Astrophysics & Cosmology
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Lecture - 21
White Dwarfs

Welcome, we have been till now mainly discussing things within the solar system and our discussion of the stars has largely concerned with the sun though the equations that we developed can be applied to all stars. Today, let us start of by discussing how distances outside the solar system are measured the most direct method for measuring distances outside the solar system is through parallax.

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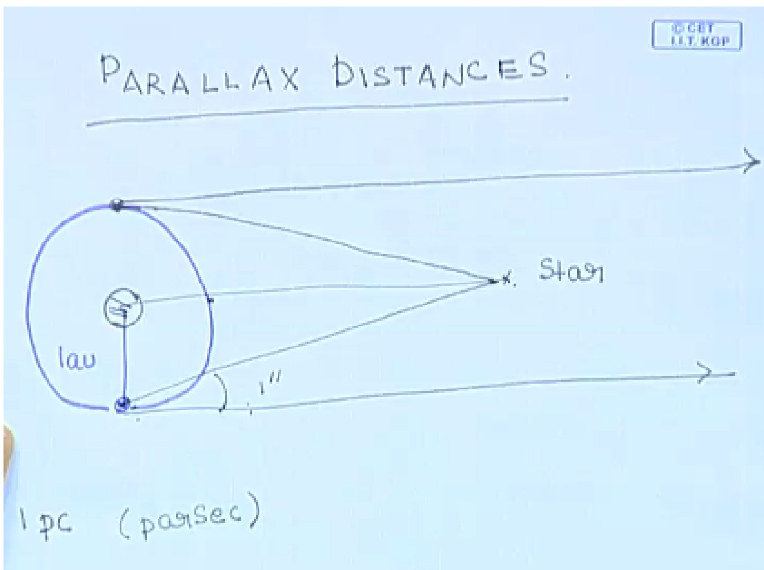

We are quite familiar with the phenomenon of parallax when we look at an object it is apparent it is angular position changes when you move. And if you look at 2 objects at different distances then the change in the angle is more for the closer object it is less for the further object so if there are 2 objects have different distances and if you move you will find relative motion between these 2 this is the basic idea in the measurement of parallax distances.

Any observer in the earth is moving around the sun and the radius of this circular motion nearly circular motion is quite very determined. That is one astronomical unit so this is the sun and let us say that this is the earth they are obviously not drawn to scale and the earth goes around the sun once every year and the radius of this circular orbit is very well known it is one astronomical unit now if you look from the earth if you observe a star there to say that this is a star we observe the star from the earth.

And this is the angular position of the star when the earth is at this position then the angular position of the star same star would have changed when 6 months later now the question is how does one measure this change one needs a reference. A reference point for a reference we consider very distant stars very distant objects so if I have a very distant object imagine a very distant object to be much beyond the size of this screen size of this paper where I am drawing so just imagine such an object.

That object the angle at which that object would appear would the change in that angle would be imperceptible much smaller than the change in a nearby object okay, so you could measure this change in angle with reference to a distant object whose angle does not change okay and an object this is how the distances for nearby objects beyond the solar system can be measured these distances are referred to as parallax distances.

And these are the this gives us the most direct estimate of distances beyond the solar city and the unit of distances beyond the solar system is based on this so the unit of distance on the solar system is a parsec which is denoted by 1 PC parsec and it is the distance where If I place a star here at this distance this parallax angle would be one arc second. So, the parallax angle between this position and this position would be one arc second.

Or the entire angle at the 6 month's interval would be 2 arc seconds, okay so a distance where if I place a star. In 6 month's interval, so I have to wait for 6 months and again measure the angular position of the star if it has changed by 2 arc seconds. Then I would know that this angle is one arc second so 1 parsec is that such is this distance and we can estimate. We can see how much calculated how much it is it is 1 astronaut so this 1 astronomical unit is 1 parsec.

The radius this into the angle this angle is the same as this angle so 1 astronomical unit the radius here is 1 parsec into this angle or 1 parsec is 1 astronomical unit divided by 1 arc second and you have to convert this into meters you have to convert this into radiance. So I leave this as an exercise for you very rather straightforward exercise if you do it you will find that this comes out to be 3.09*10 to the power 16 meters.

Okay, so this is 1 parsec this is 1 parsec that is the distance outside the solar system so within the galaxy the stars that we see we shall be talking about distances in parsecs of it so this is the first thing. Next let us consider the observations of stars or other astronomical objects the quantity that you.

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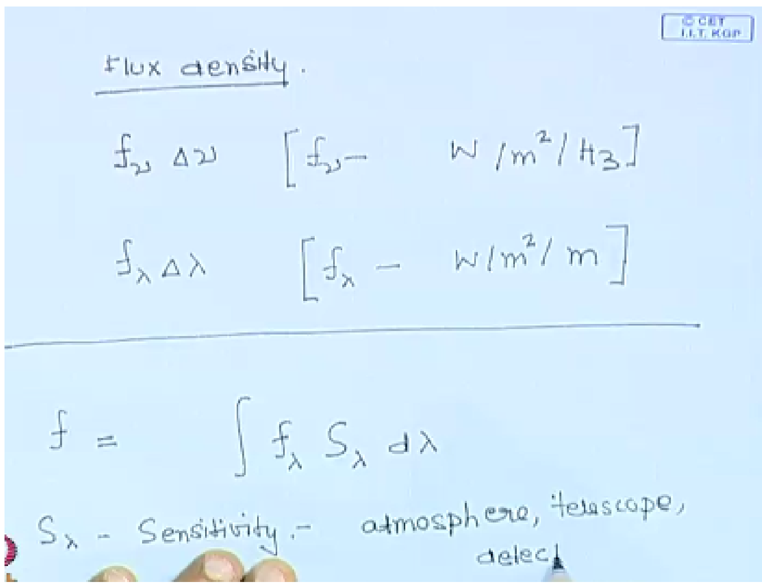

We shall start with this quantity the flux density F mu, F mu tells us the energy the energy coming per unit time interval so that is so flux density is essentially if I place a detector 1-meter square. The energy coming there per unit time interval in the frequency range the d mu. okay so this into delta mu tells me the energy coming per unit per meter square the flux of energy in one second, okay.

