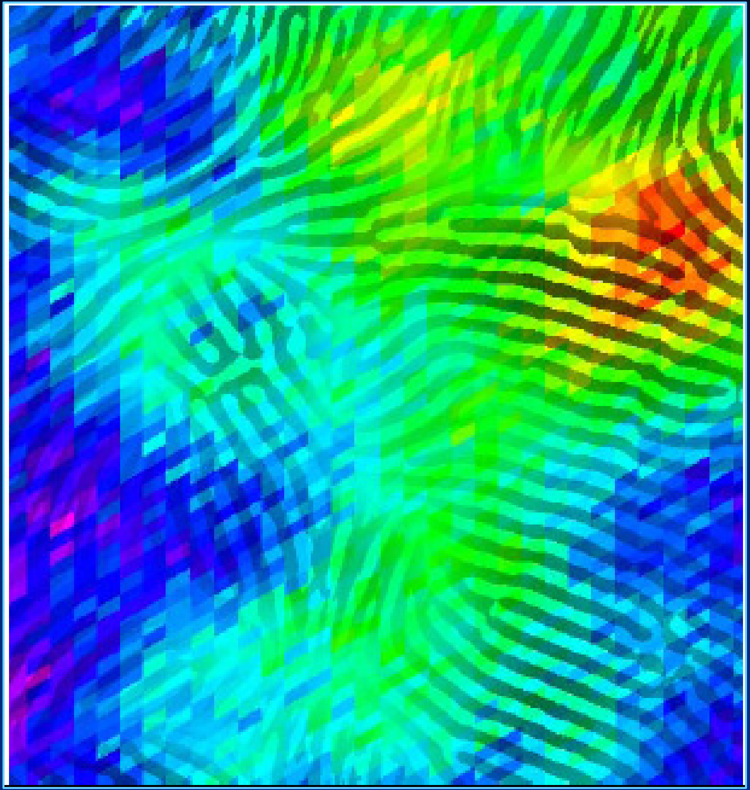
5. Understanding the Polarization of the CMB

By measuring the polarization of the CMB, which indicates how the light was scattered in the early Universe, Planck can hopefully help us understand these mysteries!

This false color image of a very small patch of CMB sky shows the direction of polarization (stripes) superimposed on the temperature anisotropies (colors).



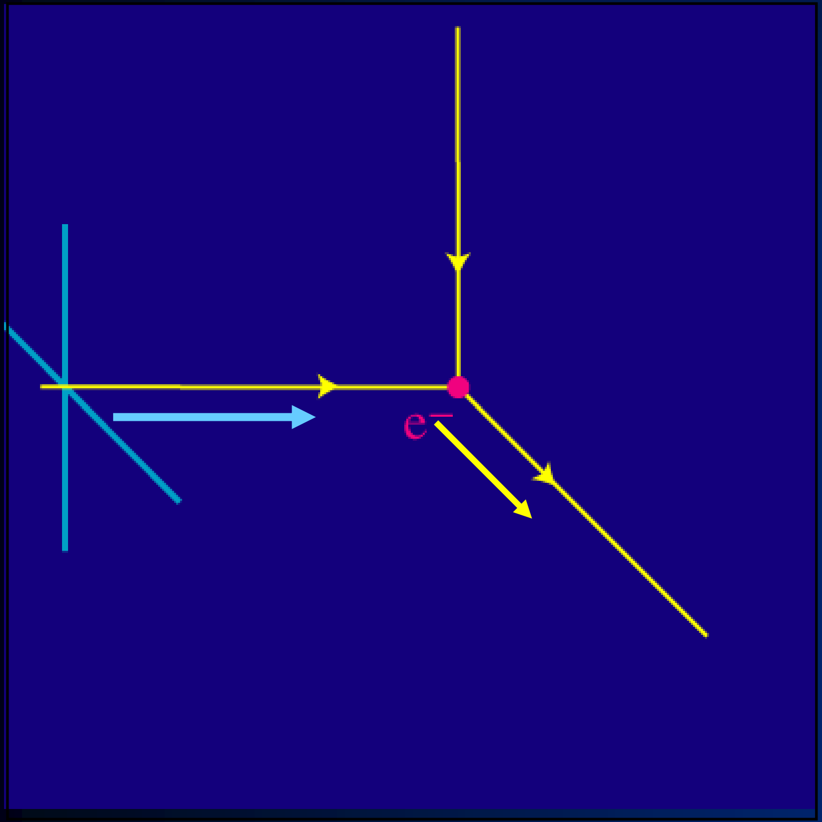
Next, we will explain something about how the CMB light is polarized, what we can observe, and how the polarization spectrum of the CMB can yield even more information than the power spectrum of the temperature variations.

