Observational effects of the early episodically dominating dark energy

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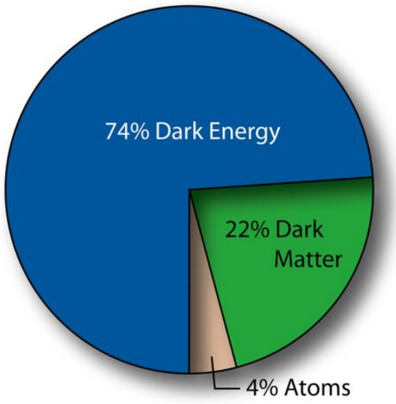
Dark Energy

Astronomical observations (such as SNIa, CMB, LSS) strongly indicate that the Universe is currently under acceleration.

The agent causing the acceleration is usually referred to as the **dark energy (DE)**, whose nature is the fundamental mystery of the current theoretical cosmology and physics.



http://lambda.gsfc.nasa.gov

Many dark energy models

(1) The cosmological constant Λ

(2) Modified matter models:

w-fluid, quintessence, k-essence, coupled dark energy, and unified models of dark energy and dark matter

(3) Modified gravity models:

f(R) gravity, Gauss-Bonnet dark energy models, scalar-tensor theories, and Dvali-Gabadadze-Porrati model

Motivation

Precision cosmology era

Now, the cosmological model parameters are measured with a few percent precision level.

The future projects for cosmological observations also forecast the sub-percent level parameter estimation in the optimistic situation (e.g., Euclid project).

Late-time domination of dark energy

It is generally considered that the effect of dark energy on the evolution of the universe at the early epoch is negligible.

Therefore, attentions have been mainly paid on the late-time behavior of the dark energy that starts to dominate the matter component only at very recent epoch, $z < 1$.

What happens if the dark energy dominates at some earlier epoch?

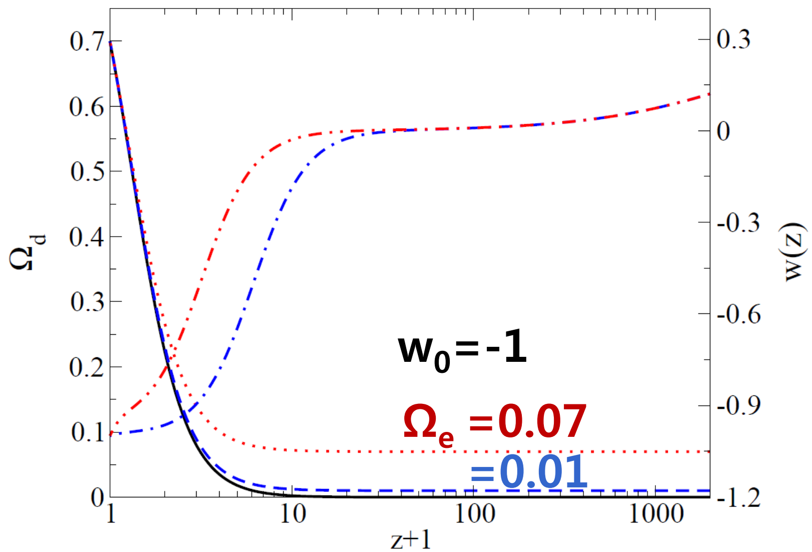
Previous studies on Early Dark Energy (EDE)

Doran & Robbers (2006, JCAP):

A simple **early dark energy (EDE) fluid model** with three free parameters: the current dark energy equation of state (**w_0**) and density parameter (**$\Omega_{de,0}$**), the dark energy density parameter in the early epoch (**Ω_e**).

$$\Omega_{\rm de}(a) = \frac{\Omega^0_{\rm de} - \Omega_{\rm e}\left(1 - a^{-3w_0}\right)}{\Omega^0_{\rm de} + \Omega^0_m a^{3w_0}} + \Omega_{\rm e}\left(1 - a^{-3w_0}\right)$$

$$w(a) = -\frac{1}{3[1 - \Omega_{\rm de}(a)]}\frac{d\ln\Omega_{\rm de}(a)}{d\ln a} + \frac{a_{eq}}{3(a + a_{eq})}$$



Doran & Robbers (2006, JCAP)

The recent constraint on the early dark energy density parameter is **Ω_e < 0.018 (95% CL)** (Reichardt et al. 2012).

Early Episodically Dominating Dark Energy (EDDE) Model

We consider an early episodically (or ephemerally) dominating dark energy (EDDE) which transiently dominates in the radiation- or early matter-dominated era, becomes sub-dominant, and then re-dominates at recent epoch as dark energy.

