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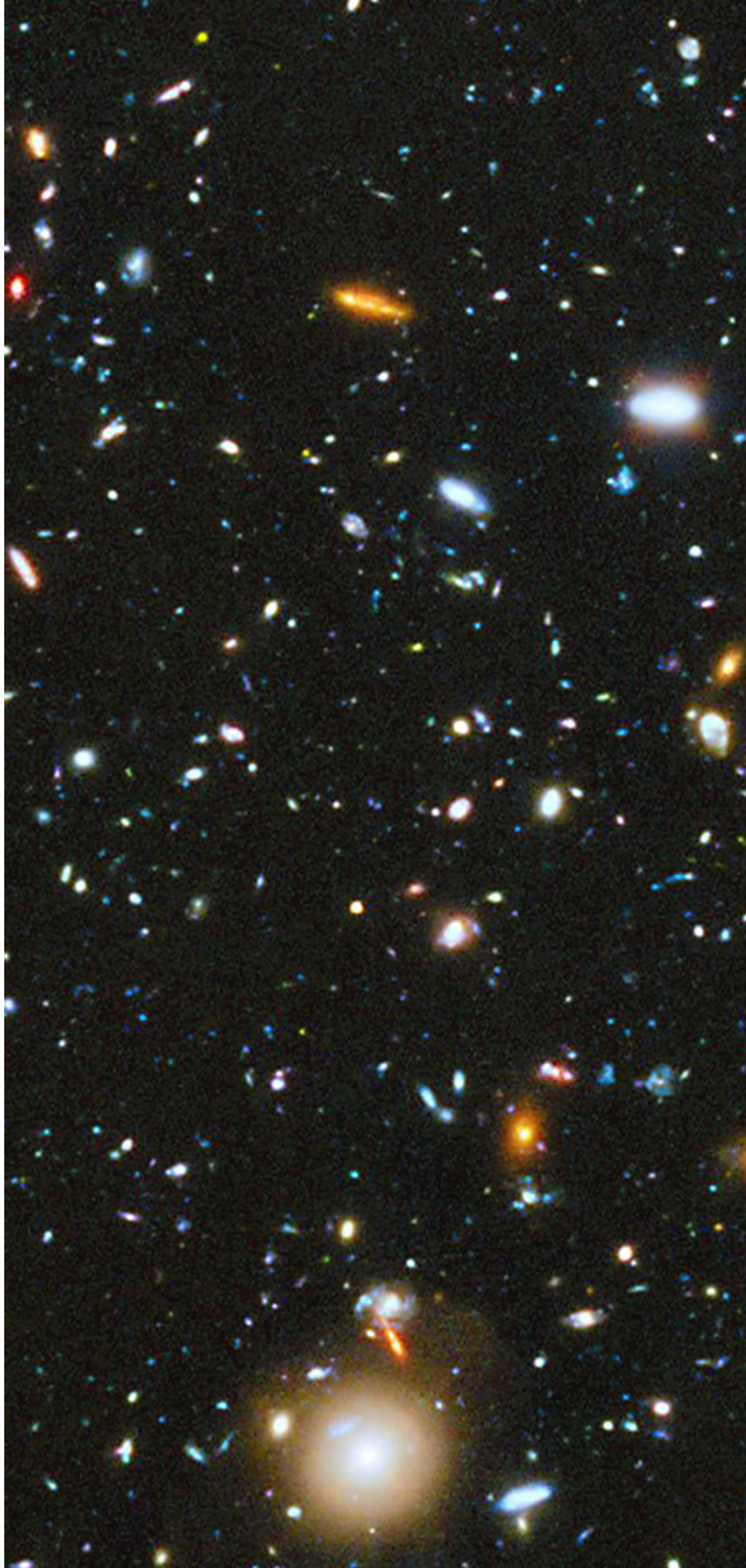
Can the mystery of Λ be solved by considering inhomogeneities?

LITERATURE REVIEW PROJECT - PRESENTATION

University of Glasgow



Outline

A model of the Universe: $\Lambda - CDM$

- Cosmological constant Λ and accelerating expansion
- What is Λ and why do we care about it?

Cosmological constant problem

- Zero-point energy of vacuum?

Inhomogeneities and timescape cosmology.

- Is the universe really homogeneous?
- Timescape cosmology
- Testing the theory

Conclusions

Λ and the accelerating expansion

In 1998, the accelerated expansion of the universe was discovered by looking at Type Ia Supernovae. [1, 2]

