Remote Sensing: Principles and Applications
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Lecture-03
Basic Laws of RS

Hello everyone, welcome to today's lecture in the course Remote sensing principles and applications. In this lecture, we will be talking about the basic laws in remote sensing which helps us to define the various energy quantities.

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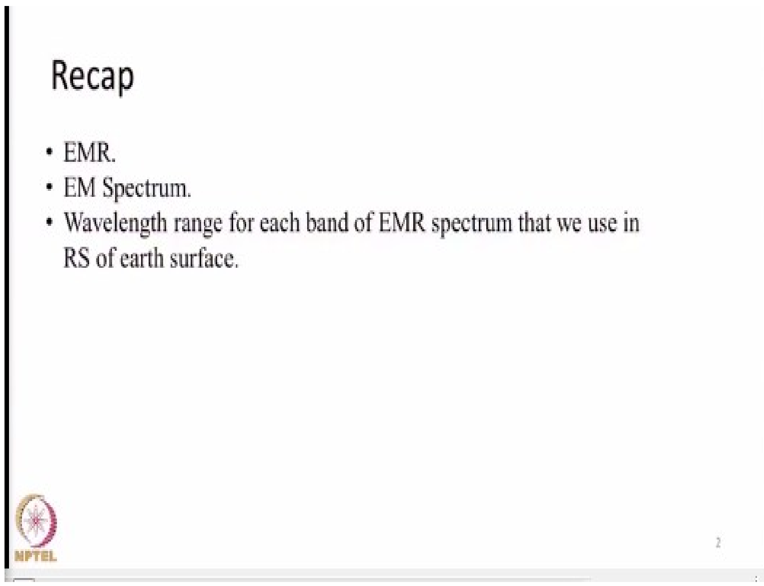

Just as a quick recap, in the last class we have discussed about what electromagnetic radiation is, how to characterize the wavelength frequency of these electromagnetic radiation. Then what electromagnetic spectrum is, then what are the classification of electromagnetic spectrum. All these topics we covered in the last class. This class we will be continuing ahead with how electromagnetic radiation is being generated in nature and how we are going to use it for remote sensing purposes.

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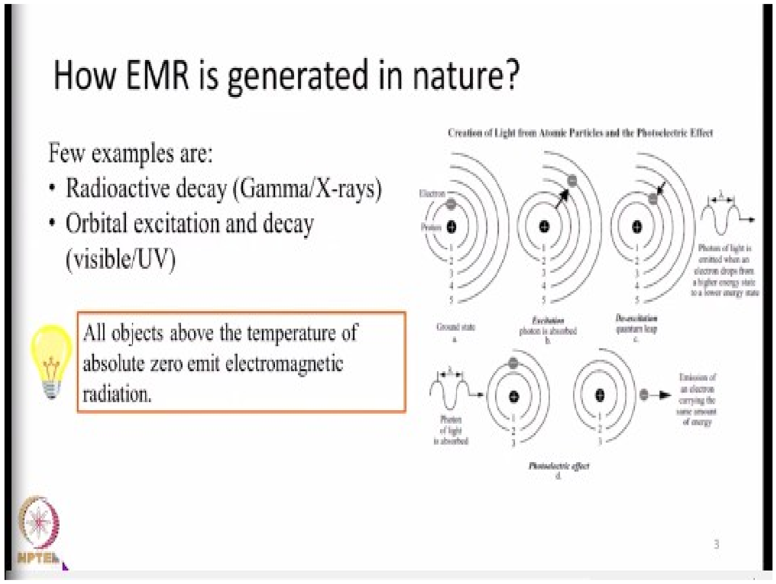

So, how electromagnetic radiation is produced in nature? In nature, EMR is produced by various processes and mechanisms. Say for example, when we switch on a bulb inside our living room, we are converting electrical energy into light energy. So, a light energy is nothing but electromagnetic radiation. We go to take X rays, so there the X ray technician will switch on the X ray machine which will generate X ray radiation and it will be irradiated on our body for getting an X ray image. So, X ray is nothing but electromagnetic radiation. So, these are simple processes that we observe in our everyday life which produces electromagnetic radiation. In addition to these, all the natural objects surrounding us, including our own body emits electromagnetic radiation continuously, because of the internal temperature we have or the internal energy we possess. So, electromagnetic radiation is naturally being produced by all objects.

