

2419-18

**Workshop on Large Scale Structure**

*30 July - 2 August, 2012*

"TBA"

B. Bassett

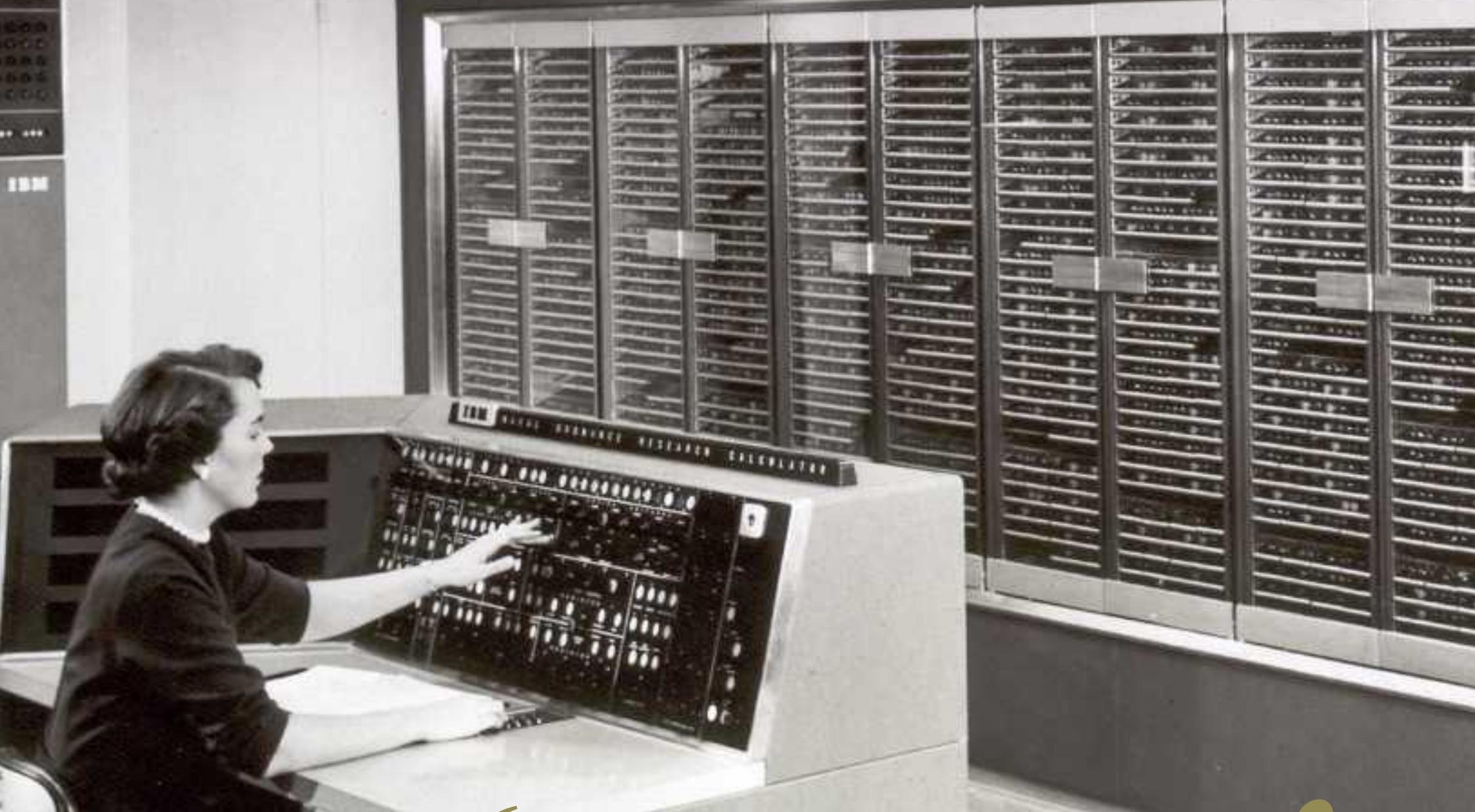
*AIMS, SAAO & UCT*



Bruce Bassett

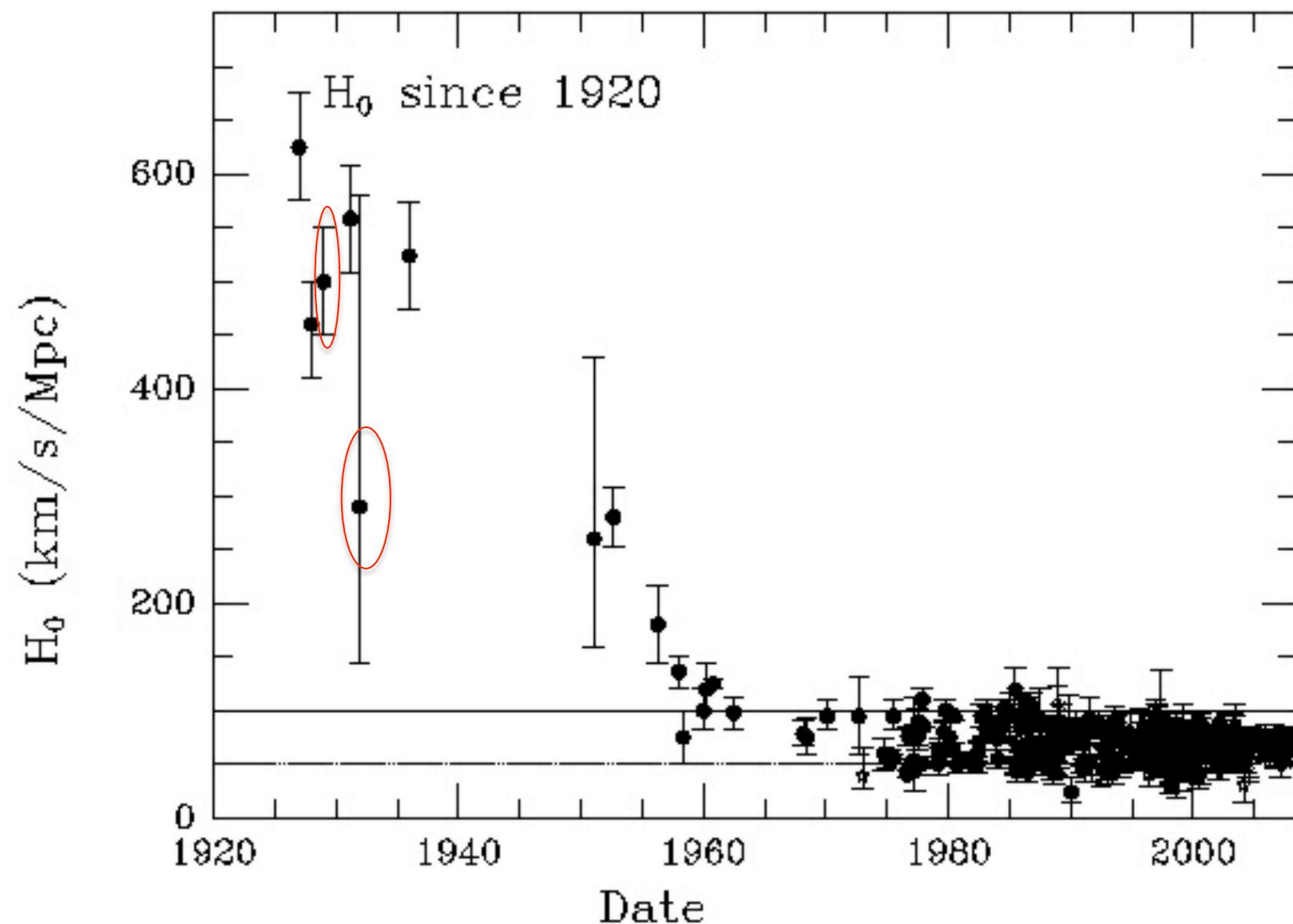
**TBA**

AIMS, SAAO & UCT



I think there is a world market for maybe five computers

– Attributed to Thomas Watson, CEO IBM



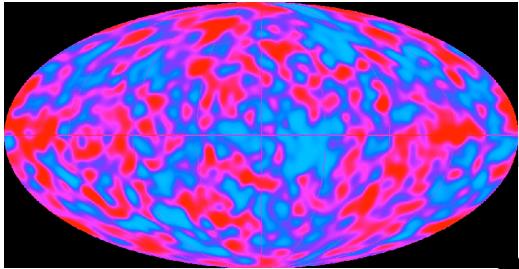
J. Huchra

# Pressures on the cosmological ecosystem driving its evolution:

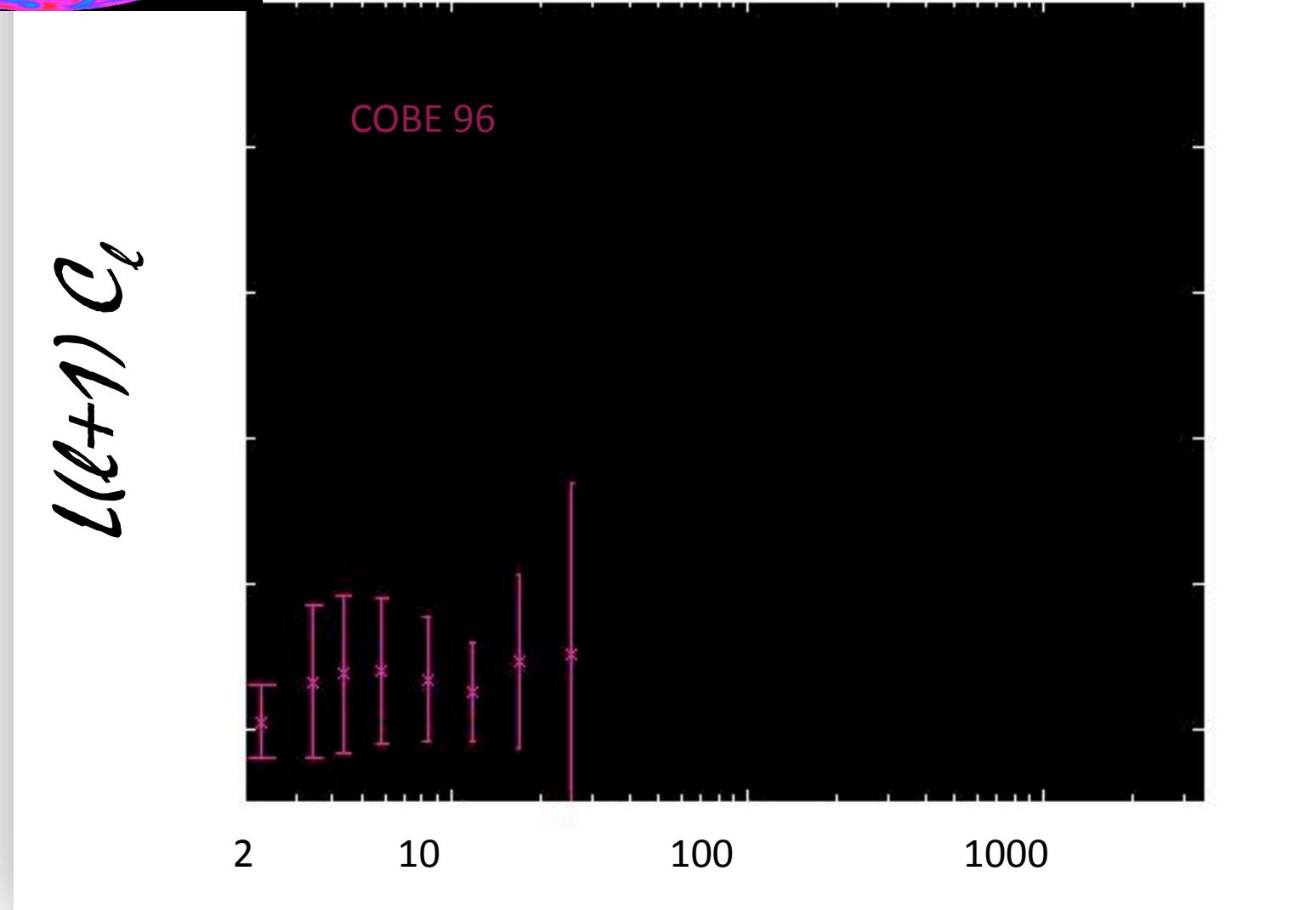
- Wonderful data and computational advances – we can measure, predict and control much more
- Occam's Razor
- New Mysteries, e.g. DM and DE
- The desire to do things properly
- Falsification and the scientific method (the difference between theorems and evidence, criminal vs civil cosmology; e.g. CP)
- The need to control systematics and the difficulties in doing this model-independently (e.g. nonlinear BAO)
- The pressure to publish, to get citations, to get funding...  
“The trouble ain't that there is too many fools, but that the lightning ain't distributed right.” – Mark Twain
- Reductionism and its limitations in cosmology (we split small scale from large scale, late from early, classical from quantum, clusters from voids etc...)



