Hyperspectral Systems: Recent Developments and Low Cost Sensors

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Outline

- Motivation
- OS Heritage in Multispectral- and Hyperspectral Instruments
- Spectral Imaging
- Definition of Low Cost
- Snap shot Hyperspectral Systems
- Scanning Hyperspectral Systems
- Verification
- Example: DESIS
- Conclusion

Motivation of Hyperspectral Imaging (HSI)

HSI support Global Earth Management in the areas

- Biodiversity and Ecological Stability
- Climate Change
- Water Availability and Quality
- Natural Resources
- Earth Dynamics and Risks

Application of Hyperspectral Imaging (HSI)

- Airborne and space-borne hyperspectral imaging
- Crop stress analysis
- Machine vision QC
- Astronomy
- CCD/Display characterizations
- Semiconductor process control

DLR-OS Heritage in Multi- and Hyperspectral Systems

Earlier developments

- Fourier spectrometer on Venus mission VENERA 15 &16
- **M**odular **O**ptoelectronic **S**canner on IRS-P3

Latest developments

- MErcury Radiometer and Thermal Infrared Spectrometer
- DESIS(DLR Earth Sensing Imaging Spectrometer)
- VIS/NIR Hyperspectral Mission EnMap FPA Development
- VIS/NIR S4 FPA Design and Verification

Spectral Imaging

- Spectral imaging is a combination of a spectral dispersive resolving element with an spatial resolving imaging system, $I(x,y,\lambda)$
- Spectral scan methods with a set of color filter
  - circular-variable filter (CVF)
  - liquid-crystal tunable filter (LCTF)
  - acousto-optical tunable filter (AOTF)
  - CVF has mechanically moving parts, AOTF and LCTF are electro-optical components
- Spatial-Scan Methods
  - Dispersion of light is achieved by grating or a prism (or combination of both)
- Time-Scan Methods by superposition of the spectral and Fourier transformation of the acquired data (Fourier spectroscopy)
  - no filters, the spectrum is measured by using the interference of light

Detector Technology

Standard detectors:

- CCD (e.g. split chip technology from e2v for SENTINEL-4)

New developments:

- CMOS (e.g. ENMAP-Detector, back side illuminated, dual column on chip single slope ADCs)

- HgCdTe or mercury cadmium telluride (MCT): Teledyne provide with CHROMA one Detector for UV/VIS/NIR/SWIR spectral range

- Strained layer superlattice (SLS)-based detectors, operated at higher temperatures than HgCdTe or InSb, which result in improved size, weight and power (SWaP)

LC Hyperspectral Instruments

Spectral High Resolution

Temporal Resolution

Low Cost Hyperspectral Instruments

Scan to come from 2D to the Cube

Snap Shot Hyperspectral

Definition of Low Cost

Name	LC		Weight
- Instrument cost	++++		50 %
- Accommodation cost	++++		5 %
- Test and Verification cost	+++		5 %
- Documentation cost	++		10 %
- In-Orbit Commissioning Phase cost	-		5 %
- Mission Cost			25 %
- Operations		--	
- Monitoring	+		
- Calibration		--	

ca. 70 %

Statement: **Clear we give something up, but we compensate by smart design and clever algorithms**

Low Cost Hyperspectral Instruments

Scan LC Hyperspectral Instruments

- Matrix Camera with tunable Filter
- Matrix Camera with variable Filter

Information of position and orientation

Snap shot LC Hyperspectral Instrument

- Single Pixel Filter
- Matrix Camera with variable Filter

Low Cost Hyperspectral Systems (Snapshot System)

Tunable Filter - VariSpec:

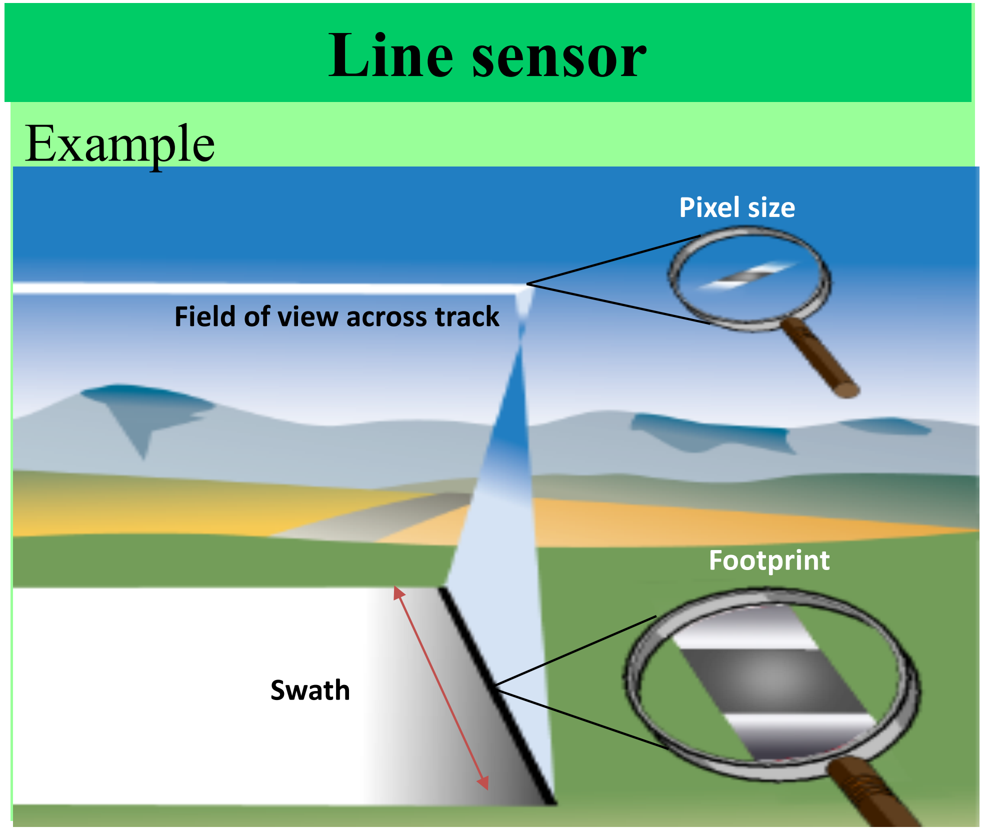
- Liquid Crystal Tunable Filters
- Tunes in wavelength continuously over hundreds of nanometers
- Imaging quality
- No moving parts (and no image shift between different bands)
- Fast, random access wavelength selection
- Compact, low power design

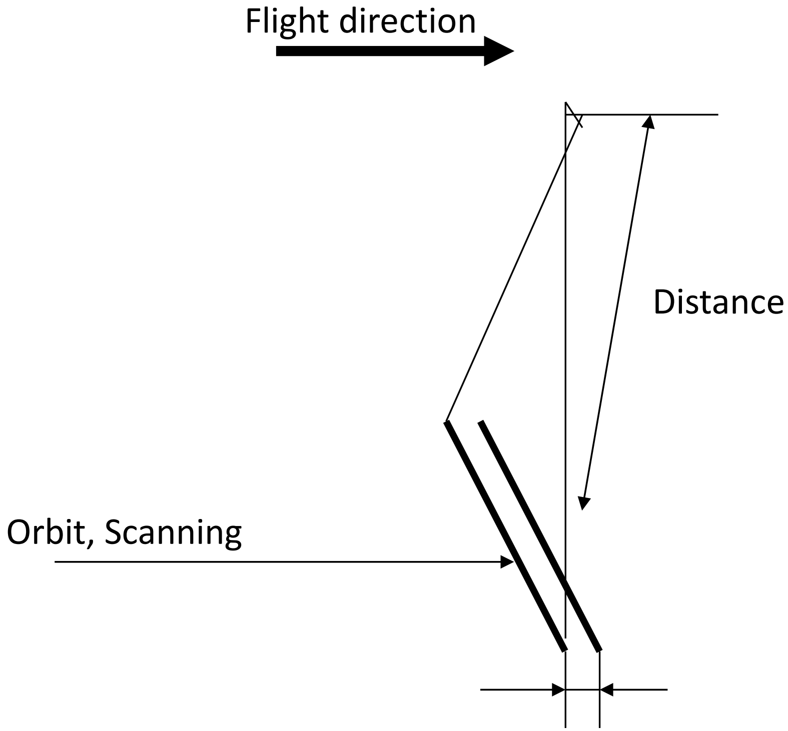
Features

- VIS, SNIR, LNIR, XNIR
- 7, 10, 20, 0,25 and 0,75 nm (width at half maximum)
- 20 mm- or 35 mm-aperture

