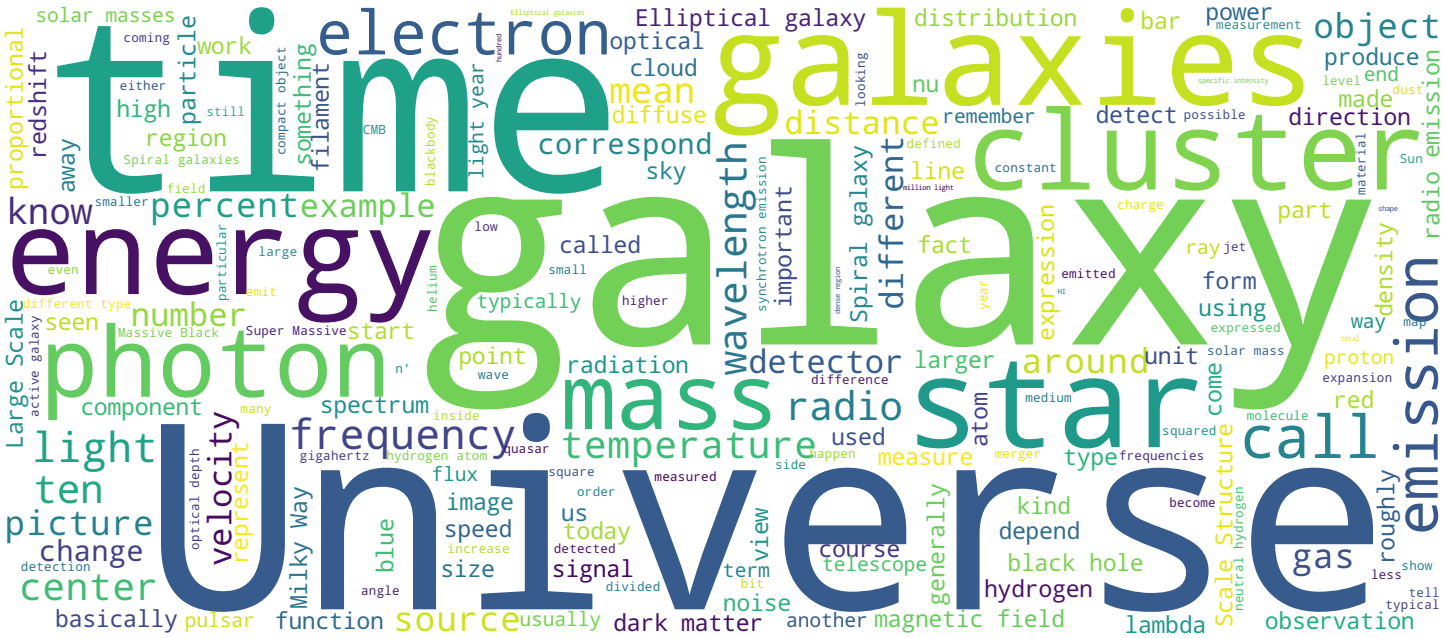
EPFL

Galaxies and Clusters

The Universe At Radio Wavelengths

Jean-Paul Knieb



EPFL

Today, we will have a look at the content of the Universe. From the Einstein equations, we know there are two main components in the Universe budget. Mass and energy. The energy is believed to be constant throughout the Universe but the mass is distributed differently as a fraction of scales. We will have a look at the big massive object in the Universe. The galaxies and the cluster of galaxies forming the large-scale structures of the Universe. I'm sure you're familiar with our own galaxy, the milky way. It can be seen with your own eyes during the moonless night as diffuse starlight crossing the sky. Beautiful, right. The more expert may also know the nearby Andromeda galaxy, our sister galaxy, which can also be seen by eye. Yet we believe there are more than hundred billions of galaxy in the whole Universe. We have a lot to discover.

Notes

Summary

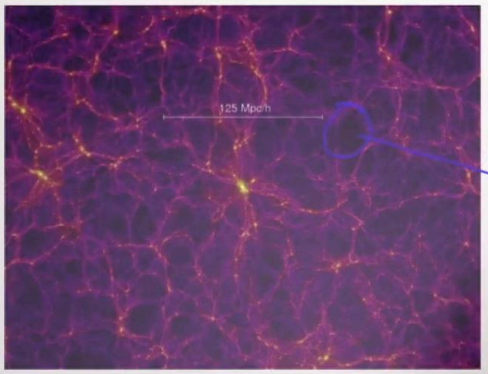
0m 05s

Content of the Universe

EPFL

The Einstein equations describe the content of the Universe with 2 components:

- Mass — Dark Matter 80% gaz 15% stars 5% BH
- Energy — linked with SPACE-TIME ~ constant



Springel et al. (Virgo Consortium)

Large Scale Structures in the Universe !

