Observational tests of an inhomogeneous cosmology

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Abstract

One of the biggest mysteries in cosmology is Dark Energy, which is required to explain the accelerated expansion of the universe within the standard model. But maybe one can explain the observations without introducing new physics, by simply taking one step back and re-examining one of the basic concepts of cosmology, homogeneity. In standard cosmology, it is assumed that the universe is homogeneous, but this is not true at small scales (a few 100 Mpc). Since general relativity, which is the basis of modern cosmology, is a non-linear theory, one can expect some backreactions in the case of an inhomogeneous matter distribution. Estimates of the magnitude of these backreactions (feedback) range from insignificant to being perfectly able to explain the accelerated expansion of the universe. In the end, the only way to be sure is to test predictions of inhomogeneous cosmological theories, such as timescape cosmology, against observational data. If these theories provide a valid description of the universe, one expects aside other effects, that there is a dependence of the Hubble parameter on the line of sight matter distribution. The redshift of a galaxy, which is located at a certain distance, is expected to be smaller if the environment in the line of sight is mainly high density (clusters), rather than mainly low density environment (voids). Here we present a test for this prediction using redshifts and fundamental plane distances of elliptical galaxies obtained from SDSS DR8 data. In order to get solid statistics, which can handle the uncertainties in the distance estimate and the natural scatter due to peculiar motions, one has to systematically study a very large number of galaxies. Therefore, the SDSS forms a perfect basis for testing timescape cosmology and similar theories. The amazing preliminary results of this cosmological test are shown here.

Preliminary results

At the moment

Using the data and models, that are currently available to us, we already managed to obtain some impressive preliminary results. At the moment we consider:

- **34000 elliptical galaxies** (within a redshift-interval of [0.01,0.1])
- distances obtained using the fundamental plane
- onlz **SDSS data** (+GalaxyZoo for classifications)
- foreground model based on an extended version of the Yang et al 2008 catalogue

The main issues with our preliminary results are:

- no foreground model below a redshift of 0.01 yet
- the simulated results to which we compare them assume perfect knowledge of the matter distribution
- the statistical analysis of the results is still very simple
- normalisation issues when comparing two different cosmologies

Our calculations are simple from a mathematical point of view (intersecting a straight line (of sight) with a bunch of spheres (the foreground model) and doing some interval nesting (the spheres might overlap) afterwards), we have to do them many (34000×155000) times. Because this is computationally very expensive, we have to use the **AstroCluster** in Vienna to perform our calculations.