When ordinary light passes through our atmosphere, it is scattered by dust particles and molecules in the atmosphere. This is why our sky looks blue, but on the Moon the sky is always black, even on the sunny side: there is no atmosphere on the Moon to scatter the light!

http://www.bradormand.com/images/sky_from_the_sky.jpg

http://www.nasm.si.edu/collections/imagery/apollo/AS12/a12images2.htm

Scattered light is almost always polarized. This diagram represents in incoming light wave coming in from the left. After interacting with a free electron, the light is scattered perpendicular to its direction of propagation. Thus, by measuring the direction of polarization of the CMB, we can get a picture of the distribution of matter at the time of recombination.

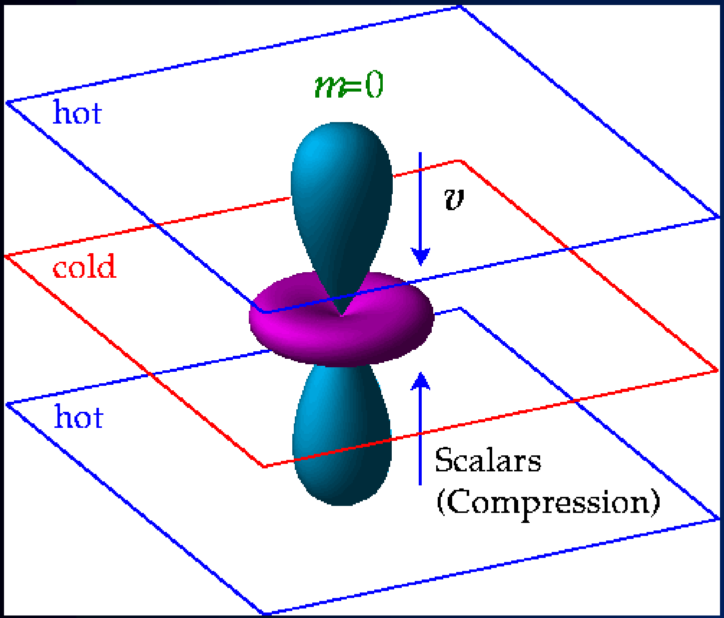


Source: http://background.uchicago.edu/~whu/

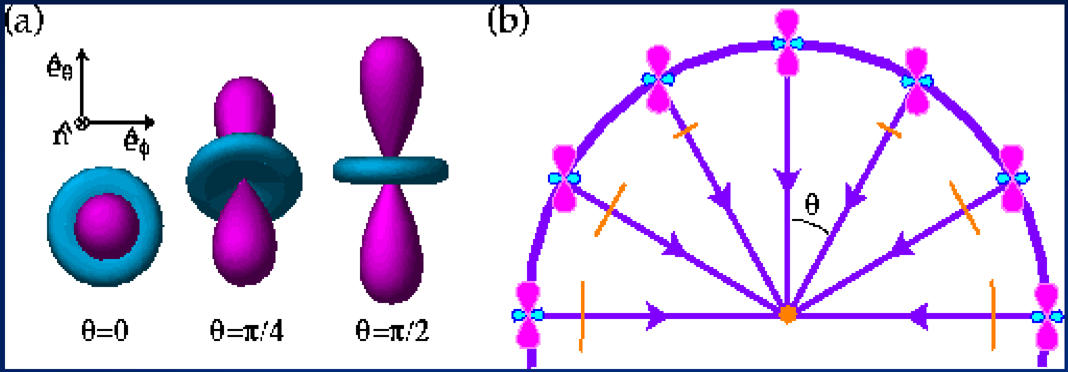
…and that's why polarizing sunglasses are said to cut the glare – they are designed to eliminate light which is polarized parallel to the ground.

