Tilted cosmology and tensions with the ΛCDM model using SNIa

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Motivation for the tilted model

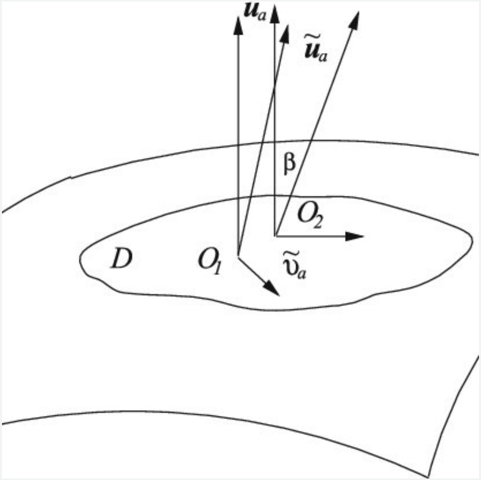
- Several alternative cosmological models have been proposed to explain observations, but most of them assume some forms of dark energy or abandon FRLW

- Large-scale peculiar motions are not wisely taken into account

- No robust analysis of the peculiar-velocity effects

The tilted cosmological scenario can in principle explain the late-time cosmic acceleration <u>without</u> the need of dark energy/modified gravity or new physics

The Tilted Cosmological Model



Employ General Relativity

observers with 4-velocity $u_a \rightarrow$ **idealised observers** following the smooth Hubble expansion

observers with 4-velocity $\tilde{v}_a \rightarrow$ **real observers** in galaxies like ours, moving relative to the Hubble frame

The tilted cosmological model - Kinematics (1/2)

In a perturbed FRW universe, using linear cosmological perturbation theory:

- The three velocities are related through the reduced Lorentz boost :

$$\tilde{u}_a \approx u_a + \tilde{v}_a \tag{1}$$

for non-relativistic peculiar velocities $(\tilde{v}^2 = \tilde{v}^a \tilde{v}_a \ll 1)$

- The expansion rates between the two frames are:

$$\tilde{\Theta} = \Theta + \tilde{\vartheta} \quad \text{and} \quad \tilde{\Theta}' = \dot{\Theta} + \tilde{\vartheta}' \tag{2}$$

with $\Theta = 3H$, $\tilde{\vartheta} = \tilde{D}^a \tilde{v}_a$ and $\tilde{\vartheta}/\Theta \ll 1$ (in the linear regime).

$\tilde{\Theta} \neq \Theta$ and $\tilde{\Theta}' \neq \dot{\Theta}$ because of peculiar motion effects only

The tilted cosmological model - Kinematics (2/2)

In a perturbed Einstein-de Sitter universe ($p = 0$ and $\Omega = 1$) the deceleration parameter measured by the real observers is:

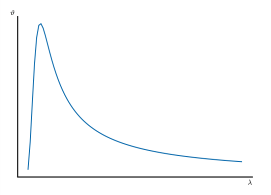
$$\tilde{q} = q + \frac{1}{9}\left(\frac{\lambda_H}{\lambda}\right)^2 \frac{\tilde{\vartheta}}{H} \quad \text{with } \lambda_H = 1/H \text{ and } |\tilde{\vartheta}|/H \ll 1 \tag{3}$$

- When $\lambda \gtrsim \lambda_H$, $\tilde{q} \to q$ and the peculiar motions fade away
- On subhorizon scales ($\lambda \ll \lambda_H$), $\tilde{q} \neq q$ and the difference can be large depending on the bulk flow scale
- The difference depends on the sign of $\tilde{\vartheta}$. For contracting bulk-flows ($\tilde{\vartheta} < 0$), $\tilde{q} < 0 \longrightarrow$ local apparent accelerated expansion for the real observers

Tsagas, 2011, DOI: 10.1103/PhysRevD.84.063503
Tsagas, Kadiltzoglou, 2015, DOI: 10.1103/PhysRevD.92.043515
Tsagas, 2021, Eur. Phys. J. C 81, 753

Parametrization of $\tilde{\vartheta}$

- We assume that locally the bulk flow contracts $(\tilde{\vartheta} < 0)$ and $q = \frac{1}{2}$
- We consider a physically motivated form of the local volume scalar $\tilde{\vartheta}$ in the tilted frame [1]



$$\tilde{\vartheta} = \tilde{\vartheta}(\lambda) = \frac{m\lambda^2}{p + r\lambda^3} \tag{4}$$

- The deceleration parameter in the tilted frame now becomes

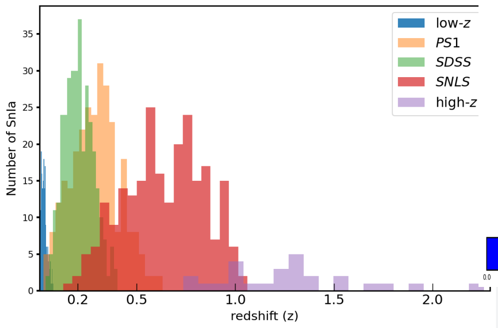
$$\tilde{q} = \tilde{q}(\lambda) = \frac{1}{2}\left(1 - \frac{m}{p + r\lambda^3}\right) \tag{5}$$

