A Gigaparsec-scale Local Void and Cosmological Principle

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arXiv: 1912.12600 & 2211.XXXXX

Tsinghua University
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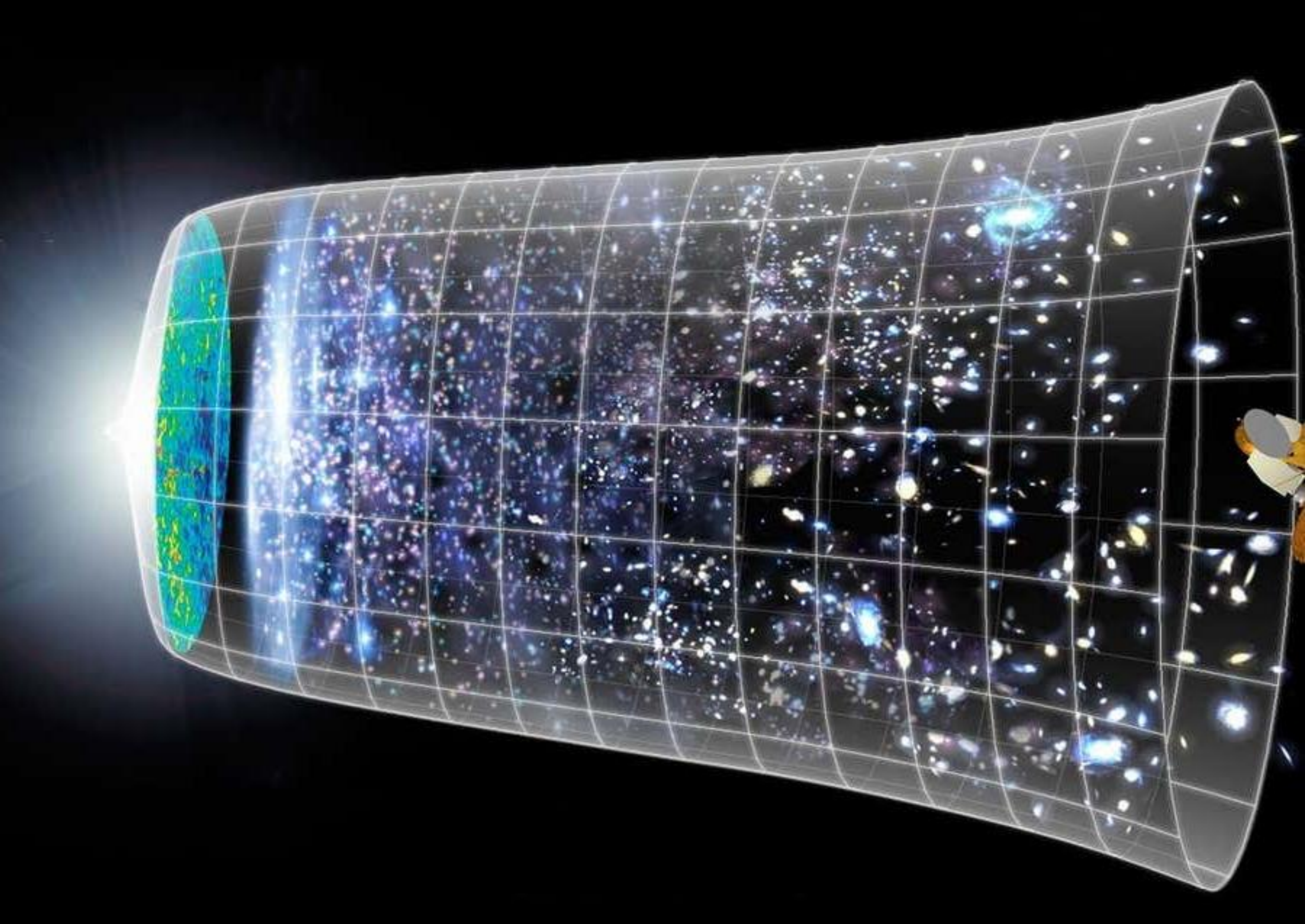


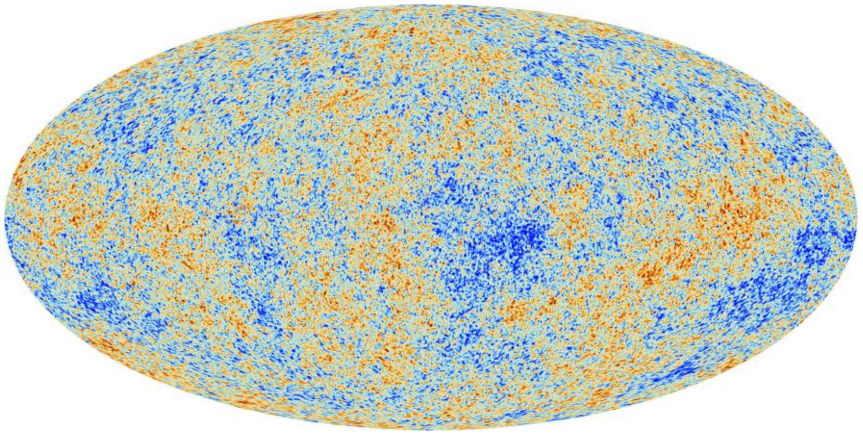
Image Credit: NASA

Cosmological Principle

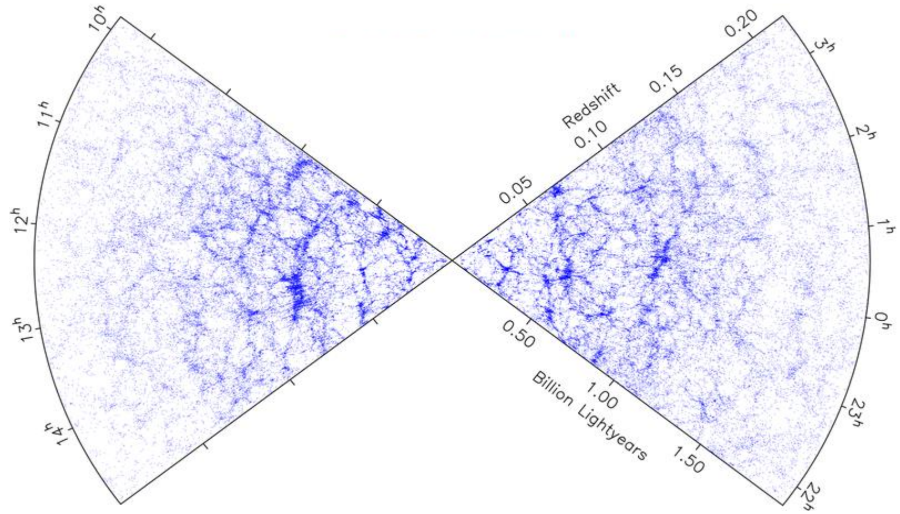
The Universe is ***homogeneous*** and ***isotropic*** on large scale, independent of location.

