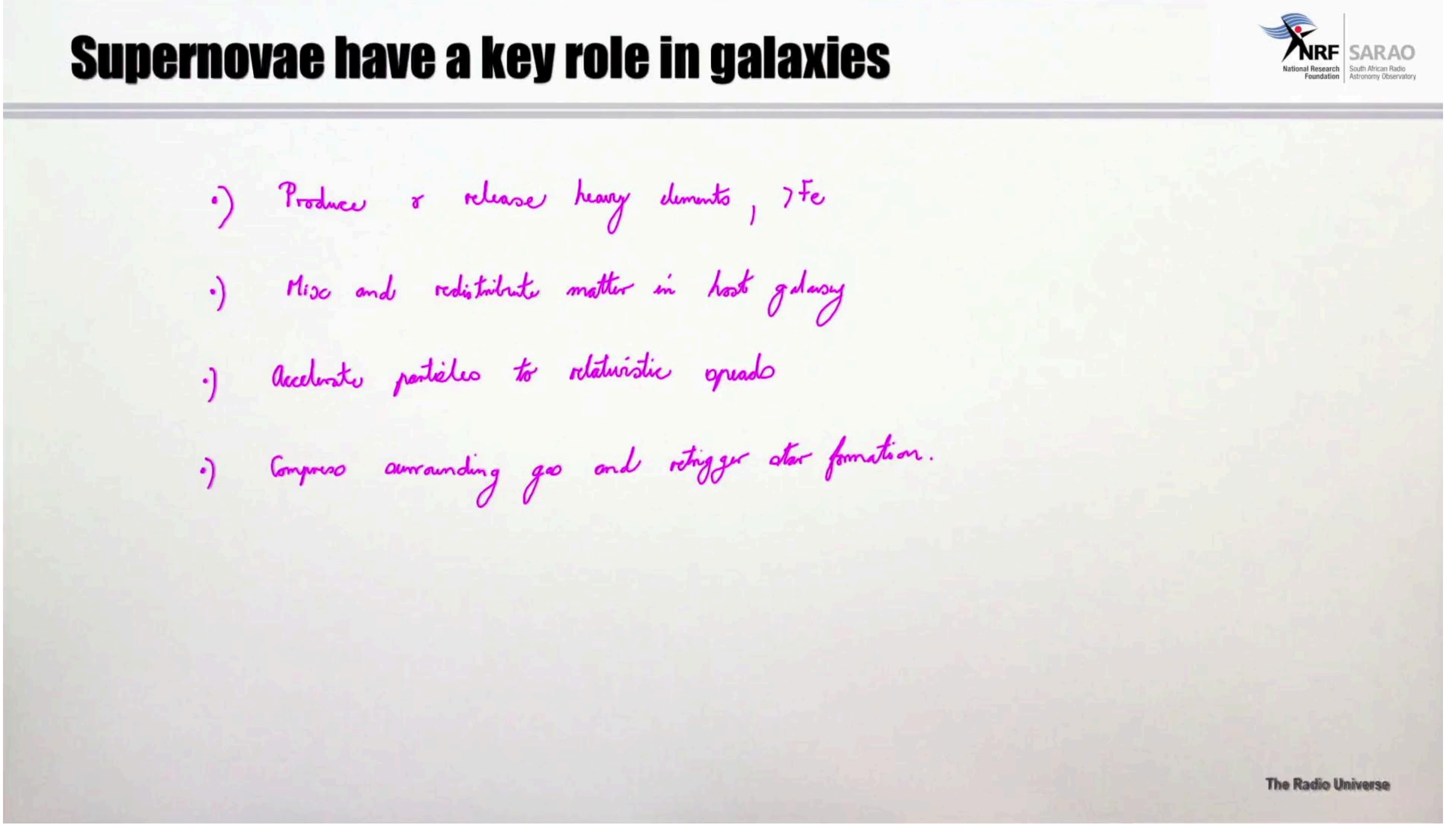


Our previous lecture ended with the bang literally. A star had just exploded and it sent a giant blast wave into the surrounding space. In this lecture, we'll focus on the evolution of the blast wave and how that changes with time and what the radio properties of the blast wave are.

