



## Comet Interceptor



### A combined Langmuir Probe – fluxgate magnetometer sensor design for Comet Interceptor

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# Compact sensors for solar system exploration

## Solar system exploration missions

- typically have the task of characterizing the in situ space plasma environment
  - the fields (magnetic field, possibly electric field)
  - the wave environment (electric field, possibly magnetic field)
  - plasma density
  - + plasma composition, velocity distributions, ...
- at the same time such missions are under heavy limitations
  - mass
  - power
  - volume
  - accommodation

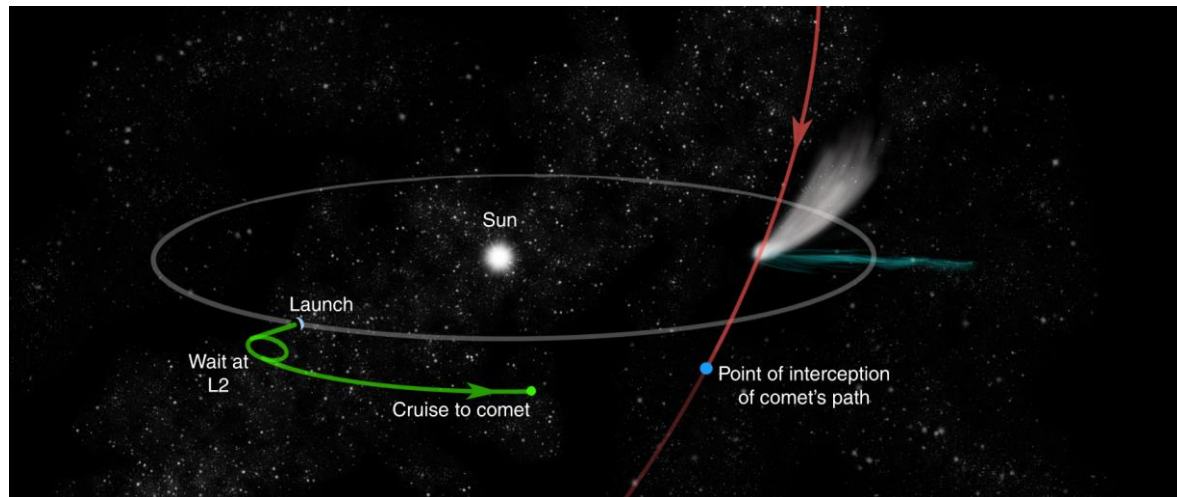
We present a compact sensor that merges a magnetometer and a Langmuir probe to provide maximum science for minimal resources in the context of Comet Interceptor.



# Comet Interceptor: Mission profile

Comet Interceptor is the ESA Science F1 mission and intends to study a dynamically *new* comet.

- Launches as secondary payload with Ariel in 2029
- Waits 1-3 years at L2
- Cruise 1-3 years to comet interception near 1 au
- Comet flyby at speed 10-80 km/s

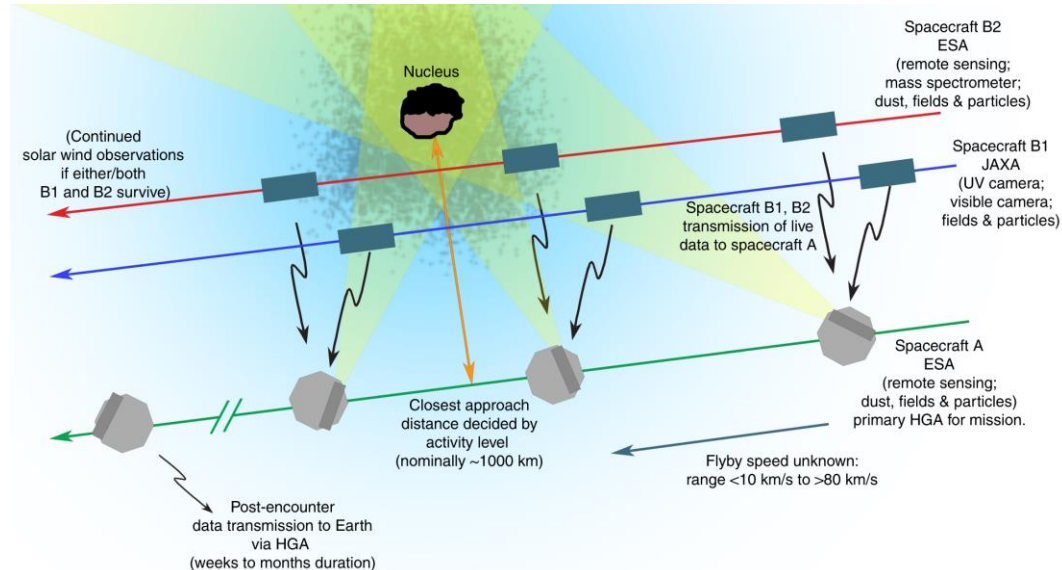




# Mission elements

Goal: obtain multi-point multi-instrument data on comet dust, gas, and plasma.

