Reconstruction, Analysis and Constraints of Cosmological Scalar Field φCDM Models

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Based on the paper: Olga Avsajanishvili, Yiwen Huang, Lado Samushia, Tina Kahniashvili,

"*The observational constraints on the flat φCDM models*", Eur. Phys. J. C78, 09, 773; 2018; arXiv:1711.11465

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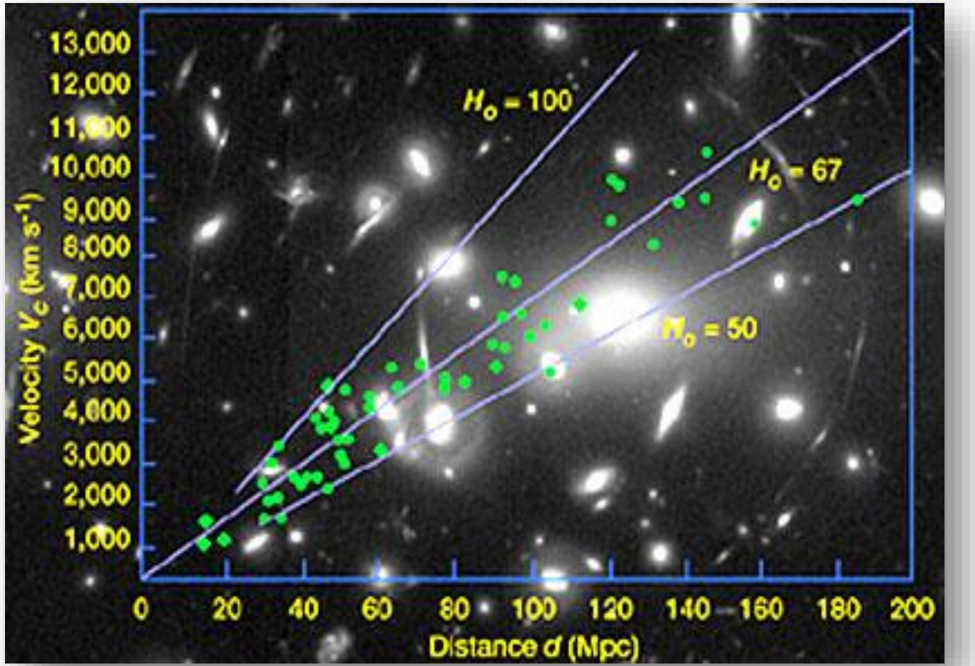
Hubble law

$$V = H_0 D$$

H_0 - **Hubble constant**

H_0 **= 67.4 km** $s^{-1}Mpc^{-1}$



Accelerated expansion of the Universe

Nobel Prize in Physics 2011

Photo: Lawrence Berkeley National Lab — **Saul Perlmutter**

Photo: Belinda Pratten, Australian National University — **Brian P. Schmidt**

Photo: Scanpix/AFP — **Adam G. Riess**

The Nobel Prize in Physics 2011 was awarded *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"* with one half to Saul Perlmutter and the other half jointly to Brian P. Schmidt and Adam G. Riess.

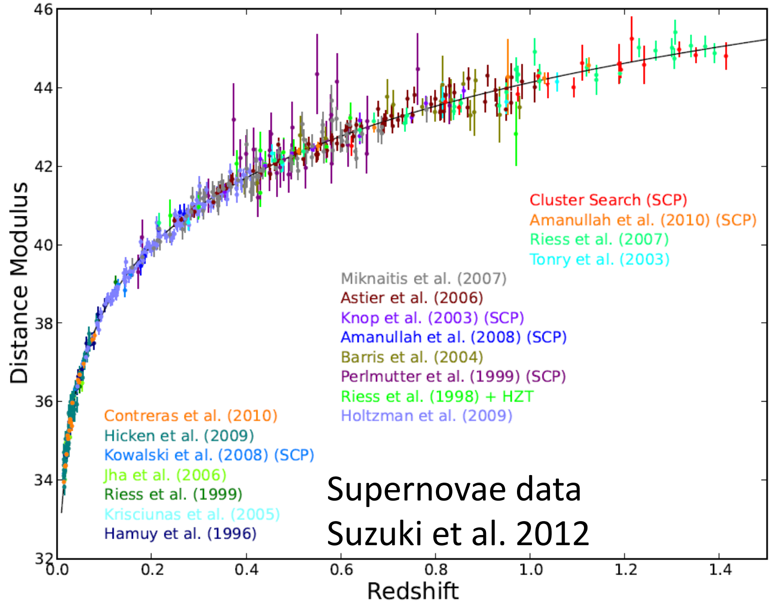
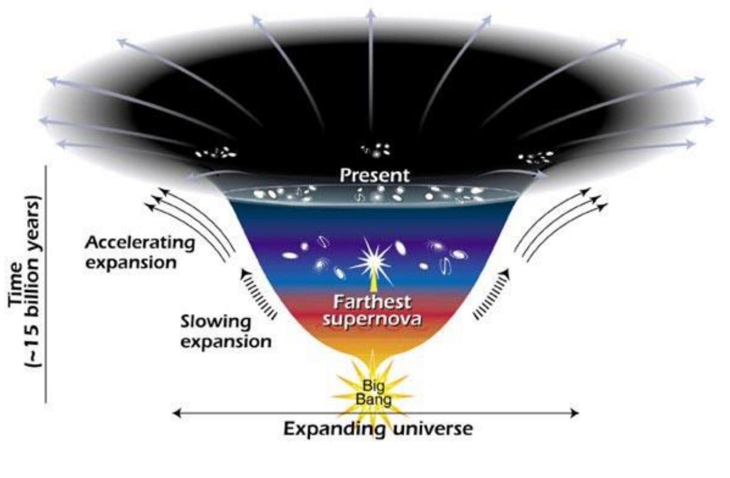


Figure 4. Hubble diagram for the Union2.1 compilation. The solid line represents the best-fit cosmology for a flat ΛCDM Universe for supernovae alone. SN SCP06U4 falls outside the allowed x_1 range and is excluded from the current analysis. When fit with a newer version of SALT2, this supernova passes the cut and would be included, so we plot it on the Hubble diagram, but with a red triangle symbol.



Dark Energy? **Modified Gravity?**

Dark energy models

- **Cosmological constant, Λ**
- **Scalar field (quintessence and phantom) models**
- **K-essence models**
- **Holographic dark energy models**
- **Barotropic fluid or Chaplygin gas models**
- **Coupled dark matter (neutrino)-dark energy models**

Cosmological constant

$$S = -\frac{1}{16\pi G}\int d^4x\sqrt{-g}(R+2\Lambda) + S_M$$

- **Λ → "concordance" ΛCDM model**

- **ΛCDM model provides the best fit for cosmological observations**

- **ΛCDM model is based on GTR for description of gravity in the Universe on large scales**

