The SCM for the NASA HelioSwarm mission

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Abstract

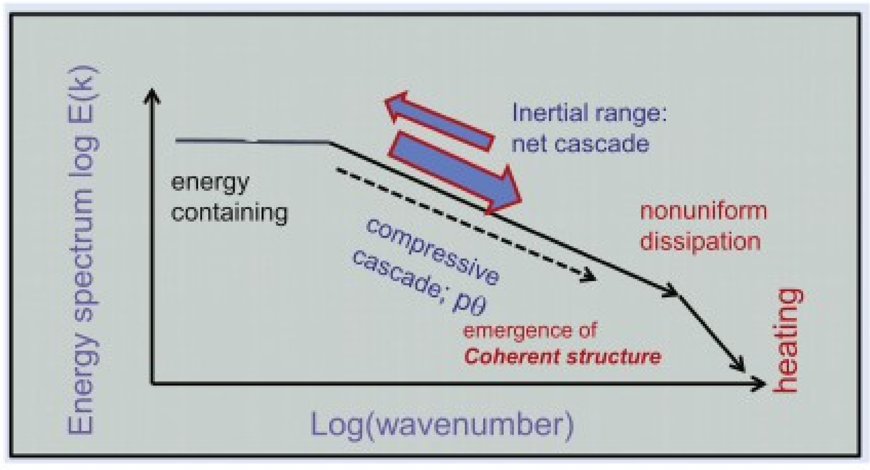
The HelioSwarm mission was selected as a MIDEX mission by NASA in February 2022 for launch in 2029 with a nominal duration of 15 months. Its main objectives are to reveal the 3D spatial structure and dynamics of turbulence in a weakly collisional plasma and to investigate the mutual impact of turbulence near boundaries (e. g., Earth's bow shock and magnetopause) and large-scale structures evolving in the solar wind (e. g., coronal mass ejection, corotating interaction region). Therefore the HelioSwarm mission will strongly contribute to the space weather science and to a better understanding of the Sun-Earth relationship. It consists of a platform (Hub) and eight smaller satellites (nodes) evolving along an elliptical orbit with an apogee ~ 60 and a perigee ~15 Earth radii. These 9 satellites, three-axis stabilised, will provide 36 pair combinations and 126 tetrahedral configurations covering the scales from 50 km (subion scale) to 3000 km (MHD scale). It will be the first mission able to investigate the physical processes related to cross-scale couplings between ion and MHD scales by measuring, simultaneously at these two scales, the magnetic field, ion density and velocity variations. Thus each satellite is equipped with the same instrument suite. A fluxgate magnetometer (MAG from Imperial College, UK) and a search-coil magnetometer (SCM) provide the 3D measurements of the magnetic field fluctuations whereas a Faraday cup (FC, SAO, USA) performs the ion density and velocity measurements. In addition, the ion distribution function is measured at a single point onboard the Hub by the iESA instrument, allowing to investigate the ion heating in particular. The SCM for HelioSwarm provided by LPP and LPC2E is strongly inherited of the SCM designed for the ESA JUICE mission. It will be mounted at the tip of a 3 m boom and will cover the frequency range associated with the ion and subion scales in the near-Earth environment [0.1-16Hz] with the following sensitivities [15pT/√Hz at 1 Hz and 1.5 pT/√Hz at 10 Hz].

Introduction

The turbulence plays a crucial rôle in the mass, momentum and energy transports notably in the magnetised plasmas.
"the most important unsolved problem of classical physics" [R. Feynman et al. 1964, The Feynman lectures on physics]

Turbulence is present in astrophysical and laboratory plasmas and can be coupled with other fundamental processes such as reconnection, shock, acceleration, heating, ...

