





Image: NASA/ESA, C.R. O'Dell

In this lecture, we will see how radiation interacts with the interstellar and intergalactic matter. Interactions occur at all spatial scales and are analysed, thanks to images and spectra, giving constraints on the physical conditions of the gas and dust in cosmic clouds. The interstellar gas, apart from the primordial hydrogen and helium, formed a few moments after the Big Bang, is created by successive generations of stars and is ejected into the interstellar medium after the death of high or low-mass stars.

Notes

Summary



0m 05s



For low mass-stars, i.e., less massive than eight solar masses, planetary nebulae are formed, while for the stars with masses exceeding eight solar masses, a supernova explosion occurs, leaving spectacular filaments, as shown in the figure. This image shows the Crab Nebula, Messier 1, that is a result of a supernova explosion visible even to the naked eye in 1054.

Notes

Summary



0m 43s



Then the gas is recycled into an interstellar medium in the galaxy like this one, Messier 51, where the hydrogen emission is well visible in the red, in the spiral arms of the galaxy. The hydrogen emission is created by the ionised gas excited by the swarm of young, massive stars visible in the blue, in the arms of the galaxy. Apart from gas and galaxies, there is also dust that absorbs background radiation. This effect can be seen here in the form of dark trails through the arms of the galaxy. The background light is absorbed by dust. From this mix of gas and dust, new generations of stars, possibly associated planetary systems, are formed.

Notes

Summary

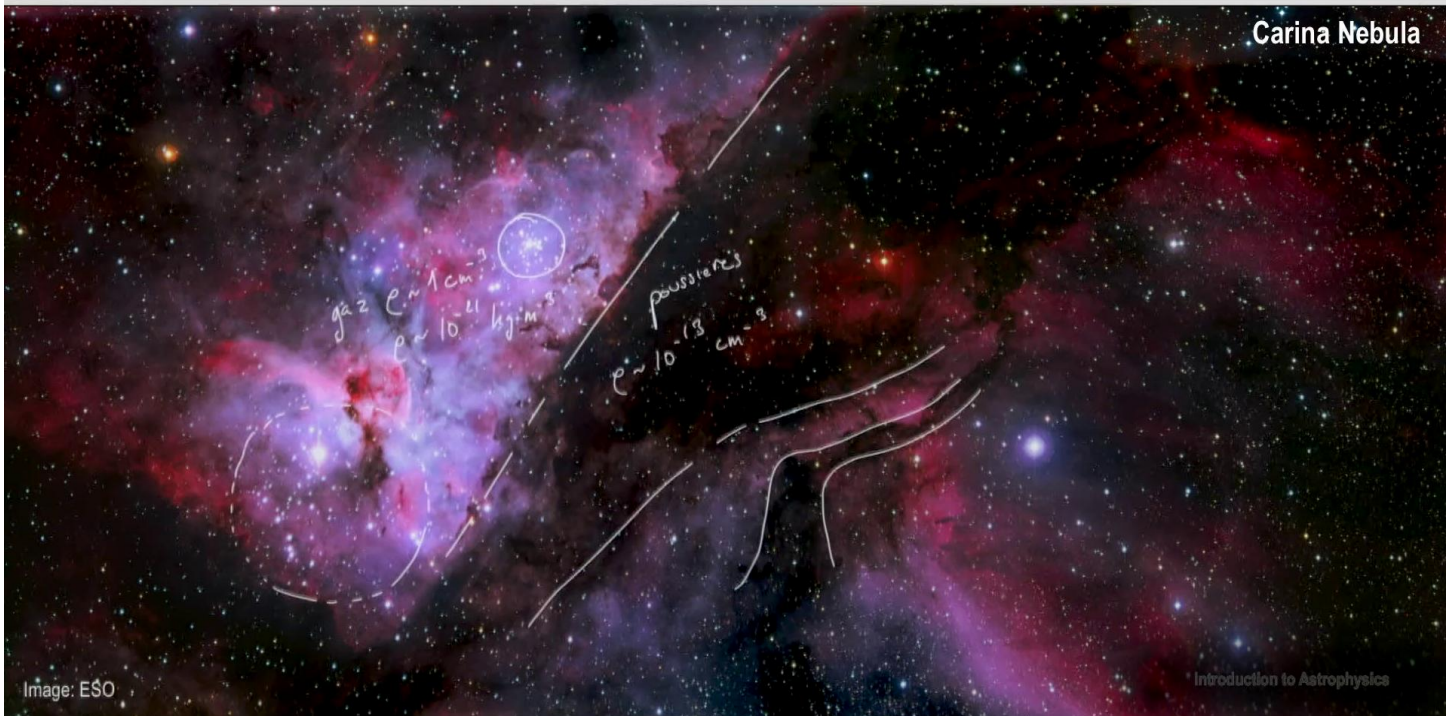




# Interstellar and Intergalactic Matter



Carina Nebula



Let's see in details what is happening in a nebula, the Carina Nebula, shown here at optical wavelengths. Some sources of ionisation can easily be identified, like in this place, a small stellar cluster, certainly composed of young, hot stars. Another stellar cluster can be seen here. Those stars ionise the surrounding gas. The gas divides into protons and electrons. Possibly, they will recombine. Electrons fall back into the lower energy level, while at the same time, emitting photons with a range of wavelengths. Each colour indicates a different emission line. As it was shown in previous chapters, the density of the gas is very low, roughly one gas particle per centimetre to the third power, which gives  $\rho$  equals 10 minus 21 kilogrammes divided by  $M^3$ . There can be great differences in the densities from one nebula to another, from one galaxy to another. This density corresponds to the ionised gas that often produces emission lines. We find also dusty regions similar to those shown before in the spiral galaxy. Dust absorbs radiation. In fact, this whole region is affected by dust absorption. Mass densities in this region are even lower, about 10 to 13 particles per centimetre to the third power, which is 10 to 13 times smaller than the gas density.