Notes

Summary

0m 05s

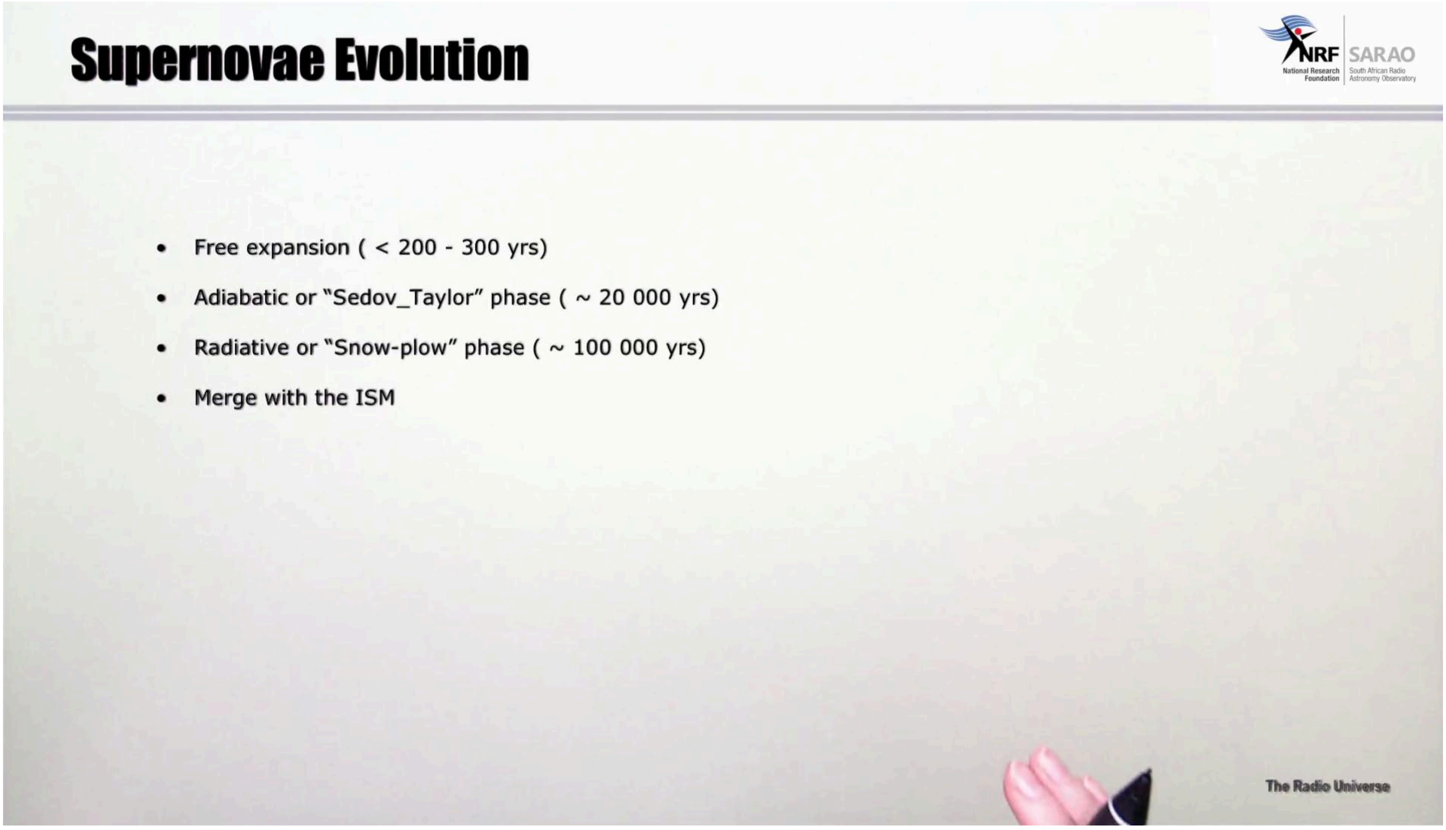


So why study supernova? Well, as mentioned in introduction, they have an important role to play in how galaxies evolve with time. The first thing that they do is they both produce and release heavy elements into the galaxy. So heavy elements are produced inside the star as we saw. But during the actual supernova heavy elements are also produced because they are a rich source of neutrons as the core was breaking down, we were producing lots of neutrons and those neutrons can bind with heavy elements to form heavier and heavier elements during the explosion and as mentioned before, all the elements heavier than iron are actually produced in a supernova because massive stars only produce elements up to iron. They mix and redistribute both these heavy elements and other matter within the galaxy so they help to sort of recycle the material in the galaxy and move it around. They accelerate particles up to relativistic speeds and we think that they are the source of cosmic rays. And they can compress the surrounding gas as the explosion expands into the ISM and it's possible that this can re-trigger more star formation.

Notes

Summary

0m 22s

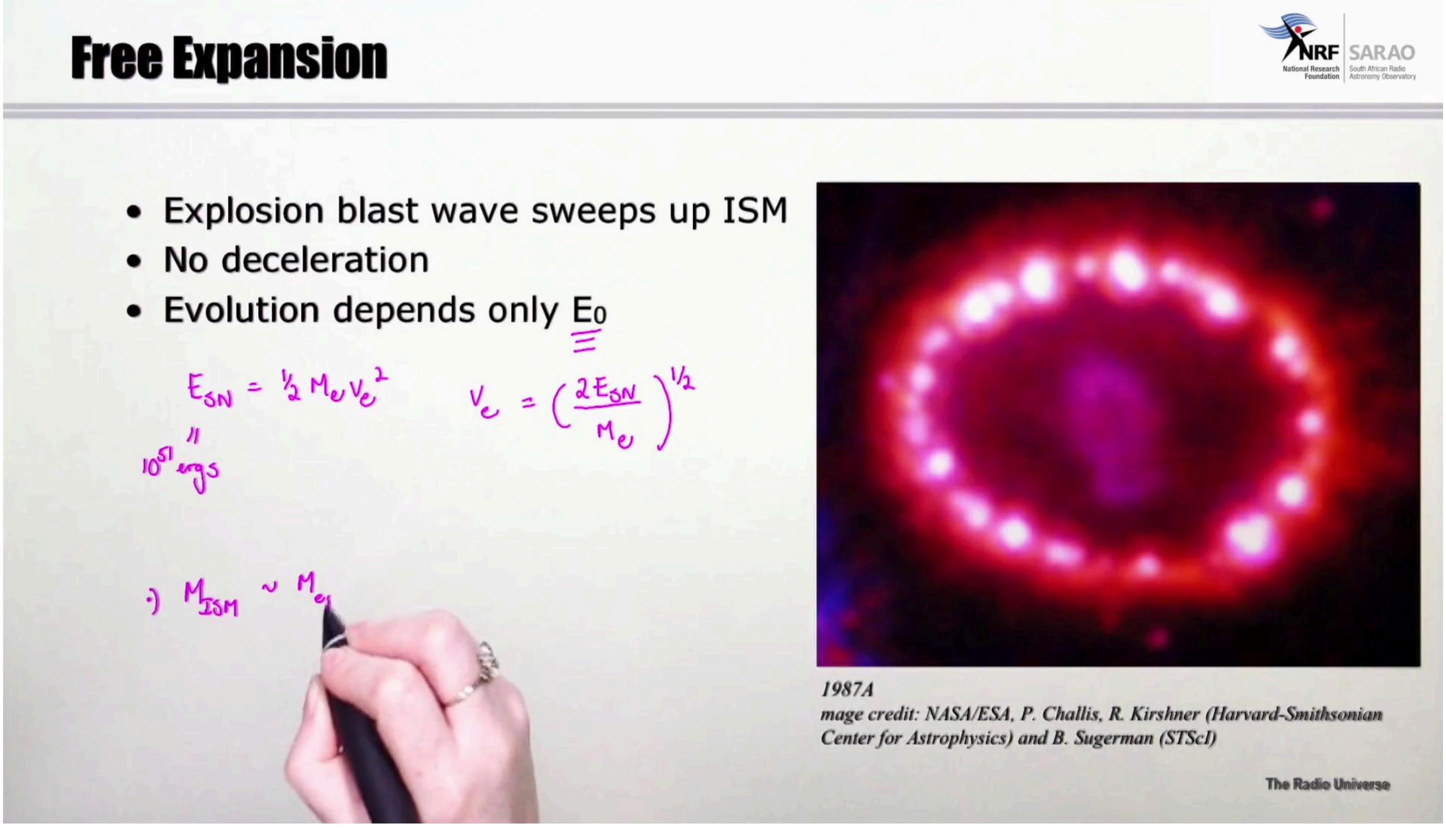


Once the supernova explosion has taken place then we're left with a supernova remnant which is essentially the blast wave and all the material contained within it. There are three defined periods of evolution in the life of the supernova remnant. The free expansion phase which lasts for a short time less than two to three hundred years, the adiabatic phase which lasts around 20,000 years and the radiative phase and after this after roughly a hundred thousand years, the supernova will lose its identity and just merge with the interstellar material inside the galaxy.

