PLANCK Education and Public Outreach

Planck Visualization Project

Seeing and Hearing the CMB

NASA JPL

esa PLANCK

UCSB

PURDUE UNIVERSITY CALUMET

Education and Public Outreach Group, Planck Mission, NASA:

Purdue University:

***Laura Cayon** (taking over for J. van der Veen)*

Purdue-Calumet, VisLab

Lead Application Developers:

Jerry Dekker, Lead Programmer

John "Jack" Moreland,

Visualization Specialist

University of California, Santa Barbara:

Department of Physics

***Jatila van der Veen** (formerly at Purdue-Cal.)*

Philip Lubin

UCSB AlloSphere

JoAnn Kuchera-Morin, AlloSphere Director

Lead Application Developers:

Basak Alper, Wesley Smith

Ph.D. candidates in Media Arts Technology

Lead P.I., Planck Visualization Project: Jatila van der Veen

Planck Project Scientist and Lead Principal Investigator at NASA/JPL:

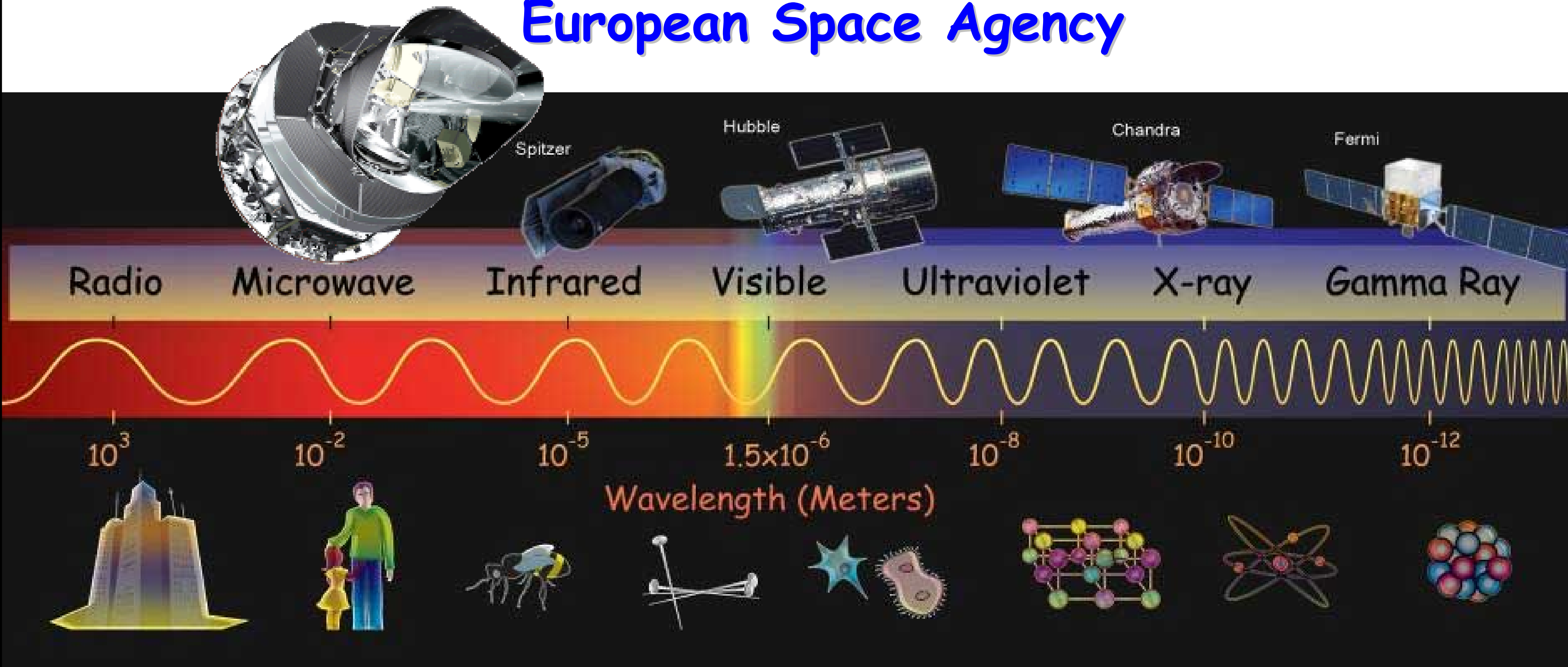
Charles R. Lawrence

Planck Launch: May 14, 2009

photo: Charles R. Lawrence

PLANCK Education and Public Outreach

Planck, joint mission with the European Space Agency



NASA Telescopes Across the Electromagnetic Spectrum

PLANCK Education and Public Outreach

Classroom Connections

The Big Idea

We know that we live in an expanding universe, in which ordinary matter comprises only 4% or less of the total matter-energy density of the universe, and in which 96% of the matter-energy density is in some DARK form that we still don't understand. How could stars, galaxies, and life have evolved if the universe were even a tiny bit different? What process caused the universe as we know it to come into being, and how will it end? The Cosmic Microwave Background, the oldest radiation we can observe, holds the clues.

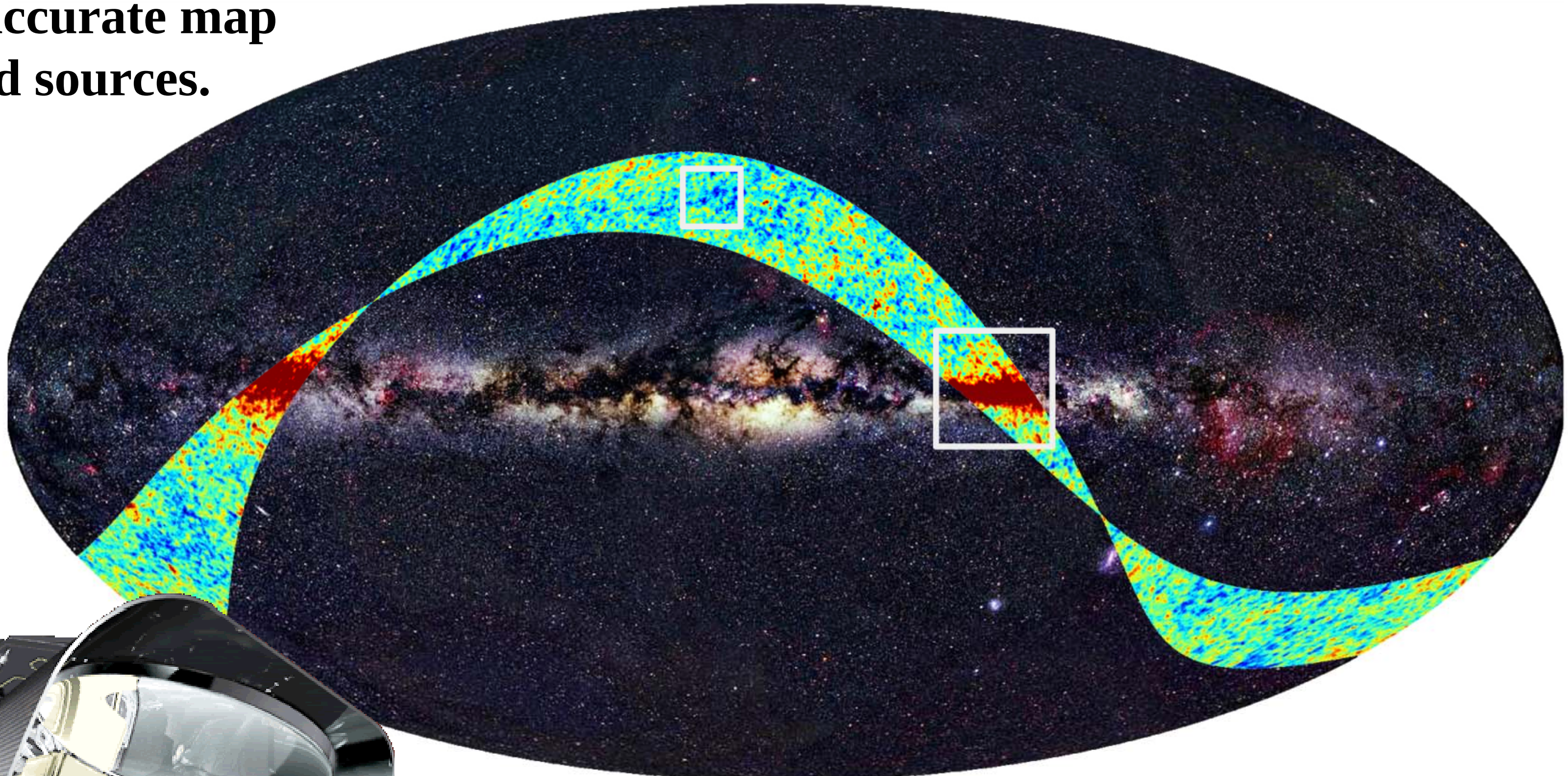
Connection to Standards

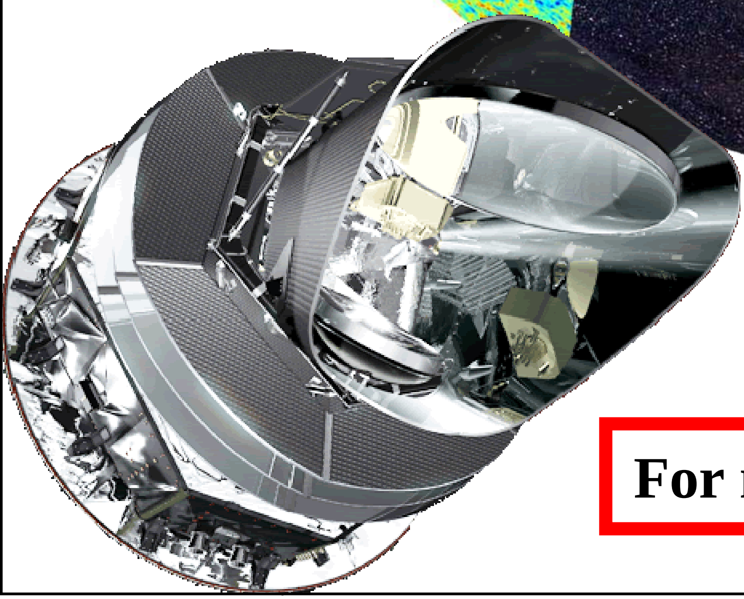
Experimental Cosmology connects to all sciences and mathematics: Physics – Astronomy – Earth Science – Chemistry – Computer Science – as well as Sociology – History – and Philosophy.

In addition, Experimental Cosmology is an INTERNATIONAL endeavor, thus you can tie the Planck Mission to your multicultural standards!

PLANCK Education and Public Outreach

Planck's purpose is to map the Cosmic Microwave Background (CMB) with a sensitivity of a few millionths of a degree Kelvin, and an angular resolution as fine as 5 arc minutes on the sky. Planck will also map the polarization of the CMB with high precision, and produce an accurate map of foreground sources.





Planck first light survey, released September, 2009.
Credit: ESA, LFI and HFI Consortia

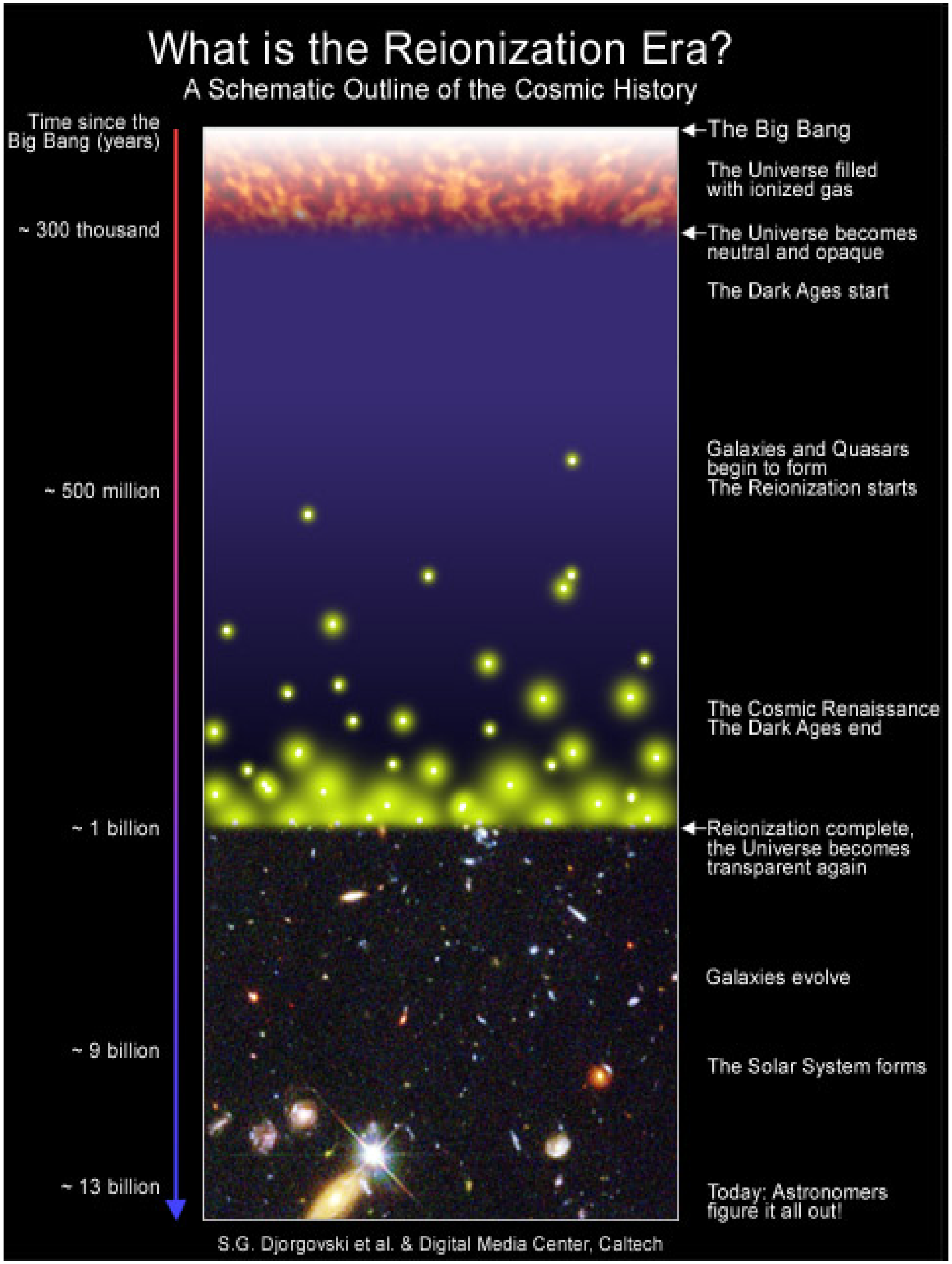
For more information, see http://planck.caltech.edu/

What is the Cosmic Microwave Background, or CMB?

