Fluid Dynamics for Astrophysics
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Lecture – 34
Solar wind: Parker's solution

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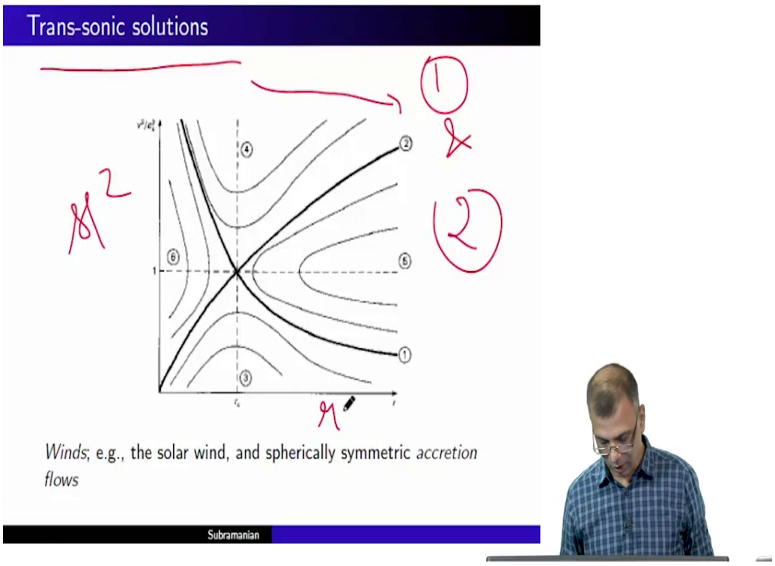

So, we are back and let us now, pay some special attention to the solar wind. We discuss this Trans-sonic solutions and turns out that only solutions of kind 1 and 2 are trans-sonic right. 1 would be this one and 2 would be this one right ok. So, I made a slight mistake when I said this last time, I will rectify it in a minute.

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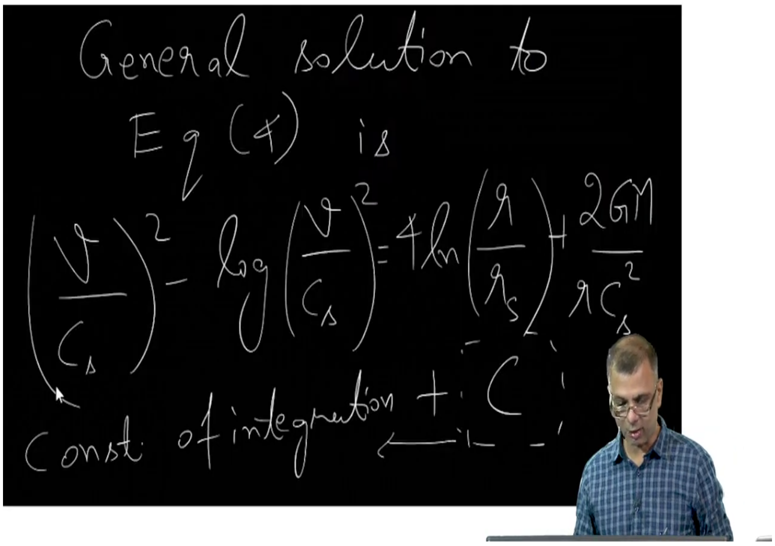

But let us now, look at the general solution once again, this. And we said that depending upon the constant of integration, you can have any one of these solutions either solution 1, solution 2 or solution of solution kind of 3 or 4 or for that matter 5 or 6. And we eliminated solutions 5 and 6 because, they are not physical all right.

So, we really need to you know worry only about the other kinds of solutions. And of those only solutions of the kind 1 these and solutions 2 these are trans-sonic, they sparse smoothly through the sonic point where you know this represents the square of the number and this represents r right.

