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cmr Prototech

esa

Multi-Needle Langmuir Probe (m-NLP) Development

TEC-EPS Final Presentation Days

ESTEC, 15.05.2018, Dr. Tore André Bekkeng

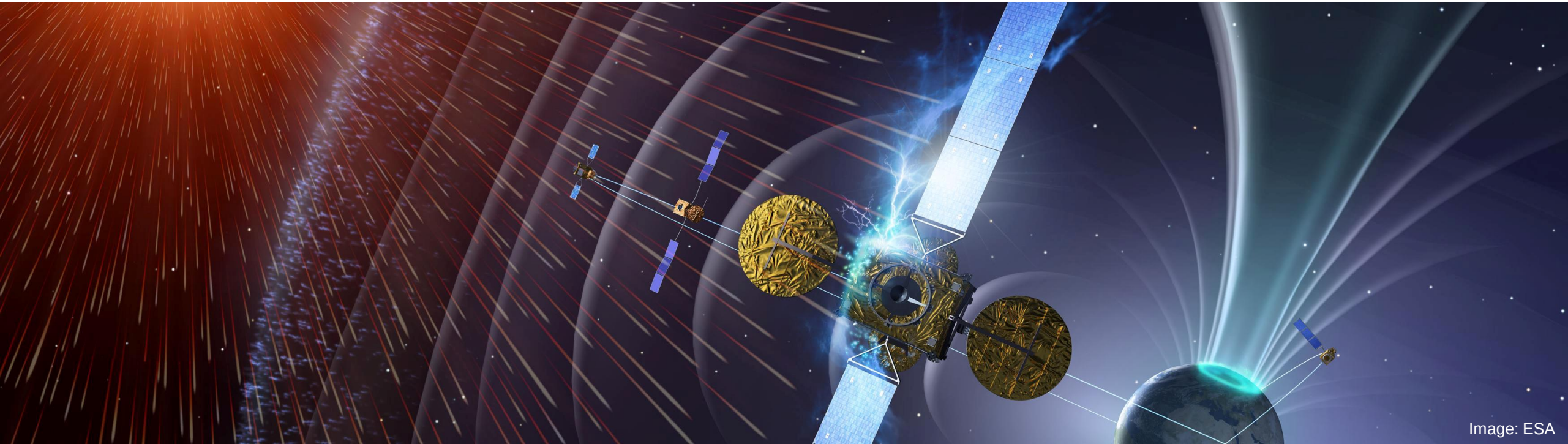
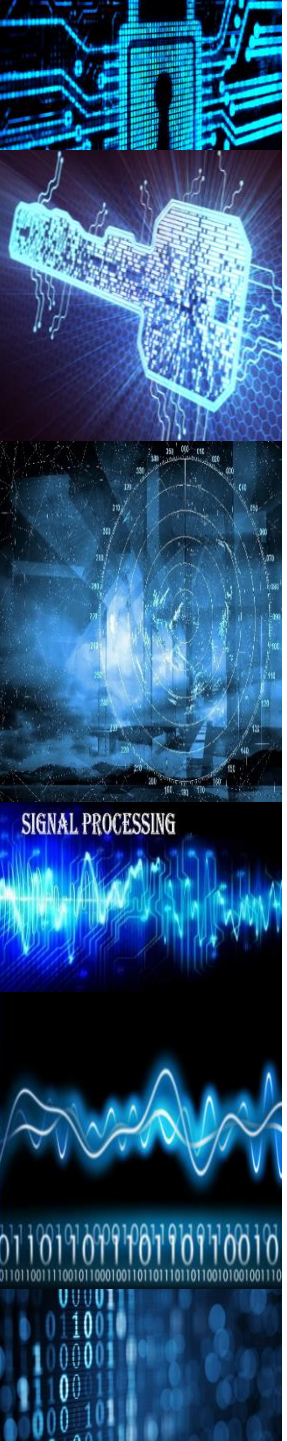


Image: ESA



Core knowledge and services

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Core competence

- Analogue signal processing
- Digital signal processing
- System design
- Software development
- Hardware development
- Command and control systems
- Subsystems
- Secure solutions
- Remote control
- Cryptology
- Space

Services

- Custom design
- Re-design of existing products
- Adaptations
- Interface design
- Life-cycle support
- System engineering
- Cleanroom facility

Main products

- Remote Crypto Distribution System (RCDS®)
- EIDEL Distributed Data Acquisition System (EDDAS)
- EIDEL Crypto Unit (ECU)
- multi-Needle Langmuir Probe
- Radio Control System for Ground-Air-Ground (SISAM)

PARTNERS AND IMPORTANT CUSTOMERS

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KONGSBERG

FORSVARSMATERIELL

Bundesamt für Informationsmanagement und Informationstechnik der Bundeswehr

Danish Defence
Acquisition and Logistics Organization

Norsk Romsenter
NORWEGIAN SPACE CENTRE

European Space Agency
Agence spatiale européenne

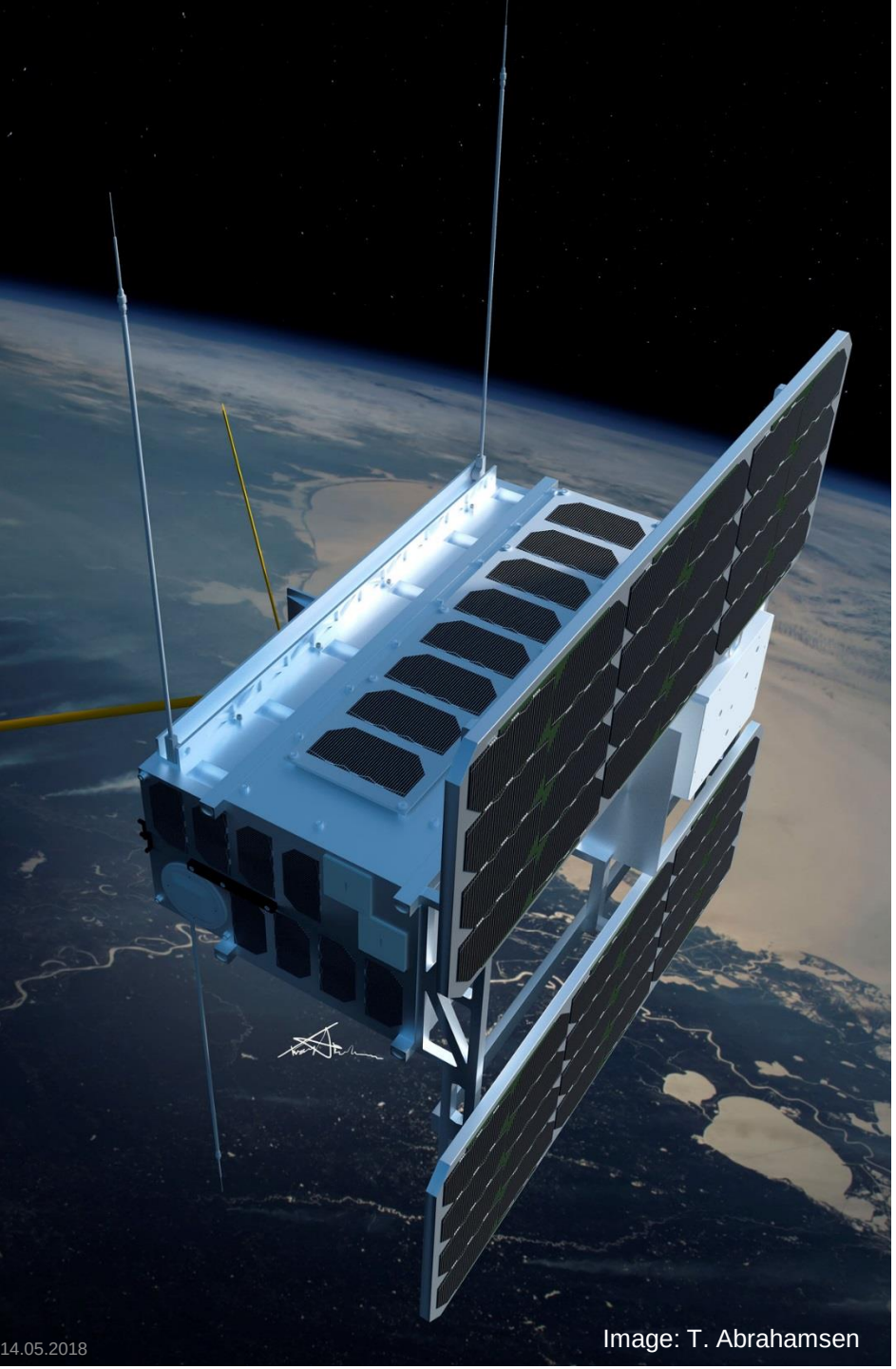
Image: T. Abrahamsen

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M-NLP Development

Rapid measurement of electron density (~5kHz, ~1m) and spacecraft potential in LEO plasmas for space weather and science applications.

CCN3 is redesigning the boom and deployment system after problems with the original design, in addition to the implementation of a SW bootloader.

Funding programme : GSTP

Contract value 2.697 M€, (incl. CCN1, CCN2 and CCN3)

Start and end dates: November 2013 to March 2018

Team:

- Eidsvoll Electronics AS (N)
- Prototech (N)
- University of Oslo (N)

TO: David Rodgers TEC-EPS (replacing Alain Hilgers)

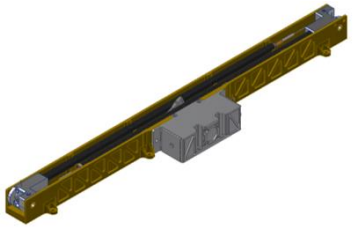
Activity – Background & Objectives

The multi-Needle Langmuir Probe (m-NLP) instrument delivered under ESA Contract No. 4000109398/13/NL/AK is based on the development of a new Langmuir probe, utilizing the new m-NLP measurement technique which allows for high-resolution F-region plasma (electron) density measurements along the orbit trajectory (gradients, turbulence, irregularities).

By this, the F-region plasma characteristics can be mapped around the globe. This is of particular relevance to assess ionospheric plasma effects on communication and GNSS signal propagation.

The activity is an extension of previous work led by the University of Oslo on the context of rocket experiments towards the industrialization of the m-NLP instrument.

The objectives of the activity has been to produce an EQM of the m-NLP assembly (Electronics Unit, Boom System and Sensors), which shall be developed, manufactured, tested and qualified.



M-NLP: What is it?

Developed as a part of the ICI sounding rocket program (University of Oslo, 4DSpace Initiative)

Measures electron density and spacecraft floating potential down to meter scale

Gives new possibilities for the understanding of the driving forces behind how e.g. the aurora affects radio communication and GNSS signals

Low-cost UiO-version included on the NORSAT-1 satellite, launched on 14 July 2017.

