



The Very Large European Telescope, based in Chile

Crédit image: ESO - Gerhard Hühdepohl

We have seen in the previous lesson the principal radiation processes in astrophysics. Radiation can be collected by telescopes, or by antennas depending on the wavelength range.

Notes

Summary





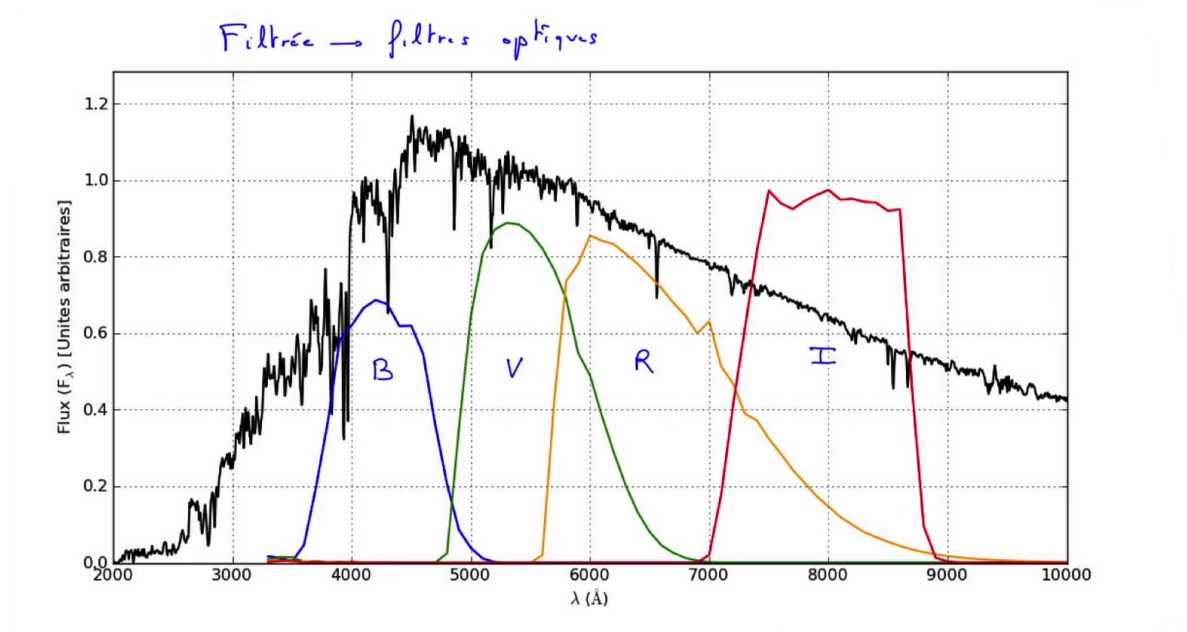
Observatories can be placed on the ground, if the atmosphere doesn't interact too much with the radiation from stellar objects, or in space. For every case, we need to be able to quantify, we have to measure the radiation. We will see in the following how astronomers measure the luminous flux, the colour of the stellar objects, and how to estimate the luminous power of stellar objects.

Notes

Summary



Analyzing Light



Introduction to Astrophysics

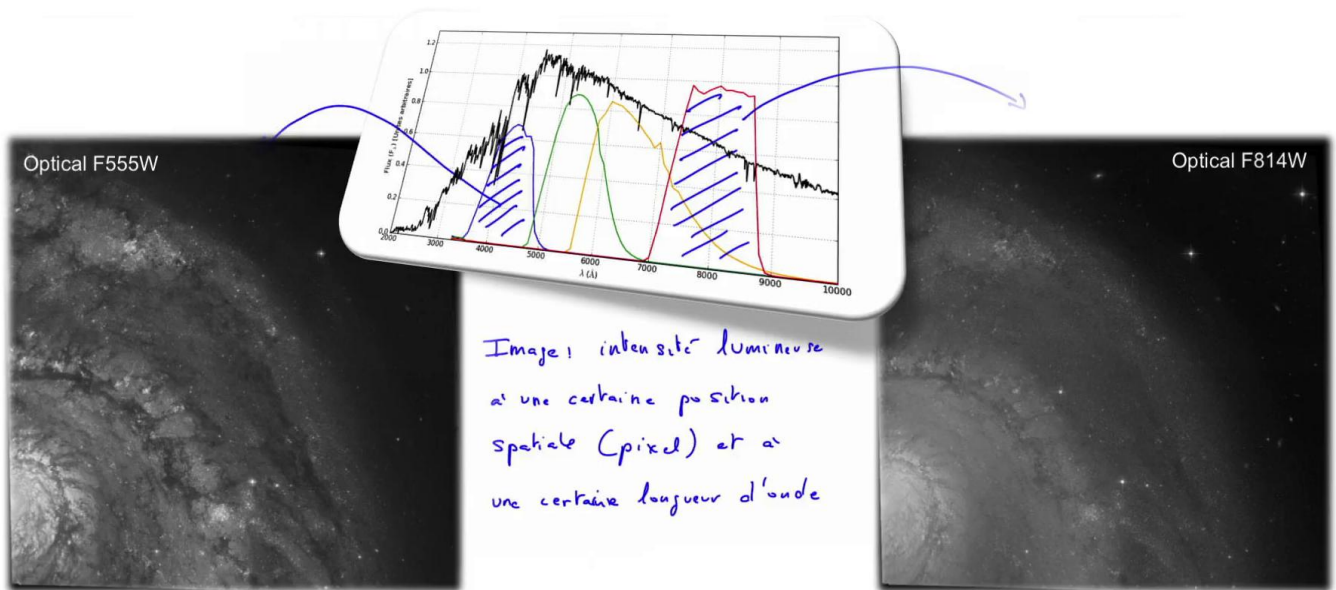
How can one analyse light? Either one analyses light through the spectrum. So the luminous intensity in function of the wavelength. Or one integrates light through filters, where we filter only certain wavelengths thanks to filters which have here a transmission curve. The high end of the curve is where we let pass the most light at a certain wavelength, and the low sections of the curve, is where less light goes through. So these filters are actually optical filters, which we put behind a telescope. So here we have a blue filter, for example, which lets only pass blue light and blocks out any other wavelength. So we can have lots of series of filters. Here is a red filter, and here another one, even redder, and here another one redder still. So light will be filtered. Here we have 4 optical filters which we can give names to. For example this one is the B filter for blue. V for green or visual. R for the red filter, and here I for infra-red. The eye starts not being able to see at the wavelengths beyond these or below these. Cameras can however, see very well at these wavelengths. So the goal of a filter, is to select ranges of wavelengths.

