Acta Astronautica 68 (2011) 1283–1291

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Launch and early operations of Herschel and Planck ☆

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ARTICLE INFO

Article history:
Received 22 January 2010
Received in revised form
31 August 2010
Accepted 1 September 2010
Available online 29 October 2010

Keywords:
Orbit control
Attitude control
Lagrange orbits

ABSTRACT

On 14 May 2009 the European Space Agency launched 2 space observatories: Herschel (with a 3.5 m mirror it is the largest space telescope ever) will collect long-wavelength infrared radiation and will be the only space observatory to cover the spectral range from far-infrared to sub-millimetre wavelengths, and Planck will look back at the dawn of time, close to the Big Bang, and will examine the Cosmic Microwave Background (CMB) radiation to a sensitivity, angular resolution and frequency range never achieved before. This paper will present the Flight Dynamics, mission analysis challenges and flight results from the first 3 months of these missions.

Both satellites were launched on the same Ariane 5 and travelled to the L2 Lagrange point of the sun–earth system 1.5 million km from the earth in the opposite direction of the sun. There they were injected to a quasi-halo orbit (Herschel) with the dimension of typically 750,000 km × 450,000 km, and a Lissajous orbit (Planck) of 300,000 km × 300,000 km.

In order to reach these Lissajous orbits it is mandatory to perform large trajectory correction manoeuvres during the first days of the mission. Herschel had its main manoeuvres on the first day. Planck had to be navigated on the first day and by a mid-course correction manoeuvre, the L2 orbit insertion manoeuvre was planned on day 50. If these slots were missed, fuel penalties would rapidly increase.

This posed a heavy load on the operations teams because both spacecrafts have to be thoroughly checked out and put into the correct modes of their attitude control systems during the first hours after launch.

The sequence of events will be presented and explained and the orbit determination results as well as the manoeuvre planning will be emphasised.

1. Introduction

1.1. Herschel

Herschel (Fig. 1) is set to revolutionise our understanding of the Universe. A versatile infrared space telescope, Herschel's main objective is to study relatively cool objects across the Universe, in particular, the formation and evolution of stars and galaxies and the relationship between the two.

- Herschel carries the largest telescope ever flown in space, with a primary mirror 3.5 m in diameter;
- it is the first space observatory to observe the entire range of wavebands from far-infrared to sub-millimetre;
- it provides the highest sensitivity in its wavelength range;
- it will cover unexploited infrared wavelengths, allowing it to study the earliest stages in the life of a star that have not been observed by other telescopes, revealing the youngest stars in our Galaxy for the first time;

☆ This paper was presented during the 60th IAC in Daejeon.

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doi:10.1016/j.actaastro.2010.09.003

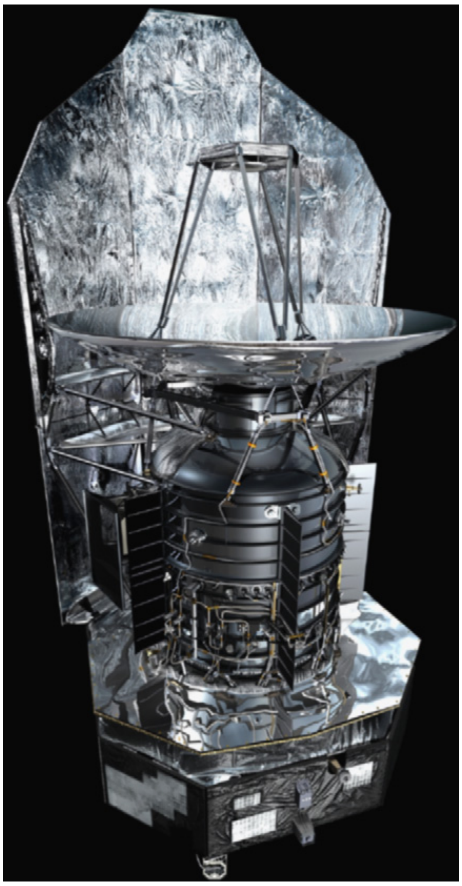

Fig. 1. Artist's impression of Herschel.

- Herschel will feature the highest-ever resolution in the far infrared;
- the first observatory capable of studying the earliest stages of star formation;
- Herschel will take the first census of star-forming galaxies throughout the Universe at the peak of star formation, allowing astronomers to chart the star formation history and evolution of galaxies in the Universe;
- it is the first observatory to take a census of ongoing star formation in our galactic neighbourhood;
- it is the most powerful tool to search for water throughout our Galaxy.

The science module carries 3 instruments; Spectral and Photometric Imaging Receiver (SPIRE), Heterodyne Instrument for the Far Infrared (HIFI) and Photoconductor Array Camera and Spectrometer (PACS).

1.2. Planck

Planck (Fig. 2) mission will be the first European sky survey mission whose main goal is the study of the Cosmic Microwave Background (CMB)—the relic radiation from the Big Bang. It will measure the fluctuations of the CMB with an accuracy set by fundamental astrophysical limits.

The spacecraft is equipped with a 1.5 m aperture Gregory type telescope and two instruments operating at radio to sub-millimetre wavelengths; High Frequency Instrument (HFI) and Low Frequency Instrument (LFI). A sophisticated cryogenic system keeps their detectors at temperatures close to absolute zero.

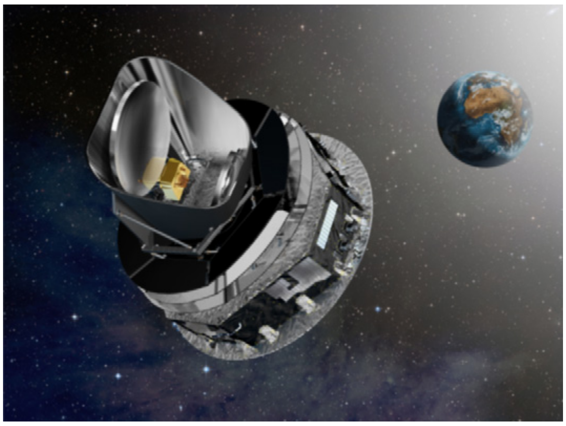

Fig. 2. Artist's impression of Planck observed at microwave wavelengths ESA's Planck observatory is the third space mission of its kind. It will measure tiny fluctuations in CMB with unprecedented accuracy, providing the sharpest picture ever of the young Universe—when it was only 380,000 years old—and zeroing-in on theories that describe its birth and evolution.

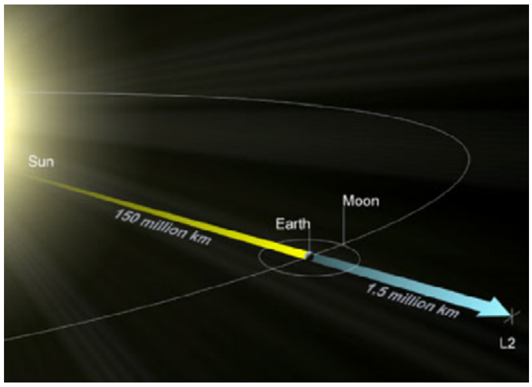

Fig. 3. Location of L2.

1.3. Lagrange point L2

The L2 point (Fig. 3) is rapidly establishing itself as a pre-eminent location for advanced spaceprobes and ESA has a number of missions that will make use of this orbital 'sweet-spot' in the coming years. L2 will become home to ESA missions such as Herschel, Planck, Eddington, Gaia, the James Webb Space Telescope and Darwin.

L2 is one of the 5 so-called Lagrangian points, discovered by mathematicians Joseph Louis Lagrange and Leonard Euler, where in the sun–earth system the gravitational forces acting between two objects and the centrifugal forces cancel each other out and therefore can be used by spacecraft to 'hover' with respect to the earth. It is located 1.5 million km directly 'behind' the earth as viewed from the sun. It is about four times further away from the earth than the moon ever gets and orbits the sun at the same rate as the earth.

1.4. Flight dynamics tasks

The project support by ESOC's Flight Dynamics Division is broken down into these elements.

- Mission analysis: Usually this service finishes far before launch and operations phase. For Lagrange point missions there is support required also for periods after launch, including the commissioning phase.
- Orbit determination.
- Manoeuvre optimisation and execution.
- Attitude determination.
- Command generation for support of attitude control system operations.
- Test and validation of all generated products and received station data.

2. Mission analysis

The Herschel/Planck mission has been designed such that an ARIANE5/ECA, with an optimum ascent trajectory, will inject the two spacecraft together close to the stable manifold of a large amplitude Lissajous orbit around L2 (Table 1). Herschel will first remain on this orbit (Figs. 4 and 7). For Planck an optimum transfer strategy from there to an orbit with a smaller maximum sun–spacecraft–earth angle of 15° has been constructed (Figs. 5 and 8).

Table 1
Herschel and Planck orbit conditions at spacecraft separation in earth fixed frame [1].

	Herschel	Planck
Inclination i(deg)	6.001	6.001
Arg. of perigee ω(deg)	162.015	162.029
Asc. node Ω(deg)	−108.010	−108.011
Perigee altitude(km)	270.085	270.828
Apogee altitude(km)	1,200,593.007	1,176,638.548
True anomaly at injection(deg)	40.208°	50.448°
Time of separation from H0(s)	1569.483	1719.835

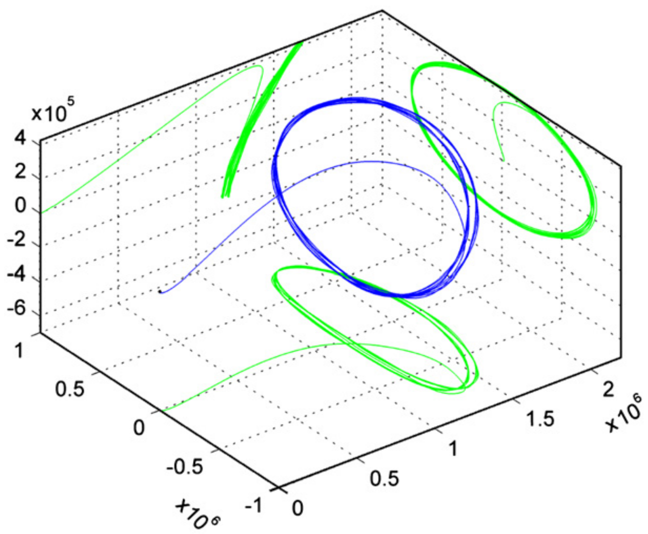

Fig.4. Herschel quasi-halo orbit in earth centred rotating reference frame propagated over 4 years [2].

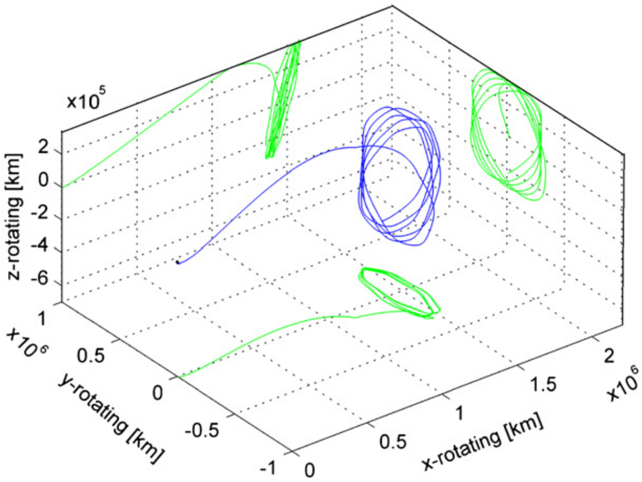

Fig. 5. Planck Lissajous orbit in earth centred rotating reference frame propagated over 2.5 years [2].

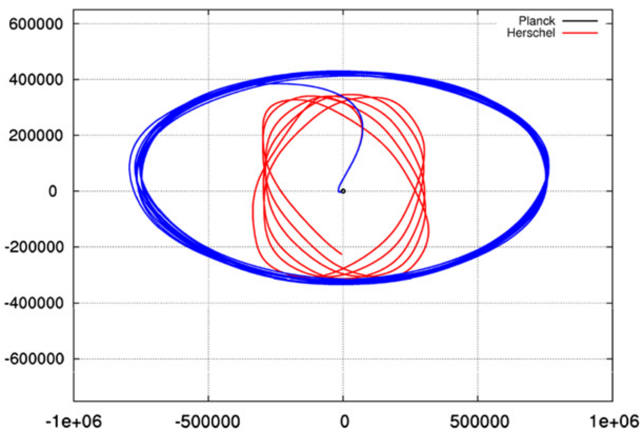

Fig. 6. Herschel (blue) and Planck (red) orbits as seen from earth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

A deviation from the Herschel orbit will be generated together with the first stochastic orbit correction manoeuvre 2 days from launch and one or two insertion manoeuvres will inject to the Planck orbit. The optimisation includes the choice of in plane and out of plane amplitudes of the target Lissajous orbits as a function of the launch time. The optimum manoeuvre strategies and the launch window guarantee a mission without eclipse for both spacecraft (Fig. 6).

In general the fast Planck transfer requires a lower apogee radius than the Herschel stable manifold transfer (Fig. 7). The 1,200,000 km apogee radius is a compromise in terms of the propellant allocation on both spacecraft.

3. Launch and separation

Herschel and Planck have been successfully placed in orbit (Fig 8)after a flawless countdown and launch by

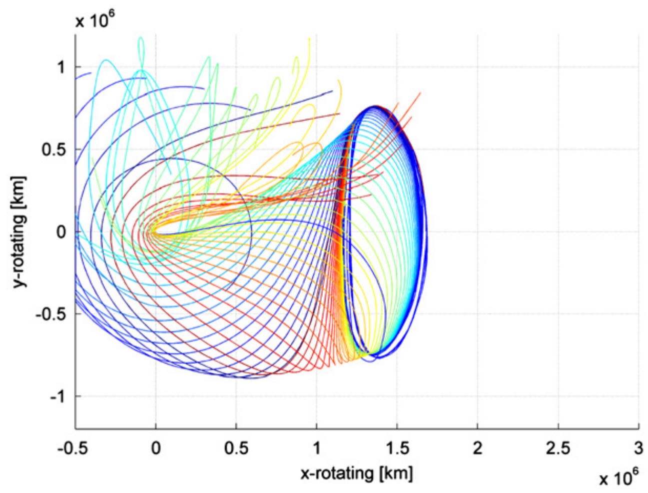

Fig. 7. Stable manifold of Herschel orbit [2].

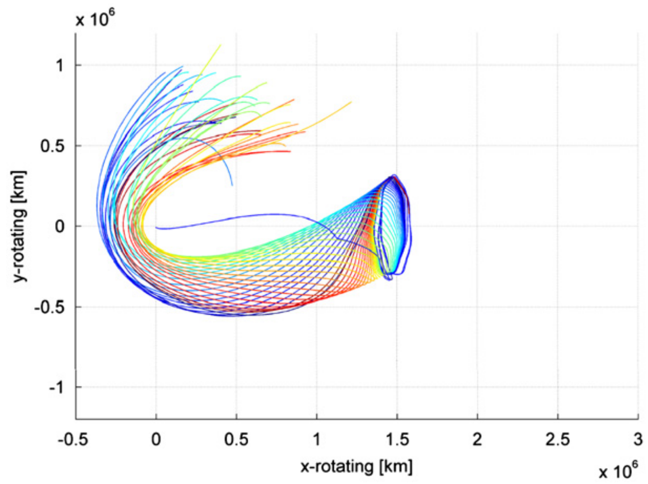

Fig. 8. Stable manifold of Planck orbit [2].

Ariane V, flight V188, at the beginning of the nominal launch window on May 14th at 13:12Z (H0). Both spacecraft separated according to plan: Herschel at 13:37:55Z followed by Planck at 13:40:25Z.

The first orbit determination using tracking data from New Norcia and Perth confirmed a very close to nominal injection with a semi-major axis higher by about 10,000 km (i.e. 0.45 sigma).

Herschel and Planck separation attitudes were observed to be nominal and within 0.1° from predicted values. The separation triggered the execution of automatic sequences on-board, including attitude acquisition, configuration of the data handling system and switch-on of the X-band transmitters. The two spacecraft were acquired by New Norcia and Perth at 13:49Z. Good telemetry was received shortly afterwards, with Herschel supported from New Norcia and Planck from Perth. Both spacecraft had acquired their nominal sun pointing attitude and a telemetry check-out performed by the Mission Control Team confirmed the overall status as nominal. The initial fuel consumption of ~0.7 kg/day on Herschel was well within expectations of ~1.0 kg/day.

Herschel's Visual Monitoring Camera delivered some excellent images of the SYLDA adapter (covering the Planck spacecraft) dropping away from Herschel (Fig. 9).

The orbital elements in earth equatorial J2000.0 reference frame at 2009/05/14 13:39:04.7 TDB with respect to the differences to the planned injection ('Sigma') underline the excellent performance of the Ariane launcher (Table 2).

3.1. *Herschel*

The separation attitude was well within the expected limits (absolute difference 0.98°):

Nominal quaternion:
[0.167607, 0.550959, 0.759223, 0.303204]
Measured quaternion:
[0.167794, 0.550078, 0.759688, 0.303534]

After separation the ACMS performed all expected activities for sun acquisition.

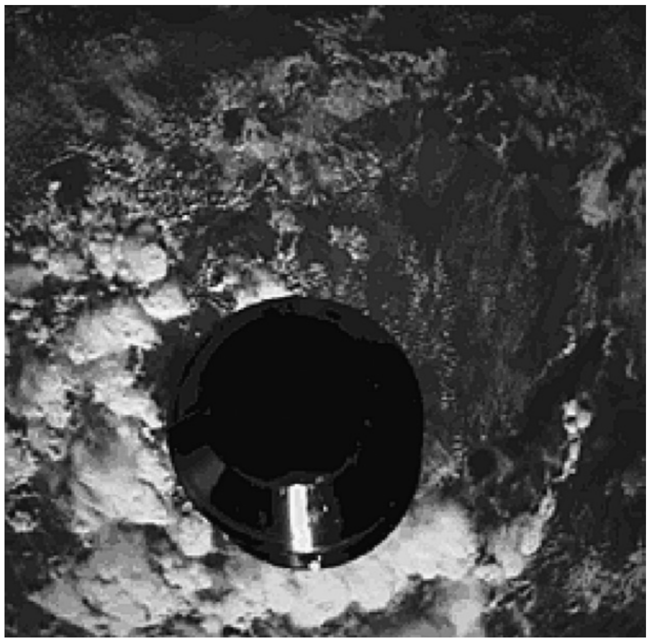

Fig. 9. SYLDA as seen from Herschel.

Table 2
Herschel and Planck separation elements.

Position/velocity	Value	Sigma [km, km/s]
X	−2730.040258	1.80530D−02
Y	7000.205895	1.71711D−02
Z	−288.073075	5.78761D−02
Xdot	−10.206359	2.23862D−05
Ydot	−0.282497	1.73558D−05
Zdot	−1.061678	4.98123D−05
Semi-major axis (km)	618,250.92	3.75410
Eccentricity	0.989246	7.58045D−08
Inclination (deg)	5.939618	2.99347D−04
RAAN (deg)	269.6816	3.36516D−03
Arg Perigee (deg)	161.833	3.41971D−03
True anomaly (deg)	39.897	8.18341D−05

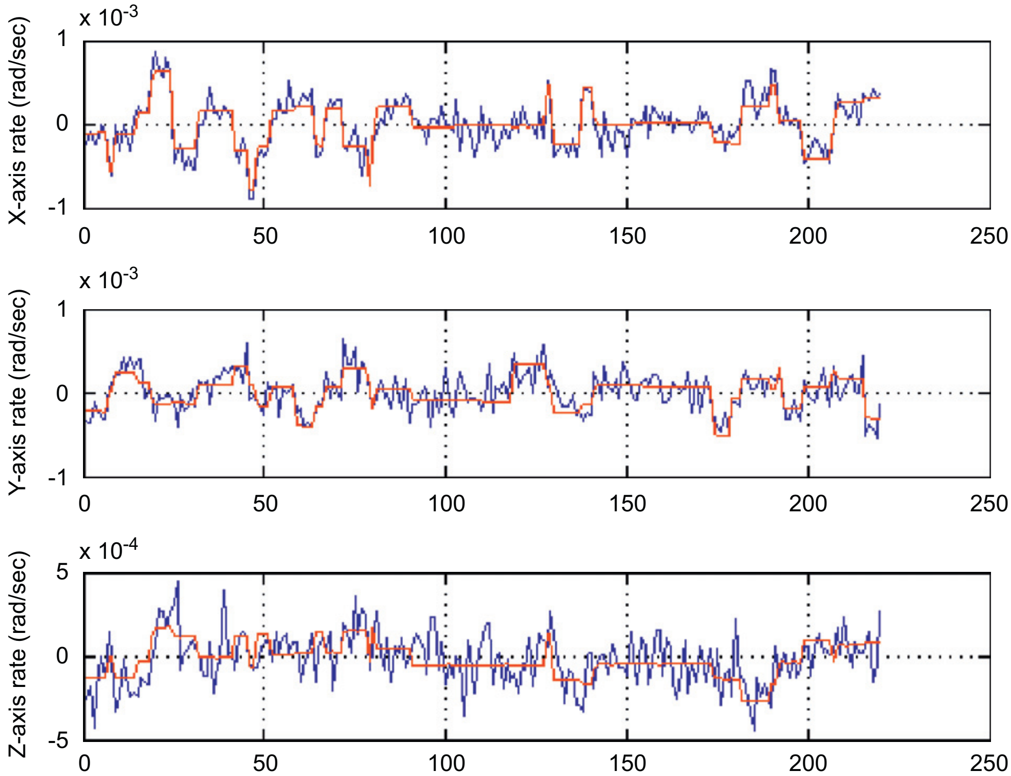

Fig. 10. Gyro rates along *x*-, *y*-, *z*-axis (red) and CRS rates (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The Attitude Measurement and Control (ACMS) subsystem performance was nominal, except that both Startrackers (STR) showed bad quality and STR-1, which was in use, was repeatedly declared unhealthy by the ACMS. Preliminary investigation showed a mismatch between the catalogue and actual star position (possible 0.5–0.8% error in focal length after switch-on suspected). The way forward has been investigated as the unit is required to perform the orbit manoeuvre. The second star tracker was also switched on and showed a similar behaviour.

The Coarse Rate Sensor (CRS) vs gyro consistency check showed no significant differences in the angular rate (Fig. 10).

3.2. Planck

Also for Planck the separation attitude was nominal:

+x-axis nominal:
$[-0.588589,\ -0.734979,\ -0.336701]$
+x-axis measured:
$[-0.589861,\ -0.733636,\ -0.337406]$

The ACMS quick checkout at separation showed a nominal status. With the excellent separation conditions the spacecraft –x-axis was, similar to Herschel, 0.1° off from sun pointing (Sun-Acquisition-Mode (SAM) actuation limit is 5°).

The nutation level was within 4.64° of the SAM actuation limit. The spin rate stayed within (nominal spin rate $\pm$ 0.5°/s) the SAM actuation limit.

The 20 N thrusters (used in SAM control) have not been used as a result of the good separation conditions.

4. Early operations

During the first day in orbit Herschel and Planck have continued to perform well. Both spacecraft have successfully completed their first orbit manoeuvres, with excellent results (within 1–2% of the planned magnitude). As the attitude of both spacecraft was controlled using star tracker measurements, this required the selection of a robust star tracker configuration to account for the previously observed sensor behaviour.

4.1. Herschel

The second orbit determination showed no significant change with respect to the first one.

The ACMS continued to perform well; however problems with the quality index of STR1 and STR2 led to the status being declared unhealthy by the ACMS software.

First Flight Dynamics analysis of STR data seemed to indicate a systematic focal length error of more than 0.5% but this was ruled out later.

In preparation of the first Trajectory Control Manoeuvre (TCM) the spacecraft was successfully commanded into Orbit Change Mode (OCM) for the first time. A delta-v manoeuvre of 8.7 m/s was further executed on 2009/05/15 at 15:16:26Z. A preliminary assessment from Doppler data indicated an over-performance of 1%, which is an excellent performance for hydrazine thrusters. The new orbit was then at 16/05/2009 17:00:00Z:

Position/velocity	Value	Sigma [km, km/s]
X	−187,460.790	1.19711D−01
Y	−308,542.035	9.52630D−02
Z	−192,87.748	7.29821D−01
*X*dot	−0.465430	5.29174D−06
*Y*dot	−1.153372	3.31068D−06
*Z*dot	−0.047617	8.36439D−06
Semi-major axis (km)	607,762.47	2.47295
Eccentricity	0.9889	6.0666D−07
Inclination (deg)	5.9398	1.67348D−03
RAAN (deg)	269.615	1.03171D−02
Arg Perigee (deg)	162.114	1.02821D−02
True anomaly (deg)	166.85	4.01139D−04

which corresponded to:

Pericentre distance [km]=6721.688 3.957D−01
Apocentre distance [km]=1208803.245 4.556D+00
Osc. orbit period [HRS]=1309.813 7.994D−03

In OCM a slew was commanded for the first time in order to run in the reaction wheels. This exercise lasted for 4 h with a fuel consumption of 1 kg.

The resulting friction torques could be reduced to [0.022 Nm, 0.041 Nm, 0.031 Nm, 0.038 Nm] with a limit of 0.018 Nm. As planned additional reaction wheel bias manoeuvres were done in the upcoming days.

Due to the unresolved STR issue a transition from OCM back to Sun-Acquisition-Mode was done.

On the second day of operations Herschel was commanded into Science Control Mode (SCM) using the reaction wheels as main attitude control device. Star tracker 2 was set as the prime sensor and star tracker 1 has been switched on to collect measurements in parallel in preparation for further analysis activities. The thermal behaviour of the latch valve as the critical connector in the propulsion system created initially some concerns and was solved by an additional heater input from the Cryogenic Control Unit. Thus it was no more required to keep the spacecraft in an attitude with respect to the sun that originally kept the valve on the warmer side of the structure.

The Flight Dynamics models for Helium venting and solar radiation torque were analysed and assessed as sufficiently accurate for LEOP operations with $\pm 5\%$ in magnitude and $<4^\circ$ in the direction of disturbance torque vector.

4.2. Planck

Also for Planck the second orbit determination showed no significant change with respect to orbit determination #1. The first transition to Orbit Control Mode (OCM) went without problems. The first delta-v manoeuvre followed with a size of 14.35 m/s on 2009/05/15 at 20:01:05 with a duration of 9137 s.

The near real time monitoring showed a nominal performance with a small over-performance by about2% from the preliminary Doppler data analysis. The manoeuvre errors of the first delta-V were eventually corrected during the mid-course and insertion manoeuvres on 5th June and 2nd July. Hence no touch-up manoeuvres for any of the spacecrafts were required in these early operations phase and fuel penalties could be avoided.

With this strategy the final LEOP orbit determination could be completed, including station data from 2009/05/14 13:45 until 2009/05/16 17:00, and showed excellent results:

Position/velocity	Value	Sigma [km, km/s]
X	−177,950.115	4.18407D−02
Y	−286,050.502	5.03236D−02
Z	−187,98.161	7.86388D−01
*X*dot	−0.483288	1.57506D−06
*Y*dot	−1.182186	9.13131D−07
*Z*dot	−0.058079	7.89110D−06
Semi-major axis (km)	547,368.31	5.216D−01
Eccentricity	0.987930	1.883D−07
Inclination (deg)	4.5558	9.526D−04
RAAN (deg)	282.565	1.366D−02
Arg Perigee (deg)	148.849	1.363D−02
True anomaly (deg)	166.610	1.143D−04

which corresponded to:

Pericentre distance [km]=6606.712 1.092D−01
Apocentre distance [km]=1088129.898 9.368D−01
Osc orbit period [HRS]=1119.510 1.600D−03

Already on the second day of operations the HFI instrument has been switched on and all bolometers produced good scientific data.

A major milestone has been passed on the 3rd day with the successful commissioning of large slews in Angular Momentum Control Mode (HCM) using the 1 N thrusters after their commissioning by a series of 3 slews over 4, 10 and 18 arcmin.

These manoeuvres were a crucial step in the ACMS testing to:

- demonstrate the capability of the platform to re-orientate its spin axis towards a target close to the current pointing;
- verify slew duration estimates;
- verify that the 1 N thruster temperatures never exceed 250 °C, and to characterise the recovery time needed to reach the required pre-heating temperature.

the results were very encouraging with an excellent slew and pointing behaviour. The manoeuvre exit conditions were met without any problems. The nutation was well damped within the slew itself and no dedicated nutation damping cycles were needed.

5. Herschel attitude anomaly

5.1. Startracker

On both spacecrafts the performance of the startrackers was initially below the expectations. Frequent drops of the STR mode out of nominal operations were mainly caused by a quality index trigger. This quality index is internally computed to provide an estimate on the performance. This parameter is expected to be close to 1 with the STR in tracking mode with 9 stars in the FOV.

Especially for Herschel the quality index was in reality scattered between 0.3 and 0.9, resulting in an attitude error around the spacecraft *z*-axis above the limit of 0.4 arcsec between the modelled and measured attitude (Fig. 11).

After a thorough analysis of potential STR internal error sources (e.g. focal length, number and postion of tracked stars, thermal stability and CCD issues) they could all be excluded as main contributors. However the limit for the quality index was not set correctly in the onboard database—this was corrected and the STR mode changes occurred much less frequently. The attitude error did not disappear.

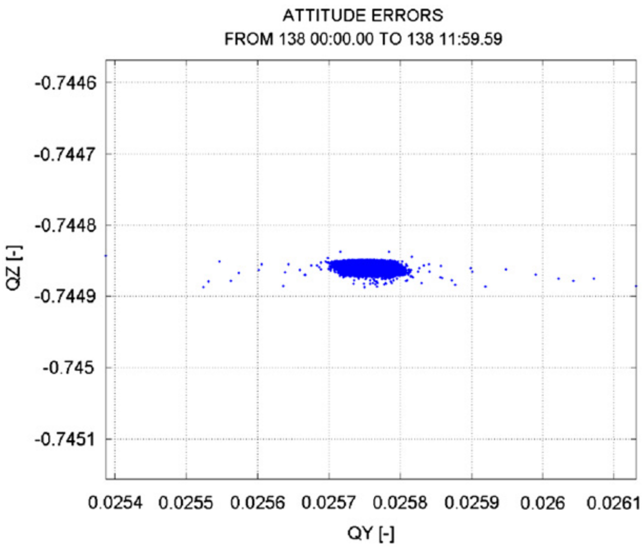

Fig. 11. Herschel attitude error.

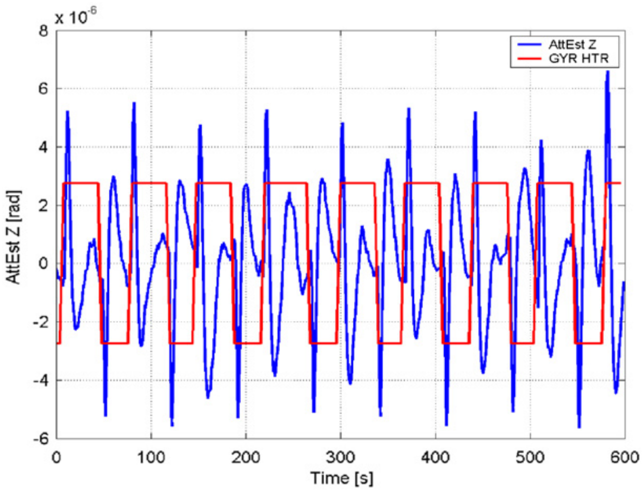

Fig. 12. Attitude error (blue) and gyro heater activation (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5.2. *The total picture*

Analysis of all involved ACMS parameters finally proved that the STR error was a real attitude offset, which occurred in the form of an oscillation of ± 8 arcsec around the *z*-axis with a period of 73 s(confirmed by gyro data). This motion could still be identified after having taken the STR out of the attitude control loop.

Eventually further analysis of sampled telemetry showed the same frequency in the gyro heater cycle (Fig. 12). It was concluded that the activation of the strong 45 W baseplate gyro heaters induced an erroneous signal in the gyros themselves. The attitude control system correctly tried to compensate for this virtual attitude error, thus leading to the observed motion of the entire spacecraft.

The anomaly was resolved by switching off the strong baseplate heaters and relying only on the weaker internal heaters for gyro thermal control where the switching logic software setup had to be revised in order to achieve the temperature baseline.

6. Navigation to L2

6.1. *Herschel*

The insertion to the orbit around the libration point was done in a single manoeuvre (1 day after launch) making use of the properties of the stable manifold leading to the requested halo orbit.

The comparison (Table 3) between the nominal (before launch), optimized (before the manoeuvre) and estimated (after the manoeuvre) parameters for the insertion manoeuvre still reflects the good insertion of the launcher, requiring less fuel than originally allocated.

6.2. *Planck*

The insertion into the orbit around the libration point was done with 3 manoeuvres:

- day 1 manoeuvre performed 24 h after launch to correct launcher dispersion errors and systematic deviations in the pericentre velocity (Table 4);
- mid-course manoeuvre to lead the spacecraft to the insertion point (Table 5);
- insertion manoeuvre the final impulse to insert Planck to the operational orbit around the liberation point (Table 6).

Table 3
Orbit parameter comparison [3].

Nominal	Optimized	Estimated
2009/05/15	2009/05/15 *T* 14:12:00Z	2009/05/15 *T* 15:16:26Z
11.696 m/s	8.691 m/s	9.014 m/s
17.640 kg	13.191 kg	13.180 kg
	22 min	22 min

Table 4
Day 1 manoeuvre [4].

Nominal	Optimized	Estimated
2009/05/15	2009/05/15 *T* 17:28:00Z	2009/05/15 *T* 20:01:05Z
10.010 m/s	14.351 m/s	14.480 m/s
10.443 kg	14.946 kg	15.959 kg
	2 h50 min	2 h34 min

Table 5
Mid-course manoeuvre [4].

Nominal	Optimized	Estimated
2009/06/05	2009/06/05 *T* 17:28:00Z	2009/06/05 *T* 17:28:06Z
157.729 m/s	153.650 m/s	155.580 m/s
130.748 kg	127.100 kg	134.016 kg
	23 h34 min	45 h39 min

Table 6
Insertion manoeuvre [4].

Nominal	Optimized	Estimated
2009/07/02	2009/07/02 *T* 11:15:00Z	2009/07/02 *T* 11:15:08Z
71.885 m/s	58.795 m/s	59.896 m/s
57.177 kg	47.339kg	50.529 kg
	15 h19 min	20 h10 min

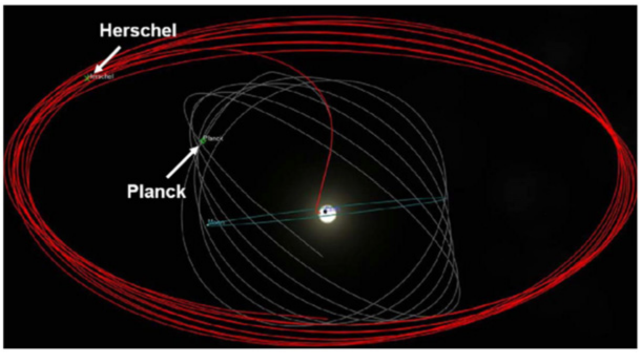

Fig. 13. Herschel and Planck location on 29 June 2009.

with the nominal, optimized and estimated parameters given in Tables 4–6.

Eventually less than 2 months after launch both spacecraft have reached their operational orbits around L2 (Fig. 13).

7. Orbit maintenance at L2

7.1. Herschel

Due to the instability of the orbit around the libration point, perturbations grow exponentially with time; e.g. an error in the orbit in a particular moment grows approximately 3 times bigger in 3 weeks. In order to keep those errors limited, perturbations should be corrected as early as possible.

At the beginning of the mission, the perturbations produced by the wheel off-loadings were unexpectedly high. In order to correct perturbations (mainly due to the large Helium venting torque) as early as possible and avoid high penalty, correction manoeuvres were scheduled every 2 weeks. After an ACMS software update on 8 July 2009, these perturbations are expected to be smaller. Manoeuvre slots are then set every 4 weeks.

The ΔV for the orbit phase is estimated to be 3 m/s per year. Assuming an efficiency of 96% and a margin of 39%, 6.1 kg of hydrazine is needed per year for orbit control. Including the budget for attitude control, 10.7 kg of fuel per year is allocated for the orbit control phase. A summary (Table 7) of the first 4 used slots for correction manoeuvres affirms these assumptions.

Table 7
First correction manoeuvres [3].

	Optimized	Estimated	Total
Slot on 2009/06/10	0.732 m/s 1.104 kg	0.732 m/s 1.162 kg	0.732 m/s 1.162 kg
Slot on 2009/06/24	0.185 m/s 0.279 kg	0.171 m/s 0.347 kg	0.903 m/s 1.509 kg
Slot on 2009/07/17	0.422 m/s 0.634 kg	0.422 m/s 0.653 kg	1.325 m/s 2.162 kg
Slot on 2009/08/14	0.158 m/s 0.237 kg	0.161 m/s 0.247 kg	1.486 m/s 2.409 kg
Budget (per year)	-	-	3 m/s 6.1 kg

Table 8
First correction manoeuvre [4].

Optimized	Estimated
2009/08/14 *T* 12:30:00Z	2009/08/14 *T* 12:30:23Z
0.114 m/s	0.117 m/s
0.108 kg	0.079 kg
3 min	7 min

7.2. Planck

For Planck, these correction manoeuvres are generally performed every 4 weeks. The ΔV for the routine orbit phase is estimated to be 1 m/s per year. Assuming an efficiency of 58% (due to the spinning spacecraft) and a margin of 35%, 1.7 kg of hydrazine is needed per year for orbit control. Including the budget for attitude control, 6.5 kg of fuel per year is allocated for the orbit control phase. The first of these correction manoeuvres was done on 14th August with a better efficiency than originally planned (Table 8).

8. Conclusion

Beyond making use of the synergies between Herschel and Planck during the development and integration

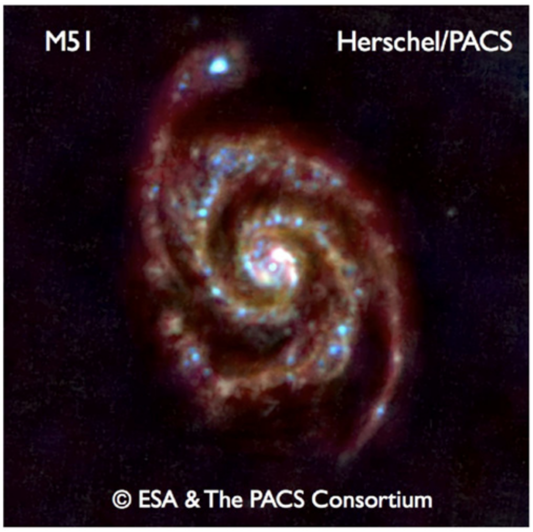

Fig. 14. Herschel first light—Galaxy M51.

phases, ESA had decided to take the risk of a double launch of 2 different spacecraft on the same launcher. This created additional effort in trajectory design because each spacecraft would have ideally required different launcher separation parameter in order to achieve the fastest and/or cheapest transition trajectory to their different orbits around the L2 Lagrange point. The chosen common separation elements were a compromise between these requirements. In the operations centre different teams for each spacecraft had to be trained and were eventually executing the operations (mainly Flight Control Team and Flight Dynamics Team). Resources had to be shared between the 2 spacecraft and in a contingency situation a decision for this allocation would have to be made.

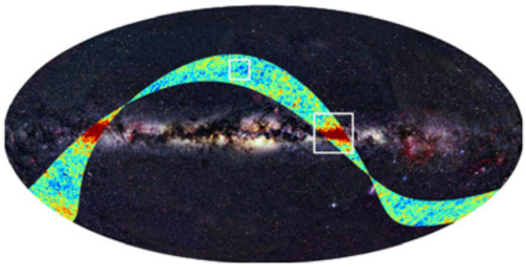

Fig. 15. Planck first light projected on a visual light image of the sky.

The excellent operations executing proofed that this approach was possible and led to the first promising scientific results (Fig. 14). After starting the cooling system of Planck consisting of 3 consecutive elements the focal plane became the coldest spacecraft in the Universe at 0.1 K (even at the coldest spots in space there is still the Cosmic Microwave Background, which Planck is going to measure, leading to a temperature of approximately 3 K), leading to excellent first scientific measurements during a first light survey from 13 to 27 August 2009 (Fig. 15).

References

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