

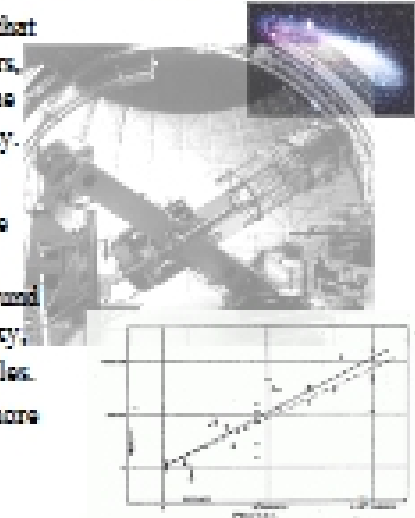
How we know what we do:

- Radar ranging - distances among planets + AU
- Measured parallaxes of stars
- Comparison of main sequences of star clusters
- Use of standard candles
 - Determining distance to Andromeda galaxy using variable stars
 - Milky Way was just one of many galaxies
 - Use of variable stars to find distance to Virgo Supercluster
 - Use of Hubble's Law
- Advances in telescope technology and space telescopes!

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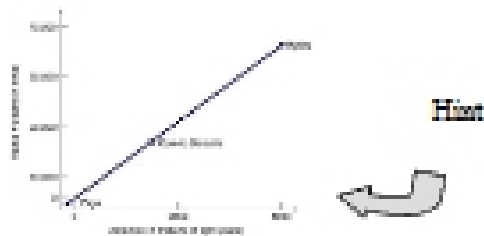
Edwin Hubble's Distance to Andromeda Galaxy

- In early 1900's it was thought that whole Universe — planets, stars, and fuzzy objects called nebulae — was contained within Galaxy.
- Our galaxy was the Universe.
- In 1923 using Hooker telescope on hazy patch of sky called Andromeda Nebula, Hubble found stars just like those in our galaxy, only dimmer -- Cepheid variables.
- More observations turned up more of these stars.
- The rest is history.



Astronomers create three-dimensional maps of the Universe by...

- using the position of galaxies on the sky and their apparent brightness as a measure of distance along the line of sight
- using the position on the sky and the redshift to determine a distance along the line of sight
- interpreting the peculiar velocities of each galaxy within its cluster through comparison of computer models of the structure formation with observations



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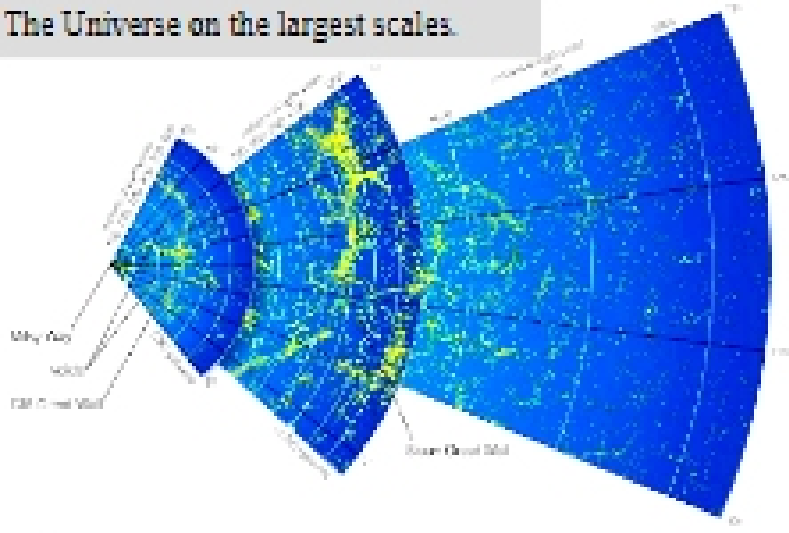
Learning Objectives

Be able to :

- Describe what the Universe looks like on the largest scales.
- Explain how we know this.
- Summarize the evidence for dark matter
 - Galaxy rotation curves
 - Peculiar motion
 - Presence of hot gas
- State the role dark matter played in the formation of large-scale structure

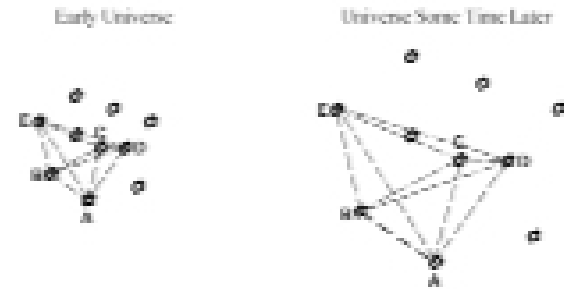
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The Universe on the largest scales.



