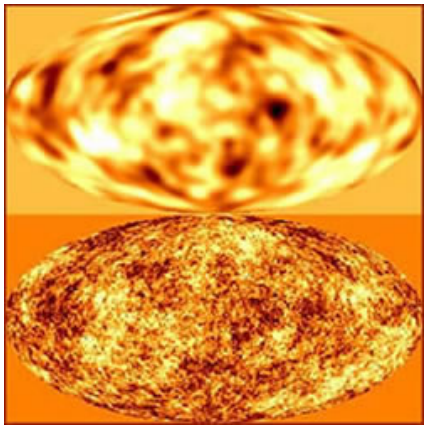
Simulating a Map of the Cosmic Microwave Background: What the Planck Satellite Will See

In the year 2007, the European Space Agency, with substantial NASA participation, will launch the Planck satellite on a mission to map the cosmic microwave background (CMB), the remnant radiation believed to be an echo of the Big Bang that started the universe. Planck is designed to map CMB temperature and polarization fluctuations with unprecedented resolution and sensitivity, but the enormous volume of data this will generate poses a major computational challenge. Can such a mountain of data be efficiently processed?

Affirmative.

Lawrence Berkeley National Laboratory researchers led by astrophysicist Julian Borrill of the Computational Research Division (CRD) have achieved a significant milestone by processing an entire year's worth of simulated Planck data at the single most CMB-sensitive frequency, producing a high-resolution CMB map in just two hours. Using NERSC's Seaborg supercomputer, the researchers ran their data on 6,000 of Seaborg's 6,080 processors at once, mapping 75 billion observations to 150 million pixels. The run was the first ever to use virtually all of Seaborg's computing processors on a single code.



These CMB maps show the 1992 COBE satellite's angular resolution of 7 degrees (top) compared to a simulation of the 5 to 10 arc-minute resolution expected from the Planck satellite (bottom).

"We've shown that we can make maps even with the volume of data we will get from Planck," says Borrill. "There's no computational show-stopper to prevent us from working with the necessary resolution and accuracy. We'll be able to make CMB maps from the Planck data that astronomers will be able to use for science."

The map was featured on a poster presented at three recent scientific conferences: the Zeldovich-90 International Conference on Cosmology and High Energy Physics held in Moscow in December 2004, the 205th meeting of American Astronomical Society in San Diego in January 2005, and the Planck Consortium meeting in Munich in January.

Collaborating with Borrill on the project were Radek Stompor of CRD and Christopher Cantalupo of the Space Sciences Laboratory at UC Berkeley, where Borrill and Stompor also hold appointments. The three colleagues give much credit to the staff at NERSC, who helped shepherd them through all the potential bottlenecks of running 6,000 processors simultaneously.

The Planck satellite, named for Max Planck, the father of quantum theory, is designed to provide enough data to yield full-sky maps in eight frequency bands in the microwave regime between 30 and 857 gigahertz (billions of cycles per second). Such maps would boast an angular resolution of 5 to 10 arc minutes and a sensitivity of a millionth of a degree. (An arc minute is a 60th of a degree; the width of the sun or the full moon viewed from Earth is about half a degree.)

To produce these maps from the Planck data, Borrill and his colleagues have developed software called MADmap, which stands for Microwave Anisotropy Dataset map-maker. MADmap capitalizes on massively parallel computational capabilities to create millions of pixels from billions of observations.