Galaxy Cluster Properties

Galaxies occur both in the field and in clusters. Most galaxies live in the field or in small groups; only ~ 20% live in big clusters.

Clusters vary greatly in properties:

	Group	**Rich Cluster**
Number of Galaxies	tens	hundreds to thousands
Size	1-2 Mpc	5-7 Mpc
Velocity Dispersion	~ few 100s km/s	500 - 1000 km/s
Masses	10^{13} M_{sun}	10^{15} M_{sun}

We live in the Local Group :

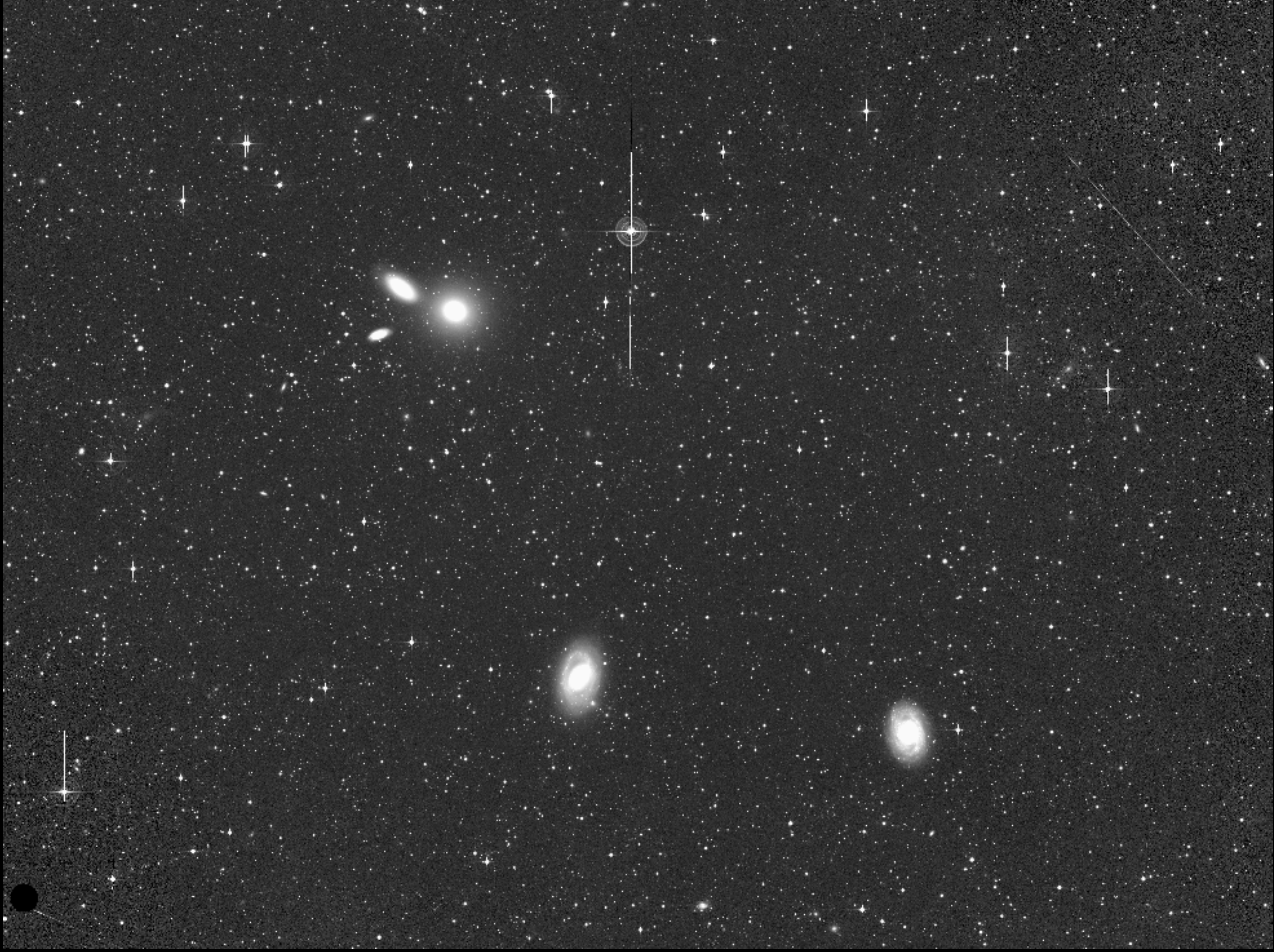
3 biggish spirals: Andromeda (M31), Milky Way, M33

relatively bright companions: LMC, SMC (Milky Way); M32, NGC 205 (Andromeda)