Notes

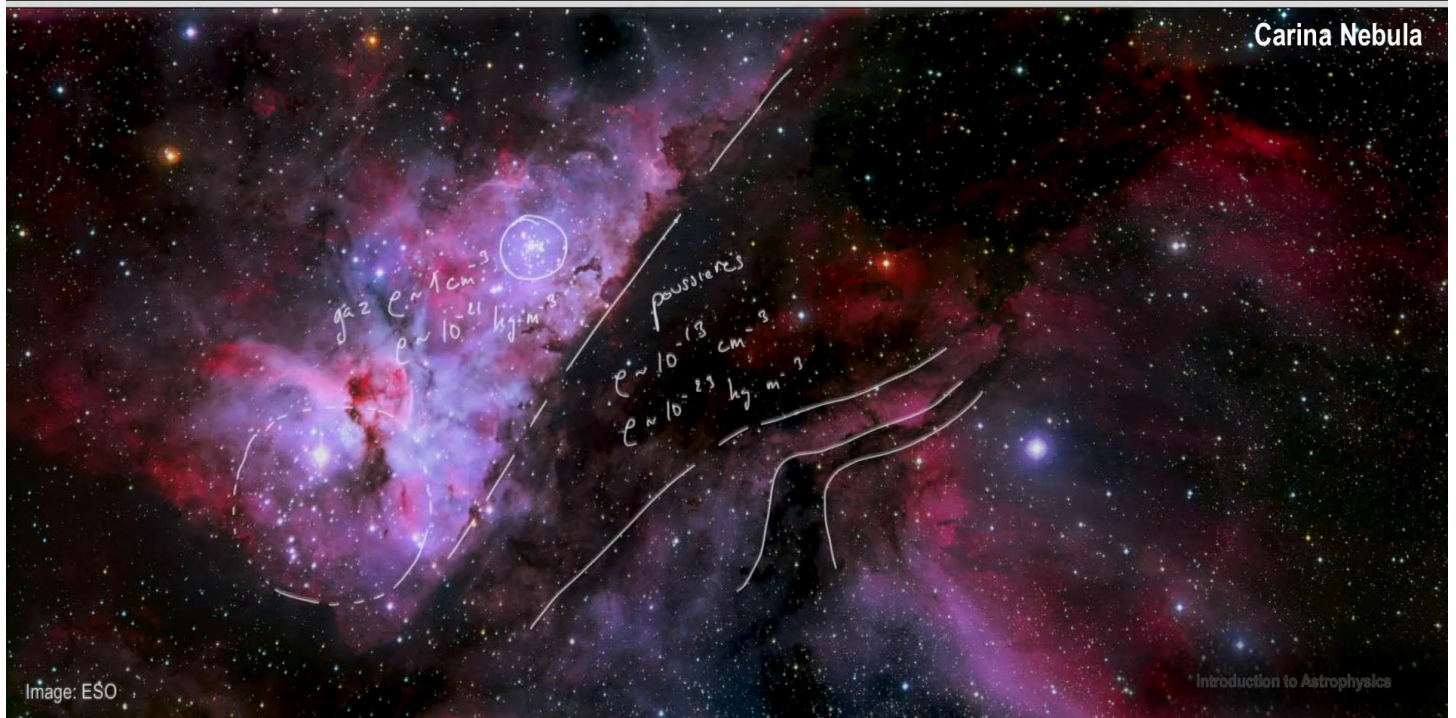
Summary



1m 52s

# Interstellar and Intergalactic Matter

Carina Nebula



On the other hand, dust particles are much heavier because the dust is composed of atoms and molecules. The mass density is one of the order of 10 to 23 kilogrammes divided by  $\text{M}^3$ . This means that there is 13 orders of magnitude less dust particles than in the gas. But in mass density, dust is only 100 times less massive per unit volume than gas.

Notes

Summary





# Interstellar and Intergalactic Matter



Our Galaxy: the Milky Way



Image: ESO

Introduction to Astrophysics

All we said previously was about gas and dust in Nebula. Let's have a closer look at the Milky Way. Objects with much larger spatial scales from this place to this other one in the slide, the distance is about 5 kiloparsec. On the previous slide, the scale was about tens of parsec. Here the scale corresponds to the kiloparsec scale. The nebula that was shown just before has roughly this size, quite small, comparing to the Milky Way. On the other hand, dust extends over a large region. Those areas correspond to dusty spots that absorb the light coming from the stars situated behind. Here are the other dust regions.

Notes

Summary

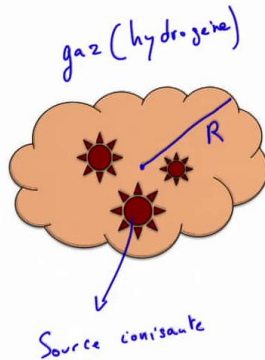


3m 59s

# The Size of Nebulae: Stromgren Sphere

$R_{\text{Stromgren}}$  → Taille limite d'une nébuleuse

$$N_{\text{ion}} = N_{\text{recombinaison}}$$



$$N_{\text{recomb}} =$$

Introduction to Astrophysics

In conclusion, the dust and the gas intervene at all scales. Let's take a look at what is happening with the ionised gas that recombines and emits irradiation, creating something we can observe nebulae. Here we will assume a gaseous nebula composed of hydrogen, so as to simplify the calculations. Of course, the composition could well be different in this cloud. Then here is a ionising source—stars. This ionising source splits the atoms of hydrogen, in this case, into protons and electrons. They do not stay in this state. They will tend to recombine and emit light. We will try to estimate the typical radius of a nebula that isn't a Stromgren radius after the astronomer who calculated it for the first time. What we will try to characterise is this limiting radius of the nebula, the Stromgren radius. As always in science, there is an equilibrium. There are ionising protons coming from the source from the centre of the nebula. Then there are electrons that recombine with the protons that were ionised by the radiation field. The flux of ionising photons is equal to the recombination ratio of the proton-electron pairs.

