HII regions

Kim McAlpine

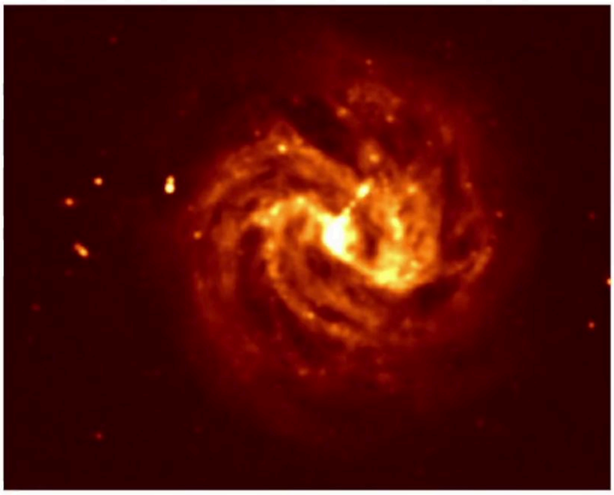
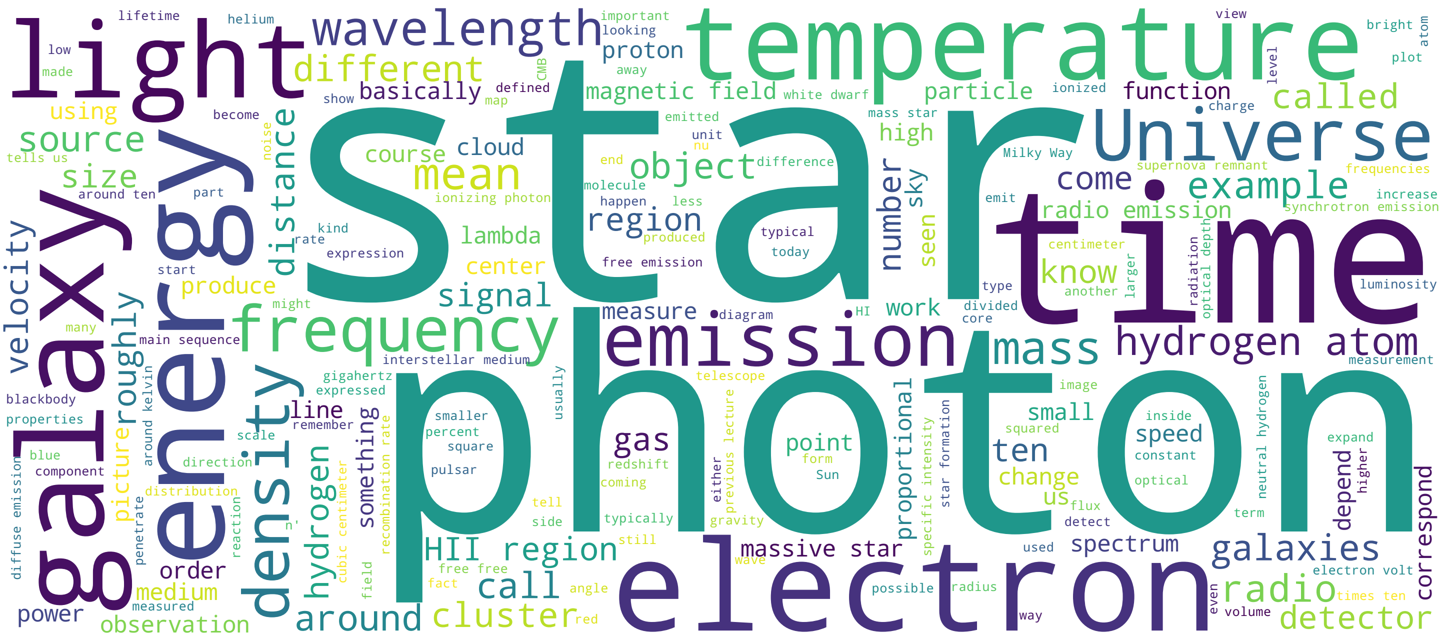


Image courtesy of SARAO



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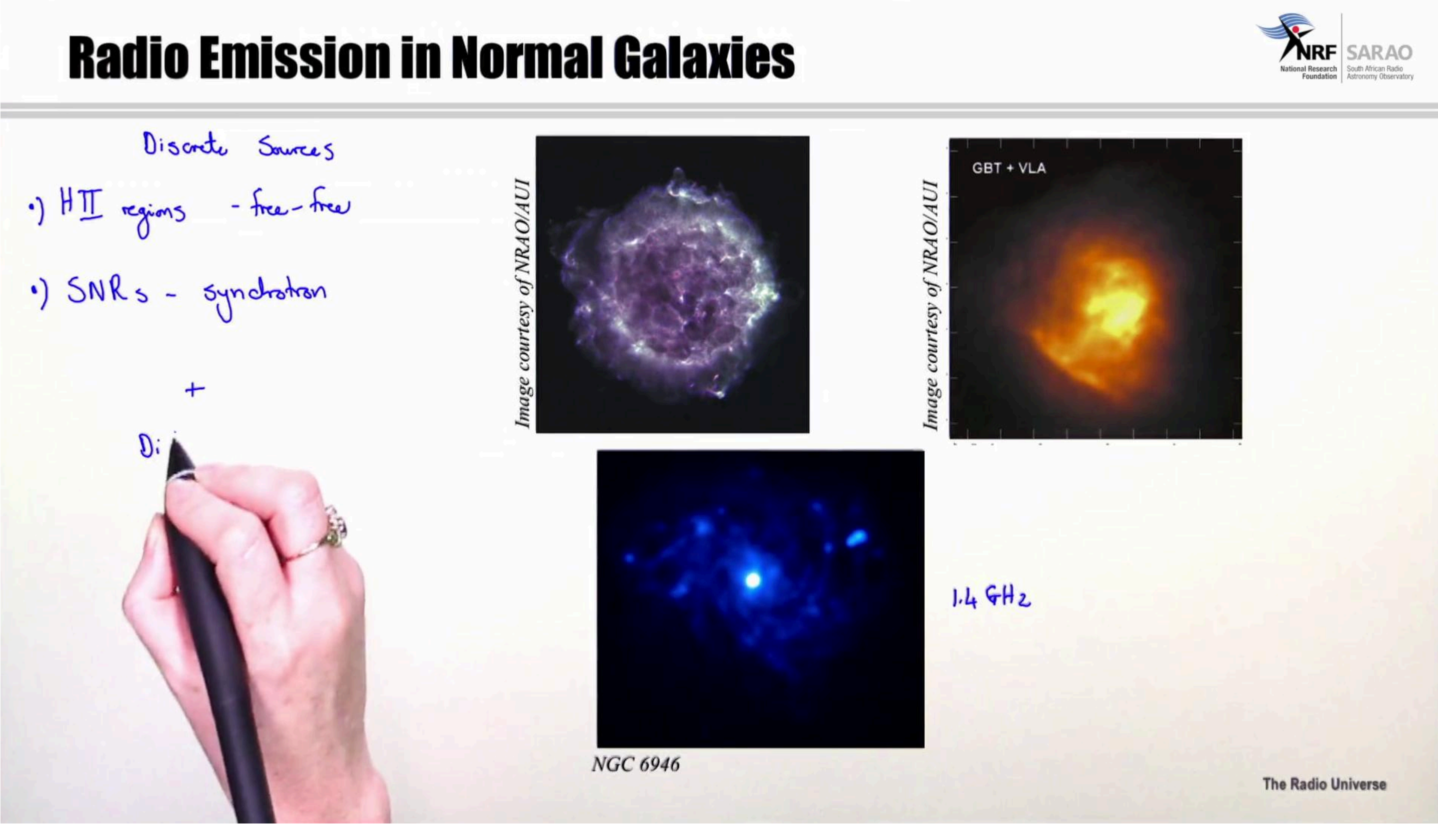
Video