lots of small, low luminsosity dwarf ellipticals and and dwarf spheroidals

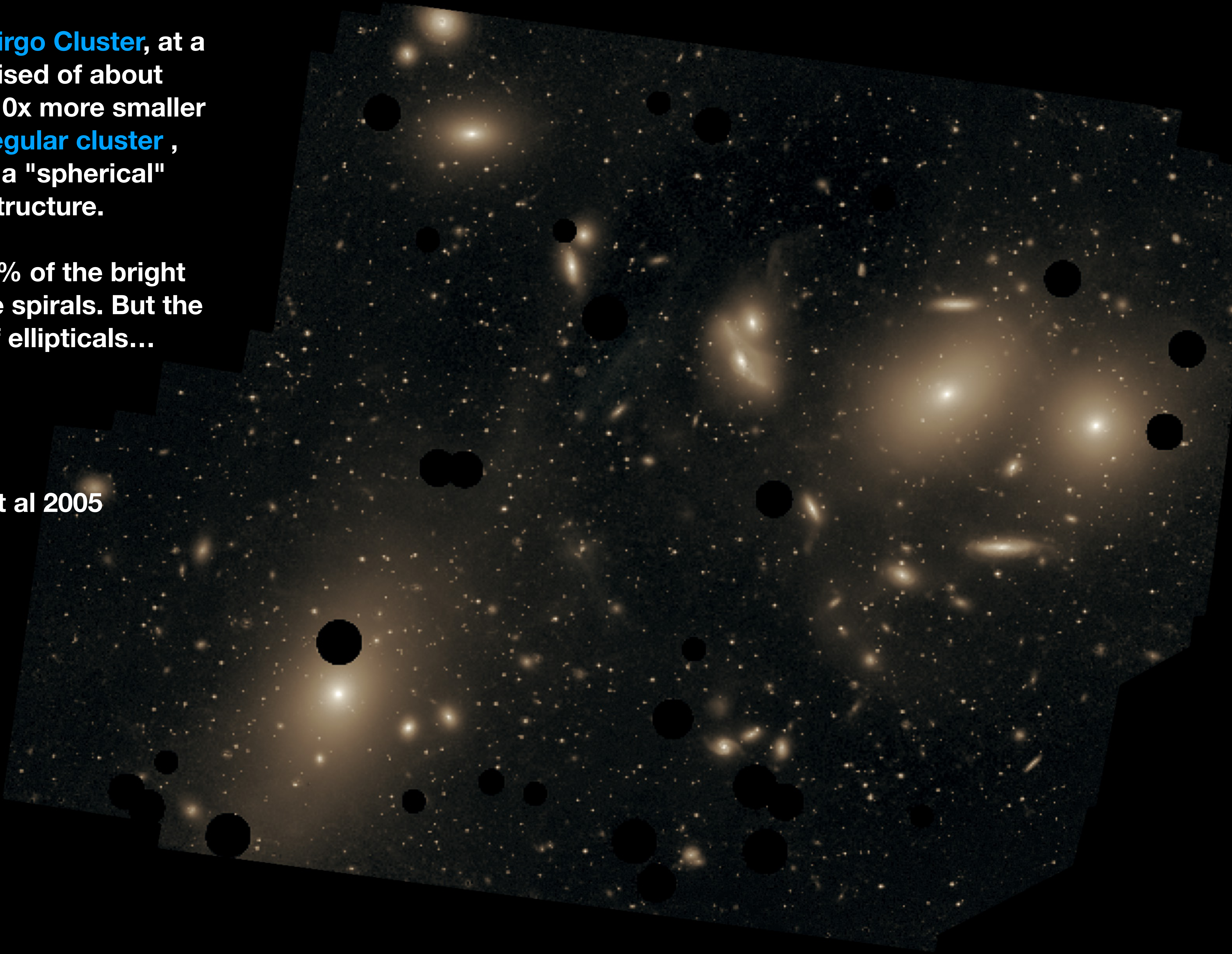
no big ellipticals!

The M96 Group, aka The Leo Group (Watkins et al 2014):

