Status of Planck
&
Prospects for B-mode with Planck

Andrew Lange & Kris Gorski
Chicago CMB Polarization Workshop
July 1, 2009
(T_{bolometer} \sim 150 \text{ mK})
Planck

- Third generation space CMB mission
- Design goal is to measure the temperature anisotropies of the CMB to fundamental limits on all scales down to 5'. Polarization is important, and a matter of intense effort. But when choices had to be made, polarization was not a design driver.
- Will launch with Herschel on an Ariane 5 rocket
- Two instruments
  - Low Frequency Instrument (LFI),
    PI=Reno Mandolesi, IASF
  - High Frequency Instrument (HFI),
    PI=Jean-Loup Puget, IAS
- Current launch date 31 October 2008

Planck is on orbit!
(Launched 5/14 6:12 AM PDT)
Distance to Earth: 1420602 km

Jun 30, 2009

Institut d’Astrophysique Spatiale
Cryogenics

- Planck will be the first cryogenic astrophysics mission without cryogens
- 20 K hydrogen sorption cooler (fully redundant)
  - Cools LFI to $\lesssim 20$ K
  - Provides precooling to HFI at $\sim 18$ K
Cryogenics — cont’d

- 4 K $^4$He JT cooler
  - Cools overall HFI structure to ~ 4 K; precools gas for dilution cooler; cools LFI cold loads

- 0.1 K $^3$He–$^4$He dilution cooler
  - Cools bolometers to 100 mK; JT expansion cools feeds, etc., to 1.6 K

Cooling system

- V-groove radiators (to 60 K)
- 20 K H$_2$ sorption coolers (JPL)
- 4 K Stirling cooler (RAL/MMS)
- 0.1 K $^3$He/$^4$He dilution cooler (CRL/BI)
All information about Planck performance in this talk is from the Planck "Bluebook"

A performance update will be issued following the system-level cryo test in late spring
## Instruments

<table>
<thead>
<tr>
<th>INSTRUMENT CHARACTERISTIC</th>
<th>LFI</th>
<th>HFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Technology</td>
<td>HEMT arrays</td>
<td>Bolometer arrays</td>
</tr>
<tr>
<td>Center Frequency [GHz]</td>
<td>30 44 70</td>
<td>100 143 217 353 545 857</td>
</tr>
<tr>
<td>Bandwidth (Δν/ν)</td>
<td>0.2 0.2 0.2</td>
<td>0.33 0.33 0.33 0.33 0.33 0.33 0.33</td>
</tr>
<tr>
<td>Angular Resolution (arcmin)</td>
<td>33 24 14</td>
<td>10 7.1 5.0 5.0 5.0 5.0 5.0</td>
</tr>
<tr>
<td>ΔT/T per pixel (Stokes I)</td>
<td>2.0 2.7 4.7</td>
<td>2.5 2.2 4.8 14.7 147 6700</td>
</tr>
<tr>
<td>ΔT/T per pixel (Stokes Q &amp; U)</td>
<td>2.8 3.9 6.7</td>
<td>4.0 4.2 9.8 29.8 ... ...</td>
</tr>
<tr>
<td>ΔT/T per deg² (Stokes Q &amp; U)</td>
<td>1.6 1.6 1.6</td>
<td>0.7 0.5 0.8 2.5</td>
</tr>
</tbody>
</table>

a Goal (μK/K, 1σ), 14 months integration, square pixels whose sides are given in the row “Angular Resolution”.

HFI will do somewhat better by end of mission
Heritage: BOOMERanG, MAXIMA, Archeops, QuAD, BICEP
Frequencies

![Graph showing frequency distribution and contributions from different sources such as total Galaxy fluctuations, dust, synchrotron, and free-free.](image)

- **LFI** and **HFI** sections highlight different frequency bands.
- **Frequency (GHz)** vs **Brightness Temperature (μK)** graph displays various emission sources and their contributions.