"IF YOU WISH TO  
MAKE AN APPLE  
PIE FROM SCRATCH,  
YOU MUST FIRST  
INVENT THE UNIVERSE."  
CARL SAGAN

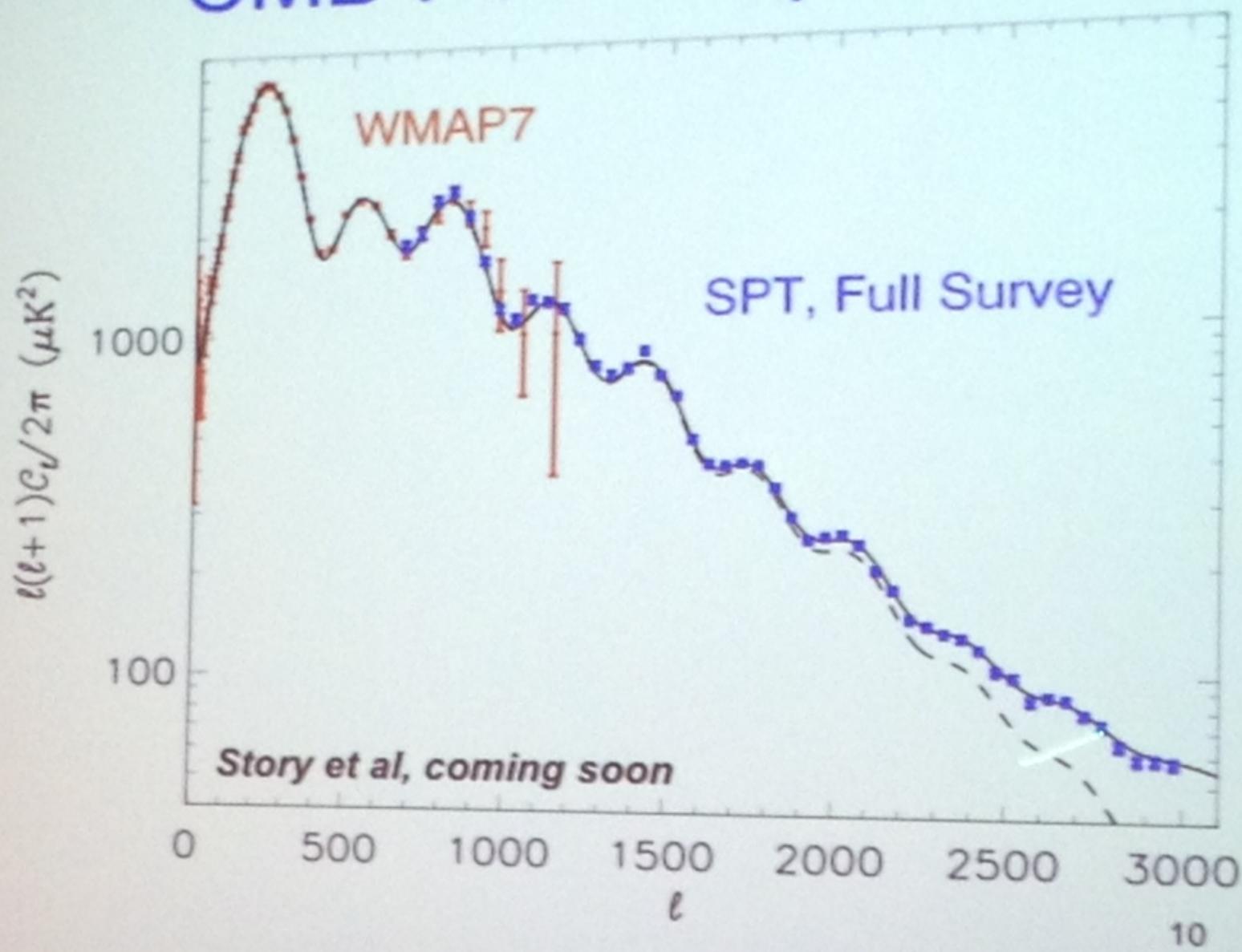


# THE CMB



$\ell$

# CMB Power Spectrum



“Liberated” from Gil Holder’s talk yesterday

# Dangers

‘ It ain’t the things you don’t know, it’s the  
things you know that just ain’t so ’

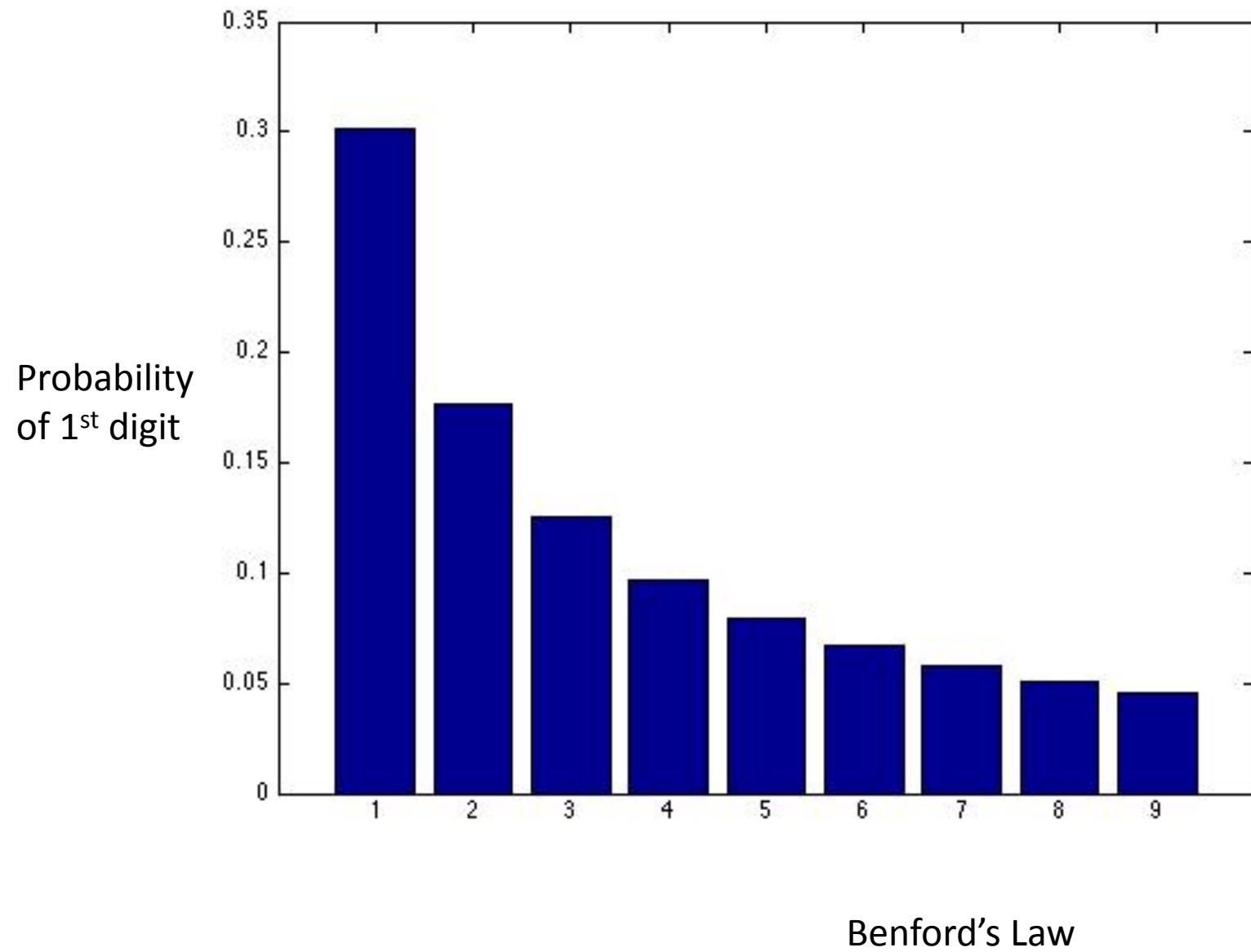
# Which list is more likely to be fraudulent?

A

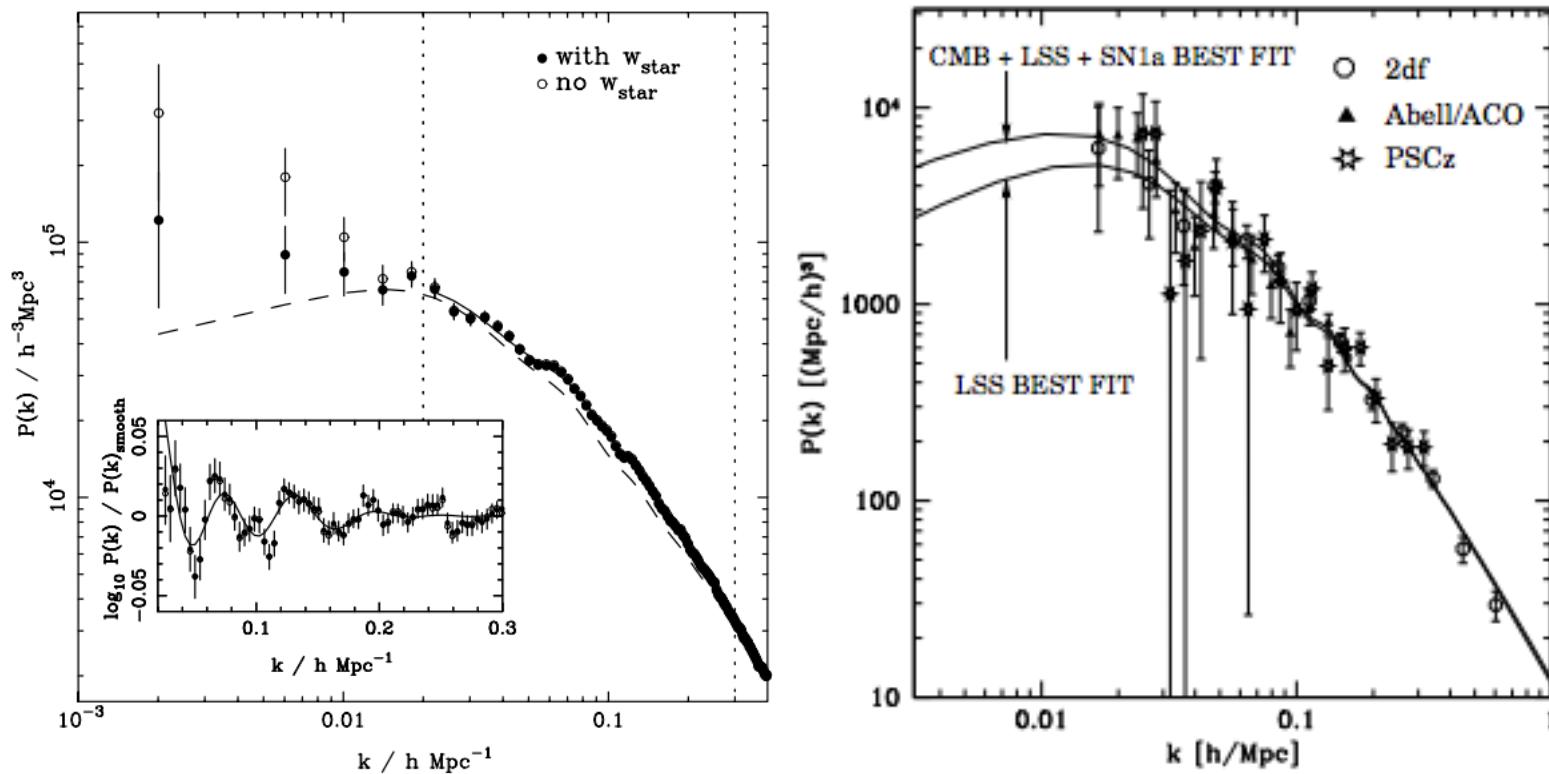
24  
31  
13  
18  
20  
66  
90  
25  
16  
11  
15

