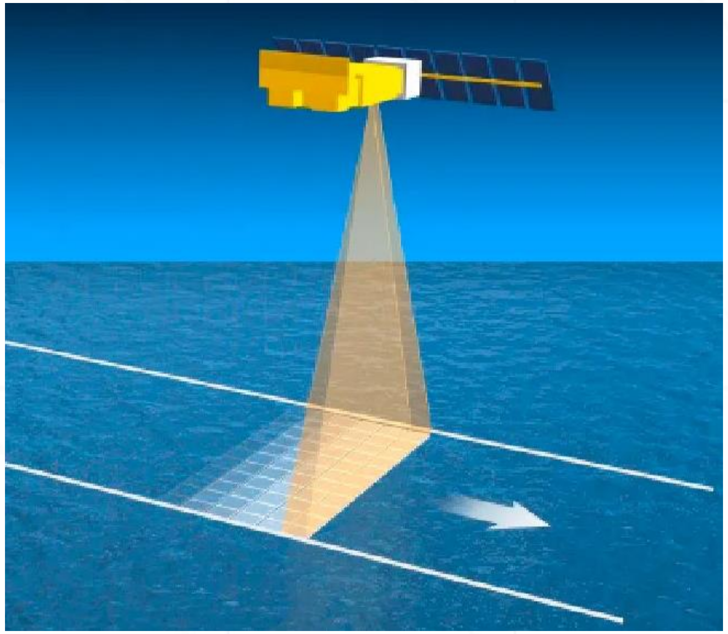
AGENIUM SPACE

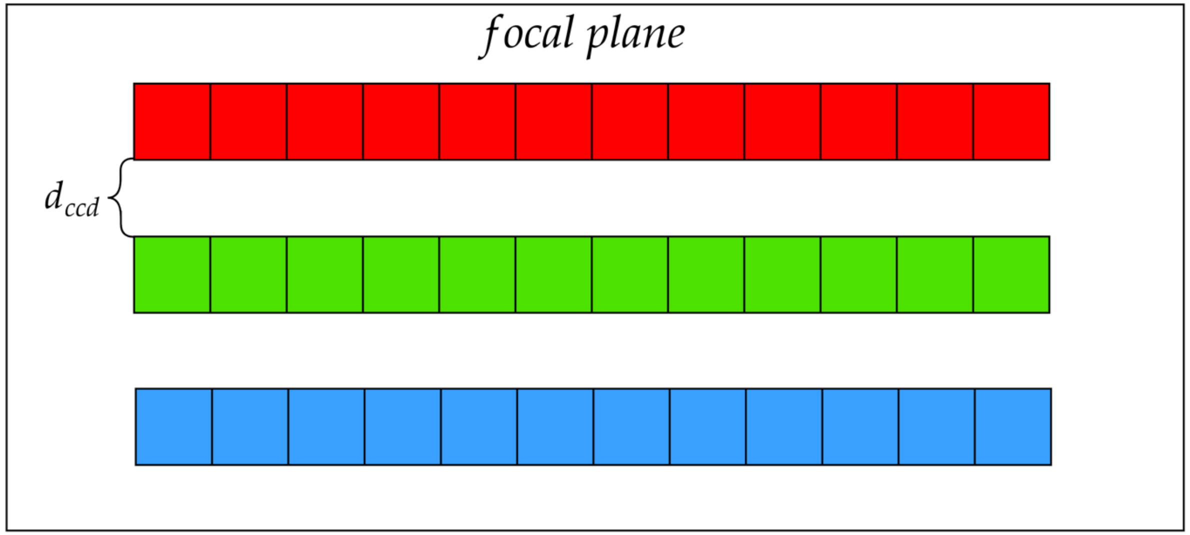
SMARTHEP Edge Machine Learning School --
25/09/2025
Real time applications in earth-monitoring satellites

Dr. François de Vieilleville

Introduction : Push-broom sensor in earth observation satellite

Passive optic





The camera scans earth line by line

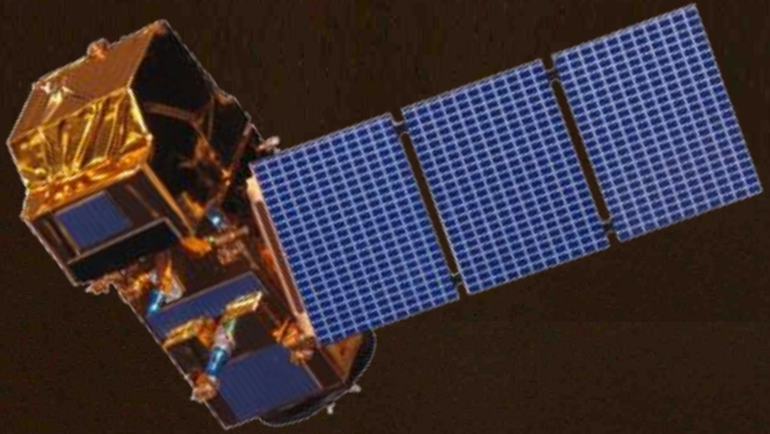
- -scan is controlled by movement (attitude, speed)
- -bands are not acquired at the same time
- -image is acquired in focal place geometry, needs reprojection

@698 kms in sun synchronous orbit

- -14 orbits/day
- - 7507.5682 m/s
- - 0.09324 ms/line

AI-boosted Space

What are the possibilities ?



RAW DATA

→ RADIOMETRIC CORRECTIONS
→ GEOMETRIC CORRECTIONS
→ ATMOSPHERIC CORRECTIONS
→ PROCESSINGS for V.A.P.

Driven for High-tier HW performance

1

→ (R.+G. CORRECTIONS ON BOARD)
→ (AI) PROCESSINGS ON BOARD

INFORMATIONS
SELECTED DATA

V.A.P.

RAW DATA

2

→ (AI) RADIOMETRIC CORRECTIONS
→ (AI) GEOMETRIC CORRECTIONS
→ ATMOSPHERIC CORRECTIONS
→ (AI) PROCESSINGS for V.A.P.

