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Dynamical Trajectories for Inflation then & now

Inflation Then $\varepsilon(k)=(1+q)(a)$ $\sim r/16$ $0<\varepsilon<1$

= multi-parameter expansion in (lnHa ~ ln$k$)

~ 10 good e-folds (~ 10^{-4} Mpc^{-1} to ~ 1 Mpc^{-1} LSS) ~10+ parameters?

r(k) is very prior dependent. Large (uniform), Small (monotonic). Tiny (roulette inflation of moduli).

Inflation Now $1+w(a)= \gamma\, f(a/a_{\Lambda eq})$ to $3(1+q)/2$

~ 1 good e-fold. Only ~2 parameters

Zhiqi Huang, Bond & Kofman 07

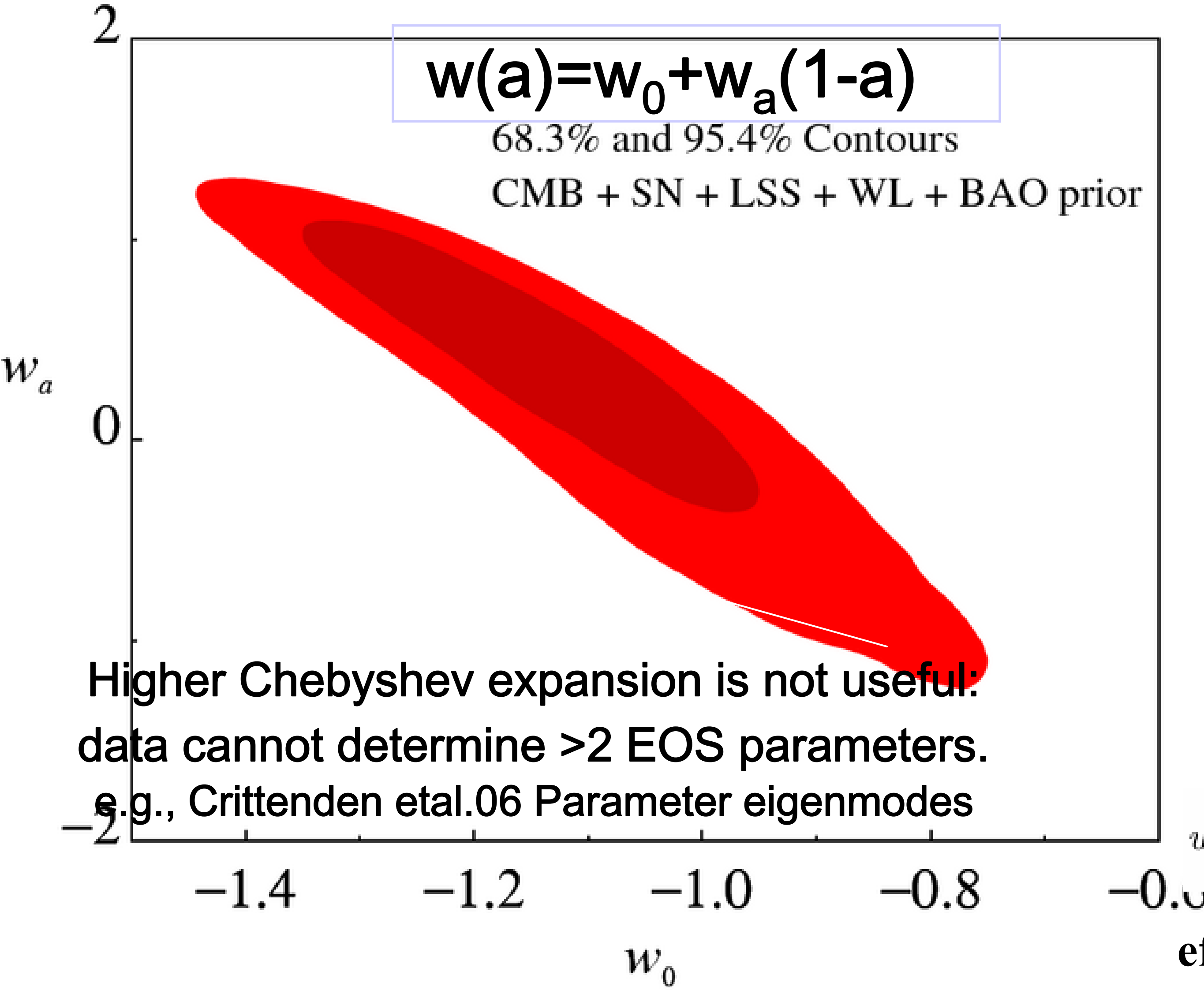
Cosmic Probes Now **CFHTLS SNe (192)**, **WL (Apr07)**, **CMB**, BAO, LSS

$$w(a) \equiv \frac{p(a)}{\rho(a)}$$

Uses latest April'07

SNe, BAO, WL, LSS, CMB data

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



Higher Chebyshev expansion is not useful: data cannot determine >2 EOS parameters. e.g., Crittenden etal.06 Parameter eigenmodes

