very early U early to middle to now U **very late U**

inflation *string theory/landscape/higher dimensions* **dark energy**

V_{eff} (ψ_{inf}) ? partial shape reconstruction reconstruct gradient V_{eff} (ψ_{inf}) ?

K_{eff} (ψ_{inf}) ? K_{eff} (ψ_{inf}) ?

trajectory probability

$-d\ln\rho_{tot} / d\ln a$ /2 => $\mathbb{P}_s, \mathbb{P}_t, V_{eff}$ (k), ψ_{inf} (k)

$= \varepsilon(k) = 1+q$, k~Ha

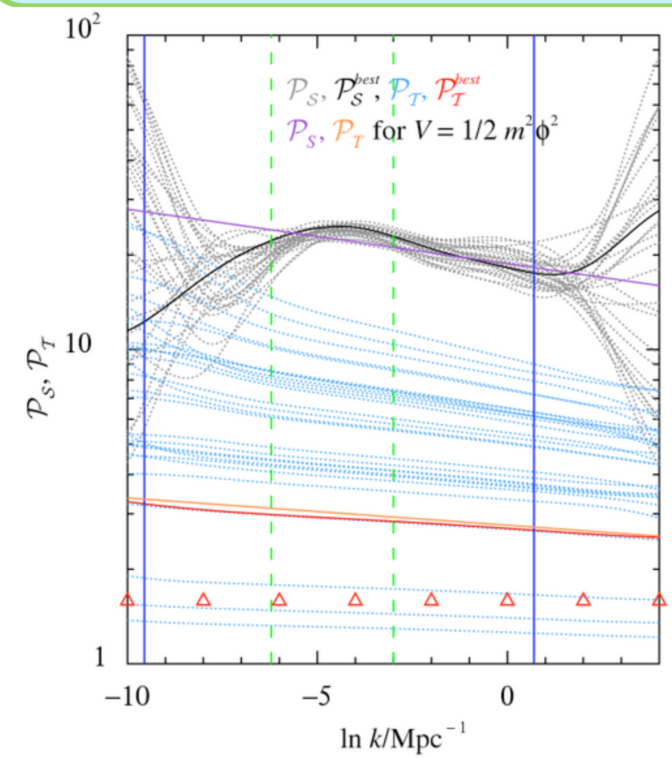
trajectory probability:

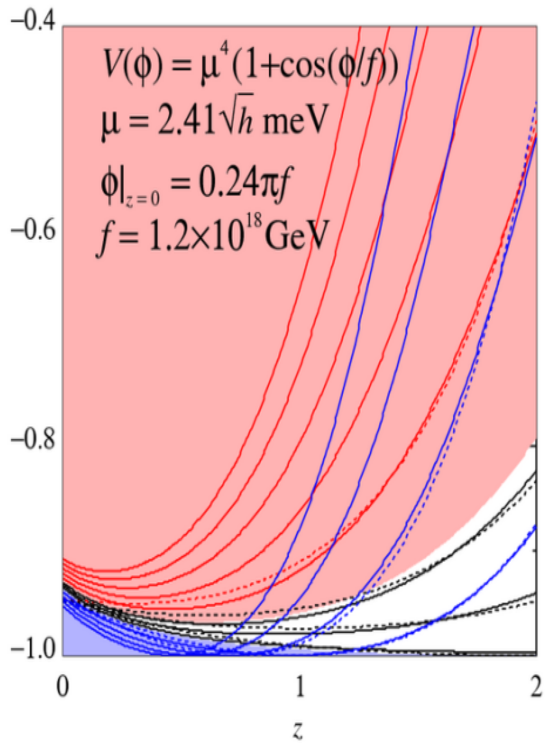
~1 e-fold => blind is bad

=> slow-to-moderate roll

$-d\ln\rho_\phi / d\ln a$ /2

$= \varepsilon_\phi(a) = (1+w)2/3$





$\varepsilon_s = (d\ln V/d\psi)^2/4$

@pivot a_{eq} **yes**

$\zeta_s = \pm 1.001\, d^2\ln V/d\psi^2/4$

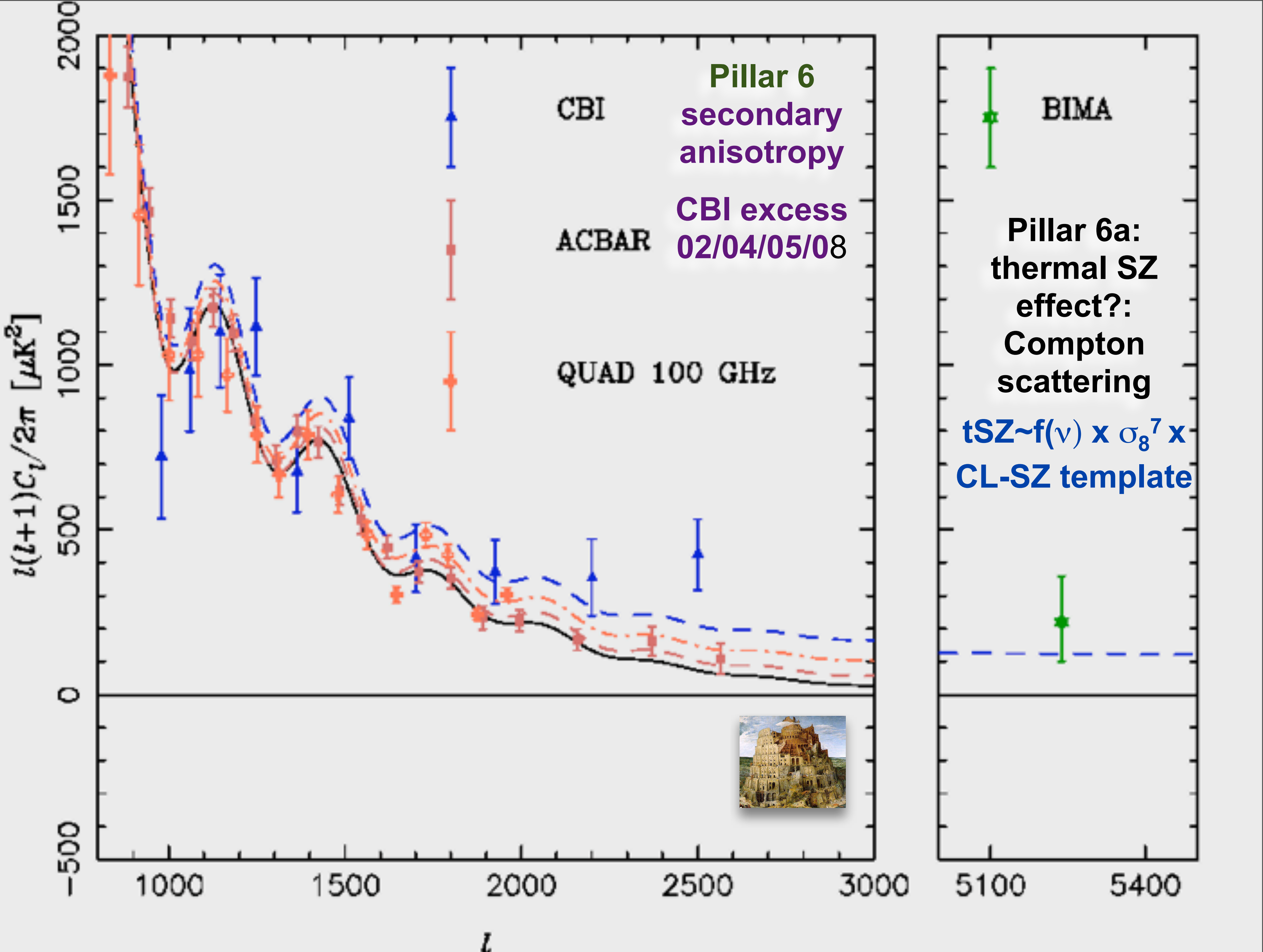
@pivot a_{eq}

$\zeta_s = d\ln\varepsilon_s / d\ln a$ x1/2

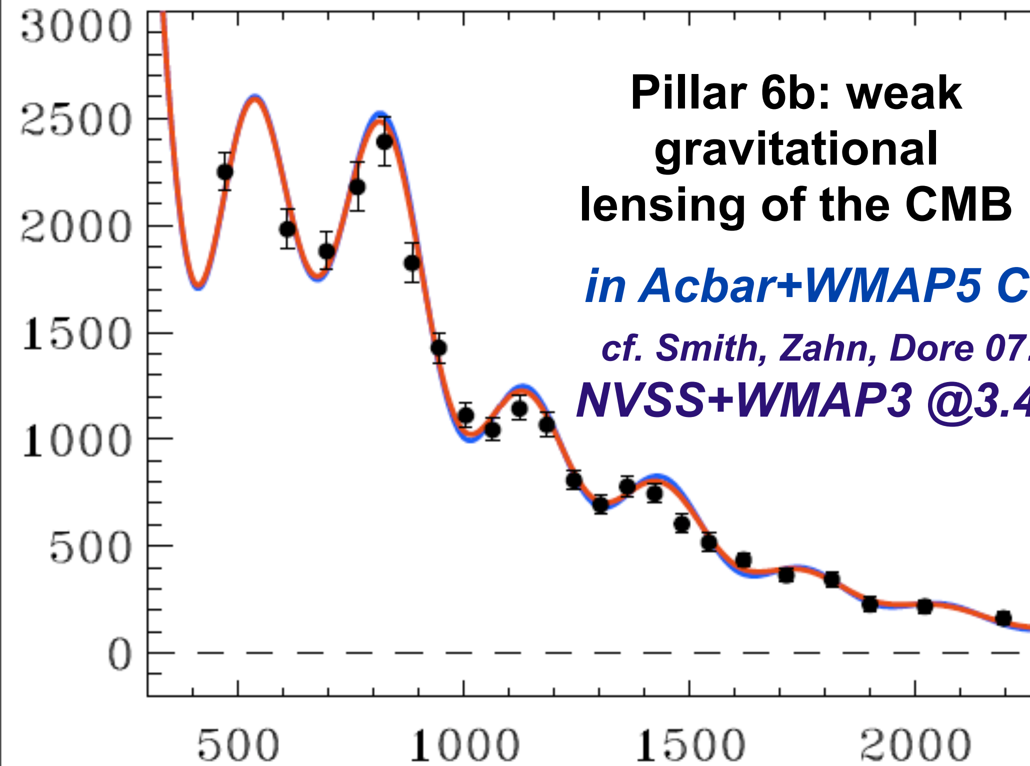
@pivot a_{eq}

Inflation now summary

- the data cannot determine more than 2 w-parameters (+ csound?). general higher order Chebyshev or spline expansion in $1+w$ as for "inflation-then" $\varepsilon=(1+q)$ is not that useful. Parameter eigenmodes show what is probed
- Any $w(a)$ leads to a viable DE model. The $w(a)=w_0+w_a(1-a)$ phenomenology requires baroque potentials
- Philosophy of HBK08: backtrack from now (z=0) all w-trajectories arising from quintessence ($\varepsilon_s >0$) and the phantom equivalent ($\varepsilon_s <0$); use a 3-parameter model $\varepsilon_\phi=(1+w(a))3/2=\varepsilon_s f(a/a_{\Lambda eq};a_s/a_{\Lambda eq};\zeta_s)$ to well-approximate even rather baroque w-trajectories, as well as thawing & freezing trajectories.
- We ignore constraints on Q-density from photon-decoupling and BBN because further trajectory extrapolation is needed. Can include via a prior on Ω_Q (a) at z_dec and z_bbn.
