



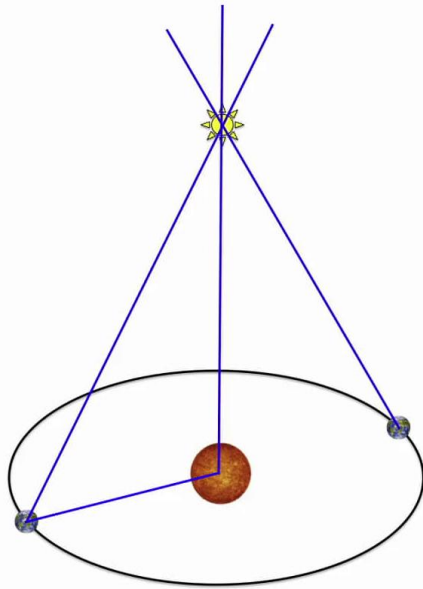
Welcome to this introductory course on astrophysics. In this first video, we will become more familiar with the astronomical objects in the Universe and we will introduce the distance and mass scales needed to characterize them.

- Notes

Summary



Spatial scales: parallax and distance



$$\begin{aligned} 1 \text{ UA (Unité astronomique)} &= 149 \cdot 10^6 \text{ km} \\ 1 \text{ al (Année lumière)} &= 9,46 \cdot 10^{12} \text{ km} \\ 1 \text{ pc (parsec)} &= 3,26 \text{ al} \end{aligned}$$

Introduction to Astrophysics

Let's first introduce the distance scales. First of all, in the solar system, we often use the astronomical unit which is the distance between the Earth and the Sun (1 AU - UA on the slides). This distance is 149 millions km, that is the distance between the Earth and the Sun. If we are interested in bigger distances, we will often measure them in lightyears (ly - al on the slides) which is the distance travelled by light during one year, at the speed of 300.000 km/s. This corresponds to a distance of 9,46 times 10^{12} km. Most of the time, we will use another distance, called the parsec. Most of the time, we will use another distance, called the parsec that we will define in the following. It turns out that this distance, numerically speaking, is equals to 3,26 lightyears. To define the parsec, we first have to define what is called the parallax. Parallax is the angle subtended by Earth's radius at a distance d , for example at the distance of this star. Here is the line of sight to the star seen from the Earth at a certain time. The star will be at a particular apparent location on the sky. Six months later for example, the parallax of this star will be different: the star will be observed at another location on the sky.

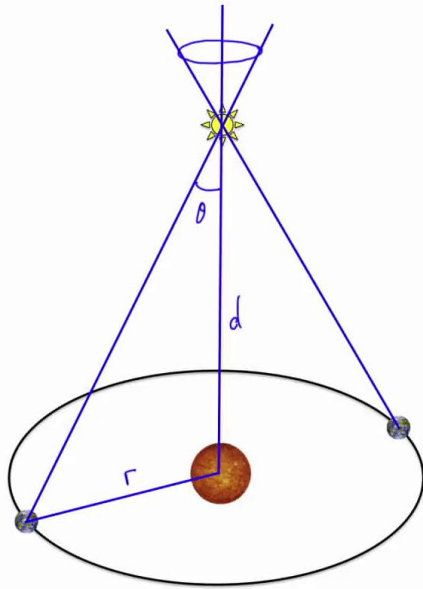
Notes

Summary



0m 20s

Spatial scales: parallax and distance



$$1 \text{ UA (Unité astronomique)} = 149.10^6 \text{ km}$$

$$1 \text{ al (Année lumière)} = 9,46 \cdot 10^{12} \text{ km}$$

$$1 \text{ pc (parsec)} = 3,26 \text{ al}$$

$$\theta = \frac{r}{d} \quad \text{parallaxe}$$

$$\text{Si } r = 1 \text{ UA et } \theta = 1''$$

$$1 = \frac{1}{d} \Rightarrow d = 1 \text{ pc (parallaxe de } 1'')$$

$$\theta ['] = \frac{1}{d [\text{pc}]}$$

Introduction to Astrophysics

The angle variation between the two positions is called the parallax. So, the parallax is an angle theta which depends on Earth's orbital radius and on the distance to the star. During the year, what we will see on the sky is the star following small ellipses whose opening angle is equal to this parallax. The parallax is simply $\theta = r/d$. We can now express things in astronomical units. If r is equal to one astronomical unit and if θ equals one arcsecond, then we can write a very simple equation : $1 = 1/d$. This obviously implies that d is also equal to 1. This 1 has the unit of a parsec, which is the abbreviation of the parallax of one arcsecond. In other words, if we express distances in astronomical units and parallaxes in arcseconds then we can rewrite that the angle theta in arcseconds is equal to 1 over the distance in parsec. That is, a parsec is the distance at which one astronomical unit subtends an angle of one arcsecond. Those are the main units of distances in astrophysics. Astronomical units are used for distances of the order of the size of a planetary system like our solar system. Otherwise, we use lightyears or parsecs. We have a direct relation between distances in parsec and angles subtended by objects in the sky.

