The invisible component of the Universe

The Dark Side of Galaxies

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Dark matter is the primary building material of galaxies and clusters. It is most prevalent in the biggest cosmic objects, like galaxy clusters, as well as in some of the smallest ones, like dwarf galaxies. Both may help us to unlock some of dark matter's secrets

According to recent estimates, normal matter - i.e. the sort the Solar System and we ourselves are made of - comprises only 4 percent of the total matter and energy present in the Universe. The dominant component of gravitationally bound objects, such as galaxies and galaxy clusters, is in fact something called "dark matter," the nature of which remains unknown. Such matter accounts for about 23 percent of the Universe's energy budget. The remaining 73 percent is accounted for by so-called "dark energy," which can take the form of a cosmological constant or quintessence. Such energy does not form structures, but causes the expansion of the Universe to accelerate.

The first signs of dark matter's presence in the Universe appeared when the

The SALT Consortium

In their pursuit of dark matter, Polish astronomers plan to use the 11-meter SALT telescope in South Africa, newly built in part thanks to a contribution from Poland dynamics of galaxies and clusters began to be studied. The observed velocities of the components of such objects (the galaxies within clusters, or the stars within galaxies) turned out to be too large to be explained by the presence of visible, luminous matter alone. If these objects really contained only what is visible to observers, the gravitational pull would be too small to create stable structures and the high-velocity components would disperse in space. At present, although no dark matter particles have been discovered, the hypothesized existence of dark matter is very well grounded in cosmology. Apart from the aforementioned dynamical arguments, its existence is also supported by the fact that without such dark matter, cosmic structures would form much more slowly and would be differently distributed in space, galactic disks would be unstable and the properties of the microwave background radiation would be different from those observed.

Galaxy clusters

Of the well-studied galaxy clusters, one of the most interesting is cluster number 1689 in the Abell catalogue (A1689). The galaxies in this cluster show a mean spectral redshift of 0.18, which means that they lie more than 600 megaparsecs away from the Earth (1 parsec = 3×10^{13} km). Such a distance implies that a few different methods can be employed to study the dark matter distribution in this cluster.

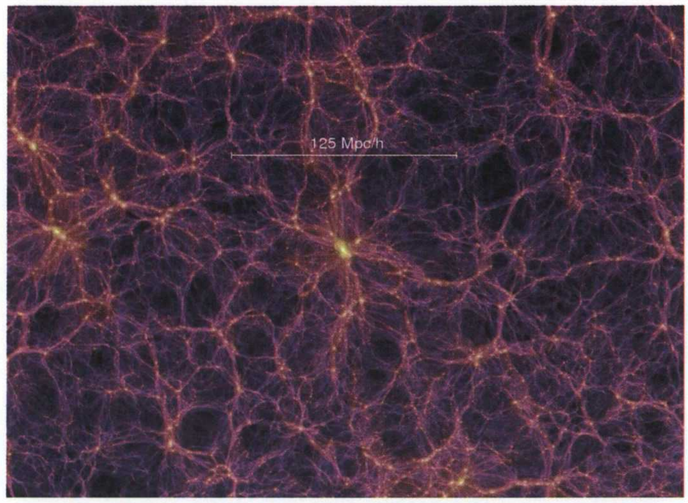
The most spectacular and modern of these methods involves analyzing distant galaxies lying behind the cluster from our point of view, whose images become distorted through gravitational lensing. This phenomenon, described by the theory of general relativity, involves the trajectory of light coming from these galaxies being bent by the matter present in the cluster. By studying these distortions one can estimate the amount and distribution of dark matter in the cluster. Images of A1689 captured by the Hubble Space Telescope enabled more than a hundred images of such lensed galaxies to be identified, and from this point of view the cluster is unique. The detailed modeling of these images yielded information about the distribution of dark matter in the cluster as well as the total mass, estimated at 2×10^{15} solar masses.

The cluster Abell 1689, the *enfant terrible* among galaxy clusters. This Hubble Space Telescope image shows, in the form of arcs, multiple images of distant galaxies distorted by gravitational lensing

The Hubble Space Telescope (NASA)

Another method for studying the distribution of dark matter relies on analyzing the properties of hot gas in the cluster. This component usually amounts to between 10 and 20 percent of the cluster mass, but its properties bear witness to the total gravitational field of the cluster (including the portion due to dark matter). The gas emits strong X-rays and this radiation can be detected by satellites like XMM-Newton. The analysis of this radiation's temperature led to an estimate of the cluster's mass at 10^{15} solar masses - half the value obtained with the lensing technique.

