6. SCIAMACHY in Orbit – The First Years

On March 1st, 2002 at 1:07 UTC, SCIAMACHY was lifted into space from Kourou as part of the ENVISAT mission (fig. 6-1). The highly precise injection into a sun-synchronous orbit saved fuel so that from an orbit maintenance point of view an extension of the mission lifetime beyond the specified five years became possible. At about 02:53:51 UTC, ENVISAT crossed for the first time the Earth equator on the night side corresponding to the start of absolute orbit no. 1. Since then, until the end of 2005, more than 20 000 orbits have been executed.

SCIAMACHY's initial operational programme reflects the requirements of the overall ENVISAT mission and the specific needs of the instrument. It was the goal to reach routine operations as soon as possible but also to perform a thorough in-orbit functional check-out and verification of the instrument. SCIAMACHY mission phases consisted of the launch and early operation phase (LEOP), the switch-on and data acquisition phase (SODAP), the main validation phase with quasi-routine operations and finally the routine operations phase. SODAP and main validation phase formed the Commissioning Phase. A time schedule is presented in table 6-1.

6.1 Commissioning Phase

Establishing the instrument activities in the Commissioning Phase, particularly SODAP, required assembling a plan including engineering and specific measurement tasks. This plan had to provide a continuous, conflict free schedule at instrument as well as on ENVISAT level which finally permitted the declaration that SCIAMACHY was ready for routine operations. The approach was to start with separate planning of engineering and measurement tasks, to integrate both to obtain a complete SCIAMACHY flow and to insert this flow into the overall ENVISAT SODAP plan.

Engineering Tasks

Instrument operations on command & control level are described in the IOM. The IOM provides the ENVISAT FOCC with all information necessary to properly operate and maintain the instrument. During SODAP these activities, which may later be used on a routine basis, had to be functionally tested and verified both in nominal and non-nominal situations. In addition, engineering settings for dedicated subsystems had to be derived. The engineering SODAP tasks comprised:

Fig. 6-1: ENVISAT launch (photo: ESA)

- mode transitions with associated parameters
- thermal operations including decontamination
- flight procedures
- routine monitoring
- processor patch & dump

These were supplemented by dedicated operations that occurred only once during SODAP. Major items included, following the first switch-on, the releases of the azimuth and elevation aperture cover mechanisms and the opening of the SRC door.

Many of the engineering functions had been tested during phase C/D on-ground. Thermal operations, however, were for the first time executed under in-orbit conditions. Therefore emphasis was put on a thorough verification of the thermal subsystems ATC, TC and Radiant Cooler. The goal was to characterise the subsystems well enough in order to be able to routinely select, after the end of SODAP, the correct parameter settings suitable to maintain OBM and detector temperatures within specified limits.

Measurement Tasks

The flexibility of the instrument required verification of many different functionalities and characterisation of a large set of parameters. In order to ensure a thorough testing of all instrument capabilities a call for proposals was issued to all parties involved in the instrument development. This resulted in a list of *Commissioning Objectives* and the required measurements to achieve these objectives during SODAP. All proposals underwent a review process where their feasibility was checked and priorities were assigned. In total more than 110 proposals were finally accepted. Some of them requested verification that states defined for routine operations worked as expected but for the majority new states had to be specified. Each new state corresponded to a new instrument onboard configuration that had to be commanded via the upload of measurement parameter CTI (Configurable Transfer Item) tables. Individual states, new ones and those already existing, were assembled to generate specific timelines. Execution of these states was triggered via the start of such SODAP specific timelines scheduled via the ENVISAT Mission Planning System.

Since some commissioning objectives required particular instrument configurations – e.g. aperture covers released, a certain thermal status – or needed as a prerequisite the output of other objectives, it was impossible to generate the full SCIAMACHY SODAP measurement plan by simply concatenating all the objectives. Furthermore, all lunar measurements could only be performed in the short monthly visibility periods. Therefore, engineering and measurement tasks were integrated at the level of individual objectives thus ensuring that all instrument prerequisites were fulfilled and the overall ENVISAT SODAP schedule adhered to. The result was the SCIAMACHY On-Board Operation Plan (SCOOP), an Excel based database of the complete SODAP period. It split this period into engineering and measurement windows. In an engineering window, SCIAMACHY operation was procedure driven while in a measurement window, the instrument operations were timeline driven and controlled by the ENVISAT MPS. Because the SCIAMACHY SODAP team was able to simulate the SCIAMACHY schedule with an accuracy < 1 sec, the SCOOP could assign absolute time information to its engineering activities prior to execution. This enabled FOCC and AOP SCIAMACHY personnel to efficiently run SODAP operations, even in non-nominal situations when the planned sequence of events had to be changed at short notice.

The measurement windows were arranged so that on entry and exit the instrument was in a well defined configuration and all timelines and states scheduled therein executed just those measurements compliant with this configuration.

The SODAP Sequence

At the time of launch the SODAP specific planning information – SCOOP, states and timelines – were available and ready for activation. The ENVISAT SODAP plan had scheduled SCIAMACHY's first switch-on for orbit 147, March 11th, eleven days after launch. Six days later, March 17th, the instrument was controlled for the first time by the ENVISAT MPS when the first timeline was executed which ran successfully the *Full Functional Test*. Because all aperture covers were still closed, no external light was collected but instead light from the internal calibration sources. The sequence of engineering and measurement activities continued until April 3rd. That day the first aperture cover, the azimuth aperture cover mechanism (AZACM), was released and the light path via the limb port opened, permitting limb and occultation observations. The long time delay between launch and the first appendage release was required to avoid possible contamination of the instrument due to outgassing from the platform. Another important milestone was reached April 15th with the opening of the SRC. This event started the passive cooling of the detectors to their nominal temperatures, i.e. from this release on, detectors could be operated under in-flight thermal conditions. Also thermal tests were now possible aiming to find the final settings for the instrument. A particular challenge for mission planning and scanner control occurred end of April with the first lunar measurement window which was successfully passed. In June SODAP had progressed so far that the final flight settings for the ATC and TC could be uploaded. OBM and detectors were now under continuous thermal control with modifications only being triggered by seasonal effects or the status of the SRC. On June 20th the third and final cover, the elevation cover aperture cover mechanism (ELACM), was removed from the light paths. It permitted light to enter SCIAMACHY via the nadir port. The engineering and measurement program focused then on finalising SODAP with the goal to begin the validation part of the Commissioning Phase in early August. With the set of *β states*, originating from the evaluation of earlier measurements, and associated timelines a configuration was specified and uploaded mid July which already came very close to the envisaged final flight definitions. SODAP ended on August 2nd, but leaving a few measurements still to be done. This was mainly due to the

