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PiCASSO

CubeSat-based scientific mission: the PICASSO experience

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Royal Belgian Institute for Space Aeronomy, Belgium

Committee for Geodesy and Geophysics, 20 January 2022

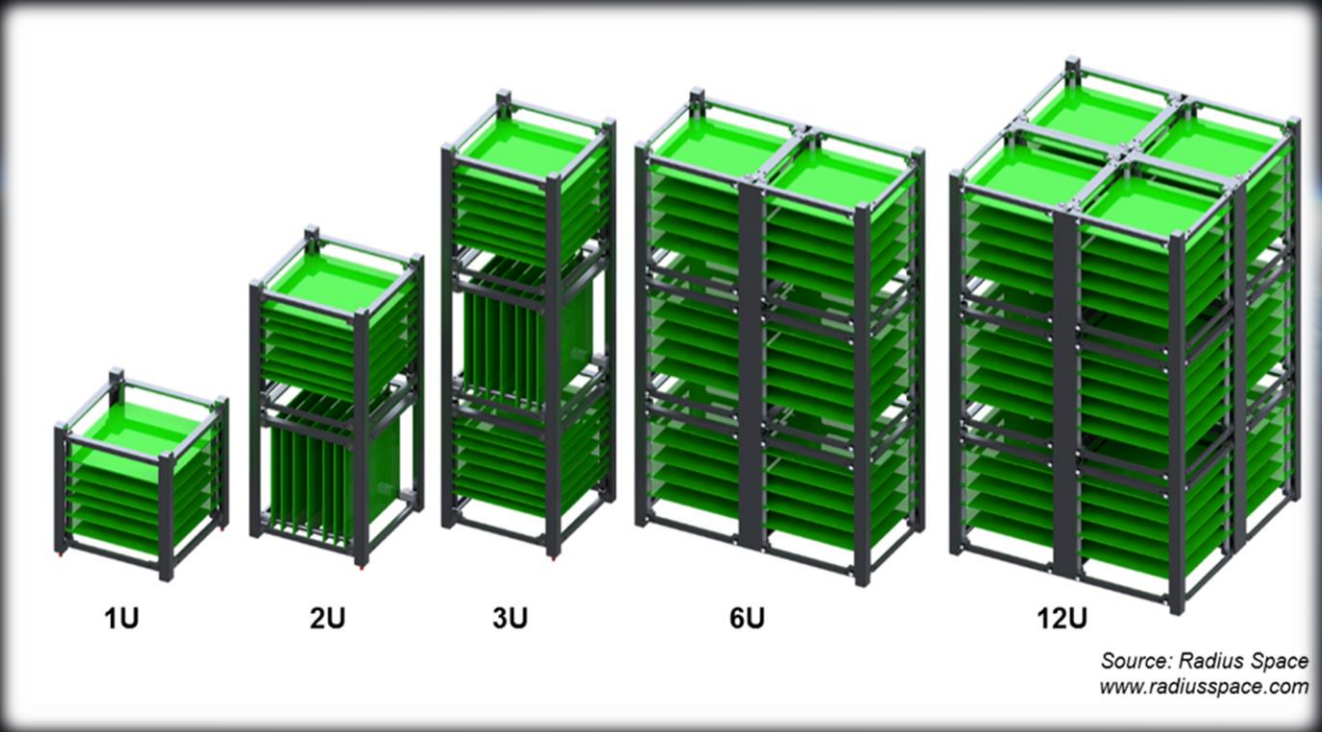
Outline

- CubeSats in a nutshell
- PICASSO mission and platform
- VISION
- SLP
- Status of the mission
- Lessons learned
- Is a CubeSat-based scientific mission a viable approach ?