The CMB is the thermal radiation left over from the hot Big Bang, 13.7 billion years ago, now observed at a temperature of 2.75 Kelvin.

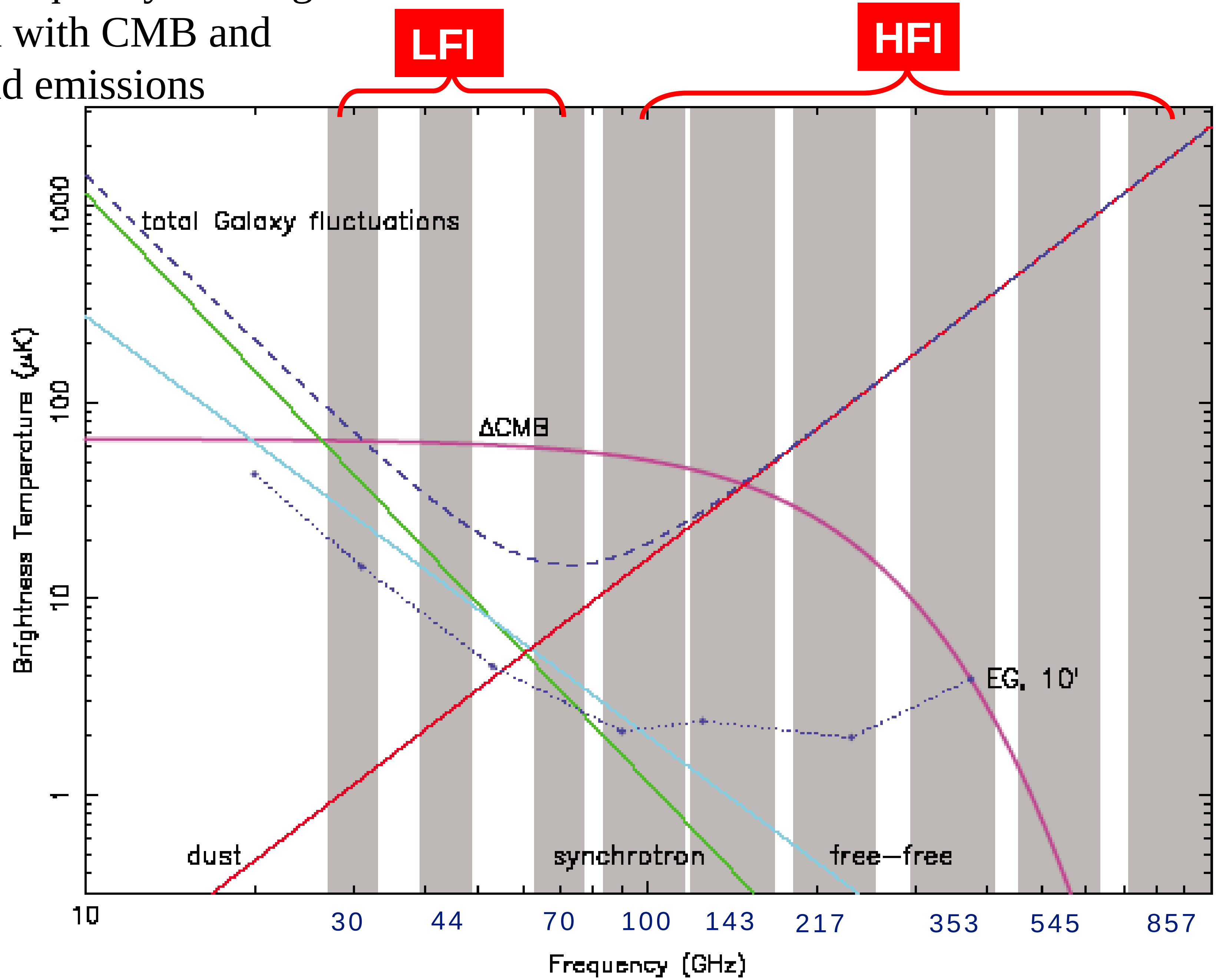
It is the oldest light we can observe, coming to us from the time when the universe first became cool enough so as to be transparent to electromagnetic radiation, approximately 380,000 years after the Big Bang.

Before this time the universe was too hot and bright to see through, and photons could not travel very far before being scattered by charged particles.

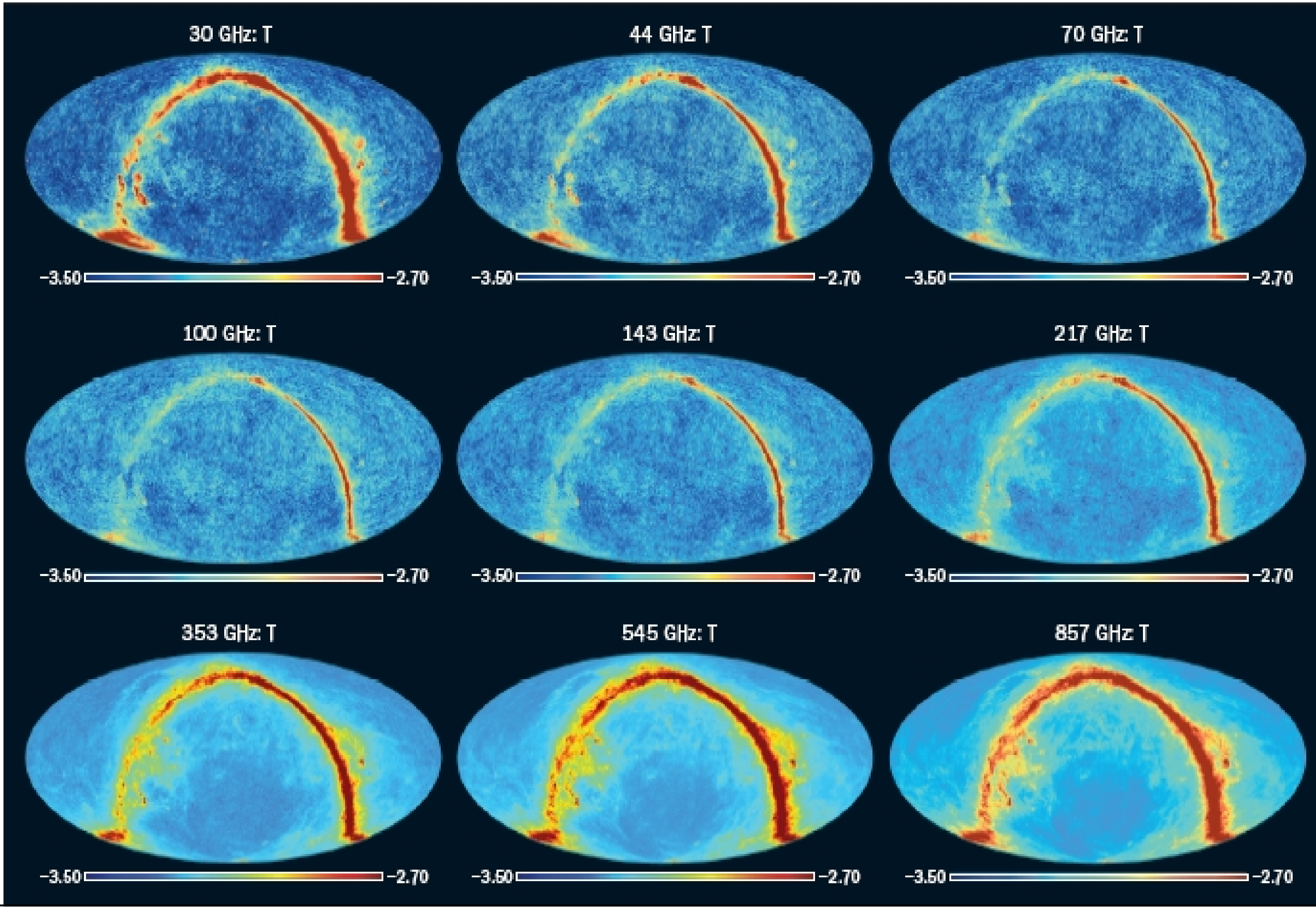


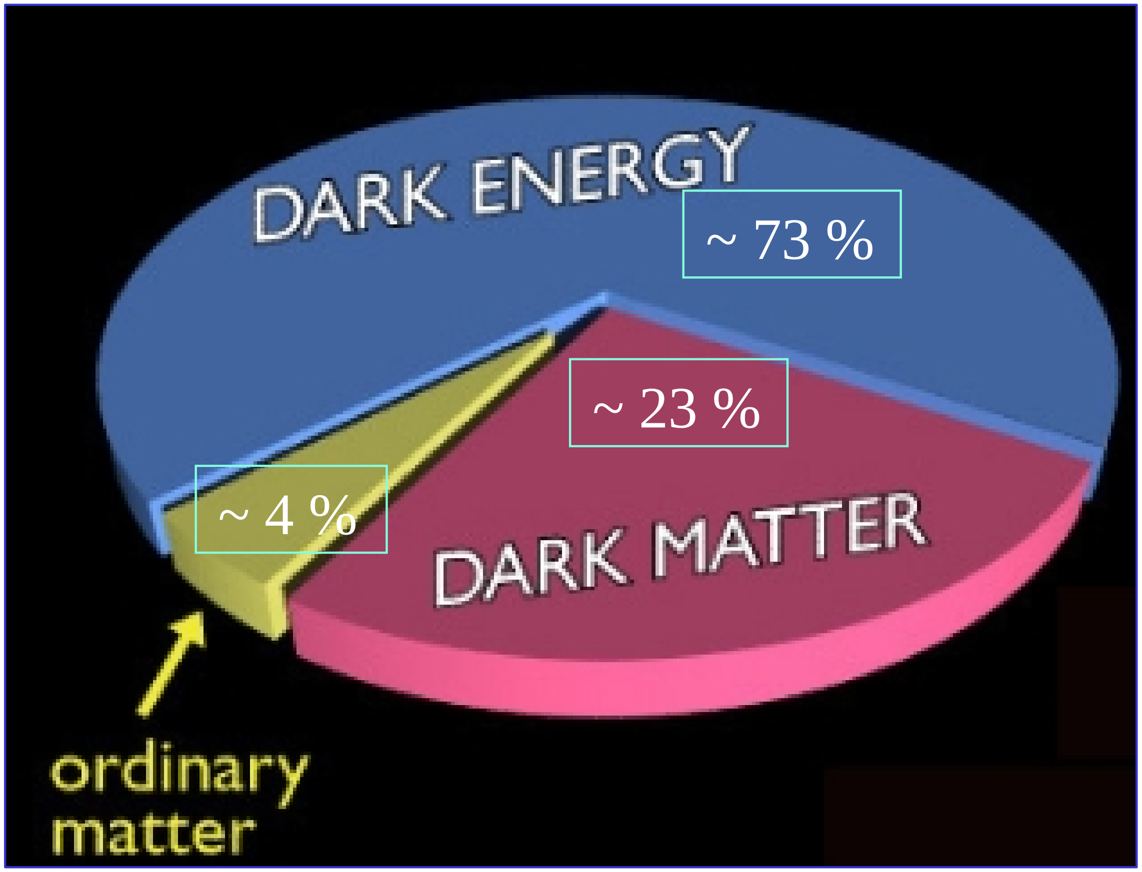
PLANCK Education and Public Outreach

Planck's frequency coverage compared with CMB and foreground emissions



Predicted sky seen by Planck in each channel, in Earth-centered coordinates.

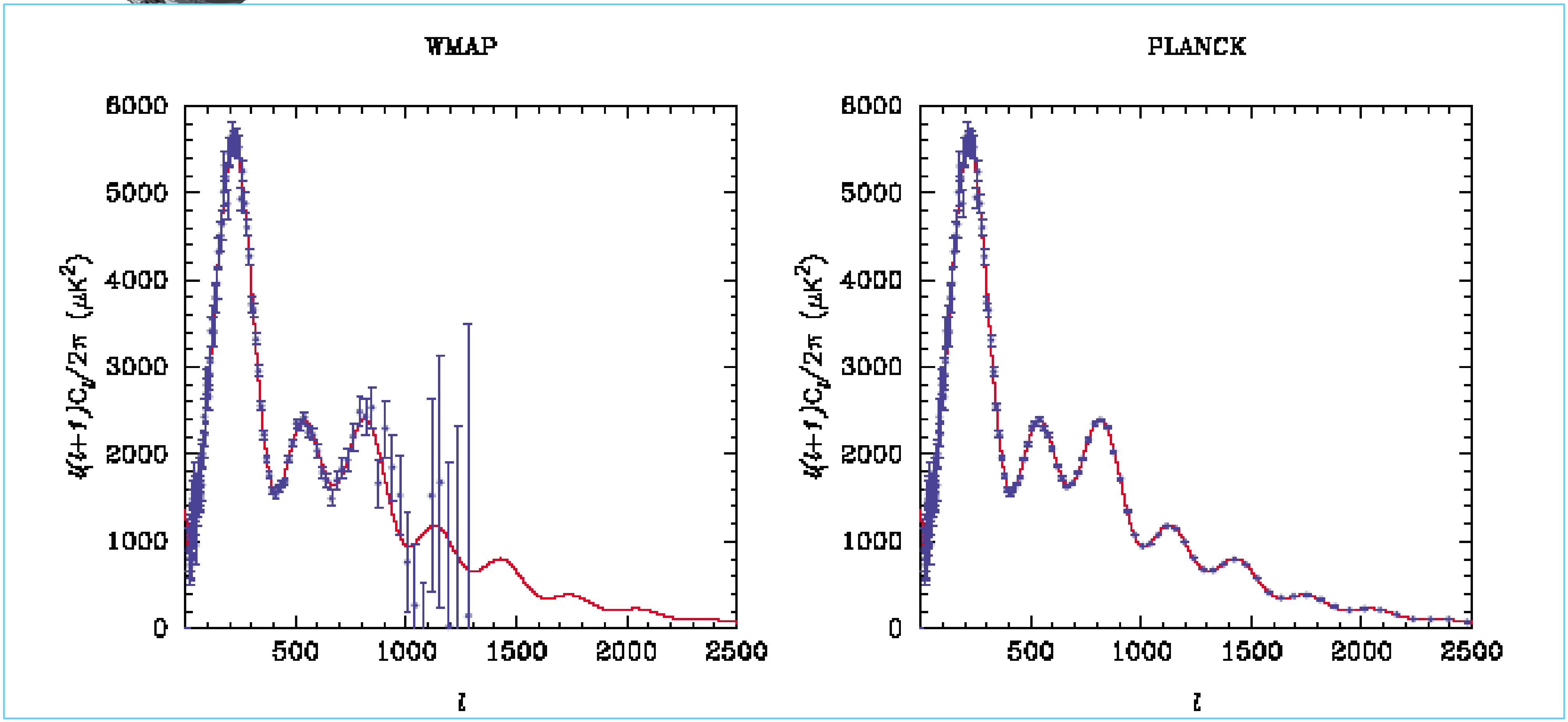




From the geometry of the universe, we understand that the average energy density is close to the so-called critical density, about 10^{-29} gr/ cubic centimeter.