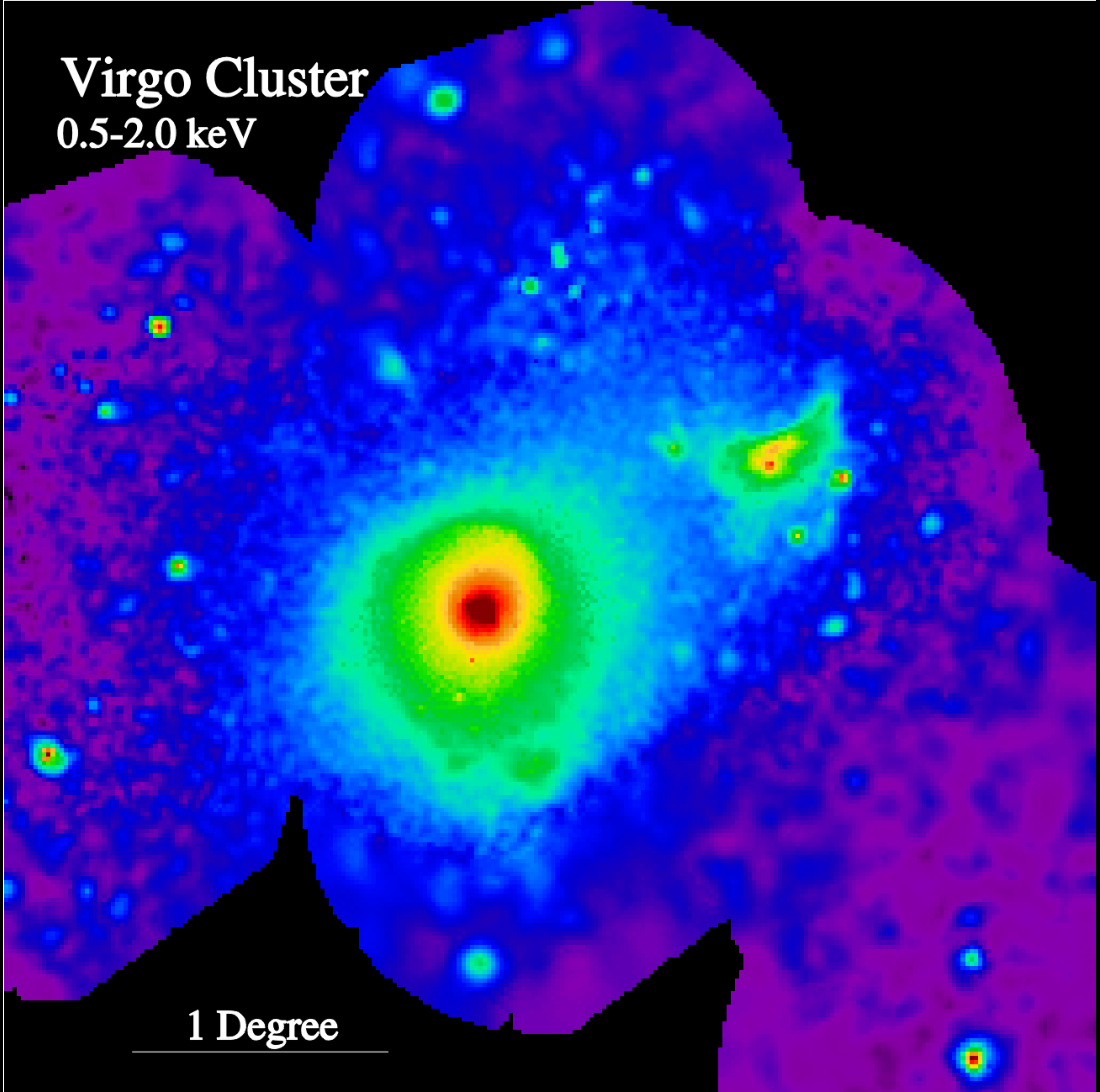


The nearest galaxy cluster is the Virgo Cluster, at a distance of 16 Mpc. It is comprised of about classified 250 large galaxies (and 10x more smaller ones), and is classified as an irregular cluster , meaning that rather than being a "spherical" cluster, it has a lot of substructure.

Virgo is a spiral-rich cluster. ~ 20% of the bright galaxies are ellipticals, the rest are spirals. But the faint galaxies are mostly dwarf ellipticals...



The core of Virgo, Mihos et al 2005


Virgo Cluster
0.5-2.0 keV
1 Degree

Further away is a very massive cluster: the Coma cluster, at a distance of about 100 Mpc. Coma is about 6 Mpc in size and contains perhaps 10,000 galaxies. Very few of the galaxies in Coma are spiral; most are elliptical and S0.

How can we get the mass of a cluster?

Method 1: If we assume the cluster is in **virial equilibrium**, we can use the velocities of the galaxies. The **virial equation** relates the kinetic energy (K) and potential energy (U) of a system in equilibrium as:

$$2K + U = 0$$

So what is the kinetic energy of the cluster? If we look at the galaxies, they would have a total kinetic energy of

$$K = \sum_{i=1}^{N} \frac{1}{2} m_i v_i^2 = \frac{1}{2} M \langle v^2 \rangle = \frac{3}{2} M \sigma_v^2$$

where v is their full space velocity and sigma is the line of sight velocity dispersion of the galaxies in the cluster.

What about the gravitational potential energy of the cluster? For a uniform density sphere:

$$U = -\frac{3}{5} \frac{GM^2}{\langle R \rangle}$$

So we can solve for the total mass of the cluster:

$$M = \frac{5 \langle R \rangle \sigma_v^2}{G}$$

Method 2: Another way to get the mass of the cluster is to use assume the X-ray gas is in **hydrostatic equilibrium**. This means that the thermal pressure of the gas is in equilibrium with the gravitational potential. Using the density and temperature of the hot gas you can then solve for the cluster mass.

Method 3: A third way of measuring the mass of the cluster is to count up all the galaxies, adopt a mass-to-light ratio for each one to determine their mass, and then tally up the mass directly.

The first two answers give reasonably consistent results. The third answer is an order of magnitude too small. *What does this mean?* Either:

- **Virial equilibrium and hydrostatic equilibrium are bad assumptions**. In this case the cluster is flying apart, because the velocities of the galaxies are greater than the binding mass. Probably not correct -- we see lots of clusters, they are not transient objects.
- **Dark matter exists on large scales in clusters!**
    - Cluster content: 10% galaxies, 20% hot gas, 70% dark matter

How do galaxies in clusters differ from those in the field? What are the properties of cluster galaxies? We have seen that in the Local Group there are no ellipticals. In Virgo -- an irregular, cluster with lots of substructure -- there are some ellipticals but mostly spirals. In Coma -- a rich, smooth cluster -- it is mostly elliptical and S0 galaxies. **The ratio of S:(E+S0) drops as the density of the environment rises.** This is called the **morphology-density relationship**.

Here is what it looks like for nearby clusters:

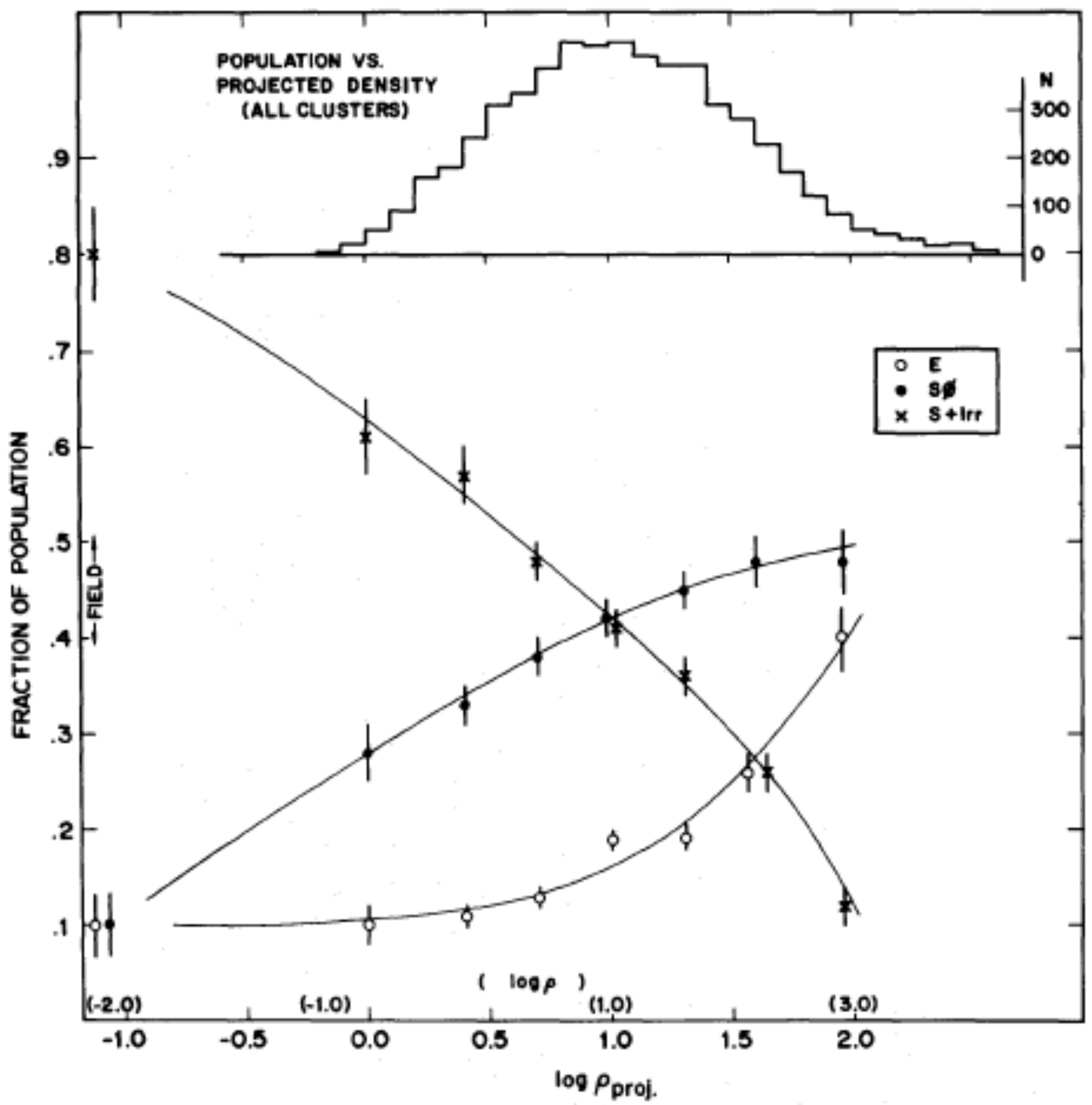
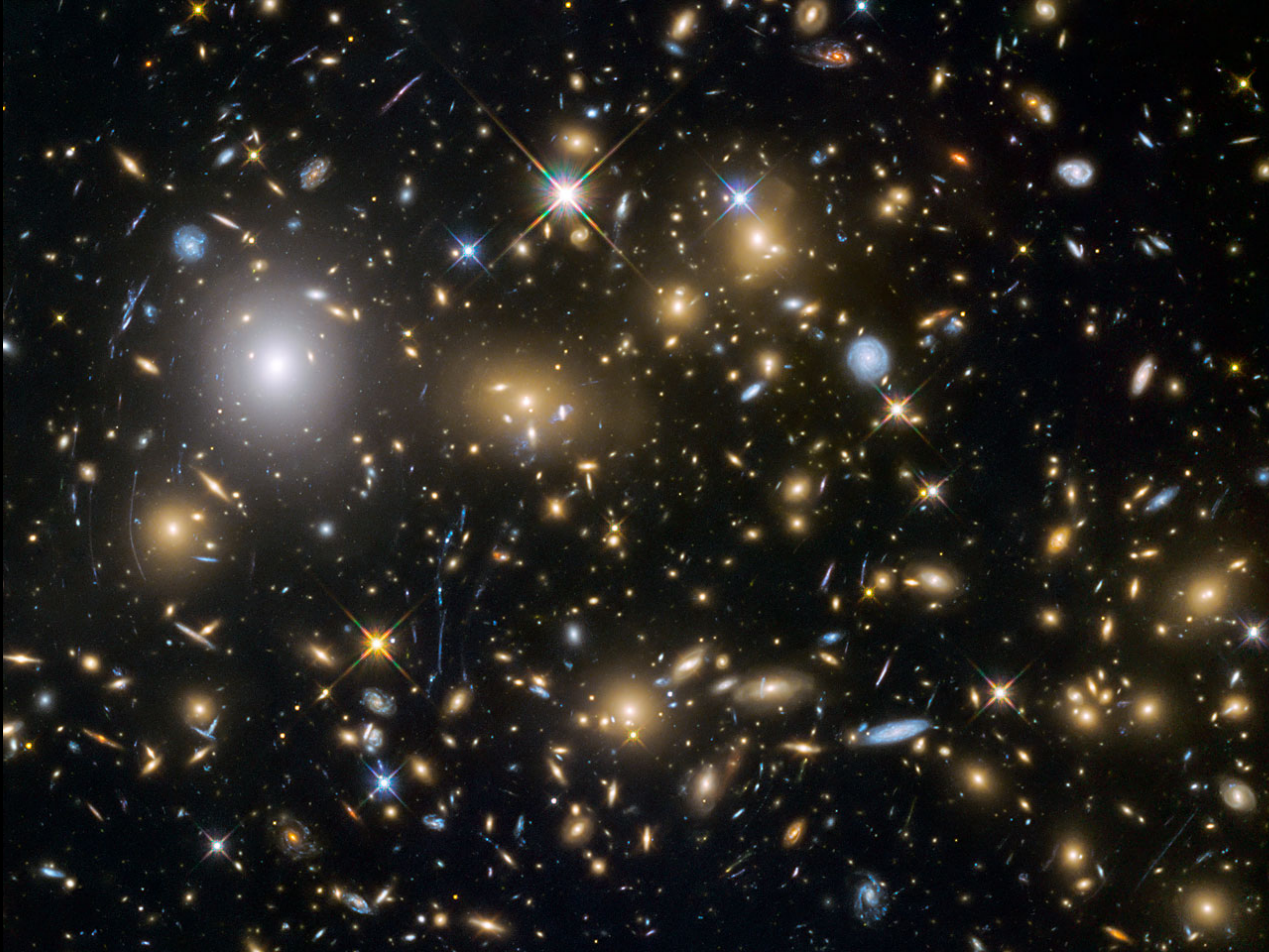


