Probing Inflation

Early Universe and Fundamental physics

J.L. Puget

Institut d'Astrophysique Spatiale
Orsay

Major questions in Cosmology

- we need to confirm the robustness of the concordance model when the relevant quantities are measured with much higher accuracy
- underlying physics mostly unknown :
  - nature of dark matter
  - nature of dark energy
  - origin of the fluctuations
  - how to explain the absence of magnetic monopoles
  - why is the geometry nearly Euclidean
- Inflation brings the last 3 within a common framework

fundamental physics and cosmology are deeply intertwinned

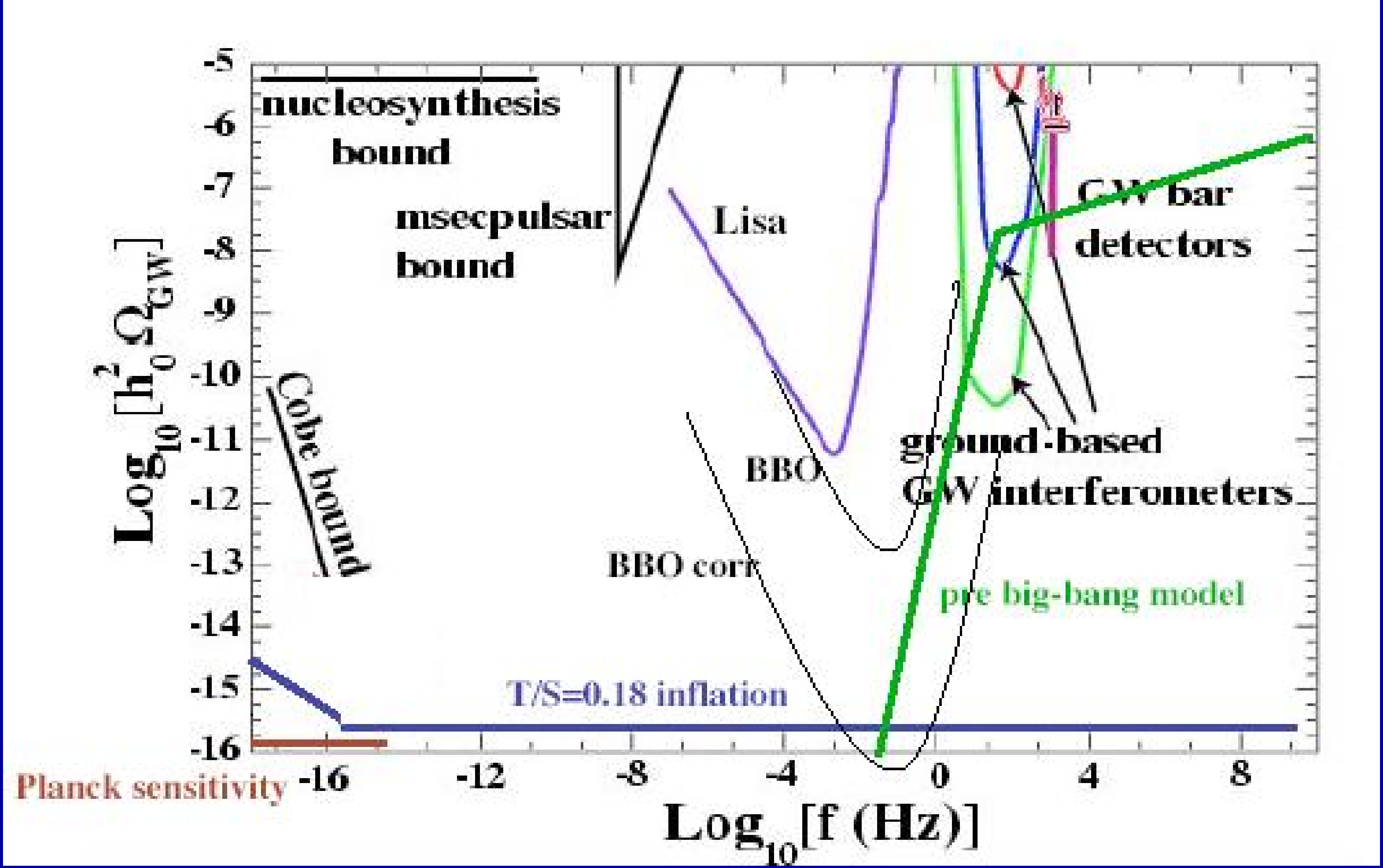
- physics behind the "dark components" of the universe:
  - dark matter as the lightest supersymetric particle
  - the equation of state of dark energy: cosmological constant or quintescence field ?
  - are both "dark components" related by an unknown physics ?
- physics of inflation
  - amount of gravity waves generated is largest if energy scale of inflation is that of the Grand Unification (10^{16} GeV)
  - slope of fluctuation spectrum depends on the inflation model
- string theory : a step towards quantum gravity
  - leads to many new early universe models: extra dimensions, branes, cyclic universe, "pre big bang physics"

