The *PLANCK* Newsletter

Issue 4 *Information and news for the Planck community* **April 2003**

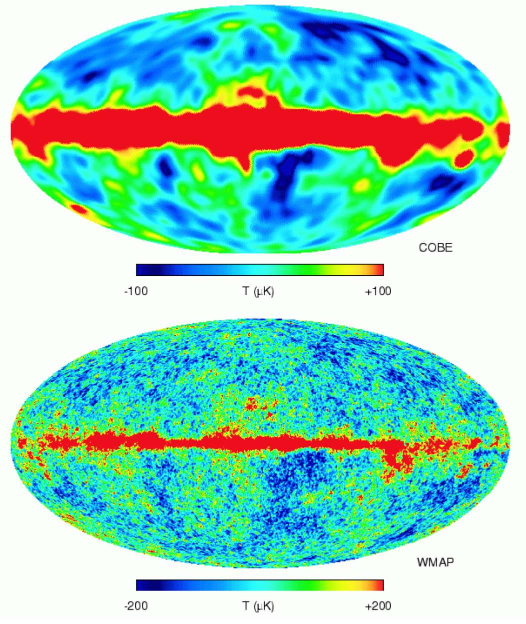
The Universe according to WMAP

George Efstathiou

On a cold evening on the 11th February I walked from the Institute of Astronomy to the Centre for Mathematical Sciences in Cambridge to see the live Web-cast announcing the first year results from WMAP. We had been eagerly awaiting these results and rumours of possible findings had been the subject of eager coffee-time gossip (much of it accurate) at the Institute over the last few months.

Chuck Bennett and David Spergel gave brief summaries of the results, after which the panel chair asked John Bahcall for his reaction to these revolutionary new findings. John responded by saying that the most revolutionary new result was there was no revolutionary new result! Broadly speaking, this is true - WMAP confirms a simple concordance model that has been built up over the last few years using many different data sets. But I was enormously impressed by the results presented at the press conference and have become even more so after reading the first set of papers from the WMAP team.

The first striking result was a graphic showing the COBE CMB map slowly morph into the high resolution sky seen by WMAP. The correspondence between the two maps was blindingly obvious – both maps show the same hot and cold



Comparison of the COBE 90 GHz map (Bennett et al 1996) with the WMAP W-band. The WMAP map has 30 times finer resolution (From Bennett et al 2003). ***Courtesy of the WMAP Science Team.***

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Four years to Launch!

J. Tauber

We are now less than 4 years from launch ! This may sound like a lot, but is not, as is reflected by the ongoing production of hardware in many areas. In spite of rumours, ESA's planned launch date is firmly set to February 2007. The pace of development has been increasing steadily over the last year, and the mood has clearly changed, from "let's plan" to "let's build". You will see some of the highlights in the updates from instruments and the Herschel/Planck Project.

Many of you have been – and probably still are – very concerned with the situation of the LFI. The good news is that the funding of the LFI prime contractor has finally been resolved and Laben is now fully in business; their immediate focus is to get the LFI system design back in hand and an updated development plan in place. The bad news is that in order to resolve the situation LFI had to (a) cut the 100 GHz channel, and (b) curtail its participation in the satellite level qualification tests. This in spite of heroic efforts by many individuals, in particular the LFI PI and PM, and the LFI JPL team. Many of the details of this saga are described in the minutes of the meetings of the Planck Science Team, available on Livelink. Further impacts will be discussed and addressed in the coming months.

I am keenly aware of the distress felt by many in the LFI Consortium, in particular those who were intimately involved with the development of the 100 GHz channel. In this respect, I would like to emphasize that the Planck Science Team is committed to treat the mission as a

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Four years to Launch

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common scientific enterprise by all participants, and will do its best to preserve the good balance and health of the Planck collaboration. I encourage you to voice your concerns and bring forward any suggestions to myself or other members of the Science Team.

The descope of LFI represents a major blow to the scientific return of Planck. In particular it means no polarization capability at 100 GHz. The HFI Consortium is currently implementing an option to its baseline, which would have the 100 GHz spider-web bolometers replaced by polarization-sensitive devices; this plan has the backing of all parties, but is now critically dependent on the availability of NASA funds to the device development funds. This situation is expected to be resolved by the end of April.

On other fronts, progress has been more even. The Science Ground Segment was reviewed in December; detailed recommendations (available in Livelink) were made to the various parties involved (LFI and HFI DPCs, the Planck Science Office). A mission-level review of Herschel and Planck was conducted by ESA in January and has given the go-ahead to full manufacturing and qualification activities. More details are provided in the various articles in this issue.