Notes

Summary



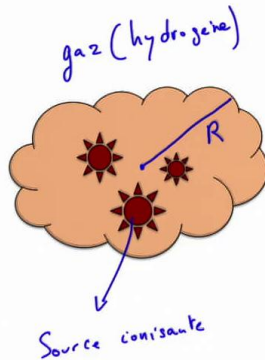
4m 44s



# The Size of Nebulae: Stromgren Sphere

$R_{\text{Stromgren}}$  → Taille limite d'une nébuleuse

$$N_{\text{ion}} = N_{\text{recombinaison}}$$



$$N_{\text{recomb}} = \frac{4}{3} \pi R^3 \cdot n_e \cdot n_H \cdot \alpha$$

↓  
Constante physique  
 $\alpha \sim 3 \cdot 10^{-13} \text{ cm}^3 \cdot \text{s}^{-1}$   
(pour  $T \sim 8000 \text{ K}$ )

Introduction to Astrophysics

The number of recombinations is equal to the volume of the nebula, 4 divided by 3 pi times  $R^3$  times the number of available proton-electron pairs. That is  $n_e$  for electrons and  $n_H$  for protons. In this equation, there is also a constant that comes from quantum mechanics, and the origins of which is not needed to be known here. It is just a physical constant that is equal to about 3 times 10 minus 13 centimetres, 3 times s minus 1 for a gas with a temperature around 8,000 kelvin, which is a typical temperature for diffused nebulae. We have calculated the recombination ratio as a function of radius, the parameter that we are interested in, and the electron and proton density in the nebula.

Notes

Summary



6m 09s

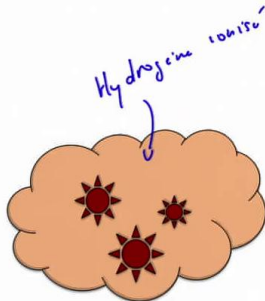
# The Size of Nebulae: Stromgren Sphere

$N_{ion}$

Source ionisation

1 étoile à  $T \sim 45000 \text{ K}$

$\lambda_{max} = 640 \text{ \AA} \text{ (UV)}$



Nomenclature :

- $^1\text{H}$  Noyau d'hydrogène
- $^2\text{H}$  Deuterium
- $\text{HI}$  Atome hydrogène neutre
- $\text{HII}$  " " ionisé

Introduction to Astrophysics

Let's calculate the number of ionising photons. For the calculations, we take a hot star as an ionising source with a temperature of about 45,000 kelvin. This star has a black body spectrum with its luminosity peak in the ultraviolet. According to the Wein law,  $\lambda_{max}$  is equal to 640 angstrom, which is in the ultraviolet part of the spectrum, where the photons carry a lot of energy, and so they can easily ionise matter. Here we have a nebula composed of ionised hydrogen. Before the calculations, let's recall a bit of nomenclature. We have talked a lot about hydrogen, so let's now present some notations. It may be that you are familiar with it, so treat it as a reminder if you have such a notation,  $^1\text{H}$ . It stands for a hydrogen nucleus. A notation  $^2\text{H}$  stands for a deuterium nucleus. In this case, there is one extra neutron in the nucleus. Let's move on to the atoms. We have now an electron that we will note as  $\text{HI}$ . This is an atom of neutral hydrogen. The electron in this atom is in its lowest possible energy state with 13.6 eV. It means that in order to ionise a hydrogen atom, 13.6 eV must be delivered. In this case, one notes  $\text{HII}$  for the ionised hydrogen.

Notes

Summary



7m 07s

# The Size of Nebulae: Stromgren Sphere



Nomenclature :

- $^1\text{H}$  Noyau d'hydrogene
- $^2\text{H}$  Deuterium
- $\text{HI}$  Atome hydrogene neutre
- $\text{HII}$  " " ionise
- $\text{H}\alpha, \text{H}\beta, \text{H}\gamma \rightarrow$  Raies emission
- $\text{H}_2$  Hydrogene moleculaire

$N_{\text{ion}}$

Source ionisation

1 etoile a  $T \sim 45000 \text{ K}$

$\lambda_{\text{max}} = 640 \text{ \AA} \text{ (UV)}$

Chaque photon a une energie  $E_\gamma = h\nu$

$$= 3,106 \times 10^{-18} \text{ J}$$

$$= 19 \text{ eV}$$

$E_\gamma > E_{\text{ion}}(\text{H})$

$\hookrightarrow 13,6 \text{ eV}$

Tout l'hydrogene est ionise

Introduction to Astrophysics

Earlier, a notation, H-alpha, H-beta, H-gamma, et cetera, was shown. Pay attention not to confuse it with the notation that was shown before. Those are the hydrogen emission lines. We can also write  $\text{H}_2$ , which indicates that two hydrogen atoms now form a molecule. Beware of all the different notations. That is all for the hydrogen nebula. Let's recall that we consider a single star with 45,000 kelvin in the centre of the nebula. The radiation peak is at 640 angstrom. Assuming that most photons belong to that peak, each photon has about the energy  $E_\gamma$  equals  $h\nu$ . Then let us imagine that all photons are indeed emitted at the peak, thus all photons have precisely that energy. The total amounts to  $1.54 \cdot 10^{-18} \text{ J}$  which corresponds to 19 eV. Obviously, those are photons with an energy higher than the ionisation energy 13.6 eV. It means that if a star surrounded by hydrogen is considered, then with a good approximation, all the hydrogen in the nebula is ionised because of the photon flux carrying an energy higher than the hydrogen-ionised energy.

