ESA Earth Observation (EO) Missions and Technology

SpaceTech 2019

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Future Missions & Instrument Division (EOP-ΦM)

(28-June-2019)

Table of Content

Institutional ESA missions

- Copernicus, Meteorological, Earth Explorers
- Technology

NewSpace

- CubeSats
- Small Sats / Scouts

“Taking the Pulse of our Planet from Space”

esa

Continue global EO leadership through European Cooperation

Generate vast socio-economic, strategic & innovation benefits

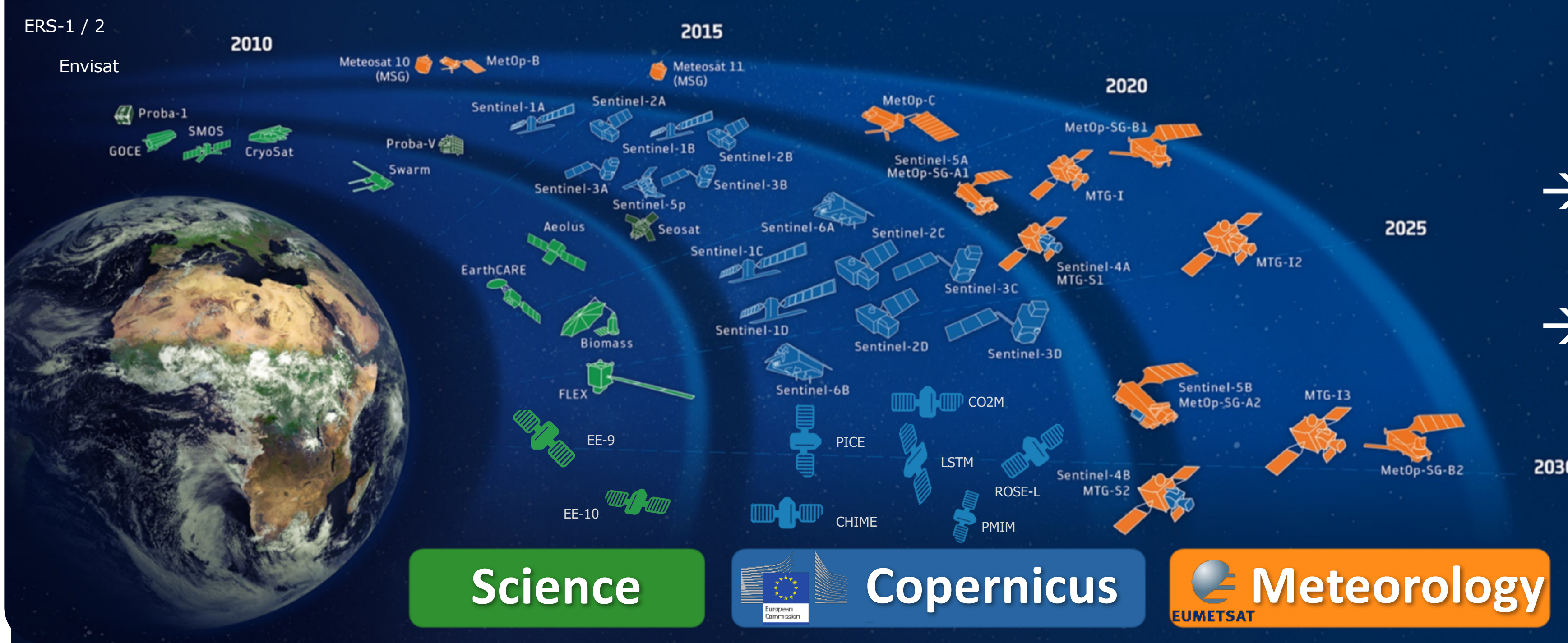
Push frontiers of new science & climate monitoring capabilities

Europe's EO leadership

esa

ESA-DEVELOPED EARTH OBSERVATION MISSIONS

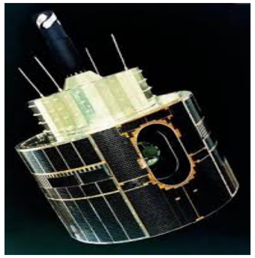
"We have the best Earth observation system in the World."
11th Annual Conference on European Space Policy
- opening speech 2019 by EC Commissioner



→15 satellites in operations

→25 satellites in development

Pioneers in Earth observation



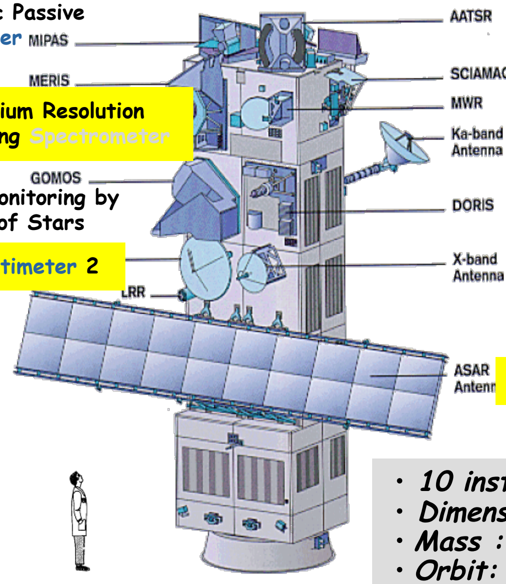
Meteosat-1 (1977): First meteorological mission

ERS-1 (1991–2000) - **ERS-2** (1995–2011) :

- a wealth of invaluable data about Earth, its climate and changing environment.

Envisat (2002–12):

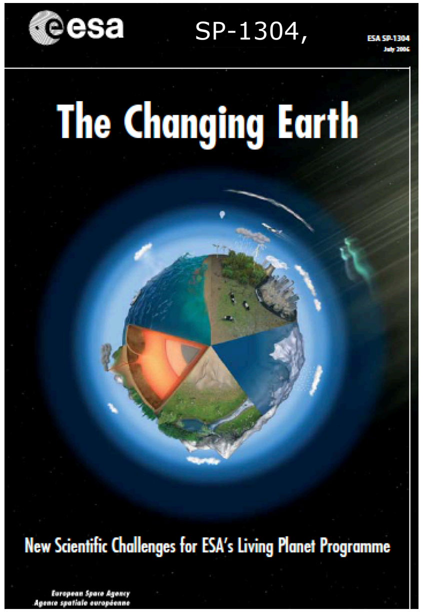
- the largest satellite ever built
- to monitor the environment, it provided continuous observation of Earth's surface, atmosphere, oceans and ice caps.



- *10 instruments*
- *Dimensions* 26m x 10m x 5m (in orbit)
- *Mass* : 8140 Kg
- *Orbit*: 800 km sun synchronous

(> 100 companies involved)

Living Planet Programme



ESA develops world-class EO systems to address

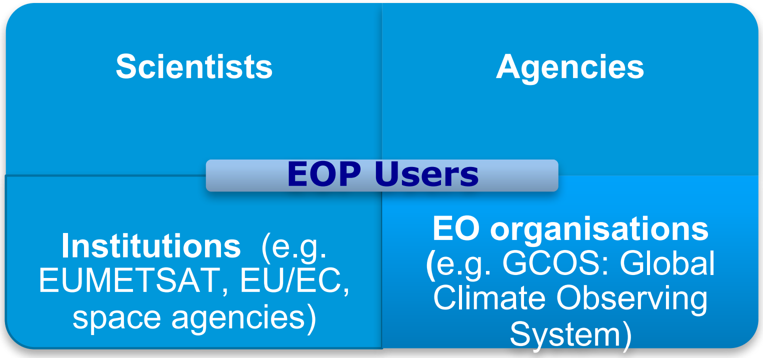
- the **__scientific challenges__** identified in the **Living Planet Programme** (SP-1304)
- other societal challenges, particularly with European + global partners.

LIVING PLANET: **__user driven__** + with wide-ranging innovations. Two broad lines:

- **Research missions** :__research driven__ + demonstrate new EO techniques.
    - Earth Explorers (EE) – its main part
- **Earth Watch missions** __driven by operational services__ + developed with/for partners
    - EUMETSAT for meteorology
    - EU for the Copernicus programme
    - Member States: e.g. Altius, Truths

Successful paradigm of **__end-to-end__** mission-orientated innovation

i.e. : science + mission concept +technology



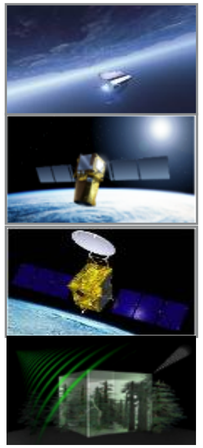
ESA EO: large range of missions - all User Driven

Colour Code:
Launched
To be launched

Living Planet
(SP-1304)

Earth Explorer
Research driven

Core Missions



GOCE
2009-2013

Aeolus
Aug-2018

EarthCARE
2021

Biomass
(EE7) 2022

Call EE10 –
Under Phase 0 study
STEREOID
Daedalus
G-Class:H2O

Opportunity

CryoSat-2
8 April 10

SMOS
2 Nov 09

Swarm
22 Nov 13

Initiating discussion
with NASA's
(Decadal Survey)

NGGM

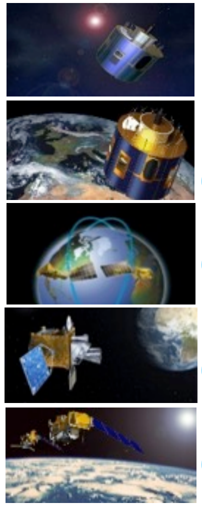
Fast Track

FLEX (EE8)
2022

Call EE9 –
Ph. A/B1 end - July 2019
FORUM
SKIM

Earth Watch
Operational Service driven
In partnership

Meteorology



Meteosat

MSG - GEO
(1 s/c x 4)

MetOp
(1 s/c x 3)

MTG - GEO
(2 s/c x 3)

MetOp SG
(2 s/c x 3)

Earth Watch
Altius, Truths

Copernicus

Sentinel 1 A/B/C/D

Sentinel 2 A/B/C/D

Sentinel 3 A/B/C/D

Sentinel 4 (on MTG)

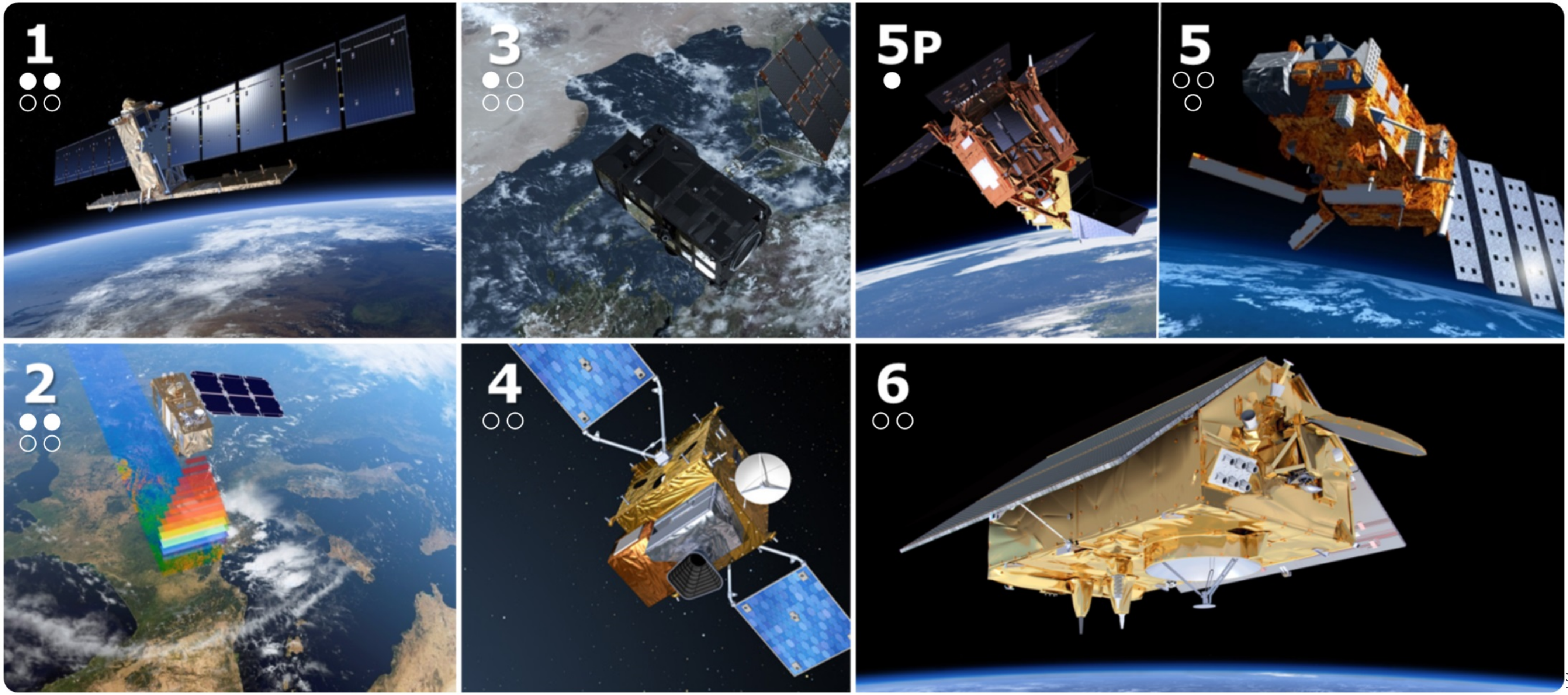
Sentinel 5 precursor

Sentinel 5 (on MetOp SG)

Sentinel 6 (Jason)

Copernicus Space Component Evolution:
CO2M, LSTM, PICE, CIMR, CHIME, ROSE-L
Sentinel-1/2/3 NG

Copernicus Program– European Leadership in EO
→ Sentinel satellites (operational)



Copernicus space component: the Sentinels

Copernicus: an Earth observation programme for global monitoring for environment and security.

