Are FFΛCDM models viable

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Are FFΛCDM models viable?

FFΛCDM = Far From ΛCDM

- Acceleration skepticism
  - Problems with SNIa?
  - Acceleration from BAO only?
- Λ and/or CDM skepticism
  - Does CMB $\Rightarrow$ CDM and Λ?
  - Does BAO + CMB $\Rightarrow$ΛCDM?
- Friedman skepticism
  - Backreaction models
  - Coasting models

1808.04597: No acceleration, just anisotropy

Evidence for anisotropy of cosmic acceleration

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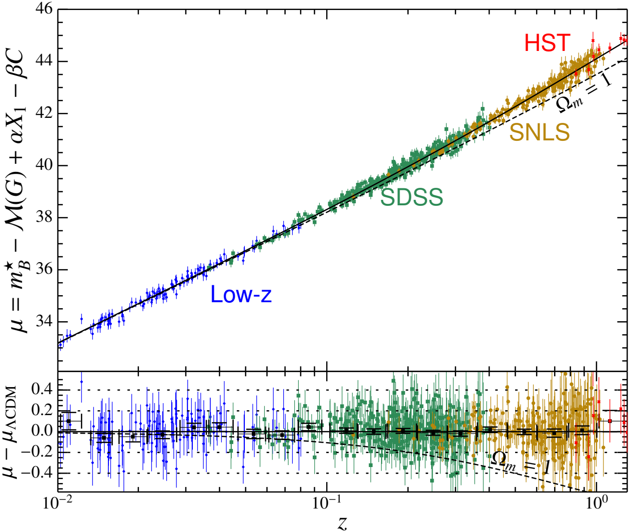
Observations reveal a 'bulk flow' in the local Universe which is faster and extends to much larger scales than is expected around a typical observer in the standard ΛCDM cosmology. This is expected to result in a scale-dependent dipolar modulation of the acceleration of the expansion rate inferred from observations of objects within the bulk flow. From a maximum-likelihood analysis of the Joint Lightcurve Analysis (JLA) catalogue of Type Ia supernovae we find that the deceleration parameter, in addition to a small monopole, indeed has a much bigger dipole component aligned with the CMB dipole which falls exponentially with redshift z: $q_0 = q_{\rm m} + \boldsymbol{q}_{\rm d}.\hat{n}\exp(-z/S)$. The best fit to data yields $q_{\rm d} = -8.03$ and $S = 0.0262$ ($\Rightarrow d \sim 100$ Mpc), rejecting isotropy ($q_{\rm d} = 0$) with 3.9σ statistical significance, while $q_{\rm m} = -0.157$ and consistent with no acceleration ($q_{\rm m} = 0$) at 1.4σ. Thus the cosmic acceleration deduced from supernovae may be an artefact of our being non-Copernican observers, rather than evidence for a dominant component of 'dark energy' in the Universe.

My executive summary: They

- Decline to transform to CMB frame
- Find SNIA Hubble diagram correlated with CMB dipole (!?)
- Fit for $\ddot{a}(t_0)$ and $\dddot{a}(t_0)$
- Find only 1.4σ evidence for $\ddot{a}(t_0) > 0$
- Show no figures

SNIa Hubble Diagram



Conclusion:
At $z = 0.5$, SNIa are fainter than what one would expect if $(\Omega_{\mathrm{M}}, \Omega_\Lambda) = (1, 0)$

and probably even if $(\Omega_{\mathrm{M}}, \Omega_\Lambda) = (0, 0)$

Simplest explanation:
The expansion is accelerating (now)

But strictly speaking, to show present acceleration we should only use low redshift ($z < 0.1$) data.