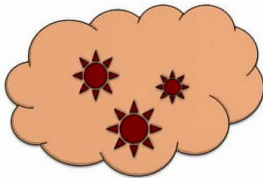
Notes

Summary





# The Size of Nebulae: Stromgroen Sphere



Comme tout l'hydrogène est ionisé  $n_e = n_H$

$$N_{\text{recomb}} = \frac{4}{3} \pi R^3 \cdot \alpha \cdot n_H^2 = N_{\text{ion}}$$

$$R_s = \left[ \frac{3 N_{\text{ion}}}{4 \pi \alpha n_H^2} \right]^{1/3}$$

$$N_{\text{ion}} = \frac{L_\nu}{E_\gamma} \quad \text{Pour } T_\nu = 45000 \text{ K}$$

$$L_\nu = 1,3 \cdot 10^5 L_\odot$$

$$N_{\text{ion}} = 1,6 \cdot 10^{49} \text{ photons} \cdot \text{s}^{-1}$$

$n_i$

Introduction to Astrophysics

We assume that all the hydrogen is ionised, and so  $n_e$  equals  $n_H$ , and there is the same number of electrons and protons. This implies that the equation for the recombination ratio can be rewritten as a function of the hydrogen atom density, and it is equal to the photon flux, carrying an energy at least sufficient to ionise the atoms. Inverting this equation, we find the radius that is the limiting radius in the equilibrium, the Stromgroen radius. It will be equal to three times the number of ionising photons over  $4 \pi \alpha$  times  $n_H$  square to the power 1 divided by 3. This is the equation for the Stromgroen radius. It is given as a function of the following values: a physical constant, the density of the nebula, and the number of ionising photons. The number of the ionising photons can be estimated in the easiest way. It is the stellar luminosity in the centre of the nebula divided by the photon energy. For a star with the surface temperature,  $T$ , 45,000 kelvin, the luminosity is equal to 1.3 times  $10^5$  solar luminosity. This implies that the number of ionising photons is equal to 1,6  $10^{49}$  photons divided by s. This gives an estimate of the number of ionising photons. Let's now estimate  $n_H$ .

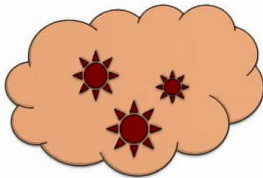
Notes

Summary



10m 25s

# The Size of Nebulae: Stromgroen Sphere



$0.1 < R_S < 100 \text{ pc}$   
petit amas d'étoiles

Comme tout l'hydrogène est ionisé  $n_e = n_H$

$$N_{\text{recomb}} = \frac{4}{3} \pi R^3 \cdot \alpha \cdot n_H^2 = N_{\text{ion}}$$

$$R_S = \left[ \frac{3 N_{\text{ion}}}{4\pi \alpha n_H^2} \right]^{1/3}$$

$$N_{\text{ion}} = \frac{L_U}{E_H} \quad \text{Pour } T_e = 45000 \text{ K}$$

$$L_U = 1.8 \cdot 10^5 L_{\odot}$$

$$N_{\text{ion}} = 1.6 \cdot 10^{49} \text{ photons} \cdot \text{s}^{-1}$$

$$n_H \sim 5000 \text{ cm}^{-3} \rightarrow R \sim 0.3 \text{ pc}$$

Introduction to Astrophysics

Notes

Summary



12m 32s



This is a wonderful example of a nebula illustrating the Stromgroen sphere, NGC602, in the small Magellanic Cloud which is a satellite galaxy of our galaxy. Here one can see a group of blue stars in the centre of the nebula that ionises the gas as far as 50 parsec from the centre. This does not imply that the nebula has its limit at 50 parsec and that there is no gas further away. What it means is that the photon flux produced by the stars in the centre of the nebula is not able to ionise the gas further away than the Stromgroen radius.

Notes

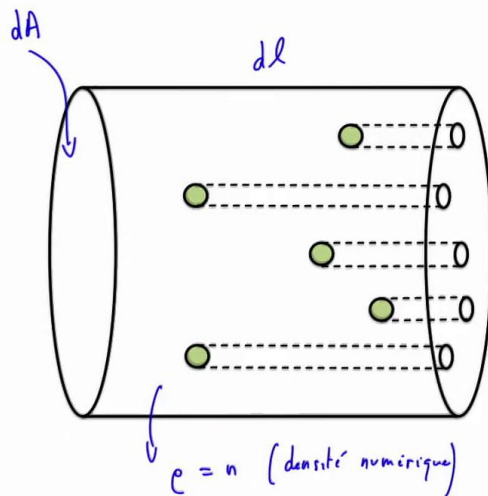
Summary

13m 22s





# Describing Light Absorption



$$C_{ext} = \pi r^2 \quad (\text{Section efficace des grains})$$

$d\tau$  : fraction masquée de  $dA$

$$d\tau = \frac{n \cdot dA \cdot dl \cdot C_{ext}}{dA}$$

Introduction to Astrophysics

We will look closer at the dust absorption. Here you can see schematically represented some dust grains with sizes much larger than the atoms or molecules. It could be compared to the dust that is on a table when one does not clean at its place, or to the chalk left on the blackboard, for example. Let's take a volume element that is characterised by the length, input and output surfaces, and the density taken in the following way. This is the numerical density, not the mass density. It gives the number of dust grains per unit volume. One can see clearly that each dust grain obscures the light that enters the volume element. Each dust grain has a cross-section that obscures a surface,  $dA$ . This allows the determination of the extinction coefficient that is simply equal to, if  $r$  is the grain radius, the cross-section of the dust grains. It is possible to estimate the fraction of the surface,  $dA$ , screened by all the dust grains. This would be simply  $d\tau$ , the number of the particles in the box times the cross-section, which we have called the extinction coefficient.  $d\tau$  is equal to  $n$  times  $dA$  times  $dl$ , where  $l$  is the cylinder volume times the cross-section over the total surface.

