GOME-2 FM3 Long-Term In-Orbit Degradation - Status After 1st Throughput Test
## Document Change Record

<table>
<thead>
<tr>
<th>Issue / Revision</th>
<th>Date</th>
<th>DCN. No</th>
<th>Changed Pages / Paragraphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>04/11/2008</td>
<td></td>
<td>Initial version</td>
</tr>
<tr>
<td>v2</td>
<td>15/07/2009</td>
<td></td>
<td>After initial instrument throughput test, instrument review and user input.</td>
</tr>
<tr>
<td>v3</td>
<td>21/08/2009</td>
<td></td>
<td>After GOME instrument teleconference 29/07/2009</td>
</tr>
<tr>
<td>v3A</td>
<td>07/12/2009</td>
<td></td>
<td>Update to fix typos and other editing problems</td>
</tr>
</tbody>
</table>
Table of Contents

1 Introduction .................................................................................................................................. 4
   1.1 Purpose and Scope ................................................................................................................. 4
   1.1.1 Document Structure ......................................................................................................... 4
   1.2 Applicable Documents .......................................................................................................... 5
   1.3 Reference Documents .......................................................................................................... 5
   1.4 Acronyms ............................................................................................................................. 5

2 GOME-2 Long-term Signal Trends ............................................................................................... 7
   2.1 Signatures ............................................................................................................................ 7
   2.1.1 Degradation Signals using Solar Mean Reference Spectra .............................................. 7
   2.1.2 Degradation Signals using On-board Calibration Lamps ................................................... 9
   2.1.3 Throughput Behaviour during Switch-off ........................................................................ 14
   2.1.4 Throughput Behaviour at Individual Wavelengths for SMR and WLS Spectra .............. 15
   2.2 Analysis of Signals (Status Summary before Throughput Test) ........................................ 17
   2.3 Potential Effects on Product Quality .................................................................................. 18
   2.3.1 General .......................................................................................................................... 18
   2.3.2 Throughput Change Related Instrument ARs ................................................................. 20

3 TEST Proposal for Additional Support of Throughput Degradation Analysis ......................... 21
   3.1 Test Setup ......................................................................................................................... 21
   3.2 Instrument Operations during Test Phase ........................................................................... 22
   3.2.1 Instrument Commanding ............................................................................................... 22
   3.2.2 Timelines ...................................................................................................................... 22

4 Test Results ................................................................................................................................ 25
   4.1 Anomalies with respect to Test Implementation Plan (Section 3) and Unforeseen Behaviour  26
   4.1.1 Anomalies ..................................................................................................................... 26
   4.1.2 Unforeseen Behaviour ................................................................................................. 26
   4.2 Temperature Signals .......................................................................................................... 28
   4.2.1 FPA Array Temperatures ............................................................................................. 28
   4.2.2 PMD Array Temperatures ............................................................................................ 29
   4.2.3 Overall GOME Temperatures ...................................................................................... 30
   4.3 Spectral Signals .................................................................................................................. 31
   4.3.1 Summary FPA .............................................................................................................. 31
   4.3.2 Summary PMD ............................................................................................................. 32
   4.3.3 Comparison with GOME-1 ........................................................................................... 32
   4.3.4 Observed Signals of the Individual Components .......................................................... 33
   4.3.5 Overall Throughput Behaviour during Throughput Test at Individual Wavelengths (cf. Section 2.1.3) ..................................................................................................................... 40

5 Conclusions after Discussions with External Partners .............................................................. 43
   5.1 Instrument In-Flight Performance Review May 2009 ....................................................... 43
   5.1.1 Test Results Summary .................................................................................................. 43
   5.1.2 Suggestions for Improvements ...................................................................................... 44
   5.1.3 Recommendations by the Instrument Review Board .................................................... 45
   5.2 GOME Scientific Advisory Group (GSAG) Meeting, May 2009 ..................................... 45
   5.2.1 Recommendation from the 43rd GSAG Meeting (Recommendation 43.1) ................... 46
   5.3 Reported Impact on Geophysical Products from 43rd GSAG and O3MSAF User Forum .... 47
   5.3.1 Increase of HCHO DOAS Fit Residuals (BIRA, M. v. Roozendael) ............................... 47
   5.3.2 Increase of NO2 and BrO Fit Residuals (IFE Bremen, Andreas Richter) ....................... 47
   5.3.3 Decrease of HCHO Vertical Columns (IFE Bremen, Andreas Richter) ....................... 48
   5.4 Conclusions and Recommendations .................................................................................. 49

6 Mitigating Actions for GOME-2 Throughput Degradation following Test Results Analysis 51
1 INTRODUCTION

1.1 Purpose and Scope

The document describes the motivation for implementing a dedicated test on the GOME-2 instrument and subsequent analysis of the results in order to initiate mitigating action to improve on the observed long-term degradation of the instrument signals, especially in the UV to visible spectral region. More in-depth analysis and conclusions drawn so far are also provided by the GOME-2 Product Validation report No. 4: Status after reprocessing G2RP-R1 [AD1] (status until June 2008) and the GOME Annual In-flight Performance Reports 2008 and 2009 [RD9][RD10]. Both documents describe in detail the degradation signals and their (potential) impact on product quality and instrument health.

The summary conclusions which have been drawn so far and which are presented here are the result of in-depth analysis of GOME-2 signals based on reprocessed level 1b data (G2RP-R1) until June 2008 and subsequent NRT data until January 2009 using the same or higher processor versions than have been used for the reprocessed data set. Additionally, all of the following have been taken into consideration: input from the GOME-2 team at EUMETSAT using all on- and off-line available monitoring tools (ARGUS – GOME-2), analysis from the GOME-2 in-flight performance review group reports and meetings (involving the instrument manufacturer, ESA SSST, the EUMETSAT instrument and processing teams), analysis from the Polarisation Study Group led by SRON (in the RAO framework) and analysis and input provided by the GOME Scientific Advisory Group (GSAG) with long-term experience in monitoring of this type of instrument (GOME-1, SCIAMACHY, GOME-2) as well as the O3MSAF user community.

An action has been given to EUMETSAT during the GOME-2 in-flight performance review meeting at Selex Galileo, Florence, 22 October 2008 ([RD7] (action items AI-11 and AI-15) “to decide on a test scenario for running detectors at a higher temperature and provide a proposal” and “to analyse and confirm similarity with GOME-1 for the throughput degradation behaviour.” This report implements the action items.

The report also proposes a new test scenario overcoming the shortcomings of the first test results described here along with further constraint targets with respect to potential future changes in instrument operations. This implements action item AI-11 with revisions made during the mid-term instrument review meeting at Selex Galileo in May 2009.

1.1.1 Document Structure

Section 2 provides an overview of the current status of signal degradation signatures from various optical paths (involving all detectors, calibration lamps, solar and earthshine radiances) through the instrument and includes a summary of conclusions and interpretations drawn so far from the observed signals, how they compare to GOME-1/ERS-2 and their (potential) impact on product quality. Section 3 details an implementation plan for issuing a test involving one day of operations with the GOME-2 detectors operating at a higher temperature, including identification of potential risks to instrument health and product quality and recovery actions. Following the analysis of test results in Section 4, Section 5
discusses and summarises the input provided by all external partners involved. Section 6 summarises the conclusions drawn and proposes the next steps to be implemented in order to arrive at mitigating actions concerning the instrument signal throughput behaviour.