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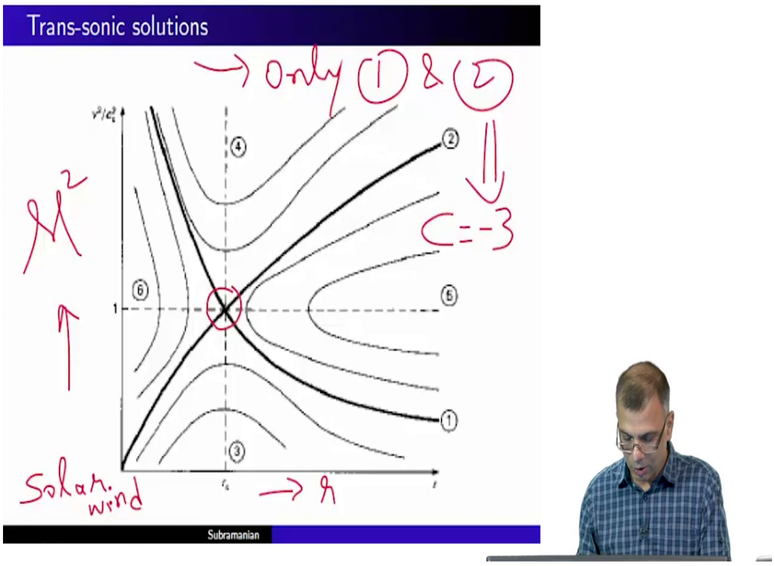

So, therefore, so, let us consider this is a little better is a slightly larger canvas to talk about and so, me (Refer Time 01:57): this is r ok. Only 1 and 2 are trans-sonic; 1 would be this and 2 would be this ok. And from the general solution, which what would be the values of C for which you would get solutions like 1 and 2 turns out that 1 and 2 for 1 and 2 you have ok.

In C equals minus 3 in here, if you have C equals minus 3 you will get solutions of the kind 1 and 2. So, this is one thing I wanted to mention before proceeding. The other thing I wanted to mention was that, I had made a mistake you see suppose we are considering the solar wind right. And so, let us now think about what the solar wind means? The solar wind as I explained may be a couple of classes earlier.

As a wind emanating from the outermost atmosphere of the sun, which is the corona ok. And so, and the outermost atmosphere of the sun, it kind of you know it essentially boils off ok.

So, the gas of the plasma near the corona is almost at rest I mean, it has a very small velocity, but it is almost at rest.

So, it is definitely subsonic, right at the surface of the sun right. And then it goes out eventually passes through a sonic point where the velocity becomes equal to the speed of sound and then becomes supersonic. So, we from among 1and 2 we should choose a solution, which is subsonic at small r and this is the sonic point mark number equal to 1.

So, we should choose a solution that subsonic at small r passes through a sonic point and at large r it becomes supersonic right. So, that would be this solution this branch 2 right, you see at small r the mark number is less than 1. And as r increases it eventually reaches a sonic point, this would be the sonic point and as r increases even further the mark number increases and becomes larger than 1.

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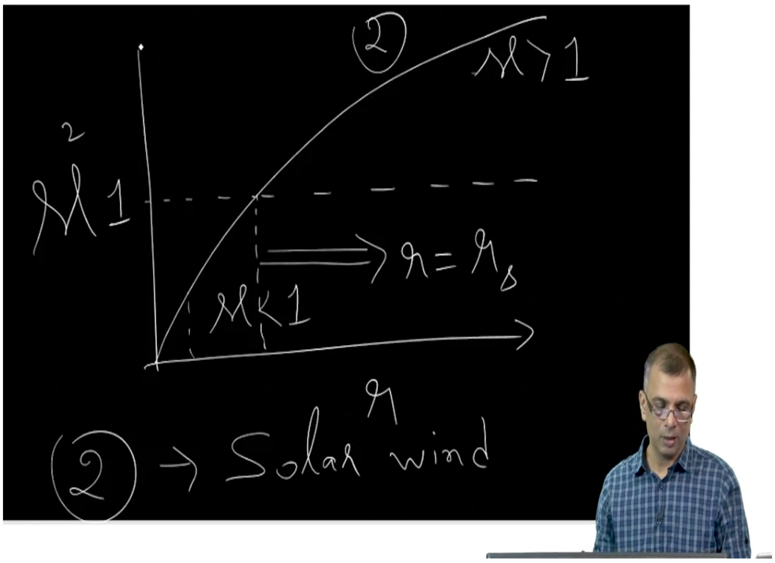

So, this kind of a solution for which, if I was to redraw the solution I mean, redraw this r number square and this is where it is 1, the kind of solution that looks like this ok. So, at small r here mark number is less than 1, at some here this would be r sonic and here, mark number is greater than 1 right. So, for larger r the number is greater than 1 and, these are solutions of the kind 2 and these represents solutions of the kind 2 represent solutions that are appropriate for the solar wind.

I had when we met last, where I had mistakenly said that solutions of the kind 1, which look like this. Which are also trans-sonic they would be appropriate for the solar wind, but you see the mistake there is that solutions to the kind 1 which look like this, they are supersonic at small r that is not what we want ok.