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



Plasmas processes 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 & **Plasma Observatory** ESA/M7 (phase A)

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 astrophysical plasma in the near-Earth environment

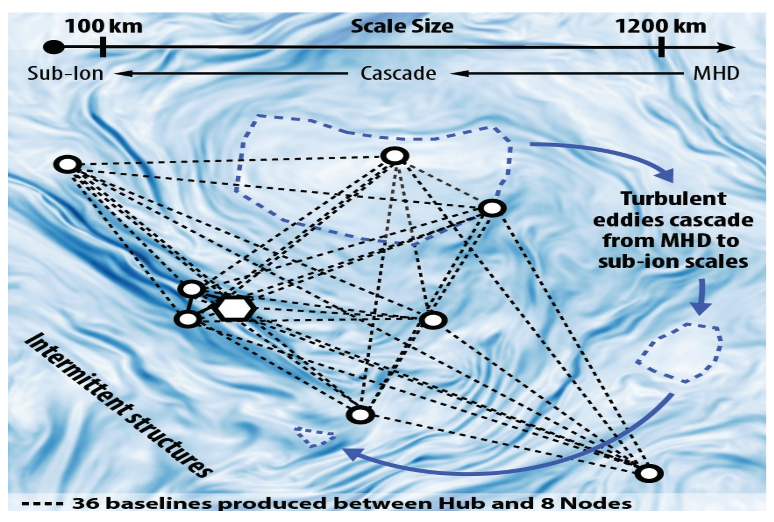
The two main objectives are:

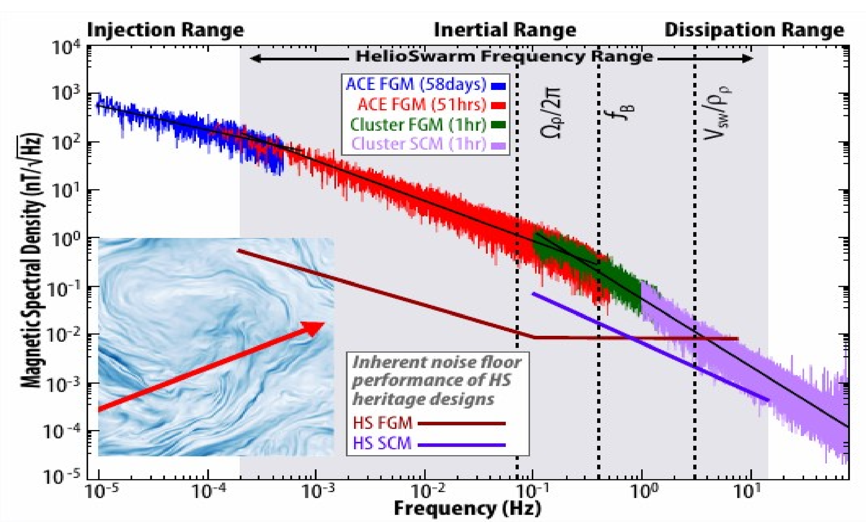
1/ To study the 3D temporal and spatial distribution of the plasma turbulence

2/ To determine the mutual impact of 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**





Mission concept

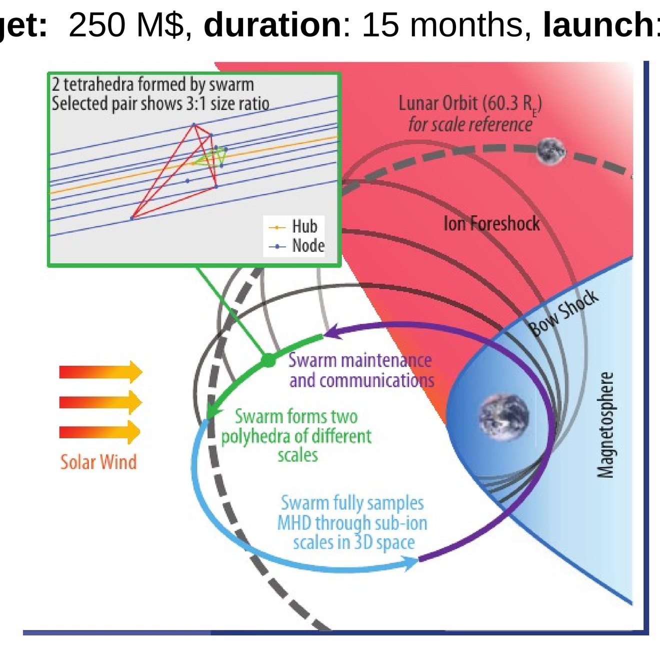
HelioSwarm was selected in phase A (9 months, 1.25 millions $/prop.) of 2019 NASA AO MIDEX call with 5 other proposals on Aug. 28th, 2020.