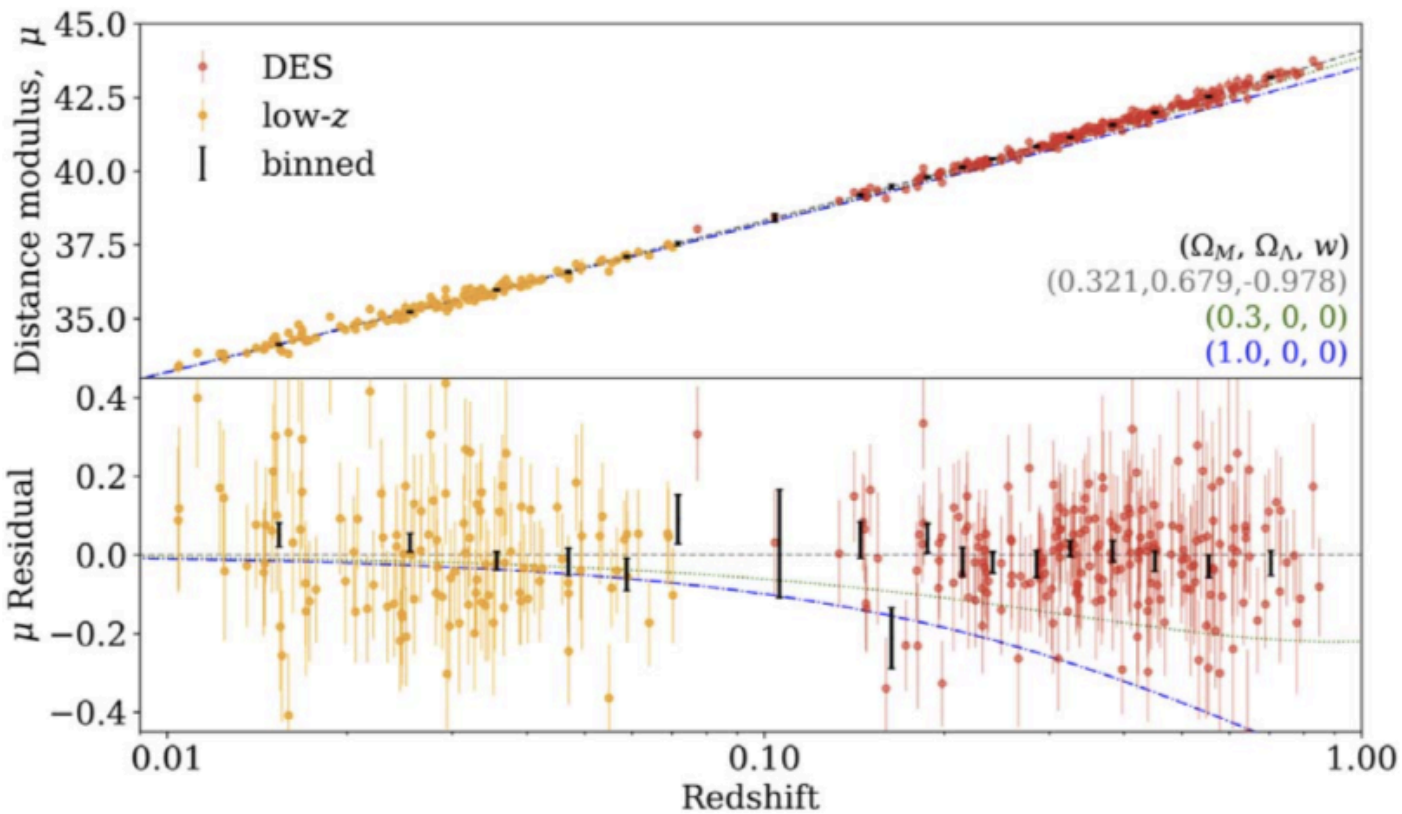


Figure 1: Distance modulus of Type Ia Supernovae plotted against redshift. [3]

The role of Λ in the accelerated expansion of the universe becomes clear if we look at one of the Friedmann's equations:

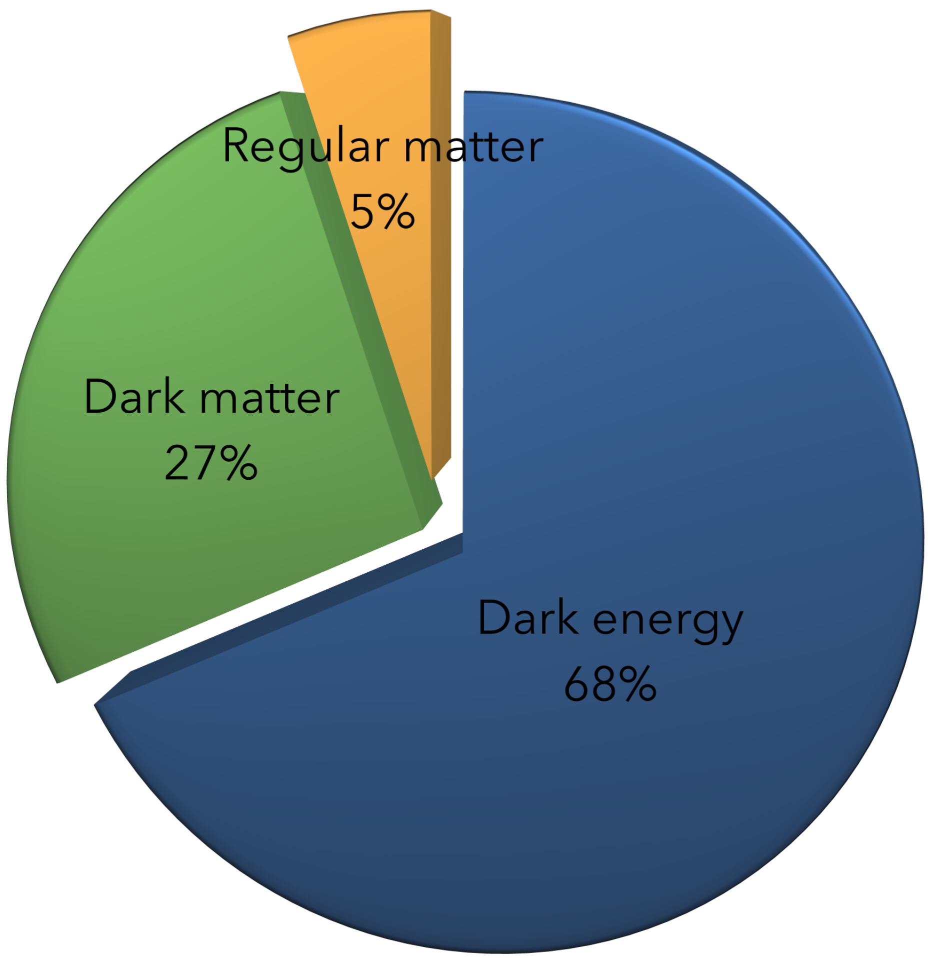
$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda}{3} \tag{1}$$