1.2 Applicable Documents

[AD1] GOME-2 Level 1B Product Validation Report No. 4: Status at Reprocessing G2RP-R1 (EUM.MET.REP.08.0327)
[AD2] GOME Annual In-flight Performance Report Jan 2007 - Sep 2008 (EUM.OPS.DOC.08.3395)

1.3 Reference Documents

[RD2] GOME-2 Level 1 Product Generation Specification, EPS.SYS.SPE.990011
[RD4] GOME-2 Calibration and Validation Plan, EPS.SYS.PLN.01.010
[RD5] GOME-2 operational processor monitoring and reporting, EUM.OPS-EPS.DOC.07.0621
[RD6] The second Global Ozone Monitoring Experiment – An overview, Technical memorandum No. 11, EUMETSAT.
[RD8] The GOME Science Advisory Group Minutes of the 42nd Meeting 13/14 October 2008, EUMETSAT, Darmstadt, Germany, EUM.MET.MIN.08.0447
[RD9] GOME In-Flight Performance Annual Review (2008), EUM.OPS.VWG.08.3512

1.4 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOAS</td>
<td>Differential Optical Absorption Spectroscopy</td>
</tr>
<tr>
<td>EQSOL</td>
<td>Equipment Switch-Off (GOME-2 instrument only)</td>
</tr>
<tr>
<td>FDF</td>
<td>Flight Dynamics Facility</td>
</tr>
<tr>
<td>FPA</td>
<td>Focal Plane Assembly (the four GOME-2 main channels)</td>
</tr>
<tr>
<td>MoM</td>
<td>Minutes of Meeting</td>
</tr>
<tr>
<td>MPF</td>
<td>Mission Planning Facility</td>
</tr>
<tr>
<td>NIR</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>NRT</td>
<td>Near-real time</td>
</tr>
<tr>
<td>PLSOL</td>
<td>Payload Switch-Off</td>
</tr>
<tr>
<td>PMD</td>
<td>Polarisation Measurement Device (the two GOME-2 polarisation measuring channels)</td>
</tr>
</tbody>
</table>
QTH | Quartz Tungsten Halogen  
RAO | Research Announcement of Opportunity  
SIOV | Satellite In-Orbit Verification  
SLS | Spectral Line Source  
SMR | Solar Mean Reference  
SRON | Netherlands Institute for Space Research  
SZA | Solar Zenith Angle  
WLS | White Light Source
2 GOME-2 LONG-TERM SIGNAL TRENDS

2.1 Signatures

The following signatures show the long-term signal degradation of the instrument in all three dimensions (time, wavelength and signal source). The signals are derived from the operational on- and off-line monitoring and reporting database facilities as well as the post-analysis tools for GOME-2 instrument and processing available at EUMETSAT (EPQM – GOME-2) as specified by the GOME-2 Calibration and Validation Plan [RD4] and the GOME-2 monitoring plan [RD5]. Data are based on the GOME-2 reprocessed data set R1 [AD1] and data from a recent double switch-off period of the instrument (September 2008). For an overview of the GOME-2 instrument layout please refer to [RD6]. The level 0 to 1b processing, and mechanisms to incorporate instrument long-term signal changes, are described in [RD2]. All aspects of instrument operations are described in detail in the GOME-2 Instrument Operations Manual (IOM) [RD1].

During nominal operations the sun is observed daily with the GOME-2 instrument. The sun serves as a stable radiometric calibration source (the Solar Mean Reference (SMR) spectrum being a necessary input to most level 2 retrieval algorithms) and can be used to monitor instrument throughput. The instrument throughput degradation (defined as the relative change in the calibrated measurement of a stable input source, e.g. the sun, where all components in the optical path can contribute to the degradation) is an important measure of instrument health and the long-term perspectives for instrument performance. Absolute changes in throughput may affect geophysical parameter retrieval quality at a point in time, where the sensitivity limits of the instruments are reached. Differences in throughput degradation for different optical paths, in particular the earthshine optical path as compared to the solar optical path degradation, may affect sensitive retrievals making use of relative measurements of both signals. Throughput changes are monitored using various light sources (sun, as well as in-flight calibration lamp measurements) which have different optical paths within the instrument.

2.1.1 Degradation Signals using Solar Mean Reference Spectra

Figure 2-1 shows the derived instrument throughput for all four main FPA channels at all wavelengths. The data are given relative to 5 January 2007 and for all 1024 wavelength bins per channel (y-axis) until 31 January 2009. Data from calibrated solar mean reference spectra taken once per day are used. The throughput degradation of the instrument varies significantly with wavelength.
Figure 2-1: Change in instrument throughput based on solar mean reference spectra taken once per day for all main channels FPA between 240 and 800 nm and from 5 January 2007 to 31 January 2009 shortly after the throughput test carried out at 27-29 January 2009
The figure indicates that a notable loss of throughput has occurred between the first sun measurements, taken at the end of December 2006, and June 2008, especially towards the UV. After 18 months the combined optical components within the solar path show a degradation of 30% around 311 nm, with no clear evidence to date of levelling off (the latter is expected from experience with the GOME-1 instrument). In contrast, there is degradation of less than 5% over the same period in the infrared (IR) at 745 nm. The large difference between the UV and IR regions in terms of throughput loss is expected based on GOME/ERS-2 experience and has previously been attributed to wavelength-dependent differential degradation of the scan mirror coating. There are however potentially contributions from degradation or contamination of other optical components or the detectors.

Figure 2-2 shows comparable throughput behaviour for the individual polarisation measurement devices PMD-S and P.

![Figure 2-2: Change in instrument throughput for PMDp (channel 5) and PMDs (channel 6)](image)

### 2.1.2 Degradation Signals using On-board Calibration Lamps

The on-board calibration lamps (White Light Source (WLS), Spectral Line Source (SLS) and LEDs) are used for regular (daily and monthly) upgrades of the calibration of the instrument in flight. Their signals are used during level 0 to 1b processing [RD2]. Here, the analysis of the calibration lamp signal degradation is used to identify differences in the degradation signature of various optical paths within the instrument (see instrument layout in [RD6]) and ideally to isolate the component which is the main contributor to the observed degradation.

The WLS spectrum provides a continuous radiance spectrum similar to the solar irradiance spectra. Figure 2-3 shows the change in throughput of WLS signals normalised to 5 January 2007 and for all wavelengths between 240 and 800 nm both for FPA and PMD measurements.
Figure 2-3: Change in instrument throughput based on WLS spectra taken once per day for all main channels FPA between 240 and 800 nm and from 5 January 2007 to 31 January 2009 shortly after the throughput test carried out at 27-29 January 2009.
The in-flight etalon correction for main channel and PMD signals is derived from the in-flight WLS spectra and an on-ground reference spectrum. The throughput plot for WLS FPA measurements (Figure 2-3) relative to a measurement taken at 5 January 2007 shows a similar etalon signal for which the amplitude appears to be growing significantly in time. A similar effect is visible for the PMD WLS throughput signals for both PMDs as shown in Figure 2-4.

![Throughput plots](image)

*Figure 2-4: Change in instrument WLS signal throughput for PMDp (channel 5) and PMDs (channel 6)*

All calibration lamp signals are spectrally resolved (via grating dispersion) except for LED signals. The latter illuminate individual detector pixels directly (each detector pixel being illuminated by one LED). The LEDs are emitting light around 400 to 600 nm (green). Figure 2-5 to Figure 2-8 therefore show the degradation of all calibration lamp signals including LEDs with respect to January 2007 (see captions) around 311, 420 and 745 nm. All calibration lamp signals degrade at a similar rate in the region between 400 and 600 nm channel 3 with the WLS signal degradation being strongest. The latter is related to additional degradation of WLS in addition to degradation in the optical path or at the detectors because of accumulation of contaminants on the bulb wall of the QTH lamp. The latter is expected to be resolved or improved by issuing special QTH lamp operations as detailed in [RD14]. Note also that the SLS throughput degradation can vary somewhat from wavelength to wavelength depending on the strong spectral variability in signal (emission line spectrum) and depending on ignition time (spikes). Over the full spectral range SLS signal degradation is consistent with SMR within 5%, whereas WLS degradation is larger than SMR by up to 20% in some parts of the spectrum [RD14]. For additional discussion of the individual calibration sources we also refer to [AD1].
Figure 2-5: Change in instrument throughput around 311 nm (channel 1, band 1b) SMR (blue line), WLS (red line), SLS (green line) and LED (black line), as taken from G2RP-R1 + R0 NRT 4.x data. Note that LEDs illuminate at 400 to 550 nm over the whole detectors, also measurements are only made once per month. The data have been normalised to an average over the first 412 orbits (29 days) starting 20 January 2007.

Figure 2-6: Same as Figure 2-5 but for channel 3, band 3 data at 420 nm
Figure 2-7: Same as Figure 2-5 but for channel 3, band 3 at 541 nm

Figure 2-8: Same as Figure 2-5 but for channel 4, band 4 data at 745 nm
2.1.3 Throughput Behaviour during Switch-off

The vertical stripes in Figure 2-1 and the spikes of throughput recovery in Figure 2-5 to Figure 2-8 point to a very dynamic behaviour of the throughput during instrument switch-offs (PLSOLS or EQSOLs). During the latter events we observe a significant recovery of throughput in the SMR signal. Note that the extreme changes observed for channel 1 are an artefact of a sudden change in etalon in channel 1 at higher temperatures compromising the analysis. The reason for this sudden change is probably also related to temperature change and the change of an etalon-inducing layer in the optical path of channel 1 during switch-off situations. A detailed analysis of throughput behaviour comparing SMR and LED around 550 nm during the double switch-off period of GOME-2 in September 2008 is shown in Figure 2-9. The signals show a significant throughput recovery after the period during which the detectors have been about 20 degrees warmer (~235 K nominal and ~255 K during switch-off) than during nominal operations. After the coolers have been switched on again a slow “recovery” to the initial degradation behaviour is observed for the main channels (FPAs). The recovery period is of the order of days. A much faster recovery (of the order of an hour) is however observed for PMDs (not shown here). Also LED and SMR signals, the former being situated directly in front of the detector and the later travelling through the whole optical path of the instrument, seem to “recover” at the same rate.

