QUIET II @ FNAL

The Search for B-Mode Polarization in the Cosmic Microwave Background Using Coherent HEMT Detectors

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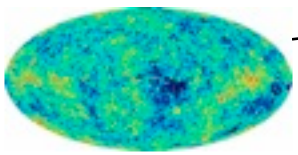
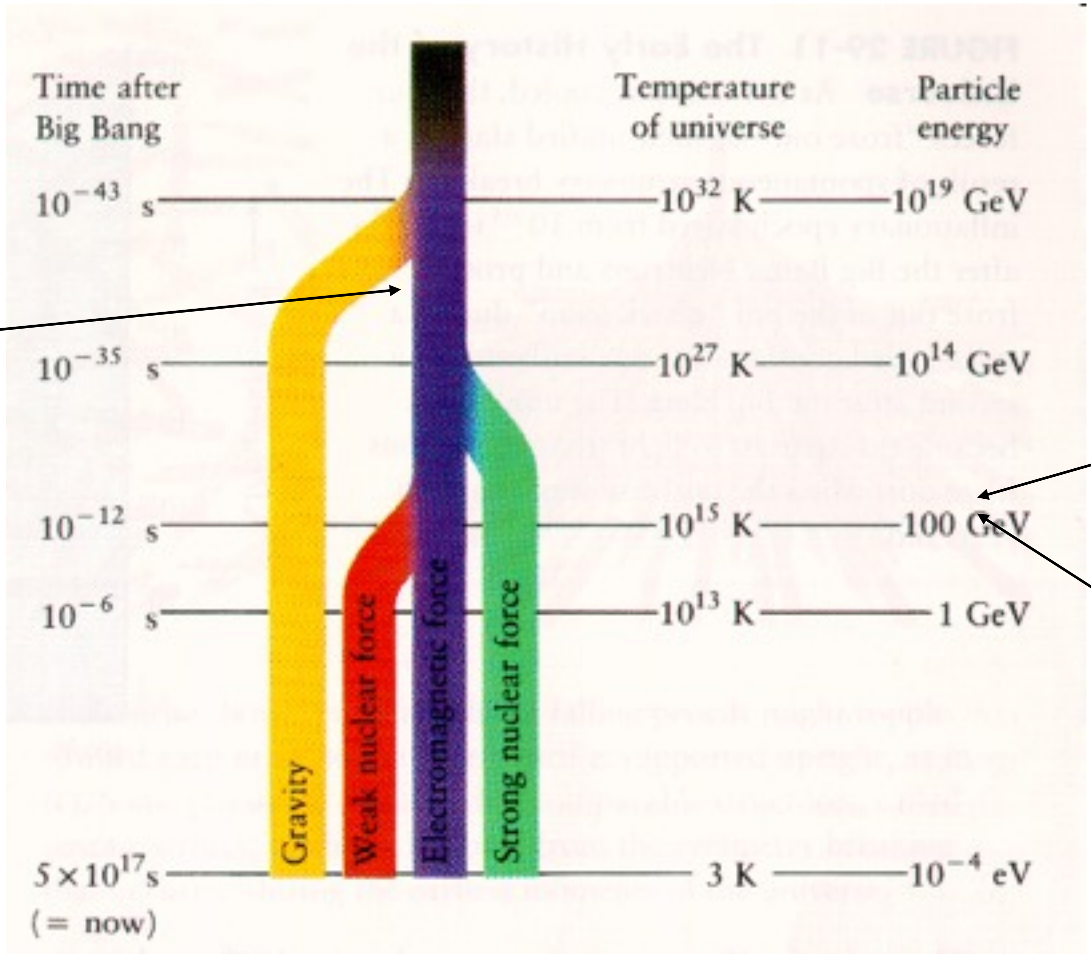
FNAL

November 12, 2009

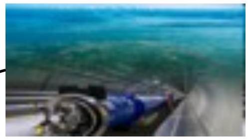
Fundamental Particle Physics

How does the proposed experiment relate to Fermilab's mission?