The author on the roof of the physics building at UCSB, wearing polarizing sunglasses!

The most commonly considered and familiar types of perturbations in the CMB fluid which could scatter, and hence polarize, the CMB radiation are called scalar modes. These modes represent perturbations in the density of the cosmological fluid at last scattering and are the only fluctuations which can form structure though gravitational instability.



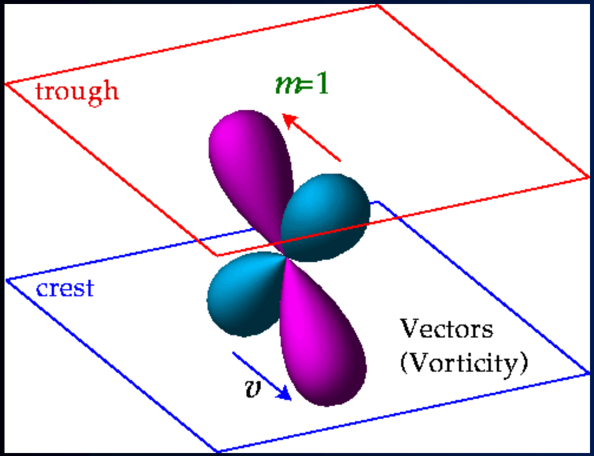
Model of compression wave in fluid.

