

The "UFO Galaxy" (NGC 2683)

Galaxies

... and clusters of galaxies

Reading: Chapter 23 & 25

Image Credit: ESA/Hubble & NASA

Discovery of Galaxies

Charles Messier (1730 – 1817) discovered 13 comets.
He also published a catalog of 110 “comet like objects.”

In 1923 Edwin Hubble discovered
Cepheid variables in M31, the
Andromeda “nebula”, which
allowed him to determine the
distance to be about 800 kpc

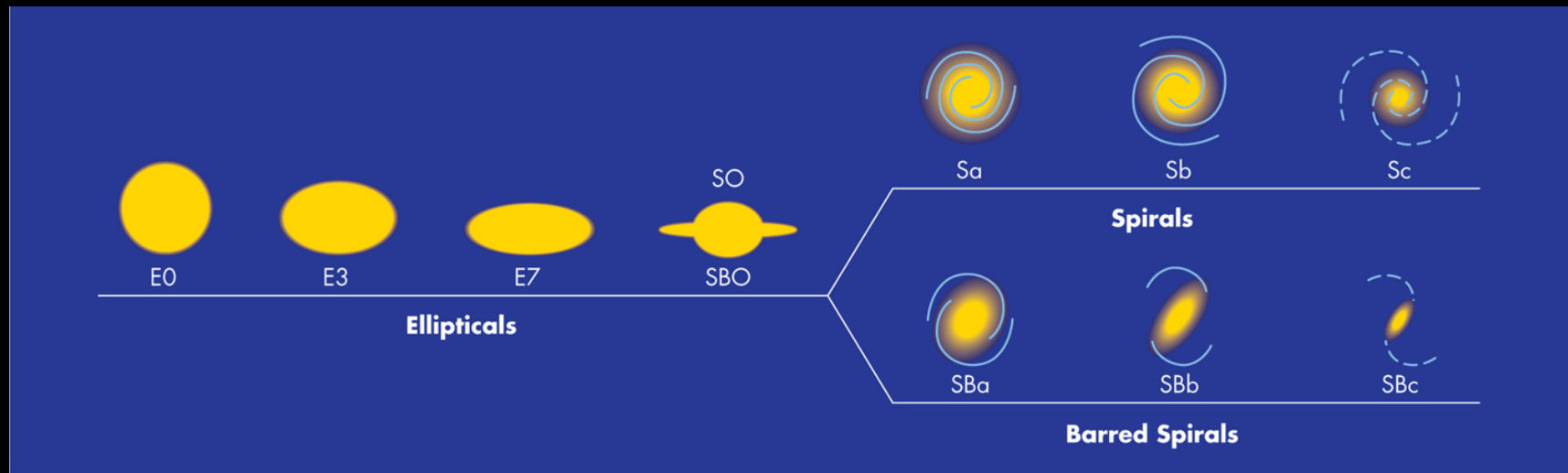
not in our galaxy!

Improved imaging revealed
another spiral galaxy.

The Messier catalog includes the Andromeda “nebula” (M31)
and companions (M32 and M110) shown here.



Types of Galaxies



In **elliptical galaxies** the motions of the stars are approximately random, which equal numbers of stars moving in all directions.

In **spiral galaxies** there is a net rotation in one direction, with or without a **central bar**, and arms in the plane of a disk.

There are also “**irregular**” galaxies, such as the Large Magellanic Cloud (LMC).

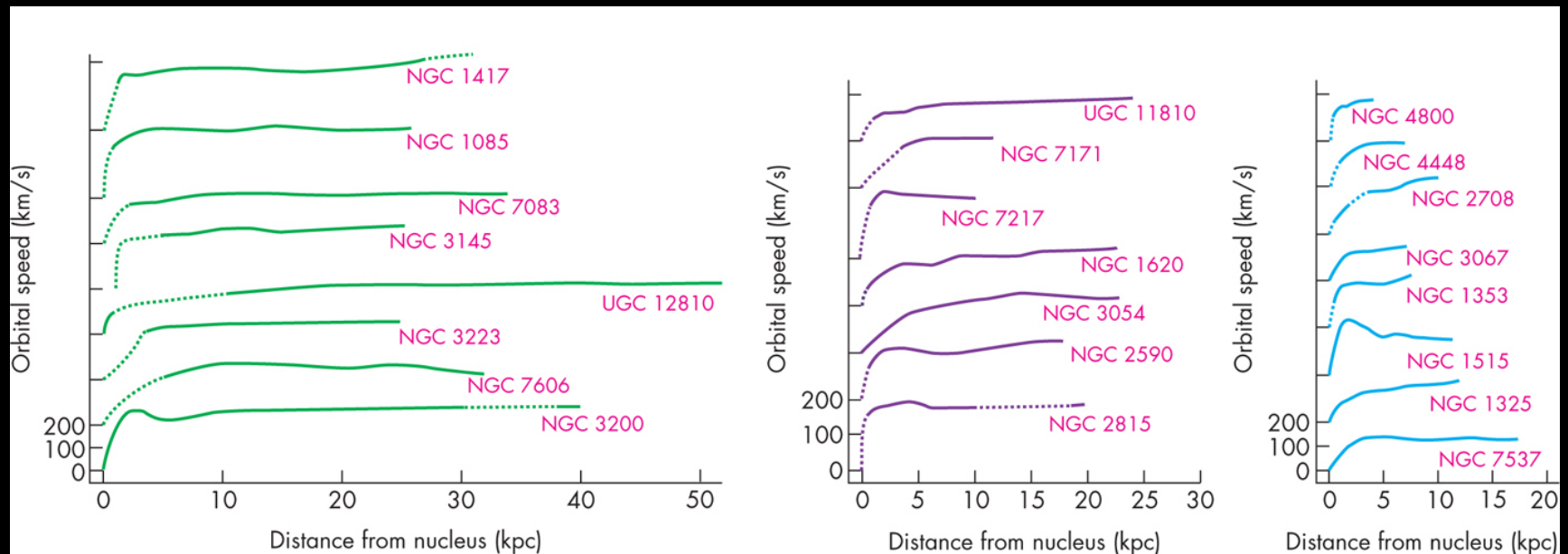
Large Magellanic Cloud

A deep-field astronomical image of the Large Magellanic Cloud, showing a dense field of stars and a bright, irregularly shaped nebula in the center.

Distance: 48 kpc

Rotation Curves and Dark Matter

Rotation speed of individual stars can be determined within other galaxies. Outside of the central bright parts of the galaxy, the rotation curves are flat.



