Emerging Technologies Challenge Workshop

EO Technology Needs at ESA

Prepared by EOP-SFT
Presented by Massimiliano Pastena

04/05/2017

Content

Overview of Earth observation Programmes:

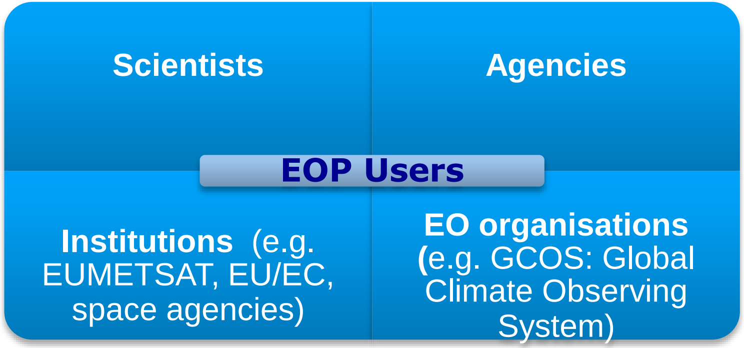
- Meteorological & EUMETSAT
- Copernicus & EU
- Earth Explorers

Future

- ESA Technology developments for EO
- mission concepts : Compendium overview

ESA Earth Observation Programmes

ESA Earth Observation (EO) activities are **user-driven** and implemented through **optional EO Programmes (EOP)**



EOP include **end-to-end** activities, i.e. from conception to exploitation of space missions, for different types of missions:

- **RESEARCH MISSIONS ➔ Earth Explorers** (Core, Opportunity, Fast-Track), for R&D and demonstration of EO techniques prior to their "operationalisation"
- **EARTH APPLICATIONS MISSIONS ➔ Earth Watch**, i.e. (pre-)operational missions in partnership, which can be
  - **Earth Watch SERVICE type:** partners EUMETSAT, EU / EC,..
  - **Earth Watch PRIVATE INITIATIVE**: with specific Member States, industry,..

ESA Earth Observation Missions

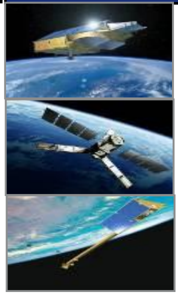
Living Planet

Earth Explorer
Research driven

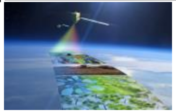
Core Missions


- GOCE 2009-2013
- ADM-Aeolus Dec 2017
- EarthCARE 2019
- Biomass (EE7) 2021

Call EE10 – (2017)

Opportunity


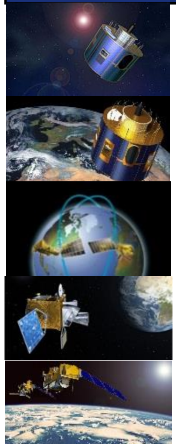
- CryoSat-2 8 April 10
- SMOS 2 Nov 09
- Swarm 22 Nov 13

Fast Track


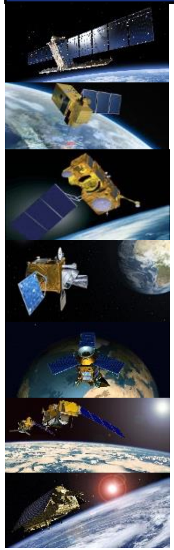
- FLEX (EE8) 2023

Call EE9 – (2017)

Earth Watch
Operational Service driven

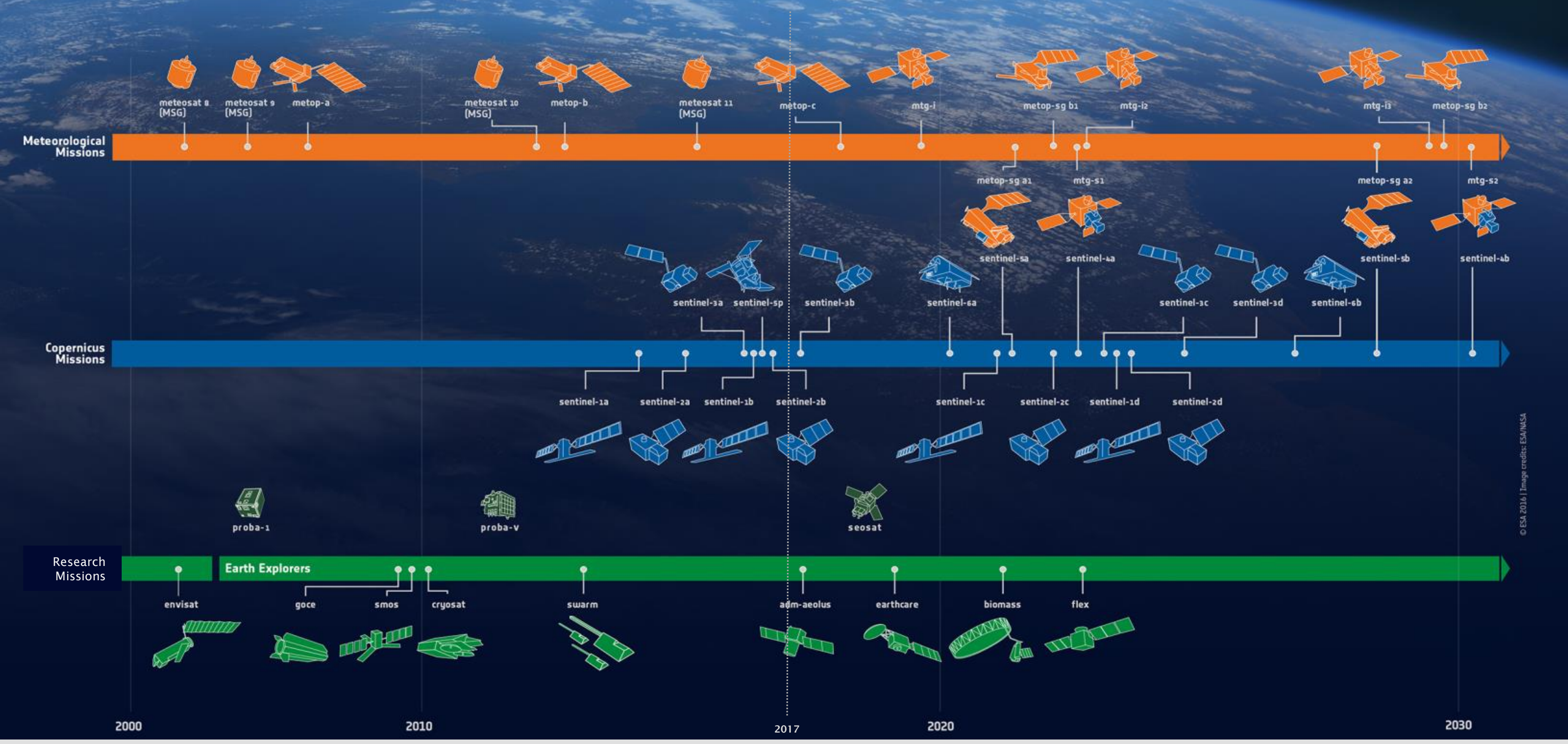
Meteorology


- Meteosat
- MSG
- MetOp
- MTG (2 s/c x 3)
- MetOp SG (2 s/c x 3)

