



- Homework due on Friday– 11:50 am
- Honor credit– need to have those papers soon!
- Exam 2 Grades are posted.
- THE FINAL IS DECEMBER 15th: 7-10pm!
– Style...

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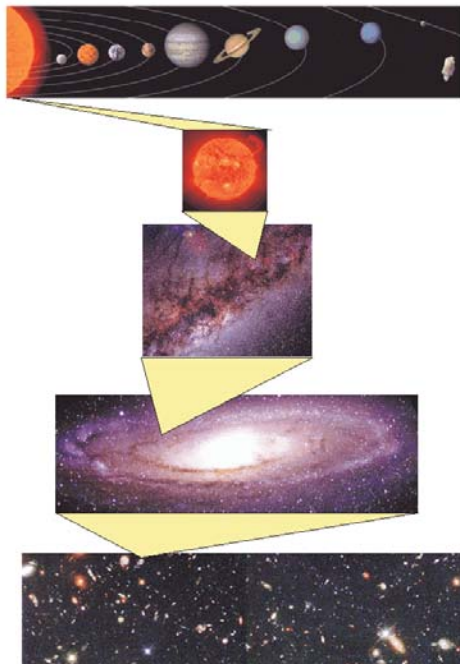
Outline



- Galaxies are the Fundamental “Ecosystems” of the Universe.
- Hubble’s Classification Scheme.
- Galaxies tend to cluster and supercluster– structures of the Universe.
- The Local Group.
- The Local Cluster.
- Dark Matter in Clusters.
- Collisions
- Hubble’s Law

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Astronomy: The Big Picture



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Galaxies are the Fundamental “Ecosystems” of the Universe



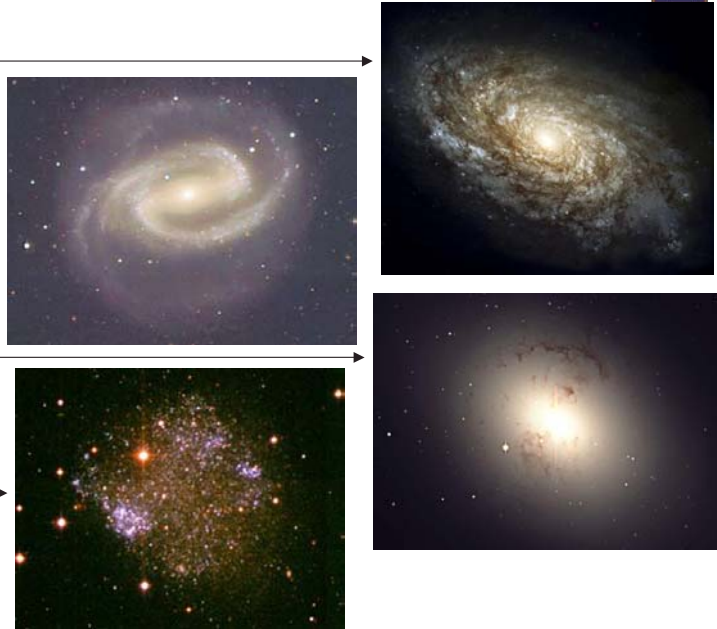
- The cosmic engines that turn gas into stars and stars back into gas.
- In between no star formation occurs– “nothing happens” in intergalactic space.
- Are recently discovered (by Edwin Hubble in late 1920’s)
- Can be classified by morphology (shapes and sizes).