To mimic the episodic behavior of the dark energy, we consider a minimally coupled scalar field with the potential

$$V(\phi) = \underbrace{V_0[(\phi-\phi_0)^2 + A]e^{-\lambda\phi}} + \underbrace{V_1 e^{-\beta\phi}}$$

Albrecht-Skordis potential	Late-time acceleration; β=0 in this talk

(1) Allows near scaling evolution.

(2) Drives the accelerated expansion.

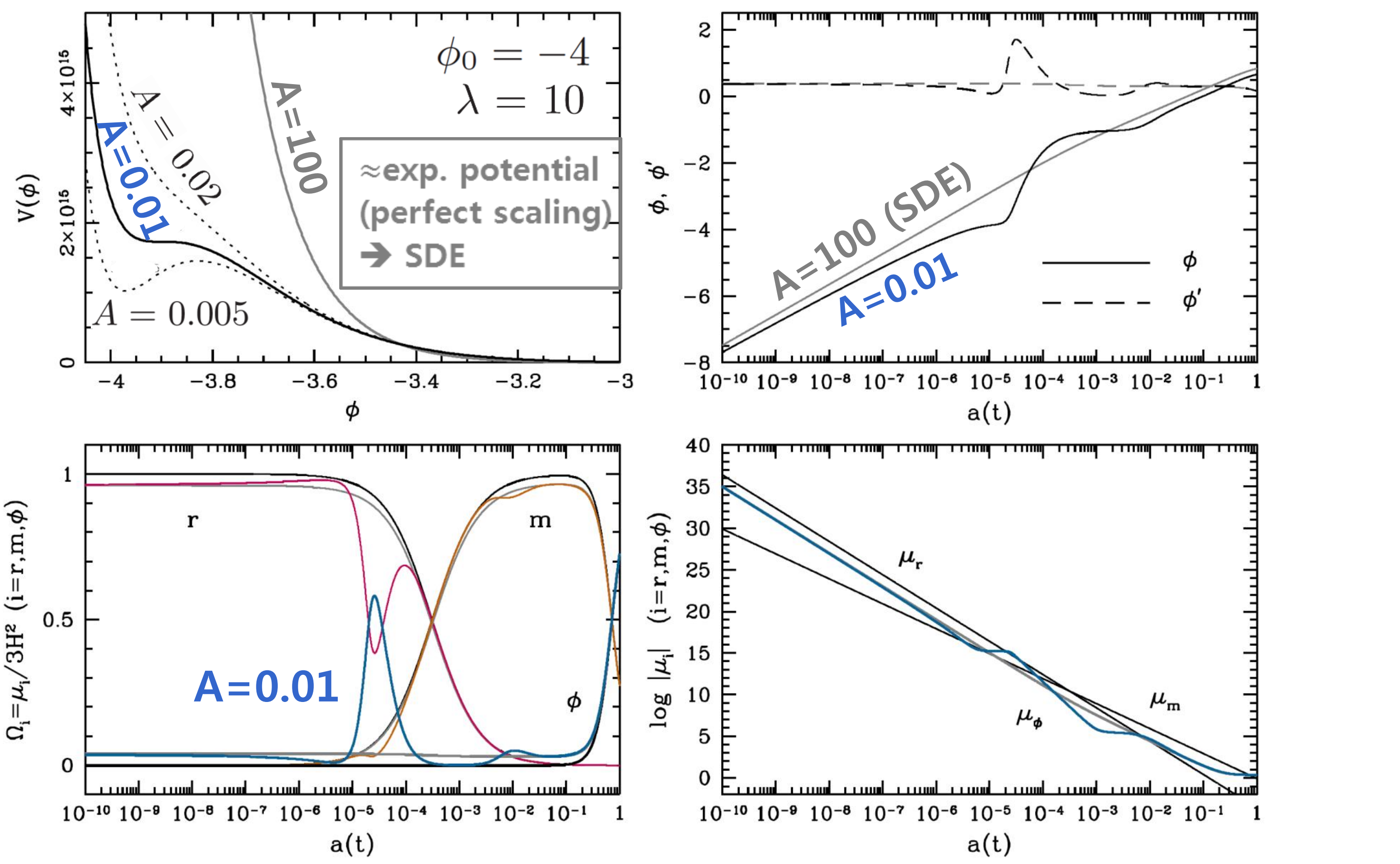
Both the permanent and the ephemeral accelerations are possible depending on A and λ.