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Analyzing Light



Images: NASA/ESA - STScI

Introduction to Astrophysics

Once the wavelength ranges are selected one can integrate the light in the filters and see the spatial distribution of the light. And that is, of course, an image. So here we have the B filter, we will integrate the light here in a certain filter. So we multiply the spectrum by the transmission curve and integrate it over all wavelengths. This will give us the flux in a certain bandwidth, and the flux in the bandwidth, in function of the spatial position, is an image. An image is the luminous intensity at a certain wavelength, and at a certain pixel. So we can take images at all wavelengths. Here we have the image corresponding to the blue filter, for the 5555 angströms filter of the Hubble Space telescope. We can do of course the same thing at different wavelengths. So we integrate the flux in one wavelength range and note the value of the minor flux in function of the position. So we get here, for example, an infra-red image at a wavelength of 8140 angströms. So here we have a galaxy as seen by the Hubble Space telescope at a red wavelength, here almost infra-red, and at a blue wavelength, here almost ultraviolet.

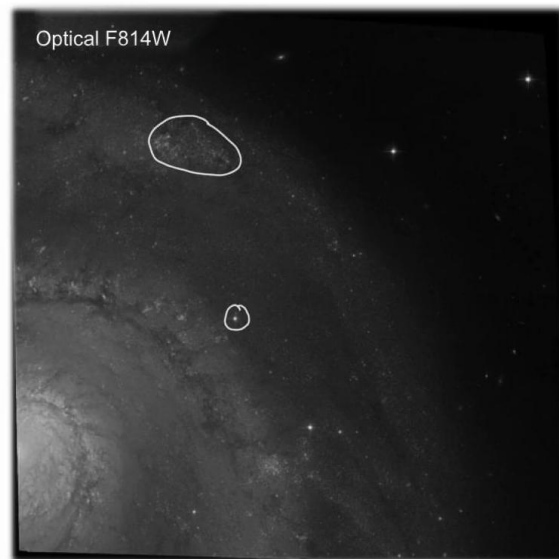
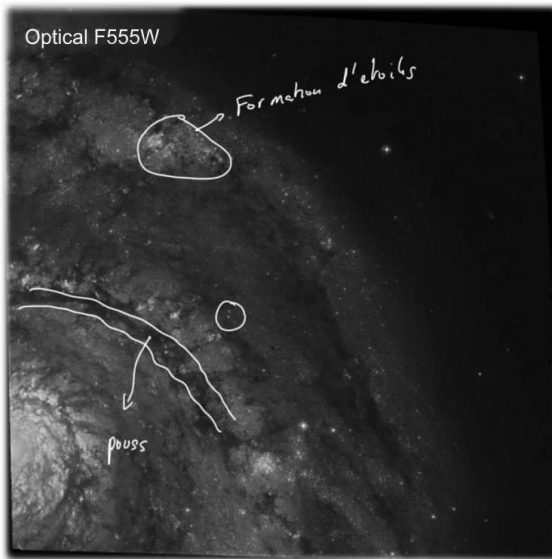
Notes

Summary



2m 04s

Analyzing Light



Images: NASA/ESA - STScI

Introduction to Astrophysics

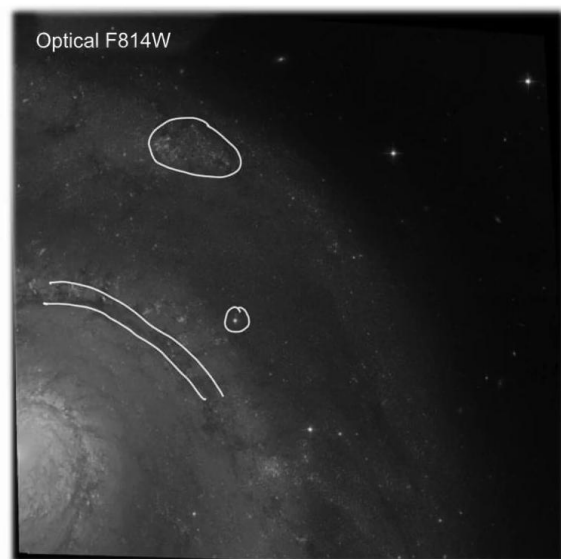
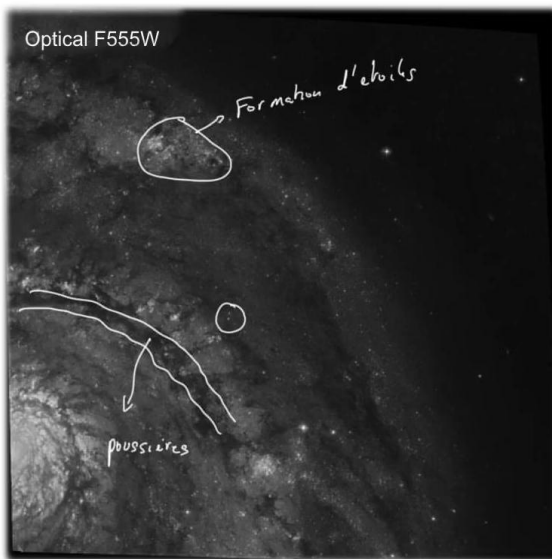
What can we see in these images? On the left here, we see an image taken with the Hubble Space telescope of a galaxy, and here the same galaxy, with the same field of view taken with an infra-red filter. What we see is obviously different since objects have different spectra's, some objects will appear more clearly on the blue filter, and others will appear more clearly on the red filter. So we see some objects of this type. If we look here, for example, we see a star that has a weak luminous flux in the optical wavelengths but a strong one in the infra-red. We know already, here, that that star is a red star. Now there are star formation zones in galaxies. Stars, we have seen in the lesson about black body radiation, when they are young, hot and massif radiate more in the blue. That is why we see here star formation zones which appear strongly in blue filters.. But the contrast with other regions is less distinct in the red filter. So we have here a zone where stars are young, hot, massif and blue. And so radiate more in the blue then in the red. We can have certain dust zones, for example. We have here one, in the spiral arms of the galaxy.