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)

→ ESA–DEVELOPED EARTH OBSERVATION MISSIONS



Outlook of Earth Watch programmes with Eumetsat

Developed in cooperation with ESA's partner, Eumetsat, as Europe's contribution to the World Meteorological Organization's space-based Global Observing System:

Meteosat Second Generation (2002, 2005, 2012, 2015) – series of four satellites providing images of Earth from geostationary orbit.

Meteosat Third Generation (2021–) series of six geostationary satellites providing images (four satellites) and atmospheric sounding (two satellites).

MetOp (2006, 2012, 2018) – series of three satellites providing operational meteorological observations from polar orbit.

MetOp Second Generation (2021–) two series of polar-orbiters, three satellites in each series, continuing and enhancing meteorological, oceanographic and climate monitoring observations from the first MetOp series.

Outlook of Earth Watch programmes with Eumetsat….the future

EUMETSAT will prepare the user consultation process that needs to be initiated with ESA in the 2025-2027 timeframe as the first formal step in the planning of future programs through an appropriate balance between observations from geostationary and low Earth orbits.

Meteosat Fourth Generation (2030-) geostationary observation.

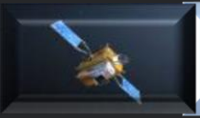
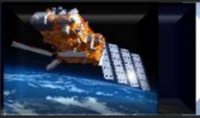
MetOp Third Generation (2040–) polar-orbiters.

More integration likely between EUMETSAT and EU assets (as for S-4/5, S6)

Outlook of Earth Watch programmes with EU/EC : Copernicus Missions (1/2)

- Copernicus is a European space flagship programme
- It is led by the European Union. ESA coordinates the space component
- Copernicus provides the necessary data for operational monitoring of the environment and for civil security
- Copernicus missions include Sentinels and contributing missions (from national Agencies and companies)

Copernicus : actual sentinels

	Sentinel	Launch	Instrument	Application	Downlink	Note	
	**Sentinel-1 A** **Sentinel-1 B**	3 April 14 25 April 16	C-Band SAR	All weather, day/night applications, interferometry	X-Band Opt.→ EDRS	polar-orbiting satellites	
	**Sentinel-2 A** **Sentinel-2 B**	22 June 15 7 March 17	Multispectral	Land applications: urban, forest, agriculture,	X-Band Opt.→ EDRS	polar-orbiting satellites	
	**Sentinel-3 A** **Sentinel-3 B**	16 Feb 16 Plan 2017	C/Ku Radar Altimeter 23.8/36.5 GHz radiometer OLCI spectrometer VIS-SWIR-TIR radiometer	Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry	X-Band	polar-orbiting satellites	
	**Sentinel-4 A** **Sentinel-4 B**	plan 2020 plan 2030	UVN Spectrometer Infrared Sounder	Atmospheric composition monitoring, trans-boundary pollution	26 GHz	Payload to be embarked on MTG (GEO).	
	**Sentinel-5 A** **Sentinel-5 B**	plan 2022 plan 2028	UVNS Spectrometer Infrared Sounder Multi-view/pol Imager	Atmospheric composition monitoring,	26 GHz	Payload to be embarked on Metop-SG (LEO).	
	**Sentinel-5 P**	June 2017	TROPOMI (passive imaging spectrometer)	Tropospheric composition monitoring	X-Band	to follow ground track of Suomi-NPP	
	**Sentinel-6 A** **Sentinel-6 B**	plan 2021 plan 2025	ESA Instruments: C/Ku Radar Altimeter and GNSS Radio-Occultation	Sea-level, wave height and marine wind speed	X-Band	partnership between EU/ESA/EUMETSAT and the NOAA/NASA	

Copernicus Evolution : Mission Concepts & Thematic Areas

(proposed as High Priority from the EC, **Current status, all TBD/TBC**):

- CO_2 Monitoring
- Polar ice/ocean interfer. altimetry
- Other polar (Arctic) observations

} ***climate change***

} ***marine & polar envir. monitoring***

- Land thermal imaging
- Soil moisture, ocean salinity
- Hyperspectral land imaging

} - ***land monitoring*** *(agriculture, food security)*
- ***emergency management*** *(geohazards)*
- ***marine envir. monitoring***

Copernicus evolution: Candidates
(concepts + technology - Current status , all TBD/TBC)

- Several key observation gaps already known. **Examples:**
  - monitoring of greenhouse gases like CO_2 (emphasised by EC)
  - high-resolution thermal infrared imaging (on Sent-2 no TIR imager like Landsat)

- Other gaps quite evident from evolution of user needs. **Examples:**
  - new data for polar regions,
  - persistent (from GEO) rapid response imaging, ..

- Role expected for follow-on's of already demonstrated EO techniques. **Examples**:
  - interferometric SAR altimetry (CryoSat),
  - hyperspectral imaging (under National Developments),
  - SMOS follow-on
  - Next Generation Gravity Mission

Copernicus Program Evolution

EO Capability	Actual Sentinels	Extended Data Availability	Sentinels Expansion	Second Generation	Instrument	Orbit
Earth Microwave (3D) Imaging	Sentinel-1 A Sentinel-1 B	Sentinel-1 C Sentinel-1 D			C Band SAR	LEO
				Sentinel-1 SG	C, L Band SAR + Rad	LEO
Earth Optical Imaging	Sentinel-2 A Sentinel-2 B	Sentinel-2 C Sentinel-2 D			Multispectral	LEO
			Sentinel-8		TIRI	LEO
			Sentinel-10		Hypespectral	LEO
				Sentinel-2 SG	MSI+TIRI SG Hyper-spectral SG OLCI+SLSTR SG	LEO
				Sentinel-3 SG	OPT	GEO
Earth Topography by Altimetry	Sentinel-3 A Sentinel-3 B	Sentinel-3 C Sentinel-3 D			C/Ku Radar Altimeter VIS-SWIR-TIR radiometer	LEO
	Sentinel-6 A Sentinel-6 B	Sentinel-6 C Sentinel-6 D			C/Ku Altimeter GNSS Radio-Occultation	LEO
			Sent.-9 TOPO		Altimeter ICE/SNOW	HEO
				Sentinel-6 SG	Altimeter LEO SG	LEO
				Sentinel-9 SG	Altimeter ref.SG	LEO
			Sent.9 HEO		Altimeter ICE SG	HEO
Earth Atmosphere by Spectroscopy	Sentinel-4 A Sentinel-4 B				UVN Spectrometer GEO Infrared Sounder GEO	GEO
	Sentinel-5 A Sentinel-5 B	Sentinel-5 C			UVN Spectrometer LEO Infrared Sounder LEO	LEO
	Sentinel-5 P				Spectrometer LEO	LEO
			Sentinel-7		CO2 Spectrometer	LEO
				Sentinel-9 HEO SG	HEO Spectrometer SG	GEO
				Sentinel-4 SG	GEO Spectrometer SG	LEO
				Sentinel-5 SG	LEO Spectrometer SG	LEO
				Sentinel-7 SG	CO2 Spectrometer SG	HEO