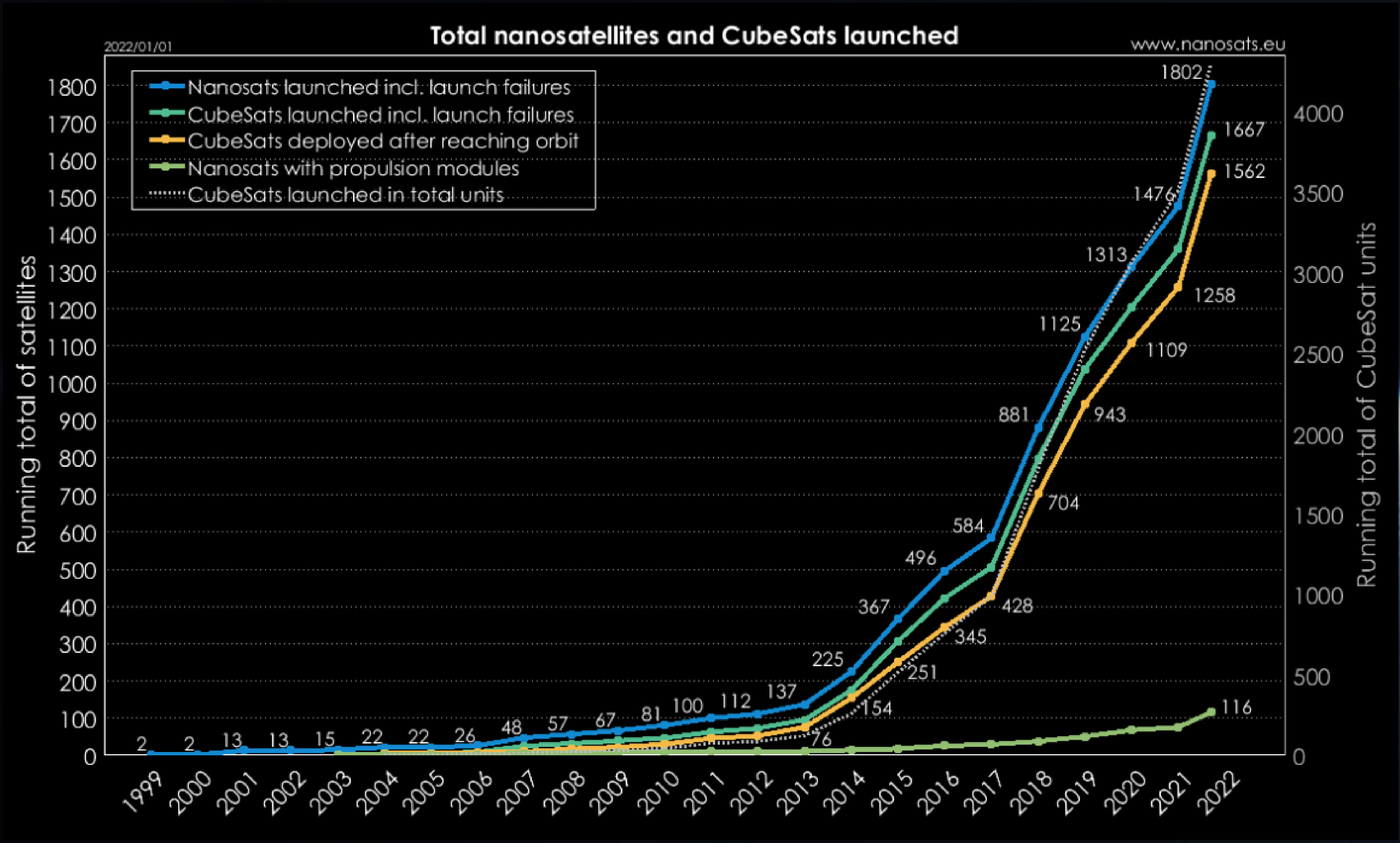
CubeSats in a nutshell

CubeSats : type of nanosatellites

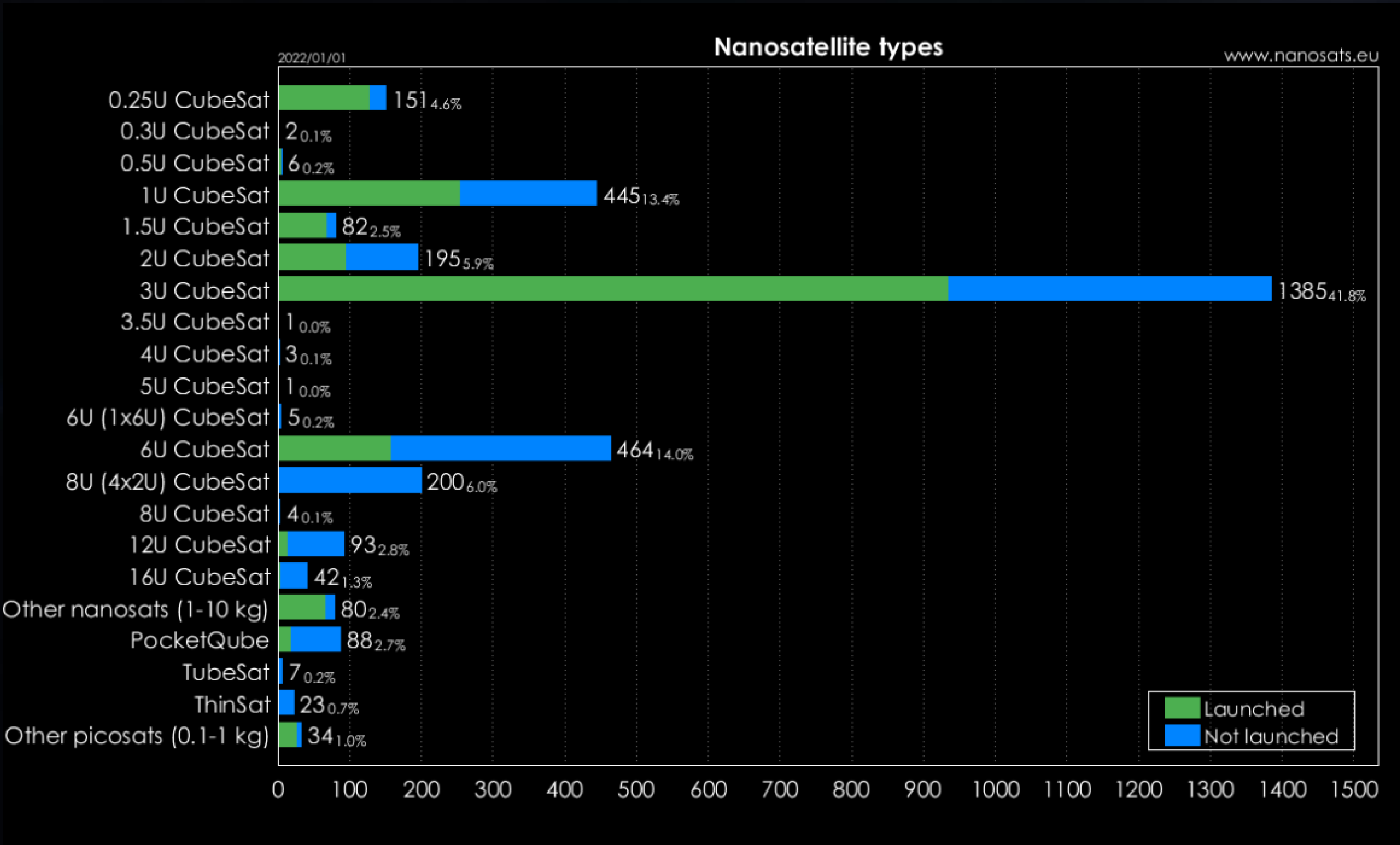
Standard dimensions: units of 10 cm x 10 cm x 11.35 cm



