Airborne Spectroscopy

Challenges - Perspectives

Part 1: Challenges — Klaus I. Itten, RSL

Part 2: Perspectives — Jens Nieke, RSL

Airborne Spectroscopy

Part 1: Challenges

... a few definitions

Imaging spectroscopy

... is the art and science of analysing hyperspectral data

whereas

Imaging spectrometry

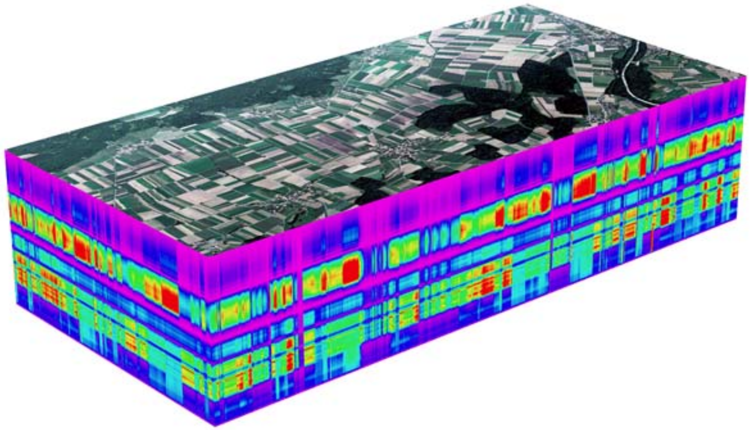
... is the engineering task and science of making the hyperspectral data available, e.g defining and building the instrument and taking the data in a meaningful way

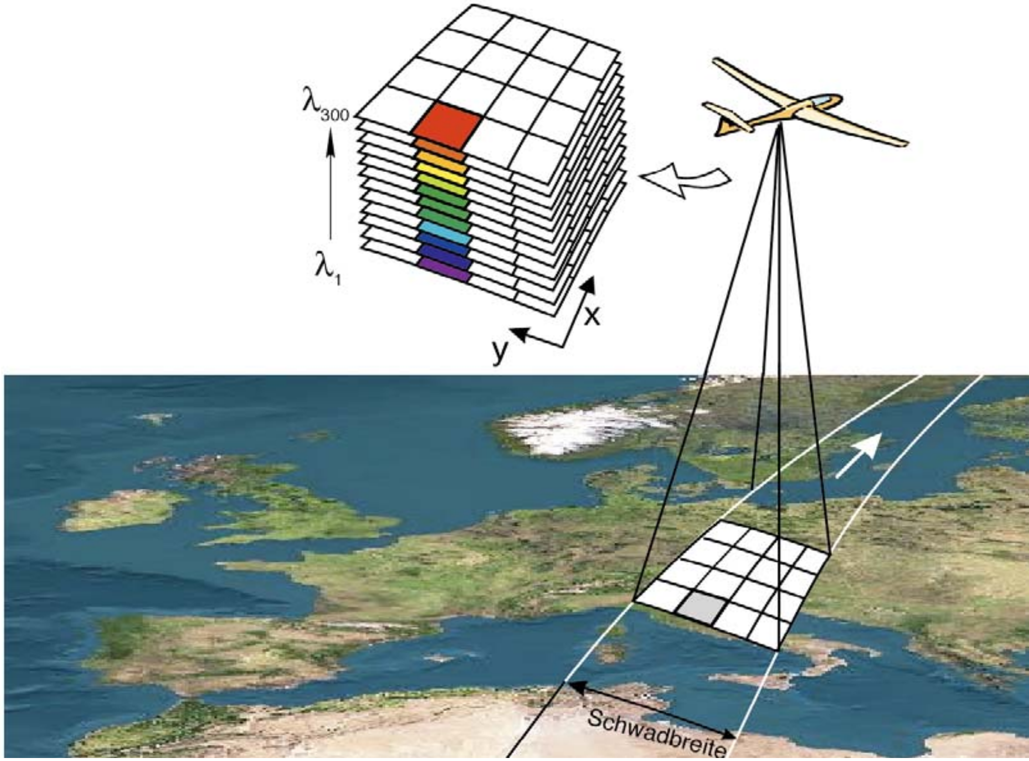
in brief, hyperspectral remote sensing means

... taking data in a great number (>>10) of spectrally contiguous bands with the aim of allowing for spectral analysis of measured objects

Imaging Spectrometry

Spectral Range: 380-2500 nm
Spectral Bands: 200-300
Flight altitude range: 2 - 20 km





Airborne vs. spaceborne imaging spectrometry

Airborne imaging spectrometry

- **higher ground resolution (IFOV) vs. space based systems**
- **more flexible in terms of time and spatial coverage**
- **local to regional scale applications**
- **cal/val for space missions**
- **applications development for space missions**
- **constrained by cloud cover**

Spaceborne imaging spectrometry

- **monitoring capability**
- **regional to global scale applications**
- **long term data archives / continuity oriented**
- **constrained by cloud cover**

Challenges in spectrometry

The challenge of airborne imaging spectrometry

- higher data rates due to lower flight altitude
- platform stability / pointing accuracy / repeatability problems
- limited swath / BRDF sensitivity
- sensor calibration
- limited operations range
- limited monitoring capability

The challenge of spaceborne imaging spectrometry

- orbit selection / repeatibility
- swath vs. ground resolution
- downlink capacity
- continuity / long term data archives
- sensor calibration and drift

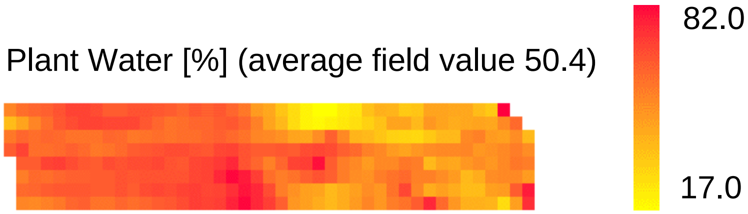
Applications

- **Vegetation and precision farming**
- **Forestry**
- **Geology**
- **Limnology**
- **Coastal water**
- **Air pollution - Trace gases**
- **Security-relevant aspects**
- **Snow and Ice**
- **Simulation, Calibration and Validation of spaceborne sensor systems**

Vegetation and Precision Farming

Plant Water Content

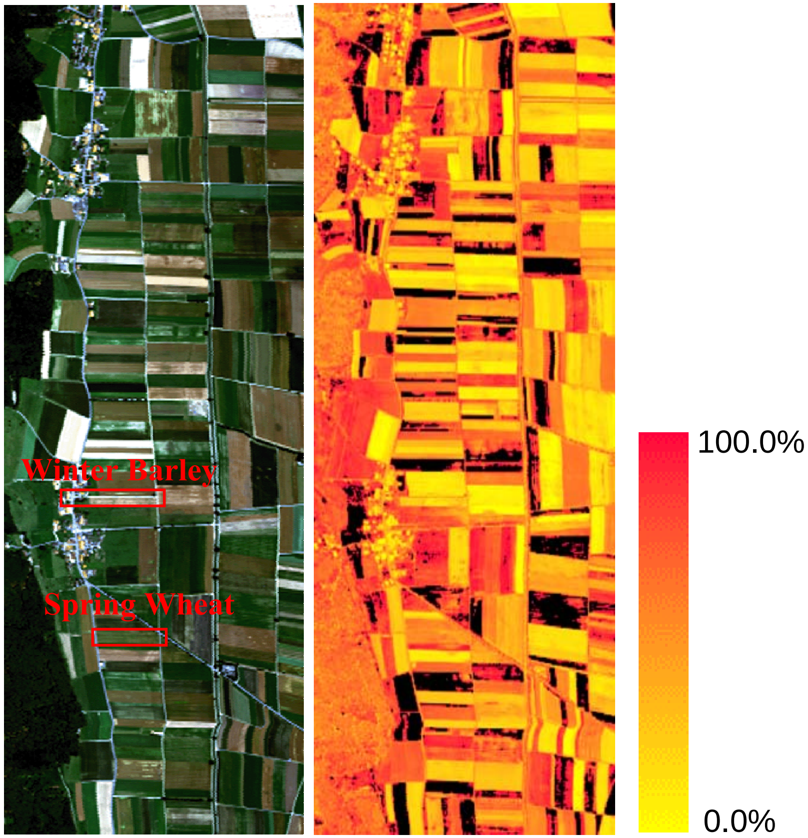
Spring Wheat July 16th 1999



Winter Barley July 16th 1999

Plant Water Content retrieval using the stepwise multiple linear regression method and laboratory data

Limpach Valley HyMap Data Set

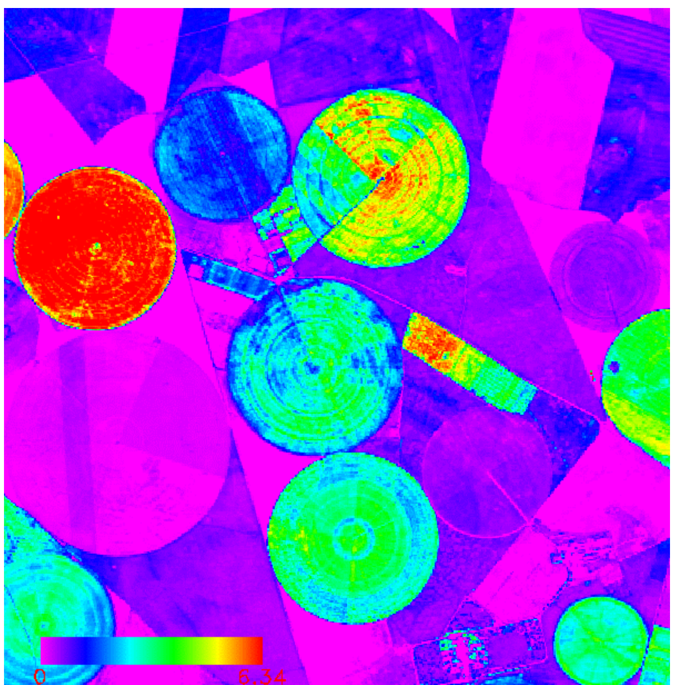


Kneubuehler (2002)