Comments in SNIa Hubble diagram

- SNIa evidence is only $\approx 5\sigma$ so adding more parameters (anisotropy) weakens evidence
- SNIa evidence is indirect (Hubble diagram) and depends on assuming $m_B^* \neq m_B^*(z)$
  $\Rightarrow$ BAO is potentially better
- While the question of present acceleration is important, a more basic question is whether cosmological observations can be globally explained by a mixture of matter and radiation (maybe baryonic matter and radiation).
  $\Rightarrow$ Use BAO and CMB

Today on arXiv:2003.10420

The impact of peculiar velocities on supernova cosmology

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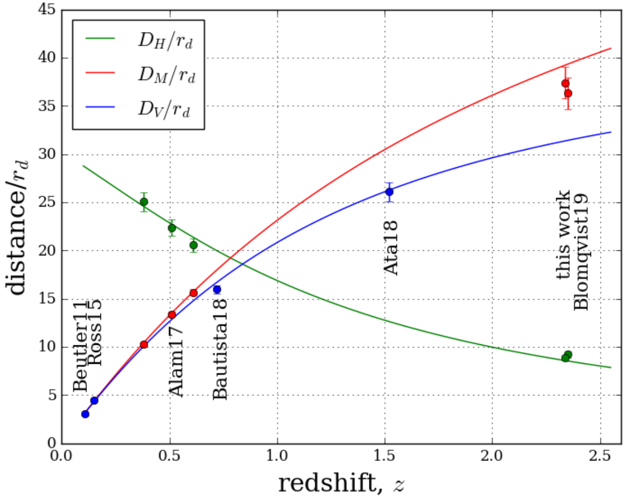
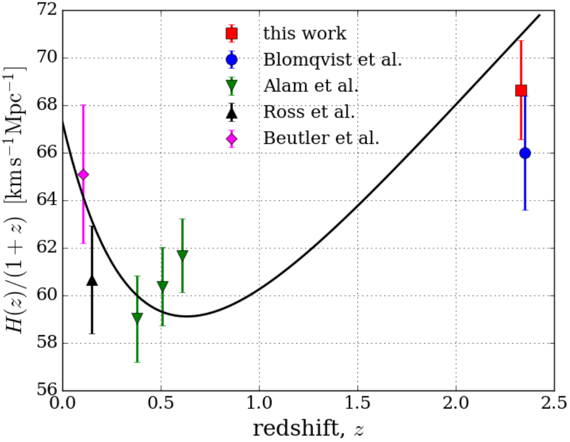
ABSTRACT

We study correlated fluctuations of Type Ia supernova observables due to peculiar velocities of both the observer and the supernova host galaxies, and their impact on cosmological parameter estimation. We demonstrate using the CosmicFlows-3 dataset that at low redshifts the corrections for peculiar velocities in the JLA catalogue have been systematically underestimated. By querying a horizon-size N-body simulation we find that compared to a randomly placed Copernican observer, an observer in an environment like our local universe will see 2–5 times stronger correlations between supernovae in the JLA catalogue. Hence the covariances usually employed which assume a Copernican observer underestimate the effects of coherent motion of the supernova host galaxies. Although previous studies have suggested that this should have $< 2\%$ effect on cosmological parameter estimation, we find that when peculiar velocities are treated consistently the JLA data favours significantly smaller values of matter and dark energy density than in the standard ΛCDM model. A joint fit to simultaneously determine the cosmological parameters and the bulk flow finds a bulk flow faster than 200 km s^{-1} continuing beyond 200 Mpc. This demonstrates that the local bulk flow is an essential nuisance parameter which must be included in cosmological model fitting when analysing supernova data.

BAO Hubble Diagrams



BAO expansion rate

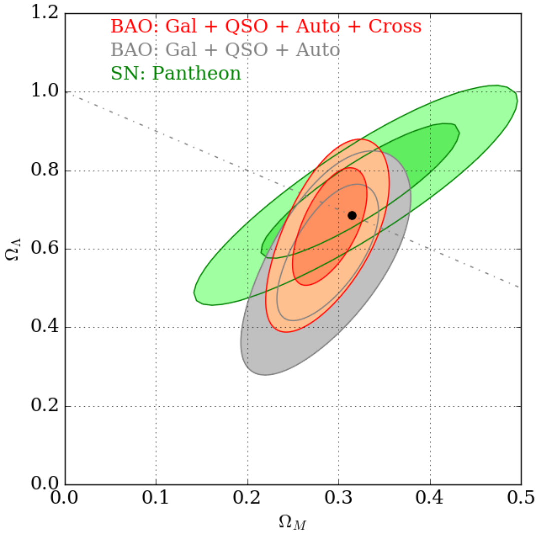


Weak evidence for
$z < 0.5$ acceleration

Better evidence for
$z > 0.5$ deceleration

Coasting model in
trouble.