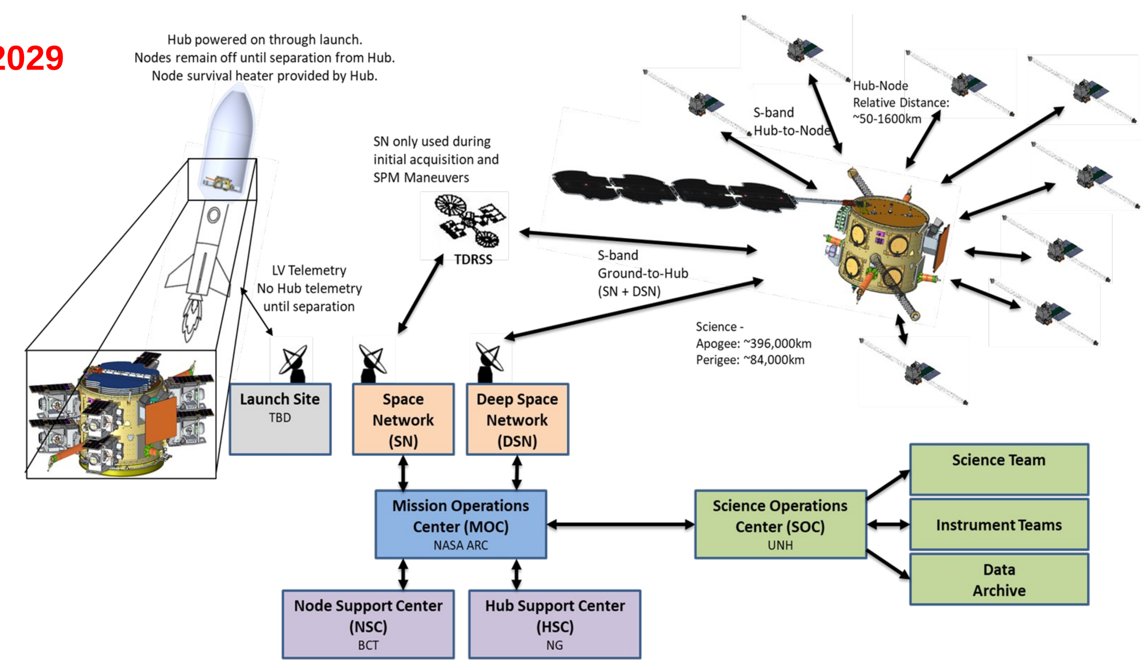
Concept Study Report (CSR)/end of phase A : July 7th, 2021 => **Selected on February 10th, 2022**
CNES review of end of Phase A: March to December 2022

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

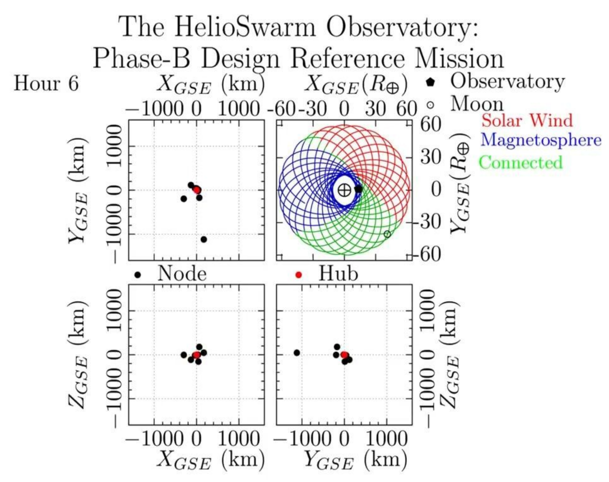
1 plateform (Hub) + 8 small identical satellites (nodes) three-axis stabilised with propulsion and allowing an analysis simultaneously at different scales with 35 pairs and 126 tetraedras from ~ 3000km (MHD) to ~ 50km (subionic)
Orbit: lunar resonance ~ 64.3 RT (far from the bow shock) and perigee at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

