SCIAMACHY	Operation Change Request	OCR No: 025
		Issue: A

Title:
Extended Moon observations

Description of Request:
Extend the coverage in ASM and ESM angle during Moon observations for two months, covering an as large as possible part of the total clear field of view in limb. It is essential that elevation scans over the Moon are made during the observations, as in state ID 54 (mos01) Moon_Scanning.
This will allow in-flight **verification of the scanner calibration** (excluding polarisation), and in-flight **absolute calibration of the limb radiance** (to an accuracy of better than 3.5%) and ASM and ESM **diffuser BSDF calibration** (to an accuracy of better than 2%), over 32 wavelength bands between 350 nm and 2.5 micrometer, with tracability to NIST.

For more details see Appendix A.

Originator: Ralph Snel, SRON	Date of Issue: 30 March 2006	Signature:

Assessment of SSAG (necessary for requests by scientists):
The validation of the Level 1 data quality, especially w.r.t. absolute calibration of Limb radiances and ASM/ESM diffuser BSDF is even 4 years after launch a topic not covered satisfactorily. The new evolvement within the ROLO project (Kieffer and Stone, 2005, www.moon-cal.org/) to establish an accurately calibrated lunar radiance database can help to improve the quality of SCIAMACHY in-flight calibration. It is therefore recommended to investigate the proposed modification of state ID 54. For a final decision the impact on lunar occultation measurements needs to assessed too.

SSAG: H. Bovensmann	Date: 5.4.2006	Signature: e-mail 5.4.2006

Classification of OCR: D

OCR Analysis (incl. Implementation Option):
The idea is to implement OCR_025 as a specific test campaign. Envisaged execution of the measurements is in two monthly visibility periods between July and October. In these periods no occultation measurements can be performed since moonrise occurs on the dayside, i.e. no conflict between science occultation and calibration measurements exists. Which months to use depends on which cycle (July/August or September/October) is due for planning after approval of the OCR.

The implementation requires definition of a test state and of a test timeline.

State:
It is planned to modify state 54 such that it can start as early as possible and end as late as possible in the MO&C window. Currently state 54 has a duration of 15.57 sec with a SDPU duration (measurement phase) of 12 sec. The nominal scan width amounts to ±0.33° with a scan duration of 2 sec.
The width of the MO&C window between an altitude of 17.2 and the edge of the limb TCFoV amounts to 124 – 182 sec. Because only one test state can be defined, we have to assume the lower limit of 124 sec. This interval must be reduced however, because tracking of the moon in elevation is complicated by the variable elevation rate and confusion of the SF at low altitudes when the moon rises on the dayside (in azimuth the moon is tracked via the Sun Follower). In the MO&C window the elevation rate varies between –0.059°/sec and –0.041°/sec depending whether the moon rises in flight direction (azimuth = 0°) or at the left/right edges of the limb TCFoV (azimuth = ±44°). Several state implementation options exist.

Option 1: Since we follow the lunar disk with a constant rate which is calculated from the positions at the start of the measurement phase, we have to ensure that the vertical scan always covers the complete lunar disk. With a lunar diameter of 0.50°-0.55° and a scan width of ±0.33° we propose to accept a vertical shift of the scanned area of about 0.04° at maximum leaving a margin of only a few 0.01°. This translates into a maximum measurement duration of 80 sec, starting at an altitude of 150 km. The stop altitude is always above 300 km. Option 1 leaves the scan motion unmodified. Scanner state table no. 54 and state duration table need modifications

Option 2: In order to improve the scan margin and to increase the duration of the moon observation period the modification of the scan via the relative scan profile is also possible. Option 1 uses relative profile 4 to produce a triangular motion of 2 sec over the upper moon half, which is inverted at each subsequent scan thus resulting in a centred scan over the complete moon of total 4 sec. A similar total scan with different width can be accomplished by using linear relative scan profile 5, centring it and again inverting the subsequent san. This would result in a first linear scan starting at the lowest scan elevation and scanning in 2 sec over the moon disk to the highest scan elevation and then reversing the scan direction in the subsequent 2 sec period. The scan width would be ±0.423°. Modified parameter tables would include scanner state table no. 54 and state duration table. Bonus of option 2 is that the margin is wider (about 0.1° on each side), i.e. the state can start earlier (at an altitude of 100 km) and last longer (95 sec). Draw-back is however that the signal would drop by about 30%. For the time of the test campaign this modified state would also replace the lunar calibration & monitoring measurements.

