Cosmological Imprint of an Energy Component with General Equation of State

Quintessence

- We consider replacing Λ with a dynamical, time-dependent, and spatially inhomogeneous component whose equation of state is different from baryons, neutrinos, dark matter, or radiation. The equation of state of the new component, denoted as *w*, is the ratio of its pressure to its energy density. This fifth contribution to the cosmic energy density is "quintessence" or Q component.

- Average energy density

$$\rho_Q = \frac{1}{2a^2} Q'^2 + V$$

- Average pressure

$$p_Q = \frac{1}{2a^2} Q'^2 - V$$

$$w \equiv p_Q / \rho_Q \in [-1, 0]$$

-1 =<w< -1/3 quintessence

w=-1 cosmology constant

w<-1 phantom energy

- All properties of the model are determined by the prescribed $w(\eta) \equiv w[a(\eta)]$

and

$$\rho_Q = \Omega_Q \rho_o \exp\left[3 \ln \frac{a_o}{a} + 3 \int_a^{a_o} \frac{da}{a} w(a) \right]$$

Luminosity Distance vs. Redshift

$$d_L(z) = c(1+z)\int_0^z \frac{du}{H(u)} \qquad \text{flat, } \Omega_K = 0$$

From the Friedmann equation, the Hubble parameter changes as:

$$H(z) = H_0\sqrt{\sum_i \Omega_i (1+z)^{3(1+w_i)}}$$

$$= H_0\sqrt{\Omega_M(1+z)^3 + \Omega_Q(1+z)^{3(1+w)}} \qquad \text{flat, } \Omega_\mathrm{Q} = 1 - \Omega_\mathrm{M}$$

w is the equation of state parameter of each component :

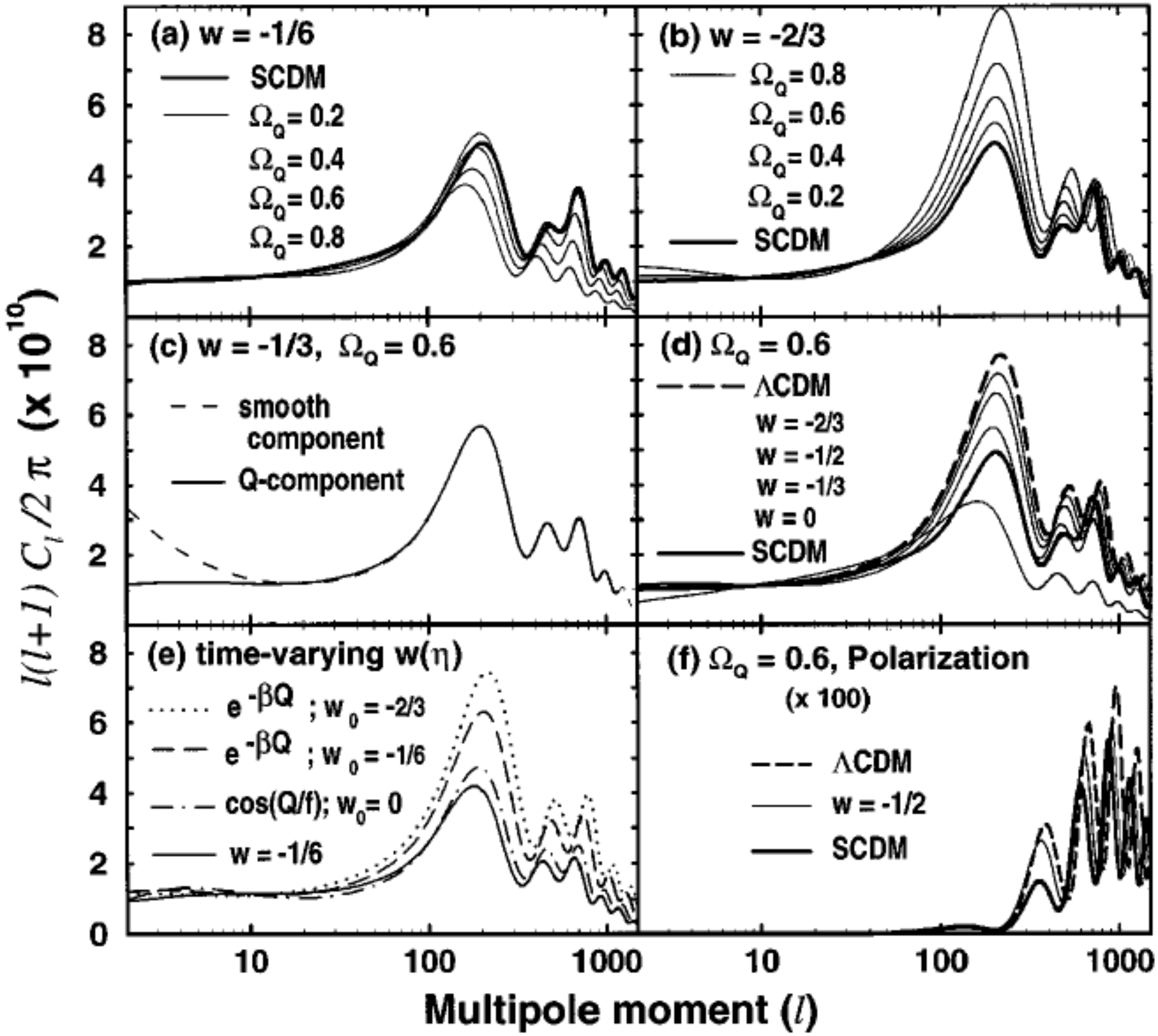
$$P_i = w_i \rho_i c^2 \qquad \rho_i \propto (1+z)^{3(1+w_i)} \propto a^{-3(1+w_i)}$$