Notes

Summary

1m 54s



The free expansion phase is effectively what it sounds like. Its when the outer ISM has really no effect on the explosion. It's essentially got a negligible pressure and the explosion doesn't decelerate. It's just moving out at a very fast rate and it's sweeping up ISM as it expands. The evolution only depends on the initial energy here and there's no slowing down of the explosion. It tends to be a very fast shock wave that travels and then behind it there are slower moving stellar ejecta. So you can work out roughly what the speed of the remnant expansion will be in this phase because you know it's not going to be decelerating. So if you take the energy of the supernova which is usually of the order of about 10 to the 51 ergs. Then you know that will be roughly equal to the average kinetic energy of the ejected material and so from that you can calculate the velocity of the expanding blast wave. Now this is the mass of the ejected material and this is the average velocity. Not all of these things will be moving at the same speed. Eventually, the mass that is swept up by arch of shock wave will be roughly equal to the mass of the material that was ejected and at this point, the expansion will start to slow down and you'll enter the next phase which is the adiabatic phase.

Notes

Summary

2m 28s

Free Expansion

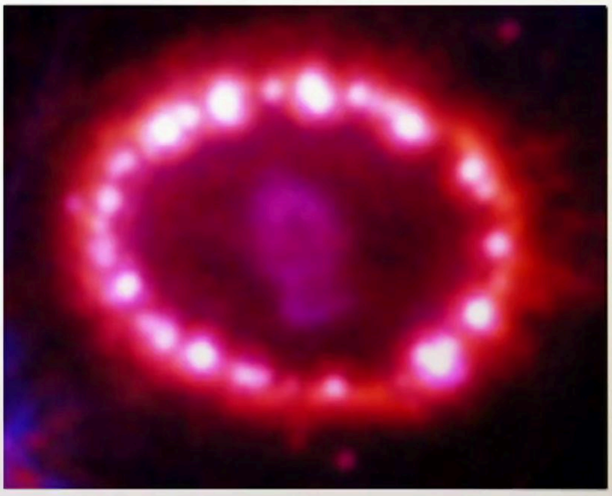
NRF National Research Foundation | SARAO South African Radio Astronomy Observatory

- Explosion blast wave sweeps up ISM
- No deceleration
- Evolution depends only E_0

$E_{SN} = \frac{1}{2} M_e v_e^2$, $E_{SN} \approx 10^{51}$ ergs

$v_e = \left(\frac{2E_{SN}}{M_e} \right)^{1/2}$

$M_{ISM} \sim M_{ej}$



1987A
mage credit: NASA/ESA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman (STScI)

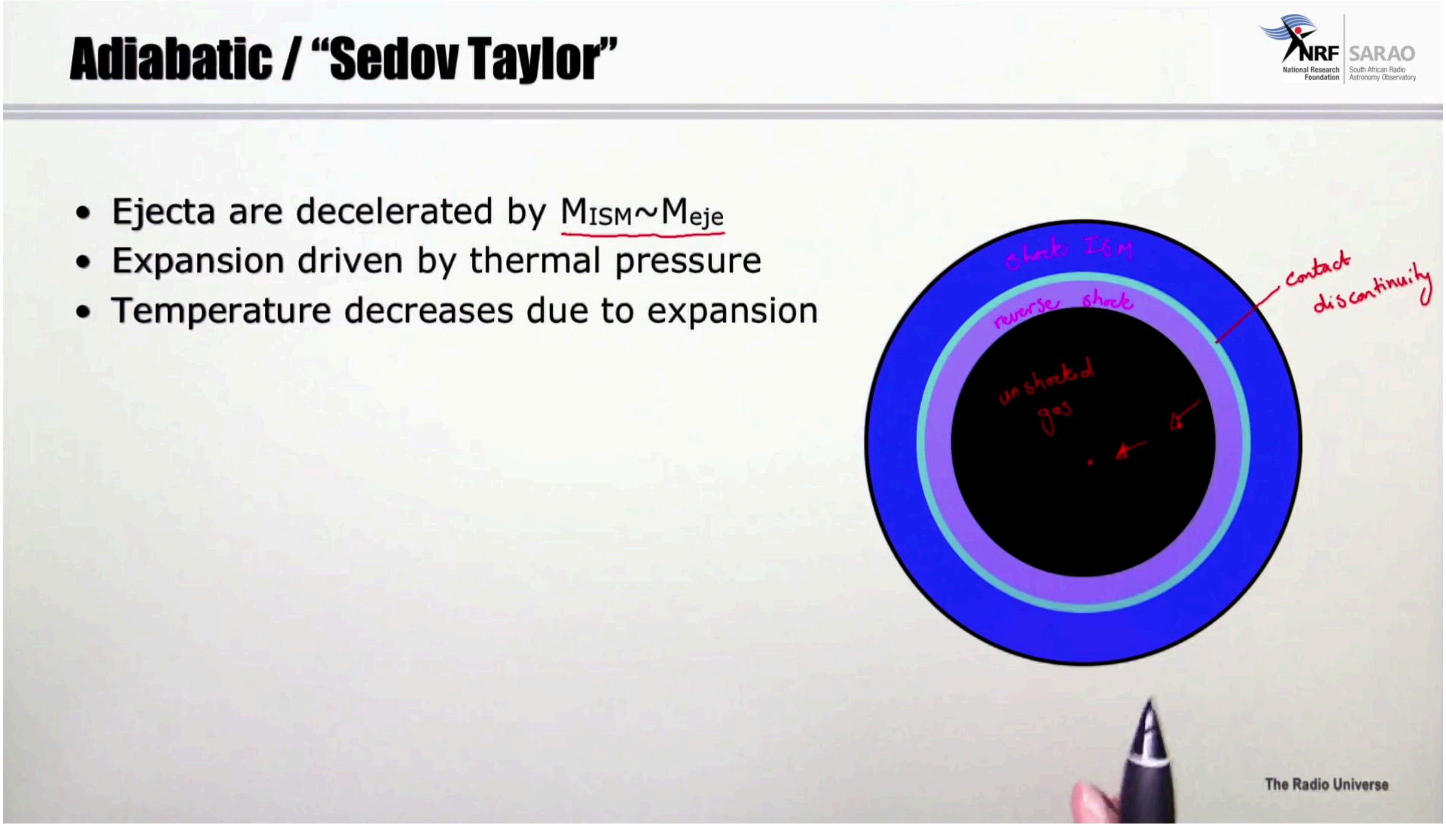
The Radio Universe

This is a picture of supernova 1987A and here you can clearly see this very bright shock front with slower moving stellar material that was ejected kind of coming in behind it.