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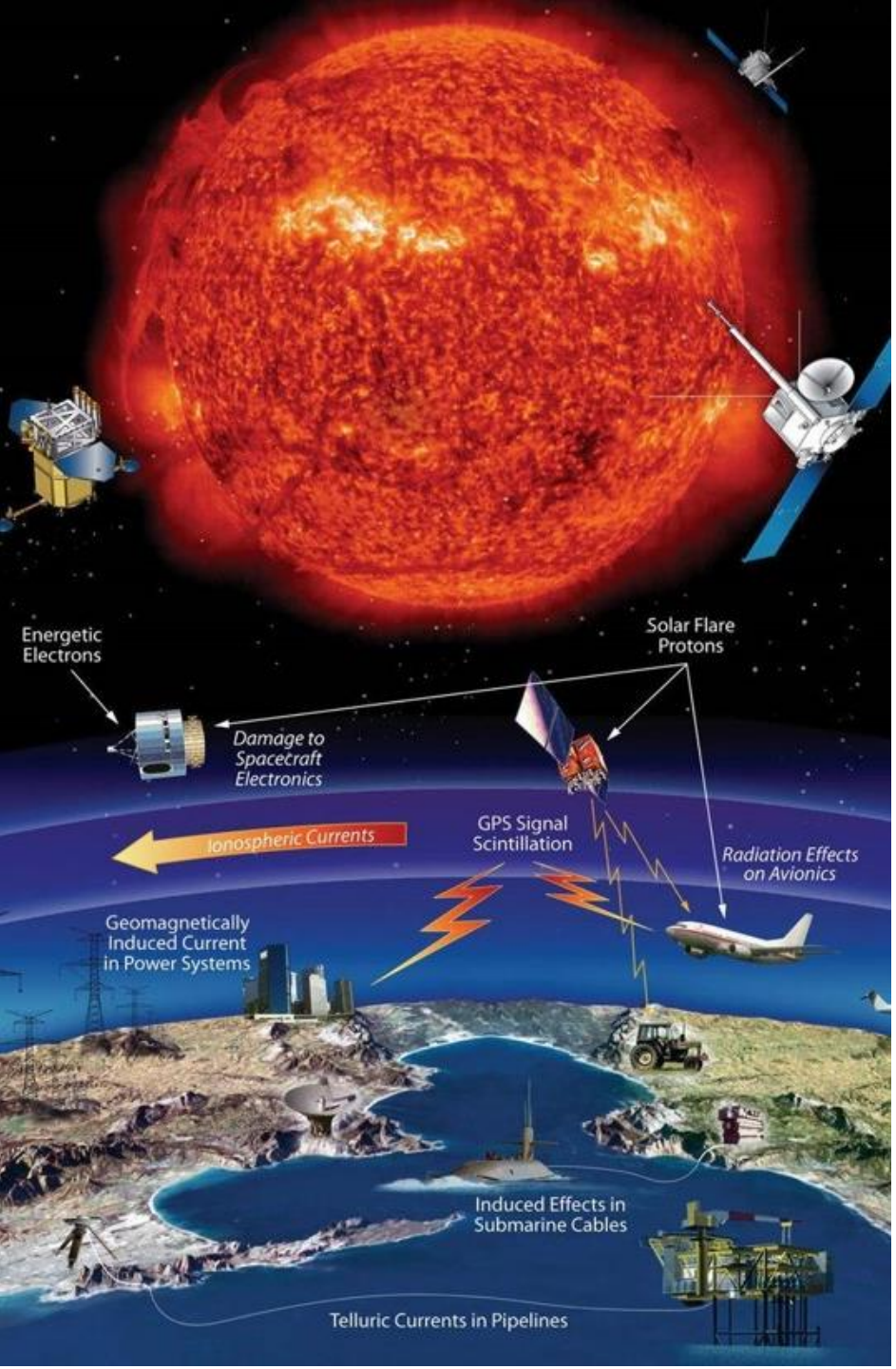

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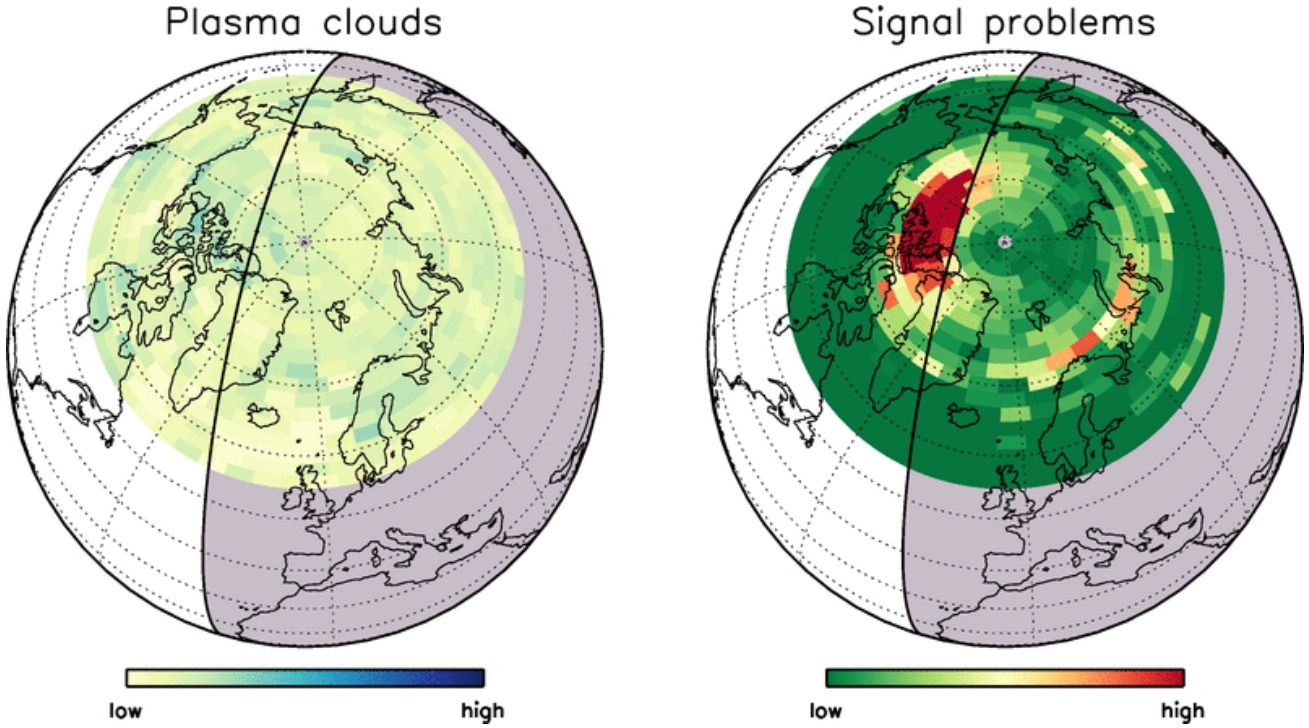
GPS disturbances at high latitudes



The strongest GPS-scintillations occur when plasma clouds enter the polar cap through the auroral oval on the dayside, and exits the polar cap through the auroral oval on the nightside.

