Introduction to Atmosphere and Space Science

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Lecture: 02
Primary Source of Energy on the Earth – The Sun

Hello, so in the last class we have seen various important aspects about the sun; few vital statistics about the sun, very few important numbers, then we have seen what are the different regions of the Sun's atmosphere, the interior of the Sun. We had an outline of various aspects where is such aspects. Today, we will continue with the discussion and we will try to see what are the important features of each of the region inside the Sun and in atmosphere of the Sun let us say.

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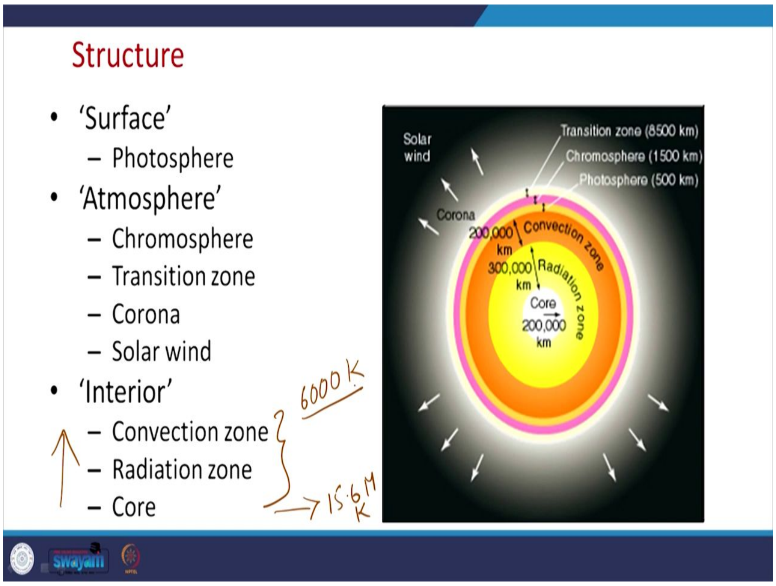

So, we have seen this; we have seen this surface of the Sun being called as the photosphere. The atmosphere of the Sun is classified into 4 different layers which are the chromosphere transition zone, corona and the solar wind. The interior of the Sun what you see below the photosphere is generally classified into 3 different parts which are the convection zone, radiation zone and the core. Like, I already mentioned that core is the region where the energy is generated and this energy travels from the core to the convective zone in different means.

And as a result of; all the energy that is generated in the core, the in the surface of the Sun which is called as a photosphere is this, the temperature of the core is 15.6 million Kelvin and as a result of the energy that is transferred from the core to the surface, the temperature of the surface is nearly 6000 Kelvin. This is also the reason that why we see the Sun to be a blackbody radiating at 6000 Kelvin, ok.

So, now, today we will discuss important aspects of each of these regions inside the Sun as well as outside the Sun. let us see. So, out of the discussion that we had in the last class I have made few curiosity questions for you just these is this are this are not generally related with the measurement, but these are more of popular science kind of questions you may want to look up in your resources let us say books or online resources.

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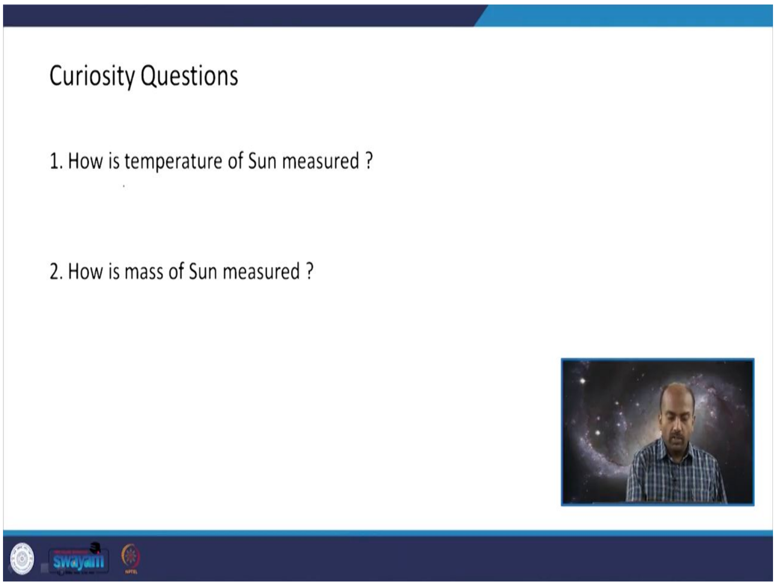

Just to see how the temperature of the Sun is measured, how the temperature of the of any let us say distant or nearby star for example. It can be measured or how the mass of the Sun is measured.

So, Sun is an object which is far away which is very far from Sun and how is the mass of the Sun measured or for exam or for that instance how is the mass of any heavenly object any planet or any Moon is measured to an accuracy that we know for sure. These are the curiosity questions you may want to look into this is just to have an idea of the answer, ok.

Now, yesterday I was talking about the differential rotation. The differential rotation is the aspect in which different latitudes of the Sun revolve at different speeds. Generally, for Earth we always know that the rotation speed of the Earth is 24 hours; that means, it takes 24 hours of amount of time for the earth to revolve around itself, this is the angular velocity or angular speed of the Earth ok. So, it in 24 hours the angular distance that is covered is 2 pi radians, right.

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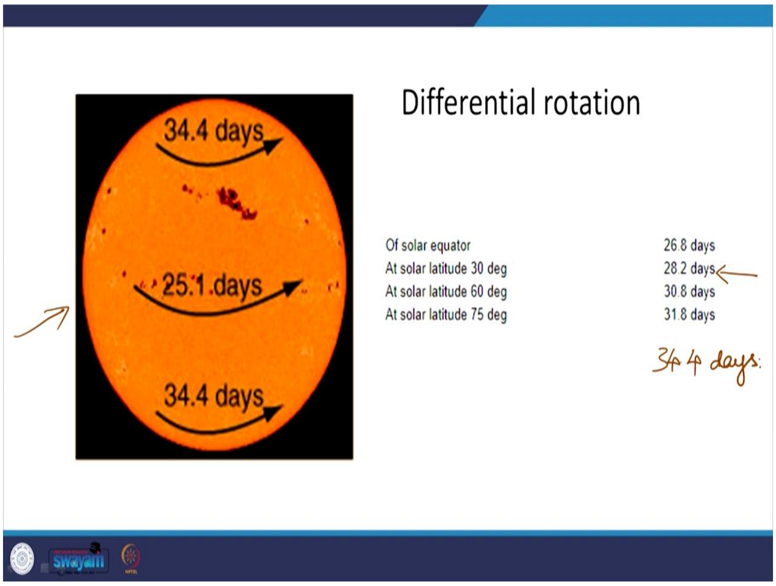

Now, for a star or for the Sun is not the same; that means, at the equator Sun nearly takes 25.1 days to revolve over on itself and at the poles it takes longer amounts of time it takes nearly 34.4 days at the poles, ok. So, this rate of at which the Sun rotates or on itself varies as a function of latitude.

So, at different latitude; so, typically, at the solar equator the rotation takes place at twenty 6.8 days at solar latitude of 30 degrees. We can see that the rate is 28.2 days and it goes on increasing till the poles which is like which is 34.4 days.

Now, what is important is now you should always remember Sun is an object made up of gases on hot plasma there is nothing else. So, the ball of plasma is rotating at different rates at different latitudes. Now, what justifies or what you know what gives you a gives a concrete proof for this is that there are things called as Sun sports. Sun sports are the are the regions which you see on the Sun which are dark in nature, ok.

So, what you can, how do you measure the rotation of this rotation of the Sun is that you can see that there the sunspots rotate at different speeds when they are at different latitudes. So, this kind of supports the idea of differential rotation.

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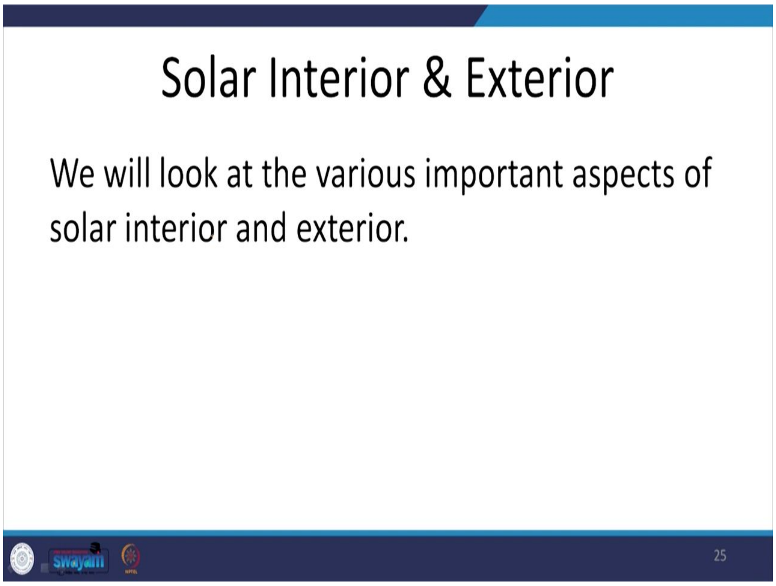

So, now what we will do is we'll look into the solar interior and exterior. So, you look at the various important aspects of solar interior and exterior, let us see what are the important aspects.

