

# The FLEX satellite mission, scientific objectives, and technical implementation, including the importance of airborne fluorescence, cal/val Scheme

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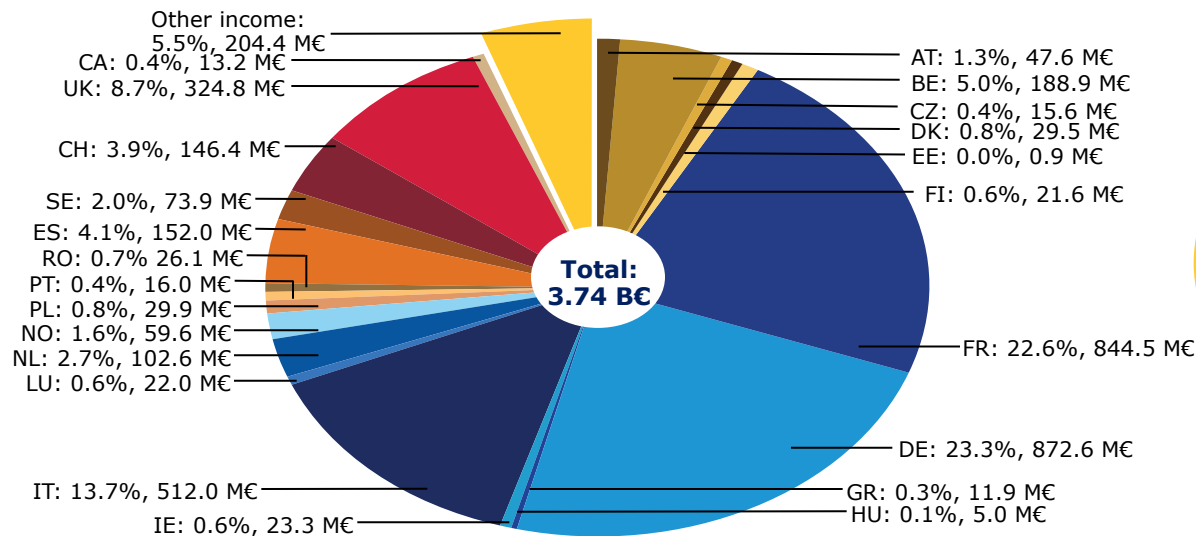
- Over 50 years of experience
- 22 Member States
- Eight sites/facilities in Europe, about 2200 staff
- 5.2 billion Euro budget (2016)
- Over 80 satellites designed, tested and operated in flight



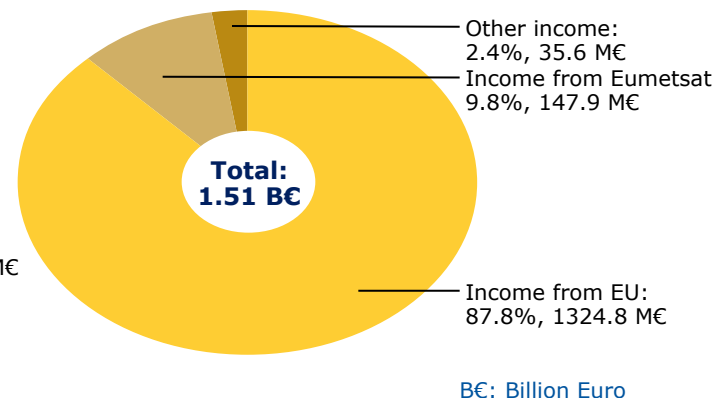
# ESA budget for 2016



## ESA Activities and Programmes



## Programmes implemented for other Institutional Partners



Total ESA budget  
for 2016: 5.25 B€



The European Union and ESA share a common aim: to strengthen Europe and benefit its citizens.

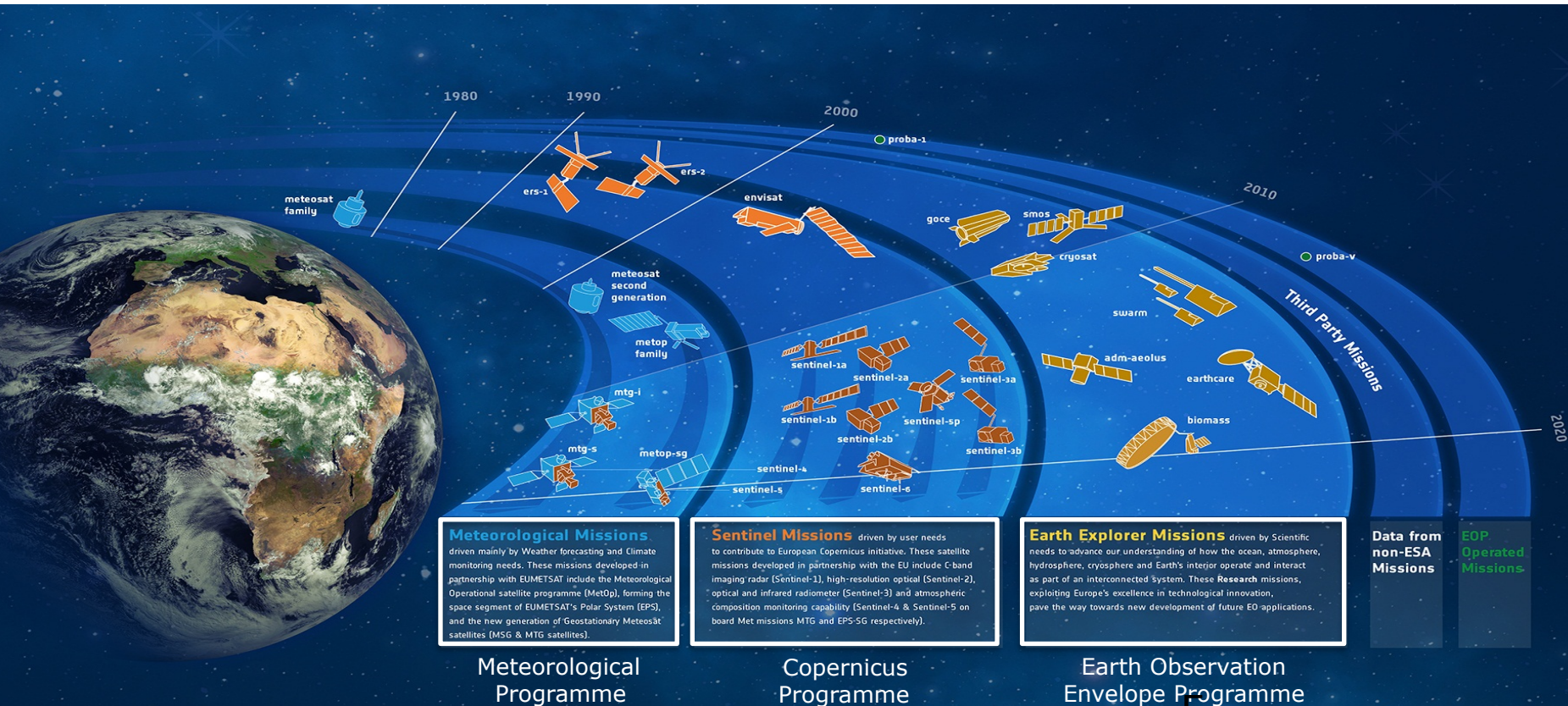
Closer ties and an increased cooperation between ESA and the EU bring substantial benefits to Europe by:

