

Beyond cosmological parameters

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**THE
COSMIC
SMÖRGÅSBORD**

CMB

GALAXY SURVEYS

DISTANT SUPERNOVAE

GRAVITATIONAL LENSING

BIG BANG NUCLEOSYNTHESIS

GALAXY CLUSTERS

LYMAN ALPHA FOREST

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THOSE PESKY PARAMETERS: WE'RE ZEROING IN! (August 2002)

•Matter Budget

■ Ordinary Matter	$h^2\Omega_b = 0.021^{+0.006}_{-0.006}$
■ Dark Energy	$\Omega_\Lambda = 0.66^{+0.10}_{-0.13}$
■ Cold Dark Matter	$h^2\Omega_c = 0.12^{+0.03}_{-0.03}$
■ Hot Dark Matter	$h^2\Omega_\nu = 0.001^{+0.04}_{-0.04}$
■ Photons	$h^2\Omega_\gamma = 0.0001$
■ Budget Deficit	$\Omega_k = 0.00^{+0.06}_{-0.06}$

(95% limits)

Dark Energy 66%

Ordinary Matter 5%

Cold Dark Matter 29%

•Early Universe

Scalar normalization	$Q \sim 10^{-5}$
Scalar tilt	$n = 0.93^{+0.12}_{-0.10}$
Running of tilt	$\alpha = ?$
Tensor normalization	$R < 0.2$
Tensor tilt	$n_T = ?$

(Post-CBI parameters from Xiaomin Wang)

•Gastrophysics

Reionization optical depth	$\tau = 0.07^{+0.16}_{-0.07}$
Galaxy bias	$b \sim 1$ (for 2dF L*)
Hubble parameter	$h = 0.65^{+0.11}_{-0.11}$

Is cosmology solved?
We still have no clue
what 95% of all stuff
is made of!

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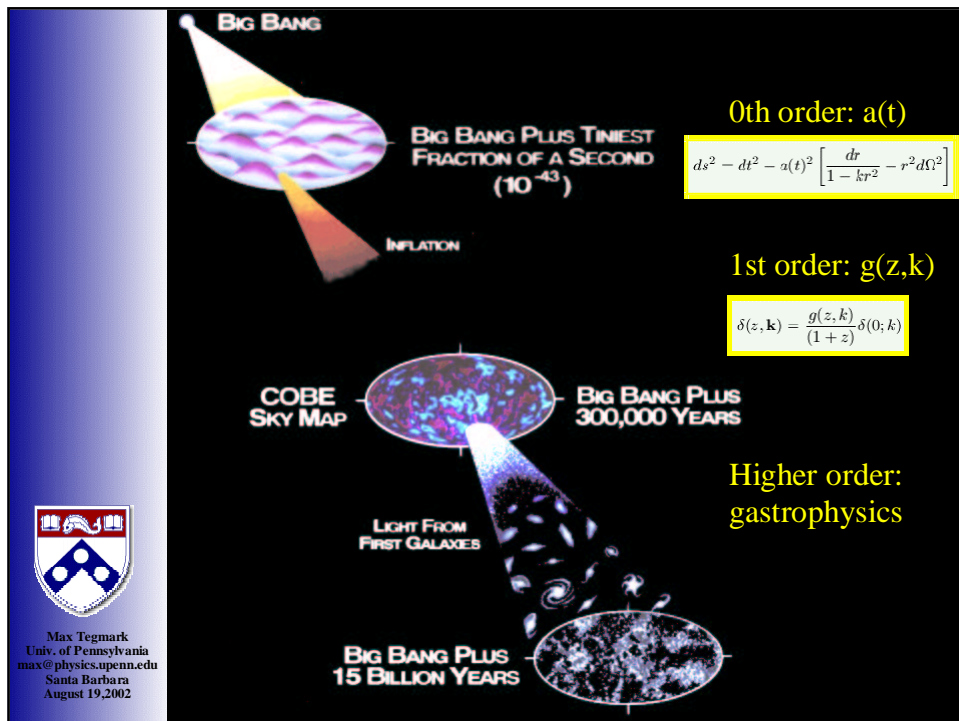
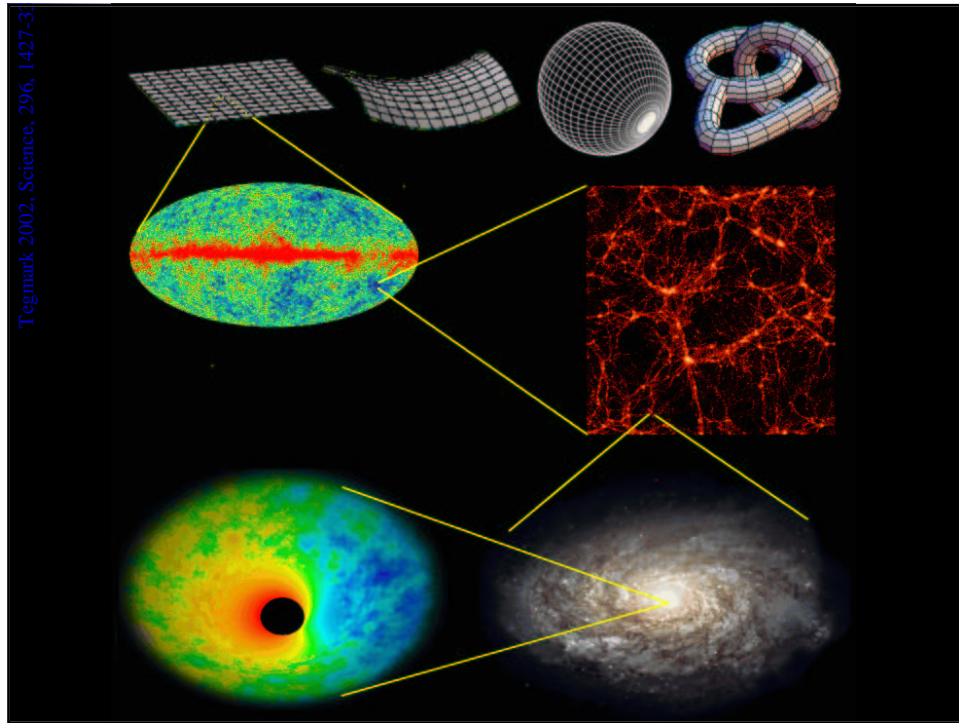
Beyond cosmological parameters, summary:

- *Test the underlying physics rather than assuming it*
- *Cosmological functions rather than cosmological parameters*
- *Measure the free functions rather than parametrizing them in a way involving untested physical assumptions - a form of data compression*

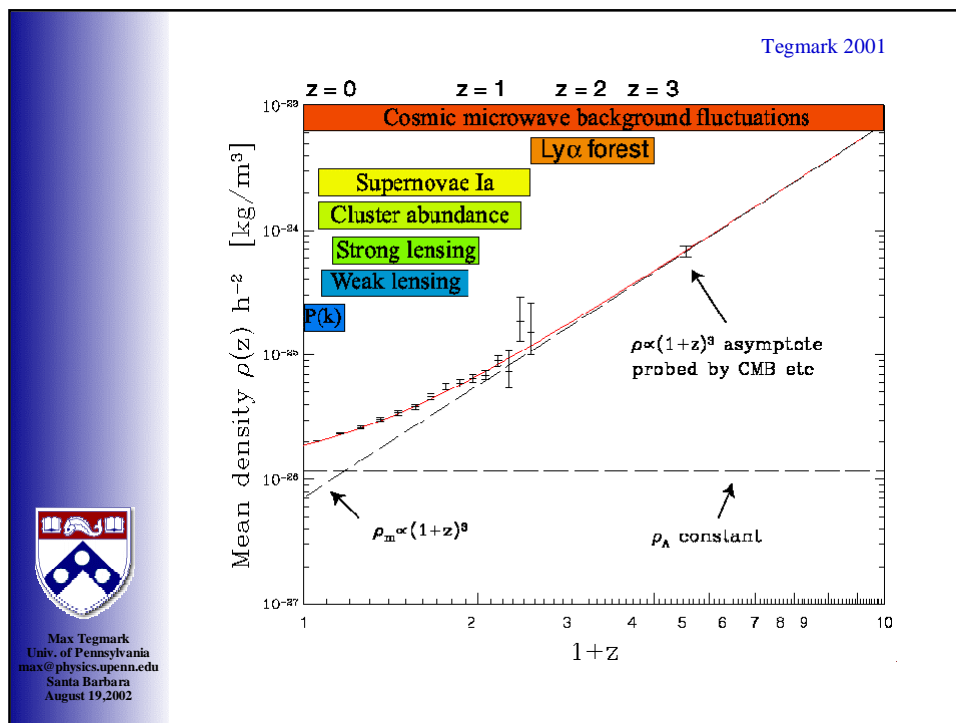
Do observations disagree with each other or with theory?

Data => Cosmological functions <= Theory

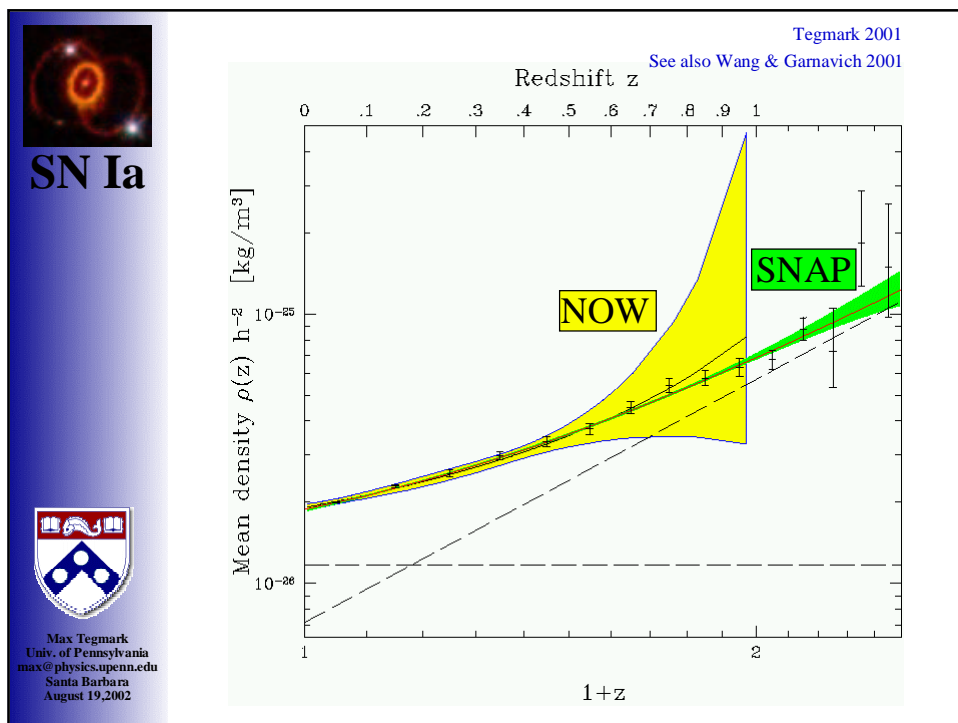
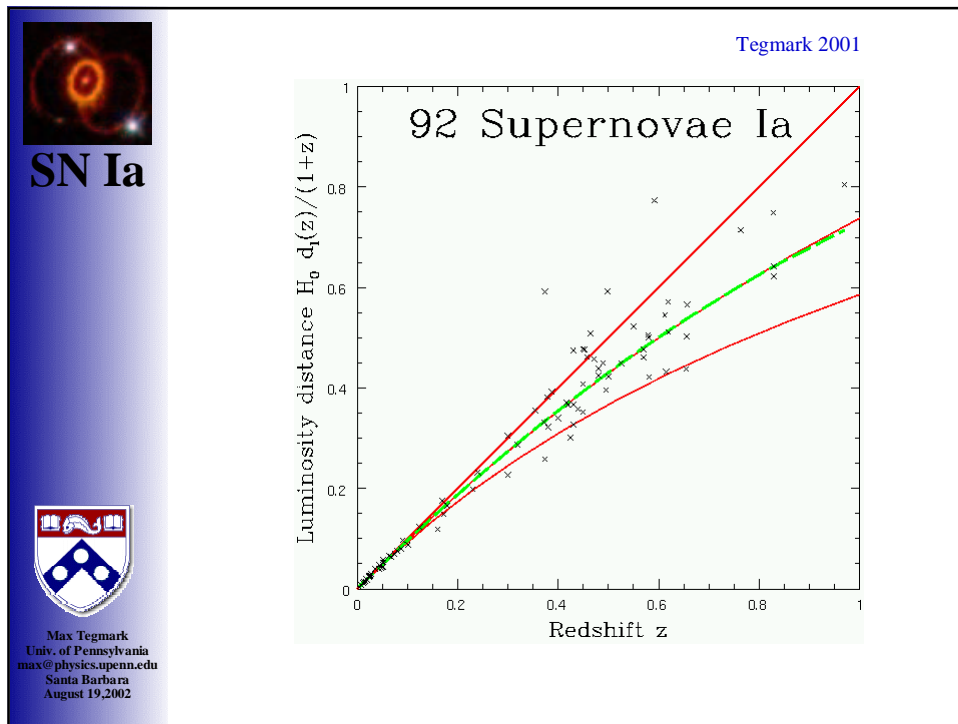
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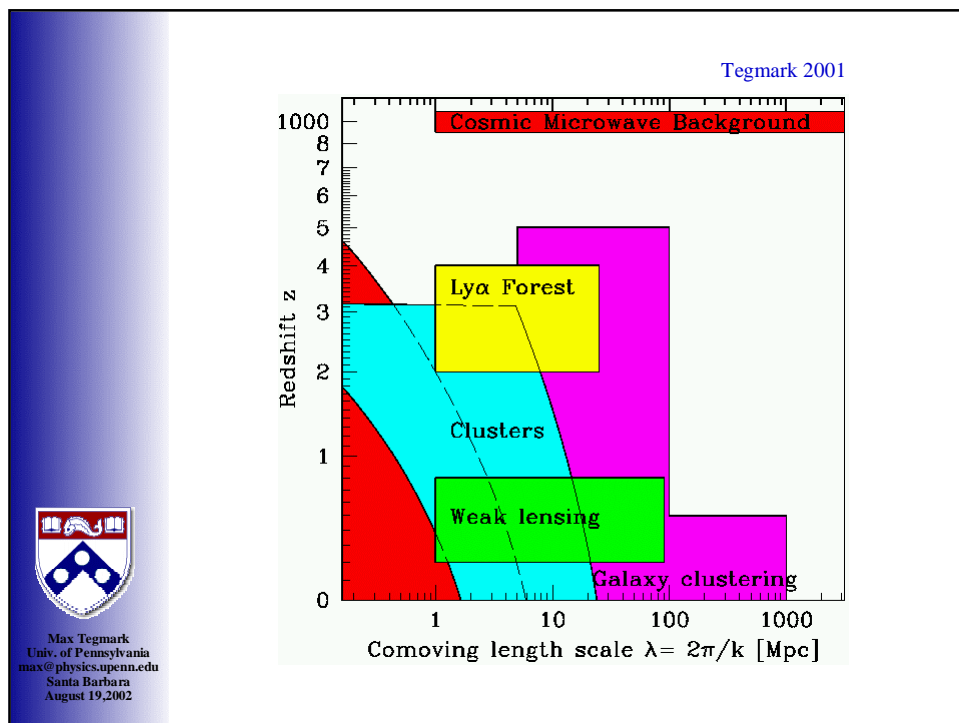
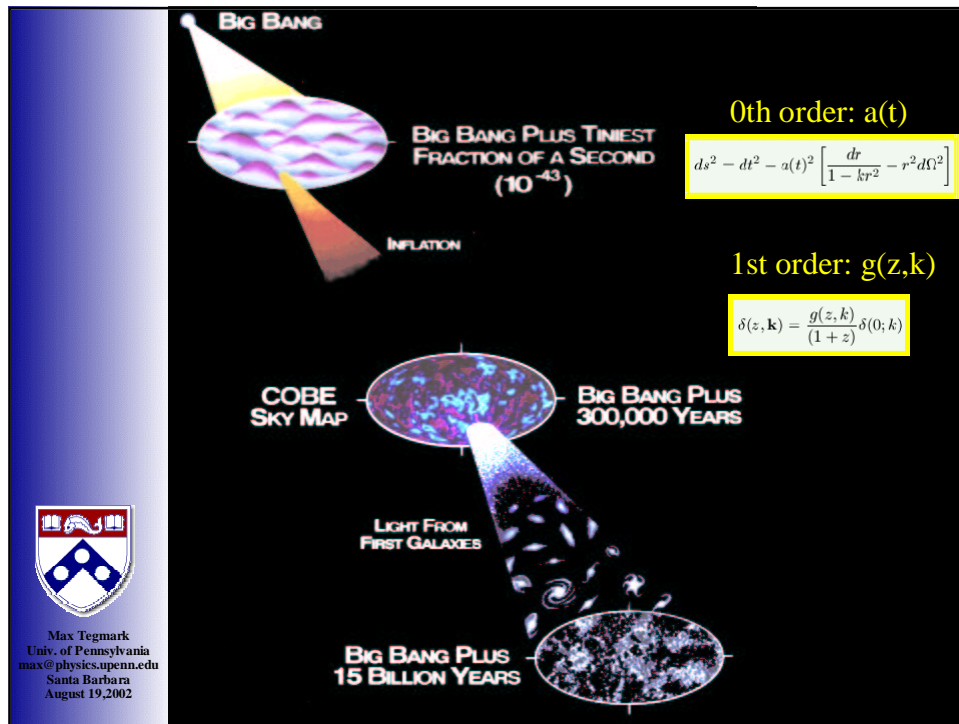


