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THE FRENCH AEROSPACE LAB

Plasma chamber tests and simulations to prepare the **CROCUS mission dedicated to detect and mitigate ESDs on small satellites**

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SPACEMON 2025 – Plasma, Dust and Micrometeorites Session

11/06/2025

ElectroStatic Discharges (ESDs) on spacecraft

- Accumulation of excess negative charge or inductive re-distribution of charge generates **potential differences** between spacecraft and space or between two points on the spacecraft
- An **electrostatic discharge** (ESD) results when electric fields associated with potential differences exceed the dielectric breakdown strength of materials allowing charge to flow in an arc

Anomalies and Failures Attributed to Charging

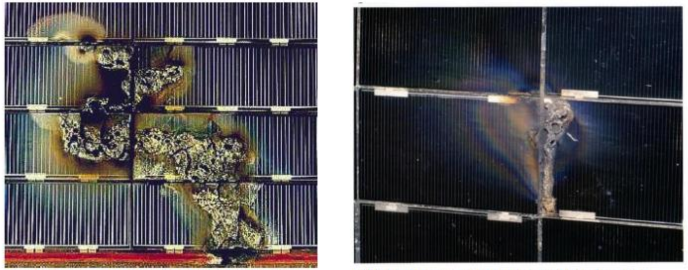
Spacecraft	Year(s)	Orbit	Impact*	Spacecraft	Year(s)	Orbit	Impact*
DSCS II	1973	GEO	LOM	Intelsat K	1994		Anom
Voyager 1	1979	Jupiter	Anom	DMSP F13	1995	LEO	Anom
SCATHA	1982	GEO	Anom	Telstar 401	1994, 1997	GEO	Anom/LOM
GOES 4	1982	GEO	LOM	TSS-1R	1996	LEO	Failure
AUSSAT-A1, -A2, -A3	1986-1990	GEO	Anom	TDRS F-1	1986-1988	GEO	Anom
FLTSATCOM 6071	1987	GEO	Anom	TDRS F-3,F-4	1998-1989	GEO	Anom
GOES 7	1987-1989	GEO	Anom/SF	INSAT 2	1997	GEO	Anom/LOM
Feng Yun 1A	1988	LEO	Anom/LOM	Tempo-2	1997	GEO	LOM
MOP-1, -2	1989-1994	GEO	Anom	PAS-6	1997	GEO	LOM
GMS-4	1991	GEO	Anom	Feng Yun 1C	1999	LEO	Anom
BS-3A	1990	GEO	Anom	Landsat 7	1999-2003	LEO	Anom
MARECS A	1991	GEO	LOM	ADEOS-II	2003	LEO	LOM
Anik E1	1991	GEO	Anom/LOM	TC-1,2	2004	~2GTO, GTO	Anom
Anik E2	1991	GEO	Anom	Galaxy 15	2010	GEO	Anom
Intelsat 511	1995	GEO	Anom	Echostar 129	2011	GEO	Anom
SAMPEX	1992-2001	LEO	Anom	Suomi NPP	2011-2014	LEO	Anom

*Anom=anomaly, LOM=Loss of mission, SF=system failure

Spacecraft Anomalies and Failures Workshop, 24 July 2014 7

(Minow & Parker, 2014)

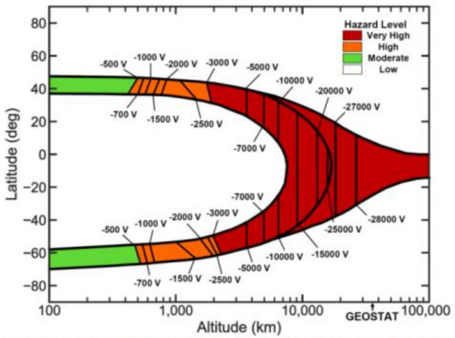
NASA-HDBK-4002B



(a) Failure caused by in-flight ESD arcing (b) Failure caused by ground ESD arcing

