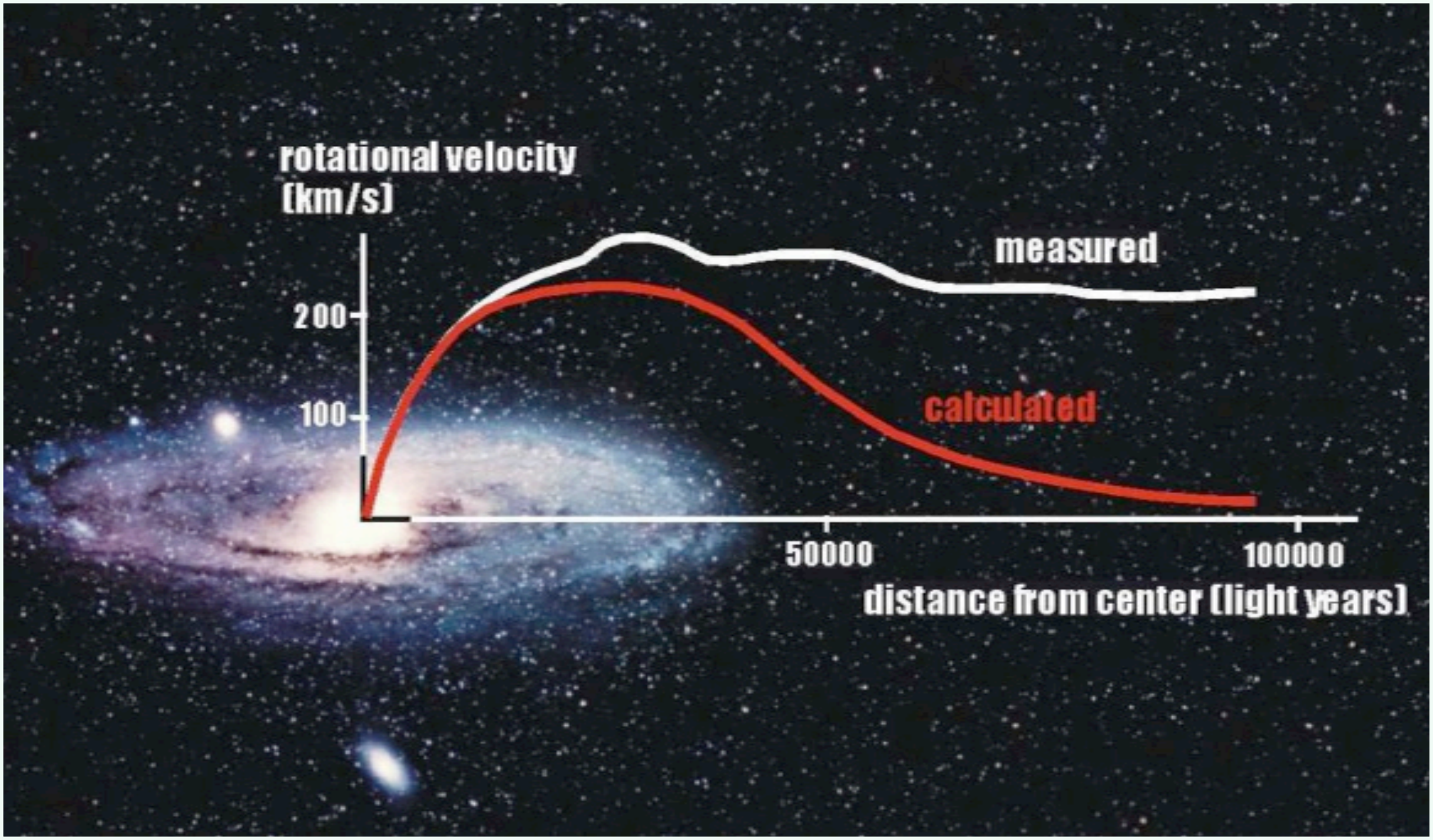
