Observational tests of an inhomogeneous cosmology

ESO TMT

by

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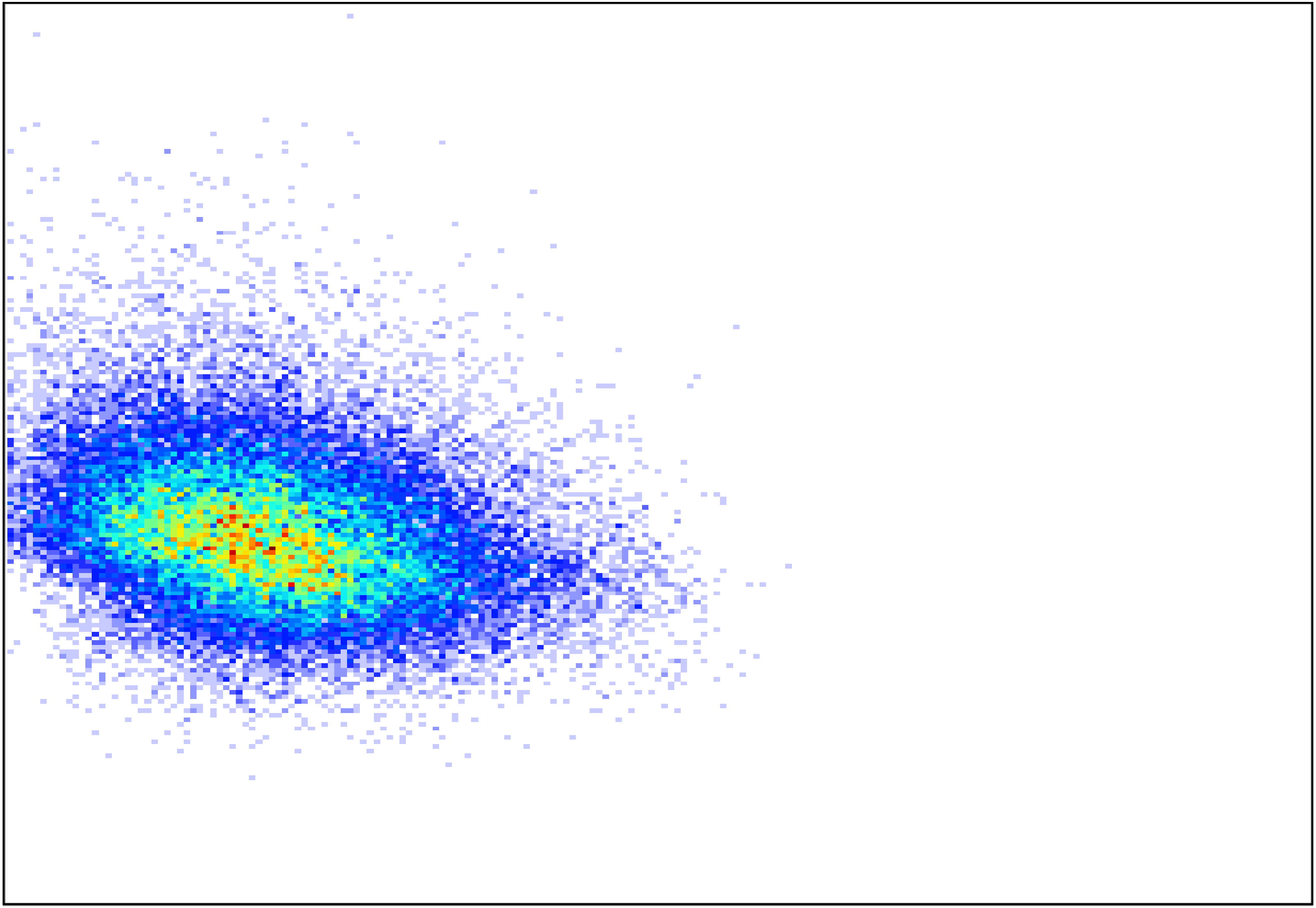

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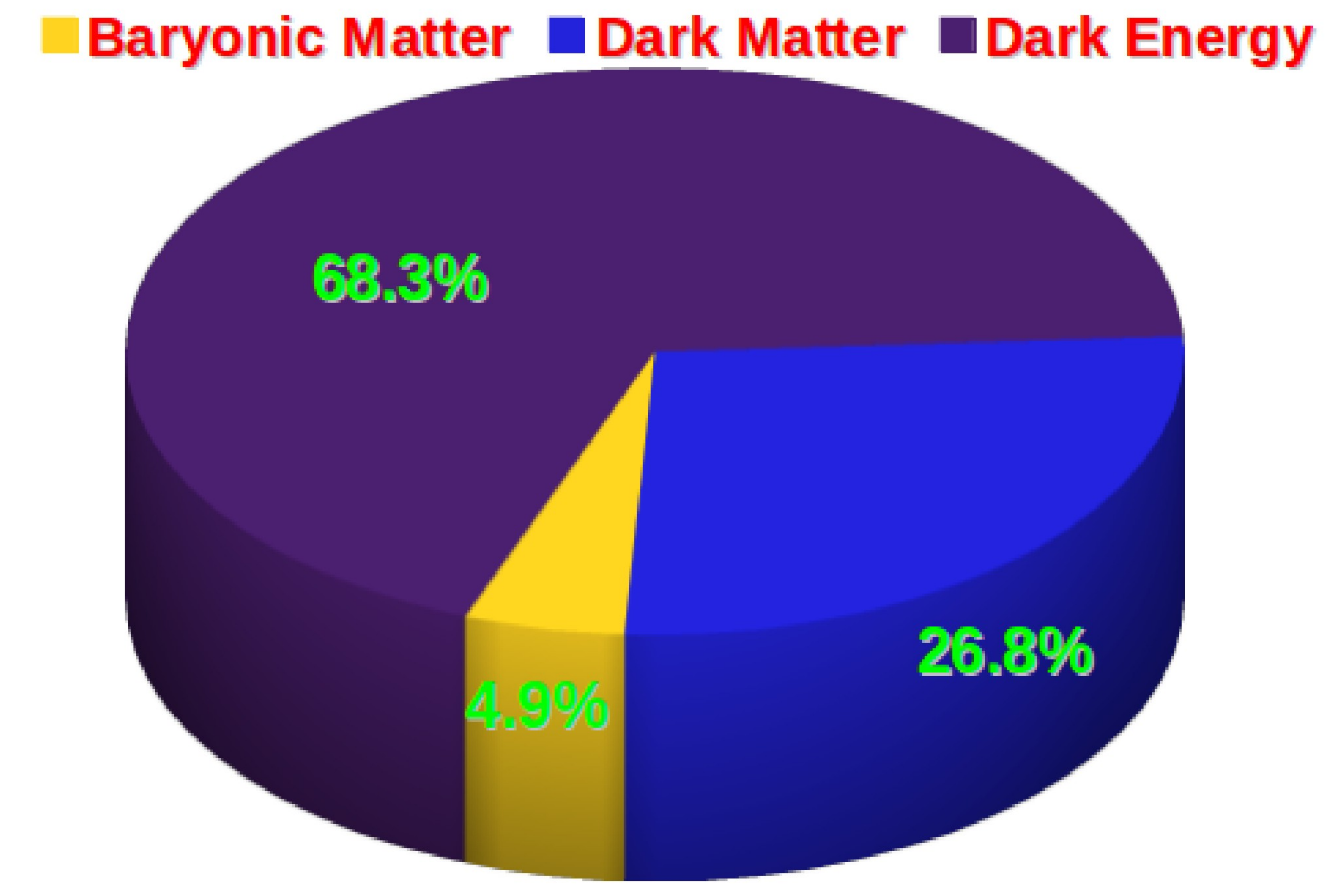
Standard cosmology