Led by the European Commission in partnership with ESA and the European Environment Agency,

- Sentinel-1 – land and ocean services. Sentinel-1A launched in 2014/Sentinel-1B in 2016.
- Sentinel-2 – land monitoring. Sentinel-2A launched in 2015/Sentinel-2B (2017).
- Sentinel-3 – ocean forecasting, environmental and climate monitoring. Sentinel-3A launched in 2016. Sentinel-3B (2017).
- Sentinel-4 – atmospheric monitoring payload (2019)
- Sentinel-5 – atmospheric monitoring payload (2021)
- Sentinel-5 Precursor – atmospheric monitoring (2017)
- Sentinel-6 – oceanography and climate studies (2020)

Copernicus – continue global leadership in EO

esa

> 225.000

registered users

= tip of the iceberg

6 operational services

Land | Atmosphere | Ocean | Climate | Disaster | Security

250 TB satellite data distributed per day

full, free & open data policy

7 satellites flying

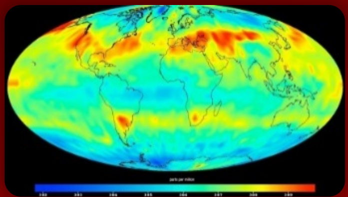
S1 ●● | S2 ●● | S3 ●● | S4 | S5P ● | S5 | S6

preparing Copernicus 4.0

European Space Agency

New Monitoring Missions – for 2025 onwards

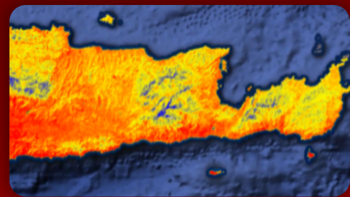
Anthropogenic CO_2 Mon. Mission



Causes of Climate Change

Land Surface Temperature Mission

LSTM



Agriculture & Water Productivity

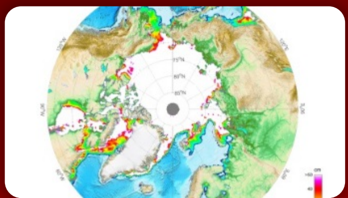
CRISTAL – Polar Ice & Snow Topography

Effects of Climate Change

CHIME – Hyperspectral Imaging Mission

Food Security, Soil, Minerals, Biodiversity

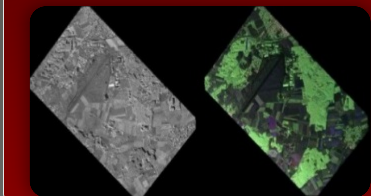
CIMR – Passive Microwave Radiometer



Sea: Surface Temp. & Ice Concentration

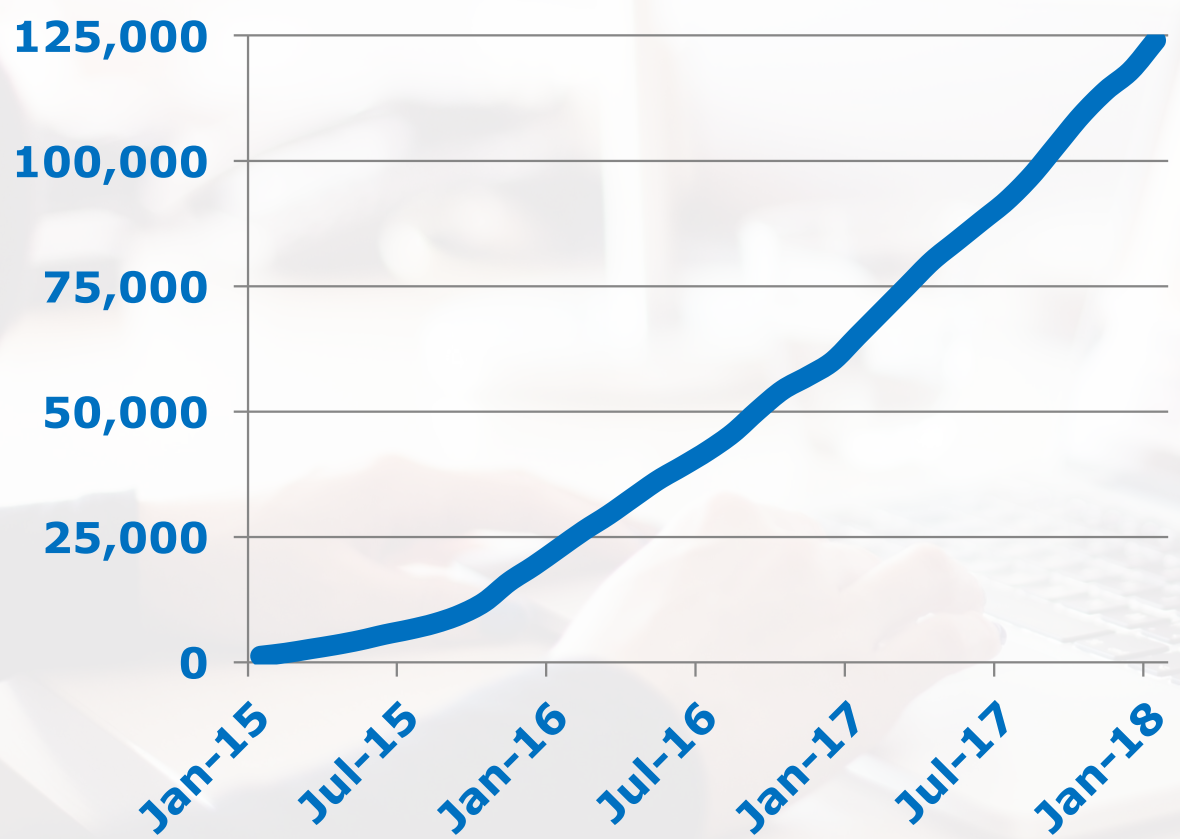
L-band SAR Mission

ROSE-L



Vegetation & Ground Motion & Moisture

Registered Sentinel Users



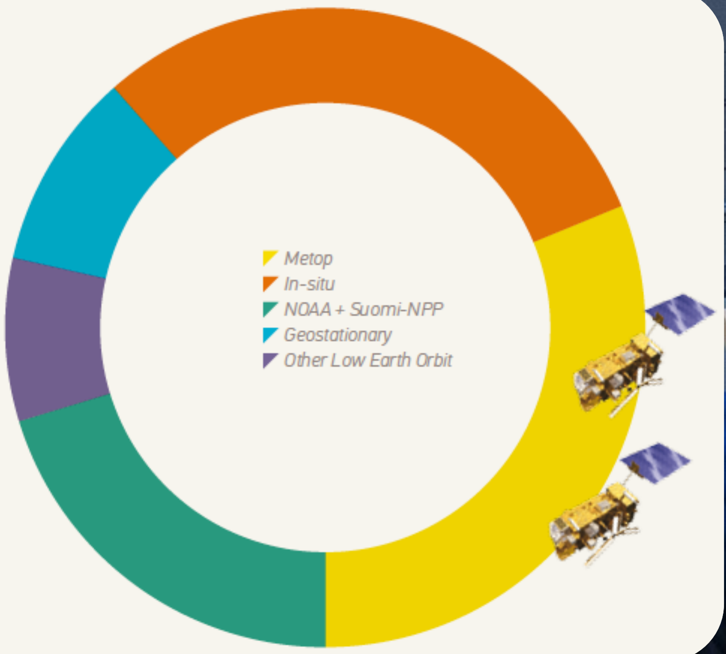
Copernicus User Uptake

The real number of users is much higher but unknown due to the free, full & open data policy.

scihub.copernicus.eu

Meteorology: Protecting Lives & Assets

esa



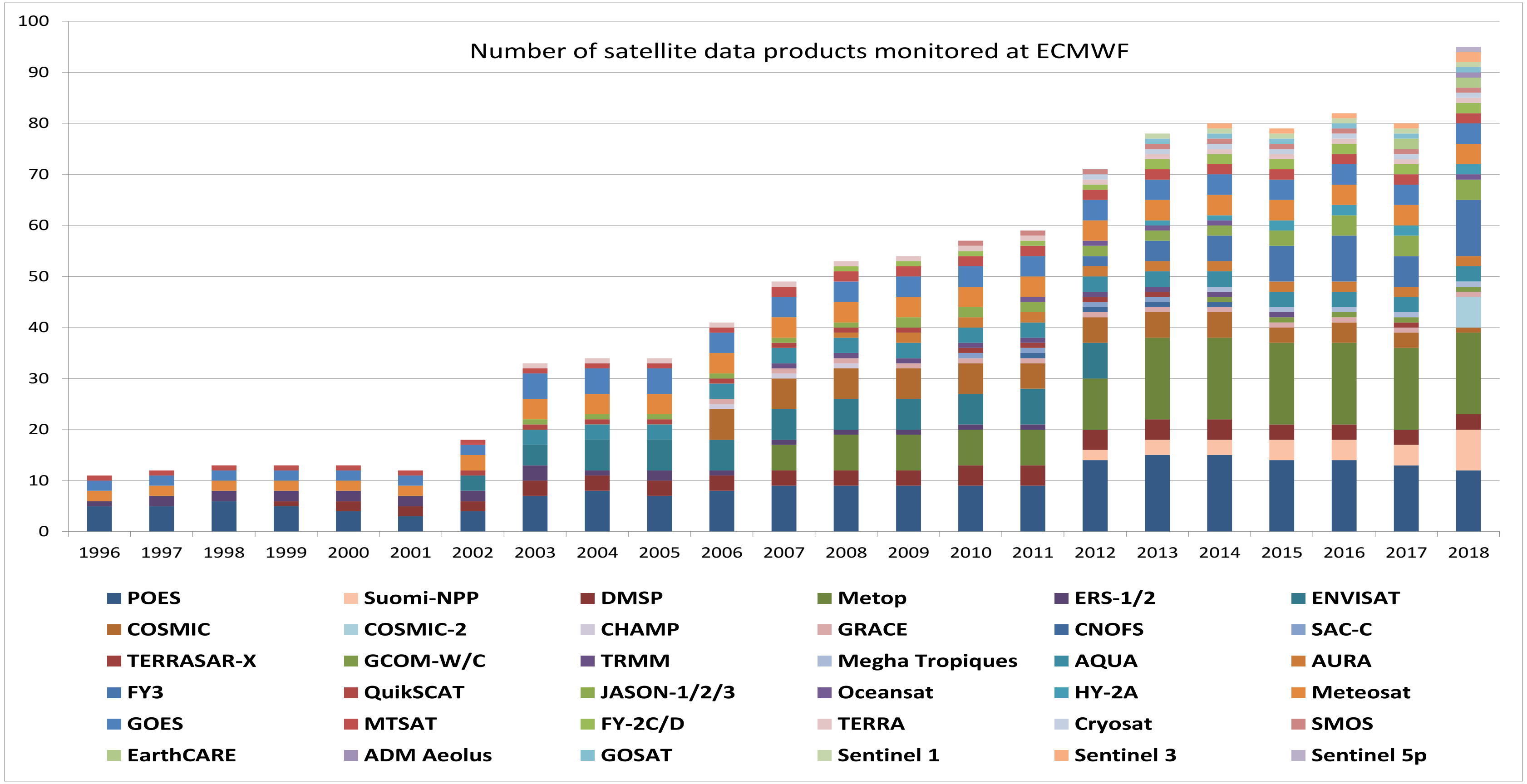
Weather Forecasting Accuracy Contributions

MetOp A+B: 44% (Europe)

NOAA+NPP: 29% (USA)

UK Met Office, 2015

ECMWF & satellite data



MetOp-A/B impact for Weather Forecast

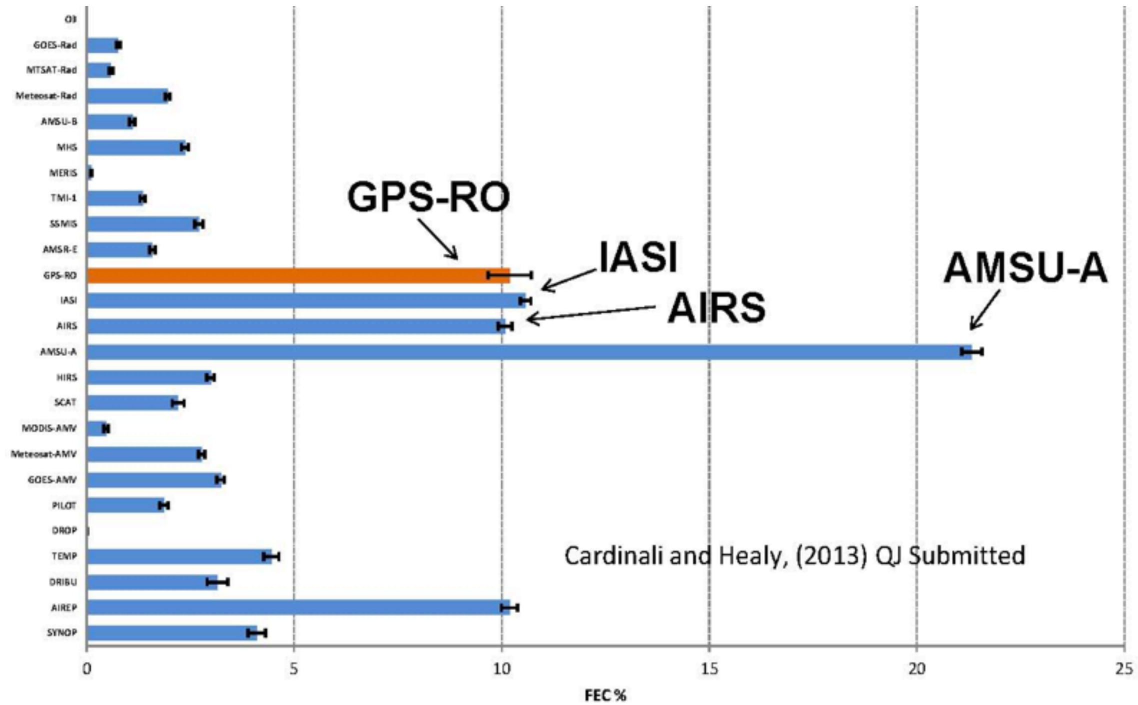
Multi-sensor combination of:

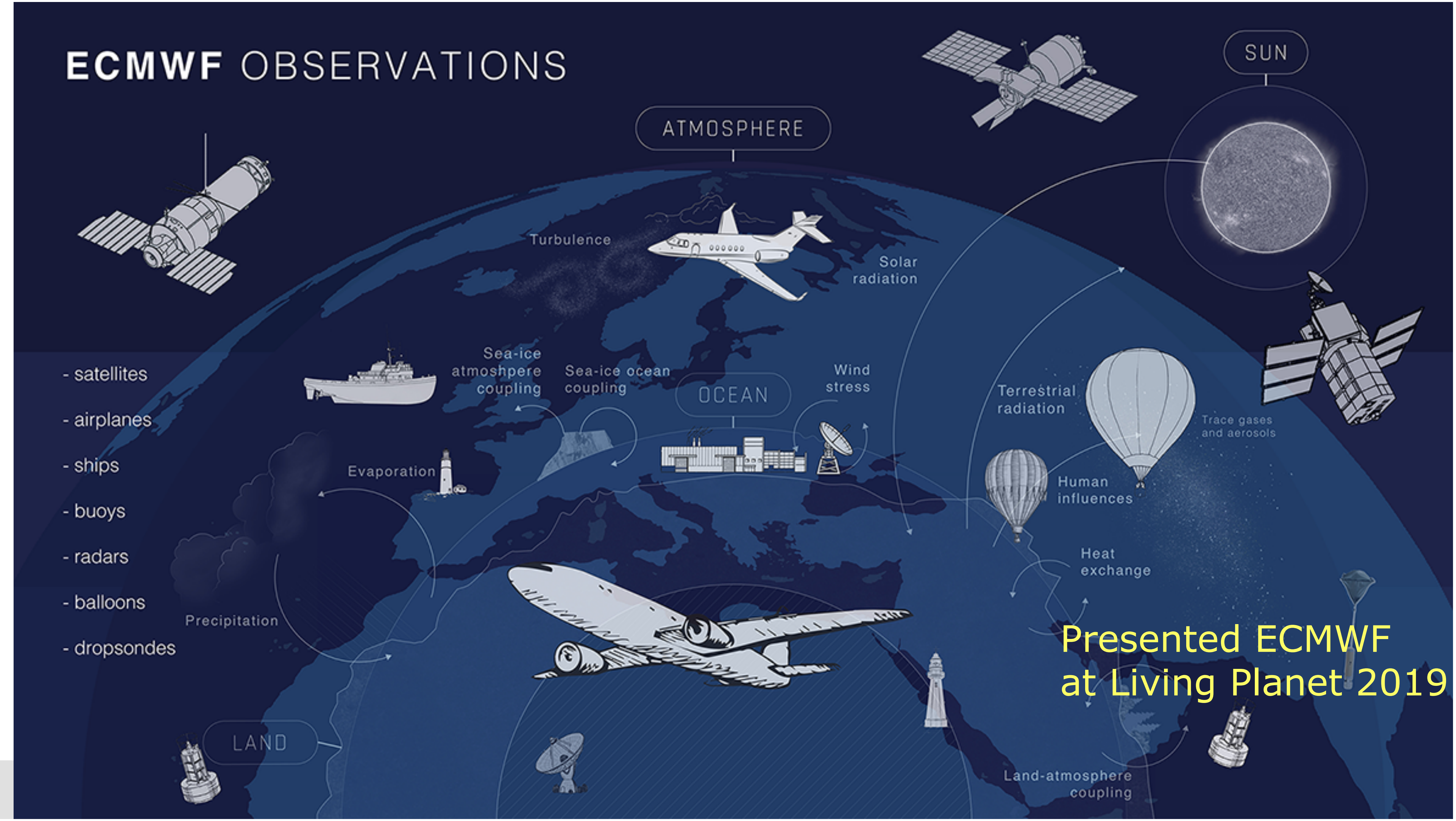
High-resolution 3D-grid:

- Horizontal : AMSU (microwave radiometer)
- Vertical :   GNSS Radio Occultation (RO)

In situ-measurements:

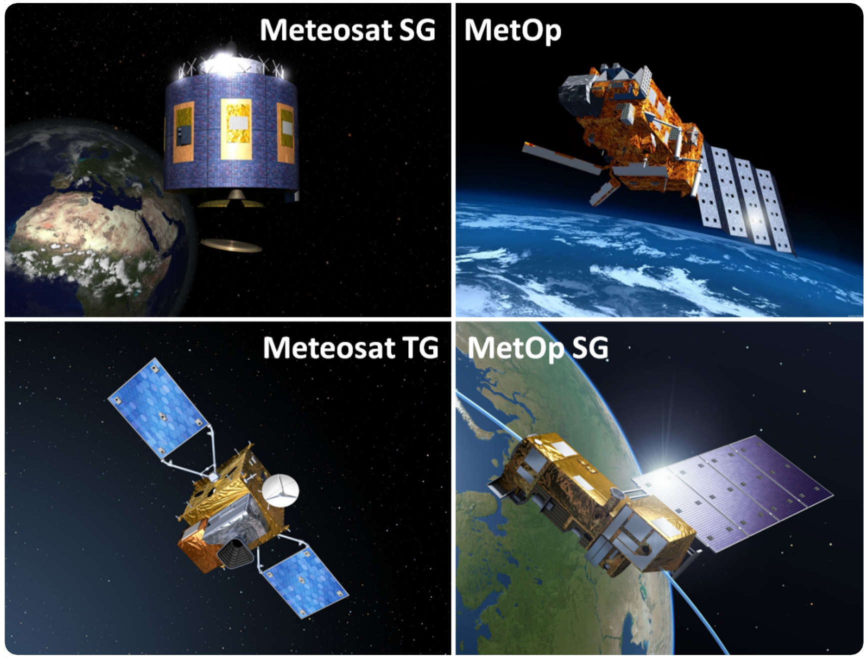
- e.g. Radio Sondes (RS) from balloons




ECMWF OBSERVATIONS
ATMOSPHERE
SUN
Turbulence
Solar radiation
- satellites
- airplanes
- ships
- buoys
- radars
- balloons
- dropsondes
Sea-ice atmoshpere coupling
Sea-ice ocean coupling
OCEAN
Wind stress
Terrestrial radiation
Trace gases and aerosols
Evaporation
Human influences
Heat exchange
Precipitation
LAND
Land-atmosphere coupling
Presented ECMWF at Living Planet 2019

Meteorological missions – with EUMETSAT as partner

GEO LEO polar



Current

Post 2020

Developed with ESA's partner, Eumetsat

- Europe's contribution to WMO (World Meteorological Organization's) space-based GOS (Global Observing System)

In GEO-stationary orbits

- MSG - Meteosat Second Generation (2002, 2005, 2012, 2015):
  - series of 4 sats
- MTG - Meteosat Third Generation (2021–)
  - 4 sats providing images + 2 sats for atmospheric sounding

In Low Earth Orbit (LEO) – Polar orbit

- MetOp (2006, 2012, 2018) – series of 3 sats with operational meteo-obs.
- MetOp-SG (Second Generation) (2021– early 2040s)
  - two series of polar-orbiters x three satellites in each series
  - continuing / enhancing meteorological, oceanographic and climate monitoring.

Future EO – Earth Explorers as S&T Flagships

esa

Flying Missions

GOCE	SMOS	Cryosat	Swarm	Aeolus
2009-2013	2009	2010	2013	2018

H_2O NaCl

Future Missions

EarthCare	Biomass	FLEX	EE-9	EE-10
2022	2022	2023	2025	2027
			2 Cand.	3 Cand.

Science & Innovation

4.700+ Reg. Users

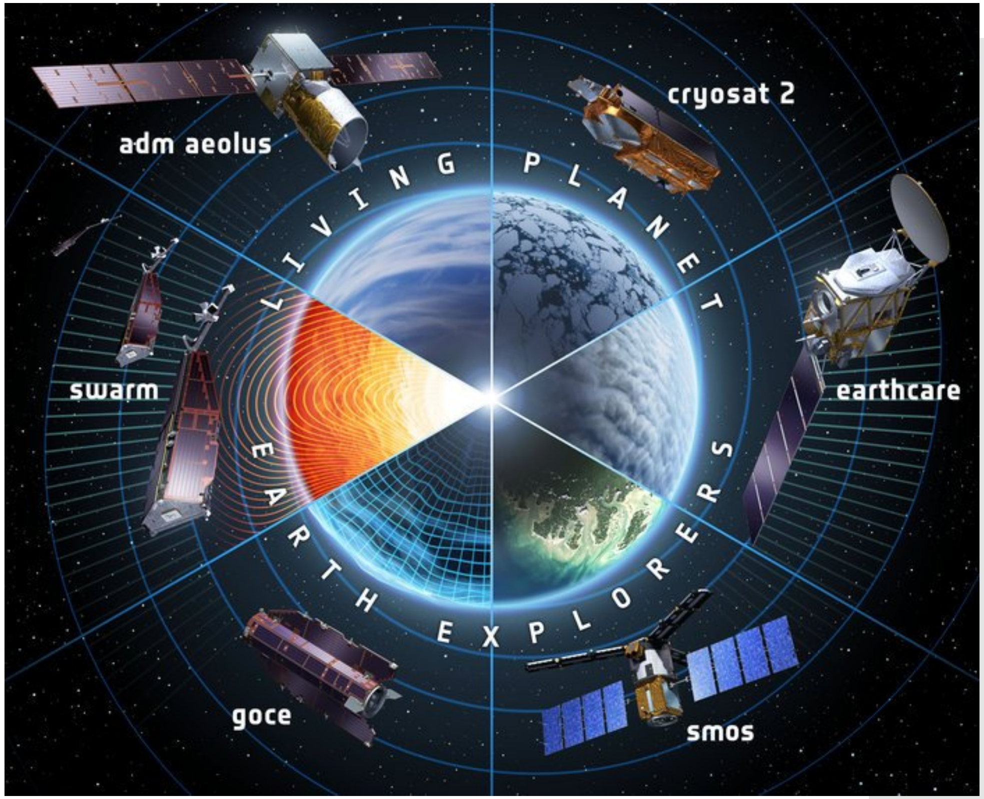
300+ Publ. per Year

High Risks for Great Rewards

Earth Explorers

These missions address critical and specific issues raised by the science community, while demonstrating the latest observing techniques.

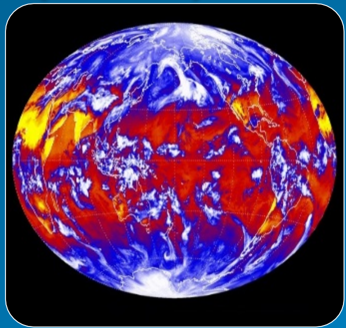
- GOCE (2009–13) studying Earth's **gravity** field
- SMOS (2009–) studying Earth's **water cycle**
- CryoSat-2 (2010–) studying Earth's **ice cover**
- Swarm (2013–) three satellites studying Earth's **magnetic field**
- ADM-Aeolus (2017) studying **global winds**
- EarthCARE (2018) studying Earth's **clouds, aerosols** and **radiation** (ESA/JAXA)
- Biomass (2021) studying Earth's **carbon cycle**
- FLEX (2022) studying **photosynthesis**
- Earth Explorers 9 & 10 to be selected

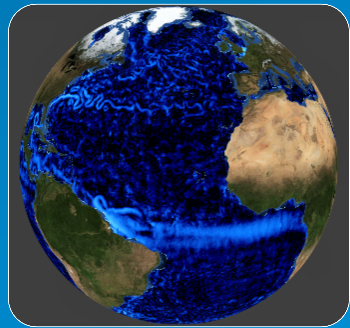


Earth Explorer-9 – Two candidates

User Consultation in July 2019

➔ one (of the 2) **selected for Phase B2/C/D (implementation)**





FORUM

Far-infrared Outgoing Radiation Understanding and Monitoring

- greenhouse effect
- climate change assessments accuracy
- Measurement in the 15 to 100 um spectrum with FTS + TIR image

SKIM

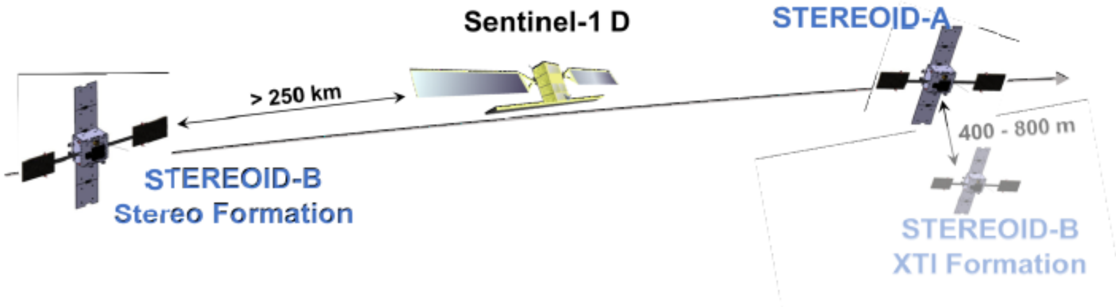
Sea-surface Kinematics Multiscale monitoring

- ocean-surface currents
- Wide-swath scanning multibeam Ka-band (36 GHz) radar altimeter

Earth Explorer 10

Stereoid

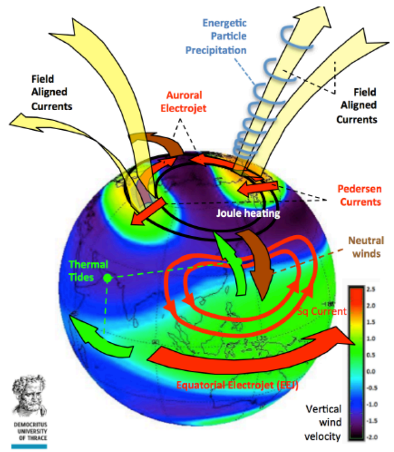
- Cryosphere (dynamics)
- Oceanography
- geosphere



Daedalus : a low Flying S/C for the exploration of the MLTI

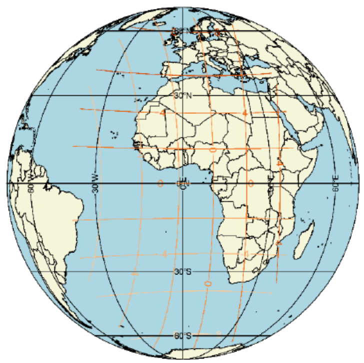
(Mesosphere, Lower Thermosphere / Ionosphere)

