Supernova test of the timescape cosmology

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In collaboration with Lawrence Dam and David Wiltshire. arXiv:1706.07236v1

The Joint Lightcurve Analysis (JLA) sample - Largest supernovae 1a catalogue: 740 supernovae

The SALT model for making supernovae 1a standard candles

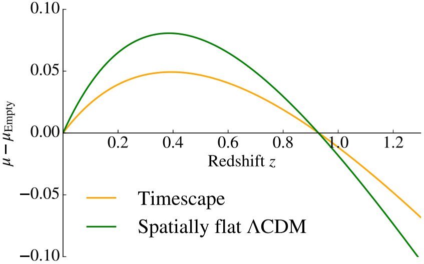
Likelihood construction of J. T. Nielsen, A. Guffanti, and S. Sarkar, 2016

Evidence for acceleration within FRW: 3σ (marginal)

Supernovae analysis of the timescape model

Distance modulus difference between flat ΛCDM and timescape

$$\mu \equiv 25 + 5\log_{10}(d_L/10Mpc)$$



The residual distance moduli $\mu_{\Lambda CDM}(z) - \mu_{empty}(z)$ and $\mu_{TS}(z) - \mu_{empty}(z)$ with the same H_0. Best fit parameters are assumed.

Outline

The timescape cosmology

D. Wiltshire, 2007

Backreaction:

$$\langle G \rangle_{\mu\nu} = 8\pi G \langle T \rangle_{\mu\nu} \qquad \langle G \rangle_{\mu\nu} \neq G(\langle g \rangle)_{\mu\nu}$$

Two-scale model of separately evolving void and wall regions. Averaging scheme: T. Buchert, 2000

Address the the problem of how to match local clocks and rulers of observers to global clocks and and rulers of an effective statistical metric

The Friedmann-Lemaître-Robertson-Walker distance-redshift relation

$$d_L = \frac{(1+z)c}{H_0\sqrt{|\Omega_{k0}|}} \operatorname{sinn}\left(\sqrt{|\Omega_{k0}|}\int\limits_{1/(1+z)}^{1} \frac{\mathrm{d}y}{\mathcal{H}(y)}\right),$$

$$\mathcal{H}(y) \equiv \sqrt{\Omega_{R0} + \Omega_{M0}y + \Omega_{k0}y^2 + \Omega_{\Lambda 0}y^4}\,,$$

$$\operatorname{sinn}(x) \equiv \begin{cases} \sinh(x), & \Omega_{k0} > 0 \\ x, & \Omega_{k0} = 0 \\ \sin(x), & \Omega_{k0} < 0 \end{cases}$$

The timescape model distance-redshift relation

$$
\begin{aligned}
d_L &= (1+z)^2 d_A, \\
d_A &= c\, t^{2/3} \int_t^{t_0} \frac{2\,\mathrm{d}t'}{(2+f_{\rm v}(t'))(t')^{2/3}},
\end{aligned}
$$

$$
f_{\rm v}(t) = \frac{3 f_{\rm v0} \bar{H}_0 t}{3 f_{\rm v0} \bar{H}_0 t + (1-f_{\rm v0})(2+f_{\rm v0})},
$$

$$
z+1 = \frac{(2+f_{\rm v}) {f_{\rm v}}^{1/3}}{3 f_{\rm v0}^{1/3} \bar{H}_0 t}
$$

Considerations when fitting an inhomogeneous model

Peculiar velocity corrections to the JLA sample CMB-redshifts

Homogeneity scale and redshift cut

Parameters of the likelihood

$\mu = m_B - M_B + \alpha x_1 - \beta c$

SALT model $\rightarrow$ 2 free parameters: α, β

Assumed distribution of intrinsic supernovae parameters:

Identical and independent gaussian distributions $\rightarrow$

6 free parameters $(M_{B,0}, \sigma_{M_B}, c_0, \sigma_c, x_{1,0}, \sigma_{x_1})$

Cosmological model $\rightarrow$

1 free parameter for timescape and spatially flat ΛCDM.