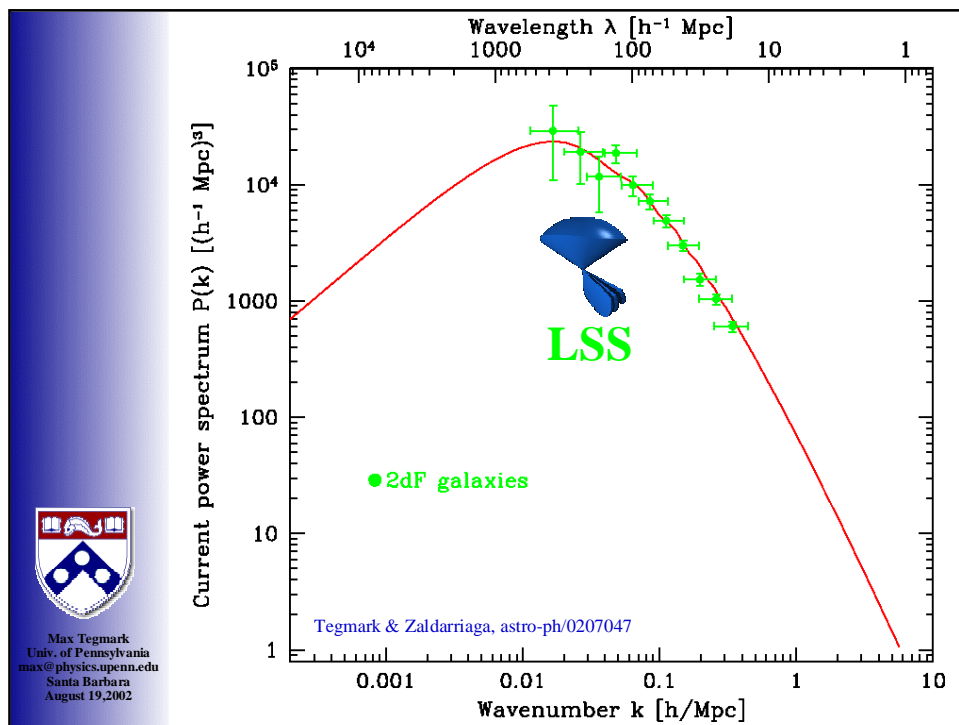
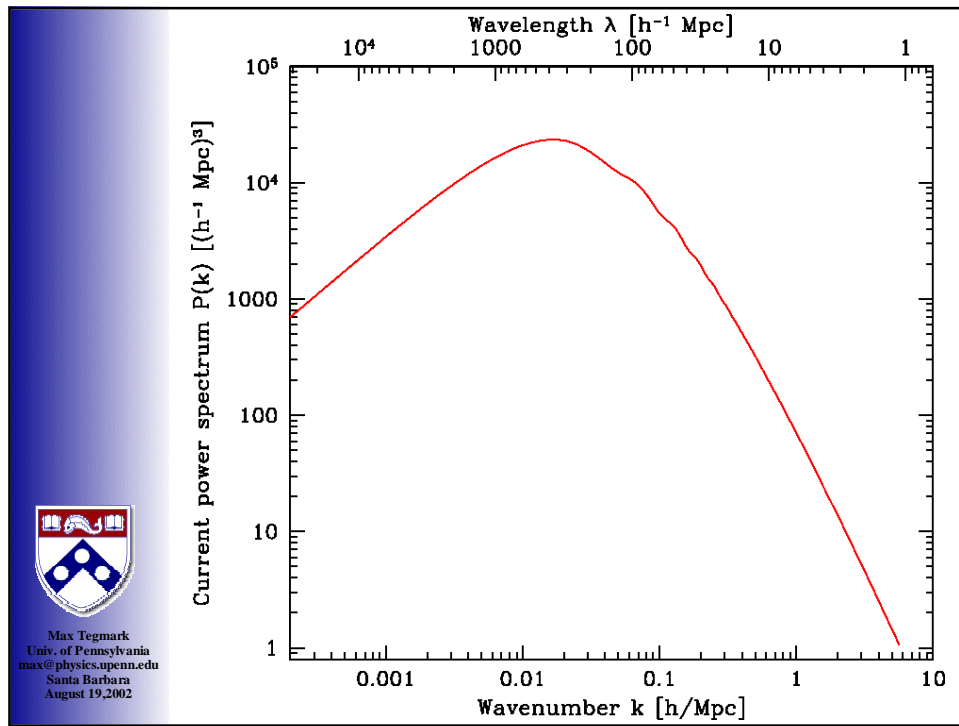
Measuring $a(t)$

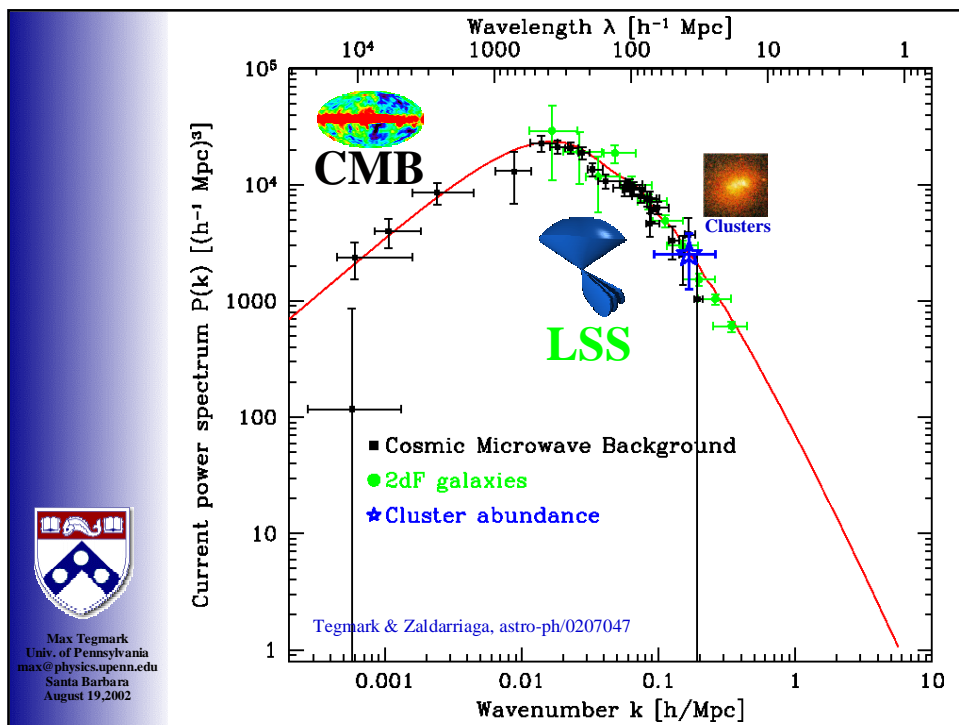
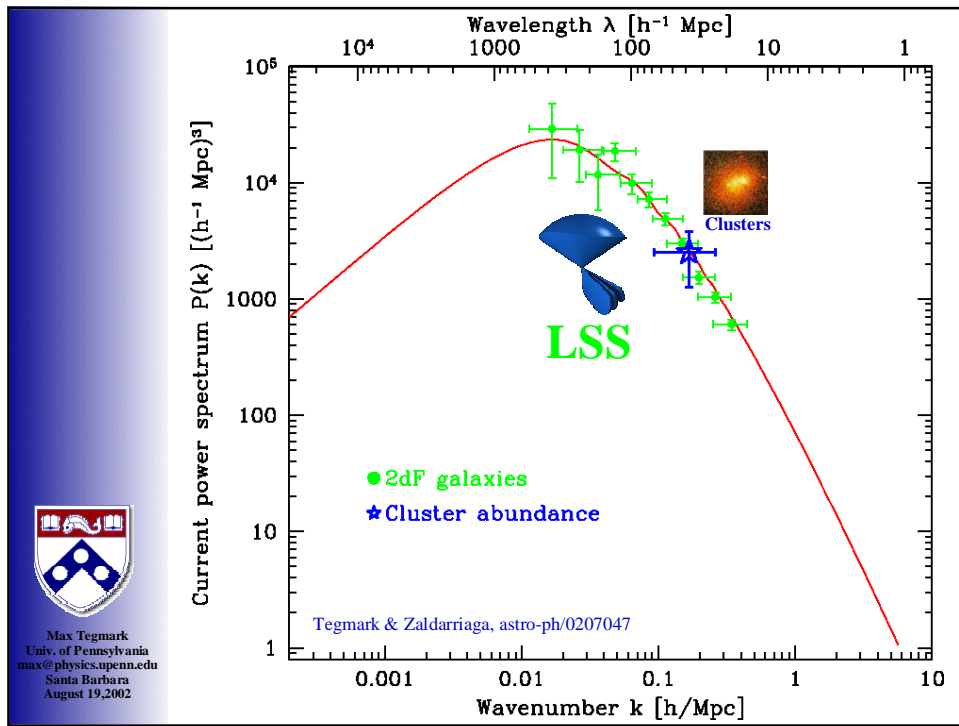


