Is Dark Energy Clustering Important?

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Dark Energy and Modified-Gravity cosmologies: DARKMOD

September 2017

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Introduction

#Our universe has experienced two accelerations in its life:

1) Inflation Era

2) Dark Energy Era

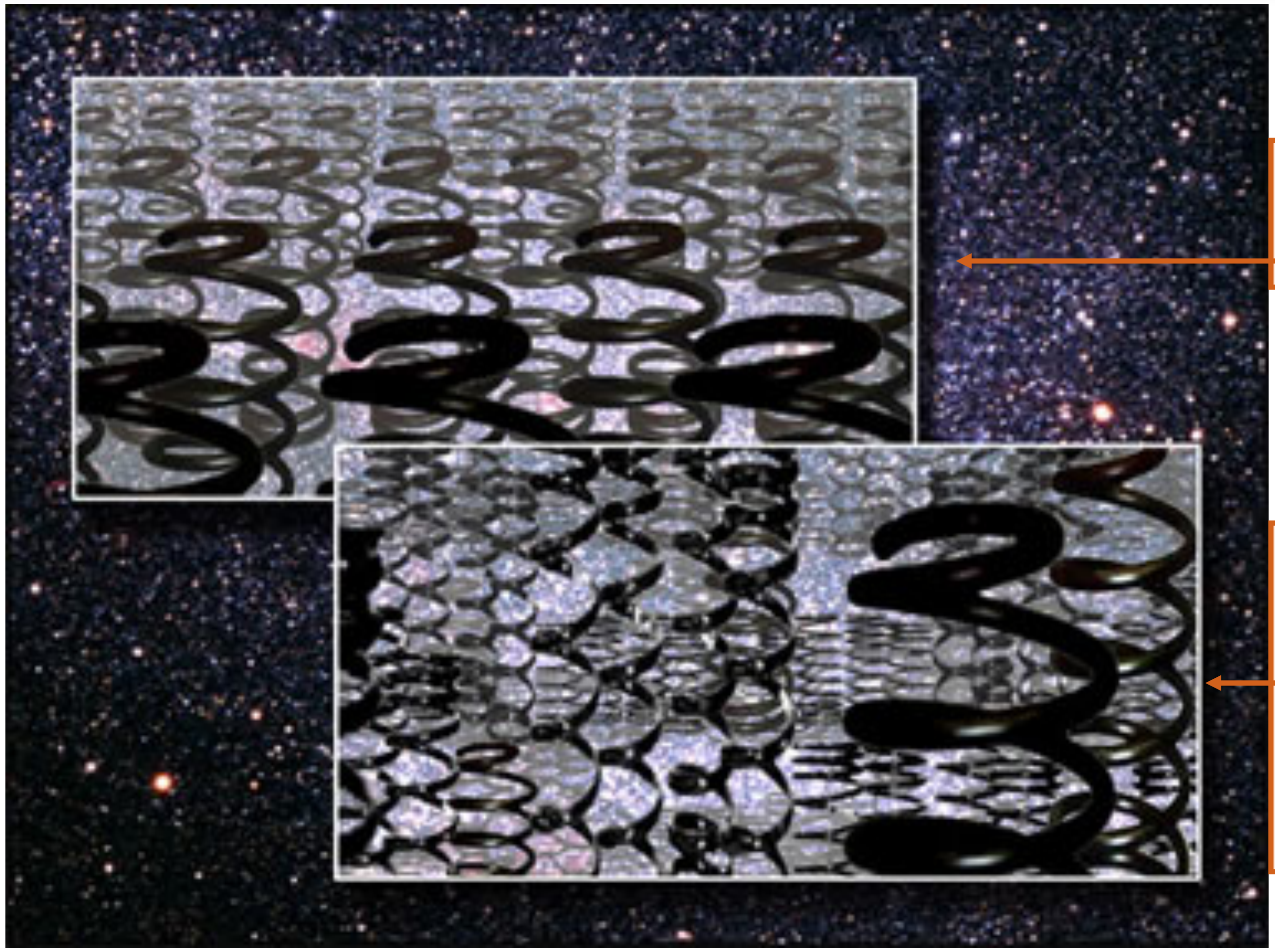
???

The simplest candidate for dark energy is the so-called cosmological constant, whose energy density remains constant.

Cosmological constant problem(Technically Unnatural)

- J. Martin, Everything You Always Wanted To Know About The Cosmological Constant Problem (But Were Afraid To Ask), Comptes Rendus Physique 13 (2012) 566 - arXiv:1205.3365

Introduction



Is dark energy static?

Is dark energy dynamic?
A new, time and space varying field.

What is our approach??

New Fluid

Modified Gravity

http://newscenter.lbl.gov/2008/03/06/dark-energys-10th-anniversary/

Perturbations

All components of universe can be investigated in two levels:

I) Background level

II) Perturbation level

* Linear perturbation $\delta \ll 1$

* Non-Linear Perturbation $\delta \gg 1$

Perturbations

By perturbation around FRW background in Newtonian Gauge, we can obtain coupled perturbed equations in Fourier space as below:

$$k^2\Phi + 3\mathcal{H}(\Phi' - \mathcal{H}\Psi) = 4\pi G a^2 \rho \boxed{\delta}\,, \quad \text{Density Contrast}$$

$$k^2(\Phi' - \mathcal{H}\Psi) = -4\pi G a^2 (1 + \boxed{w})\rho\theta\,, \quad \text{Equation of State}$$

$$\Psi = -\boxed{\Phi}\,, \quad \text{Potential}$$

$$\Phi'' + 2\mathcal{H}\Phi' - \mathcal{H}\Psi' - (\mathcal{H}^2 + 2\mathcal{H}')\Psi = -4\pi G a^2 c_s^2 \rho\delta\,,$$

$$\text{Sound Speed} \quad \delta' + 3\mathcal{H}(\boxed{c_s^2} - w)\delta = -(1 + w)(\boxed{\theta} + 3\Phi')\,, \quad \text{Velocity Dispersion}$$

$$\theta' + \left[\mathcal{H}(1 - 3w) + \frac{w'}{1 + w}\right]\theta = k^2\left(\frac{c_s^2}{1 + w}\delta + \Psi\right)\,,$$

Model Selection

Dynamical Dark Energy Model:

1) Equation of state
2) Sound Speed =====>> Clustering of dark energy
3) Anisotropic Pressure

$$w(z) = w_0 + w_1 \frac{z}{1+z}$$

====> CPL

Linder, Eric V. "Exploring the expansion history of the universe." Physical Review Letters 90.9 (2003): 091301.

Chevallier, Michel, and David Polarski. "Accelerating universes with scaling dark matter." International Journal of Modern Physics D 10.02 (2001): 213-223.

$$w(z) = w_0 + w_1 \frac{z}{1+z^2}$$

====> FSL

. C. J. Feng, X. Y. Shen, P. Li and X. Z. Li, A New Class of Parametrization for Dark Energy without Divergence, JCAP 1209, 023 (2012)

$$w(a) = w_0 a^{\alpha}(1 + \ln(a^{\alpha}))$$

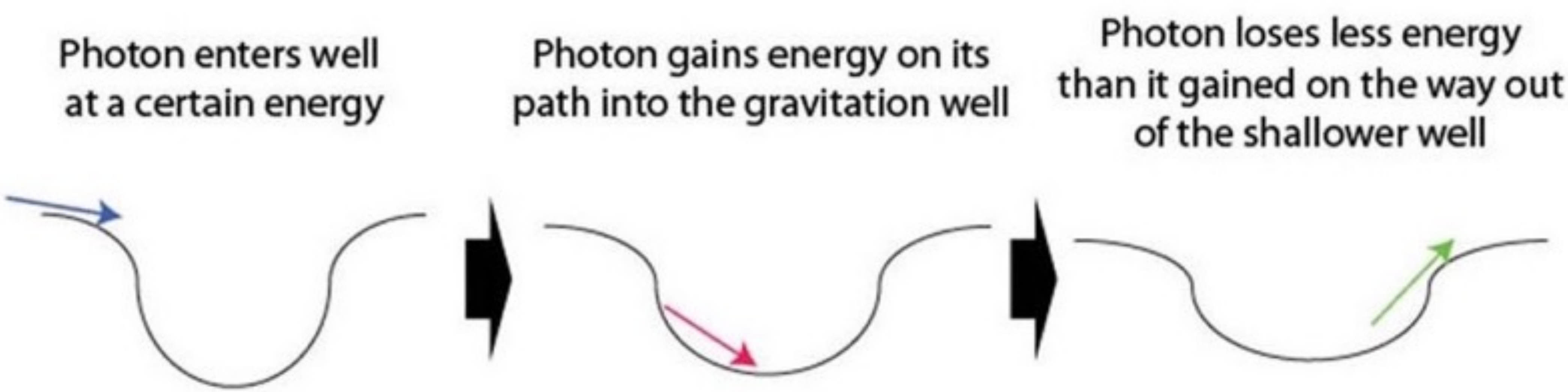
====> PL

. S. Rahvar and M. S. Movahed, Power-law Parameterized Quintessence Model, Phys. Rev. D 75, 023512 (2007)

Observational Probes of Dark Energy

Integrated Sachs-Wolfe Effect

The ISW effect is caused by the variation of the gravitational potential during the epoch of the cosmic acceleration.