CubeSats in a nutshell

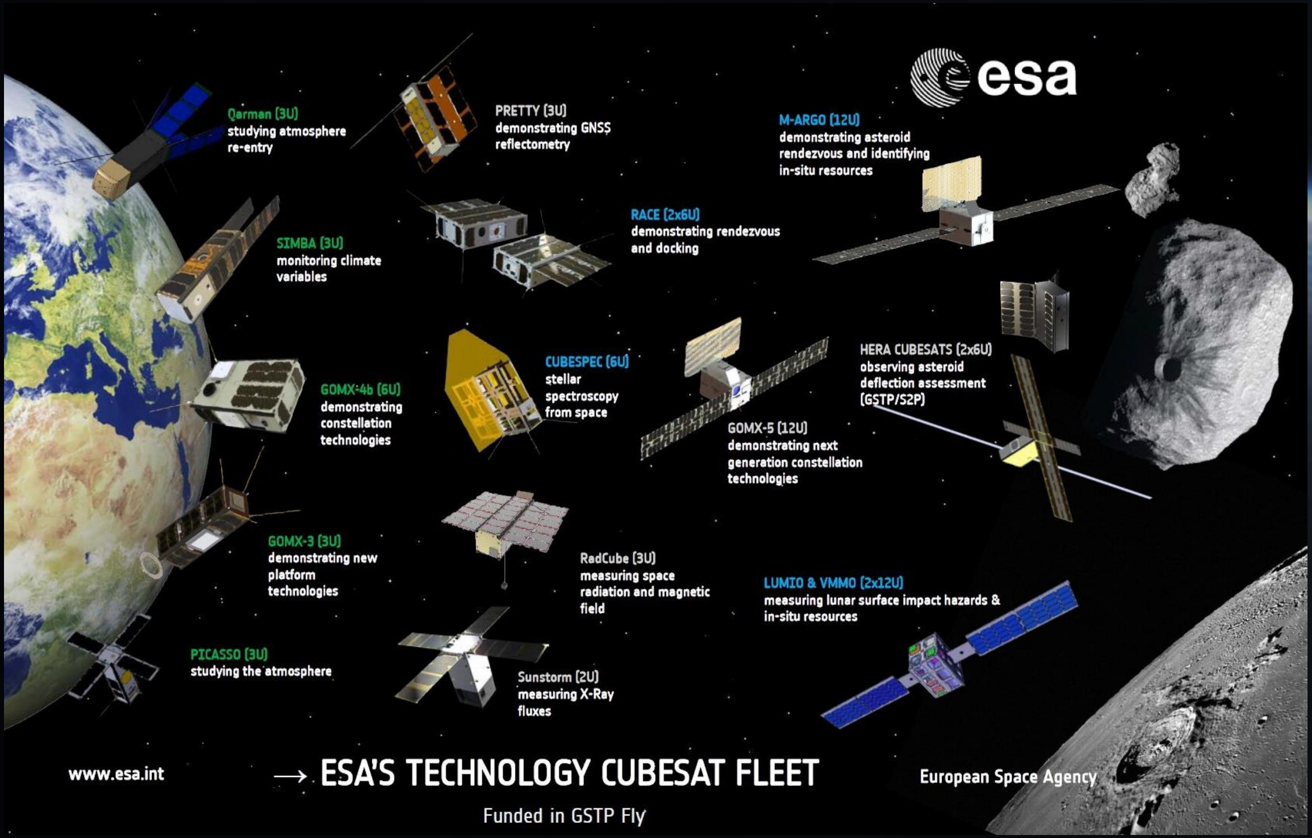


CubeSats in a nutshell



CubeSats in a nutshell

- Vast majority orbiting in LEO
- A few intended for interplanetary missions (e.g. MARCO, APEX & Juventas)

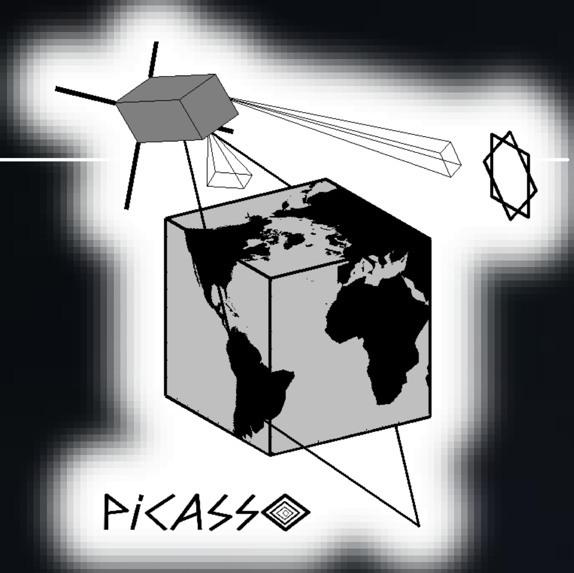


PICASSO Mission

PICASSO (**PIC**o-satellite for **A**tmospheric and **S**pace **S**cience **O**bservations):

Scientific CubeSat-based project initiated by BIRA-IASB in 2010

Since 2014: ESA IOD



CubeSats vs traditional satellites

- Lower price
- Shorter lead time

PICASSO team

PICASSO Mission

Objectives:

- Demonstrate the capacity of nano-satellites to perform scientific missions
- Anticipate the future of remote sensing and in situ measurements for Earth and planets through miniaturisation
- Bring instruments and on-board data processing components to high TRL => to be incorporated in future scientific missions with a reduced risk