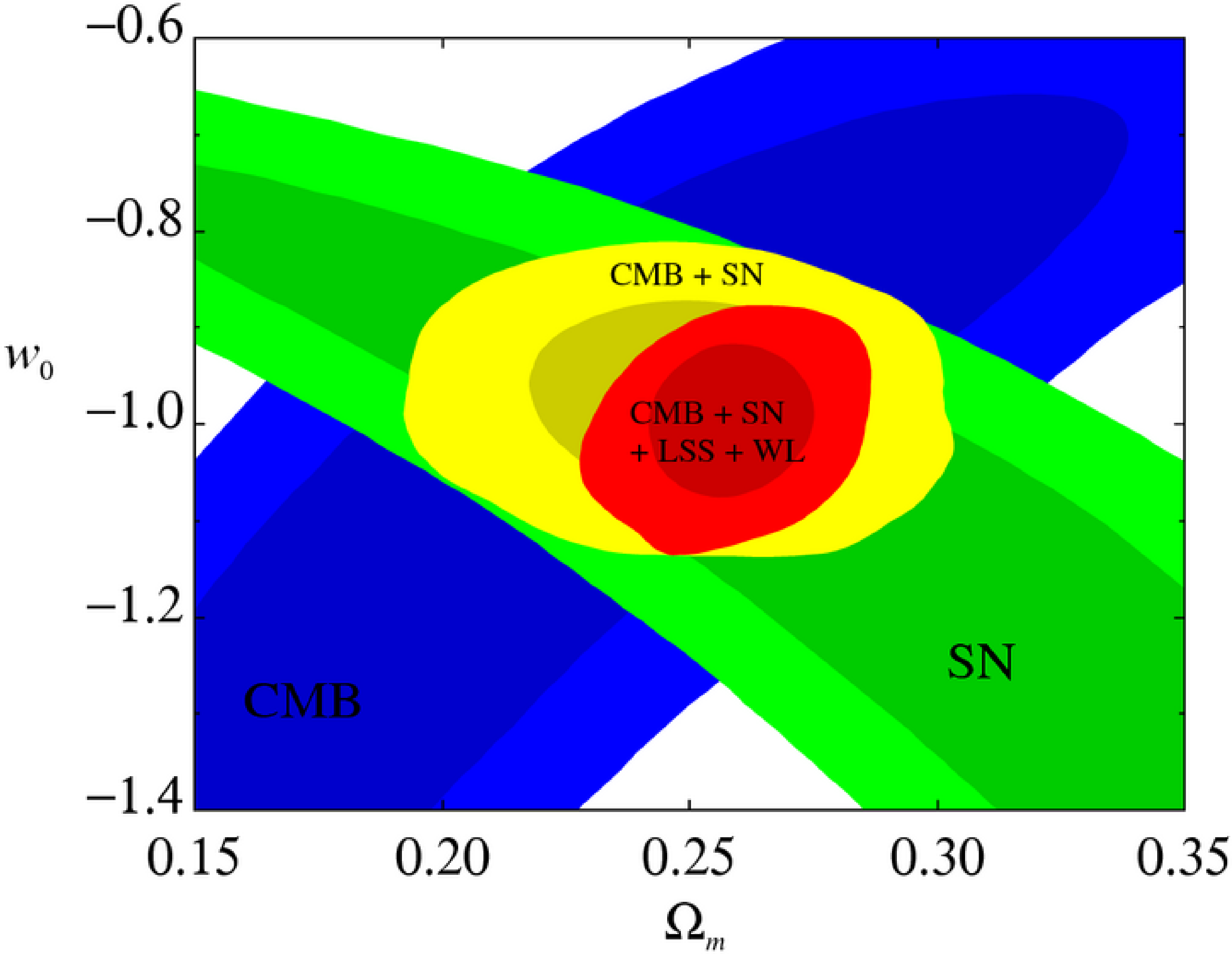
Some Models

- **Cosmological Constant (*w*=-1)**
- **Quintessence (-1≤*w*≤1)**
- **Phantom field (*w*≤-1)**
- **Tachyon fields (-1 ≤ *w* ≤ 0)**
- **K-essence (no prior on *w*)**

$$w_0 + w_a(0.264 + \frac{0.132}{\Omega_{m0}}) = -1$$

effective constraint eq.

Measuring constant w (SNe+CMB+WL+LSS)



Approximating Quintessence for Phenomenology

Zhiqi Huang, Bond & Kofman 07

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$ + Friedmann Equations

$$\begin{cases} d\theta/dN = \sqrt{\frac{3\Omega_\phi}{2}}\lambda\cos\theta - \frac{3}{2}\sin 2\theta, \\ d\Omega_\phi/dN = 3\Omega_\phi(1-\Omega_\phi)\cos 2\theta, \\ d\lambda/dN = -\sqrt{6}\lambda^2(\Gamma - 1)\sqrt{\Omega_\phi}\sin\theta. \end{cases}$$

$$\boxed{1+w=2\sin^2\theta}$$

$$\theta \equiv \sin^{-1}\frac{\dot{\phi}}{\sqrt{2\rho_\phi}}, \quad \Omega_\phi \equiv \frac{\rho_\phi}{3H^2 m_p^2}$$