Current expansion rate: 71 km/sec/Mpc

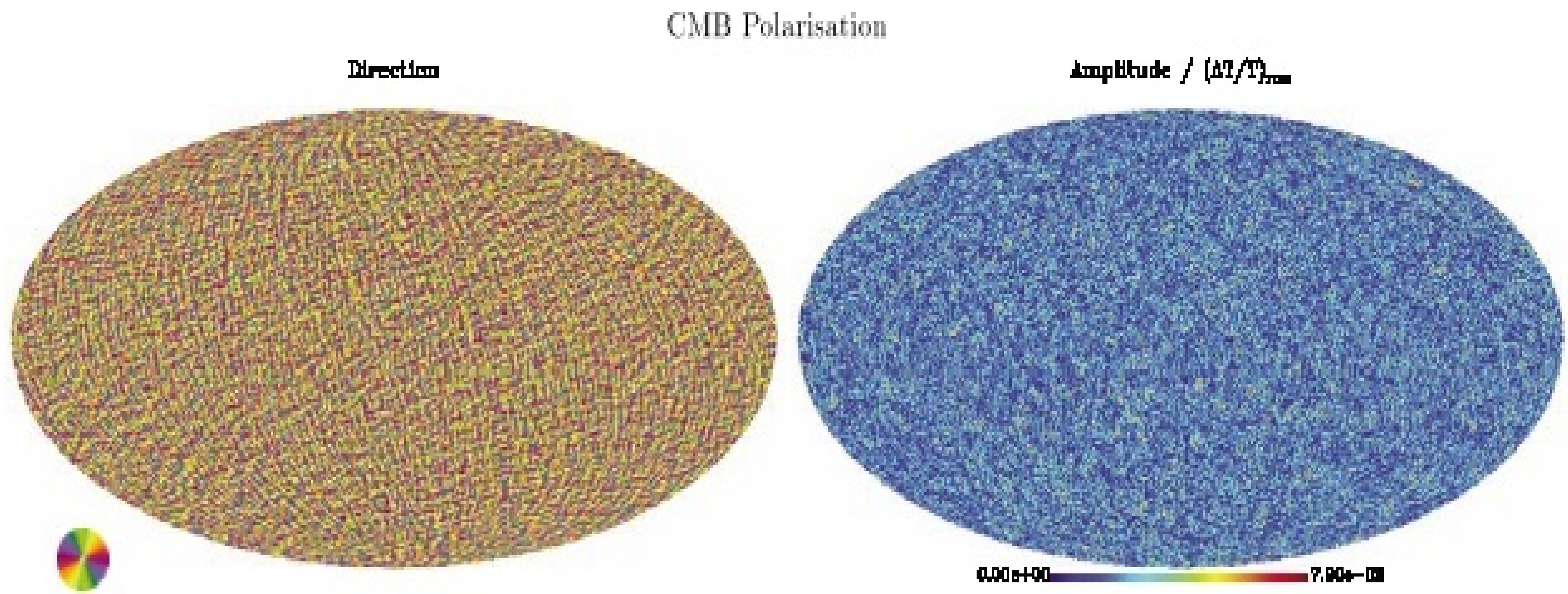
What more do we expect to learn from Planck?



1. More precise determination of the ratios of the heights of the fundamental, second, and third harmonics will permit more precise determination of the relative abundances of dark matter and dark energy relative to baryons (normal matter).

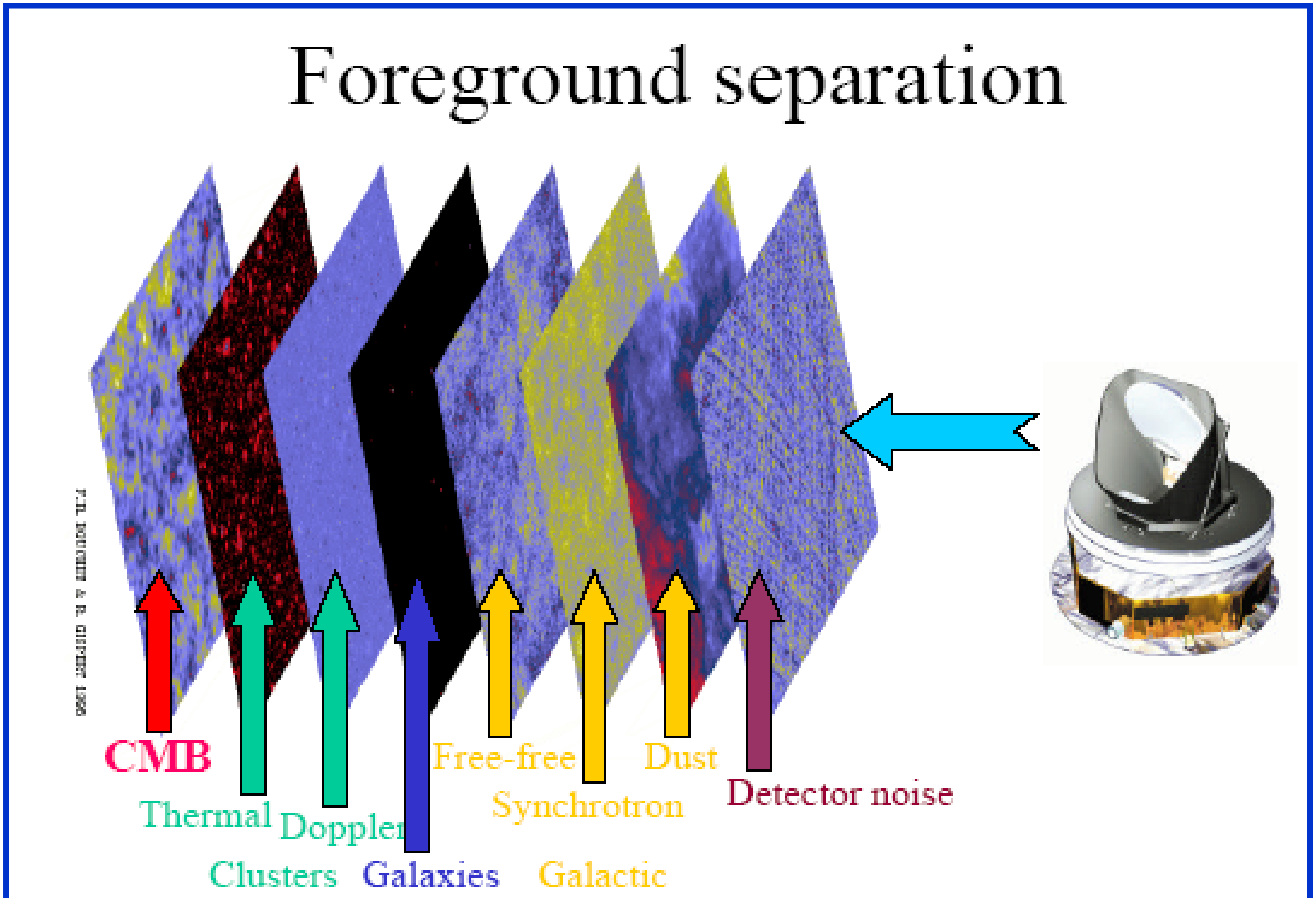
2. Finer angular resolution of Planck will sample essentially all the higher angular wave numbers accurately. These higher order peaks are effected by the distribution of dark energy between the CMB and us, and also by the effect on the CMB photons of ionized gas in galaxy clusters on their way from the CMB to our telescopes.

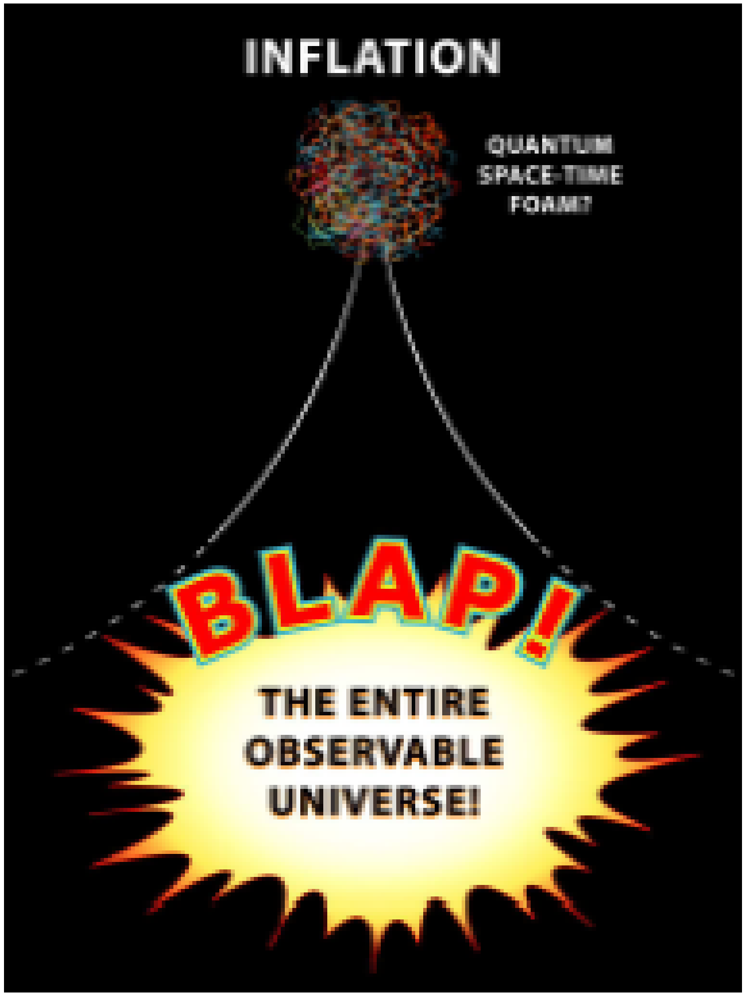
3. Planck will also measure the polarization of the CMB, which indicates how the light was scattered in the early Universe. The polarization will give us information about when the first stars formed and re-ionized the universe, and also about the velocities of the acoustic waves on the surface of last scattering.

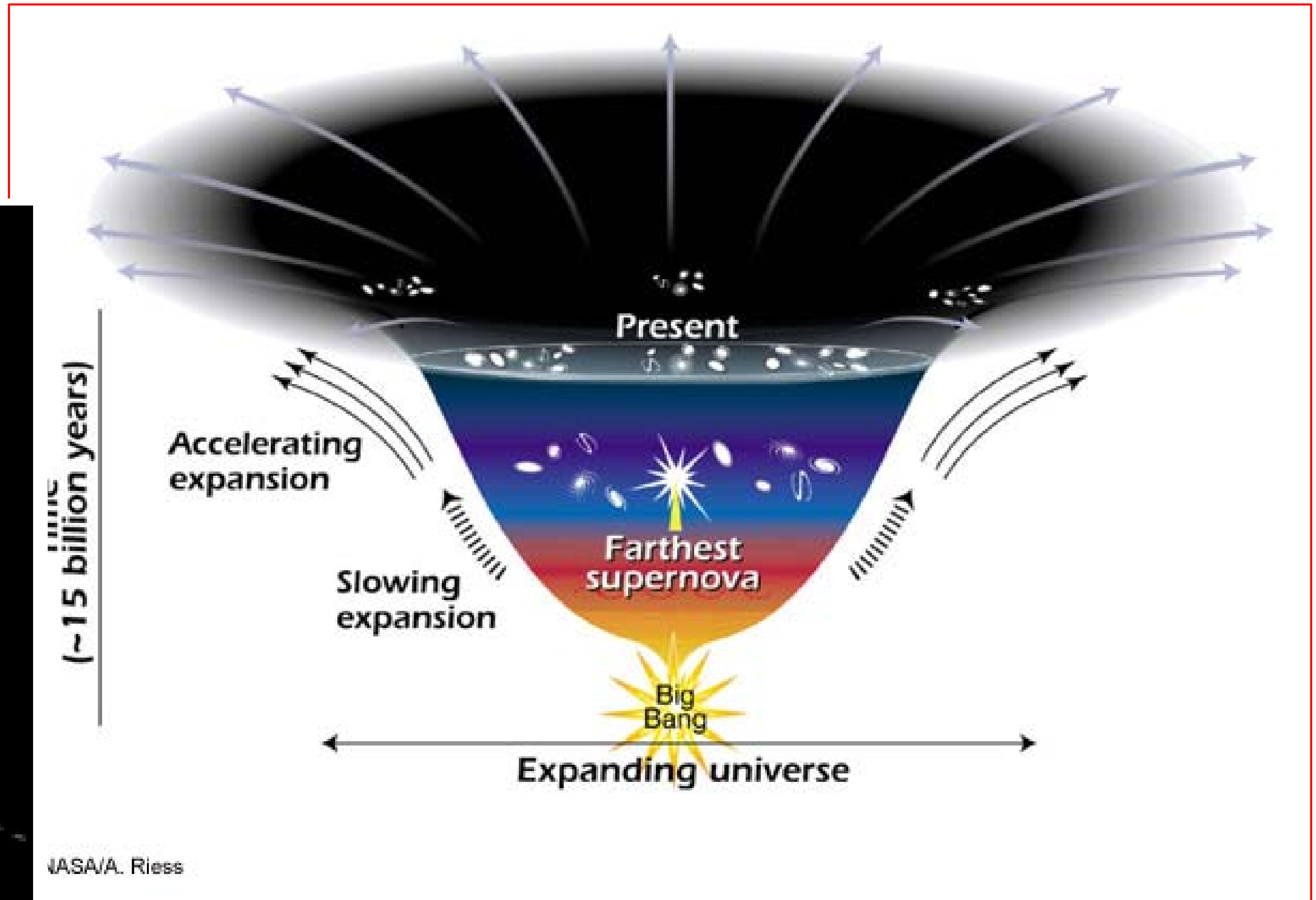


PLANCK Education and Public Outreach

The nine frequency bands will allow for accurate removal of foreground sources from the CMB maps, and the preparation of point source and cold cores catalogs, among other data products.







Planck's accurate power spectrum will help constrain the nature of this mysterious dark energy and shed light on fundamental physics, perhaps giving us information which can support or refute new theories.

