ESA Φ-lab: Current Projects & Future Perspectives - Earth Observation, AI & Quantum Computing

Artificial Intelligence (AI) Research

AI for Earth Observation (EO) - AI4EO

14 July 2024

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Contents

- **ESA Φ-lab:**
  - **Earth Observation, Artificial Intelligence**
  - **Quantum Computing**

- **ESA Φ-Lab Offices:** Explore and Invest

- **Current Projects at the Φ-lab**
  - PhilEO: **EO Foundation Model** and Evaluation Framework
  - Major TOM: Dataset in HugginFace, **Sentinel-2** & Sentinel-1
  - MapYourCity AI4EO Challenge
  - Physics Informed Neural Networks (PINN)

- **Work with us:** Collaborations and partnerships

- **Conclusion**

esa

Φ-lab

ESA Φ-lab

Climate Action, Sustainability and Science Department

Directorate of Earth Observation Programmes

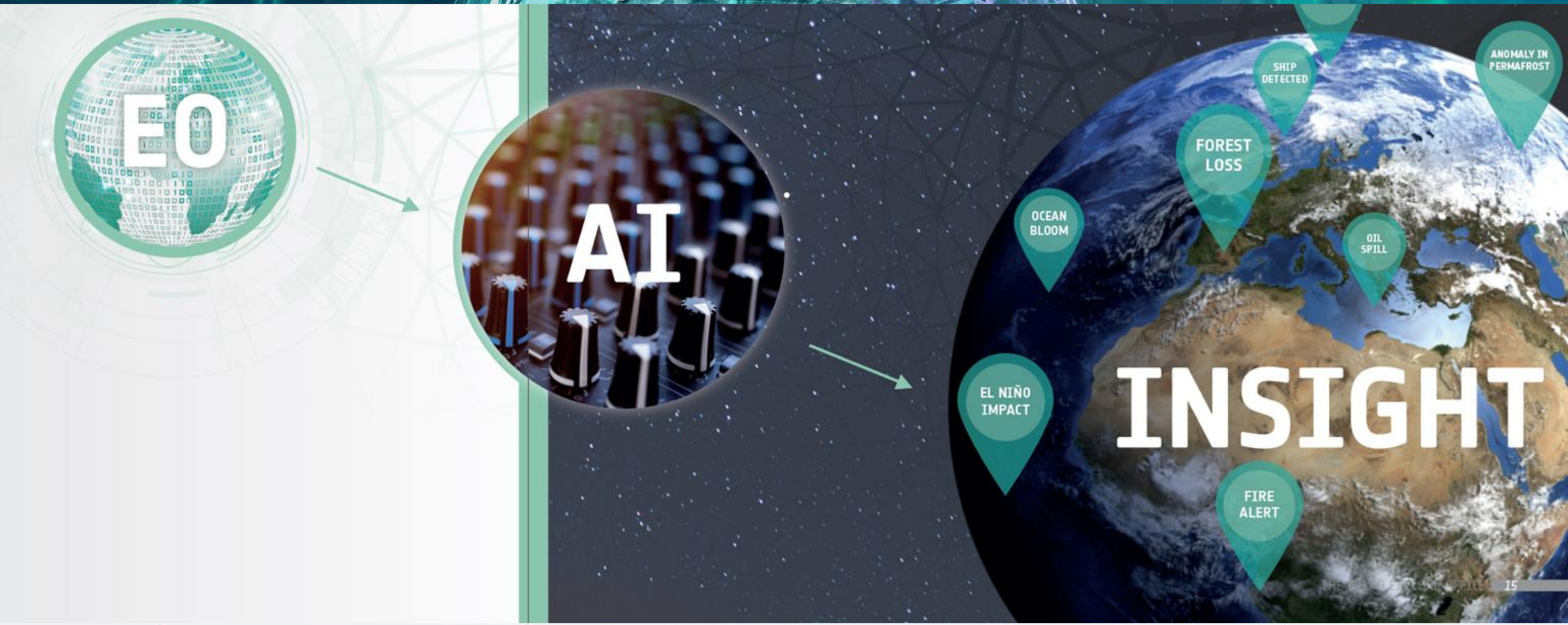
We strongly believe in
truly transformative ideas and in
the power of compelling partnerships
to accelerate the Earth Observation future

Giuseppe.Borghi@esa.int

January 2024

European Space Agency

The ESA Φ-lab - Why ?



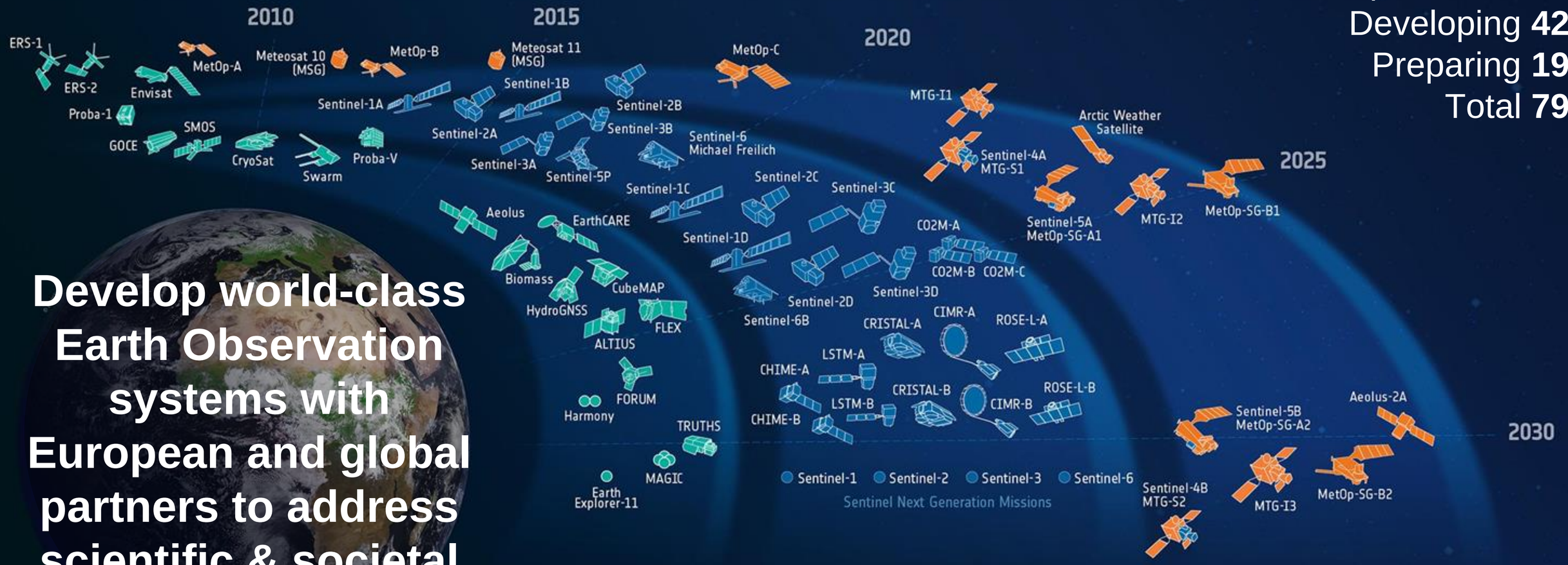
from Earth Observation to Earth Action

from data to actionable information

ESA’s Earth Observation Mission

Satellites

Heritage **04**
Operational **14**
Developing **42**
Preparing **19**
Total **79**

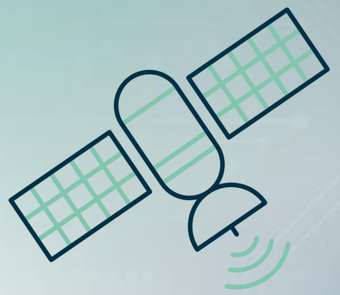


Develop world-class Earth Observation systems with European and global partners to address scientific & societal challenges

Science esa Copernicus European Union Meteorology EUMETSAT

AI opening a new dimension for EO

On Board Autonomy



Process Automation

Data Science

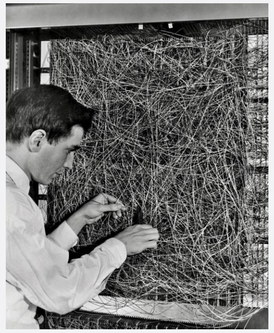
Detection/ Classification

Big Data Analytics

Super Resolution

The Great AI Acceleration

"**...** the **computational** ability to achieve **goals**." John McCarthy



Frank Rosenblatt Perceptron

1957

1950 – Age of Intelligent Machines

2008 – Siri Voice Assistant

IBM Watson wins Jeopardy

2011

1997

IBM Deep Blue beats Kasparov

2012

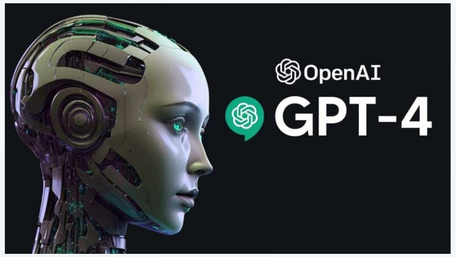
Big Bang for Deep Learning Computer Vision

2014 – Self Driving Cars

DeepMind AlphaGo, & 2017 Alphazero

2016

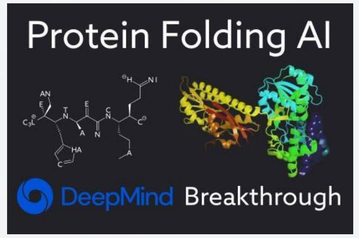
2020 – GPT-3



ChatGPT

2022

2021



Deep Mind AlphaFold

Stable Diffusion

Innovation Technologies Axis and Applications

AXIS I	AXIS II	AXIS III
Artificial Intelligence and Machine Learning	Quantum and Edge Computing	IOT, Blockchain, Web 3, Cognitive Space

- **Flight HW**
- **Flight SW applications**
- **Downstream applications**
- **End to end systems**
- **Innovative business models**

Φ-lab

The ESA Φ-lab Offices: Explore and Invest

We strongly believe in
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European Space Agency

The ESA Φ-lab Offices

Φ-lab Explore Office

Explores the innovation universe and connects together EO and digital revolution

A team of Researchers
and innovation seed funding (FutureEO)

Φ-lab Invest Office

Stimulates competitiveness by fostering the growth of entrepreneurial initiatives through investment actions from ESA Member States and private investors

A team of business innovators and a commercial co-funding programme (InCubed)

The ESA Φ-lab – What ?

Accelerate the future of Earth Observation via transformative innovation*

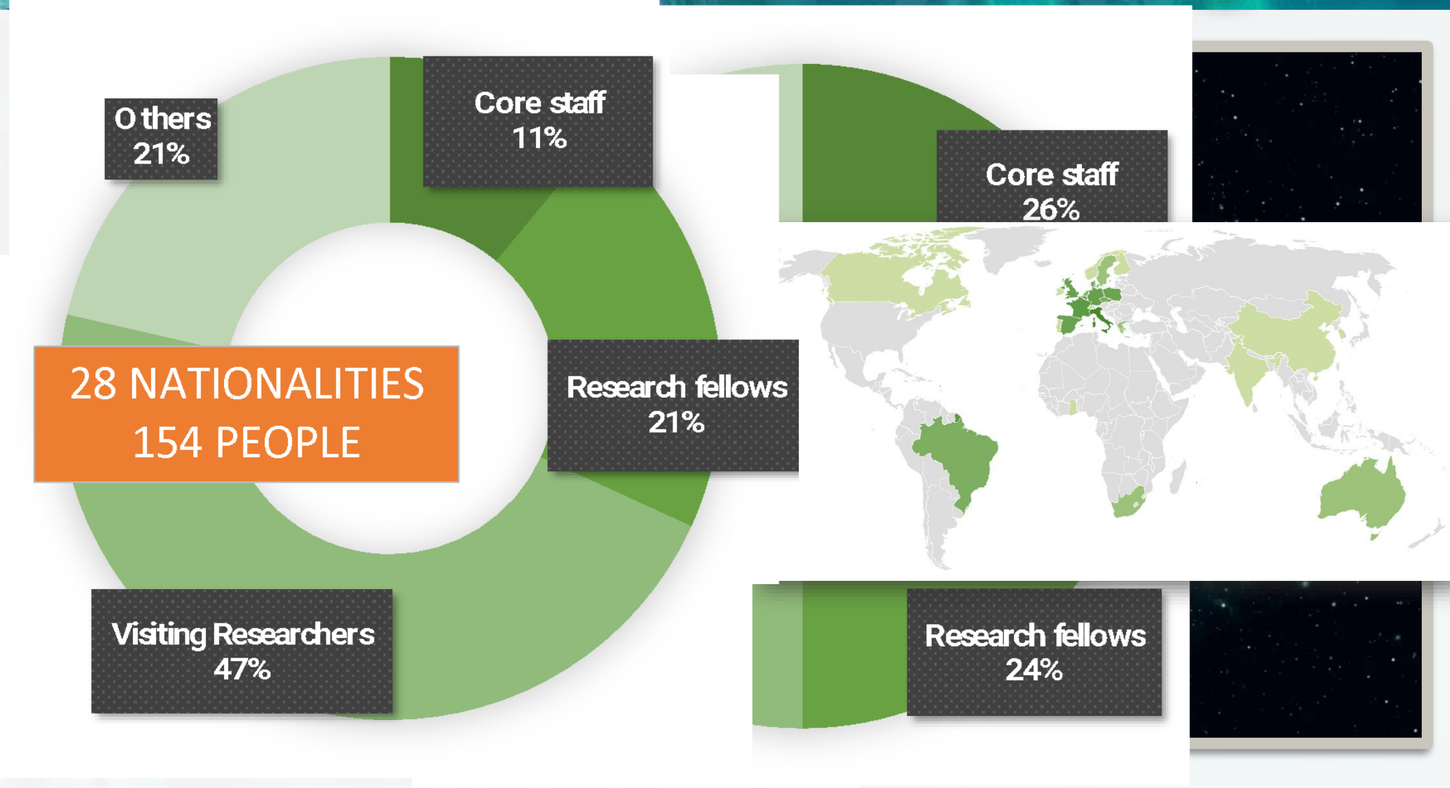
strengthening Europe's world-leading competitiveness