Phase	***Instrument Activity***	***Date***	***Orbit***
LEOP	OFF-Leo mode	01/07-Mar-2002	
SODAP	first switch-on	11-Mar-2002	147
	first MPS driven operations	17-Mar-2002	238
	first decontamination	18-Mar-2002	253
	AZACM cover released	03-Apr-2002	477
	SRC released	15-Apr-2002	653
	first lunar measurement	22-Apr-2002	753
	final ATC/TC settings loaded	10-Jun-2002	1454
	ELACM cover released	20-Jun-2002	1594
	β states loaded	17-Jul-2002	1982
	timelines with β states loaded	18-Jul-2002	1990
	end SODAP (remaining SODAP measurements inserted as *Δ SODAP* in validation phase)	02-Aug-2002	2204
Validation	start validation	02-Aug-2002	2204
	end Δ SODAP measurements	14-Dec-2002	4127
	final flight states loaded	15-Dec-2002	4143
	timelines with final flight states loaded	16-Dec-2002	4151
	first non-nominal decontamination started	19-Dec-2002	4204

Table 6-1: SCIAMACHY activities from launch to end of Commissioning Phase.

occurrence of anomalies which made it necessary to re-arrange the tight SODAP plan. Also some of the objectives required seasonally dependent observing conditions, available only in the second half of the year.

At the end of SODAP, after a period of 130 days, SCIAMACHY had successfully executed more than 21 200 MCMDs. Almost 5 500 timelines were started which triggered more than 78 000 individual states. This impressive operational record required the upload of 5 700 parameter tables and 560 timelines. Each parameter table was equivalent to reconfiguring one functionality or characteristic of the instrument. SODAP proved that the operational concept and the flight operations ground segment interfaces were well developed to handle the complex mission.

The Validation Sequence

From an instrument point of view, during the validation phase SCIAMACHY was operated in a quasi routine fashion. Only some inserted so called *Δ SODAP* measurements interrupted the nominal measurement plan. During this part of the mission, the extensive support of the ground segment was gradually reduced. SCIAMACHY now executed a continuous measurement programme which reflected the mission scenarios for routine operations. Validation scientists were provided with planning information – exact overpass times for nadir and limb observations – permitting synchronisation of ground-based, airborne and balloon borne campaigns with SCIAMACHY operations. Details are described in chapter 9.

The end of the validation phase corresponded to the end of the Commissioning Phase. Therefore the definition and upload of the final flight states and timelines was the ultimate goal to be accomplished. It occurred mid December. After another decontamination the instrument was prepared and ready for the start of the routine operations phase.

Non-Nominal Operations

Although SODAP did not show major instrument malfunctions, the original plans had to be modified due to a series of anomalies which hit SCIAMACHY right in the middle of SODAP. One type of anomaly was related to ENVISAT when a non-nominal platform status was detected and all instruments were switched off for safety reasons. A rather persistent recurring anomaly hampered SCIAMACHY between May and July 2002. Subsequent detailed failure analysis had led to the conclusion that a bug in the ICU can temporarily block its interface to the ENVISAT Pay-

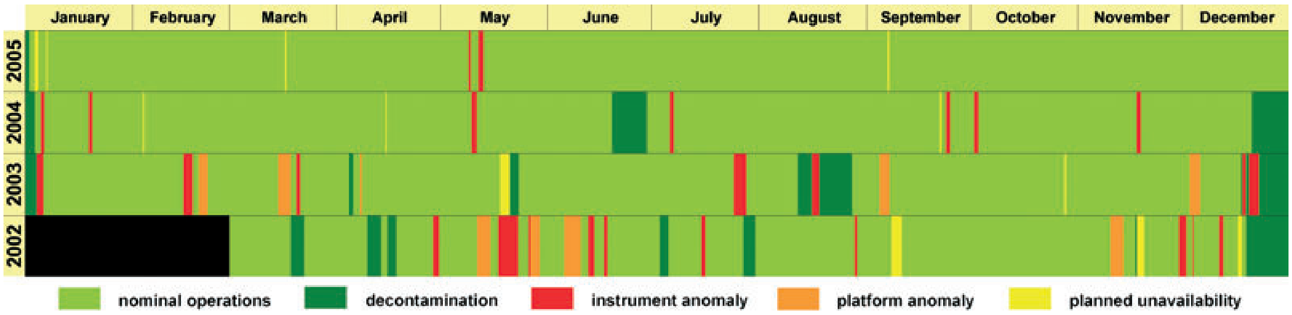

Fig. 6-2: Operations summary for the commissioning and routine operations phase. Colour coding indicates instrument availability. (graphics: DLR-IMF)

load Management Computer. This causes a transfer to a safe instrument mode lower than *Measurement*, i.e. measurements are interrupted. The error is known as *MCMD CCA check error*. In October 2002 a software patch was uploaded to correct for this ICU bug. It did not fully cure the problem – complete repair would have required a more extended patch – but ground tests have shown that the rate of the check error could be reduced to an acceptable level of 2-3 occurrences per year with the selected approach. Single Event Upsets (SEU) were the third type of anomaly which triggered operational interrupts. The instrument can suffer from a SEU when high-energy particles, most likely protons, hit electronic components and switch its status information. The particle flux increases in low-Earth orbits during phases of high solar activity in general and when crossing the South Atlantic Anomaly of the Earth's magnetic field in particular. In total about 350 orbits were lost during the Commissioning Phase due to switch offs triggered by ENVISAT, the MCMD CCA check error and SEU anomalies. Close interaction between the involved parties permitted, however, that even in the very tight schedules of the initial mission phase the cancelled activities could be repeated on time.

Non-nominal Instrument Performance

The in-orbit functional verification and characterisation progressed well in SODAP but the infrared channels 7 & 8 began to show a significant loss of radiance response in the weeks after the SRC had been opened. Investigations indicated that an ice layer growing on top of the cylindrical lens covering the detectors was responsible for this. It affects only channels 7 & 8 because these are the detectors operated at lowest temperatures. A likely source of the contaminant water is the carbon fibre reinforced plastic structure of ENVISAT. The water contained in the compound started to outgas once the platform was in orbit and condensed on the cold surfaces in channels 7 & 8. Obviously the venting holes in the multilayer insulation covering SCIAMACHY could not efficiently support the outgassing of the instrument. Over a period of only a few months the ice layer reduced the throughput in channels 7 & 8 by almost 80 % (see fig. 6-9). Methods to reduce accumulation of ice were limited and only the application of decontamination means was finally selected to become the operational countermeasure.

Decontamination

Decontamination is one of the requirements of thermal operations. Detailed pre-launch analysis had shown that the efficiency of the RRU on the SRC to dissipate energy from the detectors to open space might decrease with time due to contamination of volatile molecules on the RRU surface. Cooling via the RRU usually yields detector temperatures below the lower limit. Therefore trim heaters shall counterbalance this effect by additional heating. When contamination decreases RRU efficiency, detectors become less cold and thus TC heater power (which is used to raise temperatures to keep detectors within limits) approaches zero. To reestablish the initial RRU efficiency, a decontamination mode had been originally foreseen with the goal of removing any contaminants from the RRU by heating up the SRC for a few days. Such a SRC decontamination would either have been required when one of the TC heaters had reached a power of 0 W or, as originally required, at least twice per year. During this decontamination procedure any measurements were stopped. The SRC decontamination heaters were turned on for the warm-up phase while ATC and TC heaters remained at their current operational levels.

Because of the necessity to heat up the detectors as much as possible to effectively get rid of the ice layers on channels 7 & 8, this decontamination procedure was re-defined in the Commissioning Phase to form a Non-Nominal Decontamination (NNDEC) to be used during routine operations. During a NNDEC not only the SRC decontamination heaters provide energy to the optical sub-system but also ATC and TC heaters are switched to their maximum power. Measurements continue throughout warm-up and cool-down, contrary to what had been defined for the original decontamination procedure. In the warm-up phase of NNDEC, channels 7 & 8 reach temperatures of 267 K and the OBM approaches a temperature of -3 °C. Also the duration of the warm-up phase was extended by up to 15 days. This method no longer creates a long data gap since data analysis still permits retrieval of – somewhat degraded – information from the UV-VIS channels even at elevated temperatures.

6.2 Routine Operations Phase

In January 2003, SCIAMACHY commissioning had ended and transfer to the routine operations phase was initiated. In spite of the few discrepancies described above, the instrument entered this phase with excellent performance. The start of routine operations also meant transfer of operational responsibilities on the instrument provider side from EADS Astrium to SOST.

Routine operations are characterised by their continuity. Since spaceborne long-term atmospheric research requires measurement data to be acquired under stable conditions, both in terms of instrument configuration and performance, SCIAMACHY has the goal to maintain its baseline measurement program as long as possible. The majority of measurement sequences consists of a solar occultation each orbit, matching limb/nadir observations on the dayside and specific eclipse observations, including calibration and monitoring in the eclipse phase. Swath width in nadir and limb states is set to wide, i.e. 960 km, with an upper limit for the limb horizontal scans close to the top of the atmosphere at about 100 km. This is supplemented by calibration & monitoring activities on a daily, weekly and monthly timescale. For a typical orbital mission scenario 92 % of the orbital period is covered by measurements. The remaining 8 % are idle gaps required for potential command & control activities or are caused by the fact that the smallest possible time slice in a timeline is the duration of a state. Because of this fact the continuous seasonal changes of solar and lunar constellations cannot always be perfectly matched and cause gaps up to the duration of a state.

By the end of 2005, SCIAMACHY has already executed more than 3 years of the planned scientific programme. For most of the routine operations phase, a high level of instrument availability could be ensured. The continuous improvement of calibration & monitoring (chapter 5) permits deriving spectra with high accuracy. Together with the progress in the development of retrieval algorithms (chapter 7), data processing (chapter 8) and validation (chapter 9), this forms the basis for finally obtaining excellent scientific results (chapter 10).

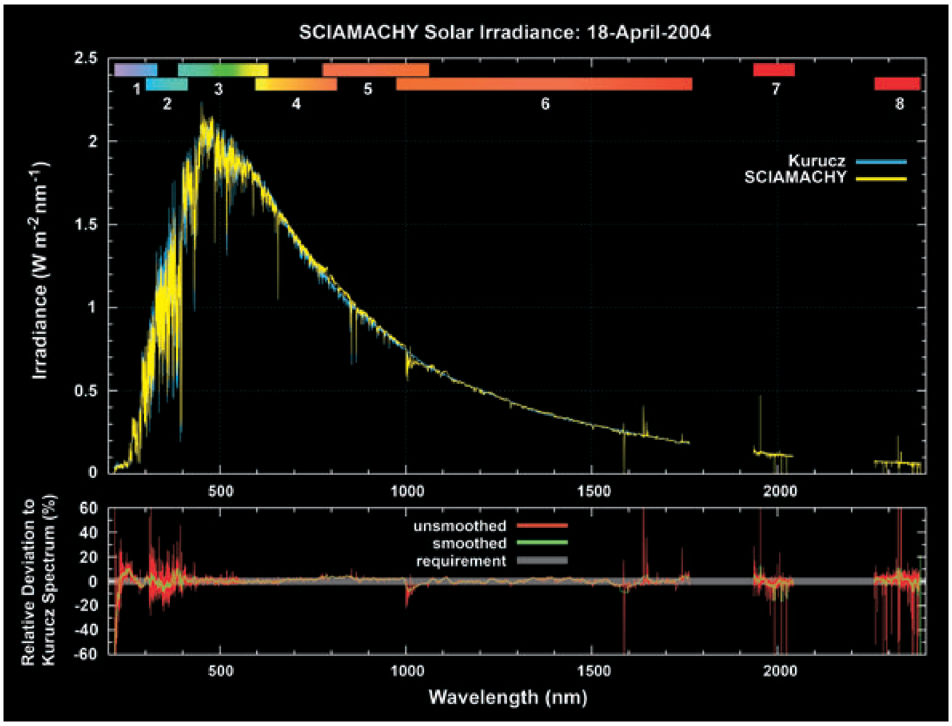

Fig. 6-3: Calibrated SCIAMACHY solar irradiance spectrum measured April 18th, 2004, in comparison to the Kurucz solar reference spectrum. SCIAMACHY data have been normalised to 1 AU sun distance. Kurucz data have been interpolated to the SCIAMACHY wavelength grid. Top: SCIAMACHY (yellow) and Kurucz (blue) irradiance as function of wavelength with the wavelength coverage of all 8 channels. Bottom: Relative deviation between the two data sets. Small deviations in the wavelength calibration can cause large fluctuations in the ratio of the spectra. Therefore, the deviation is shown as unsmoothed (red) and smoothed (green) curve. The underlying grey bar shows the ±3% requirement for the absolute radiometric calibration of SCIAMACHY which is fulfilled over almost the whole spectral range. (graphics: IUP-IFE, University of Bremen)

Instrument Activity	***Date***	***Orbit***
TC adjustment	17-Feb-2003	5062
TC adjustment	21-Feb-2003	5119
TC adjustment	27-Feb-2003	5207
modification of PET in moon states	10-Mar-2003	5358
modification of dark current sequence in eclipse & monthly calibration timelines	04-Apr-2003	5712
non-nominal decontamination	04/05-Apr-2003	5718-5736
modification of TCFoV in nadir states	08-Apr-2003	5771
TC adjustment	16-Apr-2003	5887
TC adjustment	15-May-2003	6301
non-nominal decontamination	21/23-May-2003	6384-6420
modification of tangent height in limb dark current measurement	26-May-2003	6456
modification of *WLS over diffuser* sequence in monthly calibration timelines	13-Jul-2003	7151
modification of altitude range in *limb mesosphere* state	21-Jul-2003	7265
modification of PET in dark current and NDFM monitoring states	21-Jul-2003	7276
TC adjustment	01-Aug-2003	7417
non-nominal decontamination	12/27-Aug-2003	7574-7798
modification of limb altitude range & new timeline set for improved limb/nadir matching	15-Oct-2003	8489
TC adjustment	22-Oct-2003	8591
TC adjustment	05-Dec-2003	9227
non-nominal decontamination	23-Dec-2003/03-Jan-2004	9482-9644
TC adjustment	30-Jan-2004	10023
TC adjustment	16-Mar-2004	10681
TC adjustment	01-Apr-2004	10911
TC adjustment	03-May-2004	11372
new timeline set for improved limb/nadir matching in early orbit phase	22-May-2004	11638
non-nominal decontamination	18/28-Jun-2004	12031-12174
modification of nadir states & new timeline set for increased signal-to-noise at high latitudes; includes new eclipse timelines with extended *limb mesosphere* coverage	06-Sep-2004	13172
TC adjustment	17-Dec-2004	14632
non-nominal decontamination	20-Dec-2004/02-Jan-2005	14675-14860
TC adjustment	05-Apr-2005	16192

Table 6-2: Major changes in routine operations from January 2003 – December 2005. Except TC adjustments and decontaminations they were all triggered by OCRs.

Operation Change Requests and Final Flight Configuration

From January 2003 on, SCIAMACHY followed the above mission scenarios. Deviations were only allowed when a strict configuration controlled procedure, the Operation Change Request, was pursued and approved by project management. The OCR process was introduced early in 2003 because of the high number of configurable parameters describing the instrument status. Any modification of mission scenarios, states or timelines has to be requested via an OCR. The OCR procedure includes technical analyses by SOST of the proposed change and possible implementation options. Upon recommendation by SOST and endorsement by SSAG to ensure that no other scientific requirements are violated, project management finally accepts or rejects the OCR.

An OCR may ask for a temporary modification of operations, e.g. change of vertical step width in limb states for a particular period, or result in permanent changes. In the latter case the final flight configuration, either for states or timelines, has to be altered. Such a modification must be permanently implemented in the flight operation ground segment command database to ensure that it becomes operational at each ICU re-initialisation. Temporary changes are reset to the appropriate initial final flight settings. From an operational point of view a complete state final flight configuration consists of presently 398 command tables, reflecting the measurement parameter tables described in chapter 4. Between January 2003 and December 2005 75 parameter tables had to be changed permanently as compared to the initial 'final' flight settings of December 2002. The total set of 63 'final' flight timelines were already exchanged three times onboard. In spite of the high number of 'final' flight versions, however, the overall state and timeline definitions remained rather stable throughout the routine operations phase so far. Mainly minor adjustments to state parameters or state sequences in timelines were required, but no major restructuring of their concepts.

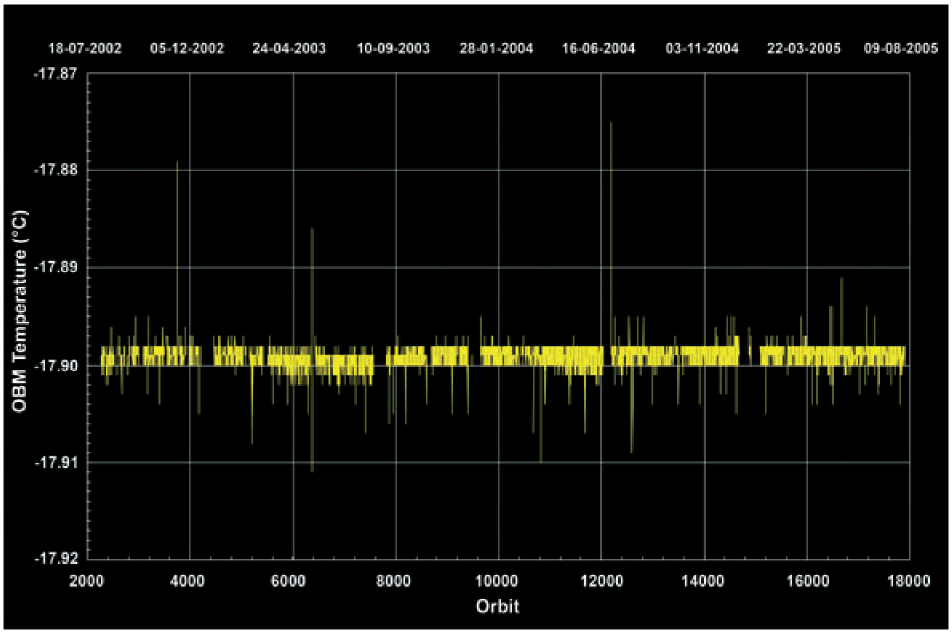

Fig. 6-4: Mean OBM temperature per orbit between the start of quasi-routine measurements in early August 2002 to August 2005, almost 3.5 years after launch. On orbit average, the ATC system keeps the OBM within 0.001 °C of the selected temperature. (graphics: DLR-IMF)

6.3 Instrument Performance

Thermal Operations

To keep the OBM and detectors within the specified temperature limits is one of the key requirements of instrument performance. Several of the parameters determining the precision of calibrated spectra, e.g. dark current or wavelength calibration, are highly temperature sensitive. Therefore, with the start of routine operations, monitoring of the thermal status of the OBM and detectors was one of the prime tasks. Each week, average OBM and detector temperatures per orbit, together with ATC heater power consumption, have to be monitored, following the procedures outlined in the IOM. The OBM temperature, since controlled via the ATC, is kept autonomously within limits. Only when an ATC heater power approaches its lower limit, new setpoints have to be defined. In the first three years of operations, the ATC settings as of June 2002 provided a very stable average OBM temperature of -17.90 °C per orbit (fig. 6-4). No adjustments were necessary. The ATC heater power history displays the predicted seasonal modulation and a decrease, most pronounced in the ATC_Nadir heater, indicating a likely need to modify ATC settings towards the end of the specified mission lifetime. Contrary to the stable ATC behaviour, the detector temperature control requires occasional manual adjustments due to environmental variations. Whenever the weekly monitoring indicates that one of the

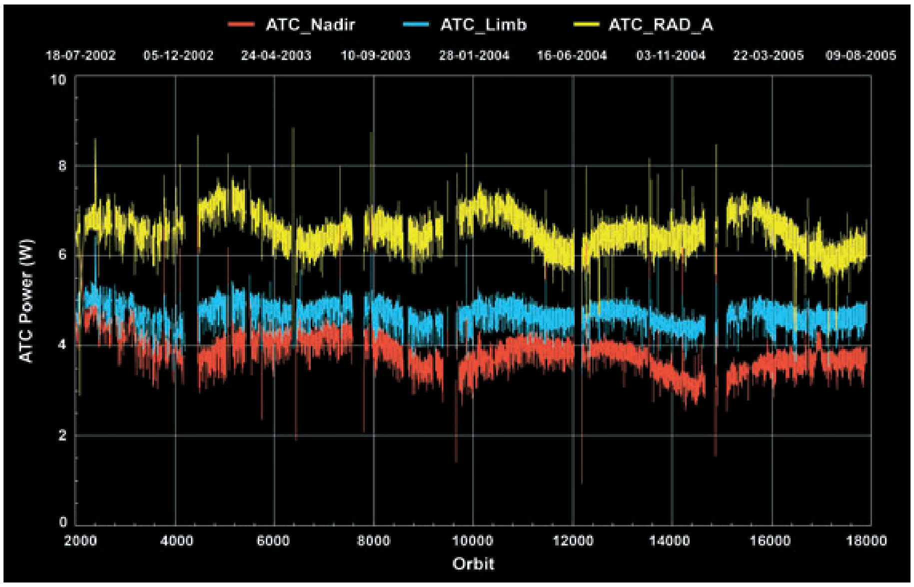

Fig. 6-5: Power consumption of the 3 heaters (Nadir, Limb and RAD_A) of the ATC system. The curve follows a seasonal variation with an expected long-term decrease most prominent for the ATC_Nadir heater. (graphics: DLR-IMF)

detectors will violate the limit in the near future, FOCC has to command new trim heater power settings to bring the particular channel temperature well back in range. Since channels 4 & 5 have the highest temperature sensitivity, most of the TC adjustments were caused by these detectors. Early during 2003 the temperatures selected by the TC settings for June 2002 were considered not to be optimum. Therefore in a number of TC adjustments during February 2003, the detector temperatures were brought into new ranges (see table 3-4 in chapter 3). Since then, control of the seasonal thermal variations requires only very few adjustments each year. For a period of 5-6 orbits after the adjustment, quality of the measurement data of the modified channel can be reduced because the temperature gradient exceeds the specified limit of 0.1-0.3 K/orbit for channels 5-8.

Decontamination, as mentioned earlier, is also part of thermal operations. Monitoring of the TC heater power led to the conclusion that RRU efficiency does not degrade with the rate estimated before launch. It was therefore decided to initiate a NNDEC only when the ice induced throughput reduction of channels 7 & 8 had reached unacceptable levels and abandoned the original requirement of two decontaminations per year. Early during the routine phase decontaminations occured more frequently since experience had to be gained about the most appropriate duration of the warm-up phase. Then, with a frequency of twice per year, NNDECs were executed, one in summer and one in winter. Due to accidental non-nominal events, either in the warm-up or cool-down, almost none of the executed NNDECs was identical. Improvement of the throughput for channel 7 after decontamination showed erratic behaviour without a clear explanation. One hypothesis is that a second cold trap exists in detector 7 which may be activated by forcing low temperatures in the cool-down of the NNDEC. This procedure was implemented operationally for the decontamination in winter 2004/2005. It removed almost all the ice

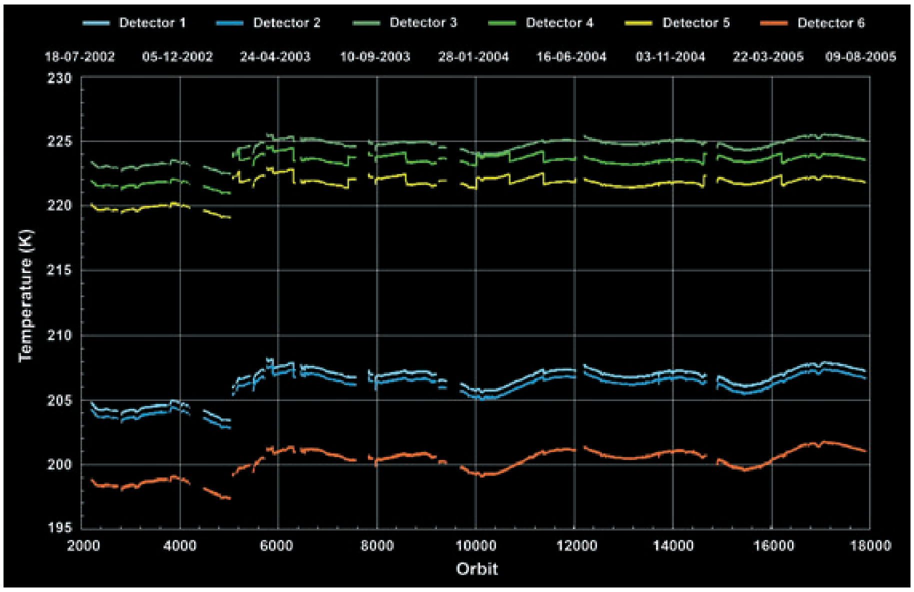

Fig. 6-6: Mean detector temperatures per orbit for channels 1-6. Decontamination intervals with elevated temperatures and periods after instrument safing with too low temperatures are omitted. The resulting curves display the seasonal variation. Steps are due to TC adjustments, mainly affecting channels 4 & 5. The increase around orbit 5000 corresponds to an overall TC correction to establish new temperature ranges. (graphics: DLR-IMF)

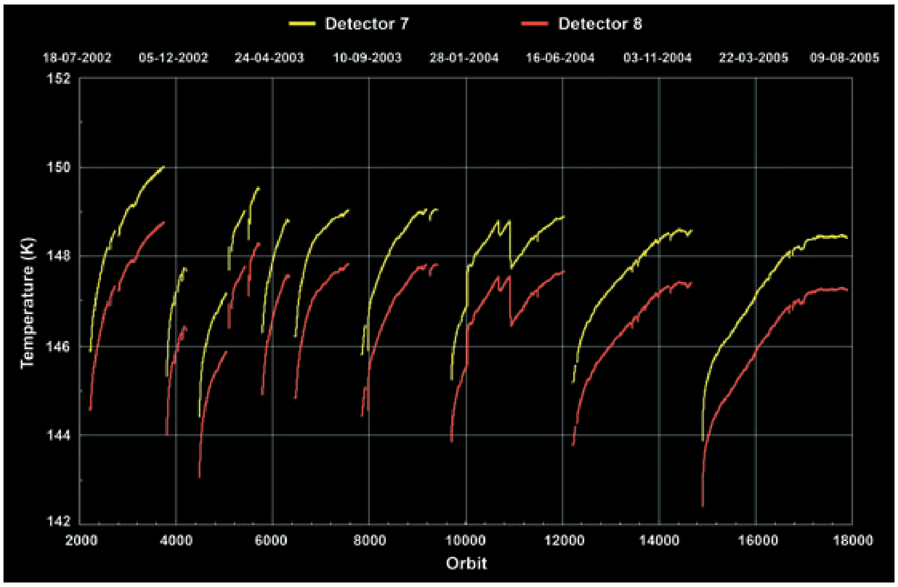

Fig. 6-7: Mean detector temperatures per orbit for the SWIR channels 7 & 8. Displayed data are as in fig. 6-6. The graphs are the result of growing ice (increase) and occasional decontaminations (drop to lower values). Between orbit 10600 and 10900 two TC adjustments had a significant impact on the SWIR detectors. (graphics: DLR-IMF)

from the light path of channel 7 and kept the reduction in channel 8 to less than 30 %.

The temperature behaviour of the infrared channels 7 & 8 is largely driven by the ice conditions. Ice also covers the gold plated aluminium structures of the detector suspension leading to an increased infrared absorption and thus radiatively heated detectors. This results in a slow but steady rising temperature. Immediately after a decontamination ice is removed and temperatures are at the selected cold level from where they start to increase – caused by the growth of the ice layer – until the next decontamination is started or an equilibrium with a stable ice layer is reached.

Optical Throughput

The regular monitoring of the optical light paths has generated a continuous record of optical throughput measurements. Although the results for the various paths differ slightly, all results provide a consistent view of the optical performance (fig. 6-8, 6-9).

UV: With an observed degradation of only about 3-4 % per year, SCIAMACHY still maintains a high throughput in channels 1 & 2. The GOME mission with similar detectors suffered from a larger decrease in sensitivity at short wavelengths.

VIS-NIR-SWIR: For detectors 3-6, variations are detected on a sub-percent level. The excellent stability permits correlation of the overall throughput with large scale features due to seasonal variations. Over short timescales even solar activity sensed via the effective sun spot area is reflected in the data.

SWIR: Throughput analysis in channels 7 & 8 provide a means for monitoring the status of the ice layers. The record of decontaminations has led to the conclusion that throughput measurements do not necessarily reflect the water content on the detectors but only in the optical path. As was learnt by the sequence of decontaminations from December 2003, June 2004 and December 2004, water might condense either on a second cold trap mimicking a water-free detector or on optical surfaces. In the first case the throughput approaches values close to 100 % while in the second case it can be drastically reduced. While detectors 7 & 8 display common trends after each decontamination, a more detailed look reveals differences not fully understood. The light path in detector 7 can become virtually ice-free but sensitivity in detector 8 is always reduced by about 20-30 % within 3-4 months.

Life Limited Items

The life limited items (LLI) in SCIAMACHY, i.e. mechanical components as NDFM, APSM and the NCWM, the mechanism to open the Nadir Calibration Window, internal calibration lamps WLS and SLS and cryogenic heat pipes shall only execute the specified number of switches, cycles or 'on' times. These numbers define the individual in-flight LLI budgets. Although the budgets have been established from on-ground life cycle tests and analyses with a margin factor of up to 2 in some cases, safe operations aim at not exceeding them over the mission lifetime. The operation of LLIs is monitored regularly and compared with the in-flight budget (fig. 6-10). From the start of routine operations, a linear increase of LLI usage occurs, just as expected from a repetitive stable measurement plan. Only during the Commissioning Phase, when specific SODAP states have executed lamp measurements or solar calibration states more frequently than nominal, or in routine operations, when an OCR has asked for temporary test measurements, the continuous LLI rate changed. With the present mission scenarios it can be expected that at the end of the specified mission lifetime solar states using the NDFM, APSM or NCWM will

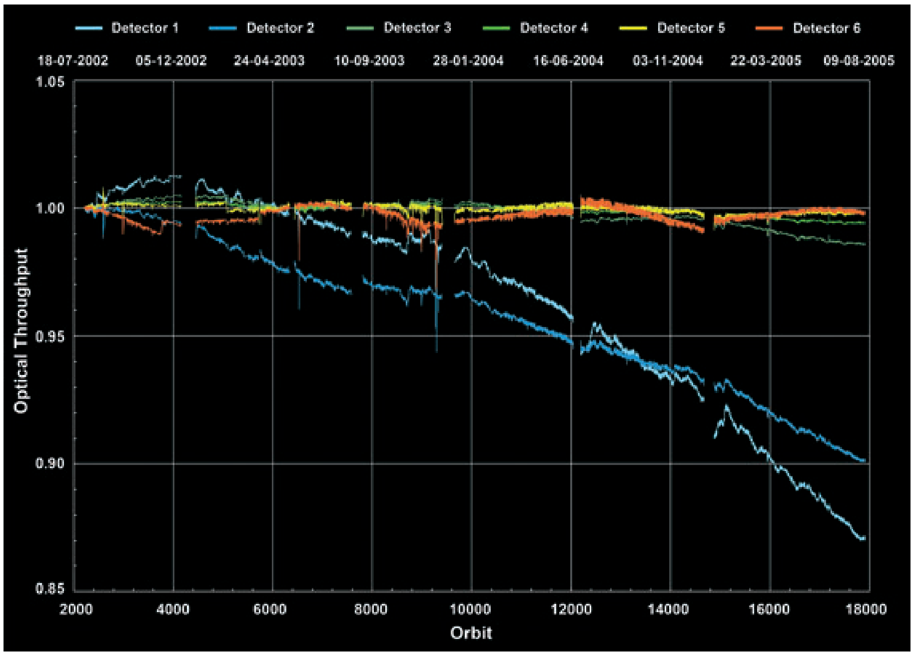

Fig. 6-8: Optical throughput for channels 1-6. As in fig. 6-6, decontamination intervals and periods after instrument safing are omitted. The information has been derived from the operational light path monitoring using the sun via the ASM and ESM mirror. (graphics: DLR-IMF and IUP-IFE, University of Bremen)

not fully reach the allocated in-flight budget while lamp measurements will remain well below this limit.

Limb Tangent Height

SCIAMACHY's limb mode is a powerful technique to sense the atmosphere with global coverage and high vertical resolution. A prerequisite for obtaining useful measurements is the accuracy with which the tangent heights can be reconstructed (*von Savigny et al. 2005*). The requirements on the knowledge of attitude and position of the spacecraft platform are particularly strict for limb geometries because the large distance – about 3200 km from the instrument to the Earth horizon – translate even small pointing uncertainties into large tangent height errors. For SCIAMACHY on ENVISAT, a pitch pointing error of 1 arcmin shifts retrieved profiles by 1 km.

Early in the mission, it was recognised that the operationally generated tangent height information differs by as much as 3 km from what was expected. The reference tangent heights were derived from the TRUE (Tangent Height Retrieval by UV-B Exploitation) method (*Kaiser et al. 2004*), which uses the so-called 'knee' as a spectral signature for retrieving limb pointing information. The TRUE results are considered reliable as long as the technique is restricted to tropical latitudes, e.g. between 20° N and 20° S, where stratospheric and lower mesospheric ozone variability is small. The offset between the operational tangent heights and those derived via the 'knee' method show a strong seasonal variation with a mean amplitude of 0.8 km and a constant bias of 0.5 km. The sinusoidal seasonal modulation is superimposed on a linear trend with a gradient of about 0.4 km per year.