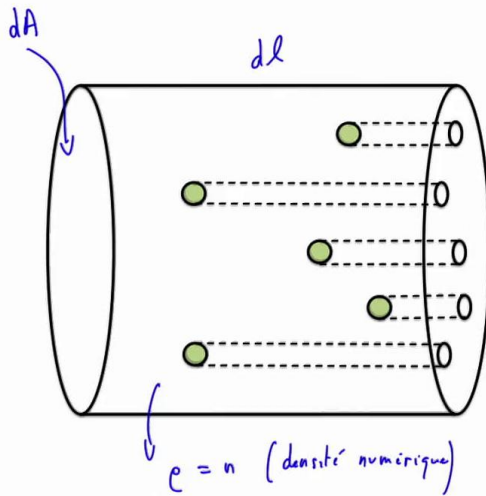
Notes

Summary



13m 58s

# Describing Light Absorption



$$C_{ext} = \pi r^2 \quad (\text{Section efficace des grains})$$

$dz$  : fraction masquée de  $dA$

$$dz = \frac{n \cdot dA \cdot dl \cdot C_{ext}}{dA}$$

$$dz = C_{ext} \cdot n \cdot dl$$

$\tau$  : profondeur optique  
(sans dimension)

$$\tau_{\text{max}} = 1 \quad \text{extinction totale.}$$

Introduction to Astrophysics

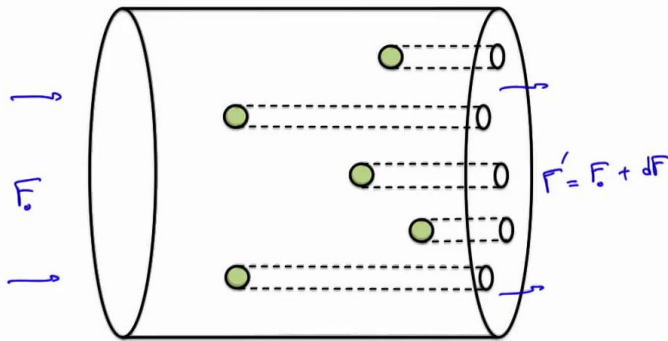
If this expression is simplified, one has the extinction coefficient times the density times the element  $dl$ . This will be called the optical depth  $\tau$ . This is a dimensionless quantity that depends on distances. One can already see that  $\tau_{\text{max}}$  equals 1 corresponds to full extinction because the obscured surface is equal to  $dA$ , and so all the radiation is absorbed.

Notes

Summary



# Describing Light Absorption



$$dF = -F \cdot \underbrace{d\tau}_{\text{fraction of flux perdu}}$$

$$\frac{dF}{F} = -d\tau$$

$$F = F_0 e^{-\tau}$$

$$\text{Avec } \tau = \int_0^D n \cdot \sigma \cdot dl$$

$$\tau = \bar{n} \cdot \sigma \cdot D$$

Introduction to Astrophysics

This is the definition of the optical depth. Let's see how to use it in order to estimate the fraction of flux that is lost. If we have the incident flux here in a given volume,  $F$  is the outgoing flux that is equal to  $F$  plus  $dF$ .  $F$  can be negative and will be in this case, as there is absorption.  $dF$  equals  $F$  times  $d\tau$ ,  $d\tau$  is the optical depth, or as it was called earlier, the fraction of the flux that is lost. There is a minus sign because of the losses, and so  $dF$  divided by  $F$  equals minus  $d\tau$ . This is a simple equation for which the solution could be written as an exponential with boundary condition that is simply the incident flux. The outgoing flux varies with respect to the incident flux.  $\tau$  is the integral from 0 to the distance of the observer, so it can be integrated along the line of sight up to the star at some distance,  $D$ . Here we have  $n$  times the extinction coefficient times  $dl$ . If we assume that there is on average,  $\bar{n}$  particles along the line of sight, we can simplify this expression.  $\tau$  would be  $\bar{n}$  means times the extinction coefficient times the distance. This is the result of the integral with the assumption that the number of particles can be approximated by some mean value from the distance 0 to the observed object at some distance  $D$ .

