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THE AIRBORNE IMAGING SPECTROMETER APEX: FROM CONCEPT TO REALISATION

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ABSTRACT

APEX (Airborne Prism EXperiment) is a project of the European Space Agency ESA focusing on high accuracy simulation, calibration and validation for spaceborne remote sensing instruments. The instrumentation comprises a hyperspectral imager for various standard airborne platforms, a fixed installed calibration home base and a complete facility for data processing and archiving. The pushbroom-type instrument accommodates two spectrometer channels covering a spectral range from 0.38 up to 2.5 micron. The spatial/spectral resolution amounts to 1000 samples at 28-degree field of view with 312 spectral bands. The overall instrument design and its built-in characterization unit will allow excellent performance stability under various flight conditions. The paper outlines ongoing activities on the design, development and realization of the imaging spectrometer, the processing and archiving facility, calibration home base and the set-up of the APEX Science and Operations Center.

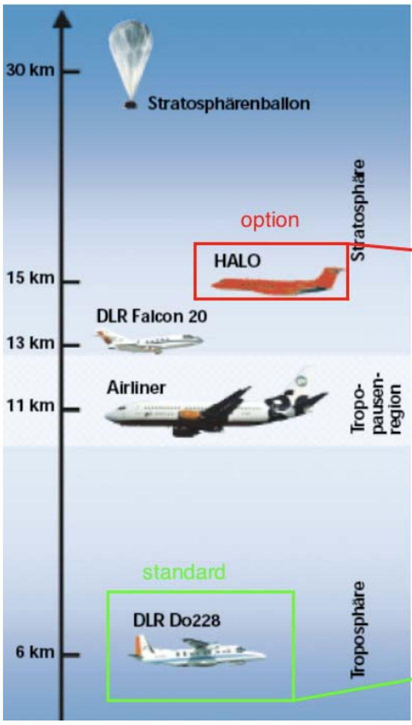
INTRODUCTION

The Remote Sensing Laboratories (RSL) identified in 1996 the necessity to initiate a project that concentrates on the definition of an airborne imaging spectrometer which could represent a precursor mission to future planned spaceborne imaging spectrometers. This project includes the definition of an airborne dispersive pushbroom imaging spectrometer (named 'Airborne Prism Experiment' (APEX)) that will contribute to the preparation, calibration, validation, simulation, and application development for future imaging spectrometer missions in space /i/, as well as to the understanding of land processes and interactions at a local and regional (or national) scale, in support for global applications /ii/. The APEX project is implemented through ESA PRODEX (European Space Agency PROgramme de Développement d'EXpériences Scientifiques), which aims at providing funding for the industrial development of scientific instruments or experiments proposed by institutes or universities, which have been selected by ESA for one of its programs in the various fields of space research (e.g., Earth observation). ESA provides administrative, financial-management, and technical support /iii/.

The APEX project started in 1997 by performing a feasibility study on the design of an imaging spectrometer /iv/, which resulted in a first performance definition /v/, and a subsequent design phase /vi/. Currently, various parts of APEX are being finalized in design, breadboarding and performance analysis of the processing chain /vii/viii/ix/x/ and the subsequent construction of the instrument is planned to be final in 2006 /xi/.

THE IMAGING SPECTROMETER APEX

The APEX system has been specified as a combination of user requirements, which have been derived from a survey of imaging spectroscopy applications /xii/ and a subsequently derived forward performance model based on these requirements /xiii/. Applications cover all varieties of environmental remote sensing targets and research, such as vegetation and soil. APEX's performance will also enable to contribute to other major applications, such as coastal and inland water monitoring, atmospheric /xiv/, geologic, vegetation, alpine research and the simulation of space sensors /xv/.



Observation parameter	DO-228	HALO	Platform independent specification
Swath	< 2.5 km	8 km	FOV = 28 deg
Ground pixel size			IFOV = 0.028 deg
High spatial mode	< 2.5 m	~ 8 m	313 bands
High spectral mode	< 4 m	~ 15 m	511 bands
Flight line length	< 250 km	900 km	about 60 min data capture with standard hard disk array

Figure 1: Selected specifications of the APEX instrument.