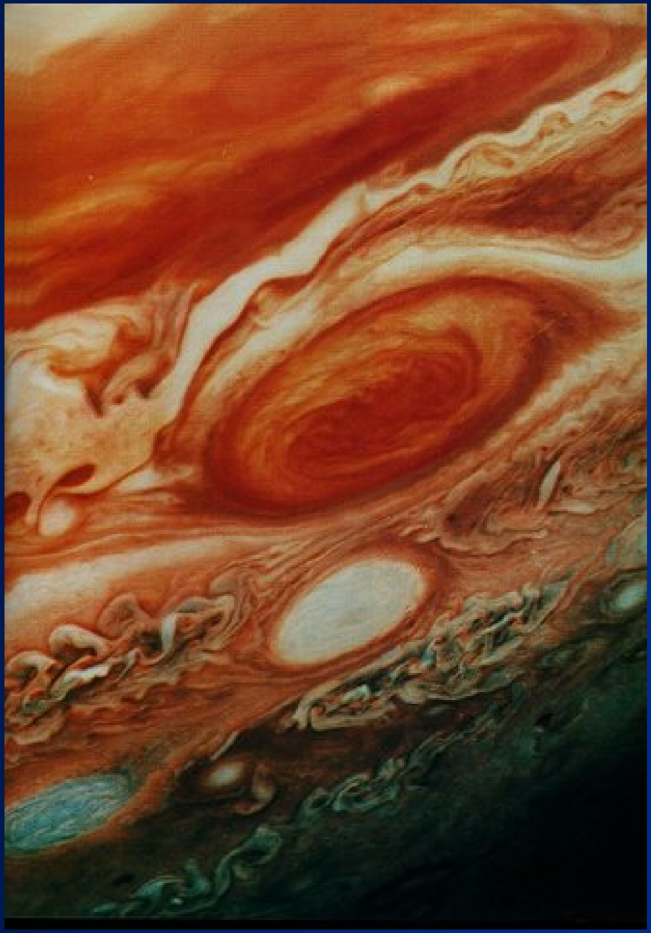


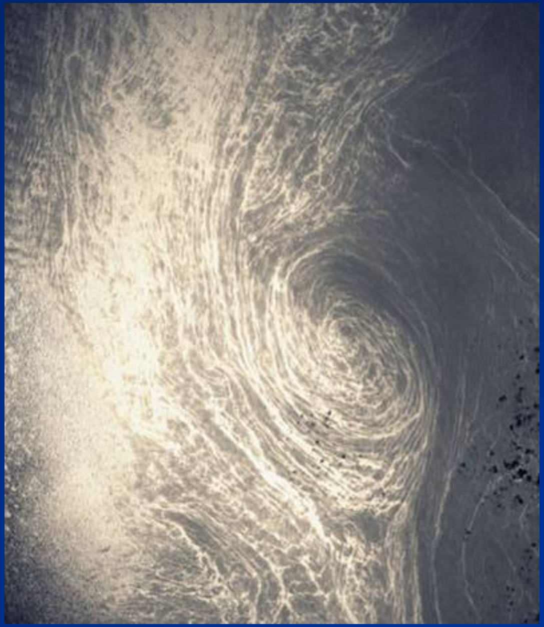
Observing a hypothetical compression wave from different angles, we see different amounts of polarization in the CMB signal.

Source of all the pink and blue models: Wayne Hu, http://background.uchicago.edu/.

Vector perturbations represent vortical motions of the matter, similar to vortices observed in water or planetary atmospheres. There is no associated density variation, and hence these modes are not expected to be observable in the CMB. (We mention them for completeness' sake!)

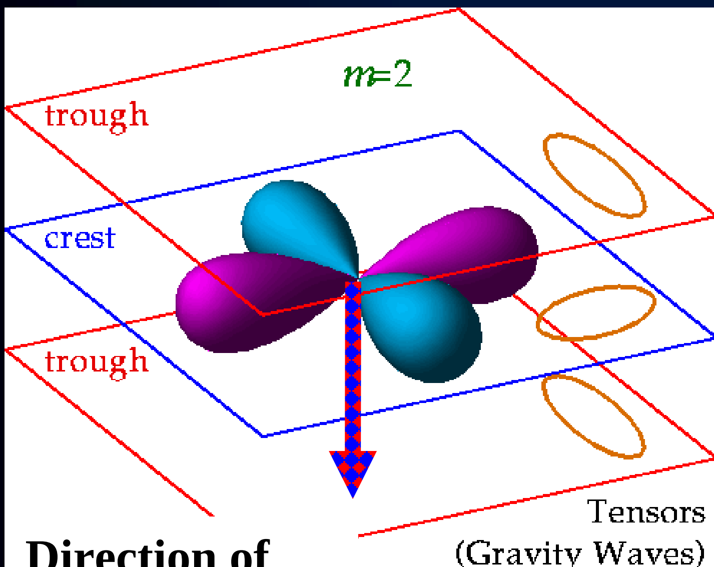






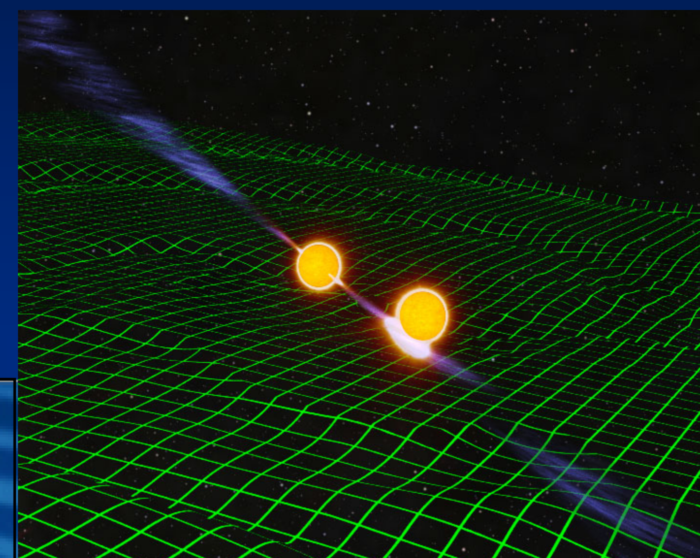
Images of vortices in planetary atmospheres from NASA planetary archives.