Notes

Summary



1m 58s

The Solar System



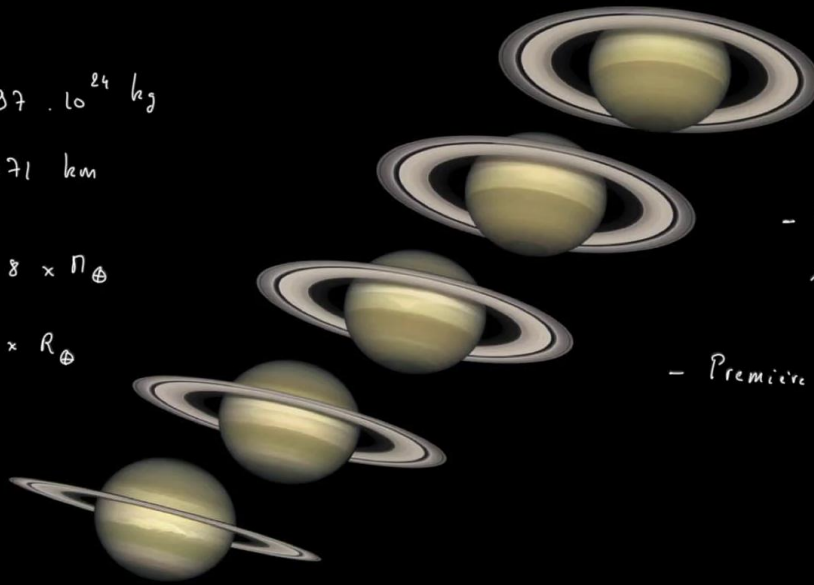
8 planètes

$$M_{\oplus} = 5,97 \cdot 10^{24} \text{ kg}$$

$$R_{\oplus} = 6371 \text{ km}$$

$$M_J = 317,8 \times M_{\oplus}$$

$$R_J = 11 \times R_{\oplus}$$



1700 exoplanètes
Planètes "extra-solaires"

- Première planète extra-solaire

1995: Mayor, Queloz

- Première détection directe : 2008

Image: NASA/ESA – Hubble Heritage

Introduction to Astrophysics

Now let's define some units of mass. For example in the solar system, you have here the planet Saturn observed at different times. In our solar system, we have eight planets we can express their masses either in Earth masses for telluric planets, that is with a solid crust, or in Jupiter masses for gaseous planets. The symbol used for Earth is a circle with a cross in its centre. The Earth's mass is equals to $5,97 \times 10^{24}$ kg. Earth's radius is 6371 km. We will often express planetary masses and planetary radii in units of Earth masses and Earth radii. If we are interested in bigger planets, we can compare for example Jupiter mass, which is 317.8 times the Earth mass, and the radius of which equals 11 times Earth radius. In addition to the eight planets of the solar system, we currently know 1700 exoplanets or extra-solar planets. The first extra-solar planet was discovered in 1995 by Michel Mayor and Didier Queloz at the Observatory of Geneva. This one was an indirect detection, measured thanks to the radial velocity of the star around which it orbits. The first direct detection was made in 2008.