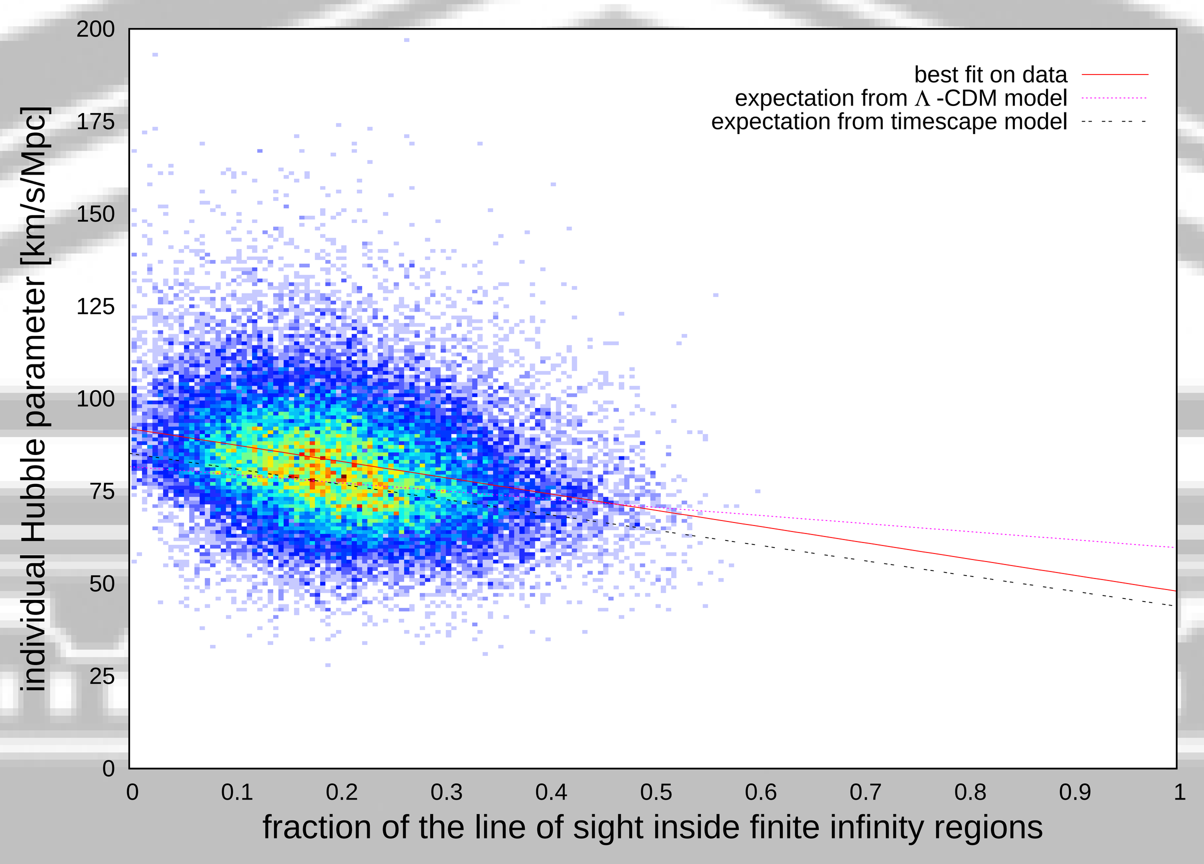

FIGURE 1: Our preliminary results based on real data. The inclination of our best fit tends to favour timescape cosmology at the moment. However, there are still several open issues with our model, which have to be addressed first before drawing any conclusions.

In the future

We want to improve our results by:

- using distances of clusters than individual galaxies
- completing the foreground model using NED
- using better estimates of the mass distribution in the foreground
- applying more advanced statistical methods to distinguish between Λ-CDM and timescape cosmology
- considering uncertainties in the foreground model for the simulations

Our test does not require any additional observation because all the necessary data can be found in archives.

Additional scientific results:

- new calibrations of the **fundamental plane** (published)
- improved model of **mass distribution** in the local universe
- **peculiar velocities**

In the end, we hope to learn if the dark energy is really necessary to explain to accelerated expansion of the universe or if it just is "the greatest blunder" of our time. **Testing timescape cosmology** is an important step on this way.

Theoretical motivation

Timescape cosmology

The general idea of inhomogeneous cosmology has been around for a very long time (Tolman,1934 and Bondi,1947). During the last 15 years significant advances were made on this initial very exotic field, mainly due to the work of Buchert (1997, 2000, 2002, 2003, 2011), Räsänen (2004, 2006, 2009, 2011), Wiltshire (2007, 2008, 2009, 2010, 2011, 2012) and others. The basic assumption is that since **general relativity** is a non-linear theory, **inhomogeneities** like voids and cluster can cause some **backreactions** (feedback), which may explain the observed accelerated expansion of the universe. To fully understand it a simple pertubative approach alone (Räsänen, 2006; Kolb et al., 2006; Ishibashi and Wald, 2006) is not sufficient. Therefore, Wiltshire (2007) developed a very sophisticated model of an inhomogeneous cosmology, which can mimic dark energy. It is called "timescape cosmology". He uses a simple two-phase model consisting of a **Swiss-cheese** distribution of **empty voids** and **dense walls** (clusters and filaments). Both regions are separated by the **finite infinity boundary** (see Fig.1), which encloses gravitationally bound regions and disconnects them from the freely expanding voids.

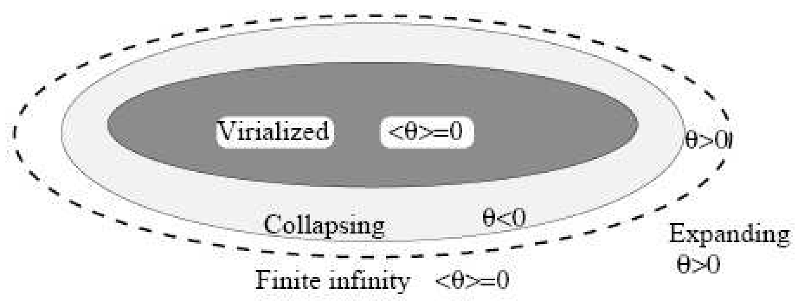

FIGURE 2: A schematic illustration of the concept of finite infinity (by David Wiltshire, 2007).