- One mother satellite + many CubeSats



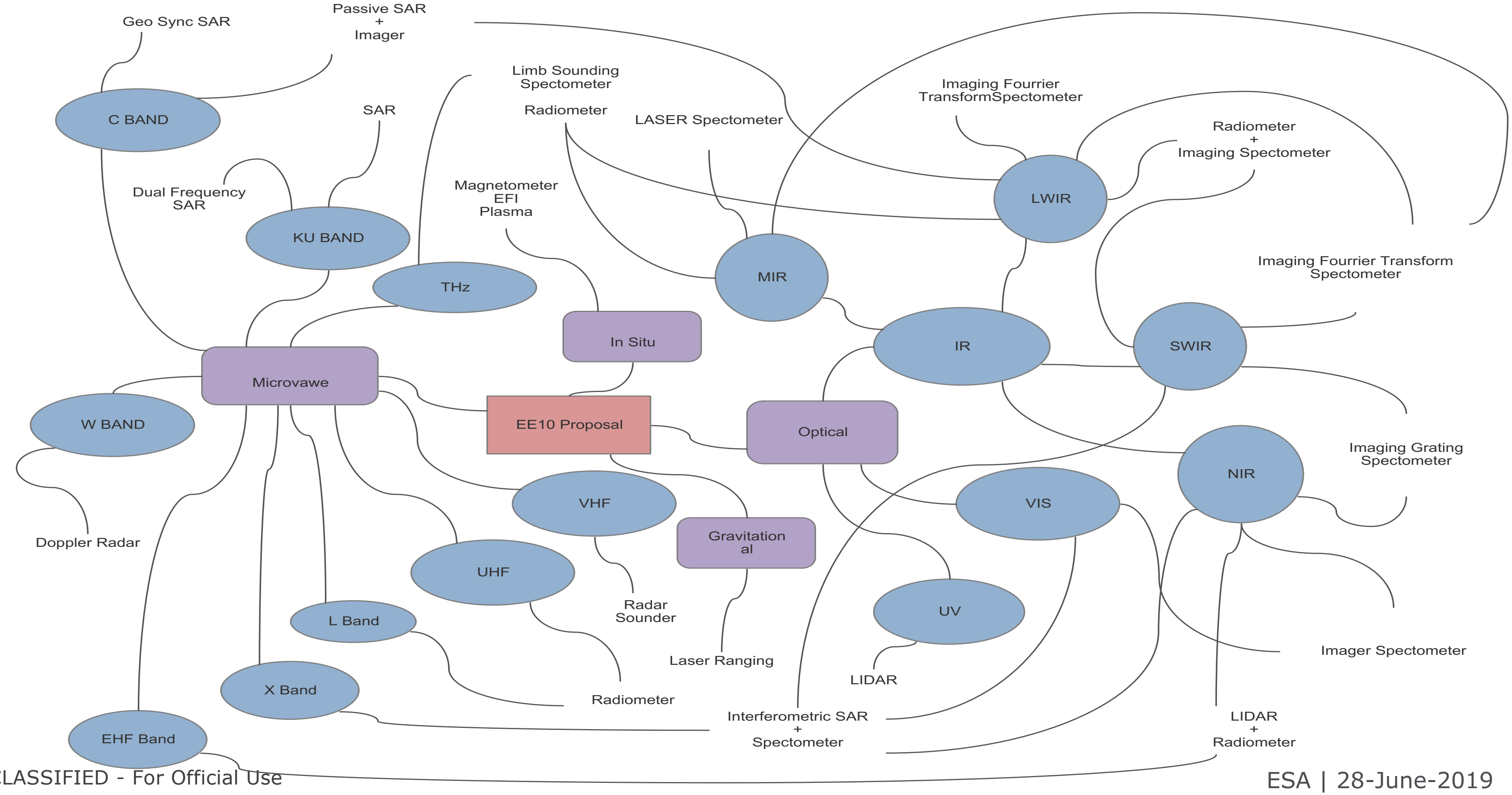
G:Class: H2O : C-band SAR from GEO

- predict rain fall,
- understand water cycle

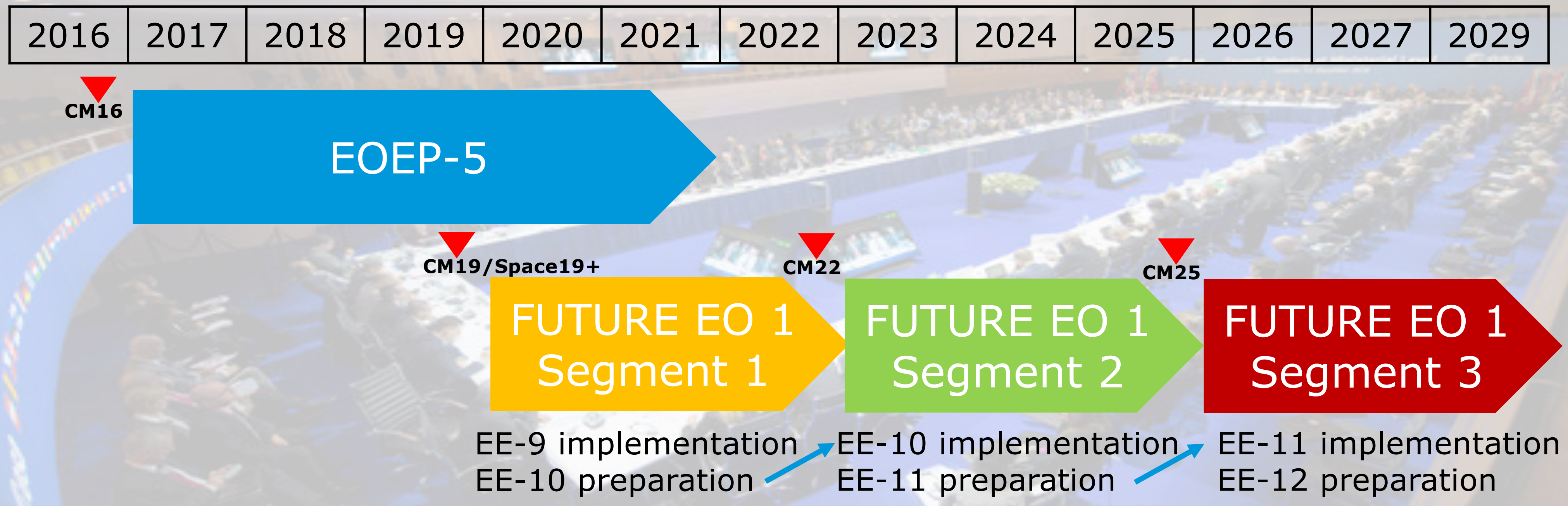


EE-10 candidate missions (21 concepts) → 3 selected for Ph.0

➔ instrument technology driven by frequency / wavelength



FutureEO phasing with Ministerial Councils (3 yrs)



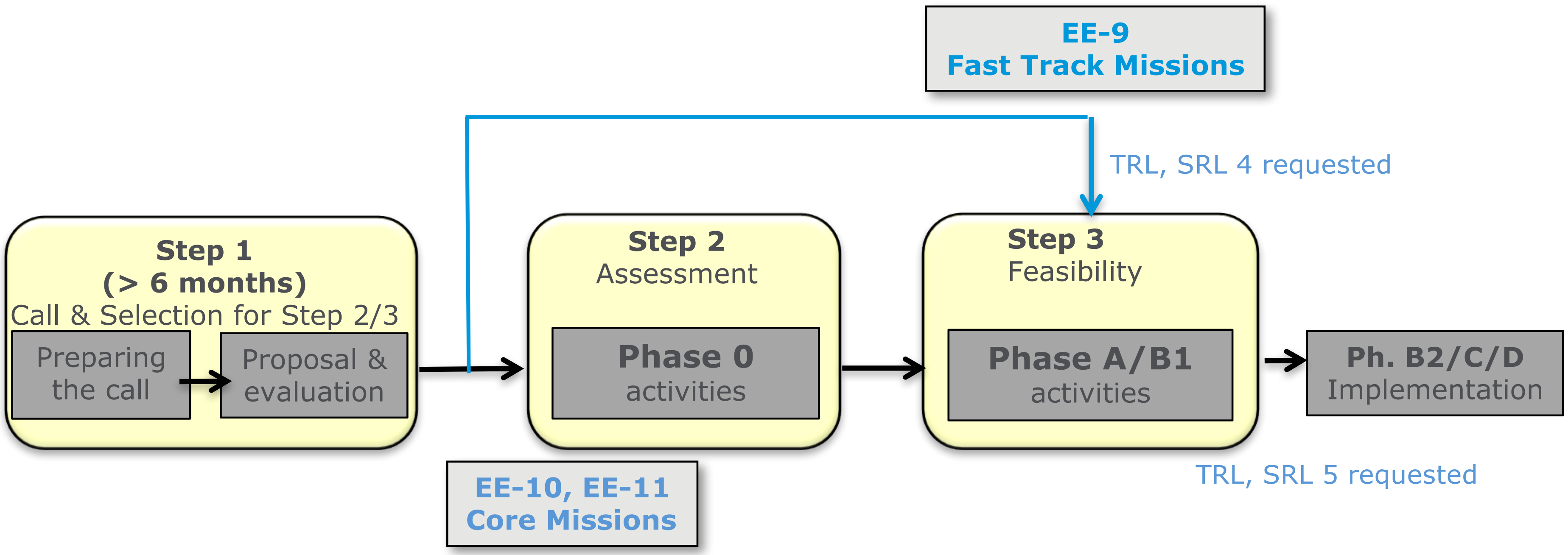
Synchronisation of EO programmes with the Ministerial Council cycle:
3-year segments FutureEO-1

Earth Explorer - EE-11
(Core Process)

Call for ideas every three years (aligned with ESA funding scheme – Council Ministers)

➔ Call for EE11: in 2020

➔ Core = Start with Ph.0



ESA EOP missions: End to End

Mission Development

System concept (upstream, downstream)

Science and applications : driver

Associate to physical / chemical processes

Inversion models (e.g. from roughness to wind speed)

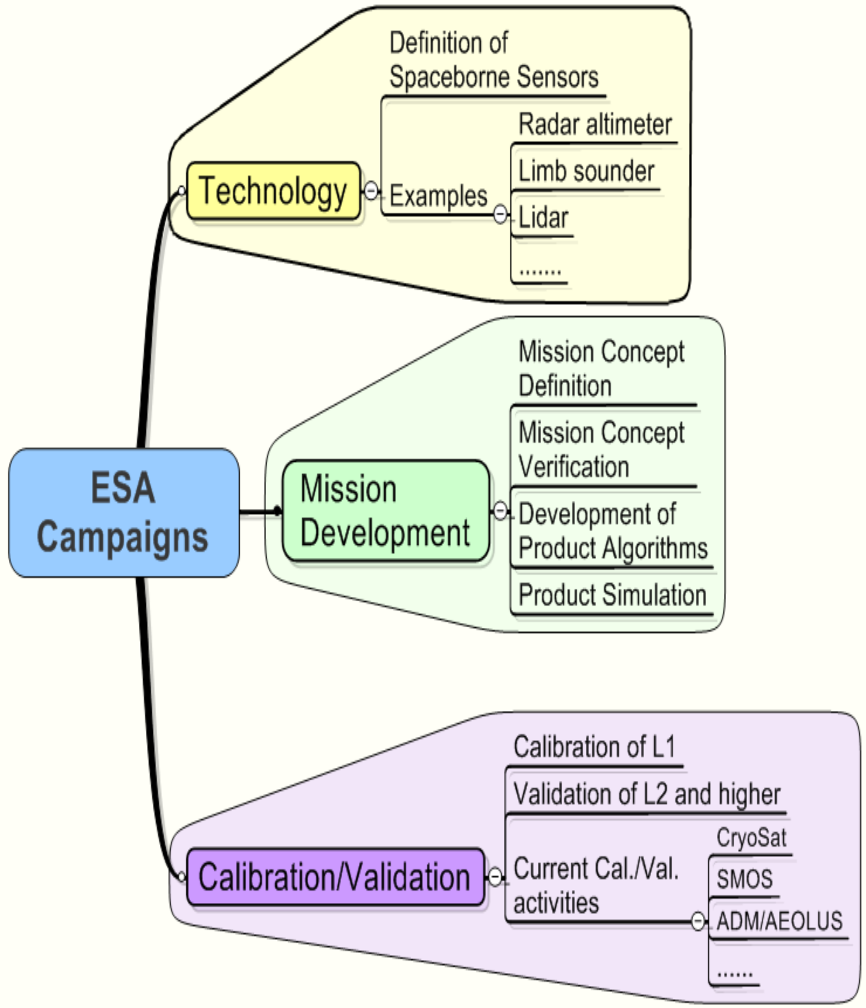
Calibration/validation

- in situ measurements
- airborne campaigns

Open data policy - archives & long term

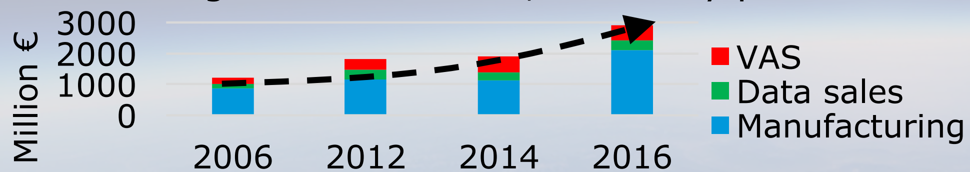
Technology : as enabler

Focus on Instruments



Europe’s place in the global EO market

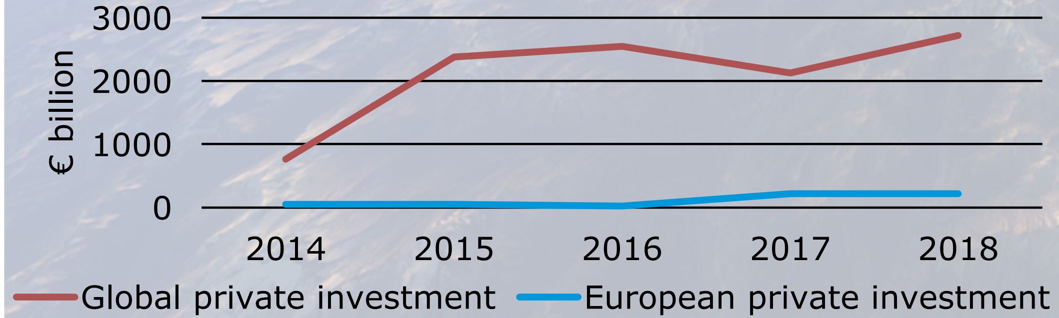
→ The EO market in Europe has seen a substantial growth throughout the decade, driven by public sales.



→ Each € invested in EOEP/FutureEO leads to **3.8€** created in Europe in GDP, technology/knowledge spillovers and **55000** job years created.