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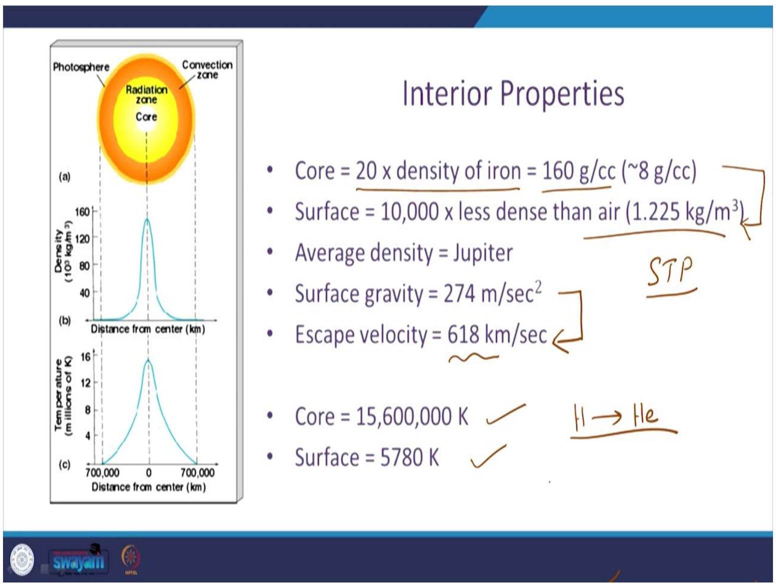

Let us say we start with the interior properties; interior is everything that exists below the photosphere. Photosphere is the visible disc that you see in the sky; photosphere is the top of the interior; I mean, this is this is the region which is which we call as the Sun below photosphere we call as the interior, ok.

From the figure what you can see is that the density of the interior is maximum at the core, at the center of the star at this point and the density decreases as you travel away from the core; that means, radially the density will decrease. And at the same time the temperature as we know already, the temperature of the core is nearly 15.6 million Kelvin and the temperature of the surface is 5800 Kelvin. So, it is it is very clear that the temperature is maximum at the core and the temperature will decrease as you travel away from the core or the center towards the surface, ok.

Now, this is a basic way in which the fluctuations are fluctuations in temperature and density can be seen right, that is fine. So, what are the physical parameters; what are the numbers which will quantify these particular changes? Let us say for example core, if you look at the density of the core. So, like I said already, Sun is a ball of hot gases and plasma. How dense can you expect it to be it is after all a gas that is it right, but due to the immense amount of compression that happens in the core and due to the immense amount of compression heating that it generates; The core of the star, core of the Sun in this case for example, is highly dense which is nearly 20 times the density of iron, ok; so, the density in numbers is 160 gram per cc ok.

The surface whereas, when you once this is the cores density and the surface density from here starts out to be very very small in comparison to what you have seen at the at the core. The density is nearly 10000 times weaker than the density of air; this is this is the density of air at STP; so, this is the density of air that we know at STP, ok.

So, what you can say is that the surface of the of this Sun is very very weak in terms of density and average density let us say average densities are roughly of the order of the density Jupiter, the planet Jupiter. The surface gravity on the photosphere is easy immensely strong because of the because of the large amount of mass that Sun has which is 10 to power of 30 kg that we have seen already, surface gravity is very very strong, 274 per meter square meter per second square.

So, which transcends to a very high value of escape velocity which is 618 kilometers per second; that means, that any object which tries to leave the gravitational pull of the Sun will require this much amount of velocity which is nearly impossible for any kind of system, right. Now, the core temperature we have seen already, core temperature is very strong and surface temperature is not that high when you compare it with the core temperature, right.

Now, starting from the core I mean yeah; so, we have already seen so, this is the hydrogen fusing to helium or the proton cycle which will generate this energy that we know that and we also seen how much is the length scale of the core, how much amount of distance from the centre of the sun, the core extends we have seen that, ok. Immediately above the core, what you have is the radiation zone; the radiation zone is the region above the top of the core, right.

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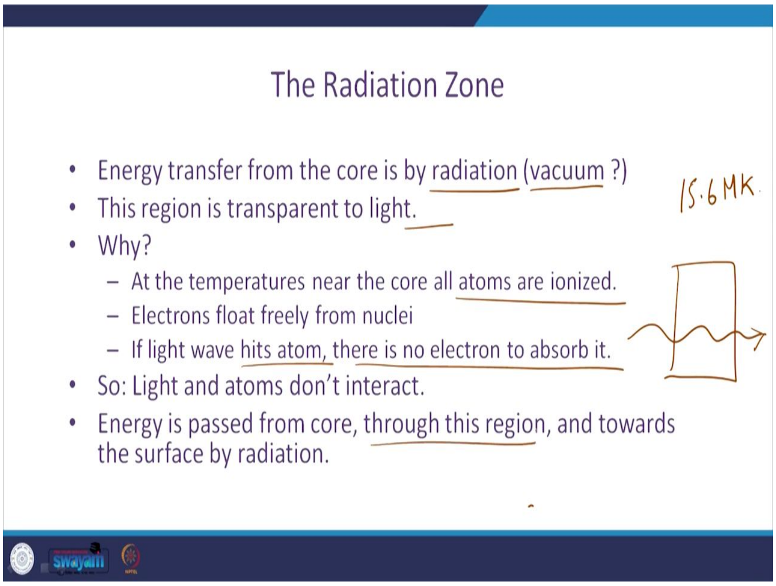

Now, let us see what are the what are the important aspects about the core about the radiation zone. Radiation zone is named because of the because of the kind of energy transfer mechanism that is existing in this particular region. So, in the core it is a it is a hot oven where the energy is generated, it heats up the radiation zone. The radiation zone is the place where the radiation transfer happens by the means of radiation.

Now, when you say radiation, radiation is the energy transfer mechanism which is most efficient in vacuum, why? Why do you say that, because in vacuum there is nothing to absorb energy right there is nothing for which hinders the travel of the electromagnetic wave, there is no medium which absorbs which scatters or which diffracts no kind of deviation happens? So, radiation is most efficient; that means, the radiation has to travel least amount of distance to be able to transfer energy from one point to other point.

So, ideally the radiation is the energy transfer mechanism which is which is the most efficient in vacuum right, when you put a medium things differ; I mean, things differ in the sense you have absorption taking place, you have diffraction taking place, you have scattering taking place so many things, right. So, but the thing is in the radiation zone which is the second layer of the solar interior, the kind of energy transfer mechanism that is dominant is the radiation, ok.

Now, this in addition to this why is radiation import; why, why is radiation ah is the only process here? There is the main question actually. The, it has been found that this radiation is transparent to light; it is transparent to light; that means, what do you mean with transparent the medium that is existing inside. The hot gas or the plasma or the particles hydrogen or helium or the heavy metals that we know for sure that they are existing inside the sun, they are not able to absorb any amount of light.

Why is this radiation transparent to light; that means, at this temperature; let us say oh so, the temperature that we started at the core always remember this 15.6 million Kelvin is; at this temperature although all the atoms are ionized; that means, you imagine any amount any atom it is heavily ionized; that means, it is completely ionized. All the electrons are stripped off from the atom and the atom is existing in the highest ionized possible state; that means, there is there is no electron which can take up the energy and get excited into an excited state.

So, it is a heavily ionized plasma where you have free electrons and you have free ions, ok. So, electrons freely flowed from the nucleus; so, they are not in a position to absorb energy. So, light waves when heat when they hit an atom there is no electron to absorb it; that means, the entire medium of the radiation zone behaves as a transparent medium for the light to propagate without any hindrance. So, as a result light and atoms do not interact.