Driven for system (HW+SW) efficiency and intelligence

EVOLUTION OF DL

DL done on the ground

DL done on at the edge (satellite)

Pros:

- Verifiable public/private data reference databases available
- Lots of computational resources at hand (GPU, TPU, …)

Cons:

- Selective data availability, high cost
- Produced as huge models, requiring a lot computational power/memory

CHALLENGES

Limited Computation power

↓

Limited energy

↓

Limited memory capacity

↓

Small models, running at low power within a limited memory consumption footprint

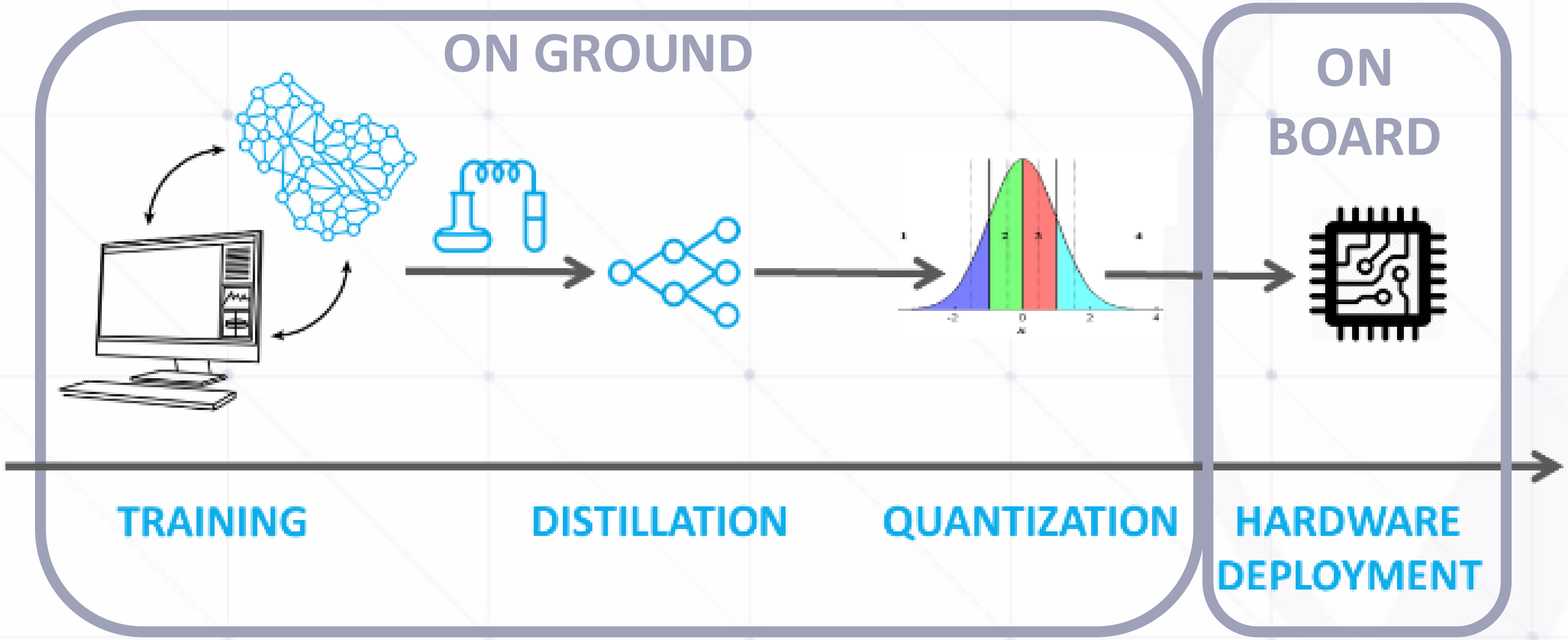
Pros:

- Enables autonomy
- Increases ROI of satellite
- Creates value-added insights
- Increases responsiveness
- Reduces the cost of downloads

Cons:

- It is constrained as hell – requires small models, running at low power within a limited memory consumption footprint

Proposed Generic Pipeline



Distillation performances

All master models are around 90% F1 score.
Distillation is measured as model's parameters reduction and attrition.

	CORTEX (Distillation SW v1)			**DEEP CUBE** (Distillation SW v2)			
	Boat (S2)	Oil spill (S1)	Ocean Features (S1)	Boat (VHR)	Clouds (S2)	Clouds/snow (S2)	Forest (S2)
Reduction Factor	x52 135M → 2.6M	x52 135M → 2.6M	x52 135M → 2.6M	x80 24M → 300k	x60 59M → 1M	x120 59M → 0.5M	x160 16M → 100k
Attrition F1 score (Distillation V1)	<2%	<8%	<5%	NA	~13%	NA	<3%
Attrition F1 score (Distillation V2)	NA	NA	NA	~5%	~6%	<5%	NA

On board AI capabilities depend on both HW and SW tooling:

Soc FPGA/FPGA:	CONS	PROS
VHDL/Verilog/HLS	Long to develop	Ad Hoc
VITIS AI (Xilinx HW)	Black Box	Short to develop
HLS4ML	Small models	Fast to develop, OSS
CPU (arm)	**CONS**	**PROS**
TensorFlow	Only FP32	Fast to develop, OSS
TensorFlowLite	INT8 backend is super slow	FP16, Fast to develop, OSS
Pytorch	INT8 backend is super slow	Fast to develop, OSS
GPU (AMD G/R series)	**CONS**	**PROS**
TensorFlow	Does not work	OSS
TensorFlowLite	C++ only backend	Short to develop, OSS
VPU (Myriad)	**CONS**	**PROS**
OpenVINO	Only fp16	Short to develop, OSS