- For general slow-to-moderate rolling 2 "dynamical parameters" (a_s, ε_s) & Ω_Q describe w to a few %. In early-scaling-exit, the information stored in a_s is erased by Hubble drag over the observable range & w can be described by a single parameter ε_s. for baroque w-trajectories, add a 3rd param ζ_s ($d\ln\varepsilon_s$ /dlna/ 2) - not-determined now & then. freeze-out w at high z, 4th param
- prior-dependence e.g. sqrt(ε_s) $-0.00^{+0.09}_{-0.13}$, a_s near 0, $0.00^{+0.20+0.42}$ $\varepsilon_s > 0$ since ε_ϕ <0 of phantom energy, negative kinetic energy is baroque
- Apr08 observations well-centered around a cosmological constant ε_s=-0.03+-0.28 a_s < 0.36 (z_s >2.0) cf. $\varepsilon_{\phi 0}$ = -0.00 +/- 0.09 if constant, $\varepsilon_{\phi 0}$ = -0.015 +/- 0.30 if a-linear model
- in Planck1yr-CMB+JDEM-SN+DUNE-WL future ε_s to +-0.07, a_s to <0.21 (z_s >3.7)
- cannot reconstruct the quintessence potential, just the slope ε_s & hubble drag info
- late-inflaton field is < Planck mass, but not by a lot
- DE may couple to matter, 5th force constraints are strong, maybe best hope in determining more about DE (chameleon example of dilaton a la Khoury and Weltman 04)



Pillar 6
secondary anisotropy
CBI excess 02/04/05/08
Pillar 6a: thermal SZ effect?: Compton scattering
tSZ~f(ν) x σ8^7 x CL-SZ template
CBI
ACBAR
QUAD 100 GHz
BIMA
l(l+1)C_l/2π [μK²]
l
2000
1500
1000
500
0
−500
1000
1500
2000
2500
3000
5100
5400

