Observational tests of an inhomogeneous cosmology

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A review of basic cosmology

- Cosmology ➔ 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

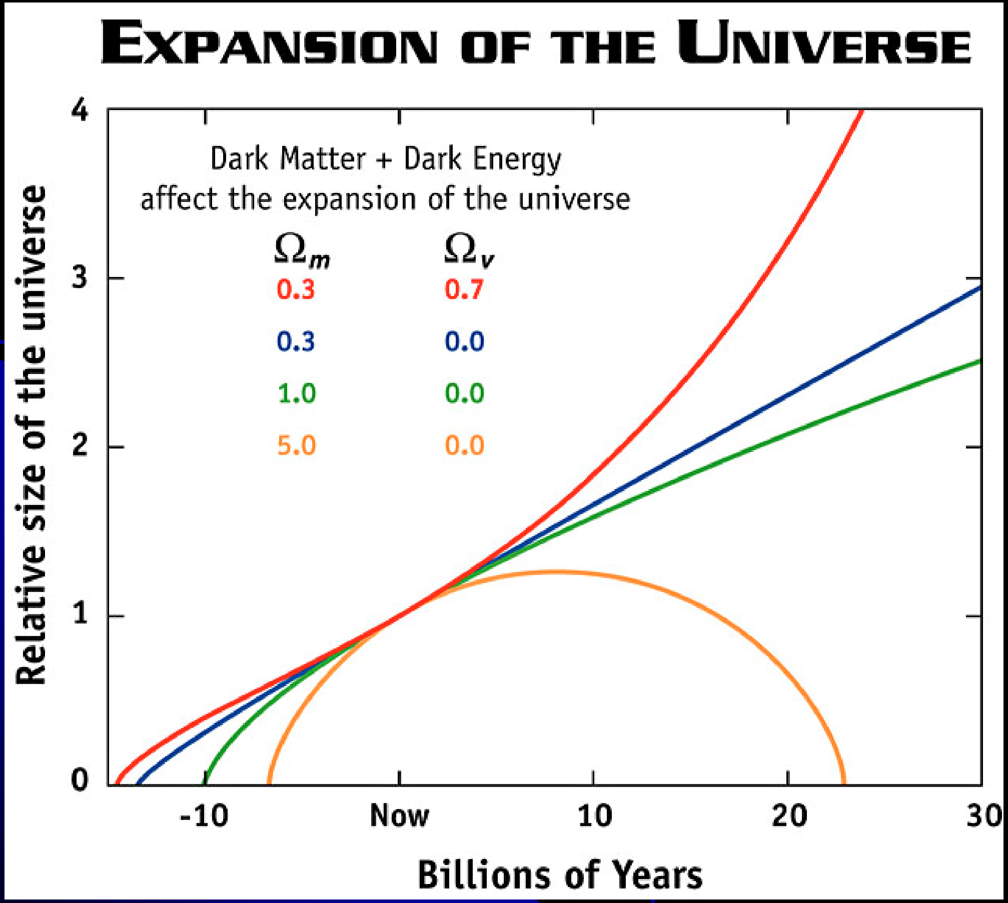
- Friedmann-Lemaître-Robertson-Walker metric

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

Friedmann equations:

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

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



by NASA

Written using energy densities:

$$\frac{H^2}{H_0^2} = \Omega_\gamma a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$

Observed accelerated expansion due to

Dark Energy?

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)

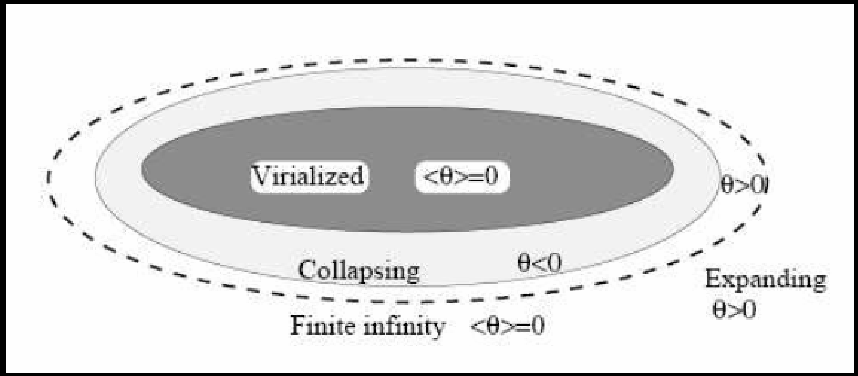
$$3\left(\frac{\dot{\bar{a}}}{\bar{a}}\right)^2 = 8\pi G\langle\rho\rangle - \frac{1}{2}\langle R\rangle - \frac{1}{2}Q \qquad 3\frac{\ddot{\bar{a}}}{\bar{a}} = -4\pi G\langle\rho\rangle + Q$$

