Introduction to Atmosphere and Space Science
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Lecture – 01
An Introduction to Earth's Atmosphere Source of Energy – The Sun

Hello; so, in this module we will try to understand the basic introductory aspects of Earth's atmosphere. So, this module is the Introduction to Earth's Atmosphere. In this module we will try to understand few very important aspects of the sun. The importance of Sun is that it is the primary source of energy for the sun and earth system.

So, in today's lecture we will try to understand or we will try to address few a very important questions like for example, what is the source of energy for the earth's system if you consider earth and its atmosphere as a single entity as a system? we have to understand what is the source of energy which drives this system. In how many ways sun and earth are coupled in that means; in how many different ways, in how many different forms the earth receives its energy from the sun.

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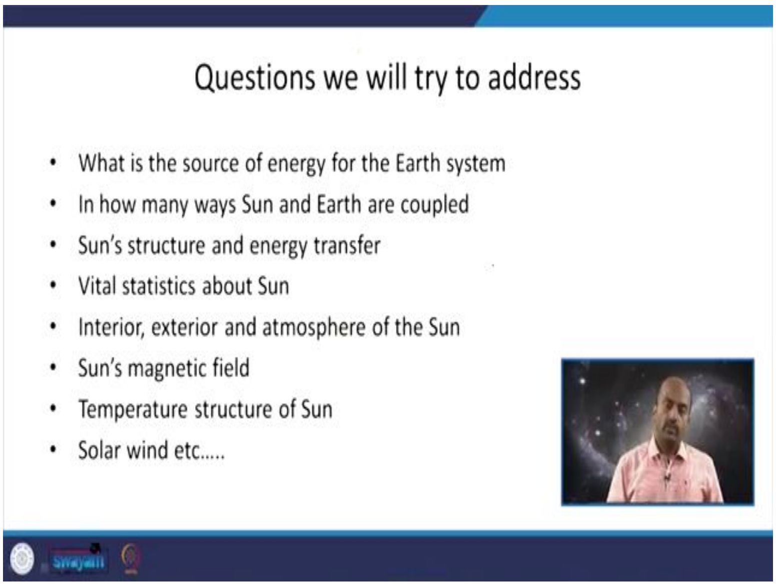

We will try to understand suns structure and various means of energy transfer that happen inside the sun as well as outside the sun. Few vital statistics about the sun, few vital very important numbers parameters which will define the size of the sun for example, a few important aspects about the interior, exterior and the atmosphere of the sun.

So, these three different parts have different means of energy transfer working in those regions, we will try to see how they are different and what is it that what is the physical process which is dominant in these regions. We will try to understand the structure and the shape of the sun's magnetic field, the temperature of the sun or the temperature structure of the sun, solar wind, etcetera few important aspects about the solar wind.

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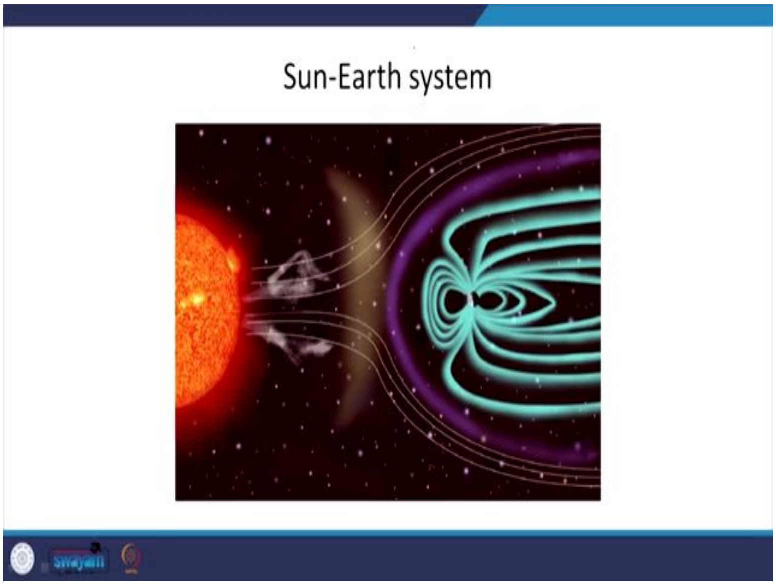

So, like we see Sun is the star which is providing energy for the earth, earth is a part of the solar system. So, all the physical, chemical and dynamical processes in the atmosphere of the earth are driven by the energy that is emitted from the sun. So, as a whole we consider this as the Sun-Earth system. So, we will try to see how what are the important aspects about this sun earth system.

When we talk about the energy, now it is beyond any doubt that the only source of energy that we have is the sun, our star. Now, if when we talk about the energy is better to have a number, let us say how much want of energy do the earth receive from the sun.

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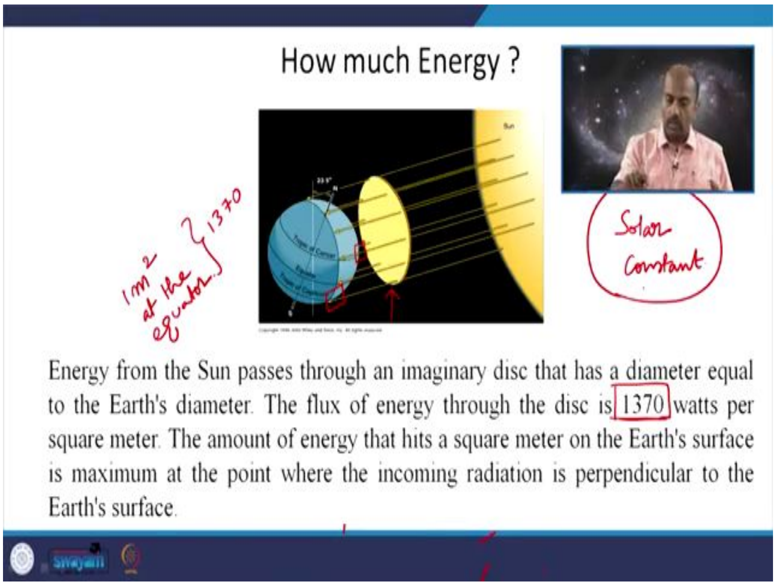

So, for this arriving at this number we need to have an approximation let us say, the approximation is that let us have an imaginary disc of diameter equivalent to the diameter of the earth which is kept at a distance of 1 astronomical unit let us say. Now, if we calculate the if we calculate or measure the amount of energy that reaches this disc or that is incident on this disc per unit surface area per unit second will be a quantity, which is called as the solar constant. So, what has been done is energy from the sun passes through an imaginary disc that has a diameter equal to the earth's diameter. The flux of energy through this disc is nearly 1370 watt per square meter.

