Dynamical Models of the Missing Energy of the Universe

Robert CALDWELL
EVIDENCE

\[ \Omega_m < 1 \]

\[ \Omega_k = 0 \]

PROBLEM

\[ \Omega_m + ? = 1 \]
... and the nominees are

**COSMOLOGICAL CONSTANT**

- **Origin:** Quantum Gravity
- **Property:** Invariant

**DYNAMICAL COMPONENT**

**QUINTESSENCE**

- **Origin:** Fundamental Physics
- **Properties:** Time varying, negative pressure, inhomogeneous
COINCIDENCE?

OR...

WHY IS $\rho_m \sim \rho_Q$?

IF $m$ & $Q$ ARE independent, explain the coincidence!

WHAT IF $m$ & $Q$ ARE COUPLED?

WHAT IS THE HISTORY OF $Q$?
Q

@ penn

{
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}

CDS: PRL 80, 1582 (1998)
CS: PRD 57, 6057 (1998)
HDWCS: astro-ph/9804285
WS: astro-ph/9804015
Quintessence

Properties & Predictions

Cosmological Concordance

Distinguishing Q from Λ

Coupling Q to DM
QUINTESSENCE
as a Scalar Field

PROPERTIES

DOMINANT \( V \)
PRESSURE < 0 \( V' \)
ULTRA-LIGHT \( V'' \)

\( \Omega_\Lambda \)
\( \omega = p_\Lambda / \rho_\Lambda \)

POTENTIALS

\( V \sim \frac{1}{2} m^2 Q^2 \)
\( m^4 [\cos(\theta_5) + 1] \)
\( m^4 e^{-\beta a} \)
\( \lambda / Q^a \)

SOME REFS:
FHSW 95
CDF 97
VL 98
FJ 97
W95
RP 88
CDS 98

FLUCTUATIONS

\( \delta Q \)
STABLE GROWTH
RESPONDS TO \( \delta_m \)
EFFECTIVE $\omega$

$$\bar{\omega} = \frac{\int da \, \Omega_Q(a) \, \omega(a)}{\int da \, \Omega_Q(a)}$$

$$\left[ \frac{d\omega}{d\ln z} \right]^2 = \frac{\int dz \, \Omega_Q(z) \left[ \frac{d\omega}{d\ln z} \right]^2}{\int dz \, \Omega_Q(z)}$$
Comparison of Quintessence with Smooth Component

\[ u(l+1)C_l/2\pi \times (10^{10}) \]

multipole moment: \( l \)

- **Quintessence** (\( \delta Q \neq 0 \))
- **Smooth Component** (\( \delta Q = 0 \))
Evolution of the Equation of State

$Q: \Omega_\Lambda = 0.7, w(t_0) = -1/3$
Evolution of Density Parameter $\Omega_q$

$Q: \Omega_q = 0.7, w(t_0) = -1/3$
Sensitivity to Time Evolution of Quintessence

$\Omega_0 = 0.7, \ w(t_0) = -1/3$

$l(l+1)C_l/2\pi \times (10^{10})$

multipole moment: $l$

- exponential potential
- cosine potential
- constant $w$
- cosmological constant
PROBES OF THE MISSING ENERGY

COSMIC EVOLUTION

RED SHIFT - DISTANCE (SNe)
RED SHIFT - VOLUME (LENSING)

FLUCTUATION SPECTRA

CMB

CLUSTERING & EVOLUTION

PECULIAR VELOCITIES
$\Omega_m - w$ plane

- $t_0 > 10$ Gyr
- $t_0 > 12$ Gyr

Baryon fraction; BNN; H

Shape; H; baryon fraction; $n_s$
Cosmological Implications of High z SNe Ia
Riess et al, astro-ph/9805201

\[ \Delta(m-M) \text{ [mag]} \]

- \( H_0 = 63.8 \text{ km/s/Mpc} \)
- \( H_0 = 65.2 \text{ km/s/Mpc} \)

red shift: \( z \)
Figure 6

cosmo-ph/9805201
Suppose CMB experiment determines:

\[ \Omega_b h^2 = 0.02 \quad n_s = 1 \]

\[ \Omega_m h^2 = 0.15 \quad r = 0 \]
COUPLING Q & DM

ZCS 98

MISSING ENERGY

SUPPLIED BY Q

COINCIDENCE

Q-DM ENERGY EXCHANGE

SIMPLIFY COSMOLOGICAL SCENARIO

PROTOTYPE

\[ L = \frac{1}{2} \partial_\mu Q \partial^\mu Q + \frac{1}{4} \bar{\psi} \gamma^\mu \psi \partial_\mu \psi + U(\varphi) + \frac{1}{2} \lambda^2 Q^2 \psi^2 \]

AC 97
\[ P(k) \, (h^3 \, \text{Mpc}^{-3}) \]

\[ k_{to} \]

\[ \text{k (h Mpc}^{-1}\text{)} \]

ZLATEV, RC, PJS '98
QCDM summary

viable:

compatible with CMB, LSS

"best fit" models in pipeline

distinguishable:

distinct from $\{S, T, \Lambda\}$CDM

parameter extraction

fundamental:

observations reveal nature of dynamical Q-component