Animation: Clausen et al., JGR, doi: 10.1002/2015JA022199, 2016

M-NLP measurement principle

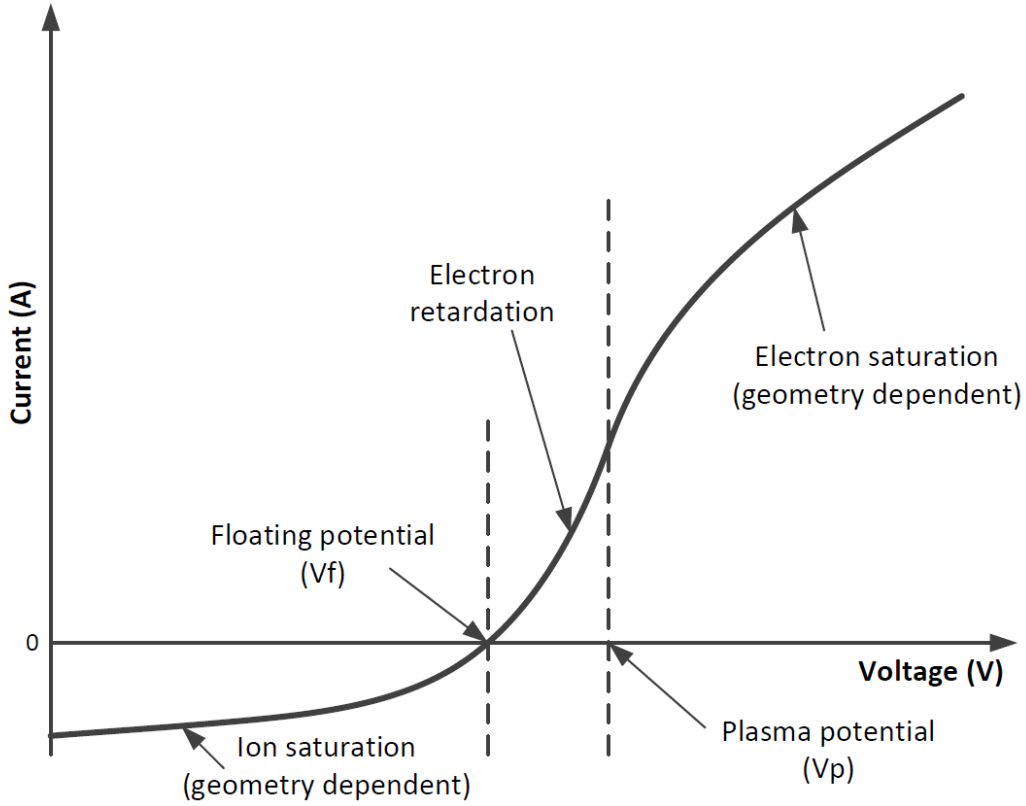


Figure: UiO

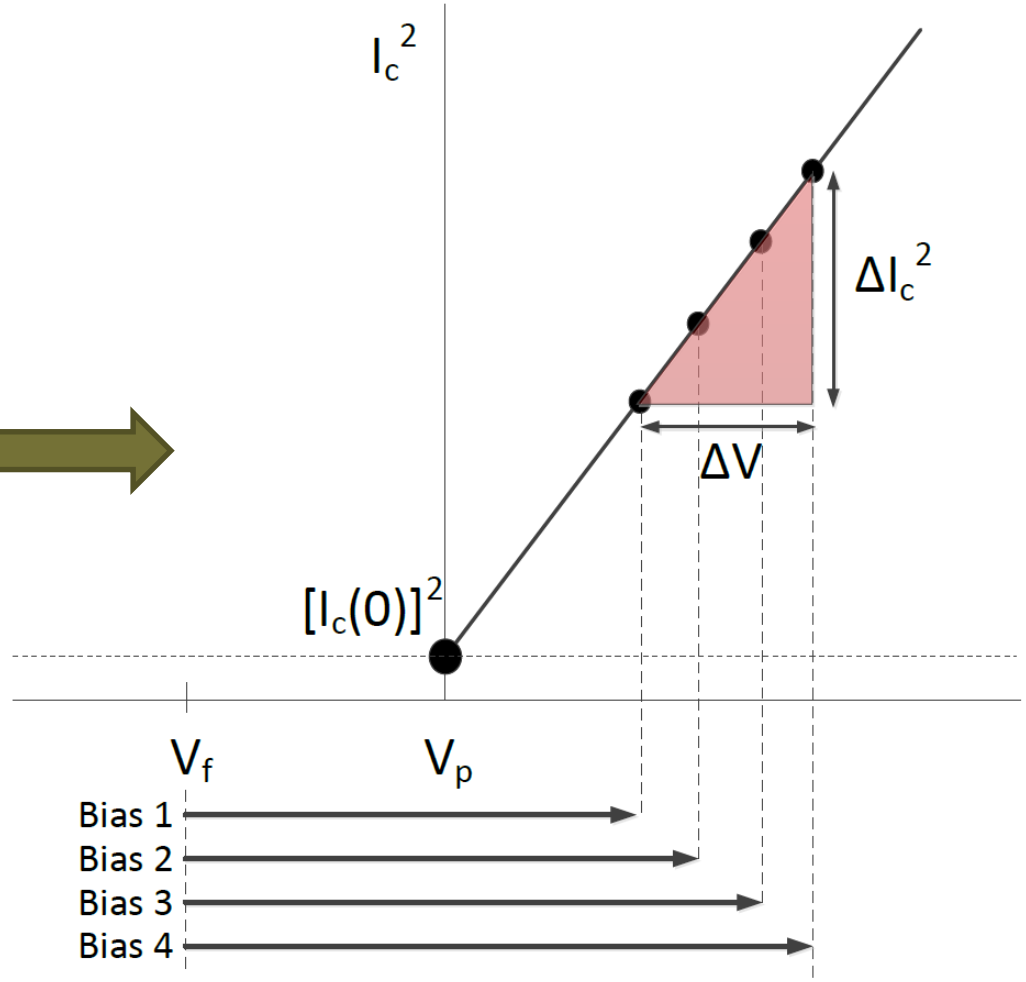


Figure: UiO

Electron density measurement – ICI-2

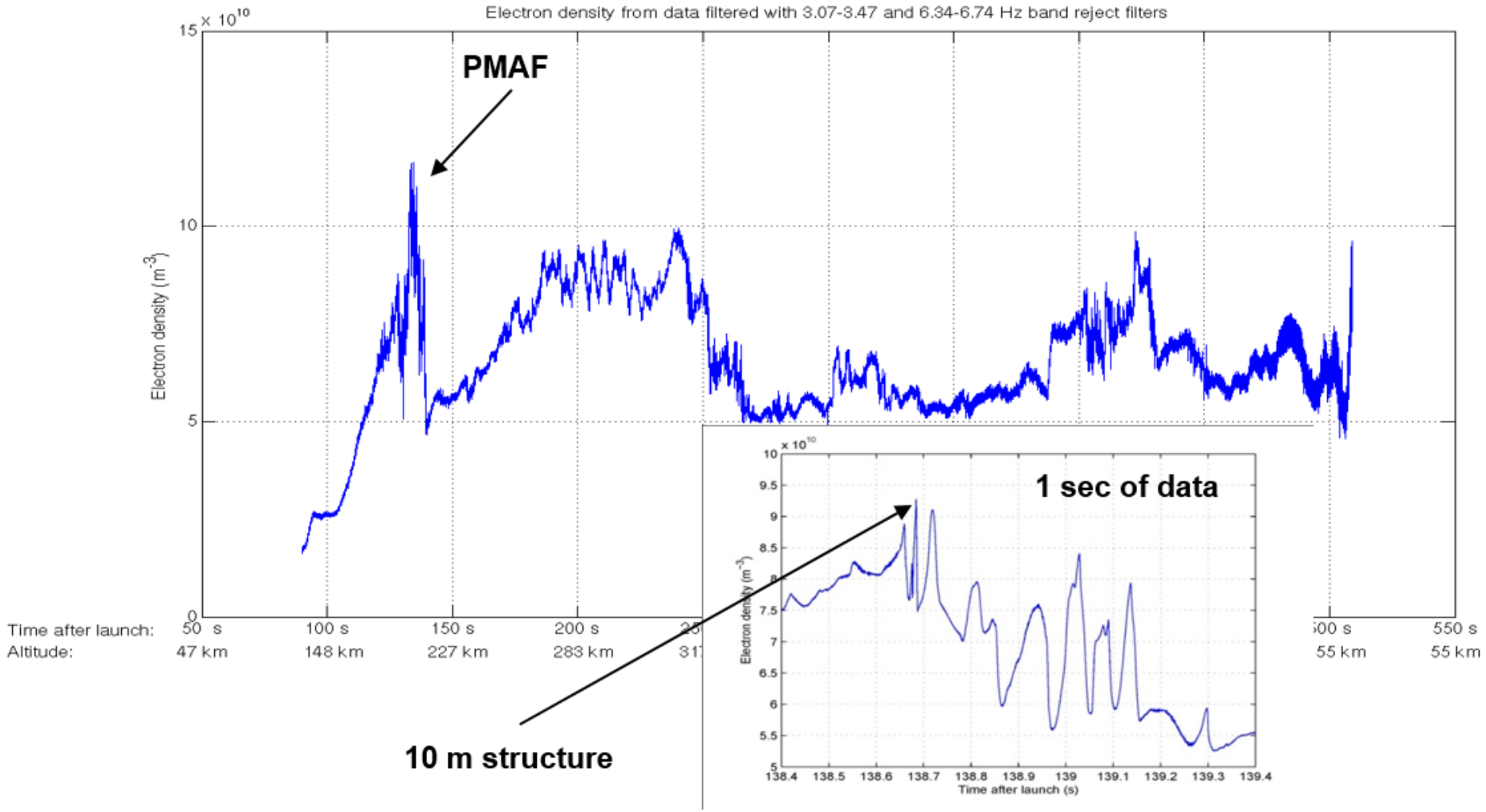


Figure: University of Oslo

Instrument design

Mechanical Enclosure – Electronics Unit

Three slots + top cover (AL-7075)

Hollow dowel pins

M4x50 bolts (4x)

EMI gasket between each slot

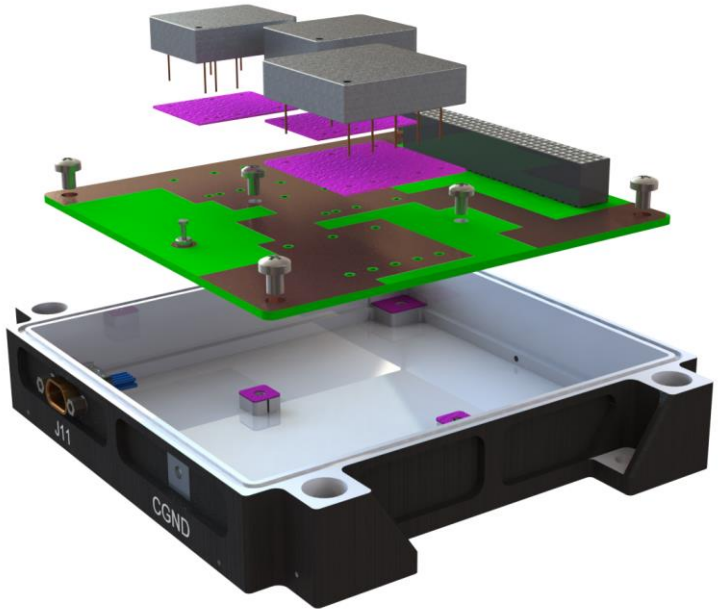
Alodine 1200S surface treatment

Aeroglaze Z307 coating on outer surfaces

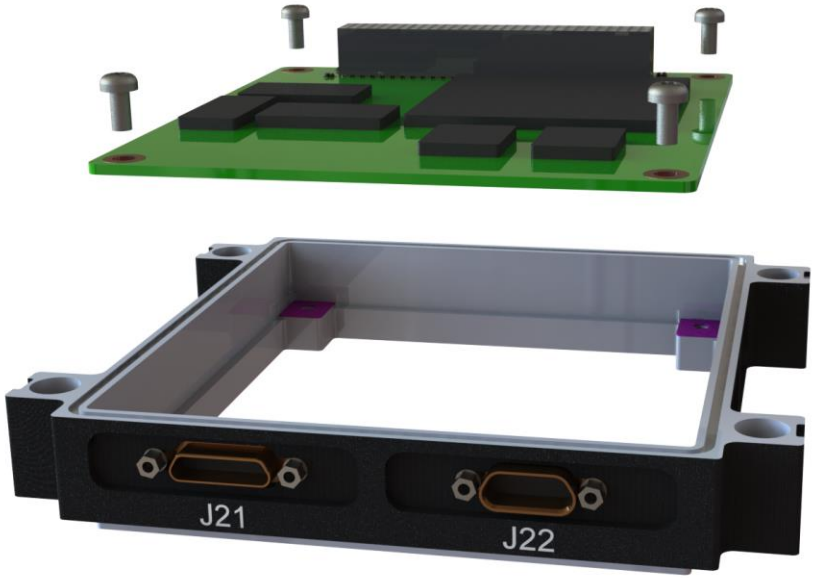
4 x M4 spacecraft mounting ears

Total mass (w/o PCBs): 525 grams

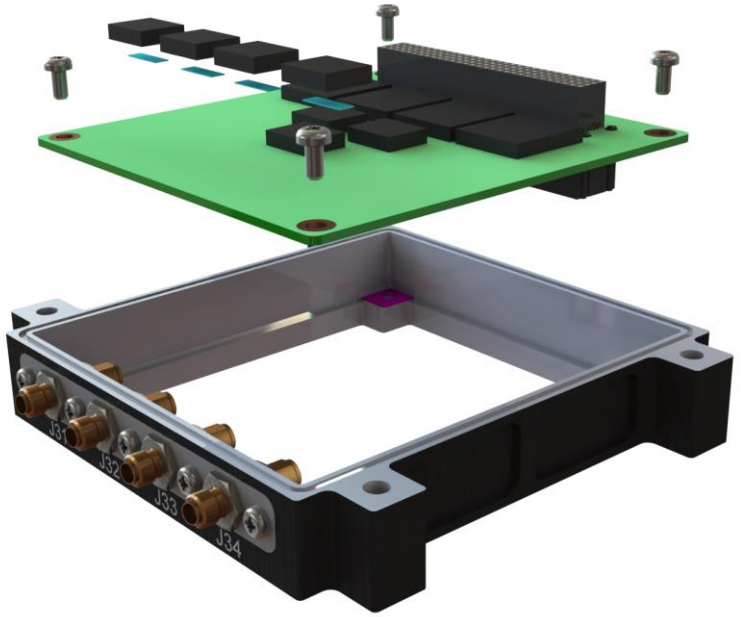
Instrument design



Power Module

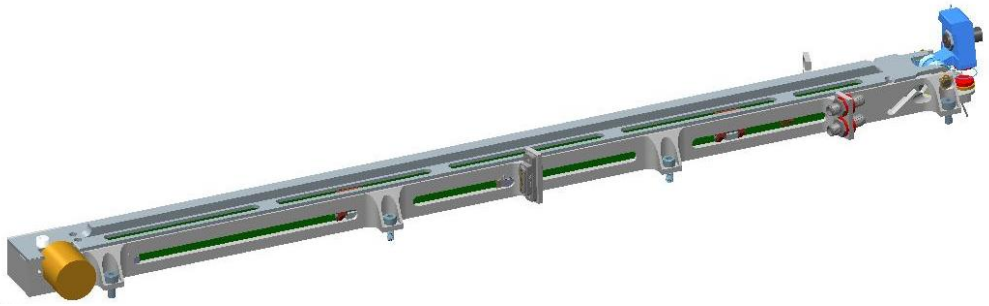


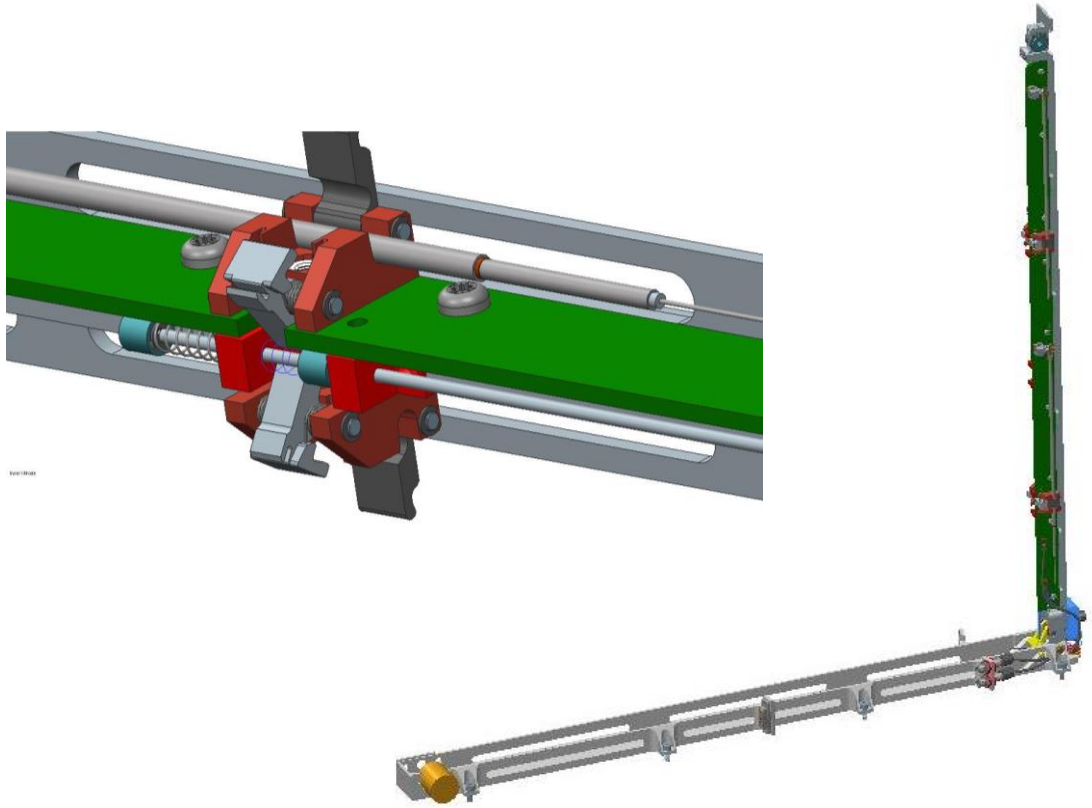
Processing Module



Analog Module

Instrument design





First boom system

Folding cassette-type design

Boom arm with probe holddown mechanisms mounted on PCBs

All four probes released simultaneously by centralized moving rod, disengages probe holddown mechanisms during boom arm deployment

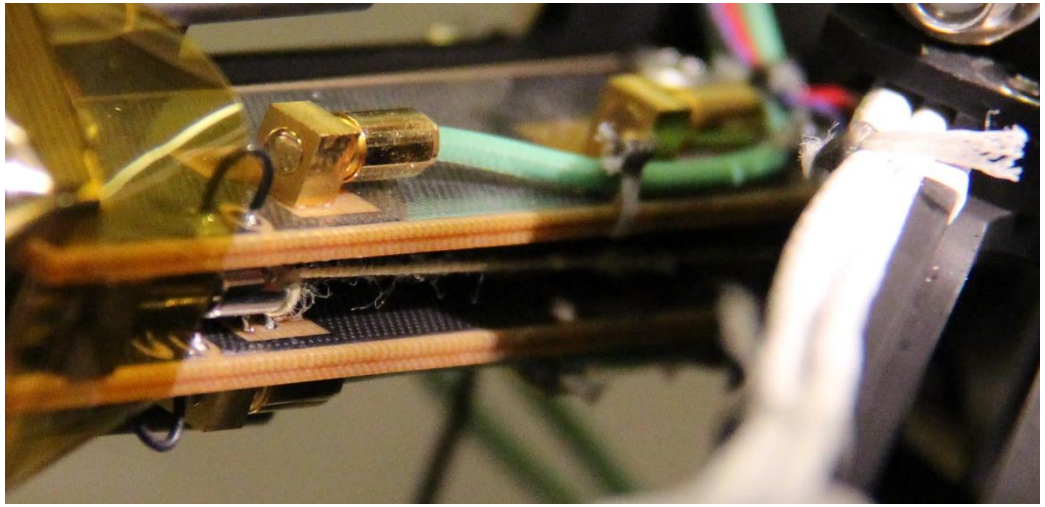
Boom system failure

Probe holddown mechanisms failed to keep the probes in a fully stowed configuration during vibration testing

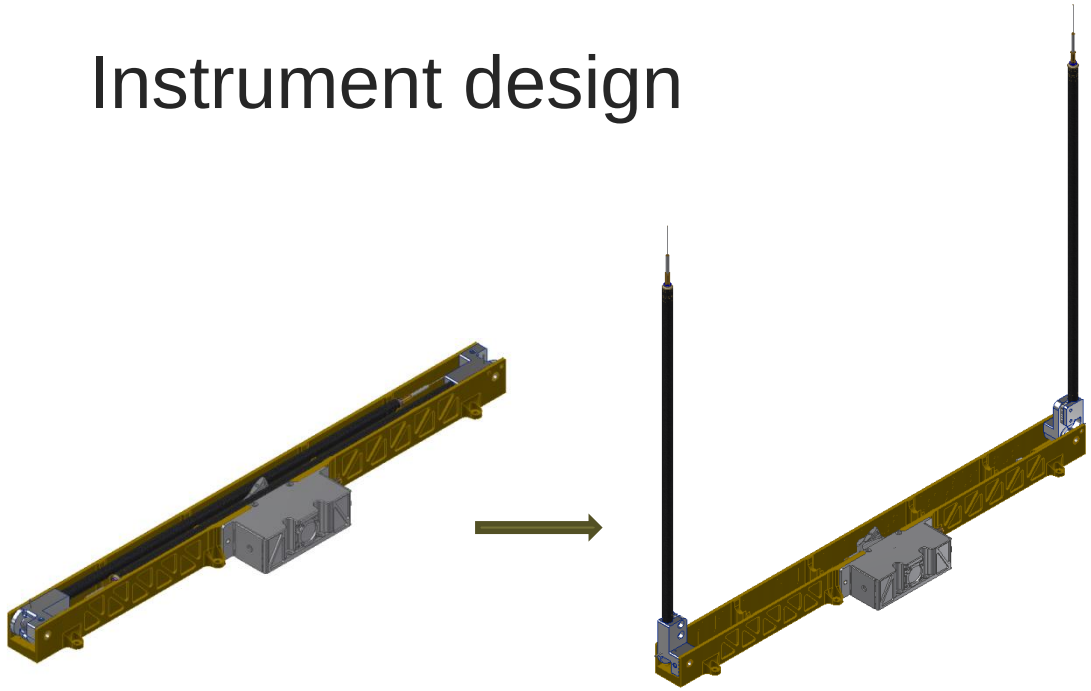
Centralized rod was prematurely retracted during vibration due to winding of a Kevlar cord → probes were partly released inside the cassette, leading to a complete destruction of the probe elements

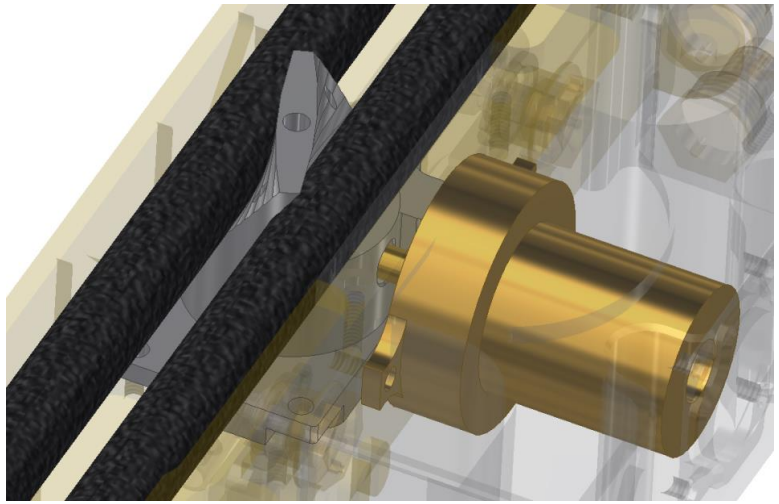
The failure investigation concluded that due to the inherent complexity of the Boom System, a redesign was deemed to have too high risk

Instead the m-NLP Boom System developed in 2015-2017 by the University of Oslo for the Norwegian NORSAT-1 satellite was taken into the project under CCN3, with adaptations to make it compatible with the contract requirements.



Instrument design





Boom system adapted from NORSAT-1

Folding cassette-type design adapted from the m-NLP boom system with flight heritage on NORSAT-1

Two boom cassettes needed to get the required four probes

Cassettes need to be mounted on either the same side or on opposite sides of the spacecraft (the m-NLP probes need to be mounted in the same orientation w.r.t. the magnetic field)

Centralized redundant pin-puller that releases both boom arm simultaneously. Redundant spring actuation.

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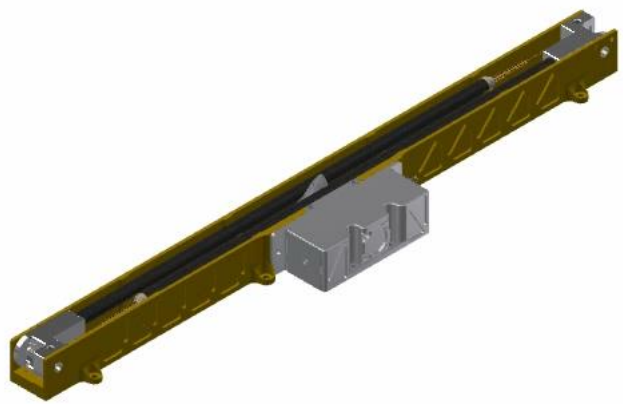
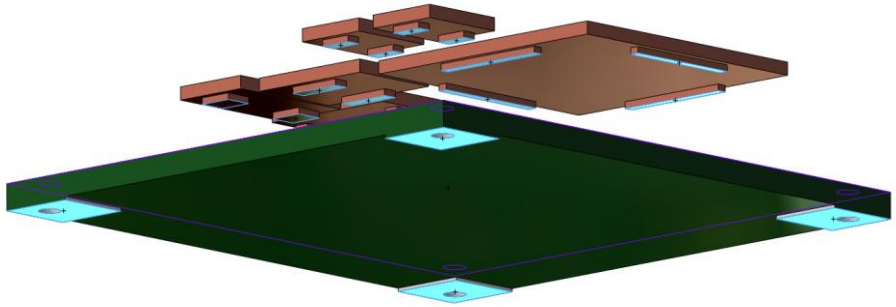
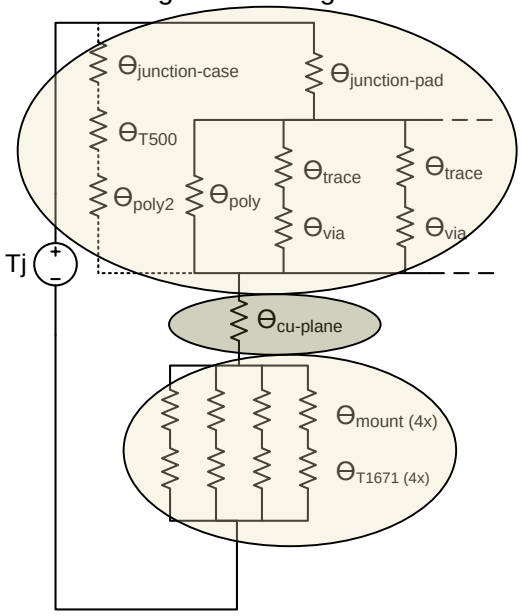


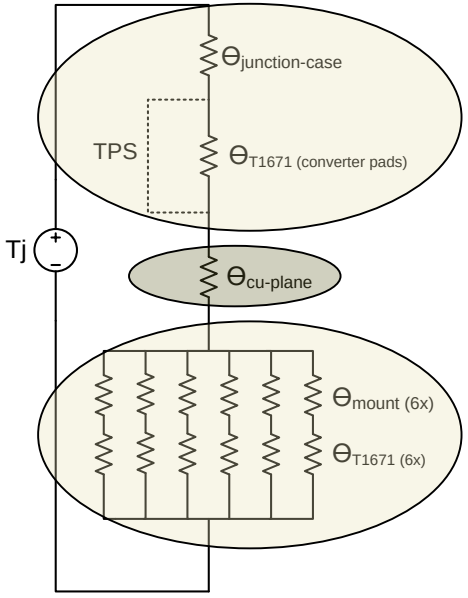
Thermal analysis – Electronics Unit



Processing- and Analog Modules



Power Module



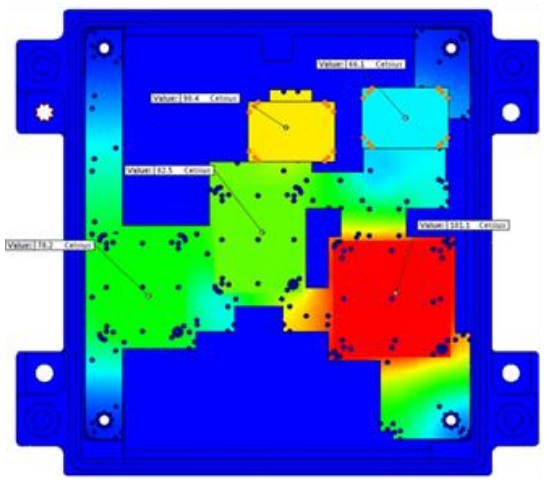
Legend:

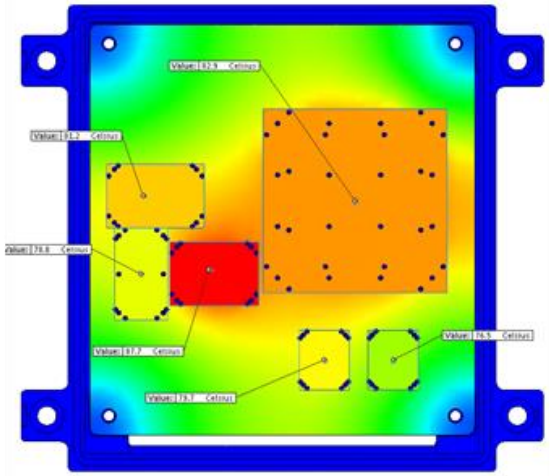
Calculated based on material properties and geometries (used as input to FEM analysis)

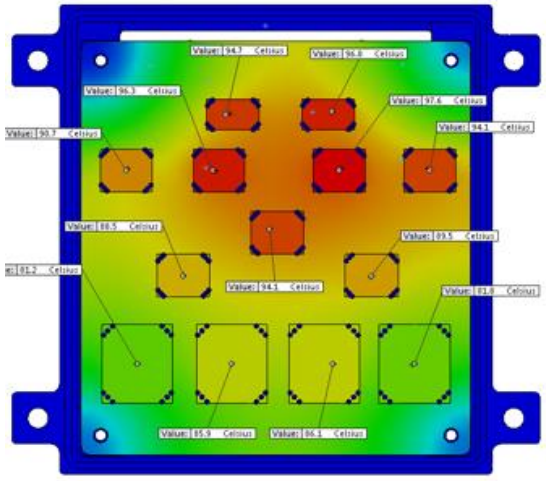
FEM analysis with equivalent thermal resistances

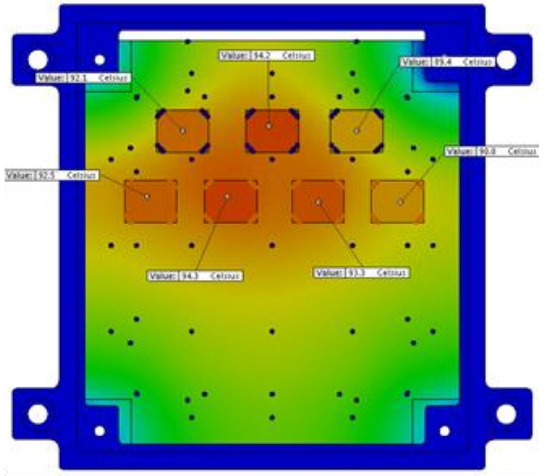
Thermal analysis – Electronics Unit

Component	Temp (°C)
5V DC-DC converter	**101.1**
+15V DC-DC converter	**78.2**
-15V DC-DC converter	**82.5**
1.5V DC-DC converter	**62**
3.3V DC-DC converter	**91**
FPGA	**85**
SRAM	**91**
NAND	**84**
EEPROM	**82**
TX	**79**
RX	**83**
ADC	**90**
AA filter	**90**
Gain	**95**
Diff. amplifier	**105**
IV amplifier	**98**
Bias/shift	**95**
Gain switch	**95**



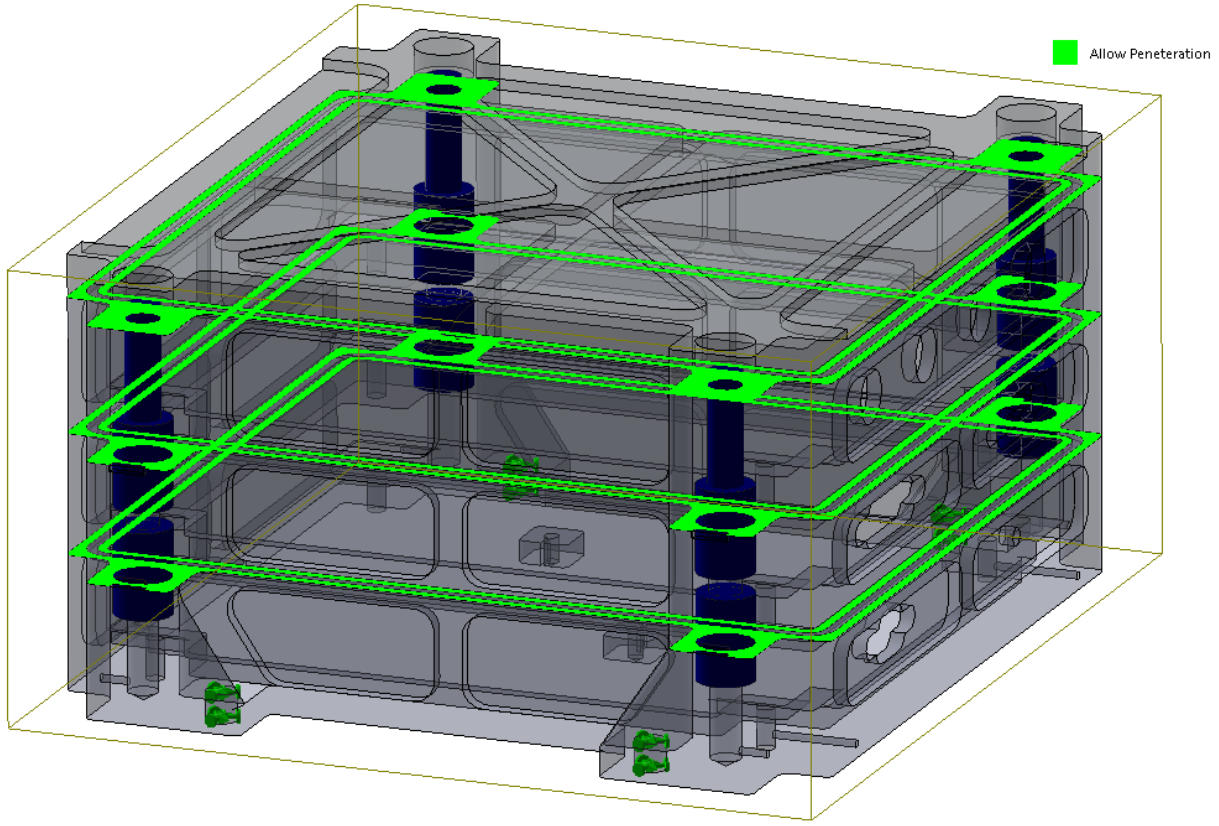


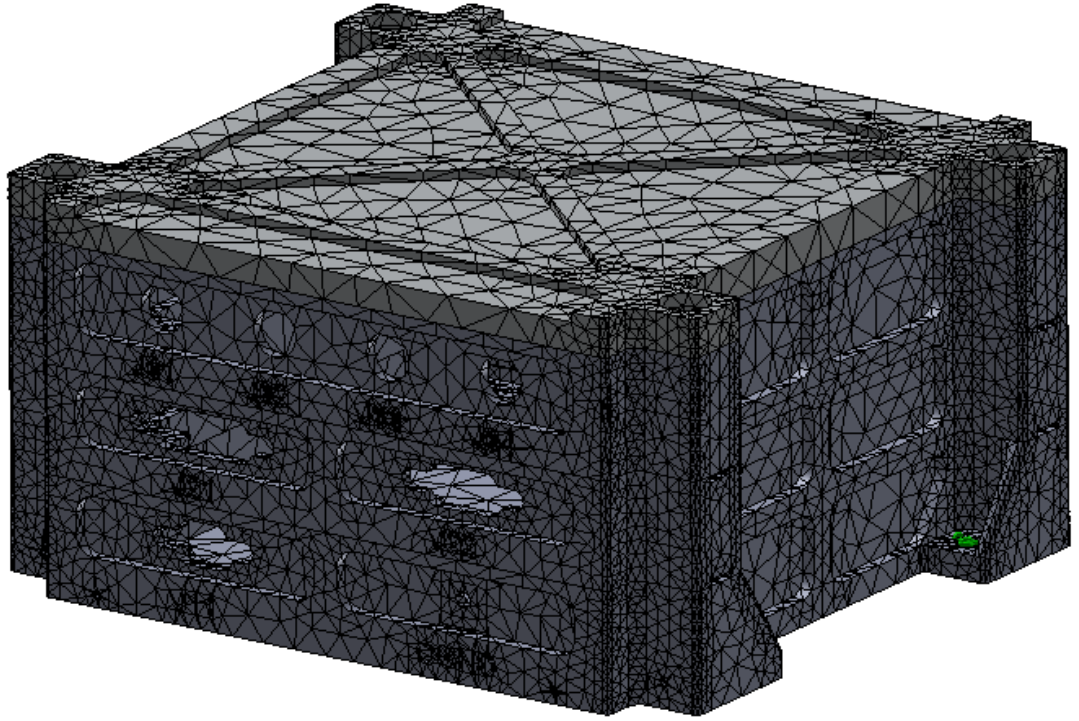




Note: Worst case power consumption
at 55°C baseplate temperature

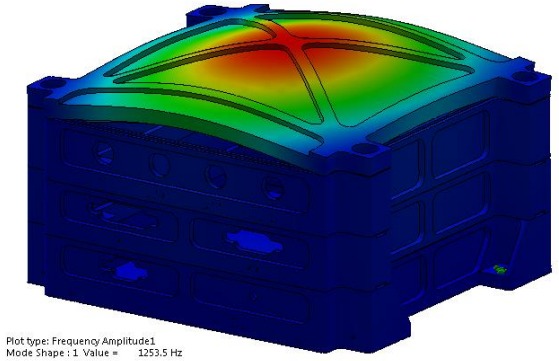
Structural analysis – Electronics Unit



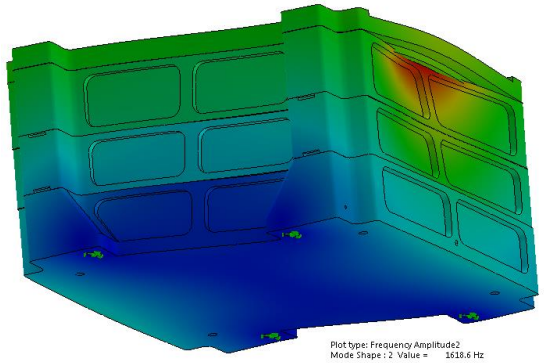


Modal analysis and dynamic analysis conducted using SolidWorks

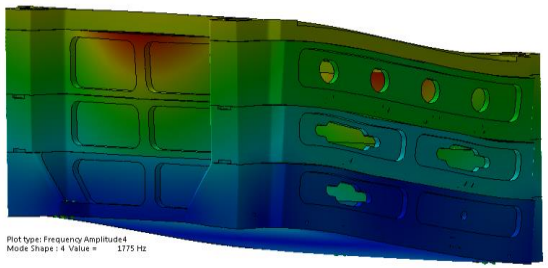
Structural analysis – Electronics Unit



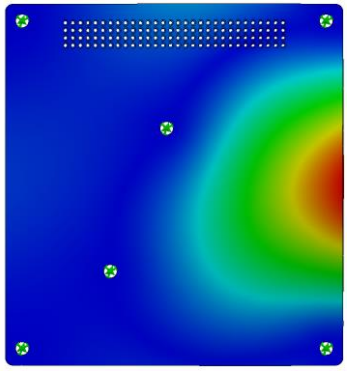
Mode 1
Z-direction 1254 Hz



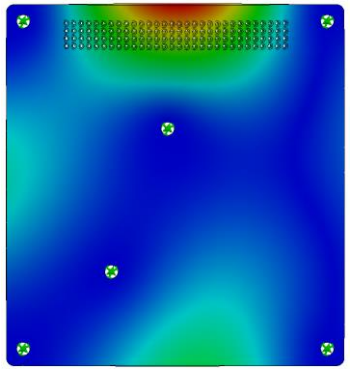
Mode 2
X-direction 1619 Hz



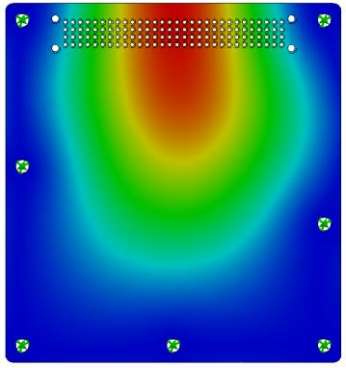
Mode 4
Y-direction 1775 Hz



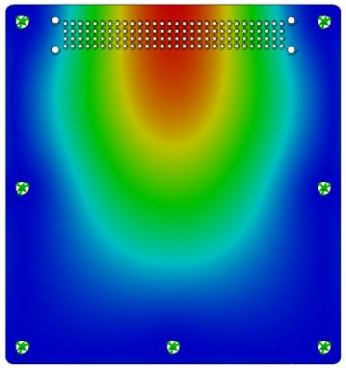
Power Module
Mode 1
Z-direction 394 Hz



Power Module
Mode 3
Z-direction 626 Hz

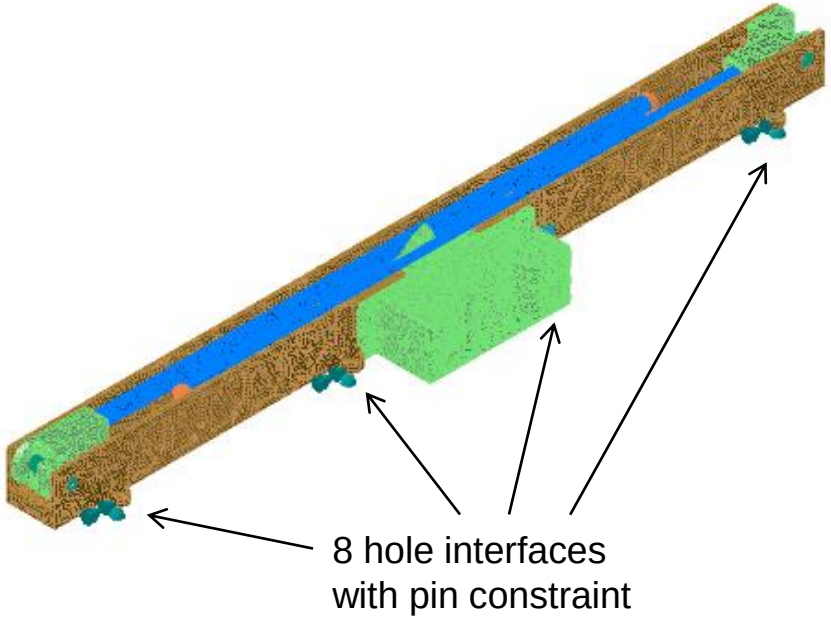


Proc. Module
Mode 1
Z-direction 390 Hz

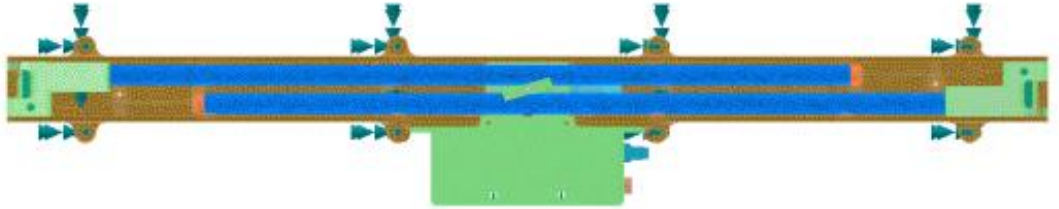


Analog Module
Mode 1
Z-direction 398 Hz

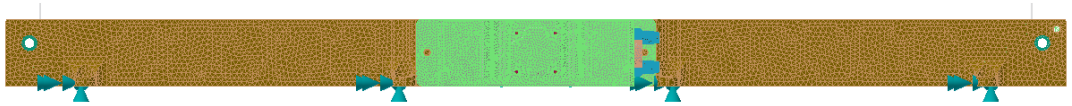
Structural analysis – Boom System



Top view

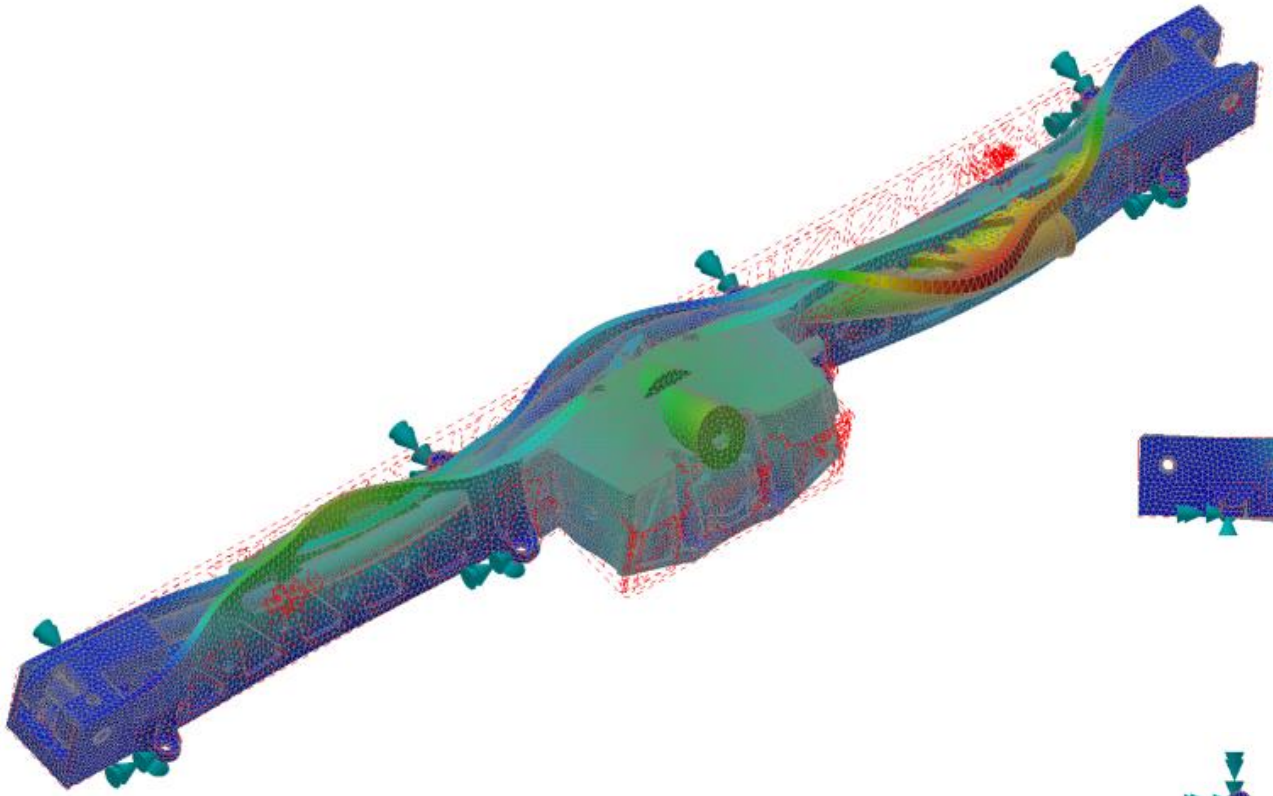


Side view



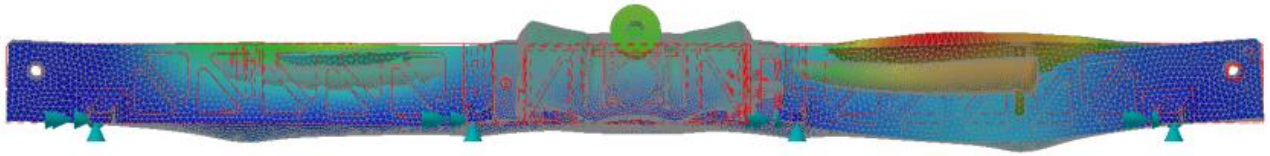
Modal analysis and dynamic analysis conducted using Nastran

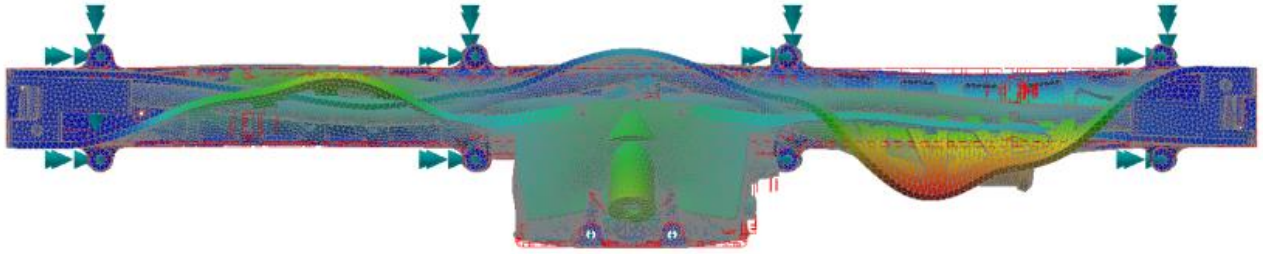
Structural analysis – Boom System



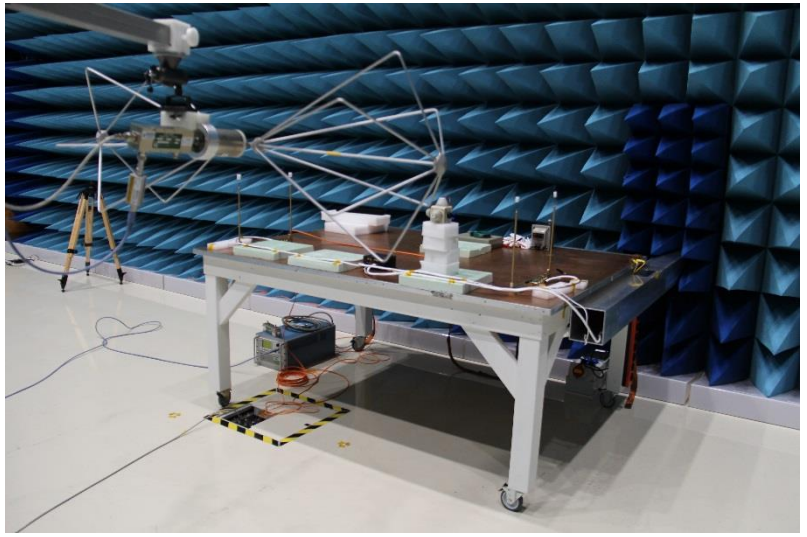
$MoS_{yield} > 84.4$

$MoS_{ultimate} > 85.5$



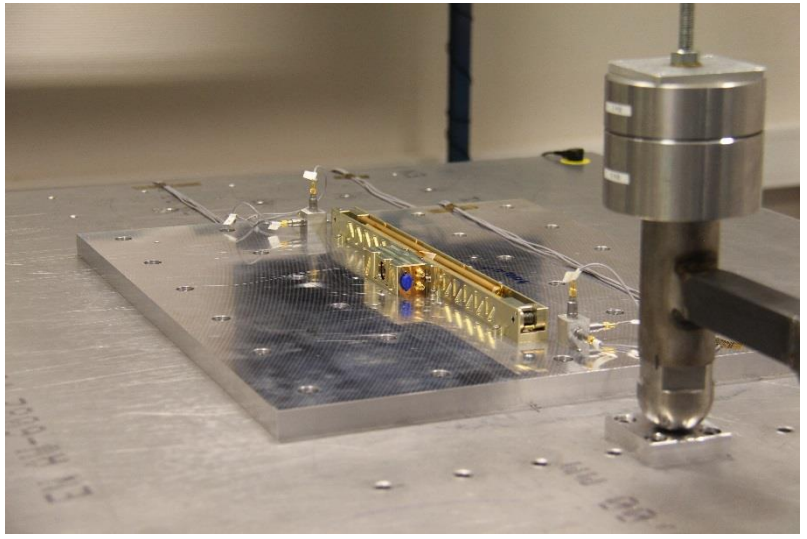


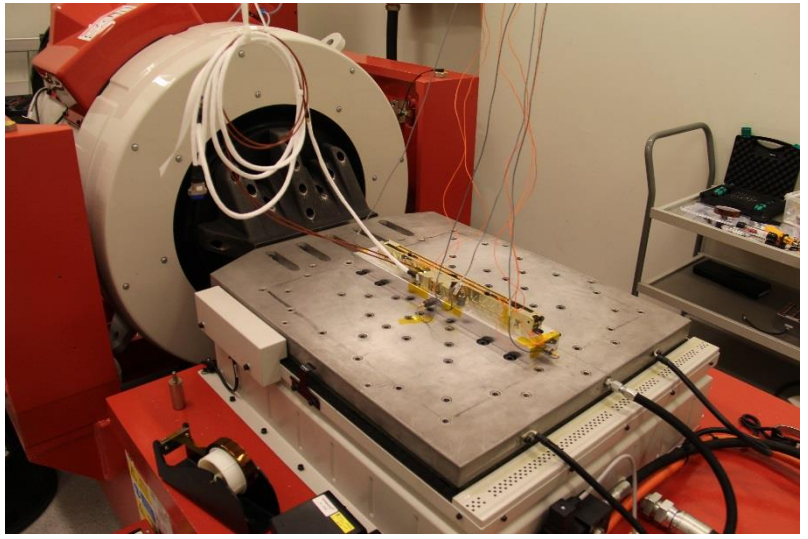
Qualification testing



EMC at ETS Maxwell (ETS/ESTEC)