VOIDS

The Radio Universe

So let's have today a look at the content of the Universe. The Einstein equation describe the content of Universe with two component. First the mass and second the energy. What we have as a mass? We have dark matter, which represent about 80 percent of the total mass. We have gas which is typically hydrogen and helium and that represent about 50 percent of the gas of the content of the mass, and we have stars, which more or less represent five percent of the content in mass. So we have diffuse matter which is dark matter and gas and we have also very compact object like stars but also black holes. What about the energy? Well, the energy is assumed to be linked with the property of space-time and is to be constant across the Universe and across the time. So what is the distribution of mass in the Universe? So basically we know that the mass distribution is different depending on the scales in the Universe. We call that the Large-Scale Structures in the Universe. Here you have a representation of a simulation, numeric simulation of the Universe. The color scheme represent the density here of the dark matter. What we see in this image? We see different characteristic, we see voids like here which correspond to empty region.

Notes

Summary

1m 18s

Content of the Universe

EPFL

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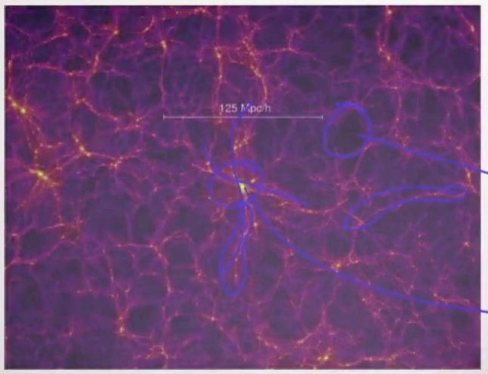

Springel et al. (Virgo Consortium)

Large Scale Structures in the Universe !

VOIDS
FILAMENTS
CLUSTERS of GALAXIES

~ 100 Mpc
~ 300 Million Light Years

The Radio Universe

We see filaments like over here or here and those represent intermediate density and at the crossing of the filaments, we see what we call clusters. Those are clusters of galaxies. So the typical scale we have of this feature are about 100 of mega parsec which correspond to about 300 million light years.

Notes

Summary

3m 20s

Tracing the Large Scale Structures

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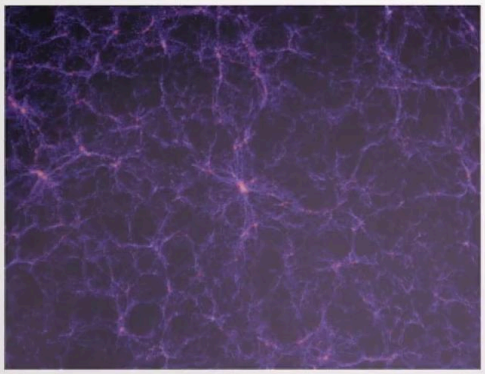
We use **Galaxies** to trace the Large Scale Structures !

- **Elliptical galaxies** old stars redder color more massive
- **Spiral Galaxies** star forming galaxies, young, blue color less massive



Springel et al. (Virgo Consortium)

In practise, Large Scale Structures are revealed by the distribution of galaxies !

red galaxy → dense regions

The Radio Universe

So let's have a look a bit more at these Large-Scale Structures. We are going to use galaxies to trace the large scale structure. Here is the pictures. The same picture as before but instead of viewing the dark matter, we view the galaxies and you see the distribution is very similar. In this representation we have two type of galaxies. We have Elliptical galaxy and we have Spiral galaxies. The Elliptical galaxies are rather made of old stars. They have redder color and we see them in this pictures as red points and those galaxy are generally more massive. In this prospect, the Spiral galaxies that you see in blue in this picture, they are star forming galaxies. They are young and they have blue colors and generally they are less massive. So in practice when we look at the Universe, the Large-Scale Structure are revealed by the distribution of galaxies and what you see in this pictures is that redder galaxy are more concentrated in dense region. So red galaxies goes to dense region. So dense regions are basically cluster of galaxy like here but there are also, you know, small groups in the filaments that you can see here.

