SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: ES1309
STSM title: Laboratory based radiometric characterization and calibration protocol for the APEX imaging spectrometer system
STSM start and end date: 18/06/2017 to 08/07/2017
Grantee name: Laura MIHAI

PURPOSE OF THE STSM:

Remote sensing techniques, such as hyperspectral imaging spectrometry, are intensively used for Earth surface investigations, providing spatial / temporal information with relatively good resolutions. Due to this fact there is an increased demand on highly accurate measurements that need to satisfy the final user requirements [1]. Accuracy and reproducibility of imaging spectrometers / spectroradiometers depends on the calibration procedures and protocols that are followed. These kind of calibrations are challenging due the large number of pixels that have to be characterized and due to the large amount of sources of uncertainty that have to be considered [2; 3].
The goal of this STSM was to participate on radiometric calibration and characterization campaign of APEX hyperspectral imaging system in order to develop a protocol that enables the imaging spectrometers calibrations replicability at different facilities.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The APEX system is an airborne (dispersive push broom) imaging spectrometer considered an advanced scientific instrument for the European remote sensing community [1]. The APEX periodic characterization and calibration it is necessary to assure the data quality. For this purpose its spectral, radiometric and geometric calibrations, which are required to estimate the calibration coefficients for the acquired imaging data [2] were done during this STSM at the Calibration Home Base (CHB) at German Aerospace Center – DLR in Oberpfaffenhofen, within its annual calibration campaign. The logical working flow for APEX calibration procedure is presented in detail on paper [3].
Before any tests, the calibration standards working parameters and the calibration configuration (including mechanical such as slits and optical components) were checked to be the same with those ones previously used, in this way assuring the calibration reproducibility.
The first step on the calibration campaign was the system installation (including the optics unit, cooling system, the power supply and the control system, see Figure 1) and geometrical alignment on the measurement stand from CHB.

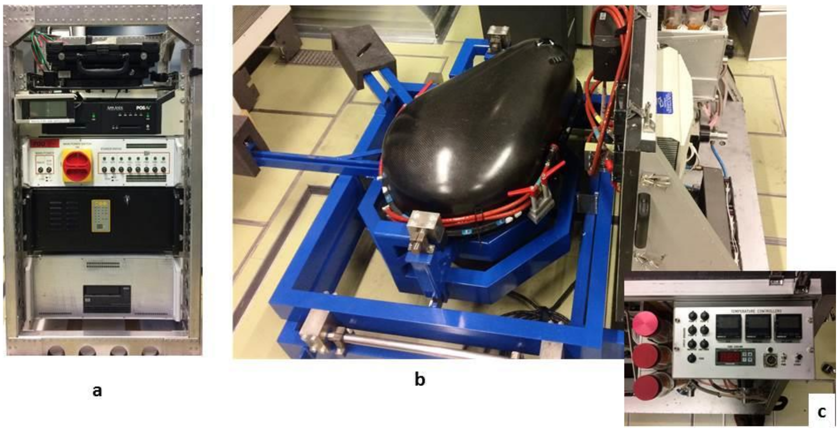


Figure1. The APEX system component: a) power supply and control PC; b) optical unit; c) cooling unit.

After installation, the alignment procedure started, for different pixel positions along the entire spectral range (VNIR and SWIR). The signal intensity was optimized all the time by changing the optical unit position on X, Y Z axes (figure 2). Live alignment check was done by dedicated TCL/TK routines while angular scans were analysed within the APEX CAL IS.

Figure 2. APEX system alignment procedure.

The signal quality was checked along and across the APEX entrance aperture (figure 3). On the along track procedure (figure 3 left), it was checked if for different collimator slit angles position, the pixel position corresponds to the one set on a previous calibration, if not this value was be corrected. The slit mounted radially in the wheel before the collimator entrance was used as a calibration target, being used to illuminate the detectors across track direction. For an optimized signal, the system position on XYZ has been reconsidered.