So, energy is passed from the core through the through this region, energy is passed from the core to this through this region and towards the surface by radiation. So, that is why since due to the extreme amount of temperatures that are involved, this entire region which is called as the radiation zone behaves as a transparent medium for the light to travel from the core towards the surface, ok.

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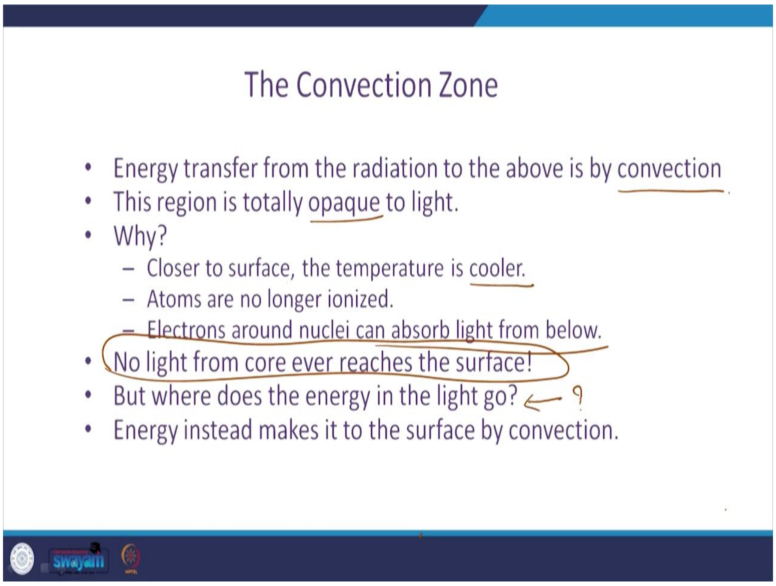

So, this is the importance about the radiation zone; now, what do you have the above the radiation zone? Above the radiation zone you have what is called as the convection zone or convective zone. The energy transfer from the radiation zone to the above or to the photosphere or to the outer side is happens by the means of convection.

Now, from your earliest classes you know that the energy transfer can take place in three different ways which are convection, radiation and conduction, right. Now, this region being a fluid in this region the energy transfer happens by the means of convection. So, what is convection? Convection is the process by which energy is transferred by the movement of matter. So, matter takes up this energy, matter moves from a point of higher temperature to a point of lower temperature it leaves the energy at the point of lower temperature, and it comes back forms a convection cell and by the means of this convection cell energies from one point to another point.

This region is highly opaque to light or totally opaque to light; that means, you will never see the light which is originating from the core; you will never see the light that is originating from the core. So, all the energy, all the light that is transferred by the radiation heats up the bottom of the convective layer, once it heats up it is simply it is a simple example, ok.

So, why is this region opaque to light because this is closer to the surface, yes, and the temperature is cooler so, there is no point of ionizing or heavily ionized atoms being existing in this region. So, ultimately; that means, that it leaves a provision for the matter to be to exist in the states of excitations and the excitations with the energy that is coming from the radiative zone, right.

So, electrons around the nuclei can easily absorb light from the below; that means, that there it is leaving the medium opaque, light is not being transferred directly from the radiation zone to the outside. So, as a result this is a very interesting aspect that no light which has been generated the core has never been able to reach the surface. This is indeed an important point where none of the light or the energy it has never been able to reach the surface of the sun. So, where does this energy where does it go, where does it go energy instead makes it to the surface by convection.

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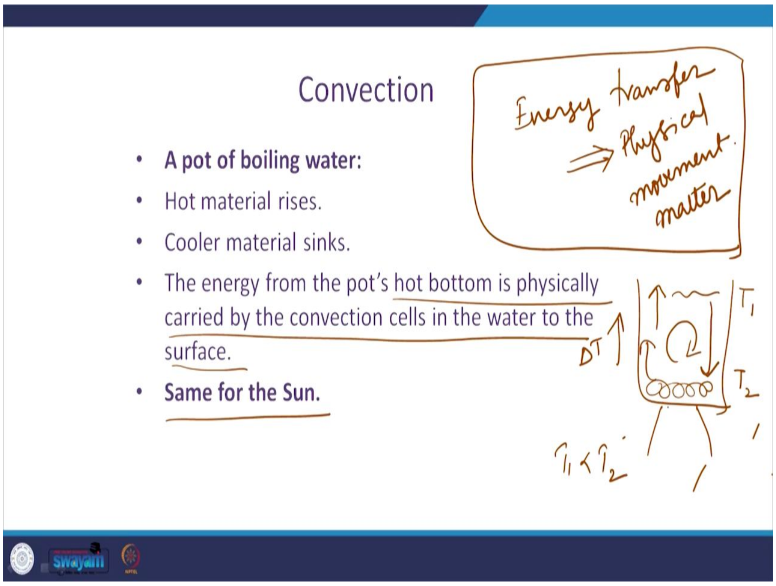

So, if you want to have a deeper understanding, a simple understanding as a matter of fact. A portal; let us considered a pot of boiling water let us say, you considered a pot of boiling water. So, you have a heat source here which is heating the water. So, what happens is the fluid which is existing at the bottom, the fluid layer that is existing at the bottom takes up this heat and it rises. Why does it rise? The temperature increases the density will decrease, something which is less dense is more likely to occupy the points above so, it rises. Here the temperature is, T1 let us say and this is T2; T1 is much less than T2.

So, since this is the there is a temperature gradient which exists in this direction; so, this is there is a temperature gradient. So, as a result this energy is deposited here and once this energy is lost the density again decreases and it will come back. So, as a result it forms a convective or convection cell, right that is it. So, the matter which is existing at the bottom of this cell has the role that it transfers energy from here to here by the means of this mechanical movement, ok.

So, the energy from the pot's hot bottom is physically carried by convection cells in the in the water to the surface; that means, so, the what I mean to say is energy transfer energy transfer requires physical movement physical movement of physical movement of the matter. What you are understanding is energy transfer in the convective zone happens by the movement of the plasma or the gas highly ionized plasma, ok.

So, this the same process exists inside the Sun for some distance, it is not throughout only at a particular height inside, the starting from the core. You have the convection which is a dominating process which is governing or which is enabling the energy transfer from one point to another point, ok

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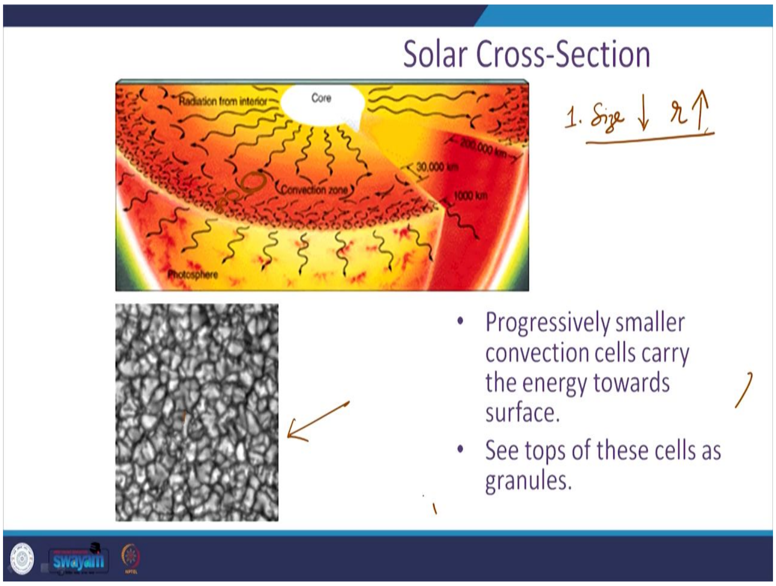

Now, so, what is the what is the what is the proof for you to believe that there is convection which is happening at the below the photosphere. The proof is that if you take a cross section. So, what you see from this figure is that you have the core of course, which we have the core which is which you see in the white color which is exist which is existing at a very high temperature. And then you have the within the core you see, what you see here the radiation is traveling from the core to the convective zone.

And then you see these convective cells which are kind of transferring the objects or the mass from one point to another point. One important thing that you see here is that the from this figure one important thing that you must notice is that the size of the convective cells decreases as you travel away from the core, ok. We will see, we will try to address why such a thing happens, ok.

So, one important thing I always wonder is that you we can hardly go near the near the surface or at least to a very large proximity of the sun. So, why do how do we know that this kind of energy transfer mechanisms or all these kinds of things may exist inside this and how do you know; I mean, how do we make sure ok. One proof that we get is when we photograph or when we take an image of the Sun at a very very magnified scale.