SCIAMACHY's findings were compliant with a detailed analysis of pointing information from GOMOS and MIPAS. ENVISAT's on-board processing of state vector parameters uplinked from ground was identified to be the source of the observed pointing inaccuracy. In a corrective action the method to

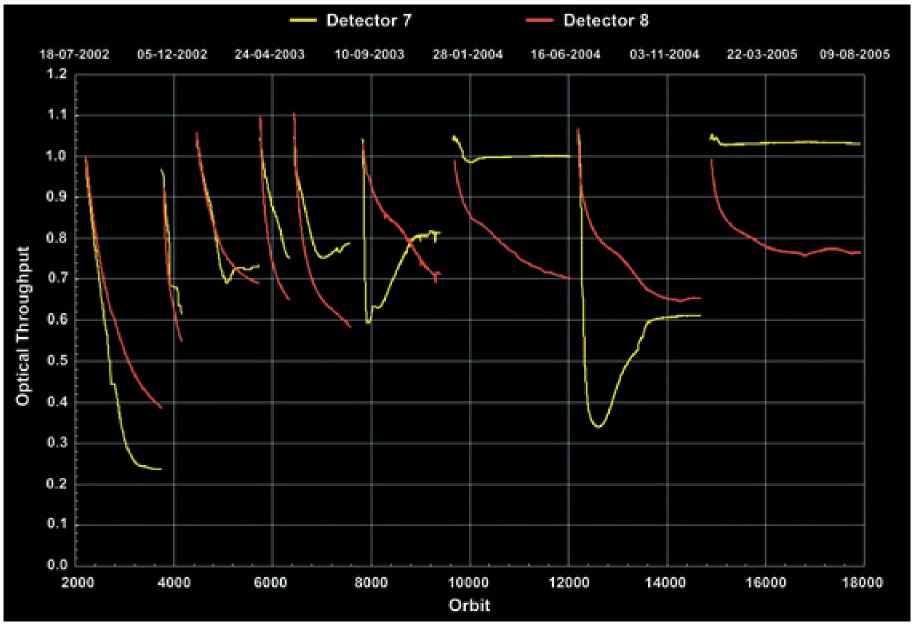

Fig. 6-9: Optical throughput for the SWIR channels 7 & 8. Similarly to fig. 6-7, a growing ice layer and its decontamination induced evaporation determines the shape of the curve. (graphics: DLR-IMF and IUP-IFE, University of Bremen)

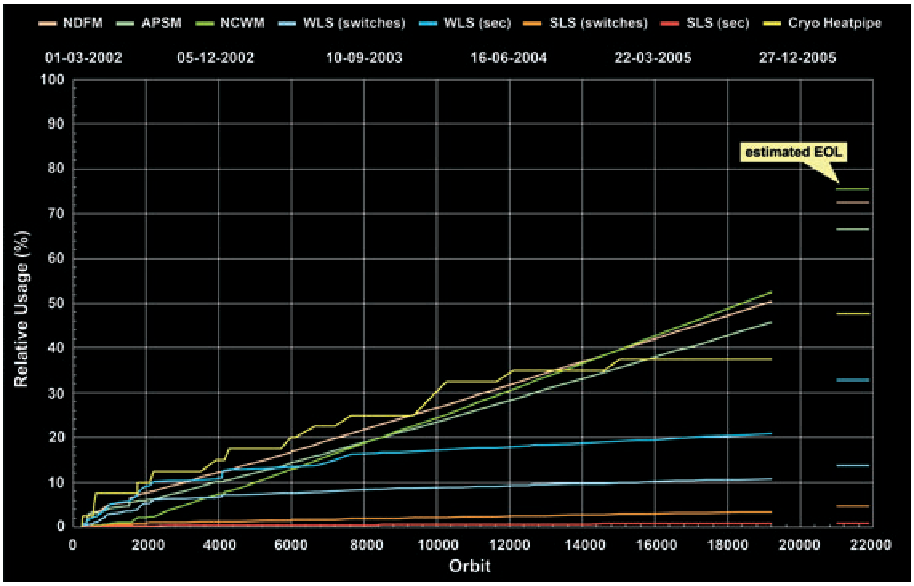

Fig. 6-10: LLI status after more than 3 years of operations. The expected End-of-Life (EOL) values for the specified mission lifetime are all below 100%. In case of a mission extension, as currently discussed, the EOL values will either be higher or the mission scenarios have to be adapted accordingly. (graphics: DLR-IMF)

derive these parameters on-ground was improved and finally implemented in December 2003 around orbit 9300. This resulted in a reduction of the tangent height jumps observed around the times of the daily updates of the on-board state vector and of the seasonal variation of the tangent height offset. Mean amplitude of the offset was now about 0.2 km with the linear gradient reduced by a factor of 3. However the bias increased to 1 km and remained practically stable over a year (fig. 6-11).

Further investigations are ongoing to understand the origin of the offset and to correct for it. The goal is to achieve an accuracy of about 300 m to fully exploit the limb data obtained by SCIAMACHY.

Moon Occultations & Anomalies

Instrument anomalies are detected by the ICU, PMTC or SDPU. How the anomalies impact on operations depends on the type of corrective action assigned to the particular anomaly. For safety reasons most of the actions transfer SCIAMACHY to a mode lower than *Measurement*. This applies to the non-nominal events described in chapter 6.1 as the major source for measurement interruptions. However, there are in addition a number of faults and events which are reported by the instrument but do not initiate a mode transition. The regular monitoring during routine operations has tracked these and found their occurrence compliant with the specification in the IOM.