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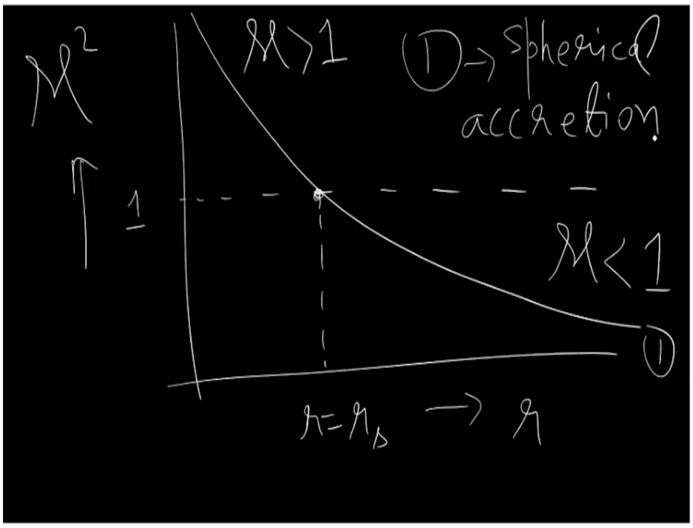

Solutions of the kind 1 would look like this r, I have one here right, and I would have something that looks like this. These would be solutions of the kind 1 and this would be the sonic point, here the mark number is less than 1 and here the mark number is greater than 1 clearly. So, what does this represent, what could this represent? This could represent gas that is kind of you know at rest at infinity at very large distances you see.

And it is attracted towards a compact object; it is trying to accrete onto a compact object and as it is attracted as it is accreting, you know the speed increases and therefore, the mark number increases right. And it eventually passes through a sonic point right, and as it accelerates even further, it comes even closer to the star right and it becomes quite supersonic ok. So, it becomes quite supersonic. So, solutions of this kind represent spherical accretion ok.

We just discussed this in some detail and we said that, if we are talking about the solar wind we really should be talking about solutions like this, solutions like 2,which start out subsonic at small radii pass through a sonic point and become supersonic at large distances right.

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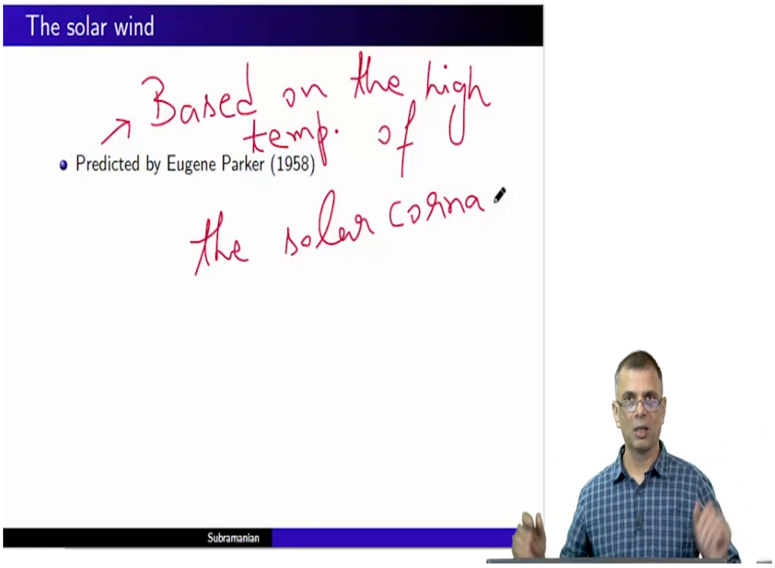

So, a little bit about the solar wind, this was actually predicted by Eugene Parker back in1958. Simply based on simply based on the high temperature of the solar corona, simply based on this fact, he surmised that there should be a wind that that is flowing outwards ok.