Notes

Summary

3m 59s

Tracing the Large Scale Structures

EPFL

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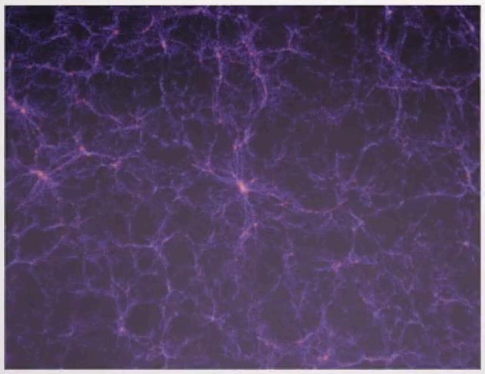


Springel et al. (Virgo Consortium)

In practise, Large Scale Structures are revealed by the distribution of galaxies !

red galaxy → dense regions
blue galaxy → low density regions
In Between IGM

The Radio Universe

Blue galaxy are generally in low density region so they are basically found in filaments and in the outskirts of cluster of galaxy and most of them, most of the galaxy in voids are also blue galaxies. In between galaxy, we have what we call the IGM, the Inter-Galactic Medium.

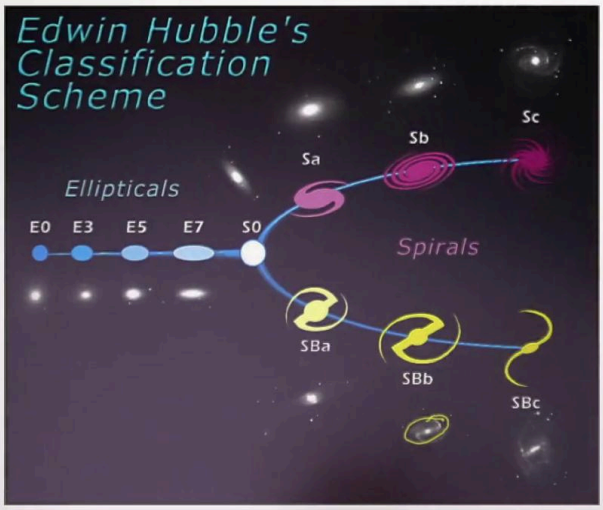
Notes

Summary

5m 45s

Galaxies – the main objects in the Universe

Galaxies are known for about 100 years – they were first called "Island Universe"



Wikipedia

Hubble Sequence: Classification scheme of Galaxies from Edwin Hubble

LOCAL UNIVERSE

* Ellipticals ~50%
* Spirals ~40%
* Barred Spirals ~10%
* Irregular galaxies

The Radio Universe

So galaxies are the main object in the Universe. They are known for about hundred of years. They were first called Island Universe. In 1999, Edwin Hubble measured the expansion of the Universe by measuring the distance to those galaxies but he also famous because he has made the classification scheme of galaxies that we call the Hubble Sequence. Here you have the Hubble Sequence where you see the Elliptical galaxies and then you have two branch of Spiral galaxies. The Elliptical galaxies are classified as a function of one number which quantify the shape of the galaxies. For the Spiral galaxies, we have two branch. One without a bar and one with a bar. The bar is at the very center part of the galaxy. So in the Hubble Sequence, we have different type of galaxy. We have the Ellipticals, which are generally the more massive. We have the Spirals which clearly spiral arms. We have the Barred Spirals with a bar at the center. We have also which is not shown in the bulk classification scheme, some irregular galaxy. So if we were looking in the local Universe at these different type of galaxies, we will find approximately about 50 percent of Elliptical, about 40 percent of Spirals without a bar and about 10 percent of Barred Spiral.