How can we observe the early universe

The inflation physics leaves signatures in the quantum fluctuations which are the expected source of all structures

- Gravity waves can reach us from the inflation time
- The universe becomes transparent to neutrinos around $z \sim 10^9$
- Photons can propagate freely only for $z < 1100$

- direct detection cannot be detected by LISA
- second generation space based LISA type detector is needed
- indirect detection by motion of pulsars



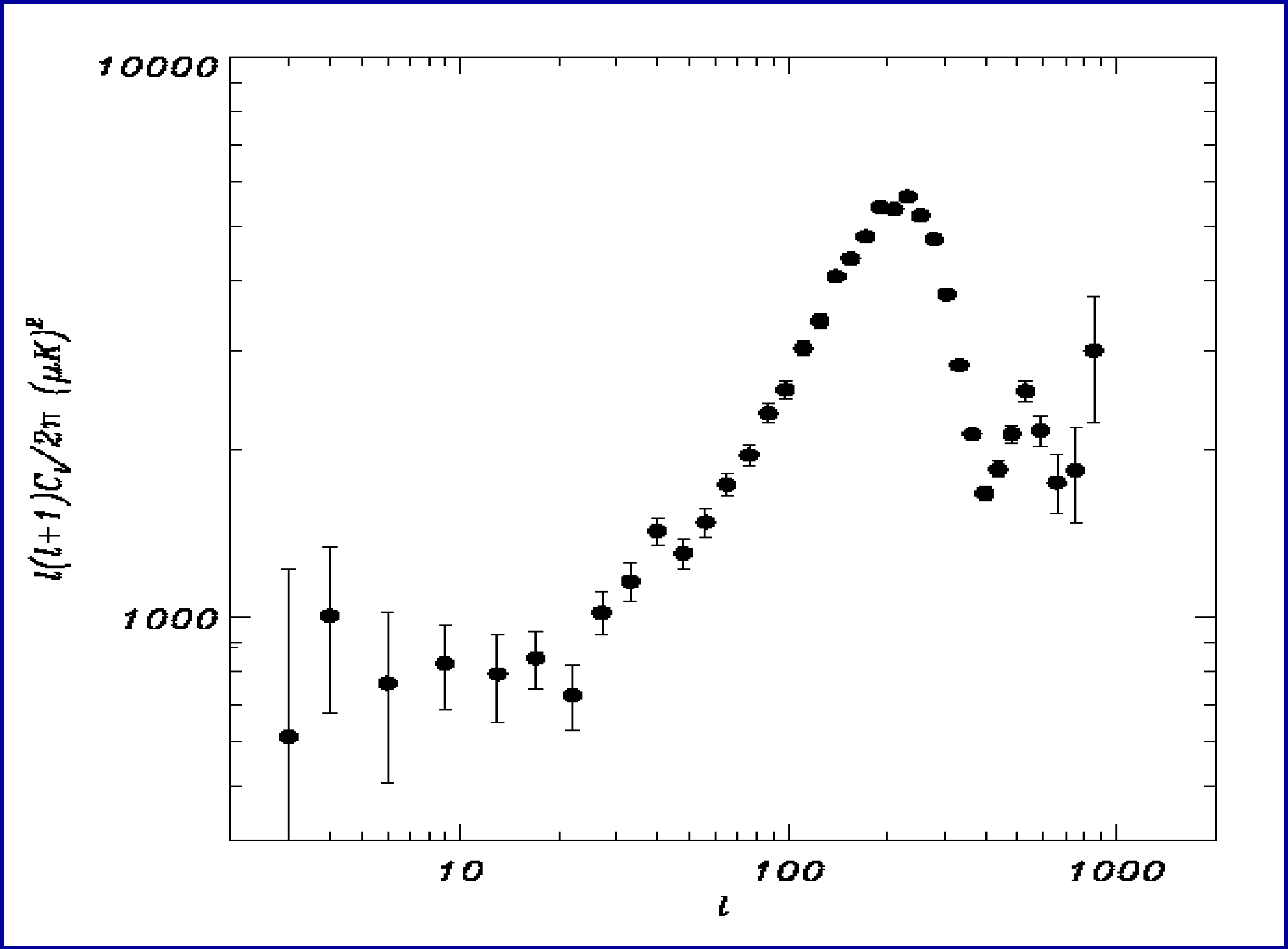
Early Universe Observations: neutrinos and photons

