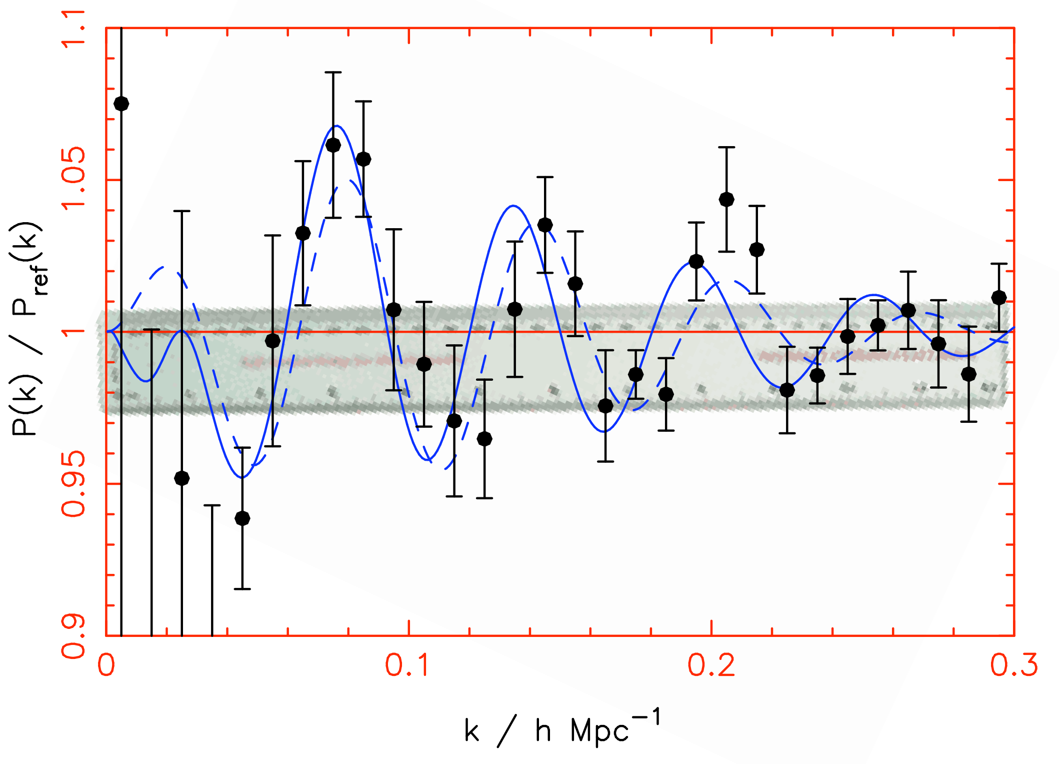
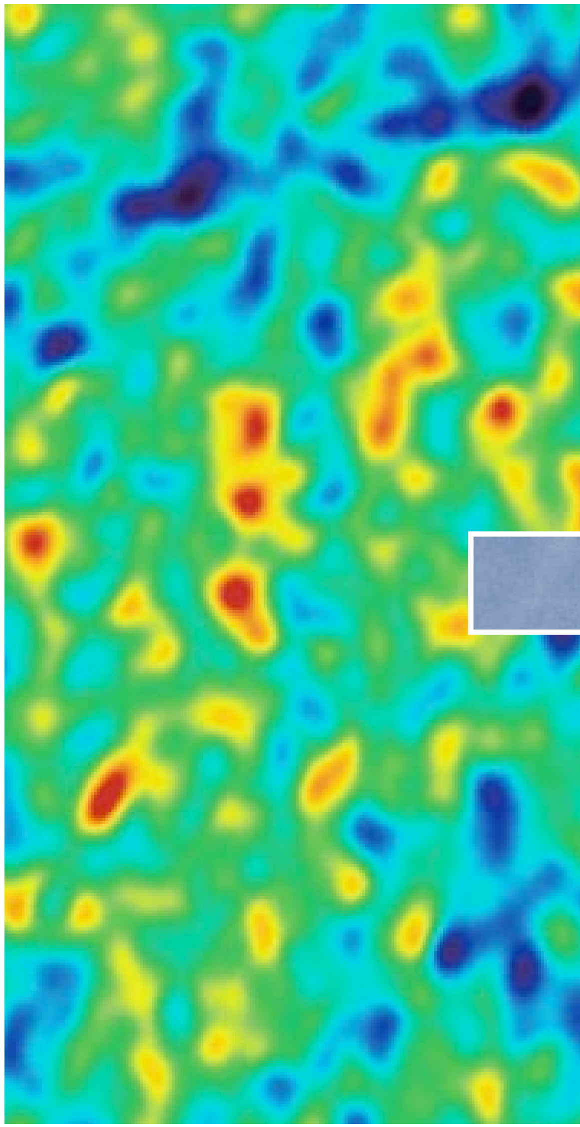
FMOS detection of Cosmic Sound

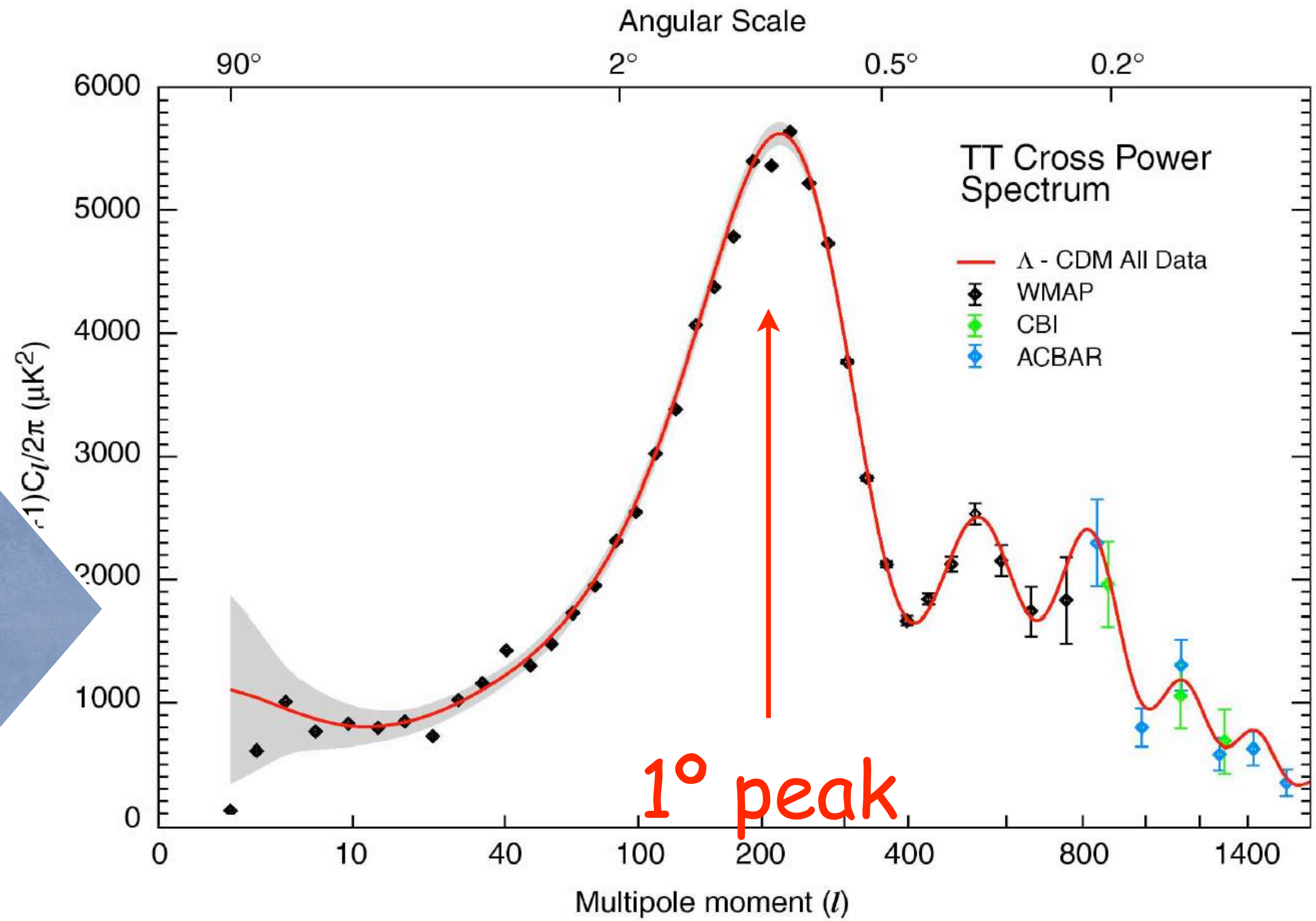
A modest proposal...

Karl Glazebrook (JHU) & Chris Blake (UNSW)



Cosmic sound in the CMB



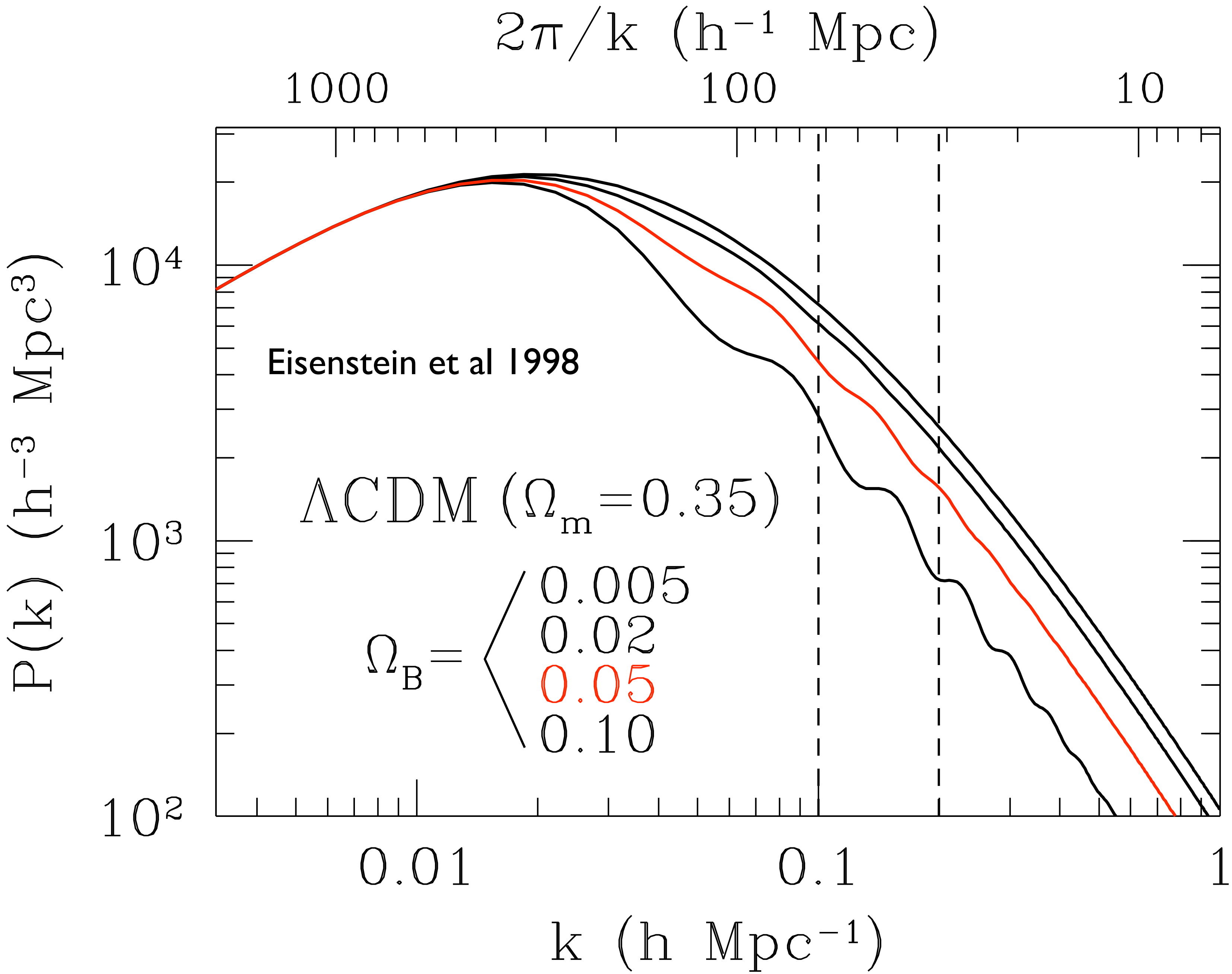


Harmonics of sound horizon

$$s = \frac{1}{H_0 \Omega_m^{1/2}} \int_0^{a_r} \frac{c_s}{(a + a_{\rm eq})^{1/2}}\, da$$