Background Evolution of EDDE Models

If $A\lambda^2<1$, the scalar field gets trapped in the local minimum at

$$\phi = \phi_0 + [1-\sqrt{1-A\lambda^2}]/\lambda$$ ➔ **permanent DE domination**

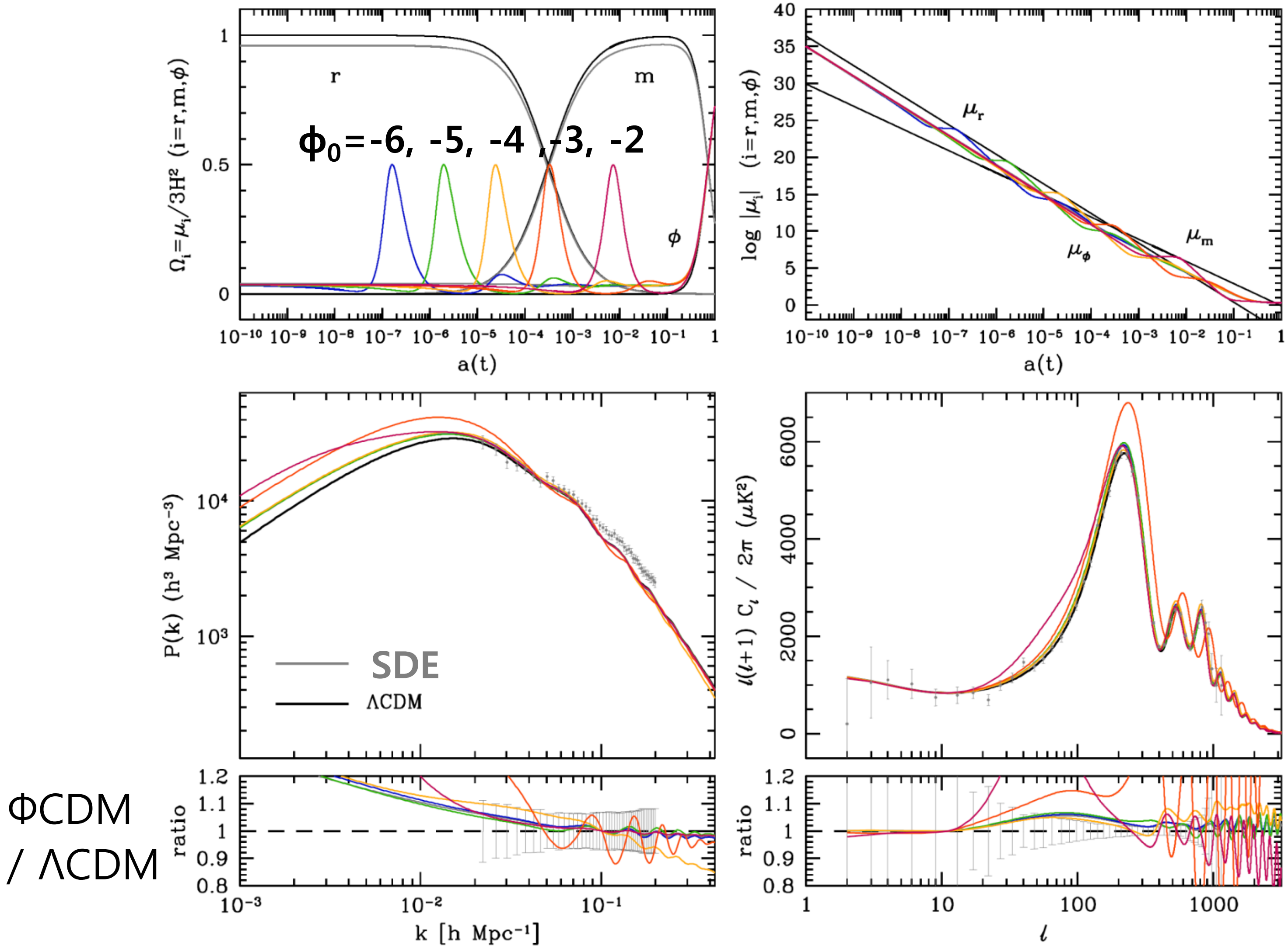
If $A\lambda^2\geq 1$, the scalar field temporarily slow down ➔ **episodic DE domination**



Evolution of background quantities, matter & CMB power spectra

The **epoch** of DE domination can be controlled by ϕ_0.