Finally, in the last few months there have been steady – and sometimes dramatic – improvements in the state of knowledge of our favorite object (the CMB), based on the results of many experiments (Boomerang, CBI, DASI, Archeops, to mention only a few), capped most recently by the release of the outstanding first-year data from WMAP. All these precursors (and many more exciting experiments being planned or built) will play a fundamental role in how we approach the data processing of Planck, and therefore we have to exploit them fully. This will be the theme for the next Planck Workshop, currently being planned by the Science Team.

Calendar of (some) Events

Planck Workshop & Joint Consortium Meetings

Date: 26-30 January, 2004 (tentative)

Place: La Laguna, Tenerife

Science Team meetings

ST16: 6-7 May, 2003 - MPA, Garching

ST17: 2-3 Sep, 2003 - DSRI, Copenhagen (TBC)

HFI Hardware Design Review

Date: 4-5 June, 2003

Place: IAS, Orsay

LFI Instrument Baseline Design Review

Date: 15-16 May, 2003

Place: IASF-CNR, Bologna

Working Group Meetings

WG7: Galactic and Solar System

Date: 30 June – 2 July, 2003 (TBC)

Place: Jodrell Bank, UK

WG6: Extragalactic Sources

Date: 15-16 September, 2003 (TBC)

Place: Imperial College, London

News from LFI

R. Mandolesi

For financial reasons LFI has had to choose a new baseline configuration without the extension to 100GHz. Small modifications now are in progress to optimise the design of LFI with the remaining 30, 44, and 70 GHz radiometers.

The new industrial contract from ASI to Laben for LFI development has been approved by ASI at the end of March 2003. To speed up the restart of the industrial activities and to recover against the Planck schedule a Joint Engineering Team (JET) has been set up by ESA and ASI involving the Laben, Alcatel, HFI and LFI, and ESA system teams.

Full optical simulations for LFI have been completed. The LFI main beam patterns were computed at high resolution, both in temperature and polarization. Representative cases were studied for several optical configurations with different edge taper and feed models (Gaussian and dual profiled). For these feed horns, full pattern simulations, both in temperature and polarization, were carried out using GRASP8 MrGTD code (combined with PO/PTD methods in the main beam region). Starting from optical simulations and sky emission templates, we evaluated the straylight contamination in the time ordered data produced by diffuse components (mainly Galactic foregrounds). The statistical moments of the simulated signal were also calculated. The results are now under evaluation within the LFI team.

The Planck Science Ground Segment Requirements Review was held on 2-4 December 2002 in Paris. The review was positive for the LFI DPC and a number of useful recommendations were made. The most important activity of the DPC at the moment is the organization of computer code at the LFI DPC site in Trieste to perform the integration of the first full pipeline Demonstration Model. In addition, the large effort on the simulation of the LFI systematic effects and their removal has been continuing. In particular the following effects are being simulated: thermal noise, sorption cooler noise, time dependant degrading effects from the sorption cooler, "1/f" radiometric noise, and cosmic rays.

News from HFI

J.-L. Puget

Instrument breadboard subsystem tests and design updates: the tests of the dilution cooler and focal plane unit (FPU) in the fall of 2002 revealed a minimum helium flow just at the upper limit acceptable to fulfill the life time requirement. Modifications have been introduced in the exchanger and in the diameter of the exit pipes which bring back the margins of the original design. This modification delayed the critical design review (CDR) for the Air Liquide activities and leads to a delay in the HFI-Cryogenic Qualification Model (CQM). The breadboard was later delivered to IAS and tested for alignment properties when cold. These tests showed displacements well within the requirements. In parallel, the tests of the breadboard models of the 4K and 20K coolers have proceeded satisfactorily.

The readout electronics do not show any excess noise down to the lowest frequency (0.016 Hz). A detailed set of tests and analysis of electromagnetic compatibility have lead to a modification of the electronic boxes and grounding scheme.