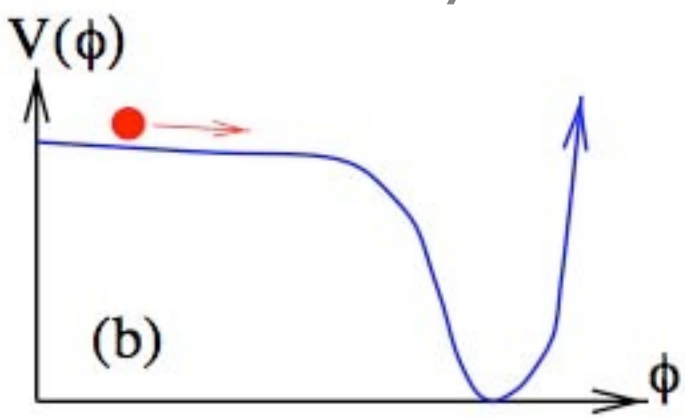
LHC



Tevatron

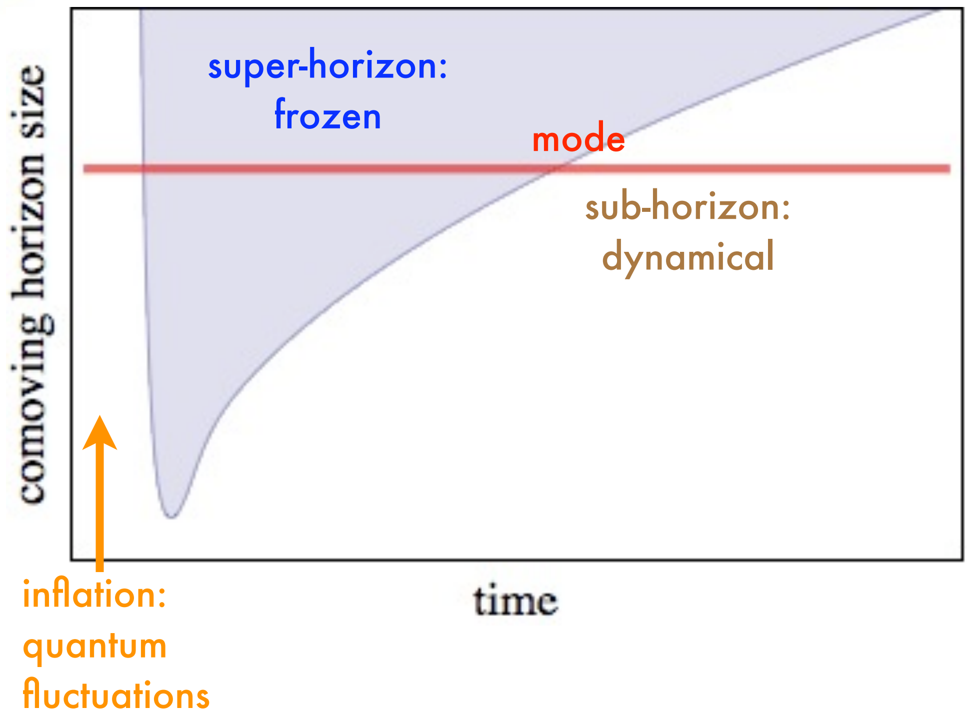
Inflation: E ~ M_{GUT}, M_{Planck}

Scalar Field Dynamics



N.B. The (normal) Higgs mass $V''(\phi_{Higgs})$ is major goal of DOE HEP program!

Dynamics:
ϕ inflaton field
h_t - grav. radiation
… any other dynamical field



Amplifier of Quantum Noise

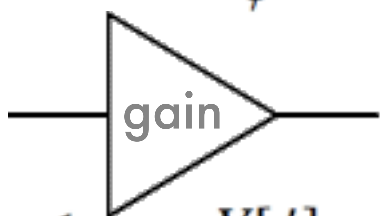
tensor modes / gravitational waves

$$\delta h_t \sim \frac{T_{\text{Hawking}}}{M_{\text{Planck}}} \sim \frac{H}{M_{\text{Planck}}} \sim \frac{\sqrt{V[\phi]}}{{M_{\text{Planck}}}^2} \longrightarrow$$

scalar inflaton field → (scalar) gravitational potential

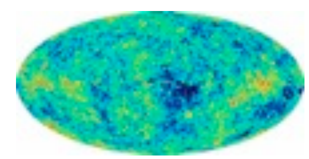
$$M_{\text{Planck}} \frac{H}{\dot{\phi}}$$

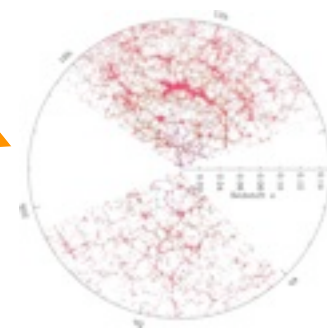
$$\frac{\delta\phi}{M_{\text{Planck}}} \sim \frac{T_{\text{Hawking}}}{M_{\text{Planck}}} \sim \frac{H}{M_{\text{Planck}}} \sim \frac{\sqrt{V[\phi]}}{{M_{\text{Planck}}}^2}$$



δh_s

$$\frac{1}{M_{\text{Planck}}} \frac{V[\phi]}{V'[\phi]}$$





10^{-5}

The Energy Frontier

CMBR / Large Scale Structure already tell us

$$E \sim \sqrt[4]{V[\phi]} = \frac{10^{-2.5}\, M_{\text{Planck}}}{\sqrt{\text{gain}}} \sim 10\, \frac{M_{\text{GUT}}}{\sqrt{\text{gain}}}$$

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If we could detect the gravity waves we could nail down the energy scales.

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We are <u>already</u> measuring physics at very large energy scales!

If we could detect the gravity waves we could nail down the energy scales.

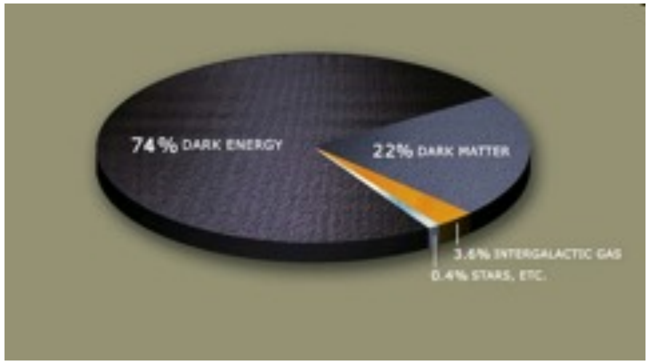
This clearly fits into FNALs mission of fundamental physics at very high energies!

Cosmology @ FNAL

Could/should the proposed experiment be part of a coherent Fermilab particle astrophysics program?

