European Geodetic Reference Antenna in Space

European Reference Antenna of Space Geodetic Techniques Enhancing Earth Science

Proposal for Earth Explorer Opportunity Mission EE-9

In Response to
Call for Proposals for Earth Explorer Opportunity Mission EE-9 (ESA/EXPLORER/EE-9)
by the

E-GRASP/Eratosthenes Team

June 2016

Science and Industrial Proposal Preparation Team

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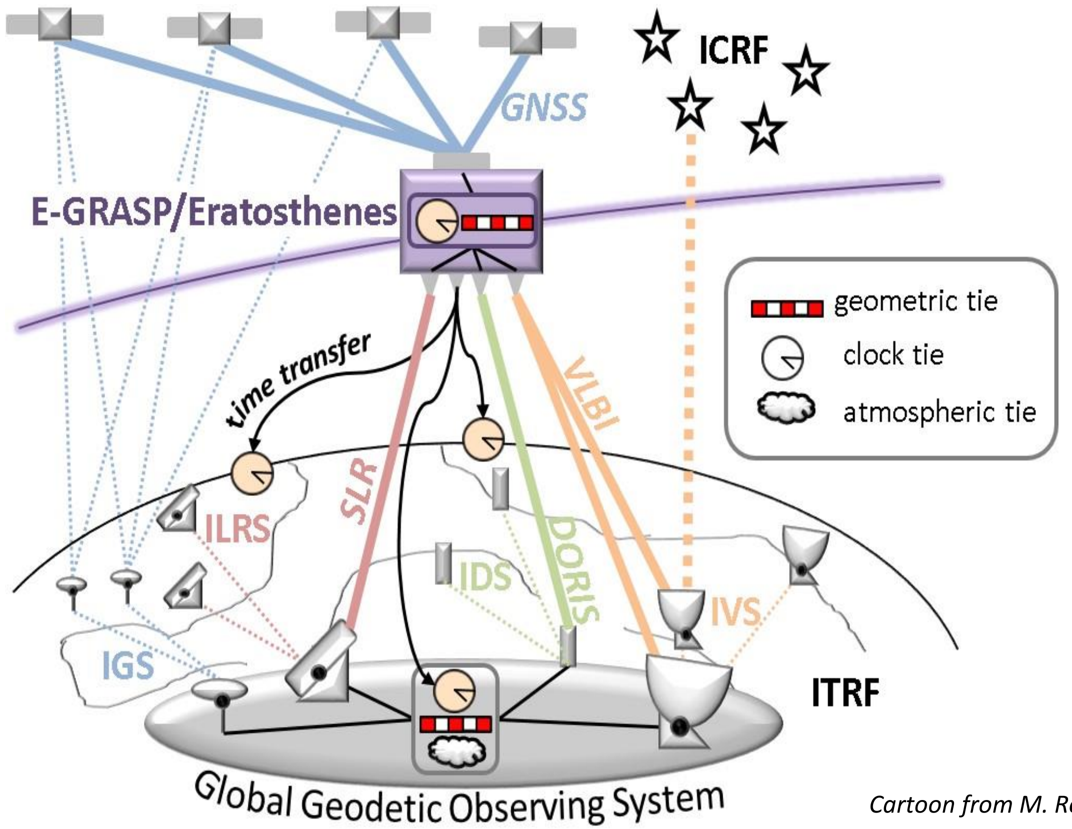
Overview

- **GRASP heritage**
  - proposal to NASA's Earth Venture mission-2 in September 2011 and December 2015
  - Selection of CYGNSS in 2012 and ??? in 2016
- **ESA Framework**
  - proposal to ESA's Earth Explorer Opportunity mission in June 2016
  - selection of 2 missions first in phase A (among 17) in December 2016
  - launch by VEGA-C around 2024
- **Payload**
  - as for GRASP (DORIS, GNSS, SLR, VLBI)
  - precise H-maser clock synchronized by T2L2
  - accelerometer ?
- **Orbit optimization**
  - "performance" eccentric orbit (762-7472 km)
  - "continuity" low orbit (⇔GRASP: 925-1400 km)
- **Science enhancing**
  - Geodesy (Earth reference system and applications)
  - Physics

