3.5 Planck

Scientific goals

In late 1992, the Cosmic Background Explorer (COBE) team announced the detection of intrinsic temperature fluctuations in the Cosmic Background Radiation Field (CBRF), observed on the sky at angular scales larger than ~10°, and at a brightness level $DT/T \sim 10^{-5}$. These fluctuations have been interpreted as due to differential gravitational redshift of photons scattered out of an inhomogeneously dense medium. They thus map the spectrum of density fluctuations in the Universe at a very early epoch. This long-sought result has established the Inflationary Big Bang model of the origin and evolution of the Universe as the theoretical paradigm. However, in spite of the importance of the COBE measurement, many fundamental cosmological questions remain open. In particular, the COBE resolution does not probe the size scale of the vast majority of structures that we see in the Universe today, e.g. galaxies and clusters of galaxies. The main objective of the Planck mission is to build on the pioneering work of COBE, and map the CBRF fluctuations with an accuracy that is set by fundamental astrophysical limits.

Mapping the fluctuations of the CBRF with high angular resolution and high sensitivity would give credible answers to such questions as: the initial conditions for structure evolution, the origin of primordial fluctuations, the existence of topological defects, and the nature and amount of dark matter. Planck will set constraints on theories of particle physics at energies larger than 10^{15} GeV, which cannot be reached by any conceivable experiment on Earth. Finally, the ability to measure to high accuracy the angular power spectrum of the CBRF fluctuations will allow the determination of fundamental cosmological parameters such as the density parameter (W_0), the Hubble constant (H_0), and the cosmological parameter (L), with an uncertainty of order a few percent.

The observational goal of the Planck mission is to mount a single space-based experiment that will survey the majority of the sky with an angular resolution better than 10 arcmin, a sensitivity better than $DT/T \sim 2 \cdot 10^{-6}$, and covering a frequency range that is wide enough to encompass and deconvolve all possible foreground sources of

Table 3.5.1. Planck model payload characteristics.

Telescope	1.5 m. (proj. apert.) Gregorian; shared focal plane; $\epsilon_{system} \sim 1\%$. Viewing direction offset 80°-85° from spin axis									
Instrument	LFI				HFI					
Center Frequency (GHz)	30	44	70	100	100	143	217	353	545	857
Detector Technology	HEMT radio receivers				Bolometers					
Detector Temperature	~20 K				~0.1 K					
Cooling Requirements	H_1 sorption cooler				H_2 sorption + 4K J-T stage + Dilution					
Number of Detectors	4	6	12	34	4	12	12	6	8	6
Bandwidth ($\Delta\nu/\nu$)	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25	0.25	0.25
Angular Resolution (arcmin)	33	23	14	12	10.7	8.0	5.5	5.0	5.0	5.0
Average $\Delta T/T$ per pixel (12 mos., 1σ, 10^{-6} units)	1.6	2.4	3.6	4.3	1.7	2.0	4.3	14.4	147.0	6670
Sensitive to linear pol.	yes	yes	yes	yes	no	yes	yes	no	yes	no

For further information on Planck, see http://astro.estec.esa.nl/Planck

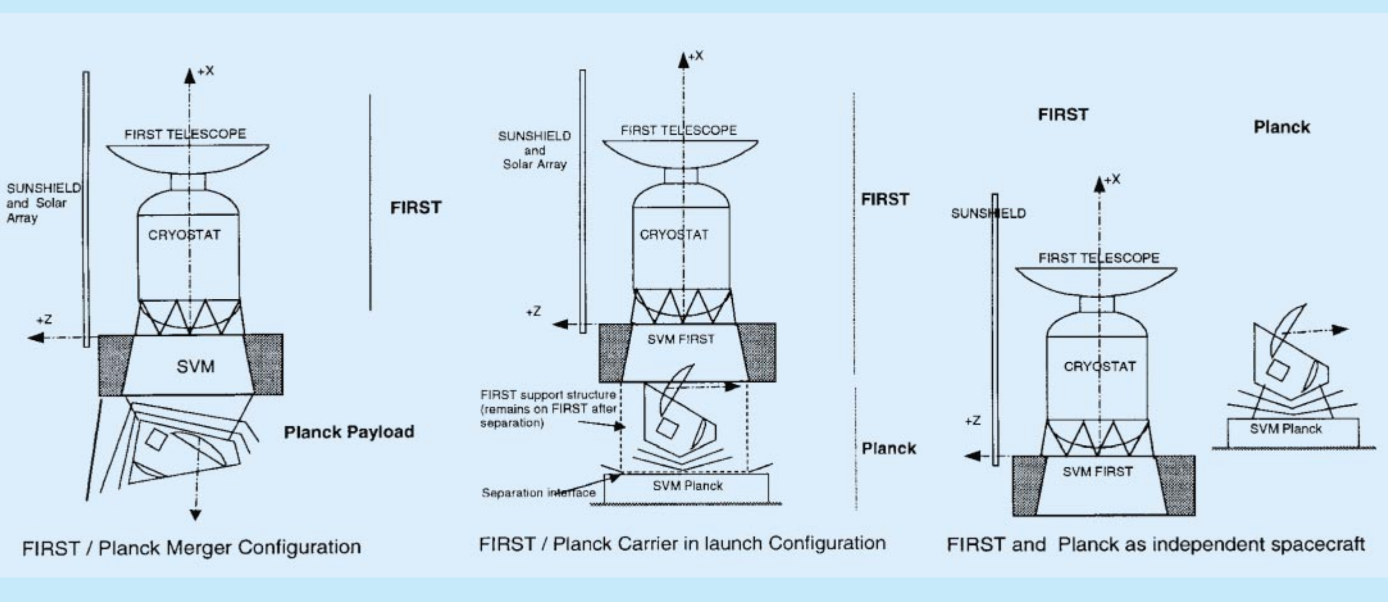

Figure 3.5.1. Options being considered for the FIRST and Planck missions.