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Analyzing Light



Images: NASA/ESA - STScI

Introduction to Astrophysics

Dust absorbs strongly blue light, but much less red light. So we have a contrast here which is very strong between dust zones and the rest of the galaxy in blue, while the contrast is much weaker here in the red. That is simply because red light passes through dust more easily than blue light.

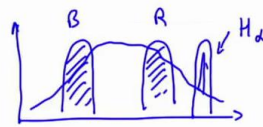
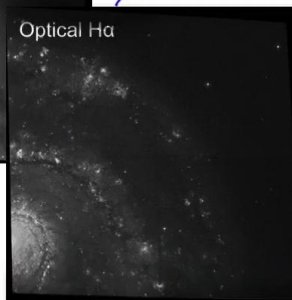
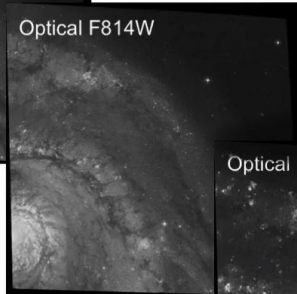
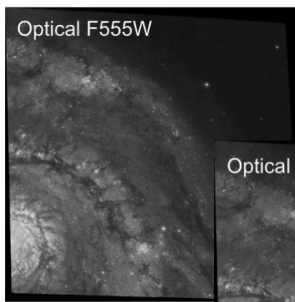
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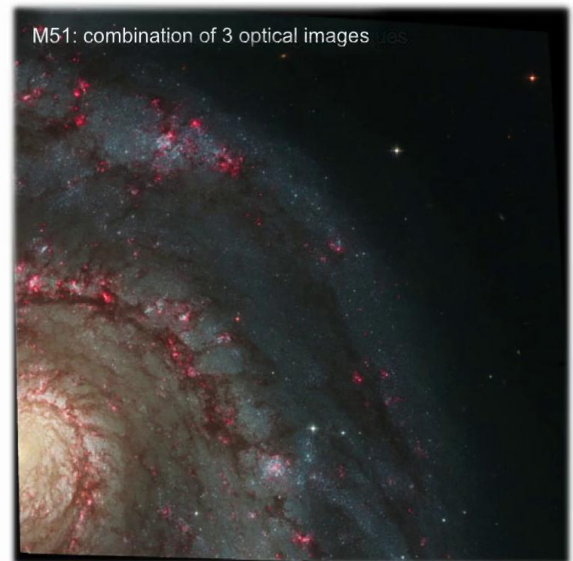
4m 47s

Analyzing Light



6563 Å

RGB



Images: NASA/ESA - STScI

Introduction to Astrophysics

A way of visualising this, is to make an image in true colors. It is more a "false colour" images but where the colours are coded so that the eye finds the color map which it is used to. To take an image in true colours, we take a spectrum, or in other words we take an image, we have for example a spectrum, we will symbolise the spectrum like this and then we take the filter, for example the blue one from the space telescope. we will integrate the light over a certain range of wavelengths. We will take the red filter we had before. We will integrate the light here, where we have the blue filter, the red filter and in this case we even added the optical H-alpha filter, which you will remember, is one the most important lines of the hydrogen atom. This line is at 6563 angströms, If we visualised it on this spectrum, it would be something rather narrow like this. This line is typical of star formation. and therefore it is interesting, which is what has been done here, to add a narrow filter, which is the H-alpha filter which will catch just that narrow hydrogen line. So now we will make an RGB image, so red, green (Visual) and blue.

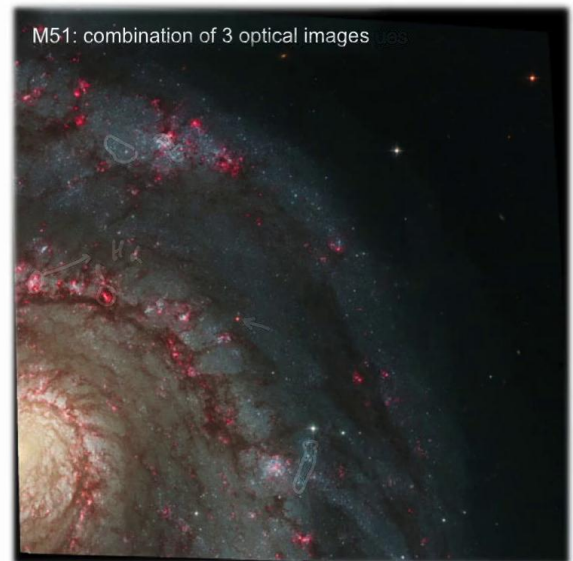
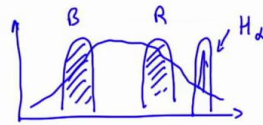
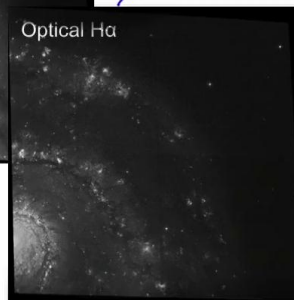
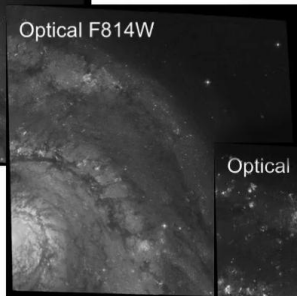
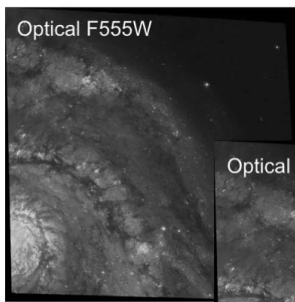
Notes

