Title: Can We Detect Dynamics in Dark Energy?

Date: Dec 03, 2007 03:15 PM

URL: http://pirsa.org/07120018

Abstract: We highlight the unexpected impact of nucleosynthesis on the detectability of tracking quintessence dynamics at late times, showing that dynamics may be invisible until Stage-IV dark energy experiments (DUNE, JDEM, LSST, SKA). Nucleosynthesis forces |wÂ•ÂŒ(0)| <0.2 for the models we consider and strongly limits potential deviations from _LCDM .
Surprisingly, the standard CPL parametrisation, w(z) = w0 +waz/(1+z), cannot match the nucleosynthesis bound for minimally coupled tracking scalar fields. Given that such models are arguably the best-motivated alternatives to a cosmological constant these results may significantly impact future cosmological survey design and imply that dark energy may be dynamical even if we do not detect any dynamics in the next decade.

Can we detect dynamics in Dark Energy?

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arxiv:0709.0526

Bruce Bassett, Mike Brownstone, Antonio Cardoso, Yabeba
Fantaye, Renée Hlozek, Jacques Kotze Patrice Okouma

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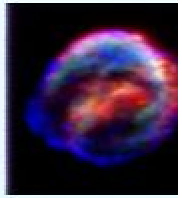
University of Sussex

1998: ???

supernovae 1a



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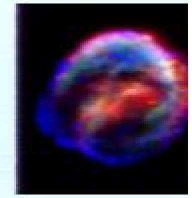
Expansion is **<u>speeding up</u>**
not
slowing down!

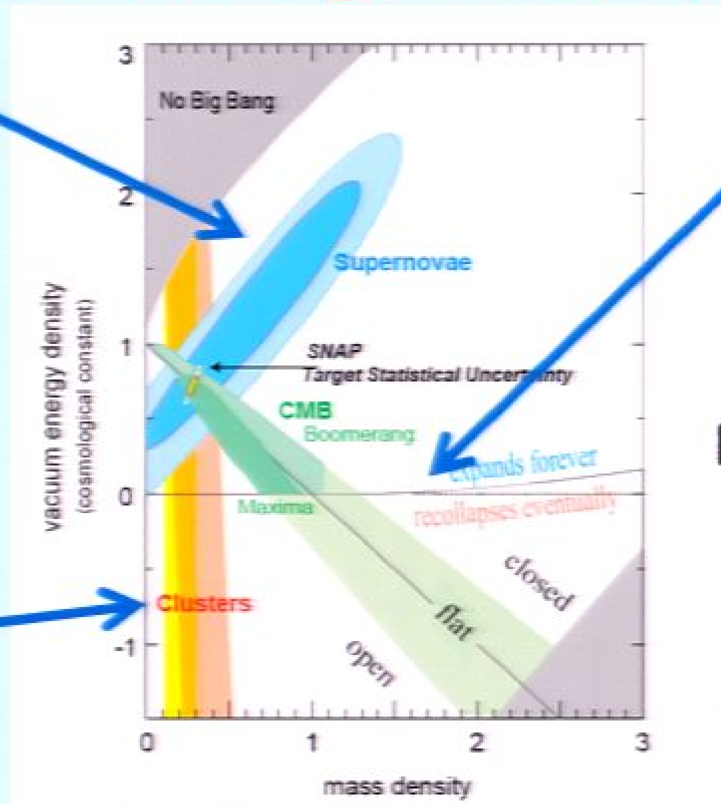
1998: ???



supernovae 1a

Expansion is **speeding up** not **slowing down!**

SN1a:
brightness is same
dimmer
↓
are farther away



CMB: power spectrum
↓
•baryons and photons pulled by gravity
•information from peak position + amplitude

Clusters
•x-ray fraction is constant
•measured fraction depends on distance

When we don't know what it is we put "dark" in front of it...
Makes it easier to get funding!"
phd comics

DARK ENERGY

Λ

- why so small?
- why now?
- 120...

Dynamics

- motivate from theory
- plenty of possibilities
- plenty of imagination..

