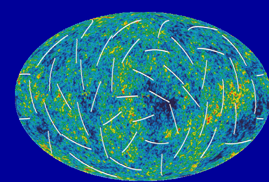
CMB and Fundamental Physics



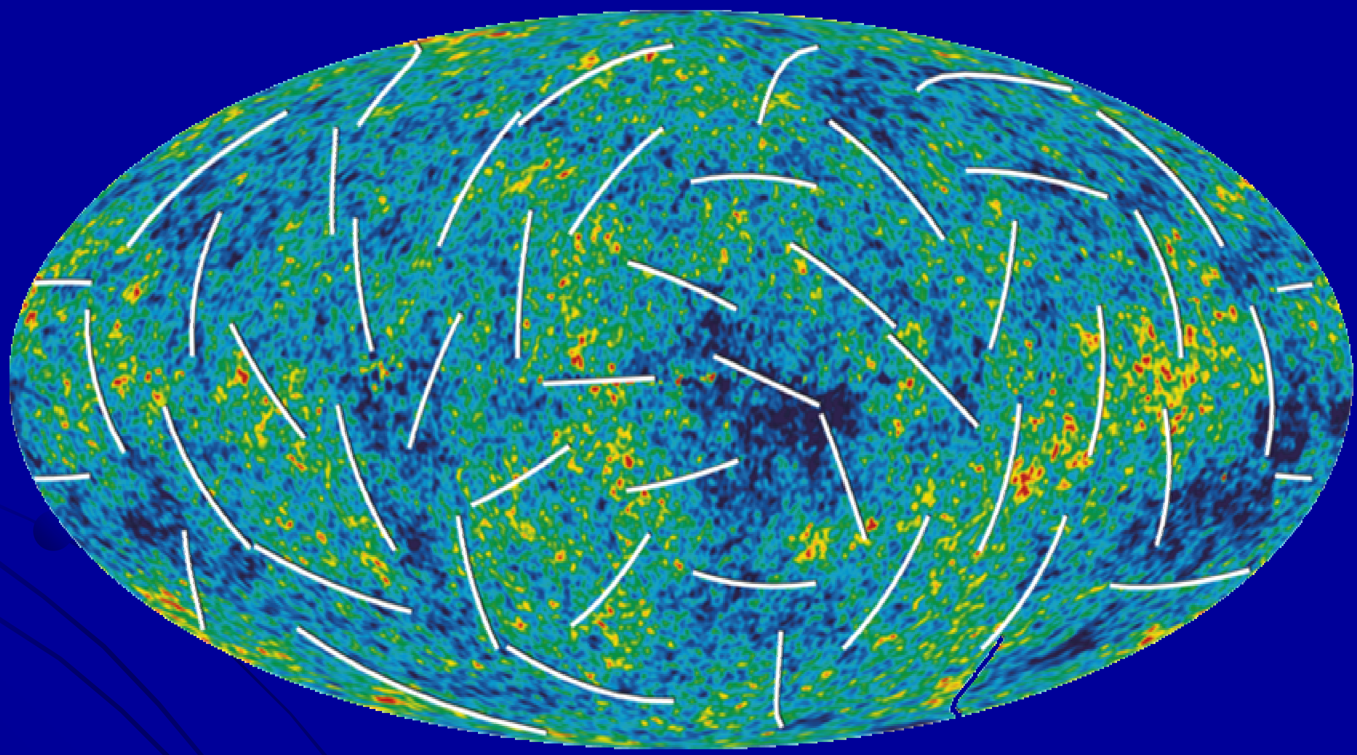
Meir Shimon

May, 2009

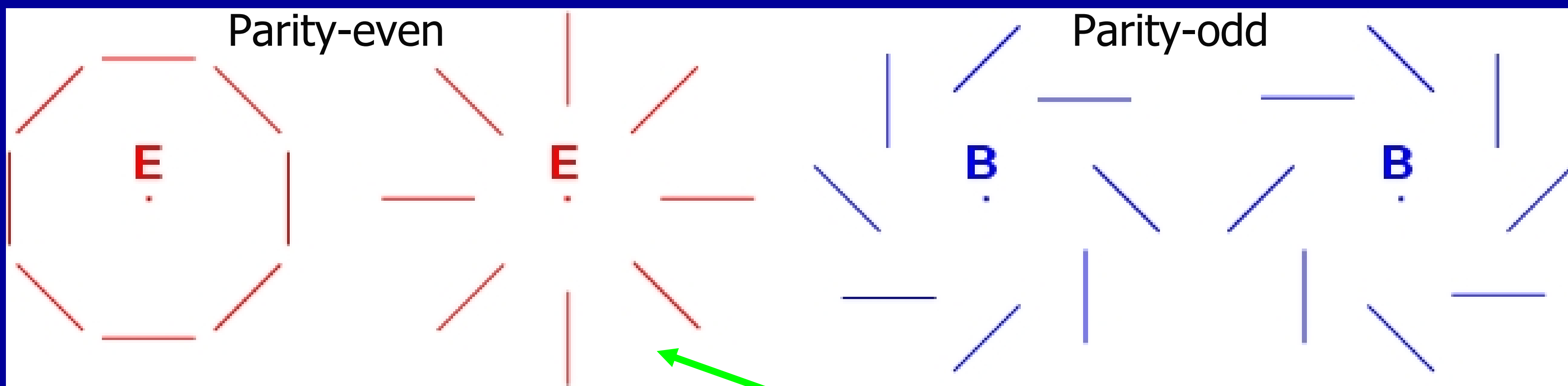
Outline

- CMB polarization and inflation
- Neutrino masses and chemical potentials
- Cosmological Birefringence
- The SZ effect and neutrino masses
- The SZ effect as a means to measure T(z)

