The SCM instruments for the NASA HelioSwarm and the ESA Plasma Observatory missions

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Abstract

The HelioSwarm (HSW) mission, leaded by H. Spence and K. Klein, is constituted by a platform (Hub) with eight small satellites (nodes) and aims at investigating the plasma turbulence in weakly collisional plasma like the solar wind. It was selected by NASA in 2022 after a competitive MIDEX phase A and its launch is now planned in 2030. The two main objectives are 1/ the study of the three dimensional (3D) structure and dynamics of the plasma turbulence, 2/ the study of the mutual impact of the turbulence near boundaries (e.g. Earth's bow shock, magnetopause) and large-scales structures (e. g., coronal mass ejection, streaming interaction regions). In particular the detailed mechanisms of the turbulent energy cascade will be investigated by measuring, for the first time, magnetic and plasma fluctuations (ion density and velocity) simultaneously, from the fluid to the subion scales.

The proposal of the Plasma Observatory mission was selected for a competitive phase A with two other missions in the framework of the seventh call for medium mission (M7) organized by ESA. The mission selection is planned in June 2026 for a launch in 2037. Its main objectives are to unveil how are particles energized in space plasma and which processes dominate energy transport and drive coupling between the different regions of the terrestrial magnetospheric system? After the Mission Consolidation Review by ESA in February 2025 followed by reformulation discussions, the mission now consists of seven identical small satellites equipped by an updated payload, still evolving along an equatorial elliptical orbit with an apogee ~17 and a perigee ~8 Earth radii. The seven satellites will fly forming two tetraedra and allowing simultaneous measurements at both fluid and ion scales. The mission will include three key science regions: dayside (solar wind, bow shock, magnetosheath, magnetopause), nightside transition region (quasidipolar region, transient near-Earth current sheet, field-aligned currents, braking flow region) and the medium magnetotail. Plasma Observatory mission is the next logical step after the four satellite magnetospheric missions Cluster and MMS.

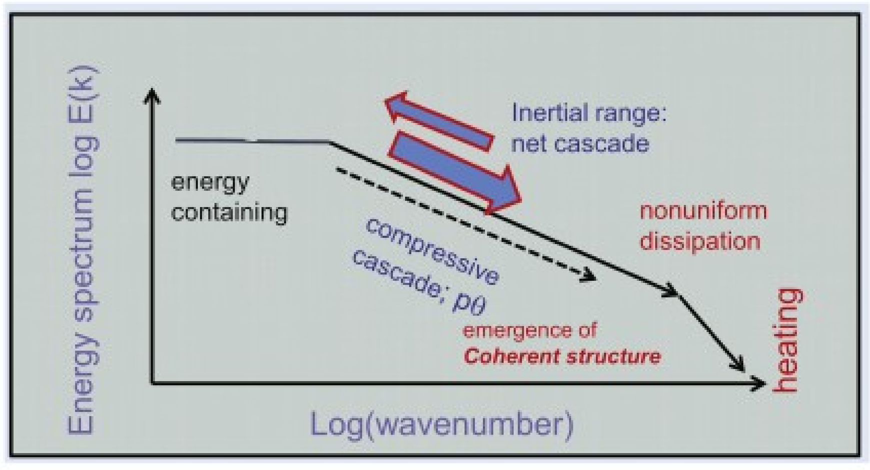
The search-coil magnetometer (SCM) proposed for these two missions, strongly inherited of the SCM designed for the ESA JUICE mission, is required on all satellites. For both missions, SCM will be delivered by LPP and LPC2E and will provide the three components of the magnetic field fluctuations. The nominal frequency range is [0.1Hz-16Hz] and [1Hz-8kHz] for HSW and PO respectively. While SCM onboard HSW will provide multiple sequences of 1-hour continous waveforms required for statistical studies of the plasma turbulence, PO-SCM will provide continuous waveforms and snapshots every 4 s, sampled at 512 Hz and 16 kHz respectively. SCM will allow to fully characterize the wave polarization at multi-points as well as to perform k-filtering at fluid and ion scales. These measurements are crucial to understand the role of electromagnetic waves in the energy conversion and partitioning processes, the plasma and energy transport, the acceleration and the heating of the plasma.