Summary



5m 09s

Analyzing Light



Images: NASA/ESA - STScI

Introduction to Astrophysics

The blue part of the image, the blue pixels will be coded with the image that was taken with the blue filter, the B-filter. For the green part of the image, the red optical image will be used and then we will take the H-alpha line for the red part. Each time a pixel has a high flux, in this image it will appear red. When it has a high flux in this image it will appear blue. and if it has a high flux in this image it will appear green. Now we can combine all this into one image, we take a weighting of the same pixel in the three images and then make a colour image. In this colour image, we can see, for example, the star we saw before, which was very red, or at least the point that was in the image and that was very red. We see the blue star formation zones, there are lots of small blue points that are massive stars in formation, Almost formed but which emit very blue radiation so very hot black bodies. And then we find a certain number of red zones, here for example. So that, is the H-alpha radiation. The pixel with high flux in this image here, H-alpha, appear in red in the image. When you see this image in false colours, they are not just there to be pretty.

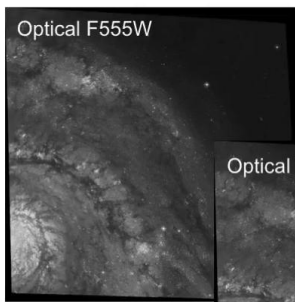
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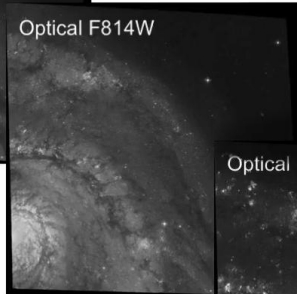


6m 36s

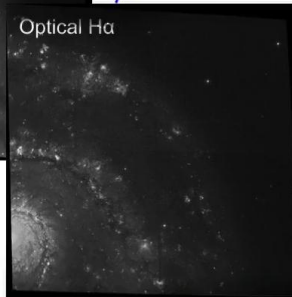
Analyzing Light



Blue

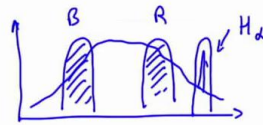


Green

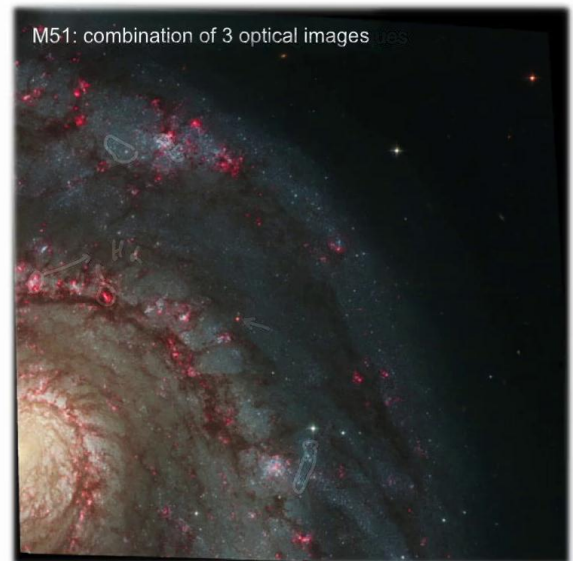


Rouge

RGB



6563 Å



Images: NASA/ESA - STScI

Introduction to Astrophysics

We can easily see, here, the physical processes that can cause different types of radiation. So in blue young, hot and massive stars. In red, gas zones ionised by massive stars. Each time we have massive stars, we see them directly in blue. But we see them also by the ionisation they cause in the hydrogen clouds. There we see the hydrogen H-alpha line which is produced by excitation of the hydrogen atoms which de-energise themselves by emitting the famous H-alpha line.

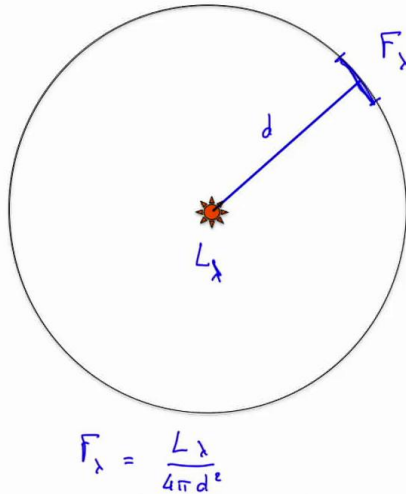
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Summary



