Inhomogeneous models of universe : an alternative to dark energy

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Since the beginning of modern cosmology using the theory of general relativity, the only models used to describe the geometry and dynamics of the Universe are spatially homogeneous. Large scale structure formation was obtained by linear perturbation of these models, which implied the hypotheses that density fluctuations and curvature are very small, hence the difficulty to form structures sufficiently rapidly. In the era of "precision" cosmology, the homogeneity assumption—which was used successfully to develop the bases of cosmology—must be considered as a zero order approximation while linear perturbation theory must be considered as a first order approximation. To go further on the influence of the inhomogeneities observed at all scales can no more be ignored, and we must begin with the larger scales. The use of inhomogeneous solutions of general relativity has therefore become unavoidable. In this fastly expanding field, a researcher of Paris Observatory, collaborating with two Polish researchers and one researcher from South Africa, has obtained fairly interesting results.

The problems of the homogeneous cosmological models

The equations of general relativity are such involved that few exact analytical solutions usable in cosmology or astrophysics are known. This is one of the reasons which contributed to the past and current success of the simplest model, the homogeneous model. Its main drawback is that 95% of the content of the Universe is unexplained. To make this so-called "concordance" model compatible with the cosmological data, more than 20% of dark matter and 75% of dark energy have been injected in it. However, the nature and properties of these new components are unknown in physics and they have been observed neither in laboratory experiments nor in the Universe. When the first observations of the light curves of remote type Ia supernovae were made, more than ten years ago, and when their interpretation in an homogeneous framework gave rise to the notion of dark energy, other proposals were made to explain these observations. The effect of the inhomogeneities was one of them.

The first inhomogeneous models

The first inhomogeneous models used to solve this problem were spherically symmetrical. Some among them were able to reproduce several cosmological data sets as well as or even better than the "concordance" model, without any need for dark energy. But, of course, they could only consider radial inhomogeneities.

Swiss-cheese models

New more realistic Swiss-cheese-type models have been used afterwards. But their "holes" were also spherically symmetric which made them rather unphysical and prevented them to solve efficiently the dark energy problem. The models which appear the best adapted to solve this problem are Swiss-cheeses whose "holes" have no symmetry at all. An exact solution of general relativity able to model such "holes" exists, but it is much more difficult to implement because of its complexity. It is currently developed by a team composed of a researcher from the LUTH, two researchers from the N. Copernicus Astronomical Center (Warsaw) and one researcher from Cape Town University.
Inhomogeneous models and structure formation

Homogeneous standard models are known to struggle with forming sufficiently rapidly the observed structures. This is the reason why dark matter must be added to accelerate the formation process. The team has shown recently that rather simple inhomogeneous models can enhance up to 8 times the speed of structure formation. Double or triple density distributions where, initially, under-dense regions are close to very small over-densities evolve very rapidly to form structures composed of voids and filaments analogous to those currently observed (see the figure).

These works, as well as other original results, are developed in a book written in collaboration which has just been published.