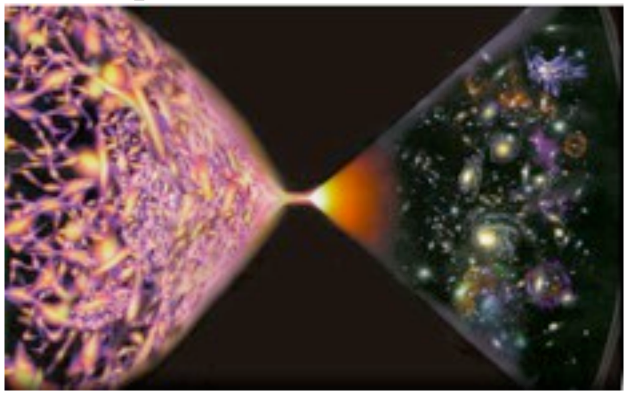
Fundamental Physics From Cosmology

Dark Sector



DM: SDSS/CDMS/COUPP/Indirect (theory)
DE: DES/CRT/JDEM

Early Universe / Inflation



Theory,
LSS: SDSS/DES/CRT/JDEM

Cosmology By Cartography

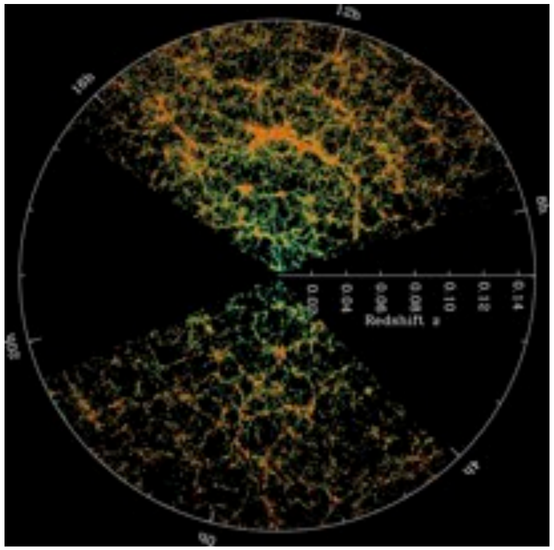
To study cosmology we need to study the things in the universe: e.g. galaxies, clouds, *etc.*

These things are generated as random noise!

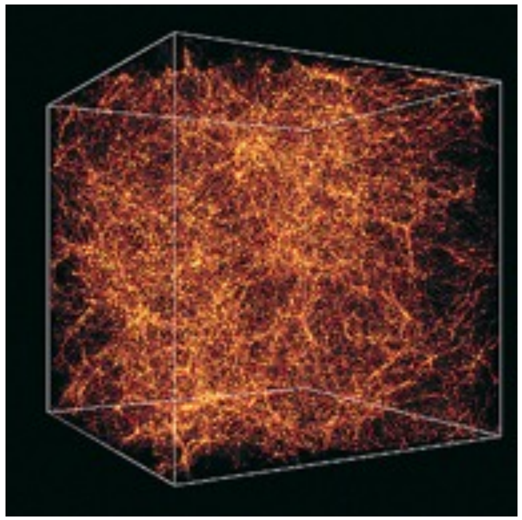
To characterize this random noise we need good statistics - *i.e.* large volumes, solid angle, *etc.*