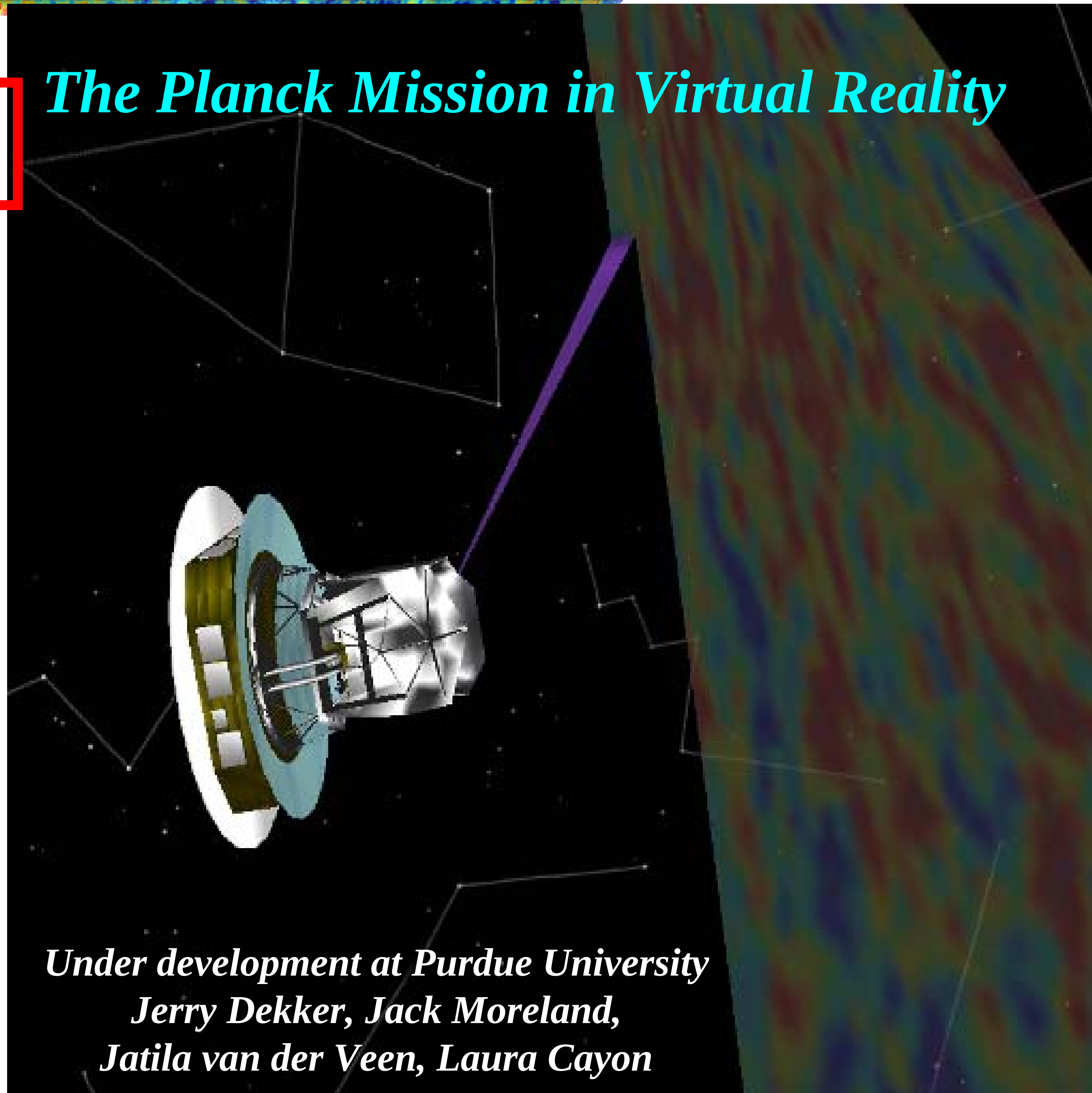
PLANCK Education and Public Outreach

The Planck Mission in Virtual Reality

Planck Education Projects:

Utilizing state-of-the-art visualization, gaming, and distributed computing technology, we are developing applications for the Planck Mission using Virtual Reality to reach the widest possible international audience.

See demo on computer:

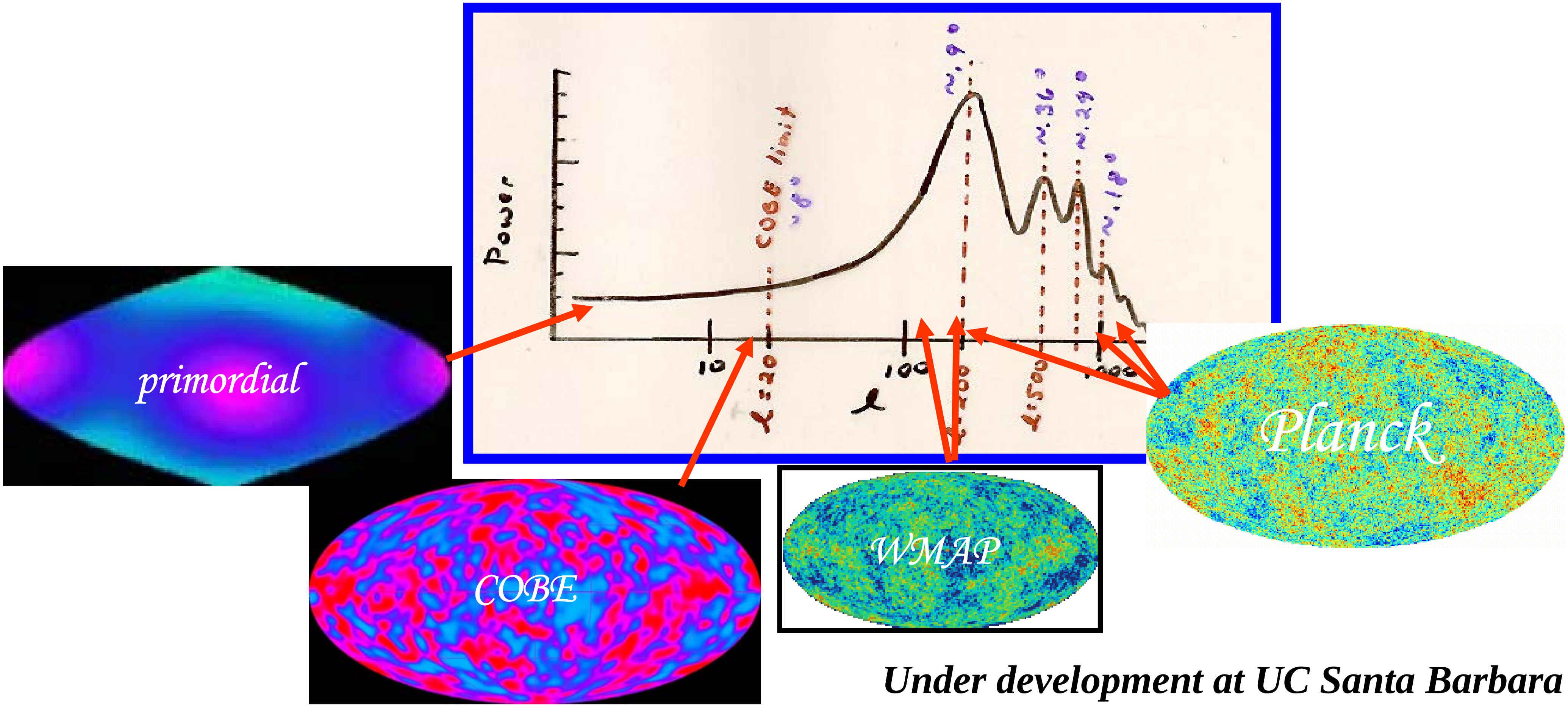


Under development at Purdue University
Jerry Dekker, Jack Moreland,
Jatila van der Veen, Laura Cayon

PLANCK Education and Public Outreach

The Music of the Cosmos

Using sound to explain how we extract information about the early universe from the power spectrum of the CMB.



Under development at UC Santa Barbara
Jatila van der Veen, Philip Lubin,
JoAnn Kuchera-Morin
Basak Alper, Wesley Smith, Ryan McGhee

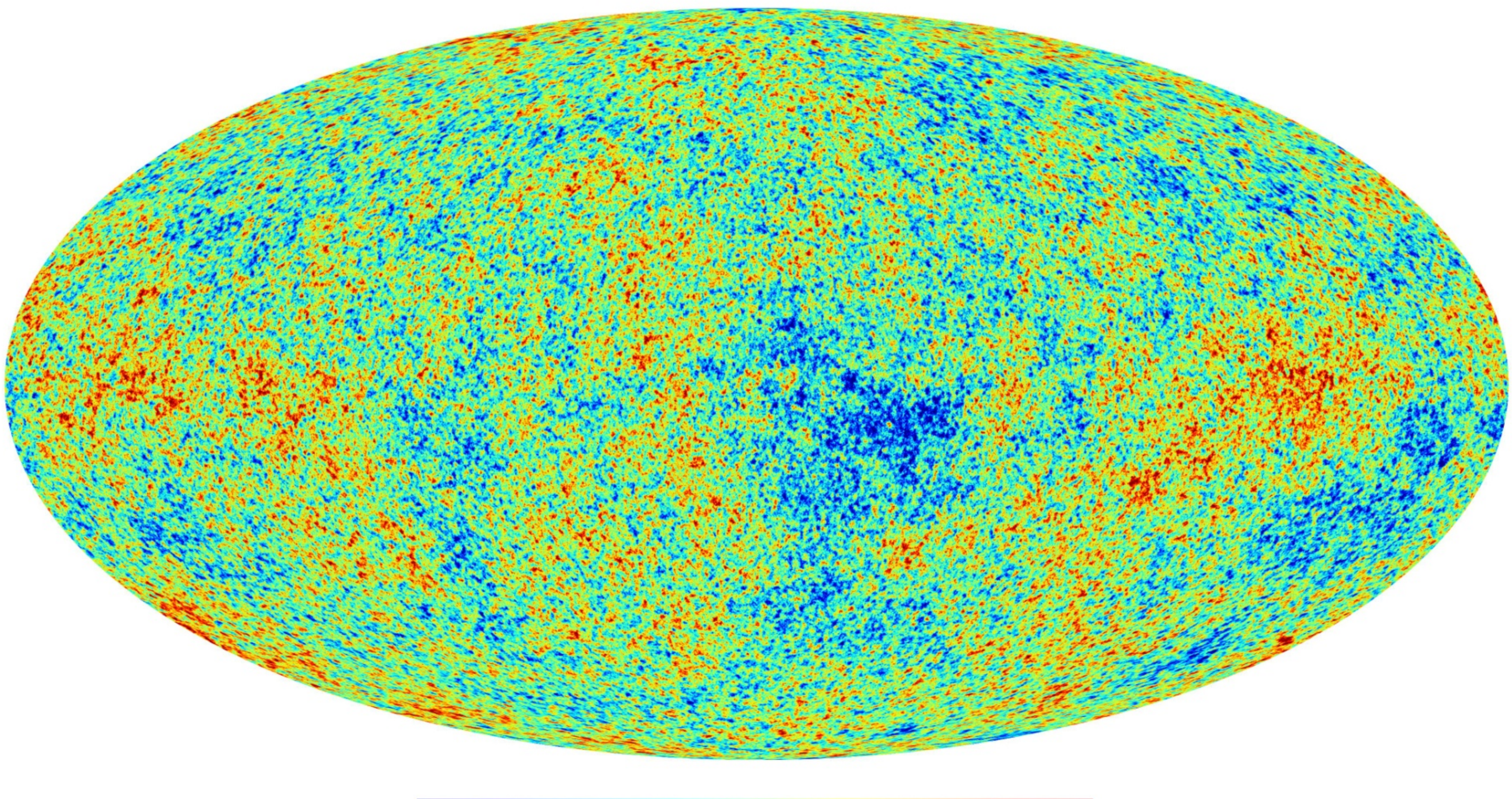
As far as we understand today, the initial conditions of the Big Bang contained quantum fluctuations. These random density variations were stretched by some 50 orders of magnitude during inflation, which took place during an unimaginably small δt from around 10^{-30} to perhaps 10^{-20} seconds after the Big Bang. Even so, the universe remained very slightly lumpy. Dark matter would have condensed out first, and collected in pockets which initiated GRAVITY DRIVEN OSCILLATIONS in the matter-radiation fluid of the universe. This is our best model for the initiation of acoustic waves in the early universe, which seeded structure formation later on.

image credit: Stephen Van Vuuren, Cardiff University http://planck.cf.ac.uk/timeline/universe/bigbang

Thus, the variations in temperature that we observe in the CMB today...