This lecture focuses on the properties of HII regions which are bubbles of ionized gas around massive stars and they are the main images of free-free emission within galaxies.

Notes

Summary

0m 05s

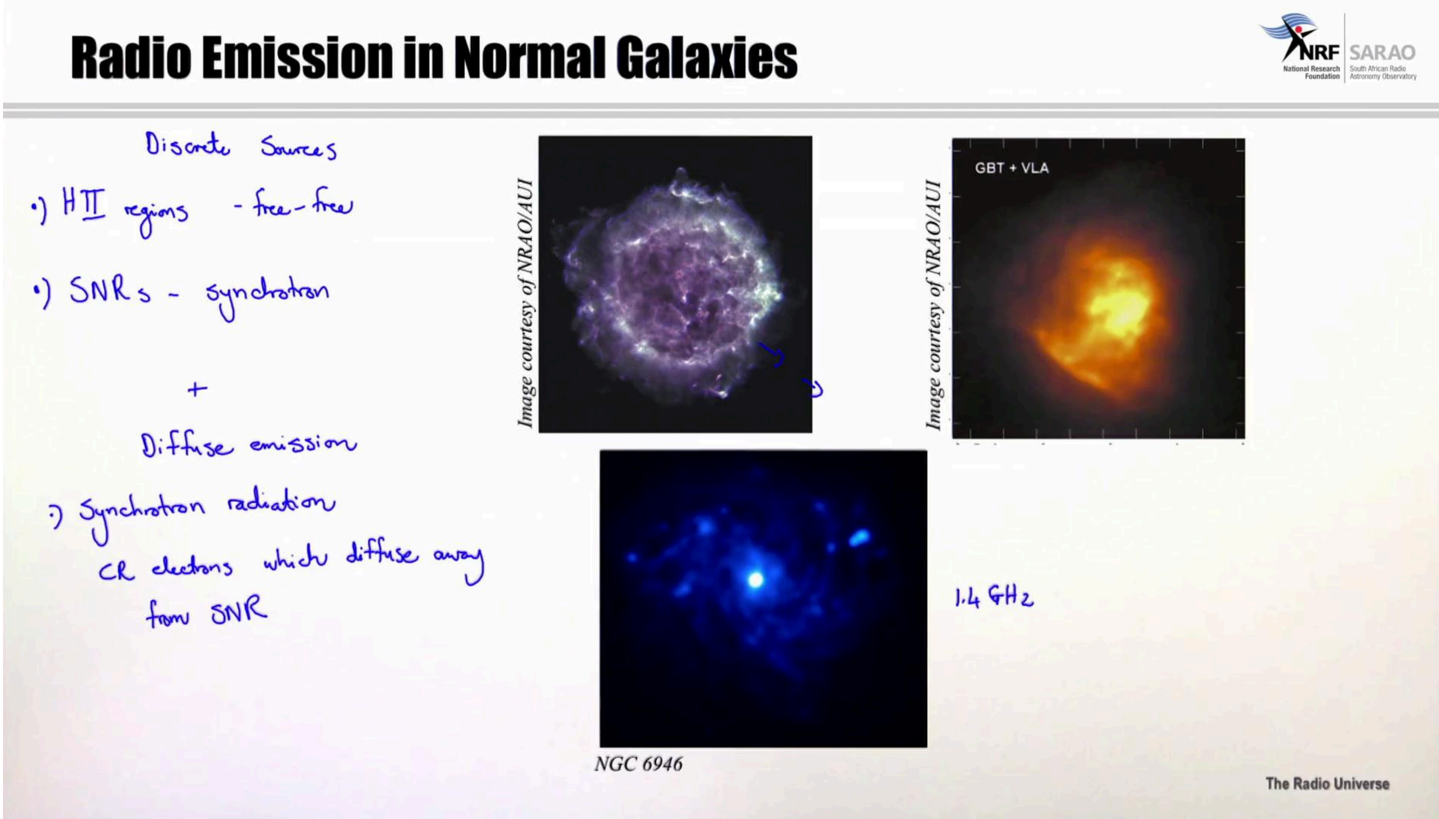


We're familiar with the idea that the optical light from a galaxy comes from the stars that are in the galaxy. So where does the radio emission in a normal galaxy come from? Well, it comes primarily from two sources. It can come from discrete sources so it can come from individual sources just like the light can come from an individual star. And there are two main types of discrete sources that produce radio emission. The first of these is HII regions. So these are regions of ionized gas around very young very hot stars and these produce free-free emission because the ionized protons and electrons are interacting and producing free-free emission through the Bremsstrahlung mechanism. This is an example of an HII region. This is the Orion nebula. Another kind of discrete source that produces radio emission are supernova remnants which we just learned about in the previous lecture and they produce synchrotron emission which is associated with electrons that are accelerated in the remnant and in the original explosion. But if you look at a picture of a galaxy in radio wavelengths, this is a picture of NGC 6946 at around 1.4 gigahertz, what you'll see is that there's a lot of diffuse emission here that's not necessarily associated with individual sources and so where does this diffuse emission come from?