In the case of across track procedure (figure 3 - right), the scan of angular response for both APEX detectors were done on different pixel position, using as a calibration target the slits mounted tangentially to the wheel at the collimator entrance. The pixel response FWHM was obtained as a function of the across track angle for the VNIR and SWIR spectral ranges, moving the light line formed by slits position and the folding mirror in the across track direction over individual detector elements (pixels). The complete description of setups used at the CHB is presented in paper [4]. Some results of the across track check are represented in figure 4.

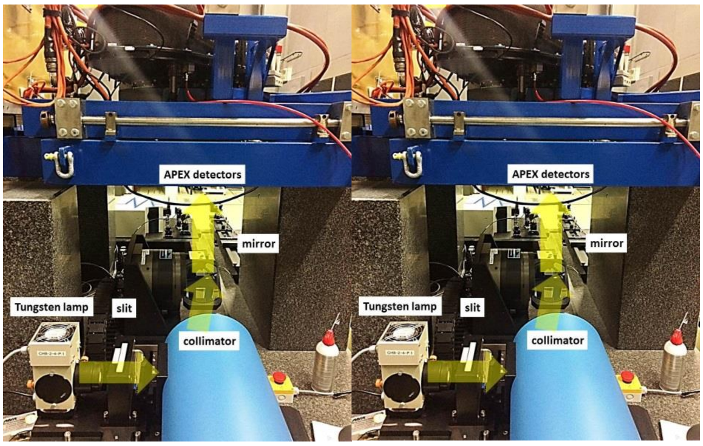


Figure 3. Along track (left) and across track (right) validation setups.

a) Tungsten lamp, b) slit in tuneable wheel, c) collimator, d) rotating folding mirror, f) paths across APEX input.

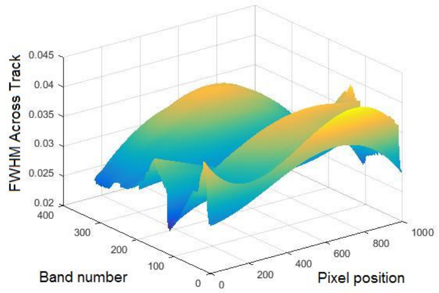


Figure 4. FWHM corrected values for the entire spectral range after the across track calibration.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The geometrical alignment, the across and along track checks were followed by the APEX spectral calibration, that allowed to find the correct values for the center wavelength and full-width at half-maximum (FWHM) parameters for all spatio-spectral pixels of the system's detectors. For this purpose a single monochromator system having a slit-collimator assembly in combination with a rotating mirror on a translation stage to generate optical stimuli was used. Slits dimensions and light source parameters were checked before spectral calibration in order to establish the calibration reproducibility. The spectral characterization and calibration setup is presented in figure 5. All tests have been carried out under dark conditions (without ambient light sources).

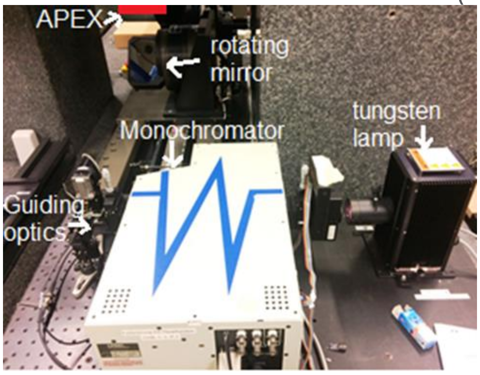


Figure 5. Spectral calibration setup.

In figure 6 represents an example of central wavelengths and FHWM values as obtained from spectral calibration MATLAB routine. Values of FWHM 0.8 and 15 nm were obtained depending on the spectral range and the pixel position.

