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Testing the cosmological principle with the CMASS galaxy sample

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Astronomy & Astrophysics

CMASS galaxy sample and the ontological status of the cosmological principle

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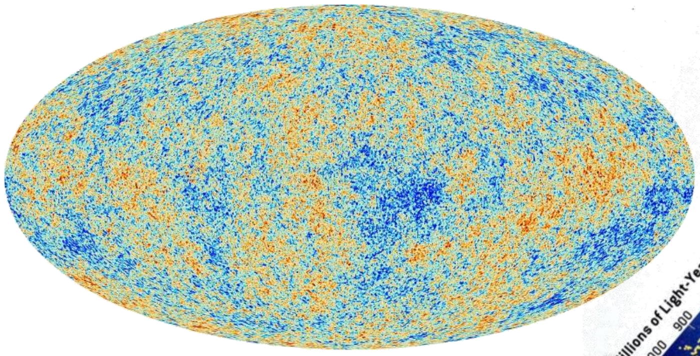
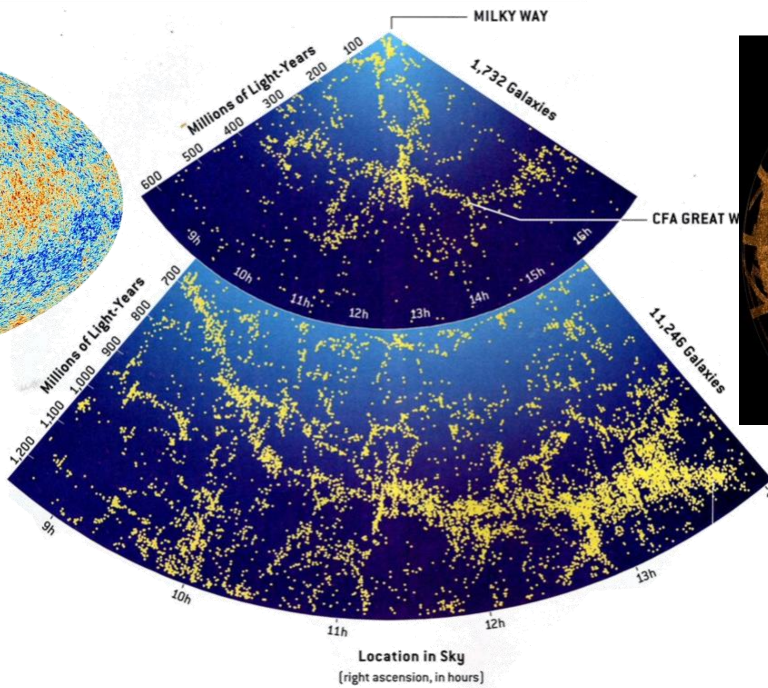
Introduction

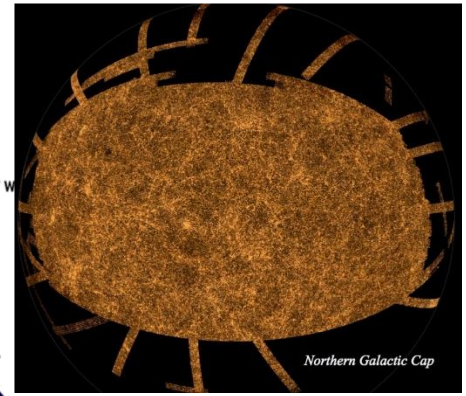
Cosmological Principle (CP)

- The universe is homogeneous and isotropic on large scales.
- The most fundamental assumption in modern cosmology.
- The CMB strongly supports isotropy around us.
- Recent LSS observations provide relevant data for testing the CP.



Planck CMB temperatures





SDSS galaxies

Previous studies on homogeneity test

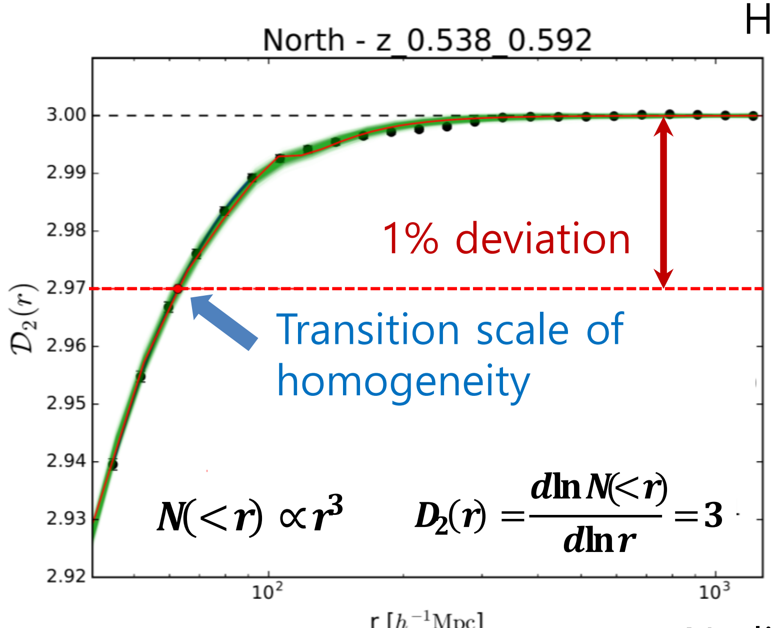
- Hogg et al. (2005) – SDSS DR7 LRG $(0.2 < z < 0.4)$

  Scrimgeour et al. (2012) – WiggleZ Dark Energy Survey $(0.1 < z < 0.9)$

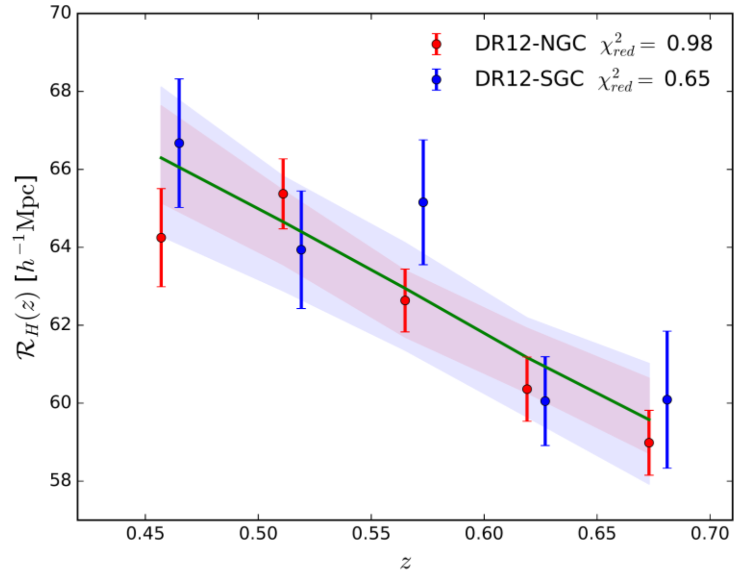
  Ntelis et al. (2017) – BOSS DR12 CMASS $(0.4 < z < 0.7)$

  - Counting galaxies within a sphere → Averaged $N(< R)$ or $D_2(R)$

  ➔ Galaxies are homogeneously distributed on $R > 70\ h^{-1}\mathrm{Mpc}$.



Homogeneity scale of the Univ., $R_H = 60{\sim}70\ h^{-1}\mathrm{Mpc}$



Ntelis et al. (2017)

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The cosmological principle is not in the sky

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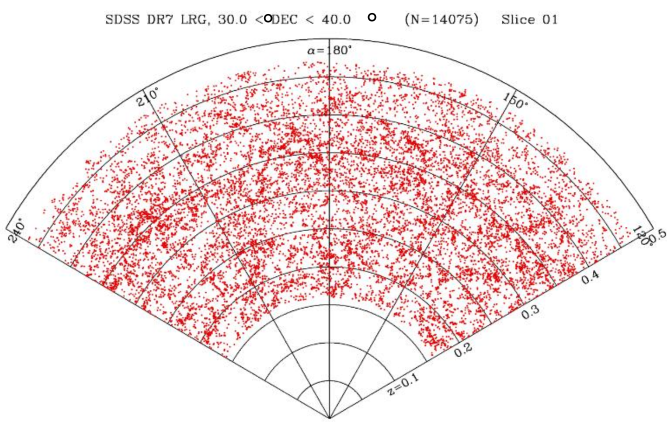
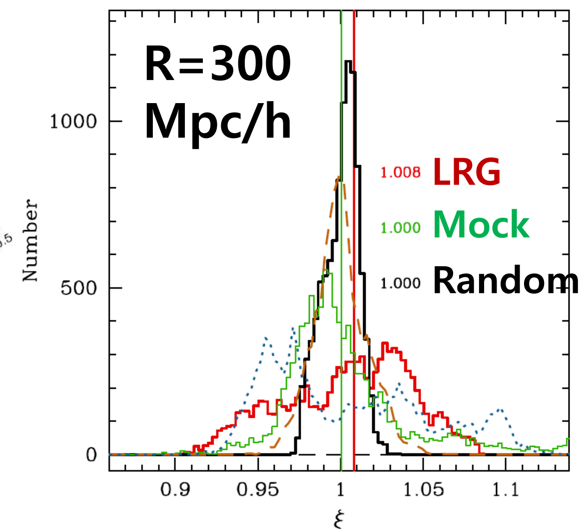
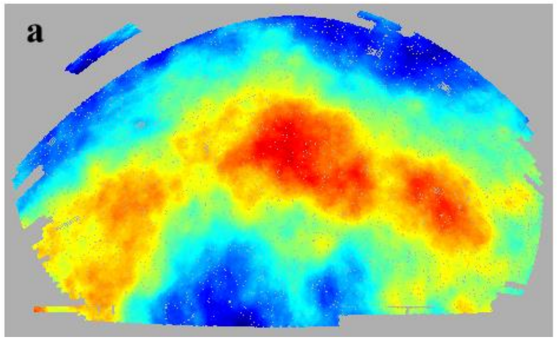
- SDSS DR7 Luminous Red Galaxies (LRG) $(0.2 < z < 0.4)$
- Average and fluctuations of galaxy number counts are used for homogeneity test.
- Even at scales up to 300 Mpc/h, the homogeneity is not established.





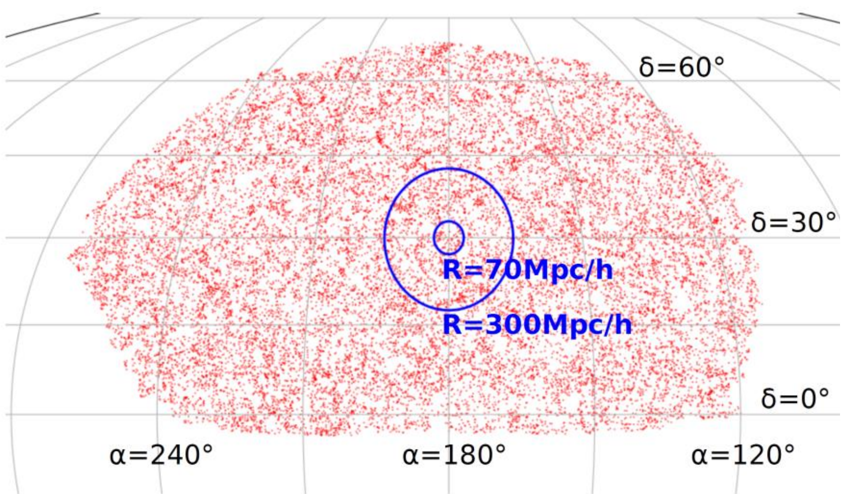
R=300 Mpc/h

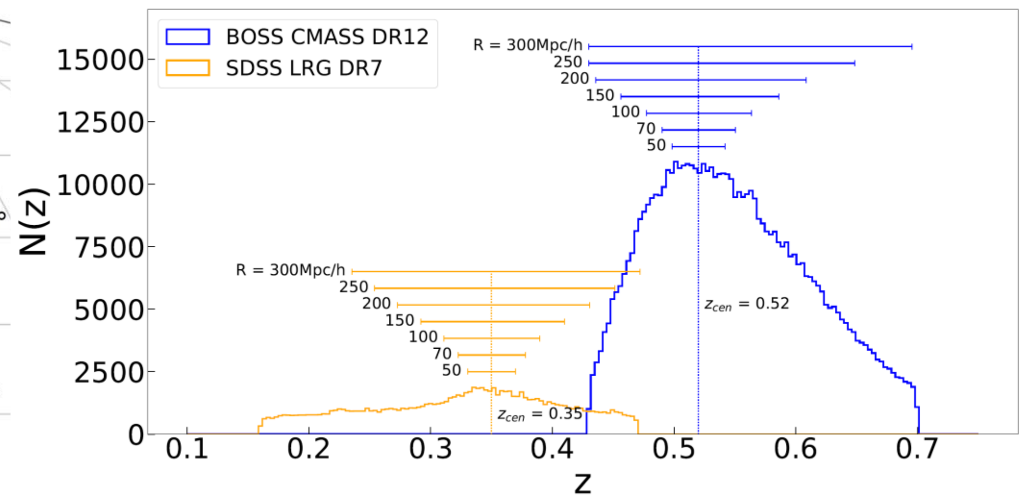


ξ (relative # density)

Data

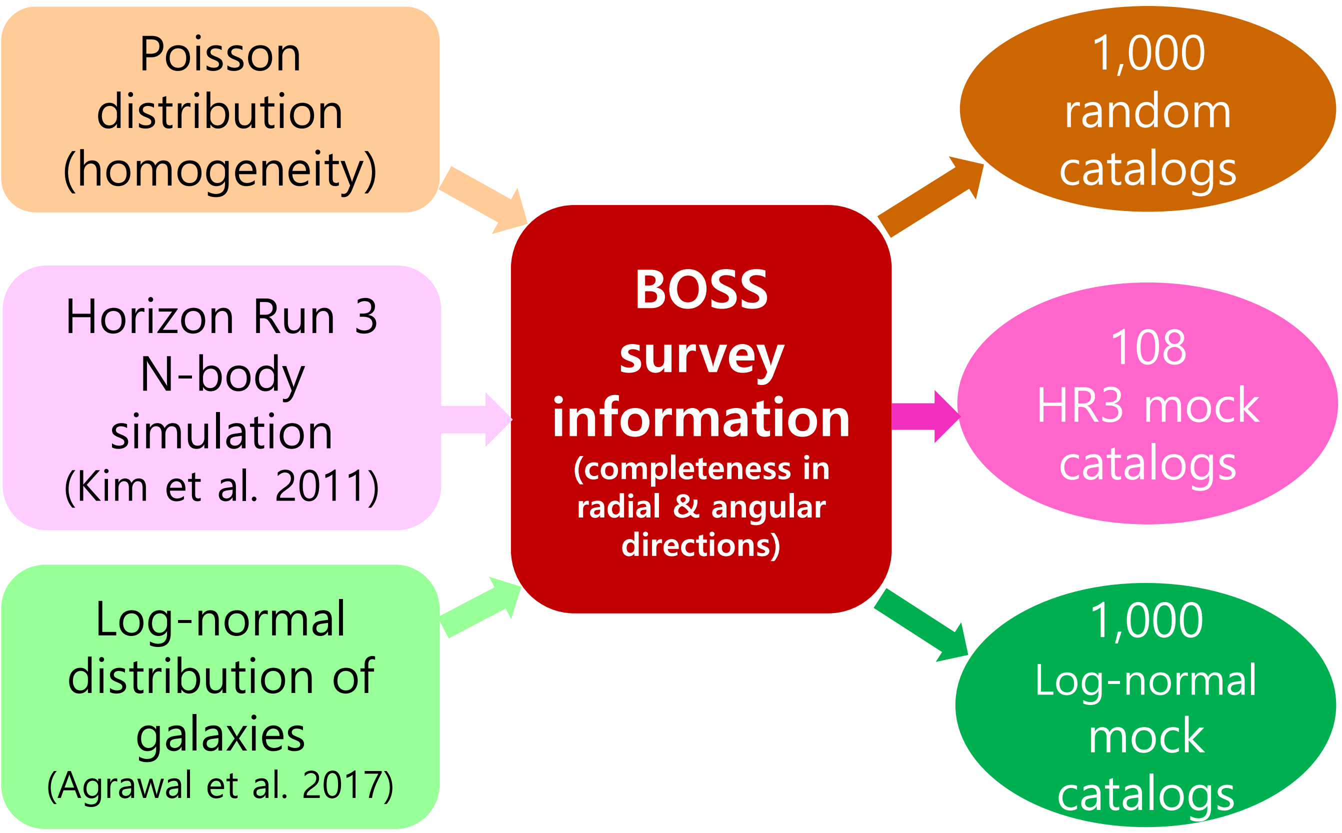
- Baryon Oscillation Spectroscopic Survey CMASS galaxy sample
  - Massive galaxies at $0.43 < z < 0.7$ ($z_{\rm cen} = 0.52$). $N \approx 930{,}000$.
    (North Galactic Cap galaxies with $N \approx 570{,}000$ used in this work)
  - Farther away and much more numerous than SDSS LRG ($N \approx 10^5$)
    → Suitable for testing homogeneity of the matter distribution.





- **Random and mock catalogs**

  - Random catalogs are used as a criterion for homogeneity.
  - Mock catalogs are used to check consistency with the current paradigm of cosmology.

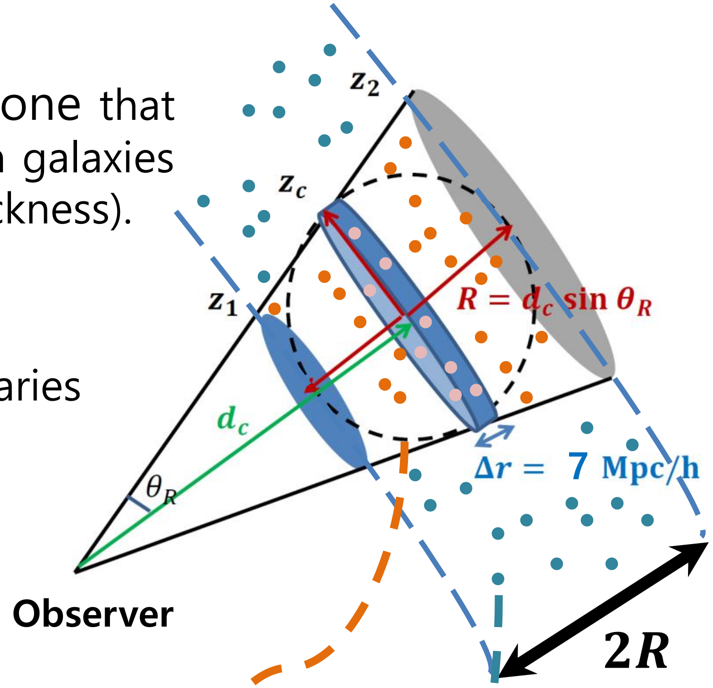


Method (counting galaxies within a truncated cone)

- Count the number of galaxies in a truncated cone that is circumscribing a sphere of radius R centered on galaxies near the central redshift $z_{\rm cen} = 0.52$ ($7\ h^{-1}{\rm Mpc}$ thickness).

- Define a statistical estimator ξ.
  - Unaffected by the radial selection effect that varies with redshift.
  - $\xi \rightarrow 1$ for homogeneous distribution.

- Measure ξ while increasing the radius R.
  - Estimate average $\langle\xi\rangle$ & std σ_ξ, and compare with random & mock catalogs.

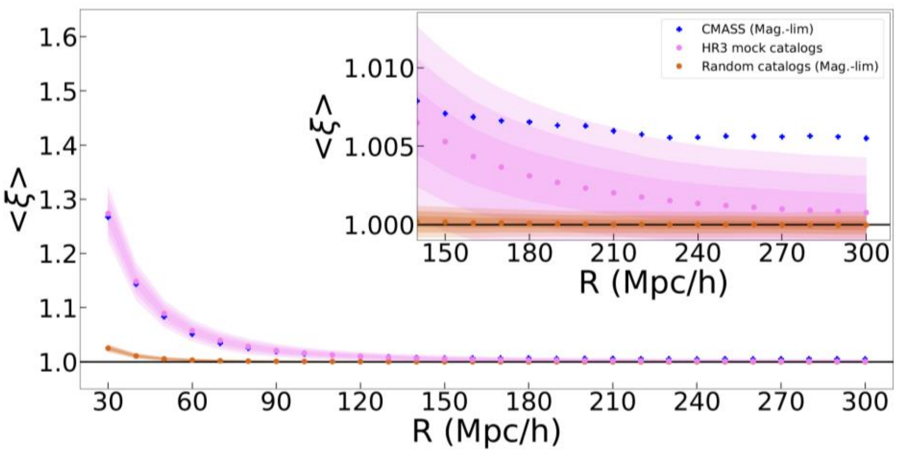


$$\xi(R) = \frac{\textbf{number density within a truncated cone}}{\textbf{number density within the whole slice of } 2R \textbf{ thickness}}$$

Results

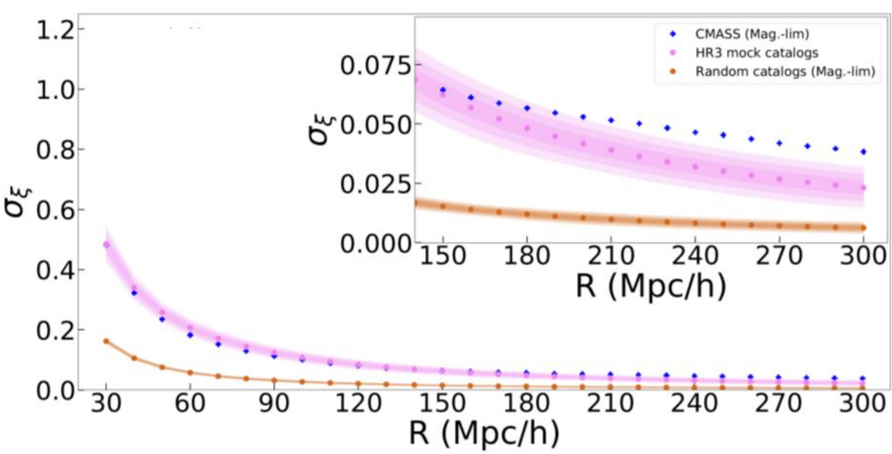
Variation of $\langle\xi\rangle$ and σ_ξ on scales R=30 - 300 $h^{-1}\mathrm{Mpc}$

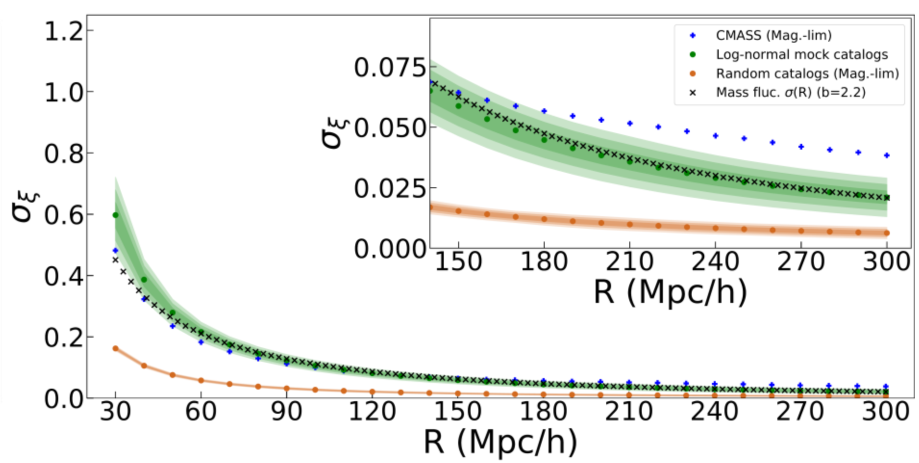
- Up to radius R=300 Mpc, $\langle\xi\rangle$ and σ_ξ in the CMASS data deviates significantly from the trend in random data.



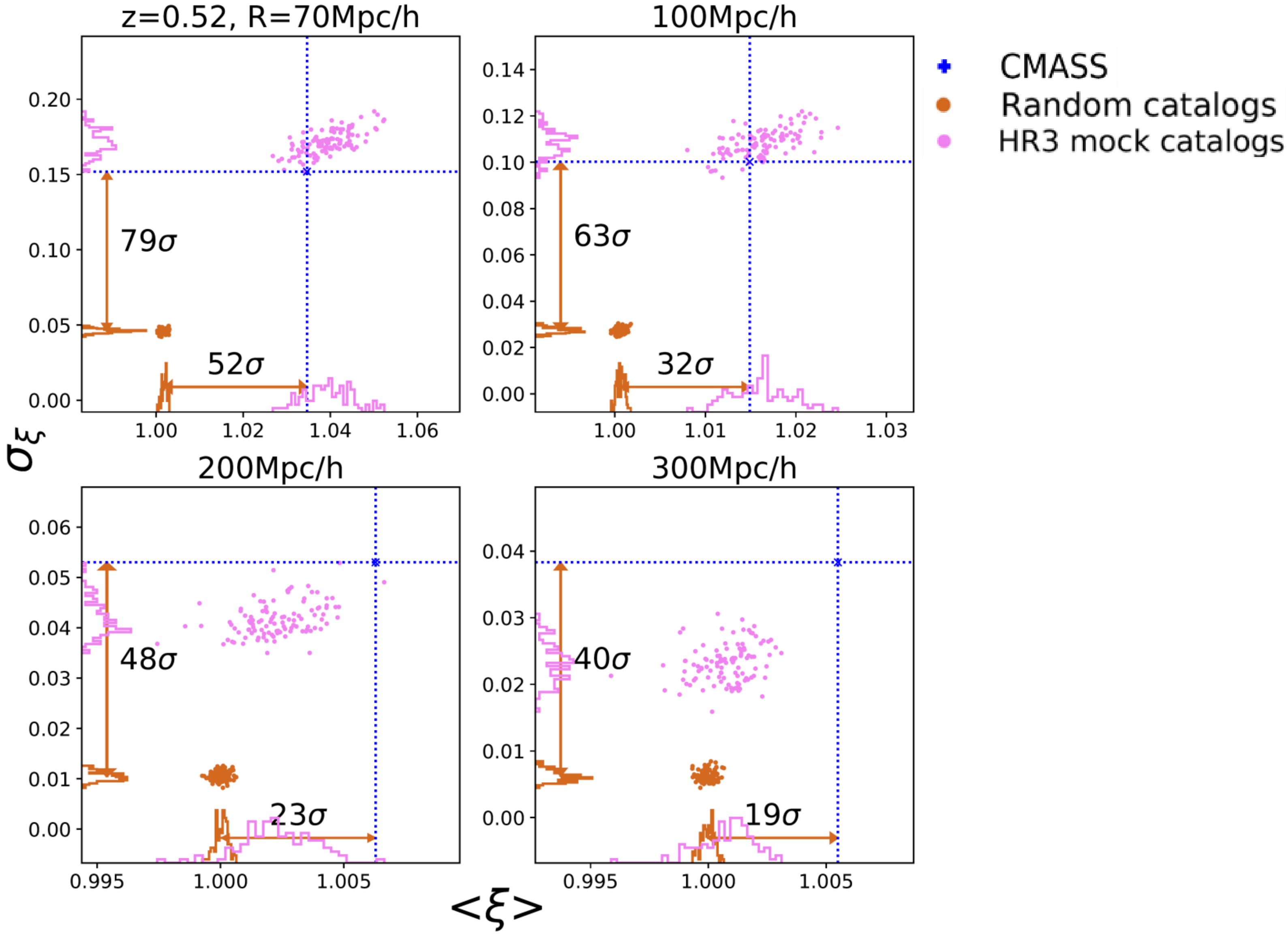
- The CMASS data show a trend consistent with (i) HR3 and (ii) log-normal mock catalogs and (iii) the direct estimation from the theoretical power spectrum.

- CMASS
- Random catalogs
- HR3 mock catalogs
- Log-normal mock catalogs
- X Mass fluctuations $\sigma(R)$ $(b = 2.2)$ (based on linear matter power spectrum)

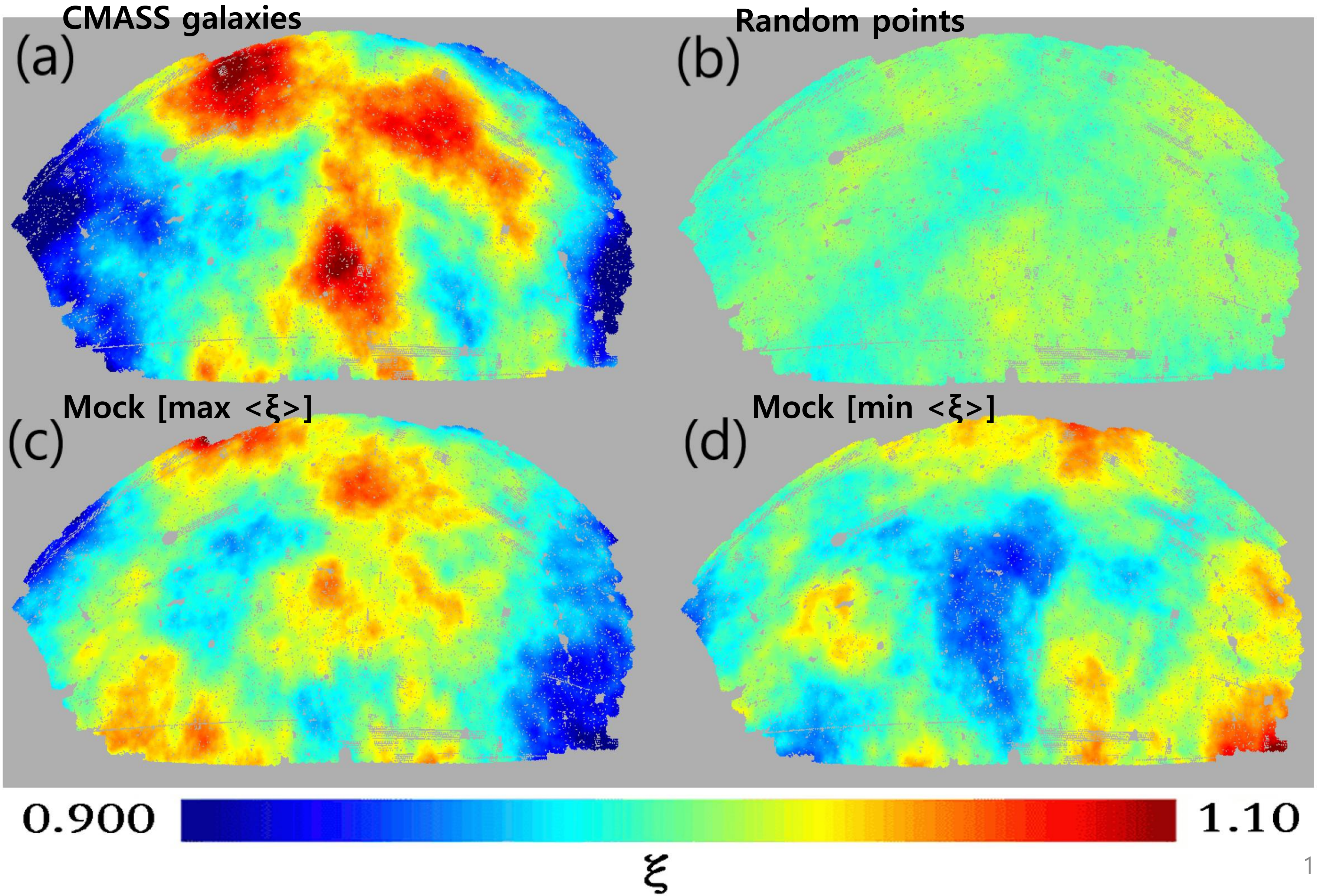




CMASS vs Random & HR3 mock catalogs (<ξ> & σ_ξ)



ξ-distribution in the CMASS survey region (R=300 h^{-1}Mpc)



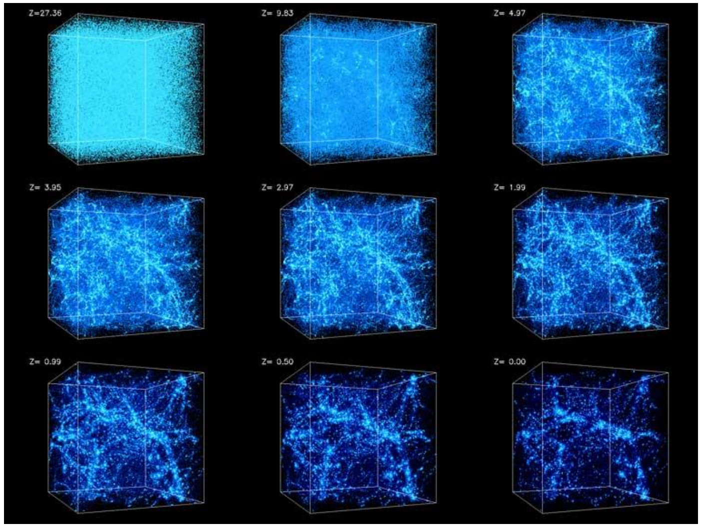
Discussion

- The observed galaxy distribution (light) and the simulated dark matter distribution (matter) are quite inhomogeneous even on a large scale.
- Does the inhomogeneous matter distribution contradict the CP? NO!

  - CP is applied to the metric. Theoretically, the Universe begins with a homogeneous & isotropic background with minute metric fluctuations.

  (The metric fluctuations, initially at the level of $\delta\Phi/c^2 \approx 10^{-5}$, still remains quite low at present, $\delta\Phi/c^2 < 10^{-4}$).

- Large matter density fluctuations are possible to exist at sub-horizon scales.



http://astro.wku.edu/astr106/structure/filaments.html

- In Einstein's gravity, the matter density is related to the curvature, which is given as the second derivative of the metric.

$$R_{ik} - \frac{1}{2} g_{ik} R = \frac{8\pi G}{c^4} T_{ik}$$

(curvature) (matter density)

$$\longrightarrow \quad a^{-2} \Delta \delta\Phi = 4\pi G \delta\rho$$

Thank You