

# Planck @ NERSC

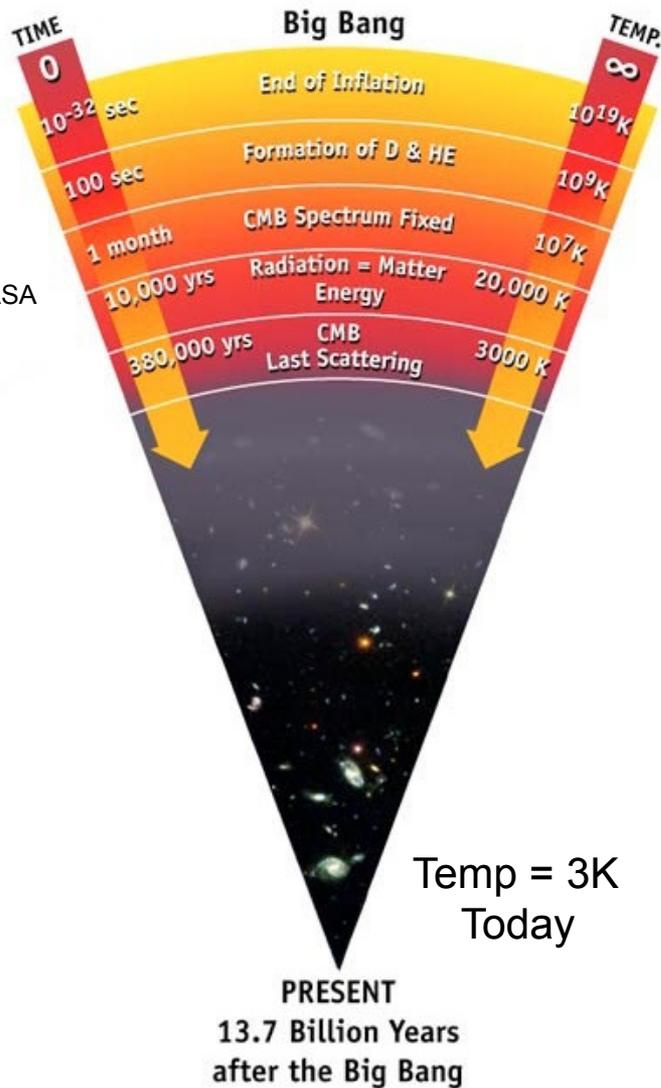
Theodore Kisner  
Computational Cosmology Center, LBNL

On behalf of the Planck collaboration



# The Cosmic Microwave Background

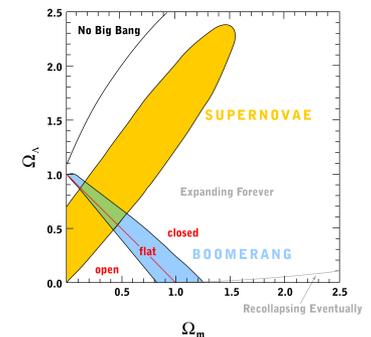
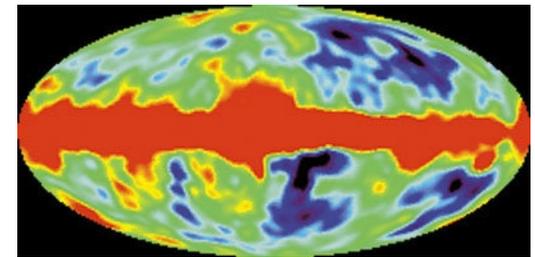
Source: NASA



- Universe begins with hot Big Bang and then expands and cools.
- After 370,000 years temperature drops to 3000K.
- $p^+ + e^- \Rightarrow H$  : Universe becomes neutral & transparent.
- Photons free-stream to observers today. They are redshifted and appear as a 3K blackbody.