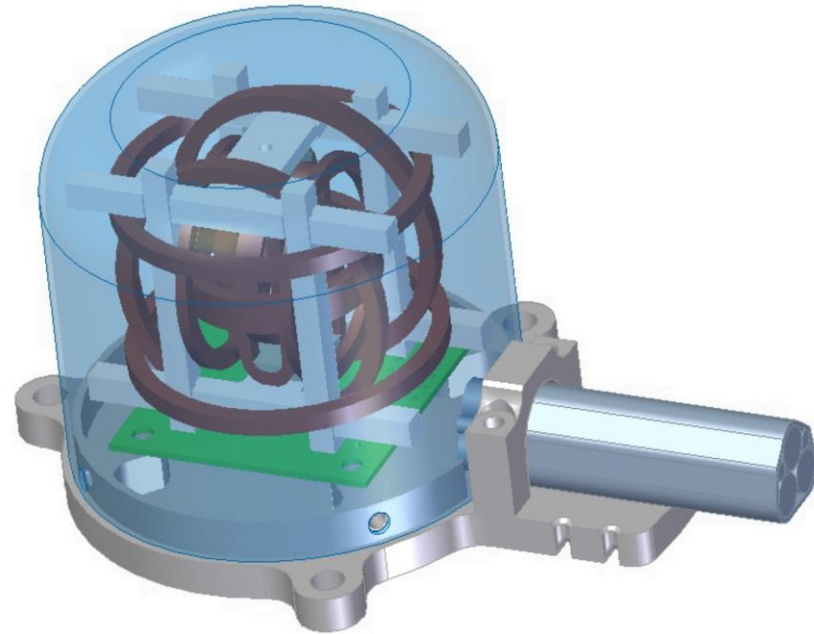
- Main spacecraft A (ESA) + Sub-spacecraft B1 (JAXA) + Sub-spacecraft B2 (ESA)
- Ground segment (e.g. LSST, ESA VLT, TRAPPIST, ...)





# The FGM sensor

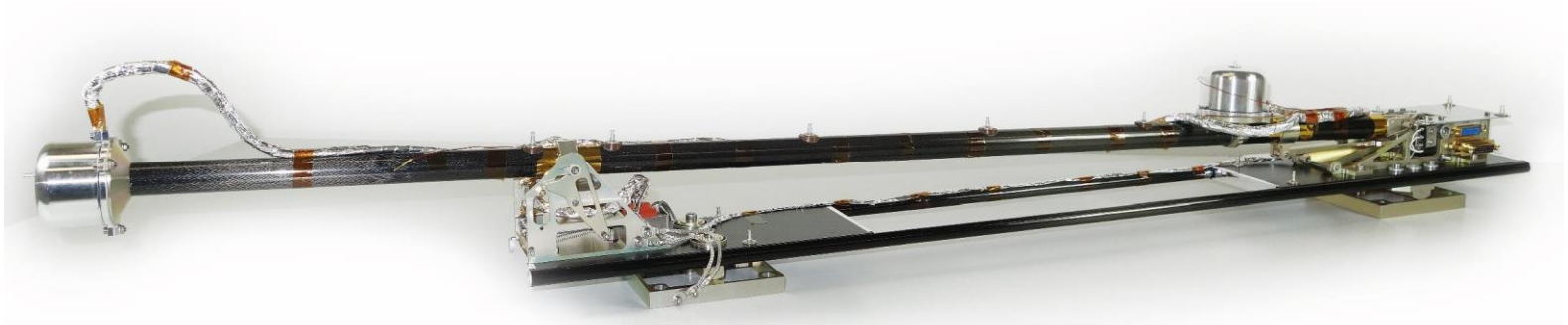
- part of the Dust-Field-Plasma sensor suite.
- a 3-axis fluxgate magnetometer.
- measurement from DC to 100s of Hz.
- adjustable range up to  $\pm 60000$  nT.
- drive signal at 9.6 kHz modulates the magnetic flux through a soft-magnetic core; the flux is detected by a sense-coil surrounding the core.
- vector measurement accurate to better than 1 nT
- noise  $< 20$  pT/ $\sqrt{\text{Hz}}$  at 1 Hz.