So F mu has dimension watts per meter square per hertz, we have already discussed the how to describe radiation or alternatively we could use F lambda which is defined so that this into delta lambda tells us the amount of energy coming per unit area per second, okay so that F lambda has dimensions watts per meter square per meter so this we shall refer to as flux density. The quantity that is measured in any astronomical observation.

Suppose I am looking at a star or a galaxy through a telescope the quantity that is measured in any astronomical observation is the flux which is the flux density into the sensitivity of the observation into D lambda and the S lambda incorporates the effect of the atmosphere that we are looking through after all every observation from the earth is through the atmosphere and the atmosphere may not allow all wavelengths to pass through equally then it also includes the telescope.

The telescope may not respond equally to all wave lengths, so that is there in the sensitivity and also the detector the final. Instrument that detects the amount of measures the amount of radiation also may not have an equal wave length response and the flux that is measured finally is an integral of the flux density over the wave length with the sensitivity and the sensitivity incorporates all of these effects yeah F this is watts already present, okay.

So, this is already there, energy per second that is watt so this is the quantity that is measured. In any astronomical observation of a source the flux right now in astronomy. It is quite it is standard procedure particularly in optical astronomy to quantify the flux the brightness of an object using units.

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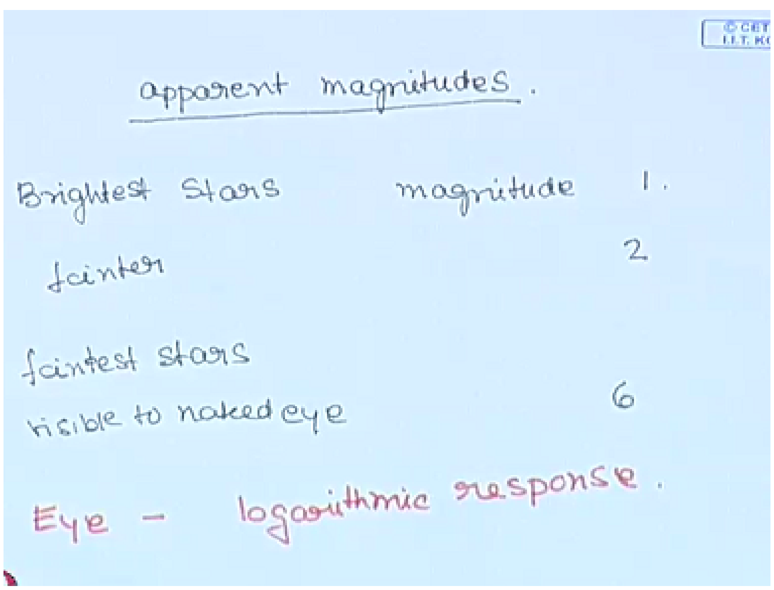

Which are referred to as an apparent magnitude this these units there were actually inherited from the ancient astronomers. The ancient Greek astronomers the classified the stars that they could see visually and the brightest stars were given magnitude 1 so the brightest stars that would that they could see were of the first had a magnitude 1. And then the ones which appeared to be roughly half of half as faint something like that they were given fainter stars but given the magnitude 2.

And the faintest stars that are visible to the naked eye these have a magnitude 6 that is the faintest which are visible to the naked eye so this was done by the ancient Greeks they classified the stars and give this as associated these kind of numbers. This kind of a scheme okay now later people discovered that the eye actually had a logarithmic response the response of the eye is not linear. If you have a linear response.

The dynamical range that is the brightest and the faintest object that you can see will not be very far apart but if you have a logarithmic response the dynamical range becomes much more, so the human eye has a logarithmic response, okay, so the eye what do you mean by this what you mean is that if you have an object and you have another object, if you increase the flux by 2 times, it will not appear twice as bright to you it will appear a by a small.

The difference will be relatively small okay it is the ratio, the log of the ratio that you will see as the brightness, the change of the brightness okay and It was later found that these magnitudes are related to the flux. By this relation.

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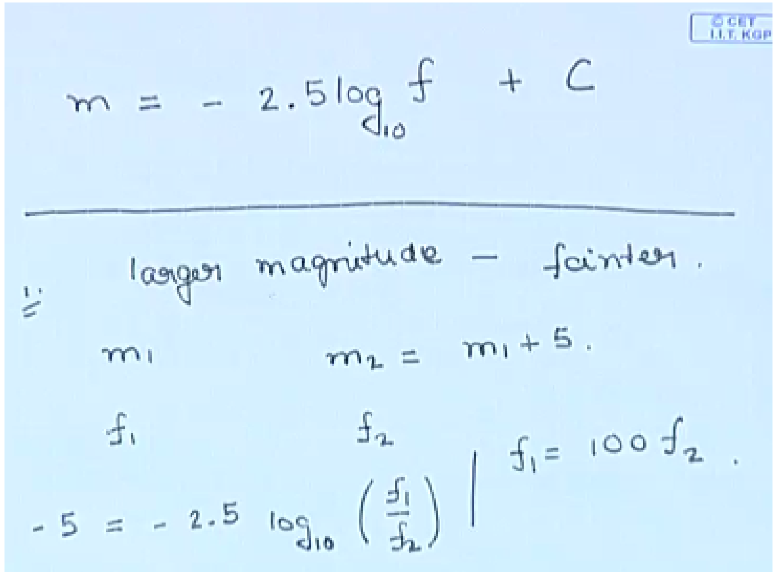