Notes

Summary

4m 07s

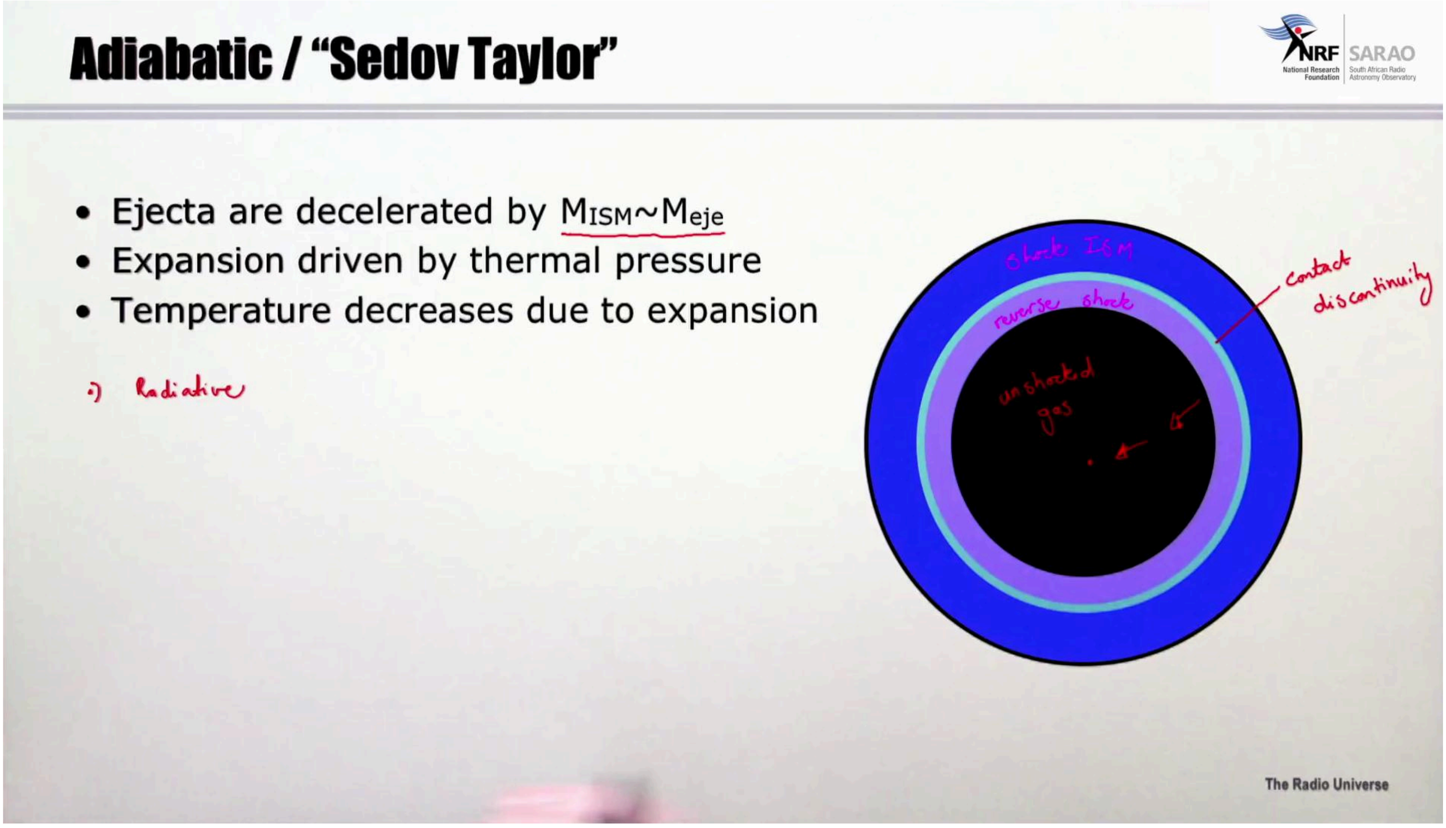


In the early early stages of the free expansion phase, there's only this initial first shock that you have to worry about. However, after some time a reverse shock will develop as the as the stellar material starts to catch up with this now slowing down outer shock. So you'll have a reverse shock that develops here. Initially, this reverse shock will propagate outwards in the same direction as the main shock but eventually it starts to propagate inwards as well. So you have a forward shock and you have a reverse shock and those are separated by something called a contact discontinuity. Outside of this main shock, the ISM isn't aware of the supernova. The gas is in exactly the same state it was before the supernova took place. On the inside here you'll have this unshocked cooler gas, unshocked gas but this reverse shock will propagate backwards over time and eventually, it will shock heat all of this inside gas as well. Once you reach this threshold where this mass of the ISM is equal to the mass of the ejected material then you enter the Adiabatic or Sedov Taylor phase. It's called Adiabatic because at this point the expansion is really driven by the thermal pressure of the hot gas here so the hot gas is expanding and it's not driven anymore by the original energy from the explosion.