In this model, a backreaction also causes significant differences in the time flow, due to effects of quasilocal gravitational energy: the universe in the middle of a void is older than in the centre of a cluster. As a consequence of the importance of the local geometry in this model, the Hubble flow is not uniform anymore and the empty voids expand faster than the dense walls. At large scales these **different expansion rates** will lead to the signature of an **overall accelerated expansion** of the universe, because in timescape cosmology the fraction of the volume occupied by voids constantly increases with time. According to Wiltshire, the dynamics of this Swiss-cheese model can be described by following equations:

$$\left(\frac{\dot{\bar{a}}}{\bar{a}}\right)^2 + \frac{\dot{f}_v^2}{9f_v(1-f_v)} - \frac{\alpha^2 f_v^{\frac{1}{3}}}{\bar{a}^2} = \frac{8\pi G}{3}\bar{\rho}_0\frac{\bar{a}_0^3}{\bar{a}^3}$$

$$\ddot{f}_v + \frac{\dot{f}_v^2(2f_v-1)}{2f_v(1-f_v)} + 3\frac{\dot{\bar{a}}}{\bar{a}}\dot{f}_v - \frac{3\alpha^2 f_v^{\frac{1}{3}}(1-f_v)}{2\bar{a}^2} = 0$$

The variable f_v denotes the volume fraction of voids in the universe, $\bar{a}$ is the scale factor and $\bar{\rho}_0$ denotes the renormalised critical density in this theory. Despite the elegance of this theory, the magnitude of these backreactions and their influence on cosmology is topic of hot discussion, with estimates on their significance from negligible to extremely important (Marra & Pääkkönen, 2010; Mattsson & Mattsson, 2010; Kwan et al., 2009; Clarkson et al., 2009; Paranjape, 2009; van den Hoogen, 2010). In the end, only a test of theory's predictions can provide an answer.

A more detail description of timescape cosmology and the test, we want to perform, can be found in our proceeding paper from last year:

http://arxiv.org/abs/1211.1926

Predictions and simulations

Testable predictions

The most accessable and most direct test of timescape cosmology is to find a **correlation** between the **individual Hubble parameter** (the Hubble parameter measured for one galaxy or cluster) and the **matter distribution** (the fraction with finite infinite regions (wall enviroment)) in the **line of sight** (to that galaxy or cluster).

- can only be measured in the local universe (Schwarz, 2010)
- difference of 17 to 22 % (Wiltshire, 2011) in the expansion rate between voids and walls to explain the observed accelerated expansion.

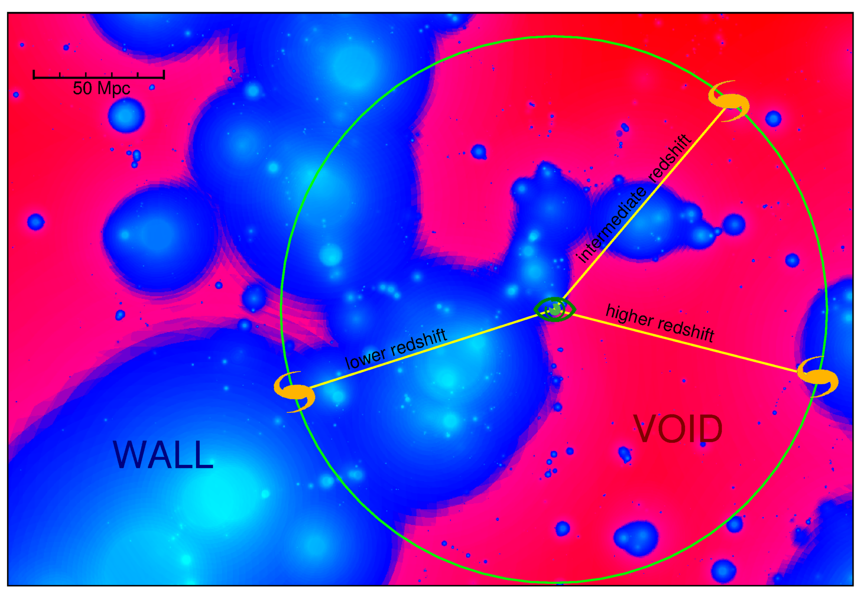

FIGURE 3: Redshift dependence on the line-of-sight matter distribution at a given distance. **Voids expand faster than walls.**

Simulations

To better qualify the expected correlation between the individual Hubble parameter and the fraction of the line sight within finite infinity regions (bound regions with an, on average, renormalised critical density), we used data from the **Millennium simulation**. One may naively assume that in the Λ-CDM model, there may be no correlation at all between the two parameters. However, one has to take account of biases due to the sample's selection and coherent infall into clusters. Assuming that the last snap-shot of the Millennium simulation provides a good representation of the present-day matter distribution in the universe, we introduce the effect of timescape cosmology artificially and compare the results for both cosmologies.