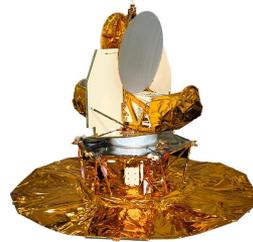
# CMB Science

- Existence is a pillar of Big Bang theory
  - Penzias & Wilson (Nobel, 1978)
- Tiny fluctuations encode the fundamental parameters of cosmology & high energy physics (COBE)
  - Mather & Smoot (Nobel, 2006)
- CMB results complement other cosmology probes
  - Perlmutter, Riess & Schmidt (Nobel, 2011)
- Planck combined with future Large-Scale Structure experiments (DES/DESI/LSST/Euclid) will probe the nature of Dark Energy

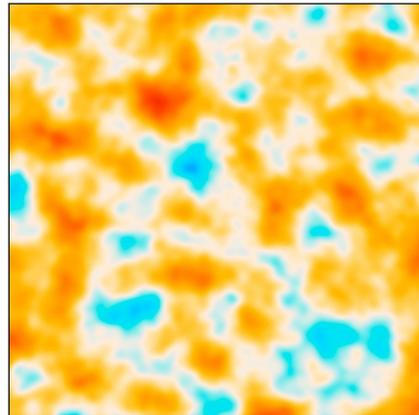


# CMB Satellite Missions

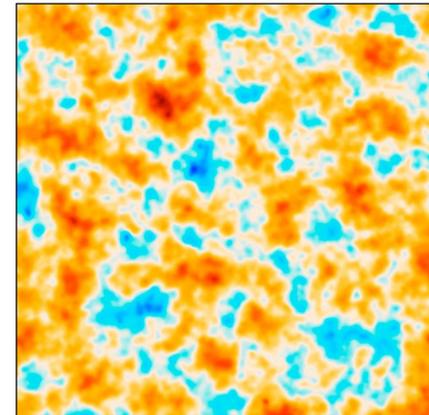
Since COBE, the race has been on to measure the fluctuations of the CMB in both intensity and polarization at higher resolution and signal-to-noise ratio.