Figure 11—Examples of Solar Array Failure

NASA-HDBK-4002B



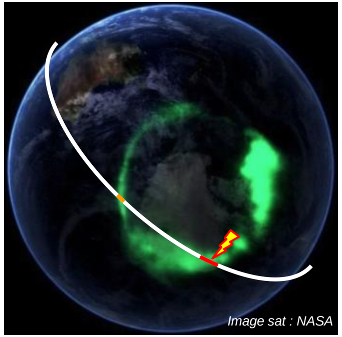
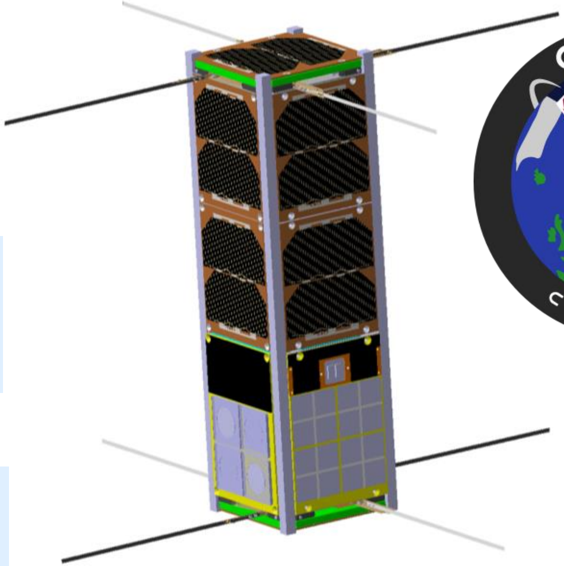


Figure 1—Earth Regimes of Concern for On-Orbit Surface Charging Hazards for Spacecraft Passing Through Indicated Latitude and Altitude Based on DMSP and Freja Observations, et al.

CROCUS mission

↳ ChaRging On CUbeSat



SCIENCE APPLICATIONS:

- **Observe keV electrons during auroral arcs**
- **Monitor the occurrence of ESDs on a CubeSat mission in LEO**
- Space weather and geomagnetic activity effects
- Space plasma matter interaction

TECHNOLOGICAL DEMONSTRATIONS IN FLIGHT:

- **Measurement of keV electron content and electrostatic charging**
- **Detection and measurement of ESDs waveforms**
- **Mitigation of charging issues** (in favoring or limiting ESDs)

→ New means of anomaly diagnosis and protections, for satellite designers for future missions

EDUCATIONAL AND OUTREACH OBJECTIVES:

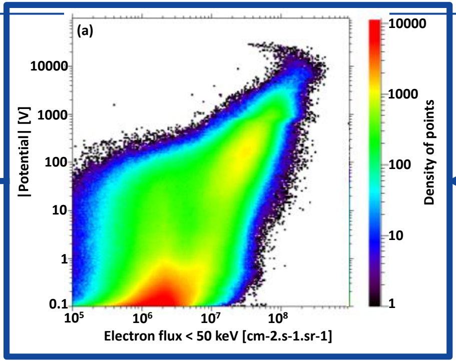
- Payload development, satellite integration, software development, training material, internships
- In partnership with Centre Spatial de l'Ecole Polytechnique (> 20 students involved)

ADDITIONNAL SCIENCE OBJECTIVES:

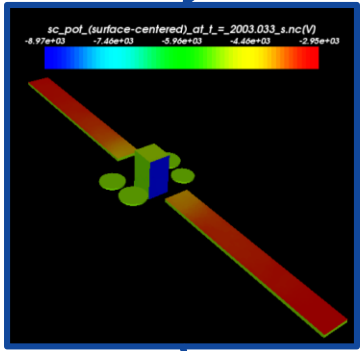
- Measure the Earth's energy (or radiation) budget (collaboration with LATMOS)
- Evaluate atomic oxygen fluxes

Scientific and Technological Approach at ONERA

Numerical Modeling

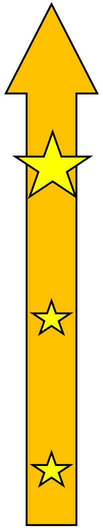


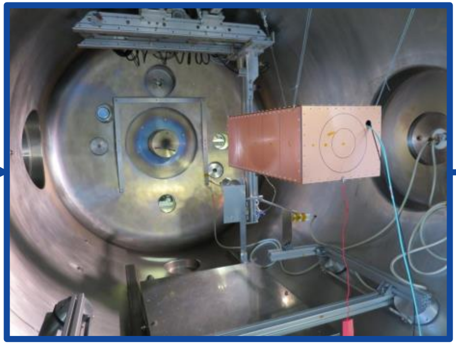
Flight meas.



CROCUS

CSEP • ONERA



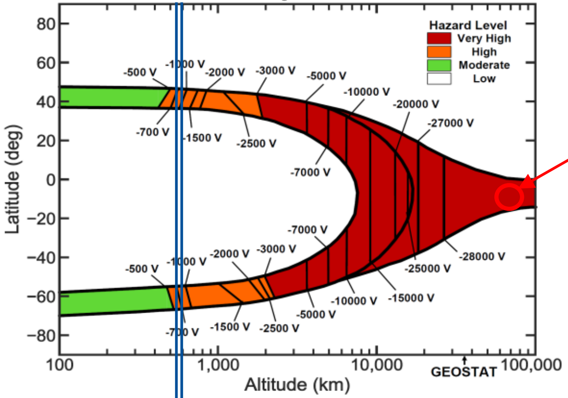


Ground meas.

