HDCRS

IEEE GRSS HDCRS Working Group
High Performance and Disruptive Computing in Remote Sensing
Summer school

Hyperspectral technology: inspiring ideas, challenges and opportunities

José López-Feliciano/Roberto Sarmiento

Institute for Applied Microelectronics (IUMA)

Hyperspectral technology: inspiring ideas, challenges and opportunities

Part I: Introduction

José López-Feliciano/Roberto Sarmiento
Institute for Applied Microelectronics (IUMA)

Outline

- The institute for Applied Microelectronics at ULPGC
- Why hyperspectral technology?
  - Some numbers
  - Applications
- Introduction to hyperspectral technology
  - The human eye
  - Multi- vs hyperspectral sensors
  - Types of hyperspectral sensors
- Ongoing projects
  - Space
  - Precision agriculture
  - Environment
  - Health

Outline

Part I

- The institute for Applied Microelectronics at ULPGC
- Why hyperspectral technology?
  - Some numbers
  - Applications
- Introduction to hyperspectral technology
  - The human eye
  - Multi- vs hyperspectral sensors
  - Types of hyperspectral sensors

Part II

- Ongoing projects
  - Space

Part III

  - Precision agriculture
  - Environment
  - Health

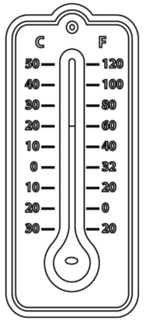
The Institute for Applied Microelectronics at ULPGC


4.079 km

The Institute for Applied Microelectronics at ULPGC

CANARY ISLANDS

POPULATION	**2,2 million**
% FOREIGNERS	**13%**
TOURISTS	**13 million/yr**



AVERAGE	**21 ºC**
WINTER	**18 ºC**
SUMMER	**24 ºC**

The Institute for Applied Microelectronics at ULPGC

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TOURISTS	**13 million/yr**

ICELAND

POPULATION	**0,38 million**
% FOREIGNERS	**24%**
TOURISTS	**5,7 million/yr**

The Institute for Applied Microelectronics at ULPGC

TWO PUBLIC UNIVERSITIES:

Univ. Las Palmas de Gran Canaria
(aprox. 20.000 students)

Univ. La Laguna
(aprox. 23.000 students)

FOUR PRIVATE UNIVERSITIES:

Universidad del Atlántico Medio
Universidad Fernando Pessoa
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The Institute for Applied Microelectronics at ULPGC

DIVISIONS

Integrated Systems Design, ISD
Communication Systems, COM
Maths, Graphics and Computation, MAGIC
Microelectronics and Microsystems, MEMS
Industrial Systems and CAD Tools, SICAD
Information Technology, TI
Microelectronic Technology, TME

FEATURES

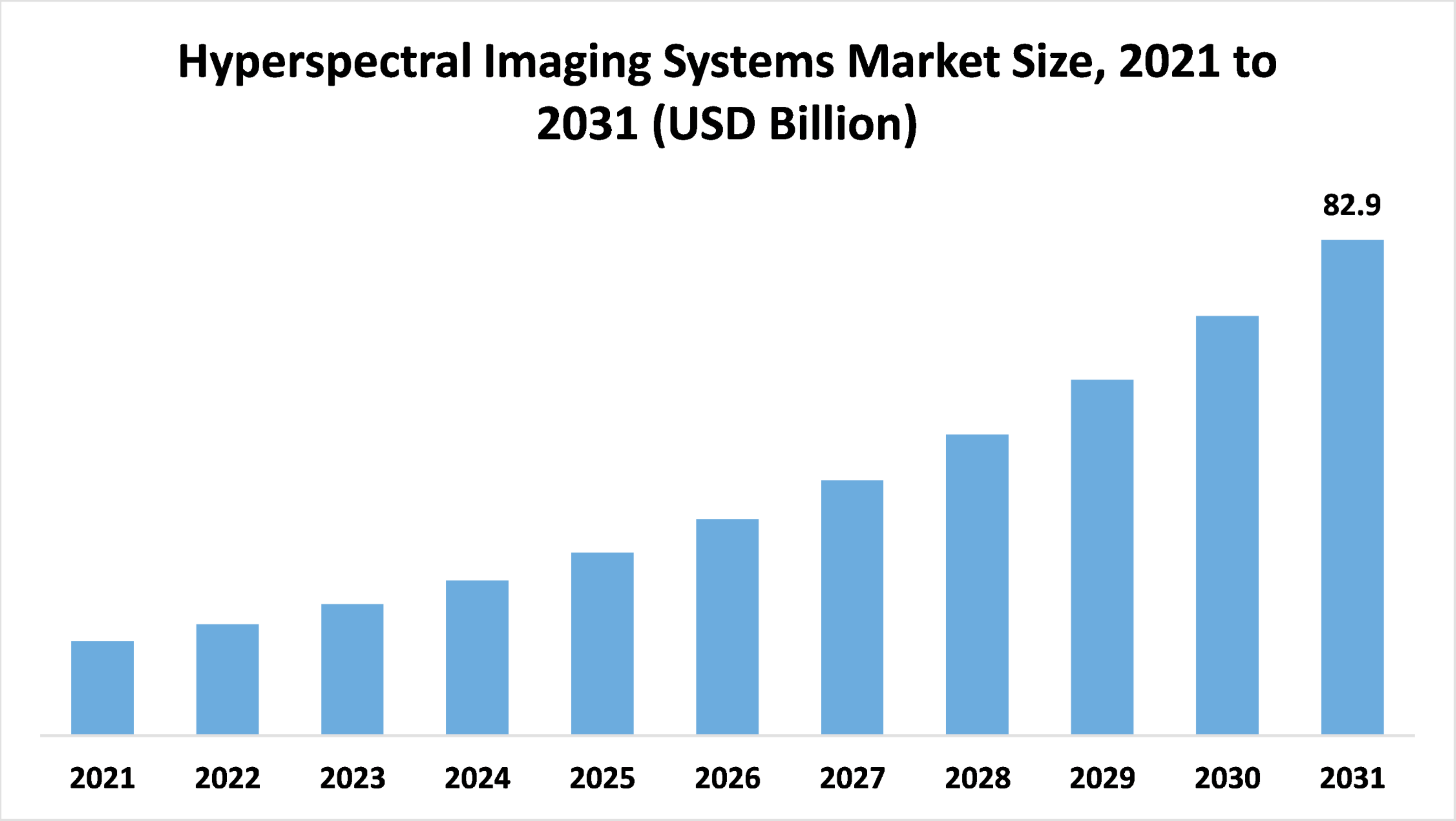
More than 130 researchers
More than 200 R&D projects

The Institute for Applied Microelectronics at ULPGC

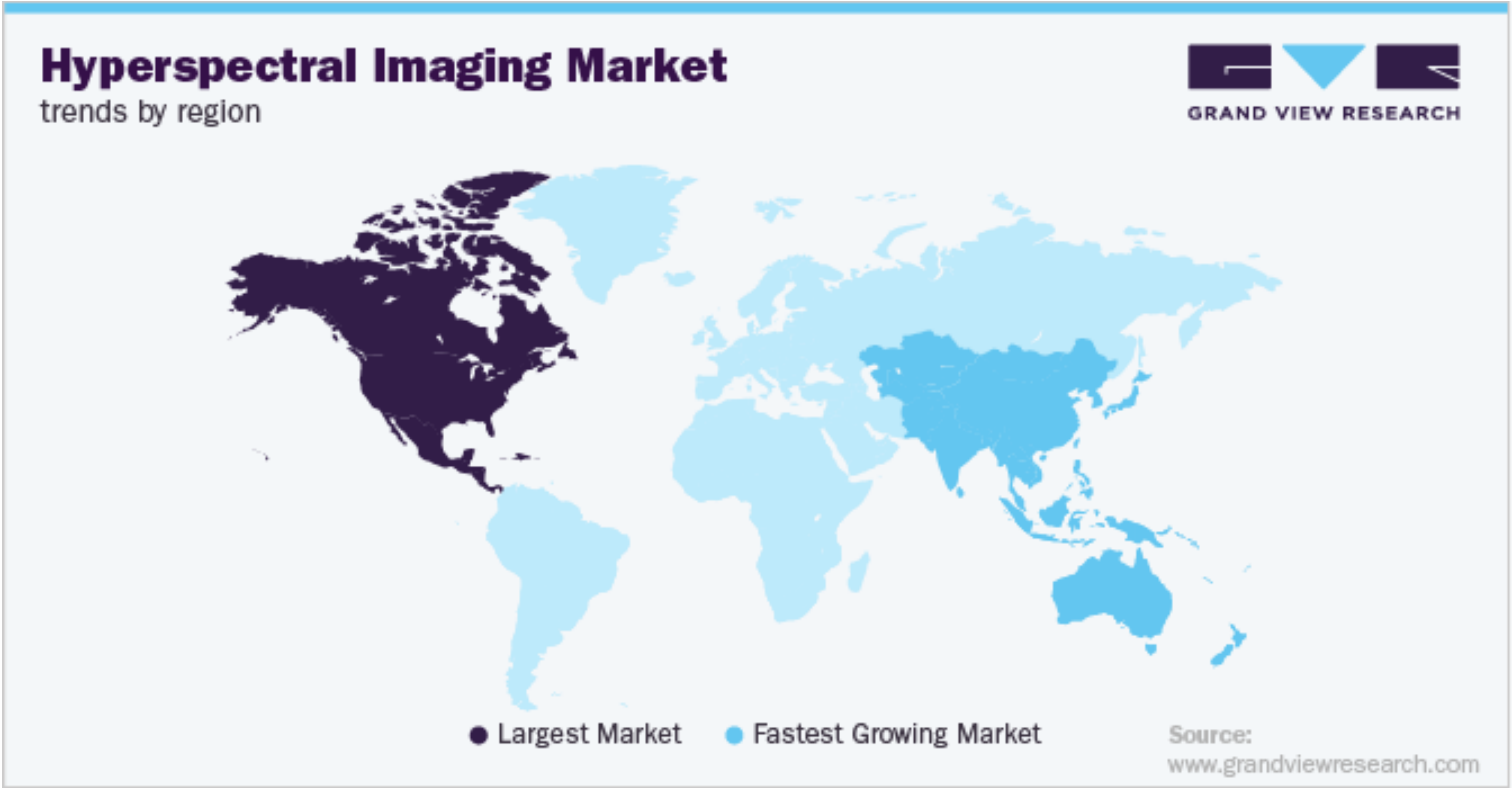
gmv INNOVATING SOLUTIONS
SINGULAR AIRCRAFT
B2SPACE
SENER Aeroespacial
indra
satlink
everis an NTT DATA Company
SATELIOT
EHANG
inmarsat The mobile satellite company™
fibersat
ThalesAlenia Space a Thales / Leonardo company
AIRBUS DEFENCE & SPACE
telenor
babcock
TELESPAZIO a LEONARDO and THALES company
ARQUIMEA
SATLANTIS
eutelsat
hispasat
PLD SPACE

The Institute for Applied Microelectronics at ULPGC

Why hyperspectral technology?



Why hyperspectral technology?



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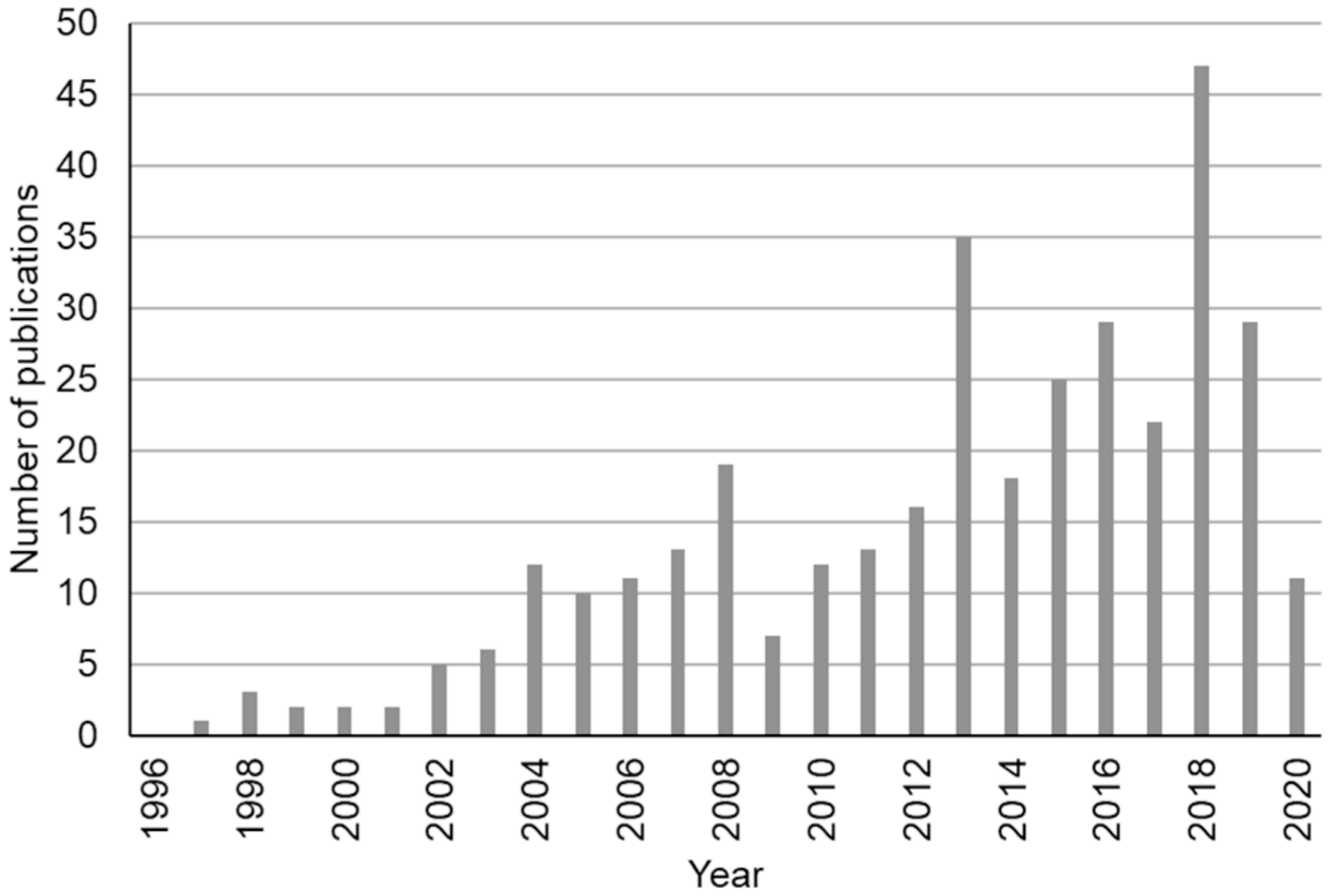

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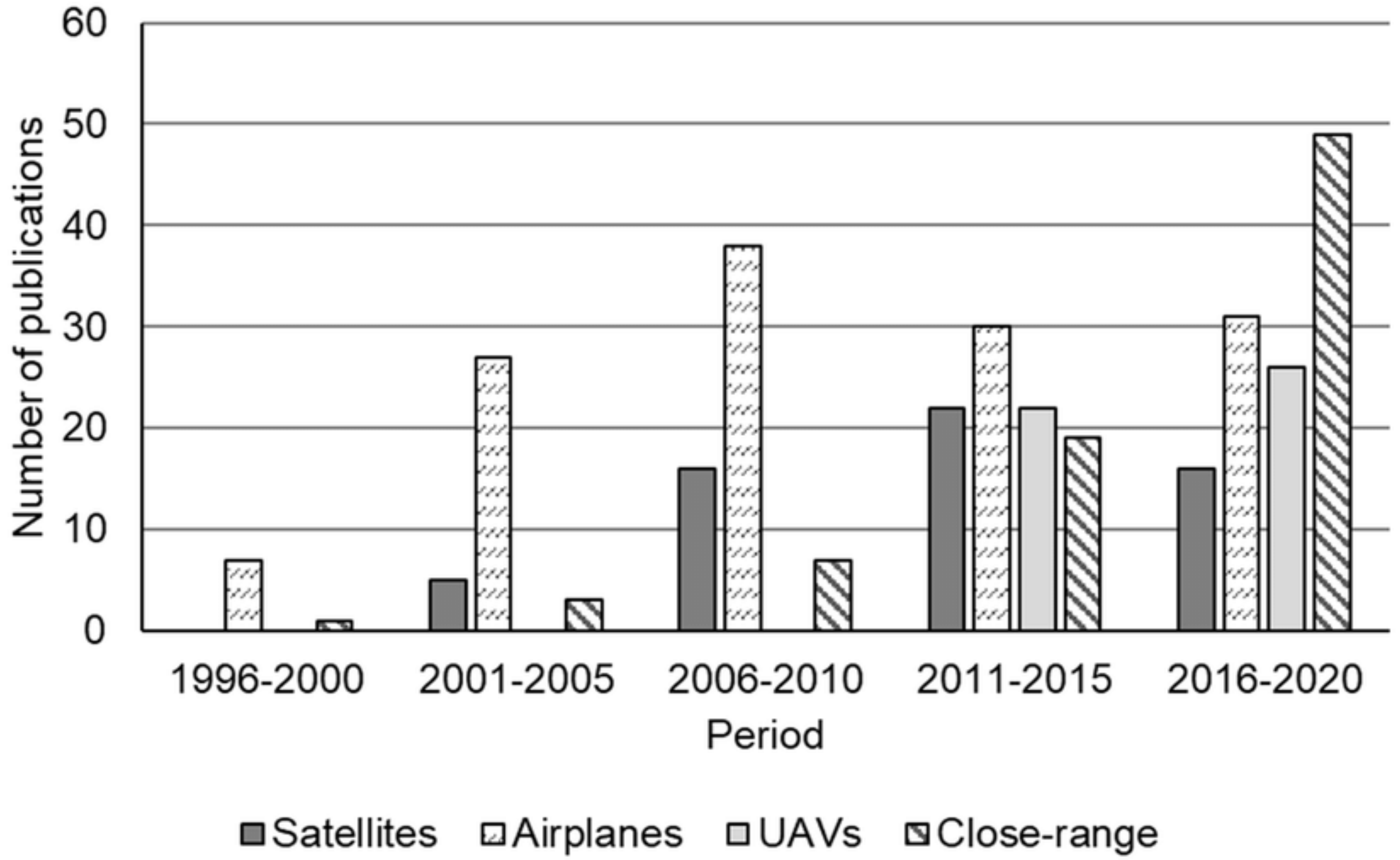

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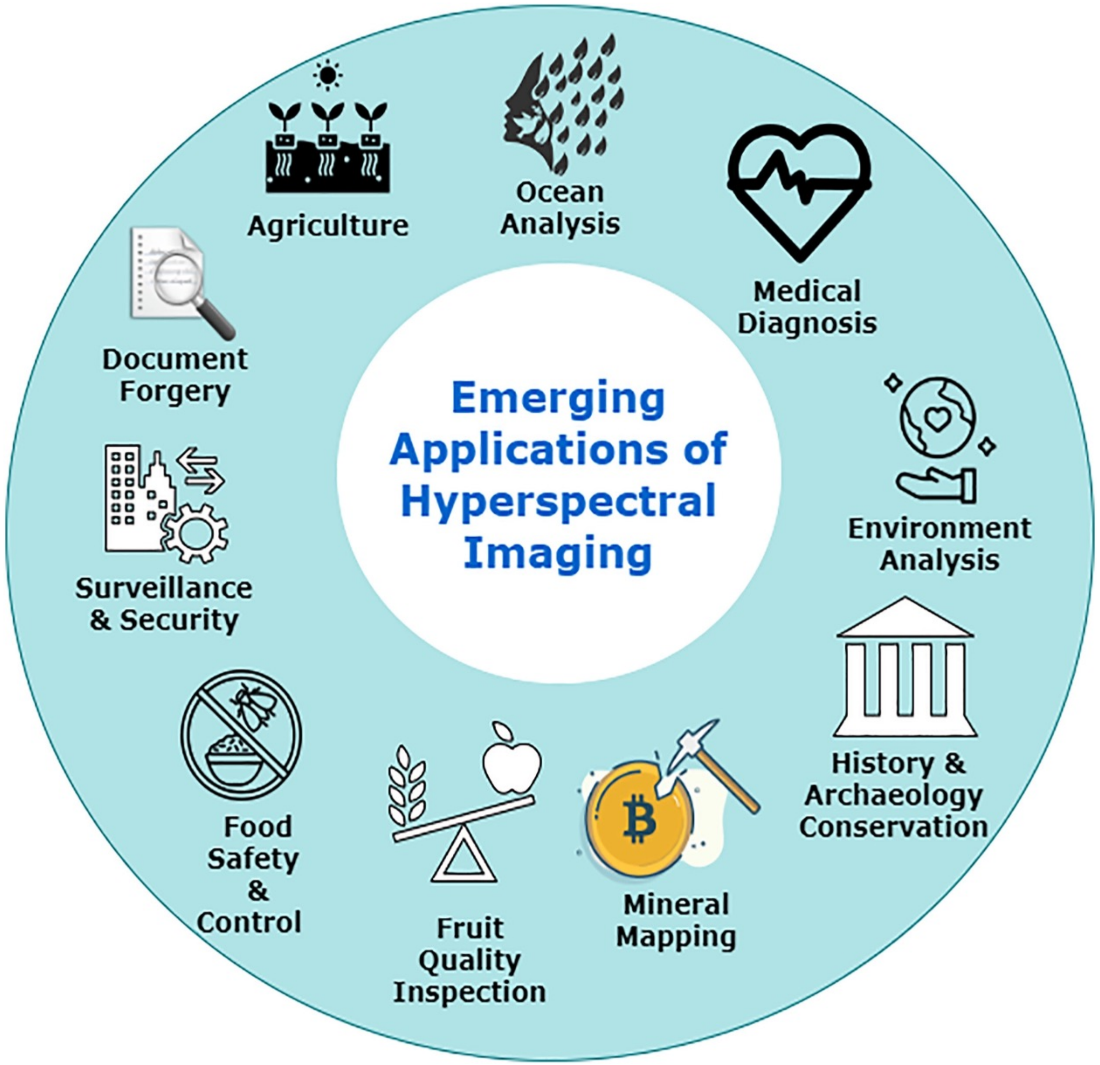
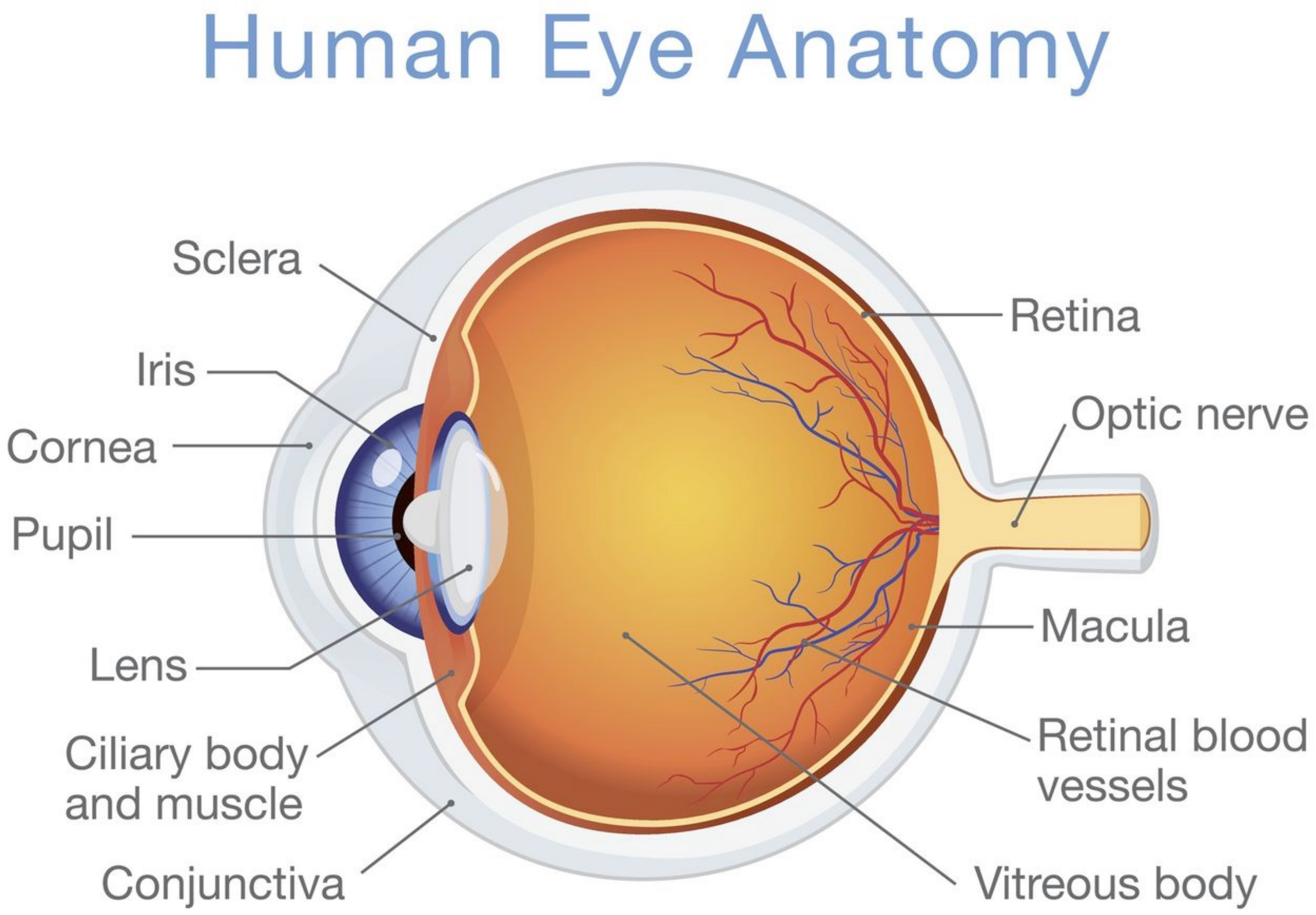


Introduction to hyperspectral technology



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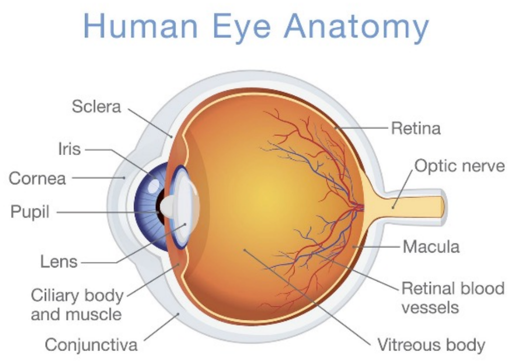


STEP 1 Light rays enter the eye through the **cornea**

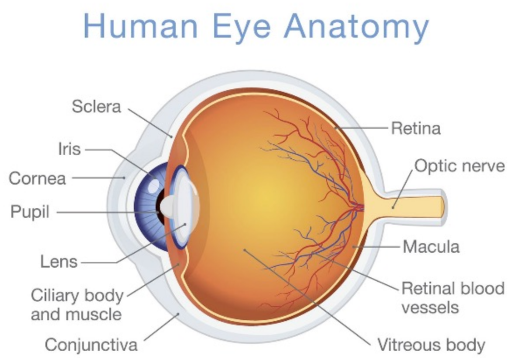
STEP 2 The **iris** changes the size of the **pupil** from very small to large in order to regulate the amount of light that is entering

STEP 3 It continues through the lens and passes through the largest part of the eye filled with a jelly-like substance called **vitreous body**

STEP 4 The light finally reaches the **retina**, the membrane at the back wall of the eye which contains photoreceptors

STEP 5 The **photoreceptors** converts light into electrical signals which travel to the brain

Introduction to hyperspectral technology



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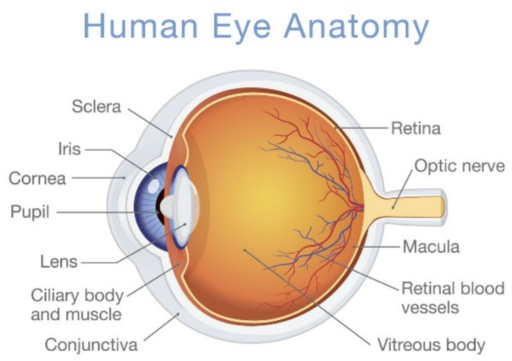

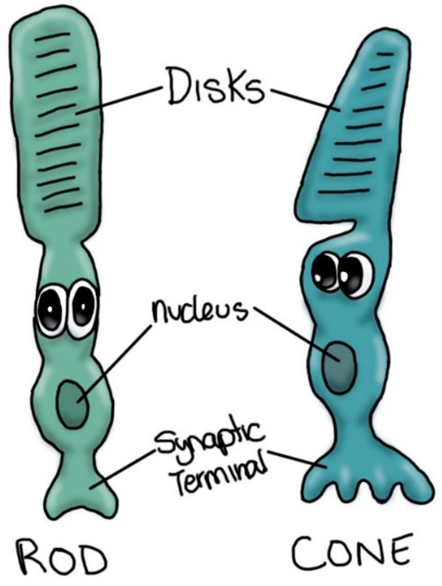

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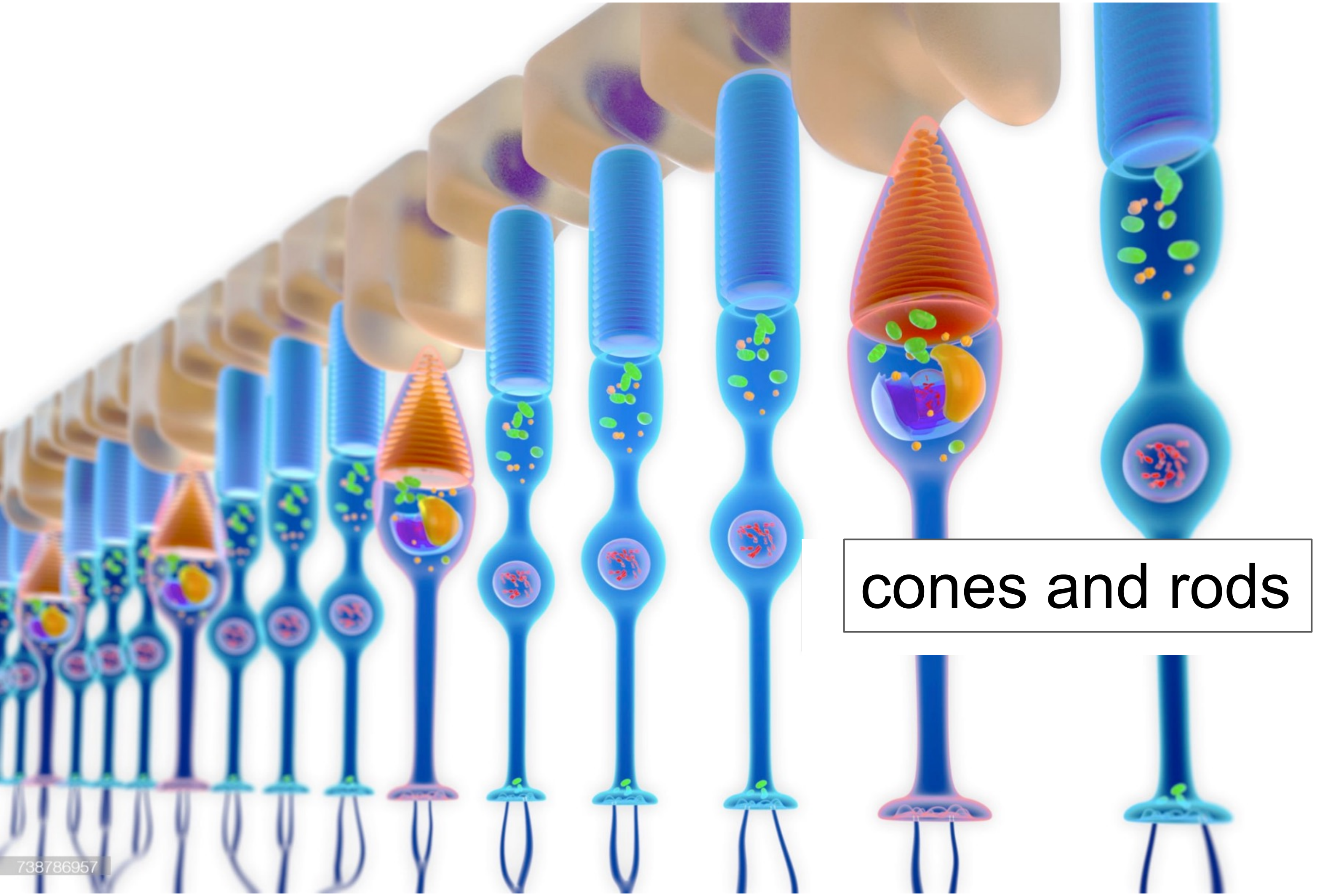
Introduction to hyperspectral technology



RODS

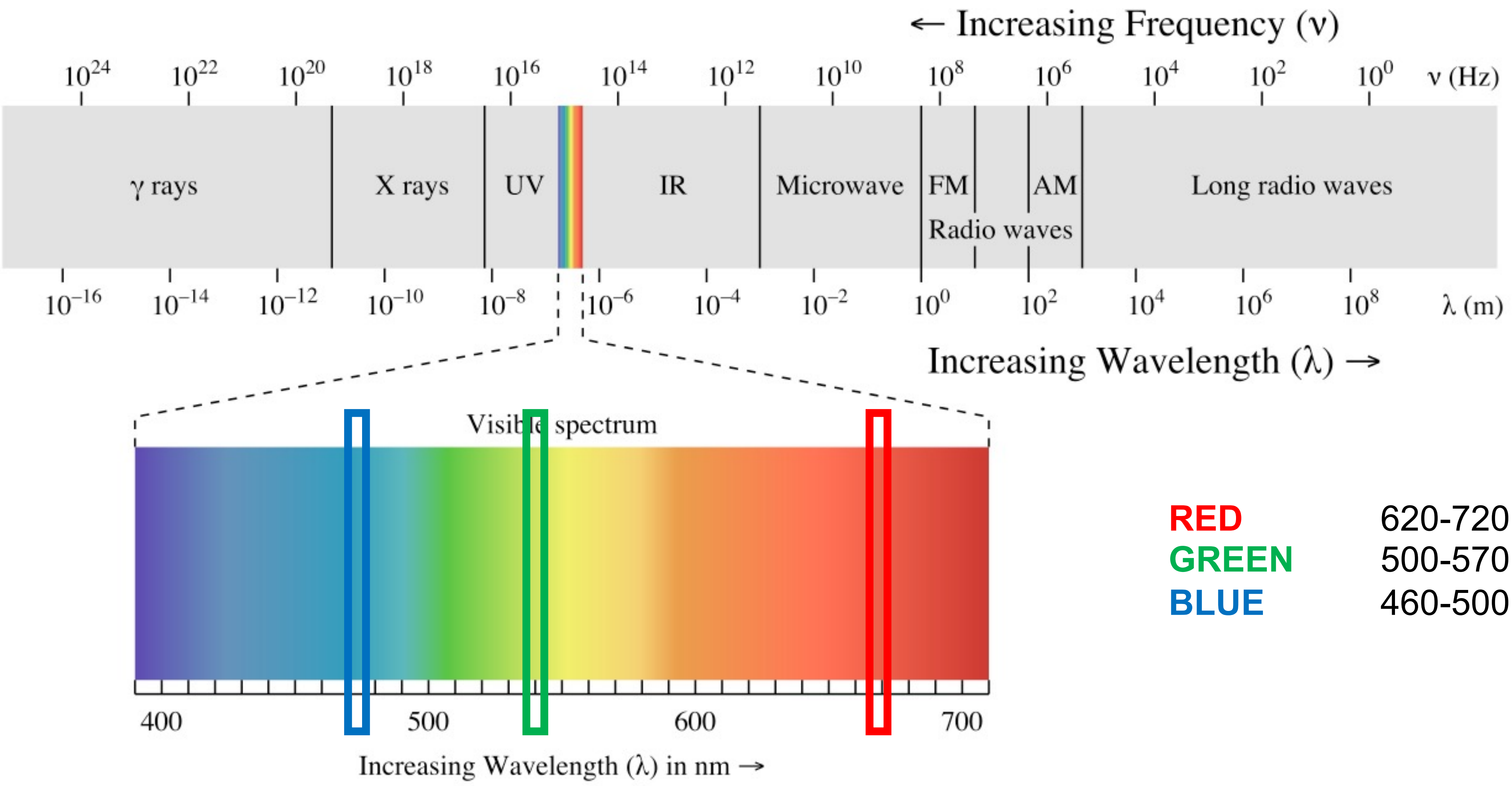
Responsible of visión at low level light
Scotopic visión
Aprox. 100 million

CONES

Contain photopigments
Active at higher light levels
Photopic visión
Perception of color
Aprox. 7 million
Three types: L (red)
S (blue)
M (green)