Philosophy:

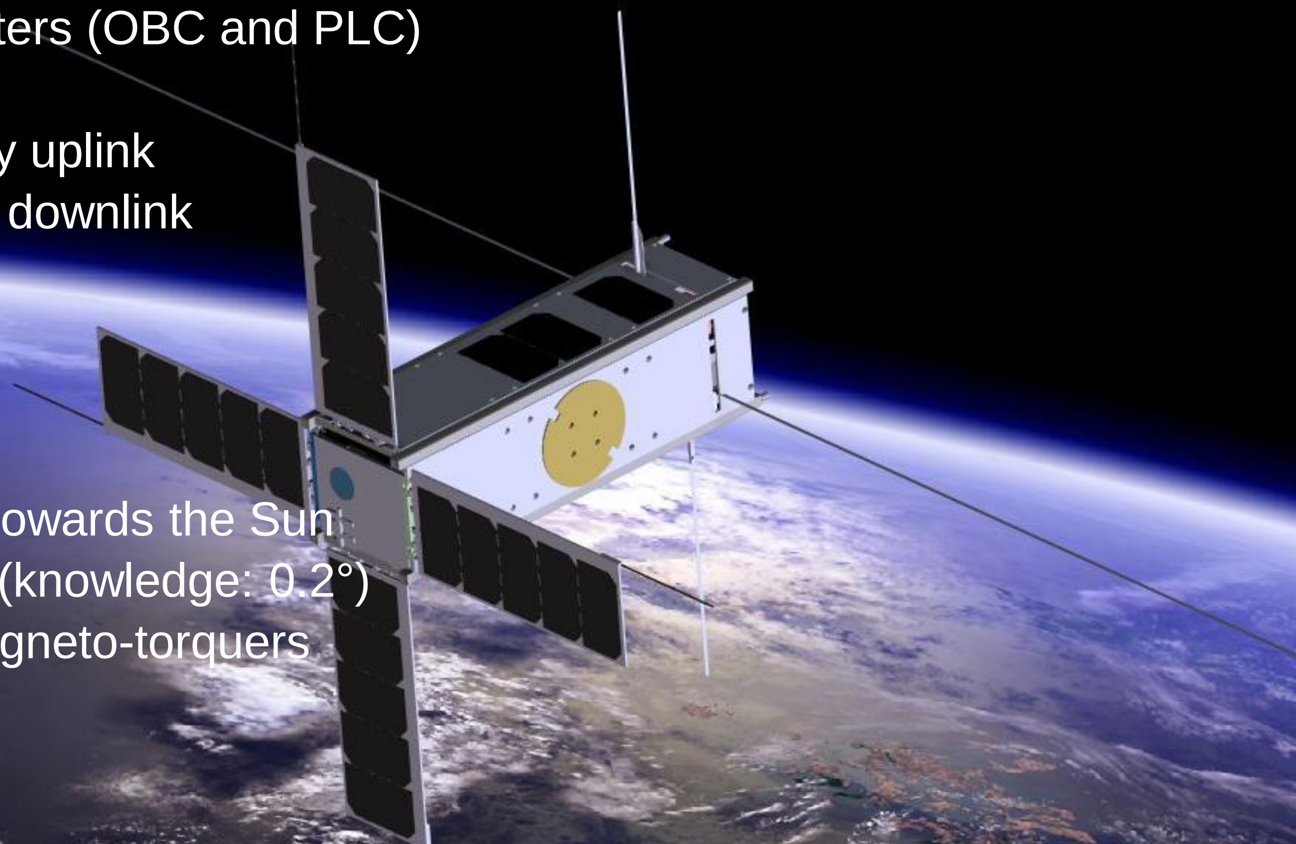
- BIRA-IASB: science only
- Platform and operation: subcontracted

PICASSO mission

Platform from *AAC Clyde-Space* (UK) :

3U CubeSat (340.5 x 100 x 100 mm), 1U for payload

- Four deployable 2U long solar panels
- Power generation: 8,7W
- Two on-board computers (OBC and PLC)
- Mass: 3,9 kg
- UHF/VHF: 400 kB/day uplink
- S-band: ~ 50 MB/day downlink



Attitude control:

Inertial flight, one face towards the Sun

Pointing accuracy: ~1° (knowledge: 0.2°)