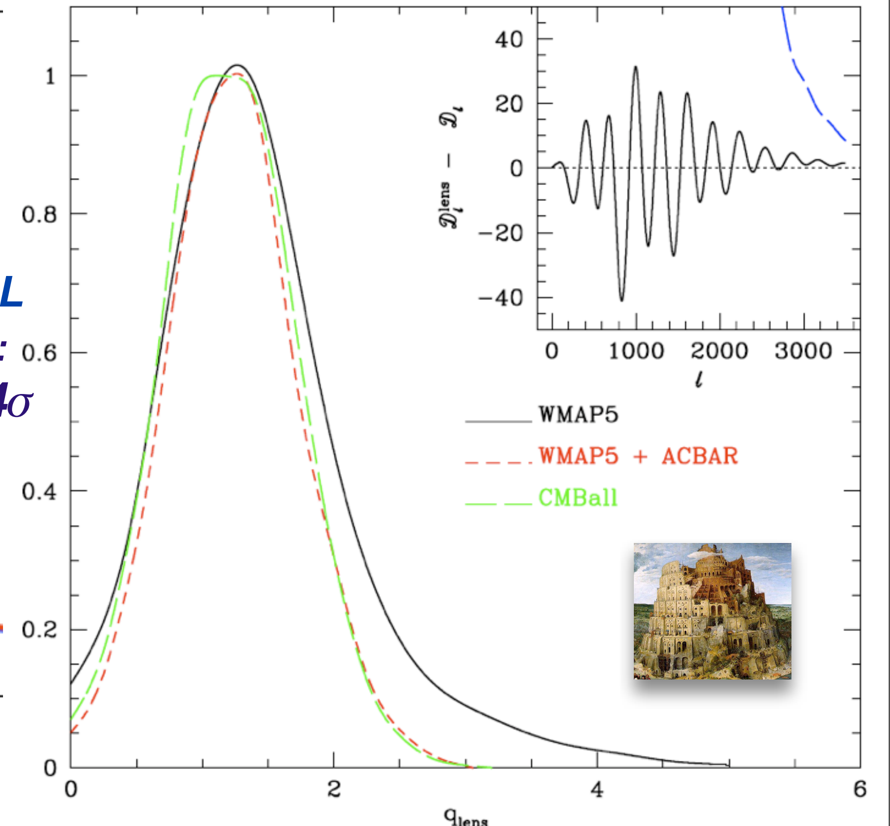


Pillar 6b: weak gravitational lensing of the CMB

in Acbar+WMAP5 C_L

cf. Smith, Zahn, Dore 07:

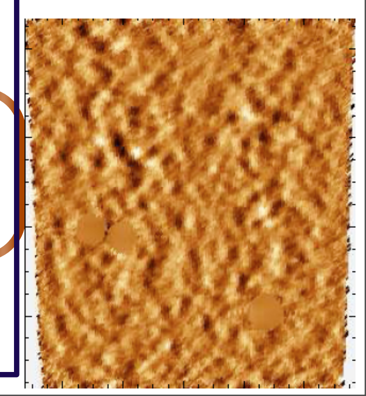
NVSS+WMAP3 @3.4σ



$$C_\ell^{lens} = C_\ell^{no-lens} + q_{lens} \Delta C_\ell^{lens}$$

$$\Delta \ln \mathcal{E} = \ln[P(\text{lens}|data, theory)/P(\text{no}-\text{lens}|data, theory)]$$

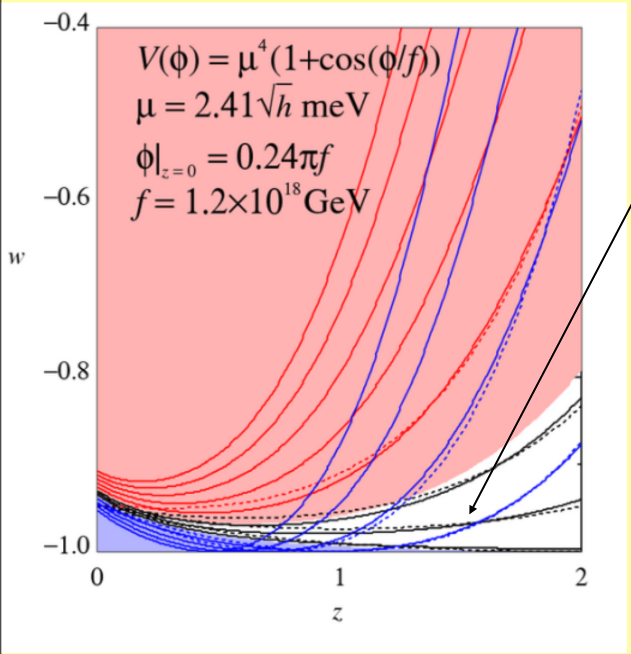
		Bayesian evidence
wmap5	$q_{lens} = 1.34^{+0.27(+1.51)}_{-0.26(-0.85)}$	$\Delta \ln \mathcal{E} = 2.04$
wmap5+ acbar	$q_{lens} = 1.23^{+0.21(+0.83)}_{-0.23(-0.76)}$	$\Delta \ln \mathcal{E} = 2.89$
CMBall	$q_{lens} = 1.21^{+0.24(+0.82)}_{-0.24(-0.76)}$	$\Delta \ln \mathcal{E} = 2.63$



Late-Inflaton $\varepsilon_\phi(a) = \varepsilon_s f(a/a_{\Lambda eq}; a_s/a_{\Lambda eq}; \zeta_s)$

3-param formula accurately fits slow-to-moderate roll & even wild rising baroque late-inflaton trajectories, as well as thawing & freezing trajectories. but not oscillating DE

Cosmic Probes Now CFHTLS SN(Union~300),WL,CMB,BAO,LSS,Lyα



slow-to-moderate roll OK

wild rise & roll up/down OK

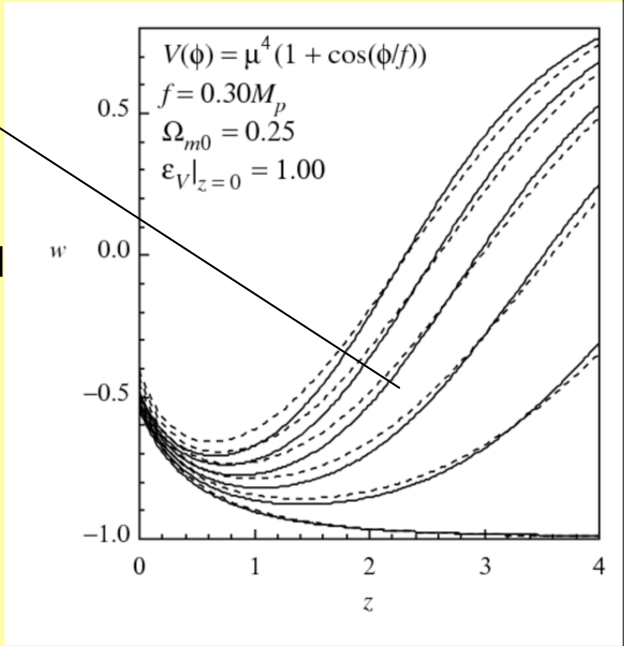
$\varepsilon_v = (d\ln V/d\psi)^2/4$ @pivot a_{eq}