Note, the observed consistent recovery during switch-offs is about 50% of the overall degradation and is likely related to changing detector temperatures (since it is also observed in LED signals; see also Figure 2-9), whereas the remaining 50% may be attributed to a source insensitive to these temperature changes such as scan-mirror degradation.

![Figure 2-9: GOME throughput at 550nm for LED (red line) and SMR (green line), immediately after recent patching attempts. Note that after the first patching attempt, several LED calibrations were performed, then several SMR. After the second patch, LED calibrations and solar calibrations were interleaved.](image-url)
2.1.4 Throughput Behaviour at Individual Wavelengths for SMR and WLS Spectra

In the following figures the instrument throughput behaviour at seven individual wavelengths (including PMD-P and S) is displayed using SMR and WLS measurements. The results are derived from the 2D matrices shown before and essentially show the same behaviour but at an individual wavelength only. What becomes more obvious from these plots is that the degradation rate is not linear anymore by the end of 2008, especially for the near-infrared (NIR) region. A first sign of the degradation rate levelling off (as observed for GOME-1 after 7 years in orbit; see below) is visible in both PMD and FPA signals.

Figure 2-10: Throughput behaviour of SMR (left panel) and WLS (right panel) signals at 240 nm (FPA only)

Figure 2-11: Throughput behaviour of SMR (left panel) and WLS (right panel) signals at 311 nm for FPA and PMD-P/S signals
Figure 2-12: Same as Figure 2-11 but at 330 nm

Figure 2-13: Same as Figure 2-11 but at 380 nm

Figure 2-14: Same as Figure 2-11 but at 420 nm
2.2 Analysis of Signals (Status Summary before Throughput Test)

During various meetings of the Polarisation Study Group, the Instrument In-flight Performance Review meeting and the GOME-2 Scientific Advisory Group meetings, the degradation signals observed have been discussed in depth (for all additional inputs given and the results of the discussion we refer to the Minutes of Meeting (MoM) and presentations given at [RD7], [RD8] and [RD9]). The results of the discussion are not yet conclusive and must therefore be tagged as preliminary. The following list summarises the main ideas relating to interpretation of the observed signals so far.

1. The spectral behaviour of the throughput change points partly to a degradation of the scan-mirror surface (coding) which was assumed to be the main cause of degradation for GOME-1 on ERS-2. However, whilst the spectral behaviour of the GOME-1/ERS-2 degradation does indeed show similarities to the spectral behaviour of throughput change for GOME-2, (cf. Figure 2-17) the involvement of the scan mirror as the primary cause is contradicted by a close to 100% recovery of throughput during switch-off (during which the instrument overall cools down).

2. The strong variation in throughput behaviour during switch-off (warming up of detectors which are cooled during nominal operations) with up to 50% recovery of the
observed overall degradation and a similar behaviour in throughput change between LED and all other sources suggests that part of the “degradation” is caused locally and directly at or in front of the detectors. Possible sources could be an ice layer (as expected from GOME-1/ERS-2) with a thin absorbing contaminant layer on top of it of as yet unknown type, with much stronger absorption in the UV than in the visible and NIR. Significant change in the temperature of the environment can potentially initiate an evaporation of a large part of the contaminant (though probably not the ice layer itself because such high temperatures have not yet been reached). The latter is supported by an analysis of the etalon behaviour during switch-offs [RD10]. The different “recovery” rates between FPA and PMD throughput could then be explained by the fact that FPA detectors are largely sealed with connection to the environment only by very narrow tubes by which exchange with the environment is possible but diffusion processes are likely to be very slow. In contrast the PMD detectors are not sealed and any contaminants which are evaporated may be collected again much more rapidly.

3. It is likely that the observed degradation signal is a combination of items 1 and 2 with an additional contribution of a potential (though currently not quantifiable) long-term degradation of calibration sources like LED and WLS, and additionally potential degradation of the diffuser plate (which can in part be quantified using SLS versus SLS over diffuser measurements).

4. Figure 2-9 shows the throughput changes as measured by LEDs and SMR during recent attempts to patch the GOME-2 scientific processor. In the first instance, only LED measurements were made on several successive orbits, followed by only SMR measurements on successive orbits. In the second instance, the SMR and LED measurements were interwoven. It can be seen that the LED output appears to be temperature dependent. In the first few orbits, before GOME-2 is thermally stable, the throughput as measured by the LEDs is higher than that measured by SMR. As the instrument warms and thermal stability is reached, relative throughput as measured by the LEDs begins to match that measured by SMR.

5. By the end of 2008 the degradation rate appears to be non-linear (start of levelling off) for all channels but most pronounced in the visible to NIR region.

2.3 Potential Effects on Product Quality

2.3.1 General

The use of degradation correction factors in the level 0 to 1 processor has been foreseen [RD2]. The G2RP-R1 reprocessed data set will be used to derive degradation correction factors which can be applied on- or offline to the level 1b radiance product. The latter can however only be implemented in a physically meaningful sense if the root cause of degradation is understood, or if the trends are expected to be stable. Currently the long-term signature is larger than has been observed with GOME-1/ERS-2 for the first two years of operations (see Figure 2-17). GOME-1 observed degradation was of the order of 20% in channel 1 and 10% in channel 2 after the first two years of operations. These levels have already been reached after about one year of operations for GOME-2 (cf. Figure 2-1). GOME-1 degradation levelled off after about 7 years of operations. If the underlying degradation mechanisms of GOME-2 are similar to those affecting GOME-1 it is currently
too early to expect any kind of slowing down or even reversal of the GOME-2 degradation process.

Sensitive retrievals of level 2 geophysical parameter concentrations from the UV to visible regions (channel 1 and 2 up to 400 nm) covering ozone, absorbing aerosol index, SO$_2$, BrO and other minor trace gases may be significantly quality affected once the signal levels fall below a certain threshold with respect to January 2007, largely due to increase in signal-to-noise ratios as signal levels drop (for first observations and analysis regarding the impact on geophysical products we refer to Section 5).

Degradation or changes in throughput behaviour also affects the processing of calibrated radiances and their quality in various ways. A detailed discussion of the current effects on processing quality is given in Section 5.7.2.3 of [AD2]. Here we list only the main issues observed so far.

1. The geographical region (high SZA) for which PMD signals are falling below a pre-defined threshold is growing. As a consequence the region for which main channel radiances are corrected for polarisation effects is shrinking.
2. The quality of polarisation correction is generally compromised by differential degradation between PMD-P and S.
3. SLS signals for channel 2 fell below a pre-defined processing threshold of 80 BU (AR. 9234). This resulted in a serious degradation of spectral calibration in this spectral region. The issue has been resolved (see next section).

Figure 2-17: GOME-1/ERS-2 throughput change of SMR since January 1996 taken always on 9th January. (Melanie Coldewey-Egbers et al., Applied Optics, Vol.47, No. 26, 4749-4761, 2008)
2.3.2 Throughput Change Related Instrument ARs

A small number of anomalies have been raised and documented, which are related to change in instrument throughput and affect or have affected the product quality. These anomalies have been addressed during the GOME-2 in-flight performance meeting [RD7].

<table>
<thead>
<tr>
<th>AR/NCR</th>
<th>Description</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR.7304</td>
<td>Loss of Throughput in GOME-2 Instrument</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>AR.9234</td>
<td>HCL lamp signal drop and degradation impacting GOME-2 spectral calibration</td>
<td>Closed</td>
<td>Integration times updated in timelines</td>
</tr>
<tr>
<td>AR.10369</td>
<td>GOME-2 PMD signal throughput degradation</td>
<td>Open</td>
<td>Proposed solutions: 1) Move Band 1 into Block C to double integration time on board 2) Perform signal co-adding on ground 3) Re-assess definitions of PMD signal level limits</td>
</tr>
</tbody>
</table>
3 TEST PROPOSAL FOR ADDITIONAL SUPPORT OF THROUGHPUT DEGRADATION ANALYSIS

3.1 Test Setup

Based on the preliminary analysis results listed in Section 2.2, the 42nd GSAG (see Section 5.4 of MoM [RD8]) and the GOME-2 In-flight Review meeting (see action 11 of MoM [RD7]) suggest to run a test on the throughput behaviour of the instrument by increasing detector temperatures to an extent that significant recovery is observed and over a longer period (for 12 orbits) with an otherwise nominally operated instrument. All four main channel detectors and the PMD detectors shall be “warmed”.