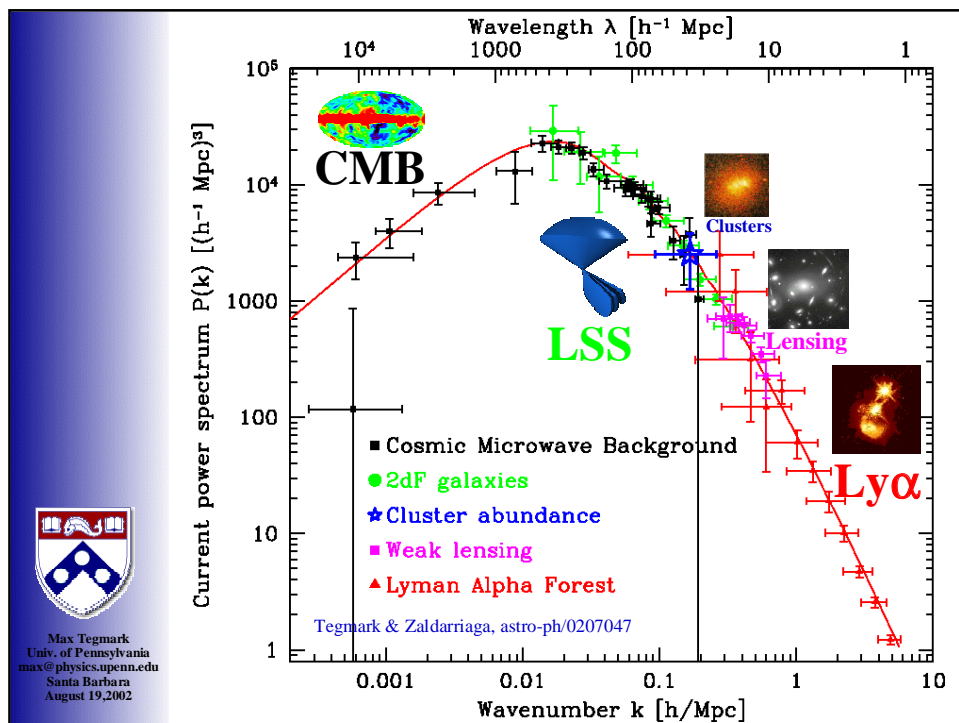
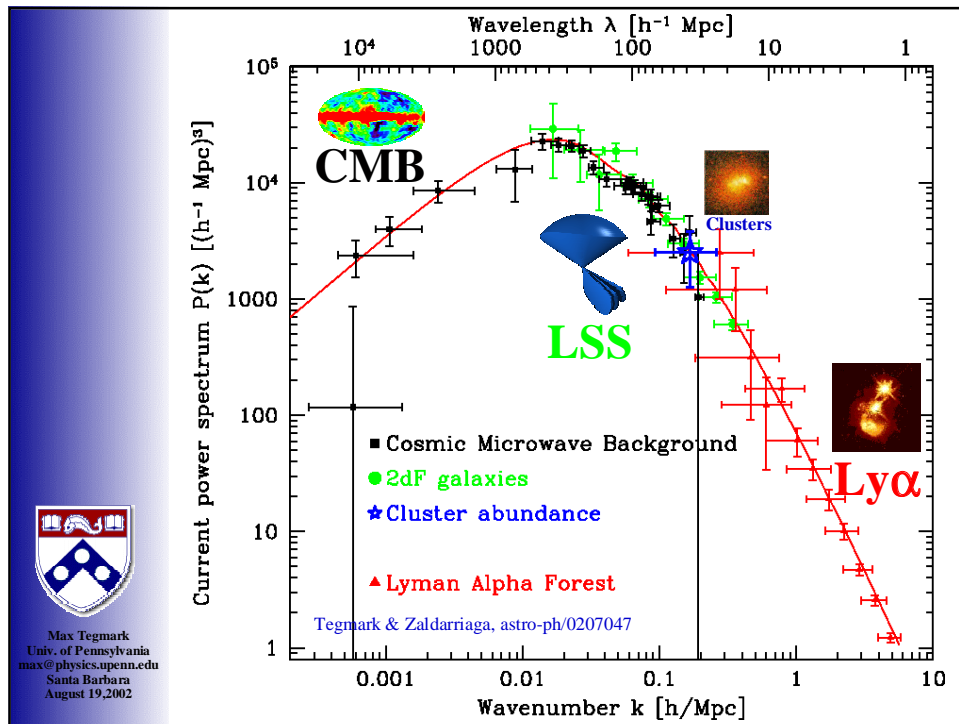
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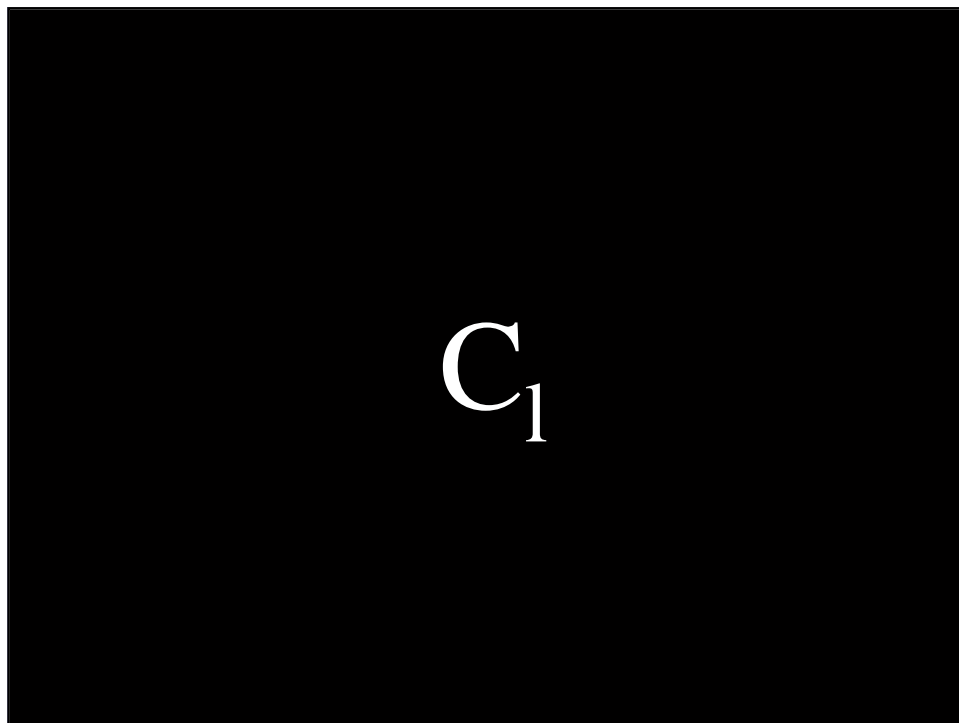
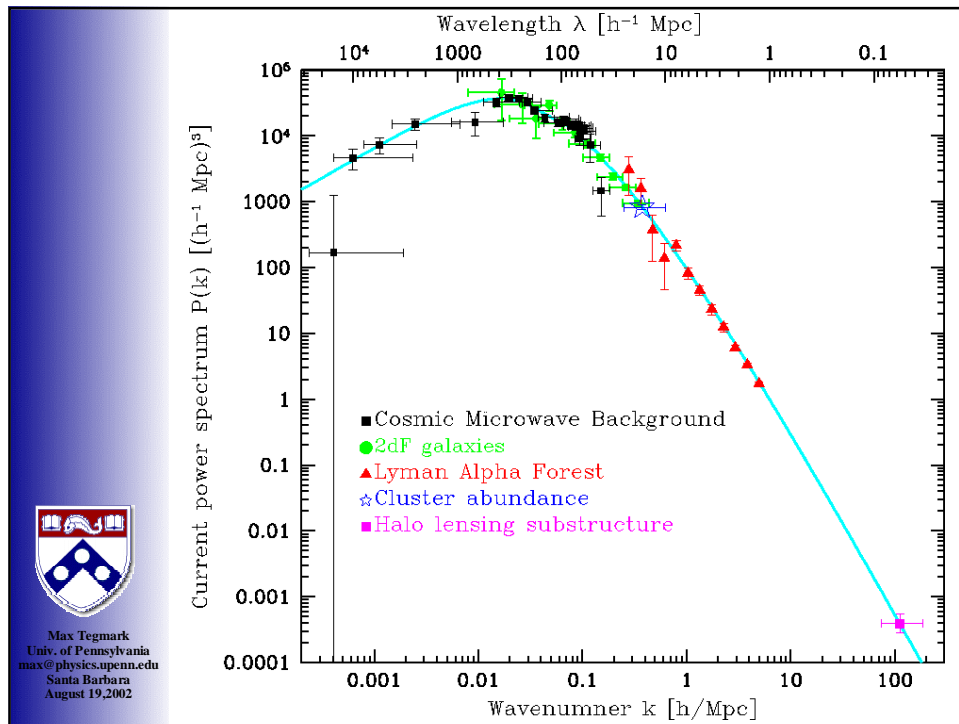


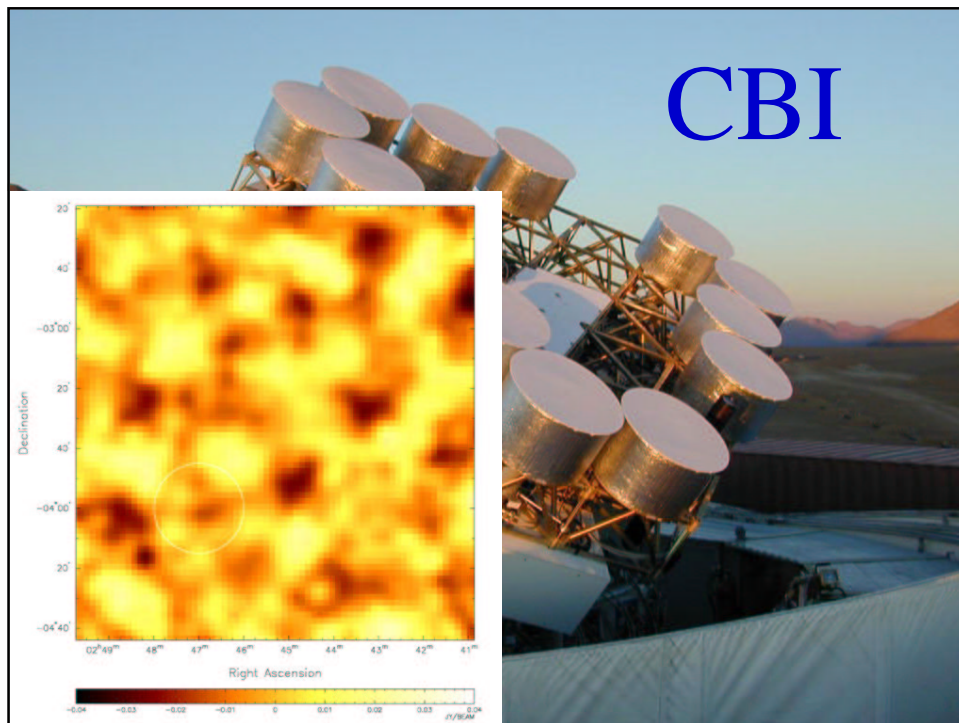


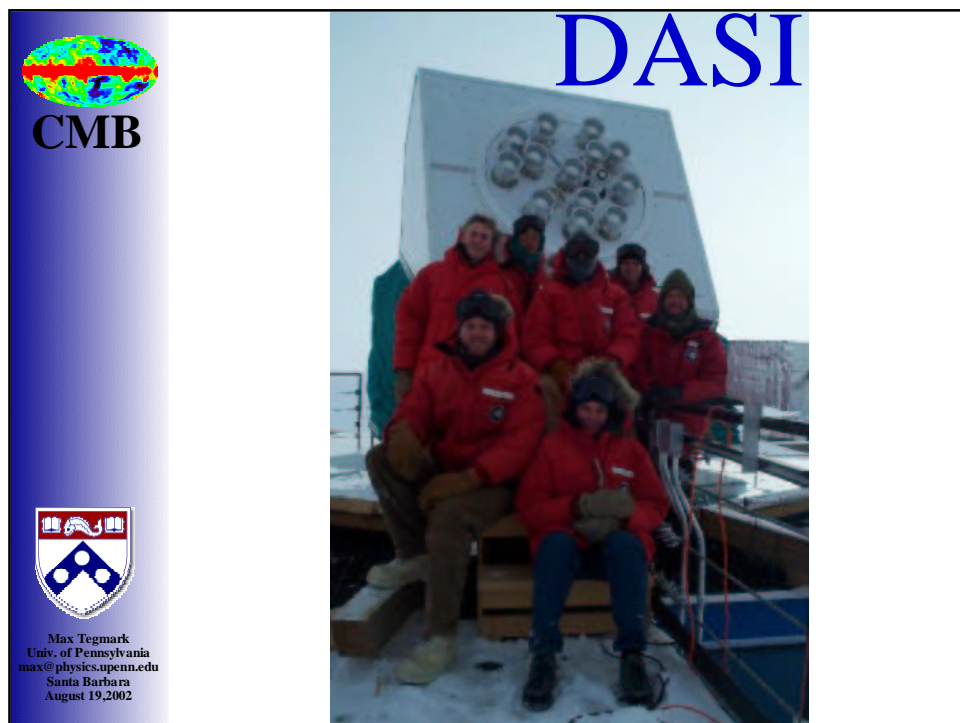
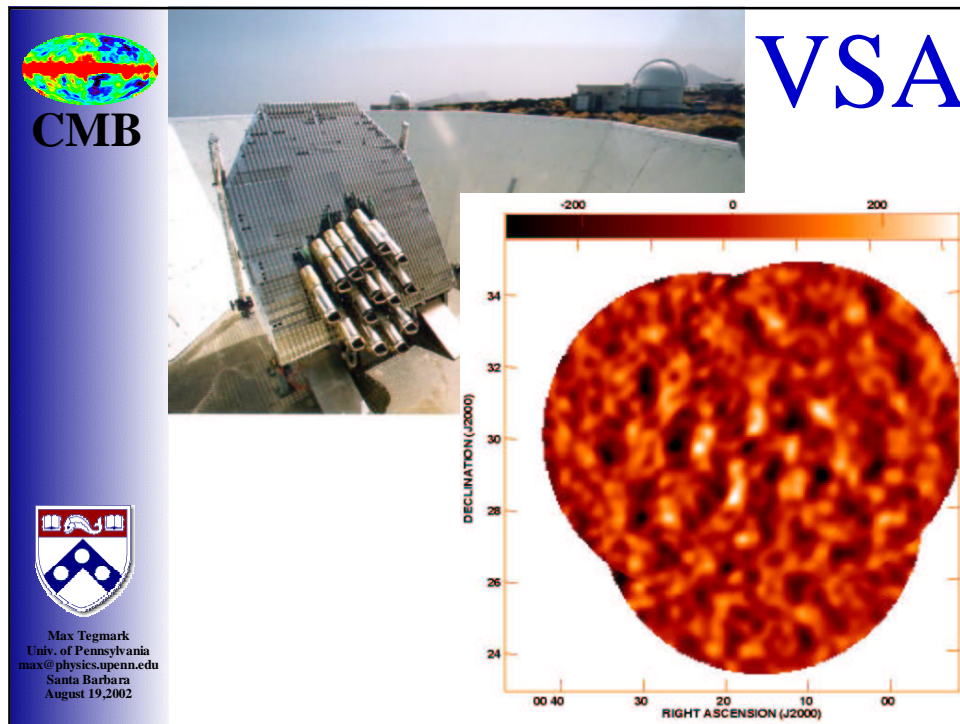