=150 Mpc

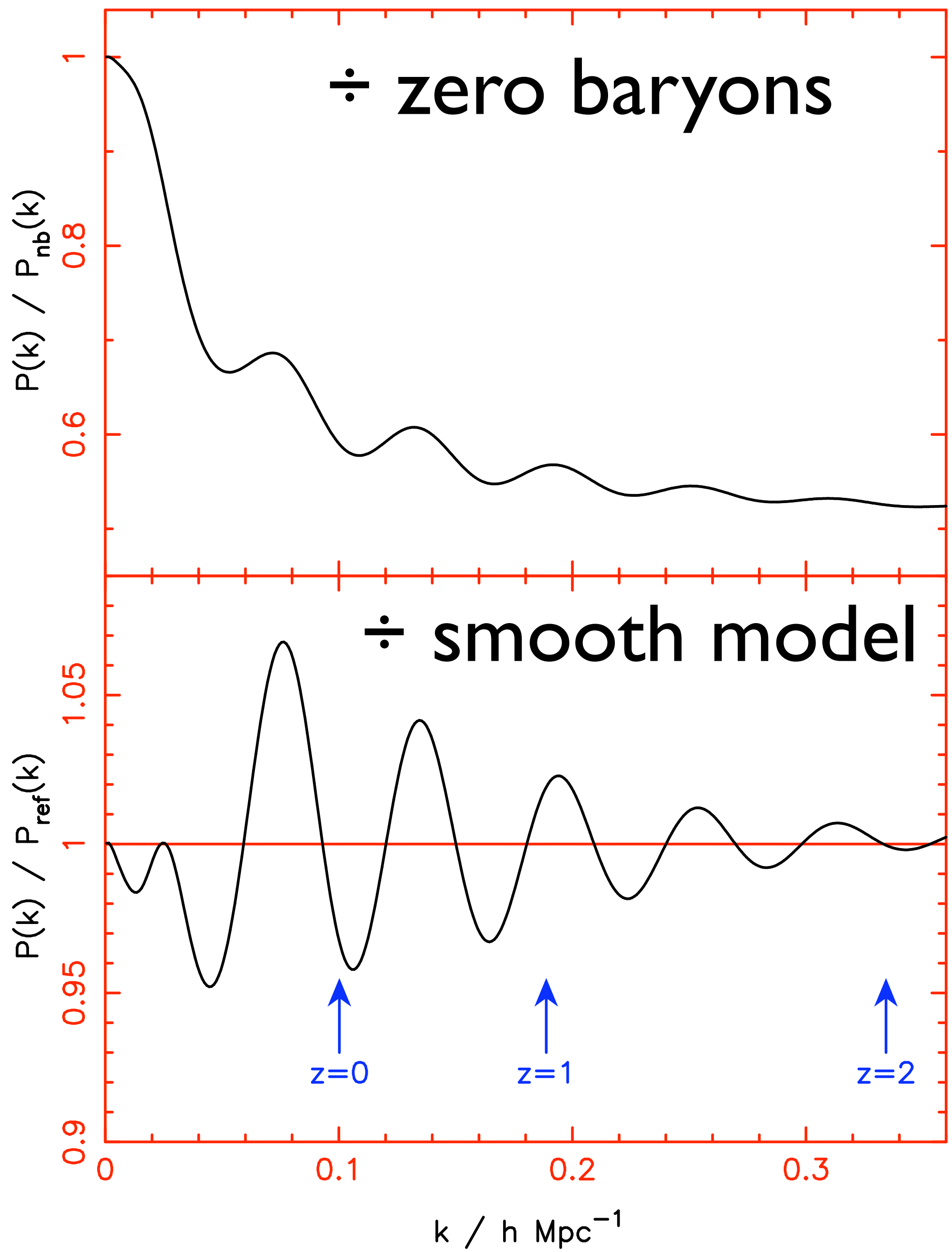
Cosmic Sound in Galaxy Clustering



Observing the sound waves

Linear galaxy clustering power spectrum

Wavelength of oscillation in Fourier space – 'wavescale' is a 'standard rod'



What use is this?

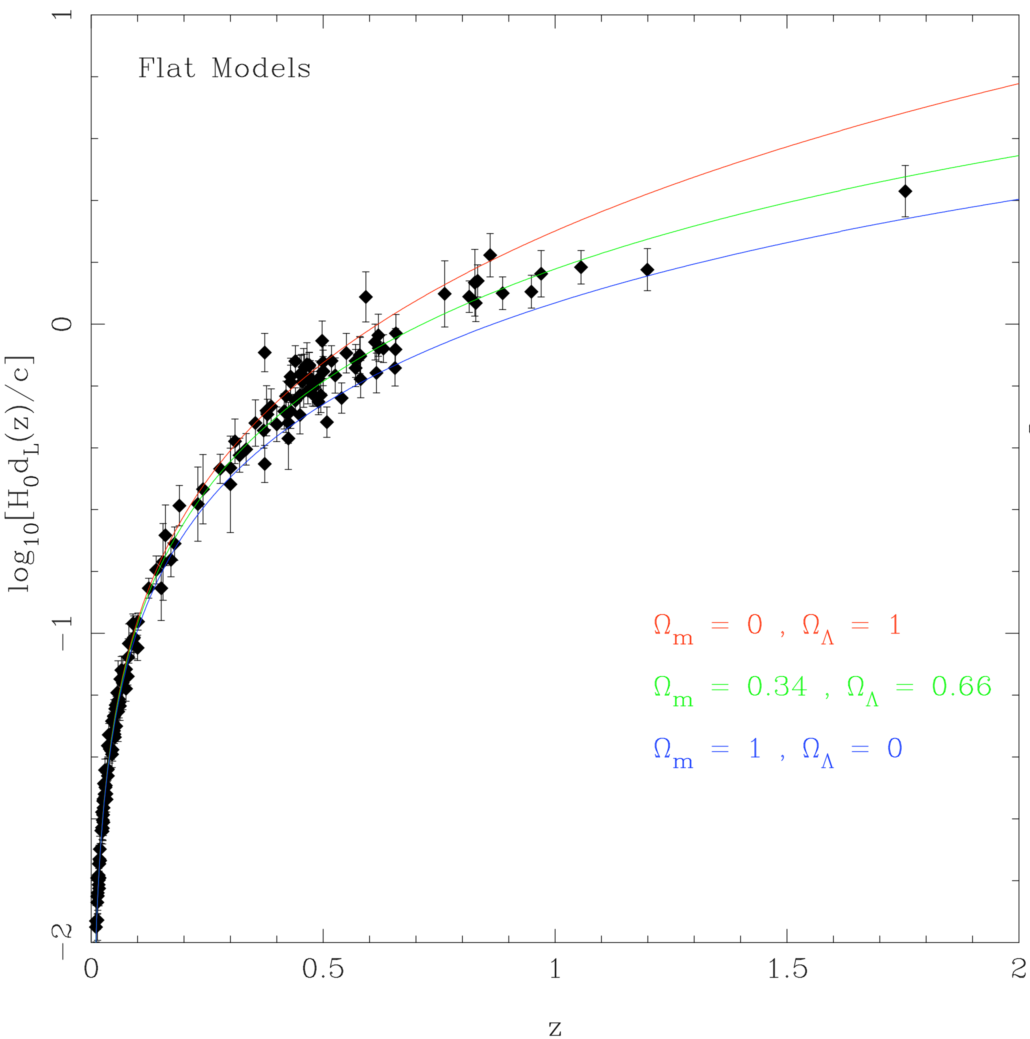
- Answer: use this standard rod is probe of COSMOLOGICAL GEOMETRY & EXPANSION HISTORY
- Big Questions:
  - What is causing the current Universal acceleration?
  - Is it pure vacuum energy or something more complex?
  - Why did it start at z~1 ?
  - What happens z>1?

What use is this?

- Precision (~1%) distance-redshift measurements can test dark energy models (parametrize: $w(z)$ vacuum: w = const. = -1)
  - $P = w\,\rho$
  - $w < -1/3 \Rightarrow$ **accelerating $a(t)$**
  - $w = -1 \pm 0.2$ indicated by current SNe data ($z_{eff} \sim 1$) + CMB flatness/Ω_m
  - ($D_L - z$ test)

Current SNe (only)