- guaranteeing Europe's full and unrestricted access to services provided by space systems for its policies,
- encouraging the increasing use of space to improve the lives of its citizens,
- increasing political visibility of space and taking full benefit from its economic and societal dimension.





# ESA Earth Observation Programmes

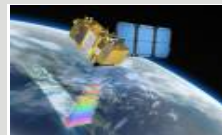


# Copernicus Dedicated Missions



## **Sentinel-1 (A/B/C/D) – SAR imaging**

All weather, day/night applications, interferometry



## **Sentinel-2 (A/B/C/D) – Multi-spectral imaging**

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



## **Sentinel-3 (A/B/C/D) – Ocean and global land monitoring**

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



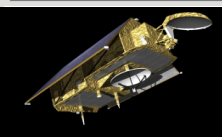
## **Sentinel-4 (A/B) – Geostationary atmospheric (on MTG)**

Atmospheric composition monitoring, trans-boundary pollution



## **Sentinel-5 Precursor/ Sentinel-5 (A/B/C) – Low-orbit atmospheric (on MetOp-SG Series A)**

Atmospheric composition monitoring



## **Sentinel-6 [Jason-CS] (A/B) – Low inclination altimetry**

Sea-level, wave height and marine wind speed



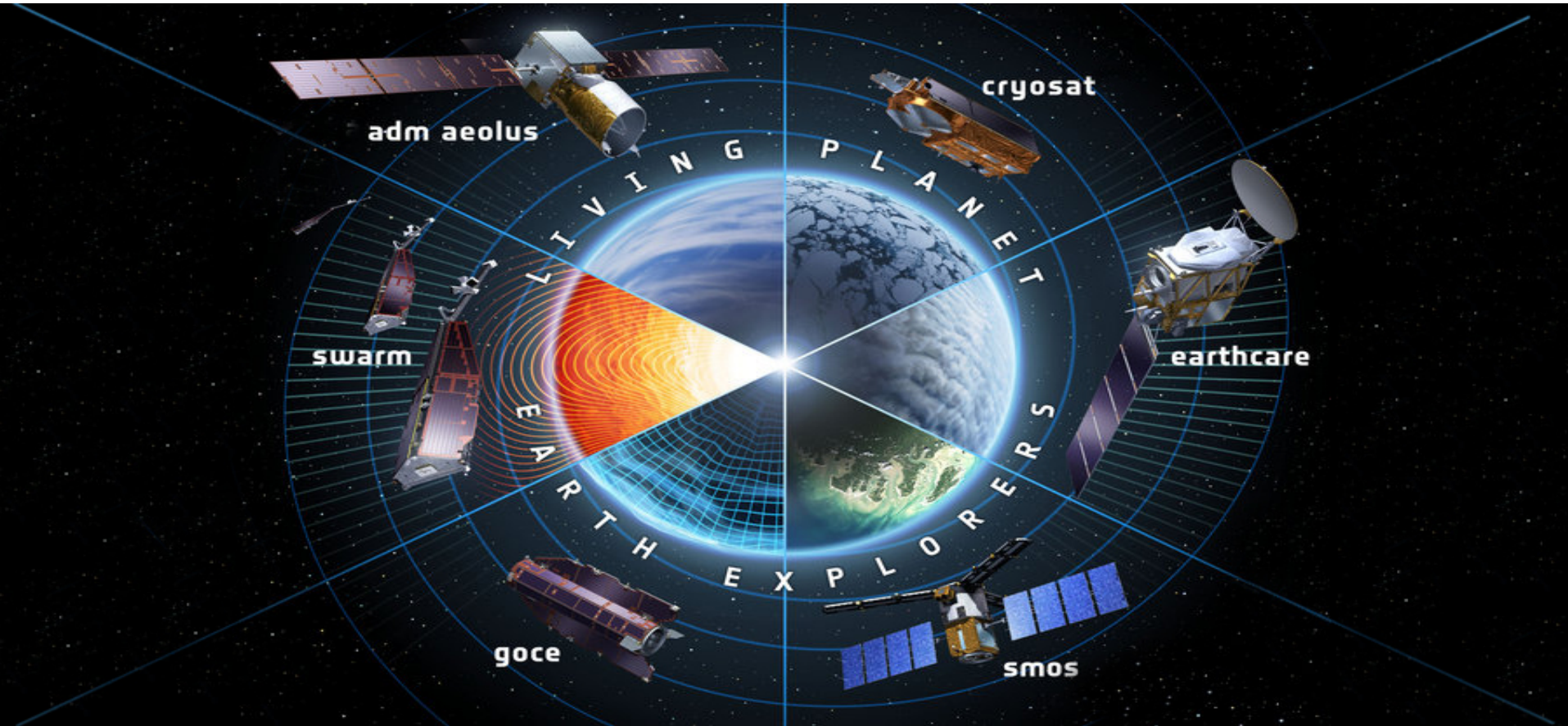
# Sentinel Expansion



- **Anthropogenic CO2 Monitoring Mission (S7)**
  - **High Spatio-Temporal Resolution Land Surface Temperature (LST) Monitoring Mission (S8)**
  - **Polar Ice and Snow Topographic Mission (S9)**
  - **Passive Microwave Imaging Mission (S9)**
  - **HyperSpectral Imaging Mission (S10)**
- 
- Preliminary observation requirements for the five above listed missions have been generated
  - These form the basis of the preparation of the ITT's for the Phases A/B1.



## Science – the Earth Explorers





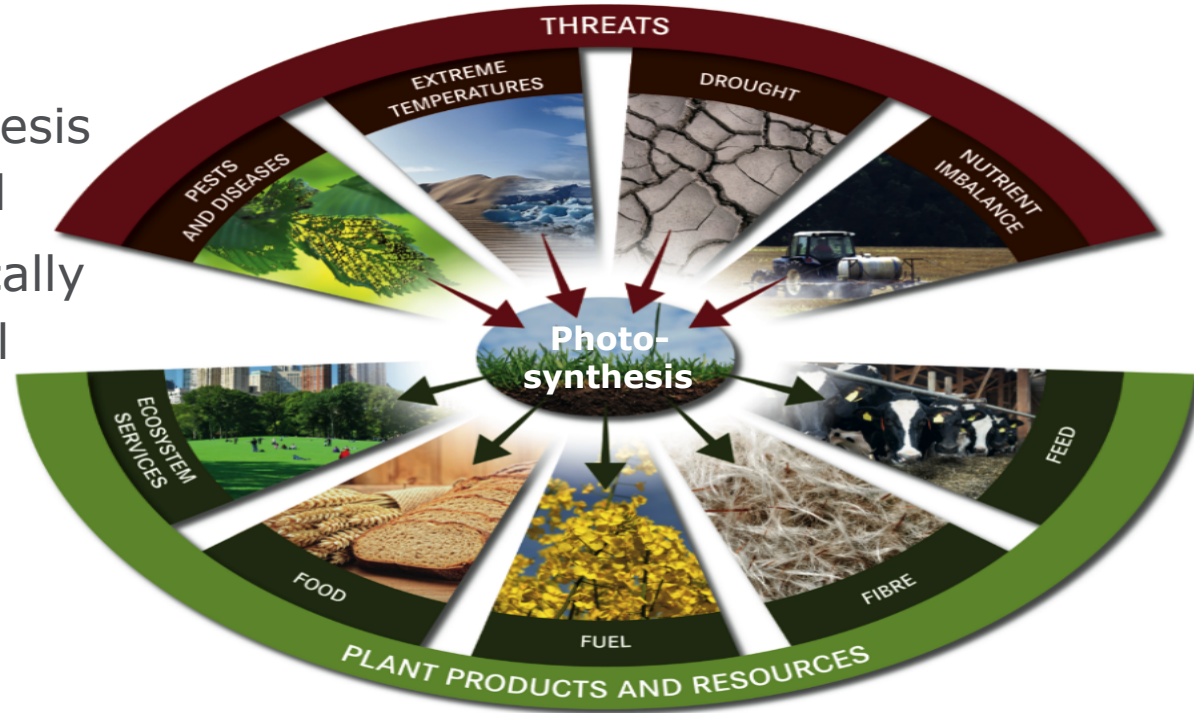
FLEX will quantify **actual photosynthetic activity** of terrestrial ecosystems