- **ΛCDM model has:**
  - **fine tuning problem**
  - **coincidence problem**

Dynamical scalar field φCDM models

The equation of state parameter

$$w = p/\rho$$

$$\swarrow \qquad \searrow$$

$w_\Lambda = -1$ — **ΛCDM model**

$w_\phi(t) \neq -1$ — **φCDM models**

where ρ is an energy density, p is a pressure

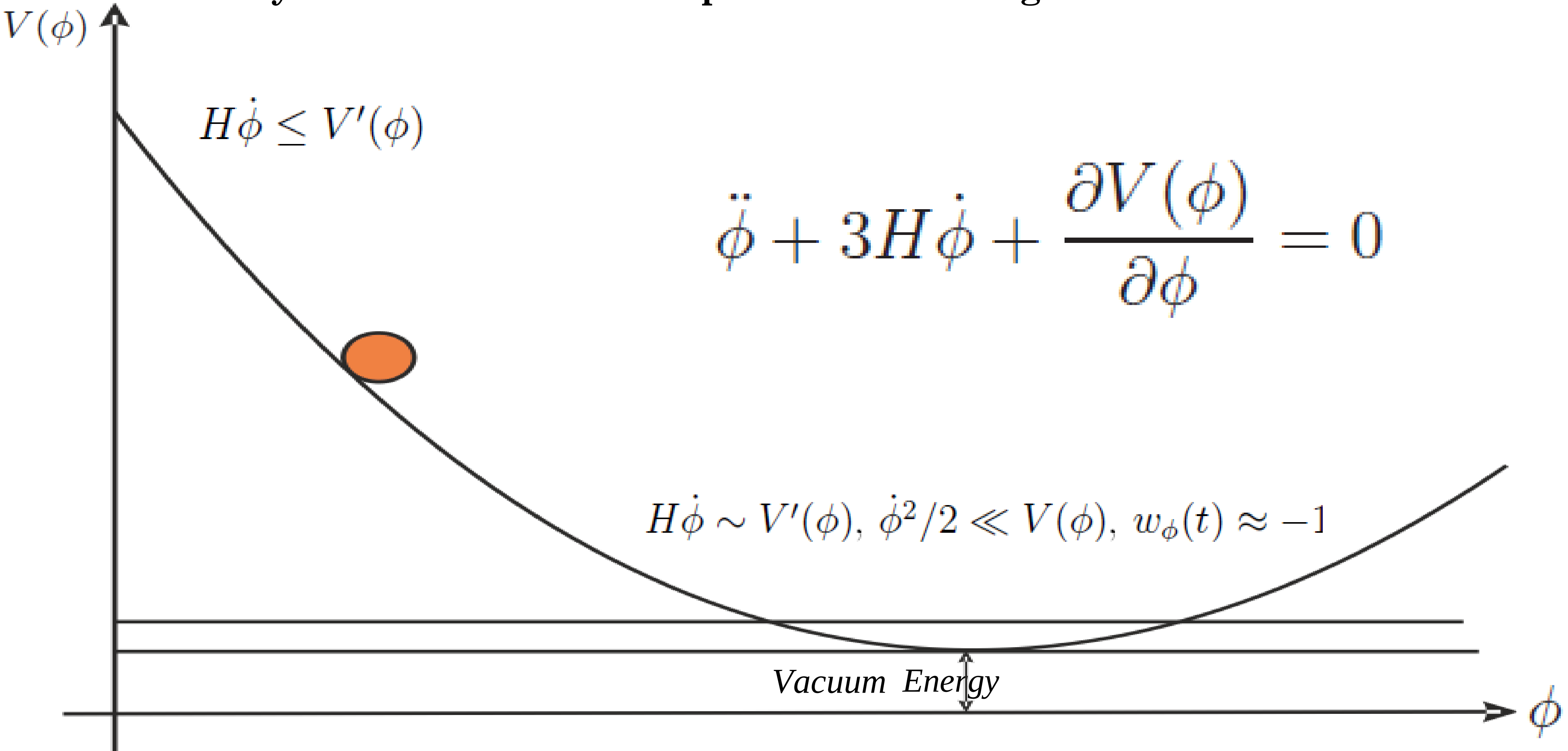
Phantom and quintessence φCDM models

$$S = \int d^4x\sqrt{-g}\Big[-\frac{M_{\rm pl}^2}{16\pi}R + \mathcal{L}_\phi\Big] + S_{\rm M}$$

Phantom models	Quintessence models
$w_0 < -1$	$-1 < w_0 < -1/3$
$\mathcal{L}_\phi = -\frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)$	$\mathcal{L}_\phi = \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)$
$\ddot{\phi} + 3H\dot{\phi} - \frac{\partial V(\phi)}{\partial\phi} = 0$	$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V(\phi)}{\partial\phi} = 0$

Quintessence

- Spatially uniform dynamical scalar field
- Slowly rolls down to the minimum of its almost flat potential
- This model avoids the fine tuning problem of the ΛCDM model
- Plays a role of the time-dependent cosmological constant



$$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V(\phi)}{\partial \phi} = 0$$

Subdivision of the quintessence models:

- **the thawing models** for which the evolution of the scalar field is fast compared to the Hubble expansion.

$$H < \sqrt{V''(\phi)}$$ - **underdamped**

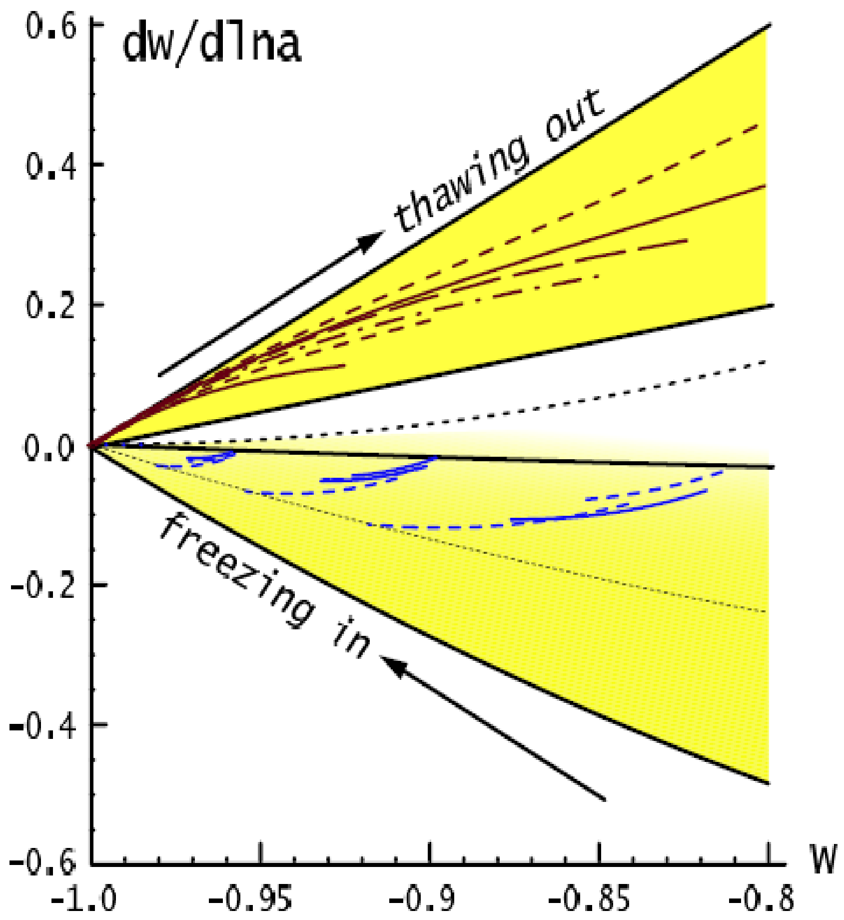
$$V(\phi) = M^{4-\alpha}\phi^{\alpha}, \alpha > 0;$$

$$V(\phi) = M^4 \exp(-\beta\phi/M_{pl}), \beta < \sqrt{24\pi}$$

- **the tracking (freezing) models** for which the evolution is slow compared to the Hubble expansion:

$$H > \sqrt{V''(\phi)}$$ - **overdamped**

$$V(\phi) = \frac{k}{2} M_{pl}^2 \phi^{-\alpha}, \alpha > 0$$



R.Caldwell & E.Linder, Phys. Rev. Lett. 95, 141301 (2005)