The imaging spectrometer design of APEX follows a classical design with refractive and dispersive optical elements /xvi/. Figure 2 shows the optical set-up. The scene is imaged, via a path-folding mirror (not shown), by the ground imager onto the spectrometer slit with 40 micron slit width. To minimize the polarization sensitivity a 'scrambler' is attached in front to randomize the polarization of the incoming light. The instrument design also foresees an In-Flight Characterization facility, where filters will be available for radiance level adaptation and calibration purposes.

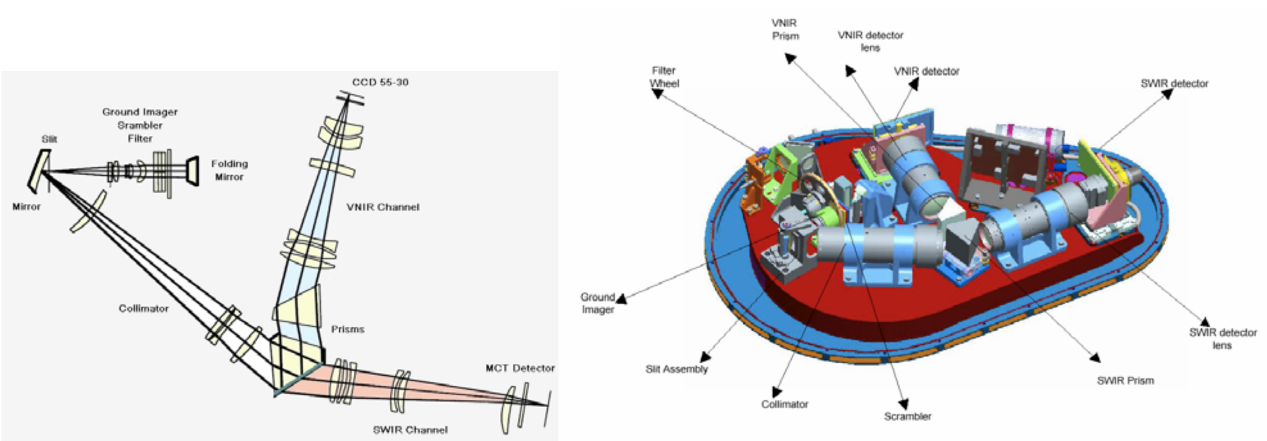


Figure 2: Optical set-up

A collimator optic directs the light to the prisms. For compensation of the distortion introduced by the prisms, a small spherical mirror is located in the collimator image field. For separating the SWIR and VNIR channel, the first dispersion prism carries on its second surface a dichroic beamsplitter coating, with high reflectivity in the VNIR region. For both channels, individual detector lenses image the spectra, for the VNIR through a second prism, onto the detector arrays. For the VNIR region a commercial CCD from E2V Technologies (GB), type CCD 55-30, back illuminated, operating in frame transfer mode, is selected. For the SWIR channel a specific detector development was performed at SOFRADIR (F), because of the required array size of 1000 by 250 pixel. The detector array is constituted of an Infrared-sensitive HgCdTe detecting module hybridized on a CMOS multiplexer. The monolithic HgCdTe module is hybridized on two identical multiplexers precisely aligned with each other. The 2-D detector module has 1000 x 256 pixels, on a 30-micron pitch, with its spatial direction parallel to the detector rows and the spectral direction parallel to the detector columns. The two spectrometers channels are aligned in a way to minimize the coregistration error.

PROCESSING AND ARCHIVING FACILITY PAF

The APEX Processing and Archiving Facility (PAF) manages the data from acquisition and calibration to processing and dissemination. The processing chain is based on analyzing in-flight acquired image data, housekeeping information (e.g., navigation data, temperature), and on-board calibration data (using the above mentioned IFC). Moreover, the CHB allows the characterization and calibration of the geometric, radiometric and spatial sensor parameters. Using the outcome of the sensor calibration, the raw image data are converted to at-sensor radiance, traceable to a certified standard (e.g., NIST, NPL, PTB).