Choudhury & Padmanabhan



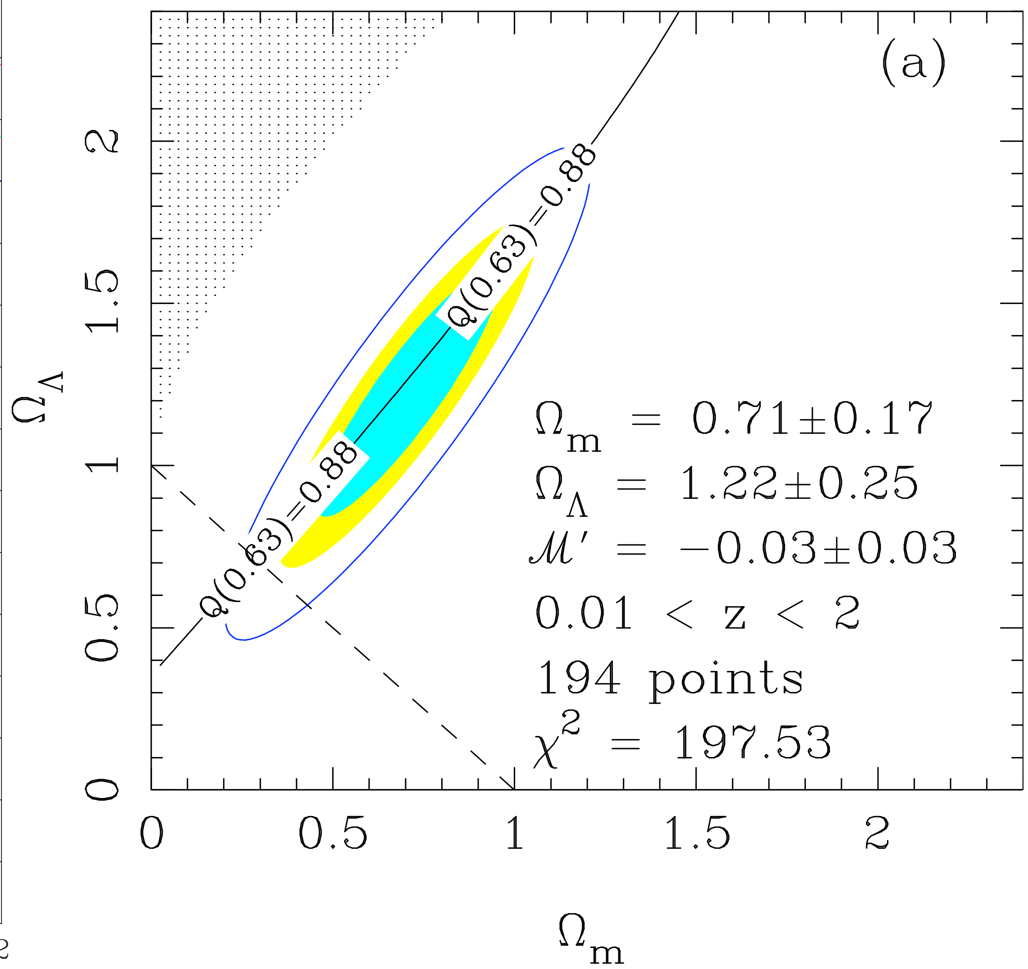
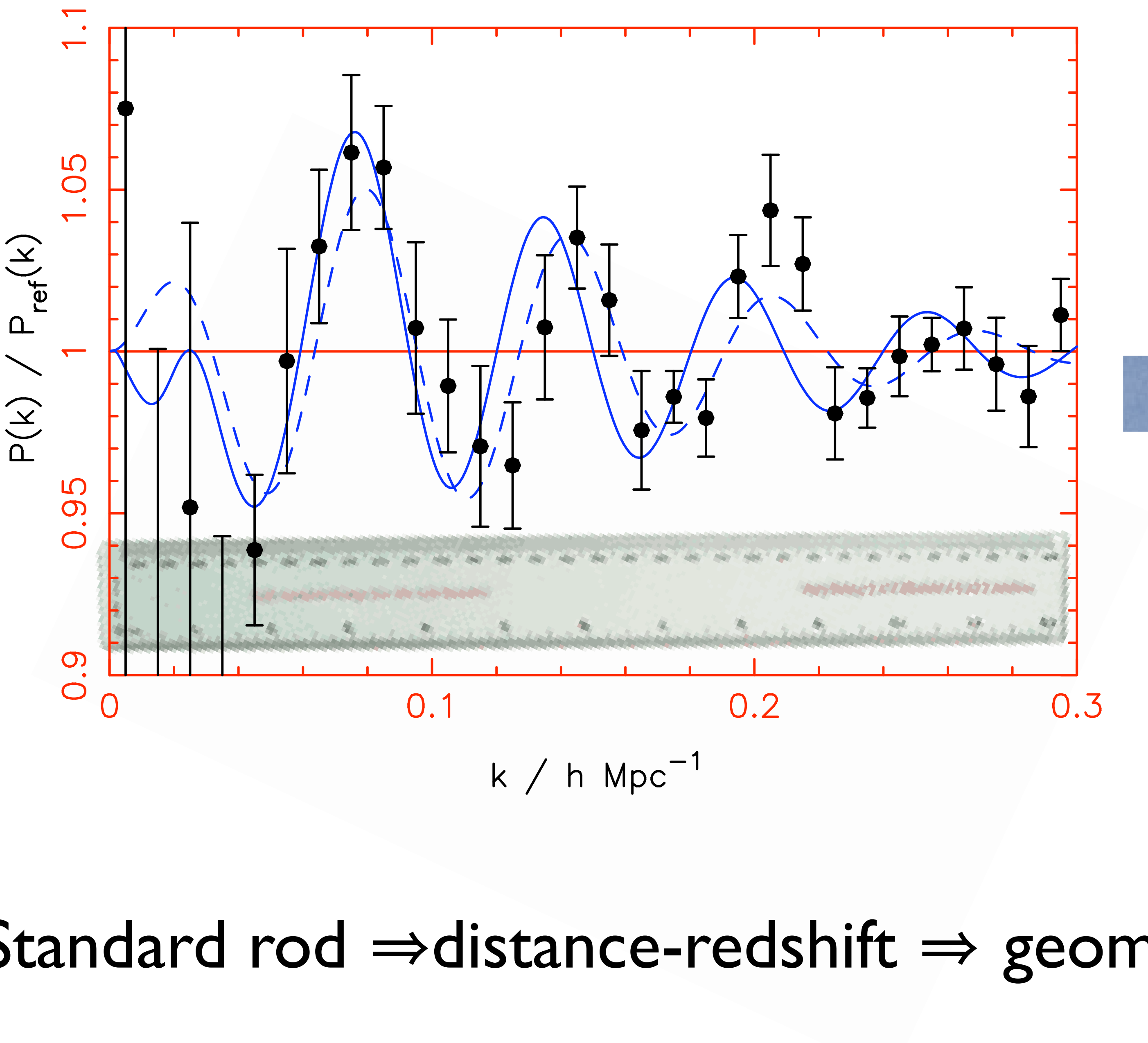
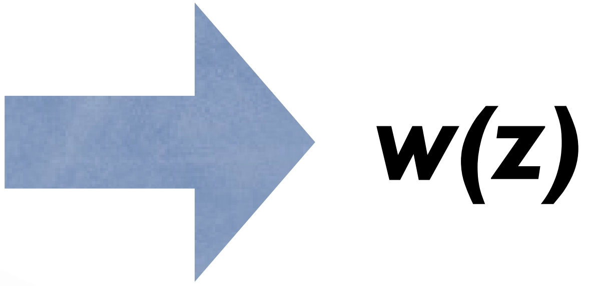


Figure 1. Comparison between various flat models and the observational data. The observational data points, shown with error-bars, are obtained from Tonry et al. (2003) and Barris et al. (2003).

The big idea...





Standard rod ⇒distance-redshift ⇒ geometry(z) ⇒w(z)

More thought...

If x(z) is comoving distance...

$$\frac{dx}{dz} = \frac{c}{H_0 \Omega_m^{1/2}} \frac{1}{\sqrt{(1+z)^3 + \left(\Omega_m^{-1} - 1\right)(1+z)^{3(1+w)}}} = c\, H(z)^{-1}$$

Angular oscillations ⇒ $D_A(z) = x(z)\,(1+z)^{-1}$

Radial oscillations ⇒ H(z) ***directly***

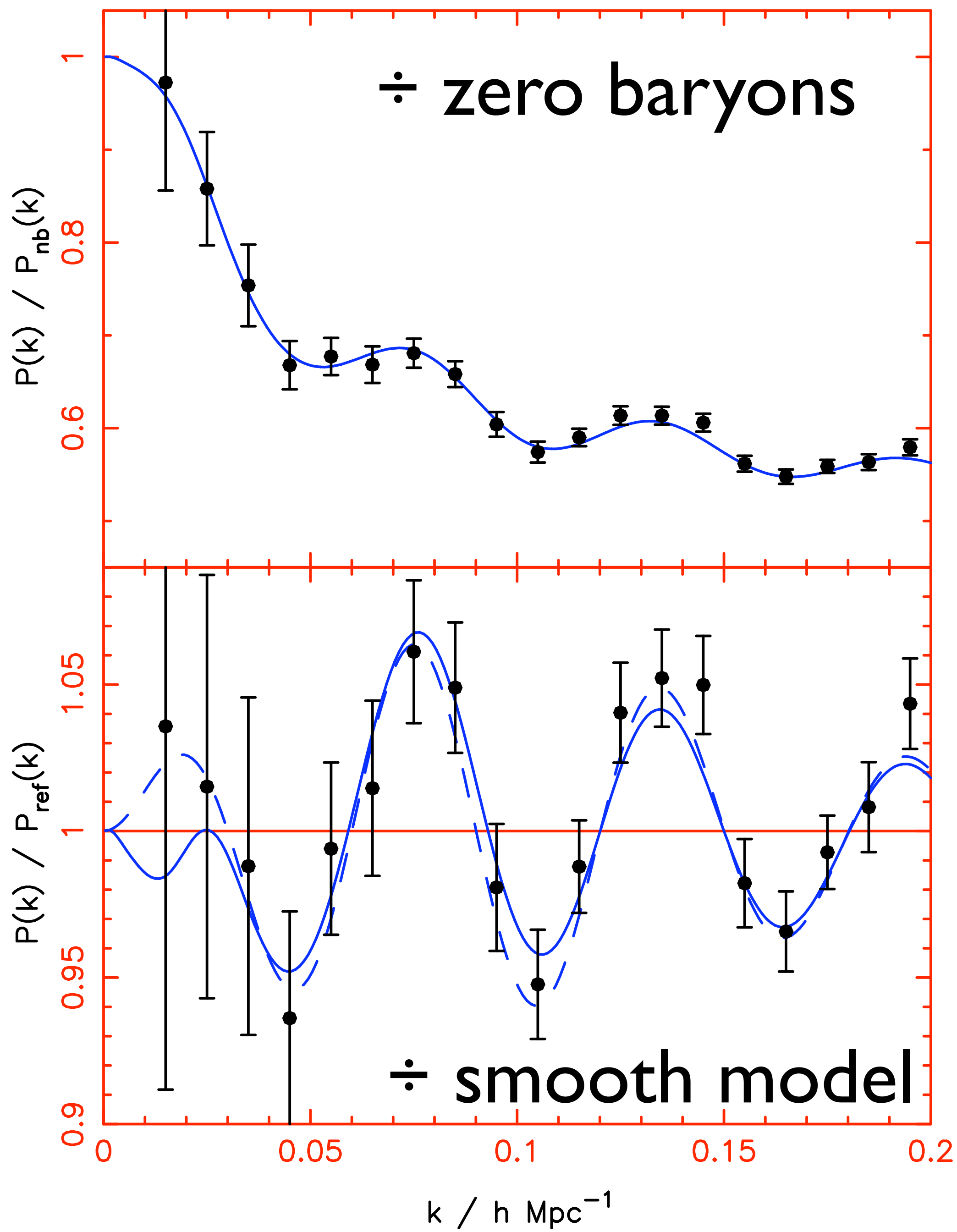
Compare SNe ⇒ $D_L(z) = x(z)\,(1+z)$

Precision measurement?

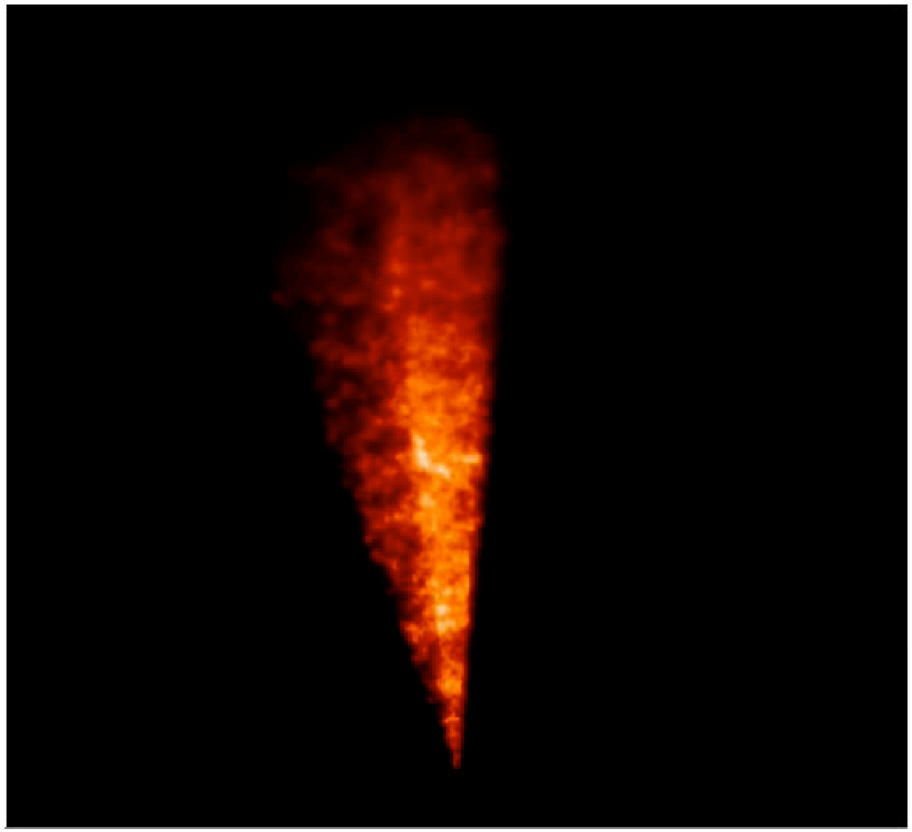
Imagine our precision could look like this at redshift z