Notes

Summary

4m 21s

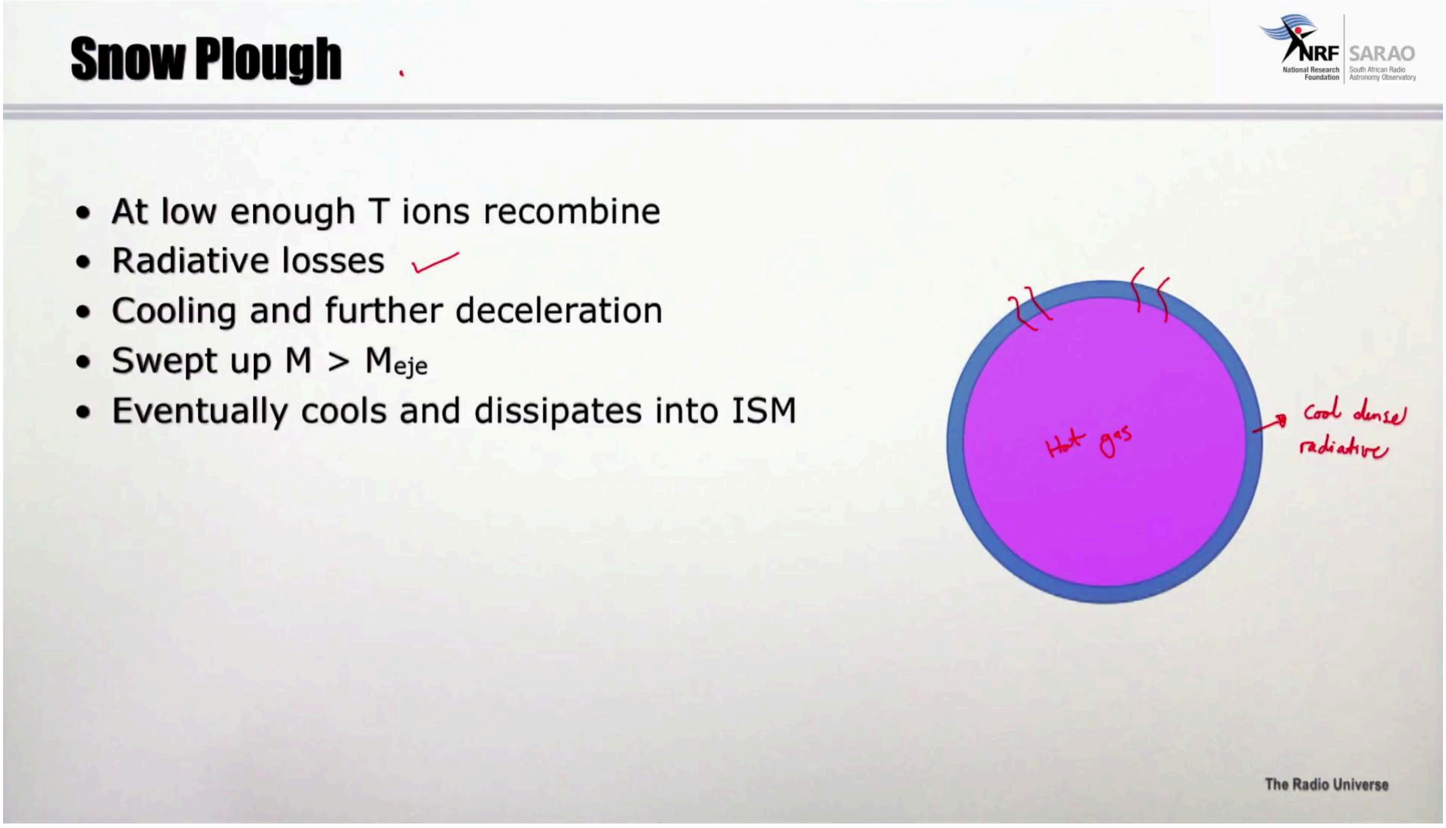


As this is expanding, the temperature is decreasing due to the expansion of the gas and it's called the Sedov Taylor phase because it uses the solutions that Sedov came up with to describe things like pressure and density inside the remnant shell at this point. At this point, the gas will be very hot and so you can essentially neglect any radiative losses so the ions are not recombining because the the energy levels and the temperatures are very high but as this expands, eventually, this inside gas will start to cool down and as the inside gas cools down it will become cool enough that eventually these ions will recombine and radiative losses will become important and so this Snow-Plough phase is also called the radiative phase because it's the phase where radiative losses become important.

Notes

Summary

6m 05s

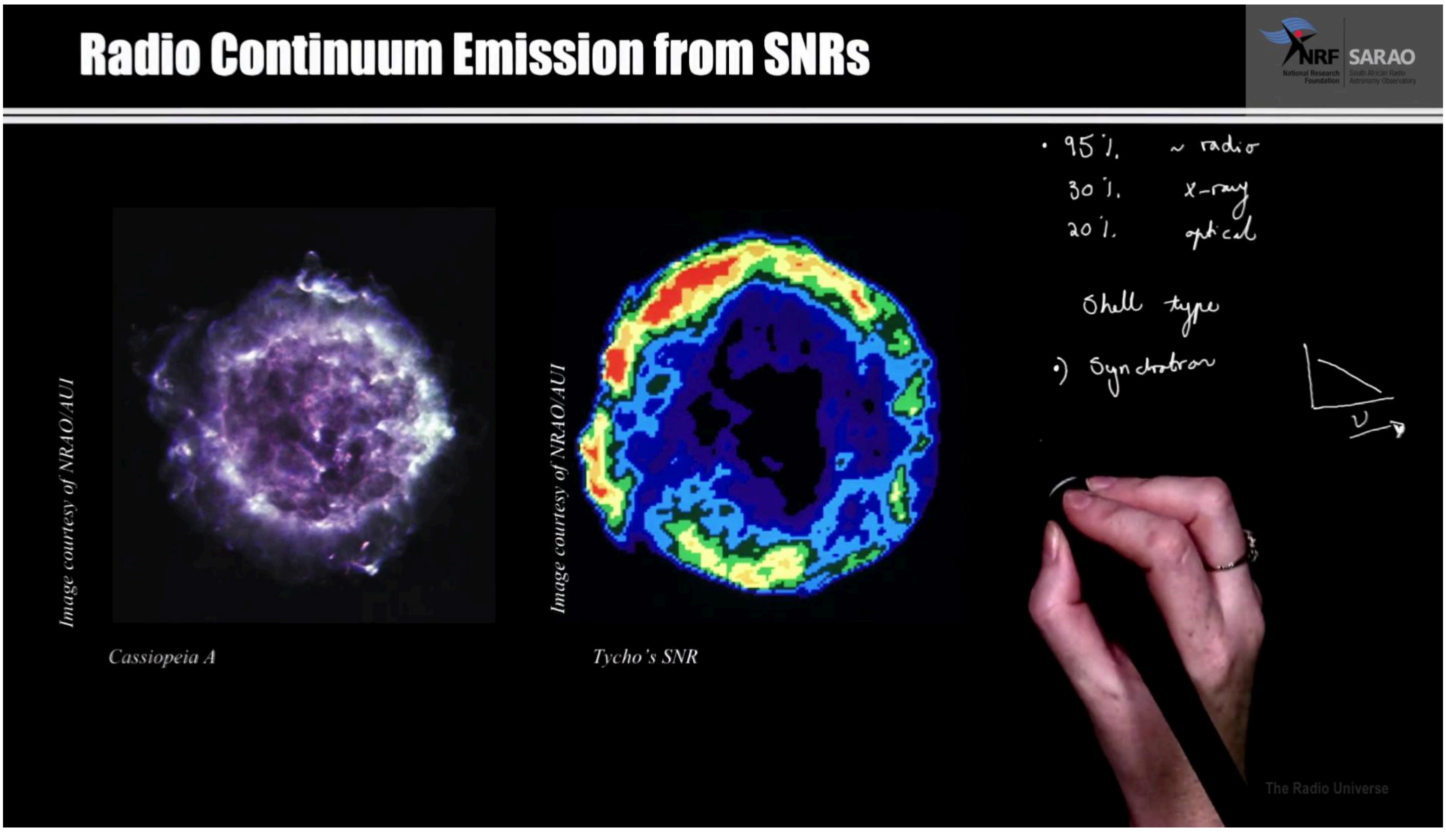


So there will be further cooling because of this radiative phase and that also means that the remnants expansion will slow even further and now you'll still be sweeping up ISM mass but the mass is now much much bigger than the original mass of the star right in your thing, in your supernova remnant and the outer rim here becomes very cool and very dense as it cools by a radiative losses but the inner region will remain hot for some time so here you'll still have hot gas. Eventually, this will have expanded and slowed down so much that the velocity will be essentially the same as the ISM. This outer shell will start to break up and the remnant loses its identity completely and it just becomes part of the ordinary ISM.