Gravitational well of galaxy supercluster - the depth shrinks as the universe (and cluster) expands

$$\Delta_\ell^{ISW}(k) = 2\int d\eta e^{-\tau}\Phi' j_\ell(k(\eta-\eta_0))$$

Observational Probes of Dark Energy

$$k^2\Phi = 4\pi G a^2 \rho\delta$$

1. Radiation-Matter era:

$\rho_\gamma \propto a^{-4}$ $\delta \propto cte$ =====> $\Phi \propto a^{-2}$ Early ISW

2. Matter dominated era:

$\rho_M \propto a^{-3}$ $\delta \propto a$ =====> $\Phi \propto cte$ No ISW

3. Dark Energy era:

$\rho_\Lambda \propto cte$ $\delta \propto cte$ =====> $\Phi \propto a^2$ Late ISW

Observational Probes of Dark Energy

Matter power spectrum

$$\boxed{P(k) = k^n T^2(k) D^2(a)}$$

"n" is Spectral Index

Linear Growth Factor

CDM Transfer Function

$$\boxed{T(k) = C_q\left(1 + 3.89q + (16.1q)^2 + (5.46q)^3 + (6.71q)^4\right)^{\frac{-1}{4}}}$$

$$\boxed{C_q = \frac{\ln(1 + 2.34q)}{2.34q}}$$

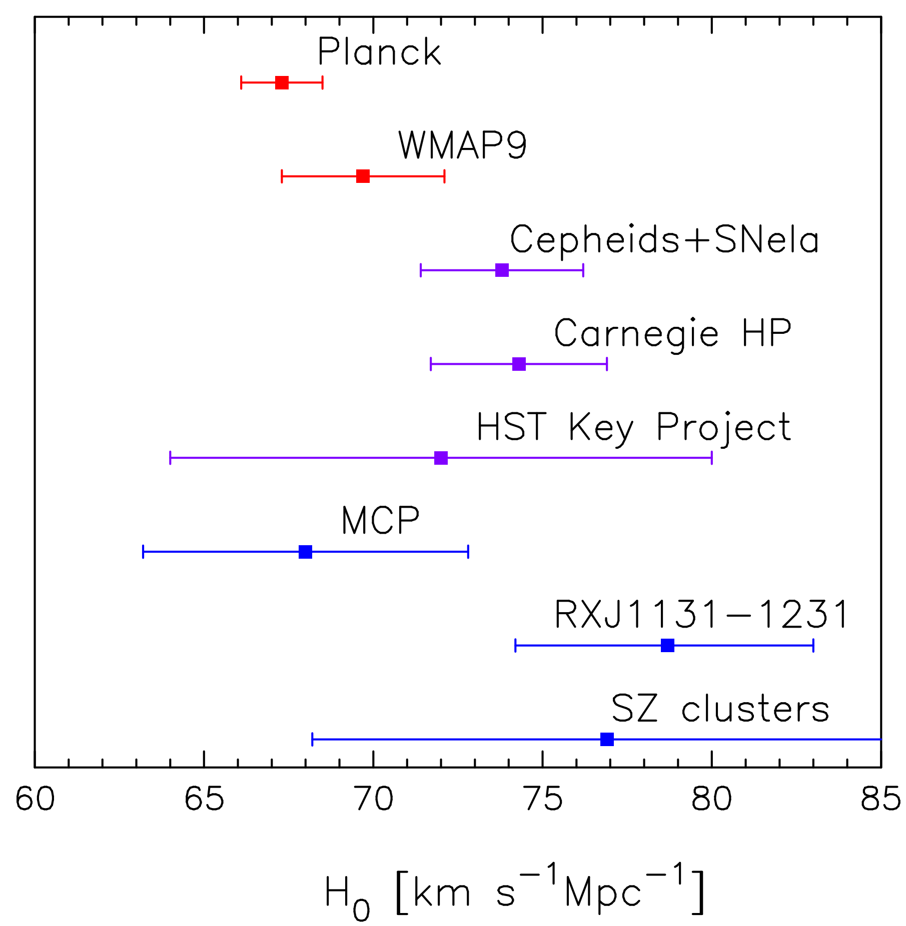
$$\boxed{q \equiv \frac{k}{\Gamma}}$$

$$\boxed{\Gamma = \Omega_{m0} h \exp\left(-\Omega_{m0} - \frac{\sqrt{2h}\,\Omega_{b0}}{\Omega_{m0}}\right)}$$

Observational Probes of Dark Energy

With the recent measurement of H0 this tension has raised to more than 3 σ between direct local measurement and the model-dependent value inferred from the Cosmic Microwave Background

$H_0 = (67.3 \pm 1.2)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (68%; *Planck*+WP+highL) $H_0 = (73.8 \pm 2.4)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (Cepheids+SNe Ia),



Ade, P. A. R., et al. "Planck 2013 results. XVI. Cosmological parameters." Astronomy & Astrophysics 571 (2014): A16.

Result: Parameter estimation from current data

parameter estimation from current data

WE use MCMC method for parameter Estimation

Cosmology parameters and also model parameters constrained as well

“Clustering of Cold Dynamical Dark Energy Models”. Aghileh S Ebrahimi, Hossein Moshafi, SMS Movahed. (

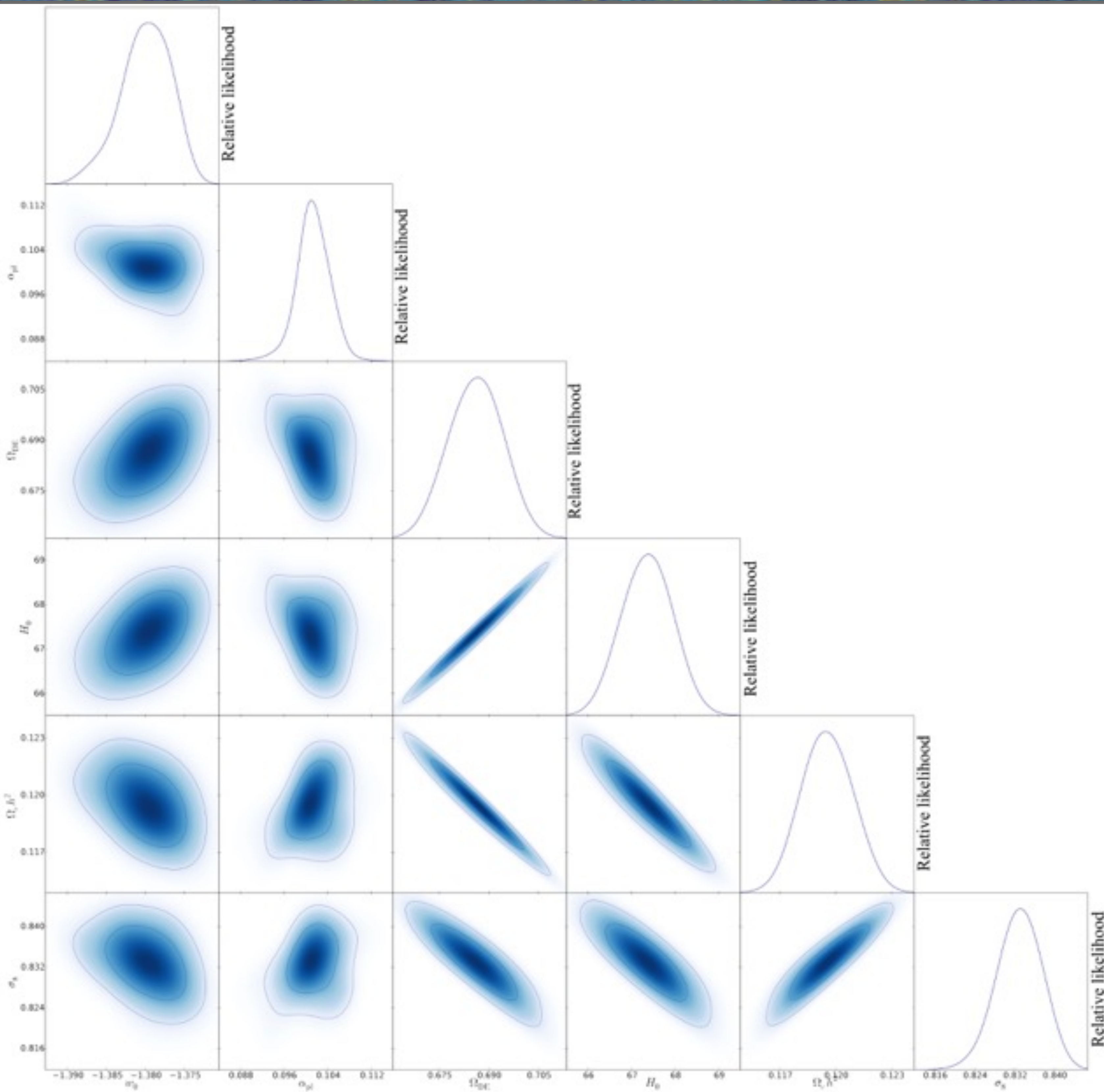
In preparation to submit to JCAP)