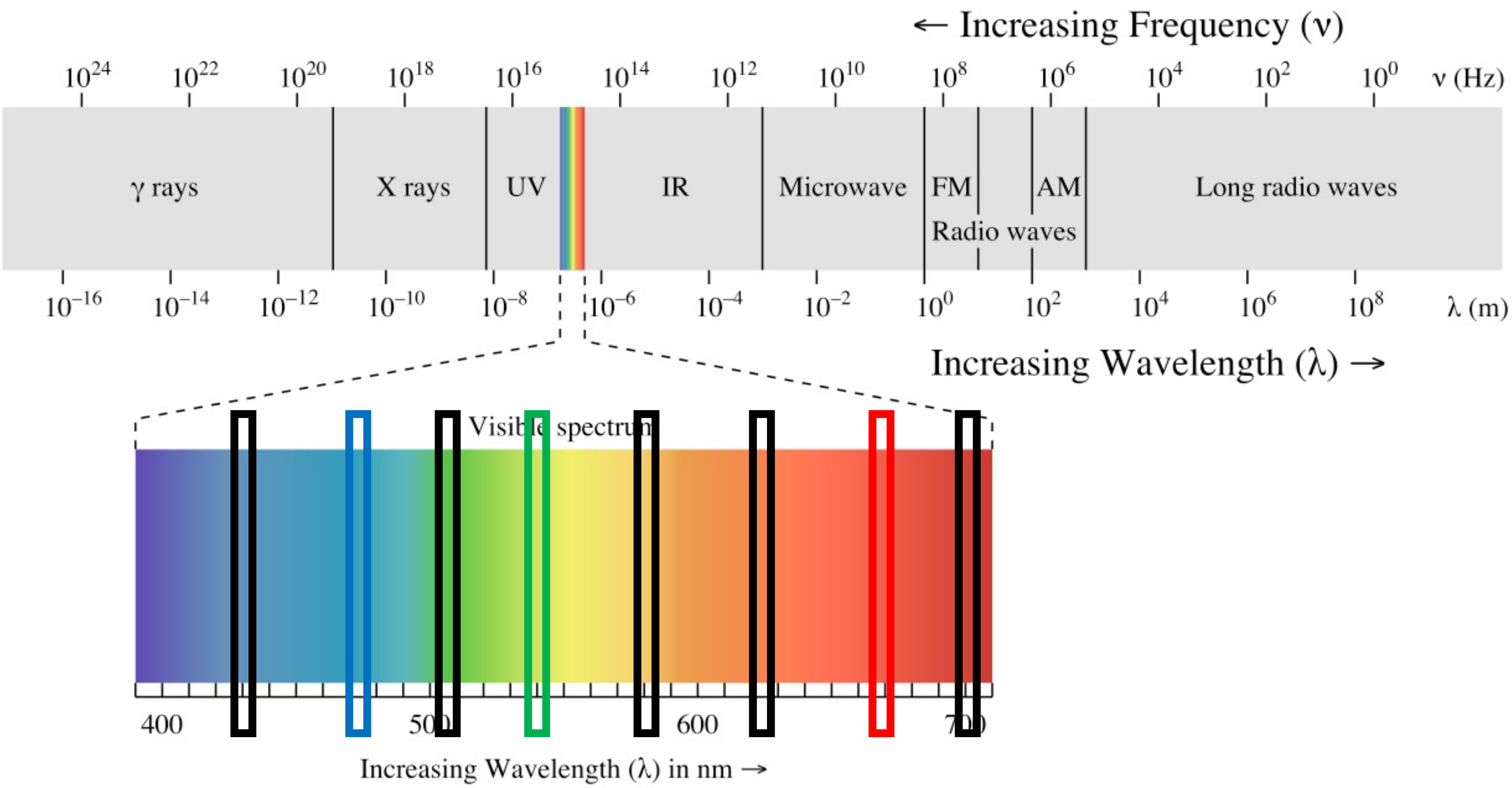
The proportion of the light recognized by these three cone types is interpreted by the brain, determining the colors

Introduction to hyperspectral technology



RED	620-720 nm
GREEN	500-570 nm
BLUE	460-500 nm

Introduction to hyperspectral technology



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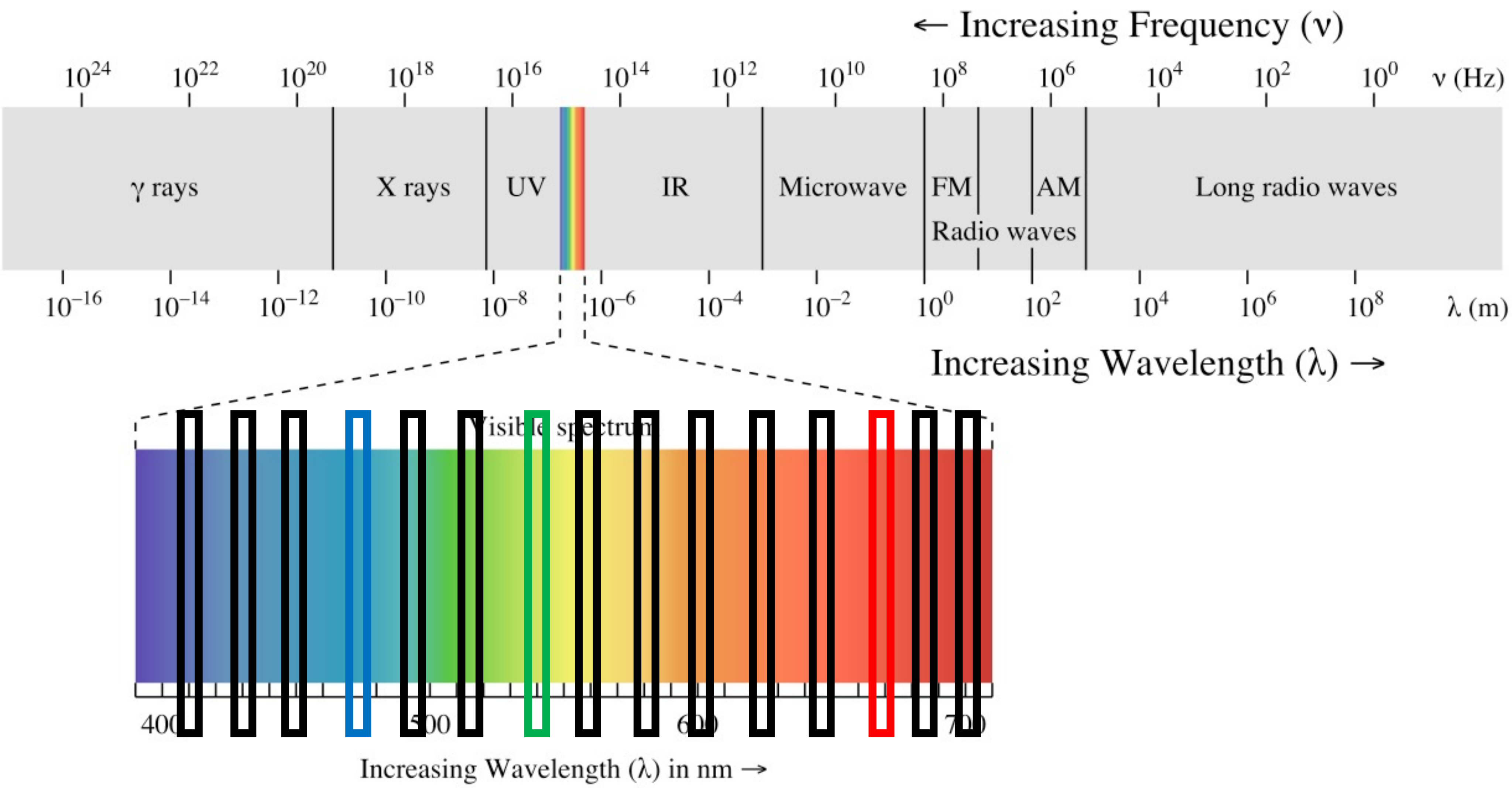

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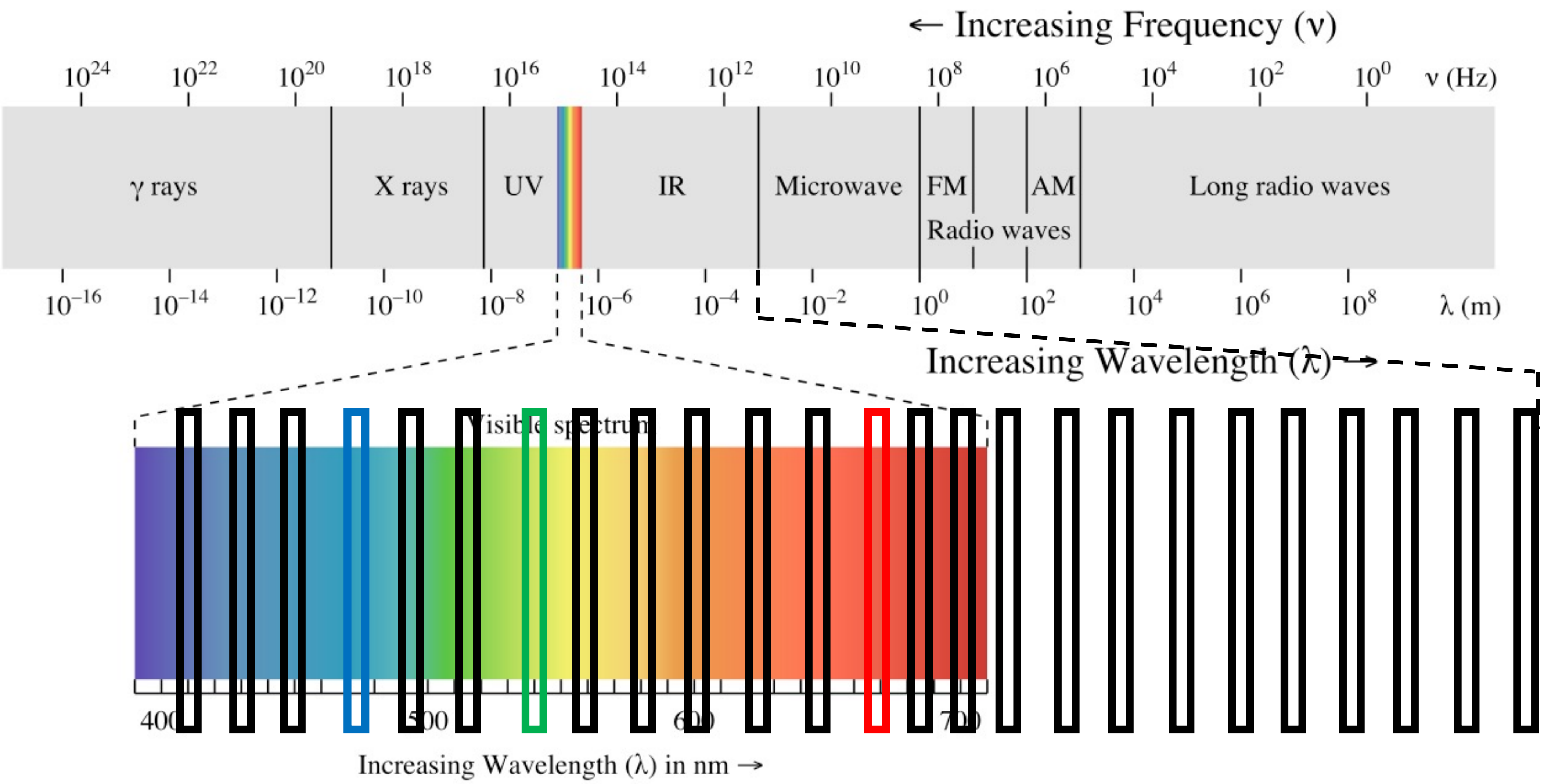

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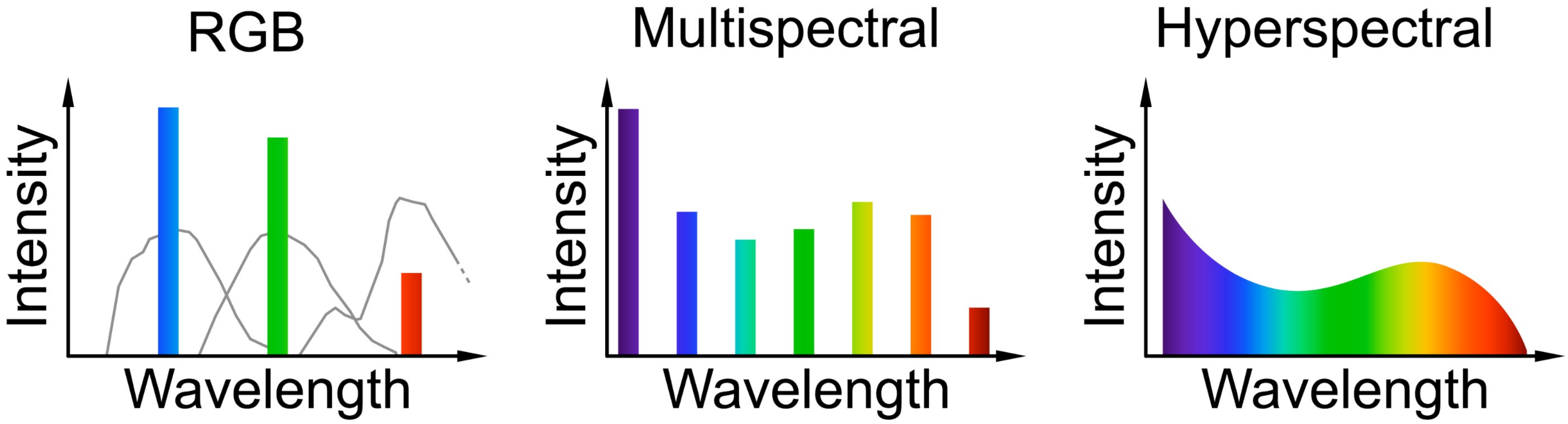

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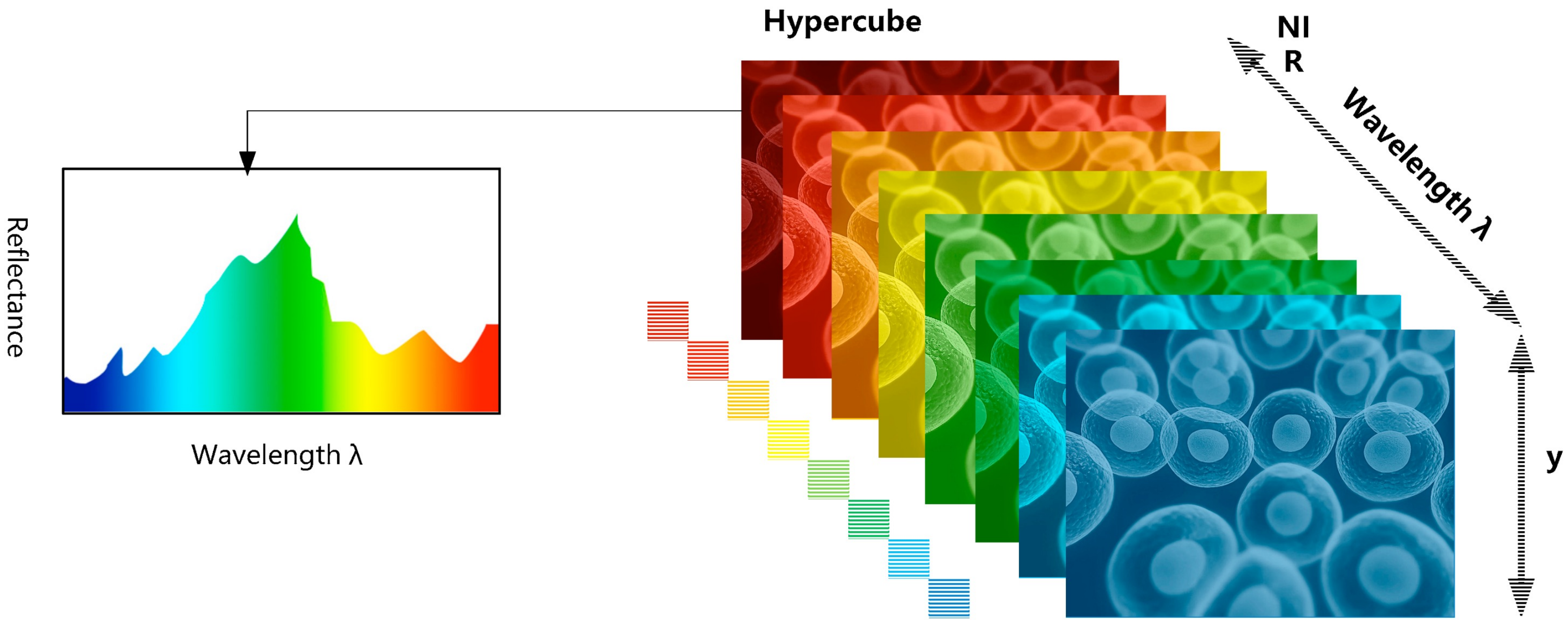

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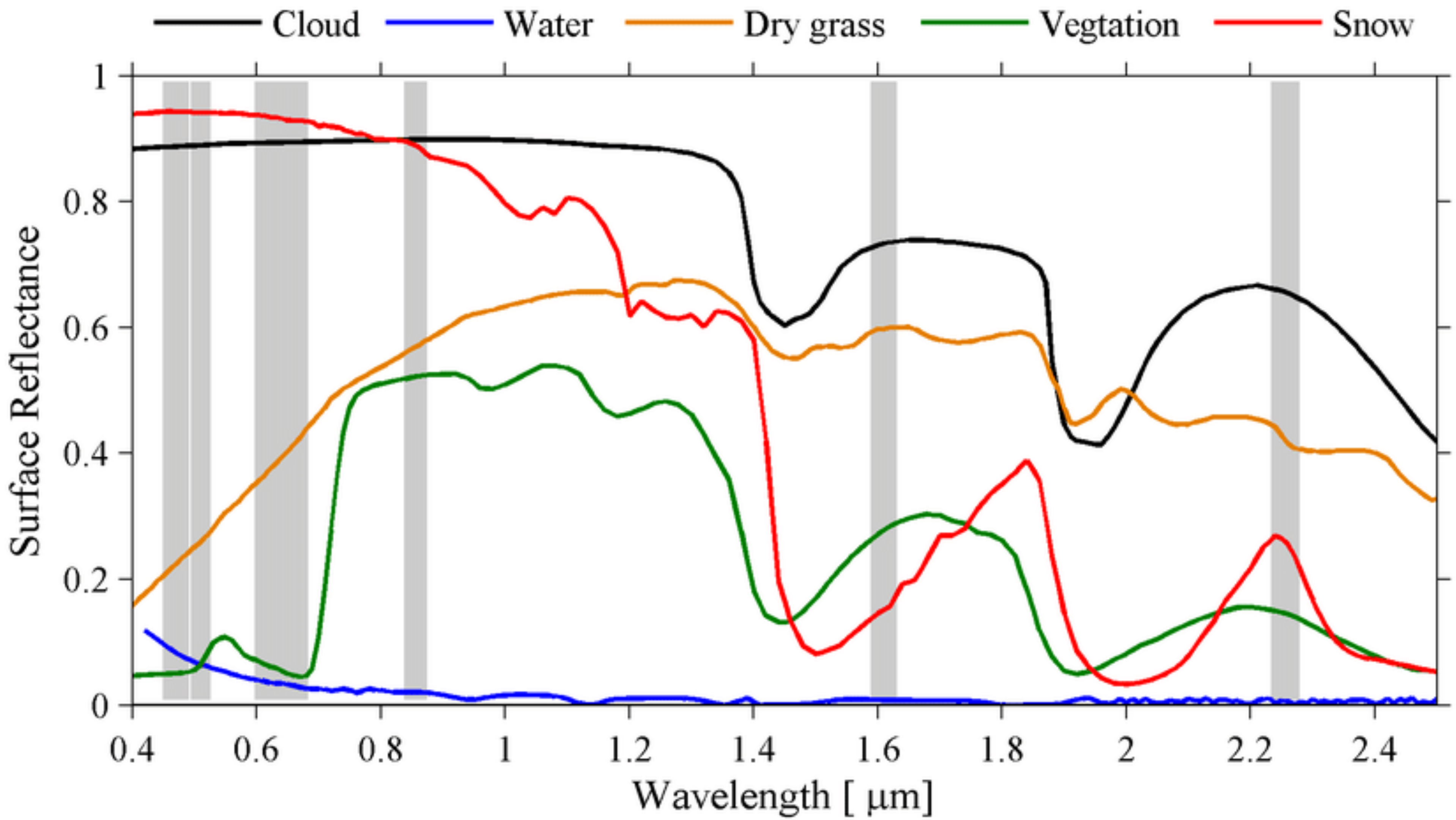

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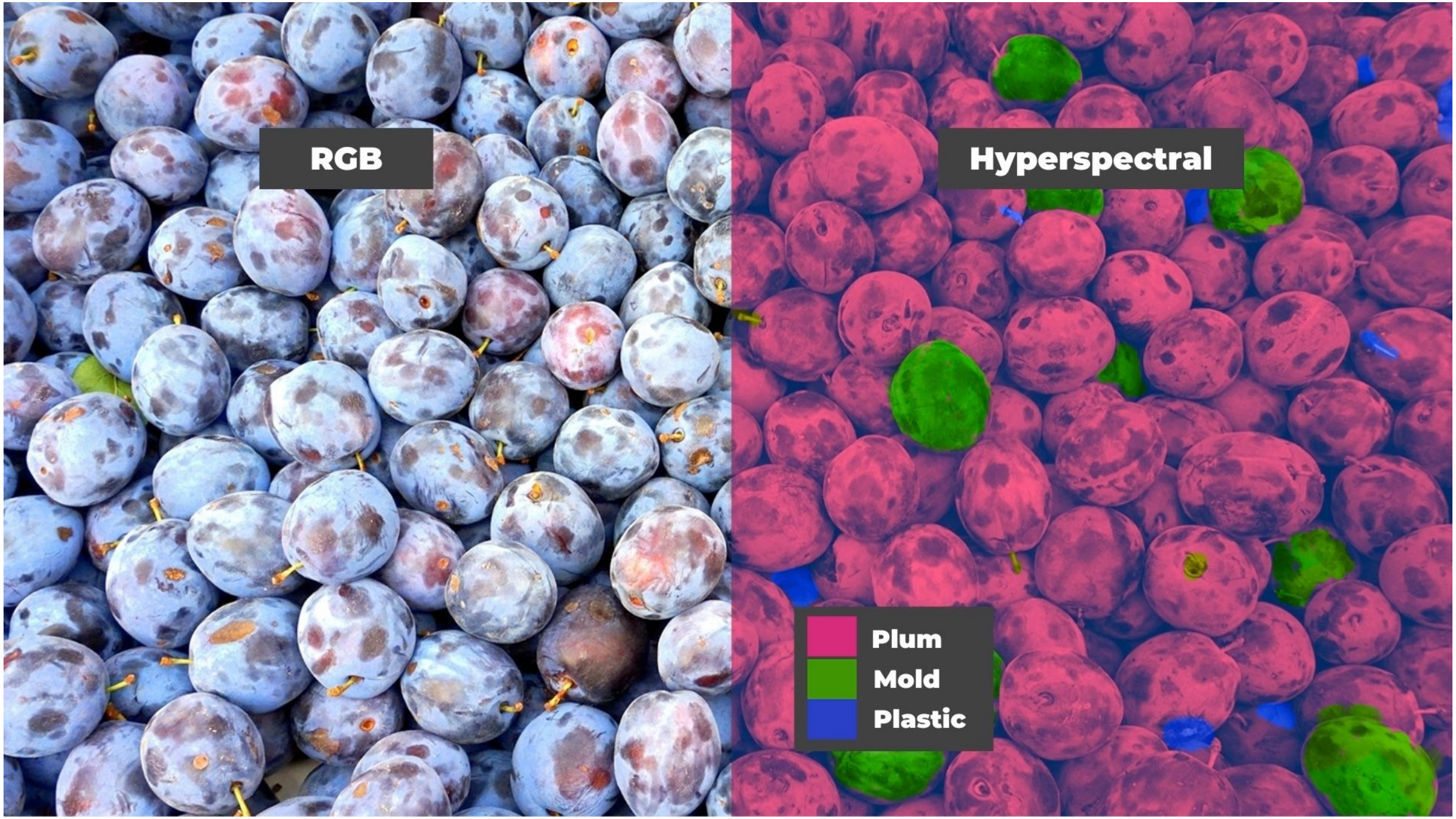

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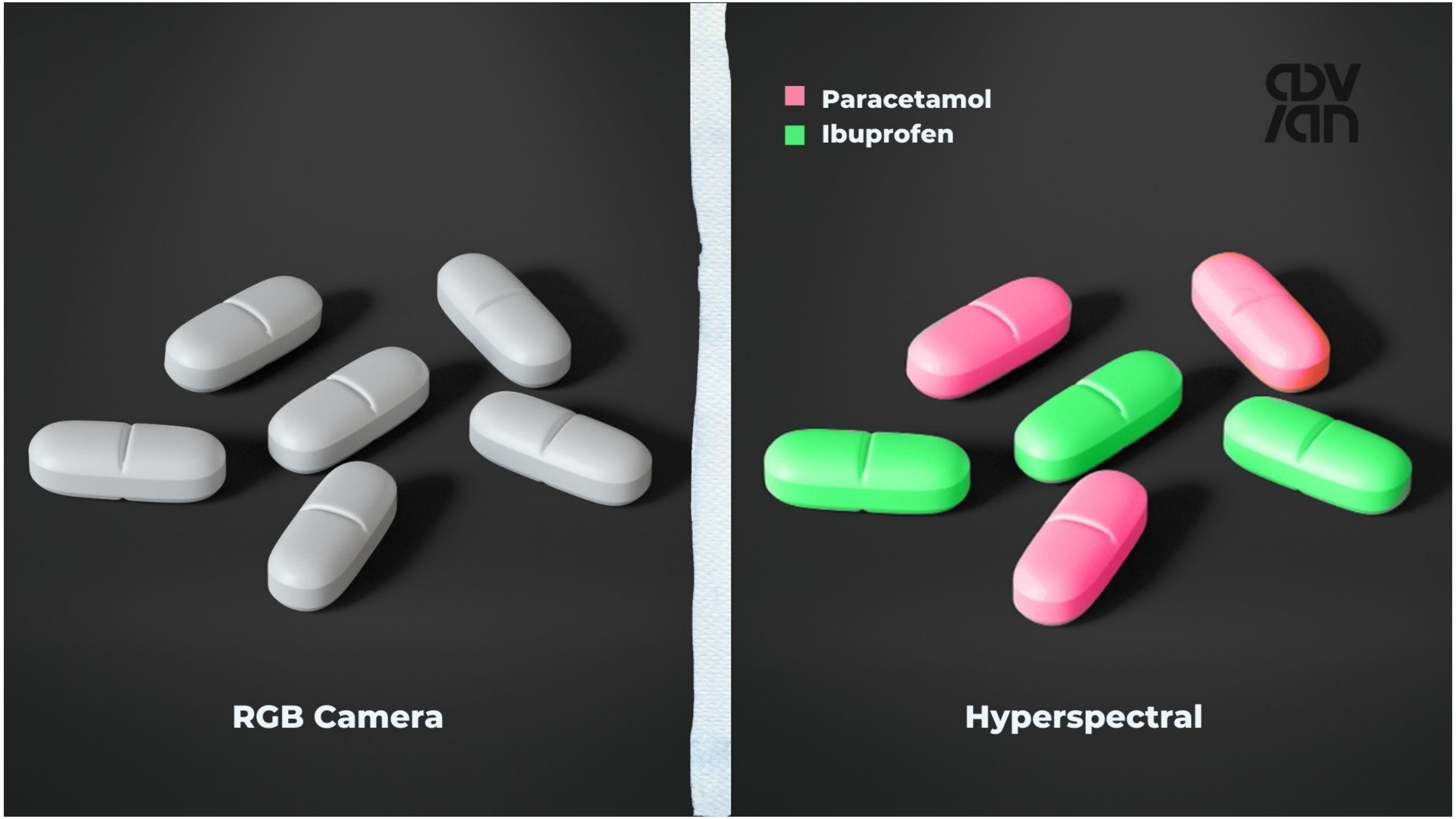
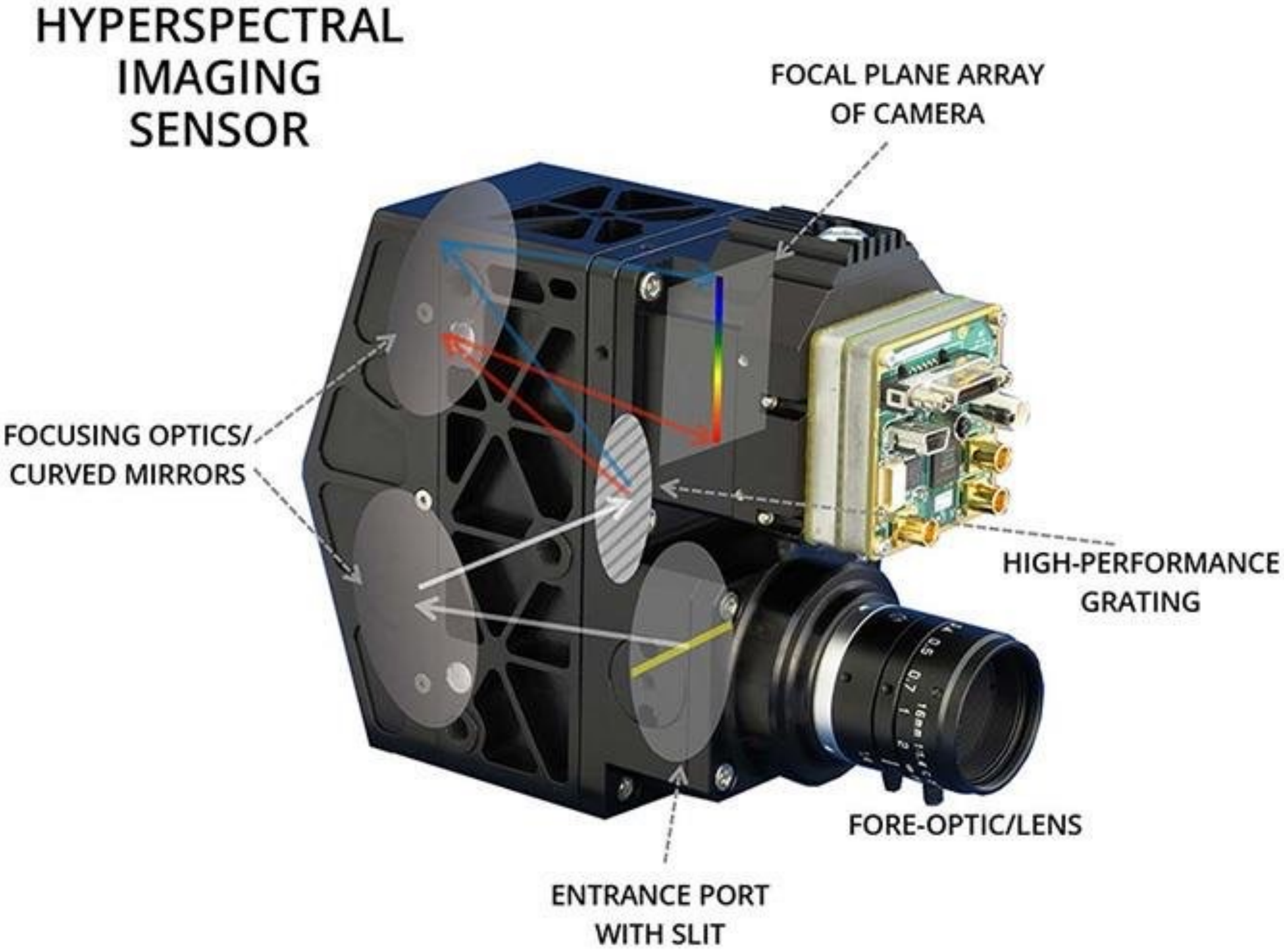


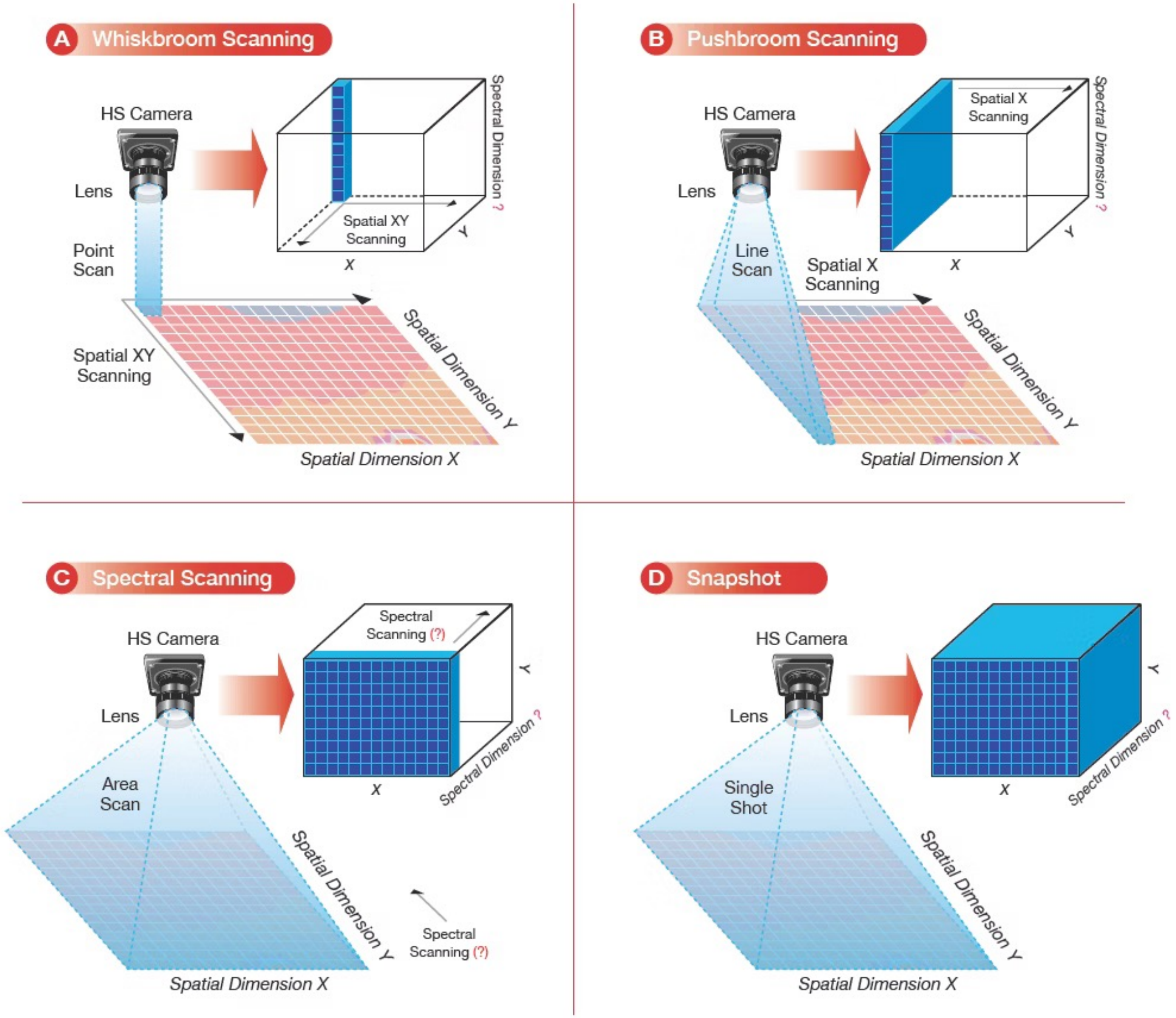
Introduction to hyperspectral technology

Seeing the invisible



HYPERSPECTRAL
IMAGING
SENSOR
FOCAL PLANE ARRAY
OF CAMERA
FOCUSING OPTICS/
CURVED MIRRORS
HIGH-PERFORMANCE
GRATING
FORE-OPTIC/LENS
ENTRANCE PORT
WITH SLIT

Introduction to hyperspectral technology



WHISKBROOM SCANNING

- Captures one single pixel at a time
- Very high spectral resolution

PUSHBROOM SCANNING

- Captures one line at a time
- Very high spectral resolution

SPECTRAL SCANNING

- Entire spatial information for all bands at a time
- Produces cubes slowly

SNAPSHOT SCANNING

- Fast for moving objects
- Limited spectral and spatial resolution

Introduction to hyperspectral technology

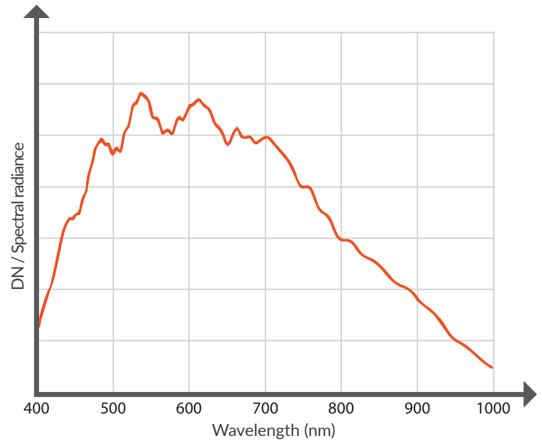
FX10

SPECIM
A Konica Minolta Company

FEATURES

- Spectral range of 400-1000 / 400-780 nm
- High spatial resolution of 1024 pixels
- High image speed of 330 FPS (full range)
- Free wavelength selection from 224 bands within the camera coverage
- Built-in image correction
- Unified spectral calibration between units
- GigE or CameraLink standard interfaces
- Easy mounting to industrial environment

SPECTRAL RESPONSE



Introduction to hyperspectral technology

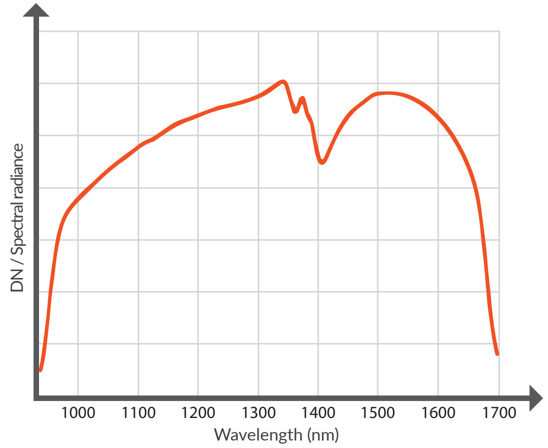
FX17

Specim
A Konica Minolta Company

FEATURES

- Spectral range of 900-1700 nm
- High spatial resolution of 640 pixels
- High image speed
  670 FPS (full range) for GigE version
  527 FPS (full range) for CameraLink version
- Free wavelength selection from 224 bands within the camera coverage
- Built-in image correction
- Unified spectral calibration between units
- GigE or CameraLink standard interfaces
- Easy mounting to industrial environment