FLIGHT-PROVEN AI

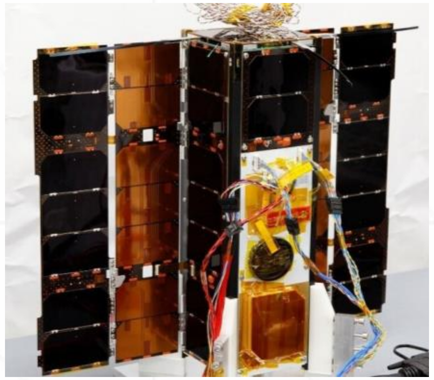
Adapting to customers' needs and HW

D-Orbit SCV004

- **Computing HW:** **Accomplishment:** First to demonstrate onboard-ML, followed by AWS, Trillium, etc.
- UniBap iX5, AI execution completed on AMD GPU cores
- **Camera**: images were pre-loaded
- **Date**: May'2022

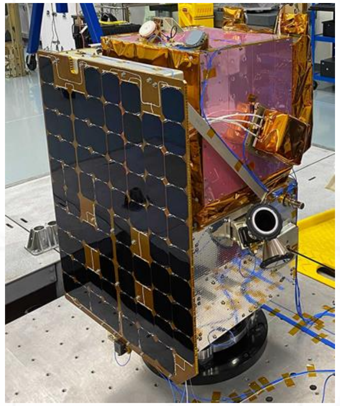
ESA OPS-SAT

- **Accomplishment:** use of FPGA to accelerate convolution computations for AI.
- **Computing HW:** Altera Cyclone V SoC, with CNNs computed on FPGA and data feed manged on ARM Cortex-A9
- **Camera:** 12MPx, RGB, bivalent
- **Date**: Q4.2022



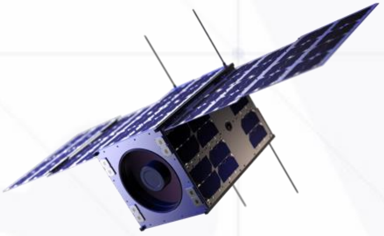
LoftOrbital Yam-3

- **Accomplishment:** installation of AI onto already launched satellite, FPGA reconfiguration in flight, updates of DNN in flight.
- **Computing HW:** SoC FPGA with Xilinx Zynq7045
- **Camera:** 12MPx, Monochromatic
- **Date**: Nov.2023



EnduroSat Balkan-1&2 ESA Copernicus Contributing Mission

- **Accomplishment-1 (ESA Copernicus Contributing Mission):** Continuous scanning of oceans for ships
- **Accomplishment-2 (Edge-SpAIce – Horizon Europe 2023):** Continuous scanning of oceans for marine-plastic littering
- **Computing HW:** SoC FPGA with Xilinx Ultrascale+
- **Camera:** 1.5m GSD, multispectral
- **Date**: 2024-2026



HW Throughput Performances

/!\ 2022 Results

No attrition between distilled models and quantized models (INT8 & FP16)

Cortex : VITIS AI <= 1.2 / DNNDK

Deep Cube : VITIS AI <= 1.4 / VART | TFLite/Pytorch | OpenVino

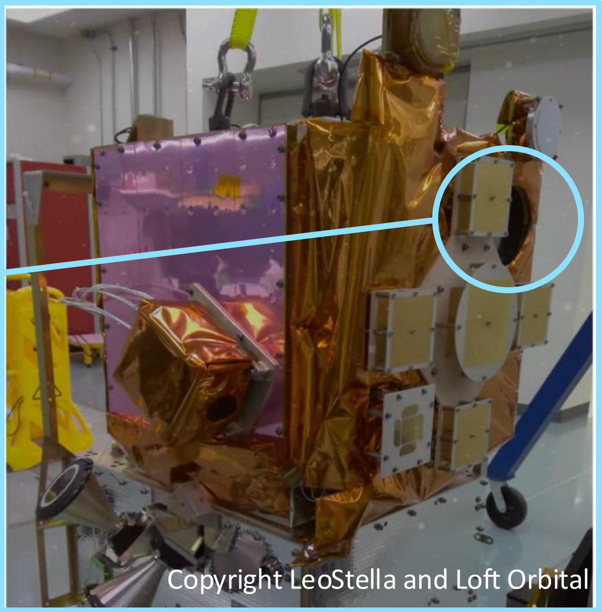
	Xilinx Zynq SocFPGA-7020 Pixels/W/s	**Xilinx ZynqUltraScale+ SocFPGA - ZU9G Pixels/W/s**	**Intel Movidius 2 VPU Pixels/W/s**	**AMD G-Series CPU/GPU Pixels/W/s**
Classification (2.6M)	NA	570k	NA	NA
Segmentation (0.1M ~ 1M)	70k to 120k	170k to 215k	170k to 350k	8K to 19K
Detection (0.3M ~ 0.4M)	115k to 190k	350k to 600k	320k to 640k	7K to 17k

In orbit service demonstration

Thanks to Occitanie Plan de Relance

IA was put on board *AFTER* YAM-3 satellite was launched
Uses Xilinx's 7000 series MPSoc-FPGA

Image payload is a panchromatic matrix 5m GSD
AI is done on RAW images



Use cases are:

- **boat segmentation**
- **boat detection**
- **cloud segmentation**

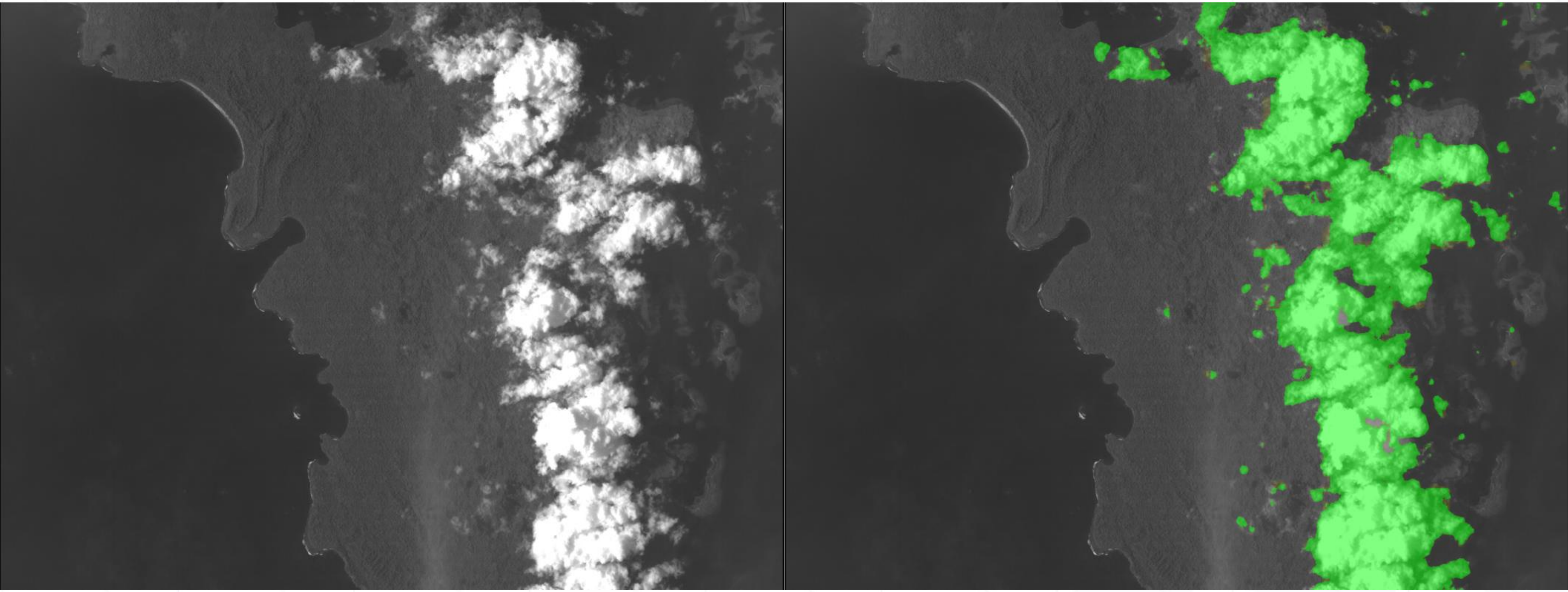
On board performances for 2W:

- **< 90 s for segmentation on 12Mpx**
- **< 30 s for detection on 12Mpx**

On board results for YAM-3
Directly on RAW data

Raw image : Panchromatic@4.75m GSD
Matrix sensor, MonoScape100, LoftOrbital Yam-3, © AGENIUM Space