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5

all observations consistent with $w = -1$

Λ

only covariant description

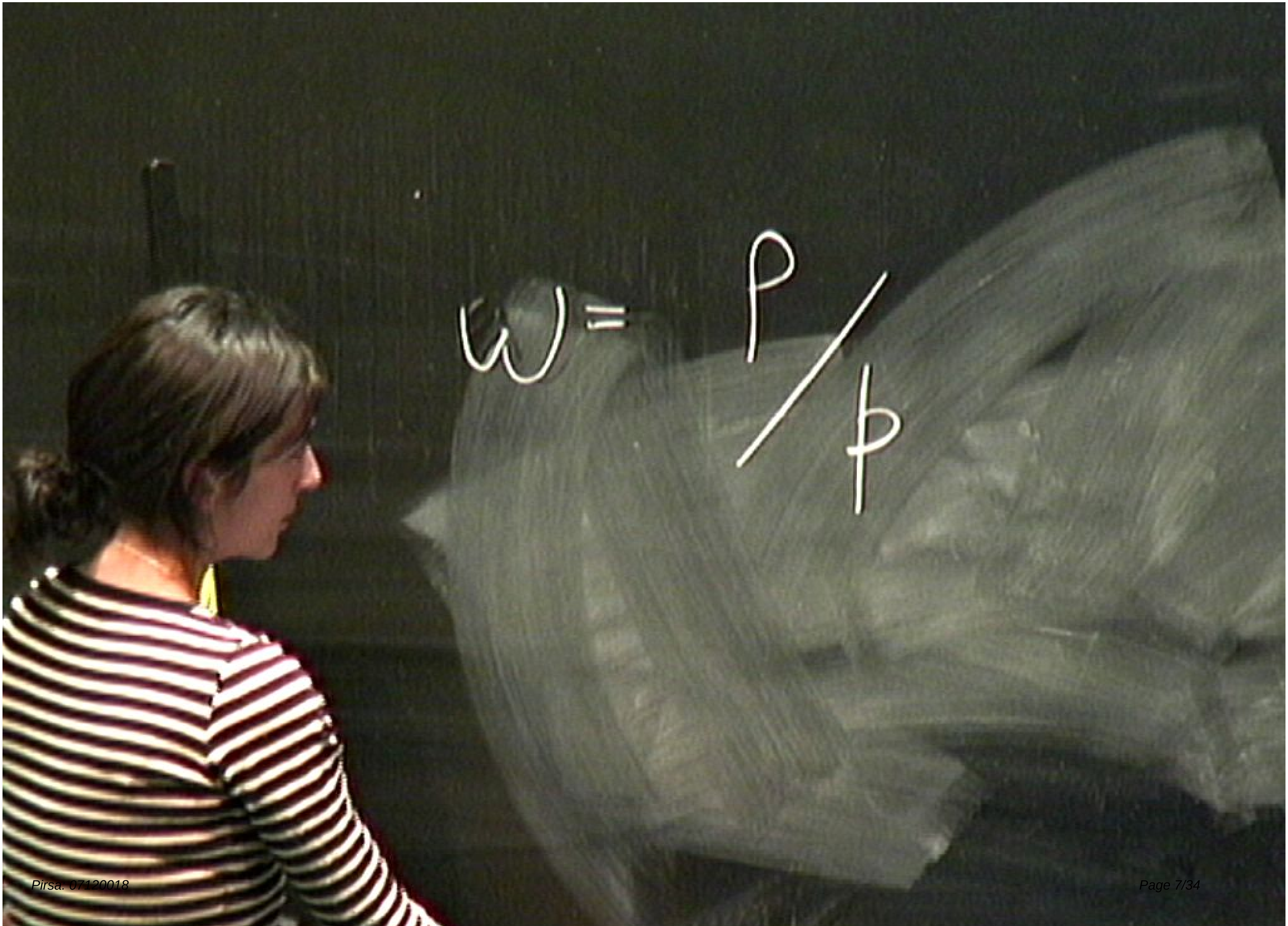
MOST PLAUSIBLE
MOST PUZZLING

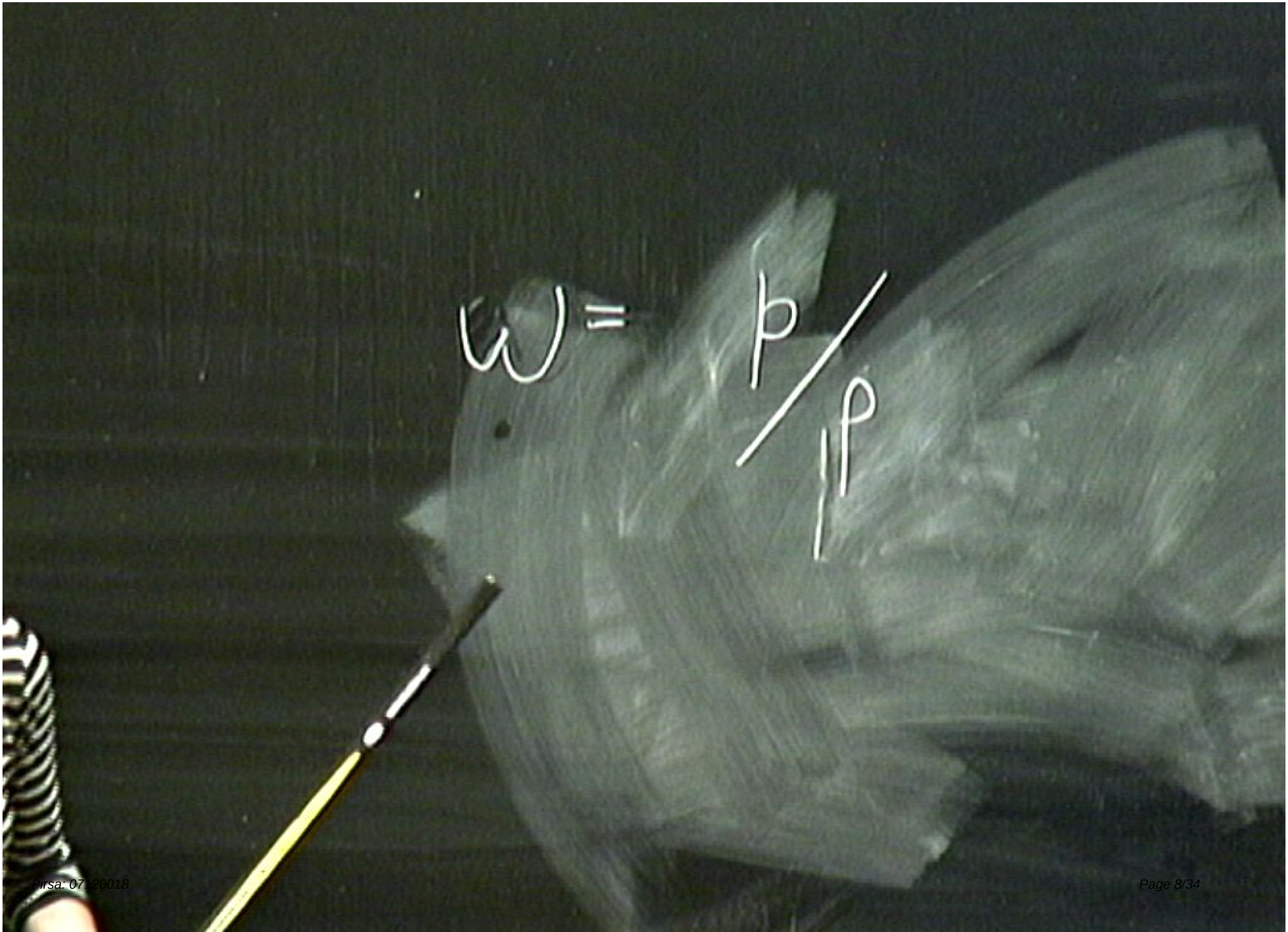
- zero point energy
- no prediction ⇒ $\rho_{\text{vac}} \propto k^4$
- energy scales phase transitions early universe

$$\rho_{\text{vac}}^{(\text{obs})} \sim 10^{-120} \rho_{\text{vac}}^{(\text{guess})}$$

It is (also) a good rule not to put too much faith in observations until they are confirmed by theory...

Sir Arthur Eddington


w = P/ρ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It's what we're looking for...

ESSENCE: deviations from Λ at $z \sim 0.5$

Wood-Vasey et al

HST: bound w' across $0.2 < z < 1.3$

Riess et al

DETF: consistency with Lambda?
time evolution ?

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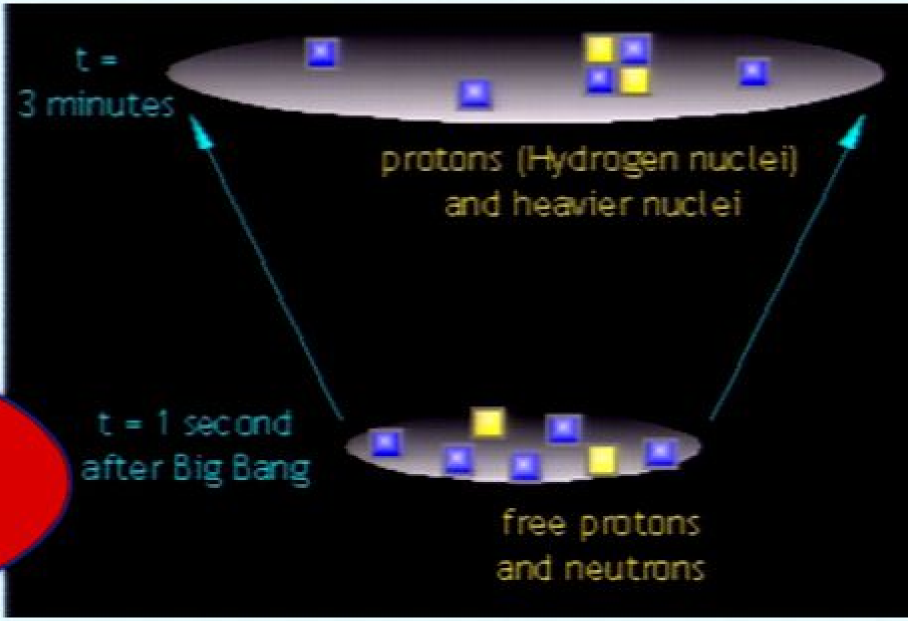
BIG BANG NUCLEOSYNTHESIS

$$T \sim 1MeV$$

➡ key difference between lambda and dynamics: **DE present at earlier times**

$$\frac{n}{p} \sim \exp\left(-\frac{m_n - m_p}{T}\right)$$

exponentially sensitive to expansion rate



freeze out: ratio fixed ➡ determine expansion rate

we know expansion ➡ we know amount of Dark Energy

Constraints on Dark Energy…

BBN

Bean, Hansen, Melchiorri (2001)

$$\Omega_{DE}(T \sim 1MeV) < 0.045 \quad \text{at} \quad 2\sigma$$

CMB

Doran et al (2005)

$$\Omega_{DE}(T \sim 1eV) < 0.04$$

Linking BBN to today… Scaling Fields!