FIG. 4.—The fraction of E, S0, and S+I galaxies as a function of the log of the projected density, in galaxies Mpc^{-2}. The data shown are for all cluster galaxies in the sample and for the field. Also shown is an estimated scale of true space density in galaxies Mpc^{-3}. The upper histogram shows the number distribution of the galaxies over the bins of projected density.

But it was hard to say much about the types of galaxies in distant clusters....
....until Hubble Space Telescope came along.

Here is a picture of **MACS J0717.5+3745**, a cluster of galaxies at z=0.55 (~2 Gpc away, seen as it was ~ 5 billion years ago). *What kind of galaxies do we see?*

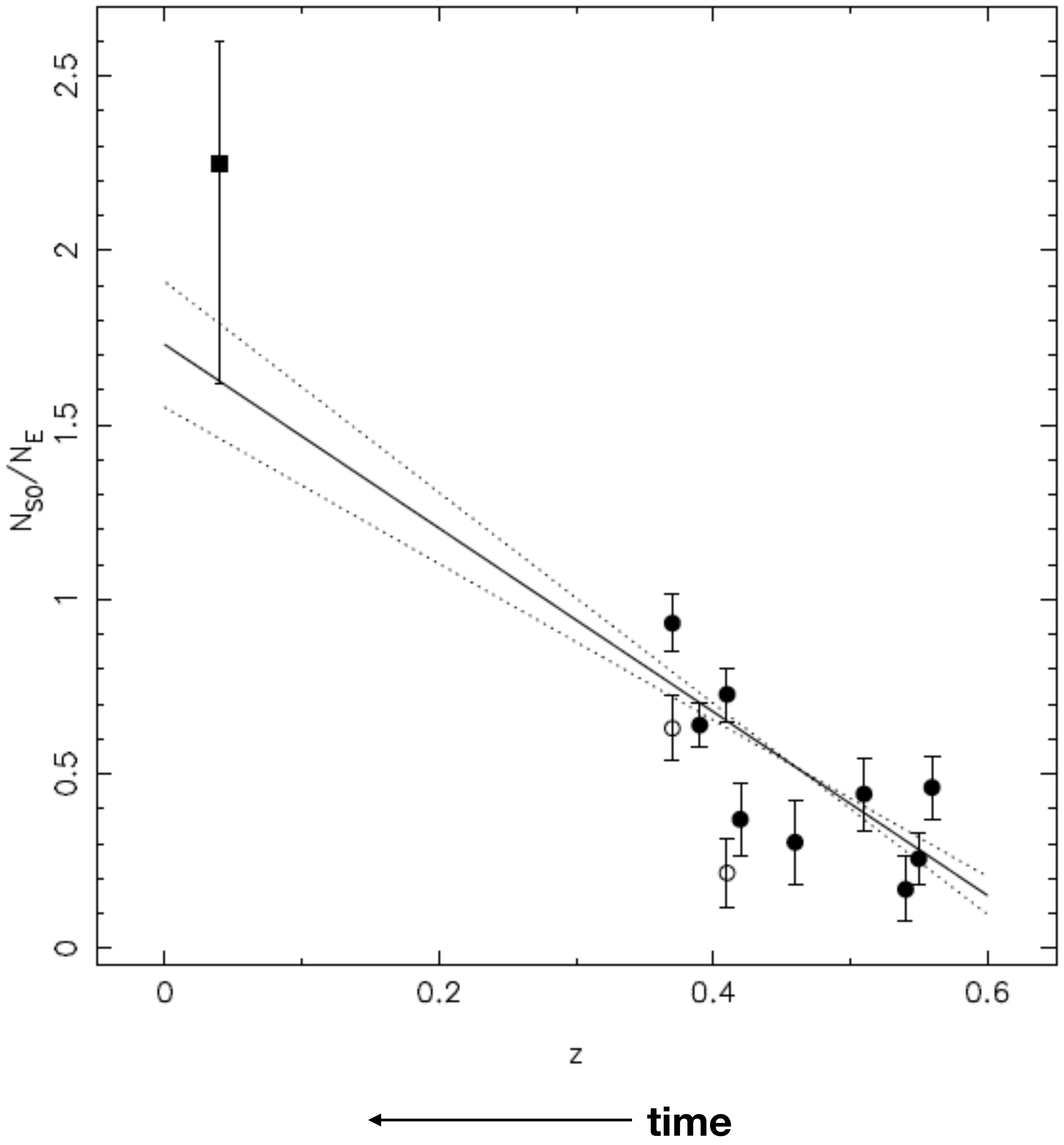


Cluster galaxies are evolving!

The fraction of ellipticals does not change much with redshift (i.e., time). But the fraction of S0s increases with time, suggesting that cluster environments are effective at transforming spirals into early type disks.