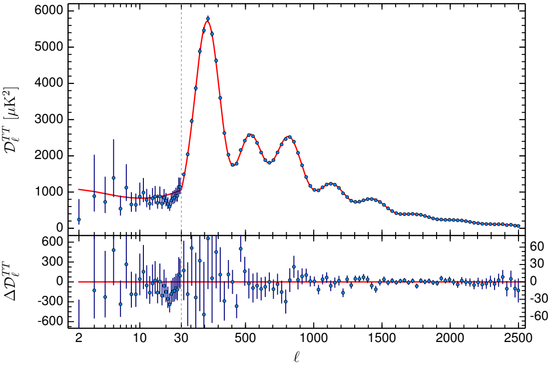
BAO and SNIa ΛCDM constraints



BAO standard ruler: a simple and robust demonstration that there's more than just matter and radiation.

But it would be nice to have more statistics ⇒DESI

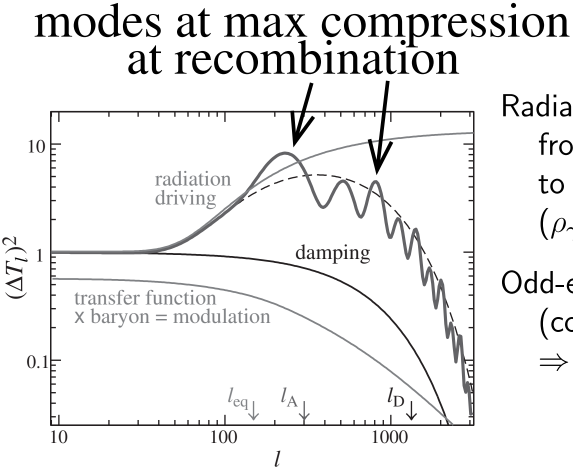
Does CMB require dark energy?



Two kinds of information:

1. Shape: peak heights, relative separations
   $\Rightarrow$ conditions at z=1090
   ρ_M, ρ_b, r_d
   $(\Omega_m h^2, \Omega_b h^2)$
2. Peak position (ℓ_1) ,
   $\Rightarrow$ angular distance to z=1090
   $\Rightarrow H_0, \Omega_k h^2$

CMB physics understood in ΛCDM (W. Hu)



Radiation driving $\Rightarrow \rho_M/\rho_\gamma$
from peak 1 height relative
to Sachs-Wolfe plateau
(ρ_γ from COBE $\Rightarrow \rho_M$)

Odd-even peak heights
(compression,rarefaction)
$\Rightarrow \rho_M/\rho_b$

Planck + COBE $\Rightarrow \Omega_M h^2 = 0.1426 \pm 0.0020$
and $D_M(z = 1090) \sim r_*/\theta_{MC} = 13.9 \pm 0.1$Gpc

Distance to Last-Scattering Surface, z=1090

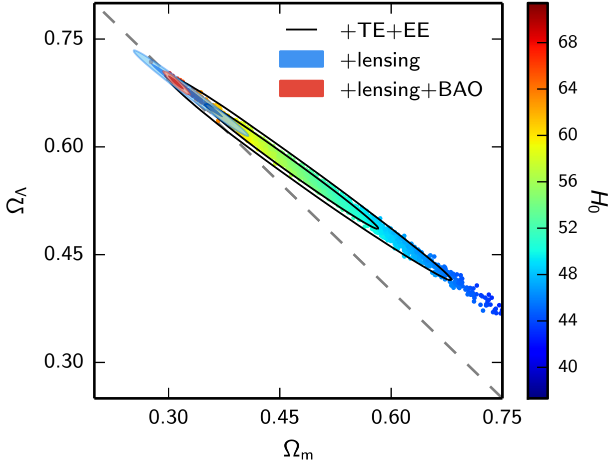
$$D(z) = \int_0^1 \frac{dz}{H(z)} \ = (c/H_0) \int_0^z \frac{dz}{[\Omega_\Lambda + \Omega_m(1+z)^3 + \Omega_k(1+z)^2]^{1/2}}$$