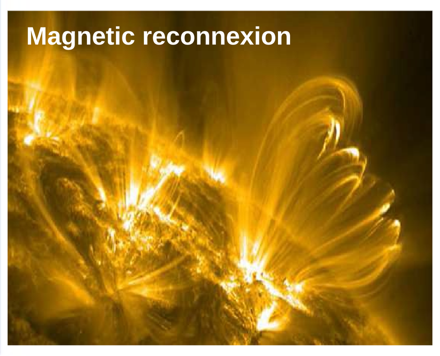
Introduction

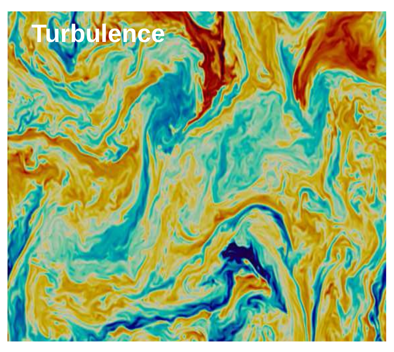
Plasmas processes (turbulence, magnetic reconnection, shocks, jets, ...) are very dynamic and involve cross-scale coupling from fluid to electron scales

=> Objective of simultaneous multi-scales (from fluid to subionic) measurements **HelioSwarm** NASA (launch 2030) & **Plasma Observatory** ESA/M7 (launch 2039)

Turbulent cascade, energy dissipation and heating
[e.g. Matthaeus et al., ApJ, 2020]







Scientific objectives

In situ study of multiscale processes related to the plasma turbulence leading to energy cascade from large scales (fluid) to small kinetic scales (ionic and subionic) and plasma heating (ions)

Focused on solar wind as a unique example of an expanding turbulent astrophysical plasma in the near-Earth environment

The two main objectives are:

1/ To study the 3D temporal and spatial distribution of the plasma turbulence

2/ To determine the mutual impact of the turbulence near boundaries and large scale structures (e. g. coronal mass ejection, interplanetary and terrestrial shocks, magnetopause, ...)

=>Thanks to **simultaneous measurements from fluid scales to subionic scales**

Fundamental questions:
1/ How are particles energized in space plasmas?
2/ Which processes dominate energy transport and drive coupling between the different regions of the Earth's magnetospheric system?

=> Need to study scale coupling and non-planarity/non-stationarity in fundamental collisionless plasma processes : shocks, magnetic reconnection, waves and turbulent fluctuations, plasma jets, field-aligned currents and instabilities.

Provide, for the first time, simultaneous measurements at fluid and ions scales in the Earth's magnetospheric system. It will revolutionise our understanding of the energy exchanges in the plasma environment of our planet with a major impact on the understanding of astrophysical plasmas too. PO is the next logical step in the field of space plasmas.

Secondary objectives
Effects of ionospheric processes on the magnetospheric system (e.g., ion outflows)
Outer radiation belts and inner magnetospheric processes
Solar wind physics and space weather science