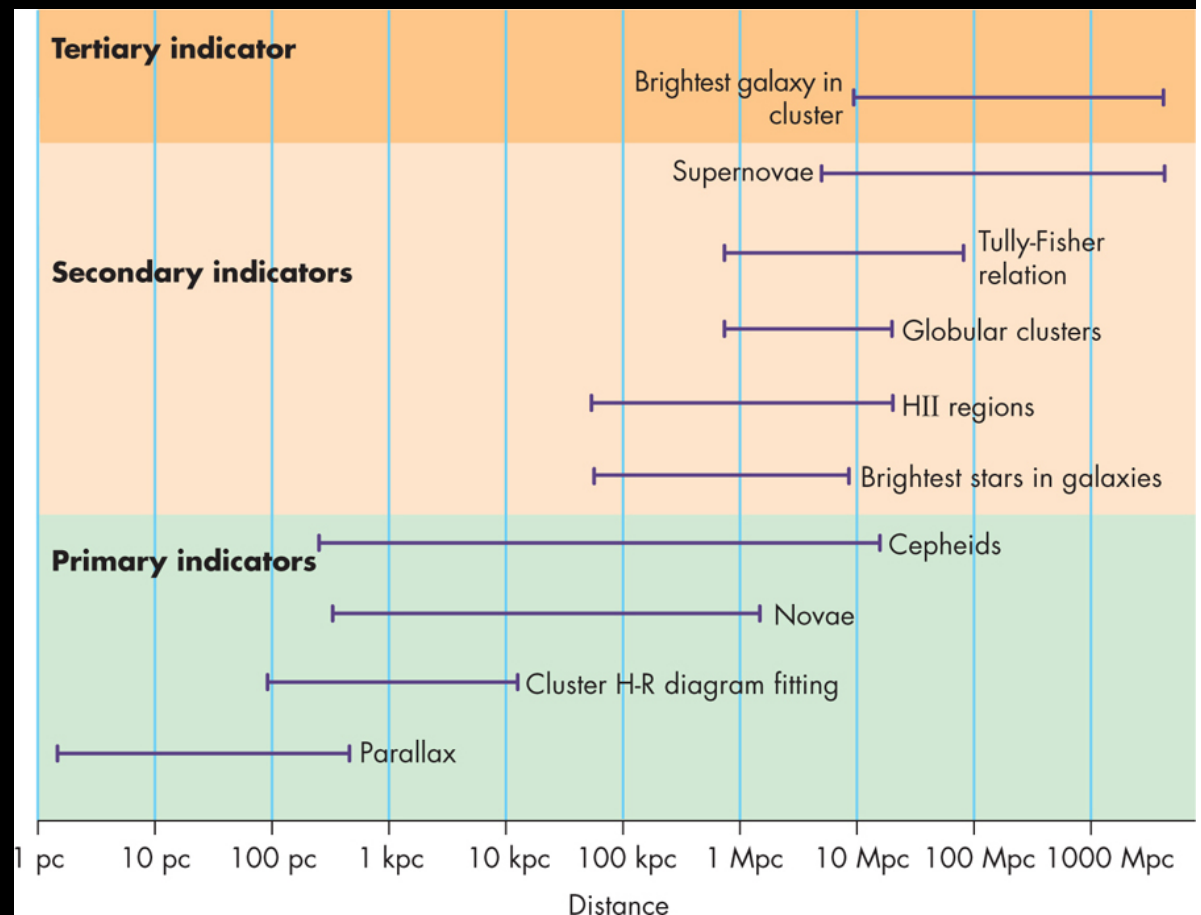
More evidence that each galaxy contains **DARK MATTER**

Cosmic Distance Ladder

No one method can be used to determine the distances to all astronomical objects. The collection of different methods is called the “Cosmic Distance Ladder”.

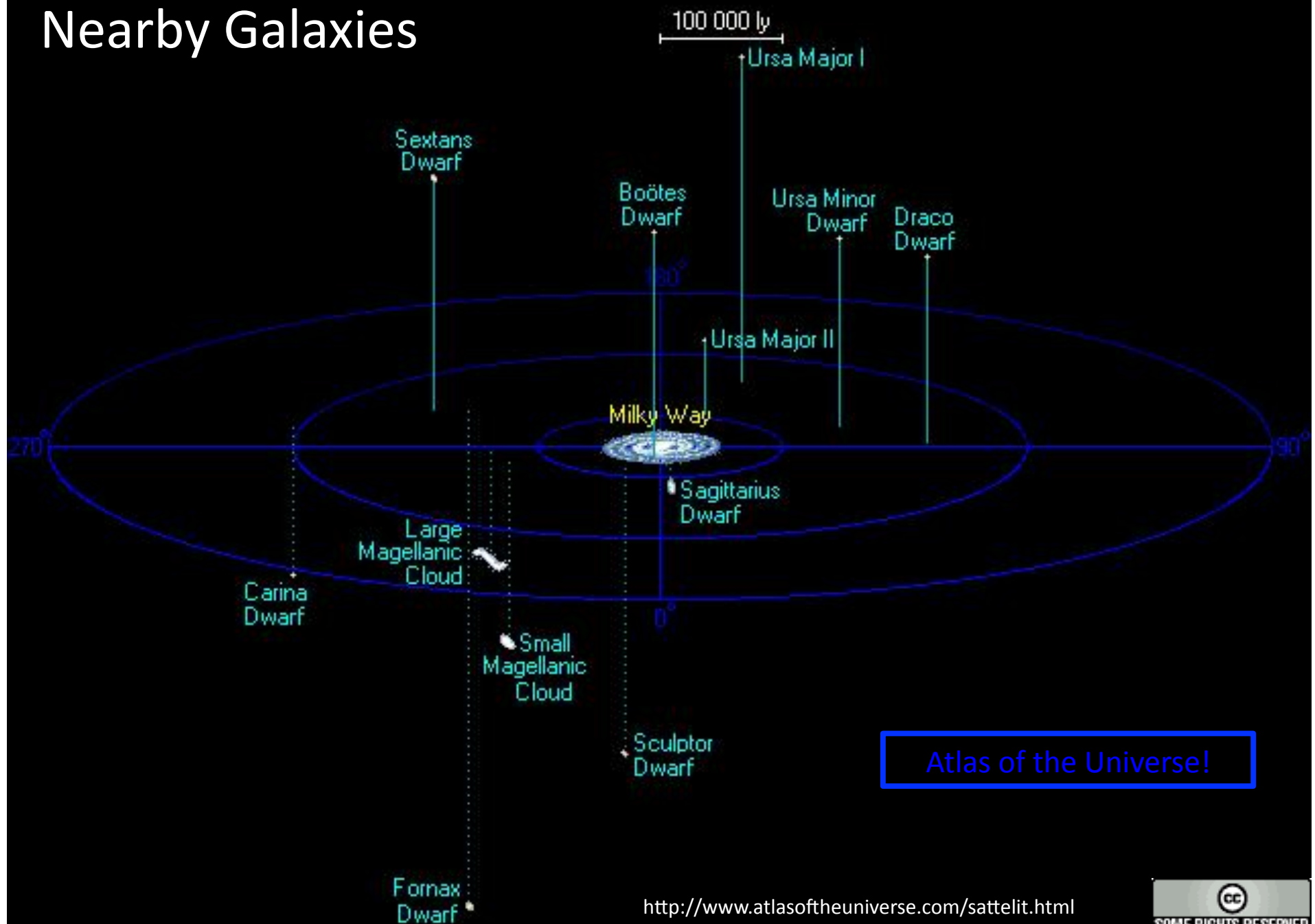
Each rung in the ladder must be calibrated with the one below it.