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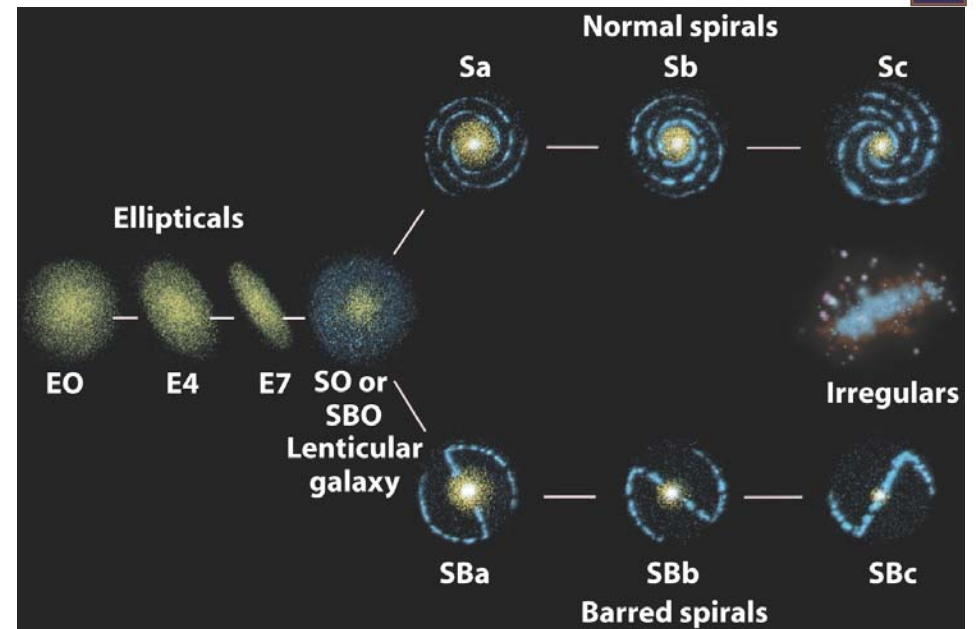
Types of Galaxies

- Spiral: $< 20\%$
- Barred Spiral: $> 57\%$
- Elliptical: $> 20\%$
- Irregular: $< 3\%$



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Hubble's Tuning Fork Diagram



Galaxies Are not Alone

- Galaxies are not scattered randomly throughout the Universe
- Galaxies are found in **clusters**
 - The Milky Way is part of the *Local Group* of about 40 galaxies
- Clusters of galaxies are clustered as well in groups called **superclusters**
 - Our Local Group is part of the *Local Supercluster*
- The majority of space is empty - called **voids**.

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The Local Group of Galaxies



Milky Way

About 40 galaxies— a poor cluster.

0.7 Mpc



Andromeda (M31)

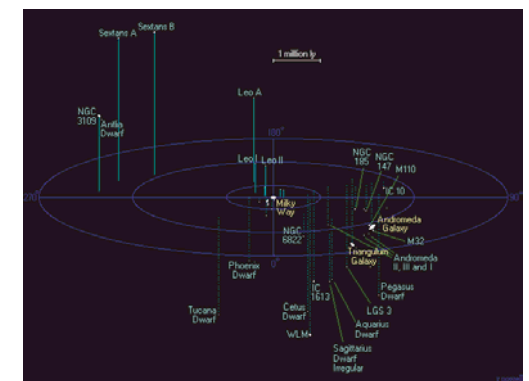
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Triangulum (M33)

