PLANCK

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Orsay

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Planck mission concept 1/3

- Planck conceived to be limited by foregrounds for T measurements
  - instantaneous sensitivity limited by photon noise (cryogenic detectors), total power measurements
  - broad frequency coverage: 30 GHz to 1 THz (2 technologies)
  - 5 arc minutes resolution for the best CMB channels
  - polarization measurements in a very broad range

- For Polarization Planck will be sensitivity limited but the broad frequency coverage (30 GHz-353 GHz) should be very good for foregrounds

- half way between WMAP and an inflation probe mission
Planck mission concept 2/3

- Spinning satellite at 1 rpm
- Orbit around L2
- Baseline mission 14 months (Helium consumption by dilution should allow up to 24 months)
- Scanning strategy based on a detection system having basically no 1/f noise down to 0.01 Hz
- Large baffle gives a very low level of far side lobes on about one half of the sky; comparison of observations of the same point 6 months apart gives a powerful tool to monitor the side lobe signal
Planck mission concept 3/3

- Two instruments
- HFI: 0.1 K bolometers
  - 6 bands from 100 GHz to 1 THz
  - Spider web and polarization bolometers (Caltech/JPL)
  - cold optics (Cardiff)
  - sensitive readout electronics with flat noise from 0.016 to 200 Hz (CESR)
- LFI : 20 K HEMT amplifiers with 4K reference loads
  - 3 bands from 30 to 70 GHz (Italy, UK, Finland)
- cooling chain:
  - passive < 60K,
  - H Sorption cooler <20K (JPL)
  - 4 K JT He cooler (RAL, Oxford)
  - 0.1 K dilution cooler (CRTBT, IAS, Air Liquide)
Planck planned capabilities

<table>
<thead>
<tr>
<th></th>
<th>LFI</th>
<th></th>
<th>HFI</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fréquence centrale (GHz)</td>
<td>30</td>
<td>40</td>
<td>70</td>
<td>100</td>
<td>143</td>
<td>217</td>
<td>353</td>
<td>545</td>
</tr>
<tr>
<td>Détecteurs non polarisés</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>(0)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Détecteurs polarisés</td>
<td>4</td>
<td>6</td>
<td>12</td>
<td>(8)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Lobe (FWHM) (arcmin)</td>
<td>33</td>
<td>24</td>
<td>14</td>
<td>(10)</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Bande passante (GHz)</td>
<td>6</td>
<td>8.8</td>
<td>14</td>
<td>(47)</td>
<td>47</td>
<td>72</td>
<td>116</td>
<td>180</td>
</tr>
<tr>
<td>Sensibilité en $I$ ($\mu$K)</td>
<td>5.5</td>
<td>7.4</td>
<td>12.8</td>
<td>(6.5)</td>
<td>6.3</td>
<td>13</td>
<td>40</td>
<td>400</td>
</tr>
<tr>
<td>Sensibilité en $Q$, $U$ ($\mu$K)</td>
<td>7.6</td>
<td>10.6</td>
<td>18.3</td>
<td>(13)</td>
<td>12.3</td>
<td>26</td>
<td>79</td>
<td>/</td>
</tr>
</tbody>
</table>
Planck Polarized planned capabilities
(and comparison to WMAP)

Sensitivity for 20 arcmin pixels,
Planck: 14 months
WMAP: 2 years

<table>
<thead>
<tr>
<th>Instrument</th>
<th>$\sigma_{\text{pix}}^P (\mu K)$</th>
<th>$s_P (\mu K \cdot \text{sec}^{1/2})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMAP</td>
<td>32</td>
<td>449</td>
</tr>
<tr>
<td>LFI</td>
<td>7.3</td>
<td>73</td>
</tr>
<tr>
<td>HFI</td>
<td>3.5</td>
<td>35</td>
</tr>
</tbody>
</table>
Planck

\[ \Delta T (\mu K) \]

- reionization
- gravitational waves
- BB
- \( \Theta E \)
- gravitational lensing

\( l \) (multipole)

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W. Hu
Measured performances: HFI

- bolometers in specs (most time constants close to the goals, a few at the specification level, NEP below or within 10% of the photon noise)
- excellent total optical efficiency measured in the ARCHEOPS flight (better than 40%)
- read out electronics: no 1/f noise down to $10^{-2}$ Hz
- many aspects of the Planck HFI concept have been tested with the ARCHEOPS balloon borne experiment
Focal Plane Unit

- Focal Plane System is FPU without horns, filters, bolometers
- it does include blind bolometers and all thermometers
FPS at Air Liquide
noise power spectrum of the electronic detection chain QM (REU + PAU + J-FET) nominal noise $7\text{nV/Hz}^{1/2}$
Blind bolometer on the Qualification model of the FPS cooled to 98mK
CQM Exchanger 1/2

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100 mK connector plate
100 mK temperature regulation
40nK/Hz$^{1/2}$
CQM FPS 100mK view

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ARCHEOPS as a Planck HFI demonstrator

• ARCHEOPS is a balloon borne experiment with a Planck HFI type focal plane
  – same bolometers, horns, filters, dilution cooler, total power readout electronics
  – Planck telescope, about 10 arc minutes resolution
  – He cryostat
  – scanning strategy similar to Planck spinning at 2 RPM
  – capability to cover 1/3 of the sky in one flight
The CMB observed by Archeops (I)

30% of the sky covered
12.6% used for CMB

2 bolometers (143+217 GHz)
(so far…)
8 millions of data points,
Sensitivity : $\sim 90 \, \mu K \cdot sec^{1/2}$
Results 1/2