What do you see is that you see this kind of images; so, this kind of image. This small patches or small areas that you see with darker backgrounds are generally called as granules. So, what you see here is that you see small cells these are these are very small shaped; I mean. you can identify the border of each of these cells you can see this they have a distinct border each of them and there is a continuum of these objects throughout, right So, this progressively smaller, these are the tops of the convective cell; that means, what you see these are generally called as the granules, these are called as the granules, ok.

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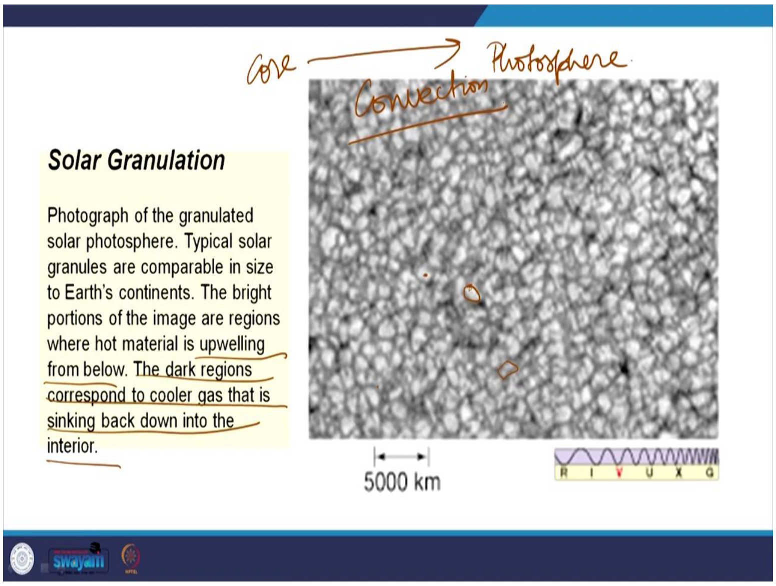

So, what is specific about them; so, what you see here is the photograph of a granulated photosphere. So, this is the photograph of the photosphere; that means, the yellow disc the yellow disc has been photographed, the very high level of distance. The typical solar granules are generally the each of these; each of these granules are comparable; each of these granules are comparable to the size of the continents on our planet. The bright portions of the of the image are region; so, the bright portions are those regions where the matter is upwelling from the bottom.

So, this is the bright portion that you see here; I mean, now that I have made it darker with this pen, but what you see is a bright portion. The bright portion that you see is the region, which is where the matter is upwelling and the darker background or the darker outline is the region where the matter is going towards the surface towards the core. The bright portion of the image are with the regions where the hot is material is upwelling from the below, the dark regions correspond to those cooler gas that is sinking back down into the interior, ok.

So, this granulation is an example that convection is the process which is bringing the energy from the core to the photosphere. So, so we have the core, we have the energy transfer from the photosphere to the photosphere so, the convection is the process which is making it possible that is it, ok.

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Now, this is a small video, ok. So, this is again the Sun imaged in a different filter what you see so many granules on this. Now, once you have reached this surface let us say.

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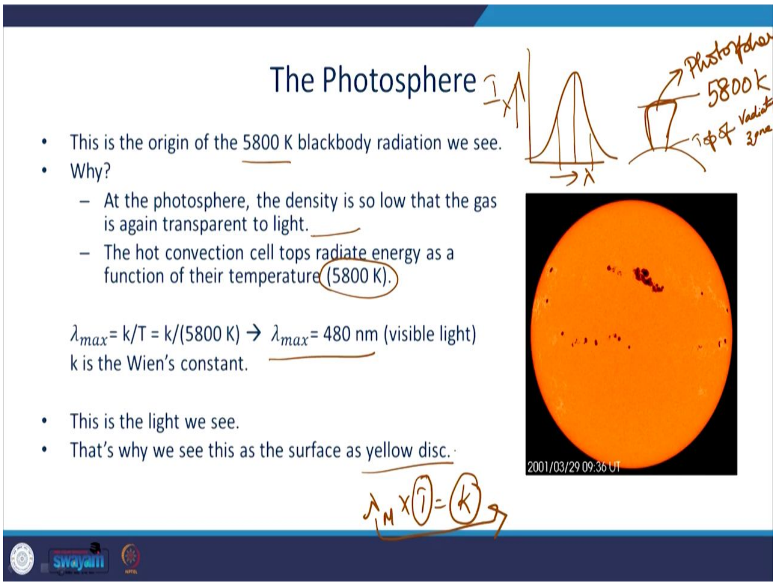

The surface is called as the photosphere. So, this is the, this is the origin of the 5800 Kelvin blackbody radiation that we see, why is it? So, at the photosphere the density is so low that the gas is again transparent or to light then it is low, I mean there is energy that is trying to escape, but there is very little amount of matter to be able to come with come and interact with the energy, ok.

So, the hot convection cell tops radiate the energy as a function of the temperature. So, now, you have you have the core, you have a convection cell like this let us say this is the top of radiation zone. So, whatever thus the event that you have kept inside has been able to heal this and this the top of this convection cell, this is the photosphere that you see and this is at a 5800 Kelvin.

So, many places you see 5800 Kelvin, you see 5700, you see 5780 Kelvin or 6000 Kelvin it is more or less the same. So, how do you get this temperature let us say, if this is the temperature what is the; what is the black body radiation maximum, if this is a blackbody radiation, then this is a spectral radiance, let us say I lambda and this we have lambda.

Now, you want to if you want to find out where does this peak exist, right. So, what is the simple law that we know is that lambda maximum times temperature is equal to constant, you call this constant as a Wien's constant, right. So, if you know the temperature at which the blackbody is radiating, it may be possible for you to get the value of lambda at which you will have maximum amount of energy being radiated out if it is the case.

Then, you substitute this into the simple formula you will get that you will have lambda max as 480 nanometers. So, which is in the visible spectrum. So, that is in the visible spectrum that is why, the suns blackbody radiation spectrum looks as if the entire energy or maximum of energy is concentrated in the visible spectrum, ok.

So, this is the light that we see the yellow light or the white light that you see. So, since it is visible, that is why we see the this as a surface as a yellow disc, ok. So, this is something about the photosphere.

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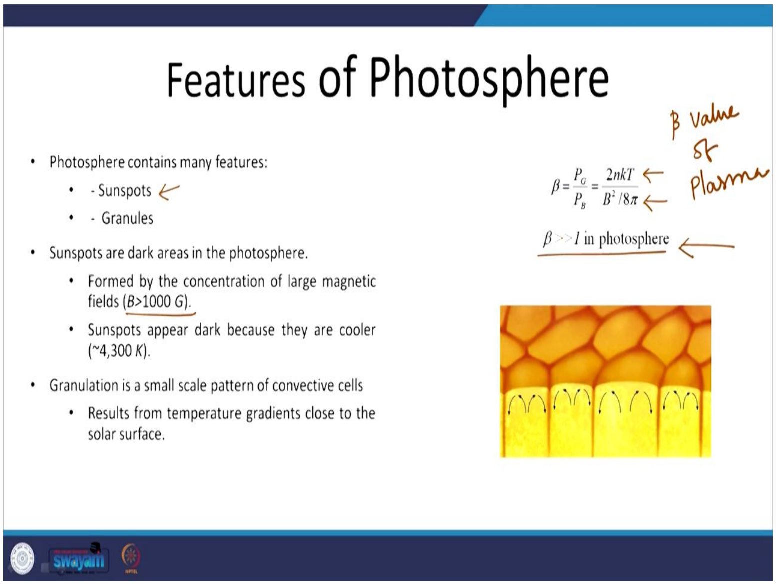

But, there are a few important features about the photosphere. Photosphere; so, for example, photosphere on the top of this photosphere you see something called as some things called as sunspots or granules. Granules we've already seen, granule is each granule is a conduct convection cell that is it. Each granule is a convection cell which is trying to transfer energy from the core to the top, ok.

Well, on the other hand another important aspect which is called as the Sun spot. Sun spots are the regions on the Sun which are lesser in temperature, but their magnetic field is enormously large. So, they their magnetic fields are typically larger than 1000 gauss ok, Sun spot appeared darker because their temp the temperature is low in comparison to the background or the in comparison to the surroundings which is nearly of the order of 4000 Kelvin, ok.

Now, here one important parameter that you may want to remember is that generally a plasma since the Sun is a plasma object, you say that you define a parameter which is called as the beta. which this beta is called as the beta value of plasma, this is called as a beta value of plasma. How do you define the beta value of plasma? Beta value of plasma is defined as the ratio of kinetic pressure to the magnetic pressure. So, this is the kinetic pressure and this is the pressure due to the magnetic field and the in the photosphere the beta is very very large, the beta value of the photosphere is very very large; that means, the kinetic pressure is enormously larger or the magnetic pressure is very very small.