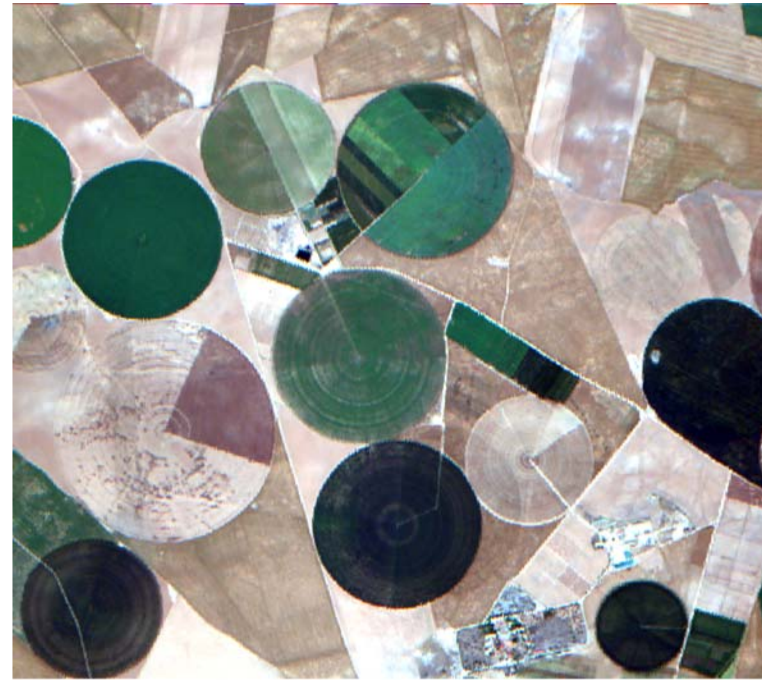
Vegetation and Precision Farming

Leaf Area Index (LAI)

LAI map derived from
HyMap' 99 Data using the
WDVI method (Clevers 1989)



LAI Map



RGB, Barrax (SP) HyMap Data

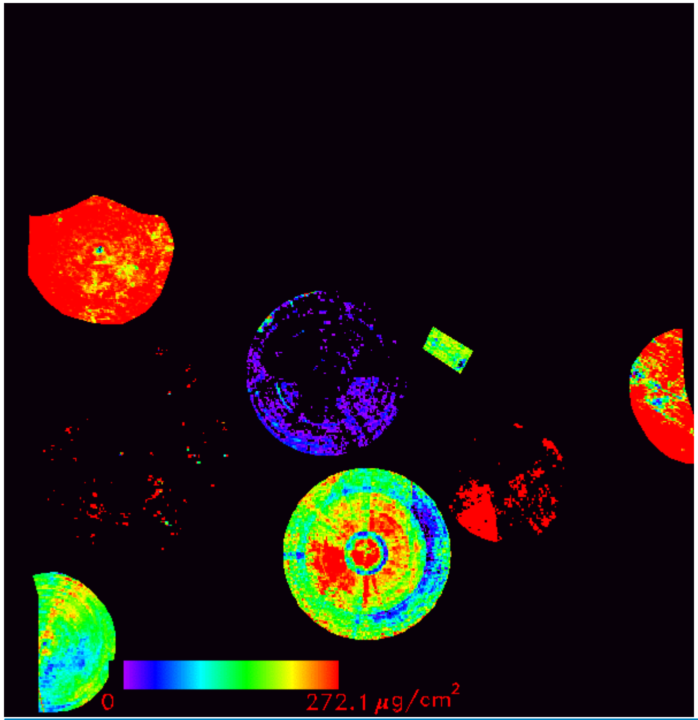
LAI and Chlorophyll are examples of derived vegetation parameters.

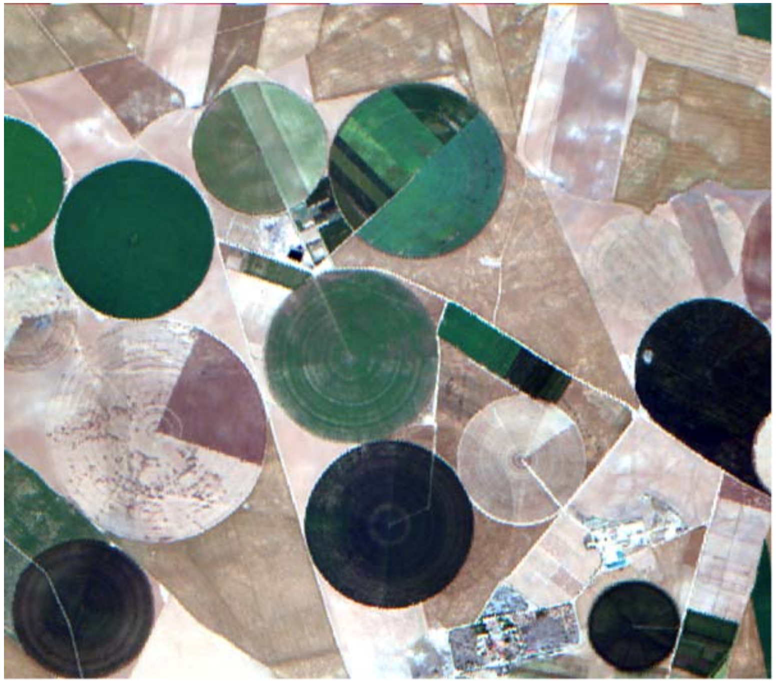
Products are used as input for ecology models.

Huber (2002)

Vegetation and Precision Farming

Leaf Chlorophyll map



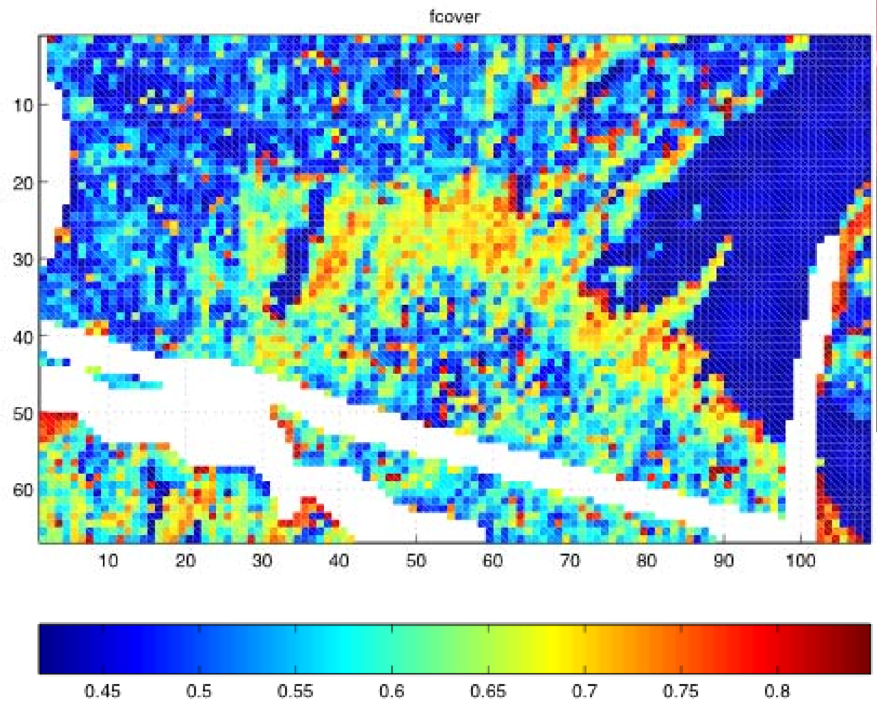


RGB, Barrax (SP) HyMap Data

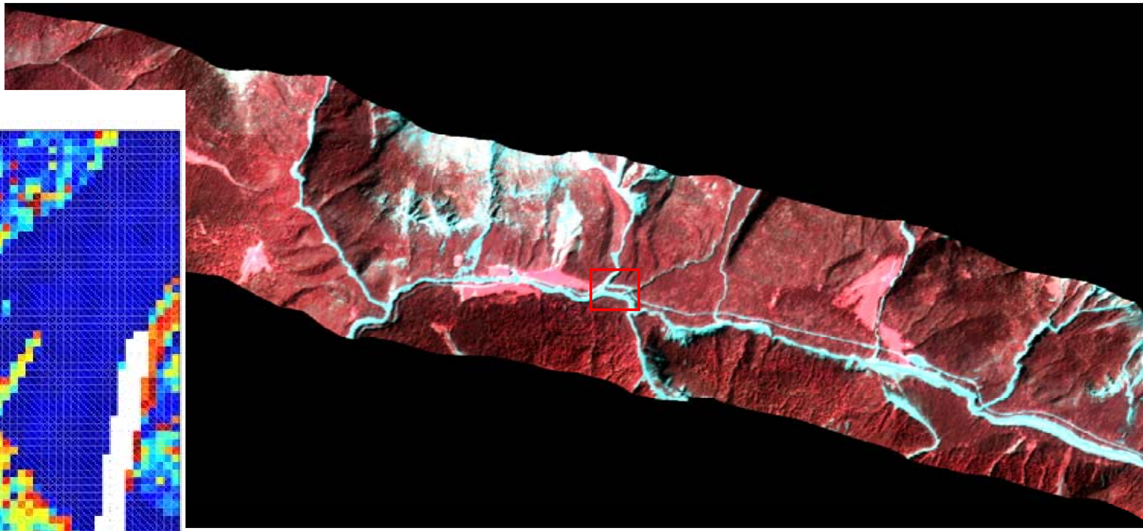
Leaf chlorophyll derived from HyMap 99 Data using a TCARI/OSAVI ratio and laboratory derived chlorophyll values

Huber (2002)

Forestry



Fractional Cover map



False-Color RGB, Swiss National Park (DAIS/ROSIS Data)

Example of derived biophysical and biochemical properties over the test sites in the Swiss National Park.

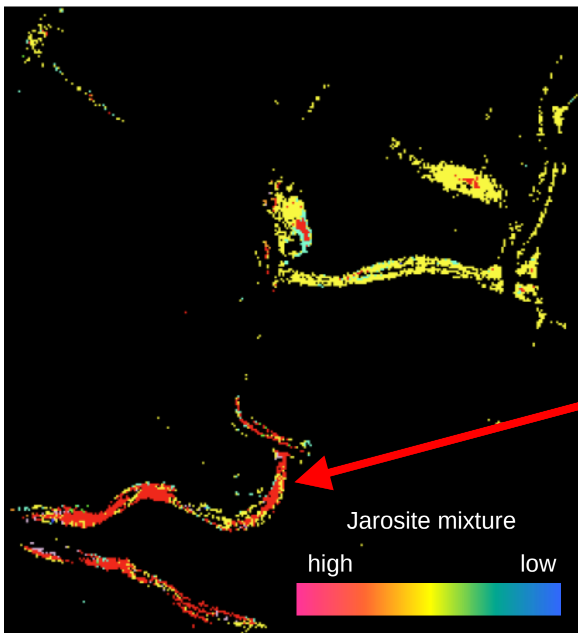
Products are used as input into fire models.

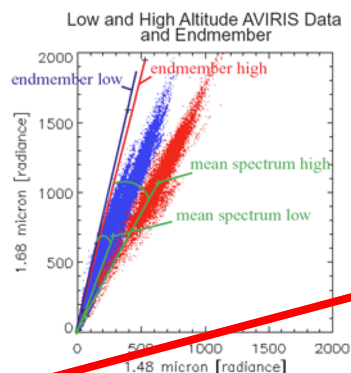
Koetz et al. (2004)

Geology

Analysis of Jarosite Mixture in Mine Tailings:
USGS laboratory spectra are used as endmembers in the analysis methods. Endmembers are pure reference spectra, which are characteristic for a specific material.
(Jarosite $KAl_3(SO_4)_2(OH)_6$ is a secondary mineral formed in acid drainage processes.)