The uncertainties for measurements vary with method.



Note the logarithmic scale!

Nearby Galaxies



Hubble's Law

In 1917 Slipher found the Andromeda galaxy was moving toward us at 300 km/s, as were 4 of 25 other galaxies he observed.

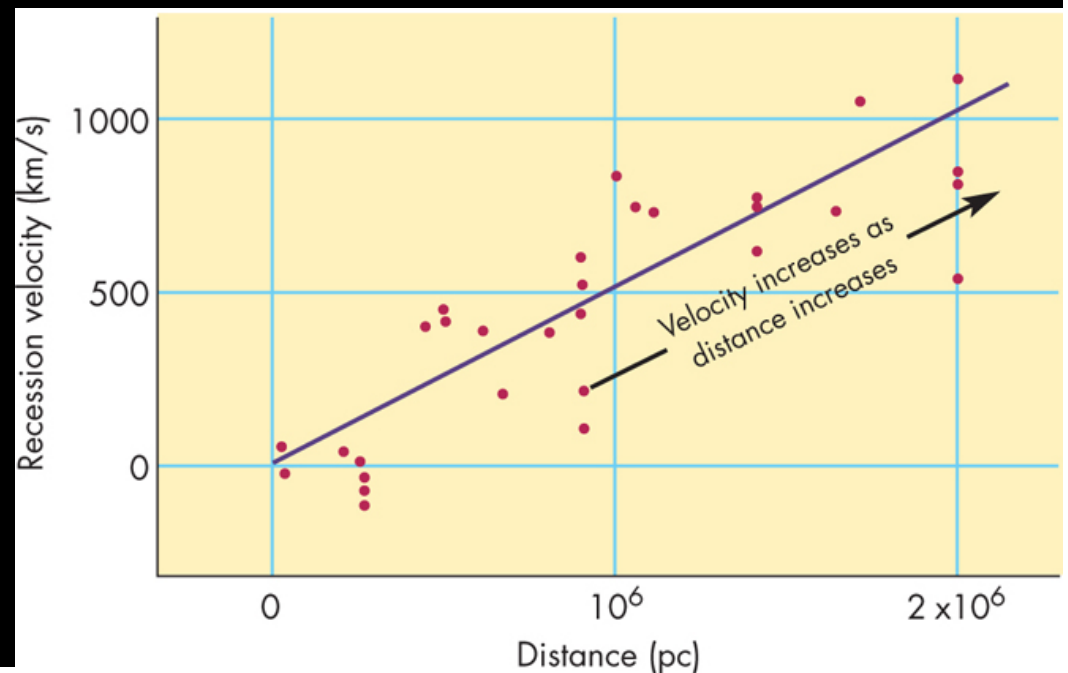
Conclusion: we are moving toward Andromeda, and away from the others.

But more complete observations found many more galaxies moving away from us (red shift), but in different directions! That's weird!

Hubble found a correlation between distance and recession velocity, now known as *Hubble's Law*:

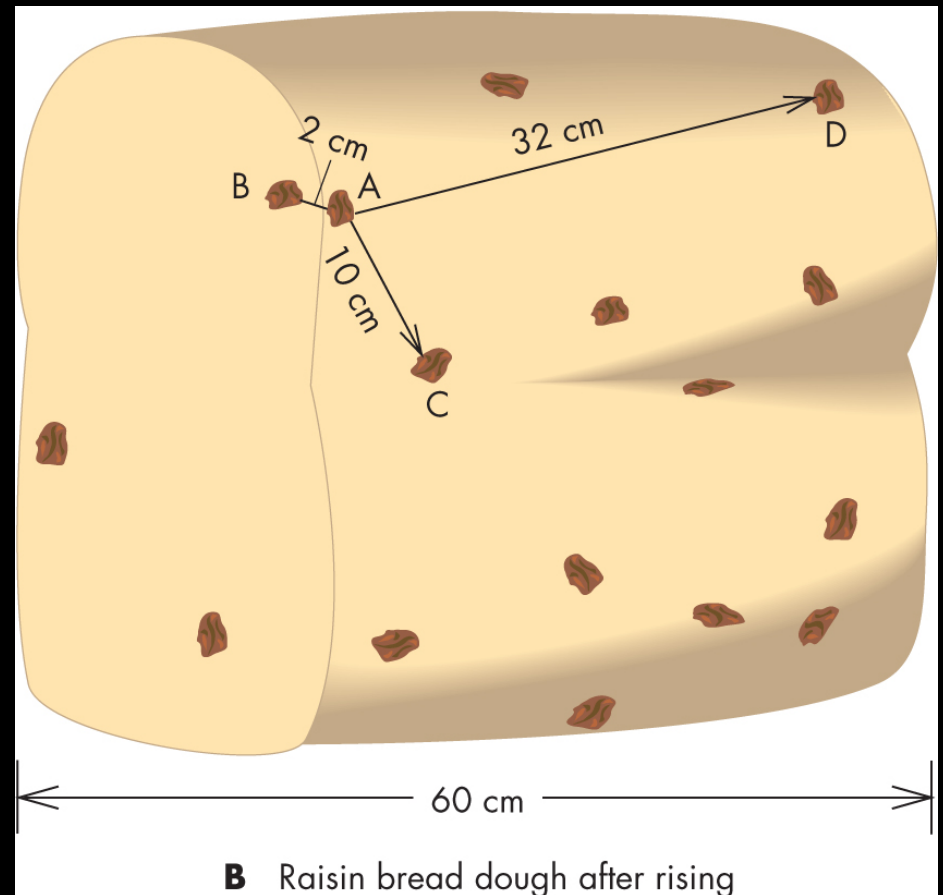
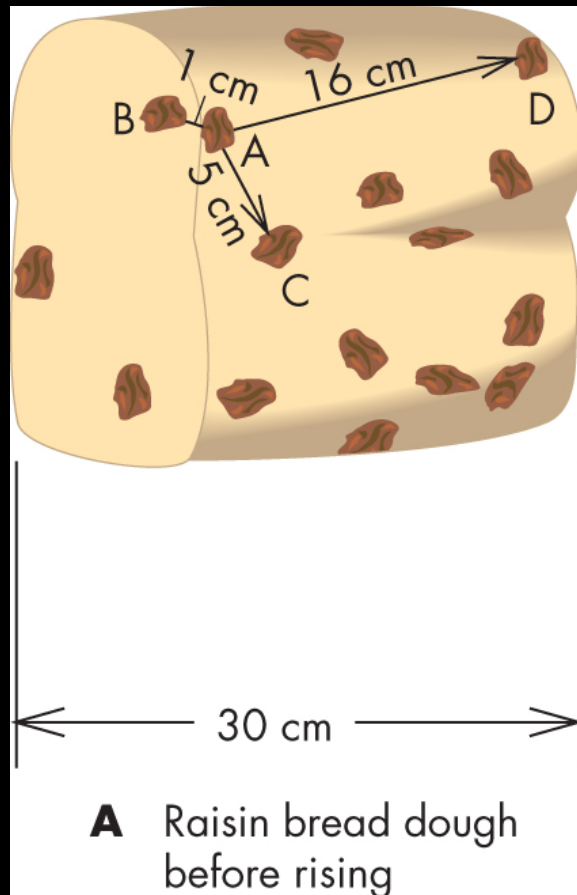
$$v = H_0 d$$