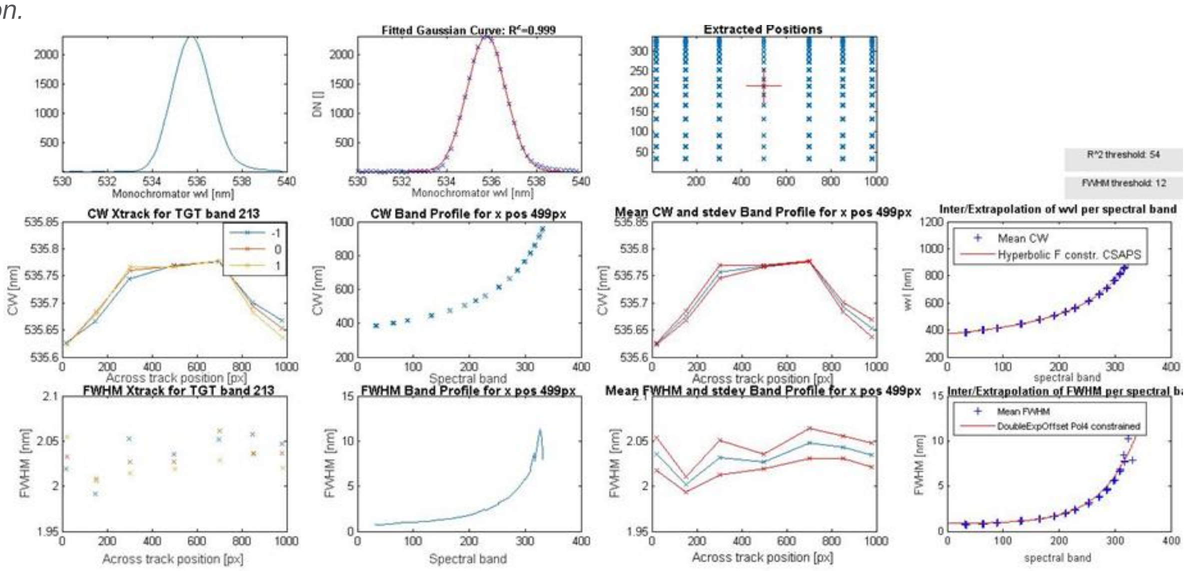


Figure 6. The spectral calibration results for a pixel position 499 and the spectral band 213.

The last step from the calibration process was the absolute and the relative radiometric calibration. The APEX *was mounted on the top of the CHB standard integrating sphere (having a diameter of 1.65 m) equipped with 18 QTH lamps operated independently for calibration at different powers. At the integrating sphere was mounted also an ASD spectrometer that is the APEX secondary calibration standard. A setup sketch is represented in figure 7.*

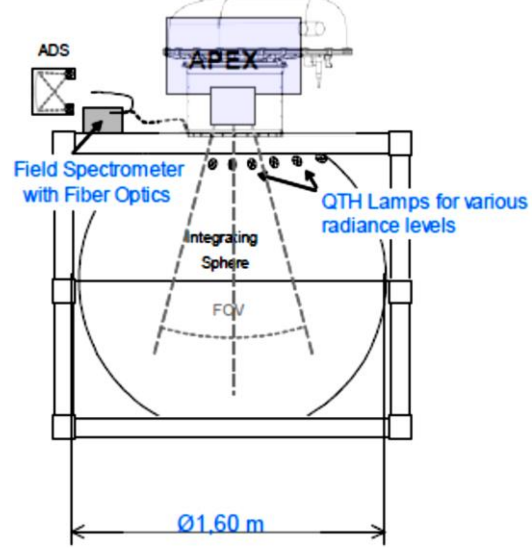


Figure 7. The APEX radiometric calibration setup sketch. [3]

First of all the raw data were corrected with the DCand dichroic mirrors effects. The adjusted APEX signal was after that compared with the ASD reference radiances which are traceable to the SVC transfer spectrometer – RASTA, calibrated at PTB. Linear regression function was applied to the spectrally convolved data for all powers and the radiometric coefficients were determined for all pixel positions (see examples in figure 8). Generally, the radiometric coefficients changes were within 10%, except some pixel positions affected by some wires fixed at the border of instrument slit.