And this is what we are going to use for our remote sensing needs. Say for example, sun, by virtue of its energy content and temperature emits EMR, which reaches the earth surface and drives various processes on the earth surface. Similarly earth also has its own internal energy and temperature, which helps the earth surface to emit electromagnetic radiation. So, are there any means to quantify the amount of radiation emitted by an object?

Yes, there are a few basic laws which helps us to quantify the radiation emitted by any object at a given temperature T.

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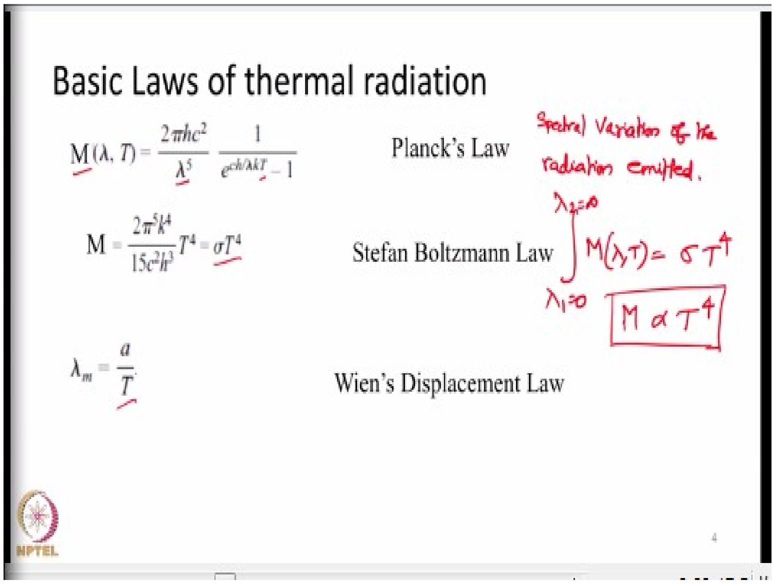

Those 3 basic laws are the Planck's law, Stefan Boltzmann law and the Wien's displacement law or Wien's law in a simpler sense. What are these law? First we will start by looking at the Planck's law. So, the Planck's law tells us, if an object is at a given temperature T, then the particular object will emit certain amount of radiation in a particular wavelength. That is Planck's law will tell us the spectral variation of radiation emitted by an object.

That is in the last class I told you when most of the natural objects emits electromagnetic radiation, it will not emit in a single particular wavelength, it will emit energy with a mix of wavelengths. So, the amount of energy emitted by an object will vary with respect to wavelength. And Planck's law will help us to estimate that amount of energy emitted by an object at a given wavelength.

Then, if we want to know the total amount of radiation emitted by the object, then Stefan Boltzmann law will help us. Stefan Boltzmann law is nothing but the integration of Planck's law over the entire range of electromagnetic spectrum. That is Planck's law will give us the spectral variation of emitted energy. If we integrate that particular equation over the entire range of wavelengths known to us that is between 0 to infinity, we will get the total radiant flux density coming out from the object. So, if we integrate Planck's law between the limits of 0 to infinity, we get Stefan Boltzmann law. And Stefan Boltzmann law suggest that the total radiant flux density of an object is proportional to the 4th power of temperature. That is as the object's temperature increases, the amount of energy emitted by an object will also increase correspondingly.