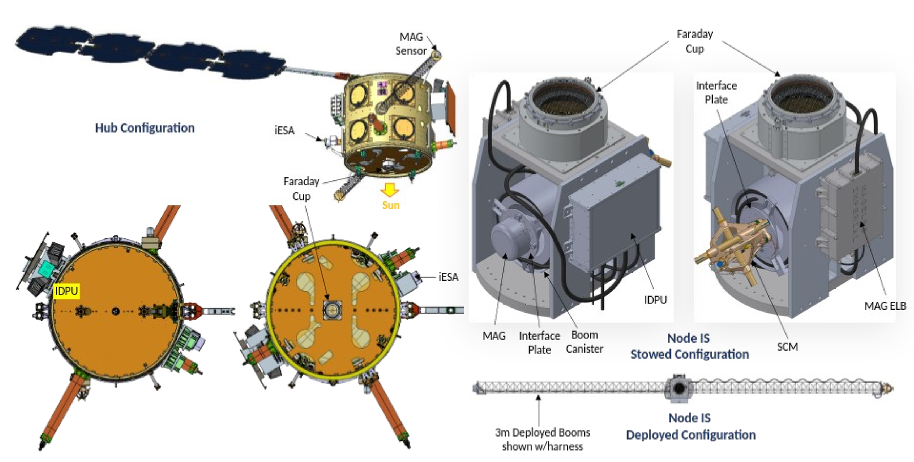
Mission concept

HelioSwarm was **selected on February 10th, 2022 by NASA**

PI H. Spence, UNH ; CoPI K. Klein, Univ. Arizona

1 plateform (Hub) + 8 small identical satellites (nodes) three-axis stabilised with propulsion and allowing an analysis simultaneously at different scales with 35 pairs and 126 tetraedras from ~ 3000km (MHD) to ~ 50km (subionic)
Orbit: lunar resonance ~ 64.3 RE (far from the bow shock) and perigee at 11.6 RE (good telemetry rates)

Budget: 250 M$, **duration**: 15 months, **launch**: 2030

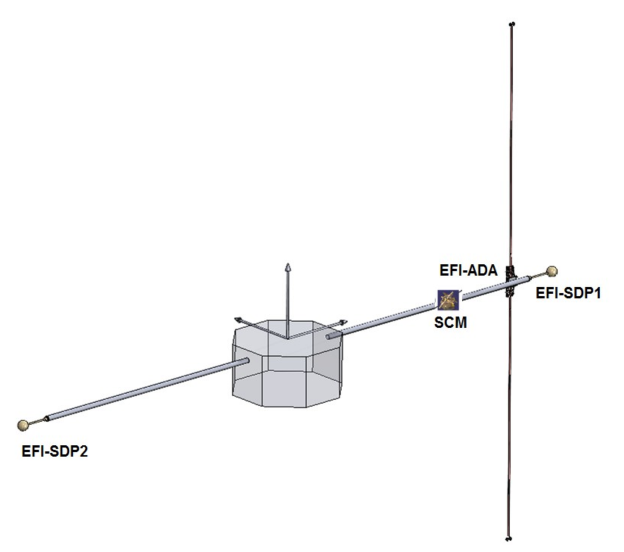


Plasma Observatory is recommended by the ESA Senior Science Committee on May 20, 2026 to the SPC

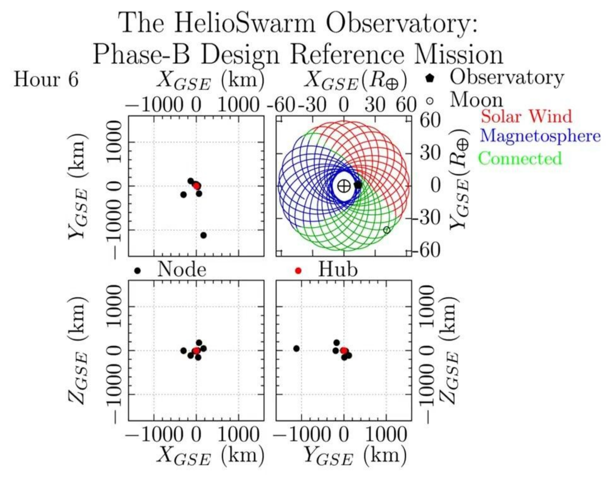
Consortium Leads : F. Marcucci, INAF, Italy ; A. Retino, LPP, France

7 small identical spinning (4s) satellites separated from 100km to 3000km
Orbit inclination : 15°, Apogee: 17RE, perigee : 7 RE

Budget: ~700 Meuros, **duration**: 36 months, **launch**: 2039

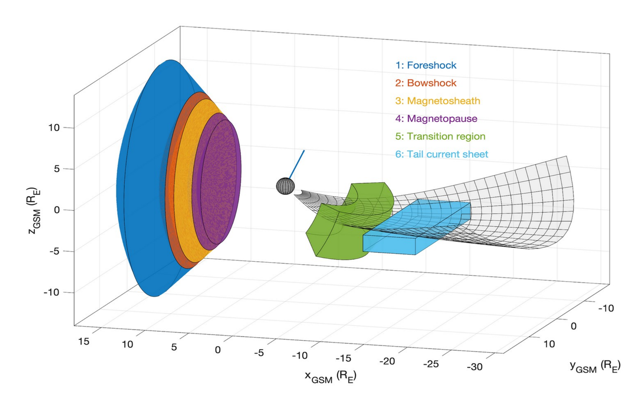


Mission concept



Data available in open access 6 months after downloading at the UNH Science Data Center
Level 2 data in s/c frame and L3 in RTN frame provided by instrumental teams
Mission milestones
Instrument PDR June 9-11 2026
Mission PDR August 18-20. 2026
Mission CDR December 2027
9 SCM FM deliveries from Dec. 2027 to April 2029
Launch : 2030
Phase E/F : 3 months of commissioning + 1 year nominal science exploitation