COBE

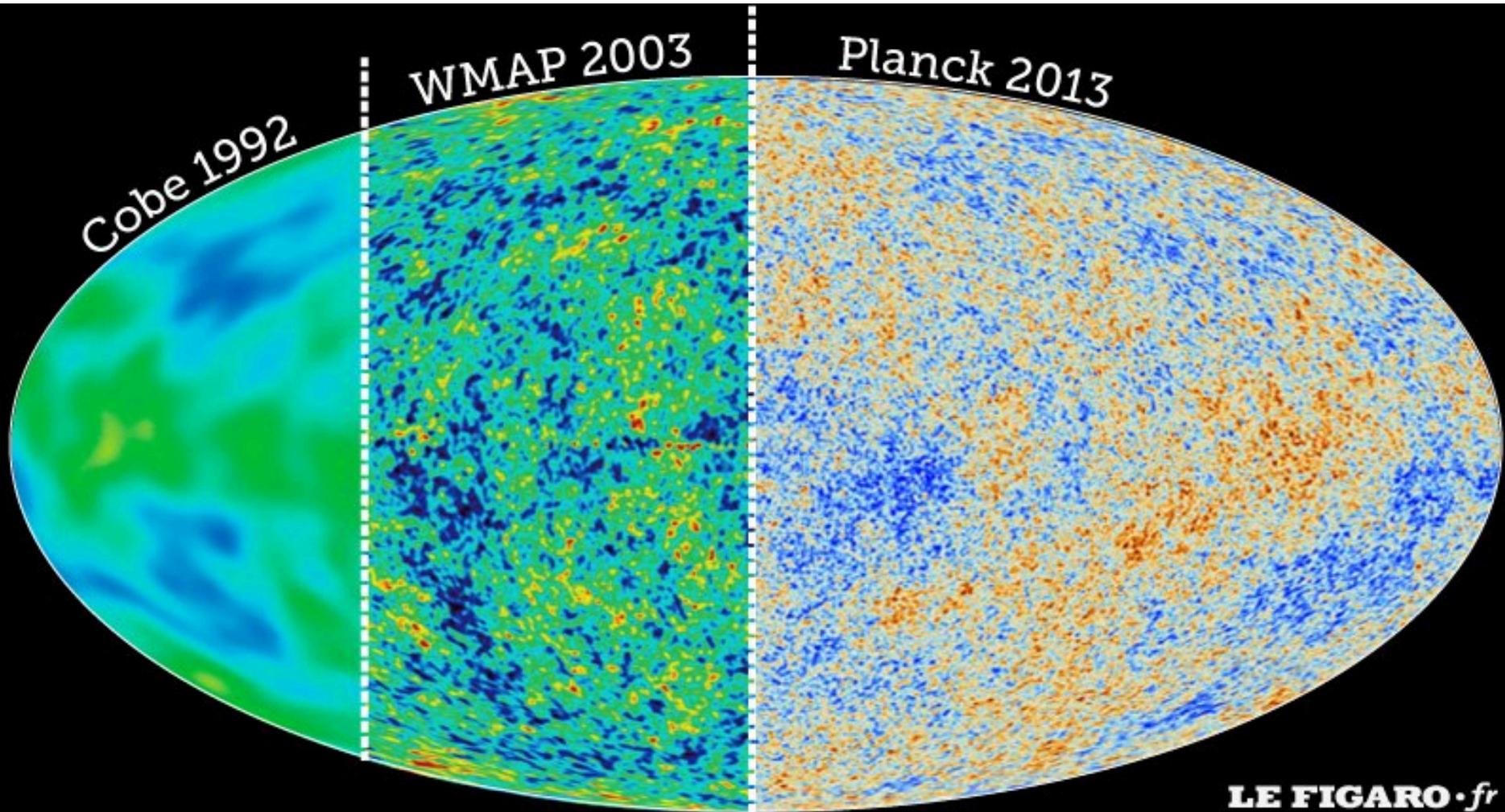


WMAP



Planck

# CMB Satellite Missions



# CMB Data Analysis

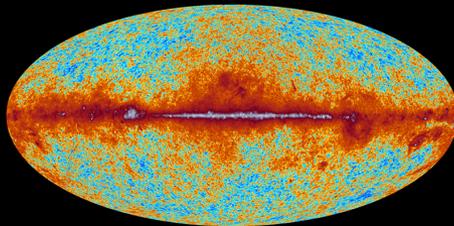
- Fainter signals and higher resolution require more data
  - COBE:  $10^9$  detector time samples
  - WMAP:  $10^{11}$  detector time samples
  - Planck:  $10^{12}$  detector time samples
  - Stage-IV CMB:  $10^{15}$  detector time samples
- Detector data is reduced into an image on the sphere (scales linearly with time samples)
- From this image, we want to estimate properties of the universe
- Making one image (from the collected data) is “easy”, but does not provide a full estimate of the uncertainties due to instrumental noise and other effects.