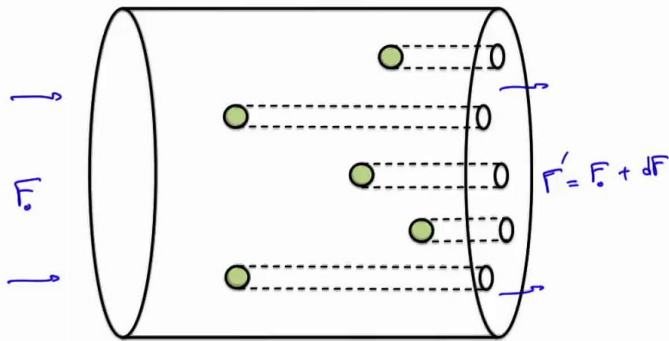
Notes

Summary





# Describing Light Absorption



$$dF = -F \cdot d\tau$$

↳ fraction de flux perdu

$$\frac{dF}{F} = -d\tau$$

$$F = F_0 e^{-\tau}$$

$$\text{Avec } \tau = \int_0^D n \cdot \sigma_{\text{ext}} dl$$

$$\tau = \bar{n} \cdot \sigma_{\text{ext}} \cdot D$$

Introduction to Astrophysics

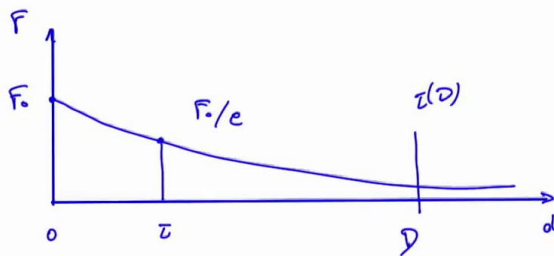
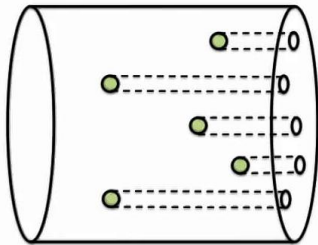
The integration is made from one volume element to another. The integration of the flux that is lost by a volume element because of the dust grains between the source and the observer, the fraction of the flux that is lost is called the extinction.

Notes

Summary



# Describing Light Absorption



$$F(D) = F_0 \cdot e^{-\tau(D)}$$

$$m - m_0 = -2.5 \log \frac{F(D)}{F_0}$$

$$= 2.5 \tau(D) \cdot \log e$$

Introduction to Astrophysics

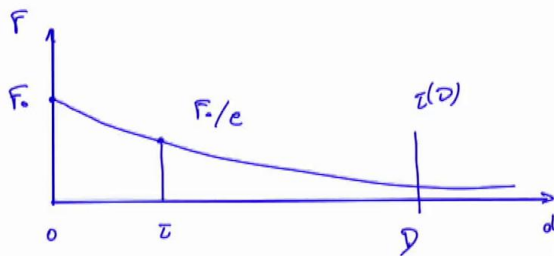
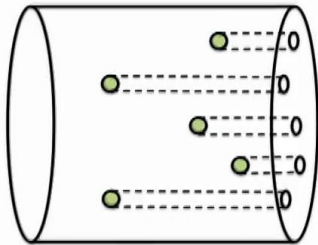
Rewriting the resulting formula,  $F$  depends on the distance of the observed object so that  $FD$  equals  $F_0$  times  $e^{-\tau(D)}$ . Let's try to illustrate that on a graph. It is simply an exponential curve. The y-axis represents the flux and the x-axis the distance. At distance 0, the flux is equal to  $F_0$ . This is the condition given in the formula. When  $\tau$  equals 0, the exponent is equal to 1, so  $F$  equals  $F_0$ . Then the flux is exponentially decreasing. At some distance  $D$ , we have  $\tau(D)$ . When  $\tau$  equals 1, the flux is equal to  $F_0$  divided by  $e$ , which means that 1 divided by  $e$  times the flux  $F_0$  is lost up to the optical path equal to 1. Astrophysicists prefer to use magnitudes. Let's take its definition. Observed magnitude minus the intrinsic magnitude before the absorption caused by the dust along the line of sight from 0 to the distance  $D$ . This is a situation in which, along the line of sight between the observer and a star, there is dust in cylinders in nebulae, et cetera. One has to integrate the absorption along the line of sight up to some distance  $D$ . Thus,  $m - m_0$  equals 2.5 times  $\log FD$  divided by  $F_0$ . Using the equation formulated before, this is equal to 2.5 times  $D$ . But one has to pay attention to  $\log e$ .

Notes

Summary



# Describing Light Absorption



$$F(D) = F_0 \cdot e^{-\tau(D)}$$

$$m - m_0 = -2.5 \log \frac{F(D)}{F_0}$$

$$= 2.5 \tau(D) \cdot \log e$$

$$m - m_0 > 0$$

$m > m_0$   $m$  apparente + grande que  $m_0$   
 ↓  
 "intrinsèque"  
 Objet est plus faible que l'objet original

Introduction to Astrophysics

This is a decimal logarithm and not a natural logarithm. One can see that  $m - m_0$  is positive, what implies that  $m$  is greater than  $m_0$ . Remember that the magnitude scale is logarithmic. There is a minus sign here, meaning that the observed source is seen with apparent magnitude greater than  $m_0$ , which is the intrinsic magnitude before the absorption. This signifies that the source has been absorbed and so fainter than the original.

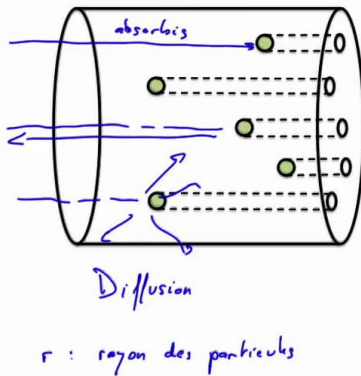
Notes

Summary



20m 49s

# Absorption, Diffusion and Reflection



- Diffusion de Mie  $r \gg \lambda$   
 $C_{ext}(Mie) \propto \lambda^{-1}$   
 Directionnelle
- Diffusion de Rayleigh  $r \ll \lambda$   
 $C_{ext}$



Introduction to Astrophysics

We have just talked about absorption, but this is not the only effect present in a volume element. Some photons that will be absorbed, some can be reflected back to the source, some reflected in an arbitrary direction. This extremely important effect is called scattering. This effect will not be described here in details. It will be qualitatively shown how scattering depends on the particles radii. There are two types of scattering. When photons propagate through dust, they are scattered in the same way fog would do. The first type of scattering is the Mie scattering. It takes place when the radius of the grains is much larger than the photon's wavelength. In this case, the extinction coefficient is equal to the one given by the Mie scattering, which is proportional to  $\lambda^{-1}$ . Another property of this type of scattering is that it is directional. It is not isotropic. It means that photons do not scatter in a random direction. They rather scatter in a direction that lies closer to the incidence direction. This is the Mie scattering. Another type of scattering is the Rayleigh scattering that takes place when the medium consists of small particles smaller than the wavelength.