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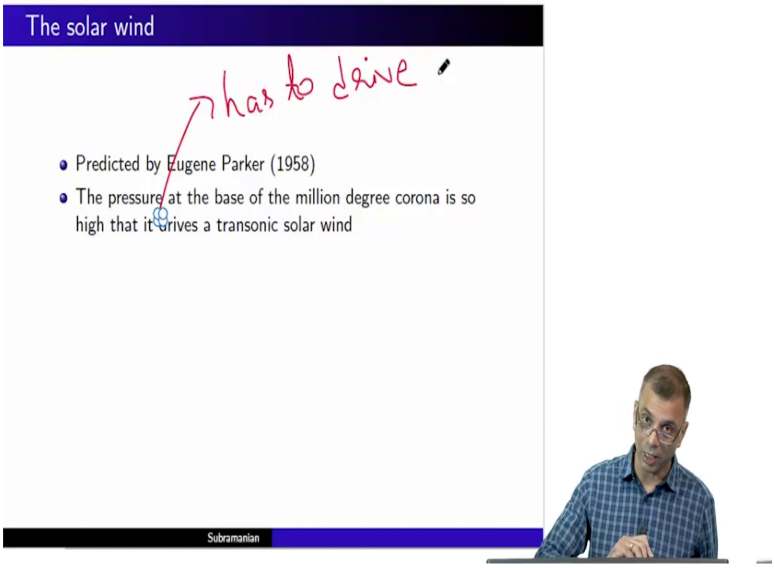

This was the main thing; he figured that the pressure at the base of the million degree corona is so high that it has to drive it, it drives or it has to drive it has to drive a trans-sonic solar wind well ok.

Well, whether the solar wind has to be trans-sonic or not is another matter, but a trans-sonic solar wind was the most elegant solution, solutions of the type two ok.

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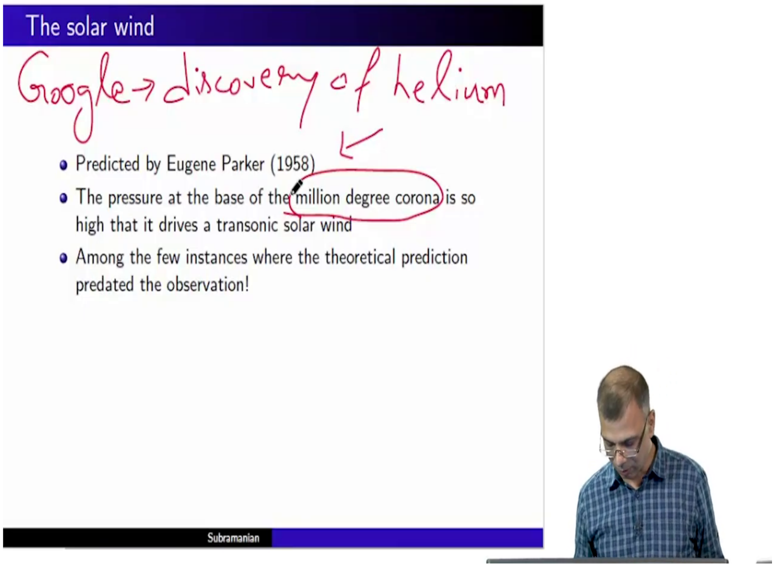

And actual discovery of the solar wind happened after 1958 in fact ok. And I will show you an instance, where you know it was shown how rather you know confirm the observational confirmation of the solar wind was quite interesting and the way it happened ok.

So, but it was among the first few instances where the theoretical prediction, predated the observation ok. So, this is quite a brilliant thing this does not happen very often ok. Most of the time there is a puzzling observation and existing theories, existing sort of you know existing understanding does not fit in. So, one has to invent or cook up or whatever a theory that fit is the observation.

Here you see this was the observational fact, that the solar corona was a million degree hot, this was the observational fact. And this was reduced from you know observations of eclipses, and one of the most important eclipse observations in fact, happen in Guntur back in nineteen forties if I am not mistaken and that is when helium was observed.

Helium was discovered, helium was discovered in the sun first and then on the earth interestingly enough ok. So, I would you know urge you to Google discovery of helium. If you Google this, you will find many interesting several interesting pieces of information and you will also find out that helium was discovered using data from a solar eclipse, that was observed at Guntur in Andhra Pradesh in India ok.

By a French astronomer called Jules Janssen if I am not mistaken. And so now, why am I saying this, this is because; this discovery of helium was one of the most important pieces in confirming that the solar corona is actually a million degrees hot. Well, it was suspected to be a million degrees hot earlier also, but that particular line that they observed was thought to be coming from entirely new element that they call Coronium ok.

It was only with this discovery that it must you know realized that, it was actually an element that was already kind a known and so, the fact that the solar corona was a million degree hot was realized soon after the discovery of helium.