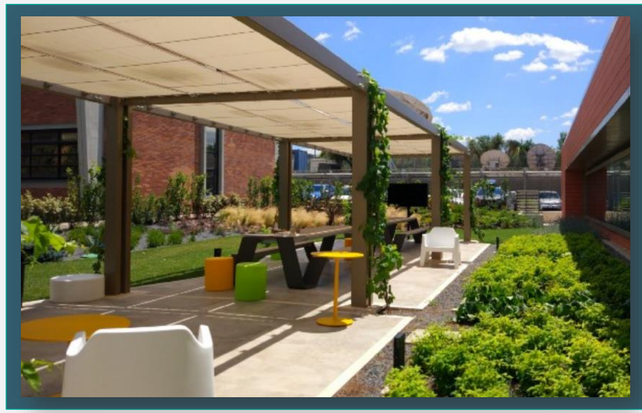
Uniquely in ESA Φ-lab **innovate and apply** under-one-roof

*transformational innovation: with the ability to completely transform or create entire industries via new technologies

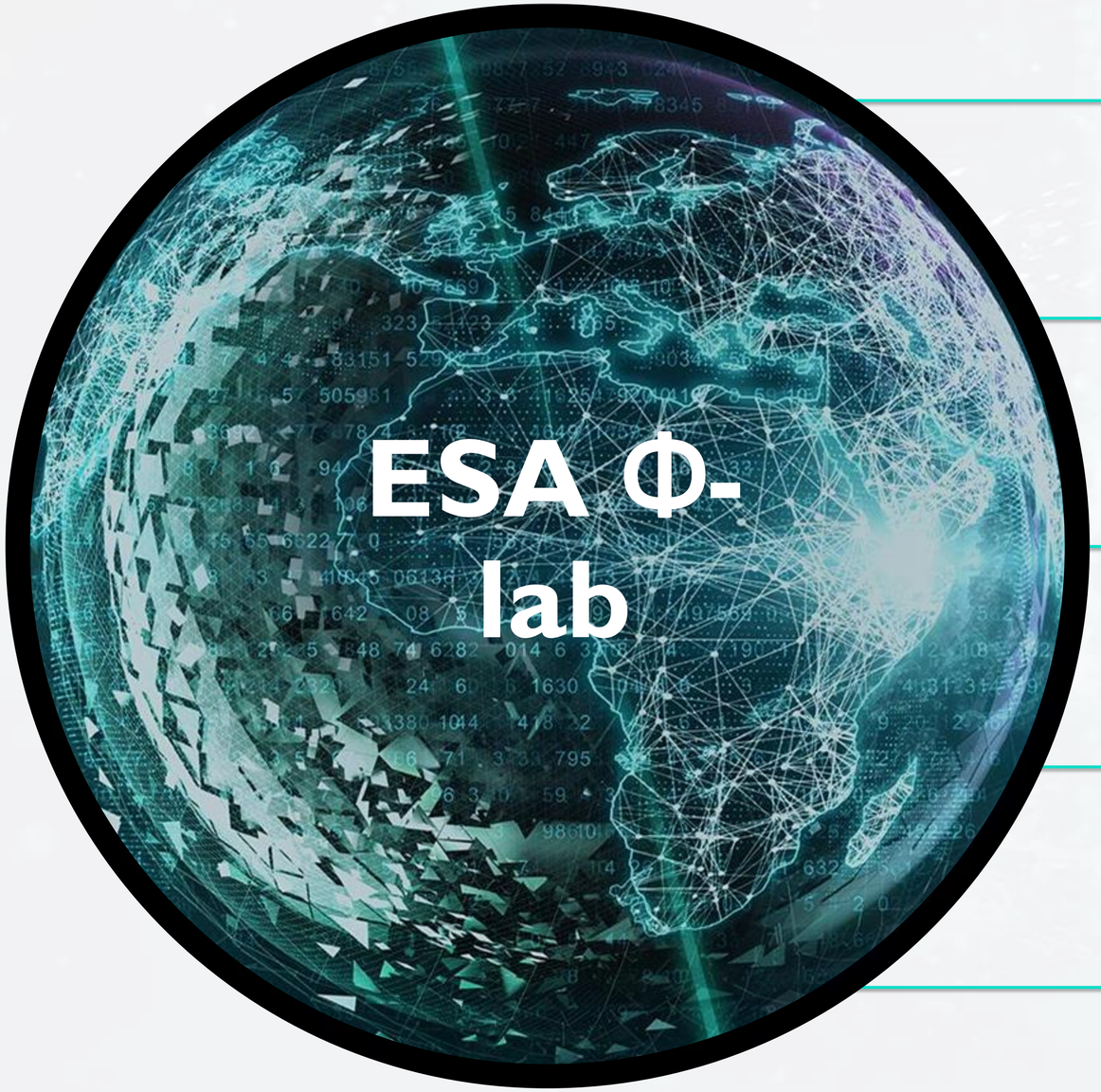
The ESA Φ-lab location and people

- Based in ESRIN, Frascati – Italy
- Established in 2018
- >20 strategic partnerships
- About 30 - 40 members





The ESA Φ-lab tools



Open Research Lab
Our collaborative and open research environment

Φ-lab Challenges
To stimulate transformational innovation

Φ-lab Community
Our network of companies, researchers, professors and key institutions

InCubed Development and Invest Actions
To facilitate access to innovation investments

Flagships programme
Key programmes as targets of our transformational innovations

Some of Φ-lab successes*

19
Contributed satellites

21
Strategic collaborations with companies, agencies, research centres and private investors

€205M
InCubed fund size

140
Activities
@62% co-funding rate

140+
Publications on peer reviewed journals and conferences

15+
Visiting Professors

70+
Visiting researchers

AI4EO
QC4EO
Contributing to European R&D agenda

*The ESA Φ-lab successes: as of April 2024

Φ-lab

ESA Φ-lab Explore Office

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European Space Agency

The ESA Φ-lab Explore Office

Our goal is to enable a connected network of talents to brings together expertise and ideas from researchers, industry, ICT players, innovators and investors to foster scalable learning from EO data, Earth Science and Computer Science

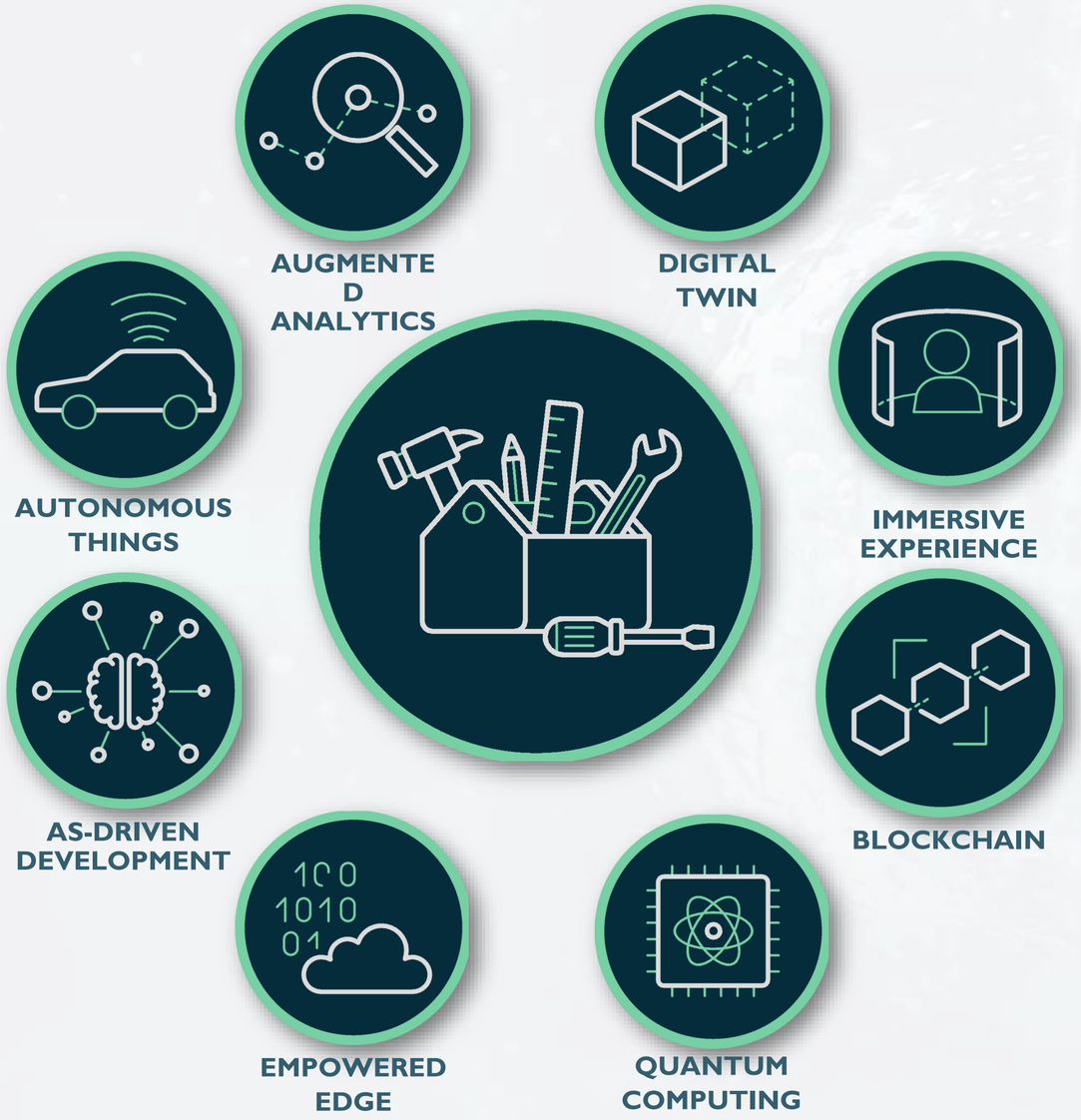
We operates as a ESA 'hub' within the network of EO academic and industrial researchers across Europe and globally

