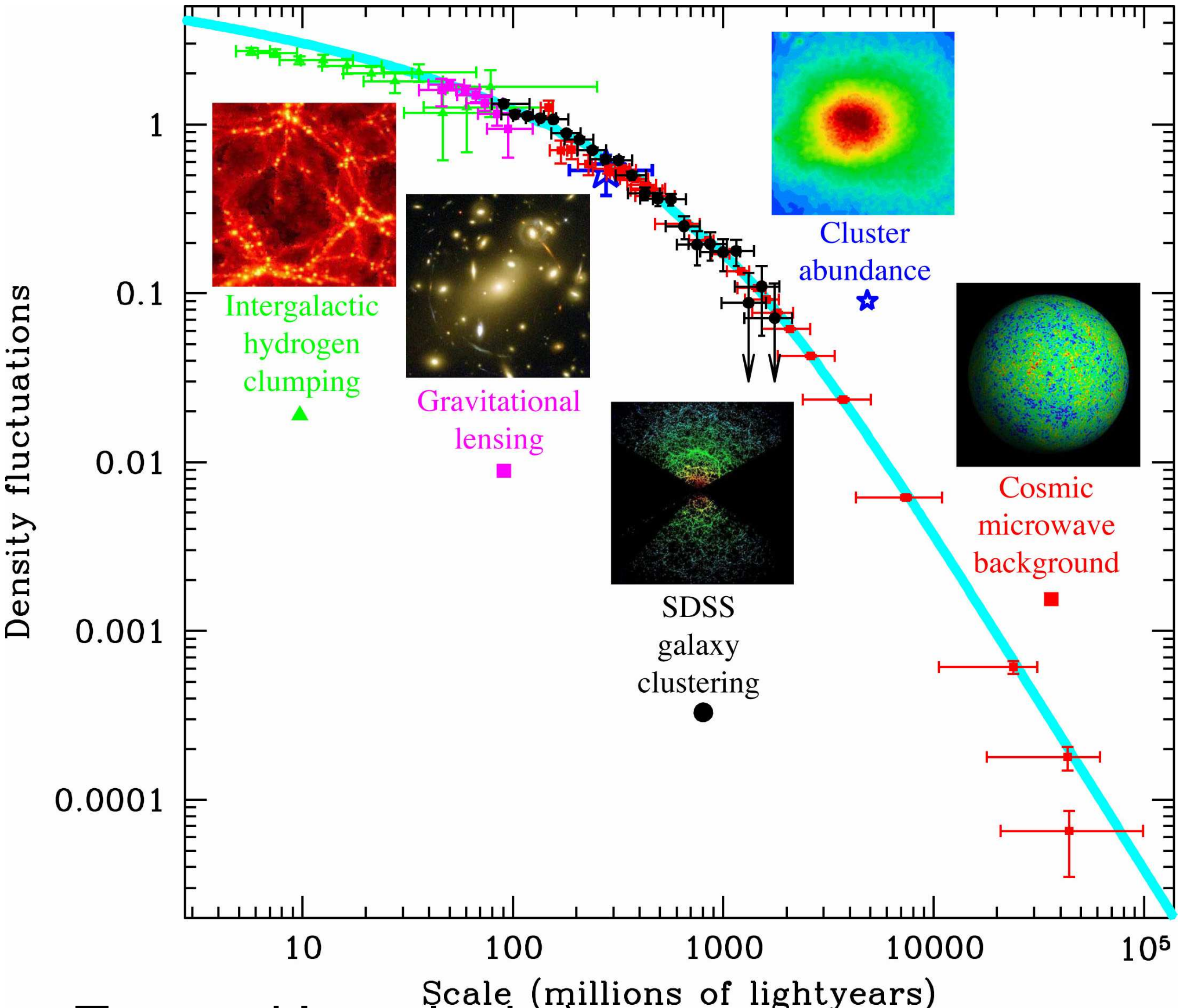
Forest in the Sky

Based in part on a lecture by X. Fan

Part II.
From Spectra
To Cosmology

Cosmology In Arabic



(from Max Tegmark's web site)

Measuring the Matter Power Spectrum From the Lyman-α Forest

$$\tau(u_o) = \sum \int_{u_A}^{u_B} \frac{n_{\mathrm{H\,I}}}{1+z} \left| \frac{du}{dx} \right|^{-1} \sigma_\alpha \, du$$

$$\sigma_\alpha = \sigma_{\alpha,0} \frac{c}{b\sqrt{\pi}} e^{-(u-u_o)^2/b^2} \, .$$