- Einstein's field equation of general relativity
- + assumption of homogeneity and isotropy
- = Friedmann-Lemaître-Robertson-Walker metric
- ==> Friedmann equations
- Best fit on observational data ==>

Λ-CDM model



Baryonic Matter
Dark Matter
Dark Energy
68.3%
26.8%
4.9%

Why do we need Dark Energy?

- Only to explain the accelerated expansion of the universe (distant supernovae type Ia – Nobel prize 2011)

What is Dark Energy?

- We do not know!!!
  - Simplest assumption: cosmological constant Λ
  - Phantom dark energy or quintessence
  - Many other models without any proof

Remarks

- There are many inhomogeneous cosmological models and theories

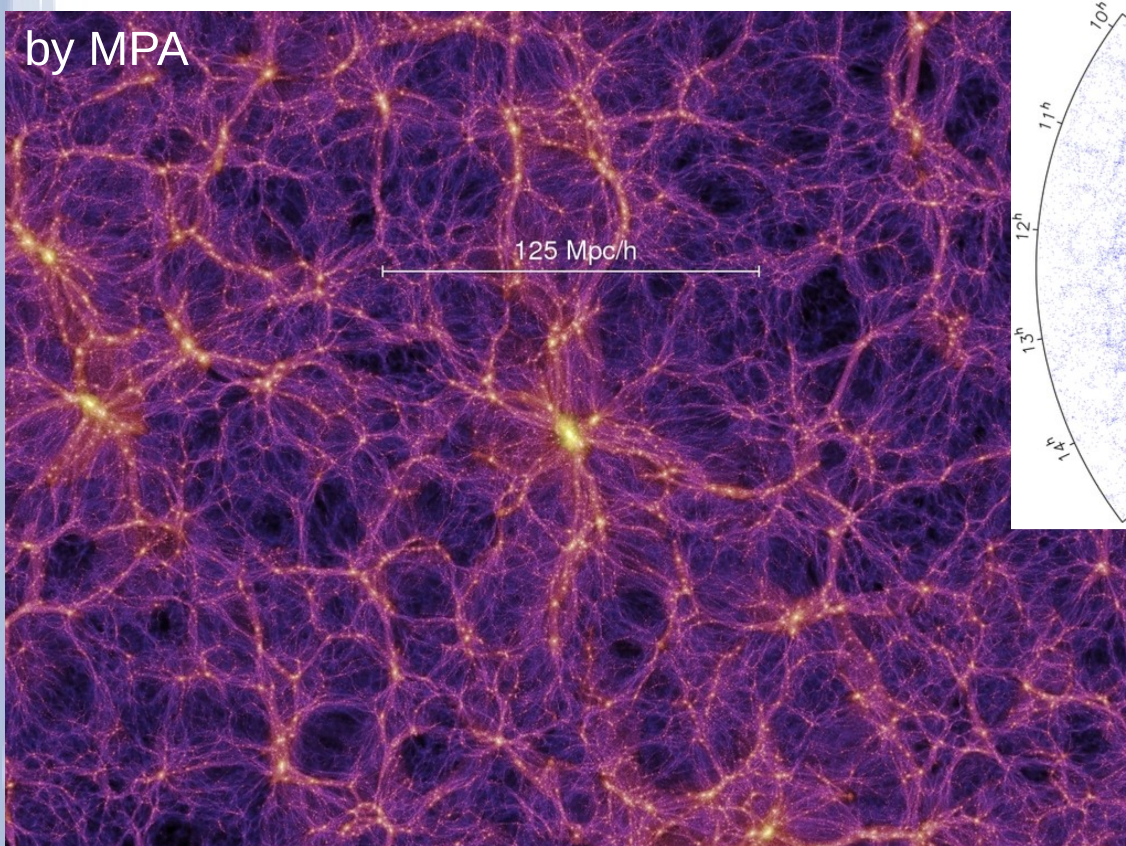
- I will **NOT** talk about:
  - Super-horizon inhomogeneities
  - The local universe is underdense compared to the rest of the universe.
  - Tilted universe theories

- I will just talk about inhomogeneities (clusters and voids) that are really there.