So, the amount of energy that reaches onto this disc is 1370 Joules per second per meter square. So, this is the amount of energy that we are talking about. So, this energy comes on to the earth's surface and will initiate all the physical and chemical processes. Now the amount of energy or the magnitude of energy is 1370. So, you always remember this number 1370 is a very important number.

So, now if the disc is; so, now, if you draw a projection of this disc's area onto the curved surface, it is very evident that what you can notice is that the amount of energy the maximum amount of energy is at the equator. That means, in 1 meter square of area receives at the equator, at the equator receives the maximum amount of energy this that is, 1 meter square of area at the equator receives 1370 watts of energy.

This same 1370 is projected onto a larger surface area over the poles; that means, equator receives maximum amount of energy and the poles receive comparatively smaller amount of energy, compared to the equator. So, this constant is generally called as the solar constant.

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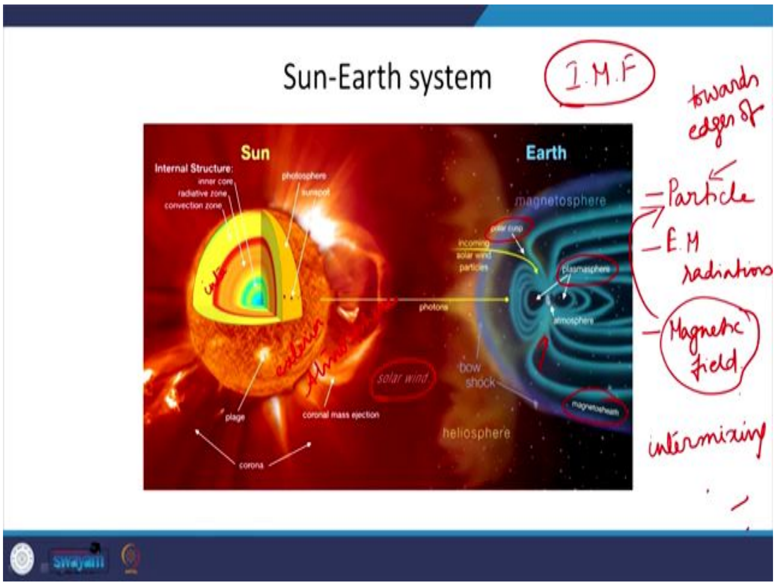

Then so, now, we see the sun in sun earth system in its full details what you see here is that sun has various regions inside it, few regions on the surface and few regions on the atmosphere. So, you have the interior here, which is the interior here, you have the exterior and you have the atmosphere.

What else do you see here? You see the sun in all its full size then you have what you call as solar wind, then earth is pictured here and then you have the magnetosphere of the earth which is kind of compressed to the side of the sun and which is kind of elongated to the anti-sun what direction. So, this complete system and various parts of this system are included into what we call as the Sun-Earth system.

So, in time we will probably try to understand or we will address a few very important aspects of these small topics let us say polar, plasma sphere, solar wind. So, from here what you can see is that sun emits energy in mainly in two different forms one as particle form, another as electromagnetic radiation.

So, what I mean to say is that earth receives energy in terms of electromagnetic radiation or in terms of particles. So, these particles are highly energetic particles, they have a lot of energy and then the third most important form of energy is the is the magnet magnetic field.

So, the particle form of energy that is emitted by the sun has a very important characteristic where in, the magnetic field is coupled with the particles or it is generally called as the intermixing of particles with the magnetic field. So, in a nutshell what we can say is that Sun and Earth are coupled by three different ways; they are coupled by the particle energy, they are coupled by the electromagnetic form of energy and they are coupled with the magnetic field.

Sun has a magnetic field and this magnetic field pervades the entire solar system; that means, this magnetic field is generally called as the interplanetary magnetic field. The interplanetary magnetic field extends from the starting from the sun towards the edges of the solar system edges of solar system. So, the sun earth system has three different forms of energies particle energy, electromagnetic energy and magnetic field.

So, now we will try to understand each and every aspect of this energy, if this energy makes entry into the earth's atmosphere, what could be the consequences. Let us say what are the what are the conditions in which particle form of energy makes entry into the atmosphere, what are the conditions in which electromagnetic radiation makes entry, such as.