8m 04s

The Magnitude System



$$m_\lambda = -2.5 \log F_\lambda$$

λ : Filtre (B, V, R, I)

$$m_X = -2.5 \log \int F_\lambda d\lambda$$

Introduction to Astrophysics

Notes

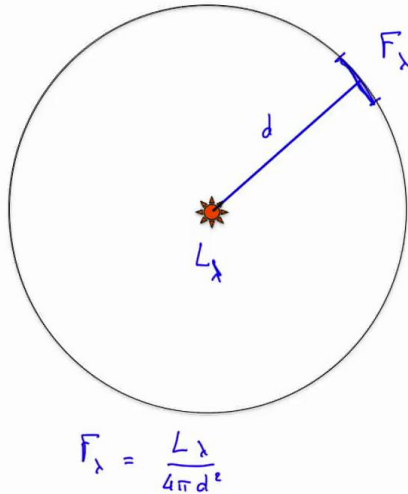
So astronomers like using logarithmic scales to quantify the luminous fluxes and the luminosities. We have already seen the luminosity, for example of a star, at a certain wavelength, let's say L_λ . And this star is situated at a certain distance from us. We will capture the radiation at a certain distance d , and this radiation will be diluted, if it is isotropic, over a sphere with a surface of $4\pi d^2$. So here we will have the flux F_λ , and this F_λ flux will be equal to, as we have seen before, L_λ , so the luminosity divided by 4π times the square of the distance. Now, to take into account what the ancients saw and with the logarithmic scale of the eye, the astronomers have decided to measure the luminous flux, not in flux, but in magnitude over a logarithmic scale. This logarithmic scale is defined as: $-2.5 \log(\text{flux})$ at a certain wavelength, λ in this case here. Now we can also integrate the flux through a filter, so we can define for example, if X is a filter, for a certain bandwidth, for example B, V, R or I as we defined earlier. So X can be one of those letters. The magnitude of the X filter will be $-2.5 \log$ base 10 of the integral $F_\lambda d\lambda$.

Summary



8m 37s

The Magnitude System



$$m_\lambda = -2.5 \log F_\lambda$$

λ : Filter (β, ν, R, I)

$$m_x = -2.5 \log \int F_\lambda d\lambda$$

$$m_x = -2.5 \log F_x$$

$L_\lambda [\text{erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}]$

Introduction to Astrophysics

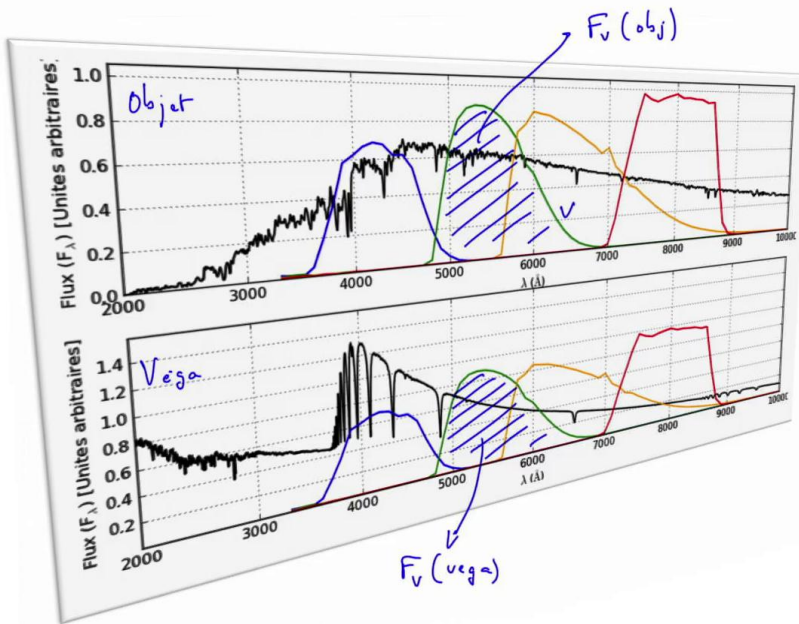
In other words we will have m_x equals $-2.5 \log$ of the total flux in X band. This flux is a flux expressed in erg by seconds, so a power by cm^2 . So we have no angströms anymore because we integrated over all wavelengths. We have a power by cm^2 , which is a power flux.

Notes

Summary



"Véga" Magnitude



$$F_v = \frac{\int F_\lambda \cdot T_v \cdot d\lambda}{\int T_v d\lambda}$$

$$\text{Avec } \int T_v \cdot d\lambda = 1$$

$$m_v(obj) = -2.5 \log \frac{F_v(obj)}{F_v(vega)}$$

Introduction to Astrophysics

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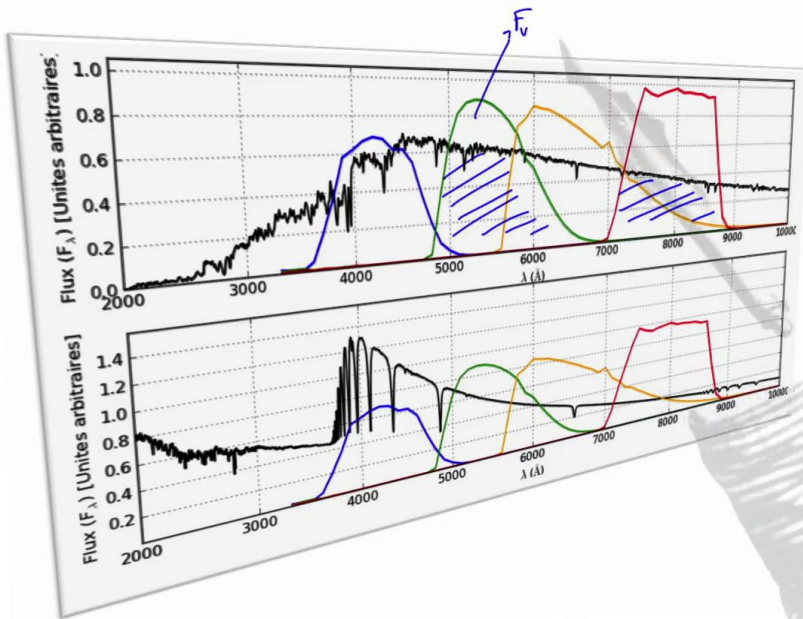
So now, how do we calibrate our flux scale ? In fact the calibration, will be the Vega star, an extremely bright star in the northern hemisphere. So we define the magnitude as being equal to zero in the V filter. Let's see how this works, we take an object of which we want to measure the magnitude and the Vega stars, so alpha in the Lyre constellation. And we will integrate the flux of the object in the V band. Here we have the transmission of the V band. We will do the same with the Vega star. Here we have a certain flux in the V band of our object. and here we have the flux in the V band of the Vega star. Of course we can do that with any other band. So the flux in the V band, will be by definition the integral of F_λ times the transmission of the V filter. And then, to simplify, we normalise and say that the transmission integral of the filter is equal to 1. In other words, we erase that term from the equation above. Now the flux will be rescaled in function of Vega, which means that the magnitude of the V filter, of our object, will be $-2.5 \log$ of the flux in the V band of the object, rescaled to the flux in the V band of the Vega star.