Notes

Summary



3m 57s

The Solar System

Hall-Bopp Comet, 4 April 1997

C. H. O. N

80 % H_2O

10 % CO

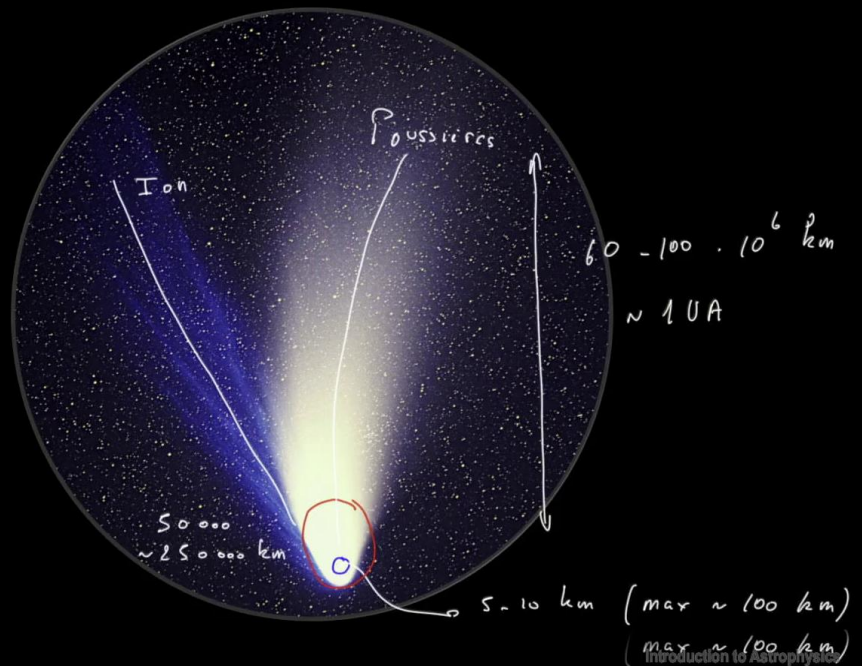


Image: E. Kolmhofer, H. Raab
Johannes-Kepler-Observatory, Linz, Austrie

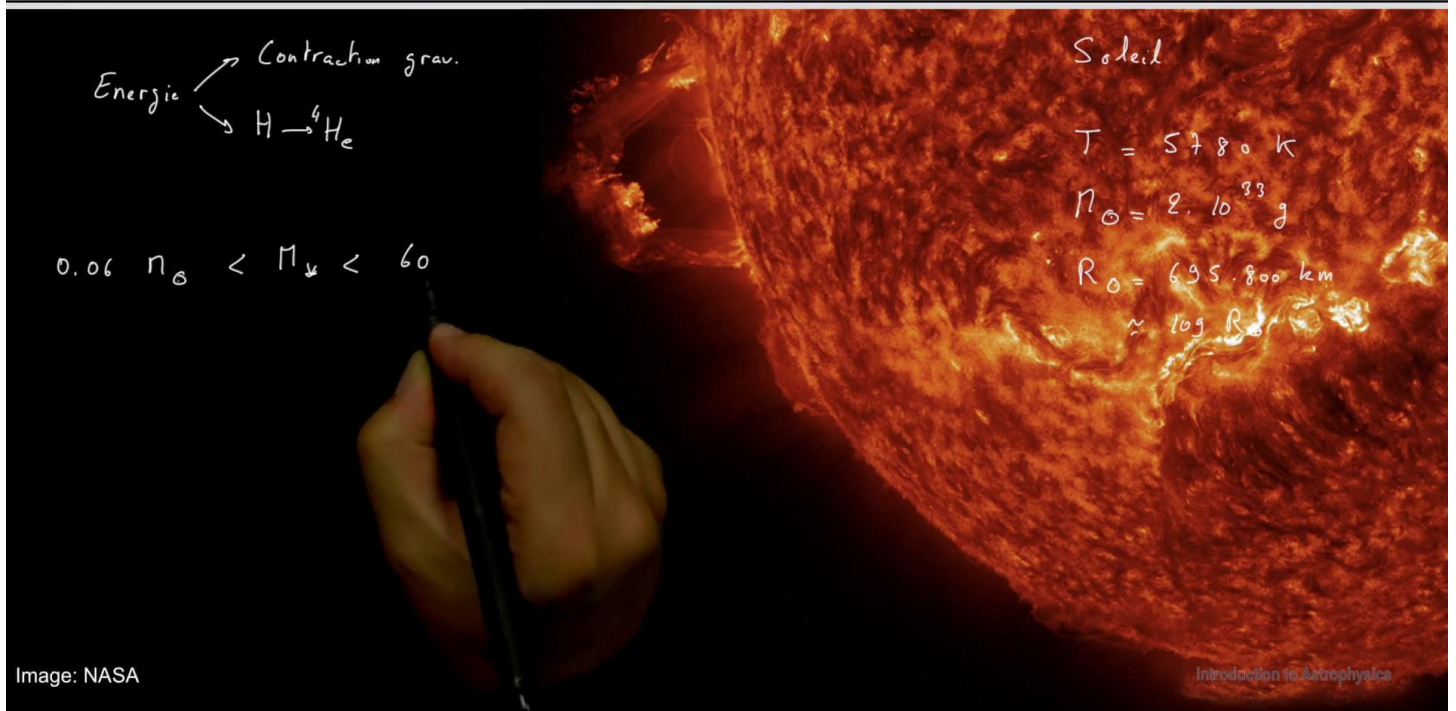
In the solar system, we don't only find planets. There are also comets for example which are sort of frozen mudballs that evaporate as they get close to the Sun. The matter ejected by the comet, by its nucleus, is pushed by solar photons along large cometary tails. So, comets have a nucleus. The nucleus is often very small, with a diameter of the order of 5 to 10 km, with a maximum around 100 km. They also have a halo. Its diameter is of the order of 50'000 km to 250 000 km. Cometary dust is ejected to form tails. For example, we see here a dust tail, made of quite heavy particles and here a tail made of ionised matter, namely ions. Light particles are over there, and heavier dusts are generally ejected on another tail. What is the composition of a comet? They are mainly composed of organic matter, C, H, O N and actually contain 80% of water. and around 10% of carbon monoxide. Such cometary tails can reach a size of the order of 60 to 100 millions km. We have then sizes of the order of the astronomical unit.

Notes

Summary



5m 51s



Let's resume our tour of the solar system. The solar system contains of course the Sun, our reference star. Note that it is the only star we know that we can directly observe the surface, that we can take pictures of. All other stars are way too small and too far for us to directly study their surface. The surface temperature of the Sun is 5'700 K This is the mass of the Sun, that will be used as a reference for the mass of other astronomical bodies. We will generally express the masses of galaxies and large astrophysical objects in terms of solar masses. This solar mass is 10^{33} grams. Here is the solar radius, that will also be used to characterise the radii of other stars for example. Its value is 695'000 km, which is roughly 109 times Earth's radius Other stars are similar to the Sun. They are powered by two phenomenon : gravitational compression, and nuclear fusion of hydrogen atoms into helium. We usually define the lifetime of a star as the time it takes to burn all its hydrogen into helium. This amount of time is the main part of a star's lifespan. The other extremely important parameter for stars is their masses. Star masses can range from 0.06 times the mass of the Sun up to 60 solar masses.