So that apparent magnitude is related to the flux like this -2.5 log 10* the flux of the flux + a constant. So it was found later that the apparent magnitude which were defined by magnitudes which were defined by the ancient Greek astronomers were related to the flux. In the measured fluxes like this it is-2.5 log base 10 of the flux + a constant. The positive search the 0 point of the magnitude right now.

So this is the definition of the apparent magnitude let us just try to see appreciation for what it tells us the first point that you have to note is the larger the magnitude. The fainter the star is to the larger the magnitude the fainter and the object is the lower the fluxes that is the first. Second, let me ask you a question suppose I have 2 sources and the magnitude of these 2 sources differ by 5. Okay so I have M1 the first source and let us see them M2 is the second source.

The magnitude apparent magnitude of the second source and M2 is M1+5, so let me ask you what is the relation between the flux of this source and the flux of this source there are 2 sources 1 and 2. let us say that this has a flux F1and this has a flux F2. The question is what is the relation between the flux of the first source and second source. There are 2 sources, this is quite straightforward so we can just subtract.

The M1-M2, let us consider M1-M2 and if you consider M1-M2, what you have is-5 = -2.5 log base 10. And you have the ratio of the 2 fluxes right F1/F2, so you want the log base 10 of the ratio of the fluxes to be 2 to be to be-2right which essentially tells us that to be rather 2 = 5, so it tells us that if f1 = 100F2 hundred times, so magnitude difference of.5.

We see corresponds to the flux going down by a factor of 100, 100, so this source is hundred times fainter than this source, so to the eye it would appear 5 times. The 5 magnitudes lower in the brightness, so this is the gives you an idea of the magnitude scale so a magnitude different 5 indicates the flux has gone down by a factor. Now these magnitudes are measured in different bands.

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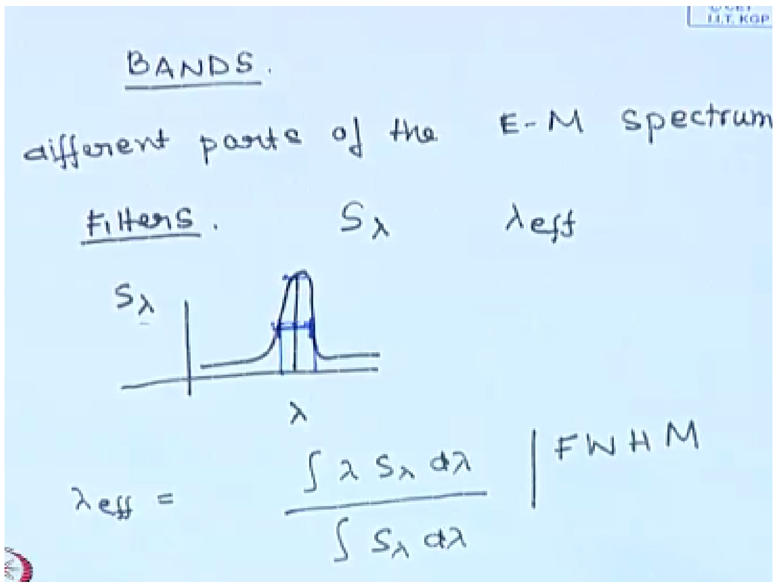

So apparent magnitudes are measured in different bands so different bands refer to different parts of the spectrum what this refers to is of the electromagnetic so in a single observation it is possible to measure the, okay before I go into this I should first tell you that the measurements of flux measuring the flux from a source is referred to as photometry this is these kind of observations are referred to as photometry.

Photometry there is another kind of observation that is possible where you measure the relative. Intensity of the light at different wavelengths such observations are called spectroscopy there you are not interested in the magnitude of the flux total flux coming but you are interested in the relative contribution in different wavelengths different parts of the spectrum such observations are called spectroscopy.

These observations are targeted at measuring the flux from a given source and the flux is measured in a specified wavelength range which is referred to as bands. So each band refers to a different part of the electromagnetic spectrum and the band is implemented through filters so you have filters corresponding to each band. So the response of the filter is there in the sensitivity as lambda which we had introduced earlier.

So if i am measuring photometry in a certain band I tell you the flux or the apparent magnitude in a certain band then this is what we do if you take in the telescope at the end of the telescope before you measure the flux you put a filter. A filter will only allow light of a certain range of wavelengths. to pass through that is what the filter does so this is a particular band and you can have different band systems.

Okay, each filter so these are filters each filter is specified so would be the filter defines the band and each filter is specified by telling you telling the effective wavelength and so this is the effective wavelength, what is effective wavelength so the effective wavelength would be lambda effective okay this is the effective wave length and this is the this gives an idea with which wave length the filter response.

So you specify the effective wave length under full width at half maximum full of it at half maximum. What do you mean by this you determine the position where you have the Maxima? Or the filter has maximum response then find out where it does have that value the width of this function at that point is the full width that half maxima, so these 2 numbers are typically provided to characterize the filter you really want to characterize it fully then you have to give the whole function as lambda.