All-Sky Footprints

Result: Parameter estimation from current data

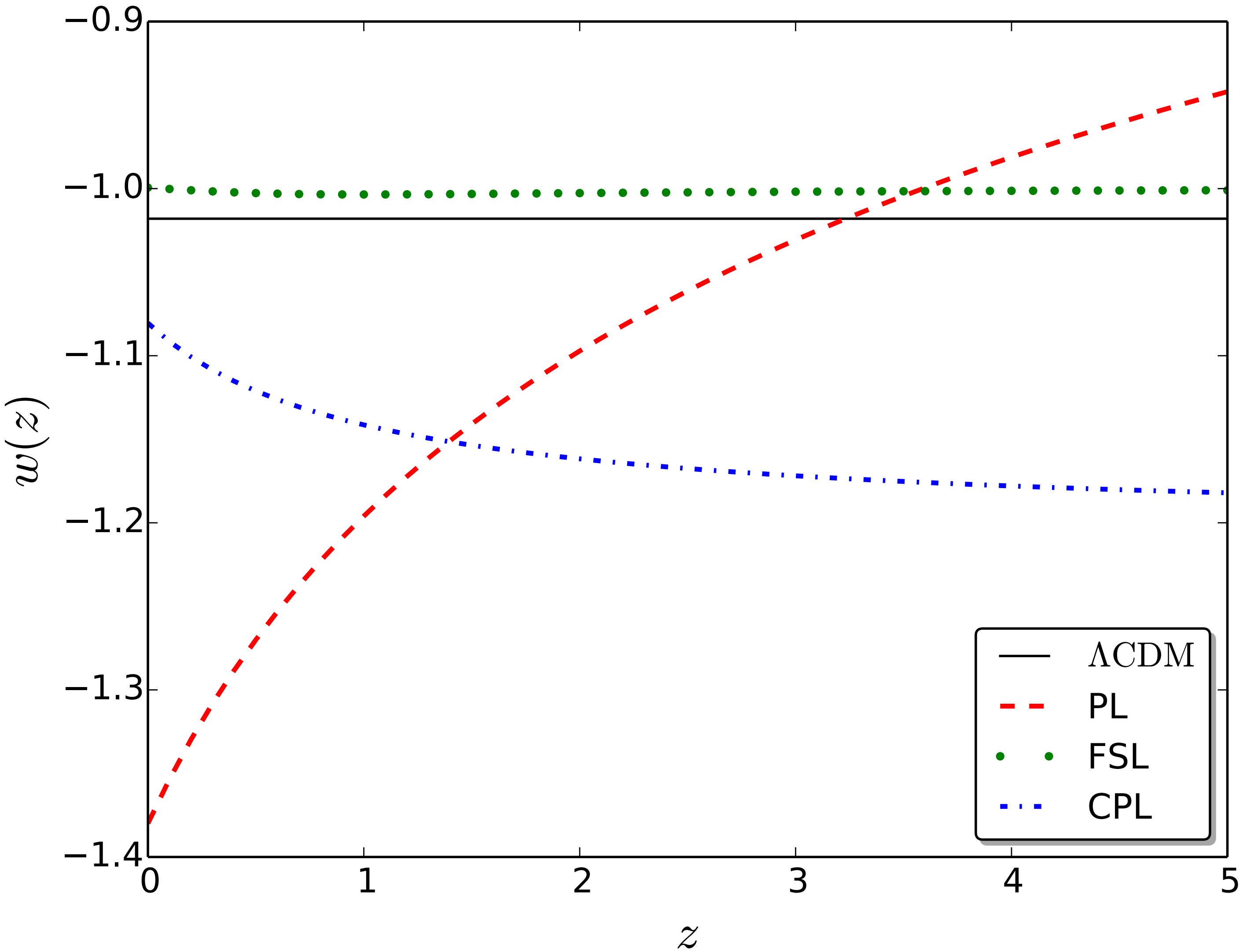
PL Model

2D contour plot



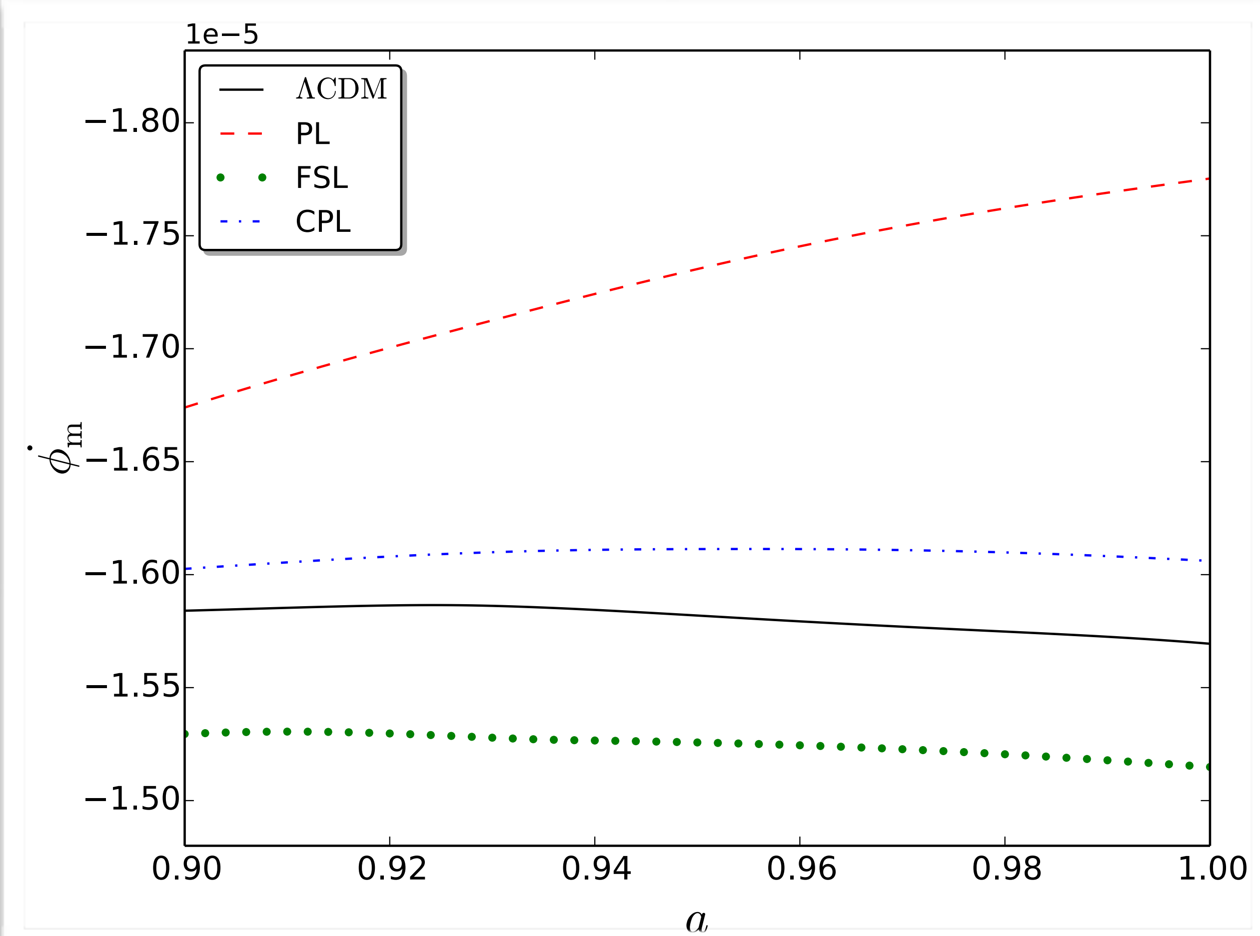
Result: Parameter estimation from current data