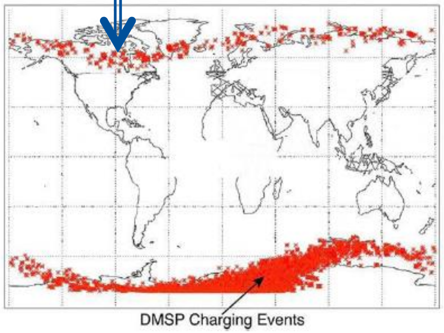
Prototyping
Flight model

Mission orbit

LEO *Image : NASA-HDBK4002B-2022*



MEO/GEO

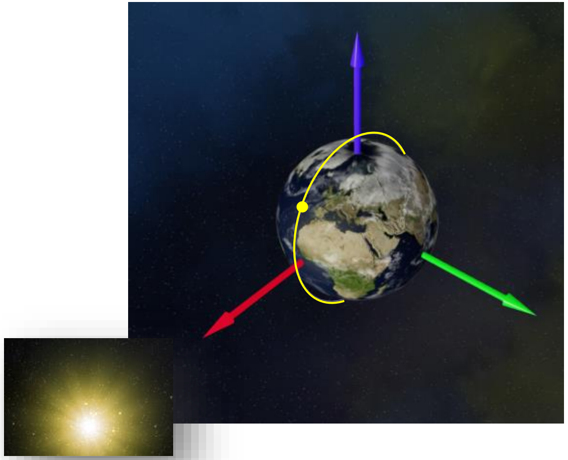


[adapted from Anderson, 2012]
DMSP spacecraft ~833km

To maximize the number of charging events and their detection, CROCUS mission will fly :

- **550-595 km of altitude**
- **a sun-synchronous orbit (SSO) and a descending node of 10am to 2pm**
- **98° inclination**

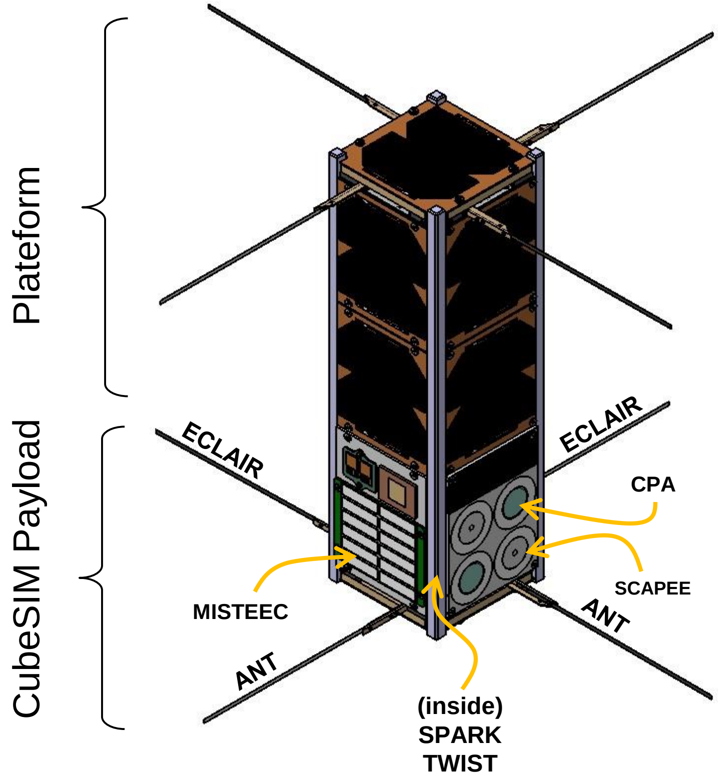
→ 3 minutes/orbit in the auroral area, and 15 orbits/day