⇓

The law of physics should be the same at different positions of the Universe



Cosmic microwave background

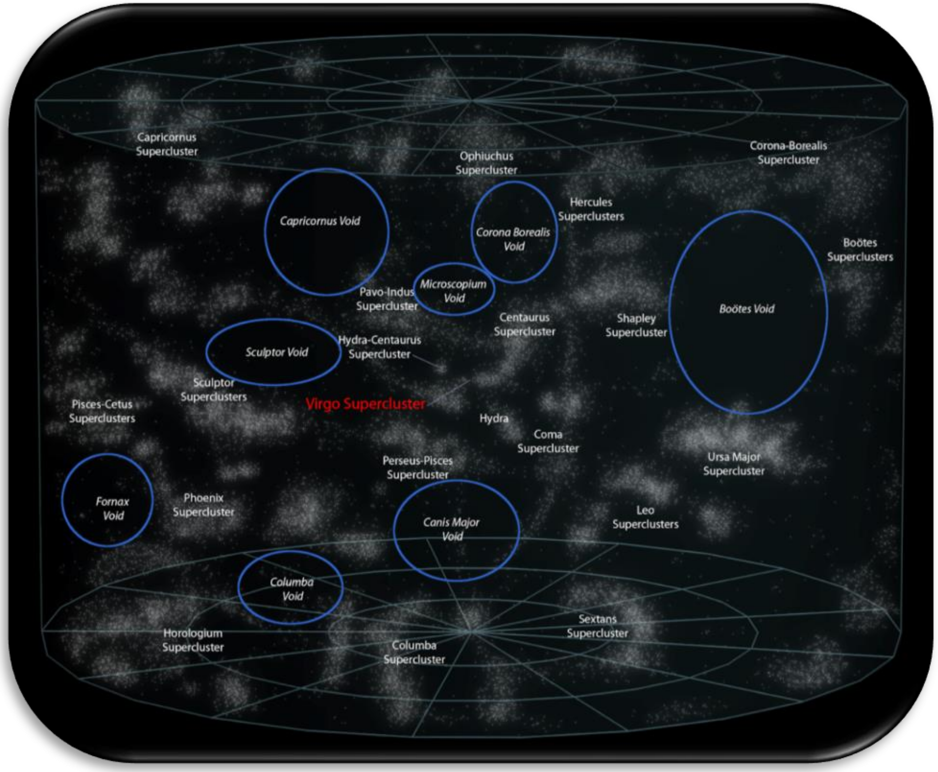


Large scale structure

Cosmic Inhomogeneity

KBC Void
308 Mpc

The List of Voids

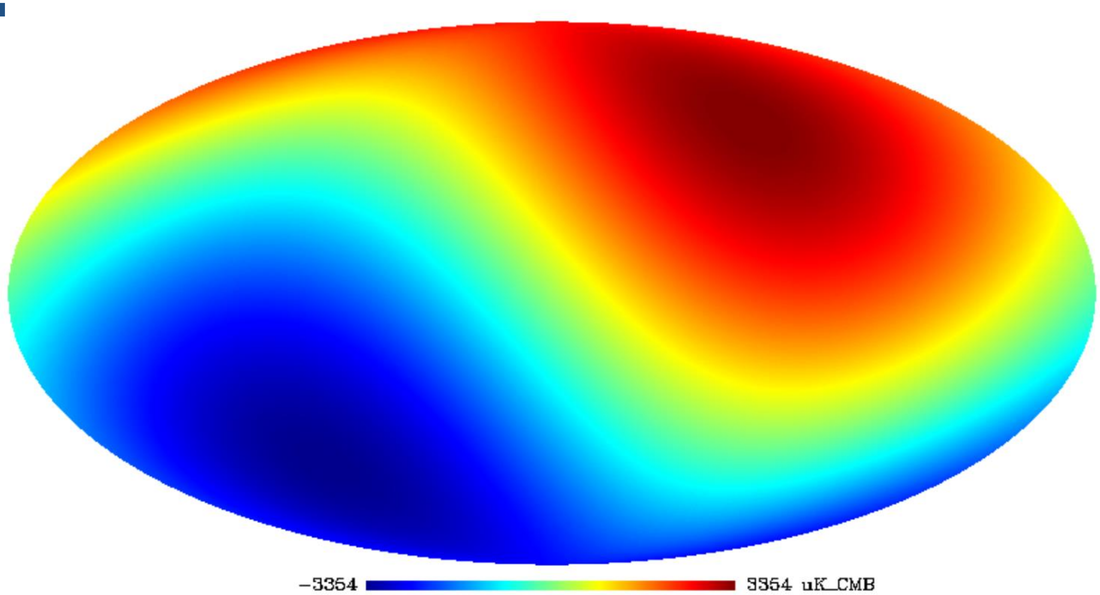


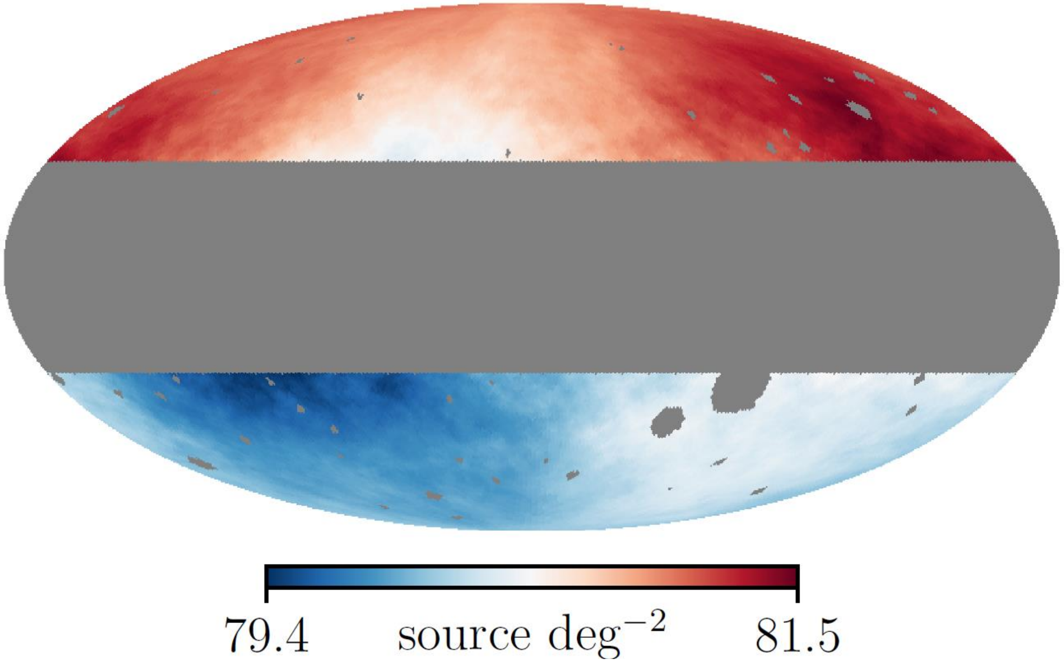
Cosmic Anisotropy

CMB Temperature Dipole

$\mathcal{D} \sim 10^{-3}$

$(264^{\circ}, 48^{\circ})$



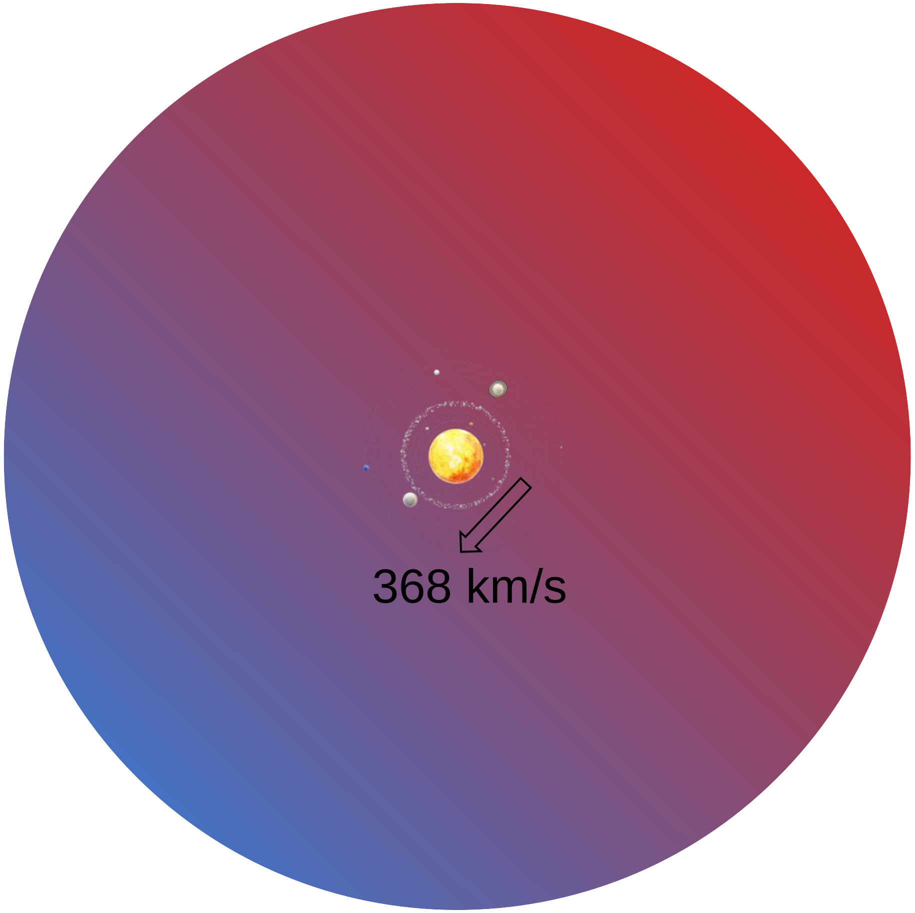


Quasar Number Dipole

$\mathcal{D} \sim 10^{-2}$

$(233^{\circ}, 34^{\circ})$

Potential Explanation



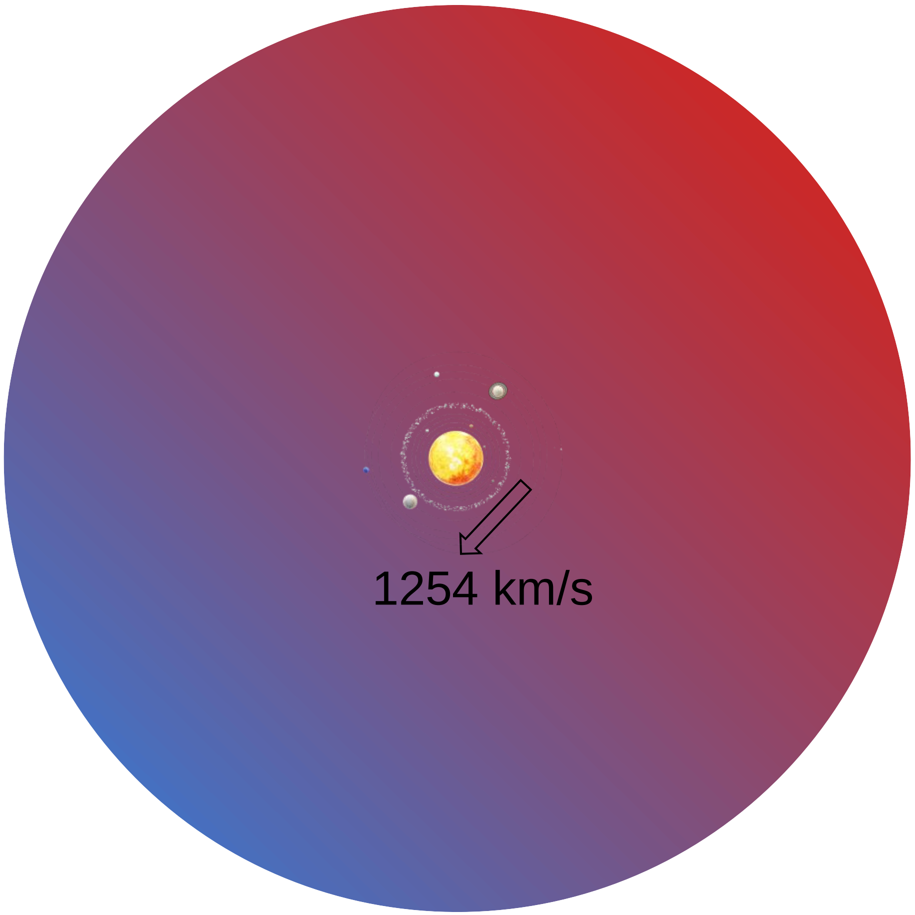
Doppler effect in CMB temperature

$$T' = \gamma(1 + \beta \cos\theta)\, T$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \quad \beta = \frac{v}{c}$$

