Expansion of the Universe

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Goals

- Understand what is the expansion of the Universe
- Understand that there is no center of the Universe
- Understand the Hubble's Law
- Analyze how to detect dark matter

Presentation

This workshop is about:

- The Origin of the Universe: Big Bang
- Galaxies: do not "move" through space, the space is the one that expands.
- The Hubble Constant : $v = H \cdot d$
- There is no centre of the universe, as there is no a central country
- The microwave background
- Gravitational lens.

Models, predictions, verification:

Experiment with tablecloth

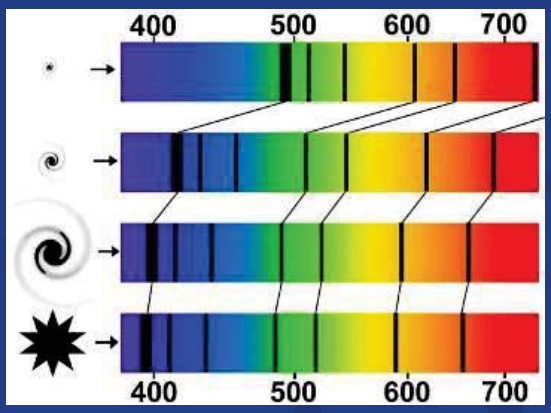
Prediction: if very quickly you pull a tablecloth from a table, nothing on the table will fall down. If we are able to verify this, our prediction is fulfilled.

The experiment works because physics is a science which permits to predict what will happen: if one pull quickly a tablecloth, friction forces do not have time to act on the objects on the table, which explains why they do not fall.

Physics that we developed on the Earth is the same one that we apply to the rest of the Universe.

Movement towards red

- The scattered light of each element shows the lines: it is the spectrum, and is characteristic for each element.
- When we observe the light from galaxies, we can see that the lines are shifted toward the red part of spectrum, and that the farther is the galaxy, the shift is greater.
- It is interpreted as a result of its movement away from us



Movement towards red

- Nearby galaxies have relatively small and irregular movements: the Large Magellanic Cloud +13 km/s, the Small Magellanic Cloud -30 km/s, Andromeda galaxy -60 km/s, M 32 +21 km/s.
- In the Virgo cluster, (50 million lyr away), all galaxies are moving away from us at speeds between 1,000 and 2,000 km/s.
- In the Coma Berenice supercluster (300 million lyr away) the speeds are between 7,000 and 8,500 km/s.

Movement towards red

- In the opposite direction, M 74 moves away at 800 km/s and M 77 at -1130 km/s.
- If we observe distant and faint galaxies, the recession velocity is even greater: NGC 375 galaxy moves away at 6200 km/s, NGC 562 at 10500 km/s and NGC 326 at 14500 km/s.
- Independently of the direction in which we observe, all, except the very close galaxies, move away from us.

Doppler effect

- If there is an ambulance, a motorcycle, or a train approaching us, we will hear a higher sound then when they move away from us
- High → the wave is shortened
- Grave → the wave is stretched

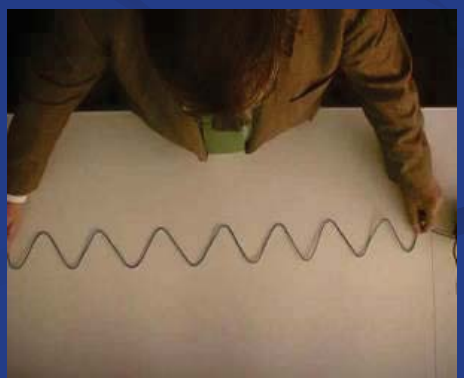
Activity 1: Doppler Effect

- The Doppler effect can be heard by rotating in a horizontal plane an alarm clock.
- When it approaches the viewer, λ is shortened and the sound is higher.
- When it goes away from us, λ is stretched and the sound is lower.
- Happens the same with the sound of motorcycle, ambulance, train ...

- The Doppler effect we detect here is due to the displacement. But it is not the same one that galaxies have due to expansion.

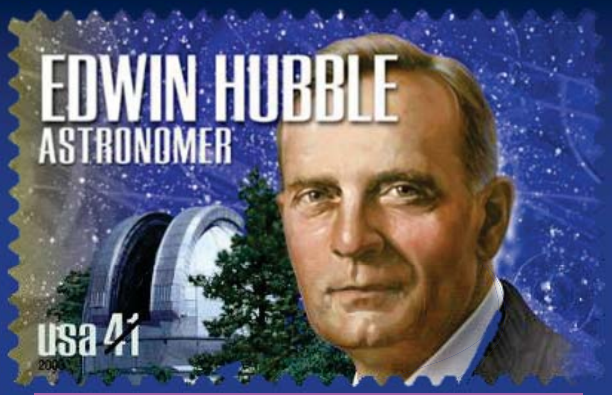
Activity 2. "Stretching" of photons

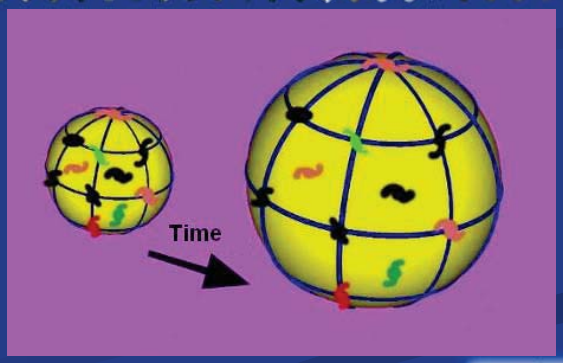
- The Universe, when it expands, "stretches" the photons in it.
- You can make a model of that stretch using a semi-rigid cable, which is used in electrical domestic.
- The longer is the photon's path, they are more stretched.