Hence, the cosmological constant was included in the standard cosmological model.

What is Λ and why do we care about it?

If we consider a fluid with negative pressure and hence repulsive gravity, then that will produce the same effect on Friedmann's equation as Λ .

This is how **dark energy** is defined. However, it has never been observed.



Trying to make sense to what dark energy is, is possibly one of the most fundamental questions of modern science.

Zero-point energy of vacuum?

In 1968, Zel' dovich had showed that the cosmological constant value could be interpreted as the zero-point energy of vacuum. [4]

From quantum field theory considerations we have that:

$$\rho_{QFT} = \frac{1}{2}\sum_{fields} g_i \int_0^\infty \sqrt{k^2+m^2}\frac{d^3k}{(2\pi)^3} \simeq \sum_{fields}\frac{g_i k_{max}^4}{16\pi^2} \tag{2}$$

This gives: $\rho_{QFT} = 5.156 \times 10^{96}\ kg\ m^{-3}$

Conversely, the observed cosmological zero-point energy density is: $\rho_\Lambda \simeq 6.4 \times 10^{-27}\,kg\,m^{-3}$

This discrepancy is known as the **Cosmological constant problem**.

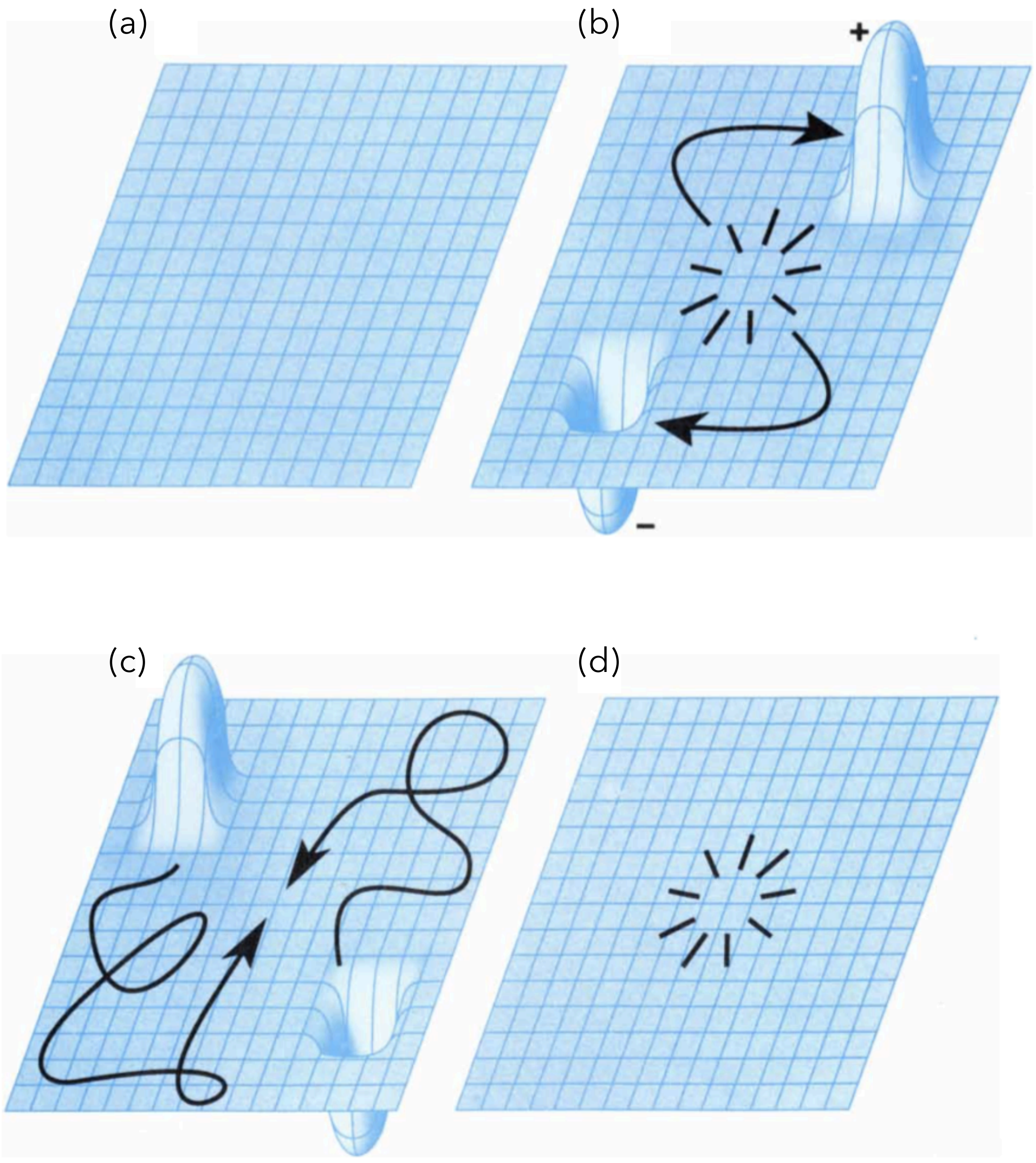


Figure 2: Schematic representation of virtual particle generation in vacuum. [5]

Is the universe really homogeneous?