Notes

Summary



Energie \swarrow Contraction grav.
 \searrow $H \rightarrow {}^4H_e$

$0.06 M_{\odot} < M_{*} < 60 M_{\odot}$
 $0.17 R_{\odot} < R_{*} < 15 R_{\odot}$
 $2640 K < T_{*} < 44500 K$
 $5 \cdot 10^6 \text{ ans} < t_{H \rightarrow {}^4H_e} < 10^{13} \text{ ans}$
 $1.2 \cdot 10^{-3} L_{\odot} < L_{*} < 8 \cdot 10^5 L_{\odot}$

Soleil

$T = 5780 K$
 $M_{\odot} = 2 \cdot 10^{33} g$
 $R_{\odot} = 695.800 km$
 $\approx 10^9 R_{\oplus}$

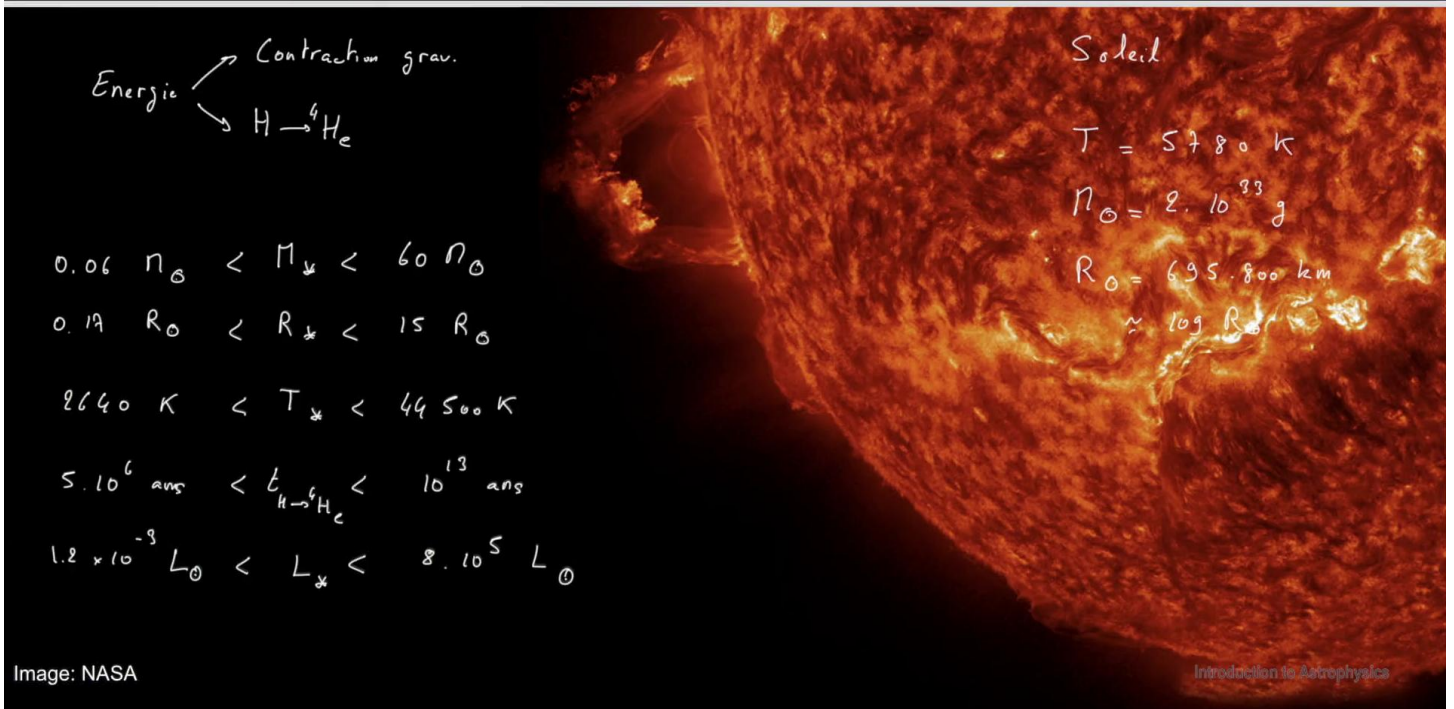


Image: NASA

Introduction to Astrophysics

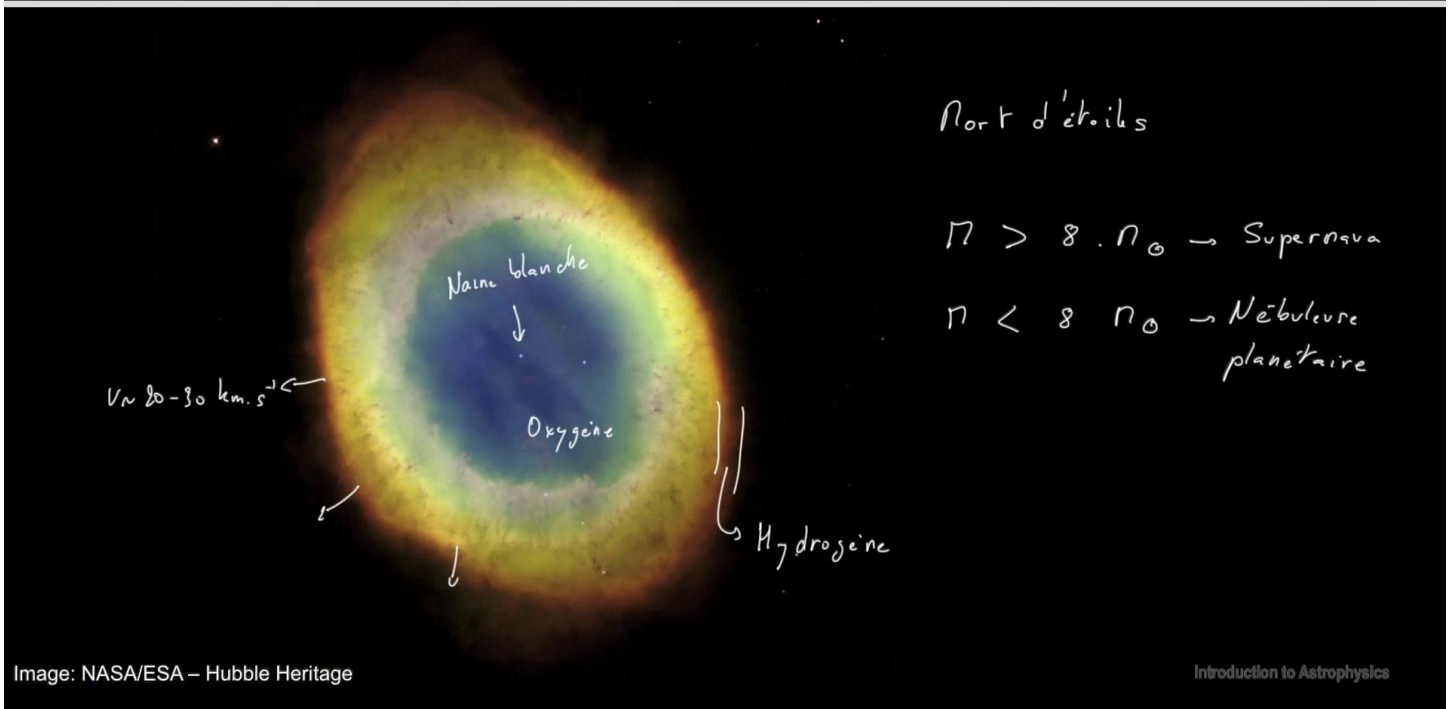
Under 0.06 solar masses, nuclear fusion reactions cannot ignite. Beyond very large masses such as 60 to 100 solar masses, the star will collapse and thus disappear. Stars radii, that we will compare to Sun's radius will range typically from 0.17 (0.2) solar radii up to approximately 15 times solar radii. This is the whole range of radii we can observe on stars. As for temperatures, the Sun has a surface temperature of 5'780 K. The coldest stars can have temperatures of the order of 2'640 K and the hottest ones around 44'500 K. The lifetime is, as mentioned before, the time needed to burn hydrogen into helium. This time varies on a very wide range, that can go from 5 times 10^6 , a few million years, up to 10^{13} years. A star can then last longer than the current age of the universe, 13,7 billion years. Stars luminosity will again be compared to the Sun's. Typically, the luminosity can vary between 1,2 times 10^{-3} solar luminosity, 1000 times less luminous than the Sun, and up to stars as bright as 8 times 10^5 solar luminosity. Most stars are in mass, radius, temperature, lifetime and luminosity ranges that are written here.

Notes

Summary



Nebulae (M42)



Stars do not have an infinite lifespan. Once they burn all their hydrogen into helium, there are two possible scenarios for the death of a star. Either the initial mass of the star is bigger than 8 times the Sun's mass, and we have a supernova, a very powerful explosion of the star, or the mass is lower than 8 times the mass of the Sun, and we have what is called a planetary nebula. Unlike what the name suggests, a planetary nebula has