0 free parameters for the empty Universe

Total: 9 parameters for timescape and the spatially flat ΛCDM.

8 parameters for the empty Universe.

Supernovae analysis of the timescape model - Results

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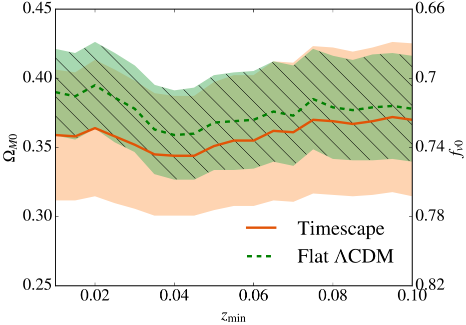
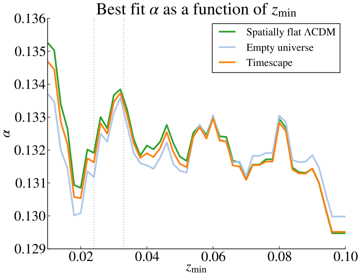
Constraining cosmological parameters

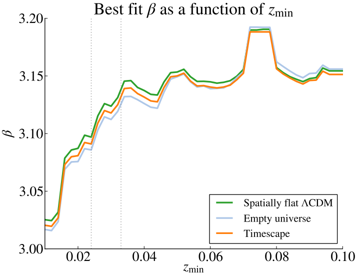


Expectation value and 1σ credible interval of Ω_{M0} as a function of redshift cut.

Supernovae analysis of the timescape model - Results



(a) *Frequentist best fit value of the SALT relation α parameter as a function of redshift cut, z_{min}.*



(b) *Frequentist best fit value of the SALT relation β parameter as a function of redshift cut, z_{min}.*

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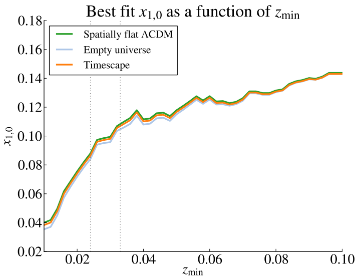
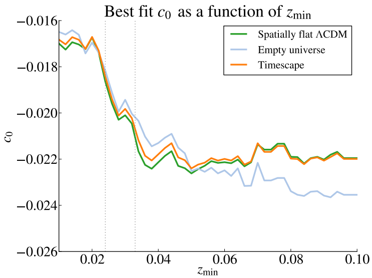
Statistical homogeneity scale and systematics in redshift



(a) *Frequentist best fit value of the mean of the intrinsic shape parameter distribution, $x_{0,1}$, as a function of redshift cut, z_{min}.*



(b) *Frequentist best fit value of the mean of the intrinsic colour parameter distribution, c_0, as a function of redshift cut, z_{min}.*

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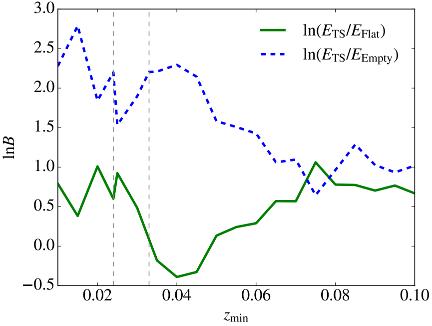
Quality of fit measures



Natural logarithm of Bayes factor as a function of redshift cut. For positive values the timescape model is favoured. E is short for Bayesian evidence.

Variation with redshift in intrinsic colour and shape parameters

D. Rubin and B. Hayden, 2016

Systematics with redshift in distribution of intrinsic supernovae parameters?