The $\Lambda - CDM$ model assumes that structure can be ignored on average and that the content of the universe can be treated as an homogeneous and isotropic fluid.

Observations suggest that the universe has complex structure and is only homogeneous on average at scales of order 150-300 Mpc.

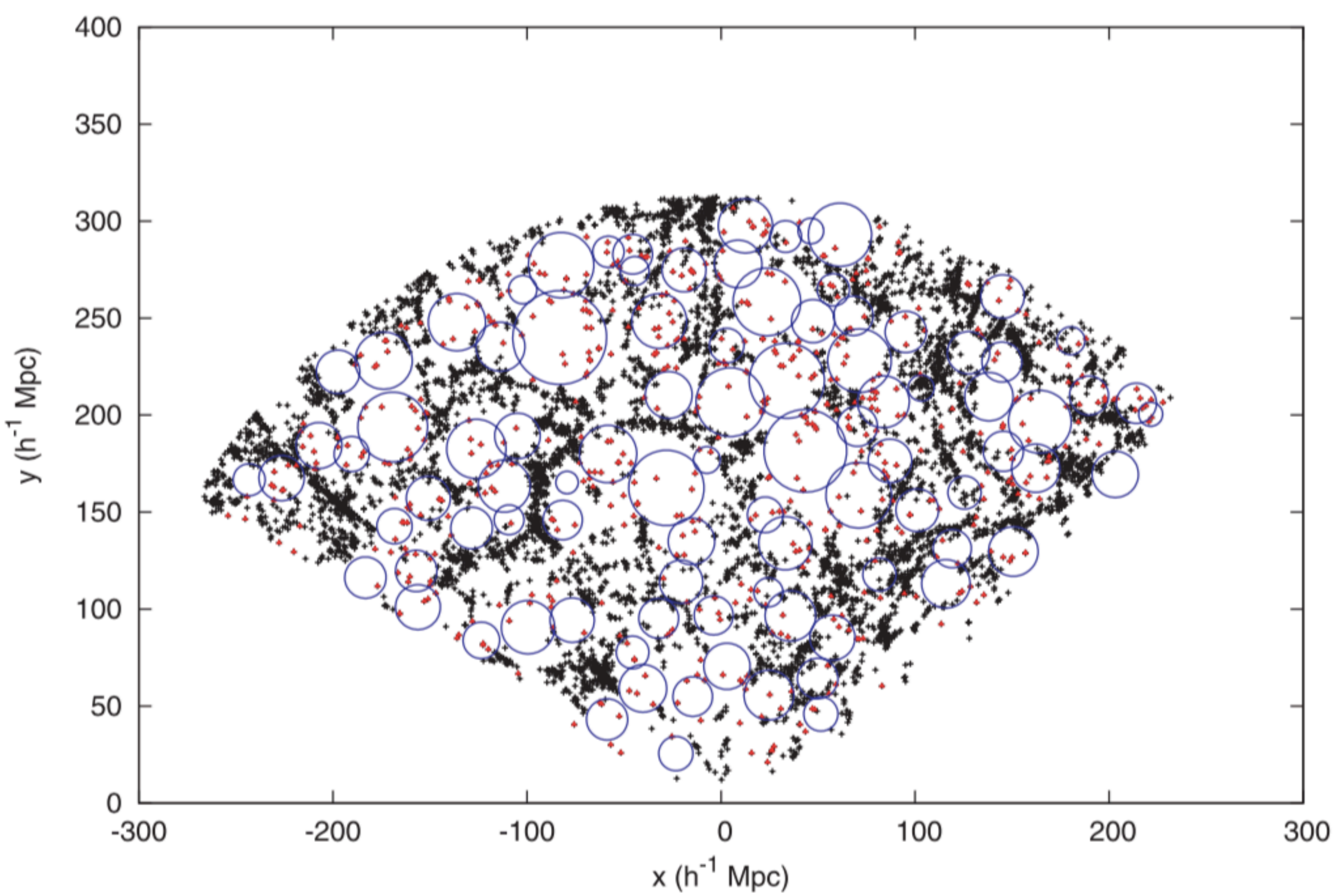


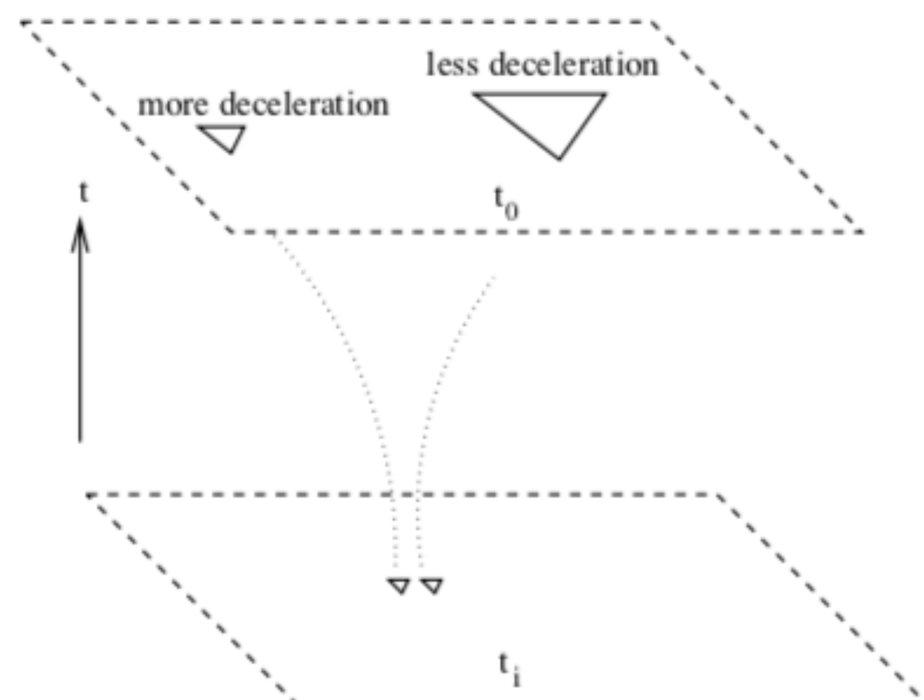
Figure 3: This plot highlights the voids in the SDSS Data Release 7. The voids are circled in blue. Voids are estimated to cover ~40% of the volume of the universe at present time. [6]

Are these inhomogeneities relevant?

Timescape cosmology

- Mainly developed by David L. Wiltshire.
- He claims that some aspects of general relativity are overlooked when applied to the standard model of cosmology.
- For an inhomogeneous universe, averaged Einstein's equations do not evolve in the same way they would for a smooth, homogeneous universe.