emission. The main scientific result of the mission will be a near-all sky map of the fluctuations of the CBRF in at least three frequency channels. In addition, the sky survey will be used to study in detail the very sources of emission that ‘contaminate’ the cosmological signal, and will result in a wealth of information on the dust and gas in both our own Galaxy and extragalactic sources. One specific notable result will be the measurement of the Sunyaev-Zeldovich effect in many thousands of galaxy clusters, leading, for example, to the determination of cluster bulk velocities over scales of ~300 Mpc out to a redshift of ~1 with a velocity uncertainty of ~50 km/s.

The model payload

The Planck model payload is currently based on an offset Gregorian 1.5 m telescope. The focal plane will be shared by clusters of detectors in nine frequency bands covering 30-900 GHz. The lowest frequency bands (up to ~100 GHz) will consist of HEMT-based receivers actively cooled to ~20 K by a H_2 sorption cooler. The higher frequency bands will consist of arrays of bolometers cooled to ~100 mK; the H_2 sorption cooler will provide precooling for a Joule-Thomson 4 K stage, to which a dilution refrigerator will be coupled. The characteristics and estimated performance of the Planck model instruments are shown in Table 3.5.1.

The satellite will be placed into a Lissajous orbit around the L2 Lagrangian point of the Earth-Sun system. At this location, the payload can be continuously pointed in the anti-Sun direction, thus minimising potentially confusing signals due to thermal fluctuations and stray light entering the detectors through a far sidelobe. From L2, Planck will carry out two complete surveys of the full sky, for which it requires 12-14 months of observing time. The spacecraft will be spin-stabilised at 1 rpm. The viewing direction of the telescope will be offset by 80-85° from the spin axis, so that the observed sky patch will trace a large circle on the sky.

Planck is a survey-type project that will be developed and operated as a Principal Investigator (PI) mission. The payload will be provided by two PI teams, who will also man and operate two Data Processing Centres, which will process and monitor the data during operations and reduce the final data set into the science products of the mission. All-sky maps in nine frequency bands will be made publicly available 1 year after completion of the mission, as well as a first generation set of maps of the CBRF, Sunyaev-Zeldovich effect, dust, free-free and synchrotron emission, and a catalogue of point sources. The time series of observations (after calibration and position reconstruction) will also eventually be made available as an online archive.

Project status

Since 1996, when Planck was selected as the M3 third medium-sized mission of ESA's Horizon 2000 Scientific Programme, budgetary pressures within ESA's scientific programme have forced a reconsideration of the original implementation plan. Currently, three implementation scenarios are being considered. In any of these scenarios, the intention of ESA is to keep the cost of FIRST and Planck together within the cap for a Cornerstone mission minus 10%:

- The baseline scenario is to combine Planck with ESA's Far Infrared and Submillimetre Telescope (FIRST; see section 3.6), i.e. to put both payloads on a single spacecraft bus and operate them sequentially (Figure 3.5.1a). In this 'merged' configuration, the FIRST/Planck satellite would be launched on a dedicated Ariane-5 rocket.
- An alternative scenario is for FIRST and Planck to remain as stand-alone missions (Figure 3.5.1c). In this configuration, Planck would most probably be launched by a Russian Soyuz-Fregat rocket.
- A third possibility is for FIRST and Planck to be launched together, but to separate during the transfer to the final orbit, and thereafter be operated independently. This is often referred to as the 'carrier' option due to the launch configuration of the two spacecraft (Figure 3.5.1b).

After in-house evaluation of these options, ESA commissioned two parallel industrial studies, by Matra Marconi Space in Toulouse, and Aerospatiale in Cannes, to assess in detail their technical feasibility and cost. The technical activities began in September 1997 and were finished in February 1998. As a result of the studies, it is now established that all three solutions are technically feasible. The costing activities will be completed in March 1998.

In parallel to the industrial studies, ESA issued to the scientific community in October 1997 an Announcement of Opportunity requesting proposals to provide instruments for both Planck and FIRST. Potential proposers were asked to assume that FIRST and Planck would be merged (as in the first scenario above), and that FIRST/Planck would be launched at the end of 2005. Proposals have been duly received in February 1998 and are undergoing an evaluation process.

ESA's intention is to make a decision on the implementation scenario for Planck and FIRST by late May 1998, once all the information deriving from the industrial studies and the instrument proposals has been gathered and analysed. At the same time, the instrument PIs will be selected. During the second half of 1998, the instrument proposals will be reiterated in order to make any modifications required by the particular implementation scenario chosen. This process will end in early 1999, when the instrument complement will be finally approved by ESA's Space Programme Committee.