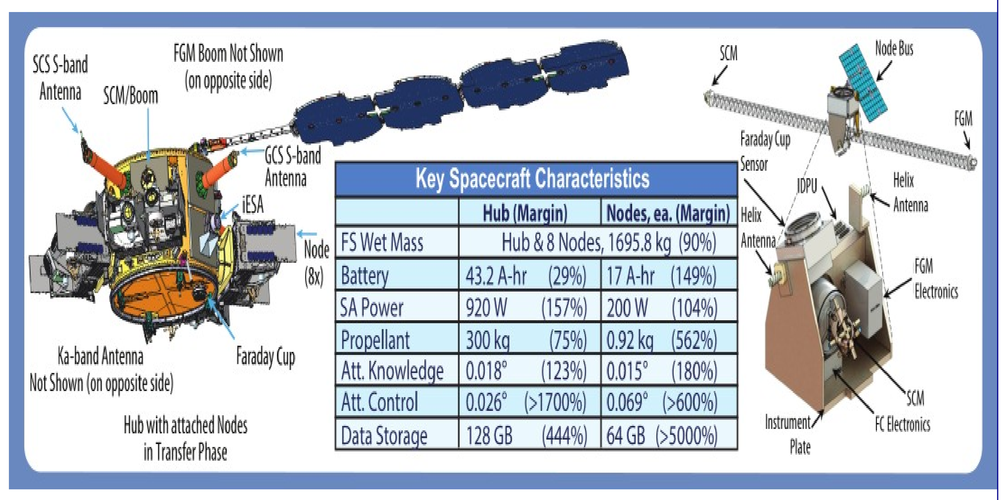
Budget: 250 M$, **duration**: 15 months, **launch**: **early 2029**





Mission concept



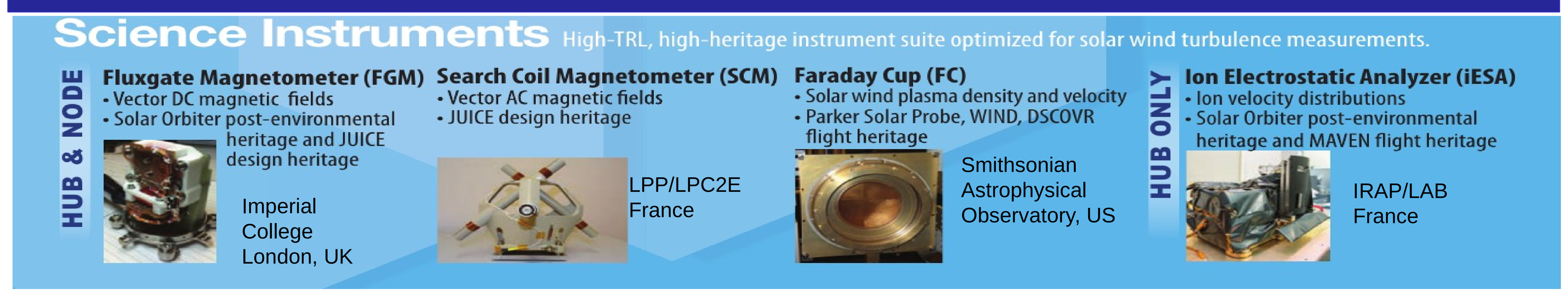


Data available in open access 6 months after downloading at the UNH Science Data Center
Level 2 data in s/c frame and L3 in RTN frame provided by instrumental teams

Mission milestones

PrePhase B: April 2022 June 2024
Phase B : June 2024 to September 2025 (EM delivery end of phase B)
Mission PDR september. 2025
Phase C : October 2025 to July 2027 (FM deliveries)
Mission CDR November 2026
Phase D : Aug. 2027 to early 2029 (satellite integrations)
Launch : ~ Janvier 2029
Phase E/F : 3 months of commissioning + 1 year nominal science exploitation