$$\mathcal{D} \cong \frac{v}{c}$$

Potential Explanation



Doppler effect and aberration in quasar number counting

$$v_o = v_r \delta(v)$$

$$S \propto v^{-\alpha} \qquad \frac{dN}{d\Omega} \propto S^{-x}$$

$$\mathcal{D} \cong [2 + x(1+\alpha)]\frac{v}{c}$$

Potential Explanation

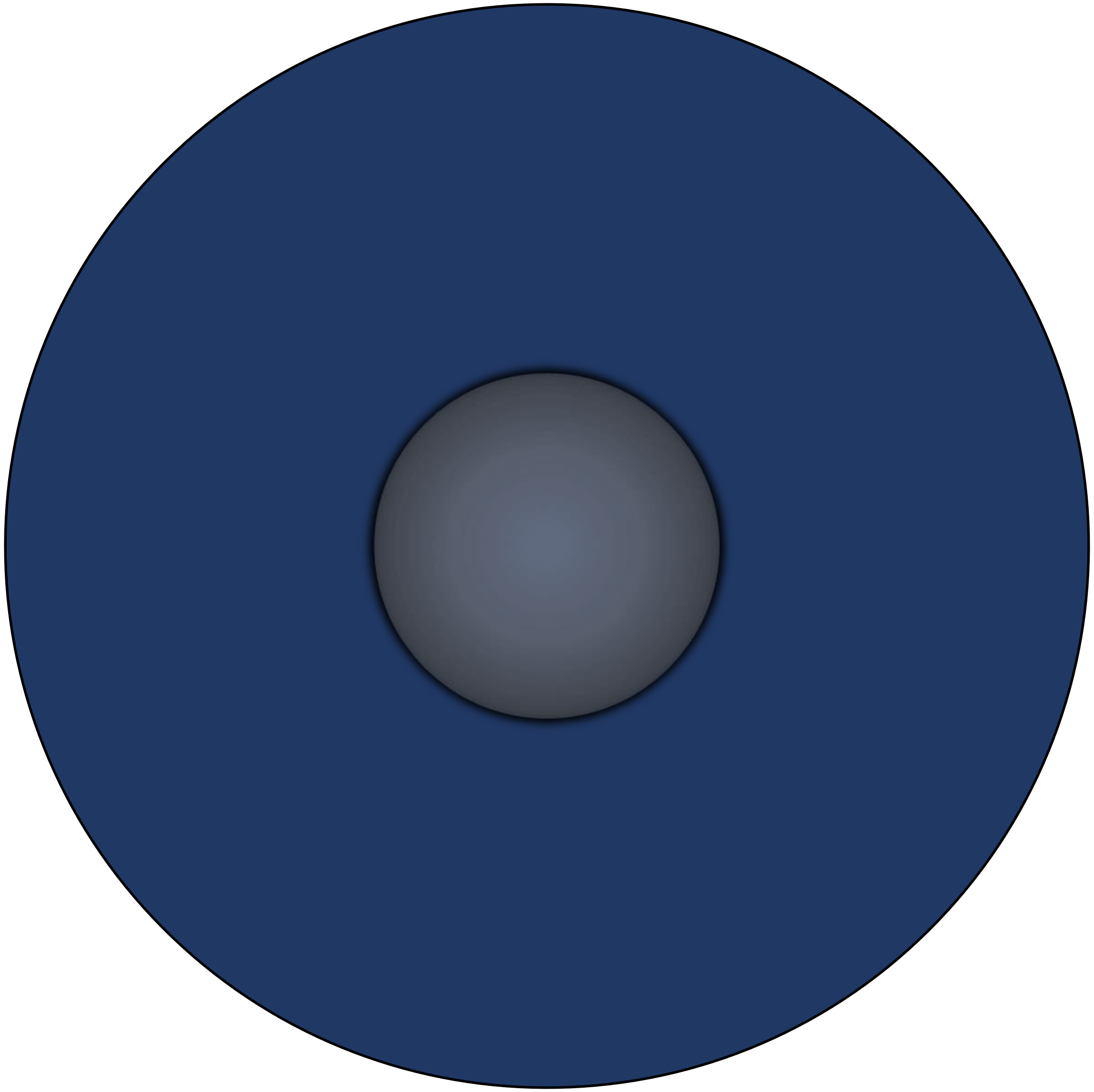
Rotating Universe

Angular velocity
$\omega < 10^{-9} rad/yr$

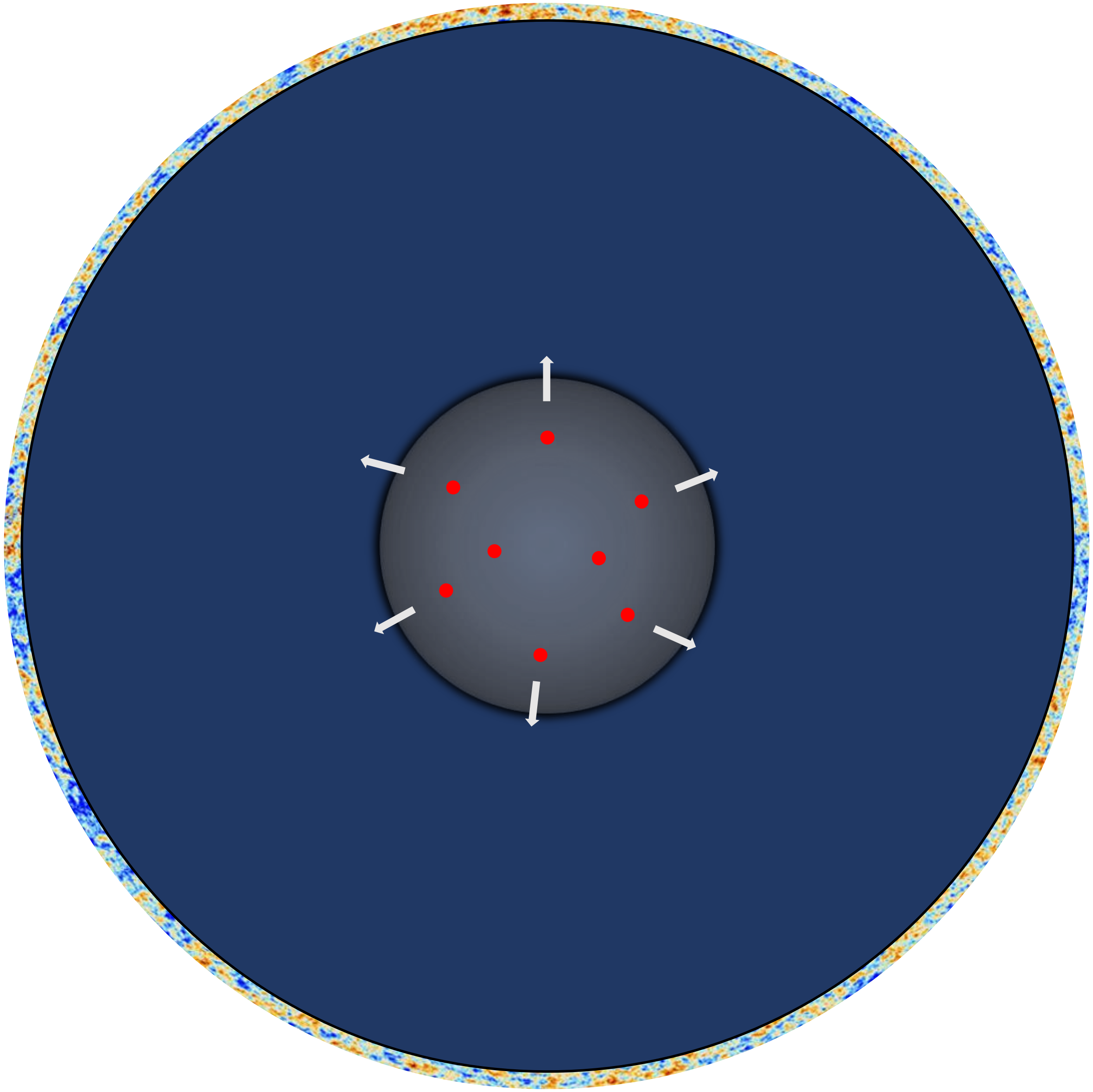
"Is the Universe rotating?", S.-C. Su and M.-C. Chu, APJ