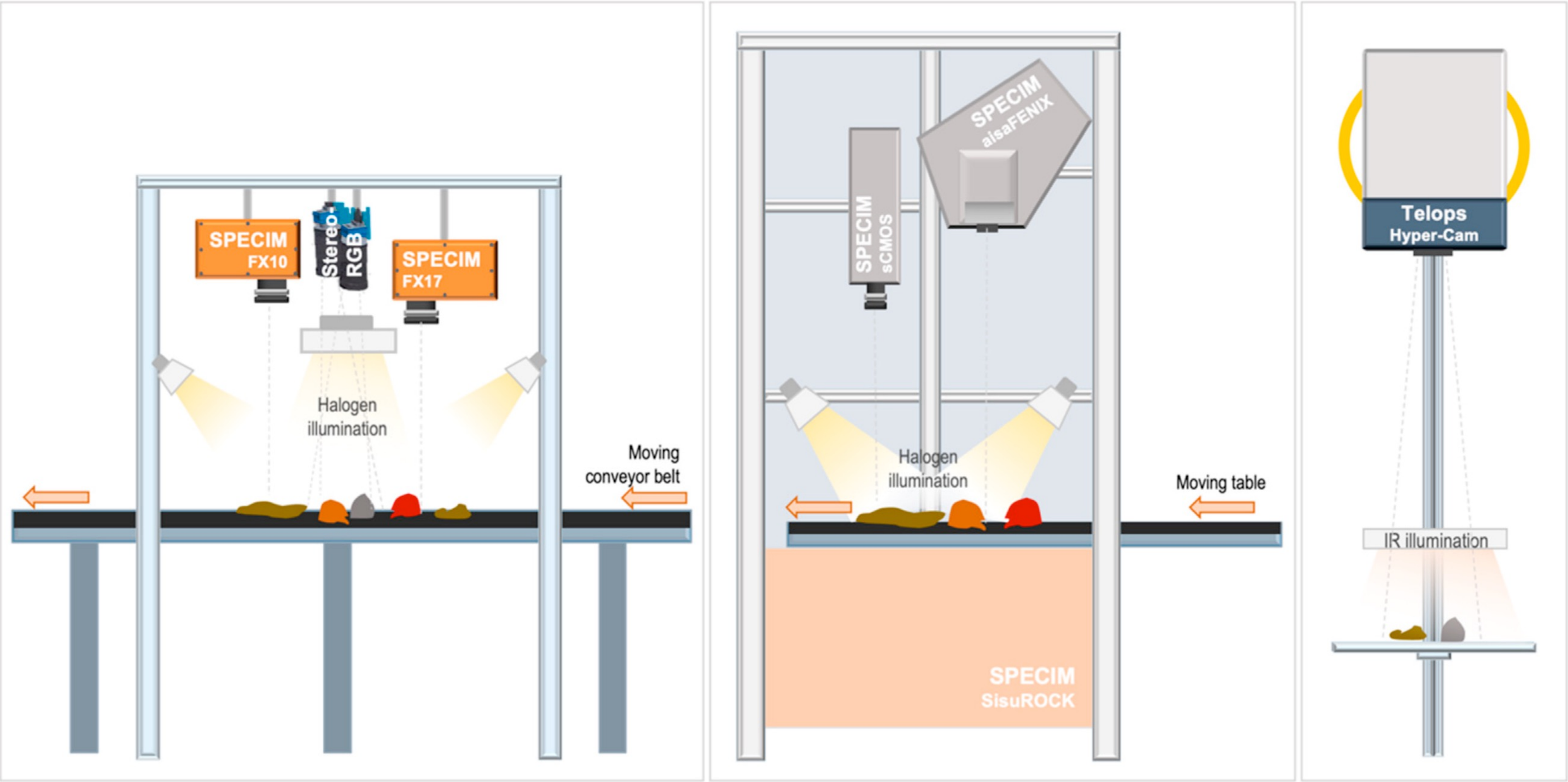
SPECTRAL RESPONSE



Introduction to hyperspectral technology

Hyperspec® SWIR	
Wavelength Range (nm)	900-2500
Aperture	F/2.0
Entrance Slit Width	25 μm
Dispersion/Pixel (nm/pixel)	6
FWHM Slit Image	6.3 nm
Slit Length	12 mm
Spectral Resolution	12 nm
Spectral Bands	267
Spatial Bands	384
Smile - Aberration-corrected	Yes
Keystone - Aberration-corrected	Yes
Detector	Stirling-cooled MCT
Max. Frame Rate (Hz)	450
Pixel Pitch	24 μm
Read A/D	16-Bit
Camera Control Interface	Base CameraLink and RS232
Weight (lb / kg)	9.6 / 4.4
Max. Power (W)	14.4

Introduction to hyperspectral technology



Introduction to hyperspectral technology

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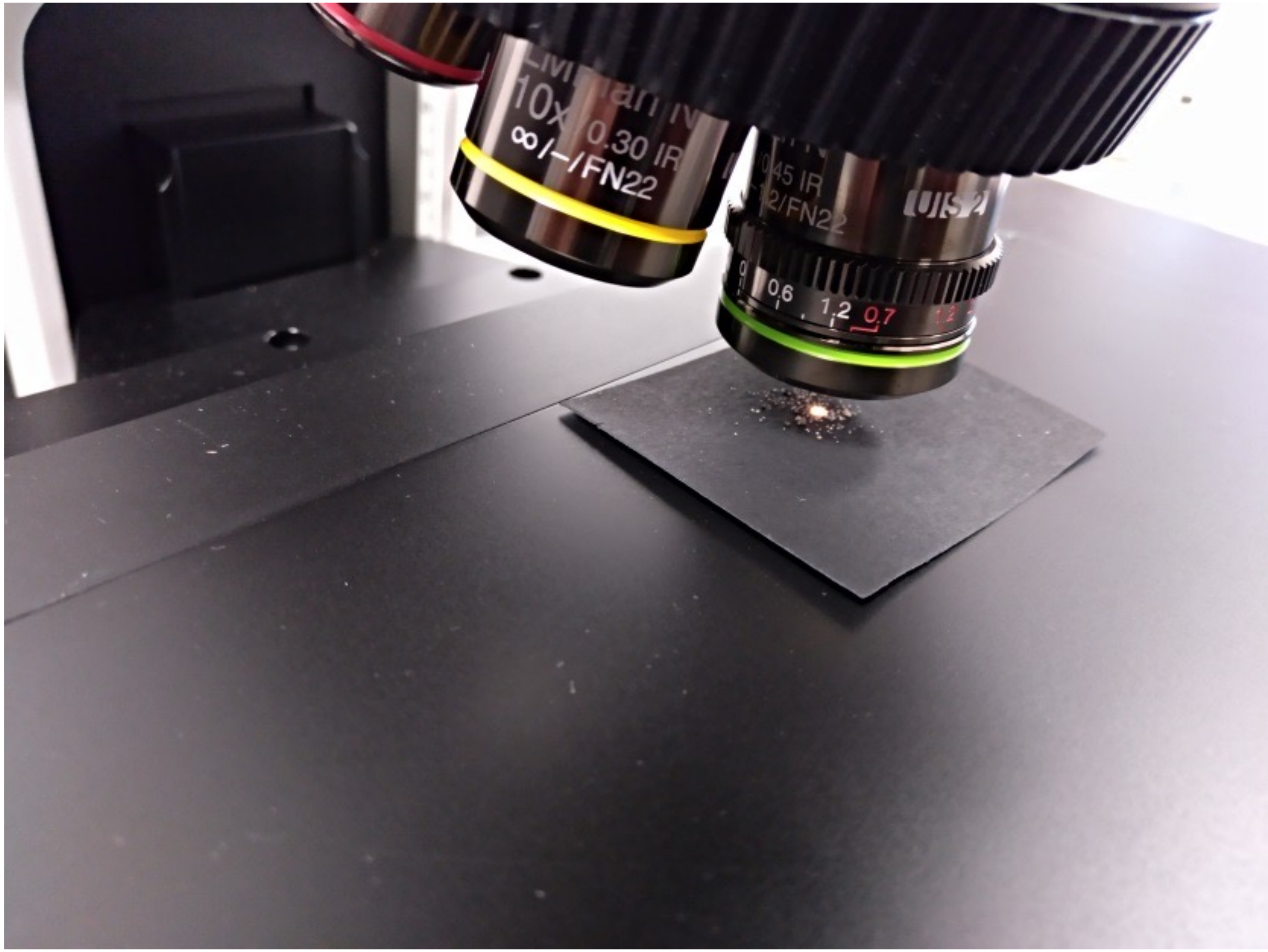

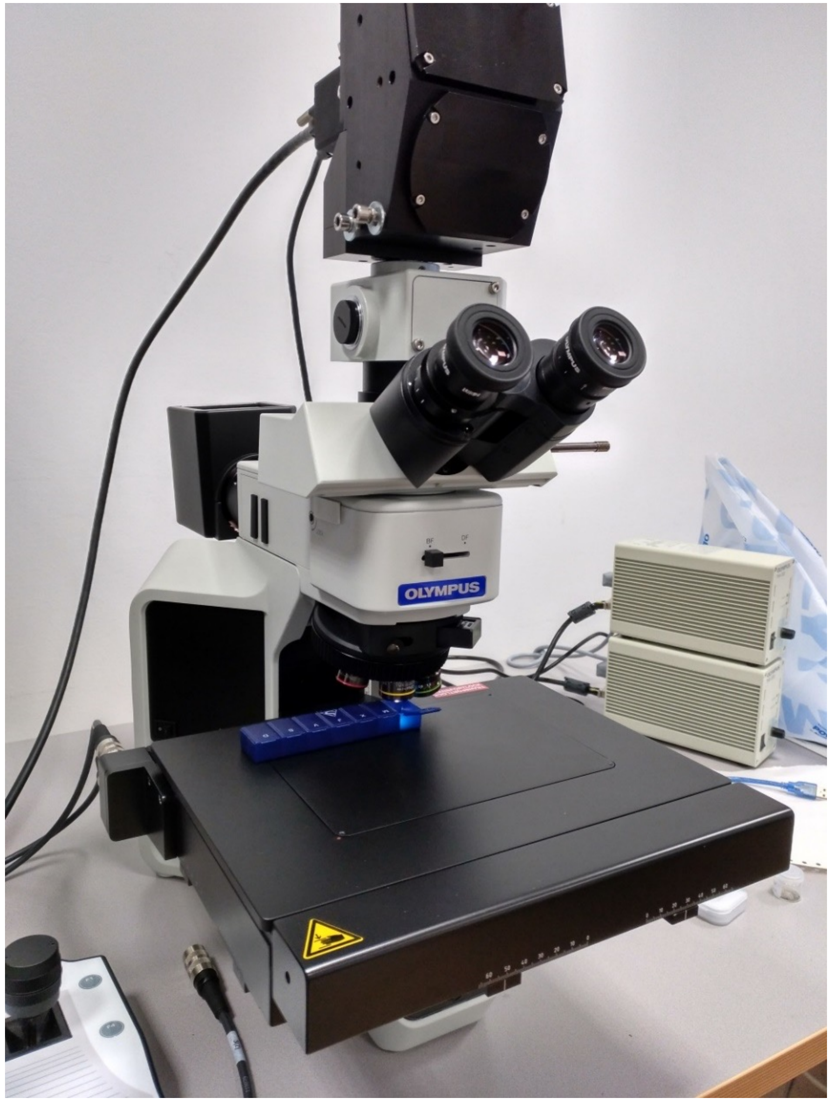

Introduction to hyperspectral technology

Introduction to hyperspectral technology

MAIN CHALLENGES

- Applications
- Compression
- Unmixing
- Reducing prices

Introduction to hyperspectral technology

MAIN CHALLENGES

- Applications
- Compression
- Unmixing
- Reducing prices

- Specially for on-board applications (i.e. satellites, drones…)
- Reduce the on-board memory requirements
- Communication channel capacity restrictions
- Reduce download time
- Lossless vs. Lossy vs. Near lossless compression
- Spatial and spectral correlation
- CCSDS-123

Introduction to hyperspectral technology

MAIN CHALLENGES

- Applications
- Compression
- Unmixing
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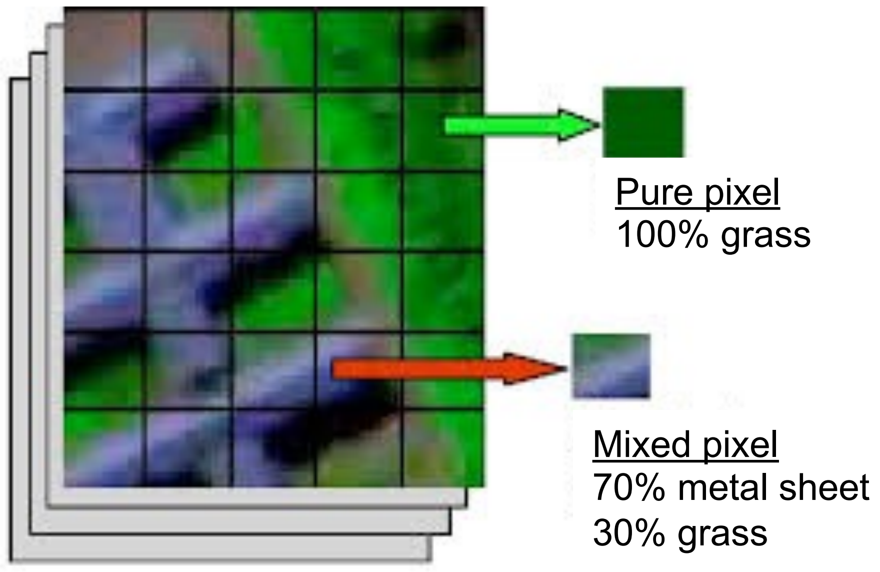

- Spectral unmixing is normally the first step in the analysis
- Pixels consist of a mixture of several materials
- Pure materials are named endmembers
- Abundances give the percentage of endmembers in a pixel

Introduction to hyperspectral technology

MAIN CHALLENGES

- Applications
- Compression
- Unmixing
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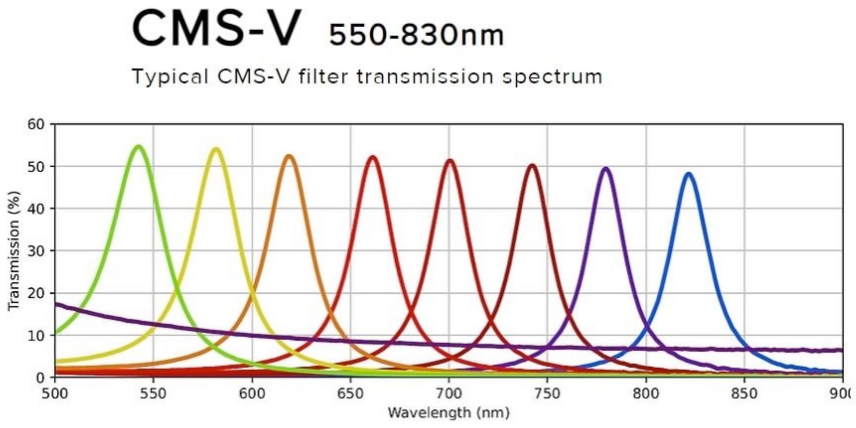
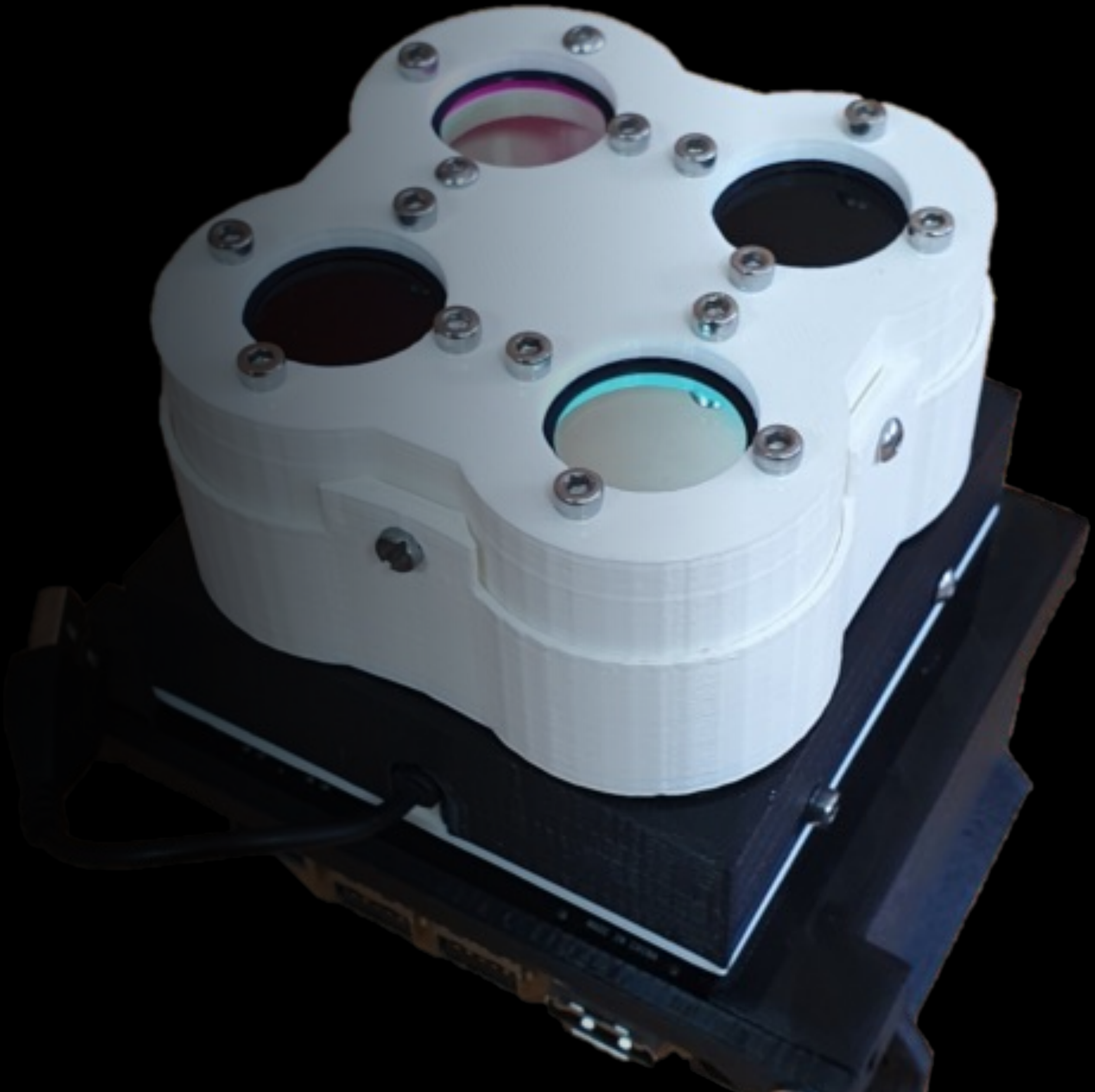


- Multispectral cameras have lower prices
- DIY cameras

Introduction to hyperspectral technology



Hyperspectral technology: inspiring ideas, challenges and opportunities

Part II: HPC on-board Satellites

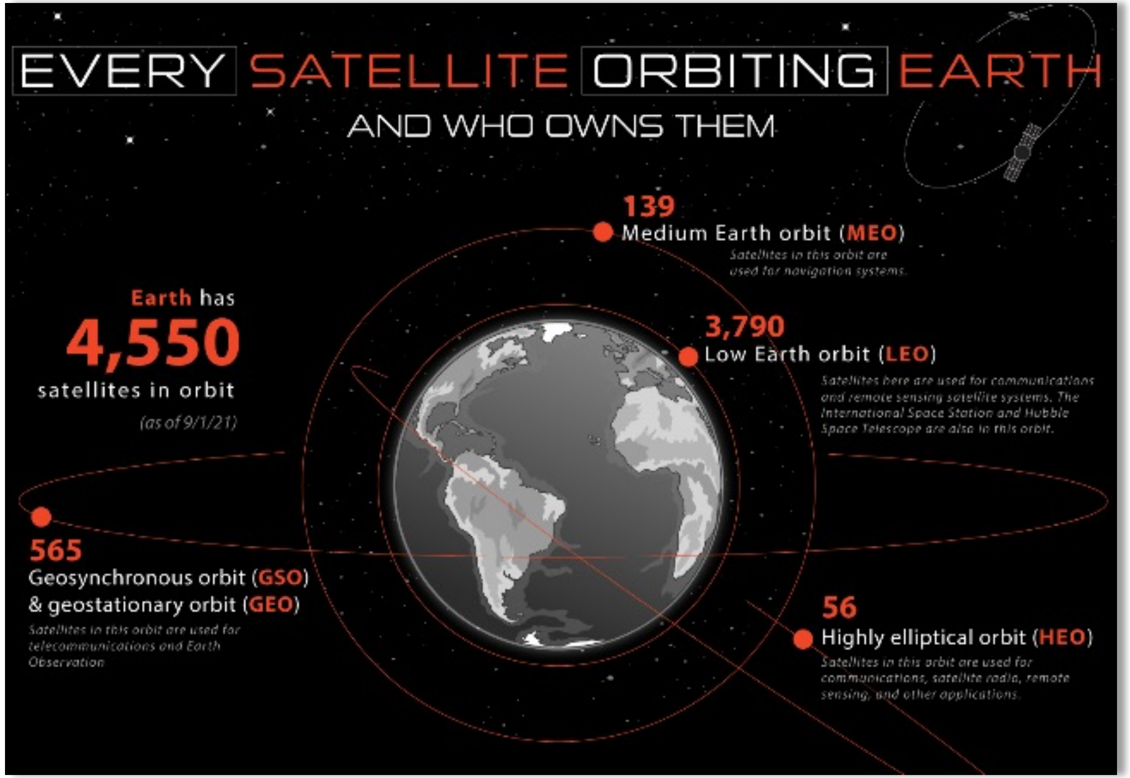
José López-Feliciano/Roberto Sarmiento

Insitutte for Applied Microelectronics (IUMA)

Outline

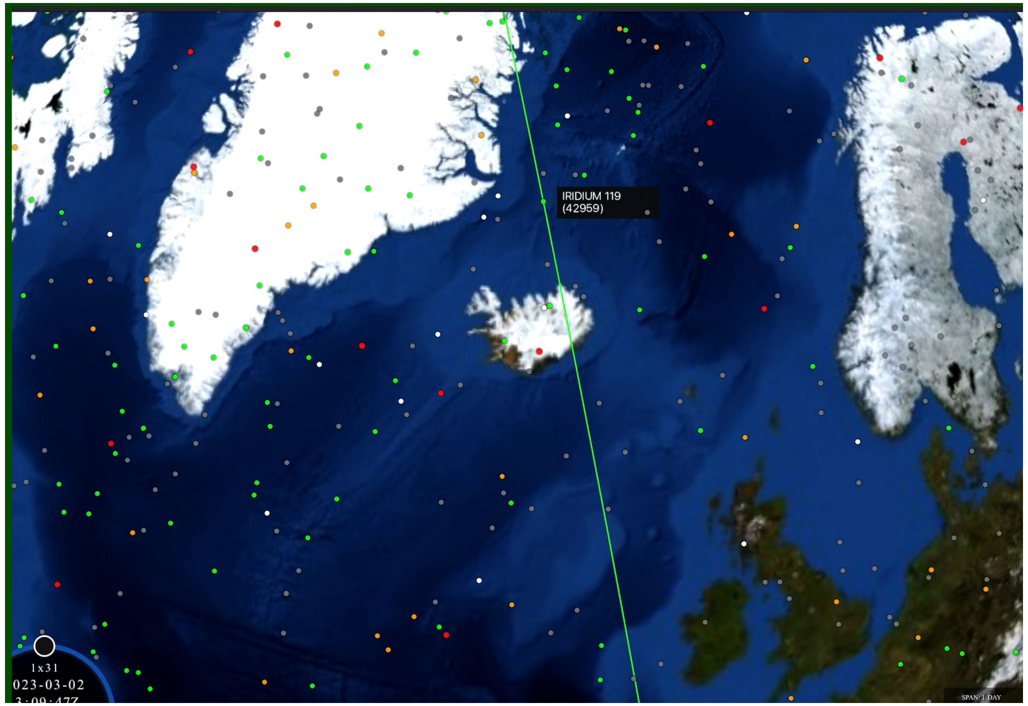
- Satellites for Earth Observation and Spacecrafts
- Satellites on-board Hardware
  - System overview
  - Payload hardware
- Technology solutions for on-board HPSC
  - Radiation effects mitigation
  - FPGAs - MPSoCs
- On-board Satellite payload data processing
  - New paradigm?
  - Data and Image Compression
  - Video Compression
  - Information Processing
- Conclusions

Satellites for Earth Observation and Space Crafts



Satellites by application	2013-2017	2018-2022
Earth Observation (EO)	58%	50%
Scientific	26%	16%
Technology	12%	10%
Communications	4%	22%
Novel applications	0%	3%

- Satellites
  - Low Earth Orbit(LEO)
  - Medium Earth Orbit (MEO)
  - Geosynchronous (GSO) & Geostationary (GEO)
  - Highly Elliptical Order (HE0)



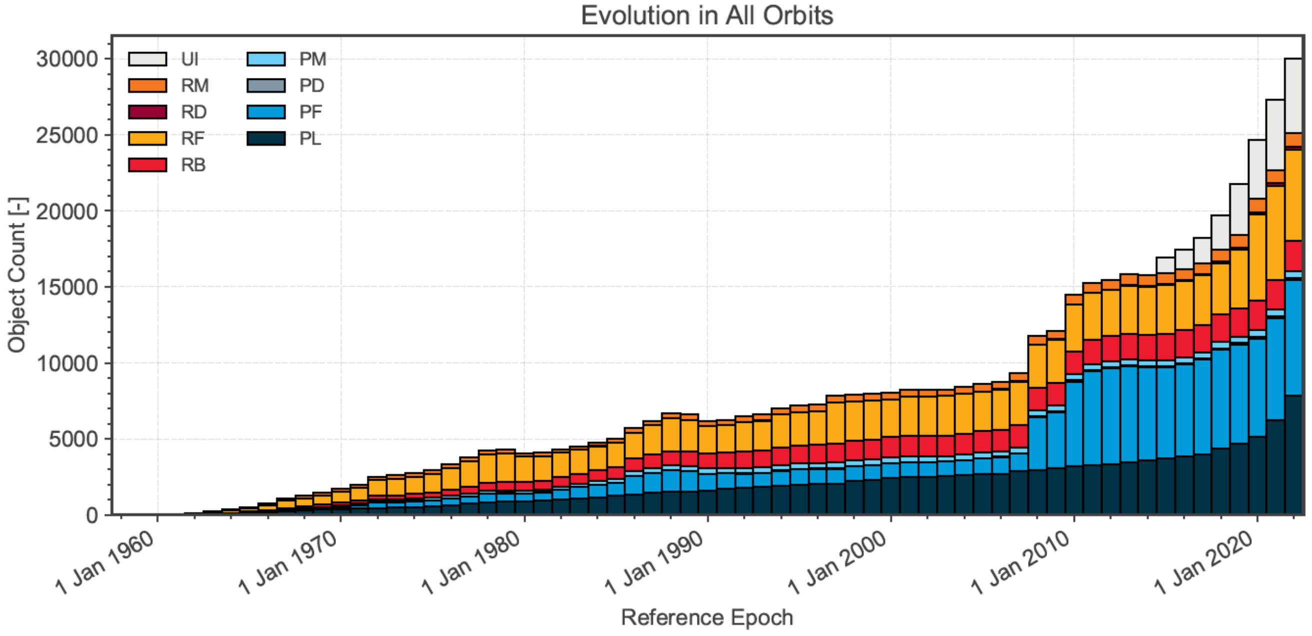
Source: spaceaware.io

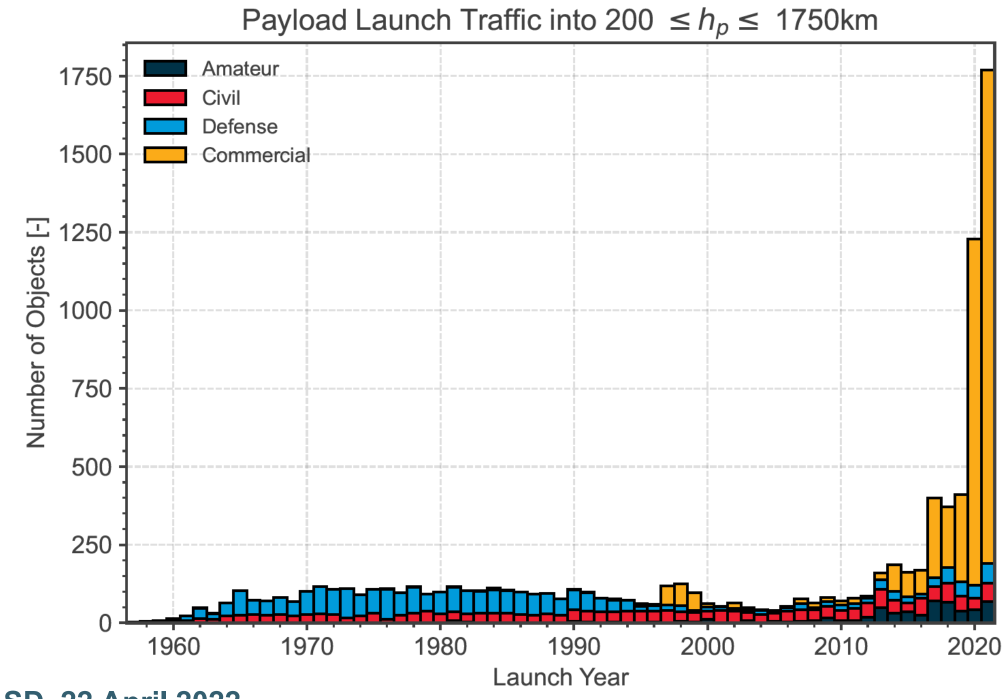
Iridium 119 (October 9, 2017) [783.2 / 786.3 km]
Period: 100.4 minutes

Satellites for Earth Observation and Space Crafts

- Satellites and debris
  - **PL Payload**
  - PF Payload Fragmentation Debris
  - PD Payload Debris
  - PM Payload Mission Related Object
  - RB Rocket Body
  - RF Rocket Fragmentation Debris
  - RD Rocket Debris
  - RM Rocket Mission Related Object
  - UI Unidentified

- Satellites
  - Commercial use satellites in low orbit has an exponential grow
  - Increase demand of *low-cost* systems for ***high-performance space computing (HPSC)*** and communications using commercial hardware
  - New era of remotely sensed big data!!

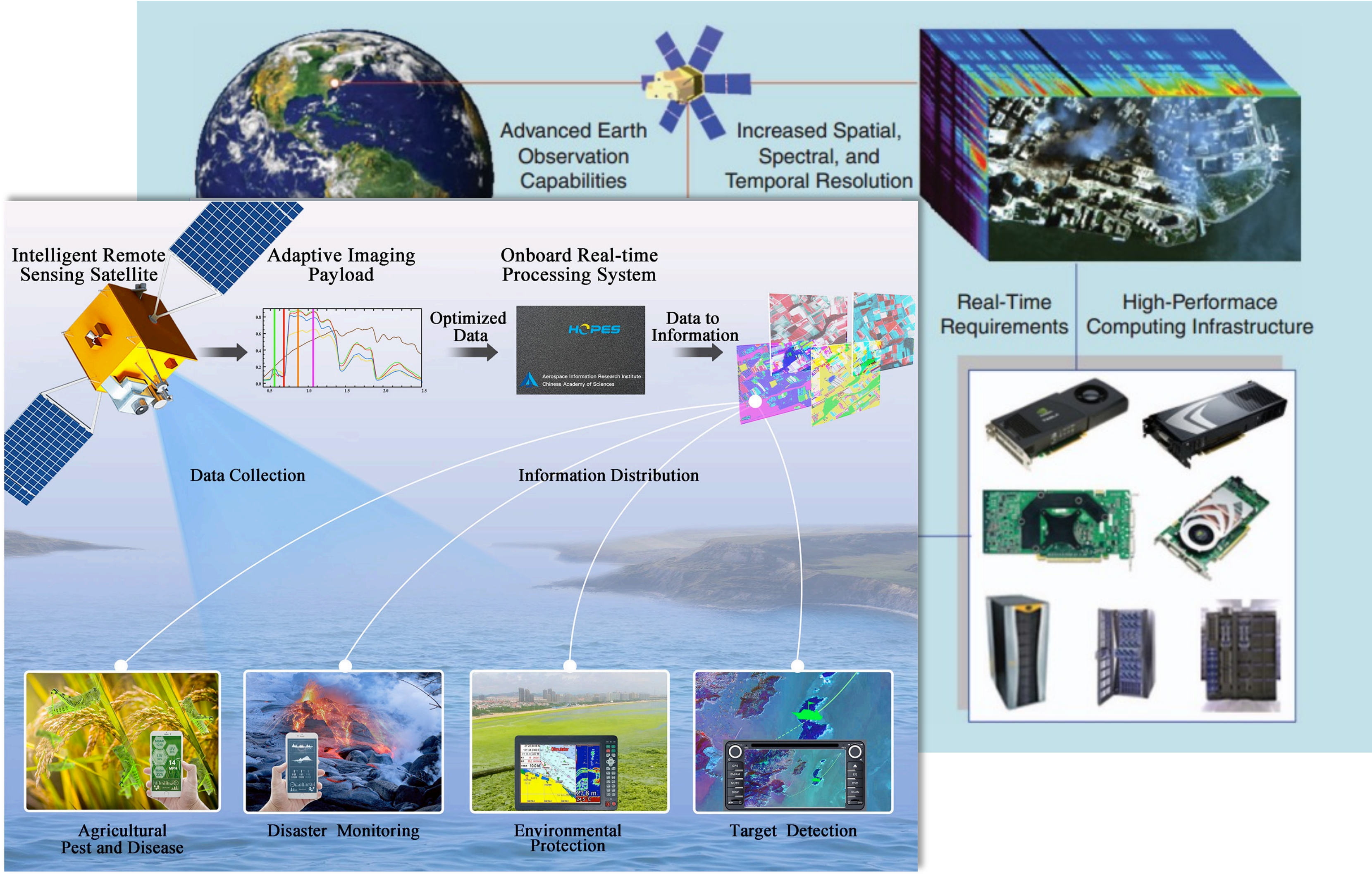




Source: ESA'S ANNUAL SPACE ENVIRONMENT REPORT, GEN-DB-LOG-00288-OPS-SD, 22 April 2022

Satellites for Earth Observation and Space Crafts

- Processing on-board is becoming mandatory
- From typical processing …
    - Radiation correction
    - Geometric correction
    - Calibration
    - Compression
- … to advanced processing:
    - Target detection
    - Classification
    - Cloud detection
    - Extract regions of interest (RoI) or crops of the scene
    - Artificial Intelligence
- *"Satellite information services are moving from large-scale ground stations to on-vehicle, onboard, and hand-held terminals for receiving and transforming"*



Bing Zhang, et al. **Progress and Challenges in Intelligent Remote Sensing Satellite Systems**, IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing, Vol. 15, 2022

Outline

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- **Satellites on-board Hardware**
    - System overview
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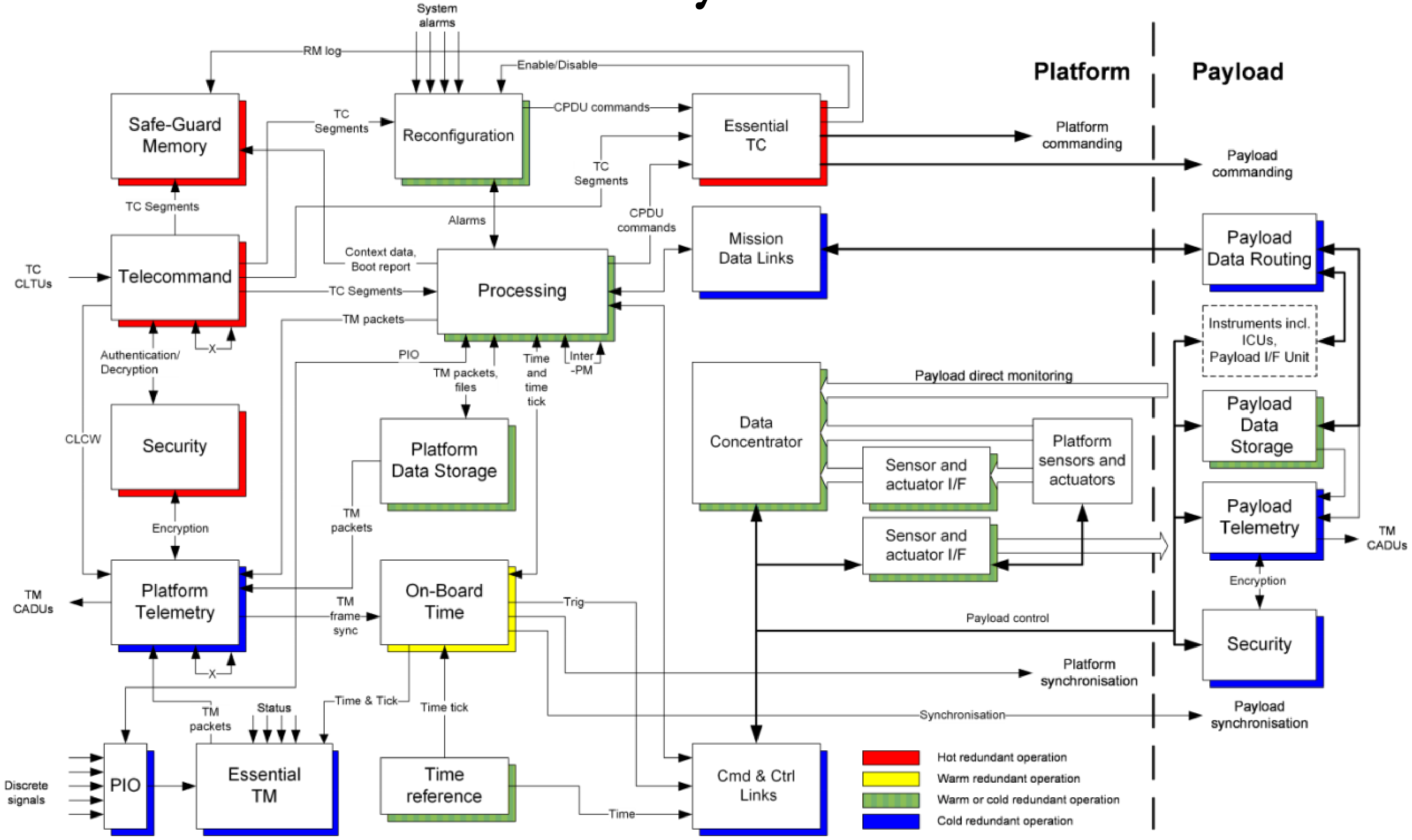
Satellite Hardware: system overview