It is expected that individual flight campaigns will collect data on the order of 100's of GB that need to undergo an offline chain of data correction and characterization processes based on previously acquired laboratory and in-flight calibration parameters. This processing chain includes conversion of raw data values into SI units, bad pixel replacement, and corrections of smear, stray light, smile and frown anomalies. A simplified block diagram of the planned processing is illustrated in Figure 3. The data acquisition process produces the top four components on the left side in the Raw Data column. The lower two components are produced during inter-mission calibration of the instrument which takes place in the CHB.

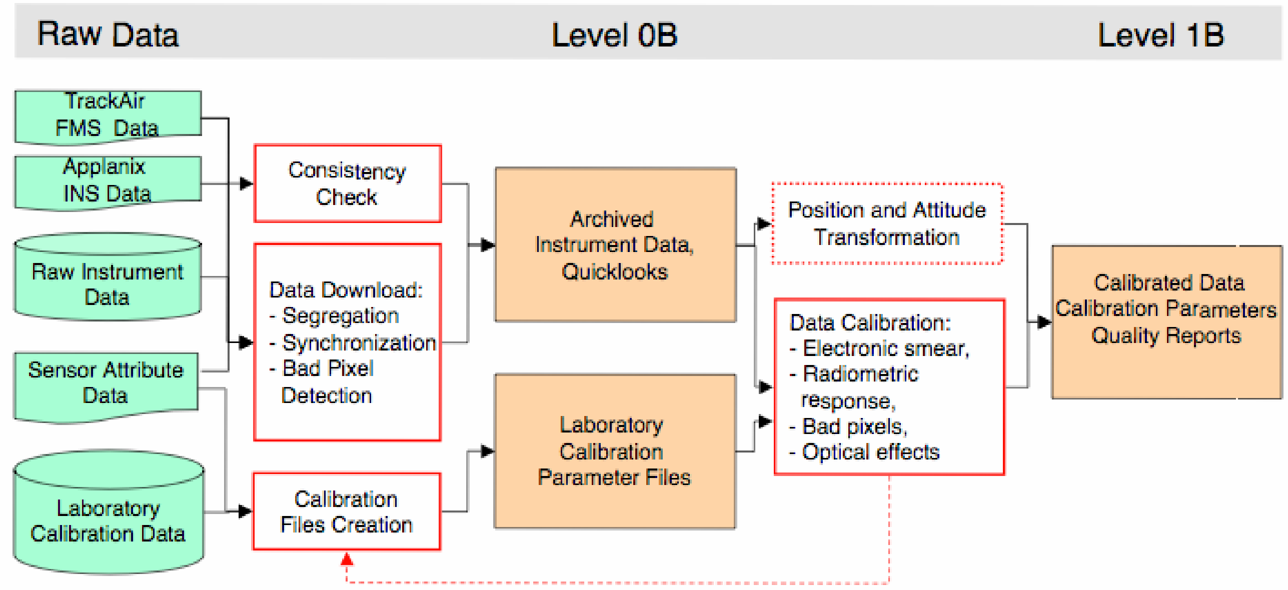


Figure 3: Generalized processing data flow from raw data until Level 1 B.

Since the raw data are generated during the flight in the onboard computer, these data need to be transferred to the off-line PAF computer. During this data transfer, quick consistency checks are made, and some simple constant-time operations can be performed such as bad pixel detection as well as generation of a high-resolution composite RGB pseudo-color quick-look image. As a result, a calibrated at sensor radiance cube will be generated in the first processing step. These data will be channel wise corrected for spectral and spatial non-uniformities. Further processing steps will generate surface reflectance taking into account environmental conditions, such as the topography and atmosphere as illustrated in Figure 4.