Summary



10m 47s

Color of Celestial Bodies: Color Index



Introduction to Astrophysics

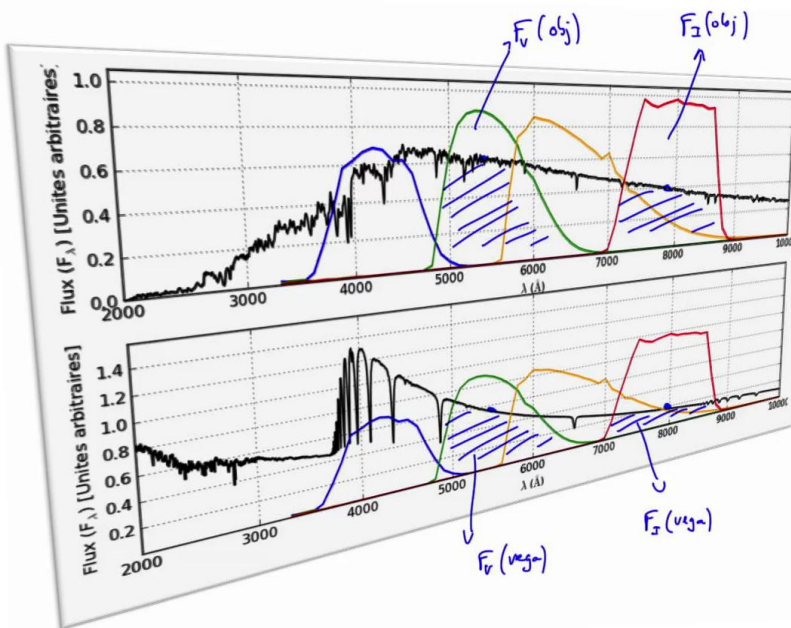
So this flux divided by this flux, we take the log minus 2.5 and we have the magnitude of our object. There is something here we don't see because in fact, we said that this, is also equal to the magnitude in the V band of the object. minus the magnitude in the V band of Vega and this is equal to : Now by definition, the Vega magnitude in the V band is equal to zero. So the magnitude of the object is the same as this one. Therefore the magnitude of an object, equals $-2.5 \log$ of the flux. and it is always rescaled to Vega. So we know by how much something is more luminous or less luminous than Vega, on a logarithmic scale, in a certain band, here the V band. And there is this -2.5 factor that transforms the objective or "quantitative" scale to a more subjective scale that is the logarithmic scale of the human eye which is of course the scale used by the ancients to characterise the brightness of the stars. So we have measured the flux of objects in different boundaries in function of the flux of Vega in different boundaries. Now we will measure the flux ratio of the same object but this time, with different boundaries. For example, here, we will have the measured flux ratio for an object in the V band.

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Color of Celestial Bodies: Color Index



$$m_V - m_I = -2.5 \log \frac{F_V(obj)}{F_V(vega)} - 2.5 \log \frac{F_I(obj)}{F_I(vega)}$$

$$m_V - m_I = -2.5 \log \frac{F_V(obj)}{F_I(obj)} - 2.5 \log \frac{F_V(vega)}{F_I(vega)}$$

Introduction to Astrophysics

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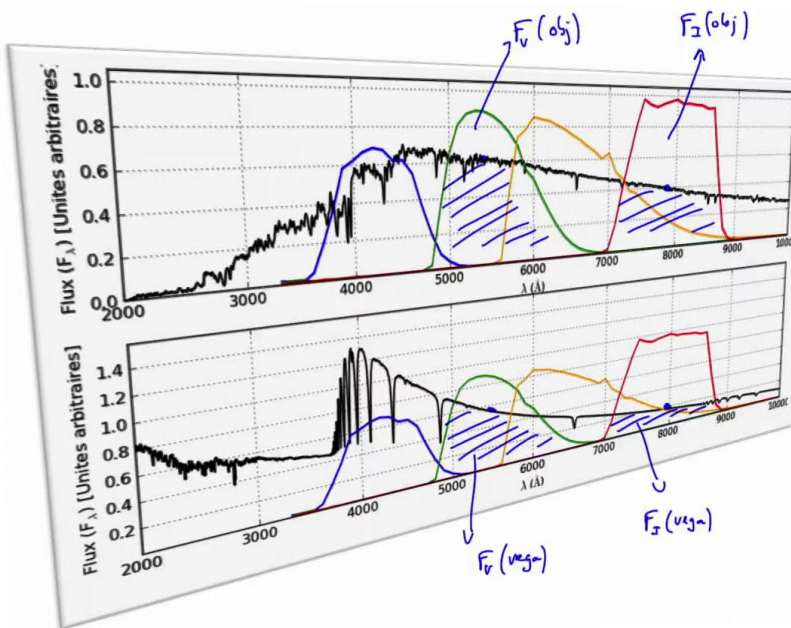
So F_V of the object and we will compare this to the flux of the same object in the I band. In other words, what we measure here, is the slope of the spectrum between the two bands. And this slope has to be calibrated, so we will measure it in function of the same flux ratio between two bands for the Vega star. I will measure the slope of my spectrum in function of the slope of the spectrum of the Vega star. So here I will define notations. We have F_V of Vega, and here F_I of Vega. and now, if we express all that in magnitudes, the magnitude of my object in the V band minus the magnitude of my object in the I band, we find the following equation, from what we have seen in the earlier slides: This is simply the magnitude difference, of my object in function of Vega, between the V band and the I band. Now we can rearrange a bit the equation. I can write m_V minus m_I . Here after rearranging the equation, what we measure here is the flux ratio of our object in the V band in function of the I band. We compare this to the Vega flux ratio in the V band in function of the I band. In other words, we look at the relative slope of my object in function of the relative slope of the Vega spectrum.