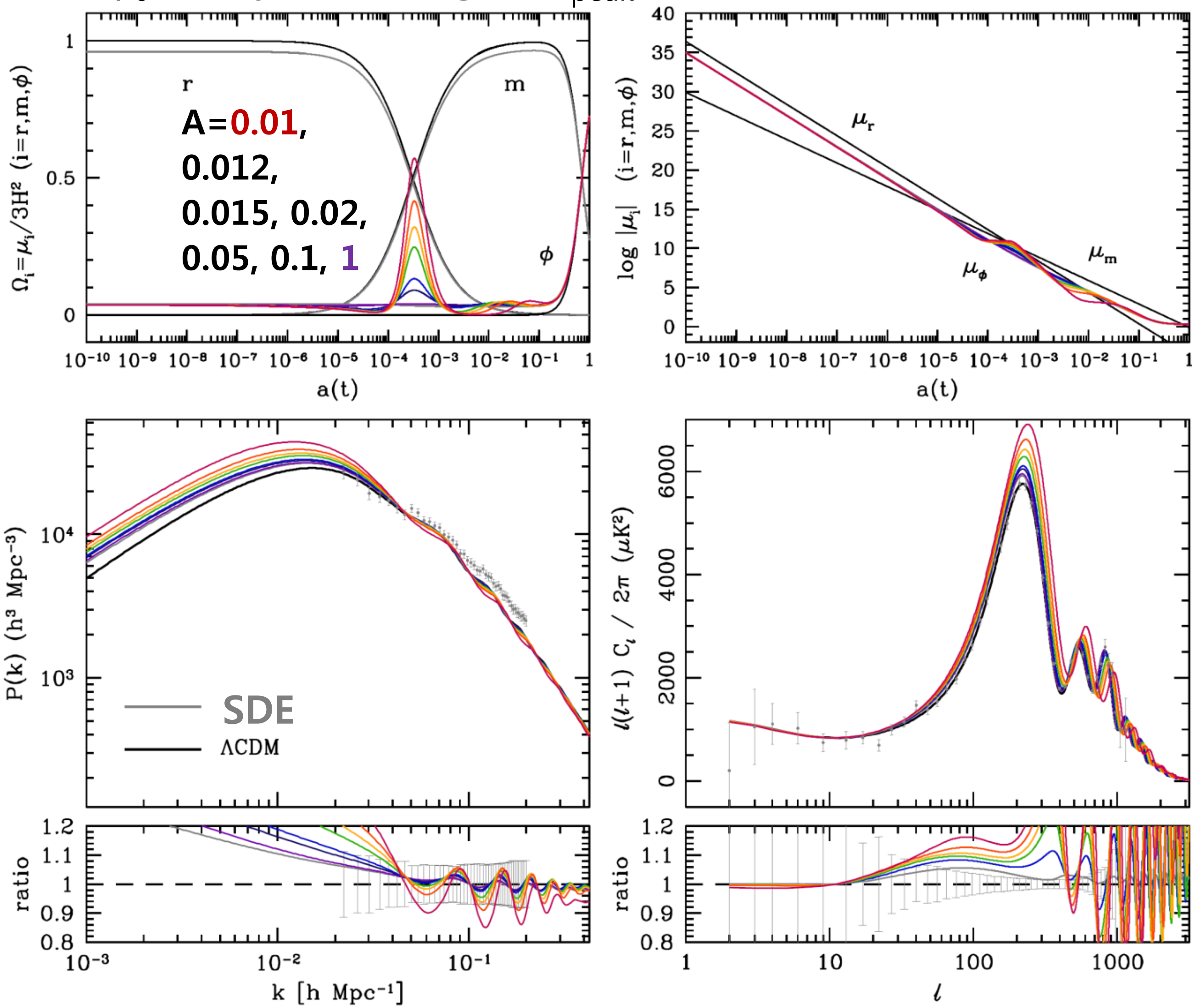
(A is adjusted to give Ω_ϕ=0.5.)



Evolution of background quantities, matter & CMB power spectra

The **strength** of DE domination can be controlled by A.

(ϕ_0 is adjusted to give z_{peak}=3000.)