Instrumentation

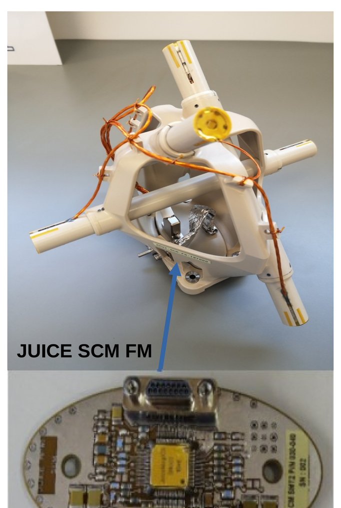


Observable	Requirement	Projected Performance	Instrument
Multi-point vector DC IMF **B**	DC to 2-Sps $\pm 100nT$ 0.15 nT per axis	DC to 16-Sps $\pm 128nT$ 0.1 nT per axis	MAG (all SC)
Multi-point vector AC IMF **B**	0.1 to 32-Sps $15/1.5$ pT/$\sqrt{}$Hz at 1/10 Hz	up to 32-Sps $6/0.6$ pT/$\sqrt{}$Hz at 1/10 Hz	SCM (all SC)
Multi-point proton density n_p	0.15 s 0.2 - 20 cm^{-3} $\pm 6\%$	0.125 s 0.1 - 50 cm^{-3} $\pm 5\%$	FC (all SC)
Multi-point proton velocity $\mathbf{v}_p$	0.15 s 250 - 800 km/s $\pm 3\%$	0.125 s 212 - 840 km/s Accuracy $\pm 1\%$	FC (all SC)
Single-point proton temperature T_p	0.3 s $10^4 - 5\times 10^5$ K $\pm 5\%$	0.15s $10^4 - 10^6$ K $\pm 1.8\%$	iESA (Hub)
Single-point temperature anisotropy $\frac{T_\perp}{T_\parallel}$	0.3 s $0.2 - 5$ $\pm 6\%$	0.15s $0.1 - 10$ $\pm 3.4\%$	iESA (Hub)
Single-point α-proton density ratio $\frac{n_\alpha}{n_p}$	Hourly Averages $0 - 40\%$ $\pm 10\%$	10 s $0 - 100\%$ $\pm 3.4\%$	iESA (Hub)

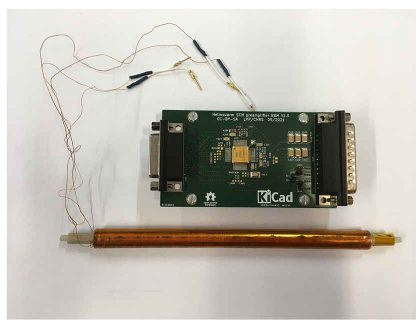
Nine Search Coil Magnetometers (SCM) delivered by LPP&LPC2E

- **9 SCMs:** measurements of 3D magnetic fluctuations [0.1,16Hz]
- **Strong heritage:** from SCM JUICE, dimensions 20x20x20cm³, 545g, 250mW, [0.1Hz, 20kHz], nominal performance during near-Earth commissioning after launch in April 2023
- **Lead instrument**: O. Le Contel (LPP)
- **Calibration lead:** A. Retinò (LPP) **Deputy**: M. Kretzschmar (LPC2E)
- **Technical Manager**: M. Mansour (LPP) **Deputy** : G. Jannet (LPC2E)
- **Lead electronics** : F. Mehrez (LPP)
- **Electronics engineers** (LPP) : D. Alison, H. Ba (Feb. 2024)
- **GSE Software developments** : C. Revillet (LPC2E)
- **Ground segment** : L. Mirioni (LPP), C. Revillet
- **PA/QA Lead** : C. Agrapart (LPC2E)
- **Mechanics Lead** : N. Geyskens
  SCM HelioSwarm prototype compliant with sensitivity requirements
(Sampling frequency 128 Hz provided by LFR/UNH)

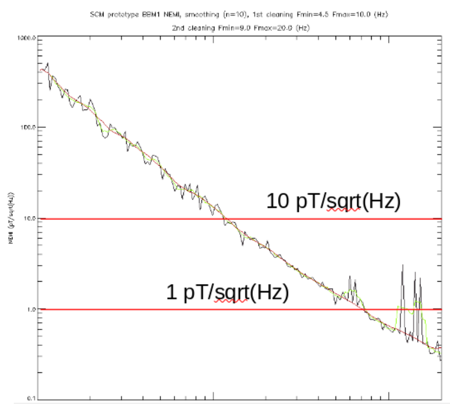
Mechanical design by DT-INSU



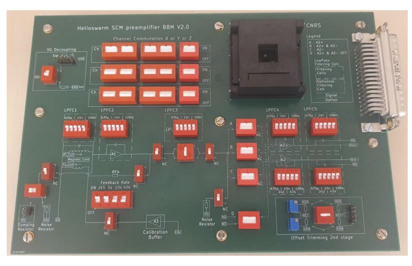
ASIC design LGEEP/LPP
Heritage: JUICE TRL 8