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

- 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



by Wiltshire, 2007

- 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

➔ **accelerated expansion** of the universe (no Dark Energy required anymore)

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

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

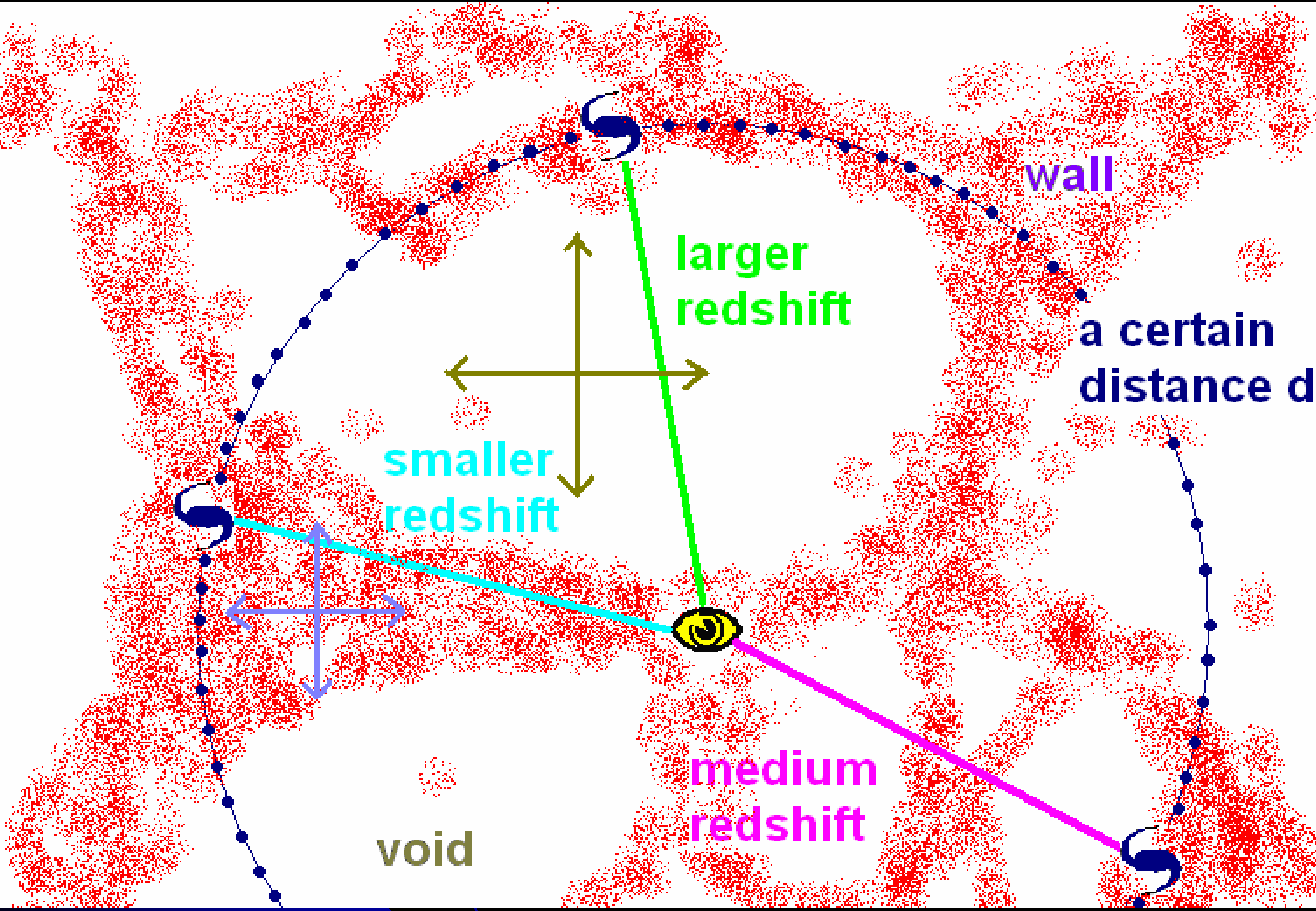
Wiltshire, 2007

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


wall
larger redshift
a certain distance d
smaller redshift
medium redshift