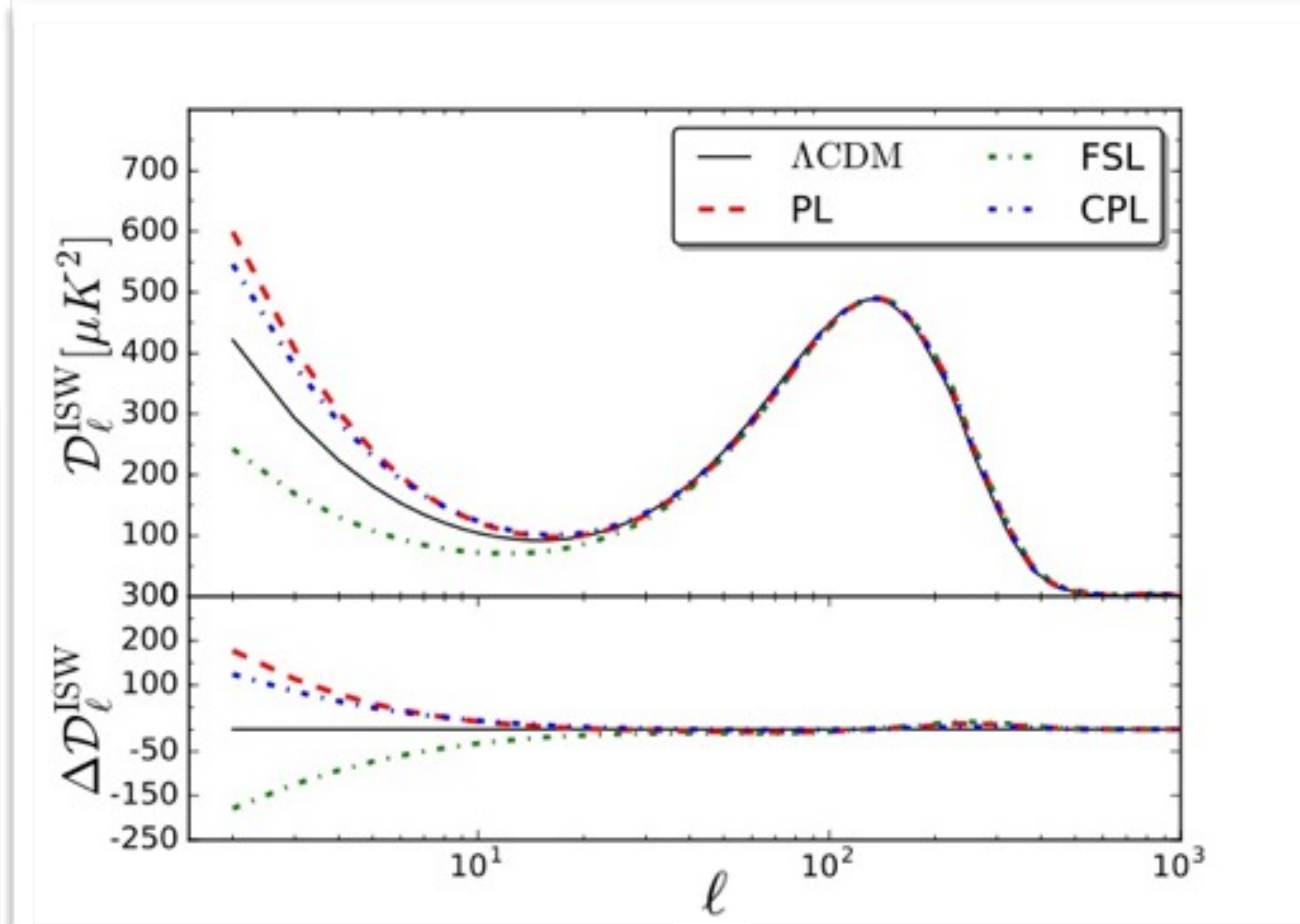
Equation of State



Result: Integrated Sachs-Wolfe Effect

Potential derivation versus scale factor

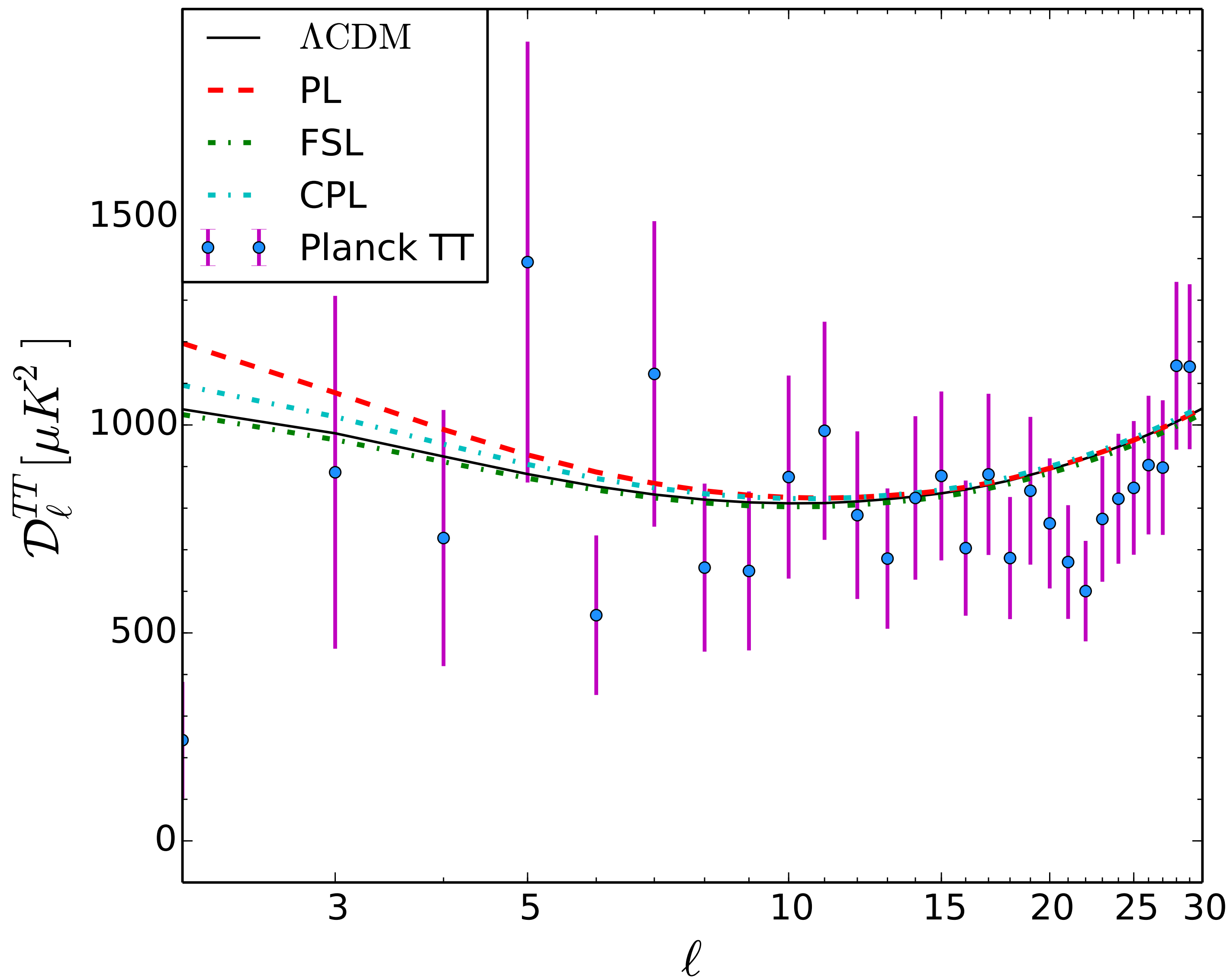


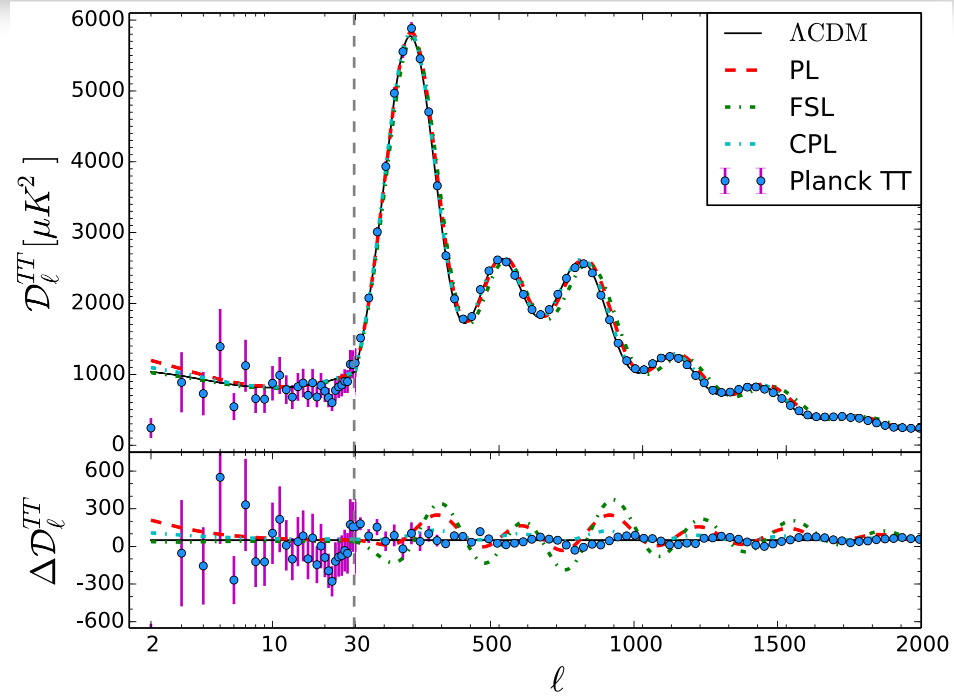


Early and Late ISW Effects