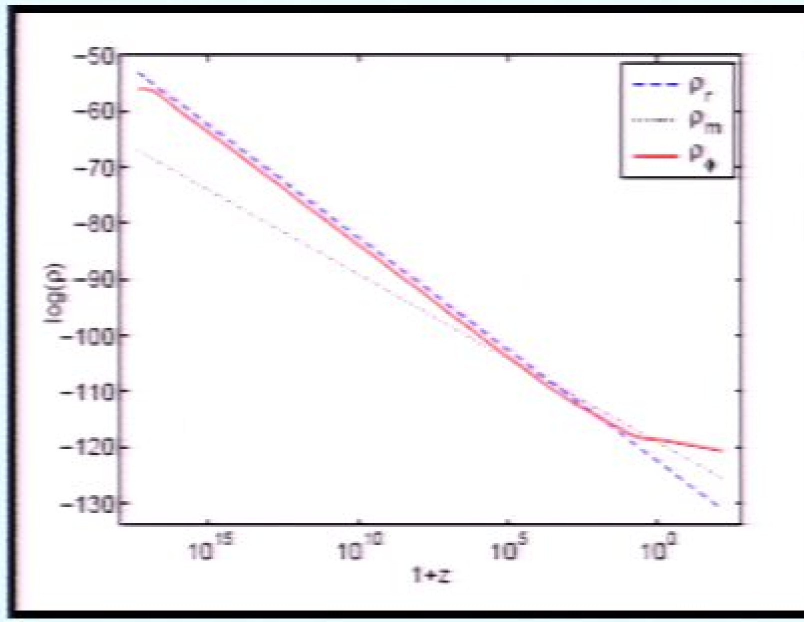
10

Definition

$$\Omega_\phi = \frac{\rho_\phi}{\rho_b} = const$$

Ratra and Peebles 199
Wetterich 199
Copeland Liddle Wands 199

- Field energy density **mimics** background
- Less dependence on **initial conditions**
  scaling regime from wide range i.c's
- Using Nucleosynthesis:



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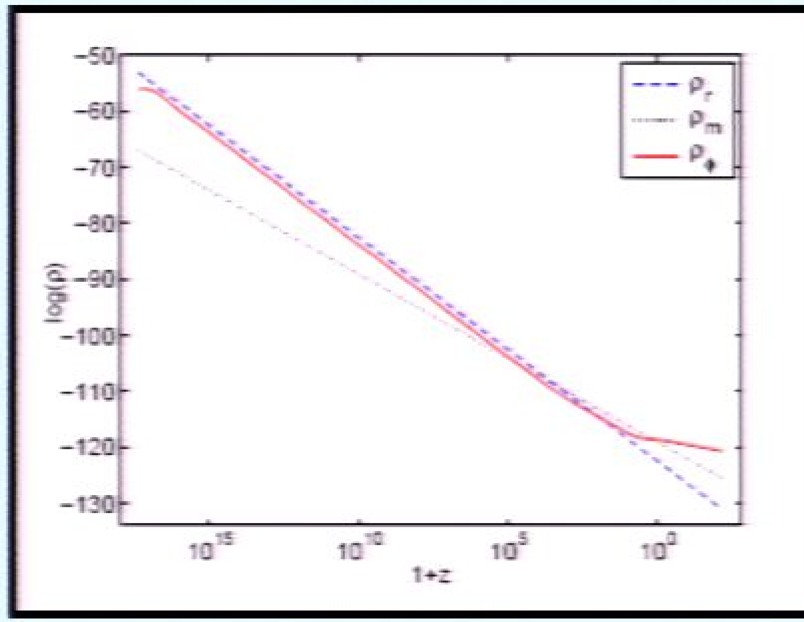

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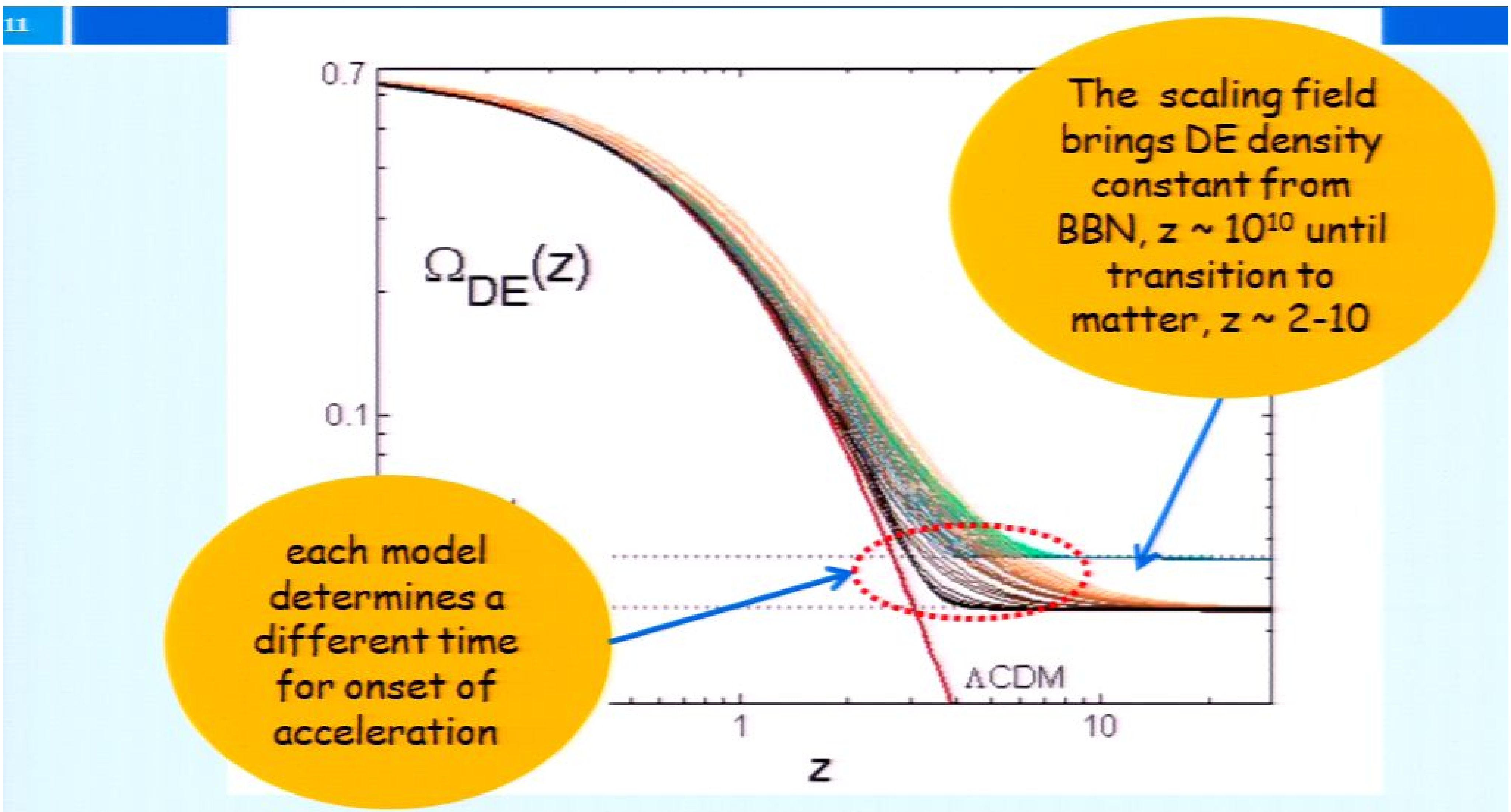
BBN+ scaling:

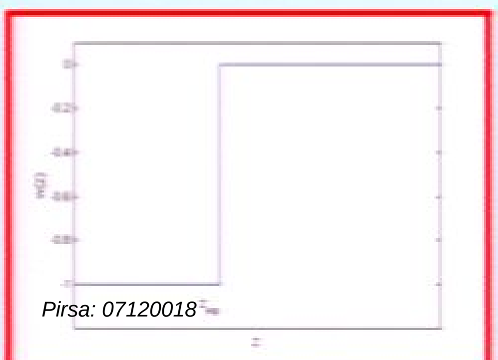

11
0.7
0.1
$\Omega_{DE}(z)$
The scaling field brings DE density constant from BBN, z ~ 10^{10} until transition to matter, z ~ 2-10
each model determines a different time for onset of acceleration
ΛCDM
1
10
z

So we take:

- ✓ Constraint at BBN
- ✓ Field ***scales*** until transition to matter

+

1. TOY MODEL:
step function for transition



2. SCALAR FIELD:
leaves scaling to dominate energy density

$$V(\phi) = M_1^4 e^{-\lambda\kappa\phi} + M_2^4 e^{-\mu\kappa\phi}$$

3. PHENOMENOLOGICAL
after transition look for famous *w(z)*'s...

BBN+ scaling:

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$$\Omega_{DE}(z_t) = \frac{\Omega_{DE}^{(0)} f(z_t)}{\Omega_{DE}^{(0)} f(z_t) + \Omega_m^{(0)} (1+z_t)^3} = 0.045$$

$$f(z) \equiv \exp\left[3\int_0^z \frac{1+w(z')}{1+z'} dz'\right]$$

saturate limit

at transition

choose w(z) and invert

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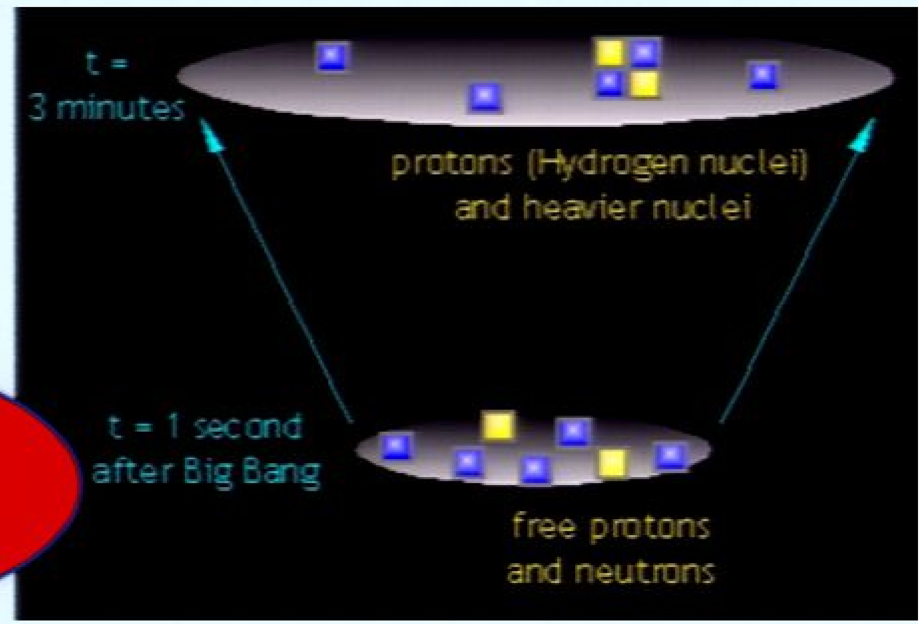

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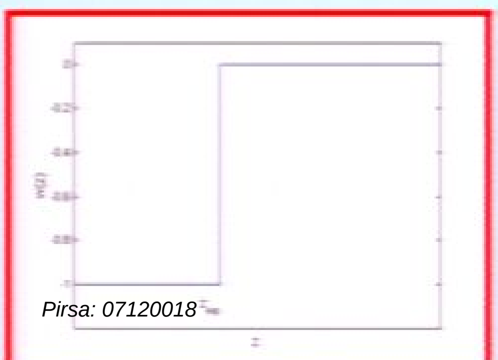
1. TOY MODEL: step function for transition
2. SCALAR FIELD: leaves scaling to dominate energy density
3. PHENOMENOLOGICAL after transition look for famous *w(z)*'s...



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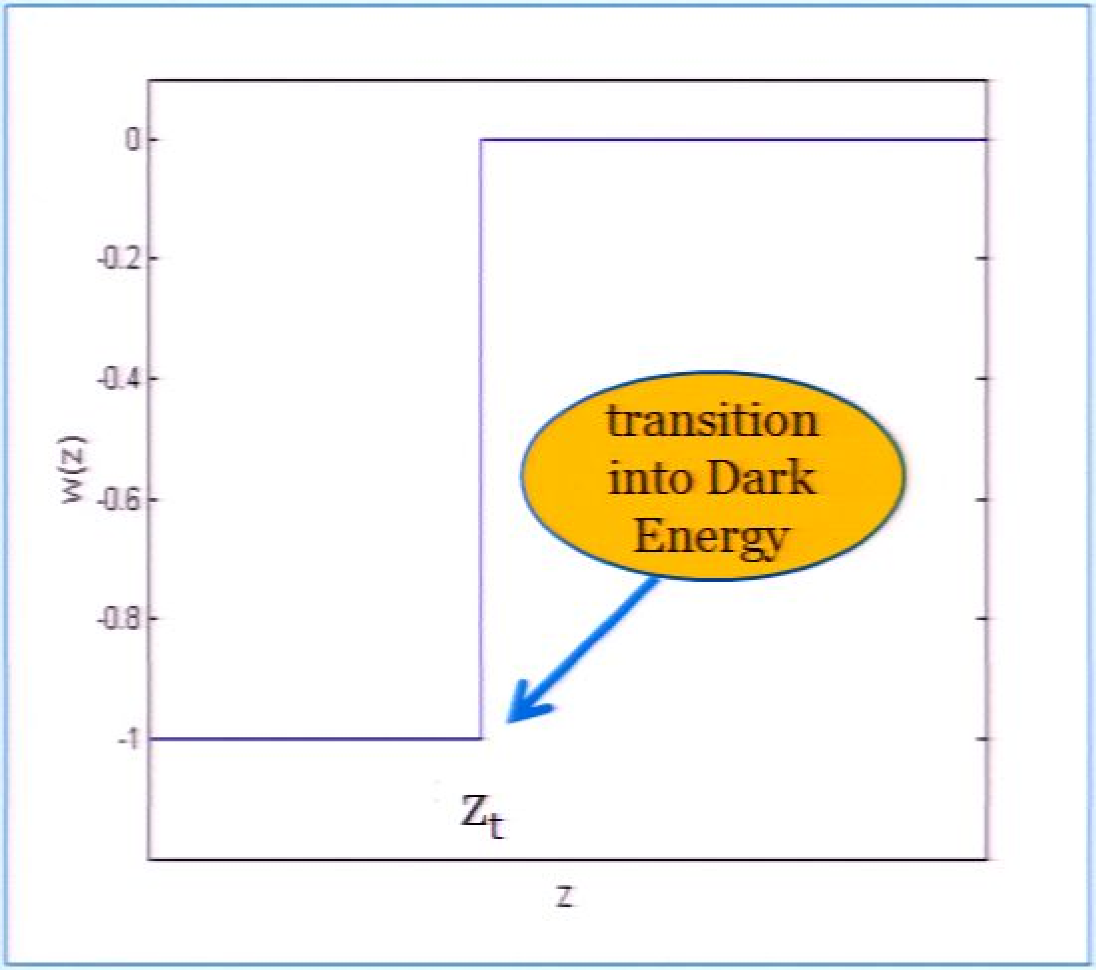
1.Toy Model: Step Function