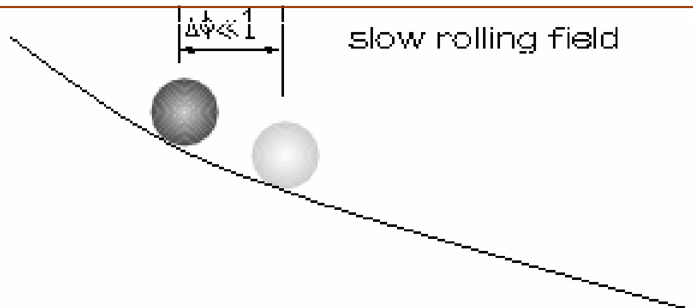
$$\gamma=\lambda^2 \qquad \lambda \equiv -m_p\frac{V'}{V}, \quad \Gamma \equiv \frac{VV''}{V'^2}.$$

slow-to-moderate roll conditions

$$\begin{cases} \frac{1}{2}\dot{\phi}^2 \ll V(\phi), \\ |V'/V| \lesssim O(1) m_p^{-1}, \\ |V''/V| \lesssim O(1) m_p^{-2}. \end{cases} \quad \text{at } 0 < z < 2$$

1+w< 0.3 (for 0<z<2) and $\gamma \sim$ const **give a 2-parameter model:** $\gamma = \lambda^2$ **&** a_{ex}

$$w(a) = -1 + \frac{1}{3}\{(\frac{a_{ex}}{a})^3 + \lambda[\sqrt{1+(\frac{a_{eq}}{a})^3} - (\frac{a_{eq}}{a})^3 \ln((\frac{a}{a_{eq}})^{\frac{3}{2}} + \sqrt{1+(\frac{a}{a_{eq}})^3})]\}^2.$$



$$a_{eq} \equiv (\frac{\Omega_{m0}}{\Omega_{\Lambda 0}})^{\frac{1}{3}} \sim 0.7.$$

Early-Exit Scenario: scaling regime info is lost by Hubble damping, i.e.small $\mathbf{a_{ex}}$

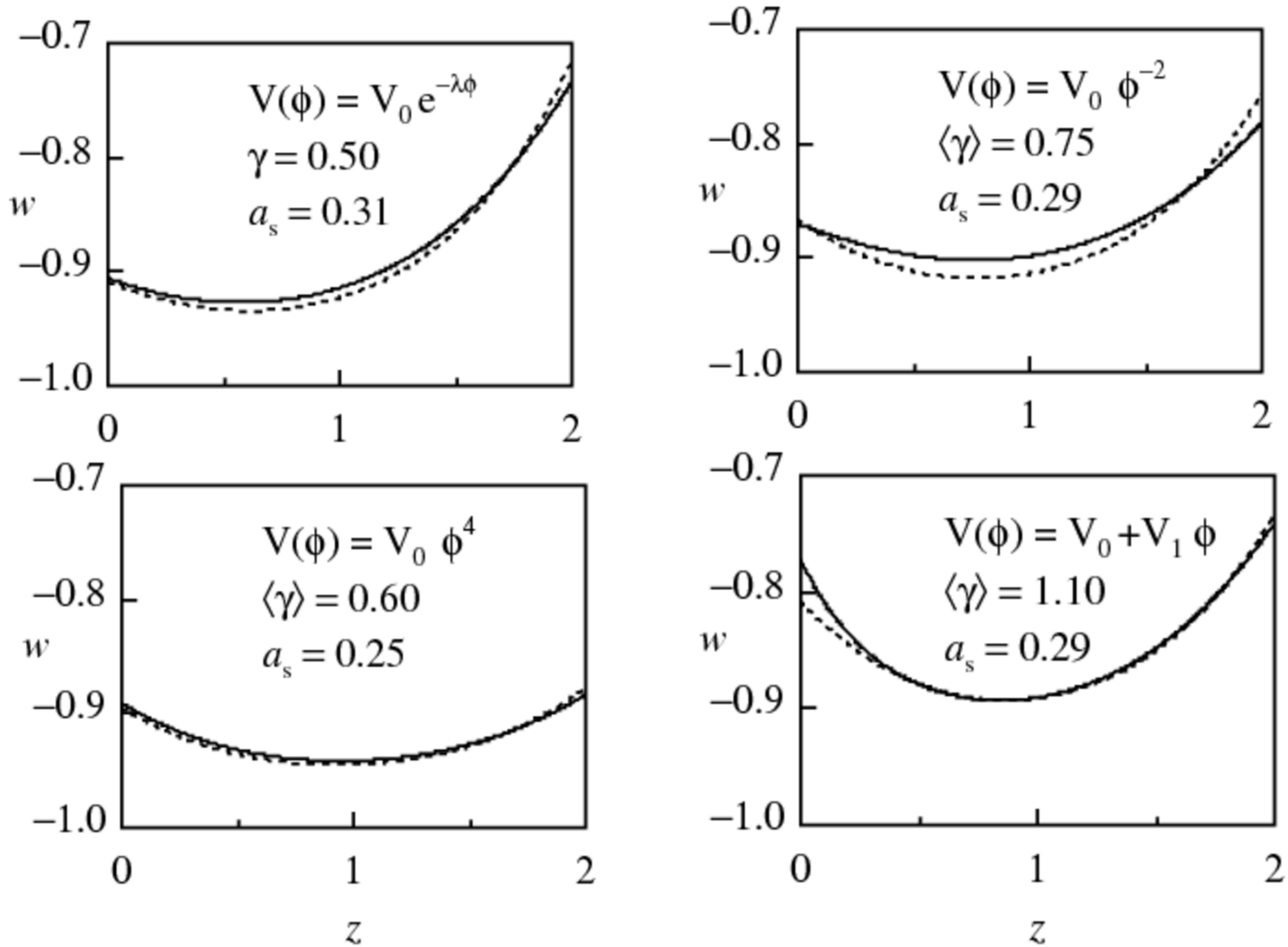
λ varies slowly not because V is exponential-like, but because ϕ is varying slowly.