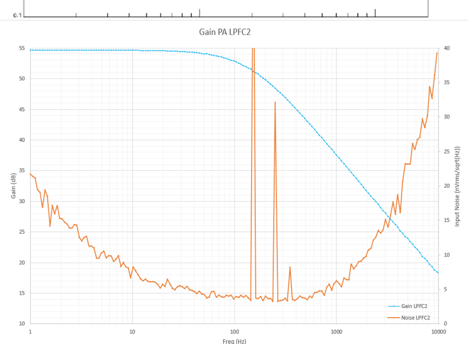
SCM HelioSwarm prototype with BBM1 PA



On going testing of filtering options to reduce the JUICE frequency range [0.1Hz,20kHz] to HelioSwarm frequency range [0.1Hz,128Hz]
Final selection planned for mid January

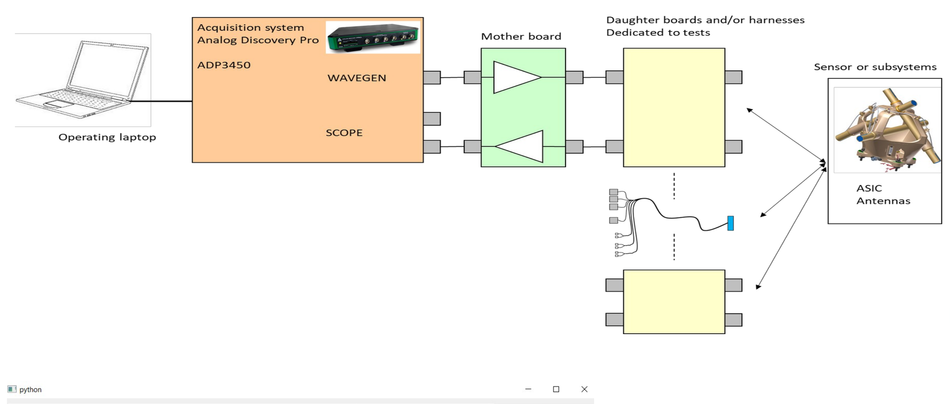


BBM2 PA for selecting filtering options

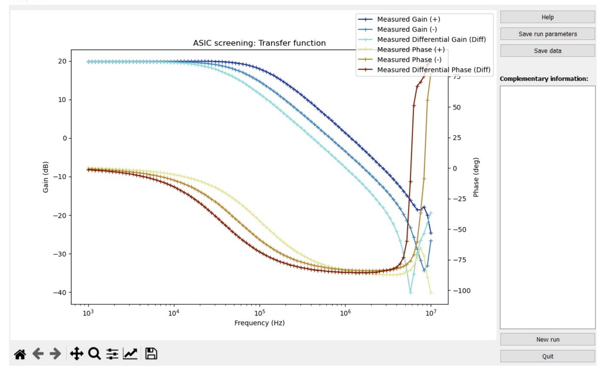


Gain & noise of one filtering option

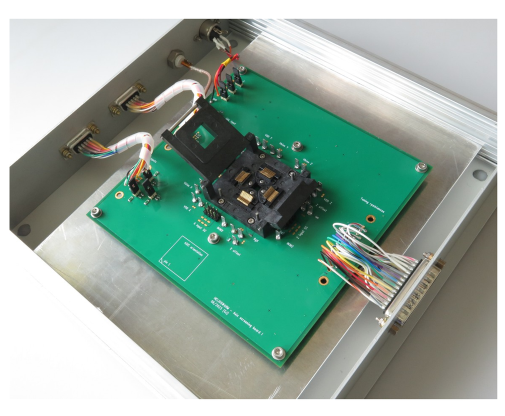
Automatised E-GSE structure (9 units to be tested and calibrated in ~ 1 year)
- Signal acquisition with Discovery pro ADP3450 (4 scope channels, 2 generator channels)
- Common mother board for signals grouping adaptation, attenuators and voltage regulation/filtering
- Test dedicated daughter boards
- 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



SGSE screenshots – transfer function measurement



ASIC screening daughter board