nothing to do with planets. Here is one of them, nebula Messier 57 in the constellation of Lyra. Planetary nebulae are due to the expansion of the outer layers of the star and the collapse of internal layers. At the end of the process subsists at the center what is called a white dwarf, surrounded by the star remnants. It is the white dwarf that will ionize the gas all around the nebula. In the external layers here, we recognize radiating hydrogen with red spectral lines. And in this part in green is the radiation of oxygen. Here is the expansion velocity of the nebula, which grows as the gas expands all around it. The expansion speed is of the order of 20 to 30 km/s. In a supernova, the speed of the external layers much later after the explosion is of the order of 2000 - 3000 km/s.

Notes

Summary



Stellar clusters (open cluster NGC 4755)



The matter ejected by stars at their death, either by a supernova or in the form of a planetary nebula, will be recycled into new stars. Here is the example of Great Orion Nebula (Messier 42) which has in its centre a cluster of young stars forming from the gas of the nebula. There are a lot of things in such picture. There is ionized gas, the density of which is around 1 particle /cm³, that is a mass density of 10⁻²¹ kg/m³. Here the gas looks quite dense, but we actually see the nebula from far away. and the density is in reality lower than in the ultra high vacuum we can produce on Earth. This concerns the gas that will emit a spectral line radiation at different wavelengths, which is generally produced by a hot source, such as a cluster of young stars, namely stars forming from the matter ejected by the death of other stars. We will also find cosmic dust. Dust absorbs background light, which is why we see all these dark stripes here or there. These are areas filled with dust. This dust is composed of grains bigger than the gas, itself composed of atoms. Dust grains are actually similar to the dust left by a chalk on a blackboard for example. This dust has a density even smaller than the gas, for example 10⁻¹³ particles /cm³, which is 13 orders of magnitude smaller than the gas density. The mass density is 10⁻²³ kg/m³.