$\varepsilon_s = -0.03 \pm 0.25$ now

$a_s < 0.36$ ($z_s > 2.3$) now

$\zeta_s = d\ln\varepsilon_s / d\ln a$ x1/2 @pivot a_{eq}

ill-determined now



ε_s to ± 0.07 then

Planck1+JDEM SN+DUNE WL,

weak a_s <0.21 then, (z_s >3.7)

3rd param ζ_s ill-determined then

cannot reconstruct the quintessence potential, just the slope ε_s & hubble drag info

(late-inflaton field < Planck mass, but sometimes not by a lot)

INFLATION NOW

WHAT IS ALLOWED?

radically variable braking in acceleration component

$$\varepsilon(k) = (1+q)(a) = -d\,\ln H / d\,\ln a$$

Blind trajectory analysis cf. data, then & now

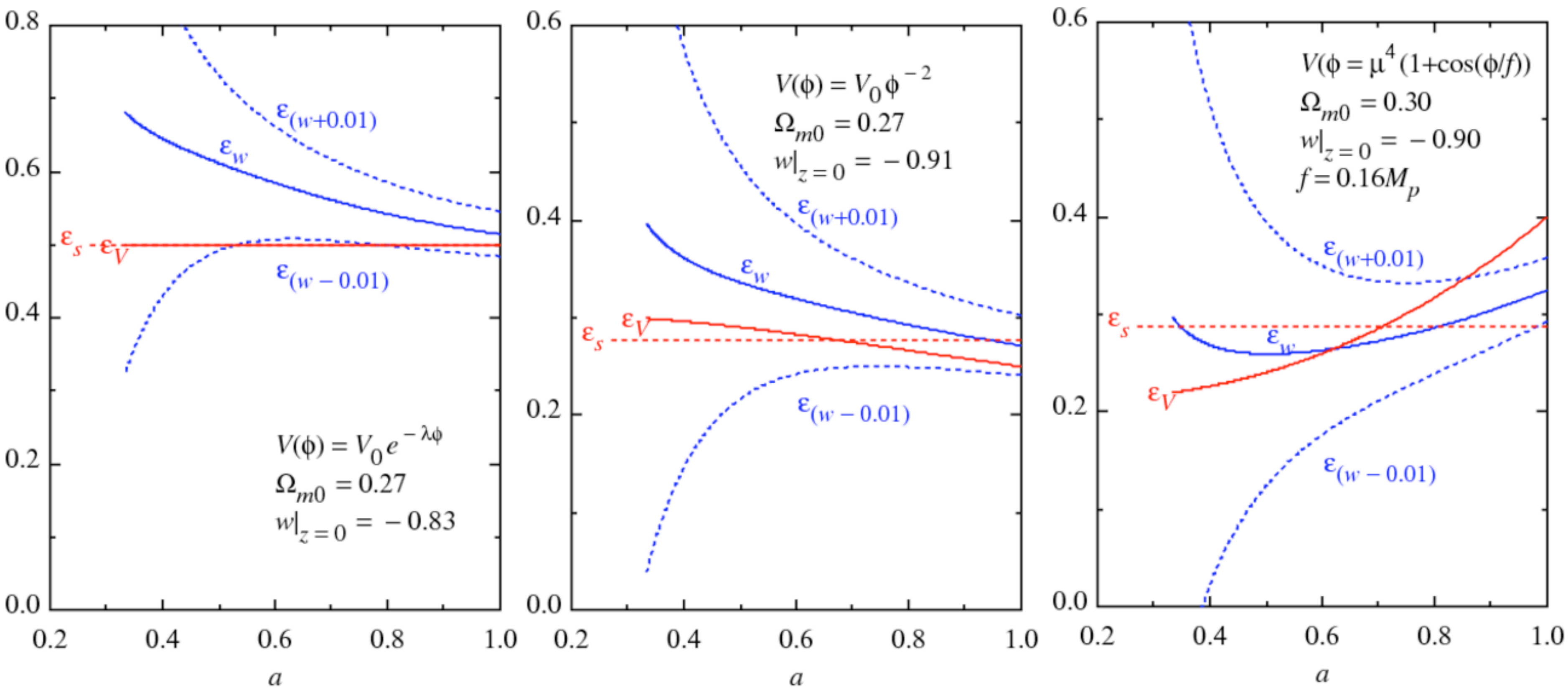
expand $\varepsilon(k)$ in localized mode functions e.g. Chebyshev/B-spline coefficients ε_b

the measures on ε_b matter - choice for “theory prior” = informed priors?