Unification of reference frames

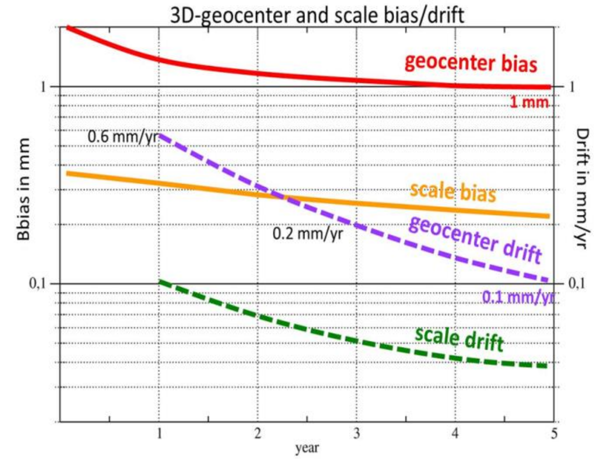


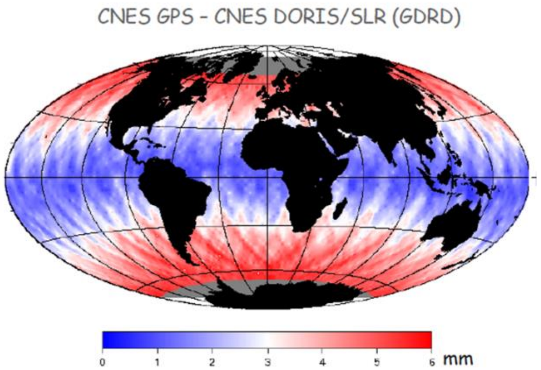
Cartoon from M. Rothacher, ETH

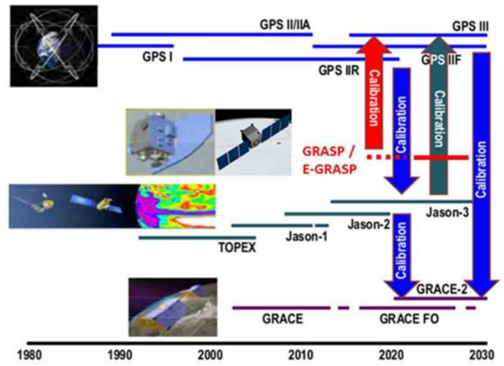
Science concept of E-GRASP/Eratosthenes including the space geodetic techniques and the corresponding co-location concepts

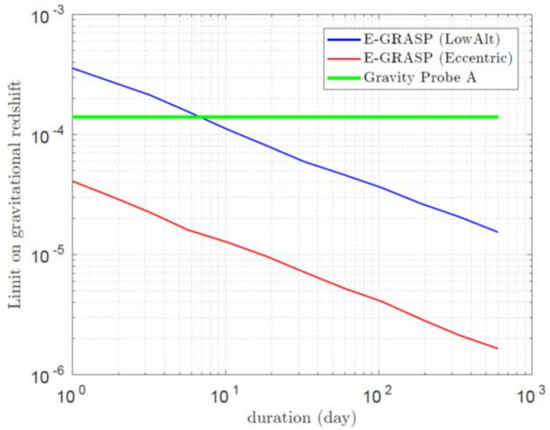
Science Objectives

- Unification of reference frames and Earth rotation
- Geocenter and scale
- Long-wavelength gravity field
- Altimetry and sea level rise
- Determination of ice mass loss
- Geodynamics, geophysics, natural hazards
- Improvement in global positioning
- GNSS antenna phase center calibration
- Positioning of satellites and space probes
- Relativistic physics









Parameters to be retrieved

Classification	Type	Parameter	VLBI	GNSS	SLR	DORIS	LLR
common, global	Satellite orbits	GNSS orbits	(√)	√	√		
		LEO orbit		√	√	√	
		LEO clock		√	(√)		
		E-GRASP orbit	√	√	√	√	
		E-GRASP clock	√	√	√	√	
	EOP	Pole coordinates	√	√	√	√	√
		UT1	√				
		LOD (Length of Day)	(√)	√	√	√	√
		Nutation	√				√
		Nutation rates	√	√	√	√	√
	Gravity field	Earth's center of mass		(√)	√	(√)	
		Low-degree coefficients		√	√	√	(√)
	TRF	Scale	√	(√)	√	(√)	√
common, local	Atmosphere	Ionospheric parameters	√	√	(√)	√	(√)
		Tropospheric parameters	√	√		√	
	TRF	Station positions	√	√	√	√	√
		Station velocities	√	√	√	√	√
	Time & Frequency	Station clocks	√	√	√	√	√
technique-specific	CRF	Quasar positions	√				
		Moon orbit					√
	Instrumental	GNSS clock		√			
		Range biases			√		√

co-location in space (E-GRASP orbit, E-GRASP clock)

co-location on ground (Tropospheric parameters, Station positions, Station velocities, Station clocks)