# FGM accommodation

- FGM is part of DFP on S/C A (there are magnetometers also on B1 and B2)
- Gradiometer configuration with an inboard and an outboard sensor
- Mounted on a high TRL deployable 1 m-boom (heritage from SOSMAG)





# The COMPLIMENT sensor

- part of the Dust-Field-Plasma sensor suite.
- Langmuir probe and a mutual impedance experiment, limited E-field capability
- measures
  - monitor the cold plasma density ( $10^2$ - $10^5$  cm<sup>-3</sup>) and electron temperature,
  - S/C potential,
  - density fluctuations ( $dn/n$ ) up to a few kHz
  - one component of the AC electric field, in the frequency range 1 Hz–5 MHz, covers the plasma frequency in the highly inhomogeneous cometary plasma as well as plasma waves
  - nm-sized dust impacts (characteristic electric waveforms)
- Normal data acquisition rate is 2 - 65 kbps.
- Peak rate is 10 Msamples/s.



|   |   |
|---|---|
| Electric field component, $\delta E(f)$ | 1 Hz – 1.4 MHz<br>2 $\mu\text{V/m} / \sqrt{\text{Hz}}$ ( $> 500 \text{ Hz}$ ) |
| Electron density, $N_e$                 | $10^2 - 10^5 \text{ cm}^{-3}$<br>$< 1 \text{ Hz}$                             |
| Density fluctuations, $\delta n/n$      | DC – 10 kHz   |
| Ion density, $N_i$                      | $10^2 - 10^5 \text{ cm}^{-3}$<br>$< 1 \text{ Hz}$                             |
| Electron temperature, $T_e$             | 0.01 – 30 eV<br>$< 1 \text{ Hz}$  |
| S/C potential, $U_{sc}$                 | $< 100 \text{ Hz}$  |
| Integrated solar EUV flux               | $< 1 \text{ Hz}$  |





# COMPLIMENT accommodation

- consists of
  - 2 probes of 8 cm diameter, 1 transmitter
  - receivers LP (DC to 1 kHz) and HMI (1 kHz–5 MHz)
  - signal generator for transmission (HMI)
- accommodation
  - spherical probes placed at the tips of ~1 m long fixed booms
    - ~1 m separation between the two probes.
    - separation distance determines the sensitivity of E-field and Mutual Impedance measurements.
  - transmitter placed on a short stick



# Resource limitations and choice

## Limitations

- comet Interceptor has multiple space elements
- financial constraints of an F mission
- piggyback on Ariel
- need for sufficient  $\delta v$  to maximize chances for comet encounters

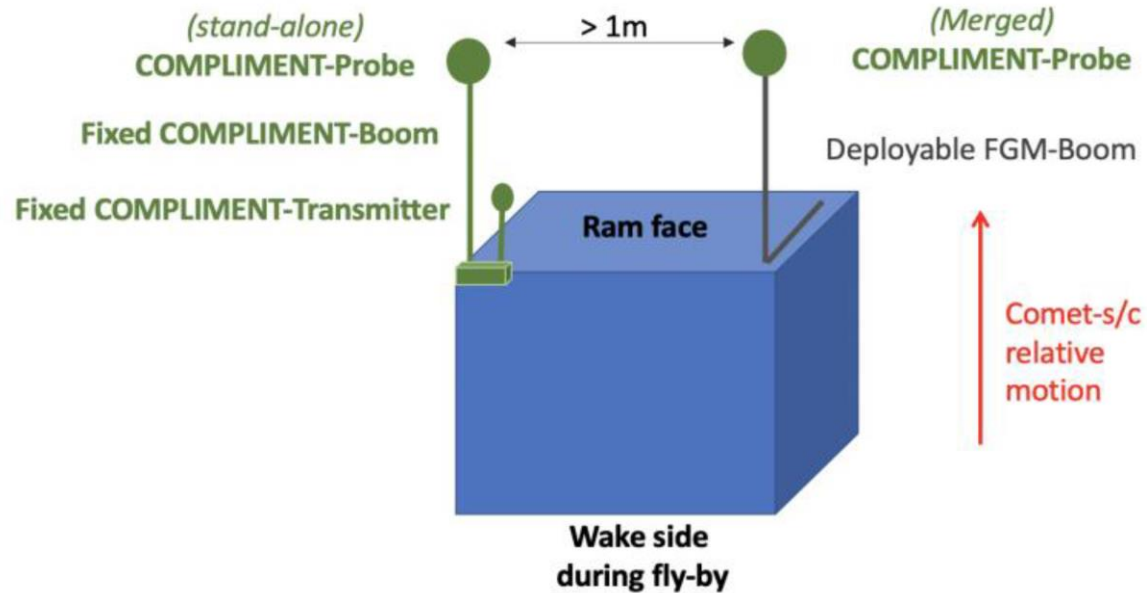
Hence there are severe resource constraints, especially on mass.