Hubble Law

- In 1930, Edwin Hubble realized that the most distant galaxies are moving away faster.
- Hubble Law : $v = H \cdot d$
- They don't move through the space: it is the space which expands, dragging the galaxies



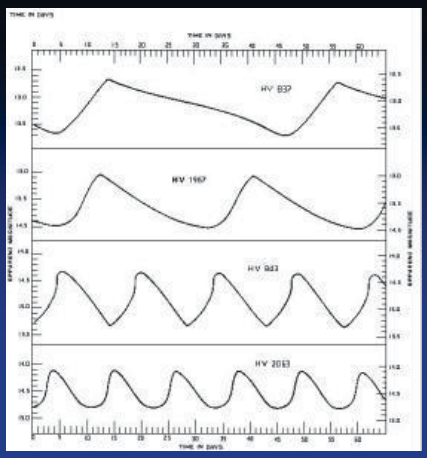


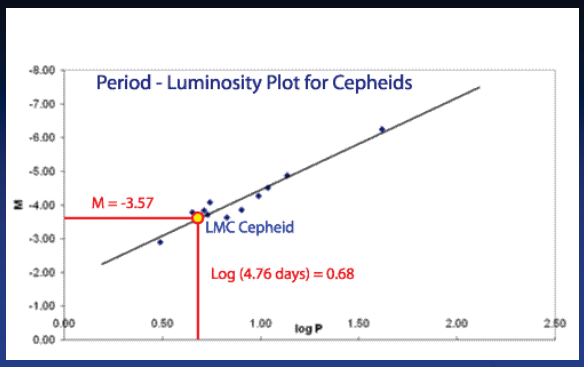
Activity 3: The Universe in a rubber

Activity 4: The Universe in a balloon

- The distance between the galaxies increases with the expansion.
- The galaxies are not moving through the balloon

Expansion of the Universe

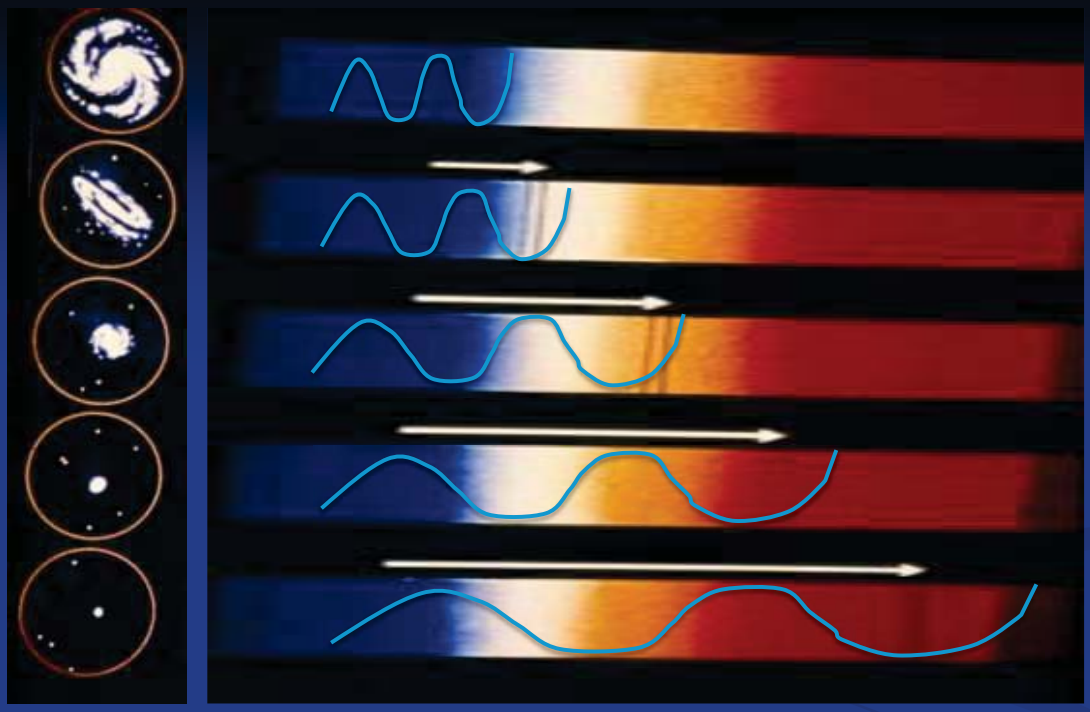




1. The distance to the nearest galaxies can be obtained from the period-luminosity relation of the Cepheid variable stars
   - From the light curve it is possible to obtain the period P
   - From the relation period-luminosity we can get the absolute magnitude M
   - With these two quantities, it is possible to measure the distance to the galaxy $d=10^{(m-M+5)/5}$ pc

To determine distances of the most distant galaxies the astronomers can use one type of supernova with similar luminosities.