Outlook: Earth Explorers (EE)

Core Missions

GOCE (2009–13) studying Earth's gravity 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

EE 10 Call to be released end of 2017

Opportunity/Fast Track

SMOS (2009–) studying Earth's water cycle

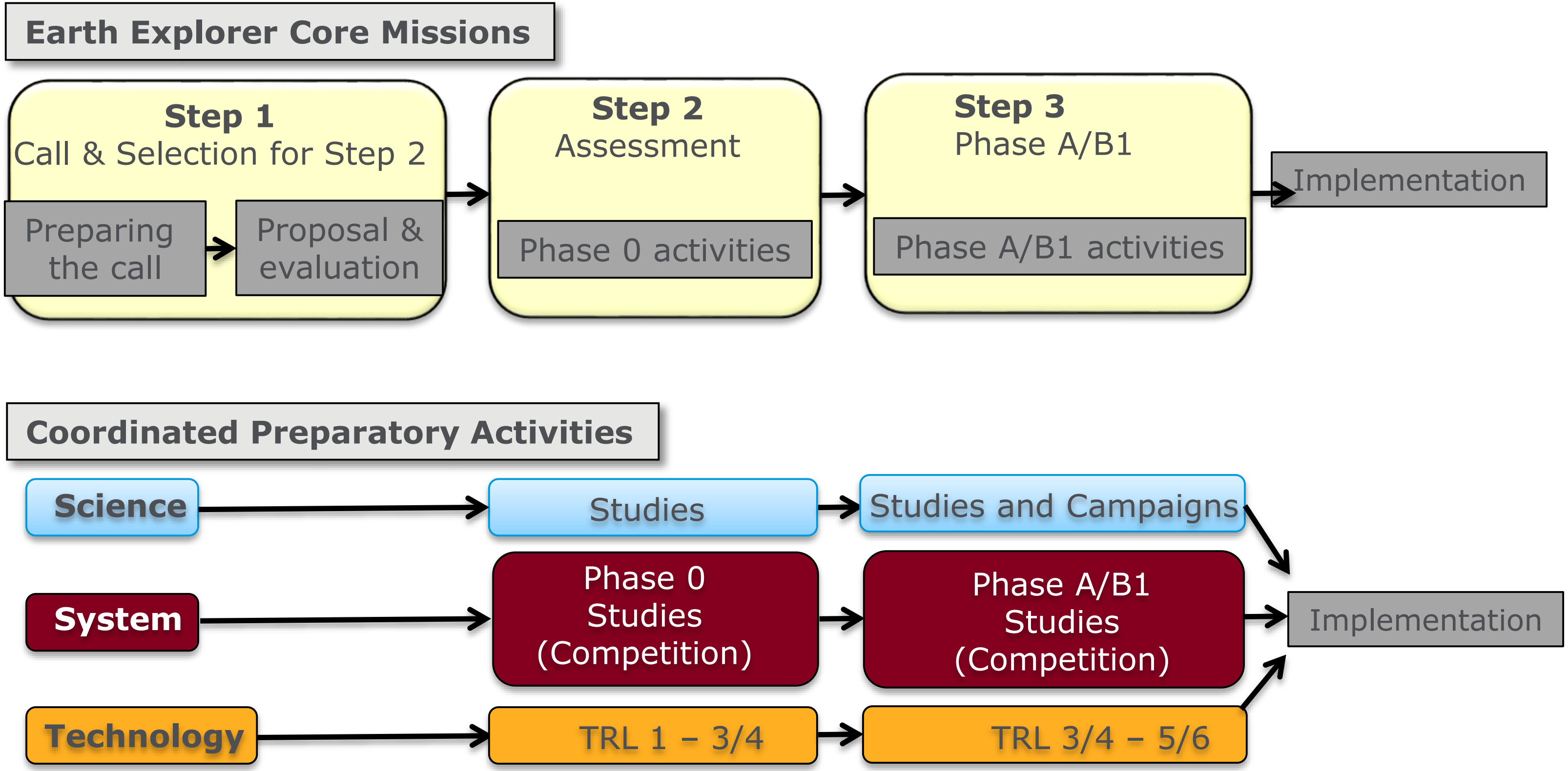
CryoSat-2 (2010–) studying Earth's ice cover