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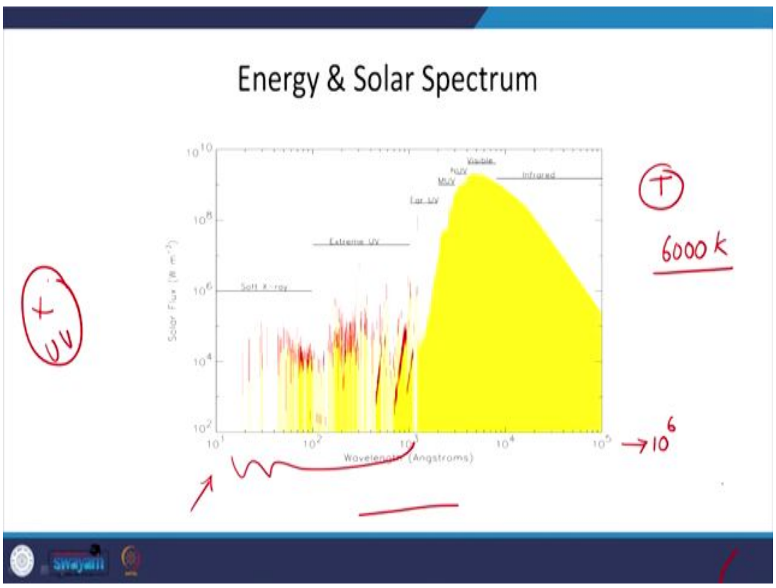

Ok; now, to begin with electromagnetic energy is the most dominant or the majority of energy that is emitted from the Sun. If you look at the electromagnetic spectrum the energy of the sun emitted in the electromagnetic spectrum, we can see that it spans over a wide range of wavelengths. It spans almost from 0.01 nanometers, all the way to 10 to the power of 5 or 10 to the power of 6 nanometers.

So, what we have on the x axis is wavelength in angstroms actually; so, this is 10 to the power of 5, 10 to the power 6 nanometers have what I have written here. And, on the y axis we have solar flux, this is the amount of energy that is contained in particular wavelength or in a particular wavelength bin.

So, this energy can be classified into different regions; let us say to begin with soft X-rays, extreme ultraviolet, far ultraviolet, middle ultraviolet, near ultraviolet, visible, infrared, far infrared, soft X-rays. So, on the x axis smaller the wavelength higher is the energy so, that is why we generally say that the soft X-rays are the most energetic radiations. So, they contain more amount of energy and infrared radiation is the least amount of energy that is coming from the sun.

So, this is the general solar spectrum or electromagnetic wave spectrum. So, the spectrum or the shape of the spectrum is a characteristic of the temperature of the blackbody or the temperature of the object which is emitting this particular spectrum. So, this so, this spectrum is valid as long as the temperature remains nearly 6000 Kelvin. So, 6000 Kelvin is the approximate temperature of the sun; so, that is why this spectrum looks like this, ok. We will talk more about these aspects in the coming slides.

So, the entire spectrum let us say the entire spectrum is of course, is entering into the atmosphere of the earth. But, most importantly the spectrum in the ultraviolet ranges is very important for causing all the physical and chemical processes or for initiating all the physical and chemical processes in the atmosphere. So, this part is generally the X-rays and the ultraviolet; so, X-rays and UV, these two energy ranges are very important for the atmosphere of the earth.

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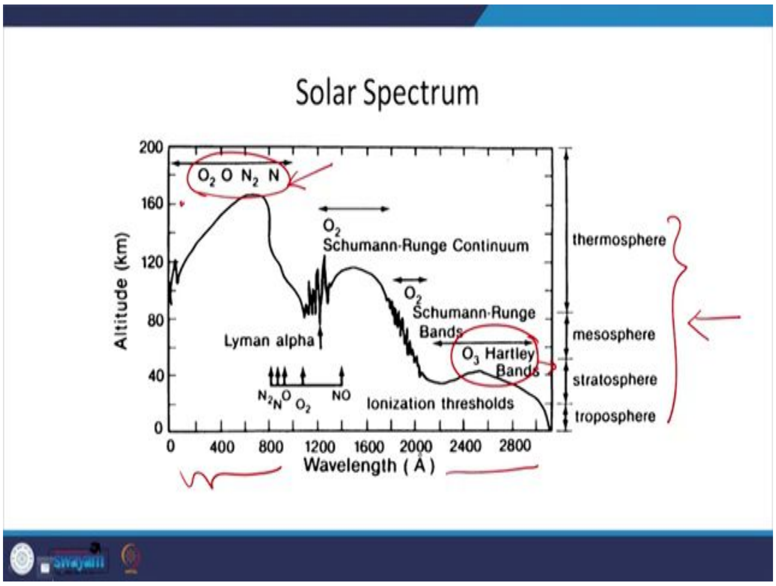

So, if you just take a zoom in what you see on the x axis is the wavelength in the in the angstroms. So, 0 to let us say 3000 angstroms and on the y axis you have the altitude, what it means is that. So, the incoming solar radiation get in this wavelength range gets absorbed at these altitudes. So, this curve that you see indicates the altitude of the absorptions, and on the y-axis you on the here you have the major chemical species, these are the major chemical species which will try to absorb this incoming solar radiation.

So, from the basic understanding we already know the major chemical species that is present in the atmosphere of the earth is the oxygen and nitrogen. So, on the on the y2 axis you have the respective region or the layer of the atmosphere. So, what you can understand from this figure is that different parts of the solar spectrum get absorbed by different species and at different heights or different altitudes.

Let us say for example, the most energetic parts, let us say these (indicated in referred slide), are absorbed at an altitude of 160 kilometers or 200 kilometers and if you see this energetic radiation are generally absorbed by ozone which is very well known to exist in the stratosphere. So, what I mean to say is our existing understanding is well supported by the solar spectrum absorption at different altitudes.

Now, what does this radiation do when it when it travels into the atmosphere. So, radiation has the very peculiar property, it has photons each photon has an amount of energy a fixed amount of energy, this amount of energy is spent only when it sees an equivalent amount of energy in terms of an excitation.

So, different parts of the solar radiation let us say, we have seen X-rays, ultraviolet, visible, infrared, far infrared so many things. So, different parts of the solar radiation will have different roles to play or different kind of physical processes or chemical processes to initiate in the atmosphere. For example, if you consider the X-rays. X-rays have the most amount of energy they have they are very energetic. So, they can ionize atoms and molecules; that means, any known atom or molecule, if you take its ionization potential or dissociation potential what you can see that X-rays have that high energy to be able to ionize any atom or dissociate any molecule.

So, and all the known species will mainly be able to absorb the X-rays; that means, X rays are absorbed or by almost all gases.