Expansion of the Universe



2. The recession velocity is measured in the spectrum:

$$v = (\Delta \lambda / \lambda) * c$$

Expansion of the Universe

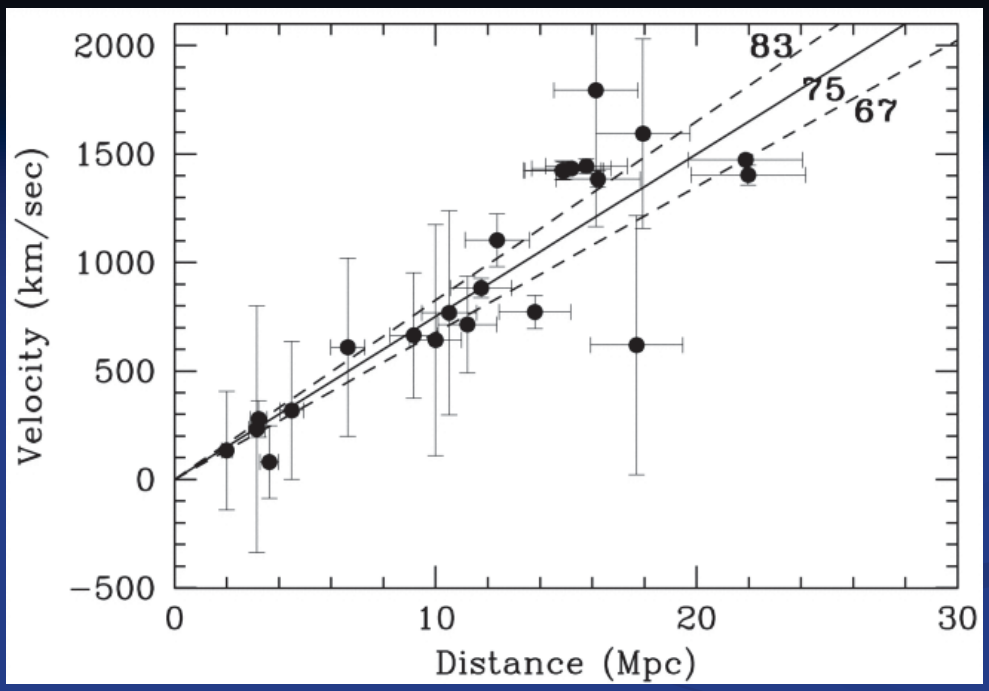
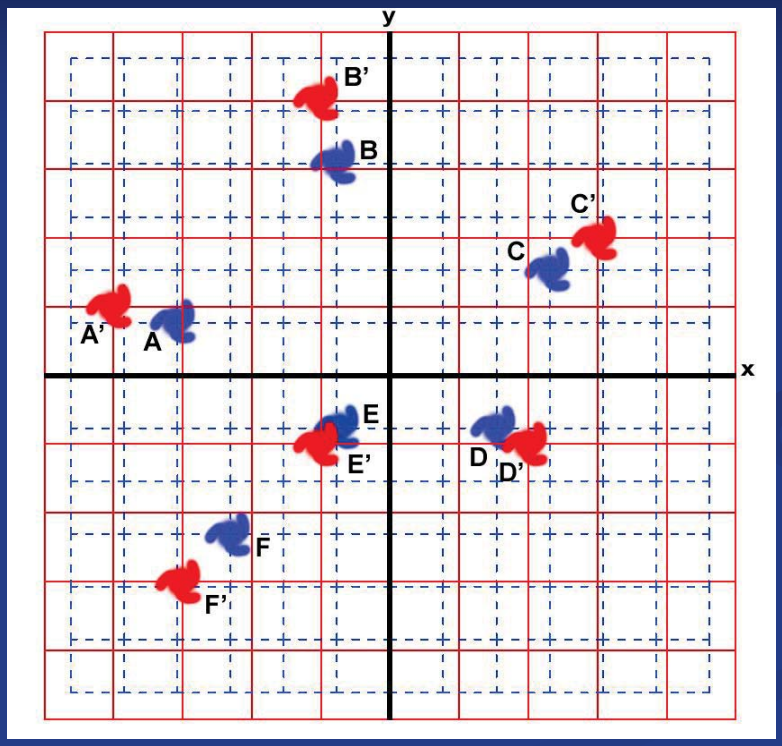


Fig. 1 from Freedman et al, 2001, ApJ, vol 553, p47.

3. The Hubble constant is the slope of the relation: $v = H_0 \cdot d$, where H_0 is the rate of expansion of the Universe: $H_0 = 72$ km/s/Mpc