Chevallier-Polarsky-Linder (CPL) parameterization

$$w(a) = w_0 + w_a(1 - a)$$

$$w_0 = w(a_0 = 1),\ w_a = (dw/dz)|_{z=1} = -a^{-2}(dw/da)|_{a=1/2}$$

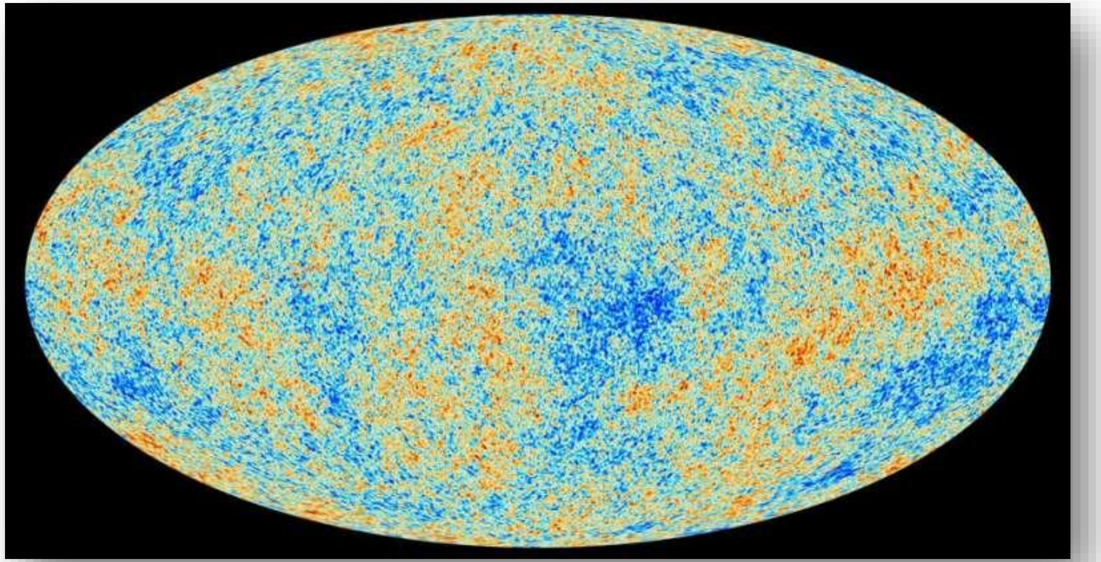
$dw/da > 0$ for quintessence thawing models

$dw/da < 0$ for quintessence freezing models

M.Chevallier & D.Polarski, Int. J. Mod. Phys. D 10, 213 (2001)

What is the influence of the dark energy model on the evolution of large-scale structures?

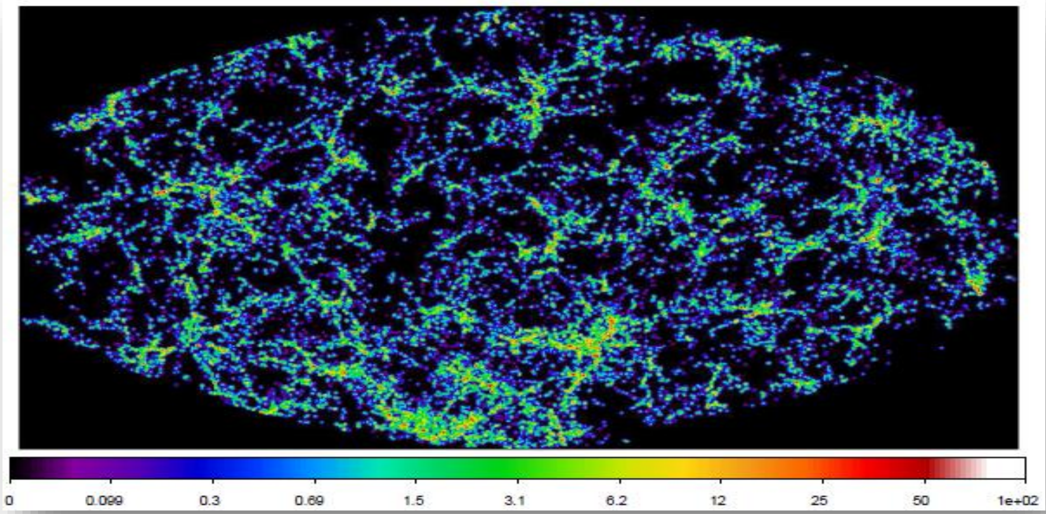
CMB map from Planck space experiment

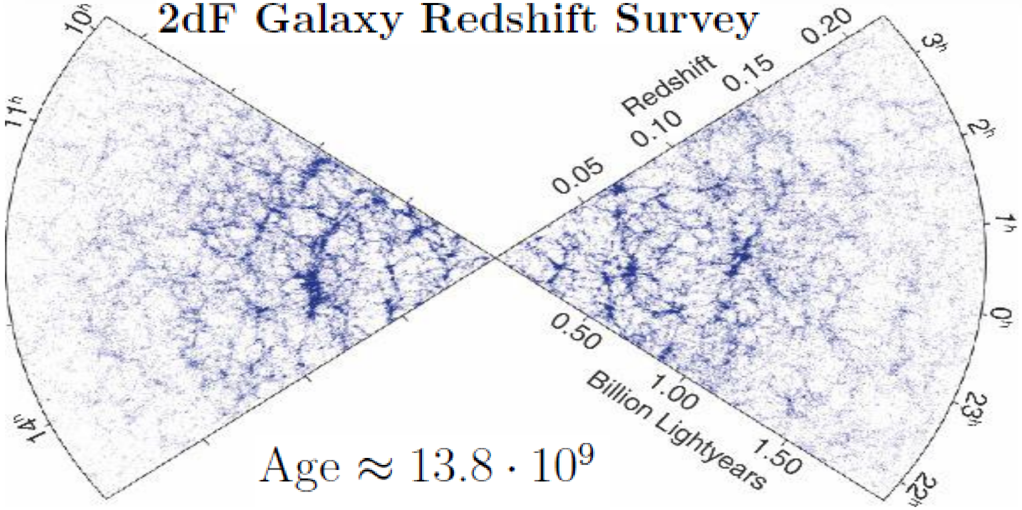


$$\frac{\Delta T}{T} \sim \frac{\Delta \rho}{\rho} \approx 5 \cdot 10^{-5}$$

$$\text{Age} \approx 3.8 \cdot 10^{5} \text{ years}$$

Cosmic Web (SDSS)





$$\text{Age} \approx 13.8 \cdot 10^{9}$$

Influence of the φCDM model on the formation of the large-scale structure in the universe

The growth rate

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

The linear perturbation equation

$$D'' + \left(\frac{3}{a} + \frac{E'}{E}\right)D' - \frac{3\Omega_{\mathrm{m},0}}{2a^5 E^2}D = 0$$

The linear growth factor

$$D(a) = \frac{\delta(a)}{\delta(a_0)}$$

The matter density fluctuations

$$\delta = \frac{\rho(\vec{r},t) - \langle\rho\rangle}{\langle\rho\rangle} \qquad \delta(a_{\mathrm{in}}) = \delta'(a_{\mathrm{in}}) = 5\cdot 10^{-5}$$

F. Pace, J.-C. Waizmann and M. Bartelmann, Mon. Not. Roy. Astron. Soc. 406, 1865 (2010)

γ - parameterization

- **Fractional matter density** $\Omega_m(a) = \frac{\Omega_{m0} a^{-3}}{E^2}$
- **Growth rate function** $f(a) = \frac{d\ln D(a)}{d\ln a}$
- **Fitting formula** $f(a) \approx \Omega_m^\gamma(a), \quad \gamma$ is a growth index

L.M.Wang & P.J. Steinhardt, Astrophys. J. 508, 483 (1998)

For the ΛCDM model $\gamma \approx 0.55$, while for the Dvali-Gabadadze-Porrati braneworld model $\gamma \approx 0.68$

$$\gamma = \begin{cases} 0.55 + 0.05(1 + w_0 + 0.5 w_a), & \text{if } w_0 \geq -1 \\ 0.55 + 0.02(1 + w_0 + 0.5 w_a), & \text{if } w_0 < -1 \end{cases}$$