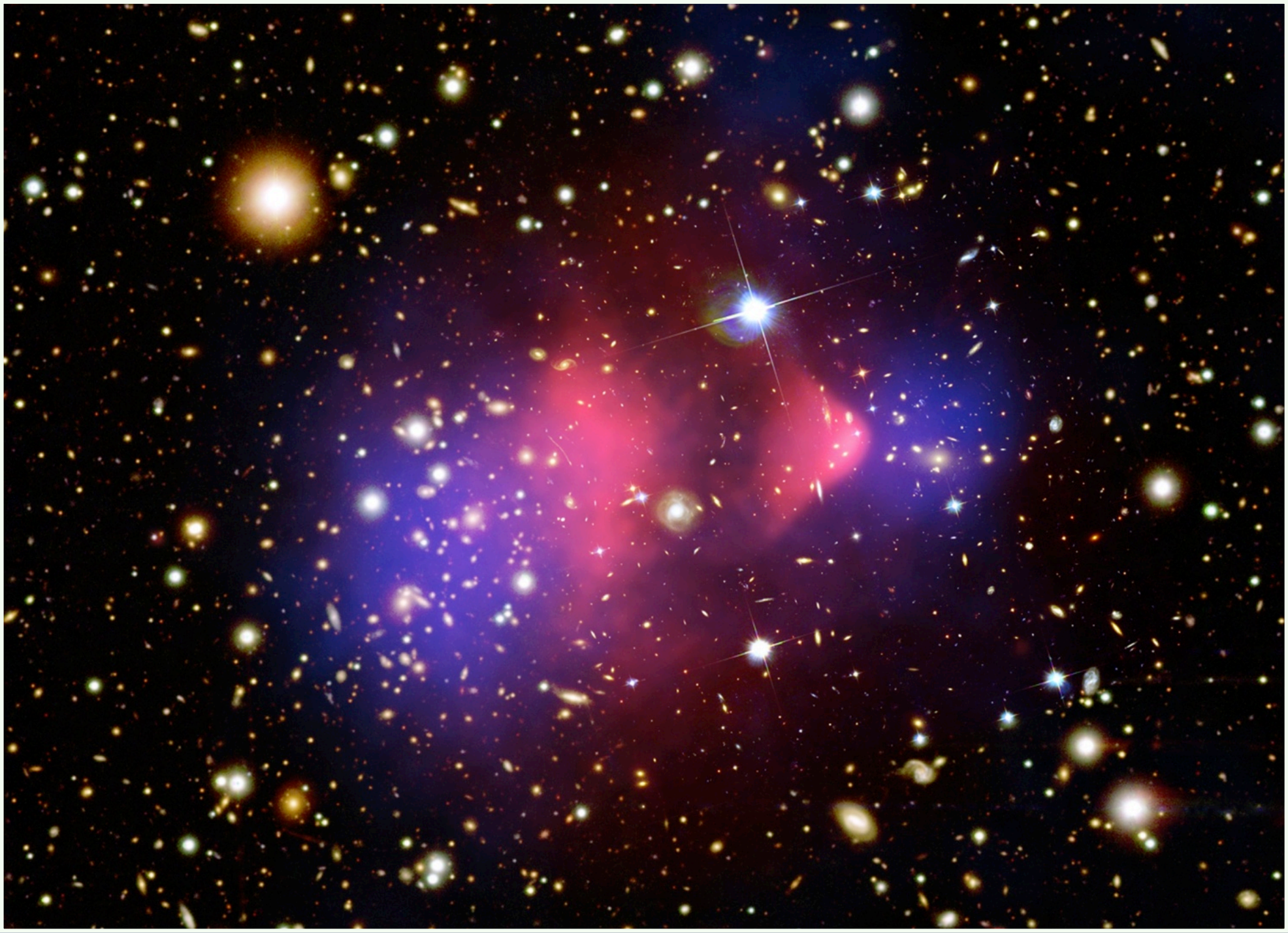
Dark Matter