Notes

Summary

0m 16s

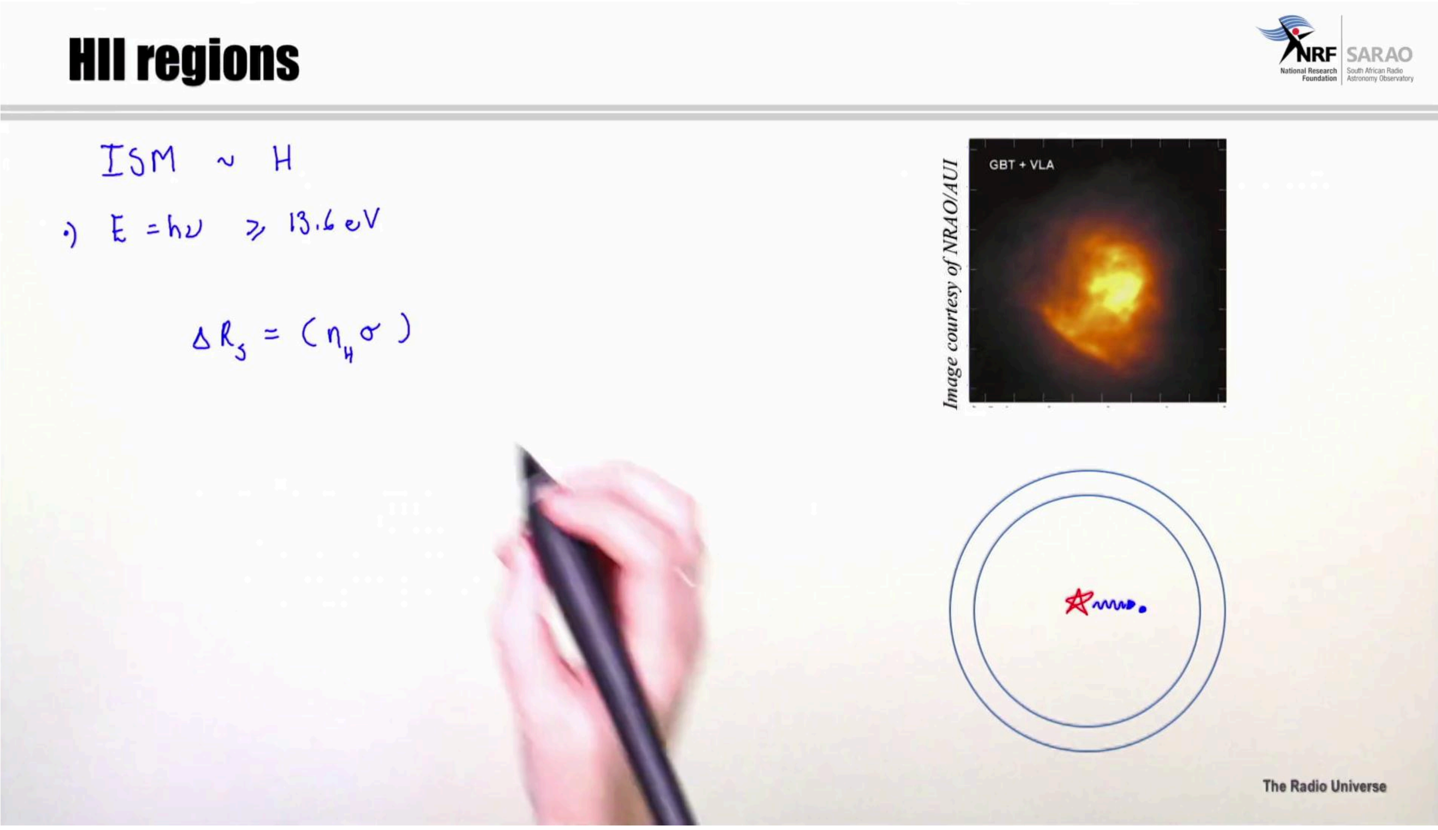


Well, most of this diffuse emission is also synchrotron radiation and so it's thought that this diffuse synchrotron radiation comes from cosmic ray electrons that were originally associated with the supernova remnant that have now long since diffused away from the original remnant which has merged with the interstellar medium. So it's caused by cosmic ray electrons which diffuse away from their original supernova remnant.