# CMB Data Analysis

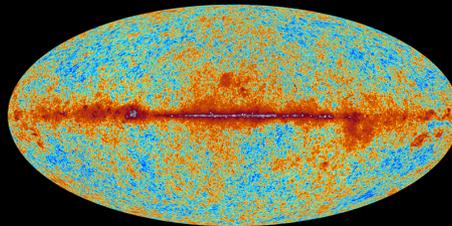


planck

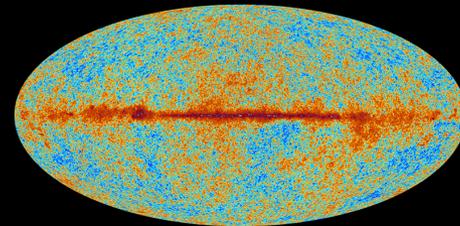
*The sky as seen by Planck*



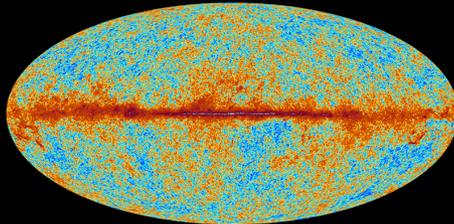
30 GHz



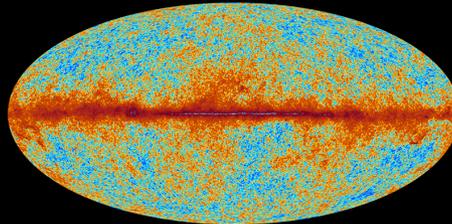
44 GHz



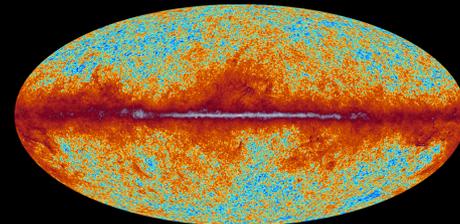
70 GHz



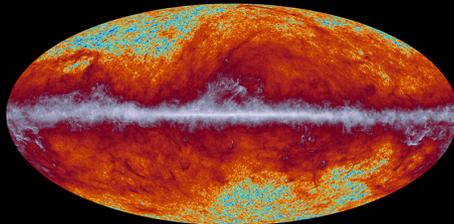
100 GHz



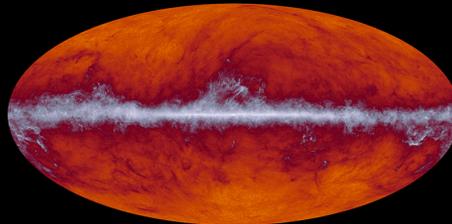
143 GHz



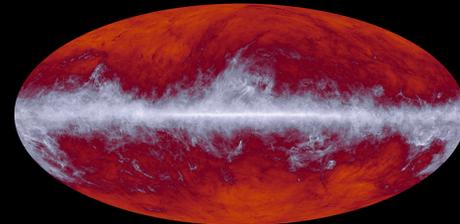
217 GHz



353 GHz



545 GHz



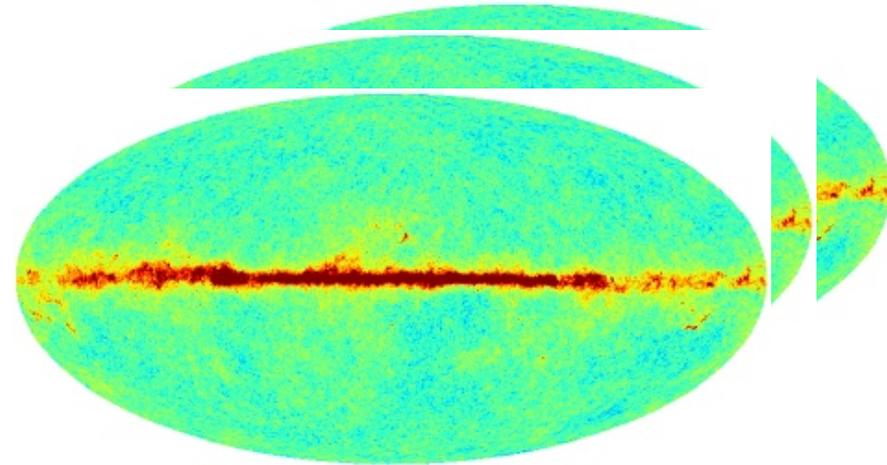
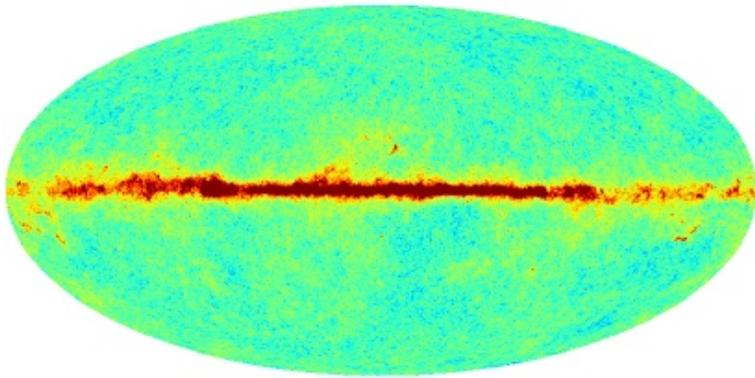
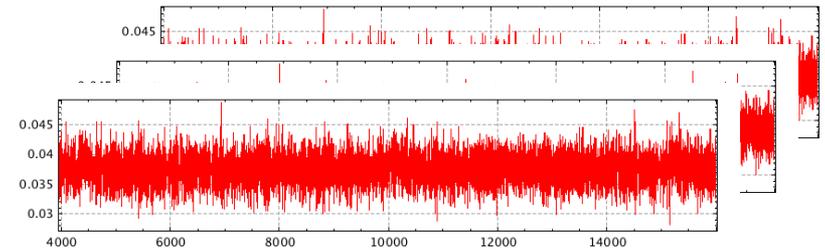
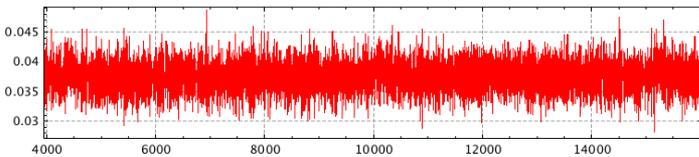
857 GHz