The missing mass in the universe

Matter represents around 30% of the energy density in the universe. Out of this, most of the matter (around 85%) is dark, as it neither emits nor absorbs light, and its nature remain unknown

Evidence and Motivation





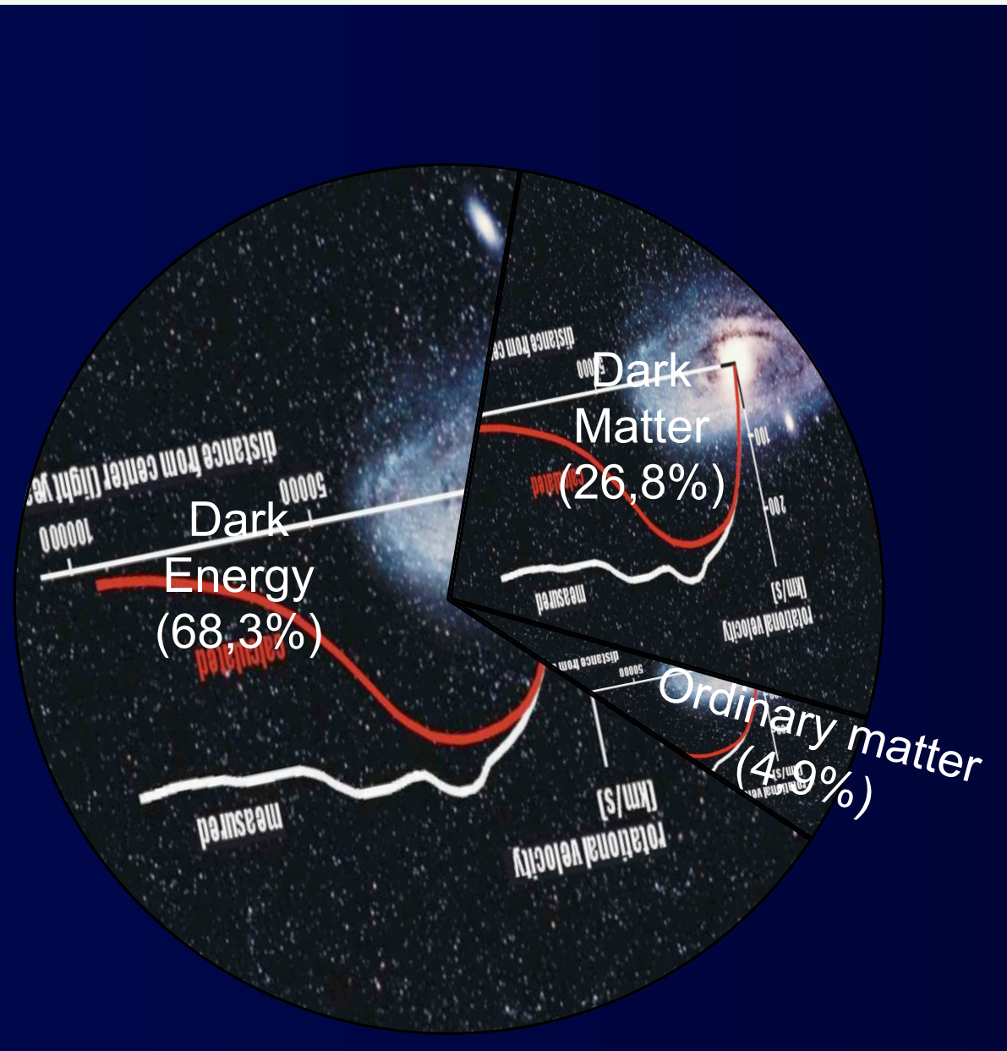
Gravitational lensing

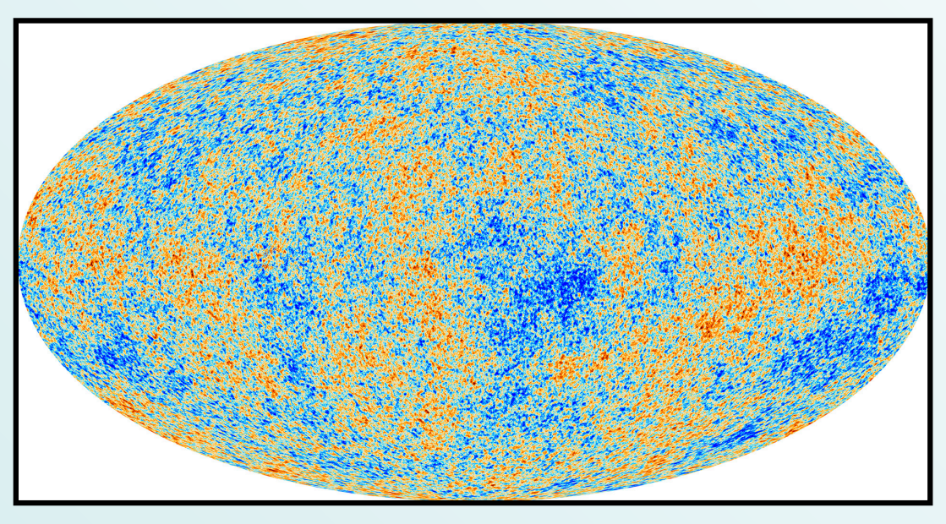
General Relativity explains that trajectories of light bend in gravitational fields. Hence, if there is a very massive object between a distant light source and us, the observed image is distorted into arcs around the mass distribution. This allows to measure the amount of intermediate mass, which often is larger than that measured by other methods. An example is the **Bullet Cluster** (left image), where the mass measured from gravitational lensing (false blue) is larger than that measured using X-ray emission (false red). This is consistent with two colliding clusters of galaxies, in which ordinary matter (red) smashes and emits X-rays upon heating, while dark matter halos (blue) are non-interacting and pass through each other.