- cosmological neutrinos background is undetectable with any technology imaginable today
- although photons decouple late, models indicate that the CMB keeps a good inprint of the fluctuations generated at the end of inflation
  - physics of the universe after reheating is governed by the standard model of particle physics
  - it is close to thermodynamic equilibrium and the perturbations are small: $<10^{-5}$ (linear physics)

Anisotropies of the Cosmic Microwave Background

- CMB anisotropies have thus been recognized for more than 20 years as the potentially most powerful tool to probe fluctuations generated in the early universe
  - intensity anisotropies:
    - mostly due to adiabatic density fluctuations (scalar modes)
    - depends on cosmological parameters
  - polarization anisotropies :
    - E mode: removes degeneracies, improves accuracy of astrophysical measurements (lensing for example)
    - B modes: primordial gravity waves (tensor modes) lensing of the CMB anisotropies (dark energy)

WMAP and balloon experiments (Boomerang, Maxima, Archeops) have demonstrated that the CMB behaves as the model predicted



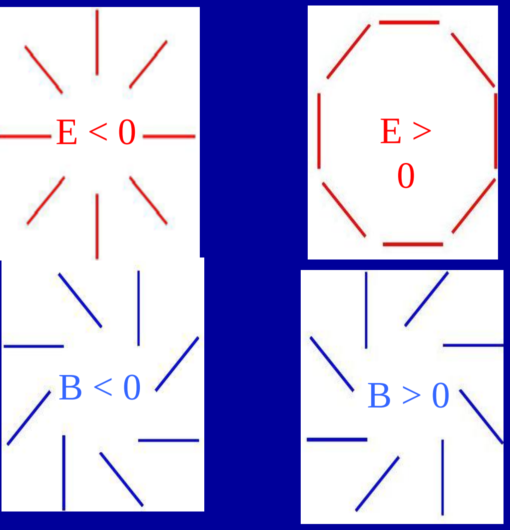
Bennett et al, 2003

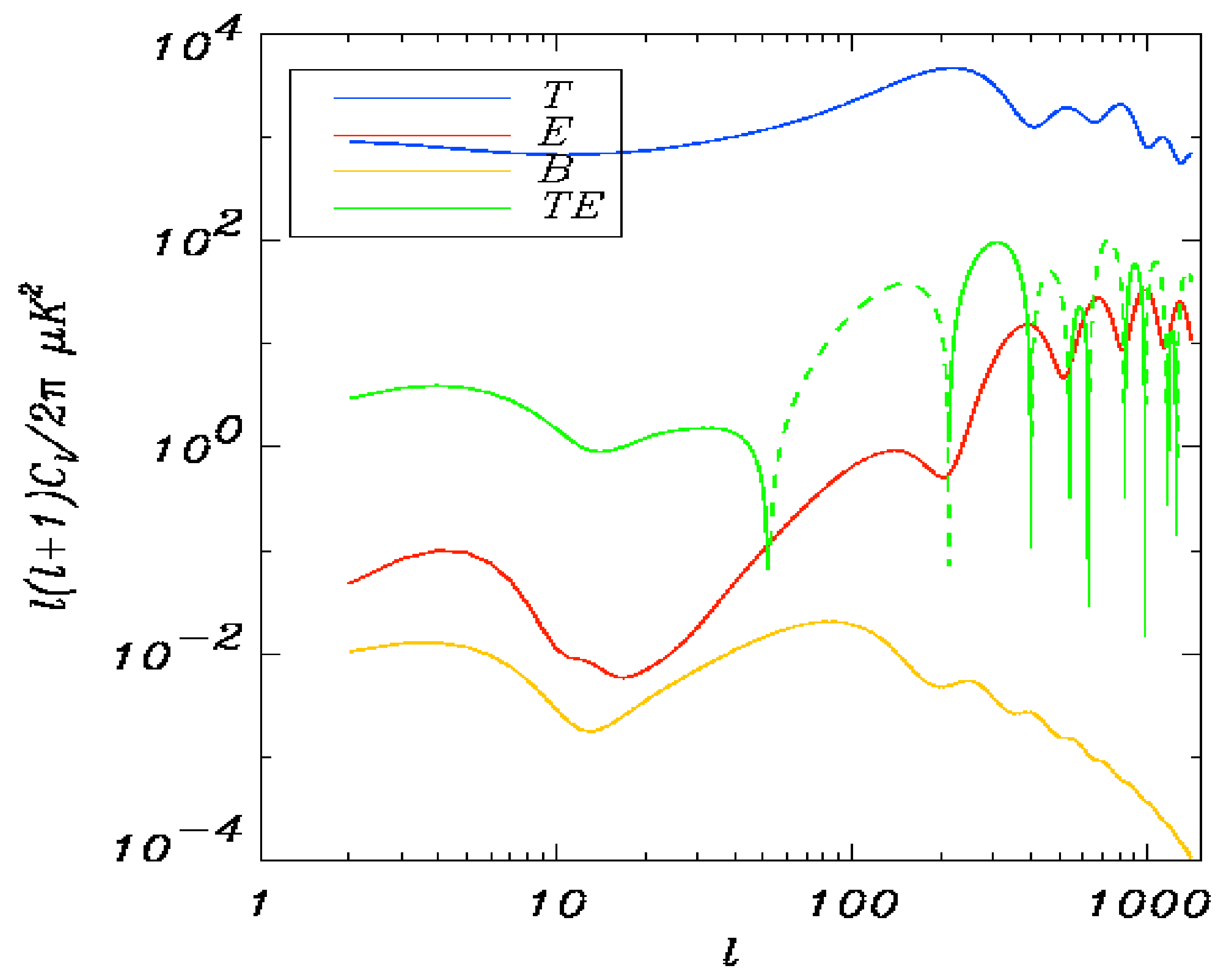
Anisotropies of the Cosmic Microwave Background

- CMB anisotropies have thus been recognized for more than 20 years as the potentially most powerful tool to probe fluctuations generated in the early universe
  - intensity anisotropies:
    - mostly due to adiabatic density fluctuations (scalar modes)
    - depends on cosmological parameters
  - polarization anisotropies :
    - E mode: removes degeneracies, improves accuracy of astrophysical measurements (lensing for example)
    - B modes: mostly due to primordial gravity waves (tensor modes) + lensing of the CMB anisotropies (dark energy)