A local structure may exist and influence the observations

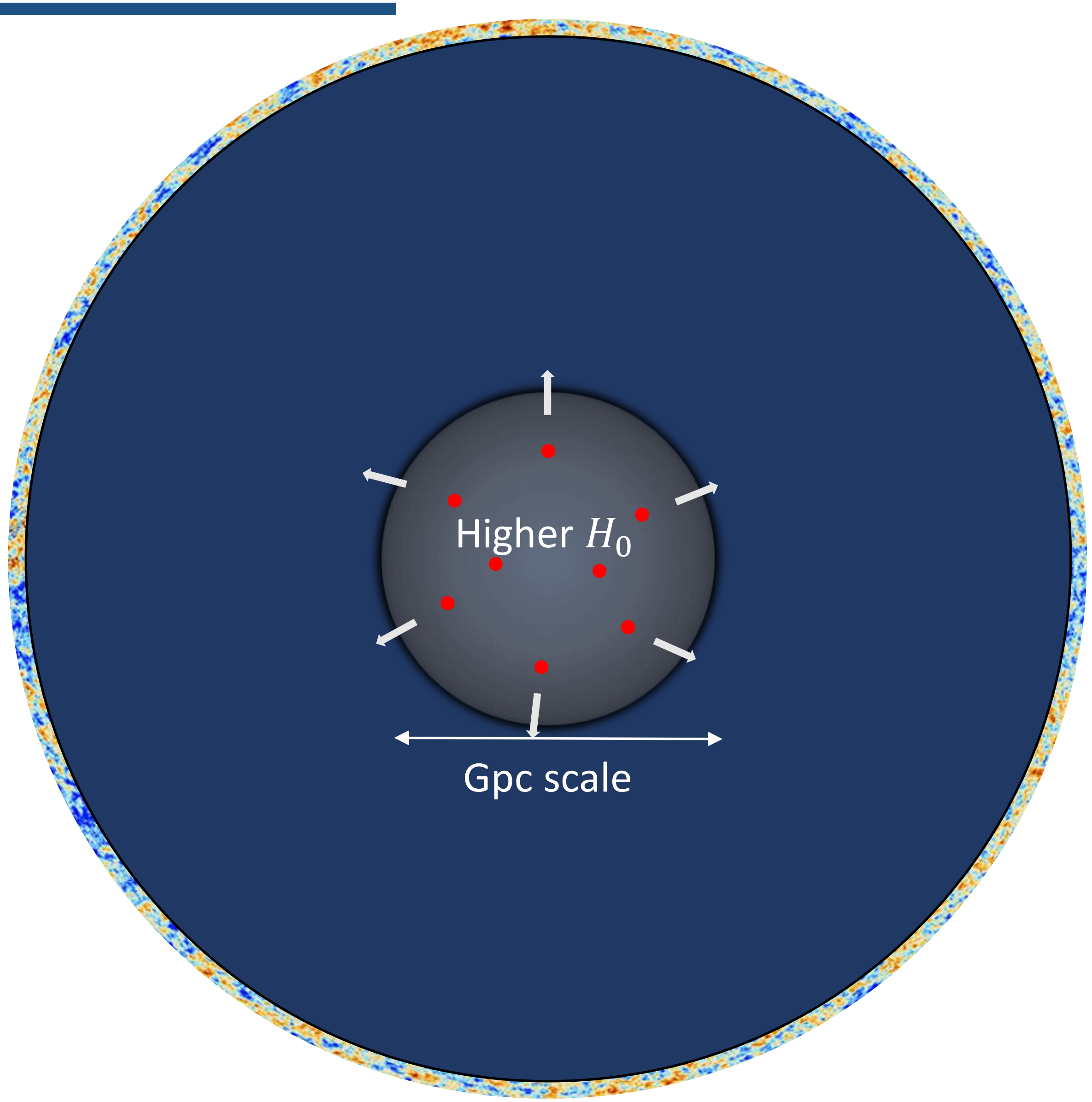
A Local Void



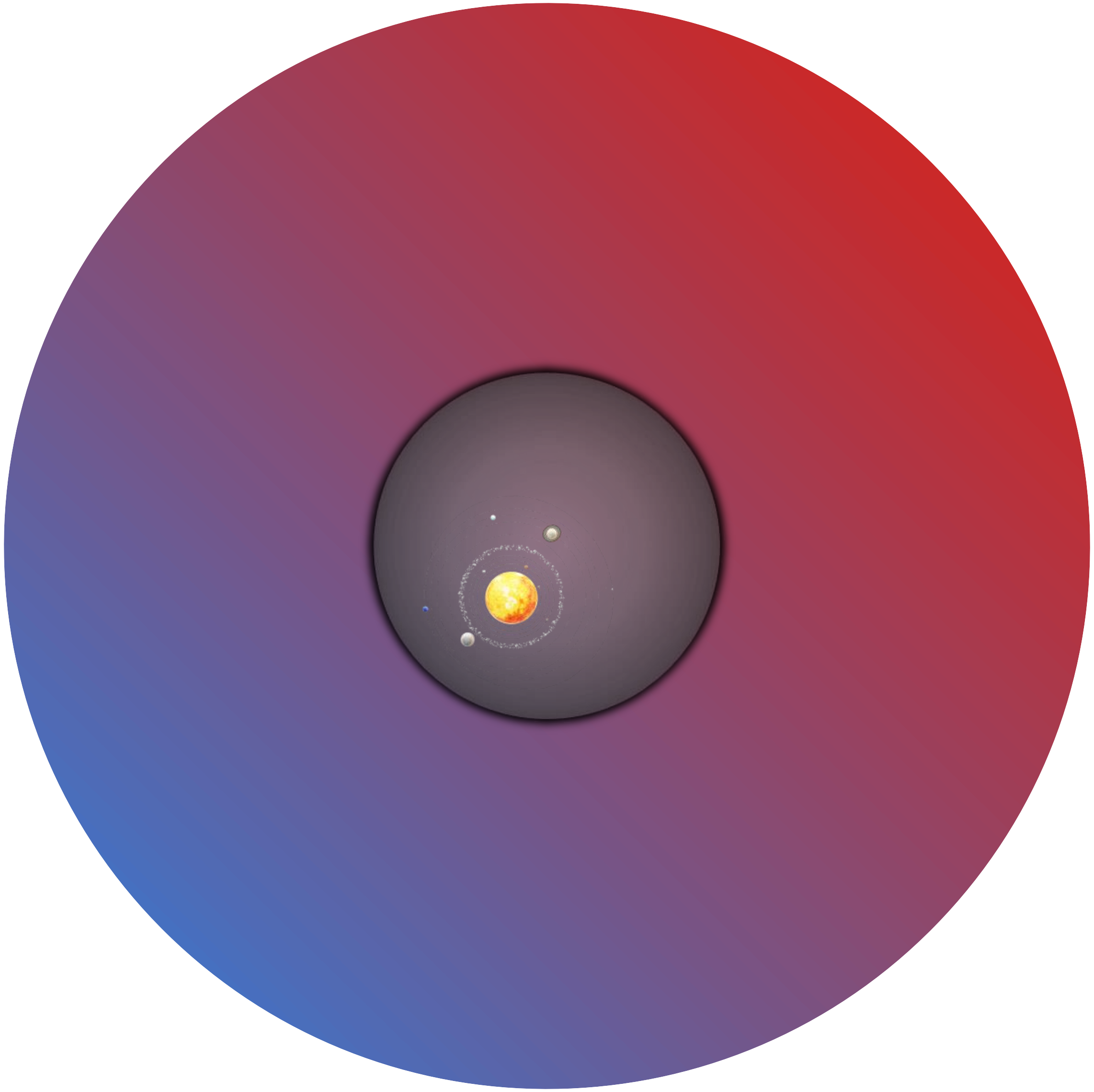
A Local Void & H_0



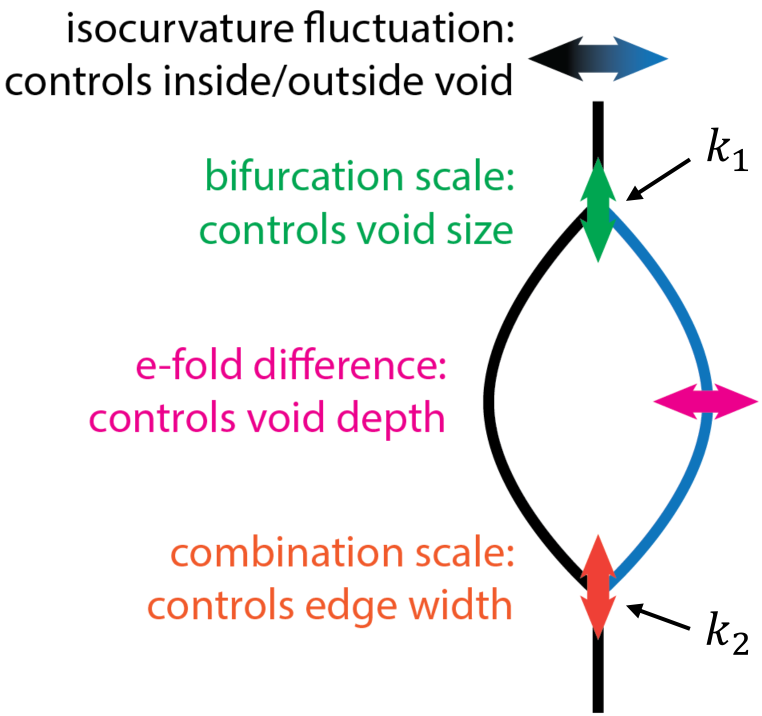
A Local Void & H_0

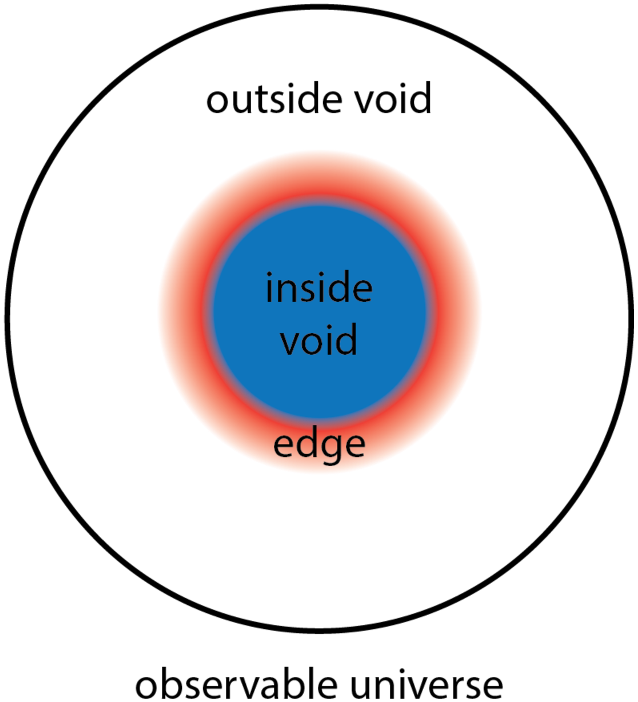


A Local Void & Dipole



Multi-Stream Inflation





We parameterize the void profile by introducing δ_V, r_V and Δ_r

$$\delta(r) = \delta_V \frac{1 - \tanh((r - r_V)/2\Delta_r)}{1 + \tanh(r_V/2\Delta_r)}$$

Here, the void shape is decided by the multi-stream inflation potential

$$\delta_V \sim \delta N, \quad r_V \sim \frac{1}{k_1}, \quad \Delta_r \sim \frac{1}{k_1} - \frac{1}{k_2}$$

Hubble tension in a Gpc-scale local void

Qianhang Ding, Tomohiro
Nakama, Yi Wang, 1912.12600

LTB Metric & H_0

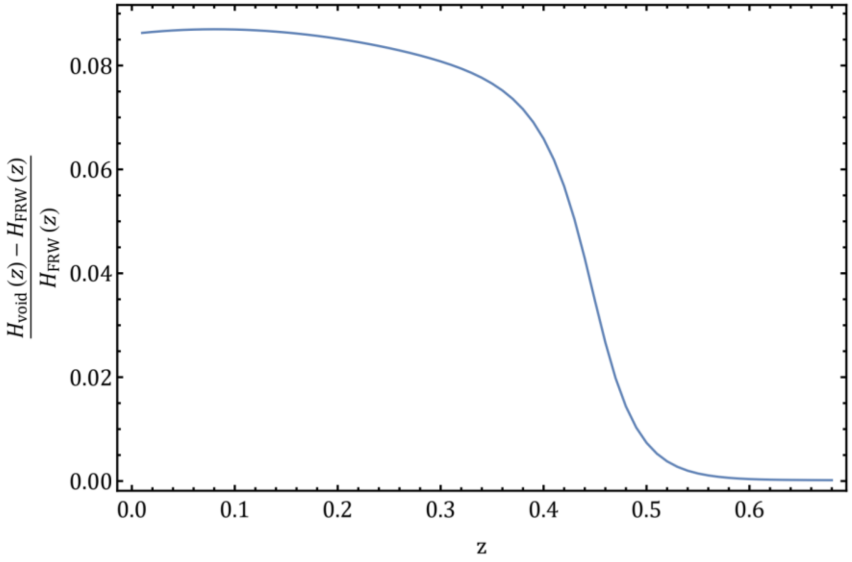
In order to describe spacetime in void model, we use the Lemaitre-Tolman-Bondi (LTB) metric:

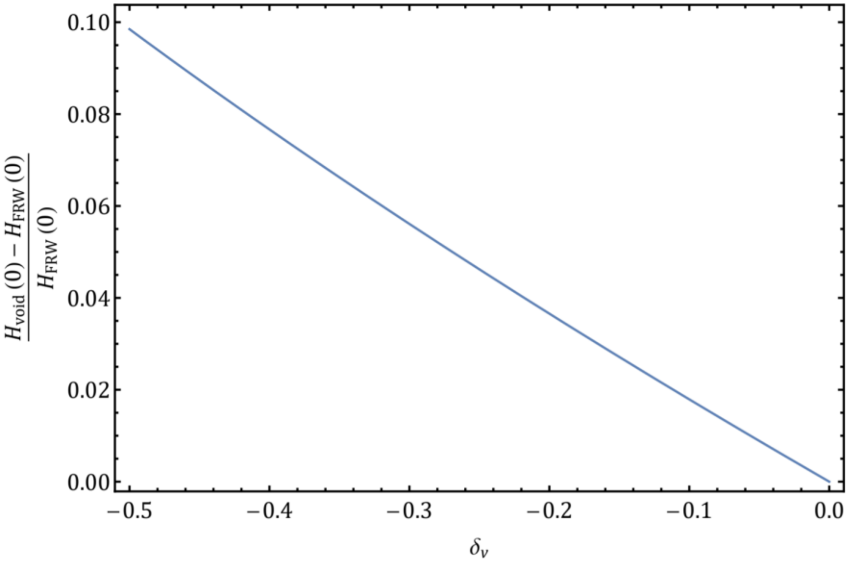
$$ds^2 = c^2dt^2 - \frac{R'(r,t)^2}{1-k(r)}dr^2 - R^2(r,t)d\Omega^2$$