The constant slope, H_0 , is known as the Hubble constant.



Interpretation: the universe is expanding in all directions!

Analogy: raisin bread, with rising dough

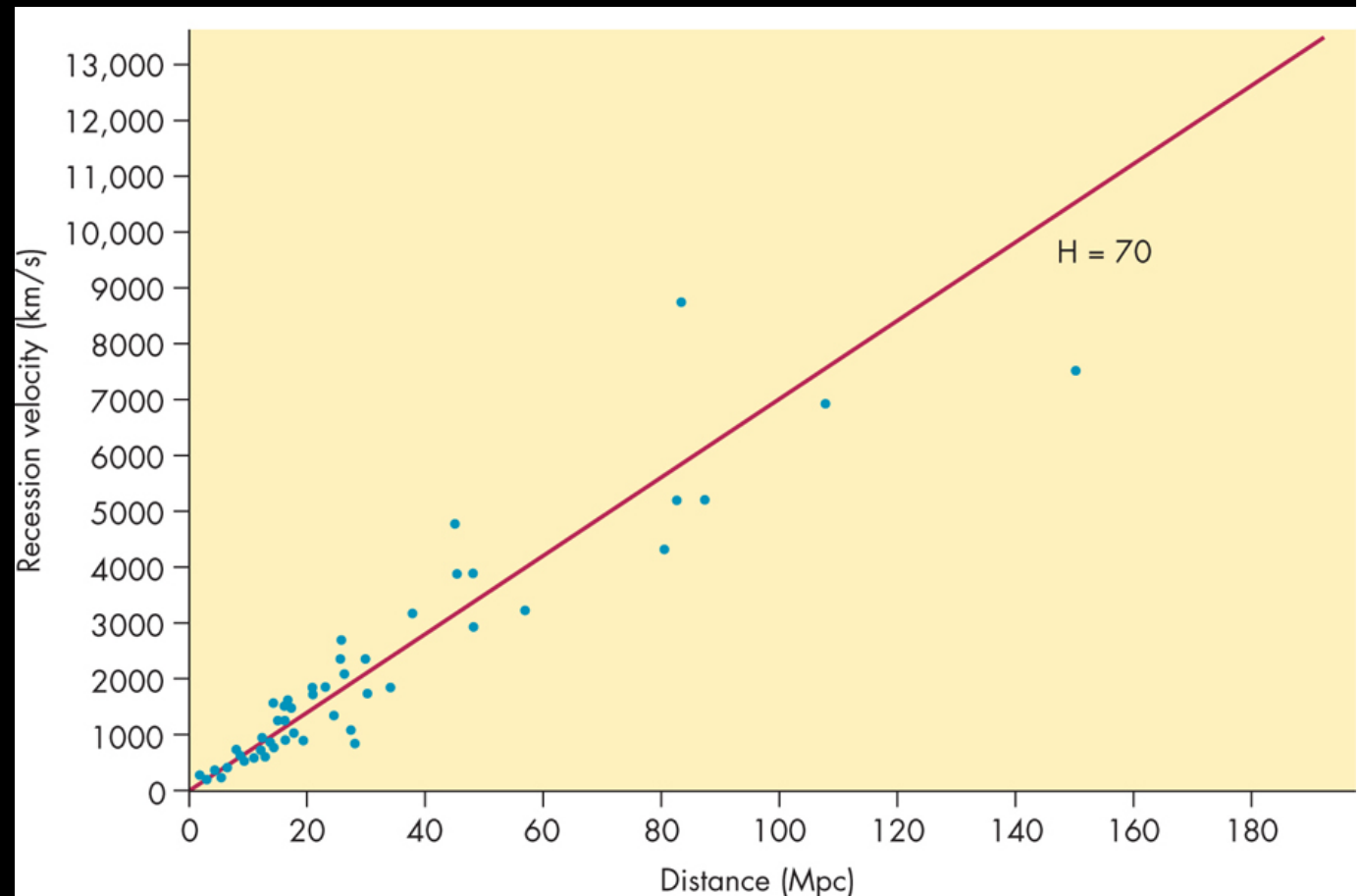


Net result: red-shift can be used to measure distance!

For many years different measurements of the Hubble Constant yielded values close to either 50 or 100, but not in between.

There was great disagreement.

More recent measurements seem to agree on around 74 (km/s)/Mpc



Measurements in 2011 using infrared camera on the Hubble Space Telescope (HST) gives:

$$H_0 = 73.8 \pm 2.4 \text{ (km/s)/Mpc.}$$

The Hubble Deep Field

Hubble Space Telescope

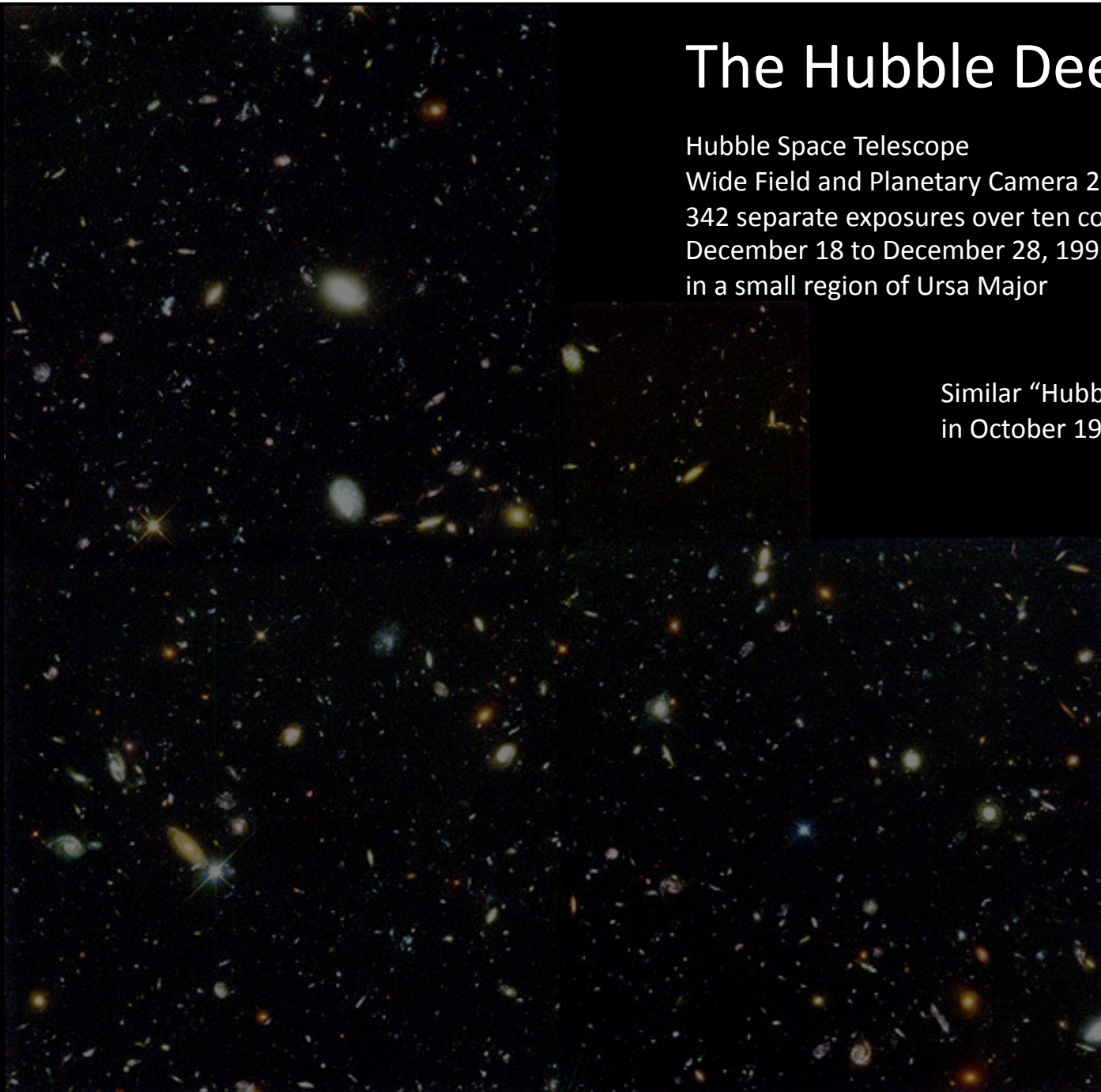
Wide Field and Planetary Camera 2

342 separate exposures over ten consecutive days

December 18 to December 28, 1995

in a small region of Ursa Major

Similar "Hubble Deep Field South"
in October 1998



Hubble Deep Field

ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA

HST WFPC2

ESO Deep Field

55 hour exposure from the ESO Visible and Infrared Survey Telescope for Astronomy (VISTA), a 4.1 meter telescope in Chile.

200,000 galaxies! 17,000 x 11,000 pixels



<http://blogs.discovermagazine.com/badastronomy/2012/03/23/an-ultradeep-image-thats-full-galaxies/>

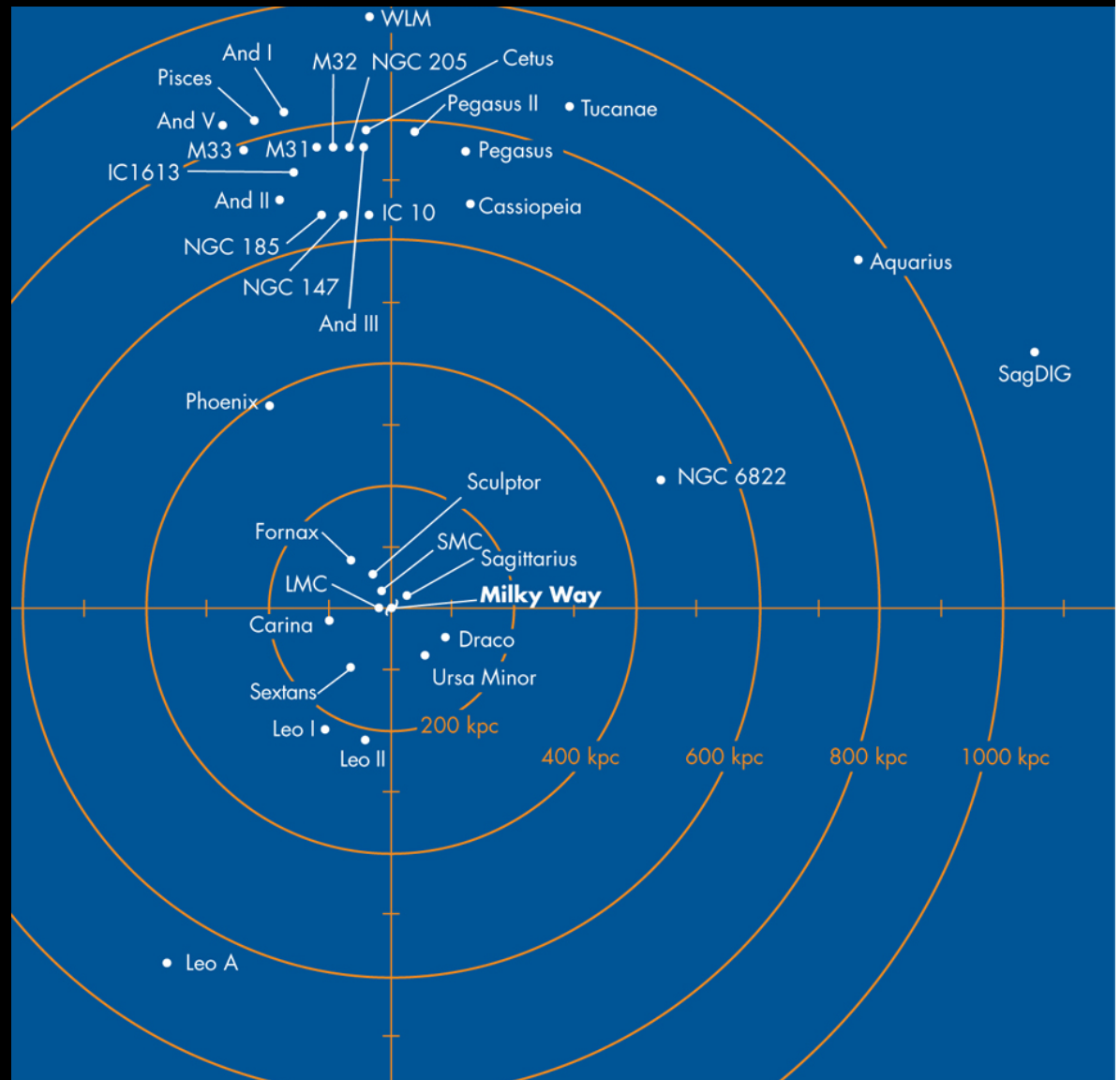
Clusters of Galaxies

Galaxies appear to be distributed in clusters.