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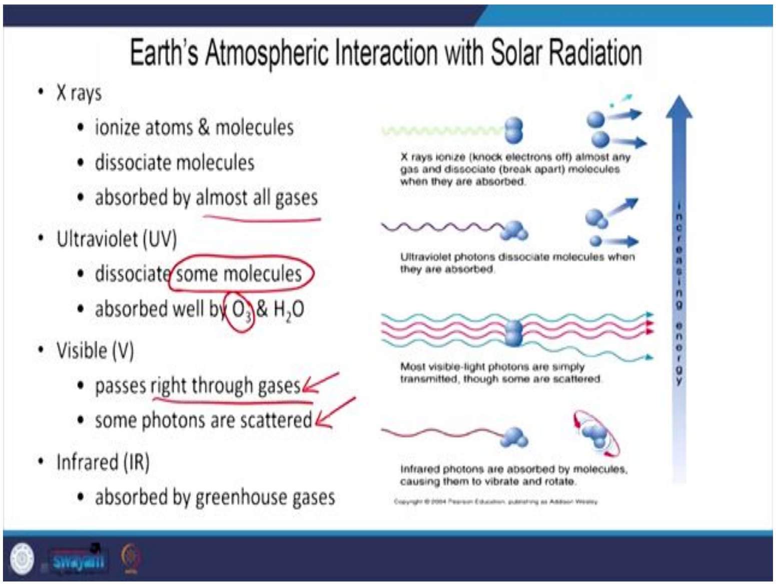

So, these are the most energetic, X rays are the most energetic ultraviolet radiation are of course, energetic, but not as energetic as the X rays. So, they will not be able to dissociate all atoms or molecule all molecules as such they will be ultraviolet will be able to dissociate some molecules. So, some molecules can only be dissociated by the ultraviolet radiation.

So, one very famous molecule that we are very interested or we are very well very much familiar is the ozone. So, ozone is well absorbed or ozone is a very good absorber for ultraviolet radiation. So, the reaction is initiated for the formation of ozone by ultraviolet radiation. So, then you have the visible radiation, visible radiation is least energetic I mean it has very amount very little amount of energy that is left inside.

So, they would not be absorbed by any gas as such, they will pass right through the gas; that means, the entire atmosphere is transparent for the visible radiation so, it will not be absorbed by any. But of course, some photons are scattered here the infrared of infrared of course, is really the least energetic part of the solar spectrum. So, hardly anything will absorb the infrared photons.

So, now from the previous slides we have been able to understand at least one very important aspect that we want to remember for the rest of our life is that sun is the only source of energy for all the physical, chemical and dynamical processes in the earth's atmosphere.

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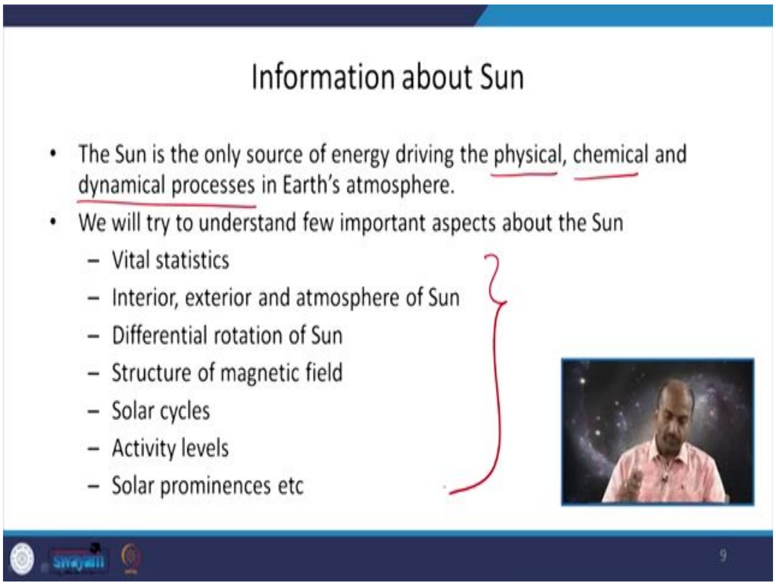

So, you always remember, you have the physical process, you have the chemical process and you have the dynamical processes. All these processes are primarily driven by the sun, there are secondary drivers which may initiate these processes, but these secondary processes are also driven by the sun.

Now, at this point it is very important although not directly connected that we understand various aspects about the sun itself. What is sun? How does it look like? Why does it look like the way it does? What is inside the sun? What are the various temperature scales that exist inside the sun?

Let us say and does the sun emit the same amount of radiation throughout from eternity to eternity will it keep on emitting the same amount of radiation; will it change over a period of time; does the sun have any cycles just like any other star any other main sequence star; does the sun has any amount of magnetic field, how does the magnetic field look like; does the sun rotate if it rotates will it rotate uniformly from the equator to the pole if it is not rotating like that are there any consequences of that; is there any connection between the rotation of the sun and the magnetic field of the sun, things like that, ok.

So, we will try to understand few important aspects. So, these are the various aspects that I want you to understand at the end of this let us say probably this the couple of lectures that will follow from here, ok.