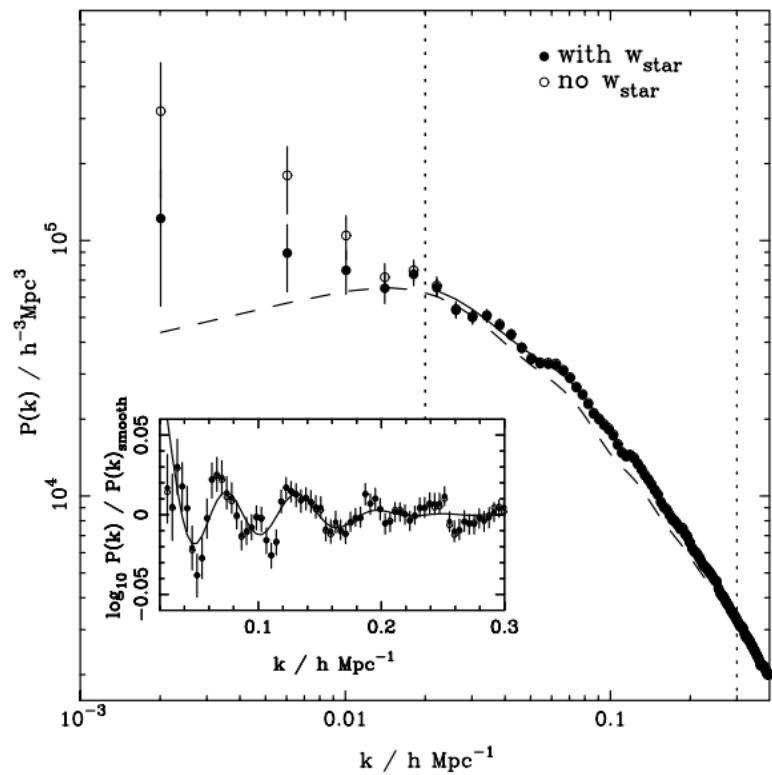
B

14  
33  
87  
91  
82  
57  
24  
46  
60  
74  
94

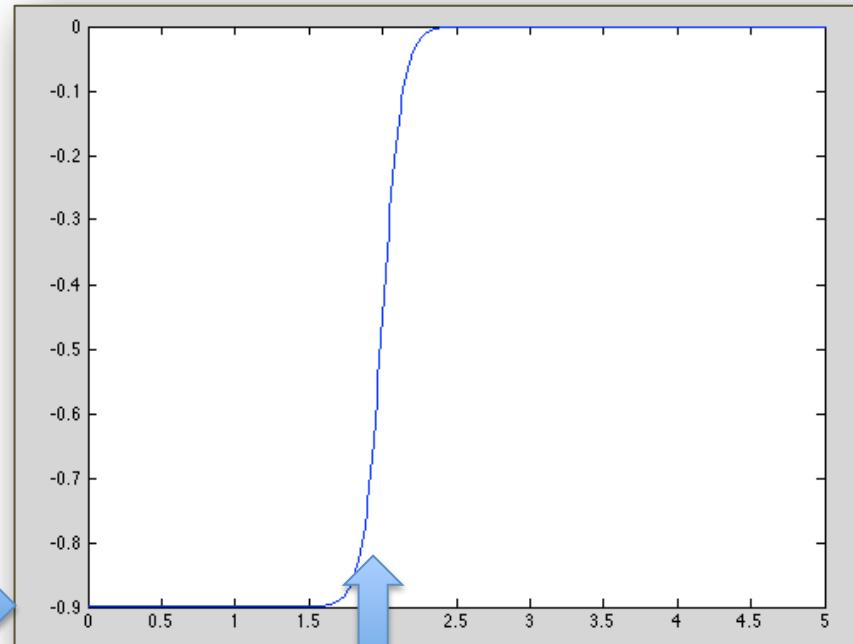


# The claim of a sudden transition in $w(z)$ circa 2002



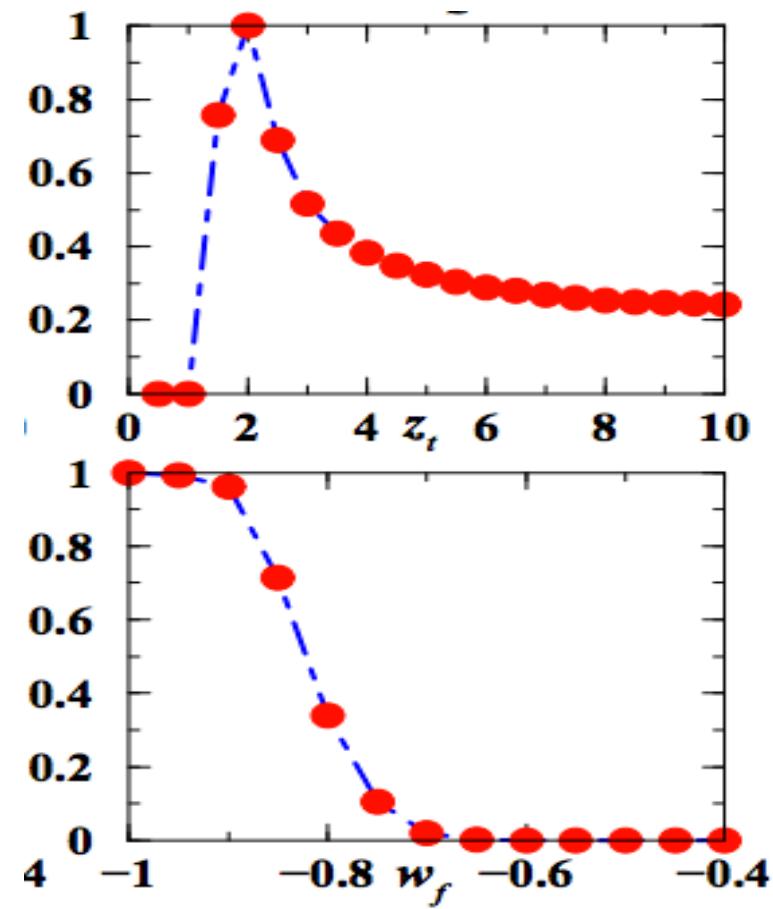
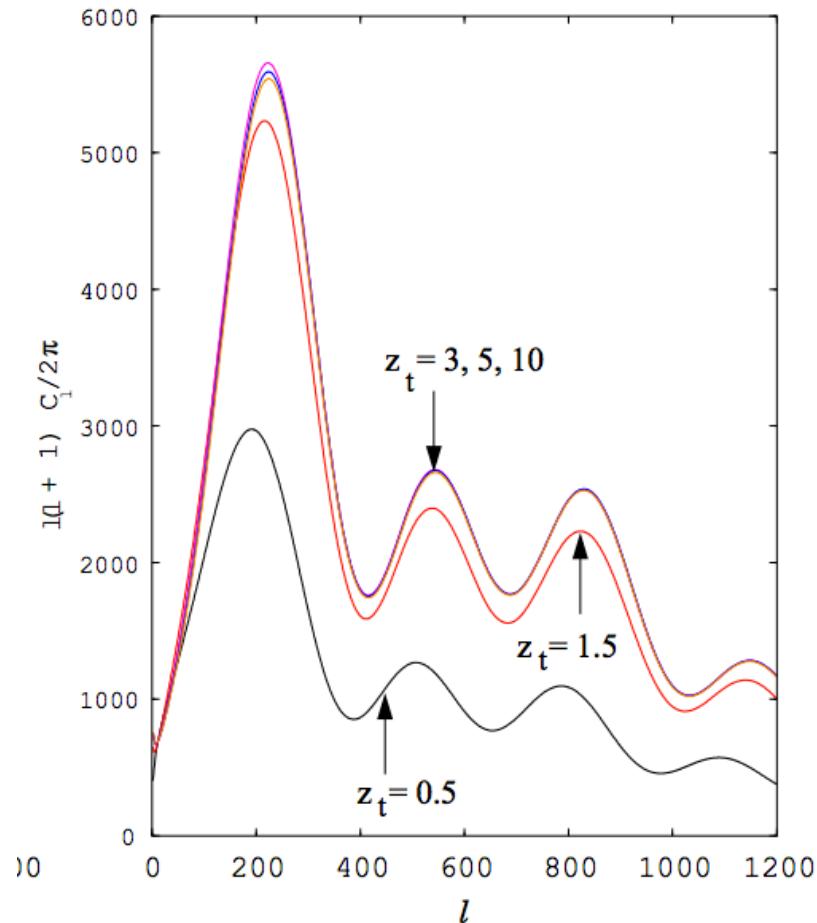


$W_f$



$z_t$

# The claim of a sudden transition in $w(z)$ circa 2002



Crucially we assumed  $n_s = 1$  and  $\tau = 0$

# *Why did we assume $n_s = 1$ and $\tau = 0$ ?*

- Because “everyone” did so at the time and it was easiest.
- Because we did grid computations, even though MCMC had been published a couple of years before.
- We made the obvious mistake of not looking at what might cause the same effect – reductionism “failed”

# PHYSICS: Is Universe Open, Closed or Both?

*Continued from A1*

according to Hawking's longtime colleague, Caltech physicist John Preskill. But Hawking, like Einstein—to whom he is frequently compared—has a habit about making outrageous proposals that turn out to be right. "He has a feel for what is the right answer," Preskill said.

A blithe spirit trapped in a deflated body, Hawking, 56, communicates through a computer attached to a voice synthesizer. His disembodied voice booms out like the wizard of Oz. He smiles easily, if awkwardly, his mouth stretching into wide grins, his eyes brightening with delight at his own jokes and puns.

*Open most days, closed Mon. and Tues.*



AL GOLUB/Los Angeles Times

Hawking proposed that this open and shut universe comes into being from nothingness in the form of a pea instanton—a particle of space and time. An instanton is not so much a thing as an event.

Hawking called it a pea because it would not be perfectly spherical, but rather distorted. This pea instanton, he said, could evolve into either an open or a closed universe.

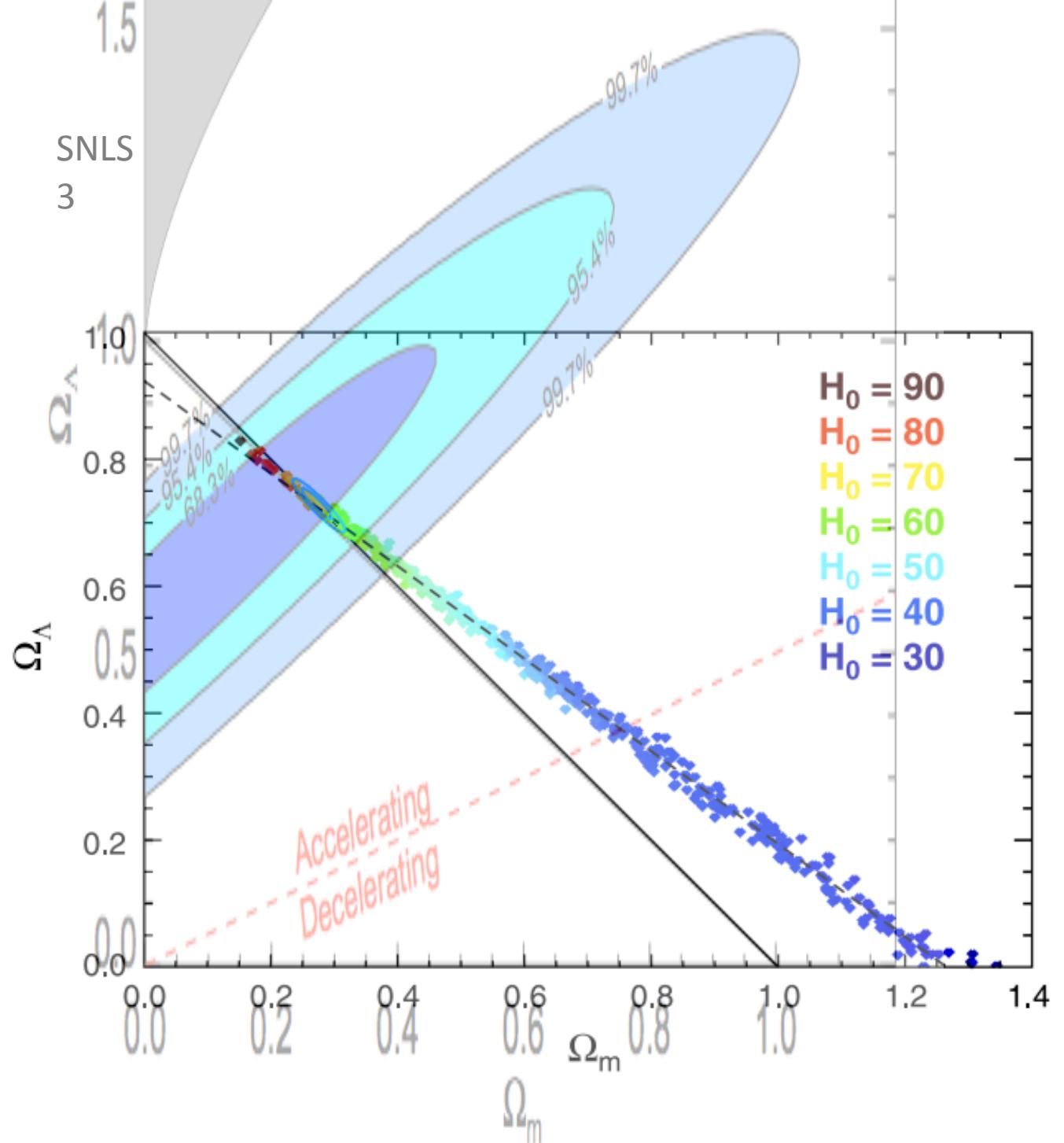
In fact, he said, "there is a whole family of pea instantons."