Jarosite influenced areas





RGB, copper mine in Arizona (US) AVIRIS Data

Ph. Meier (2002)

Water constituents

Methodology:

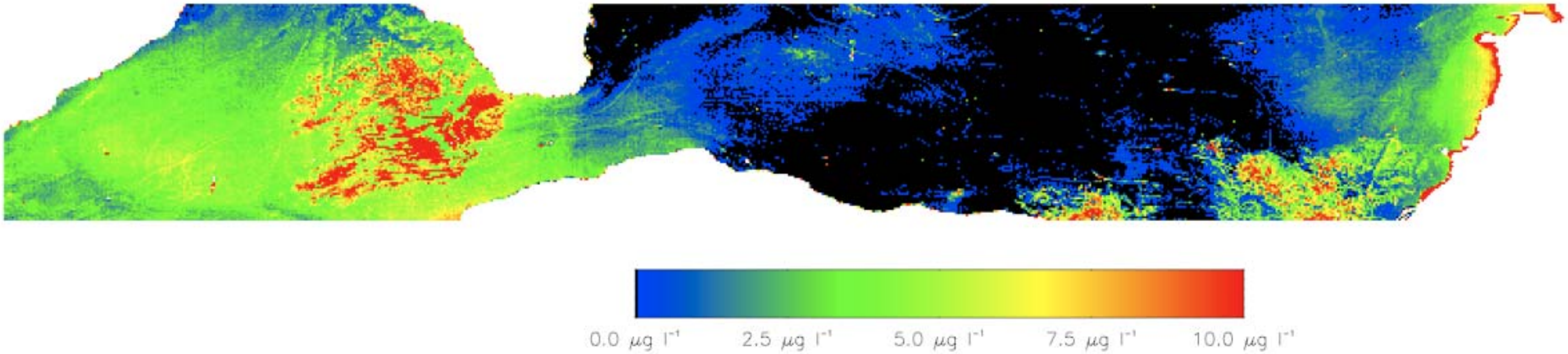
(1) correction for atmosphere effects,

(2) correction for air-water interface effects,

(3) inversion of the sub-surface radiation for the determination of the quality parameters such as chlorophyll a or suspended matter.

=> Comparison of different methods on CASI imaging spectrometer over Lake Zug

Chlorophyll a concentration from CASI in 1999 over Lake Zug (CH)

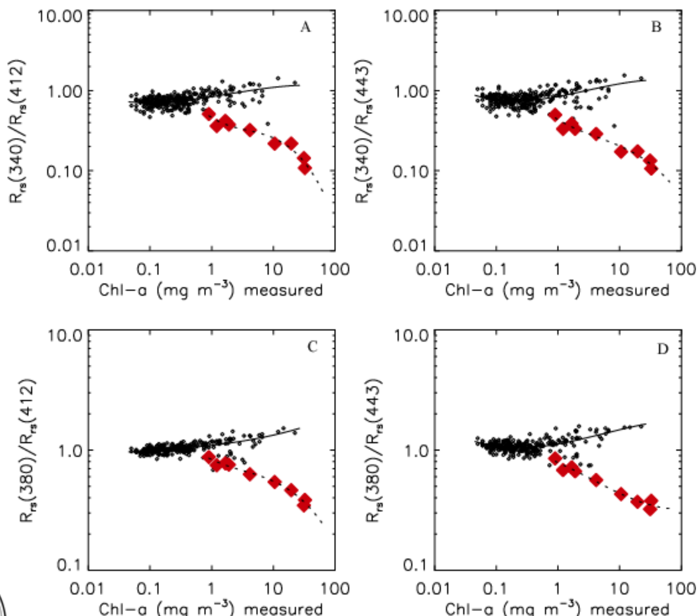


Keller (2001)

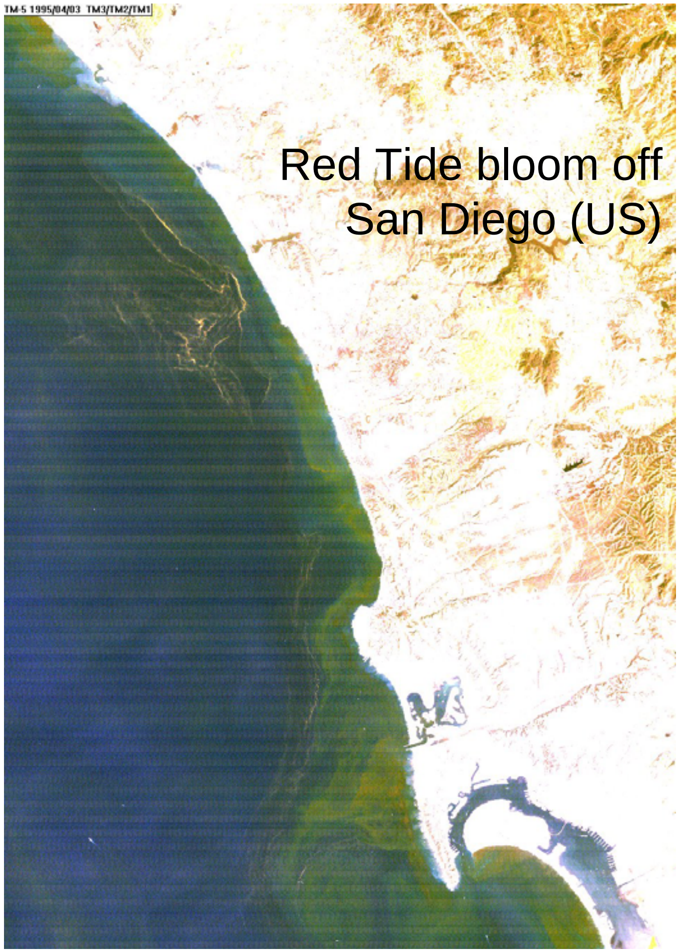
Coastal Waters

Exceptional blooms ("red tides" or Harmful Alga Blooms (HABs)) in coastal areas are detectable with airborne imaging spectroscopy.

Toxic Dinoflagellate blooms detection



Toxic Dinoflagellate blooms results in low $\frac{nLw380}{nLw412}$ ratio!

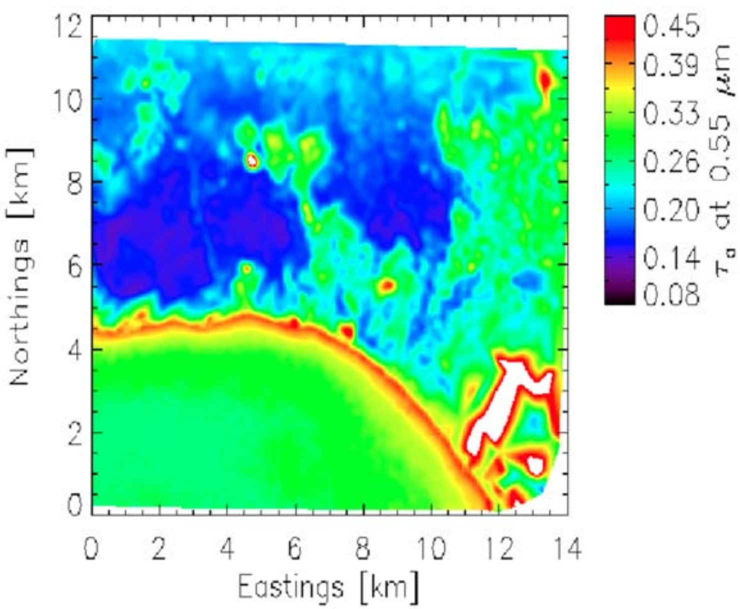


Kahru & Mitchell (1998) © Scripps Institution of Oceanography

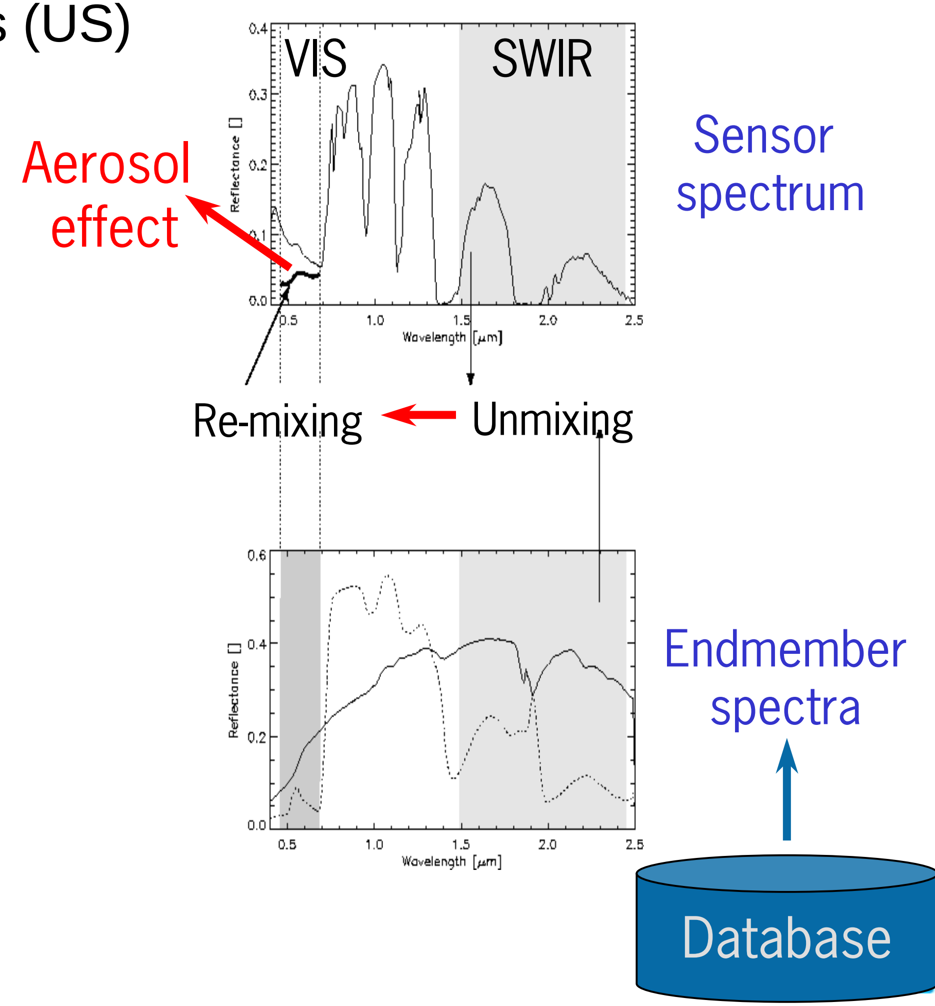
Air Pollution

Aerosol optical depth retrieved from AVIRIS-Imaging Spectrometer data over Santa Monica, Los Angeles (US)