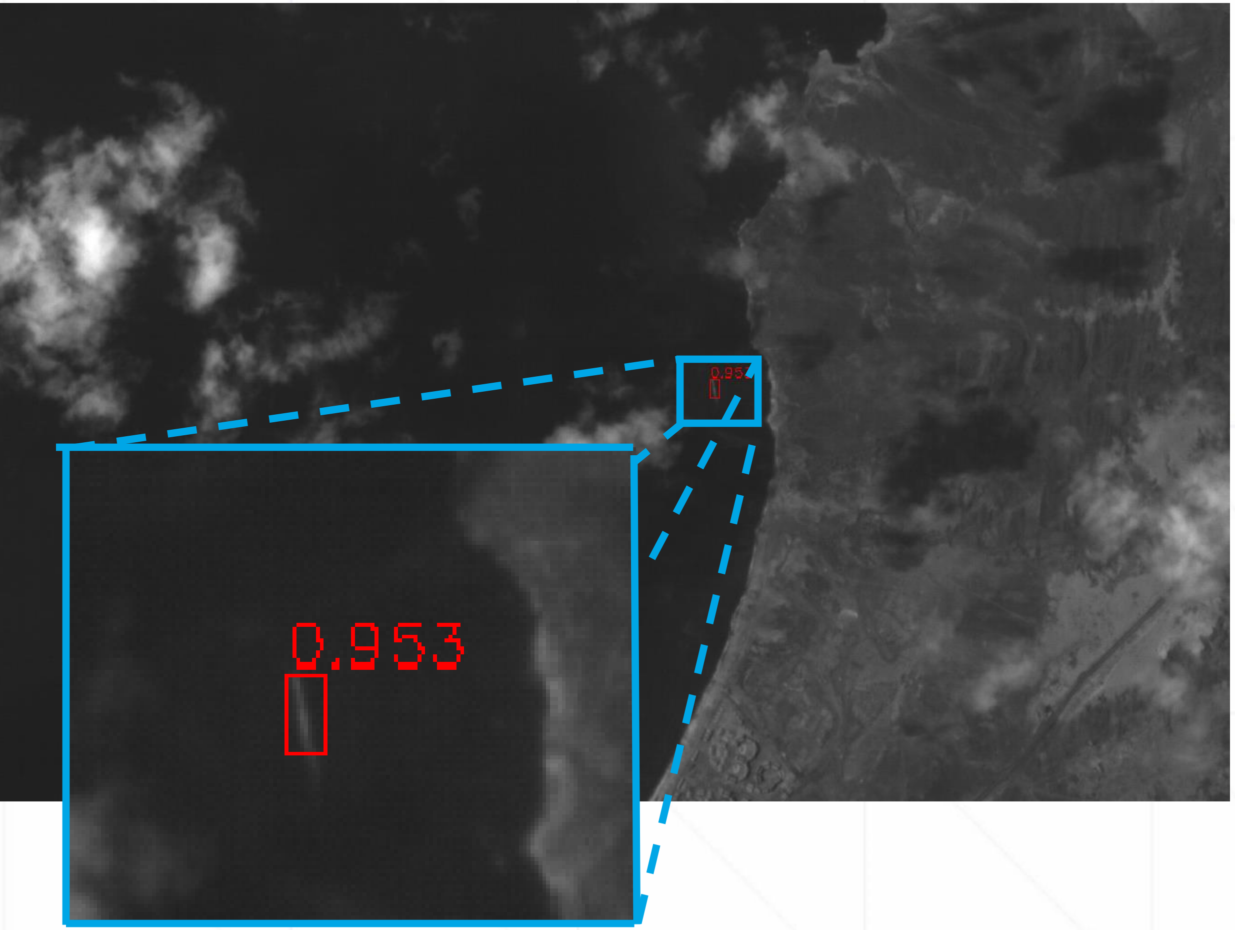
Clouds masked



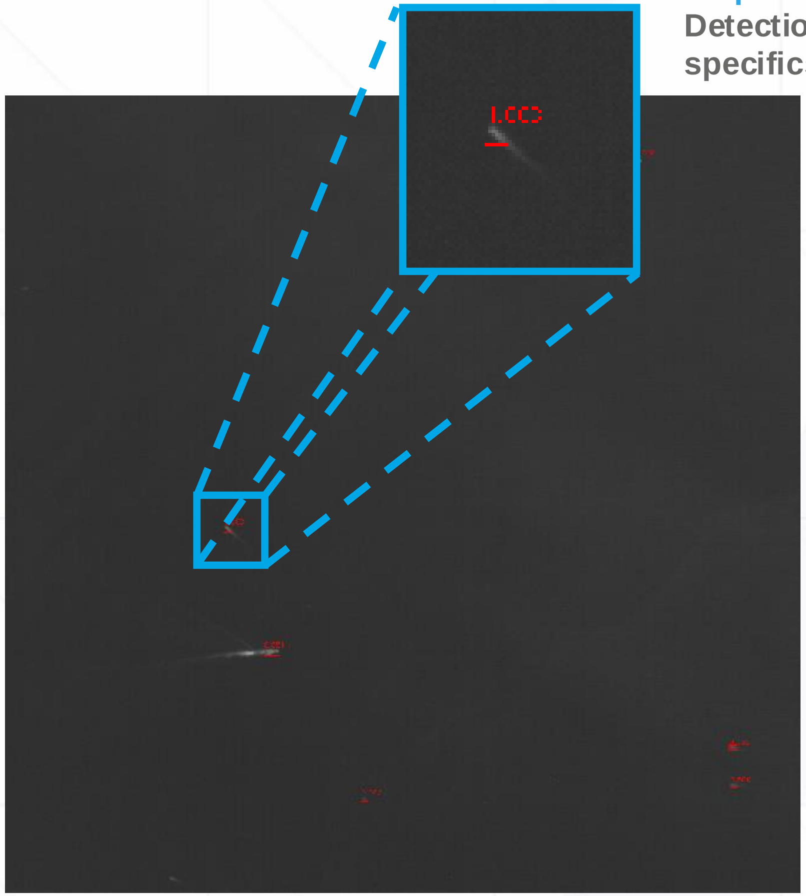
On board results for YAM-3

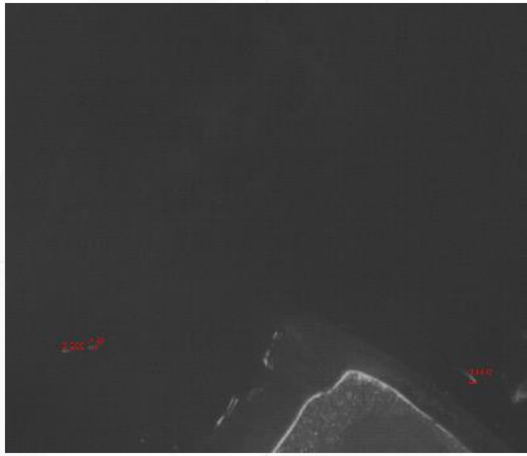
Directly on RAW data

Raw images : Panchromatic@4.75m GSD
Matrix sensor, MonoScape100, LoftOrbital Yam-3, © AGENIUM Space



Ships detected
Detection algorithm tuned to camera specifics after more images acquired