The most frequent anomaly of the latter kind is triggered during lunar occultation states. SCIAMACHY's occultation measurements use the rising sun or moon as a target, usually acquired in at least one axis by the Sun Follower. The wide field of view of the SF receives not only light from the solar or lunar disk but also from the surrounding area, including the atmosphere. While the sun has a surface brightness higher than the illuminated atmosphere, the moon at a low altitude and sunlit white clouds are similar in intensity. As long as moonrise occurs over the nearside of the terminator (dayside), it turned out that the SF is regularly confused by the bright atmos-

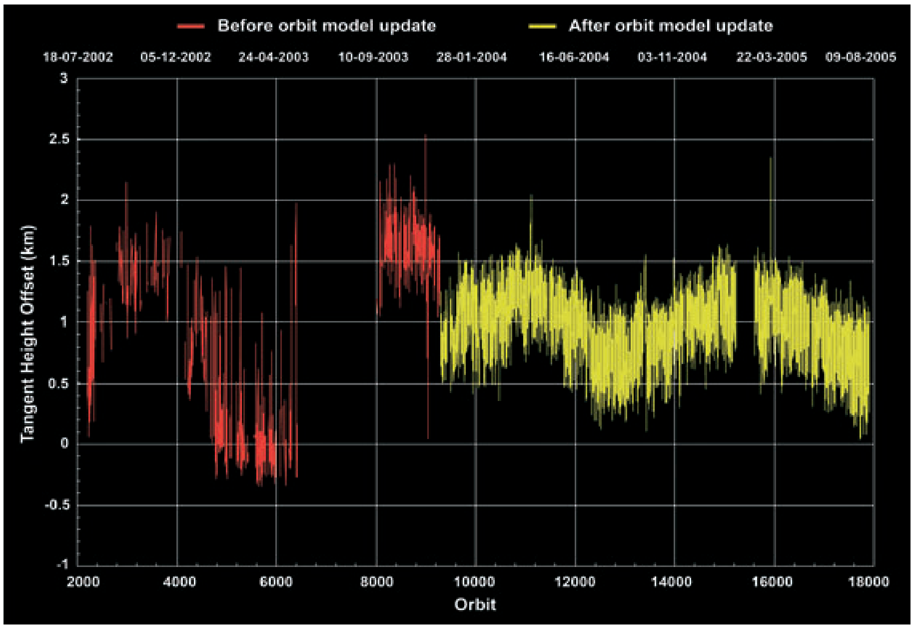

Fig. 6-11: Tangent height offsets as determined from operational data products and TRUE retrieved profile information. Prior to December 2003 the bias had a strong harmonic variation. After the update of the on-board propagator model this variation is reduced but a constant offset persists. (graphics: DLR-IMF and IUP-IFE, University of Bremen)

phere and therefore cannot acquire the moon. To avoid a series of anomaly warnings of the type mentioned above, it has been decided to observe lunar occultations only when moonrise occurs over the farside of the terminator (nightside). This reduces lunar occultation opportunities to about 50%.

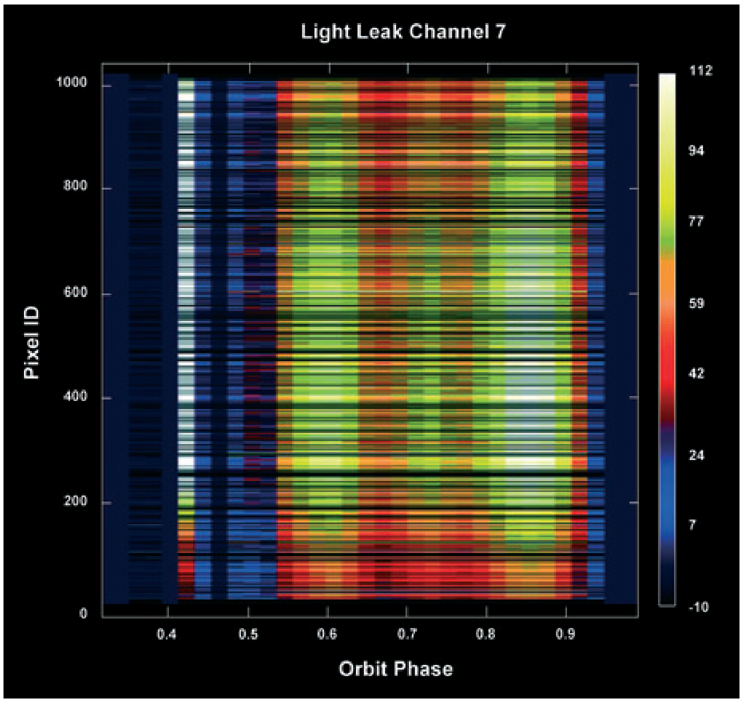

Fig. 6-12: Mean light leak signal for all pixels in channel 7 as a function of orbit phase. The x-axis shows the orbit phase (eclipse corresponds to phase 0.95-0.40, sunrise occurs at phase 0.41), the y-axis the pixel number in channel 7. The colours indicate the size of the light leak signal in BU/sec. (graphics: DLR-IMF and SRON)

Light Leak in Channel 7

After launch it was discovered that channel 7 shows a spurious signal in limb dark measurements that is much higher than the spatial stray light found in the other channels. This signal has no spectral signature and is a broadband feature, excluding that it is caused by light passing through the optics of the instrument. The explanation requires a tiny hole – termed *light leak* – in the channel 7 detector module, where light can enter the instrument and illuminate the detector without being dispersed first. Investigations to characterise the light leak were done using limb dark current measurements at 250 km altitude. At this tangent height and after correction of the data for non-linearity, dark signal and spectral stray light, the residual signal should be caused by the light leak alone, because no light from the Earth is expected. No contribution from the spatial stray light mentioned below has to be considered since this is only a fraction of the light leak signal and can be neglected here.

Fig. 6-12 displays the mean residuals after correction of all analysed data, i.e. the signal caused by the light leak. The derived light leak signal is spectrally smooth, with a systematic behaviour as a function of orbit phase. However, variations over one month can be quite large (50 BU/sec), nearly comparable to the size of the light leak signal. Therefore, the light leak is not only a function of orbit phase but more likely a function of viewing geometry combined with the presence of regions with high albedo, e.g. caused by clouds. Correction of the light leak signal is a prerequisite for the generation of high quality calibrated spectra in channel 7 and subsequent trace gas retrieval. Further analyses are necessary to achieve this goal.

Spatial Stray Light in Limb Measurements

During analysis of limb data it was discovered that these measurements suffer from spatial stray light. This was not expected and was first noticed in measurements taken at 150 km tangent height where no atmospheric light should be present. The measurements at 150 km were originally intended to determine the orbital variation of the dark signal in channel 8 serving as an optional dark correction for limb measurements. Investigations *(van Soest 2005)* show that the additional signal was not caused by a light leak because spectral structures such as air glow emissions and atmospheric absorptions are visible in the measurements. This means that the signal is spectrally dispersed and thus goes through the optics of the instrument. Comparison with MERIS data revealed that the stray light does not correlate with the intensity of the scene at the sub-satellite points ruling out the possibility that light leaking through the nadir port is subsequently directed into the telescope. Measurements of limb scans at high altitude and at a lower tangent altitude of 10 km result in a good correlation confirming that the stray light is caused by light entering the instrument through the slit from regions outside the IFoV. The stray light impact is highest in channel 2-4 and is very low in channels 1, 5 and 6. The effect of the stray light on the limb retrievals will be assessed in future investigations. In order to avoid corrupted limb dark current measurements, the final flight instrument configuration has been adjusted early during the routine operations phase by raising the tangent altitude from 150 km to 250 km. At this height the spatial stray light is reduced by an order of magnitude to 5-10 BU/sec, thus allowing an estimation of the orbital dark variation.