Observational tests of an inhomogeneous cosmology

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A review of basic cosmology

- Cosmology \rightarrow \text{applied General Relativity}

- Einstein's field equation

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \]

- Cosmological principle:
  homogeneity and isotropy

- Friedmann-Lemaître-Robertson-Walker metric

\[ ds^2 = c^2 dt^2 - a(t)^2 \left[ dr^2 + f(r) \left[ d\theta^2 + \sin(\theta) d\varphi^2 \right] \right] \]
**Friedmann equations:**

\[
H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2} \rho - \frac{Kc^2}{a^2}
\]

\[
\dot{H} + H^2 = \frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2} (\rho + 3p)
\]

**Observed accelerated expansion due to Dark Energy?**

Written using energy densities:

\[
\frac{H^2}{H_0^2} = \Omega_r a^{-4} + \Omega_M a^{-3} + \Omega_K a^{-2} + \Omega_\Lambda
\]
Timescape cosmology

- The universe isn’t homogeneous
  - voids and clusters

- General relativity is a non-linear theory.

- The averaging on large scales has to be modified.

- Back reaction from inhomogeneities expected.
**Perturbative approach: Buchert’s scheme (Buchert 2000)**

\[
3 \left( \frac{\dot{a}}{a} \right)^2 = 8\pi G \langle \rho \rangle - \frac{1}{2} \langle R \rangle - \frac{1}{2} Q \\
3 \frac{\ddot{a}}{a} = -4\pi G \langle \rho \rangle + Q
\]

\[
\partial_t \langle \rho \rangle + 3 \frac{\dot{a}}{a} \langle \rho \rangle = 0 \\
Q = \frac{2}{3} \left( \langle \theta - \langle \theta \rangle \rangle^2 \right) - 2 \langle \sigma \rangle^2
\]

**Perturbation theory alone is not sufficient (Räsänen, 2006)**

**Importance of local metric, abolishing the universal time parameter in cosmology ➔ timescape cosmology (Wiltshire, 2007)**
- two phase model
- Separated by a finite infinity boundary
- Walls have a renormalized critical density
- Voids are empty
- We are in wall environment ➔ our observations of the global parameters of the universe have to be recalibrated
Nowadays the universe is dominated by voids.

Different expansion rates in different environments due to the local metric.

Voids expand faster than walls

\[ \dot{a}^2 + \frac{f_v^2}{9 f_v (1 - f_v)} - \frac{\alpha^2 f_v^{1/3}}{\bar{a}^2} = \frac{8\pi G}{3} \rho_0 \frac{\bar{a}_0^3}{\bar{a}^3} \]

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

Wiltshire, 2007
Observational features

- CMB-power spectrum, cosmic rays, ...
- Different Hubble parameters depending on the environment:
  - Void regions expand about 15-20% faster than wall regions
- Observed Hubble parameter should depend on the foreground (fraction of wall regions in the line of sight) (Schwarz 2010)
- Effect averages out at the scale of homogeneity
- optimal distance between 50 and 200 Mpc

- requires redshift and another independent distance indicator, like the fundamental plane

- lots of data required

- homogenous sample on a large area of the sky: e.g. elliptical galaxies from SDSS

- one also has to model the foreground
Data sources

- **Sloan Digital Sky Survey (SDSS) DR8**
  - Photometric data (model magnitudes and effective radii in 5 different filters and)
  - Extinction map (Schlegel et al. 1998)
  - Spectroscopic data (redshift, central velocity dispersion)

- **GalaxyZoo (SDSS-based citizen science project for galaxy classification - Lintott et al. 2008 & 2010)**

- **Masses from the (SDSS-based) catalog of groups and clusters by Yang et al., 2008**
Performing the test

- Recalibrating the fundamental plane
  - 70,000 elliptical galaxies from SDSS
  - classified by GalaxyZoo (+additional constraints)
  - redshift range \([0, 0.15]\)
  - using a new high quality K-correction (Chilingarian et al. 2010)
  - RMS in SDSS r-band <10%

\[
\log(R_0) = a \cdot \log(\sigma_{cor}) + b \cdot \log(I_0) + c
\]
Modeling the foreground

- Getting positions, redshift based distances of more than 350,000 galaxies from SDSS
- Masses from Yang et al. 2008 (SDSS DR4 based) or estimated from mass/light ratios
- Homogeneous spheres with a renormalized critical density

A part of the foreground model between 100 and 150 $h^{-1}$ Mpc
Finial analysis

- Calculate the “individual Hubble-parameters” of a quality selected sample of about 10 000 elliptical galaxies with $z < 0.1$ using the fundamental plane distances and the redshift from SDSS.

- Calculate fraction inside finite infinity region by intersecting the spheres with the line of sight to those galaxies.

- Compare them and make a plot.
Summary

- Using the fundamental plane to calculate distances
  - additional output: new coefficients for the fundamental plane
- Comparing distances and redshifts
  - additional output: peculiar motions
- The foreground model
  - additional output: masses of clusters and galaxies + peculiar motions
Testing timescape cosmology

First results look promising, but there still several open questions in our models.

Positive results would be a major discovery.

Intermediate results would favor Dark Energy theories with a Chameleon effect such as $f(R)$ modified gravity.

Negative results would support the $\Lambda$-CDM.

CAST LIGHT ON DARK ENERGY
ANY QUESTIONS?