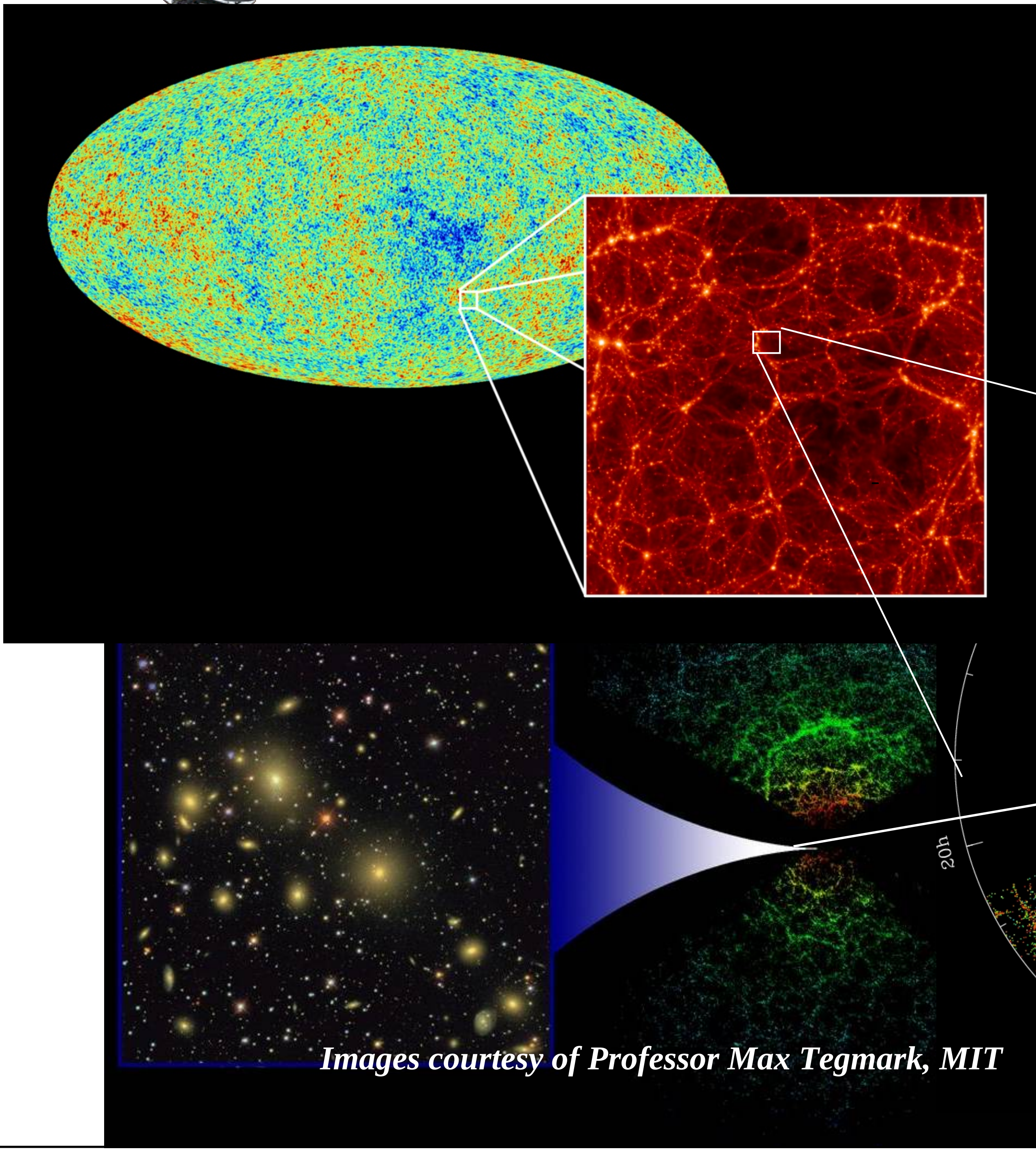
$$\boxed{\frac{\Delta T}{T} \propto \frac{\Delta \rho}{\rho}}$$

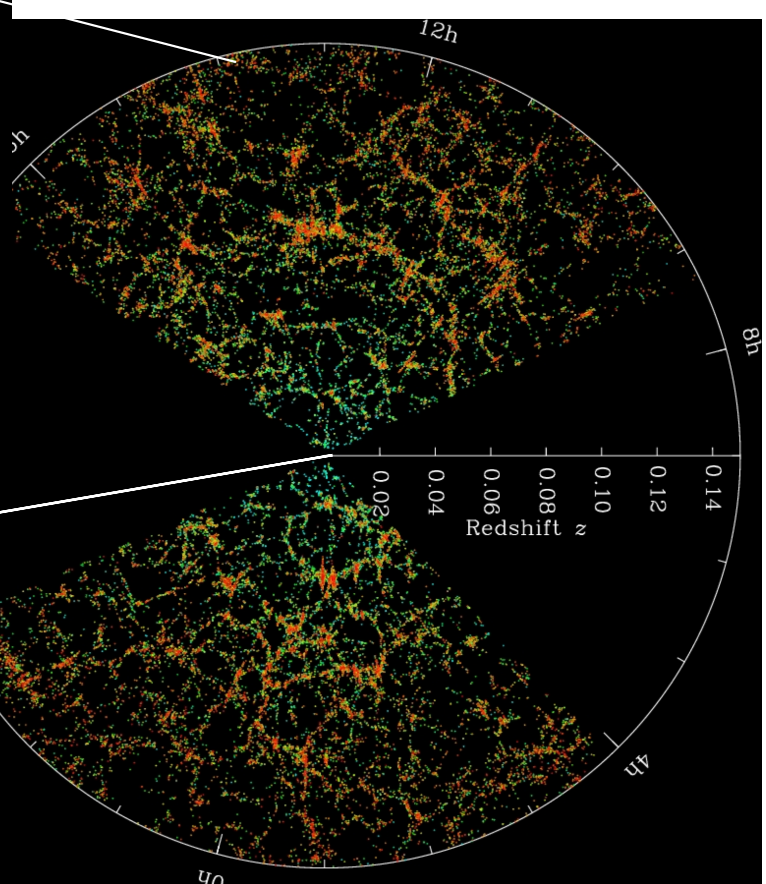
...tell us about variations in density in the early universe.



PLANCK Education and Public Outreach

Those gravity-driven pressure waves in the matter-radiation fluid of the early universe not only left their imprints in the light of the CMB; they determined the distribution of matter and energy in the universe at later times, as seen in the large-scale clusters and walls of galaxies.





Images courtesy of Professor Max Tegmark, MIT

PLANCK Education and Public Outreach

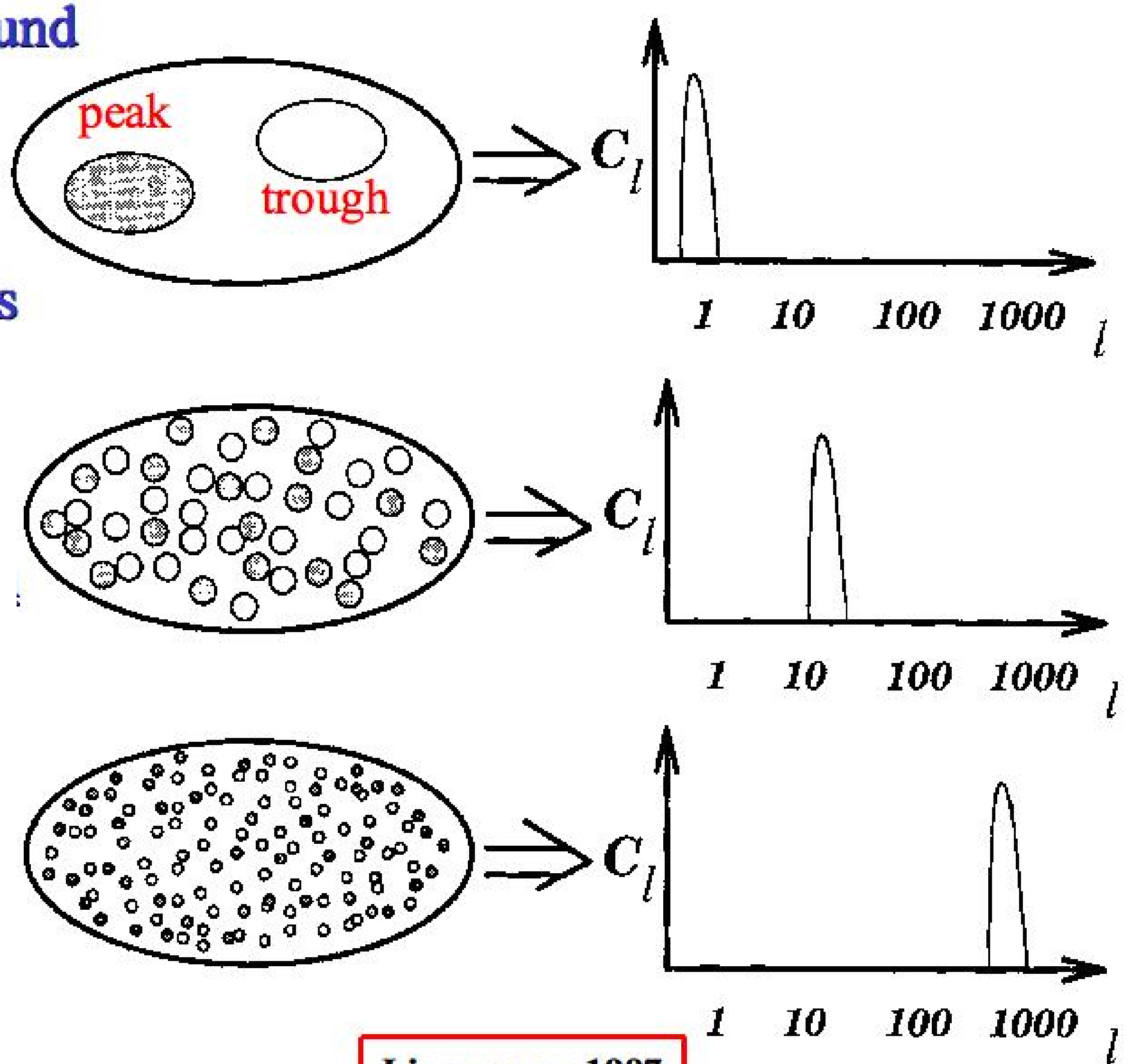
Extracting the Music of the Cosmos

Sky Maps → Power Spectra

We "see" the CMB sound as waves on the sky.

Shorter wavelengths
are smaller frequencies
are higher pitches

Using mathematical analysis techniques similar to those used by sound engineers, we get a POWER SPECTRUM of the distribution of acoustic waves on the last scattering surface – the time when matter and radiation first separated, and the universe became transparent to electromagnetic radiation.

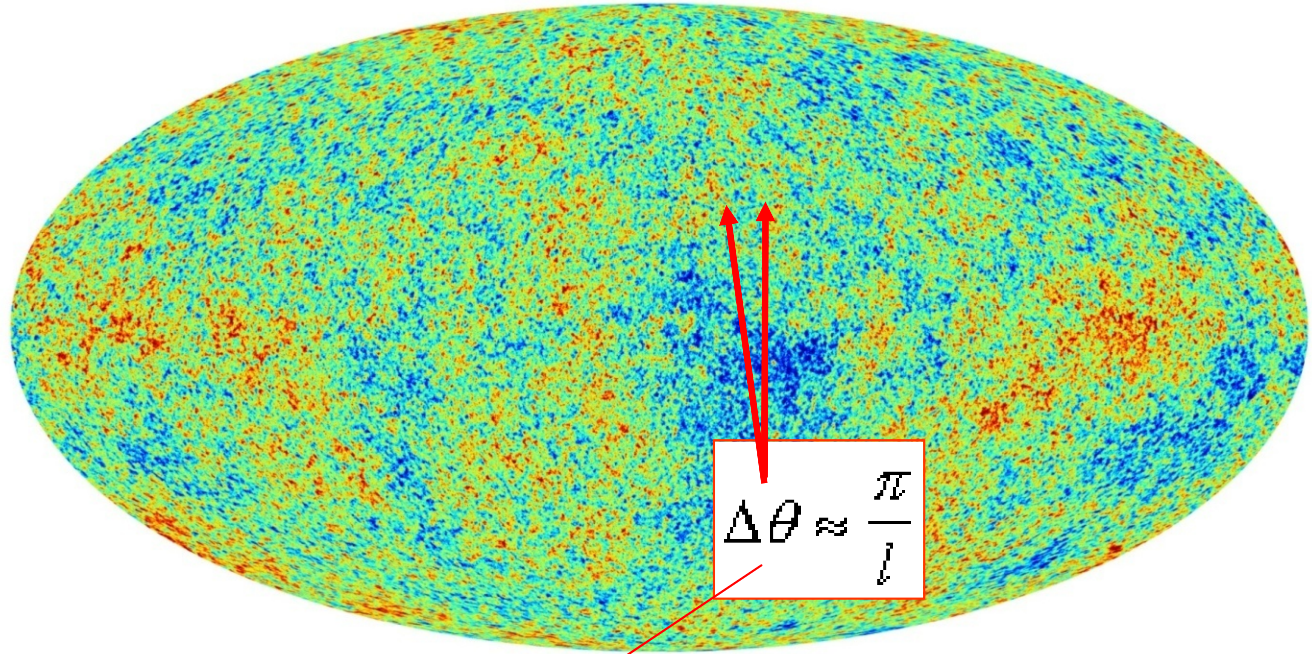


Lineweaver 1997

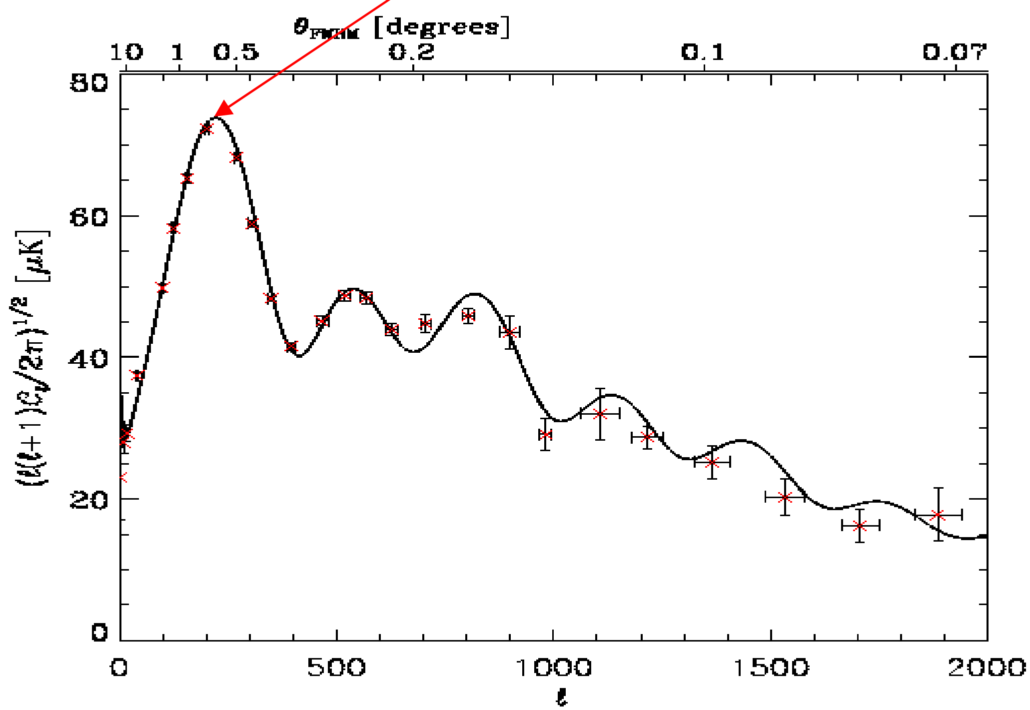
Slide courtesy of Mark Whittle, University of Virginia