The Milky Way is in the “Local Group” of 54 galaxies (includes dwarf galaxies)

1 kpc = 1000 pc

1 Mpc = 1000 kpc
= 10^6 pc



Nearby Groups

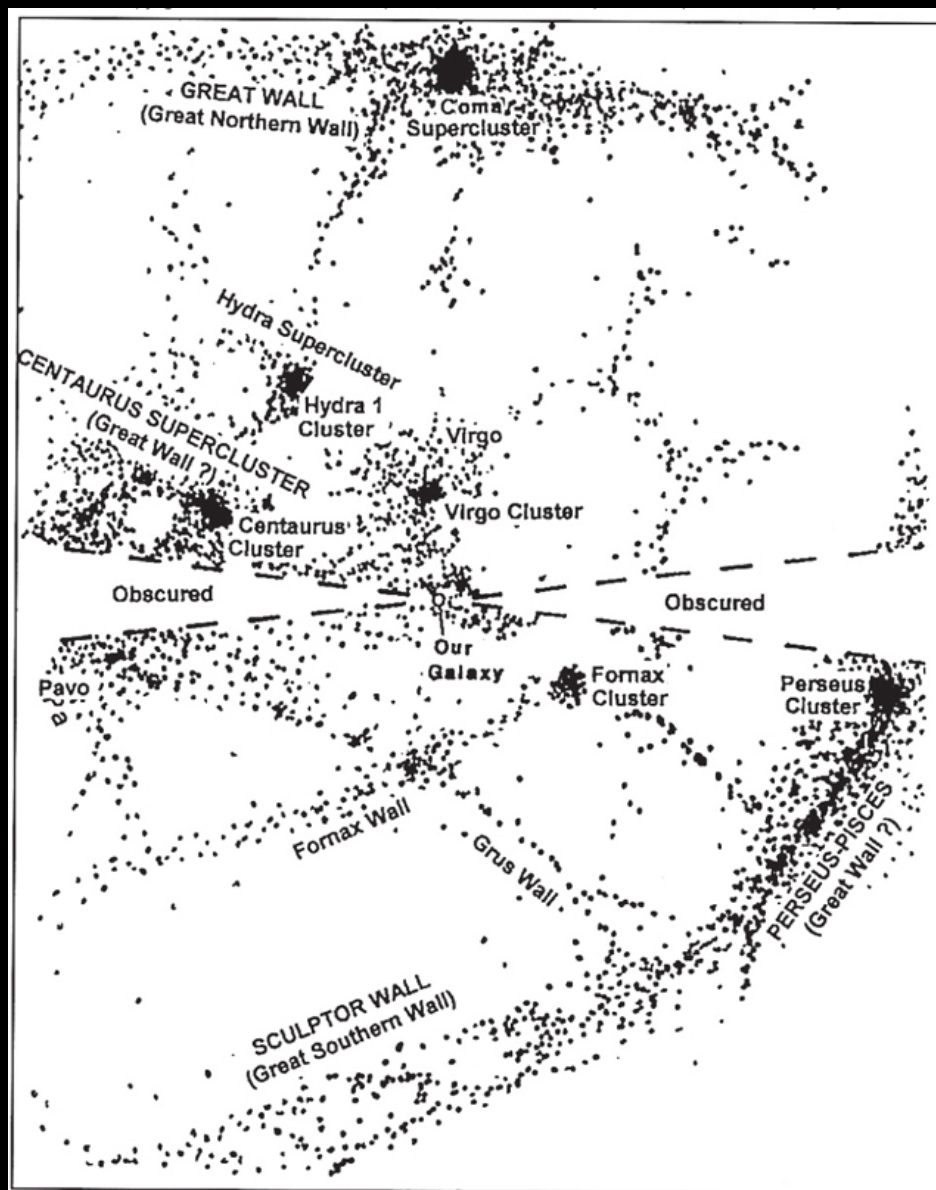


Central region of the Virgo Cluster, which contains M84 and M86, at a distance of about 20 Mpc