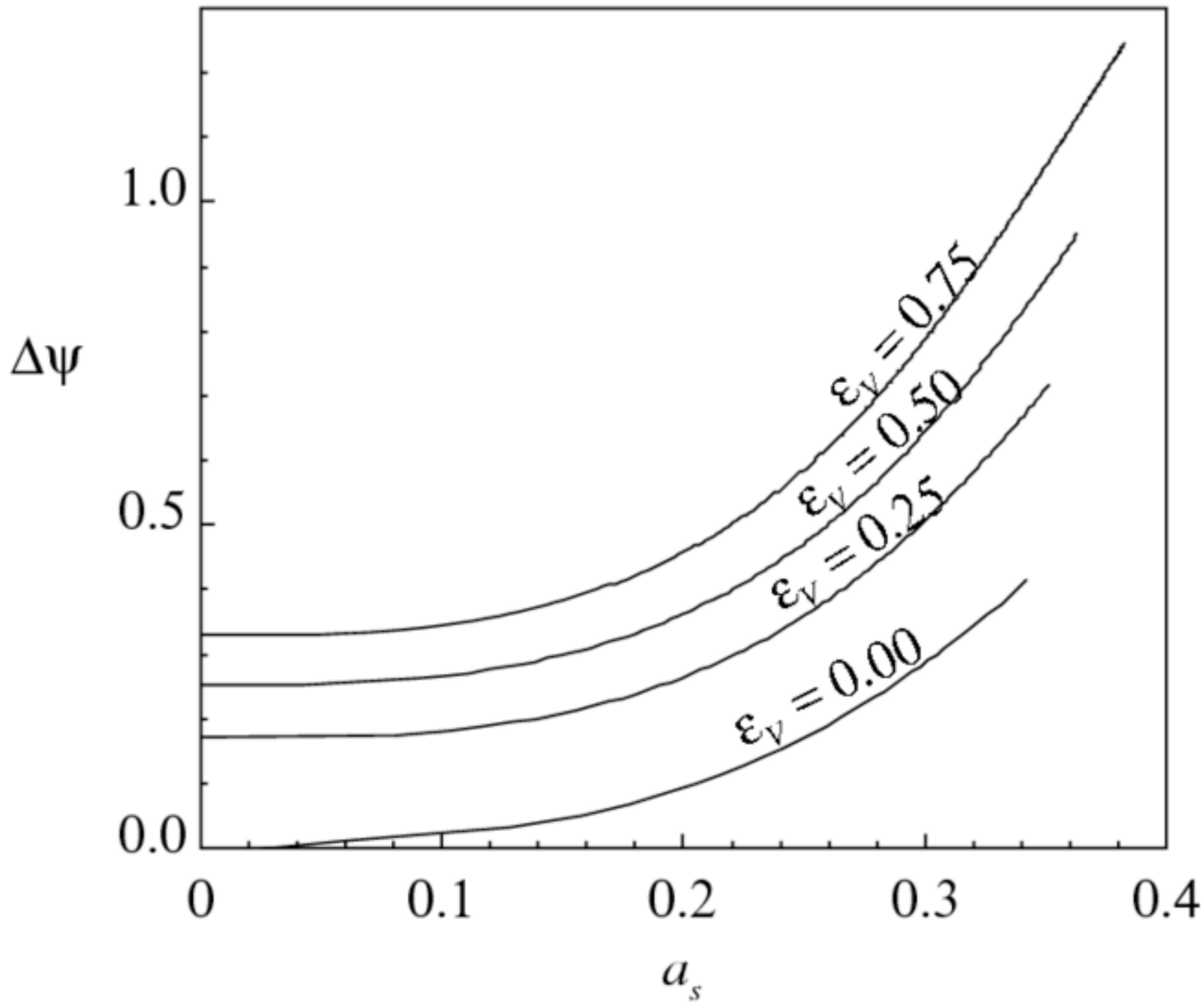
ε_V trajectories are slowly varying: why the fits are good

Dynamical $\varepsilon_w = \varepsilon_\phi\, \varepsilon_s / \varepsilon_{\phi\text{-approx}}$ **cf. shape $\varepsilon_V = (V'/V)^2\,(a)\,/(16\pi G)$**

& ε_s is ε_v uniformly averaged over 0<z<2 in a



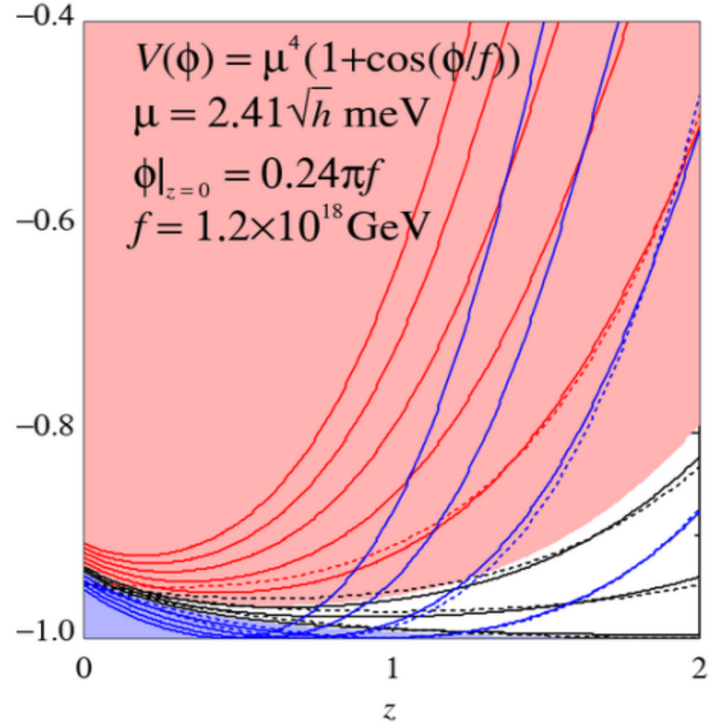
the quintessence field is below the reduced Planck mass