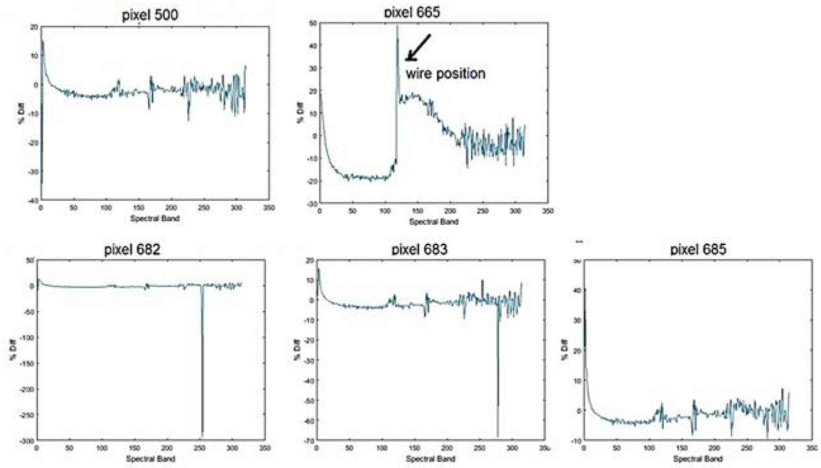
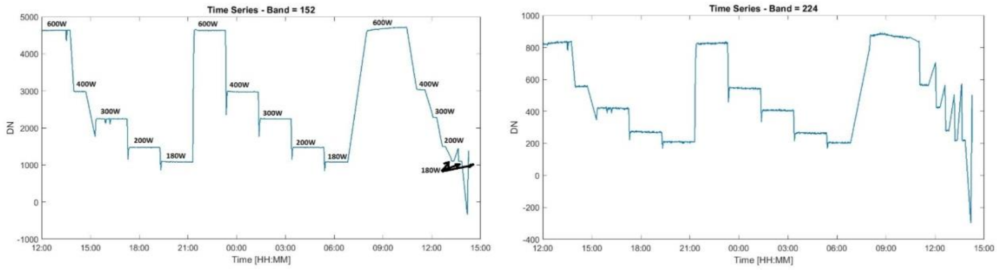


Figure 8. The APEX system radiometric coefficients difference between stability period and calibration period.

Beside the instrument radiometric calibration, we also focused on the study of medium and long-term stability of APEX, since the last campaign results presented high system instability. Data processing and analysis were done based on the APEX Calibration Information System (CAL IS) [1] to access spectral data and metadata with Matlab routines at the University of Zurich, Remote Sensing Laboratory in the following two weeks of this STSM.
For the stability tests the presented radiometric calibration setup was mainly used (figure 7). Multiple tests were run on the day before the radiometric calibration and few minutes before calibration, for all integrating sphere illuminations levels, as can be seen in figure 9. The stability along two hours were registered for each power level selected for the standard integrating sphere. The first measurements were run for 20 hours before the calibrations (one set of data during the day period and the second during the night before radiometric calibration). The last stability checks were done before radiometric calibration of each power level, referred to as 'warm-up period'. Depending on the band and the pixel position, during the warm-up period the APEX showed some kind of instability at the power level change. The last three tests were done reseting the calibration lamp inside the APEX. In order to better understand the possible sources of instability, that was observed on the last flight campaign, we started to analyze if there is a dependence of the APEX signal (figure 11) on the optical base plate

and PSU temperatures (figure 10). The dark current was measured before each power level signal measurements. If we consider the figure 10-11, the OSU temperature varied between two values; it is possible that the sensitivity of the temperature sensor is lower then the signal changes. In the case of stability checks no nitrogen was purged into the APEX optical unit, with constant presure of around 1050 mbars. Along the warming period the nitrogen was purged, keeping a pressure of around 800mbars inside of the APEX optical unit. Some water absorption lines are increased in time along the stability period especially for higher power levels (600W and 400W, figure 11- night), peaks that disappear when the nitrogen is used(figure 11-before radiometric cal.). Since higher signal variations were noticed for the warming period (>40%) (figure 11-13), we started to investigate the changes on dark current signal along these tests (figure 13), to see if these variations are due to electronics malfunctions or not.



a *b*

Figure9. APEX signal variation along 27 hours of run for different optical power levels set to the integrating sphere for band a)152 and b) 224, with pixel position 685.