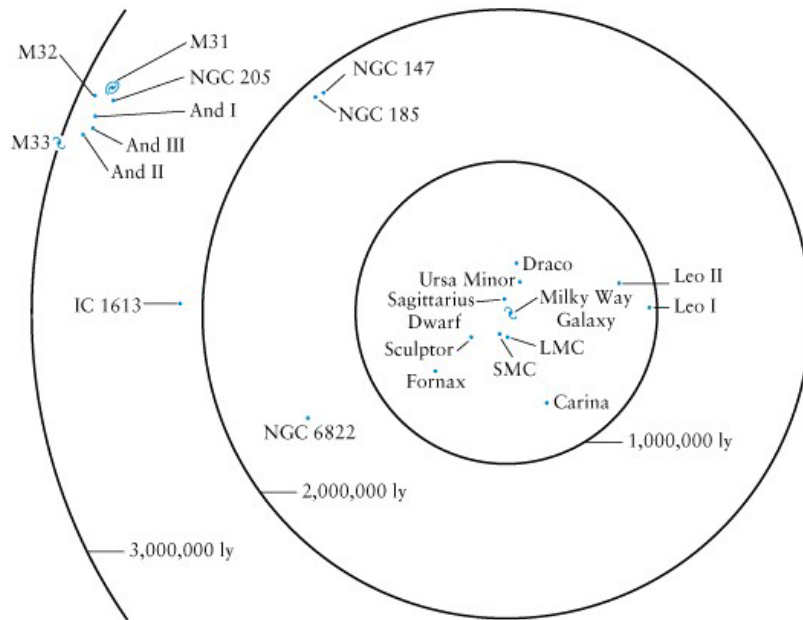


Local Group Dwarf galaxies



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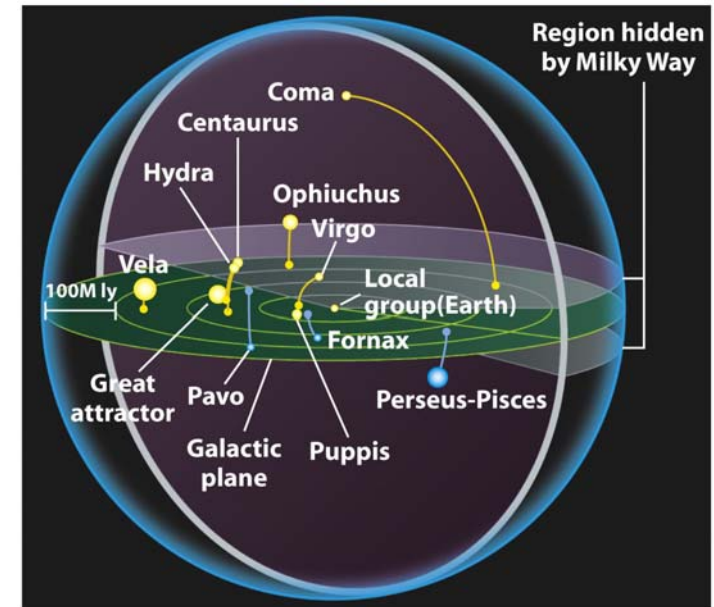
The Local Group of Galaxies



The Local Galaxy Clusters



- 800 Mly sphere, centered on the Earth
- Galaxies live in clumps called clusters, which are in clumps called superclusters



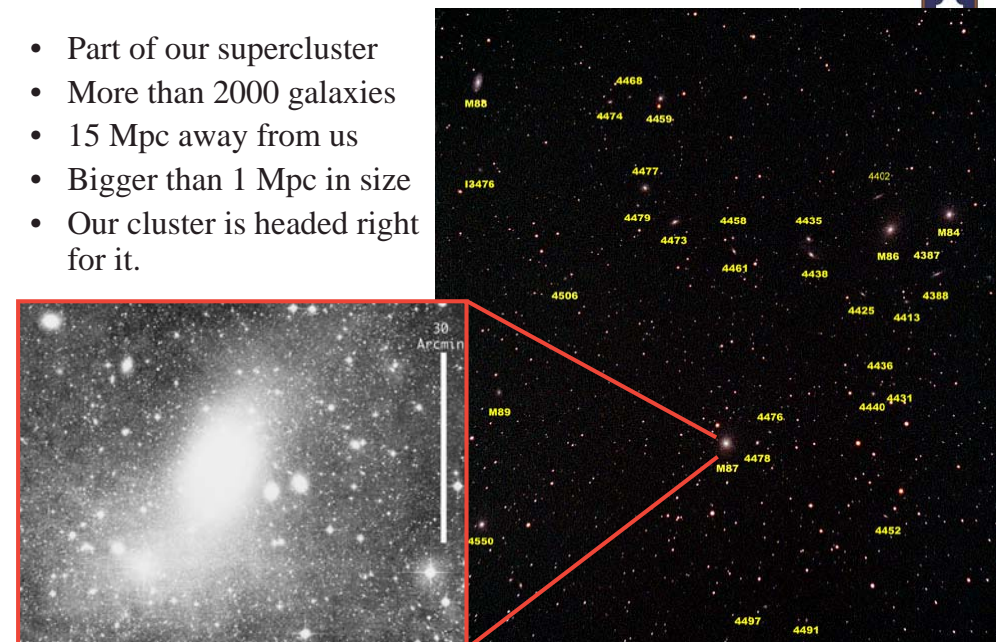
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Virgo Cluster

The Virgo Cluster



- Part of our supercluster
- More than 2000 galaxies
- 15 Mpc away from us
- Bigger than 1 Mpc in size
- Our cluster is headed right for it.



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Fornax Cluster

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Hercules Cluster

Giant Ellipticals

- Often 1 or 2 in a large cluster
- More ellipticals in general in clusters.
- Grow by accretion.
- How are they formed?
- Nature or Nurture?