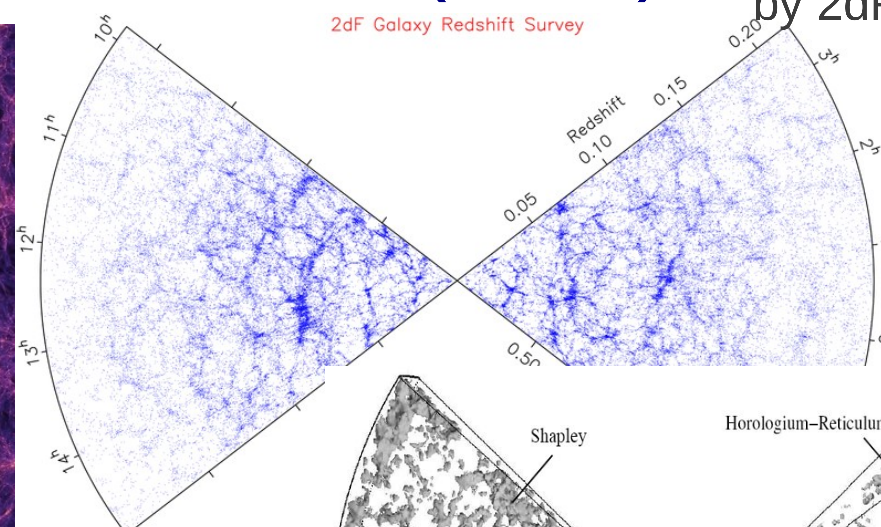
Timescape Cosmology

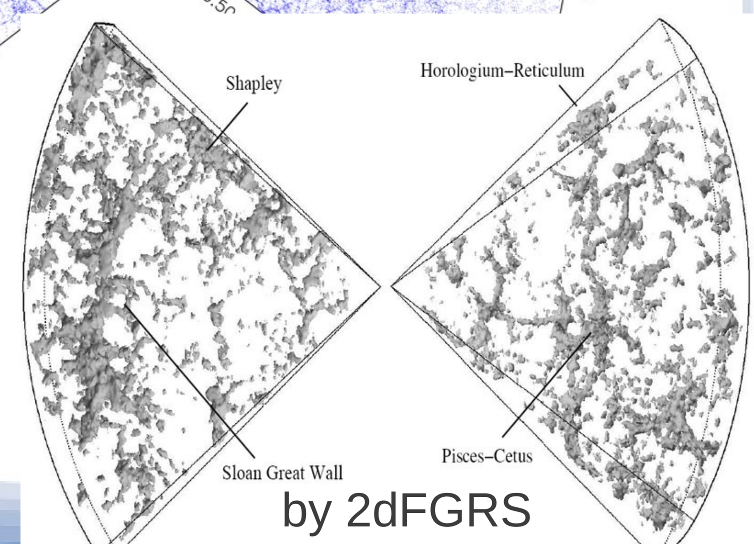
- cosmological model based on the assumption that the universe is **NOT** homogeneous

==> voids and clusters+filaments (walls)



by 2dFGRS





by 2dFGRS

- We live in an inhomogeneous universe (**FACT**).
- General Relativity is a non-linear theory (**FACT**).
- ==> averaging over large scale and high density contrast has to be modified.
- Back-reactions from inhomogeneities expected
- A pertubative approach to this problem is insufficient, life is more complicated.

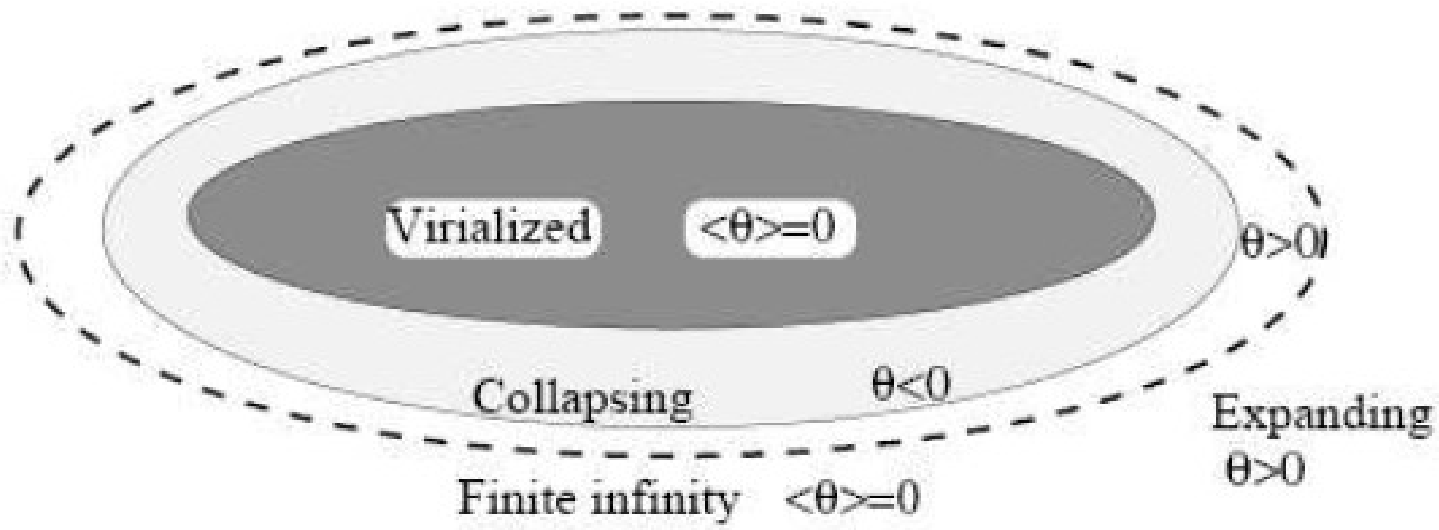
- Dropping the cosmological time parameter (Wiltshire, 2007) and increasing the importance of the local metric.

- Assuming a two phase model (voids and walls) ==> Swiss-cheese model (or fractal bubble model)

Voids: *empty = open geometry*

Walls: *renormalized critical density = flat geometry*

- Different clock rates in walls and voids
- Two phase are separated (in the model) by a so-called finite infinity boundary.



- Lapse function demands a reinterpretation of some of the CMB feature.

Consequences of this theory

- Time flow different in voids and walls
- Voids expand faster than walls
- At last scattering the universe was very close to homogeneity (**FACT**).
- Structure formation made it inhomogeneous and caused the apparent accelerated expansion

- Today the matter distribution in the universe has void-dominated fractal bubble structure (**FACT**).
- The voids-fraction of a comoving volume increases by time due to **different expansion rates of voids and walls**.
- On long time scales, the average expansion rate approaches the void expansion rate.
- An observer, who assumes a FRLW geometry may interpret it as an accelerated expansion

One naturally gets an

accelerated expansion

without

the need of

Dark Energy!

- Nice theory, isn't it?