Summary



13m 41s

Color of Celestial Bodies: Color Index



$$m_V - m_I = -2.5 \log \frac{F_V(obj)}{F_V(vega)} - 2.5 \log \frac{F_I(obj)}{F_I(vega)}$$

$$m_V - m_I = -2.5 \log \frac{F_V(obj)}{F_I(obj)} - 2.5 \log \frac{F_V(vega)}{F_I(vega)}$$

V - I } indices de couleur
B - V }

↑
Filtre le plus bleu "à gauche"

B - V grand : objet rouge

B - V petit : objet bleu

Introduction to Astrophysics

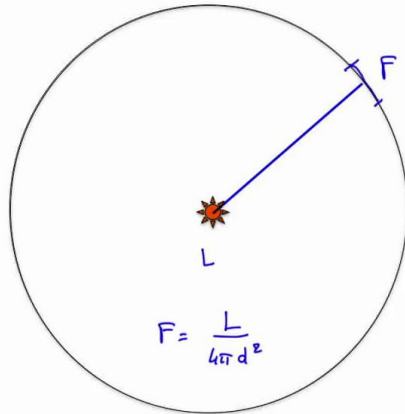
So we look at the colour of the object, compared to that of Vega. So in practice we will use different colour indexes. So instead of writing m indexed V and I, often we will write in big letter like this. For example V minus I, B minus V, and we will define colour indexes, and in these colour indexes, we will always put the bluest filter left. With these conventions, a big colour index will be typically a red object, and a weak colour index will be a blue object. For example B - V big is typically a red object. so redder then Vega. and B - V small will be a blue one, so bluer then Vega, since everything is scaled to the Vega star.

Notes

Summary



Absolute Magnitudes and Distance Modulus



M : mag abs \rightarrow magnitude d'un objet s'il était vu à une distance de 10 pc

$$m = -2.5 \log F$$

$$m - M = -2.5 \log \frac{L}{4\pi d^2} - 2.5 \log \frac{L}{4\pi (10)^2}$$

Introduction to Astrophysics

So we have defined the fluxes, the luminosities, the magnitudes, and the colour of the stars and stellar objects in general. We will now define another extremely important quantity in astrophysics: the absolute magnitudes. In fact the magnitude of an object seen at a distance of 10 parsecs. So we will say that absolute magnitudes are in fact visual magnitudes : the small m we saw earlier, seen from a distance of 10 parsecs. That is the magnitude of an object, if it is seen from 10 parsecs. So of course the visual magnitude, which is $-2.5 \log$ of the flux, where the flux is again what we defined before L . That is the luminosity of an object, diluted over a certain surface here where we have a certain flux. And the flux is equal to $4\pi d^2$. So the absolute magnitude, will $-2.5 \log$ of flux, when d is equal to 10 parsecs. We can calculate the difference between the 2 magnitudes : the visual magnitude rescaled to Vega and the magnitude at ten parsecs. So again we use the definition of magnitudes $-2.5 \log$. So the flux, is L divided by $4\pi d^2$ and the absolute magnitude as we said, is the flux of the object if it is seen from 10 parsecs away. So we use here already the right units: four pi times ten squared.

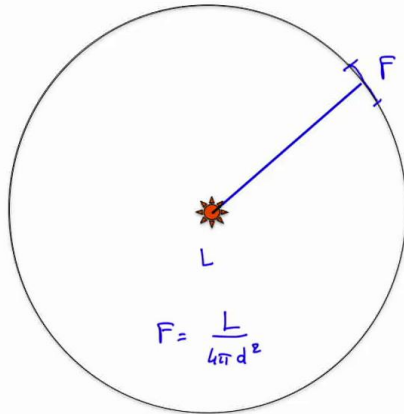
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16m 07s

Absolute Magnitudes and Distance Modulus



M : mag abs \rightarrow magnitude d'un objet s'il était vu à une distance de 10 pc

$$m = -2.5 \log F$$

$$m - M = -2.5 \log \frac{L}{4\pi d^2} - 2.5 \log \frac{L}{4\pi (10)^2}$$

$$= -2.5 \log \frac{10^6}{d^2}$$

$$m - M = 5 \log d - 5$$

module de distance

Avec d en pc.

Introduction to Astrophysics

Now, we see that this is equal to $-2.5 \log$ of ten squared over d squared. In other words, m minus M , is equal to $5 \log d - 5$. And that is an absolutely fundamental equation in astrophysics. A key result since it is this equation which allows us to measure distance, thanks to, for example, standard candles, supernovas or Cepheid stars which we will see later. This is called the distance module with d in parsecs. By definition, the difference between apparent magnitude and absolute magnitude, is $+5 \log(d)$ in parsecs -5 . So we can immediately see that if we can get an object for which we measure the apparent magnitude and for which we know, in an independent manner the absolute magnitude, we will be able to know its distance. The measurement of the distance is one of the tasks are extremely important in astrophysics. Measuring the distances and the mass, are two key components for the understanding of the formation and evolution of stellar objects.