In the case of the FPA detectors, control loops are in place that can be used to maintain stable detector temperatures. The target temperature can be set independently for each detector to a resolution of 0.00763 K, however all detectors will be commanded with the same target temperature in steps to arrive at a target temperature of 265 K, i.e. 30 degrees warmer than the current nominal operations temperature of the main channel detectors. The target temperature mimics the situation during previous instrument switch-off events. The temperature increase shall be taken in steps of 5 degrees: 235, 240, 245, 250, 255, 260 and 265 K, each lasting for three orbits of operations. It should be noted that at the higher target temperatures, the detectors may not necessarily be actively cooled throughout the entire orbit.

In the case of the PMD coolers, there is no control loop and the coolers cannot be commanded independently. The Peltier coolers can only be set to Off, GroundLine (low power) and FlightLine (high power). For this test, both PMD detectors shall be put on ‘ground line’. It is expected that the detectors will stabilise at approximately 268 K and then exhibit orbital fluctuations. The PMD coolers will be put on ground line at the beginning of the test since the detectors are within a few kelvin of their lower limits on the flight line and the reduced output of the FPA coolers at the higher FPA target temperatures may cause a breach of yellow or even red limits.

Dedicated timelines shall be issued during the test orbits comprising measurements of all calibration sources (SLS, WLS, LED), dedicated dark measurements for these calibrations, as well as two dedicated periods of dark measurements with integration times of 0.09375 and 6 seconds in order to investigate the impact of the temperature change on the instrument noise level. The latter calibrations, except for SUN, shall be issued during dark-side eclipse. On the bright side of the orbit nominal NOT1920 scanning shall be carried out. The NRT dissemination via EUMETCast shall be stopped during the test including the following recovery period going back to nominal operation temperatures and subsequent checks on data quality of approximately 2 to 4 orbits.

A detailed implementation procedure (instrument commanding) and an analysis of potential impact on instrument health are provided in the next section.
3.2 Instrument Operations during Test Phase

In the design of instrument operations, the following points are considered:

i. Since the Peltier loops will never be put into heating mode, an update to the on-board monitoring limits for the duration of the test is not deemed necessary.

ii. The operation will be performed entirely by GOME timelines due to the proven robustness of the facilities in place to generate syntactically correct and safe timelines and the minimum impact on day-to-day operations.

iii. Each timeline should be as far as possible a stand-alone unit. For control of hardware, this is mandatory; for control of software functions it is recommended. The main point to watch out for is that the coolers are always deactivated before any change in target temperature, so that no assumption is made about the previous setting.

iv. Each timeline must be designed to start at SZA90-580s.

3.2.1 Instrument Commanding

Instrument commanding will be performed by the same process/procedures that were used during SIOV. A STOL file describing the timelines that need to be loaded and activated on each orbit will be updated and placed on the system. FDF events will be used to automatically generate a STOL file containing all the SZA90-580s times. Finally, a STOL procedure triggered by the spacecraft operator will be used to tie these two together and uplink the necessary commands. Command deconfliction with the MPF schedule will be performed on the Thursday before the test when the MPF schedule is available.

Only slot 15 shall be used for this test so that all the slots used during nominal operations are preserved in RAM.

Each time a new timeline is run from slot 15, it will be loaded into slot 15 at SZA90-610s (i.e. 30 s before execution). This is handled by the process outlined above.

After the test, GOME FPA detectors will be returned to their nominal temperatures at a pre-planned time, using timelines. It may be possible that the lower Peltier outputs will reduce the optical bench temperatures to below 273 K, so reverting the PMD coolers back to the flight line will need to be scheduled sometime after the test based on actual temperatures at the time. The command to set the PMD coolers to ground line can be slotted in between two timelines using time-tagged commands, so this operation will not interfere with routine operations.

3.2.2 Timelines

The operation, including setting of target temperatures, will be performed using timelines. The timelines must also perform nominal Earth Scan, LED, SUN, SLS and WLS measurements as well as their dark signal corrections. The timelines will also perform all the necessary temperature changes.
The timeline naming convention will be as follows:

GOME_LTL_15_M02_THR[TTT][L]x01,

where TTT = FPA target temperature in kelvin and L is the PMD cooler line to be used (G for ground, F for flight).

Figure 3-1 shows the generic standard timeline to be used, without the target temperature or PMD line selection specified. For the purposes of this test, the timeline shall have the following flavours:

GOME_LTL_15_M02_THR235Gx01
GOME_LTL_15_M02_THR240Gx01
GOME_LTL_15_M02_THR245Gx01
GOME_LTL_15_M02_THR250Gx01
GOME_LTL_15_M02_THR255Gx01
GOME_LTL_15_M02_THR260Gx01
GOME_LTL_15_M02_THR265Gx01

For the dark signal measurements at 0.09375 and 6 s that are made to establish the effect of temperature on noise, the following timeline has been derived from NOT1920x06:

GOME_LTL_15_M02_THRDRKxx01
### Figure 3-1: Standard throughput monitoring timeline with target temperature changes