Given the precision of modern astronomical measurements, this discrepancy is rather large. The first guess that occurs to a cosmologist in this case is the possibility that the cluster is not in equilibrium, but rather in a state of merging with another group of galaxies, which would undermine some of the assumptions in the models. The X-ray image of the cluster should then be strongly perturbed; however, that of A1689 is extremely regular. By analyzing the distribution of velocities for almost 200 galaxies in the cluster we came to the conclusion that there might indeed be a different reason for the discrepancy. The distribution differs significantly from the usual distribution for regular and isolated clusters. Using N-body computer simulations, currently an important tool in cosmological studies, we discovered that a similar distribution of velocities may be caused by the presence near the cluster of a different object of comparable mass, placed precisely along the line of observation.



THE VIRGO CONSORTIUM

N-body computer simulations are currently one of the most important tools in cosmological studies. One visualization of the output of the Millenium Simulation, a massive computational effort carried out at the Max Plank Institute – the largest N-body Simulation to date, containing over 10 billion particles

Although such an object does not affect the cluster directly, because its distance is many times greater than the size of the cluster, it is able to distort the observed distribution of galactic velocities. The presence of such an object could also explain the discrepancy in the cluster mass estimates.

Dwarf galaxies

On the opposite side of the scale of cosmologically interesting objects in terms of mass, one finds the dwarf galaxies. Because their light is extremely weak they can be studied in detail only in our closest neighborhood, within the limits of the Local Group of galaxies, where there are about 40 of them. This number, incidentally, has itself vexed cosmologists for some time; according to simulations there should be about 300 such objects in the Local Group. This discrepancy has even been referred to as "the problem of missing satellites."

One particularly interesting class of Local Group dwarf galaxies are the spheroidal galaxies, so called due to their shape, similar to miniature elliptical galaxies. Their luminosities are many (about a million) times smaller than those of normal-sized galaxies, like the Milky Way or the Andromeda galaxy. Their masses, however, are surprisingly large. These masses can be estimated in a way similar to that employed for galaxy clusters (looking at individual stars rather than individual galaxies), by analyzing the distribution of stellar velocities. Such estimates lead to the conclusion that the so-called mass-to-light ratio (the basic measure of the amount of dark matter) is extremely large in these objects, on the order of a few hundred solar units. If the objects contained only stars, the ratio should remain in the range of 1-10 such units.

The main difficulty in estimating the masses of dwarf spheroidal galaxies is caused by the fact that most of them are located rather close to the Milky Way and therefore influenced by its gravitational field. Interaction with the Milky Way can lead some stars to be stripped from the dwarf galaxy. In effect, some of the stars we count as members of the galaxy may not belong to it at all, and their velocities might not be good tracers of the dark matter content in the dwarf galaxy under consideration. Recently we have studied a nearby spheroidal galaxy in the constellation of Draco from this point of view, showing that depending on the sample of stars chosen for the analysis estimates of the galaxy's mass can differ by orders of magnitude, while always remaining consistent with the hypothesis of the predominant presence of dark matter.

The precise determination of the masses of dwarf galaxies is of great importance for cosmology, since it has an impact on estimates of their expected abundance in the Universe (more massive objects are less abundant). In particular this bears upon the prospects for solving the missing satellites problem. The influence of the Milky Way on the mass estimates can be eliminated by analyzing objects at larger distances. One example of such a spheroidal galaxy is the object in the constellation of Cetus, lying at a distance of about 800 kiloparsecs from us in a relatively empty region of the Local Group. We plan to observe this galaxy soon using the newly built (with a contribution by Poland) 11-meter SALT telescope in South Africa. ■

Further reading

Łokas E. L., Prada F., Wojtak R., Moles M., Gottloeber S., (2005). The complex velocity distribution of galaxies in Abell 1689: implications for CDM mass modeling. MNRAS, submitted, http://xxx.lanl.gov/abs/astro-ph/0507508

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