1+w< 0.2 (for 0<z<10) and $\gamma \sim$ const **give a 1-parameter model:**

$$\boxed{w(a) = -1 + \frac{\lambda^2}{3}\{\sqrt{1+(\frac{a_{eq}}{a})^3} - (\frac{a_{eq}}{a})^3 \ln((\frac{a}{a_{eq}})^{\frac{3}{2}} + \sqrt{1+(\frac{a}{a_{eq}})^3})\}^2}$$

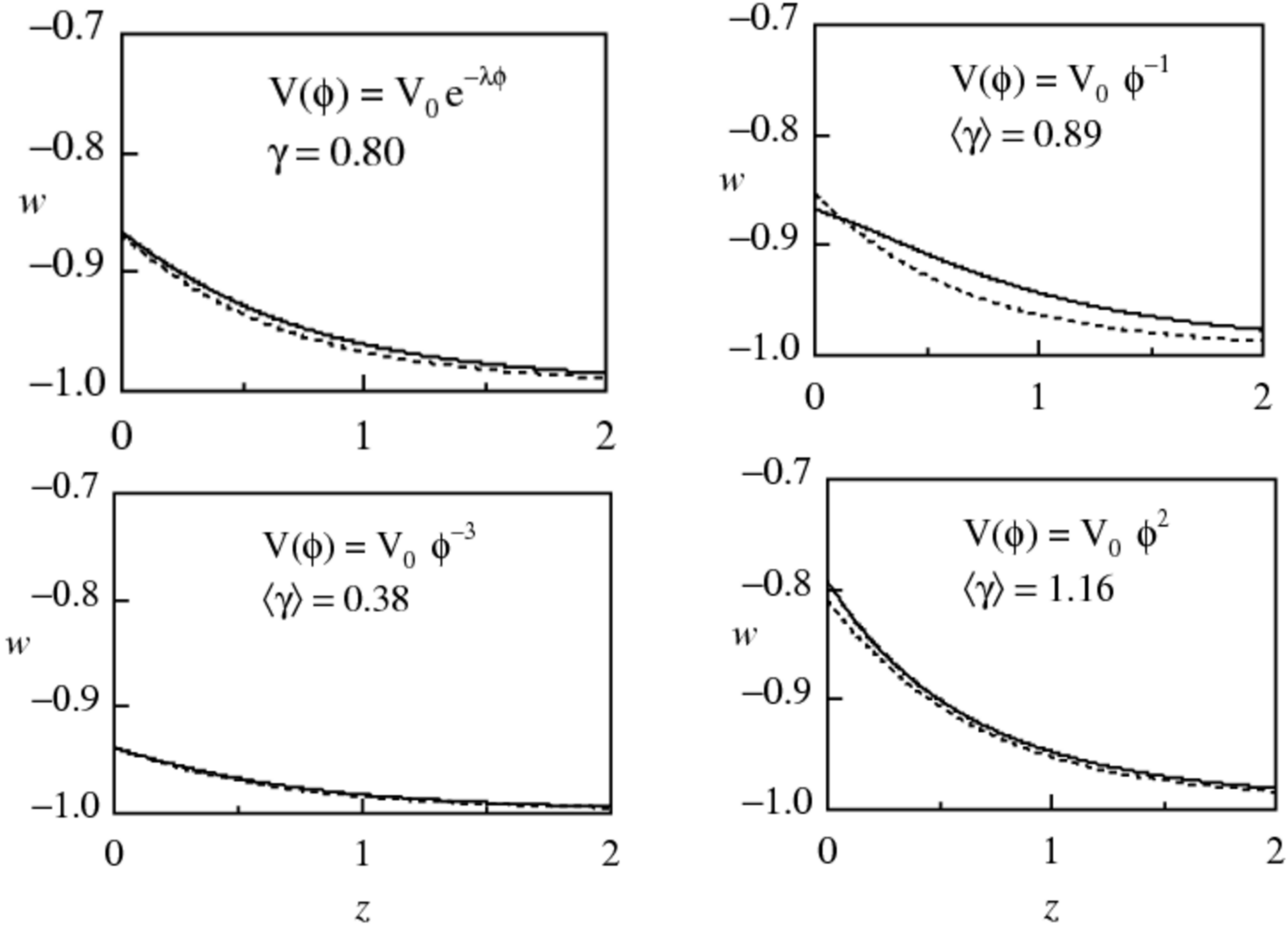
w-trajectories cf. the 2-parameter model

the field exits scaling regime at $a \sim a_{ex}$ **$\gamma = (V'/V)^2$ (a) a-averaged at low z**