Notes

Summary



Orders of Magnitude

Object	<i>m</i> mag apparente	<i>M</i> mag absolue
Sun	-26,8	+4.8
Full Moon	-12	Invisible
Venus	-4	invisible
Bételgeuse (supergiant)	+0,5	-5,6
Andromeda Galaxy	+3,4	-20,7
Distant Quasar	+25-28	-30

Introduction to Astrophysics

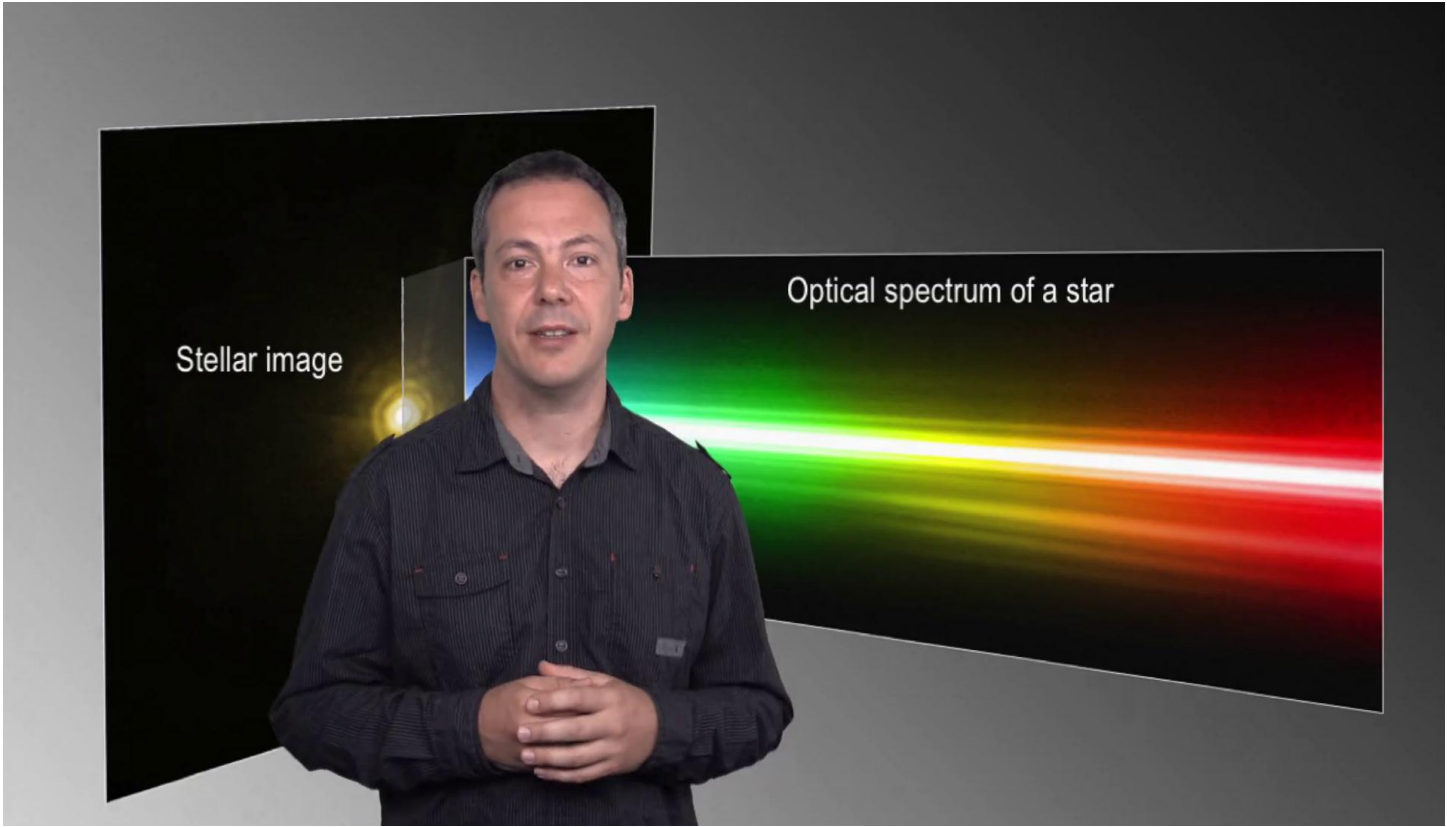
Now some orders of magnitudes, magnitudes of well known objects. So here we have the apparent magnitude for a series of objects. And here we have the absolute magnitude of different objects. So this is the absolute magnitude. This is of course the apparent magnitude that an object would have if it was placed at a distance of 10 parsecs. So the Sun has the smallest magnitude of all objects in the sky, so it the brightest object, in appearance at least. Because if we put it at 10 parsecs its magnitude is plus 4.8. Plus 4,8, is around the magnitude that the almost invisible to the naked eye objects have. So the Sun, at a distance of 10 parsecs, would be a weak star indistinguishable from the rest, in fact almost invisible to the naked eye. So, now, at the complete opposite of the scale, we take an extremely weak object, with a high, positive magnitude, so for example some very distant quasars. These objects are almost invisible with the biggest actual telescopes. And if we put these object at a distance of 10 parsecs, they have a magnitude of minus 30. So they would be, if they were at ten parsecs from us, a lot brighter, three magnitudes brighter than the Sun. So we can see through this comparison of apparent magnitudes and absolute magnitude, to which degree the distance of the stars dominates what we perceive from their radiation.

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18m 56s





The challenge in astrophysics is to imagine, to modelize the physical processes that account for the received radiation. This radiation can be captured in form of an image or a spectrum. It is these and only these, that will permit us to understand the functioning of the stars that compose the universe.

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20m 19s