CMB Polarization and Inflation



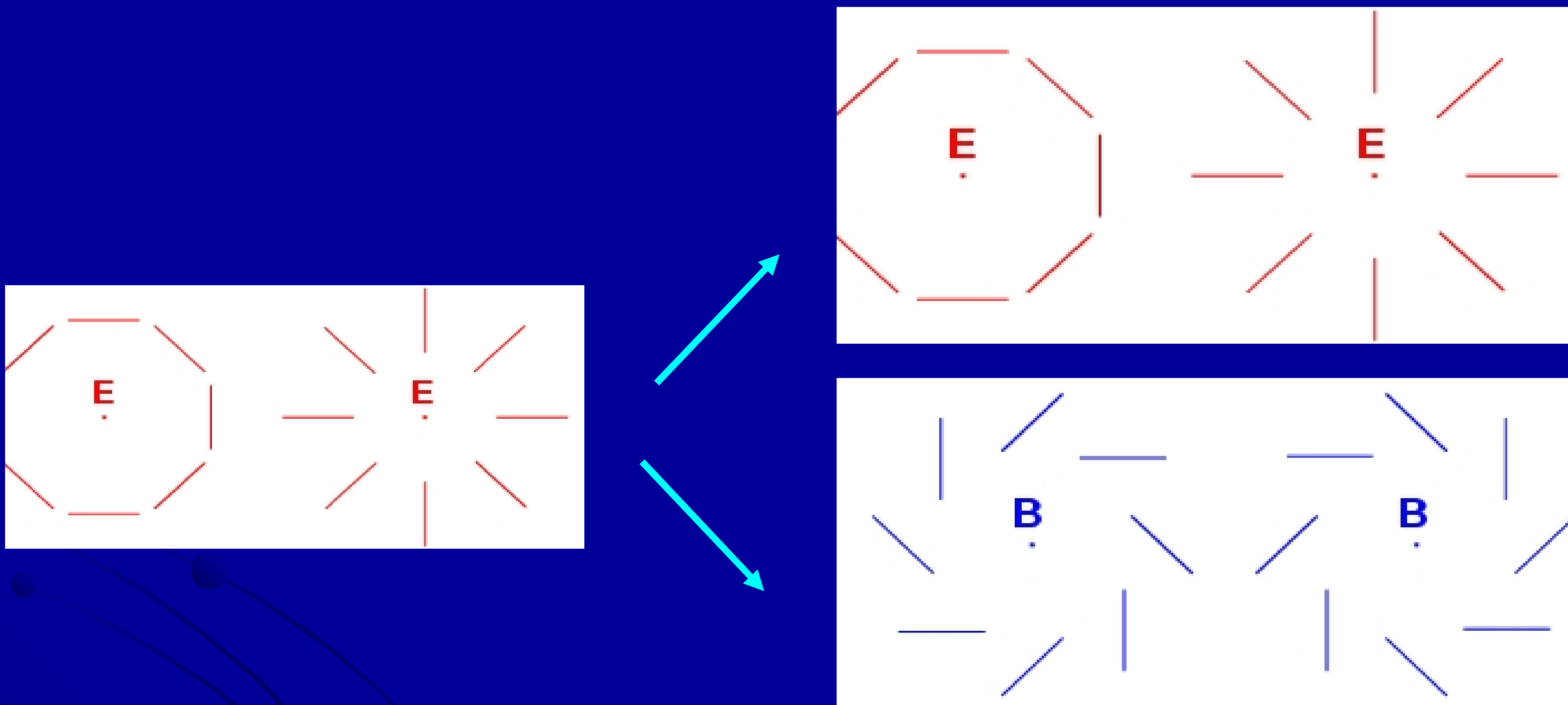
E-Mode vs. B-mode Polarization



Density perturbations
(scalar modes)

Gravitational waves
(tensor modes)

CMB Lensing by the LSS



B-mode generated by gravitational waves and 'contaminated' by gravitational lensing

Scalar vs. Tensor Perturbations

$$A_s^2 = \frac{V^3}{M_P^6 (V')^2}$$

$$A_t^2 = \frac{V}{M_P^4}$$

model-dependent

$$\delta\rho = V'(\phi)\delta\phi$$

model-independent

tensor - to - scalar ratio

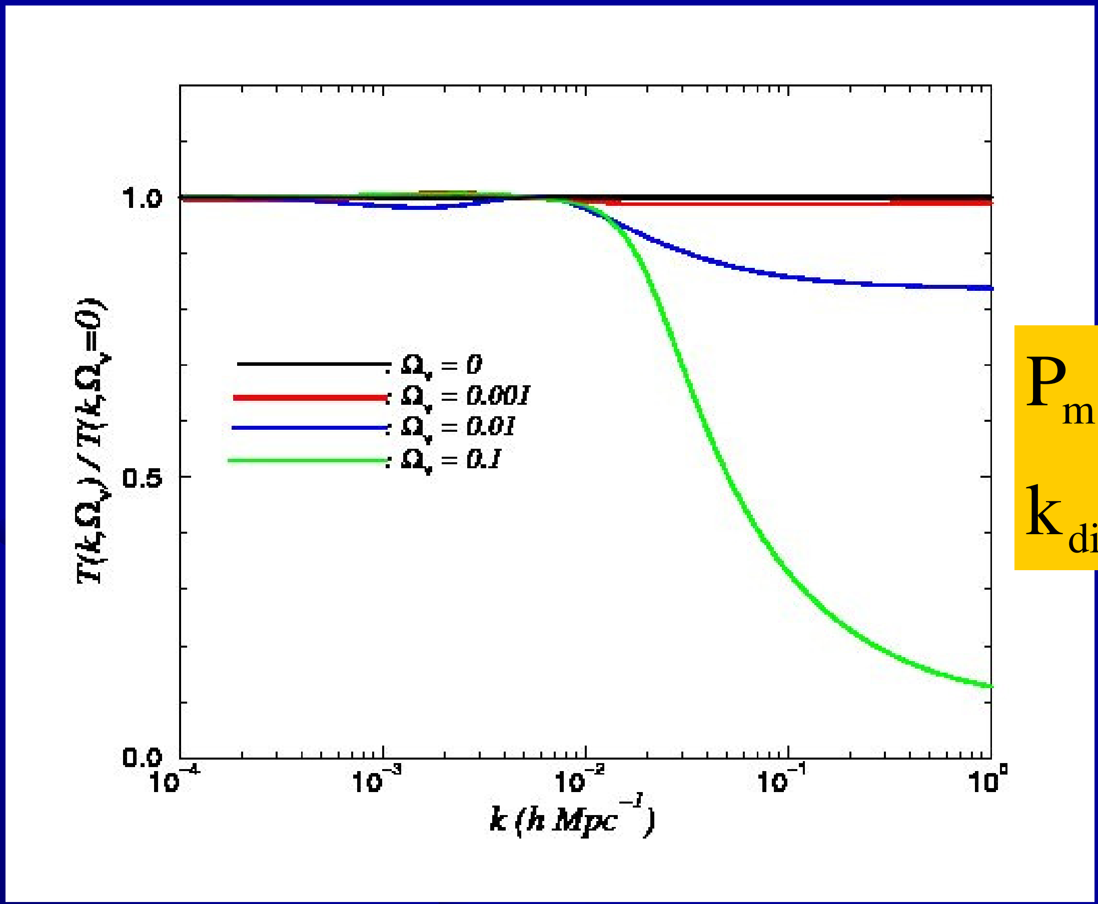
$r \approx E\text{^}4/[3.8\times 10^{16}\,\mathrm{GeV}]^4$

Neutrino Masses and Chemical Potentials

- If neutrinos are relativistic at recombination they may imprint on the CMB temperature anisotropy through the Integrated Sachs Wolfe effect

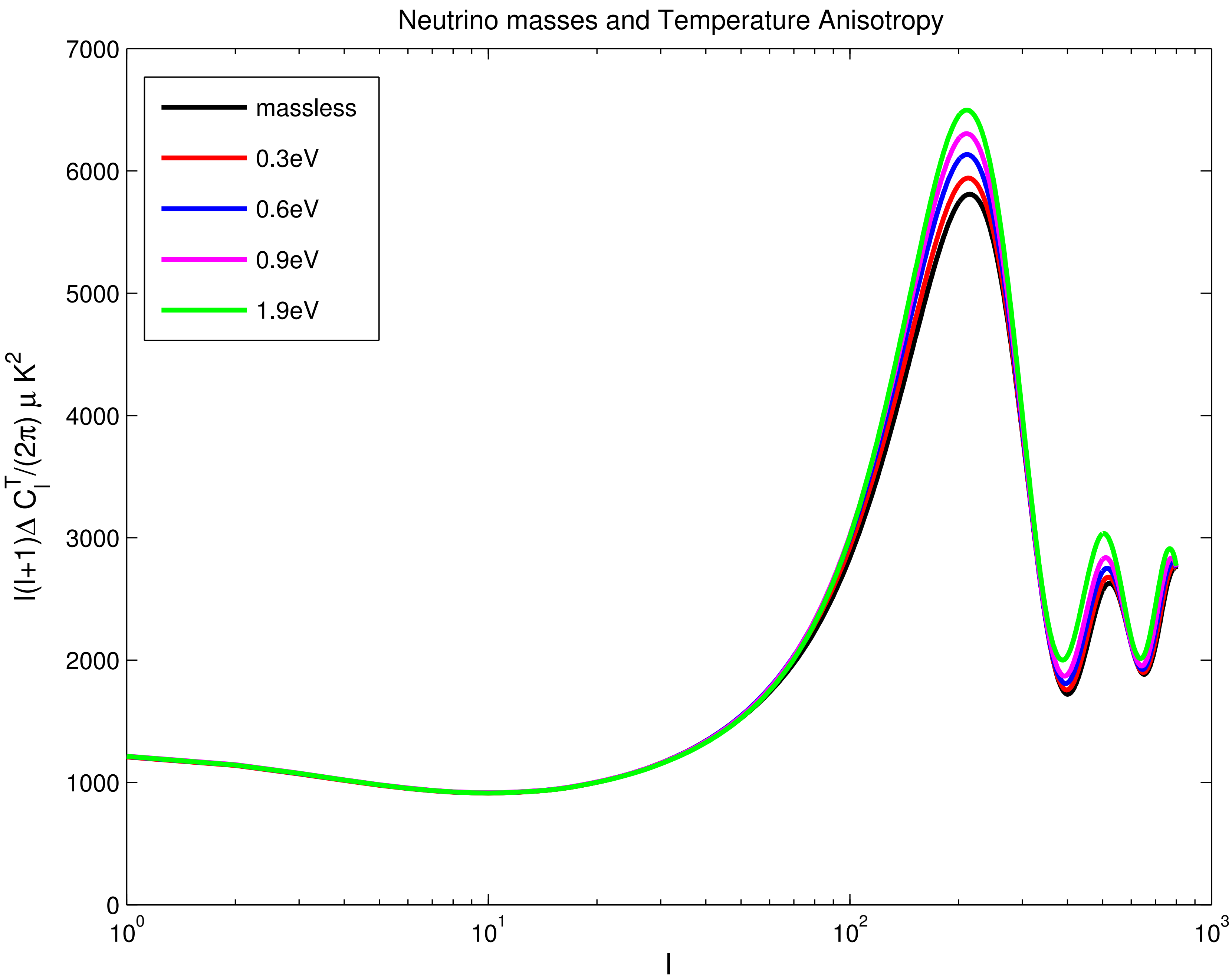
$$\frac{\Delta T}{T} = \int \frac{\partial \varphi}{\partial t} dl$$

Damping at the Era of Structure Formation



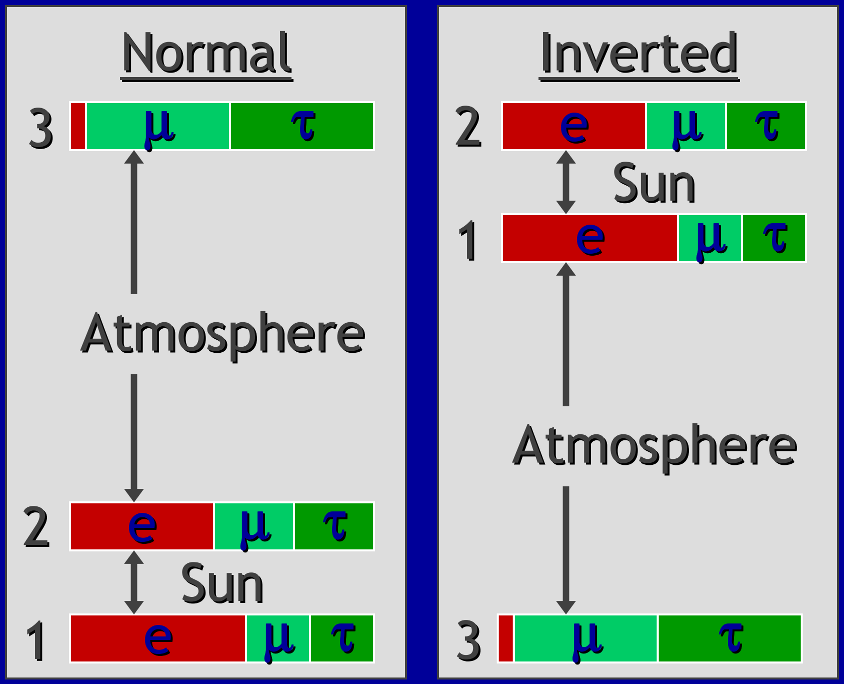
$$P_m(k;z) = AK^n T^2(k;z)$$

$$k_{diff} \approx 0.015\left(\frac{m_{\nu,tot}}{1\,eV}\right)^{1/2} \Omega_m^{1/2} h^{-1}$$


Neutrino masses and Temperature Anisotropy
massless
0.3eV
0.6eV
0.9eV
1.9eV
7000
6000
5000
4000
3000
2000
1000
0
$l(l+1)\Delta C_l^T/(2\pi)\ \mu K^2$
10^0
10^1
10^2
10^3
l

Neutrino Oscillations

$$M_e^2 = \sum_{i=1}^{3} |U_{ei}|^2 \, M_i^2$$



Solar neutrinos

$$\delta m_{12}^2 \equiv m_1^2 - m_2^2 \approx 8.0 \times 10^{-5}\,\mathrm{eV}^2$$

$$\delta m_{23}^2 \equiv m_2^2 - m_3^2 \approx 2.4 \times 10^{-3}\,\mathrm{eV}^2$$

Atmospheric neutrinos

At least one neutrino is heavier than 0.05 eV

Lepton Asymmetry

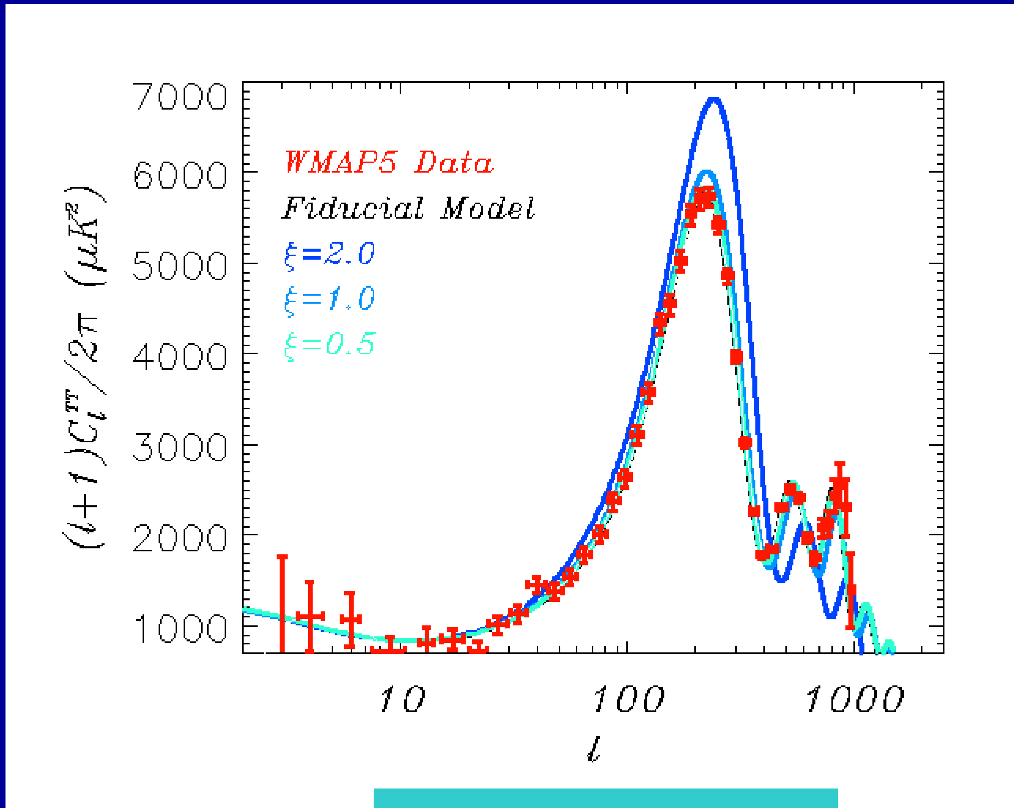
$$f(p;T_\nu,\xi_\nu)=\frac{1}{\exp(\frac{p}{T_\nu}\pm\xi_\nu)+1}$$

$$\xi_\nu\equiv\frac{\mu_\nu}{T_\nu}$$

$$\rho_\nu+\rho_{\bar\nu}=\frac{7}{8}\frac{\pi^2}{15}T_\nu^4[1+\frac{30}{7}(\frac{\zeta}{\pi})^2+\frac{15}{7}(\frac{\zeta}{\pi})^4]$$

Riotto & Kinney (1999),

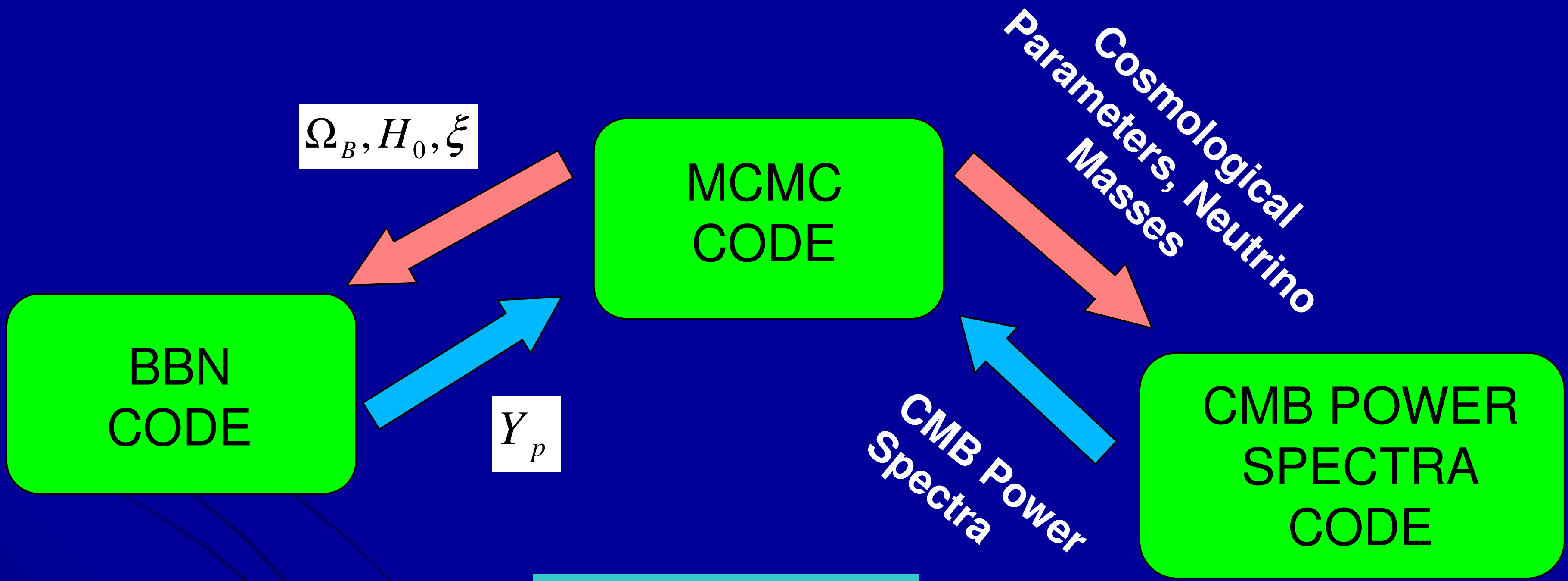
Lesgourgues & Pastor (1999)



Miller et al. (2009)

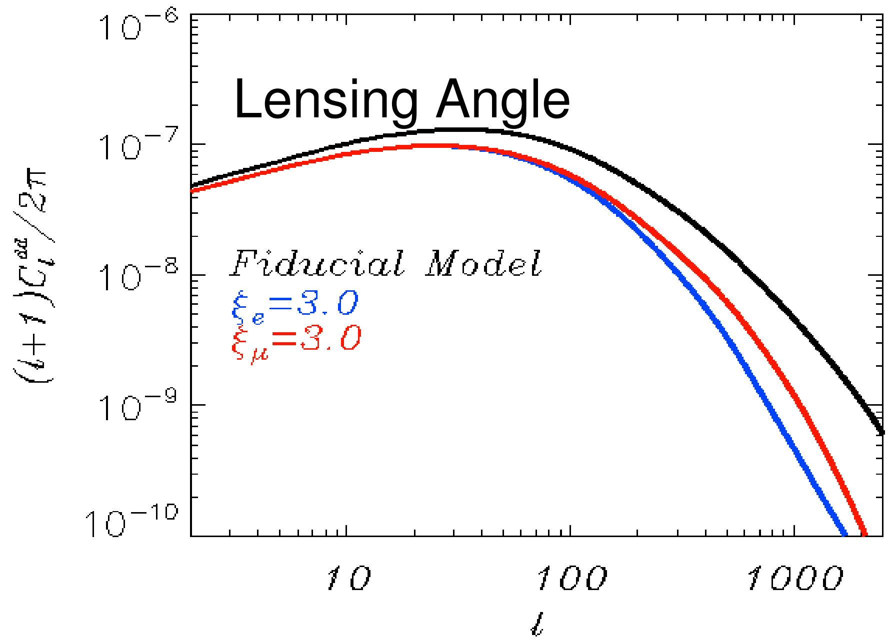
$$L\equiv\sum_\nu\frac{n_\nu-n_{\bar\nu}}{n_\gamma}=\frac{1}{12\varsigma(3)}\left[\sum_\nu(\xi^3+\pi^2\xi)\left(\frac{T_\nu^0}{T_\gamma^0}\right)^3\right]$$

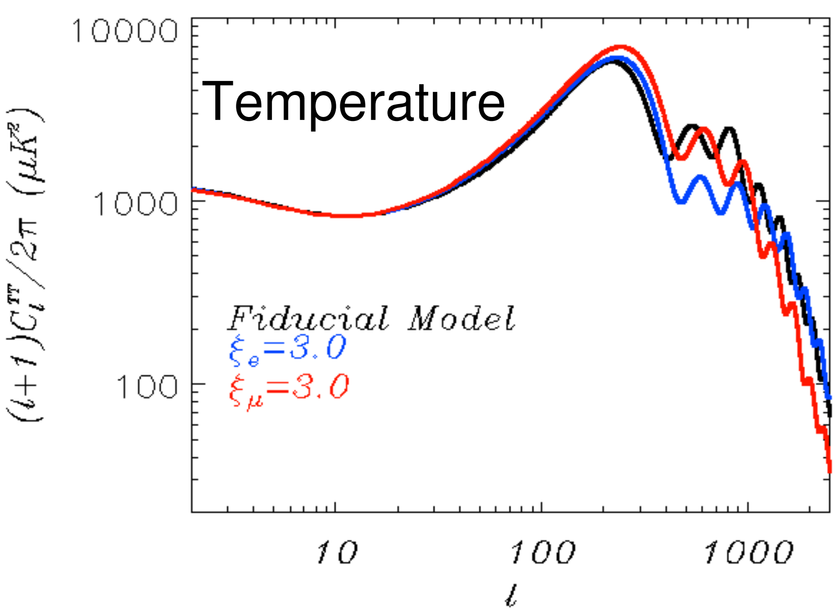
Flow Chart of BBN+CMB

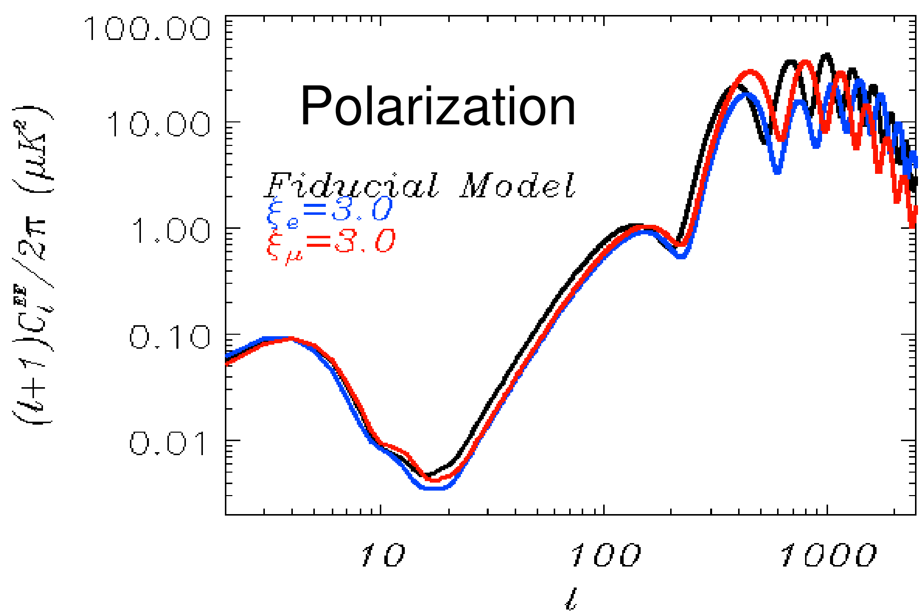


Miller et al. (2009)

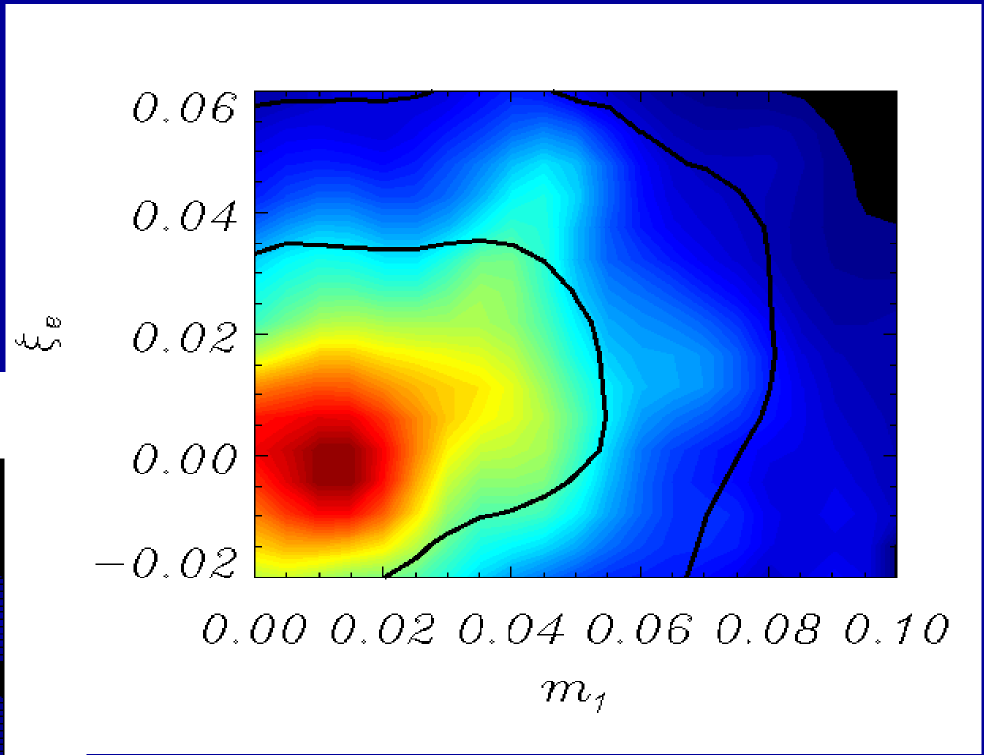
Degeneracy Parameter: Impact on Power Spectra