$$u \equiv \frac{\bar{H}}{1+\bar{z}} (x - \bar{x}) + v_{\mathrm{pec}}(x) \, ,$$

Let’s ignore thermal broadening and peculiar velocities

Fluctuating Gunn-Peterson Approximation

$$u_o \equiv \frac{\bar{H}}{1+\bar{z}}\,(x-\bar{x})$$

$$\begin{aligned}
\tau \propto \rho_b^2 T^{-0.7} &= A\rho_b^{\beta}\ , \\
A &= 0.433\left(\frac{1+z}{3.5}\right)^{6}\left(\frac{\Omega_b h^2}{0.02}\right)^{2}\left(\frac{T_0}{6000\ \mathrm{K}}\right)^{-0.7} \\
&\quad \times \left(\frac{h}{0.65}\right)^{-1}\left[\frac{H(z)/H_0}{3.68}\right]^{-1} \\
&\quad \times \left(\frac{\Gamma_{\mathrm{H\,I}}}{1.5\times 10^{-12}\ \mathrm{s}^{-1}}\right)^{-1}\ ,
\end{aligned}$$

FGPA II

In FGPA there is a direct non-linear local relation between the gas density and the optical depth or flux.

⇓

The flux and the matter power spectra are linearly biased with respect to each other on sufficiently large scales.

Measuring the Flux PS

- For a given cosmology, run a PM simulation with > 20 chimp box size.
- Assume T_0, γ, and A.
- Generate many LOSs.
- Measure flux power spectrum – this is 1D PS.
- Turn 1D into 3D.

$$P_F(k) = -\frac{2\pi}{k}\frac{d}{dk}P_{F,1\mathrm{D}}(k)$$

Main Assumption

$$P_{\mathrm{F}}(k) = b^2(k) P_{\mathrm{L}}(k)$$

(and, actually, b(k) = const on large scales)
It does not have to be true, but it actually is.

Use a simulation to measure b(k).

In Practice:
Mean Opacity

- We have flux as a function of velocity: F(u)
- Compute the fluctuations in the flux: δF/<F>

A tricky part:

- Observationally we can measure <F>

- Theoretically, we must normalize our spectra to have the same <F>, or, equivalently:

$$\bar{\tau}_{\rm eff} \equiv -\log\left(1 - {\rm DA}\right) \equiv -\log\left(\langle F \rangle\right)$$

In Practice:
Fixing Loose Ends

Recall:

$$n_{\mathrm{HI}} = 3.0 \times 10^{-11} A \left(\frac{1+z}{4} \right)^6 (1+\delta)^{2-0.7(\gamma-1)} \ \mathrm{cm}^{-3}$$

$$A = \left(\frac{2 \times 10^4 \, \mathrm{K}}{T_0} \right)^{0.7} \left(\frac{\Omega_b h^2}{0.02} \right)^2 \left(\frac{0.5}{J_{\mathrm{HI}}} \right)$$

Thus: $\tau_{\mathrm{eff}} = \tau_{\mathrm{eff}}(A)$.

$\tau_{\mathrm{eff}}(A) = \tau_{\mathrm{eff,\,obs}} \rightarrow A$

In Practice: Mean Opacity II

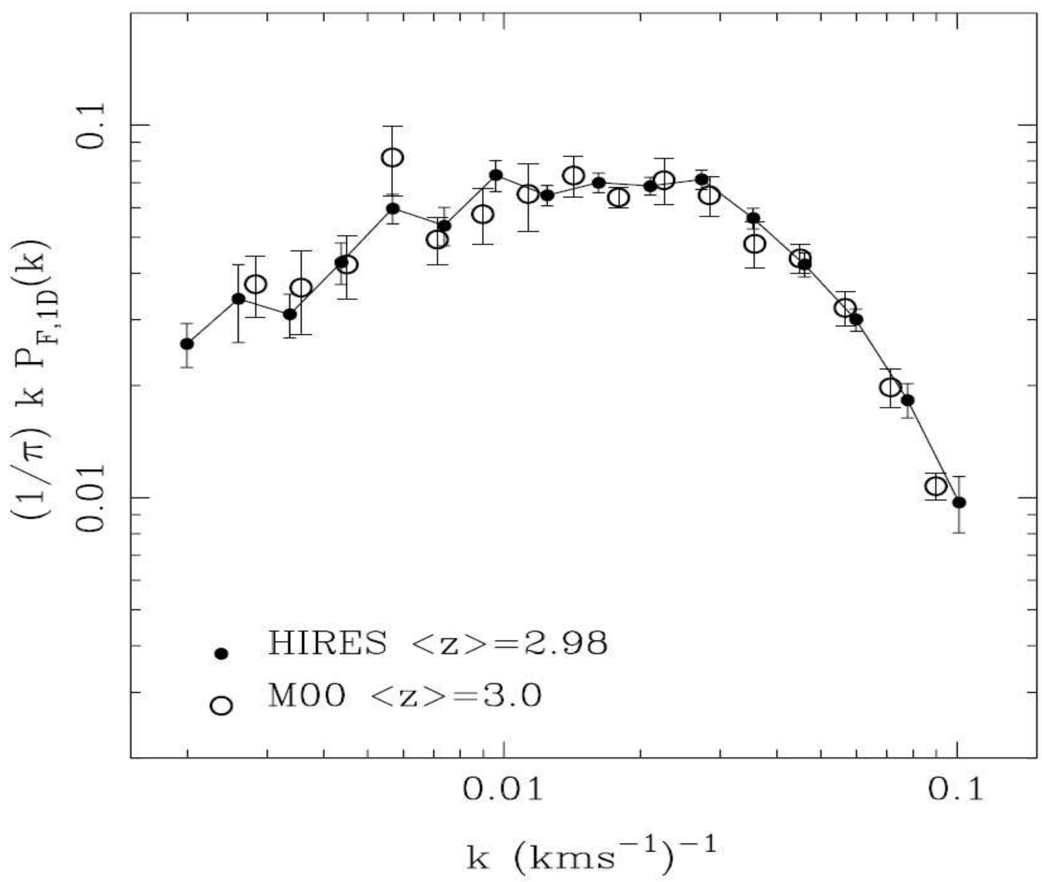
The most accurate measurements come from Kirkman et al, 2005, MNRAS, 360, 1373:

Table 2. Measured IGM DA values in $\Delta z = 0.2$ redshift bins.

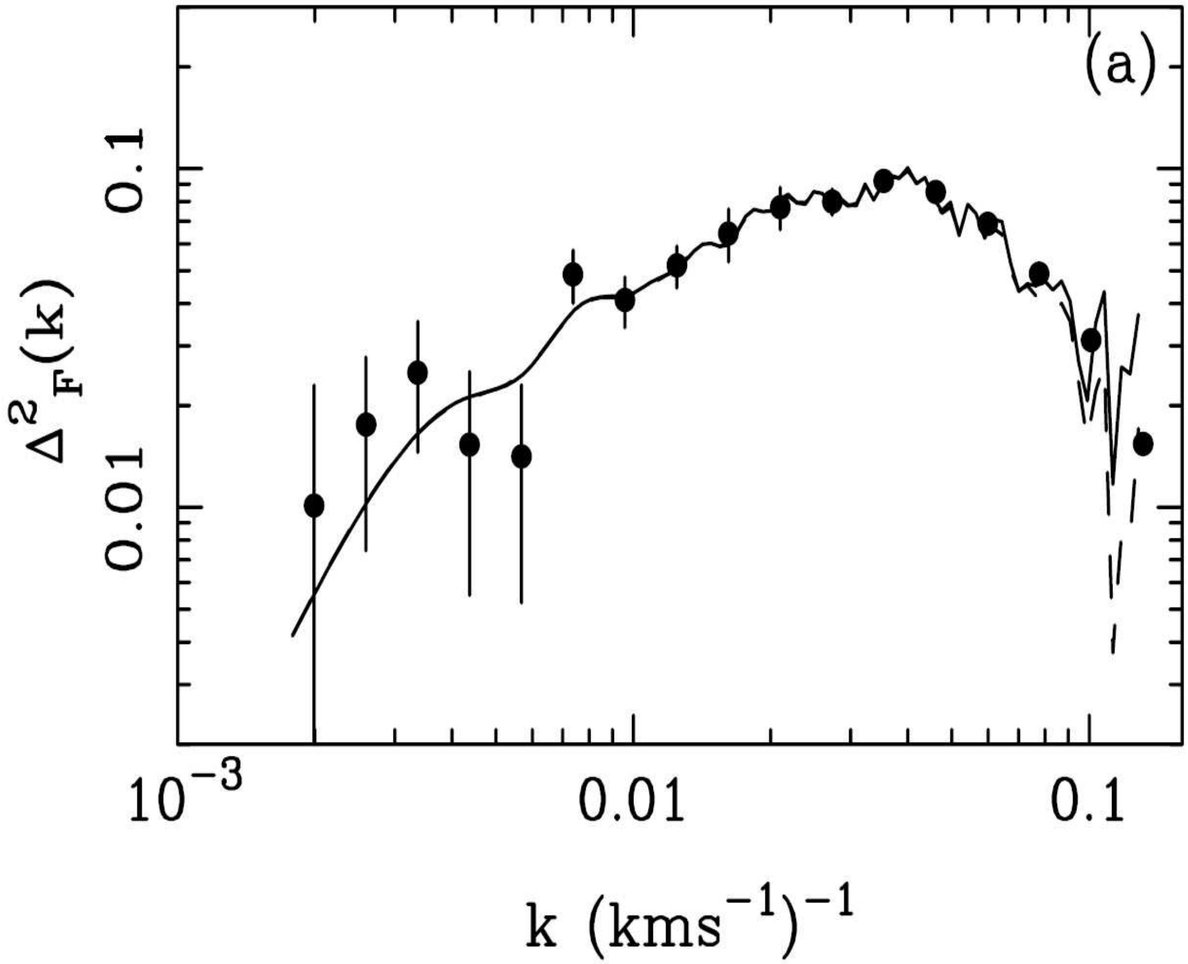
z centre	DA	σ_{DA}	Fit DA	Fit σ_{DA}
1.6	0.098	0.015	0.0851	0.0057
1.8	0.099	0.006	0.1044	0.0055
2.0	0.128	0.006	0.1262	0.0055
2.2	0.143	0.013	0.1507	0.0054
2.4	0.202	0.014	0.1780	0.0059
2.6	0.213	0.014	0.2083	0.0074
2.8	0.250	0.016	0.2417	0.0101
3.0	0.252	0.015	0.2783	0.0139
3.2	0.338	0.024	0.3183	0.0187