Notes

Summary

7m 00s

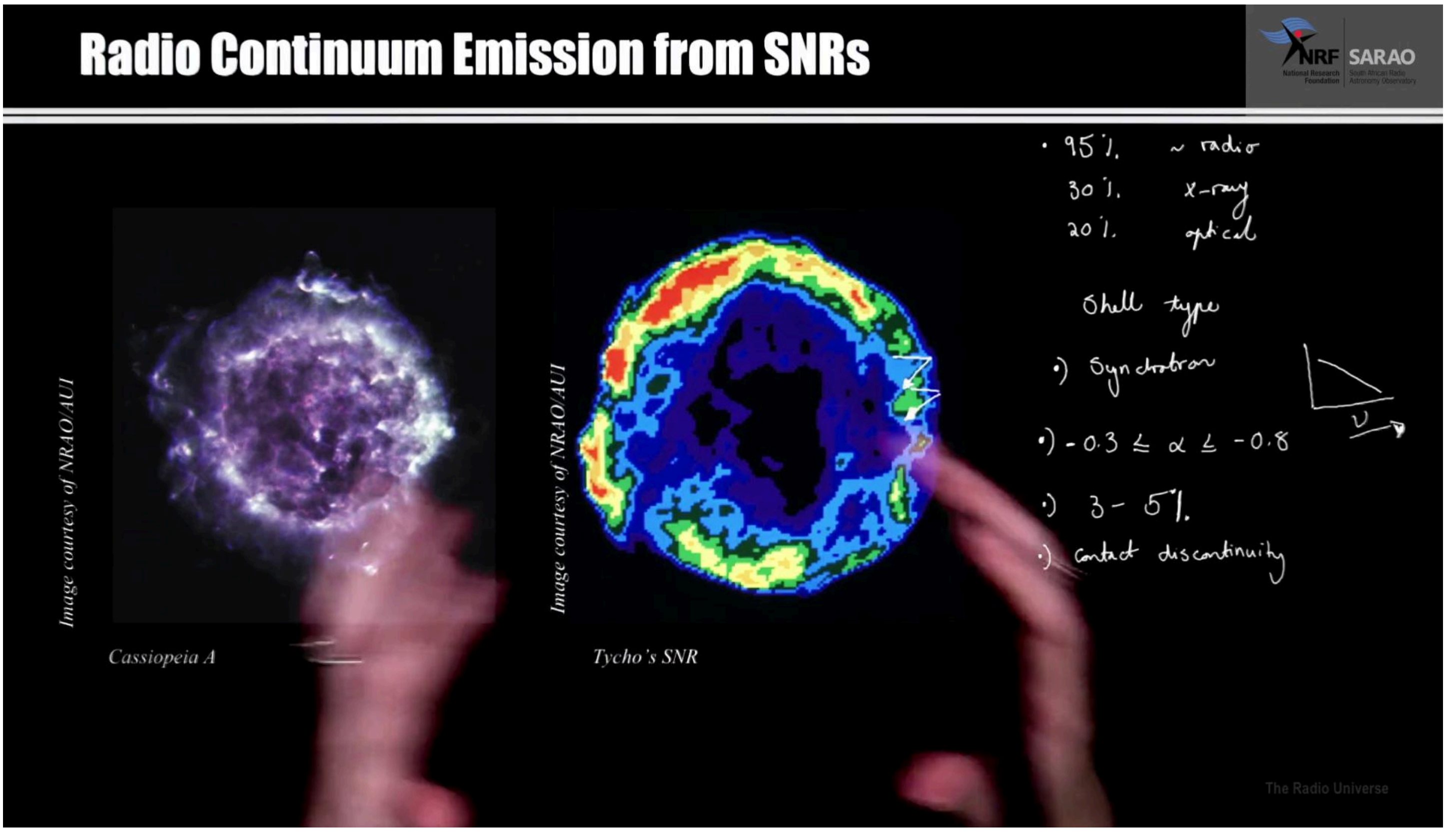


So almost all supernova remnants emit in the radio. Something like 95 percent of all known supernova remnants have radio emission which is compared to only maybe 30 percent have confirmed x-ray and 20 percent in the optical. There are effectively two classes of supernova remnants that you see in the radio which is based on the morphology so how they look. The first of these is the shell type of supernova remnant and we have an example here of Cas A and Tycho's supernova remnant which are both shell type and from here you can see that most of the emission is coming from this shock front on the outside. So in the shell type of supernova remnants, the emission is synchrotron emission and in fact, one of the main ways that you can identify supernova remnants is by looking for extended sources that have non-thermal synchrotron spectrum spectra and remember from our lesson on thermal and non-thermal spectra what that means is that the spectrum is going to be increasing towards lower frequencies. So if you look for a non-thermal spectrum from a diffuse source then you're fairly certain that what you're seeing is a supernova remnant.