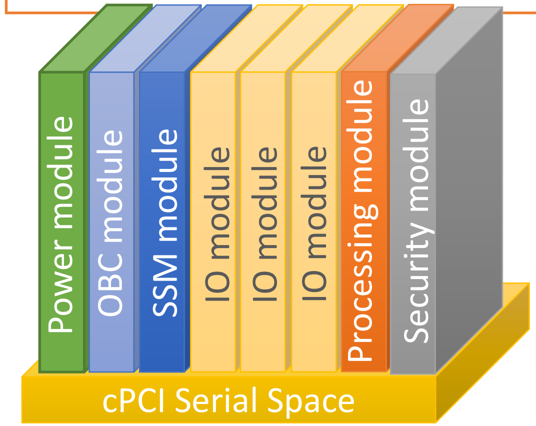
- ESA SAVOIR (Space AVionics Open Interface aRchitecture)
- Complex but solved: modular solution

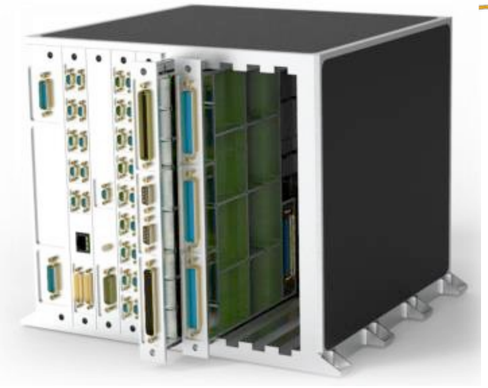
Satellite Hardware: system overview

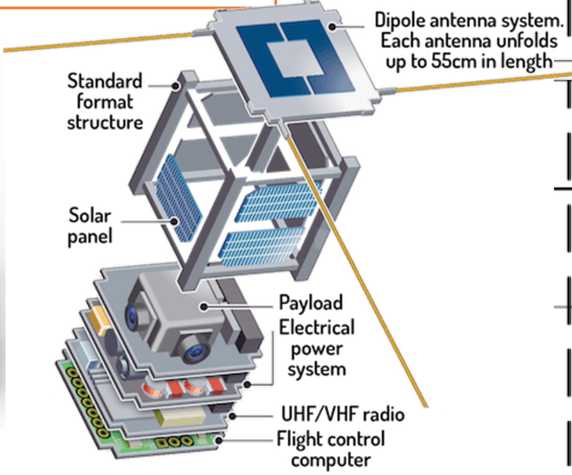
System
alarms

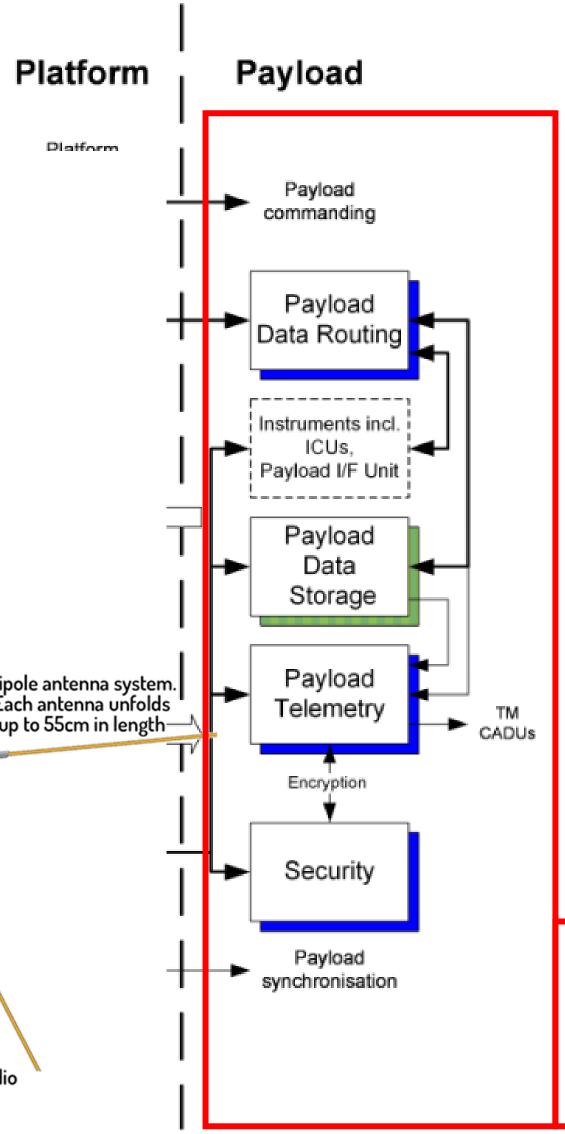
Advanced Data Handling Architecture Modules Products (ADHA-MP):

- ADHA On-Board Computer Module (AOBCM)
- ADHA Mass Memory Module (A3M)
- ADHA Computing Modules (supporting Artificial Intelligence)
- ADHA Generic I/O Module (RTU/ICU modules)
- ADHA Specific I/O Module for AOCS sensors & actuators
- ADHA Specific I/O Module for propulsion valves
- ADHA Data Processing Modules
- ADHA Motor Drive Electronic Modules
- ADHA Security Modules for PF and/or









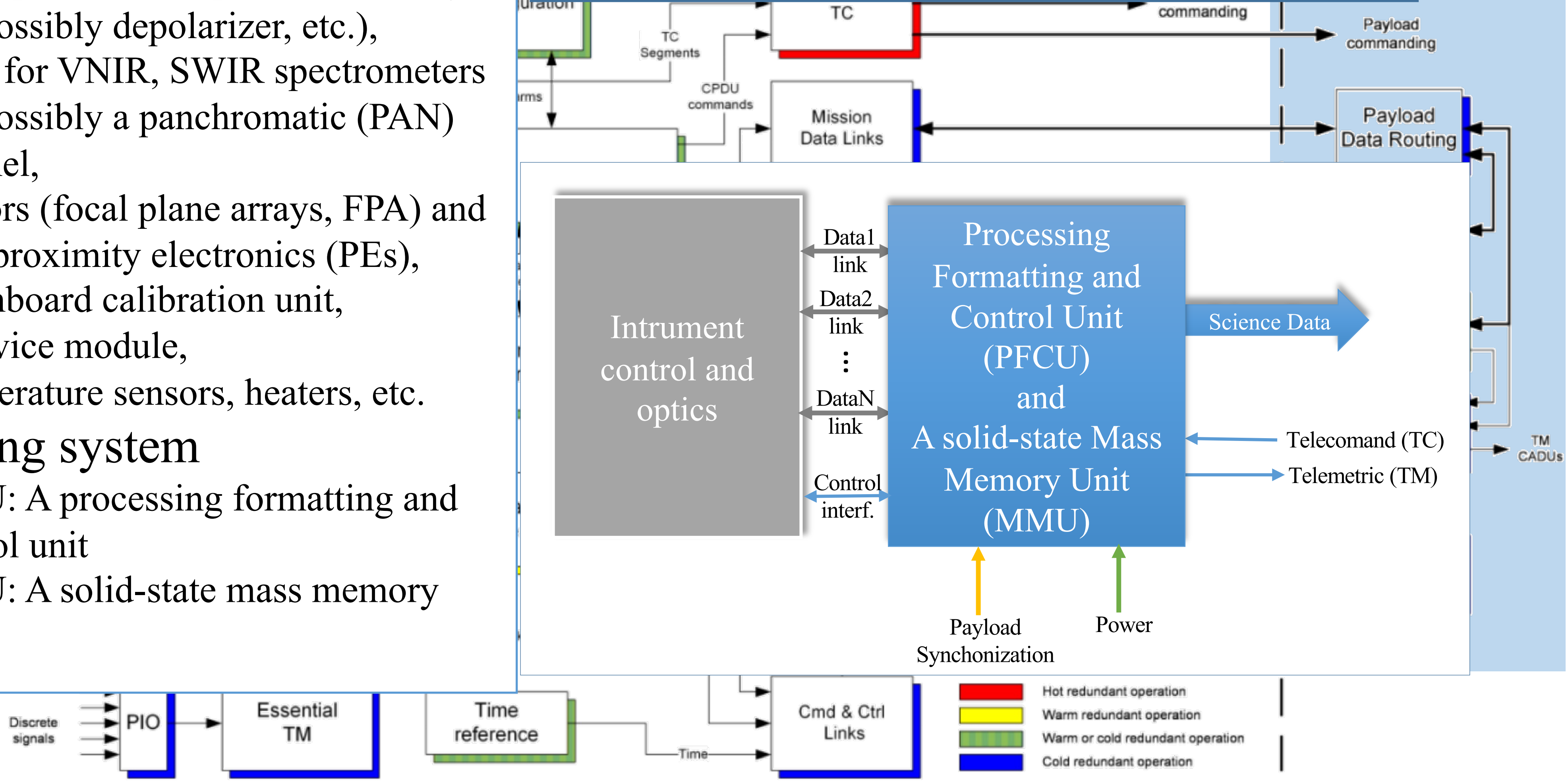
- ESA SAVOIR (Space AVionics Open Interface aRchitecture)
- Complex but solved: modular solution

- High Performance Computing in Space??

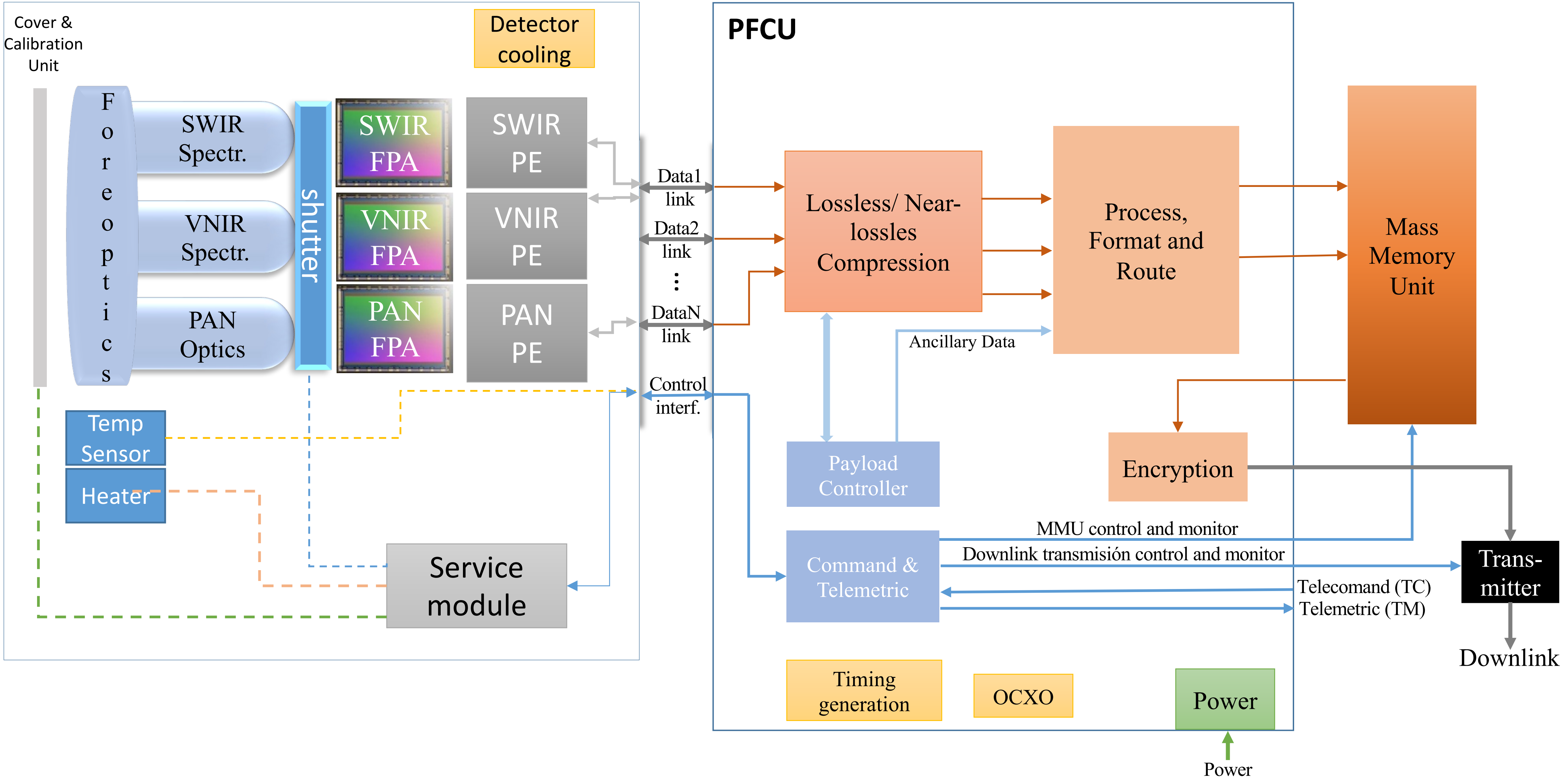
Satellite Hardware: payload processing

- Acquisition system:
  a) Fore-optics (telescope, slit assembly, and possibly depolarizer, etc.),
  b) Optis for VNIR, SWIR spectrometers and possibly a panchromatic (PAN) channel,
  c) Sensors (focal plane arrays, FPA) and their proximity electronics (PEs),
  d) An onboard calibration unit,
  e) A service module,
  f) Temperature sensors, heaters, etc.
- Processing system
  a) PFCU: A processing formatting and control unit
  b) MMU: A solid-state mass memory unit

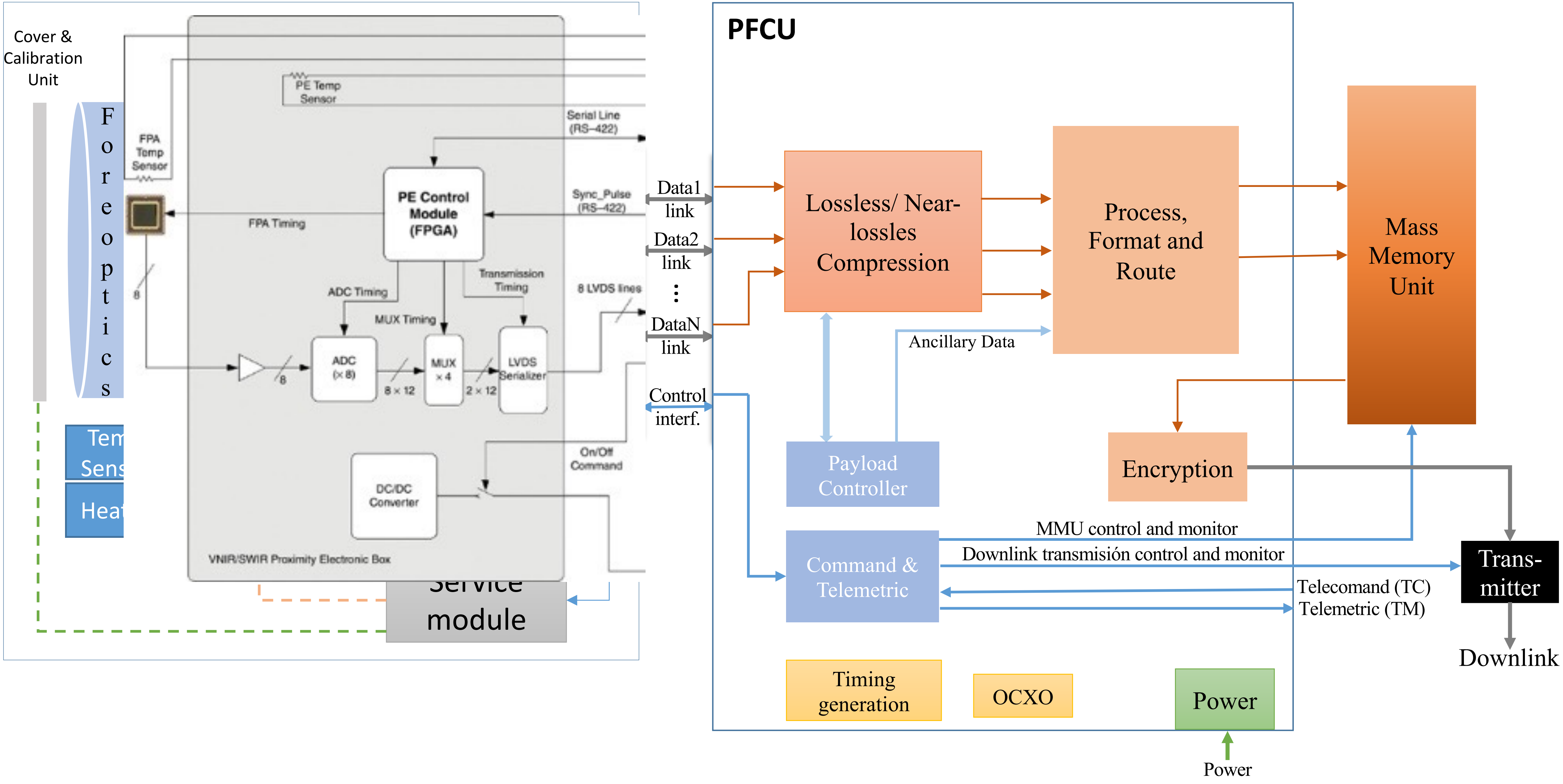
Instrument control and onboard data handling (ICODH)



Satellite Hardware: payload processing



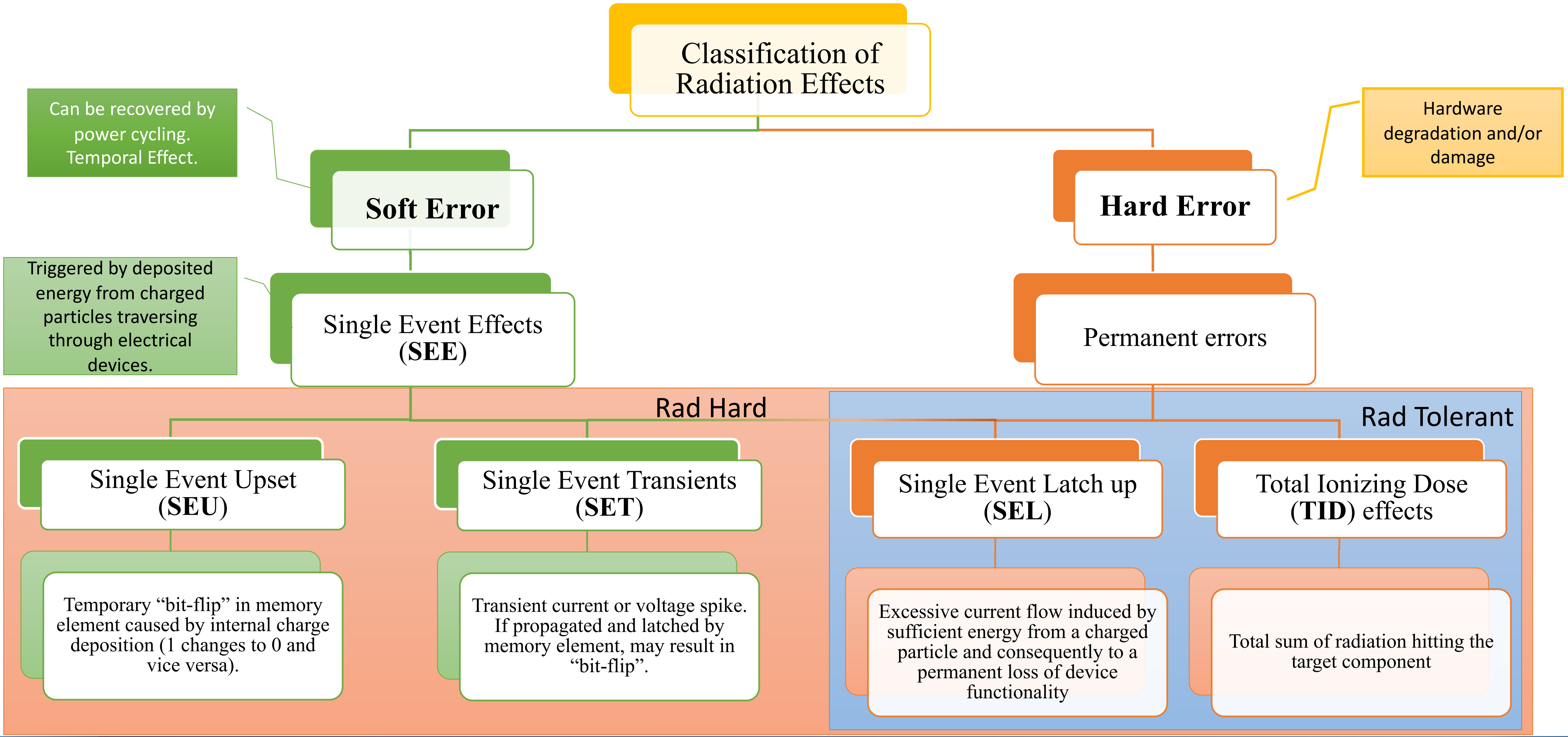
Satellite Hardware: payload processing



Outline

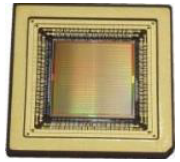
- Satellites for Earth Observation and Spacecrafts
- Satellites on-board Hardware
  - System overview
  - Payload hardware
- **Technology solutions for on-board HPSC**
  - Radiation effects mitigation
  - FPGAs - MPSoCs
- On-board Satellite payload data processing
  - New paradigm?
  - Data and Image Compression
  - Video Compression
  - Information Processing
- Conclusions

Radiation effects mitigation

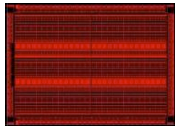


Technology solutions for on-board HPSC

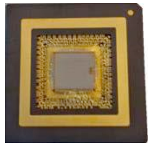
- The computing power of typical on-board computers is strongly limited by the volume, power and mass of nanosatellites.



ATF280F (Atmel, 180nm)

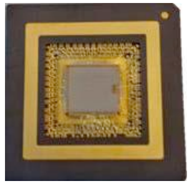


BRAVE-medium (ST, 65nm)

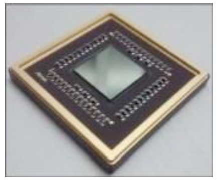


NGMP/GR740
Cobham Gaisler /ST/E2V/ESA

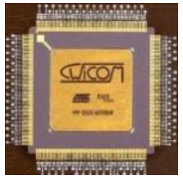
AT697 LEON2FT (Atmel, 180nm)



NGMP/GR740 (ST, 65nm)



VT65 (ST, 65nm)



CWICOM (Atmel, 180nm)

µProcessors/µControllers

It focus on computation, requires peripheral ICs, supports fastest generic computation, and has typical power consumption higher than 10 Watt.

FPGAs

It is a Re-programmable logic, has IP-cores for specific and complete micro-controllers, provides fast and low power for specific functions, has higher power than micro-controllers.

OBDH

Hardware of the satellite **on-board Data Handling** computing platforms

ASICs

It is a complete hardware solution for specific application, supports IP-cores for specific function, and has fast and power efficiency.

MP-SOCs

It provides a complete hardware and generic application. It has the smallest complete systems.

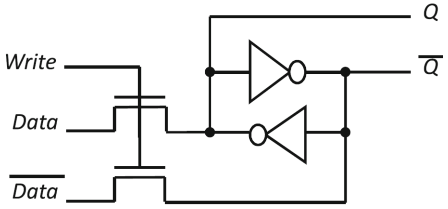
RTG4™

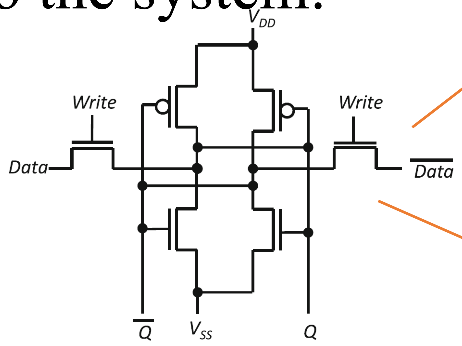
Kintex™UltraScale™ XQRKU060

NanoXplore NG-Ulitra

Technology solutions for on-board HPSC: FPGAs

- Programmable logic to provide configurability to the system:
  - SRAM technology:
    - The most used
    - Non-permanent
    - Reconfigurability
    - No radiation hardness





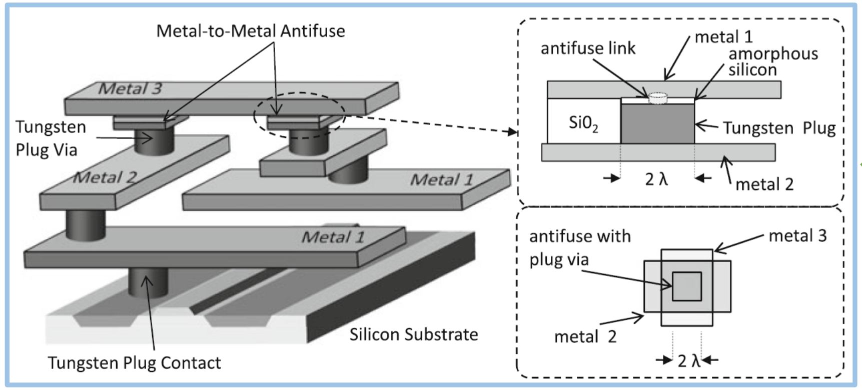
- Virtex-4QV
- Virtex-5QV
- XQRKU060 UltraScale

XILINX (AMD)

- NG-Medium
- NG-Large
- NG-Ultra

NanoXplore

  - Antifuse technology
    - Permanent
    - Radiation hardness
    - One Time Programmable (OTP)
    - Best performance

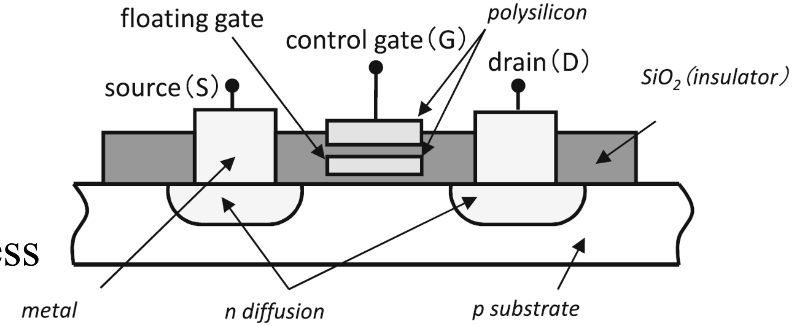


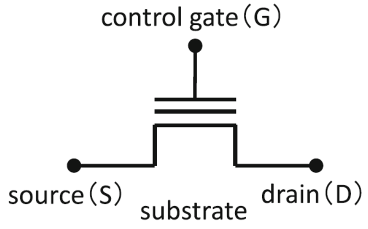
- RTAX series

Microsemi (Microchip)

- RTG4 FPGAs
- RT ProASIC3
- RT PolarFire

  - FLASH memory
    - Permanent
    - Reprogrammable
    - Medium radiation hardness

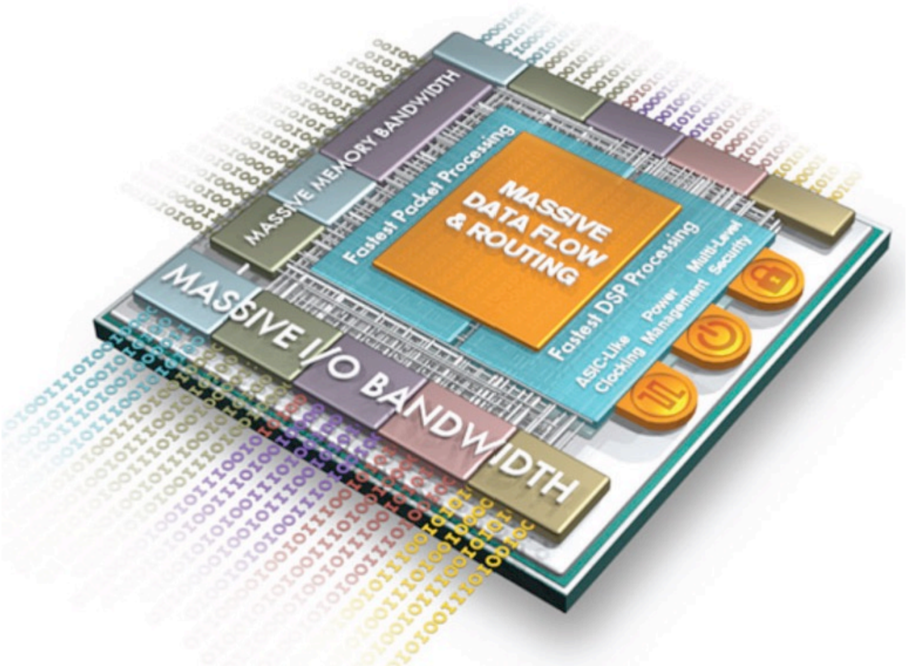




ALTERA (Intel)

FPGAs

Example FPGA: Rad Tolerant

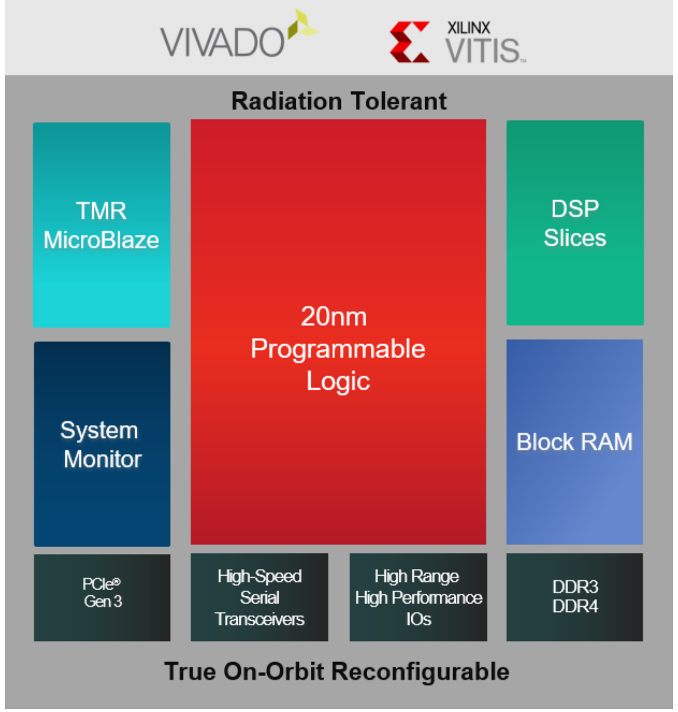


	Virtex-4QV XQRV4QV	Virtex-5QV XQRV5QV	RT Kintex UltraScale XQRKU060
Radiation Hardness	Tolerant	Hard	Tolerant
Process (nm)	90	65	20
Memory (Mb)	4.1 to 9.9	12.3	38
System Logic Cells (K)	55 to 200	131	726
CLB Flip-Flops (K)	49.1 to 178.1	81.9	663
CLB LUTs (K)	49.1 to 178.1	81.9	331
Transceivers	None	18 at 3.125Gb/s	32 at 12.5Gb/s
User I/O	640 to 960	836	620
DSP Slices	32 to 192	320	2,760

Xilinx® Radiation Tolerant (RT) Kintex® UltraScale™ XQRKU060 FPGA

- 20 nm technology
- Key advantages of RT Kintex UltraScale:
  - True Unlimited On-Orbit Reconfigurable Solution
  - >10X DSP Compute increase for Processing Intensive Algorithms & Analytics
  - Full Radiation Tolerance across All Orbits
  - 331K 6-inputs LUTs; 2760 DSPs.

- MicroBlaze™ processor technology, fault tolerant, fail-safe, 32-bit RISC CPU, which can be instantiated within the FPGA.
  - This soft IP achieves a performance above 300MHz
  - Requires approximately 7,400 LUTs and 6,400 flip-flops
  - Has been implemented using a TMR



FPGAs - MPSoCs

- 28 nm STMFDSOI process technology.
- On-chip thermal monitoring capability.
- Processors
  - A full System-On-Chip (SoC) based on a quad-core ARM Cortex R52
- FPGAs
  - 4-Input Look-up tables (536928 LUTs).
  - LUT expender to support up to 16 bits boolean functions.
  - Advanced interconnect network to support random logic and coarse grain block functions.
  - DSP Blocks for complex arithmetic operations (1344 DSPs).
  - User memories with variable width and depth.
  - Configuration modes: Master Serial SPI (Single, Sequential, TMR), SpaceWire.
  - Dedicated lowskew distribution network for clock, reset and load enable signals.

Interfaces

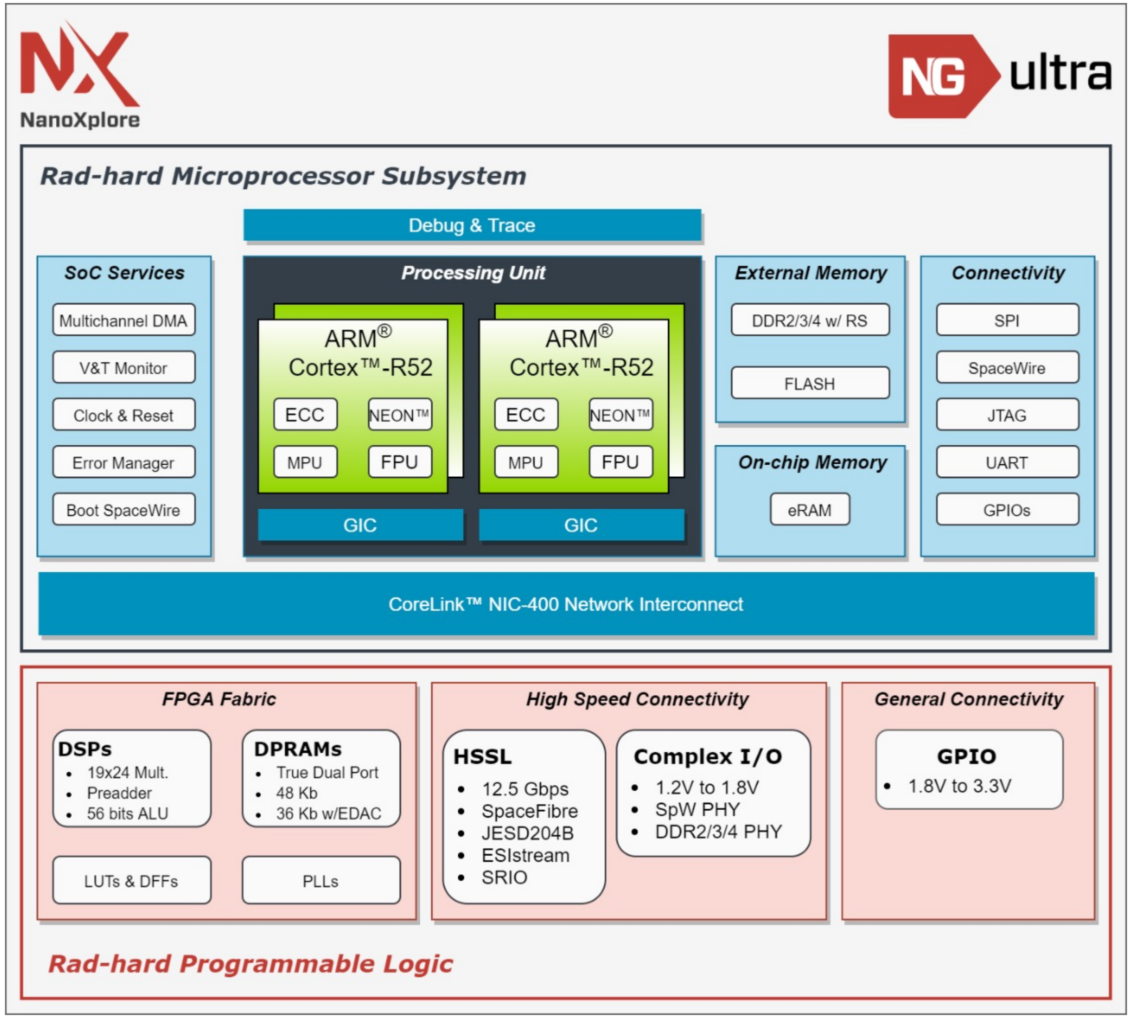
Integrated Space Wire interface available for user applications.
Multiple I/O powering support from 1.2V to 3.3V
Embedded logic to support DDR2, DDR3 and DDR4.