The Friedmann equation in LTB metric is

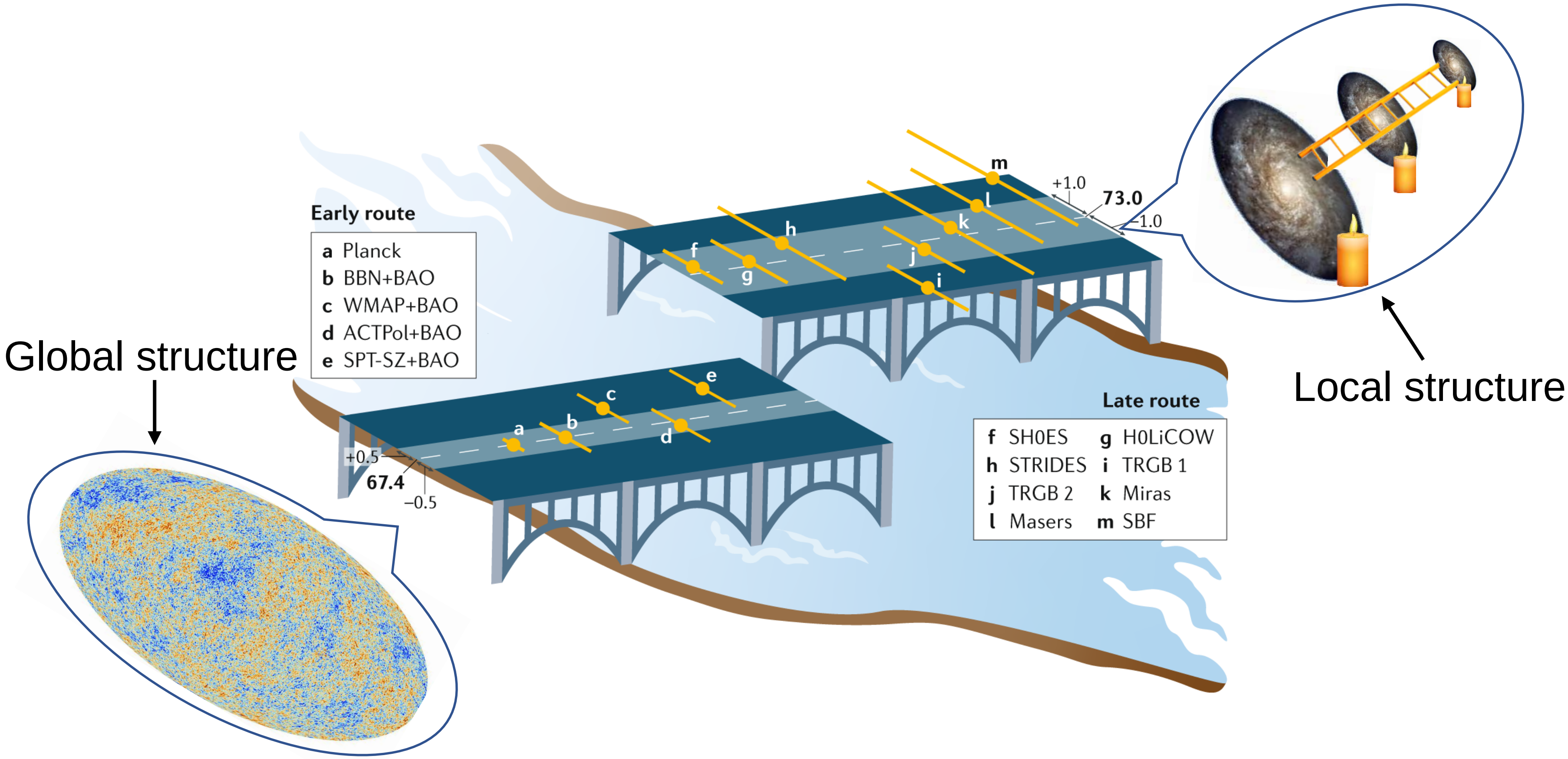
$$H(r,t)^2 = H_0(r)^2\left(\Omega_M(r)\frac{R_0(r)^3}{R(r,t)^3} + \Omega_k(r)\frac{R_0(r)^2}{R(r,t)^2} + \Omega_\Lambda(r)\right)$$

Which can introduce different Hubble parameters in local void



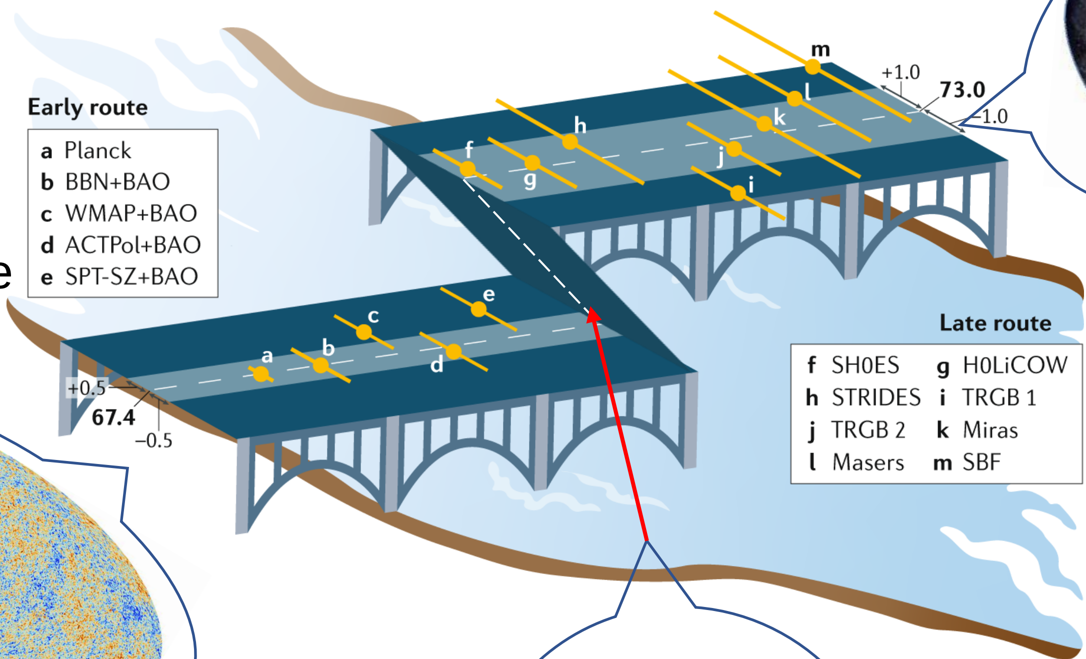


Hubble Tension

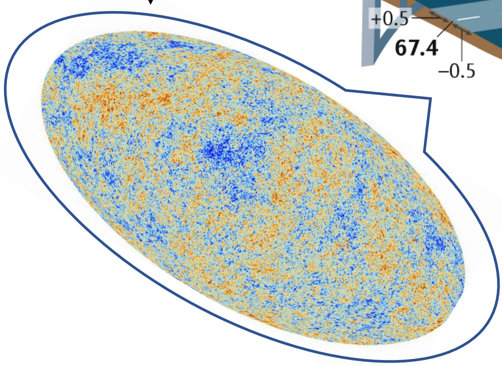


Riess, Adam G. "The expansion of the universe is faster than expected." *Nature Reviews Physics* 2.1 (2020): 10-12.

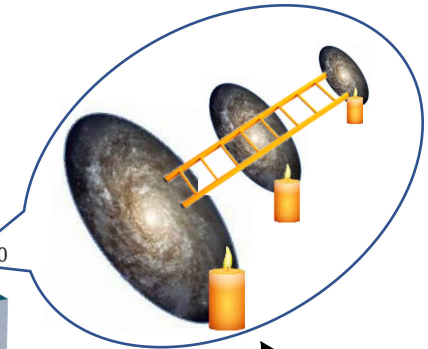
Hubble Tension

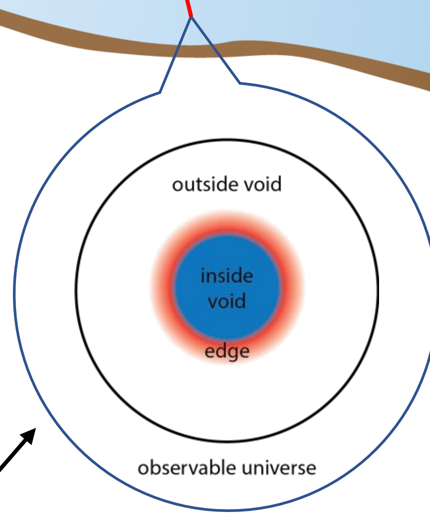


Global structure

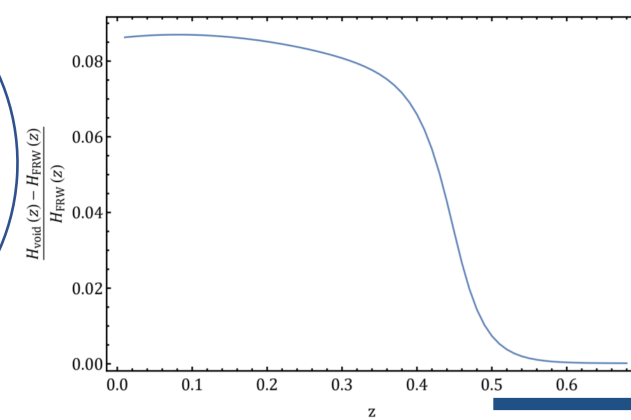


Local structure





Local void structure



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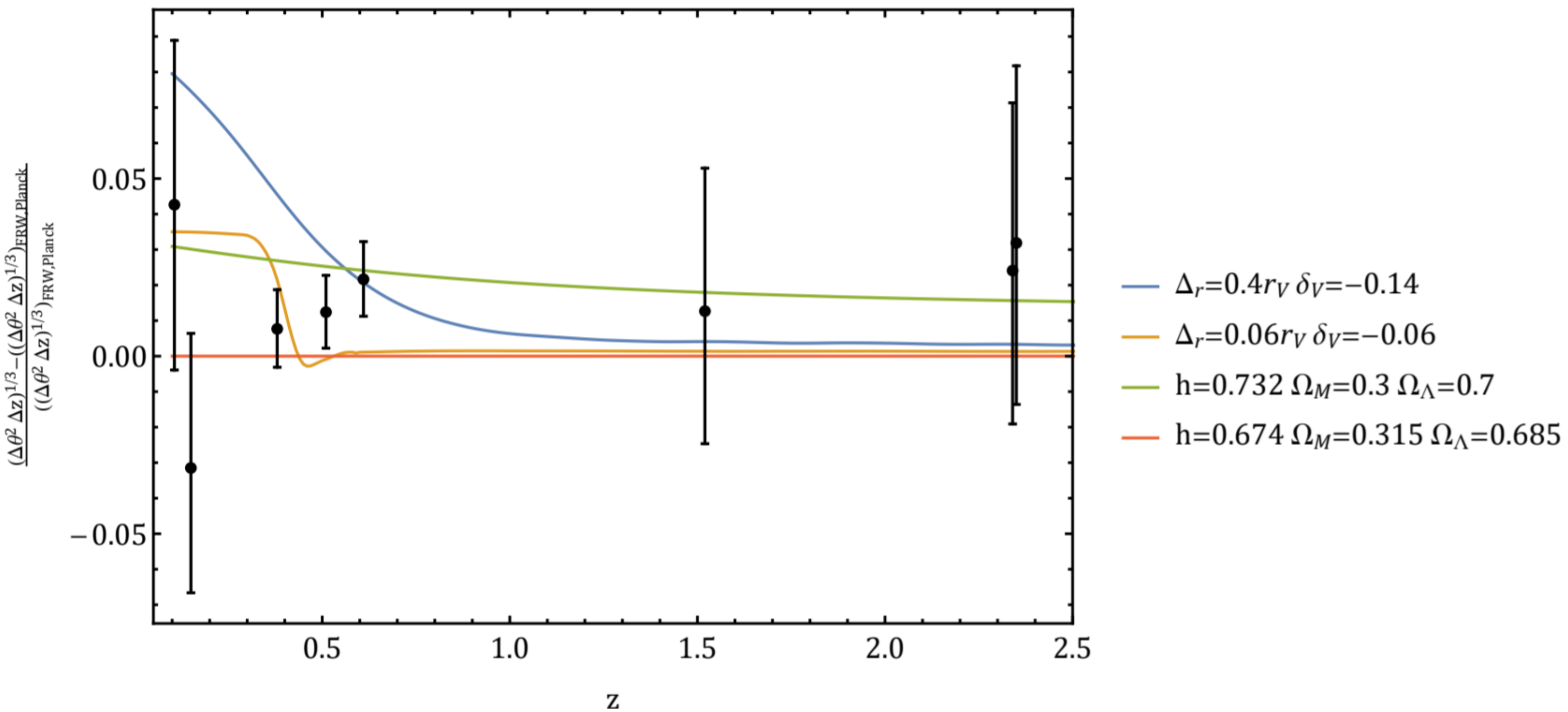
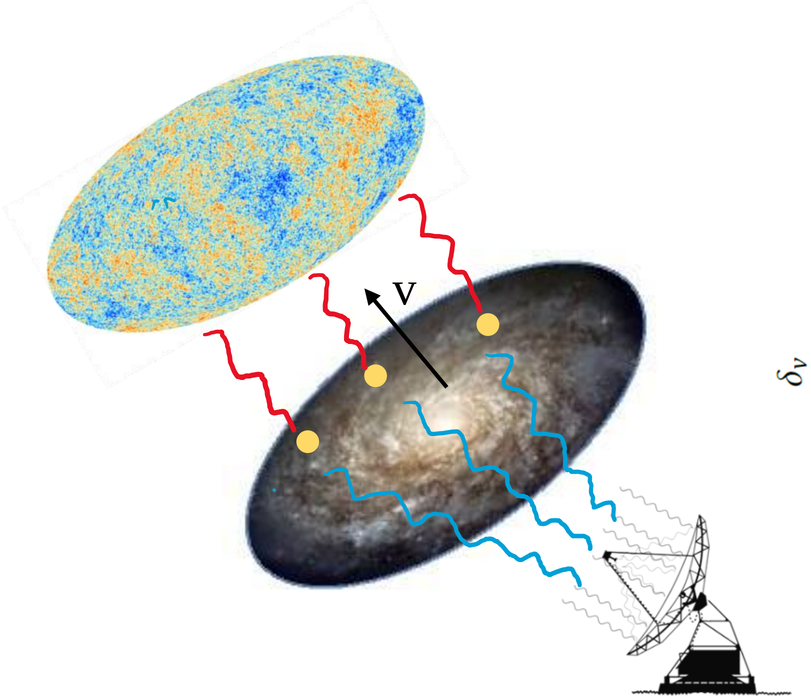
BAO observation