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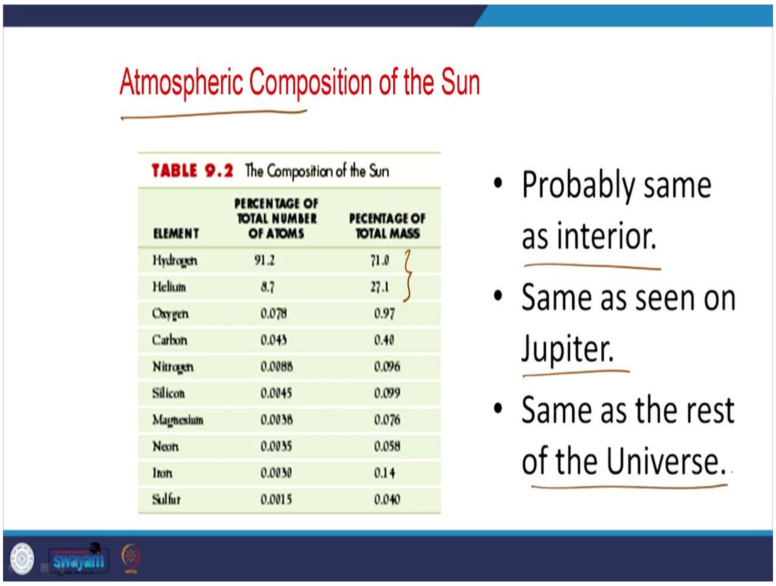

ELEMENT	PERCENTAGE OF TOTAL NUMBER OF ATOMS	PECENTAGE OF TOTAL MASS
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

Now, once you cross the photosphere, the photosphere is the top of the Sun once you cross it, you see what is called as atmosphere just like the Earth you cross the above the surface of the Earth, above the ground you have the air the envelope of air which is surrounding the planet and bound by the gravity and you call this as the system is called is called as the atmosphere.

So, just like the Sun we have talked about the interior of the sun. We are talked about the surface of the sun; the surface of the Sun is the photosphere. Once you cross the surface, once you cross the photosphere you call whatever that exists is as the atmosphere. The atmospheric composition is moral as the similar as the interior, it is not that you have new elements or new components existing you have hydrogen and helium still dominating the composition either in terms of number of atoms or in terms of mass, ok. Now, so, this is the same as interior or same as any other planet or any other the rest of the universe, ok.

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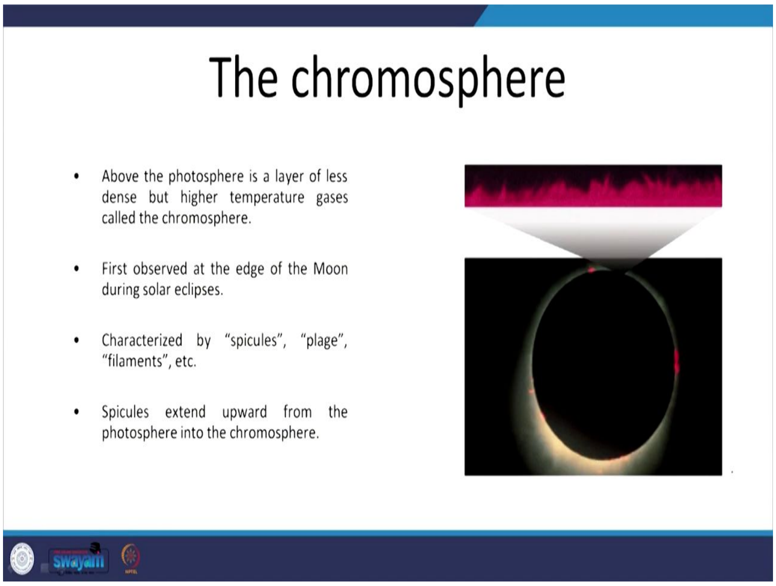

Now, above the photosphere, the mid region that you see is generally called as the chromosphere. The above the photosphere is a layer of gases which is very very less dense, but high temperature gases called as the chromosphere. So, this the chromosphere was known to be existent after it was it was observed during a total solar eclipse; total solar eclipse gives you an opportunity to see what is surrounding the photosphere, ok.

So, the chromosphere is characterized; that means, chromosphere has many features such as spicules, plage, filaments and these things, ok. So, each has different reason for the occurrence of the formation, but the chromosphere is the place where all these features will exist. So, this for example, spicules extend upwards from the photosphere into the chromosphere. So, chromosphere is the place where you see all these things.

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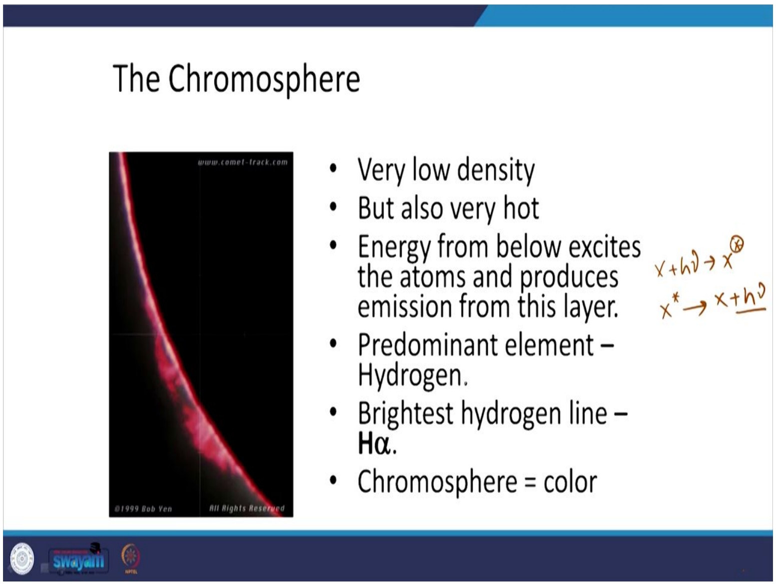

So, few things about chromosphere is there, chromosphere is very low in density it is also very very hot. Energy from the below excites the atoms and produce emissions in this layer; that means, energy atoms take up the energy get excited and when they subsequently travel to this the ground state they will release energy, they will release emissions; this emissions can be in any part of the spectrum. So, predominant element in the promise fear chromosphere is mainly the hydrogen and the brightest emission that you see is a H alpha, ok.

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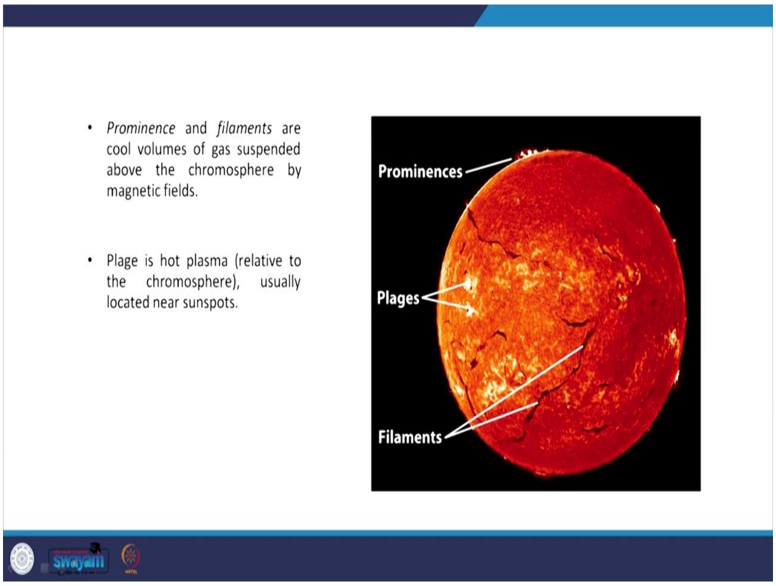

Now, prominences and filaments; so, we have seen about spicules. Prominence the other aspects about the chromosphere are prominences and filaments. Prominences and filaments are the cool volumes of gas that are suspended above the chromosphere by magnetic field. So, by the virtue of magnetic fields volumes of gases are suspended, this you call as prominences. Pledge is hot plasma relative to the chromosphere usually, located near the Sun spots, near the Sun sports you see near the Sun sports the hot plasma that exists is generally called as the pledge