Erick Linder, Phys. Rev. D 72, 043529 (2005)

$$w_0 = w(a_0 = 1),\ w_a = (dw/dz)|_{z=1} = -a^{-2}(dw/da)|_{a=1/2}$$

Phantom Potentials

Name	Form	Reference
Fifth power	$V(\phi) = V_0\phi^5$	Scherrer & Sen (2008*a*)
Inverse square power	$V(\phi) = V_0\phi^{-2}$	Scherrer & Sen (2008*a*)
Exponent	$V(\phi) = V_0 \exp(\beta\phi),\ \beta = \text{const} > 0$	Scherrer & Sen (2008*a*)
Quadratic	$V(\phi) = V_0\phi^2$	Dutta & Scherrer (2009)
Gaussian	$V(\phi) = V_0(1 - \exp(\phi^2/\sigma^2)), \sigma = \text{const}$	Dutta & Scherrer (2009)
pseudo-Nambu-Goldstone boson (pNGb)	$V(\phi) = V_0(1 - \cos(\phi/\kappa)),\ \kappa = \text{const} > 0$	Frieman et al. (1995)
Inverse hyperbolic cosine	$V(\phi) = V_0(\cosh(\psi\phi))^{-1},\ \psi = \text{const} > 0$	Dutta & Scherrer (2009)

Quintessence Potentials

Name	Form	Reference
Ratra-Peebles	$V(\phi) = V_0 M_{\rm pl}^2 \phi^{-\alpha}$; $\alpha = {\rm const} > 0$	Ratra & Peebles (1988*b*)
Ferreira-Joyce	$V(\phi) = V_0 \exp(-\lambda\phi/M_{\rm pl})$; $\lambda = {\rm const} > 0$	Ferreira & Joyce (1998)
Zlatev-Wang-Steinhardt	$V(\phi) = V_0(\exp(M_{\rm pl}/\phi) - 1)$	Zlatev et al. (1999)
Sugra	$V(\phi) = V_0 \phi^{-\chi} \exp(\gamma\phi^2/M_{\rm pl}^2)$; $\chi, \gamma = {\rm const} > 0$	Brax & Martin (1999)
Sahni-Wang	$V(\phi) = V_0(\cosh(\varsigma\phi) - 1)^g$; $\varsigma = {\rm const} > 0$, $g = {\rm const} < 1/2$	Sahni & Wang (2000)
Barreiro-Copeland-Nunes	$V(\phi) = V_0(\exp(\nu\phi) + \exp(\upsilon\phi))$; $\nu,\ \upsilon = {\rm const} \geq 0$	Barreiro et al. (2000)
Albrecht-Skordis	$V(\phi) = V_0((\phi - B)^2 + A)\exp(-\mu\phi)$; $A,\ B = {\rm const} \geq 0$, $\mu = {\rm const} > 0$	Albrecht & Skordis (2000)
Urẽna-López-Matos	$V(\phi) = V_0 \sinh^m(\xi M_{\rm pl}\phi)$; $\xi = {\rm const} > 0$, $m = {\rm const} < 0$	Urena-Lopez & Matos (2000)
Inverse exponent potential	$V(\phi) = V_0 \exp(M_{\rm pl}/\phi)$	Caldwell & Linder (2005)
Chang-Scherrer	$V(\phi) = V_0(1 + \exp(-\tau\phi))$; $\tau = {\rm const} > 0$	Chang & Scherrer (2016)

Phantom φCDM model

- **The first Friedmann's equation** $$E(z) = H(z)/H_0 = (\Omega_{\mathrm{r0}}(1+z)^4 + \Omega_{\mathrm{m0}}(1+z)^3 + \Omega_\phi(z))^{1/2}$$
- **The scalar field equation** $$\ddot{\phi} + 3H\dot{\phi} - \frac{\partial V(\phi)}{\partial \phi} = 0$$
- **The energy density of the scalar field** $$\rho_\phi = -\frac{\dot{\phi}^2}{2} + V(\phi)$$
- **The pressure of the scalar field** $$p_\phi = -\frac{\dot{\phi}^2}{2} - V(\phi)$$
- **The equation of state parameter** $$w_\phi = \frac{-\dot{\phi}^2/2 - V(\phi)}{-\dot{\phi}^2/2 + V(\phi)}$$
- **We consider the flat universe**

Quintessence φCDM model

- **The first Friedmann's equation** $$E(z) = H(z)/H_0 = (\Omega_{r0}(1+z)^4 + \Omega_{m0}(1+z)^3 + \Omega_\phi(z))^{1/2}$$

- **The scalar field equation** $$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V(\phi)}{\partial \phi} = 0$$

- **The energy density of the scalar field** $$\rho_\phi = \frac{\dot{\phi}^2}{2} + V(\phi)$$

- **The pressure of the scalar field** $$p_\phi = \frac{\dot{\phi}^2}{2} - V(\phi)$$

- **The equation of state parameter** $$w_\phi = \frac{\dot{\phi}^2/2 - V(\phi)}{\dot{\phi}^2/2 + V(\phi)}$$

- **We consider the flat universe**

Criteria for Selection of Solutions

We have found the solutions describing the reliable universe, for which the following three criteria must be simultaneously fulfilled:

1. The matter and DE equality ($\Omega_{\rm m} = \Omega_\phi$) has happened relatively recently, $a \in (0.6; 0.8)$;
2. The growth rate of the matter density fluctuations, $f(a)$, and the fractional matter density, $\Omega_{\rm m}(a)$, are parametrized by the Linder γ-parametrization, $f(a) \approx \Omega_{\rm m}^{\gamma}(a)$;
3. The chosen current EoS parameters values should correspond to the expected current EoS parameter values for these models: for the phantom models $w_0 < -1$; for the quintessence models $-1 < w_0 < -0.75$: for the freezing type $dw/da < 0$, for the thawing type $dw/da > 0$.

Model Parameters and Initial Conditions for Phantom Potentials

Phantom potentials	Free parameters	
$V(\phi) = V_0\phi^5$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(10^{-3} \div 10^{-2})$	$\phi_0(3.37 \div 3.94)$ $\dot{\phi}_0(523 \div 563.6)$
$V(\phi) = V_0\phi^{-2}$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(30 \div 50)$	$\phi_0(2.83 \div 5.15)$ $\dot{\phi}_0(471.4 \div 600)$
$V(\phi) = V_0 \exp(\beta\phi)$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(1 \div 20)$	$\beta(0.08 \div 0.3)$ $\phi_0(0.2 \div 9.14)$ $\dot{\phi}_0(79.8 \div 830.9)$
$V(\phi) = V_0\phi^2$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(1 \div 20)$	$\phi_0(0.67 \div 2.8)$ $\dot{\phi}_0(191 \div 450)$
$V(\phi) = V_0(1 - \exp(\phi^2/\sigma^2))$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(5 \div 30)$	$\sigma(5 \div 30)$ $\phi_0(0.67 \div 2.8)$ $\dot{\phi}_0(191 \div 450)$
$V(\phi) = V_0(1 - \cos(\phi/\kappa))$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(1 \div 4)$	$\kappa(1.1 \div 2)$ $\phi_0(2.3 \div 3.37)$ $\dot{\phi}_0(420 \div 500)$
$V(\phi) = V_0(\cosh(\psi\phi))^{-1}$	$H_0(50 \div 90)$ $\Omega_{m0}(0.25 \div 0.32)$ $V_0(10^{-3} \div 10^2)$	$\psi(10^{-3} \div 1)$ $\phi_0(1.4 \div 2.3)$ $\dot{\phi}_0(310 \div 420.7)$