3 reaction wheels + magneto-torquers

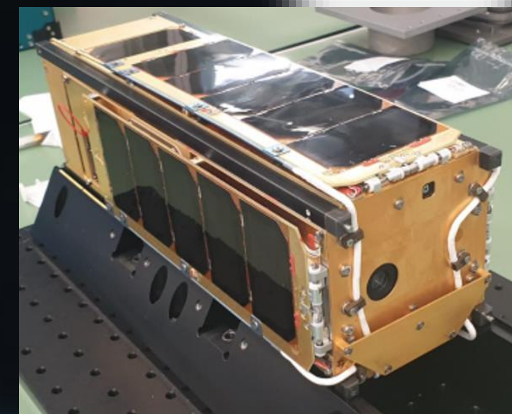
Star tracker

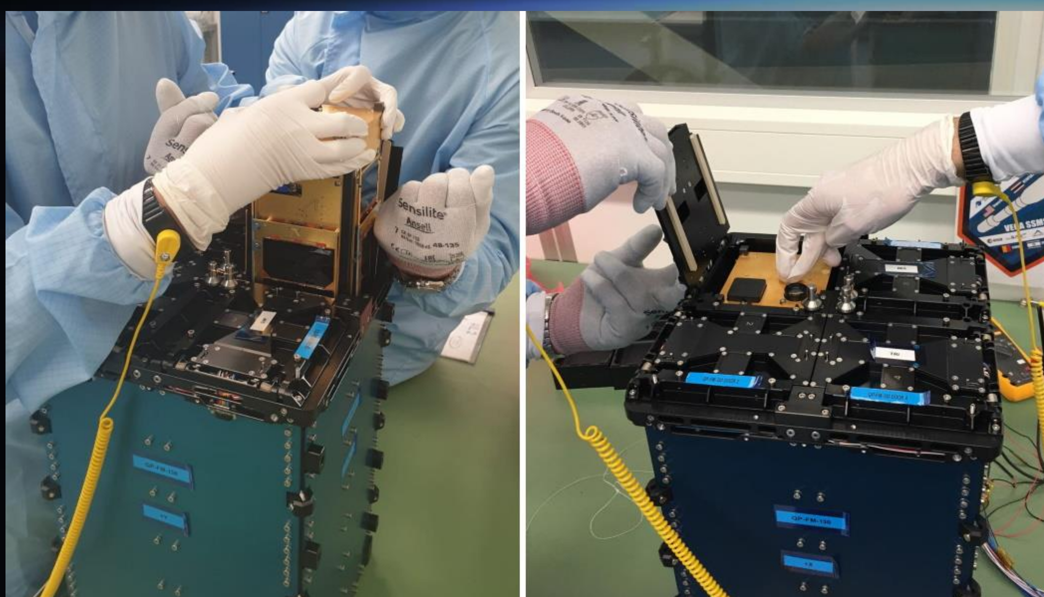
Fine Sun sensor

GPS

PICASSO Mission

- Launch: 3 September 2020 (Kourou, Vega launcher)
- Orbit: high inclination (97.5°), Sun-synchronous
- Altitude: 534 km (period 95.3 min)





PICASSO mission

Payload

VISION (Visible Spectral Imager for Occultation and Nightglow):

Visible and near-infrared hyper-spectral imager

Objectives

- Polar and mid-latitude stratospheric ozone vertical profile
- Upper atmosphere temperature profile

SLP (Sweeping Langmuir Probe):

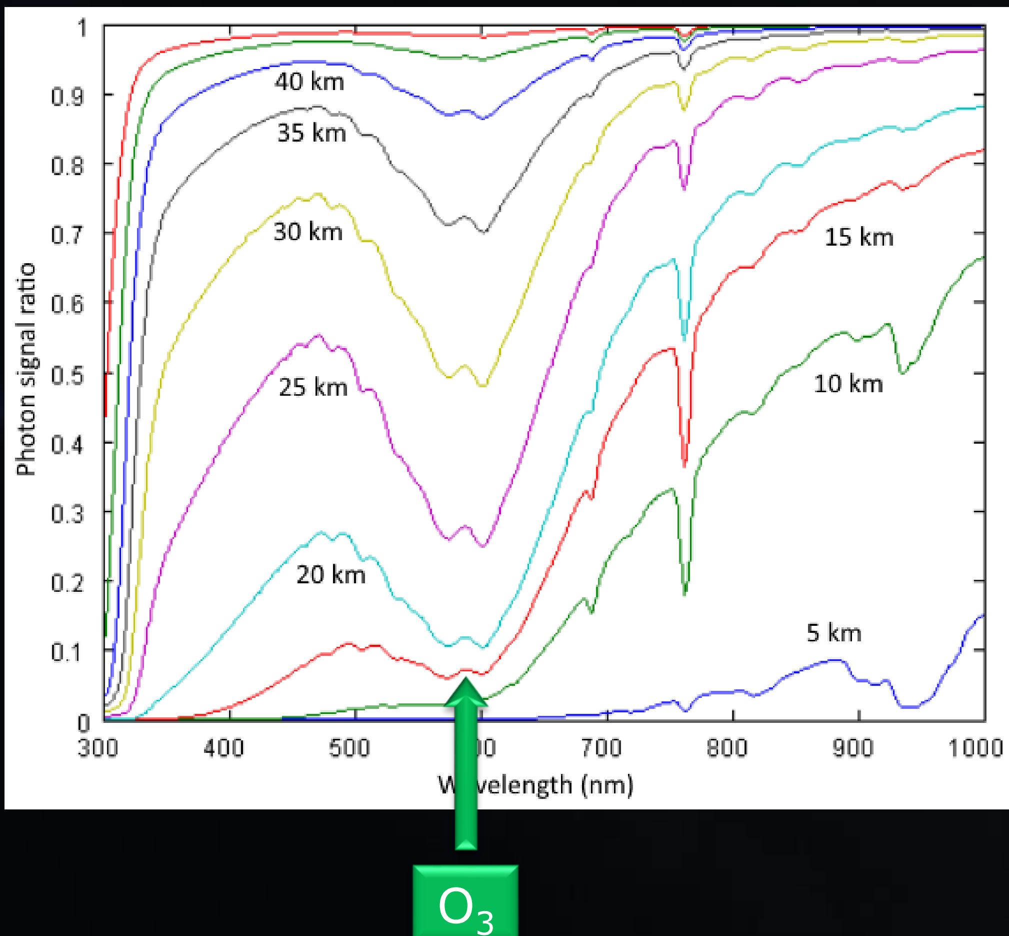
Four channel Langmuir probe instrument

Objectives

- Plasma density, electron temperature and spacecraft potential

VISION: ozone retrieval

VISION scientific goal 1: polar and mid-latitudes **stratospheric ozone** vertical profiles