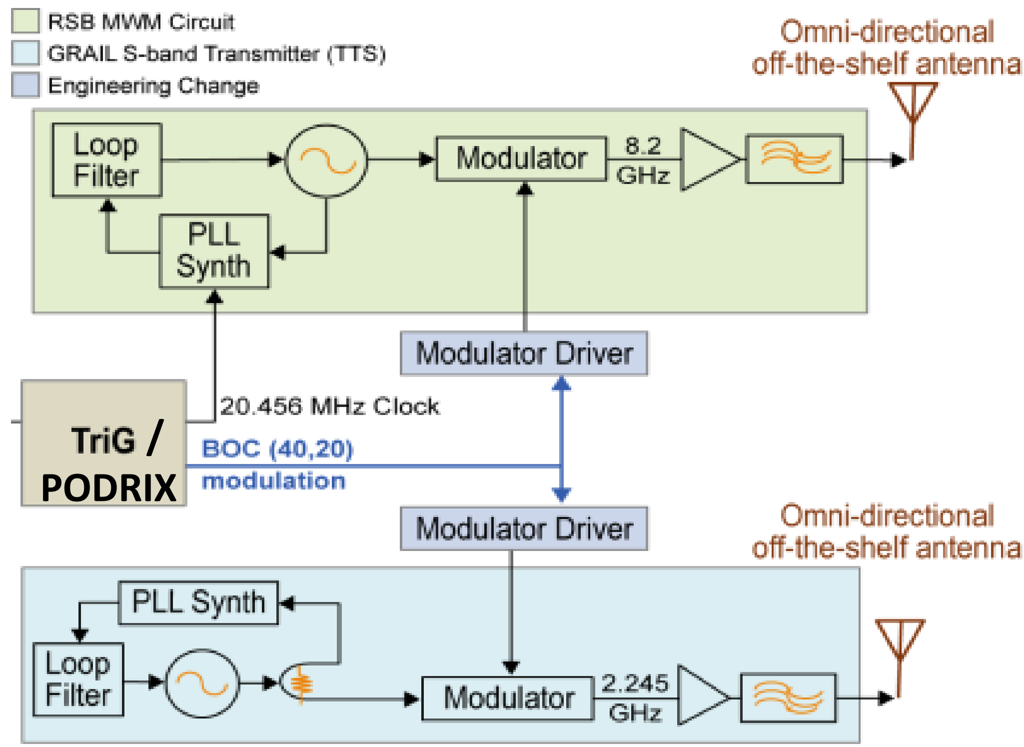
Orbits (continuity and performance scenarios)

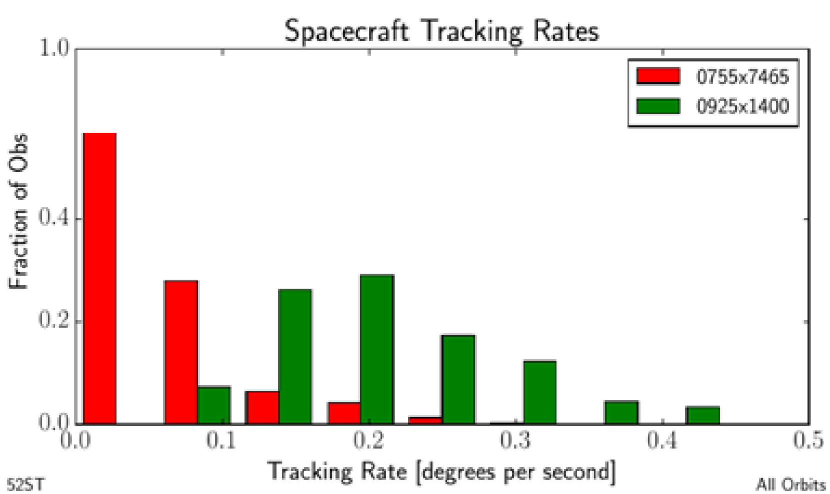
	GRASP scenario	E-GRASP scenario
Perigee altitude	925 km	762 km
Apogee altitude	1400 km	7472 km
Inclination	100.2°	63.4°
Node velocity	.98 deg./day (SSO)	-.97 deg./day
Perigee velocity	-2.35 deg./day	Frozen at equator
Orbit period	109 mn	178 mn