For the filter along with everything else okay but the filter will finally determine. The sensitivity of this is telling you the sensitivity of the filter here what i am showing here is the sensitivity of the filter, okay so this is a very commonly used band system of photometric bands it is referred to as the U.B.V photometric.

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UBV photometry

Table 1: This shows the definition of the UBV bands. The Solar luminosit and corresponding absolute magnitude are also shown for each band. From Binney & Merrifield,1998[2]

Band	$\frac{\lambda_{eff}}{\text{nm}}$	$\frac{\text{FWHM}}{\text{nm}}$	$\frac{L_{\odot}}{10^{25}\text{ W}}$	$M_{\odot}$
U	365	66	1.86	5.61
B	445	94	4.67	5.48
V	551	88	4.64	4.83

U stands for ultraviolet, so let me discuss this U is ultraviolent B is blue and V is visible, so this is the standard this is a very standard photometric band system okay which is which are refereed to UBV bands and this table here shows you the effective wavelength gross warning each of these bands so there are 2 filters one corresponding to U one corresponding to B one corresponding to V.

So when you do any optical observation if you are using this you mean we you know when trees keep the light when you get make and when you look at astronomical source you measure the flux of light through each of these 3 filters and you convert them into the apparent type you chose you and this is this U filter allows light centered at 365 nanometers to pass through and it has a full width, half maxima of 66 nanometers.

Okay, the blue band is given over here and the visual band is given over here. The full width that half maxima are also given for reference this table also shows the solar luminosity in these bands, so if i look at the sun how much energy does the sun emit in this particular band , okay so it did in astronomy it is very common practice to refer to the luminosity of a astronomical sources in terms of the solar luminous.

So when we are doing this for in the U band this tells you the solar luminosity in the U band. This tells you the solar luminosity in the blue band and the do the solar luminosity in the visual band this is in units of 10 to the power 25 watts, okay this column actually.

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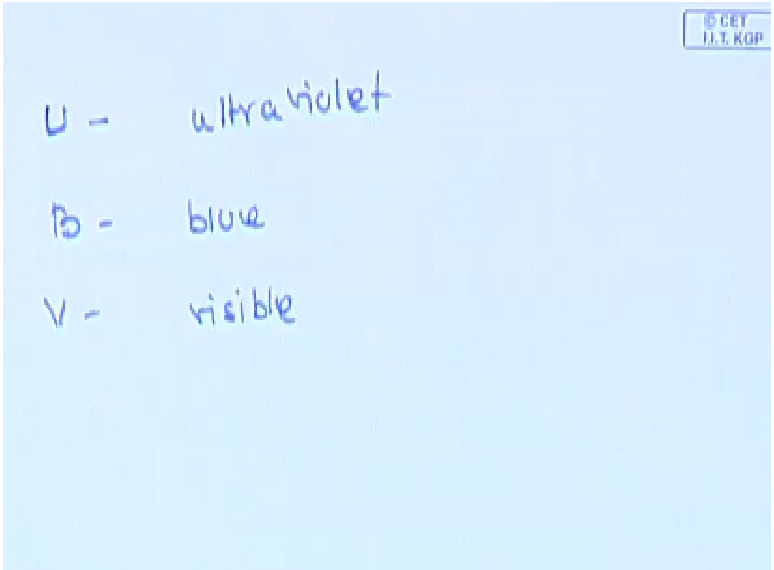

So this is a very classic photometric scheme the UBV photometry

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Table 3: Characteristics of the SDSS photometric system. From Fukugit
et. al. 1996[31].

Band	$\frac{\lambda_{eff}}{A^\circ}$	$\frac{FWHM}{A^\circ}$	Q (Flux sensitivity)
u	3557	599	0.0181
g	4825	1379	0.110
r	6261	1382	0.101
i	7672	1535	0.0766
z	9097	1370	0.0354

Now there are band systems which extend much beyond all the way to the infrared so this table shows you these Sloan Digital Sky Survey this is a very recent recently completed, actually it is nearly complete now, the Sky Survey, the Sloan digital sky survey shows you the photo matric system that was used in the Sloan Digital Sky Survey they have not used these U BV bands. For any image in this in the sky any astronomical source in the sky.

This survey, this has surveyed the entire sky, most of the sky maybe not the entire sky but most of the northern sky at least and they have used this band system so they have measured the flux in these 5 bands and note that the bands here extend from ultraviolet all the way into the infrared the Z band and i band these out in infrared okay so there are a variety of a possible band systems and it is very important.

When you interpret astronomical observations that you know the band in which the observation was made otherwise the it is meaningless so if somebody tells you this is the flux coming from a source somebody does put on and tells you the flux or tells you the apparent magnitude then you should know the band in which the photo matching band system in which the observations were done this is the first thing.

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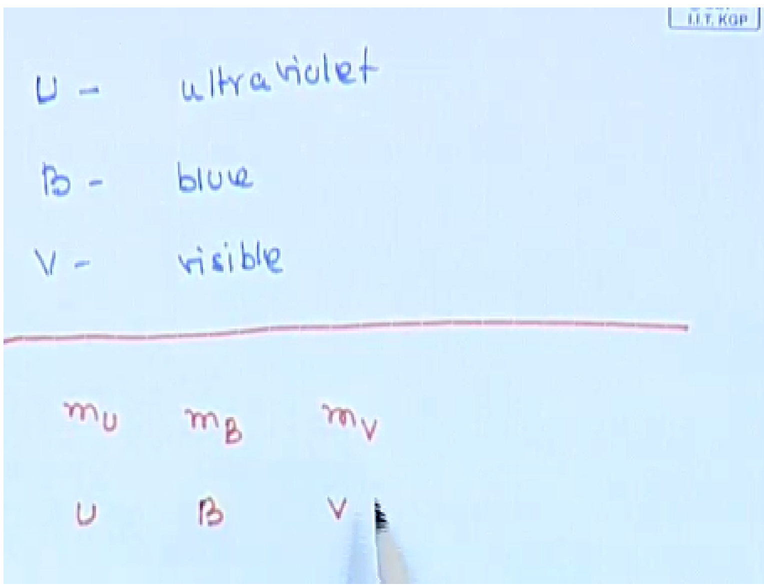