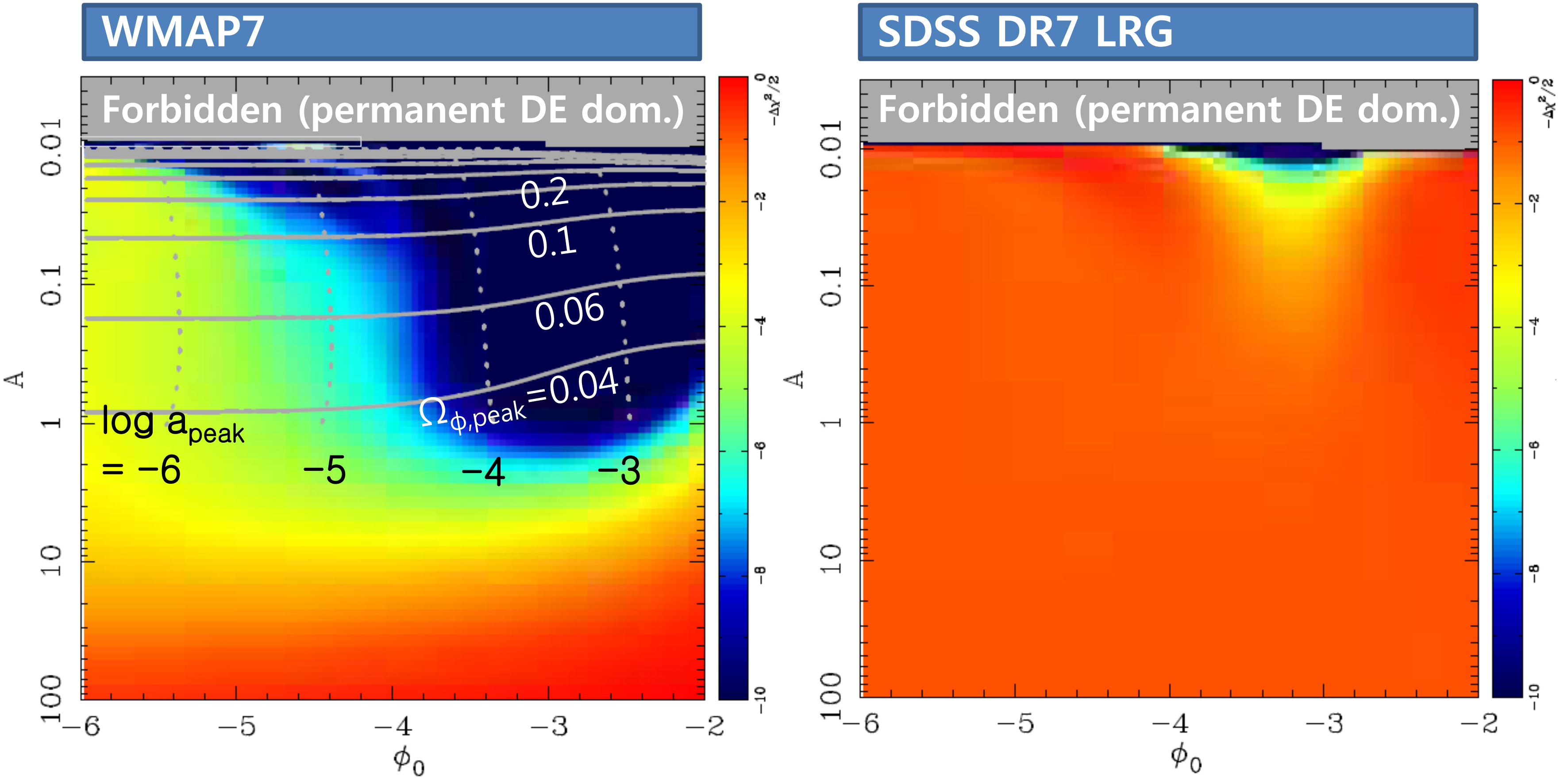


ΦCDM / ΛCDM

Relative logarithmic probability of potential parameters (ϕ_0, A) favored by WMAP7 and SDSS DR7 LRG data.

Only the potential parameters ϕ_0 and A are probed in a gridded space while others are fixed with those of best-fit ΛCDM model.

The type Ia supernovae are insensitive to potential parameters in this space.



Exploring parameter constraints in the early episodically dominating dark energy models

Modified CAMB+COSMOMC (Lewis and Bridle 2002, PRD)

Evolution of the scalar field perturbations are considered.

Automatic search for initial conditions of ϕ, ϕ', $\delta\phi$, $\delta\phi'$.