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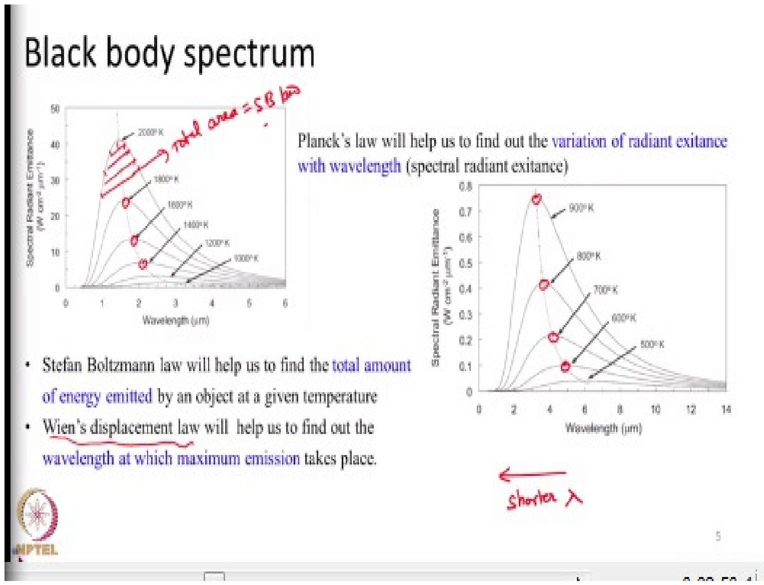

So, first we will see this with few example plots. In this particular slide we have two graphs, each telling us what is the amount of electromagnetic radiation emitted by different objects at various temperatures. If we look at this particular figure, here we have objects temperature ranging from 1000 Kelvin to 2000 Kelvin. You can see, as the temperature increases the amount of energy emitted by an object increases correspondingly as given by Stefan Boltzmann law. And also these curves do not intersect, that is as the object temperature increases at any given wavelength the amount of energy emitted by an object will be increasing. So, these curves normally will not intersect, they will be lying one above the other. As object temperature increases at all given wavelengths the energy emitted will increase, that is one thing. And one more thing you can notice in this particular plot is each and every point here is estimated using Planck's law. That this Planck's law will tell us if an object is 2000 Kelvin or given wavelength say 1 micrometer, what will be the energy emitted? at 2 micrometer what will be the energy emitted? So, each point on this curve can be estimated using Planck's law.

And then using Stefan Boltzmann law, we can calculate what is the total amount of energy emitted, that is the total area contained within this curve. So, the total area will be given by

Stefan Boltzmann law. Then again if you observe these figures, we can know that for each curve there is one particular wavelength at which the peak emission occurs. So, here what I am marking in red circles is the particular wavelength at which peak emission occurs for each and every object at various temperatures.

So, this characteristic wavelength at which peak emission occurs is given by Wien's displacement law or Wien's law. So, Wien's displacement law will help us to find out the wavelength at which maximum emission takes place. And one more important observation we have to do is, as the object's temperature increases, this particular wavelength at which the peak emission occurs moves continuously towards the shorter side or shorter wavelengths, we can see.

So, as the object temperature increases, the wavelength at which the peak emission occurs will be moving continuously towards shorter wavelengths. So, the few important observations I am just summarizing it again. For objects at two different temperatures, if you plot these Planck's equation as like graphs, then those 2 curves will not intersect with each other. That is for any given wavelength, the amount of energy emitted by an object at a higher temperature will always be higher than the energy emitted by object at lower temperature.

These curves will not intersect, then the total area contained within this curve will increase when the object's temperature increase. Then there is a particular characteristic wavelength at which peak emission occurs. As the object temperature increases, this characteristic wavelength will shift towards shorter side or shorter side of wavelength. So, this is the major observations we have to do with respect to these laws.

And here in this slide I have given the basic equations for the three laws. So, the first one is the equation for Planck's law,

$$M(\lambda, T) = \frac{2\pi h c^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

second one is the equation for Stefan Boltzmann law,

$$M = \sigma T^4$$

and third one is the Wien's displacement law,

$$\lambda_m = \frac{a}{T}$$

So, λ_m is the wavelength corresponding to the peak radiation coming up from an object is given by a/T. From the three laws, we are able to find out what is the energy emitted by an object?