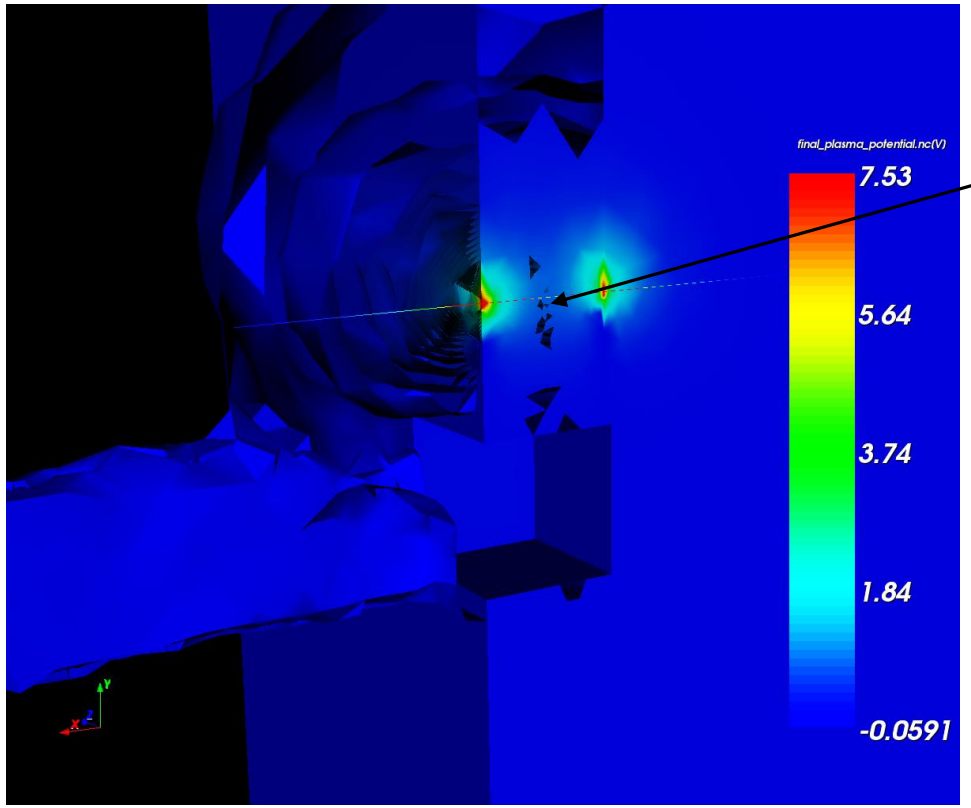
TVAC at TEC-MSL (ESTEC)

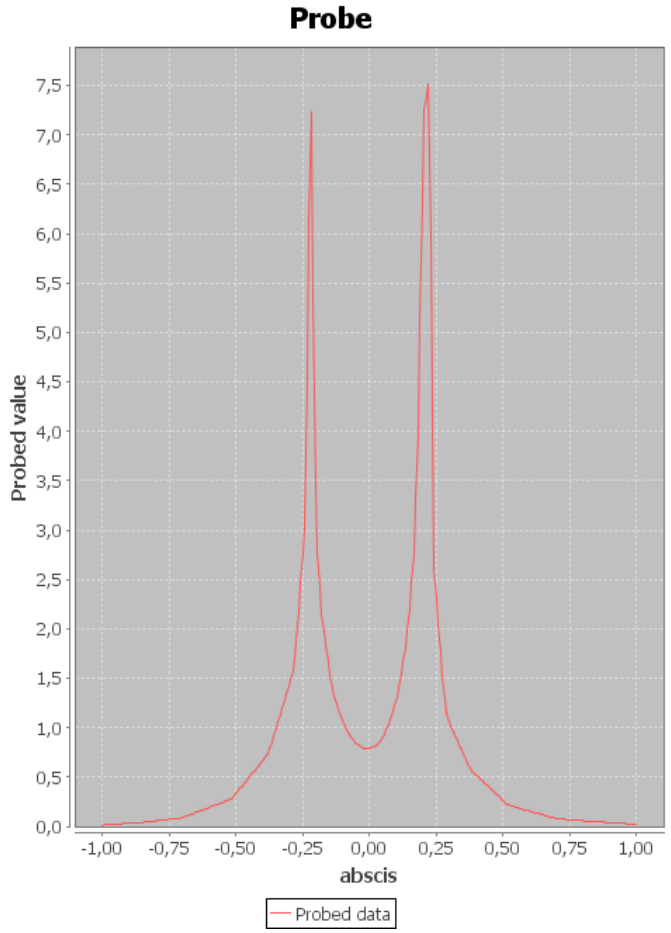




Shock and Vibration at Kongsberg Norspace (Horten, Norway)

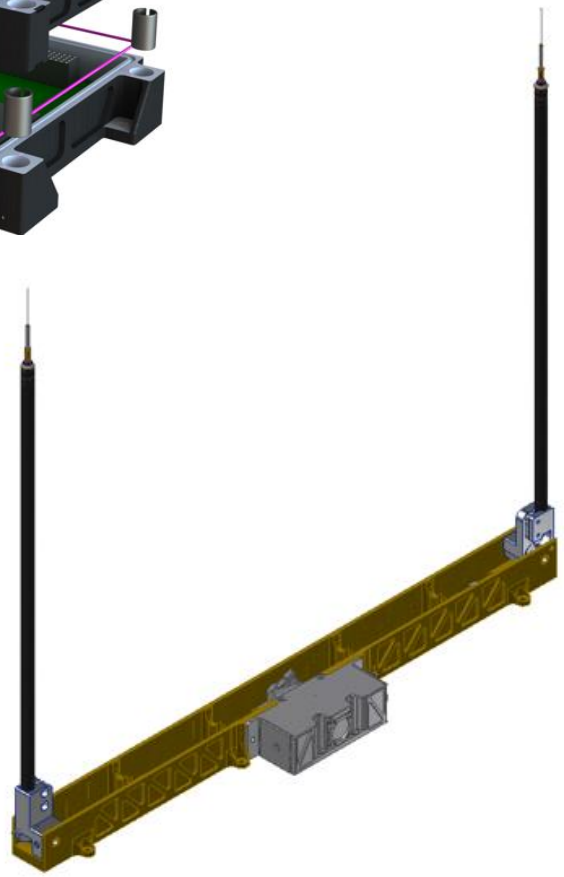
SPIS modelling





A performance model has been developed in SPIS to verify instrument functionality

Probe shielding distance has been simulated for the entire electron density range, for all typical LEO plasma, and for all instrument bias voltages



Key numbers

Parameter	Min	Nom	Max	Unit
Power Input				
Input voltage	22	28	38	V
Input power, normal operation	4.5	4.65	5.1	W
Input power, boom deployment (nominally 25 ms)	16	-	43	W
Electical Interfaces				
RS422 baud rate	19 200	460 800	921 600	bps
Electron density range	10^8	-	10^{12}	m^{-3}
Mechanical weights and dimensions				
Mass of electronic unit	-	0.813	-	kg
Total mass of boom system (two cassettes)	-	0.676	-	kg
Mass of harness (belonging to electronics unit)	-	0.265	-	kg
Mass of harness (belonging to two boom systems)	-	0.400	-	kg
Electronic unit dimensions (W x H x D)	-	122x61x109	-	mm
Boom dimensions, deployed (W x H x D)	-	400x384x65	-	mm
Harness lengths	-	1.5	-	m
Operational Environment				
Electronics unit temperature, operational	-30	-	55	°C
Electronics unit temperature, non-operational	-40	-	60	°C
Boom system pre-deployment	-50	-	60	°C
Boom system deployment	-50	-	60	°C
Boom system post-deployment	-50	-	60	°C
Spacecraft floating potential wrt. plasma potential	-7.5	-	+7.5	V


Image: ESA

Key aspects

On-board storage for > 24 hours of processed density and potential data at the highest sampling rate

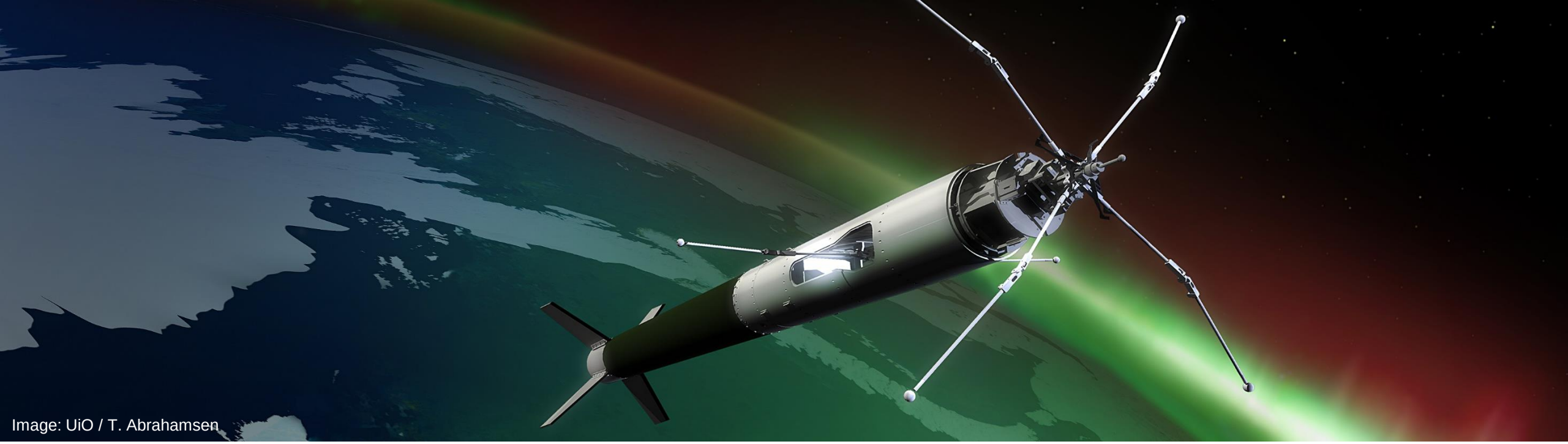
Radiation tolerant up to >50 krad

Examples of data rates for different operational modes:

Mode	Sample rate		
	100 Hz	1 kHz	5 kHz
Processed data	1 619 bps	16 185 bps	80 926 bps
RAW data	6 462 bps	64 616 bps	323 083 bps

Accumulated data per orbit (800 km altitude, 1h 41min orbit time):

Mode	Sample rate		
	100 Hz	1 kHz	5 kHz
Processed data	1.17 MB	11.7 MB	58.5 MB
RAW data	4.67 MB	46.7 MB	233.4 MB