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

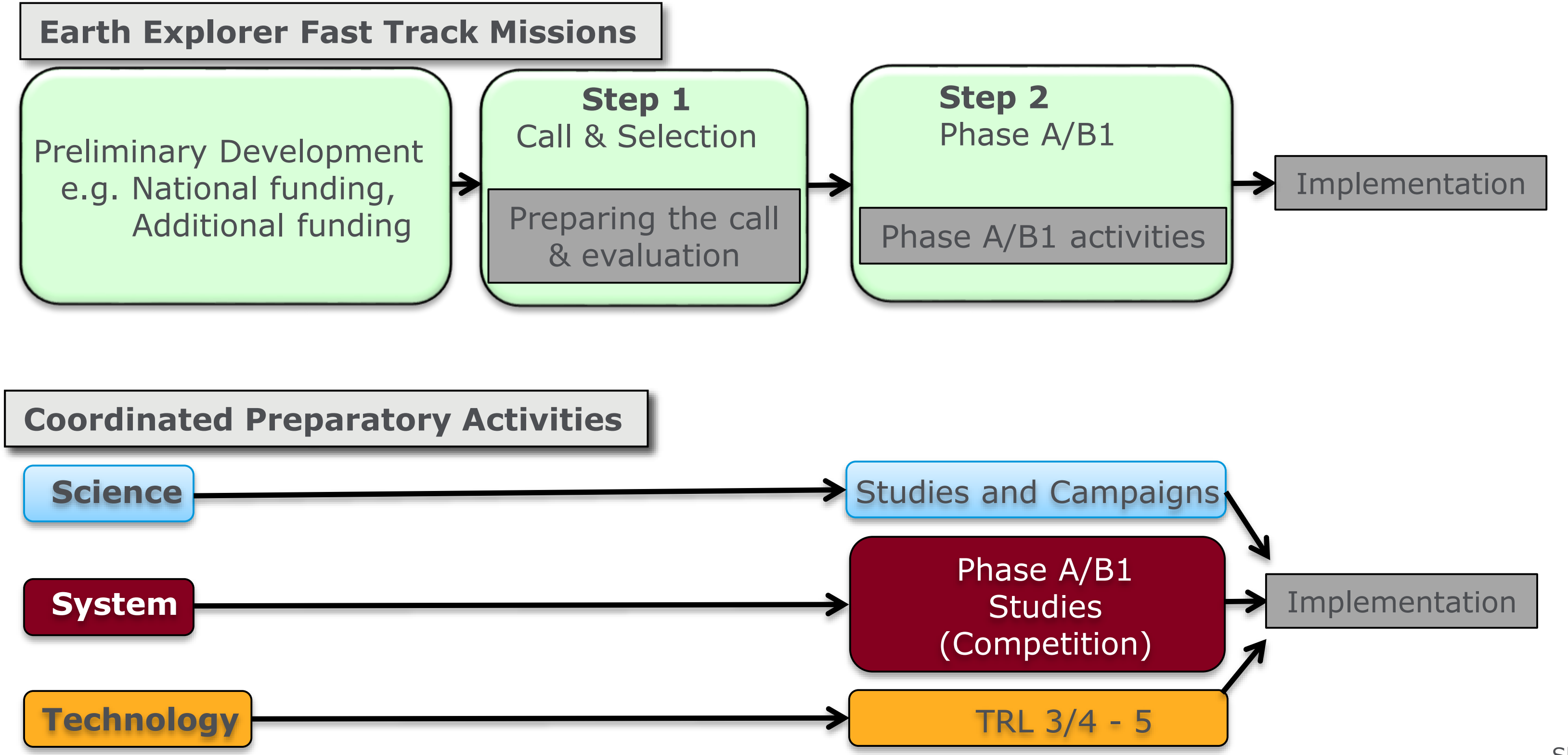
FLEX (2022) studying photosynthesis

EE 9 proposals expected tor 1st Jun. '17, selection by PB-EO is 1. Nov. '17

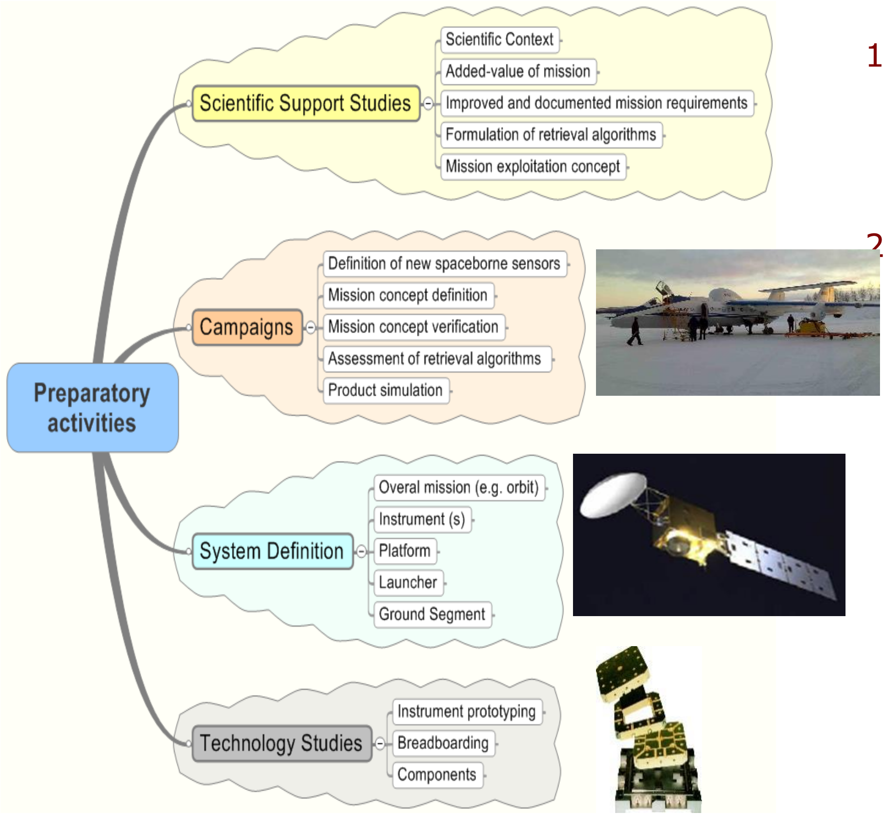
EE Core mission activities vs preparatory activities