- ***What processes could drive this evolution in the galaxies?***
- ***How would these account for the morphology-density relationship?***

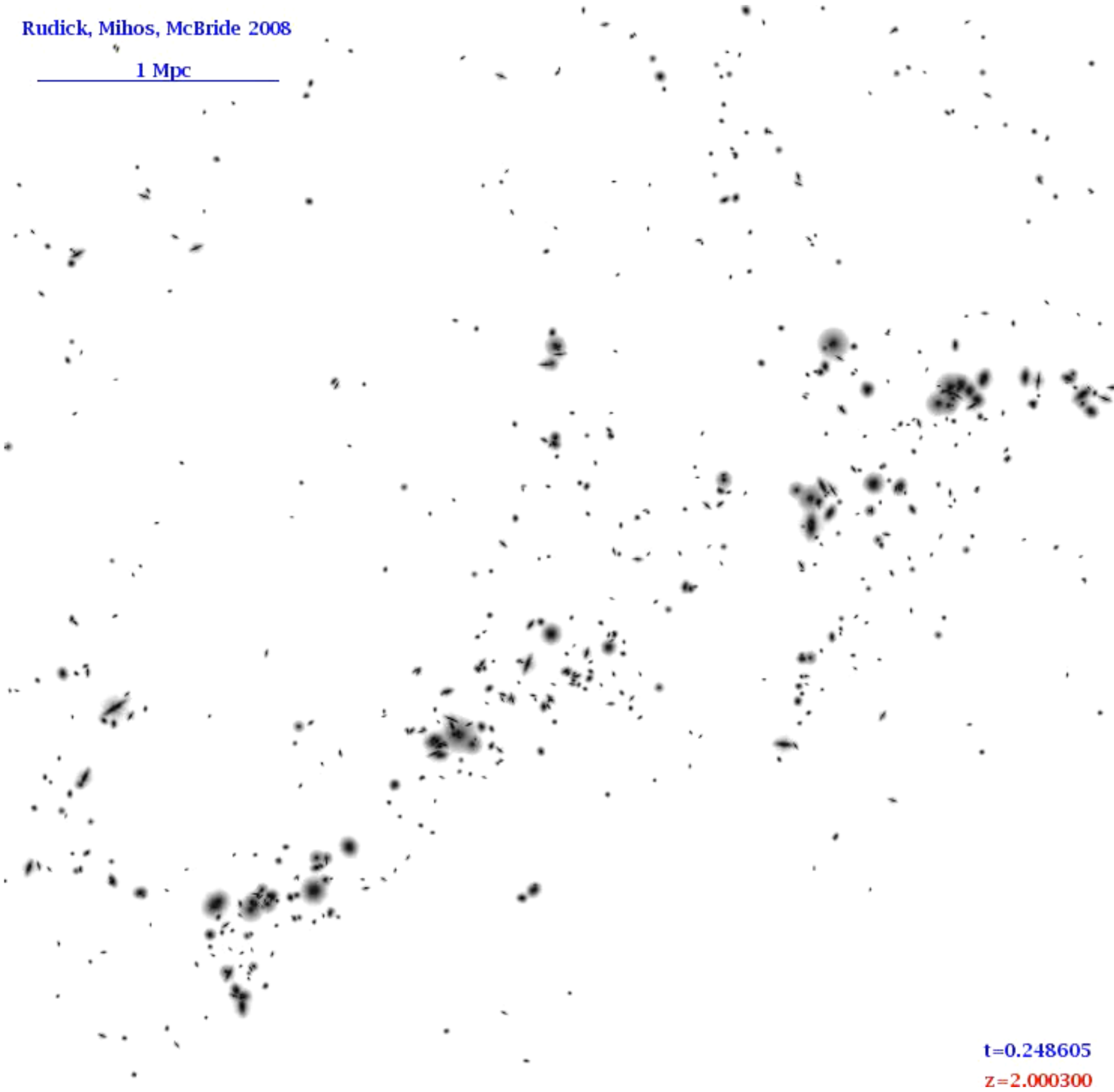
(From Dressler et al 1997)



Also, the **clusters themselves are evolving!** As we shall see when we study cosmology, **galaxy clusters are the last objects to form** in the Universe. Clusters form **hierarchically**, from smaller groups falling together under the influence of gravity. As they "collapse", they mix together and become virialized.

Which is a more evolved cluster, Coma or Virgo? Why?

Galaxy clusters are a great laboratory for studying the evolution of galaxies and the evolution of the universe...