  BUT

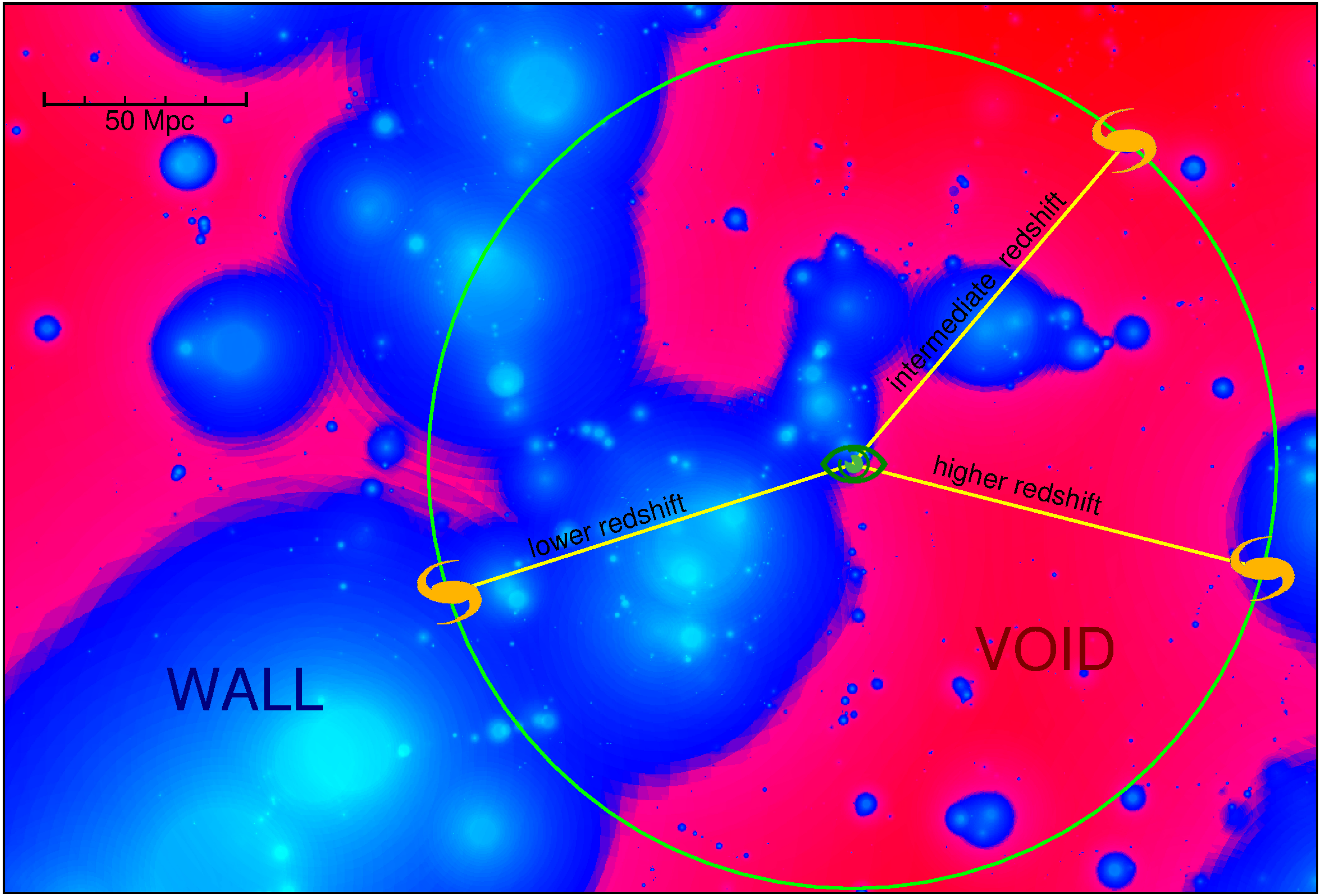
- Are these back-reactions strong enough to explain the cosmic acceleration?
- Proper calculations (beyond two-phase models) are hard to make due to the complexity of the equation of General Relativity
- Estimates are ranging from negligible to extremely important (Marra et al. 2010, Mattsson et al. 2010, Kwan et al. 2009, Clarkson et al. 2009, Paranjape 2009, van den Hoogen 2010)

Only tests can provide an answer!

Designing the test

- In timescape cosmology

  voids expand faster than walls.
- Measuring the distance independently from the redshift.
- Large sample distributed over a large area of the sky:
  - To avoid local effects
  - To deal with uncertainties in the distance indicator
  - To handle the natural scatter due to peculiar motions



50 Mpc
intermediate redshift
higher redshift
lower redshift
VOID
WALL

Preparing the test

- A huge and homogeneous dataset

  ==> SDSS + NED
- A redshift-independent distance indicator

  ==> fundamental plane of elliptical galaxies
- A model of the mass distribution in the local universe ==> derived from SDSS + NED
- Simulated data to estimate potential biases