PLANCK Education and Public Outreach

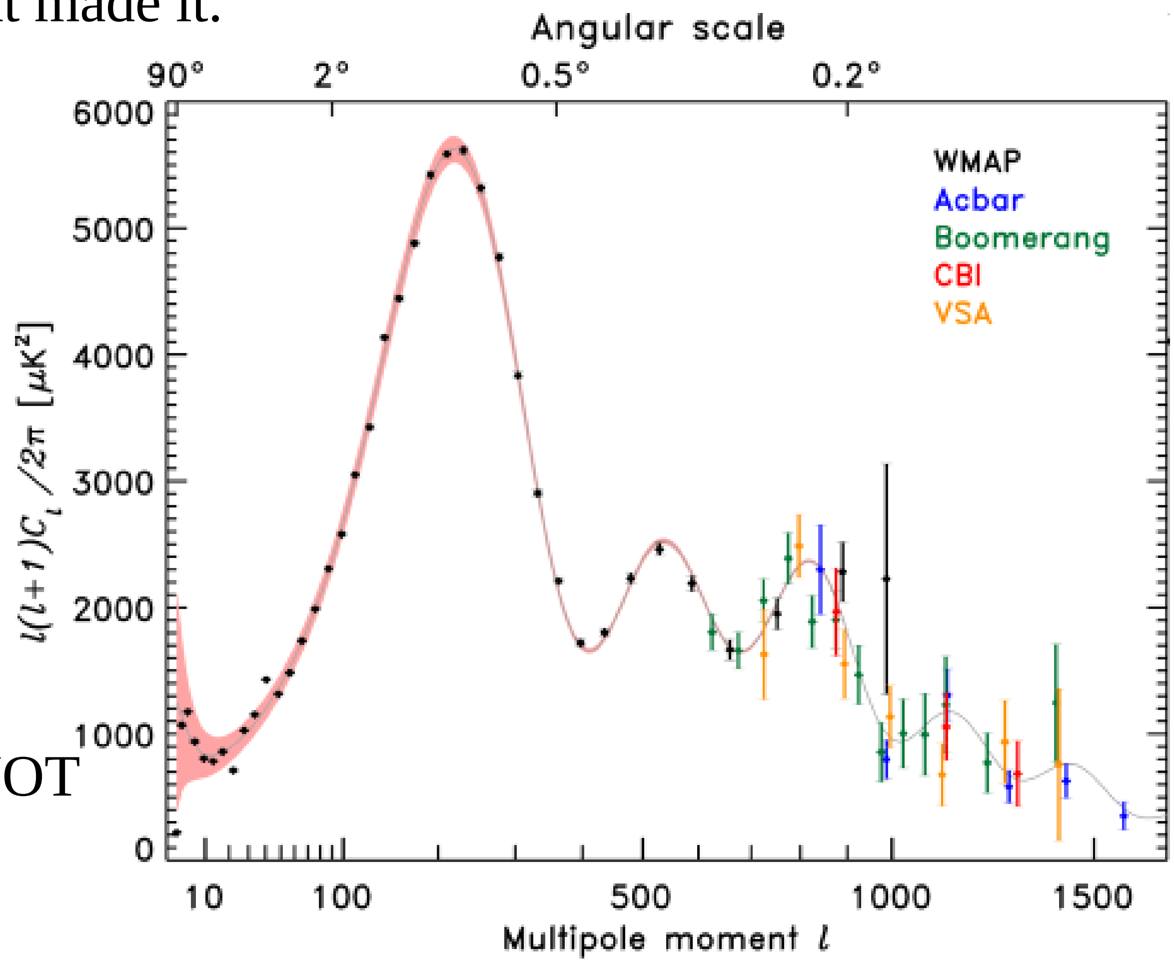
As photons scattered for the last time off these primordial acoustic waves, they underwent red or blue shifts, depending on whether they were escaping from a gravity well, or scattering off a high. The result we see as anisotropies in the temperature of space.



Anisotropies of ~1^0 in the CMB correspond to the ***horizon*** at the time when matter and radiation separated, some 380,000 years after the Big Bang. This size corresponds to the ***fundamental*** – the first peak in the CMB power spectrum.



The power spectrum contains the clues as to the physical characteristics of the universe, much as the power spectrum of a sound can tell you about the characteristics of the instrument that made it.



- From the power spectrum of the distribution of CMB temperature anisotropies, we can tell the wavelength of the fundamental and higher harmonics at the time of last scattering;

- Because the initial quantum fluctuations in the Big Bang were ***random***, the power spectrum can NOT tell us how to correlate specific temperature anisotropies in the CMB, which are at red shift 1100, with actual galaxies today, which are at very much smaller red shifts.

In the early universe:

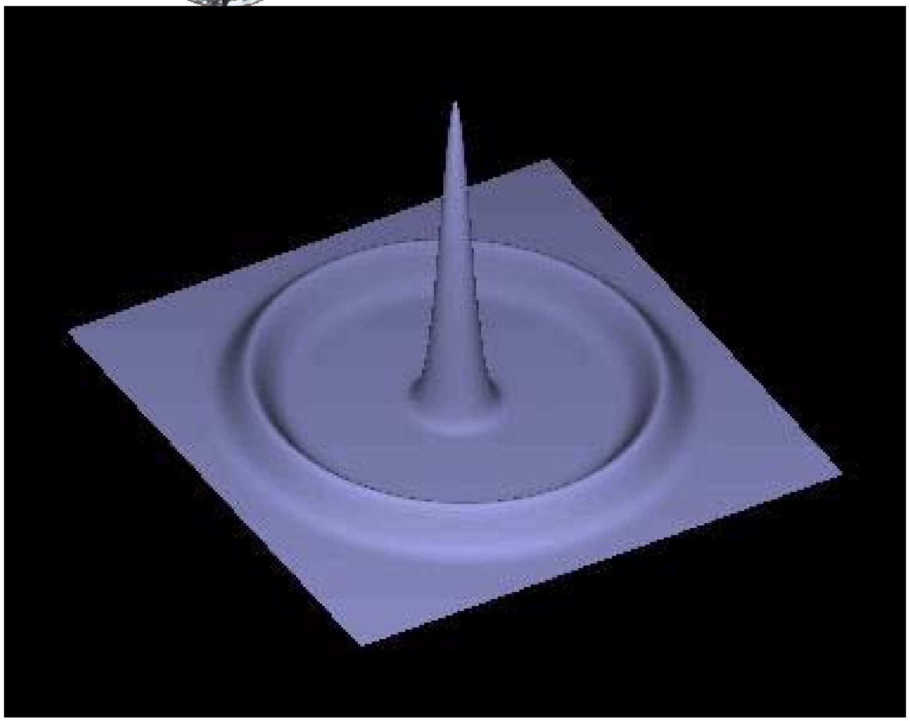
$$\boxed{v_{sound} = \frac{c}{\sqrt{3}} = \frac{3x10^{8}\, m/\sec}{1.73} = 1.73x10^{8}\, m/\sec}$$

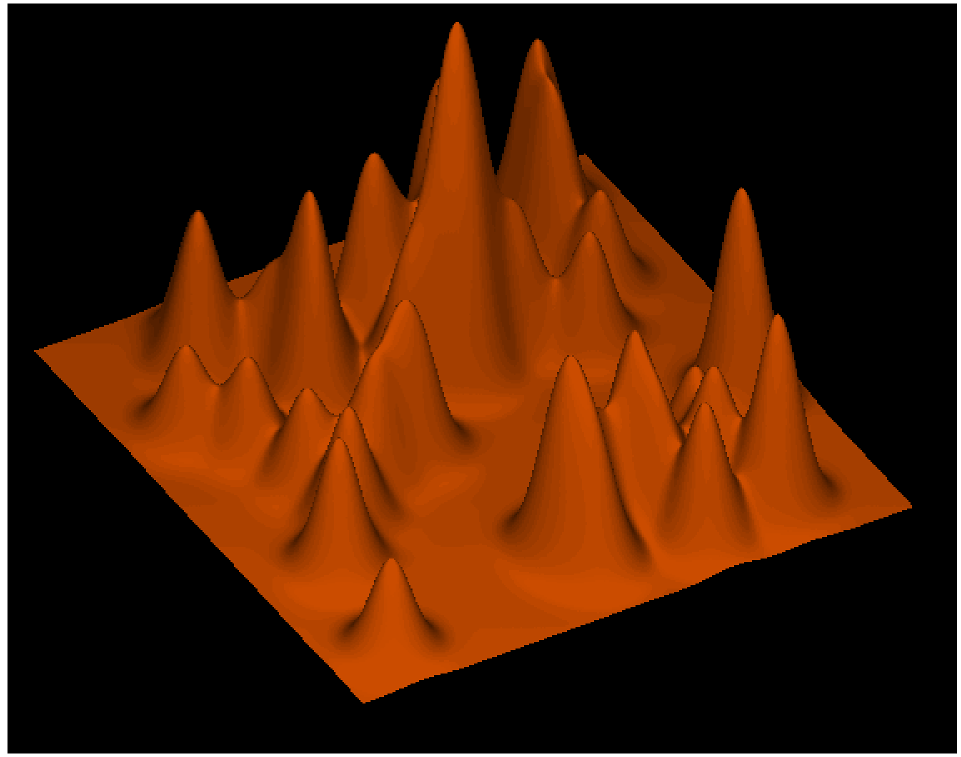
The fundamental wavelength on the CMB tells the distance that the longest wave, with the lowest tone, traveled in the first 380,000 years of the universe's existence. Converting 380,000 years into seconds, and multiplying by speed of sound gives us the approximate size of the fundamental in "real" units:

$$380{,}000\, yrs \times 3.15\times 10^{7}\,\frac{\sec}{yr} \times 1.73\times 10^{8}\,\frac{m}{\sec} = 2.08\times 10^{21}\, m$$

$$2.08 \times 10^{21}\, m \div 9.46 \div 10^{14}\, m/ly \cong 220{,}000\, ly$$

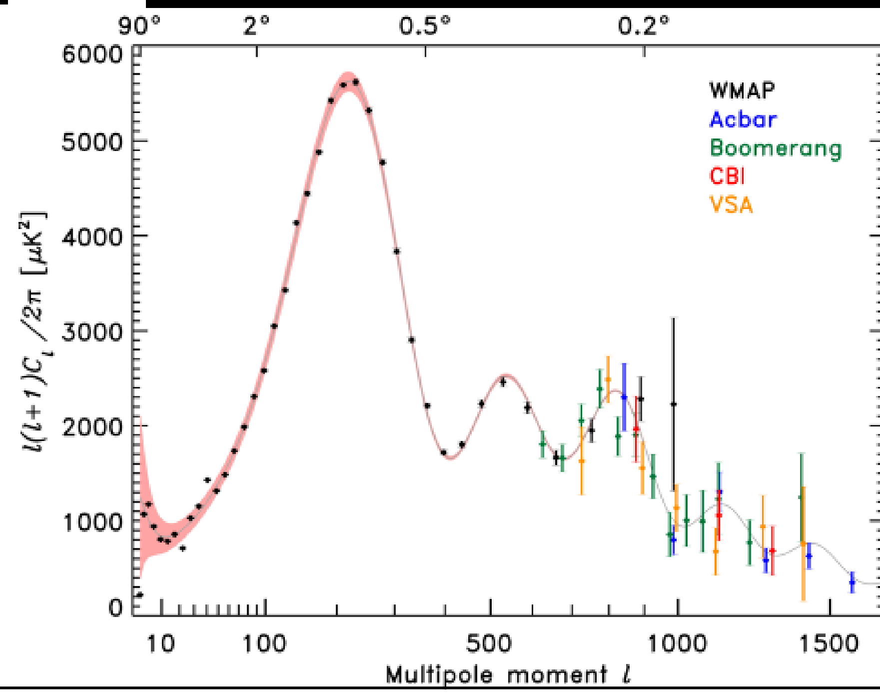
Thus, 220,000 light years is the wavelength of the fundamental 'note' of the CMB. This means 1 wave every 220,000 years!





Simulation of primordial acoustic waves – Daniel Eisenstein

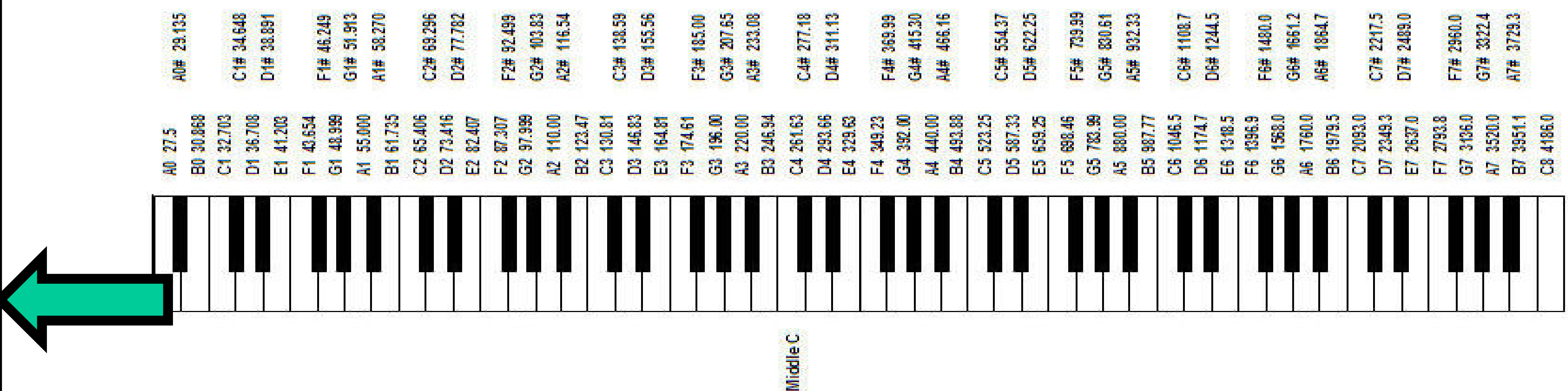
fundamental wavelength ~ 220,000 light years at the time of recombination



PLANCK Education and Public Outreach

1 wave /220,000 years, or 1 wave in 6.94×10^{12} seconds gives
$1/6.94 \times 10^{12} = 1.44 \times 10^{-13}$ Hz