Tensor fluctuations in the CMB should come from gravitational waves in the early universe. If we can detect these polarization states In the CMB, then we can possibly probe the era of time BEFORE recombination.

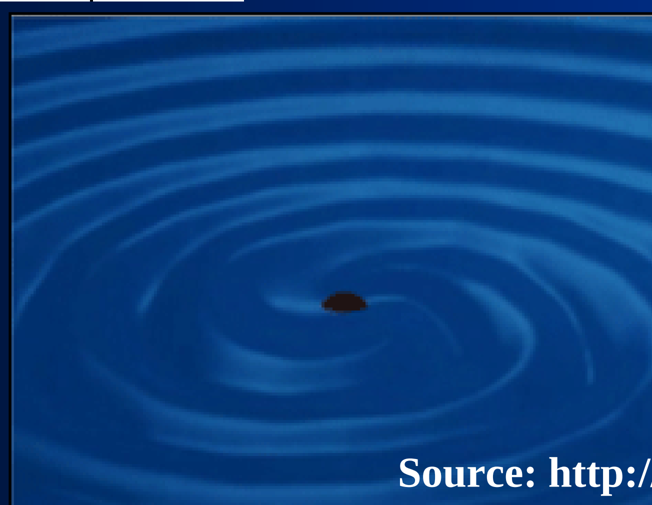


Direction of Propagation = towards viewer

Gravity waves are amazing phenomena which are caused by any large moving masses, and distort the shape of spacetime itself!