Option 3: In order to compensate for the signal reduction of option 2 the angular variation of relative profile 5 could be reduced (note: This profile is currently used in final flight state ID 38. To still produce the identical maximum left position of state ID38 the reduction of the angular variation of relative scan profile 5 would have to be balanced by changing the relative scan profile factor in table scanner state parameter for state ID38 accordingly). The optimum range of reduction of the scan speed (scan width) should be defined by the originator of OCR_25 (and signal experts). For the time of the test campaign this modified state would also replace the lunar calibration & monitoring measurements.

Option 1 is most straightforward. Option 2 requires a change in the evaluation strategy and option 3 even impacts another final flight state and needs to be adjusted accordingly.

Option 1 modification (after discussion with R. Snel): Since complete coverage of the lunar disk is not a prerequisite for the implementation of the measurements (incomplete coverage at the end of the state can be flagged by analysing the PMD signal), the vertical range has been extended slightly. Now option 1 assumes a starting altitude of about 100 km and a measurement duration of 92 sec.

Timeline:
In timeline set 9 a timeline 13 is defined which executes state 54 modified as described above. Timeline header information (moon fixed event) will be defined accordingly.

SOST: M. Gottwald, E. Krieg, DLR-IMF (ESA, Industry if necessary)	Date: 25/04/2006 and 27/04/2006	Signature: via e-mail 25/04/2006 and 27/04/2006

Approval of Proposed Implementation:
The modified option 1 describes the preferred implementation.

Originator Approval: R. Snel, SRON	Date: 27/04/2006	Signature: via e-mail 27/04/2006
SSAG Approval: H. Bovensmann	Date: 15/05/2006	Signature: via e-mail 15/05/2006

Decision / Approval:
OCR shall be implemented as proposed by DLR-IMF.

DLR Approval: Ch. Chlebek	Date: 9.6.2006	Signature: e-mail, 9.6.2006

Implementation by SOST:
The modified option 1 will be implemented in the monthly lunar visbility windows in July and August (orbit 22734-22821, 6-12 July and orbit 23158-23236, 4-10 August). No lunar occultation would have been executed in these periods since the moon rises on the dayside. The following temporary changes to state ID54 will become effective.

States:
Scanner state parameter table (duration of phase 3 = 90000 msec and repetition of relative profile of phase 3 = 44)
State duration table (SDPU duration = 1472 BCPS, WM = 23528 cts, state duration = 24469 cts and WSR = 179 cts)

Timelines:
Two test timelines (set 09, sub-ID 01) are required. Timeline 13 will execute the modified state 54 and test timeline 42 will run a single nadir state (ID06). Timeline 42 is scheduled just prior to timeline 13 in order to minimise the idle phase.

When the August lunar window has come to an end, the final flight settings of state 54 will be re-established. If analysis of the moon test measurements would suggest a further campaign in September and October (these months are still without moon occultations), the modified settings would be maintained.

SOST: M. Gottwald, E. Krieg. DLR-IMF	Date: 30/05/2006	Signature: via e-mail 30/05/2006

Appendix A

Kieffer and Stone (Astron. J. 129:2887-2901, 2005 June) have published a model capable of predicting integrated Moon radiance in 32 filter bands ranging between 350 nm and 2.4 micrometer. The model allows prediction of the irradiance of the Moon for any phase within a week around full Moon, but excluding the hours just around full Moon. Effects of libration, and of maria and highlands, are taken into account. The average residual between the model and the measurements (over 80000) is less than 1%, and the model is actively being used in lunar calibration of several spacecraft instruments and can track sensor response changes at the 0.1% level.

Absolute calibration is currently tied to Vega and photometric standard stars, but efforts are underway to tie the radiometric calibration to the scale of the National Institute of Standards and Technology (NIST). Deviations between the model and a scaled laboratory spectrum of the reflectance of an apollo sample of Moon soil are about 3.5% RMS. As more data become available the calibration will improve.

A preliminary investigation into the use of this model for possible in-flight calibration of SCIAMACHY has shown promising results, with RMS differences between observed scia lunar radiances and the model of better than 2% (after the use of a filter band specific scaling factor) for those wavelengths where scia is most stable. This indicates that relative radiometric calibration for scia limb radiance can be derived from Moon measurements at this level.