Model Parameters and Initial Conditions for Quintessence Potentials

Quintessence potentials	Free parameters	
$V(\phi) = V_0 M_{\rm pl}^2 \phi^{-\alpha}$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$	$V_0(3 \div 5)$ $\alpha(10^{-6} \div 0.7)$
$V(\phi) = V_0 \exp(-\lambda\phi/M_{\rm pl})$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(10 \div 10^3)$	$\lambda(10^{-7} \div 10^{-3})$ $\phi_0(0.2 \div 1.6)$ $\dot{\phi}_0(79.8 \div 338.9)$
$V(\phi) = V_0(\exp(M_{\rm pl}/\phi) - 1)$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(10 \div 10^2)$	$\phi_0(1.5 \div 10)$ $\dot{\phi}_0(350 \div 850)$
$V(\phi) = V_0 \phi^{-\chi} \exp(\gamma\phi^2/M_{\rm pl}^2)$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(10^{-2} \div 10^{-1})$ $\chi(4 \div 8)$	$\gamma(6.5 \div 7)$ $\phi_0(5.78 \div 10.55)$ $\dot{\phi}_0(680.6 \div 879)$
$V(\phi) = V_0(\cosh(\varsigma\phi) - 1)^g$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(5 \div 8)$ $\varsigma(0.15 \div 1)$	$g(0.1 \div 0.49)$ $\phi_0(1.8 \div 5.8)$ $\dot{\phi}_0(360 \div 685)$
$V(\phi) = V_0(\exp(\nu\phi) + \exp(\upsilon\phi))$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(1 \div 12)$	$\nu(6 \div 12)$ $\phi_0(0.014 \div 1.4)$ $\dot{\phi}_0(9.4 \div 311)$
$V(\phi) = V_0((\phi - B)^2 + A)\exp(-\mu\phi)$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(40 \div 70)$ $A(1 \div 40)$	$B(1 \div 60)$ $\mu(0.2 \div 0.9)$ $\phi_0(5.8 \div 8.45)$ $\dot{\phi}_0(681 \div 804.5)$
$V(\phi) = V_0 \sinh^m(\xi M_{\rm pl}\phi)$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(1 \div 10)$ $m(-0.1 \div -0.3)$	$\xi(10^{-2} \div 1)$ $\phi_0(0.5 \div 2.5)$ $\dot{\phi}_0(190 \div 367)$
$V(\phi) = V_0 \exp(M_{\rm pl}/\phi)$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(10^2 \div 10^3)$	$\phi_0(5.78 \div 10.55)$ $\dot{\phi}_0(680.6 \div 879)$
$V(\phi) = V_0(1 + \exp(-\tau\phi))$	$H_0(50 \div 90)$ $\Omega_{\rm m0}(0.25 \div 0.32)$ $V_0(1 \div 10^2)$	$\tau(10 \div 10^2)$ $\phi_0(0.01 \div 0.075)$ $\dot{\phi}_0(9.4 \div 32)$

MCMC Analysis

- **The normalized Hubble parameter:** $E(z) = H(z)/H_0 = (\Omega_{\mathrm{r0}}(1+z)^4 + \Omega_{\mathrm{m0}}(1+z)^3 + \Omega_\phi(z))^{1/2}$

- **The angular diameter distance:** $$d_A(z) = \frac{1}{H_0(1+z)} \int_0^z \frac{dz'}{E(z')}$$

- **The combination of the growth rate of the matter density fluctuations and the matter power spectrum amplitude,** $f(a)\sigma_8(a)$ **:**

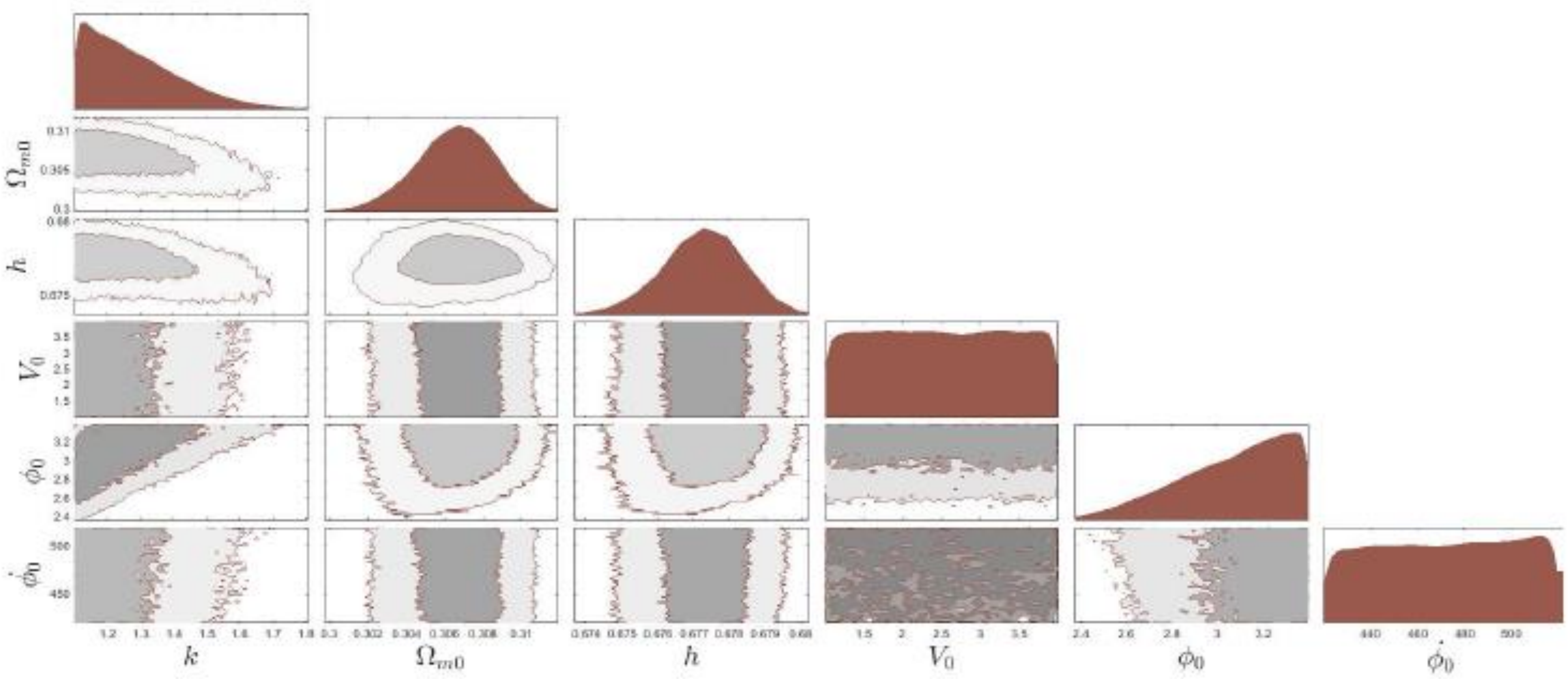
$$\sigma_8(a) \equiv D(a)\sigma_8, \ \sigma_8 = 0.815 \ \text{(Planck 2015 results. XIII)}$$