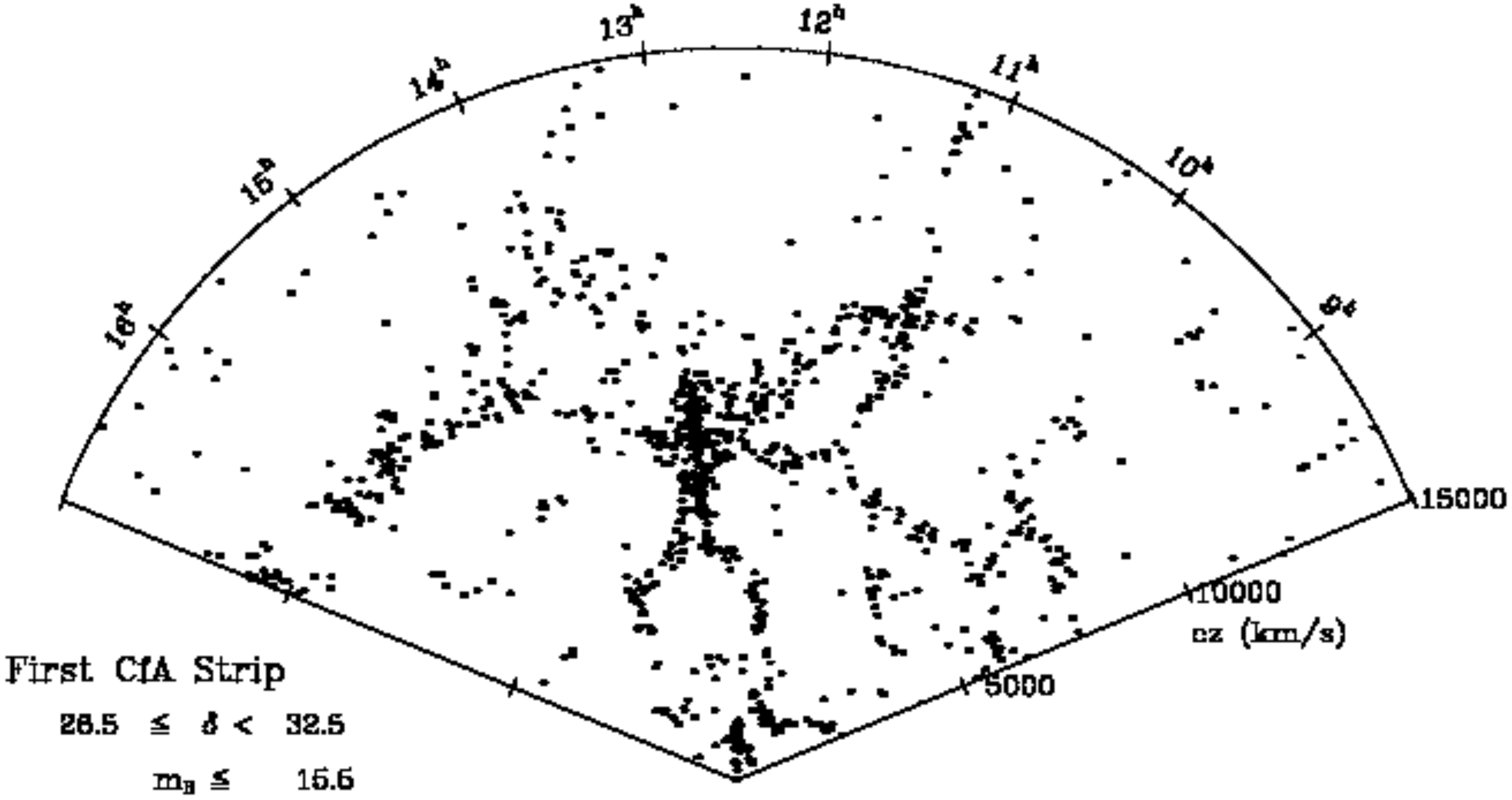
On even larger scales, structure exists in the Universe...

1985: The Stickman Cometh

Look at a picture from the **CFA redshift survey**. Think of it as a pie slice of the universe: the angular coordinate is position on the sky, while the radial coordinate is radial velocity, which is proportional to distance by the Hubble constant.

Galaxies are not distributed evenly in the universe. They are found along "walls" and "filaments" and there are vast "voids".

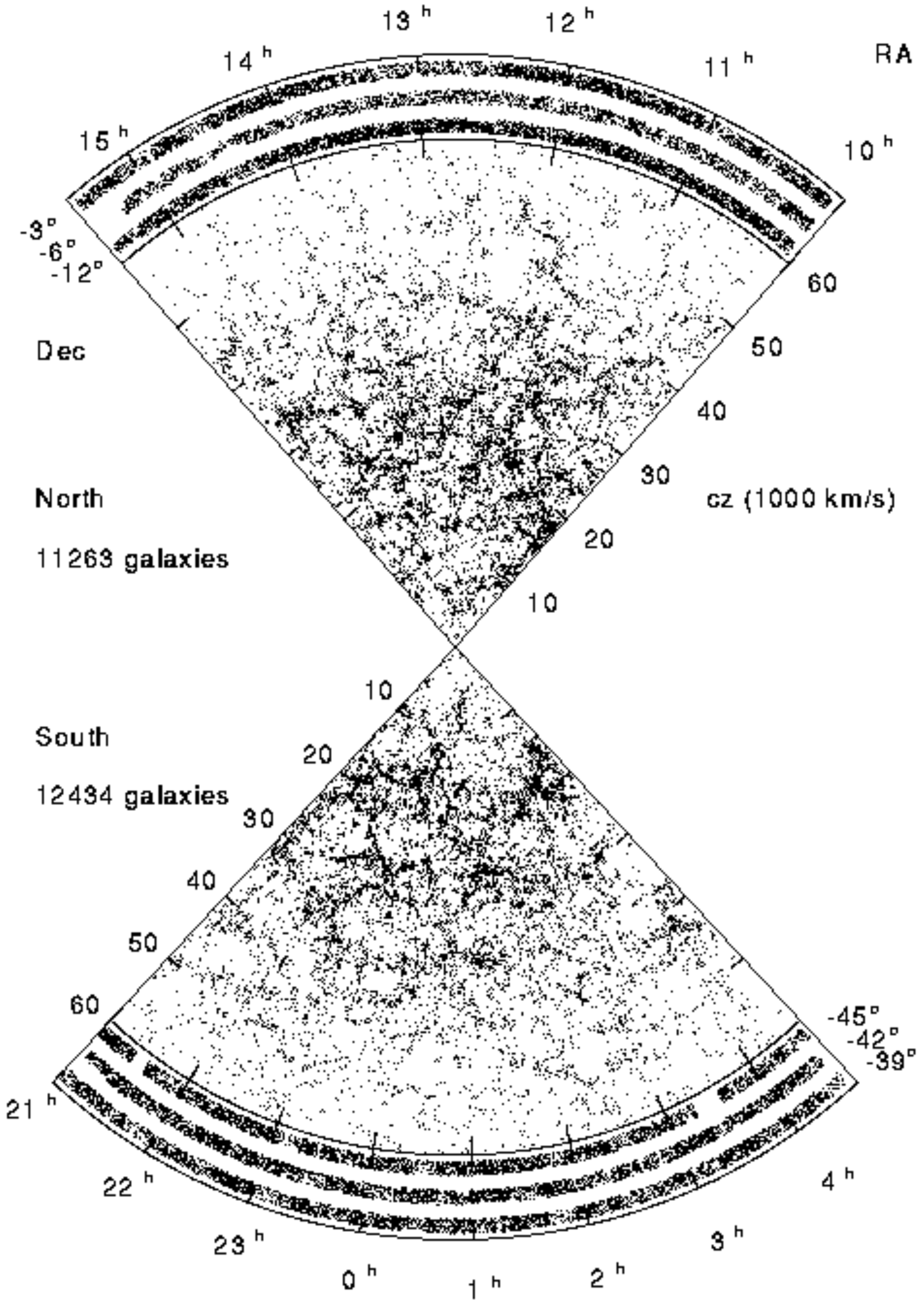
- **Bootes Void**: 100 Mpc away, 75 Mpc in diameter
- **The Great Wall**: 200 Mpc in length, ~ 10 Mpc thick.