Aerosol Optical Depth Map over Land



Bojinski et al. (2004)



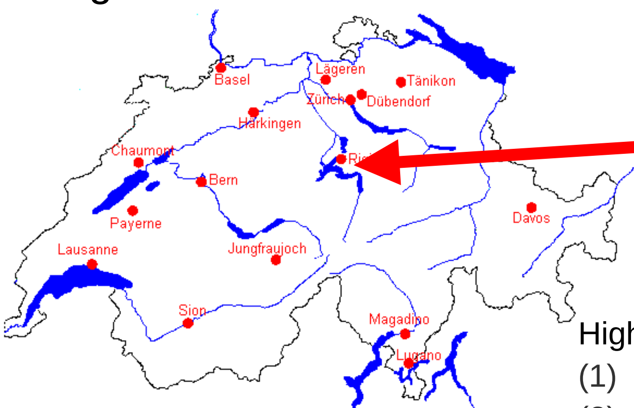
Air Pollution

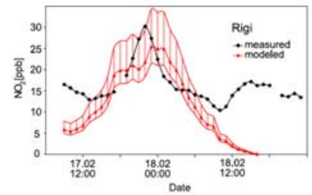
Spaceborne global NO_2 Measurements:

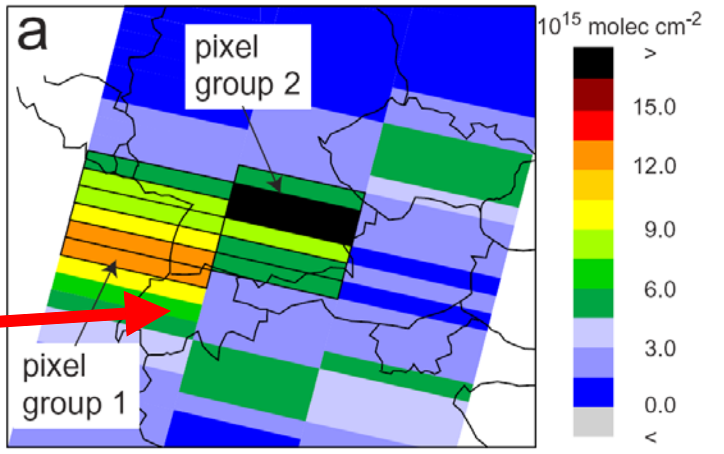
e.g. GOME (40 x 320 km²), OMI (24 x 13 km²)

Local In-Situ Measurements:

e.g. NABEL stations







scale gap!

High needs for better air quality monitoring:

(1) Monitoring of trace gases in regional scale

(2) Maps of pollution and transport in urban scale, e.g., airports

(3) Validation of space sensor measurements in sub pixel grid

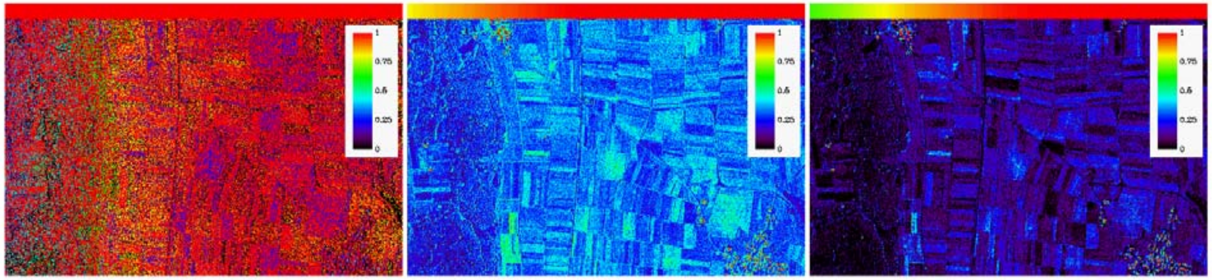
Airborne imaging spectroscopy allows to retrieve NO_2 (and CH_4) in local/regional scale with a spatial resolution of ~ 30 m and a column retrieval precision of ~ 10%.

Kaiser, Schaub (2004)

Security Relevant Aspects

Detection potential of camouflaged targets in rural environments

Target detection of camouflaged objects in rural environments



Black (=0) no detection potential; Red (=1) strong detection potential. The three images represent from left to right a forward scattering target, nadir view and backward scattering target.

Challenges in spectroscopy

The challenge of spectroscopy

- **spectrum analyis requires calibrated data**
- **high geometric and radiometric preprocessing requirements**
- **high cal/val requirements**
- **requires coordinated data take / simultaneous field investigations**
- **forward and inverse modelling of radiation transfer dealing with atmosphere and objects, including BRDF and HRDF**

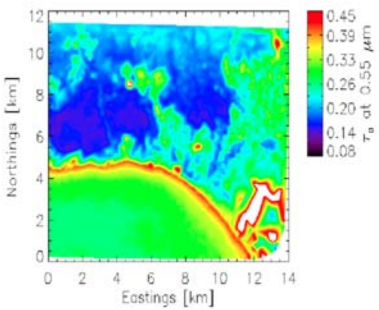
- **Europe needs a greater capacity for airborne spectrometry (such as APEX and ARES) and ultimately the spaceborne mission SPECTRA**

Airborne Spectroscopy

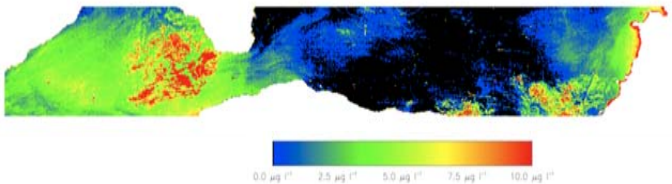
Part 2: Perspectives

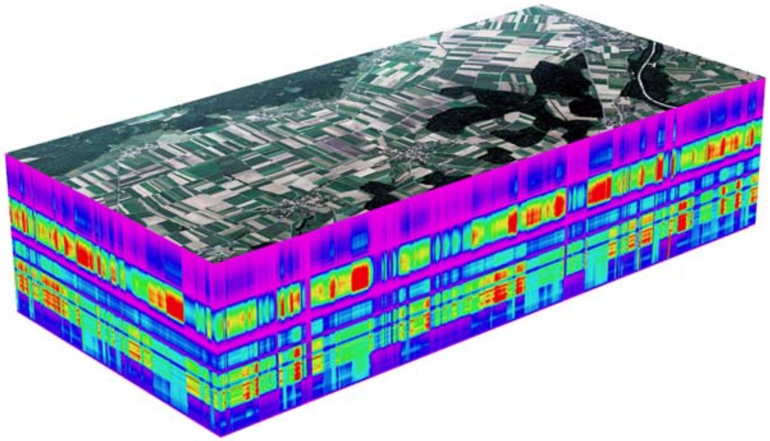
Hyperspectral Applications

Air Pollution

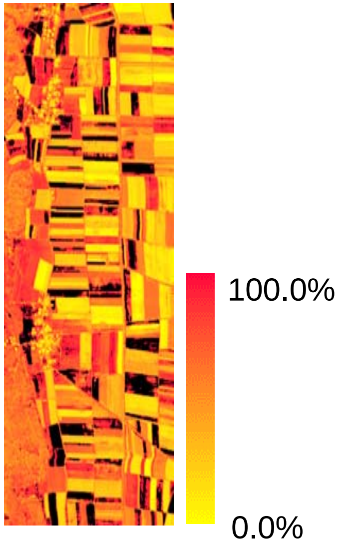


Water Quality

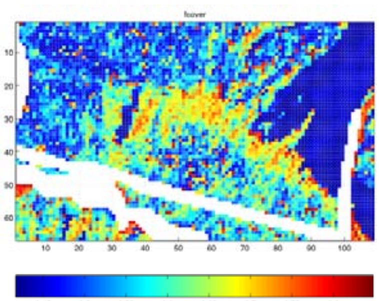




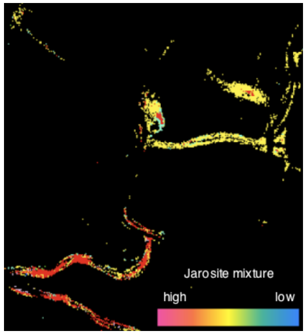
Precision Farming



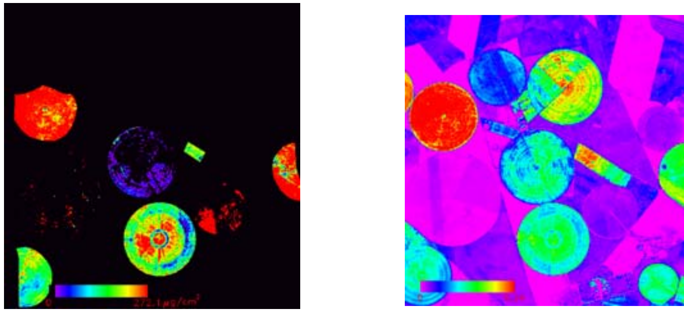
Forest Fire Modeling



Natural Hazards



Ecology Modeling



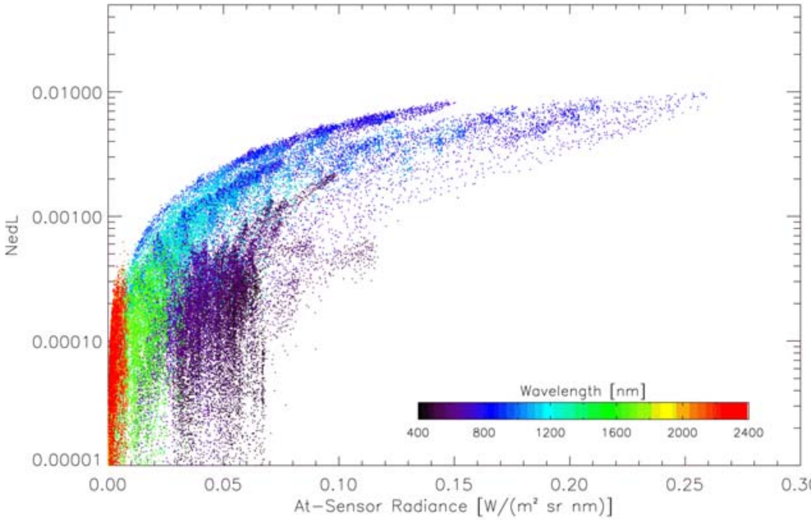
Definition of application-driven user requirements

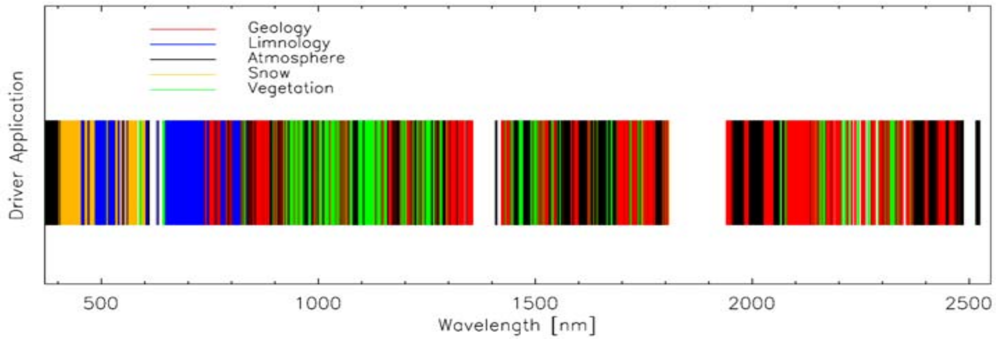
Goal: Development of advanced methods for bio-geophysical parameter retrieval of

Vegetation,
Soils, rocks & minerals,
Snow & ice,
Atmosphere,
Coastal and inland waters analysis

and cross calibration with spaceborne EO systems

Modeled LAI as a function of NedL and at-sensor-radiance to determine SNR requirements for imaging spectrometers.