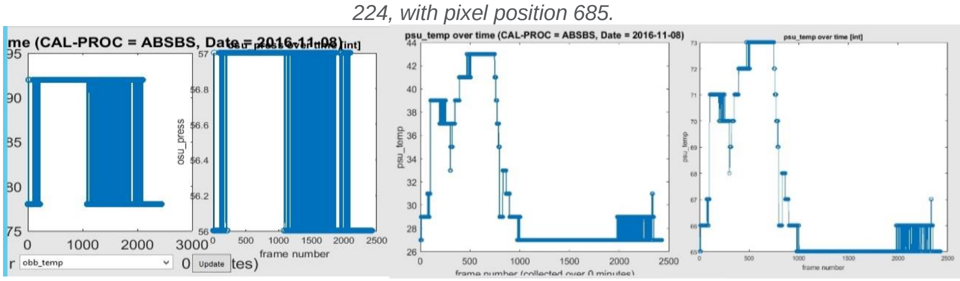
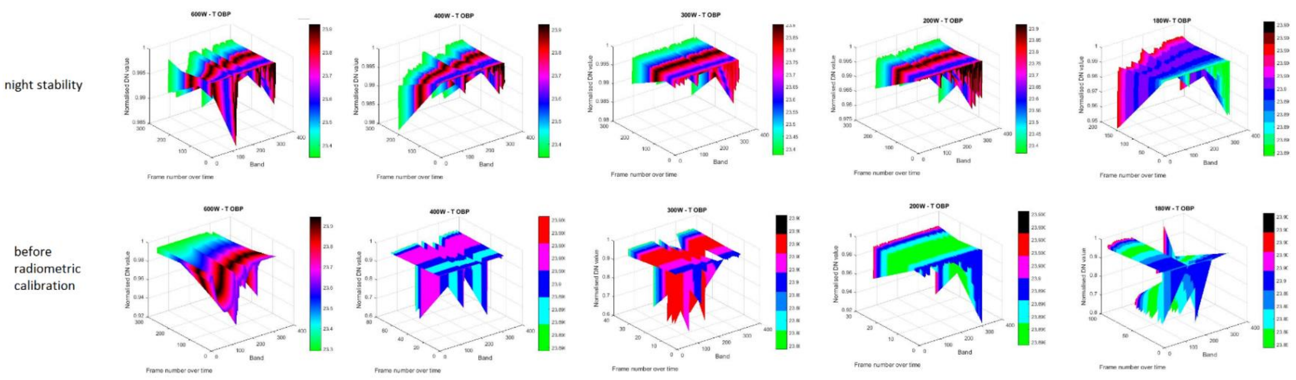


Figure 10. OBP and PSU temperature variations in time.