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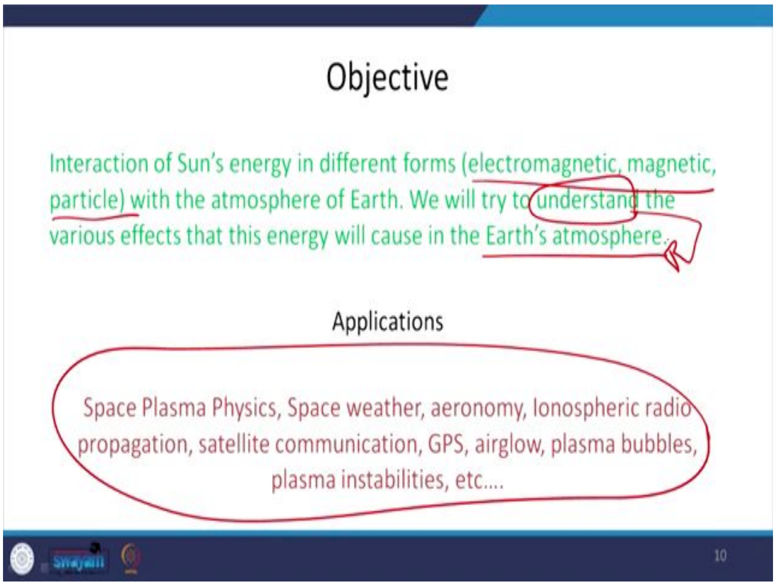

Now, the main objective is that the interaction of Sun's energy in different forms, electromagnetic, magnetic and particle with atmosphere the earth we have seen that. We will try to understand the various effects of this energy influx into the atmosphere. So, the or main objective is to understand how does the earth's atmosphere respond to these different forms of energies. It is very good I mean, and there is energy which is coming and if it is coming what is it doing, we will try to understand that, ok.

So, it has a this particular aspect or this particular understanding this understanding itself, this understanding itself leads to a very diverse areas of research or areas of technology or applications as such. So, this will many different aspects of science and technology, originate or make use of this understanding. For example, the space plasma physics or space whether or aeronomy ionospheric radio propagation, plasma, instabilities, satellite communication, GPS, airglow, plasma bubbles, plasma instabilities etcetera. So, what I mean to say is that all these various aspects of science and technology are very much dependent on the understanding of this sun and its energy on the earth earth's atmosphere. So, this all these areas make potential use of the understanding; let us see how these two things are coupled in between.

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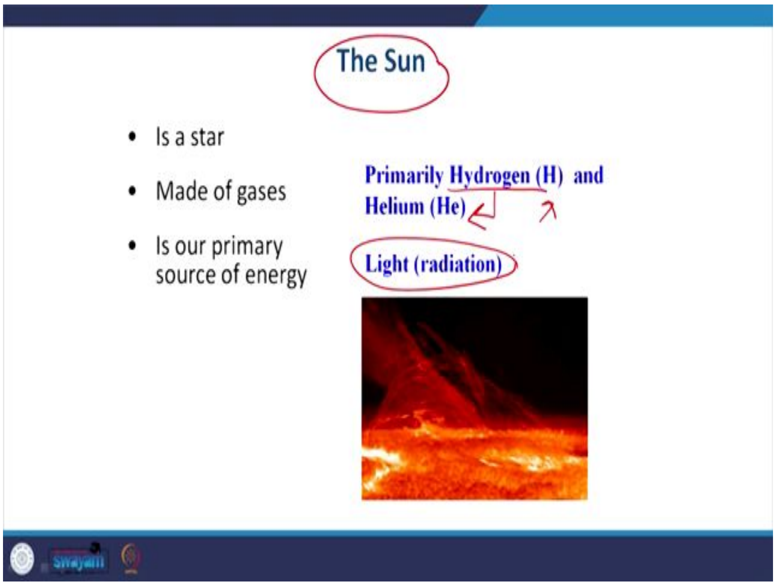

Now, let us look at few very important aspects of this sun itself ok, sun. So, what is sun? Sun is. What is sun? Sun is a star; what type of star we will see. So, sun is primarily a star, the only star in our solar system. Sun is made up of gases primarily hydrogen and helium. Hydrogen is fused to form helium; you will you will keep seeing sun as long as there is hydrogen left inside the sun to be able to fuse to form helium. And, sun is the primary source of energy for us for Earth and of this energy light or the electromagnetic radiation is the main source of main form of energy.

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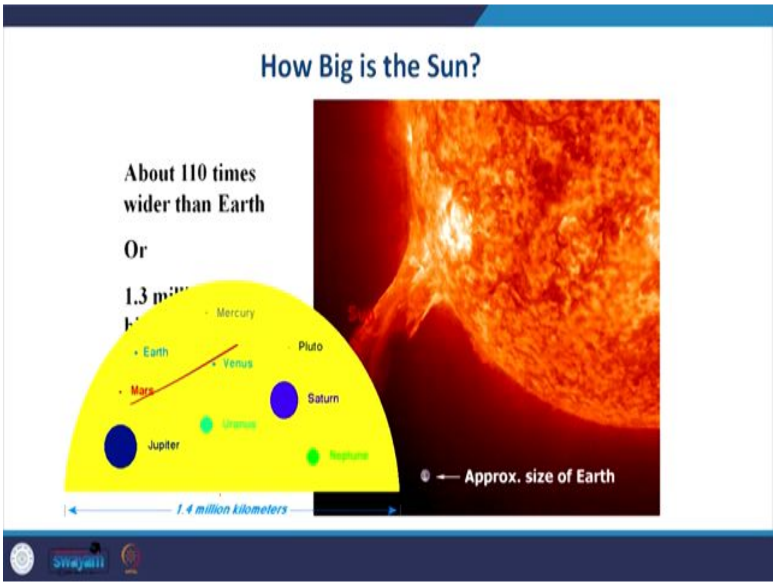

So, how big is the sun, let us say for example for size comparison? Sun is about nearly 100 times the size of the earth and you put it in the length scale the diameter of the sun is nearly 110 times the diameter of the earth or it is 1.3 million times bigger than the earth. So, if you compute the volume then you take a ratio you will get 1.3 millions and if you put it for comparison so, sun is by far this largest object in our solar system and 98 percent of the solar mass of the solar system is just the sun. So, the diameter of the sun is nearly 1.4 million kilometers, the density is a different thing, but the size of the sun is to this dimension. So, for this comparison earth is a very small object in the solar system.