Now, what Parker did was he figured that, if the corona is a million degree hot then the pressure is so high that the pressure in the corona the pressure right there is so, high that it cannot be you know the corona cannot be held back the outer atmosphere cannot be held back by the gravity of the sun; it has to expand and flow outwards in a manner of a reminiscent of solution two, that we have just discussed ok. And this is among the few instances, where the theoretical prediction predated the observation.

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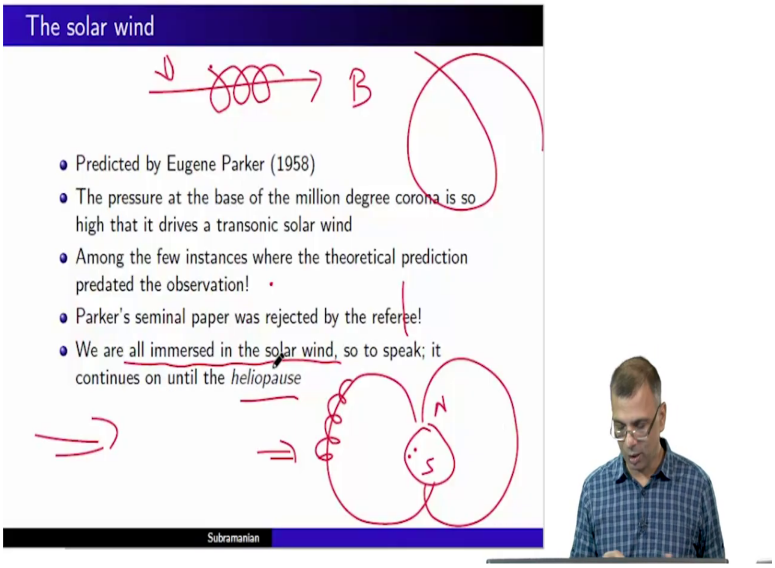

Turns out that this idea was so radical that, it was thought to be you know wrong and Parker's seminal paper was actually rejected by the referee ok.

And it was only after a lot of you know give and take and that Parker finally, managed to have his paper accepted and sure enough few years later the accuracy of the validity of his prediction was proved outstandingly right, and this is the solar wind was indeed observationally confirmed ok.

So, this is quite a remarkable story. In a sense, we are all immersed in the solar wind, you see the solar wind is something that emanates from the sun and it flows outwards ok. And it flows outwards and goes on keeps going on up until it hits up until I think beyond the of Neptune or even beyond Pluto ok.

And it continues on until the ram pressure of the solar wind, cannot take it any further ok. The pressure of the surrounding interstellar medium is so large that it acts as a wall and in some sense it blocks the solar wind ok, and that place is called the heliopause ok. And in some sense, the solar system is thought to be that volume, which is permeated by the solar wind ok, up until the heliopause people think of that as the solar system.

So, we are of course, well within the heliopause. So, we are also immersed in the solar wind as we speak. We are immersed in the solar wind, when the solar wind from the sun which is a stream of highly charged particles, hot particles, it is streaming past us, it is streaming past the earth as we speak. We are immersed in the solar wind the only thing is of course, the charged particles do not enter the earth's atmosphere ok.

The earth has it is magnetic field and the magnetic field protects the atmosphere from the charged particles entering it and that is because, you know if you have a magnetic field like so. And magnetic field pointing this way, and you have a charged particle it is caught in the magnetic field, it exhibit is it you know it rotates ok. It exhibit is circular motion and if it also has a component of velocity that is parallel to the magnetic field, the motion becomes helical like this ok.

So, a charged particle that is seeking to enter like this, cannot come in, it gets caught in the magnetic field. Of course, how well it gets caught in other words how large is the radius of gyration like this or is a radius of gyration like this that depends upon the strength of the magnetic field that depends upon the combination that depends upon two things. That depends upon the strength of the magnetic field and the energy of the charged particle.

So, if the earth was somewhere here, and this would be the geomagnetic field which sort of you know is a dipole like this, you know the earth is something like this. And the geomagnetic field is a dipole ok.

So, this would be the North Pole and this would be the South Pole. If you are standing in the equator it looks somewhat like this, there is a kind of so, a charged particle coming in like this, gets caught. And it you know gyrates along the magnetic field whereas, if a charged particle is coming like this, towards the poles it has relatively easy access ok.

I am saying all this simply to explain this statement; you know simply to explain this particular statement, that we are all immersed in the solar wind, ok. In other words we standing here on the earth, we are all immersed in the solar wind. The solar wind is blowing past the earth all the way and it goes this way ok.