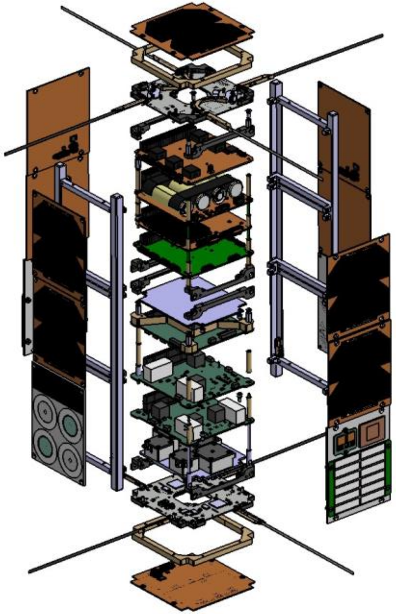


Seeing the small time spent in exposed areas along the orbit (compared to MEO or GEO), 2 working modes are used:

- Passive mode: **nominal mode**, expected for GEO or MEO
- Active mode: **to trigger or limit ESDs actively**, in increasing or decreasing artificially the potential differences, to test the payload and get data

CROCUS Satellite Design





3U format
2U solar panels
UHF radiocommunication
Detumbling after injection in orbit

Ground Support Equipment

PHEDRE - Toulouse

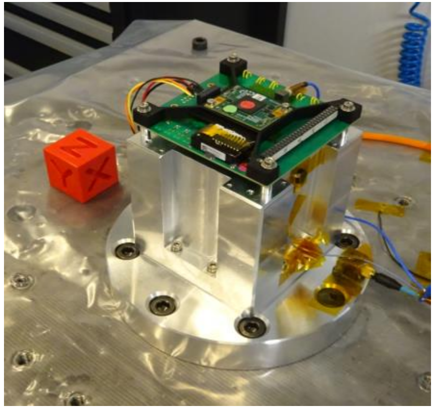
Thermal vacuum

-150°C à +150 °C

EVT - Châtillon

Thermal vacuum

-30°C à +80 °C



PIT - Guyancourt

Vibrating tests

JONAS - Toulouse

Ionospheric plasma

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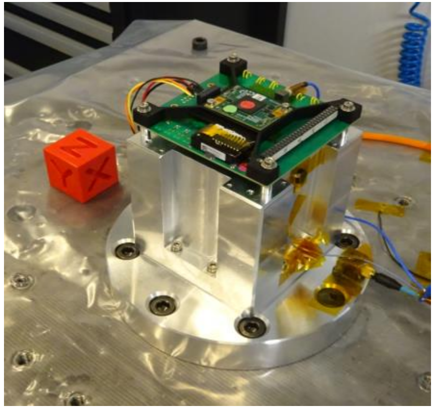


PIT - Guyancourt

Vibrating tests

JONAS - Toulouse

Ionospheric plasma

JONAS, vacuum/plasma chamber

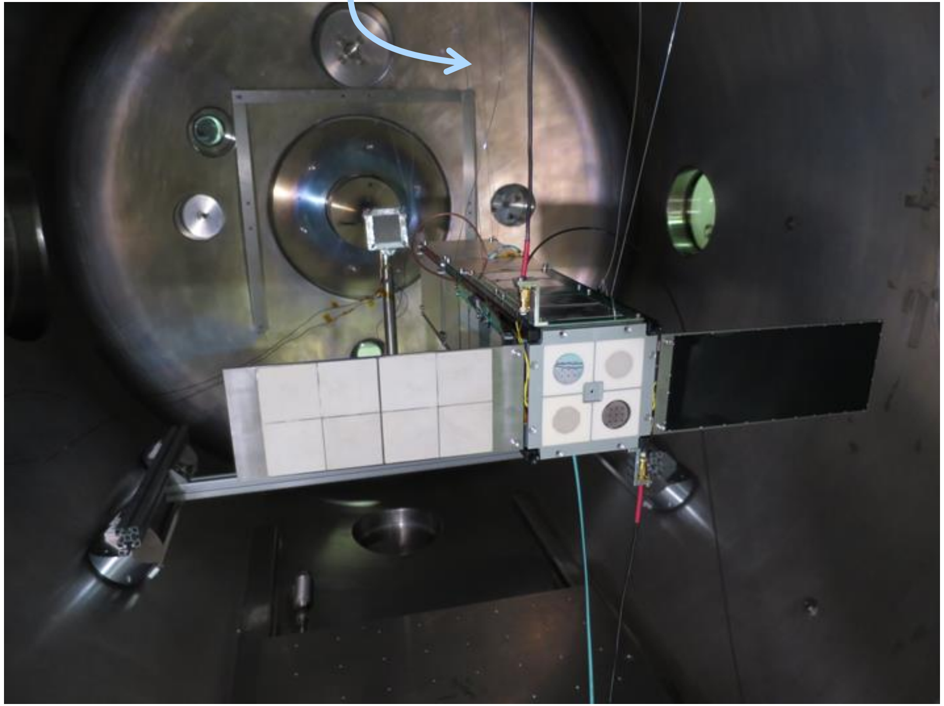
FACILITY FOR FUNCTIONNAL TESTS

- **e- gun** represents LEO / GEO arcjets
- **VUV source** represents solar photons
- **KP probe** measures surface potential
- **Ground segment data acq.**