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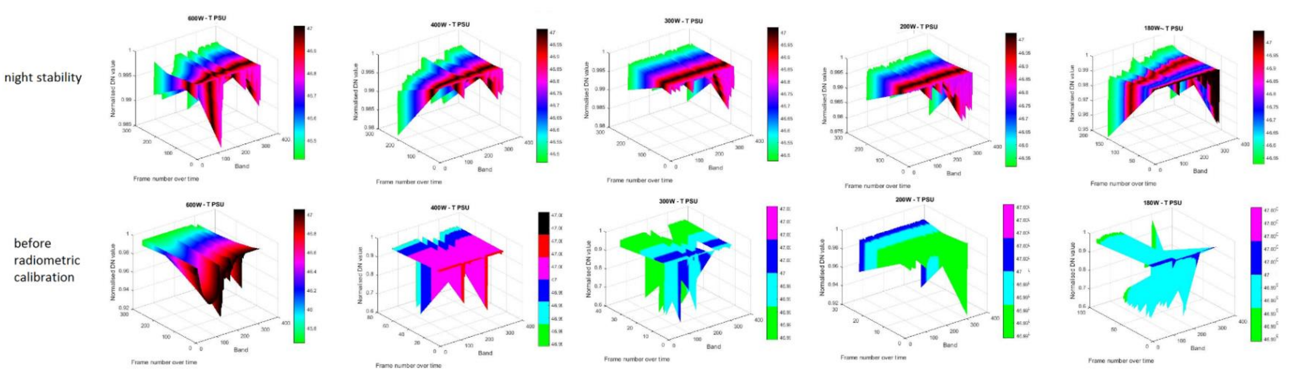
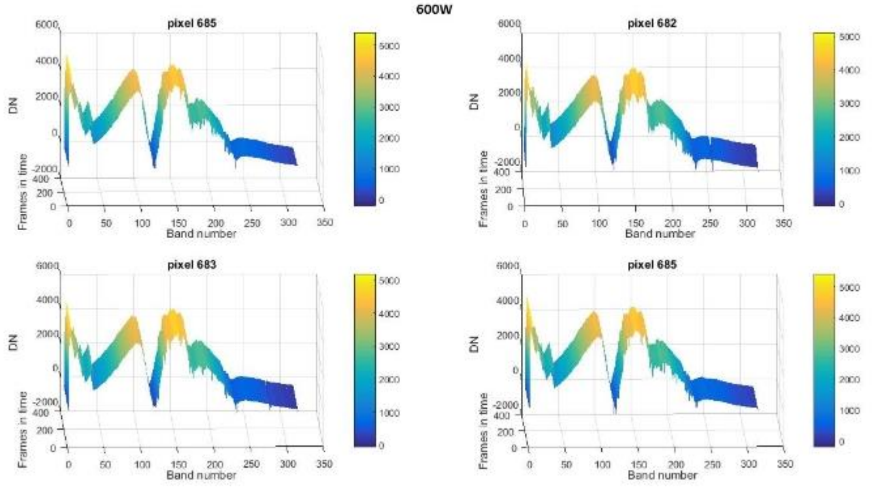


b

Figure11. APEX signal dependence on the: a) optical base plate temperature (OBP) and b) PSU temperature for different integrating sphere output optical power.



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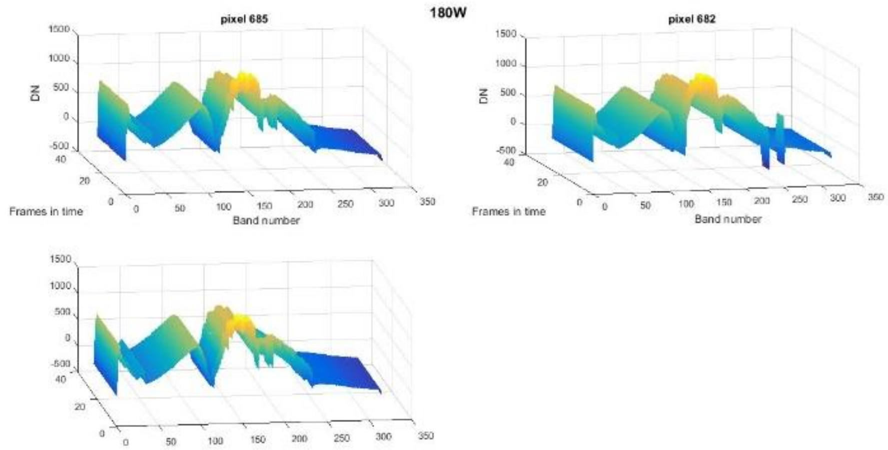

b

Figure12. 3D representation for APEX signal variation in time, for all spectral bands, a)600W and respective b)180W setup for the standards integrating sphere, during the warming up period before radiometric calibration.