Okay, the second point here is that the apparent magnitude in the U band for example will be referred to as MU. The apparent magnitude in the B band will be referred to as MB and the apparent magnitude in the V band will be referred to as MV, it could to be referred as U, or it could be referred to as UB and V, okay so there are different notations to refer to the apparent magnitude in different terms right.

So astronomical observations are quantified in this way, now the measured magnitude it is quite obvious that this depends on the distance because the flux we know depends on the distance it follows 1/the distance square so the measured magnitude also depends on the distance okay but there is something called color.

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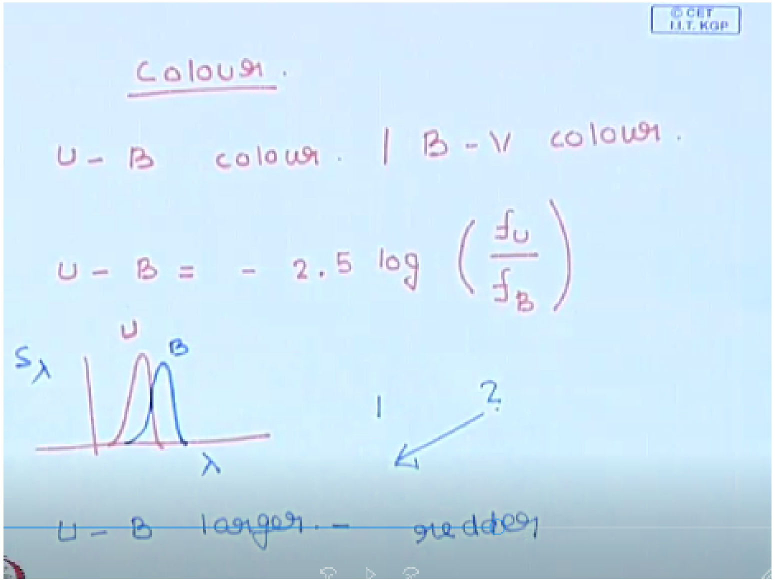

One can define something called a color and you can have different kinds of colors so you could have U-B color. So what is the U–B color it is the difference in the magnitude in the U band and the B band. So U-B band = -2.5 log the flux in the U band divided by the flux in the V band you could also have a B-V color and this again will be the ratio of the flux in the blue band to the flux in the visual band what do these colors tell us.

Okay so the color gives us some an estimate of what we actually mean by color in when we use the word color in daily parlance so when I refer to the color of an any object i am wearing a white T. Shirt okay or this is a red pen it essentially refers to the relative contribution of the radiation in different wavelength bands which is what the color quantifies it is a relative contribution in different wavelength bands.

So the U-B color will tell me the ratio of the light coming in this band that is called is the U band to the light the flux of radiation in the blue band this is wavelength and this is an S length, okay into different parts of the wavelength so a larger U- B so suppose I have 2 sources one which there are C 1and 2 and 2 has a U- B which is larger. Okay so for 2 U-B is larger, what does that tell us it tells us that the U-B Is larger implies that for 2?

The blue flux is more than the ultraviolet flux relative to one because this is a larger value this is a positive value. But this this is a positive value this is more for the second source its being more tells us that for the second source this issue is smaller the blue has more flux than the ultraviolet so this implies that the source 2 is redder. Ultraviolet more as it has more of the larger wavelength complement which is what we refer to as red for most astronomical sources. If you think of, if you can think of the radiation as being a black body spectrum.

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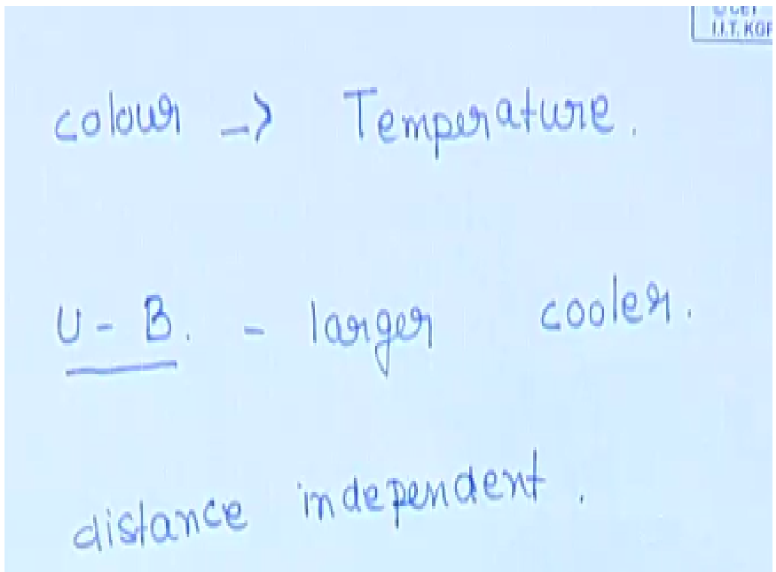

The color then the color gives an estimate of the temperature so for if you think of the source if you can think of the radiation from the source in terms of the black body spectrum which we have already discussed then the color is gives an estimate of the temperature and the larger the color so let us look at the U-B color so if it is larger it tells us that the flux in the blue band is more than the flux in the ultraviolet.