  ==> Millennium simulation

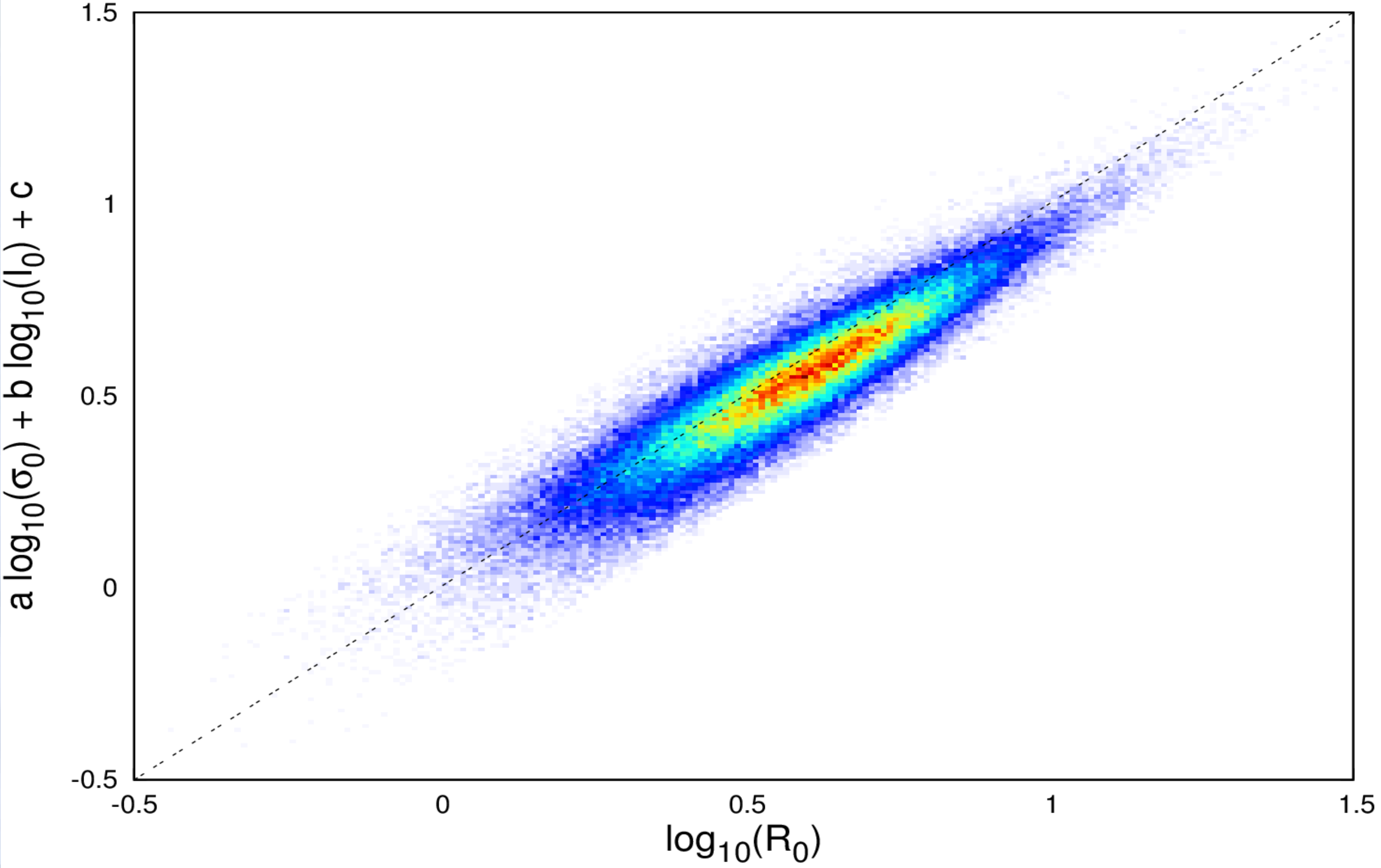
The fundamental plane

- Elliptical galaxies (not dwarfs)

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

- Empirical relation between 3 global parameters:
  - physical effective radius
  - central velocity dispersion (distance independent)
  - surface brightness (distance independent)

- We did our own calibrations on SDSS DR8 data using about 93 000 galaxies (see Saulder et al 2013).



- We get an accuracy for the distance of individual galaxies of 18.6% in the SDSS z band.

Foreground model

- Using SDSS data and filling up the incompleteness for very low redshifts ($z<0.01$) with NED data
- Halo mass–luminosity estimation as first estimate
- Cluster finder
- Assigning masses based on the peculiar motions inside clusters

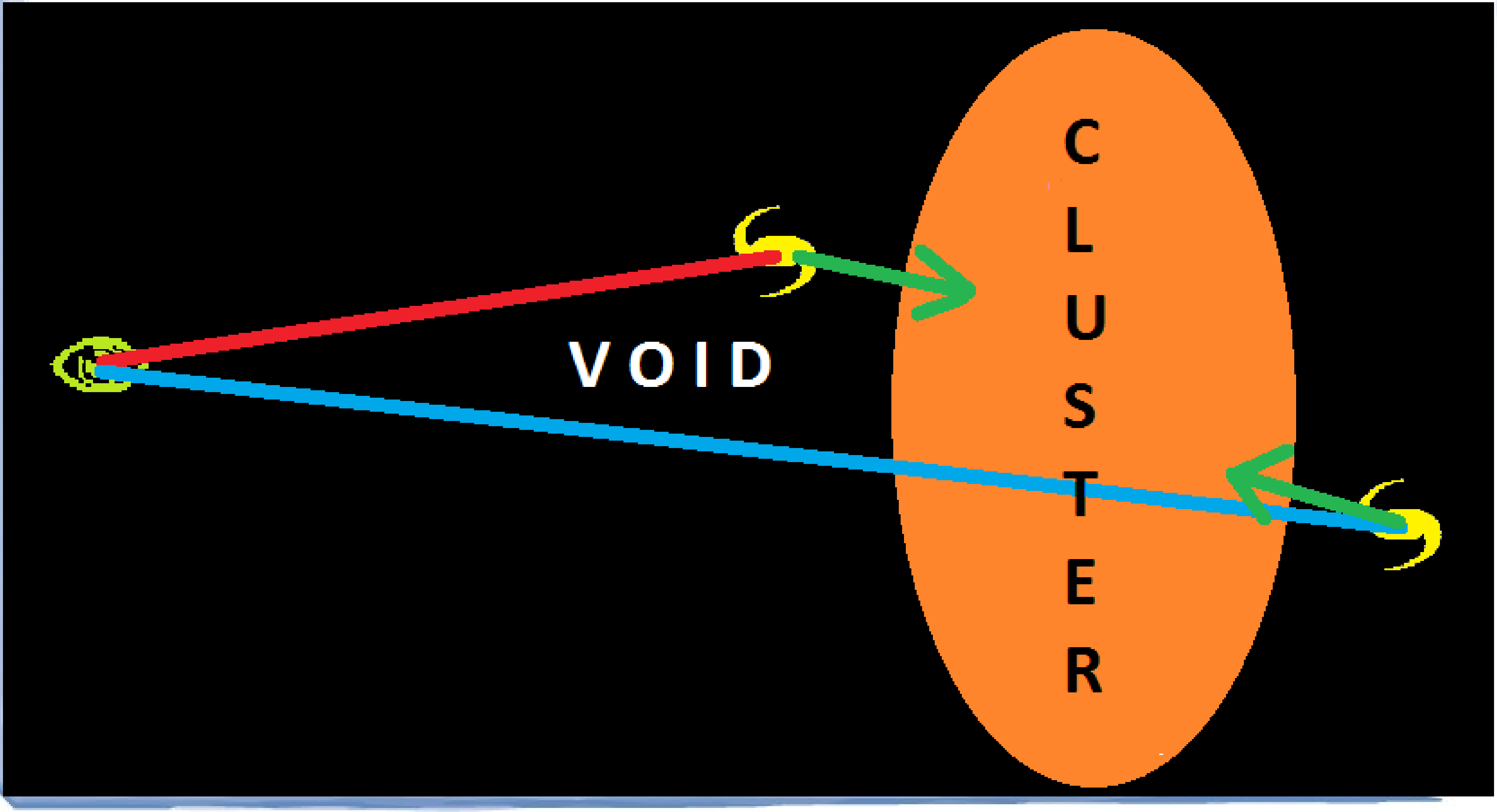
- So far we were using the Yang et al, 2007 catalogue, with all its problems.