void

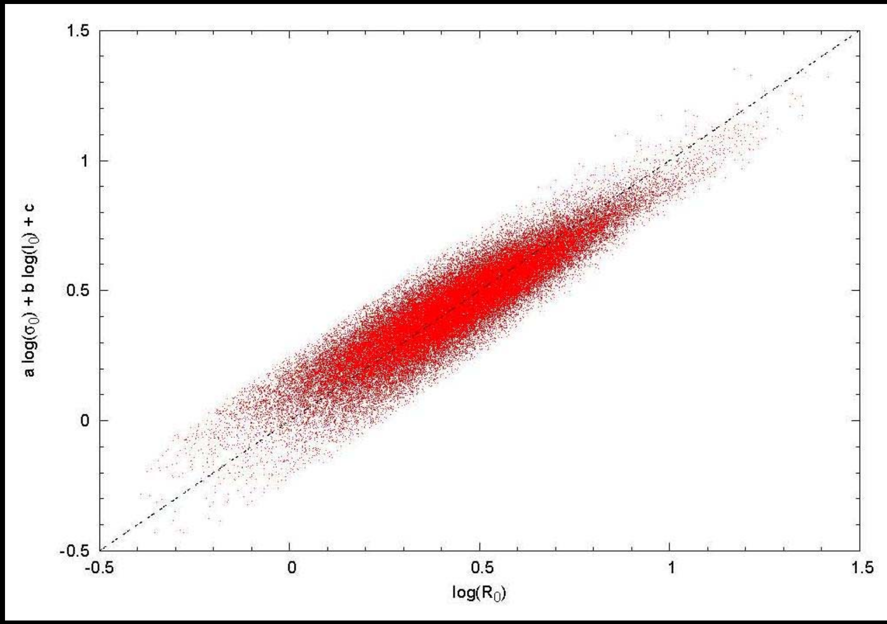
- optimal distance between 50 and 200 Mpc
- requires **redshift** and another **independent distance indicator**, like the fundamental plane
- lots of data required
- homogenous sample on a large area of the sky: e.g. elliptical galaxies from SDSS
- one also has to model the foreground

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

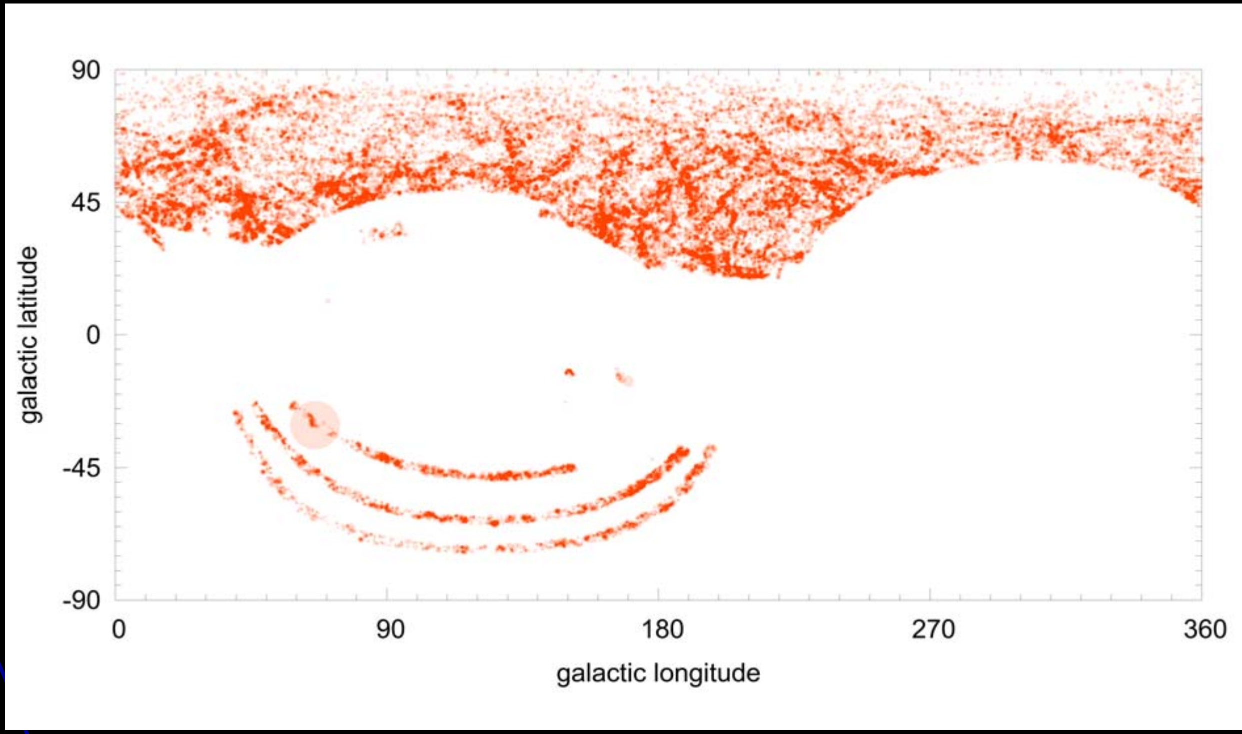
Performing the test

- Recalibrating the fundamental plane
  - 70000 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