CMB spectra: temperature, E and B polarization

3 observables : T, E, B

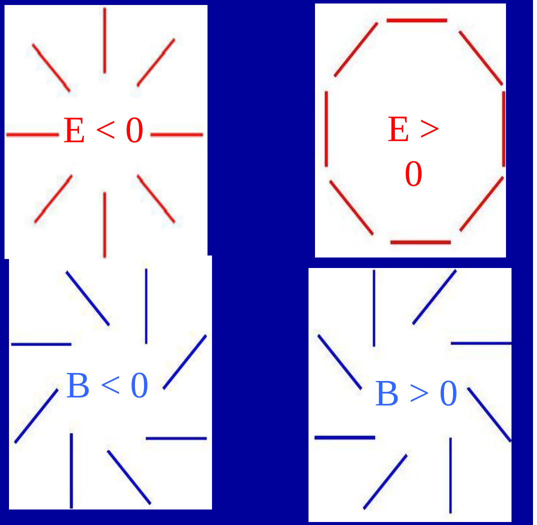


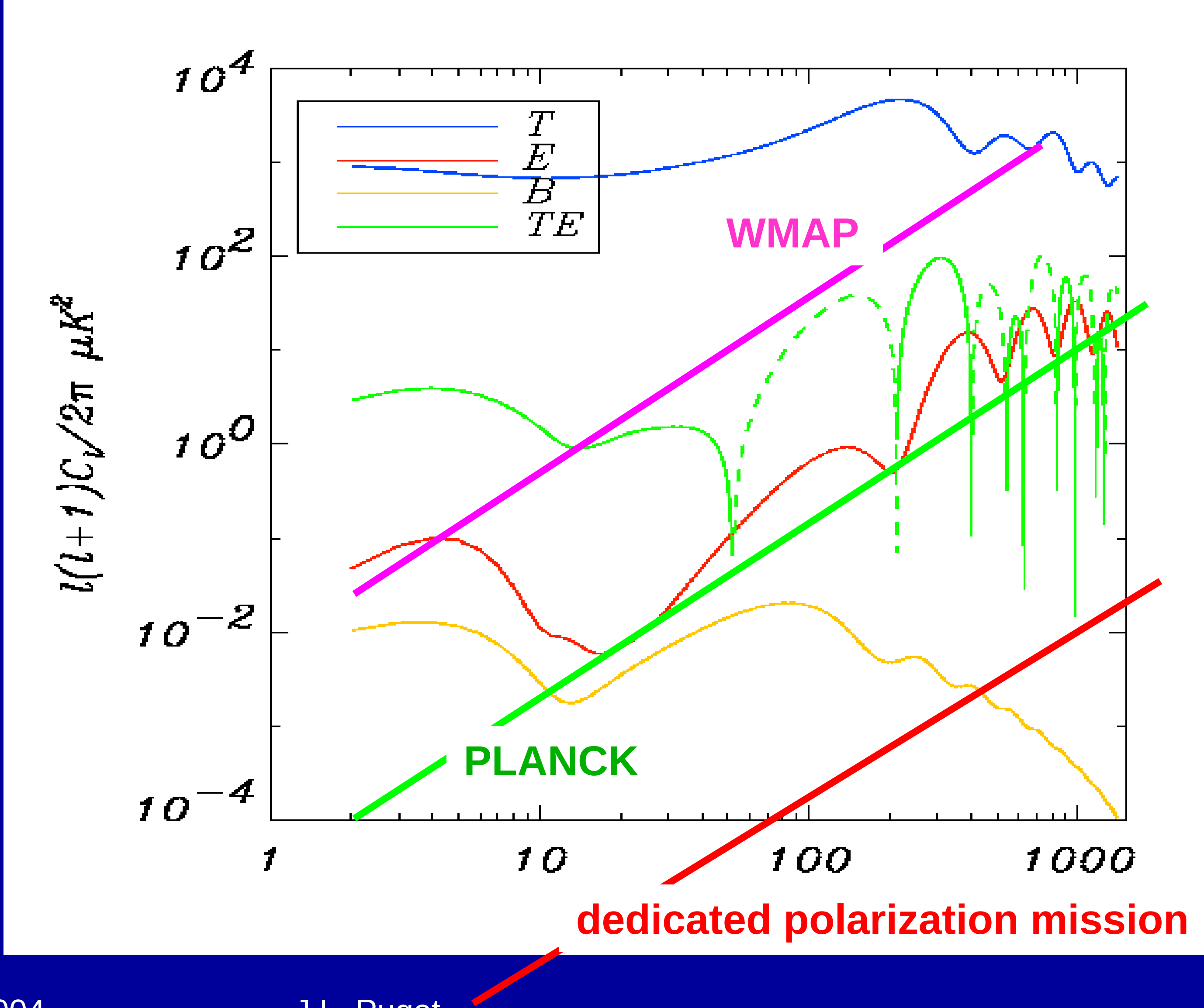


B polarization power spectrum is 5 orders of magnitude weaker than T for tensor/scalar = 0.1 !