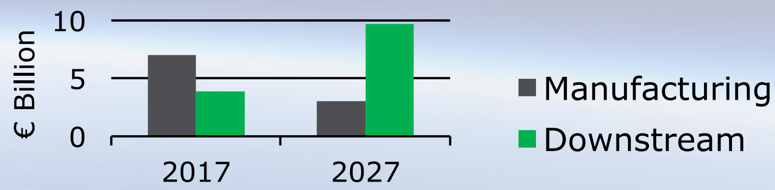
PWC, 2019

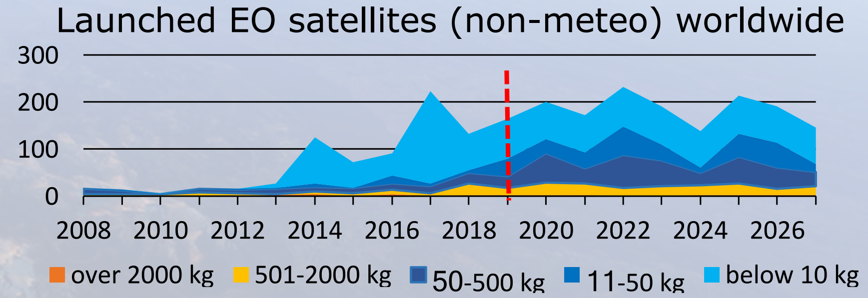
European vs Global private investment levels

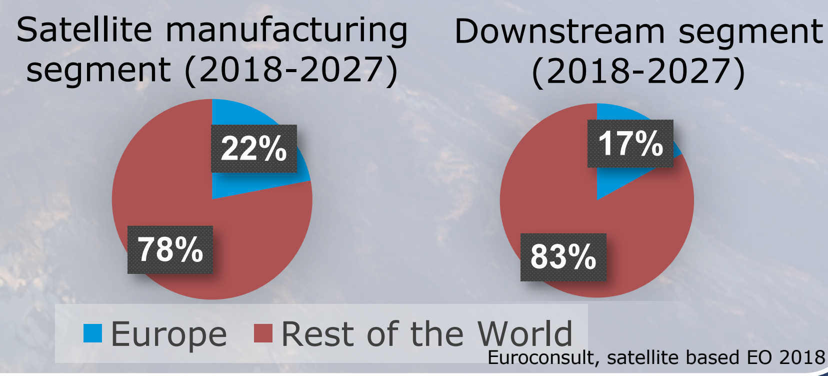


Bryce 2019, ESPI 2019

EO market decade projections

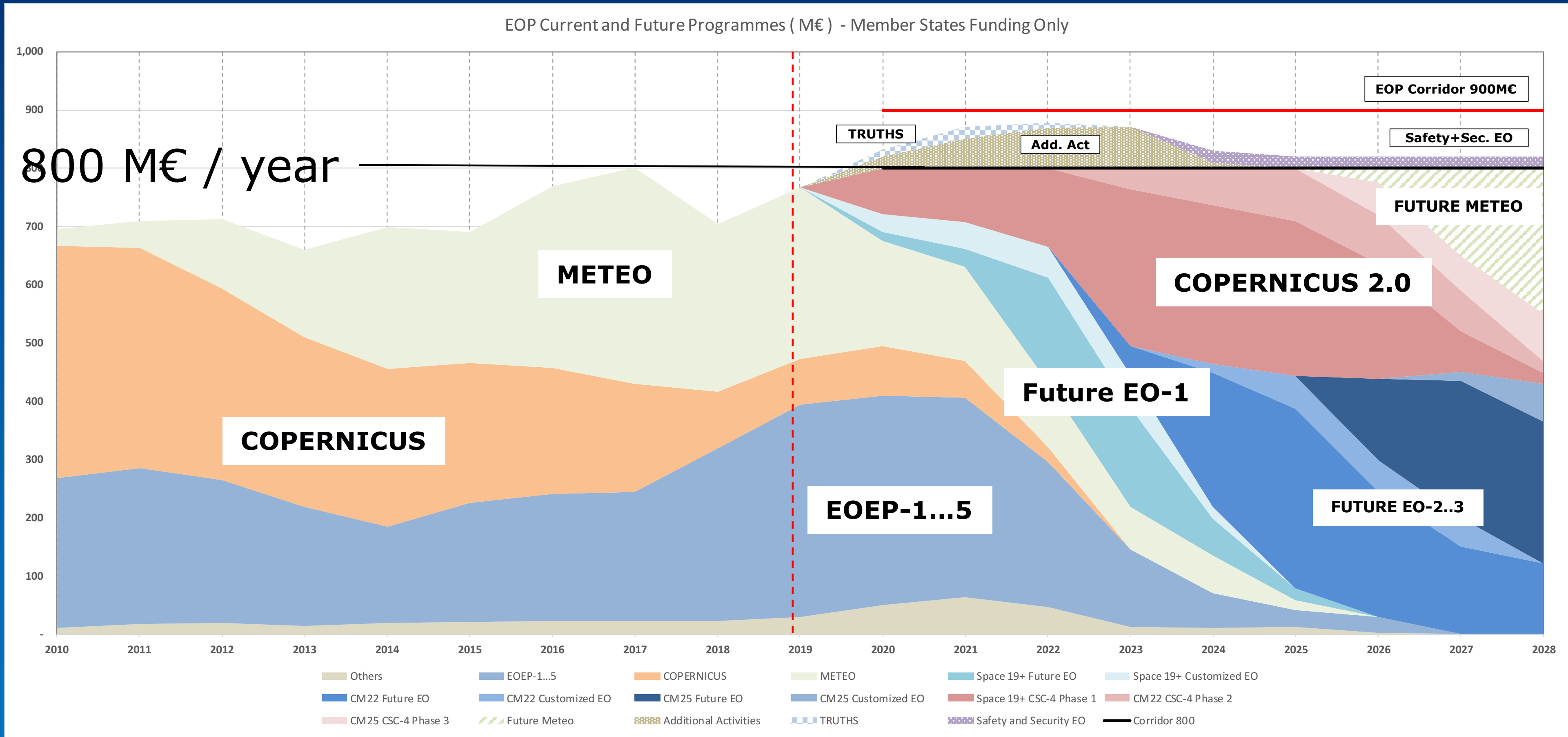






Euroconsult, satellite based EO 2018

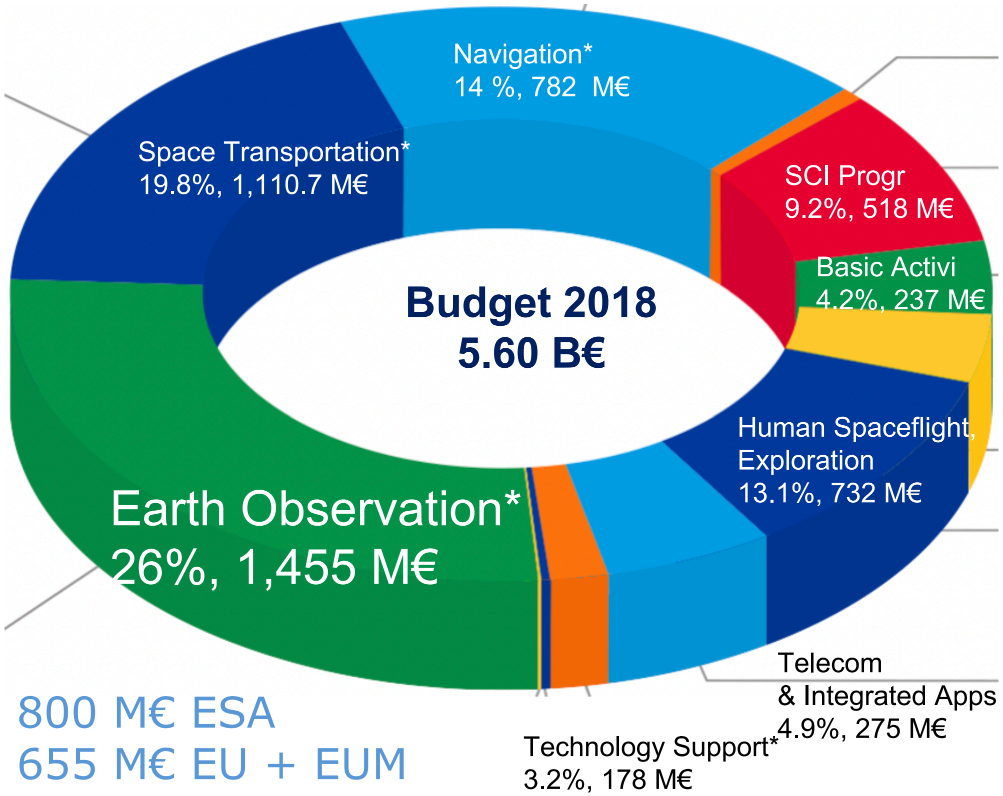
EOP funding in ESA - from Member State



ESA budget for 2018: by domain

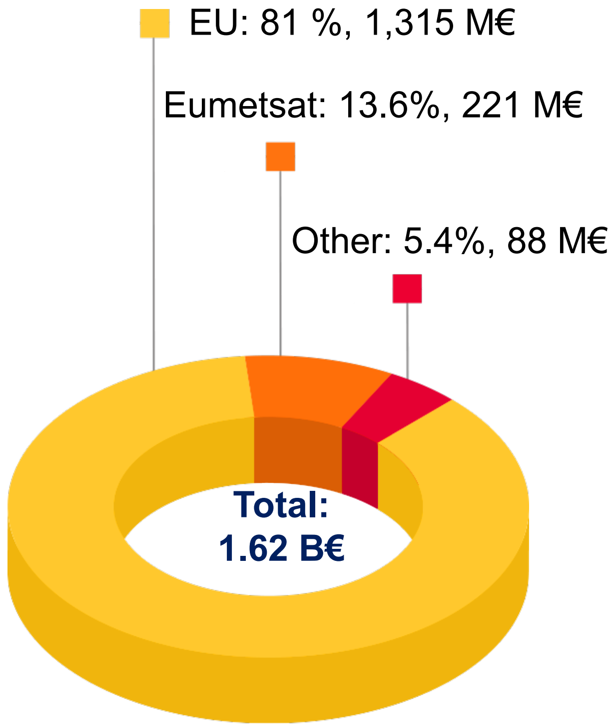
B€: Billion Euro

M€: Million Euro



800 M€ ESA
655 M€ EU + EUM

Total ESA (2018):
4 B€
+ 1.62 B€ other income



Rising EO Benefits for Europe

Future EO

socio-economic benefits & spill-overs

€1 → €3.8 return

+55 000 job years

Copernicus

€ 92 – 191 billion

benefits by 2035

EUMETSAT

€ 16 – 63 billion

benefits 2020-2040


Future EO – 21st Century Innovation
esa
Hardware & Technology
Big & Small
HAPS
Operations
Increased Data Diversity & Volumes
BIG DATA
EO AFRICA
Safety & Security
EO contribution to ESA-wide pillar
21st Century EO
Software & Applications
Machine Learning
Artificial Intelligence
Data Analytics
Internet of Things
Cloud Computing
European Space Agency

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Institutional ESA missions

- Copernicus, Meteorological, Earth Explorers
- ➔ Technology

NewSpace

- CubeSats
- Small Sats / Scouts

EOP – part of ESA Technology Strategy

ESA Technology Strategy

Version 1.0 (corr1)
03/12/18

Ref. ESA/IPC(2018)93 in bluedocs

A CALL FOR ACTION

TECHNOLOGY STRATEGY

1 The New Context for Space Technology Developments

2 From Mission Needs and Technology Innovation to Technology Themes

Adv.Manufacturing, Design to Produce, CleanSpace, Cybersecurity

3 Technology Development Targets

S/C development time, cost efficiency, faster development / adoption, space debris

4 Technology Portfolio Strategy

Enabling Core, Enhancing, Game-Changing Technology

MISSION NEEDS AND TECHNOLOGY INNOVATION

5 Mission Needs

5.3 Applications Technology Needs

Telecom, Navigation, Space Transportation , Generic

5.3.2 Earth Observation (3 pages) → https://tec.prox.esa.int/sites/TECNET/Shared%20Documents/Forms/AllItems.aspx OR https://bluedocs.esa.int/sites/migration/6/2808/Meeting%20Documents/ESA_IPC_2018_93_EN.pdf

5.4.3 Generic Technology

6 Technology Innovation

6.1 Electric, Structures, Avionics, Power, RF & Optical Sys, …

Summary in the next slide

ESA EO Technology : <u>Enabler</u> of a User Driven approach
Science & Services (land, ocean, ice, atmosphere, …)

Higher performance / cost ratio

- **New Measurements** (enabler)
- **Higher spatial, temporal, radiometric** resolution
- Instruments in the **whole spectrum** (RF, Optical) – active & passive
- Higher **lifetime** (7 yrs → 10 yrs or more)
- Increased **flexibility** (adv. manufacturing, on-board re-programmable FPGA)
- Faster to design/develop and deploy
- Long-term data **continuity** → BIG DATA + AI
- Lower **cost** (**spin-in** techno, COTS , multi-providers)

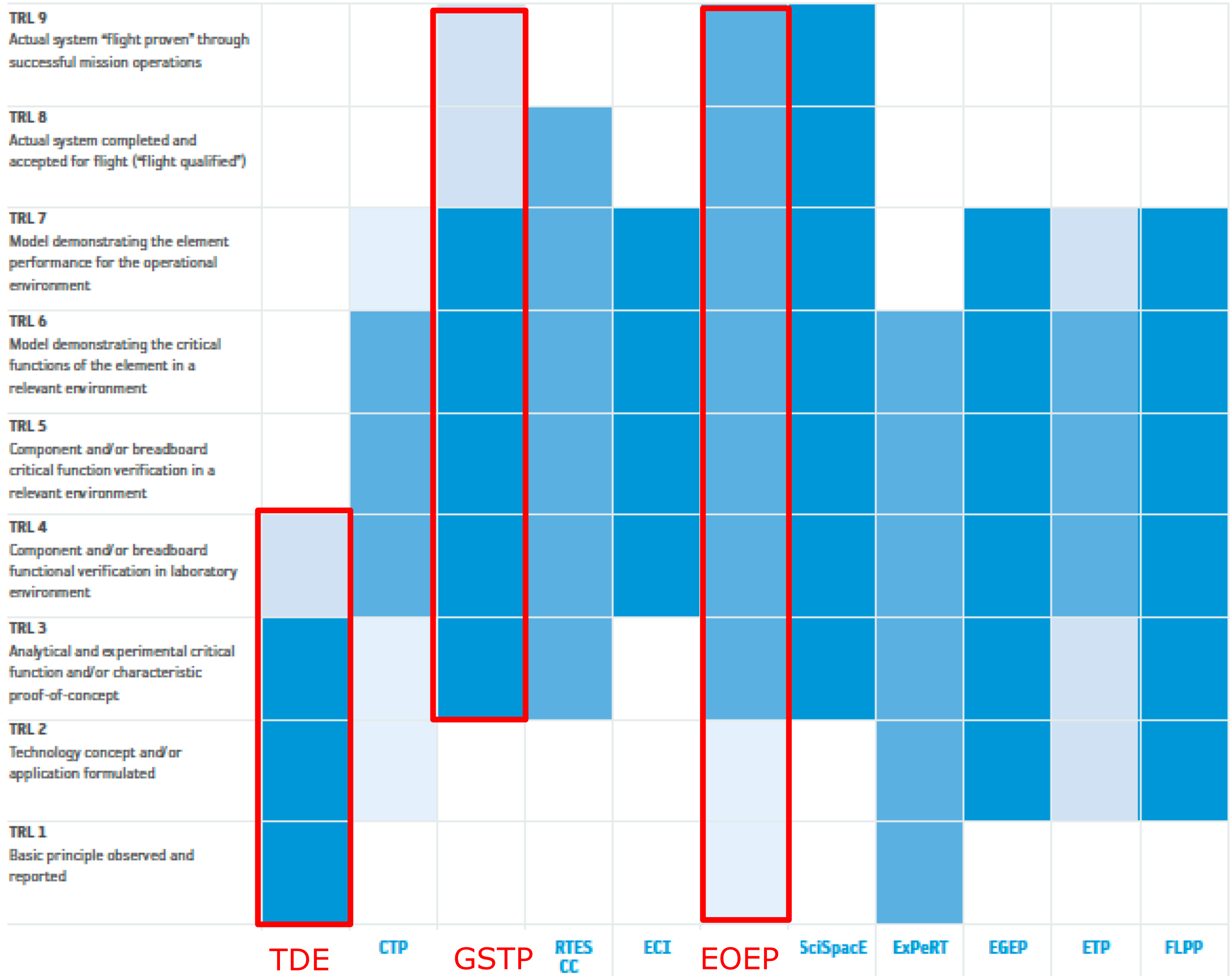
Miniaturisation and constellations (incl. convoys and formations)

- More **autonomous** platform & operations
- **Distributed** G/S
- Synchronisation (ISL beacon, GNSS)
- Efficient access to space (launchers)
- lower cost, fast-to-market ability, adaptability and flexibility.

