Quantised primordial power spectra

PARALLEL SESSION: COSMOLOGY - EARLY UNIVERSE AND THE ORIGIN OF STRUCTURE (F)

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Quantised primordial power spectra

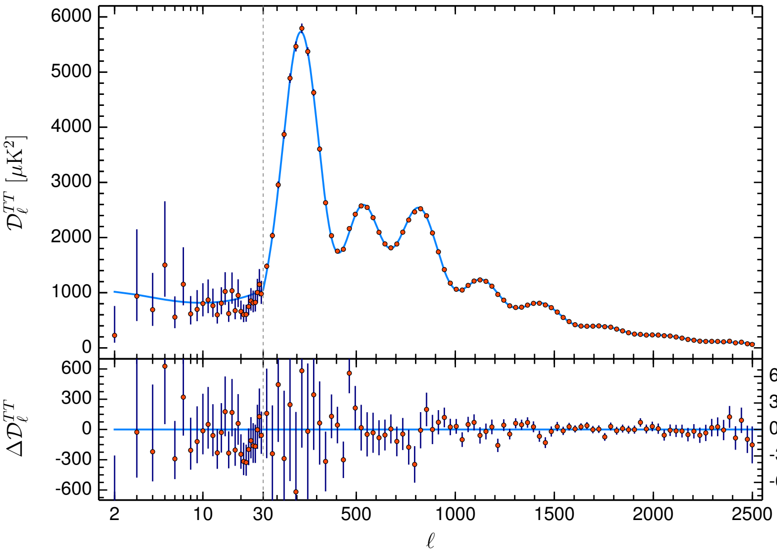
Observational motivations for quantised primordial power spectra

Future conformal boundary theories

Kinetic initial conditions

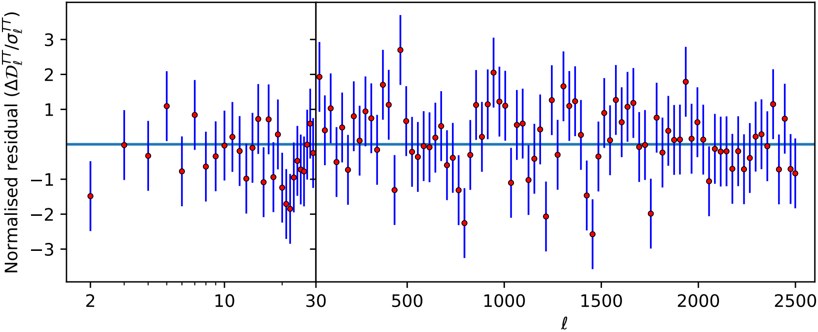
Observational motivations for quantised primordial power spectra

Features in the Planck data?



Features in the Planck data?

Normalise residuals to have unit standard deviation:



1. low quadrupole ($\ell = 2$) and suppression of power $\ell < 30$.
2. $\ell \sim 20$ feature.
3. (faint) oscillatory characteristics in high-ℓ residuals.

Quantised primordial power spectra

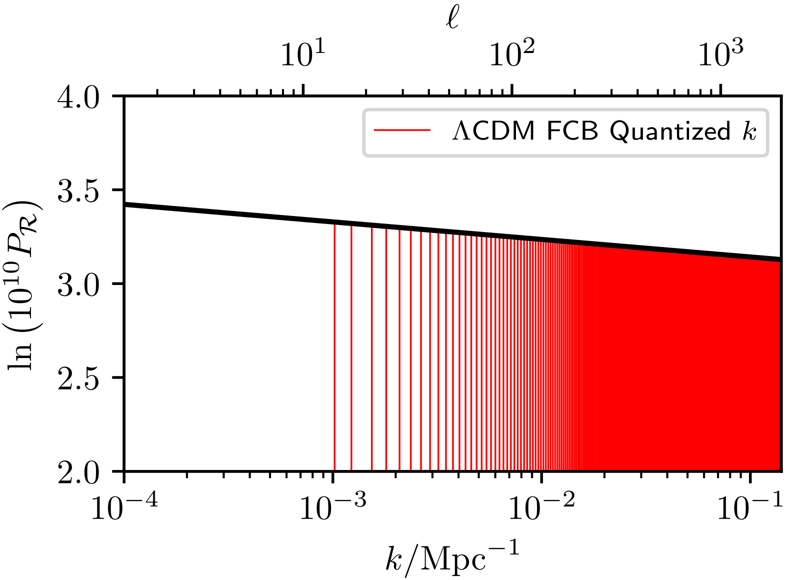
- From inflation, primordial power spectrum $\mathcal{P}_\mathcal{R}(k) \approx A_s\left(\frac{k}{k_*}\right)^{n_s-1}$.
- What if, instead of a continuous set of wavevectors, only a discrete set are allowed?
- Practically amounts to changing transfer convolution:

$$C_\ell \sim \int \mathcal{P}_\mathcal{R}(k)\Delta(k)dk \to \sum_{k_i \in \text{allowed } k} \mathcal{P}_\mathcal{R}(k_i)\Delta(k_i)$$

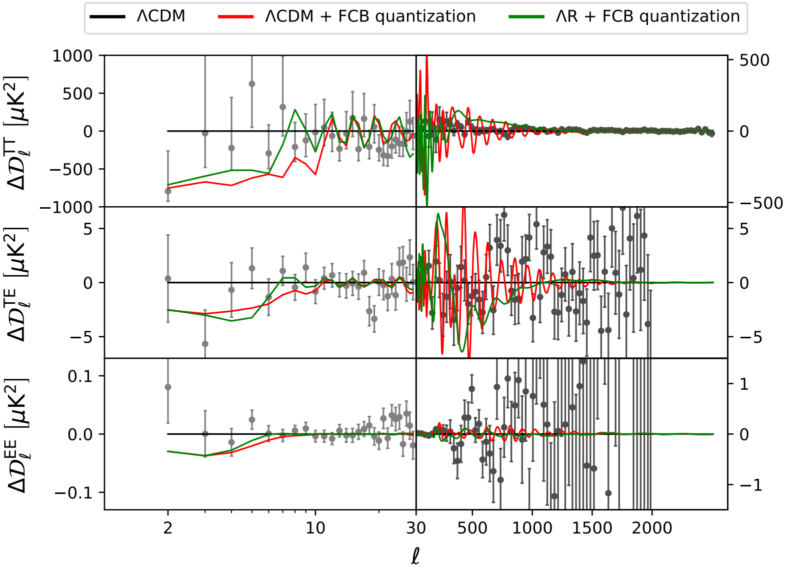
.

- For example, allowed k could have linear spacing Δk, starting at k_0.
- Quantisation occurs naturally in closed universes, but mechanisms exist for creating the same in flat or open universes.
- "Improved cosmological fits with quantized primordial power spectra" (Bartlett, Handley & Lasenby, Jan 2020).