- Absorption increases when looking deeper in the atmosphere (smaller tangent heights)
- Ozone retrieved from the **Chappuis band** (~600 nm)
- Measurement at 3 λ (or more)
- Target: 5 % accuracy, 1-km vertical resolution, over the stratosphere

VISION: temperature retrieval

VISION scientific goal 2: mesosphere and stratosphere **temperature** profiles

- **Method 1:** shape of the Sun (refractive flattening)
- **Method 2:** Sun light dilution

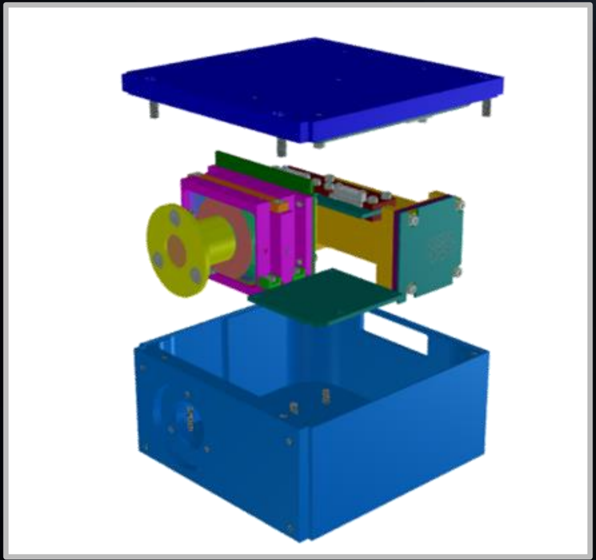
⇒ expected accuracy: 2 K below 72 km

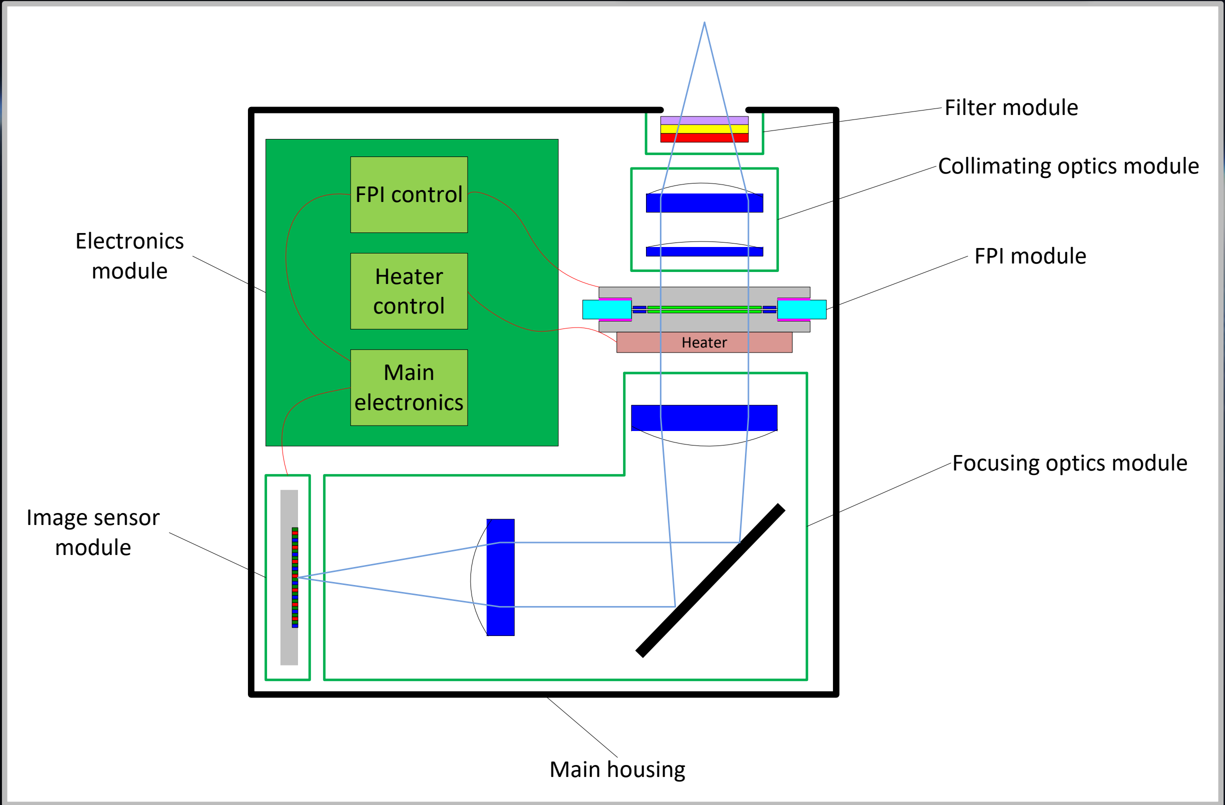
VISION: instrument

VISION instrument developed by **VTT**, Finland

Spectral imager

- Fabry-Perot interferometer
- Sensor = commercial CMOS array 2048x2048 RGB
- Field of view: 2.5°
- Dimensions: 97x97x50 mm