INFLATION NOW

PROBES NOW

- Cosmological Constant (w=-1)
- Quintessence ($-1 \le w \le 1$)
- Phantom field ($w \le -1$)
- Tachyon fields ($-1 \le w \le 0$)
- K-essence (no prior on w)



trajectory probability: ~1 e-fold => blind is bad => slow-to-moderate roll ++

$-d\ln\rho_\phi / d\ln a /2$

$= \varepsilon_\phi(a) = (1+w)2/3$

$= \varepsilon_s f(a/a_{\Lambda eq}; a_s/a_{\Lambda eq}; \zeta_s)$

$\varepsilon_s = (d\ln V/d\psi)^2/4$ @pivot a_{eq}

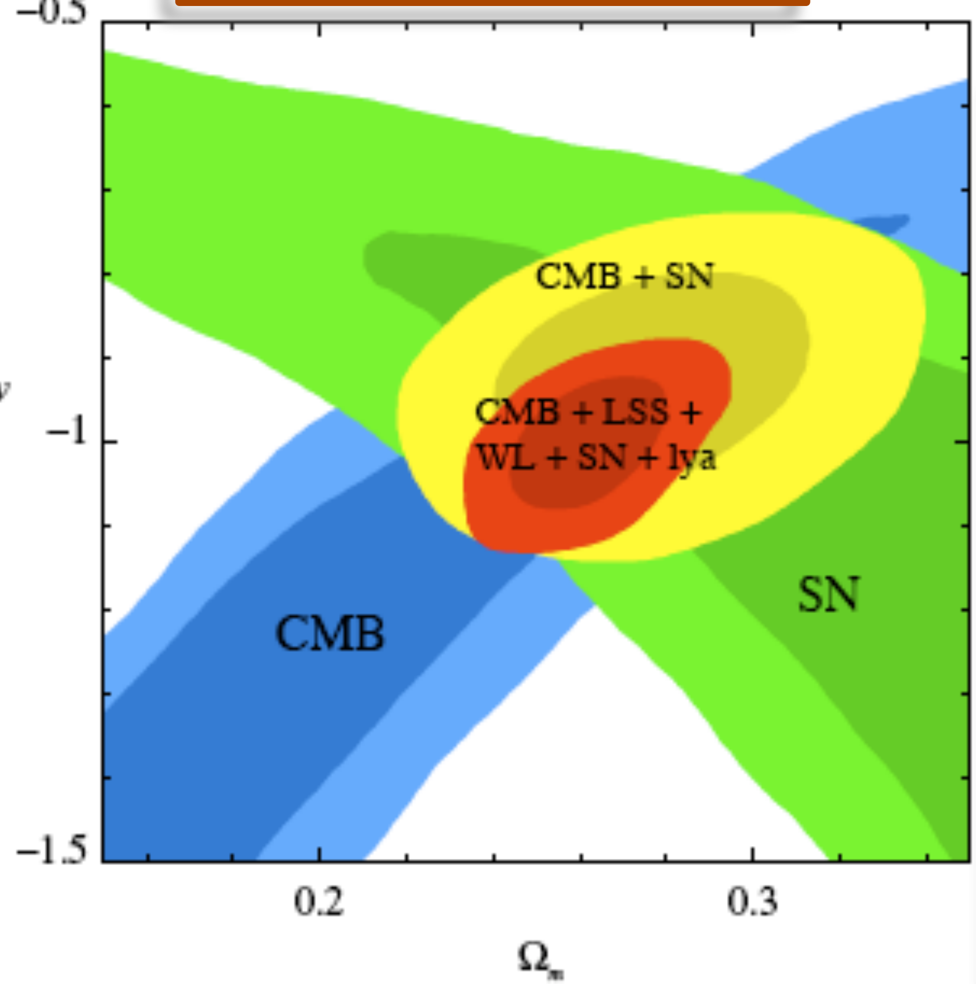
$\zeta_s = +-1.001 d^2\ln V/d\psi^2 /4$ @pivot a_{eq}