Notes

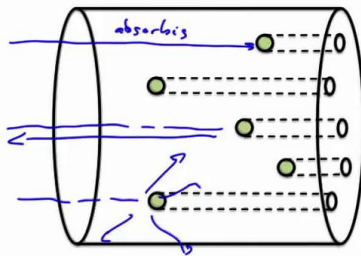
Summary



21m 31s



# Absorption, Diffusion and Reflection



Diffusion

$r$  : rayon des particules

- Diffusion de Mie  $r \gg \lambda$

$$C_{\text{ext}}(\text{Mie}) \propto \lambda^{-1}$$

Directionnelle

- Diffusion de Rayleigh  $r \ll \lambda$

$$C_{\text{ext}}(\text{Rayleigh}) \propto \lambda^{-4}$$

Isotrope

Plus efficaces aux courtes longueurs d'ondes

Introduction to Astrophysics

Notes

For this type of scattering, the extinction coefficient depends even stronger on the wavelength as  $\lambda^{-4}$ . Rayleigh scattering is isotropic. In conclusion, if light is scattered by large grains, the scattering is directional and is more efficient for shorter wavelengths. The dependence law is  $\lambda^{-1}$ . The Rayleigh scattering arises for small particles. It is isotropic, and also depends on the wavelength. It is more effective for the blue light than for the red light because of the dependence of the extinction coefficients as  $\lambda^{-4}$ . Both types of scattering are more effective for shorter wavelengths.

Summary



23m 06s

# Absorption, Diffusion and Reflection



The consequence of the scattering can be observed on Earth. Both types of scattering can be noticed on this slide. Firstly, the scattering that makes the sky blue. This is a scattering by atoms. All the particles whose radius is very small compared to the wavelength, the wavelength is of the order of hundreds or thousands of angstrom. Obviously, it is the case of the Rayleigh scattering that is isotropic. It was said that the scattering is more effective for the bluer light. This is the reason why the sky is blue and why there are no visible structures. The uniform blue colour is caused by the isotropic property. Now what happens in the cloud? The cloud is composed of water drops. Here we can find droplets of water with radii much larger than the wavelength. In this case, the leading process is the Mie scattering that is directional. This is the reason why one can see obvious structures in the cloud. If the scattering was isotropic, the structures would not be visible in the clouds.

