Large scale structure and dark energy

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Chapter 1

Introduction

The standard cosmological model starts with Big Bang, followed by a rapid period of expansion of the universe called inflation. After that, tiny almost homogeneous fluctuations that conform the primordial universe, start to grow while universe expands now in a relatively slow rhythm. 380,000 years after the Big Bang, the temperature is low enough to make the universe become neutral after the recombination of atoms with electrons. Photons are almost free of interactions since then and reach us in the form of a Cosmic Microwave Background (CMB). We can measure the spatial anisotropy spectrum of CMB temperatures and compare it to the expected spectrum of acoustic oscillations. This comparison provides a direct geometrical test from which we can deduce that universe is flat or nearly flat. This can be explained if we introduce a new constituent in the universe apart from matter, the dark energy. Dark energy acts as anti-gravity that accelerates the expansion and is also observed through standard candles Supernovae Ia. Although there is a well motivated model that can explain observations, neither dark matter nor dark energy are known elements, so it is important to use the large amount of newly available data to obtain tighter constraints on the constituents of the universe, the evolution of growth perturbations, the expansion history, and also other alternatives, such as modification of gravity at large scales.

The cosmic expansion history tests the dynamics of the global evolution of the universe and its energy density contents, while the cosmic growth history tests the evolution of the inhomogeneous part of the energy density. By comparing both histories, we can distinguish the nature of the physics responsible of the acceleration of the universe: dark energy or modified gravity. Most of the observational evidence for the accelerating universe comes from geometrical tests that measure directly $H(z) = \dot{a}/a$, the expansion rate of the universe, such as measurements of the luminosity distance using standard candles (Sn Ia) or measurements of the angular distance using standard rulers as baryonic acoustic oscillations. Observations of the cosmic expansion history alone can not distinguish dark energy from modified gravity, since the expansion history H(z) can be reproduced by any modified gravity model, by changing the energy equation of state w. The additional observational input that is required is the growth function $\delta(z) = \frac{\delta\rho}{\rho}(z)$ of the linear matter density contrast as a function of redshift (usually used as the normalized growth function $D(z) = \delta(z)/\delta(0)$) (see Chapter 8.6).

In the first part of the thesis, we study the Integrated Sachs-Wolfe effect (ISW), through the cross-correlation between large scale clustering, traced by galaxies (in our case from the catalog SDSS) and primordial temperature fluctuations from CMB (using the catalog WMAP). Photons that come from the last scattering surface can be red or blue shifted by the time evolution of fluctuations in the gravitational potentials created by large scale structures, which are traced by the large scale galaxy distribution. The ISW effect gives us information about dark energy (DE), because DE modifies the evolution of dark matter gravitational potential. There is no ISW effect in a flat universe without DE (ie in the Einstein-de-Sitter universe) because in this case the gravitational potential remains constant (in the linear regime, which corresponds to large angular scales). In principle, the ISW effect can probe dark energy independently from other observations, such as Supernovae Ia.

The correlation between galaxies in redshift space can also be used to study the evolution of the dark matter gravitational potential in a way that is complementary to the cross-correlation of galaxies with CMB photons. In the second part of the thesis, we will study this effect in the luminous red galaxies of the SDSS. These galaxies trace very large volumes which is important to have more signal, and they have a known evolution which make easy to work with them.

Finally, the third part of the thesis is a summary in catalan, an official language of the University of Barcelona.