Criterion	GRASP	E-GRASP
Multi-technique visibility (% of seven days)	36.3 %	79.3 %
Mutual visibility for VLBI (baseline ≥ 6500 km - % of seven days)	0.0 %	37.5 %
Number of passes per day for all stations	2	3
Mutual visibility for GPS (% of seven days)	100.0 %	99.4 %
Empty sectors over four weeks (mean value)	71.1 %	5.1 %
Total radiation dose over three years (with 1cm Al shielding)	5.9 krad	5.3 krad

VLBI-transmitter

Key microwave circuitry in the VT is inherited from the GRAIL RSB (green shading) and the GRAIL TTS transmitter (blue shading). The antennas (no shading) are existing flight hardware available to E-GRASP. The Modulation Drivers (mauve shading) will be added as an engineering change.

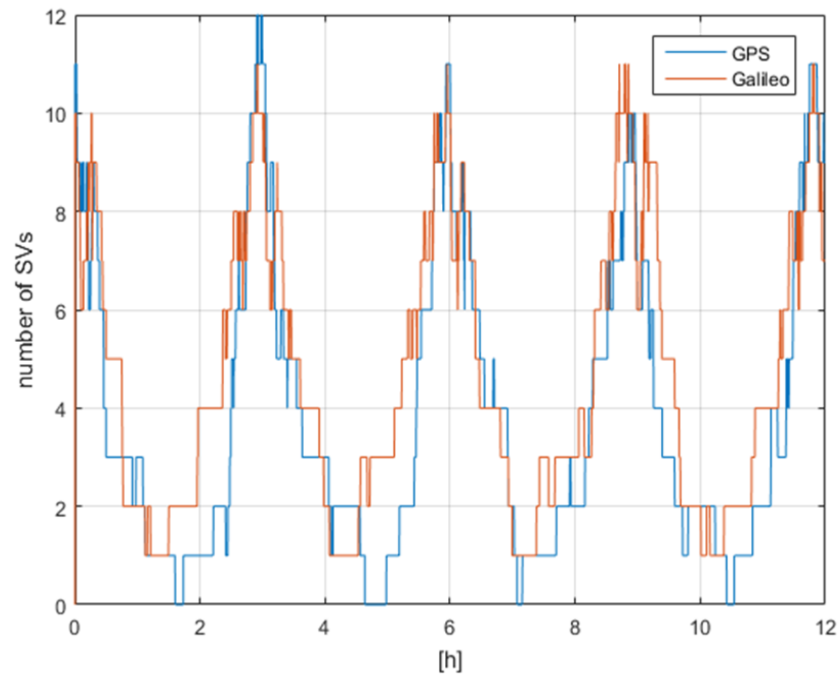




Nearly 90 % of observations for the proposed E-GRASP orbits require tracking speeds no larger than 0.1 degrees per second and can therefore be supported by all IVS VLBI stations.