- Research Lab
- Flag Ships
- Φ-lab Community
- Challenge Program

Link to ESA Φ-lab Explore Office - Research & Innovation strategy, 2020

Innovation cycle to deliver transformative and viable ideas

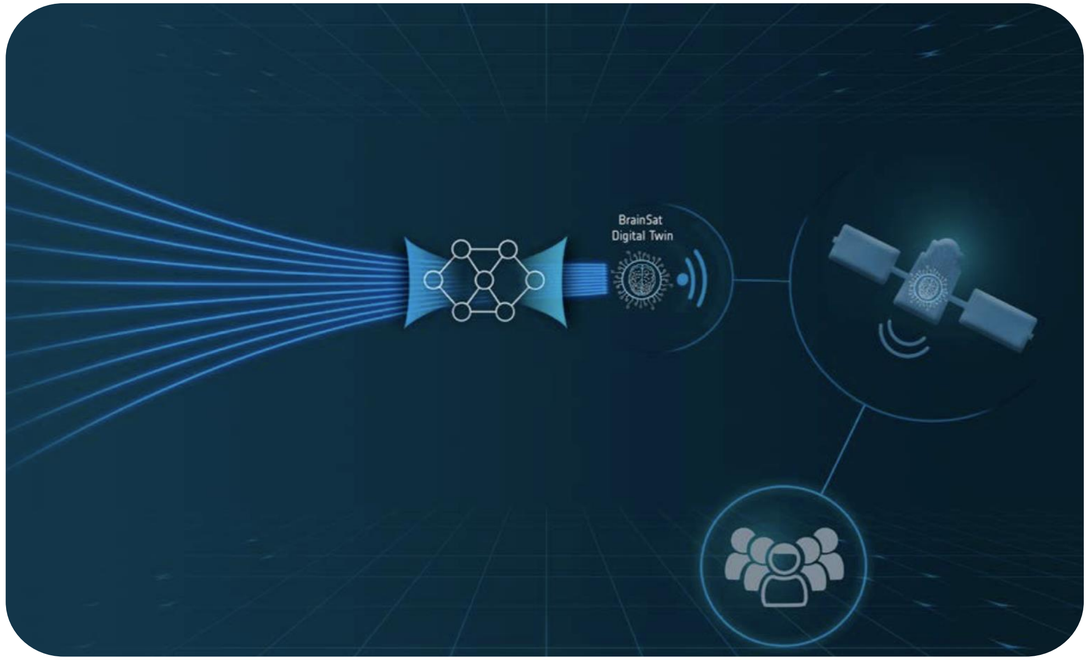
We work on

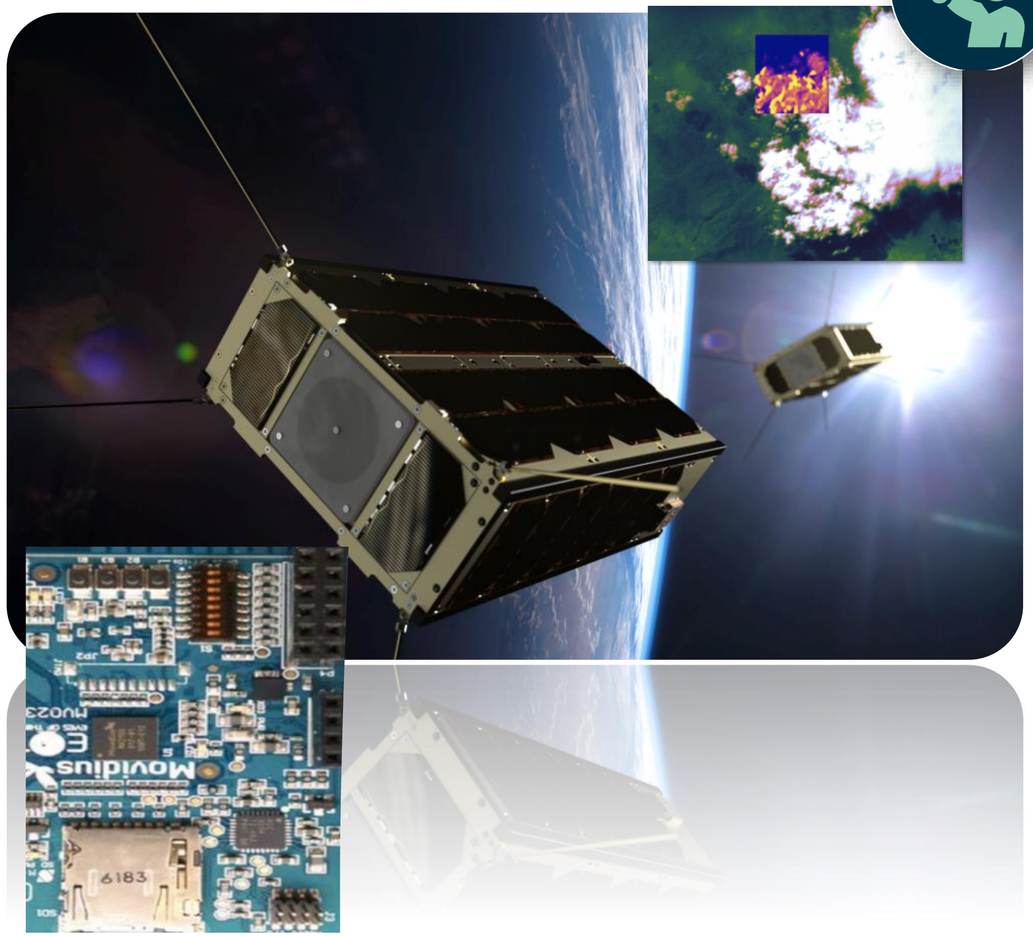


Φ-lab Explore innovation cycle is

- Focus on a meaningful problem
- Connect expert partners
- Enable solutions developing capacity
- Experiment "fail and recover fast" on use cases

Edge Computing in Earth Observation



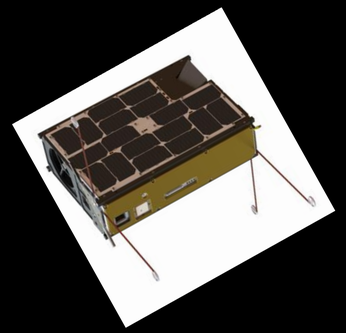


> *The value of satellite-based EO no longer grows with the ability to collect and transmit data back to Earth, it increasingly lies with the ability to transmit customer-relevant insight in real-time.*
>
> **Peter Platzer,**
> *Spire, Φ-week 2019*

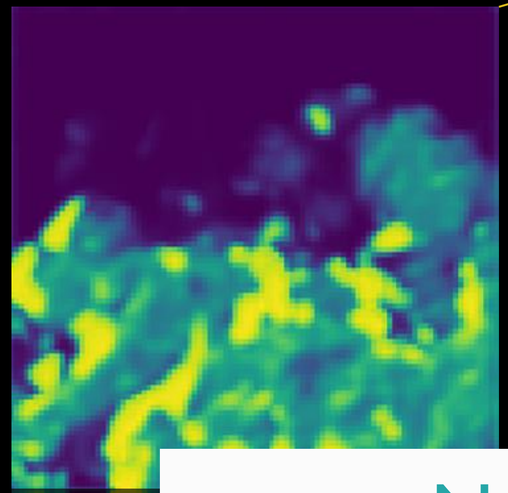
Actionable insight in space, low latency, autonomy

18

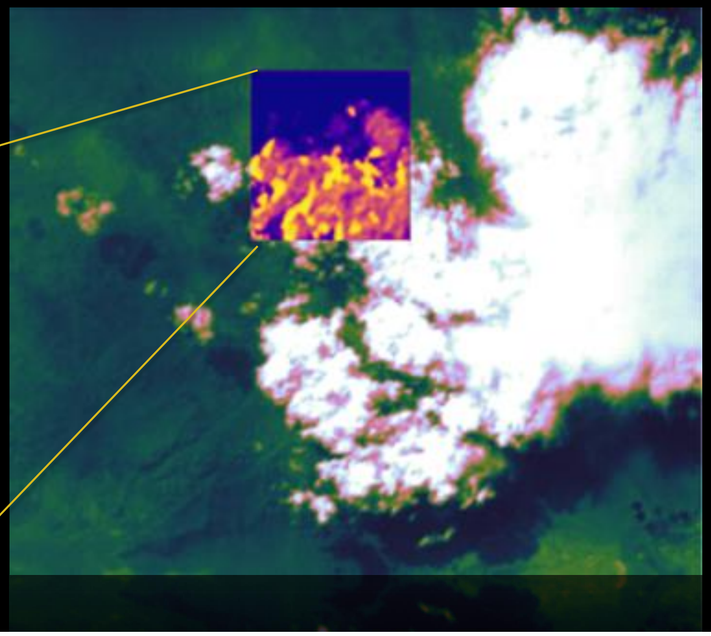
Φ-sat-1 is the first AI-powered European EO mission



AI-computed Cloud mask



Cloud mask superimposed on the hyperspectral image



Now AI on Φ-sat-2,
On Copernicus expansion missions and more..

The Myriad 2 chip

Image: Maximilien Brice/CERN

AI chip and the Φ-sat-1 neural networks are perfectly working with the expected performance

Φ-lab-powered satellites and constellations

FFSCAT / Φ-sat1

First IOD with GPU and AI model for EO with miniaturised hyperspectral

UBOTICA (IE) | COSINE (NL)

Launch : 2020

Φ-sat2

Pushing agility with easy deployment/update of AI

Open Cosmos (UK)

Launch : 2024

Wild Ride

IOD with in-orbit Rapid Flood Mapping

D-Orbit (IT/UK)
UNIBAP (SE) | FDL (UK)

Launch : 2021

Dashing Through the Stars

IOD with first-ever onboard training of AI model for EO

D-Orbit (IT/UK)
UNIBAP (SE) | FDL (UK)

Launch : 2022

Intuition-1

Optimized AI pipeline from raw data, with ground/onboard continual learning

KpLabs (PL)

Launch : 2023

Progres.LU

Polarimetric radio-occultation mission

SPIRE (LU)

Launch : 2023

OroraFire

Thermal IR constellation for wildfire detection

OroraTech (DE)

Launch : 2024

MicroLidar

Greenhouse-gas detection

AIRMO (DE)

Launch : 2025

MSCM

MultiSpectral companion mission of Sentinel-2

Aerospacelab (BE)

Launch : 2024

AI EXPRESS

HPC and AI in-orbit platform

Planetek (IT)

Launch : 2024

MANTIS

Constellation of VHR MS satellites

Open-Cosmos (UK)

Launched : 2023

SAT4EOCE

VHR MS payload w/ TDI on CMOS detector, AOCS

DEIMOS (ES)
SSTL (UK) | Te2v (UK)

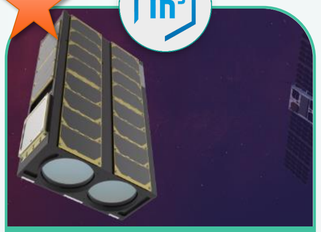
Launch : 2024

HIVE

Thermal IR constellation for agro-industry

ConstIlr (DE)

Launch : 2024



Hyperfield

Highly integrated satellite combining HYP and AI/ML-based analytics

Kuva Space (FI)

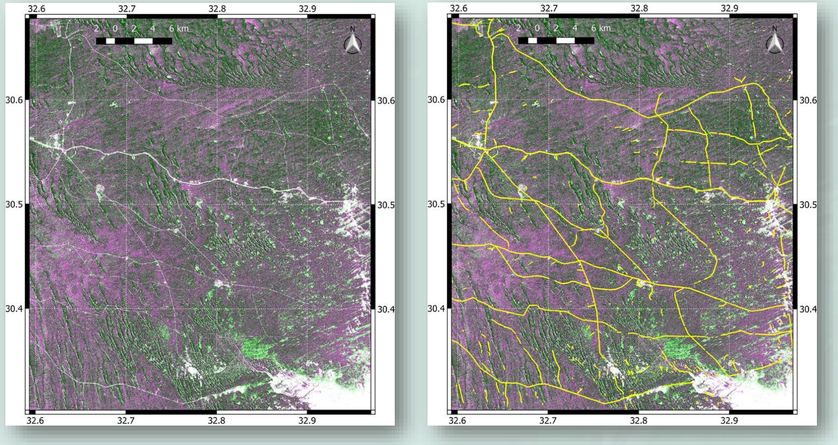
Launch : 2024

Fully Φ-lab supported

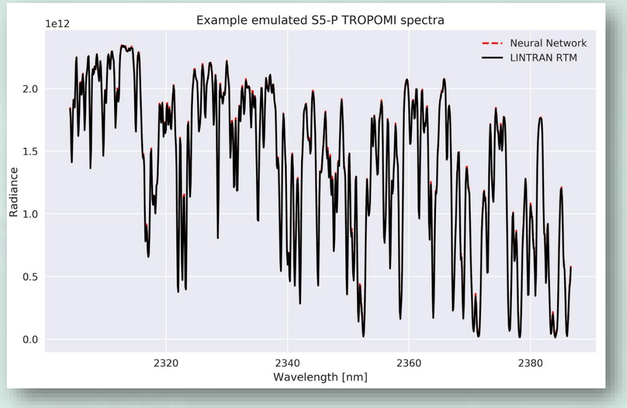
y Φ-lab Explore Office

y InCubed

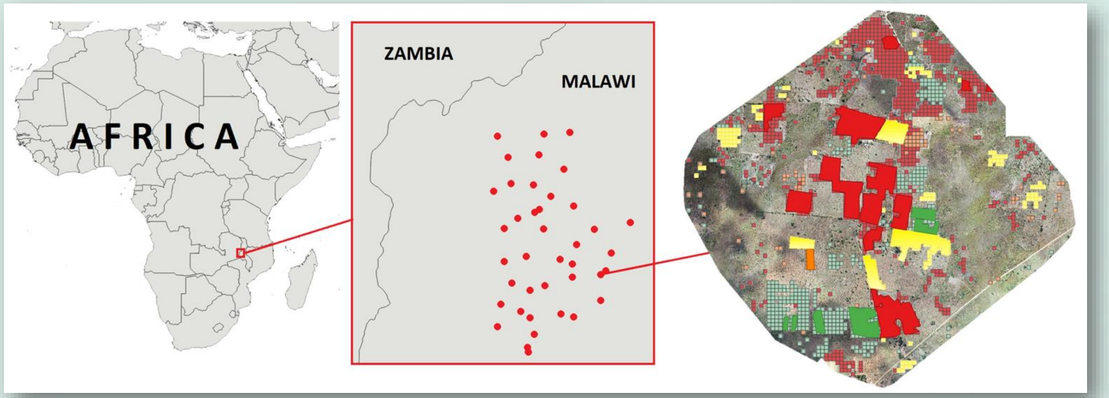
EXPLORE - Use Cases: Some examples



Infrastructure monitoring in desert regions



Physics-aware machine learning emulation of RTMs
Copernicus Sentinel-5p **methane retrieval**

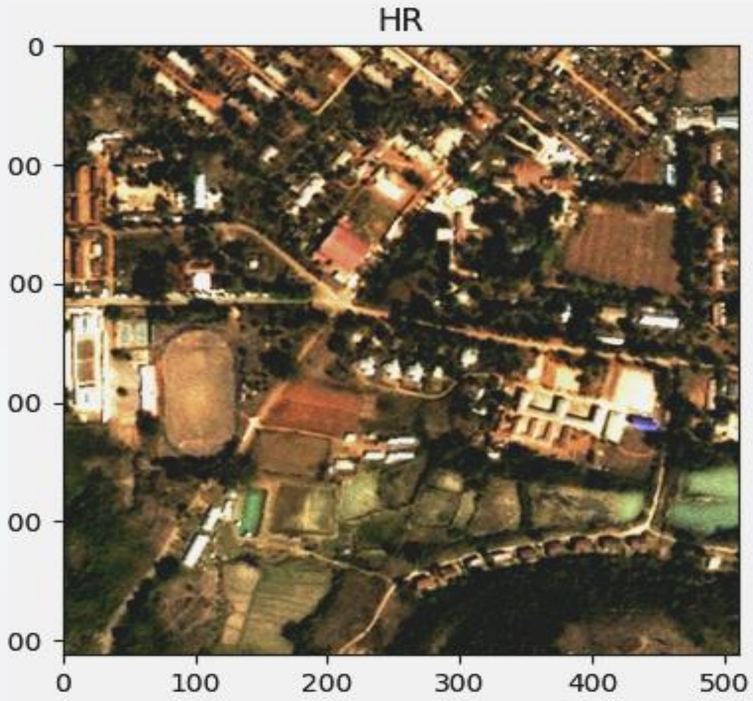


Crop types mapping using **drones, Copernicus Sentinel-2 and daily life images**

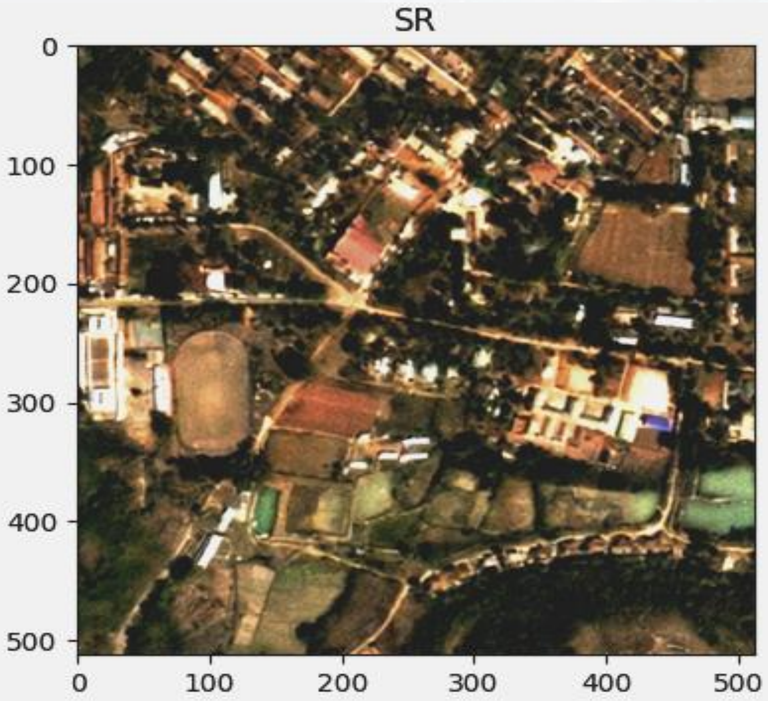
ICEYE Use of AI for SAR image for **on-board object detection and classification**

Enhancing S-2 resolution

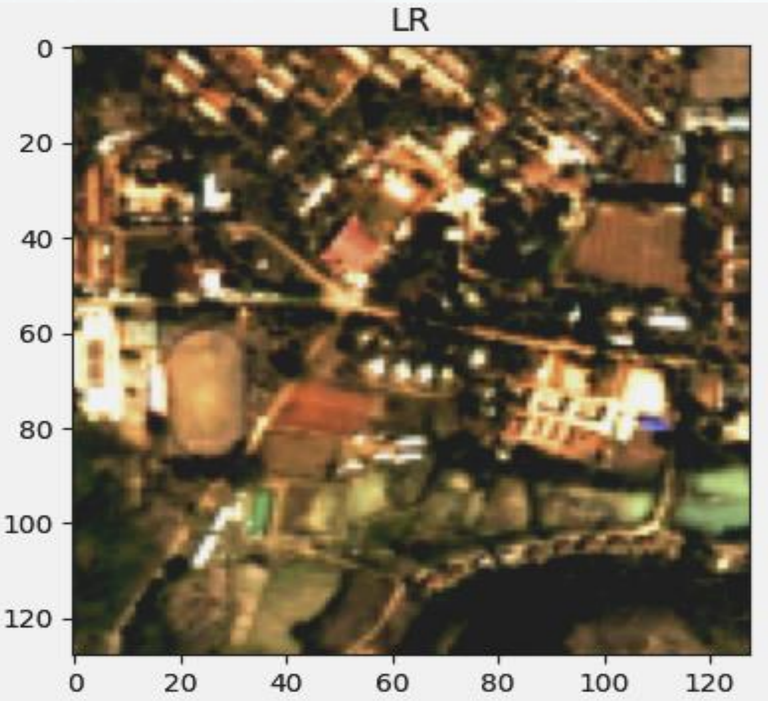
High-res ground truth



Super-res (2.5m)



S-2 (10m)



Need for:

- **Uncertainty estimation**
- **Robustness vs Hallucinations**

Courtesy AI project Open SR, **Uni Oxford**, Uni Valencia, Brockman Consult

QC4EO

AI-enhanced Quantum Computing for EO

CERN

esa

DLR

ECMWF

JÜLICH Forschungszentrum | JÜLICH SUPERCOMPUTING CENTRE

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

NICOLAUS COPERNICUS ASTRONOMICAL CENTER OF THE POLISH ACADEMY OF SCIENCES

UNIVERSITY OF WARSAW

JAGIELLONIAN UNIVERSITY IN KRAKÓW

ellis European Laboratory for Learning and Intelligent Systems

Work with us: It is easy

- Visiting Professor
- Visiting Researchers (Industrial and Scientific)
- ESA Research Fellowships
- ESA Co-funded PhD
- ESA Young Graduate Traineeships (YGT), Internships, National trainee

(some) Collaborations and parternships

ETH

TUM

Technische Universität Berlin

POLITECNICO MILANO 1863

EPFL

CERN

DLR

ASI Agenzia Spaziale Italiana

SatCen European Union Satellite Centre

ECMWF

Die Österreichische Hagelversicherung

VNIVERSITAT DE VALÈNCIA

unicef

WFP

Università di Roma Tor Vergata

Jožef Stefan Institute

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

KP LABS

IIASA

Università degli Studi del Sannio

PI SCHOOL
MACHINE INTELLIGENCE MEETS HUMAN CREATIVITY

PRIMO SPACE

ICEYE

cosine

SATLANTIS

ThalesAlenia Space
a Thales / Leonardo company

OHB

planet.

OPEN COSMOS

CGI

LEONARDO

OVHcloud

TELESPAZIO
a LEONARDO and THALES company

e-geos
AN ASI/TELESPAZIO COMPANY

Maker Faire

ellis
European Laboratory for Learning and Intelligent Systems

FDL

CLAIRE

Collaboration opportunities at Φ-lab

Join the open Φ-lab as an
Industrial or University Visiting
Researcher,
Visiting Professor, Research Fellow, PhD,
YGT, Intership, etc.
to explore together transformational
ideas

With funding

1. Φ-lab's Invitation To Tender on ESA-STARS
   - Foundation Models, Generative AI, QC4EO, Edge computing, Web 3.0, etc..
2. InCubed : partnership development of commercial products or services
3. Open Space Innovation Platform : co-funded research or researchers
4. EO Science4Society : no SOW, 100/200K, 6/18 months
5. ESA Technology Programmes like GSTP and TDE

5 funded collaborations schemes

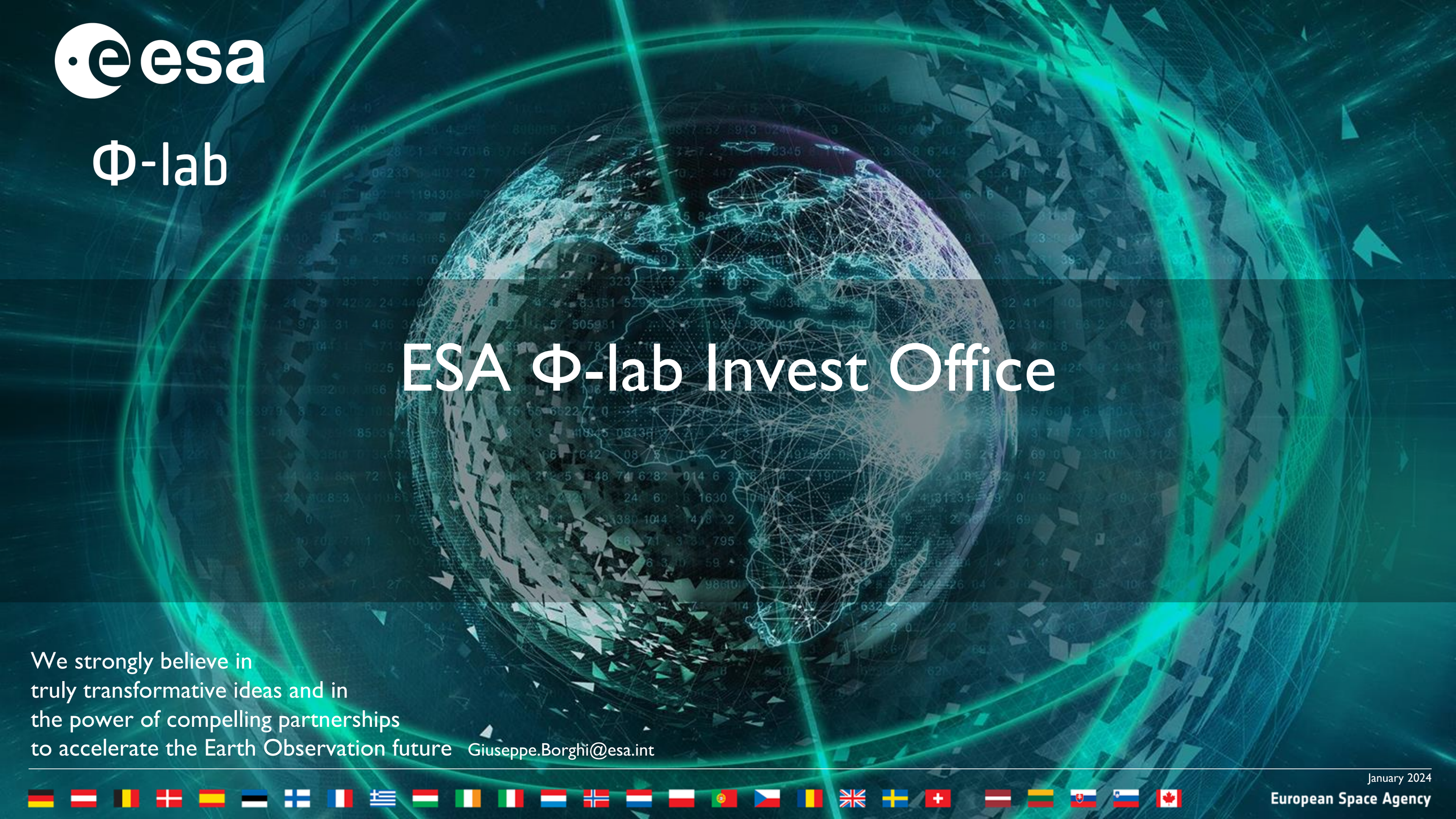
1. **Specific ITTs Issued by Φ-lab**
   - Φ-lab issue during the year specific requests for proposal published on ESA EMITS

2. **InCubed.esa.int : development of commercially viable products or services**

3. **OSIP Open Discovery Ideas Channel (ODIC) – co-funded research or researchers**
   - Up to 90k€ for PhD student or postdoc
   - Provides access to ESA expertise, facilitates students or post-doctoral fellows to spend time at the Φ-lab

4. **EO Science4Society**
   - EO Science4Society
   - EO Science4Society Invitation to Tender
   - Future EO open call for proposals – no SOW, 20 p. proposal, Regular innovative activities 200K/18 months or Fast innovative activities 100K/6 months Innovative, 3-month proposal cycle

5. **ESA Technology Programmes**
   - GSTP – TRL 3-8, higher budget, 2-3 months turnover, activity defined by TO and partner, supported by delegations
   - TDE – lower TRL, slightly more complicated setup, activity as above but more solid workplan



ESA Φ-lab Invest Office

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Giuseppe.Borghi@esa.int

January 2024

European Space Agency

The ESA Φ-lab Invest Office

Our goal is to stimulate and develop all transformative actions that ESA can leverage to strengthen European EO industrial competitiveness and leadership