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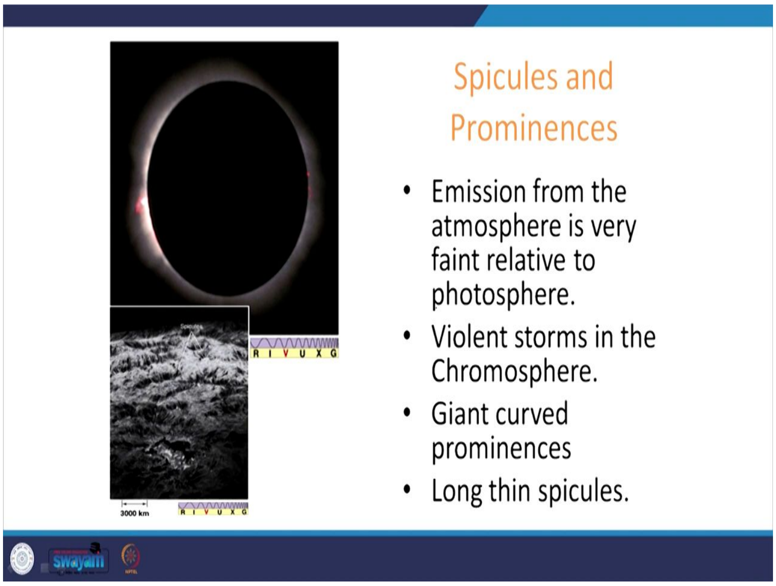

So, apart from this you also have what are called as the prominences. So, emissions from the atmosphere is are there very weak and they are very weak in comparison to the photosphere; that means, you have a very strong background which is called as a photosphere. That means, if you draw a spectrum the source, the photosphere is a very bright source in front of the that part of the source every other emission you will never be able to see; that is the reason that you keep Moon between you and the sun.

Then you will be able to see this minor or spectroscopically insignificant features only in the presence of in the in the in at the times of solar eclipse and it is chromosphere is also the region where violent storms occur, we will talk about what are storms. So, giant curved from you see a lot of interesting features in the chromosphere.

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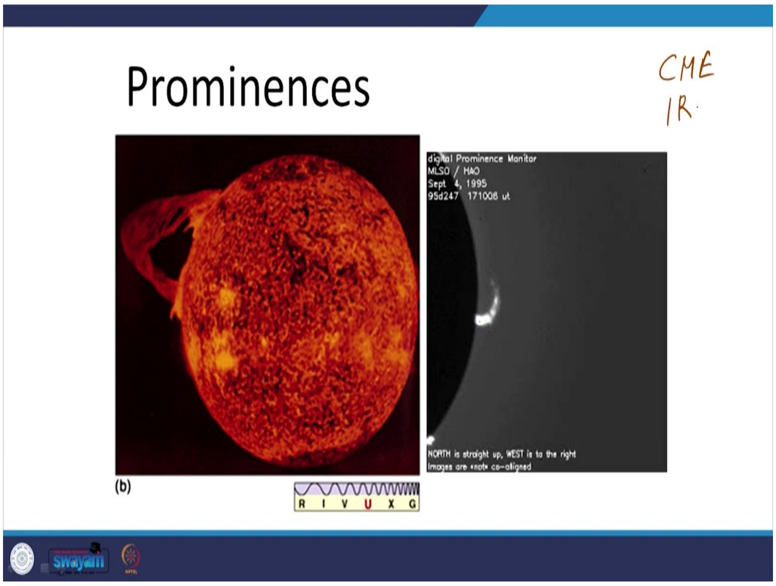

Prominences are generally the events, are the unique times when Sun emits huge amounts of plasma into the outer space or into the interest interplanetary space. So, for example, one important prominence is let us say a Coronal Mass Ejection or a solar flare in the in the different parts.

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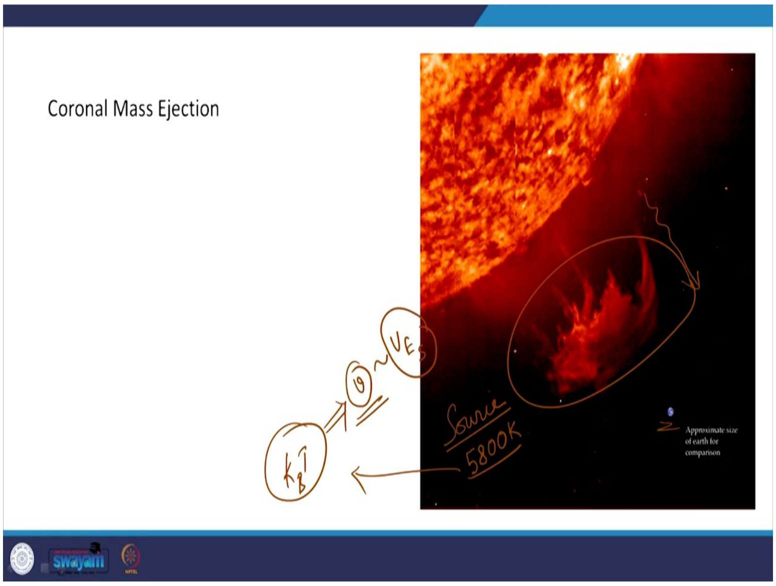

So, prominences can be can pose a serious or dangerous threat for the for the mankind or for the planetary system itself. So, for example, one prominence is a coronal mass ejection which due to some magnetic processes which happened on the sun, a hot amount a hot plasma was released from the Sun which escapes into the space. If you put a comparison with the size of the Earth, the plasma is very large the bubble of plasma is enormous in size of course. So, what does it tell you, it tell it tells you that this plasma can pose serious threat for the various things that we have built our built around ourselves, ok.

Now, now yeah what is important from this discussion let us say from this point what if it has invoked your curiosity. Now, we have already seen the gravitational pull of the Sun is very very strong and the escape velocity is in 100 of kilometers per second, right. So, for the plasma to exist or to escape this gravitational pull it needs a source of energy which is definitely not 5800 Kelvin; that means, what I am trying to say in terms of simple thermodynamics is that you take a source of energy.

You heat gas at 5800 Kelvin, you calculate the amount of energy by this and then you convert this energy into velocity of the gas molecule. This velocity of the gas molecule will not be in the order so, that it reaches the escape velocity of the sun, that eventually means that there are other processes which are able to send plasma at velocities more than the escape velocity, ok.

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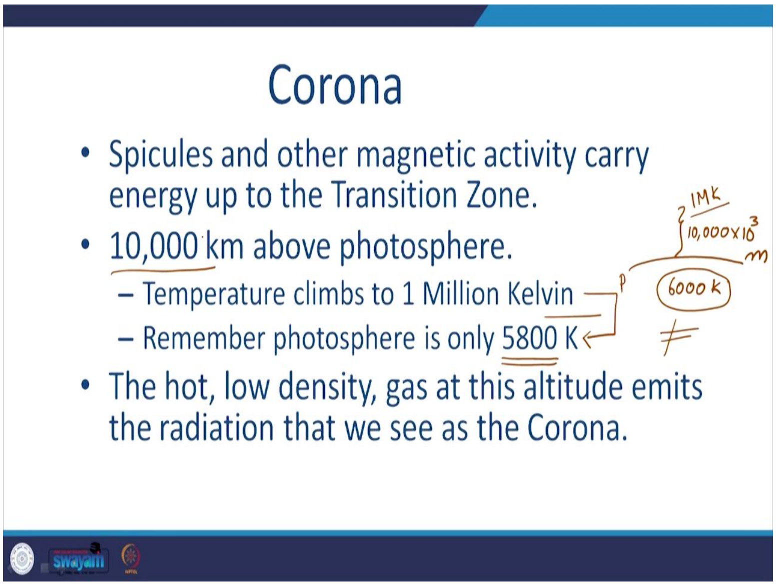

Then above the; so, we have seen the chromosphere we have seen the photosphere, we have been seen the hemisphere then about the chromosphere the region of the sun’s atmosphere is called as the corona. So, corona is the region where the spicules and other magnetic activity carry energy up to the transition zone and above it you have the corona. So, 10000; so, this is typically 10000 kilometers above the photosphere and temperature here again climbs to 1 million Kelvin, temperature here climbs to 1 million Kelvin, it is a very large temperature.

So, you should always remember this number in comparison to this number, right. The hot low-density gas at this altitude emits radiation that we see as corona. So, what is important is temperature in the corona, let us say at 10000 Kelvin. So, you take the photosphere, you take the photosphere let us say P is the photosphere then you travel to 10000 kilometers ok; 10000 kilometers.

