Earth Observation Technologies at the European Space Agency (ESA)

Presenter: Josep.Rosello @ esa.int

EO Technology Coordination & Frequency Management Section (EOP-ΦMT) in ESA

Location: ESTEC (NL)

Plenary session on 23 June 2020

Make it simple, but not simpler

Quote: A. Einstein

NASA	↔	esa
Earth Science Division	↔	Earth Observation Programme Directorate (D/EOP)
ESTO EARTH SCIENCE TECHNOLOGY OFFICE	↔	Coordinated EOP & Corporate ESA Technology programmes
Decadal Strategy for EO from space (Survey)	↔	Living Planet Programme
NOAA	↔	EUMETSAT
USGS	↔	No equivalent

reality is not as simple at the Table above !

Contents:

- Main ESA's EO programme lines
- Small Sats
- EO technology drivers & examples

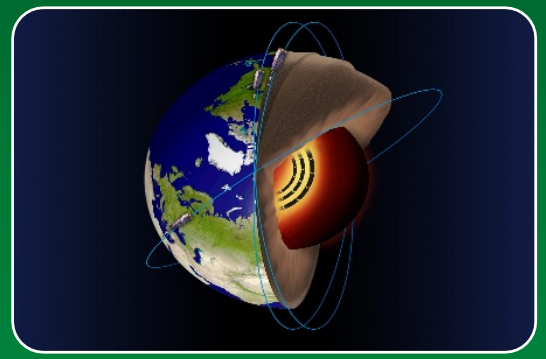
Devising Earth Observation Missions

Overall Feature: User Driven (Living Planet Programme)

Research Missions

Member States

Earth Explorers & Scouts



Ideas from science partners in Member States (Open Calls)

Earth Watch Missions

EU

Copernicus (Sentinels)

EUMETSAT

Meteorology Climatology

Industry

InCubed

- User needs from institutional partners & industry
- Mission definition by ESA with industry, partners & users

A successful Track-Record

ESA-Developed Earth Observation Missions

Satellites

15 in operation

25 under development

12 in preparation

2010

ERS-1

ERS-2

Envisat

Proba-1

SMOS

GOCE

CryoSat

2015

Meteosat 10 (MSG)

MetOp-B

Meteosat 11 (MSG)

Sentinel-1A

Sentinel-2A

Sentinel-1B

Sentinel-2B

Proba-V

Swarm

Sentinel-3A

Sentinel-3B

Sentinel-5P

Aeolus

Seosat

Sentinel-6A

Sentinel-2C

Sentinel-1C

EarthCARE

Sentinel-3C

Biomass

Sentinel-1D

Sentinel-2D

Sentinel-3D

Sentinel-6B

FLEX

2020

MetOp-C

Sentinel-5A MetOp-SG-A1

MetOp-SG-B1

MTG-I

Sentinel-4A MTG-S1

2025

MTG-I2

Sentinel-5B MetOp-SG-A2

MTG-I3

MetOp-SG-B2

2030

FORUM

New Sentinels (TBC):
CO2M, LSTM, CIMR, CRISTAL, CHIME, ROSE-L
Evolution:
Sentinel-1/2/3topo/3optical/6 NG

EE10
Harmony, Hydroterra, Daedalus

EE-11

Science esa

Copernicus

Meteorology EUMETSAT

Scouts (small sats)

Cooperation (NASA): Mass Change / Gravity Constellation

Earth Explorer 9: FORUM (in Phase B1)

Key for climate change science

Radiation emitted
by the Earth into space

First ever FTS instrument
covering the far IR
6-100 µm

FTS: Fourier Transform Spectrometer

FORUM (EE-9) Phase A/B1

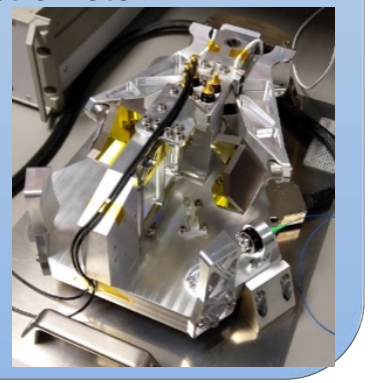
Optical instrument & pre-developments (x 2 parallel studies)

Interferometer mechanism
double pendulum Fourier Transform Spectrometer

- Breadboard
- Micro-vibration test
- Speed stability test

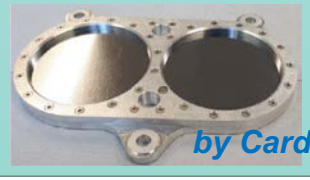
by OHB (DE)

by OHB (DE)



Beamsplitter
diamond plate, Mylar/Polypropylene pellicles covering 6-100 um spectral range

by ABB (CA)



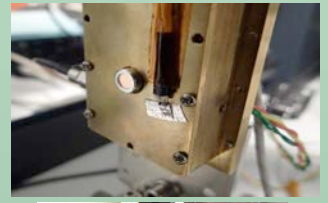
by Cardiff Univ. (UK)

- Manufacturing
- Coating
- WaveFront Error, Transmission
- Thermal cycling

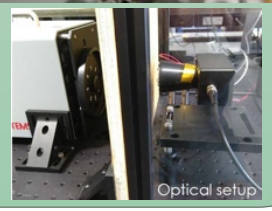
Detection chain
pyroelectric DLATGS at ambient temperature

- Breadboard
- Noise measurement
- Detector response

by Airbus (FR)

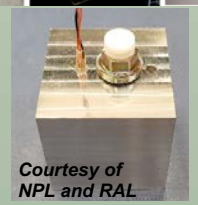


by OHB (FR)



Blackbody
black coatings test in FORUM spectral range 6-100 um

by MICOS (CH) and PTB (DE)



Courtesy of NPL and RAL

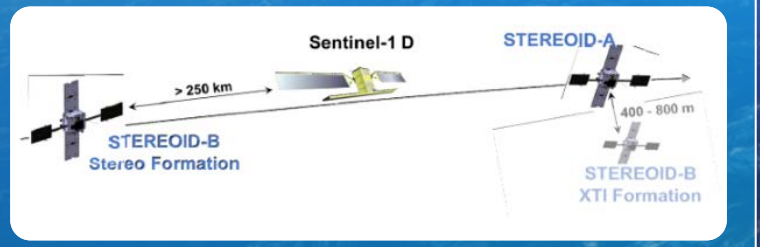
- Coating choice
- Emissivity test
- Environmental tests
- Phase change cell

Earth Explorer 10 – 3 Candidates in Phase 0 (until end 2020)
Launch ~2027/28

Harmony

Applications

- Cryosphere
- Oceanography
- Geosphere



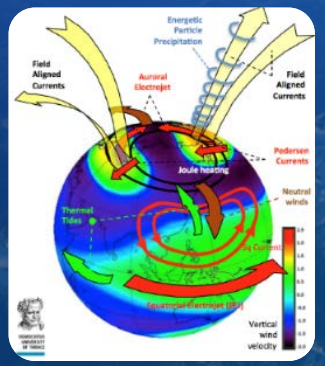
C-band Bistatic SAR:
Passive followers of Sentinel-1

Two <500 kg spacecraft

Daedalus

Explore lower thermosphere & Ionosphere:

- heating processes, Temp.
- composition structure



One smallsat in elliptical orbit at <200 km perigee

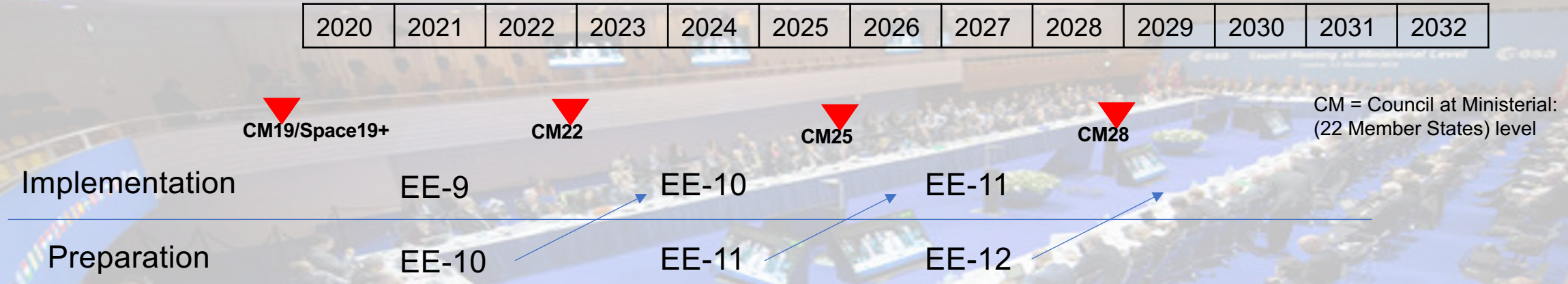
Hydroterra

Science on daily water cycle

- for weather forecasting,
- hydrology,
- mountain cryosphere

Geosynchronous
C-band SAR

Synchronisation to 3-years funding cycles



Contributions from US scientists: as proposers and in Mission Science Advisory Groups (MAGs)

Earth Explorer-11 Call (EE-11) currently open : https://eopro.esa.int/

- **Letter Of Intent Deadline** – Friday 18-Sep-2020

Aeolus-FO

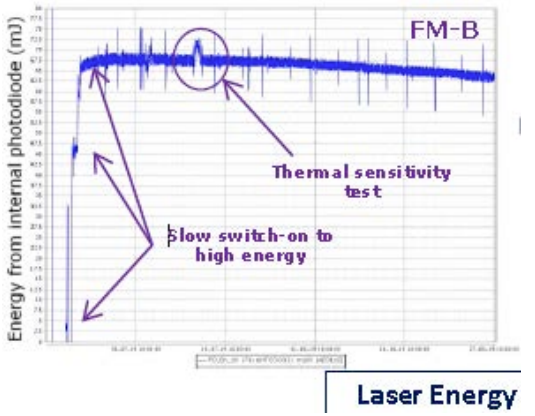
FO: Follow-On

Aeolus data assimilated in ECMWF operational environment

(in Jan. 2020 : i.e. < 1.5 yrs after launch)

Many Lessons Learned from ALADIN (1st Doppler wind lidar, in UV)

- Early
  - Procurement of ”pressurized” instrument
  - Definition of Testing approach (vacuum, thermal, lifetime, OGSE)
- Change to redundant FM-B (~10 months after launch)
- airborne campaigns, more TM, oscillator alignment, materials



Following EUMETSAT Council interest in Aeolus Follow-on

→ESA is initiating preparatory activities on the most critical items

Activity	Tender type
1 x Detector for Wind lidar (EM)	Teledyne e2v (UK)
2 x Transmitter Laser Assembly –(EM)	Fraunhofer ILT (DE) , and Leonardo (IT)
1 x Instrument consolidation study	Airbus (FR)

Mission of Opportunity for ESA-NASA cooperation: on Mass Change / Gravity Constellation

Start Phase A for a Next Generation Gravity Mission – NGGM

- GRACE II + NGGM joint return > sum of the 2 missions

Two satellite pairs in '**Bender formation**'

- 1 pair near-polar + 1 pair high-inclination (~ 70 deg)
- In-line formation, 100 km sat-to-sat distance

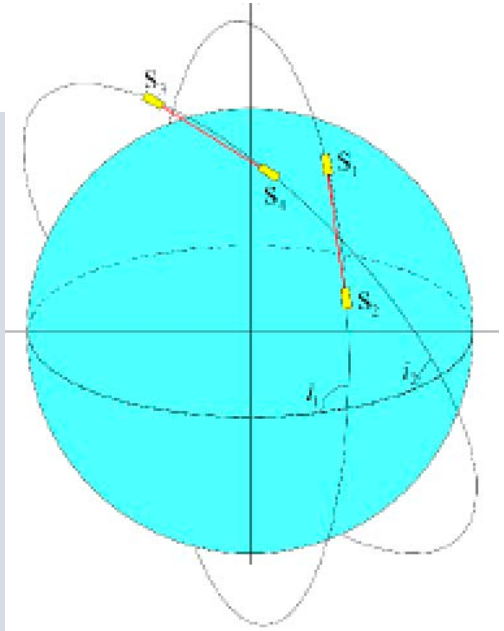
7-yr (11-yr goal) lifetime at constant altitude

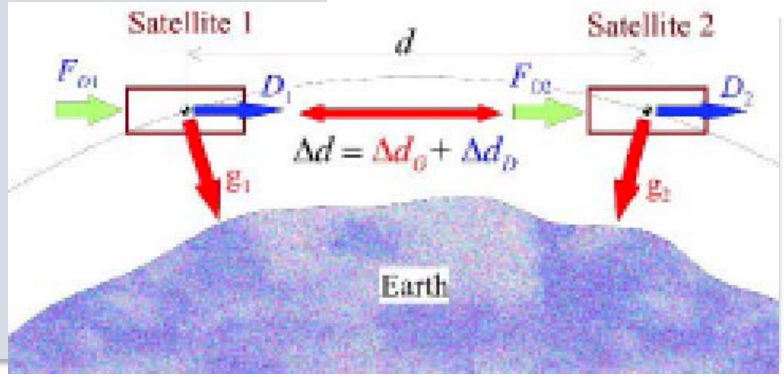
- ~340 km: minimum altitude compatible with on-board resources

Time-variable gravity, 1-mm accurate geoid

Sat. Laser ranging + accelerometry + POD (GNSS)