## Choosing From Many Possible Universes

So why does it appear that our universe is open? Here, Hawking involved himself in a bit of

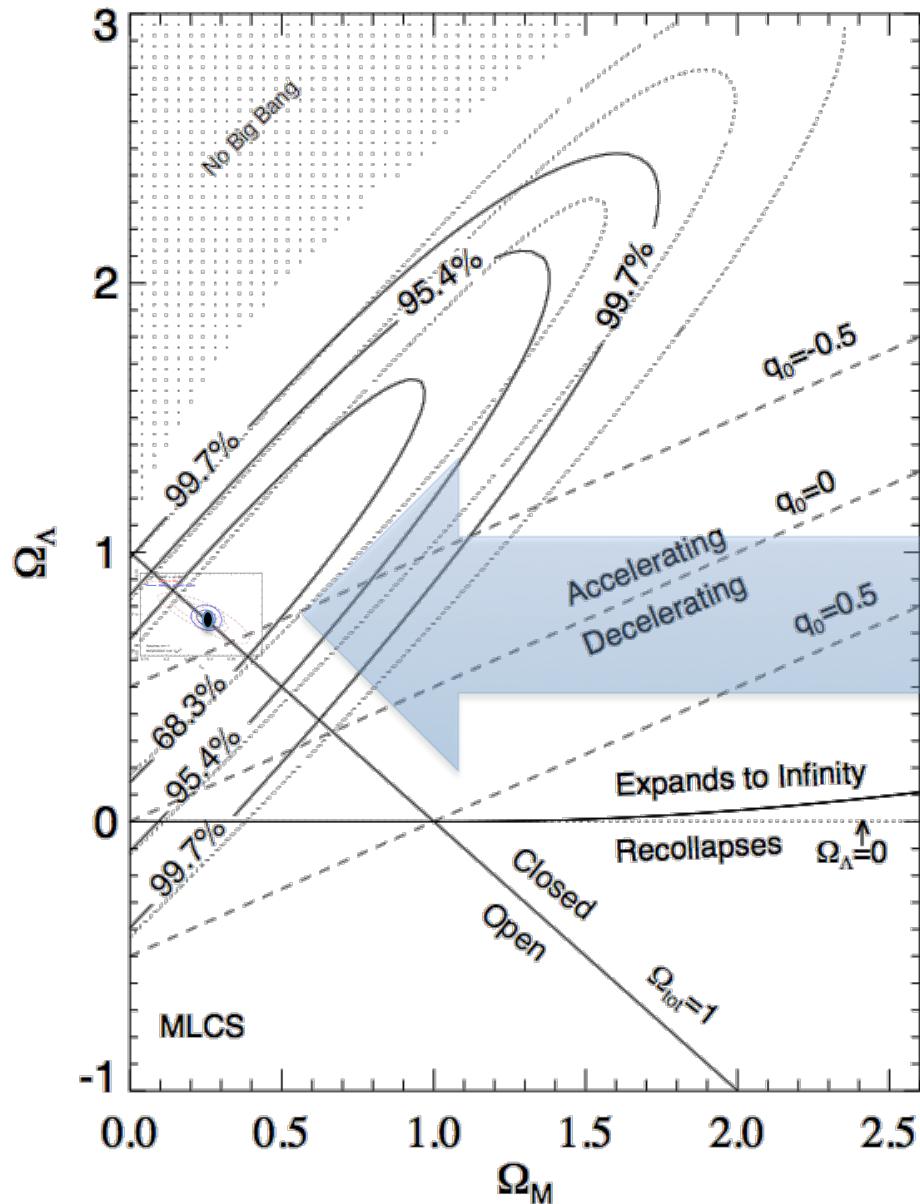
1998

R. Tabbash, Pvt. Comm.

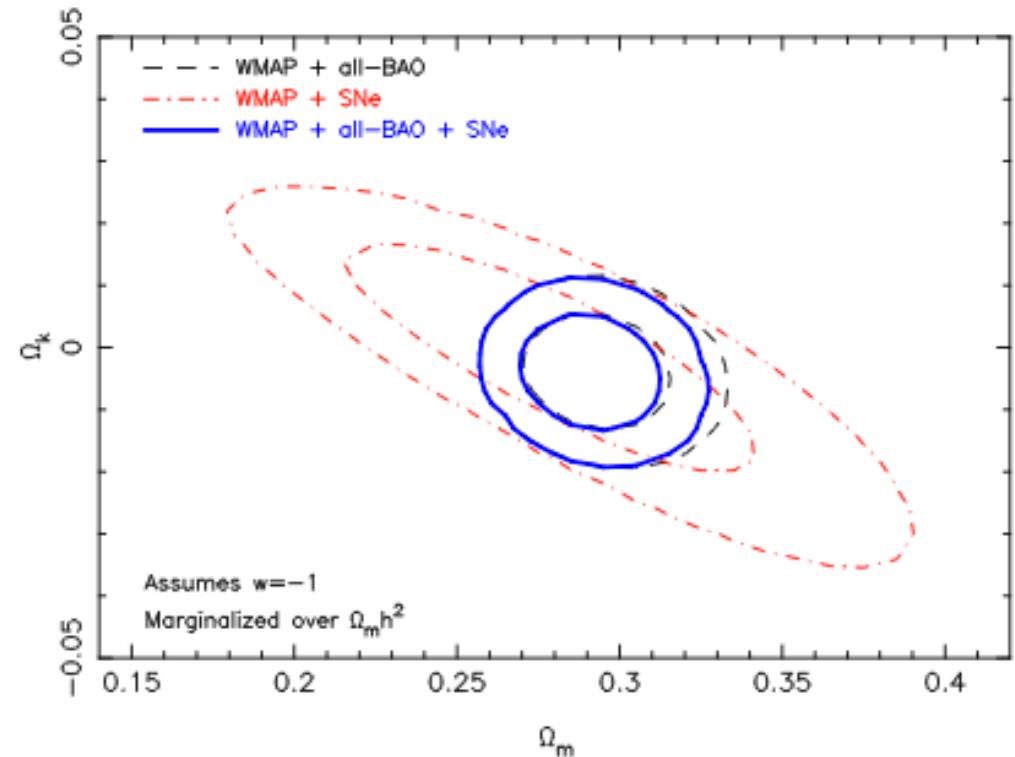


WMAP 7

# How far have we come since 1998?



Riess *et al*, 1998



Blake *et al*, 2011

How much of our constraint on  
curvature is coming from the  
distance to the surface of last  
scattering



# Curvature-Dynamics Degeneracy

- Even with perfect **distance** measurements there is a perfect degeneracy between **the curvature** ( $\Omega_k$ ) and **w(z)** (Weinberg, '73)

$$d_L(z) = \frac{(1+z)}{H_0 \sqrt{-\Omega_k}} \sin \left( H_0 \sqrt{-\Omega_k} \int \frac{dz'}{H(z')} \right)$$

$$\{d_L(z_i)\} \rightarrow \{w(z_i), \Omega_k\}$$


$N$                      $N+1$

# Put another way...

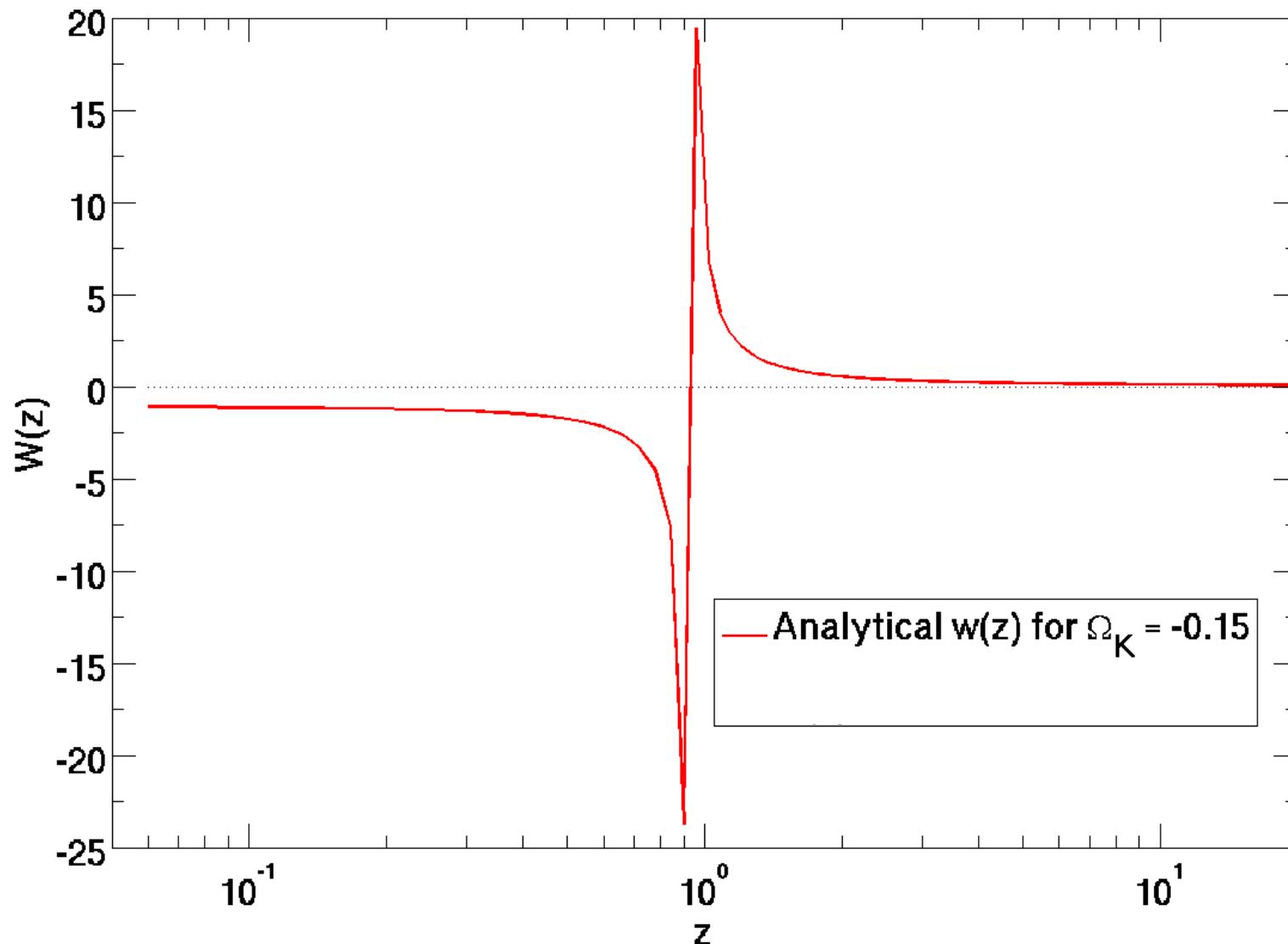
$$\Omega_k = \frac{[H(z)D'(z)]^2 - 1}{[H_0 D(z)]^2}$$

- E.g. BAO+SN Ia
- This equation is independent of GR...