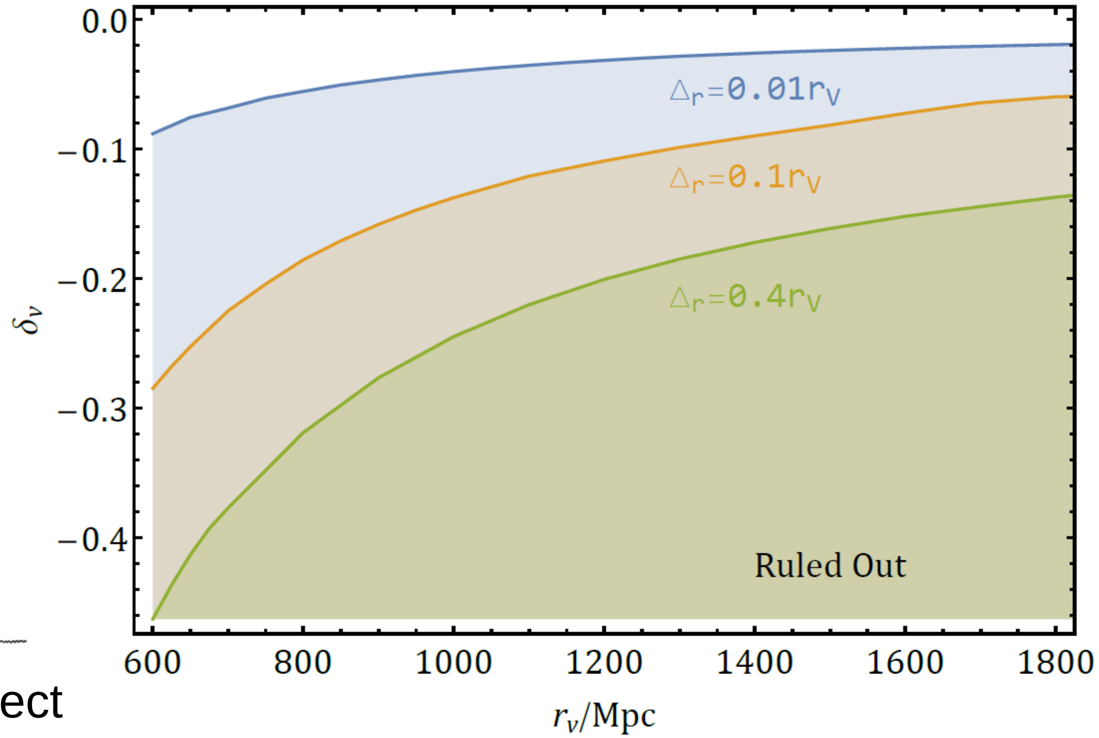
$$(\Delta\theta^2\Delta z)^{1/3} = \frac{z_{BAO}^{1/3} r_d}{D_V^{FRW}(z_{BAO})}$$

$$D_V^{FRW}(z_{BAO}) = \frac{1}{H_0}\left[\frac{z_{BAO}}{h(z_{BAO})}\left(\int_0^{z_{BAO}} \frac{dz}{h(z)}\right)^2\right]^{1/3}$$

Kinematic SZ Effect



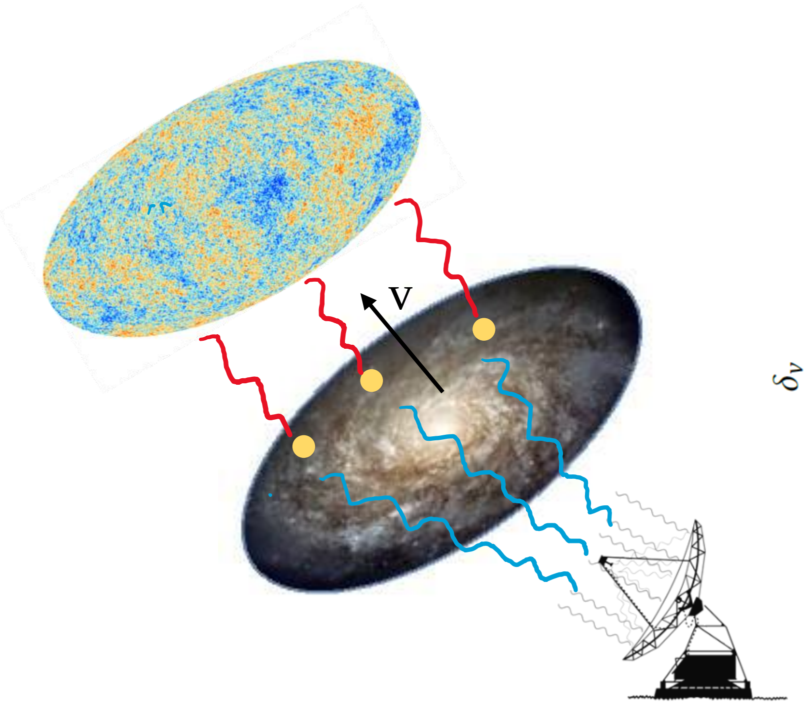
Kinematic Sunyaev-Zeldovich effect



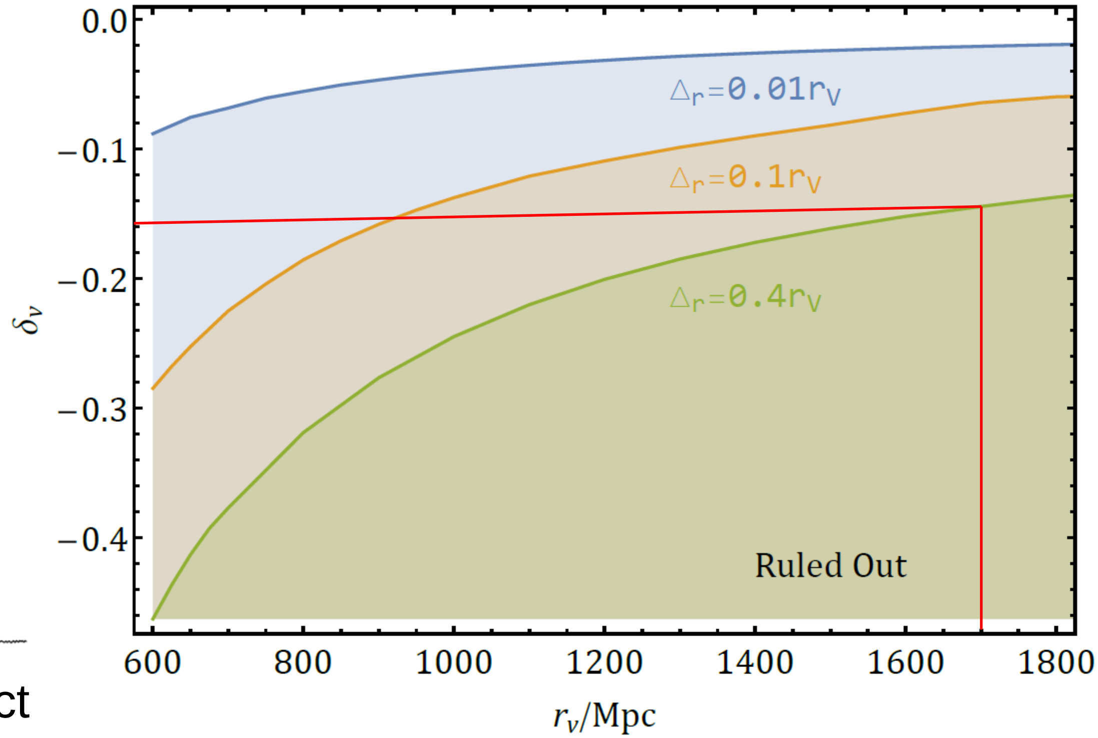
$$\Delta T_{kSZ}(\hat{n}) = T_{CMB} \int_0^{z_e} \delta_e(\hat{n}, z) \frac{V_H(\hat{n}, z) \cdot \hat{n}}{c} \, d\tau_e$$

$$T_{CMB}^2 D_{3000} < 2.9 \mu K^2 \quad D_\ell \equiv \frac{\ell(\ell+1)}{2\pi} C_\ell$$

