DJORGOVSKI: All right. Let's get on to the continuum radiation. Most of that is thermal radiation, thermal continuum, or blackbody. And this is a traditional plot of what the spectrum of blackbodies looks like. And that refers to radiation field that's in the thermal equilibrium with whatever matter. So it's a completely hypothetical object, except for the early universe, which is a perfect blackbody.

And the laboratory equivalent to it would be an enclosed cavity. It's kept in a fixed temperature with a tiny little hole that doesn't disturb equilibrium too much. And radiation from it will have this spectrum.

This sounds a little idealized, but in reality, actually, a lot of things look like this. And stars have spectra of not perfect blackbodies, but pretty damn close. And certainly, inside stars, which are optically thick, the blackbody radiation applies.

So the quantitative description of this was invented by Max Planck, which was the other step towards quantum mechanics. And he purely empirically came up with the formula that describes the spectrum of blackbodies.

Now, here is the set for temperatures differing by an order of magnitude. And you can notice a couple things. This is a log-log plot. So straight line is a power law. And at the low frequency end, you see there are straight power lines that have slope of minus 2. That's called the Jean part of the spectrum.

Then there is a peak. Then there is a cut off, which is exponential. And in fact, that's what Planck incorporated in his formula. He introduced quantization of energy using this constant that bears his name. And nobody understood why this formula worked until it was explained by Einstein and others. So a few things about blackbody spectrum-- first, the peak, where the maximum is, shifts with temperature. The hotter bodies will have the peak at higher frequencies. Now, it's kind of intuitively clear. And that's called the Wien displacement law. And there is directly near proportion between the two.

For energy, energies much less than this peak energy, of a Boltzmann constant times temperature, then this Rayleigh-Jeans law applies. It's roughly quadratic proportion and directly proportional to temperature.

So this is often used in radio astronomy, even though origin of the radio waves may not be thermal at all, you can still, from their intensity, ask, what's the equivalent temperature to which this would correspond? It's called a brightness temperature.

Another important part about blackbody radiation is to compute its energy density or total luminosity of an object. It turns out that energy density inside a black body cavity, or star filled with hot gas, is proportional to the fourth power of temperature. And if you let the size go, then of course, the emergent flux will be then also proportional to the fourth power of temperature. And the constant of proportionality is called the Stefan-Boltzmann constant. And it's called Stefan-Boltzmann formula.

So the luminosity for a given black body will be proportional to the fourth power of temperature. But also the bigger surface area more light go at. And so it has to be proportional to square of the radius. And so luminosity is to a really good approximation given by a formula like this. It goes as the square of the radius, fourth power temperature. Aside from 4 pi, that's spheric geometry, the Stefan-Boltzmann constant, which has this value.

Now, you can measure the luminosity of anything, regardless of whether it's powered by thermal radiation or not. And then you can just ask if this were blackbody, what would be its temperature to give me this much luminosity?

And so regardless of what the actual shape of the spectrum is, we define effective temperature as what would be the temperature of blackbody that emits the same kind of luminosity? And for sun, this is close to 6,000 degrees Kelvin.

And the peak of that is in the yellowish part of the spectrum. And our eyes are most sensitive during the daytime to those frequencies. Isn't that amazing how evolution works? So if we lived on a planet around the red dwarf star, we would probably be having eyes that are sensitive to near infrared.

Well, blackbodies do happen, actually. And the very best one known, better than any laboratory measurement, is the cosmic microwave background, which is thermal relic of the big bank. You can think of the whole universe as a cavity which is in thermal equilibrium. And the temperature of that radiation is 2.73 degrees Kelvin. And there are no known deviations from it. It's really remarkable.

OK. There are other kinds of continuum mechanisms. The one that's really important in astronomy is called synchrotron emission. You probably know from EM that if an electron moves in magnetic field, it's at some angle relative to its vector of motion. There will be a Lorentz force. That means the electron will be accelerated. If it's accelerated, that means it is going to radiate. And exactly how depends on the speed. At low speeds, it will just keep going in circles. And it's called synchrotron emission.

As you increase the speed, approach the speed of light, it starts moving like a helix like this. And it shines light in a cone, which gets lighter and tighter the closer you are close to the speed of light. And that's called synchrotron emission. And essentially, it's like you have cosmic accelerator.

Now, spectra of synchrotron emission tend to be parallel, for the most part. There is cut off at both high and low end. But parallel is very different from blackbody spectrum. And so here, on a log-log plot of spectral emissivity versus frequency, you can see a typical parallel, which would be slope of minus 1, is relative to the blackbody spectra.

So if you can imagine them at the peak of blackbody, then there is excess both at low frequencies and at high frequencies. And this is how we find quasars, by and large, because their spectra are not thermal. They are often close to the power spectrum. So stars don't have spectra like this. But strange things like active galactic nuclei do.

And this is what they look like. These are images-- well, the top image is in radio waves at 5 gigahertz with VLA. This is a famous radio galaxy, Cygnus A. You see there is a little core, which is the central engine. And there is jets of electrons that have been accelerated close to the speed of light. And then plasma dissipates--makes these big blobs of plasma that shine in synchrotron light. So that's what sources look like in radio.

The bottom one is the jet of M87, a giant elliptical galaxy in Virgo cluster. And this is visible light picture. Synchrotron transmission is not confined to radio. It can be x-rays or gamma rays or visible light, as well the radio.

Another favorite object is the Crab Nebula. You've probably seen the picture on the right. That's invisible light. This is a supernova remnant-- filaments of exploded star. If you look in radio, you see something very similar, but this is not thermal emission. This is emission from electrons moving in magnetic field that is confined to the supernova remnant.

And the final source of continuum emission, which is also thermal of sorts, but not blackbody, is so-called thermal bremsstrahlung, which is a German word that means "breaking radiation." And for some reason, people still use the German word.

It's simply you have a plasma. There's electrons and positive ions. Electron scattering off of positive ion will be accelerated. That means it's going to radiate. The higher the temperature, the more these things will happen because of the square of the density. So it is essentially due to thermal motions inside this fully ionized plasma, but it's not the blackbody itself. But it's a continuum.

And the typical places where we can see such things are, say, clusters of galaxies, which are filled with this hot gas and temperatures of millions or 10s of millions of degrees Kelvin, so the shining x-rays.