Quantised primordial power spectra

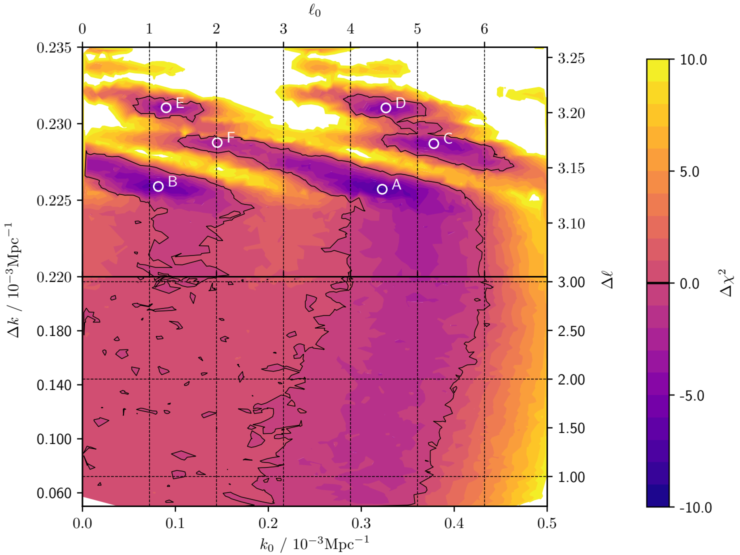


Physical effects of quantisation

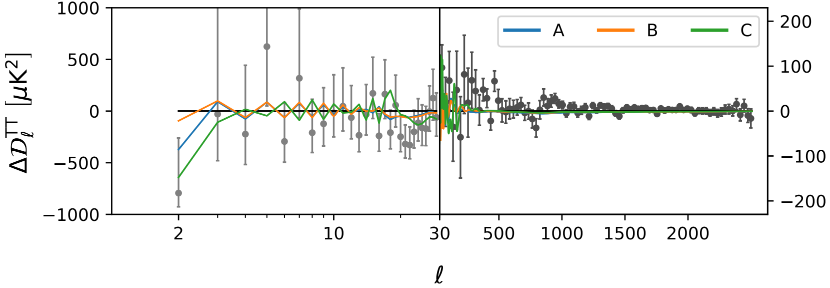


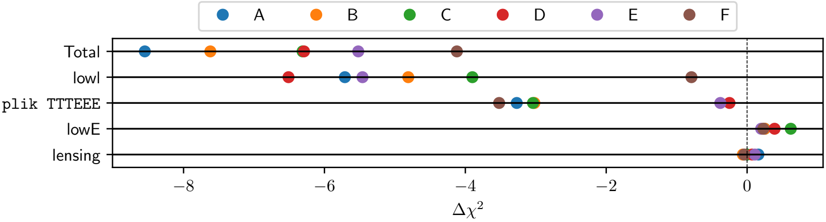
Optimal quantised spectra, $\Delta\chi^2 = -8.55$

Best-fit with Planck 2018 TT,TE,EE+lowℓ+lowE+lensing likelihood



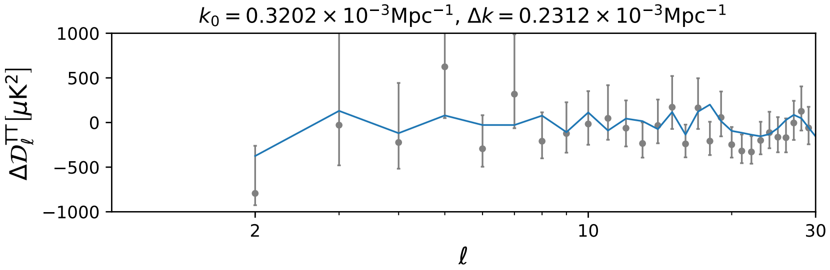
Breakdown of fit





How good are these fits?

- $\Delta\chi^2 = -8.55$ is nominally quite an improvement on ΛCDM.
- This comes at the cost of two new parameters associated with the lowest wavenumber k_0 and quantisation spacing Δk.
- The parameters are also finely tuned, incurring an Occam penalty in the Bayesian evidence similar in degree to the improved fit.
- Ideally would have a models that are more predictive.

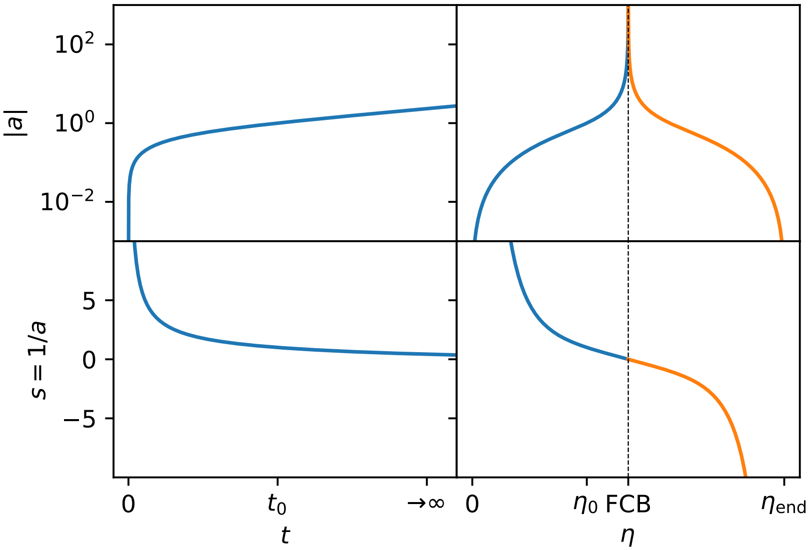


Future conformal boundary theories

The future conformal boundary

- Extrapolating our current cosmology, the universe "ends" in a Dark energy dominated phase.
- As $t \to \infty$, the universe enters a de-Sitter state $a \sim e^{H_\infty t} \to \infty$.
- This is a coordinate singularity, at a finite conformal time in the future.
- Evolutions of various cosmological components may be continued through this "future conformal boundary".
- Distinct from Penrose's conformal cyclic cosmologies (CCCs).
- "Radiation, Cold Dark Matter Perturbations and the Future Conformal Boundary" (Lasenby, Handley et al, Jan 2020).