So we know that the black body spectrum the peak shifts with the temperature. And the source gets redder as it gets cooler it will get bluer as it gets hotter, okay so the more energy will be there in this band for a hot source and more energy will be there in this band for a relatively cool source. So this if it is larger it tells us that I am looking at a cooler source, okay so the color gives an estimate of the temperature the color information is independent of distance.

Since it is a ratio of fluxes is distance independent okay and we shall be referring to color in the future in the subsequent discussion. The color of radiation from different sources, so color refers to the difference in magnitude s or log of the ratio of the fluxes at different bands.

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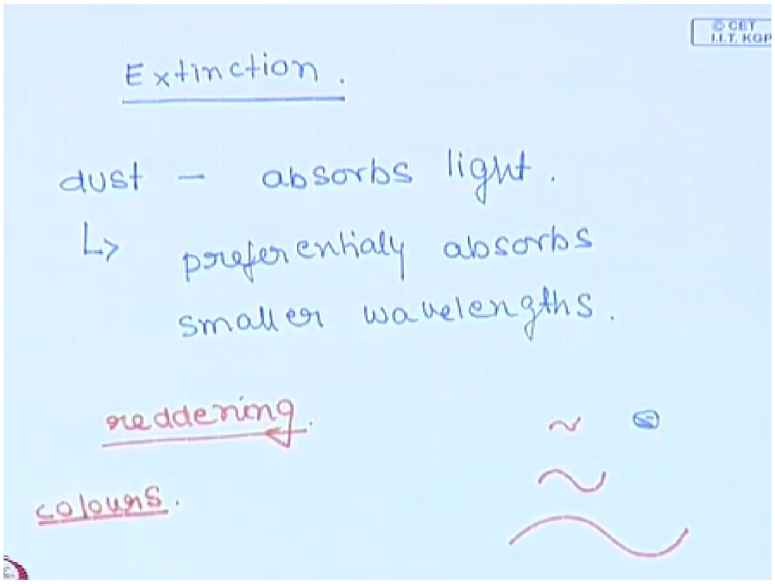

Next thing and that we need to discuss is extinction in the interstellar medium so extinction whenever we do any astronomical observation, we are looking at sources through the interstellar medium so the region between stars is not empty it is filled with material and we know that there is dust particularly in the plain of our galaxy there is dust, okay, so the dust absorbs light this is what is this is what is referred to as by extinction this is what we mean by extinction interstellar extinction.

Dust grains, these are grains of particles and there which there between the stars they absorb light and if you measure the apparent magnitude of a distant object of a star it has been diminished the flux has been diminished in addition to the diminishing due to the distance and also is diminished due to the extinction, the extinction also has another effect this effect arises from the fact that dust preferentially absorbs smaller wavelengths.

So this process is more efficient in absorbing radiation of smaller wavelengths as compared to that of larger wave lengths, okay this has to do with the size of the dust grains so the dust grain have a size like this it will be more efficient in absorbing radiation whose wavelength is smaller than this than it is in observing absorbing wave length which is larger and it will be wavelengths which are much larger than this will just pass through they will not even notice that the dust is there.

So the dust is very effective in absorbing high frequency or small wave length light and it does not it does not affect the radar light as much, okay does it affected so what does? will do is it also causes reddening. It will make the radiation to appear redder so when you are looking at astronomical sources through dust. They will appear redder and then the radiation gets reddened and relatively what it started out with.

And this is then noticeable in the colors so the color gets redder so the color increases essentially so not only do the flux does the flux not only does the magnitude increase but the color also increases it gets red okay and if you have some idea about the spectrum of the source to start with then one can construct combinations of color.

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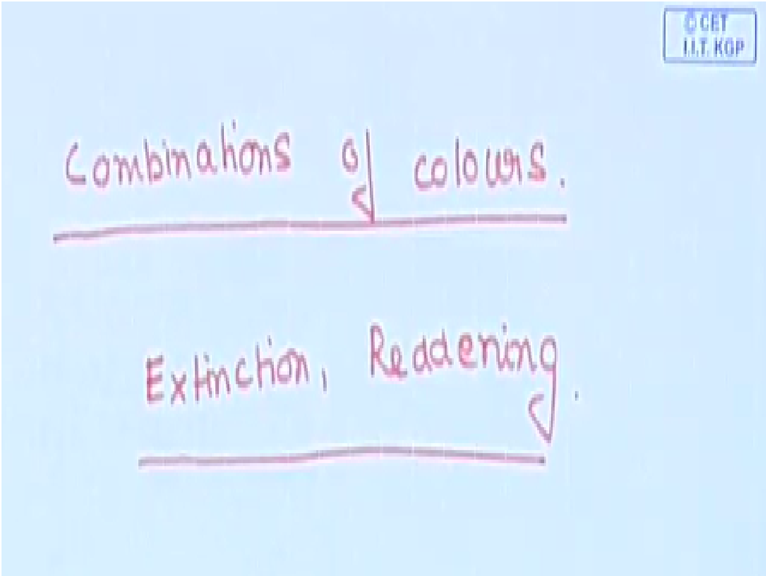

So one can look at combinations of the colors and one can then explicitly find out the work out how much absorption has taken place one can act from this one can work out the amount of extinction and reddening by using combination of colors, okay so let me remind you what the basic idea is again the dust absorption is not uniform at all wavelengths. So it appears the radiation it causes the radiation to appear redder.