Activity 5: Calculation of the Hubble constant

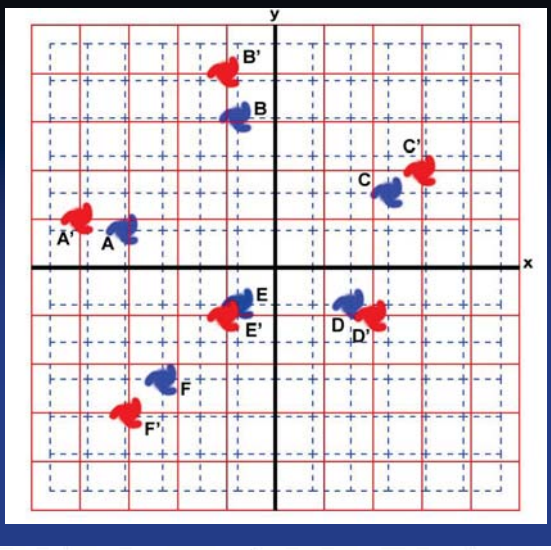


Blue = Universe before expanding

Red = Universe after expanding

Activity 5: Calculation of the Hubble constant

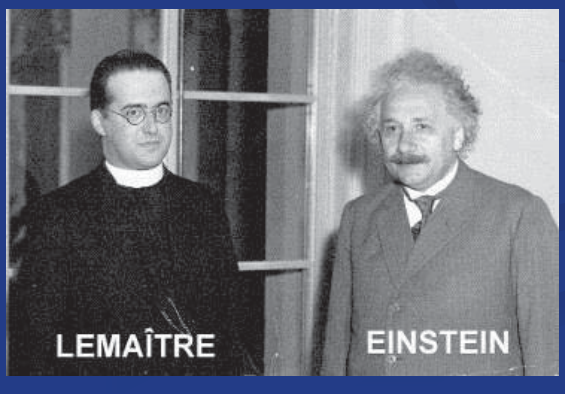
Galaxy	Coordinates x,y	d=distance to origin	Δd	$v = \frac{\Delta d}{\Delta t}$	$H = \frac{v}{d}$
A					
A'					
B					
B'					
C					
C'					
D					
D'					
E					
E'					
F					
F'					



Galaxy	Coordinates x,y	d=distance to origin	Δd	$v = \frac{\Delta d}{\Delta t}$	$H = \frac{v}{d}$
A	(-4, 1)				
A'	(-4, 1)				
B	(-1, 4)				
B'	(-1, 4)				
C	(3, 2)				
C'	(3, 2)				
D	(2, -1)				
D'	(2, -1)				
E	(-1, -1)				
E'	(-1, -1)				
F	(-3, -3)				
F'	(-3, -3)				

Big Bang

- If we go back, there was a time when everything was united: Universe in expansion.
- Georges Lemaître, solving the equations of relativity, came to the idea of an expanding universe that began as a "cosmic egg".



Big Bang

- Name of the Big Bang: big explosion.
- Fred Hoyle, with certain anti-religious prejudices, thought it seemed too consistent with the idea of a Creator
- S & T made a competition to rename it. 12,000 proposals. None was better.

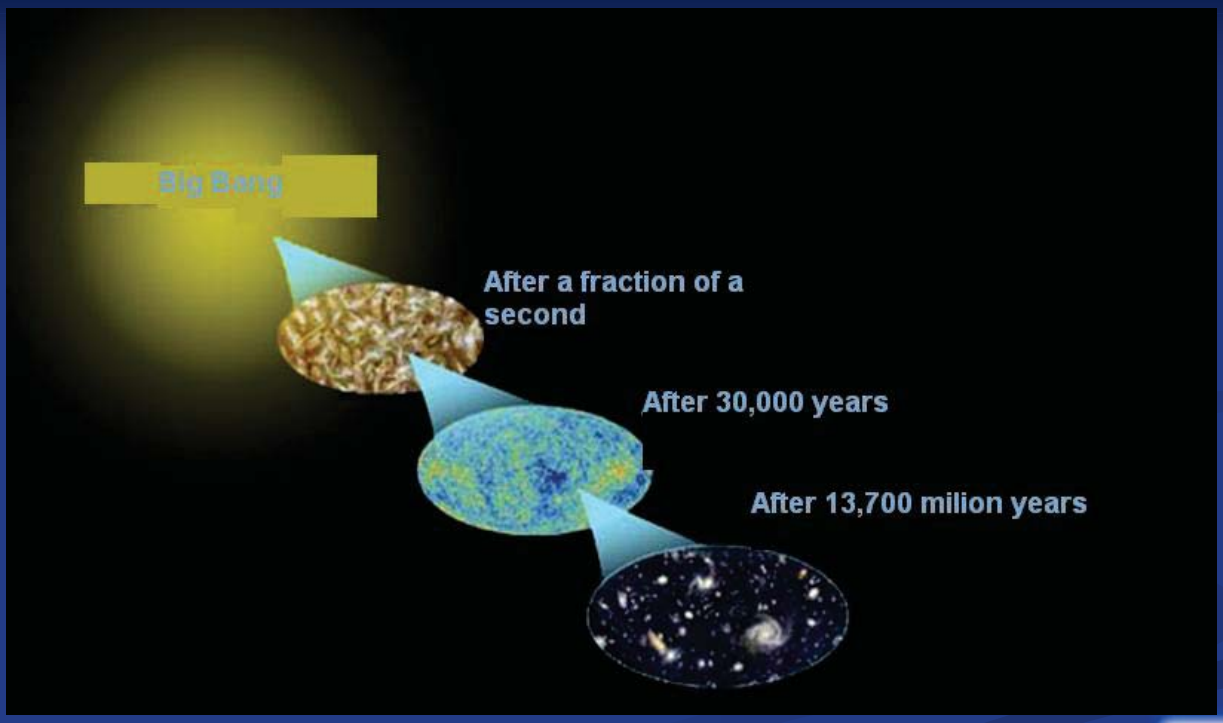
Big Bang

- Before the Big Bang? We do not know anything.
- What was the cause? Why it happened? And why it has the observed physical laws?
- Physics is about how the existing things work, not about why do they exist.
- Physics studies the matter from its origin (since the Big Bang), not before, nor it studies the reason or purpose of why it exists. These are philosophical, religious, but not scientific questions.
- 2 errors: make religion from science and doing the science from religion. They have their own field of study, method, and way of seeing the complex reality.