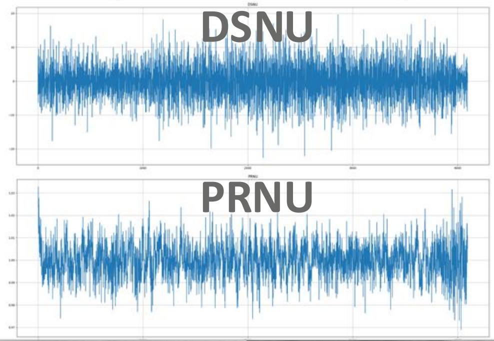




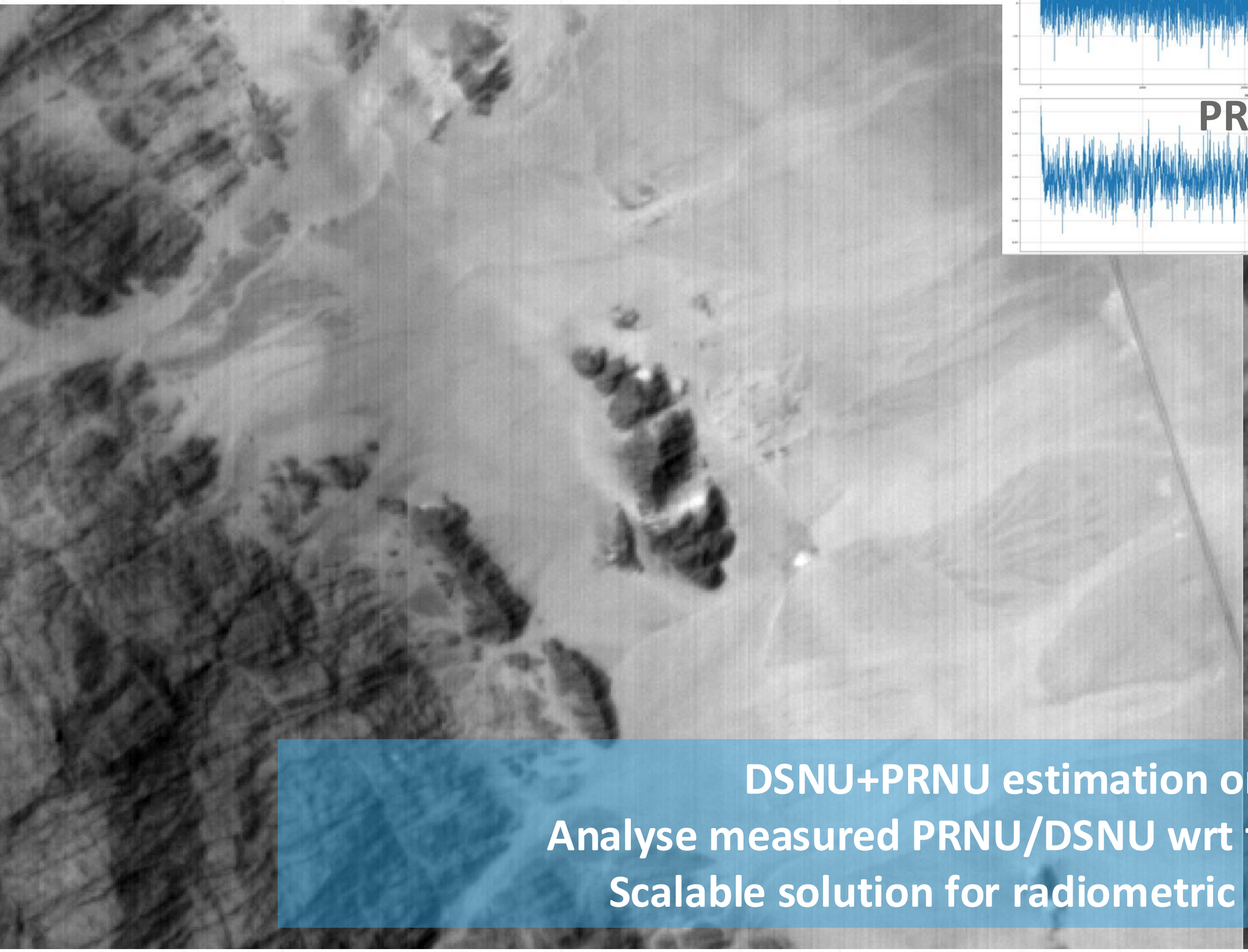
Future on-board processing ?

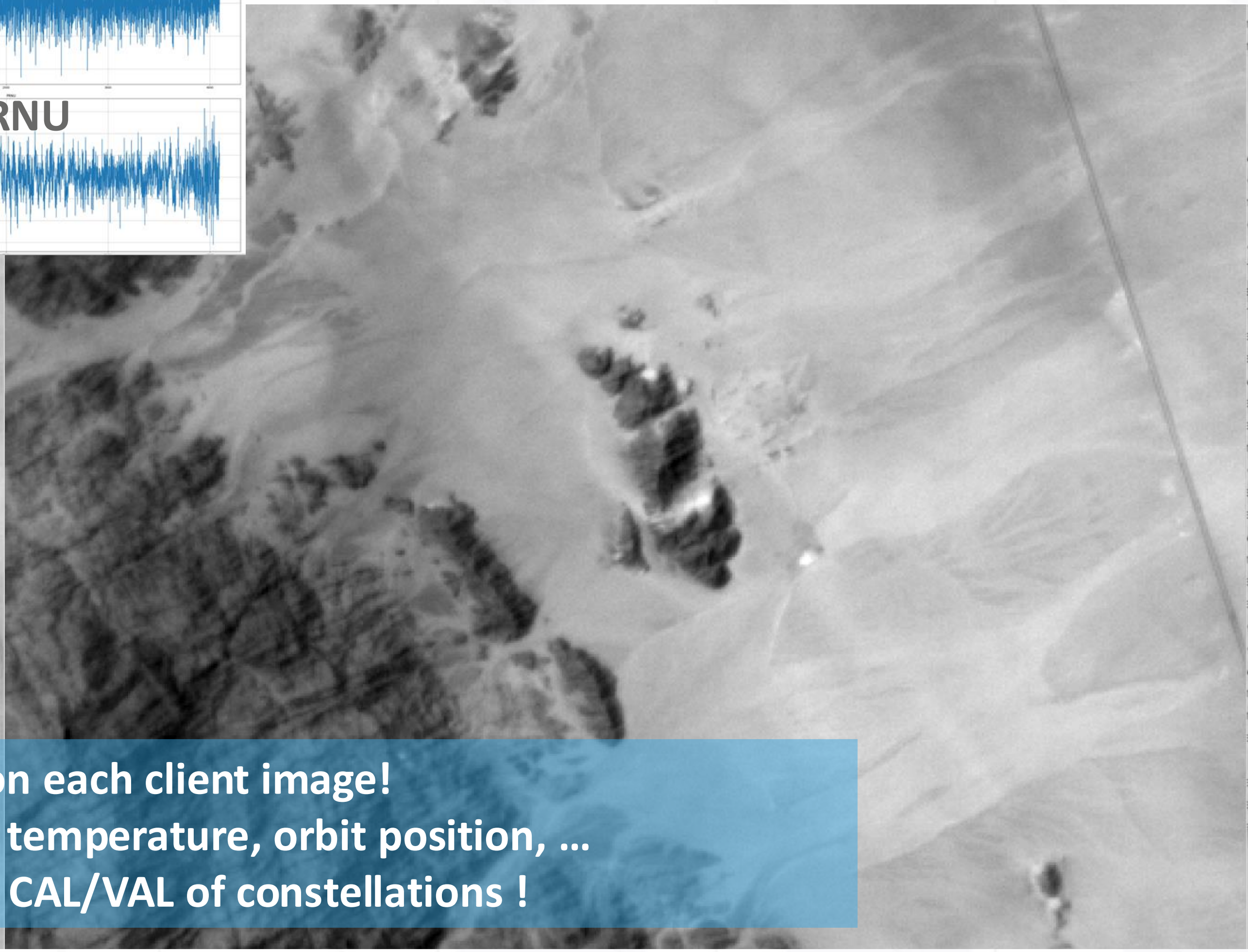
Case of DSNU + PRNU estimation and correction for CAL/VAL activities