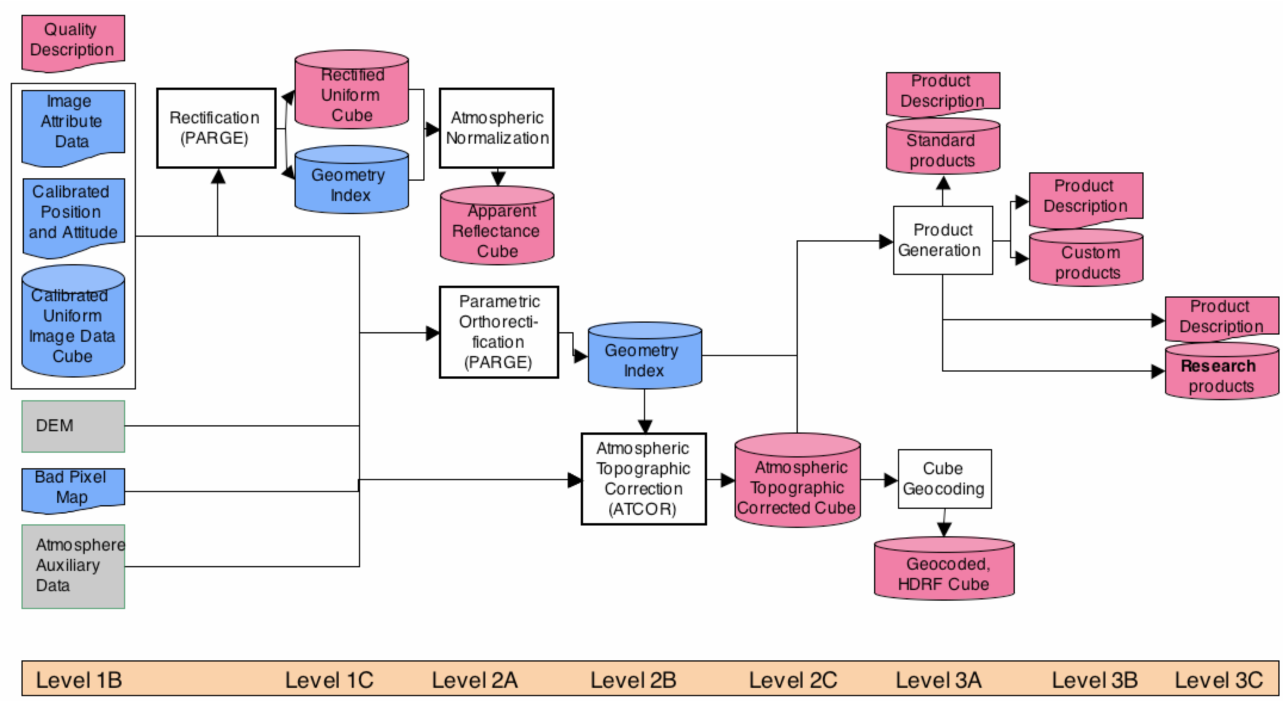


Figure 4: Generalized processing data flow from Level 1 B to higher-level product. In general three categories of products will be generated in the PAF, i.e., standard, custom and research products

The PAF will generate three categories of products, i.e., standard, custom and research products. Standard products – as a result of automatic processing – will be generated for each flight/campaign. An example is the above mentioned Level 1b product. The second category of products is the custom products generated on special request and/or with user interaction. These products require semi-automatic processing of validated methods / algorithms. This is why custom products will be available upon user-request only. An example would be an atmospherically and topographically corrected product (Level 2C), where the user delivers correction measurements (in form of vicarious calibration results) and/or a special digital elevation model. The third category of products consists of research products, which will be processed by operator (or via special web-based GUI). This kind of product is available to dedicated scientific users only. The goal is to test new methods / algorithms, which are under development and still need to be validated. This research product generation is supported by the PAF software using a flexible plug-in structure. Algorithm developers are able to provide their own algorithms, so that third party users are able to make use of new routines and scientific calculations. A documentation of the algorithms is provided by the developers in form of algorithm theoretical basis documents.

APEX SCIENCE AND OPERATIONS CENTER

In the APEX exploitation phase (Phase E), the APEX team in organized in an APEX Science Center (ASC) and an APEX Operations Center (AOC). The ASC is hosted at RSL in Zurich (Switzerland) and the AOC is located in Mol (Belgium) and hosted by VITO.

One objective of the ASC is to foster the use of imaging spectrometer data and the development of new scientific algorithms in close cooperation with scientific users, experts and algorithm developers. Another objective is to monitor APEX calibration, validation and long-term performance. Also calls for airborne/field experiments will be announced via the ASC. In this center the new interface between PAF and algorithm developers will be established. A documentation of all APEX related algorithms is provided in form of algorithm theoretical basis documents.