- **The range of the redshift values,** $z \in (0.15; 1.85)$

- **The variances correspond to the predicted values for DESI data**

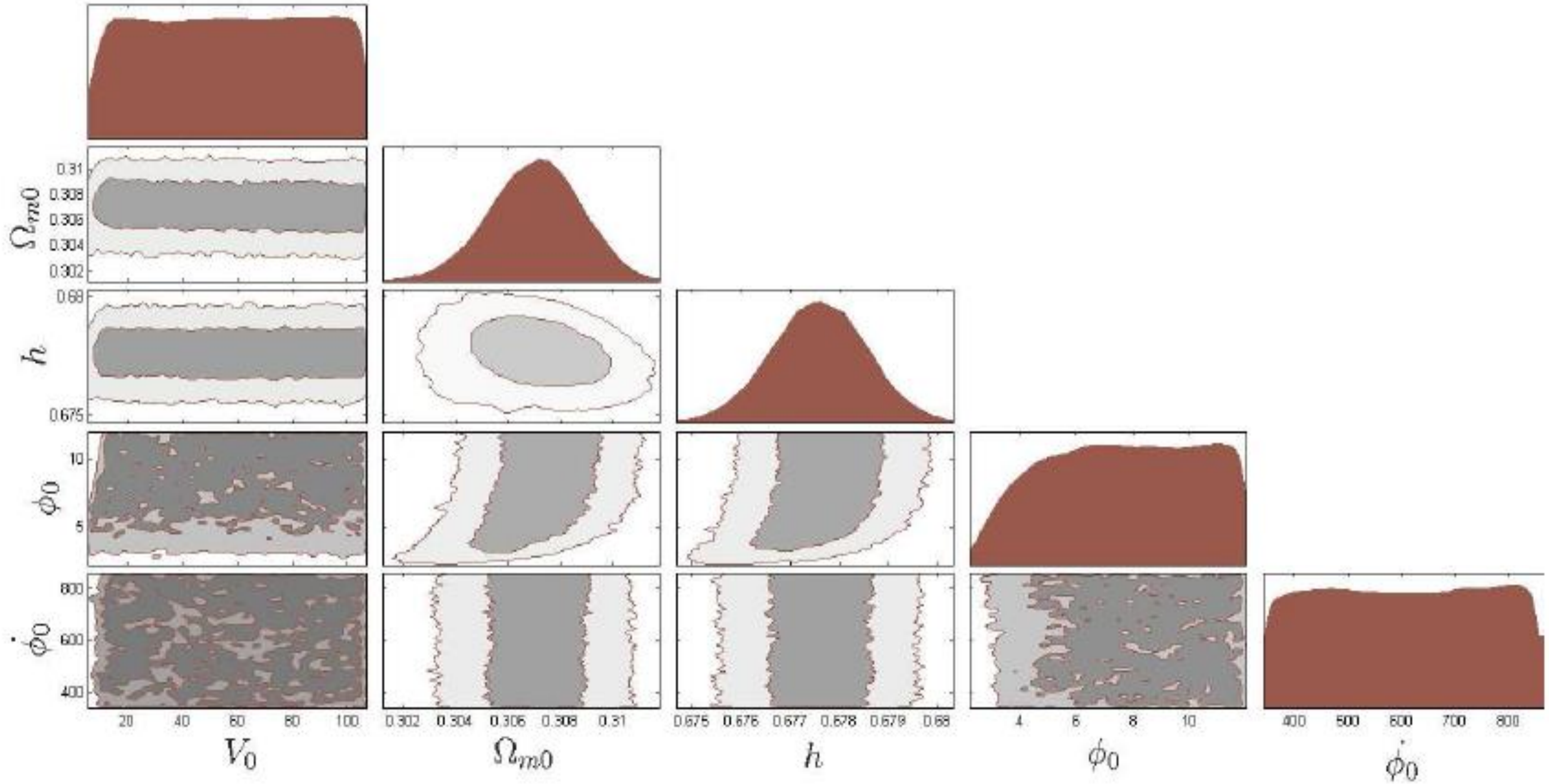
A. Font-Ribera, P. McDonald, N. Mostek, B. A. Reid, H. J. Seo and A. Slosar, JCAP **1405**, 023 (2014)

MCMC Results



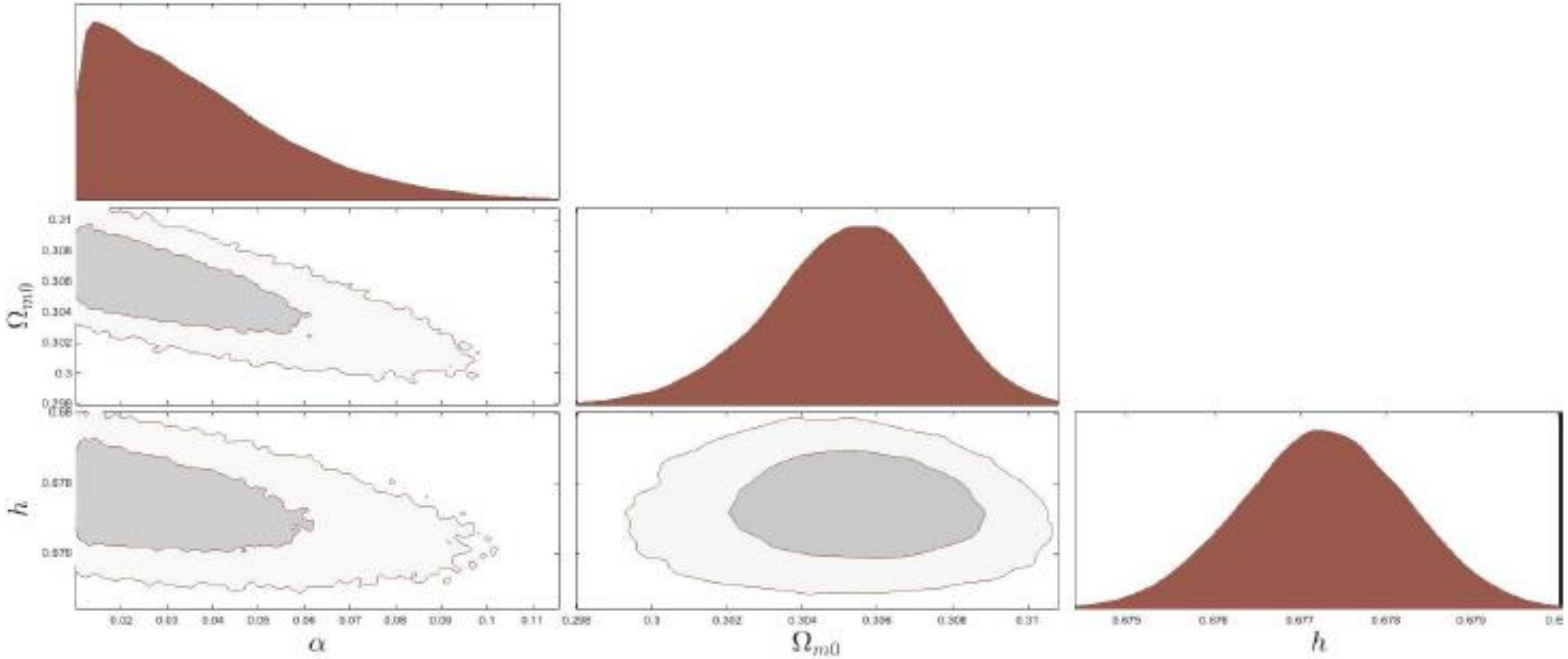
The 2σ confidence level contours for pairs of the free parameters (k, $\Omega_{\rm m0}$, h, V_0, ϕ_0, $\dot{\phi}_0$), for which the ϕCDM model with the phantom pseudo-Nambu-Goldstone boson potential $V(\phi) = V_0(1 - \cos(\phi/\kappa))$ is in the best fit with the ΛCDM model.