Notes

Summary



Stellar clusters (open cluster NGC 4755)



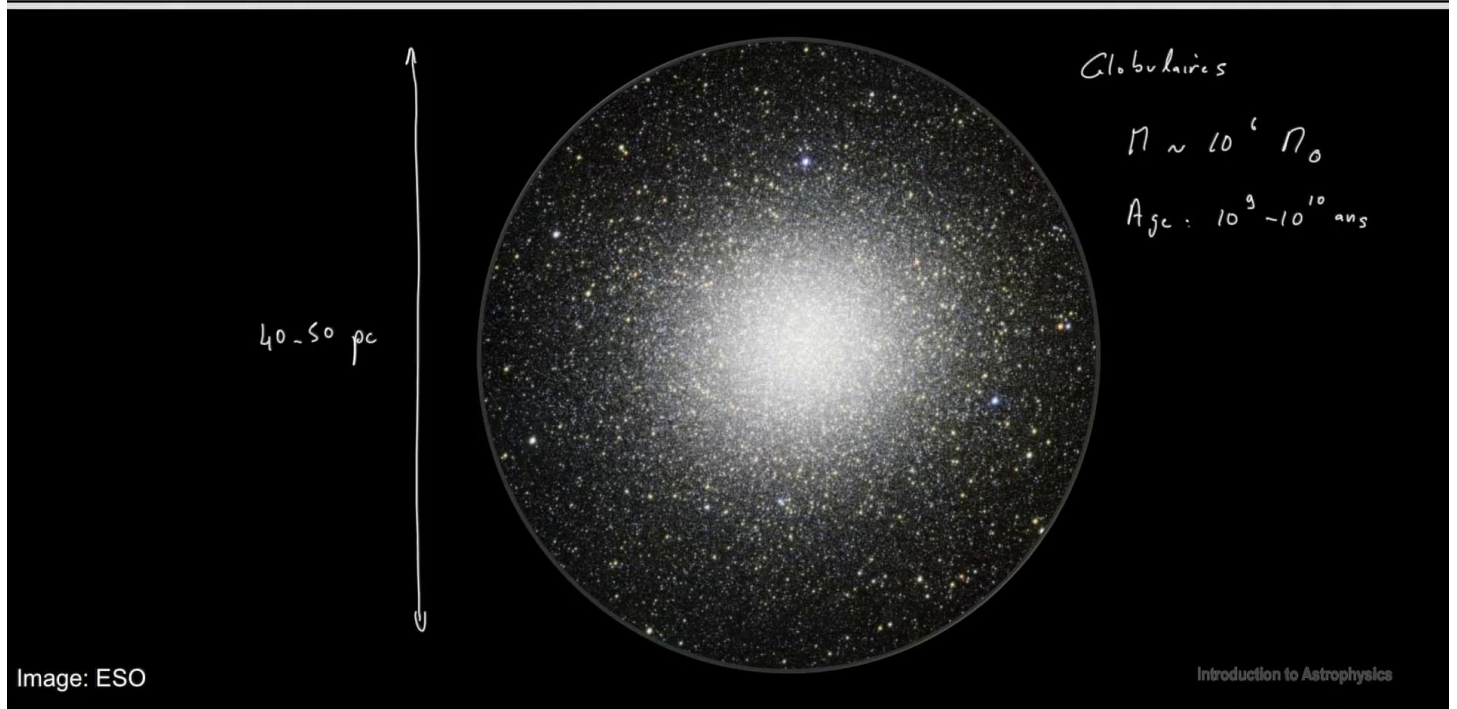
We can of course imagine a situation where all the gas has been recycled into stars. It is usually the case in what we call open clusters. For example we see here in NGC 4755 a variety of young stars, here and there. All the blue stars in this cluster are at the same distance from us. The stars in the cluster have approximately the same age. The stars in this open cluster are very young, with an age around 10^8 years, which is small in comparison to the age of the universe, around 13.7 billion years. The size of such a cluster is around 10 parsec. It is also the size of the nebulae who give birth to such clusters.

Notes

Summary



Stellar clusters (globular_cluster Ω Centauri)



In a galaxy like our Milky Way, we find young stellar clusters, open clusters or non-open clusters as well as globular clusters, such as this one here. A globular cluster is much more massive than an open cluster. The typical mass of an open cluster ranges from a few hundreds to a few thousands solar masses. The mass of a globular cluster is of the order of 10^6 solar masses. The mass of a globular cluster is of the order of 10^6 solar masses. Globular clusters are relatively old star clusters. The age of the stars is of the order of 10^9 up to 10^{10} years. Such clusters can be found in the periphery of galaxies. They are bigger than open clusters, with typical diameters of 40 to 50 parsecs.