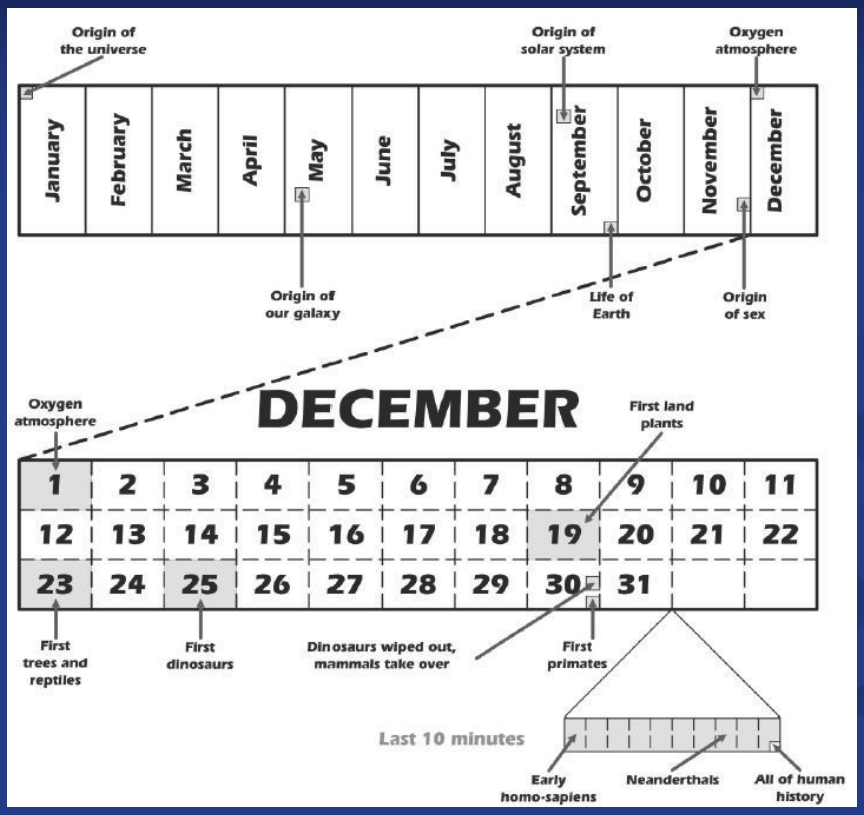
Big Bang

- Fluctuation of the quantum vacuum?
- Emptiness is not nothing, it exists.
- Multiple Universes? Indemonstrable by definition. Non-Scientific theory

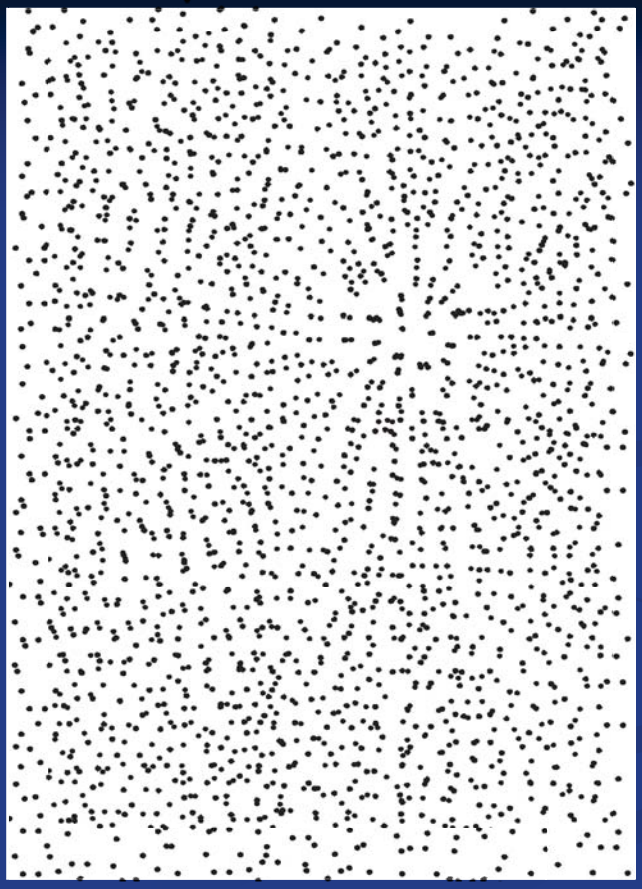
Evolution of the Universe



Development of the Universe



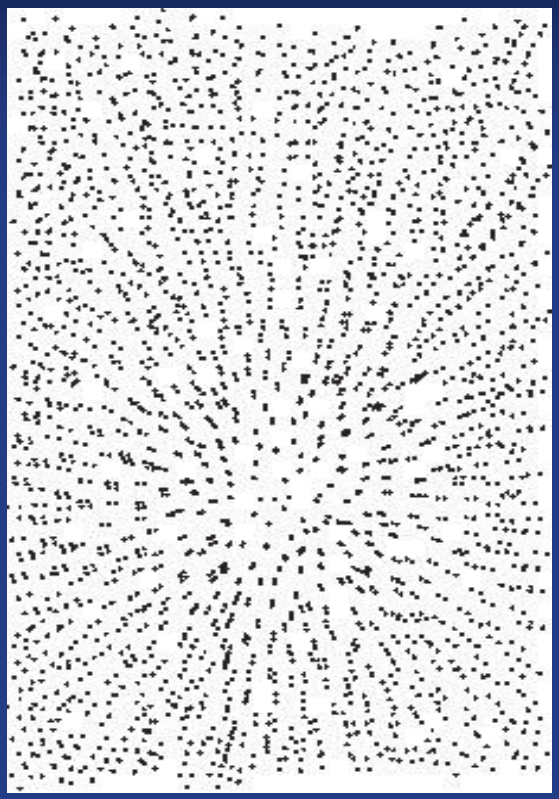
Activity 6: There is no center of expansion