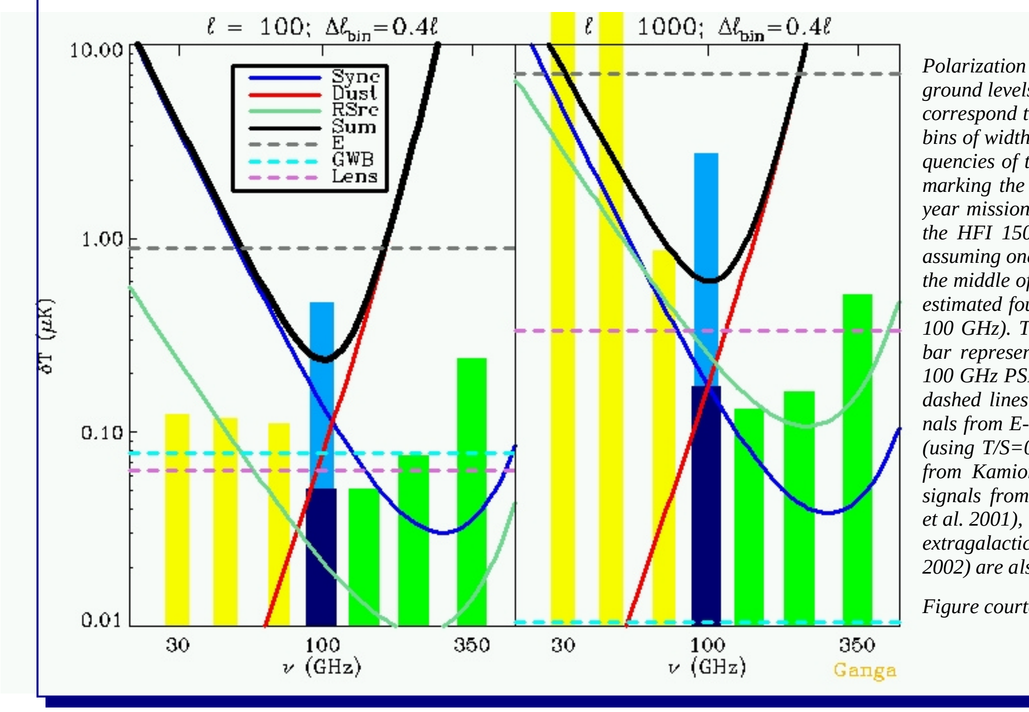
The integration and test plan of the HFI has now been detailed and a Hardware Design Review will take place at the beginning of June concentrating on these aspects and on the on-board software. Overall the design of the CQM is now stable and the building of the elements is going on with a schedule leading to a delivery to ESA in February 2004 (TBC) instead of November 2003.

The calibration activities are now planned in detail including links with the relevant DPC elements (DMCI, level 1, QLA).

The Flight Model schedule is still on track for delivery in January 2005. In terms of design, there is an important pending question concerning the 100 GHz channel. Following the loss of the LFI 100 GHz channel, and the growing importance of polarization measurements for Planck, the possibility of replacing the 4 HFI 100 GHz spider-web bolometers by 4 Polarization Sensitive Bolometers (PSBs) has been studied. It has been concluded to be feasible by using four existing readouts planned for redundant thermometers. The modifications of the 100 mK plates have been studied and the changes have been approved by the Science Team, the Herschel/Planck Project, CNES and PPARC. NASA will give its answer to the request for funding of these 4 PSBs at the end of April. The base line with the 4 spider-web bolometers will remain as a back up as long as necessary.

The compelling science case for this modification is illustrated in the Figure below, which shows that the low frequency foregrounds have a frequency dependence such that measurements of these foregrounds relying only on the LFI low frequency channels and the 90 GHz WMAP channel will degrade the polarization capabilities of the HFI. For this reason it is essential to make every effort to include PSBs at 100 GHz in the HFI.

As mentioned before, the DPC elements linked to the tests and calibration activities for the CQM at the end of 2003 and beginning of 2004 have been reviewed to insure their availability in time. The Levels 2 and 3 of the DPC are proceeding satisfactorily. Some IDIS elements (e.g. DMCI) raised some worries at the recent ground segment review and actions have been agreed to address them.



*Polarization noise sensitivities and predicted foreground levels for Planck, in CMB units. The two panels correspond to l=100 and l=1000, with power spectrum bins of width 0.4*l. The three yellow bars mark the frequencies of the LFI channels, with the top of each bar marking the 1-sigma noise estimates assuming a two-year mission. The three green bars mark the same for the HFI 150, 220 and 353 GHz polarized channels, assuming one year of observation. The light blue bar in the middle of the plot again represents the same for the estimated four-year mission for WMAP (shown only at 100 GHz). The dark blue bar overlapping the WMAP bar represents the expected sensitivity for 4 pairs of 100 GHz PSBs if they were to fly on Planck. The three dashed lines represent, respectively, the expected signals from E-modes, B-modes from gravitational waves (using T/S=0.1) and B-modes from lensing [estimated from Kamionkowski & Hivon (2002)]. The expected signals from Galactic synchrotron (blue; Baccigalupi et al. 2001), Galactic dust (red; Prunet et al. 1998) and extragalactic radio sources (light green; Mesa et al. 2002) are also shown, with their sum plotted in black.*

Figure courtesy of K. Ganga (IPAC).