MCMC Results



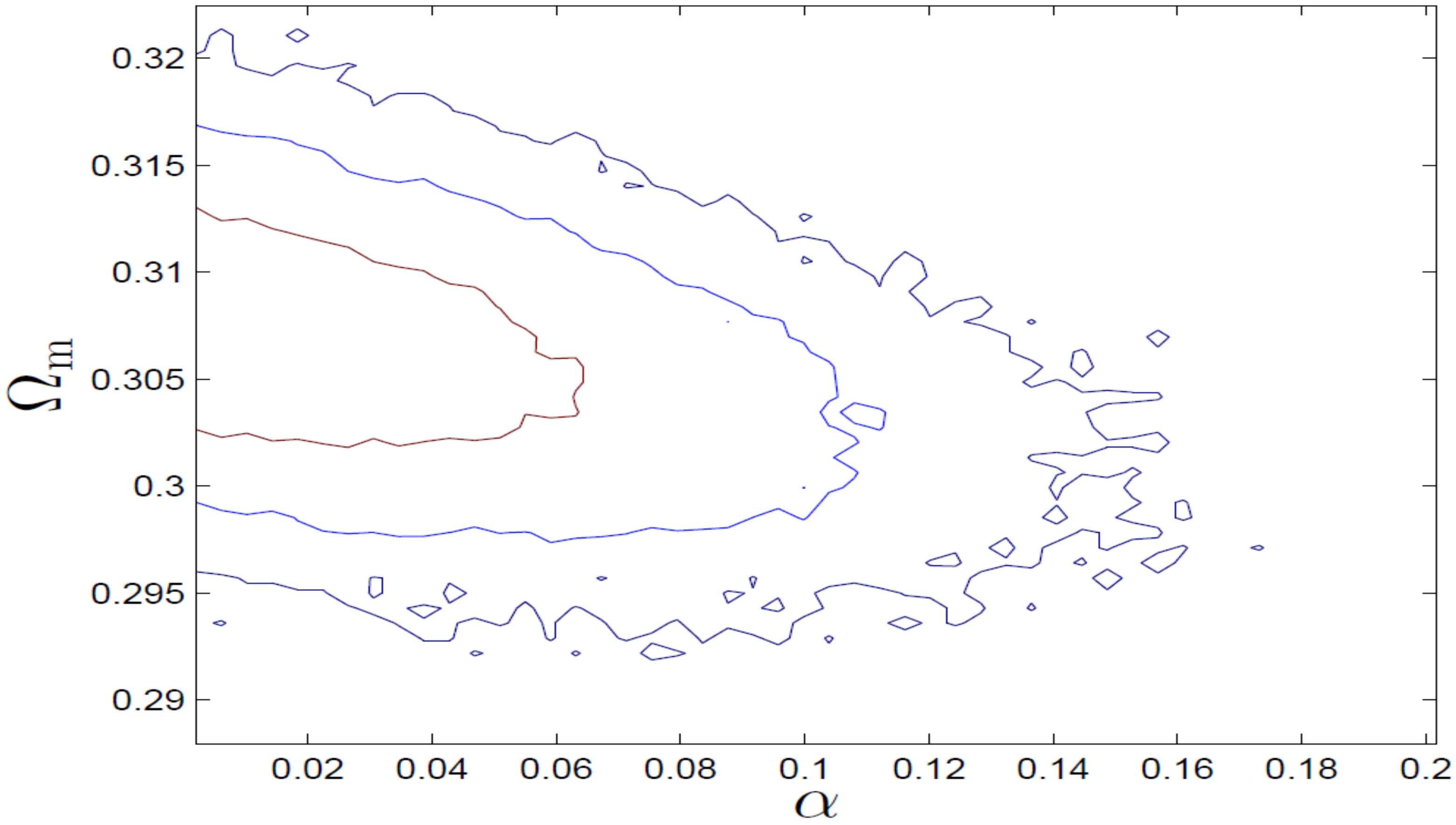
The 2σ confidence level contours for pairs of the free parameters (V_0, $\Omega_{\rm m0}$, h, ϕ_0, $\dot{\phi}_0$), for which the ϕCDM model with the Zlatev-Wang-Steinhardt potential $V(\phi) = V_0(\exp(M_{\rm pl}/\phi) - 1)$ is in the best fit with the ΛCDM model.

MCMC Results



The 2σ confidence level contours plots for various pairs of the free parameters (α, $\Omega_{\rm m0}$, h), for which the ϕCDM model with the Ratra-Peebles potential $V(\phi) = V_0 M_{\rm pl}^2 \phi^{-\alpha}$ is in the best fit with the ΛCDM model.

MCMC analysis with upcoming DESI data



Carrying out the MCMC analysis with upcoming DESI data, we obtained ranges of α and Ω_m parameters, $0 < \alpha \leq 0.16$ and $0.296 < \Omega_m < 0.32$ at 3σ confidence level, where the Ratra-Peebles ϕCDM model is compliance with the ΛCDM model.

Bayesian Statistics

- **Akaike information criterion**

$$AIC = -2\ln\mathcal{L}_{\rm max} + 2k,$$

$$\mathcal{L}_{\rm max} \propto \exp(-\chi^2_{\rm min}/2)$$

k is the number of observations

Akaike, H. (1974), *IEEE Transactions on Automatic Control* **19**(06), 716–723

- **Schwarz information criterion**

$$BIC = -2\ln\mathcal{L}_{\rm max} + k\ln N,$$

N is the number of the model parameters

Schwarz, G. E. (1978), *Annals of Statistics* **06**(02), 461–464

- **Bayes evidence**

$$\mathcal{E} = \int {\rm d}^3\boldsymbol{p}\,\mathcal{P}(\boldsymbol{p}),$$

$\mathcal{P}$ is the posterior likelihood

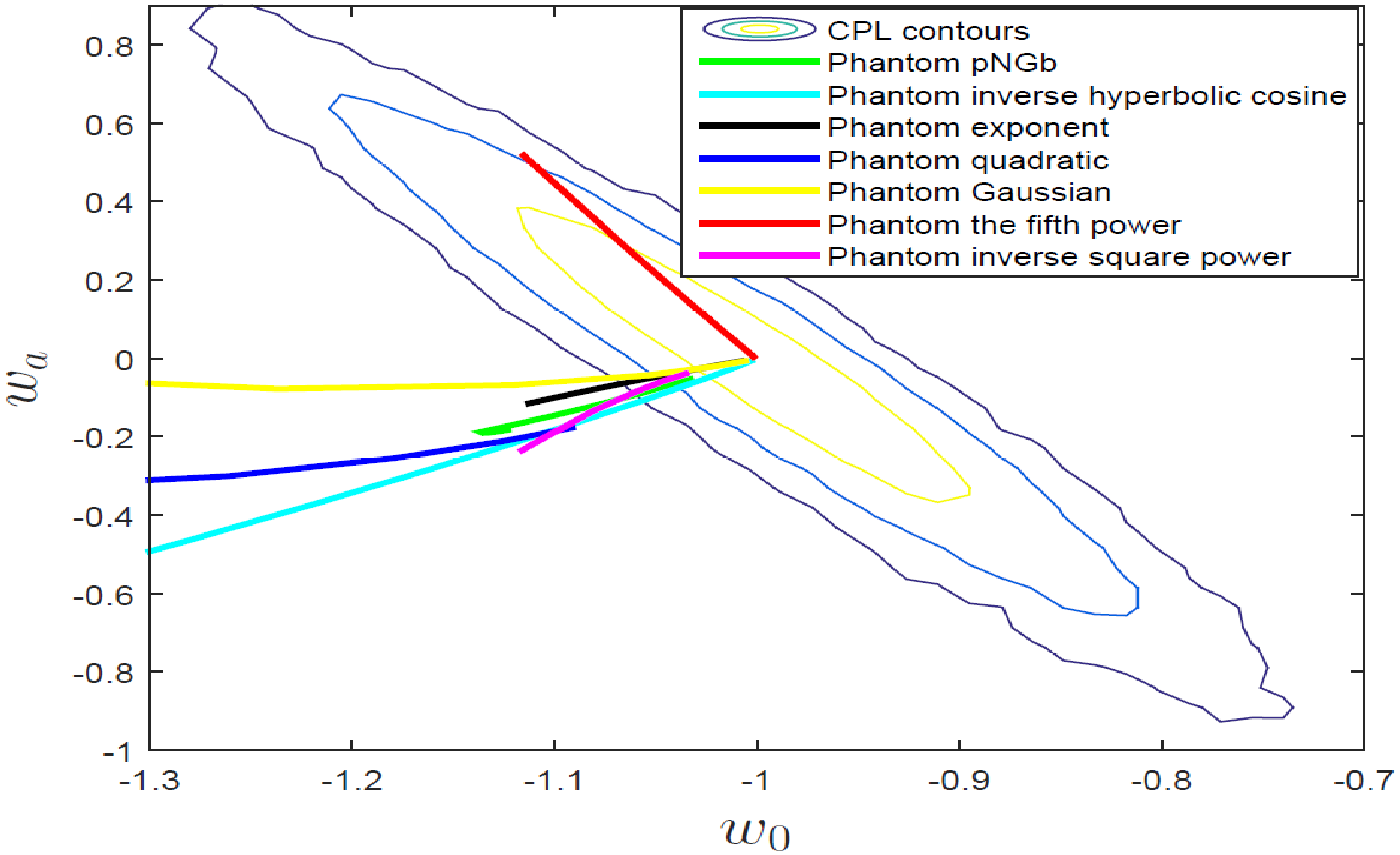
Bayesian Statistics for the Phantom Potentials