## Combine a Langmuir probe and FGM sensor

- Save mass
- 2 COMPLIMENT + 1 FGM boom  $\rightarrow$  1 COMPLIMENT + 1 Merged sensor boom
- Less Field-of-View obstruction for other instruments
- Easier to accommodate
- Better control over interference between FGM and COMPLIMENT



# Current accommodation plan



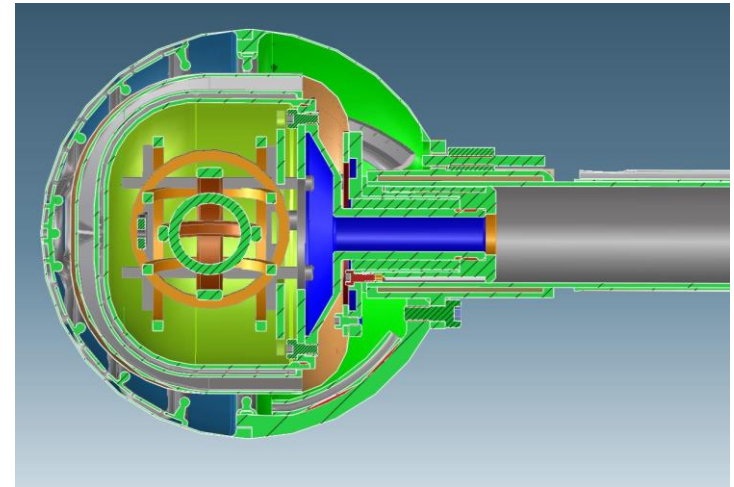
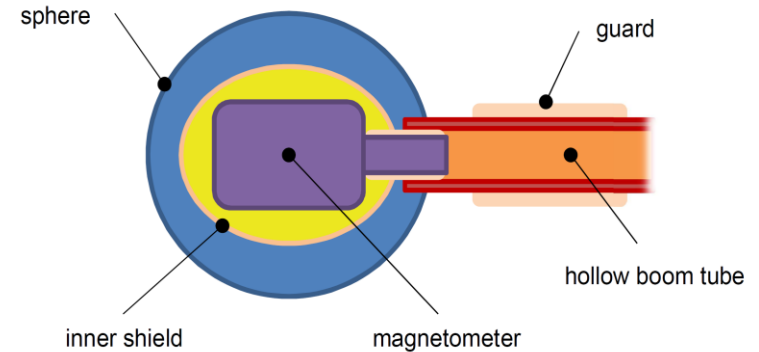


# Sensors

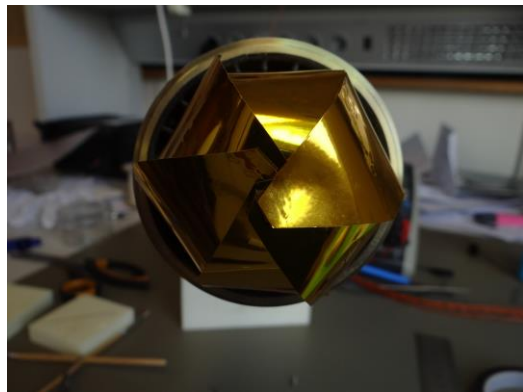
The sensors are 8 cm diameter spheres.

- (a) A “merged sensor” that holds FGM inside. This requires an inner shield between the sphere and the FGM to reduce interference, which is kept in place by a scaffolding in soft material glued onto the FGM cover and inside the sphere halves.
- (b) A “standalone sensor” which is identical but without magnetometer, inner shield, scaffolding.

The spheres are made of Al with a wall thickness of 0.3 mm because of mass limitations.





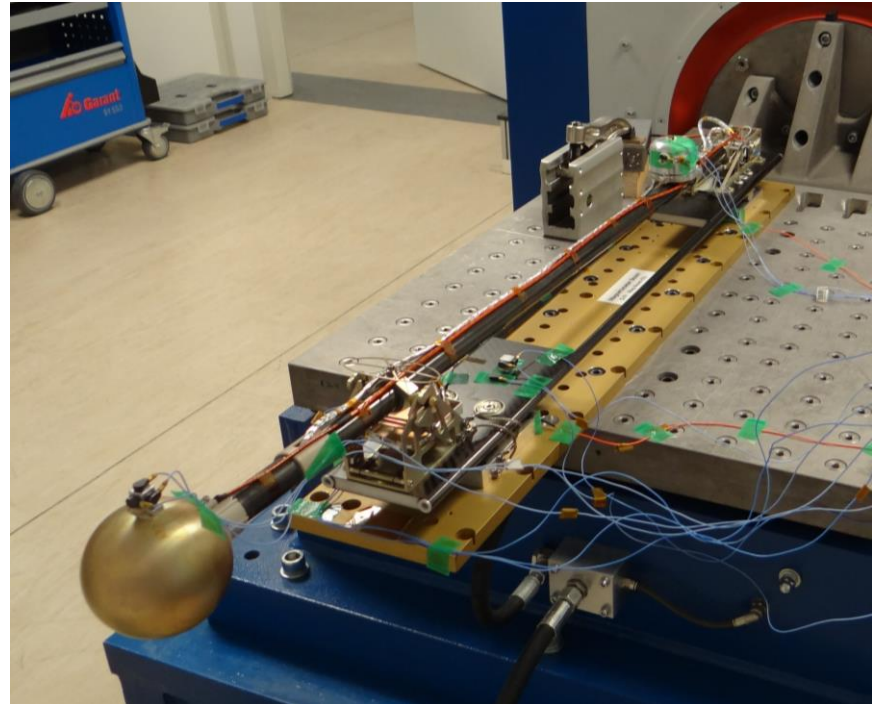






# Testing and Characterization

Vibration testing has been performed successfully with the merged sensor on the deployable boom.

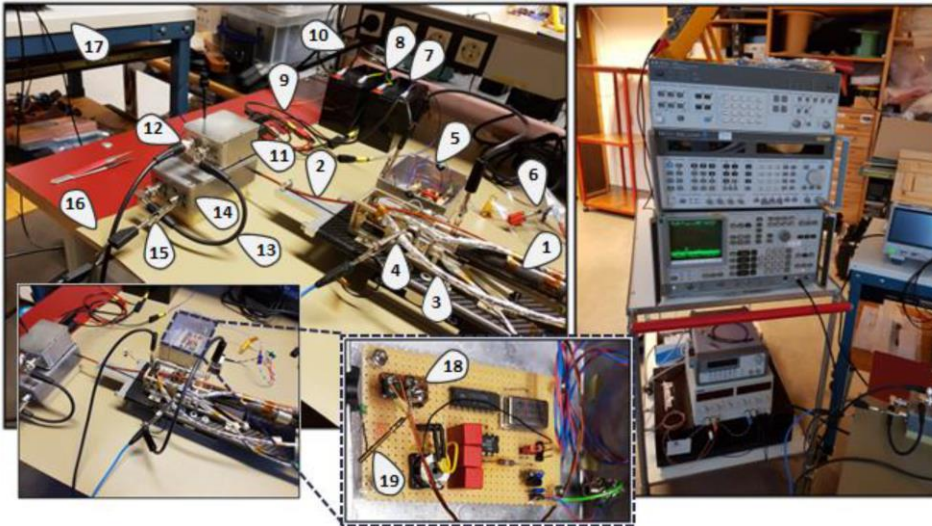




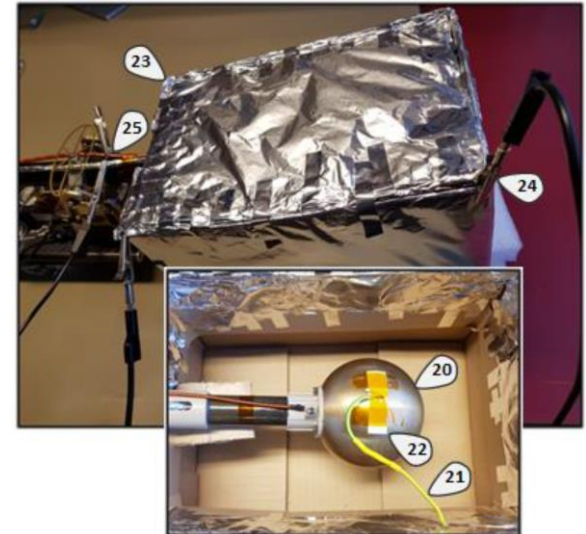
# Electric interference testing

Electric tests have been performed to determine FGM interference to the probes.

