High Altitude Java

The software behind an ESA-sponsored airborne imaging spectrometer

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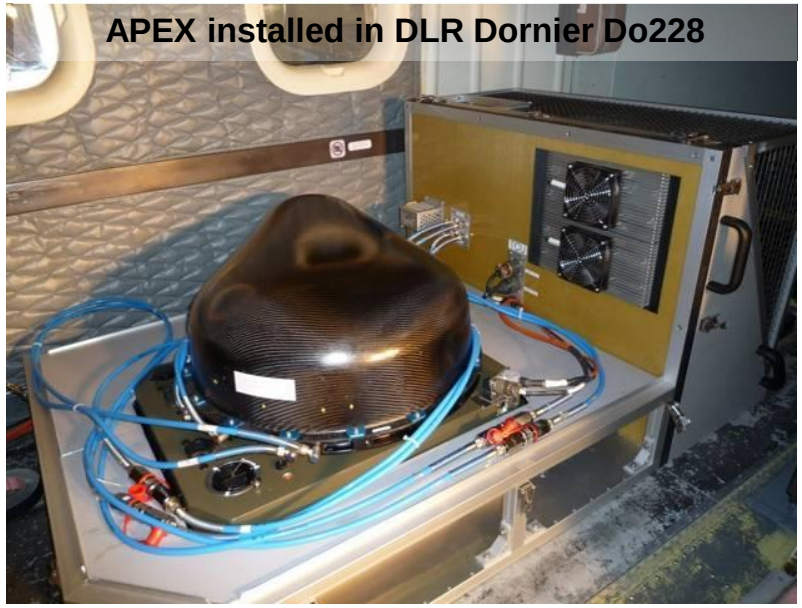
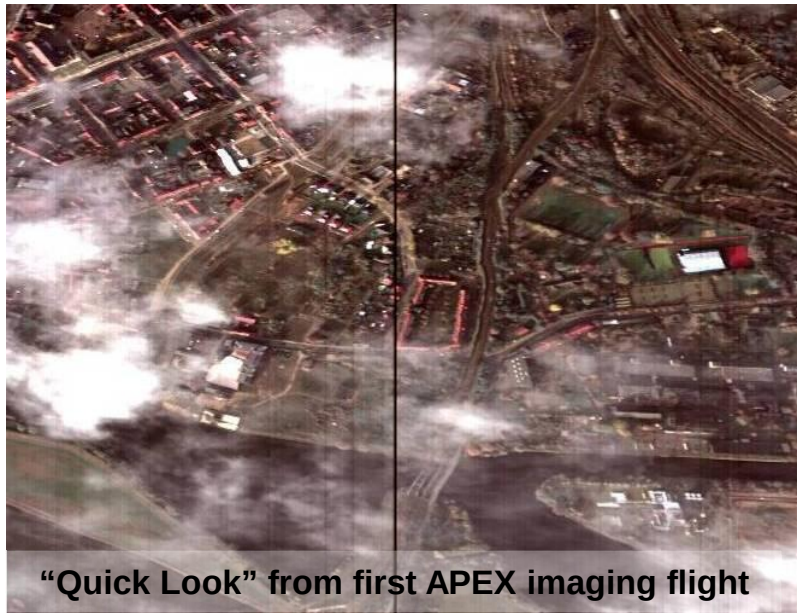
Airborne Prism EXperiment

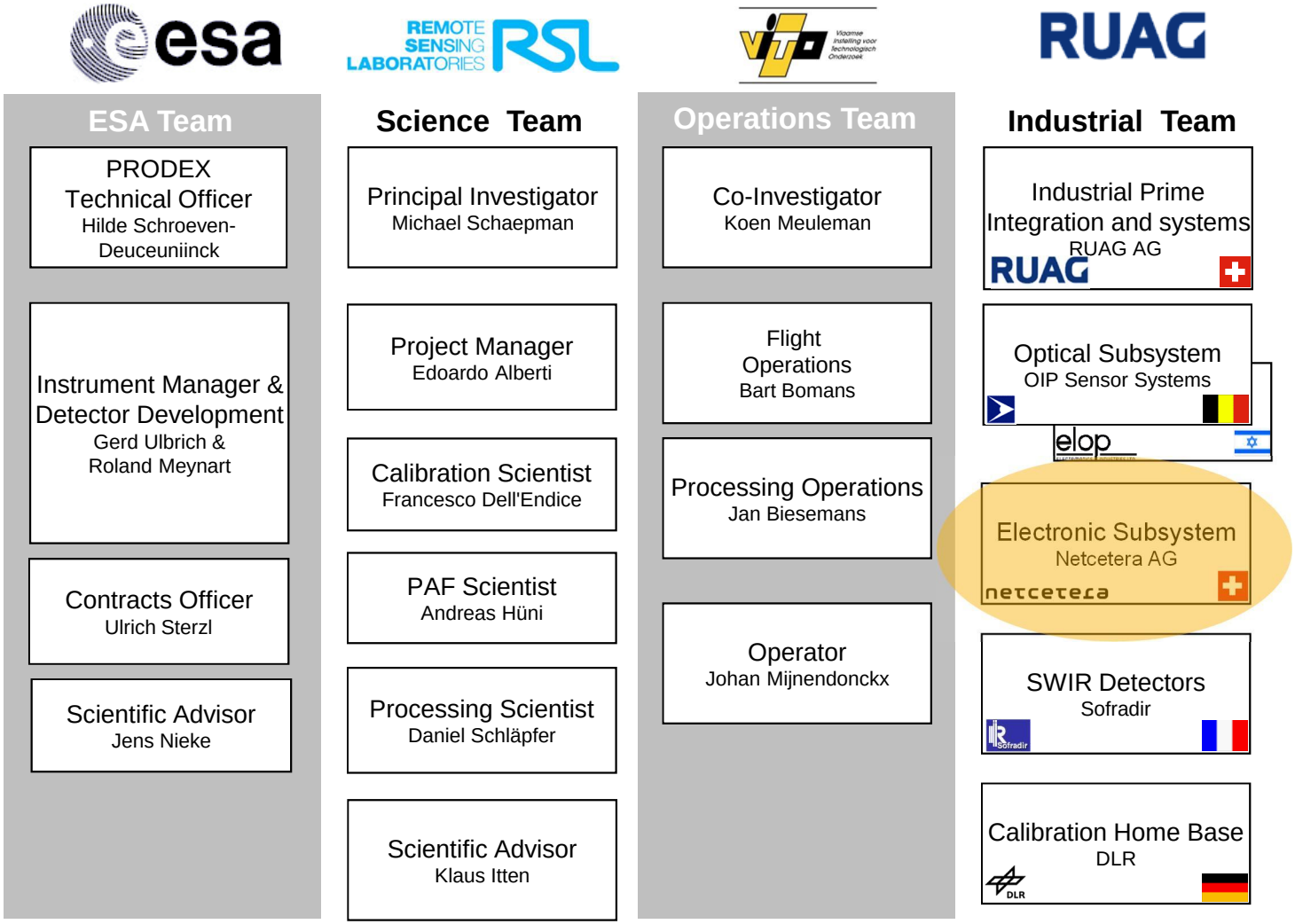

APEX installed in DLR Dornier Do228

- **The Mission**
  - Airborne earth-observing “camera”
    (pushbroom imaging spectrometer)
    ~500 bands instead of 3 (red, green, blue)
- **Selected Software**
  - Data Acquisition/Control/Monitoring
    Flight plan triggered camera control
    Imagery/Positional/Calibration/Environmental data
    Near real-time “waterfall image” monitoring
  - Offline processing
    Instrument calibration support (Seasonal)
    Radiometric/spatial correction (Per campaign)
    Parametric ortho-rectification (Per campaign)
    Atmospheric correction (Per campaign)


“Quick Look” from first APEX imaging flight

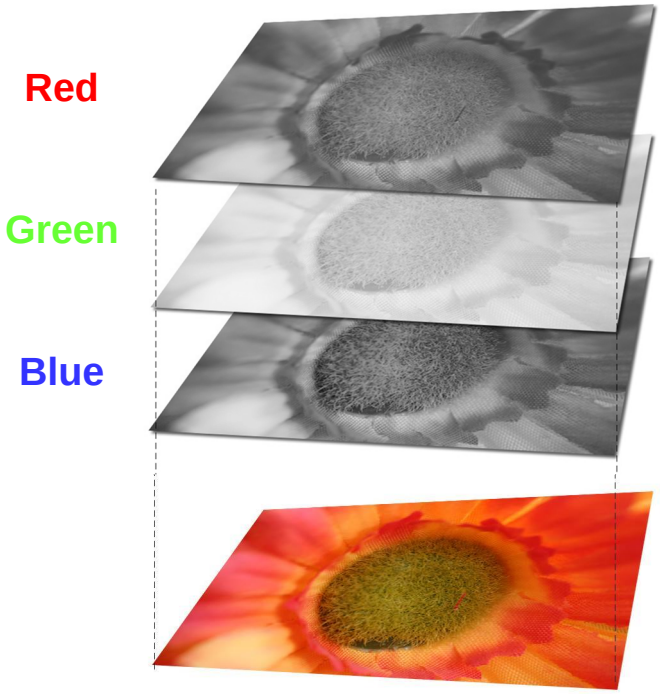
The Mission

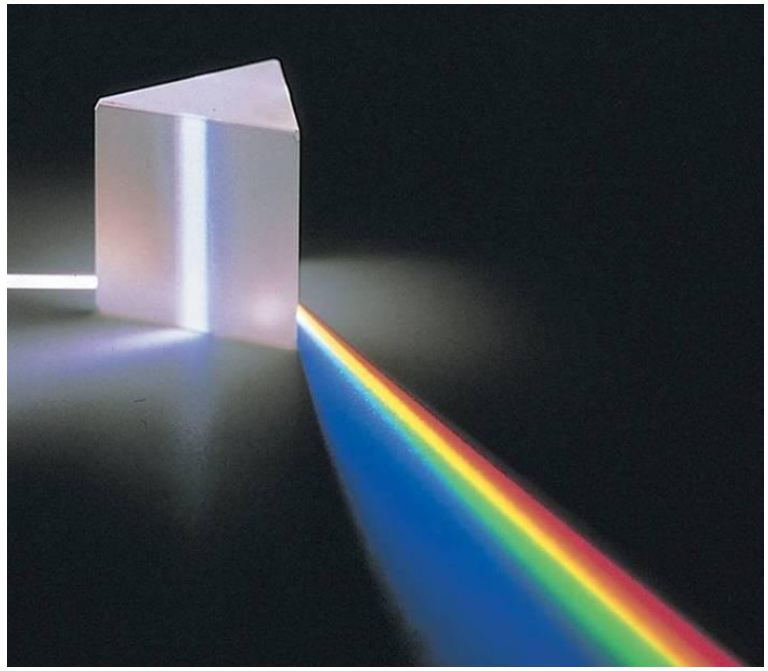
Who: the APEX team



What: imaging spectroscopy

simultaneous acquisition of spatially ***coregistered images***, in ***many narrow, spectrally contiguous bands***, measured in ***calibrated radiance units***





Digital Camera: 3 bands (red,green,blue)