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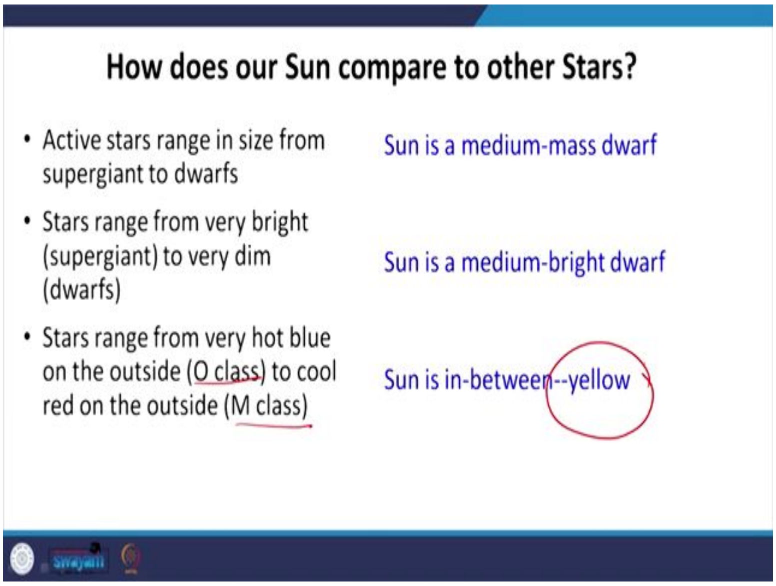

So, sun is a star of course, so, what kind of star is it or how does it compare to other stars. So, generally active stars range in sizes from supergiant to drafts. So, in that way sun is a medium mass dwarf in terms of size, it is a medium mass dwarfs and stars range from very bright for example, super giants to very dim dwarfs.

So, in that way sun is a medium bright dwarf and in terms of let us say temperature or the color, stars range from very hot blue on the outside which are generally called as the O class stars, to cool red on the outside which are M class stars. So, sun falls in between let us say sun is a in between yellow. So, you see sun in yellow color right, we know that.

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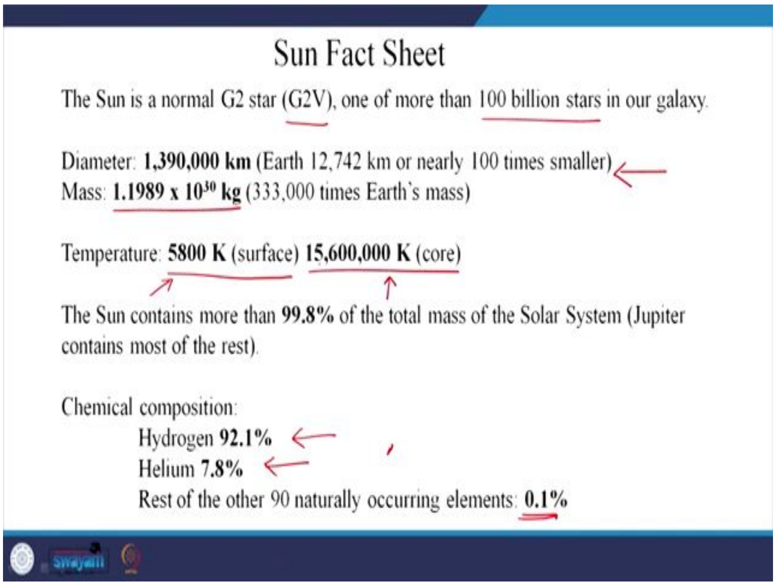

So, let us see some quick facts about the sun. So, sun is this G2 star the spectral classification of sun is G2V which is one of more than nearly 100 billion stars in our galaxy. The diameter of the sun is like we see is nearly 110 kilo meter 110 times the diameter of the Earth. Mass of Sun is a this is a very important number, you always remember this number this comes handy in many calculations that we do.

So, mass of sun is nearly 1.2 10 to the power of 30 k g which is nearly 3,33,000 times the mass of the earth. The temperature of the sun at the surface is 3000 5,800 Kelvin and temperature at the core is nearly 15.6 million Kelvin.

Sun contains more than 99.8 percent of the mass of the solar system and the rest of the solar system including every all there all the planets, all the debris, all the asteroids everything comes together in the 0.2 percent of the mass of the solar system. And, the primary chemical composition is hydrogen which is 92.1 percent, helium which is 7.8 percent and the rest of 19 other naturally occurring elements constitute nearly 0.1 percent of the mass of the sun.

So, one very important aspect that you should always remember is the temperature on the surface the bright yellow disc that you see in the sky is existing at the 5800 Kelvin temperature. The temperature of the core which we will never see nobody will never see is at a temperature of 15.6 million Kelvin, ok.

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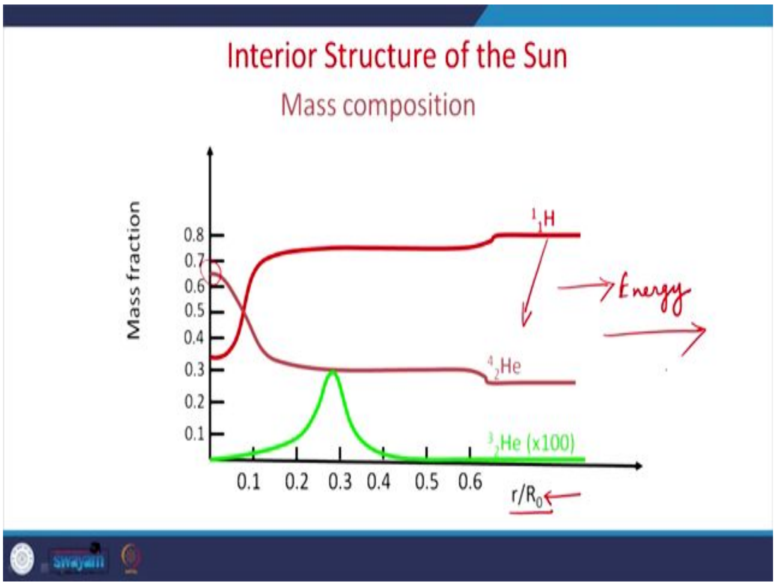

Now, if you look at the interior structure of the sun, it looks something like this. So, on the x axis what you have is r by R naught; R naught is the radius of the sun. So, this fraction indicates or this fraction starts from the center which is 0 to 0 to 1 0.9 or 1 which is the surface of the sun.