Evolution through the future conformal boundary



Consequences of the future conformal boundary

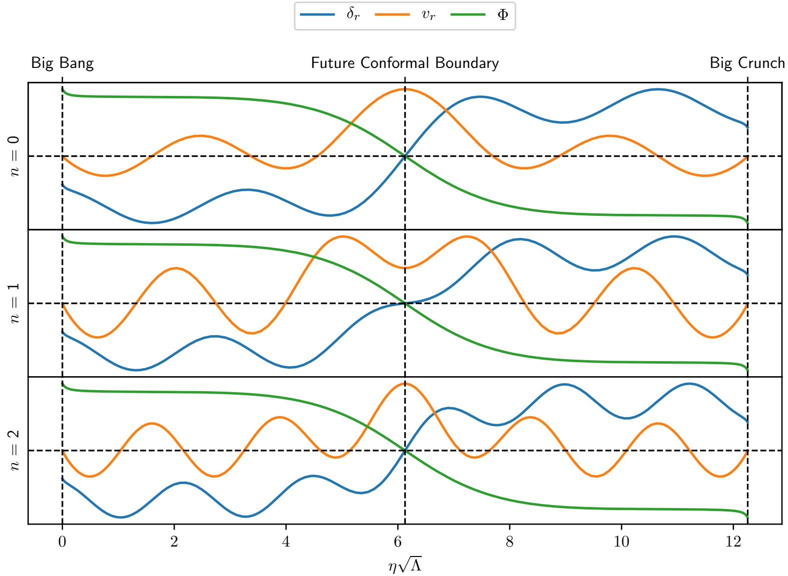
Theoretical observations:

- The scale factor a is not a physical quantity.
- Metric: $dt^2 - a^2 dx^2 \Rightarrow$ physics is blind to the sign of the scale factor.
- $s = 1/a$ would be equally appropriate as a variable.
- s remains finite and smooth through the boundary where $a \to \infty$.

Physical consequences:

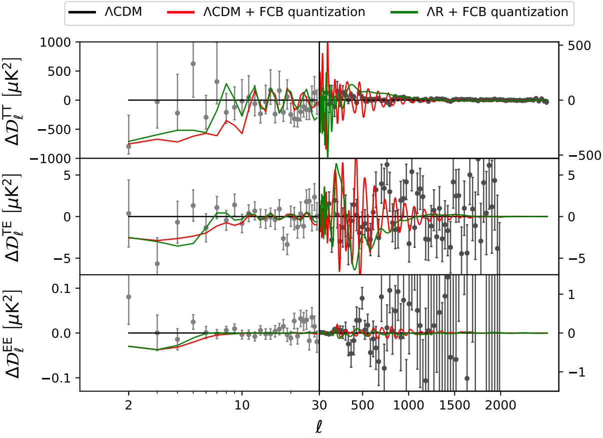
- For a perturbative approach to be valid, first-order perturbations must remain finite at all times.
- Requiring this at the beginning and end of the universe means only a discrete set of wavenumbers are allowed.

Allowed wavenumbers



Poor predictions in practice

- $\Delta k = 0.272\times 10^{-3}$
- $k_0 = 0.701 \times 10^{-3}$
- Worse fitting than continuous spectra



The future of future conformal boundary theories

Key points:

- The quantisations predicted by future conformal boundary theories are of the correct order of magnitude.
- Full analyticity is challenging for matter: Is $\rho_{\mathrm{m}} \sim a^{-3}$ or $|a|^{-3}$?
- Correcting this discrepancy may be the key to bringing these theories into observational consistency.

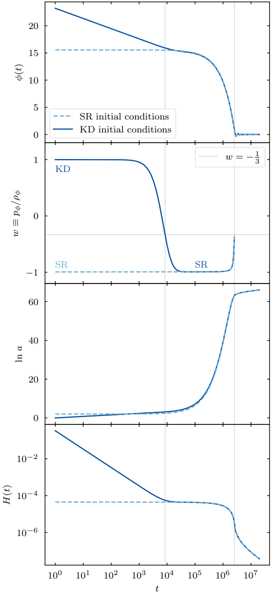
Future work:

- How does inflation fit into this picture?
- Can a compensator field ϕ create a full analytic continuation?