Imaging spectrometer: 100s bands

What: visualizing “non-visible” wavelengths…

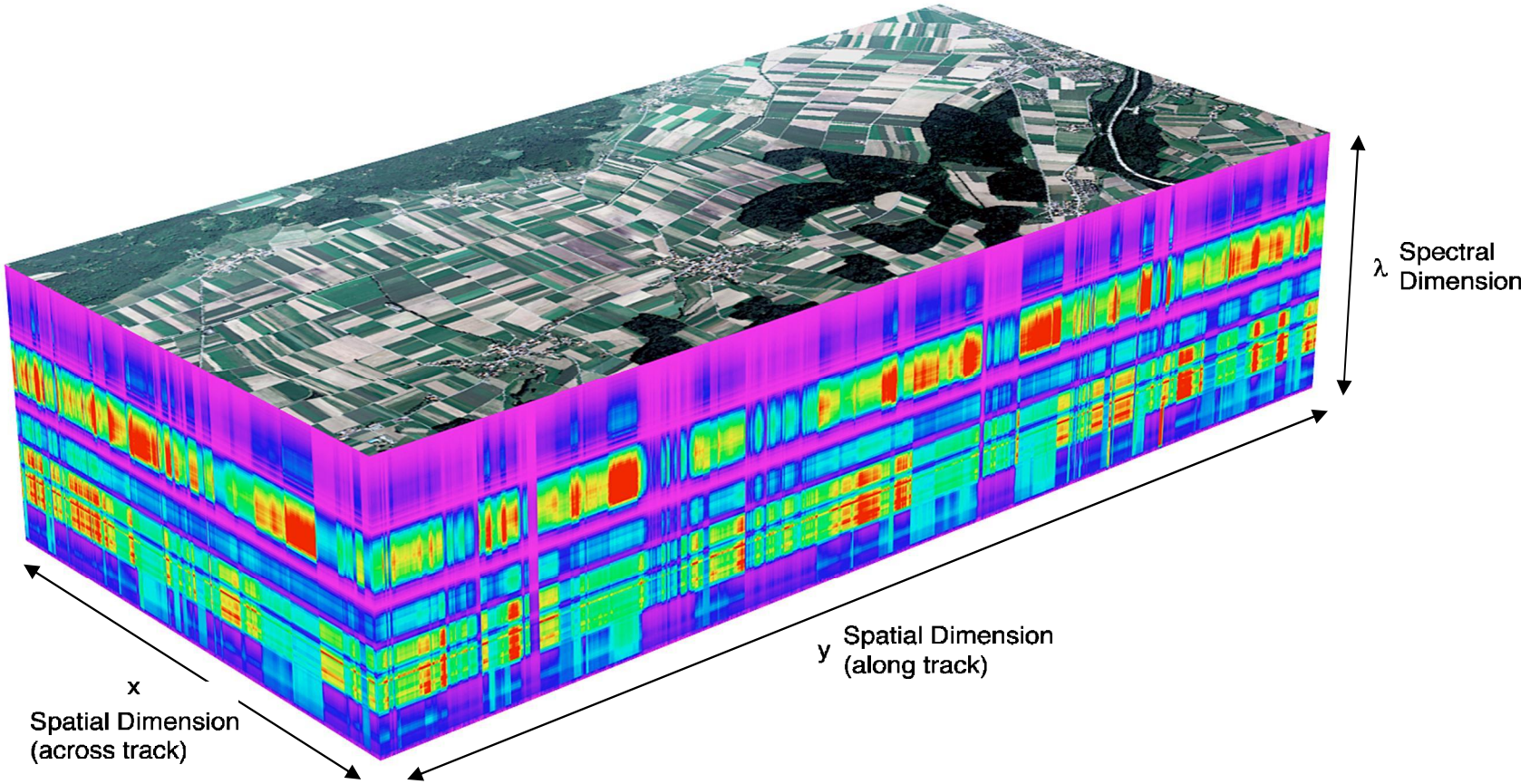



ultraviolet — visible (blue, green, red) — infrared



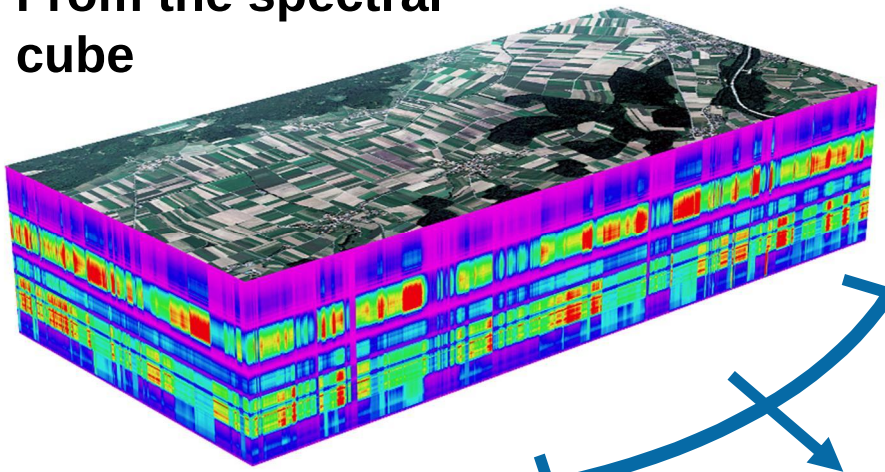

Photos: Austin Richards, *Alien Vision,* ISBN: 0819441422

What: “data cube” w/100’s of bands

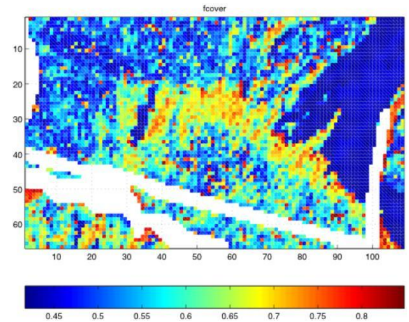


Why: imaging spectroscopy applications

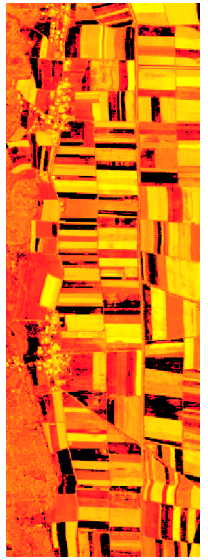
From the spectral cube



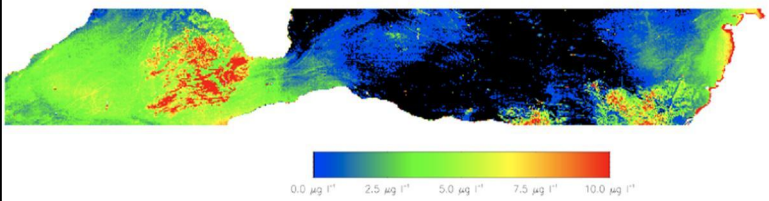
Forest Fire Modeling



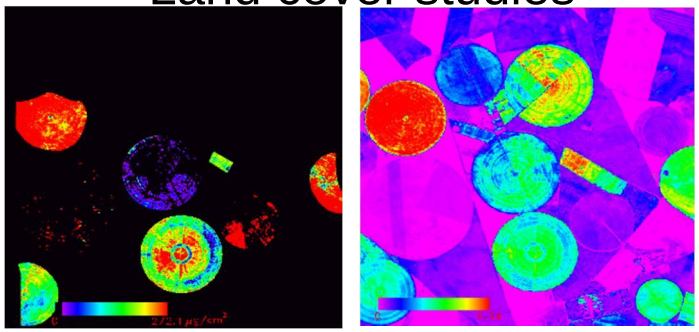
Precision Farming



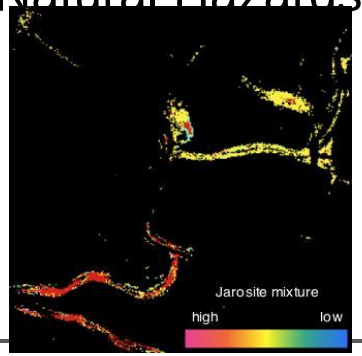
Water Quality



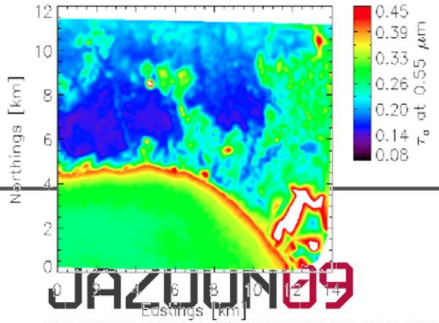
Land cover studies



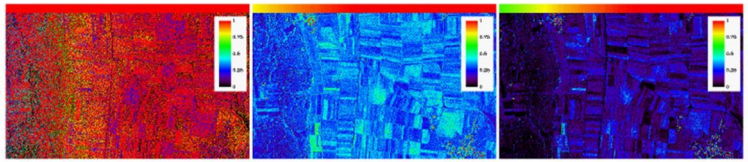
Natural Hazards



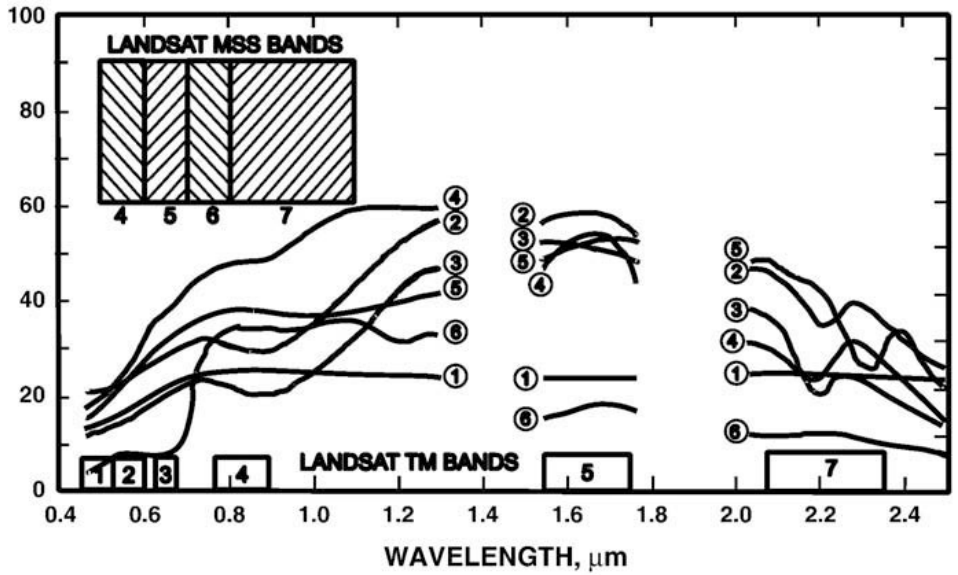
Air Pollution



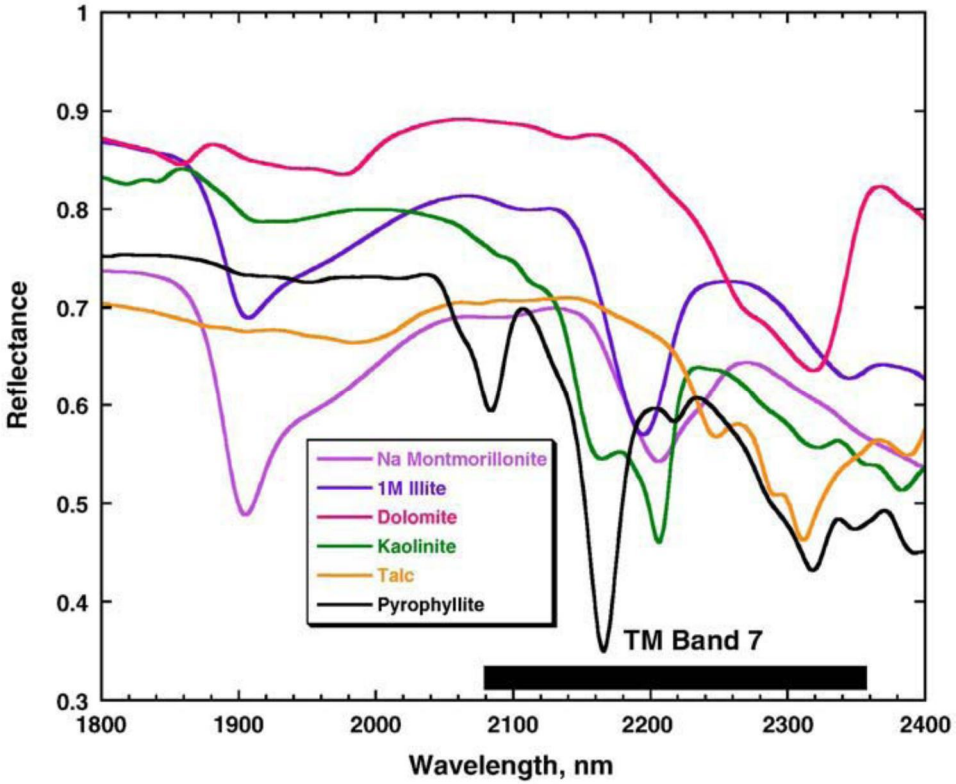
Security relevant analysis



Why: 100s of bands? Isn't ~10 enough?



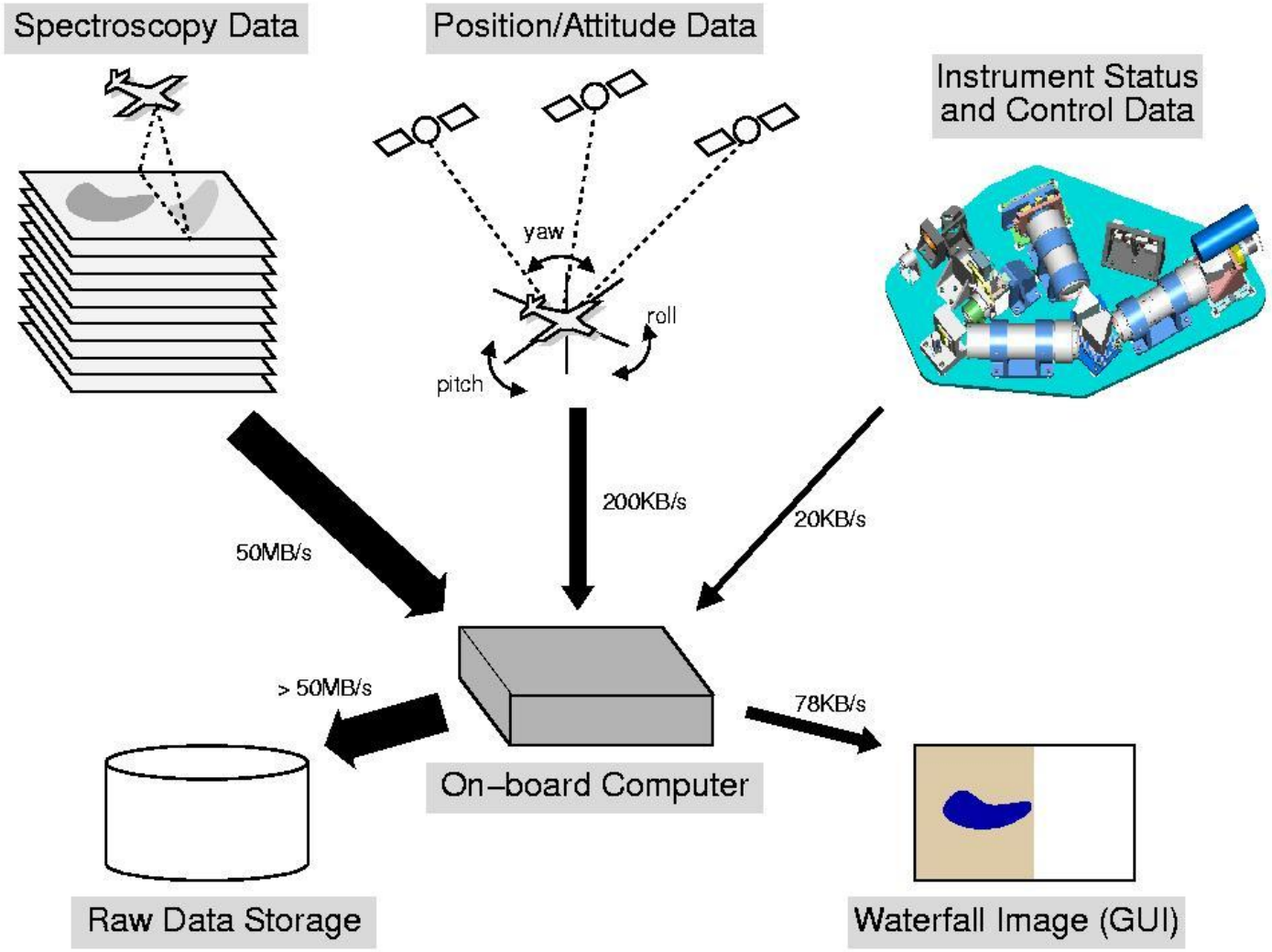
1) basalt; 2) hematite coating and montmorillonite;3) hematite coating and alunite; 4) kaolinite; 5) dolomite; 6) vegetation. (Courtesy of NASA/JPL)



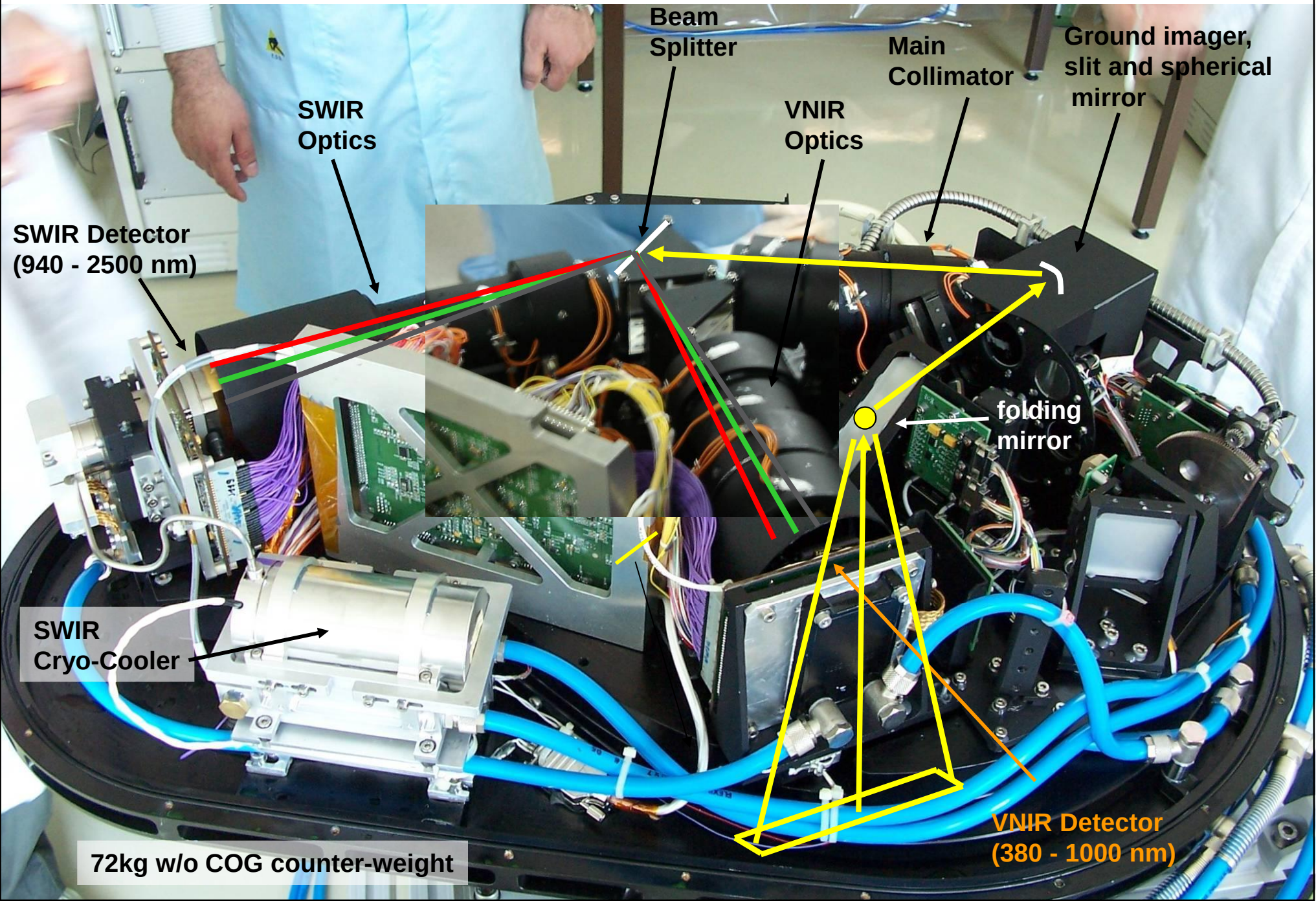
7 bands (Landsat) not detailed enough!

Goetz, A. F. H., Three decades of hyperspectral remote sensing of the Earth, Remote Sensing of Environment (2009), doi:10.1016/j.rse.2007.12.014

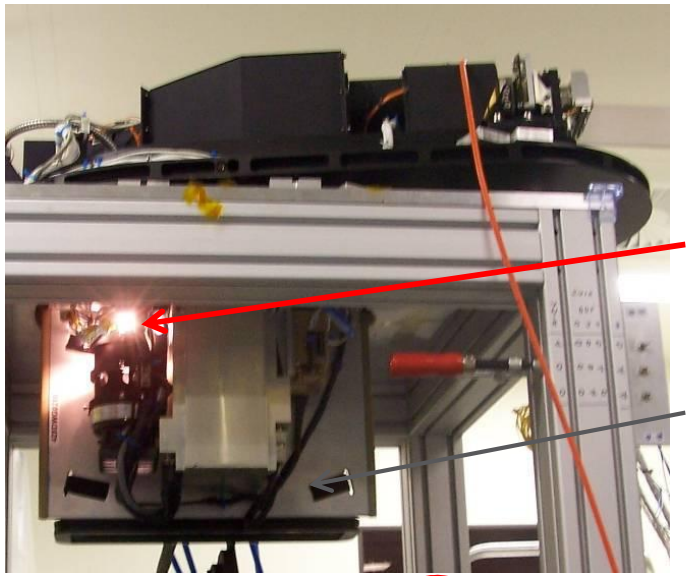
How: airborne data acquisition



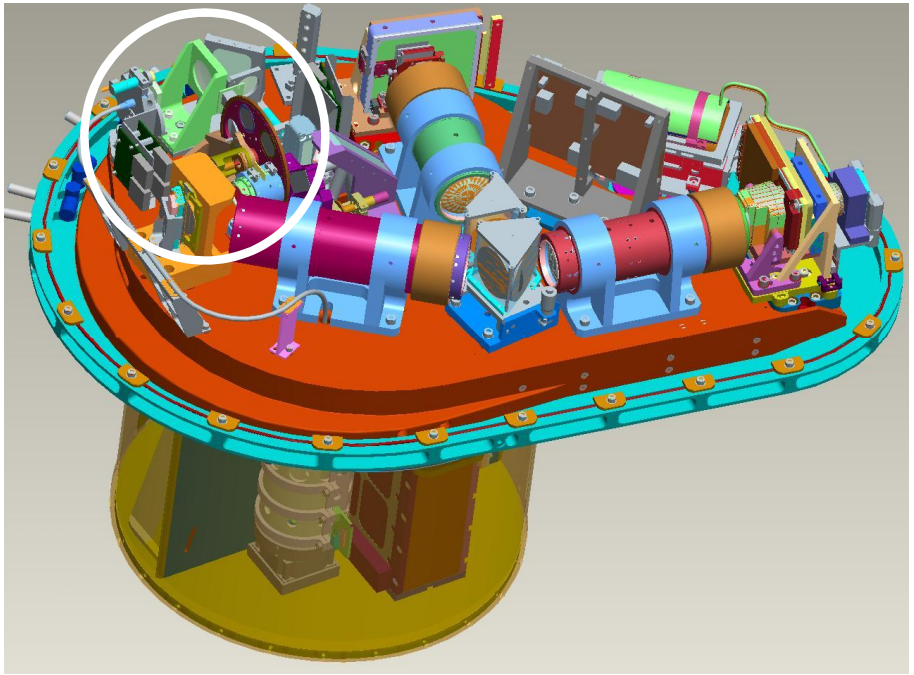
How: the optical sub-unit

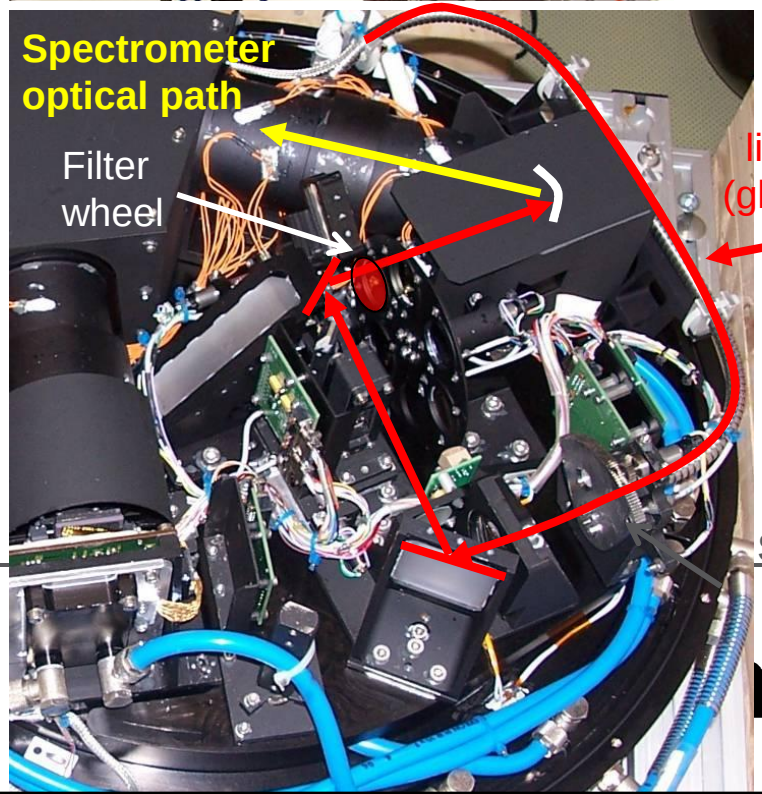


How: the in-flight characterization facility



The **IFC** is a tool designed to **investigate** the overall instrument (radiometric, spectral, geometric) **stability** during the flight





Available Filters on the filter wheel:

- 3 Bandpass (color) Filters
- 1 Rare Earth Material (NIST) filter
- 1 Neutral Density (gray) filter

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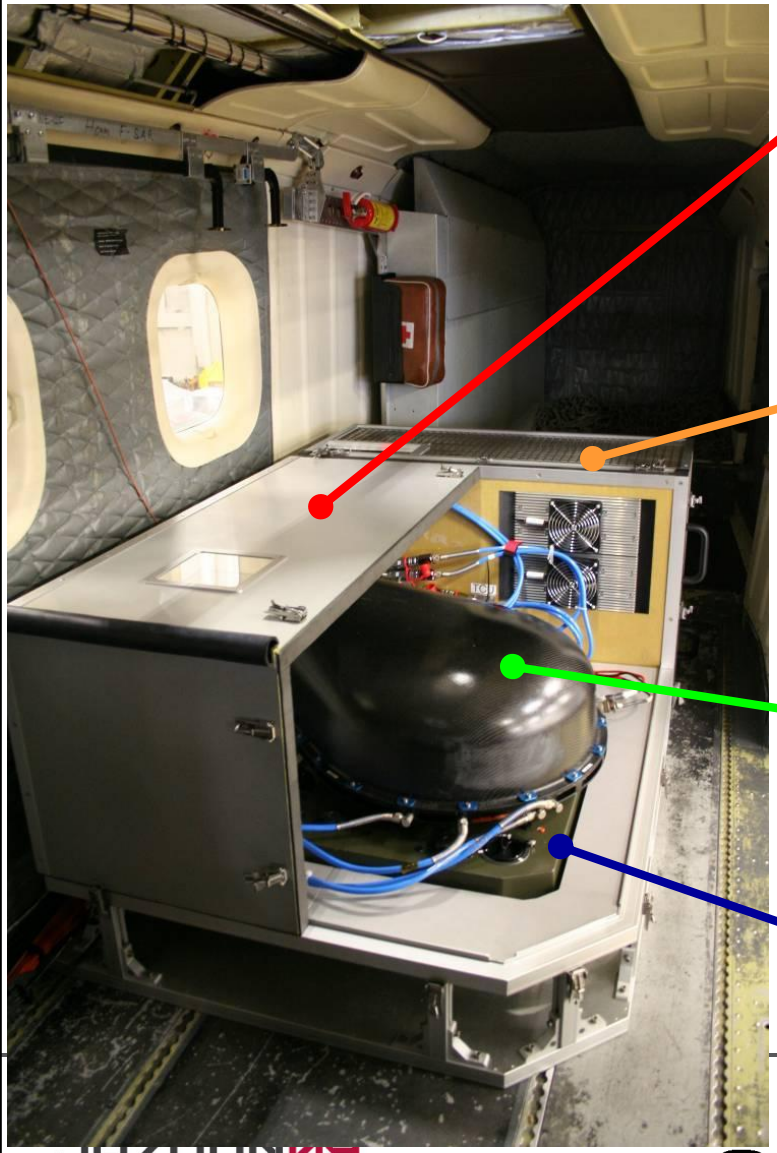
How: instrument deployment (DO-228)

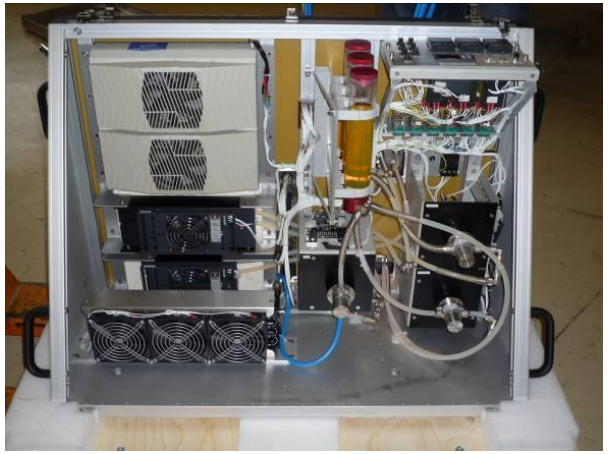


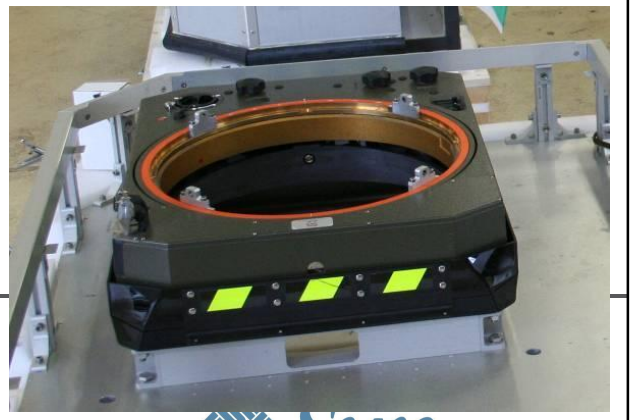
Environmental Thermal Control (ETC) Box

Thermal Control Unit (TCU)

Optical Subsystem Unit (OSU)

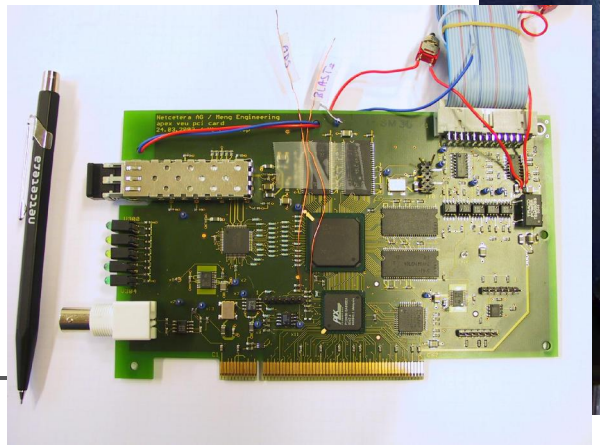
Stabilising Platform (Leica Pav30)





How: electronics deployment (DO-228)

Operator rack workstation for flight operations



On laptop:
- Operator's interface
- Flight Management System (FMS) (Track'Air)

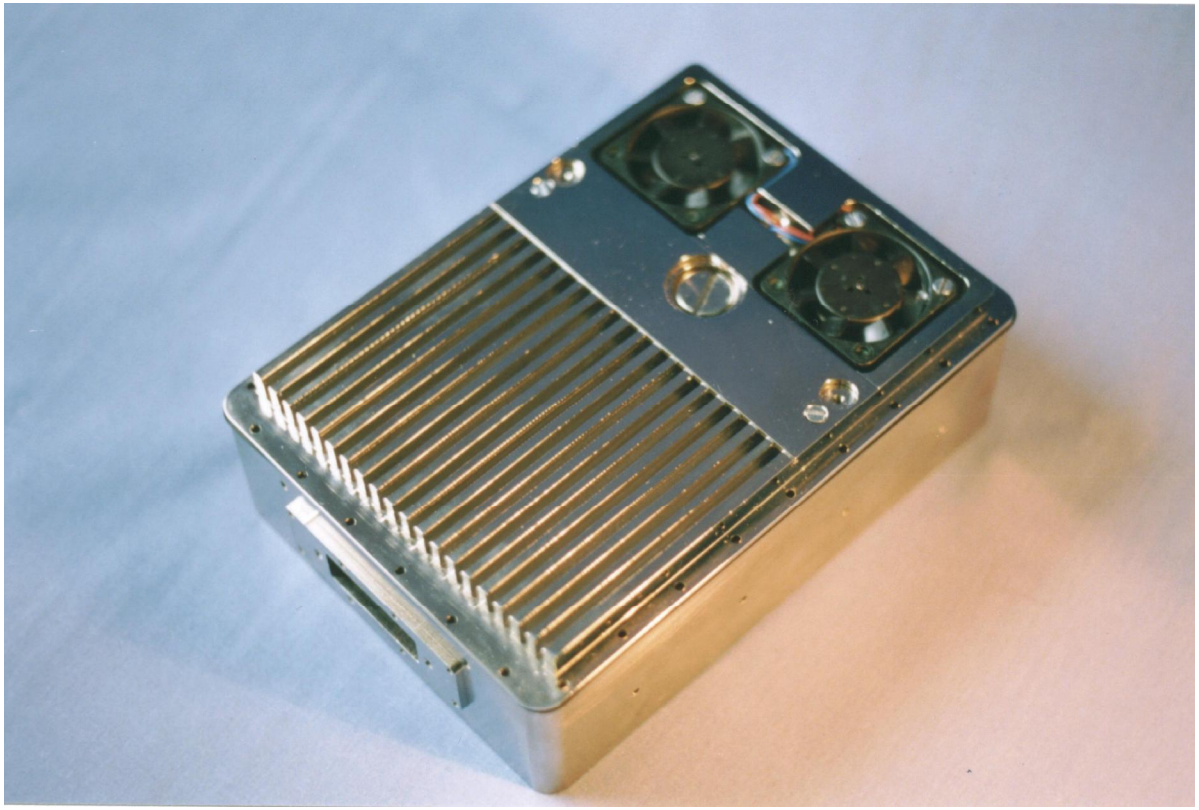
Navigation sub-system (Applanix POS/AV)

Power Distribution

Main control computer (CSU)

Storage Unit (Solid State Disks and tape)

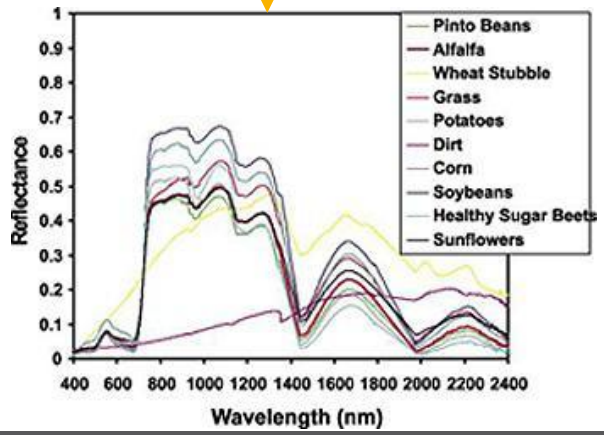
Aside: Originally, array of sealed hard drives

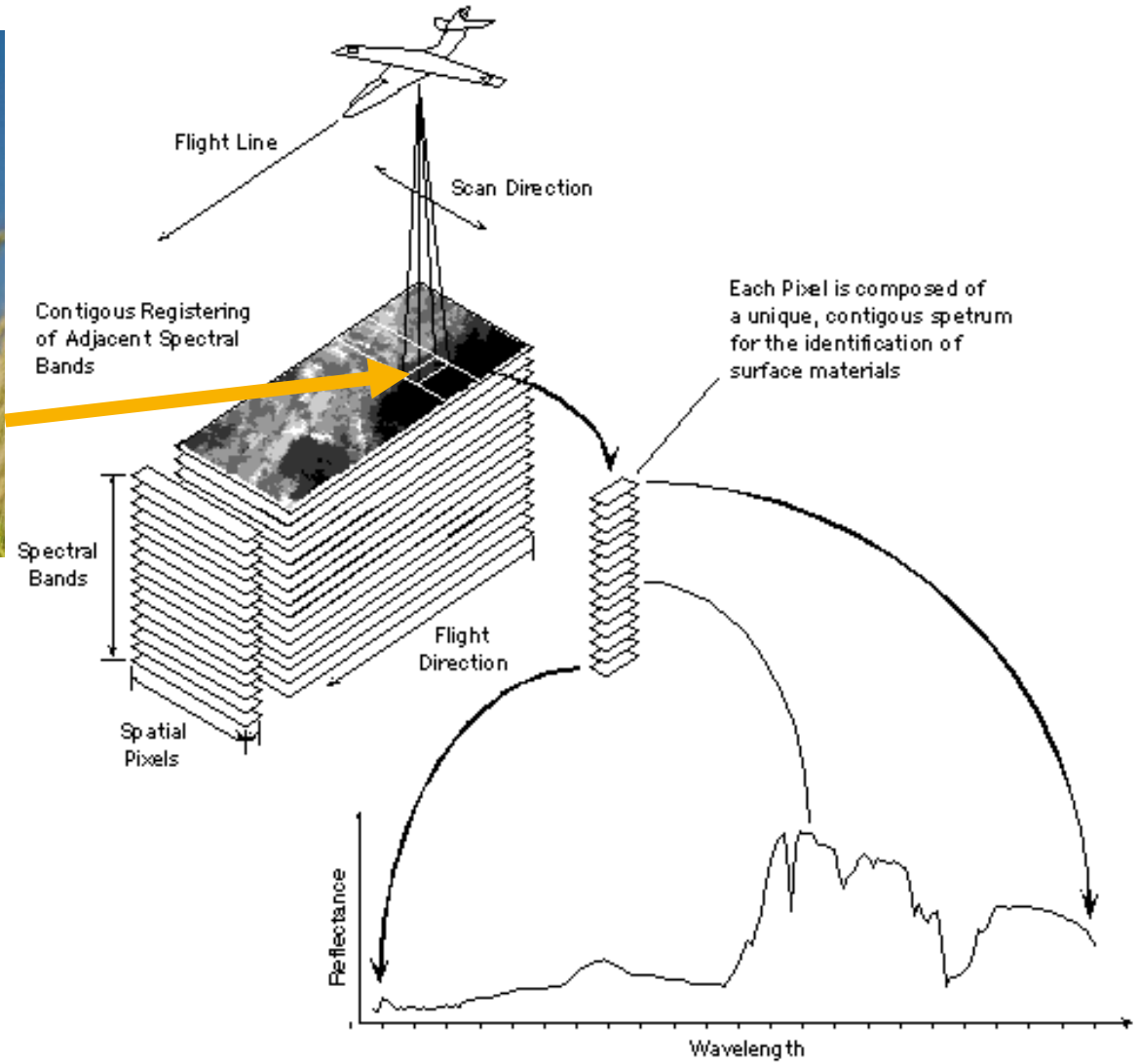


Consumer Hard-drives don't work at high altitude

We've since moved on to SSD tech…

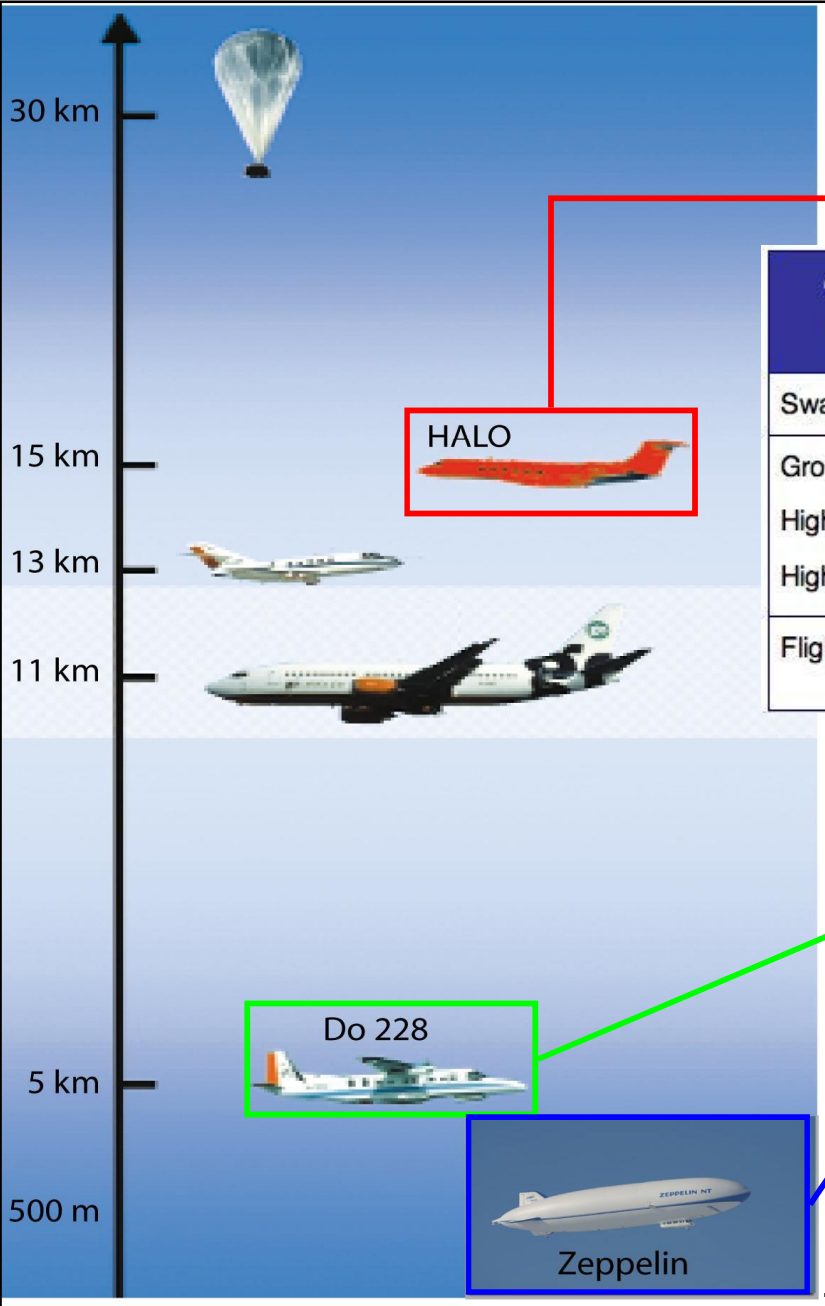
How: remotely + ground-sensed spectroscopy





Remote Sensing Tutorial, Nicholas M. Short, Sr.

How remote?



Observation parameter	Zeppelin (H~ 500 m)	DO-228 (H< 5000 m)	HALO (H~ 14000 m)	Platform independent specification
Swath	0.25 km	< 2.5 km	8 km	FOV = 28 deg
Ground pixel size				IFOV = 0.028 deg
High spatial mode	0.25 m	< 2.5 m	8 m	~ 300 bands
High spectral mode	0.4 m	< 4 m	15 m	~ 500 bands
Flight line length	100 km	< 250 km	700 km	~ 60 min with standard hard disk array

April 2008: DLR Do228 Air Worthiness Certification

October 2008: 1st test flight (DLR Do228)

End 2009: DLR HALO Air Worthiness Certification

[Other platforms under evaluation]

Selected Software

Aside: Real-Time Java (JSR-001, JSR-282)

- Java RTS is Sun's implementation of JSR-001 (Final Release 3 – Jul 2006)
  - Real-Time Threads, Scheduling, and Synchronization
  - Avoiding Garbage Collection via Immortal and/or Scoped memory
  - Asynchronous handling of jvm-external events
  - ATC (one thread can "throw exception" in another)
  - Time and Timers
  - Direct access to physical memory

- Also: JSR-282 "to fill in some minor gaps" (Early Draft Review – May 2009)

"the ability to reliably and predictably respond to a real-world event"

Aside: Real-Time Java (not used in APEX)

> Standard Java

```
while (true) do {
  acquire_data();
  now = System.currentTimeMillis()
  Thread.sleep(next_period – now);
  send_data();
  next_period += period;
}
```

> Real-Time Java

```
setPriority(my_RTPriority);
setReleaseParameters(myPeriodParam);
while (true) do {
  acquire_data();
  RealtimeThread.waitForNextPeriod();
  send_data();
}
```

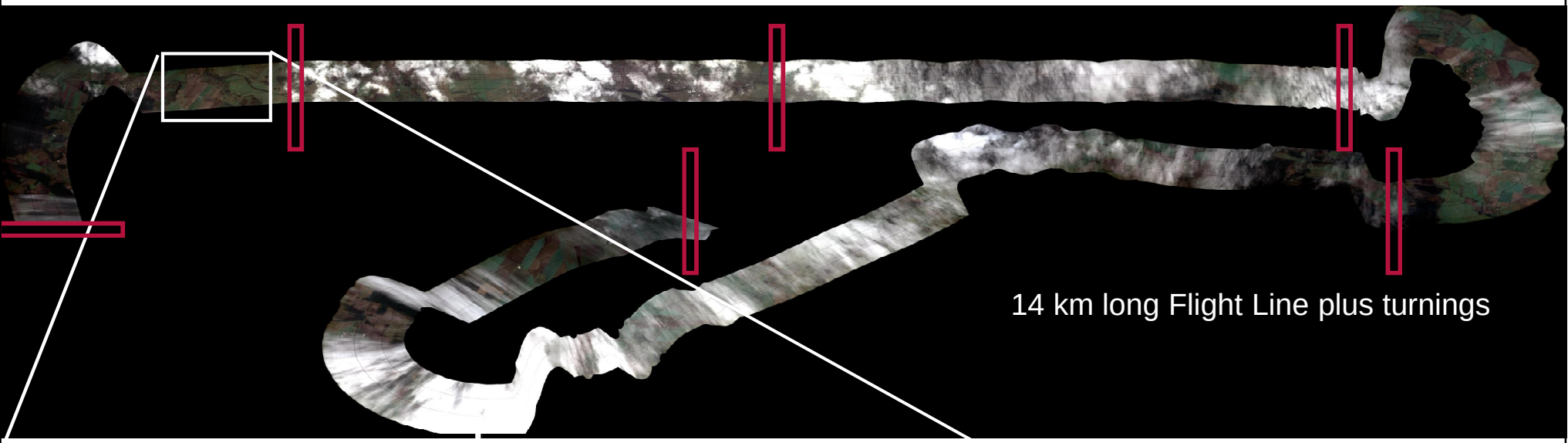
e.g. Real-Time Java's **RealtimeThread** + **RawMemoryAccess** *could* be used to implement APEX's current producer/consumer acquisition logic

Code adapted from Bertrand Delsart, Real-Time Java for Latency Critical Banking Applications

Selected APEX Software

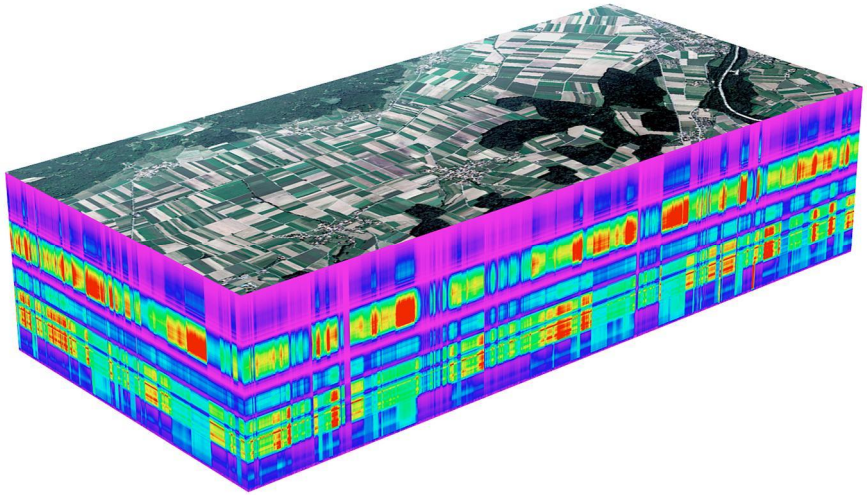
- Data Acquisition/Control/Monitoring (some examples)
  - Flight plan triggered camera control
  - Multi-sensor data (w/temporal synchronization)
    Imagery
    Positional
    Calibration
    Environmental
  - Near real-time “waterfall image” monitoring
- Offline Processing (some examples)
  - Instrument calibration support (Seasonal)
  - Radiometric/spatial correction (Per campaign)
  - Parametric ortho-rectification (Per campaign)
  - Atmospheric correction (Per campaign)

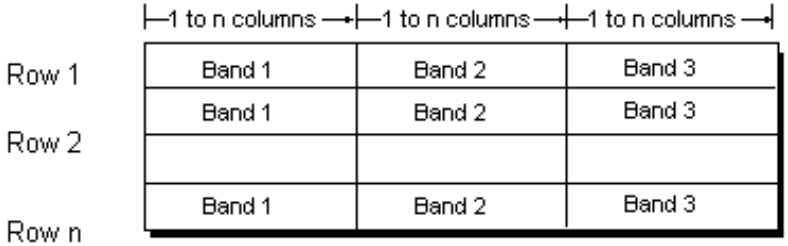
Acq: Flight-plan triggered camera control



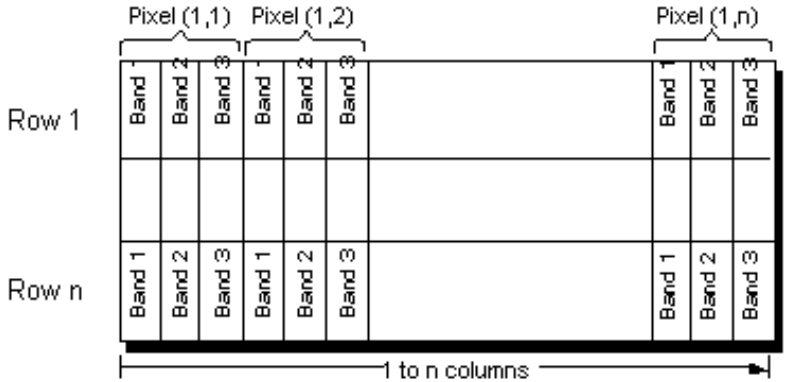
Sun microsystems

Aside: options for 3-D Data Arrangement

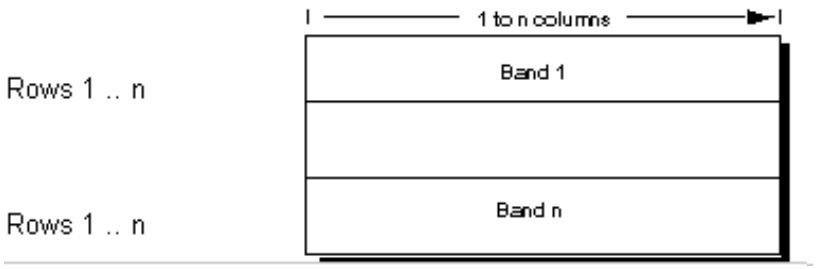




Band interleaved by Line (BIL) - compromise



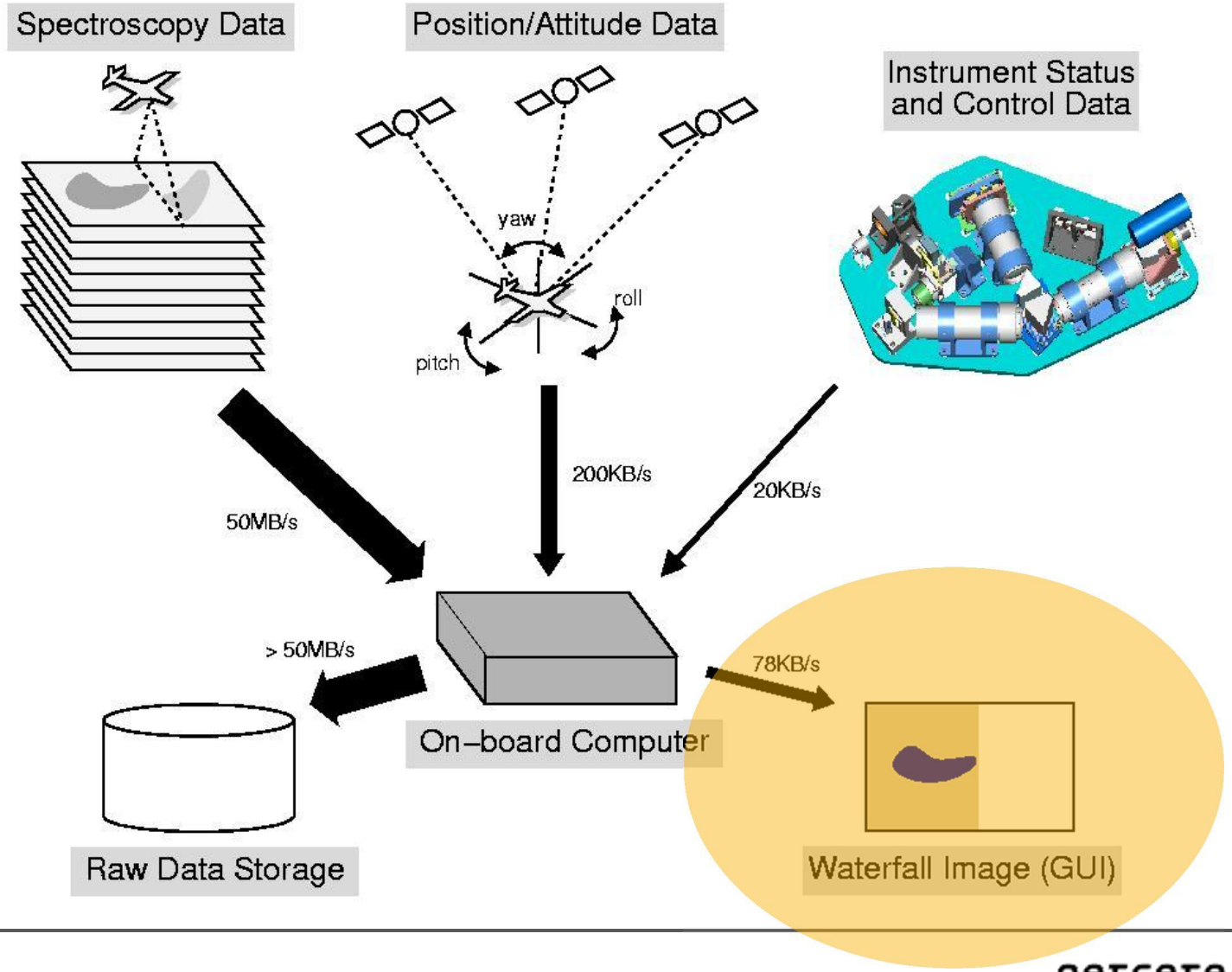
Band interleaved by Pixel (BIP) - spectral



Band Sequential (BSQ) - spatial

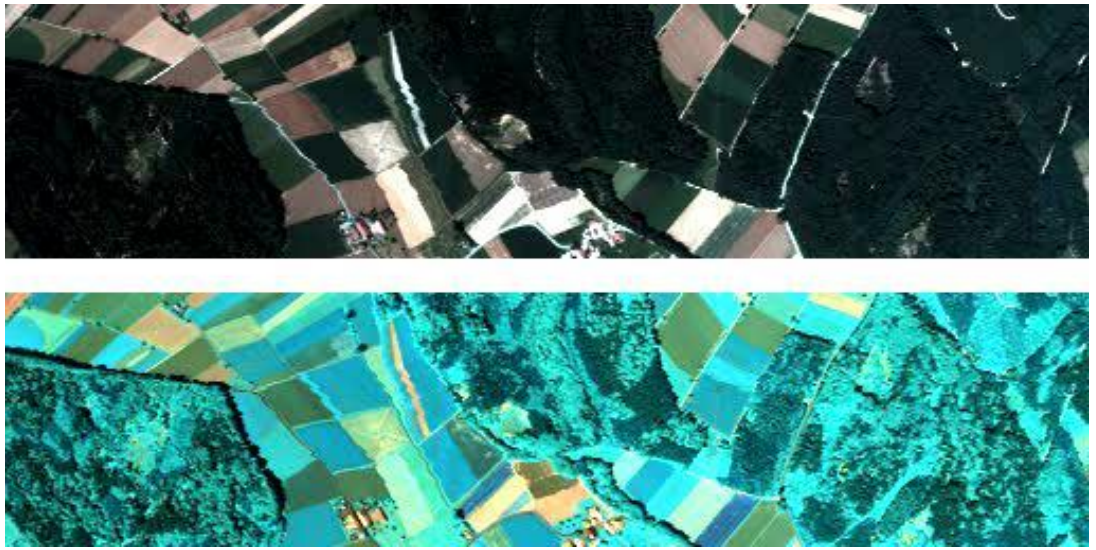
Figures, Phil Hurvitz, U. Washington

Acq: waterfall image viewer



Acq: waterfall image viewer

- **What**?
  - A “false color” line-by-line preview of incoming data…
- **Why**?
  - Verify proper “operation mode” – calibration vs acquisition
  - Verify “frame-rate/integration time settings”…
  - Verify “band settings/groupings” for this application…
  - Verify pilot’s flight path is as expected…



“did we remove the lens cap?”
“do we have the right ‘shutter’ speed?”
“is the subject within the frame?”

Aside: queuing theory issues and near-real time

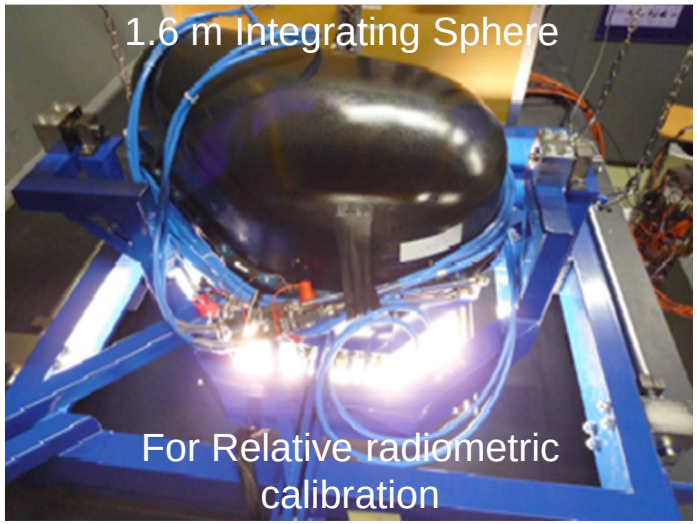
```
DatagramPacket dgram = new DatagramPacket(new byte[msgsize], msgsize);
    while (isrunning && udpsock != null) {
      try {
        udpsock.receive(dgram);
        if (dgram.getLength() == msgsize) {
          dataProcessor.processData(dgram.getData());
        } else {
          LOGGER.error("Bad packet, len = " + (dgram.getData()));
        }
      } catch (java.net.SocketTimeoutException e) {
        LOGGER.info("No lines received for “ + timeoutms + " ms");
        dataProcessor.repaint();
        // expect to sometime receive nothing…
      } catch (java.io.IOException e) {
        LOGGER.error("udp receive error!");
      }
    }
```

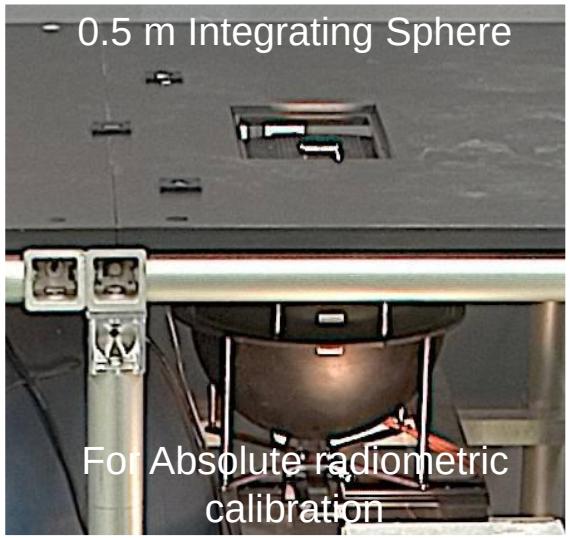
UDP – expect dropped packets and data underflow or overflow.

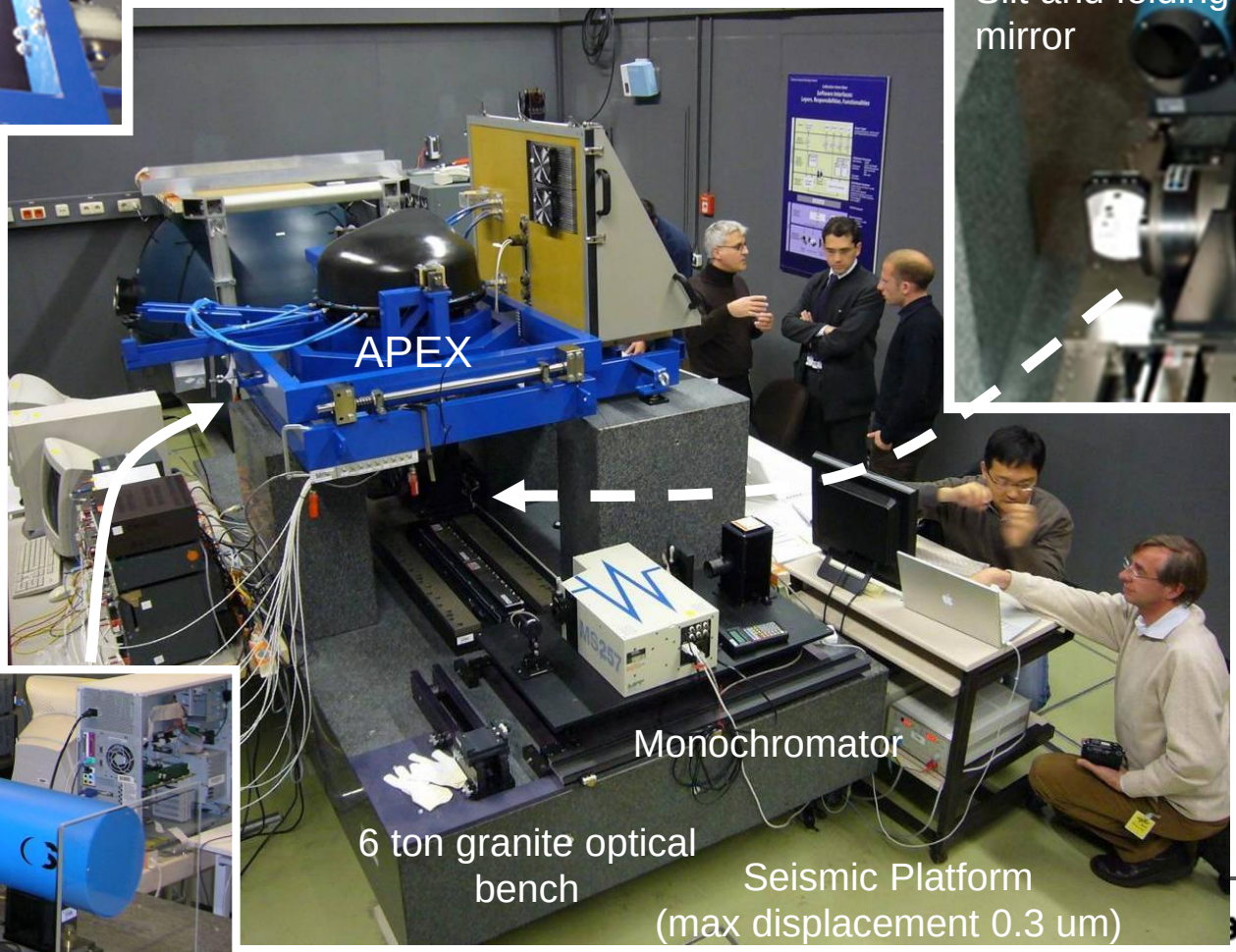
Server logic tries to keep waterfall buffer 20-80% full for handling bursts and variable frame rates.

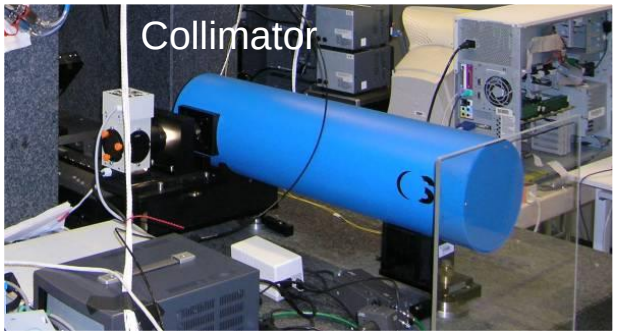
Offline: Seasonal Calibration (CHB@DLR Munich)*

** Under ESA-EOP Contract*
Status: Acceptance review successful Jan 2007



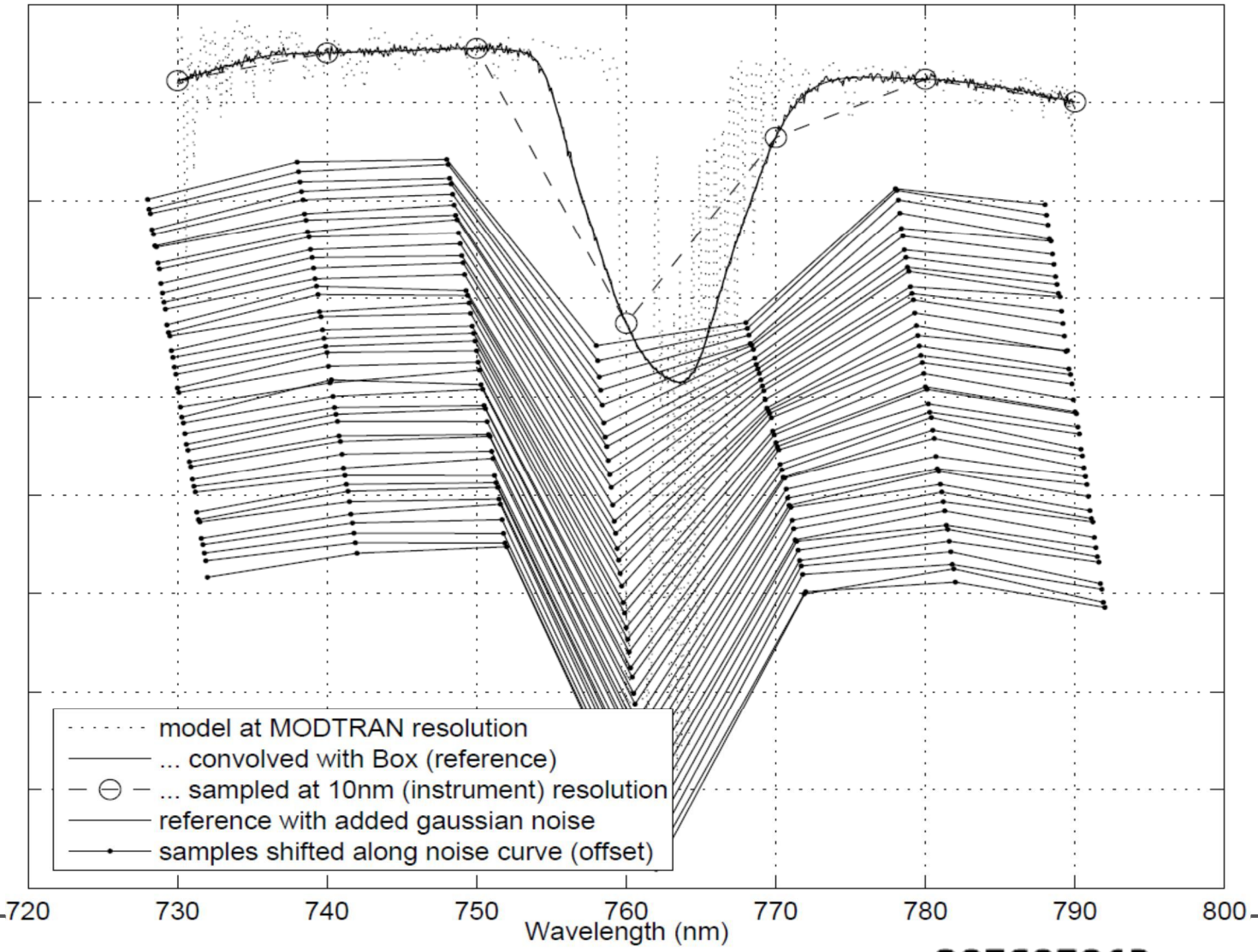






Offline: Image feature-based calibration

Well-known Fraunhofer line “A” (due to atmospheric oxygen) used to calibrate potential instrument band center shifts

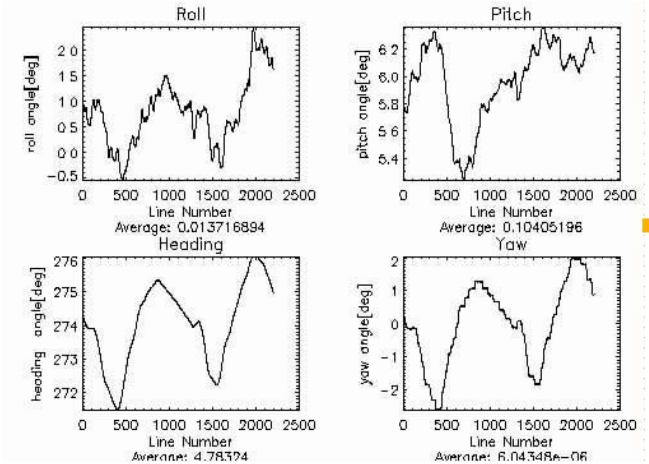


Offline: Radiometric calibration

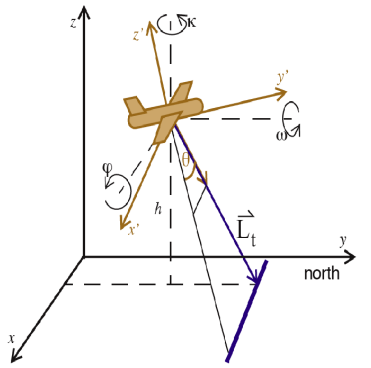
Converting recorded *digital numbers* to physical parameters in *calibrated radiance* units

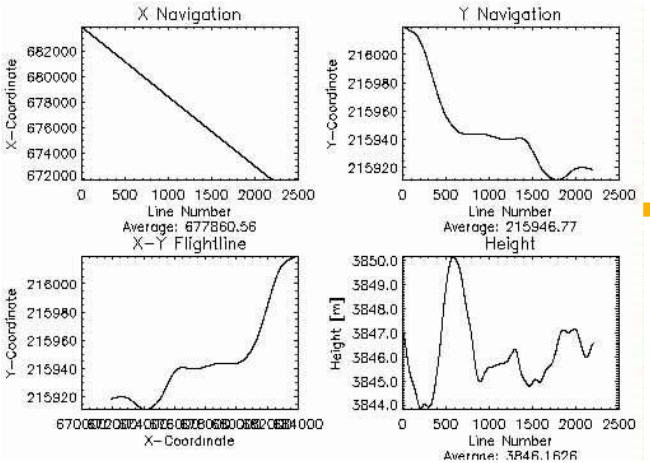
Illustration, CRIM - Centre de recherche informatique de Montréal