Notes

Summary

7m 58s

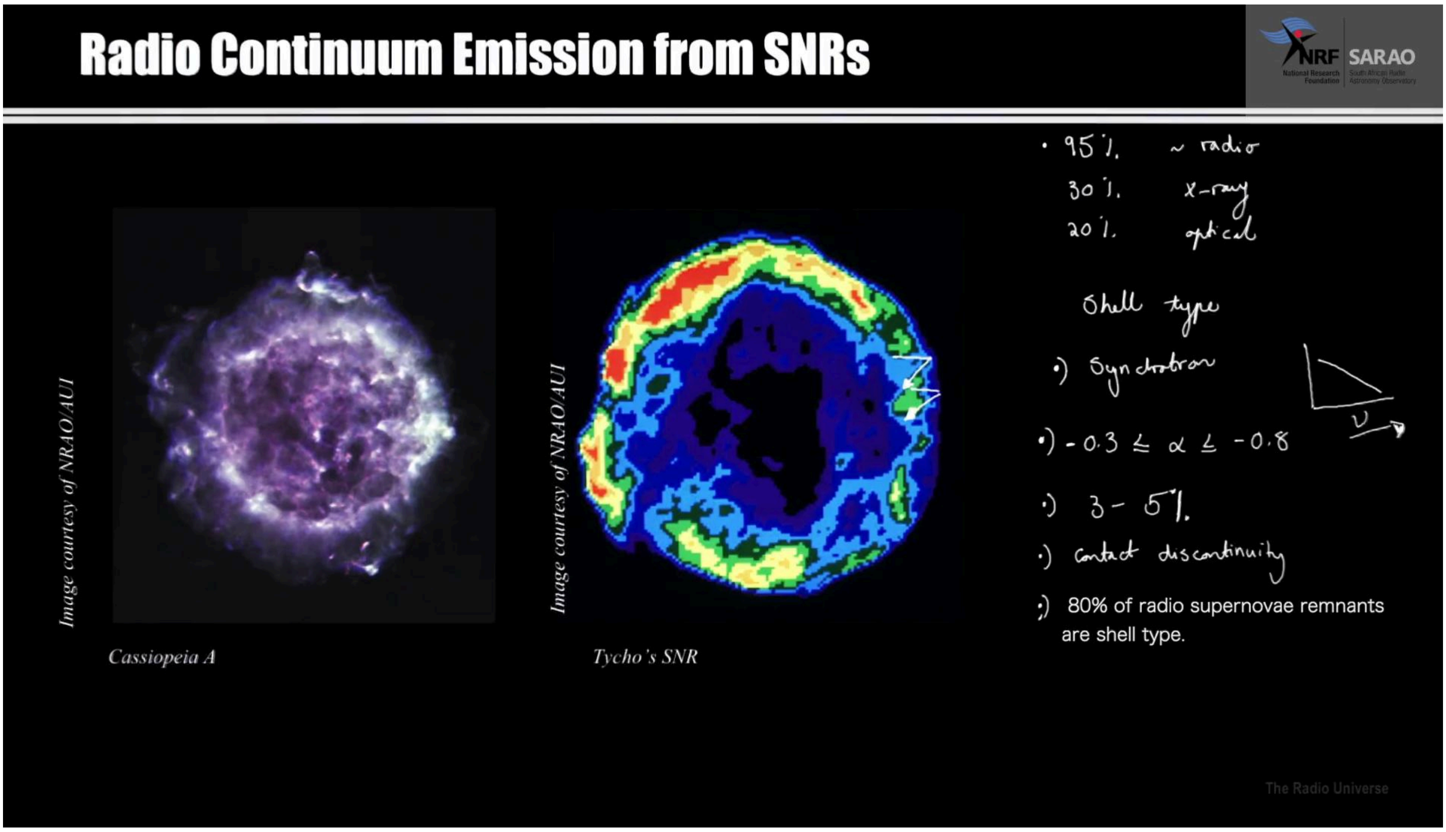


In these shell type supernova remnants, they typically have spectral indices of about minus 0.3 to about minus 0.8 so from a sort of normal steepness to a flattish spectrum. They're not very highly polarized. They're only about 3 to 5 percent polarized. So in order to have magnetic fields, I mean to have synchrotron emission, what you need is a magnetic field and a relativistic electron. And so where do these two elements come from in supernova remnants? Well, the cosmic ray electrons can be accelerated in the initial explosion but that tends not to provide you with enough energy to get the energy levels that you see in this spectra. Remember that the spectrum here tells you about the energy profile of your electrons. And so it's believed that the electrons are accelerated here at the contact discontinuity that they can be reflected back and forth across this contact discontinuity between the two shocks and that can accelerate the electrons to higher and higher speeds. So the electrons come from the contact discontinuity and the magnetic field is probably the magnetic field of the interstellar medium that existed before this star exploded.