NANOSAT MOCKUP

- **Test** of engineering models
- **EPS** with batteries
- **Scopes ESD** on-board detection
- **Communication** with optical fiber
- **Nylon wires** fixes the mockup

→ Floating satellite



Ground segment

Antenna

Control room

CubeSIM Payload: list of instruments

	Instrument	Objective	Success criteria
Detect keV e- and ESDs	ANT/TWIST	Detect transients in S/C absolute potential	Voltage drop of less than 100 V in 500 ns
	ISC/TWIST	Detect transients in harnesses	20 mA - 1 A peak 100 ns - 10 µs duration 50 ns - 500 ns raise time
	CPA	Detect positive and negative differential charging	+100 V/s (IPG charging) -100 V/µs (ESDs and FO)
Increase the potential difference → Favor ESDs	ECLAIR → active	Charge artificially the spacecraft	More negative than -400V
	MISTEEC → passive	Trigger ESDs at triple point	For an IPG below +400V
	SPARK → active	Inject an waveform representative of an ESD	200 mA peak 500 ns duration 100 ns raise time
Decrease/limit the potential difference → Limit ESDs	SCAPEE → 2 passives → 2 actives	Emit electrons when the spacecraft is negatively charged	Few 10s µA @ -300V

CubeSIM Payload: list of instruments

Detect
keV e- and ESDs

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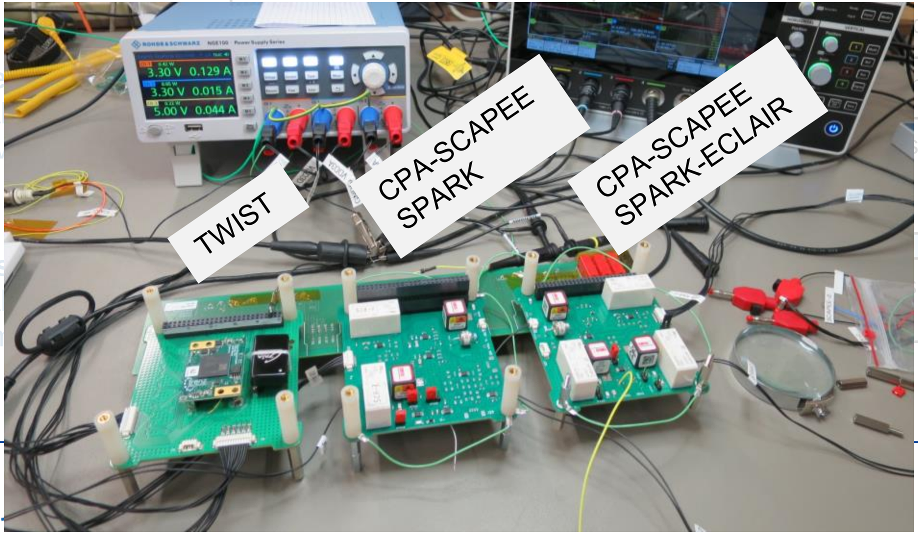
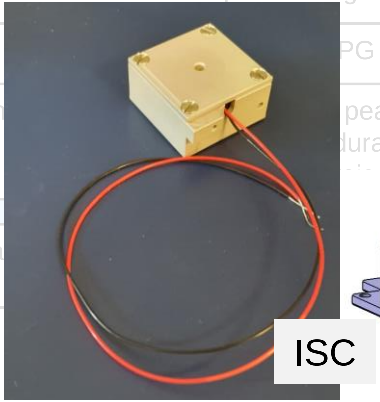
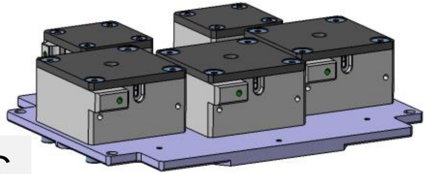
Incre
potential
→ Fav