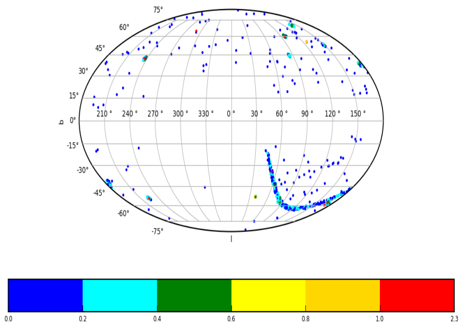
[1] K. Asvesta, L. Kazantzidis, L. Perivolaropoulos, C. Tsagas, 2022, DOI: 10.1093/mnras/stac922

The Pantheon compilation

JLA + additional SnIa from PanStarrs and HST
(Scolnic et al. (2018) arXiv:1710.00845)

1048 SnIa out to redshift $z \sim 2.3$





K. Asvesta, L. Kazantzidis, L. Perivolaropoulos, C. Tsagas, 2022, DOI: 10.1093/mnras/stac922

✓ **Construct the theoretical apparent magnitude (m_{th}) for the tilted model**

Eq.5 can take the form

$$\tilde{q}(z) = \frac{1}{2}\left(1 - \frac{1}{\alpha + b\, d_r^3(z)}\right) \quad \text{with} \quad d_r(z) = H_0\, \bar{\chi}(z)/c \tag{6}$$

- The Hubble rate at any redshift connects with the deceleration parameter through

$$\tilde{H}(z) = H_0 \exp\left[\int_0^z \left(\frac{1+\tilde{q}(u)}{1+u}\right) du\right] \tag{7}$$

- The Hubble free luminosity distance of the SNIa :

$$\tilde{D}_L(z) = H_0(1+z)\int_0^z \frac{dz'}{\tilde{H}(z')} \tag{8}$$

- The theoretically predicted apparent magnitude :

$$m_{th}(z) = 5\log_{10}\tilde{D}_L(z) + M + 5\log_{10}\left(\frac{c/H_0}{1Mpc}\right) + 25 = \mathcal{M} + 5\log_{10}\tilde{D}_L(z) \tag{9}$$

Results

$$\chi^2_{min}(\mathcal{M}, \alpha, b) = (m_{obs,i}(z) - m_{th}(z))\ C_{ij}^{-1}\ (m_{obs,j}(z) - m_{th}(z)) \quad (10)$$

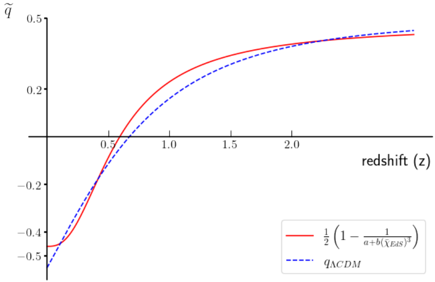
- C_{ij} is the total covariance matrix of the SNIa (sys+stat)
- We calculate χ^2 for the case of an Einstein-de Sitter bulk flow model

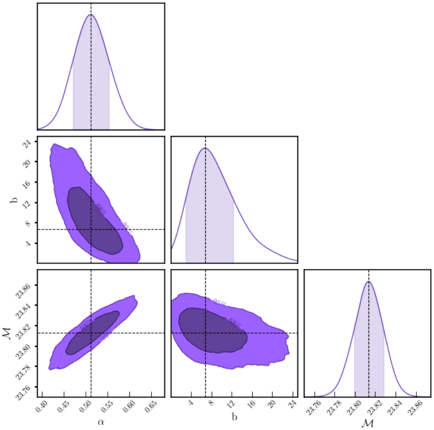
Model	$\mathcal{M}$	α	b	Ω_{0m}	$\chi^2_{\rm min}$	$\chi^2_{\rm red}$
ΛCDM	**23.809 ± 0.011**	–	–	**0.299 ± 0.022**	**1026.67**	**0.981**
T-EdS	$\mathbf{23.813^{+0.015}_{-0.014}}$	**0.512 ± 0.041**	$\mathbf{6.7^{+5.6}_{-3.8}}$	**1.0**	**1026.76**	**0.982**

K. Asvesta, L. Kazantzidis, L. Perivolaropoulos, C. Tsagas, 2022, DOI: 10.1093/mnras/stac922

Result The tilted cosmological model performs equally well with ΛCDM ($\chi^2_{red} \approx 1$)

Evolutionary behaviour of $\tilde{q}$ and confidence levels





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3 Things to take away from this talk

- The obtained profile of $\tilde{q}$ is very close to the one of ΛCDM
- The transition redshift from deceleration to acceleration, in the tilted model using SNIa, is close to the one from the ΛCDM model
- Fit the SNIa data to the tilted model and found an apparent late-time cosmic acceleration without the need of dark energy/MG

What comes next?

- One prediction of the model is the presence of a dipole in the distribution of deceleration measured in the tilted frame
- Allow for a directional dependence in the spatial distribution of $\tilde{\vartheta}$ and consequently on the tilted deceleration parameter ($\tilde{q}$) $\rightarrow$ test for dipolar modulation on $\tilde{q}$
- Test our results with the recently published SNIa data, Pantheon+ and future SNIa surveys (LSST) or galaxy clusters
- Test our results with other cosmological probes that extend in greater redshifts such as quasars


Thank you