Galaxy Clusters

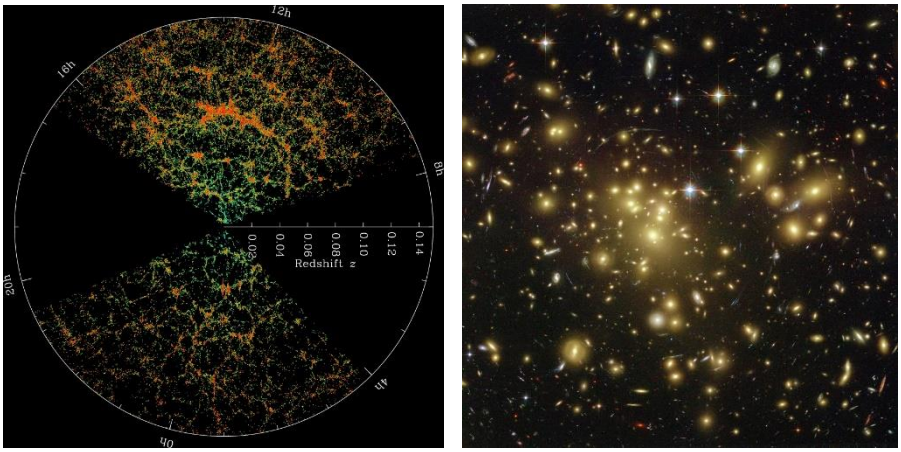
Galaxies are not scattered randomly across the Universe. They gather together into a gigantic cosmic web of filaments and sheets wrapping enormous voids. At the knots of this network, galaxy clusters are the largest gravity-bound cosmic structures.

On the scale of the history of the Universe, clusters are the last structures to have formed in a long process during which galaxies slid along filaments to converge on these regions, the densest in terms of galaxies. Because of their size, which places them between galaxies and large-scale structures, clusters offer insights into the formation of galaxies and serve as benchmarks for determining cosmological parameters, such as the matter density in the Universe and the relative proportions of ordinary matter, dark matter – of as yet unknown nature – and dark energy, the most recently discovered cosmic constituent.

The most remarkable characteristic of galaxy clusters is the presence of gas between galaxies. As this gas is extremely hot (several ten million Kelvin) and behaves essentially like a blackbody, it emits very abundant radiation, mainly in the X-ray band. The very large mass of the clusters is what traps this gas and gives it such a high temperature. The more massive a cluster, the hotter its gas. X-

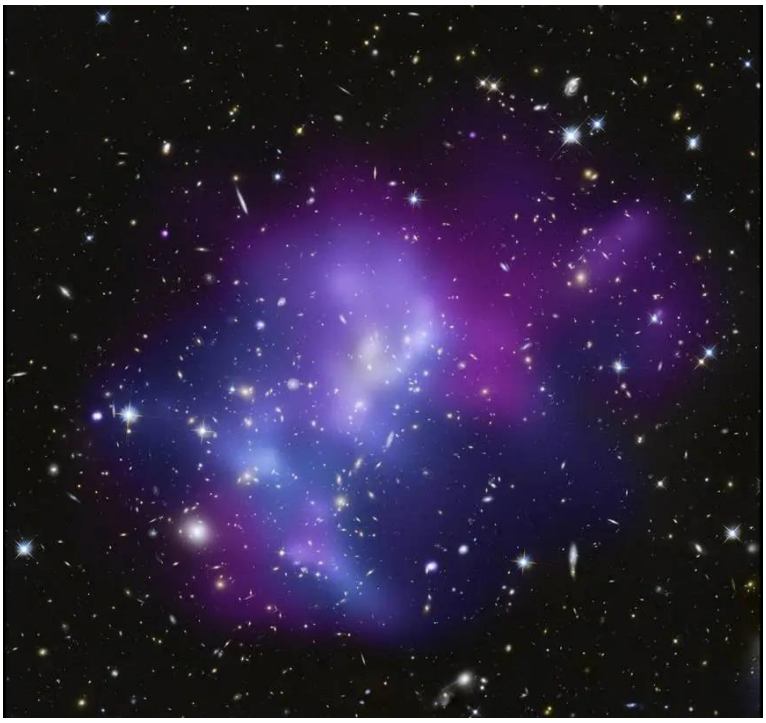
Large-scale structures of the Universe

Bottom left: Distribution of galaxies in the local Universe produced by the SDSS, an astronomical survey project that aims map 25% of the sky and collect data on more than a hundred million celestial objects. Each dot represents the location of a galaxy, and the colour represents their luminosity: the brightest are red, the least luminous are blue. Galaxies outline the large-scale structures as alignments along intergalactic filaments.
Bottom right: Galaxy cluster Abell 1689, located at 2.2 × 10^9 ly, is made up of several thousand galaxies.



Credit: M. Blanton/The Sloan Digital Sky Survey, NASA/N. Benitez (JHU)/T. Broadhurst (The Hebrew University)/H. Ford (JHU)/M. Clampin (STScI)/G. Hartig (STScI)/G. Illingworth (UCO/Lick Observatory)/The ACS Science Team/ESA

ray study of galaxy clusters enables us to estimate their temperatures, and, therefore, to determine their masses and follow their evolution at different times in the Universe's history.



Credit: X-ray image, NASA/CXC/IfA/C. Ma et al.; optical image, NASA/STScI/IfA/C. Ma et al.

The image on the right shows a galaxy cluster forming from the merger of smaller clusters. This merger took place along an intergalactic filament and, in the process, the gas temperature increased due to the clusters colliding. By measuring the temperature of the hot gas in a large number of galaxy clusters after such mergers occurred, we can determine the total masses of the clusters, since mass is responsible for heating the gas. Thus, it has been found that the total mass of a cluster is 5 to 10 times greater than that of all the matter capable of radiating, both that contained in all the galaxies in the cluster and that of the gas spread between them. Within galaxy clusters, most matter is thus likely to exist in another form – dark matter.

A galaxy cluster

Composite image of galaxy cluster MACSJ0717.5+3745, located at 5.4 × 10^9 ly. The diffuse X-ray radiation observed by the Chandra satellite comes from intracluster gas heated up to 2 × 10^8 K. The colour varies according to the gas temperature, from red (colder) to blue (hotter).

The study of galaxy clusters as a population also makes it possible to track the rate at which they have formed over time. This is a direct result of parameters such as the density of matter in the Universe (ordinary matter and dark matter) or that of dark energy. By examining galaxy clusters alone, we can therefore define a possible range for the parameters governing the overall history of the Universe's expansion. Complemented by other approaches, such as the primordial fluctuations of the Universe, studies of galaxy clusters provide a scenario for the evolution of the Universe on very large scales.

Translated from 'Les amas de galaxies',* Passeport pour les deux infinis, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG