THE CURRENT STATUS OF THE HERSCHEL/PLANCK PROGRAMME

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Abstract

The Herschel/Planck ESA programme combines two ESA missions of the HORIZON 2000 programme, the cornerstone mission of Herschel, formerly called the Far InfraRed and Submillimetre Telescope (FIRST), and the third medium sized mission, Planck.

Herschel is a multi-user observatory, observing in the far infrared and sub-millimetre part of the electromagnetic spectrum, in the wavelength range from 60 to 670 μm. The Planck mission is a survey mission dedicated to map the anisotropies of the temperature of the cosmic background radiation.

Both missions are planned to be launched in February 2007 on a single ARIANE 5 launcher from the European Space Port of Kourou. Both missions use orbits around the 2nd Lagrangian libration point L2, that is approximately 1.5 million kilometres away from the earth in the anti-sun direction.

The programme has just started with the spacecraft development and the paper will give an overview on the Herschel and Planck system design, the planned project implementation and the actual status of the programme.

1. Introduction

The Herschel/Planck Programme combines two missions of the European Space Agency (ESA) long-term scientific plan Horizon 2000. It is a programme implementing the two scientific missions Herschel, formerly known as the Far Infrared and Sub-millimetre Telescope (FIRST) and the Planck mission.

Herschel is the fourth cornerstone mission of ESA, a multi-user observatory, dedicated to perform astronomical observations in the far-infrared and sub-millimetre wavelength range. The detectors in the focal plane units of the scientific instruments are cooled to cryogenic temperatures in the range of 0.3 to 2K in order to reach the necessary sensitivity for the observation of a variety of weak radiation sources.

Planck is the third Medium Size mission (M3) in ESA's long-term scientific plan Horizon 2000. It will produce a full map of the sky, imaging the temperature anisotropies of the Cosmic Microwave Background (CMB) at a sensitivity level of $\Delta T/T = 2 \times 10^{-6}$ and an angular resolution of 10 arc-minutes. For this type of measurements the Planck detectors require cryogenic temperatures, 0.1K for the bolometers in the High Frequency Instrument (HFI) and 20K for the HEMT (High Electron Mobility Transistors) in the Low Frequency Instrument (LFI). There is a further need for a cold (40K - 65K), low emissivity telescope.

The combination of the two missions into one programme was driven by achievable economy of scale and the technical advantage of common developments for both spacecraft. Both spacecraft are developed completely parallel, join during the launch campaign and will be launched on one Ariane 5 launch vehicle.

This paper describes the present Herschel and Planck spacecraft design, the main technical challenges and provides an outlook on the development plan and schedule. Sect. 2 provides an overview of the Herschel/Planck mission and a system description of the Herschel and Planck spacecraft concepts. Sect. 3 introduces the spacecraft development approaches. Finally Sect. 4 gives an overview of the present programmatic status and an outlook to the near future.

2. Herschel/Planck Mission and Spacecraft

The Herschel programme is one of the observatory type missions of the European Space Agency (ESA). It is a multi-user mission and targets the far-infrared and sub-millimetre part of the spectrum. The key scientific topics for Herschel are deep broadband extra-galactic photometric surveys, follow up spectroscopy of objects discovered during the survey, investigation of physics and chemistry of interstellar medium including star formation, observational astro-chemistry of gas and dust and detailed high resolution spectroscopy of comets and planets.

Herschel was conceived (under different names, e.g. heterodyne spectroscopy mission, far infrared and submillimetre telescope) in the early 1990's. The phase A study was completed in March 1992. The mission was approved for implementation by the ESA Science Programme Committee as fourth Cornerstone in November 1993. In the following years the mission definition was refined in order to optimise and improve the scientific return and with the objective to reduce the overall mission costs. A number of

Proc. Symposium *'The Promise of the Herschel Space Observatory'* 12–15 December 2000, Toledo, Spain
ESA SP-460, July 2001, eds. G.L. Pilbratt, J. Cernicharo, A.M. Heras, T. Prusti, & R. Harris

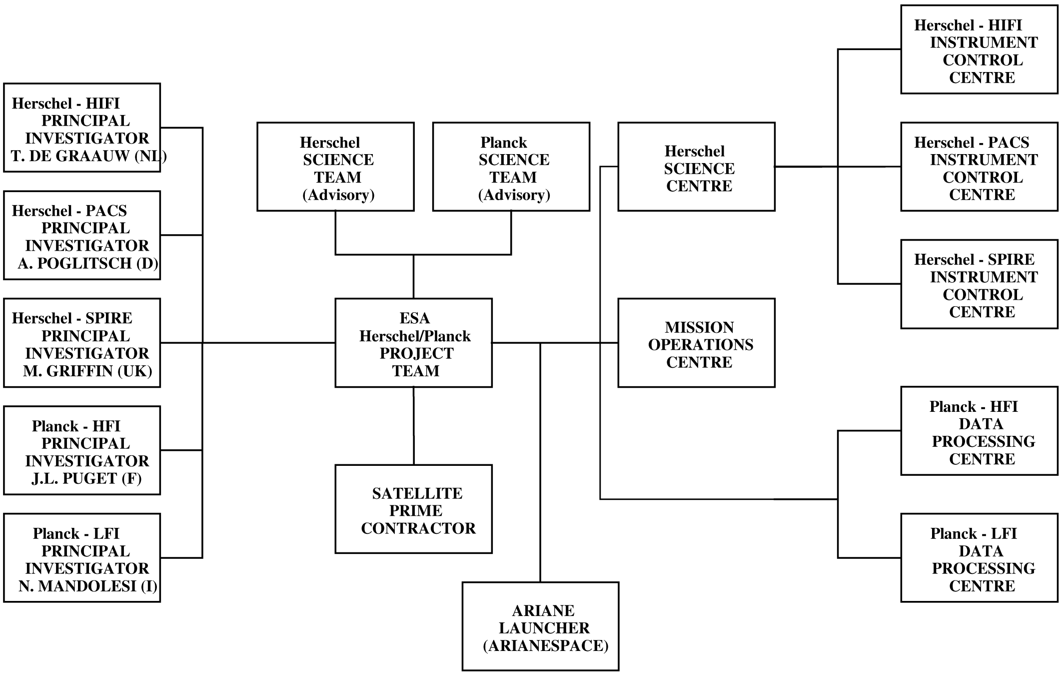

Figure 1. Herschel/Planck Project Organisation

similarities of the FIRST mission with that of Planck, another ESA mission raised the question whether one could combine both missions. Planck is the third Medium Size mission (M3) in ESA's long-term scientific plan Horizon 2000. The Planck mission objective is to provide a map of sky in submillimetre and millimetre waveband that the shows the temperature of anisotropies of the Cosmic Microwave Background (CMB) at higher sensitivity than ever before.

Several studies were performed to identify the best technical concept for the combined mission concept. These studies included a version with both payloads on one spacecraft that would share its resources for a sequential mission. Planck would start in this scenario with one sky survey, followed by Herschel for early deep surveys with the Planck second sky survey afterwards and the rest of the mission devoted to Herschel. The baseline scenario selected at the end of these studies was a solution with two completely separate spacecraft that would join at the launcher. This concept was used as a reference concept for the industrial invitation to tender sent to industry on 1 September 2000. The industrial proposals were received in early December 2000 and were thoroughly evaluated. At the time of this conference the selection of a prime contractor had not yet taken place. This paper, however, has been completed after the start of the industrial development and the design description given below takes this into account, i.e. the design description is based on the input provided by the proposal from Alcatel Space Industries (France, Cannes).

2.1. Herschel/Planck Project Organisation

The overall project organisation is shown in Fig. 1. The ESA project team, located at ESTEC, in Noordwijk, the Netherlands is in the centre of the organisational structure. The ESA project is responsible for the management of development, launch and in-orbit commissioning of both satellites. The main partners involved in the development are the Principal Investigator Groups, the science teams, industry – the satellite contractors –, the launcher authority and science and spacecraft operation teams. Since the programme consists of two spacecraft, commonality of tasks including ground segment activities is being actively exploited, not only within the ESA project and industry, but also within the five Principal Investigator groups.

2.2. Launch, Transfer and Orbit

Both – the Herschel and the Planck spacecraft – will be launched with one single ARIANE 5 launch vehicle from Kourou. During the launch Planck is on place of the lower passenger, inside a launcher adapter, the SYLDA 5 that carries the Herschel spacecraft. After burnout and separation from the lower ARIANE composite the upper stage is drifting half around the earth before the last stage is ignited and puts the composite into the required transfer trajectory towards the second Lagrangian Point L2 (see Fig. 2). Different strategies for separation of the spacecraft are being exploited, taking consideration of the constraints of the satellites w.r.t. the sun direction. Even though both

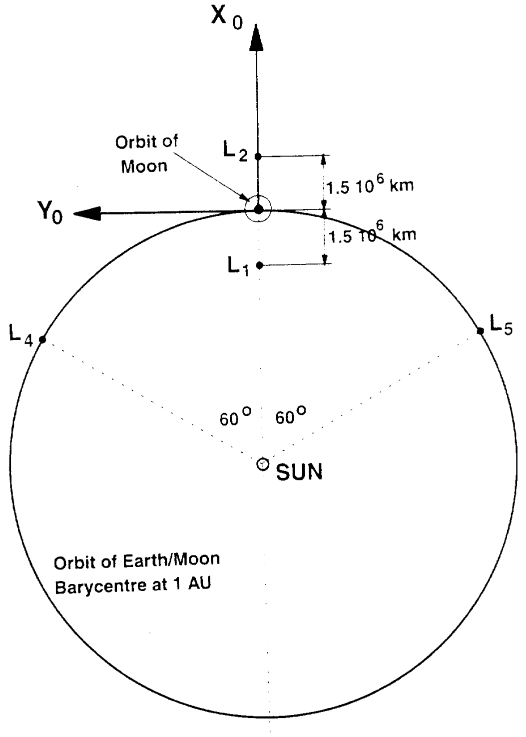

Figure 2. L2 Orbit location

satellites will finally be in an orbit around L2, these orbits are quite different. Herschel will acquire its final orbital position at around 1.5 million km from the earth with only a minor correction manoeuvre after a transfer time of approximately six months. This orbit is a large Lissajous orbit, i.e. an orbit around L2, with diameter of about 700000 km or an sun-s/c-earth angle up to 30°. Planck requires a smaller orbit around L2, with a maximum sun-s/c-earth angle of 10°and will therefore perform a major insertion manoeuvre three months after launch. The Orbits around the L2 are unstable and without orbit corrections the spacecraft would deviate exponentially from the nominal one. Small correction manoeuvres, applied in monthly intervals will, however, maintain the orbit close to the nominal one. Figure 3 shows the transfer trajectories and the two orbits for Herschel and Planck. In order to avoid that the spacecraft pass through the earth shadow within their orbital lifetime, small eclipse-avoidance-manoeuvres are carried out as necessary (approximately twice a year).

2.3. Herschel Spacecraft Design

The Herschel spacecraft design concept is shown in Fig. 4. A modular concept has been chosen. The Herschel extended Payload Module (H E-PLM) is the upper part of the satellite and mounted on top of the Service module (SVM). The E-PLM consists of the cryostat, the Herschel telescope and the sunshield and sunshade. The Herschel telescope is a 3.5m diameter Cassegrain system, diffraction limited at 80 μm and operating at an orbital temperature of 70K to 90K. The telescope is protected from sun illumination by the sunshade. The focal plane units of the three scientific instruments are located at the focus of the telescope inside the cryostat. The cryostat is protected in a similar way as the telescope from direct sun illumination via the sunshield, that acts also as solar array for the spacecraft. The temperature of the outer shell of the cryostat has been calculated to be similar to that of the telescope at around 80K.

The SVM is mounted below the H-EPLM and carries all spacecraft electronics and those units of the scientific instruments that operate in an ambient temperature environment. The interface of the spacecraft to the launcher is at the level of the SVM with a standard clampband interface.

Dimensions:	9.3 m high x 4.5 m diameter
Herschel telescope diameter:	3.5 m
Total mass:	2970 kg
Solar array power:	1450 W
Cryogenic lifetime at L2:	3 years

The Herschel spacecraft is three-axis stabilised and points very accurately, e.g. with a relative pointing accuracy of below 0.3 arcsec, to specific objects selected for this observatory mission. The normal operational mode of the spacecraft is to observe autonomously for a period of 21 hours a day, collecting the scientific data in a solid state recorder onboard and downlink the data during the ground contact time of 3 hours.

2.4. Herschel E-PLM

The cooling concept for the Herschel Instruments is based on the proven principle used for the ISO mission. The temperatures required in the instrument focal plane are provided down to 1.7 K by a large superfluid Helium Dewar (helium at 1.6 K), sized for a scientific mission of 3.5 years (3 years operation at L2, 6 months transfer time). This is achieved with a total amount of around 2500 litres of Helium as a cryogen. The cryostat provides as lowest service temperature 1.7 K to the instruments. Further cooling down to 0.3K, required for two instruments (SPIRE and PACS bolometers) is achieved by dedicated ^{3}He sorption coolers that are part of the respective instrument Focal plane unit.

The Herschel cryostat is to a major extent making use of the technology developed for building the ISO cryostat and was one of the elements that allowed the reduction in development risk, effort and costs.

In orbit the liquid Helium is maintained inside the tank by means of a phase separator (sintered steel plug). The heat load on the tank is evaporating the Helium over the

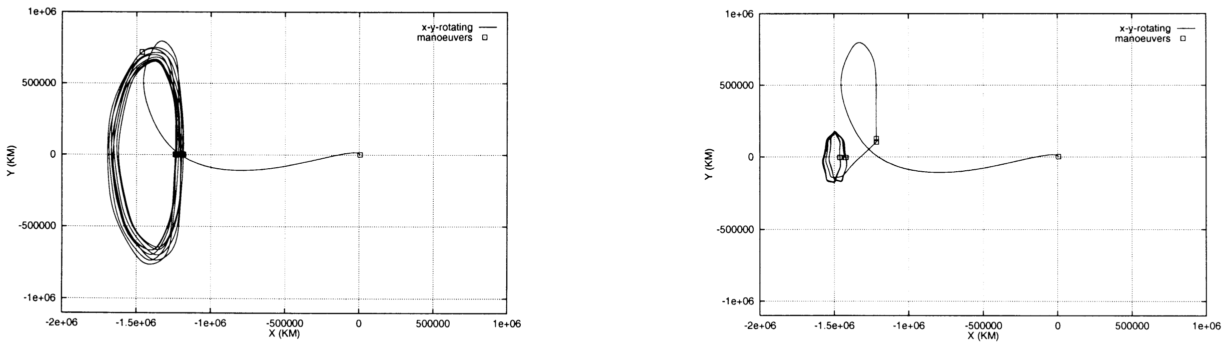

Figure 3. Herschel and Planck Transfer Trajectories

mission time at a rate of about 200 g a day. The enthalpy of the gas is efficiently used to cool parts of the instruments that do not require the low tank temperature (two level at around 4 K and around 10 K stages). After leaving the instruments the gas is further used to cool the 3 thermal shields of the cryostat.

The space side of the Cryostat Vacuum Vessel (CVV) is used as a radiator area to cool the CVV on orbit to a final equilibrium temperature of about 80K. This radiator area is coated with high emissive coating to achieve low temperatures in the L2 orbit. The other outer surfaces of the CVV are covered by Multi-Layer-Insulation (MLI), in order to insulate it from the warm items (satellite bus and Sunshield). The outer layer of the MLI is optimised for the lowest temperature of the CVV.

The outside of the cryostat is the mechanical and thermal mounting base for the Herschel telescope and some units of the scientific instruments.

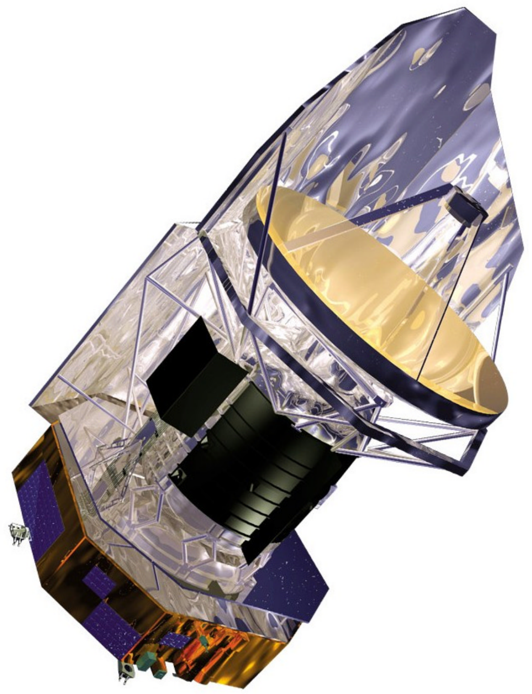

Figure 4. Herschel Satellite

2.5. Herschel Telescope

The Herschel telescope is of a Cassegrain type with a primary mirror of 3.5 m diameter. The telescope is located outside and above the cryostat. The focus is approximately one meter below the vertex of the primary mirror, inside the cryostat. The telescope interface is a triangular structure that is held via a set of struts from the cryostat. The primary mirror is held by isostatic mounts from this triangle. The tripod assembly with the secondary mirror at its end is mounted to the structure of the primary mirror. The telescope is protected by the sunshade from direct radiation from the sun. The expected orbital temperature is below 80 K. Further main parameters of the telescope are summarised in Table 1.

2.6. Planck Spacecraft Design

The Planck spacecraft design concept is shown in Fig. 6. As for Herschel a modular concept has been chosen. The Planck Payload Module (PPLM) is the upper part of the Planck satellite and mounted on top of the Service module (SVM). The main elements of the PPLM are the V-groove shields that isolate the telescope and the focal plane unit thermally from the SVM, the cryogenic radiator baffle, the telescope and the focal plane unit. The Planck telescope is an offset aplanatic system with a projected aperture of 1.5 m. The line of sight of the telescope is 95 degrees from the nominal sun direction, the sun facing in that case the bottom of the spacecraft. The telescope is thermally anchored at the cryogenic radiator that acts at the same time as baffle and cooled down in orbit to a temperature around 50 K. The integrated focal plane unit of the High Frequency Instrument (HFI) and the Low Frequency Instrument (LFI) is mounted in the focal plane of the telescope, below the primary reflector. The thermal design of the Planck Payload Module allows to provide a temperature background of below 60 K, however, consid-

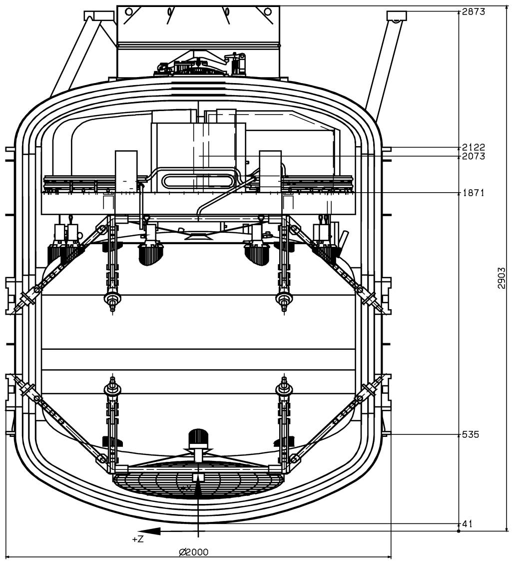

Figure 5. Herschel Cryostat

Table 1. Main Requirements of the Herschel Telescope

Parameter	
Primary reflector diameter	3500 mm, f/0.5
Telescope focal length	27 000 mm
Operating wavelength	60 μm to 670 μm
Operating Temperature	60 K to 100 K
Eigenfrequency	$>$ 45 Hz lateral $>$ 60 Hz axial
Overall height	$<$ 1700 mm
Overall mass	$<$ 260 kg
WFE requirement	$<$ 6μm rms

ering a heat loads on each of the V-groove shield in the order of Watts.

The SVM is mounted below the PPLM and carries all spacecraft electronics and those units of the scientific instruments that operate in an ambient temperature environment. The interface of the spacecraft to the launcher is at the level of the SVM with a standard clampband interface. Of specific interest are the radiator panels for the Compressors of the 20 K Sorption Cooler, which require a large radiative area with heat pipes to dissipate their 500 W power on a radiator below 280 K. The Planck SVM also carries the solar array on its lower face.

The key characteristics of the Planck satellite are:

Dimensions:	4.1 m high x 4.2 m diameter
Planck telescope projected diameter:	1.5 m
Total mass:	1430 kg
Solar array power:	1655 W
Operational lifetime:	21 months

The Planck spacecraft is a low spinning system, with a spin rate of 1 rpm. The normal operational mode of the spacecraft is to observe autonomously for a period of 21 hours a day, collecting the scientific data in a solid state recorder onboard and downlink the data during the ground contact time of 3 hours.

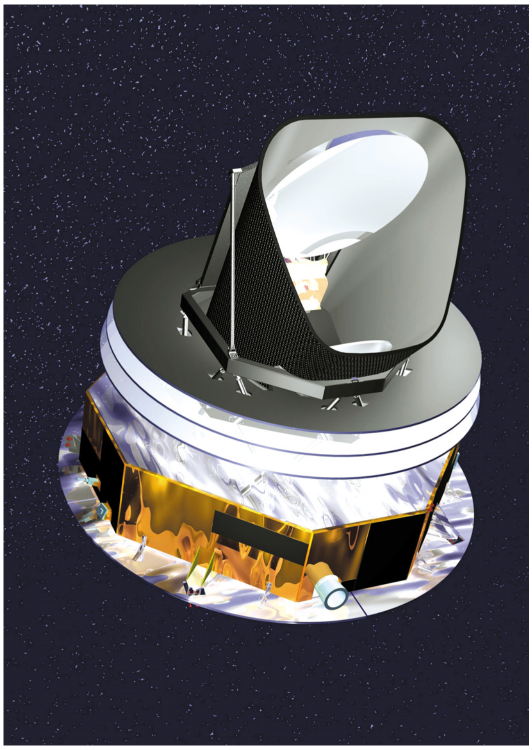

Figure 6. Planck Spacecraft

3. Herschel/Planck Development

The procurement and development of Herschel and Planck has been combined in order to maximise the advantages of commonality. The Herschel/Planck development schedule is shown in Fig. 7. The overall development at system level is planned, following a protoflight environment, with only one complete model of each satellite being developed. The plan for Herschel and Planck is founded on a number of basic elements:

– The Herschel cryostat is strongly relying, in terms of design and definition, on the experience gathered with the ISO programme. This means that it is permissible to implement a protoflight model philosophy. This, however, still means a full qualification programme of the cryostat. This is achieved by an early development of the Herschel flight model of the cryostat. This hardware is used to carry out early in the development mechanical and thermal performance tests (lifetime). This removes performance uncertainties and results in a solid basis for the flight model testing after delivery of the flight model instruments.

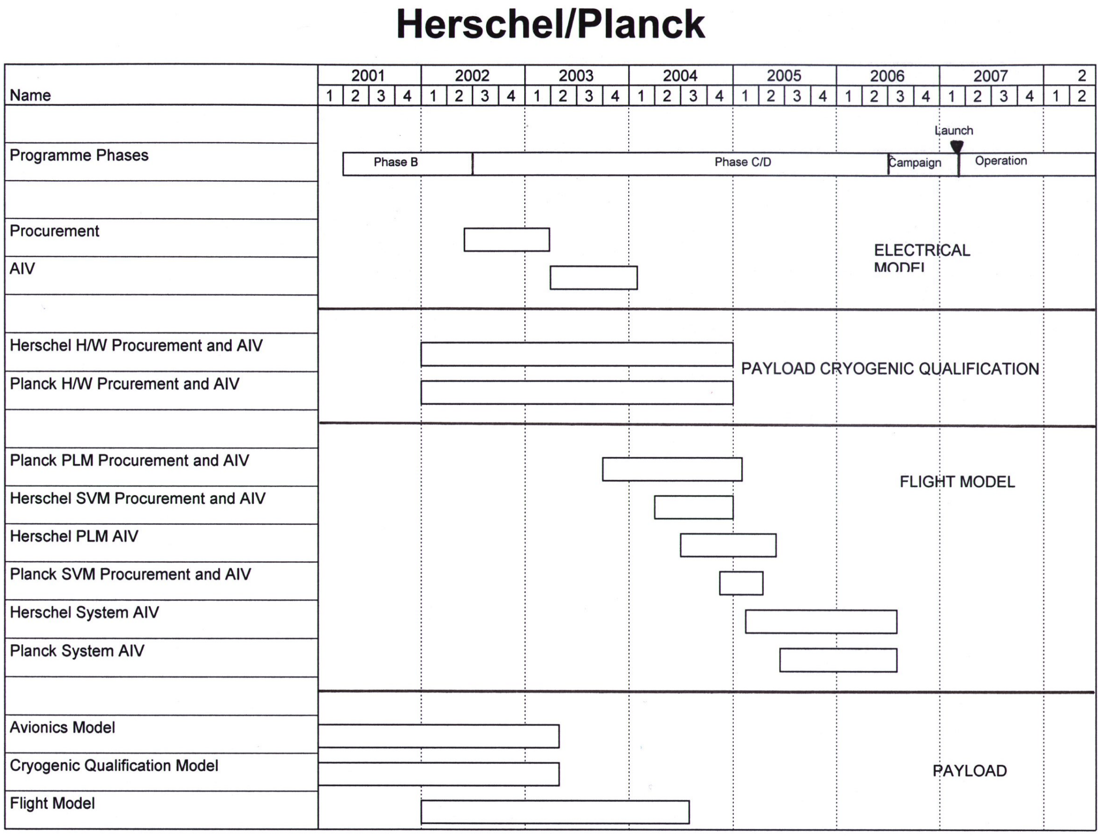

Figure 7. Herschel/Planck Development Schedule

- There is a definitive need to test the qualification models of the scientific instruments in a spacecraft 'system' environment. This test should be decoupled as far as possible from the main system development. This is being realised for Planck by a dedicated qualification model of the Planck Payload Model. The main test objectives with this model are mechanical verification and specifically the performance of the cryogenic radiator that provides passive cooling down to 60 K and is a critical development. For performance verification of the Herschel instrument cryogenic qualification models a representative cryostat, the modified qualification model of the ISO cryostat, that by design exhibits a lot of similarities to Herschel has been selected.
- The satellite service module development criticality is around the avionics part (mainly the data handling and the ACMS). In order to mitigate the corresponding development risk a dedicated avionics model of the spacecraft has been defined that will be used to verify the electrical interfaces. This model will be further used as a representative testbed for the verification of the onboard software.
- The Herschel Telescope is the one most critical development item of the system and has been separated from the main spacecraft development effort. The Herschel telescope is provided by Astrium SAS (France, Toulouse) as a separate development activity directly carried out by ESA. The development activities for the flight model telescope are close to the start.

The reflectors of the Planck telescope are provided to the programme via a memorandum of understanding between the Danish Space Research Institute and ESA. The planned start of the development in European industry is in the summer of 2001.

4. Project Implementation and Status

As shown in the schedule in Fig. 7 the spacecraft development phase has started in April 2001 with the kick-off of the main industrial contractors, i.e. Alcatel Space Industries (France) as prime contractor and responsible for the Planck Payload Module, Astrium GmbH (Germany) as responsible for the cryostat development and the Herschel Spacecraft Testing and finally Alenia Spazio (Italy) as responsible for both service modules for Herschel and Planck. Main activities and milestones for the coming year are the completion of the industrial team through a competitive procurement process and the completion of the preliminary design with a PDR in Summer 2002.

Acknowledgements

The spacecraft design and further data presented above is the result of the work performed by European industry and many ESA staff (at ESTEC and ESOC). I gratefully acknowledge their contributions. I would like to thank the Herschel/Planck Scientific teams who work on the development of the payload instruments and the ESA Herschel/Planck project team.