GNSS

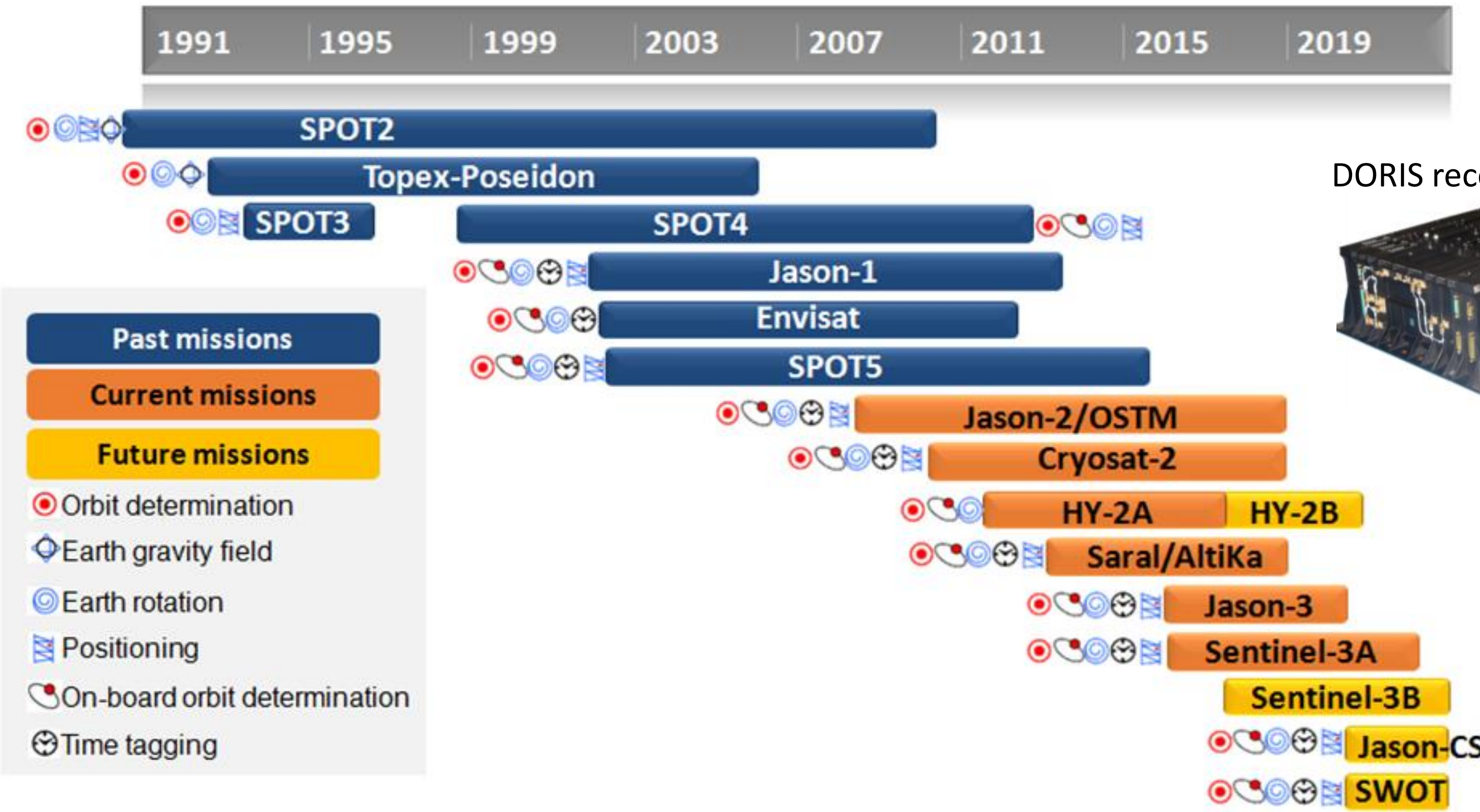
PODRIX is a multi-constellation (GPS & Galileo) multi-frequency (L1/E1, L2 and L5/E5a) GNSS receiver platform from RUAG Space GmbH which is currently under development to be qualified in 2016. PODRIX is a direct continuation of the RUAG Space GPSR-G2 legacy GPS-receivers for Precise Orbit determination (POD), which are used on many European missions such as SWARM, SENTINEL 1,2,3 A/B, EARTHCARE



Identifier number of the visible space vehicles along the orbit with one zenith antenna over 12 hrs. A GNSS space vehicle is considered as visible in case the received carrier to noise ratio on L1/E1 exceeded the 27dBHz, which corresponds to the acquisition threshold of the RUAG GNSS receiver (credits RUAG).