EE Fast track mission activities vs preparatory activities

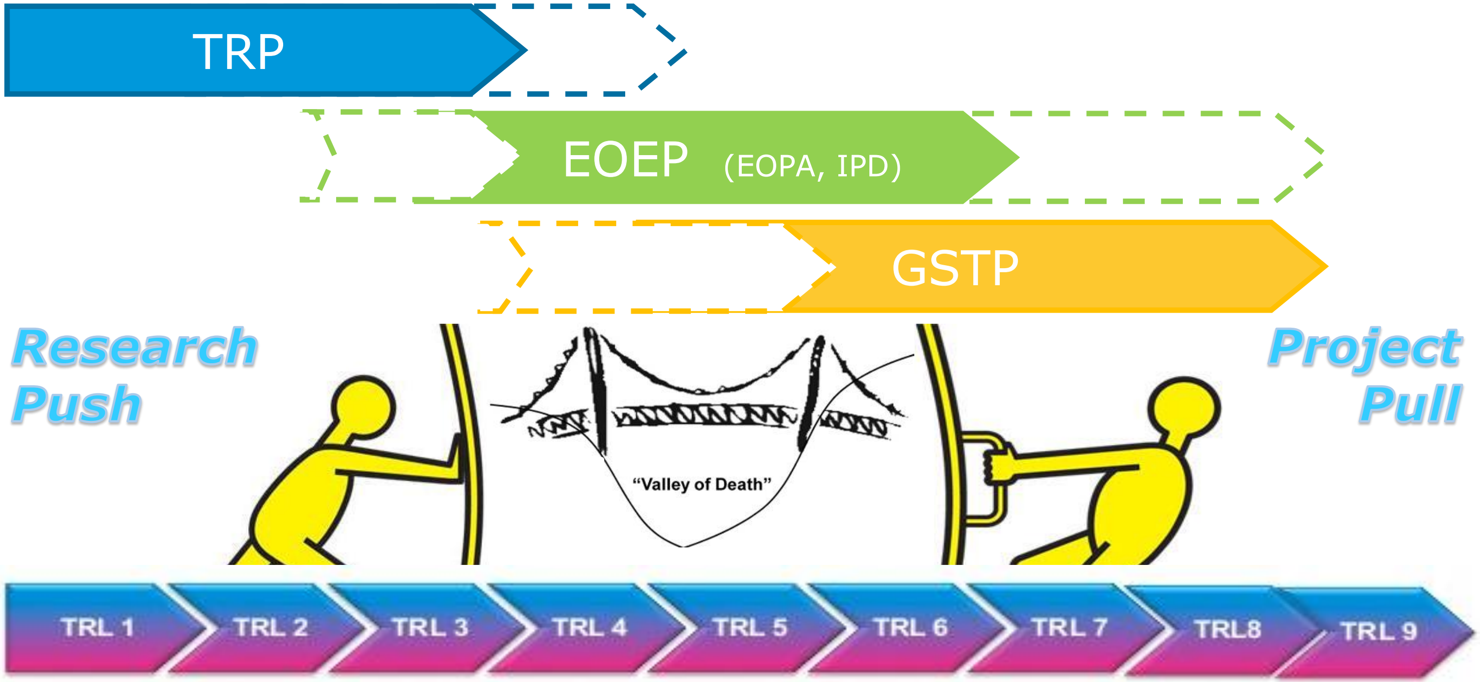


What is a preparatory activity?



1. EOEP preparatory activities include all necessary activities to define and evaluate future EO space borne missions (Earth Explorer, Copernicus, meteorological,..)
2. Driving elements include:
    - ➢ Scientific challenges summarised in “The Changing Earth”, SP-1304
    - ➢ Associated observation, mission and technology requirements
    - ➢ Mission preparation through Phase-0 (Pre-feasibility) and Phase-A/B1 (Feasibility)
    - ➢ Foster new ideas, cooperation opportunities and prepare technologies, also for European independent capabilities
    - ➢ ESAC recommendations

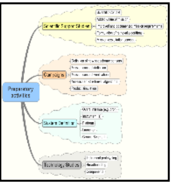
EOP technology founding scheme vs TRL level



- **TRL 1**: Basic principles observed and reported
- **TRL 2**: Technology concept and/or application formulated
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof-of concept
- **TRL 4**: Component and/or breadboard ***functional verification*** in laboratory environment
- **TRL 5**: Component and/or breadboard ***critical function verification*** in **a** relevant environment
- **TRL 6**: Model ***demonstrating the critical functions of the element*** in a relevant environment
- **TRL 7**: ***Model demonstrating the element performance for the operational*** environment
- **TRL8**: Actual system completed and ***accepted for flight ("flight qualified")***
- **TRL 9**: Actual system "flight proven" through successful mission operations

EECM preparatory activities: BIOMASS example

Example: BIOMASS Core Mission Phase A (now in Phase B)



System

- BIOMASS Phase A System Study (x2), addressing:
  - Space segment : payload, platform
  - Mission analysis and operations
  - Launcher
  - Ground segment
  - Critical technologies
  - Programmatics

Technology

- Large P-Band SAR antennas critical breadboard (x2)
- Very Large P-Band Antennas performance verification methodology & Facilities
- P-Band HPA technology assessment
- Very large space antenna aperture – demo model
- P-Band Reflector antenna Feed elements
- P-band ice sounding radar demo development
- P-band passive sub-array development
- Very large space antenna aperature architecture trade-off (x2)
- SSPA breadboard (incl. circulator/switch, power divider and calibration coupler) (x2)
- Study of P-Band transponder with ionospheric correction capabilities (x2)

Science and Campaigns

- Development of algorithms for forest biomass retrieval
- Study of ionospheric disturbance mitigation schemes
- Assessment of the BIOMASS retrieval error on flux
- P-Band SAR wave interaction and information retrieval
- Analysis of BIOMASS secondary objectives

e.g.

- TropiSAR campaign (completed)
- TropiScat campaign (on-going)
- BioSAR 2 campaign (completed)
- BioSAR 3 campaign (completed)

End-to-end Performance Evaluation and System Support

- BIOMASS End-to-End Mission Performance Simulator
- OpenSF end-to-end (E2E) simulator framework infrastructure
- Modern attitude control of EO satellites with large flexible elements (x2)