- Laser Ranging with 2 options: enhanced transponder vs retroreflector



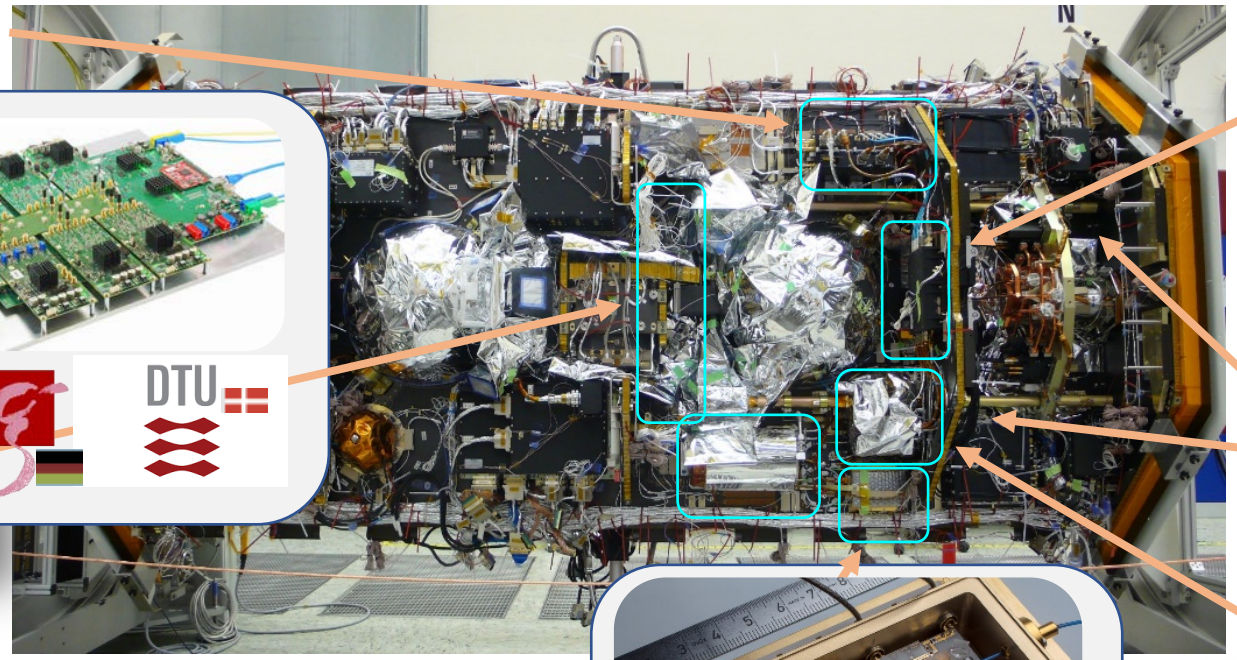


Laser Ranging Instrument Units

[Source: Airbus/JPL]

JPL

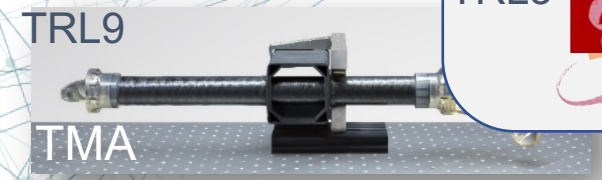
TRL9



TRL3

DTU

TRL9



HENSOLDT

TRL9

Ball

Photline

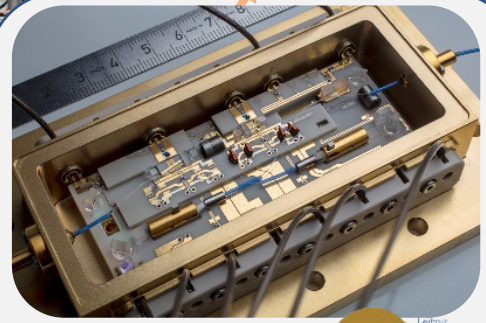
TRL9

TESAT SPACECOM

TRL4

NPL National Physical Laboratory

TRL4



FBH Ferdinand Braun Institut

TRL7

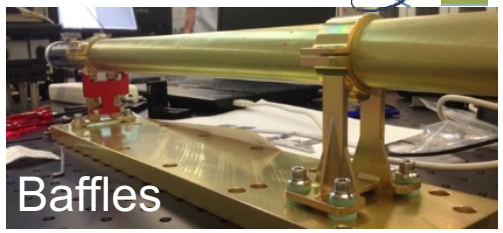
Fraunhofer ILT

TRL9

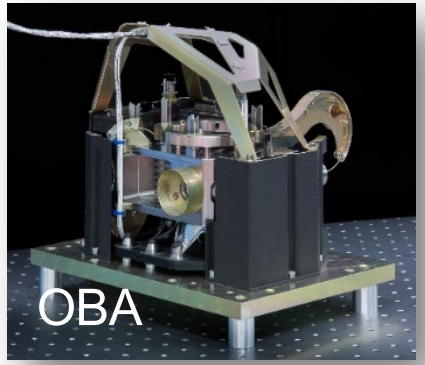
APCON

DLR

TRL9

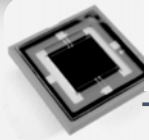


TRL9



AIRBUS DEFENCE & SPACE

DLR



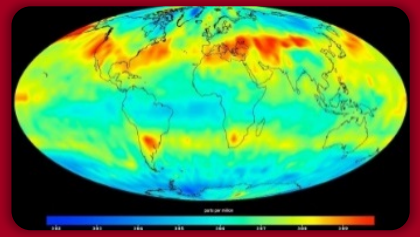
ThalesAlenia Space

TRL3->5

Copernicus new Sentinels

Phase B1 completed in Q2-2020

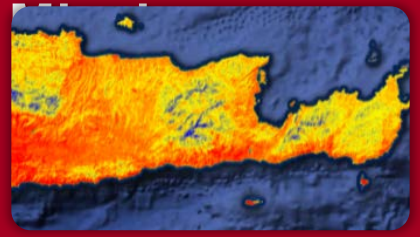
CO2M - Anthropogenic CO_2 Monitoring



Causes of Climate Change

Imaging spectrometer

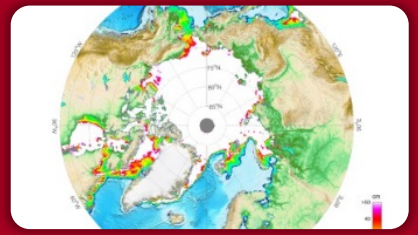
LSTM – Land Surface Temperature Mission



Agriculture & Water Productivity

TIR multispectral imager

CIMR – Passive Microwave Radiometer

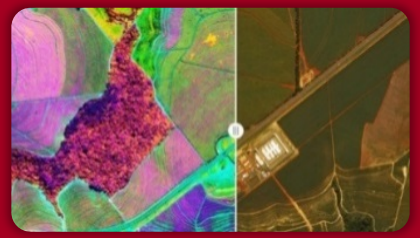


Sea Surface Temp.& Ice Concentration

Imaging (L to Ka-band)

Radiometer

CHIME – Hyperspectral Imaging Mission



Food Sec, Soil, Minerals, Biodiversity

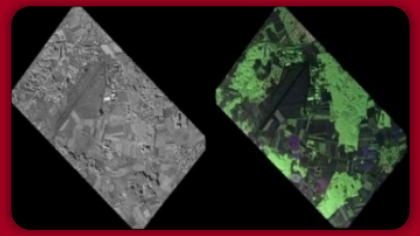
Hyperspectral VNIR-SWIR imaging spectrometer

CRISTAL – Polar Ice & Snow Topography

Effects of Climate Change

Altimeter

ROSE-L – L-band SAR Mission



Vegetation& Ground Motion & Moisture

L-band SAR

Sentinel Evolution / Next Generation (NG)

Data continuity as a driver, but with better performance + new products

S1-NG trade-offs

Procurement to start end 2020 / 2021 :

- Phase A/B1:
  - S1-1 NG (C-band SAR)
  - S3-NG Topographic
  - S6-NG (S6-a was renamed S6-Mike Freilich, due to long ESA-NASA collaboration)

- Phase 0 :
  - S2-NG Optical Instrument - with MSI-NG
  - S3-NG Optical - i.e. with OLCI-NG & SLSTR-NG

    (synergies with Landsat NG , LSTM and CHIME)

EO Technology drivers
&
Examples

ESA's EO Technology drivers

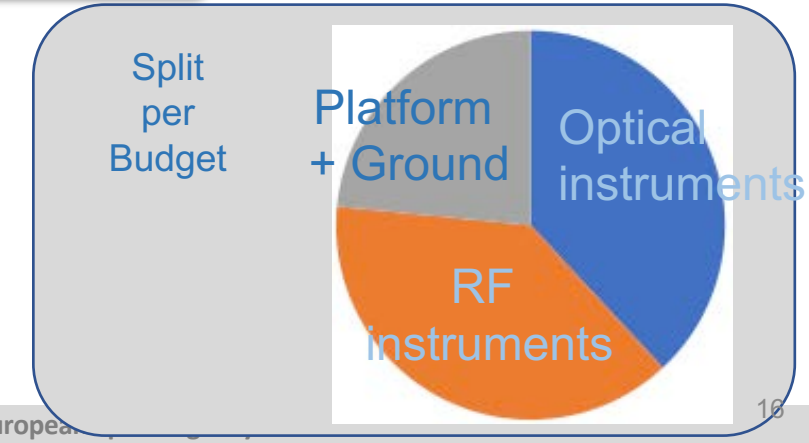
Higher performance / cost ratio

- **New Measurements/instruments** (enabler)
  - **Higher spatial, temporal, radiometric** resolution
- Lower recurring **cost**
  - Evolution to **Platform Standardisation** & multi source suppliers
  - **Spin-in** techno: e.g. COTS
  - Lifetime & flexibility (FPGAs)
- **Big Data** (AI enabler) & Data continuity

Miniaturisation and constellations

- More **autonomous** platform & operations & synchronisation
- **Distributed** Ground Segment

Not limited to LEO: also HEO & GEO orbits relevant for EO.



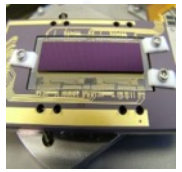
ESA's EOP technology across ESA programmes and beyond ESA missions

In Instruments (from components to full Models)

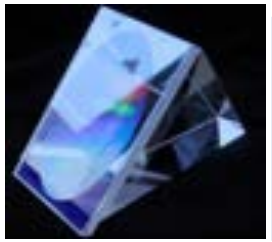
like ESTO ACT

like ESTO IIP

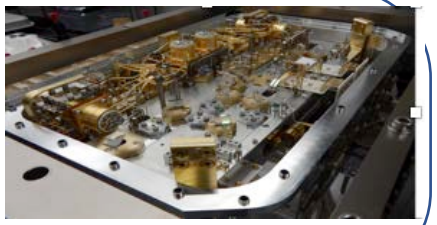
SWIR detector
→ APEX(airborne), Sent-2, PRISMA, Sent-5p, HYPER-X,..



SWIR Gratings
→ Designed for CarbonSat (EE-8) and ACADIA
→ Candidate for CO2M



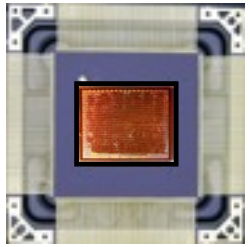
FULAS (Laser source)
→ Candidate for Aeolus-FO Baseline for Merlin (CNES, DLR)



In Platform & Instrument

accelerometers
→ CHAMP & GRACE GOCE, candidate NGGM

AGGA ASIC
GPS/Galileo receiv. all Sentinels, MetOp-SG Radio Occ. Earth Explorers, commercial



FEEP Thrusters
candidate NGGM
→ Iceye (NewSpace)

K-band downlink
MetOp-SG, Copernicus HPCM, commercial

Also in Airborne campaigns

like ESTO AITT

- Aeolus collocations
- ACADIA (by OHB) for CO2M

and Big Data

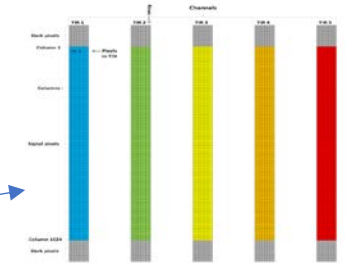
like ESTO AIST

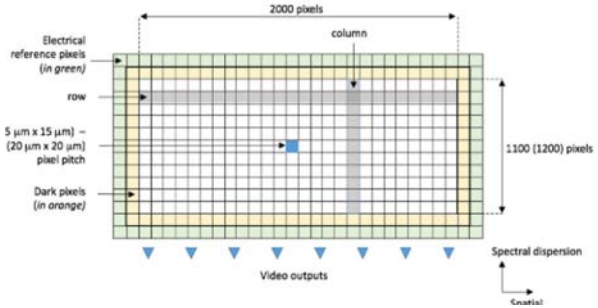
- Acquisition / Organization / Analysis / Information
- Φ-lab

Pre-development for new Sentinels

DETECTORS:

- **TIR** cryo-cooled for the High Spatio-Temporal Res. **LSTM** Mission ➔ AIM (DE)
- VIS-NIR-SWIR for HyperSpectral Imaging Mission (**CHIME**) ➔ AIM (DE)
- VIS-NIR-**SWIR** for the Anthropogenic **CO2** Monitoring Mission ➔ Lynred (FR)

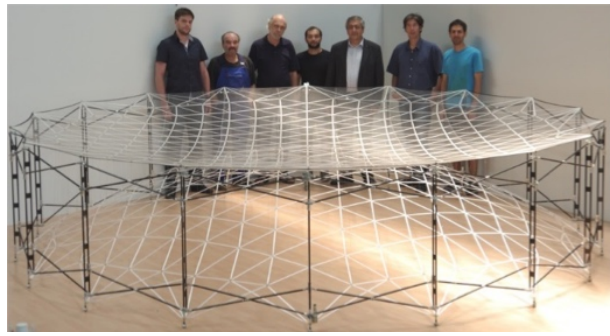




Large Reflector Antenna for low frequency SAR and imaging microwave radiometer ➔ HPS (DE)

(target: CIMR + ROSE-L , benefitting Hydroterra, and S1-NG too)

5 m BB



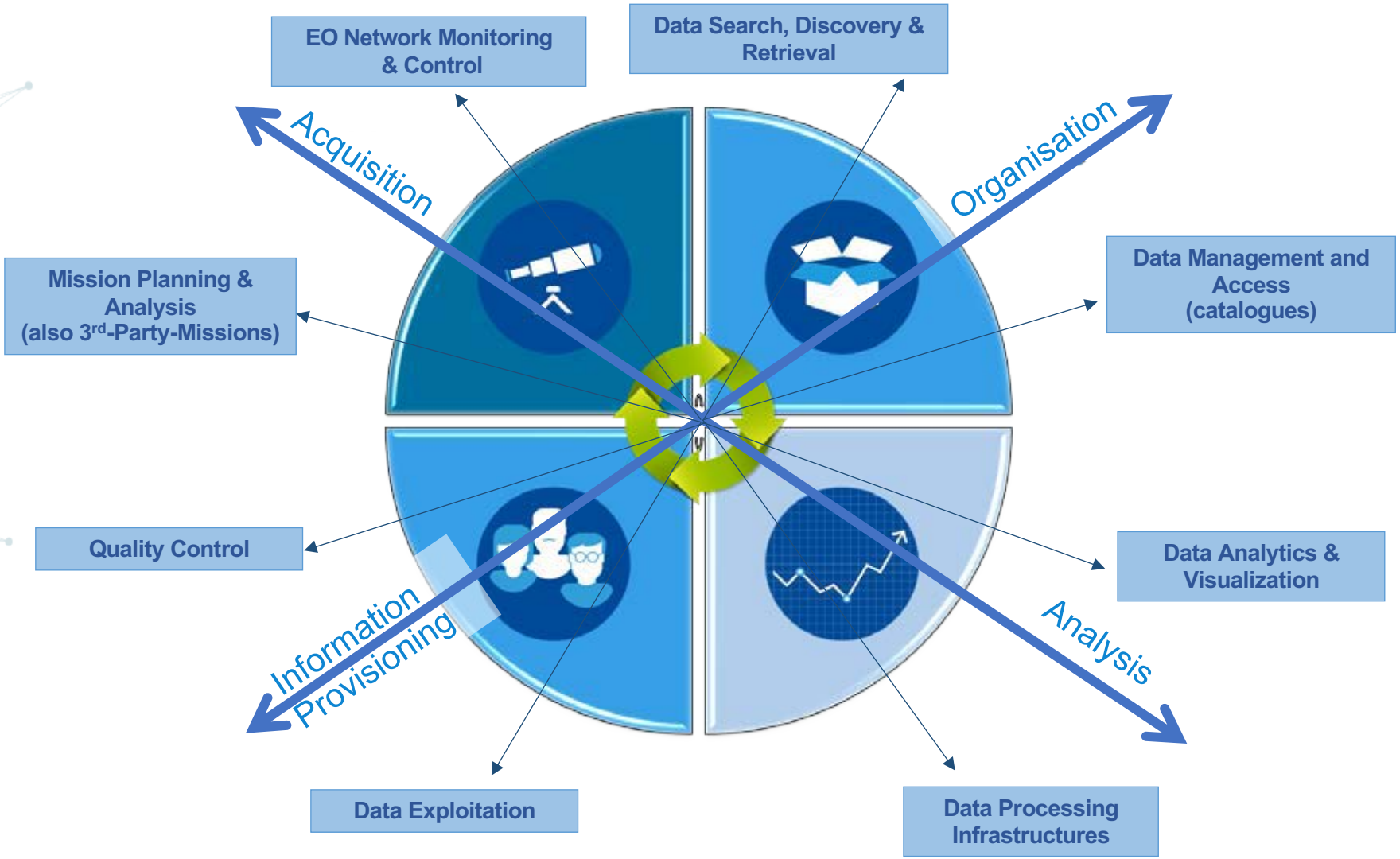
Instrument pre-developments: **CO2M** & **CRISTAL MW Radiometer**

Data lifecycle :
Reference framework

BIG DATA &

like AIST

Only Copernicus > 250 TB / day



EO Small Sats

Miniaturisation

Revisit time ⬇

Three lines:

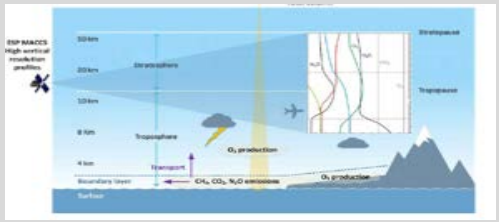
- **Scouts**
- **InCubed**
- **Φ-sat(s)**

Scout Missions

- Driven by EO application or science
- Open data policy (as all other ESA EO programmes)
- Selected already with TRL, SRL ≥ 4

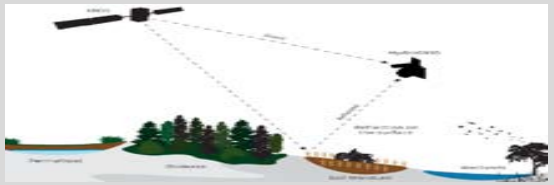
4 concepts in feasibility evaluation (out of 17 proposed)

ESP-MACCS



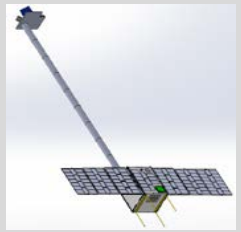
3 x 8U Cubesats
Earth System processes

Hydro-GNSS



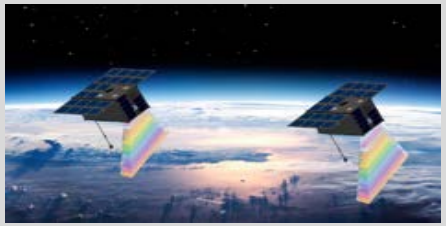
45 kg mini Sat with GNSS-R
Biomass, soil moisture, ice

NanoMagSat



4 x 12U Cubesat
Nano magnetic field

TANGO



2 x 16U Cubesat
Anthropogenic greenhouse

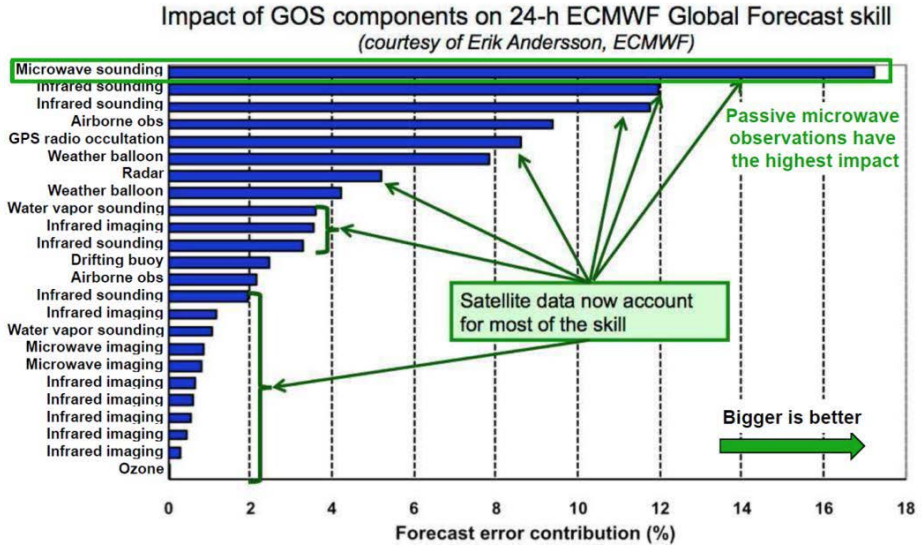
1 or 2 to be implemented (30 M€ each – industrial development cost)

- Selection in Q4-2020
- Launch planned in the 1st half of 2024 (3 years development)

Artic Weather Satellite (AWS)

Microwave sounding – miniaturized wrt MWS in MetOp-SG

Part of Earth Watch Programme,
driven by Sweden, but 12 countries subscribed



Same budget range (~30 M€) as Scouts

- driven by Sweden : Omnisys Instrument **(already high TRL)**
- incl. development, launch, ≥ 1 year operations

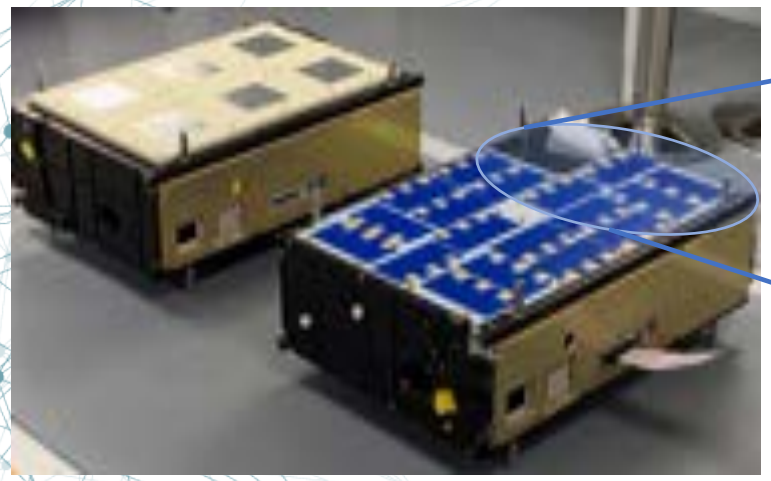
Not as miniaturized as NASA ESTO Tempest-T,
but with other system advantages and frequencies :

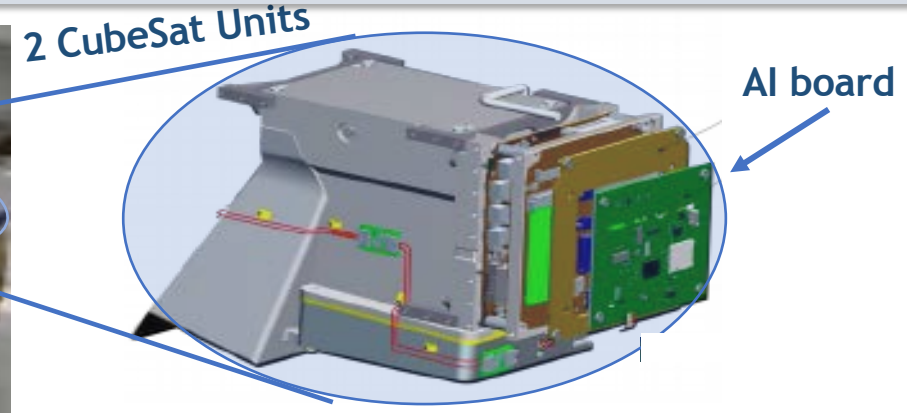
- 54 GHz, 89 GHz, 166 GHz, 183 GHz and 325 GHz bands (TBC) using four sets of feedhorns

New Space : Φ-sat(s)

FFScat from **Copernicus Master Challenge** – Vega PoC SSMS Launch imminent (delayed due to CoVid-19)
with 2 nanosats:

- 6U CubeSat with GNSS-R + L-band Radiometer
- 6U CubeSat with HyperScout + **Φ-Sat-1** experiment (AI for Cloud Detection → data reduction)





HyperScout-2
Hyperspectral
+ TIR + AI added

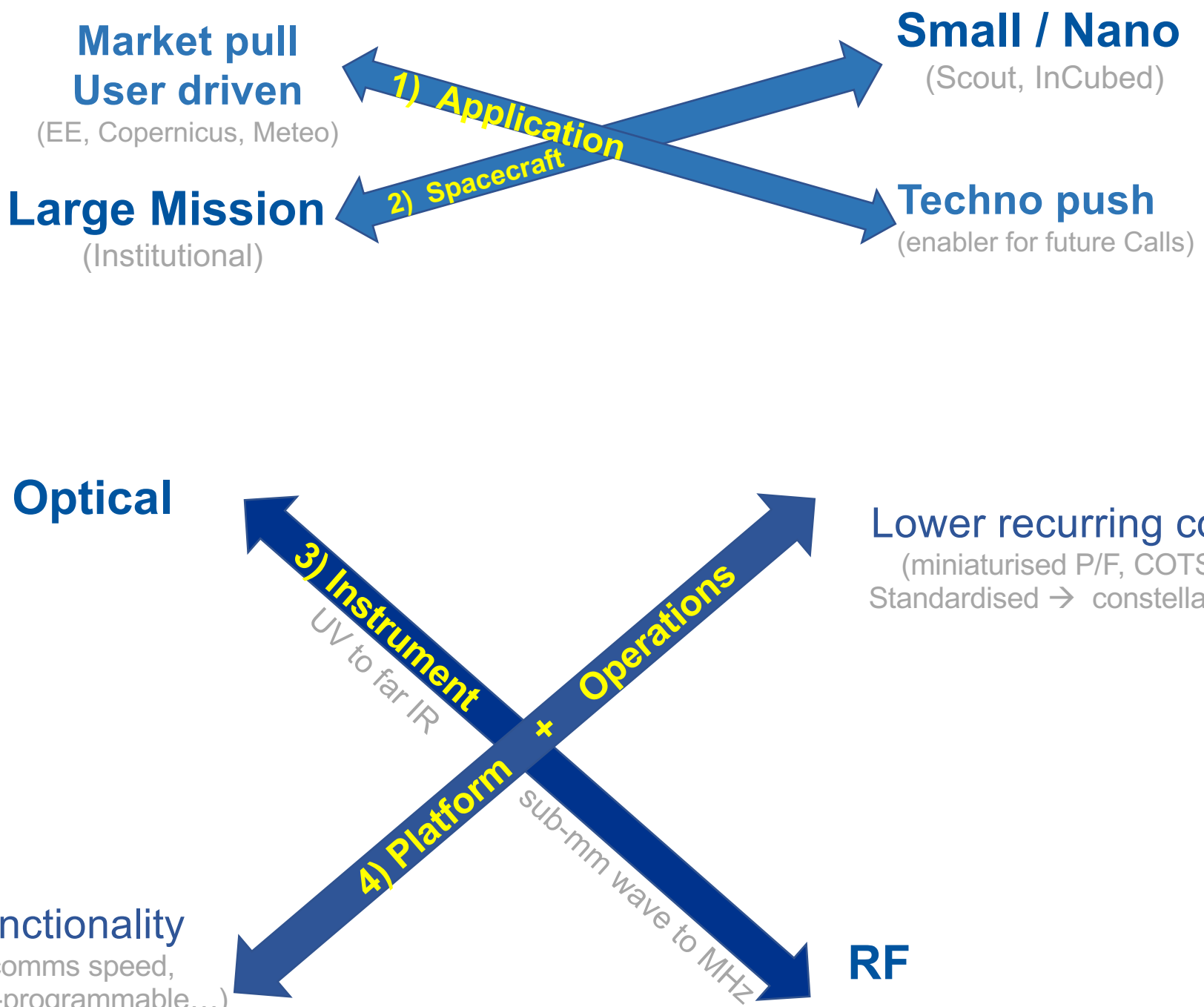
like Invest

Call for Φ-sat-2 (Evaluation of 17 proposals just completed)
http://blogs.esa.int/philab/

- Artificial Intelligence required (e.g. autonomy, detection/alarm, …)
- Kick Off : In fall 2020
- Feasibility Phase (4 months)
- Development Phase (1 year) → Launch planned in 2022
- ≥ 1 year operation

Conclusion in 4D

ESA EO Technology



More collaboration

We share visions

- Earth Science @ NASA & Earth Observation @ ESA

Well established: Data exchanges & Campaigns & US / European scientist exchanges (Mission Advisory Groups)

Collaboration in new missions :

- NGGM & MCDO on Mass Change
- BIOMASS antenna reflector – from USA
- Sentinel-6-Mike Freilich & Sentinel-6b : US radiometer + RO instrument from USA
- New Sentinels: CRISTAL, CIMR, CHIME, LSTM, ROSE-L,
- Sentinel-2 NG & Landsat NeXT
- Many possibilities in different forms : Convoys, formations, …