ESA Technology Programmes

EOP Technology under 3 programmes:

- TDE (former TRP): up to TRL 3-4
- GSTP : higher TRLs
- EOEP : all TRLs (from concept to flying products)



Technology focus on Instruments

Preparing new instruments and observation techniques
- RF & Optical
- from concept, Components & HW demonstrators, up to qualified models
- for satellites (and airborne campaigns)

Big data challenges

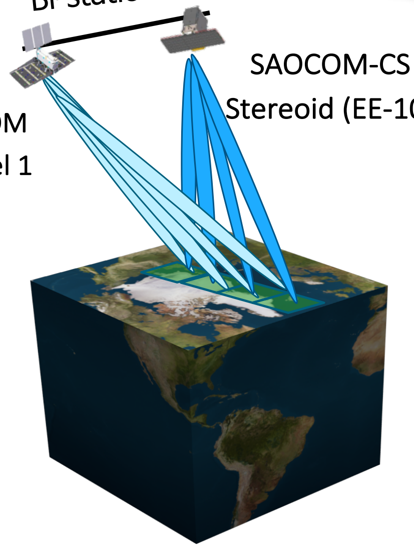
Bi-static SAR

SAOCOM-CS

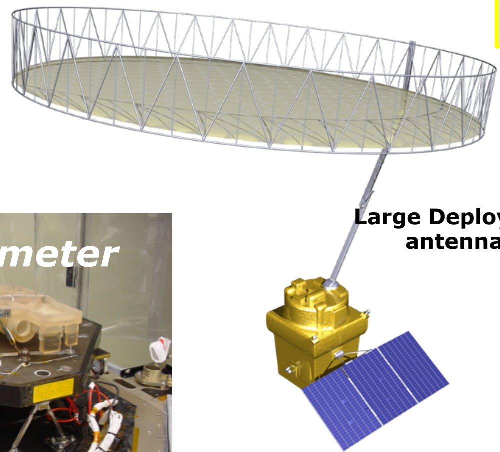
Stereoid (EE-10)

SAOCOM

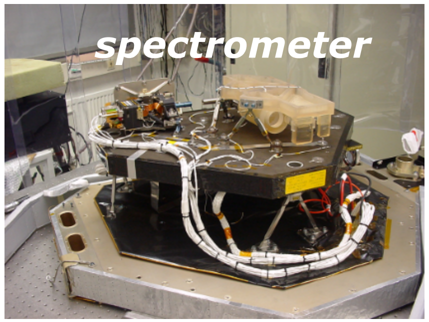
Sentinel 1

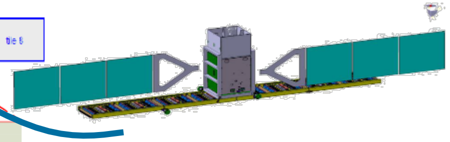


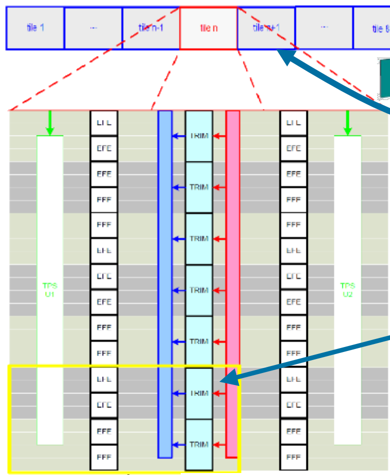
Horn antenna



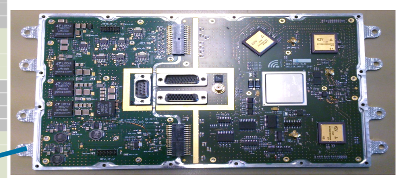
Large Deployable antennas





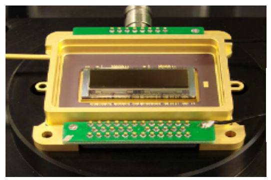


Integrated Tile Demonstrator



Digital Beamforming Unit (TRIM)

Airborne campaigns



IR detector Array

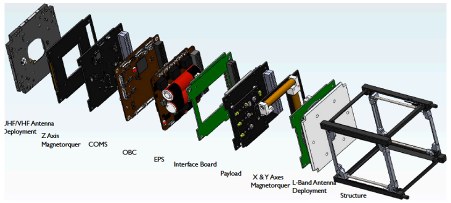
Reduce recurring cost → STANDARD PLATFORM → more for the Payload

Problem: Technology push disconnected from system needs

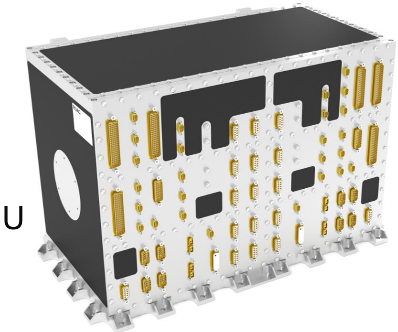
Platform Needs:

- **Architecture changes**
  - Miniaturisation
  - more Integration (units → boards → components)
- **Standardisation**:
  - Common interfaces (electrical & mechanical form-factor)
  - Interchangeable Modules ➔ multi-suppliers
- Increased **functionality → for constellations**

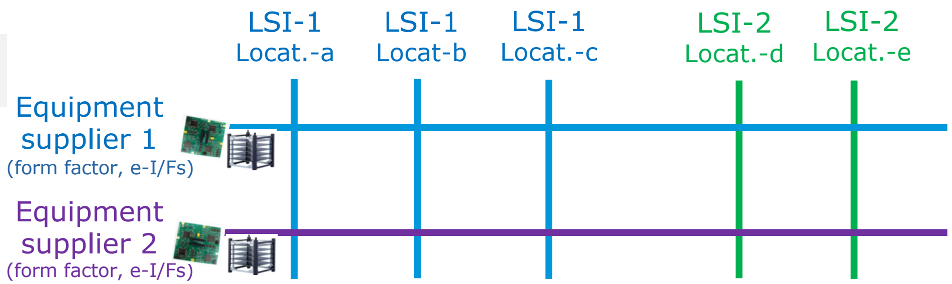
Standardisation done for Cubesats ➔ big success



Multi-board SMU:
OBC, GNSS, SSMM, mini-RIU



➔ Foster Integrators/SME collaborations

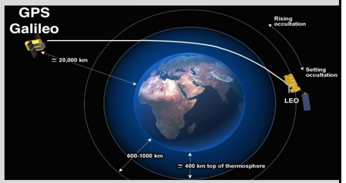


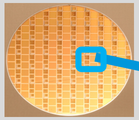
Platform optimisation → more Payload / Science

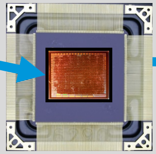
<u>Advanced GPS-Galileo ASIC (AGGA-4)</u>

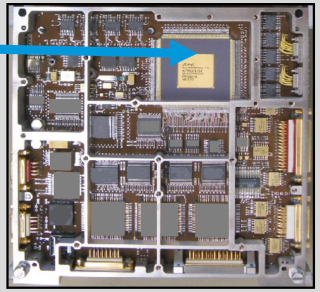
EOEP funding → **ASIC** (**enabler**)

GSTP funding → **GNSS Receivers**









By Airbus, ATMEL, RUAG

(~6 Million gates with **180 nm** process)

Programs adopting AGGA-4:

- MetOp-SG (P/F & RO inst.), S1c/d, S2c/d, S3c/d, S6, Proba-3, Neosat, others TBC (e.g. Biomass, Flex)
- CSO, SARah, + Comp.Adv Sat. 500 (S Korea), **Mohammed VI**
- Vega-C

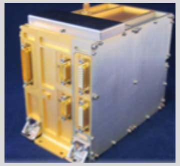
<u>Future</u>:

- **COTS FPGAs –** reprogrammable on-board **(7 nm)**
  L1 freq. & multi-GNSS (GPS, Galileo)
- **A niche for ASICs (28 nm): multi-GNSS freq. → top accuracy**

<u>**26 GHz** (K-band)data **downlink** (up to 10 Gb/s)</u>

EOEP funding for **System studies → enabler**

- **EOEP, GSTP, TRP, ARTES,**
  for **OB / OG** Antennas, OB Tx / OG Rx), Propagation, …



Tesat

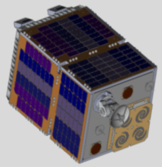
Adaptable speed (**Gbit**/s)
Transmitter

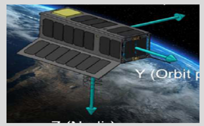
Konsberg

20 cm

Programs adopting the 26 GHz band:

- MetOp-SG, MTG, EDRS, Euclid ➔ next Generation Sentinels (TBC)
- NASA (JPSS-1, NISAR, PACE, …), … JAXA, SARah, …
- **feasible for small sats : two ESA studies**
  - **150 kg. P/F** (with SSTL)
  - **CubeSats** (with Calisto-SSBV)





Technology enablers for small sats

- GaN SSPA – power amplification
- Smaller antenna (steerable or agile satellite)

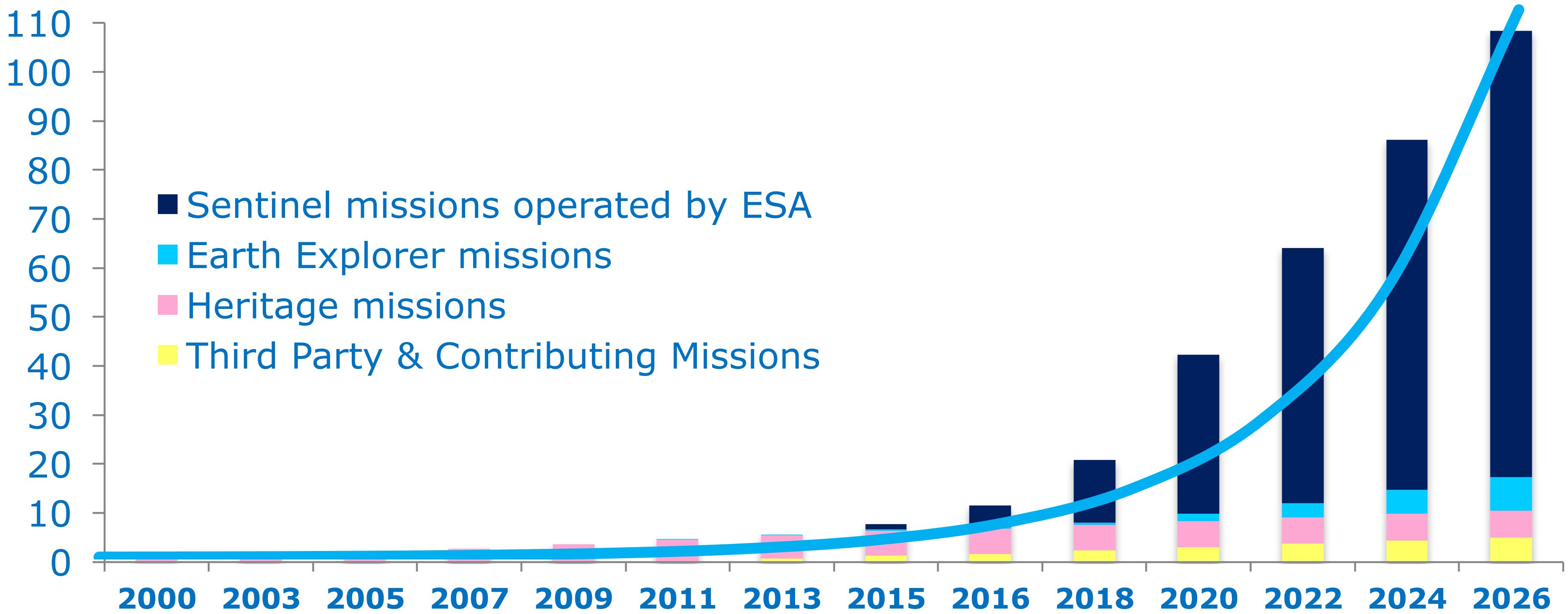
Time to start Q/V band comms (more Bw)

Big Data Revolution

ESA EO Data Archive

Petabyte

1 Gb/s (@ 10 min, 15 orbits) ~ 1 Tbyte/day
➔ 3 yrs for 1 Pbyte



Artificial Intelligence & Big Data for EO

How to navigate these oceans of data?

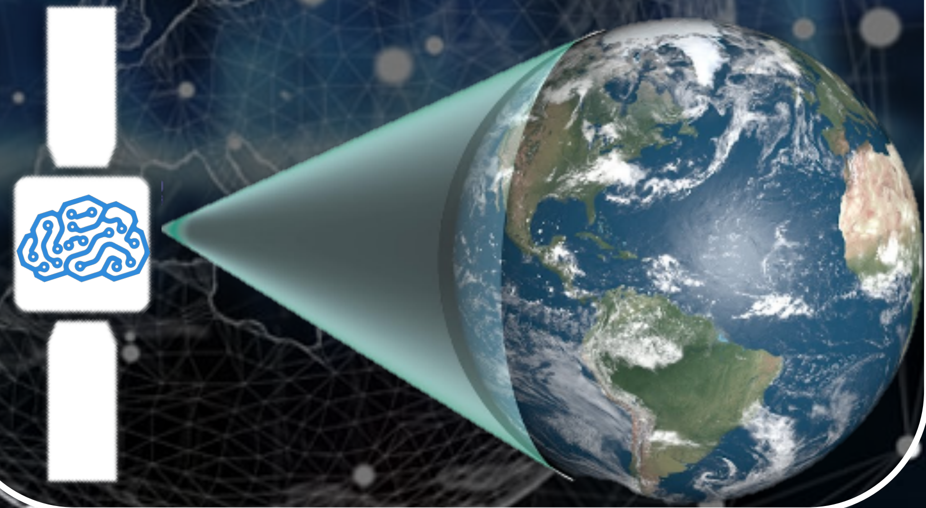
Three new analytical techniques are increasingly being offered within solutions utilizing satellite imagery:

Machine learning

Predictive analytics

Automatic change detection.

A full optical Earth coverage of the Earth at 3m GSD represents about 57 Terapixels.



The Big data Analytics market was estimated in 2016 at the value of €5.1B.