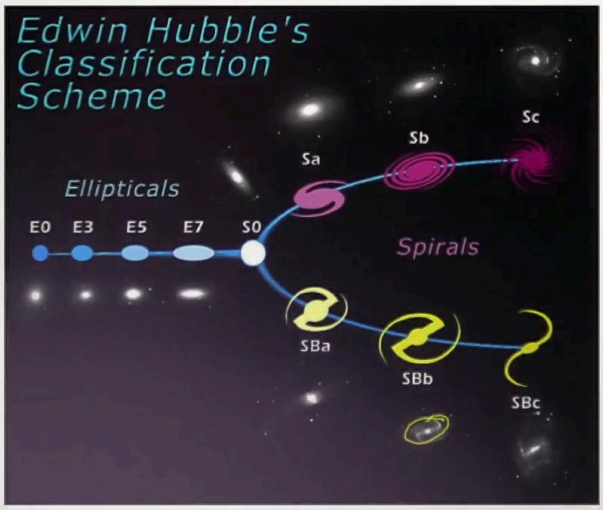
Notes

Summary

6m 16s

Galaxies – the main objects in the Universe

Galaxies are known for about 100 years – they were first called "Island Universe"



Wikipedia

Hubble Sequence: Classification scheme of Galaxies from Edwin Hubble

LOCAL UNIVERSE

* Ellipticals ~50%
* Spirals ~40%
* Barred Spirals ~10%
* Irregular galaxies ~ a few %

$10^9 - 10^{11}\ M_\odot$

Separation ~ 1 Mpc ~ 3 MLy

The Radio Universe

And then, of course, we have just a few percent of irregulars. The typical mass of a galaxy is about ten to the nine or ten to the eleven solar mass and the typical separation between galaxies is about one mega parsec, which is about three million light year.

Notes

Summary

8m 16s

Mass components in an Elliptical Galaxy

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Elliptical Galaxy: NGC 1132

M. West (NASA/ESA – Hubble Heritage)

Mass components in an elliptical galaxy:

- **Dark Matter Halo** outskirts
- **Compact Objects** stars same color same age

STBH

$10^5 \rightarrow 10^{13}\ M_\odot$

~25% still forming stars

The Radio Universe

So what are the mass component in Elliptical galaxy? Here we see a beautiful picture of the Elliptical galaxy NGC 1132. This picture was made by the Hubble Space Telescope. So what we have as a mass component in an Elliptical galaxy? So we have first, what we call the Dark Matter Halo. Where is it? It's kind of diffuse. We don't see it and it's usually located in the outskirts of the galaxy. Then we have these diffuse light which are made of compact objects. So those compact objects are basically stars, and generally, as you see they all have the same color. So that means they have also the same age. At the very center, there is what we call a Super Massive Black Hole. There is a wide range of Elliptical galaxy. The smaller of them have maybe ten to the five solar mass and the most massive Elliptical galaxy are of the order of ten to 13 solar masses. Although most of the Elliptical galaxy don't form any new stars, there are still about 25 percent of them that are still forming stars at low rate.

Notes

Summary

8m 50s

Mass components in a Spiral Galaxy

EPFL

Spiral Galaxy: NGC 3596

T. Burchell and B. Saxton (NRAO/AUI/NSF)

Mass components in a spiral galaxy:

- Dark Matter Halo
- Diffuse Gas/Dust
- Compact Objects

outskirts

BLUE → Neutral Hydrogen
RED → Ionised gas

STARS
STBH

Bulge
Spiral arms

$10^8 - 10^{12}\ M_\odot$

The Radio Universe

What are the mass component in a Spiral galaxy? Here we have a beautiful picture of the Spiral galaxy NGC 3596. Contrary to the Elliptic galaxy, we have more components in a Spiral galaxy. We have the dark matter halo which is also diffuse like in Elliptical galaxy and it's also mostly located in the outskirts. We have diffuse gas and dust and here we see different colors that represent different type of gas. We have the blue light which represent the neutral hydrogen and the neutral hydrogen is detected in at radio wavelengths. We have the red gas component which represent the ionized gas. Typically here is this ionized hydrogen and we have the more compact object which are also diffuse and correspond here to white light which are also made of stars and also at the very center we have a Super Massive Black Hole. This particular Spiral galaxy has no bar at the center. But we can still see two components. We can see the buldge which is the very bright part at the very center and we see the spiral arm that go around the galaxy. The typical mass of a Spiral galaxy goes from ten to the eight to ten to the twelve solar mass.