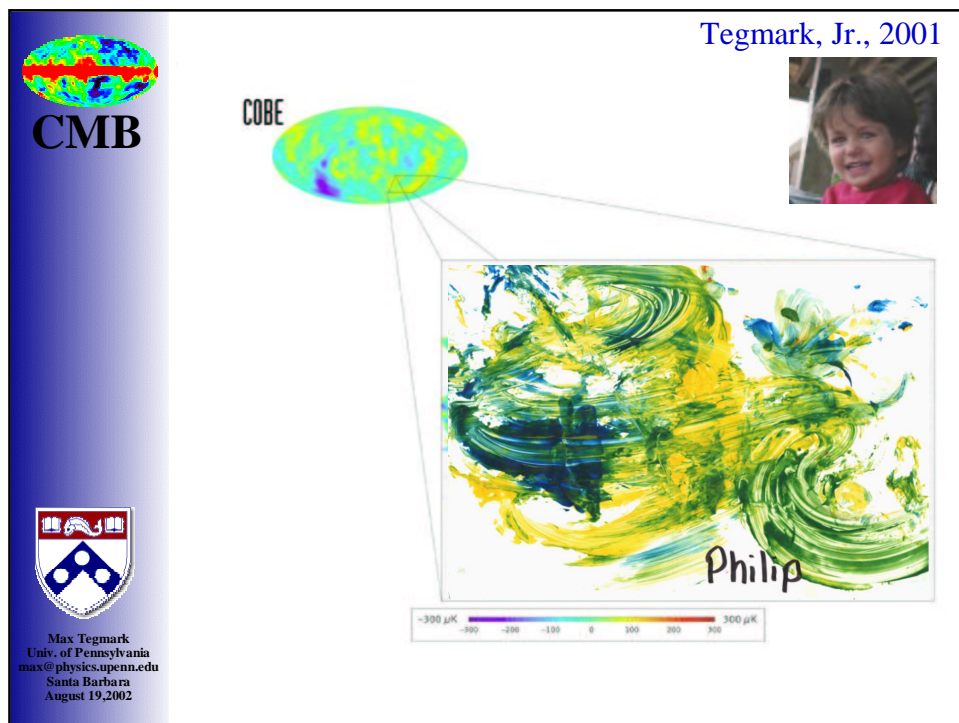
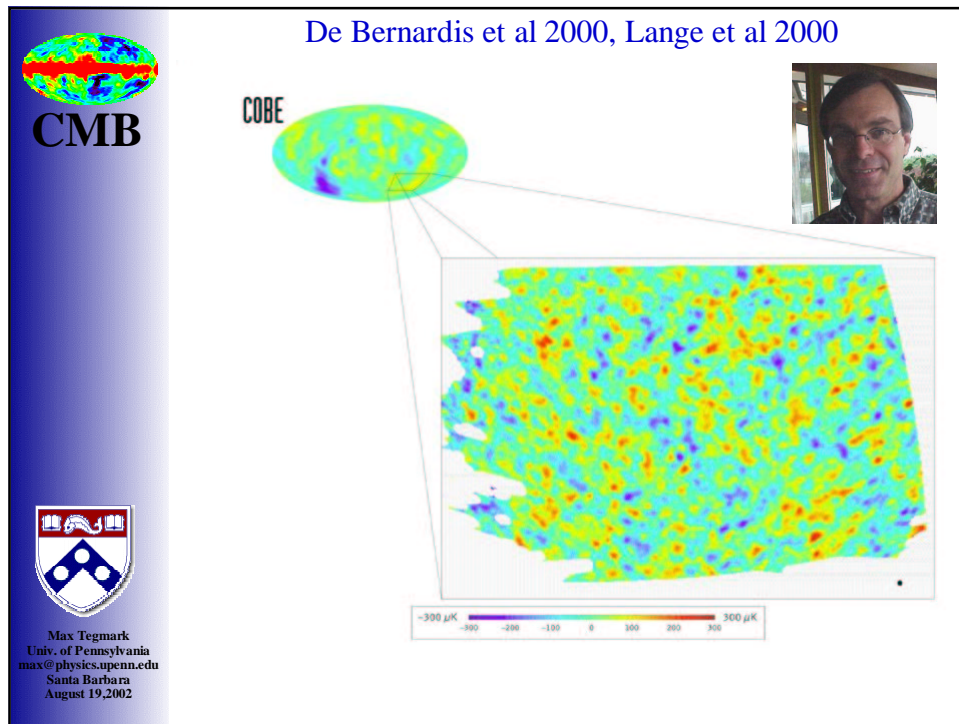


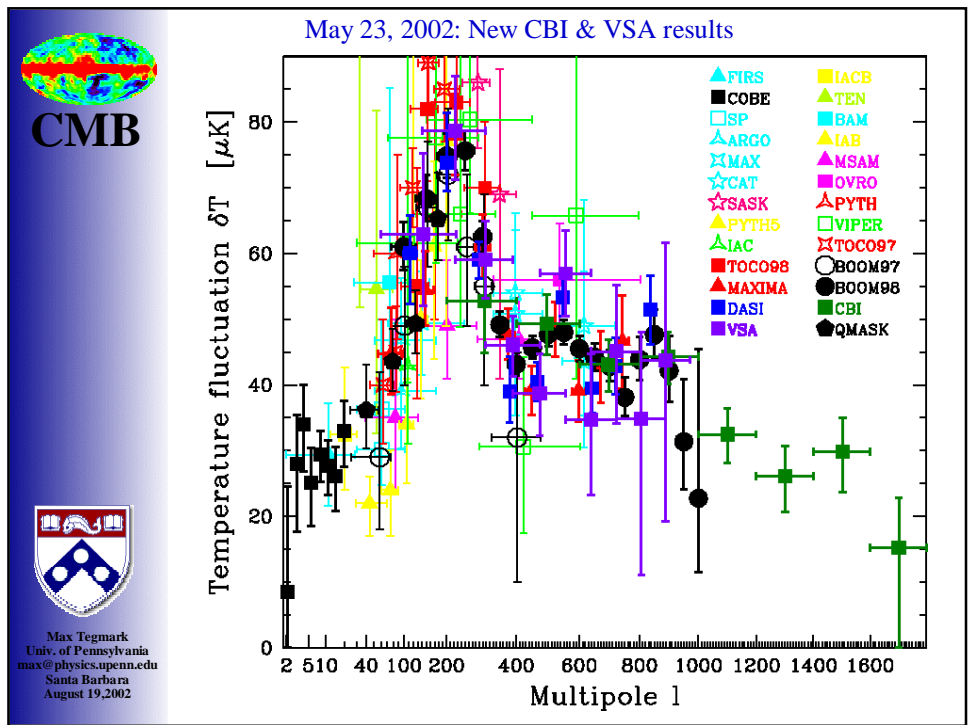
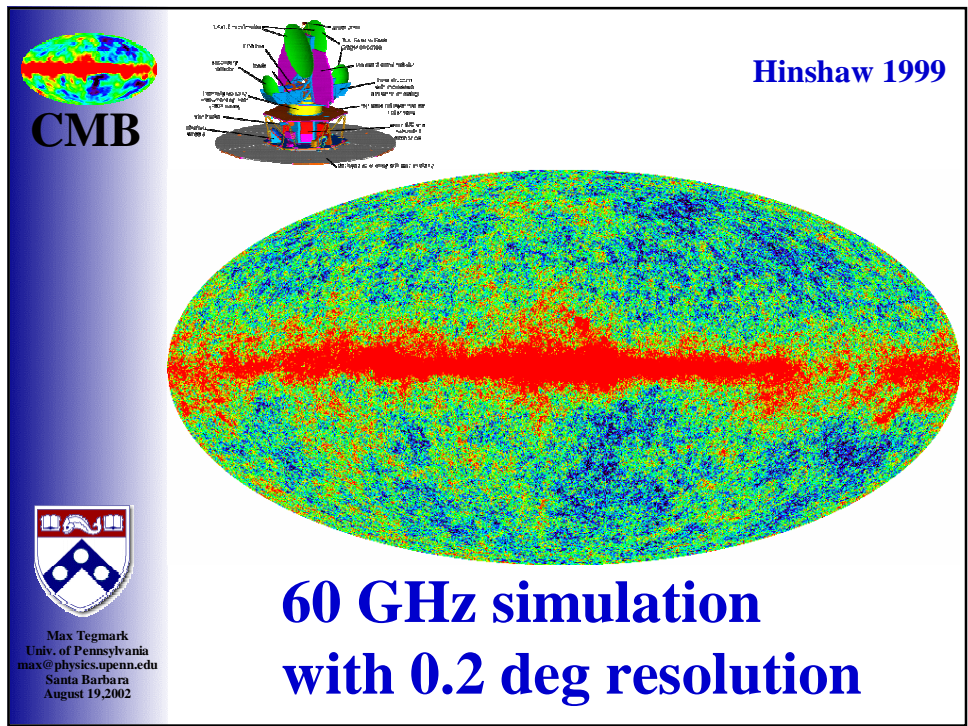


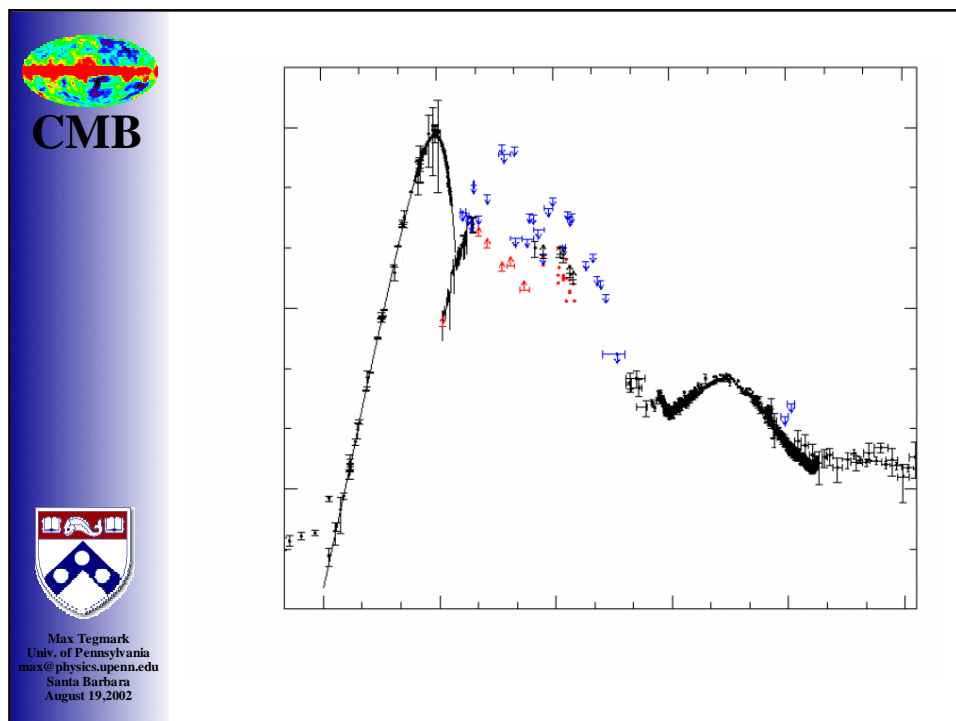
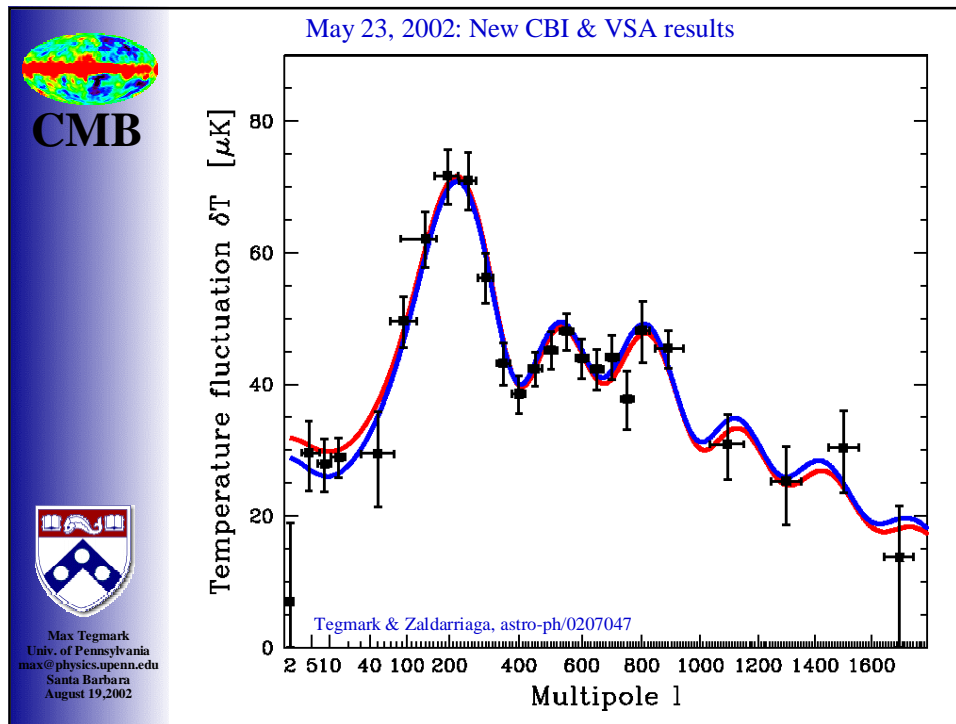


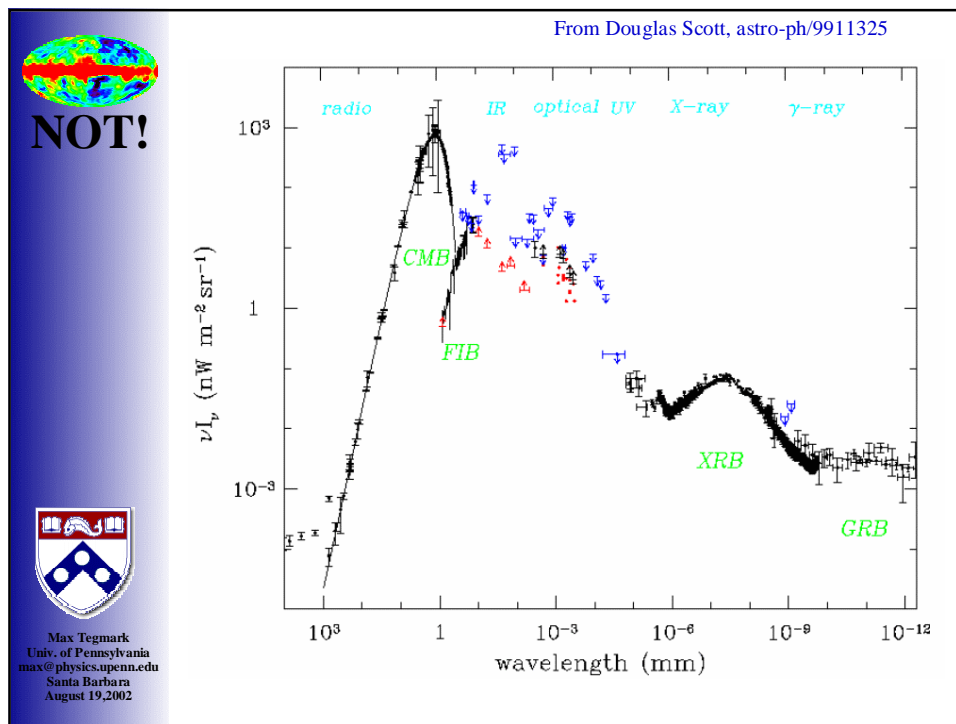




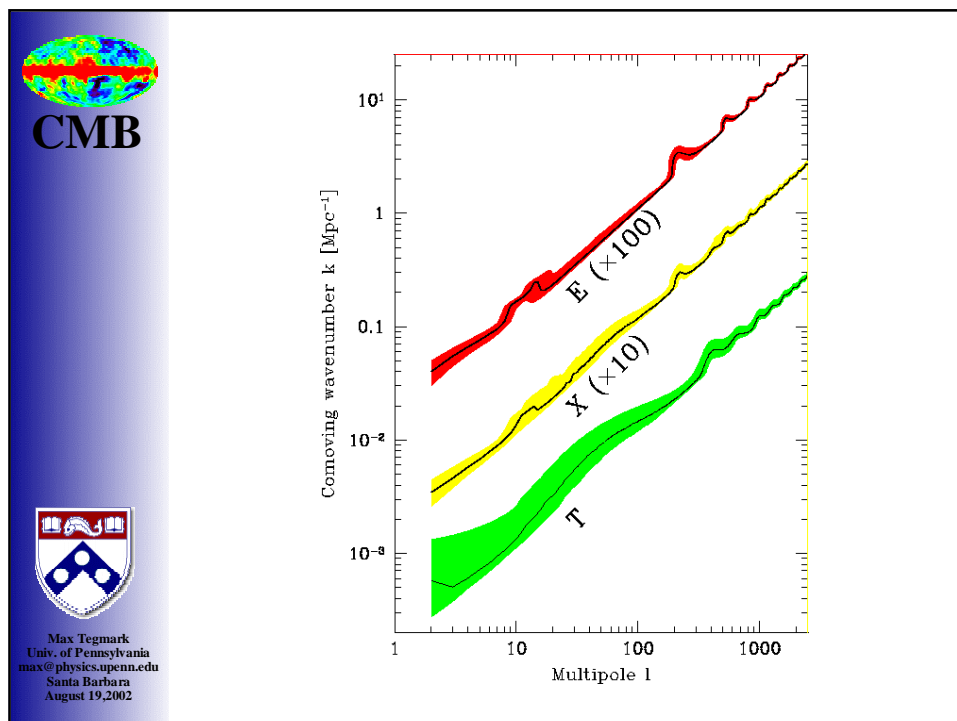
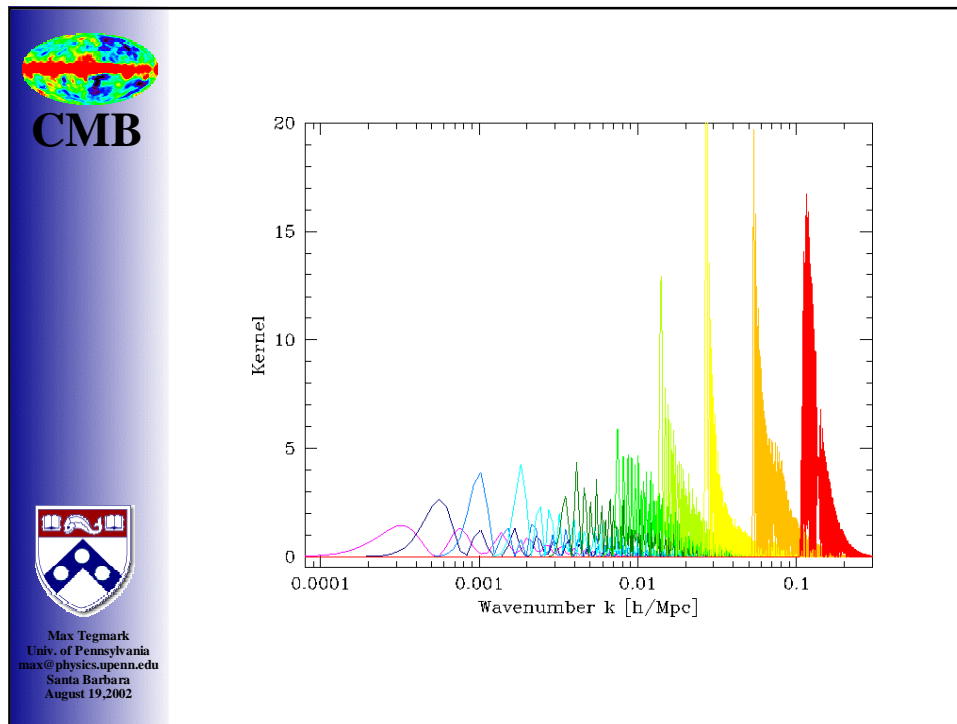


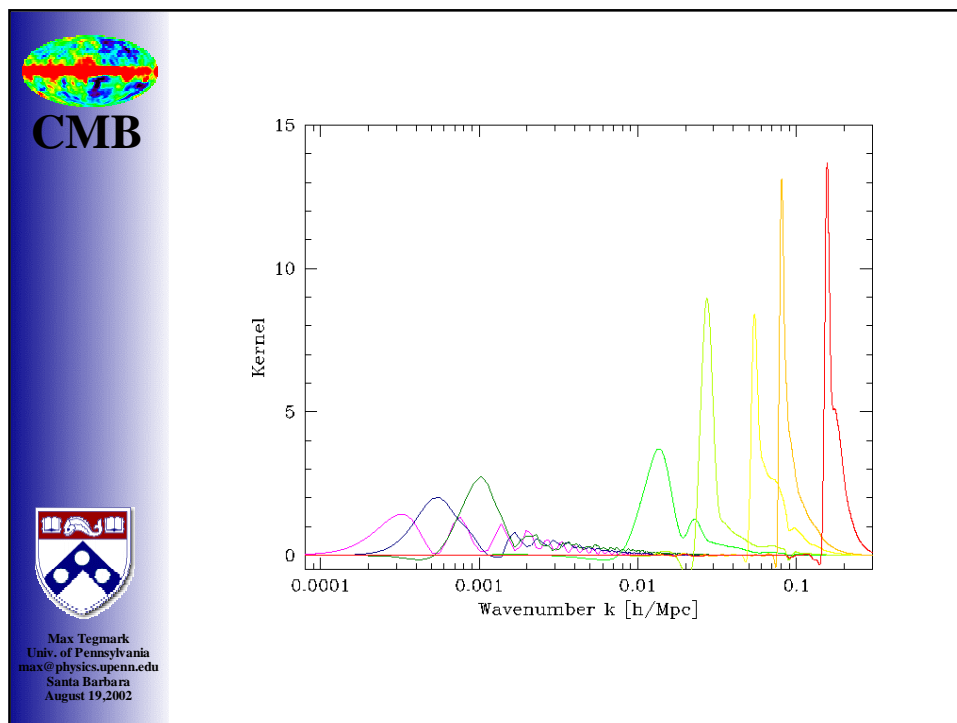
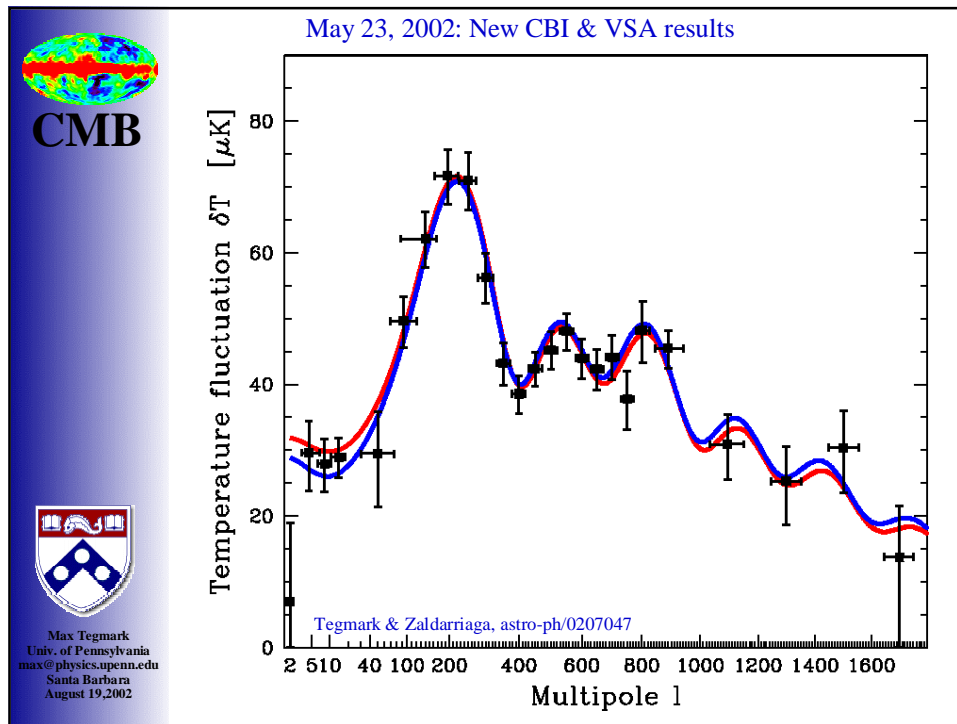


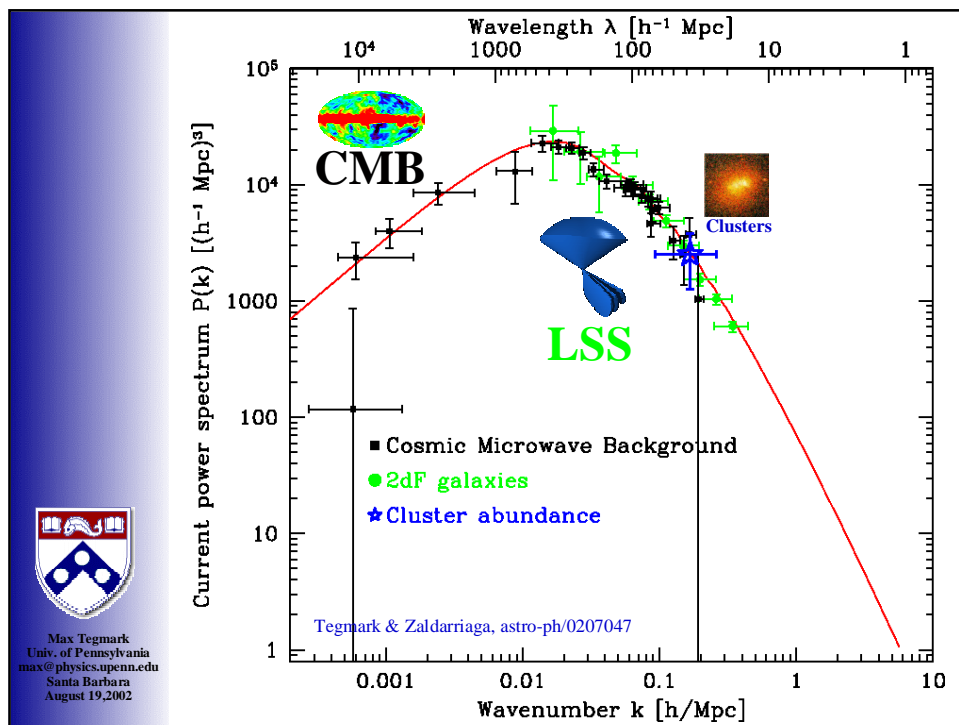
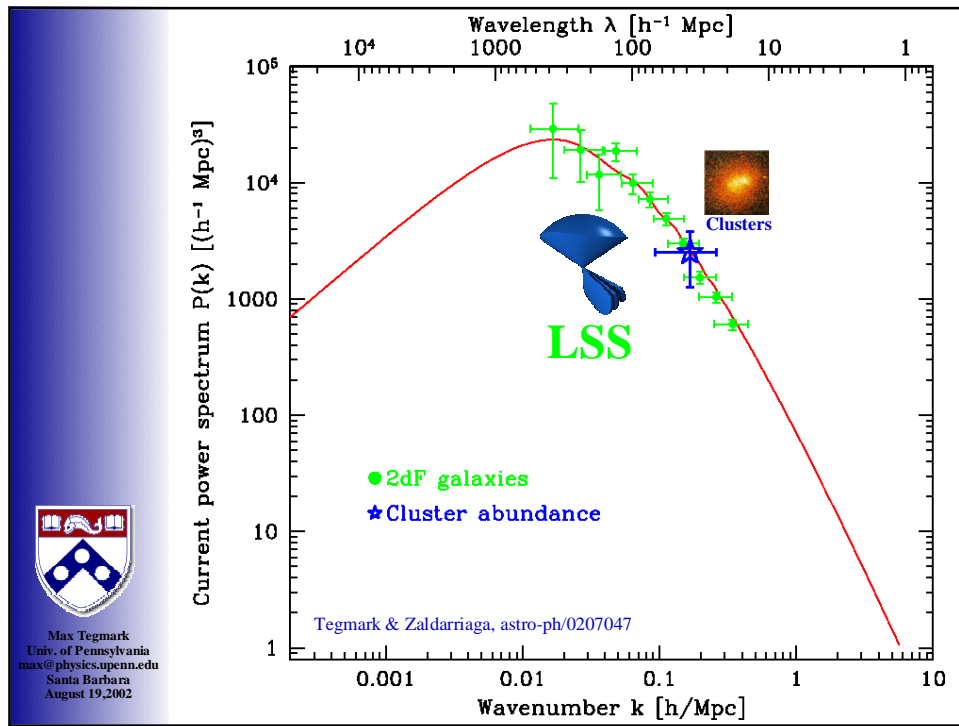




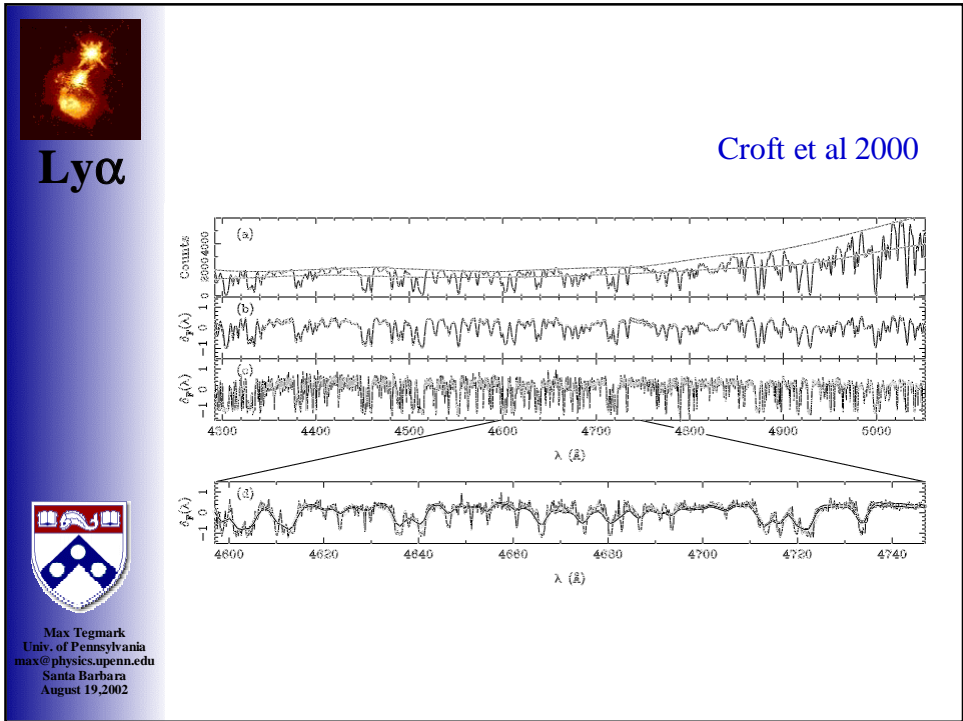
Measuring $P(k)$ with CMB

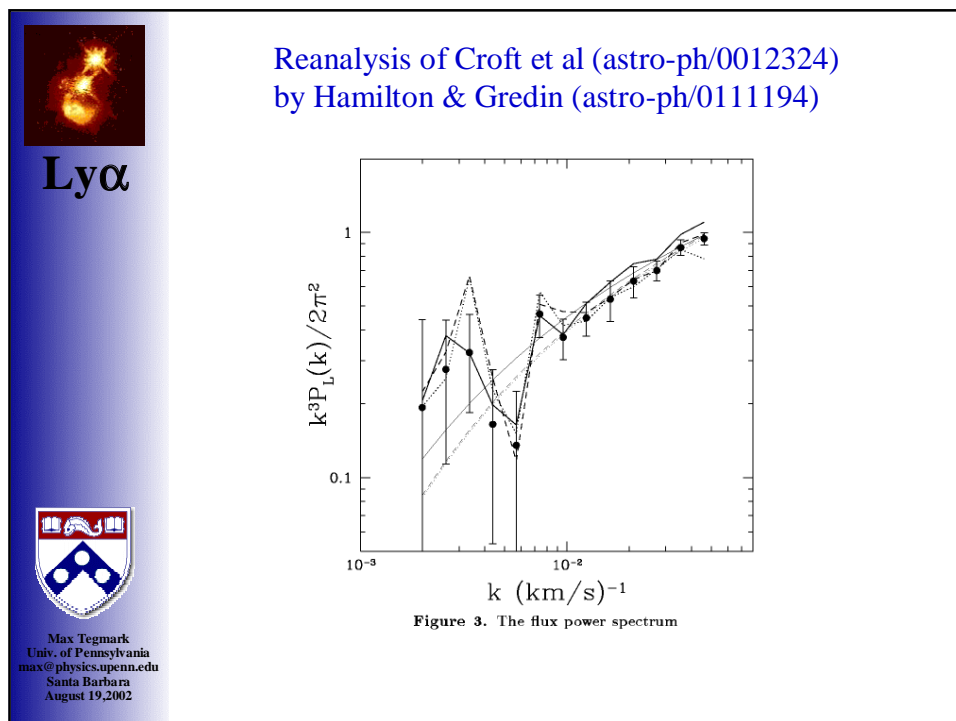
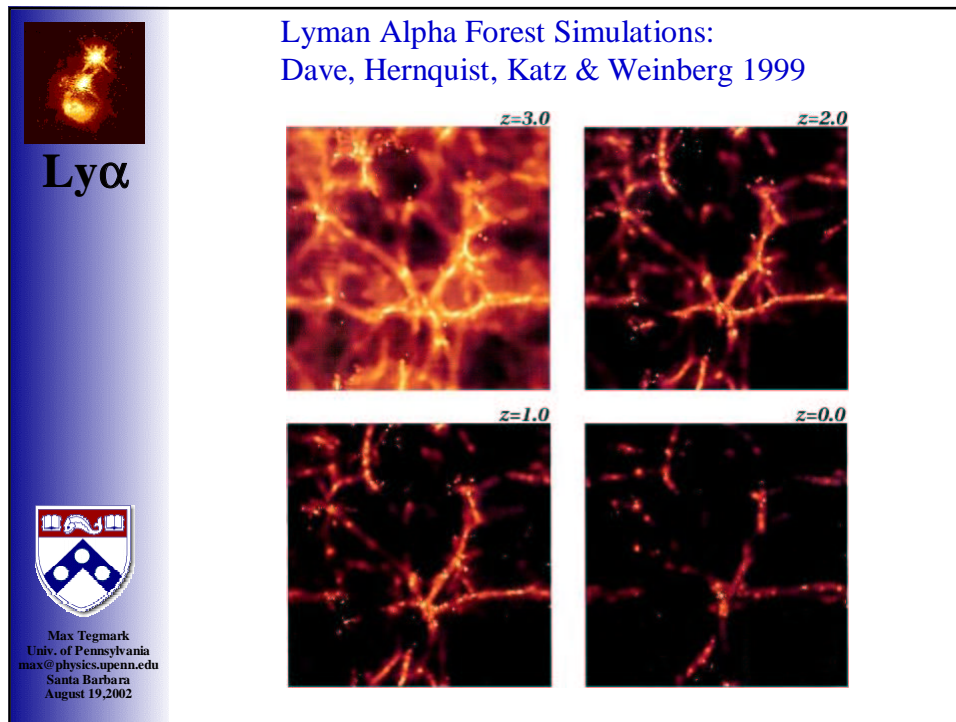


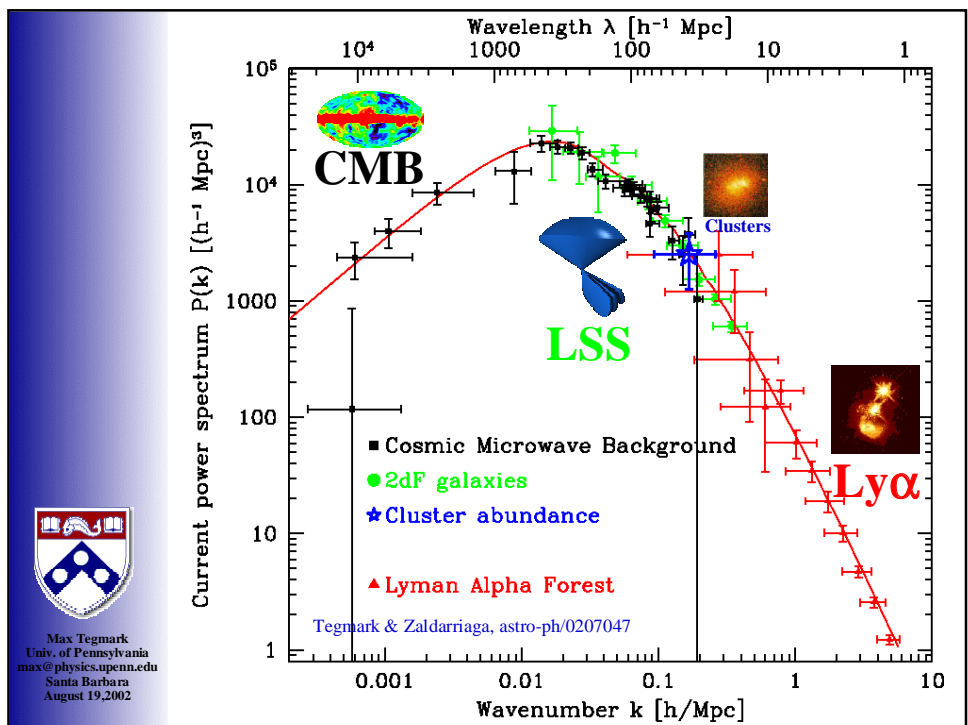
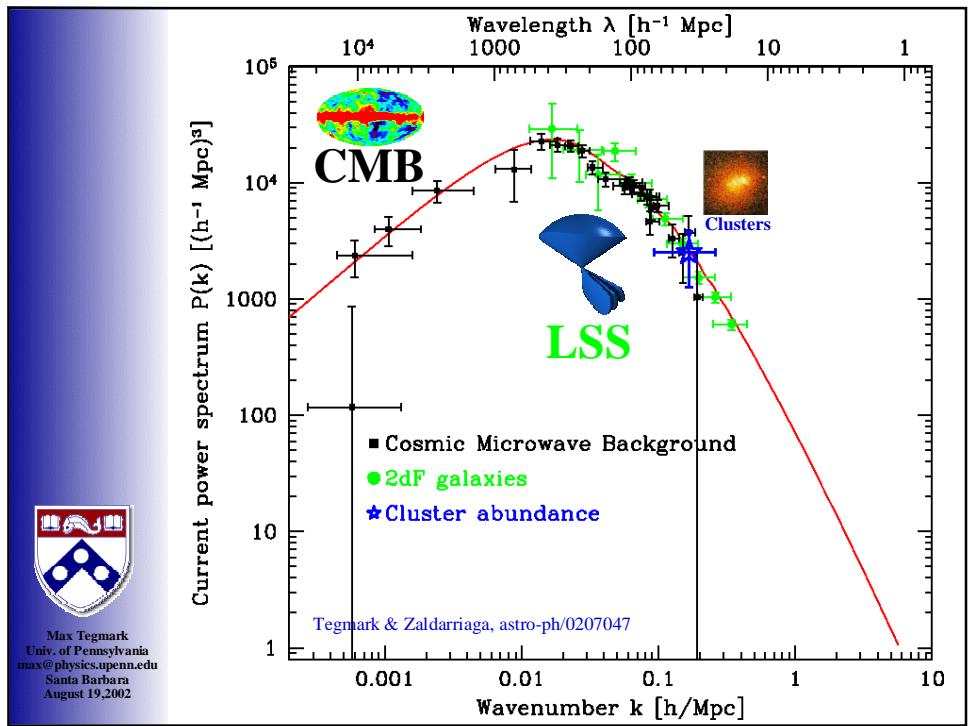




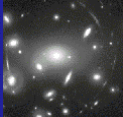
Measuring $P(k)$ with the Ly α F









Measuring $P(k)$ with weak lensing

 **Lensing**

Gravitational lensing

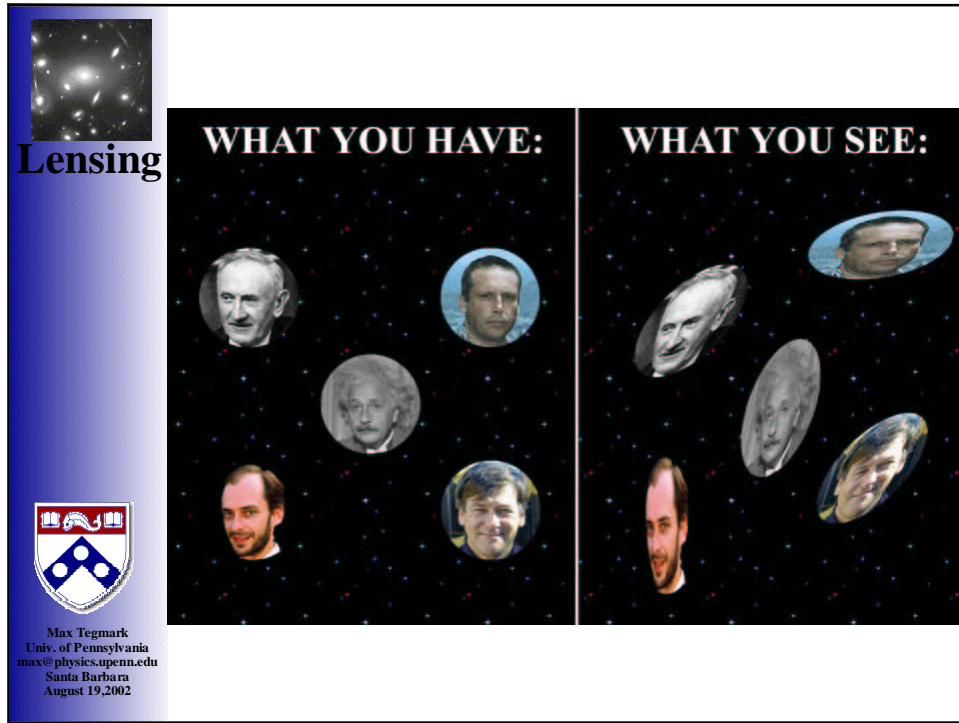


Galaxy Cluster Abell 2218 HST • WFPC2
NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08




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Lensing

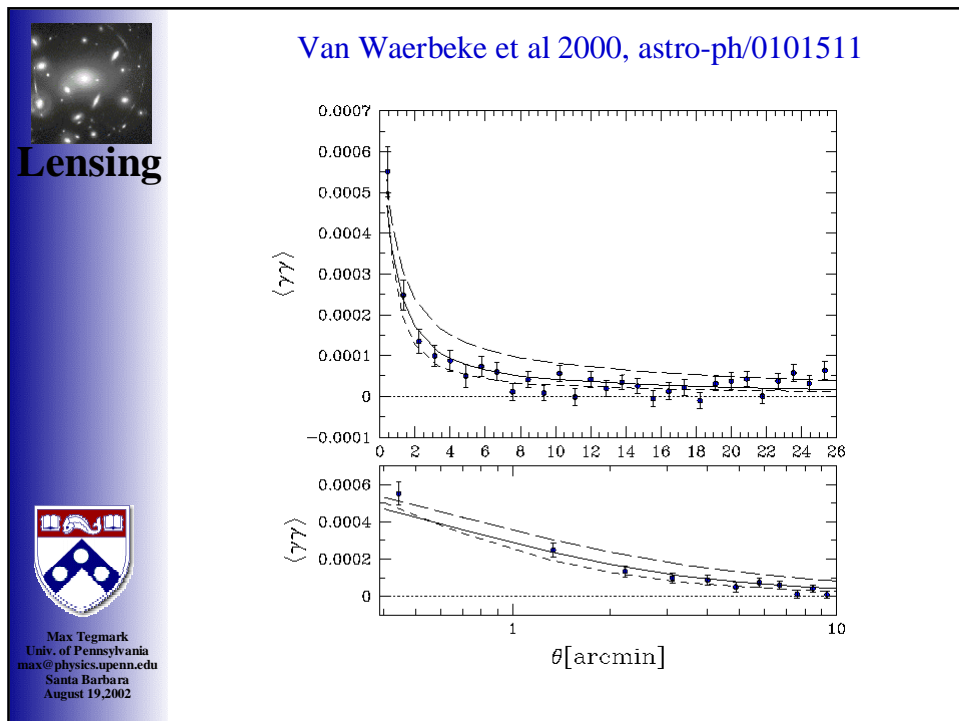


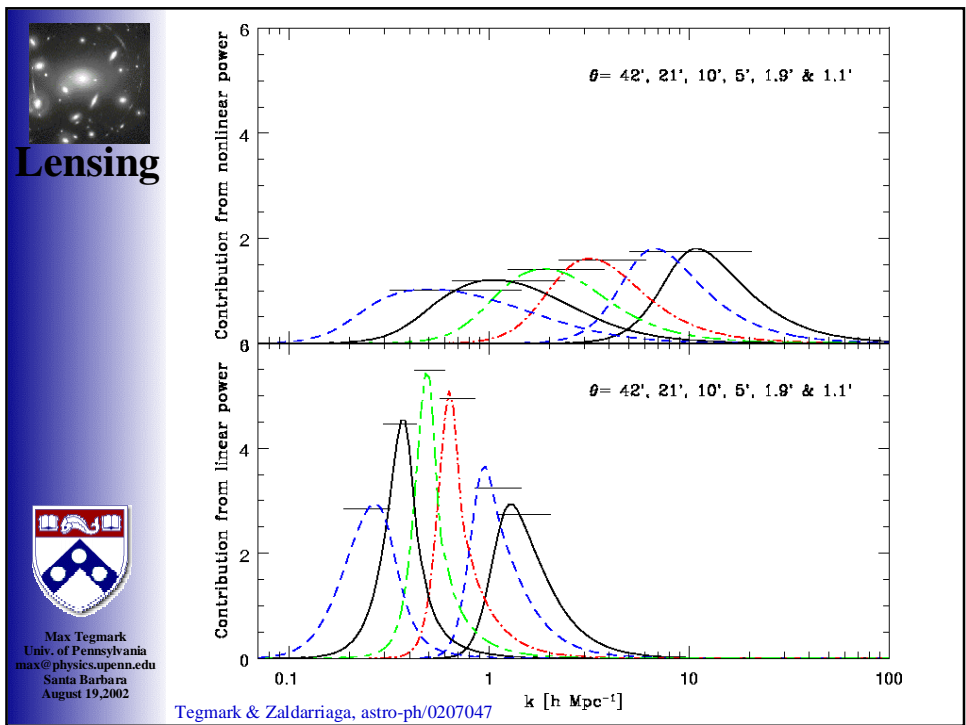
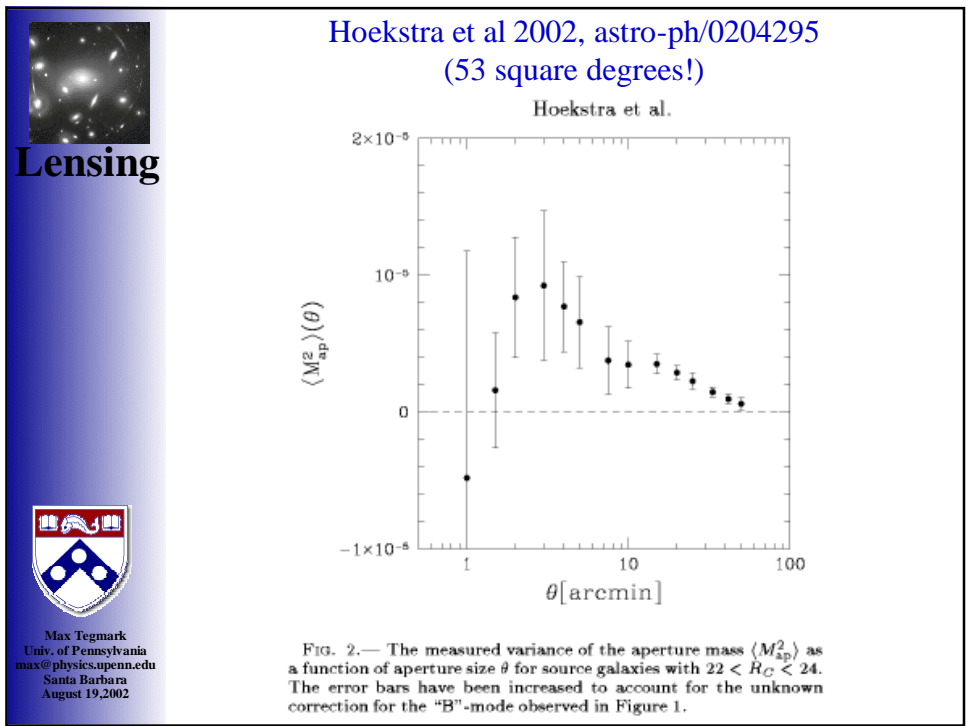
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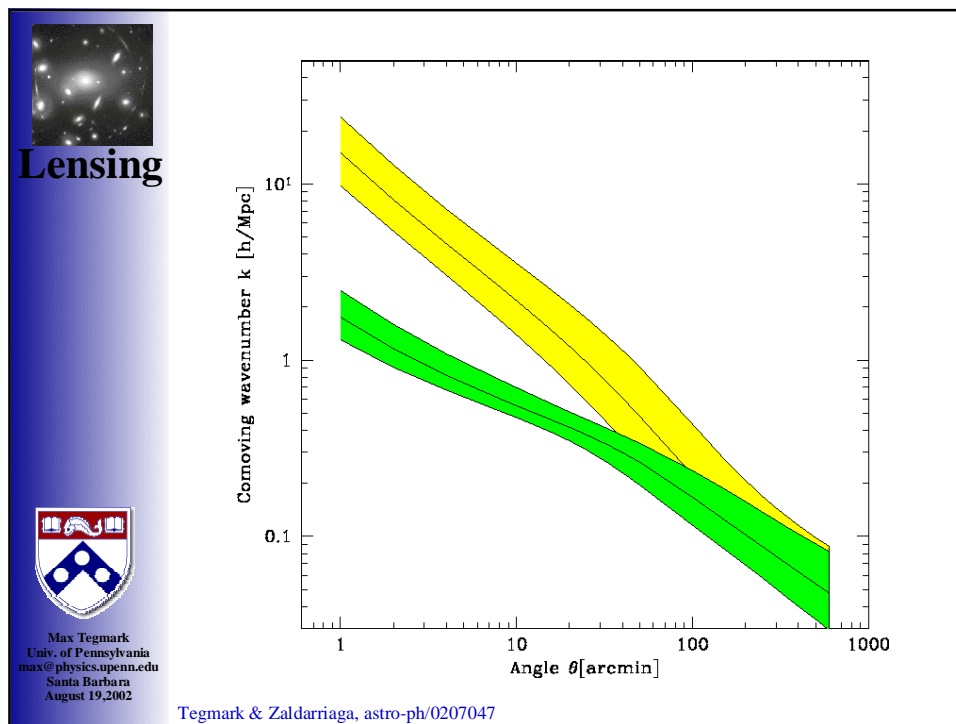
WHAT YOU SEE:



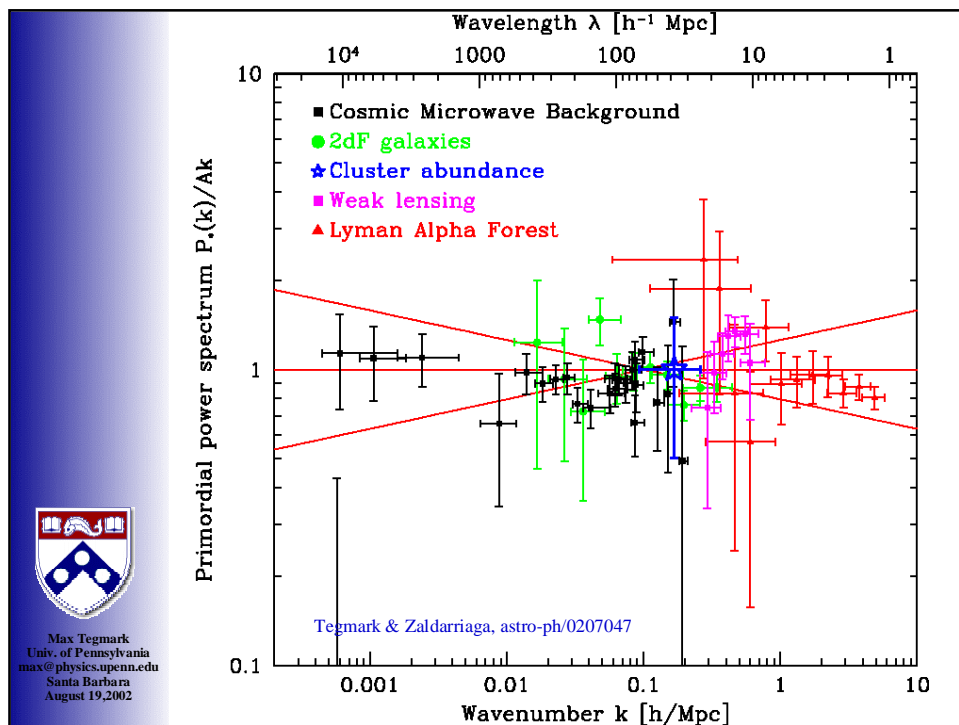
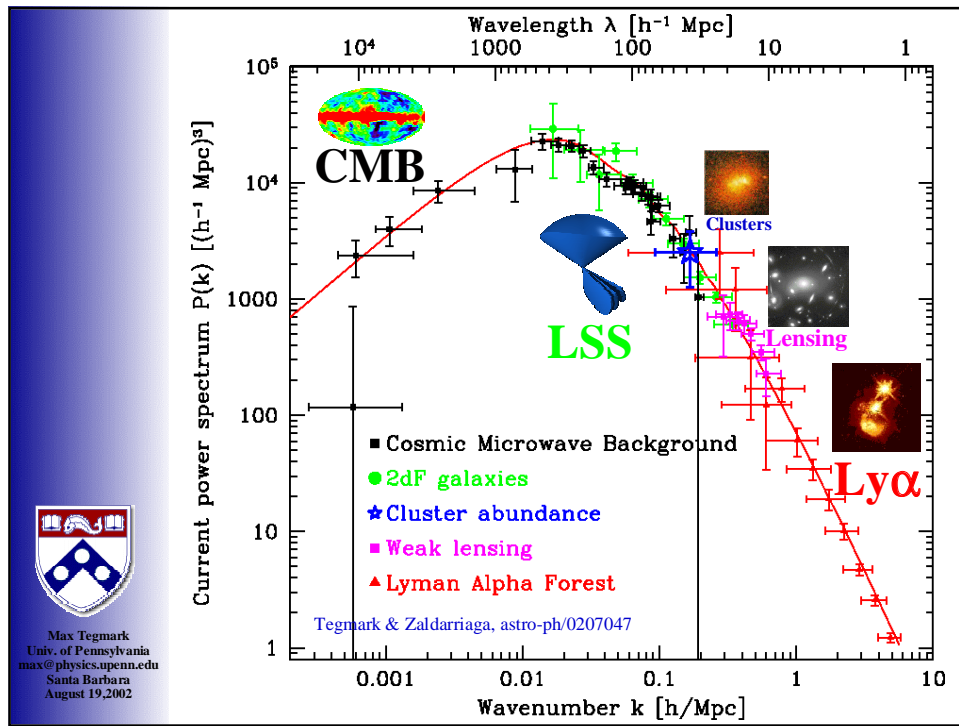
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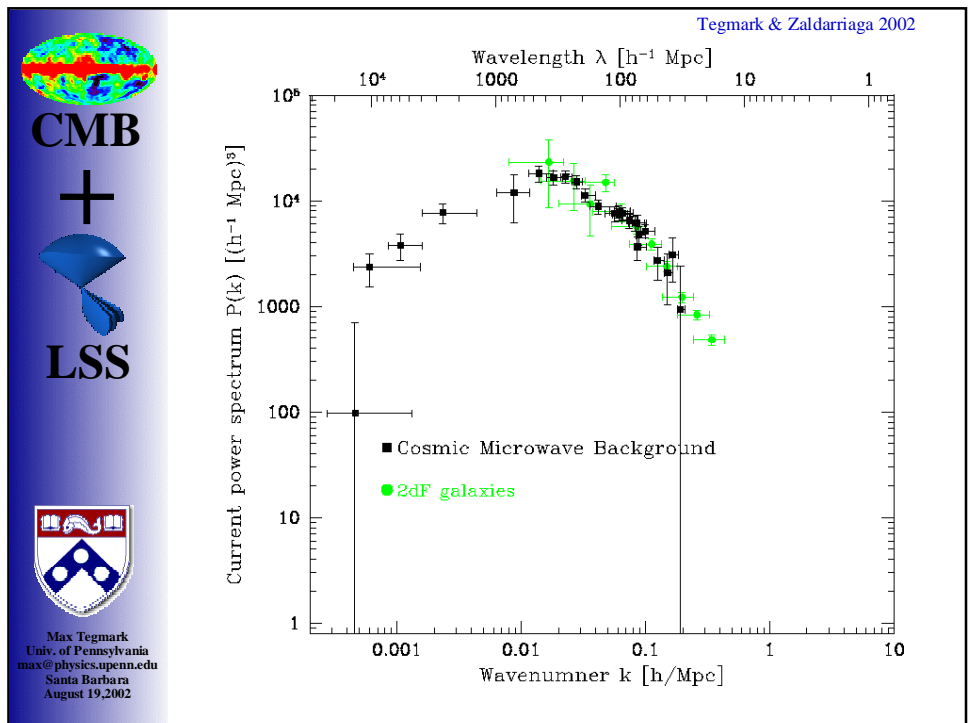
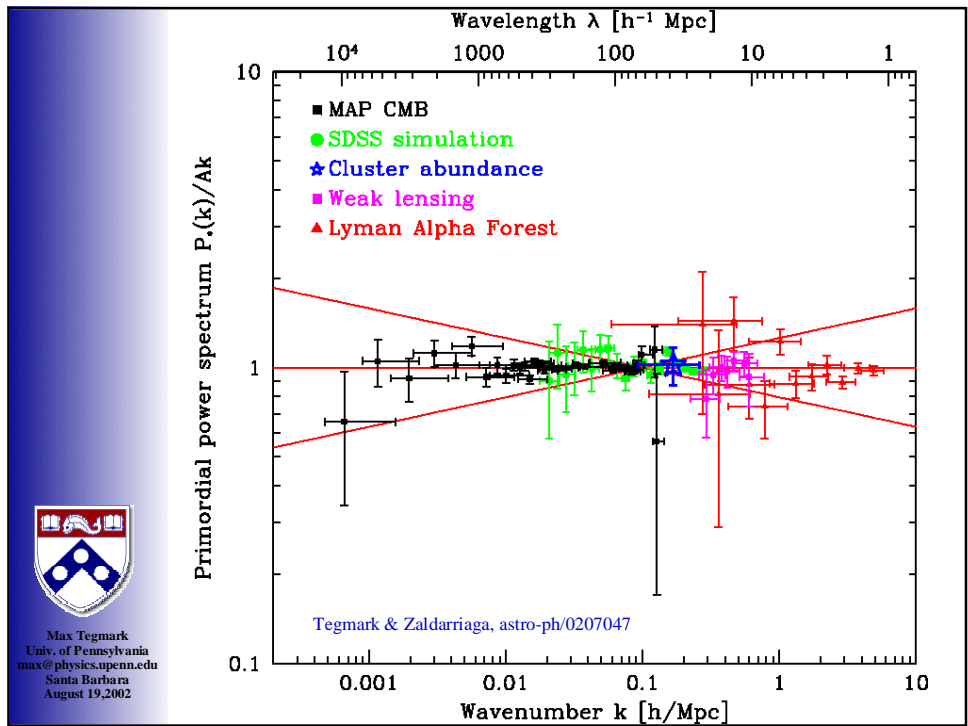


