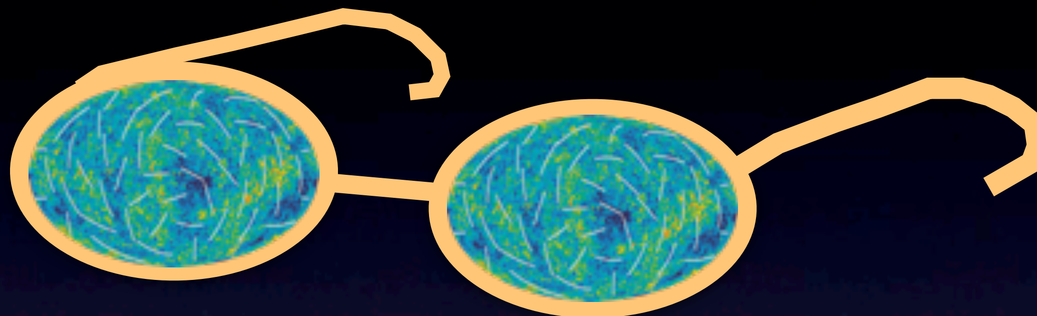
Seeing Cosmic Neutrinos Through CMB Lenses



Brian Keating

w/ Meir Shimon, Nathan Miller, Chad Kishimoto, Cristel Smith & George Fuller

8 February 2010 INT Seattle

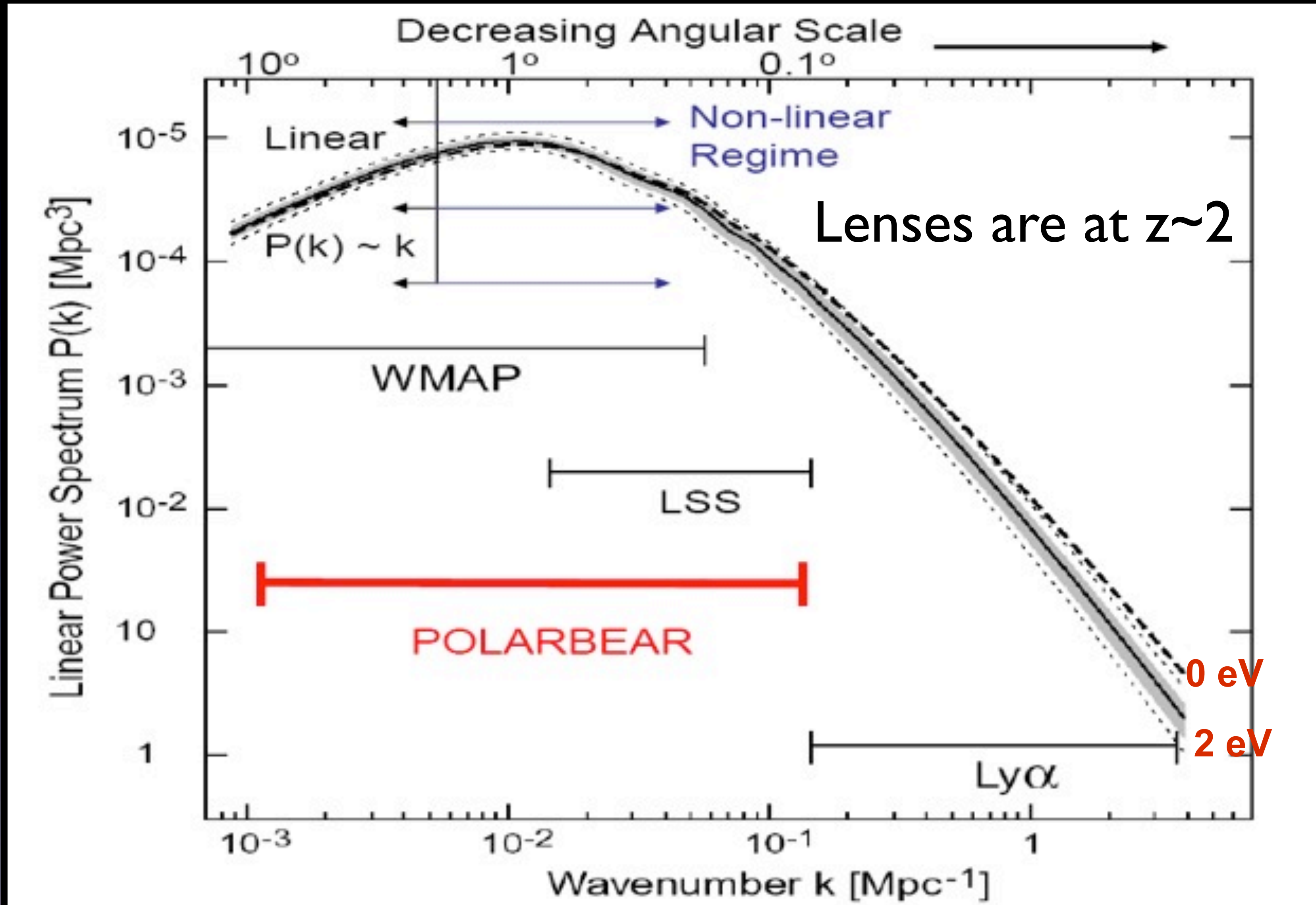
http://cosmology.ucsd.edu/

Neutrinos: Challenges and Opportunities!

- CMB Lensing is weak! Under 100 nK.
- Fortunately, we know that the unlensed CMB is very-nearly gaussian & we ~know the lensing power spectrum, with and without neutrinos.
- We can use the observed non-gaussianity (tri-spectrum) & the statistics of the CMB. Assume lensing causes any non-guassianity (Hu & Okamoto).

Cosmology is complementary: lensing potential is mainly sensitive to $\sum_{\nu} m_\nu$

P(k) & Neutrinos



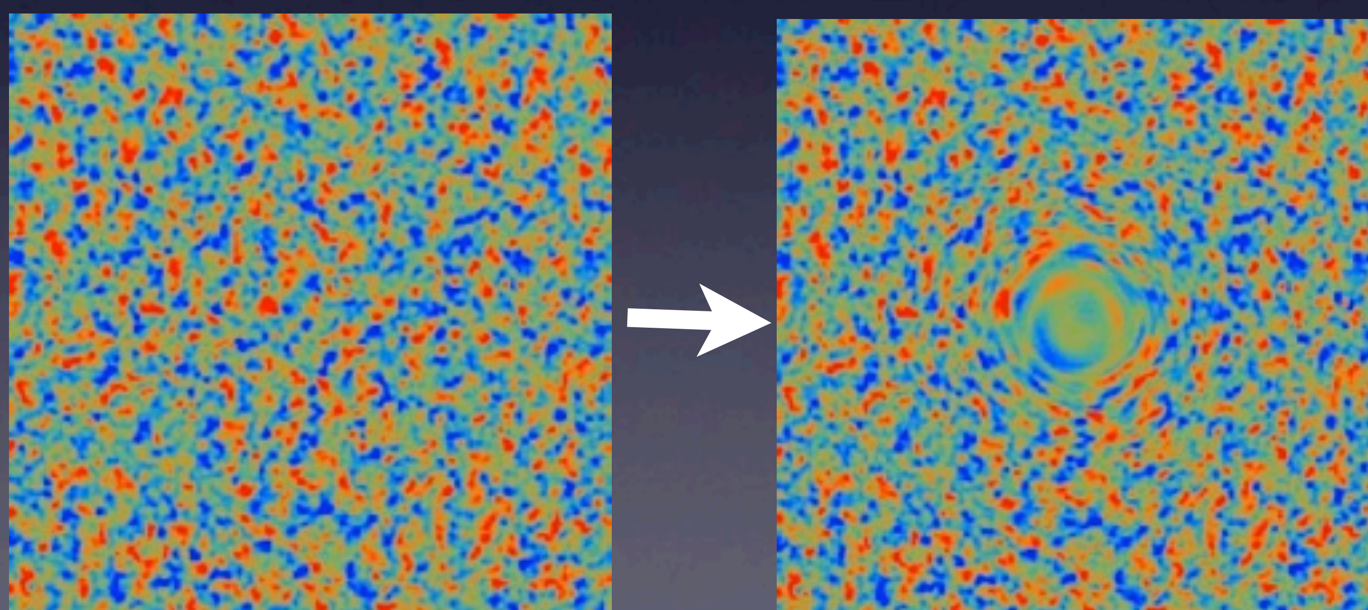
So, if we can get P(k) we can weigh the neutrinos!

Lensed CMB T,E, & B

$$T(\hat{n}) = \tilde{T}(\hat{n} + \mathbf{d}(\hat{n}))$$

Transverse gradient of the lensing potential creates new CMB signals

$$\mathbf{d}(\hat{n}) = \nabla_{\perp}\psi(\hat{n})$$



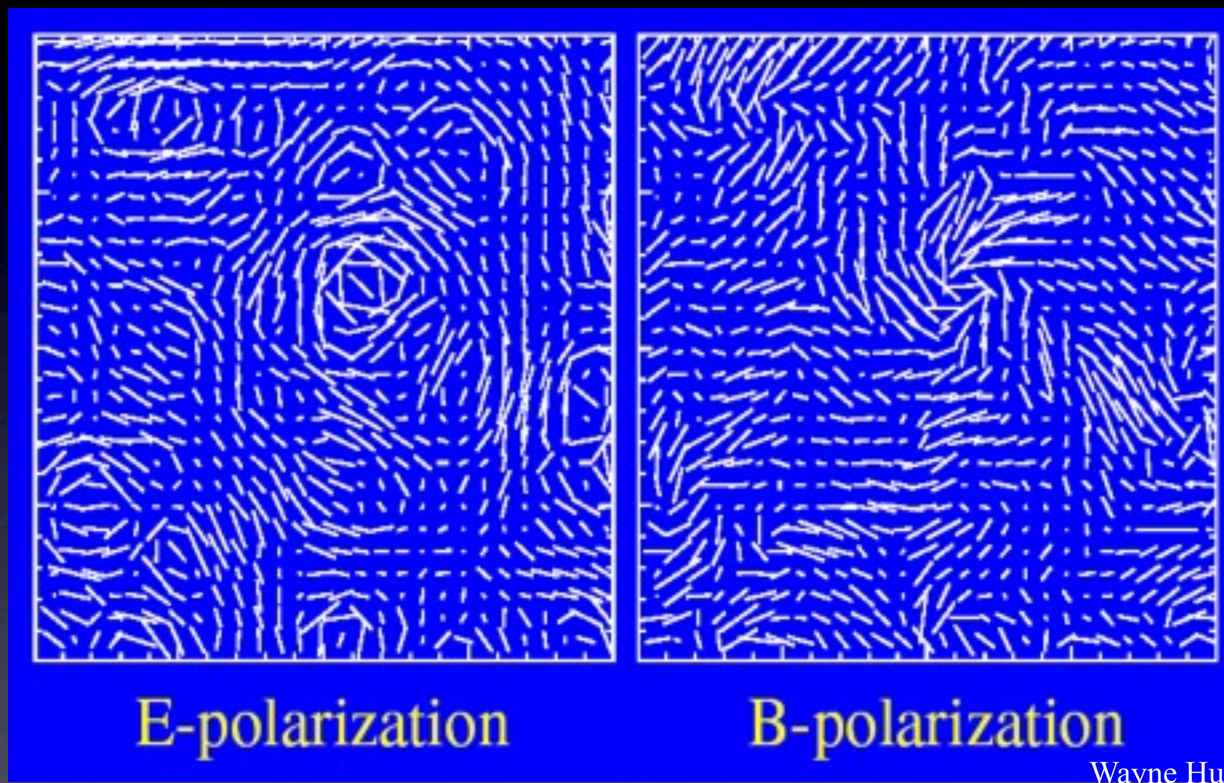
Why is Polarization Essential?

- E is more sensitive than T to lensing. E-modes are caused by velocity gradients, whereas T is caused by both velocity and density gradients.
- B is *extremely* sensitive since it's a whole new signal at small angular scales.
- EB correlations are forbidden without lensing. Therefore, they are the *most sensitive* to the deflection angle (Kaplinghat et al, Lesgourges et al), and to neutrino physics (M_ν and ξ, Shimon et al.) .

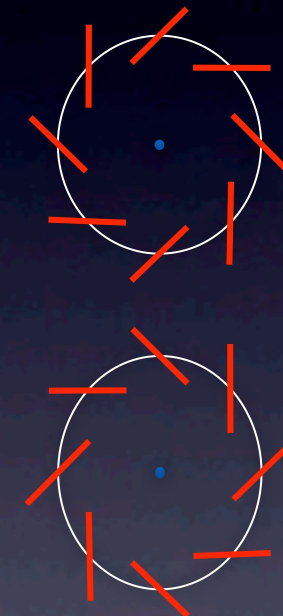
Polarization Patterns

Polarization Generation by Thomson Scattering

E-mode

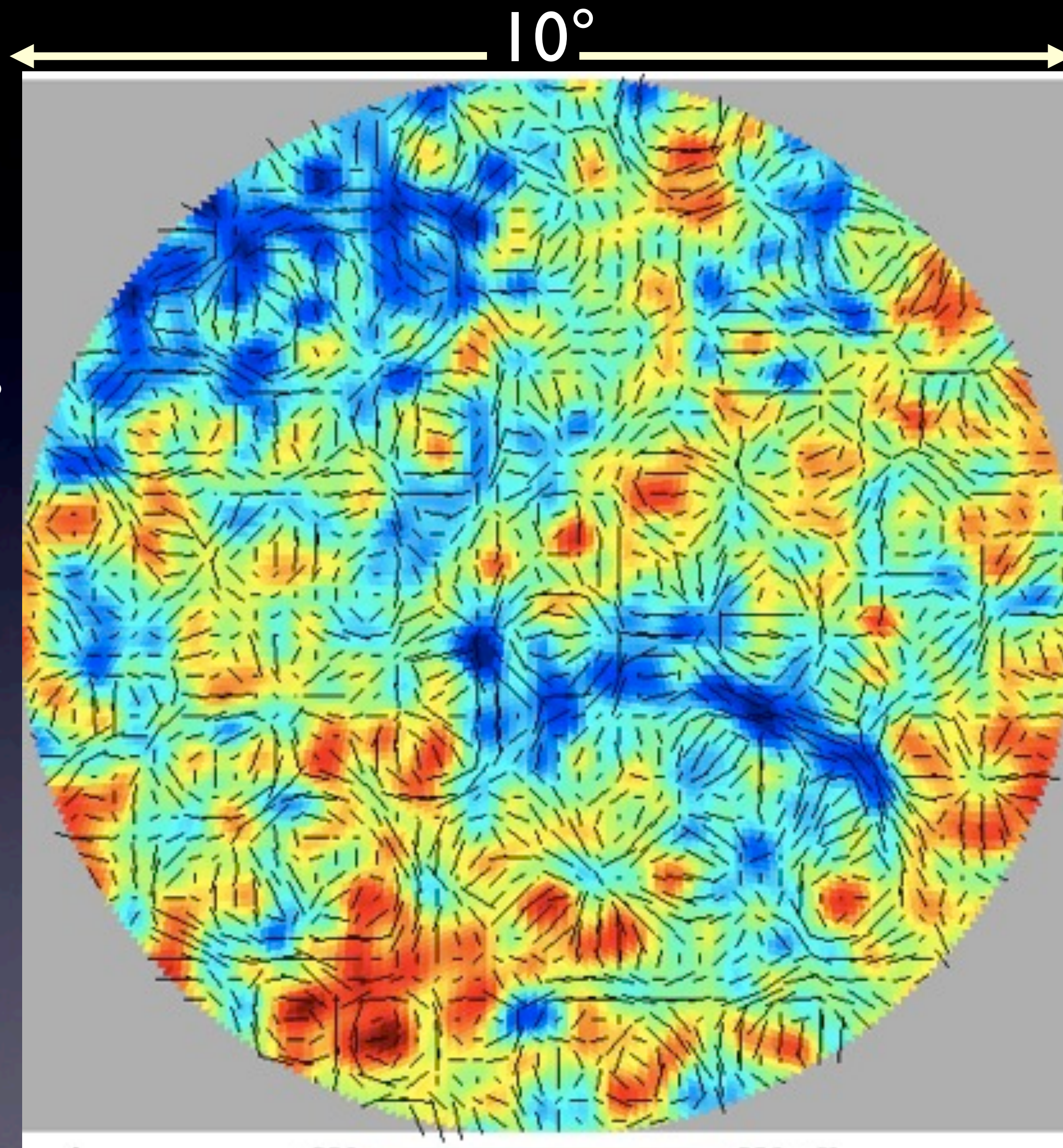


B-mode



- Density fluctuations lead to E-mode
- Gravitational Waves & Lensing lead to: B-modes

“Blink and You’ll Miss It!”



CMB Map

GWB: > 2° scales

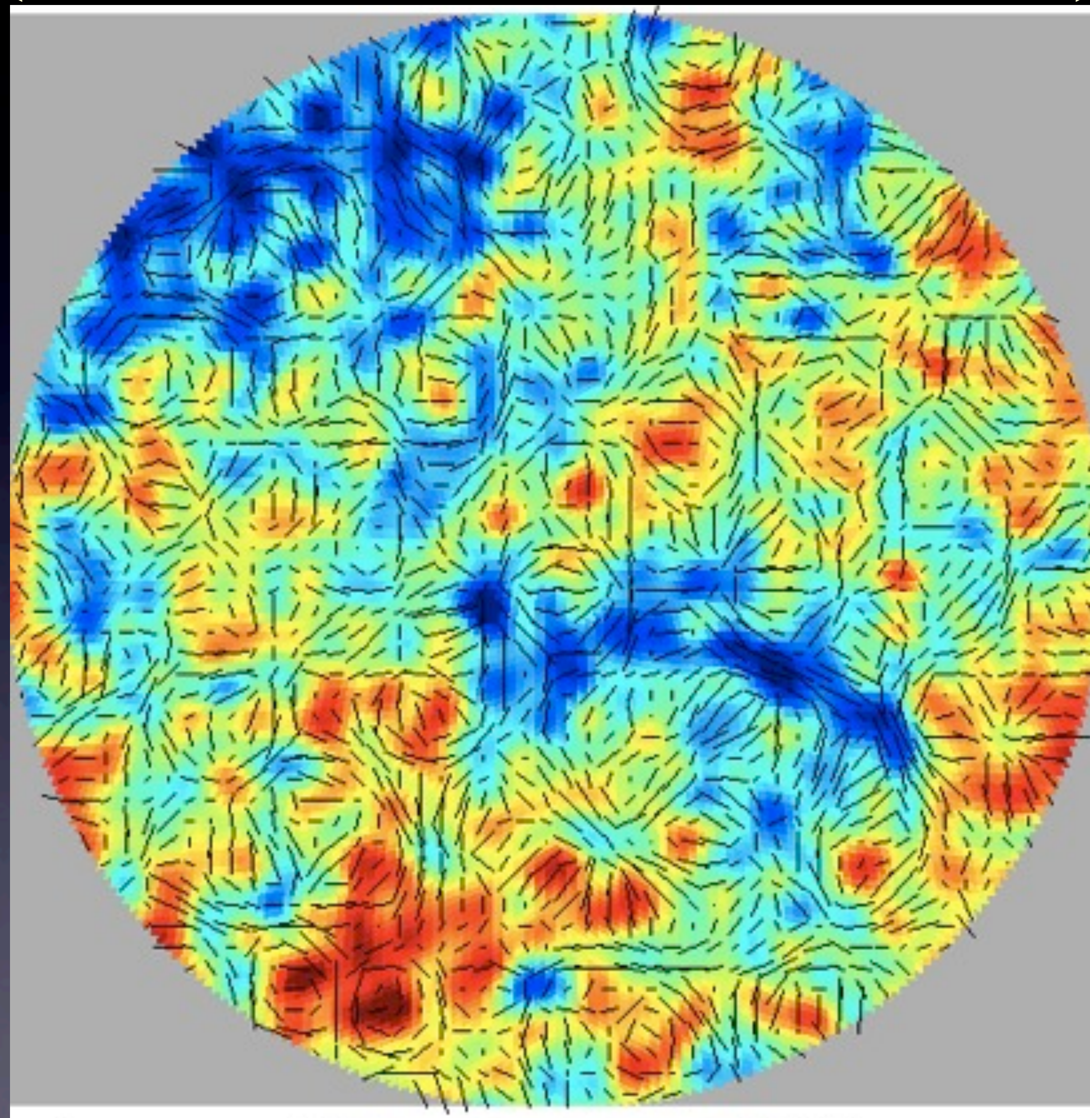
Lensing, m_ν < 0.1°

Helmholtz’s Thm:
“grad”: even parity
“curl”: odd parity

Without B-modes

“Blink and You’ll Miss It!”

10°



CMB Map

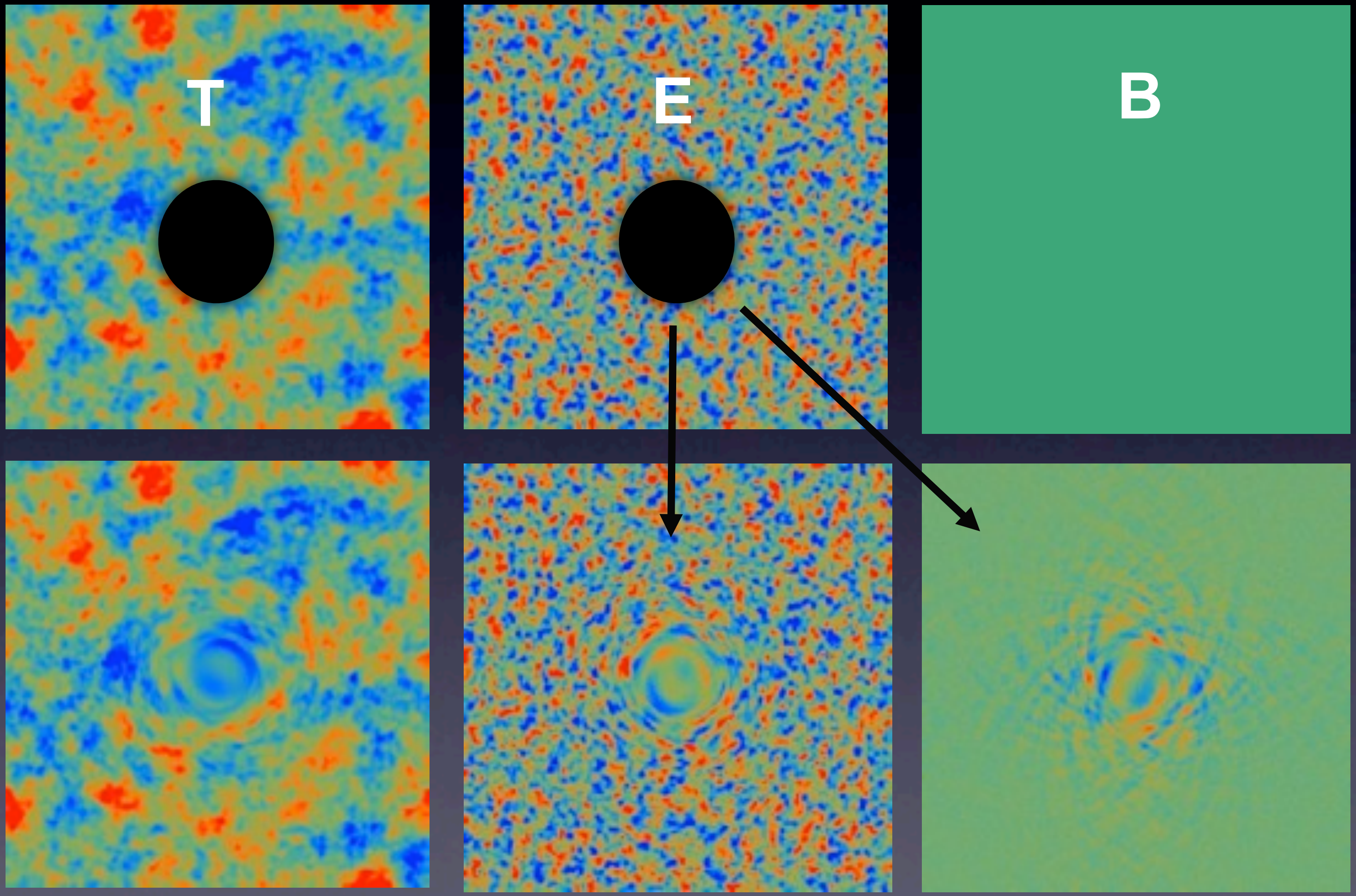
GWB: > 2° scales

Lensing, m_ν < 0.1°

Helmholtz’s Thm:
“grad”: even parity
“curl”: odd parity

With *30 nK* B-modes!

“Is this Better or Worse?” Before & After Lensing Maps



Hu & Okamoto 2002

POLARBEAR Collaboration

University of California at Berkeley
Kam Arnold
Daniel Flannigan
Wlliam Holzapfel
Jacob Howard
Zigmund Kermish
Adrian Lee P.I.
Marius Lungu
Mike Myers
Roger O'Brient
Erin Quealy
Christian Reichardt
Paul Richards
Chase Shimmin
Bryan Steinbach
Huan Tran P.M.
Oliver Zahn

Lawrence Berkeley National Lab
Julian Borrill
Christopher Cantalupo
Theodore Kisner
Eric Linder
Helmuth Spieler

University of Colorado at Boulder
Aubra Anthony
Nils Halverson Co. I

University of California at San Diego
David Boettger
Brian Keating Co. I
George Fuller
Nathan Miller
Hans Paar
Ian Schanning
Meir Shimon

Imperial College
Andrew Jaffe
Daniel O'Dea

Laboratoire Astroparticule & Cosmologie
Josquin Errard
Joseph Martino
Radek Stompor

KEK
Masashi Hasumi
Haruki Nishino
Takayuki Tomaru

McGill University
Peter Hyland
Matt Dobbs

Cardiff University
Peter Ade
Carole Tucker

Designed to Measure B-modes Generated by:
1)Inflationary Gravitational Waves
2)Lensing of the CMB

POLARBEAR: A High Energy Polarimeter

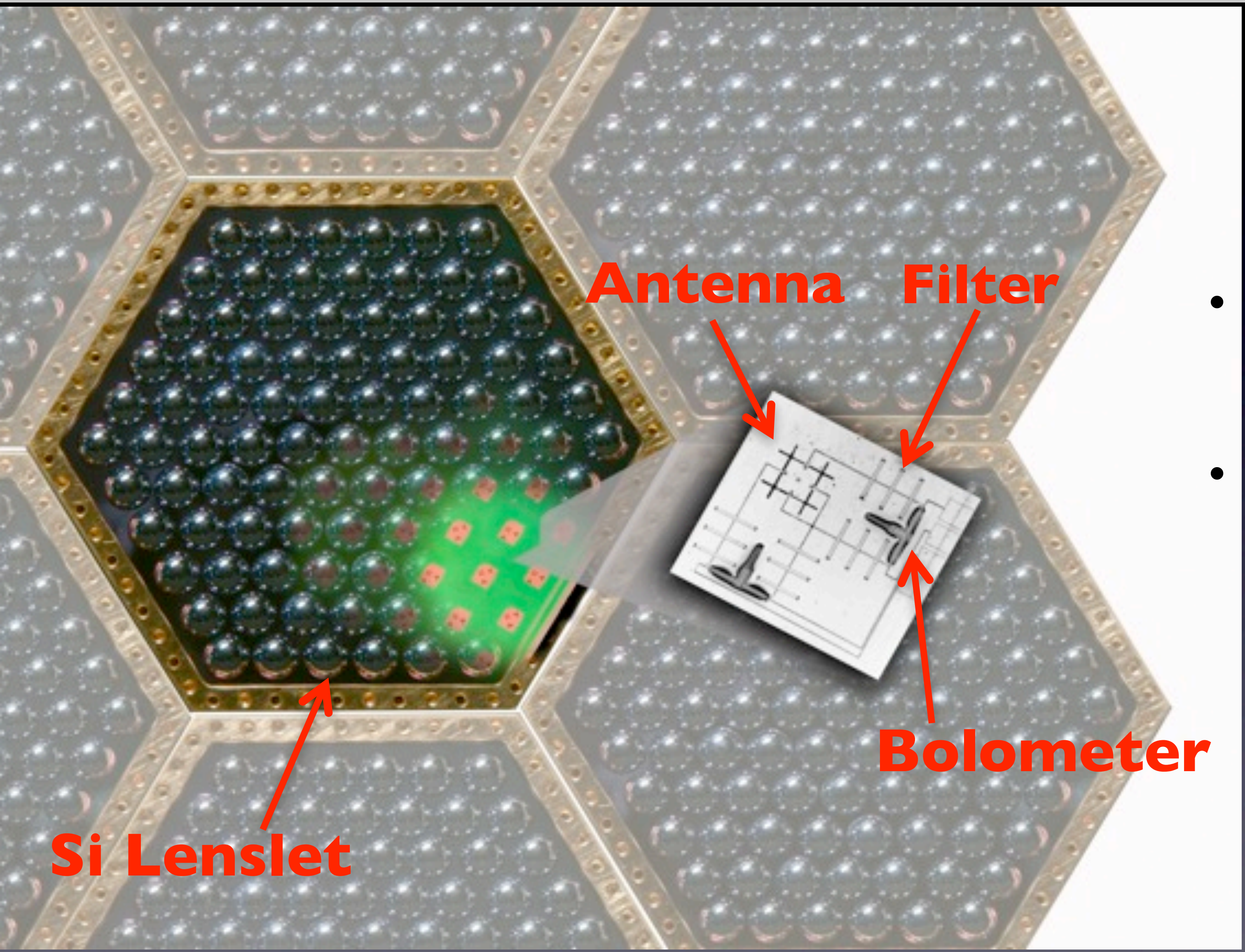
Testing phase at Cedar Flat, CARMA, Near Bishop, CA

First light next mor

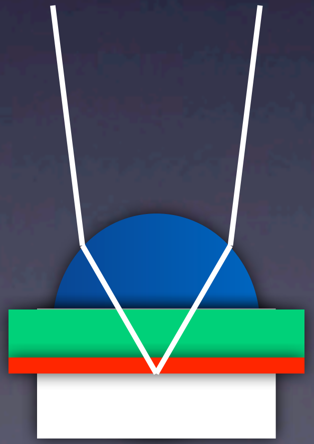
http://mountainpolarbear.blogspot.com/

http://www.youtube.com/watch?v=WY4SNIla3zk

POLARBEAR Detector Array

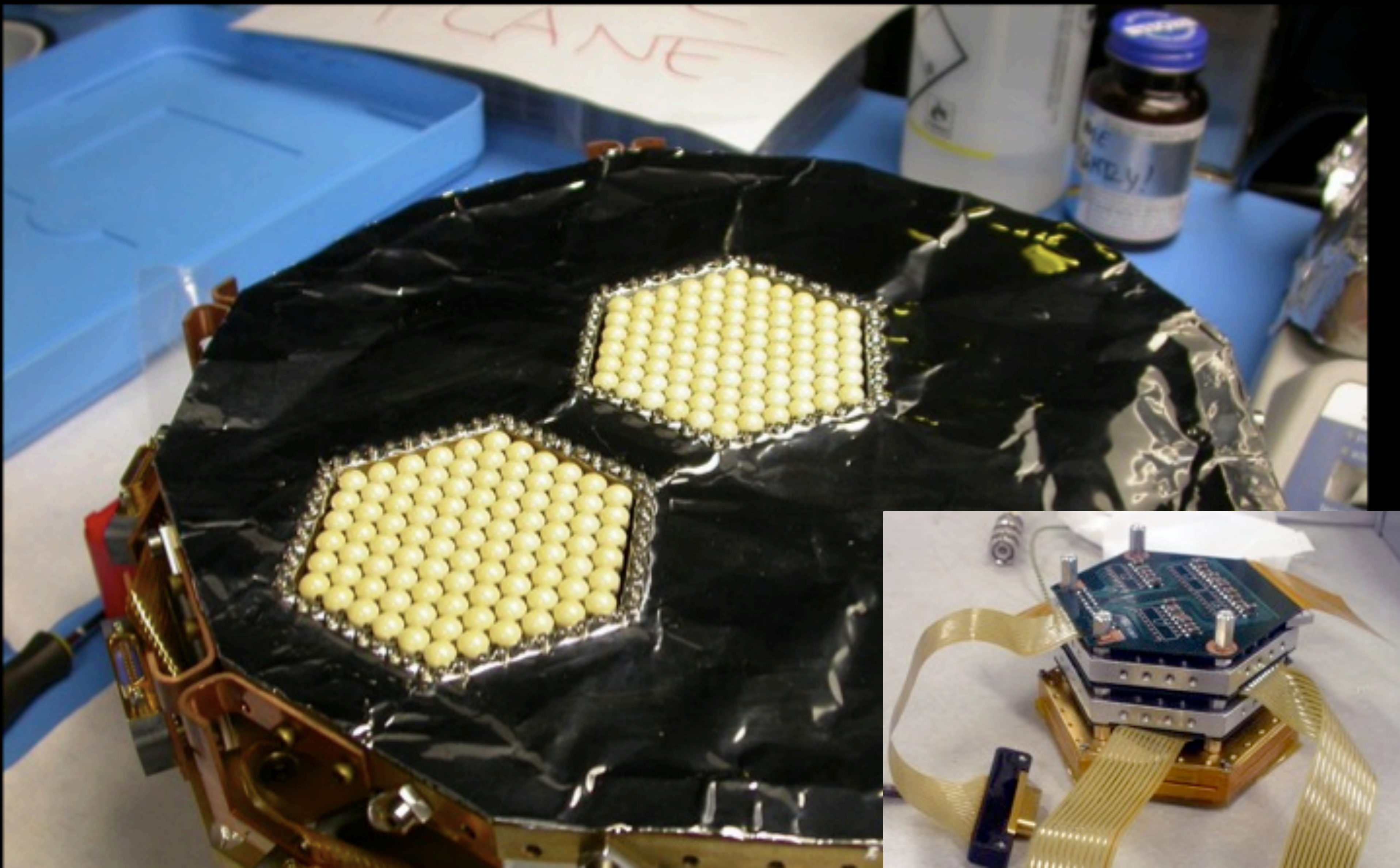


- 637 Pixels/ 1274 bolometers
- 150 GHz

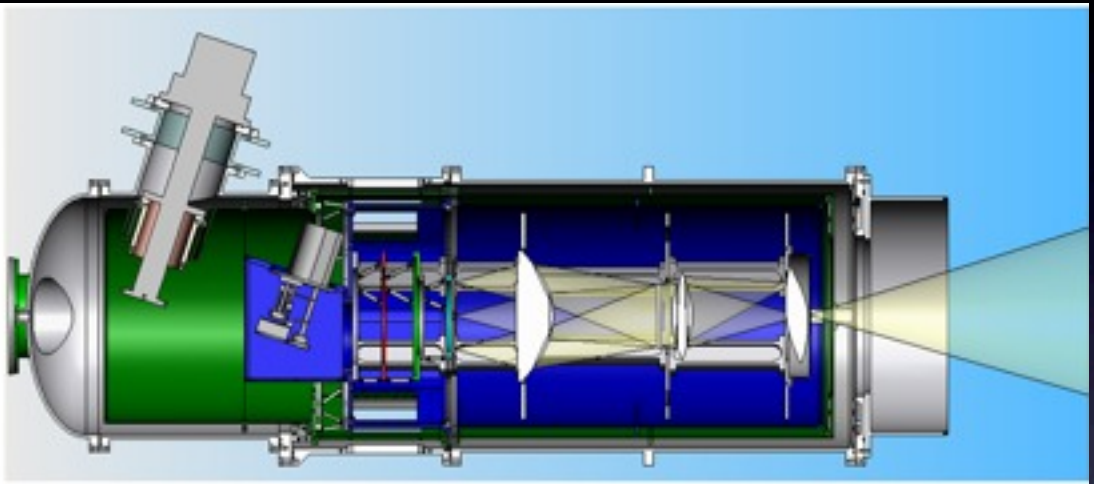


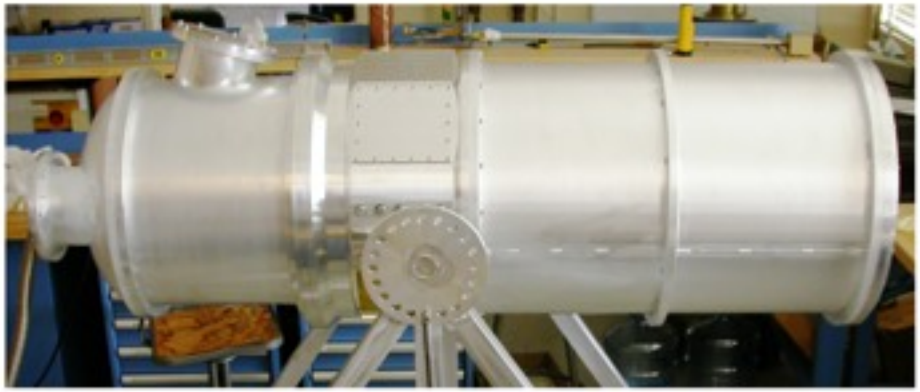
UCB/LBL

Focal plane



The POLARBEAR Receiver





2m

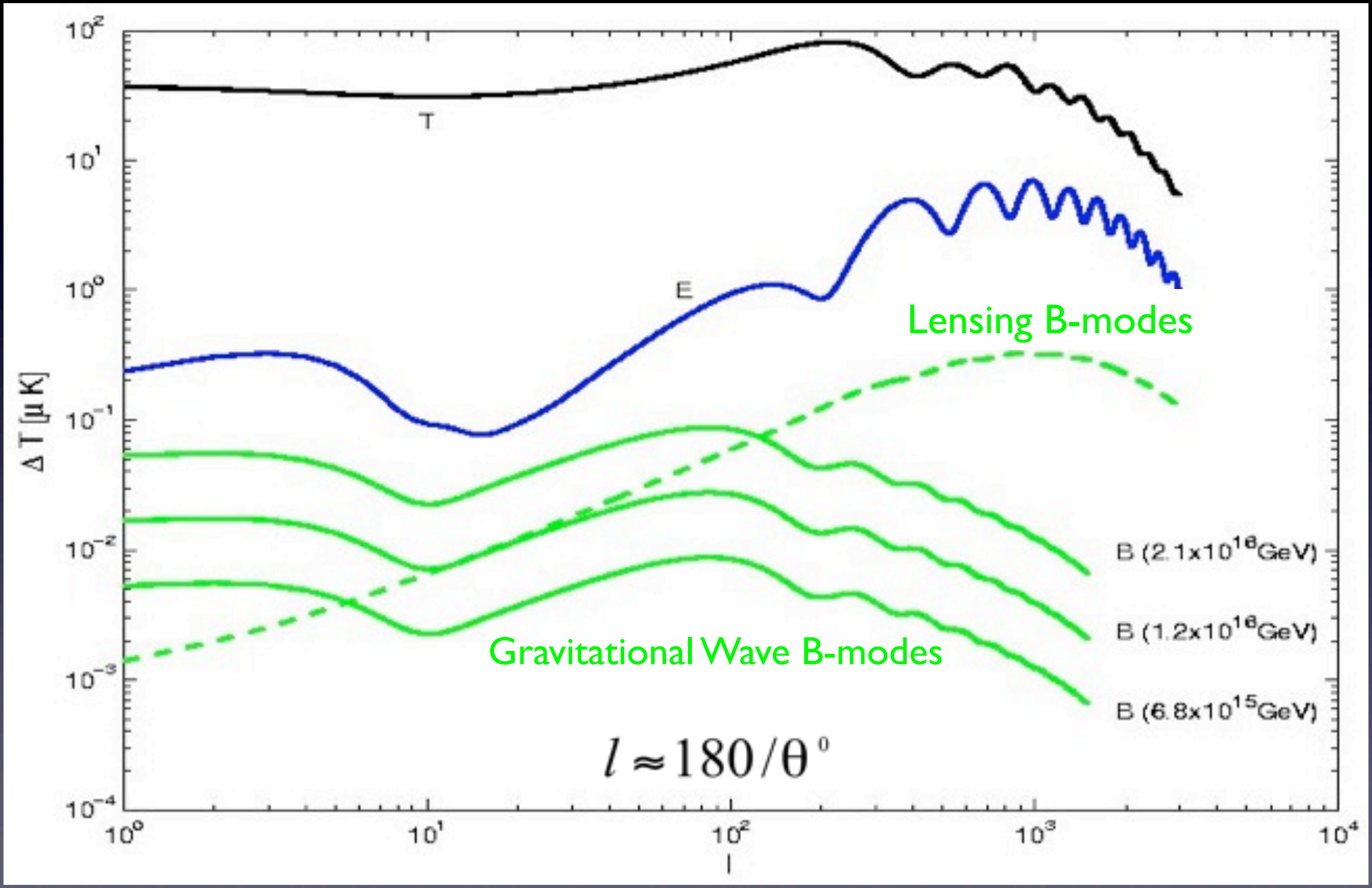
Cold Reimaging Optics

- Three HDPE lenses
- HWP

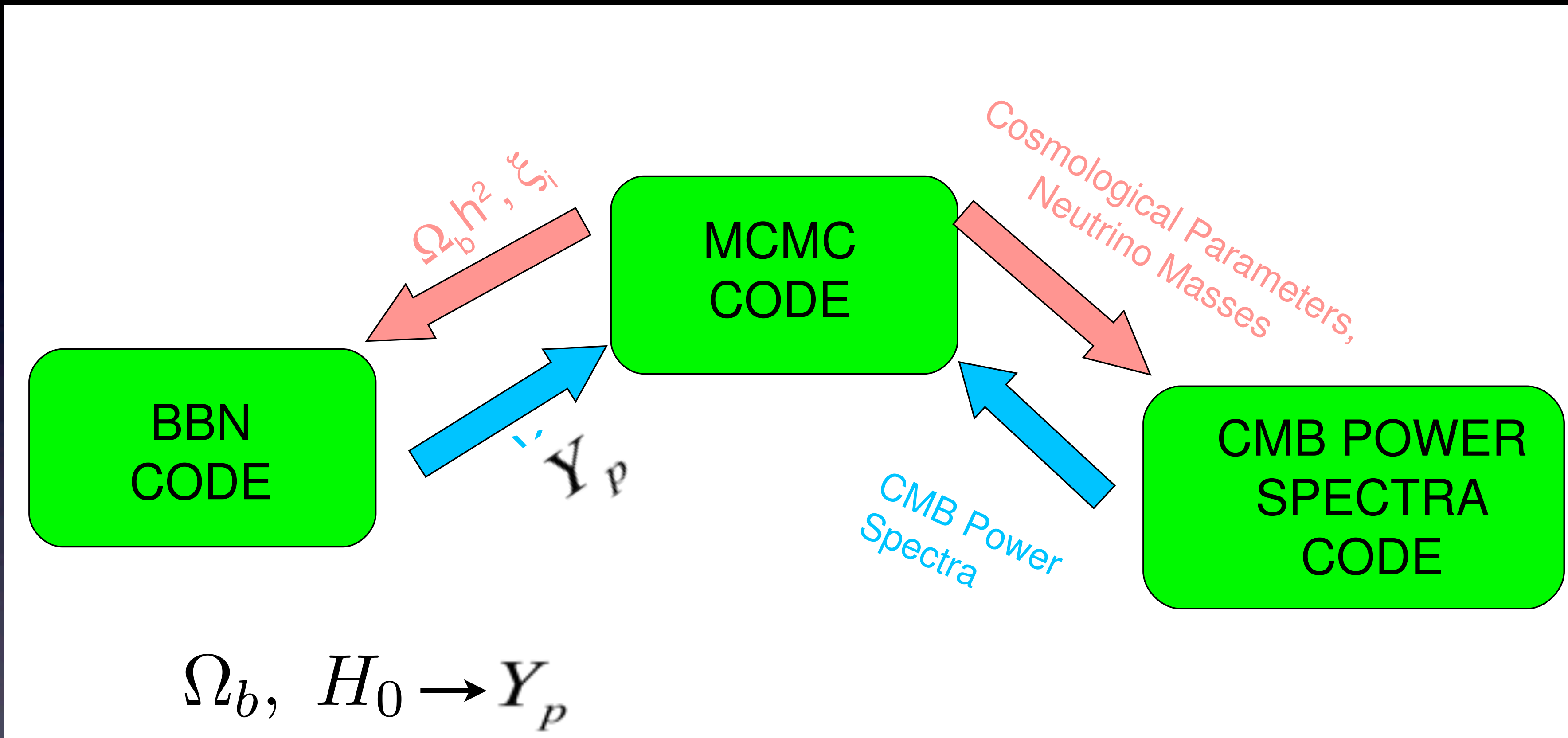
Cryogenics

- Cryomech Pulse-tube cooler
- Simon-Chase ‘He10’ refrigerator
- Operating now at 0.250 K

The Challenge of B-Mode Detection



Self-consistent treatment of Neutrino, BBN & CMB



Shimon, Miller, Kishimoto, Smith, Fuller & Keating (2010)
arXiv:1001.5088

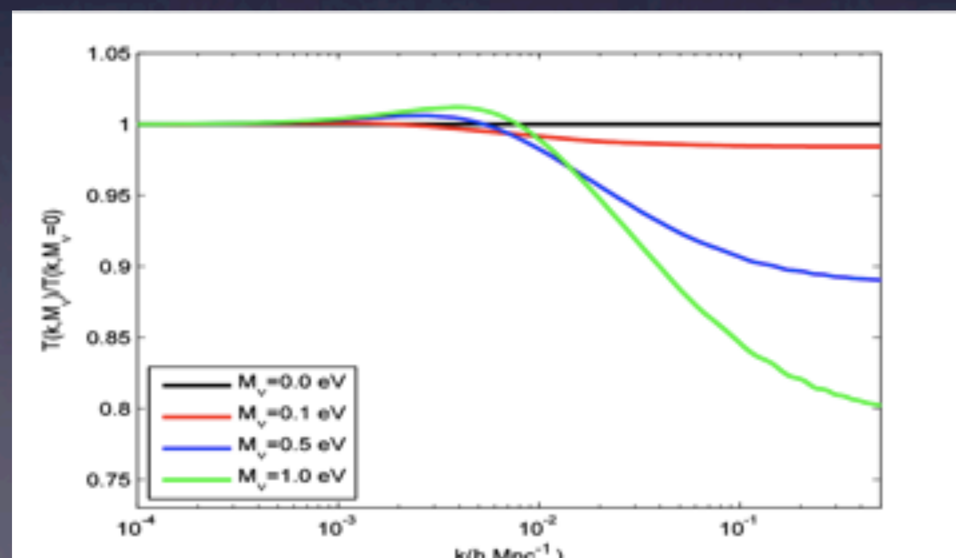
The Relationship Between C_l and P(k)

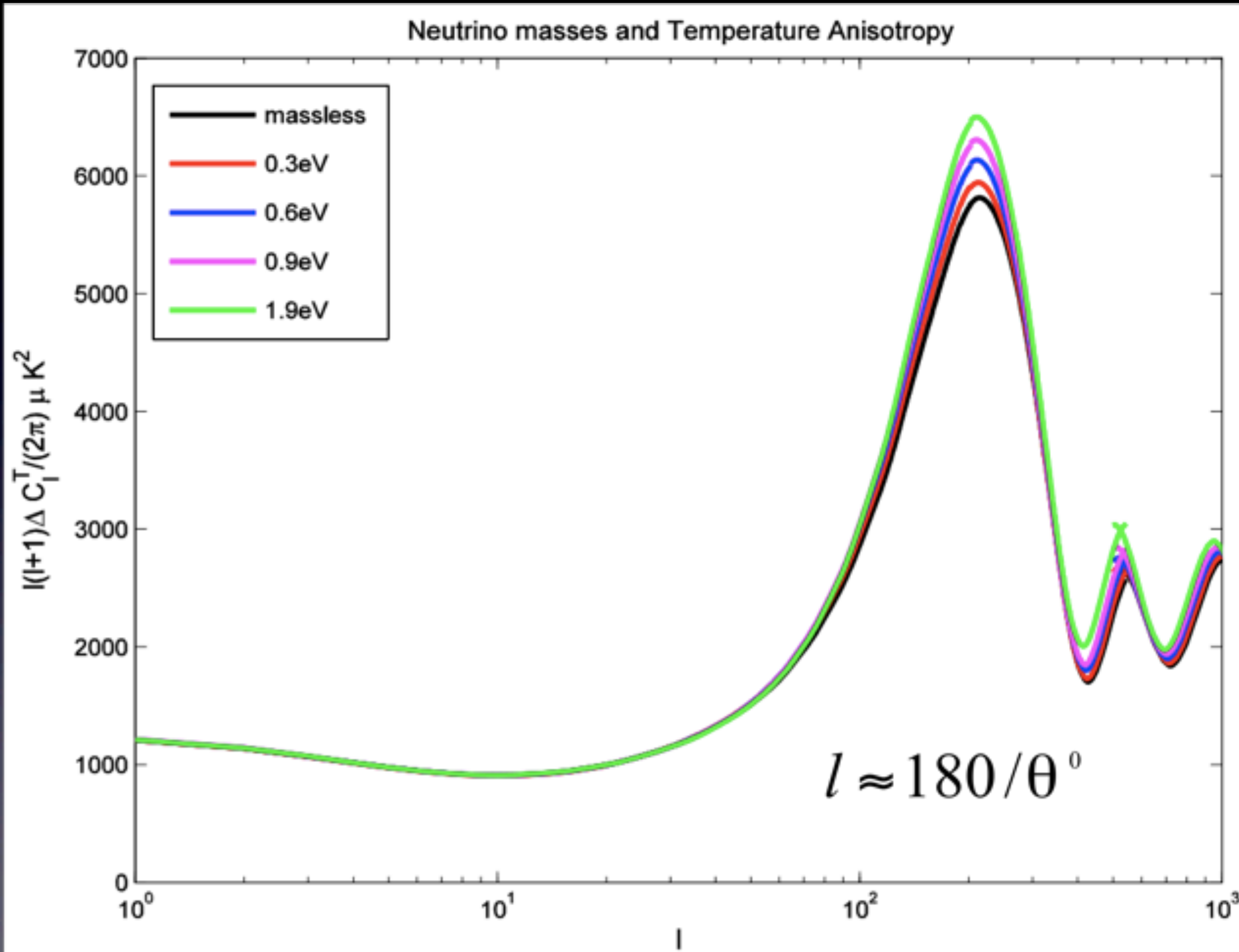
$$C_l^X = 2/\pi \int dk\, k^2 M_l^X(k)$$

$$M_l \approx P_\psi(k) T^2(k,t) j_l^2(kt)$$

Where: $$P_\psi = A k^n$$

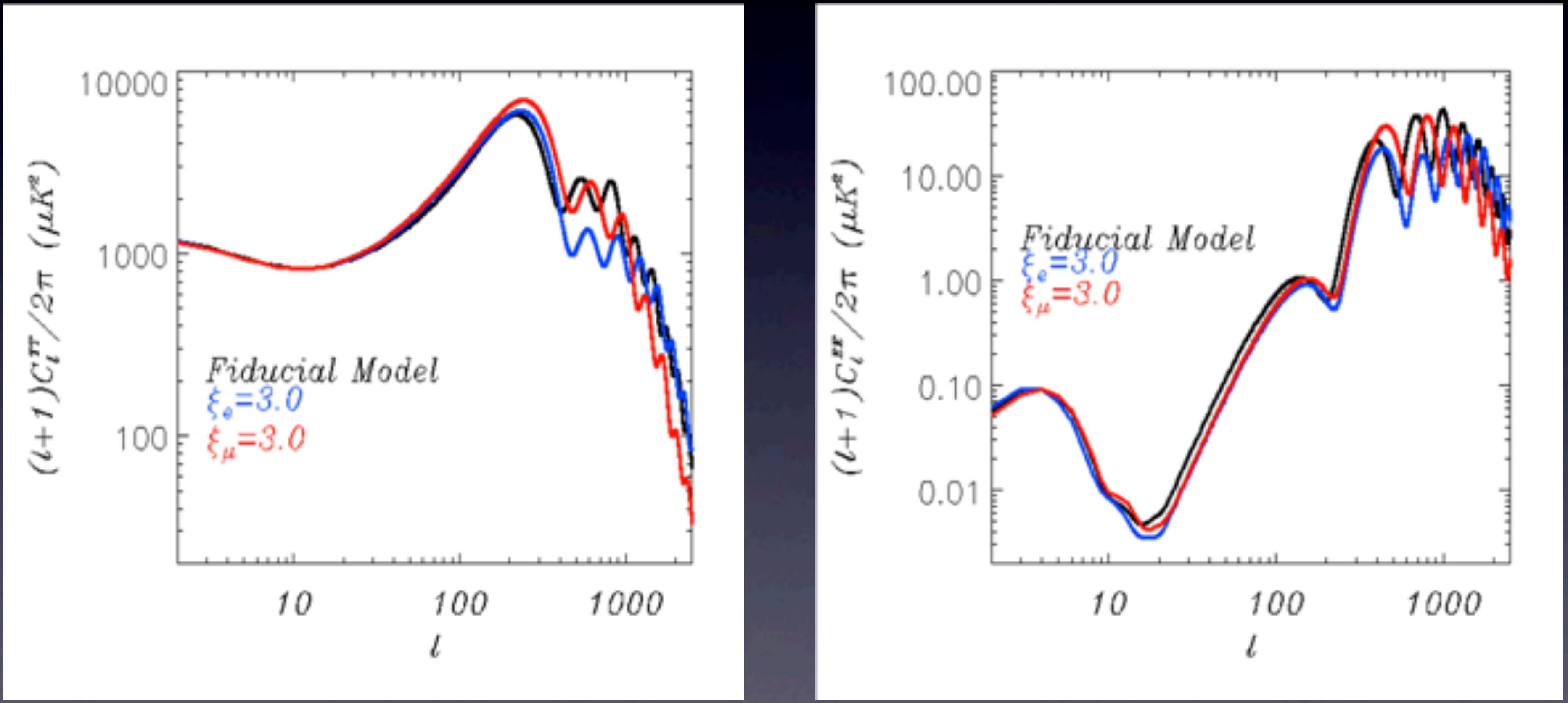
T, the Transfer function from the Primordial P(k) to the Observed P(k)





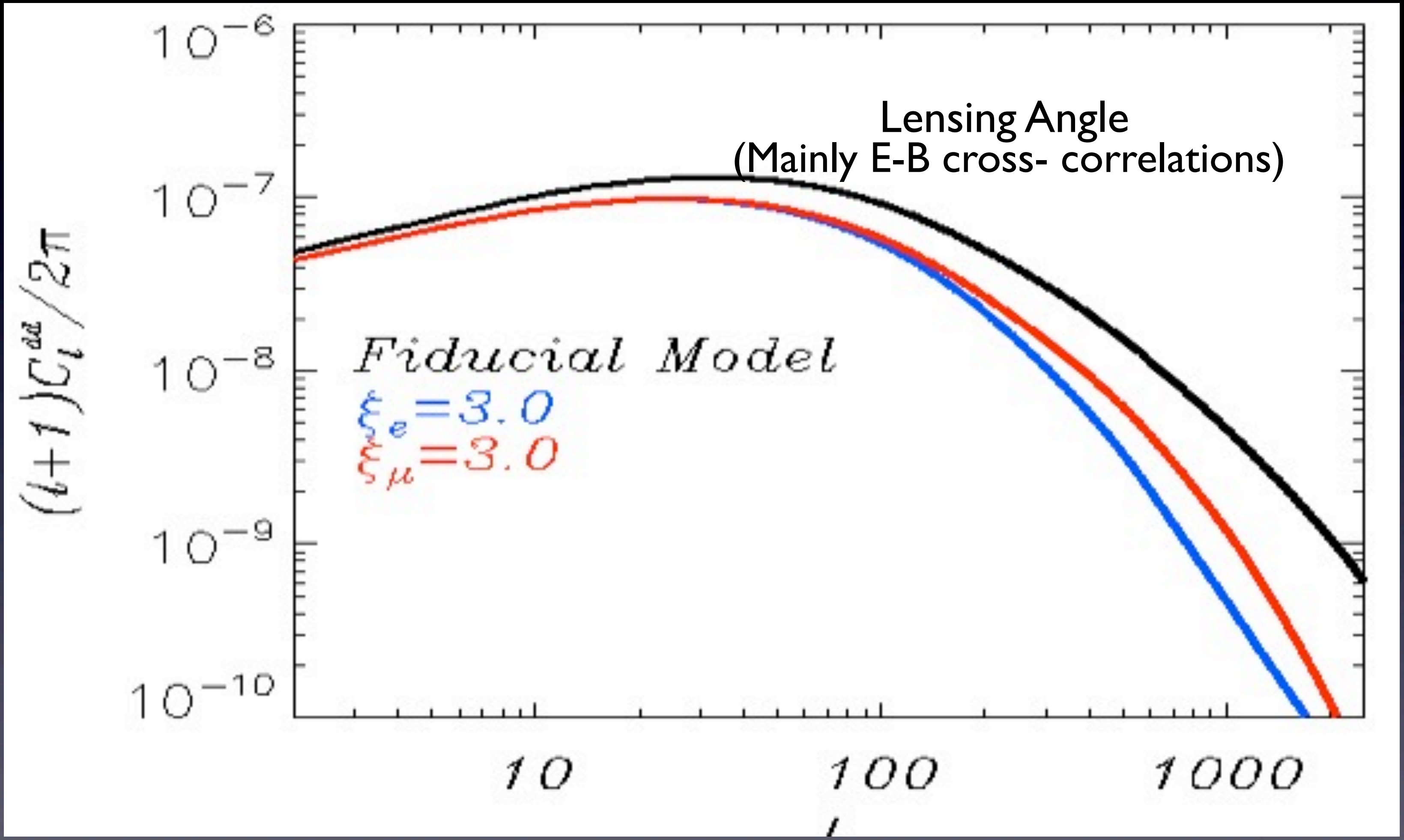
Caution: Instrumental noise, systematics, & Cosmic variance

Degeneracy Parameter: Direct impact on Power Spectra



Shimon, Miller, Kishimoto, Smith, Fuller & Keating (2010) arXiv:1001.5088

Degeneracy Parameter: Lensing Angle Power Spectra



Shimon, Miller, Kishimoto, Smith, Fuller & Keating (2010) arXiv:1001.5088

From Power Spectra to Likelihoods

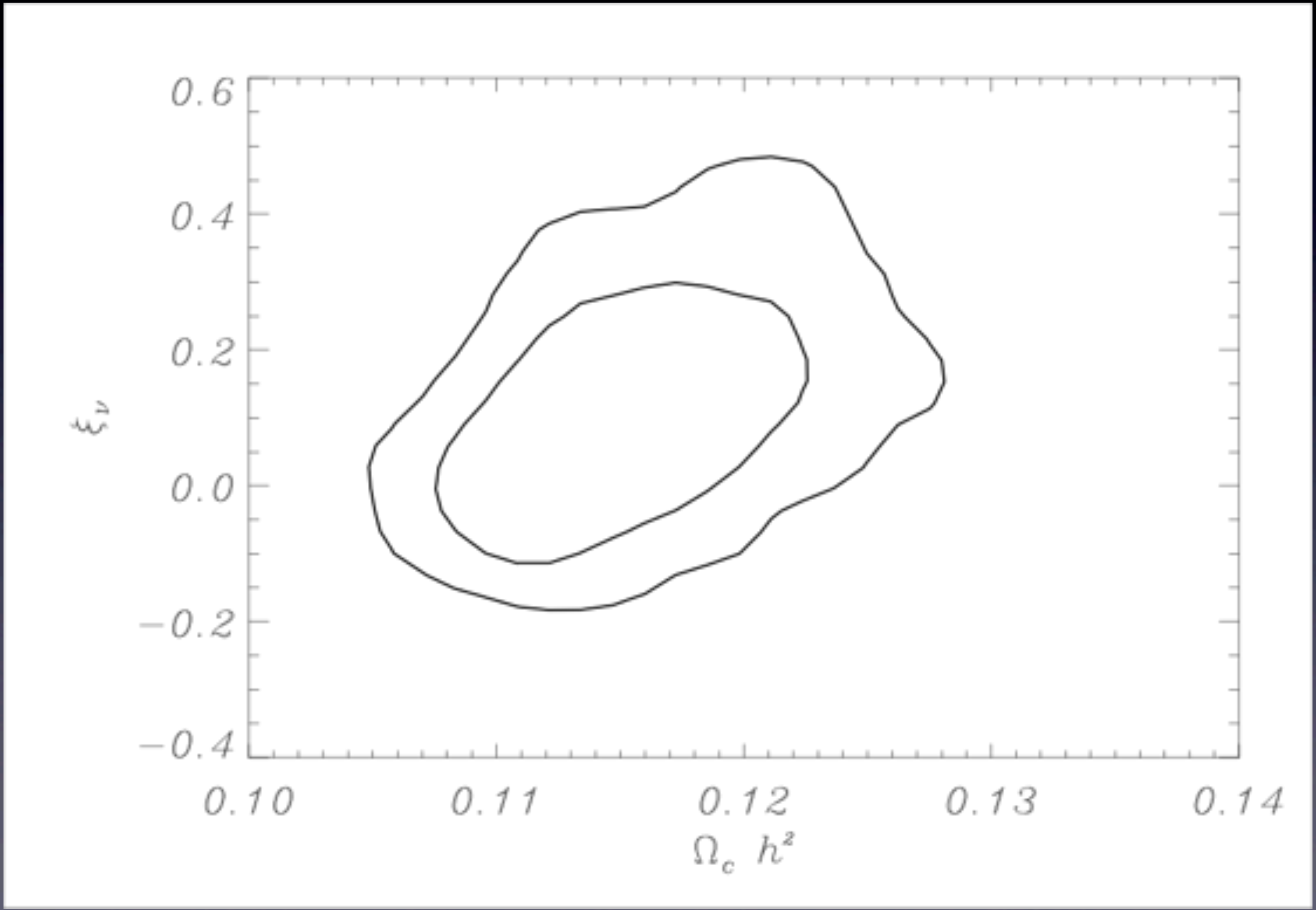
$$L = L(\hat{C}_l^X; \overline{C}_l^X), \quad x \in (T, E, B)$$

observed

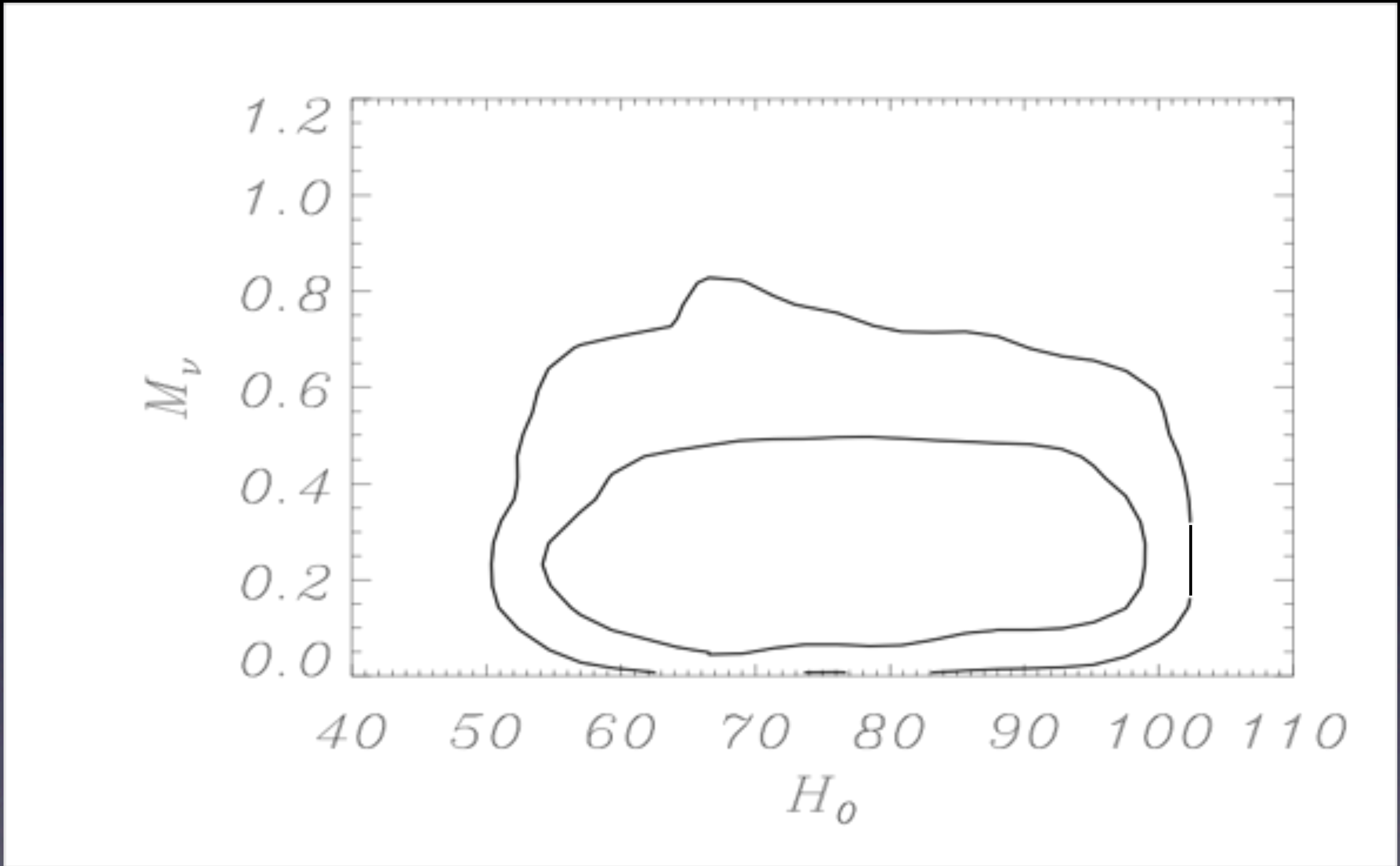
theoretical

$$-2\ln(L) = \sum_l [(2l+1)(\ln \overline{C}_l^T + \hat{C}_l^T / \overline{C}_l^T - 1) - (2l-1)\ln \hat{C}_l^T]$$

Forecast for POLARBEAR
The ξ - $\Omega_c h^2$ Degeneracy



Forecast for POLARBEAR
The M_ν-H_0 Plane



Shimon, Miller, Kishimoto, Smith, Fuller & Keating (2010)
arXiv:1001.5088

Forecasted CMB 2σ Upper Limits on Neutrino Parameters

$$-0.005 < \xi_{\nu_e} < 0.07$$
$$\xi_{\nu_\mu} < 2.6$$

BBN, Abundances

$$M_\nu < 0.29\text{eV}$$
$$\xi_{\nu_e} < 0.11$$
$$\xi_{\nu_\mu} < 0.49$$

PLANCK

$$M_\nu < 0.75\text{ eV}$$
$$\xi_{\nu_e} < 0.62$$
$$\xi_{\nu_\mu} < 1.1$$

POLARBEAR

$$M_\nu < 0.20\text{ eV}$$
$$\xi_{\nu_e} < 0.045$$
$$\xi_{\nu_\mu} < 0.29$$

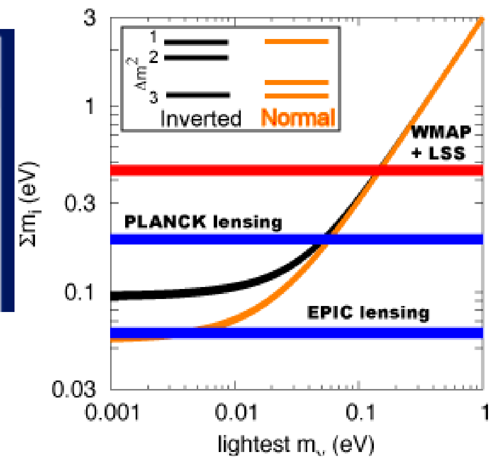
CMBPOL/EPIC

Shimon, Miller, Kishimoto, Smith, Fuller & Keating (2010) arXiv:1001.5088

“To See Lensing, Use a Big Mirror!”

CMBPOL References

cmbpol.uchicago.edu
(Including Dodelson et al, Smith et al.)



Bock et al. "**Study of the Experimental Probe of Inflationary Cosmology (EPIC)–Intemediate Mission for NASA's Einstein Inflation Probe**"
astro-ph/0906.1188
"Spacebear"