Correlation between older host galaxies and narrower-light-curve, and selection effects

$\rightarrow$ 12 additional parameters

$$x_{1,0} \rightarrow x_{1,0,J} + x_{z,J} z, \qquad \text{and} \qquad c_0 \rightarrow c_{0,J} + c_{z,J} z$$

J=1,2,3,4 indicates the four sub-samples of the JLA dataset

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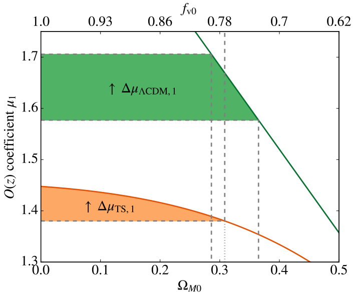
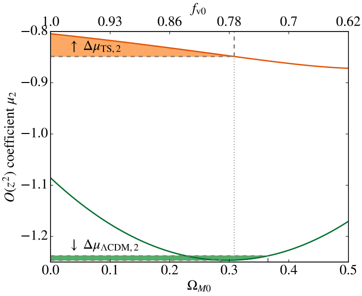
The distance modulus expansion in redshift



(a) *The change in the distance modulus $O(z)$ coefficient in going from the NGS16 best fit to the fit with 12 additional parameters.*



(b) *The change in the distance modulus $O(z^2)$ coefficient in going from the NGS16 best fit to the fit with 12 additional parameters.*

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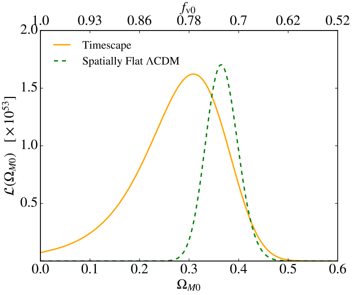
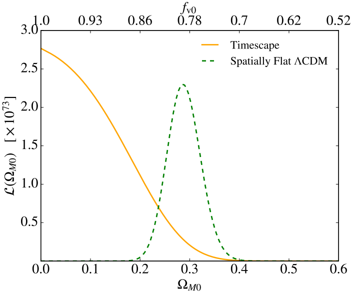
12 extra parameters and drift of the likelihood function



(a) *Profile likelihood in Ω_M for simple gaussian distributions of intrinsic colour and shape parameters.*



(b) *Profile likelihood in Ω_M for redshift dependence in the distribution of the intrinsic colour and shape parameters.*

Summary

General issues in fitting an inhomogeneous cosmology to supernovae data

The JLA sample is consistent with small apparent acceleration within the timescape model framework

The timescape model and the spatially flat ΛCDM model fits the JLA sample equally well

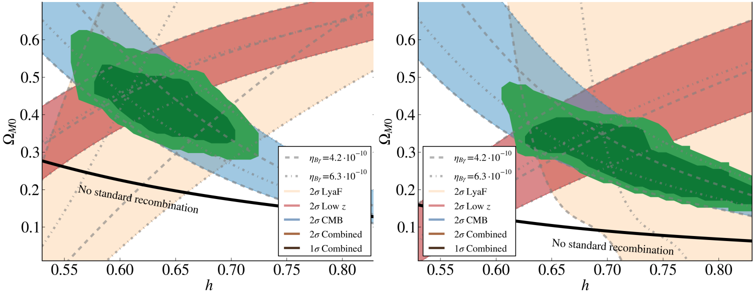
Systematics in supernovae parameters and degeneracy with the cosmological model

Future work: Bias correction to the JLA sample apparent magnitudes constructed using a fiducial ΛCDM model

Non parametric prior analysis

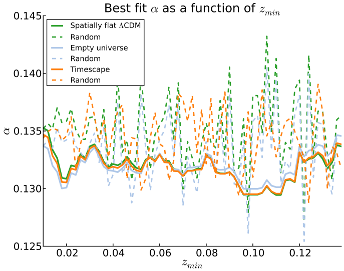
Model independent determination of the peak locations of the CMB A. Aghamousa et al., 2015

Estimates of the BAO angular scale at different redshifts T. Delubac et al., 2015. E. Aubourg et al., 2015, S. Alam et al., 2016.