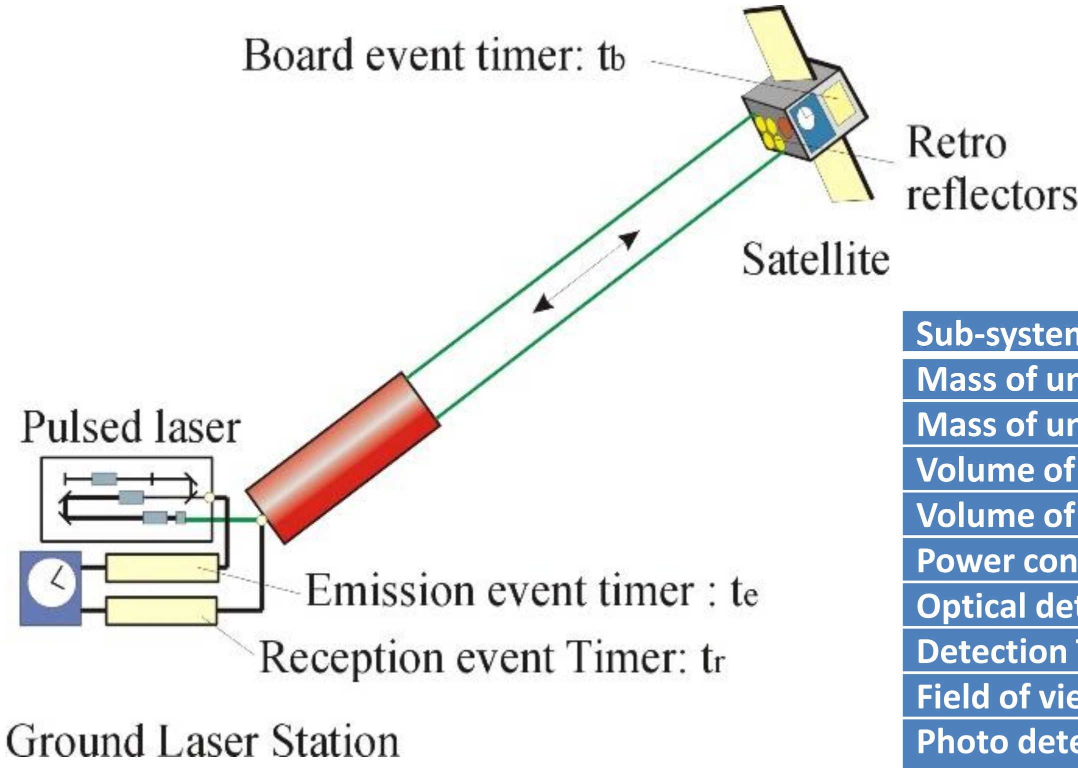
DORIS

- High precision CNES Doppler measurement system (accuracy < 0.3 mm/s)
- Up to 7 dual frequency channels
- Routine high precision measurement mode reached autonomously.
- Direct impact on next altimetric missions tracked with DORIS



DORIS receiver box and antenna

SLR and T2L2 (Time Transfer by Laser Link / OCA)



11 rings with a total of 245 cubes radius of the array about 10 cm because of different velocity aberrations between apogee (30 µrad) and perigee (60 µrad) as proposed by GFZ

Sub-system	Characteristics
Mass of unit A	0.5 kg
Mass of unit B	4 kg
Volume of unit A	50x50x100 mm^3
Volume of unit B	150x150x150 mm^3
Power consumption	30 W
Optical detection wavelength	532.1 nm
Detection Threshold	Single photon
Field of view @ perigee	28°
Photo detection Standard deviation	20 ps RMS @ single photon
Event timer Standard Deviation	1 ps RMS

Principle: for every laser pulse, the laser station measures the start epoch t_e and the return epoch t_r after reflection on the satellite retroreflectors. The T2L2 payload records the arrival epoch on-board t_b

T2L2 flight model (part B) designed for Jason-2 mission

Mini PHM

Mini-PHM derives from PHM (Passive Hydrogen Maser) technology already in flight in the frame of Galileo Global Navigation System.

Leonardo-Finmeccanica

Specification	Mini-PHM
Output Frequency	10.00285741 MHz (fH/142)
Output Level	+ 7dBm (Main and Auxiliary outputs)
Frequency Drift (/Day)	≤ $1x10^{-14}$ after 1 week < $1x10^{--15}$ after 30 days
Allan deviation ($1s<\tau<10^4s$)	< $1x10^{-12}$ x $\tau^{-1/2}$ max < $7x10^{-13}$ x $\tau^{-1/2}$ typical
Freq. sensitivity to temperature	< 1 $x10^{-15}$/°C
Freq. sensitivity to Main Bus Voltage	≤ $3x10^{-15}$/V
Dimensions	210 x 485 x 218 mm
Mass	12 Kg
Main Bus Voltage	50V ± 1V
Power consumption (W)	≤ 54 W at -5°C baseplate ≤ 47 W at +10°C baseplate
Qualification Temp. Range	- 15°C to +20°C
Lifetime (MEO Orbit)	>12 years
Allan deviation (s)	
1	$6.5x10^{-13}$
10	$1.4x10^{-13}$
100	$6.3x10^{-14}$
1000	$2.2x10^{-14}$