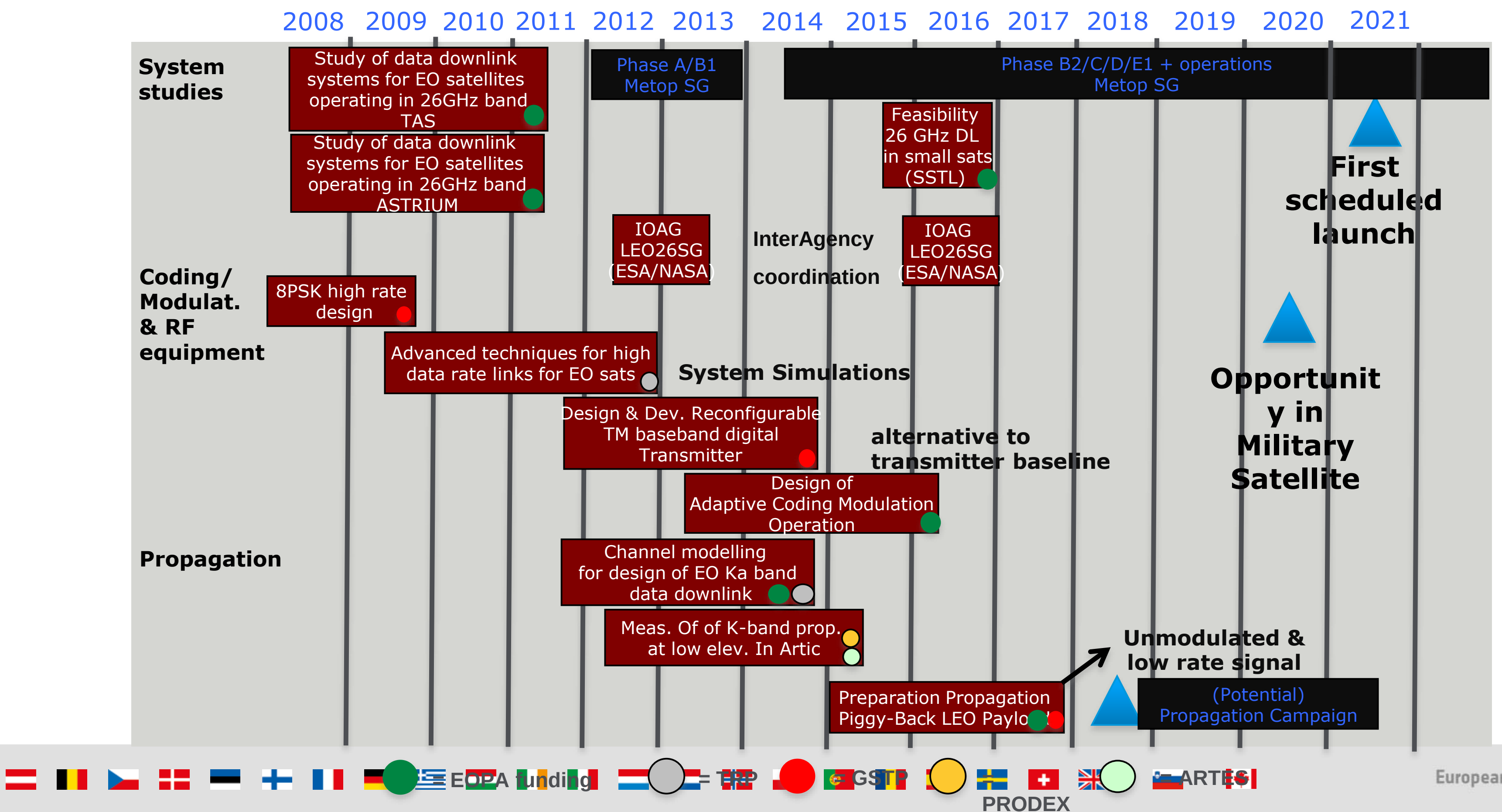
= EOPA

= IPD (also EOP)

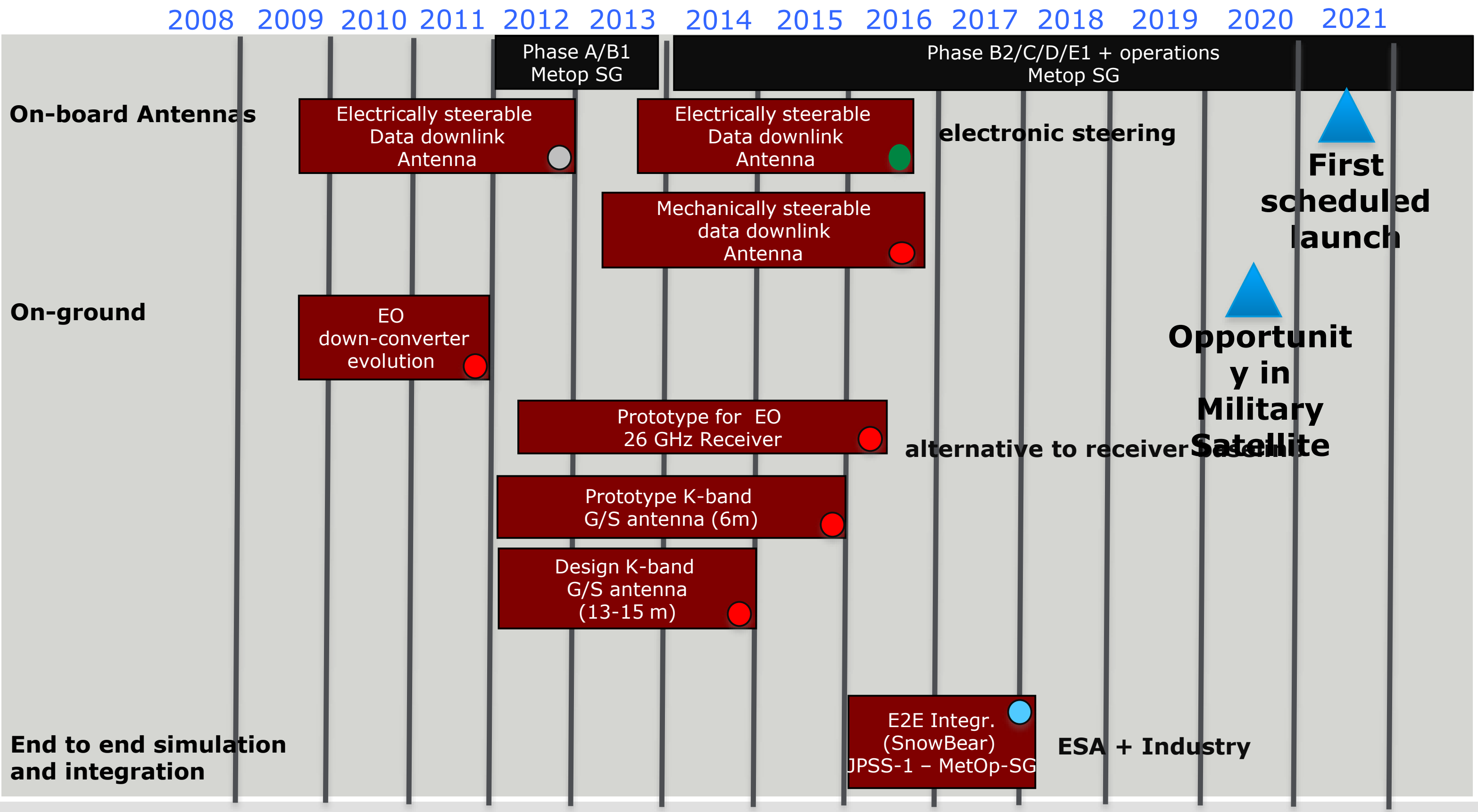
= TRP / GSTP

= GSP

Example : Overview of 26GHz Downlink Development



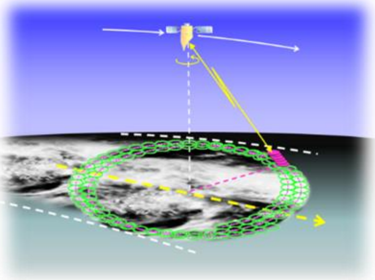
Example : Overview of 26GHz Downlink Development



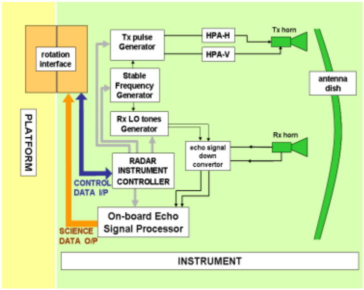
= EOPA funding = TRP = GSTP = PRODEX = PROJECT

Achievements - TRP 4000101855 – Swath Precipitation Radar Instrument

Airbus Defense & Space (UK)	**Duration – 24 months**



Background and justification
Numerical weather prediction models are continuously updated as new observations become available. Scatterometer derived winds are routinely assimilated, but they provide no information on the vertical profile of the wind. This is vital for improved weather forecasting and climate change predictions.