Radiation Tolerance

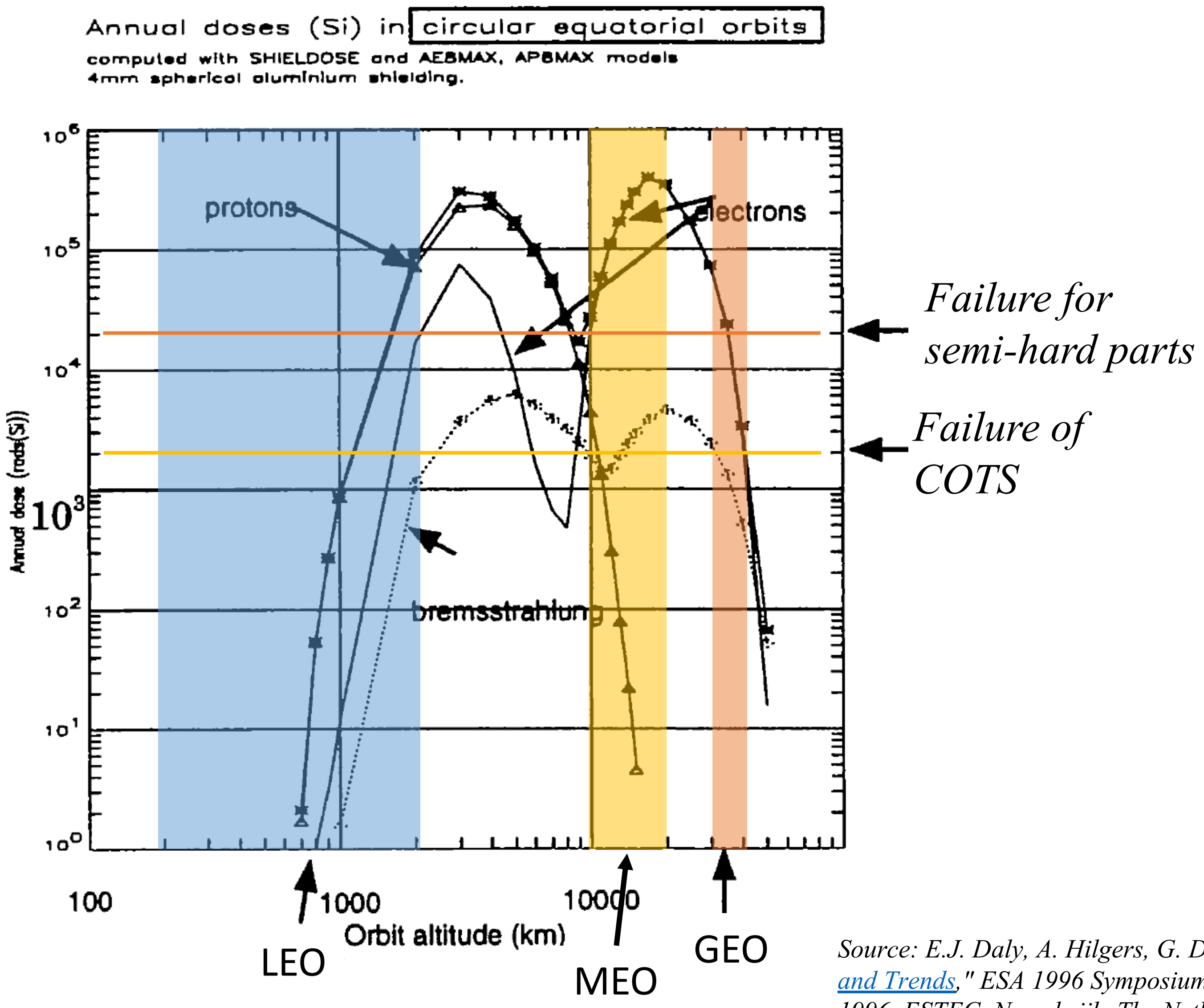
Radiation hardening by design in configuration memories and registers.
SEU immune up to LET > 60MeV.cm2/mg.
Total ionizing dose > 50Krads (Si).
Embedded EDAC for user memory mitigation.
Embedded configuration memory scrubbing.
Fast automatic memory configuration repair.
Embedded bitstream integrity check (CMIC).

Example MPSoC: Rad hard

NanoXplore NG-ULTRA: European FPGA



Radiation effects mitigation



Radiation annual dose

- Possibility to use COTS in many of LEO missions.
- But SEU errors are possible.
- Techniques to mitigate this errors:
  - Hardware Triple Module Redundancy (TMR) or Double Module Redundancy (DMR).
  - Software processing in two processors at the same time
  - Error Correction and Detection with Memories.
  - Memory scrubbing.
- Xilinx provides Soft Error Mitigation (**SEM**) IP:
  - Enhanced correction capabilities, essential bits monitoring and fault injection for validation.

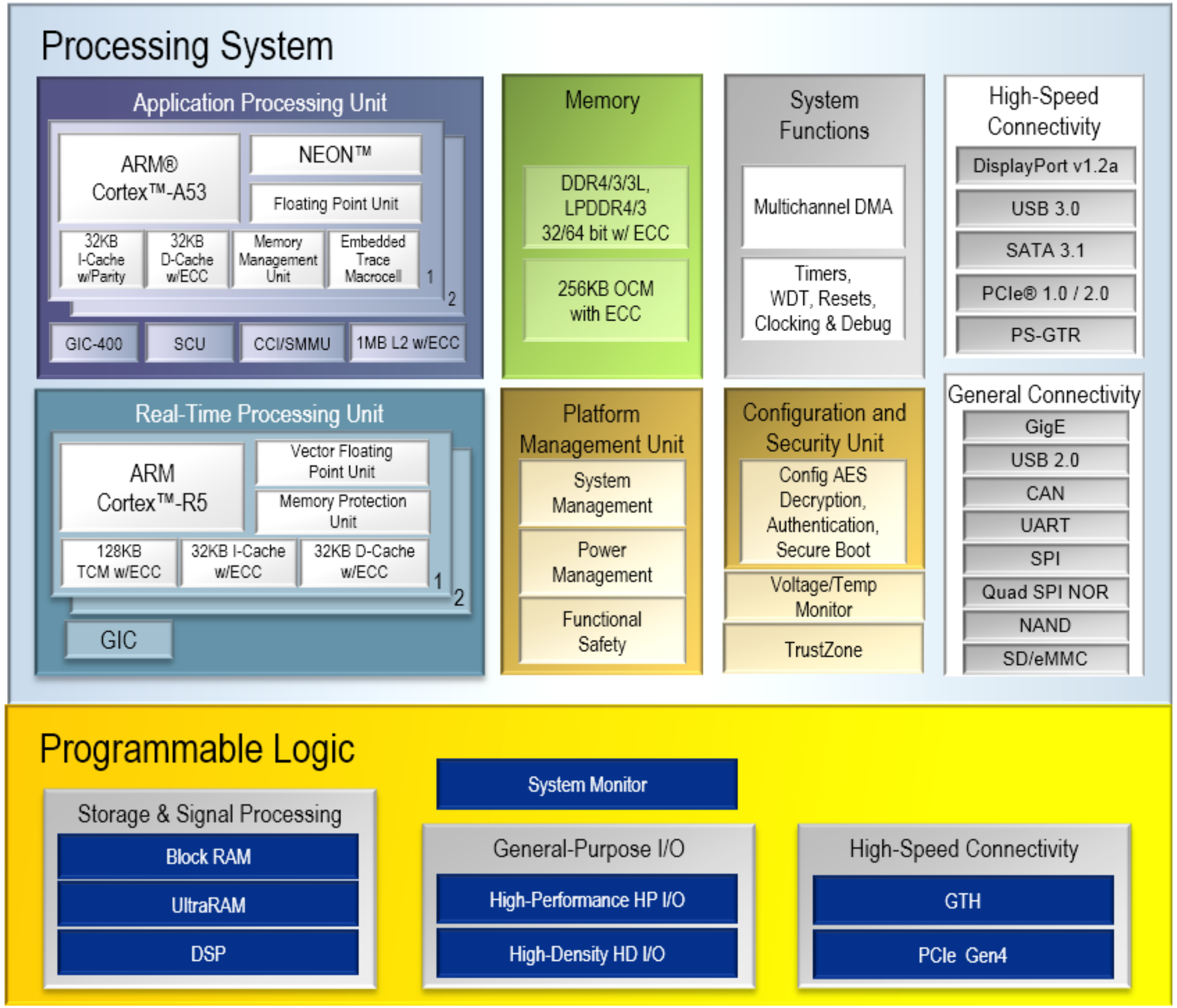
Source: E.J. Daly, A. Hilgers, G. Drolshagen, and H.D.R. Evans, "Space Environment Analysis: Experience and Trends," ESA 1996 Symposium on Environment Modelling for Space-based Applications, Sept. 18-20, 1996, ESTEC, Noordwijk, The Netherlands

FPGAs – MPSoCs

Example MPSoC: : COTS HPSC

Zynq UlstrScale+

- Based on Zynq Ultrascale+
- XCZU4CG-2LE-I (low power, industrial temperature range).
  - 2 ARM Cortex-A53 up to 1.5 GHz for computing
  - 2 ARM Cortex-R5 up to 600 MHz for Real-Time.
  - NEON engine is a specialized vector processing engine.
  - 1 GB of DDR4-2400 with EDAC.
  - Programmable logic.
- External PS interfaces: I²C, SPI, CAN, RS-485, UART



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On-board Satellite payload data processing

Digital processing on-board

- Calibration.
- Compression.
- Object detection.
- etc.

It is different in space? Yes!!!

- High processing power.
- Different missions: different objectives.
- Difficulties to adapt to different payloads, requiring custom solution.
  - i.e.: Earth observation vs. debris detection.

Space standards

- CCSDS standards.

Lack of testing data

HPSC: High Performance Space Computing

- It is hard to achieve onboard real-time processing without systematic optimization design for specific targets.
- *“The key to a breakthrough is the development of new computing architectures, such as information extraction algorithms for non strict quantitative data processing”.**
- Cross-level collaboration architectures of algorithm-software-hardware is required.
  - Heterogenous Computing.

Two examples:

- Adaptative compression based on cloud removal
- IA for object detection and tracking.

* Bing Zhang, et al. **Progress and Challenges in Intelligent Remote Sensing Satellite Systems**, IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing, Vol. 15, 2022

On-board Satellite payload data processing

Example 1

Copernicus HPCM (High Priority Candidate Missions)
CHIME (Copernicus Hyperspectral Imaging Mission For The Environment)

Copernicus Hyperspectral Imaging Mission (CHIME)

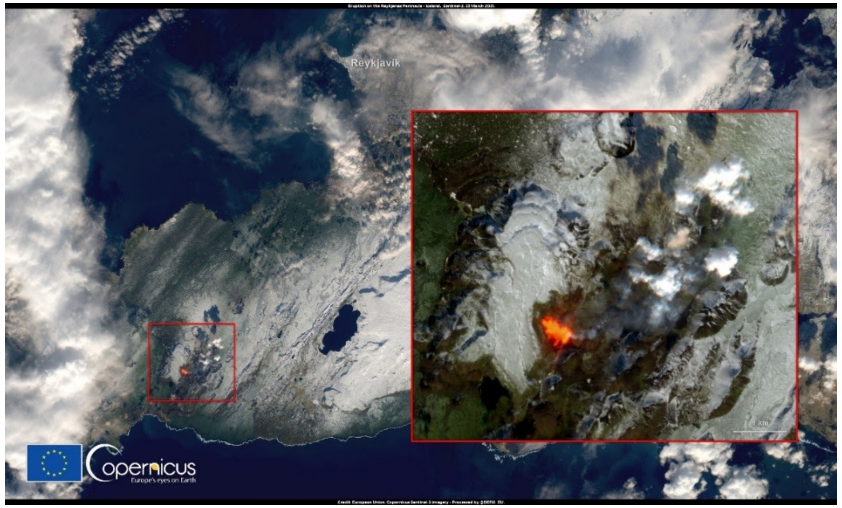
The CHIME mission aims to augment the Copernicus space component with precise spectroscopic measurements to derive surface characteristics in support of the monitoring, implementation and improvement of policies in the domains of raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, snow, forestry and the urban environment.

Agriculture

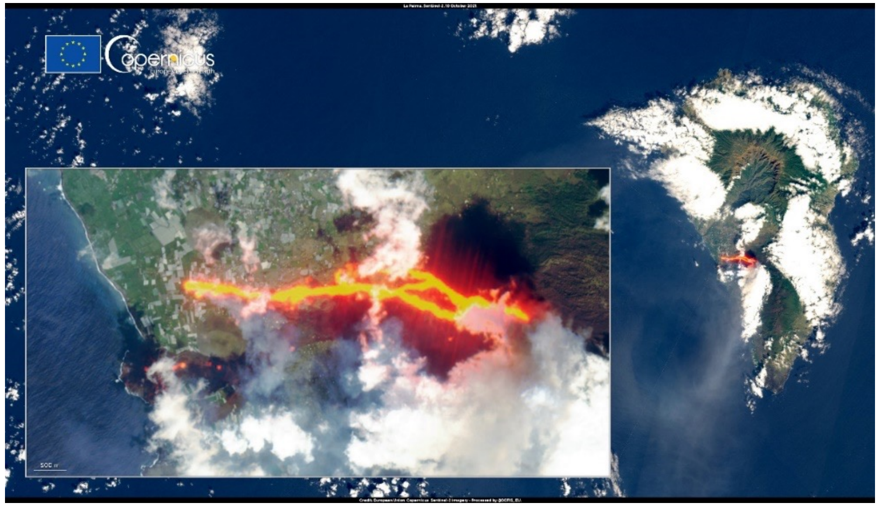
Biodiversity Monitoring

Urban Monitoring

455 M EUR*



Volcanic Eruption at the Krýsuvík-Trölladyngja volcanic system, Iceland. This image, acquired by one of the Copernicus **Sentinel-2** satellites on 23 March 2021, shows the volcanic eruption in Iceland's Reykjanes peninsula.



Volcanic Eruption in La Palma, Canary Islands, Spain. This Image acquired by one of the Copernicus **Sentinel-2** satellites on 10 October 2021, shows the lava stream from the Cumbre Vieja volcano.

On-board Satellite payload data processing

Copernicus HPCM (High Priority Candidate Missions) CHIME (Copernicus Hyperspectral Imaging Mission For The Environment)

Example 1

Copernicus Hyperspectral Imaging Mission (CHIME)

The CHIME mission aims to augment the Copernicus space component with precise spectroscopic measurements to derive surface characteristics in support of the monitoring, implementation and improvement of policies in the domains of raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, snow, forestry and the urban environment.

Agriculture

Biodiversity Monitoring

Urban Monitoring

455 M EUR*

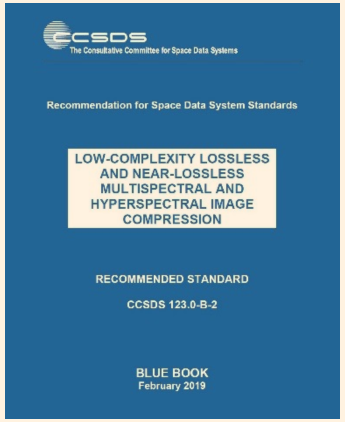
- System requirements:
  - Future space mission to complement COPERNICUS "Sentinels"
    - 2 Hyperspectral sensors (VNIR and SWIR) with 220 spectral bands each.
  - High volume of data => On-board Compression mandatory.
  - Clouds covers more than 50% of the Earth surface.
    - Significant presence of Clouds in CHIME continuous acquisitions.
    - Opaque Clouds are less useful to estimate Earth surface properties.
  - Possibilities to increase on-board data reduction with a selective compression applied on clouds.

European Space Agency.
Thales Alenia Space in Spain.
Thales Alenia Space in France.
IUMA/ULPGC.

- System requirements:
  - Performance requirements.
    - Real time: one sample per cycle.
    - 125 MHz of clock frequency.
  - Xilinx® Radiation Tolerant (RT) Kintex® UltraScale™ QRKU060 FPGA

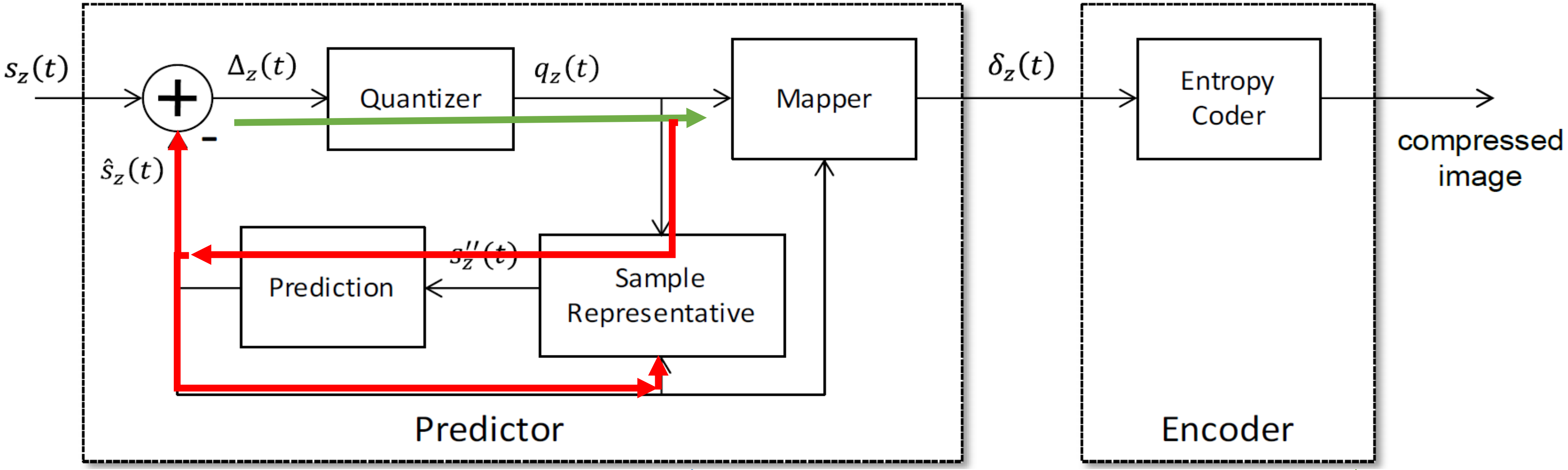
On-board Satellite payload data processing

Example 1



CCSDS 123.0-B-2

Lossless and Near-lossless Multi/Hyperspectral Compressor



Wide local sums

x1 $s''_{z,y-1,x-1}$	x1 $s''_{z,y-1,x}$	x1 $s''_{z,y-1,x+1}$
x1 $s''_{z,y,x-1}$	$s''_{z,y,x}$	

Narrow local sums

(Favours pipelining)

x1 $s''_{z,y-1,x-1}$	x2 $s''_{z,y-1,x}$	x1 $s''_{z,y-1,x+1}$
$s''_{z,y,x-1}$	$s''_{z,y,x}$	

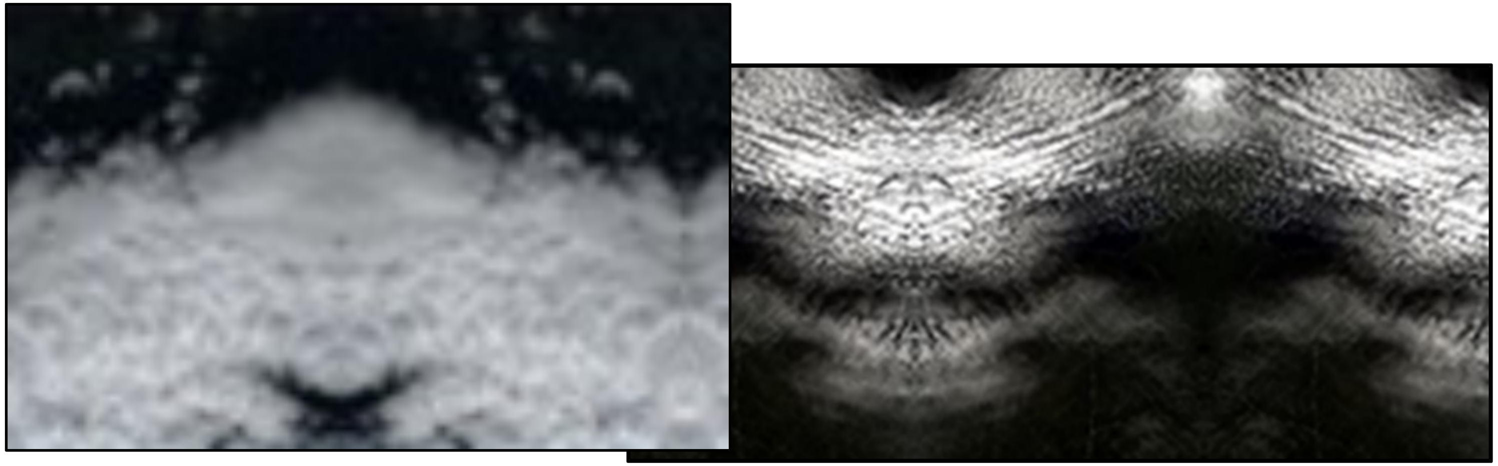
Predicts the current sample with a weighted sum of neighbors

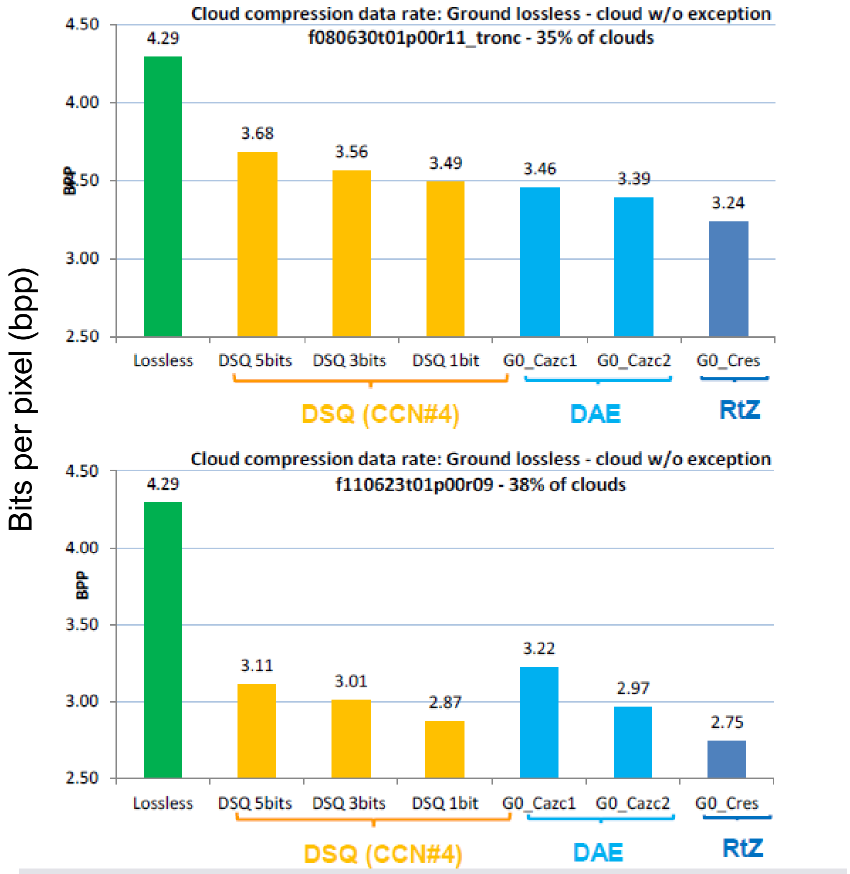
Rice encoding technique. Minimizes the number of bits in a coded block of J samples

On-board Satellite payload data processing

Example 1

- Solution analysis
  - Solution 1: **DSQ**. Some bits of pixel-clouds are set to 0.
  - Solution 2: **DAE**. Different errors for pixel-clouds and pixels-no_clouds.
  - Solution 3: **RtZ**. Set the residuals of cloud-pixels to '0'.
- Best in performance RtZ (12% better than DSQ) but introduce outliers.
- Selected: **DAE** (Not the best but it doesn't create outliers).
- Tested with AVIRIS images.

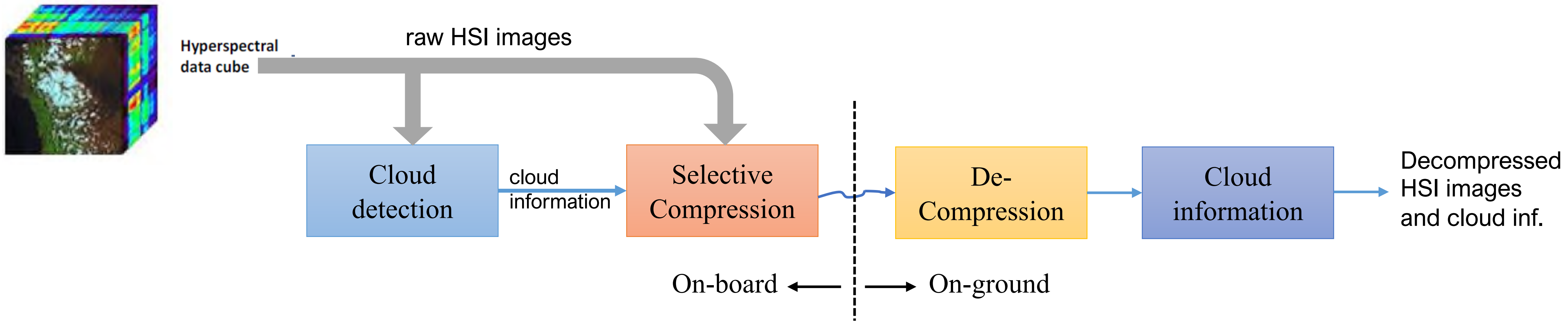




On-board Satellite payload data processing

Example 1

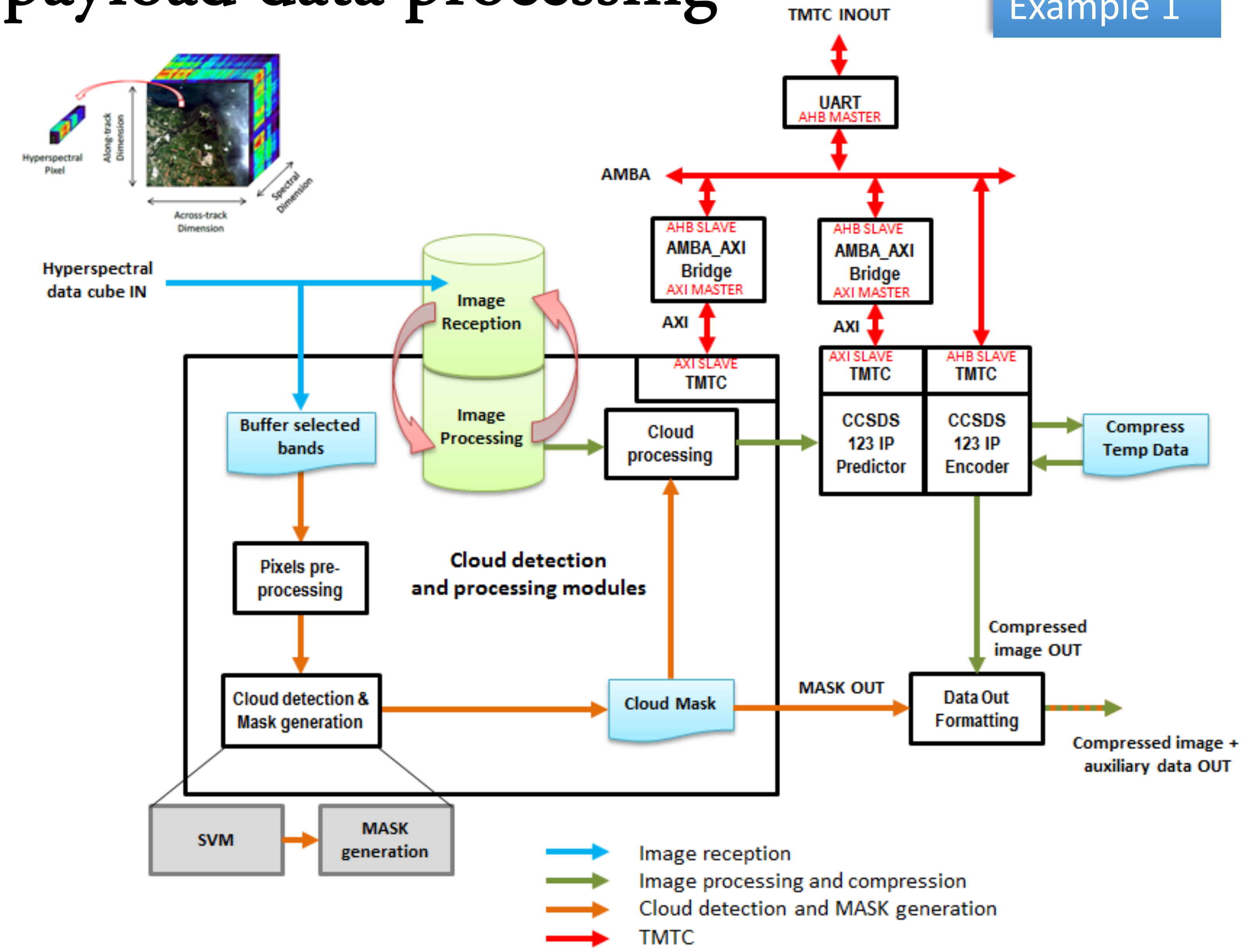
- Cloud detection and processing algorithms.
- Selected for implementation in the Demonstrator:
  - Cloud Detection: Support Vector Machine (SVM) approach
    - Cloud mask generation: indicates per each pixel if it is cloud (mask = '1') or not (='0')
  - Cloud Processing
    - Pre-quantization for the pixels detected as cloud to improve posterior compression in less useful areas



On-board Satellite payload data processing

Example 1

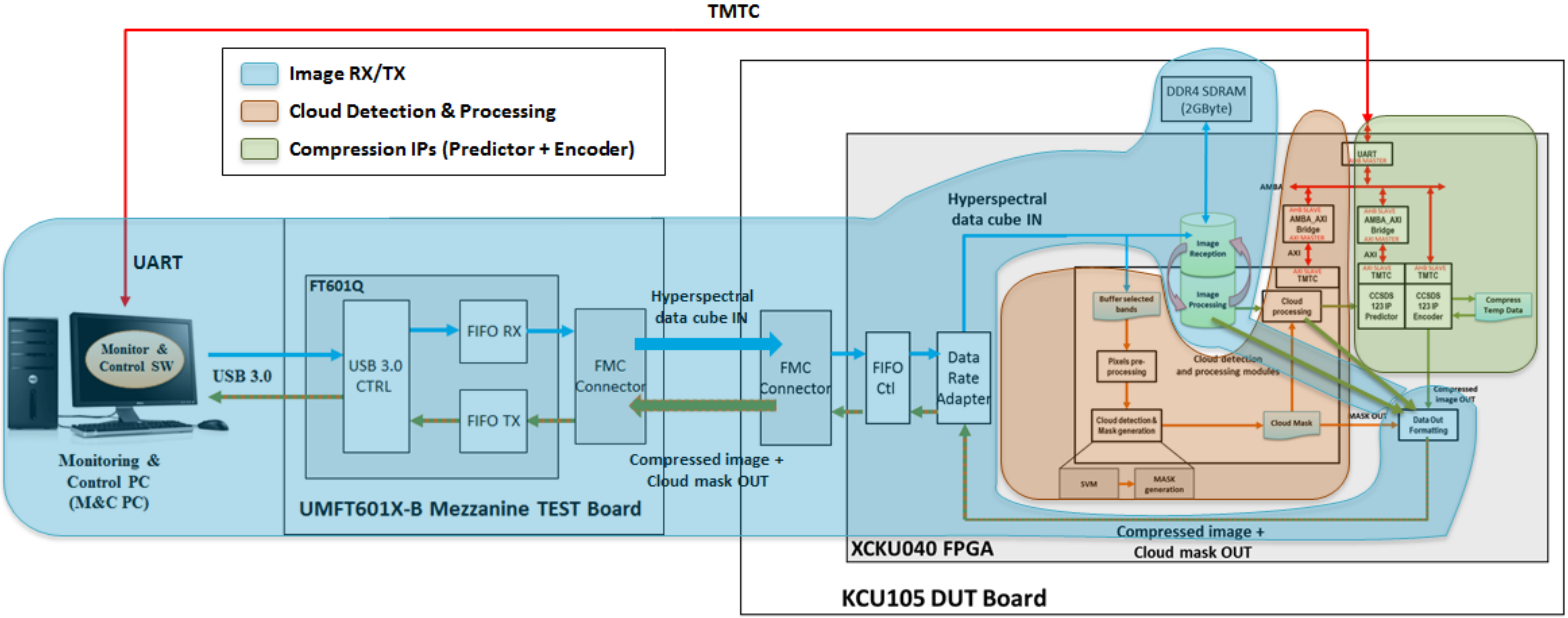
- Image reception up to 2Gbps (16 bit samples processed at 125 MHz clock cycle)
- Cloud detection over selected bands: Cloud mask
- Cloud processing
- CCSDS 123 Compression
- Data formatting: processed image + cloud mask
- Compressed image transmission
- TMTC (Telemetry and Telecommand) module for design configuration



On-board Satellite payload data processing

Example 1

- Demonstrator TEST Procedure

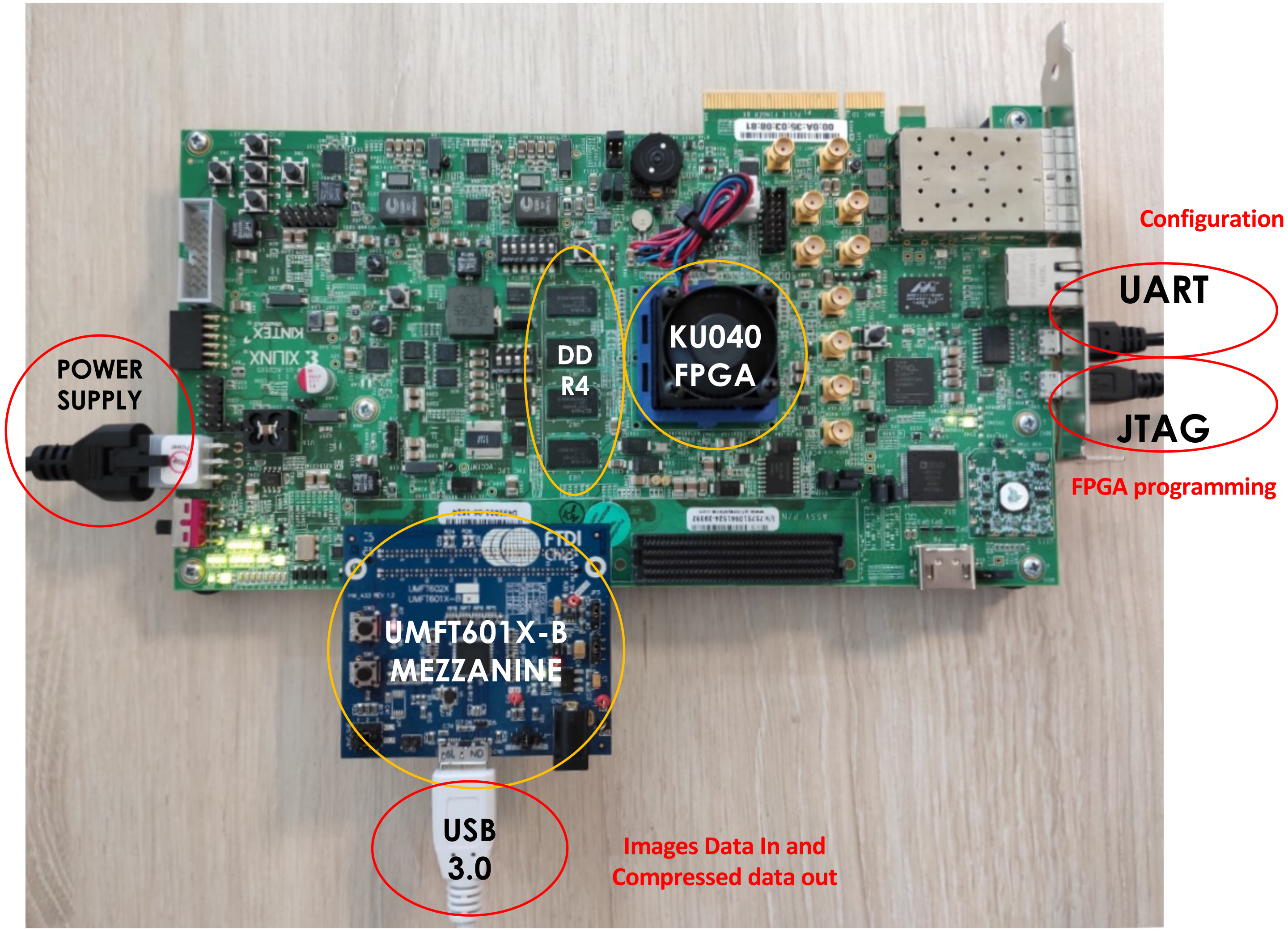


On-board Satellite payload data processing

Example 1

HW Description: KCU105 DUT board + UMFT601X-B Test Mezzanine

- UMFT601X-B Mezzanine
  - Manufacturer: FTDI
  - USB 3.0 to FIFO interface bridge
  - 2 parallel FIFOs with up to 32 bits at 66,67 MHz (Max 2,13344Gbps)
- KCU105 board
  - Manufacturer: Xilinx
  - FPGA: Xilinx Kintex Ultrascale, XCKU040-2FFVA1156E
  - External Memory: 16 Gb DDR4
  - Control interface: UART
  - Data Input and output interfaces: FMC connector
  - USB JTAG to program the FPGA



VIDEO

VIDEO
AN EU-FUNDED H2020

VIDEO IMAGING DEVICE FOR EARTH OBSERVATION

EXAMPLE 2

AMOS ADVANCED MECHANICAL AND OPTICAL SYSTEMS
UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA
pyxalis
POLY-SHAPE addiCtive manufacturing
ThalesAlenia Space a Thales / Leonardo company

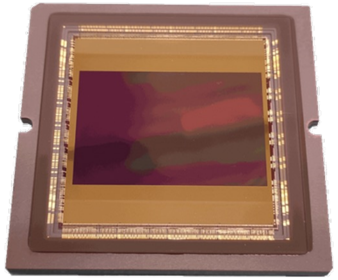
This project has received funding from the European Union's H2020 research and innovation programme under grant agreement No 870485.