The AOC will interact with all user requests, such as flight requests, archived data search, flight planning, user support, etc. A description of the infrastructure available at the AOC is given in Debruyn et al./xvii/.

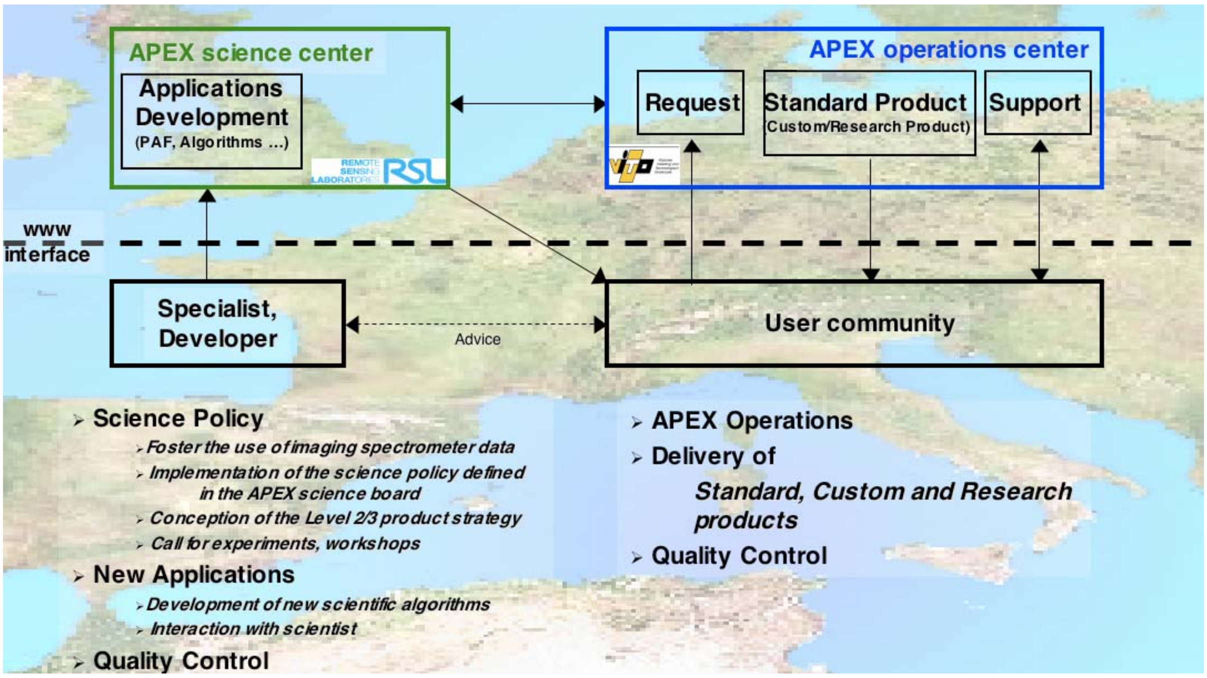


Figure 5: APEX Science and Operations Center during Exploitation Phase.

CALIBRATION HOME BASE (CHB)

The Calibration Home Base (CHB) with dedicated spectral, radiometric and geometric calibration facilities allows full laboratory characterization and calibration of APEX. The CHB is located at DLR in Oberpfaffenhofen near Munich (Germany).

The CHB consists of a 1.6 m integrating sphere to enable the radiometric calibration and an optical bench for the spatial and spectral calibration of APEX. The entire set-up makes use of high stable design mechanism, such as a rigid granite optical bench, a perfect isolated fundament (seismic block) and special air bearings. This is why a high positioning accuracy in the range of microns and arc seconds can be guarantied.