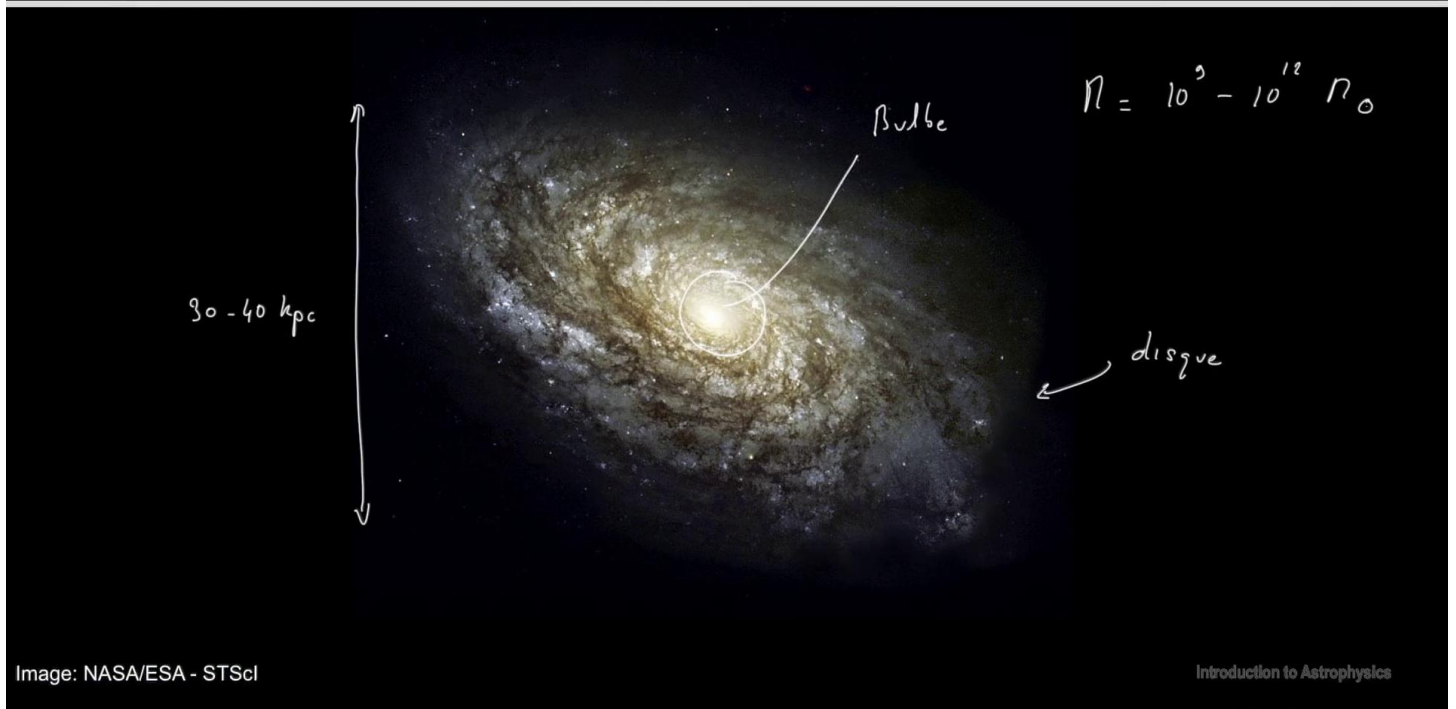
Notes

Summary



16m 27s

Galaxies (Spiral Galaxy NGC 4414)



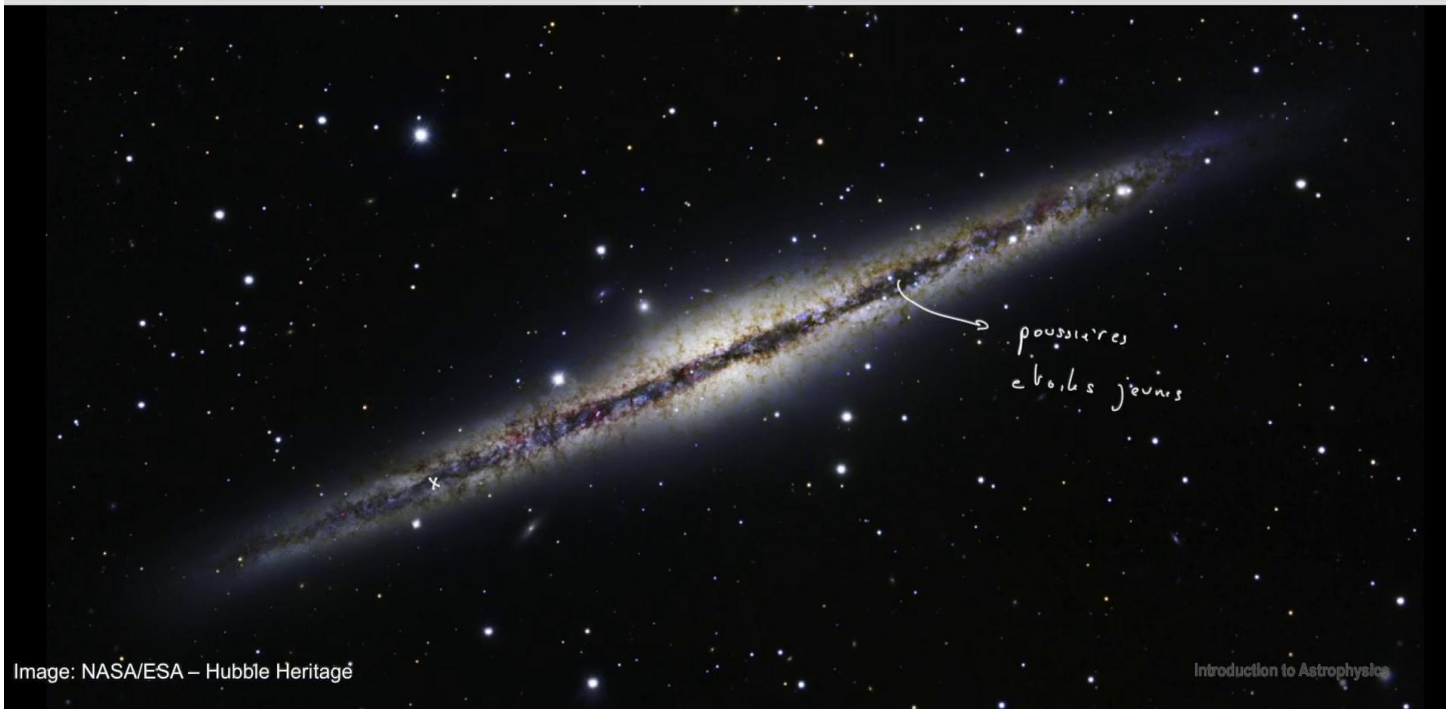
Stars, planets, nebulae, star clusters are all elements of galaxies. A galaxy is a much bigger object than everything we've seen so far. Here you have a spiral galaxy like our Milky Way, which is named after its spiral structure that you see in a disk with a bulge in its centre. So here is the bulge, and here is the disk. Old stars are in the centre, while young stars are usually formed in the arms. What we don't see in this picture is a halo of dark matter all around, in which are also the globular clusters. At the scale of this picture, the previously seen globular cluster is completely invisible. If it was visible, it would appear as a tiny dot, just like these. As for the diameter of a galaxy, you remember stellar clusters have sizes of 10, 40, 50 parsecs. Here we have galactic disks with a diameter of 30 to 40 kiloparsecs. The mass of a spiral galaxy is of the order of 10^9 up to 10^{12} solar masses.