On-board Satellite payload data processing

Example 2

Video Imaging Device For Earth Observation

- The project aims to develop a highly-disruptive technology for a next-generation instrument offering Video Observation of Earth.
- A novel architecture will be demonstrated, based on state-of-the-art technologies for **mirrors** (freeform), **structures** (additive manufacturing) & **detection** (new generation detector & processing chain).
- It will allow to answer new types of problematics and missions, anticipating the emergence of on-board smart algorithms.
- Partners:
  - Thales Alenia in Space France SAS (coordinator)
  - Thales Alenia in Space Spain
  - **University of Las Palmas de Gran Canaria**
  - Poly-Shape (now AddUp)
  - Pyxalis
  - AMOS

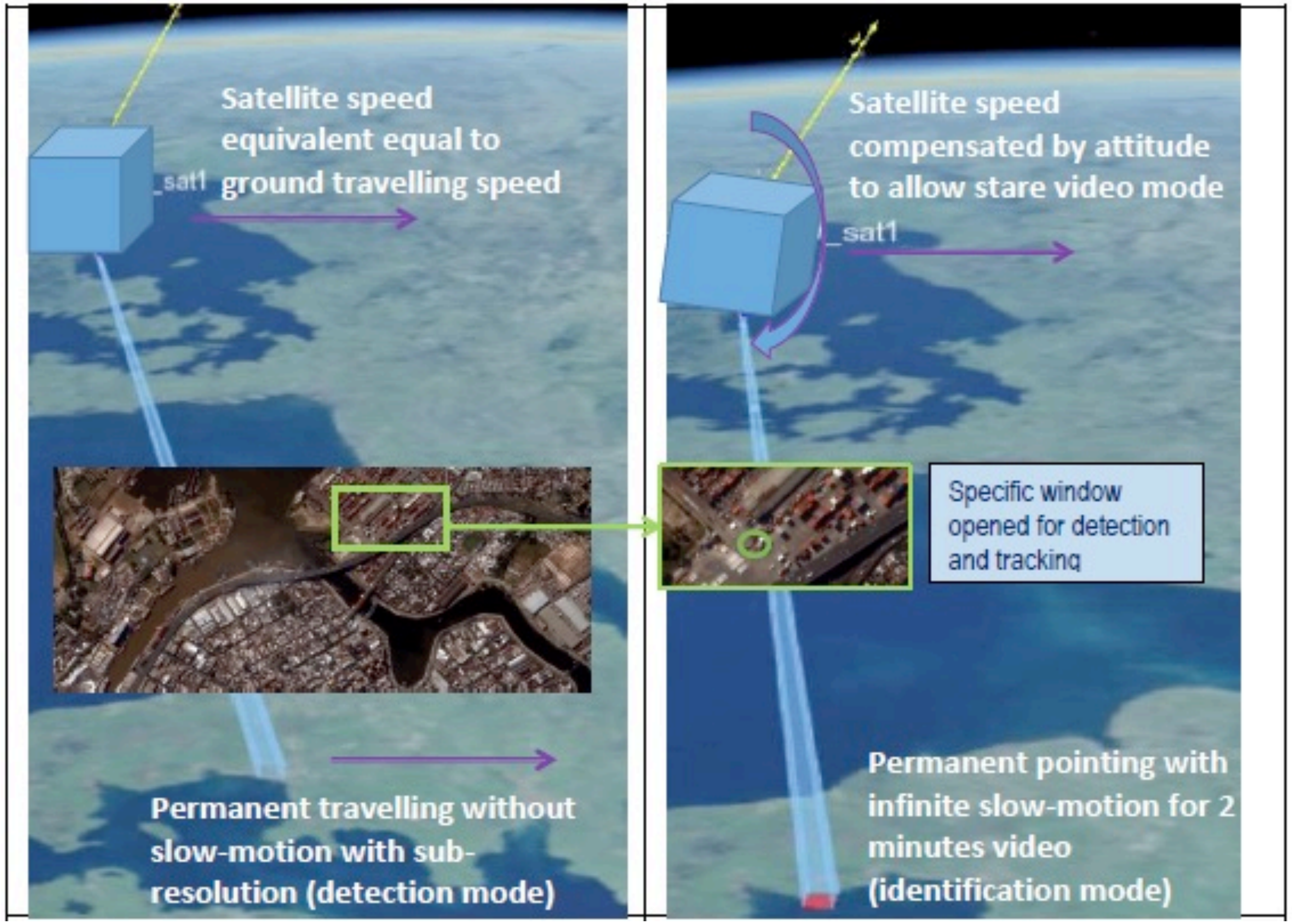


Gigapyx RGB sensor from Pyxalis is expected to provide a large image in terms of spatial resolution (48Mpixels). 10 FPS for HD video sequences

On-board Satellite payload data processing

Example 2

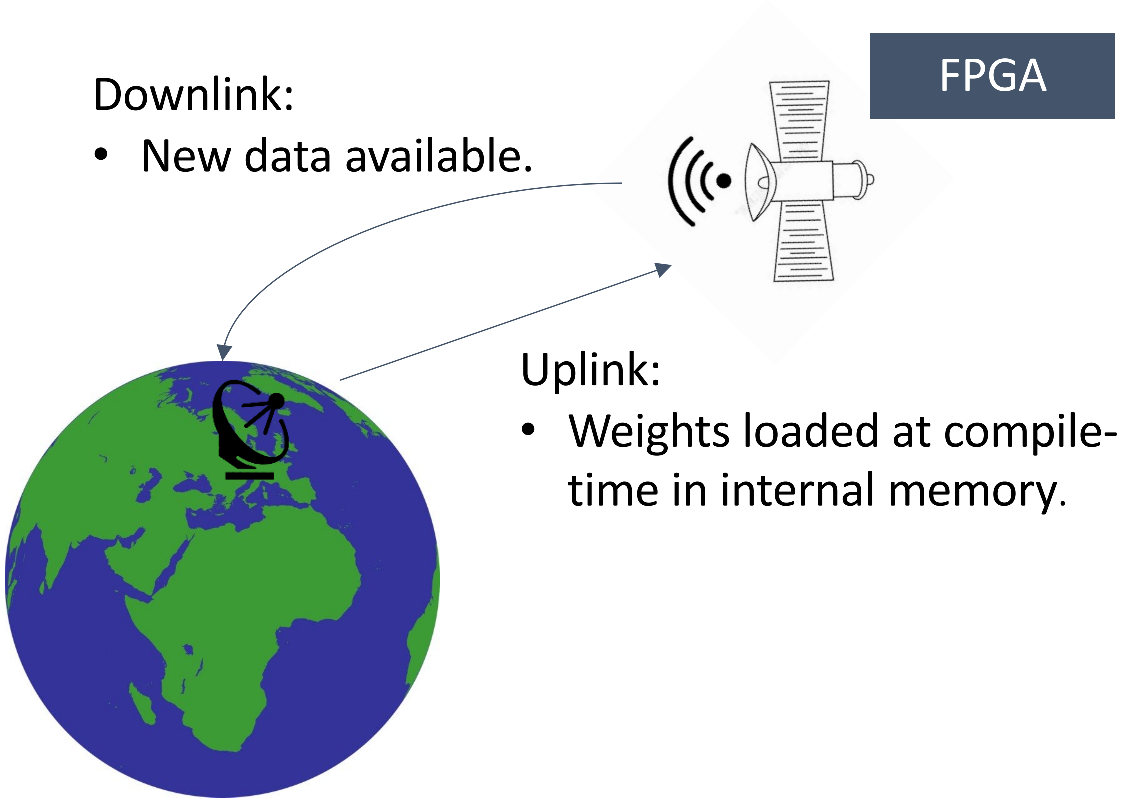
- GOALS OF THE VIDEO CHAIN
  - Capable of perform high-resolution RGB images and video monitoring on an extremely wide scene.
  - Two modes of operation: detection (image mode) and compression plus tracking (video mode).
    - **Image mode:** detecting objects in the acquired scene.
    - **Video mode:** tracking of the object of interest and smart video compression of the ROI.
  - Flying trajectory and speed known in advance → Motion estimation seems not relevant.
  - Adapt the video compression ratio depending on the satellite available resources and to the available downlink bitrates.
  - Implemented on a Radiation Tolerant FPGA: Xilinx UltraScale XCKU060.



On-board Satellite payload data processing

Example 2

- Detection: Proposed detection solution
  - Based on convolutional neural networks (CNNs)
  - High detection capabilities
  - A single CNN architecture can be trained for different purposes.
  - The detection performance can be modified by replacing the pre-trained weights without modifying the network architecture.



High Level tools:
Python - Keras, Tensorflow

Training of the CNN:
- Different weights depending on use case.
- NN can be re-trained and weights uploaded via the uplink.

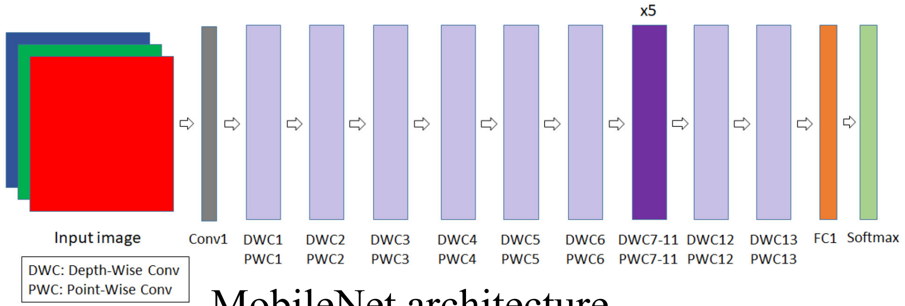
R. Neris, A. Rodríguez, R. Guerra, S. López and R. Sarmiento, "**FPGA-Based Implementation of a CNN Architecture for the On-Board Processing of Very High-Resolution Remote Sensing Images**," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 3740-3750, 2022, doi: 10.1109/JSTARS.2022.3169330.

Y. Barrios, R. Neris, R. Guerra, S. López and R. Sarmiento, "**Speeding up FPGA Prototyping on Space Programs with HLS Workflow. Use Case: Video Compression On-board Satellites**," 2022 37th Conference on Design of Circuits and Integrated Circuits (DCIS), Pamplona, Spain, 2022, pp. 01-06, doi: 10.1109/DCIS55711.2022.9970056.

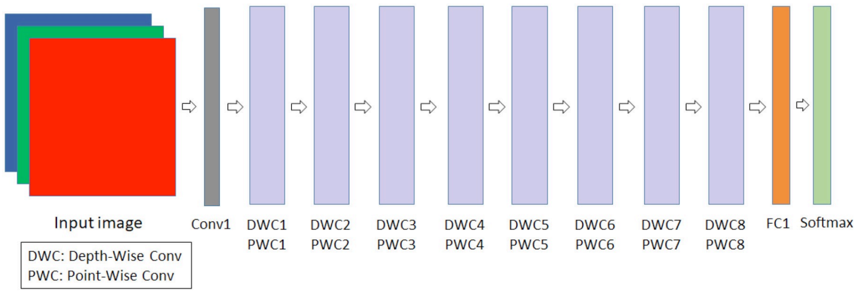
On-board Satellite payload data processing

Example 2

- Detection: architecture overview
  - 10 different architectures analyzed at Keras.
  - MobileNet-Reduced:
    - Good compromise between accuracy and complexity.
    - Number of filters divided by 4 compared to standard MobileNet.
  - Detection strategy:
    - Each video frame will be independently processed as an RGB image by the CNN.
    - Processing the received lines without waiting for the full image.
    - Each image will be processed applying a sliding window with a certain stride and overlap.
    - A window size of 256x256 pixels should give enough margin for target detection.



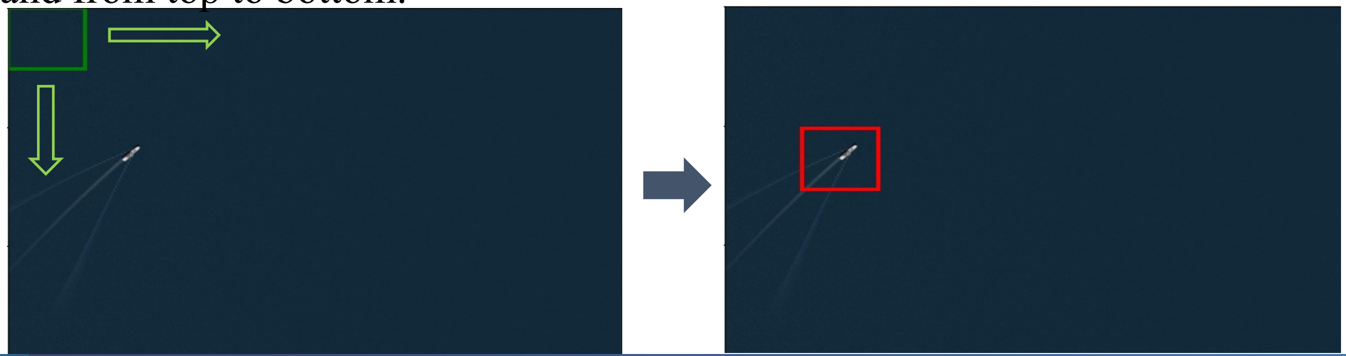
MobileNet architecture



MobileNetv1Lite.

The window moves from left to right and from top to bottom.

Ship detected.

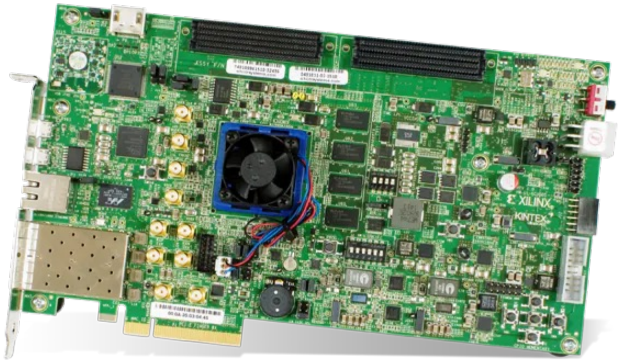


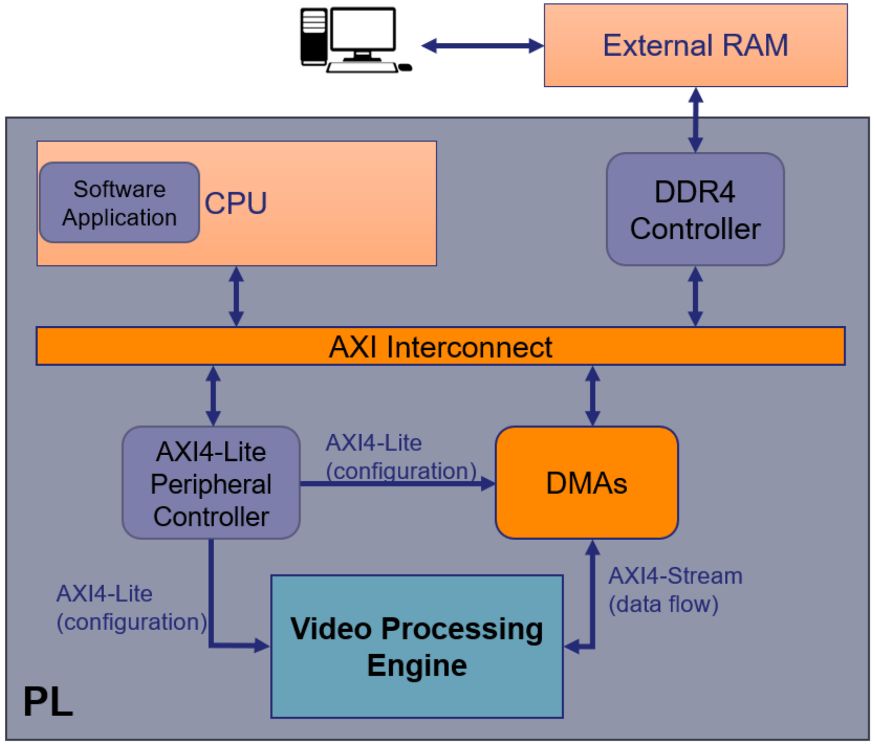
- reduction in the number of filters by a factor of 4
- activation of the *shallow* option which removes five stages of the network.
- This modified architecture, named MobileNetv1Lite, gives a reduction of 96.15% in the number of trainable parameters.

On-board Satellite payload data processing

Example 2

- SYSTEM: TEST SET-UP
  - The whole video processing have been validated.
    - A test set-up has been developed on a Xilinx Kintex UltraScale **XCKU040** FPGA.
    - The whole validation set-up also runs at a clock frequency of **200 MHz**, except the DDR4 controller (300 MHz).
  - A test dataset comprised by short video sequences where boats are captured at different locations was created.
  - Three outputs are generated (one per compression instance) and sent back to the control PC, independently decompressing them with an in-house software compliant with the CCSDS 123.0-B-2 standard.
    - The three decompressed files are merged into a single YCbCr video sequence for visualization purposes.





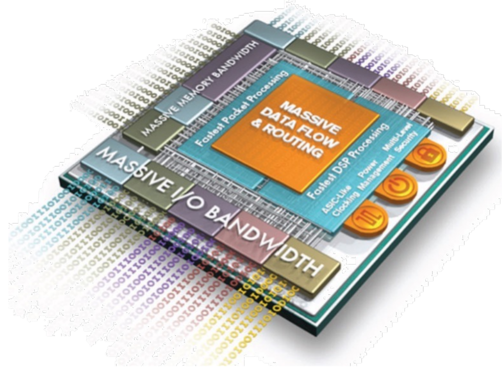
Module	BRAMs	DSPs	Registers	LUTs
Detection Network	229.5 (38.3%)	1405 (73.1%)	134284 (27.6%)	136960 (56.5%)
Video compressor	322 (53.6%)	176 (9.3%)	37557 (7.9%)	44660 (18.4%)
TOTAL	551.5 (91.9%)	1581 (82.3%)	171841 (35.5%)	181620 (74.9%)

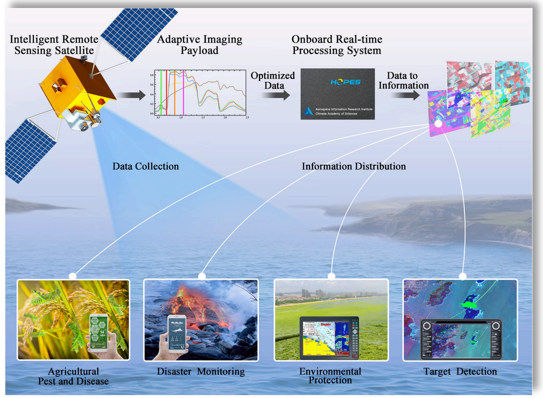
Outline

- Satellites for Earth Observation and Spacecrafts
- Satellites on-board Hardware
  - System overview
  - Payload hardware
- Technology solutions for on-board HPSC
  - Radiation effects mitigation
  - FPGAs - MPSoCs
- On-board Satellite payload data processing
  - New paradigm?
  - Data and Image Compression
  - Video Compression
  - Information Processing
- **Conclusions**

Conclusions
High Performance Space Computer

- New Space (NS) is a completely new approach.
  - Smaller satellites.
  - More computation on-board.
  - Shorter earth-to-Space time.
  - Constellations (mainly in Low Earth Orbit).
  - Private funding.
  - One satellite many solutions.
- HPSC: High Performance Space Computing is a hot topic today.
  - Modular systems.
  - Demand computing on-board.
  - Standardization is required.
  - Needs to use the last technological advances (FPGAs, etc).
  - Using COTS for LEO orbits.
- Example 1: CHIME mission.
  - New mission in the Copernicus program.
  - Long life with public information.
  - Reduce information on cloudy scenes.
- Example 2: European VIDEO project.
  - Use a complex approach for Space.
  - Image mode and video mode.
  - CNN for ship detection with possibility to adapt.

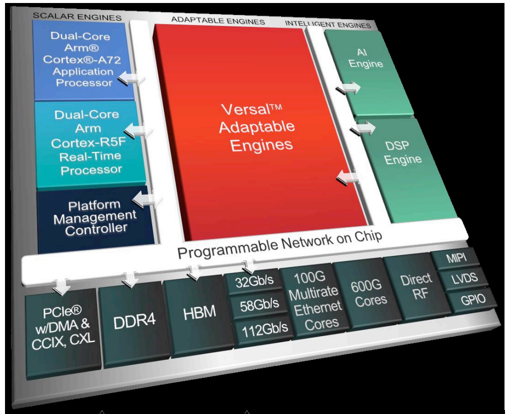




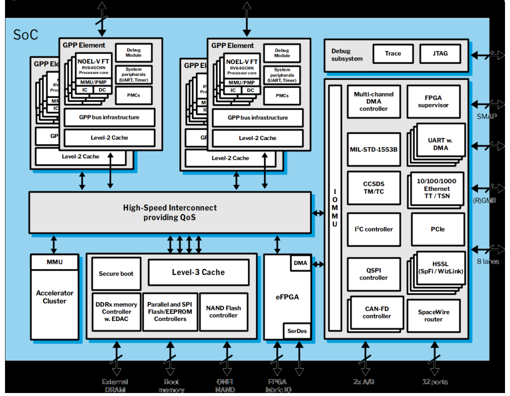
Conclusions

Future of HPSC

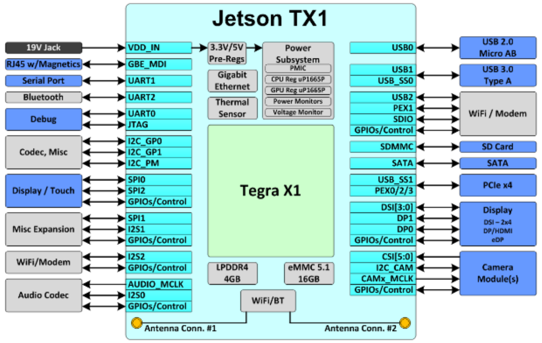
- AMD-Versal MPSoC
  - Full system on a chip
  - 2xARM Cortex-A72; 2X ARM Cortex-R5F; AI Engine; DSP-Engine; Programmable Logic; NoC; etc. etc.



- RISC-V
  - New standard on Space?
  - Link between HPSC and HPC on ground?
  - Solutions: NOEL-V, Microchip Polarfire, De-RISC, Occamy, etc.
  - ESA: The RISC-V in Space Workshop, 12/2022 http://microelectronics.esa.int/riscv/rvws2022/index.php



- GPUs
  - Nvidia Jetson Nano, TX1, etc.
  - W. S. Slater, N. P. Tiwari, T. M. Lovelly and J. K. Mee, "***Total Ionizing Dose Radiation Testing of NVIDIA Jetson Nano GPUs***," 2020 IEEE High Performance Extreme Computing Conference (HPEC), Waltham, MA, USA, 2020, pp. 1-3, doi: 10.1109/HPEC43674.2020.9286222.
  - C. Adams, A. Spain, J. Parker, M. Hevert, J. Roach and D. Cotten, "***Towards an Integrated GPU Accelerated SoC as a Flight Computer for Small Satellites***," 2019 IEEE Aerospace Conference, Big Sky, MT, USA, 2019, pp. 1-7, doi: 10.1109/AERO.2019.8741765.



- Quantum computing
  - Disruptive computing in this workshop!

Hyperspectral technology: inspiring ideas, challenges and opportunities

Part III: Additional projects

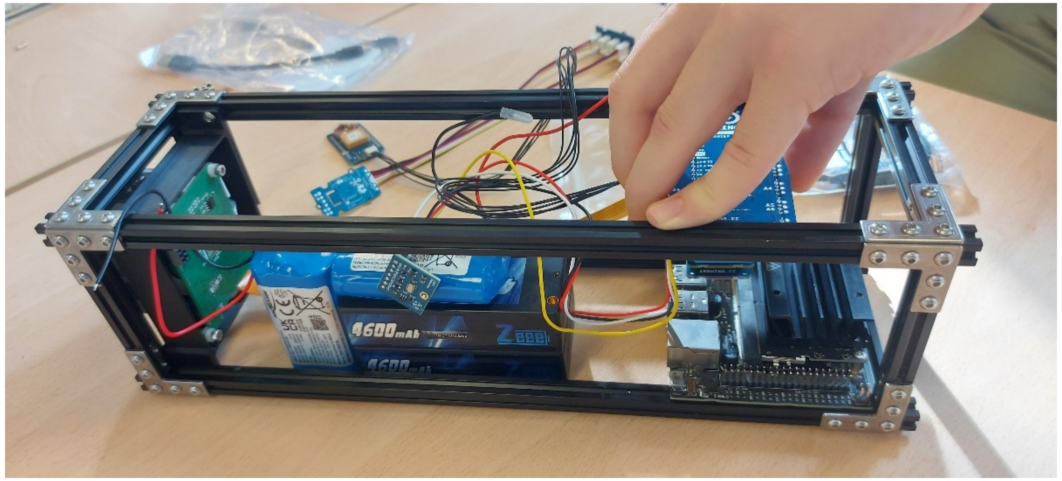
José López-Feliciano/Roberto Sarmiento
Institute for Applied Microelectronics (IUMA)

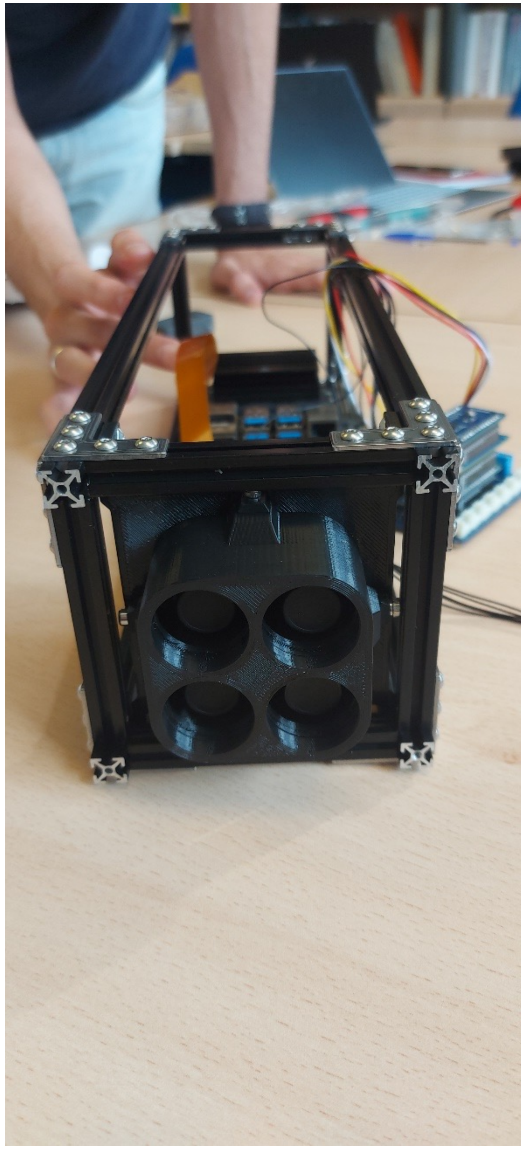
Outline

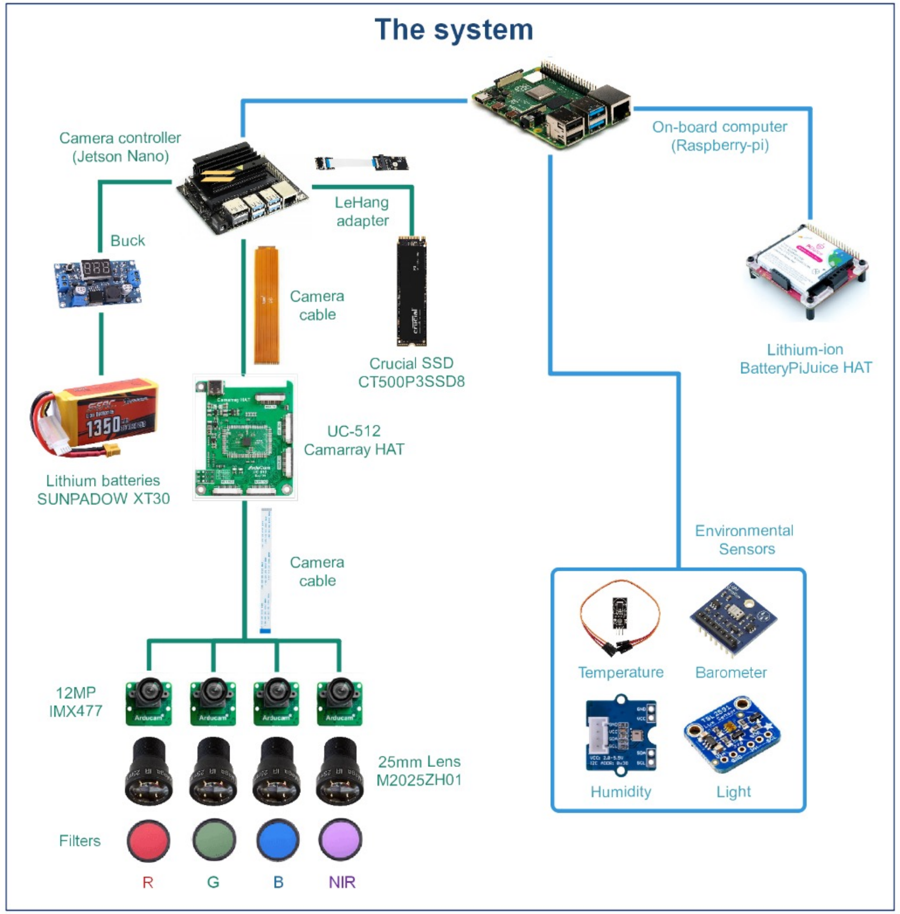
- The institute for Applied Microelectronics at ULPGC
- Why hyperspectral technology?
  - Some numbers
  - Applications
- Introduction to hyperspectral technology
  - The human eye
  - Multi- vs hyperspectral sensors
  - Types of hyperspectral sensors
- Ongoing projects
  - Space
  - Precision agriculture
  - Environment
  - Health

Past and on-going projects

SPACE







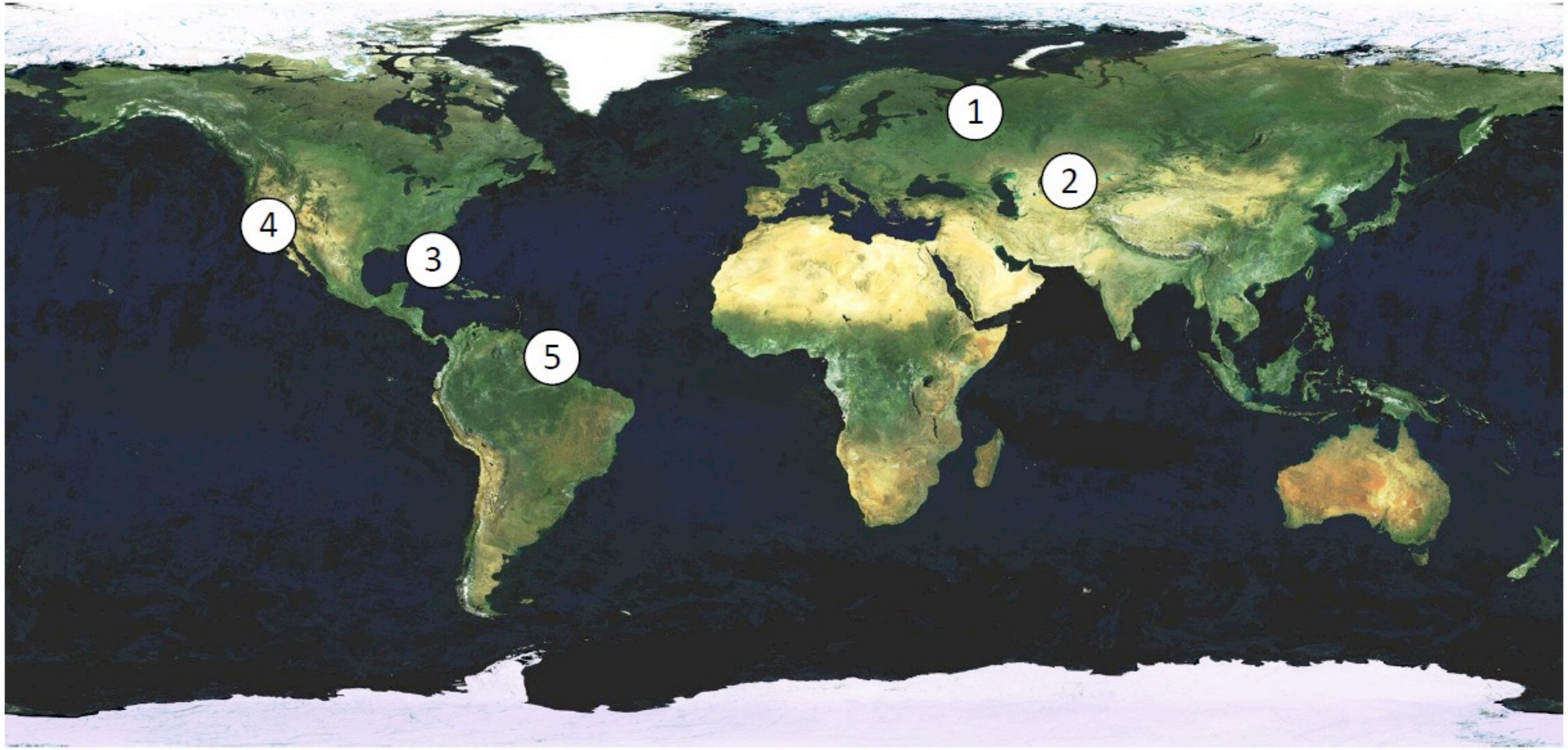
Past and on-going projects

SPACE

B2SPACE

Past and on-going projects

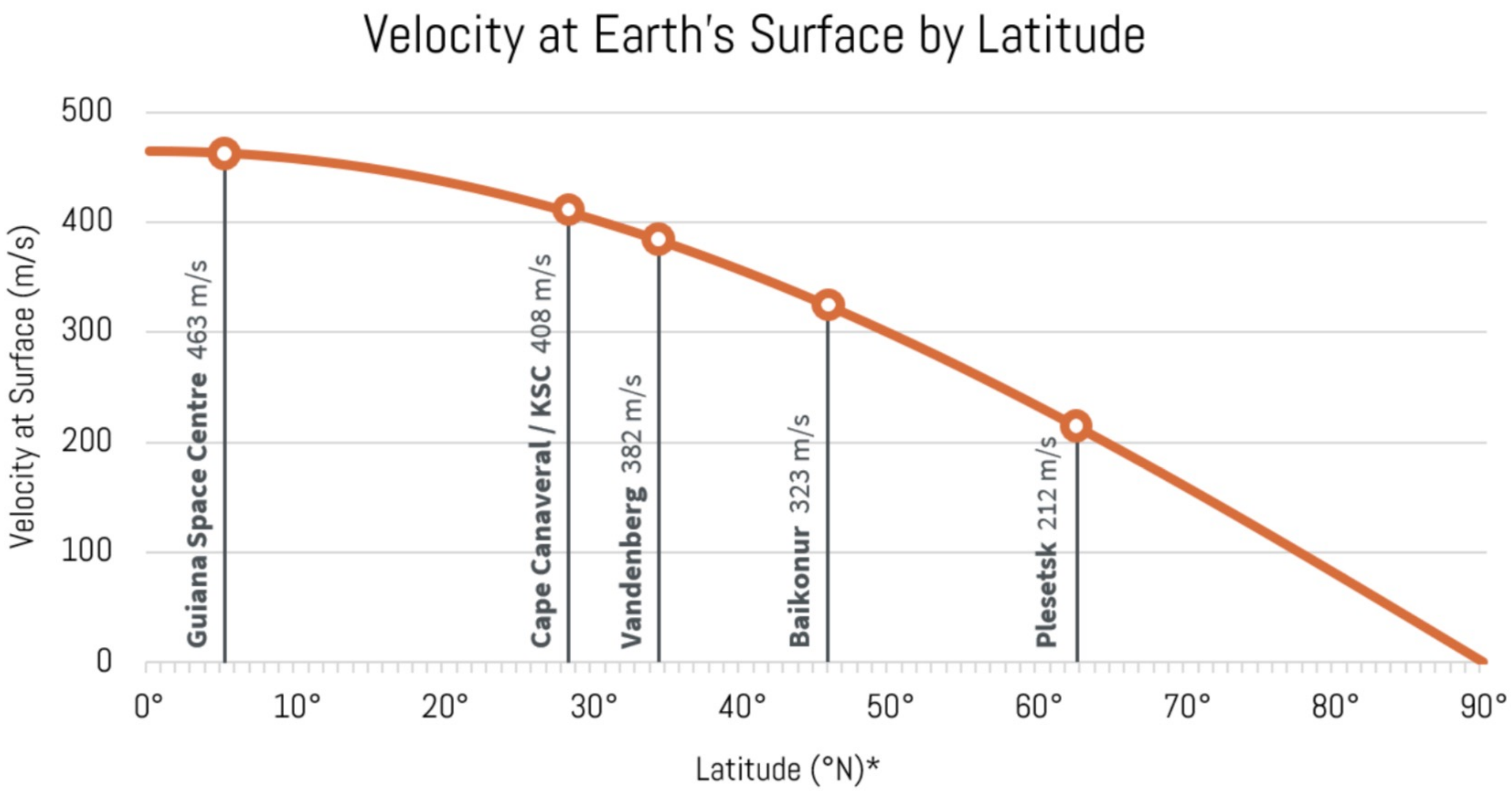
SPACE



1. **Cosmódromo de Plesetsk**
   1966
   1957-2021: 1589 lanzamientos
2. **Cosmódromo de Baikonur**
   1957
   1957-2021: 1431 lanzamientos
3. **Cabo Cañaveral**
   1958
   1957-2021: 935 lanzamientos
4. **Base Aérea Vandenberg**
   1959
   1957-2021: 625 lanzamientos
5. **Puerto Espacial Kourou**
   1970
   1957-2021: 296 lanzamientos