- https://lot-qd.de/en/news/product-application-news-spectrum/international-spectrum-e22/tunable-varispec-filter-covers-a-variety-of-spectral-ranges/

Low Cost Hyperspectral Systems (Line Scan System)





MTF[Ny] = > 2 / PI

$$t_{sample}[s] = \frac{GSD}{Speed}$$

(Smear lower or equal one Pixel)

Low Cost Hyperspectral Systems (Snapshot and Line-Scan System)

IMAC (https://www.imec-int.com/en/hyperspectral-imaging)

150+ bands line-scan spectral imager solution:

- Translation movement is needed to capture the hyperspectral image.
- (150+ spectral images of 2-4MPx resolution each after one single scan).
- Acquisition rate of 1360 lines/s

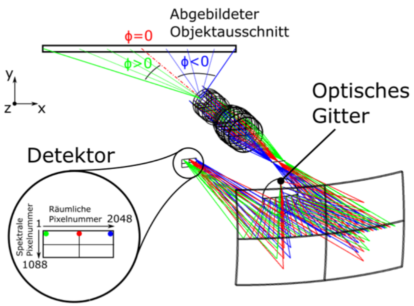
32 bands snapshot tiled spectral imager solution:

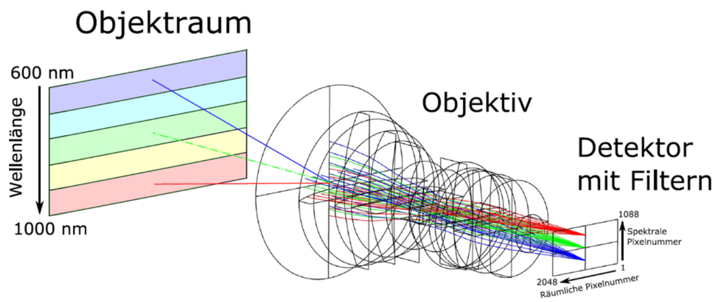
- For snapshot, IMEC has designed an imager with 32 spectral bands (within 600-1000 nm) having 256x256pixels spatial resolution each (30-60 data-cubes/s)

16 bands snapshot mosaic spectral imager solution:

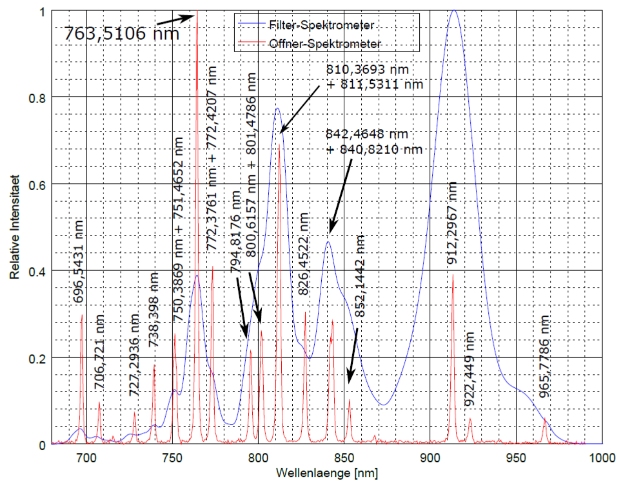
- IMEC did process one spectral filter 'per-pixel' on a full mosaic of 4x4 = 16 spectral bands (within 460-630 nm) cameras integrated on one single chip

Comparison of a Grating Spectrograph and a Filter hyperspectral camera





- Grating Spectrograph is realized is based on Offner design
- Filter camera is an ultra compact system in comparison to the Offner-Spectrograph
- Both systems has the same detector and the same optics
- The spectral resolution of the Offner spectrometer is significantly better than that of the filter spectrometer.