BBN + scaling + $\begin{cases} w(z_t) = 0 \\ w(0) = -1 \end{cases}$

$$z_t > 2.6$$

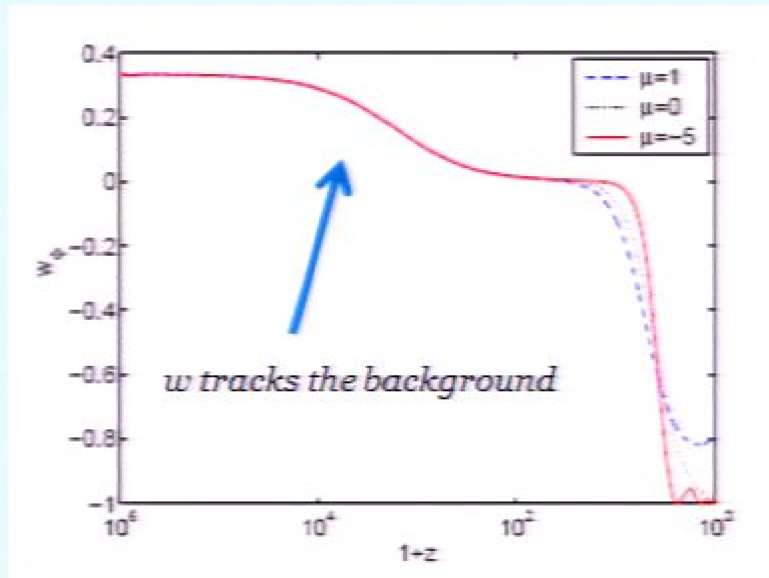
transition doesn't happen within reach of most DE probes...!

$z_t \sim 1$ needs $w = -1.88$

2. Double Exponential Potential

$$V(\phi) = M_1^4 e^{-\lambda\kappa\phi} + M_2^4 e^{-\mu\kappa\phi}$$

BBN + $\Omega_\phi \sim 0.7$, $\Omega_m \sim 0.3$ *sets* $\lambda, M_2, \mu^2 < 2$



- saturate BBN bound $\mu = 1$
  to maximize deviations from LAMBDA…
  …examine detectability

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1.Toy Model: Step Function

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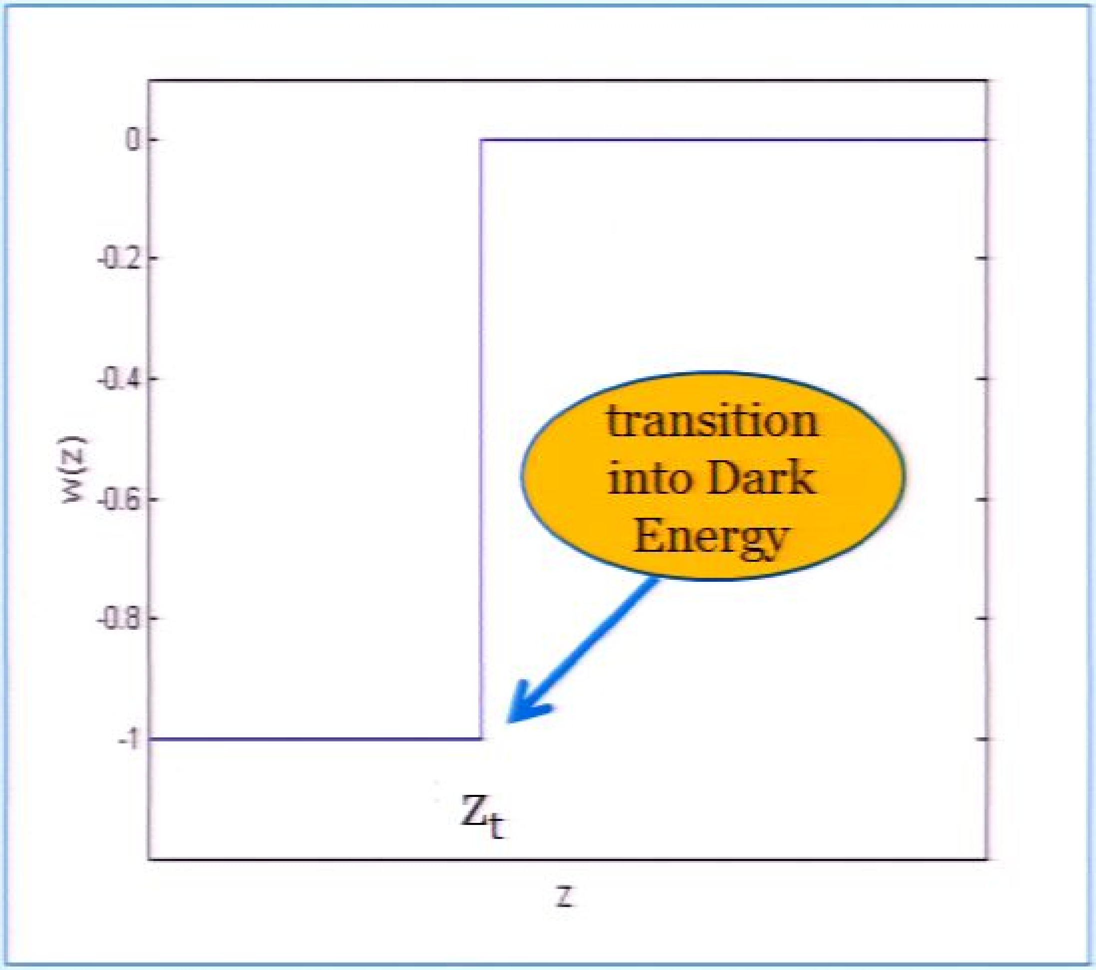