Cosmology By Cartography

Large Scale Structure



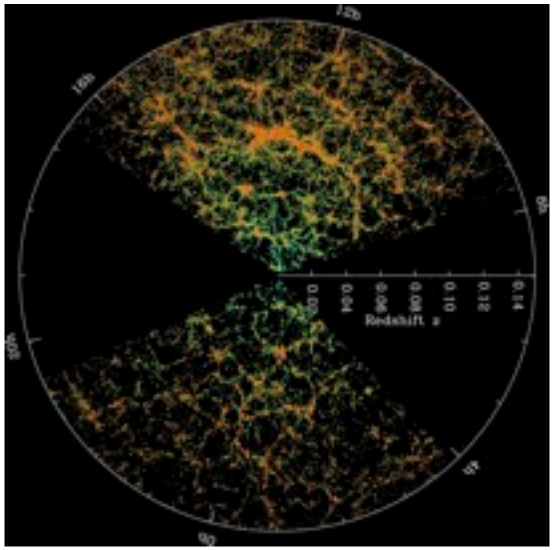
SDSS/DES/CRT/JDEM



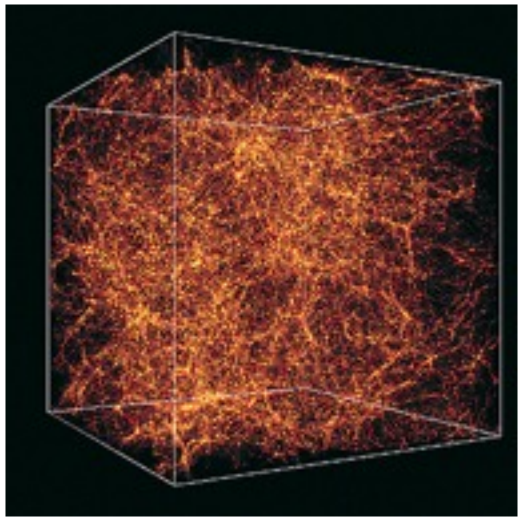
Cosmological Computing

Cosmology By Cartography

Large Scale Structure



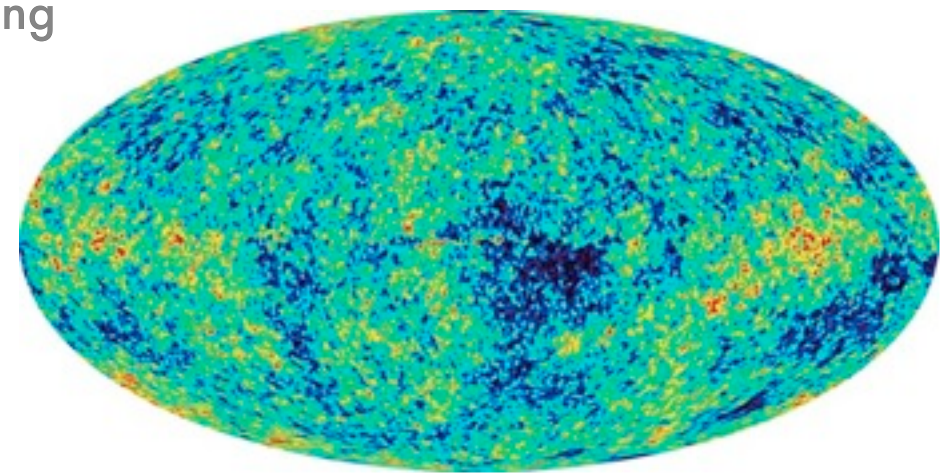
SDSS/DES/CRT/JDEM



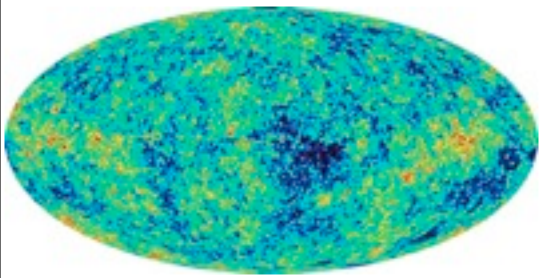
Cosmological Computing

CMBR

<u>No FNAL involvement save theory!!</u>



CMBR put the "precision" in Precision Cosmology



"LSS! We don't need no stinkin LSS!"

Parameter	*WMAP* 5 Year Mean[b]	*WMAP*+BAO+SN Mean
$100\Omega_b h^2$	2.273 ± 0.062	$2.267^{+0.058}_{-0.059}$
$\Omega_c h^2$	0.1099 ± 0.0062	0.1131 ± 0.0034
Ω_Λ	0.742 ± 0.030	0.726 ± 0.015
n_s	$0.963^{+0.014}_{-0.015}$	0.960 ± 0.013
τ	0.087 ± 0.017	0.084 ± 0.016
$\Delta^2_{\mathcal{R}}(k_0^c)$	$(2.41 \pm 0.11) \times 10^{-9}$	$(2.445 \pm 0.096) \times 10^{-9}$
σ_8	0.796 ± 0.036	0.812 ± 0.026
H_0	$71.9^{+2.6}_{-2.7}$ km s^{-1} Mpc^{-1}	70.5 ± 1.3 km s^{-} Mpc^{-}
Ω_b	0.0441 ± 0.0030	0.0456 ± 0.0015
Ω_c	0.214 ± 0.027	0.228 ± 0.013
$\Omega_m h^2$	0.1326 ± 0.0063	$0.1358^{+0.0037}_{-0.0036}$
z^d_{reion}	11.0 ± 1.4	10.9 ± 1.4
t^e_0	13.69 ± 0.13 Gyr	13.72 ± 0.12 Gyr

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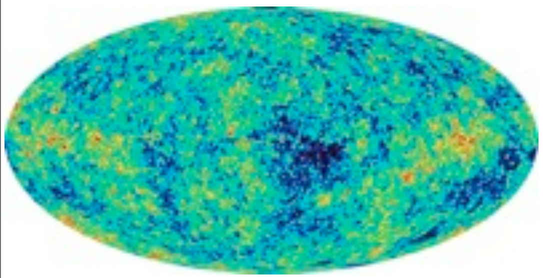

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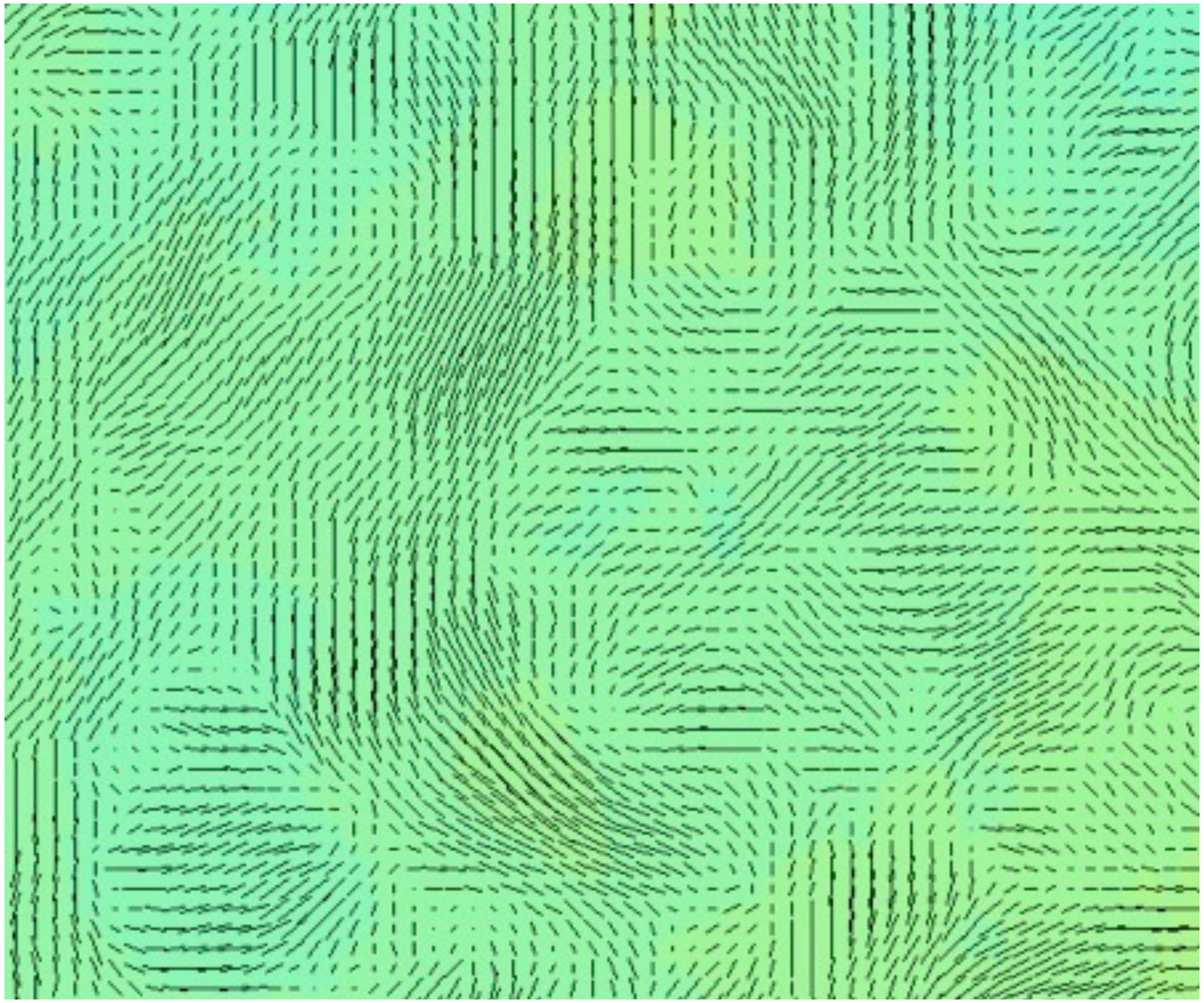
“LSS! We don’t need no stinkin LSS!”