Offline: Orthorectification

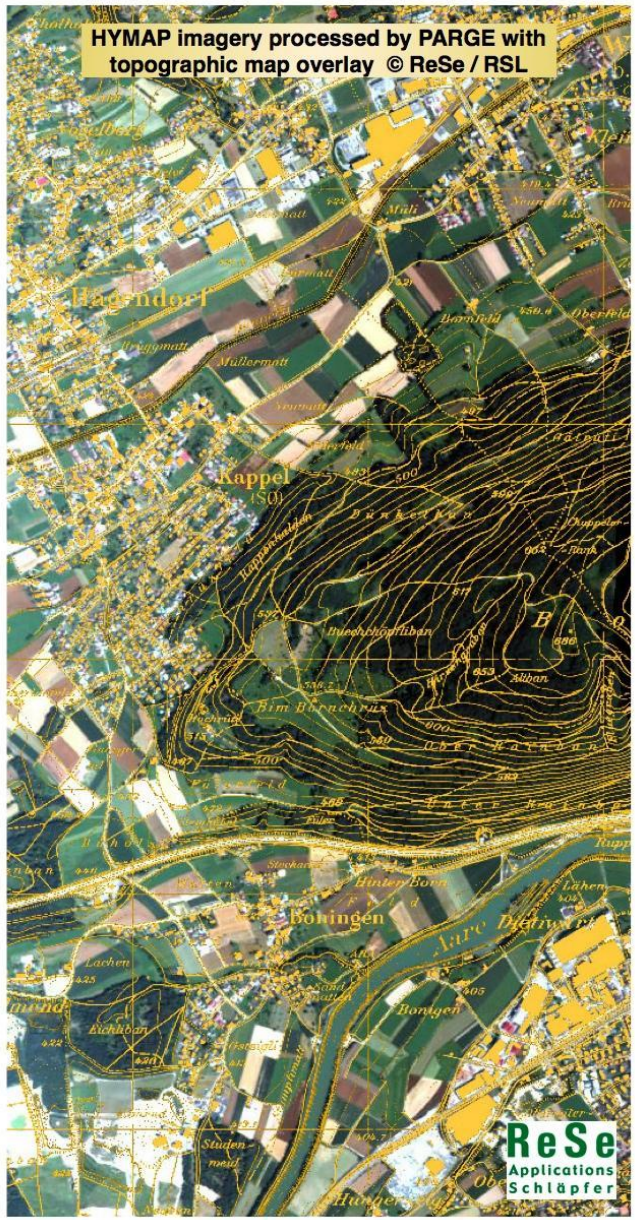


attitude





GPS

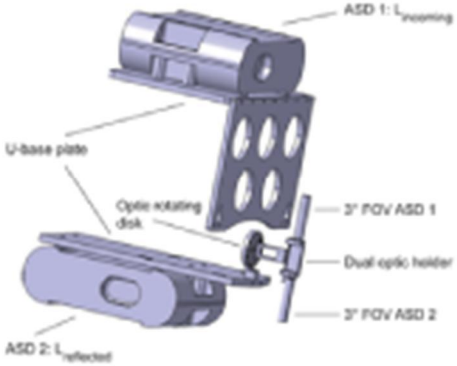


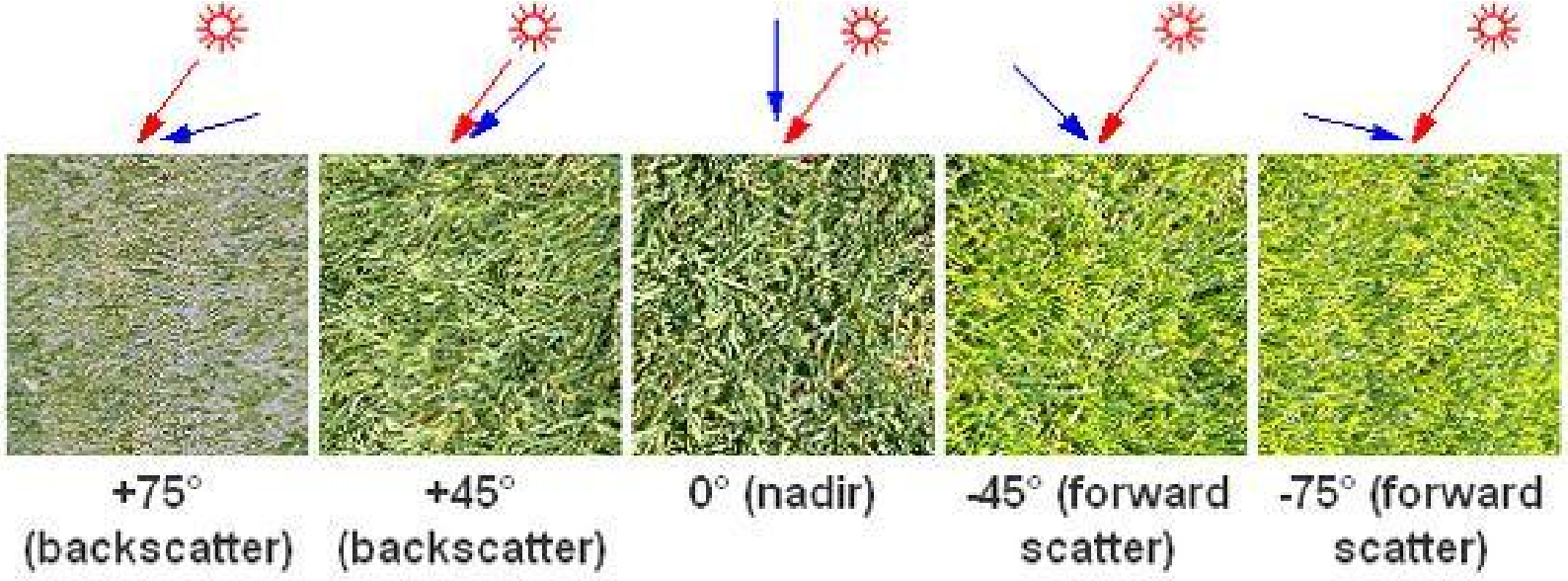
Offline: ATCOR - Atmospheric Correction

Using radiative transfer algorithms based on atmospheric optical properties to derive surface reflectance by inversion

Image: Satellite Imaging Corporation, satimagingcorp.com

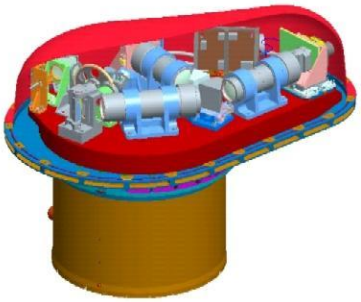
Offline: BRDF Correction





BRDF effects can be seen as stripes in freshly mowed grass

Offline: Product Generation



Instrument Data

APEX
Level 0 - 1C Processor

Level 1C Product

Calibrated, uniform Image Cubes

APEX
Level 2A – 2C Processor

Level 2A-2C Products

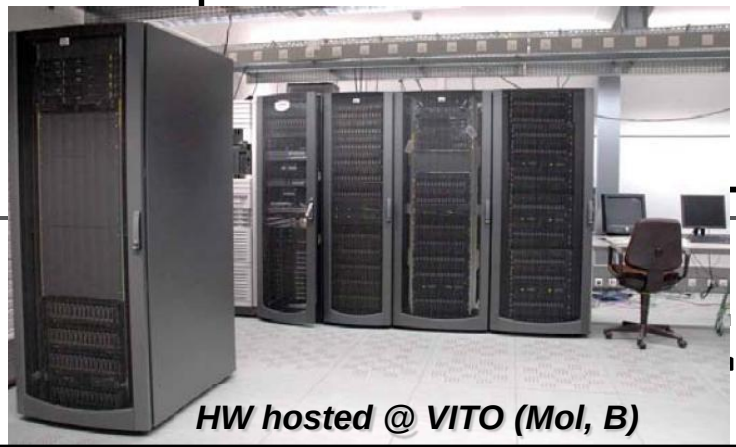
Geographically, Atmospherically and BRDF corrected data

APEX
Level 3A – 3B Processors

Level 3A-3B Products

Quantitative and qualitative Thematic Maps and Variables

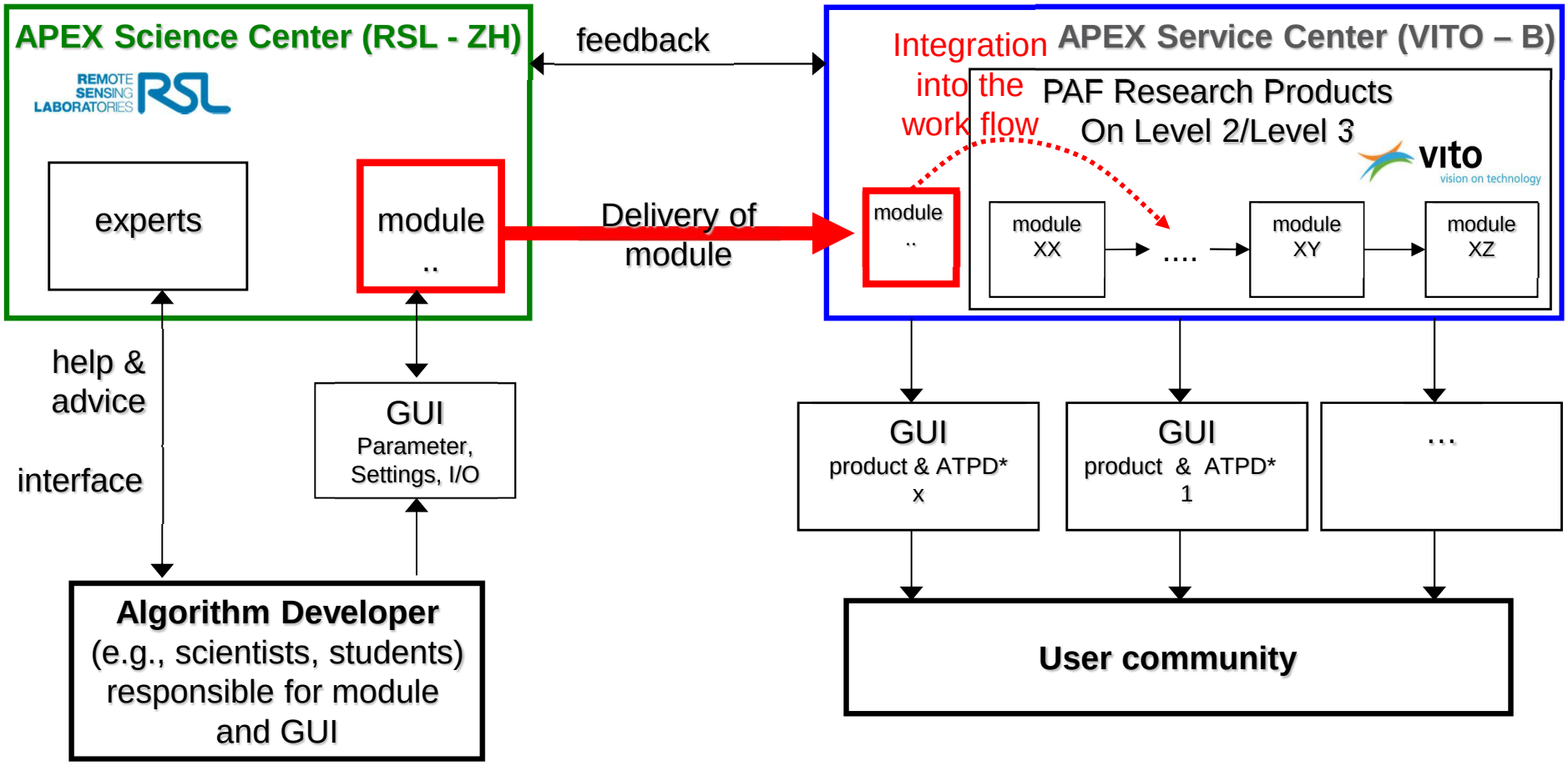
- Vegetation
- Limnology
- Snow
- Gas & Aerosols



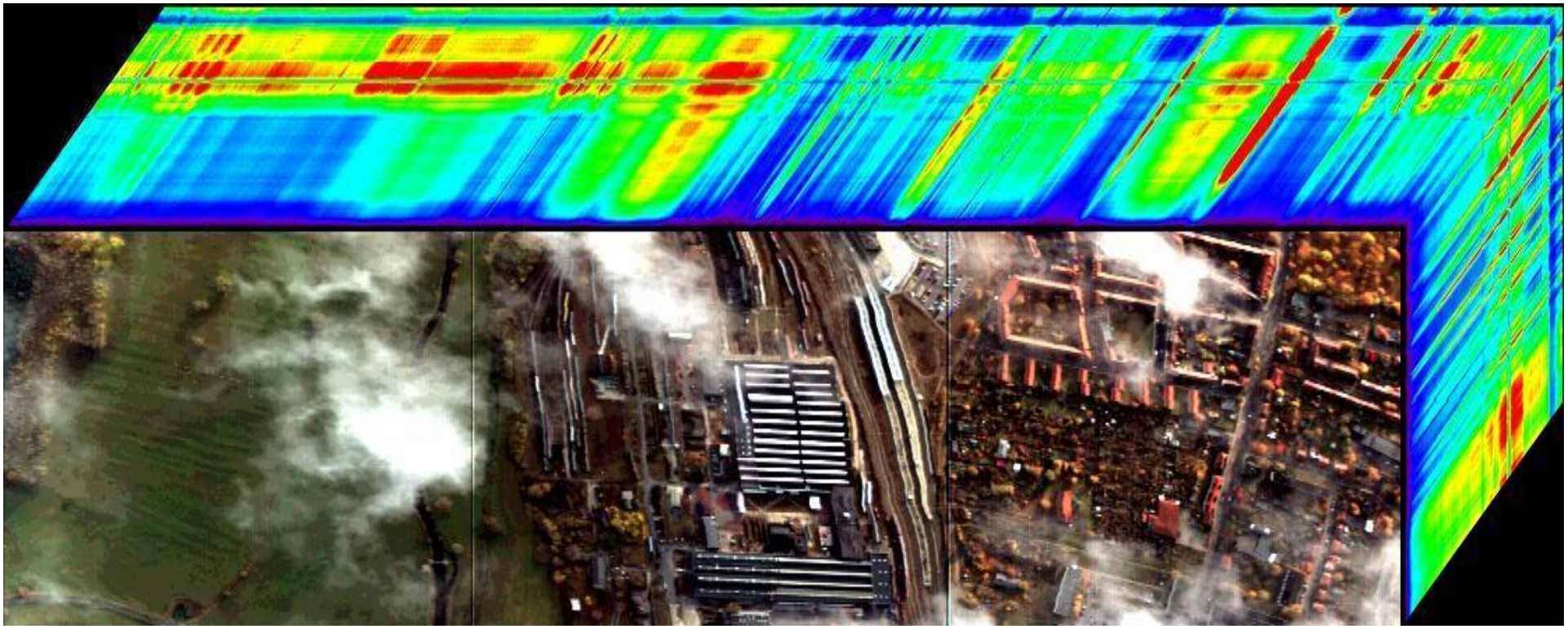
HW hosted @ VITO (Mol, B)

Offline: Do-it-yourself Module/Algorithm dev?

Can integrate customized processing module at any point of the processing chain.



Test Flight over Wittenberge (D), 31/10/2008



1st Radiometrically Calibrated APEX Cube

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Mission Status/Timeline