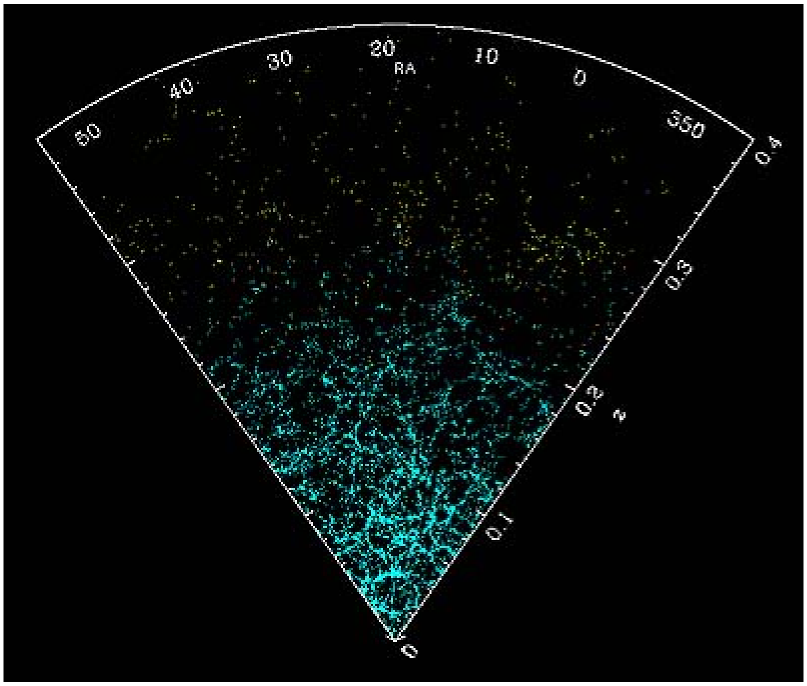
Modern Cosmology

Man hath weav'd out a net, and this net throwne
Upon the Heavens, and now they are his owne.
John Donne

Gravity and Ducks

If you look at a map of the distribution of galaxies in the local universe, you might be surprised to find that the galaxies do not seem to be laid down uniformly, but seem to cluster together. But it is not that surprising that the galaxy distribution is not uniform; if galaxies were uniform, the universe would be organized like a huge crystal. No known laws of physics would lead to such a crystalline universe.



The distribution of galaxies in a slice of the SDSS spectroscopic survey

To understand how galaxies cluster, consider a distribution of ducks on a pond. Some ducks wander off by themselves, but most ducks, most of the time, are found in small groups of two or three or more that tend to travel together. Ducks tend to cluster, and this clustering is not a result of chance. Ducks tend to want to be near one another.

Like ducks, galaxies cluster not out of chance, but because they want to be near one another. Of course, unlike ducks, galaxies have no desires; the thing that makes them "want" to be together is the force of gravity. Since gravity is always attractive, it will attract galaxies toward one another. So as the universe ages and evolves, you would expect that galaxies would become more and more clustered.

Clustering is understood and measured in terms of statistics. For example, if a biologist wants to study the clustering behavior of ducks, he or she must study many groups of ducks, at many different times on many different ponds. If an astronomer wants to study the clustering of galaxies, he or she must have a very large systematic survey - a map - of where galaxies are. The Sloan Digital Sky Survey will provide such a map.

With the SDSS's map, astronomers will be able to answer an important question about the large-scale structure of the universe: at how big a scale do you have to look before the universe starts to look uniform?

Astronomers were not very surprised to find that our own galaxy, The Milky Way, was a member of a group of some twenty galaxies. They were also not surprised to find that that our local group was a member of a cluster of some two thousand galaxies. But when looking on larger scales, they expected to find well-ordered and sensible phenomena. They did not expect to find the perfectly ordered universe the ancient Greeks envisioned, but they believed that once they looked out beyond their local neighborhood, within a few hundred million light-years, the average properties of the universe would become predictable.

The Biggest Structures?

But as larger and deeper sky surveys were done in the 1980s and 1990s, astronomers were surprised to find that there were clusters of clusters, or superclusters, of galaxies that formed huge walls and thin sheets that surrounded large areas with very few galaxies, called voids. On the largest scales seen so far, the distribution of galaxies looks like a gigantic foam of soap bubbles.

One of astronomy's basic questions today is, "What is the largest structure in the universe?" We have found clusters and superclusters, and now even clusters of superclusters, but are there superclusters of superclusters, and so on? In other words, at what scale do galaxies, or clusters or galaxies, appear to be randomly distributed?

This question is important for understanding the birth and evolution of the universe. Some of the most basic predictions of theories of the early universe concern how matter was initially distributed. Since the distribution of galaxies seen today evolved from this initial distribution, knowledge of the large-scale distribution and clustering of galaxies today is one of the few tests that can distinguish between different theories of the early Universe.

The Sloan Digital Sky Survey was designed to make precisely this fundamental measurement. By systematically observing a wide area to great distances, scientists should be able to measure the amount of clustering on all these scales and use their results to constrain theories of the early universe.

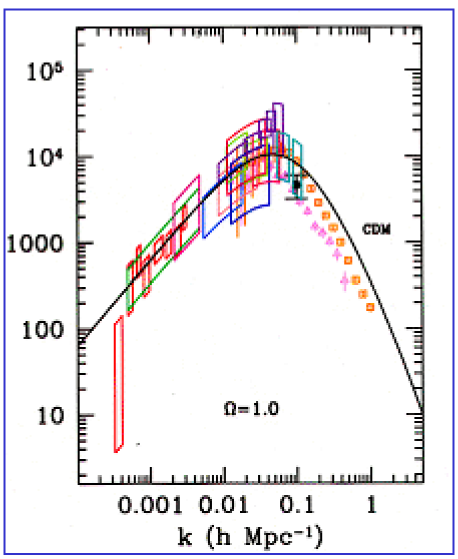
Clustering at three increasing scales: group, cluster, supercluster

Noise and Galaxy Clusters

But if the SDSS proves astronomers right, and the universe is uniform over the largest scales, then why do galaxies form clusters and superclusters at smaller scales? The answer to this question lies in "random noise processes," which have analogous examples in everyday life.

Examples of random noise processes are the sound of static on an old radio, or the sound of a waterfall, or the distribution of waves on the surface of the sea. In each of these cases, every time you listen or look, what you hear or see is different than what you heard or saw before. However, it is also obvious that you are hearing the same waterfall or radio, or looking at the same sea.

In all of these cases, the statistical properties of the sounds or waves are the same. Taking the sea as an example, although the water surface is always changing, the distribution of the number of waves and their heights have some well-defined average properties. By observing a very large portion of the sea at once, or a small portion for a long time, you can figure out the general properties of ocean waves.



A power spectrum shows how waves with different wavelengths contribute to a whole. Random noise processes show up at shorter wavelengths. A power spectrum like this could be used to analyze ocean waves - or the structure of the universe.

Astronomers working with data from the Sloan Digital Sky Survey will perform a similar analysis on the distribution of galaxies revealed in their map of the Universe. Just as the waves in a part of the sea can give information about the water depth and wind strength, the way galaxies cluster can tell cosmologists a lot about how matter was distributed in the early universe, and what physical processes have worked to change the clustering since then.

Knowing how galaxies cluster can give cosmologists information on other fundamental properties of the universe as well. For example, cosmologists will be able to use these data to measure the density of the universe. Knowing the universe's density will help them decide between various theories of dark matter, which will allow them to predict the ultimate fate of the universe.