Notes

Summary

1m 52s

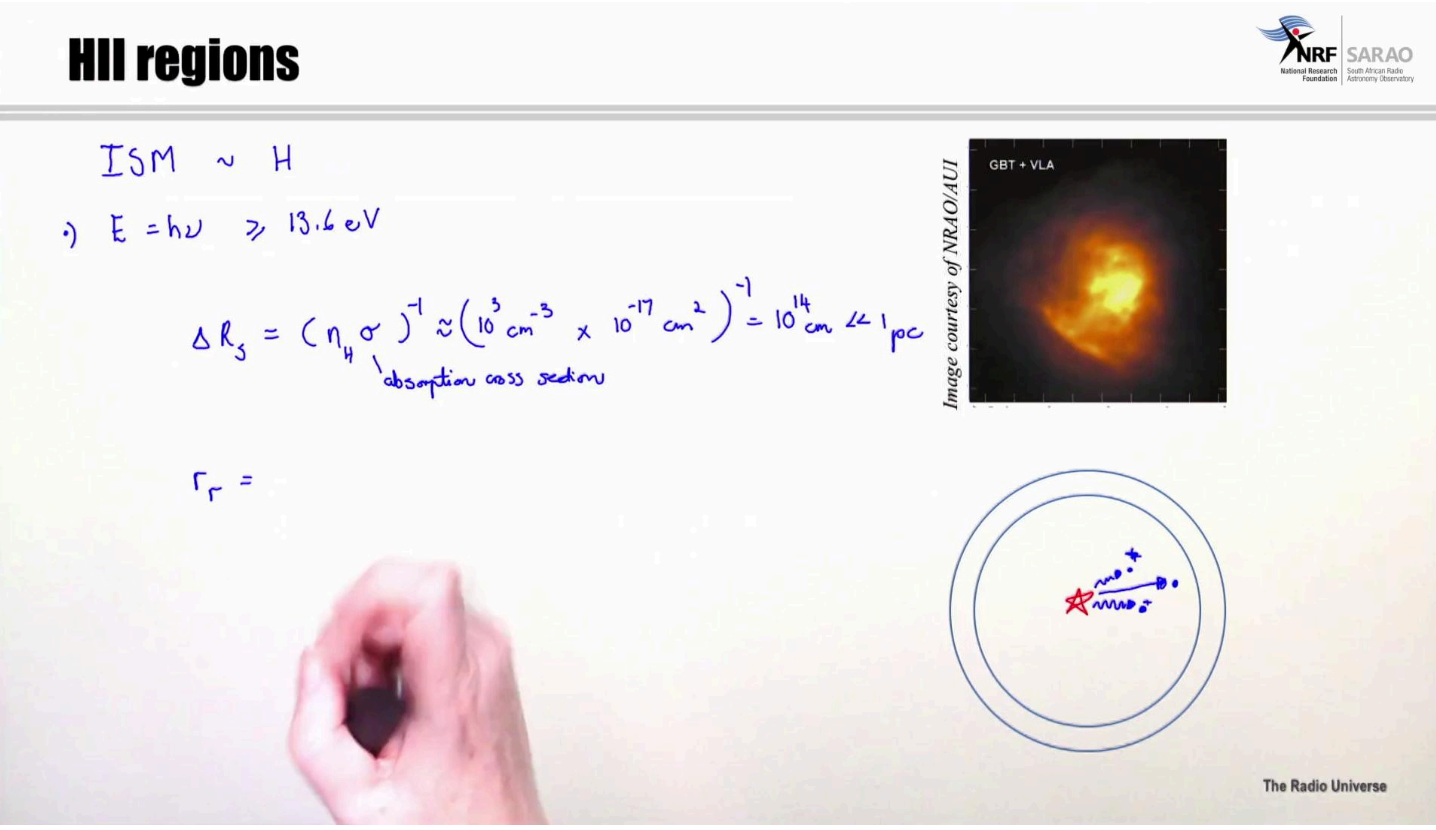


We'll talk a little bit more about HII regions as we haven't already explored those in a previous lecture. The interstellar medium, the medium that's between stars in a galaxy, mostly consists of hydrogen and a little bit of helium. When a star turns on if that star is hot enough, it's possible that it will be able to photo-ionize the hydrogen so the photons will be energetic enough to strip an electron off this hydrogen atom and turn it into HII. In order for this to happen, you have to have enough energy to overcome the binding energy of the electron to the hydrogen atom. Remember that energy is equal to the frequency of the light and in this case in order to photo-ionize hydrogen you must have more energy than around 13.6 electron volts. When you have this ionizing photon that comes from the star that's just switched on, it will travel some distance into the interstellar medium before it encounters a hydrogen atom to photo-ionize. How far is this distance on average? Well, the distance it penetrates before encountering a hydrogen atom will depend on the inverse of the density of hydrogen in the medium and also on the absorption cross-section of hydrogen atom to the photon where the absorption cross-section just says how likely is it that a photon encountering a hydrogen atom will ionize it.

Notes

Summary

2m 27s

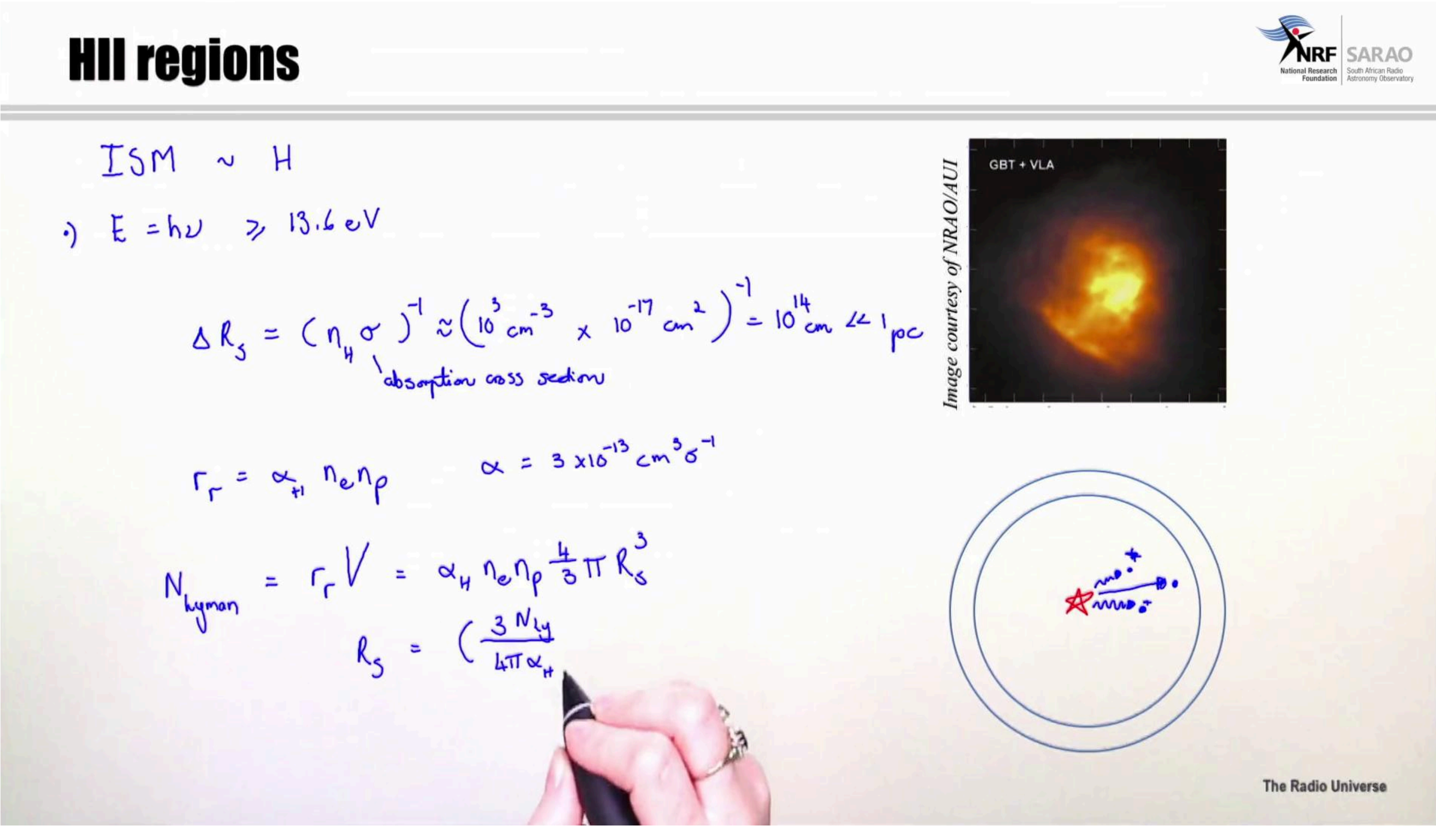


So for a typical density in the interstellar medium you might have something like ten to the three atoms per cubic centimeter and the absorption cross-section has a value of ten to the minus 17 centimeters squared. So what that means is that the photon will only penetrate a very short distance before it's absorbed by an intervening hydrogen atom of ten to the 14 centimeters or less than one parsec. So once these hydrogen once the star has photo-ionized all the nearby hydrogen atoms so that they're now all positive ions, there won't be any nearby neutral hydrogen atoms to absorb it and so the photon will, once you've ionized in the region close to the star, the photon will be able to penetrate further out to ionize the neutral hydrogen encounters there so it will become more transparent to the ionizing photons once you've ionized everything nearby. And so this ionized region around the star will essentially expand once the star has switched on. At some point, these positive protons will bump into electrons in this medium and they can recombine and so the size of this HII region will grow until you reach a point where the recombination rate is equal to the ionization rate and the recombination rate depends on the density.