Simulations

- Millennium simulation for Λ-CDM cosmology
- Matter distribution from the Millennium simulation for timescape cosmology assuming the last snapshot represents the today's distribution well enough.
- We consider:
  - Malmquist bias
  - Sample selection (only ellipticals)
  - Measurement errors
  - Uncertainty in the distance measurement
- We do not consider yet
  - Uncertainties in the foreground model

Coherent Infall

- It creates a similar effect as expected from timescape cosmology.

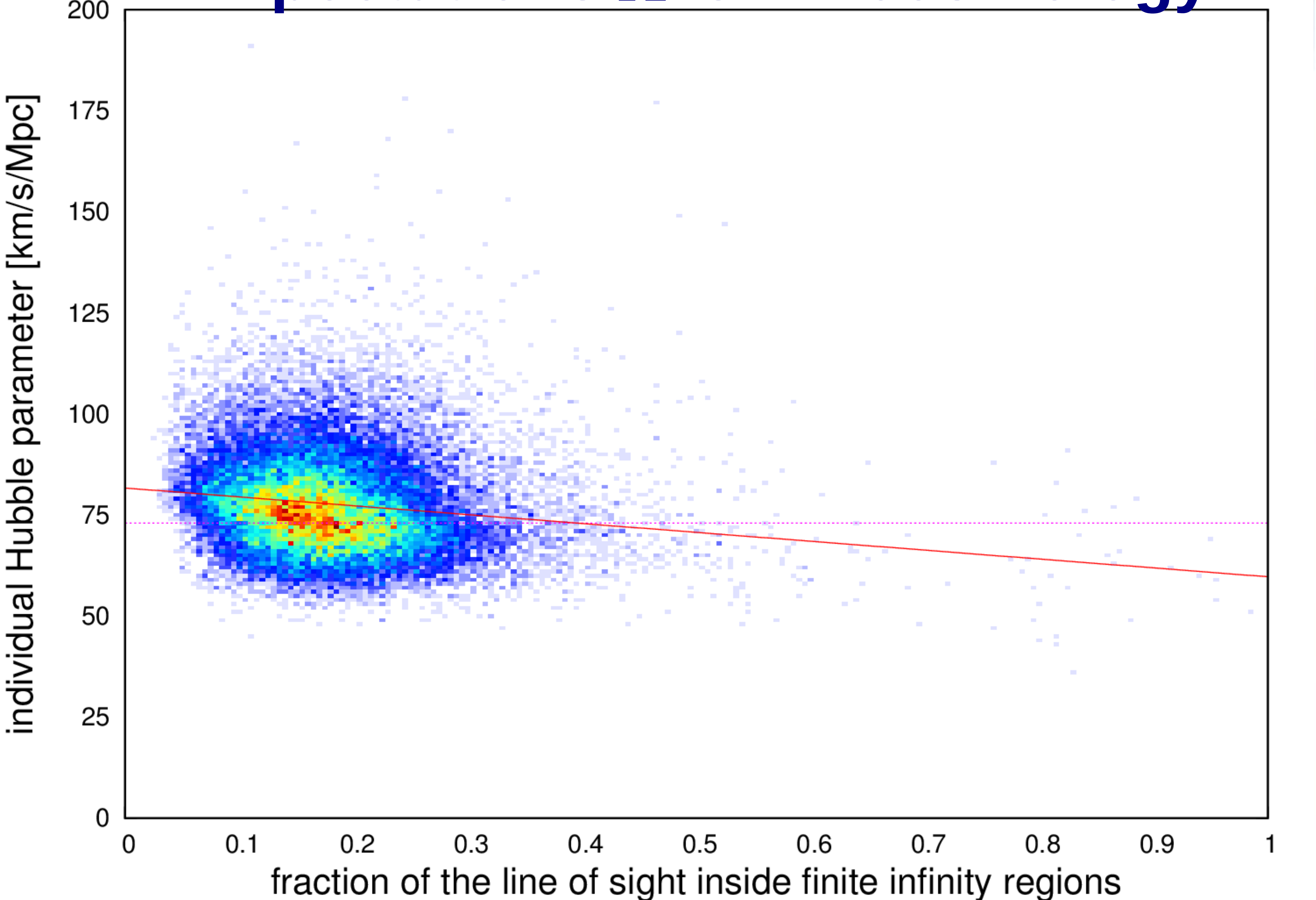


Performing the test

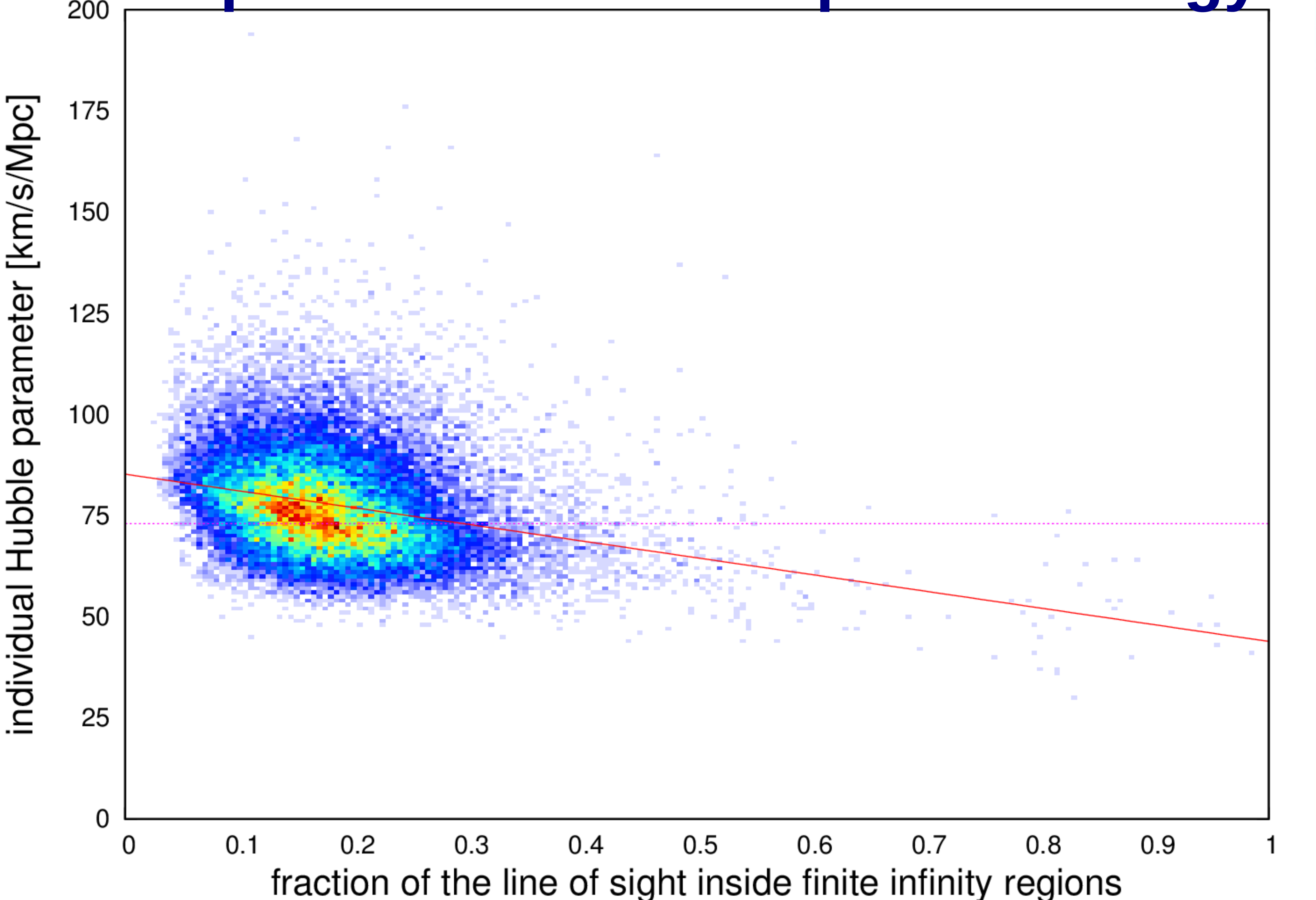
- Assign spherical finite infinity regions for all clusters, groups and galaxies in the foreground model.
- Estimate the distance to thousands of ellipticals galaxies using the fundamental plane.
- Calculate the “individual Hubble parameters” for those galaxies

- Calculate the fraction of the line of sight which lies inside finite infinity regions to those galaxies using the Astro-Cluster in Vienna.
- **PLOT** it the **“individual Hubble parameters”** against the **fraction of the line inside finite infinity regions**
- Compare the results with the simulated data.
- Perform some statistical analysis