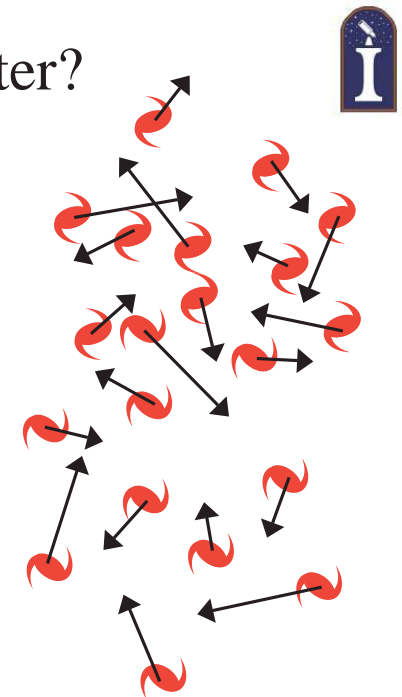
NGC 4881
Coma Cluster
HST · WFPC2

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ST ScI OPO PF95-07 · January 1995 · W. Baum (U.WA), NASA

Dark Matter?

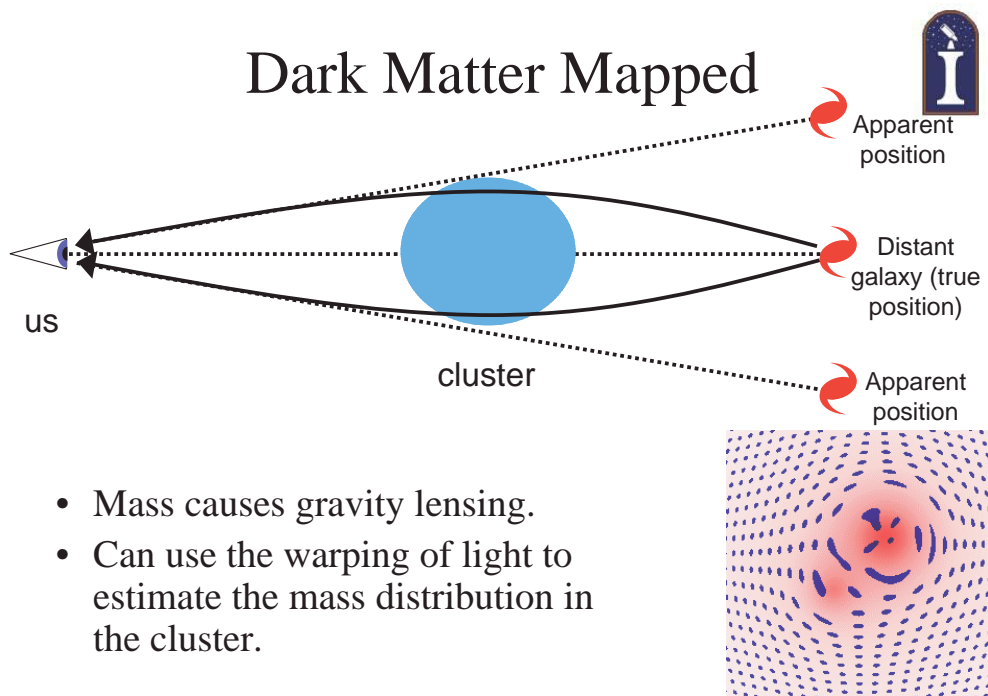
- If the clusters only have the visible mass in the cluster, then the cluster should dissipate.
- Not enough mass to hold the cluster together.
- Visible matter must only be about 1% of the total mass.
- Dark Matter.



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Dark Matter Mapped



- Mass causes gravity lensing.
- Can use the warping of light to estimate the mass distribution in the cluster.

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N. Wright (UCLA)



Gravitational Lens
Galaxy Cluster 0024+1654

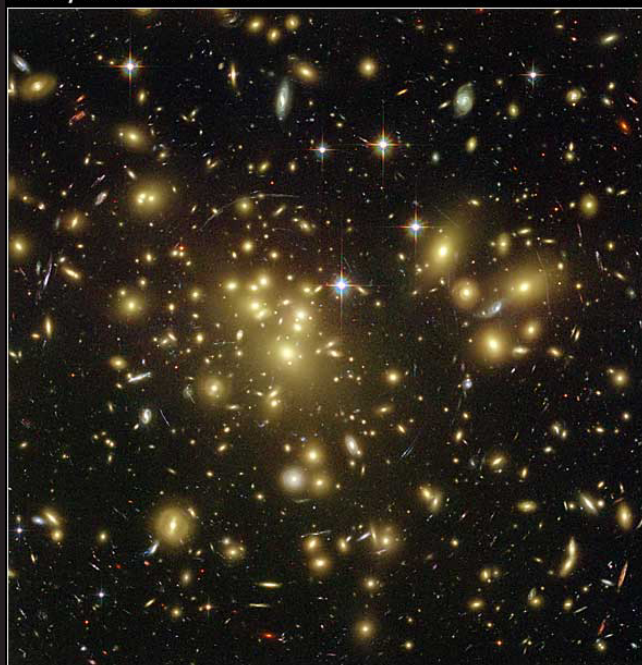
HST • WFPC2

PRC96-10 • ST ScI OPO • April 24, 1996

W.N. Colley (Princeton University), E. Turner (Princeton University),
J.A. Tyson (AT&T Bell Labs) and NASA