Science is the driver, technology is the enabler (quote from G. Komar)

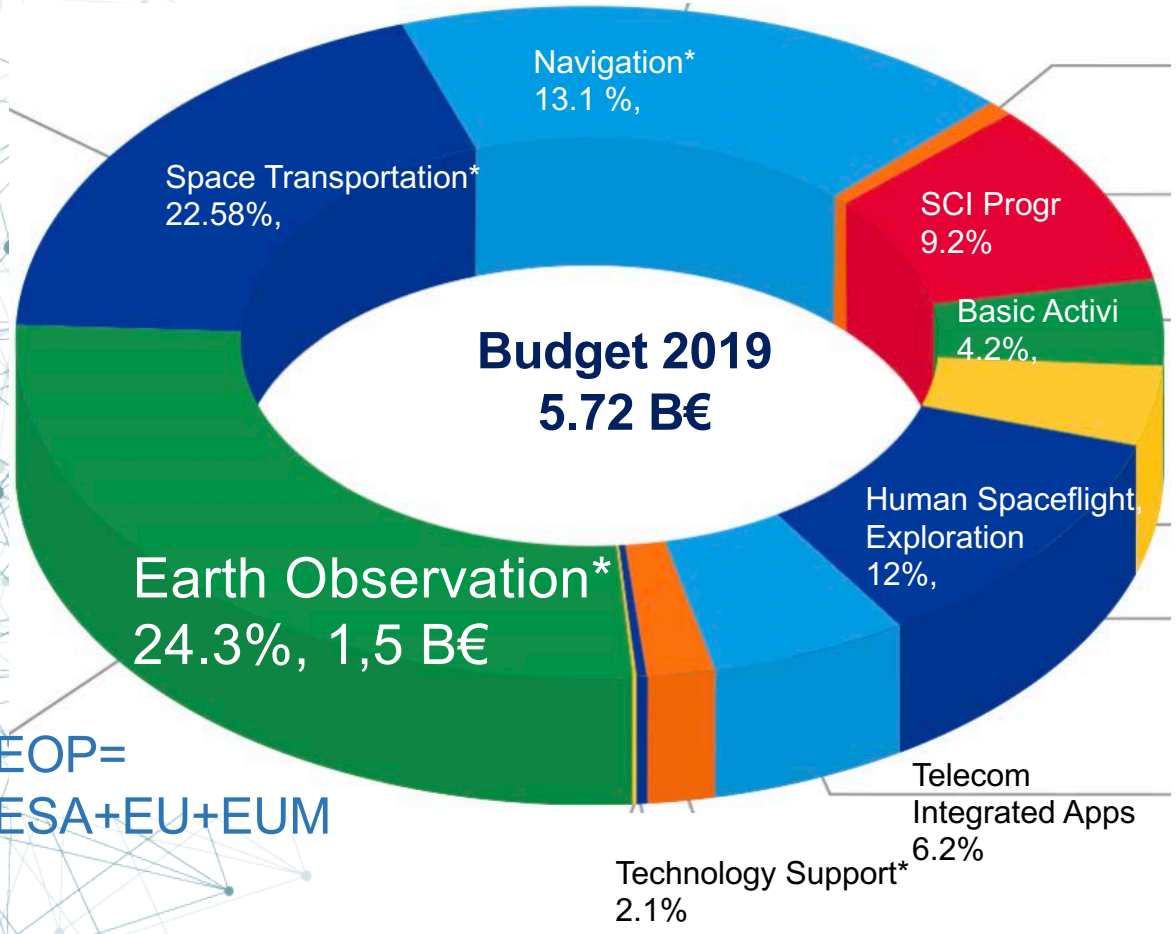
- ESTF is very inspiring - Thank you !
- Open ESA EOP and Technology workshops (at ESTEC, ESRIN, …)
- Other possibilities – we're open for discussion

Room for increasing collaboration !