A better way to write it:

$$D(z) = \int_0^z \frac{dz}{[\ H_0^2 + \Omega_m H_0^2[(1{+}z)^3 - 1] + \Omega_k H_0^2[(1{+}z)^2 - 1]\ ]^{1/2}}$$

$D(z)$ depends on $\Omega_{\mathrm{M}} H_0^2$ (fixed by CMB), H_0^2, and $\Omega_k H_0^2$
Transformation $D(z) \to D_M(z)$ adds further $\Omega_k H_0^2$ dependence.

Does CMB require dark energy?



Allowed values of $(\Omega_\Lambda, \Omega_m, H_0)$ have $\Omega_m h^2 = 0.14$ and $D_M(z = 1090) =$ 13.9 Gpc.

$\Omega_\Lambda = 0$ requires $h \approx 0.33$

$(\Omega_m, \Omega_\Lambda, h) =$ (0.314, 0.685, 0.673) (flat)
(0.74, 0.37, 0.44)
(1.31, 0.0, 0.33) no dark energy

C_ℓ from Baryon-only models

Baryon + $m_\nu = 1$ eV model (S. McGaugh, arXiv:1404:7525)

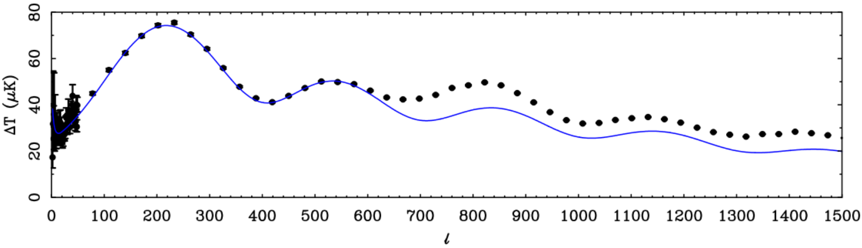
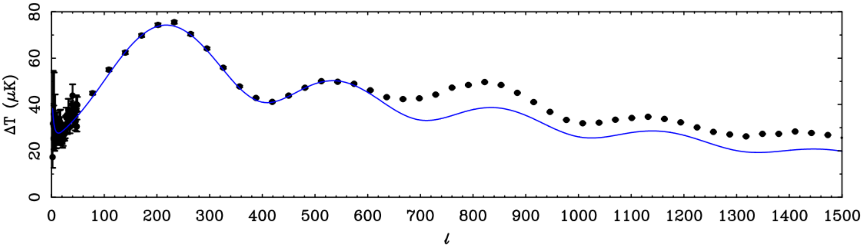


Fig. 7 shows the acoustic power spectrum from Planck (102) together with the prediction of a model devoid of CDM (89; 27). In the absence of CDM, baryonic damping dominates and one should see a spectrum in which each peak is smaller in amplitude than the one preceding it. When CDM is present, there is an additional forcing on the oscillations. This manifests as the observed third peak exceeding the amplitude of the no-CDM model.

"The third and subsequent peaks are a clear victory for ΛCDM."

C_ℓ from Baryon-only models



Model differences:

- ΛCDM: nearly homogeneous medium. Baryons oscillating in $\phi_{CDM} \approx 10^{-5}$ potential wells
- Baryons only: No CDM potential wells to drive oscillations
- Dirac-Milne: Non-homogeneous (matter/antimatter domains)

  $\Rightarrow \Delta\phi = 0$ for $\lambda > r_{domain}$

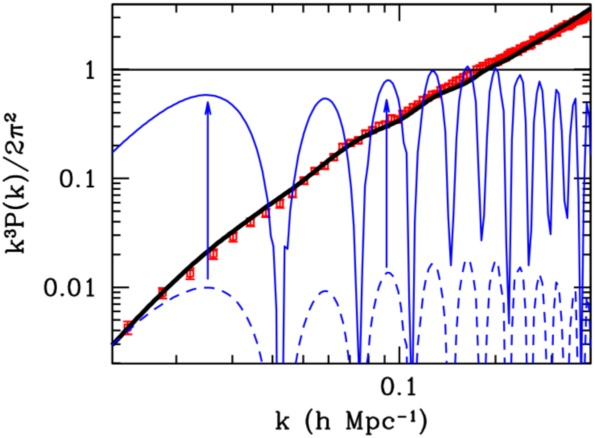
  $\Rightarrow \Delta\phi = 1$ for $\lambda < r_{domain}$