Notes

Summary



Galaxies (Spiral Galaxy NGC 891)



Here is another example of a spiral galaxy. As mentioned before, in a spiral galaxy you have a bulge, here, and a disk that you see now here edge-on. This is the spiral galaxy NGC 891 seen edge-on. What you see here is a halo around the bulge, composed of old stars. Here are the spiral arms seen from the side, composed of young stars and of dust absorbing the background light, just like we saw earlier on with the nebula Messier 42, the Great Orion Nebula, that was showed as an example of diffuse nebula. In the disk you have dust and young stars. The Milky Way looks like that. Obviously we can't see our own galaxy from outside, but if we could see the Milky Way from outside, we would place the Sun here, at $\frac{2}{3}$ of the distance between the centre and the exterior of the galaxy. Again, the whole system is surrounded by a halo of dark matter, that by definition does not emit any light.

Notes

Summary



Galaxies (Elliptical Galaxy ESO 325-G004)



Peu ou pas de poussières
Peu ou pas de gaz
Peu de formation d'étoiles
 $10^7 M_{\odot} < M < 10^{13} M_{\odot}$

Image: NASA/ESA – Hubble Heritage

Introduction to Astrophysics

Spiral galaxies are one kind of galaxy. There are also elliptical galaxies, which as their name suggest have an elliptical shape. They are often at the centre of galaxy clusters. This is why you see here other galaxies around it. All these galaxies are at the same distance from us and the central galaxy is an elliptical one, which is actually a sort of ball of old stars with random orbits around a centre of gravity. Contrarily to spiral galaxies, they contain little or no dust. They also contain little or no gas and form only a few stars. Their masses covers a much wider range than spiral galaxies, between 10^7 and 10^{13} solar masses. They are generally encountered at the centre of clusters of galaxies.

Notes

Summary



20m 00s

Galaxy Clusters (Abell 1689)



This is a cluster of galaxies. At the centre of a galaxy cluster, we usually find a main elliptical galaxy, as we can see here. We actually see a lot of elliptical galaxies, even quite far from the centre. There are also spiral galaxies, and virtually all types of galaxies. They all orbit around a common centre of gravity. Galaxy clusters are the heaviest gravitationally bound structures in the universe. They obviously contain visible matter, but are also surrounded by a halo of dark matter, just like individual galaxies, spiral galaxies, elliptical galaxies. The masses involved are really huge, between 10^{14} to 10^{15} solar masses.

Notes

Summary



21m 07s



All the astronomical objects that we just saw, from the smallest to the largest, the lightest to the heaviest, are part of a whole, the universe, the study of which is called cosmology. In the picture behind me is an overview of the whole universe in a single picture. This is the Hubble Ultra Deep Field. a picture taken by the Hubble space telescope that simultaneously shows in a single shot 10'000 galaxies, illustrating the diversity of the worlds surrounding us. It is by studying such pictures in details, at different wavelengths, different resolutions and perhaps at different eras that we can trace down the history of the galaxies formation, stars, planets,..., in short, the whole universe. Two essential tools to study the trajectories of astrophysical objects and measure their masses are the three Kepler's laws and the Virial theorem. These will be the topic of the next videos.

Notes

Summary



21m 59s