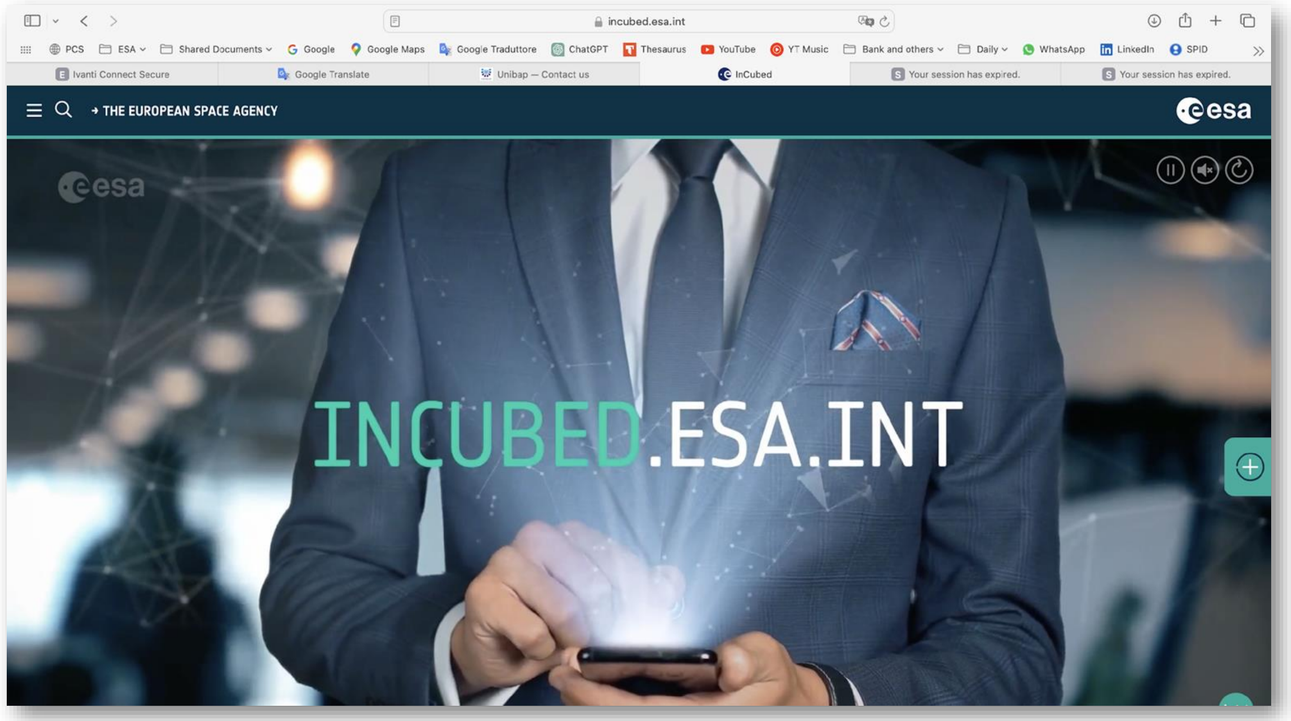
In this role ESA behaves not as customer but as the de-risking partner and facilitator stimulating competitive growth of the economic operator

Φ-lab co-invest program

Invest Action

Φ-lab Community

Invest in Industrial Innovation (InCubed)



€205M
InCubed fund size

150
Activities
@62% co-funding rate

100k€
to
>15m€
Project size

NATIONAL DELEGATIONS

ESA

INDUSTRY

Personalised technical and commercial guidance

Zero-equity and zero-IPR

ESA stamp of credibility

Privileged access to commercial services enabling your development

Access to ESA EO facilities and Φ-lab community

ESA Φ-lab Invest Office

Φ-lab co-invest program

Offers investment opportunities to support and develop innovative and commercially viable products and services. Encourages high-risk/high-potential developments mitigating the technical and financial risks. Implemented via the ESA InCubed+ Program

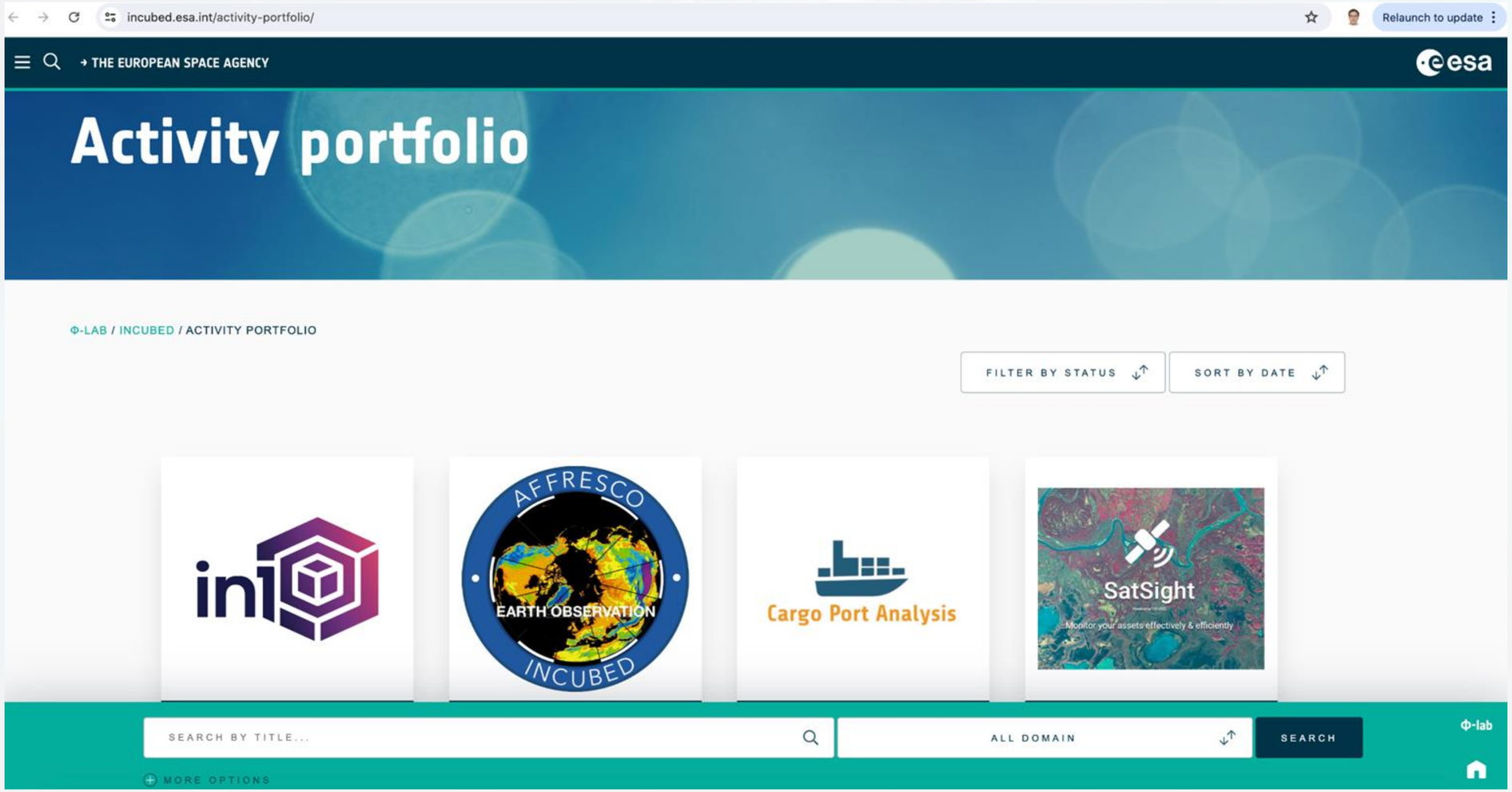
Invest Action

Accelerates access to risk capital tools for innovation funding to our ecosystem, in particular start-ups and SMEs

Φ-lab Community

Fosters industry-to-industry and industry-to-academia synergies and cooperation to accelerate adoption of innovative business solutions

http://incubed.esa.int/activity-portfolio



InCubed Activities – Some examples

Innovative solutions for VHR EO satellites, AOCS and the Instrument for high-quality VHR **satellite imagery and geo-analytics**

deimos elecnor group · SURREY · TELEDYNE e2V Everywhereyoulook™

EO PLUG-IN HUB

Improve **potato production yield**. A paradigm change for Earth observation integration in the agro-food industry

GeoVille · HLB research and consultancy in agriculture · HERMESS · eodc

ai4eo SOLUTION FACTORY

Combine EO data and AI tools to **identify new business cases** addressed with customized solutions, created in a knowledge base and modules repository factory

DFKI · VISION IMPULSE

AIX SMART IN-ORBIT DATA PROCESSING

AI-express (AIX) is a hybrid edge ecosystem based on **state-of-the-art technologies (AI** with dedicated processing units and Blockchain) targeting reactivity, responsiveness, and **low-latency**

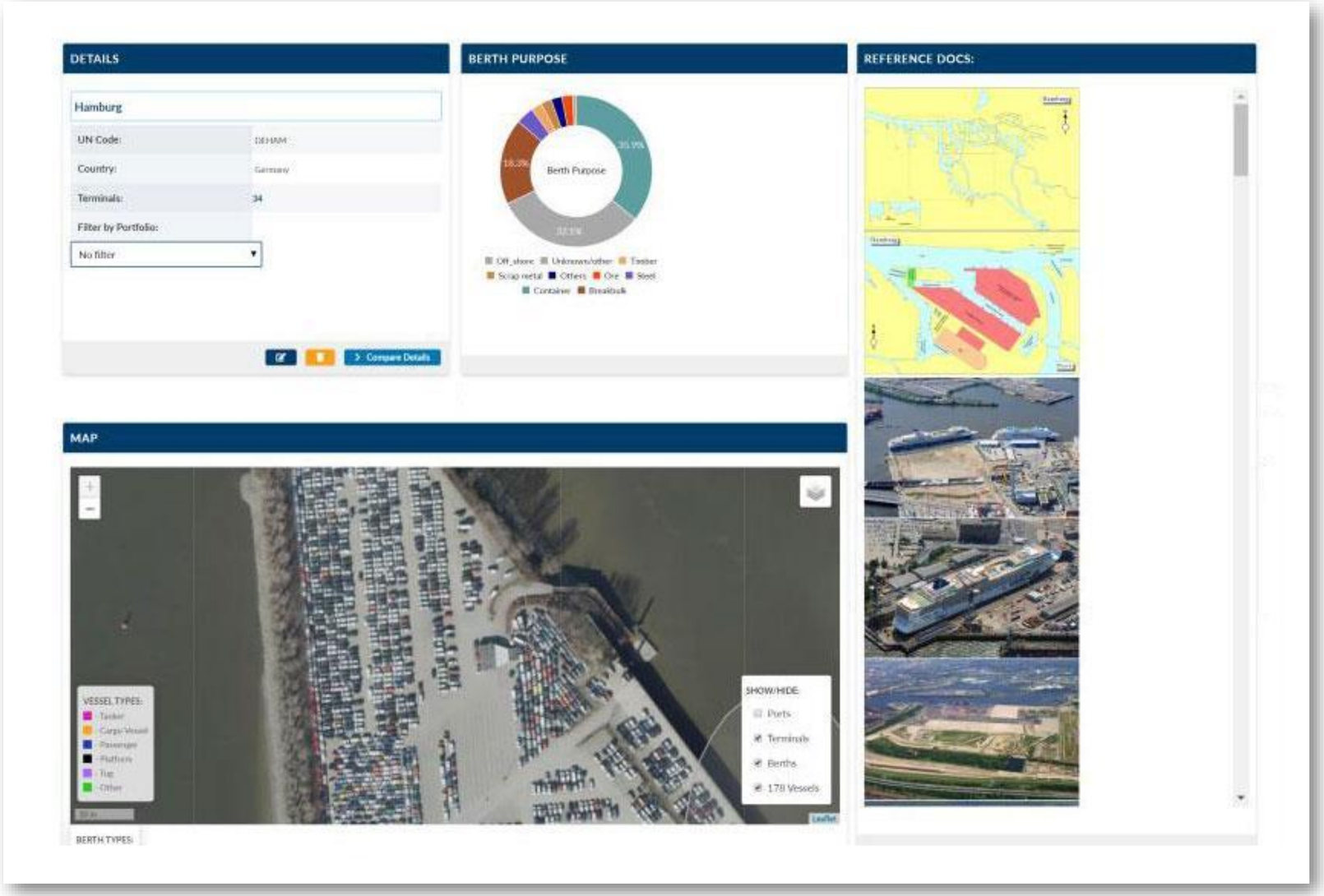
planetek italia · AIKO INFINITE WAYS TO AUTONOMY · D-ORBIT

InCubed Activities: Cargo Port Analysis Using EO and GNSS

skytek

- Cargo Port Analysis by Skytek (IE) for the **insurance and reinsurance industry.**

- The existing product (REACT) was extended to incorporate more advanced modelling and processing of new data sources including **space assets, EO imagery and Navigation data.**
  - As a result, this platform provides a more detailed and enhanced overall picture of **risk exposure to the insurance industry**.