Result: Integrated Sachs-Wolfe Effect

Temperature power spectrum for low l in more detail

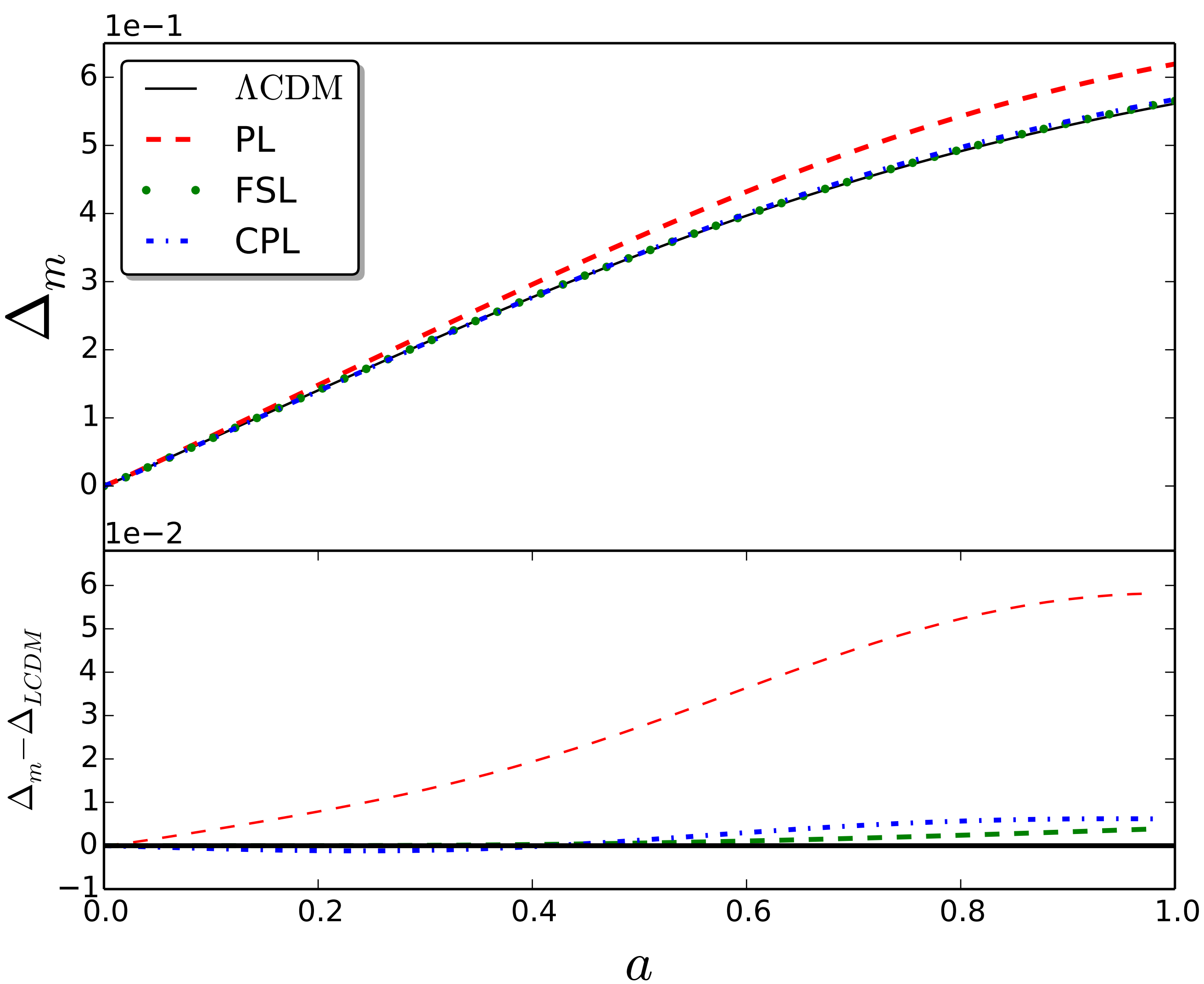


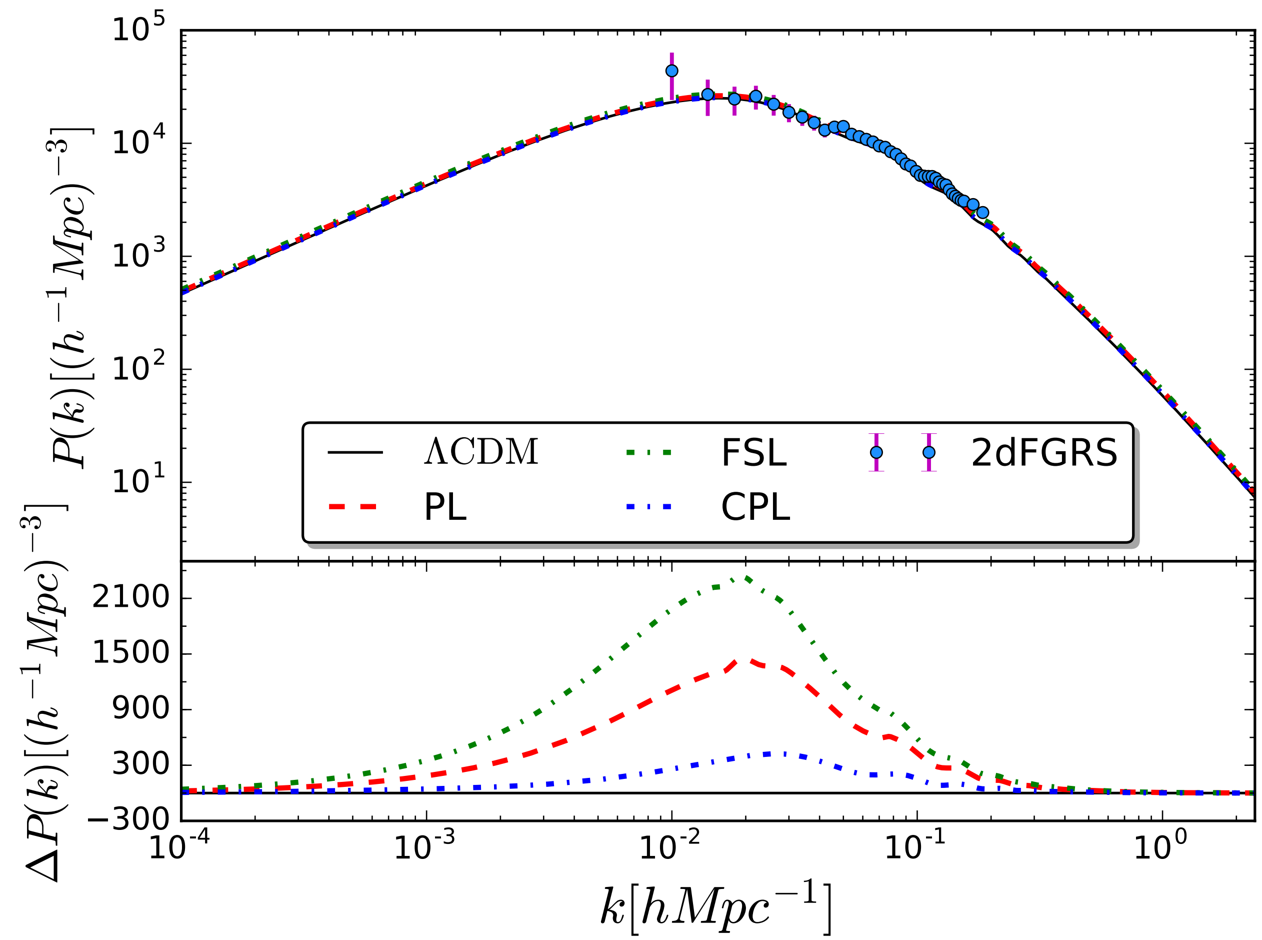


Temperature power spectrum of DDE Residuals with respect to LCDM model are shown in the lower panel.