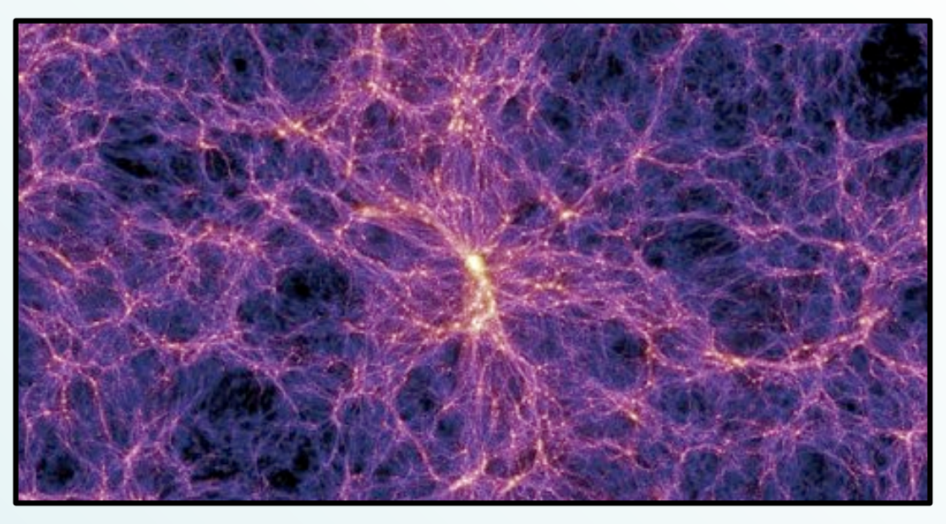
Dark matter in our galaxy?

The dynamics of spiral galaxies like the Milky Way can be studied using Newton's law, which provides the **rotation curves** (figure above). The theoretical prediction for such curves is that linear speeds should decrease beyond a value associated to the size of the visible disk of stars in the galaxy. The observational data however show that rotation curves stay approximately constant to very large distances. This suggests the existence of a distribution of extra gravitating matter which had not been accounted for.

Such studies suggest that visible galaxyes are immersed in **Dark Matter halos**, carrying far more matter than meets the eye.







Cosmic Microwave Background and Large Structure Formation

The Cosmic Microwave Background brings us the information about the time of **decoupling of matter and radiation** (when the universe was some 380.000 years old), after which ordinary matter started to clump down and form **structures**. This radiation filling the universe has a black body spectrum with temperature 2,7K. Its inhomogeneities signal density contrasts at those times, which produced gravitational clumping to form small structures. However, simulations assuming only the visible matter content show that **ordinary matter would have had no time to form large structures as we see in our universe today**. Therefore, the universe as we know it requires a component of matter density not interacting with radiation and which hence could have started gravitational clumping and structure formation at a much earlier stage.

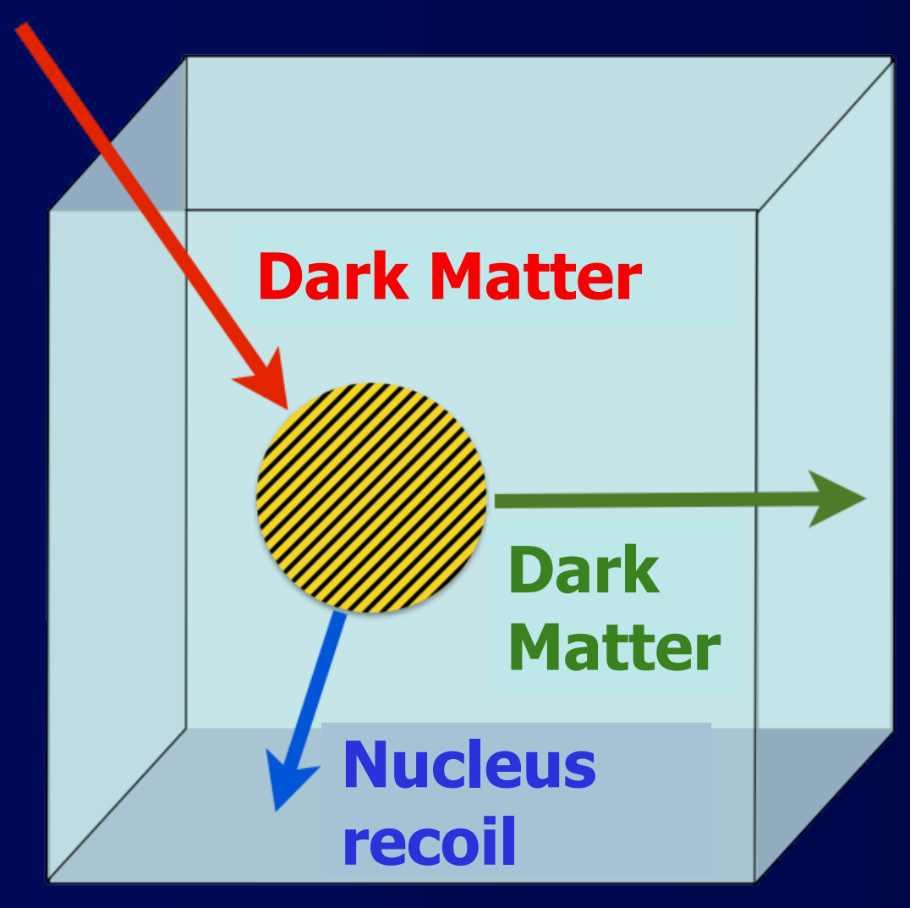
Looking for Dark Matter particles...