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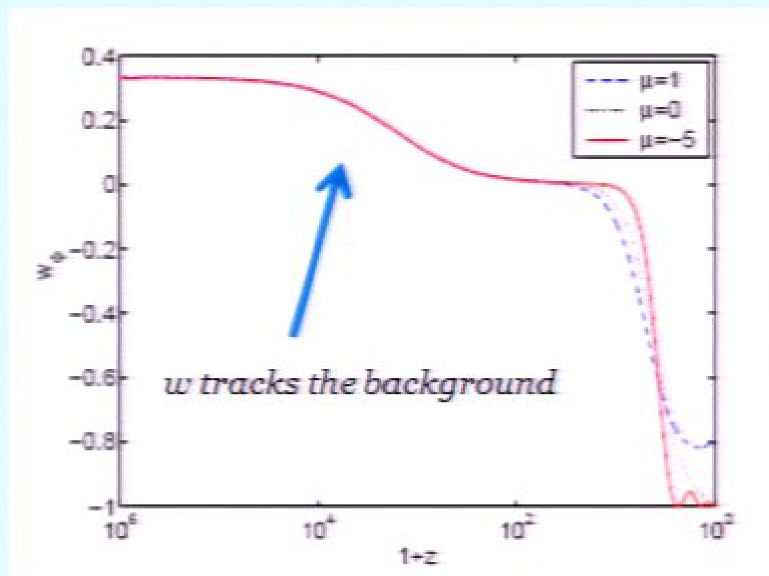

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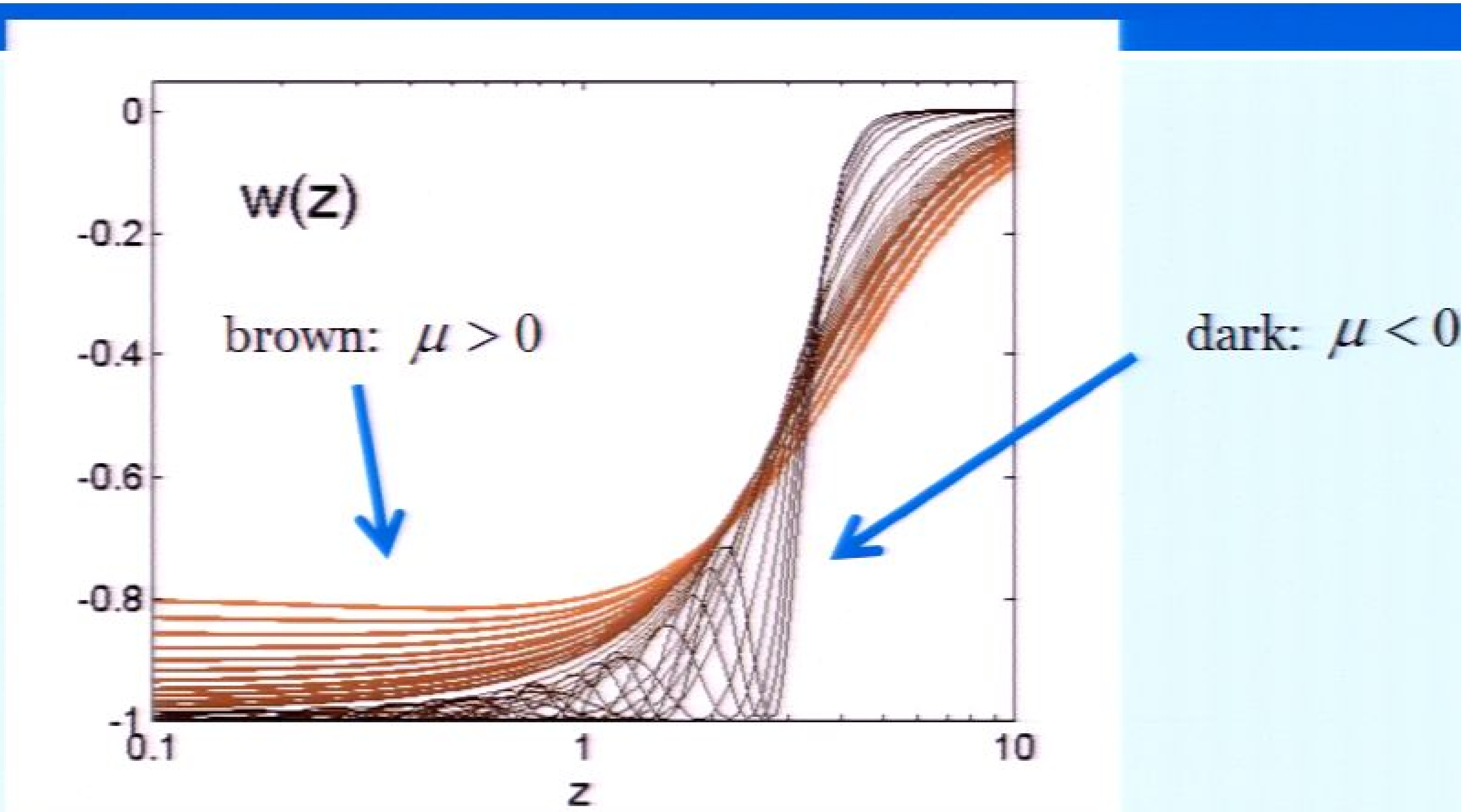
Double Exponential Potential



• if w today close to 2σ boundary $(\mu = 1)$

detectability is within reach of Stage IV experiments

Double Exponential Potential

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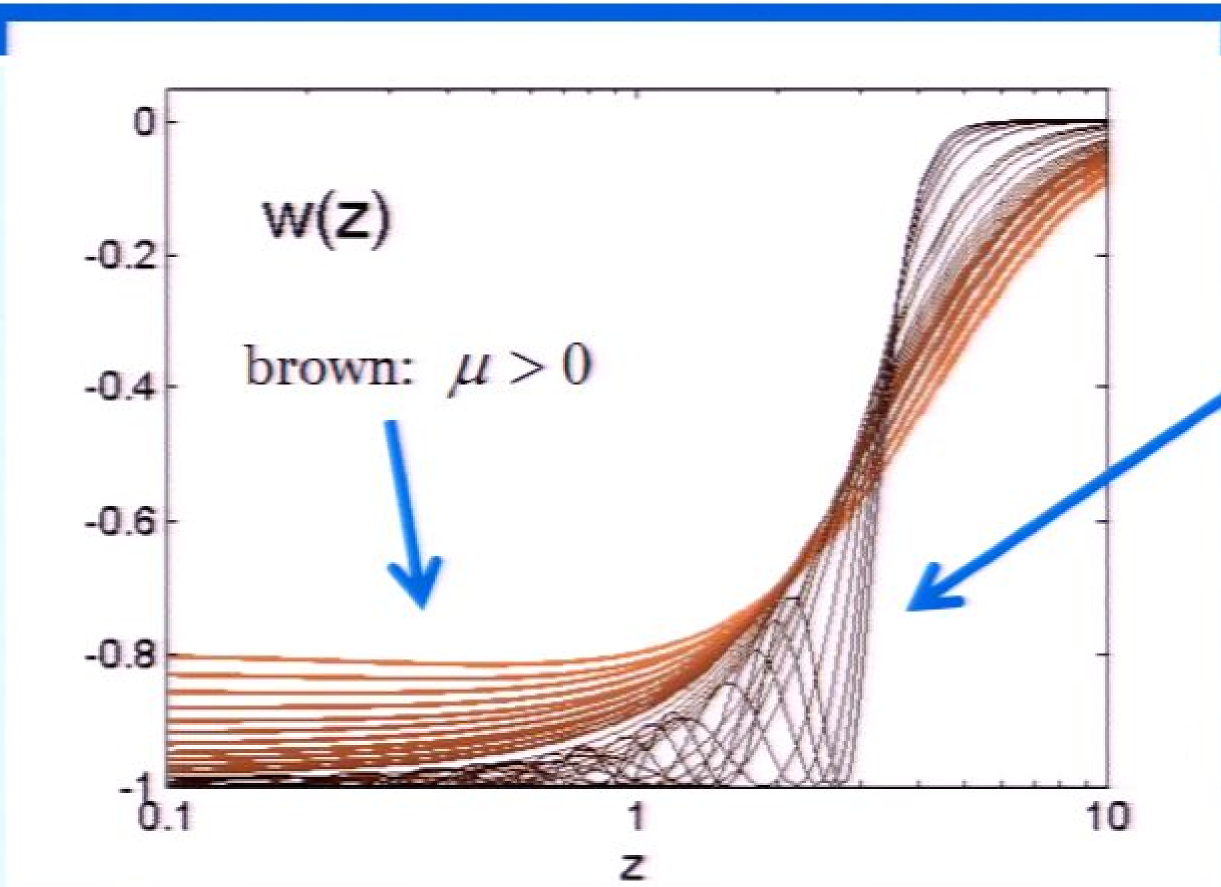