Kinetic SZ Effect



Kinetic Sunyaev-Zeldovich effect



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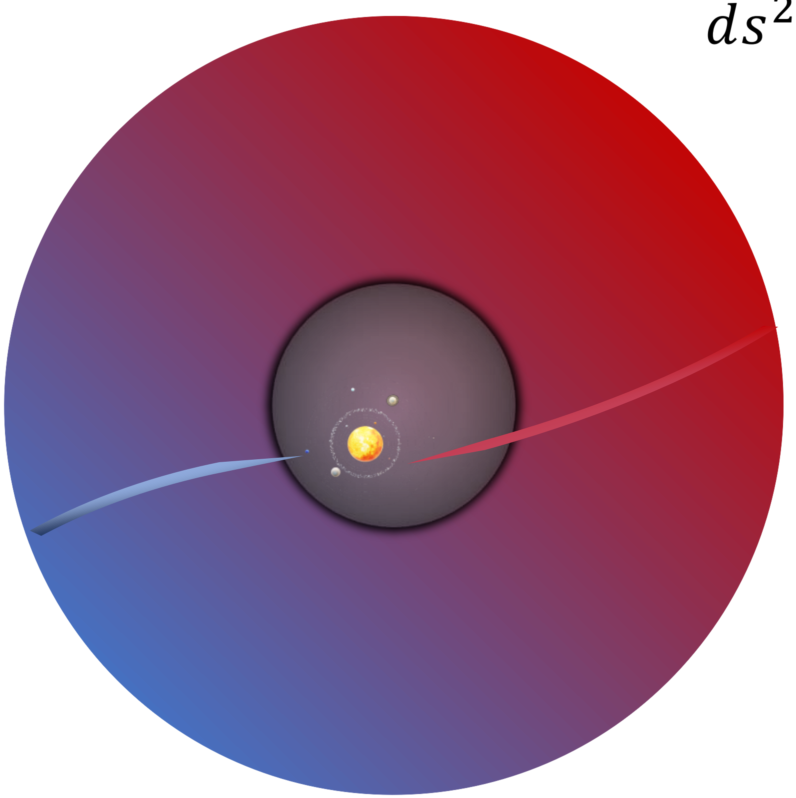
Cosmic dipoles in a Gpc-scale local void

Tingqi Cai, Qianhang Ding,
Yi Wang, 2211.XXXXX

Geodesic Equations



LTB Metric

$$ds^2 = c^2dt^2 - \frac{R'(r,t)^2}{1-k(r)}dr^2 - R^2(r,t)d\Omega^2$$

Geodesic Equations

$$\frac{d^2x^\mu}{d\lambda^2} + \Gamma^\mu_{\alpha\nu}\frac{dx^\alpha}{d\lambda}\frac{dx^\nu}{d\lambda} = 0$$

$$1 + z(\lambda_e) = \frac{\tau(\lambda_r)}{\tau(\lambda_e)}$$

Initial Conditions

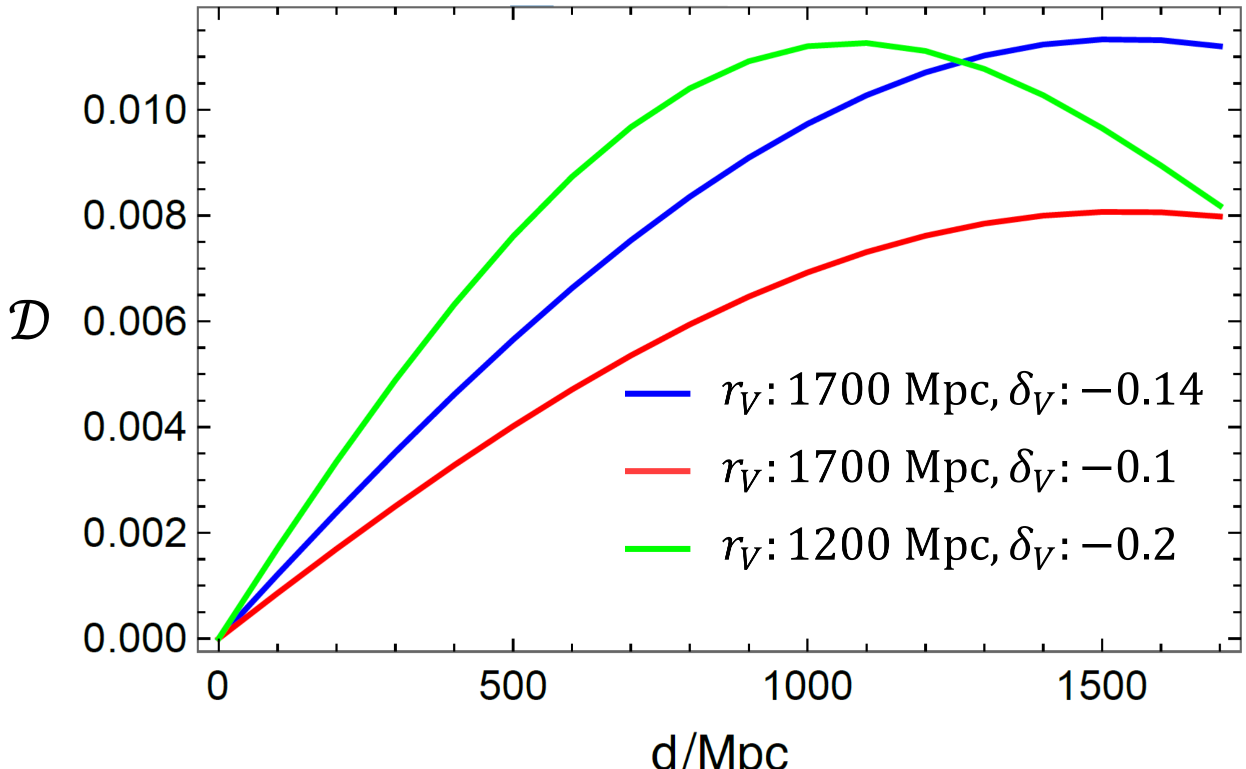
The location of observers r
and the observational angle θ

CMB Dipole

Temperature anisotropy

$$T(\hat{n}) = \frac{T^*}{1+z(\hat{n})} \qquad \frac{\Delta T}{\bar{T}} = \frac{T(\hat{n}) - \bar{T}}{\bar{T}} = \frac{\bar{z} - z(\hat{n})}{1+z(\hat{n})}$$

$$\bar{T} = \frac{1}{4\pi}\int T(\hat{n})\, d\Omega \quad 1+\bar{z} = \frac{T^*}{\bar{T}} \quad \mathcal{D} = \int_0^{2\pi}\int_0^{\pi} \frac{\Delta T}{\bar{T}}(\theta) Y_{10}^* \sin\theta \, d\theta d\varphi$$



CMB Dipole

Temperature anisotropy

$$T(\hat{n}) = \frac{T^*}{1+z(\hat{n})} \qquad \frac{\Delta T}{\bar{T}} = \frac{T(\hat{n})-\bar{T}}{\bar{T}} = \frac{\bar{z}-z(\hat{n})}{1+z(\hat{n})}$$

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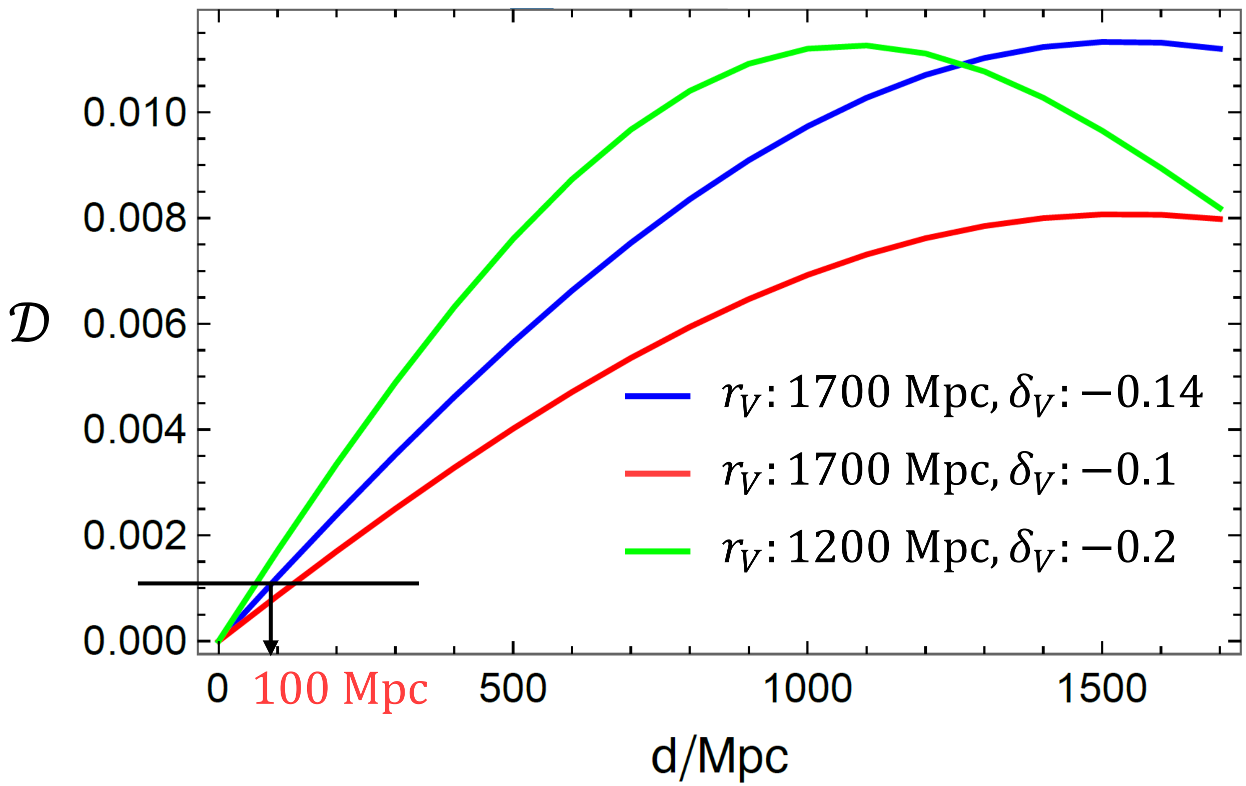
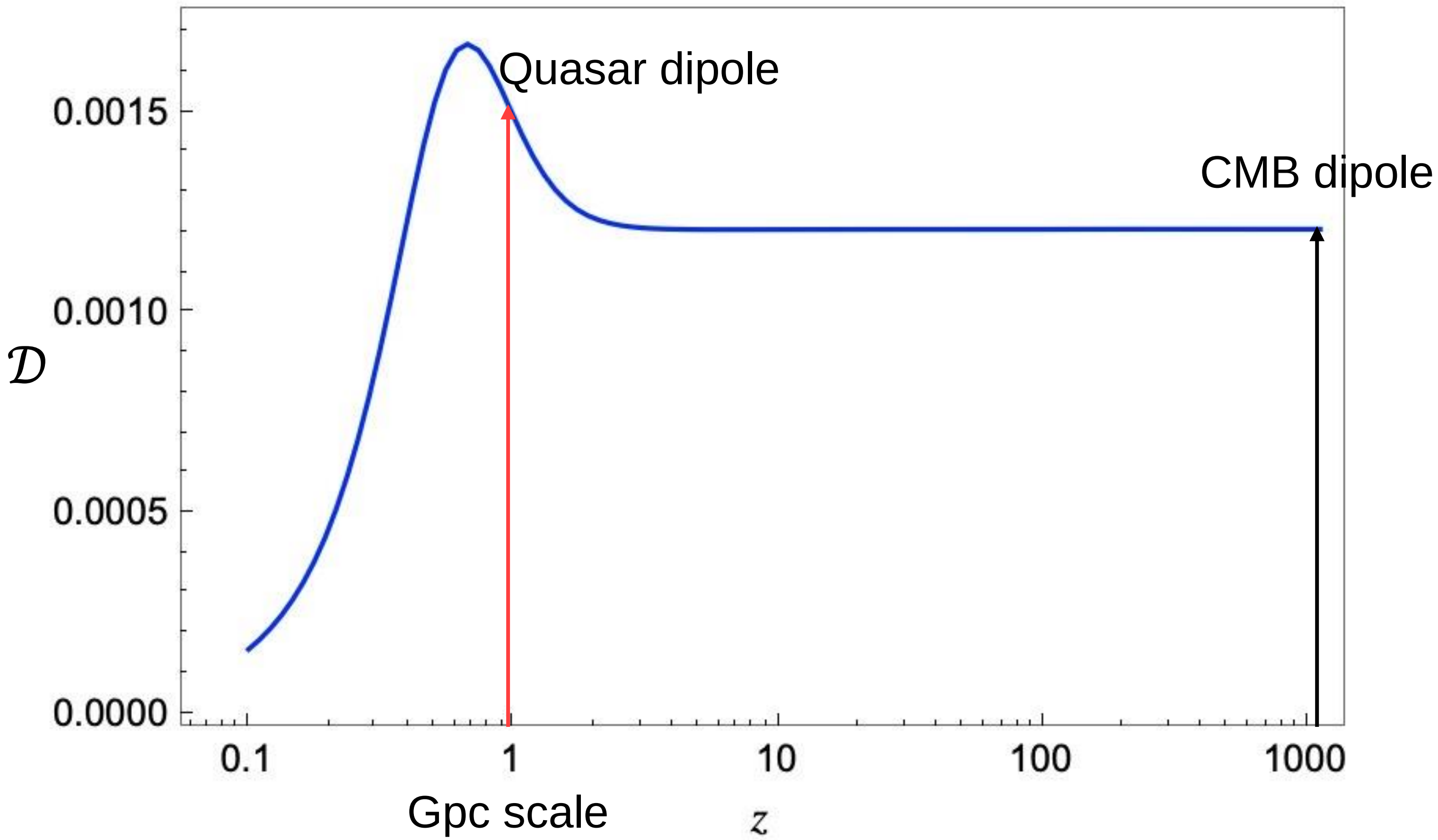