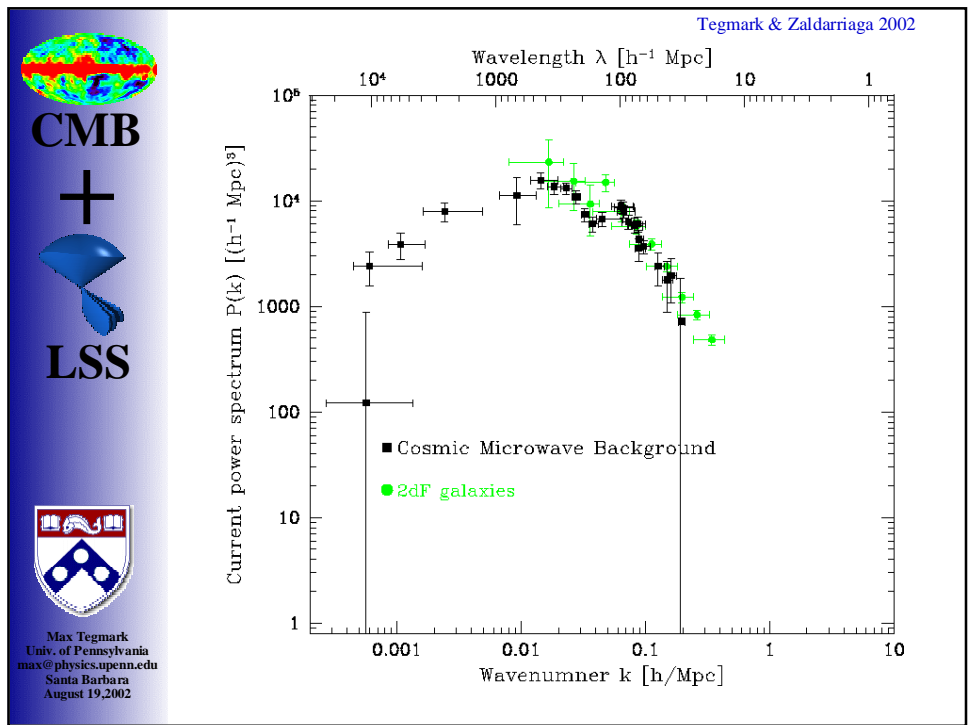
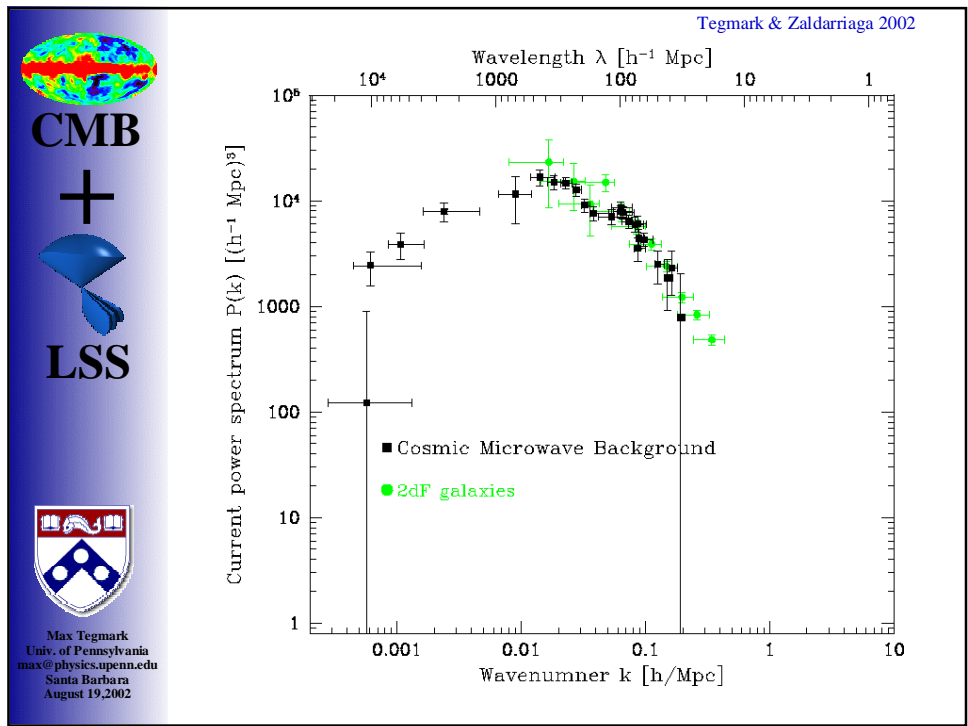


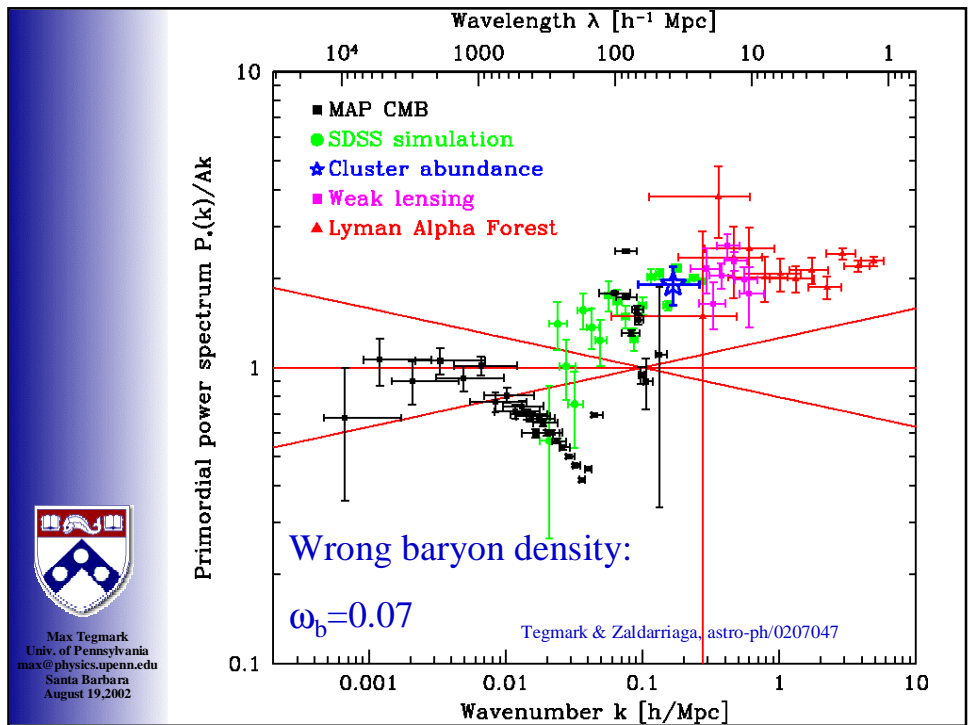
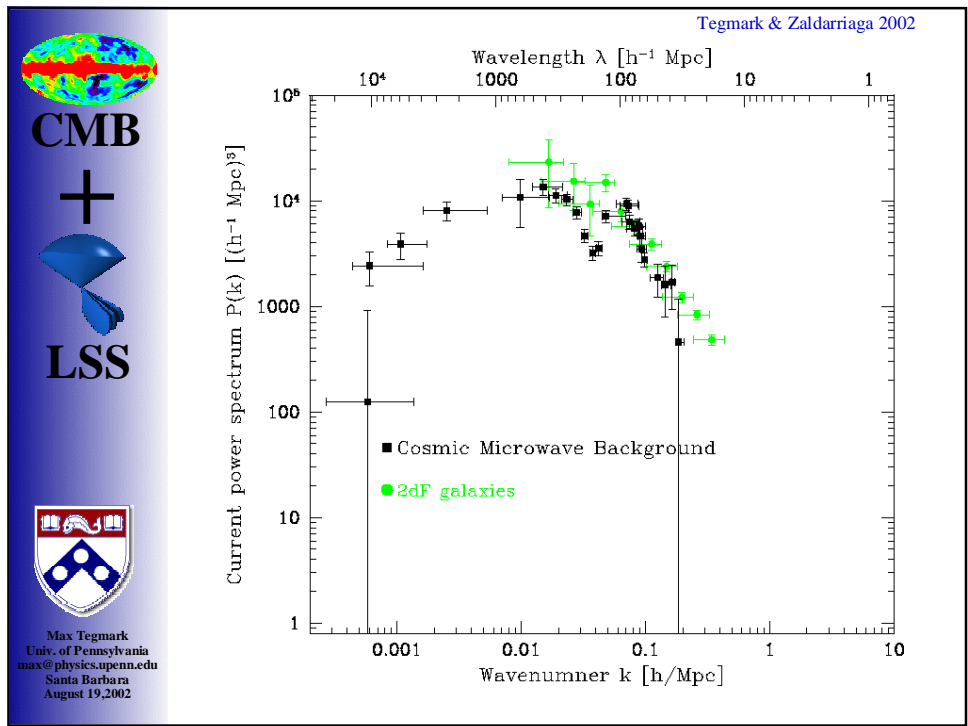


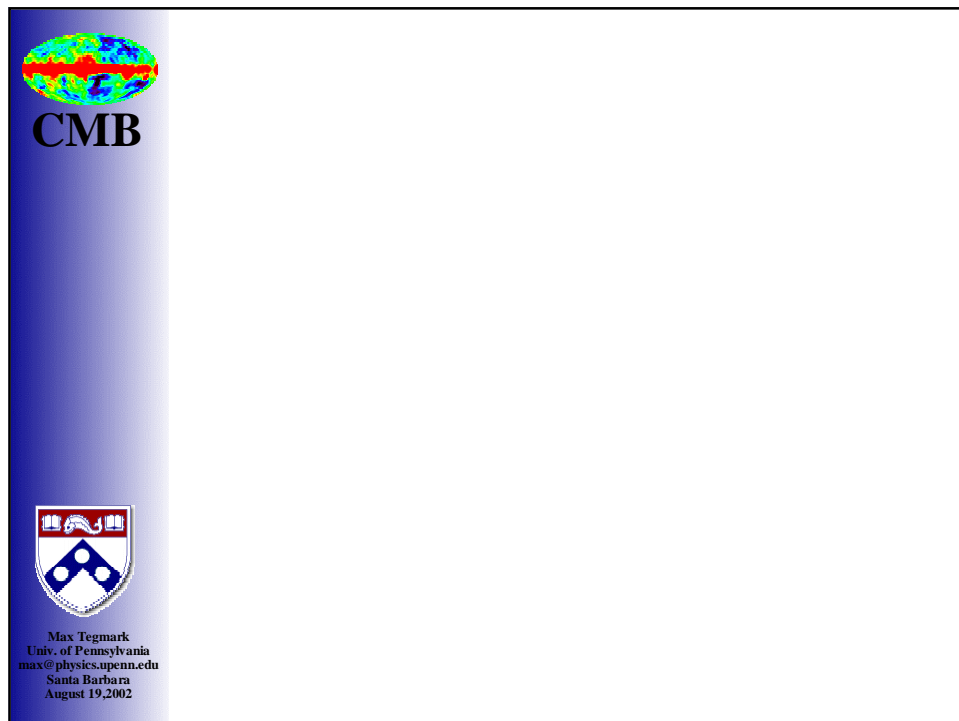
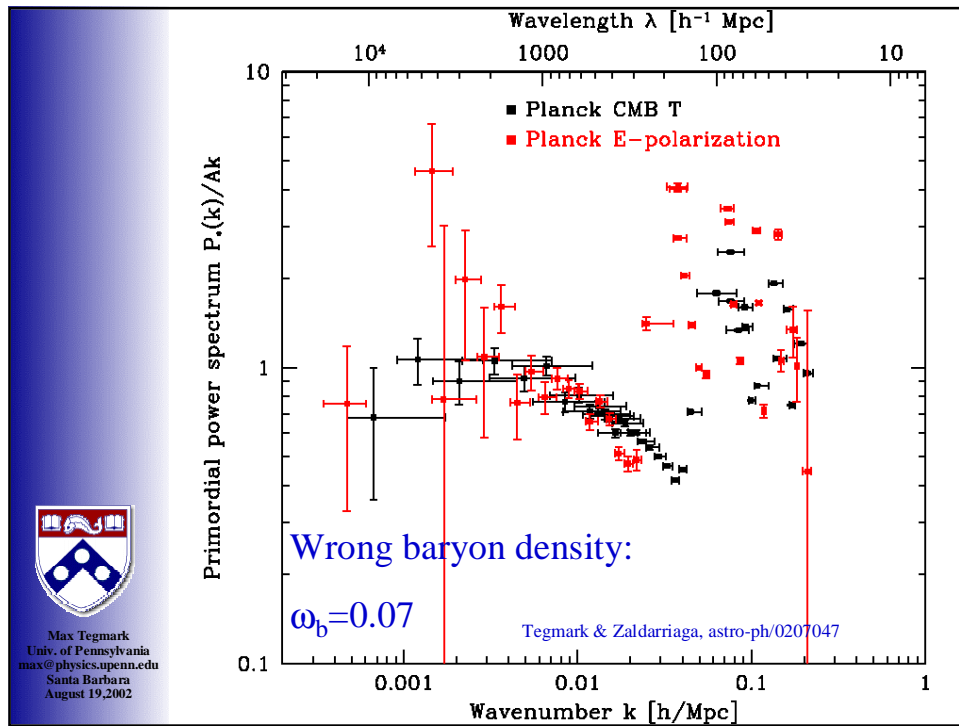
Measuring the primordial power spectrum $P_*(k)$











Beyond cosmological parameters, summary:

- Test the underlying physics rather than assuming it
- Cosmological functions rather than cosmological parameters
- Measure the free functions rather than parametrizing them in a way involving untested physical assumptions - a form of data compression

	$a(t)$	$g_s(z, k)$	$P_s(k)$	Ω_k	$x(z)$	Gastro
Physics						
Early Universe			⊕	⊕		
Dark energy	⊕	⊕				
Dark matter	+	⊕				
Neutrinos	+	⊕				
First light						⊕
CMB observable						
Primary CMB	⊕	⊕	⊕	⊕	⊕	
OV, KSZ	+	⊕	⊕	+	⊕	+
Thermal SZ	+	⊕	⊕	+		
CMB lensing	+	⊕	⊕	+		
Rees-Sciama		⊕	⊕			
Other observable						
SN Ia	⊕					
LSS	+	⊕	⊕	+		+
Ly α forest	+	⊕	⊕	+	+	+
Lensing	+	⊕	⊕	+		



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Do observations disagree with each other or with theory?

Data \Rightarrow Cosmological functions \Leftarrow Theory