1990s: More Data

The LCRS Redshift Survey:

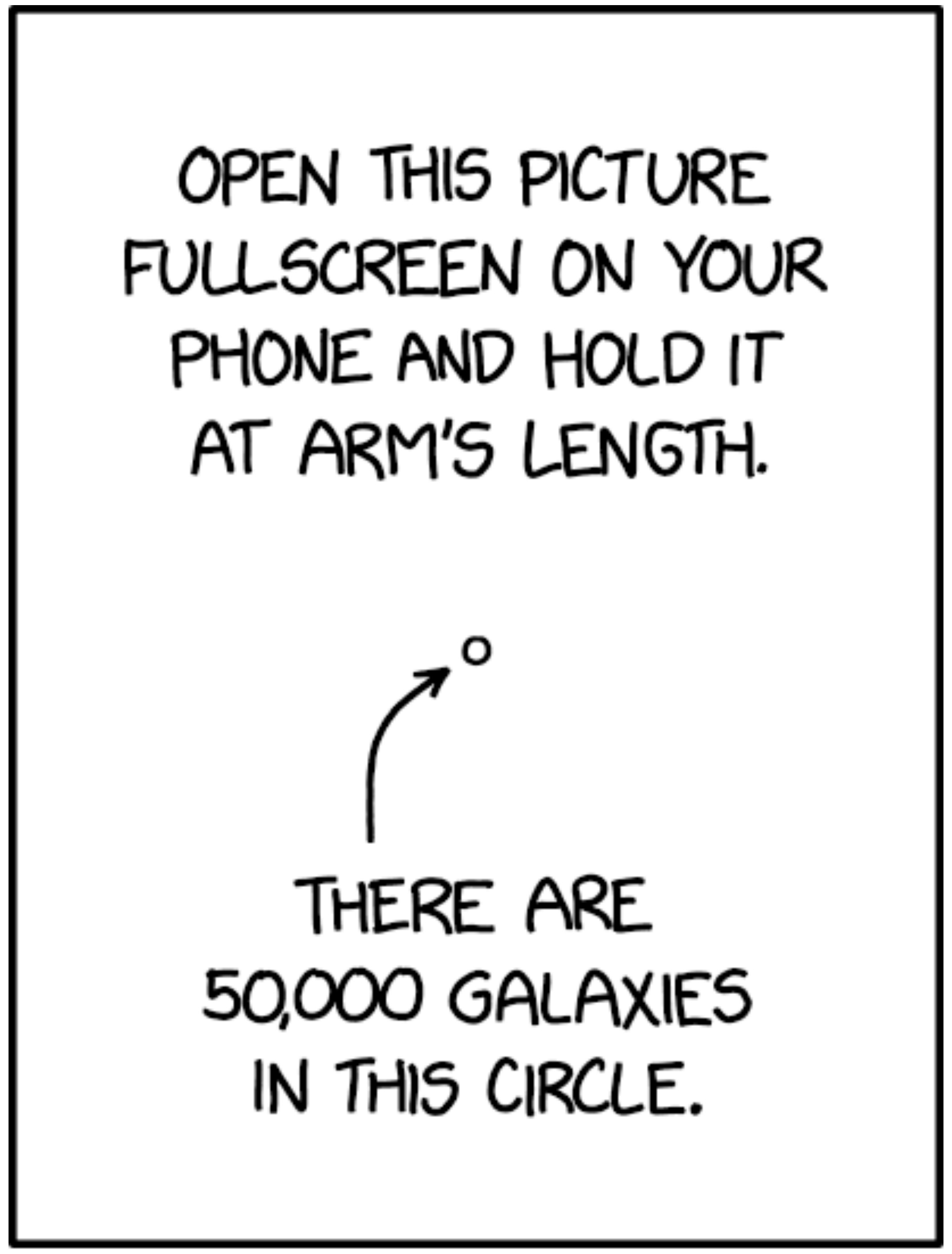
The Universe has structure on very large scales!



2000s: The Sloan Digital Sky Survey

Galaxies in the SDSS main redshift survey, from [Zehavi et al 2011](). *Note that red galaxies cluster together more strongly than blue galaxies.*

We need to explain how all this structure came to be.



ASTRONOMY FACT: THERE ARE TOO MANY GALAXIES.