Raw image
Push-broom sensor, MultiScape50, © KAUST & SIMERA



PRNU+DSNU corrected

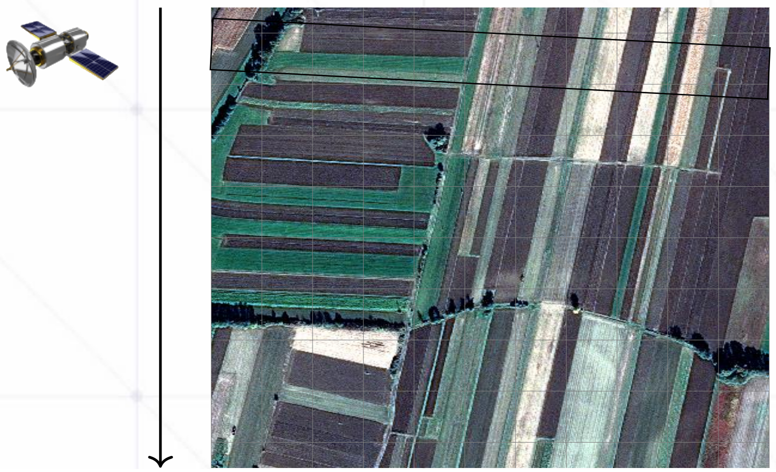




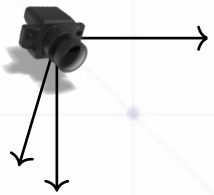
DSNU+PRNU estimation on each client image!
Analyse measured PRNU/DSNU wrt temperature, orbit position, …
Scalable solution for radiometric CAL/VAL of constellations !

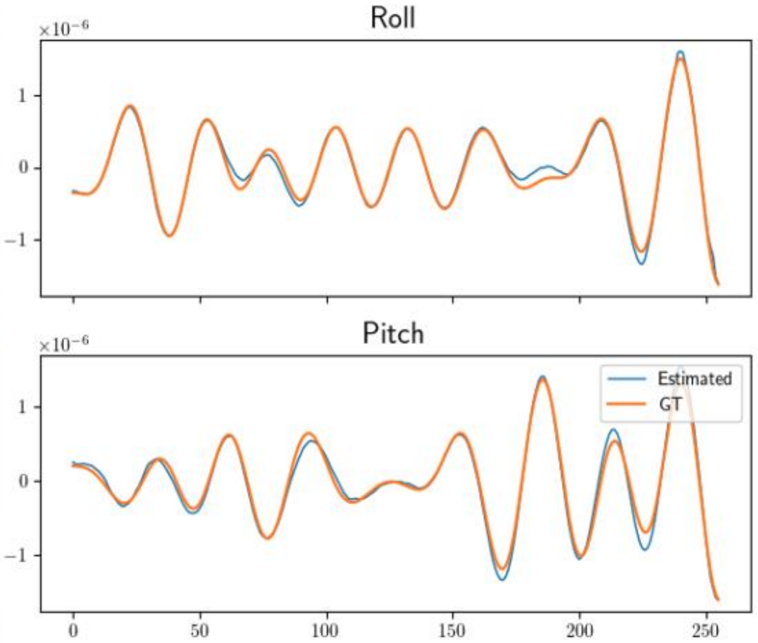
Improve on-ground processing

Case of vibration estimation and correction for geometric improvements



moving direction





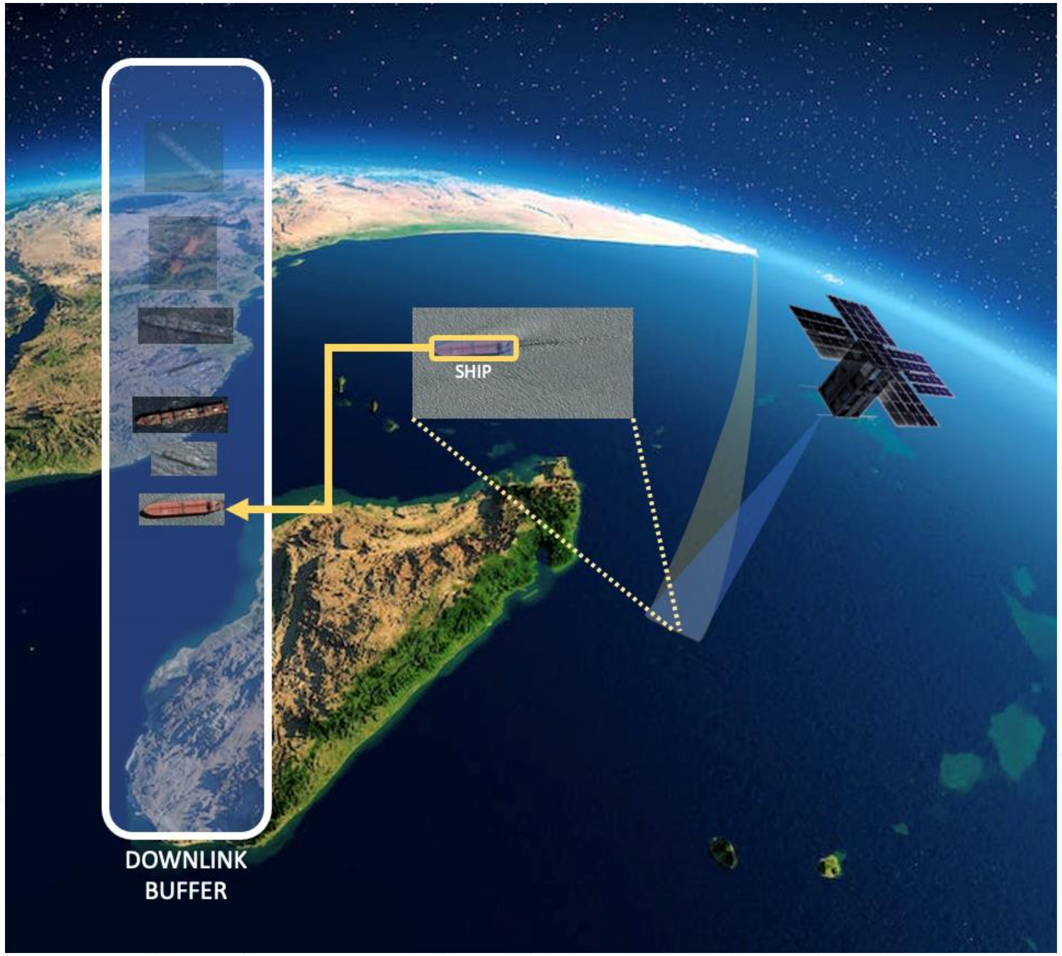
VHR example:

- LEO orbit at 500km,
- 0.2 ms for acquisition of 1 line
- High-tier star tracker has 30Hz rate

→ Vibration frequencies can be above 1KHz !

ADCS informations cannot help to mesure such fast variations!

Benefits of AI onboard
A simple example



Detection is made onboard of 16-u sat

Fast download of :
-Image patch with detected object for analysis
-Georeferencing & alarm

→ Faster response system

→ Selection of ROI

→ « Tip and cue » : task other satellite with better imagery

→ Continuous screening in near real-time

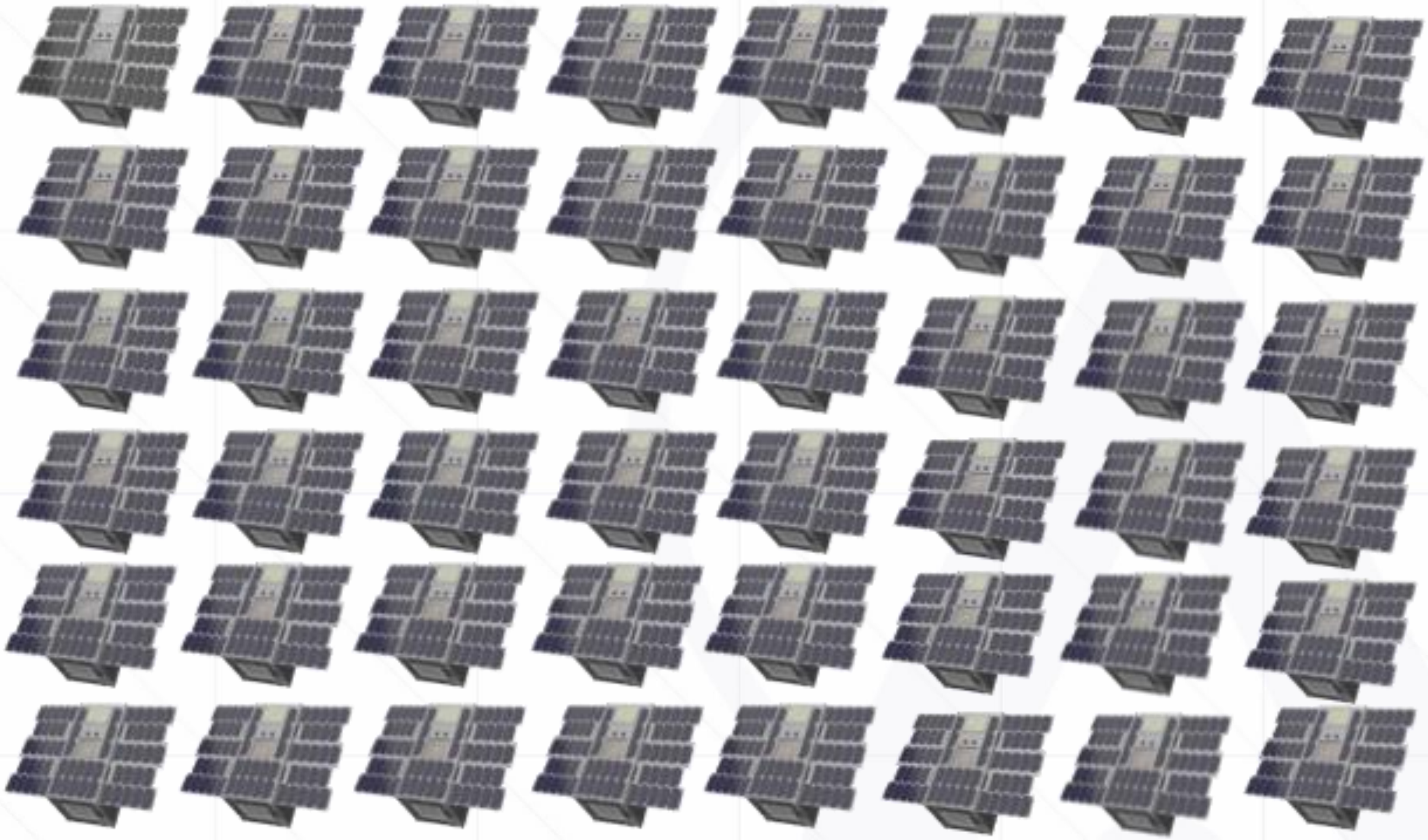
The future ?
Change of paradigm

~100 Meur

~70cm GSD

VS

~100 Meur



~150cm GSD

~(50-70) 16U cubesats

HW Throughput Performances

/!\ 2024 Partial Update

	Xilinx ZynqUltraScale+ SocFPGA - ZU9G Pixels/W/s VITIS 1.4	Xilinx ZynqUltraScale+ SocFPGA - ZU9G Pixels/W/s VITIS 3.0
Segmentation (0.1M ~ 1M)	170k to 215k	~2M