w-trajectories cf. the 1-parameter model

ignore a_{ex} $\gamma = (V'/V)^2$ (a) a-averaged at low z



Include a w<-1 phantom field, via a negative kinetic energy term

$\varphi \to i\varphi$ ➔ $\gamma=\lambda^2 < 0$

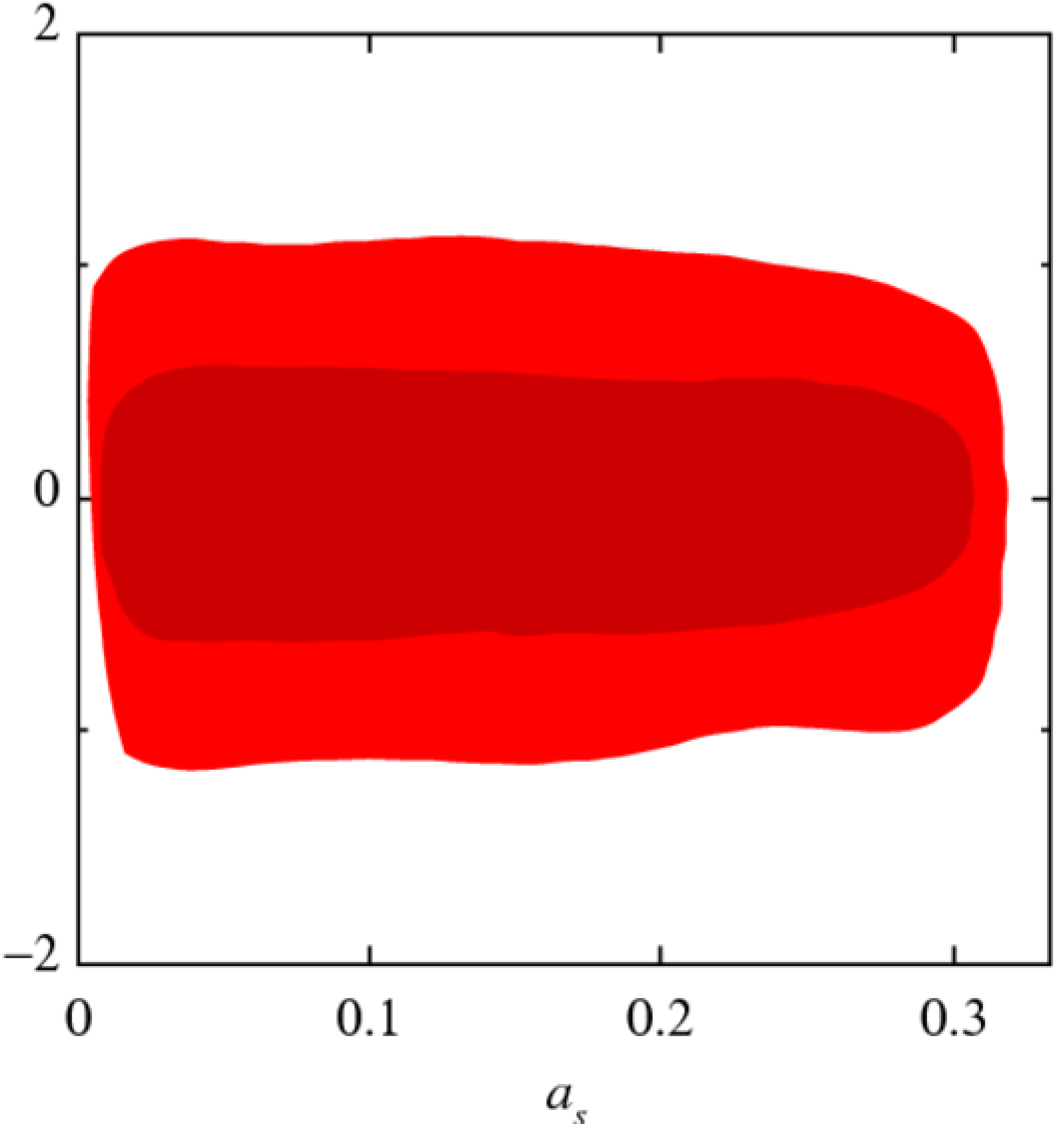
$$w(a) = -1 + \frac{\lambda^2}{3}\left\{\sqrt{1+\left(\frac{a_{eq}}{a}\right)^3} - \left(\frac{a_{eq}}{a}\right)^3 \ln\left(\left(\frac{a}{a_{eq}}\right)^{\frac{3}{2}} + \sqrt{1+\left(\frac{a}{a_{eq}}\right)^3}\right)\right\}^2$$

$\gamma>0$ ➔ quintessence

$\gamma=0$ ➔ cosmological constant

$\gamma<0$ ➔ phantom field

Measuring $\gamma=\lambda^2$ (SNe+CMB+WL+LSS)