When instead of the lunar radiance the lunar albedo is used, thus combining scia limb measurements of lunar radiance and solar irradiance, it is possible to derive the BSDF of the on-board diffusers relative to the Moon albedo. Since the lunar albedo is spectrally bland, with very shallow and broad (hundreds of nm) spectral features, this allows an excellent verification of the radiometric calibration of SCIAMACHY. Assuming the comparison between the lunar irradiance model and the apollo soil sample is representative and the errors for the 32 wavelength bands are randomly distributed, this would allow derivation of an in-flight diffuser BSDF with an absolute overall error of better than 1%.

The need for extra measurements

Over a month, the Moon traverses the entire total clear field of view (TCFoV) of SCIAMACHY, while it changes phase and thus intensity and colour. It was found that the calibration of the scan mirrors does not cover the entire TCFoV, and that an extrapolation of the angular range covered by the on-ground measurements was needed. Currently, there are a few hundred useful lunar measurements, which allows investigation of correlation between the residuals and any parameters affecting the model and the measurements, such as lunar phase, Sun-Earth distance, Moon-Earth distance, libration angles, time (instrument degradation), and scan angles. Some of these parameters correlate with eachother as well, complicating *ad hoc* improvements of the residuals. Depending on wavelength, the largest correlations were with:
- time (in particular in the UV, where there is known degradation)
- ESM angle
- ASM angle

and with some of the parameters of the lunar model, which are beyond our control.

This suggests that, firstly, there is instrument degradation, and secondly, the scanner calibration is not sufficient for these Moon measurements. These two aspacts may very well be related, since it is the ESM mirror which is degrading fastest, which implies that the scanner calibration angular dependence is changing as well.

A dedicated effort to measure the scanner calibration as a function of ESM and ASM angle is possible using the Moon as a predictable radiance source. Since the lunar model is for the radiance integrated over the entire lunar disk (and thus by definition irradiance, but not in the meaning normally applied for SCIAMACHY, i.e. using the on-board diffuser), the observations of the Moon must be performed using a scanning motion as in state ID 54.

State 54 is executed when the Moon is well above the atmosphere, and runs for a duration of only 12 seconds. During this time, the Moon traverses a small part of the TCFoV, mostly in elevation. The azimuth range of the TCFoV is covered over the Moon visibility period, typically about a week, from - 40 to +40 degrees, with normally one observation per day, resulting in a few widely spaced azimuth angles covered during that visibility period.

In order to better cover the TCFoV, longer measurements than those done in state 54 could be done, possibly also starting at lower altitude, giving better elevation coverage, and more frequent measurements than once a day, e.g. every orbit during which the Moon is visible, resulting in better azimuth coverage.

Since the instrument is slowly changing, one period of intensive measurements is better than a longer period of dispersed measurements, thus providing a snap-shot of the scanner calibration. Since the lunar model does not yield accurate predictions too close to full Moon, a gap in the azimuth coverage will result. Repetition of the measurements in the next moon visibility period will most likely have the gap at a different azimuth (TBC by SOST), suggesting that two Moon visibility periods should be observed with the proposed type of coverage.

Analysis of the observations

State 54 yields scans over the Moon, which allow simple calculation of the spatially integrated intensity of the Moon. These Moon irradiance measurements are corrected for known instrumental effects such as memory effect, non-linearity, dark signal, scan-angle dependent relectivity of the scan mirrors, etc. The resulting signal is normalised to a reference Sun-Moon distance and a reference Moon-Envisat distance, and integrated over the spectral bands used in the lunar irradiance model. The ratio of the resulting scia band intensity with that predicted by the lunar model is the in-flight radiometric calibration of SCIAMACHY in those 32 bands. Systematic variation of the ratio with scan angle would suggest scanner calibration problems.

If the scia Moon observations are normalised with the corresponding Sun over diffuser measurement (either ESM or ASM), and the lunar model is used to output disk-averaged reflectances rather than radiances, the ratio between the scia integrated filter bands and the lunar model values can be used to derive the in-flight BSDF of the diffuser used for the solar measurement.

Since these measurements can be obtained totally independent from on-ground calibration or Earth radiance measurements, they provide an independent means for validating SCIAMACHY level 1 spectra.