Milestone in Reflector Development

H.U. Nørgaard - Nielsen

For the provision of the reflectors the Danish Space Research Institute has, in collaboration with ESA, made a contract with ASTRIUM GmbH, Friedrichshafen. To focus the microwaves from the Sky onto the two detector systems the Planck payload contains two reflectors, each being a part of an ellipsoid. The reflectors will be made out of Carbon Fiber Reinforced Plastic (CRFP) in a honeycomb structure which consists of 2 facesheets and a core assembly inbetween. This ensures that the reflectors meet the stringent requirement on the thermal stability, namely that the desired form of the reflectors is kept when they are cooled down to 35K.

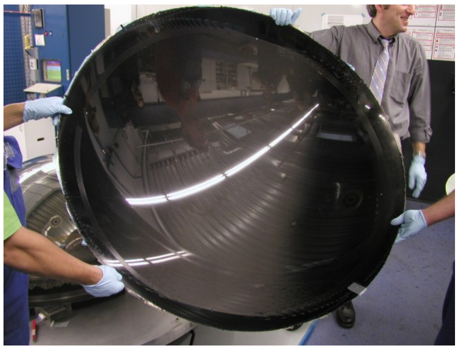
The moulds for the reflectors have been polished by REOSC/SAGEM, Paris. The mould for the secondary reflector is fulfilling the requirements and delivered to ASTRIUM, while the primary mould is in the final polishing procedure.

The mould for the secondary reflector.

ASTRIUM has produced the first facesheet from the secondary mould and also the first core assembly. The next important milestone in the reflector programme will be the tests in July 2003 of the optical performance of the secondary reflector at cryogenic temperatures. These tests will be performed at the Centre Spatial de Liège, Belgium, to be followed by the tests of the primary reflector in October 2003.

The next all-Planck meeting

Two years ago we held the first, and very well attended all-Planck workshop at ESTEC, in The Netherlands. Last year a Joint Consortium meeting was held in Santander, focusing on Working Group activity. Following these successful experiences, the Science Team is preparing a combined all-Planck workshop and Joint Consortium meeting, to be held in Tenerife (Spain), in the last week of January 2004. The meeting will be hosted by the Instituto de Astrofísica de Canarias (contact: R. Rebolo), and is likely to consist of a 3-day plenary conference, followed by half a day of parallel Consortium meetings, and one day dedicated to Working Group activities. Book that week in your agendas, and watch this space for more information!



A facesheet of the secondary reflector CRFP coming out of the mould.

News from the H/P Project Team

T. Passvogel

The Preliminary Design Review of the Herschel and Planck spacecraft has been completed successfully by the end of the year 2002. The announcement from Arianespace in September 2002 to provide a more powerful launcher to Herschel and Planck resolved to a major extent the issue of the overall launch mass.

The build-up of the industrial consortium is nearly completed and all flight equipment contractors have been selected. The activities can now solely focus on the design issues and the work is now progressing towards the unit detailed designs and design reviews, together with release of the first hardware manufacturing for the qualification models and in a few cases also flight model items. The Attitude Control and Measurement Subsystem contractor, Dutch Space, has recently passed its Preliminary Design Review.

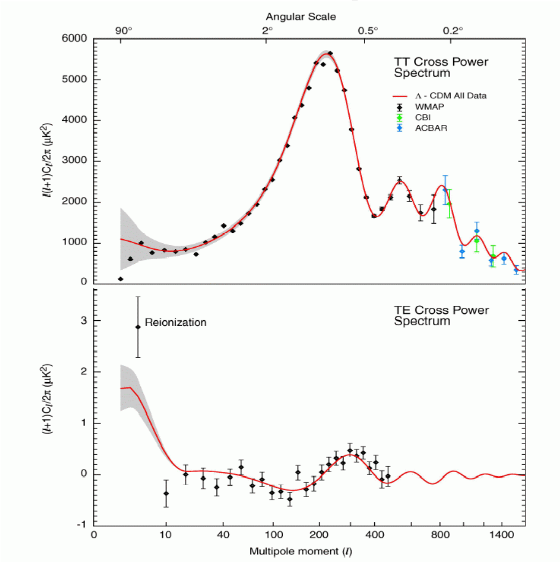
The design work on the Planck Payload module, consisting of the Planck telescope and the V-Groove shields is progressing well after completion of the Preliminary Design Review Meeting with the industrial Contractor in January. The Planck Telescope Reflector hardware manufacturing makes good progress with the completion of the qualification model of the secondary mirror scheduled for May 2003. The replication mould of the Primary mirror is under final completion at the polisher and the start of the manufacturing will follow closely afterwards.

Major work has also been carried in the definition of the Planck system testing, especially for the cryogenic performance test of the Payload Module in the cryogenic test facility in CSL in Liege. This test will verify the thermal performance of the V-Groove system and will allow functional and performance testing of the instruments. The facility is expected to be ready by April 2004, in time for the qualification model test campaign. In order to preserve this test plan for the qualification model of the spacecraft and in view of the late start of the industrial work in industry for LFI a work around has been defined to allow full testing of the HFI instrument when no LFI qualification model will be available.