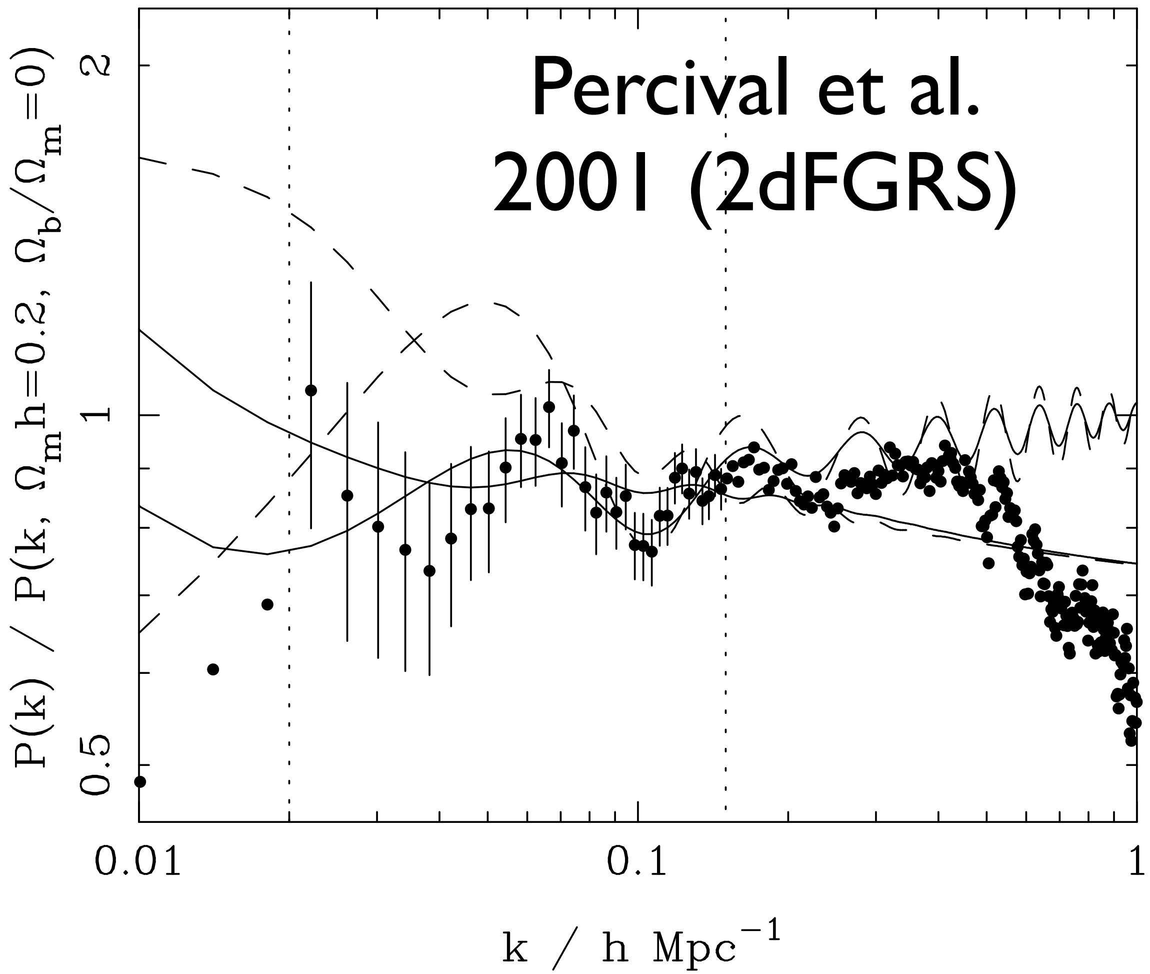
We could measure this 'wavescale' to a few % accuracy

We would measure D(z) to few %.



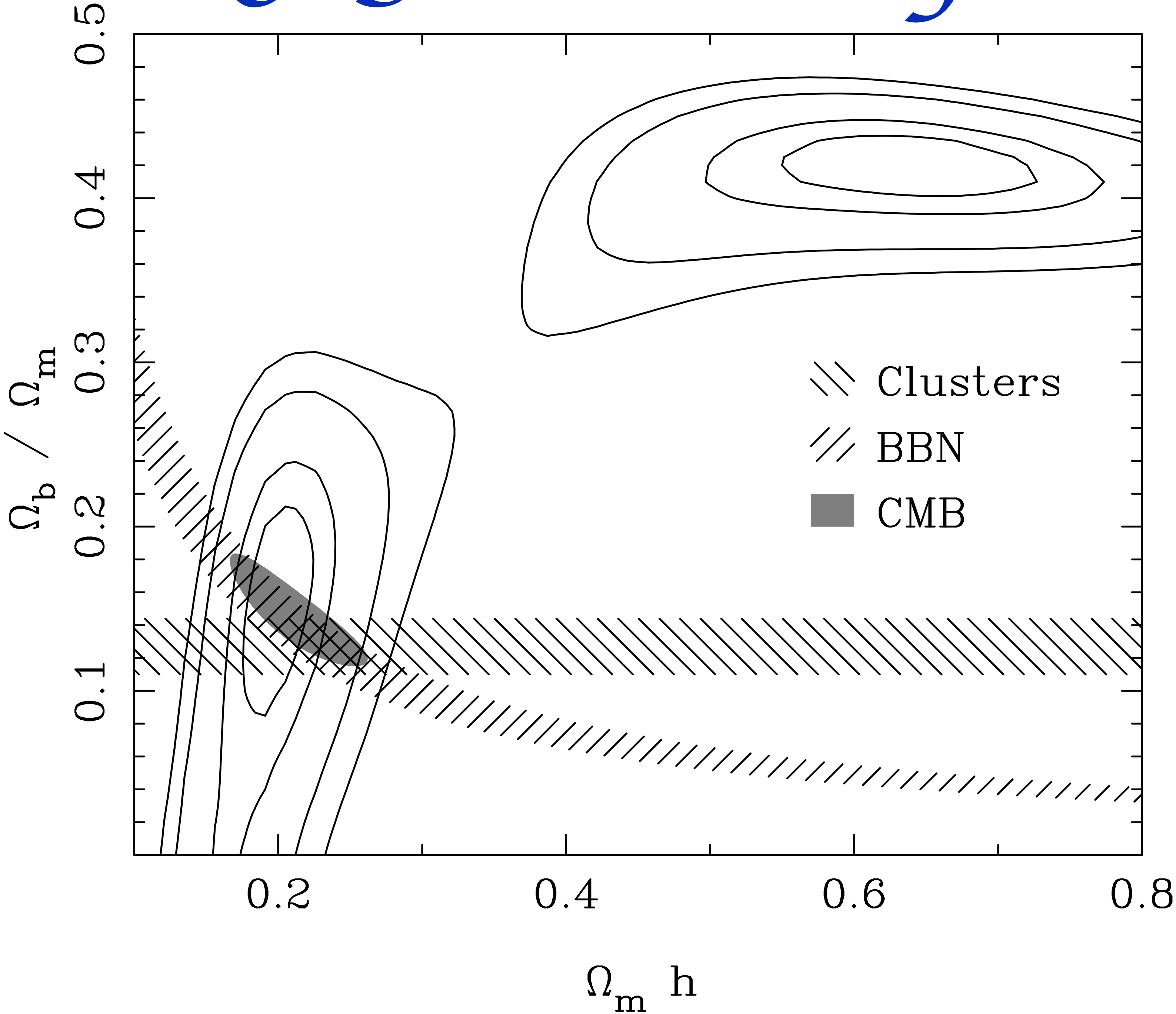
Baryon Wiggles in 2dFGRS?





95% significant detection

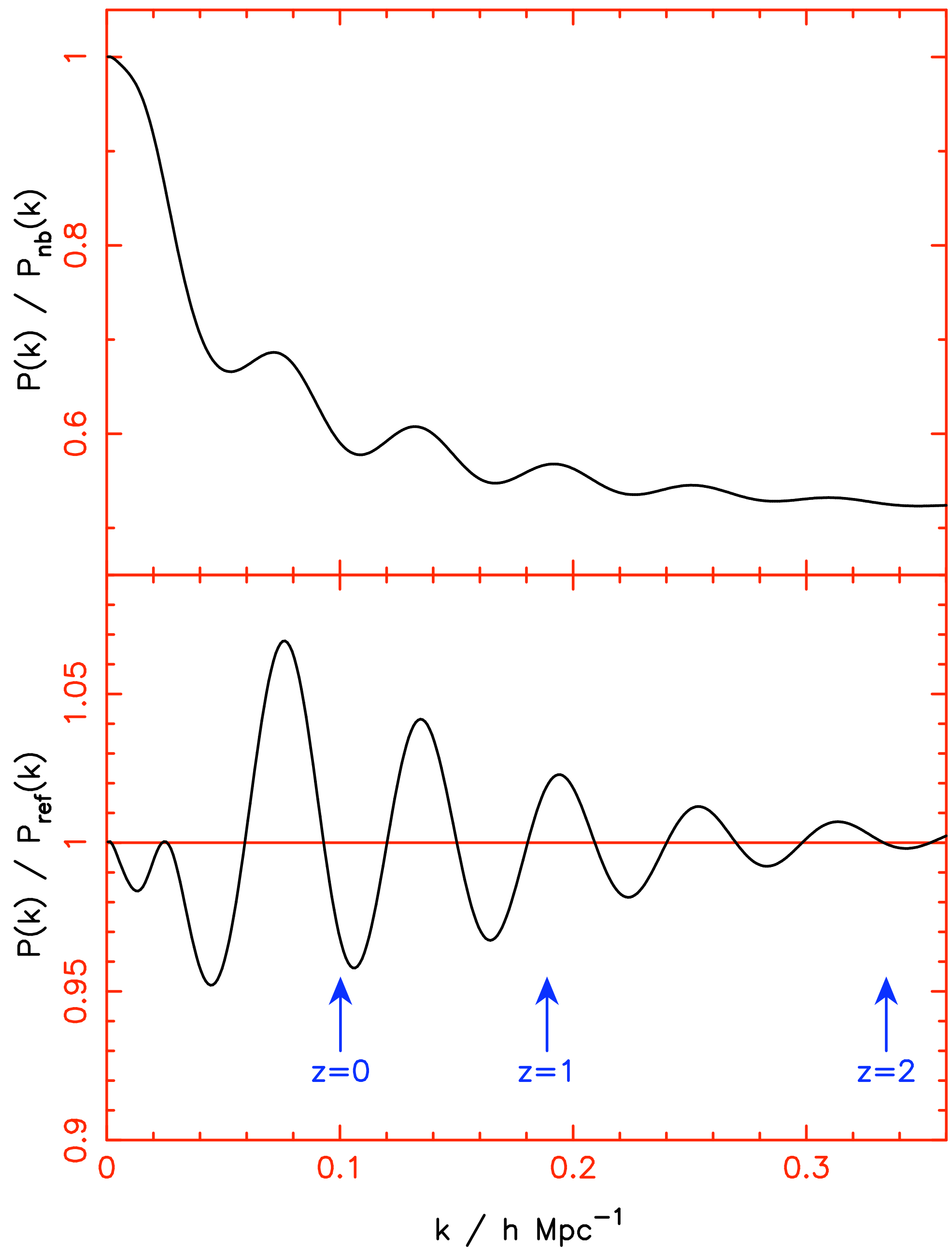
2dFGRS baryons



High-z is better

See more peaks

More leverage in D(z)



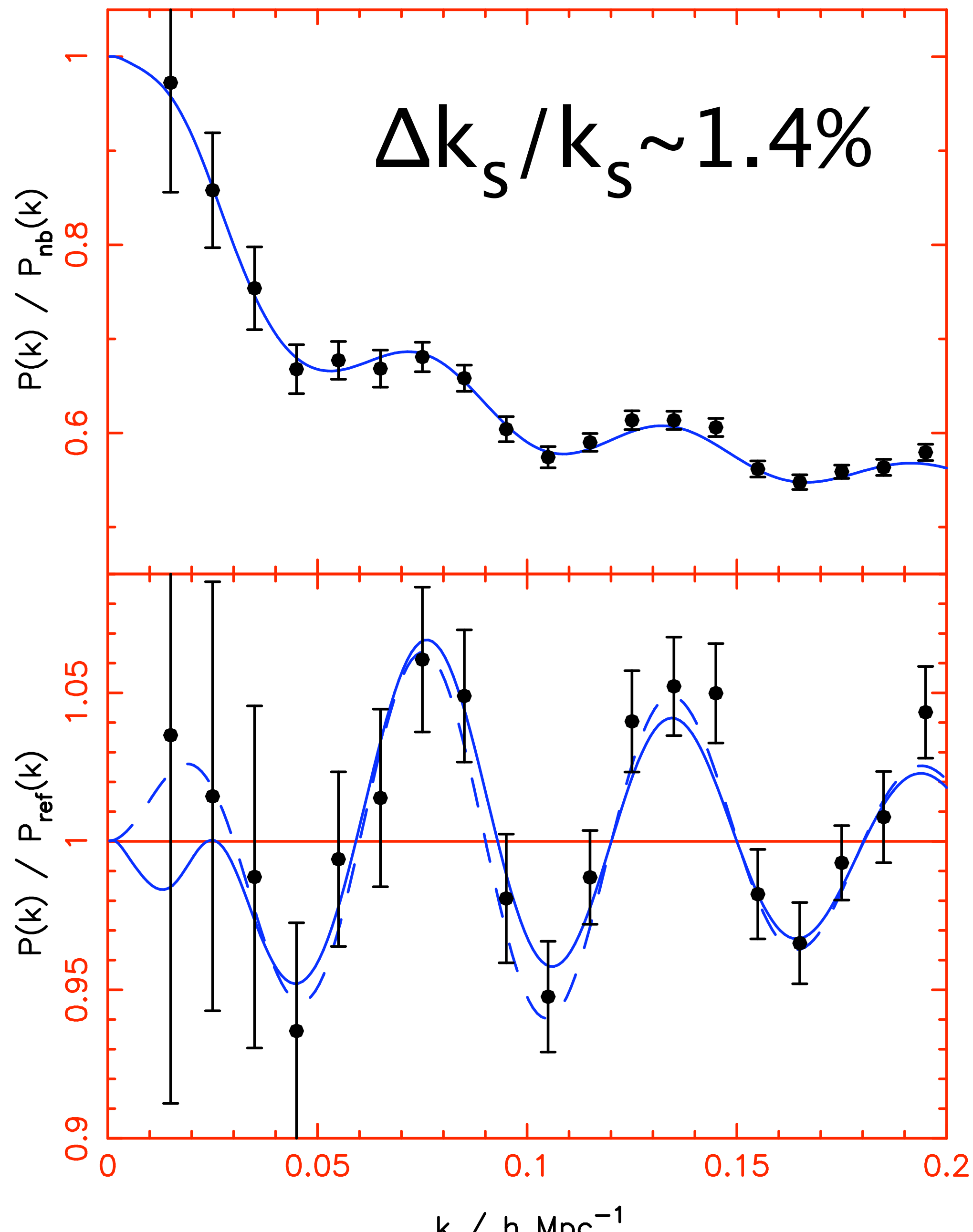
Simulated high-z surveys

2×10^6 galaxies

$0.5<z<1.3$

600 deg^2

($6\,V_{sloan}$)