# CMB Data Analysis

Quantifying uncertainty (with Monte Carlo techniques) is the ***dominant cost*** of the entire analysis

$O(1000)$  Simulated Data

Real Data



Cosmological Parameters

NERSC User Group Meeting 2014

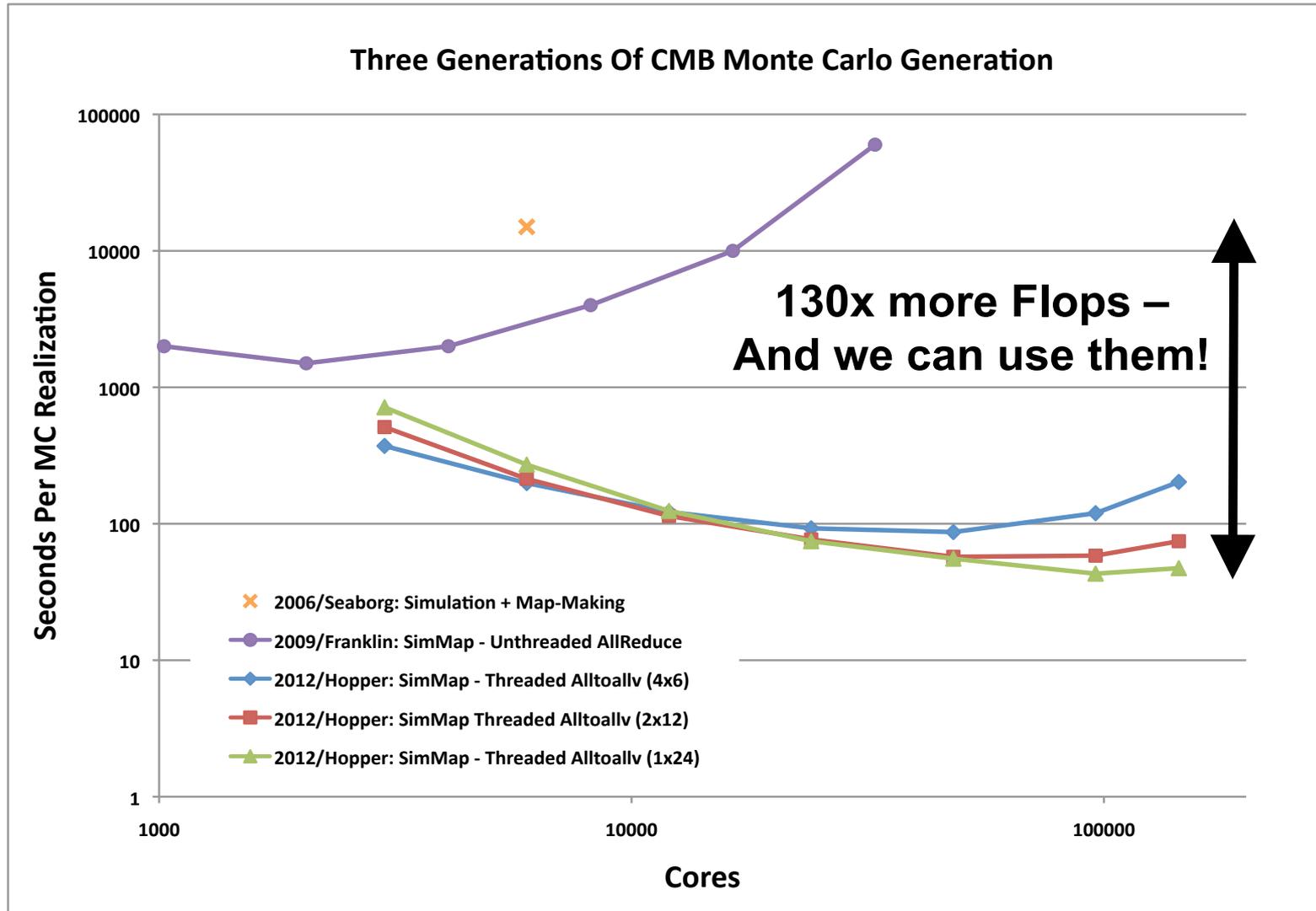
# NERSC is a Mission Critical Resource

- Reliability: both uptime and planned upgrade cycles
  - Planck work spans more than a decade at NERSC
- User Support: highly skilled (to help with our specific problems), and high availability (24/7) for our international collaboration.
- Project support:
  - Good baseline resources and ability to buy additional levels of support
  - Priority boosts for fast turnaround at working meetings
  - Early access to new facilities for “power users”

# Planck NASA / DOE M.O.U.

- Signed in 2007, renewed in 2010
- DOE guarantees an annual NERSC/HEP allocation for the mission lifetime:
  - sets minimum level, request/receive much more!
- NASA provides:
  - FTEs to ensure efficient use of these resources
  - funds for exceptional levels of service
    - 32TB => 100TB NGF
    - planck cluster => cabinet of Carver
- Provides a model for large-scale, interagency collaboration