Result: Matter Power spectrum

Density contrast





Matter power spectrum

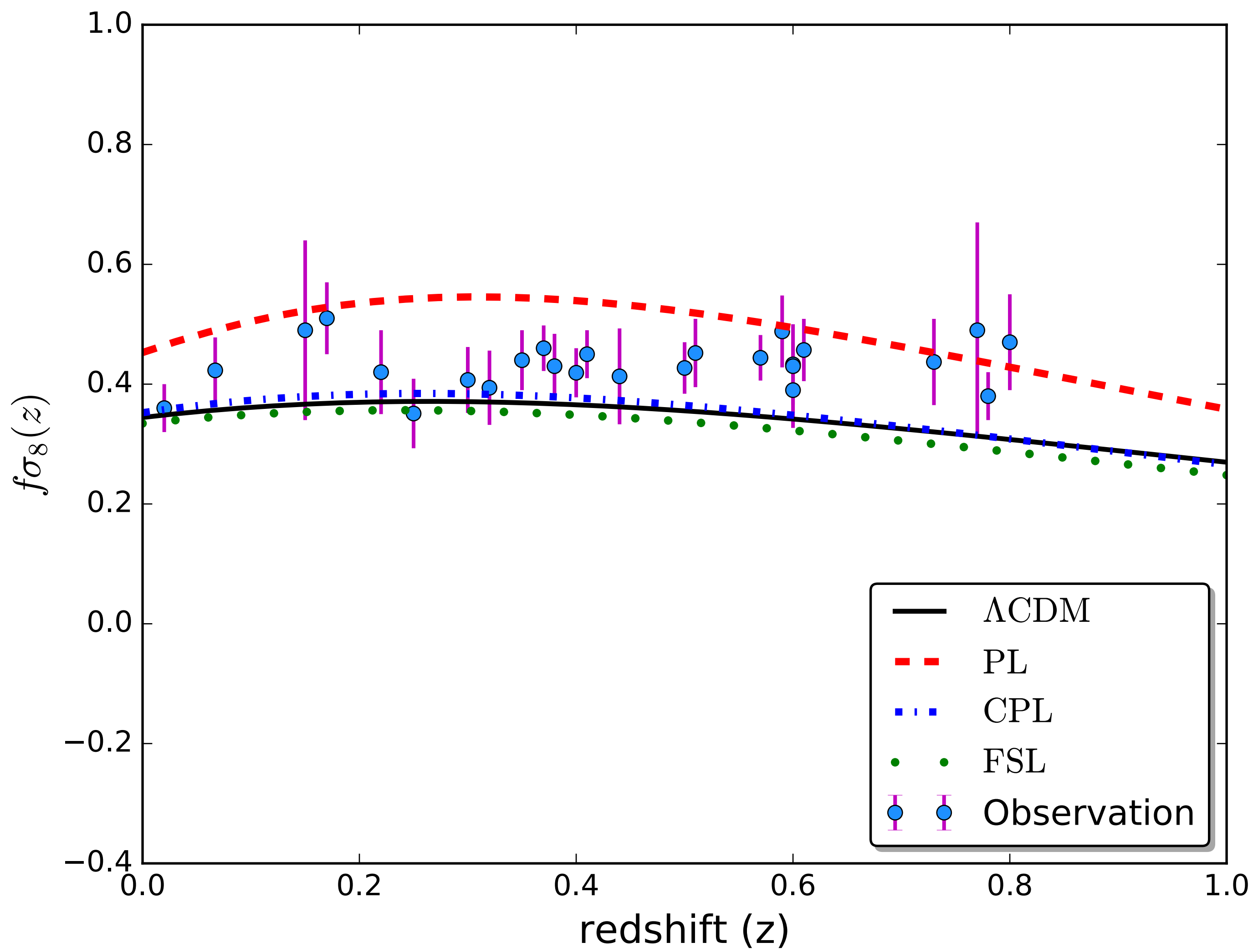
Data: http://www.roe.ac.uk/~jap/2df/

Result: f\sigma_8

$$\boxed{f\sigma_8(z)}$$

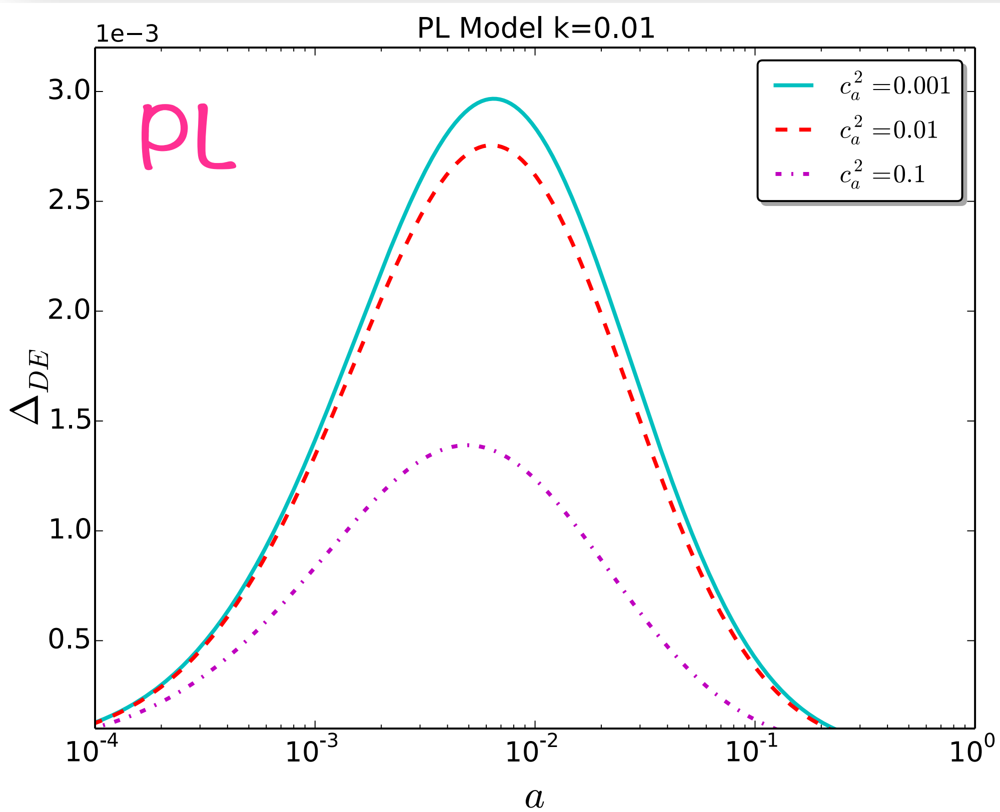
$$\boxed{f(a) = \frac{d\ln\delta}{d\ln a}}$$