PO Key Science Regions (KSR)



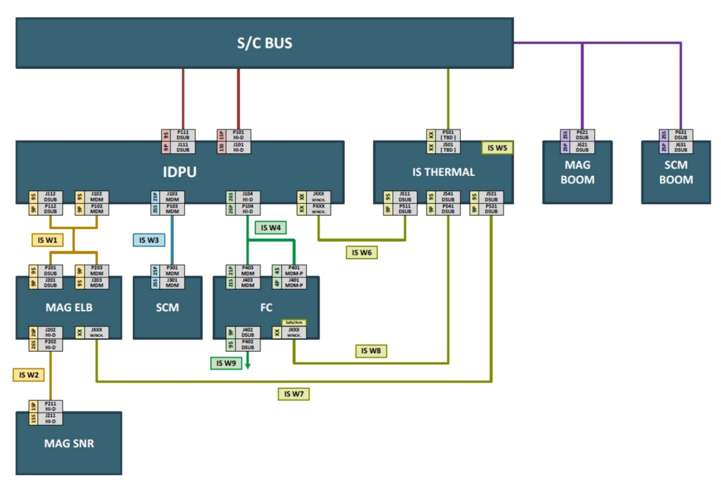
Data available in open access 3 months after downloading through the ESA Heliophysics archive (HPA)

Mission milestones
Mission adoption Review September-November 2028
Phase B2 Kick off November 2029
Instrument PDR January-July. 2030
Instrument CDR January-February 2033
Launch : 2037
Phase E/F : Commissioning+ 3 year nominal science exploitation

Instrumentation

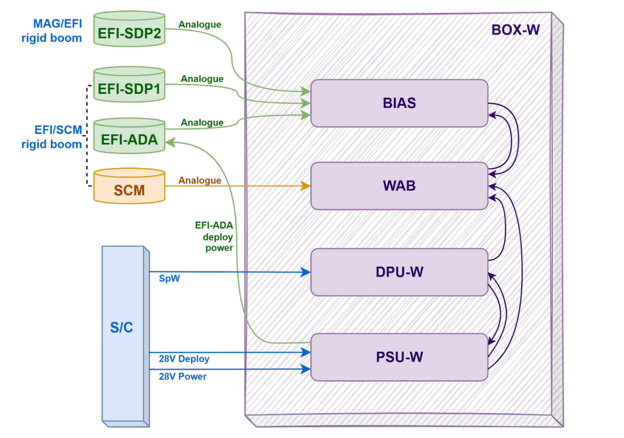
HelioSwarm

- Magnetometer (MAG/IDPU)x9 : DC IMF B 2Hz,+/-100nT, 0.15nT
- Search-Coil Magnetometer (SCM/IDPU)x9 : AC IMF B 32 Hz, 15, 1.5 pT/qrt(Hz) @ 1/10Hz
- Faraday Cup (FC/IDPU)x9 : np, vp @ 0.15s, 0.2-20 p/cc, 250-800km/s
- Ion Electrostatic Analyzer (iESA)x1 (Hub, separate DPU) : np, vp, Tp, Tperp,p/Tpara,p @ 0.3s, nalpha/np @ hourly averages