And the earth kind of presents a bit of an obstacle to the solar wind, but that is ok, the solar wind is has so much ram pressure that it really does not care. The blows right past the earth and goes on beyond the orbit of Pluto ok, until it hit is the heliopause ok.

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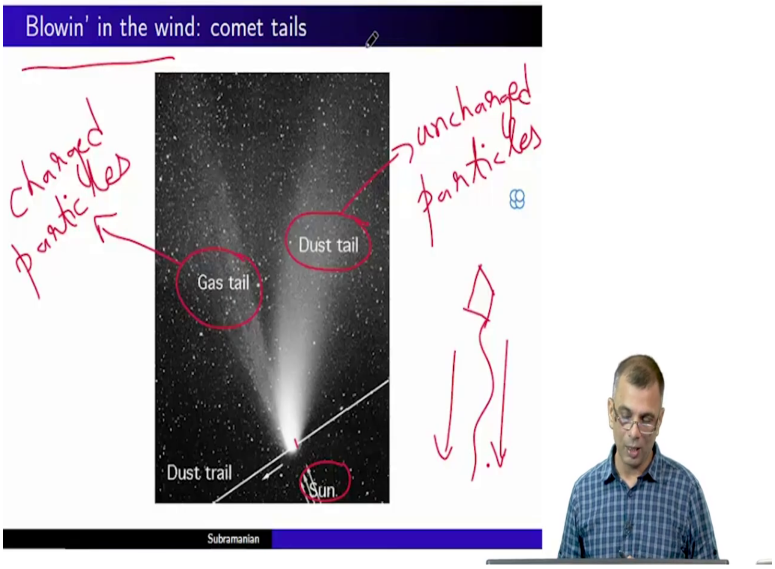

So, this is the thing and so, this is an interesting observation, it kind of tells you how the solar wind was discovered. You see this is where the sun is.

So, the sun is towards here ok, the sun is somewhere here. And this would represent a comet that is blowing past like this, sorry the sun is somewhere here and these arrows point in the direction of the purported solar wind ok. So, here is a comet that is you know going this way, and I am sure you know about comets, comets are you know objects from the Kuiper belt that often you know, they are very solar system objects and several of them pass through our field of view every year.

And this would be a typical comet and it turns out that it has two kinds of tails ok. It has what is called a dust tail and these would be essentially uncharged particles ok. And this would be a gas tail, which comprises of somewhat of charged particles not all, but some of them. And the remarkable observation was that the gas tails always pointed away from the sun, the gas tails always point away from the sun.

Somewhat like a kite ok. So, you remember when you fly kites and you have the tail of your kite, the tail of your kite always points always blows in the wind like this ok. The tail of your kite is as an indicator of the wind direction. If a wind is blowing like this, the tail of the kite will be pointing along the wind and that is exactly what gas tails seem to do ok.

They are always pointing away from the sun. It is almost as though there is a wind blowing away from the sun ok, and that is influencing the tail of the comet this would be the comet and that is influencing the tail of the comet more specifically, that is influencing the tail of the comet which comprises charged particles. That is because, although we have not alluded, we have not talked about magnetic fields at all.

So, far turns out that the solar wind also carries, also I mean you know essentially combs out the intrinsic magnetic field of the sun ok. And it combs it out into a pattern ok and so, what these charged particles are actually doing are they are following the large scale magnetic field from the sun, which is drawn out by the solar wind. So, the solar wind is essential to this description ok. The fact that the charged particles are following the magnetic field which is drawn out by the solar wind that is a secondary.

I mean you know it is an important effect, but that is a secondary effect. So, in some sense, this was one of the first proofs of the existence of a solar wind ok. All right so, this is one thing, but I do not want to leave you with an impression that the solar wind problem is completely solved far from it actually ok. There are a few other complications to the solar wind problem it is like this.