Notes

Summary

4m 03s

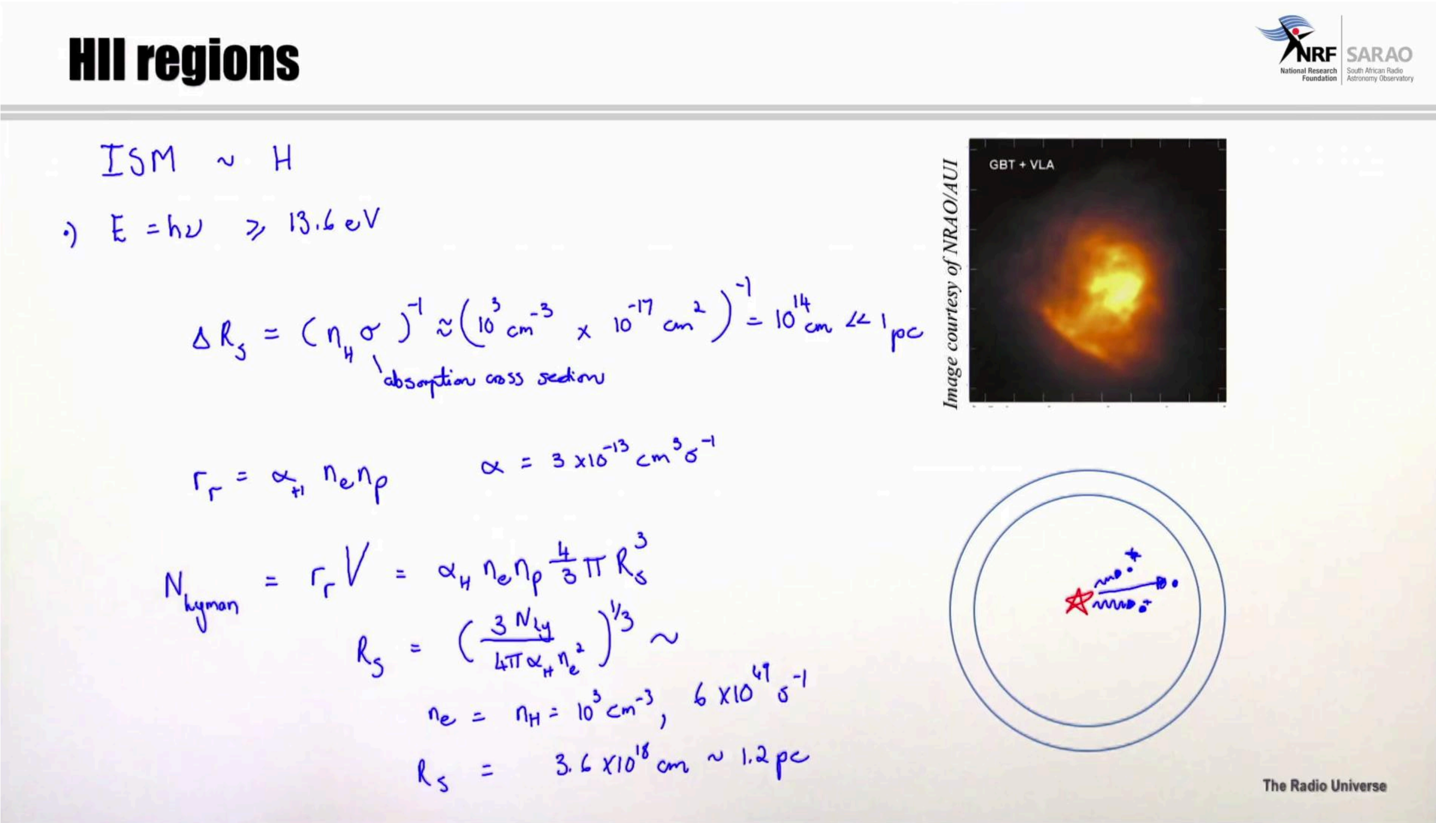


Well, it's proportional to the density of the electrons and the density of the protons and so, therefore, we can say the recombination rate is equal to some constant times this density where this constant is called the recombination coefficient. For a hydrogen atom this has a typical value of around three times ten to the minus 13 cubic centimeters per second. So from this you can work out roughly what the size of this radius of ionized material or this ionized bubble will be if you know how many ionizing photons are coming from the central star. So if you know the rate of production of ionizing photons, these are sometimes called Lyman photons or Lyman continuum photons then you can say that for every Lyman photon produced by the star, a hydrogen atom will be ionized and the star will be stable when all that ionization is equal to the recombination rate in the volume. So you say the recombination rate times the volume of the star. So that is equal to alpha 'H' times the density of the electrons and the protons times the volume of the region which you can then rearrange to solve for the radius of the region.