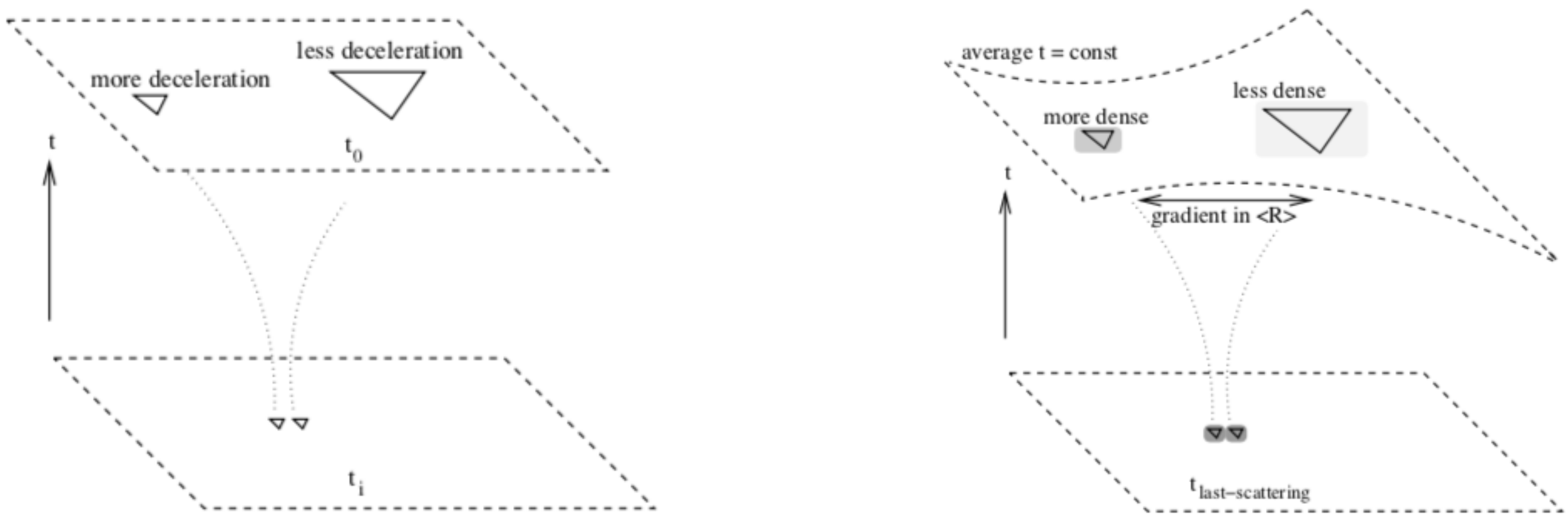
Figure 4: Two inertial frames in spacetime are homogeneously expanding at first and they then undergo a **deceleration at different rates**. The frame that is decelerating more will have a smaller proper time τ . [8]



$$\alpha_1(t) > \alpha_2(t) \implies \tau_1 < \tau_2$$

Timescape cosmology

According to Wiltshire's theory, the following phenomena are equivalent:



$$\alpha_1(t) > \alpha_2(t) \implies \tau_1 < \tau_2$$

Figure 5: Two equivalent phenomena. This allows us to relate gravitational energy and spatial curvature. [8]

- The universe has not a unique time.
- The relative clock rate implies a gradient in gravitational energy.

In timescape cosmology, dark energy is interpreted to be a misidentification of these gravitational energy gradients.