Reminder:

- Stars, galaxies, clusters: all gravitationally bound systems.
- Gravity has overwhelmed the expansion at these levels.
- Expansion is among the huge filaments containing clusters of galaxies



The Local Group

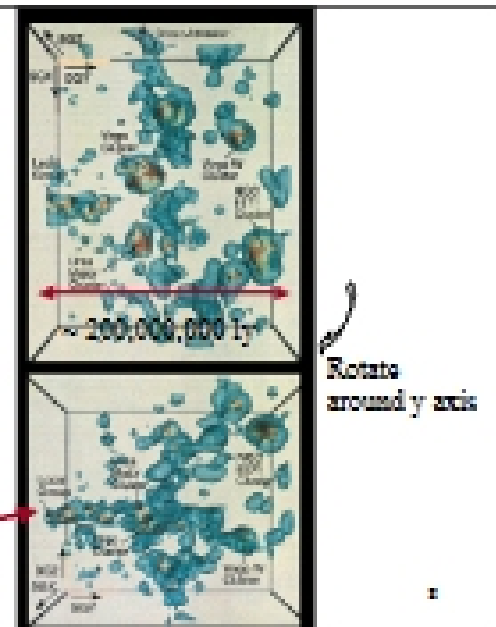
- Our neighborhood of galaxies is rather sparse compared to others.
- Roughly 40 galaxies; all but 3 (maybe 4) being small irregular or dwarf galaxies.
- No giant ellipticals!

What the Universe looks like on larger scale.

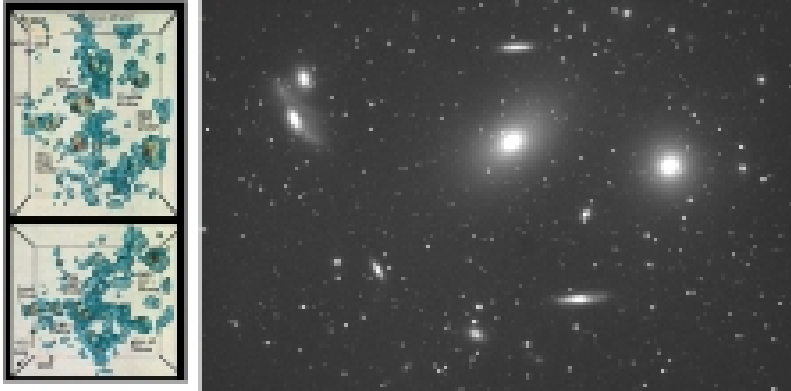
Perspective?

Scale?

You are here



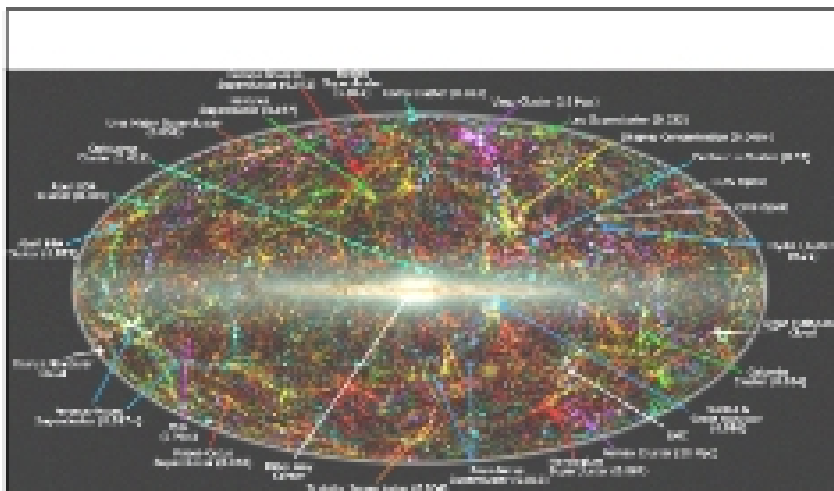
Virgo Supercluster ~60,000,000 light years away



Redshift measures 400 km/sec LESS than Hubble expansion would suggest.

Huge cluster is gradually slowing the Local Group down.

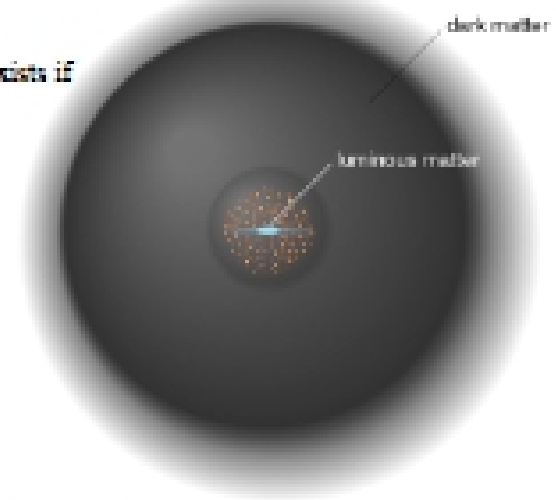
Other "nearby" clusters of galaxies



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Discovering dark matter

How do we know it exists if we can't "SEE" it?



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