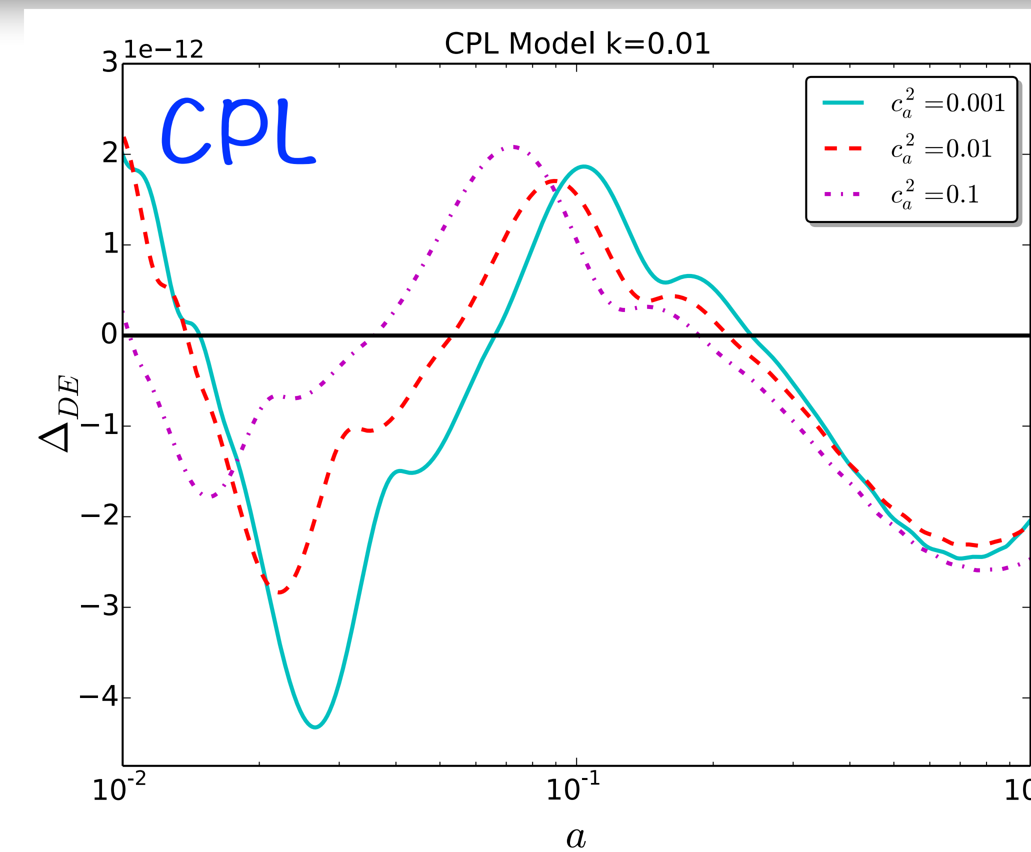
$$\boxed{\sigma(M,z) = [\frac{D^2(z)}{2\pi^2}][\int_0^\infty k^2 P(k) W^2(kR)\, dk]^{1/2}}$$