Galaxy Cluster Abell 1689

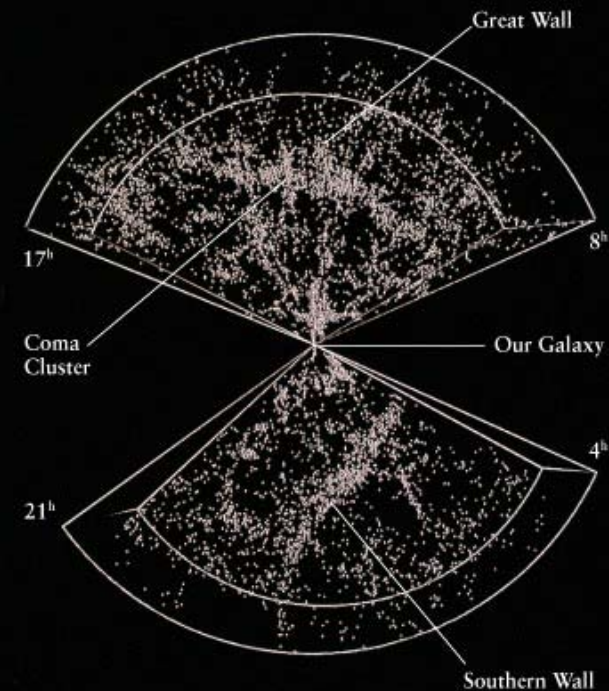
HST • ACS



NASA, N. Benitez (JHU), T. Broadhurst (Hebrew Univ.), H. Ford (JHU),
M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory),
the ACS Science Team and ESA

STScI-PRC03-01a

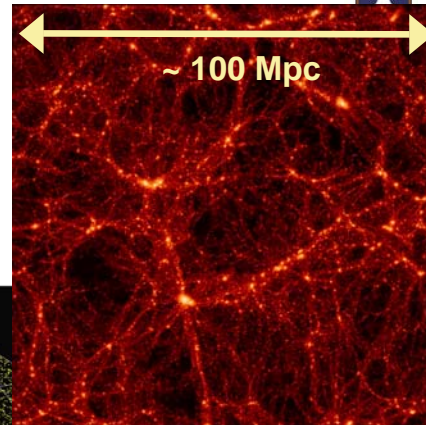
Each dot
represents a
single galaxy



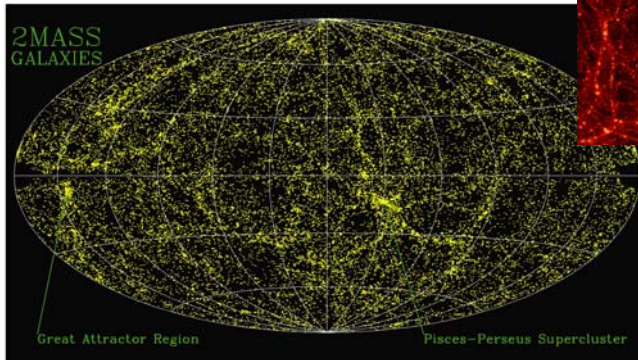
Structure of Universe



- Superclusters are distributed in Universe.
- Filamentary structure.
- Voids of nothing between them.