Past and on-going projects

SPACE



Past and on-going projects

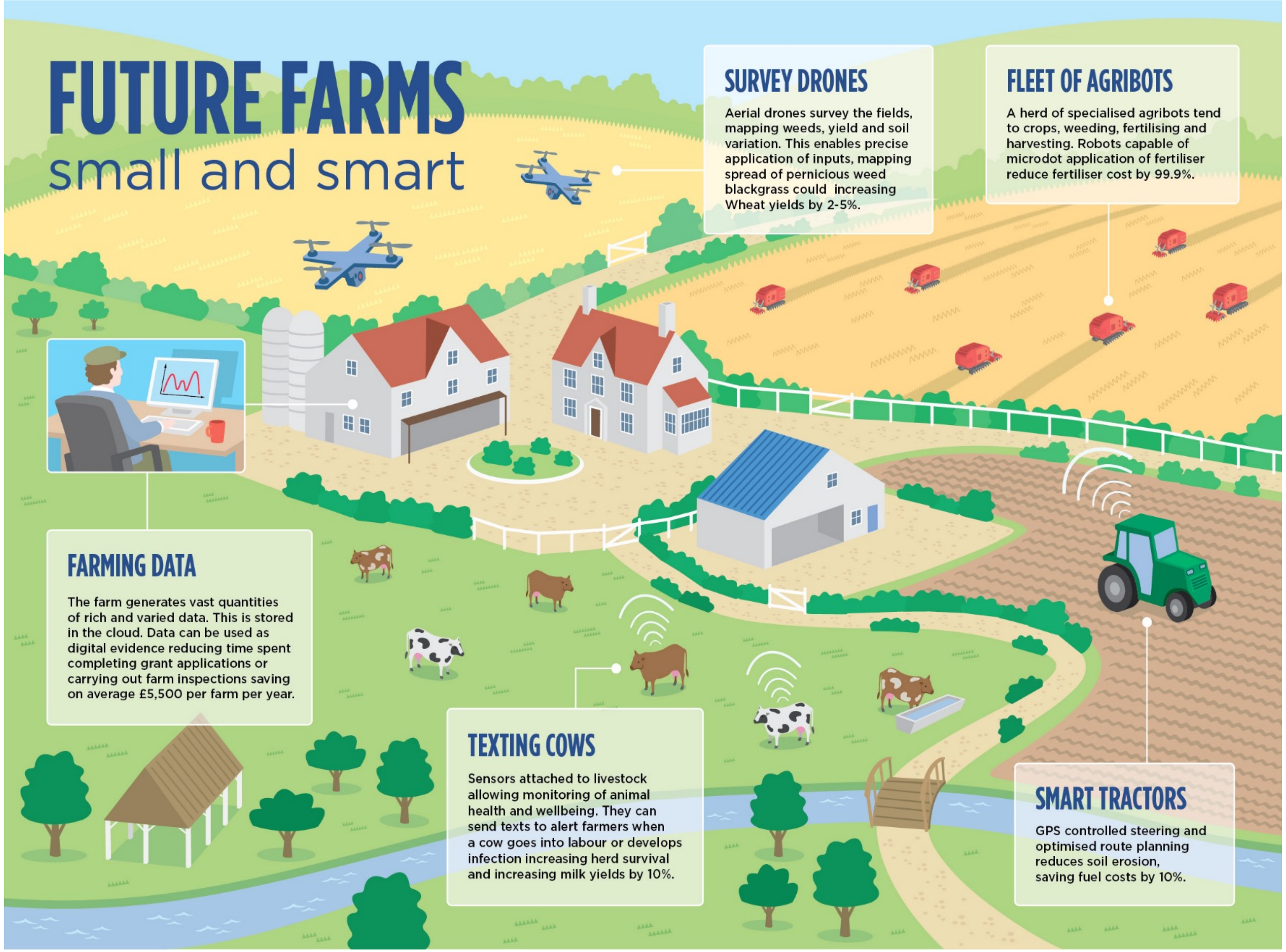
Past and on-going projects

SPACE

San Marco Platform (Kenya)
1964-1988

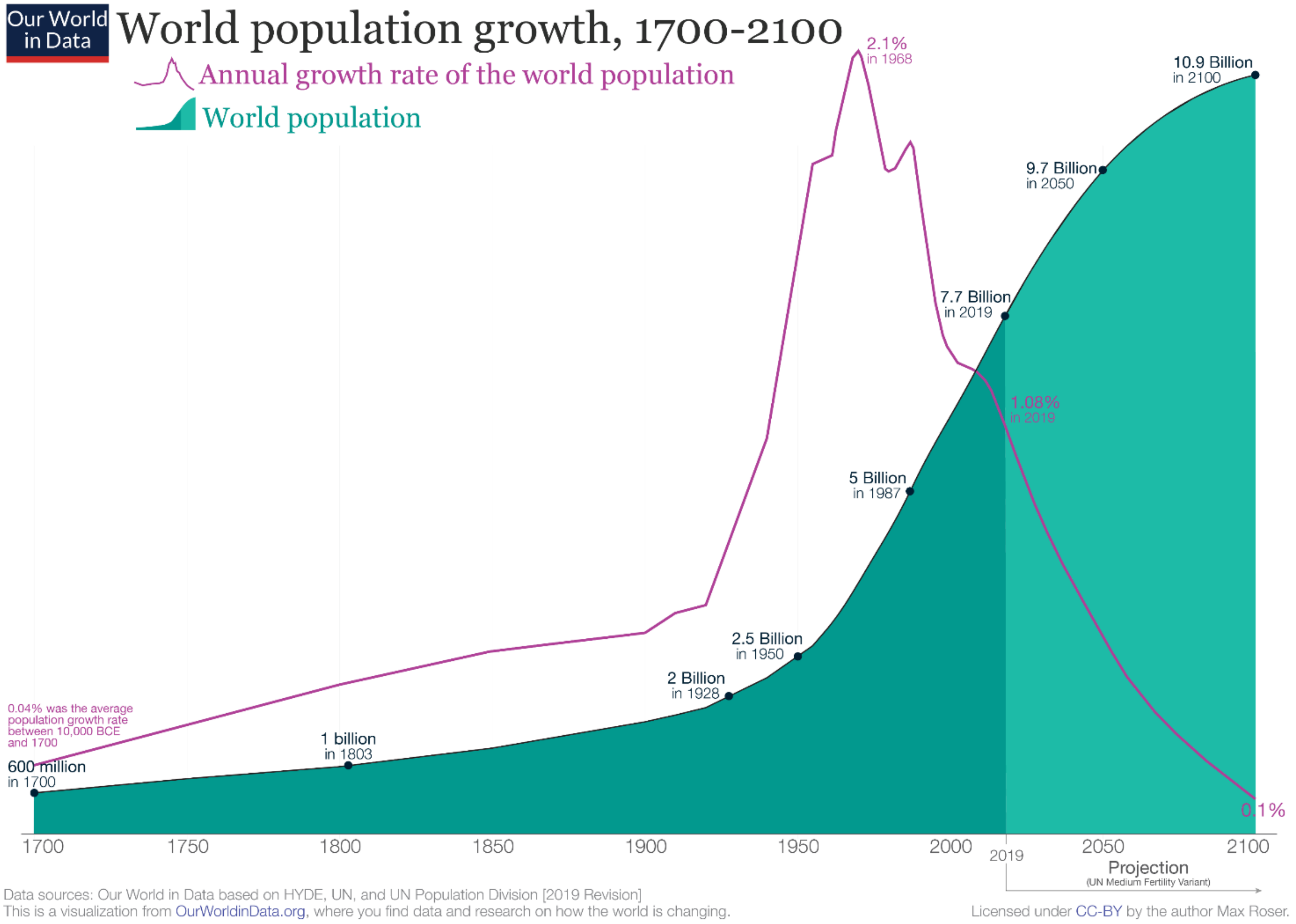
Past and on-going projects

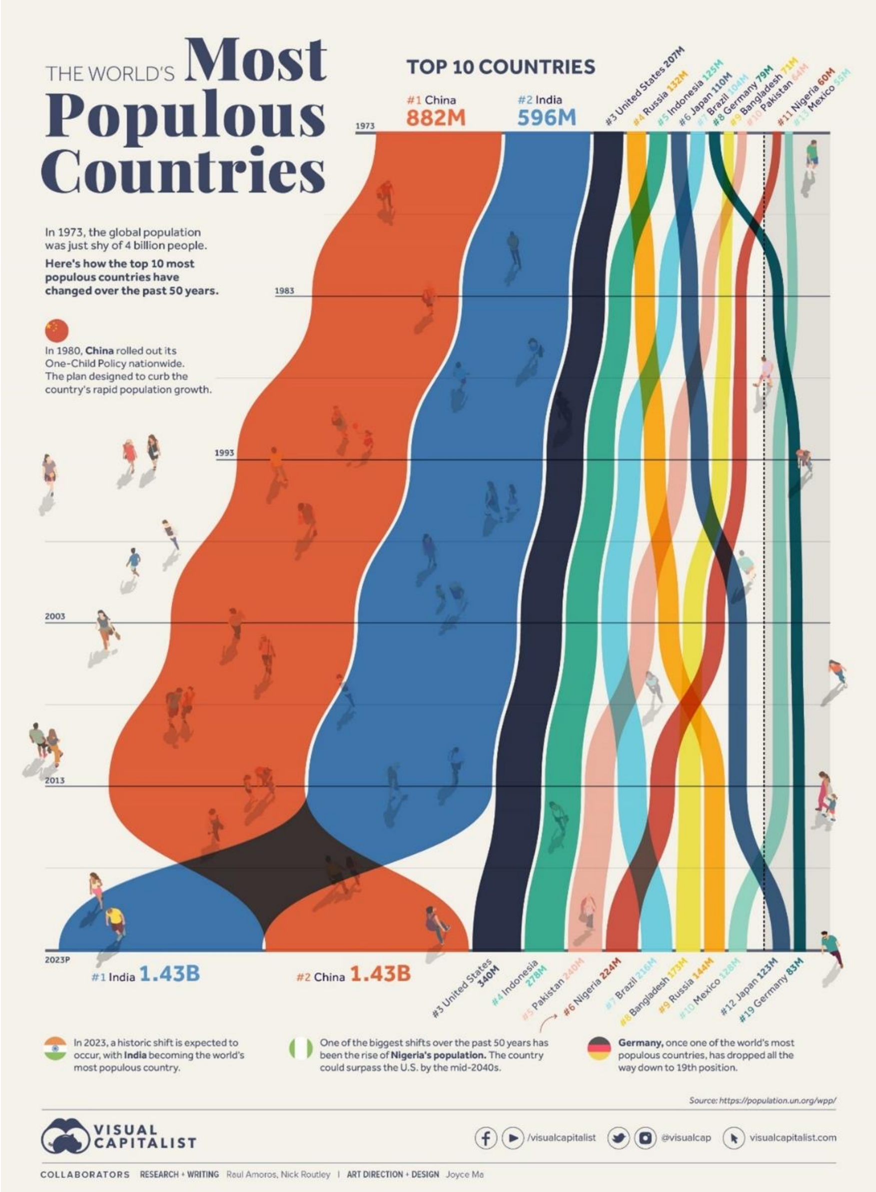
PRECISION AGRICULTURE



Past and on-going projects

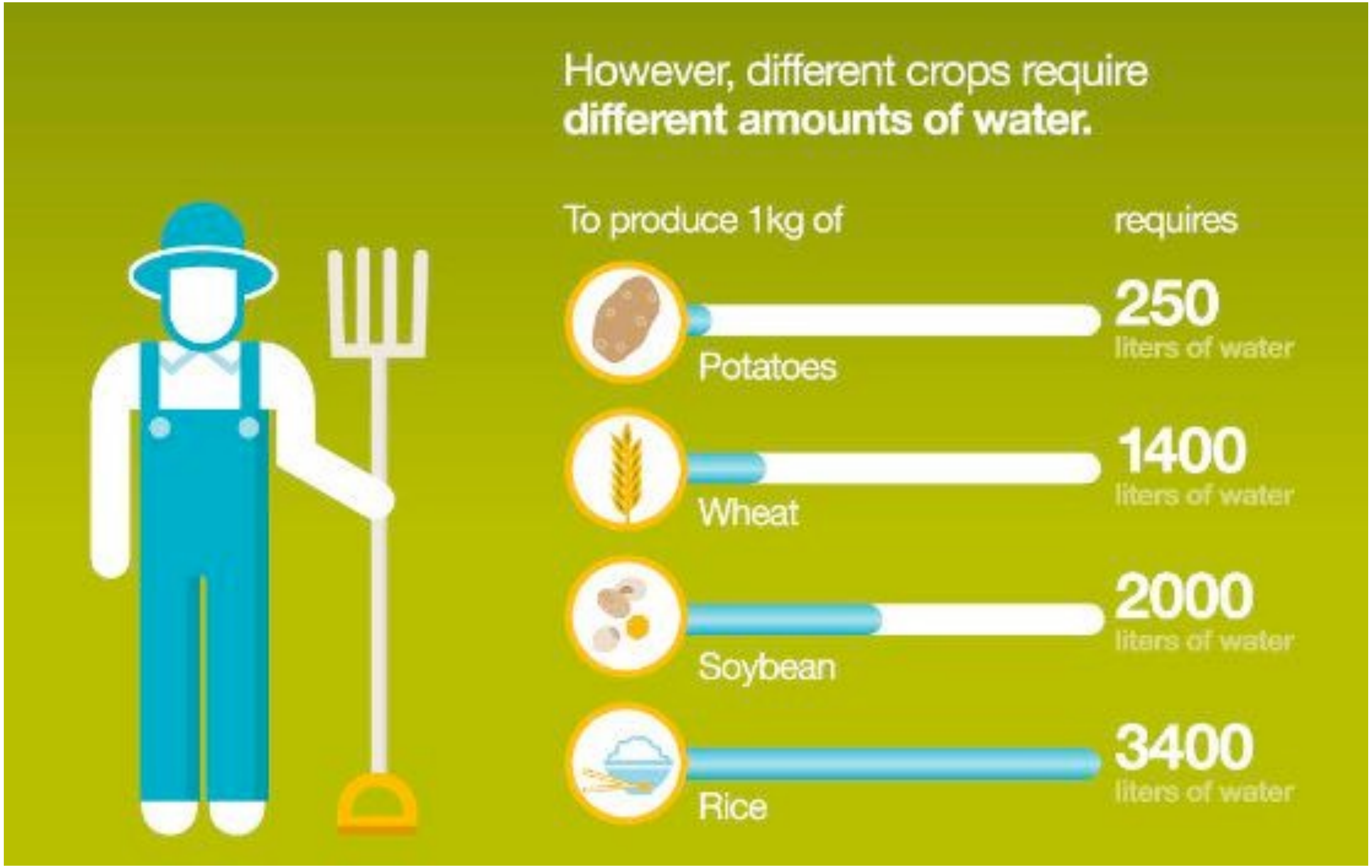
PRECISION AGRICULTURE





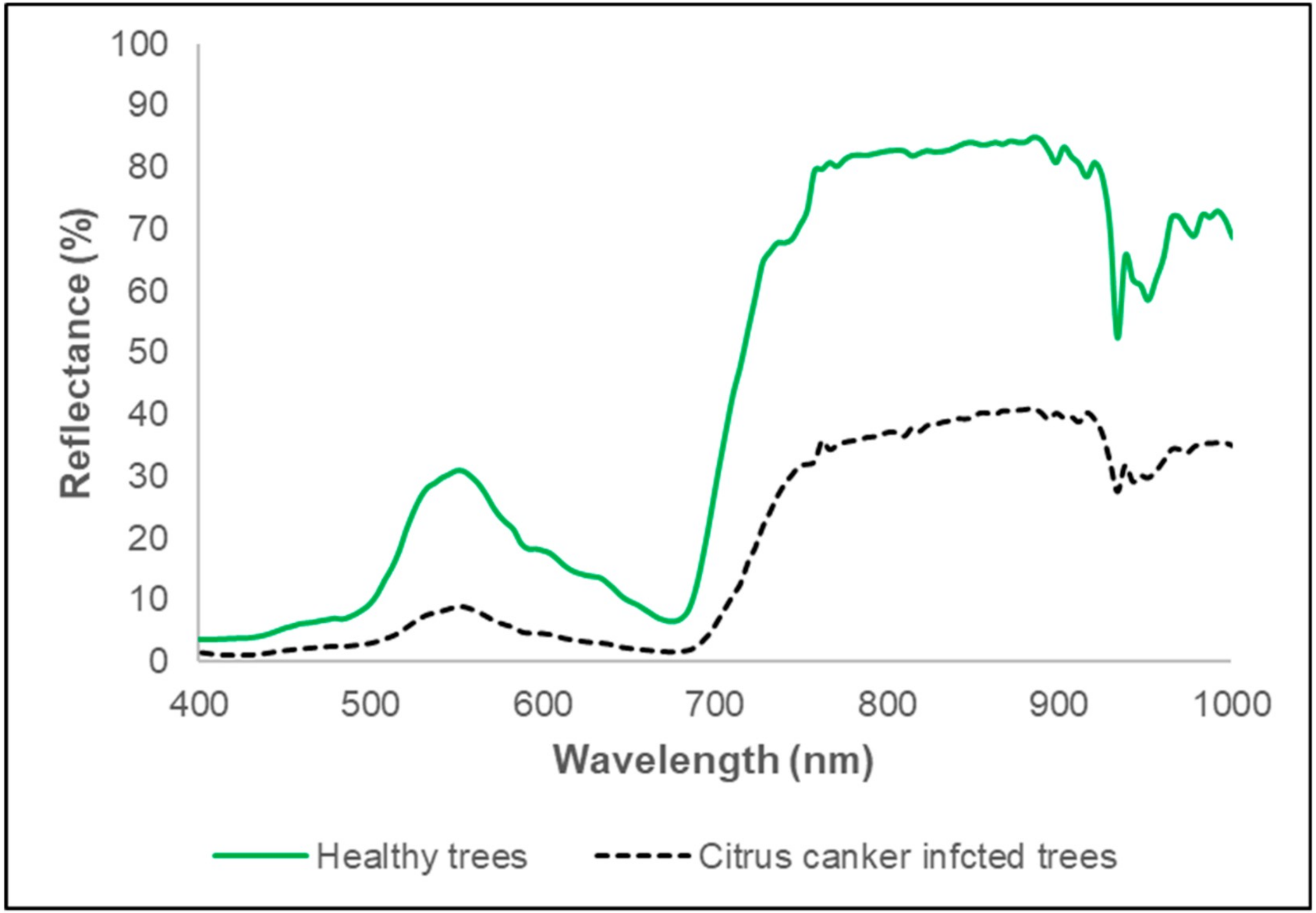
Past and on-going projects

PRECISION AGRICULTURE

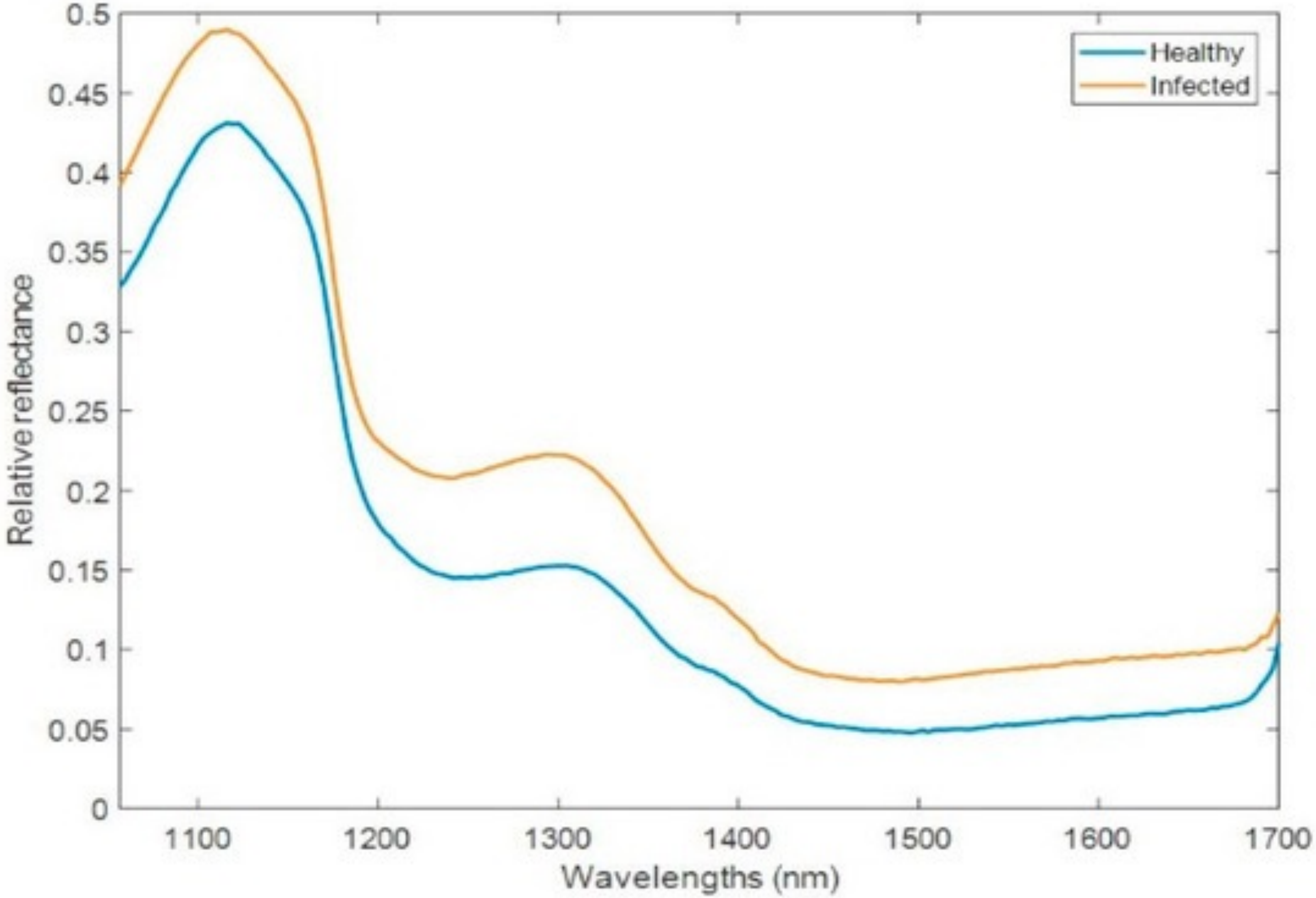


Past and on-going projects

PRECISION AGRICULTURE

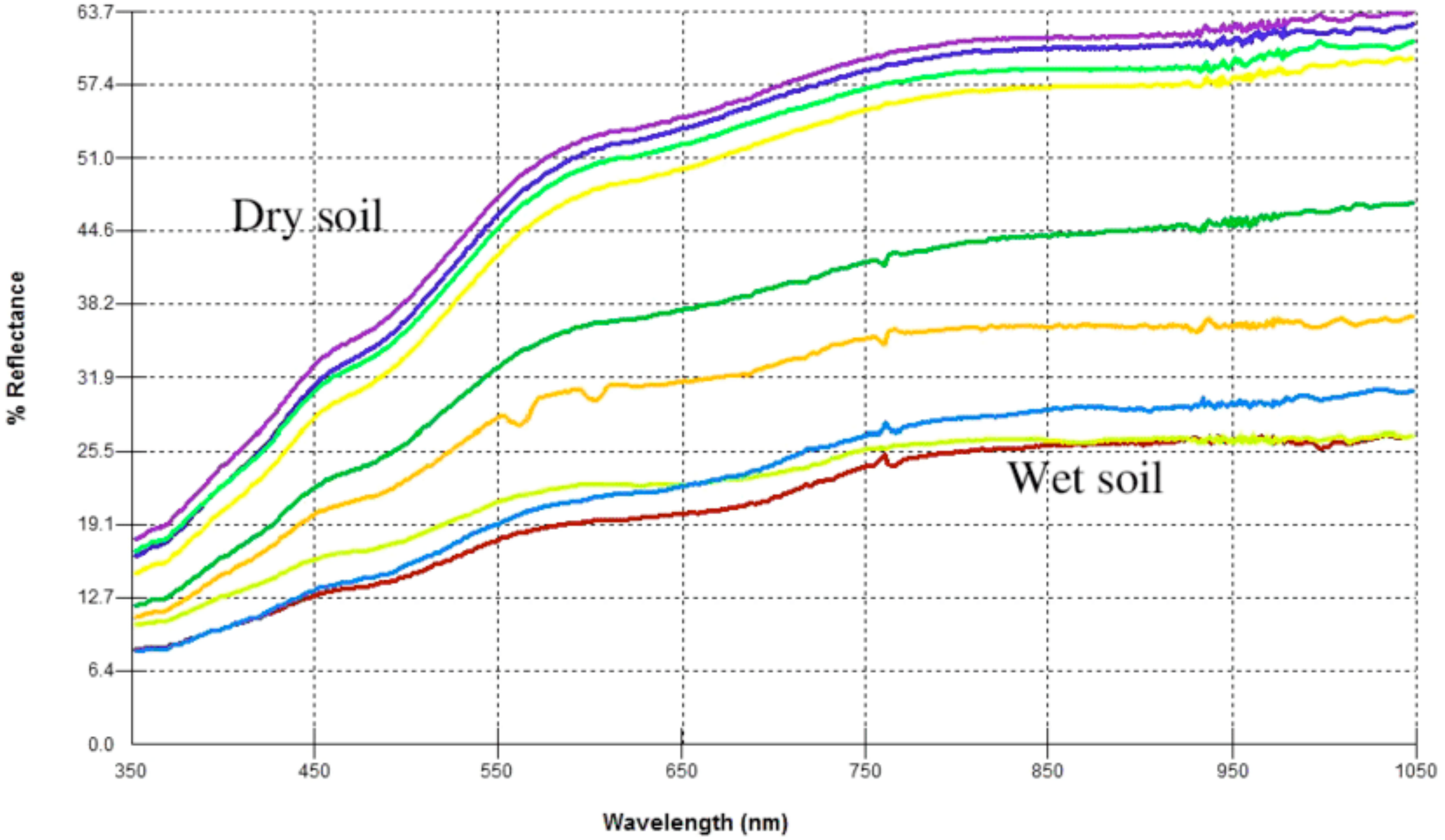


Past and on-going projects

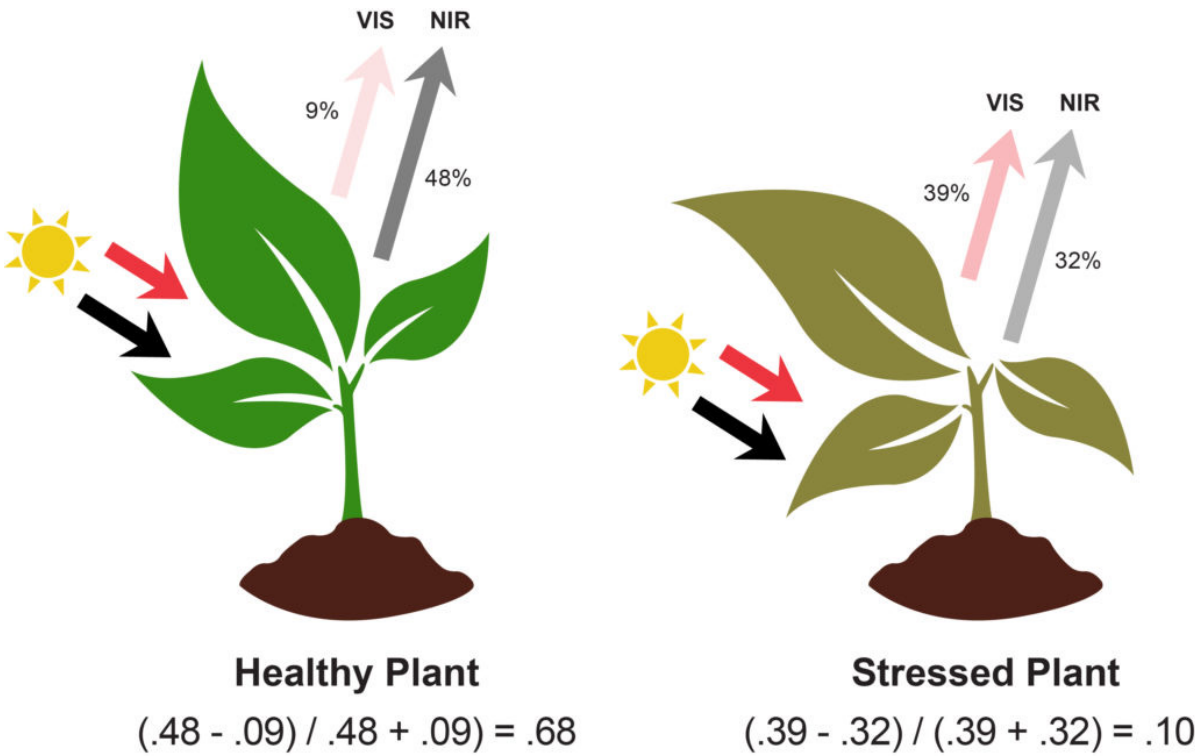


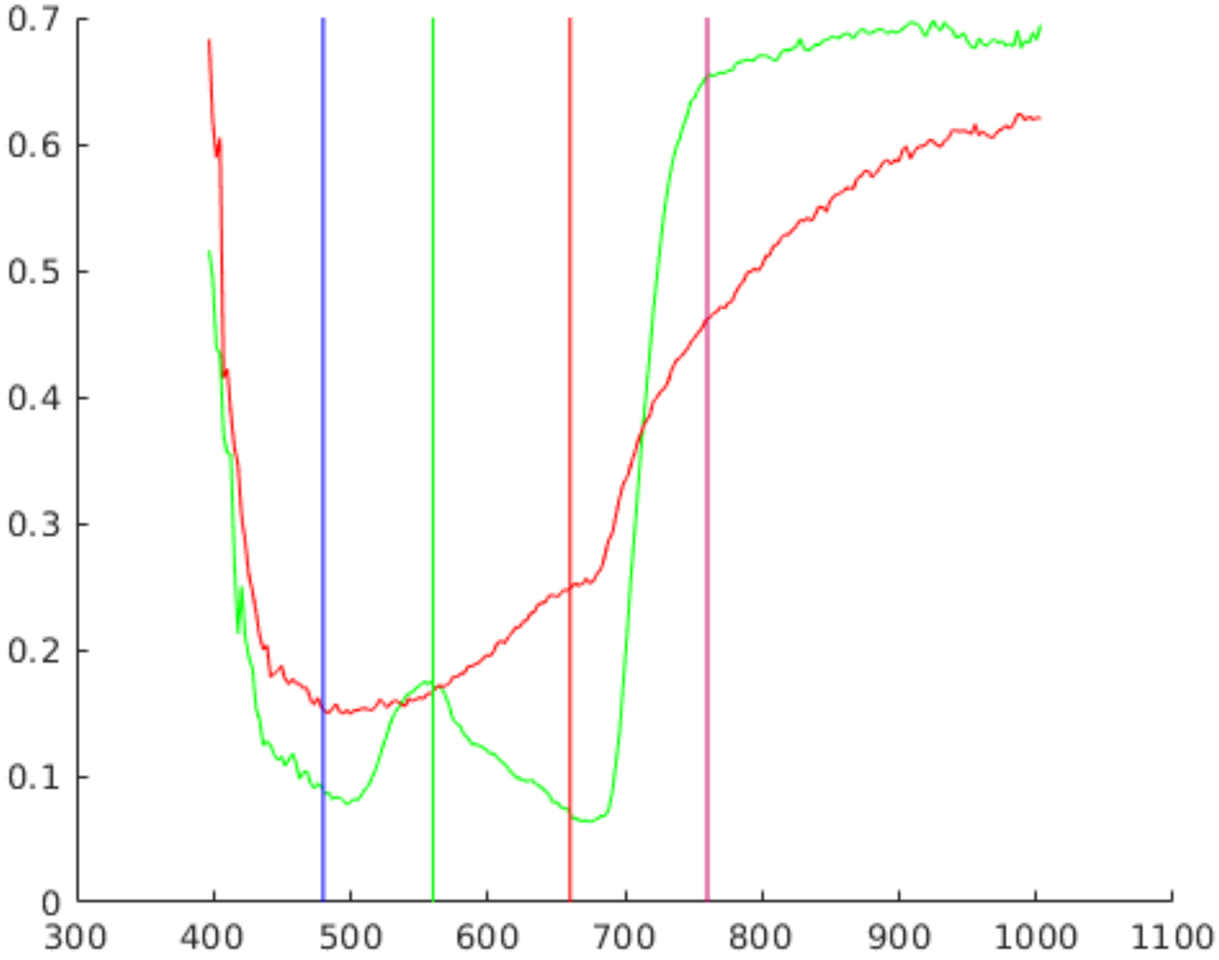
Past and on-going projects

PRECISION AGRICULTURE



Past and on-going projects



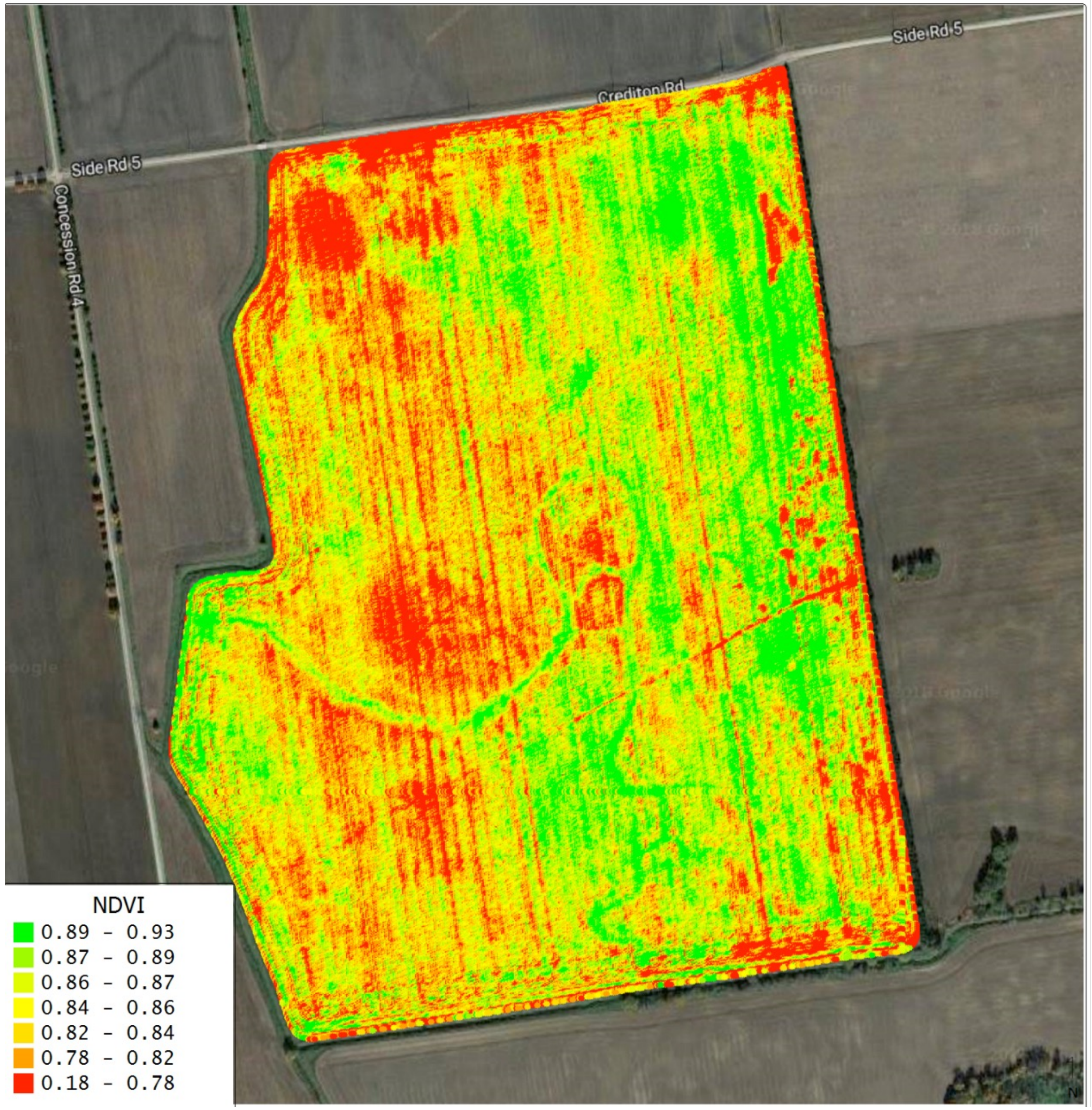


$$0 \leq NDVI \leq 1$$

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Past and on-going projects

PRECISION AGRICULTURE

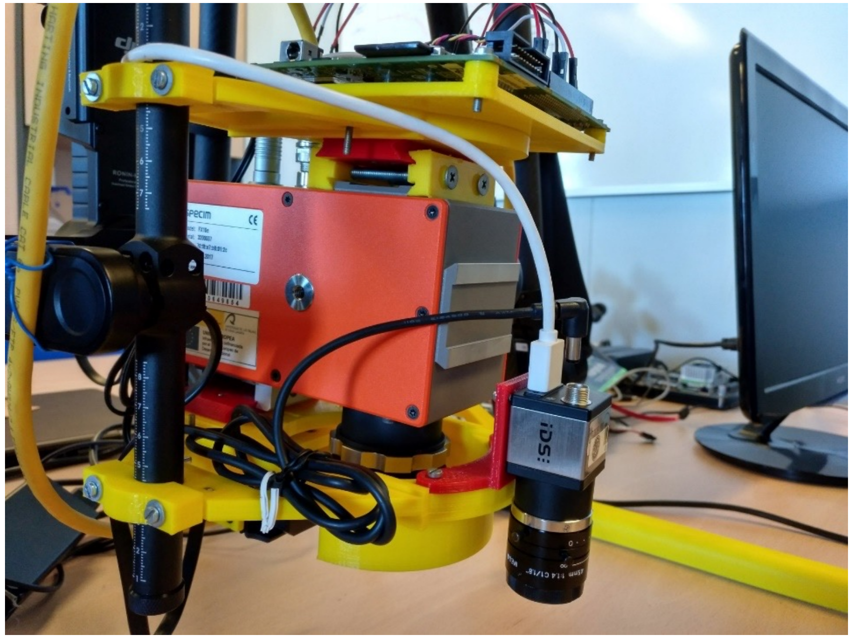


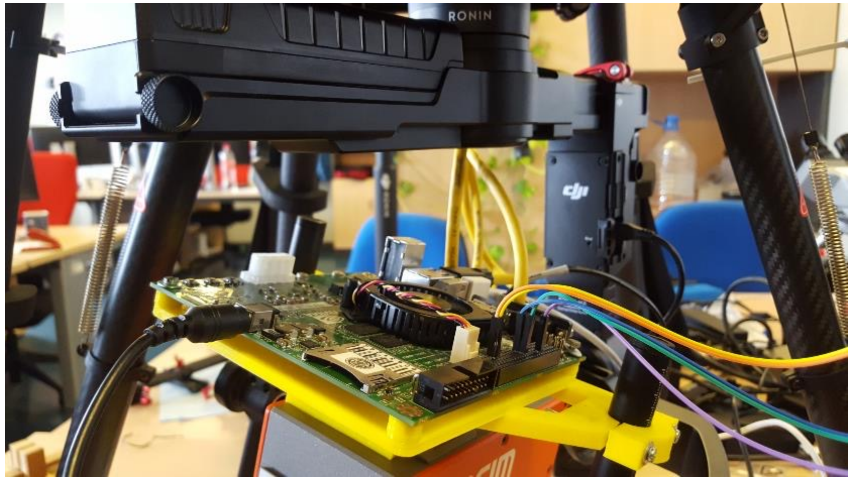
Past and on-going projects

PRECISION AGRICULTURE

Past and on-going projects

PRECISION AGRICULTURE

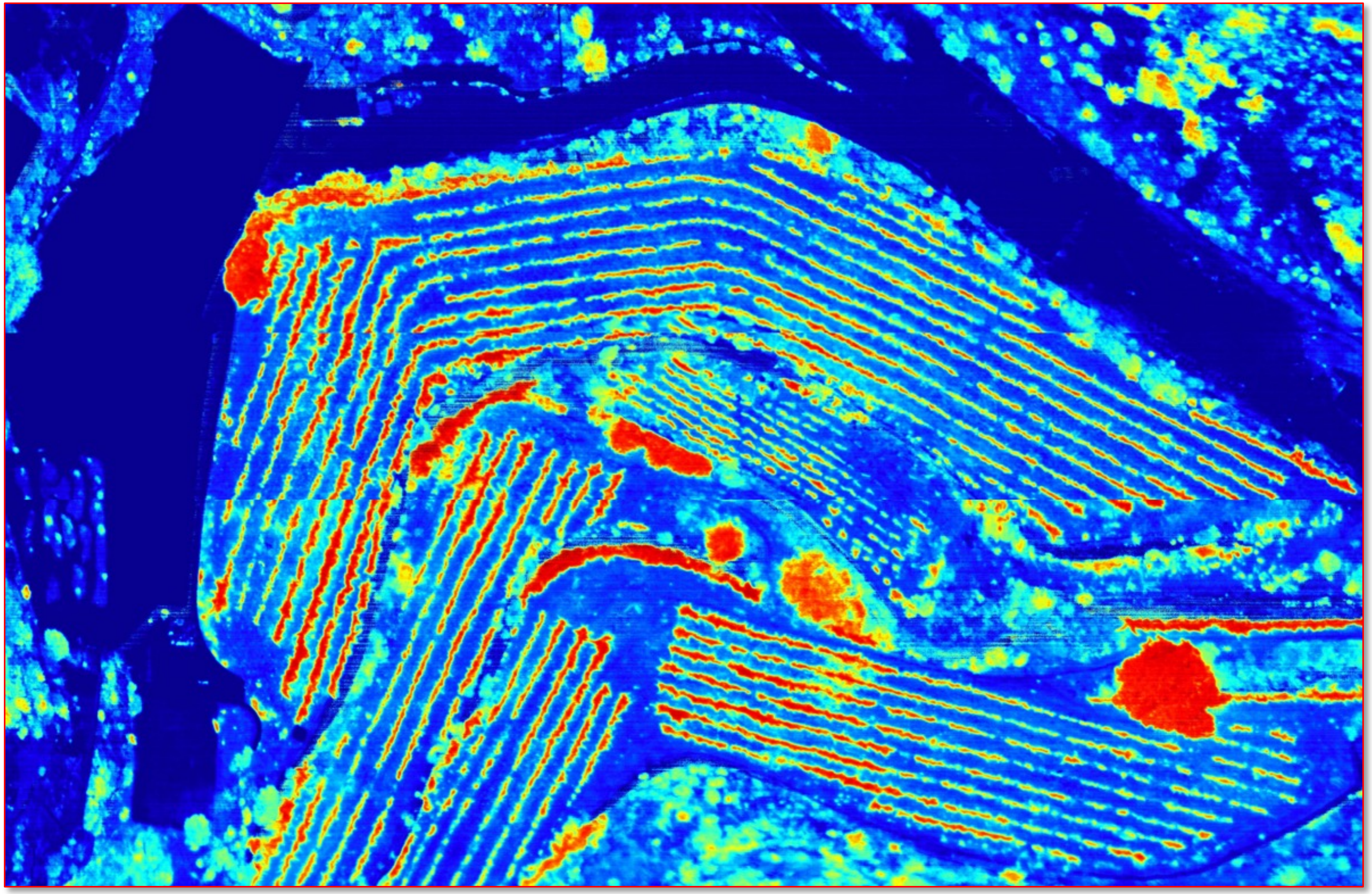




Past and on-going projects

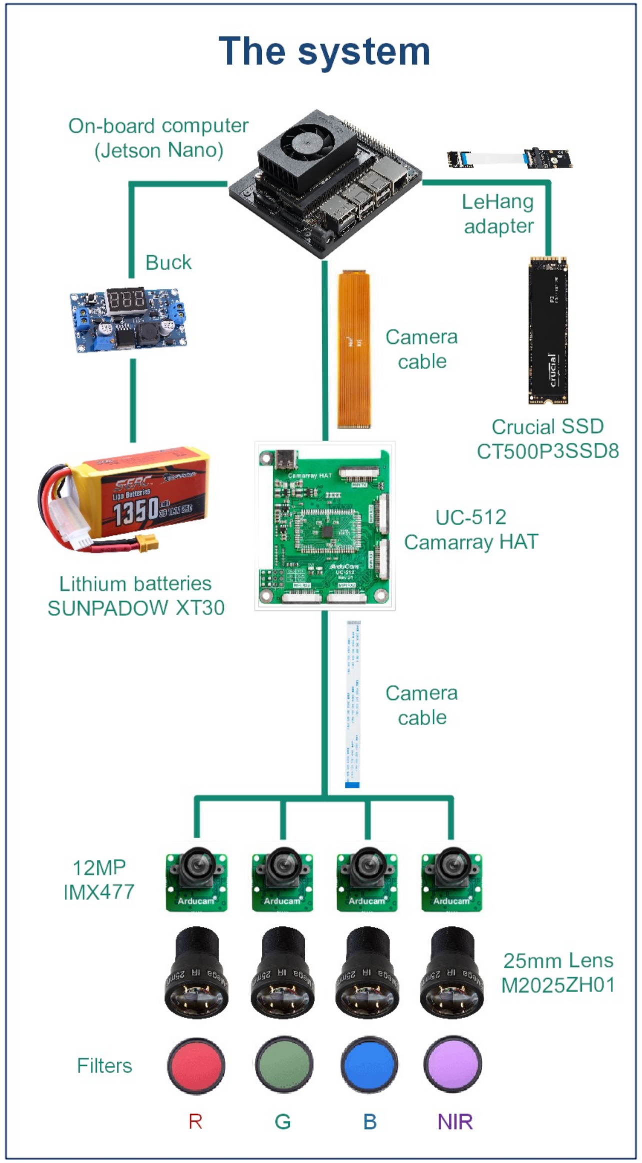
Past and on-going projects

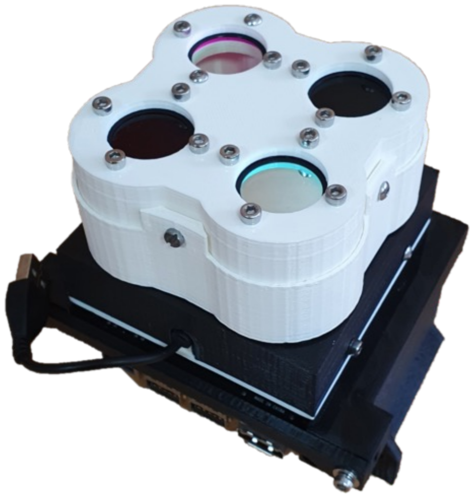
PRECISION AGRICULTURE



NDVI false color image of a vineyard (taken from a UAV in Gran Canaria)

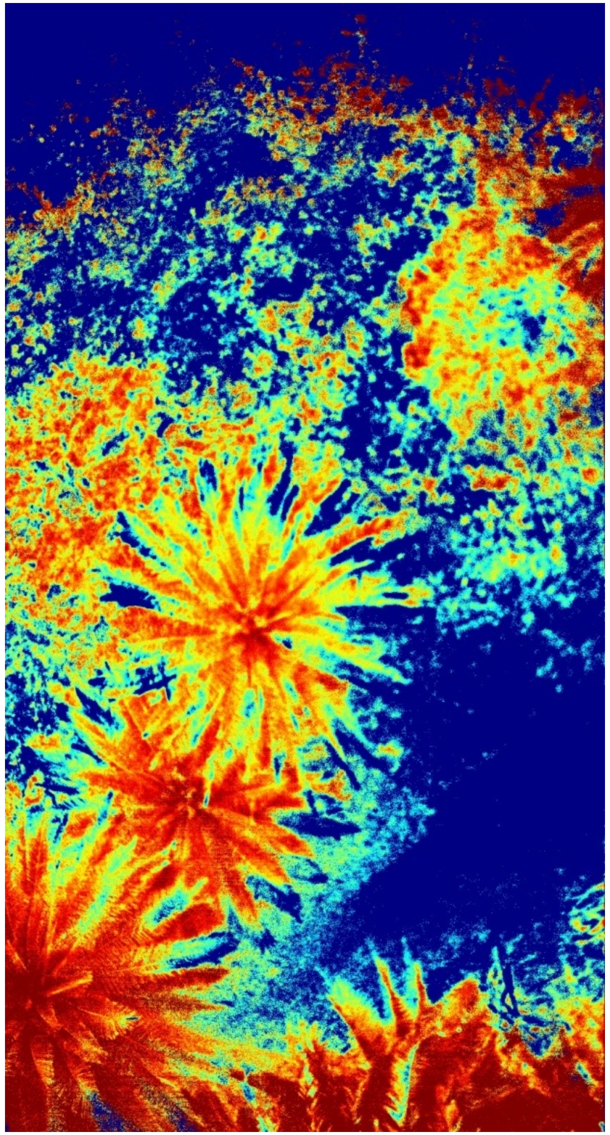
Past and on-going projects





Past and on-going projects

PRECISION AGRICULTURE

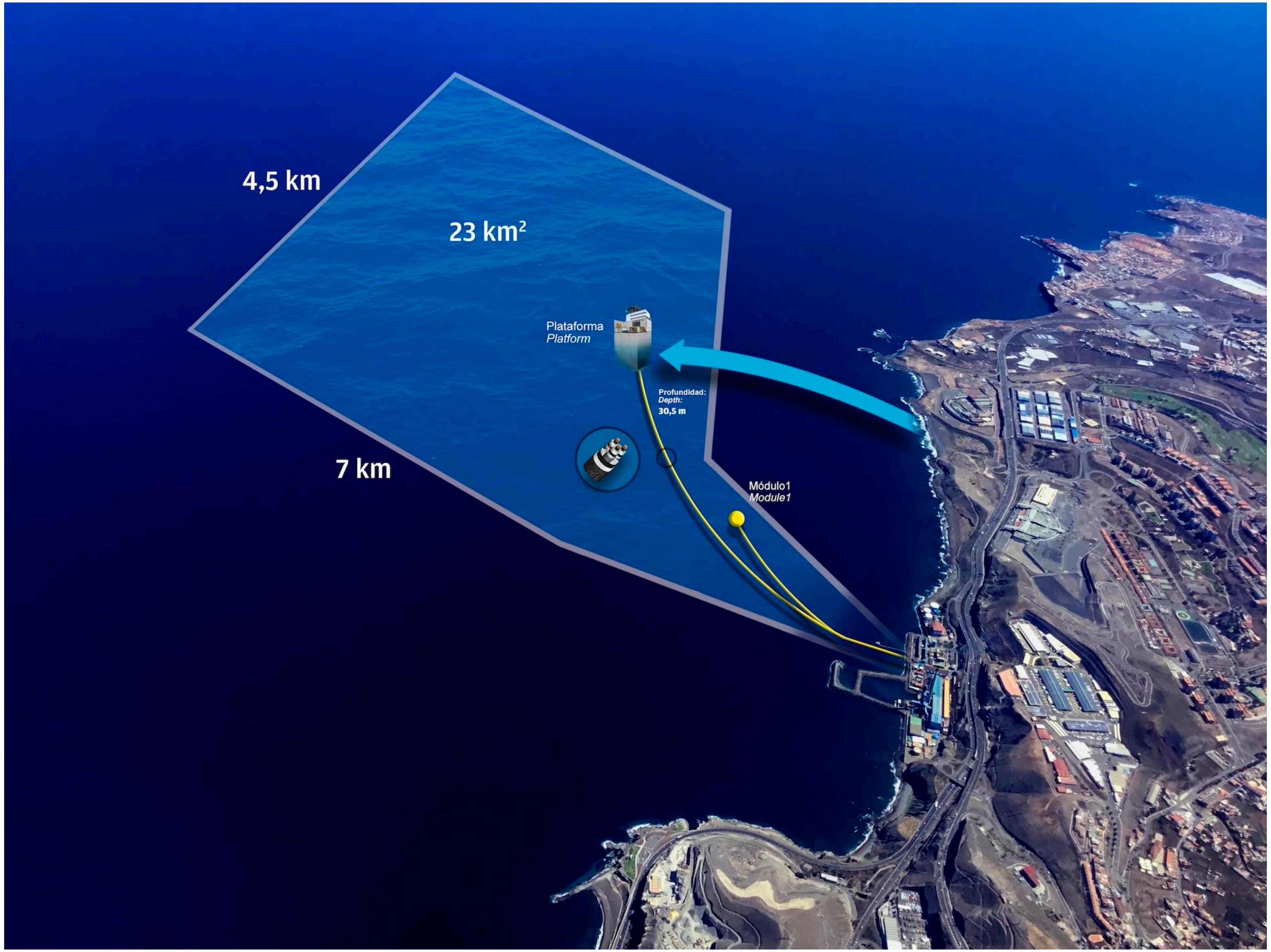


Past and on-going projects

ENVIRONMENT

PLOCAN Plataforma Oceánica de Canarias

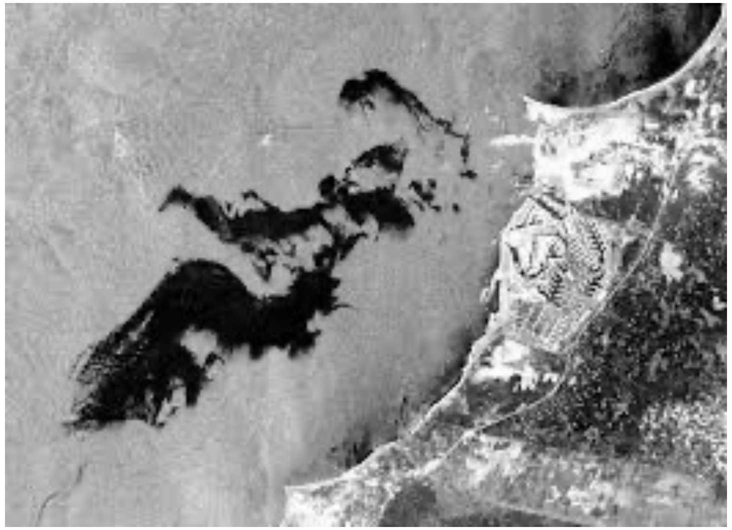
Past and on-going projects

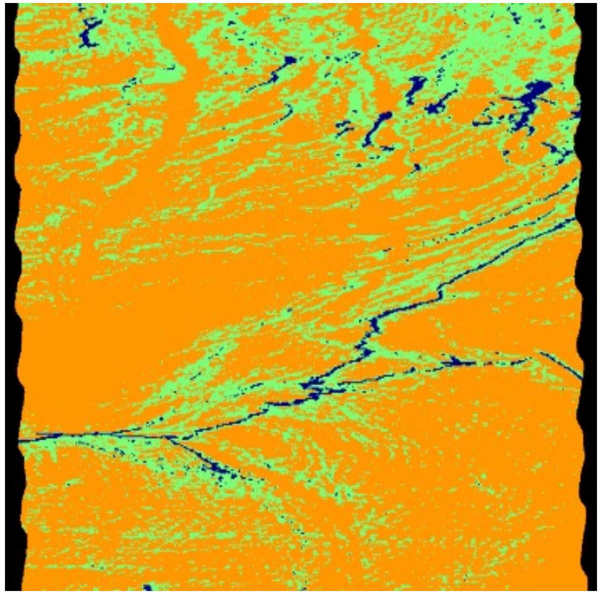


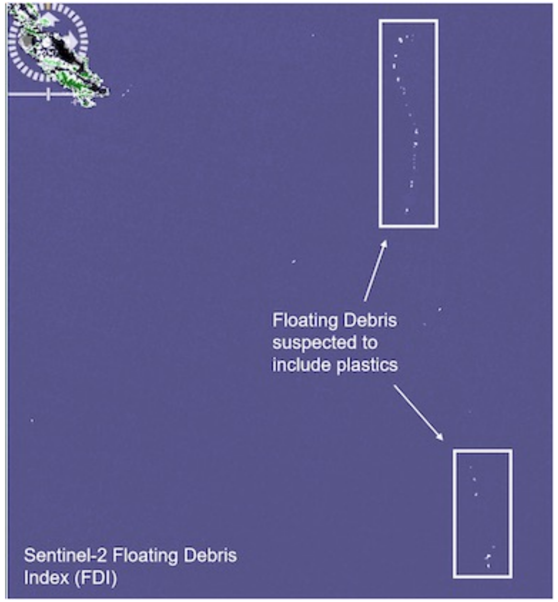
Past and on-going projects

CURRENT LINES OF STUDY

- Spectral analysis of oil spills
- Unsupervised semantic segmentation NN
- Detection of floating debris at sea







Past and on-going projects

- **DEEP WATER HORIZON**

  Location: Gulf of Mexico in 2010

  Duration of discharge: 3 months

- **NORMALIZED DIFFERENCE OIL INDEX**

$$NDOI = \frac{\lambda_{599} - \lambda_{870}}{\lambda_{599} + \lambda_{870}}$$

- **AVIRIS SENSOR**

  224 bands in VNIR-SWIR

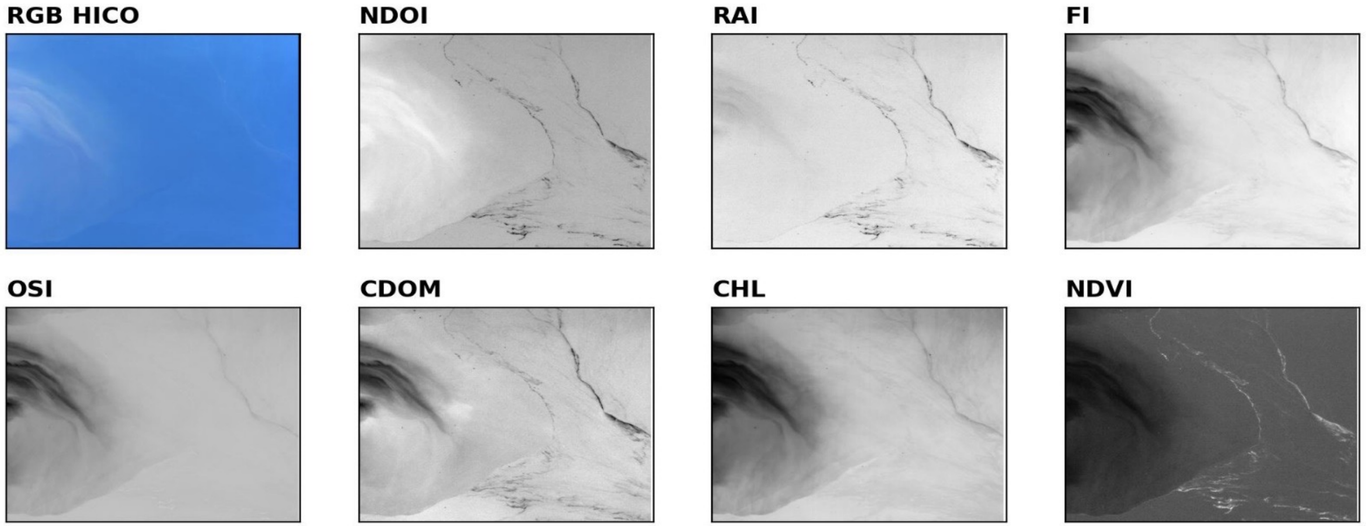
MODIS - 28º14’53”N 87º17’22”W

Past and on-going projects

ENVIRONMENT

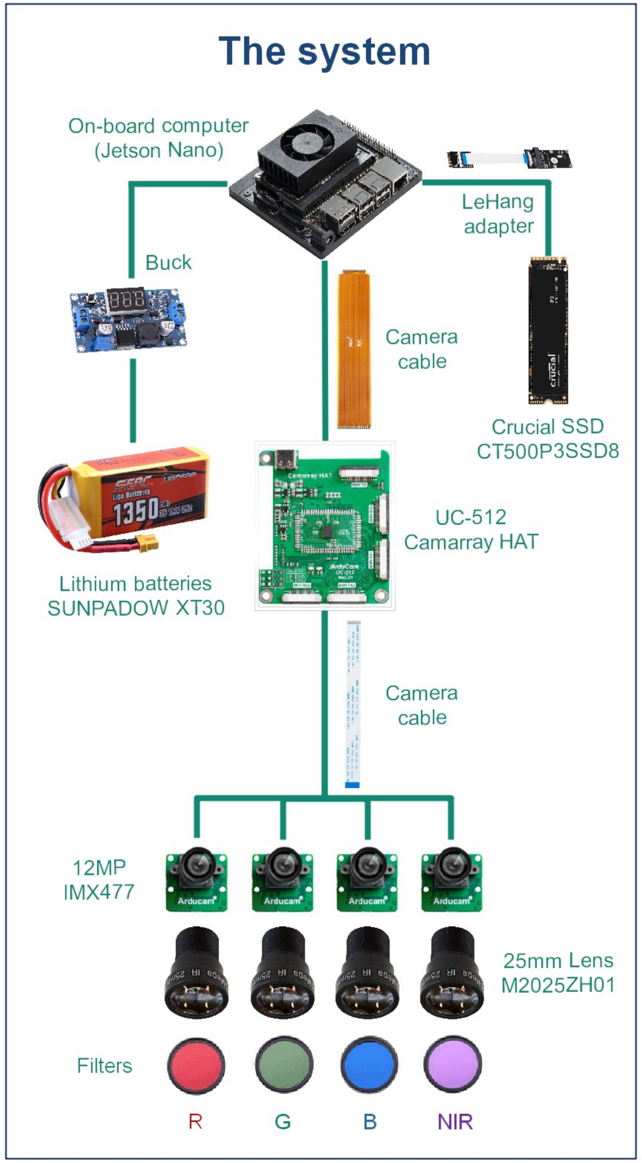
MOST CITED INDICES FOR IDENTIFYING SPILLS.

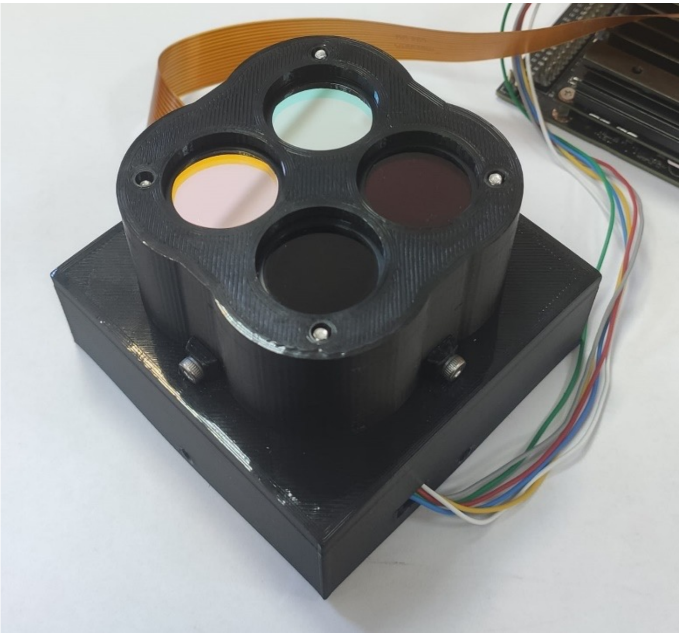
Index	Equation	Measured property
RAI	(Blue - IR) / (Blue + IR) $\sqrt{\sum_{i=1}^{N} b_i{}^2}$	Oil fluorescent characteristics
FI	(Blue - Red) / (Blue + Red)	Oil fluorescent characteristics
OSI	$(DN_{\lambda_{Red}} - DN_{\lambda_{Yellow}})/(\lambda_{Red} - \lambda_{Yellow})$	Existence of crude oil
CDOM	R_{565}/R_{660}	Seawater characteristics
CHL	$log(max(R_{433,490,510})/R_{555})$	Surface chlorophyll a
NDVI	(NIR - Red) / (NIR + Red)	Live green vegetation



Past and on-going projects

ENVIRONMENT





ELECTRICAL VTOL

ENDURANCE
Aprox. 6 hors

ECONOMICAL SOLUTION

Past and on-going projects

ENVIRONMENT

SINGULAR AIRCRAFT

FLYOX I

THE SKY WORKER

MTOW	4000 kg
PAYLOAD	1850 kg
ENDURANCE	25 hours
AUTONOMOUS	
AMPHIBIOUS	
REMOTELY PILOTED	

Past and on-going projects

HEALTH

NEW BRAIN CANCER DECISION SYSTEM

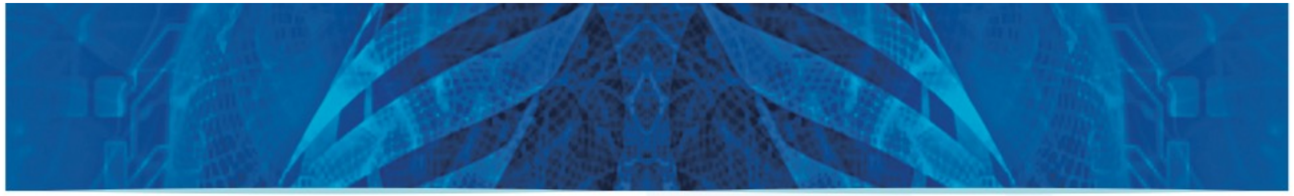
The main goal of the HELICoiD project is to apply hyperspectral imaging techniques to the precise localization of malignant tumours during surgical procedures. The HELICoiD project will develop an experimental intraoperative setup based on non-invasive hyperspectral cameras. This will be connected to a platform running a set of algorithms which are capable of discriminating between healthy and pathological tissues. **The prototype will be developed with the aim of recognising cancer tissues during the surgical procedure in real time.** This information will be provided to the surgeon via different display devices, and in particular by overlaying the conventional images with a simulated colour map to indicate the probability of any currently exposed tissue being cancerous. To meet these real time and in vivo cancer detection requirements, a hardware/software partition of the final platform will be derived, which will depend on the computational load requirements of the algorithms which are developed.