So, what you see from this figure is that the temp the mass fraction let us say. So, all these the primary chemical compositions hydrogen, helium and helium-3 these three will vary in a in a quite interesting way. Let us say for example, at the core you have hydrogen and as you move away from the core the hydrogen concentration starts increasing and it starts increasing, it goes increasing.

What you interestingly at this at the core you see maximum amount of helium or the hydrogen; that means, hydrogen has fused to form helium at the core. So, you see helium at the core and this concentration decreases as you travel away from the core; that means, that you have maximum amount of helium existing at the core and maximum amount of hydrogen existing everywhere else. So, ultimately you have hydrogen fusing to form helium is what drives the sun.

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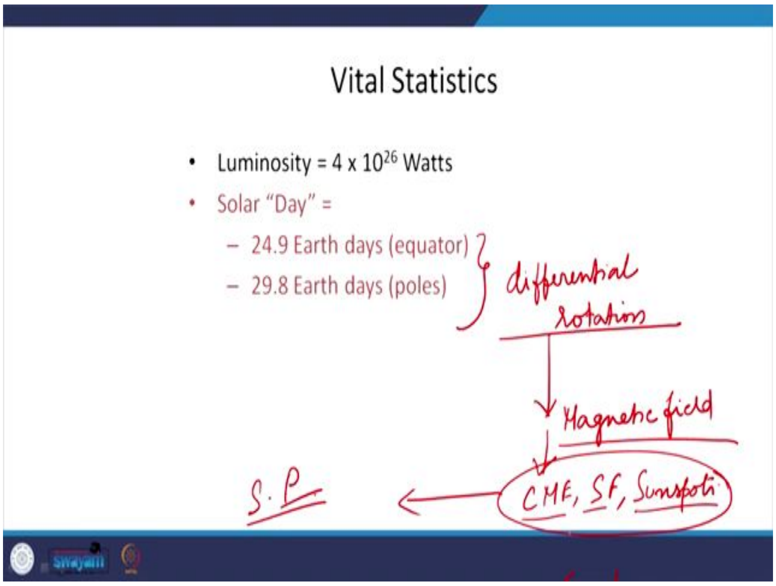

A few very important statistics the luminosity of the sun is 10 to the power of 26 Watts and solar day just like the earth as it revolves around itself. Sun has different types of rotations it will be complicated; we will not discuss about all those different types of rotation; one very important rotation is that it rotates around itself just like the earth.

The interesting aspect about this rotation is that this rotation is not uniform across the latitudes. Sun revolves faster at the equator and slower at the poles. So, as a result of this aspect of different rotation speeds at different latitudes is generally called as differential rotation. This differential rotation is a very important aspect, this differential rotation is what complicates the magnetic field of the sun.

Of course, this is a discussion for the future let us say the magnetic field of the sun is complicated by this differential rotation and ultimately this different differential rotation is what generates the coronal mass ejections or solar flares or sunspots all other aspects of sun which are generally called as these. These are called as solar prominences solar prominences.

So, the differential rotation complicates the suns magnetic field as a result of this complication we get to see the coronal mass ejections, solar flares, sunspots. These aspects, all these aspects are generally called as the solar prominences. We will try to At the end of let us say probably this module, we will try to understand the important aspects about these solar prominences.

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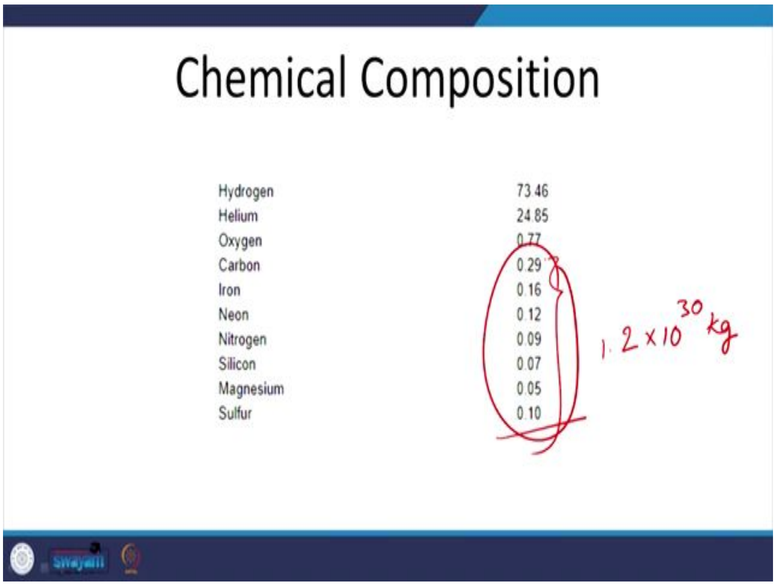

And the chemical composition. So, rest aside these are the minor chemical species also have some amount of mass and when you calculate over a fraction of 1.2 10 to the power 30 kg these small fractions are not so small.