# Planck Map Making Performance

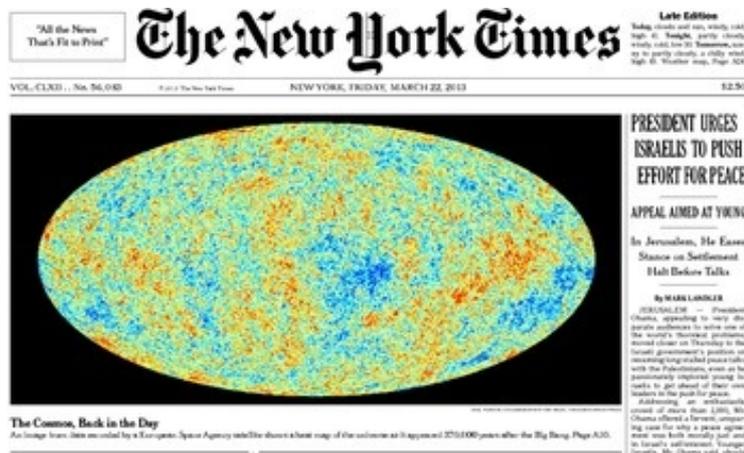


# Scientific Impact

- Running our tools at NERSC, we have
  - 1000 realizations of the Planck mission – CMB & noise
  - 250,000 individual maps using 10M CPU-hours.
  - By far the largest CMB Monte Carlo set ever produced.
- The first cosmology results from Planck have been released.
- There will be at least one more (maybe two) data releases in the coming year or so.

# Scientific Impact

- Planck named in the top 10 breakthroughs of the year by Physics World.
- Planck named in BBC's best space images of the year.
- Planck results on the cover of the New York Times and Science News.
- Planck papers from the first release have more than 1000 citations in 10 months!



# Acknowledgements

- NERSC has played a key role in the science results from Planck. A huge thank you is in order for NERSC leadership and staff!
- C<sup>3</sup> team at LBNL working on CMB data analysis:
  - Current: Julian Borrill, Ted Kisner, Reijo Keskitalo, Aaron Collier, Josquin Errard
  - Past: Radek Stompor, Chris Cantalupo, Reese Baird, Rajesh Sudarsan
- Many more...