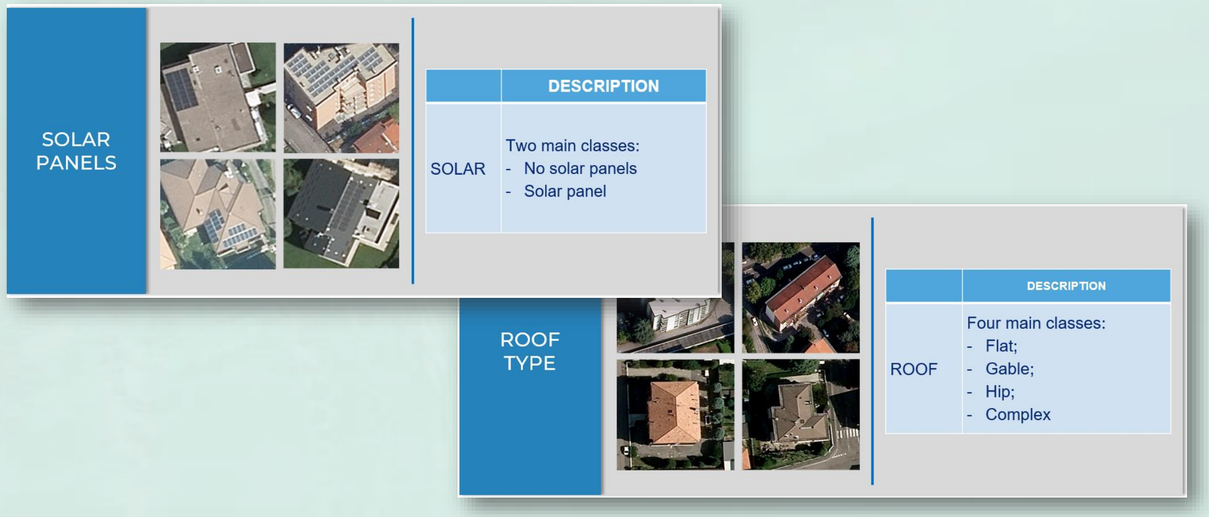


Commercial AI4EO examples - InCubed ESA programme

Sat4Flood

Globally visualizes the **risks of levee failure** based on the most recent EO satellite data.
This development combines the innovative technologies of satellite high-resolution **soil moisture data** with Interferometric SAR **deformation data.**

Deep Property



Enabling **automated extraction of building features** with AI-based techniques **applied to geospatial datasets.**
The core market is the **re/insurance sector,** where these fine-granularity data **improve the businesses' efficiency** in multiple areas **including underwriting risk modelling and pricing.**

InCubed Activities – Some examples

ConstellR HiVE

High-resolution VEgetation monitoring to enable **“more crop per drop”** with MicroSatellites

constellr OHB

MultiSpectral Companion Mission

To provide a **daily global coverage, high quality multispectral data product,** with interoperability with Sentinel-2 data products.

aerospacelab

ORORA TECHNOLOGIES

To **combat global wildfires**, they'll close current thermal-infrared satellite data gap, enhancing **wildfires detection,** and enabling **new business models.**

mantis

MANTIS is a demonstration mission to **develop, build, launch and operate an innovative nanosatellite** that will fly a high resolution camera

OPEN COSMOS Terrabotics Space to Earth Analytics SATLANTIS

InCubed Activities – Some examples

SaferPlaces

A **Digital Twin Platform** able to support multiple users in **assessing data-driven decisions for flood risk** for **cities**. **Open EO-Data and AI-based models** are combined into a cloud-computing environment to provide incredible insights in terms of **flood risk intelligence.**

MEEO geeo

Signaleyes

A clear view on change

SignalEyes analyses **spatial changes in objects including buildings, trees, water courses and roads.**

NEO

HyperScout-2 for the FSSCAT mission. **Miniaturized hyperspectral and thermal imaging** coupled with Artificial Intelligence for breakthrough **operational space missions**

cosine

HYPERFIELD

Hyperfield service provides global, **daily and actionable real-time data** on ecological assets through spaceborne hyperspectral imaging and AI. This novel **small satellite-based solution** enables creating a constellation of tens of satellites highly cost-efficiently, **providing affordable data** even for developing countries.

KUVA SPACE

VTT

Boost European EO commercialisation

Fast Innovation and Talents

Generate unique competitive advantage via **talent creation and fast innovation**

+

Mitigate/Share Risks

Mitigate industrial Dev. and Mkt. risks exploiting ESA huge technical, programmatic, and industry understanding and via anchor customer actions

+

Access to Risk Capital

Stimulate **private risk capital,** and synergise with the public ones to scale up

+

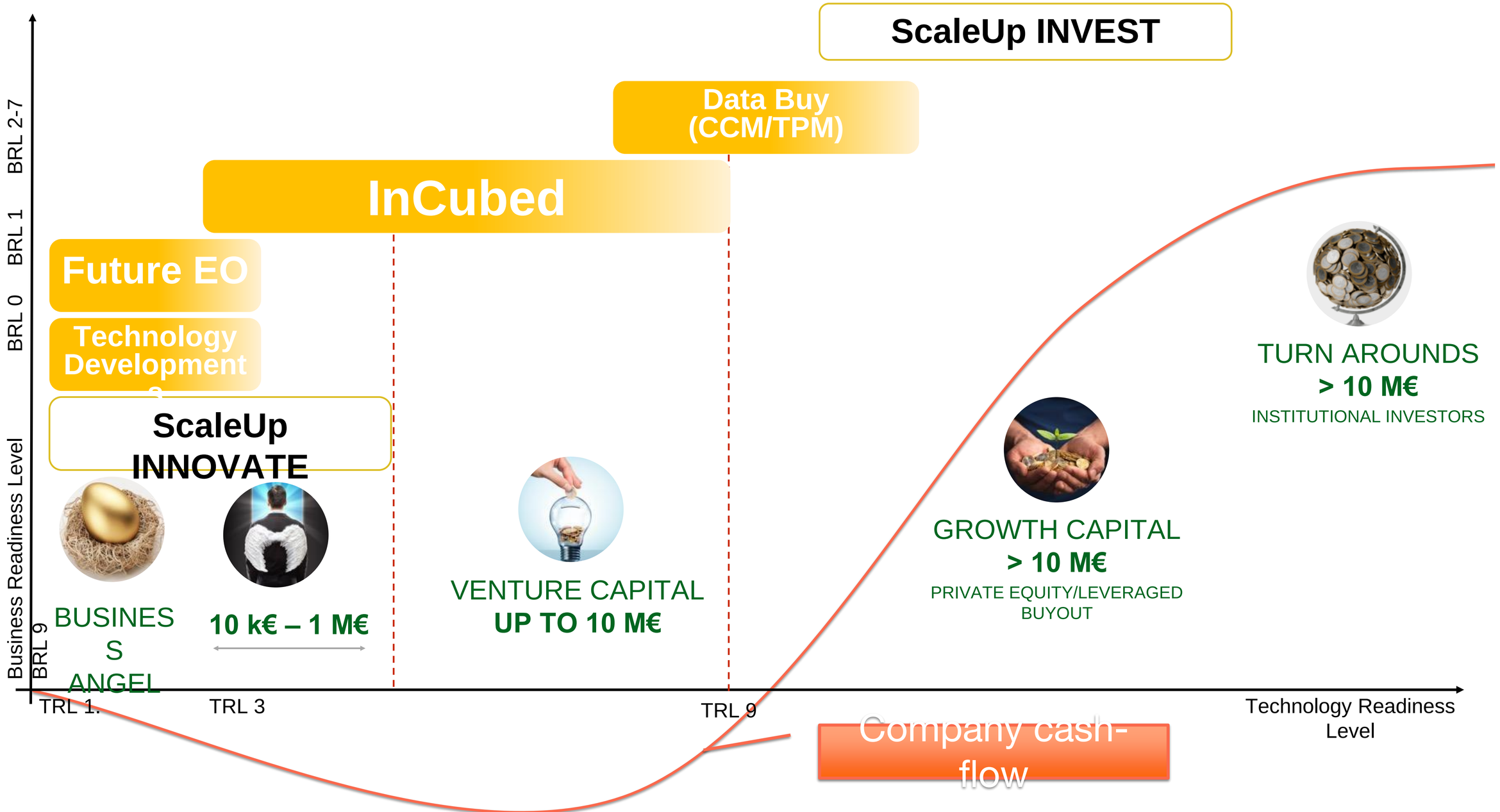
Easy Regulations

New Space tailored regulations and procurement rules **minimizing burden and uncertainty**

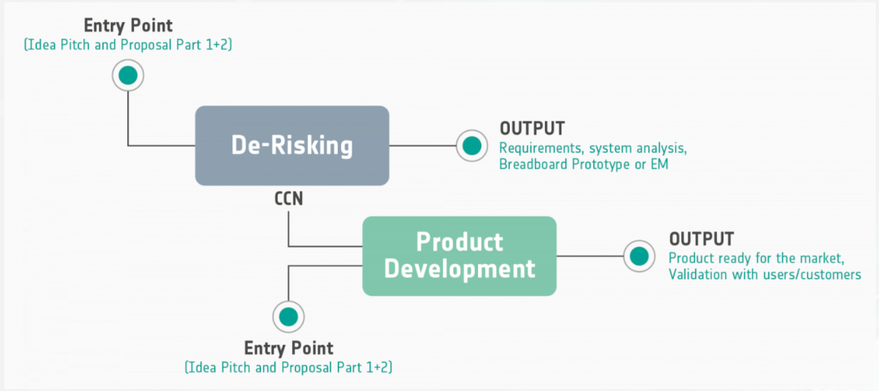
ESA roles

1. **ENABLER** of a sustainable commercial EO by **closing know-how and technology gaps**
2. **PARTNER** the development of **innovative product/services** to **reduce dev and fin risk**
3. **CUSTOMER** of commercial products and services to r**educe market risks** (e.g. anchor customer)

ESA contributions in the EO company life-cycle



InCubed Process - How to apply | InCubed.esa.int

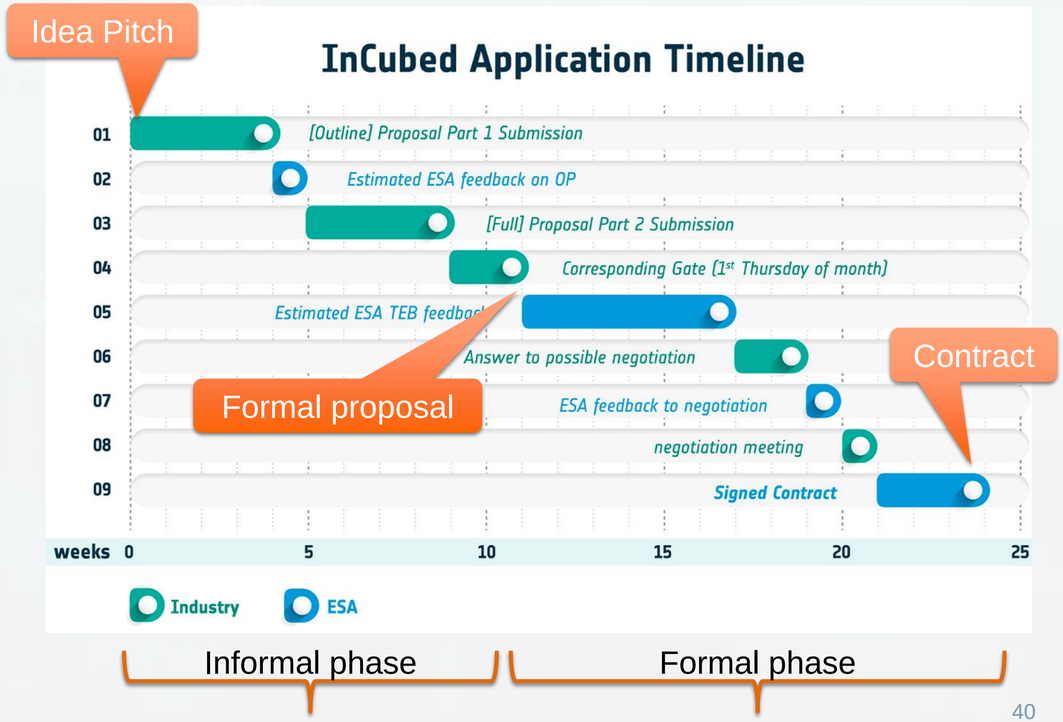


Cycle	TRL	ASRL	Funding Level up to % (of total allowable cost)		Funding level for Universities or Research Institutes with no commercial Interest in the Product
			Large Companies	SME	
De-risking	Up to 4-6 [1]	Up to 3	Up to 75%	Up to 80%	Up to 100% of maximum 30% of the cycle costs
Product development	Up to 7 (8 for IOV)	4 Up to 8	Up to 50%	Up to 80%	Up to 100% of maximum 30% of the cycle costs

[1] Depending on the technological or market risks as assessed by the Agency

Cycle	Main activities	Objectives
De-risking	Technical study, technical riskmitigation excluding any qualification or industralization	for all segments: system analysis, Business analysis, EM, breadboard of prototype of full to partial end-to-end integrated system
Product development	Development, qualification, verification, indusrialization and validation	Space: (E)QM or similar Ground/Data: verified product in a (pre)operational environment OPTIONAL: Validation of all segments in a (pre)operational environment

Austria, Belgium, Czech Republic, Denmark
Estonia, Finland, Germany, Greece
Hungary, Ireland, Italy, Luxembourg
Netherlands, Norway, Poland, Portugal
Romania, Slovenia, Spain, Sweden
United Kingdom



Φ-lab

Current Projects at the Φ-lab

We strongly believe in
truly transformative ideas and in
the power of compelling partnerships
to accelerate the Earth Observation future