FLEX will provide **physiological indicators** for vegetation health status

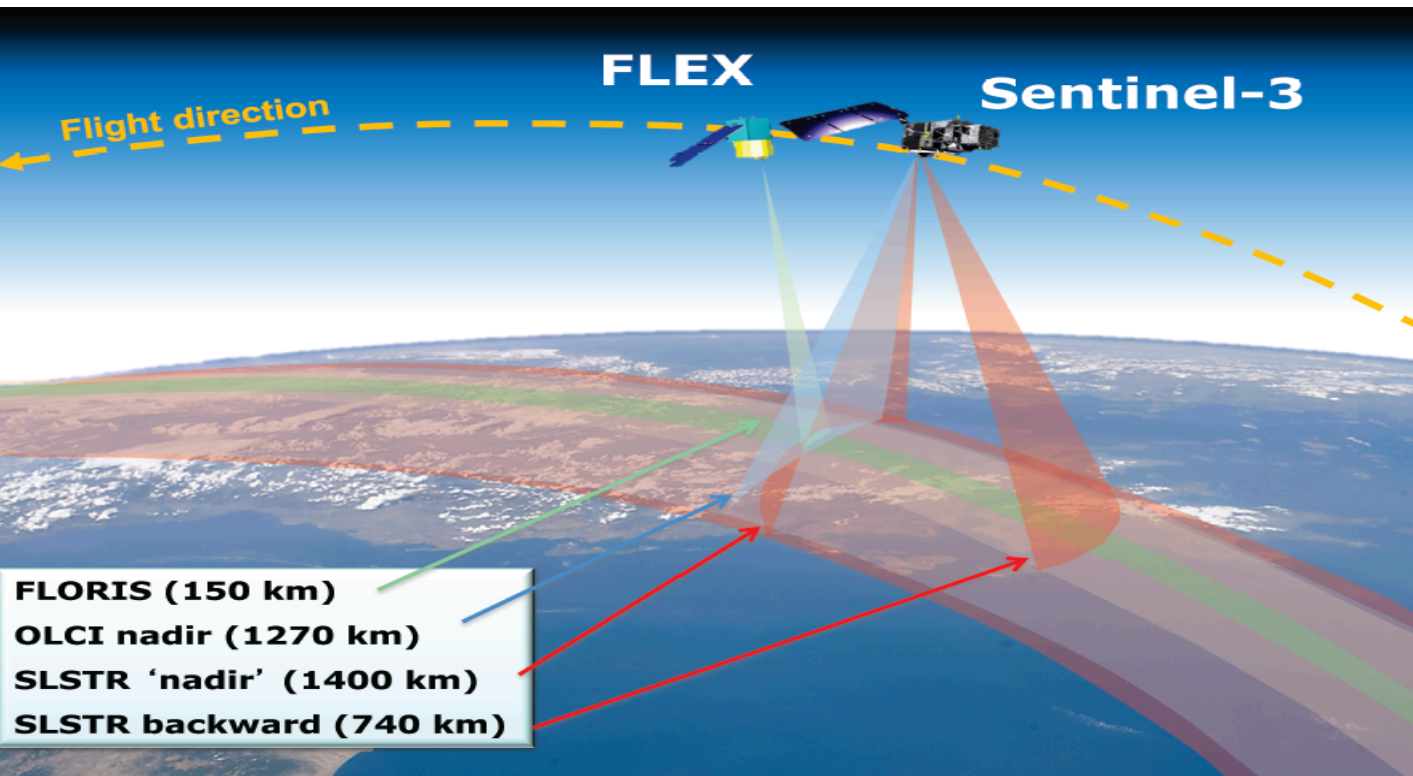
by direct measurements of **vegetation fluorescence** at relevant spatial scales

# Photosynthesis is the central metabolic process that determines plant productivity

- Efficiency of photosynthesis is dynamically regulated
- Photosynthesis dynamically adapts to environmental stress



# FLEX / S3 tandem concept



## Altitude:

~815 km

## Local solar time:

10:00 LTDN

## Temporal co-registration:

< 6s (G) / 15s (T)

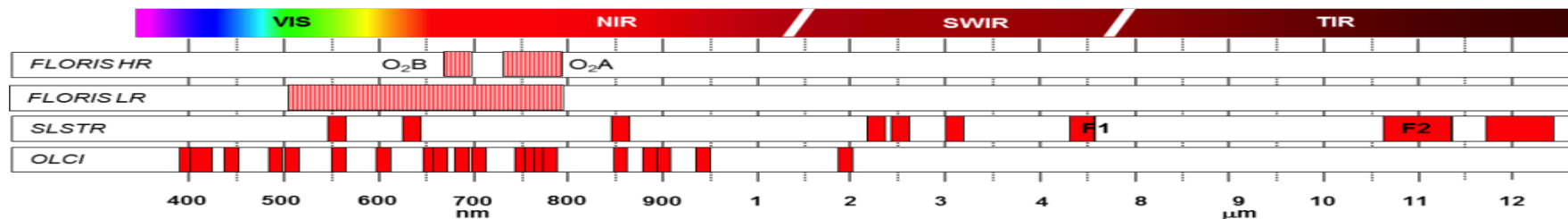
## Spatial coverage:

-56 to 75 degree latitude,  
land + major islands,  
coastal zones 50 km

## Spatial resolution:

0.09 km<sup>2</sup>

# FLORIS / S-3 band configurations



## FLORIS (300 m SSD\*)

- Fluorescence
- Photochemical Reflectance Changes
- Atmospheric correction
- True reflectance

\* Spatial Sampling Distance

## S-3 OLCI (300 m SSD)

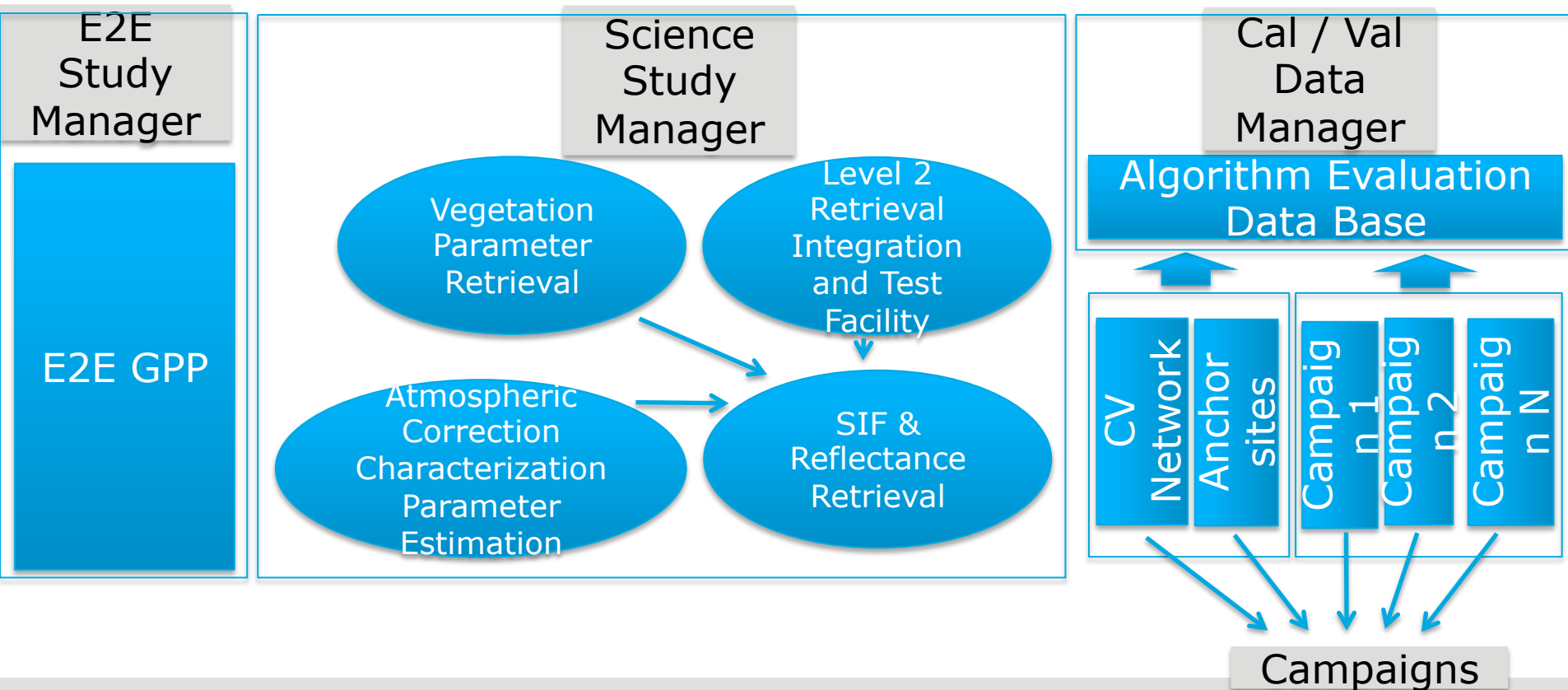
- Camera 4 – 250 km swath
- O1 to O21 (400 to 1000 nm)
  - Aerosols and water vapor
  - Biophysical variables (Chlorophyll, LAI, ...)
  - Reflectance
- O9 to O16 (510 to 779 nm)
  - Cross calibration
- Context information

## SLSTR (500m – 1 km SSD)

- S1 to S6 and F1/F2
  - Aerosols, surface reflectance
- SWIR S4 to S6
  - Reflectance
- TIR S7 to S9
  - Temperature
  - Clouds (cirrus)



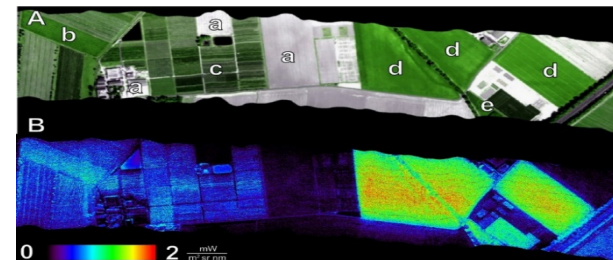
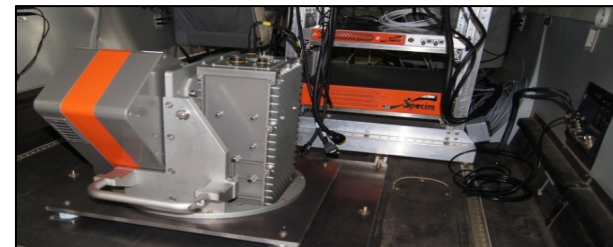
# FLEX Study Structure



# Airborne demonstrator *HyPlant*

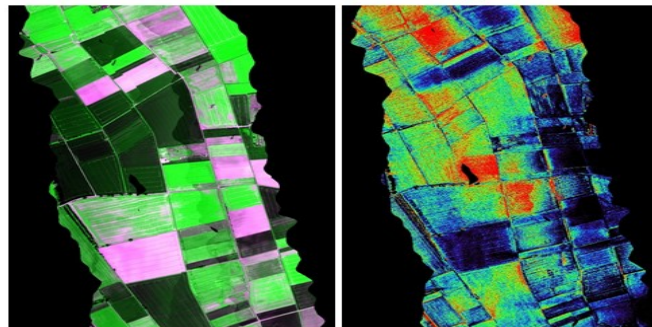


- *HyPlant*: Airborne imaging spectrometer with FLEX like characteristics
  - VIS/NIR module: 3 - 12 nm spectral res.
  - Fluorescence module: 0.25 nm spectral res.
  - 1 -3 meter spatial resolution
- 2012 – 2015: various campaigns around the world, including Germany, France, Finland, Czech Republic, Italy, Poland, and the USA

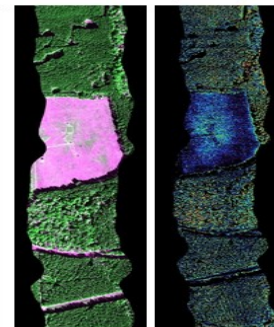


**Greatly improved understanding of the link between fluorescence and plant function**

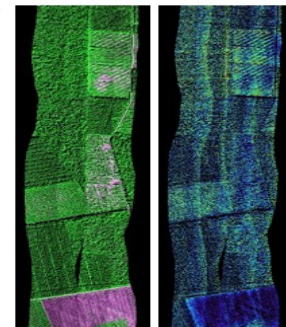
Agriculture  
Seelhausen (Germany)



Mixed Forest  
Duke (USA)



Agroforestry  
Parker Track (USA)



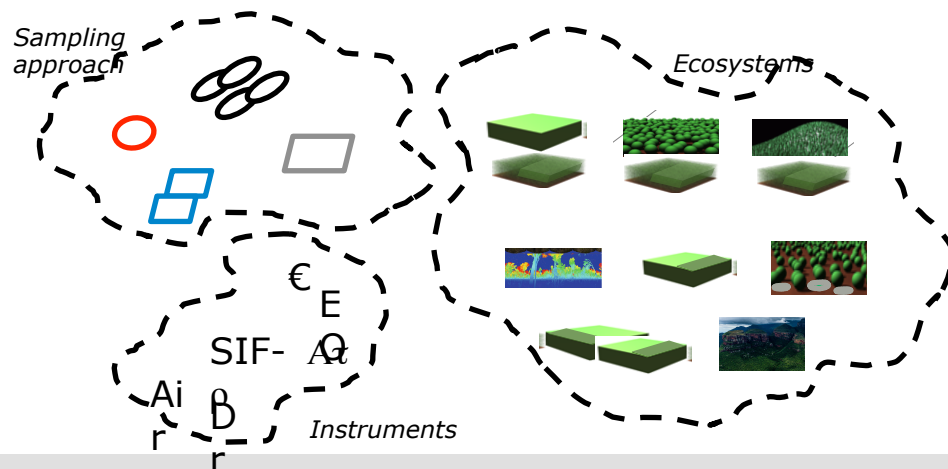
# Fluorescence (FLoX) Box



- FloX is an automated field spectroscopy device capable of collecting unattended, continuous, long-term hyperspectral measurements.
- FloX is specifically designed to passively measure Chlorophyll fluorescence induced by sun, under natural light conditions.



## Mapping of heterogeneous FLEX pixels





# General Objectives for a major campaign in 2018



- Further develop FLEX mission concept
- Perform S2/S3 calibration/validation during Phase E1 of S3B (estimated Launch Date: March 2018)
- Explore S8/S10 Mission concepts

## By Means of:

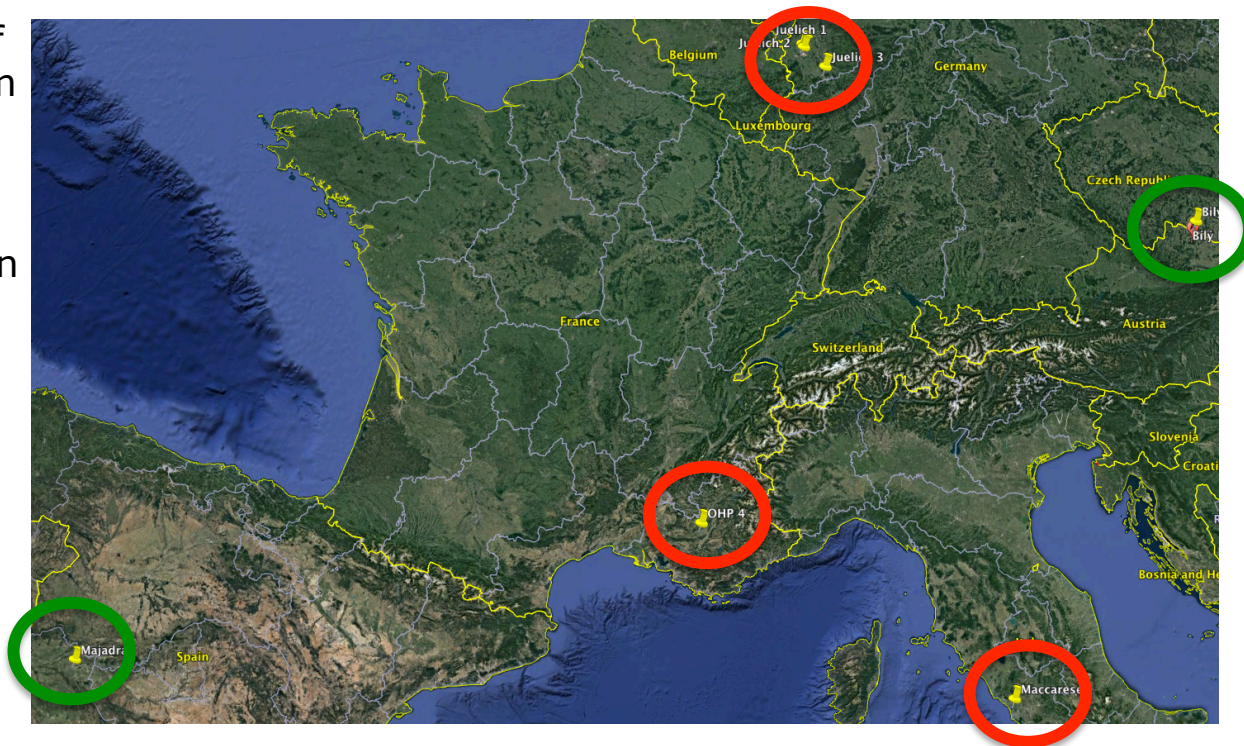
- Collecting airborne hyperspectral data over representative monitoring sites, concurrent with ground-based measurements for time intervals compatible with spaceborne missions (5-10 days) over a period of 2 -3 month during the growing season 2018
- Oversampling during Intensive Observation Periods (IOP) with S3B special setting

## This leads to:

- Documenting the information content of multi-temporal imagery for the mapping of agricultural, forest, coastal and snow conditions.