Decreas
potential
→ Lin

cecraft
More negative than -400V
nt
PG below +400V
sen
peak
duration
pa







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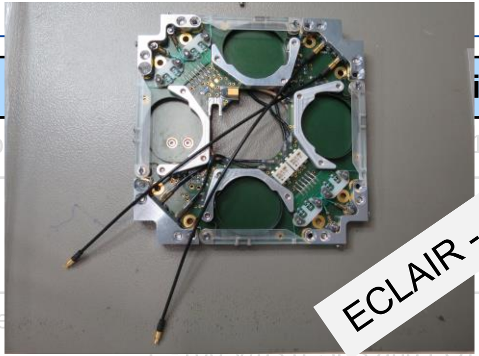
CubeSIM Payload: list of instruments



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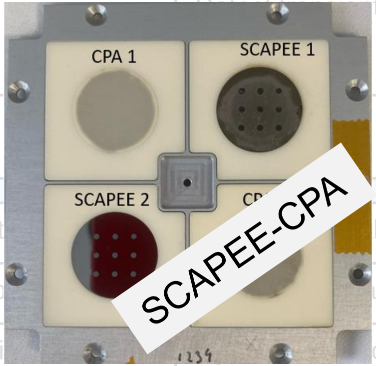

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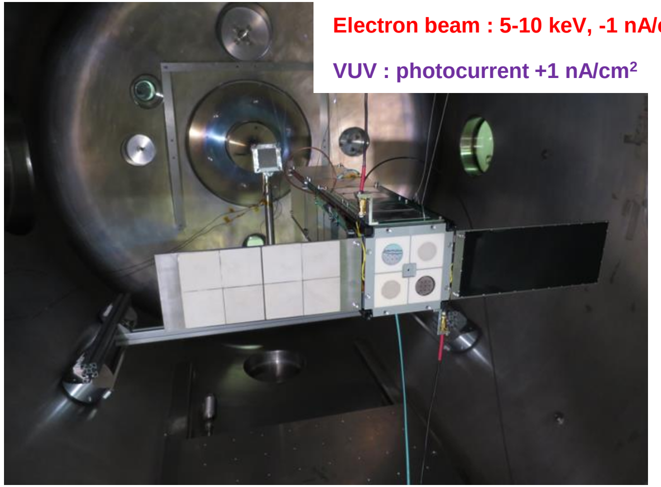
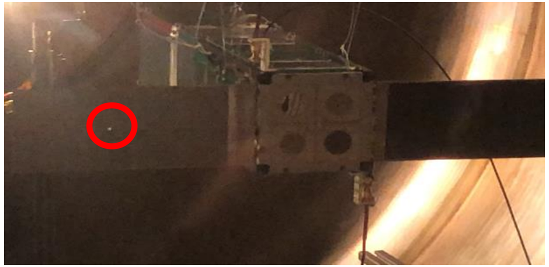
EM Testing in Charging Conditions: ESD detection