Data sets

WMAP 7-year CMB power spectra (T, TE, EE) (Larson et al. 2011)

SDSS DR7 Luminous Red Galaxies power spectrum (Reid et al. 2010)

Hubble constant (from HST): H_0=74.2±3.6 km/s/Mpc (Riess et al. 2009)

Models

(1) ΛCDM

(2) SDE (ϕ_0, A)=(-3, 100) : Scaling dark energy model

(3) Model I (ϕ_0, A)=(-4, 0.015) : DE domination at radiation era

Model II (ϕ_0, A)=(-3, 0.02) : 〃 near radiation-matter equality

Model III (ϕ_0, A)=(-2, 0.04) : 〃 at early matter era

Basic free parameters of flat φCDM model :

$\Omega_b h^2$: physical baryon density

$\Omega_c h^2$: physical dark matter density

H_0 : Hubble constant [km/s/Mpc]

τ : reionization optical depth

n_s : spectral index of scalar-type perturbation

r : ratio of tensor- to scalar-type perturbations

log A : $\ln[10^{10} A_s]$ where A_s is the primordial super-horizon power in the curvature perturbation on 0.02/Mpc scale

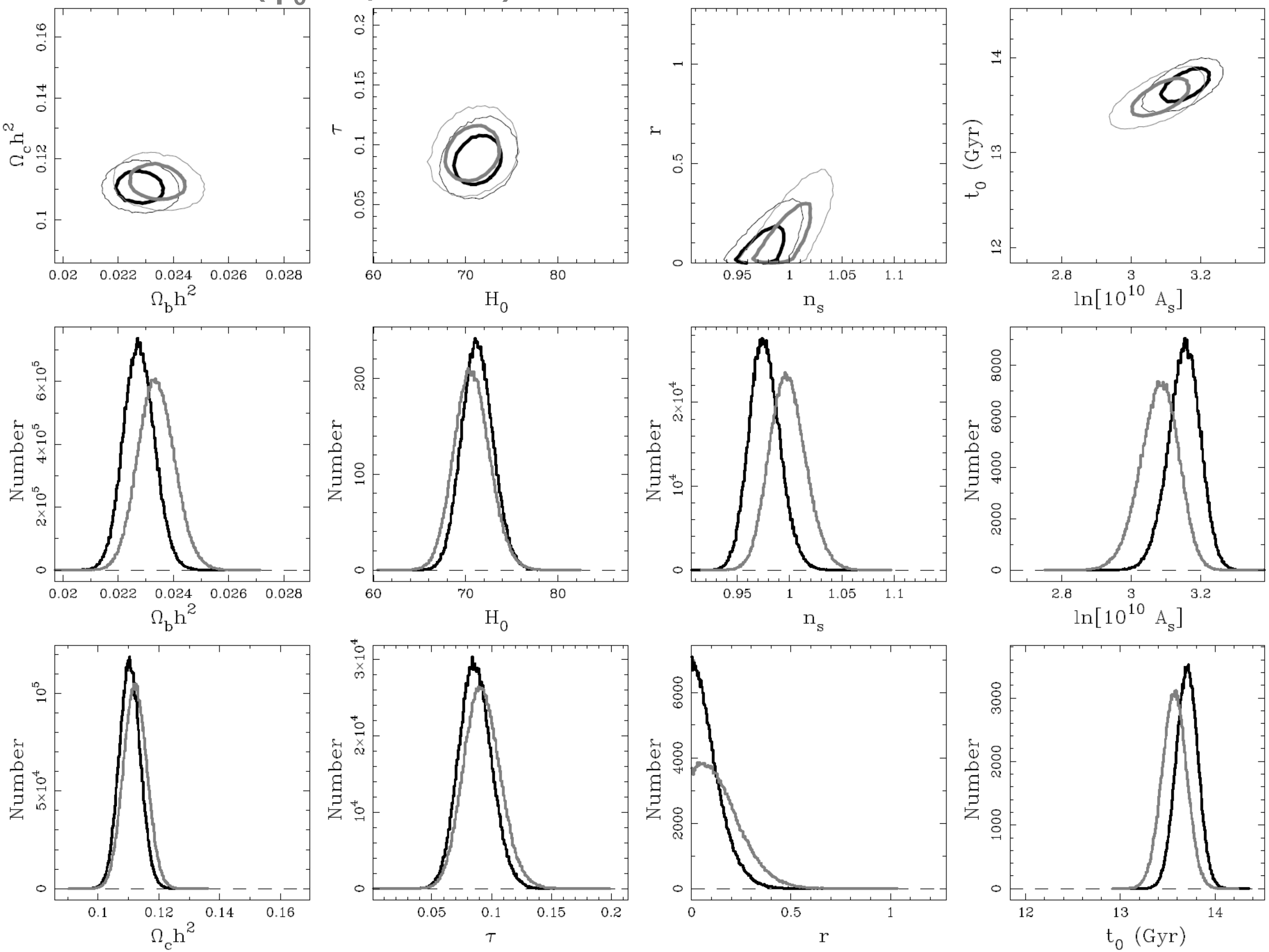
Quintessence parameters :