$\mathbf{a_{ex}}$

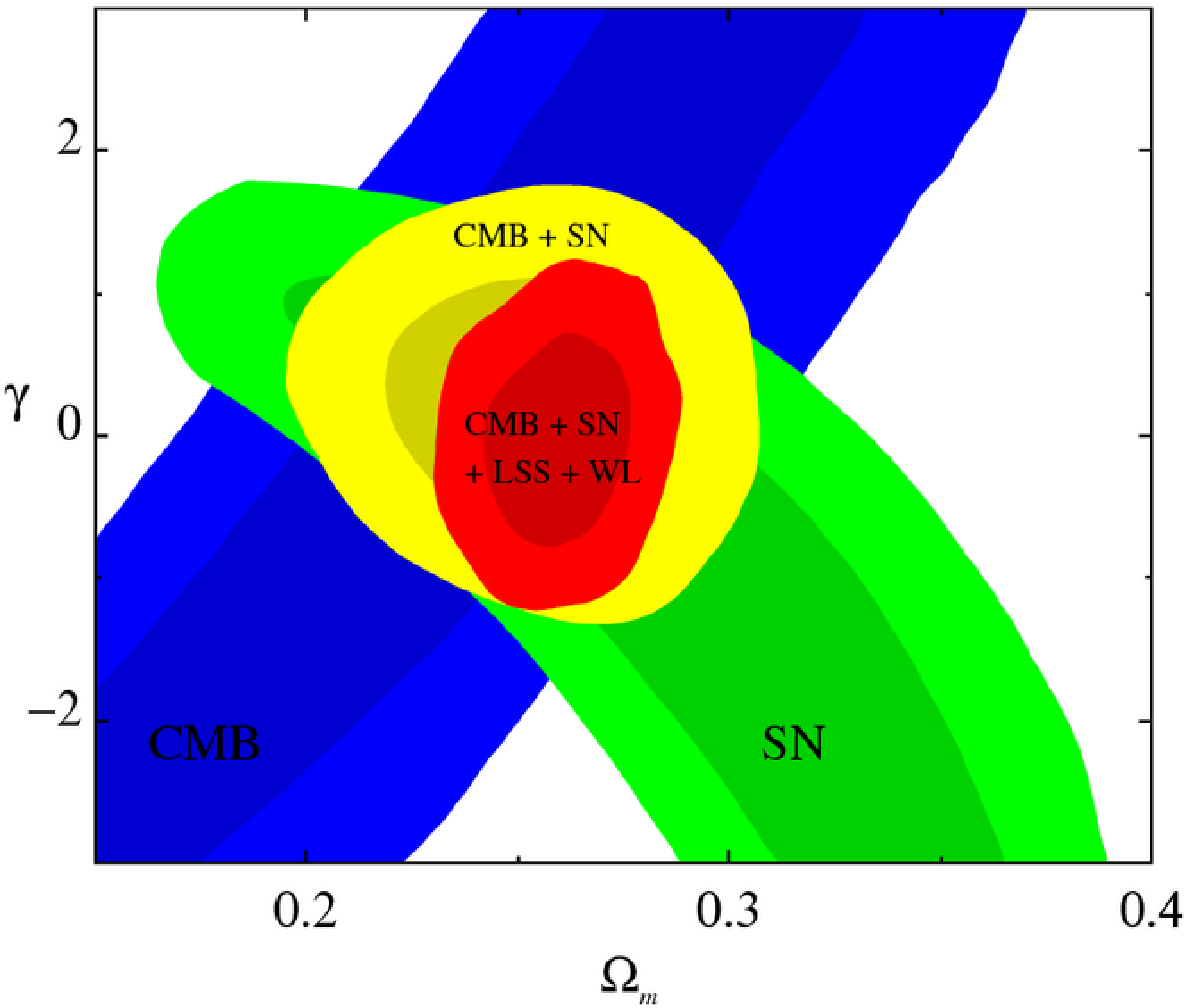
Well determined

γ

undetermined

$\mathbf{a_{ex}}$

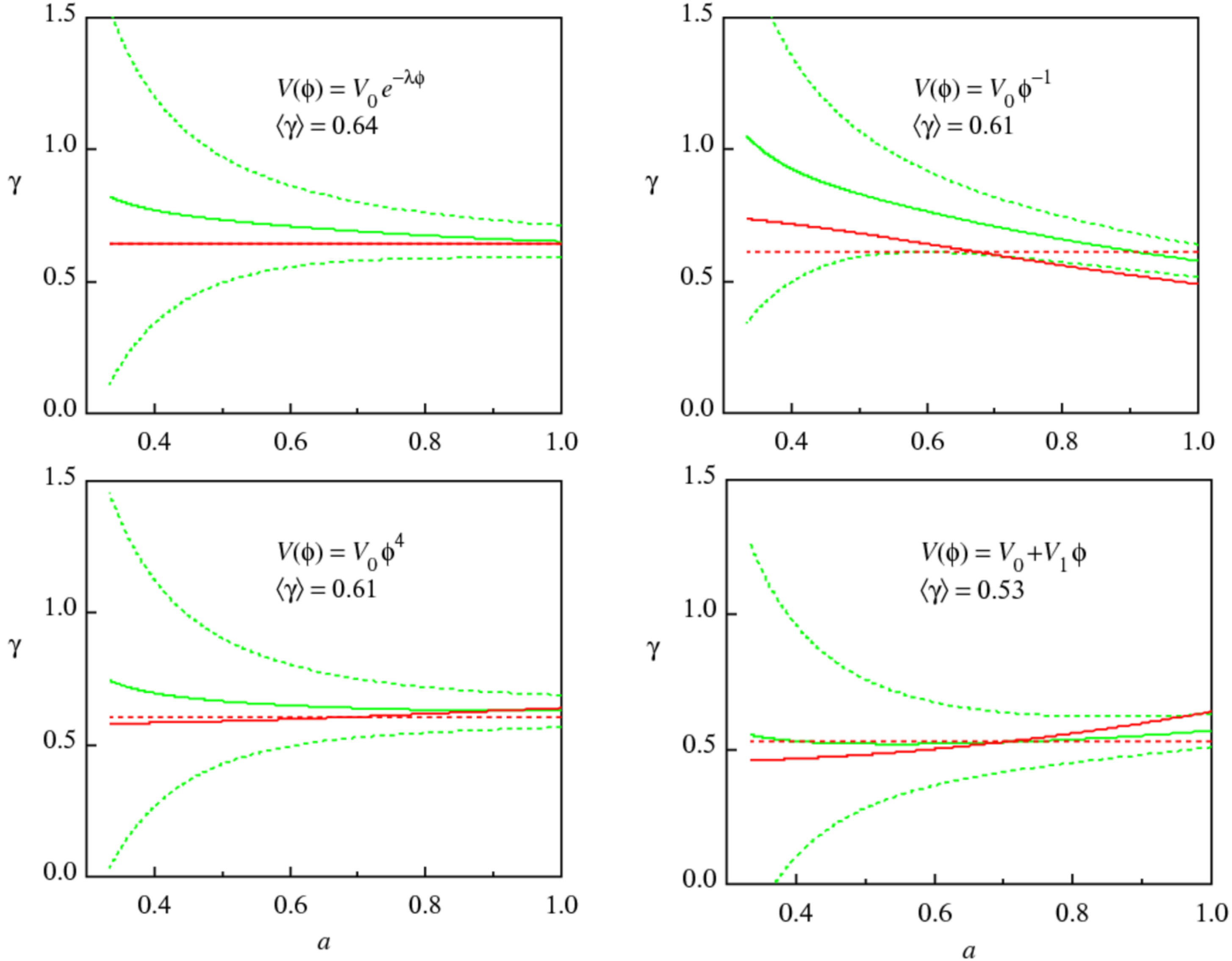
Measuring $\gamma=\lambda^2$ (SNe+CMB+WL+LSS)