And this can be used this to construct combinations of colors which allow you to determine from the division how much extinction and reddening have really occurred they would occur together, okay they do not occur separately that is the main point and using this you can actually work out how much of extension has taken place and correct for it, okay So this is I think that one has to bear in mind the next point is that of distance.

So the apparent magnitude allows us to quantify the apparent brightness of a source now what about the effect of distance. Suppose, I want to compare not the apparent bright nature brightness of a source a source could appear bright because it is near another source could appear faint because it is far away but in reality the fainter source could intrinsically be brighter than the one that appears to be so the faint.

The one that appears to be faint good intrinsically be brighter than the one that appears to be bright to us so we would like to have something which allows us to compare the intrinsic brightness of the sources, okay that is what is done by using the absolute magnitude.

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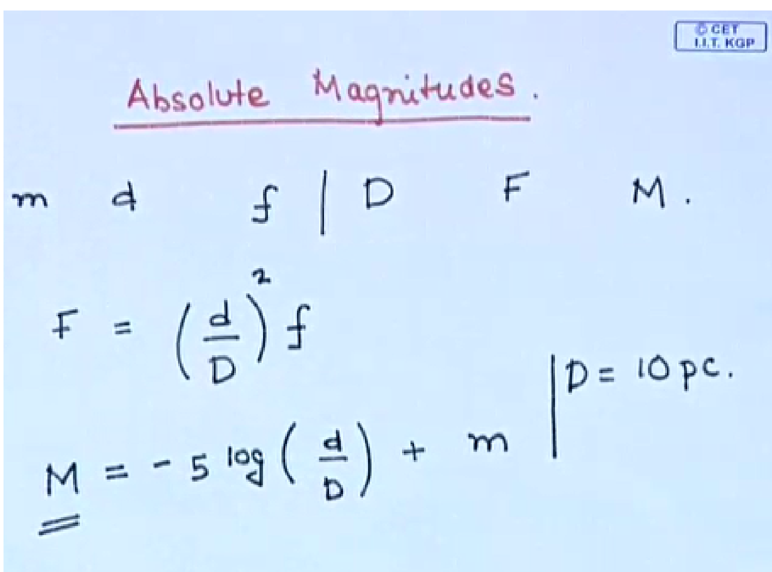

So let us consider a source at a distance D and from which we are measuring a flux F okay let us now ask the question that if the same source were placed at a distance capital D what would be the flux F and it is quite obvious that if the flux scales. Inversely as the distance squared so this would be right so it would be proportional to the distances squared the ration of the distances squared into the flux when it was at a distance.

Now so let us now use this and ask the question what if my source. At a distance small D. has an apparent magnitude smaller m so this has at the center but at magnitude M., what is the magnitude? corresponding so all that we have to do is take a log of both sides and multiply with -2.5 and the constant will cancel out it will appear for both of them so it will cancel out so what we have is M = 2.5 it will become 5 log.

So this will be a log of this into -2.5 s a log of this into there should be a – here right there – I, i take a log and then multiply with -2.5 that will give it a magnitude corresponding to a distance capital D. So I have to take log here and then that multiply with -2.5 which will give me -5 okay and so this is it now to compare the intrinsic brightness of sources what we do is we place them at a distance D = 10 parsecs and this is what is referred to as the absolute magnitude.

Okay we refer to this as the absolute magnitude so if you place the source at a distance any source at a distance of 10 parsecs what is the apparent magnitude that it would have that is what is referred to as the absolute magnitude but this is used to compare the intrinsic brightness of different sources, intrinsic velocity and it is called the absolute magnitude. So let us now go back to our band The U.V.B photometry band before we do that.

So that we can now go back and ask the question what is the 0, what sets the 0 of the of the magnitude scale let us go back and now ask the question what sets the 0 of the magnitude scale the 0 of the magnitude scale is set very is the 0 for which source is the 0 that unless you know that. You will never know how to bend words the measured magnitude into a flux.

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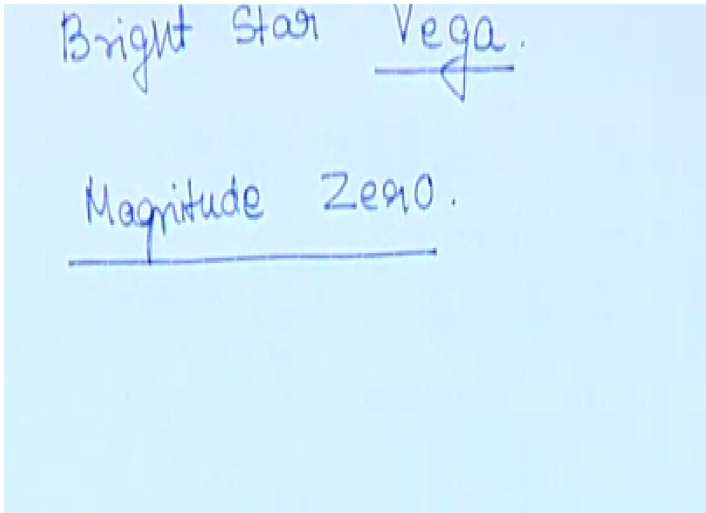

So the 0 is determined using a bright star followed Vega, so this has magnitude apparent magnitude 0. This sets the 0 point of the magnitude scale having told you this now let us go back to the table that we were looking at.