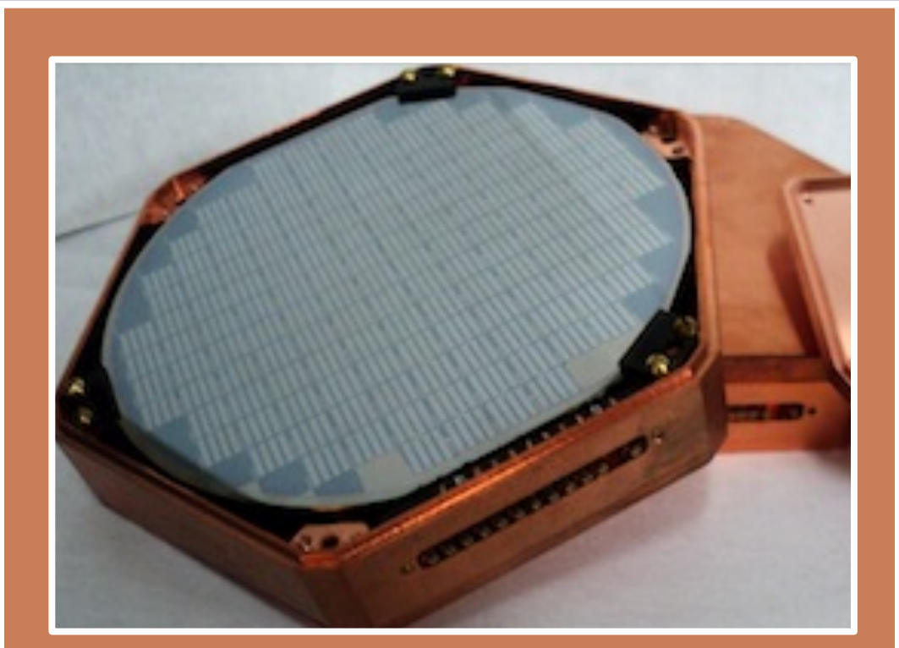
Indirect Detection

Particles of dark matter in the universe may **decay**, or collide and **annihilate**, into Standard Model particles. The later can reach Earth and be detected. Indirect detection experiments try to observe such particles, specially **photons, neutrinos or antimatter**, which would provide information about the nature of dark matter. Some of the indirect detection experiments are IceCube, Antares, and Fermi-LAT and the forthcoming CTA, in which the IFT participates.