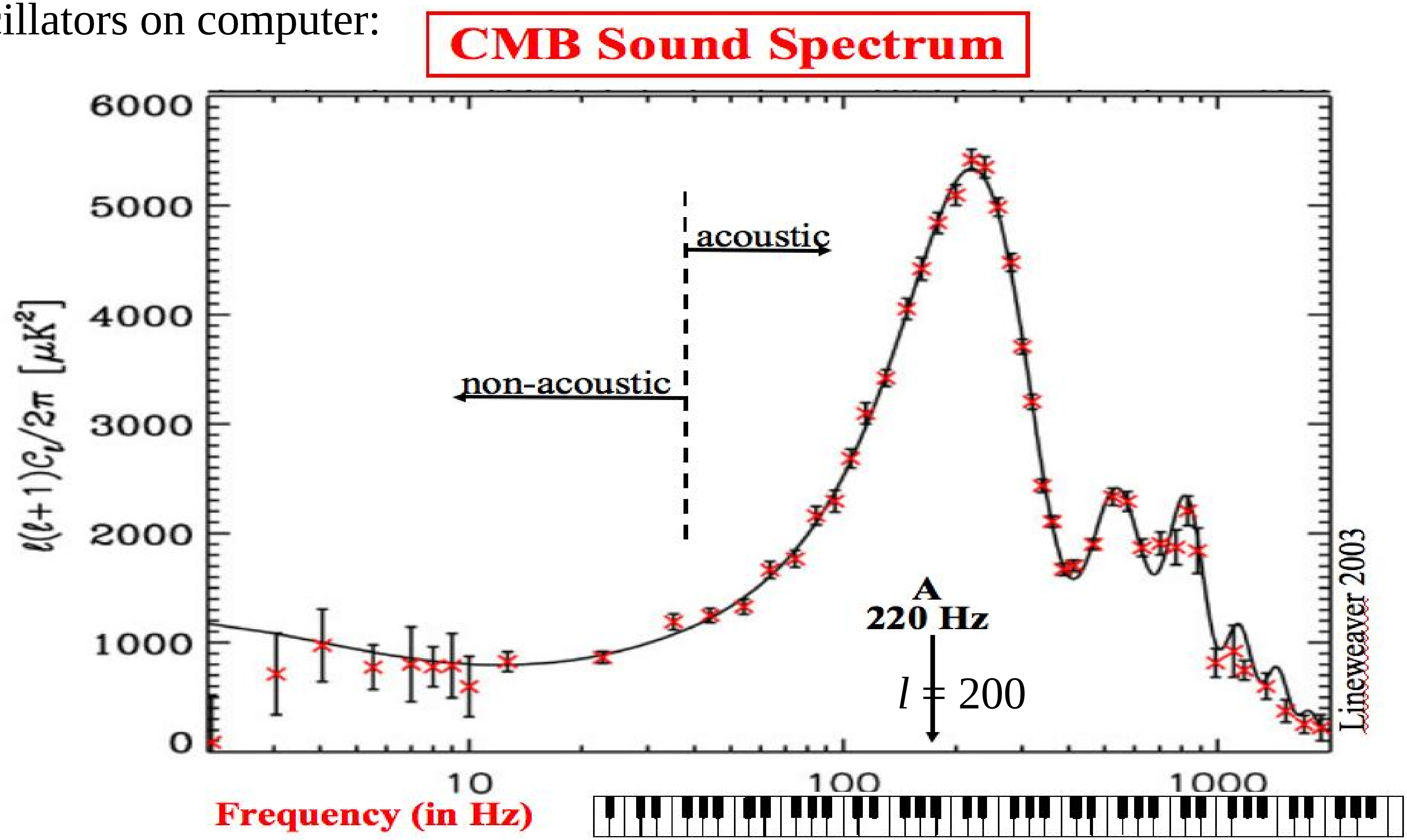
Human hearing ranges from ~ 20 Hz to 20,000 Hz, thus the fundamental tone of the universe is between 1.4×10^{14} and 1.4×10^{17} times LOWER than human hearing, or 47 octaves below the lowest note on the piano (27 Hz)



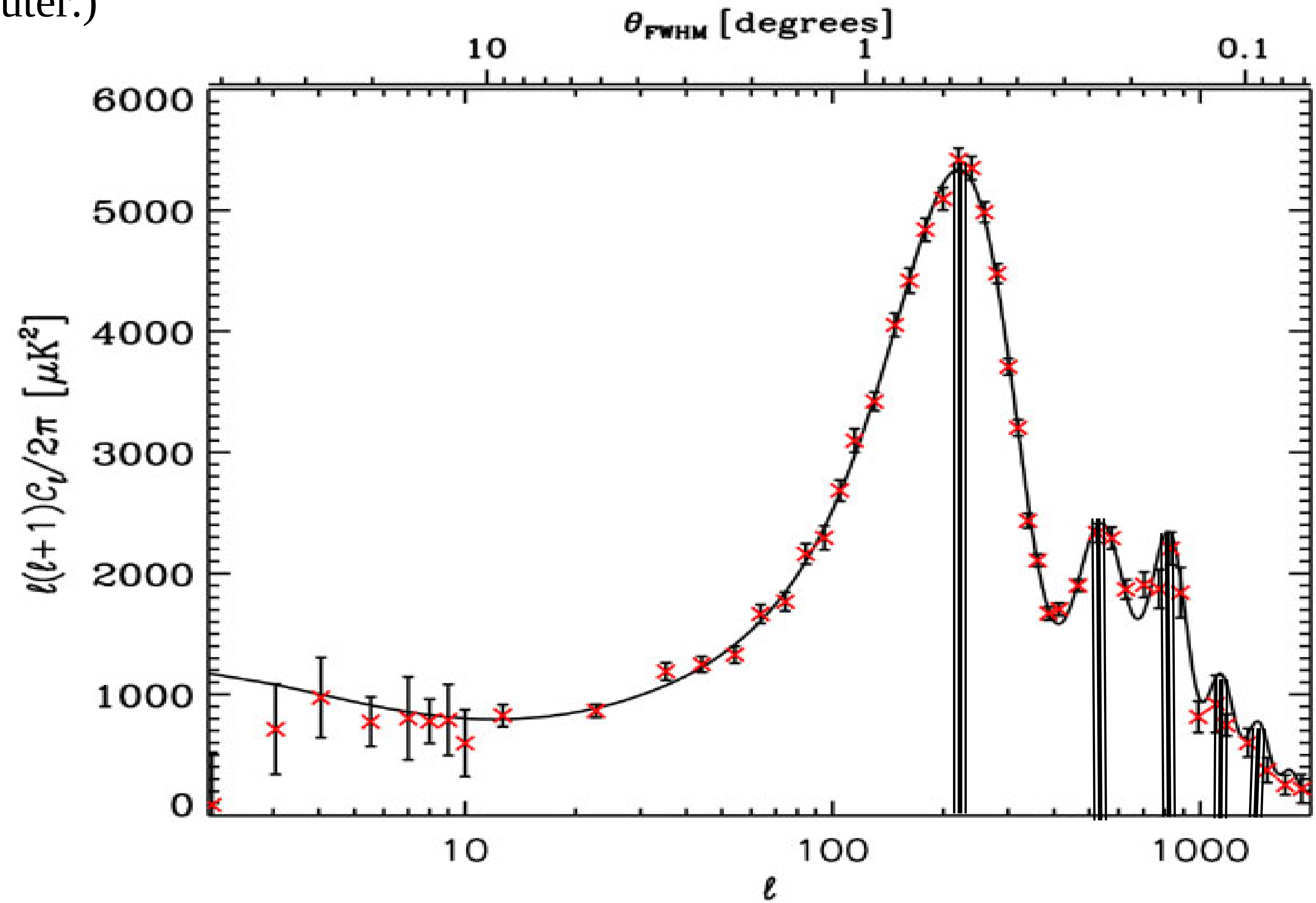
Go down 47 more octaves.

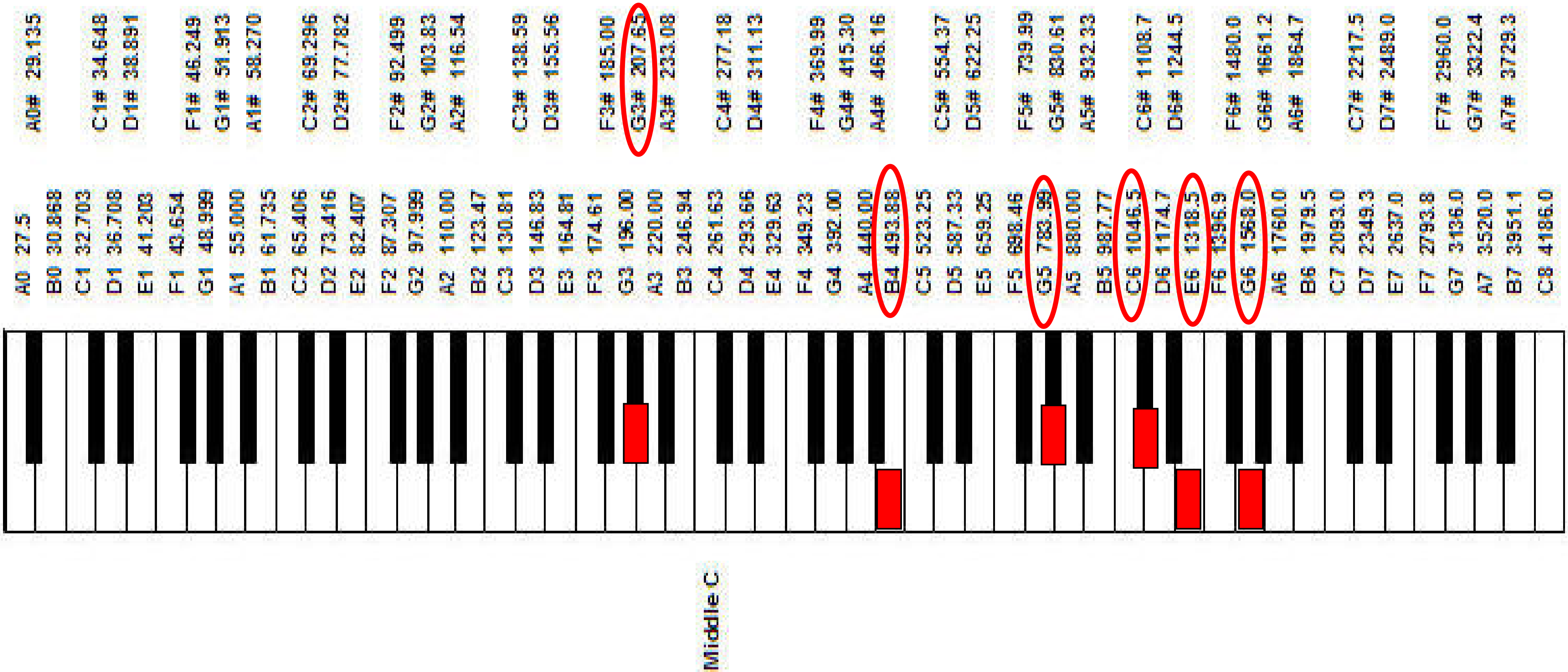
PLANCK Education and Public Outreach

…But if we simply map angular wave number to frequency, we can synthesize the sound of the CMB in the humanly audible range, from its angular power spectrum. Hear sample of synthesized sounds of the CMB from 3,000 granular oscillators on computer:



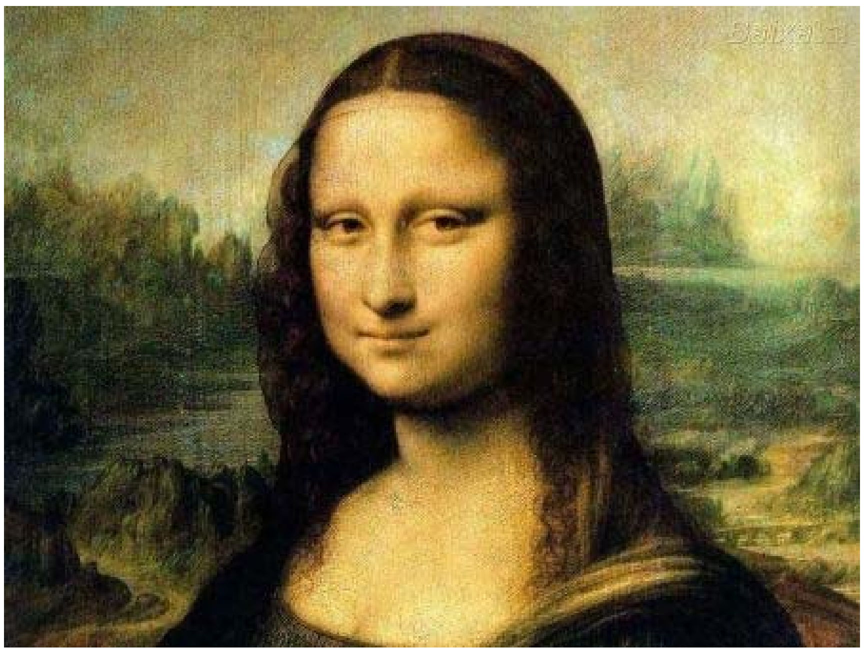
…and we can take that sound and apply a series of filters to get out the fundamental and higher harmonics, to produce an eerie sounding chord. (See computer.)



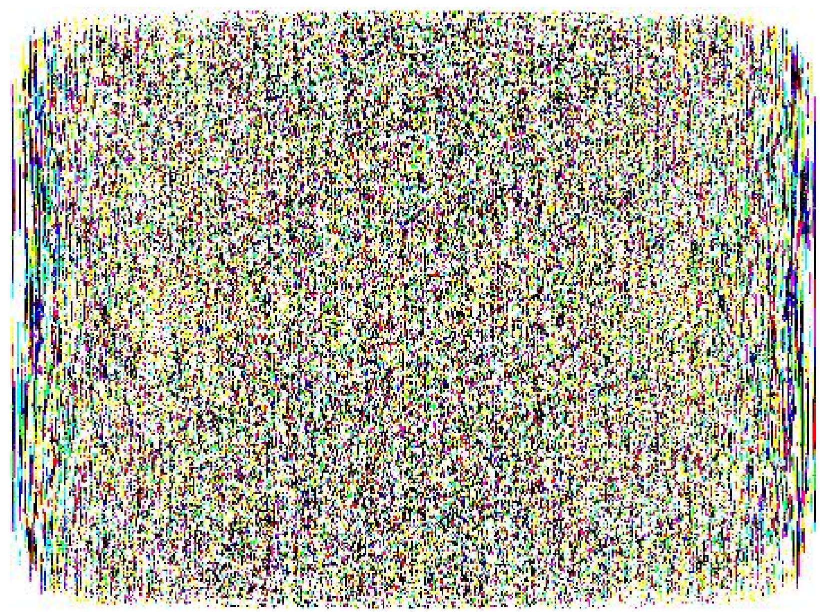


If you try to play the “cosmic chord of the CMB” on the piano, it would sound something like this…

The CMB power spectrum is the 2-D FFT (in spherical harmonics) of the temperature map, so it does not contain any phase information. Thus, to simply recreate sounds (in audible range) from the power spectrum, is a bit like taking an FFT of a picture, or a song, randomizing the phases, doing the inverse FFT, and trying to recreate the original picture or song.