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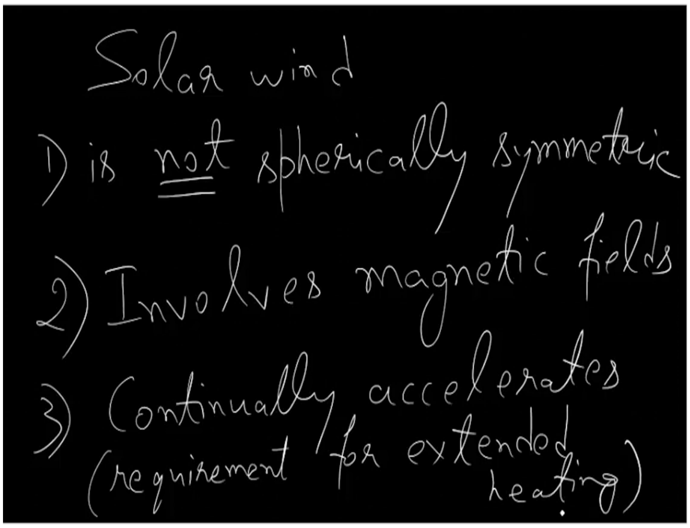

The solar wind the solar wind is not spherically symmetric ok. Although, our solution which we just described is a spherically symmetric solution to 0th order it is a very good description, that is the main thing I want a convey here. What is more it involves magnetic fields, which we did not discuss at all. In other words, the solar wind is magnetized, so magnetized fluid which we did not discuss at all ok.

So, this is another thing and what is more, the solar wind continuously continually accelerates, in other words there is a requirement for extended heating, in other words you remember our description what it does is, it takes the description of the solar wind which looks like this; it takes a hot plasma at the base of the corona and it passes it through the sonic point and as it you know moves out.

Obviously, it is getting cooler, that is why it s getting accelerated. The internal energy of the plasma is being converted into the kinetic energy. The bulk kinetic energy of the solar wind and that is why the bulk kinetic energy of the solar wind is increasing, and you know the number becomes larger than 1 and that is why. Now, turns out that observations are pointing out that it is actually, accelerating more than what this curve would predict.

In other words, there is a need for there is a requirement for extended heating, even as a solar wind flows out ok. And this is not accounted for in our simple minded solutions. So, these 3 points are just to you know give you an understanding, but the problem is not really solved yet; there are several other interesting features, while the basics of the problem are well laid out by these simple solutions the details and some very important details are far from clear.

Now, let me show you one interesting observation, which has to do with this point the fact that the solar wind is not spherically symmetric.

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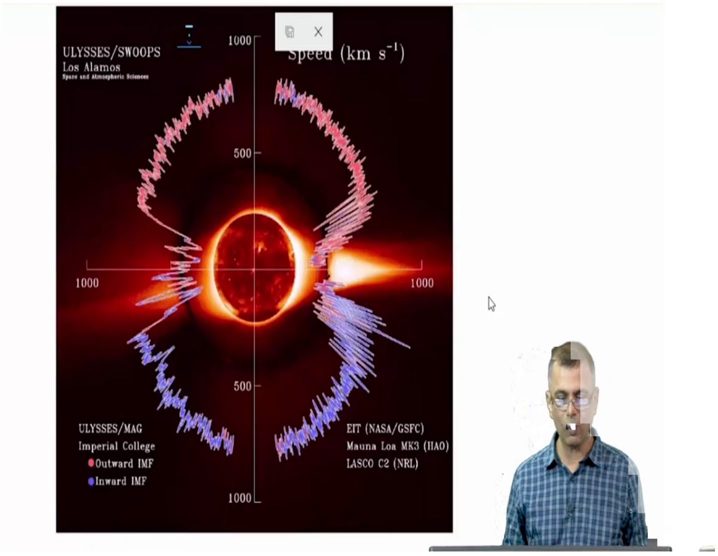

And, that is given by this picture. What this is? There was a spacecraft called Ulysses. Ulysses out here and this particular swoops is an instrument about Ulysses and this is a pretty old spacecraft.

If you Google Ulysses, you will find out when it flew and what the spacecraft did was it took a pass over the sun, all the way from the poles from the South Pole to the equator to the North Pole and back ok. And these are actual observations, these are observations of the sun taken with I mean these are observations, which are superimposed ok.

These are observations of the of the sun taken with extreme ultraviolet imaging telescope aboard the soho spacecraft and these are observations of the extended solar corona super pose, it is not this and this do not come from the same instrument they are superposed here for visual clarity ok.

And so, this is essentially the solar corona, the inner solar corona and these comprise streamers and everything. But these are slightly you know this is for context ok, this one and this one are for context. What we are really interested in are these lines now, what are these lines, these are measurements of solar wind velocity ok. So, you have 1000 here and 500 here.

So, what this is saying is that, around the equator, you see this is the equator of the sun and around the equator the solar wind velocity is around you see this 500 is here so, this 500 would be somewhere here also ok. So, around the equator the velocity of the solar wind is around 500 kilometers per second, something like that around the equator here, here also here. Here turns out that it is even lower, 500 would be somewhere here for instance.