# Identified **core** and associated areas so far:

- All sites will span a gradient of surface reflectance values from dark to bright targets (i.e. forest, crop, bare soil)
- Surface temperature, emissivity, Mineral Composition Soil Classes
- Detailed Atmospheric information available at all sites (e.g. aeronet, lidar)
- Ground networks (e.g. ICOS) will provide additional information on surface fluxes, soil moisture



# S3B OLCI special campaign settings



- To perform in-flight spectral calibration using the atmospheric absorptions.**

- 1 week Duration (hopefully to be repeated)
- Orbit tbd
- Maccarase as the current proposal
- Tests on ground to be performed in October 2017

Absorption band	Number of continues $\mu$ bands	CCD lines (to be updated)	Gain setting
H (483 – 489nm)	6	494, 493,..., 489	7
H $\alpha$ (653 - 658 nm)	5	358, 357,..., 354	7
O2A (757 – 778 nm)	18	275, 274,..., 258	7
Ca (852 – 858nm)	5	199, 198,..., 195	7
High (998-1010nm)	11	82, 81,..., 72	7
Total: 45			
<i>* note, 45 <math>\mu</math>bands (out of 45+1 smear) are allocated, hence all <math>\mu</math>bands will be used.</i>			

- To perform FLEX like measurements to test the atmospheric characterization**

- Same setup as above
- Primarily, measurements from camera 4
- Test the atmospheric characterization spectral cross-calibration, and the final ortho-rectification
- Test mission performance for Photochemical Reflectance Index (PRI)

Band	Number of continues $\mu$ bands	CCD lines (to be updated)
PRI 1 (531 nm) center	3	TBD
PRI 2 (570 nm) center	3	TBD
H $\alpha$ (653 - 658 nm)	5	TBD
O2A (757 – 778 nm)	18	TBD
O2B (679 – 695 nm)	16	TBD
Total: 45		

- To perform S8/S10 related measurements?**

# Identified Airborne Instruments



- **HYPLANT (FLEX, S2, S3, S10)**
  - 370 to 2500 nm with 3nm spectral resolution in the VIS/NIR spectral range
  - 10nm spectral resolution in the SWIR spectral range.
- **HYSPEX (S2, S3, S10)**
  - Spectral sampling ~3nm VNIR
  - 10nm spectral resolution in the SWIR spectral range.
- **APEX (S2, S3, S10)**
  - VNIR 0.55 – 8 nm over spectral range (unbinned)
  - SWIR 5 – 10 nm over spectral range
- **CASI (S2, S3, S10)**
  - Hyperspectral VNIR Imager, Up to 288 Spectral Channels
- **TASI (S8):**
  - Airborne Hyperspectral Thermal Imager (8-11.5 microns)
  - 32 Spectral Channels, 40° FOV, 600 Spatial Imaging Pixels



# Mission Specific Needs on ground?



- Atmospheric characterization by means of photometry, lidar at all identified sites
- Surface flux measurements available at all identified sites
- Soil moisture measurements?
- Lysimeter available at Juelich site

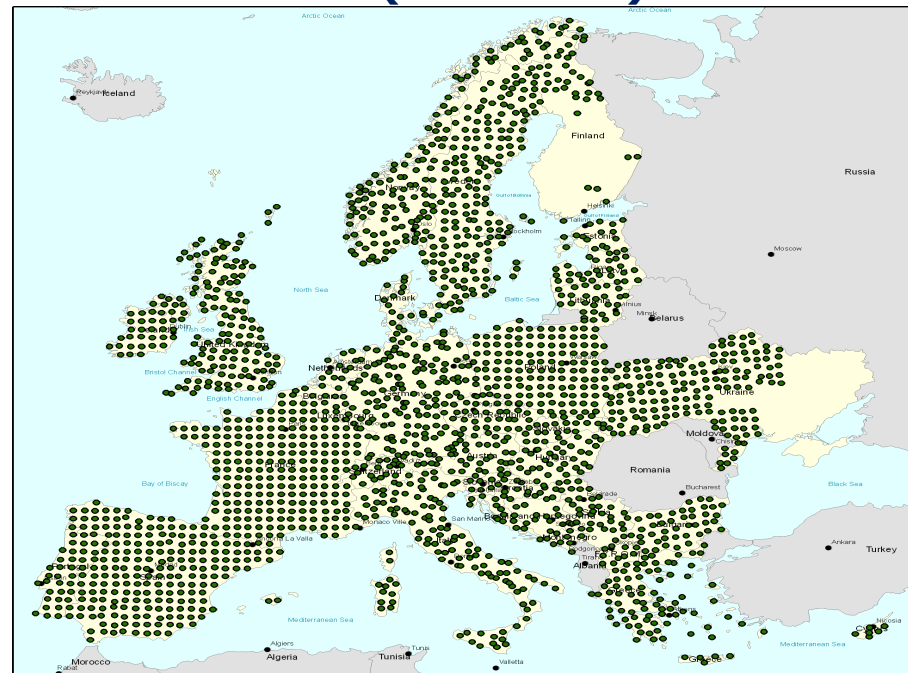
TASI to measure:

- Surface temperature & emissivity,
- Mineral Composition, Stratigraphy & Structural Geology / Rock Types / Soil Classes / Detection of Metals, Plastics, and other Anthropogenic Materials

**What else is needed?**



## Grazing land soil (Gr) 0-10 cm (N = 2024)



(From Reimann et al., 2009, Fig. 2, p.9)

**33 countries - 5.6 million km<sup>2</sup> - 4132 soil samples in total**

# Conclusions



- Growing season 2018 as an opportunity during S3B commissioning phase
- Multi user, multi-Agency campaign utilizing Satellite, airborne + Ground-based infrastructure
- Contribution from Germany (enmap), Italy (prisma), US to be identified
- Any other contribution welcome
- Potential date for experimenter Meeting: 13/11 – 17/11 2017



# Future Validation Approach



The validation activities have two main goals: the first one is to provide products with documented and associated traceable error bars; the second goal is to gain knowledge in the algorithm and sensor characteristics in order to improve their quality and reliability.