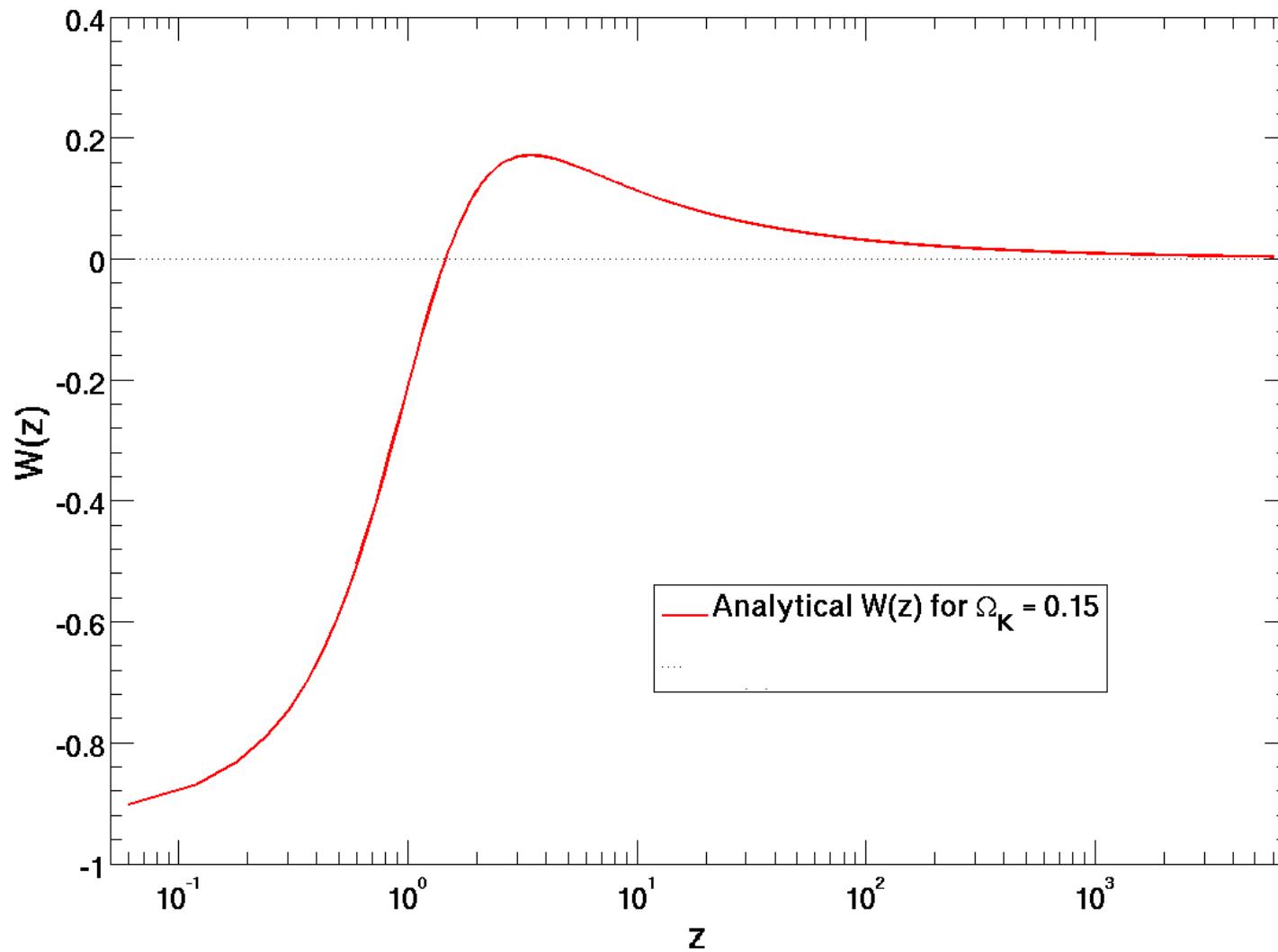
So how flat is the Universe, *really*?

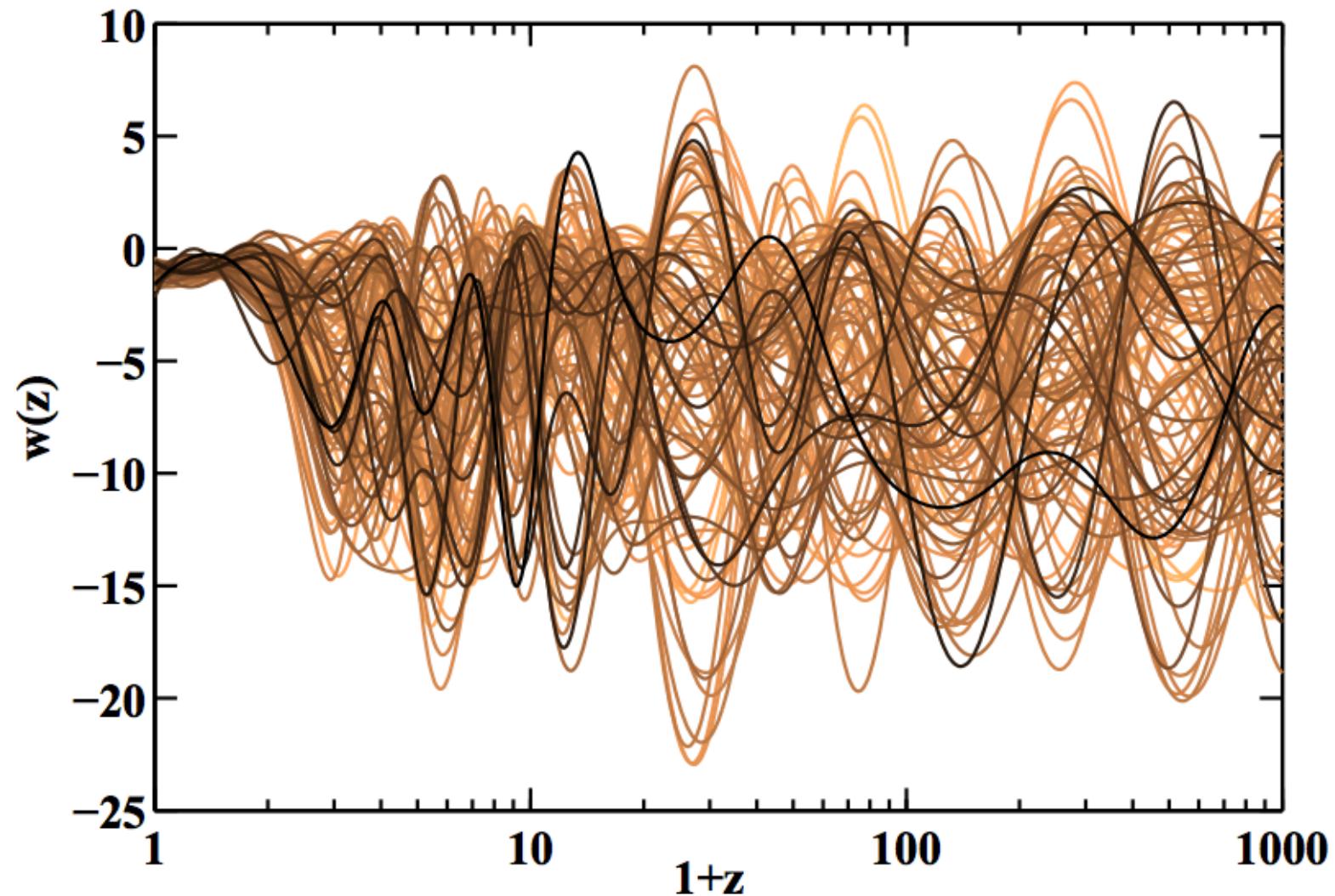
Work with Patrice Okouma and Yabebal Fantaye