In Practice: 1D Flux Power Spectrum

(Croft et al. 2002, ApJ, 581, 20)



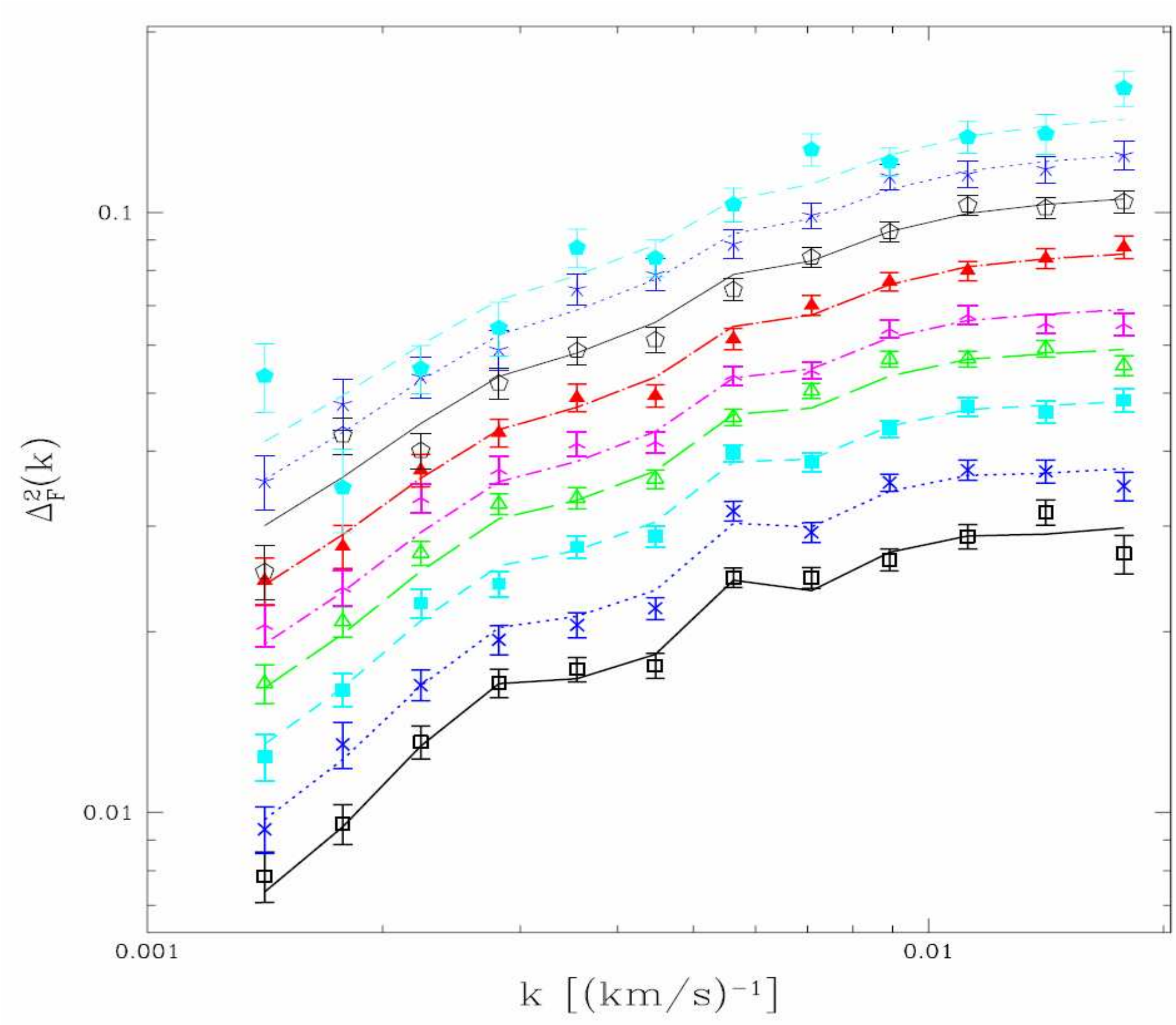
In Practice:
3D Flux Power Spectrum



$$\Delta_F^2(k) \equiv \frac{1}{2\pi^2} k^3 P_F(k)$$

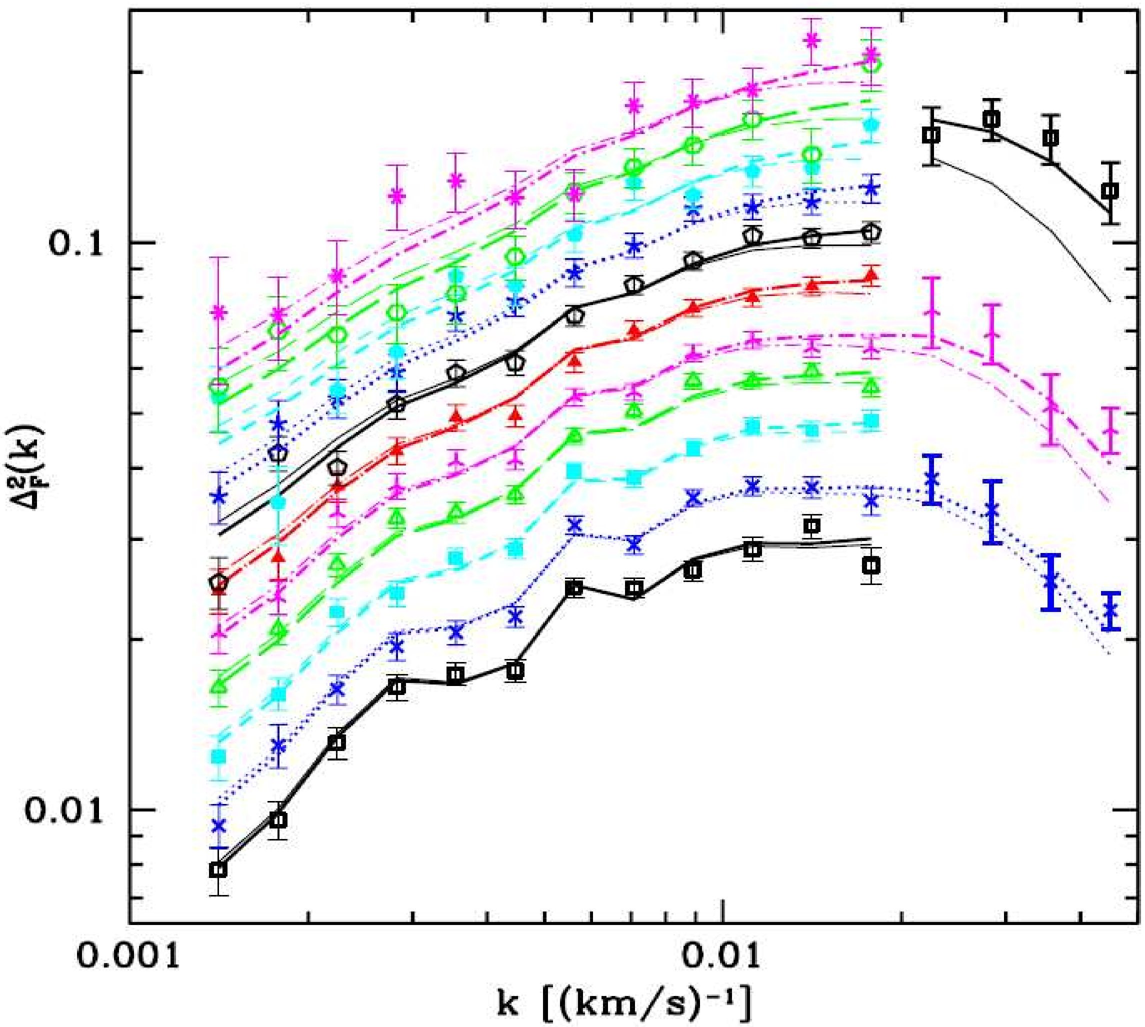
(dimensionless)