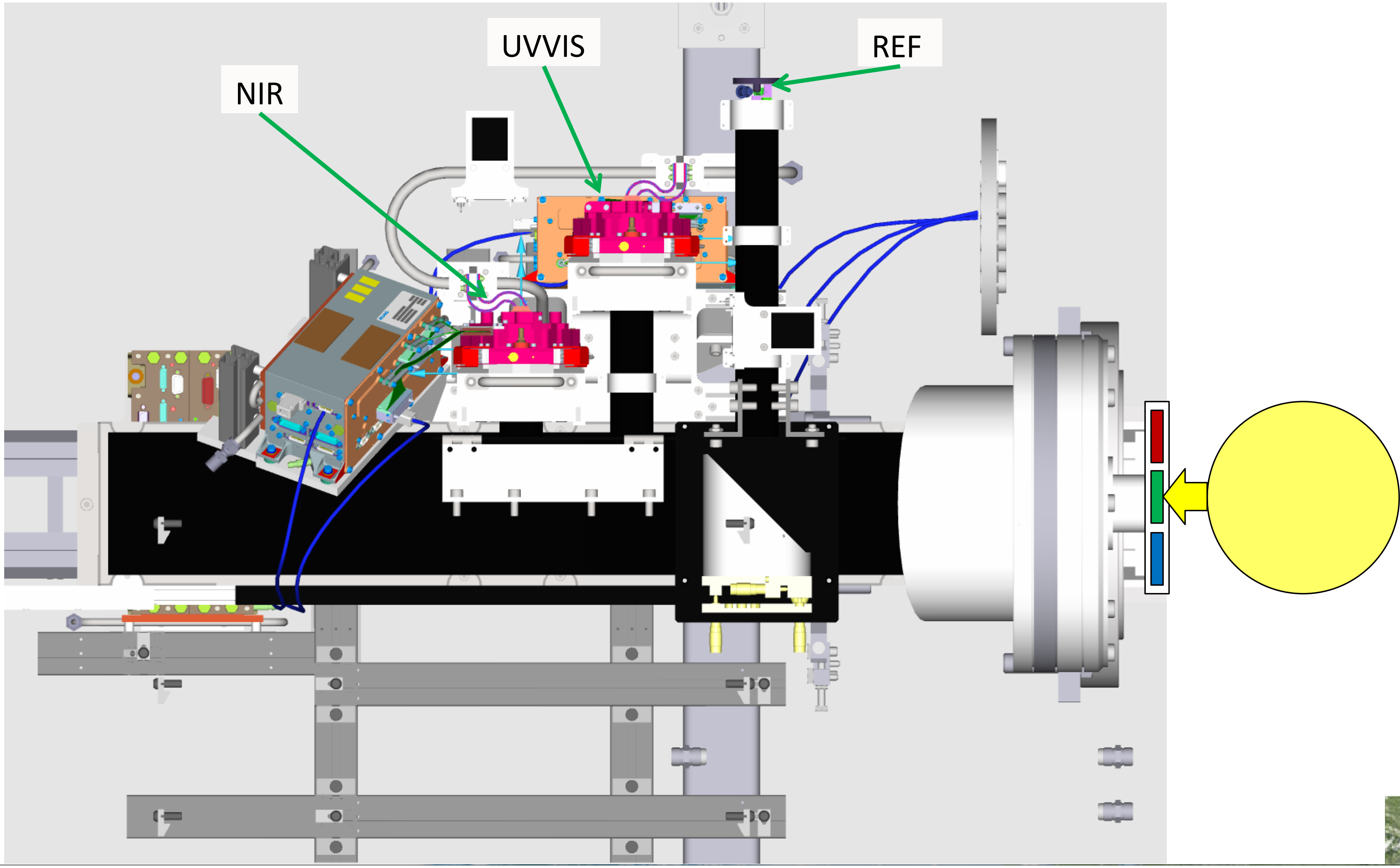


Verification

The following physical quantities must be measured:

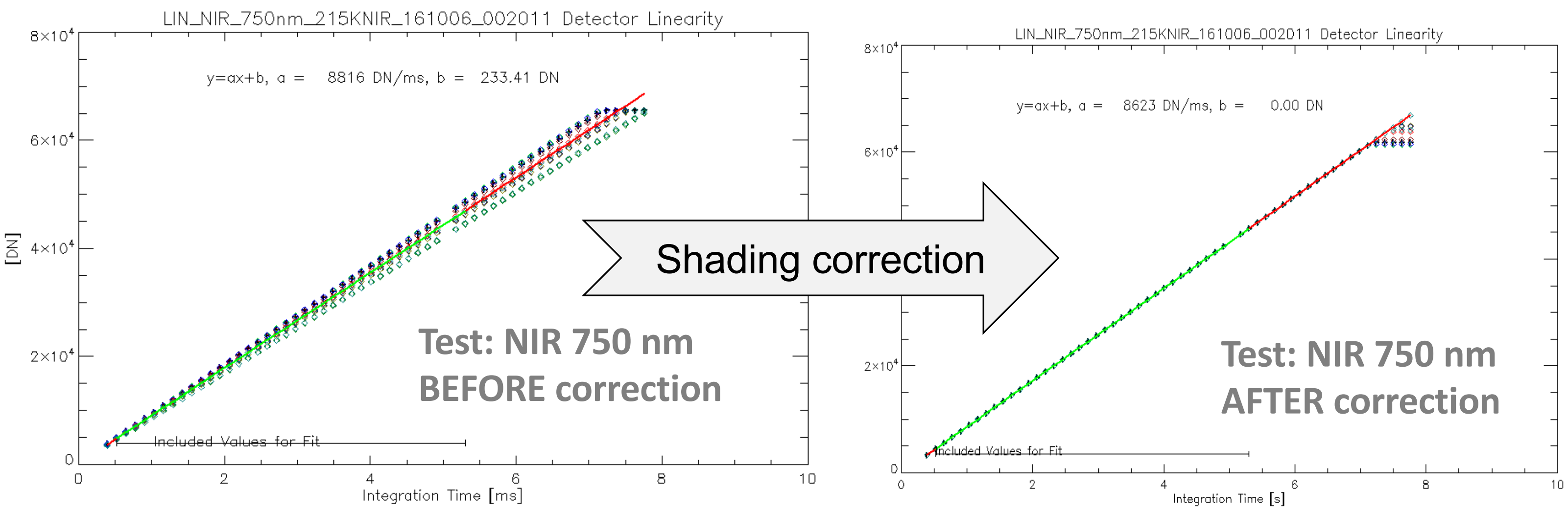
- Dark signal (DS) and DS non-uniformity
- Linearity, pixel related response (PRNU), non-linearity
- System gain
- Memory Effect / Remanence
- Cross –Talk
- Stability over 24 h
- Random Telegraph Signal (RTS)
- FPA LED Calibration
- Quantum Efficiency
- Defects (bad- and dead pixel)

Verification (SENTINEL-4), Experimental Setup



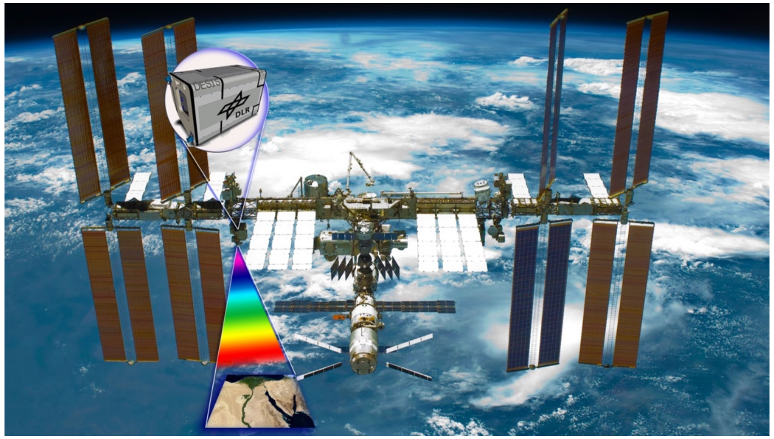
Verification (SENTINEL-4), Lineariy Measurement