- Archeops had some atmospheric low frequency noise, and thermal systematics from the 10K shield which were monitored and removed, temperature stability was excellent
- instantaneous sensitivity $90 \mu K/Hz^{1/2}$
- response calibrated on the dipole (consistent with planets and galaxy)
- total optical efficiency (transmission and bolometer absorption efficiency) measured, best bolompeters were over 40% (requirement for Planck is 25 %)
Results 2/2

• comparison with WMAP: calibration factor 1.1
• sensitivity in 12 hours on 30 % of the sky is 2.5 lower than WMAP in one year (all sky)
• instantaneous sensitivity is 2.3 times lower than the goal for Planck which is very close to the expected factor due to the higher background
• this confirms the expected sensitivity of Planck and the gain we should get with respect to the WMAP data
Archeops and WMAP

\[(\text{Archeops} + \text{WMAP})/2\]

\[(\text{Archeops} - \text{WMAP})/2\]

**Same Sky!**

*Work in progress…*

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spectra on Archeops coverage

data fit with error bars in both coordinates

\begin{align*}
\text{nside} &= 512 \\
\text{fcut(archeops)} &= 0.1/38 \text{ Hz} \\
\text{nopond}
\end{align*}

\begin{align*}
\text{chi}^2 &= 23.6/24 \\
\text{goodness of fit } q &= 0.48
\end{align*}
Archeops maps

Feb 7th 2002
12 hours of night data

First submillimetric maps at 15 arcmin resolution, 30% sky

- 545 GHz, 550 µm
- 353 GHz, 850 µm (Polarized)
- 217 GHz, 1.4 mm
- 143 GHz, 2.1 mm

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RESULTS

I (353 GHz)

17% of sky, Galactic anticenter

Smoothed, 1deg

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Signal to noise

\[ \frac{(Q^2 + U^2)}{(\sigma_Q^2 + \sigma_U^2)} \]

Smoothed, 1deg

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<table>
<thead>
<tr>
<th>$P$ (%)</th>
<th>$\theta$ (deg)</th>
<th>(8.5 \pm 0.7 \pm 2.6)</th>
<th>(85 \pm 2.8 \pm 3.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 ± 1.8 ± 1.8</td>
<td>59 ± 4.7 ± 1.0</td>
<td>5.3 ± 3.1 ± 1.5</td>
<td>101 ± 13.6 ± 6.3</td>
</tr>
<tr>
<td>22.2 ± 3.4 ± 4.0</td>
<td>78 ± 3.7 ± 0.8</td>
<td>7.2 ± 2.8 ± 4.1</td>
<td>133 ± 11.5 ± 3.8</td>
</tr>
<tr>
<td>7.5 ± 0.9 ± 1.5</td>
<td>46 ± 3.6 ± 2.0</td>
<td>&lt; 3.4</td>
<td>23 ± 16 ± 105</td>
</tr>
<tr>
<td>23.3 ± 6.7 ± 9.7</td>
<td>175 ± 7.5 ± 3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.3 ± 2.9 ± 2.6</td>
<td>87 ± 6.7 ± 2.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.3 ± 1.7 ± 3.5</td>
<td>89 ± 3.2 ± 1.1</td>
<td></td>
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</tr>
</tbody>
</table>

**Taurus complex**
Dust will be the major foreground for CMB temperature measurements at high frequencies.

Serkowski et al
Heiles

Expectation of at least 3% in submm

No measurement on large scales available yet.
Planck curve with a $\nu^2$ emissivity law (green continuous line). XXX put a, b, c, and d on the Fig.

(displayed only between 210 and 1000 $\mu$m), the DMR data points at 90, 33 and 31 GHz and the WMAP data points at 3.2, 4.9, 7.3 and 9.1 mm (all these data points are in black on Fig. 1). We fit the DIRBE 100, 140 $\mu$m and FIRAS spectra (200 < $\lambda$ < 500 $\mu$m) with a modified Planck curve with a $\nu^2$ emissivity law (the result of the fit is displayed on Fig. 1). We know that this fit is inconsistent with FIRAS data below 800 GHz where an excess component is detected (Reach et al. 1995, Finkbeiner et al. 1999). However, we are not interested here in this component. We only concentrate on the millimeter part on the spectra and how it relates to the far-IR emission. In this framework, the $\nu^2$ modified black body is well representative and useful for comparison between spectral far-IR and millimeter shapes.

First, we see that there is a strong millimeter excess (with both DMR and WMAP data) with respect to the $\nu^2$ modified black body. This excess decreases significantly (by a factor of about 5 at 3.2 mm) when the HI column density increases, although the far-IR emission remains nearly constant (at the $\sim$6% level). The far-IR emission is dominated by the so-called Large Grain dust component. The millimeter excess is thus not likely associated with this dust component.

We can go further by removing to the WMAP emission the corresponding free-free and synchrotron emission (removing also the $\nu^2$ modified black body does not change the conclusions). The residual WMAP emission is shown on Fig. 1 (red stars) and detailed in Table 1. First, at each frequency, the residual emission exhibits a strong decrease (by about a factor of 4) with HI column densities (from bin 1 to 4). Second, the residual emission decreases from 3.2 to 9.1 mm in each HI bin. On Fig. 2 are shown the WMAP residual emissions for the 4 bins at 3.2, 4.9, 7.3 and 9.1 mm, normalised to the 90 GHz DMR residual emission (the 31 and 53 GHz DMR residual emissions have also been computed but are not displayed to avoid confusion. Results, although more noisy, are in very good agreement with WMAP). This figure shows that we do not detect any significant variations in the spectral shape of the residual emission\(^3\). Thus, the residual emission, al-

\(^3\) This however will have to be quantified when smoothed WMAP data with error bars will be available. But note that
Importance of foregrounds for very sensitive polarization measurements:

- the synchrotron spectral index is variable
- The dust polarization is high
- the dust emission long wavelengths spectrum is somewhat flatter than expected