Testing the theory

Recent simulations have produced promising results that match with the observations.

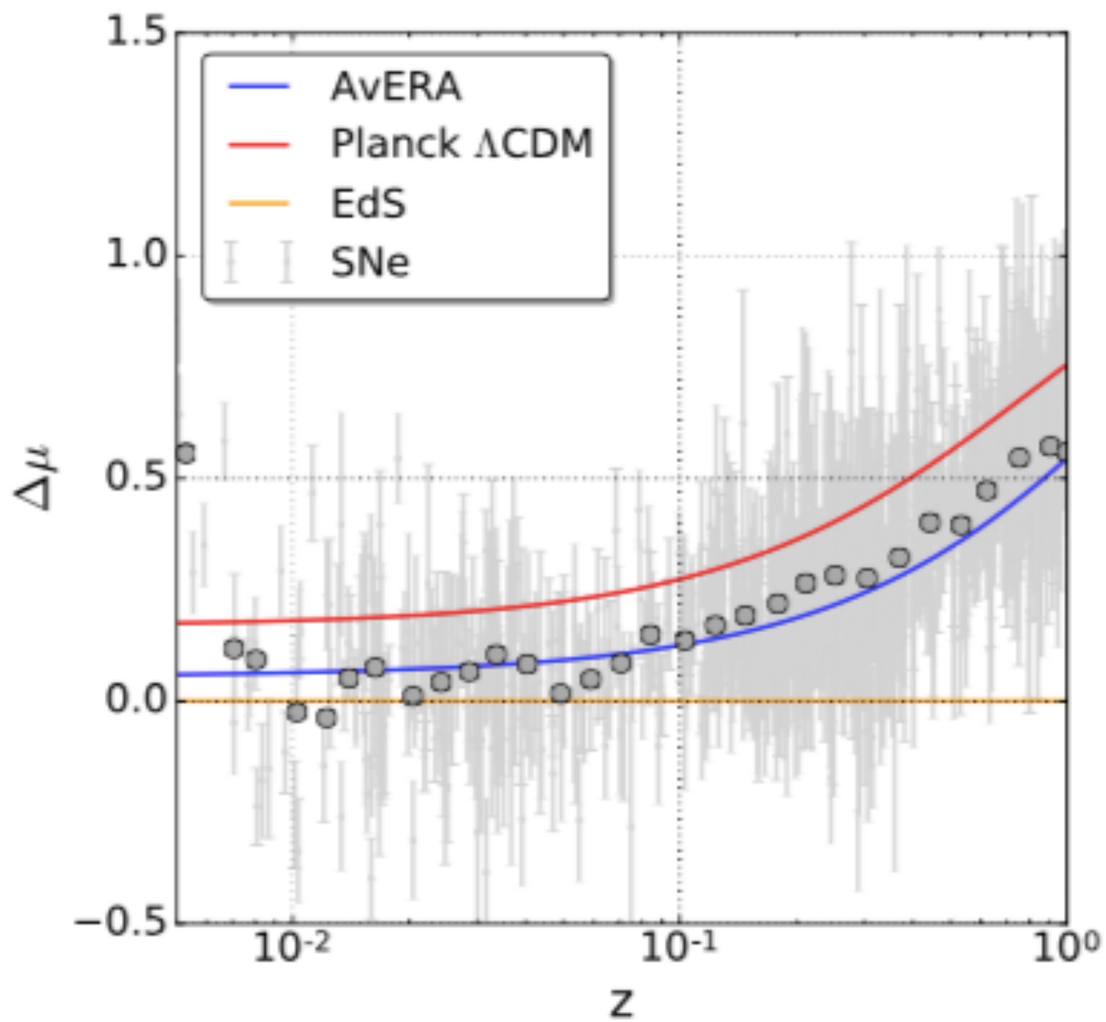
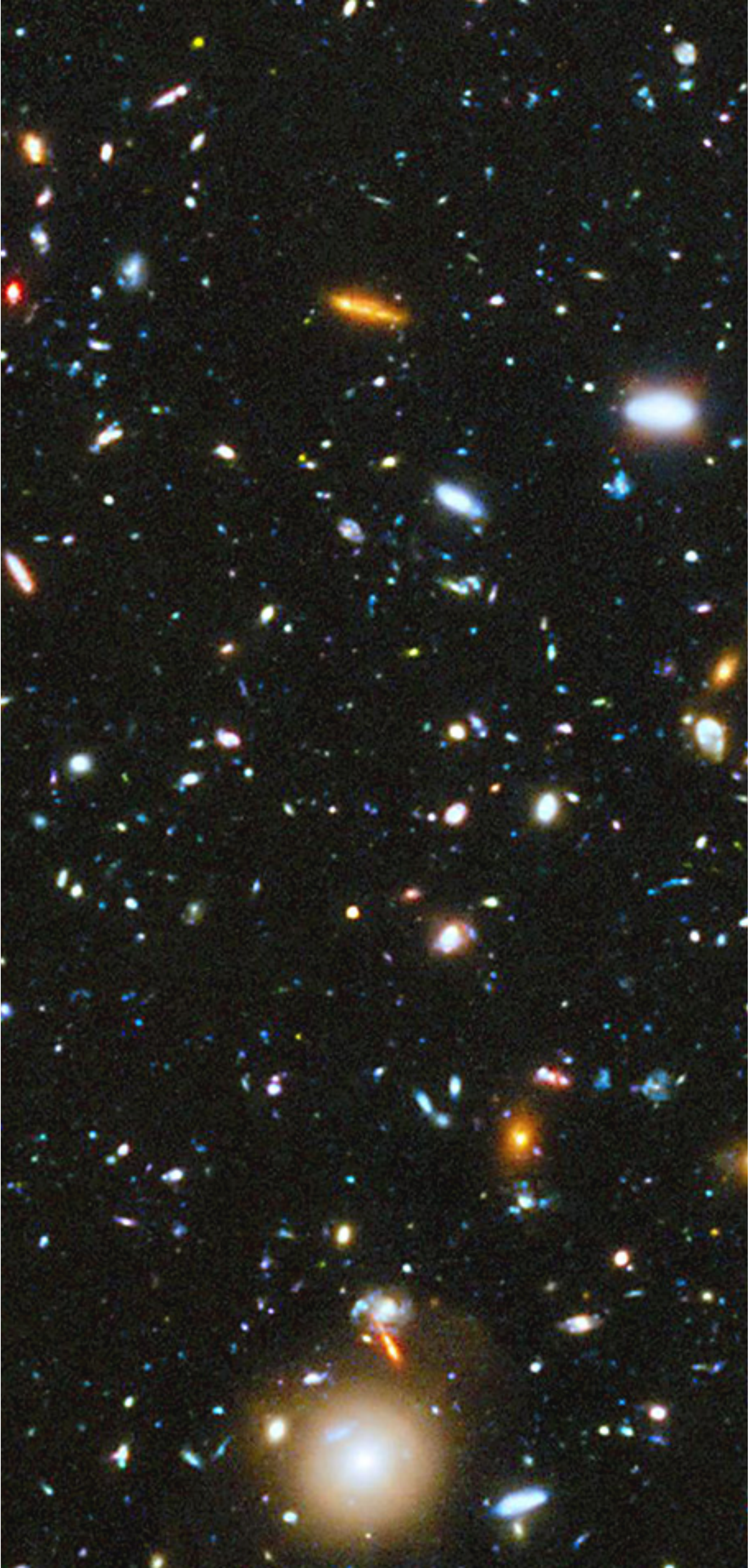