In Practice:
The Power of Sloan



z
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2

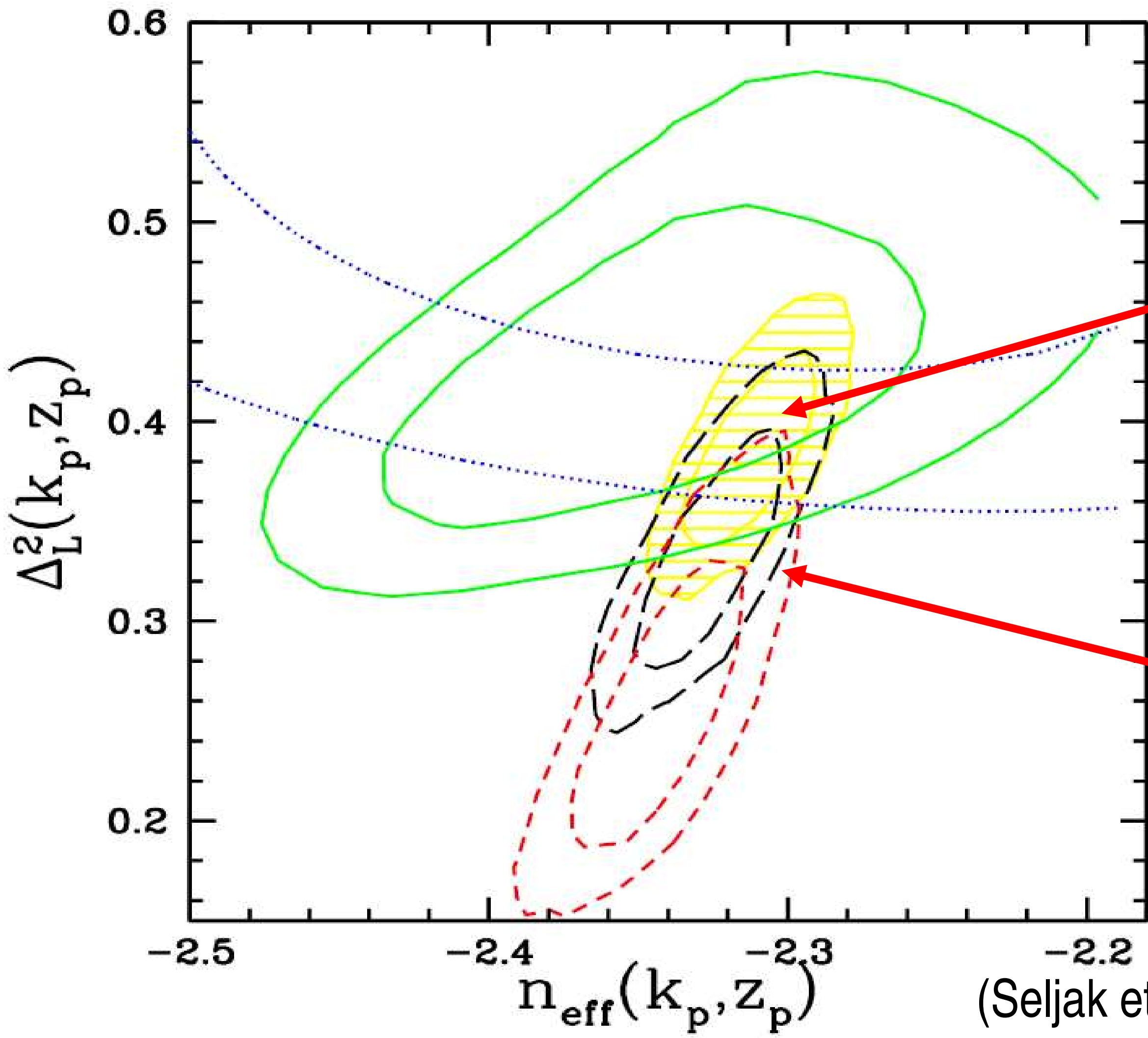
In Practice:
The Power of Sloan II



Uros Seljak:

~~Sterile neutrino~~

In Practice:
The Power of Sloan III
(and a vision test)

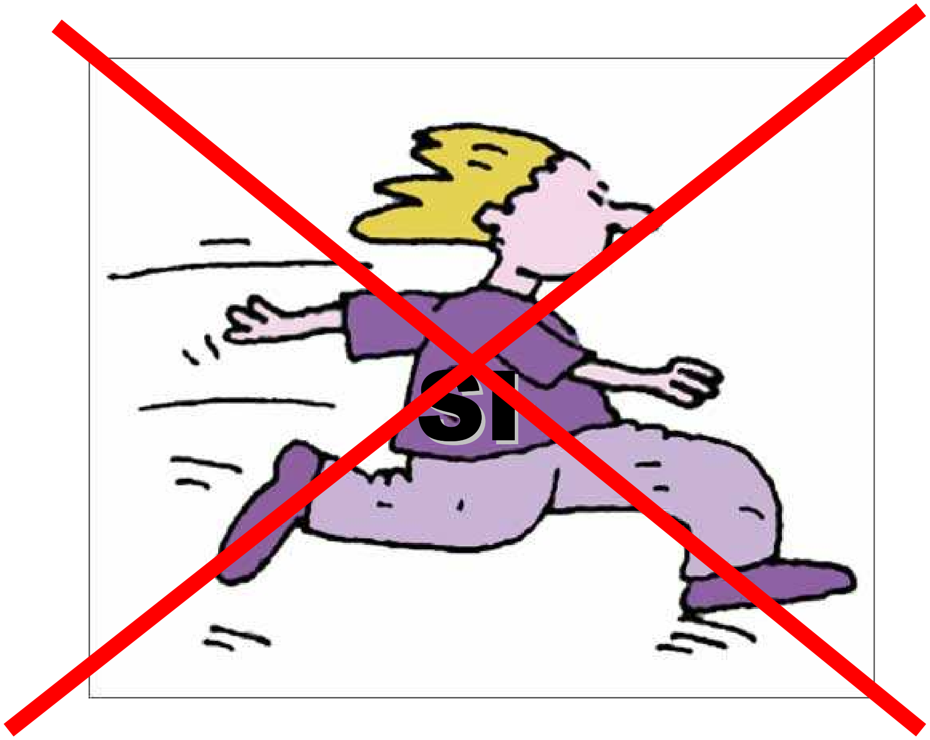


With Ly-a forest

W/o Ly-α forest

(Seljak et al 2006, astro-ph/0604335)