<table>
<thead>
<tr>
<th>Slot</th>
<th>GOME_LTL_15_M02_THRTT77L xx01</th>
<th>Throughput Calibration Timeline (Sun, SLS, WLS, LED) + 1920 km swath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>Mode Description</td>
<td>[Throughput parameters and notes]</td>
</tr>
<tr>
<td>1</td>
<td>PMD raw transfer mode</td>
<td>60 s 60 s 6 0.5 345.25 s</td>
</tr>
<tr>
<td>2</td>
<td>PMD Sun readout mode</td>
<td>60 s 60 s 6 93.97</td>
</tr>
<tr>
<td>3</td>
<td>Dark signal</td>
<td>442 s 1000 s 7.7 12.2 123.615.5 1.5 1.5 0.75 0.75 0.75 0.75 0.375 0.375 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>4</td>
<td>SUN calibration</td>
<td>210 s 20 s 3.5 474.7 9.7 96.2832.1 1.5 1.5 0.75 0.75 0.75 0.75 0.375 0.375 Fixed 314.2 Nadir nom off off off Normal Open ON ON ON 0111 (Sun)</td>
</tr>
<tr>
<td>5</td>
<td>PMD nominal readout mode</td>
<td>60 s 60 s 684.11.4 03.645.1</td>
</tr>
<tr>
<td>6</td>
<td>PMD band transfer mode</td>
<td>60 s 60 s 650.11.5 03.695.1</td>
</tr>
<tr>
<td>7</td>
<td>Nadir scan (earth view)</td>
<td>2000 s 1600 s 46.8 656.11.6 83.135.5 1.5 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 SCAN 0104 Nadir nom off off off Normal Closed ON ON ON 0001 (Nom)</td>
</tr>
<tr>
<td>8</td>
<td>Nadir scan (earth view)</td>
<td>78 s 450 s 1.3 3504.59.4 83.664.2 6 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 SCAN 0104 Nadir nom off off off Normal Closed ON ON ON 0001 (Nom)</td>
</tr>
<tr>
<td>9</td>
<td>Nadir scan (earth view)</td>
<td>246 s 760 s 4.1 3582.59.7 97.602.3 6 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 SCAN 0104 Nadir nom off off off Normal Closed ON ON ON 0001 (Nom)</td>
</tr>
<tr>
<td>10</td>
<td>PMD Line Select</td>
<td>60 s 60 s 3920.63.8 102.221.5</td>
</tr>
<tr>
<td>11</td>
<td>Dark signal</td>
<td>60 s 60 s 3834.63.9 102.576.5 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>12</td>
<td>FPA 1 Target Temp</td>
<td>60 s 60 s 3840.64.0 102.931.5</td>
</tr>
<tr>
<td>13</td>
<td>FPA 2 Target Temp</td>
<td>60 s 60 s 3840.64.1 103.286.5</td>
</tr>
<tr>
<td>14</td>
<td>FPA 3 Target Temp</td>
<td>60 s 60 s 3852.64.2 103.641.5</td>
</tr>
<tr>
<td>15</td>
<td>FPA 4 Target Temp</td>
<td>90 s 90 s 3900.64.3 103.096.5</td>
</tr>
<tr>
<td>16</td>
<td>Dark signal</td>
<td>400 s 1000 s 3840.64.4 104.951.5 1.5 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 0.1875 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>17</td>
<td>Dark signal</td>
<td>190 s 840 s 3434.72.8 132.650.6 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 0.75 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>18</td>
<td>Dark signal</td>
<td>190 s 840 s 4524.75.4 143.411.6 6 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>19</td>
<td>PMD raw transfer mode</td>
<td>60 s 60 s 4704.75.6 154.994.5</td>
</tr>
<tr>
<td>20</td>
<td>PMD readout mode</td>
<td>60 s 60 s 4710.75.6 154.419.5</td>
</tr>
<tr>
<td>21</td>
<td>PMD LED readout mode</td>
<td>60 s 60 s 4716.75.6 154.774.5</td>
</tr>
<tr>
<td>22</td>
<td>PMD IT setting</td>
<td>60 s 60 s 4772.75.6 154.929.5 9 9 12 12 6 7.5 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>23</td>
<td>LED</td>
<td>210 s 20 s 4902.81.7 165.782.9 9 9 12 12 6 7.5 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0101 (LED)</td>
</tr>
<tr>
<td>24</td>
<td>PMD IT setting</td>
<td>60 s 60 s 5112.62.2 170.24.9 0.49975 0.49975 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0101 (LED)</td>
</tr>
<tr>
<td>25</td>
<td>Dark signal</td>
<td>190 s 840 s 5118.62.3 176.665.3 3 3 0.75 0.75 0.75 0.75 0.75 0.75 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>26</td>
<td>Wavelength calibration</td>
<td>210 s 20 s 5298.83.3 170.783.3 3 3 0.75 0.75 0.75 0.75 0.75 0.75 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0100 (Spec)</td>
</tr>
<tr>
<td>27</td>
<td>PMD IT setting</td>
<td>60 s 60 s 5505.9.1 154.254.6 0.375 0.375 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>28</td>
<td>Dark signal</td>
<td>190 s 840 s 5514.9.1 157.999.6 6 6 3 3 6 3 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
<tr>
<td>29</td>
<td>Radiometric calibration</td>
<td>210 s 20 s 5694.9.4 147.347.6 6 6 3 3 6 3 Fixed 3269 Nadir nom off off off Normal Closed ON ON ON 0101 (Rad)</td>
</tr>
<tr>
<td>30</td>
<td>PMD raw transfer mode</td>
<td>60 s 60 s 5902.9.8 134.191.5</td>
</tr>
<tr>
<td>31</td>
<td>PMD Sun readout mode</td>
<td>60 s 60 s 5910.9.6 134.564.5</td>
</tr>
<tr>
<td>32</td>
<td>Dark signal</td>
<td>End 4FPO 5916.9.6 134.208.5 1.5 1.5 0.75 0.75 0.375 0.375 Fixed 2300 Nadir nom off off off Normal Closed ON ON ON 0111 (Dark)</td>
</tr>
</tbody>
</table>

Total time (up to last time) 5016 (Nominal Orbit Duration 6083)
4 TEST RESULTS

The test has been carried out starting with the first non-nominal test timeline (GOME_LTL_15_M02_THRDRKx01) executing on board at 27 January 2009, at 6:40:19 UTC (see schedule below) for orbit 11800. The PMD coolers have been put to ground line at the same day 09:27 UTC sensing time.

Test schedule and non-nominal timeline activation times as implemented during 27-29 January 2009. Note that yellow indicates the instrument was being operated with the PMD coolers on ground line.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Orbit</th>
<th>Instrument Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tue 27-Jan-2009 06:40:19</td>
<td>11800 SZA90N-580</td>
<td>GOME_LTL_15_M02_THRDRKx01</td>
<td></td>
</tr>
</tbody>
</table>
4.1 Anomalies with respect to Test Implementation Plan (Section 3) and Unforeseen Behaviour

Anomalies and unforeseen instrument behaviour have been observed which compromise the analysis of the results to some extent.

The analysis of PMD throughput behaviour cannot be carried out using solar measurements. This means that a potential impact of the diffuser on the throughput for PMD by changing instrument temperatures (decreasing during the test) cannot be evaluated.

Because the target temperature could not be reached (see below) the mimicking of previous switch-off conditions is additionally compromised.

4.1.1 Anomalies

The following anomalies have been detected during the test. All ARs are related to timeline issues.

i. Etalon could not be processed at first because of problems with timeline (AR 10783). This has been fixed for the results displayed here by reprocessing the test orbit data offline.

ii. Some dark measurements needed for calibration of on-board spectral lamp signal and sun could not be used because they were taken outside eclipse (SZA<118: timeline issue).

iii. PMD signals for SUN are lost because of erroneous timeline (wrong PMD transfer mode) (AR 10838).

<table>
<thead>
<tr>
<th>AR/NCR</th>
<th>Description</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR.10783</td>
<td>GOME-2 throughput test timeline sequence</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>AR.10838</td>
<td>Wrong PMD read-out mode for solar measurements GOME-2</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>throughput test timeline</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1.2 Unforeseen Behaviour

It was well known that at higher cold target temperatures, the ambient temperatures around the FPA detectors may be below the cold target temperatures for some or all of the orbit, resulting in a loss of thermal control. However, this point was reached earlier than anticipated.

Immediately after GOME is activated after a switch-off due to e.g. an anomaly, the Optical Bench Temperatures (ONA0113 Predisperser Prism Temp) are seen to fluctuate at around 265 K. The FPA detector temperatures exhibit more variation through the orbit, but fluctuating about a point which is approximately 3 K lower. Figure 4-1 illustrates these GOME temperatures after the EQSOL on 16 February 2009. Note that at the time GOME had been switched off for just over 20 hours.
Figure 4-1: GOME optical bench (ONA0113) and FPA1 detector temperatures following EQSOL on 16 Feb 2009

Based on observations such as these, it was assumed that with a warm running GOME, the ambient FPA detector temperatures would be somewhat higher than 260-265 K.

During the throughput tests, the optical bench temperatures were observed to fall slightly, as can be seen in Figure 4-2. This was expected since the PMD coolers were outputting less power from the start of the test after the switch to ground line, and the FPA coolers were outputting less and less power at each change in target temperature. However, the most important observation is that the maximum FPA detector temperatures achieved were about 258 K with a ±2 K orbital variation. With the target temperature at 260 K, the Peltier loops were only able to control the FPA detector temperatures at the warmest part of the orbit, and with a target temperature of 265 K there was no control of FPA detector temperatures at all.
4.2 Temperature Signals

4.2.1 FPA Array Temperatures

The overall temperatures of the FPA detectors during the tests are illustrated in Figure 4-2. It can be seen that each time a throughput timeline is run, the FPA detector temperatures have a sharp spike as the coolers are temporarily disabled. Also, this spike is larger at lower target temperatures when the target temperature is further away from the ambient temperature.

Figure 4-3 shows the FPA detector temperature in detail during the first THR235Gx01 timeline, which can be considered a worst case scenario. Recalling Figure 3-1, it can be seen that the detectors are switched off immediately before the target temperature change. The FPA detectors regain thermal stability within 15 minutes. Only Earth Scan dark signal corrections are made in this time, so during all calibration measurements and their respective dark signal corrections, the FPA detectors can be considered thermally stable.
Figure 4-3: FPA array temperature during the 1st THR235Gx01 timeline

It can be also seen in Figure 4-2 that the natural ambient FPA detector temperature was around 258–261 K. This meant that the last temperature setting with stable temperatures was 255 K. This has impacted the extent of the test and is discussed in detail in Section 4.1.2.

4.2.2 PMD Array Temperatures

During the throughput tests, the PMD detector coolers were set to their ground line (i.e. low power cooling).

From Figure 4-4, it can be seen that the PMD array temperatures reacted very quickly to the switch to ground line and that the overall temperature was reasonably stable compared to the natural orbital variation during the test. Due to the reduced output of the Peltier coolers, the PMD array temperatures cool down throughout the test until about midnight on 28/29 January 2009 when the FPA cooler target temperature is returned to 235 K. This is illustrated clearly in Figure 4-5.
4.2.3 Overall GOME Temperatures

Overall, GOME temperatures were seen to fall for the duration of the test as expected due to reduced power consumption of the Peltier coolers.