WMAP highlights

George Efstathiou

(Continued from Page 1)
spots on the large scale and the WMAP picture reveals small scale structure with the characteristic scale of the sound horizon at recombination.Chuck Bennett showed a picture of the power spectrum estimates together with the best fitting adiabatic inflationary model prediction. The error bars on the WMAP measurements at multipoles l<500 are tiny and the model fits the data almost perfectly. This is a triumph, both for theorists and experimentalists. If we assume that the Universe is spatially flat, the WMAP data pin down the baryon and dark matter densities to within about 5%. Furthermore, spatially flat models require a cosmological constant. All of this is consistent with the simple concordance model but now with much smaller errors on the parameters.



*The WMAP angular power spectrum. (**top**:) The WMAP temperature (TT) results are consistent with the ACBAR and CBI measurements, as shown. The best fit running index CDM model is shown. The grey band represents the cosmic variance expected for that model. (**bottom**:) The temperature-polarization (TE) cross-power spectrum, $(l + 1)C_l/2p$. (Note that this is not multiplied by the additional factor of l.) The peak in the TE spectrum near l» 300 is out of phase with the TT power spectrum, as predicted for adiabatic initial conditions. The antipeak in the TE spectrum near l»150 is evidence for superhorizon modes at decoupling, as predicted by inflationary models. (From Bennett et al 2003.)*
Courtesy of the WMAP Science Team

But there is a major new surprise: their measurements of the temperature-polarization cross-correlations require a high optical depth for secondary reionization. The inferred optical depth is $\tau \approx 0.17$, much higher than most people would have thought, implying that the intergalactic medium was already significantly reionized at a redshift of about 20. This is a revolutionary new result! It implies that star formation began early in the Universe's history and that UV photons were produced efficiently, probably because the first generation of stars were skewed to high masses. It is the first time that we have had any direct evidence for fully formed astrophysical objects at redshifts **z**>6.5 and the results bode well for projects such as SWIFT, SIRTF, ALMA and JWST, that are targetting the formation of the first stars and galaxies in the Universe.

Most inflationary models predict a scalar spectral index, n_s, that is close to scale invariant (n_s = 1). The deviations from scale-invariance depend on the form of the inflationary potential, and if detected would offer the first observational tests of physics related to the inflaton field. There are some hints of a deviation from scale-invariance. For spatially flat models, the WMAP data alone indicate $n_s = 0.99 \pm 0.04$; combined with CMB data extending to higher multipoles and adding constraints on the matter power spectrum from the 2dF Galaxy Redshift Survey, the WMAP team find $n_s = 0.93 \pm 0.04$; adding in matter power spectrum estimates at smaller scales deduced from Ly α absorption lines yields $n_s = 0.93 \pm 0.03$ with possible evidence for a scale-dependence of the spectral index. My own view is that we should take these results as an indication of a possible trend, rather than a firm result, because there are significant astrophysical uncertainties in interpreting the data on galaxies and Lyα lines. However, it is clear that we are now entering the era of direct observational tests of inflationary models. Distinguishing between the plethora of inflationary models and uncovering signatures of fundamental theories will be the central aim of future CMB experiments, including Planck.

One other result, that received little coverage at the press conference but which I find striking, is the confirmation of the low amplitude of the quadrupole first measured by COBE. This has been known for a long time, but most of us have not attached too much weight to this result because of the large cosmic variance at low multipoles and the possibility of some residual Galactic contamination. The WMAP team have made a convincing case that Galactic contamination is unimportant, and according to their analysis, the probability of finding such a low quadrupole is around 2 10^{-3}. At face value, this is a significant discrepancy with the simple concordance model. Perhaps the best way of testing this would be to cross-correlate the WMAP data with deep galaxy surveys and try to find a direct signature of an integrated Sachs-Wolfe anisotropy. Failure to detect such a signal would point to new physics.

The Planck Blue Book

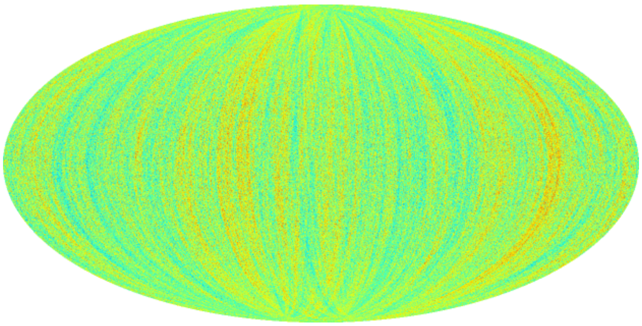
The updated scientific case of Planck, or “Blue Book” is in advanced stages of preparation. A strategic decision was taken some months ago by the Science Team to delay publication until the results of WMAP were released. The impact of these results is now being incorporated into the draft version, as well as the recent payload reconfigurations (LFI 100 GHz and possibly 100 GHz PSBs).
We were rather disappointed that the last Newsletter’s call for a Blue Book cover picture had no response. Due to the publication delay, there is a new chance for you to submit your ideas to the Science Team.