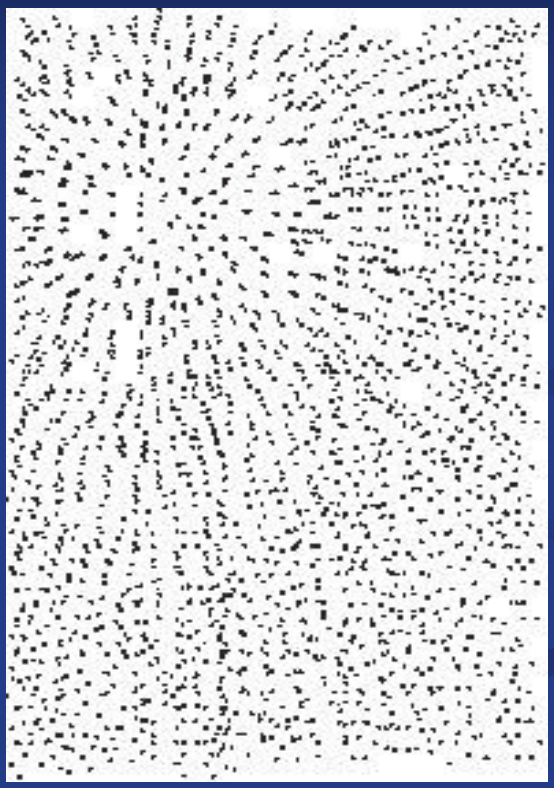


100%

105%

Activity 6: There is no center of expansion



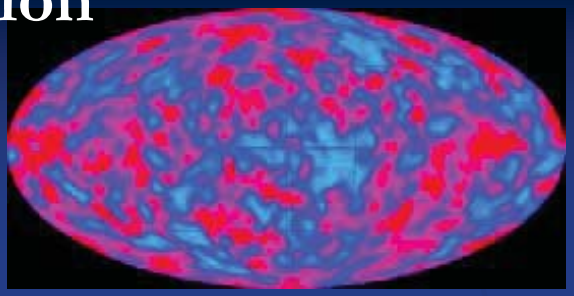


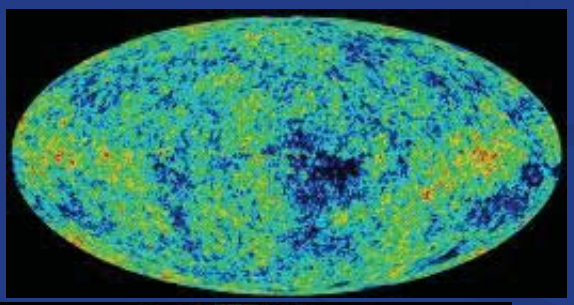
Cosmic Microwave Background (CMB) Radiation

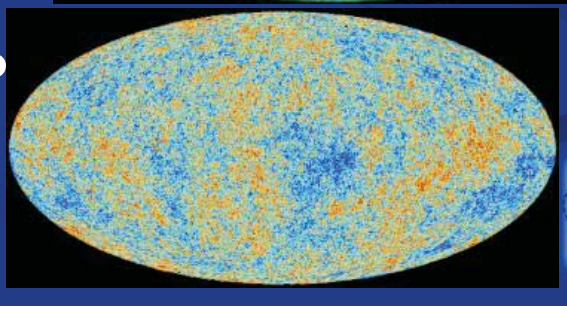
- Radiation which became free at 380,000 years after the Big Bang.
- Over time, as space expands, the CMB photons expanded in their wavelength.
- They are now in the microwave region

Cosmic Microwave Background (CMB) Radiation

- The COBE, WMAP and PLANCK missions made a map of the sky of CMB radiation, every time with more detailes, detecting small fluctuations: imprints of lumps of matter from which galaxies began to form







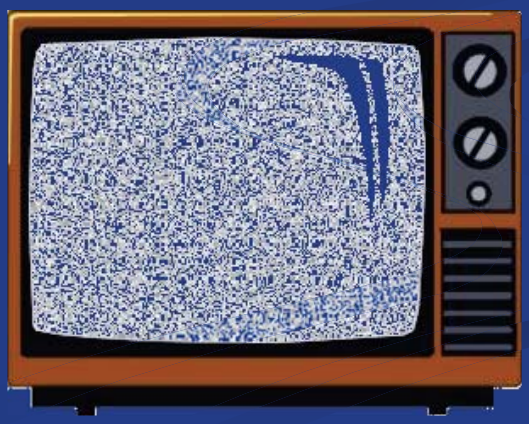
Activity 7: Cosmic background radiation

•>300,000 years after the Big Bang, the photons were separated from matter and began to travel freely through the universe.

