DJORGOVSKI: So now let's talk about the main sequence, which is not the place where stars are mainly sequencing, but that's where most of them are for most of the time. It's just a cartoon version comparing different sizes of stars, M being the coolest ones. There are no stars cooler than that. There are brown dwarfs cooler than that, and there are no stars brighter than so-called O type. And we'll see shortly why.

So, definition of the main sequence is it's the locus, on this HR diagram, where stars burn hydrogen into helium in their core, in the way that we discussed last time. And it turns out, also, that's where they'll spend most of their lifetime. Then, we also now know that it's really a sequence of masses. The lowest mass stars are the coolest, least luminous ones. The highest mass stars are the most luminous, hottest ones.

And it turns out that the mass is, by far, the single most dominant parameter that determines all properties of stars. Chemical composition matters, but not nearly as much. And so, essentially, stars are to good approximation, a one-dimensional family of objects.

I give you 10 to the 34 grams of hydrogen and helium, you're going to get a star, and can predict in great and gory detail exactly is going to happen to it.

Now, the lower end is the cutoff of the brown dwarfs, which we talked before. Stars that are not massive enough to achieve enough temperature and density in the core to ignite hydrogen, although it might burn some deuterium, those objects are brown dwarfs. They just cool off.

And on the high end, there is also a limit, and it's called the Eddington limit. It's due to famous astronomer Eddington, who actually established most of the stellar astrophysics. And it works like this. Well, actually, in a moment.

So, a star will burn hydrogen to helium, and as it does that, it changes very little. Now, there is a certain limit called Chandrasekhar-Schonberg limit. It means that once you turn 10% of your star mass into helium, it tends to evolve all the way.

So massive stars tend to achieve higher densities and pressures in the middle because, as you recall, the probability of thermonuclear reactions is a very strong function of temperature. And some level density, but mostly temperature, because you need high kinetic energies of nuclei to penetrate the Coulomb barrier.

That means that even small changes in core temperature will have a large effect on the thermonuclear energy. So it turns out that luminosities of stars are not proportional to their mass. They're proportional to something that's close to the fourth power of their mass. It's different power in different parts of that sequence, but roughly you have 4.

And because the lifetime is going to be, essentially, amount of fuel divided by luminosity, how fast you burn the fuel, the lifetime and main sequence is going to be a strong function of mass, with the most massive stars lasting at least, typically, a few million years. And the least massive stars can last tens of billions of years.

So, once the burning of hydrogen ends, most stars will expand and become the red giants. And I'll talk about this in a second.

So here are the typical lifetimes on the main sequence. A pretty high mass star, 25 solar masses,-- that's not the highest-- will last only four million years in a main sequence. The Sun will last more like 12 billion years. We're four and a half billion years into that, and so we've got ways to go. And a 1/2 solar mass star will last 700 billion years. So, low-mass stars were there forever, essentially.

If you cut the Sun, and look at the composition, right? You will find out that initially, it was a nice mixture of hydrogen and helium, 75% of hydrogen, 25% of helium. But because it's been burning hydrogen to helium, hydrogen's depleted in the middle. On the other hand, helium is then created. And that contains about 1/3 of the solar radius.

So, mass determines everything. Now, we're talking about luminosity versus log temperature diagram. Because the Stefan-Boltzmann formula, which has three variables in it, radius, temperature, luminosity, 1 equals sine, the radius is then completely defined.

And so, if you look at the theoretical HR diagram, lines of equal radius are diagonal. A star of a given temperature, if it's larger, the radius is going to be more luminous. And the other way around. And so now that mass is determined, star's luminosity, and temperature, and therefore radius, therefore density, everything is determined.

The energy transfer does differ. We talked about this a little bit. And for a really high-mass star, there is a convective core, because it's too opaque for energy to be radiated away through slow photon diffusion. And then, most of the star is radiative. For an intermediate mass star, like the Sun, there is a radiative core, and convective envelope. The opposite. And really low-mass stars, like M dwarfs, are fully convective.

The plasma is too cold, and absorbs photons so efficiently, that the star has to boil, in order to transfer energy out.

So here's the Eddington limit. This is what sets the maximum luminosity a celestial source of any kind can have for its mass. And it applies to stars, as well.

So there is a radiation pressure from the luminosity of the star. Electrons and ions, which are coupled to them electrostatically, absorb photons, and they're pushed outwards. So, stars drive simple stellar wind, that's just pushed by the stellar radiation. The Sun has solar wind. Some stars give much, much higher stellar wind.

Now at the same time, there is gravitational pull to these ions and electrons. So when the two are equal, that gives you a limiting luminosity with your mass. If a star at that mass, meaning at that gravity, is more luminous than this particular limit, that means radiation pressure will prevail. The star will just kind of blow out there and all about.

And so for a given mass, given a gravitational pull, there is a limiting luminosity. It's called Eddington luminosity, and it's given by this formula. It's linearly proportional to mass. And this is of the order of a few 100,000 times the solar luminosity. So we are safe. But it can also invert this, and express Eddington mass for a given luminosity that is given here.

Now remember, luminosity is not linearly proportional to mass, because of non-linearity of nuclear reactions. So on the one hand, you have a 45 degree line, luminosity proportional to mass, that defines the Eddington limit.

On the other hand, you have a very steep, almost 4 power parabola. The mass at which the two lines intersect is the highest mass a star can have. Beyond that, it would just blow its envelope out. It's a self-regulating system in that regard.

There are ways to bypass this a little bit, but by and large, it's a good reasoning. And the most massive stars are roughly 100 solar masses. You never see anything bigger than that.

On the other hand, we have red dwarfs. And let's see, they're fully convective. They're very slow burning. Because they're convective, the magnetic field also bubbles up to the surface more often. And you may remember, in the case of the Sun, it's the emergence of these magnetic fields that are all threaded and looped, that can cause spots and flares and eruptions. Same things happen on these low mass stars, only much more so.

Young red dwarfs, that still have a lot of magnetic field to get rid of, can have solar flares that there are many orders of magnitude. More than the biggest solar flares that we have here now. And what happens after a sufficient number of billions, 100 of billions of years, the thing kind of just slowly cools off, and gets darker and darker. A white dwarf. Or some people call it a black dwarf.

So, for most stars, certainly intermediate mass ones like the Sun, the main sequence lifetime ends when hydrogen in the very center has completely burnt out, and there is helium. Therefore, you cannot burn anymore. Its mass is not hot enough for helium to burn. And a star burns hydrogen in a shell, but around an inert core of helium.

When that happens, the structure of a star changes. It will slowly puff up. Because it puffs up to a sufficiently large radius, the temperature will go down for a given amount of energy production. That means it's red, it's going to be red. And this is how a red giant forms.

So this goes on. The red giant becomes bigger and bigger. More luminous. Core shrinks. At some point, it shrinks enough, so temperature and density are sufficient to ignite helium.