Equipment at boom root



Faraday cage and probe at boom tip



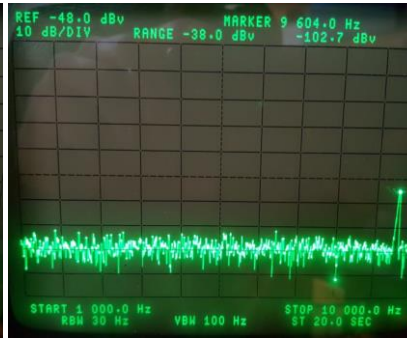




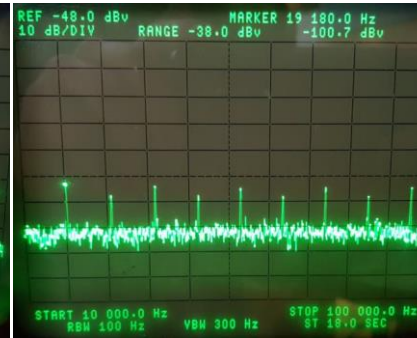
## Merged sensor response



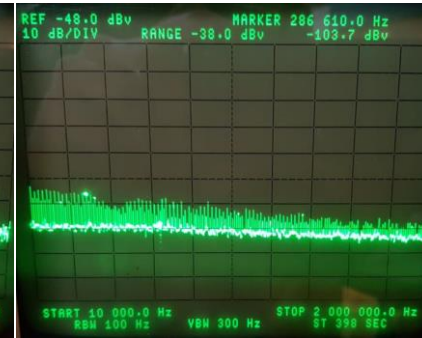
1-300 Hz



1-10 kHz



10-100 kHz



10 kHz – 2 MHz

- The FGM driver at 9.4 kHz is well visible, as well as a large number of harmonics.
- The interference introduced by FGM is limited to less than 4  $\mu$ V limit (-100 dBV).
- Proper signal conditioning, shielding and grounding needed.
- The harmonics are very sharp, damped, at well-defined frequencies.
- They can be removed a posteriori.



# Magnetic characterization

A characterization of the magnetic interferences has been performed in a magnetically clean environment in Chambon-la-Forêt, and using a Solar Orbiter SCM engineering model.

Driver signal and multiple harmonics are visible

- Intensity decreases with distance
- They are damped
- They are very sharp

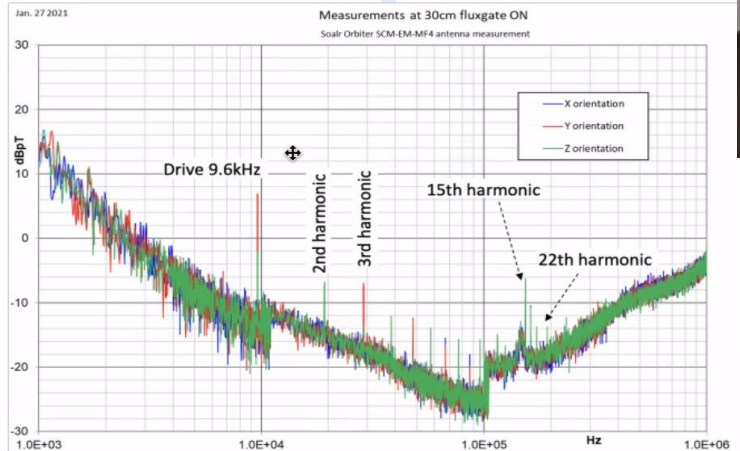
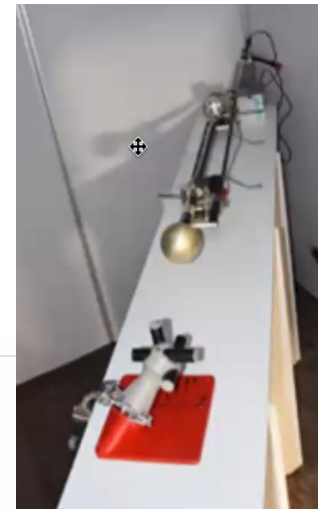