Instruments characteristics and TRL

Unit	Manufac-turer	Volume [mm³]	Mass [kg]	Power [W]	Key Performance	Flight Heritage	TRL
Laser Retro-Reflector	GFZ / ASI / INFN	Ø 200, h 100	1	-	1 mm	PN-1A	7
GNSS receiver GNSS antenna	RUAG	280x240x81 Ø 200, h 87	3 .8	15	1 mm	Swarm, Sentinel, Earthcare	8
DORIS receiver DORIS antenna	TSA	388x366x173 Ø 160, h 427	18 2	22	.3 mm/s	Sentinel3, Jason	8
VLBI-Transmitter S-band antenna X-band antenna	JPL	190x210x60 100x100x6 Ø 44, h 200	3 .3 .4	10	1 mm	GRASP	6
T2L2	OCA	50x50x100 150x150x150	0.5 4.5	30	100 ps	Jason-2	4
OUS (with redundancy)	Leonardo/ Spectratim	210x485x218	24	≤ 56	10^{-14}	Galileo	6
Σ			54.8	133			
Micro-STAR	ONERA		12	12	10^{-11} m/s/√Hz	GRACE, GOCE	4

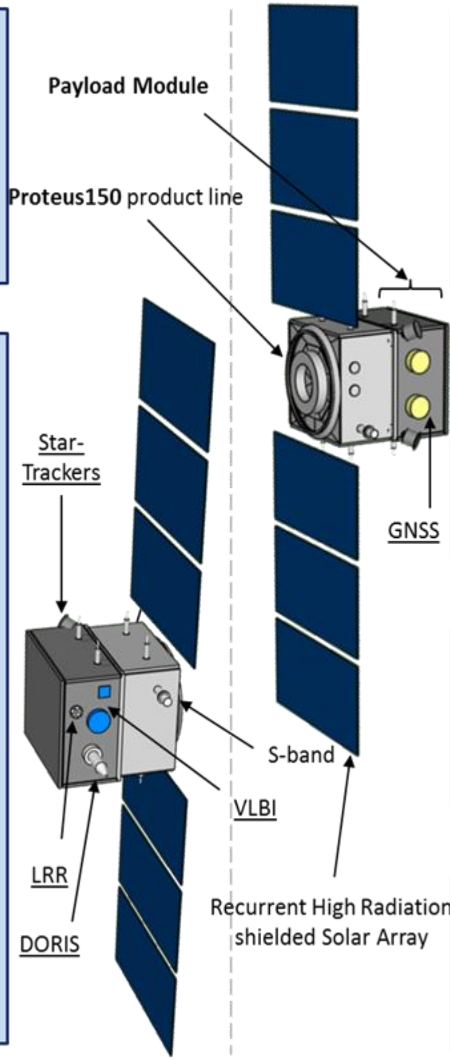
Mission architecture

Mission requirements

- High elliptical orbit with enhanced observations opportunities.
- Multiple payload to drastically improve TRF knowledge with multiple application

Satellite

- Instruments & Star-Trackers on a dedicated Payload Module
- Recurrent radiation-shielded Solar Array (SA)
- Platform Proteus150 with structure adaptation to support the Solar Array
- Satellite dry mass < 500 kg
- Attitude Control : reaction wheels
- Uncontrolled reentry : lowering perigee with chemical propulsion
- TMI & TTC : S-band
- Scientific data 220 Mbit/day
- Yaw Steering to optimize power along the orbit



Mission

- High elliptical orbit : 762 - 7472 km
- Inclination 63°
- 5 years lifetime
- Launch in 2024

Launcher

- VEGA-C main and only passenger
- Compatible with VEGA Fairing
- Direct injection

Ground Segment

- Flight Operation Segment in ESOC
- Payload Data Ground Segment

Instruments

- DORIS
- VLBI
- LRR/SLR
- GNSS

E-GRASP challenges and recommendations

- Improving the TRF passes by a unique system, integrating all space geodetic techniques on one platform, with orbit and calibration optimized, in order to meet the present-day science requirements

- The TRF available today needs an improvement by a factor of 5, as a minimum (recent ITRF2014 results)

- The accuracy of the Terrestrial Reference Frame (TRF) impacts directly the orbit determination of altimetric satellites and land motion estimation at tide gauges and consequently the quantification of the sea level variations in space and time.

- More generally, global studies on the mass budget of the earth-ocean-atmosphere system and on global tectonics require an accurate TRF.

- "Earth observations must become more precise. We require information about current trends at a scale measured in millimeters to detect changes of the Earth system with sufficient precision, to meet society's future needs", *Report of the UN expert committee on "Global Geospatial Information Management", 2014*