gravitational attraction $\propto \rho + 3P/c^2 \propto \rho(1+3w_i)$

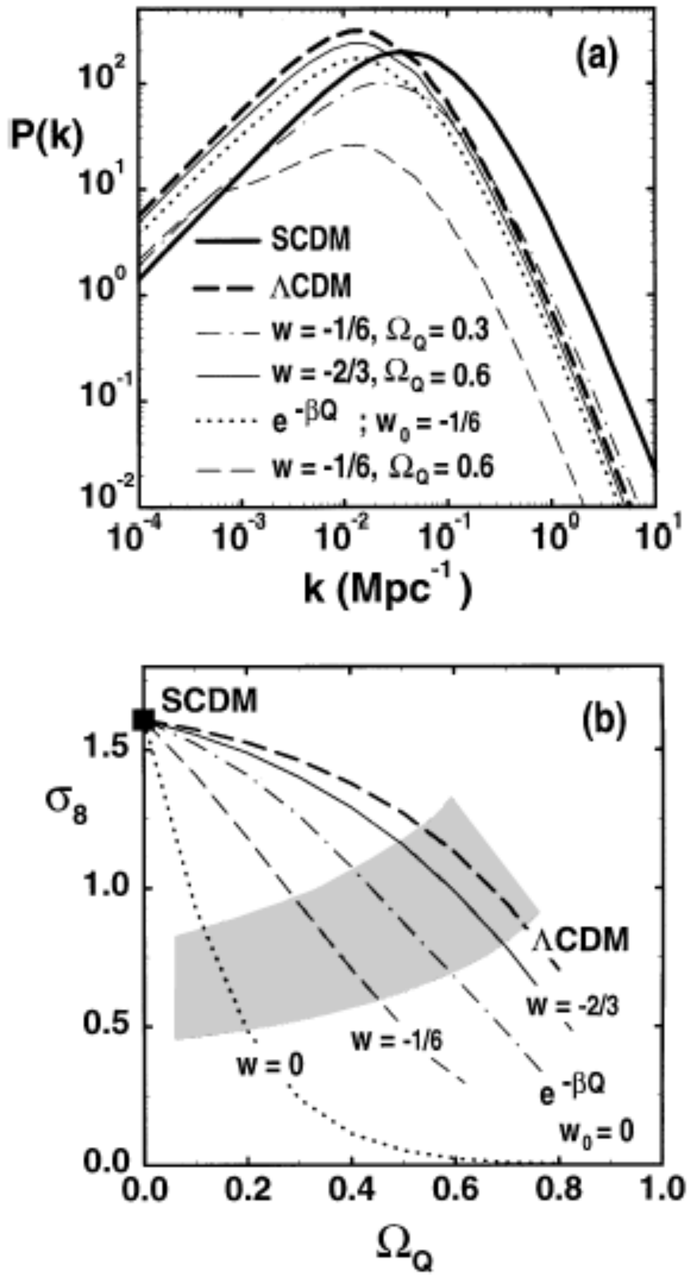
matter (dark/normal): w = 0 $\quad \rho \propto (1+z)^3$

radiation: w = +1/3 $\quad \rho \propto (1+z)^4$

cosmological constant: w = -1 $\quad \rho \propto (1+z)^0 = \text{const}$



(a) w = -1/6
SCDM
Ω_Q = 0.2
Ω_Q = 0.4
Ω_Q = 0.6
Ω_Q = 0.8
(b) w = -2/3
Ω_Q = 0.8
Ω_Q = 0.6
Ω_Q = 0.4
Ω_Q = 0.2
SCDM
(c) w = -1/3, Ω_Q = 0.6
smooth component
Q-component
(d) Ω_Q = 0.6
ΛCDM
w = -2/3
w = -1/2
w = -1/3
w = 0
SCDM
(e) time-varying w(η)
$e^{-\beta Q}$; w_0 = -2/3
$e^{-\beta Q}$; w_0 = -1/6
cos(Q/f); w_0 = 0
w = -1/6
(f) Ω_Q = 0.6, Polarization
(x 100)
ΛCDM
w = -1/2
SCDM
$l(l+1)\,C_l/2\pi$ (x 10^{10})
Multipole moment (l)



(a)
P(k)
k (Mpc^{-1})
SCDM
ΛCDM
w = -1/6, Ω_Q = 0.3
w = -2/3, Ω_Q = 0.6
$e^{-\beta Q}$; w_0 = -1/6
w = -1/6, Ω_Q = 0.6
(b)
SCDM
σ_8
ΛCDM
w = -2/3
w = -1/6
w = 0
$e^{-\beta Q}$
w_0 = 0
Ω_Q

In conclusion, we find that the “quintessence” hypothesis fits all current observations and results in an imprint on the CMB anisotropy and mass power spectrum that should be detectable in near-future experiments.