Schlaepfer & Schaepman (2002)

Driver application for the radiometric requirement

Key Requirements 1/2 for APEX

- Field of View (FOV) – Swath: ± **14deg with 1000 across-track pixel**
- Instantaneous Field of View (IFOV): **0.028 deg**

- Flight altitude range: **3,500 – 10,000 m.a.s.l.**
- Standard aircraft interface for: **Dornier Do-228 on stabilizing platform PAV 30 from LH-Systems**
- Spectral range: **VNIR: 380 – 1000 nm, SWIR: 940 – 2500 nm**
- Spectral channels: **VNIR: 312 (prior binning), SWIR: 199**
- Spectral sampling interval: **380 – 1050 nm: < 5 nm, 1050 – 2500 nm: < 10 nm**
- Center wavelength accuracy: **< 0.2 nm**

Key Requirements 2/2 for APEX

- FWHM: ≤ **1.75 Sampling interval**

- Spectral / Spatial Misregistration: **< 0.1 pixel**
- Spatial co-registration between VNIR and SWIR channel: **goal: 0.16 pixel**

- Polarization sensitivity: **less 0.03 in VNIR, less 0.05 in SWIR (goal)**

- Instrument temporal radiometric uncertainty within a flight section: **better 0.02**
- Radiometric performance accuracy: **instrument shall allow absolute calibration accuracy up to 0.03 (goal)**
- Interval for instrument re-calibration: **after a complete flight season**

Scope of APEX

APEX: Airborne Prism EXperiment:

APEX is an airborne simulator for the support and development of future spaceborne Earth Observation systems.

APEX will be able to

Simulate,

Calibrate, and

Validate

planned ESA imaging spectrometer missions, e.g, SPECTRA etc.

APEX will foster the use of imaging spectrometer data in Europe and will support the application development for imaging spectroscopy products.

APEX is a joint Swiss/Belgian ESA PRODEX project with support from ESA Earth Observation Preparatory Programme and will complemented by other European initiatives, such as ARES (GFZ, DLR Germany)

APEX Organization

ESA Team
- PRODEX Technical Officer — José Gavira Izquierdo
- Instrument Manager & Detector Development — Gerd Ulbrich & Roland Meynart
- Contracts Officer — Ulrich Sterzl

Science Team
- Principal Investigator — Klaus Itten
- Project Manager — Jens Nieke
- PAF Scientist — Johannes Kaiser
- Processing Scientist — Daniel Schläpfer
- Computer Scientist — Jason Brazile
- Scientific Advisor — Michael Schaepman

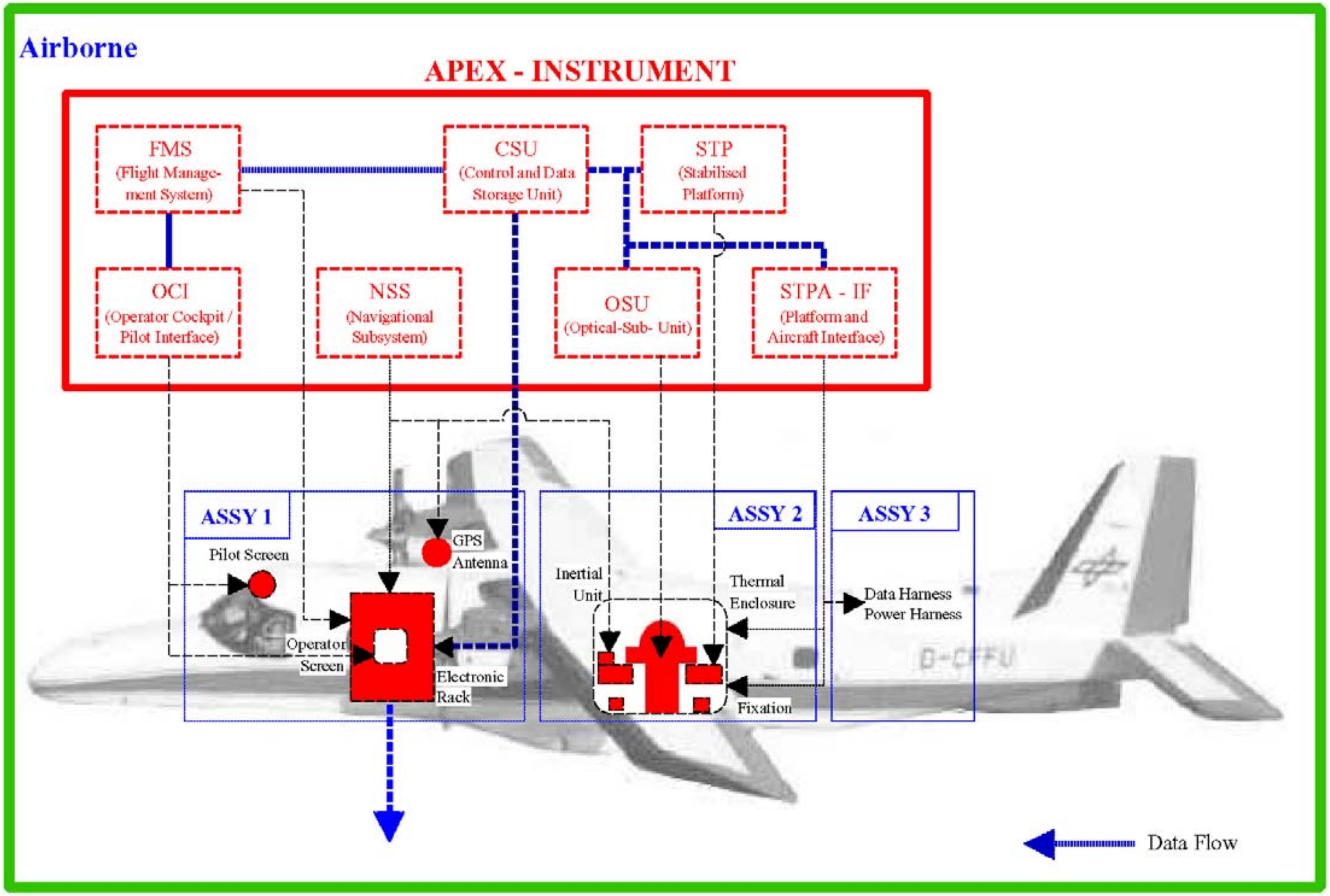
Operations Team
- Co-Investigator — Walter Debruyn
- Instrument/Flight Operations — Koen Meuleman
- Processing Operations — Pieter Kempeneers
- Operator — Johan Mijnendonckx

Industrial Team
- Industrial Prime — HTS AG
- Optical Subsystem — OIP Sensor Systems
- Electronic Subsystem — Netcetera AG
- SWIR Detectors — Sofradir
- Calibration Home Base — DLR

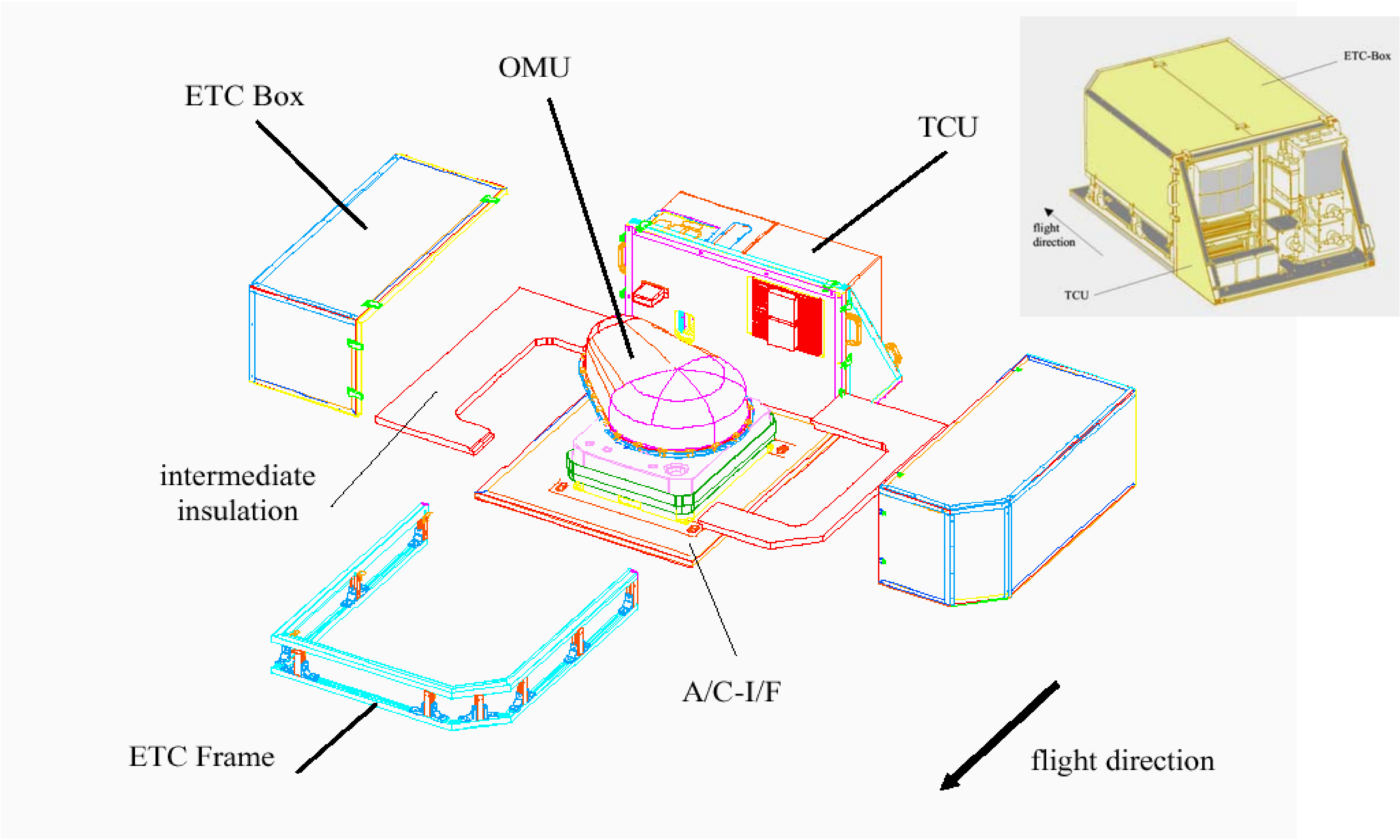
APEX Instrument description

- **Hyperspectral Imager for various standard airborne platforms, e.g.:**
  - Do228, Cessna types: T207A, C208B, 404, Twin Otter, Short SC7 Skyvan
  - Falcon F20 (pressurized A/C for altitudes above 7.5 km)
- **Pushbroom instrument with 2 spectrometer channels**
  - Spectral Range: 0.38 up to 2.5 micron
  - Spatial/spectral Resolution:
  - 1000 samples @ 28° FOV, about 300 spectral bands
- **“In-Flight Characterization Unit” (IFC) for excellent performance stability**
- **Thermal Control Box for stable instrument operation independent from A/C environmental conditions**