The Level-S Package

Matthias Bartelmann and Martin Reinecke

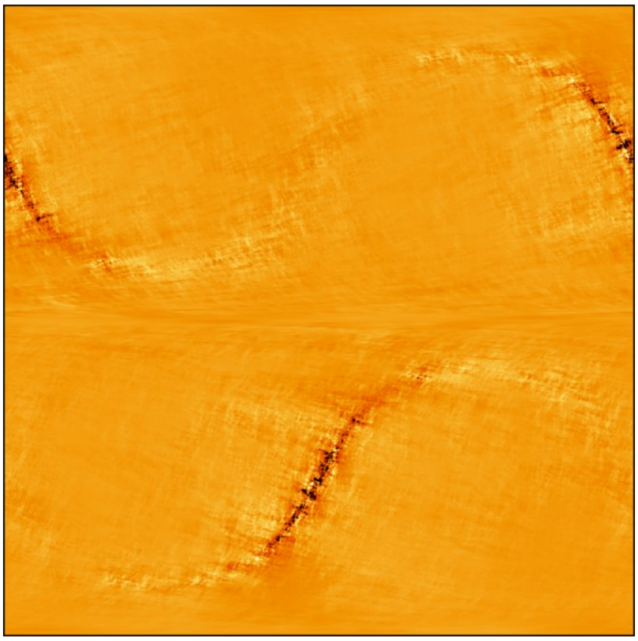
Planck Level S, or the activity leading to Planck simulated data, is just coming out of its third development phase. The first phase started in fall 1999. Its main goal was to assemble a simple simulation pipeline primarily from existing modules which had been developed and implemented by various groups throughout both Planck consortia. For that goal to be achieved, it was necessary to come up with sufficiently simple interface definitions such that the outputs of one module could be read and understood by the next. It was decided at the time that data can be transferred between modules through intermediate FITS files, and that modules had to be written such that parameters were read from simple ASCII parameter files. Among other advantages, this interface design allowed easily combining modules written in different programming languages. The first version of the Level-S package was able to produce time-ordered temperature measurement data in all Planck frequency bands, performing convolutions of arbitrary beam patterns with full-sky maps, and it could also simulate 1/f noise.

The second phase was devoted to extending the package, adding modules required for a more realistic data simulation, and extending the functionality of the existing modules into the same direction. The first module for computing systematic noise was added during that phase, the package gained the functionality to compute polarised data, modules computing the signal contribution from point sources and from the dipole were added, and the treatment of beam patterns was improved, allowing them to be decomposed into simple cores and detailed wings, and thus the accuracy of the convolution to be increased. Massive production of simulated data was started during that phase.



Simulated sky map showing only 1/f noise, computed using the parameters of one of the LFI 30-GHz channels.

In the third phase, which began just short of a year ago, the code base of the Level-S package was consolidated. All individual modules were checked for agreement with language standards, thus improving portability. Several modules were parallelised, and their performance was in some cases substantially increased by improved memory alignment. Now, it compiles cleanly on four different major UNIX platforms, on three of them on both 32 and 64 bit architectures. The package manual, which was regularly updated ever since Level-S activities began, has recently undergone major revision as the package compilation and usage became ever easier.



Simulated result of convolving a polarised beam with polarised microwave sky. The data are arranged in rings.

The entire source code can be downloaded from the IDIS CVS repository, located at:
http://astro.estec.esa.nl/planck_scripts/cvsweb,
and the code documentation is contained in Livelink under "Planck/DPC Common/Simulations/Technical Notes". Comments and contributions are welcome. A bi-weekly teleconference is held to facilitate information flow between Level-S and HFI/Level-2; other parties are welcome to join.
Much simulated data is available through the web interface at MPA: http://planck.mpa-garching.mpg.de/SimData/.
Should data be needed which cannot be found there, we are happy to assist in producing them, either by running simulation jobs or by helping with installing the Level-S package at other places.