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Detectability: Hubble rate

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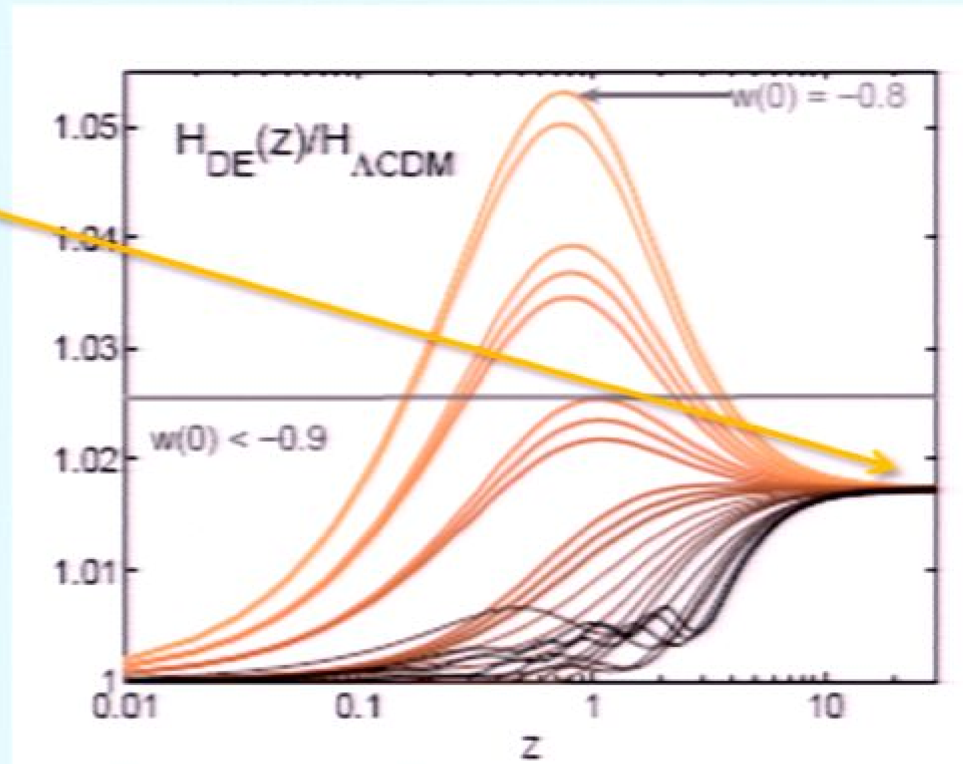
$$\frac{H_{DE}}{H_\Lambda}(z \geq z_t) = \sqrt{\frac{(1+zt)^3}{(1-\epsilon)(1+z_t)^3 + r}}$$
$$\leq \sqrt{\frac{1}{1-\epsilon}}$$
$$= 1.017 \text{ for } \epsilon = \frac{3}{4}0.045$$

$w(0) < 0.9$

Deviations of ***H(z)*** from LCDM < ***2.7%***

Largest deviation at ***z~1***



University of KwaZulu Natal

Distance Modulus

- Distance modulus $\Delta\mu = 5\log\left(\frac{d_{L,\mathrm{DE}}(z)}{d_{L,\Lambda}(z)}\right)$

  where (assuming flatness)

$$
\begin{aligned}
d_L &= \frac{c}{H_0}(1+z)\int_0^z \frac{dz'}{E(z')} \\
\text{and } E(z) &= \frac{H(z)}{H_0}
\end{aligned}
$$

If

$$
\begin{aligned}
\frac{H_{\mathrm{DE}}(z)}{H_\Lambda(z)} &< 1+\alpha^2 \\
\rightarrow \frac{d_{L,\mathrm{DE}}(z)}{d_{L,\Lambda}(z)} \propto \frac{H_\Lambda}{H_{DE}} &> \frac{1}{1+\alpha^2}
\end{aligned}
$$

plots of distance modulus see paper

3. Standard Parametrization… CPL

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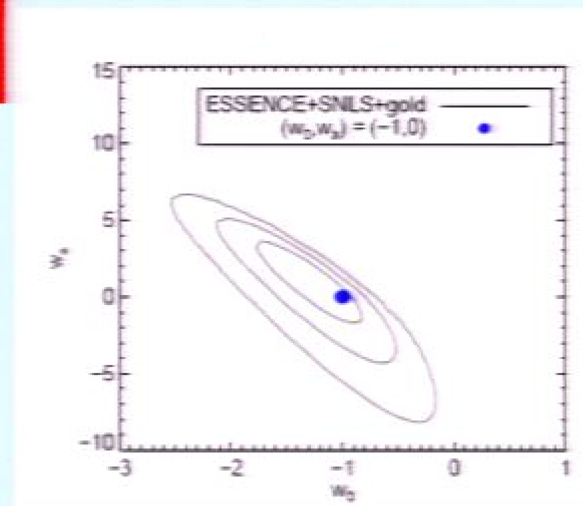
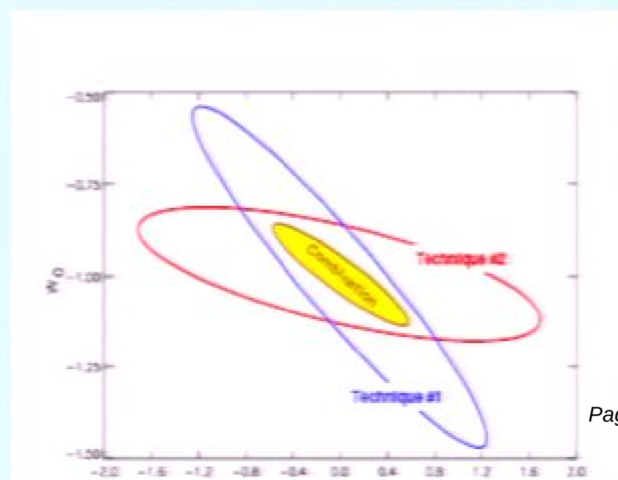
$$w(z) = w_0 + w_a(1 - a) = w_0 + w_a \frac{z}{1+z}$$

Chevallier Polarski (2001)
Linder (2003)