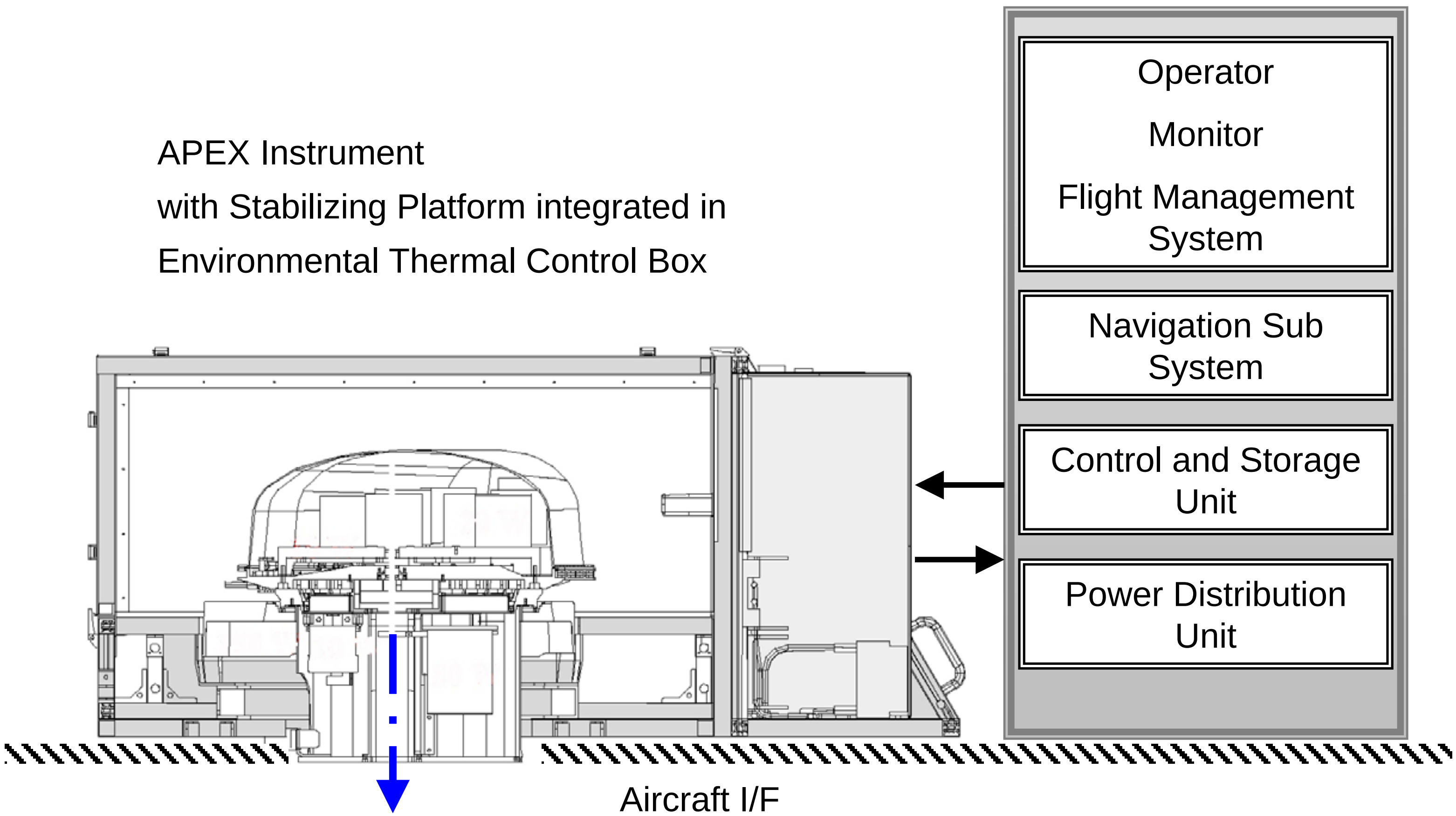
Schematic APEX Instrument Components



Instrument Set-up

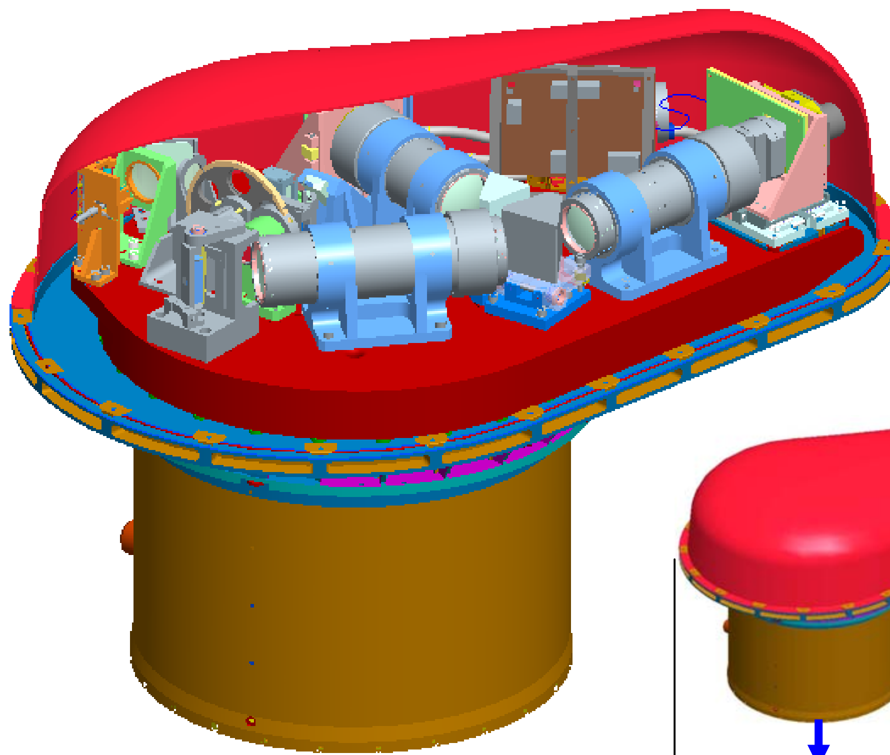


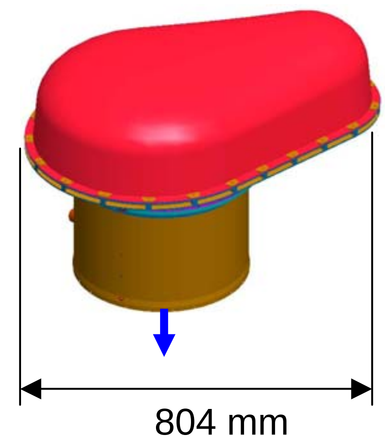
Instrument Set-up in Aircraft



APEX Hyperspectral Imager

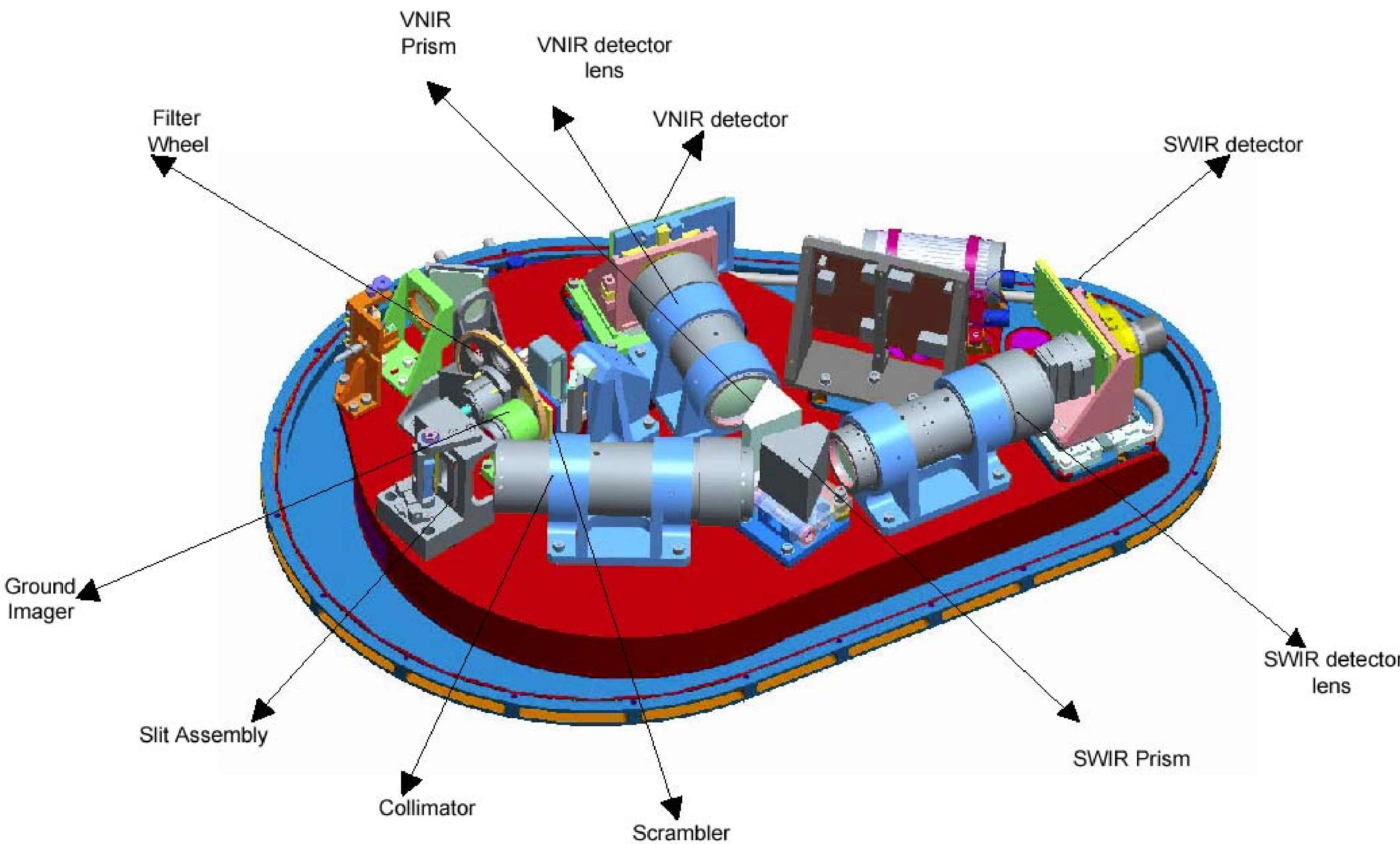
- Sealed spectrometer compartment
- Thermal stabilized during operation: Better 2 ºC, gradient less 0.5 ºC
- Max. deformation of Optical Base Plate (OBP) less 0.040 mm due to air pressure variations
- Co-registration error VNIR-to-SWIR channels about 0.5 pixel
- Overall mass: 72 kg, without counterweight for COG adjustment



