New constraints on dark matter with the Hubble Space Telescope

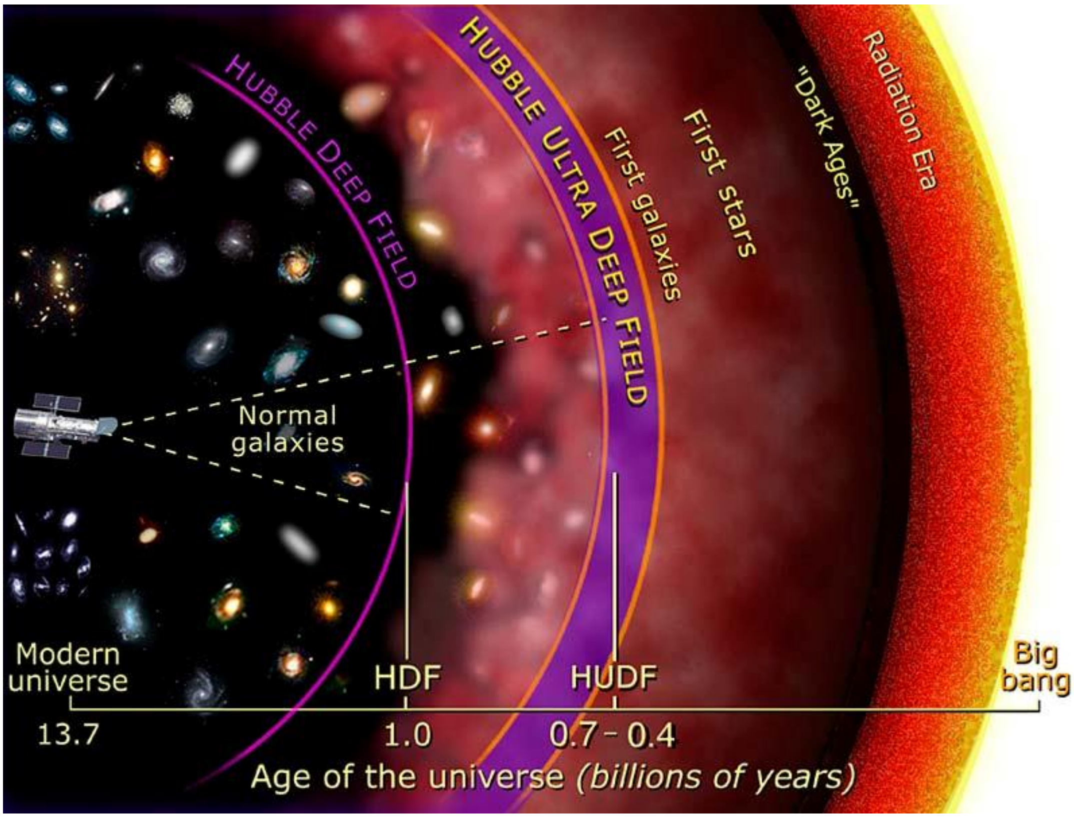
In an article recently published in *The Astrophysical Journal Letters* scientists from the Paris Observatory and the Astronomical Observatory of Rome-INAF, Italy, have developed new methods to constrain the nature of dark matter by using the observations of distant galaxies of the Hubble space telescope. This is the first time that such stringent constraints are obtained. These results pave the way for what could be unveiled for dark matter by the upcoming James Webb Space Telescope.

Galaxy clusters are one of the objects observed especially with the Hubble Space Telescope Deep Field. The gravity force of these clusters distorts and magnifies the light from the distant galaxies. Hubble captures the light thus amplified revealing the distant galaxies and gives us a glimpse of what might be revealed by the next space telescope James Webb.

Figure 1: Deep Hubble Space Telescope image of the massive galaxy cluster Abell 2744.

Massive clusters of galaxies distort and amplify light from galaxies that lie behind them and thereby act as lenses because of the effect of gravity: This phenomenon called "gravitational lensing" allows the Hubble telescope to see distant galaxies that would otherwise be too small and too weak to observe. These enlarged images allow to know the density, number and distribution of distant galaxies that are the first to form, and this allows to study the dark matter that constitutes the major part of these galaxies.

Dark matter forms the major part (81%) of the mass of the Universe. It is different from ordinary visible matter formed by atoms and manifests itself mainly through the action of gravity; dark matter is one of the essential components of galaxies. In such proportions, dark matter and gravity play a decisive role in the formation and structure of galaxies.



Recently, the deep field observations of the cluster Abell 2744 and 0416 MACS were used to observe distant galaxies with ultra-faint magnitudes in the epochs between 600 million years after the Big Bang and 900 years after the big bang (corresponding to a red shift z between 10 and 6). Such measurements provided constraints on these stages of the evolution of the universe, of star formation and on the process involving ordinary matter in distant galaxies.

However, the power of these observations to constrain the nature of dark matter had not been used before. This was the task that has recently accomplished the scientific team collaboration from Rome Observatory and Paris Observatory (see Reference here below). The team shows that these observations provide an unprecedented opportunity to obtain robust constraints on the masses of the particles that make up dark matter. Using these observations, the team combined expertise in theory and analytical and numerical calculations to robustly constrain and discriminate dark matter candidates *independently of the processes involving ordinary matter in galaxy formation.* Comparing the computed predictions by the team with the observed abundance of ultra-faint galaxies, very stringent constraints were obtained. These are the stringentest constraints obtained from the counting of galaxies.