Figure 4-6 below shows that optical bench temperatures dropped by just under 2 K.
4.3 Spectral Signals

4.3.1 Summary FPA

During the test a systematic recovery of throughput with temperature and dependent on the spectral range has been observed. The rate of recovery for the main channels 1 and 2 is about 2 to 2.5% per 5 degrees of temperature based on the solar mean reference (SMR) and white light source (WLS) signals. The relative spectral line source (SLS) signals are quite noisy – probably due to small shifts in line position with temperature – such that complete spectral analysis of recovery rates is difficult to determine for these signals. However, at individual (stable) wavelengths the recovery rate for SLS signals is consistent with that of WLS and SMR. These conclusions are compromised by a strong etalon-like residual appearing at temperatures of 250 K and higher for SMR in channel 1, which is correlated with a strong throughput recovery for WLS in the same spectral regions and for the lowest wavelength only (see detailed plots below). The origin of this etalon is still unclear and a problem in data processing or with etalon-related processing settings can currently not be excluded. The recovery of 2.5% per 5 K otherwise appears to be robust over the complete spectral range of FPA channels 1 and 2.

FPA channels 3 and 4 show a significantly lower recovery with a maximum of 1% per 5 degree temperature change (or lower) peaking at both ends of channels 3 and 4.
The LED signals (green light) show a spectrally flat behaviour in recovery at a rate of just below 1% per 5 degrees.

All sources show a consistent behaviour in throughput change for FPA around 541 nm (used as LED reference wavelength) confirming the previously-summarised findings for FPA signals. There is a spurious step function in LED recovery rates introduced at temperatures of 250 K and for detector pixels higher than 680 (channel 1) and lower than 1100 (channel 2). The origin of these jumps is currently unknown.

A levelling-off of the rate of recovery with respect to temperatures is not observed for the current test scenario.

Overall the test led to a maximum SMR signal recovery (reached in channel 2) with respect to a reference Kitt Peak spectrum by 10% at temperatures around 259 K.

Changes in the shape of the etalon for FPA appear to be quite small during the test and for all channels, with the exception of the already-mentioned strong change in etalon for channel 1 at temperatures higher than 250 K.

*It should be noted that recovery of the throughput back to pre-test levels was almost immediate. This is a previously unexpected behaviour which has not been observed in previous switch-off events (for details see Section 2.1.4 and for a discussion of this feature see Section 5).*

### 4.3.2 Summary PMD

Temperatures of PMDs have only changed once (at the beginning of the test) from 232 K to 266.5 K and back to nominal temperatures after the test. During the test, temperatures for PMD decreased continuously showing some orbital variations from 266.5 K to about 264 K.

The initial throughput recovery for PMDs is observed to be between 2% (visible) and 15% (UV) for WLS signals, which is close to the observed recovery rate for FPAs (2.5% per 5 degrees in the UV; note the lower initial and the higher target PMD temperatures reached!). Because of the decreasing PMD detector temperatures, the PMD throughput decreased consistently by close to 2%.

The maximum LED signal for PMD recovery is 4.5% with a very flat spectral behaviour as expected.

Due to the timeline anomaly (see Section 4.1) PMD signals for SUN were not acquired!

Similarly as for the FPAs, etalon changes for PMD were generally quite small during the test.

### 4.3.3 Comparison with GOME-1

The following table lists the throughput degradation of GOME-2 before and during the test at the highest temperature attained of 259 K and with respect to the Kitt Peak reference
spectrum around one wavelength per channel, and additionally lists the throughput loss of GOME-1/ERS-2 as displayed in Figure 2-17 in the same wavelength region after 2 years of operation (2007 to 2008).

<table>
<thead>
<tr>
<th>Channel #</th>
<th>GOME-2 (235 K)</th>
<th>GOME-2 (259 K)</th>
<th>GOME-1/ERS-2 (approx. values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>10-20</td>
<td>8.5-17.5</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>8.5</td>
<td>0</td>
</tr>
</tbody>
</table>

### 4.3.4 Observed Signals of the Individual Components

#### 4.3.4.1 LED (FPA)

Figure 4-7: LED signal ratio for FPA with respect to the pre-test signal (taken during the monthly calibration at 11 January 2009 at 235 K). Three averaged measurements per temperature level (235, 240, 245, 250, 255 and 259 K) are displayed for all 1024 detector pixels per channel.
4.3.4.2 LED (PMD-P)

Figure 4-8: LED signal ratio for PMD-P with respect to the pre-test signal (taken during the monthly calibration on 11 January 2009 at 232 K). The averaged measurement ratios show results for temperatures gradually decreasing from 266.5 K to 264 K. Results are displayed for all 256 detector pixels per PMD channel.

4.3.4.3 LED (PMD-S)

Figure 4-9: Same as Figure 4-8 but for PMD-S
4.3.4.4 WLS (FPA)

Figure 4-10: Same as Figure 4-7 but for WLS measurement ratios

4.3.4.5 WLS (FPA) Focussed

Figure 4-11: Same as Figure 4-10 but zoomed in on the y-axis
4.3.4.6 WLS (PMD-P)

![Graph showing WLS (PMD-P)]

Figure 4-12: Same as Figure 4-8 but for WLS signals

4.3.4.7 WLS (PMD-S)

![Graph showing WLS (PMD-S)]

Figure 4-13: Same as Figure 4-9 but for WLS signals
4.3.4.8 SLS (FPA)

Figure 4-14: Same as Figure 4-7 but for SLS measurement ratios

4.3.4.9 SMR (FPA)

Figure 4-15: Same as Figure 4-7 but for SMR measurement ratios
4.3.4.10 SMR with respect to Kitt Peak Reference Spectrum (FPA)

Figure 4-16: Solar mean reference spectrum for FPA with respect to the Kitt Peak reference spectrum. Three averaged measurements per temperature level at 235 K (red line), 240, 245, 250, 255 and 259 K (purple line) are displayed for all 1024 detector pixels per channel.

4.3.4.11 Throughput Behaviour All Sources at 541 nm (FPA)

Figure 4-17: Throughput behaviour at 541 nm (channel 3) relative to the second test orbit measurement at 27 January 2009 8:00 UTC. LED (red), WLS (blue), SLS (green) and SMR (purple) signals are shown. Variations in SLS are due to multiple successive switch-ons of the spectral lamp leading to intensity variations in the lamp output. The missing SMR values are a known “feature” of the collection of SMR monitoring data by the GOME-2 level 0 to 1b processor.
4.3.4.12 Throughput Behaviour All Sources at 425 nm (FPA)

Figure 4-18: SLS voltages during throughput tests

Figure 4-19: Same as Figure 4-17 but at 425 nm (channel 3)
4.3.4.13 Etalon (FPA + PMDs)

![Etalon graph]

Figure 4-20: Etalon as derived from WLS measurements by the level 0 to 1b processor for FPA (channel 1 to 4 until detector pixel 4096) and the two PMDs (4097 to end). Three averaged etalon per temperature are shown at 235, 240, 245, 250, 255 and 259 K. The strong etalon change in channel 1 occurs at 250 K to higher temperatures.

4.3.5 Overall Throughput Behaviour during Throughput Test at Individual Wavelengths (cf. Section 2.1.3)

The FPA throughput-test signal (spike) does NOT show the typical medium-term exponential “recovery” of the nominal degradation rate as has been observed for previous switch-off situations (e.g. during the latest EQSOL event in February 2009; for details see also Section 2.1.3) and for FPA signals only (see Figure 4-21 and Figure 4-22). In contrast, the throughput behaviour during and after the test appears to follow the “one-off” pattern observed also earlier for the PMDs. This behaviour is evident for both SMR and WLS signals and at all wavelengths.
Figure 4-21: Instrument SMR signal throughput behaviour at 330 nm relative to January 2007 for the period of January and February 2009, covering the throughput test controlled detector temperature change by the end of January 2009 and a recent complete switch-off period of the instrument during the February 2009 EQSOL event. Note that PMD SMR signals during the throughput test in January 2009 could not be acquired (AR. 10838).
Figure 4-22: Same as Figure 4-21 but for WLS signals
5 CONCLUSIONS AFTER DISCUSSIONS WITH EXTERNAL PARTNERS

The test results have been discussed with various partners, in particular the direct impact on level 1b data quality (Instrument Review Meetings, GSAG), the subsequent impact on the quality of the derived geophysical products to date, and the potential future implications and perspectives (GSAG and O3MSAF user forum) for product quality. Observations and recommendations relevant for future operations or mitigating actions are highlighted in green.