CMB spectra: temperature, E and B polarization

3 observables : T, E, B



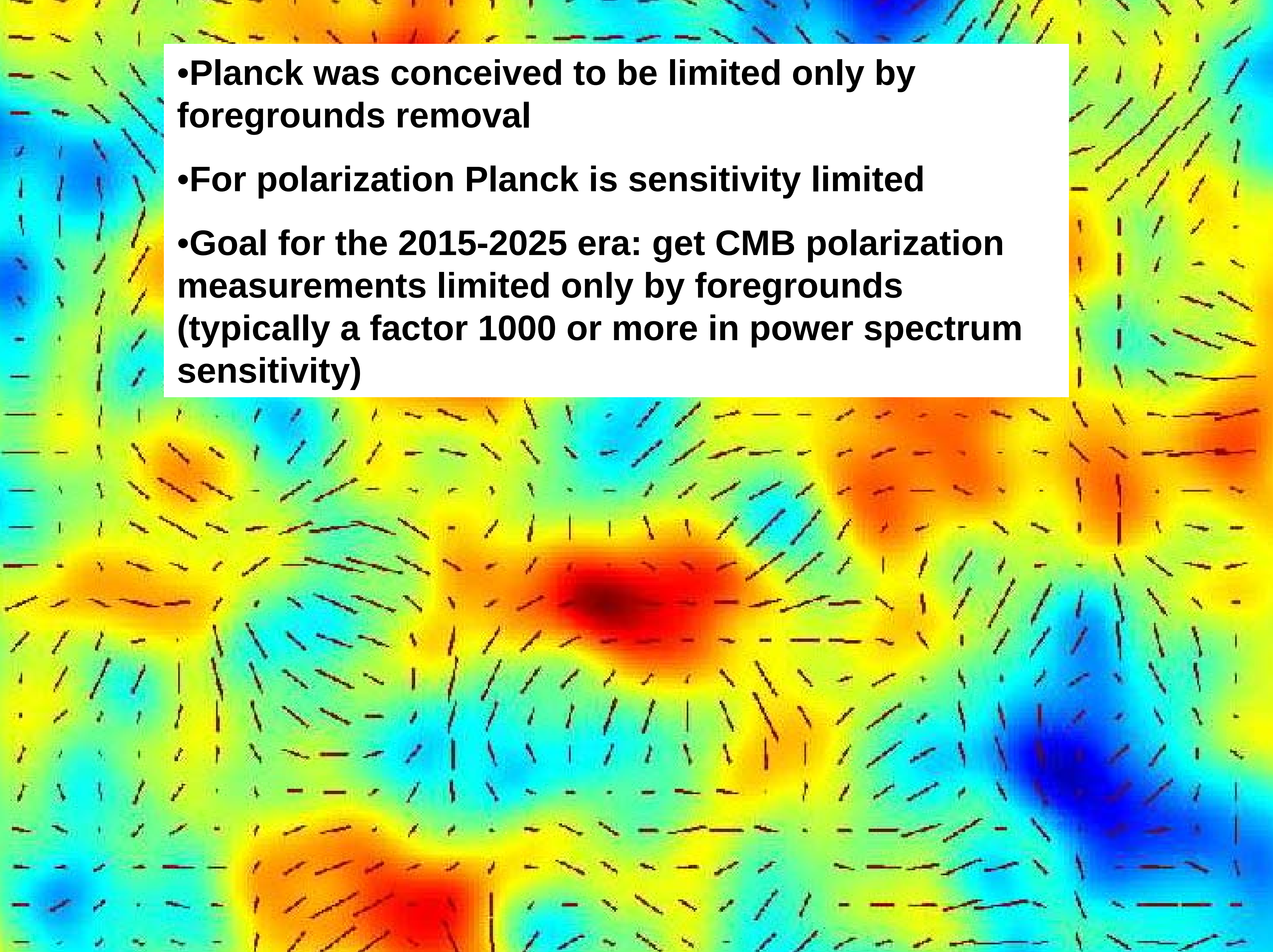


WMAP

PLANCK

dedicated polarization mission

B polarization power spectrum is 5 orders of magnitude weaker than T for tensor/scalar =0.1 !



- Planck was conceived to be limited only by foregrounds removal
- For polarization Planck is sensitivity limited
- Goal for the 2015-2025 era: get CMB polarization measurements limited only by foregrounds (typically a factor 1000 or more in power spectrum sensitivity)

critical technologies

- low spatial frequencies and optimal foreground removal can only be done from space
- cooling detectors to very low temperatures
  - allows to have detection limited by the photon noise of the background (fundamental limit per detector)
  - the Planck dilution cooling at 0.1 K in space is a unique European technology (stability 30 nK/Hz$^{1/2}$)
- gain of 10^3 in power spectrum sensitivity requires to have large arrays of detectors
  - 10^4 instead of a dozen per channel for Planck
  - Europe has many developments under way for these
  - necessary technology for FIR and X-rays future space observatories (see M. Griffin, G. White, G. Hasinger)

Which fundamental questions could be answered by CMB polarization experiment

- confirm the robustness of the concordance cosmological model
- does fluctuations originates during an inflation period or in some pre big bang era ?
- do we see any evidence for extra dimensions (branes) ?
- find if the inflation energy scale is the Grand Unification one (10^{15} to 10^{16} GeV)
- measure the neutrino mass with 0.05 eV accuracy
- contribute to improve much the accuracy of astrophysical measurements (for ex of the dark energy equation of state with lensing in the optical)
- provides a unique map of the microwave polarized sky