Figure 7: Fit of different models for Type Ia Supernovae measurements. The blue line represents a timescape-like model, whereas the red line is a fit for the currently accepted cosmological model. Finally, the yellow line is a fit for the Einstein de Sitter universe. [9]

However, the theory still needs validation. This is expected to happen in the coming years, with missions such as the Euclid satellite and the CODEX experiment.



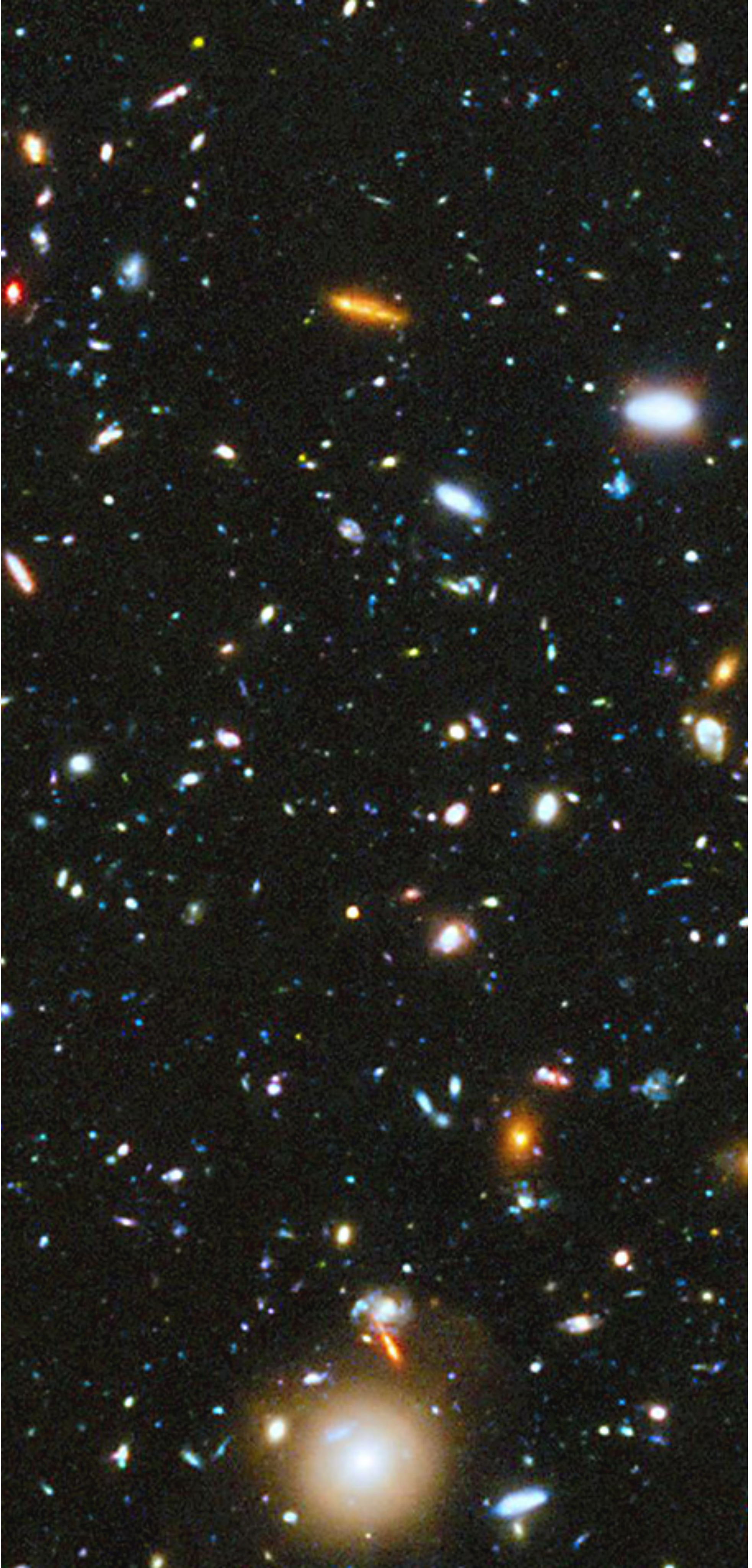
Conclusions

The standard cosmological model has successfully passed a number of observational tests, but it does not seem to answer some fundamental theoretical issues. In this presentation:

- The role of Λ in the standard cosmological model was briefly presented.
- The theoretical issues related to the cosmological constant were introduced.
- The assumption of an homogeneous universe was questioned.

It was argued that:

- Timescape cosmology could provide a viable solution.
- The theory has passed some observational tests but still requires further validation.
- Future experiments will provide insight on this problem.



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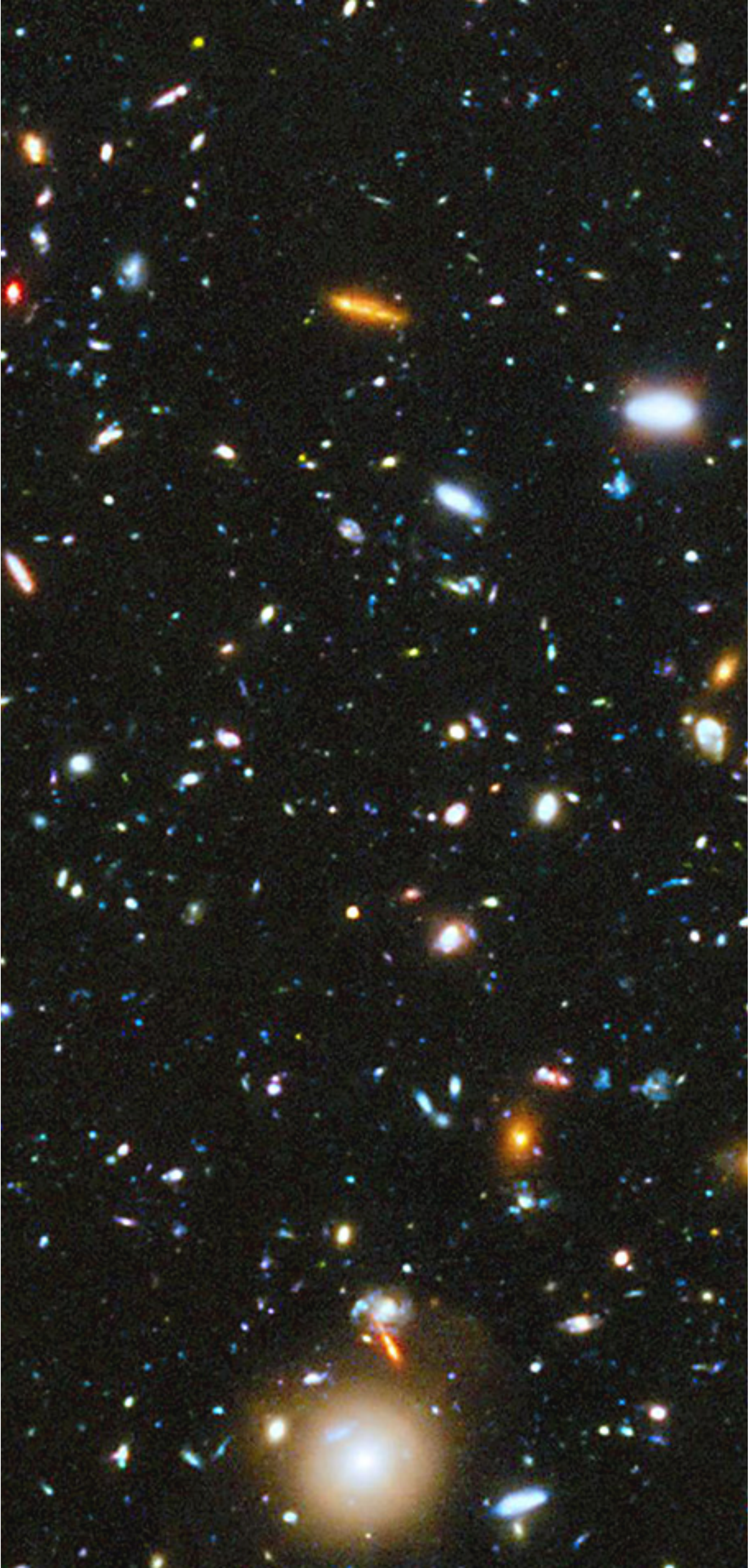

Thank you for your attention.

Questions?