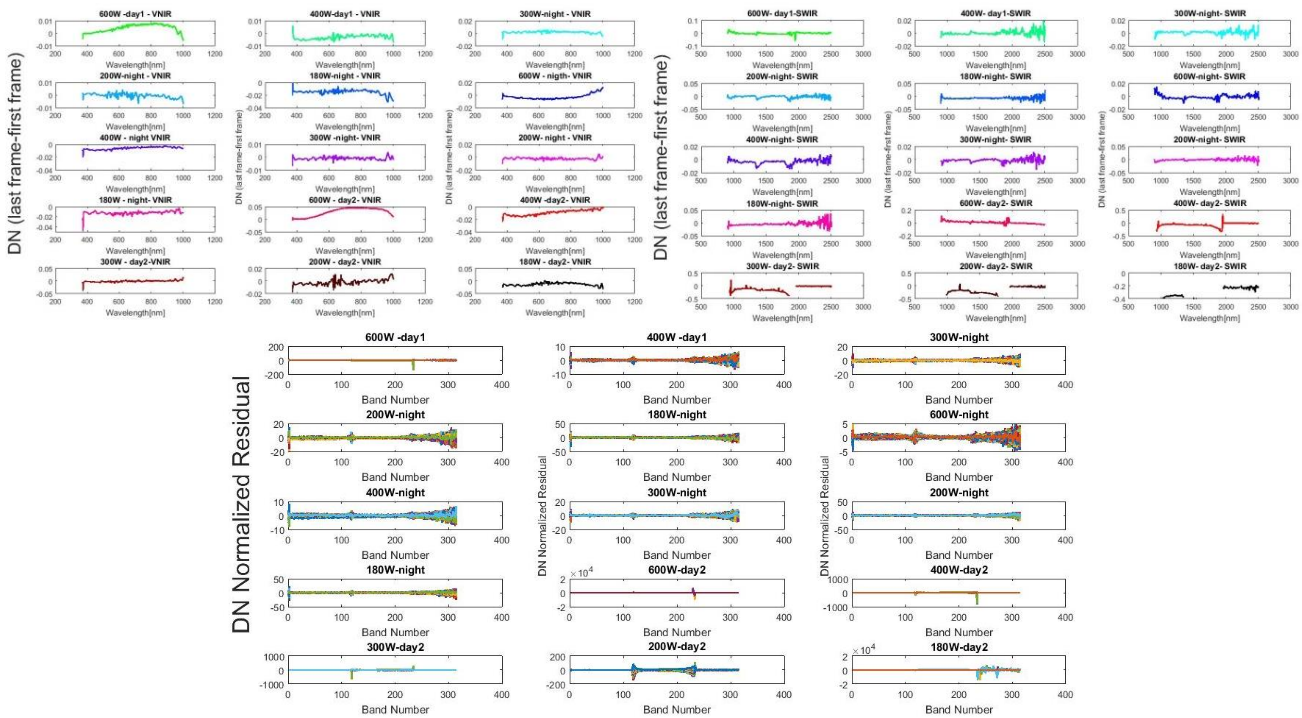

Figure13. The changes in APEX signal a) considering the difference between the last and the first frame for pixel position 500, VNIR and

SWIR bands and different levels set-up for the standard integrating sphere. A linear fit was applied to the measured signal. b) The changes induced to the raw data applying the linear fit, represented as residual data in percentages, along the stabilization time of 27 hours.