5.1 Instrument In-Flight Performance Review May 2009

5.1.1 Test Results Summary

The outcome of the throughput test was summarised recently in the Annual Instrument performance report for 2009 [RD10] which was presented during the Mid-Term instrument performance meeting at Selex Galileo in May 2009 [RD11]. The summary provided in the review report is provided here for reference:

5.1.1.1 Summary FPAs

1. During the test a spectrally dependent systematic recovery of throughput was observed with increasing temperature. The rate of recovery for the main channels 1 and 2 is about 2 to 2.5% per 5 degrees of temperature based on the solar mean reference (SMR) and white light source (WLS) signals. The relative spectral line source (SLS) signals are quite noisy – probably due to small shifts in line position with temperature – such that complete spectral analysis of recovery rates is difficult to determine for these signals. However, for individual (stable) wavelengths the recovery rate for SLS signals is consistent with that of WLS and SMR. These conclusions are compromised by a strong etalon-like residual appearing at temperatures of 250 K and higher for SMR in channel 1, which is correlated with a strong throughput recovery for WLS in the same spectral regions for only the lowest wavelengths. The origin of this etalon is still unclear and a problem in data processing or with etalon-related processing settings can currently not be excluded. The recovery of 2.5% per 5 K otherwise appears to be robust over the complete spectral range of FPA channels 1 and 2.

2. FPA channels 3 and 4 show a significantly lower recovery with a maximum of 1% per 5 degree temperature change (or lower) peaking at both ends of channels 3 and 4.

3. The LED signals (green light) show a pixel-independent recovery at a rate of just below 1% per 5 degrees.

4. All sources show a consistent throughput change for FPAs at wavelengths around 541 nm (used as the LED reference wavelength) confirming the summary given previously for FPA signals. There is a spurious step function in LED recovery rates introduced at temperatures of 250 K and for detector pixels higher than 680 (channel 1) and lower than 1100 (channel 2). The origin of these jumps is currently unknown.

5. A levelling-off of the rate of recovery with respect to temperatures is not observed for the current test scenario.
6. Overall the test led to a maximum SMR signal recovery (reached in channel 2) with respect to a reference Kitt Peak spectrum of 10% at temperatures around 259 K.
7. Changes in the shape of the etalon for FPAs appear to be quite small during the test and for all channels, with the exception of the strong change in etalon for channel 1 at temperatures higher than 250 K as already mentioned.
8. It should be noted that return of the throughput back to pre-test levels was almost immediate. This is unlike FPA behaviour observed in previous switch-off events (for details see Figure 4-21 and Figure 4-22) and is more representative of the behaviour of the PMD throughput during switch-off events. The Dale Resistor Relay was not active during this test. During normal switch off-events, this relay is closed and the Dale resistor warms up the FPA back-plates whenever the radiator temperature is lower than 250 K. This produces higher FPA detector temperatures than could be achieved during the test.
9. Having the Dale resistor enabled during the test would have allowed a higher FPA target temperature to be achieved, possibly making the test results more positive.
10. The transient spikes in FPA temperatures do have an impact on measurements since the timelines are so packed with measurements.

5.1.1.2 Summary PMD

1. Temperatures of PMDs have only changed once (at the beginning of the test) from 232 K to 266.5 K and back to nominal temperatures after the test. During the test, temperatures for PMDs decreased continuously showing some orbital variations from 266.5 K to about 264 K.
2. The initial throughput recovery for PMDs is observed to be between 2% (visible) and 15% (UV) for WLS signals, which is close to the observed recovery rate for FPAs (2.5% per 5 degrees in the UV; note the lower initial and the higher target PMD temperatures reached!). Because of the decreasing PMD detector temperatures the PMD throughput decreased consistently by close to 2%.
3. The maximum LED signal for PMD recovery is 4.5% with a pixel-independent behaviour as expected.
4. Due to the timeline anomaly PMD signals for SUN were not acquired!
5. Similarly to the FPAs, etalon changes for PMD were generally quite small during the test.

5.1.2 Suggestions for Improvements

1. Update of timelines to prevent processing problems and show PMD SMR spectra.
2. Update of timelines such that we only have the cooler switch-offs at each temperature change and not on subsequent orbits with the same temperature.
3. Closure of Dale Resistor Relay to reproduce switch-off conditions for the FPA detectors, allowing a higher target temperature. Possibly even heating.
5.1.3 Recommendations by the Instrument Review Board

The following recommendations concerning the outcome of the test and the subsequent discussions of the results have been put forward by the instrument performance review board [RD11]:

- Should the throughput test be repeated, it is agreed the coolers should still be switched off in the first timeline run for a new temperature level. Subsequent timelines at the same level should keep the coolers on.
- More analysis is required to understand steps in LED signal ratios for channels 1 and 2 which have not previously been observed.
- In addition, the apparent recovery of WLS signals in channel 1 (below pixel 500) above 250 K is not yet understood. It is probably not significant, as there is basically no light from the WLS at these wavelengths (below 250 nm). To be analysed further.
- Permanently operating the instrument at a higher detector temperature will only be feasible if the expected increased current and memory effect noise at higher temperatures is not compensating for the expected gain in signal. In this case the only option left is to find an efficient decontamination mode, which would very likely require heating the detectors.1
- EUMETSAT presented the advantages and disadvantages of performing an additional throughput test. While an overall improvement of throughput is desirable, there is a small risk of impact on the instrument state such that significant re-tuning of calibration parameters is required. Taking this risk may be justified if the achieved throughput gain is significant.
- Overall, throughput degradation as observed today does not significantly decrease the accuracy of the level 2 products. However, it might do so during the nominal GOME-2 lifetime.

An action (AI 7) has been put on Selex Galileo to consider additional measures (pre-flight and in-orbit) for Metop B/C to minimise contamination inside the detector enclosure.

5.2 GOME Scientific Advisory Group (GSAG) Meeting, May 2009

The 43rd GSAG meeting was held at EUMETSAT on 26-27 May 2009 [RD12]. The GSAG consists of scientific experts with long-term experience (at Principal Investigator level) of the GOME-2 type of instruments (GOME-1 and SCIAMACHY). Note that due to experience with SCIAMACHY decontamination efforts, the GSAG members do not consider an outgassing exercise as being realistic. The time scales for substantial outgassing are much too long, due to the fact that the detectors are enclosed with only a small tube providing a route for evacuation to space, to achieve significant and substantial effects for continuous operations. In contrast, operating the instrument at higher temperatures continuously should be considered.

1 Note that this point has slightly been revised with respect to the original minutes of the meeting for the instrument review in May 2009 [RD11]. In a recent teleconference (29 July 2009) Galileo has clarified with respect to the original MoM that the increase in temperature will increase the noise (current and memory effect) on the read-out. An additional test in which higher temperatures will be reached must still be performed in order to determine if the increase in noise is larger than the gain in signal caused by the increase in temperature.
The results of the throughput test and lessons learned so far have been presented to the group and the discussion has been summarised as follows [RD12].

- Throughput decreases linearly in time, 18-20% per year at 311 nm, and is consistent for all calibration sources, including LEDs. This indicates a large contribution from (contamination on) the detector to the throughput degradation. The spectral shape of the degradation is somewhat different from GOME-1. A significant differential degradation is observed between PMD_p and PMD_s.
- During the throughput test and in the UV, a recovery of ~10% (out of 45%) is observed; at 540 nm ~3% (out of 10%). A return to low throughput levels is immediate, much faster than after instrument switch-offs. This could be related to the environment being colder after instrument switch-offs, making detectors less of a cold trap.
- J. Burrows recommended re-checking GOME-1/GOME-2 differences (design, detector, Peltier cooler, glue) as potential sources of contaminants which have not been observed/released for GOME-1 with the instrument manufacturer.
- It has been proposed that a new throughput test is performed with controlled heating of the detectors above 270 K in order to reach the expected point of evaporation of contaminants with the aim of better understanding the effect and ultimately improving performance.
- J. Burrows advocates permanently operating the instrument at a higher temperature if the outcome of a new throughput test supports this.
- As a result of throughput degradation, fitting residuals increase significantly over time. Furthermore the observed HCHO column decreases over time and a bias correction has to be applied.
- Throughput degradation generally leads to a faster increase over time of DOAS fit residuals as compared to GOME-1 and SCIAMACHY.