CMB + BAO: two important conclusions

- 1. Rule out baryon only models
- 2. Give zero curvature in ΛCDM models

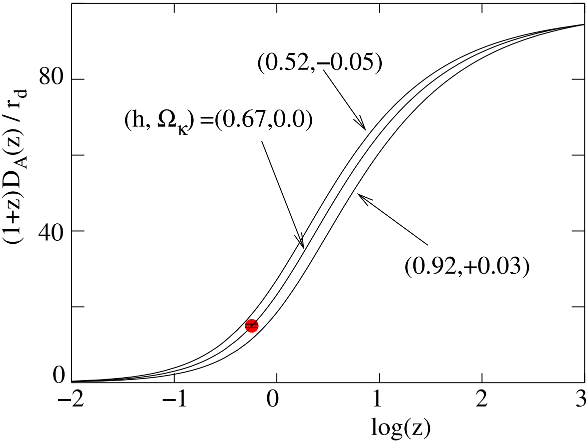
1. Late time $P(k)$ from Baryon-only models

Scott Dodelson, arXiv:1112.1320



BAO much stronger than in ΛCDM. (The biggest problem for MOND)

2. Three models that give the same $D_M(z = 1090)$



$(\Omega_M h^2, \Omega_B h^2)$
$= (0.142, 0.0227)$
$r_d = 147.36$ Mpc

$(h, \Omega_k) = (0.67, 0.0)$
$(h, \Omega_k) = (0.52, -0.05)$
$(h, \Omega_k) = (0.92, 0.03)$

CMB + BAO: $\Omega_k = -0.0001 \pm 0.0054$

If ΛCDM is not the truth, this is either an incredible accident or incredible confirmation bias.

Friedman skepticism I: backreaction

See, e.g. Heinesen & Buchert, arXiv:2002.10831

The Friedman equation breaks down when the universe is inhomogeneous enough to form bound structures. The acceleration is induced by structure formation, solving the "why now?" problem. Some problems:

- No predictions for, e.g., a Hubble diagram
- While the density is now inhomogeneous, the metric is not ($\phi < 10^{-5}$).
- No sign of backreaction in perturbation theory
- No sign of backreaction in fully-relativistic N-body simulations: [Adamek, Clarkson, Daverio, Durrer, Kunz arXiv:1706.09309]
- Physics education depends on finding exact solutions and then perturbing (e.g. hydrogen atom). In the presence of backreaction, this would not work for cosmology.

Friedman skepticism II: coasting models

e.g. Dirac-Milne [arXiv:1110.3054, arXiv:1804.03067]
$\dot{a} = const. \Rightarrow H(z) = (1+z)H_0$ (matter-antimatter domains give zero gravitation at large scale.

Two problems:

- $D_M(z = 1090) = 2430068.Mpc \Rightarrow r_d = 26$Gpc. So the BAO peak seen at 150Mpc at low redshift cannot have the same origin as the acoustic peaks seen in the CMB. The agreement between r_d derived from the CMB anisotropies and the r_d seen at low redshift is an accident.
- H_0 is a free parameter unrelated to density. Why then does $H_0^2 \approx 8\pi G\rho_0/3$? (We live in a special epoch when it looks like the expansion rate obeys the Friedman equation.)

Conclusions

- Evidence for current acceleration is fragile, depending on SNIa
- Evidence for past acceleration (inflation) is perhaps stronger; If it accelerated in the past, we shouldn't be too surprised if it starts up again.
- CMB and BAO strongly suggest that there is more in the universe than just baryons and more than just baryons and CDM. The simplest "more" is Λ, implying current acceleration.
- If it's not exactly ΛCDM, what makes ΛCDM such a good approximation?
- It's good to keep an open mind. (whether or not you like ΛCDM)