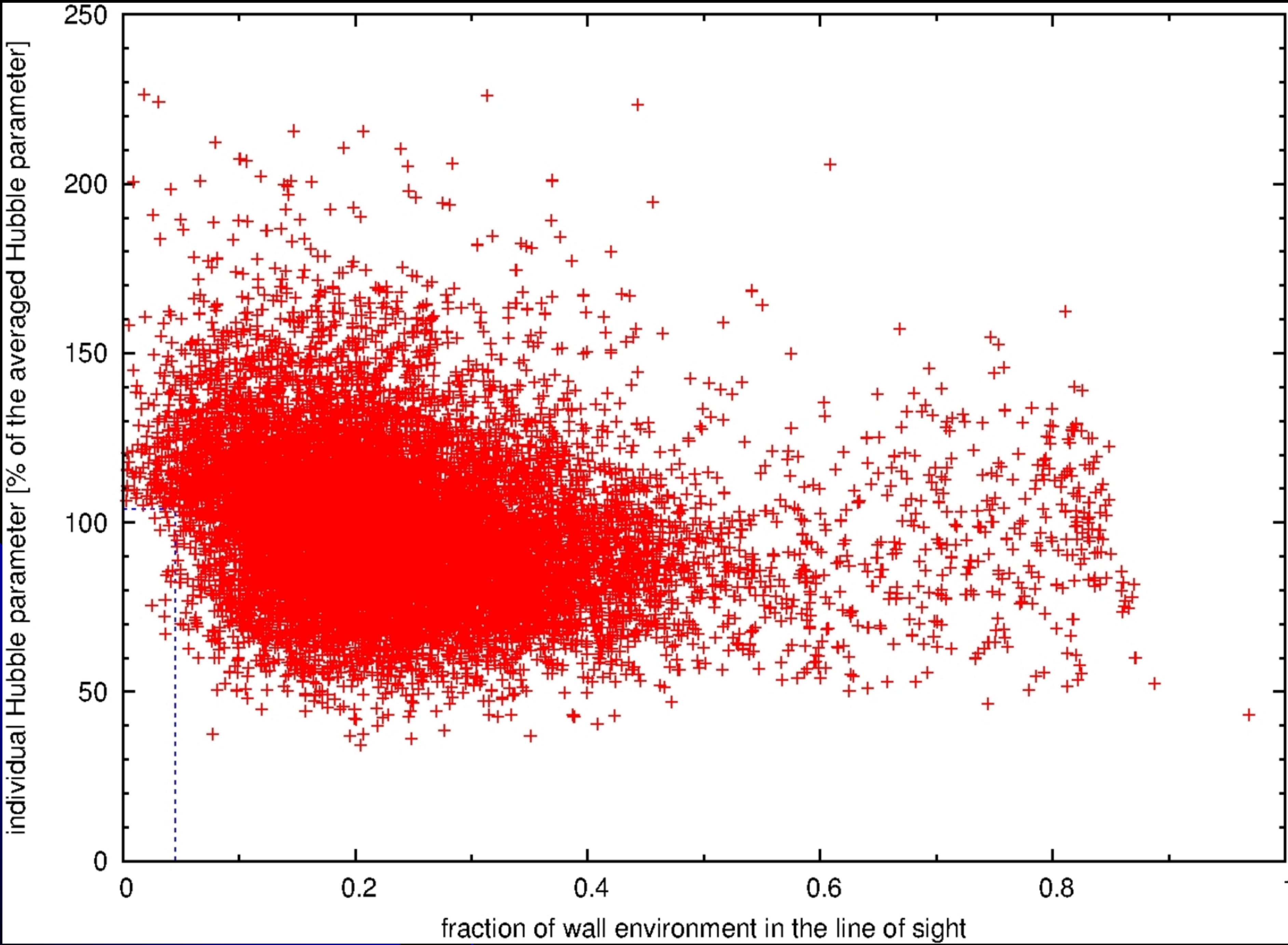
A part of the foreground model between 100 and 150 h^{-1} Mpc

- 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**.



individual Hubble parameter [% of the averaged Hubble parameter]
fraction of wall environment in the line of sight
0
50
100
150
200
250
0
0.2
0.4
0.6
0.8
1

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 Λ-CDM.

CAST LIGHT ON DARK ENERGY

ANY QUESTIONS?