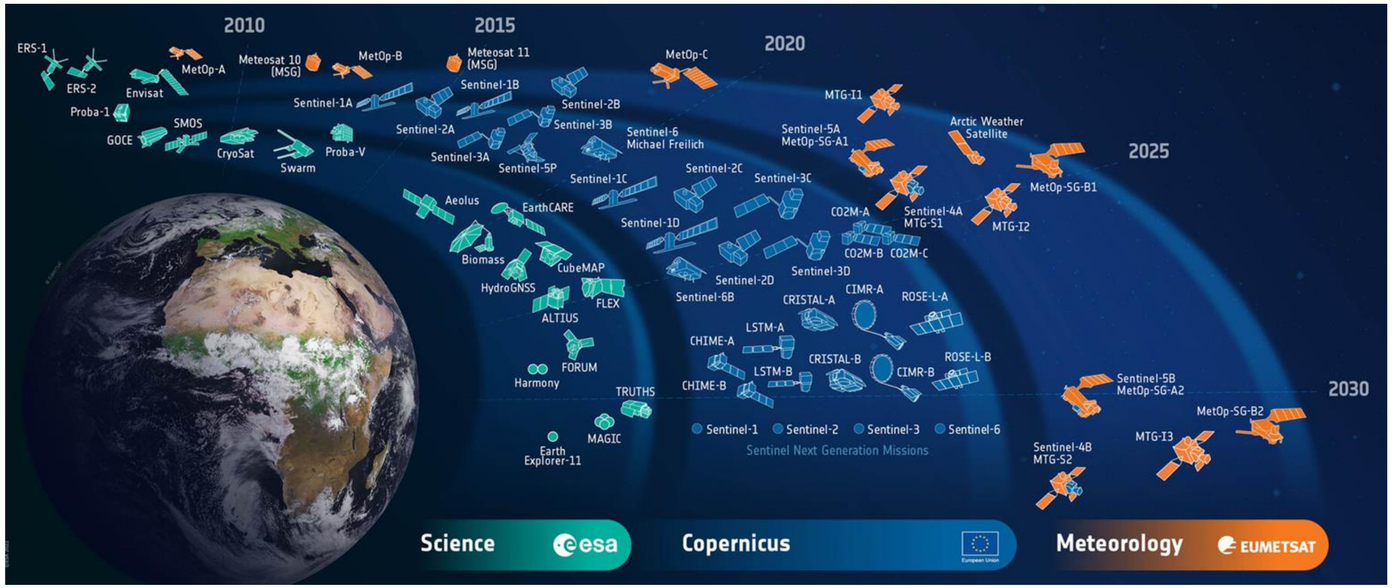
Giuseppe.Borghi@esa.int

January 2024
European Space Agency

EO Foundation Model and Evaluation Framework

Φ-lab: Nikolaos Dionelis, Jente Bosmans
Joint work with: Casper Fibaek, Luke Camilleri, Andreas Luyts, Bertrand Le Saux

EO Foundation Model



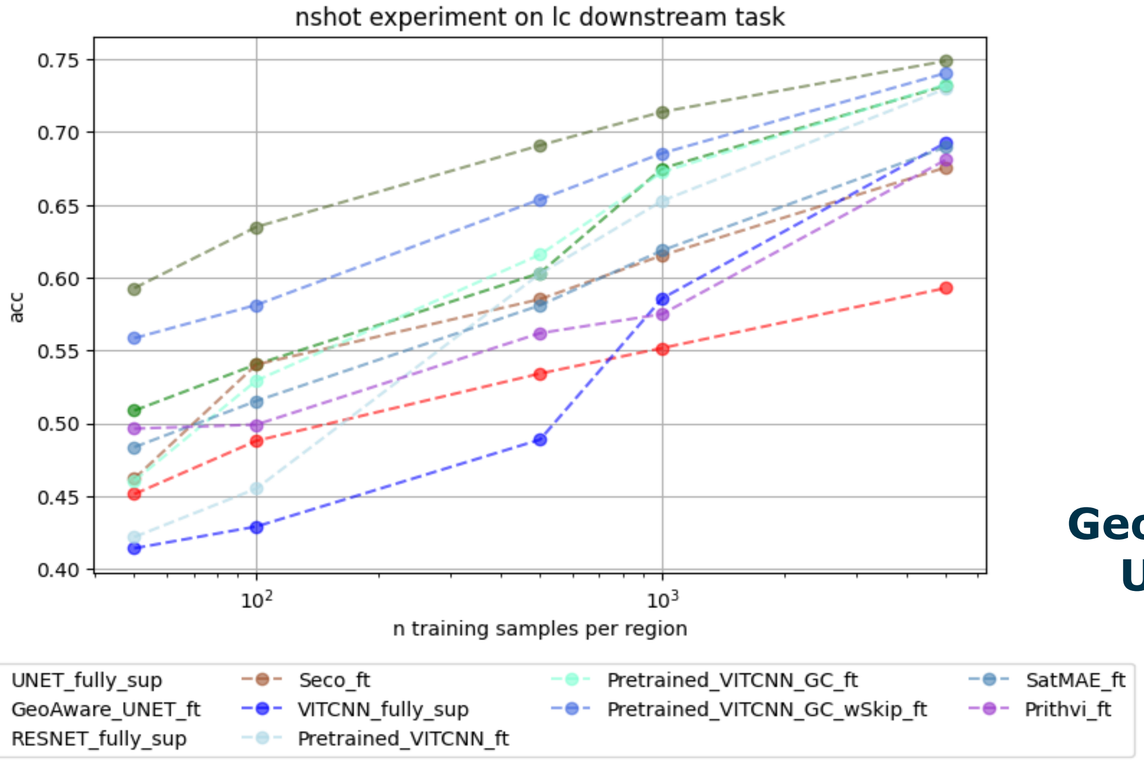
Importance & Motivation

- Large amounts of **unlabelled data** are captured by satellites
  - Copernicus **Sentinel-2** constellation: Generates 1.6TB of data *daily*
- EO and remote sensing: Data-rich domain
  - Well-suited to AI and deep learning

- **Lack of annotated data**
  - Labels
    - Need *time*, are expensive, & can be labour-intensive & imperfect

- The focus is on **Foundation Model** approaches
  - **Self-supervised learning** methods using unlabelled data
  - Satellite data information:
    - **Geo-location longitude & latitude**

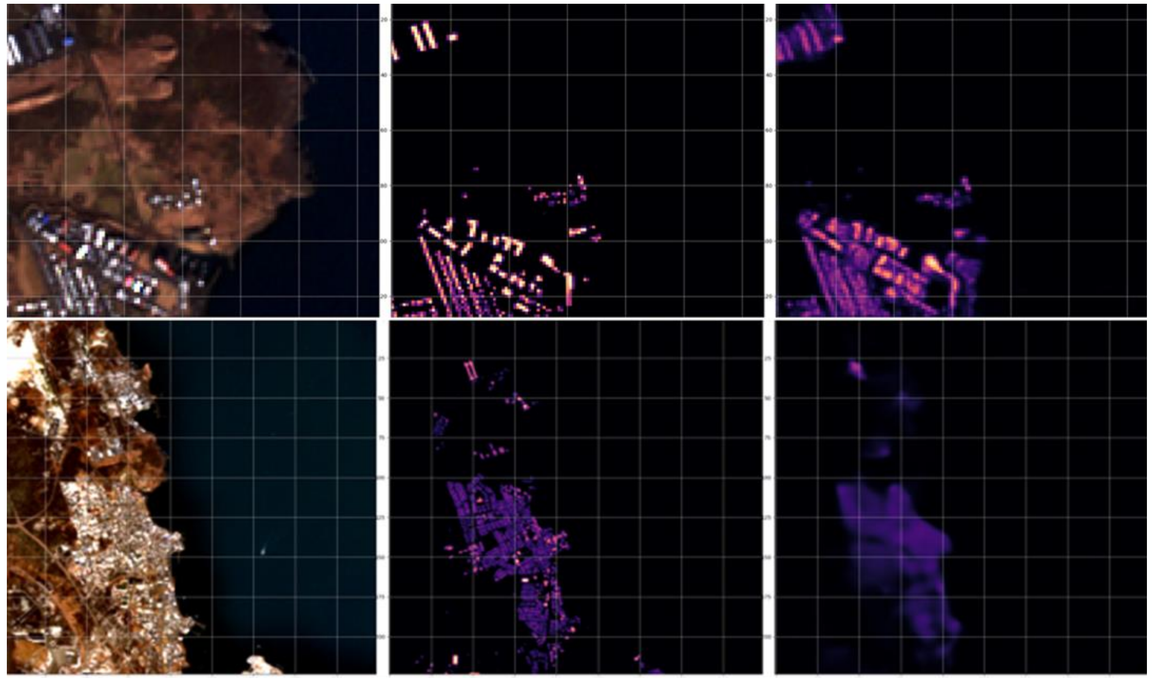
Evaluation and Results



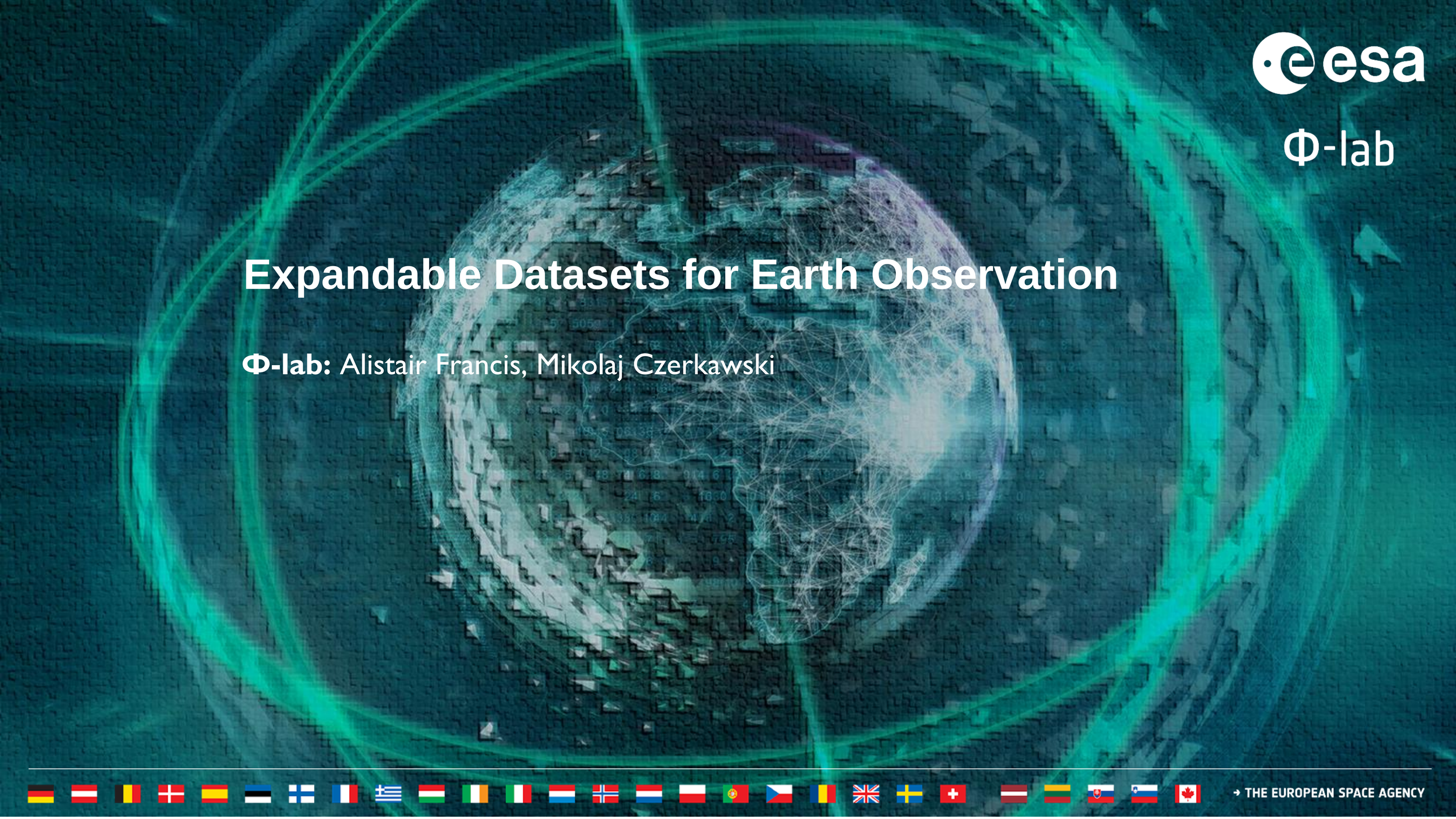
Semantic segmentation land cover classification (lc)

Geo-aware U-Net:

Prithvi:



Building density estimation



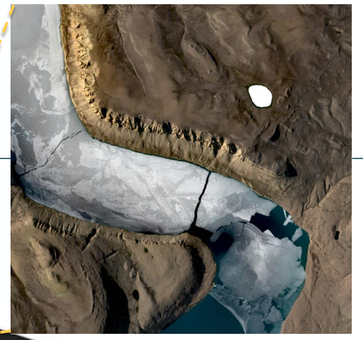
Expandable Datasets for Earth Observation