Objective
To develop a radar instrument to provide wide coverage of 3D vectors of tropospheric winds and precipitation which would operate in cloudy regions and hence complement ADM-Aeolus

Achievements and status
The original activity was re-aligned to focus more on the wind vector extraction than on precipitation. The result is a conically scanning radar at 94GHz which emits pulse polarization pairs in order to cover a swath of 800km with 50km horizontal and 1km vertical resolution. It is capable of measuring wind speeds up to 160m/s with an accuracy <2m/s. The instrument has reached the stage of an advanced concept. Renamed Wind Retrieval Radar Nephoscope – WIVERN

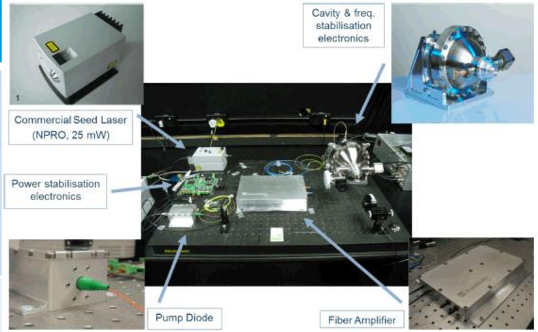
Benefits (vs expectation)
An instrument has been conceived which would add significantly to scientific understanding of weather and climate change

Next steps
Under the IPD budget, ground tests are being carried out at Chilbolton (UK) and airborne tests over the Great Lakes in Canada to prove the concept.

Initial TRL	Current	Final	and/or Target TRL
1	2	3	5

Achievements - T117-309MM + T116-044MM High-Stability Laser with Fiber Amplifier + Laser Stabilization Unit for Interferometric Earth Gravity Measurements - 3/y MJ

SpaceTech (D), Fraunhofer ILT (D), ADS (D), NPL (UK)	Duration: 36 months



Background and justification:
Laser technology development for a Next Generation Gravity Mission (NGGM) as GOCE follow-on. The NGGM measurement principle is based on laser interferometry between two satellites flying in a LEO formation with up to 200 km distance. Laser frequency stability requirements are one order of magnitude more challenging than the current specs for eLISA.

Objective:
Develop an elegant breadboard of a high-stability laser consisting of a master oscillator (MO), fibre-based power amplifier (FPA) and an optical cavity (OC) for frequency stabilisation. Demonstration of a space-worthy design for all the subunits (representative environment and interfaces, limited environmental testing on component and subunit level).

Achievements and status:
Completed with full achievement of all objectives in terms of performance, thermal and mechanical modelling as well as radiation and thermal testing.

Benefits (vs expectation):
Space-worthy hardware (HSL-EBB) ready for further environmental testing.

Next steps:
Raise TRL of FPA and OC to TRL 5 (subunit) / TRL 7 (components) within GSTP

Initial TRL 3	Current	Final 4	Target TRL 4

Earth Observation Mission Concepts Compendium 2017

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estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
T +31 (0)71 565 6565
F +31 (0)71 565 6040
www.esa.int

Earth Observation Mission Concepts Compendium

2017

Prepared by	Pierluigi Silvestrin;Joerg Callies;Sven Wittig;Massimiliano Pastena EOP-SF
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Date of Issue	01/05/2017
Status	Under review

European Space Agency
Agence spatiale européenne

Overview of over 40 EO mission concepts

- From P-band to UV
- Constellations and Companions
- Concepts vary very strongly in their definition (from pre-phase 0 to full phase-A)
  (e.g. CDF studies to EE7 candidates like Premier, CoreH2O)
- System Concepts & Technology funded by:
  - EOEP lines (EOPA, EWD, IPD, STSE)
  - and/or corporate programmes (TRP/GSTP)

Graphic Comparison

Science Domain: Atmosphere (AT), Snow and Ice (SI), Land (LA), Ocean (OC), Magnetic/Gravity (MG), Disaster/Safety (DS)
Orbit: LEO, GEO
Type: Single (SI), Companion (CP), Constellation
Instrument – Active: RADAR (RAD), LIDAR (LID), Scatterometer (SCA), Laser Occultation (LOC), RF Occultation (RFO), Altimeter (ALT), Laser Interferometer (LAI)
Instrument – Passive: Imager (IMG), FT Spectrometer (FTS), GNSS Reflec/Occul (GOR), Radiometer (RAD), Disp Spectrometer (DSP), RADAR (RAD), Sounder (SOU), Gradiometer (GRA)
Spectrum: UV, VIS, NIR, SWIR, MIR, TIR, FIR, mm, W, V, ka ku, X, C, S, L, P
µm: ,01 0,4 0,75 1,3 3 6 15 300 1000
GHz: 110 75 40 12 8 4 2 1