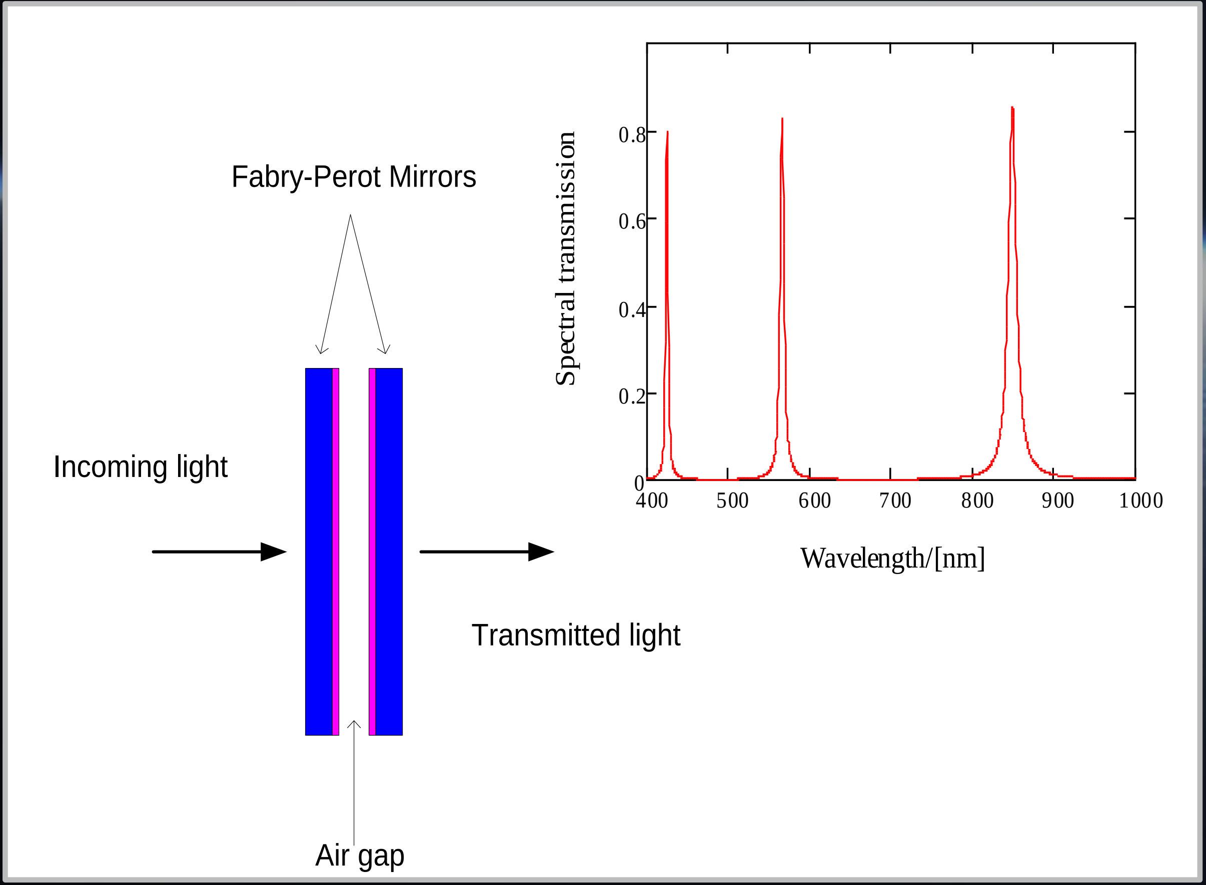




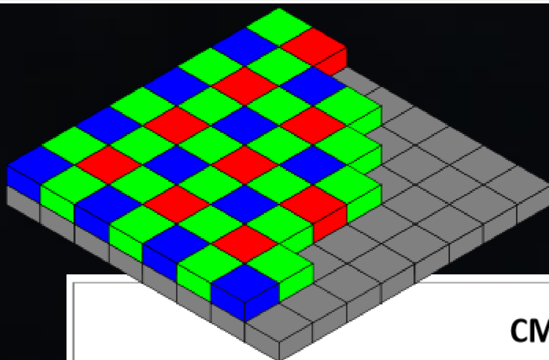
VISION: instrument

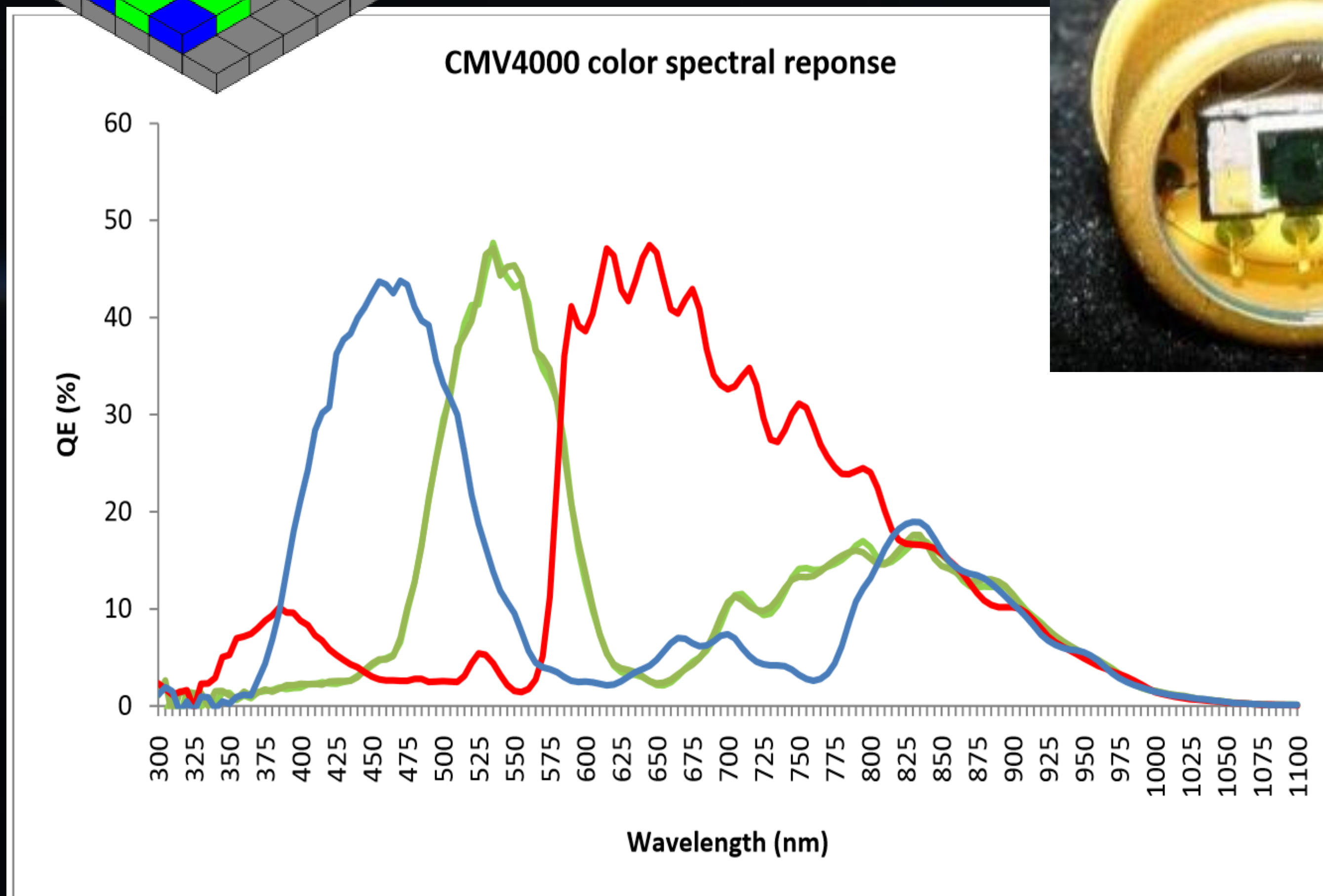
Fabry-Perot interferometer principle

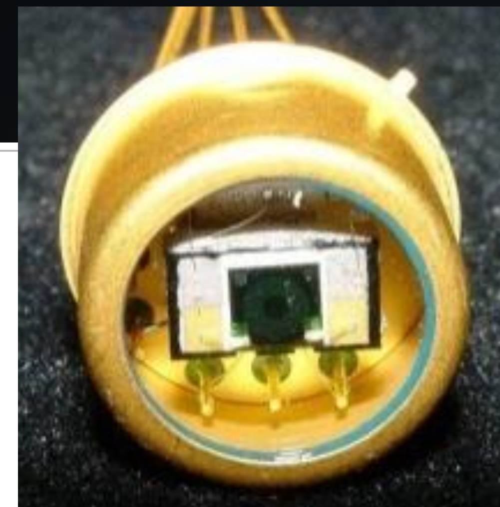