Flight Heritage

Mission name	Launch date and site	Mission type
ICI-2	December 2008, Svalrak Launch Facility, Svalbard	Sounding rocket, 350 km apogee
ECOMA 7, 8 and 9	December 2010, Andøya Space Centre, Norway	Sounding rockets, 135 km apogee
ICI-3	December 2011, Svalrak Launch Facility, Svalbard	Sounding rocket, 350 km apogee
NASA 36.273 MICA	February 2012, Poker Flat Research Range, Alaska	Sounding rocket, 350 km apogee
ICI-4	February 2015, Andøya Space Centre, Norway	Sounding rocket, 350 km apogee
Maxidusty 1 and 1b	June/July 2016, Andøya Space Centre, Norway	Sounding rocket, 135 km apogee
NORSAT-1	July 2017, Baikonur Cosmodrome, Kazakhstan	Satellite, 586 x 608 km, 97.61º

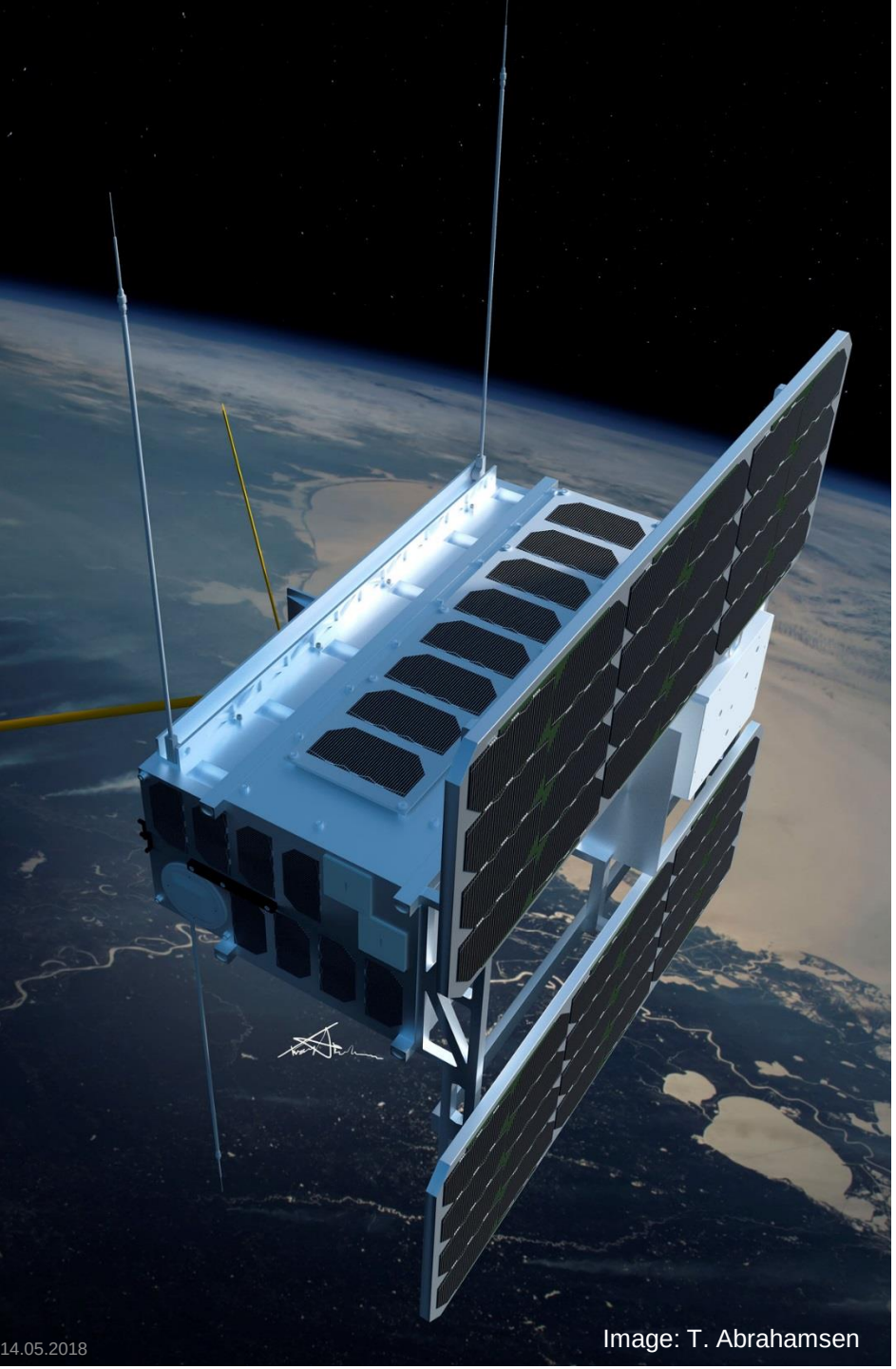


Image: T. Abrahamsen

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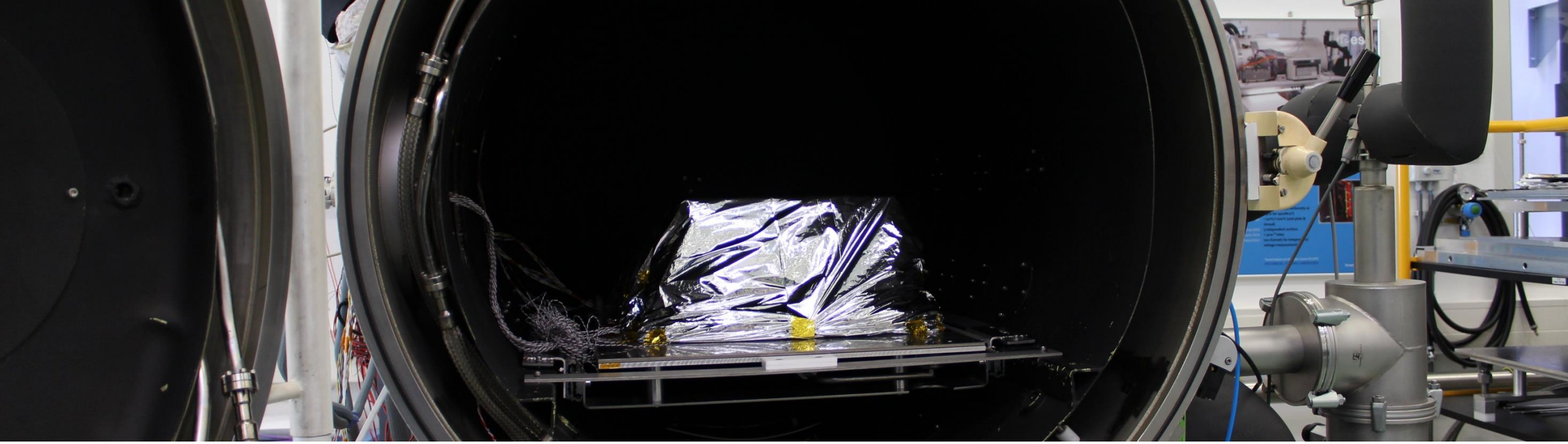
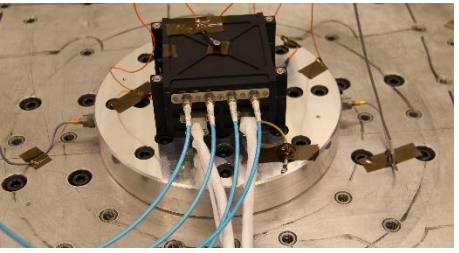
Orbital considerations and instrument accommodation

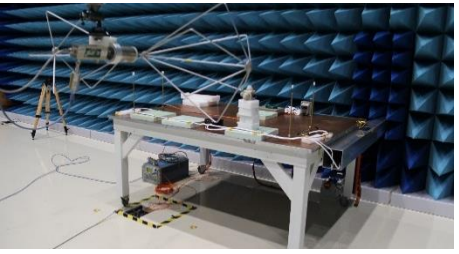
Preferred orbital height is 350 to 800 km

Probes have to be placed such as they all have the same orientation w.r.t. the magnetic field (due to different values for Te perpendicular and parallel to the magnetic field)

Boom system should be mounted such that the probes are not situated in wake regions behind satellite structures ← induces measurement error due to perturbed plasma







Project achievements and instrument capabilities

The m-NLP Electronics Unit and Boom System(s) have been successfully developed, tested and qualified according to the requirements in the SoW

Electron density can be measured over a measurement span of more than 4 decades (default: $10^{8}m^{-3}$ to $10^{12}m^{-3}$), at sampling rates up to 5 kHz

Platform potential can be sampled between -7.5V and +7.5V at up to 5 kHz sampling rate

Bootloader functionality for in-flight software updates (CCN3)

On-board storage for > 24 hours

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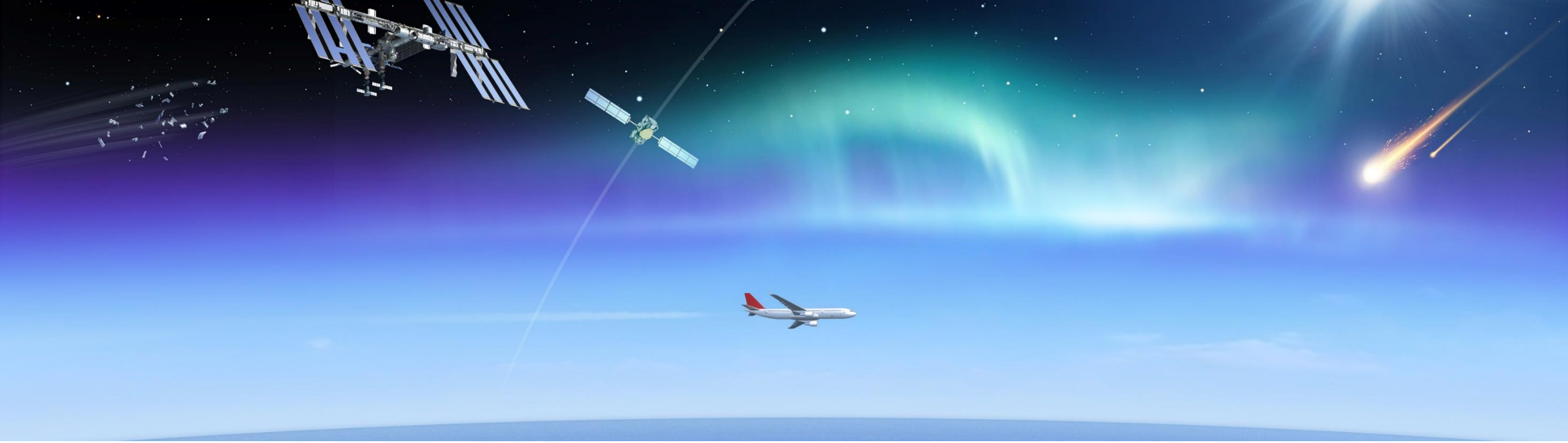

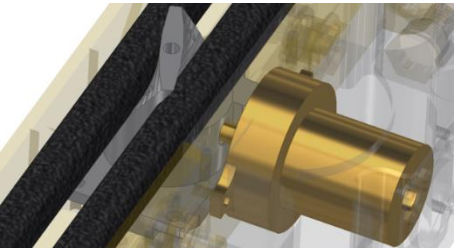

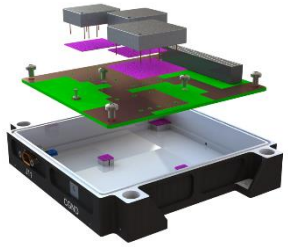

Future prospects

Instrument is currently a part of the ESA SSA D3S study

On-ground forecasting services for radio communication / GNSS signal integrity and availability are being researched and developed

A novel miniaturized electron emitter (up to 150 uA of electron current) originating from the CubeSat version of m-NLP has been identified as a possible future development – Will benefit all instruments doing plasma diagnostics in LEO

EIDEL
EIDSVOLL ELECTRONICS AS

Tore André Bekkeng:
tab@eidel.no
+47 97122396

www.eidel.no

Eidsvoll Electronics AS
Nedre Vilberg veg 8
N-2080 Eidsvoll
Tel no: +47 63 95 97 00