That is spectral variation of energy, what is the total amount of energy and what is the wavelength at which the maximum radiation is emitted. Is there a way to find out the energy emitted corresponding to that particular peak wavelength? Please pause the video for a few seconds and think over it. That is how to find the maximum amount of radiation emitted by an object corresponding to the peak wavelength of emission, please pause the video for a few seconds and think over it.

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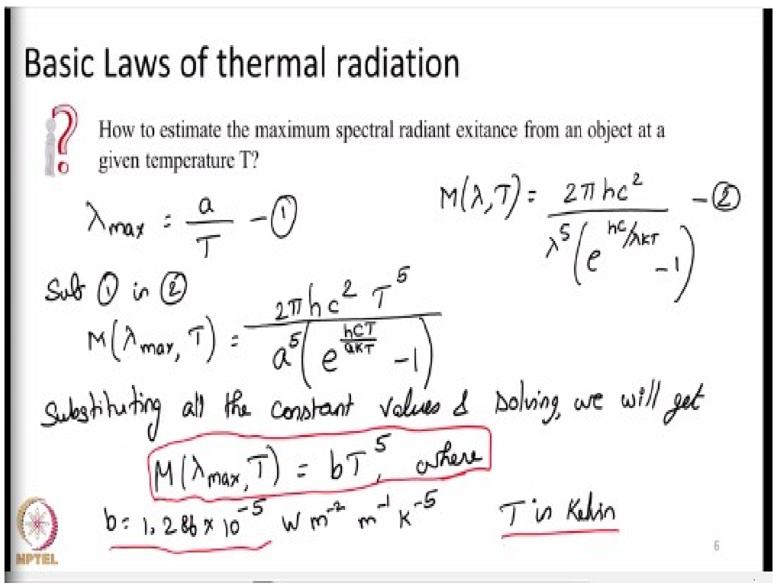

The solution to this particular question is given in this slide. You have to substitute Wien displacement law in Planck's law. That is Wien's displacement law will give us the wavelength at which peak emission occurs. So, if we can substitute this law into Planck's law and solve the equation, we will get the energy emitted by an object at the wavelength of peak emission. That is at λmax, what is the amount of energy emitted by an object.

So, this equation also will take form very similar to Stefan Boltzmann's law here. That is the M corresponding to λmax for an object at a given temperature T = b T^5 where b is another constant, the units are given here and T to be substituted in Kelvin. Before we proceed further, I just wanted to ensure that few things are kept in mind regarding these laws.

First thing is the units with which we get the output from this law and in which units we should provide inputs. That is the major thing regarding units and then the value of constants. We should be really careful about the units and constants, when we work with these three laws in order to get accurate results.

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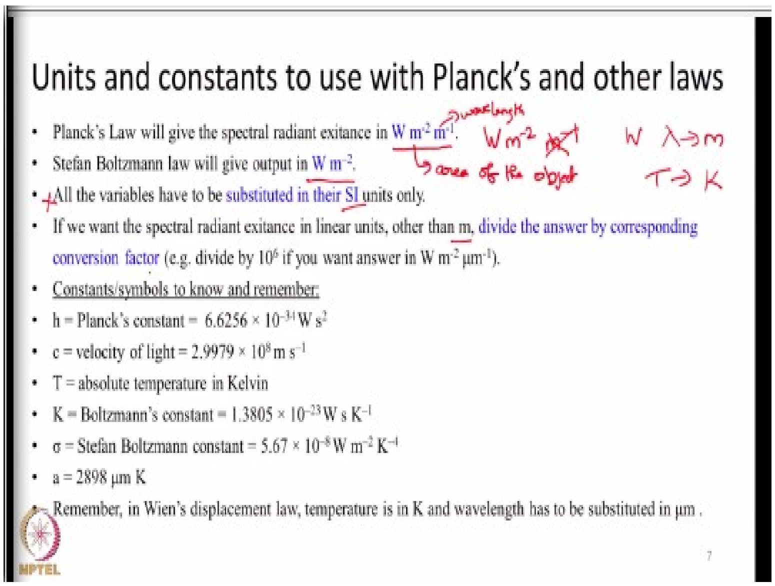

First thing to notice, the Planck's law will give the spectral radiant exitance with the unit of watt/m^2/m of wavelength. Like when we just look at this unit, it may look a little odd to us, that is it reads watt/m^2/m. So, cannot we cancel them together? No, it is not. It is the amount of energy or the power emitted by an object, that is what is the unit for power per m^2 area of object per meter wavelength.