So, you have the photosphere temperature at 6000 Kelvin and at this point, at 10000 Kelvin 10000 kilometers, the temperatures are 1 million Kelvin. Now, how is it; thermodynamically how is it possible, you have the system or you have this heat source existing at 6000 Kelvin, how do you how can you expect? This heat source is able to heat to a temperature more than itself; I mean, this is thermodynamically not acceptable, this is not acceptable, no.

So, how is this possible; how is this what are the other physical processes which may be acting in this region which are able to heat the plasma to the temperature more than the source itself, ok. Now, corona is; so, we see coronas 10000 kilometer above you have the gas which is called as corona.

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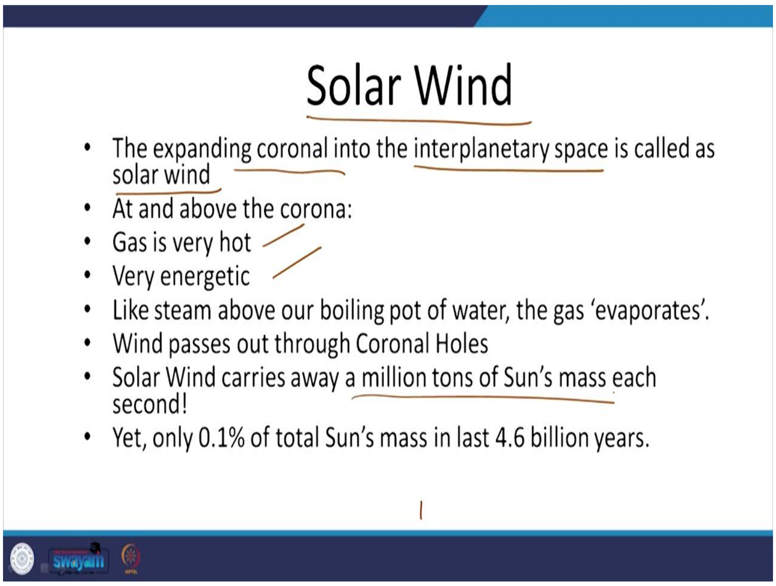

Now, the expanding corona; the corona that expands into the interplanetary space is generally called as the hot expanding corona into the interplanetary space is generally called as this solar wind. So, solar wind exists at the coronal boundary and above the corona. So, here the gas is very very hot, it is extremely energetic in nature and it looks like a steam above the boiling pot of water. So, the gas that evaporates is similar to the solar wind that is leaving the sun.

So, again solar wind of course; so, from this itself solar wind we can say that solar wind of course, leaves the Sun, it travels away from the Sun. So, wind passes through the coronal holes of course, here solar wind carries away millions of tons of suns mass each second. So, every second it carries away millions of tons of solar mass.

So, it primarily consists of electrons, hydrogen, ions, helium ions and few other let us say He-2, -4 things like that, ok. So; that means, that one so, you have the corona and the expanding the hot expanding corona into the interplanetary space is called as the solar wind. Since, the solar wind is leaving away from the Sun we say that it is carrying away a lot of solar mass with itself.

So, solar wind travels of course, to the edges of solar system or to the to the point of heliosheath ok, but what you see is what you see is that at the end of let us say even 4.6 billion years. So, for the Sun the age of the Sun which has elapsed already, it has it has not been able to carry more than 0.1 percent of the solar mass ok; that means, there is some amount of mass transfer, but it is it is insignificant, that is it.

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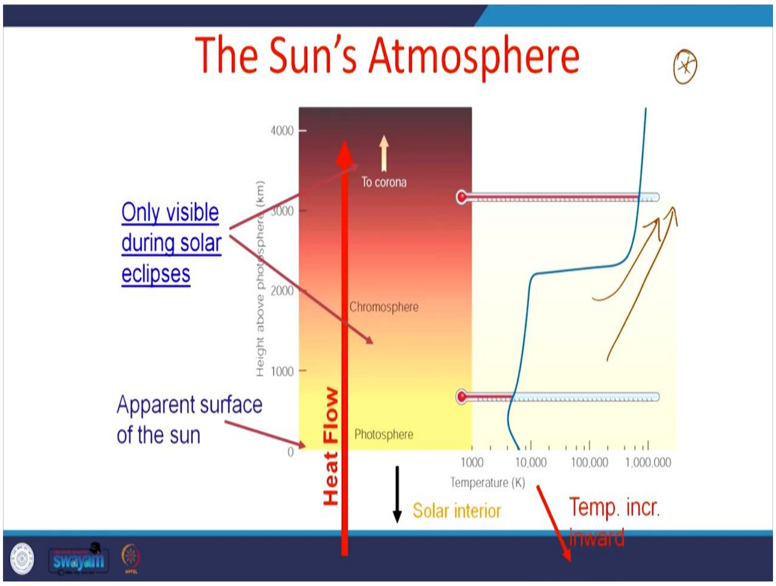

If you look at this figure what is important about this figure is that, the level 0 on the y axis is tells you the surface or the surface which is also called as the photosphere and you take this height. So, the important thing is the temperature starts from somewhere 6000 Kelvin something like that then it rises. So, this increase that you see, this increase that you see is very very crucial; I mean, its general physics or the usual physical laws cannot explain. How does the temperature increase as a function of height because there is no source and there is no source here as well, right; so, there is no source, here this is vacuum.

So, how does the temperature increase as you go away from the source is a very important or very complicated physical process. So, now, what have we done so far, we have seen how is the energy generated and how is the energy generated inside the Sun from the core to the photosphere, then we have seen what are the regions of the Sun above the surface the chromosphere, the transition zone, the corona, the solar wind, ok.

So, throughout this we have seen various important numbers which are characteristic of that particular region ok, then so after all this then 1 more important aspect is that solar spectrum let us say.

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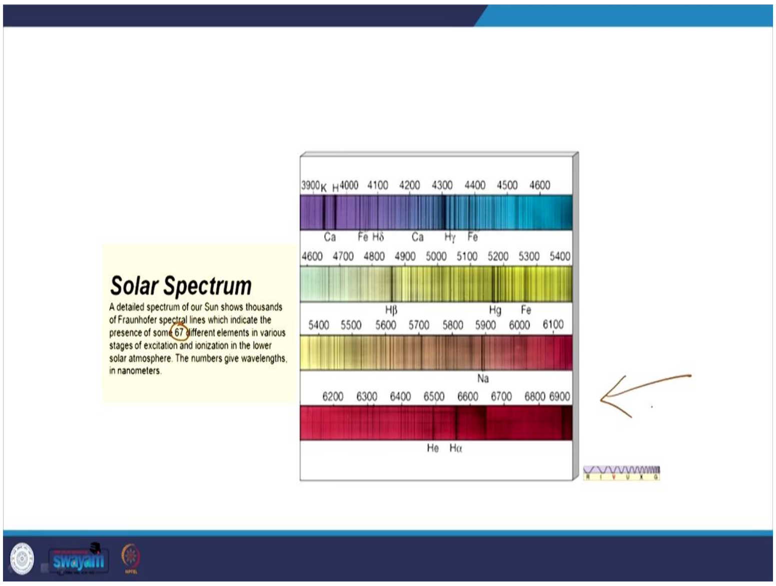

So, one we cannot we cannot understand all these things, if we do not have a spectrum and in spectroscopy is the method by which we can prob anything which emits energy. So, a solar spectrum is a detailed spectrum of Sun and it shows thousands of Fraunhofer lines which indicate the presence of nearly some 67 different elements in various stages of excitation.

Of course, different stages of excitation will release different, will release or absorb different amount different lights at different wavelengths and they will be absent from the spectrum, then you know that this particular element is existing on the Sun or in that most of the sun, right. So, you see the solar spectrum will look something like this.