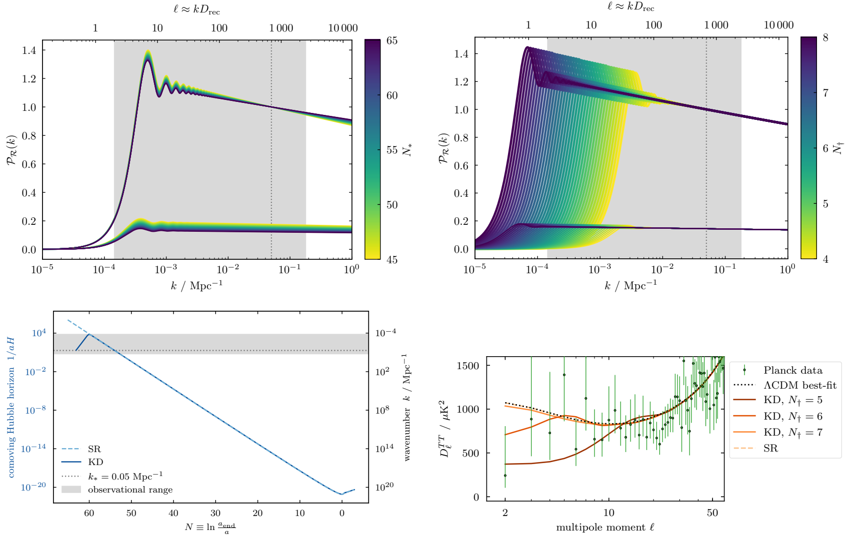
Kinetic initial conditions

Kinetic initial conditions

- If inflation starts late, effects of finite inflation may be observable.
- "Just enough inflation" theory: $N_{\rm tot} \sim N_\star + 10$.
- Suppression of power and features in spectra.
- Pre-inflationary phase generically has $\dot\phi^2 \gg V(\phi)$: kinetic dominance.
- Solutions and theory independent from $V(\phi)$.
- "Kinetic initial conditions for inflation" (Handley, Hobson & Lasenby arXiv:1401.2253).
- "A case for kinetically dominated initial conditions for inflation" (Hergt, Handley, Hobson & Lasenby arXiv:1809.07185).



Kinetic initial conditions



- Hergt, Handley, Hobson & Lasenby arXiv:1809.07737

Quantum initial conditions

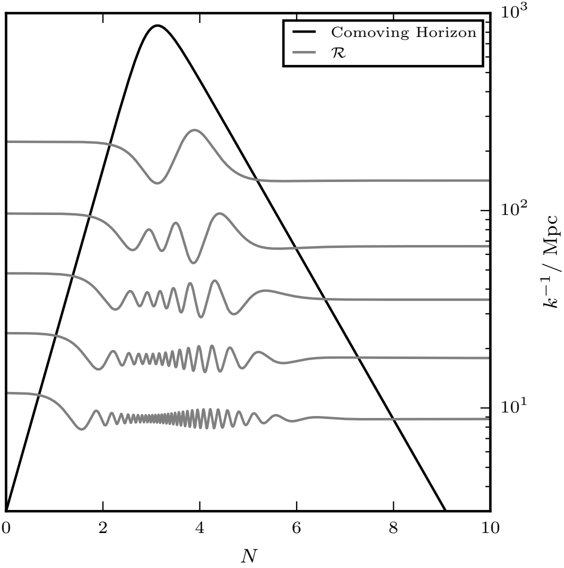
- Primordial power spectrum $\mathcal{P}_\mathcal{R}$ governed by freeze-out values of comoving curvature perturbation $\mathcal{R}$.
- Traditionally one sets initial conditions for $\mathcal{R}$ (or equivalently the Mukhanov variable $v = z\mathcal{R}$) via quantum mechanical considerations.
- For de-Sitter, vacuum clearly defined by Bunch-Davies prescription.
- In just enough inflation, for large modes (small k) the quantum mechanics is much less clear.
- "Novel quantum initial conditions for inflation" (Handley, Lasenby & Hobson arXiv:1607.04148).