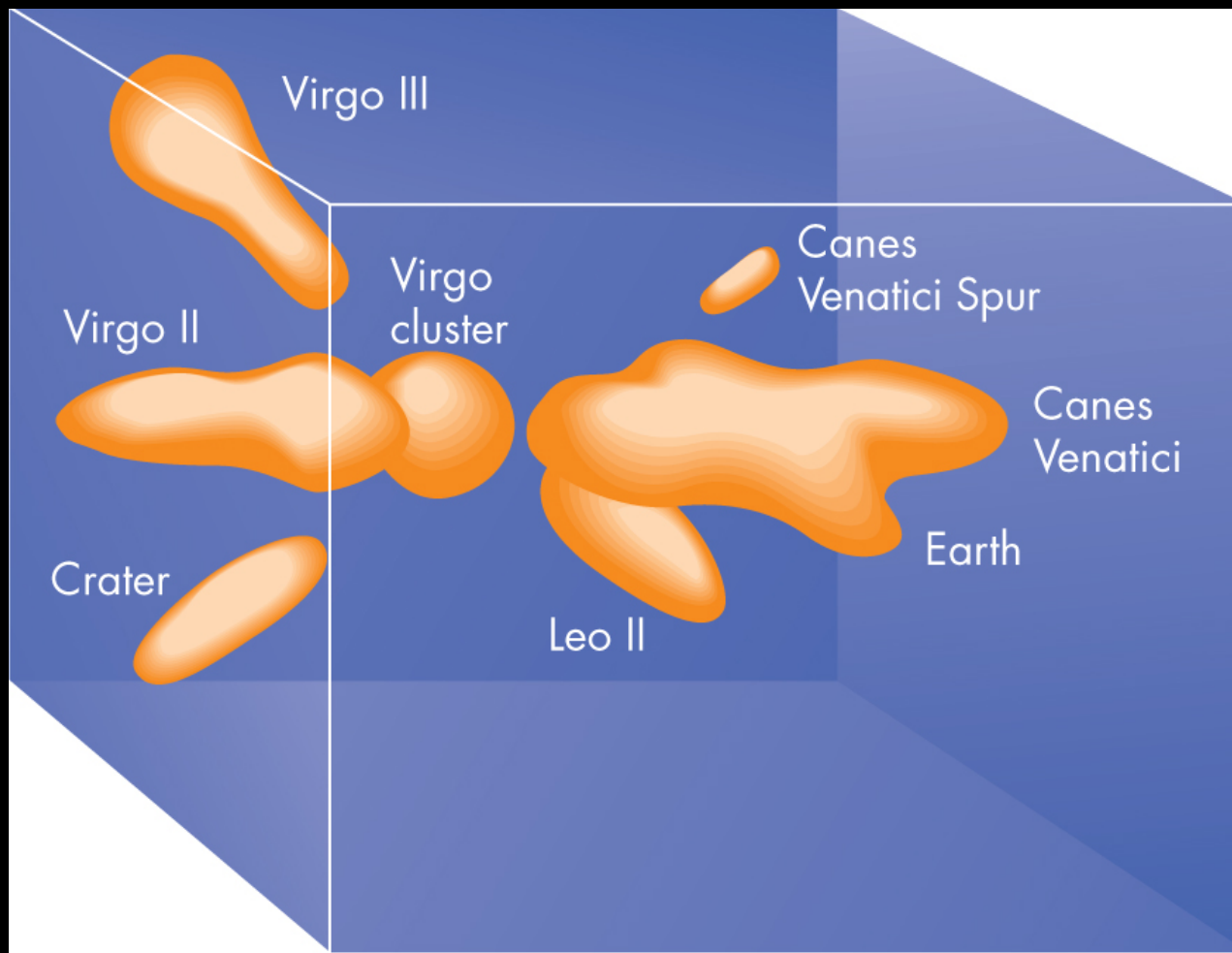


Central region of the Coma Cluster, at a distance of about 90 Mpc

Voids, Walls, and Superclusters

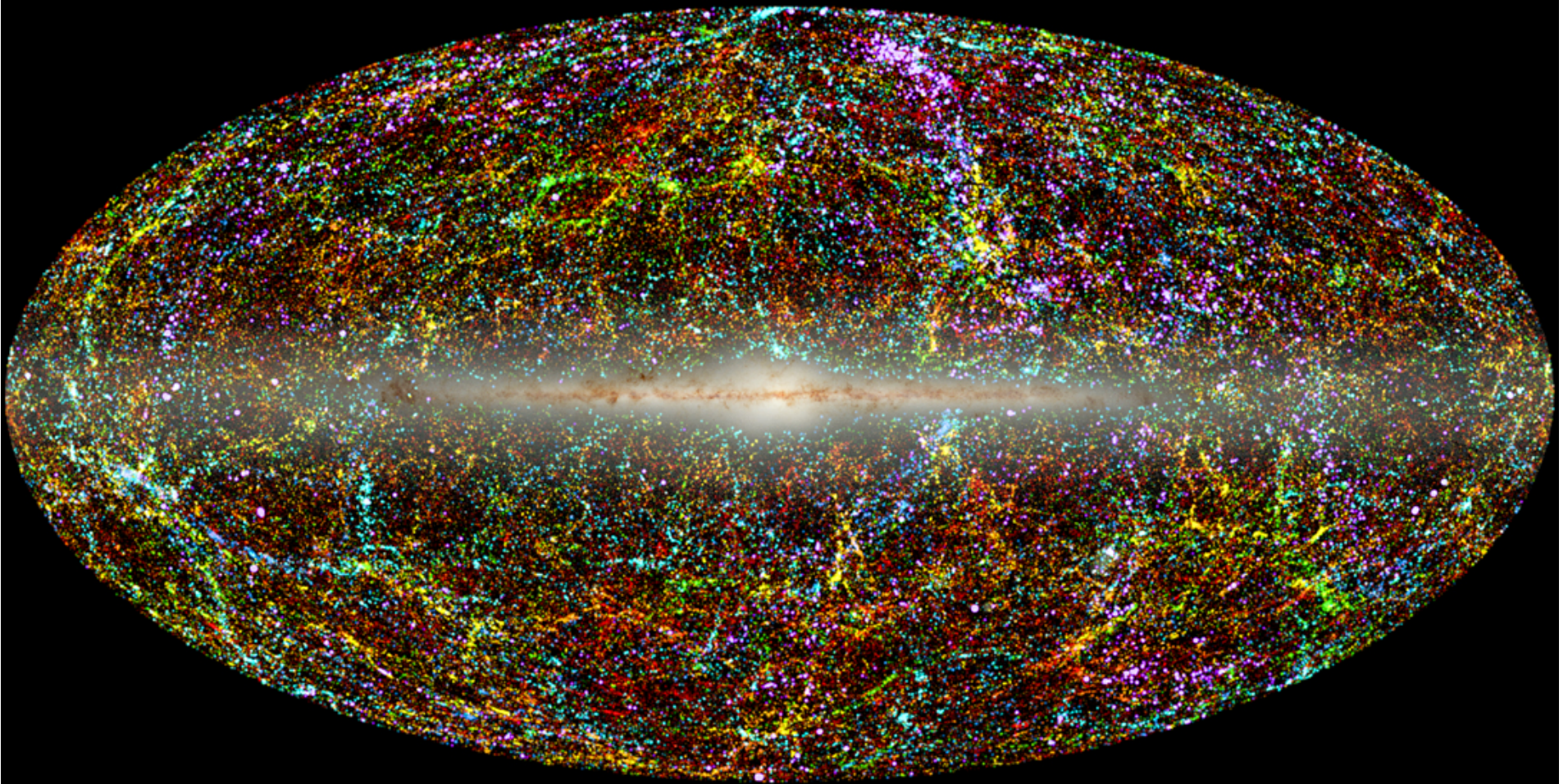


Local Supercluster



The local supercluster, centered approximately on the Virgo cluster

Millions of Galaxies



“Large Scale Structure in the Local Universe:
The 2MASS Galaxy Catalog” (2004)
By Thomas Jarrett (IPAC/Caltech)