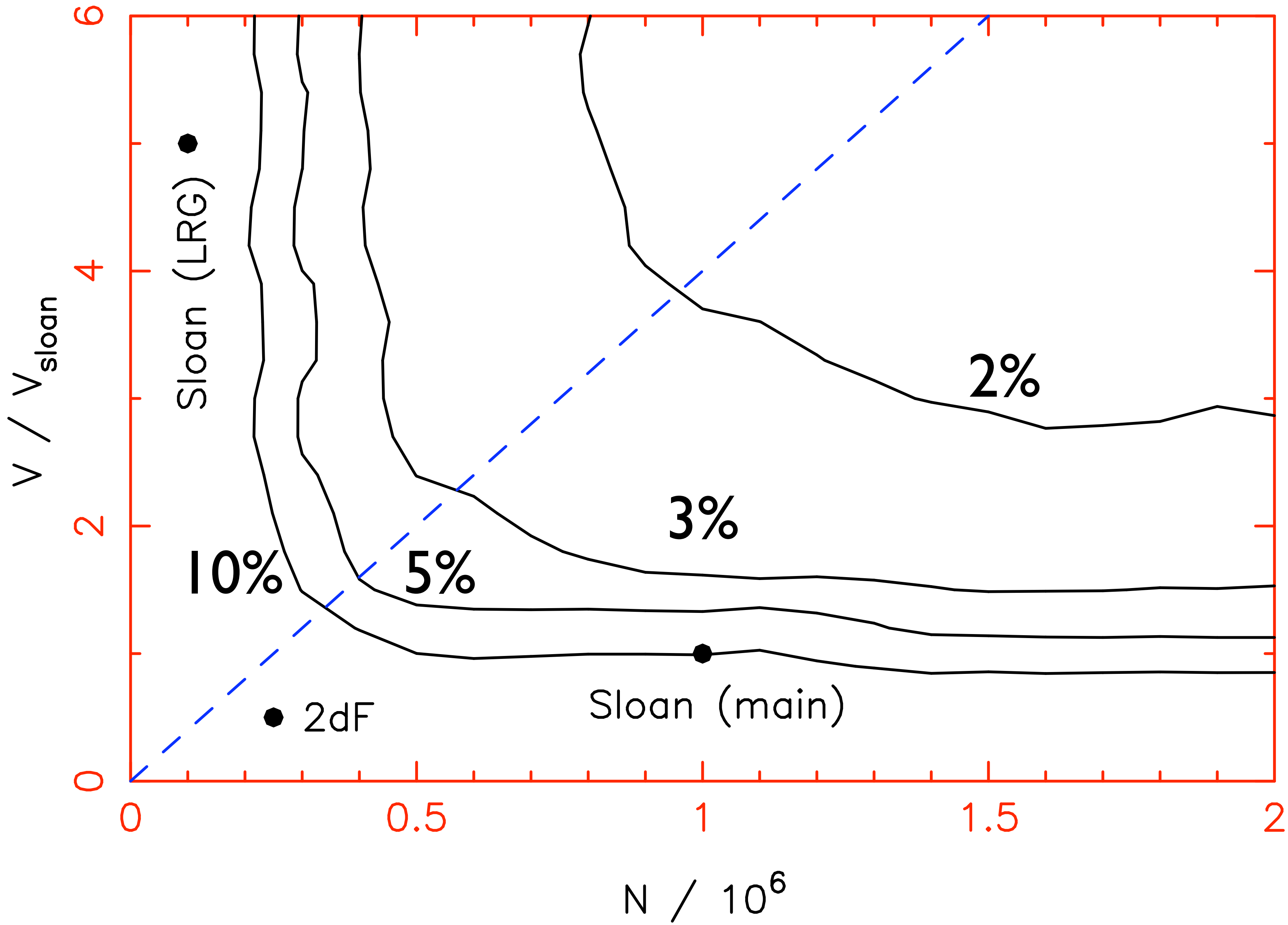


Blake & Glazebrook 2003

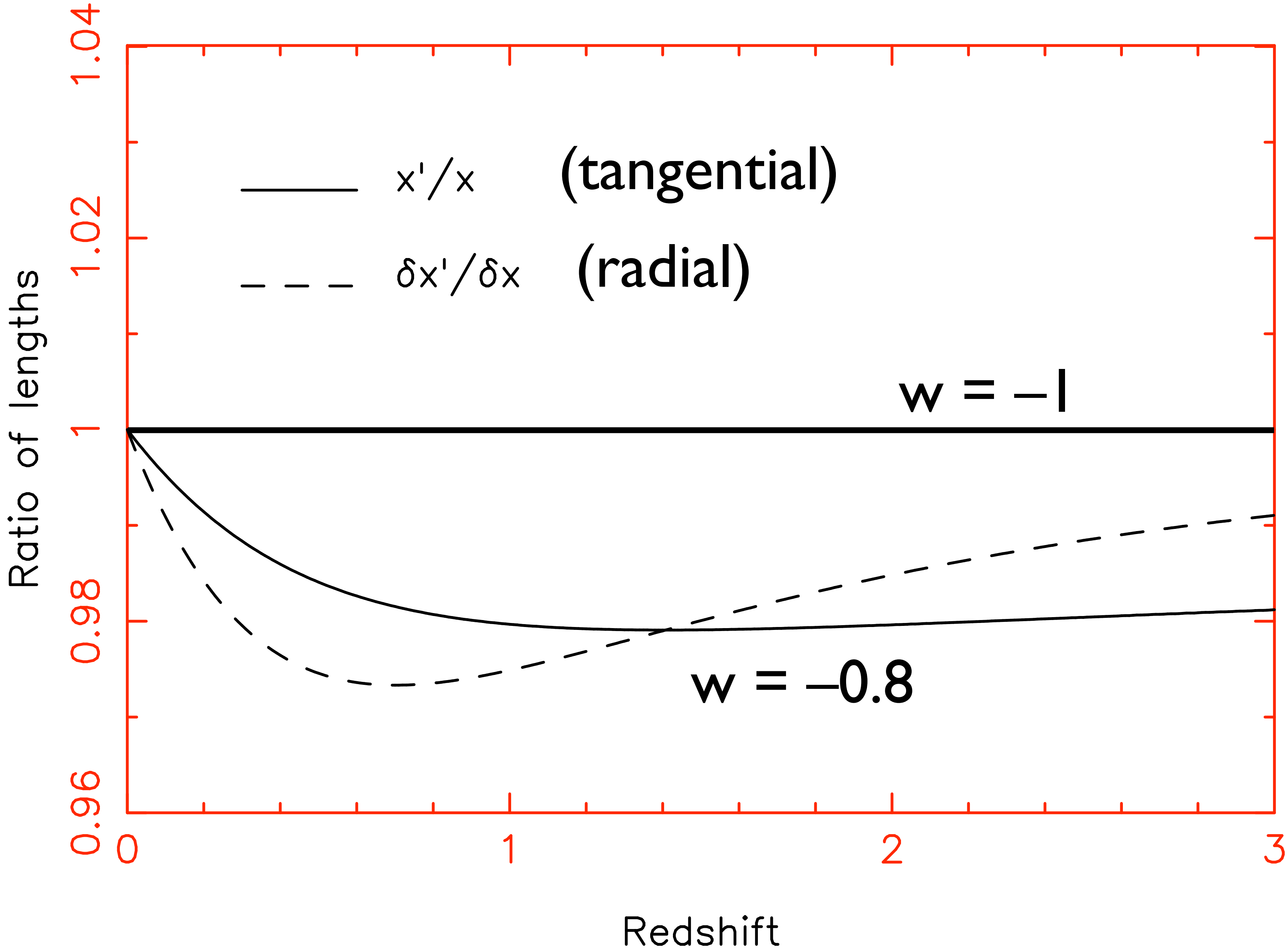
(ApJ 594, 665)

- Remove overall shape from P(k)
- Fit model of exponentially decaying sinusoid, treat wavescale as free parameter
- k_s(true)–k_s(measured) represents accuracy one can recover D(z)
- i.e. Δk_s = 1% at z=1 means D(z=1) is determined to 1%