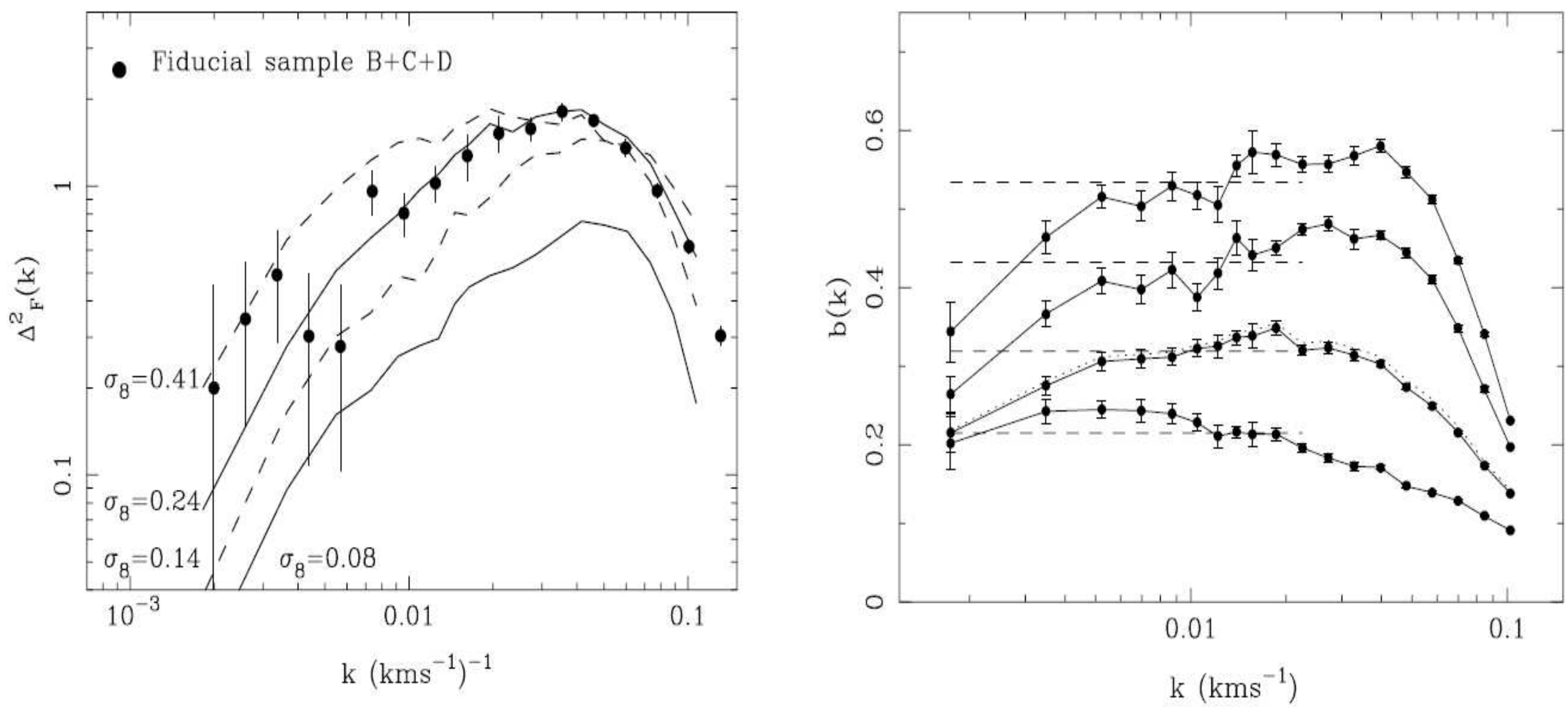
In Practice:
The Power of Sloan IV



(Seljak et al 2006, astro-ph/0604335)