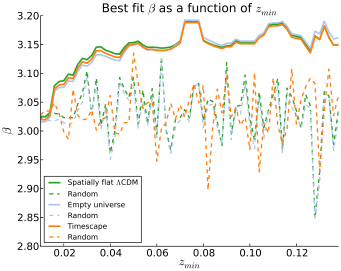


(a) *CMB and BAO contours for the timescape model.* (b) *CMB and BAO contours for the ΛCDM model.*

Supernovae analysis of the timescape model - Results

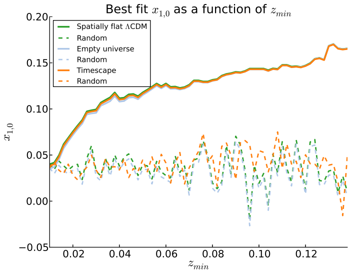


(a) *Frequentist best fit value of the α parameter as a function of redshift cut, z_{min} as compared to that of random drawings.*

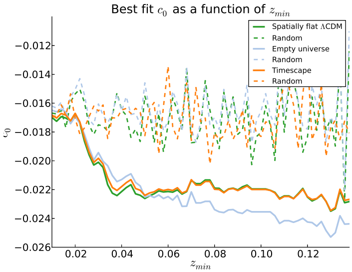


(b) *Frequentist best fit value of the β parameter as a function of redshift cut, z_{min} as compared to that of random drawings.*

Supernovae analysis of the timescape model - Results

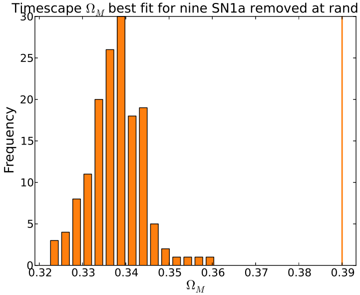


(a) *Frequentist best fit value of* $x_{1,0}$ *parameter as a function of redshift cut,* z_{min} *as compared to that of random drawings.*

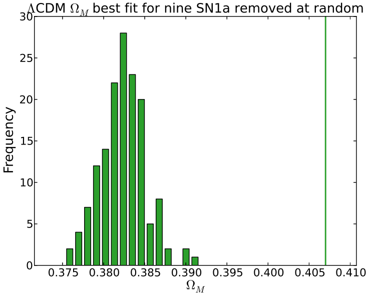


(b) *Frequentist best fit value of* c_0 *parameter as a function of redshift cut,* z_{min} *as compared to that of random drawings.*

Supernovae analysis of the timescape model - Results



(a) *Best fit Ω_M timescape parameter distribution, removing nine supernovae at random. Compared to the best fit Ω_M value removing the nine supernovae of the HST sample*

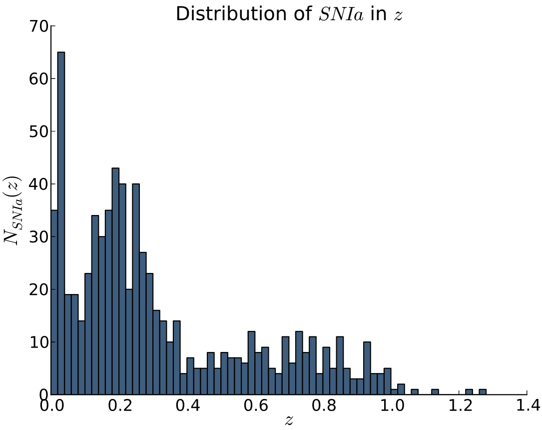


(b) *Best fit Ω_M ΛCDM parameter distribution, removing nine supernovae at random. Compared to the best fit Ω_M value removing the nine supernovae of the HST sample*

The Joint Lightcurve Analysis sample

1. Supernovae of type 1a.
2. low-z, SDSS, SNLS, Riess HST
3. Redshift z; Direction on our sky (ϕ, θ); Apparent magnitude transformed to 'the rest-frame B-band' m_B; Light curve shape x_1; Color correction c

The Joint Lightcurve Analysis sample



Distribution of supernovae as a function of redshift transformed to the CMB frame.