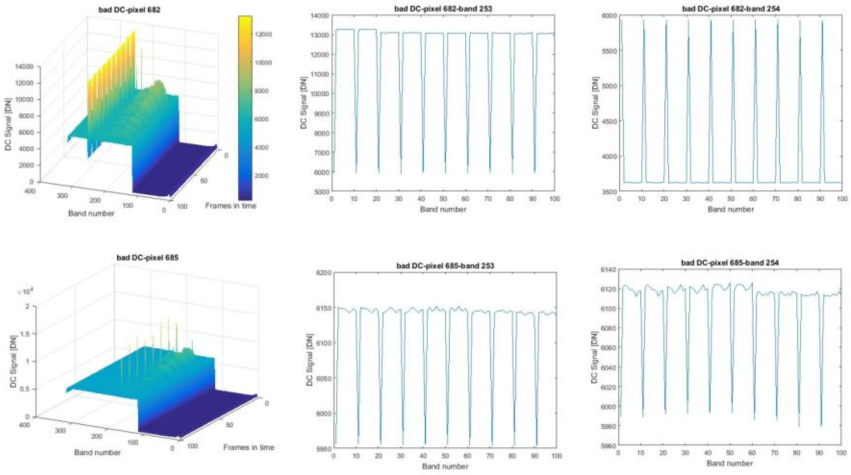

Figure14. Dark current represented for different pixel and bands positions along the stability tests before each radiometric calibration step.

Very high changes apeared in the case of DC also when the measurements started, being reduced after a period of time, suggesting that a stability period of the system is very important before each measurement campaign, to avoid incorrect results being registered. These spikes appear to be related to some electronic system artefact.
The spectral shift due to pressure instability was also cheked for analysis period at RSL Zurich (figure 15). The highest differences was noticed due to dichroics effects on the signal, being affected by pressure inside the optical unit of the system.

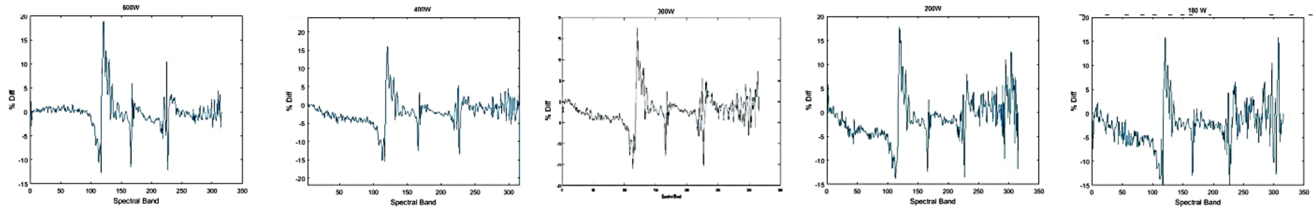

Figure15. The spectral shift due to dichroic defects and temperature effect, comparing the data from the stability night and the data before irradiation.

<u>Preliminary conclusions:</u>
During the STSM at DLR Calibration Home Base and University of Zurich all planned objectives were approached, including the spectral and radiometric characterization and calibration of the APEX system, as a part for the annual calibration protocol, with a complex data analysis using APEX CAL IS routines in MATLAB.
Since the system showed a high radiometric instability during the last measurements campaigns, we investigated the system stability in time in relation to some possible sources of instability: temperature variations of the optical base plate and PSU, electronics mal-functioning. The results of this study proved good mid-term and long term system stability, but not so good for warming periods before radiometric calibration. So one conclusion can be that the APEX is stable if a warming period of around 2 hours is considered. Also, the pressure inside the optical unit of APEX has to be maintained constant, in order to not introduce errors on measured data, due to the spectral shift inducing radiometric changes due to the dichroic coating. An important next step that should be done in the near future is the stability check at different temperatures that fit the temperature values in the flight time (-20 up to 20 ^{0} C), in this way obtaining more realistic results. Also, the mid and long term APEX stability has to be repeated, in order to check the reproducibility of our results.

Bibliography
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[3] Nieke, J; Itten, K I; Meuleman, K; Gege, P; Dell'Endice, F; Hueni, A; Alberti, E; Ulbrich, G; Meynart, R. "Supporting facilities of the airborne imaging spectrometer APEX". In: 2008 IEEE International Geoscience &Remote Sensing Symposium, Boston, US, 06 July 2008 - 11 July 2008, 502-505.
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FUTURE COLLABORATIONS (if applicable)

The collaboration will continue in order to better understand the sources of instability of imaging spectrometers considering measurements conditions similar with the ones in the flight time and to optimize the protocols for spectral and radiometric calibration.