Precision vs Size



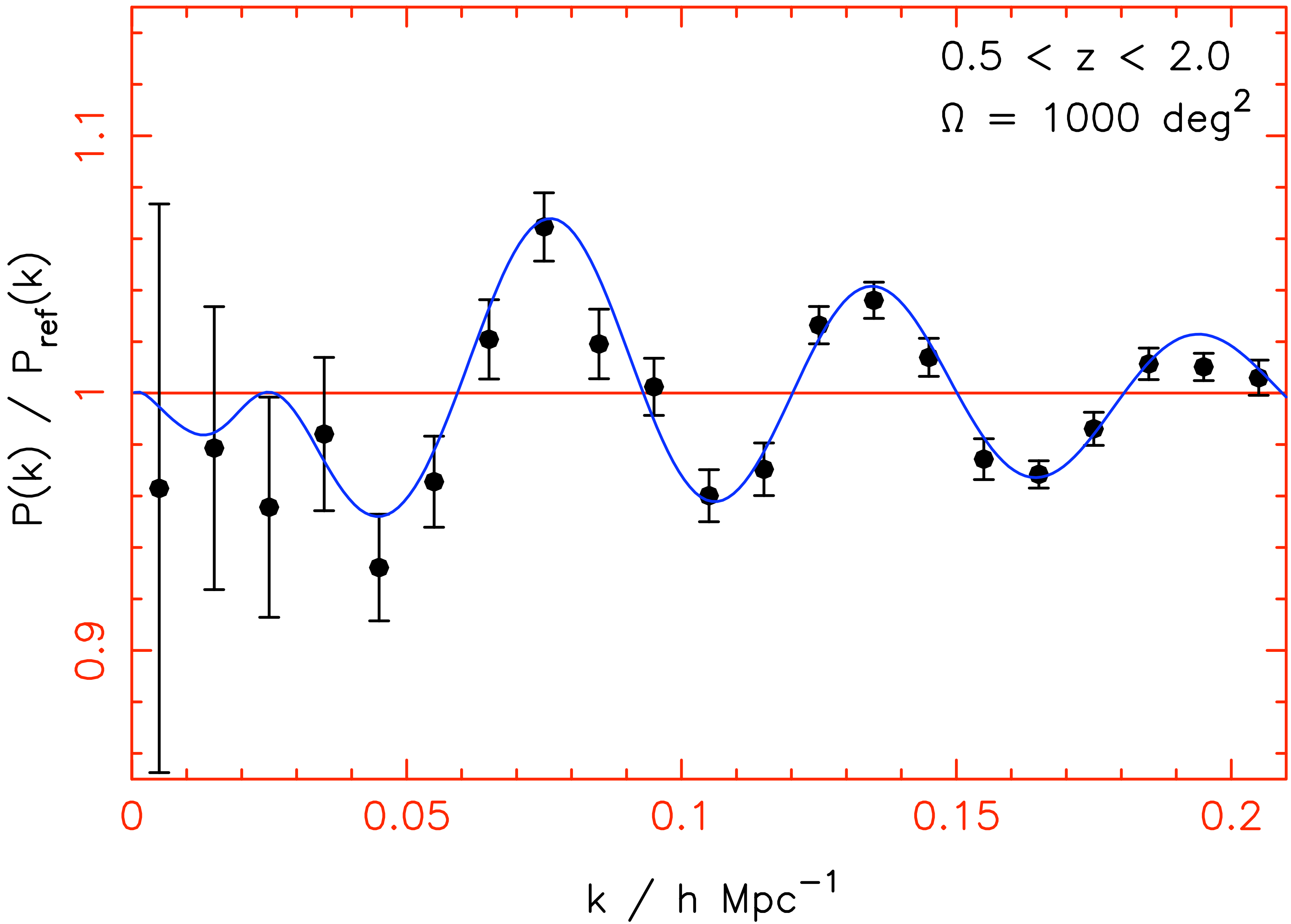
Required accuracy



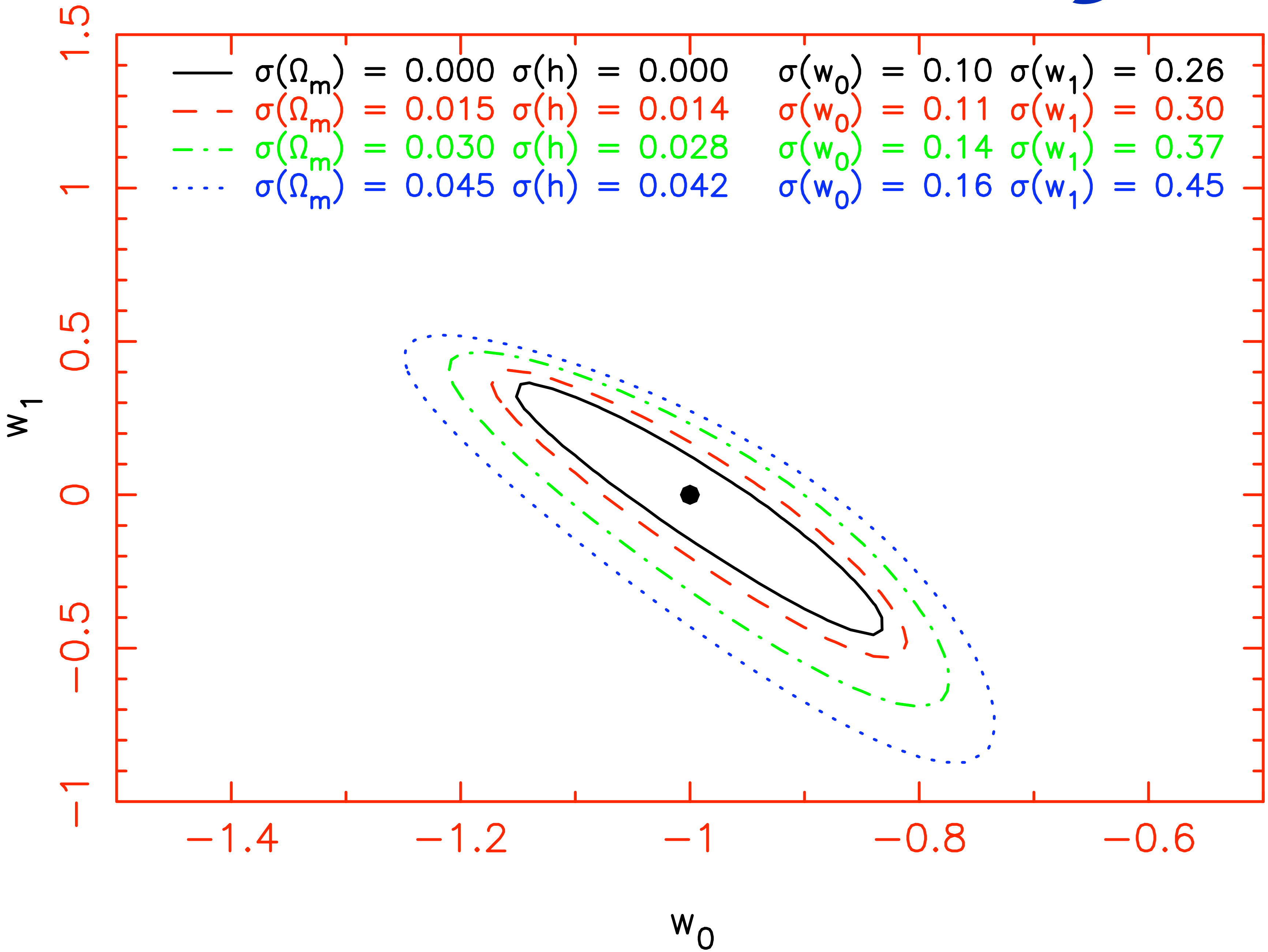
Simulated FMOS surveys

- Assume 1000 deg^2 ~ 5×10^6 galaxies
- Redshift coverage $0.5<z<2$ (Hα from 1–2μm)
- $w(z) = w_0 + w_1 z$
- How well can one do?

Simulated P(k)

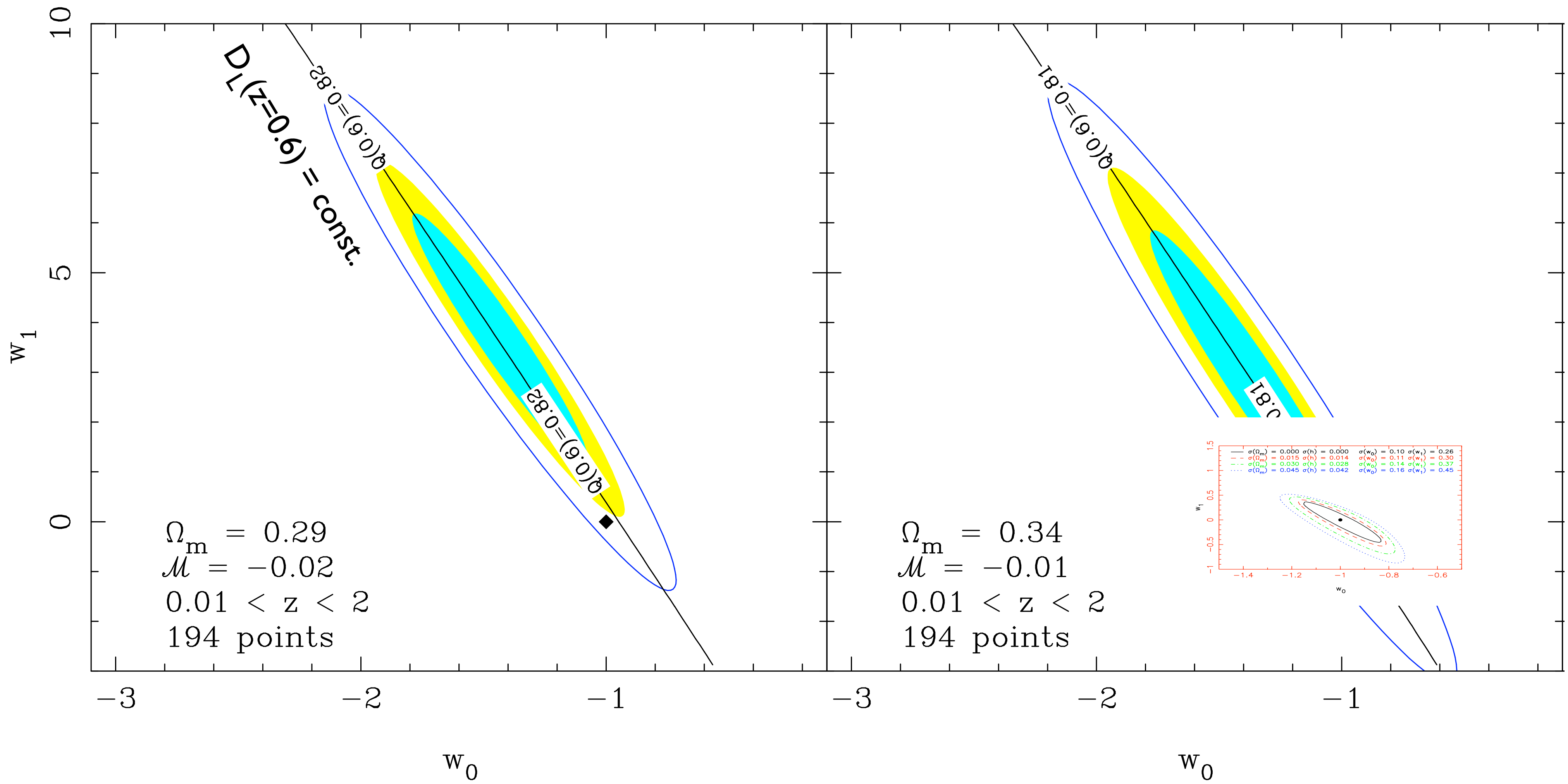


FMOS survey



σ(Ω_m) = 0.000 σ(h) = 0.000 σ(w_0) = 0.10 σ(w_1) = 0.26
σ(Ω_m) = 0.015 σ(h) = 0.014 σ(w_0) = 0.11 σ(w_1) = 0.30
σ(Ω_m) = 0.030 σ(h) = 0.028 σ(w_0) = 0.14 σ(w_1) = 0.37
σ(Ω_m) = 0.045 σ(h) = 0.042 σ(w_0) = 0.16 σ(w_1) = 0.45
1.5
1
0.5
0
−0.5
−1
w_1
−1.4
−1.2
−1
−0.8
−0.6
w_0

How competitive?



Choudhury & Padmanabhan (flat models)

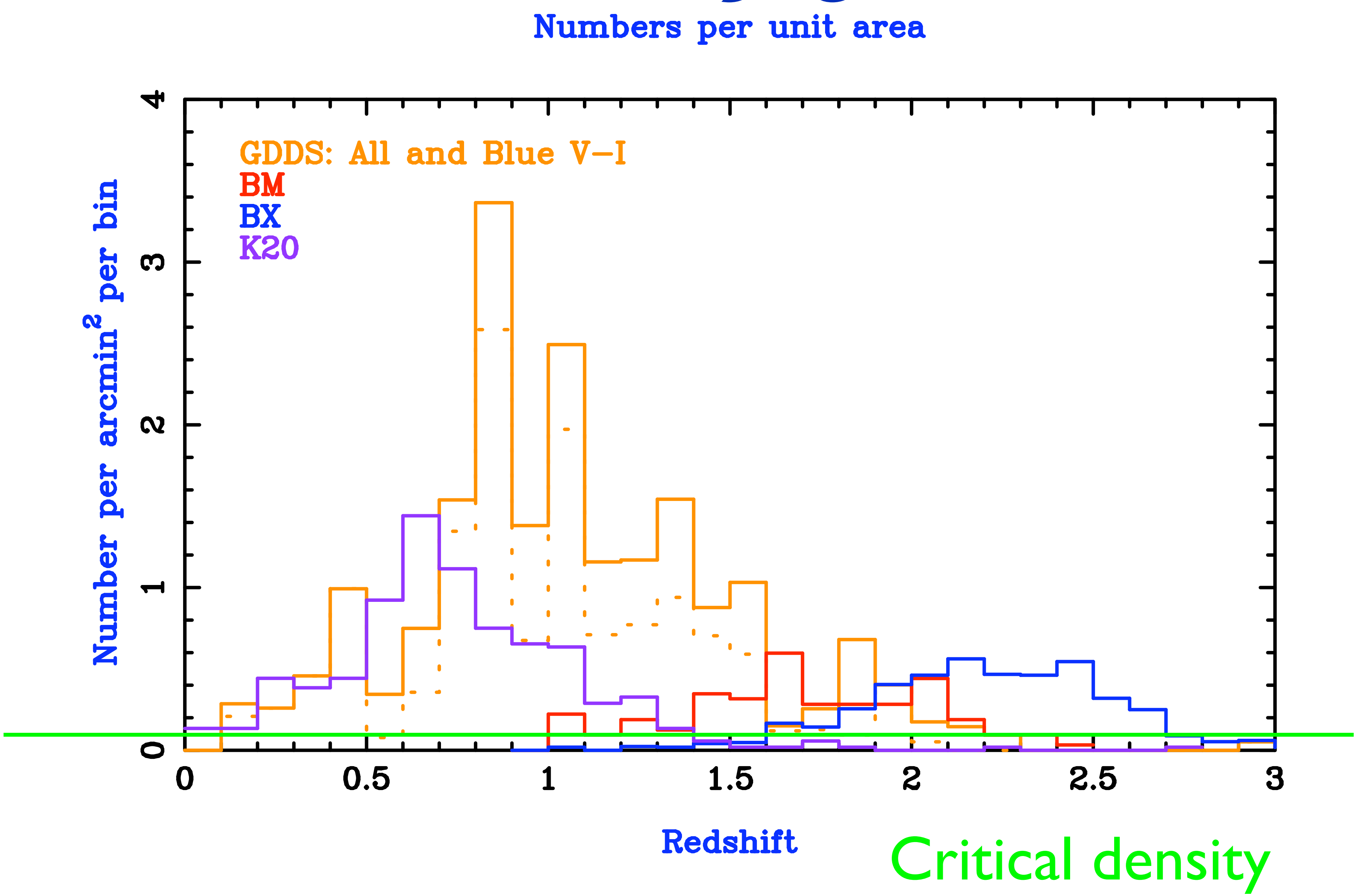
Very!