So, this meter corresponds to wavelength, this meter corresponds to per unit area of the object and W is the unit for power we know it is watt. So, this is the power emitted by unit area of object per unit wavelength that is given by Planck's law. Stefan Boltzmann law, we are integrating everything with respect to wavelength from 0 to infinity. So, this third meter square will go off, so we will get the units in watt/m^2.

The total power emitted by an object per unit meter square area. So, these are the units of outputs from Planck's law and Stefan Boltzmann law. And one more thing we have to note carefully is all the variables that we substitute in these 2 equations must be in their SI units. That is wavelength should be substituted in units of meters, temperature should be substituted in the unit of Kelvin and so on.

So, everything in this particular equation has to be done in their SI units only. So, normally in the last lecture when I introduce you to electromagnetic radiation, I said, for remote sensing purposes we will not use meter to denote wavelength, instead we will be using nanometers, micrometers or even centimeters for microwave and so on. But when we substitute those values in these equations, we must substitute in units of meters for us to get accurate results.

Then if we want to calculate the spectral radiant exitance in linear units other than meters, we have to divide the answer by corresponding conversion factor. That is by normal convention we will be interested to calculate, what is the power emitted by an object per unit micrometer wavelength or per unit centimeter of wavelength rather than a meter of wavelength. If we want to calculate that, we have to divide the output from Planck's law by the corresponding units.

That is, if you want to convert Planck's into watt/m^2/micrometer of wavelength, we have to divide the output from Planck's law by 10^6 because 1 micrometer = 10^{-6} meters, so this conversion factor we have to use. So, these are some important things we have to remember about using this laws. Then some of the important constant values that we often use in this particular course are given here.

And I have again repeatedly said everything with units, and T absolute temperature given everything mentioned. Just remember one thing, only in Wien's displacement law this particular constant has been calculated with units of micrometers. So, the output from Wien's displacement law will directly be in micrometers, just by mere definition of this constant with unit of micrometer, the output from Wien's displacement law also will be micrometer.

But anyway we can convert them between various units based on our needs. We know the conversion factor, how to convert between micrometer, nanometers, centimeter, meter? All these conversion factors well known to us, so we can convert.

The next topic to be understood is, what are the source of EMR available for us to do remote sensing? So, remote sensing can basically be carried out either in active manner or passive manner, what is active manner? Active manner means, I have a sensor which absorbs radiation but that sensor itself has the capacity to produce EMR, and it will send that EMR towards the object of interest and will get the signal back.

So, the sensor itself will produce the EMR send it towards the object, receive it back and store it. So, such sort of sensors which can produce EMR as well as receive EMR, we call them as active sensors. A very simple example we use in our everyday life is a camera with a flash attached to it. So, if we switch on the flash and take a picture, what happens, the camera itself produce white light which travels towards the object falls on the object and gets reflected back and get stored in the camera itself, so camera is a very good example for active sensor.

Similarly in remote sensing also we can produce the intended electromagnetic radiation with a given wavelength or a frequency and use it for remote sensing purposes. On the other hand a sensor can merely observe the radiation coming in from the earth surface. Either the radiation can be coming in from the sun or directly emitted by Earth. Such sensors which merely absorbs the radiation coming in from an object are known as passive sensors.

So, passive sensors a good example from our everyday life is a camera with the flash switched off. So, without flash means the camera has to rely on the energy from the surroundings either the lights we use or sun's radiation. So, remote sensing can be carried out both in active way and passive way. In active way, the sensor itself will have the capacity to produce EMR, send it towards the target and receive it back. Whereas in passive mode, the sensor has to rely on external sources of energy, so what are these external sources of energy for passive mode of remote sensing?