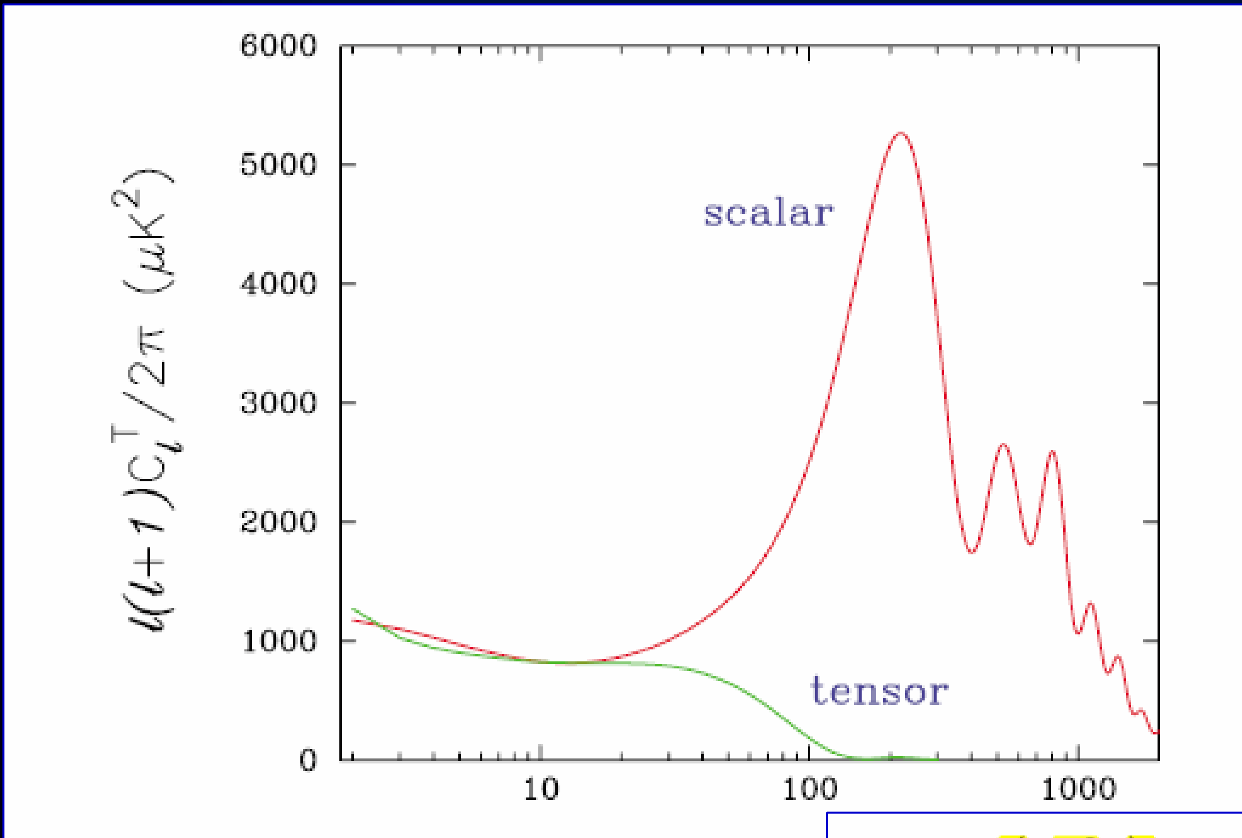


Source: http://www.johnrowe.org/



Source: http://www.universe.nasa.gov/gravity/

The tensor fluctuations are much more difficult to detect, being of much smaller amplitude than the scalar fluctuations, but we hope that Planck's very sensitive instruments will be able to resolve them.



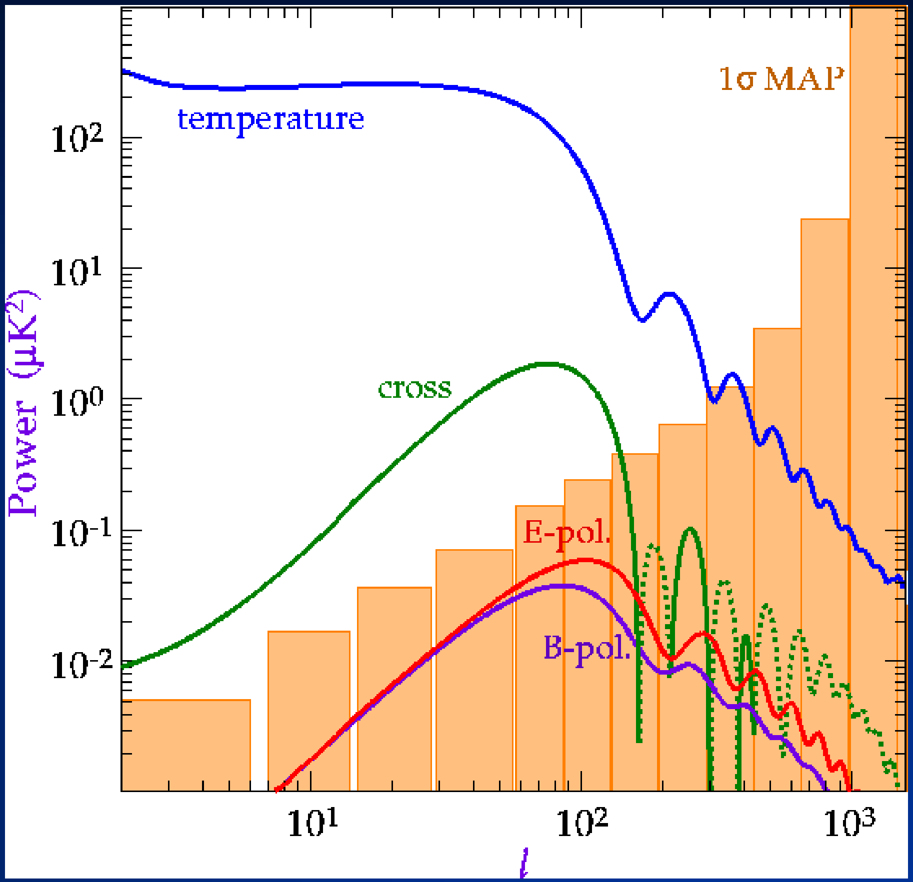
$$P_{\rm S}(k) \simeq \left(\frac{H^2}{16\pi^3\dot{\phi}^2}\right)_{(k=aH)} \quad \text{(scalar perturbations)},$$

$$P_{\rm T}(k) \simeq \left(\frac{H^2}{4\pi^2 m_{\rm Pl}^2}\right)_{(k=aH)} \quad \text{(tensor perturbations)},$$

Each of these polarization patterns on the sky can be separated into electric field (E) and magnetic field (B) components.