We **consider**:

- errors in the **redshift-measurement**
- **peculiar motions**
- the **Malmquist-bias**
- the selection of **elliptical galaxies only**
- uncertainties in the **distance measurement**

We do not yet consider:

- uncertainties in modelling the matter distribution from observations
- differences between extension of the finite infinite regions derived from the observed and the simulated matter distribution
- future enhancement in the distance measurement by using clusters instead of individual galaxies
- potential influence from the choice of the observer galaxy

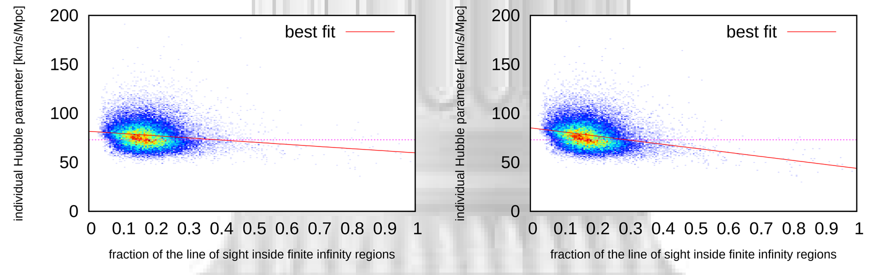

FIGURE 4: The **expectation** for the **Λ-CDM model** and **timescape cosmology** from simulated data. With an simple fit, one is already able distinguish between the two cosmologies. More sophisticated statistical methods will provide even better criteria.

Observational data

To perform the suggested test one needs:

- **redshift** data
- an **independent distance indicator**
- a large **homogeneous sample** covering a large area of the sky
- a model of the **mass distribution** in the local universe

Therefore, we use:

- the Sloan Digital Sky Survey (SDSS)
- GalaxyZoo (for galaxy classification)
- the NASA Extragalactic Database (NED)

The fundamental plane

$$\log_{10}(R_0) = a \cdot \log_{10}(\sigma_0) + b \cdot \log_{10}(I_0) + c$$

For practical reasons, we decided to use the fundamental plane of giant elliptical galaxies as our distance indicator.
It is a relation between:

- the physical radius R_0
- the central velocity dispersion σ_0
- the renormalised surface brightness $\log_{10}(I_0)$

Using the largest sample ever and the best available correction, we managed to achieve an accuracy in the **distance measurement** for individual galaxies of about **15%**.

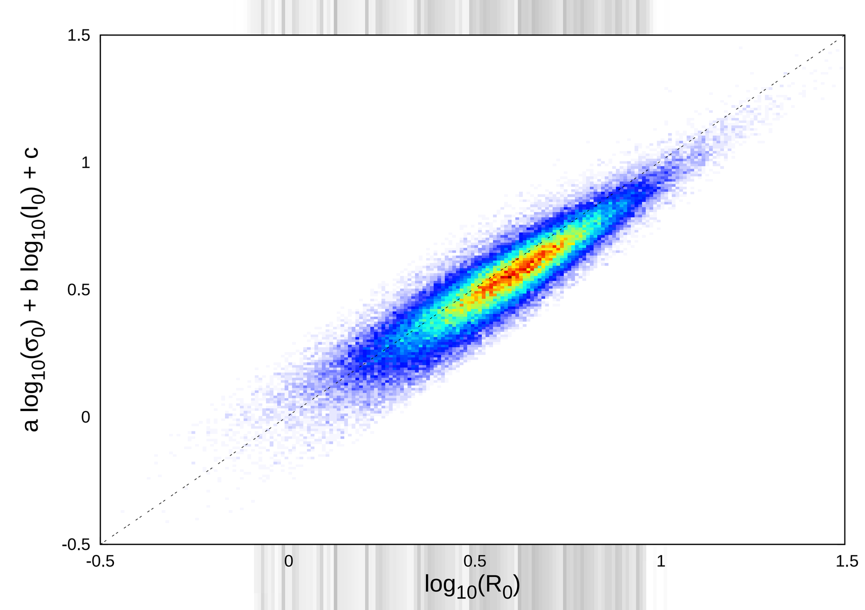

FIGURE 5: Our new calibration of the fundamental plane using about 93000 elliptical galaxies from SDSS DR8.

More details on our calibrations of the fundamental plane can be found in our recently accepted paper:

http://arxiv.org/abs/1306.0285

The foreground model

Since available SDSS-based catalogues of the mass distribution in the local universe are significantly more incomplete than claimed, we will build our own model using:

- **SDSS** DR8 redshifts
- **NED** (since SDSS is highly incomplete for redshifts lower than 0.01)
- a group finding algorithm (in development) bases on Eke et al., 2003
- **masses** derived from peculiar motions inside clusters
- masses from halo mass-luminosity relations (Yang et al., 2009)
- comparison with mock catalogues