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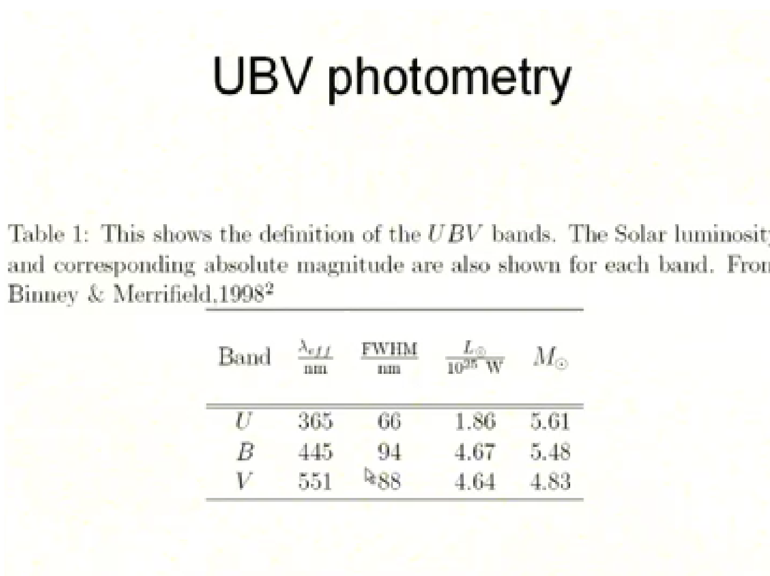
UBV photometry

Table 1: This shows the definition of the UBV bands. The Solar luminosity and corresponding absolute magnitude are also shown for each band. From Binney & Merrifield,1998[2]

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U	365	66	1.86	5.61
B	445	94	4.67	5.48
V	551	88	4.64	4.83

Let us look at the table, okay now here the last column in this table tells us the absolute magnitude corresponding to the solar luminosity the solar radiation so the sun has an absolute magnitude of 5.61 in the U band, what does it mean it means that if the sun were kept at the distance of 10 parsecs and the word then measure the flux in the U band the magnitude would be 5.61, okay so you can use this also if you wish.

Because to convert any magnitude to units of the solar luminosity or to convert into units of watts because here you see this solar luminosity is given in terms of watts.

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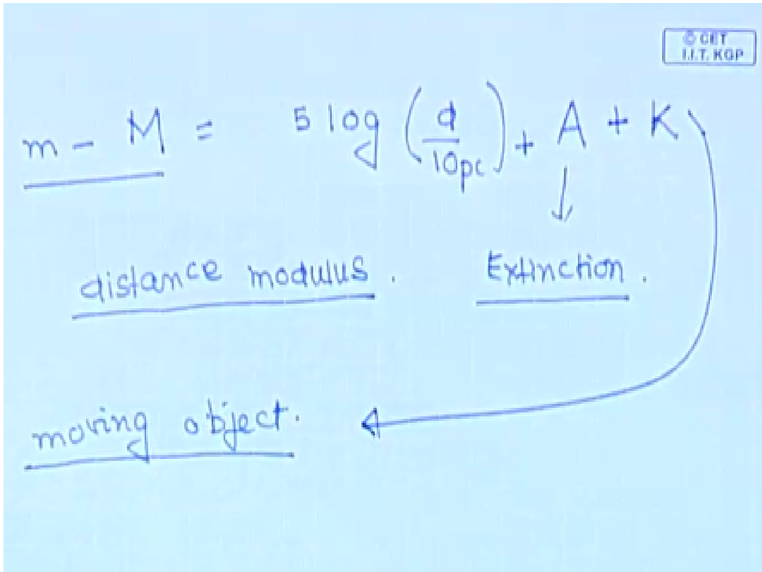

Okay finally i have to mention that the difference between the apparent magnitude and the absolute magnitude gives an estimate of the distance so this distance should read parsecs d, so if I know the apparent fake and measure the apparent magnitude of an object if I know its absolute magnitude this gives an estimate of the distance to that object this number is called the distance modulus. There are 2 effects which need to be included in this the first effect is the effect of extinction.

For the same source it could appear fainter due to extinction that this is telling us that it will appear fainter because of the distance but it could also appear fainter due to extinction, okay so if you or if you know these 2 and you want to estimate the distance then you have to correct for the fact that the source could be faint. Because of extinction also right so you have to put in this extinction a bear in mind that this extinction coefficient is extremely wave length dependent.

So it would be different in different bands this is the first thing the second point so this takes into account extinction The second point is for a moving object if you look at in a moving object. Then its light gets the frequency gets shifted and absolute magnitude refers to the flux in the rest frame of that object. The apparent magnitude refers to the flux measured by us so we are measuring letter C. In the U band and the object.

Let us say is moving towards us then what we measure in the U band in the objects rest frame would have to be could be in the blue band, okay so one has to correct for this effect also and one can in principle correct for this if you know the spectrum of the object the spectral distribution and this is corrected by introducing something called the K correction.

Which takes into account the fact that when you look at a particular band sitting here it corresponds to a different band in the rest frame of the object this refers to the flux measured by us the apparent flux apparent magnitude this refers to the flux in the rest frame of the object, okay so that is incorporated through the K Corrections is called the K correction and it is important in cosmology where the sources are shifting away from us so one has to be incorporate the K correction.

So let me stop here. Let me remind you what we have discussed today. We have discussed first the length scale measured by parallaxes and I told you what a parsec means. Second we discussed magnitudes the system in which you measure the flux of astronomical sources and I told you what a magnitude was it is a logarithmic scale there more of the magnitude higher the magnitude the fainted the source let me stop today's discussion.