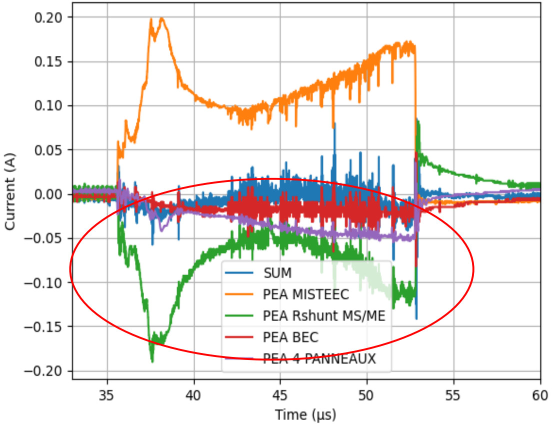
Electron beam : 5-10 keV, -1 nA/cm²

VUV : photocurrent +1 nA/cm²

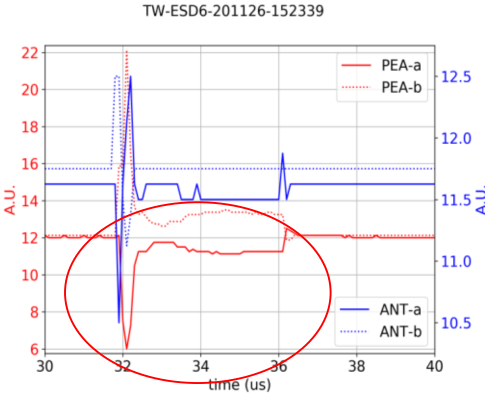
ESD initiation on MISTEEC



ESD transient characterization with EGSE



ESD detection with TWIST



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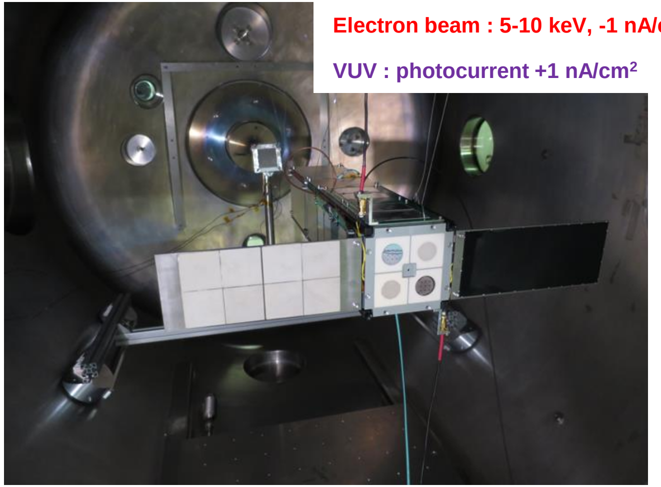
EM Testing in Charging Conditions: charge reducing with SCAPEE



Electron beam : 5-10 keV, -1 nA/cm²

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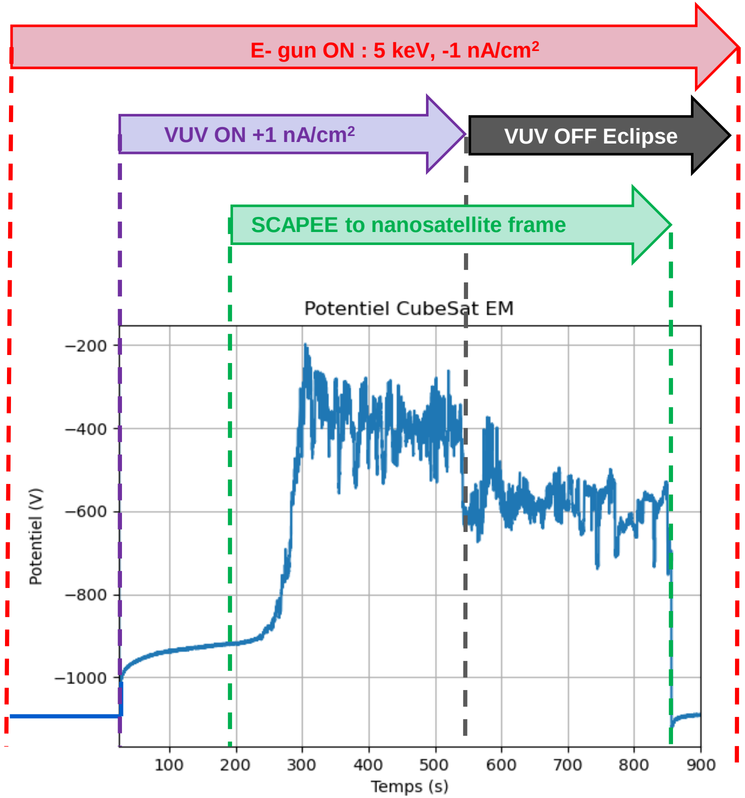

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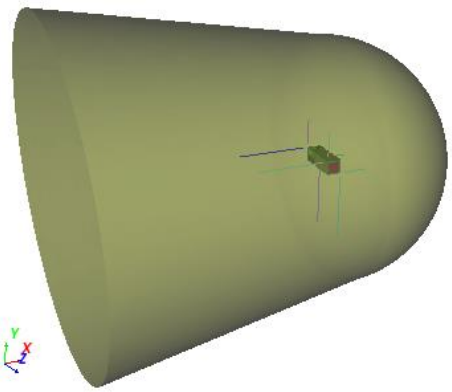
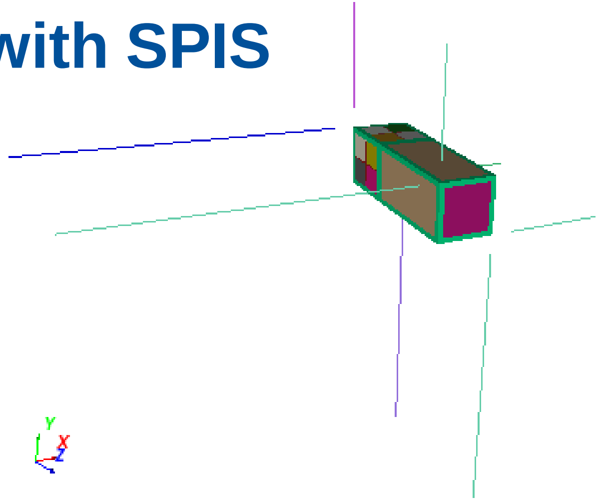
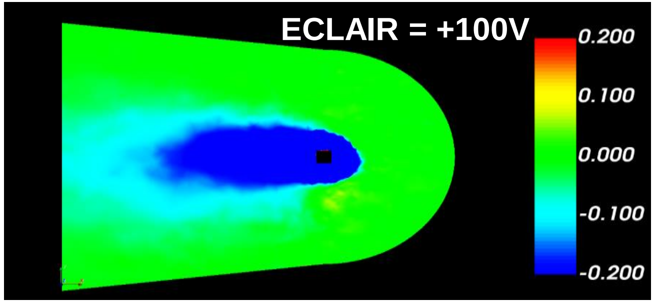
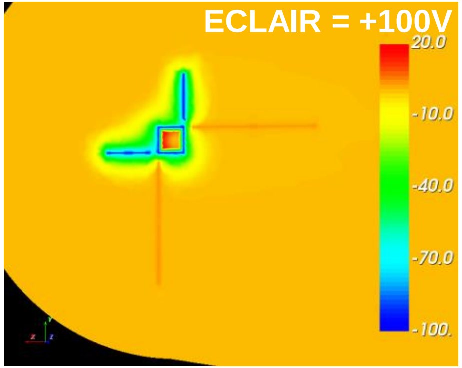
Active Science Mode Modeling with SPIS