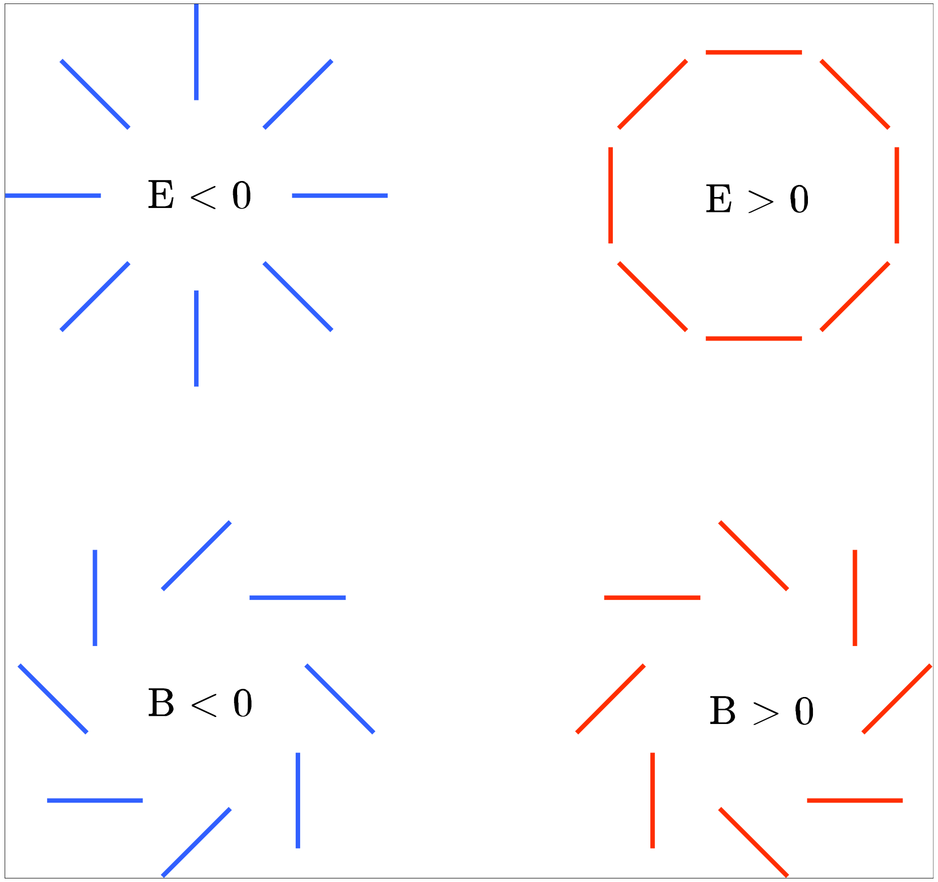
N.B. for some things you do, e.g. Dark Energy.

E & B Polarization



E & B Polarization

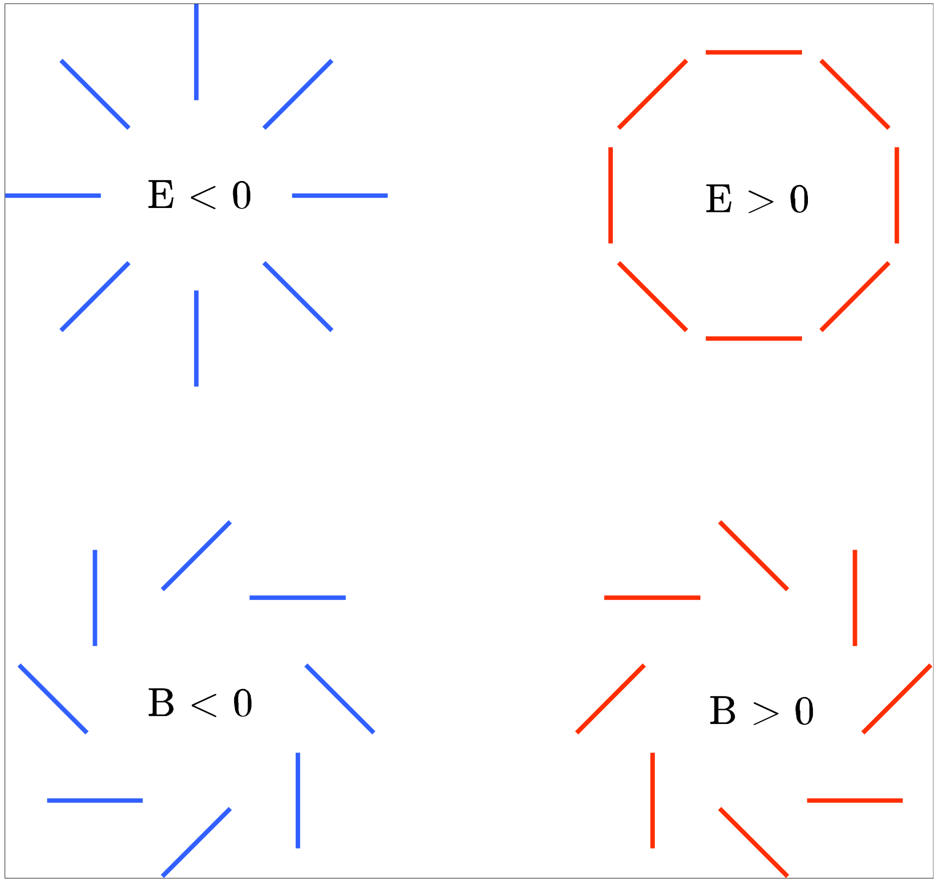
E / B decomposition developed at FNAL in 1996.