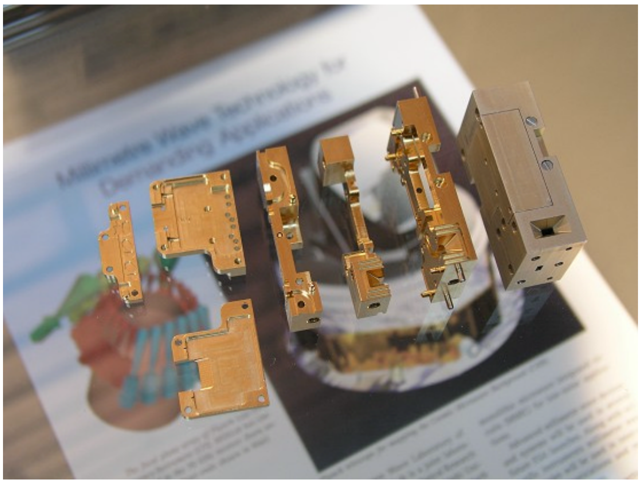
The package has become quite powerful. Recent additions include modules which simulate non-ideal satellite pointings, the true dipole taking the spacecraft's motion into account, and a new point-source convolver able to handle moving point sources, e.g. planets. The package is sufficiently modular that other systematic effects can easily be added. Groups throughout Planck which want to include new modules are invited to contact us. This year, we plan to integrate the Level-S package with the IDIS Process Coordinator and the IDIS Data-Management Component. The necessary software layer for embedding simulation modules written in languages like Fortran or C++ into Java, the so-called Java Wrapper, has been developed at MPA and will soon be ready for integration.

Planck Teams in Finland

J. Tuovinen

Finland has a significant contribution to Planck, both in terms of instrument hardware and of scientific support. With regard to science, there is a strong involvement from several Finnish cosmology and astronomy groups. The involvement is twofold: firstly, the physics of the fluctuations in the primordial cosmic microwave background (CMB) is being studied by the team members at the Department of Physical Sciences, University of Helsinki, and at the Helsinki Institute of Physics; and secondly, the physics of the foreground objects is being studied by the team members at Metsähovi Radio Observatory and Tuorla Observatory, and at the Observatory of the University of Helsinki.

The work carried out by the LFI Finnish instrument team (MilliLab, Ylinen Electronics, and Metsähovi Radio Observatory) covers the development of the Front-End Modules (FEM) and Back-End Modules (BEM) at 70 GHz. The activities of the Finnish team includes, in other words, all the high frequency components for 70 GHz up to the flight hardware level except the horns, OMTs, and waveguides between FEMs and BEMs.



Half of a LFI 70 GHz Front-End Module (FEM). This compact match box size component houses four MMIC low noise amplifiers and two phase shifters. The total gain is 35 dB. Also, a small horn to the 4 K reference load is included.

Presently, development of the Elegant Breadboard Model (EBB) has been completed and designing and manufacturing of the Engineering Model (EM) is going on. The EBB of LFI 70 GHz receivers have demonstrated state-of-the-art performance with a 25 K noise temperature, 16 GHz bandwidth, and a 1/f knee frequency of 25 mHz. The FEM of this receiver is shown above. Key components of the LFI 70 GHz receivers are the Monolithic Microwave Integrated Circuit (MMIC) chips. Low Noise Amplifiers (LNA) and phase shifter MMIC components are fabricated using Indium Phosphide (InP) process. InP is the best substrate for integrated circuits at higher millimeter wave frequencies. Before packaging the chips in a metal block, they are tested extensively on-wafer both are room and cryogenic temperatures.

Cryogenic on-wafer testing. MMIC components are tested at MilliLab's unique cryogenic on-wafer test facility before mounting them in the metal packages with waveguide connections.

New Insights on Galactic Dust by WMAP

Martin Giard and Xavier Dupac

Among the wealth of new results from the first year of observations of the Wilkinson Microwave Anisotropy Probe (WMAP), the one addressing the spectral index of Galactic dust is quite unexpected. In their paper on foreground emission, Bennett et al. (2003, astro-ph 0302208) show that the WMAP data clearly point to a spectral index of $\beta = 2.2$. The index β is the exponent of the power law in frequency, which is multiplied with the blackbody law to fit the dust emission spectrum. For theoretical reasons, the value of β was thought to be between 1 and 2. Previous large-scale observations favoured $\beta = 2$ (Boulanger et al. 1996). Large values of β were already measured at higher frequencies using the French two-metre stratospheric submillimetre telescope PRONAOS (see e.g. Dupac et al. 2002 A&A 392, 691). These are consistent with laboratory measurements on cold solids by Agladze et al. (1996 ApJ 462, 1026) and Mennella et al. (1998 ApJ 496, 1058). Moreover, both PRONAOS and laboratory data indicate that the dust spectral index varies with the grain temperature. Higher values of β were found at lower temperatures. The clue to this problem might lie in low-temperature quantum physics of the large dust grains. However, another interpretation has been proposed by Lagache (2003, astro-ph/0303335), who finds no spectral index change but extra millimetre emission in the WMAP data at high Galactic latitude. She attributes it to small transiently heated dust grains.