Direct Detection

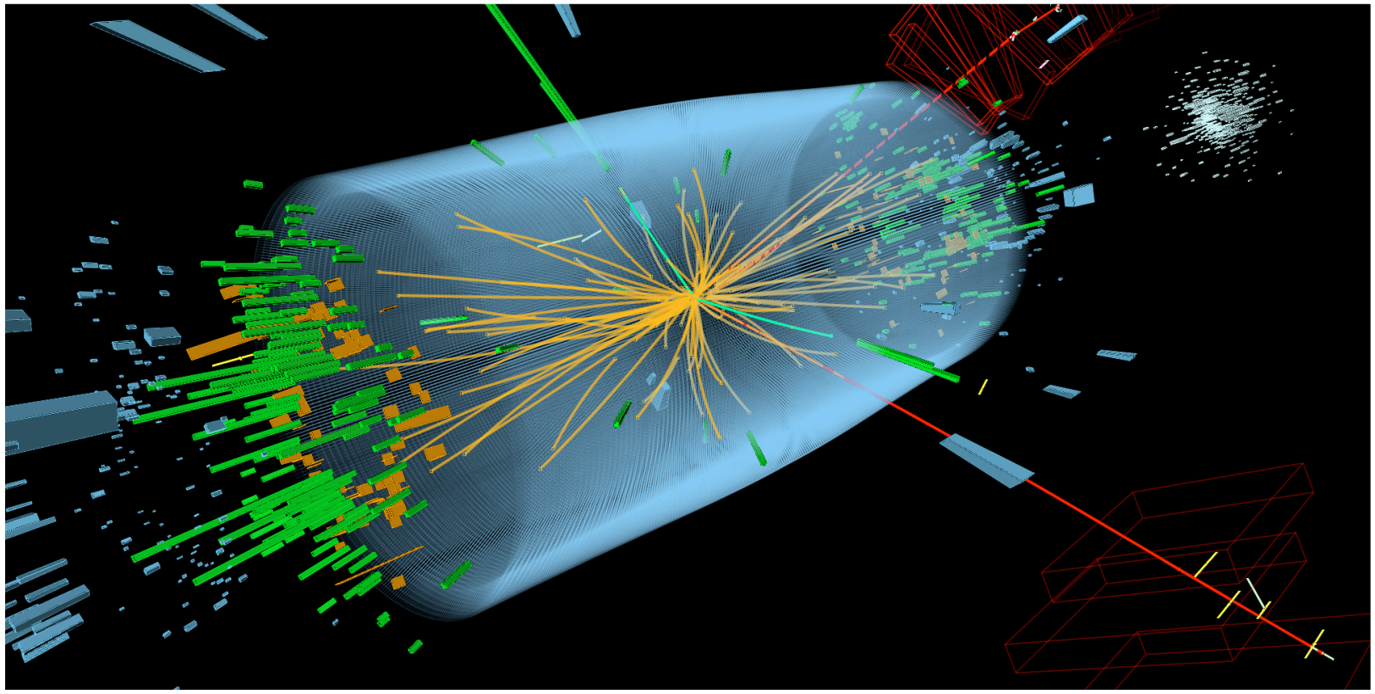
We are continuously receiving a flux of particles from the universe, part of which may correspond to dark matter particles. Direct detection experiments try to observe the **recoil of nuclei in the detector** caused by **elastic collisions** of dark matter particles from the universe. To suppress the background of collisions from **cosmic rays**, they are filtered out by locating these experiments deep underground. They are moreover surrounded by several layers of material specifically designed to absorb most such background particles.
The Cryogenic Dark Matter Search (CDMS) experiment, in which the IFT participates, uses Germanium crystals at cryogenic temperatures to search for dark matter.





Detectors in the CDMS experiment

Colliders



The search for dark matter particles at particle colliders is a difficult one, since they carry no electric charge and leave no track in detectors. Nevertheless, there are efficient techniques to identify candidate events by searching for **missing energy**, for instance in production together with a jet, or in production as endpoint of cascades of decays of heavier particles, as in many supersymmetric models.