E & B Polarization

E / B decomposition developed at FNAL in 1996.

Because scalar modes have no parity they cannot (to linear order in δh) produce B-modes. B-modes make excellent probe for gravity waves on large scales.



Appropriateness

CMBR polarization studies such as QUIET-II fits into the existing program of "cosmology by cartography" and complements the current programs such as DES.

PASAG

In the context of the PASAG recommendations, is the science in the proposal interesting and/or compelling today?

PASAG has been asked to comment on request for a relatively small level of support for Fermilab participation in QUIET II, a CMB experiment located in Chile that aims to make sensitive low-frequency measurements of the CMB polarization over intermediate angular scales. To make these measurements, QUIET implements a novel technology that allows thousands of radiometers to be mass produced and packed into the focal plane of the telescope. QUIET II is an important project to pursue as it makes use of a pioneering technology (MMICs) and covers a unique range in the frequency—multipole moment parameter space. The project includes among its leadership several outstanding particle physicists from both university groups and from Fermilab.

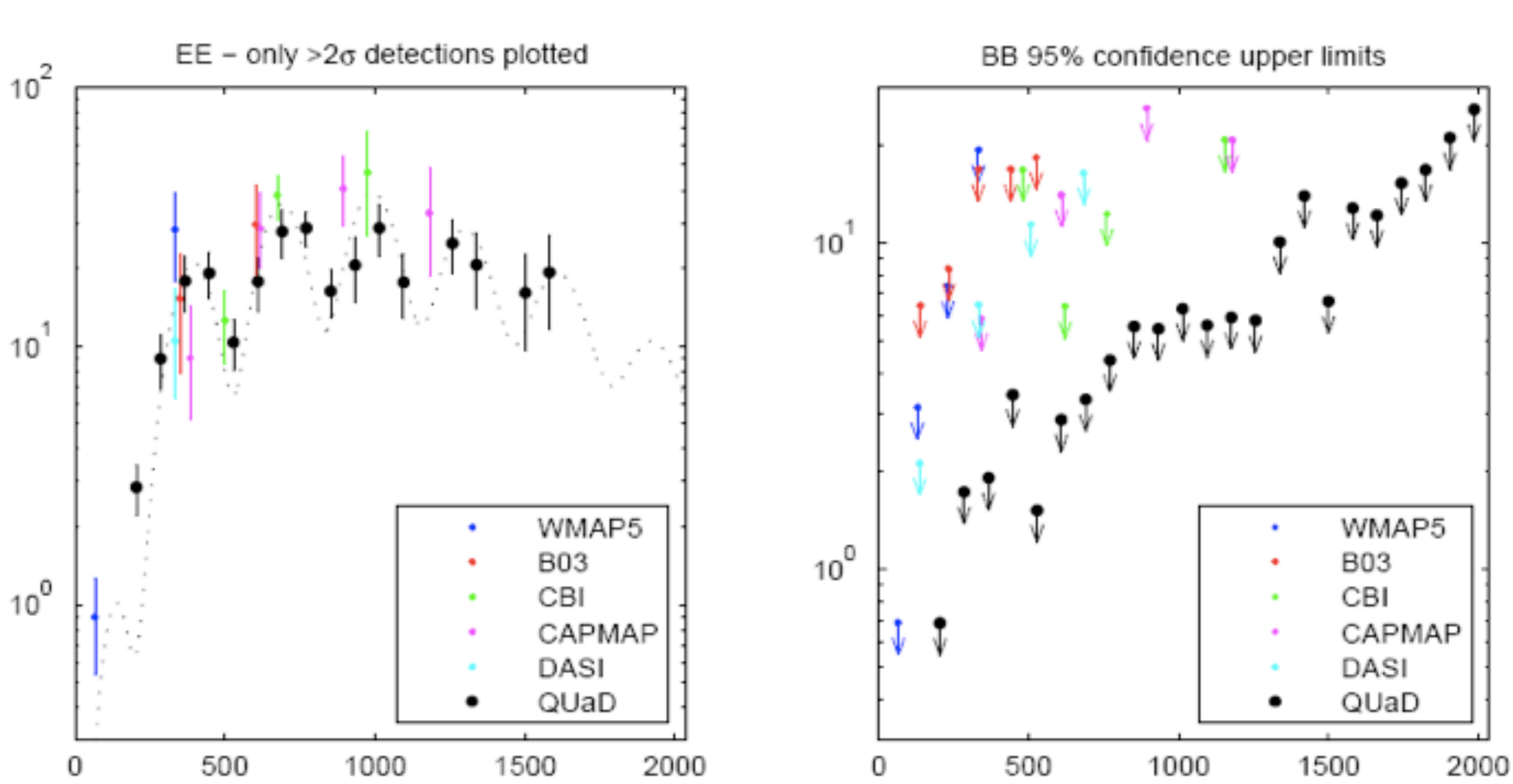
While QUIET I has been pursued primarily with non-HEP funding, HEP has unique capabilities to offer the project as it moves to the next step, QUIET II:

(a) Fermilab has unique large-scale fabrication capabilities required to mass-produce the detectors;
(b) HEP scientists have valuable experience with the high-speed electronics the project will require;
(c) the approaches to data analysis and related capabilities that have been developed for particle physics experiments will become increasingly important to CMB science as the scope of CMB experiments, and scale of the collaborations, increases.

Recommendations:

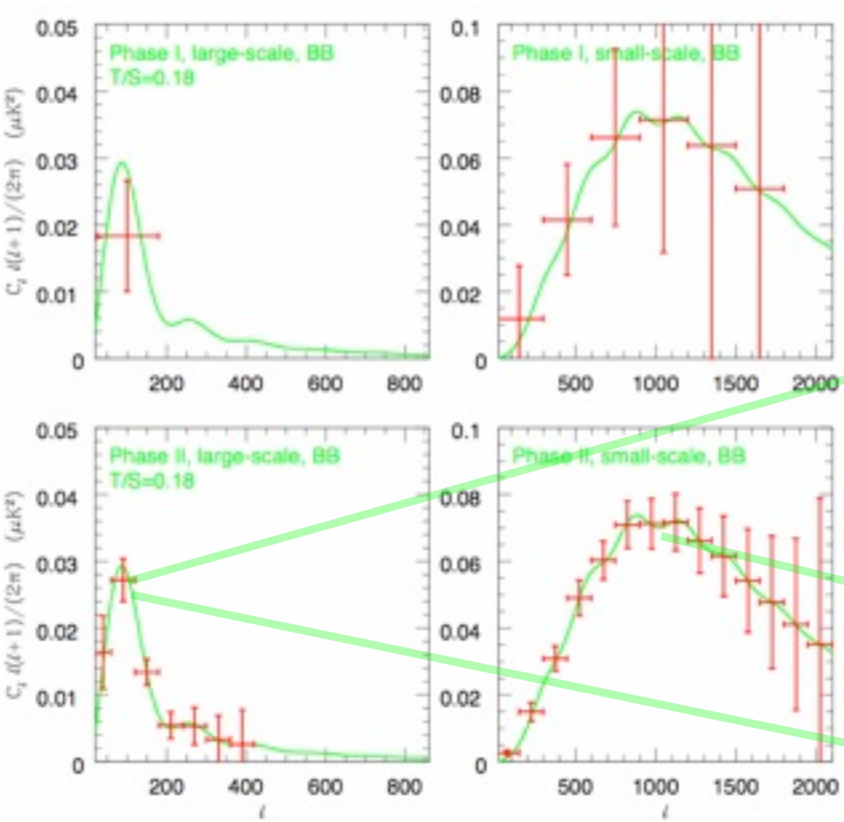
PASAG recommends that QUIET II be supported at the proposed scope under all budget scenarios.

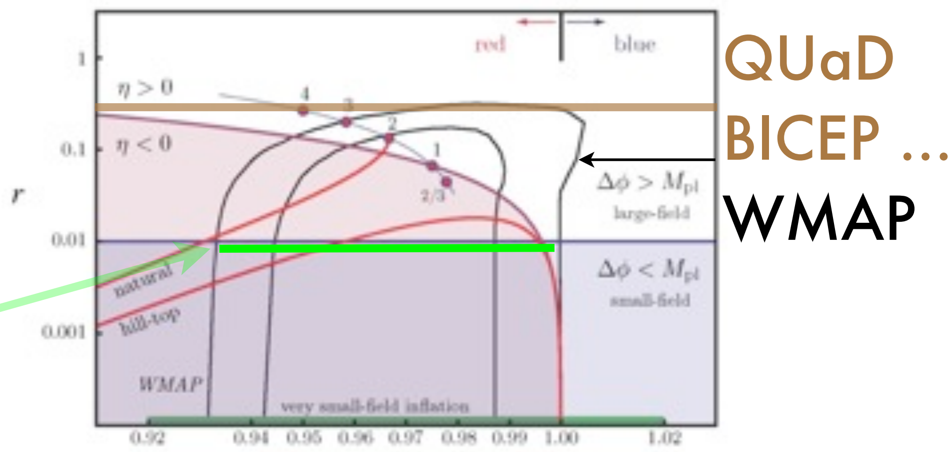
Rapid Progress in the Search for B-modes