Redshift Dipole

$$\frac{\Delta T}{\bar{T}} = \frac{T(\hat{n}) - \bar{T}}{\bar{T}} = \frac{\bar{z} - z(\hat{n})}{1 + z(\hat{n})}$$



Quasar Dipole

Cosmic redshift in quasar number counting

$$v_o = v_r \delta \qquad \delta = \frac{1+\bar{z}}{1+z(\hat{n})} \qquad S \propto v^{-\alpha} \qquad \frac{dN}{d\Omega} \propto S^{-x}$$

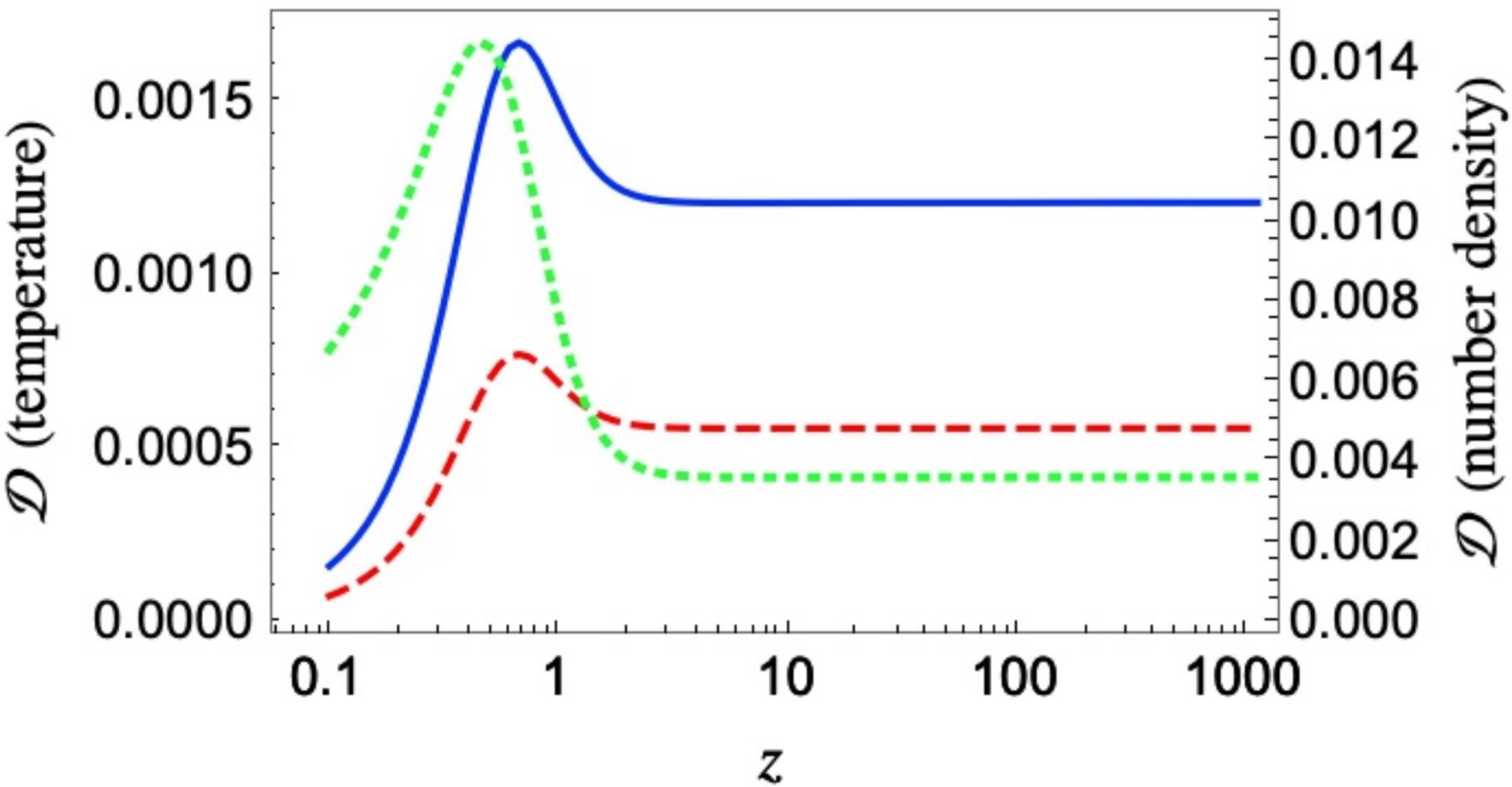
$$\mathcal{D} \cong [2 + x(1+\alpha)] \frac{\bar{z} - z(\hat{n})}{1+z(\hat{n})}$$

Assumption: quasar number density ∝ matter density

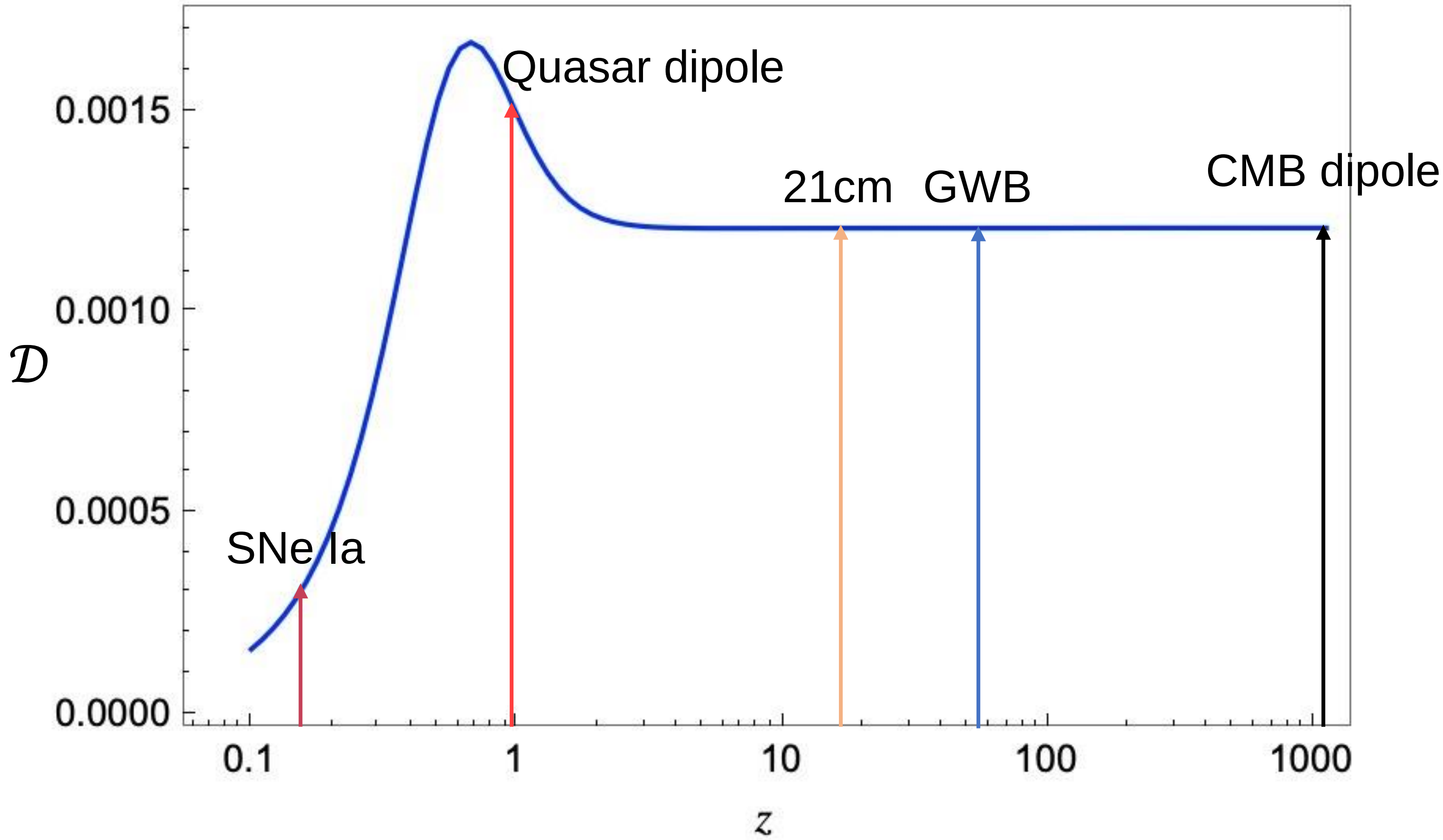
$$\mathcal{D}_Q \sim \mathcal{D}_M$$

$$\frac{\rho dV}{d\Omega}(\hat{n}) \cong \frac{\rho a^3 r^2 dr d\Omega}{d\Omega} = \frac{\rho(\hat{n}) r(\hat{n})^2 dr}{(1+z(\hat{n}))^3}$$

Quasar Dipole



Cosmic Dipole



Cosmic dipoles in global signals indicate the profile of the local structure.

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