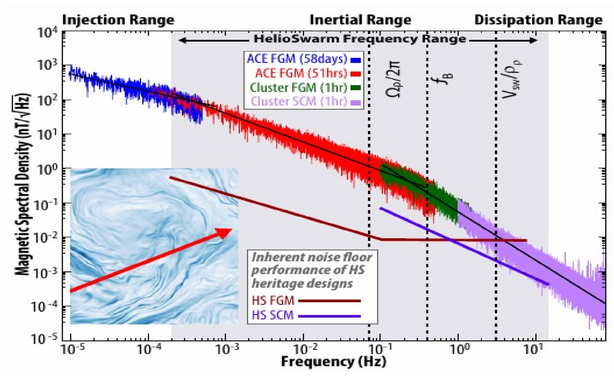
Plasma Observatory

- **BOX-P (Particle and magnetometer electronics box)**
- **IMCA**: Ion Mass Composition Analyzer (10 eV-30keV, 3D VDF at 2 s)
- **MAG:** Fluxgate magnetometer (2 units, DC to 128Hz)
- **IEPC:** Ion and Electron Plasma Camera
- Two Top-hat electrostatic analyser designs with toroidal heads (10eV-25keV, 3D VDF at 0.25s)
- **EPE:** Energetic Particle Experiment
- Two detectors per species (e-, H+) from (30keV-600keV, 3D VDF at 4s)
- **WAVES Suite (see Figure)**
- **BOX-W (Waves electronics box: BIAS, WAB, DPU-W, PSU-W)**
- **SCM:** High-frequency magnetic fluctuations [1Hz, 8kHz]
- **EFI:** DC and AC electric fields (Spin-plane Double Probe [DC,100kHz] and Axial Dipole Antenna [10Hz, 100kHz])



SCM Flight Models delivered by LPP&LPC2E

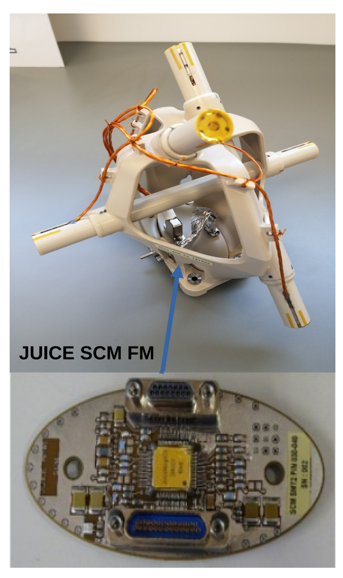
- **HelioSarm**
- **9 SCMs:** measurements of 3D magnetic fluctuations [0.1,16Hz]
- **Lead instrument**: O. Le Contel (LPP)
- **Calibration lead:** A. Retinò (LPP) **Deputy**: M. Kretzschmar (LPC2E)
- **Technical Manager**: J. Gironnet (LPP) **Deputy** : G. Jannet (LPC2E)
- **Lead electronics**: F. Mehrez (OMEGA)
- **Electronics engineers** (LPP) : D. Alison, H. Ba (Feb. 2024-May2026)
- **GSE Software developments** : C. Revillet (LPC2E)
- **Ground segment** : L. Mirioni (LPP), C. Revillet
- **PA/QA**: C. Agrapart (LPC2E, Lead), O. Mbeumou (Hendsoldt)
- **Mechanical and thermal analyses** : N. Geyskens, C. Berthod (DT-INSU)



Strong JUICE SCM heritage:
nominal performance during near-Earth commissioning after launch in April 2023

JUICE SCM heritage	
Observables	AC magnetic vectors
Dimensions (mm)	178x215x204
Mass (kg)	0.627
Power (W)	0.250
Frequency range	1Hz to 20 kHz
Sensitivity (nT²/Hz) @ [1, 10, 100, 1000, 8000] Hz	[10^{-3}, 1.5×10^{-6}, 5×10^{-9}, 10^{-10}, 5×10^{-10}]