Computer simulation (A. Jenkins)

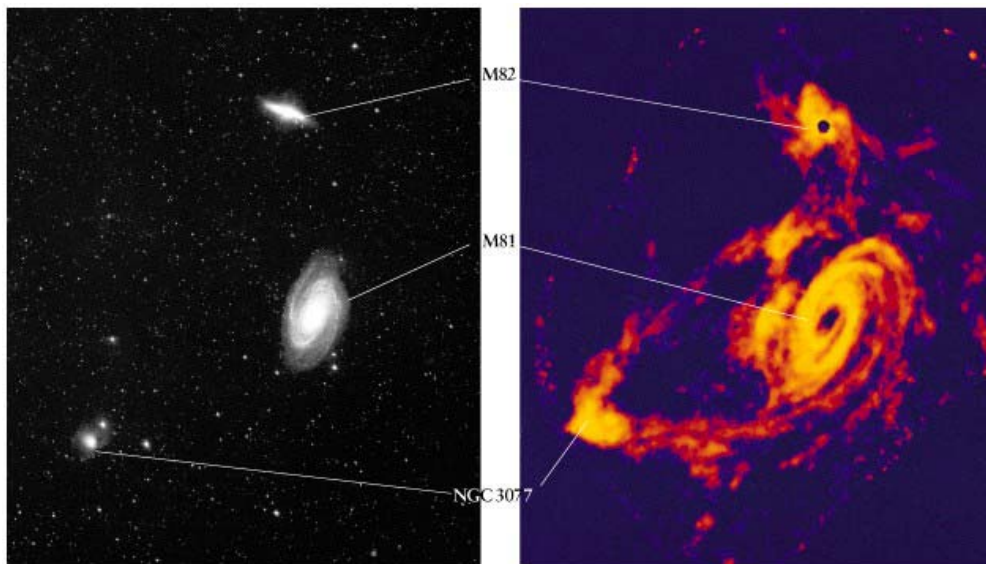


Three galaxies, M81 (big), M82 (medium), and NGC 3077 (small).

Are they related to one another?



Collisions



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Galaxies Collide



NGC 2207 &
IC 2163

NGC 7676
“The Mice”



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Collisions



- They do not involve colliding stars– but rather gravitational fields
- Might form hot intergalactic gas
- Could initiate rapid star formation - called *Starburst Galaxies*
- Collision causes stars to be scattered into “tails”
- Causes galaxy mergers called “galactic cannibalism”

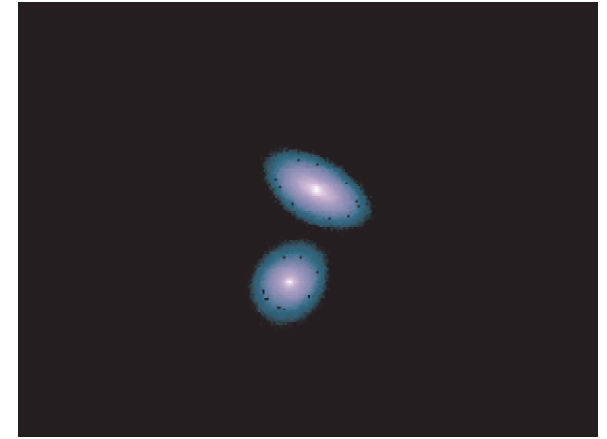
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Galaxy Collisions