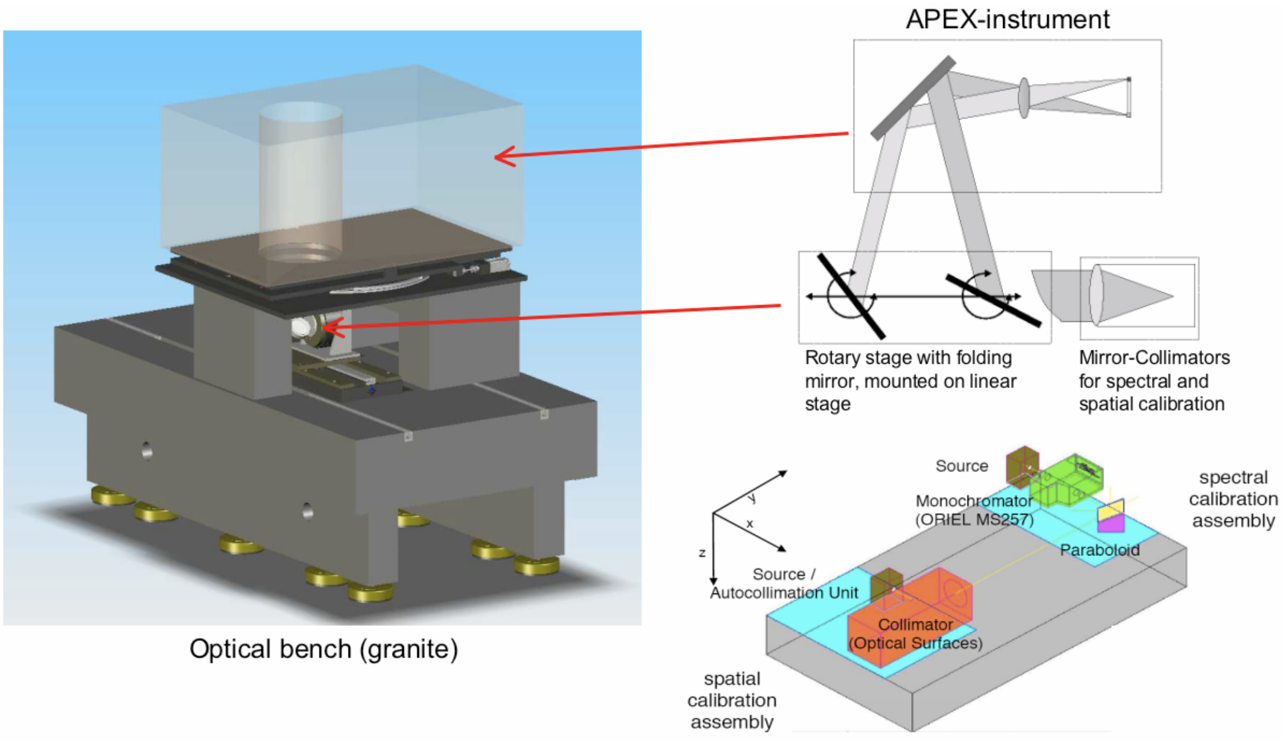


Figure 6: Schematic view of the CHB set-up with fixed APEX instrument, fixed spectral/ spatial calibration assembly and move-/tiltable folding mirror.

A special design will be realized for the calibration bench, where the spatial and spectral characterization measurements of APEX will be performed over the entire swath of ±14 degrees. Due to the overall system mass, APEX will be kept in fixed position during the characterization measurements. The calibration bench consists of collimators (stimulus assembly) with a move- and tiltable folding mirror underneath the instrument. The two-collimator concept offers the possibility of using two different collimators (see collimator 1 and 2 in Figure 6), to facilitate directing of radiation from two light sources on the detector for the spectral and spatial calibration tasks. The key element of the concept is the device for moving and flipping the folding mirror between the collimators. As the actual position and direction of the reflected beam depends on the translatory and angular position of the mirror, the synchronized control of both actuators is a very demanding task. The concept also allows an automated execution of the measurement cycles. More details on CHB design and bread-boarding activities were recently described in /xviii/.

CONCLUSIONS

APEX instrument developments are on the way to close the breadboarding and detailed design activities with the goal to perform the first acceptance flight in the year 2006. The CHB will be available during the instrument-manufacturing phase and for executing the verification, characterization and calibration tests of the instrument. The SWIR detector flight models are under preparation and were delivered by Sofradir (France) end of 2004 for integration.

Further on, also the following activities were successfully finalized:

- the realization of the Processing and Archiving Facility PAF (version 0.5 release),
- design and breadboard of the In-Flight Characterization facility IFC,
- layout of the APEX Science and Operations Center,
- design and procurement of long-lead items of the Calibration Home Base CHB.

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