Figure 6.3 – Measurements at 30cm +Y position (spectrum)

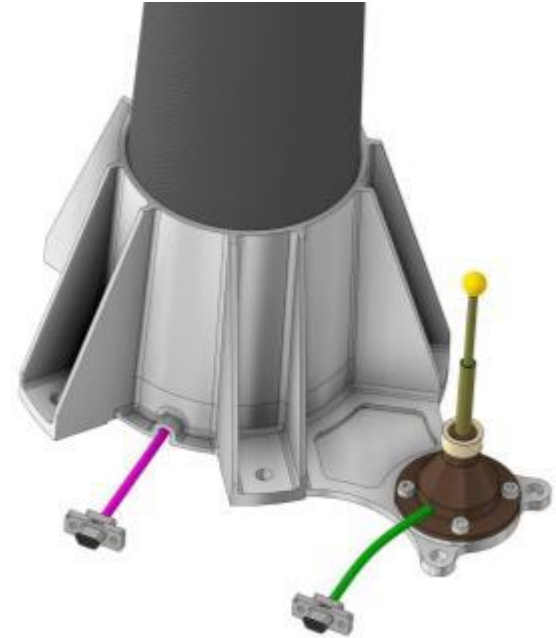




# Transmitter configuration

Different transmitter configurations have been tried out

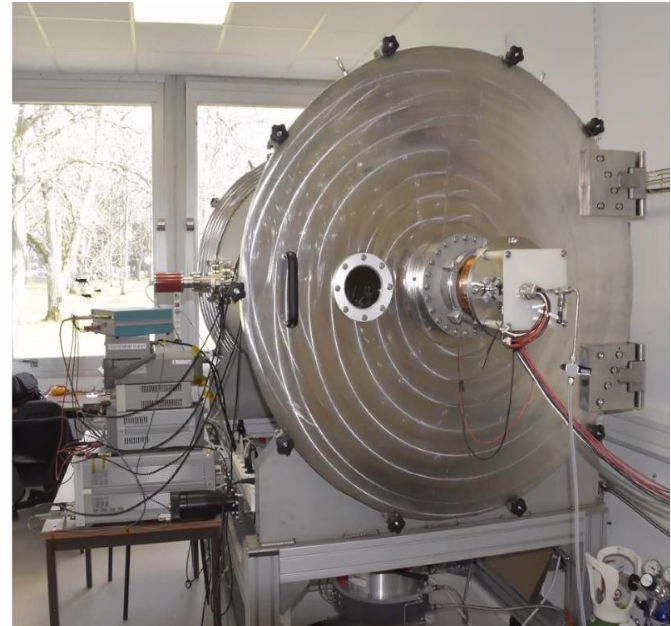
- Position of the transmitter close to the conducting s/c surface is a problem
- Use merged and/or companion sensor for transmission, and transmitter for reception





# End-to-end tests

End-to-end tests have been carried out in the plasma chamber at LPC2E in Orléans, confirming that FGM does not negatively impact COMPLIMENT HF measurements.





# Conclusion

A merged fluxgate – Langmuir probe sensor has been built and tested.

- Removes the need for one boom
- Low mass
- Interference between both can be dealt with
  - Inner shield
  - Proper grounding
  - A posteriori removal of residual FGM driver and harmonics

Merged + companion sensor provide (at high cadence)

- Magnetic field
- Electric field and waves (1 component)
- Ion and electron density, electron temperature
- S/C potential, integrated EUV flux
- nanodust impacts

This can therefore form the core of an in situ plasma characterization package



# Consortium

Merged sensor development was sponsored by ESA through EXPRO contracts for rapid payload maturation.

## *COMPLIMENT team*

- P. Henri – LPC2E Orléans – Lead + High-frequency electronics + transmitter
- N. Edberg – IRF-U Uppsala – Low-frequency electronics
- J. De Keyser – BIRA-IASB Brussels – Probe assemblies
- J. Peterson – IRF-K Kiruna – Fixed boom

## *FGM-A team*

- U. Auster – TU Braunschweig – Magnetometer and deployable boom



**THANK YOU!  
MORE INFO?**

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