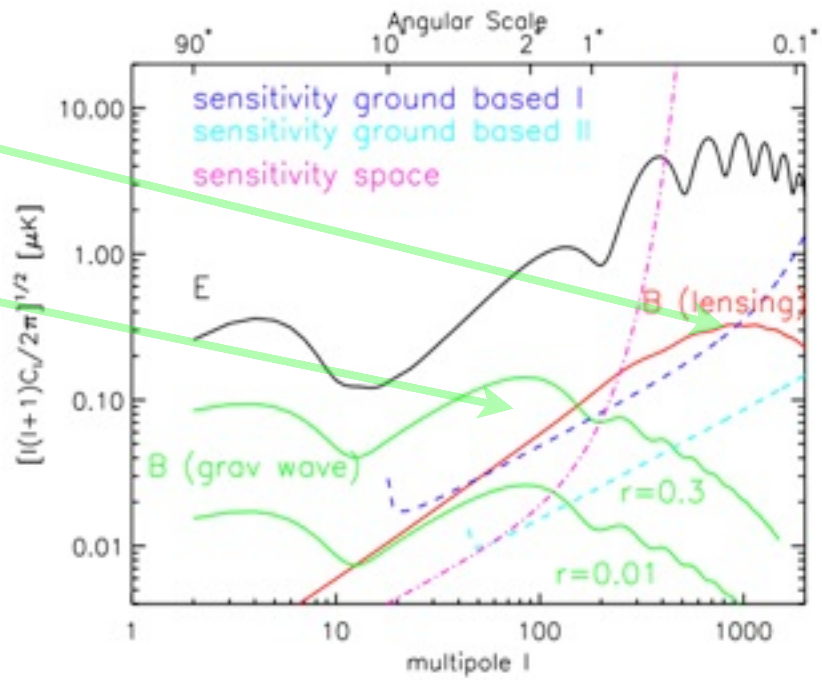


QUAD: Pryke et al. 2008

How does QUIET-II fit in?







Excellent chance of GW detection at design sensitivity!

Appropriateness

It would be a shame if FNAL were not to contribute to the discovery of B-modes which may happen in the next generation of experiments.

Summary

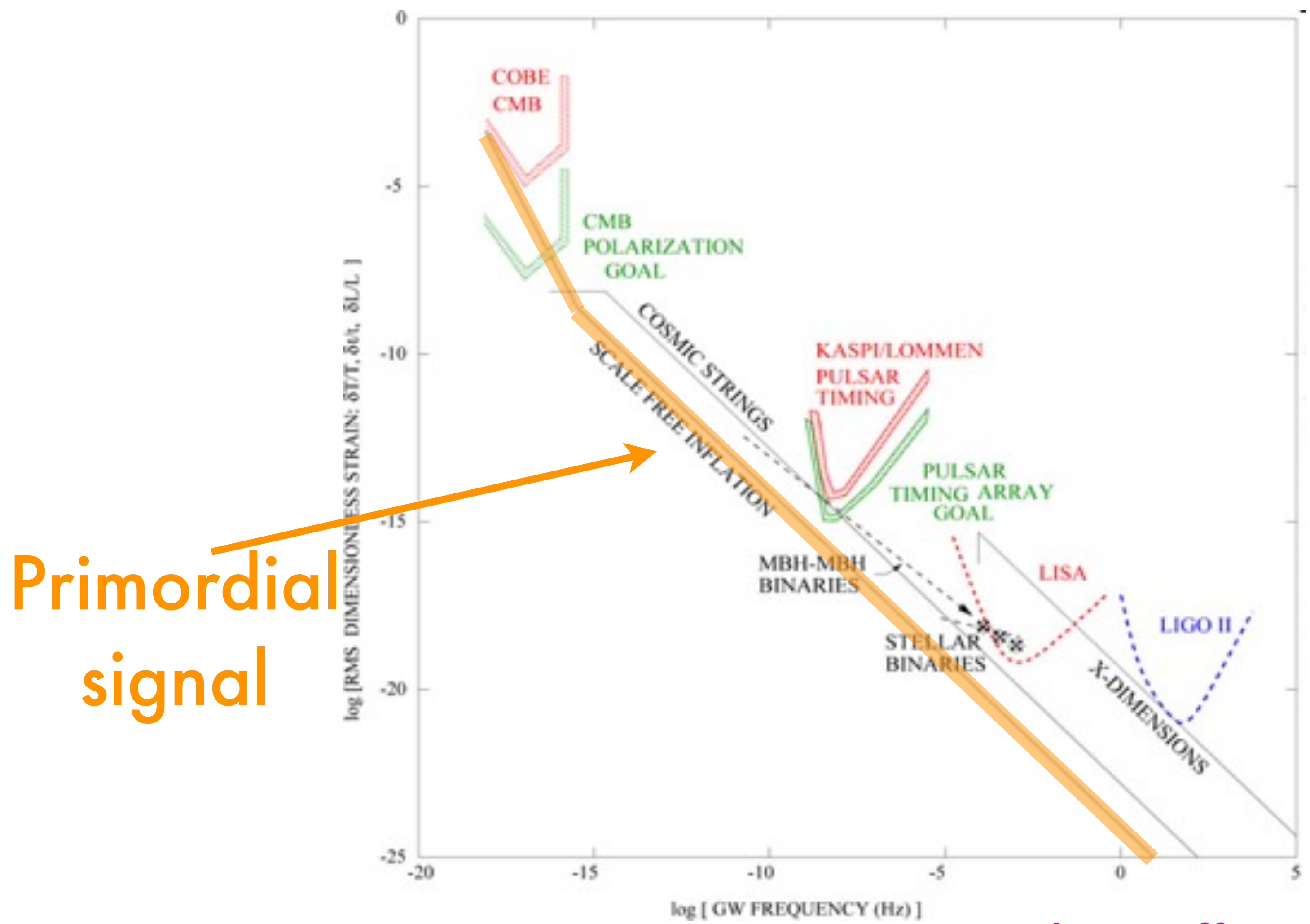
- QUIET-II clearly fits within overall FNAL mission as well as current astrophysics program.
- QUIET-II has good chance of detecting primordial gravity waves which is an important diagnostic of the very early universe (inflation) and of particle physics at very high energies.

Additional Slides

Role of Astro-Theory Group

- Science analysis
  - Dodelson / Stebbins / postdocs
- Dodelson has experience w CMBR data
- We are currently studying cosmic shear
  - this is mathematically the same as polarization.

How To Detect Tensor Modes? (gravitational radiation)



Baker, Jaffe, Lommen 2003