Dark Matter in the Universe

Back in 1933, Fritz Zwicky had, on the basis of his studies on galaxies, argued for the existence of dark matter in the universe. By studying the dynamics of galaxies, he concluded that the mass to light ratio of galaxies and clusters of galaxies required far more mass than explained on the basis of stellar origin of their light.

Although the evidence was there, it took some decades for astronomers to appreciate the significance of dark matter. By the 1970s, the feeling that dark matter might easily exceed visible matter was strengthened mainly by evidence on two counts.

First, the astronomy with waves of 21-cm wavelength arising from internal changes in the hydrogen atom revealed that there are clouds of neutral hydrogen circling around galaxies at distances much in excess of their visible boundaries. Had all mass of a galaxy been confined to its visible part, the rotational speed of the cloud should have dropped in inverse proportion to the square root of its distance from the galactic centre. This does not happen; the rotation curves are flat, i.e., the rotational velocity more or less stays constant out to distances twice or thrice the visible radius of the galaxy. Unless one is prepared to modify the laws of motion and gravitation suitably, the conclusion has to be that there is extra matter present beyond the visible boundary, matter that can’t be seen.

The second line of evidence, also noted by Zwicky, concerns the motions of galaxies in clusters. If in a self gravitating system of galaxies, a state of statistical equilibrium is reached, then there should be an approximate equipartition between the kinetic and potential energies. In actual clusters, the kinetic energy far exceeds the potential energy. This discrepancy can be resolved either by assuming that the clusters are not relaxed (i.e., in equilibrium), or by postulating a large amount of dark matter at rest, which contributes to potential energy but not the kinetic one.

Today, experts may disagree in their estimates of how much dark matter there is, but all would agree that a major component of the universe is simply not visible. Attempts to locate and estimate dark matter in the form of small sub-stellar objects in the halo of our Galaxy by gravitational micro-lensing are underway. A major issue currently being debated is whether all dark matter is baryonic (i.e., made of ordinary particles like the neutrons and protons) or non-baryonic (i.e., made of as yet unfamiliar species like massive neutrinos, axions, photinos, etc. whose existence has been conjectured by particle physicists). In the big bang scenario, this issue is very important particularly for understanding the growth of large scale structure in the universe.