2 HOW DO GALAXIES FORM AND EVOLVE?

The evolution of galaxies is the ultimate chicken-and-egg situation. Did the shapeless matter first gravitate together in larger structures, giving birth to stars and then to supermassive black holes? Or did the black holes form first and then trigger the creation of the first generation of stars in the centers of galaxies?

GALAXIES, GALAXIES EVERYWHERE

The Hubble Ultra Deep Field is one of the most important deep images of recent years. Hubble has imaged nearly 1,000 galaxies in this so far deepest visible-light image of the cosmos. This galaxy-studded view represents a "deep" core sample of the universe, cutting across billions of light-years, showing galaxies of various ages, sizes, shapes, and colors. The smallest, reddest galaxies may be among the most distant known, existing when the universe was just 800 million years old. The nearest galaxies — the larger, brighter, well-defined spirals and ellipticals — are seen as they were about one billion years ago.

“ Galaxy clusters are the largest gravitationally bound objects we know.”

The formation and evolution of galaxies is one of the most hotly debated topics in modern astronomy. Why do we see different types of galaxies, and how do the supermassive black holes that are found in all, or nearly all, galaxies fit into the equation?

Important clues to the origin of galaxies are found by looking at surveys of large areas of the sky. Some regions are more densely populated than average, with galaxies found in small groups, or in large crowds of thousands of galaxies, called galaxy clusters. Clusters are often grouped in superclusters and even larger structures that extend across large swathes of the mappable universe.

Galaxy clusters are the largest gravitationally bound objects we know and have a well-populated central core and a spherical shape. Typically, their sizes range between 5 and 30 million light-years, while their mass is of the order of one million billion solar masses. Compared to the fields outside the clusters, the cluster centers are populated almost solely by elliptical and lenticular (or S0; on the border between ellipticals and spirals) galaxies, with hardly any ongoing star formation. So, there is a clear connection between the environment and the galaxy types found. This relationship makes many scientists believe that spirals were once numerous in clusters but have been transformed into elliptical or lenticular systems via galaxy mergers.

ABELL 1703, A MASSIVE GALAXY CLUSTER

Located in the northern celestial hemisphere, Abell 1703 is composed of hundreds of galaxies, here seen in yellow. Most of these are elliptical galaxies. The cluster galaxies act as a powerful cosmic telescope, or gravitational lens, that bends and stretches the light from more distant galaxies (many of which are spirals). In the process it distorts their shapes and produces multiple banana-shaped images of the original galaxies. Abell 1703 is located 3 billion light-years from Earth.

Looking Back in Time

A single human lifetime, or even the lifetime of the entire species, is far too short to observe the evolution of a galaxy. But the speed of light comes to our rescue in a curious way. It is a very high speed indeed — roughly 300,000 kilometers per second — but it is still finite. Galaxies are millions or even billions of light-years (the distance traveled by light in a year) away from Earth. Due to the finite speed of light, the more distant an object is, the longer the travel time of the light to Earth, and so the further into the past we observe it once the light arrives. Observing a distant galaxy is like traveling back in time. This gives us the ability to study the changes in galaxies over time by observing them at different distances, and thus at different epochs.