Mechanical design by DT-INSU



ASIC design LGEEP/LPP
Heritage: JUICE TRL 8

- **Plasma Observatory**
- **7 SCMs:** measurements of 3D magnetic fluctuations [0.1,8kHz]
- **PI**: O. Le Contel (LPP)
- **CoPI:** M. Kretzschmar (LPC2E)
- **Technical Manager**: J. Gironnet (LPP) **Deputy** : G. Jannet (LPC2E)
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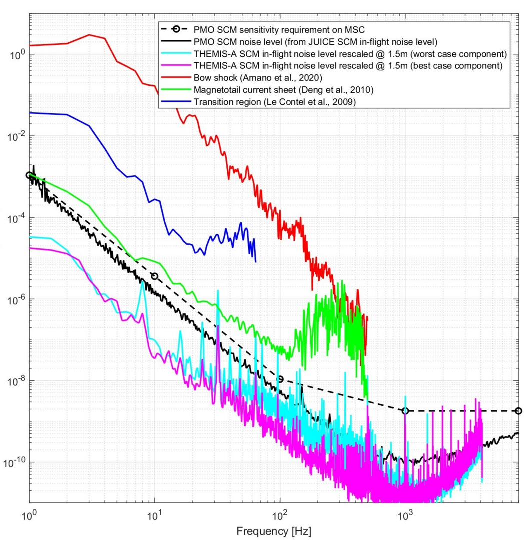
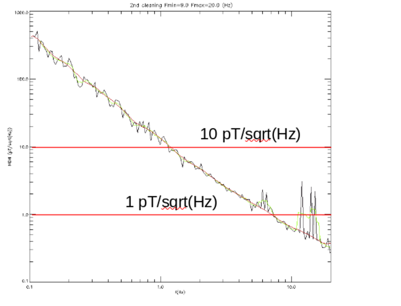


Spectra representative of the expected power spectral density of magnetic fluctuations for the three KSRs are shown (red for dayside bow shock, blue for the transition region and green for the mid magnetotail).

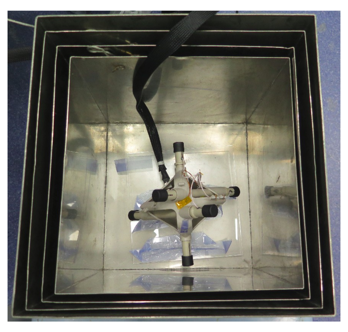
To estimate the possible broad-band noise generated by the PO s/c and measured by SCM, the broad-band noise emitted by a THEMIS probe and measured by THEMIS SCM located at 1 meter from the s/c has been rescaled at the expected 1.5m distance from the s/c (worst/best case components in cyan/magenta).

The PO SCM requirements are shown for reference (black dashed line) indicating that SCM will be able to properly measure natural emissions to address PMO science goals in the KSRs.

SCM HelioSwarm prototype compliant with sensitivity requirements (Sampling frequency 512 Hz provided by IDPU/UNH then downsampled to 32 Hz)

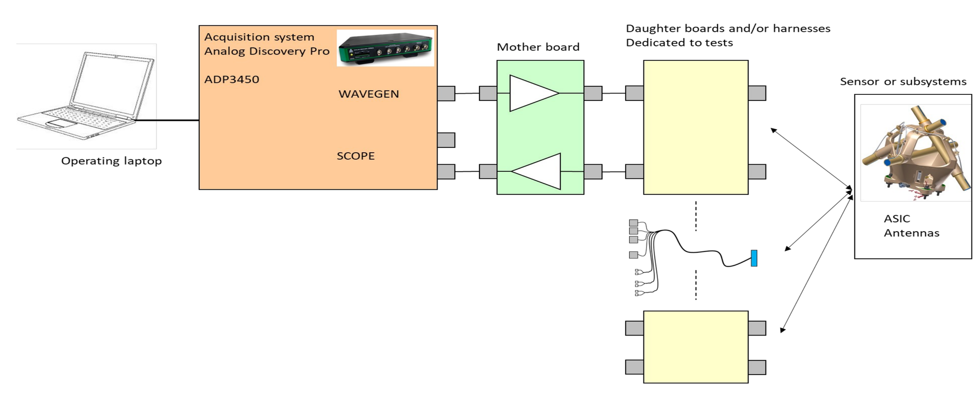


HelioSaws SCM prototype sensitivity



HelioSaws SCM EM testing before gluing

Automatised E-GSE structure developed for HelioSwarm (~ 10 units to be tested and calibrated in 1,5 year)
- Signal acquisition with Discovery pro ADP3450 (4 scope channels, 2 generator channels)
- Common mother board for signals grounding adaptation, attenuators and voltage regulation/filtering
- Test dedicated daughter boards
- Software (Python) MASCOTS driving the ADP3450 displaying results and doing required calculations
- ASIC screening board ready. First tests planned in January with first version of MASCOTS



E-GSE general view

cnes