# Mimicking flat $\Lambda$ CDM Distances at every redshift

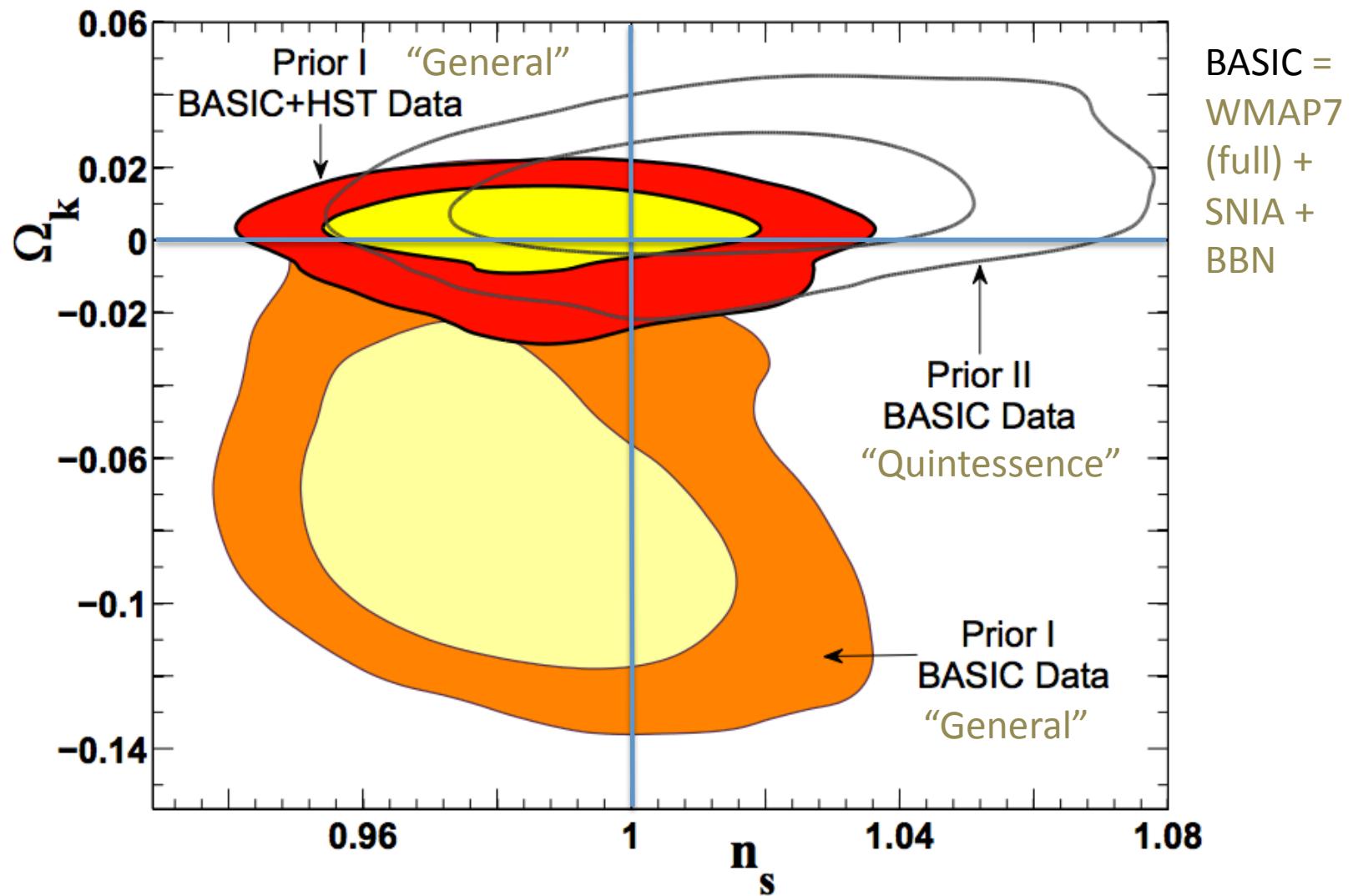


# Mimicking flat $\Lambda$ CDM Distances at every redshift

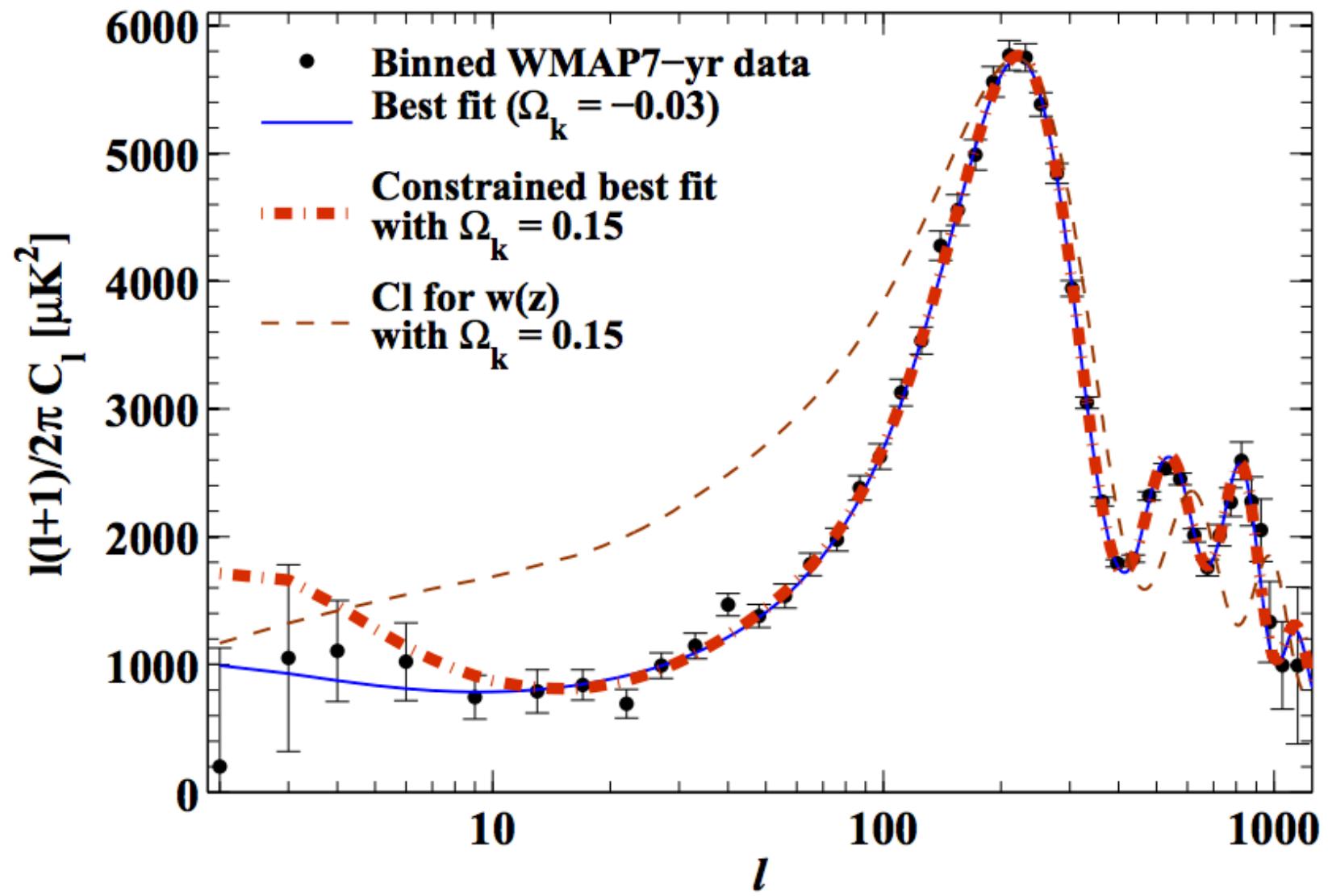




# Our Results



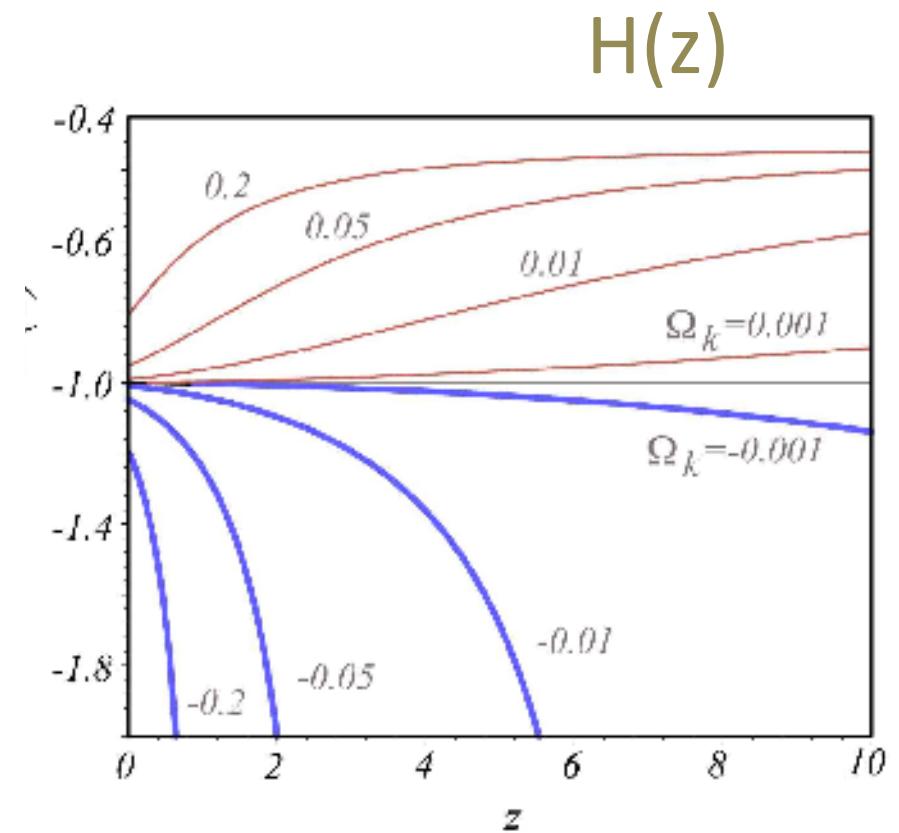
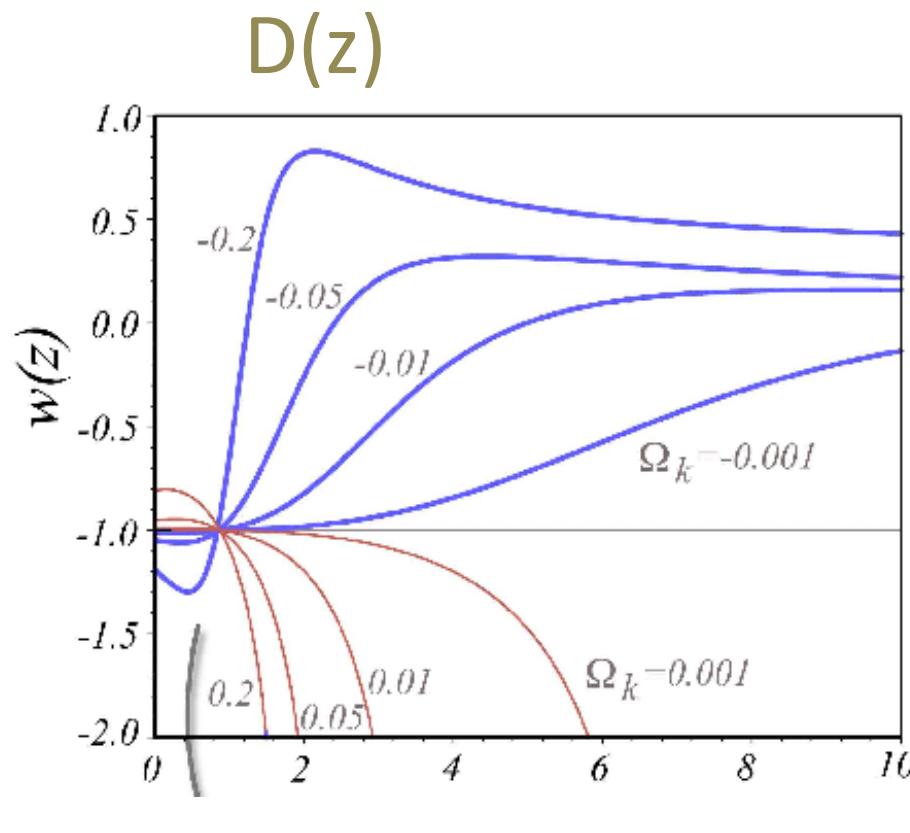
- With only modest priors on  $H_0$ , or a Quintessence prior, the Universe is still close to flat, but **not** because of the 1<sup>st</sup> peak.
- Caveats: assumed GR, speed of sound of unity, adiabaticity and only allowed for constant  $n_s$ .
- Why is the error on  $\Omega_k$  only about 0.01?



1207.3000

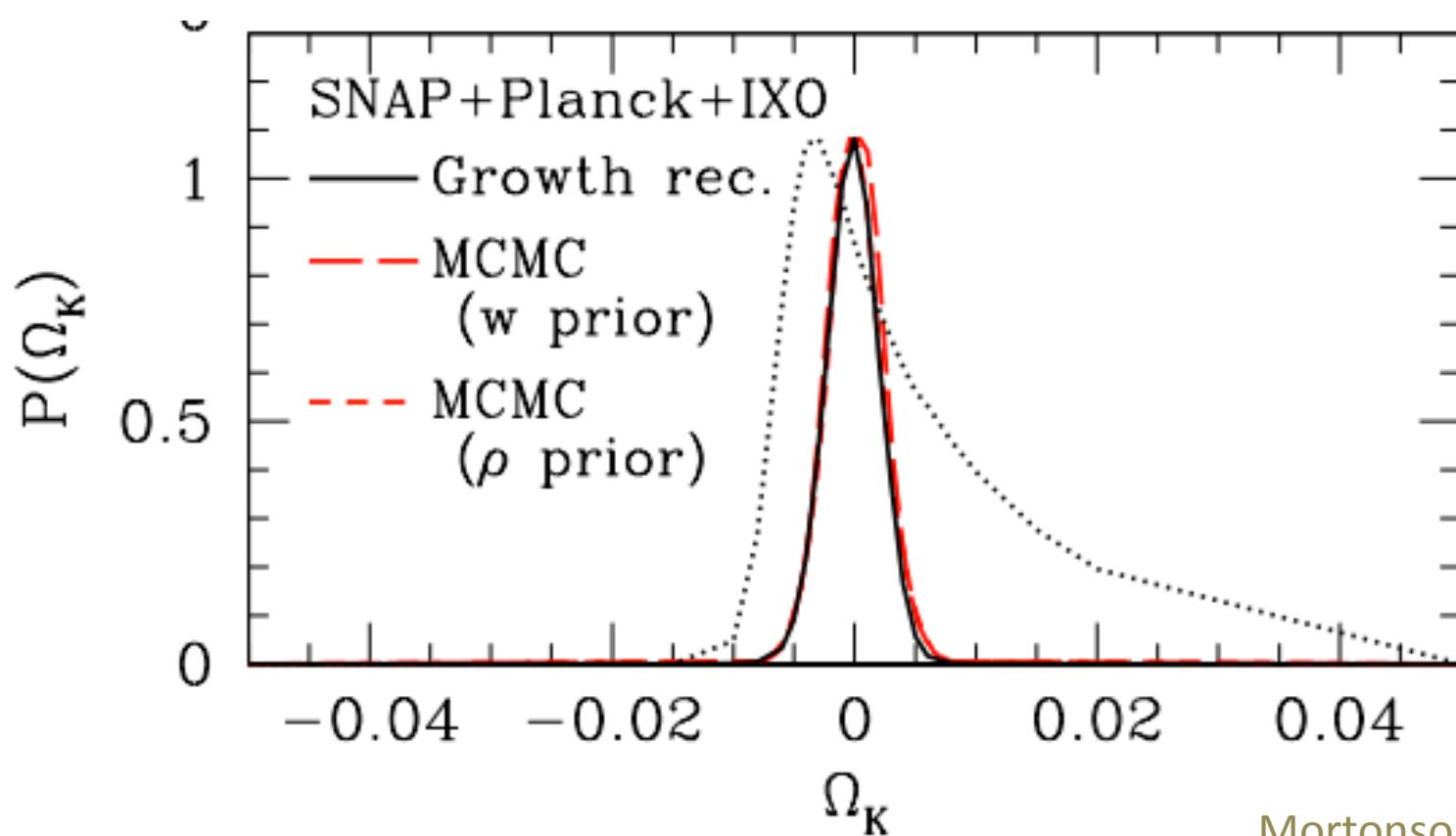
# Why? II

- It isn't possible to match both flat  $\Lambda$ CDM distances and  $H(z)$  simultaneously