Table of Content

Institutional ESA missions

- Copernicus, Meteorological, Earth Explorers
- Technology

➔ NewSpace

- CubeSats
- Small Sats / Scouts
- Trends

The Space 4.0 Era

Space 1.0
Astronomy

Since millennia

Space 2.0
Space Race

Since 1958

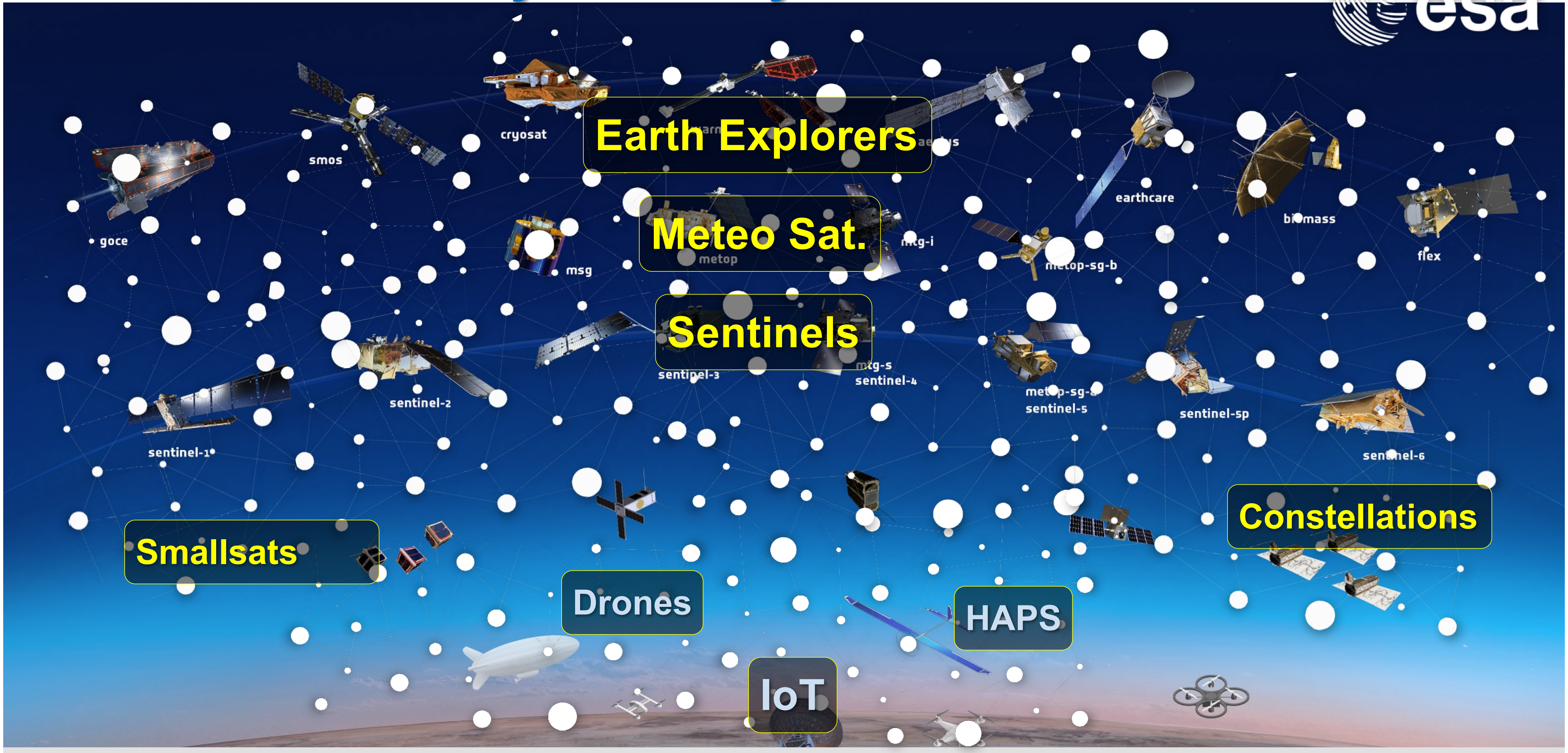
Space 3.0
Int. Cooperation

Since Fall of the Wall

Space 4.0
Space for Society

Now

EO architecture – system of systems



European Space Agency

Small Sats objectives and approach for ESA EO (1)

Final Objectives

- enhance ecosystem of **science/application/service capabilities**
- strengthen **competitiveness** of European smallsat operators (e.g. cal/val)

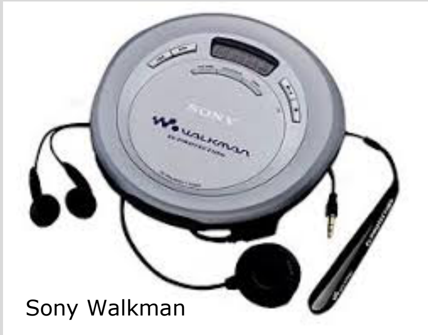
Approach (near term)

- Challenge / Calls to enable **steady flow of SmallSat ideas and Concepts**
    - from industry, wider EO community
- Relevant scenarios analysed where Small Sat missions focus on
    - detection
    - fast revisit & high spatial resolution
    - modest (spatial, radiometric) performance complement to Sentinels / Meteo.

Why small technology ?

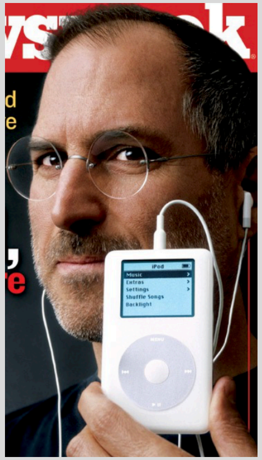
App. 1.0

App. 2.0



Vision with a purpose

(in the pocket, Multi-CDs)



App. 3.0

Enablers

MP3

Application / Science is the driver,
Technology is the **ENABLER** !!

Vision

- all in one
- ubiquitous

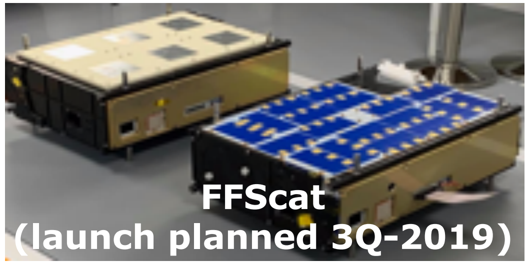
App. 4.0

Any parallel for Φ-space ?

Small Sat at EOP-Φ

Sentinel Small Sat. (S^3) in Copernicus Master Challenge

- FSScat (UPC Barcelona) selected in 4Q-2017 : with two 6U Cubesats
  LAUNCH planned in August 2019 on Vega-SSMS PoC



Small EO **Instruments** - Defining up-to-date EOP landscape

- For Microwave Instruments : 2 studies: (Omnisys, HARP) – ending in 2Q-2019
- For Optical Instruments : 2 studies initiated in Q1-2019 (SSTL, Cosine)

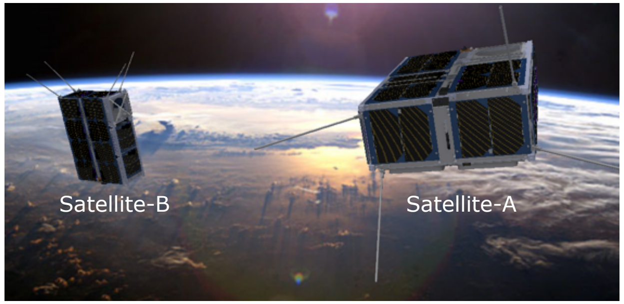
ideas → GSTP Elem.3 (Fly)
3 EO-related studies in 2019

ideas ↓

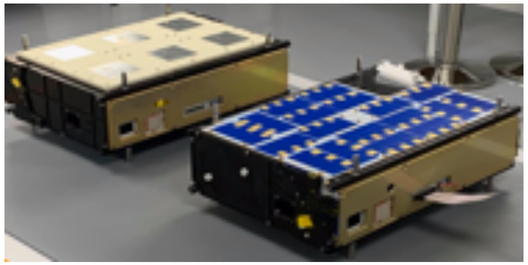
New SmallSat challenge (SCOUT missions)

- up to 4 Sys. Consolidation studies 400 k€ each → ITT June 2019
- Mission industrial cost (Space + Ground + Launch + IOC) ≤ 30 M€ → launch 2024

Sentinel Small Sat (S^3) Challenge - FSSCAT



FSSCAT - artist view



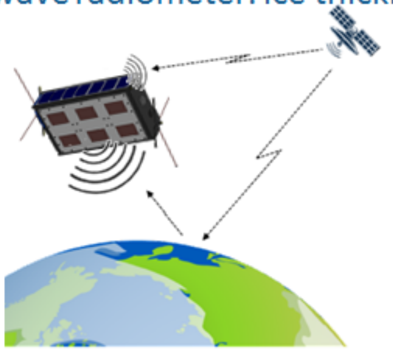
Real FSSCAT

- Winner of the 2017 Copernicus Masters "ESA Small Satellite Challenge"
- An innovative mission consisting of two 6U Cubesats embarking scientific and techno-demonstrator payloads
- Mission concept proposed by Universitat Politècnica de Catalunya (UPC) and developed by a consortia composed by:
  - UPC: Microwave Radiometer and GNSS reflectometer
  - UPC: Radio inter-satellite link (ISL)
  - Cosine: Hyper-spectral (HyperScout) instrument (VNIR), enhanced with TIR and **Artificial Intelligence**
  - Golbriak: Optical ISL
  - Tyvak International: Platform/system integrator + Operations
  - Deimos Engeharia: PDGS
- Launch in Vega SSMS Proof of Concept (PoC) expected in Q3-2019

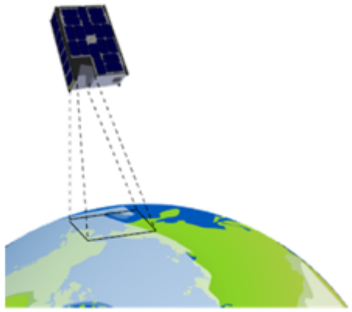
Overview of FSSCAT

Mission definition

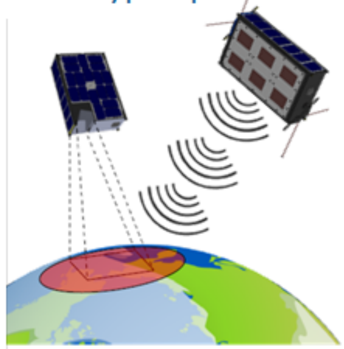
FMPL-2 Sea Ice Observations:
GNSS-R: sea ice & water pond mapping
Microwave radiometer: ice thickness



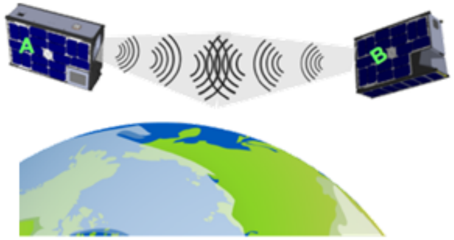
Hyperscout Observations
Terrain Clasification
Change detection



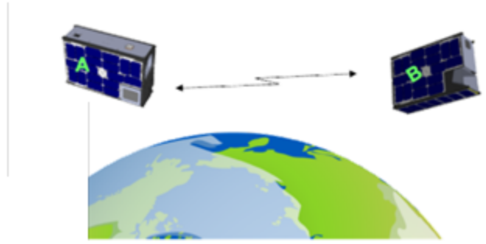
FMPL-2 + Hyperscout Observations:
Microwave radiometer: soil moisture
Hyperscout: hyperspectral observation



Optical Inter-Satellite Link (O-ISL) experiment

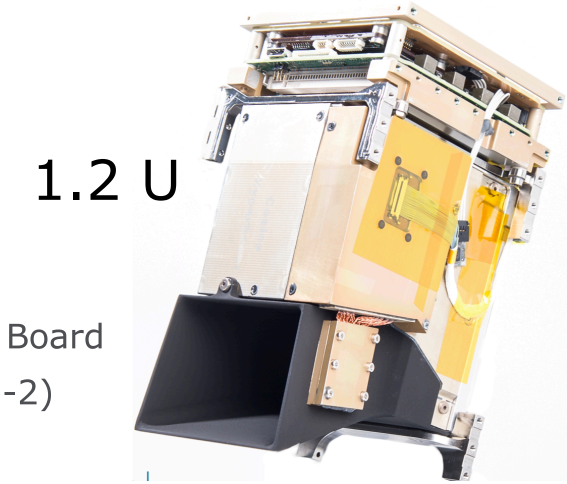


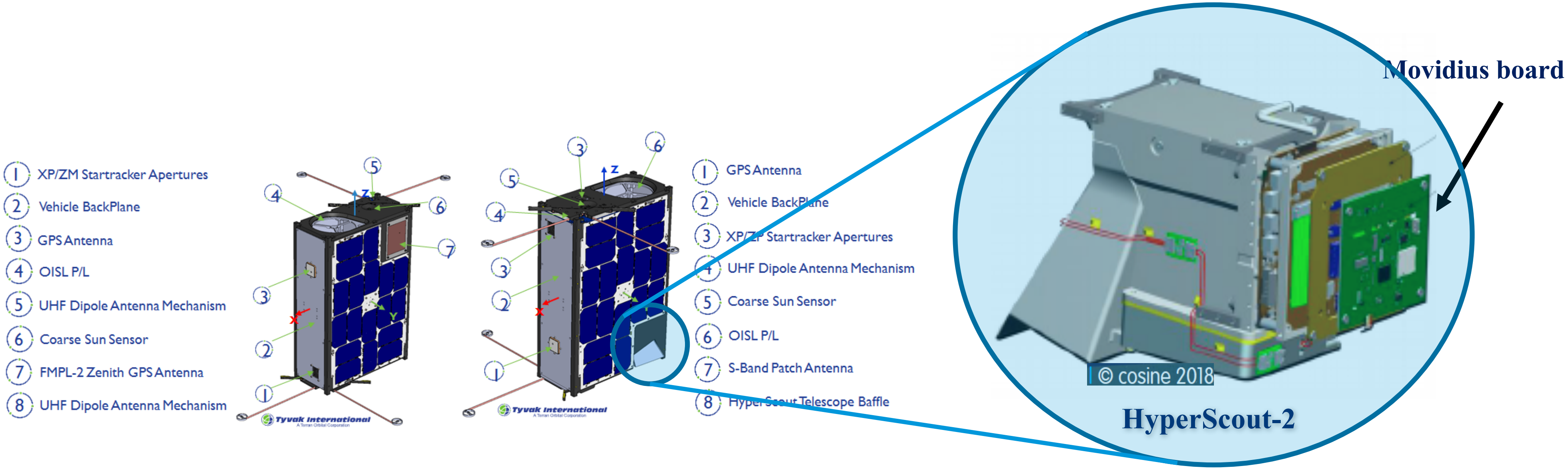
Federated Satellite Systems experiment (FSSExp)



Phi-Sat

- Phi-Sat : Hyperspectral instrument of FSScat enhanced with:
  - ✓ Thermal InfraRed (TIR)
  - ✓ Artificial Intelligence (AI) - Kick Off in Dec-2018
    - First IOD of Artificial intelligence for **Cloud detection** Using Myriad 2 Movidius Board
    - Objective: **downlink only cloud-free data** (2/3rds in the case of Sentinel-2)
    - Challenge: Reliability of learning process using non-fully representative data





Future EO Microwave **Instruments** for Small Satellites

Main objective:

- Review of past, current & planned small satellite initiatives.