$\zeta_s = d\ln\varepsilon_s / d\ln a$ x1/2 @pivot a_{eq}

INFLATION NOW　　　*PROBES NOW*

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

$1+\mathbf{w_0} = -0.0 \pm 0.06$



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

$1+\mathbf{w_0} = -0.01 \pm 0.19$

$\mathbf{w_a} = 0.0 +0.6-0.8$

piecewise parameterization

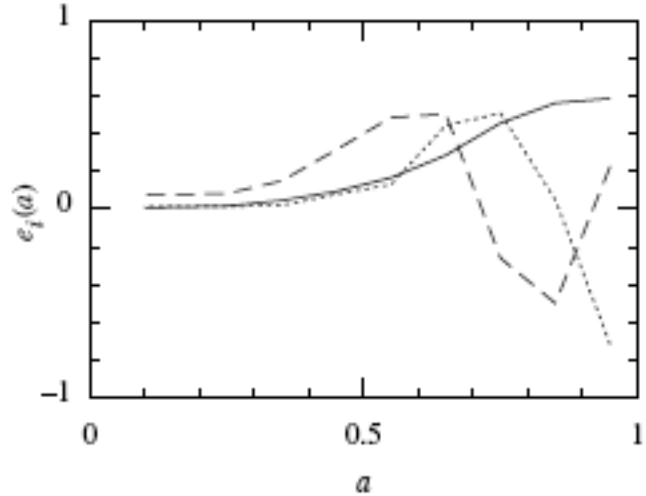
4,9,40 modes in redshift

9 & 40 into Parameter eigenmodes

data cannot determine >2 EOS parameters

DETF Albrecht etal06, Crittenden etal06, hbk08

σ_1**=0.13**　σ_2**=0.33**　σ_3**=0.58**



. $\varepsilon_{\phi 0}$ **= 0.0 +/- 0.09 if constant,** $\varepsilon_{\phi 0}$ **= -0.015 +/- 0.3 if a-linear model**

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique

Dick Bond

25 years cifar

Inflation Then $\varepsilon(k)$ ~r/16

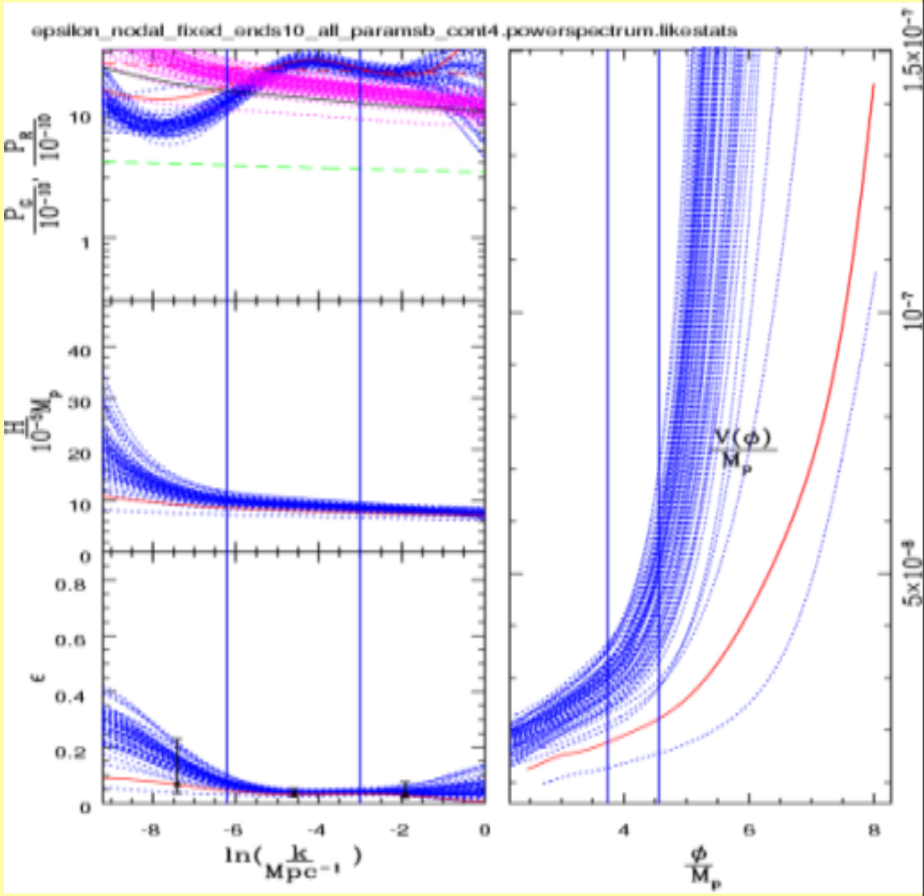
= mode expansion in lnHa ~ lnk

be blind: all $\varepsilon < 1$ *trajectories* give *allowed* potential & kinetic energies

~10 good e-folds k~10^{-4}Mpc^{-1} to ~ 1 Mpc^{-1}

~ 10+ parameters? H(ϕ), V(ϕ)

Bond, Contaldi, Huang, Kofman, Vaudrevange 08



Inflation Now *all* $\varepsilon_\phi < 1$ *trajectories* give *allowed* potential & kinetic energies

but... do not be blind:… ~1 good e-fold. only ~2params

get $\varepsilon_s = (d\ln V/d\psi)^2/4$ @ pivot pt

Huang, Bond & Kofman 08