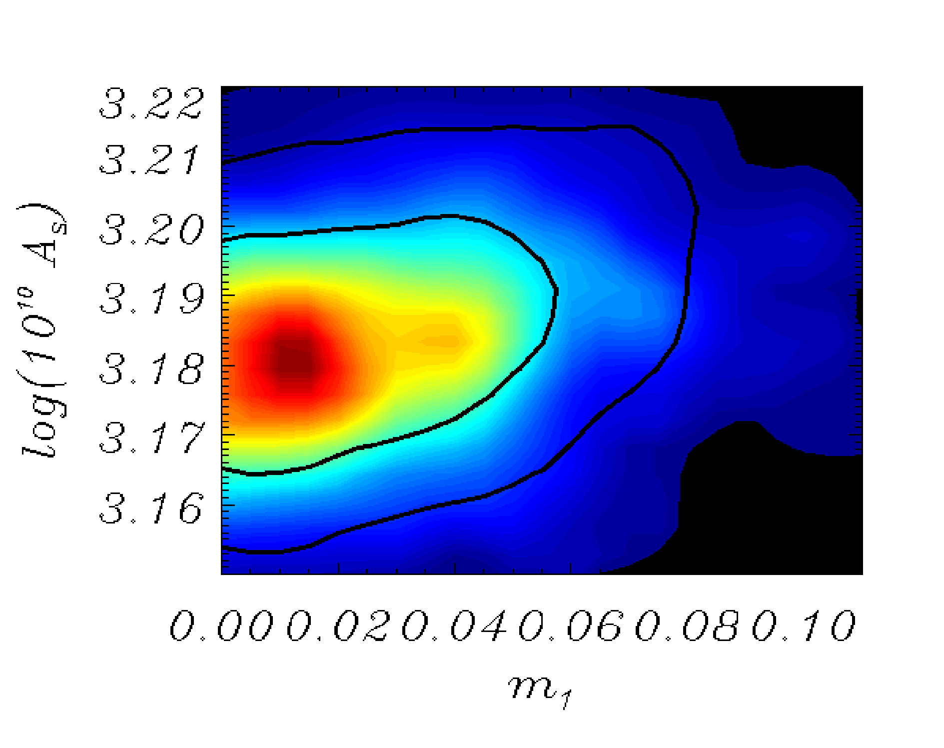




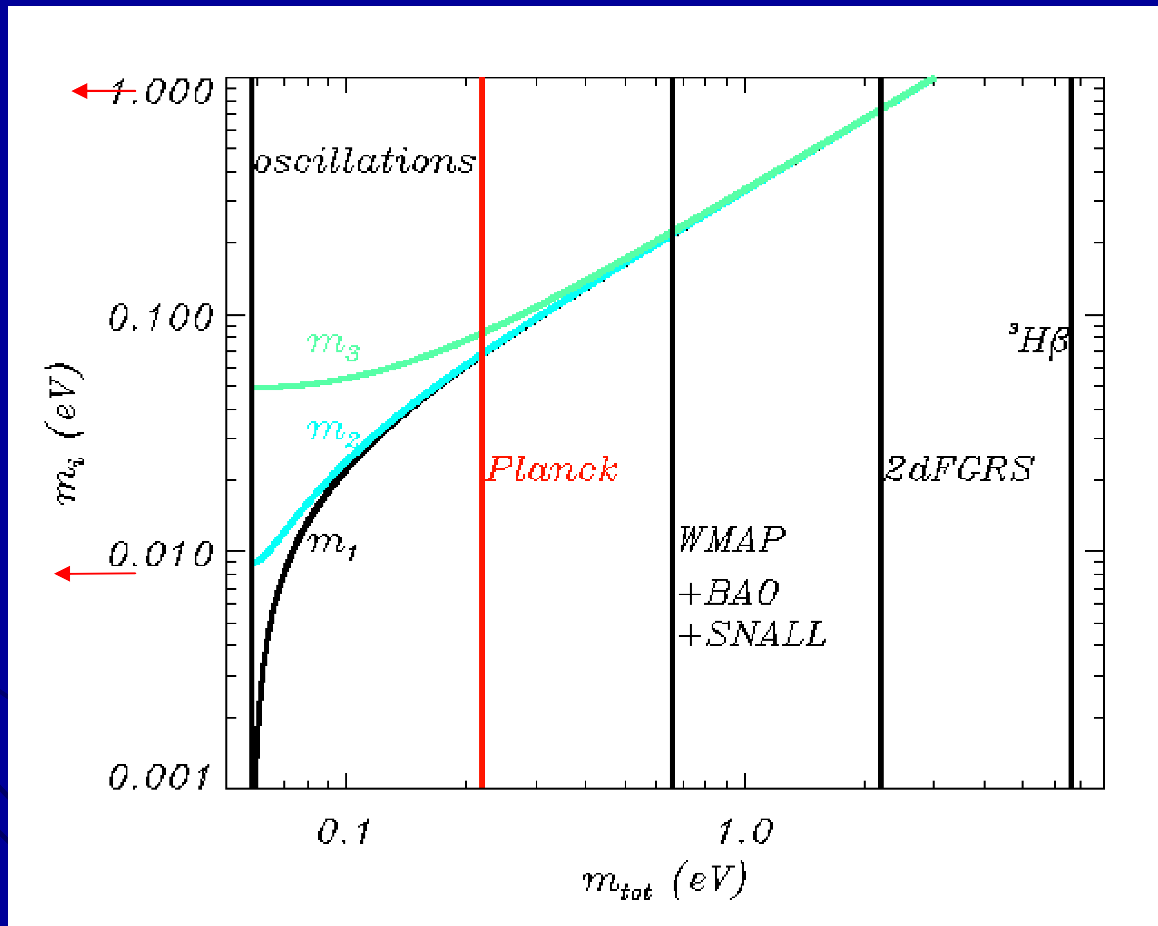


2D Likelihoods for Planck

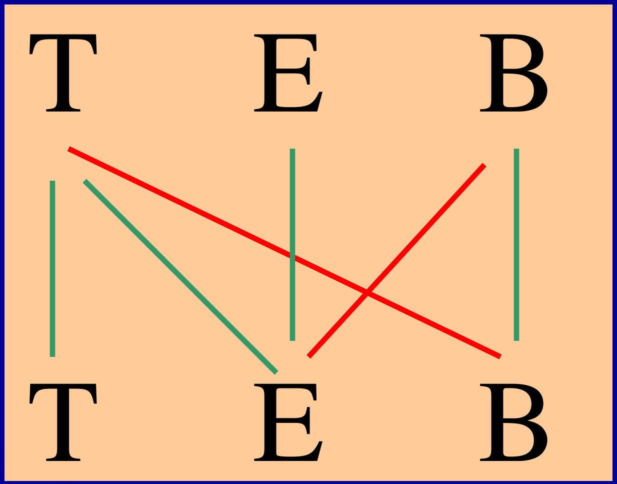




Limits on Neutrino Parameters from PLANCK



Cosmological Birefringence



primordial universe is

parity - even (?) $\rightarrow$ TB=0=EB

Parity Violating Interactions

$$L \propto E^2 - B^2 \rightarrow E^2 - B^2 + g\vec{E}\cdot\vec{B}$$

Carroll, Field & Jackiw (1990)

These are the e.m. E and B, not to be confused with the E- and B-modes

$$\omega^2 = k^2 \pm (4\pi g_\chi \dot{\chi})\, k$$

The new term is charge - blind and parity violating :

$\mathrm{E} \rightarrow \mathrm{E}$

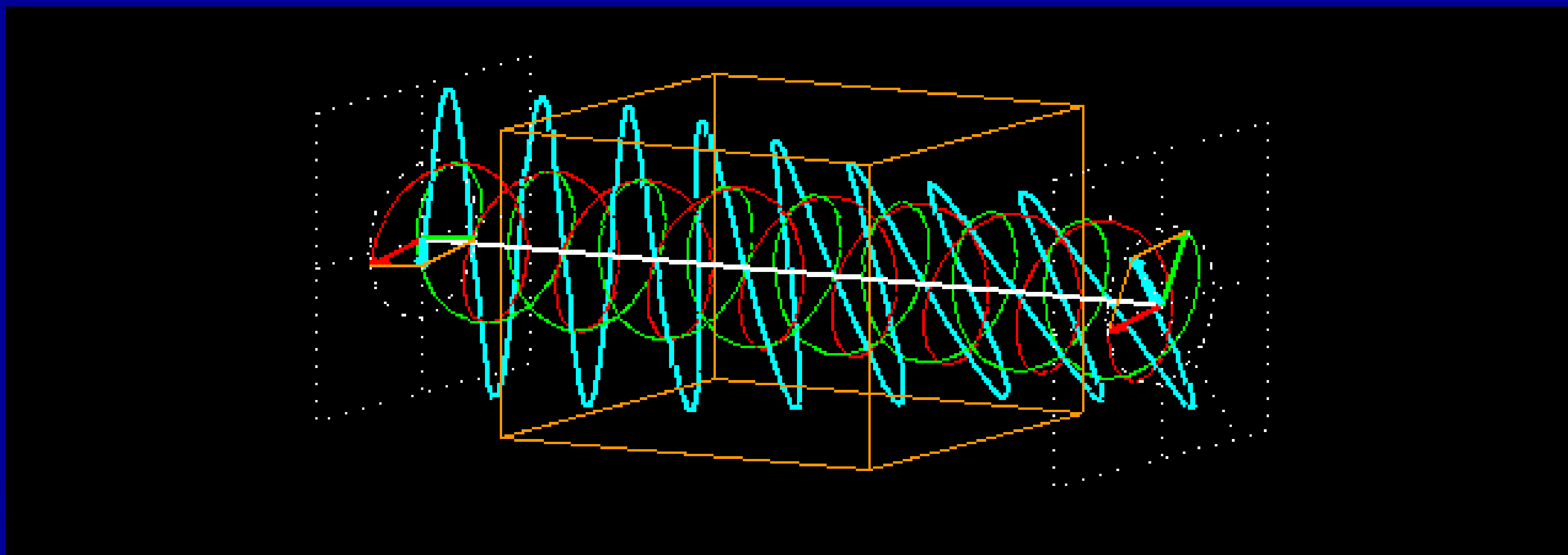
$\mathrm{B} \rightarrow -\mathrm{B}$

Therefore by the CPT theorem needs

violate time - reversal

g is χ, ϕ ?

Rotation of Polarization Plane



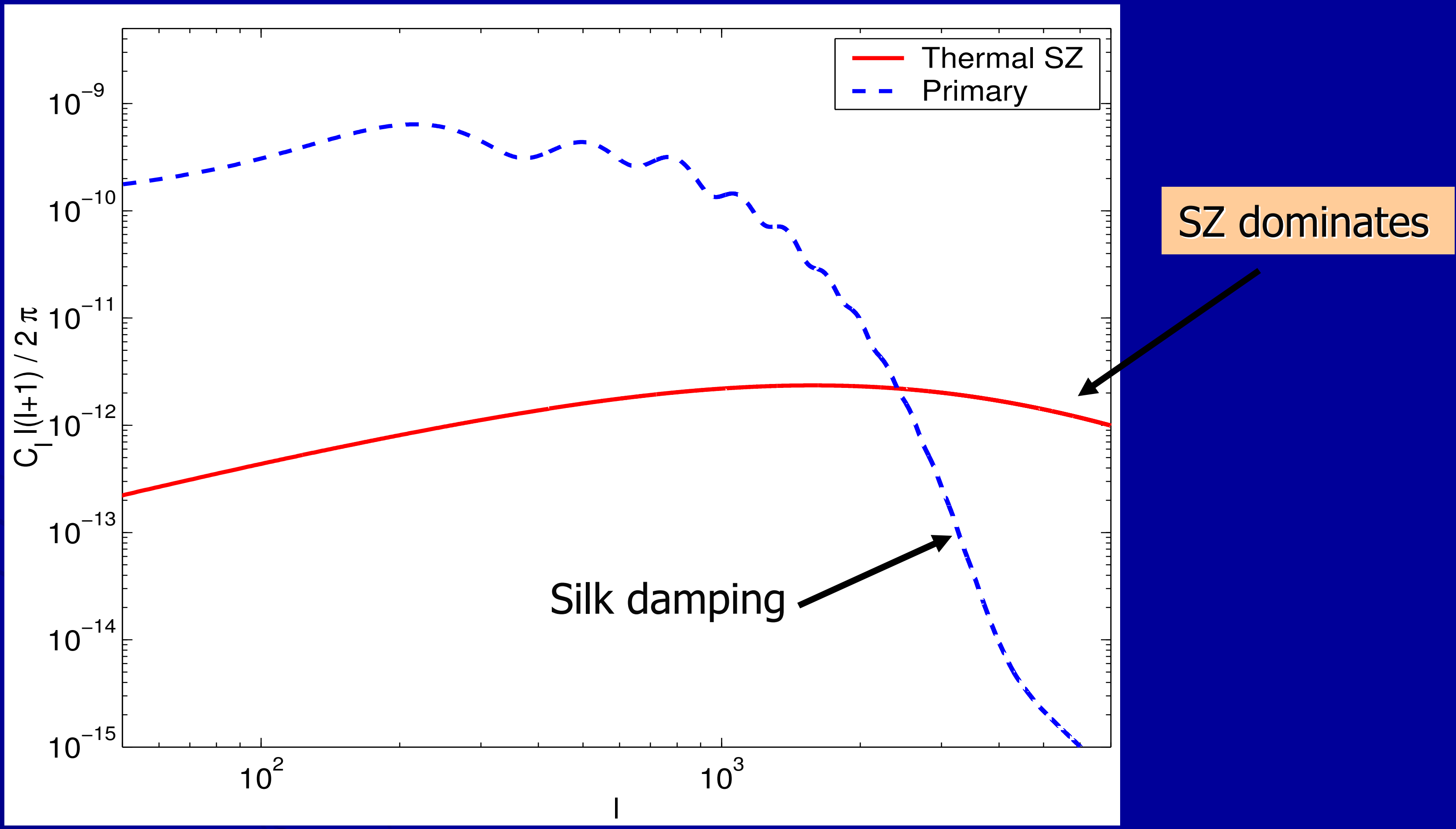
Rotation of the polarization plane $\Rightarrow$
mixing Q and U $\Rightarrow$
converting E $\rightarrow$ B $\Rightarrow$
inducing `forbidden' TB and EB

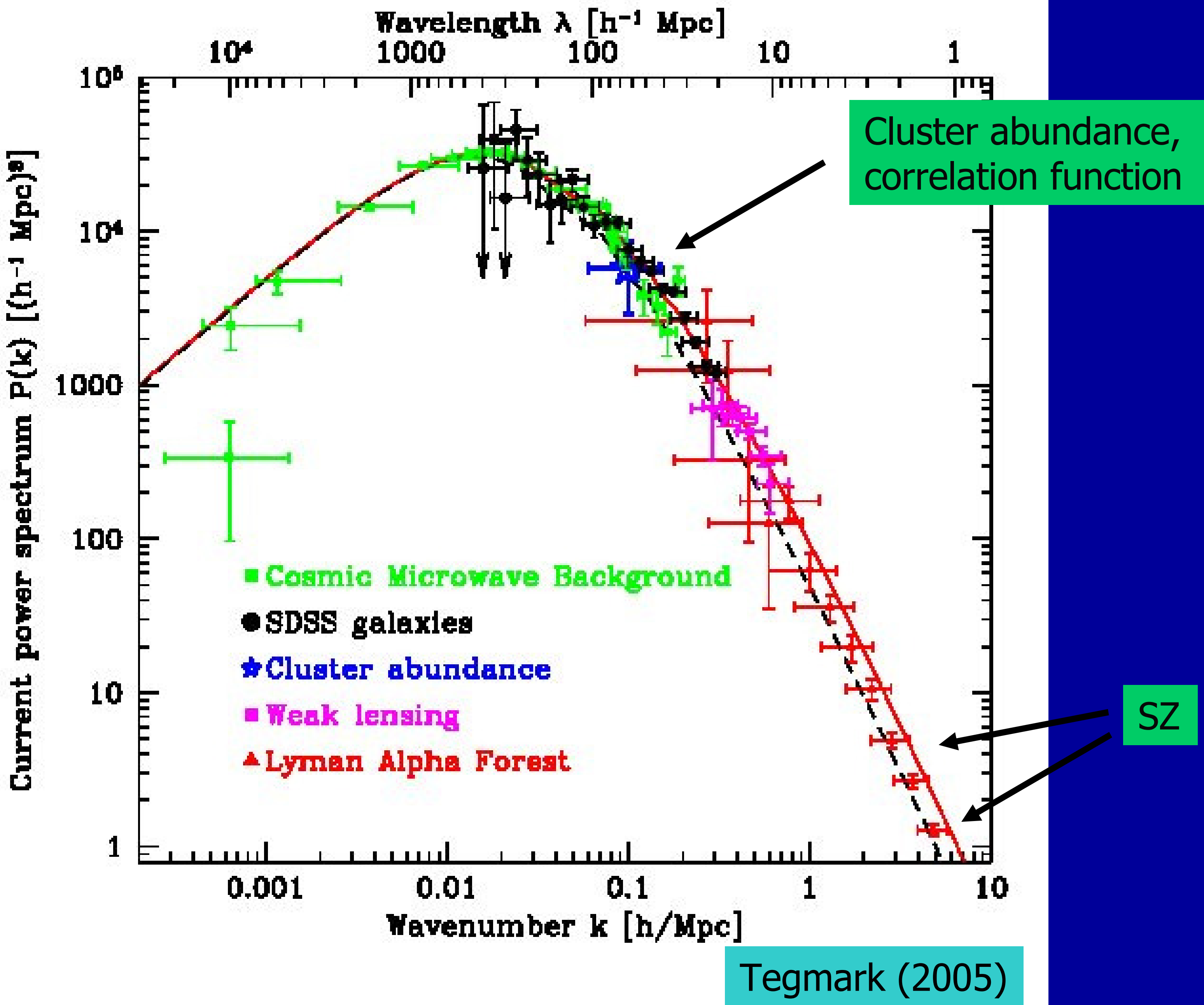
Beam systematics,
Miller et al. (2009)

SZ Effect and Neutrino Masses

- CMB comptonization by galaxy clusters
- Independent of redshift
- Dominates the power spectrum on small scales

SZ Power Spectrum




Wavelength λ [h⁻¹ Mpc]
10⁴
1000
100
10
1
10⁵
10⁴
1000
100
10
1
Current power spectrum P(k) [(h⁻¹ Mpc)³]
Cosmic Microwave Background
SDSS galaxies
Cluster abundance
Weak lensing
Lyman Alpha Forest
0.001
0.01
0.1
1
10
Wavenumber k [h/Mpc]
Cluster abundance,
correlation function
SZ
Tegmark (2005)

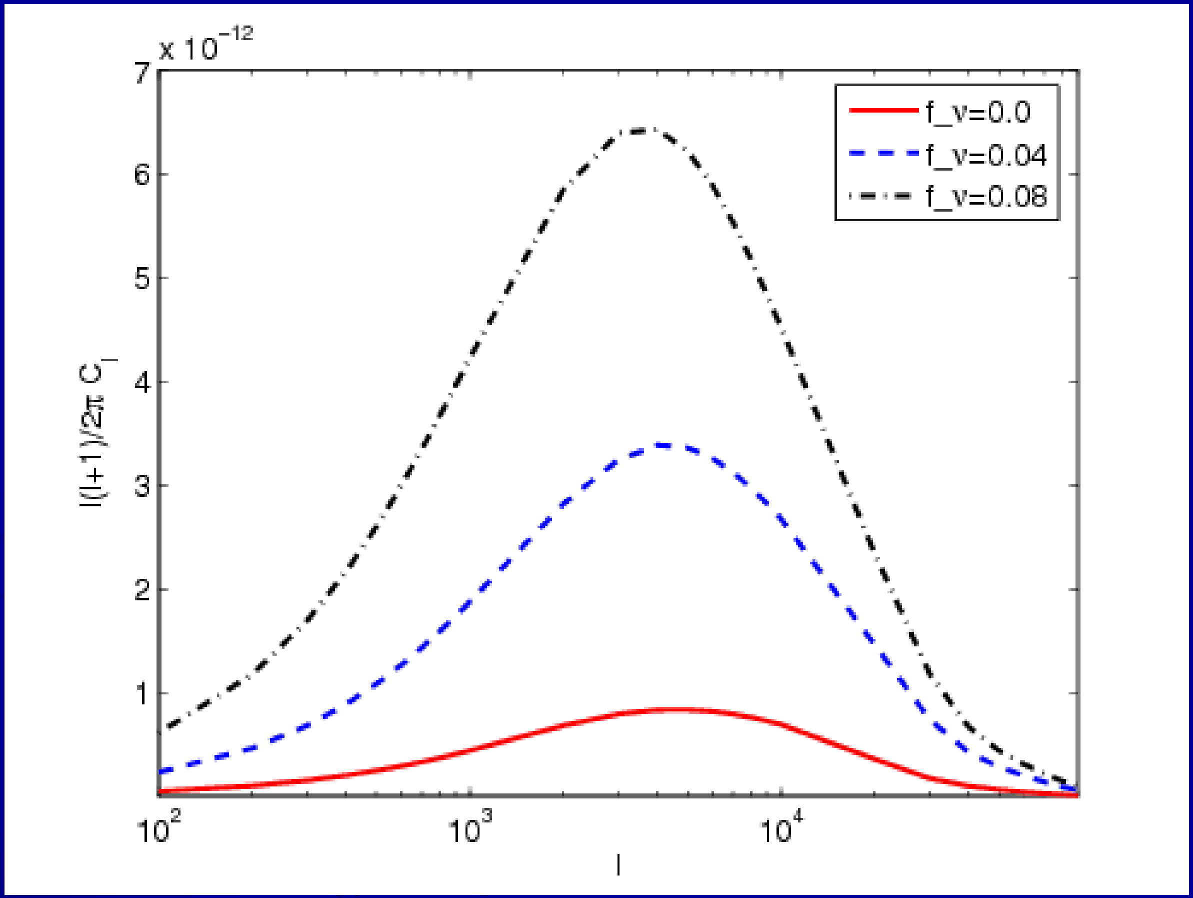
Neutrino Masses from Cluster Correlations and Number Counts

- SPT (10% sky coverage) will set upper bound on total neutrino mass of

  1.1 eV (from correlation function alone)
- Adding number counts tightens this limit to 0.72 eV
- DUO+ SPT+LSST+PLANCK will presumably constrain total mass down to 0.034 eV

Wang et al. (2005)

SZ Power Spectrum with Massive Neutrinos



$$f_\nu \equiv \frac{\Omega_\nu}{\Omega_M}$$

Sadeh, Shimon & Rephaeli (2009), in prep.

Non-Standard CMB Temperature Scaling and the SZ Effect

$$\Delta T_{SZ} / T_{\mathrm{CMB}} = \tau \theta_e F(x)$$

τ is the optical depth

$$\theta_{\mathrm{e}} = \mathrm{kT_e} /(\mathrm{m_e c^2})$$

$$\mathrm{x} = \mathrm{h}\nu/(\mathrm{kT_{CMB}})$$

$$S \propto N \propto V \cdot T^3 \rightarrow$$

$$T \cdot a = const. \rightarrow$$

$$T(z) = T_0(1+z)$$

- Non-standard evolution, i.e. non-adiabatic evolution, will result is departure from the standard scaling, e.g.

$$T(z) = T_0 \cdot (1+z)^{1-\alpha} \longrightarrow x = h\nu/(kT) \rightarrow x(1+z)^{\alpha}$$

Fabbri, Melchiorri & Natale (1978)

Rephaeli (1980)

- From a sample of 13 clusters

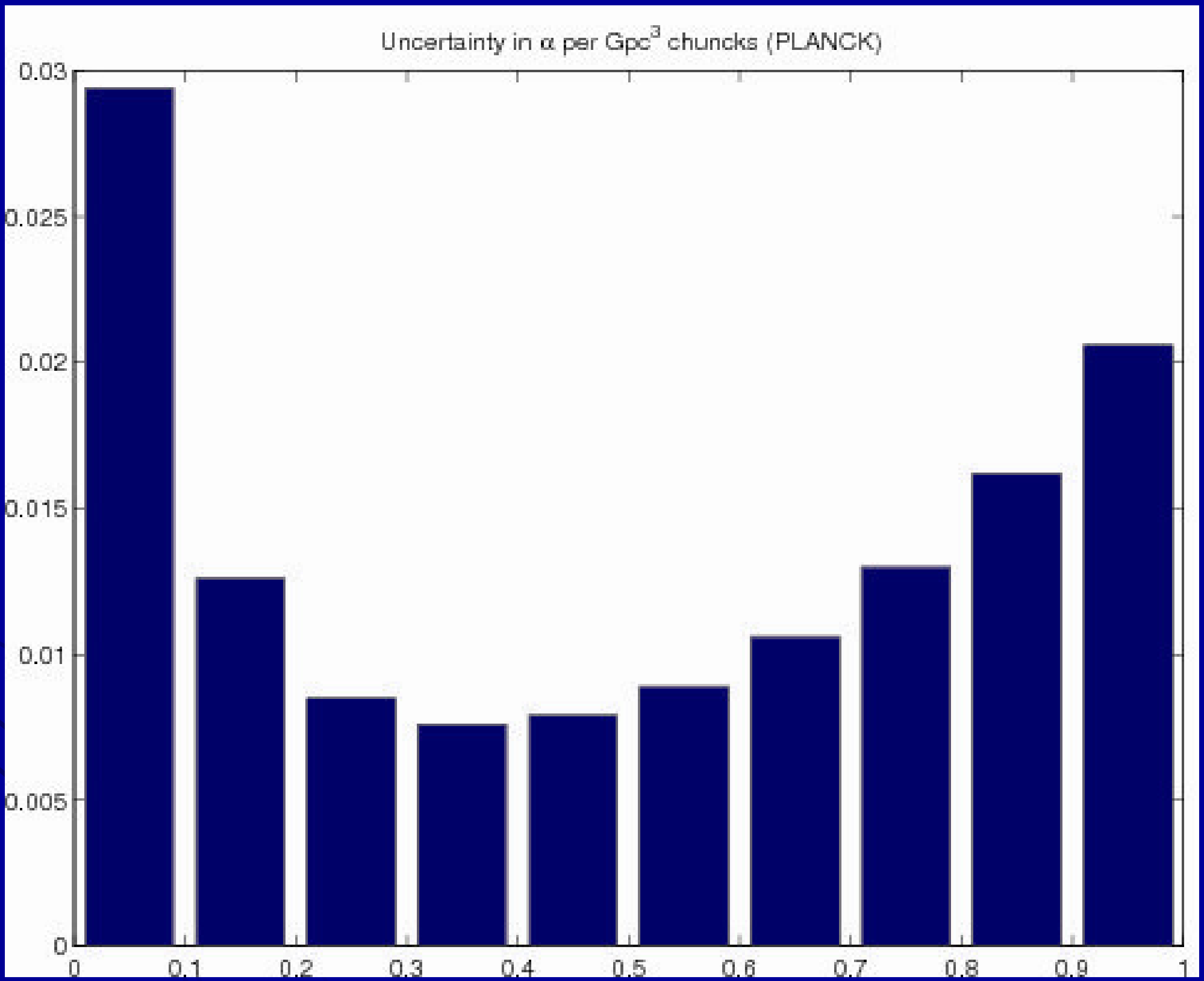
$$\alpha \leq 0.10\,(68\%\ \mathrm{CL})$$

Luzzi et al. (2009), in prep.

- Forecasted upper limits for PLANCK and ACT

$$\alpha_{\mathrm{PLANCK}} \leq 0.0014\,(0.0027)$$
$$\alpha_{\mathrm{ACT}} \leq 0.0008\,(0.0067)$$

Shimon & Rephaeli (2009), in prep.



Uncertainty in α per Gpc^3 chuncks (PLANCK)
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Summary I

- Energy scale of inflation
- LSS probes: trace the LSS and neutrino masses + chemical potentials via the effect of neutrino diffusion
- Chemical potentials: rule out or constrain scenarios of Lepton Asymmetry ?
- Cosmological Birefringence: constraining quintessence and axion models with CMB

Summary II

- SZ is likely to improve on neutrino mass constraints from standard number counts and correlation
- Non-standard temperature scaling
  can be constrained with SZ spectrum

Real-world effects (such as astrophysical foregrounds, beam systematics, etc.) may compromise this science and a considerable effort is being made to optimize our experiments: data-analysis techniques, foreground removal, beam systematics, etc, towards meeting the challenging requirements of B-mode detection and fine-scale anisotropy…