Field parameters: ϕ_i, $\dot{\phi}_i$ (background) $\delta\phi_i$, $\delta\dot{\phi}_i$ (perturbation)

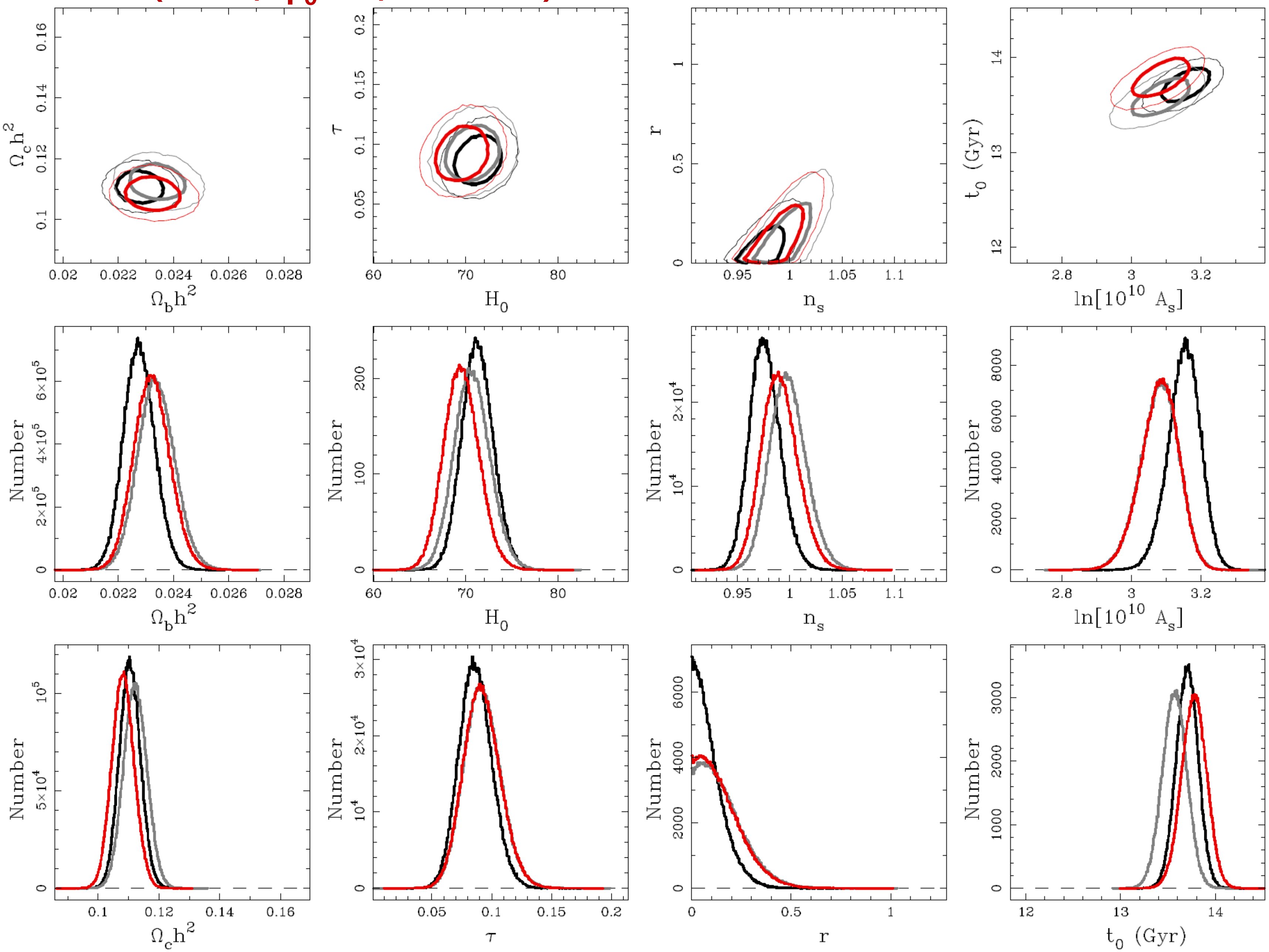
Potential parameters: **$V_0=1$, $\lambda=10$, A, ϕ_0 (fixed)**

$\beta=0$, $V_2=\Lambda$ (like cosmological constant)