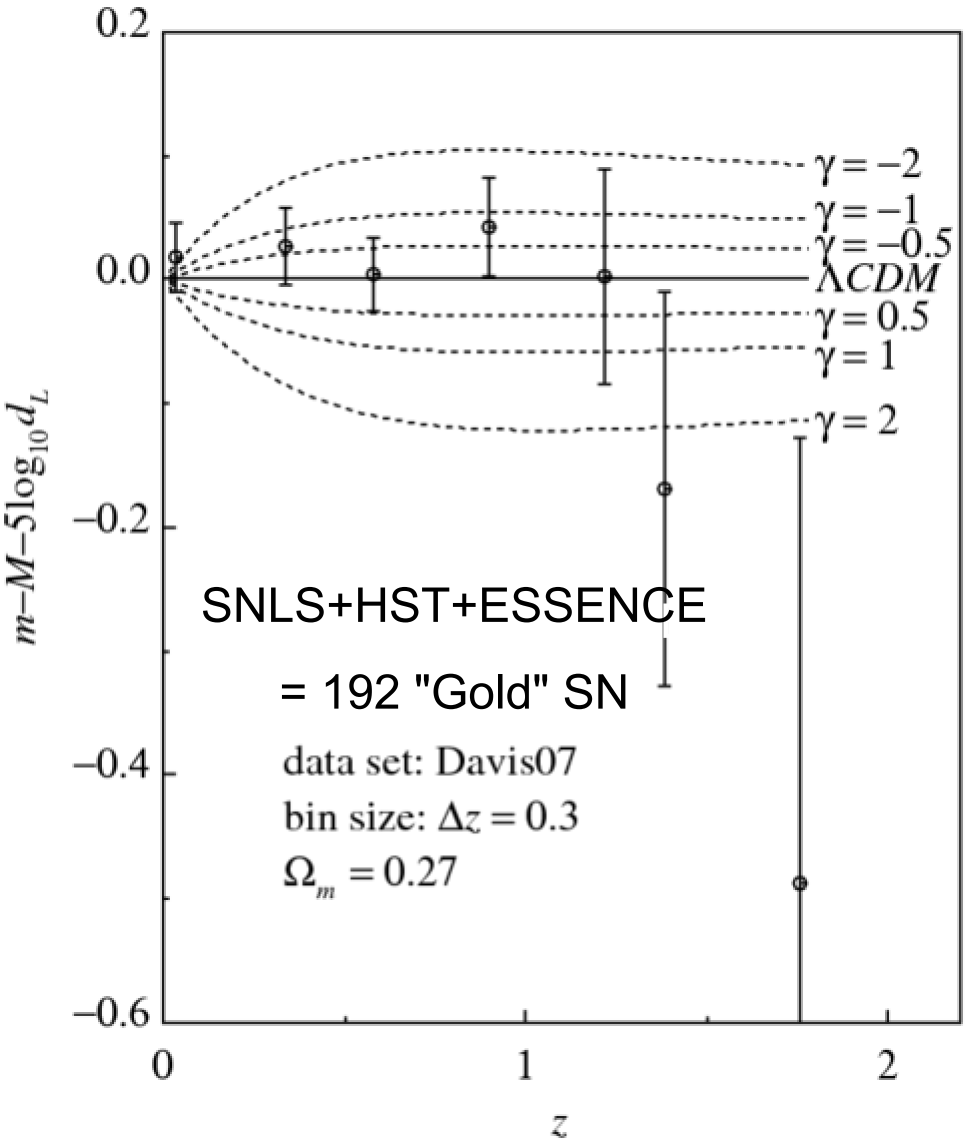
Modified CosmoMC with Weak Lensing and time-varying w models