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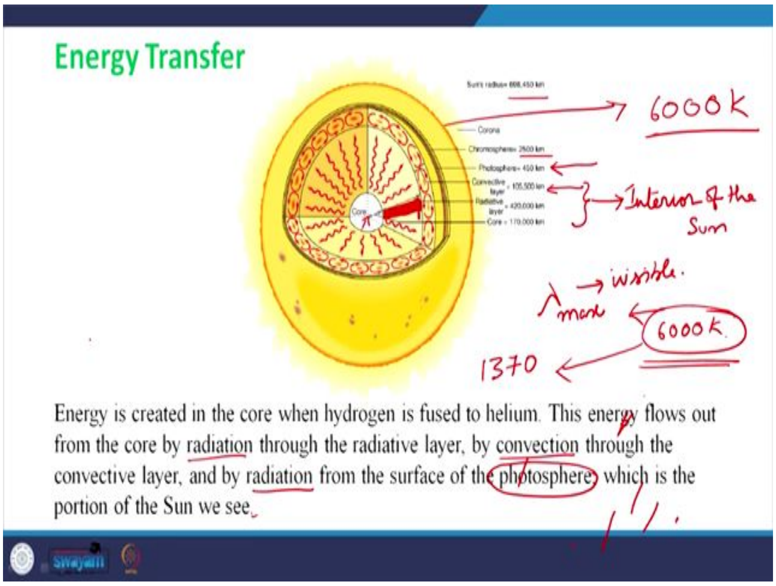

Ok, now, let us look at the energy transfer mechanism inside the sun. Now, we very well know that hydrogen fusing to the proton cycle which makes hydrogen to fuse into helium releases an amount of enormous amounts of energy, this process is called as the nuclear fusion. And, nuclear fusion is something that happens at the core where the energy is related energy is released of course. Now, once the energy is released, this energy reaches the edges of the sun or the photosphere or the boundary of the sun, right.

Now, the important aspect that I am trying to say here is that energy is of course, generated at the core, energy is created at the core when it is created it travels by different means starting from the core. So, energy is created in the core when hydrogen is fused it to form helium, this energy flows out from the core by radiation through the radiative layer. So, you now you see radiation by through the radiative layer and by convection through the convective layer and by radiation from the surface to photosphere which is the portion of the sun that we see.

So, photosphere is the bright yellow disc that you see the with you with your naked eye sometimes, right. Now, let us just look at these sizes. So, Sun's radius is the 6,98,450 kilometers if it is the radius the size of the core, let us say starting from 0, the core exists up to a height of 1,70,000 kilometers.

So, 0 to 1,70,000 kilometers is just the core, this is where energy is generated that is it and above the core you may lay at the top of the core up to a height of 4,20,000 kilometers you have the radiative layer. And above the radiative layer when the radiative layer stops, it is the radiative in this, this entire region is the radiative layer this entire region is the radiative layer. We will see we will try to see why is this called radiative layer, but not nothing else, ok.

Then from the top of the radiative layer up to a height of 1,05,500 kilometers you have what is called as the convective layer. This is where these three regions let us say core, radiative layer and convective zone or converter layer are generally called as the interior of the sun; if these are the interiors what is the surface? The surface of the sun is called as the photosphere which spans over nearly 450 kilometers. And above the photosphere up to a height of 2500 kilometers is what you have the chromosphere and above the chromosphere you have the corona. So, these are the different these are the different layers of the sun different parts of the sun.

Now, what one important point that I would like to make here is that. So, you have a heat source inside the object you have this source inside a system, let us say it is not an adiabatic system, let us say you have a heat source where the heat is generated here. Now, the edges of this system are heated to 6000 Kelvin, it does not really matter what is the heat source inside, for all practical purposes what matters for us is this 6000 Kelvin.

So, the core or the temperature of the core or the energy the existence at the core does not really matter, what really matters for us is the temperature that we see outside the 6000 Kelvin. The 6000 Kelvin is what gives you 1370 Watts per meter square or the 6000 Kelvin is what, the 6000 Kelvin is what? It gives you lambda max in the visible spectrum, ok. So, this is some aspect about the energy transfer.

So, one important (Refer Time: 32:44) is that temperature the energies created the core, this energy travels through a distance of let us say 6,98,450 kilometers, and this energy travels and heats up the outer disc to 5800 Kelvin is the standard number, but it is for convenience we always make it 6000 Kelvin, ok. This is about the energy transfer, now we will just now we will have a look inside this star we will try to see how it looks like.

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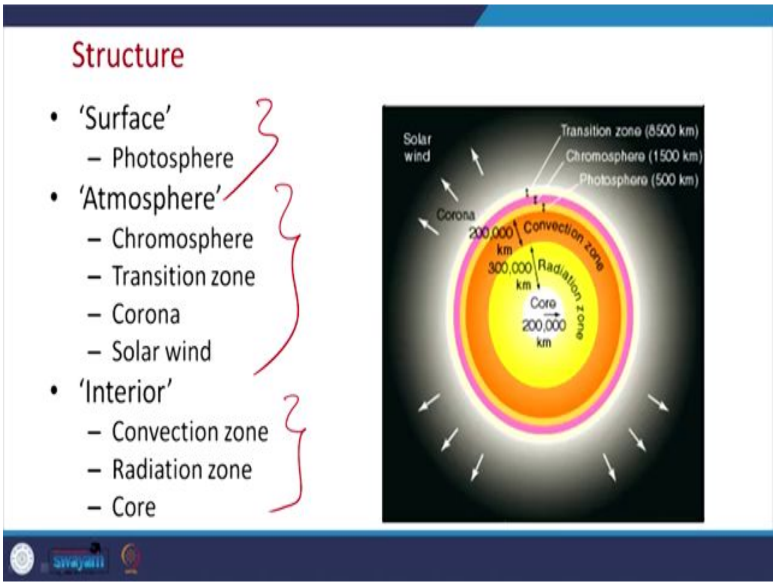

So, the structure of this sun is generally a surface is photosphere; atmosphere is chromosphere transition zone, corona, solar wind; interior is the core radiative zone and convective zone or convection zone. So, this is how it looks like, yes. So, this is something about how energy is released from the sun, how it reaches in and how many different forms this energy reaches the earth.

Now, we have learned something about the forms of energy and how it is generated, where it is generated. In the coming lecture we will try to understand each and every important aspect about the interior, about the atmosphere and about the surface.

Thank you.