The Hitchhiker's Guide to the Galaxy *(peculiar velocities)*

Francesco Sorrenti

Département de physique théorique, Université de Genève

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Cosmic dipole tensions

Cosmological principle → For many far away sources, we expect a similar dipole as the CMB

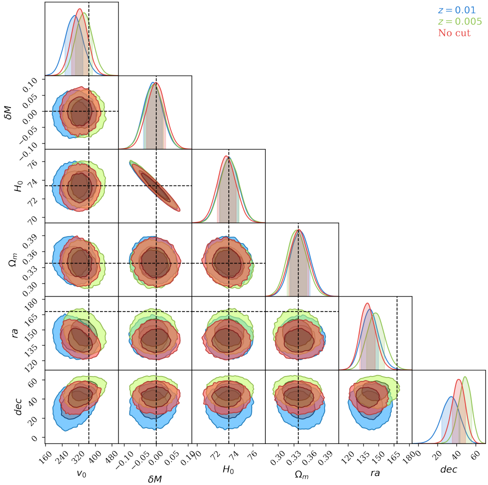


Figure: SF et al., 2022

In Sna Ia of Pantheon+

Planck direction is excluded at more than 3σ!

A bulk motion?

CF4 in disagreement with ΛCDM!

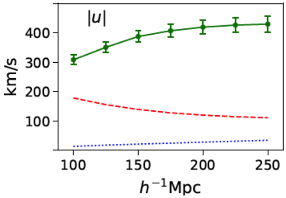
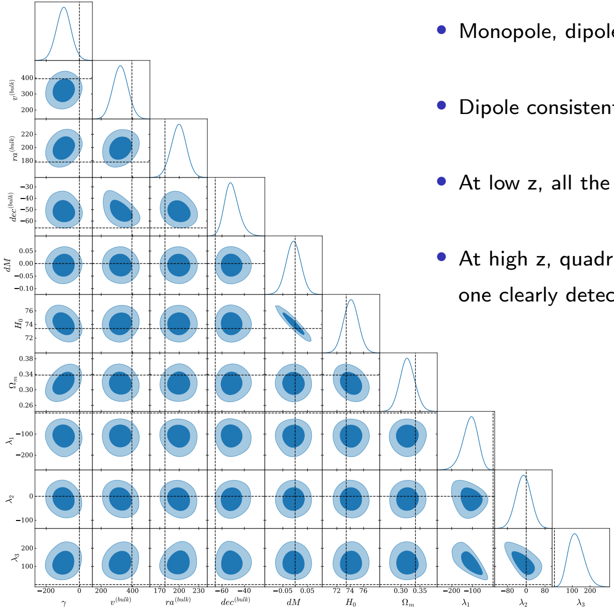


Figure: Watkins et al., 2023

The low multipoles in Pantheon+ *(2403.17741)*



- Monopole, dipole, quadrupole are detected
- Dipole consistent with CF4
- At low z, all the multipoles are of the same order
- At high z, quadrupole is more relevant and the only one clearly detected

How to define $\mathbf{v}_{pec}$

In term of redshift:

$$cz = H_0 r + \hat{\mathbf{r}} \cdot \mathbf{v}_{pec}, \quad (1)$$

Following Helmholtz decomposition:

$$\mathbf{v}_{pec} = \mathbf{v}_{\mathbf{G}} + \mathbf{v}_{\mathbf{R}}, \quad (2)$$

with: $\mathbf{v}_{\mathbf{G}} = -\nabla v, \qquad \nabla \cdot \mathbf{v}_{\mathbf{R}} = 0$

We define divergence θ and vorticity $\boldsymbol{\omega}$:

$$\theta = \nabla \cdot \mathbf{v}_G \quad (3)$$

$$\boldsymbol{\omega} = \nabla \times \mathbf{v}_{\mathbf{R}} \quad (4)$$

from which:

$$k^2 P_V = P_\theta + P_{\boldsymbol{\omega}} \quad (5)$$

$\rightarrow$ Vorticity is usually *neglected*

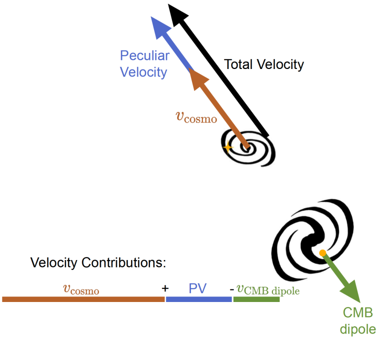


Figure: Credits: 2110.03487

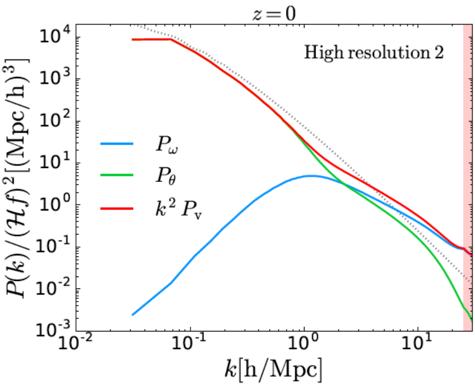
Vorticity power spectrum

From *Jelic-Cizmek et al. 2018*, we know that vorticity is important at late time (k ~ 1 h/Mpc)

We can model it as:

$$P_{\boldsymbol{\omega}} = \frac{\beta\, k^{\vartheta}}{1 + \left(\frac{k}{k_*}\right)^{\varphi}} \quad (6)$$

with k_* pivot scale and β, φ, ϑ free parameters



Next step

- Applying the model to the data


SO LONG AND...
Thanks for all the fish!