Notes

Summary

5m 44s

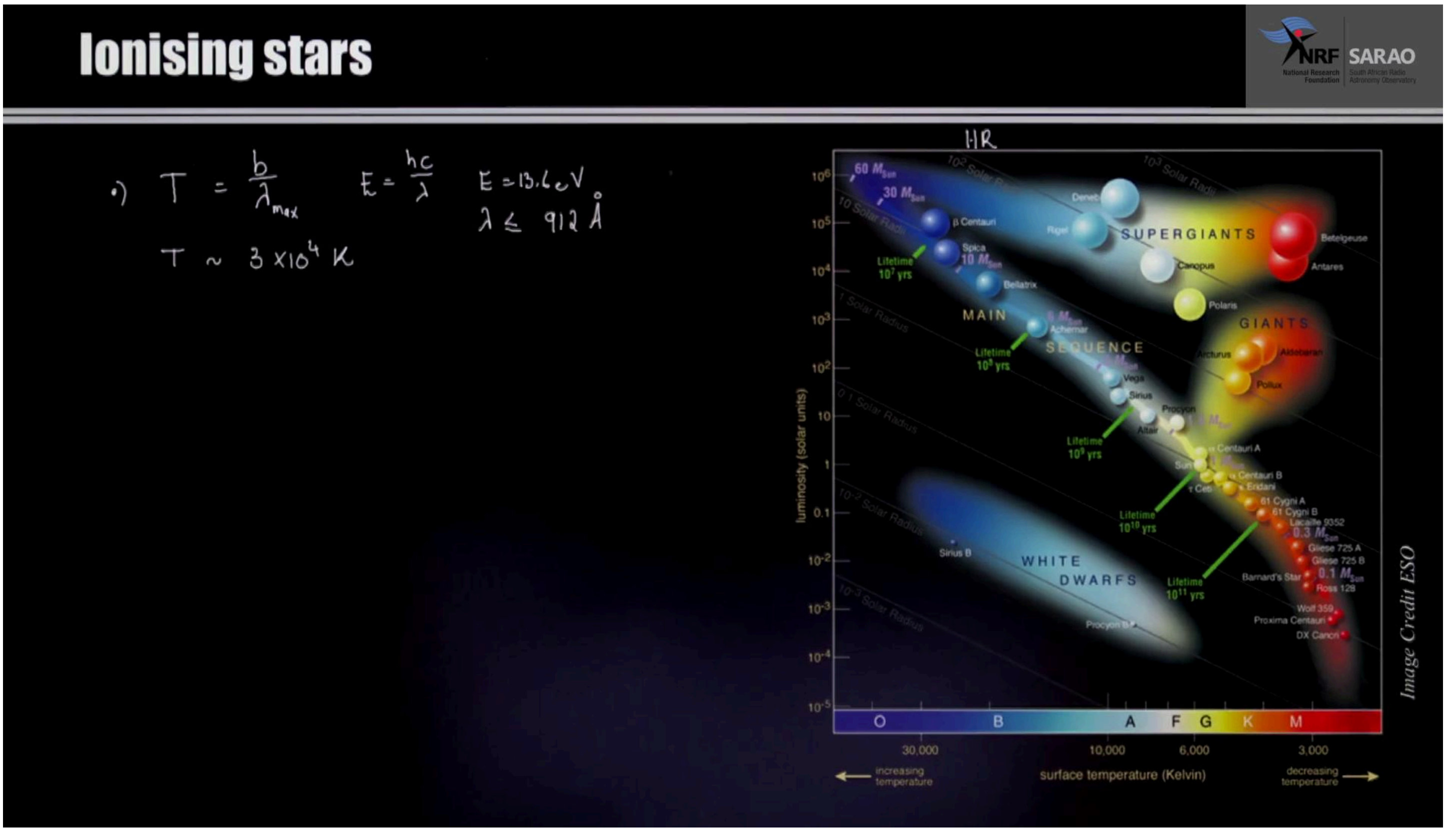


If you solve this equation for a typical density for the interstellar medium of around 'nH' is equal to ten to the three per cubic centimeter, we notice here we've replaced this 'ne' squared then with roughly the density of hydrogen because we can say that the density of electrons will be equal to the density of the protons which is equal to the density of hydrogen. So if we substitute this as being the density of electrons and we say that typically ionizing stars produce around six times ten to the 49 ionizing photons per second then we come up with a typical radius here of around 3.6 times ten to the 18 centimeters which is around 1.2 parsecs which is still very small.

Notes

Summary

7m 27s

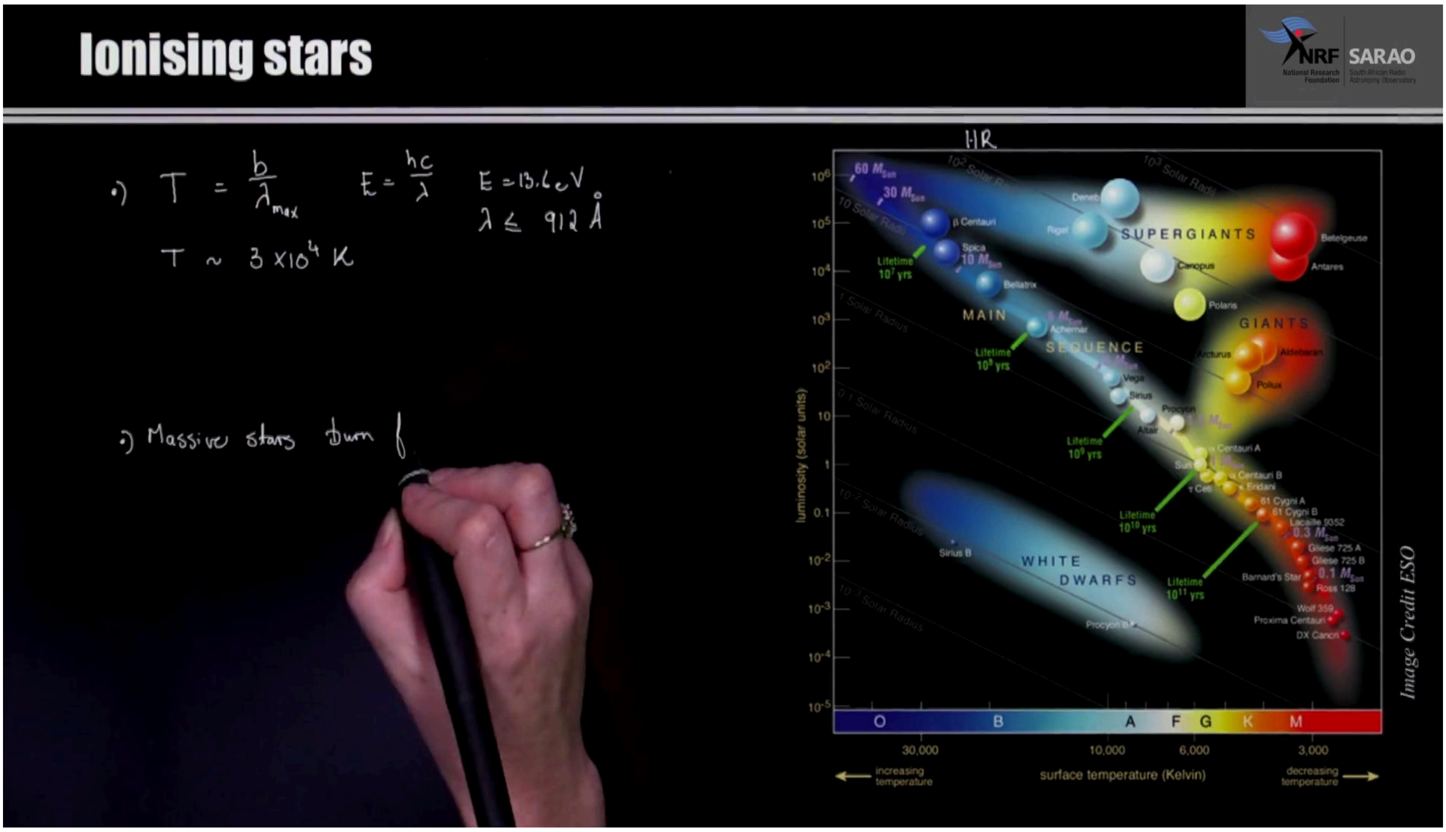


In order to ionize hydrogen we require a very hot star and that's because we have this inverse relationship between temperature and the maximum wavelength of the emission that's produced for a blackbody. You'll remember this from our previous lecture. We also have a relationship between the energy of a photon and its wavelength. So when we say that we require an energy of around 13.6 electron volts what we're actually saying is that we need a photon with a wavelength that's effectively shorter than around 912 angstroms which falls roughly in the UV region of the wavelength space. So in order to have a star that produces most of its emission at a wavelength of around 912 angstroms, we need a temperature of a roughly 30,000 kelvin. Stars have a very tight relationship between their luminosity and their temperature and this plot of stellar luminosity versus temperature has a special name. It's called the Hertzsprung–Russell diagram or the HR diagram. When a star is born where it falls on this diagram where we have this very tight relationship called the main sequence of star formation depends mostly on its mass.