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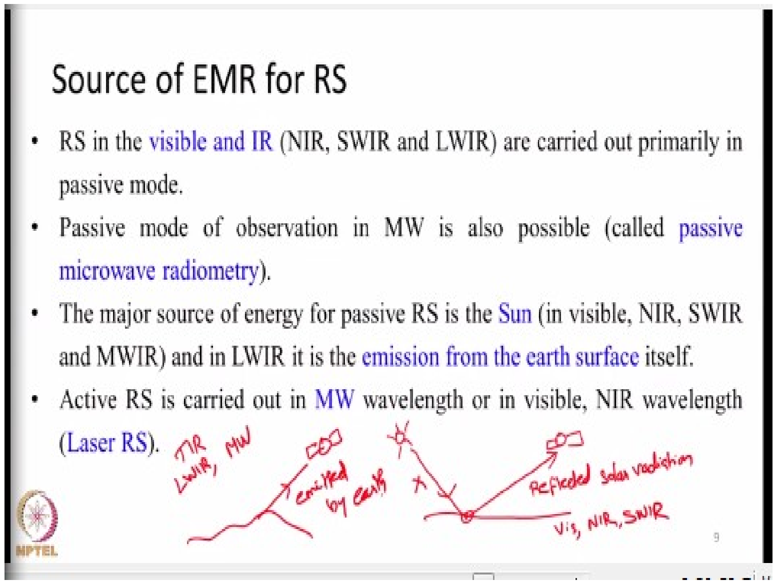

So, in passive mode of remote sensing, the external source of energy is primarily the radiation coming in from the sun. So, when we do remote sensing in the visible, NIR, SWIR and to some extent MWIR domain, the energy that we receive or we sense using passive sensor are essentially coming in from the sun.

Sun provides us the energy required to do remote sensing. On the other hand if we perform remote sensing of earth surface in the long wave infrared portion or if we do passive remote sensing in the microwave portion, then such energy levels are naturally emitted by earth surface features itself and not coming in from the sun. So, sun and earth are essentially the primary source of electromagnetic radiation for passive mode of remote sensing.

And in the shorter wavelengths, that is visible, NIR and SWIR wavelengths, the primary energy source is sun. In longer wavelengths, such as microwaves or thermal infrared that is long wave infrared, the primary source of energy is earth itself. In active mode we do active remote sensing, in visible as well as microwave domain. That is in visible we produce laser lights and do laser remote sensing similarly we do microwave remote sensing using active microwave sensors. So, what do we study in passive remote sensing basically? First we will talk about passive remote sensing then we move to active. In passive, especially in shorter wavelengths of visible, NIR and SWIR wavelengths, what we observe is the amount of solar radiation reflected by the object of interest.

See this is like the object of our interest, some land surface here, there is sun, we have our sensor here. So, solar radiation will be coming in, this will interact with the object of interest and a portion of it will be reflected back. So, the sensor will essentially see the reflected solar radiation, so this is true primarily in the visible, NIR and SWIR bands. On the other hand in TIR or to be more precise in the LWIR bands and microwave bands also, sun's incoming radiation is almost 0. So, whatever is observed by remote sensing sensor is primarily emitted by earth surface. So, in shorter wavelengths, we are observing the reflection nature of a object, how much the object is reflecting? In longer wavelengths, in LWIR and microwave domains, we are naturally observing what is the emitted radiation from earth surface features itself. So, this is the source we use for our natural remote sensing purposes.