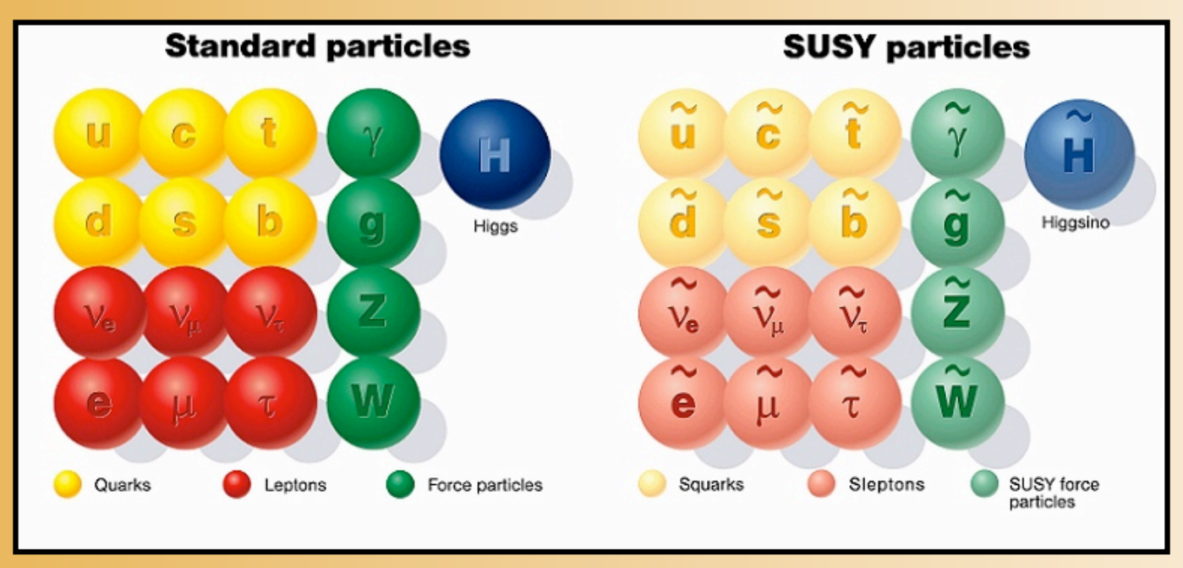
... and proposing theoretical models

Supersymmetry

Supersymmetry proposes that each particle of the Standard Model should have a partner particle, with same charges, different spin, and much heavier mass.

In most supersymmetric models, the **Lightest Supersymmetric Particle (LSP)**, usually the neutralino or the sneutrino, is stable and provides a good candidate to explain cosmological dark matter.

In addition, supersymmtry is well-motivated as a solution to the hierarchy problem for the **Higgs boson mass**, and is ubiquitous in fundamental theories like **string theory models**.

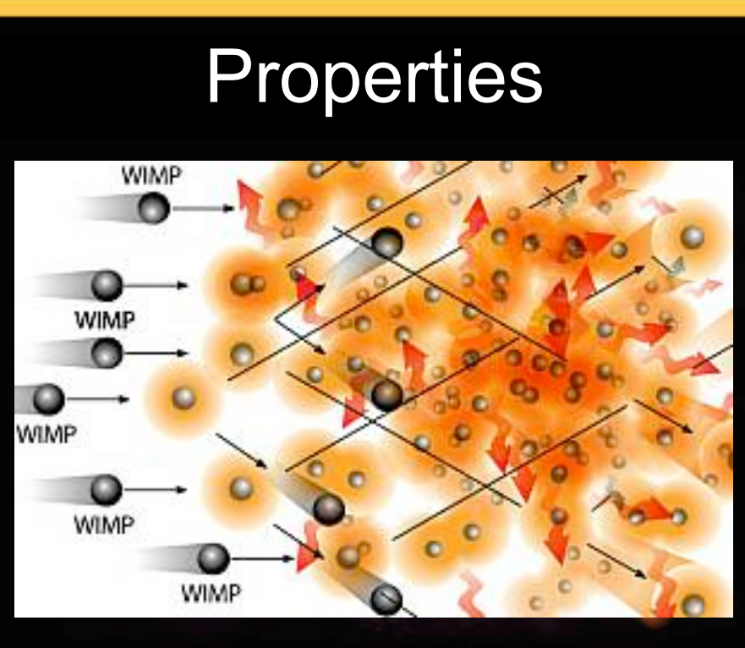


Axions

Axions are particles providing a plausible extension of the Standard Model, as they solve its **strong CP problem**. They are also good candidates for dark matter, with the peculiarity of **not having been in thermal equilibrium**, in contrast with most dark matter candidates. The axion mass range is fairly flexible, although certain mass ranges have been excluded by observational data.