Notes

Summary

8m 33s

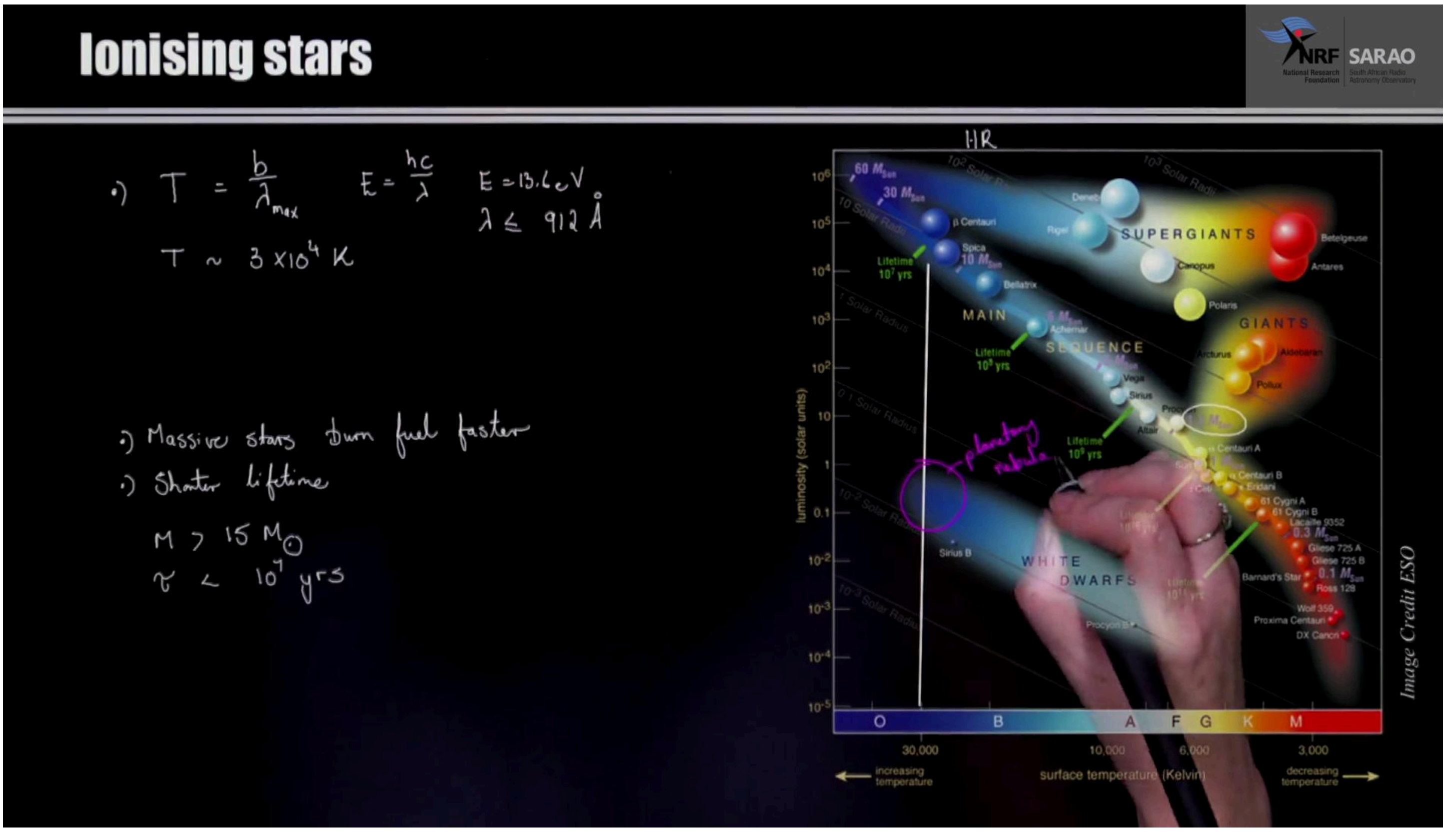


So if you're a very high mass star then you'll have a very high temperature and a very high luminosity and the reason for this is because the pressure is very high in the core of the star and so the nuclear reactions which are burning here proceed at a very high rate and produce a very high thermal energy and, therefore, a lot of large luminosity. And so this relationship is not an accident because you need this very high thermal pressure and this high luminosity and a high mass star in order for it to remain stable against its own gravity and so the main sequence defines the region where the star is able to produce enough energy to remain stable against its own gravity. So if we look here on this diagram what it tells us is the temperature, the luminosity and here we've got marked off the various stellar masses of the stars. So, for example, a 10-solar mass star here has a temperature of around 30,000 kelvin where a 1-solar mass star has a much lower temperature of around 7,000 kelvin. Because the reactions in these very massive stars are proceeding at such high pressures and temperatures they're, therefore, proceeding at a very high rate and that means that very massive stars burn through their fuel at a very high rate.

Notes

Summary

10m 07s

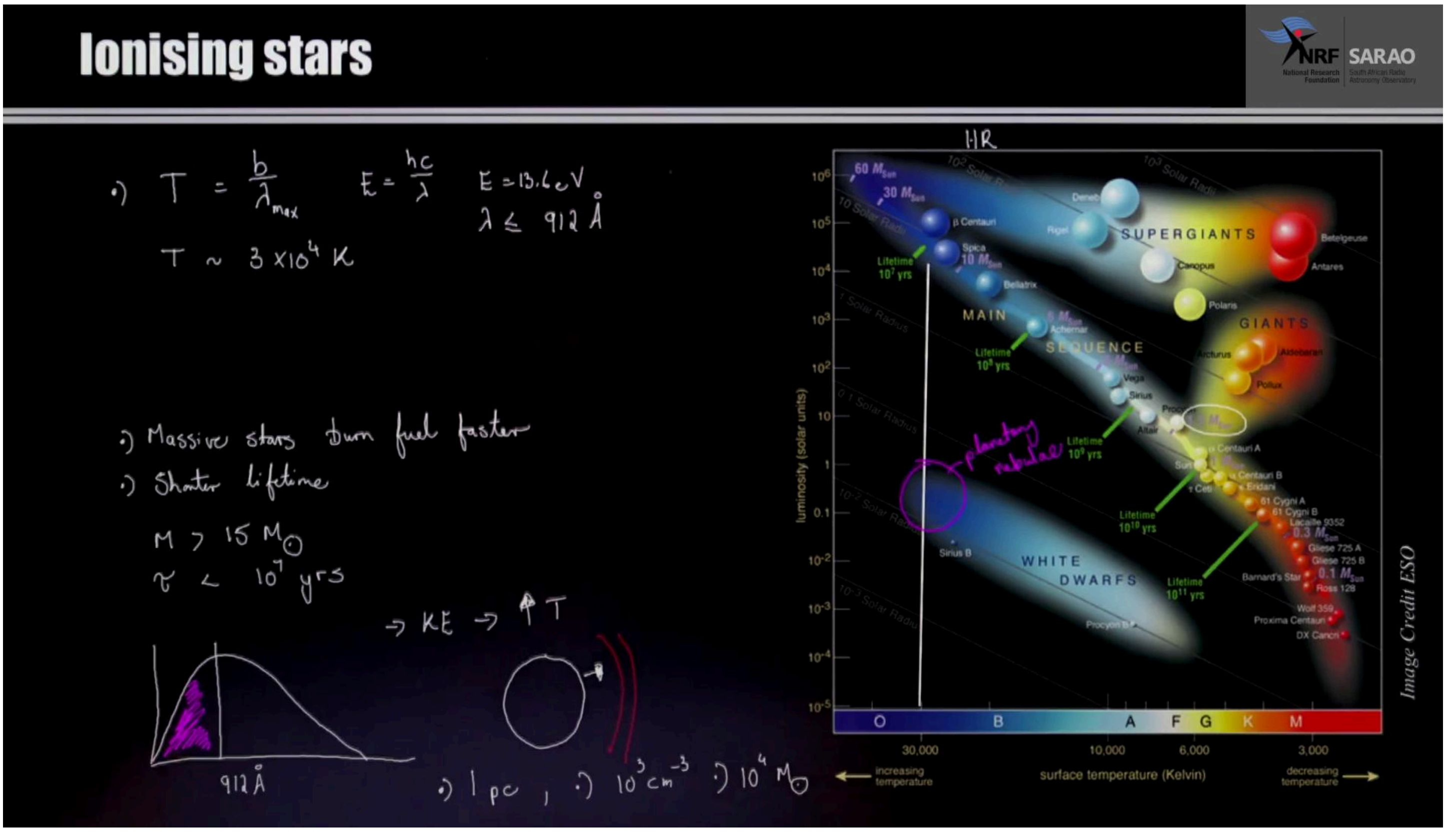


And what that means is that they have a very much shorter lifetime. On this diagram is also marked roughly the expected lifetime of any star so the time it will take to exhaust its fuel considering the rate of reactions that are going on within its core. And so for very massive stars lifetime is only ten million years whereas for a star with roughly the mass of our Sun, the lifetime is more like a billion years. So if we consider that we need a star with a temperature of around 30,000 kelvin what that tells us from this diagram is that we will need a star that has a mass that's greater than roughly 15 times the mass of our Sun and that this star will have a lifetime which is roughly around ten to the seven years. The only other stars on this diagram which reach temperatures that are potentially hot enough to ionize hydrogen are the very top region of the white dwarf part of the plot. Here main sequence stars. Here you have supergiants and giants and here you have the white dwarfs. If you have a white dwarf that's ionizing hydrogen then it's called a planetary nebula and it's not called a necessarily an HII region.

Notes

Summary

11m 36s

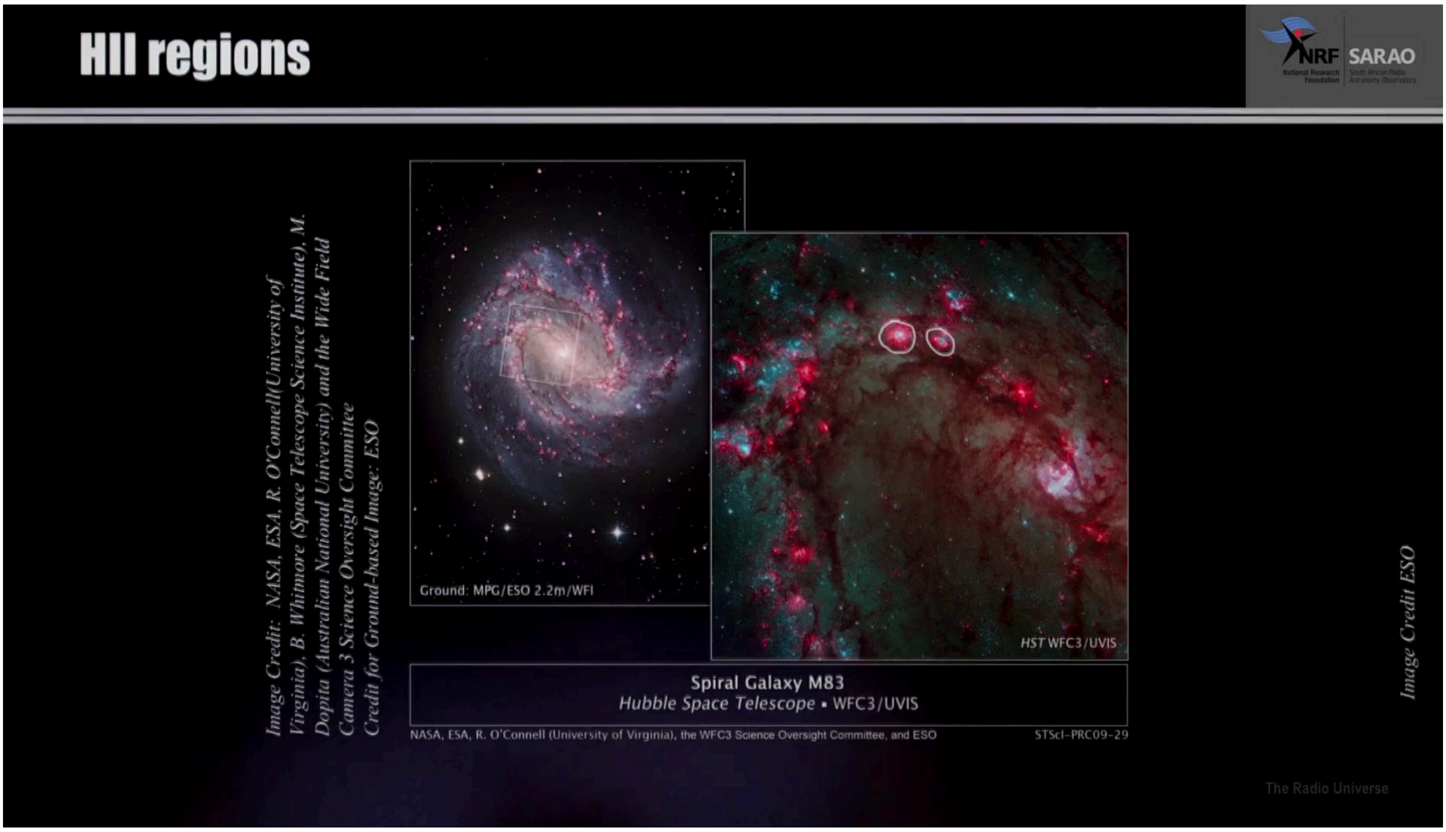


Remember that blackbody emission had a characteristic shape and so now we have a star which is ionizing hydrogen and its peak wavelength is such that most of its emission is produced at around 912 angstroms. But here there will be a large number of photons which have excess energy above the energy required simply to ionize the hydrogen and this excess energy will then be translated into kinetic energy of the hydrogen atoms, I mean, of the electrons and so this will work to increase the temperature of the gas and as that increases the temperature, the gas will then expand. So your HII region will expand and it can expand very rapidly and also cause a shock wave which can cause compression of the nearby gas and also retrigger further rounds of star formation. So the primary characteristic of HII regions is that they're relatively small, they have a size of around one parsec, they have a density of around ten to the three per cubic centimeter and they have a mass of around ten to the four solar masses and they're mostly producing free-free emission in the radio because of the ionized material inside them.

Notes

Summary

13m 01s



Here we have an example that's very familiar to us now where we see all these HII regions in red but this is an optical picture of the HII region and here we've zoomed in even closer so you can see how these very small regions are around very hot very massive ionizing stars.

Notes

Summary

14m 31s