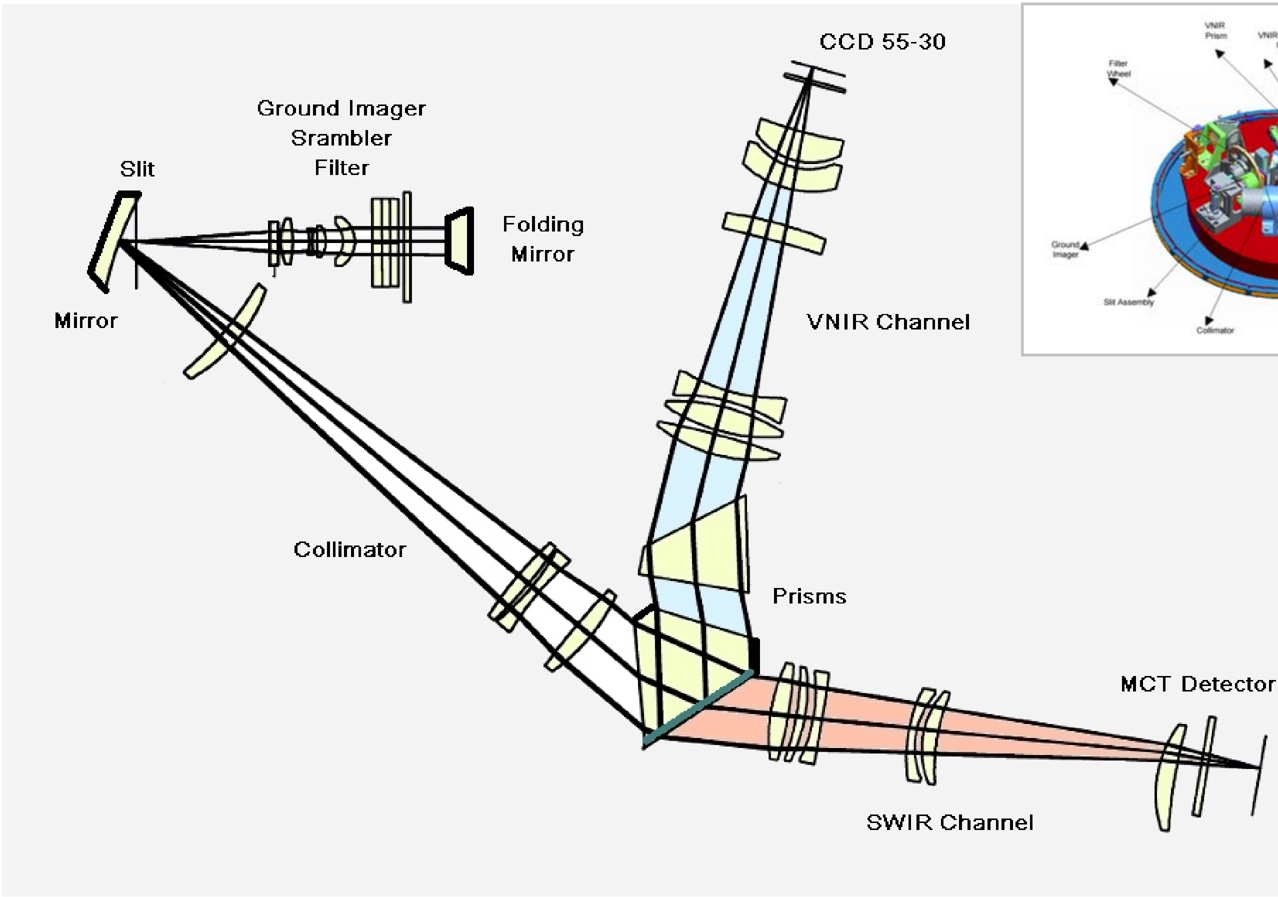


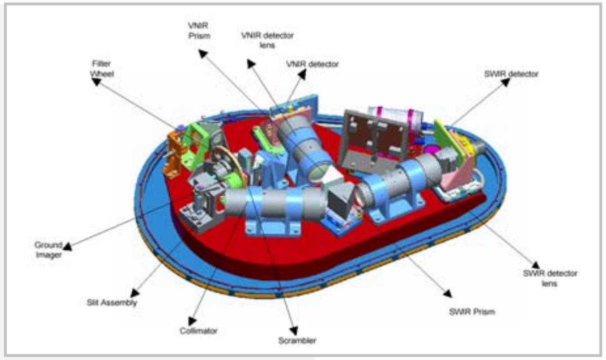
Fits into PAV-30 Stabilizing Platform, Opening diameter 443 mm

Spectrometer - Design Concept

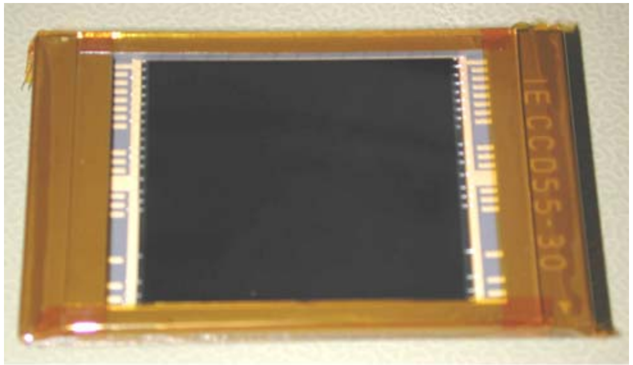


Spectrometer - Optical Design Concept



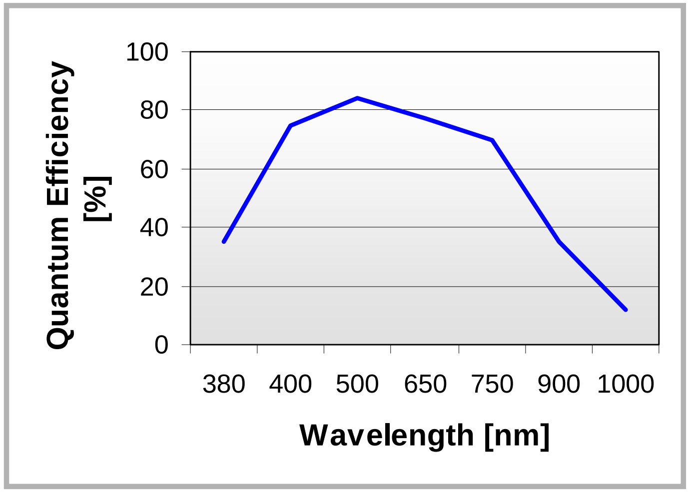


VNIR- Detector



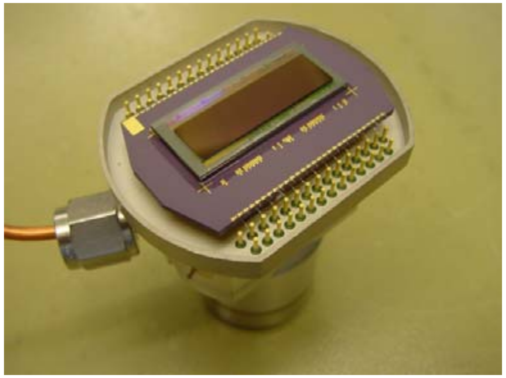
Type CCD 55-30 from E2V Technologies (GB)

- **Frame transfer mode,**
- **1252 x 1152 pixel (used 1000 x 393)**
- **Pixel pitch 22.5 x 22.5 µm², fill factor 100%**
- **Back illuminated**
- **Operated in non-inverted mode**
- **Read out frequency 7 Mpix/s**
- **Operated in dither clocking mode without cooling**
- **integration time independent from frame transfer time**

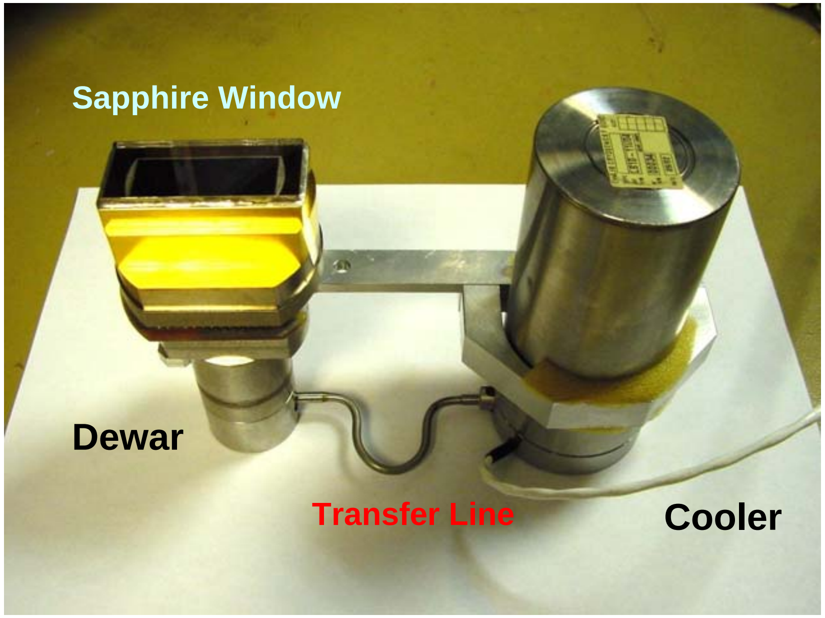


SWIR Detector

- HgCdTe detector array - hybridized on CMOS multiplexer
- 1000 x 256 square pixel, 30x30 μm^2, addressable readout, fast operation
- Integrated in cryostat cooler assembly
- WL range: 0.94 – 2.50 micron
- QE: > 55 % average
- $T_{op.}$: 130 – 165 K