# The future

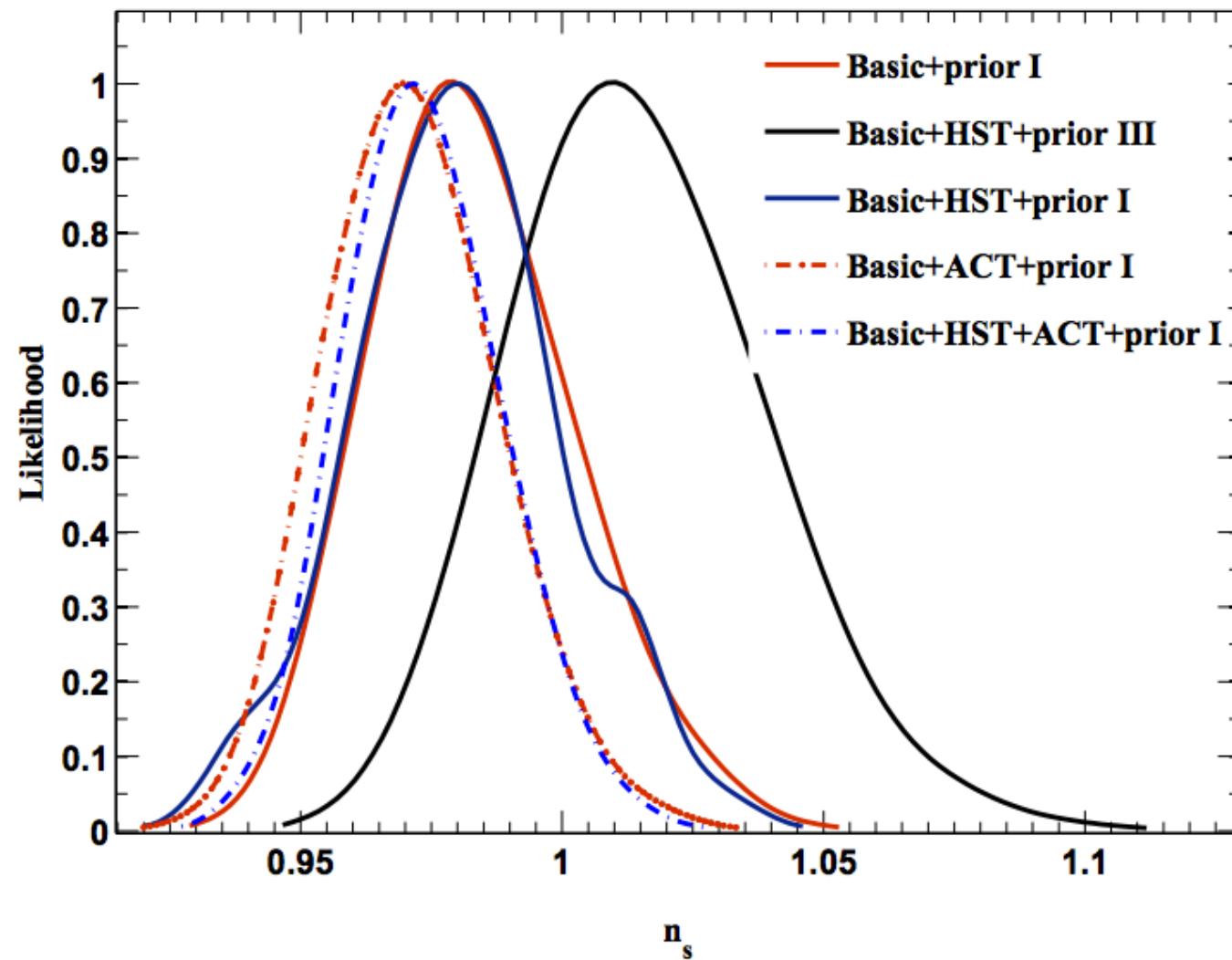
$$G'' + \frac{3}{2} \left( 1 + \frac{\Omega_k(x)}{3} - w(x)\Omega_{\text{DE}}(x) \right) \frac{G'}{x} - \frac{3}{2}\Omega_m(x)\frac{G}{x^2} = 0,$$



Mortenson, 2009

...if future measurements find positive curvature  
at  $\Omega_k < -10^{-4}$  then the framework of the eternally  
inflating multiverse is excluded with high  
significance.

Guth & Nomura, 1203.6876

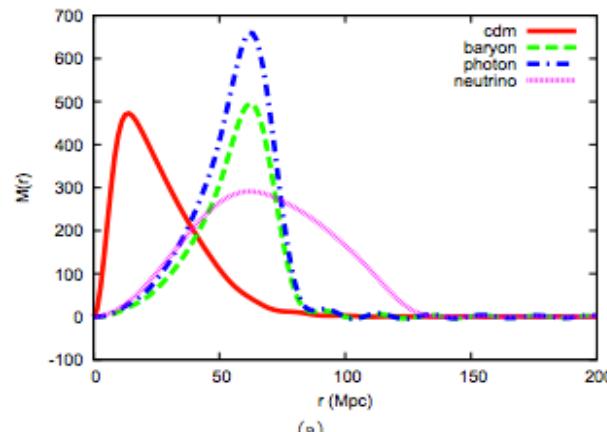


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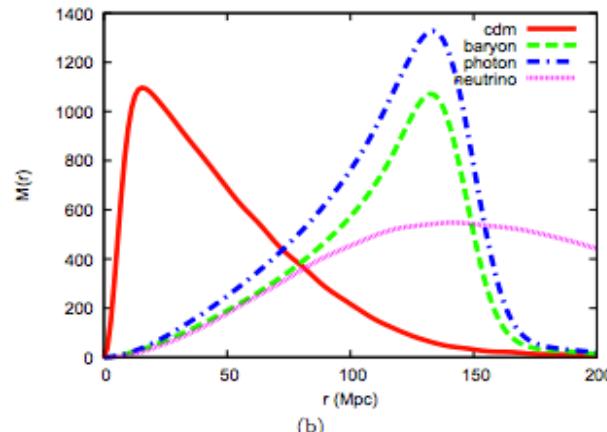
Another example...

How robust are BAO, *really*?

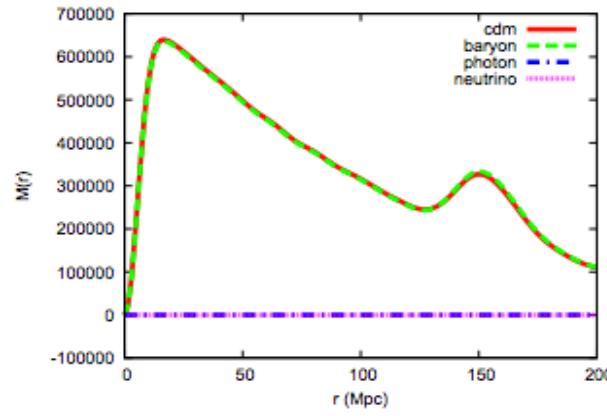
## Adiabatic



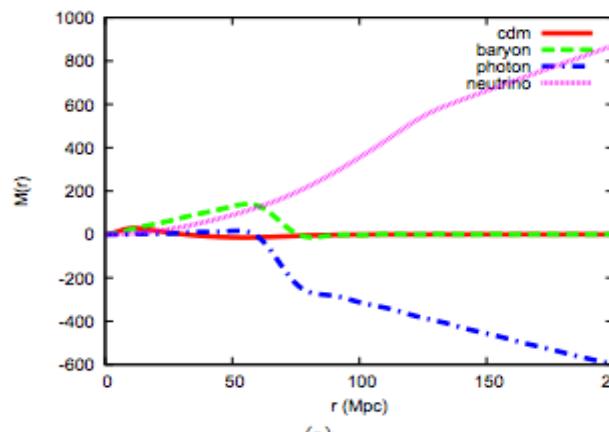
(a)



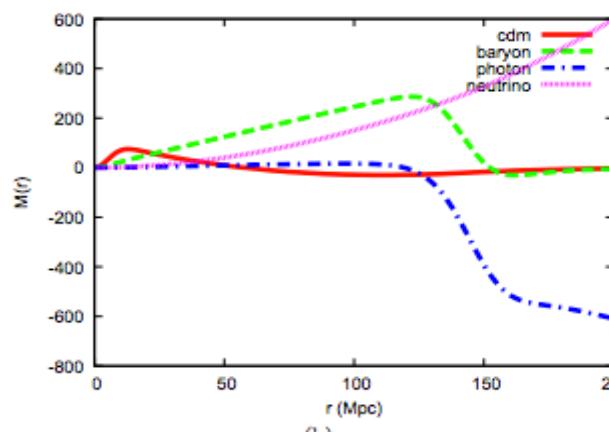
(b)



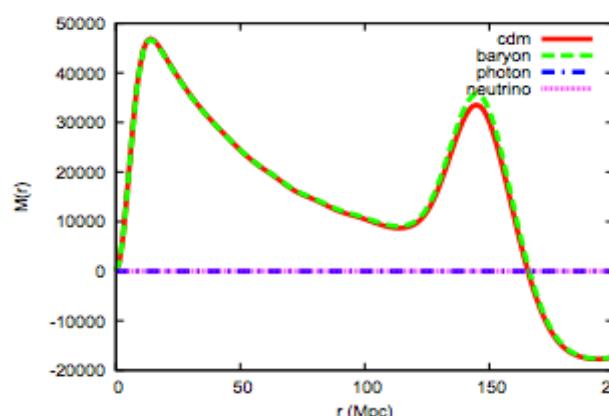
## NID



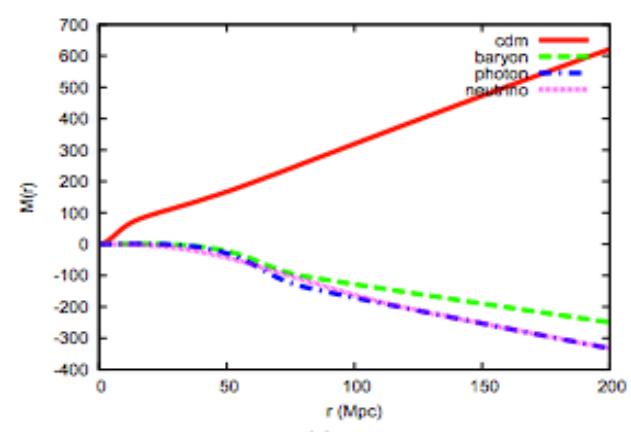
(a)



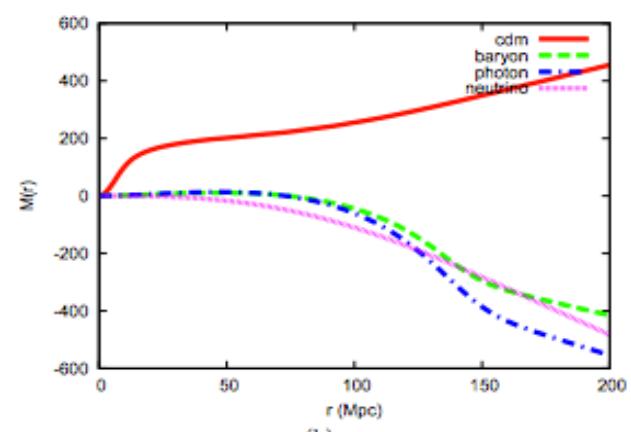
(b)