And you know it is around 500 ok. However, around the poles you see 1000 is here and so, this would be something like 800 or so 800, 900 something like that. So, around the poles you see right exactly at the pole data is missing, but around the poles you see the solar wind velocity is much higher, it is around 800 to 900 kilometers per second whereas, around the equator the solar room velocity is lower ok.

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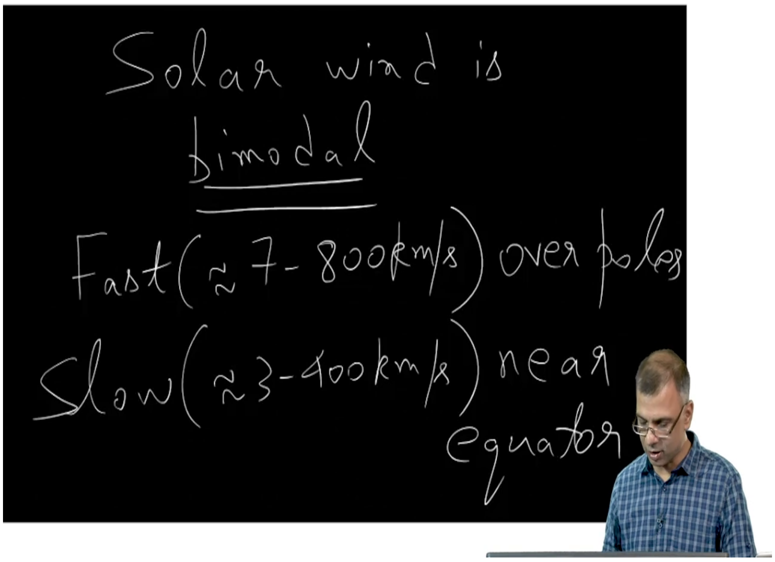

So, therefore, the message to take away from this is that, the solar wind is bimodal, there is a fast around I do not know 7 to 800 kilometers per second over the poles, and slow meaning around 3 to 400 near equator. This is the message that this figure is telling you ok. So, clearly this is not a spherically symmetric solar wind, no a spherically symmetric solar wind would have the same speed irrespective of the equator in the pole right.

So, clearly this is not a spherically symmetric solar wind, so this is you could say a drawback of the theory that we just you know outlined, and what is causing this by modality well.

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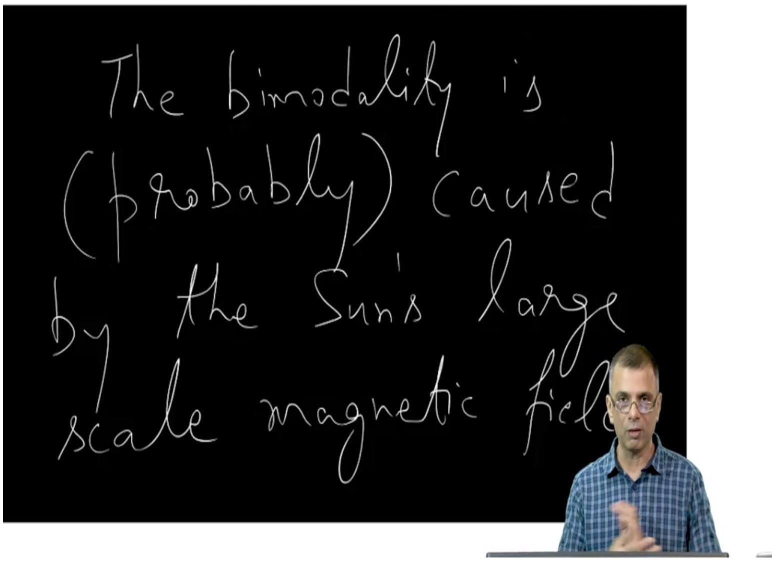

Roughly speaking, the bimodality is I would really say probably not quite clear caused by the sun's large scale magnetic field, and these are issues that we will large scale magnetic field.

So, what we will do is we will take this up, we will take things like magnetic fields and everything a little later and when we start incorporating magnetic fields into our equation, and start discussing the field of magneto hydrodynamics. So, we will stop our discussion of the solar wind here, and we will take up a little more about spherical accretion and there on start to discuss a disc like accretion next. So, we will stop here for now.

Thank you.