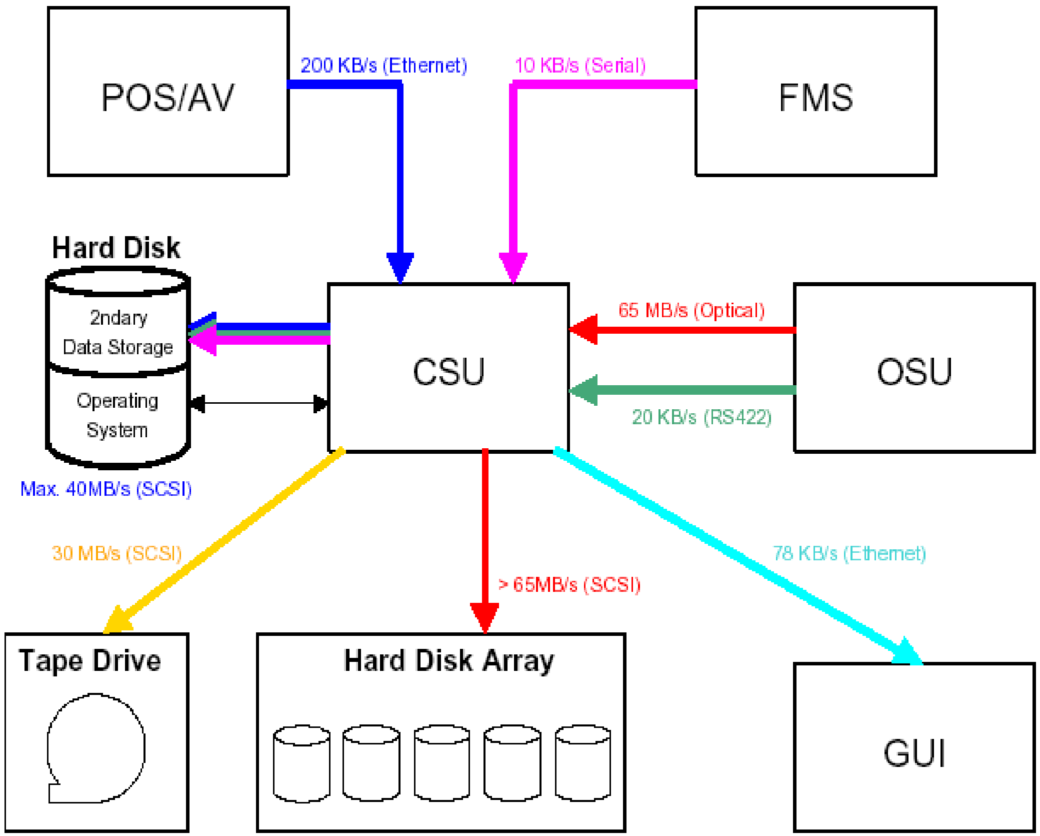


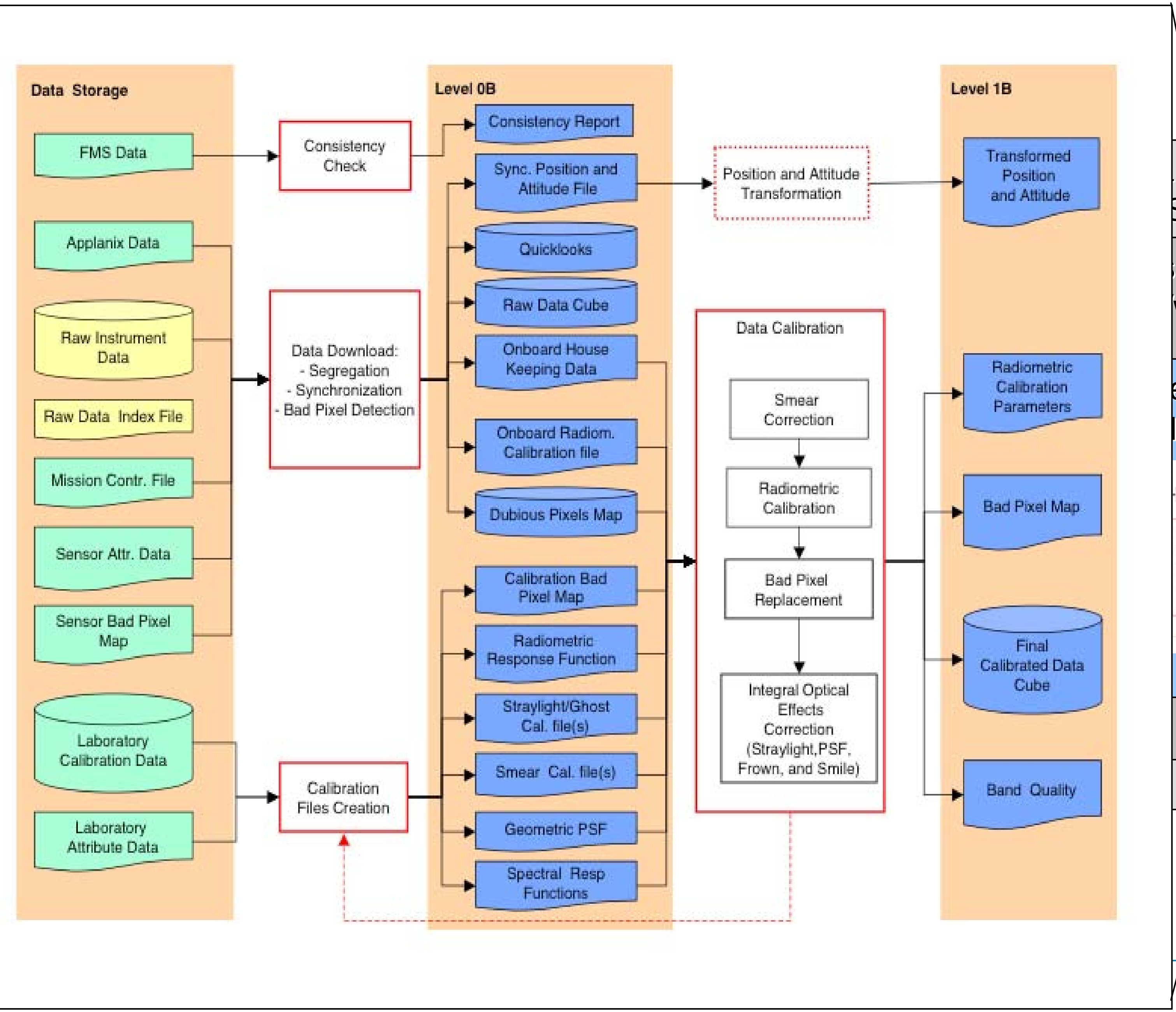
Focal Plane Assembly BB



Pre-EM Detector with Cryostat/Dewar Assembly

APEX Electronic: Data Streams Overview





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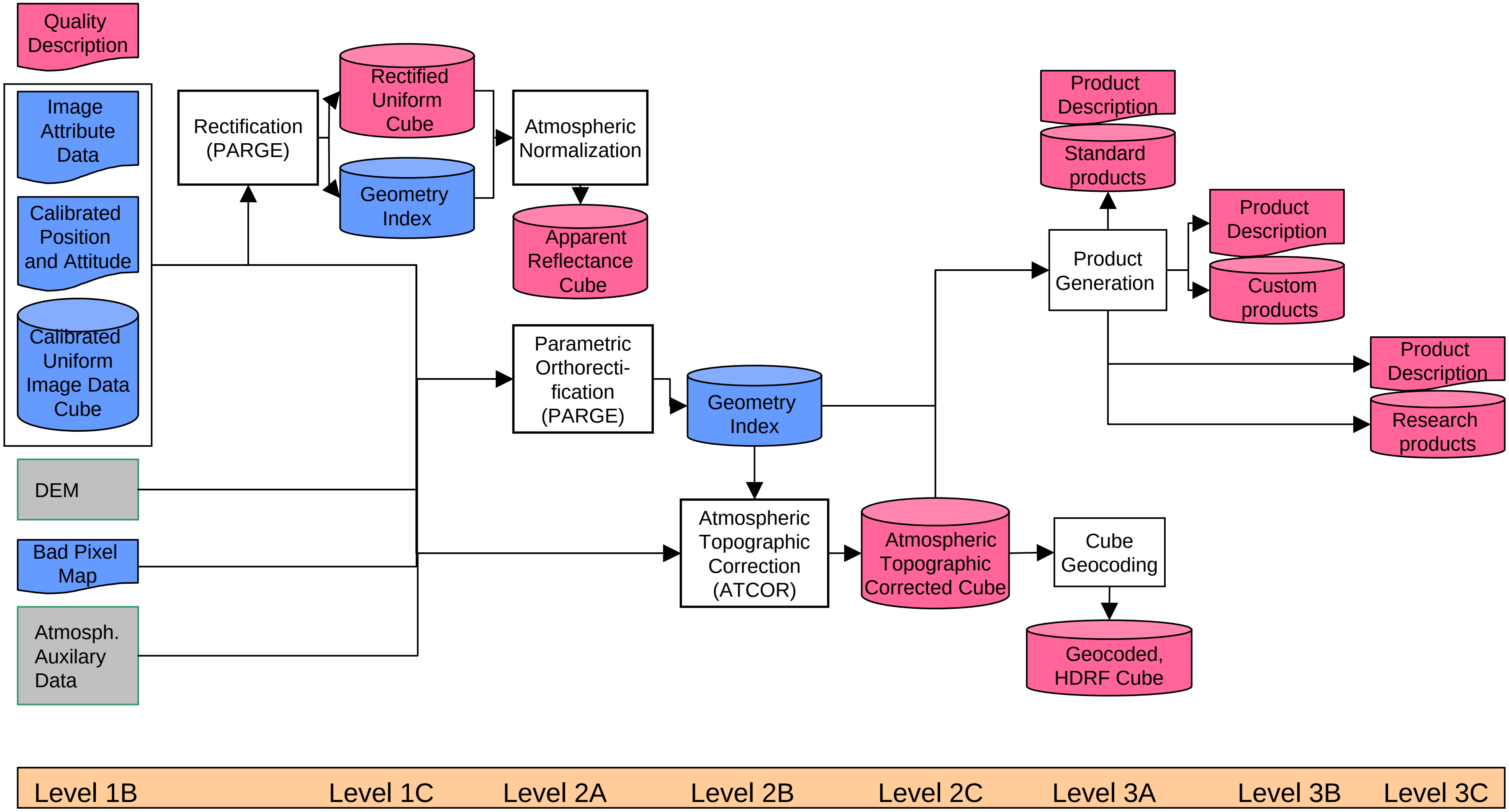
APEX higher processing Level 1B, 1C, 2, 3



APEX - Schedule / Conclusion

- **Phase C/D – begin July 2002**
  - Baseline Design Review – September 2002
  - Preliminary DR – close out 7 May 2003
  - Critical DR – close out planned Mar 2005
  - Acceptance Review – 1st quart. 2006
- **First acceptance flight – springtime 2006**
- **Exploitation - as of mid 2006**
- **Envisaged operation time 5 - 10 years**

Call for experiments will be released for the 2006/07 time frame.