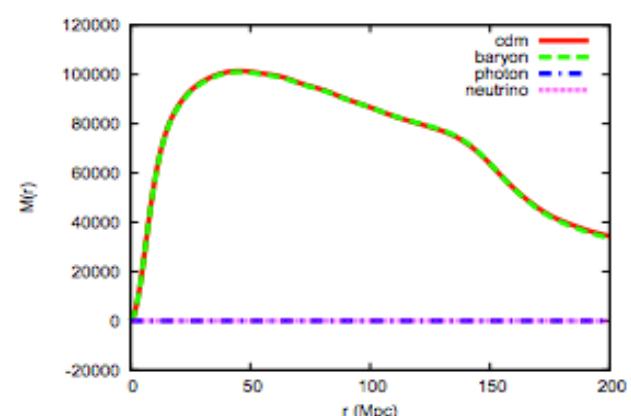
## CI



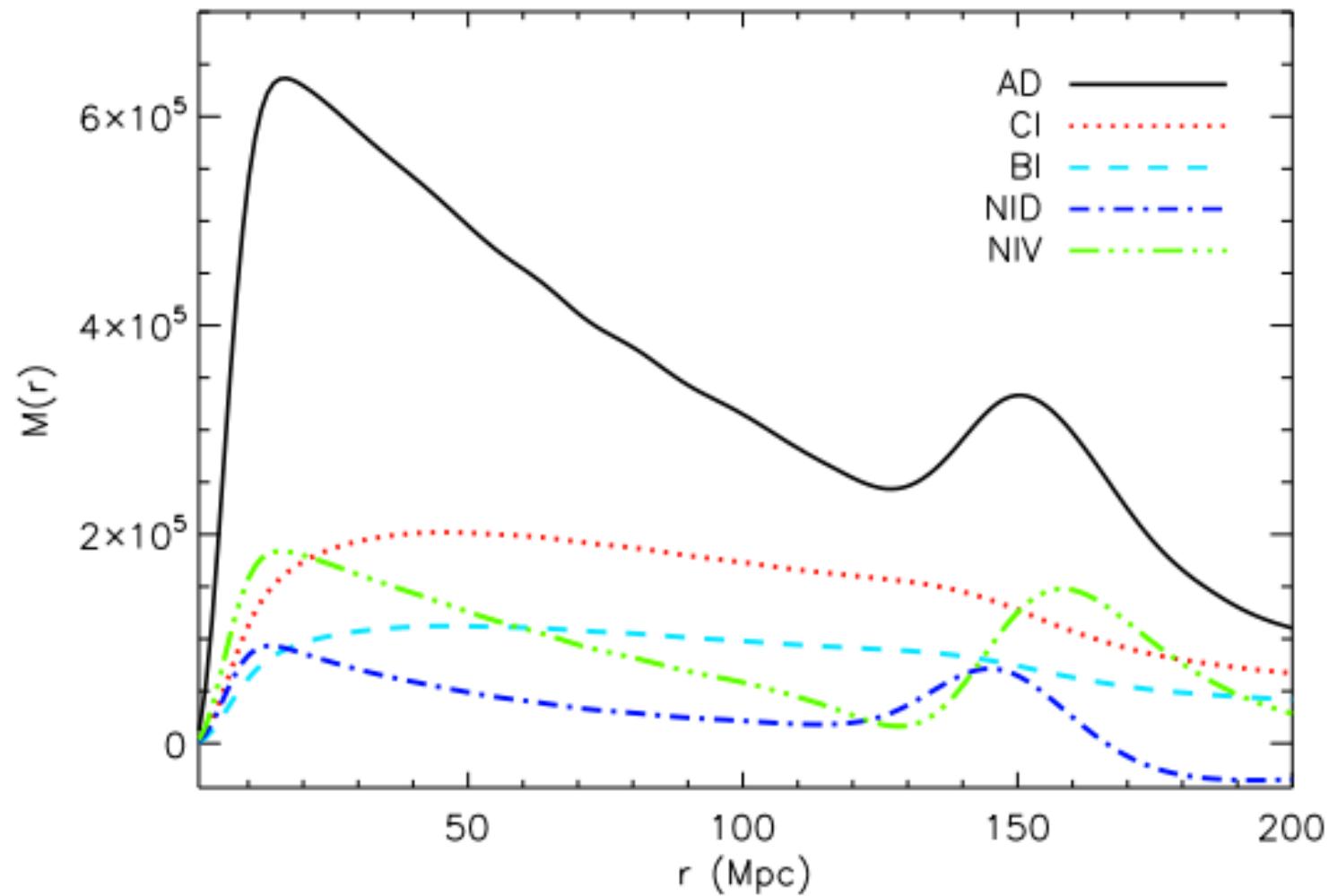
(a)

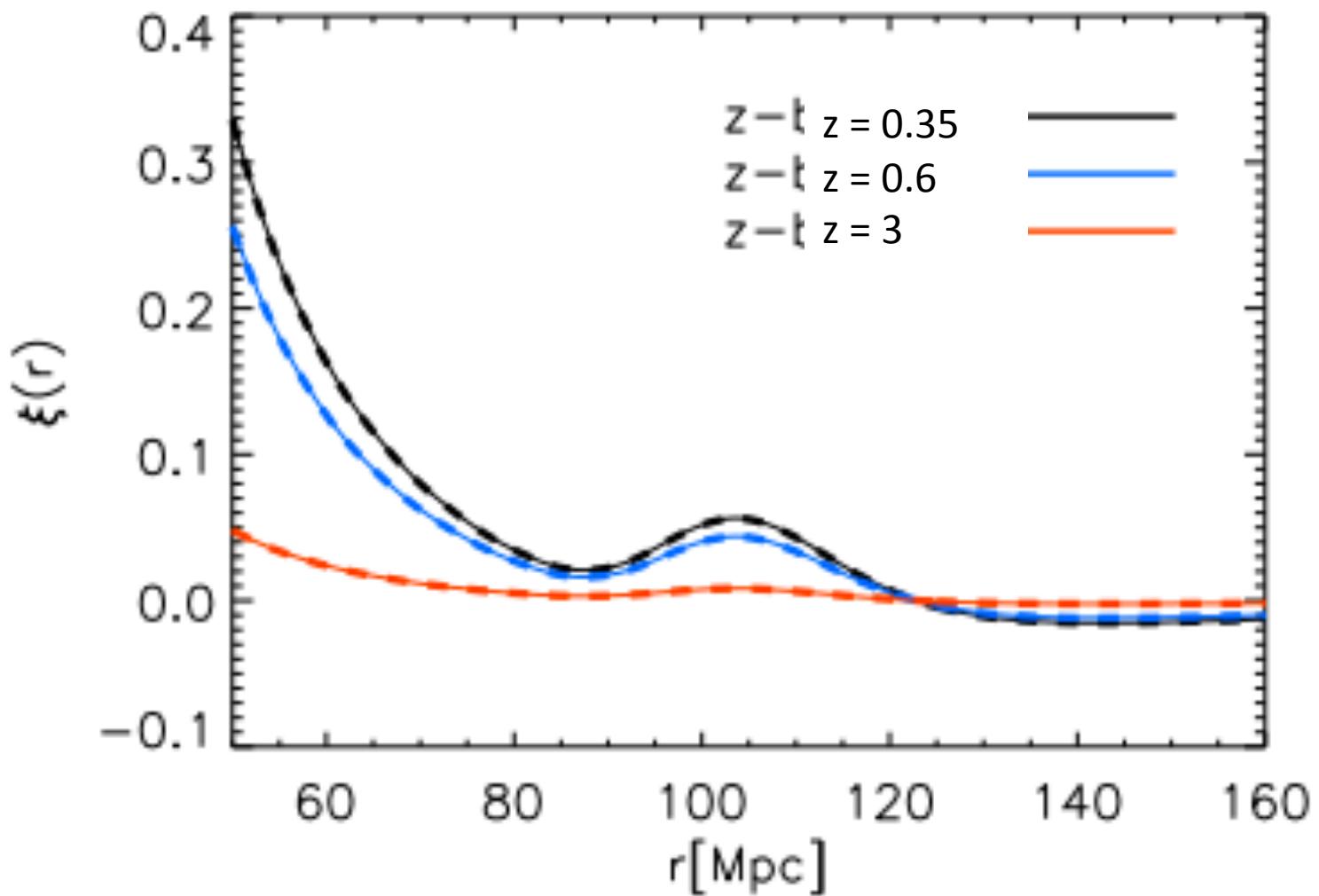


(b)



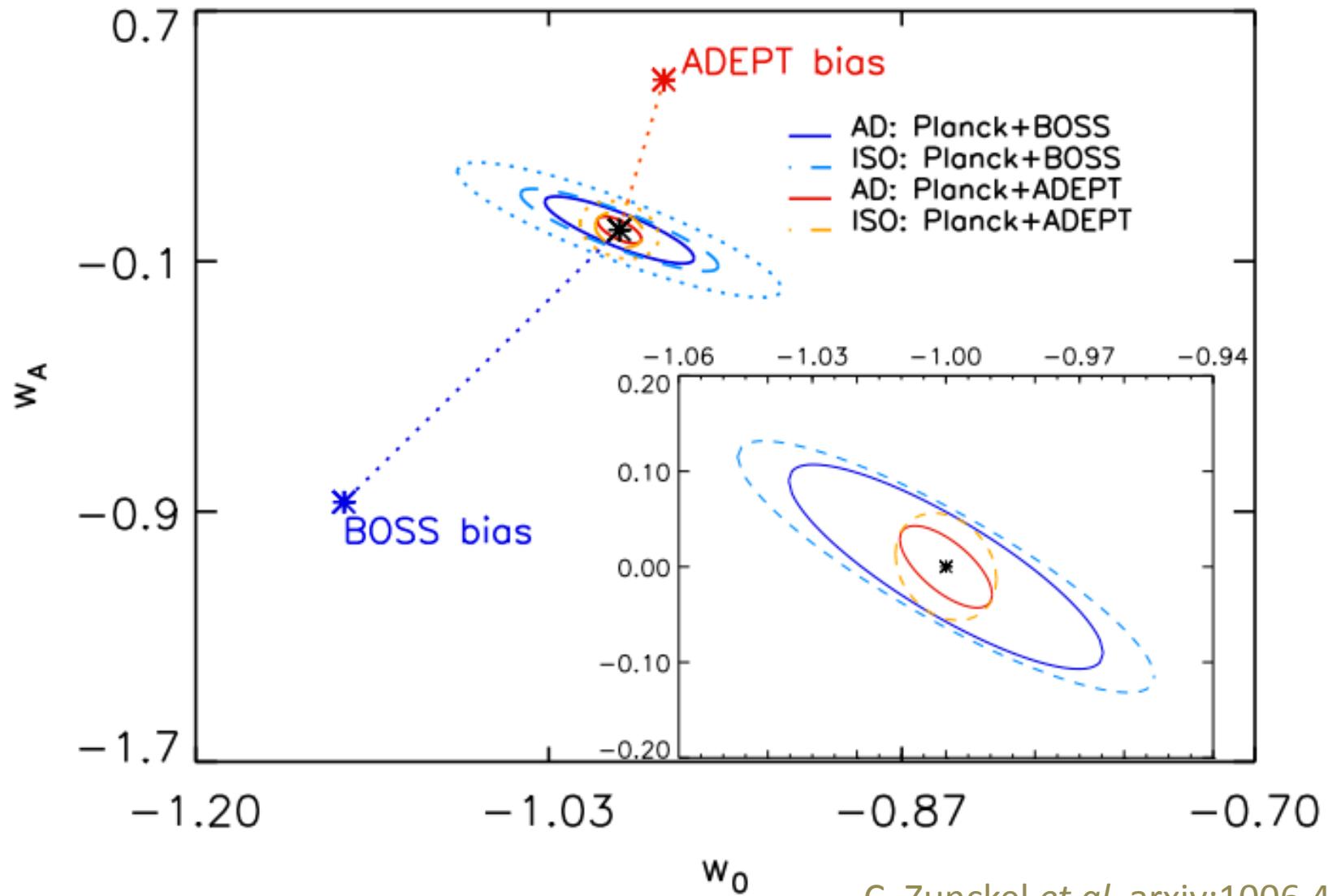
(b)





$w_0 = -1.07$   $w_a = -0.133$  vs Adiabatic  $\Lambda$ CDM

# $10\sigma$ biases possible from isocurvature modes invisible to Planck



# Raises Interesting Questions

- NIV mode – should we care?
- “Absence of evidence is not evidence of absence”
- Classic example of the limits of reductionism in cosmology – will this always be true?
- Do the right things, along with the easy things...be careful not to assume  $\tau = 0$ ,  $n_s = 1$ .