•By expanding the space, photons extended their wavelength, currently λ= 2 mm, equivalent to T = 2.7 K = -270 ° C.

Activity 7: Cosmic background radiation

•We can detect it with an analogue TV. In an empty channel, one out of ten points comes from microwave background radiation.



Dark Mater: Spin table which compensates the terrestrial gravity atraction

Black Holes are invisible, but we know that they exist because their gravitational force make the stellar systems to move around them.

Although the dark matter is invisible, one way to detect it is by observing and studying the behavior of near objects.

Another way to detect dark matter: gravitational lensing

The mass of a gravitational lens acts like an optical lens distorting the surrounding space and deflecting the light of a distant object.

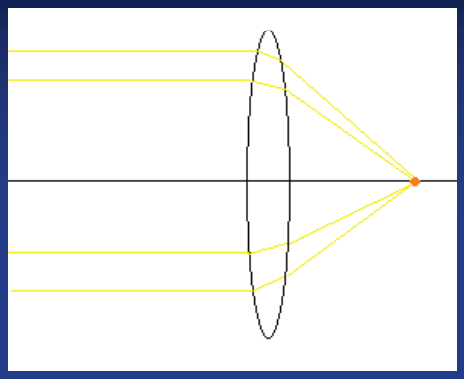
Gravitational lenses

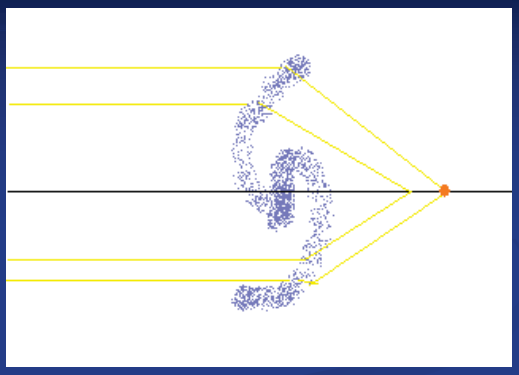
- Light always follows the shortest possible path
- If the surface is curved, the line is curved

Why light bends when passing near a body?

- If there is a mass, the space is curved and the shortest path between two points is a curve.
- A similar situation can be seen using the Earth globe.

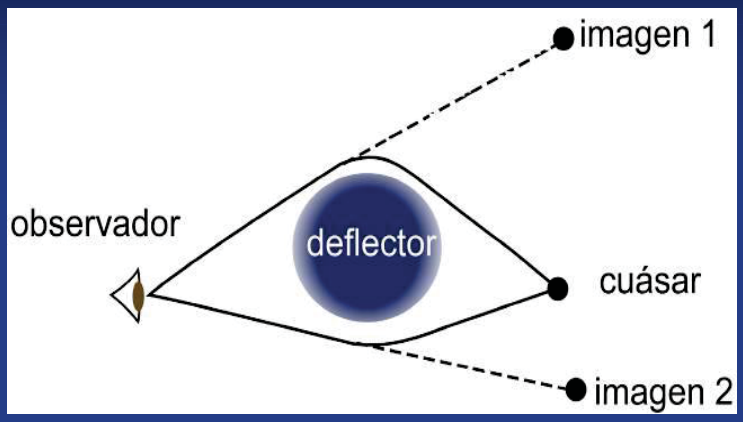
How do gravitational lenses work?

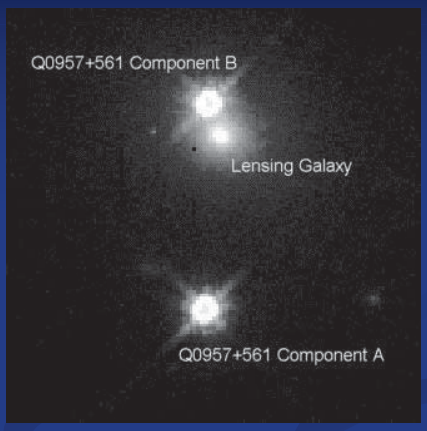




- For a convex optical lens, the lens focuses the parallel rays of light into one point: the focus.
- For a gravitational lens, the lens (e.g. galaxy or group/cluster of galaxies) focuses the light rays into a line instead of a point; this can introduce several distortions in the image.

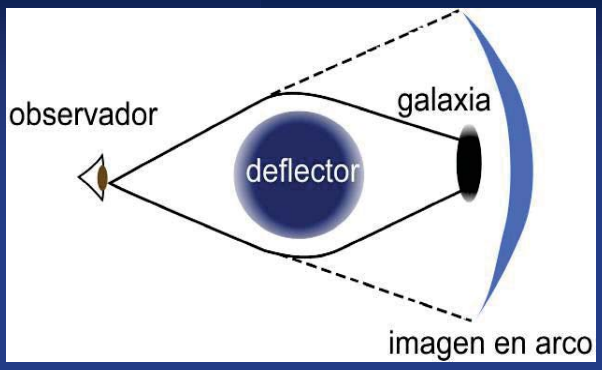
Position changes and multiplication





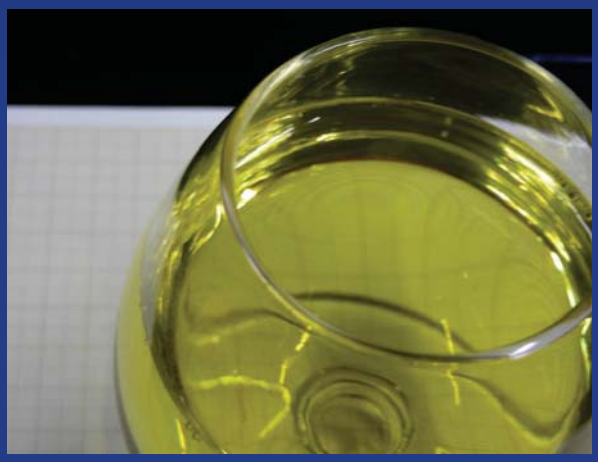
- The deflection produces the apparent position of star, galaxy, or quasar
- Gravitational lenses are not perfect, the largest ones can produce multiple images.