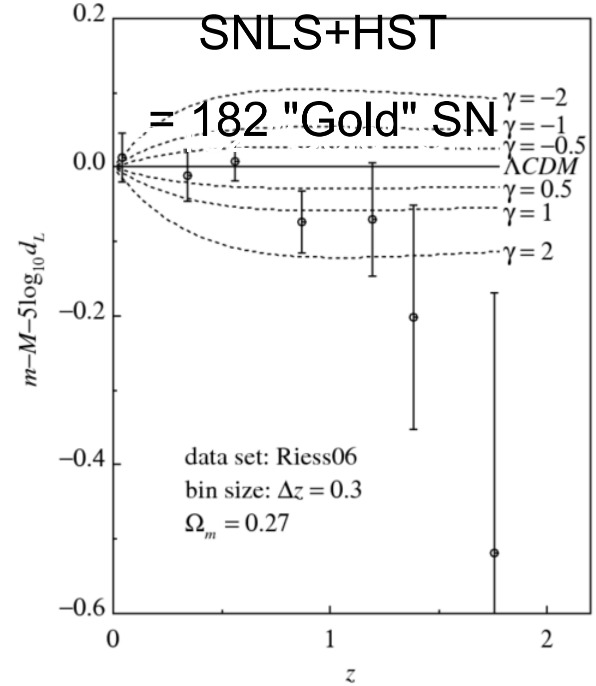
γ-trajectories cf. the 1-parameter model

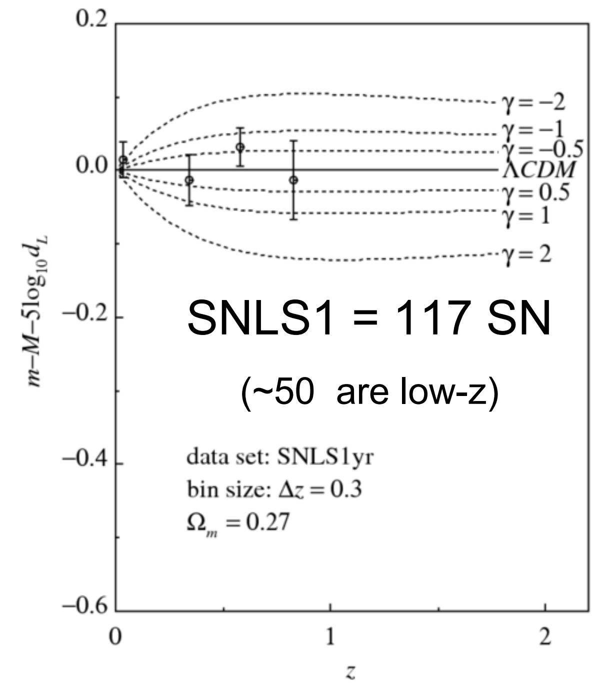
$\gamma=(1+w)(a)/f(a)$ cf. $(V'/V)^2\,(a)$



45 low-z SN + ESSENCE SN + SNLS 1st year SN
+ Riess high-z SN, all fit with MLCS







Inflation now summary

- The data cannot determine more than 2 w-parameters (+ csound?). general higher order Chebyshev expansion in 1+w as for "inflation-then" $\varepsilon=(1+q)$ **is not that useful** – cf. Roger B & co.
- The $w(a)=w_0+w_a(1-a)$ expansion requires baroque potentials
- **For general slow-to-moderate rolling one needs 2 "dynamical parameters" (a_{ex},γ) to describe w to a few %**
  (cf. for a given Q-potential, IC, amp, shape to define a w-trajectory)
- In the early-exit scenario, the information stored in a_{ex} is erased by Hubble friction, w can be described by a single parameter γ. a_{ex} is not determined by the current data
- phantom (γ <0), cosmological constant (γ=0), and quintessence (γ >0) are all allowed with current observations γ **=0.0+-0.5**
- Aside: detailed results depend upon the SN data set used. Best available used here (192 SN), but this summer CFHT SNLS will deliver ~300 SN to add to the ~100 non-CFHTLS and will put all on the same analysis footing – very important.
- Lensing data is important to narrow the range over just CMB and SN

Inflation then summary

the basic 6 parameter model with no GW allowed fits all of the data OK

Usual GW limits come from adding r with a fixed GW spectrum and no consistency criterion (7 params). Adding minimal consistency does not make that much difference (7 params)

r (<.28 95%) limit come from relating high k region of σ_8 to low k region of GW C_L

Uniform priors in $\varepsilon(k) \sim r(k)$: the scalar power downturns ($\varepsilon(k)$ goes up) at low L if there is freedom in the mode expansion to do this. Adds GW to compensate, breaks old r limit. T/S (k) can cross unity. But monotonic prior in ε drives to low energy inflation and low r.

Complexity of trajectories could come out of many-moduli string models. Roulette example: 4-cycle complex Kahler moduli in Type IIB string theory TINY $r \sim 10^{-10}$

a general argument that the normalized inflaton cannot change by more than unity over ~50 e-folds gives $r < 10^{-3}$

Prior probabilities on the inflation trajectories are crucial and cannot be decided at this time. Philosophy: be as wide open and least prejudiced as possible

Even with low energy inflation, the prospects are good with Spider and even Planck to either detect the GW-induced B-mode of polarization or set a powerful upper limit against nearly uniform acceleration. Both have strong Cdn roles.