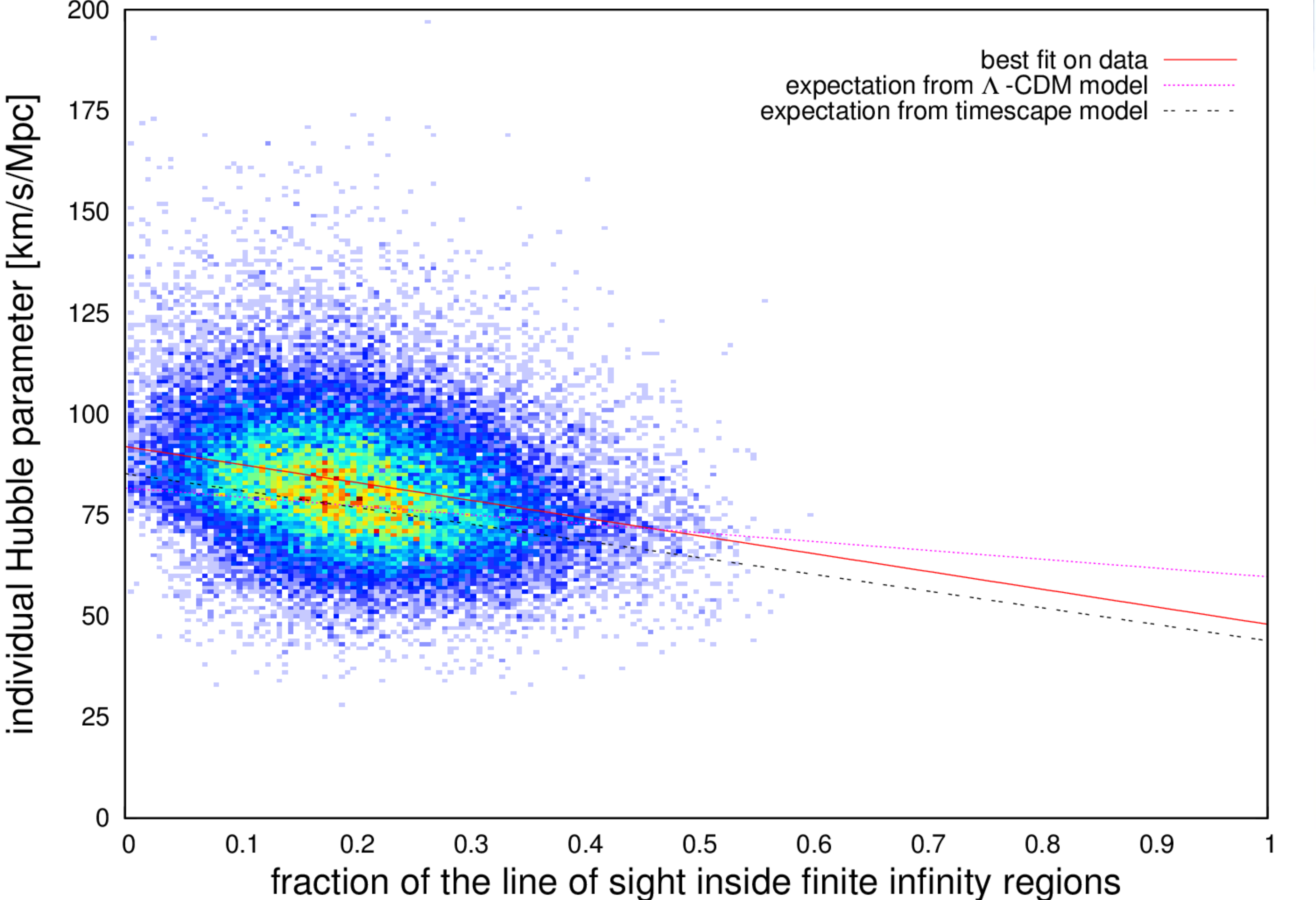
Expectations Λ-CDM cosmology



Expectations timescape cosmology



Real Data



best fit on data
expectation from Λ -CDM model
expectation from timescape model
individual Hubble parameter [km/s/Mpc]
fraction of the line of sight inside finite infinity regions
200
175
150
125
100
75
50
25
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

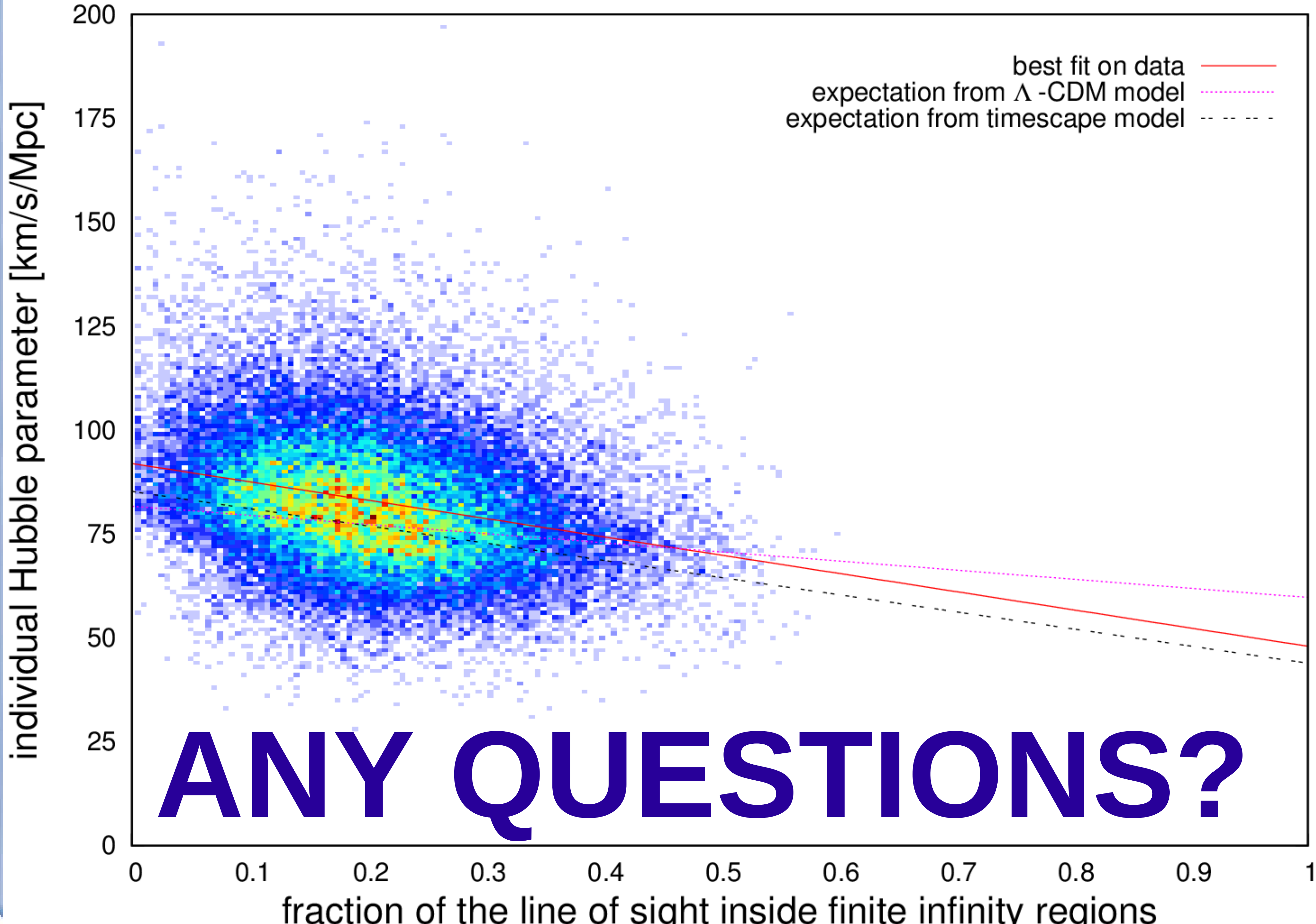
Conclusions & Summary

- It is possible to perform a test of timescape cosmology without any additional observations.
- Currently the test favour timescape cosmology over the standard model.
- However, there are several issues which have to be addressed before drawing any definite conclusions.

- Currently no galaxies in the foreground model with z<0.01 ==> will be filled with NED data
- Yang et al, 2007 catalogue used for foreground model is incomplete ==> do-it-ourselves catalogue is work in progress
- Simulated data does not consider any errors in modelling the foreground yet ==> on to-do list
- Statistical analysis is still too simple ==> Bayesian approach is planned
- Planned improvement: use groups and clusters with several elliptical galaxies instead of individual galaxies to reduce the error in the distance measurements.

- Additional science output of the project:
  - New calibrations of the fundamental plane (already published in Saulder et al, 2013)
  - A reliable catalogue of the matter distribution in the local universe (work in progress)
  - Lots of data on peculiar motions
- Providing a solid test of timescape cosmology against the standard model

CAST LIGHT ON DARK ENERGY



ANY QUESTIONS?
best fit on data
expectation from Λ -CDM model
expectation from timescape model
individual Hubble parameter [km/s/Mpc]
fraction of the line of sight inside finite infinity regions
0
25
50
75
100
125
150
175
200
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1