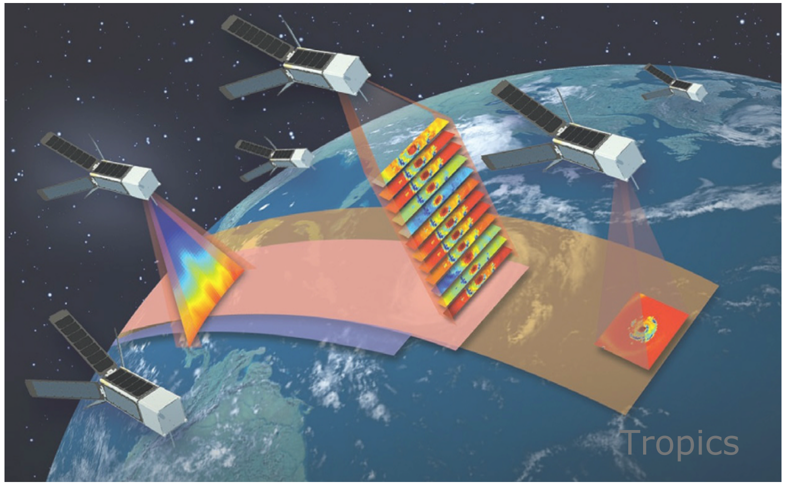
➔ Identify opportunities and **roadmap**

- Focus on microwave/ (sub)millimetre wave EO instrumentation (<100Kg) & on payload part.

2 parallel (complementary) studies:

1. Harp (Prime), Aalto University. 100% Finnish team.
2. Omnisys(Prime), OHB-Sweden, Chalmers University (Sweden)

Same exercise done for **Optical Instruments**



SmallSat Challenge – Scout Missions

- Goal is to:
  - foster concrete ideas for innovative SmallSats
  - respond to evolving EO environment (science techno)

- Scope : (emits.esa.int AO 1-9901)
  - A "Scout Mission" shall have a **science/application** (non-commercial) focus, with the aim of providing incremental science :
    - ✓ either addressing niche applications on its own right
    - ✓ or as complement to other missions, e.g. Earth Explorers, Copernicus Sentinels, Meteorology missions or National missions.

- Plan for implementation
  - 4x System consolidation study: (6 months) → 400 k€ x 4 studies
  - 2x Industrial **development cost, launch and in-orbit-commissioning** → 30 M€ x 2 projects
    - ✓ 1^{st} launch: 1Q-2024
    - ✓ 3 years schedule through new methodologies (e.g. use of COTS, recurring platforms)

Scout Mission Concepts

- ”SmallSat Challenge” renamed “Scout Mission”

- System Consolidation (up to 4) studies: **400 k€** each over 6 months

○ Issuing of ITT (AO 1-9901):	June 2019 (in preparation)
○ Kick-off	Nov. 2019
○ Completion	May 2020

- Industrial development cost, launch and in-orbit-commissioning :

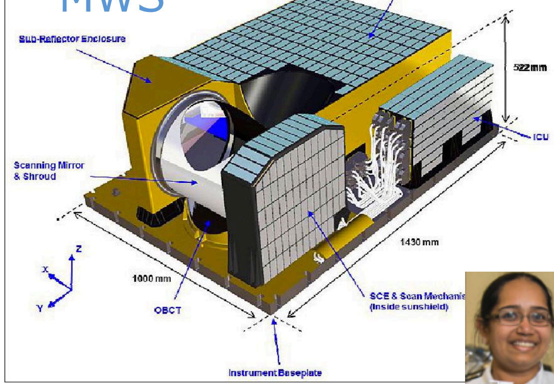
○ ACEO advice on science/application value:	July 2020
○ PBEO decision for implementation of 1 or 2 concepts:	Sept. 2020
○ KO of implementation phase	Q1 2021
○ Launch	Q1 2024 (~3 yrs)

Example of good candidate for Scout mission

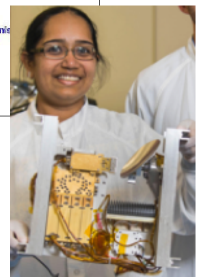
→ Microwave Sounding for Numerical Weather Prediction

Specification	Operational MWS (MetOp-SG)	6U CubeSat TEMPEST-D * (NASA, launched 2018)	Remarks for Small Sat
Nb. channels	24	5	Volume limitations
Channel Freq (GHz)	23-229 GHz	87, 164, 174 178, 181	Miniaturisation - easier in high freq.
Mass	150 kg	4 kg	a fraction
Power	110 W	7 W	
Volume	100x143x52 cm	10 x 20 x 30 cm	
Altitude	820 km	400 km	
Resolution at nadir	17 km	12.5 km (25 km @ 87 GHz)	Comparable
NE∆T (K)	0.2 - 0.7	0.2 - 0.7	Comparable

MWS



Tempest-D



Going beyond CubeSat should bring the most effective result, while enabling constellations

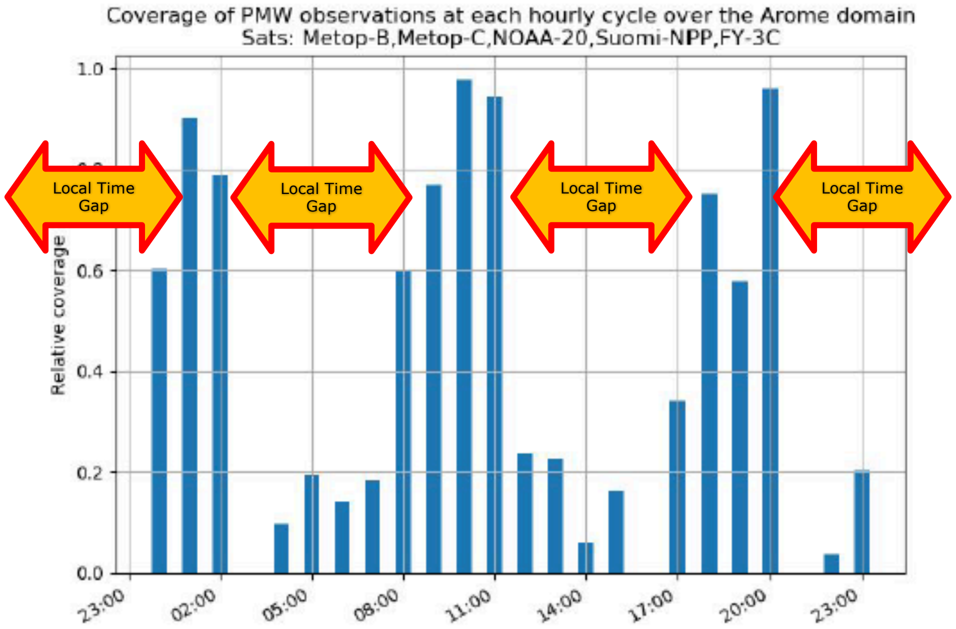
- System / platform aspects :
  - Higher reliability/lifetime,
  - More resources, e.g. power, thermal control, full orbit operation, downlink data rate
  - Better pointing & pixel geolocation accuracy
- Instrument aspects:
  - Better radiometric accuracy/stability
  - More channels

* NASA ESTO InVest: esto.nasa.gov

Gap identification for Passive MW-Sounding

- GEO satellites do not cover latitudes north of 70°N.
- Constellation of satellites in multiple orbit planes could provide:
  - low latency,
  - high (hourly) revisit time and
  - cover gaps in local time not covered by existing assets

In Red MetOp AMSU Track



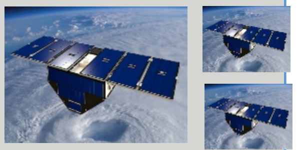
GNSS-Reflectometry: similar path to Radio Occ., but 10 years later

R&D

- ESA OPPSCAT studies (2000)
- UK TDS-1 (Jul-2014, still on)- SSTL
  (campaign funded by Block-1)
- Cosmic-2R announced

Institutional

- NASA EV-2 Cyclone GNSS (CYGNSS)
  (Dec-2016) **8 nanosats** (25 kg each)



Europe leading !

Data potential:

- Sea wind speed **< 2 m/s RMS error** with TDS-1 (like ASCAT)
- Land, ice, …

Complements others (like Radio Occ.)

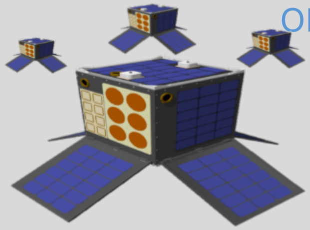
- scatterometers with higher **revisit time**

ORORO = Orbital Radio Occultation & Reflectometry Observers

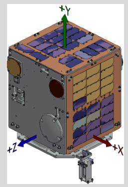
Feasible in nano/microsats → ORORO concept by SSTL

Spire Coming Up (3U Cubesats)

Pretty (Univ. Graz)

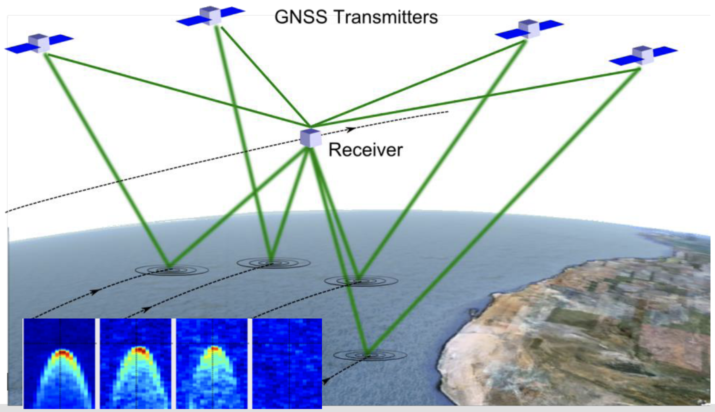


ORORO - SSTL's
27U Cubesat

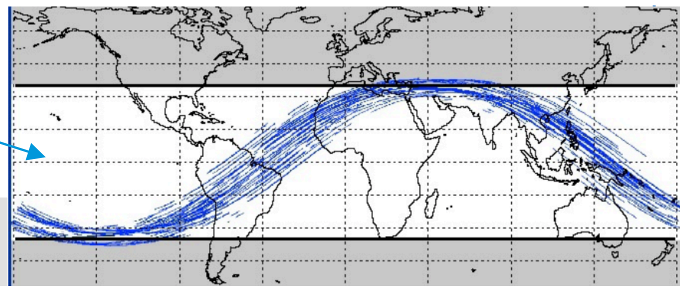


Constellations & Temporal revisit !!

DOT-1 (20 kg)
unch 3Q-2019



CYGNSS (8 sats)
coverage
in 90 min.

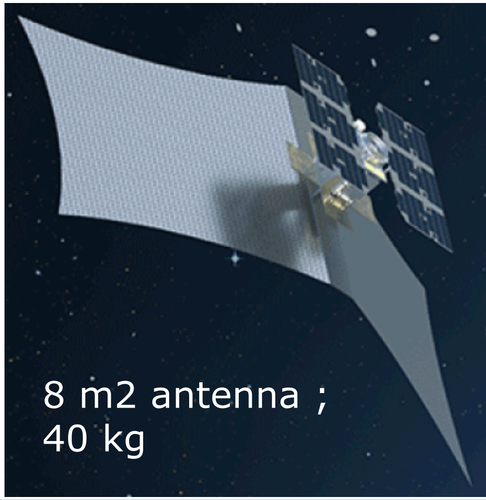


Big vs Small

Sentinel-1

2300 kg ; 12 m. antenna

ICEYE



Capella Space

Something needs to give in

NewSpace **complementing** Institutional

(not competing)

	INSTITUTIONAL	Small Sats
Innovation	1st one – proves the technique works	Takes lessons learned
Lifetime	7 → 10 years (LEO) - rad-toler., thermal Ctrl, redundant Sub-Sys	2-5 years (TBC) - COTS, redundancy at constellation level
Margins	- all signal chain steps optimised / calibrated - big margins taken	- simplified (e.g. miniaturised) - reduced margins
Resolution driver	1st: spatial & radiometric	1st : temporal
Application	**Scientific** driven	Change detection, - trigger other sys: e.g. HAPS, hi-res. sat
Calibration	**Absolute** calibration ==> becomes the **REFERENCE** - incl. In-situ, airborne, …	**Relative** calibration vs Institutional - much simpler - SW corrections (Art.Int. / statistical)
Scaleability	Expensive	Constellation possible (miniaturised)
Data	Open Source + **Continuity**	Data Buy policy as income
Ops & Processing	Need to automate / innovate	Challenge: vertically integrated vs good partnerships
Launch	Also institutional, so far	One orbital plane , but if more ?
Funding	Public + per continent	Mixed (incl. venture capital) & Global

Future EO: leveraging the digital revolution
(Technology as enabler)

10^x More Data

Expanding EO Landscape: Copernicus 2.0 + Meteo SG + Science + Commercial / SmallSat Constellations..

HAPS, UAV,..

IoT, Open Data

Rapid Innovation

Cloud Computing
Big Data Analytics

AI, esp.
Deep Learning,
Autonomous Syst.

Miniaturisation
& Integration

New Solutions / Partnerships

Demo end-to-end distributed smart sensing systems (AI+EO+HAPS … +IoT)

Environment for Rapid Innovation / Prototyping, to test ideas via Proof of Concept, Challenges, Hack, Research/Sprint

Foster New Partnerships (e.g. ICT, startup, investors, non-space users), New start-up

CHALLENGES → **OPPORTUNITIES** → **SOLUTIONS**

Summary

<u>EARTH OBSERVATION</u> : USER DRIVEN with wide range of innovation

- Weather Forecast , Climate Change , Agriculture, …
- Disaster Monitoring , Urban Planning, …

For the people & the planet

- Unique/calibrated way to measure all over
- Re-enforcement of International agreements (Paris)

Science is the driver, **TECHNOLOGY** is the enabler

- Higher **performance / cost** ratio   (also faster design & deployment)
- Opening to Constellations (Space 4.0) → revisit time

<u>Large range of Technologies</u> (in collaboration with D/TEC- D/OPS):

- from concept to qualified equipment
- from micro (component) to macro (equipment, system)
- focus on instruments - all Freq. (RF, Optical) , but also Platform & downstream

Technology Trends:

- **Spin-in** : COTS + digitisation (re-program on-board) + smart manufacturing + Artif.Int.
- **Miniaturisation** opening new applications: for Institutional & Space 4.0
- **Standardisation** required - to foster industrial collaboration

Conclusion

Institutional & Newspace : Complementary

- High spatial – radiometric resolution vs high revisit with small sat
  - ✓ Science driven vs change detection driven
  - ✓ Learning & Learding with margins vs simplifying

- Lots of nuances : technical and non-technical
  - ✓ Learn the system vs use the lessons learned
  - ✓ Miniaturisation helps, but some physics laws remain
  - ✓ Mind the users, but also the downstream partners in the added value chain
    (one data source / competence often not enough)
  - ✓ Completeness – see it as a service:
    - ✓ satellite(s)
    - ✓ launch(es) : quantum leap → size/mass of sats matters
    - ✓ operations (automate) + processing