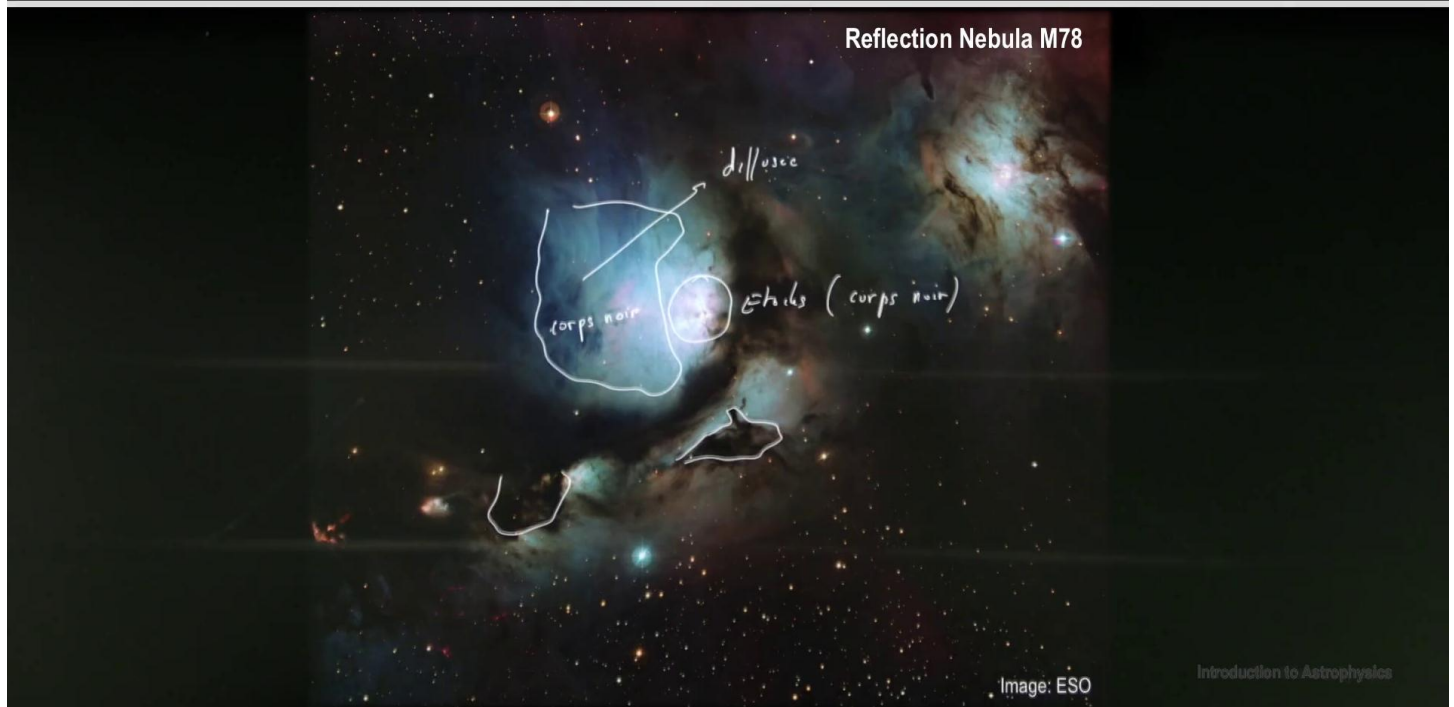
Notes

Summary



23m 58s

# Absorption, Diffusion and Reflection



It works in the same way for nebulae that are also clouds. Here is a reflection nebula M78 in the constellation of Orion, reflection or diffusion nebula. It is basically the same. In the centre of the nebula, there are stars. One can find some dusty regions that absorb light. There will be an extinction coefficient is related to these areas. There are also some areas where the light is scattered. How to see this in practice? The spectrum of a star is a black body spectrum. The spectrum of a nebula should be composed of emission lines because of atoms that can be ionised by stars. After the ionisation, they recombine and generate emission lines. But this is not the case here. Those stars are not able to ionise the surrounding matter. Instead, the light is scattered. If the spectrum was taken in this area, it would be a black body spectrum. The same spectrum that the one of the stars illuminated the matter around them. That is why obtaining spectra of astronomical objects is so important. If one has a spectrum that shows lines, the effects present in a nebula are not the same as for the nebula that has a black body spectrum.

Notes

Summary



25m 23s

# Effect on the Color of Celestial Bodies

Absorption et diffusion : Plus efficaces aux courtes longueurs d'ondes

=> rougissement

=> pour observer un objet très absorbé par la poussière  
il faut observer à grande longueur d'onde

Introduction to Astrophysics

In the latter case, there is light scattering, while in the former case, atoms are ionised and then they recombine. What is the final balance between the different processes? In the nebula, there is light scattering and the absorption that both are more effective for shorter wavelengths. That implies two things. The first one, the absorption is responsible for the fact that the observer sees a source weaker, as if it was emitting less light. Also, if the light is absorbed or scattered more effectively for shorter wavelengths, it implies that sources observed through dust are reddened. This is the interstellar and intergalactic reddening. This was the first conclusion. If one wants to observe sources whose light is strongly absorbed, the observations must be done in the infrared. Light with longer wavelength propagates through matter more easily. The observations are not so simple because it may happen that the source does not emit light at longer wavelengths. One has to adapt the means to the goal of the observations, at least as far as observations through dust is concerned.

Notes

Summary



26m 46s

# Effect on the Color of Celestial Bodies

Indice de couleur intrinsèque  $(B-V)_0 = B_0 - V_0$

$$\left. \begin{array}{l} B = B_0 + A_B \\ V = V_0 + A_V \end{array} \right\} \text{ en magnitudes}$$

$$B - V = (B - V)_0 - (A_V - A_B) \quad \text{avec } A_B > A_V$$

$$= (B - V)_0 + \underbrace{E(B - V)}_{\text{exces de couleur}}$$

$$(B - V) > (B - V)_0 \Rightarrow \text{objet est rougi par la poussière}$$

Introduction to Astrophysics

Notes

Let's look at the quantitative description of reddening and its influence magnitudes. It was said that the colour of objects is measured using the colour index, the intrinsic index. It will be called  $B$  minus  $V_0$  and is equal to  $B_0$  minus  $V_0$ .  $B$  is linked to  $B_0$  through absorption, which can be, in turn, expressed as an optical depth. This is for the blue filter. For the  $V$  filter, which is redder than  $B$ , one has two magnitudes. Both are affected by absorption. Subtracting one equation from the other gives  $B$  minus  $V$  equals  $B$  minus  $V_0$  minus  $A_V$  minus  $A_B$  with  $A_B$  greater than  $A_V$  because the blue light is absorbed stronger. As it was seen before, this equation could be rewritten as  $B$  minus  $V_0$  minus a new term,  $E$ ,  $B$  minus  $V$ , that is used to characterise the reddening of stars.  $E$   $B$  minus  $V$  is the colour excess.  $B$  minus  $V$  greater than  $B$  minus  $V_0$  because  $A_B$  greater than  $A_V$ . It was shown that larger colour indices correspond to red stars. Smaller colour indices correspond to bluer stars. Provided that the bluer filter is placed on the left side of the index, the observed index is greater than the intrinsic index, what implies that the observed source is reddened, thanks to the colour indices and to the colour excess. It is possible to quantify the way in which the stellar objects are reddened by dust in the interstellar and intergalactic medium.

Summary





# Chromatic Absorption of Light



A direct illustration of this effect, a nebula, in fact, a cloud composed of dust seen at different wavelengths. This image corresponds to the optical wavelength, the limit in the blue light. This image was taken in near infrared. The wavelengths increases in this way across the slide. This is the infrared image. One can easily see that in the image with the dust, all the radiation from the background is blocked and scattered by the dust. It is lost. It does not reach the observer. When going further in the near infrared, one can see more and more stars. Near the edge of the nebula, one can see more and more stars. One can see more and more stars when going to the centre, even more at longer wavelengths. In this image, almost all the stars can be seen through the dust. This is a cloud of dust in the Milky Way, Barnard 68 that could be delimited in this way. This is an image in false colour, with the visible light in the blue channel, the near infrared and the green channel, and the infrared in the red channel. Looking at this image, one can at one see a large cloud of dust located along the line of sight to the observer.

Notes

Summary



30m 05s



Light constantly interacts with matter. Thanks to these interactions, the analysis of the light gives us valuable information. The last two lectures showed that this analysis is quite delicate. All the physical processes at play must be taken into account simultaneously. Continuous absorption or absorption lines, continuous emission or emission lines, chromatic absorption, reflection, scattering, which, in fact, is also a chromatic phenomenon. Also, one needs to consider chromatic effects caused by the Doppler effect, rotation, thermal agitation of molecules that sometimes broaden the emission and absorption lines. All these phenomena play a role at some point, an important role in our understanding of astronomical objects.

Notes

Summary

31m 42s