Group	Science Domain	Orbit	Type	MISSION CONCEPT	Instrument – Active	Instrument – Passive	Spectrum
Optical	AT	LEO	SI	SPACEWAVES	LID	FTS	NIR, TIR
Optical	AT	LEO	SI	EXCALIBUR	LID		SWIR
Optical	LA	LEO	SI	LASER Altimeter	LID, ALT		NIR
Optical	AT	LEO	SI	FORUM		IMG, FTS	TIR, FIR
Optical	LA, OC, DS	GEO	SI	GEO-HR		IMG	PAN
Optical	LA, OC, DS	GEO	SI	GEO-OCULUS		IMG	UV, PAN, NIR
Optical	LA	SSO	SI	NYX		IMG	VIS, NIR
Optical	AT	LEO	SI	SPEX		IMG	VIS, SWIR
Optical – TIR	LA	SSO	SI	TES-GAP		IMG	MIR, TIR
Optical – TIR	LA	SSO	x2	TIREX		IMG	VIS, NIR, TIR
Optical	SI	HEO	SI	Hosted Arctic Imager		IMG	VIS, NIR, SWIR, MIR, TIR
Optical	AT	SSO	x24	OMNISAT-HAPI		IMG	VIS
RF	SI	LEO	SI	CoreH2O	SAR		Ku, X
RF	OC	SSO	SI	OSCM	InSAR		Ku
RF	SI, LA, OC	LEO	SI	HRWS	SAR		C
RF	SI, LA, OC	LEO	SI	Ka-Band SAR	SAR		Ka
RF	LA	LEO	x4	HABITAT	SAR		L
RF	SI, OC	POL	SI	Cryosat EC	SAR, ALT		Ku/Ka
RF	AT, SI, LA, OC	LEO	CP	STEREOSAR		SAR	C
RF	AT, SI, LA	GEO	SI	GEOSTARE	SAR		Ku, X, L
RF	AT	LEO	CP	WIVERN	RAD		W
RF	AT	GEO	SI	GOMAS		SOU	MW
RF	SI, LA	POL	SI	GLACIES	SOU		P
RF	OC	LEO	x12	MICROWAT		RAD	Ku, X, C
RF	AT, LA, OC	LEO	SI	SMOSops		IMG, RAD	L
RF	SI, OC	LEO	SI	IRAC	RAD, ALT		Ku/Ka
RF	AT, SI, LA, OC	SSO	x30	ORORO		GOR	L
RF	AT, LA, OC	LEO	SI	GEROS-ISS		GOR	L
Combined Optical/RF and others	AT	LEO	CP	PREMIER		IMG, FTS, RAD	TIR, FIR
Combined Optical/RF and others	AT	LEO	x4	ACCURATE	LOC, RFO	GOR	SWIR, K
Combined Optical/RF and others	MG	SSO	x2	NGGM	LAI	GRA	
Combined Optical/RF and others	MG	LEO	SI	CAI		GRA	
CONVOY MISSIONS	SI, OC	SSO	CP	Passive SAR (S1)		SAR	C
CONVOY MISSIONS	SI, OC	SSO	CP	Laser altimeter (S3)	LAI		VIS, NIR
CONVOY MISSIONS	SI, LA, OC	POL	CP	Ku Scatterometer (MSG)	SCA		Ku
CONVOY MISSIONS	LA	SSO	CP	TIR Imager (S2,S3)		IMG	TIR
CONVOY MISSIONS	LA	SSO	CP	IR Imager (S2,S3,JPSS)		IMG	MIR, TIR
CONVOY MISSIONS	LA	POL	CP	Spectrometer (MetOp-SG)		DSP	MIR
CONVOY MISSIONS	LA	LEO	CP	TIR Imager (S2) NASA		IMG	TIR
CONVOY MISSIONS	LA	SSO	CP	Passive SAR (S1)		SAR	C
CONVOY MISSIONS	AT	POL	CP	Spectrometer (MetOp-SG)		IMG	MIR
CONVOY MISSIONS	AT	POL	CP	TIR Imager (S2/3) NASA		IMG	TIR

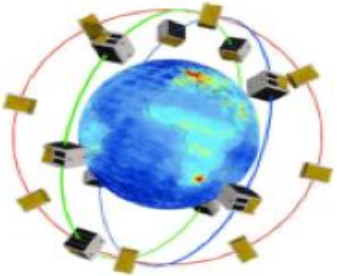
Each Concept has a Single Page Summary

Example →

Key concept parameters

12 OMNISAT-HAPI CONSTELLATION

Science Domain	Atmosphere
Instrument Type	Multispectral Imager
Wavebands	VIS
Spat. Resolution	400 - 600 m
Swath	200 km
Orbit / Lifetime	SSO / 4 years
LDTN	08:00 / 12:00 / 16:00
Revisit	1 hour
Coverage	Global
Satellites	24 x (constellation)



Wet Mass	Peak Power	Downlink
38 kg (✓ Vega)	60 W	5 Mbit/s

Objectives

Mission Objective:

Measurement of tropospheric nitrogen dioxide (NO2) content with high temporal resolution to issue NO2-related health alerts in near real-time for city targets.

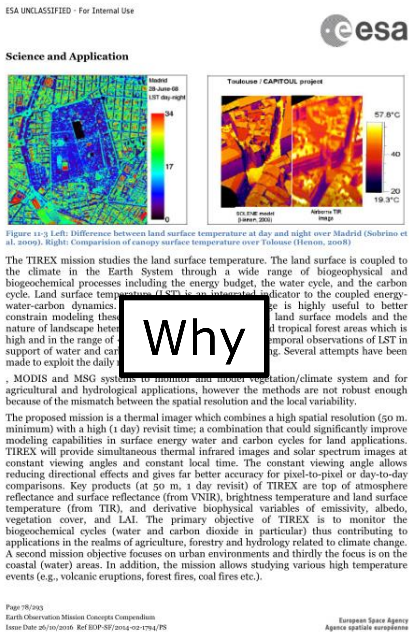
Origin

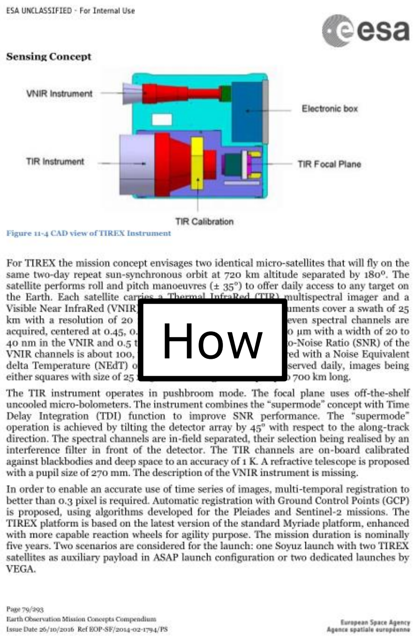
Concept Origin:

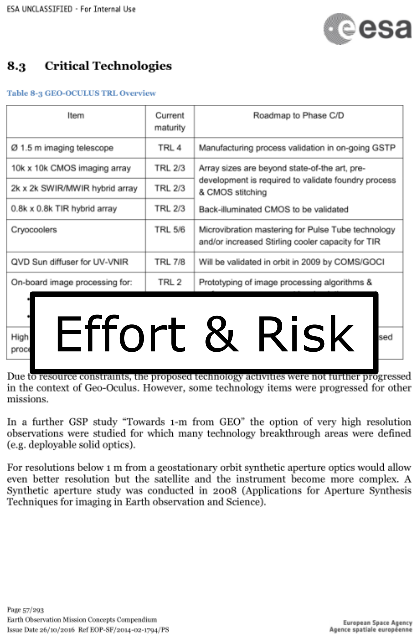
In 2015 the OmniSat-HAPI (High-resolution Anthropogenic Pollution Imager) Nanosat constellation mission was selected as one of two winners of the ESA SysNova R&D Studies Competition for Innovation.

The mission concept was then further reviewed during a CDF study at ESA [RD-65-1].

Concept in Detail (example)







Science and Applications

Sensing Concept

Critical Technologies

Distribution of EO Mission Concepts Compendium

ESAconnect EOP-Community LINK

or directly requested via email to:

- Massimiliano.Pastena@esa.int
- Joerg.Callies@esa.int