Planck Visualization Project

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Photo: Herschel-Planck launch Photo credit: Charles. R. Lawrence, NASA/JPL
Planck is a Mission led by the European Space Agency, with significant participation by NASA.

Planck’s purpose is to map the Cosmic Microwave Background radiation (or CMB) - the oldest light we can detect - 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 is the third generation of satellite to map the entire sky in microwave and infrared wavelengths, after COBE and WMAP, but with unprecedented detail.
Planck E/PO Goals:

- Explain the importance of this mission in ways that the public can understand, and make them EXCITED about it even before the data are finished being collected!

- Explain why we need such sensitive instruments

- Explain how we can derive so much information about the universe from such obscure measurements* (i.e., we don’t have any pretty pictures of galaxies!)
arc-minute temperature map

angular power spectrum

structure formation!
fundamental physics!
meaning of life!
What is the CMB?

What the @#*& is a power spectrum?
And how can they tell so much from that one graph?
That’s a map of temperature? How can you see temperature?
Yeah, and I thought that outer space was black!
What is the Cosmic Microwave Background, or CMB?

The CMB 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 – free electrons and protons.
Understanding the minute temperature fluctuations in the CMB is important because it tells us about variations in density in the early universe which gave rise to the large scale structure we see in the universe today.

Images courtesy of Professor Max Tegmark, MIT
In order to make such determinations, Planck has two sets of ultra-sensitive detectors, which measure the temperature of space in 9 different frequency bands, with a sensitivity of a few millionths of a degree! This is why some of them are kept at temperatures colder than space itself!

**HFI (High frequency Instrument):** an array of microscopic temperature sensors called *spider web bolometers*, cooled to 0.1 K.

**LFI (Low frequency Instrument):** an array of radio receivers using high electron mobility transistor mixers, cooled to 20 K.
Planck’s resolution is said to be equivalent to being able to resolve a bacterium on top of a bowling ball, and its sensitivity has been compared with detecting the heat output of a rabbit in space, at the distance of the Moon, by a person standing next to the detector on Earth (neglecting atmospheric attenuations).
E/PO Tools:

Web pages, press releases, videos, podcasts, vodcasts, animations, etc...

Animation by Christophe Carreau, ESTEC
Music by Richard Strauss
1. Interactive Simulation of the Planck Mission Designed for Virtual Immersive Spaces ... but which also run on PCs, and which will run on Macs

2. Understanding how we derive information from the Power Spectrum of the CMB through Music

3. Visualization and Sonification of the CMB and universe prior to recombination in Virtual Immersive Spaces
Planck Interactive Immersive Simulation

Controlled from a flight simulator screen...
...the user can explore the mission from launch...

...to orbital insertion...

to data gathering operations...

from any vantage point in the solar system.
3-D option for the PC
Hi-tech visualization facilities:

- VR facilities
- Planetaria
- Virtual Classrooms

Museums and Science Centers

- Thousands of potential sites!
- DVDs for Museums and mass dist.
- Kiosk interactive display
- Passive viewing as movie

Web Distribution

- Download, single computer
- Interactive served application
- Computers in classrooms

Popular Culture

- iPhone application
- Google Universe
- Screen savers

Available in a variety of 3-D technologies, from simple anaglyph to high-tech varieties.

Currently still in development. If you want a copy, ask me or send email to jatila@physics.ucsb.edu.

Demo/play session after lunch

PLANK
Education and Public Outreach

Distribution goals:

- Thousands of potential sites!
- DVDs for Museums and mass dist.
- Kiosk interactive display
- Passive viewing as movie
"Listening" to the Oldest Light of the Universe

Understanding how we extract information about the Universe from the Power Spectrum of the CMB through Music

CMB Sound Spectrum

Frequency (in Hz)

220 Hz
a few milliseconds of time delay

13.7 billion years of time delay!
The variations in temperature that we observe in the CMB ... 

\[ \frac{\Delta T}{T} \propto \frac{\Delta \rho}{\rho} \]

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

Variations in density:
- Dark matter creates gravity wells
- Baryons fall in
- Radiation pressure pushes out

HARMONIC OSCILLATIONS

animation by Wayne Hu, University of Chicago
Pressure waves in a fluid are mechanical waves, just like sound waves that we can hear!