Notes

Summary

10m 33s

Active/Non-Active Galaxies

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Active Galaxy: Hercules A

NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

Most galaxies harbour at its centre
a super massive black hole SMBH

$10^5 - 10^8 \, M_\odot$

- quiet → non-active
- active
  - * quasar visible light
  - * jet in radio

The Radio Universe

We have two different type of galaxies. The active and non-active galaxies regardless whether they are Spiral or they are Elliptical galaxy. What you see in this nice picture is the active galaxy, Hercules A. You know most galaxy harbour at their center a Super Massive Black Hole which also we write as SMBH. The Super Massive Black Holes are typically of mass ranging from ten to the five to ten to the eight solar masses. The black hole can be quiet and then it correspond to a non-active galaxy or it can be active and then, of course, we can detect the active galaxy by different phenomena. We can either detect it as a quasar and that you would see it in the visible light or you can detect it through radio observation and then you will see jets in radio.

Notes

Summary

12m 29s

Cluster of Galaxies

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MACS J0416.1-2403

NASA, ESA, CXC, NRAO/AUI/NSF, STScI, and G. Ogrean (Stanford University)

Cluster of galaxies are located at the crossing of filaments

CG
* 100 to 1000 galaxies
* blue : hot X-ray gas
* red : radio emmition
* DM.

~ few million light year across
~ masses : $10^{13} - 10^{15}$ $M_\odot$
100'000 clusters in the universe

The Radio Universe

Now let's move to cluster of galaxies. So as the name says, the cluster of galaxy is a collection of galaxies that are bonded together by the mass of the system. So as we've said at the beginning, cluster of galaxy are located at the crossing of filaments. A cluster of galaxy is typically containing 100 to 1000 galaxies. You see the galaxy here are the white spot and you see they come with different size and they're regrouped at the center of the system. You also see two types of light. You see in blue the hot X-ray gas and in red light, you see the radio emission of the gas. And, of course, there's another component that we don't see which is the dark matter. The typical size of cluster galaxy is about a few million light year across. The most massive cluster of galaxy have typically masses which are ten to the thirteen to ten to the fifteen solar masses and we know that there is about hundred of thousands cluster of galaxies in the Universe.

Notes

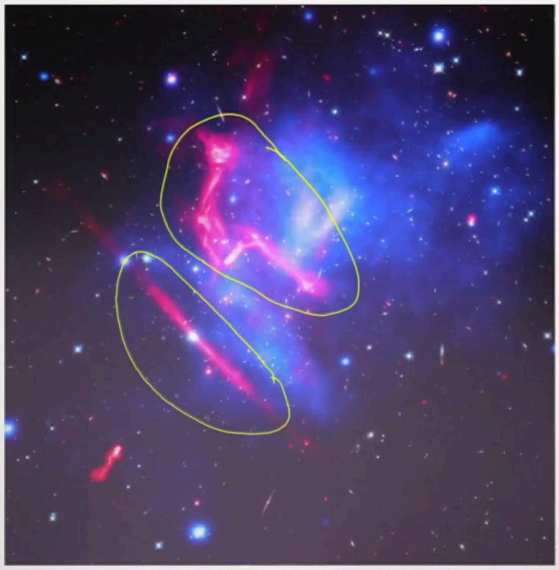
Summary

13m 49s

Cluster of Galaxies

EPFL

MACS J0717.5+3745



NASA, ESA, CXC, NRAO/AUI/NSF, STScI, and R. van Weeren (Harvard-Smithsonian Center for Astrophysics)

Cluster of galaxies are build through merger of smaller units

Merger of 3-4 clusters.

Blue X-ray hot gas

Red Radio emission

Radio schock fronts

The Radio Universe

Here in another example of a cluster galaxy which is called MACS J0717. This cluster in particular and as most of the cluster in fact has been built through the merger of smaller units. This particular cluster is a merger of three to four smaller clusters. A merger of cluster is a very particular event and it will produce different light. As before, what we see in blue light is a detection of the X-ray hot gas. What we see in red is the radio emission. We see different components in red. Over here, we have what we call radio shock fronts. These shock fronts are produce by the merging of these sub-units. Over here, we can see an active galaxy in the cluster that also display those jets that interact with the cluster of hot gas. So as you see, we have different kind of cluster of galaxies.

Notes

Summary

15m 30s

We have seen some of the basic quantities of galaxy and cluster of galaxy in the Universe. This very massive system come with different size and masses and they allow to trace the Large-Scale Structure of the Universe. Galaxies and cluster of galaxies are also interesting object on their own as they have different properties that changes as function of time. So to start understand galaxy evolution we will have to learn a bit more on the life cycle of star. One of the key component of a galaxy. We will have a look at this in our next session.

Notes

Summary

16m 53s