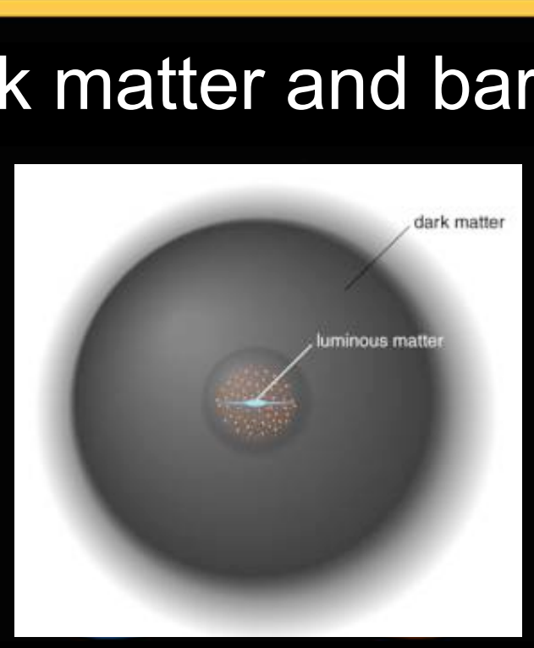
Open puzzles

Properties



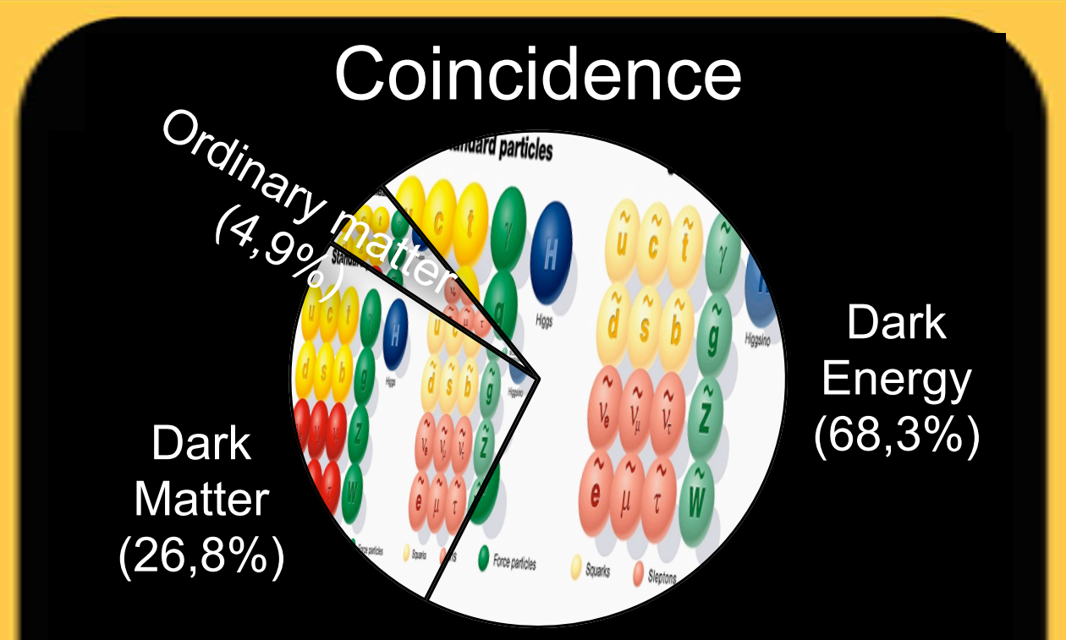
The true nature of dark matter remains unknown. For instance, what is the dark matter particle mass? Experiments keep on exploring its parameter space, excluding large chunks to pin down these properties.

Dark matter and baryons



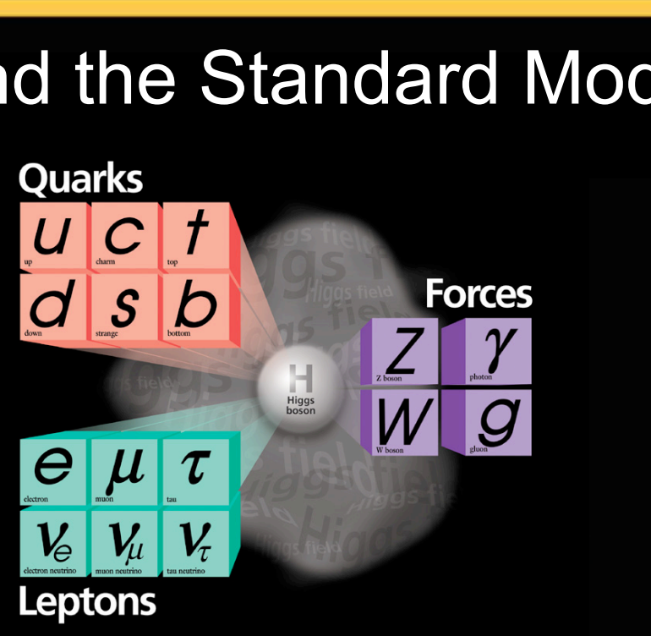
Model for dark matter halos in galaxies are still far from accurate. What is the density distribution? what is the halo size? More in general, understanding the interplay between baryonic matter and dark matter at different scales remains an exciting challenge.

Coincidence



The densities of dark matter and visible matter are comparable, a surprising fact given their very different production mechanisms. Is this coincidence the reflection of an unknown common physical origin?

Beyond the Standard Model



No particle in the Standard Model is a good candidate for dark matter, hence we should look beyond. Is dark matter a key to understand New Physics at the electroweak scale?