- Widely used
- Surveys use it for constraints on dynamics

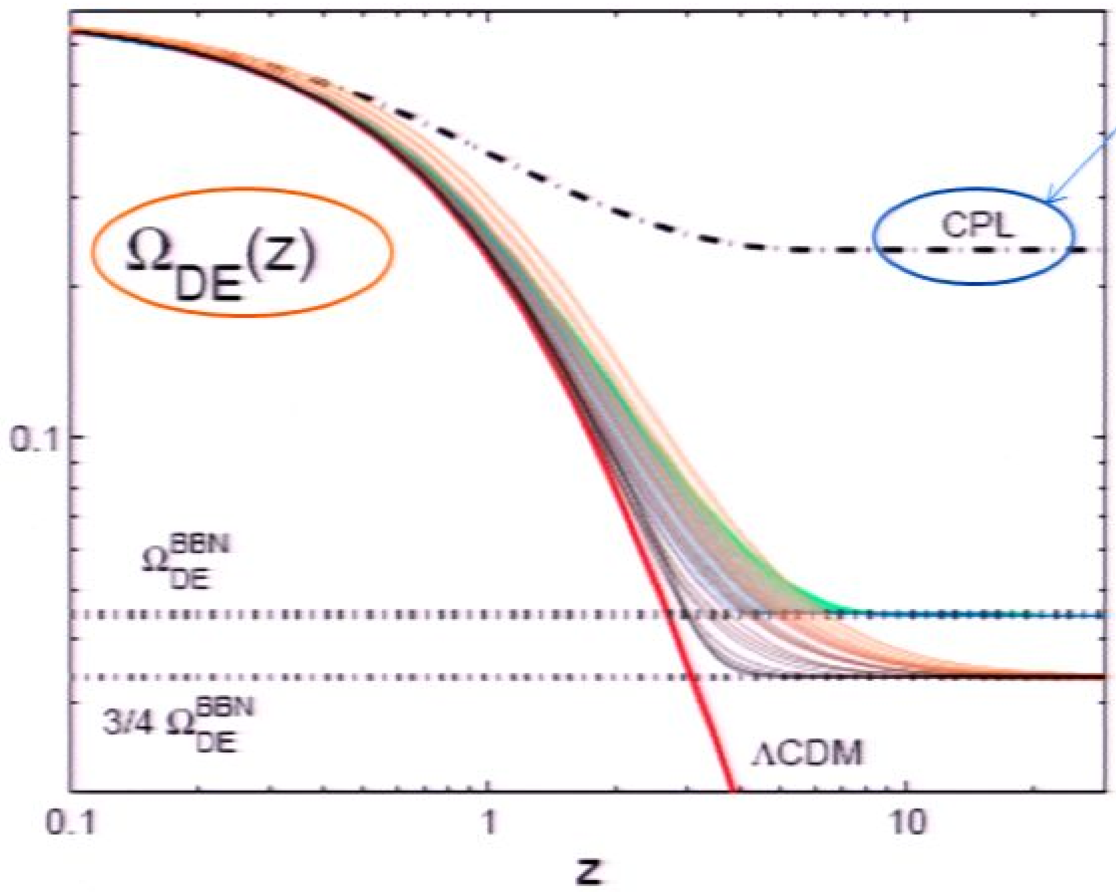


- Basis for **DETF's Figure-of-Merit!** (evaluates merit of ongoing and future DE studies)



Failure of CPL...

...to meet nucleosynthesis constraints with a scaling field



w_{CPL} cannot bring Ω_{DE}

from

$\Omega_{DE}(z_t) = 0.045$

to

$\Omega_{DE}(0) = 0.7$

if

$$\begin{cases} w(0) = -1 \\ w(z_t) = w_m = 0 \end{cases}$$

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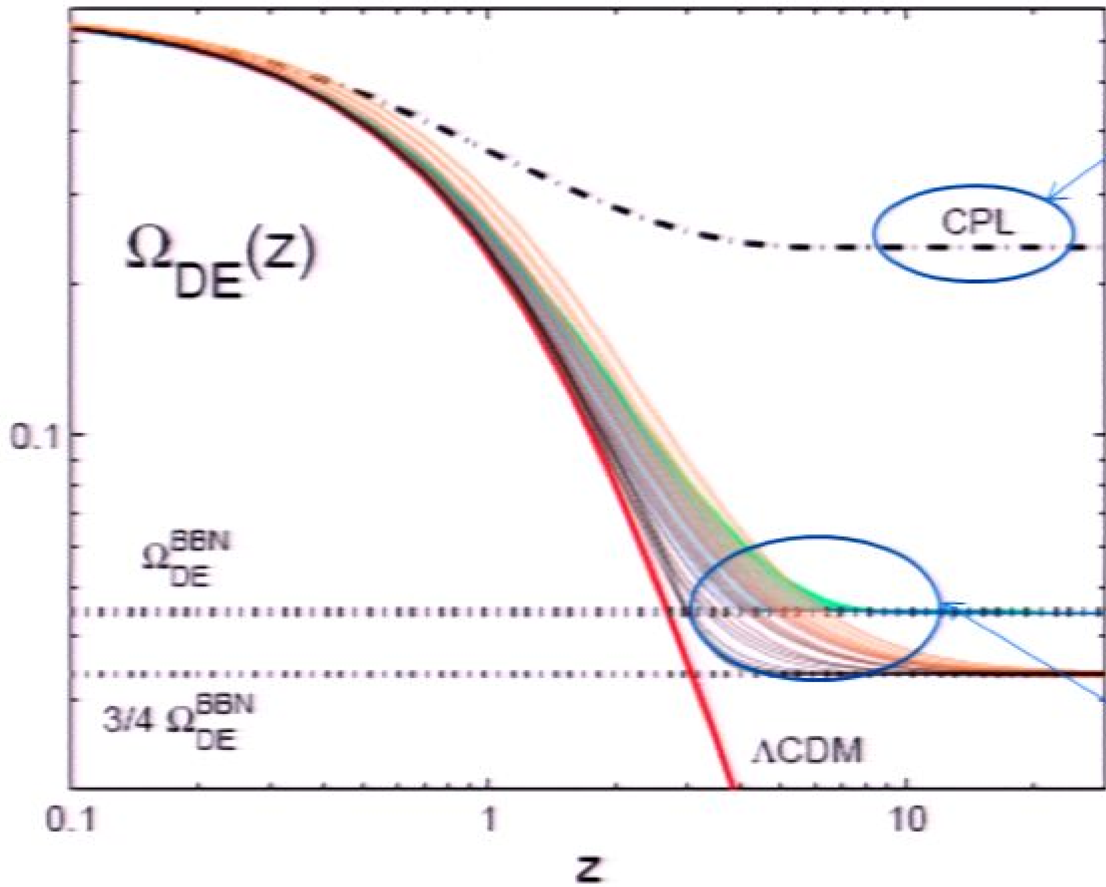

- Maximum value of w_{CPL} is

$$w_{CPL} = w_0 + w_a$$

- asymptotically $w = 0$ but never reaches

Double Exponential Potential

CONCLUSIONS

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- Scaling fields among best alternatives to LAMBDA
- BBN constraints on Ω_{DE} at $T \sim 1 MeV$ **strong limits** on dynamics
- Constraints Hubble rate **detectability** not garanteed within next decade surveys
- if w today close to maximum we can detect dynamics with Stage IV
- Standard CPL parametrization fails to meet BBN with a scalar field
- Important because **figure-of-merit**

→ using this parametrization may systematically point away from quintessence scaling models