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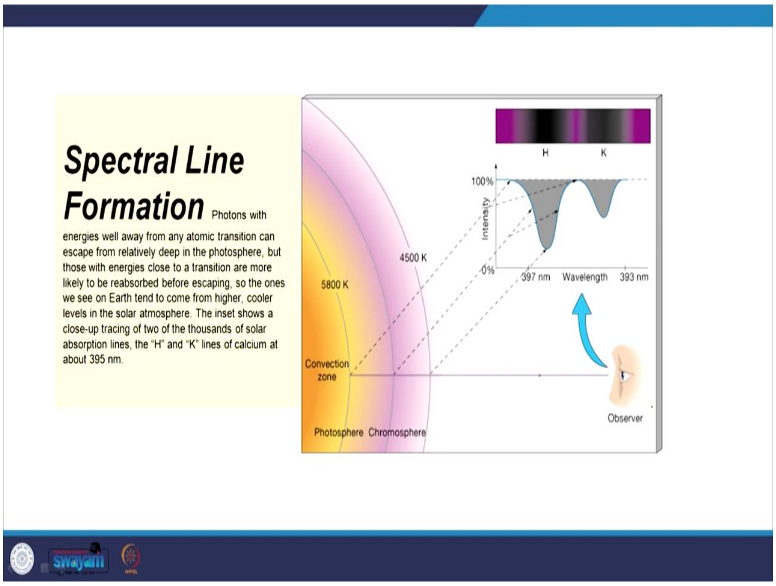

So, what is important about this solar spectrum? So, photons with energies well away from any atomic transition can escape from relatively deep in the photosphere ok, but those with energies close to the transition are more likely to be reabsorbed before escaping of course. So, the ones we see on the Earth tend to come from the higher or cooler levels in the solar atmosphere naturally. So, this inset shows the close-up tracing of two of the thousands of solar absorption lines hydrogen-potassium lines of calcium at about 395 nanometers.

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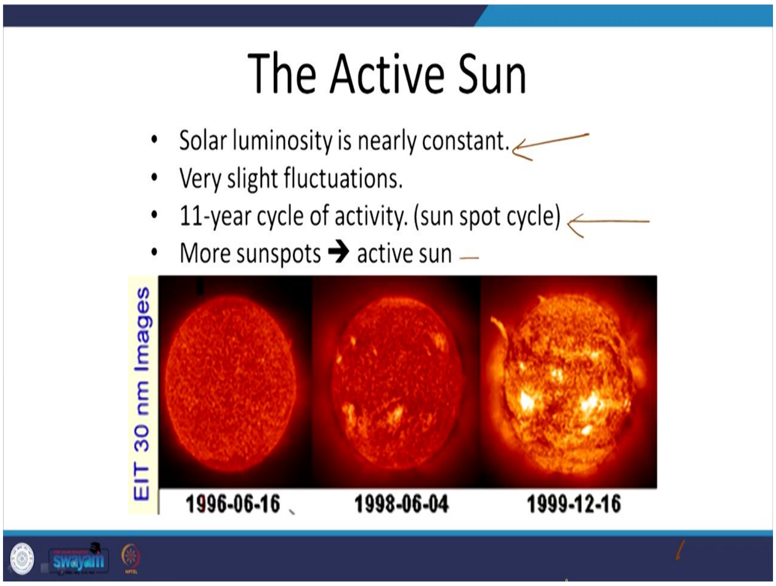

Now, apart from all these aspects of energy transfer and various layers of the Sun as a star is remains at a uniformly luminosity level, and very slight fluctuations are seen in the active Sun when the when the Sun is active. Sun follows, this is a very important aspects Sun follows what is called as the 11-year sunspot cycle; that means, every 11 years it will be it will be changing from a maximum to the minima. So, you have more Sun spots, Sun is assuming to be very active; they have less Sun spots, and is assumed to be less active that is it, ok.

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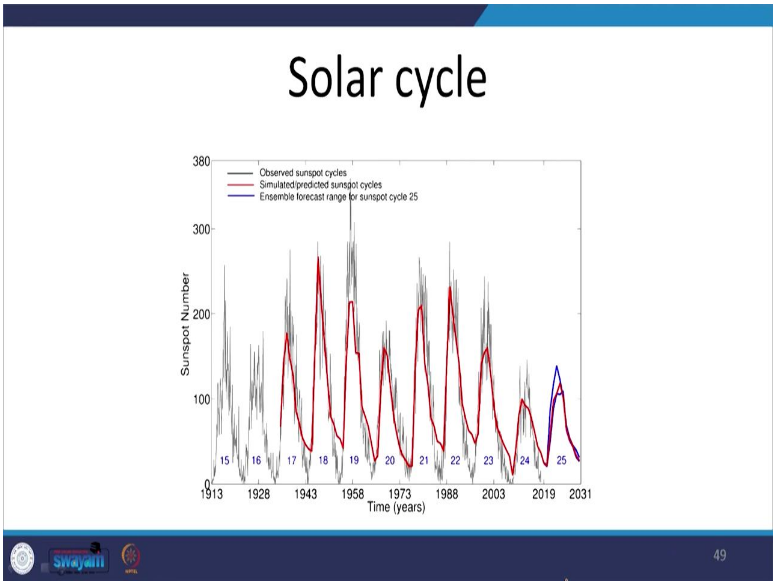

Now, over the past let us say 100 years, the number of sunspots have been varying. So, Sun spots. So, the number of sunspots is not a constant. So, what is Sun spots? Sport is the region where the magnetic field is enormously large and the temperature is significantly smaller than the temperature of the photosphere.

Now, like I said so, the Sun spots always appear in groups in pairs and Sun spots more the Sun spots, Sun is more violent and less the Sun spots, the Sun is quite. More number of Sun spots exist; that means, more number of prominences are to be found; that means, if the Sun is very active more number of coronal mass ejections are more number of solar flares are expected naturally and why do the sunspots appear. I mean there is a very very involved discussion I mean probably we will take it up some other time.

So, what has been seen is that the sunspots appear in numbers and they their appearance in number will increase and decrease and it follows a cycle, and this cycle the length of, the periodicity of this cycle is 11 years. So, every 11 years some oscillates from a maxima to minima, this is the minima and is the maxima. So, what you see here is the black one that you see are the measured number of sunspots, ok.

So, suns Sun has a magnetic field if you say if you ask why do the Earth has a magnetic field Earth has a magnetic field, right. So, why; so, why Earth has a magnetic field? Earth has a magnetic field because the molten core of the Earth is rotating because it is a its a fluid, it is hot its rotating it generates a dynamo, this dynamic generates a magnetic field, that is simple.

On the other hand, the sun's magnetic field is can is slightly different, the magnetic field of the Sun is generally is mainly produced by the flow of electrically charged ions and electrons. Of course, charged I electrons and ions will produce an electric will produce a current and if the current is changing in time then you will have a magnetic field. The changing magnetic field of the Sun governs many aspects of solar activity. So, the creation of sun's magnetic field: the solar interior is composed of highly conducting and highly ionized plasma we know that.

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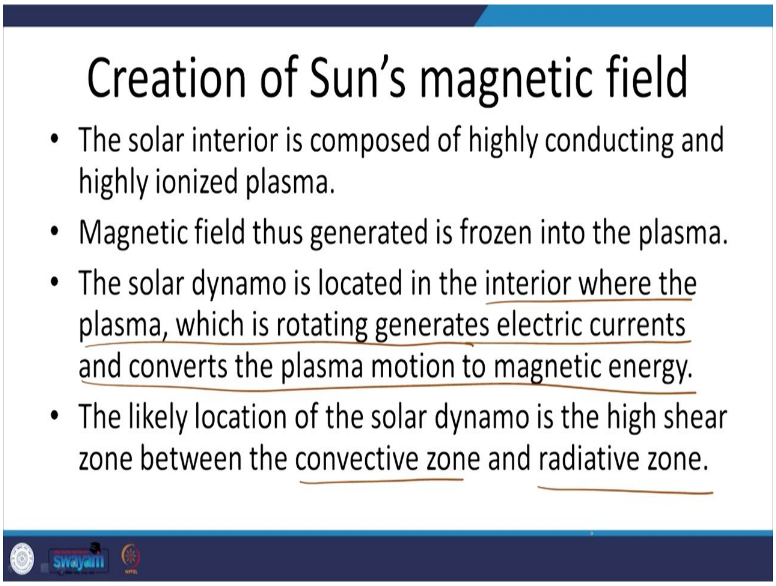

Magnetic field thus generated is frozen into the plasma. So, the magnetic field is frozen or inter coupled with the plasma; so, plasma and magnetic field cannot be separated. So, the solar dynamo is, dynamo is the place where it is the magnetic field is generated. The dynamo is located in the interior where the plasma which is rotating, generates electric currents and converts the plasma motion to magnetic energy. And the likely location, likely location of the solar dynamo is the high shear zone between the convective zone and the radiator zone.

So, I mean these all this important points or this is a based on various different models of study there is a different thing, ok. So, so this was something about various aspects of sun. So, we started our discussion saying that since the Sun is the only source of energy. It is very important for us to understand how the suns energy effects or modulates various physical, chemical and dynamical processes on the on the Earth or in the atmosphere. So, for us to have a form understanding we need to have good knowledge of what is sun, how is Sun giving its energy and stuff like that, ok. So, this is where we stopped will continue in the next class.