Notes

Summary

9m 28s

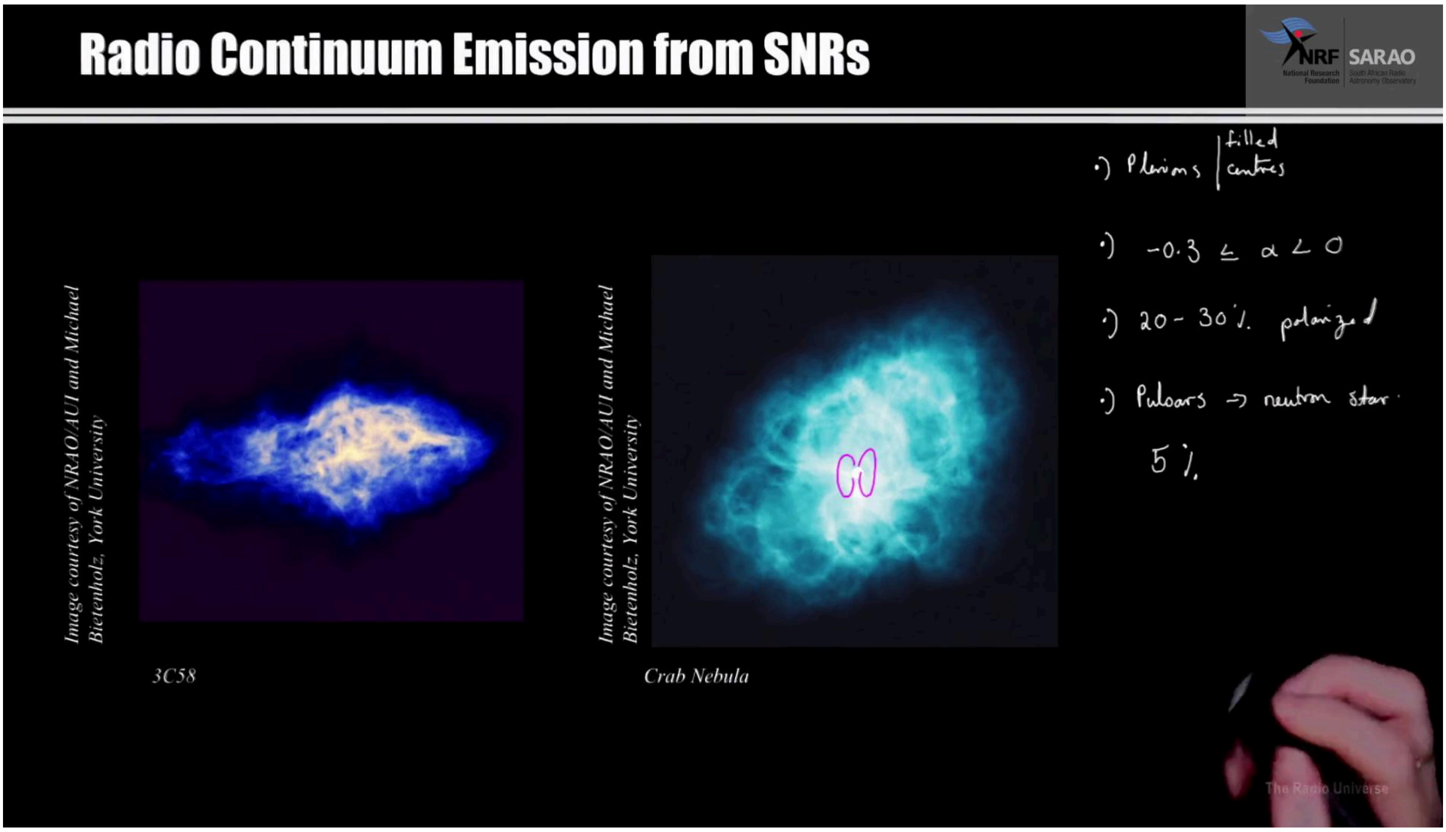


So as it was sitting there, there was a really some existing magnetic field which is now being swept up with the supernova remnant and possibly amplified at the shock fronts here. So the next type of supernova remnant is what we call the filled shell supernova remnant.

Notes

Summary

10m 50s

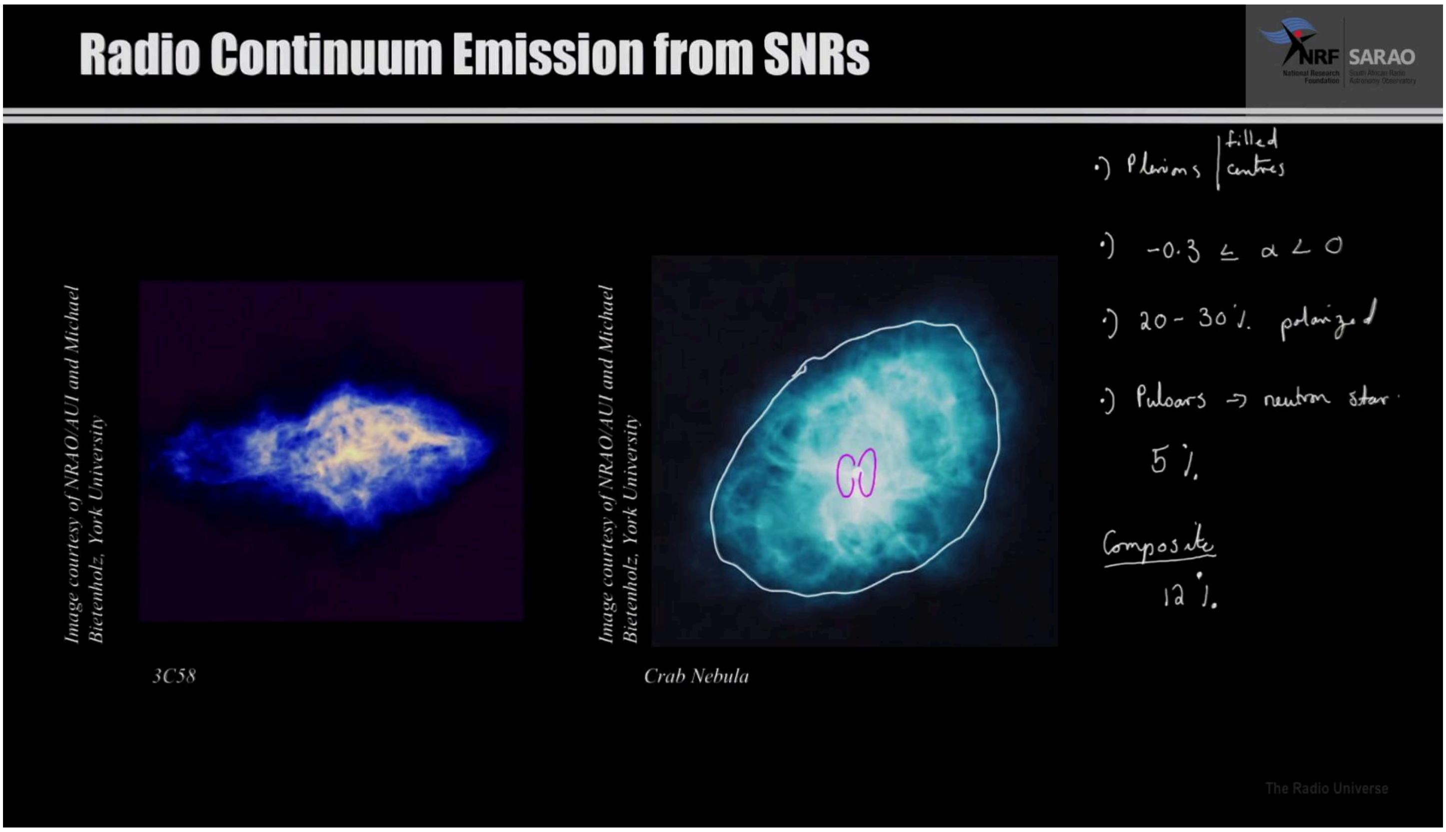


So in the filled shell supernova remnant, here's two examples of them; 3C58 and the Crab Nebula. In both of these, you can see that instead of having the bulk of the emission come from the edges, you have a brighter radio source in the center and so these are called either filled centers or plerions. So these tend to have a much flatter synchrotron spectrum than the shell type of supernova. Their spectra tend to be around 0.3 to about zero but they're still non-thermal so the primary source of emission here is still synchrotron emission. They tend to be much more highly polarized, around 20 to 30 percent polarized. And in this case, it's believed that there is a pulsar which is a type of neutron star in the center here which provides a magnetic field which is providing most of the synchrotron emission here. So you'll be learning more about pulsars in the next lecture but simply know that they're a type of neutron star which emit radiation at regular intervals and that they have effectively magnetic fields here which are interacting with the electrons and providing the synchrotron emission here. So roughly five percent of supernovae are of this filled center kind.

Notes

Summary

11m 17s



But there's another type which is the composite type which is exactly what it sounds like. Its sources that have both in types of emissions so they have a strong emission in the center but they also have emission from the rim on the outside and in that case, there's a higher percentage of those. There's roughly 12 percent of supernovae are part of this composite And the remainder of the known supernova remnants have more complicated morphologies that are not easy to fit into these two classifications.

Notes

Summary

12m 47s