Frozen initial conditions

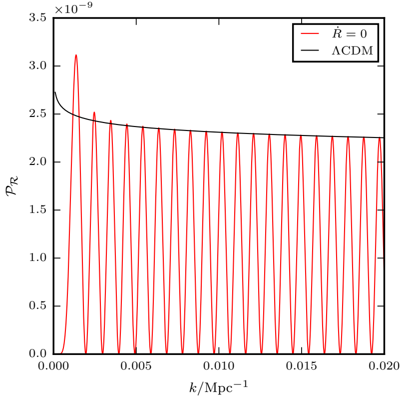
- Proposal:

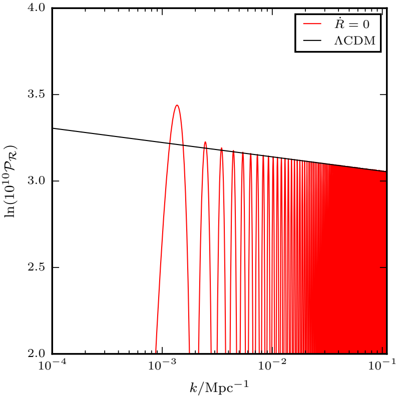
$$\lim_{t\to 0} |\mathcal{R}| \sim \mathrm{const}$$
$$\lim_{t\to 0} \dot{\mathcal{R}} = 0$$

- Perturbations remain valid.
- Cosine mode/real component is selected.
- Acoustic oscillations on horizon exit.



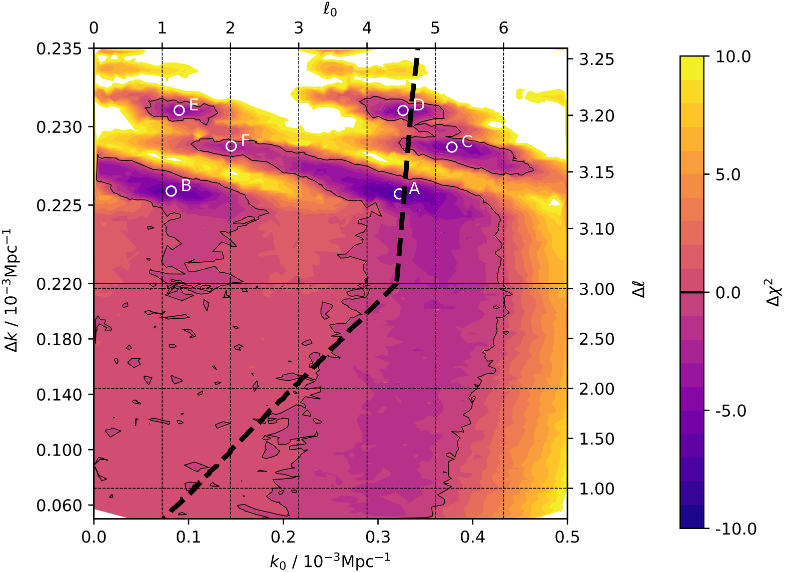
Frozen power spectra





- Pseudo quantised power spectrum $\mathcal{P}_\mathcal{R} \approx A_s \left(\frac{k}{k_*}\right)^{n_s - 1} \times \cos^2(\omega k + \phi)$.
- k_0, Δk are a function of when inflation starts.
- "Rapid numerical solutions for the Mukhanov-Sazaki equation" (Haddadin & Handley, arXiv:1809.11095v2 Jan 2020).

Observational consequences



Further work

- Full Bayesian parameter estimation and model comparison.
- Quantum consequences/interpretation of frozen initial conditions.
- Implications for the effects of the future conformal boundary?
- Currently being explored by Thomas Gessey-Jones (Part III student).

Summary

- Quantised primordial power spectra have an intriguing observational motivation, able to simultaneously reproduce suppression of low-ℓ power, the $\ell \sim 20$ feature and oscillations at high ℓ.
- The future conformal boundary is a coordinate singularity, and naturally induces a quantised primordial power spectrum of the correct order of magnitude, but inconsistent with observations.
- Kinetic initial conditions/just enough inflation models combined with frozen initial conditions produce a pseudo-quantised spectrum which compellingly can recover the 'sweet spot' best-fit with a single additional cosmological parameter.