5.2.1 Recommendation from the 43rd GSAG Meeting (Recommendation 43.1)

Starting from the observation that the throughput has been significantly reduced in two years of routine GOME-2 operations, and that this is already having an impact on the quality of a number of level 2 data products, the group recommends that EUMETSAT perform a second throughput test as quickly as possible in order to establish the temperature at which the throughput can be significantly increased, and to quantify the effect of performance in all aspects. Based on the outcome, the detector temperature should then be permanently raised.

An action has been put on ESA to collect and provide information on the differences between GOME-1 and GOME-2 affecting the throughput at the detector (e.g., glue, Peltier coolers, bake-out strategy, operations).
5.3 **Reported Impact on Geophysical Products from 43\textsuperscript{rd} GSAG and O3MSAF User Forum**

During the 43\textsuperscript{rd} GSAG (see above) and the O3MSAF user forum held at Halkidiki (2-5 June 2009) various partners have presented evidence of the impact on the continuous throughput degradation of the instrument on level-2 geophysical products. The main impact is currently an unprecedented (with respect to the precursor instruments GOME-1 and SCIAMACHY) fast increase of fit residuals and retrieval noise. The results presented are briefly summarised in the following subsections (see also [RD12]):

5.3.1 **Increase of HCHO DOAS Fit Residuals (BIRA, M. v. Roozendael)**

The long-term increase of DOAS fit residuals for sensitive (minor) trace gas retrievals like HCHO is progressing at a faster pace for GOME-2 (green dots, Figure 5-1) than has been observed for GOME-1 (blue dots) and SCIAMACHY (grey dots). By the beginning of 2009 GOME-2 fit residuals for HCHO have reached the current level of the SCIAMACHY residuals in orbit since 2002. The overall higher level of residuals than for GOME-1 can be explained by the smaller GOME-2 ground pixel size, which is however similar than the SCIAMACHY pixel size.

![Figure 5-1: Long-term development in RMS values for HCHO DOAS fit residuals for GOME-1 (blue dots), SCIAMACHY (grey dots) and GOME-2 (green dots). Note that SCIAMACHY and GOME-2 have similar ground pixel sizes (similar integration times) as compared to the much larger GOME-1 footprint (longer integration time). (Courtesy M. v. Roozendael, BIRA)](image)

5.3.2 **Increase of NO\textsubscript{2} and BrO Fit Residuals (IFE Bremen, Andreas Richter)**

The same effect as for HCHO can be observed for NO\textsubscript{2} and BrO DOAS fit residuals. NO\textsubscript{2} is operationally retrieved from GOME-2 channel 3 and the increase is smaller than for the BrO fit residuals which use radiances values from channel 2. This is explained by the faster degradation in channel 2 (see previous sections). Generally the increase observed for both NO\textsubscript{2} and BrO appears to accelerate towards the end of 2008 and beginning of 2009.
5.3.3 Decrease of HCHO Vertical Columns (IFE Bremen, Andreas Richter)

For sensitive retrieval of minor trace gases like HCHO the impact of the throughput degradation can also be observed in the retrieved vertical columns (VC) themselves. Figure 5-3 shows the long-term drift of HCHO retrieved VC over the Central Pacific where HCHO is abundant at a constant background level (no sources). The observed drift is therefore referred to as a consequence of the increase in fit residuals (see Section 5.3.1) and/or a systematic offset (additive DOAS Term) due to the observed long-term throughput degradation.

Figure 5-2: Long-term development in RMS values for NO₂ and BrO DOAS fit residuals for GOME-2. The upper panel shows results for NO₂ fit residuals from channel 3 and the lower panel shows the same results for BrO retrieved from channel 2 (courtesy Andreas Richter, IFE Bremen).
Figure 5-3: Long-term drift in the vertical column values of retrieved HCHO. Here the HCHO has been retrieved in a pristine area (Central Pacific) with very low but constant values and no sources (courtesy Andreas Richter, IFE Bremen).

The different impact of increase in fit-residuals and drifts in absolute VC values for HCHO are also shown in Figure 5-4.

Figure 5-4: Observed shift in the retrieved VC for HCHO between 2007 and 2009 (left panel). The overall scatter in VC as a result of increases in fit residuals is also observed when comparing the two envelopes for HCHO VC statistics (right panel). (Courtesy Andreas Richter, IFE Bremen)

5.4 Conclusions and Recommendations

The overall findings, discussions and recommendations collected from the input of external partners and with respect to the observed throughput degradation of the instruments can be summarised as follows:

In-depth analysis of the results of the instrument throughput test completed at the end of January 2009 and of long-term degradation-related instrument signatures have been carried out for both level 1 signal response and level 2 data quality by the instrument review team
The main conclusions to date are:

- The main sources of the observed dynamic throughput degradation are very likely associated with scan-mirror degradation and an additional contribution by an attenuating layer directly in front of or on the detectors. The latter is inferred from systematic degradation patterns of the LED calibration light sources situated directly in front of the detectors, consistent with all other on-board calibration sources, and their recovery response.
- The observed recovery of throughput during instrument switch-offs and, in a controlled way, during the instrument throughput test, is linked to detector temperature at a rate of roughly 1 to 2.5% recovery per 5 degrees temperature increase depending on wavelength (with the largest recovery rates of 2.5% in the UV channels).
- Detector temperatures as high as those achieved during instrument switch-offs (around 265 K as compared to 235 K during nominal operations) could not be achieved during the dedicated test. The root course of this is understood and can be overcome by putting the actively controlled Peltier cooling system into heating mode.
- The maximum recovery which can be achieved by increasing the temperature towards 270 K is currently unknown. However, it is expected that the scan mirror contribution will still be significant.
- From SCIAMACHY ‘outgassing’ experience it is not expected that short-term outgassing campaigns (of the order of days) can substantially improve the situation in the long term because of the low on-board partial pressures and the limited escape routes for potential contaminants and water vapour out of the detector encapsulations.
- Long-term analysis of rms values derived from level 2 retrievals, as well as the observed long-term changes in the quality of Stokes fractions from level 1b data, clearly point to very small but statistically significant long-term degradation of the product quality due to instrument throughput degradation. The GSAG and the O3MSAF user community have therefore indicated (during recent meetings held in May and beginning of June 2009) that they would be in favour of EUMETSAT and its partners carrying out additional investigations and measures in order to improve on the long-term trend assessment and perspective with respect to the instrument throughput levels.

Test orbits of level-1b data taken during the previous throughput test at various detector temperatures in January 2009 are available on the GOME-2 CalVal ftp server under

ftp://epscv@ftp.eumetsat.int/out/GOME/ThroughputTest/

for all interested users. Please consult the provided readme file for information on the details of the test, especially with respect to the sequence of temperature changes carried out before nominal day-side data acquisition.

(See also GOME-2 CalVal Newsletter #21 on the EPS CalVal Extranet site at http://www.eumetsat.int/EPSCalValExtranet/Main/GOMECalVal/index.htm?l=en.)
**Recommendation:** As a consequence of the discussions and findings listed above there is a clear recommendation from all partners for issuing a second instrument throughput test. The second test shall have the following targets:

1. Reaching higher temperatures at around 270 K by operating the coolers in heating mode, thereby overcoming the limitations of the previous test.
2. Collect enough nominal earthshine data (longer duration of test) to evaluate the potential impact of decreasing signal-to-noise values on the quality of all GOME-2 products.
3. The test shall be set up such that the collected results will be able to support investigations (including level 1b and 2 quality impact studies) on the feasibility of operating the GOME-2 instrument routinely at higher temperatures within the near future.

**6 MITIGATING ACTIONS FOR GOME-2 THROUGHPUT DEGRADATION FOLLOWING TEST RESULTS ANALYSIS**

In line with the findings and recommendations put forward by the EUMETSAT GOME-2 team and all external partners involved, it is recommended to issue a second throughput test as soon as possible with targets as defined in the previous sections, resolving the currently outstanding issues and in order to be able to define the required future mitigating actions. Currently, the most promising candidate for mitigating actions is operating the instrument routinely at higher temperatures, gaining enough throughput to compensate for the expected decrease in signal-to-noise values. Targeting a substantial decontamination of the instruments is currently referred to as unlikely. However, this has to be confirmed by a test of the response of the throughput to a time-limited substantial increase in detector temperatures significantly above 300 K.

For the purpose of a second throughput test a new dedicated technical implementation document shall be issued referring to the results and recommendations described in this document and based on the already existing procedures (timelines, operations and commanding sequences etc.) from the throughput test described here.