**PLANCK**

Lawrence—7

2008 January 28
Simulated Planck Temperature Maps
## Rough Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (months)</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>0</td>
<td>end 2008(?)</td>
</tr>
<tr>
<td>Cruise, cooldown, checkout</td>
<td>3</td>
<td>3/2009</td>
</tr>
<tr>
<td>First sky survey</td>
<td>6</td>
<td>9/2009</td>
</tr>
<tr>
<td>Second sky survey</td>
<td>6</td>
<td>3/2010</td>
</tr>
<tr>
<td>ERCSC (based on first sky survey)</td>
<td></td>
<td>6/2010</td>
</tr>
<tr>
<td>Analyze first year data</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Release results based on first year</td>
<td></td>
<td>3/2012</td>
</tr>
<tr>
<td>Extended mission</td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>
Tentative Plans for First Data Release

- Based on two sky surveys
- Calibrated data
- Frequency maps
- Component maps (CMB, synchrotron, dust, etc.)
- Source catalog
- 50–100 papers
- Likelihood function
So what?
Planck and WMAP: Temperature Anisotropies

- Planck has
  - > 10 × the sensitivity of WMAP
  - 3 × the angular resolution
- Limited by cosmic variance well into the damping tail.
- WMAP measures \(\sim10\%\) of the \(\ell\) modes with SNR \(\geq 1\). Planck will get them all.
A Dramatic Advance

Large increase (3–10×) in precision of cosmological parameters

⇒ high discovery potential

WMAP has confirmed the Standard Model

Planck will challenge it

Projected WMAP likelihood
Projected Planck likelihood on Hubble constant
Planck will tighten constraints on parameters in important ways

WMAP4

WMAP4 + SPT/ACT

Planck 1 year

(running $n_s$)
Lots of physics at $\ell \sim 500 \rightarrow 2000$!
It will be important (and interesting) to separate out the SZ contribution to the power spectrum (and Planck will do this well)
Planck will measure EE with high precision from $\ell \sim 40 \rightarrow 1200$
One might learn about reionization from details of low $l$ EE, but not from Planck......
Non-CMB Science Example: Discrete Sources

- Planck will measure the entire sky at 9 frequencies from 30 to 857 GHz
- At frequencies above 100 GHz, Planck will be the only all-sky survey since FIRAS
- Planck sensitivity to compact sources is $> 10^4$ times better than FIRAS!!
  - FIRAS: 7° resolution, NO discrete sources
  - Planck: 5' resolution at 350, 550, 850, and 1400 μm; 7' at 2 mm; 10' at 3 mm
  - $[\theta \text{FIRAS} / \theta \text{Planck}]^2 > 7000$

Simulation. ~ 100,000 sources over sky. Those not seen in IRAS will include: high-z ULIRGs, < 15 K dust, SZ clusters, radio bright galaxies.

FIRAS 300 μm
NO SOURCES
The Early Release Compact Source Catalog

- To enable follow-up observations with, e.g., Herschel, a catalog of bright sources will be released about 19 months after launch, based on the first full sky survey.