Φ-lab: Alistair Francis, Mikolaj Czerkawski

MajorTOM

esa
Φ-lab

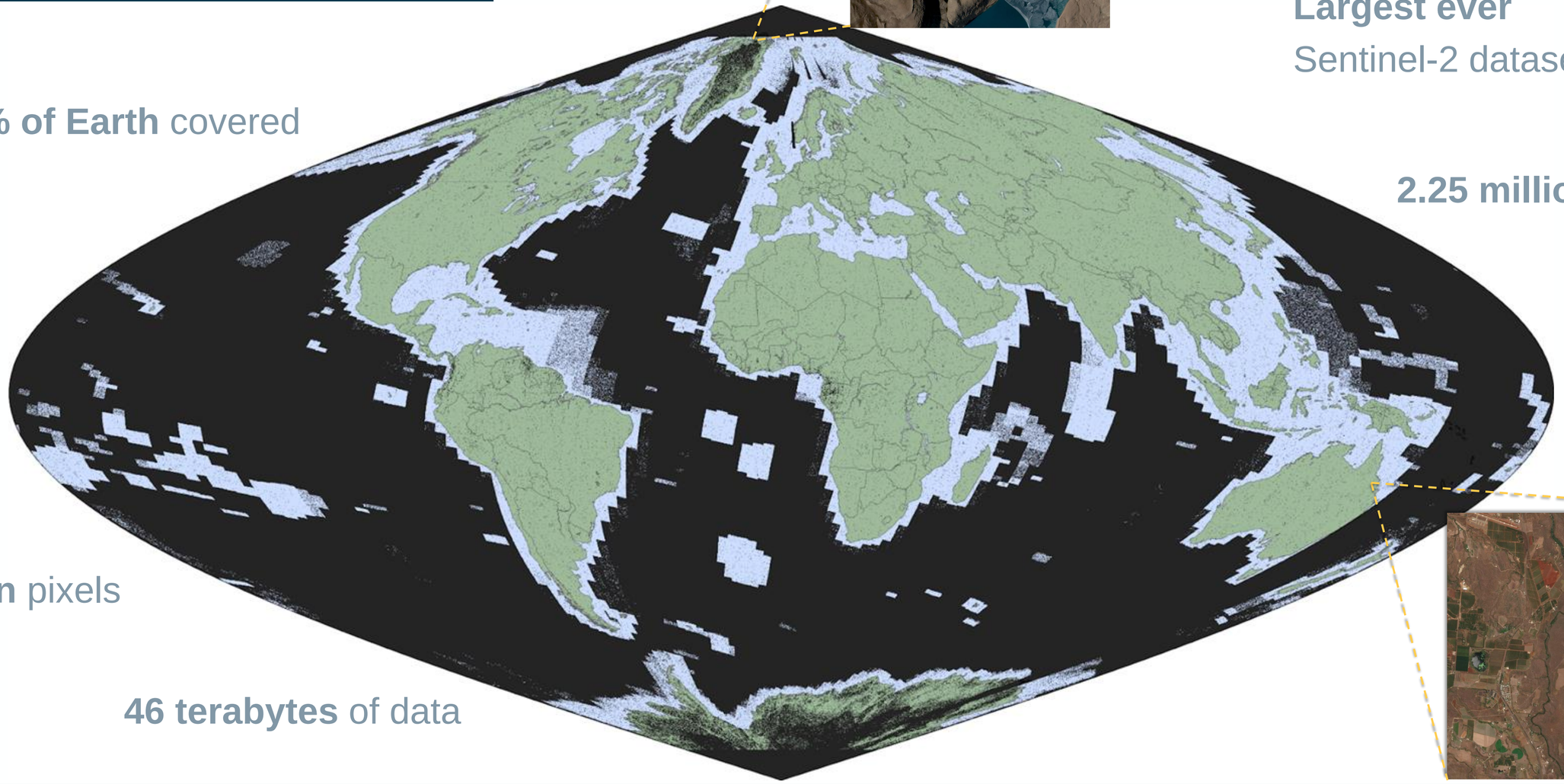
Major TOM Core: Sentinel-2



Largest ever
Sentinel-2 dataset

50% of Earth covered

2.25 million images



2.5 trillion pixels

46 terabytes of data

MajorTOM

- **Major TOM:** Terrestrial Observation Metaset
- **Framework** to build largest ever EO datasets for AI
- **Simple, repeatable format:** combine Major TOM datasets together easily
- **Distributed freely:** partnership with Hugging Face to deliver data to anyone, anywhere
- **Collaborative project:** expandable and managed by open-source community

Major TOM's grid system. Each grid point gets a sample of data. 200km grid visualised, real data in 10km grid.

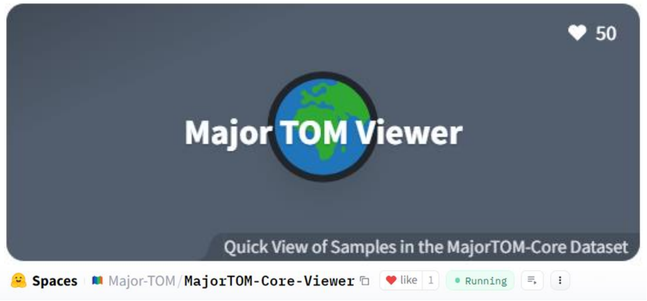
MajorTOM

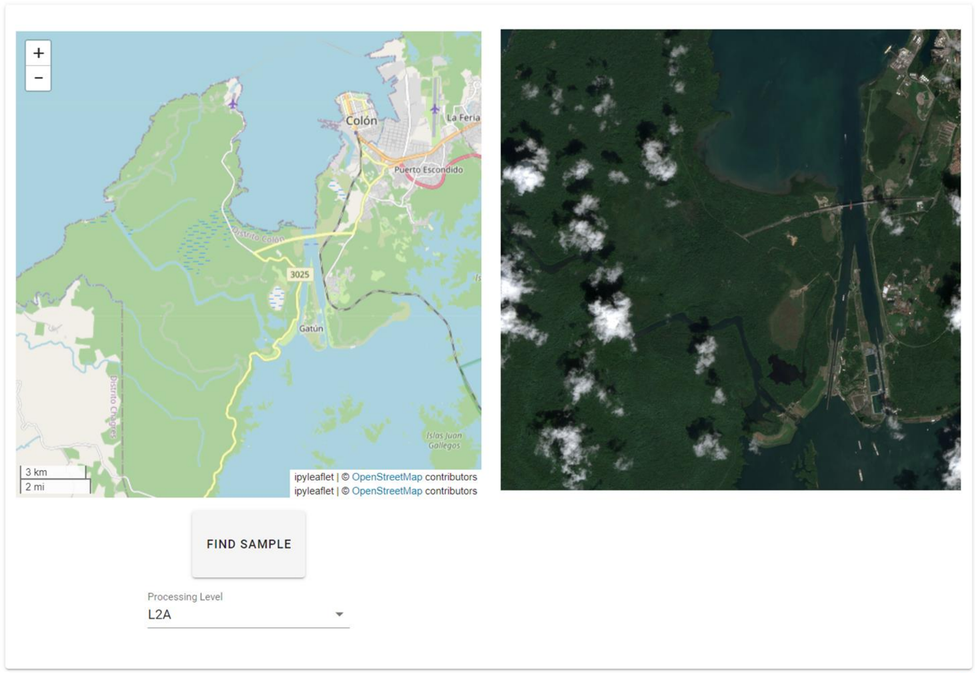
Φ-lab

Since recent release:

- Major TOM is now a **trending dataset** on Hugging Face
- The online viewer app is currently featured as a HF **space of the week**
- The **community** organisation on HF **is growing** rapidly with an influx of new members
- Setting foundations for truly open EO data

Explore data in our web app:





Using AI for Estimating Building Construction Year from Multi-Modal Dataset

Φ-lab: Nikolaos Dionelis, Nicolas Longepe

AI4EO Challenge

Estimating Construction Year of Buildings from Multi-Modal Dataset

Example images from new cross-view dataset: Street-view & satellite VHR images

Challenge MapYourCity: http://ai4eo.eu
To participate: http://platform.ai4eo.eu
Video for the challenge: Video and BiDS Recording
Dataset: http://www.eotdl.com/datasets/AI4EO-MapYourCity
GitHub webpage: http://github.com/AI4EO/MapYourCity

The problem we want to solve

Efficiency of buildings

- Construction epoch as a proxy of energy efficiency of buildings

Determine and measure the efficiency of buildings

- Large scale: Cities, For every building

Aim: Predict the construction epoch of buildings

Given both street-view and satellite images of buildings

- Generalization to *new*/ previously unseen cities
- Show that satellite images improve the performance
- Examine whether only satellite images can be used

The more general problem

General methodology

Data fusion

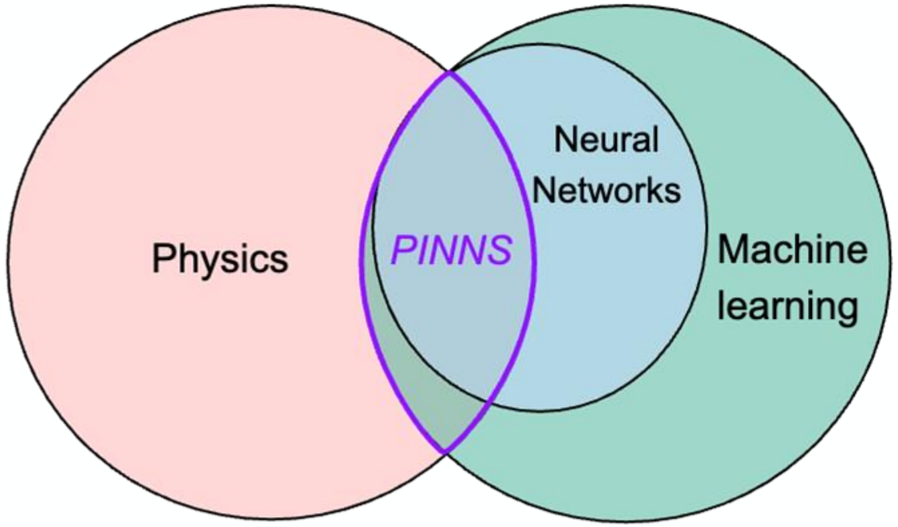
- Street-view images
- Satellite images

Latent feature space: Concatenate

Ocean Topography with Implicit Neural Representation

Φ-lab: Peter Naylor, Bertrand Le Saux
Science Hub: Florian Le Guillou, Marie-Hélène Rio

PINNs: Physics Informed Neural Networks



How do we incorporate physics into Machine Learning?

PINNs:

- Definition: NNs that incorporate physical knowledge
- Idea: In low data availability setting, enables interpolation and extrapolation of data by respecting the underlying physics

Function Approximation

- Uses physics simulation, or solvers to build dataset pairs for training ML models
- Approximate the real physics through image generation

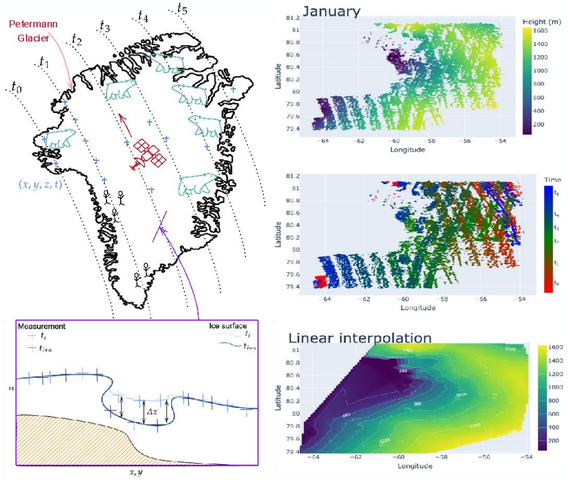


Fig. Ice Sheet monitoring

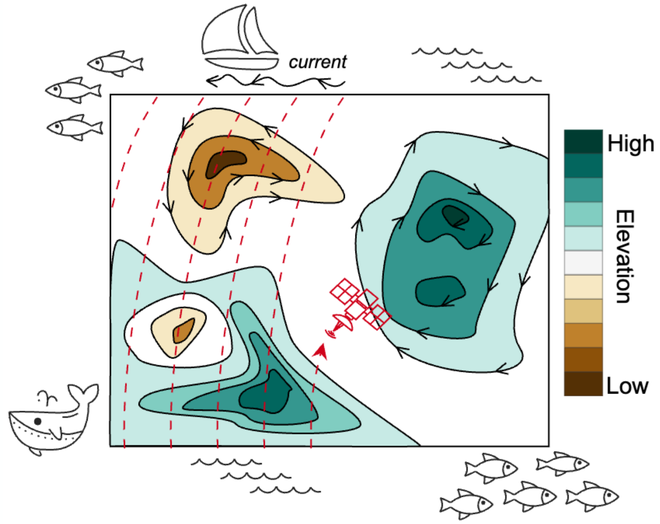
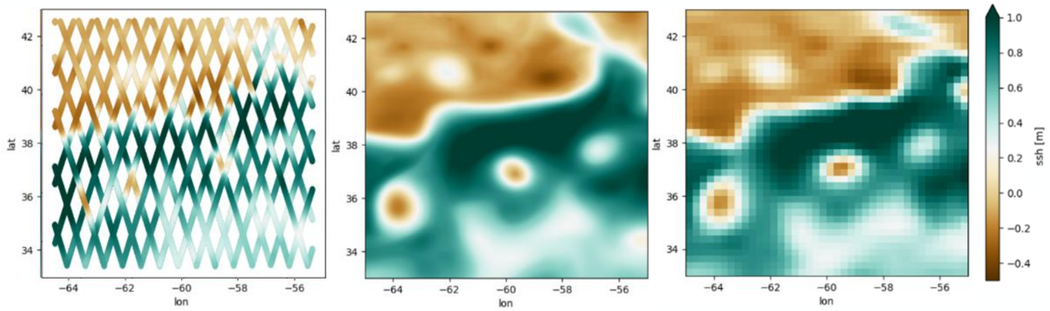


Fig. Ocean Topography



(a) Altimetry data **(b)** Reference **(c)** DUACS

Fig. Sea Surface Height

Conclusion

- **ESA Φ-lab:**
  - **EO**, **AI**, Quantum Computing
- **The ESA Φ-lab Offices:**
  - Explore Office
  - Invest Office: Incubed
- **ESA Φ-lab Satellites and Constellations**
- **Collaborations and partnerships**
- **The current projects at the ESA Φ-lab**

Thank you for your attention. Questions ?

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To know more, visit our website:

philab.esa.int incubed.esa.int