The integration of hyperspectral imaging and intraoperative imaged-guided surgery systems should have a direct impact on patient outcomes. Potential benefits include: allowing confirmation of complete resection during the surgical procedure, avoiding complications due to "body mass shift", and providing confidence that the goals of the surgery have been achieved.

A multidisciplinary consortium composed of surgeons, pathologists, ICT engineers, mathematicians and physicists has been created. Two European hospitals will be involved, as end-users, in setting the requirements for, and conducting validation of, the tools and systems developed within this project. If hyperspectral imaging techniques are demonstrated to be practical for surgical applications then it is expected that European industry related to hyperspectral imaging will be well placed to exploit this opportunity for growth.


2

To offer the best prospects for success, this project will adopt the algorithms-architectures-implementations co-exploration paradigm. It is our belief that translation of hyperspectral image technology to real-time medical applications cannot be achieved by developing algorithms, architectures and implementations separately. Rather, this goal is better served by adopting a fully integrated approach from the outset.



Project co-ordinator:

Dr. Gustavo M. Callicó
Associate Professor
University of Las Palmas de Gran Canaria
Research Institute for Applied Micoelectronics (IUMA)
Campus Universitario de Tafira. Building A-212
E-35017, Las Palmas de Gran Canaria, Canary Islands. Spain
Phone: +34 928 451 271
gustavo@iuma.ulpgc.es
Visit: www.helicoid.eu

Pictures:

1: Brain cancer operation at University Hospital Dr. Negrin.

2: HELICoiD hyperspectral cameras.

3: Surgeons and operation theatre at University Hospital Dr. Negrin.

4: Simulation of the surgeons display with the results of the algorithm. Real image and tumour map.

Co-funded by the European Union

HELICoiD

HypErspectral Imaging Cancer Detection

FP7-618080 (FP7-ICT-2013-C)

A Collaborative Project supported by the Seventh Framework Programme of the European Comission

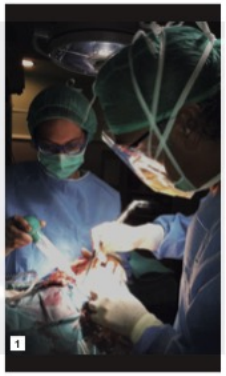
CHALLENGES OF BRAIN CANCER DETECTION

Brain cancer is one of the most important forms of the disease, and is a significant economic and social burden across Europe. The most common form is high-grade malignant glioma, which accounts for approximately 30-50% of primary brain cancers, with multiform glioblastoma making up 85% of these cases. These types of gliomas are characterized by fast-growing invasiveness, which is locally very aggressive, are in most cases unicentric and are rarely metastasizing.

Despite the introduction of new aggressive treatments combining surgery, radiotherapy and chemotherapy, there continues to be treatment failure in the form of persistent or locally recurrent tumours (i.e. recurrence at the primary tumour location or within 2-3 cm of adjacent tissue). Median survival periods and 5-year survival rates for anaplastic astrocytomas are only 36 months and 18% respectively, whereas for glioblastoma multiforme these are 10 months and less than 5%, respectively.

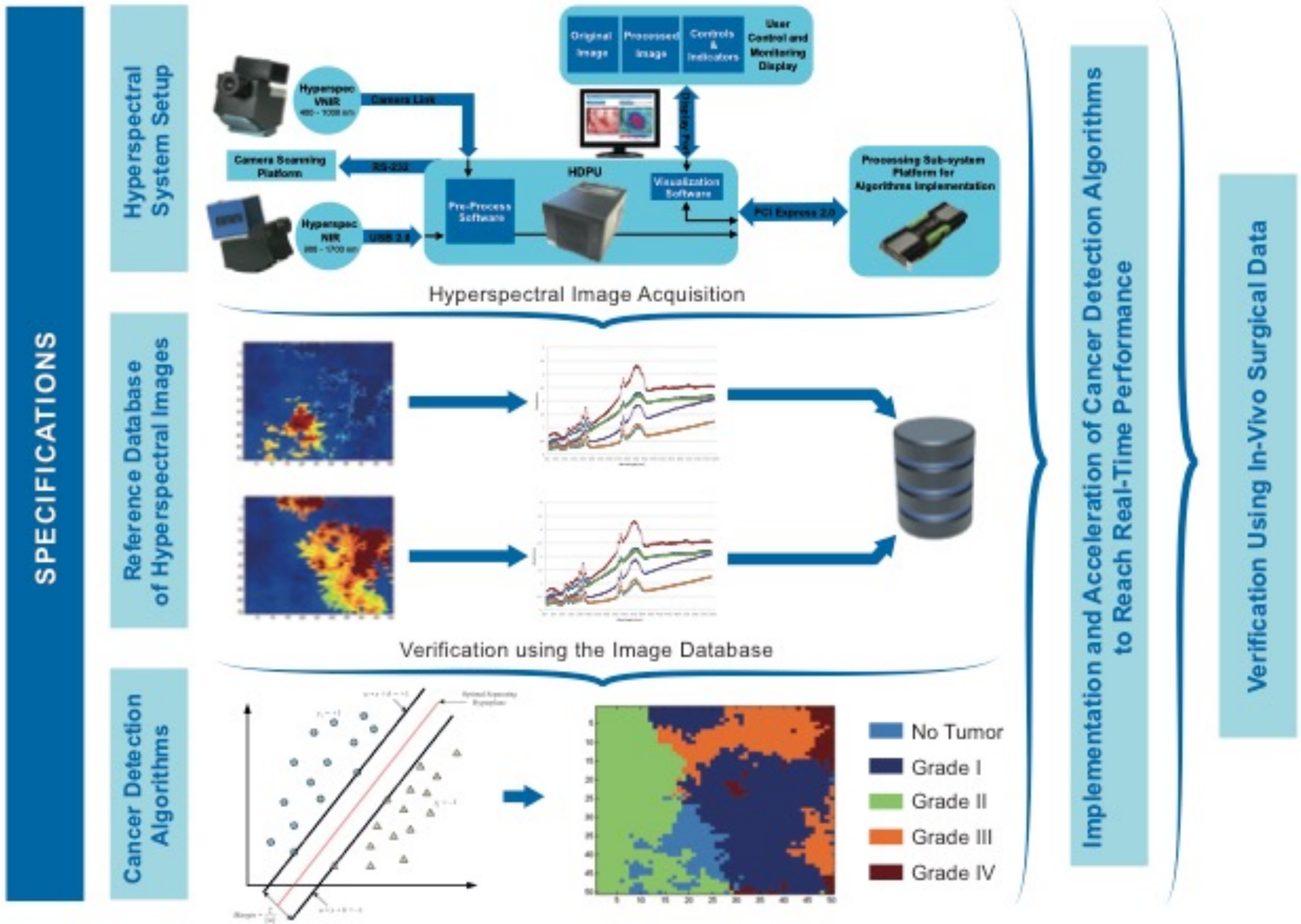
The relevance and importance of complete resection for low grade tumours is well known, especially in paediatric cases. However, traditional diagnoses of internal tumours are based on excisional biopsy followed by histology or cytology. The main weakness of this standard methodology is twofold: firstly, it is an aggressive and invasive diagnosis with potential side effects and complications due to the surgical resection of both malign and healthy tissues; and secondly, diagnostic information is not available in real time and requires that the tissues are processed in a laboratory.

There are several alternatives to conventional optical visualisation through a surgical microscope, including magnetic resonance imaging (MRI), computed tomography (CT), ultrasonography, Doppler scanning and nuclear medicine. Unlike these approaches, hyperspectral imaging offers the prospect of precise detection of the edges of the malignant tissues in real time during the surgical procedure.


1

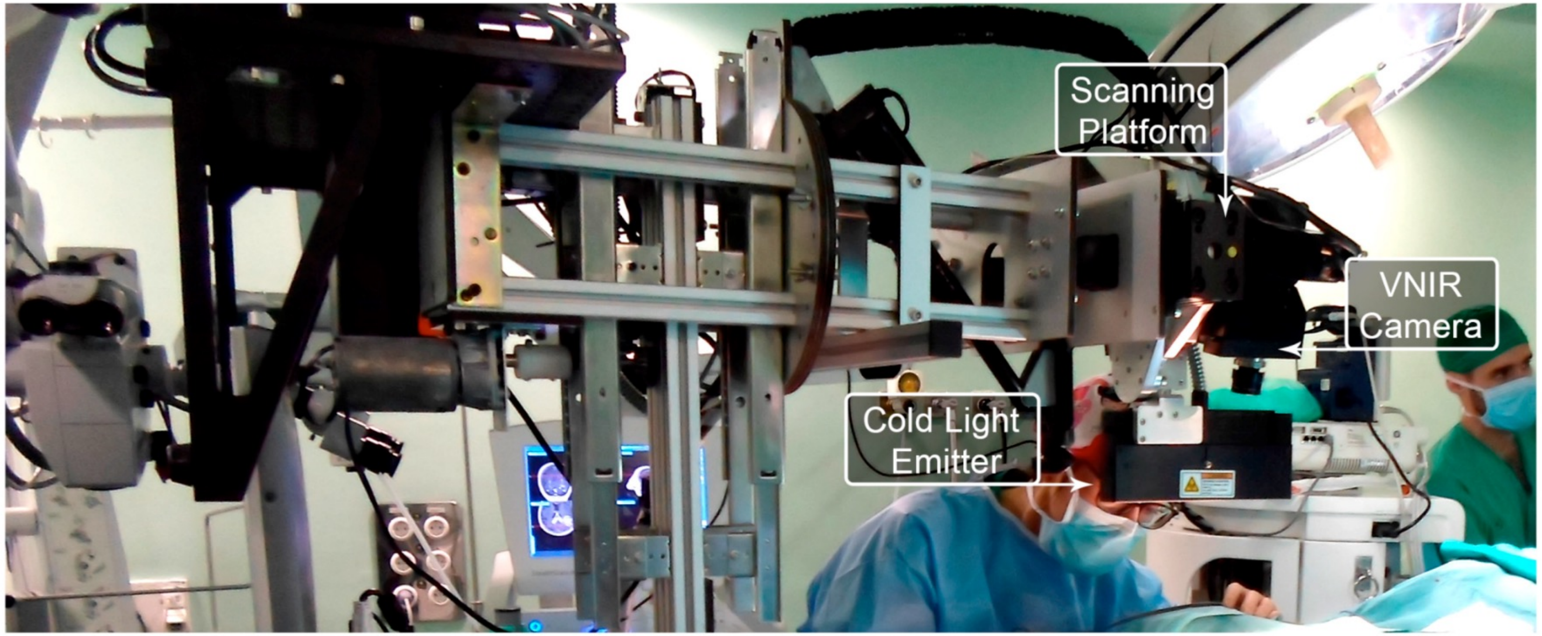
Past and on-going projects

HEALTH

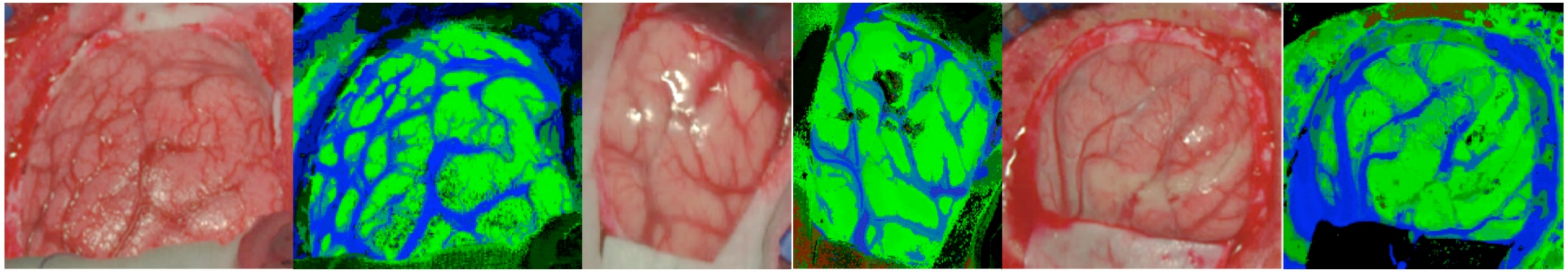


Past and on-going projects

HEALTH



(a)



(b) (c) (d) (e) (f) (g)