Dark matter and "sterile" neutrinos

In particular, the high density of galaxies observed at the time z å 6 (900 million years after the Big Bang) has a very important impact on galaxy formation models especially for dark matter particle candidates with masses of the order of thousand electron volts (a kilo eV or keV, corresponding to 10^{-36} gr, for comparison an electron has a mass of 511 keV). Dark matter composed of particles with masses of the order of keV is called "warm" as opposed to the so-called ñcoldò dark matter in which the particles are much heavier and slower.

The most studied candidate of the warm dark matter are hypothetical neutrinos called "sterile neutrinos". The sterile term is used to distinguish it from the known active neutrino of the Standard Model of elementary particles that has an electric charge and interacts by the weak interaction. Sterile neutrinos do not interact (or interact negligeably) with the particles of the Standard Model (hence the name "sterile"), they interact only through the gravitational interaction. [And they can decay through the usual quantum mechanical radiative process into active neutrinos].

The mass of the dark matter particle determines the initial spectrum of density structures, which produces through non linear evolution the formation of the cosmic structures. Thus, the different spectra are labeled according to the mass of the particles, there is a correspondence between these spectra and the particle mass.

By comparing the measured abundance of galaxies with the calculated abundance allow to distinguish the dark matter candidates: The warm dark matter model is the one that best matches the observations and the team found that the lower bound for the reference mass of the warm dark matter particles (thermal relics) is m Ó2.1 keV with a 3ů confidence level and m Ó2.4 keV with 2ů confidence level. These constraints in turn translate on the mass of the sterile neutrino candidates.

The corresponding constraints for the mass of the sterile neutrinos depend on the production mechanism of these neutrinos, and in all the studied cases, for the more known mechanisms, these contraints place the masses of the dark matter sterile neutrinos in the interval between 6 keV and 10 keV.

In the future, these results can be further improved through a higher statistics in the Hubble Deep Field (passing from the 167 galaxies used in this study to 450 galaxies at z ~ 6). These results can be further combined with the observations of clusters and galaxies in the X-ray domain, and they pave the way for what could be unveiled for dark matter by the successor to Hubble, the James Webb Space Telescope, whose launch is expected in 2018 .

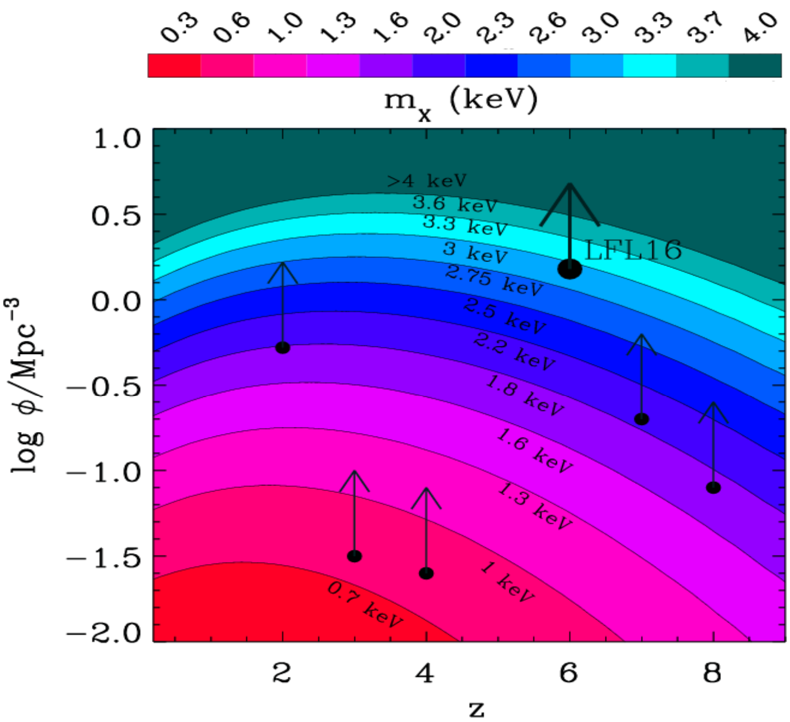


Figure 2. The curves show the maximum density of galaxies (vertical axis) calculated for different values of the mass m of the dark matter particles shown in different colors, (for the reference or thermal particles) and as a function of the different times (in the horizontal axis designated by the different "redshifts" z). These abundances are compared with the observations to obtain constraints on the reference mass m of the dark matter particles, the strongest constraint being the obtained in this paper with the recent observations at z = 6 (indicated with the largest black circle, the other black circles indicate the previous limits).

Reference:

A Stringent Limit on the Warm Dark Matter Particle Masses from the Abundance of z = 6 Galaxies in the Hubble Frontier Fields

N. Menci, A. Grazian, M. Castellano, N. G. Sanchez.

The Astrophysical Journal Letters, Volume 825, Issue 1, article id. L1, pp. (2016).

To know more:

Constraining the Warm Dark Matter Particle Mass through Ultra-deep UV Luminosity Functions at z=2
N. Menci, N.G. Sanchez, M. Castellano, A. Grazian,
The Astrophysical Journal 818, 90 (2016)