Contact : Josep.Rosello@esa.int

Back Up Slides

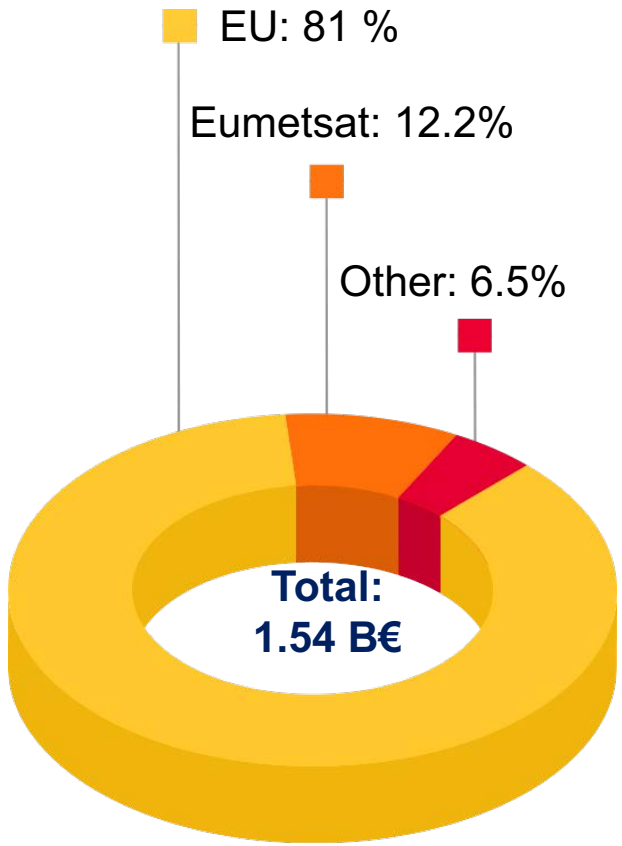
ESA budget for 2019: by domain

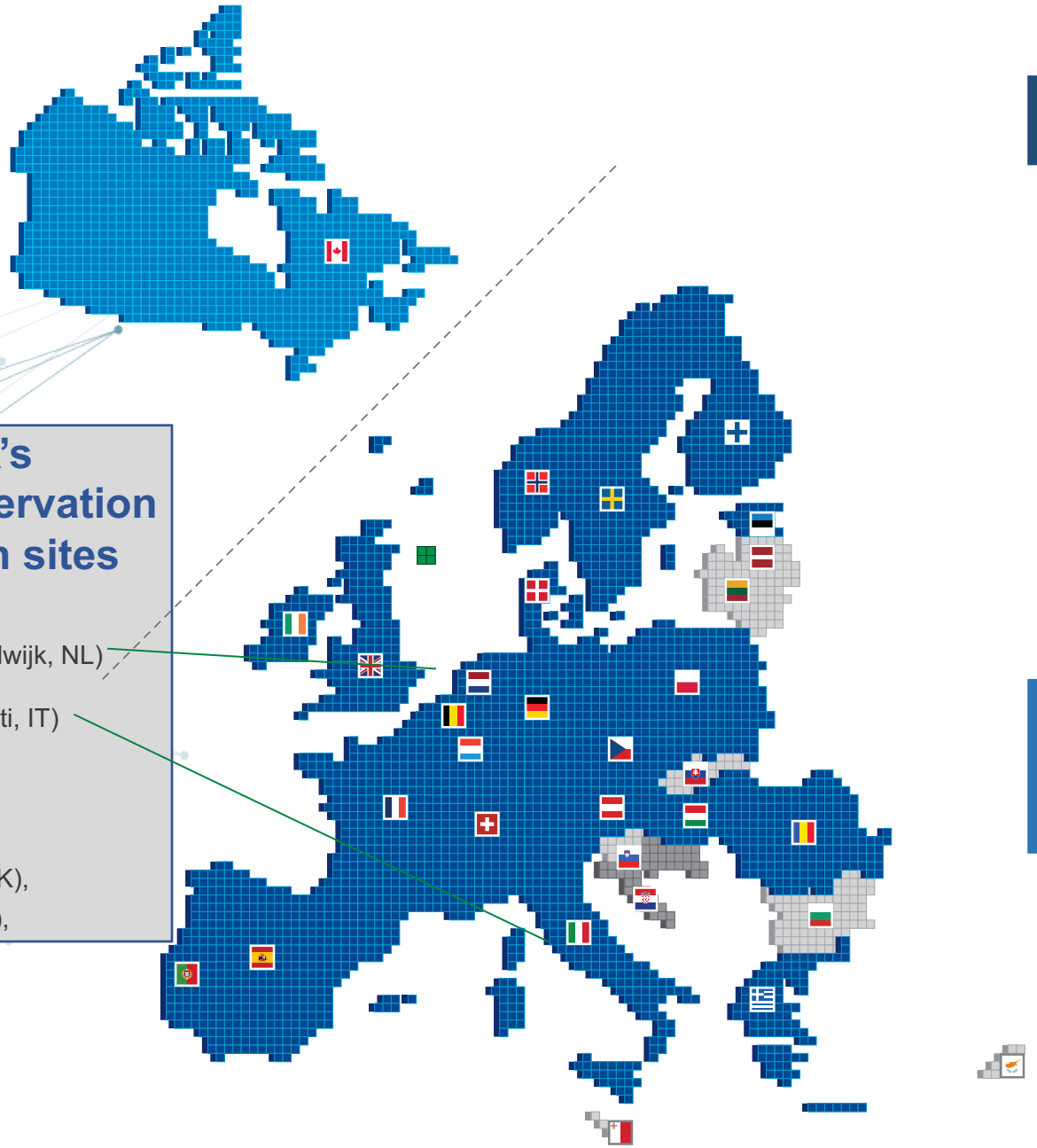


Total ESA (2019):

4.18 B€ from ESA Member States

+ 1.54 B€ other income





ESA's Earth Observation in 2 main sites

ESTEC (Noordwijk, NL)

ESRIN (Frascati, IT)

and 3 more

HQ (Paris, FR)
ECSAT(Harwell, UK),
EBO (Brussels, BE),

ESA's 22 Member States

All EU members, except two (*)

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

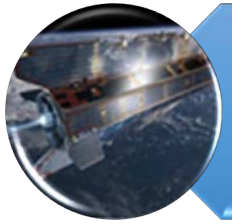
Cooperation Agreements

7 other European States & Canada

Research missions: Earth Explorers

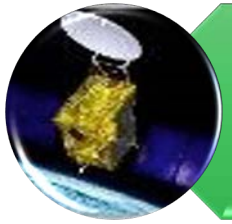
NB: Research missions include also Missions of Opportunity (e.g. potential cooperation ESA-NASA for gravity monitoring)

Core Missions

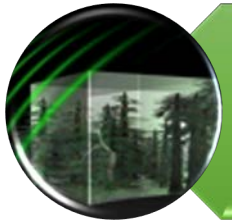


GOCE (2009–13)
Earth's gravity field

ADM-Aeolus (2018-)
global winds



EarthCARE (2022)
Earth's clouds, aerosols and radiation (ESA/JAXA)

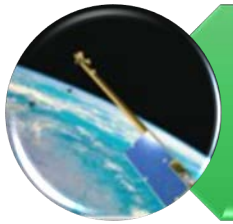


Biomass (2022)
Earth's carbon cycle

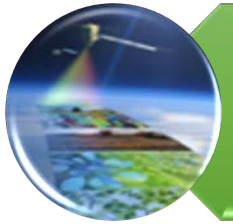
Opportunity & Fast Track

SMOS (2009–)
Earth's water cycle

CryoSat-2 (2010–)
polar ice elevation



Swarm (2013–)
three satellites,
Earth's magnetic field



FLEX (2024)
photosynthesis

Copernicus Sentinel Satellites

Sentinel 1 (A/B/C/D)
SAR Imaging

All weather, day/night applications, interferometry

Sentinel 2 (A/B/C/D)
Multispectral Imaging

Land applications: urban, forest, agriculture, …
Continuity of Landsat, SPOT

Sentinel 3 (A/B/C/D)
Ocean & Global Land Monitoring

Wide-swath ocean colour, vegetation, sea/land surface temperature, altimetry

Sentinel 4 (A/B)
Geostationary Atmospheric

Atmospheric composition monitoring, pollution; instrument on MTG satellites

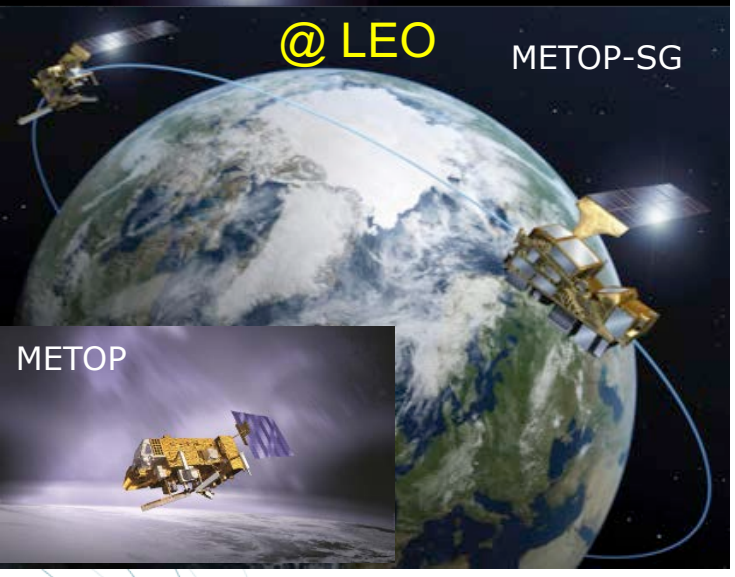
Sentinel 5 (A/B/C) & Precursor
Low-Orbit Atmospheric

Atmospheric composition monitoring; instrument on MetOp-SG satellites

Sentinel 6
Jason CS (A/B)

Altimetry reference mission

Meteorology missions



Developed for, and in partnership with, EUMETSAT. Europe's contribution to the World Meteo. Org. (WMO)'s space-based Global Observing System (GSO):

Meteosat

- **Second Generation** (2002, 2005, 2012, 2015) – series of 4 satellites.
- **Third Generation** (2023–) – two series providing imagery (4 satellites) and atmospheric sounding (2 satellites). MTG embarks the Sentinel-4 sensor

MetOp

- (2006, 2012, 2018) – series of 3 satellites.
- **Second Generation** (2023–) - two series x 3 satellites in each series, continuing and enhancing observations. MetOp-SG embark the Sentinel-5 sensor

ESA develops prototype satellites and procures recurrent satellites
EUMETSAT procures launchers and LEOP services and operates the satellites