<table>
<thead>
<tr>
<th>Channel</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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</thead>
<tbody>
<tr>
<td>Freq (GHz)</td>
<td>30</td>
<td>44</td>
<td>70</td>
<td>100</td>
<td>143</td>
<td>217</td>
<td>353</td>
<td>545</td>
<td>857</td>
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<tr>
<td>Wavelength (m)</td>
<td>10000</td>
<td>6818</td>
<td>4286</td>
<td>3000</td>
<td>2098</td>
<td>1382</td>
<td>850</td>
<td>550</td>
<td>350</td>
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<tr>
<td>Beam (')</td>
<td>33</td>
<td>24</td>
<td>14</td>
<td>9.5</td>
<td>7.1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<tr>
<td>F(mJy)/[dT/T*10^3]</td>
<td>6818</td>
<td>7557</td>
<td>6040</td>
<td>5007</td>
<td>4461</td>
<td>2833</td>
<td>1761</td>
<td>346</td>
<td>8.97</td>
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<tr>
<td>Noise dT/T*10^6</td>
<td>2.0</td>
<td>2.7</td>
<td>4.7</td>
<td>2.5</td>
<td>2.2</td>
<td>4.8</td>
<td>14.7</td>
<td>147</td>
<td>6700</td>
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<tr>
<td>Noise (mJy)</td>
<td>13</td>
<td>19</td>
<td>25</td>
<td>9</td>
<td>13</td>
<td>9</td>
<td>20</td>
<td>46</td>
<td>52</td>
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<tr>
<td>Confusion (mJy)</td>
<td></td>
<td>4</td>
<td>6</td>
<td>17</td>
<td>43</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMB noise (mJy)</td>
<td>78</td>
<td>80</td>
<td>61</td>
<td>64</td>
<td>56</td>
<td>31</td>
<td>16</td>
<td>3</td>
<td></td>
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<tr>
<td>Dominant noise</td>
<td>CMB</td>
<td>CMB</td>
<td>CMB</td>
<td>CMB</td>
<td>CMB</td>
<td>CMB</td>
<td>Noise</td>
<td>Noise</td>
<td>Confusion</td>
</tr>
<tr>
<td>10-sigma ERCSC goal (mJy)</td>
<td>790</td>
<td>820</td>
<td>660</td>
<td>650</td>
<td>580</td>
<td>330</td>
<td>310</td>
<td>630</td>
<td>1048</td>
</tr>
</tbody>
</table>

Bill Reach
IS PLANCK THE TEST OF INFLATION?

As the launch of the Planck spacecraft approaches, Eric Hand investigates what the mission could mean for the predominant theory of the moments after the Big Bang.
Polarization sensitivity does not make a polarimeter...
Minneapolis, March 2003.....

**Does a satellite make sense?**

*(yes, much like going to the dentist makes sense...)*

**+:**
- Stable, clean environment
- Long integration time
- Entire EM band available

**-:**
- 5 - 10 year old technology
- $$$ (but still << mOIF)
- CDRs, ICDs, WPAs
- It can blow up [ P(>5%)]
- You will get old
- You might get beat ....
Planck will revolutionize our understanding of the mm-wave polarized sky

\[ \ell = 100; \Delta \ell_{\text{bin}} = 0.4\ell \]

- WMAP 4 year
- LFI 2 year
- HFI 1 year
- Proposed 100 GHz polarized HFI channel, 1 year
Planck could detect evidence for the GWB:

Primordial B-modes, fingerprint of Inflation. (Shown for T/S = 0.1, a high value?)

Lensing B-modes (a foreground)

All sky
6 (or 7) polarized channels from 30 to 350 GHz
Angular resolution sufficient to detect lensing mode.
The advantages of space...
Ideal Scan Strategy for All-Sky Polarization Measurement

Planck

N-hits (1-day)

Angular Uniformity* (6-months)

WMAP

EPIC

*<cos 2β>^2 + <sin 2β>^2
“You don’t observe the CMB with the scan strategy you wish you had - you observe the CMB with the scan strategy you have.”
Planck–HFI 100+143+217 GHz T & E Sensitivity

FWHM = ? arcmin 32 detectors [8•I, 12•(Q&U)]
Planck–HFI 100+143+217 GHz T, E, & B Sensitivity

1 year of observations, 32 detectors [8×I, 12×(Q&U)]

Temperature

Signal & Noise (below)

Polarization

E-mode

B-mode

E & B Noise

sqrt(C_l) [μK]

Multipole Order l

r = 0.30
0.10
0.05
0.03
0.01

K.M. Gorski 09
Conclusions

• Planck will not detect a cosmological B-mode

• Planck will test Inflation via:
  – a high-precision measurement of $n_s$
  – high sensitivity to non-gaussianity

• A sub-orbital experiment designed to probe CMB pol at $l < 20$ is important
  – Reionization history (a real cosmological signal!)
  – Understand foregrounds for EPIC
  – Search for the elusive B-mode….