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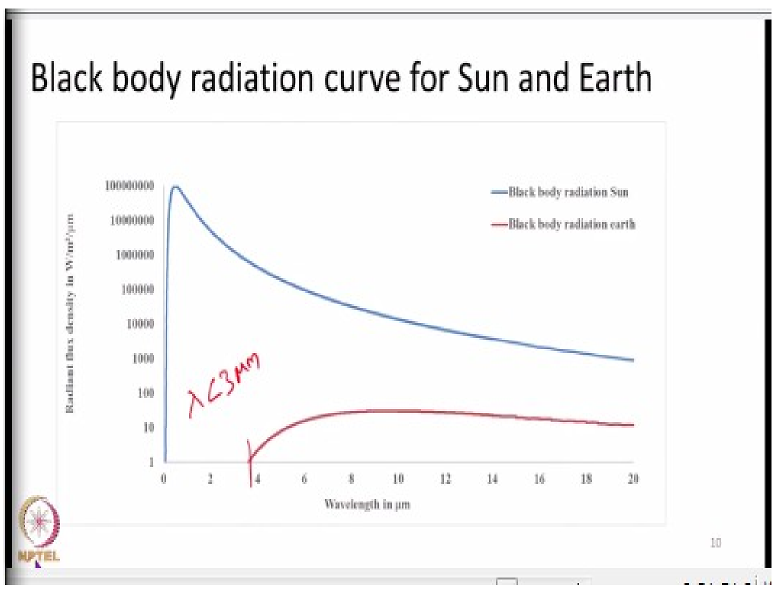

So, this is just to drive home the point, this is the blackbody radiation curve for sun and earth. The blue line is for sun and the brown line is for earth, we can see sun is a very good source of energy, especially in shorter wavelengths. That is why in SWIR bands, in wavelength less than 3 micrometers basically, whatever we sense in passive remote sensing is primarily driven by sun's energy whereas in longer wavelengths earth's emission also takes place and whatever we observe is primarily from Earth.

So, this is for like an ideal blackbody whatever curve is given here, in later classes we will see what blackbody is and how much solar radiation will deviate from this curves. All these things we will see later but just to give you information that in shorter wavelengths, sun's incoming radiation is much higher. So, we are primarily sensing reflected solar radiation whereas in longer wavelengths we are primarily sensing earth emitted radiation.

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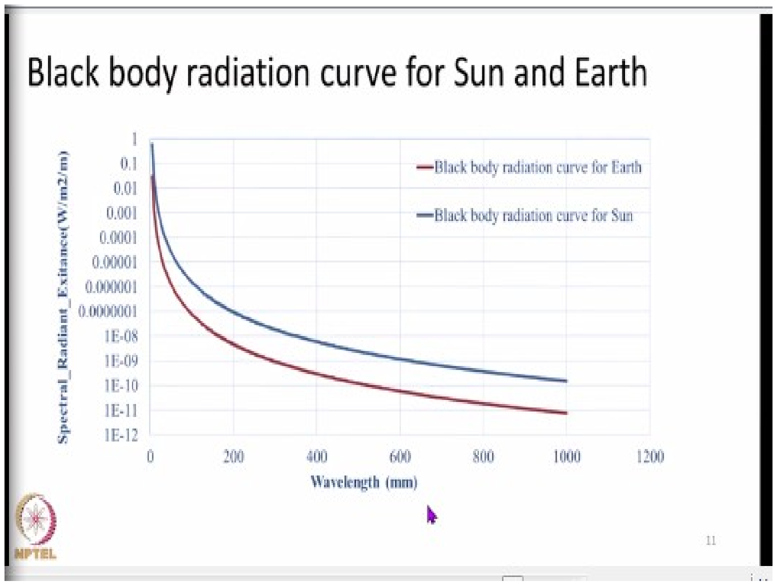

So, this is again gives you the emitted energy by sun and earth at longer wavelengths, that is here by X axis is in millimeters, it goes all the way up to 1000 millimeters. So, this is just the Planck's law plotted for different variation for temperature corresponding to sun and earth. Like roughly we assume sun to be at a temperature of 5800 Kelvin and earth we assume to be at a temperature of 300 Kelvin and I plotted these curves, just to give you some information about what is the amount of radiation coming in from this objects?

So, just to summarize what we have learnt in today's lecture? We have learnt the basic laws which helps us to calculate the amount of radiation emitted by an object. And how to use them for calculating the amount of radiation emitted at a given wavelength, the total amount of radiation and also to calculate the wavelength at which peak emission occurs. Then we also saw the primary source of energy we use for our remote sensing purposes. So, with this we stop this lecture, thank you.