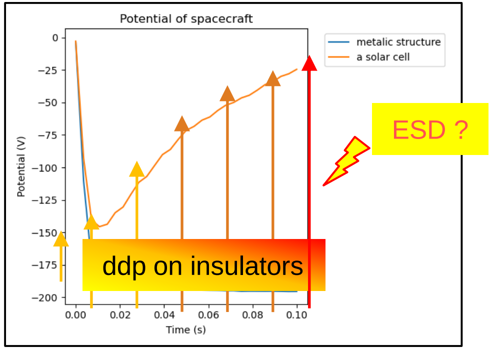








ECLAIR = +200V



Conclusions and Future Work

- Charging can cause significant damage to spacecraft resulting in loss of mission, loss of functionality, loss of money

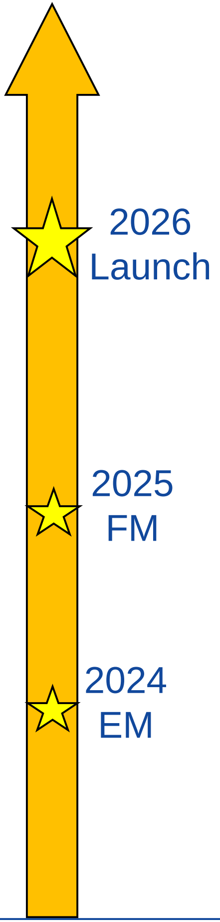
  → needs to build new means to monitor and mitigate them on spacecrafts

- We have tested the EM into a plasma vacuum chamber to validate the working of the instruments in space conditions

- We perform also simulation to predict and understand the charging events

- We plan to launch CROCUS in the end of 2026, for 3 year of flight

- We will analyze CROCUS data using ground tests in ionospheric plasma chamber coupled with SPIS numerical simulations



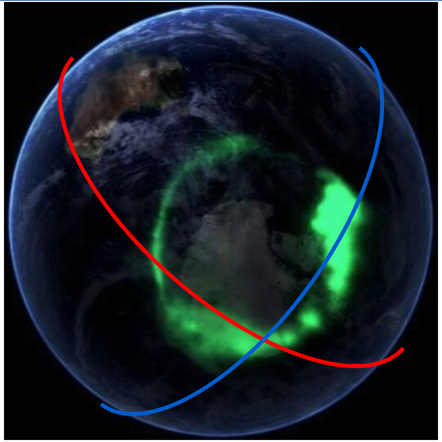
The CROCUS mission project is supported by ONERA ONSAT-1 program in partnership with Centre Spatial de l'Ecole Polytechnique

BACK UP

Profil de mission

- Orbite SSO ~ 550 à 590 km

- Cas chaud : orbite LTAN 0600
- Cas froid : orbite LTAN 0000



- Satellite 3U non pointé
- Algorithme de detumbling BDot
- Vitesses de rotation limites selon detumbling
  - OFF : 20 °/s; 18 s/tr; 2 tr/min; 200 tr/orbite
  - ON : 0,1 °/s; 3600 s/tr; 6 °/min; 1,5 tr/orbite