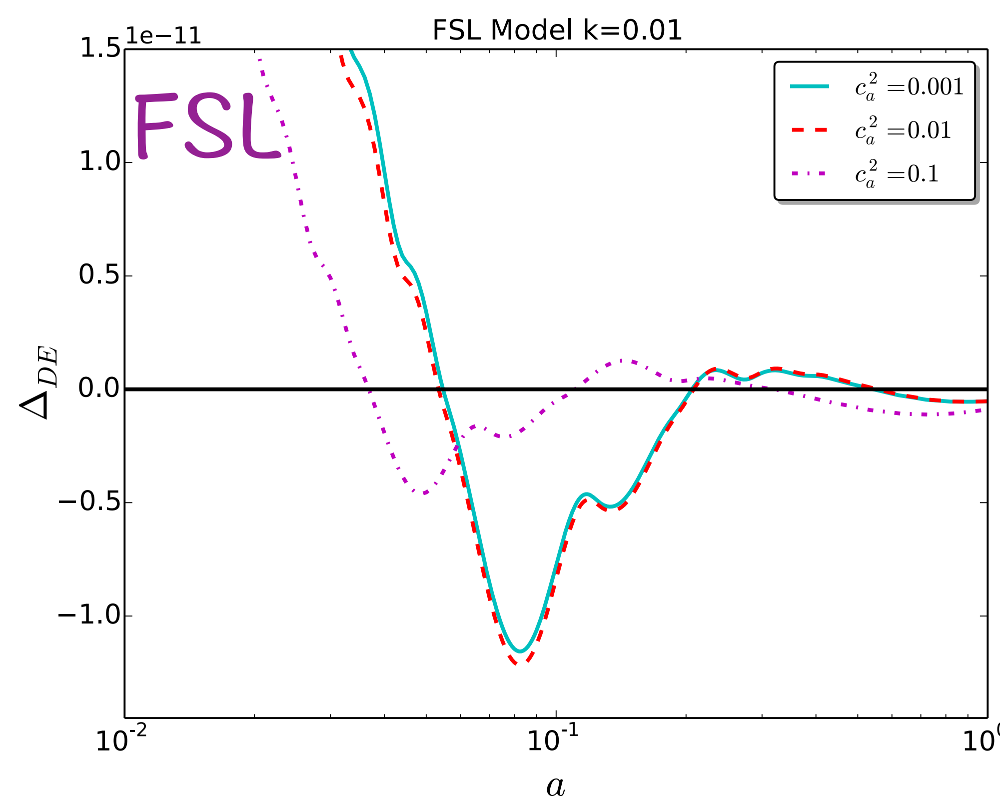


Data: astro-ph:1703.10538

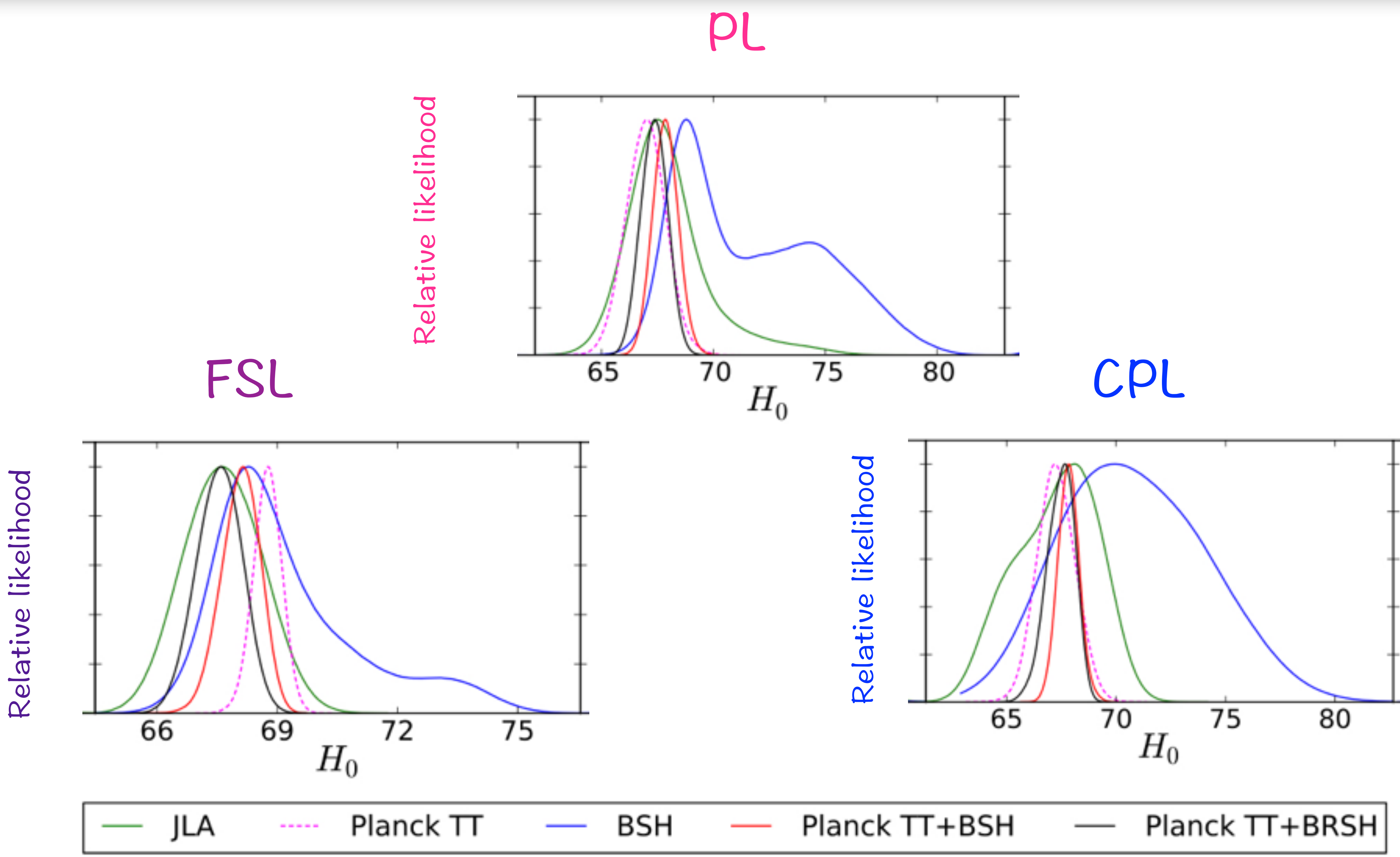
Result: Dark Energy Clustering



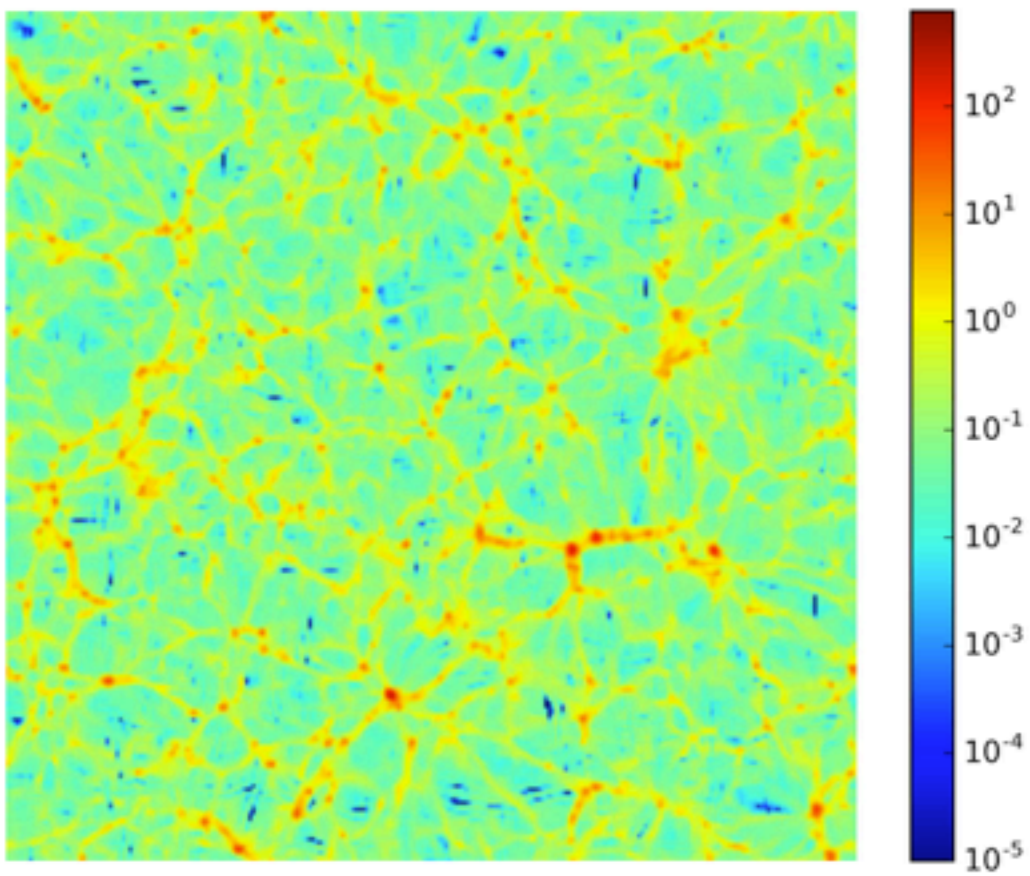


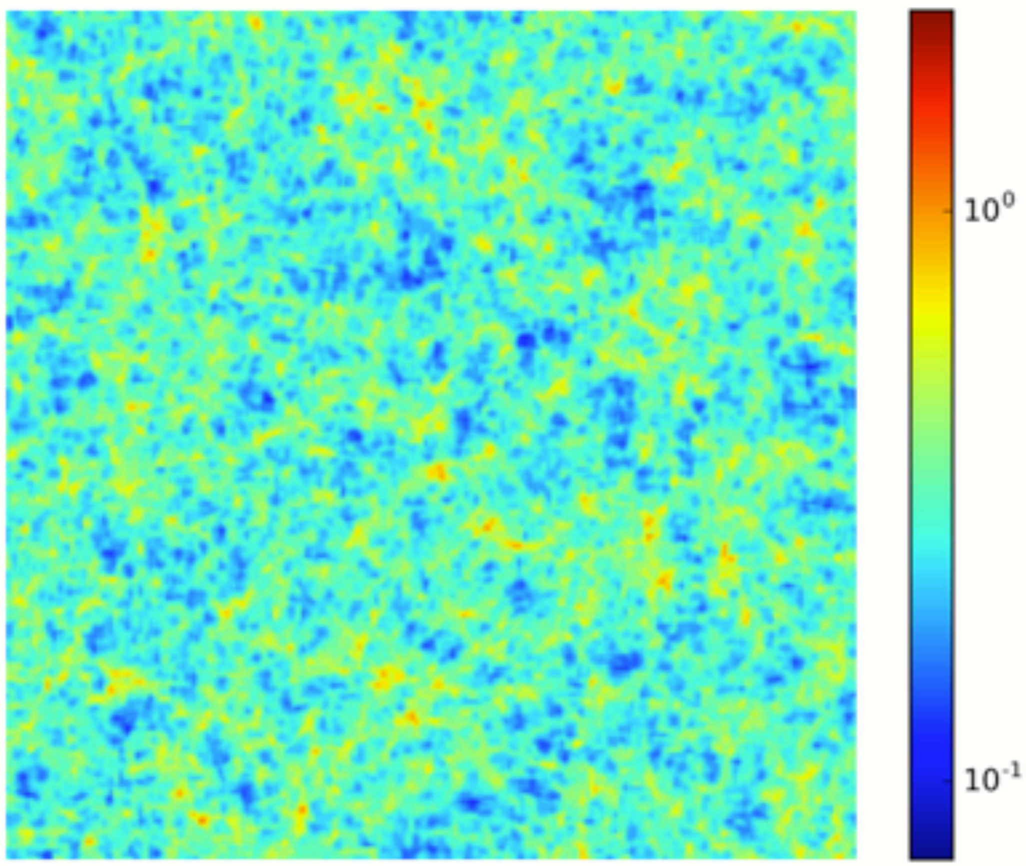


Result: Hubble Tension



Result: N-Body Simulation of Dynamical Dark Energy Molel





"Can Dark Energy models Effect on Shape of Voids?" Aghileh S Ebrahimi, Alireza Vafae sadre, Saeed Tavasoli, Farbod Hassani. (In Preparation to submit to MNRAS)

Conclusion

- PL as crossing model behave such as matter in early universe but CPL and FSL exhibit LCDM behavior equation of state.
- PL exhibits more potential variation and as result of this exhibits more ISW effect. But The models Couldn't solve power deficit problem.
- All models are consistent with matter power spectrum data.
- PL as crossing model exhibits clustering of dark energy with amplitude 10^(-3).
- Peak of likelihood analysis for PL and CPL model exactly overlap in SNIa and CMB data and it can improve H_0 tension.
- Pl shows different behavior in N-body simulation.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спасибо
dank je
thank you
gracias
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mochchakkeram
dziękuję
go raibh maith agat
obrigado
sagolun
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