Great, but realistic?

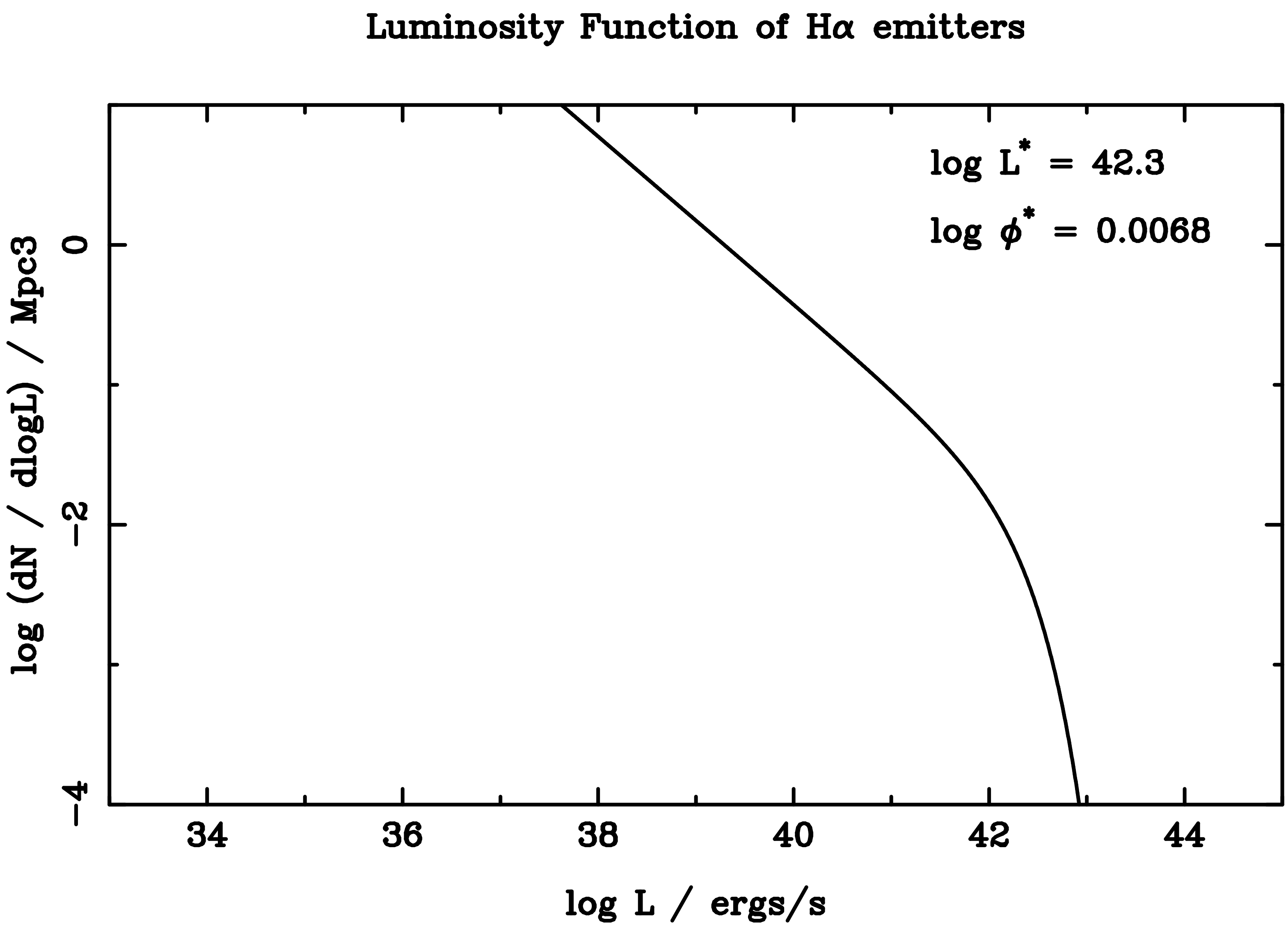
- Survey areas 500 - 1000 deg^2 required
  - (2000 - 4000 FMOS fields!)

- Exposure times and target selection?
- Galaxy numbers:
  - Critical space density:
    1.3×10^{-3} galaxies/Mpc^3
    $\equiv$1000 galaxies/deg^2/Δz=0.2 bin ($1<z<2$)

Numbers of galaxies

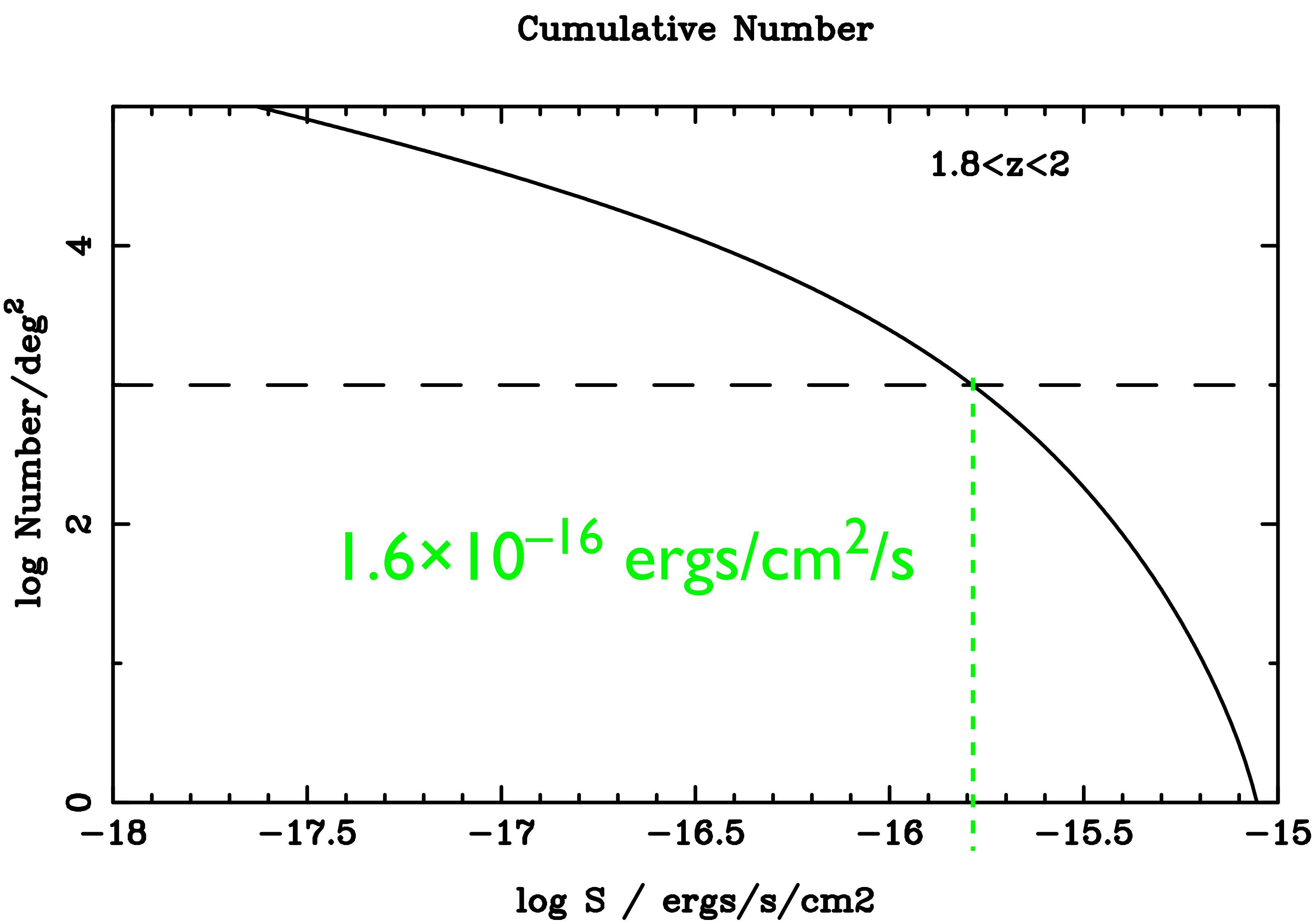


Hα LF z>1



LFs: Hopkins et al. , Yan et al.

Hα number-flux z>1



Easy?

FMOS numbers

User inputs in bold

Wavelength	**18000**	Angstroms
Galaxy mag at wavelength	**22.3**	AB mags
Line Flux in SRE	**16**	1e-17 ergs/cm2/s
Fraction of light in aperture (fudge)	**0.7**	e.g. 0.7 for slit width ~ seeing
Mag in slit	22.6872549	mags
Fnu from object cuum	3055.795513	nJy/m^2
Flambda from object cuum	2.82944E-22	W/m^2/A
Photons from object cuum	0.002560579	ph/m^2/A/sec
Photons from object line	1.013574661	ph/m^2/sec
Telescope area	**40**	m^2
System efficiency atm->detector	**20**	%
Exposure time for one integration	**900**	***seconds on target***
Spectral SRE size	27	Angstroms
SRE size along slit	1.26	arcsec
Slit width	1.26	arcsec
Detected object electrons	497.7766447	per SRE
Detected line electrons	7297.737557	per SRE
Cuum Signal/noise per integratio	**2.663614873**	**per SRE**
Line Signal/noise per integration	[illegible]	
Number of integrations	[illegible]	
Total exposure	900	secs

Mag zero point	**3631**	Jy (AB mags)	
Sky brightness	**19.4**	mags/arcsec^2	**inter-OH**
Fnu from sky	63099.54809	nJy/m^2/arcsec^2	
Flambda from sky	5.84255E-21	W/m^2/A/arcsec^2	
Photons from sky	0.052873762	ph/m^2/A/sec/arcsec^2	
Pixel spatial size	**0.42**	arcsecs	
Pixel spectral size	**9**	Angstroms	
Object spatial size	**3**	pixels	
Slit width	**3**	pixels	
Dark count rate	**0**	electrons/sec/pix	
Scattered OH rate	**0**	electrons/sec/pix	
True sky	2.014617246	electrons/sec/pix	
Readnoise	10	electrons/sec/pix	
Det .back. electrons	16318.39969	per SRE	
Back. noise	131.2188999	per SRE	
Sky subtraction fac.	**1.414**	sqrt(2) or 1	
Sky/Object cuum	**32.782574**	**per SRE**	
Spec Resolution R=	666.6666667		

Practical survey

- Need wide-field deg-scale IR spectrograph: FMOS and ??
- ~ 5 bins width $\Delta z=0.2$ covering $0.5<z<2$ (1–2 μm coverage minus atmospheric gaps)
- ~5000 galaxies / deg^2 = 900 per FMOS FOV (note number of galaxies required $\propto$ $bias^{-2}$)
- 1000 deg^2 requires 300 clear Subaru nights at 30 mins per field. ~ 2dF survey. (interesting w(z) for ≥ 500 deg^2)