So we can use techniques from MUSIC to analyze the CMB.
In a nutshell:

Resonating systems have a fundamental and higher harmonics which are the frequencies at which they naturally vibrate.

The wavelength of the fundamental is determined by the size of the instrument and the speed of sound waves that travel from one end to the other.
The larger the resonating system, the lower the tones it can produce.
A power spectrum tells you what frequencies are present in a sound.

Pure tone played on a computer with a frequency of 440 Hz:

*Looks and sounds different when played on a clarinet:*
Systems occurring in Nature also have natural resonant frequencies, such as the Sun, but with MUCH longer wavelengths, here scaled to the human hearing range.

Source: bison.ph.bham.ac.uk/
The CMB represents the last time that light scattered off the acoustic waves of the early universe, thus the power spectrum of the CMB contains the information that can tell us about the characteristic properties of the Universe...
Just as the power spectrum of the last dying chord
( ~ 2 ms )

... contains the harmonics that tell you
the characteristic properties of this instrument.
Anisotropies of $2^0$ and smaller in the CMB correspond to the fundamental and higher harmonics in the power spectrum of the CMB.
Converting meters to light years, we get:

\[ 2.08 \times 10^{21} \text{ m} \div 9.46 \div 10^{14} \text{ m/ly} \approx 220,000 \text{ ly} \]

Could any living creature hear a sound wave with a wavelength of 220,000 light years?
The lowest frequency that humans can hear is around 20 Hz, slightly lower than the lowest note on a piano (27 Hz).

So the answer is NO. The lowest note of the universe is $20 / 1.44 \times 10^{-13}$, or $1.88 \times 10^{14}$ times LOWER than the lowest note humans can hear, or 47 octaves below the lowest note on a grand piano!
Scaled up by around 50 octaves, the CMB would sound something like this:
Amplitude of temperature anisotropies scaled to units of micro-Kelvin^2 vs frequency (in Hz). The graph shows two distinct regions: acoustic and non-acoustic. The acoustic region is marked at 220 Hz. The figure is adapted from the website of Mark Whittle, University of Virginia.
Scaled up into the range of human hearing, and cleaned up using Fourier analysis, we can make out the fundamental and higher harmonics of the CMB:
Changing the properties of the universe would give it a different power spectrum...which would sound different.
The Virtual Universe: Visualization and Sonification of the Early Universe

Interactive, Immersive Simulations of the Early Universe based on the Power Spectrum of the CMB

Under development at UC Santa Barbara
PIs: Jatila van der Veen, Philip Lubin, Department of Physics;
JoAnn Kuchera-Morin, Director of AlloSphere
Lead Programmers: Wesley Smith, Basak Alper
Matt Wright, project manager of the AlloSphere
We are working on a way to model the CMB and evolution of the universe prior to recombination in the AlloSphere facility at UCSB. When completed, our visualizations will be made available to planetaria and any VR facilities that request them, and for individual computers.
Goal:

CMBFAST

power spectrum

temperature map

project in AlloSphere

map in Sound and Visualization

work backwards

to Big Bang

User can change parameters within a pre-determined range, then fly around inside the universe before recombination!
Now we understand!

What the @#*%& a power spectrum is...
And how they can tell so much from that one graph...
And what that multicolored map of space means...

But I’m still not sure of the meaning of Life...
All of these are Works In Progress.

Informal session this afternoon for anyone who wants to play with the Planck Mission Simulation and play with more sounds and power spectra!

Slides will be on the dotAstronomy website in pdf format. Email me if you want the complete set of sound files:

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