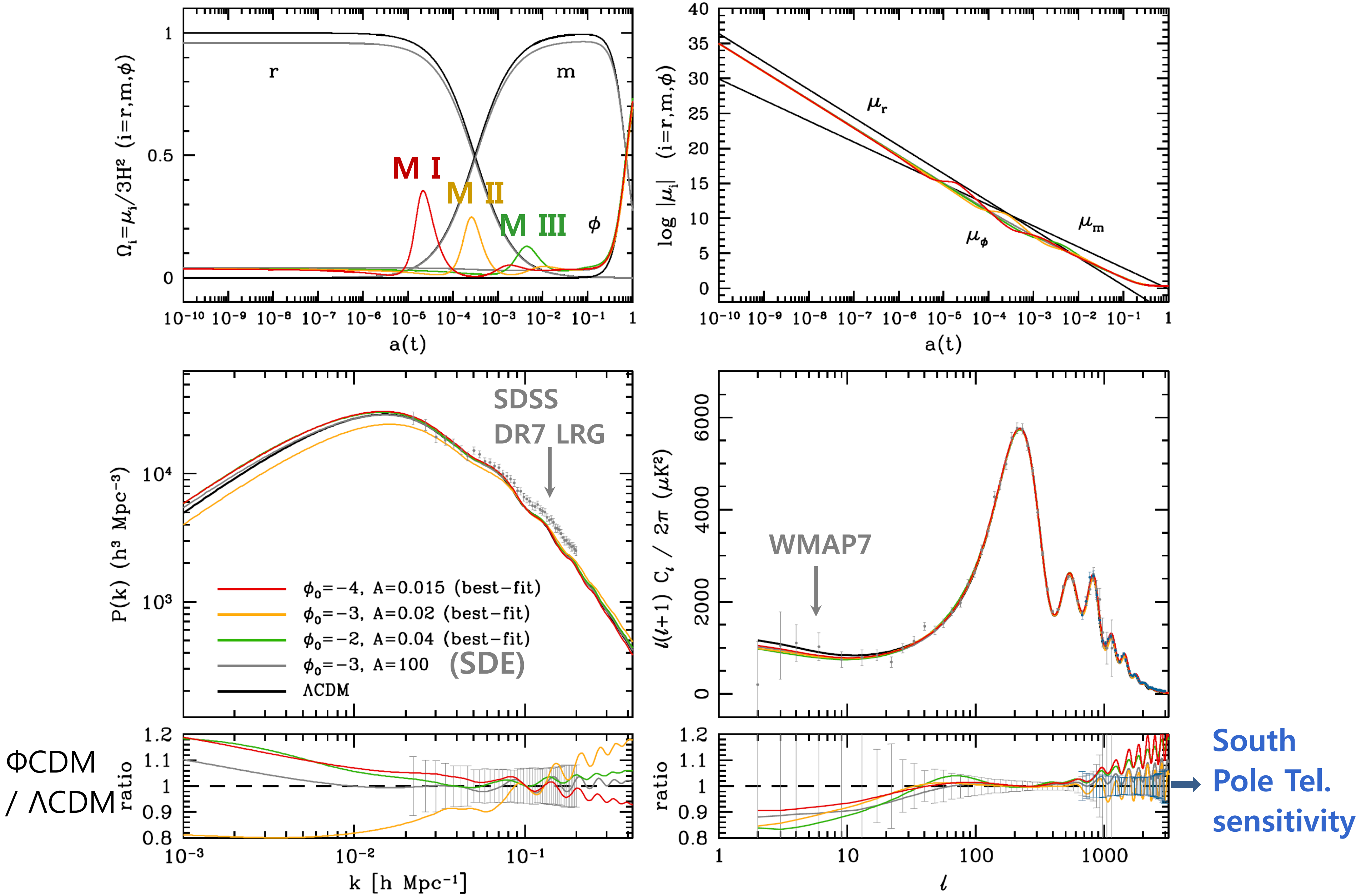
ΛCDM vs SDE (ϕ_0=-3, A=100)



Model I (EDDE, ϕ_0=-4, A=0.015) - DE domination at radiation era



Evolution of background quantities, matter & CMB power spectra for best-fit EDDE models



Summary

In this work, we investigate the observational effects of **early episodically dominating dark energy (EDDE)** based on a minimally coupled scalar field with the Albrecht-Skordis potential, where the epoch and strength of the transient dark energy domination can be controlled by the potential parameters.

The episodic DE domination affects the evolution of background and perturbation quantities. Compared with ΛCDM model, the estimated parameters can differ significantly, e.g., in cases of DE domination near radiation-matter equality or at early matter era.

Our EDDE model parameters can be more tightly constrained by the recent and forthcoming observations (e.g., SPT, Planck, SDSS III).