The accuracy in the uncertainties has a long term impact for most EO applications and in particular for climate applications.

The validation activities are a key component of a Mission, as it is the foundation for user credibility into the mission data. Validation activities require continuous effort during and after the mission life time.

***CEOS Definition: Calibration is the process of quantitatively defining a system's responses to known, controlled signal inputs. Validation, on the other hand, is the process of assessing, by independent means, the quality of the data products derived from those system outputs.***



# Validation Approach



A validation program is composed by a set of different complementary activities bringing elements that need to be combined together in order to produce consolidated and confident validation results.

In a generic manner the different components for a validation program are the following:

- Validation against precise Reference Measurements: few points but precise,
- Validation against in-situ: more points less precise,
- Validation against others sources: inter-satellite comparison,
- Validation against models: data assimilation rejection statistics, integrated model analyses...,
- Validation using Level 3 data (i.e. merged data): statistical comparison between various Level 3 from various sensors constitutes an extremely useful tool (mean, median, sd, bias, RMS.... for selected zones, transects, latitudinal bands, seasonal trends... ) for a cross-validation of the products,
- Validation using monitoring tools: statistics, trend, systematic quality control, etc.

All the components are important and necessary; the first point is of particular importance because it gives a reference properly characterised and traceable to standard on which the Validation results can be anchored.

# Validation Organisation



For each mission, a **validation plan** constitutes the baseline description for the validation activities. The activities are implemented by different contributors who interact all together under the responsibility and coordination of the Mission Data Quality Manager.

**VALIDATION TEAM** : The validation team completes the MPC activities by providing independent validation measurements and/or independent analysis. The team members are selected through an open call process. The intention of this call is to create scientific validation teams to provide structured coordination of international activities that contribute to validation across the entire mission operations (i.e. Phase E1 and E2).

## **Mission Performance Centre (MPC)**

The Mission Performance Centre is in charge of the overall validation providing the synthesis of the results.

**MPC S1, MPC S2, MPC S3, MPC S5P have been set-up.**

## **Mission Quality Working Group (QWG)**

## **Mission Data Quality Manager**

The information are then discussed, further processed in the **Quality Working Groups** which provide synthetic results to the Mission Managers, used for improving the products quality and the products knowledge.

## **The Validation Teams:**

The validation team complete the MPC activities by providing independent validation measurements or independent analysis.

**S2VT, S3VT, S5PVT have been set-up.**

## **Reference Measurements providers**

Specific activities need to be put in place for providing mandatory FRMs (ex: BOUSSOLE, Infra-Red radiometers...etc...)

## **User community and international forum:**

The validation program benefits from the feedback from:

- Workshops/conferences (ESA or international)
- Bilateral relations (NASA, NOAA, CNES, DLR, UKSA, JRC, EUMETSAT...etc...)
- Coordination within **CEOS WGCV (WG on Cal/Val)**

\* For the specific case of Sentinel-3, EUMETSAT coordinates together with ESA the validation activities and also provides validation infrastructures and internal expertise which complement the MPC/SVT approach.

# FLEX Cal/Val Setup



- A**: Comparison of satellite with in situ measurements: this is the traditional and most straightforward approach to validating any given parameter. It involves a direct comparison of satellite-derived value with collocated and simultaneously acquired measurement from ground-based instruments. It corresponds to the CEOS direct validation using a bottom-up approach;
- B**: Radiance-based validation. Uses top-of-atmosphere in conjunction with a radiative transfer model to simulate ground radiance using atmospheric properties (top-down);
- C**: Inter-comparison with similar products:
- D**: Time series analysis ;
- E**: Indirect validation through numerical RTMs.

*Categories A may represent the most important approach to be undertaken, but also categories D and E, and at certain point C, should be stimulated*





# Sites terminology



*According the characteristics of the site, its equipment and sampling approach, we can distinguish different typologies and, for the FLEX mission, we can think a constellation of different sites, which provide data suitable for the different validation schemes*



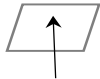
**Core sites.** permanent set-up of ground fluorescence and atmospheric instruments for continuous measurements during the FLEX mission. Cal/Val sites with high performance and intercalibrated ground instruments for satellite data intercomparison They can be homogeneous or heterogeneous, with different sampling strategies . These sites will allow cal/val approaches defined in categories A and E, and should match with other networks sites (mainly FLUXNET and CEOS cal/val network).



**Support/Specialized sites.** These sites are defined on-demand. This means that they are not equipped for long term fluorescence measurements and they can be planned every two years according the FLEX campaign plans (airborne demonstrator). They can include a variety of purposes for short-term/one-shot experiments, manipulations, etc. As core sites, they should be equipped with mobile ground spectrometers and will also serve for A and E.



**Auxiliary sites.** These would be distributed worldwide, and only monitored by regular sampling of fluorescence via drones. These sites improve the validation A, and help to generate the intercomparison for category C.



**Extrasites.** These sites are groups of FLEX pixels selected worldwide. (fluorescent and nf target).

# Thanks for your attention