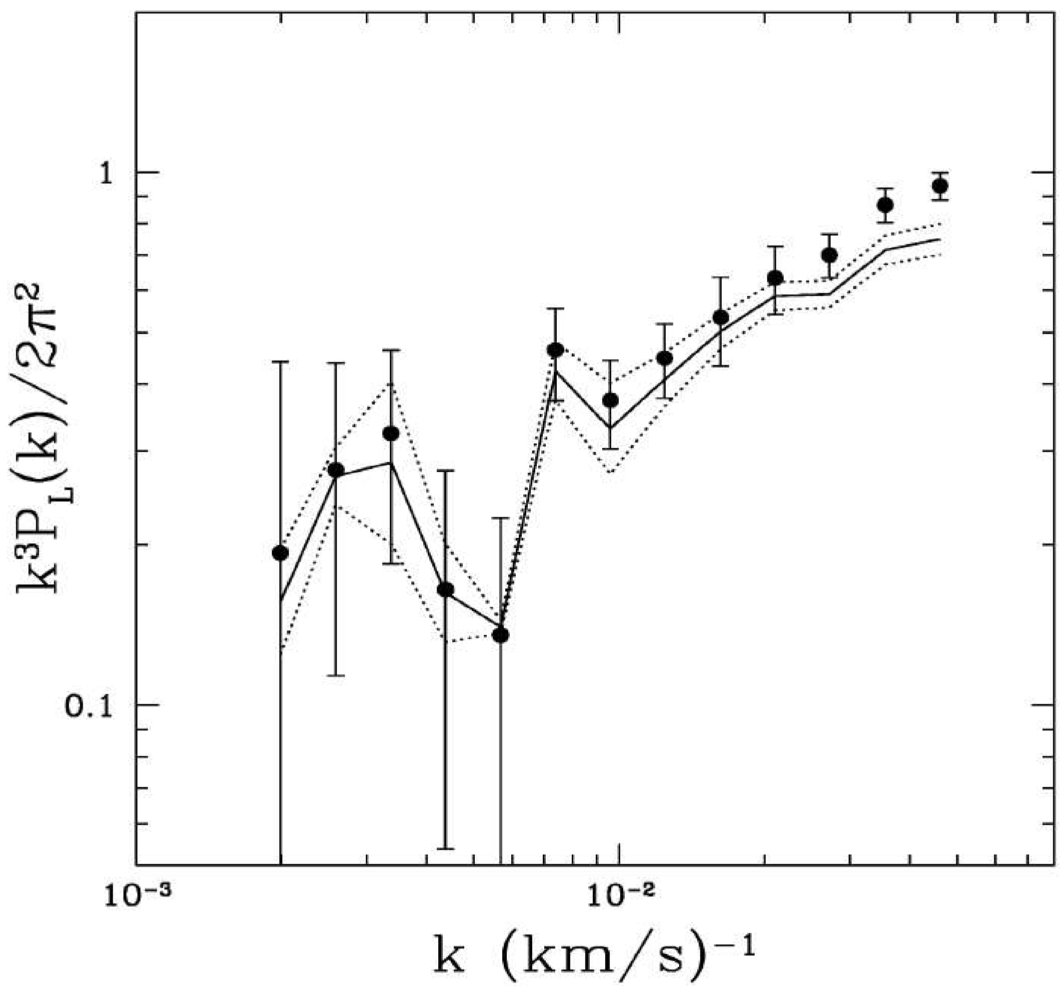
In Practice:
Measuring the Bias

Using a simulation to fit the data:



Main conclusion: $b[k,P_L]$, not constant

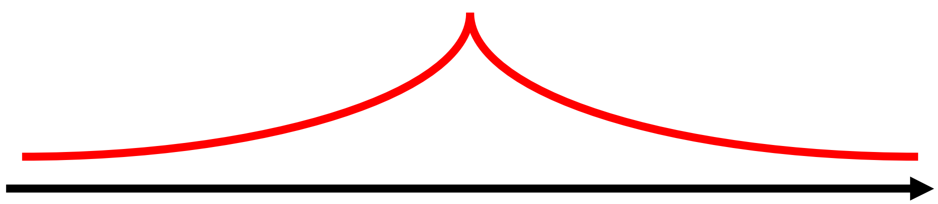
In Practice: Recovered Matter Power Spectrum



The Devil is in the Details

Computing the flux power spectrum:

- Have $\delta(x)$, need δ_k
- Use FFT? But a LOS is not periodic!
- Solution #1: make it periodic with a mirror flip



- Solution #2: Use Lomb Periodogram

Lomb Periodogram

$$P_N(\omega) \equiv \frac{1}{2\sigma^2}\left\{ \frac{\left[\sum_j (h_j - \overline{h})\cos\omega(t_j-\tau)\right]^2}{\sum_j \cos^2\omega(t_j-\tau)} + \frac{\left[\sum_j (h_j - \overline{h})\sin\omega(t_j-\tau)\right]^2}{\sum_j \sin^2\omega(t_j-\tau)} \right\} \qquad (13.8.4)$$

Equation # from The Book

Scales

- Filtering scale: 30 h^{-1} kpc
- Thermal broadening: 150 h^{-1} kpc
- Continuum fitting scale: 50 h^{-1} Mpc

A sensible simulation:

- 256^3
- Resolution ~80 h^{-1} kpc
- Box size ~20 h^{-1} Mpc

A superb simulation:

- 1024^3
- Resolution ~40 h^{-1} kpc
- Box size ~40 h^{-1} Mpc

The End

Title