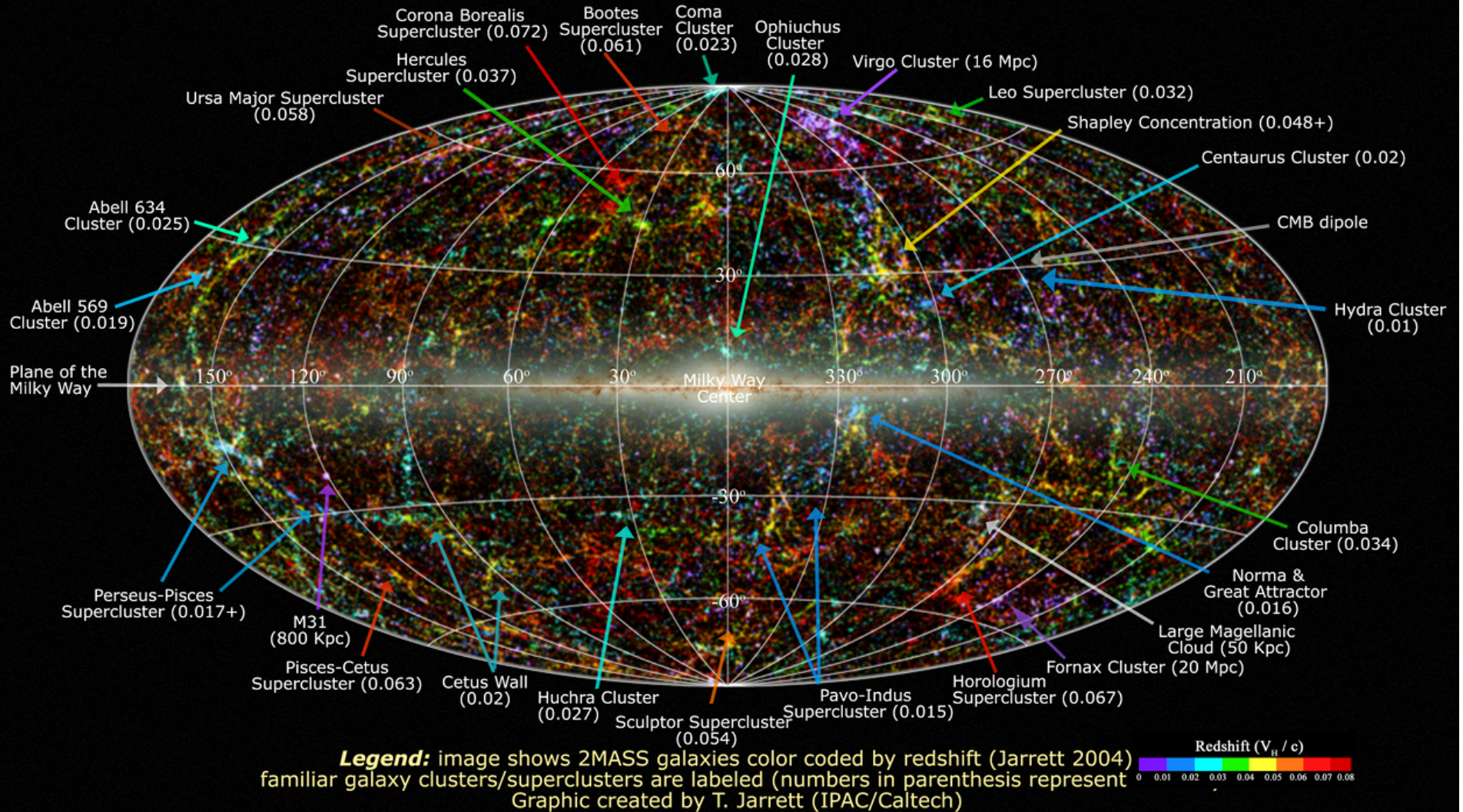
<http://spider.ipac.caltech.edu/staff/jarrett/papers/LSS/>

Panoramic view of the entire night sky in
near infrared, including:

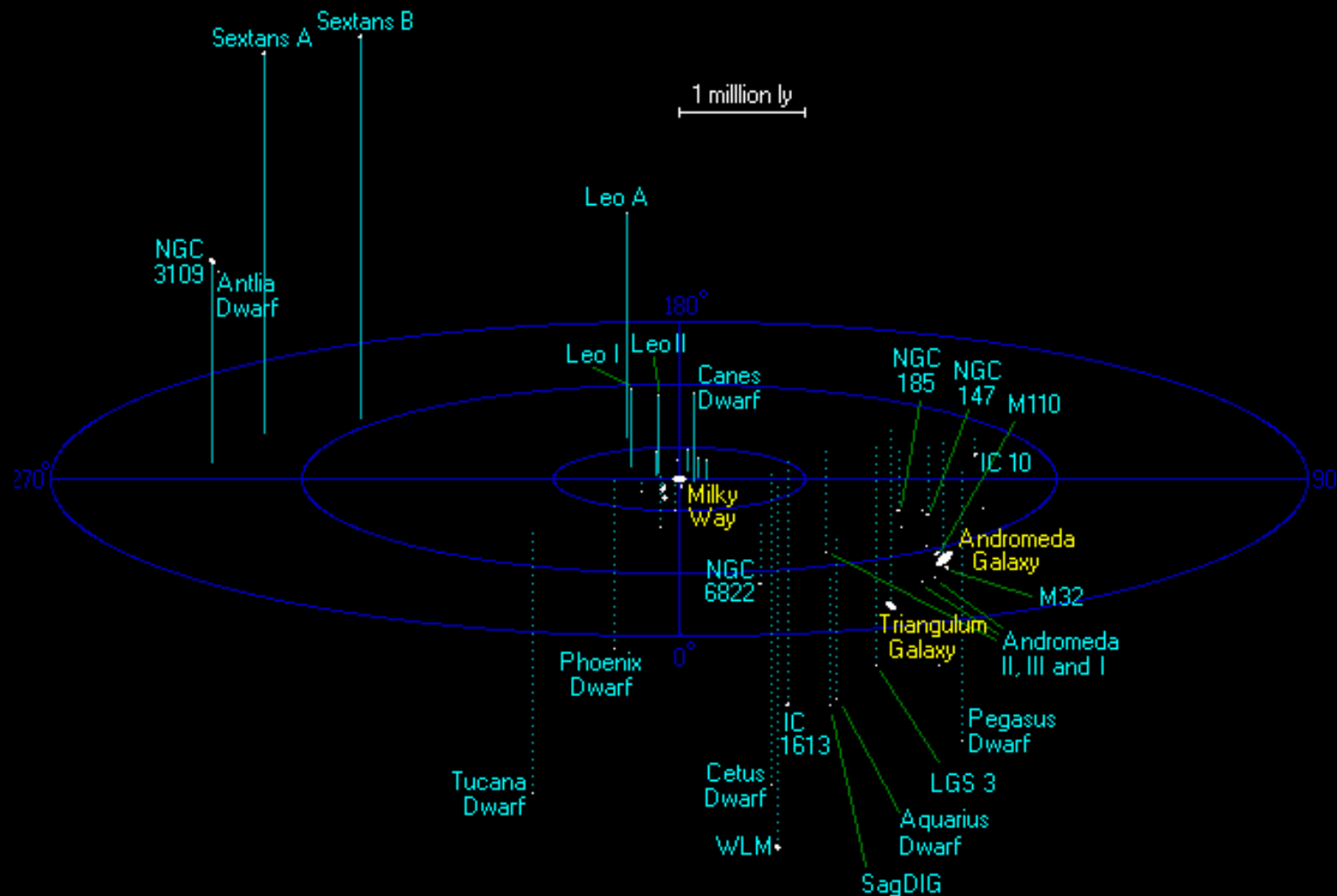
1.5 Million galaxies

500 Million Milky Way stars

Large Scale Structure in the Local Universe



The Local Group



Atlas of the Universe!

Summary

- Estimates suggest that there are about 350 billion galaxies in the universe!

(That's about the same as the number of stars in the Milky Way)

- They are distributed in clusters, and clusters of clusters
- Almost all are receding away from us, and from each other, due to cosmic expansion