E-modes arise primarily from density variations prior to recombination. B-modes are sensitive to the depth of re-ionization of the CMB after recombination, thus understanding B-polarization can yield information about the ionization history of the Universe.

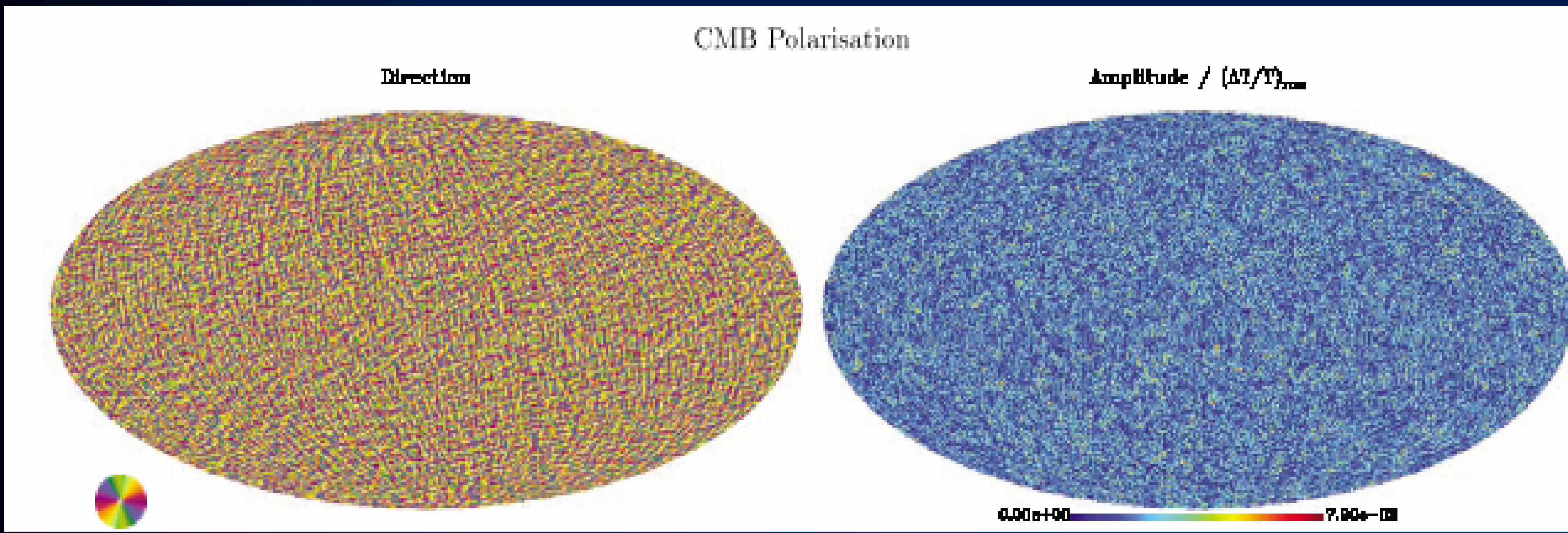
This graph compares the expected amplitudes of the temperature, E, and B polarization power spectra, and their cross correlation.



For the most complete on-line reading material about CMB polarization, as well as other CMB basic science, please visit the web pages of Wayne Hu at the University of Chicago, http://background.uchicago.edu/~whu/polar/webversion/polar.html.

PLANCK

Planck will measure the polarization of the CMB at high angular resolution, hopefully with sufficient sensitivity to measure both E and B modes.



so, stay tuned!

Launch date: December 31, 2008!