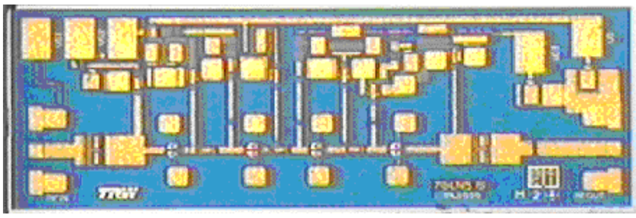
These issues are certainly of prime interest for PLANCK. With a spectral coverage which includes both the PRONAOS and WMAP wavelength ranges, PLANCK will have a unique opportunity to investigate the physics of cold solid matter.

HEMT Low Noise Amplifiers and CMB Observations

M. Bersanelli

Several successful CMB experiments carried out in the last decade have shown great potential of instruments based on low-noise transistor amplifiers (HEMT – high electrom mobility transistors). HEMT-based CMB measurements have been carried out both with differential receivers and interferometers at frequencies up to 90 GHz (e.g. Saskatoon, CAT, TOCO, Python, QMAP, CBI, DASI, Beast), often in ground based observations exploiting the atmospheric windows below 15 GHz, and around 35 GHz and 90 GHz. The recent WMAP results, with front-end receivers cooled at ~90K, provide a powerful demonstration of the capability of such devices for CMB space observations.

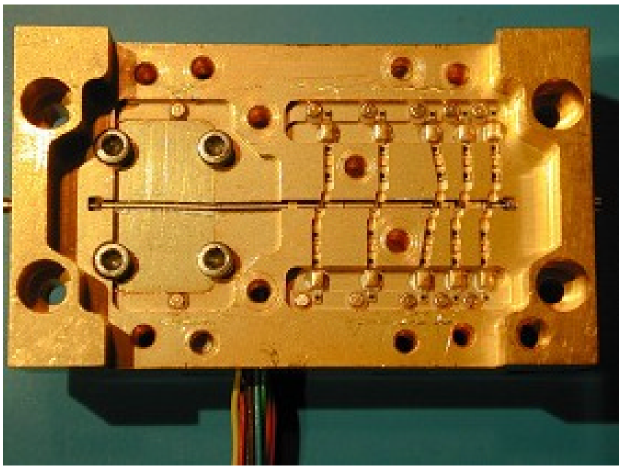
HEMT devices display a unique combination of features, including very low noise performance, wide bandwidth, operability at cryogenic temperatures and very low power consumption. The current generation of HEMT amplifiers is based on indium phosphide (AlInAs/GaInAs/InP heterostructure) which yields better noise performances and lower power consumption than the more traditional gallium arsenide (GaAs) technology. Corrugated feed horns are typicaly used to couple receivers with the sky or optical system, and very low sidelobe levels (down to -90dB) have been demonstrated. Designs optimised for good primary illumination and low edge taper include double profiled feeds, and high performances have been demonstrated at high frequencies.



Photograph of a microstrip LNA processed at TRW. Chips size is 2.1x0.8 mm^2

Progress in cryogenic HEMT noise temperature has been dramatic. In the late 70's, advances in GaAs field-effect transistors, combined with cryogenic cooling, made noise performances competitive with parametric amplifiers. In the past decade, further major improvements were obtained, leading in the mid 90's to state-of-the-art noise temperatures of ~15K at 40-50 GHz, and ~50 K at 60-75 GHz. Receivers based on SIS (Superconductor-Insulator-Superconductor) junctions cooled to ~4 K are capable of quantum limited detection, and are competitive with HEMTs in the millimetre regime (e.g. in the atmospheric window at wavelengths ~3mm; however, they are limited in bandwidth.

Today, the best low-noise amplfiers (LNA) measured performances are those obtained as part of the LFI "elegant breadboard" (EBB) models at 30, 70 and 100 GHz, developed and tested by the LFI teams in the U.K., Finland and USA respectively. The font-end is cooled at a physical temperature of 20K, as it will be during flight operation. TRW has produced chip designs with a measured noise temperatures around 35 K at in the 90-110 GHz band, and recent measurements of LNAs at 70 GHz and 30 GHz show typical noise temperatures of 30K and 8K in the 20% bandwidth. These high performances were obtained with very low power dissipation, compliant with the LFI thermal budget requirements. Some of these HEMT LNAs have been incorporated in flight-like front-end module LFI prototypes, which establish world-record performances in the 30-100 GHz range for noise, bandwidth and low power consumption.



44-GHz 5-stage LNA in Front-End Module RF section. The LNA is to the right, and the location to the left is ready to receive the phase switch on its lipped carrier.

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