- Linearity evaluation performed by integration time variation (ca. 100 steps) and fixed irradiance
- Shading from illumination have to be corrected
- Full well capacity (FWC) = 65,536 DN
- Signal derivation < 80 DN ≙ 0.0013 %

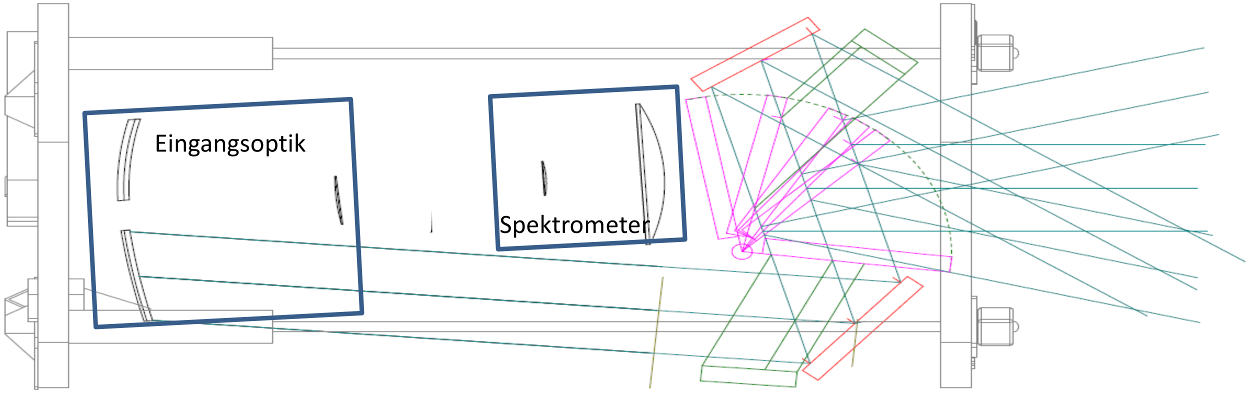


Example: **D**LR **E**arth **S**ensing **I**maging **S**pectrometer For the ISS-MUSES platform

- MUSES: **M**ultiple **U**ser **S**ystem for **E**arth **S**ensing
- Commercial imaging platform for International Space Station (ISS)
- Cooperation with Teledyne Brown Engineering
- Four instruments accommodation, robotically serviceable
- Instruments can be swapped
- MUSES platform was installed Mid 2017



DESIS Concept



GSD:	30 m (400 km)
Spectral Range:	400 – 1000 nm
Spectral Resolution:	2.55 nm
Nr. Channel:	235
Pixel:	1024
BRDF Angle:	+/- 40°
MTF[NY]:	>10%(System)
SNR*:	>150

(*: September 15, 11:00, 30° Sun)

Research Goals of DLR

Fluorescence:

e.g. Chlorophyll Fluorescence Effects on Vegetation (680–690-nm)

Night applications:

Spectral distribution (diffuse) night sky **brightness in cities**
Cloud characterization over cities at night
Spectral characterization of cloud to cloud **lightning**

Combination DESIS with high resolution VIS:

What impact has the BRDF function
Influence of the **surface BRDF** used for atmosphere correction and better understanding of the atmospheric **volume scattering**

Conclusion

- There are now a large number of hyperspectral cameras for airborne and space applications in the development and in part available
- Airborne cameras are now available with standard principles but also as a low cost application (line scan with filter camera)
- Space cameras are based on traditional principles (e.g. grating & Offner design), but we expect low cost cameras in the near future
- Initial investigations show that hyperspectral systems based on standard principles are much better than filter cameras
- The verification of the detector and the overall system is very complex and has to be handled adequately for hyperspectral systems
- It is necessary to clarify the conditions under which they can be used for different application