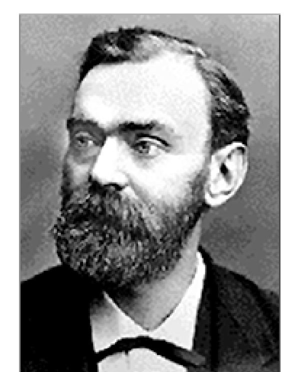
Issues

- Looks easy but can we SELECT the Hα bright population to put fibers on them??
  - Narrow band imaging?
  - Broad-band imaging +photo-z + rest-frame UV cut?
- Need a LOT of deep imaging data over hundreds deg^2.
- Even at ~ 1 hour per field can still cover substantial volume and do this science

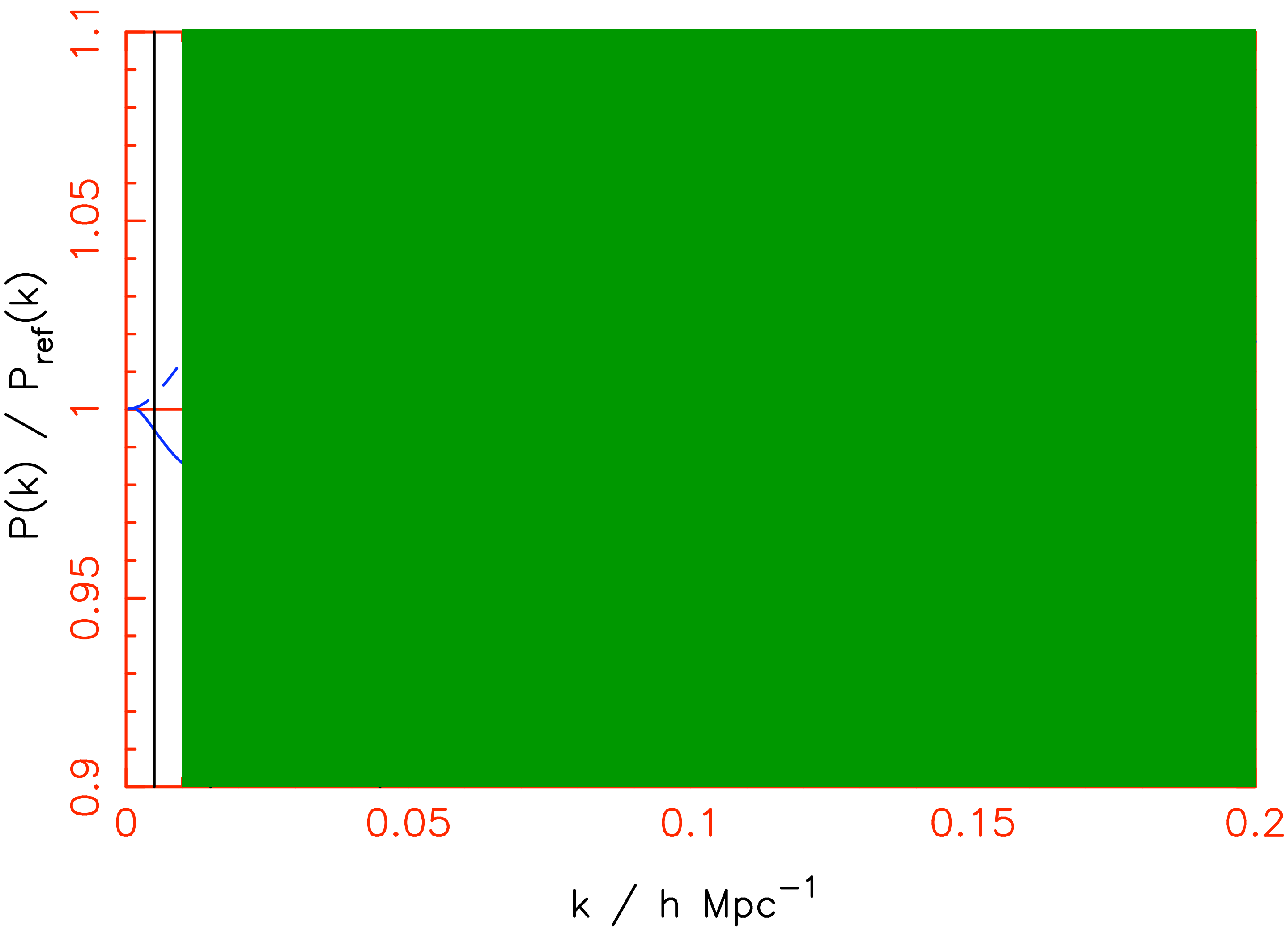
Conclusions

- FMOS measurement of cosmic sound is possible, and can be quite precise.
- Can constrain dark energy *equation of state* to an order of magnitude better than current/near-future SNe data
- No other instrument can do this
- Can be done in feasible number of nights
- Result would be of major cosmological significance. Major FMOS success.

Go for it!



Photometric redshifts?



$$\times \exp\left(-\frac{k_z^2}{k_0^2}\right)$$

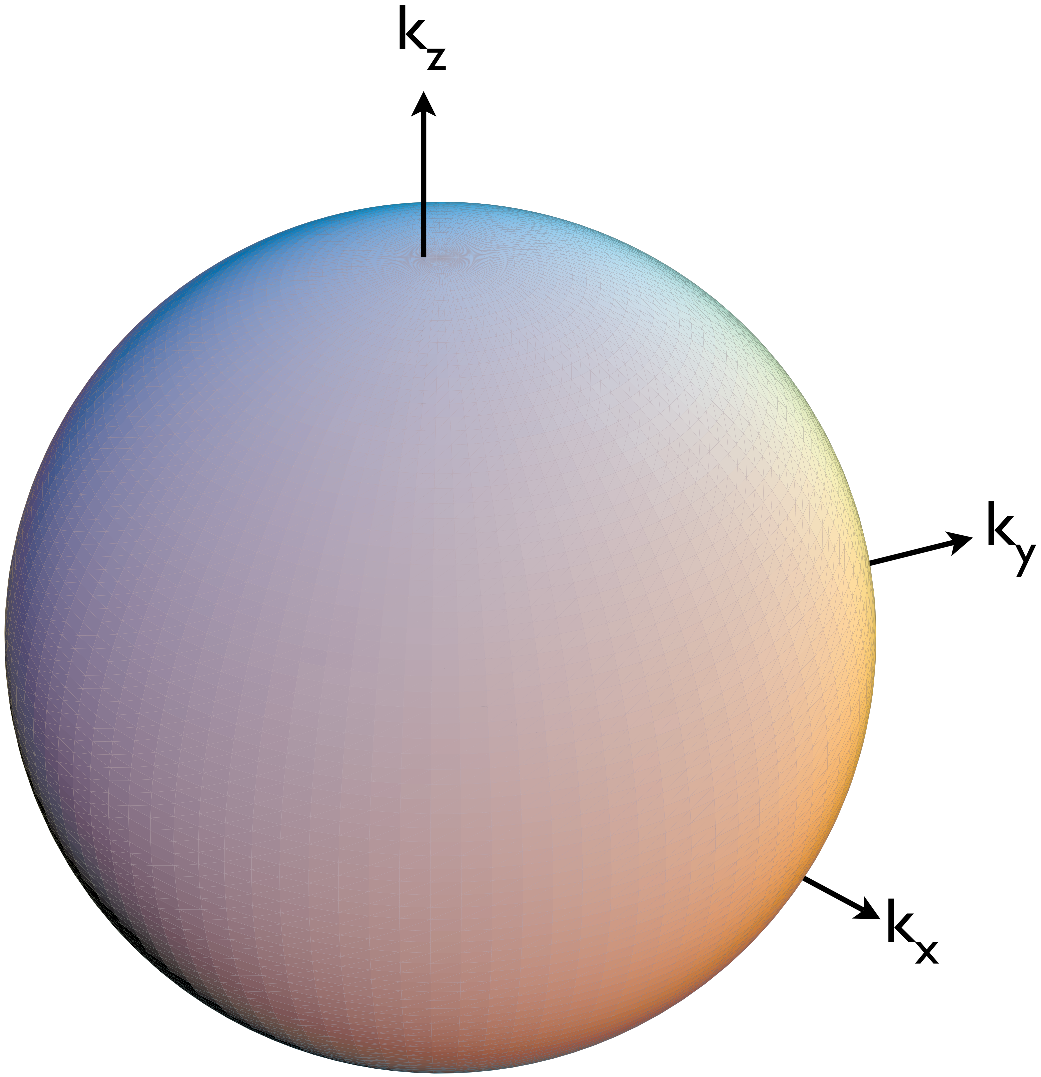
suppressed *radial* modes.

If $\frac{\sigma_z}{1+z} = 0.03$

$\Rightarrow k_0 = 0.01$ at z=1

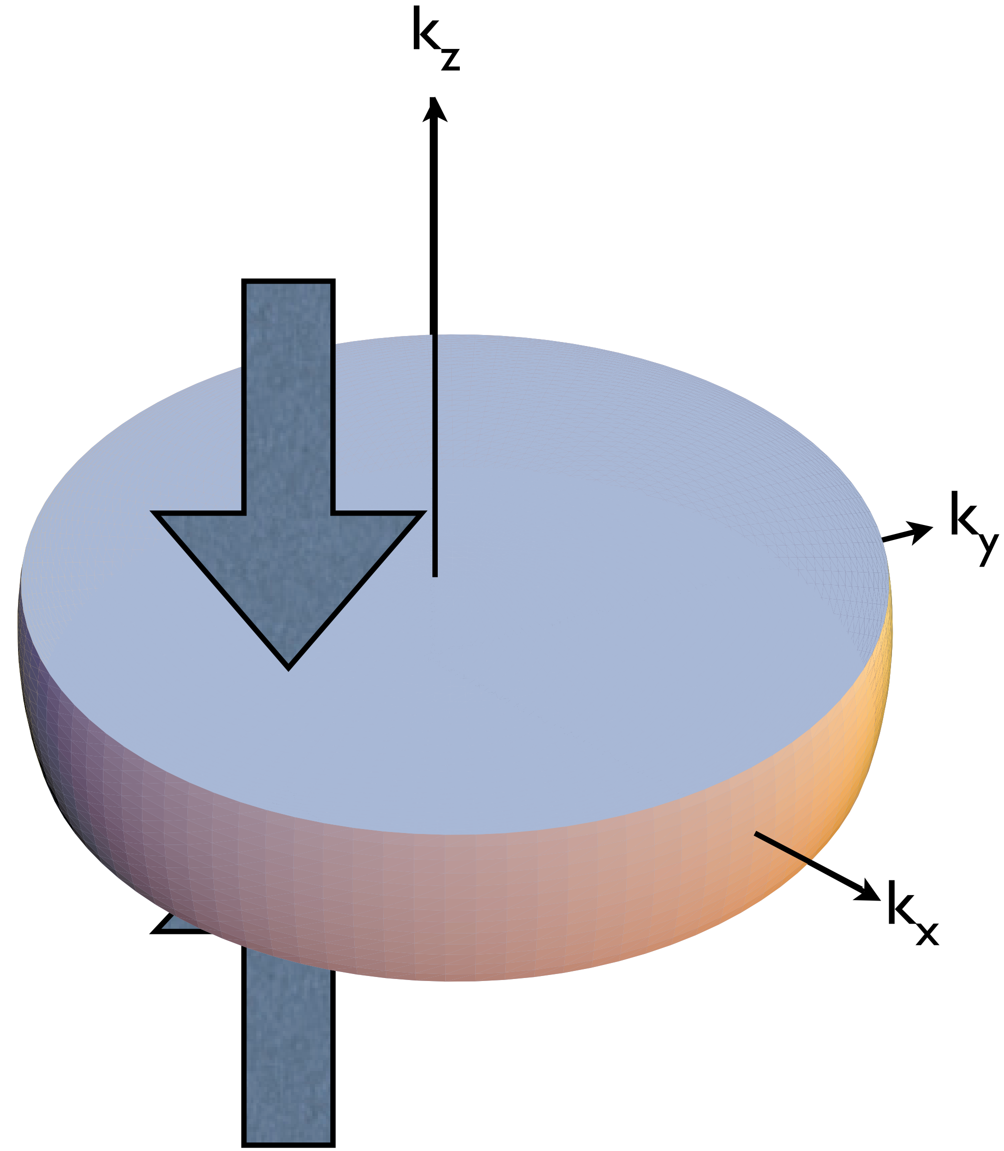
(i.e. only see >100 Mpc modes)

Spectroscopic survey |k|<0.2



N modes

Photo-z survey



N/20 modes for $\frac{\sigma_z}{1+z} = 0.03$