Phantom potentials	AIC	BIC	Bayes factor
$V(\phi) = V_0\phi^5$	10.0	18.7	0.0921
$V(\phi) = V_0\phi^{-2}$	10.0	18.7	0.0142
$V(\phi) = V_0 \exp(\beta\phi)$	22.4	12.0	0.0024
$V(\phi) = V_0\phi^2$	10.0	18.7	0.0808
$V(\phi) = V_0(1 - \exp(\phi^2/\sigma^2))$	12.0	22.4	0.0113
$V(\phi) = V_0(1 - \cos(\phi/\kappa))$	12.0	22.4	0.0061
$V(\phi) = V_0(\cosh(\psi\phi))^{-1}$	12.0	22.4	0.0056

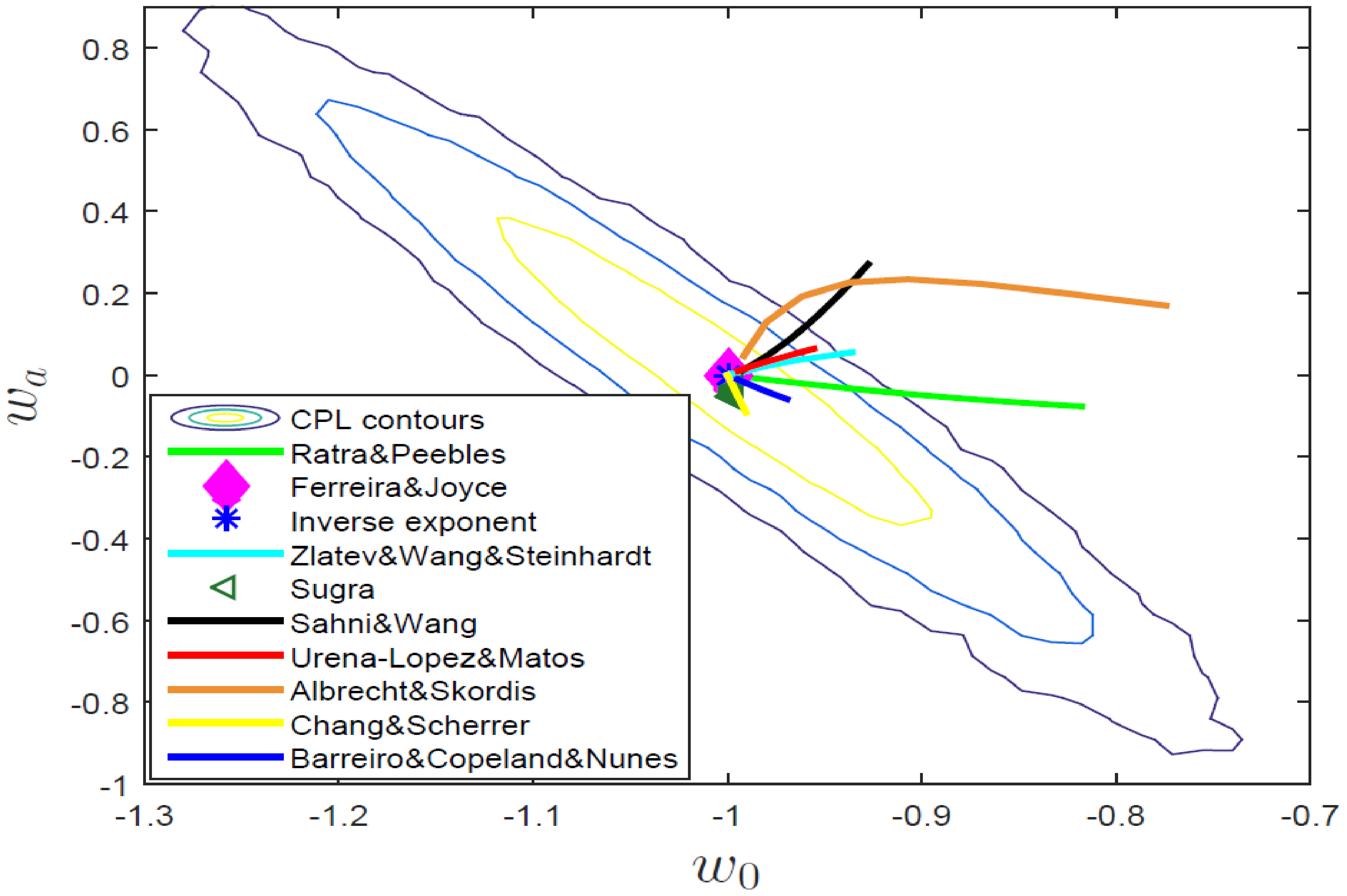
Bayesian Statistics for the Quintessence Potentials

Quintessence potentials	AIC	BIC	Bayes factor
$V(\phi) = V_0 M_{\rm pl}^2 \phi^{-\alpha}$	10	18.7	0.5293
$V(\phi) = V_0 \exp(-\lambda\phi/M_{\rm pl})$	12	22.4	0.0059
$V(\phi) = V_0(\exp(M_{\rm pl}/\phi) - 1)$	10	18.7	0.0067
$V(\phi) = V_0 \phi^{-\chi} \exp(\gamma\phi^2/M_{\rm pl}^2)$	14	26.2	0.0016
$V(\phi) = V_0(\cosh(\varsigma\phi) - 1)^g$	14	26.2	0.0012
$V(\phi) = V_0(\exp(\nu\phi) + \exp(\upsilon\phi))$	14	26.2	0.0053
$V(\phi) = V_0((\phi - B)^2 + A)\exp(-\mu\phi)$	16	29.9	0.0034
$V(\phi) = V_0 \sinh^m(\xi M_{\rm pl}\phi)$	14	26.2	0.0014
$V(\phi) = V_0 \exp(M_{\rm pl}/\phi)$	10	18.7	0.0077
$V(\phi) = V_0(1 + \exp(-\tau\phi))$	12	22.4	0.0024

Phantom φCDM Models in the CPL Phase Space



Quintessence φCDM Models in the CPL Phase Space



Subclasses of the Potentials

Attractor solution	Usual solution
Sugra	Zlatev-Wang-Steinhardt
Urẽna-López-Matos	Sahni-Wang
Albrecht-Scordis	quadratic
Chang-Scherer	Gaussian
Barreiro-Copeland-Nunes	fifth power
pNGb	inverse square
inverse hyperbolic cosine	
exponent	

Subclasses of the Potentials

Undistinguished from ΛCDM model	Undistinguished or Distinguished from ΛCDM model	Distinguished from ΛCDM model
Ferreira-Joyce	Ratra-Peebles	phantom quadratic
inverse exponent	Zlatev-Wang-Steinhardt	
Sugra	Albrecht-Skordis	
Chang-Scherrer	Sahni-Wang	
Urẽna-López-Matos	pNGb	
Barreiro-Copeland-Nunes	inverse hyperbolic cosine	
fifth power	exponent	
	Gaussian	
	inverse square	

Conclusion

1) We reconstructed quintessence and phantom scalar field φCDM models using the phenomenological method developed by us.

2) Using the Bayesian statistical analysis, we could not uniquely identify the preferable φCDM models compared to the fiducial ΛCDM model based on the predicted DESI data, and the ΛCDM model is a true model.

3) Mapping φCDM models in the phase space of the CPL-ΛCDM contours, we could identify the subclasses of these models, which:

i) have the attractor and usual solutions,

ii) can be distinguished from the ΛCDM model,

iii) cannot be distinguished from the ΛCDM model,

iv) can be either distinguished or undistinguished from the ΛCDM model at present epoch.

Thank You for Your Kind Attention!