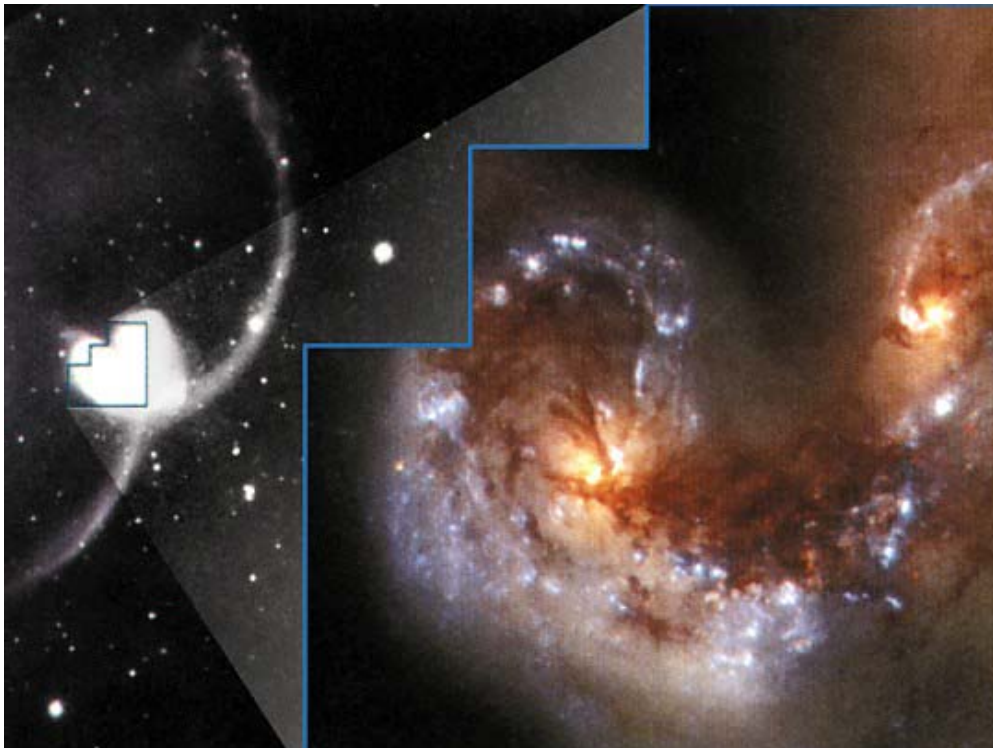


Computer simulation of two galaxies colliding by John Dubinski and Lars Hernquist



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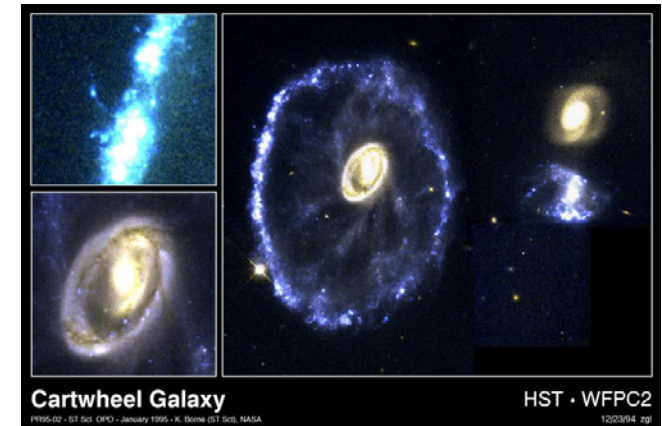
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Starburst Galaxies



- Galaxies with enhanced rates of star formation
- Usually forming massive stars for a short period (few Myr).
- Probably due to collisions



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How are Galaxies Moving?



It's 1928, and Edwin Hubble is measuring how galaxies move. What does he find?

- a) More galaxies receding than approaching.
- b) More galaxies approaching than receding.
- c) About equal numbers of each.

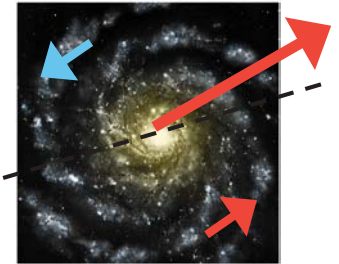
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Run Away



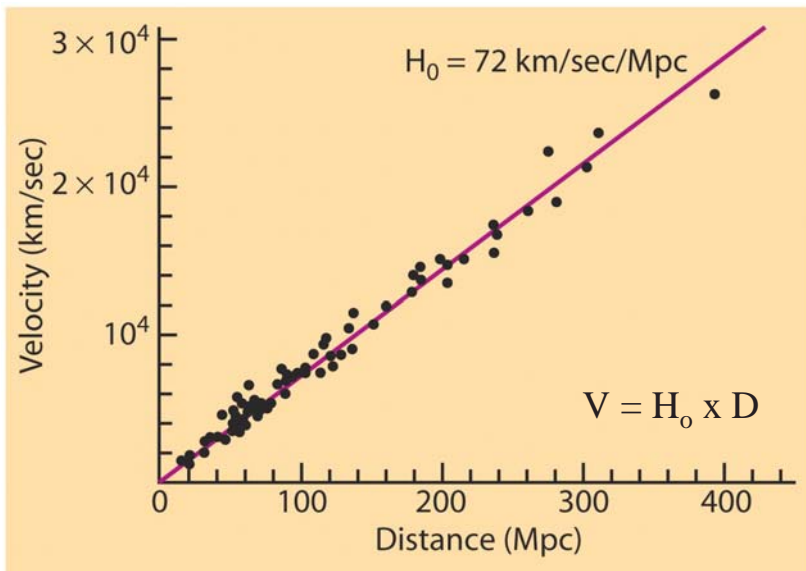
- Most Galaxies are moving away from us.
 - Did you bathe today?
- The farther away, the faster they are moving away.
- Or $V \propto D$
- The overall spectrum is the sum of all the emission.
- The rotation speeds are small wrt recession speed



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Hubble's Law



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