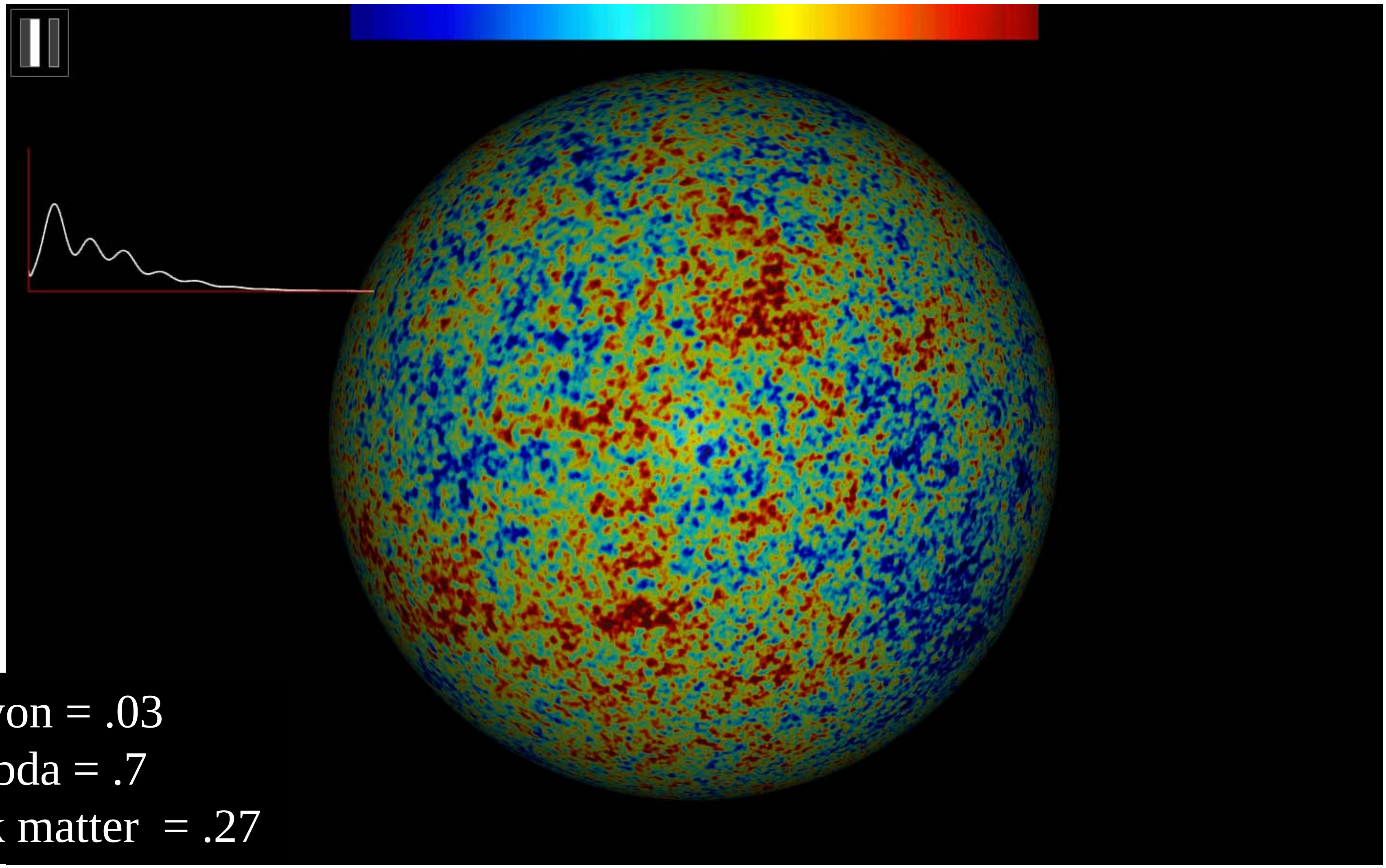
2-d FFT
Randomize the phases,
inverse FFT



Both of these images have the same Power Spectrum.

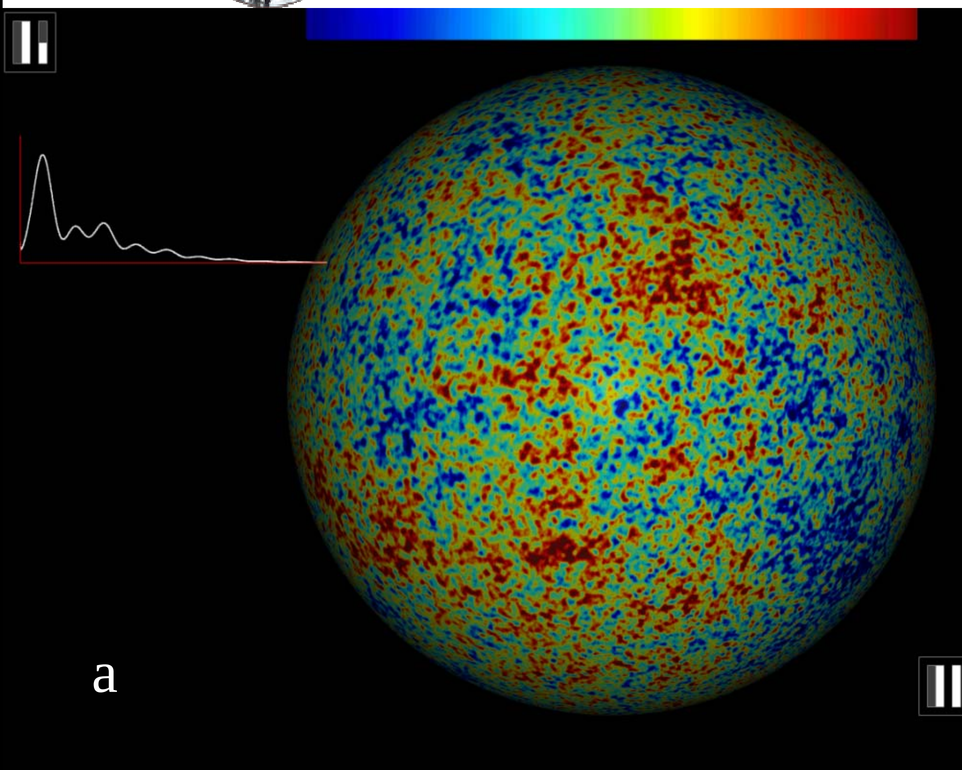
PLANCK Education and Public Outreach

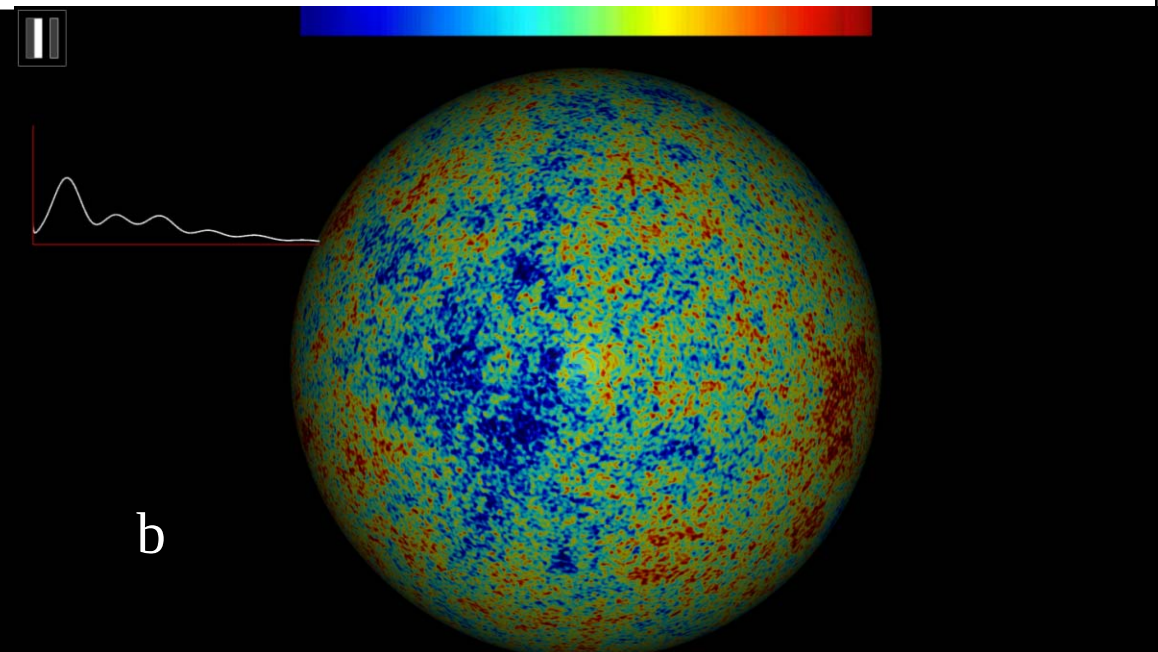
At UC Santa Barbara we are working on a project to visualize and sonify the time evolution of the matter power spectrum of the early universe before recombination, using the software CAMB. We can change the content of baryons, dark matter, and ‘lambda’ to get a different universe…



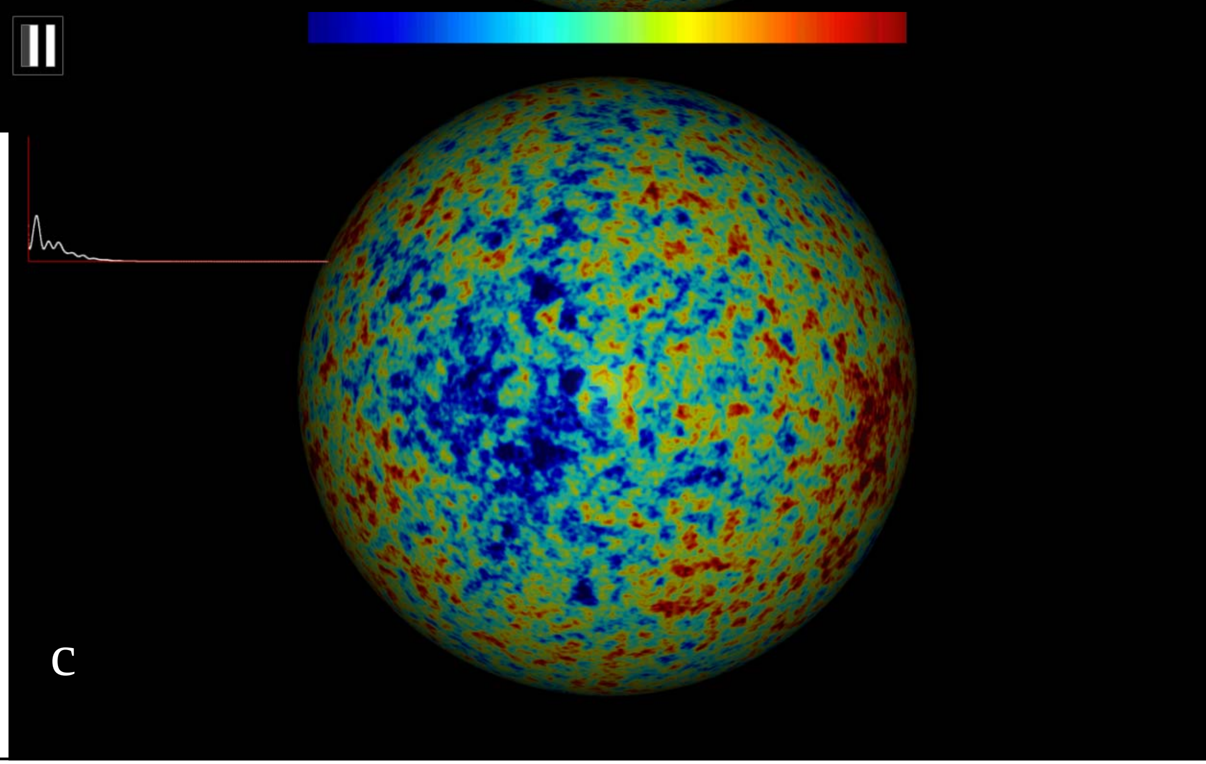
omega-baryon = .03
omega-lambda = .7
omega-dark matter = .27

PLANCK Education and Public Outreach

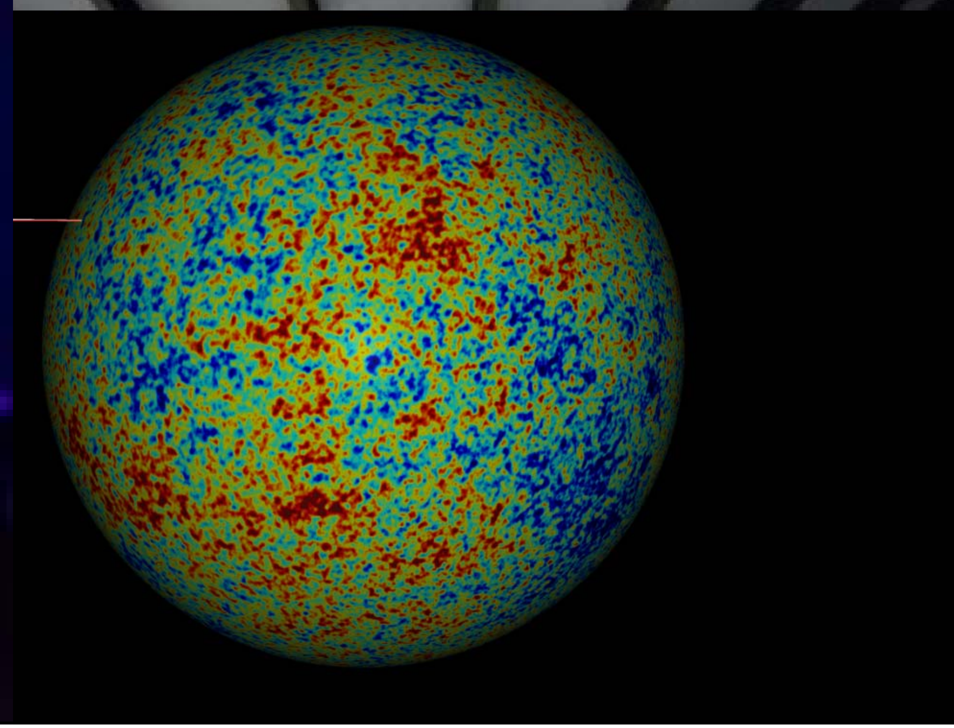




a) too much baryonic matter
b) too little lambda energy
c) too much lambda energy



…and in our big VR facility, the AlloSphere, we are developing a way to visualize and sonify the CMB and the early universe before recombination, so that we can simulate conditions in the early universe before recombination!



These simulations are very much *works in progress!*

Available during this poster session:

- View the simulation on a PC with red-cyan anaglyph glasses, complements of the Planck Mission E/PO Group
- Listen to synthesized sounds simulating the CMB
- Name that tune: listen to randomized files of known tunes
- Take home: souvenir Planck glasses and some pretty pictures

For further information: see http://planck.caltech.edu

contact: jatila@physics.ucsb.edu