Deformation



- If the deflected body is an extended astronomical source, the resulting images produce a set of bright arcs.
- *"if the lens system is perfectly symmetrical, the rays converge and the result is a ring".*
- If the deflected body is a star or a quasar, the image is a point.

Activity 8: Simulation of the space deformation with a glass of wine



- If you put the glass of white wine on graph paper and look through the wine, you can see this deformation.

Activity 8: Fix a flashlight and move slowly while looking through the glass of wine

- This simple model shows that "matter" can reproduce distortions in images observed "through" it.

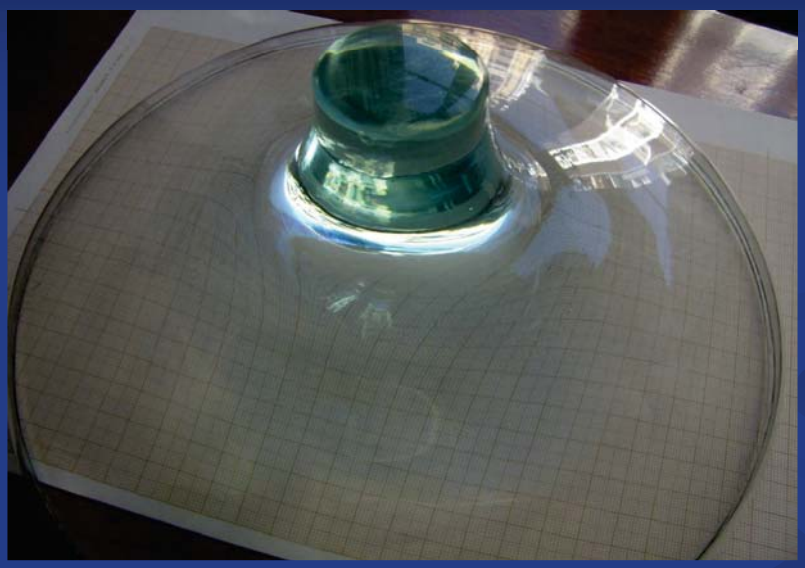
Activity 8: Fix a flashlight and move slowly while looking through the glass of wine

Fragment of arc

Amorphous figure

Einstein cross.

Activity 8: Simulation of the deformation with the foot of a glass



- If we place the base of a vine glass on a graph paper we can see the deformation.

Activity 8: Looking through the "bottom of a glass"

- Just cut the bottom of the glass.

Activity 8: Looking through the "bottom of a glass"

Arc fragment

Einstein Cross

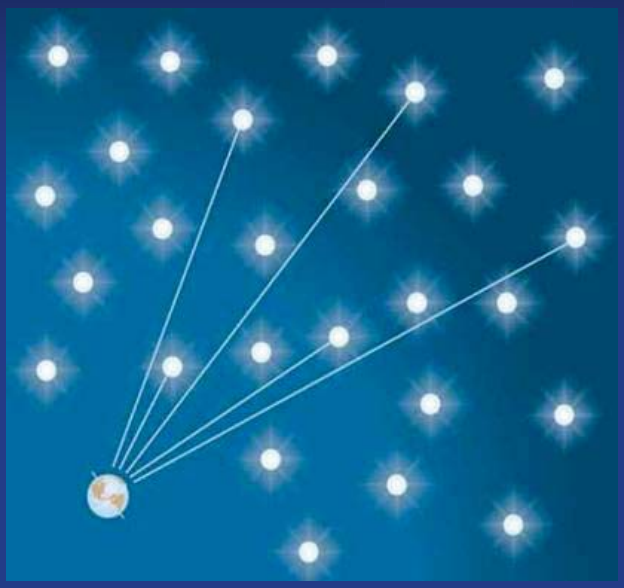
Einstein ring

Why is it dark at night?

Olbers suggested that if:

- The universe is infinite in extent.
- The stars are uniformly distributed throughout the universe.
- All stars have a similar luminosity throughout the Universe…

Dark Night



An infinite Universe will have an infinite number of objects and should be bright during the night

Why is it dark at night?

Then :

- Any point on the sky would be bright, not black, since there would be always a distant star shining.
- The number of stars in each "onion layer" of the sky is proportional to r2, and their light is inversely proportional to r2, where each layer provide the same amount of light at the Earth. If there are infinite layers, the sky should appear bright at night.

Why is it dark at night?

Mistakes:

- Due to expansion, more distant stars look more reddish (less bright).
- But above all, the sky doesn't have an infinite age. There are no infinite layers of stars.

The night can be dark!

Thank you very much
for your attention!