- Fabry-Perot + spectral filters: up to 3 modes
- Tuneable air gap: piezo actuator
- Range: ~400-800 nm, FWHM: < 10 nm



VISION: instrument

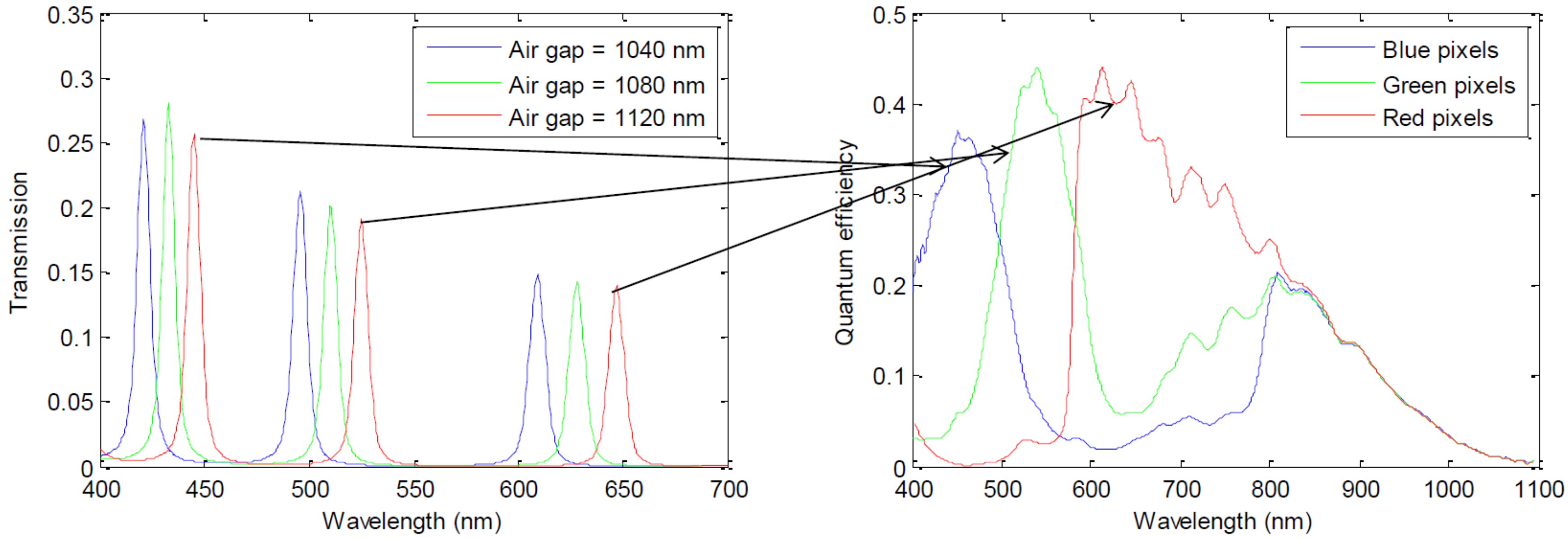






VISION: instrument

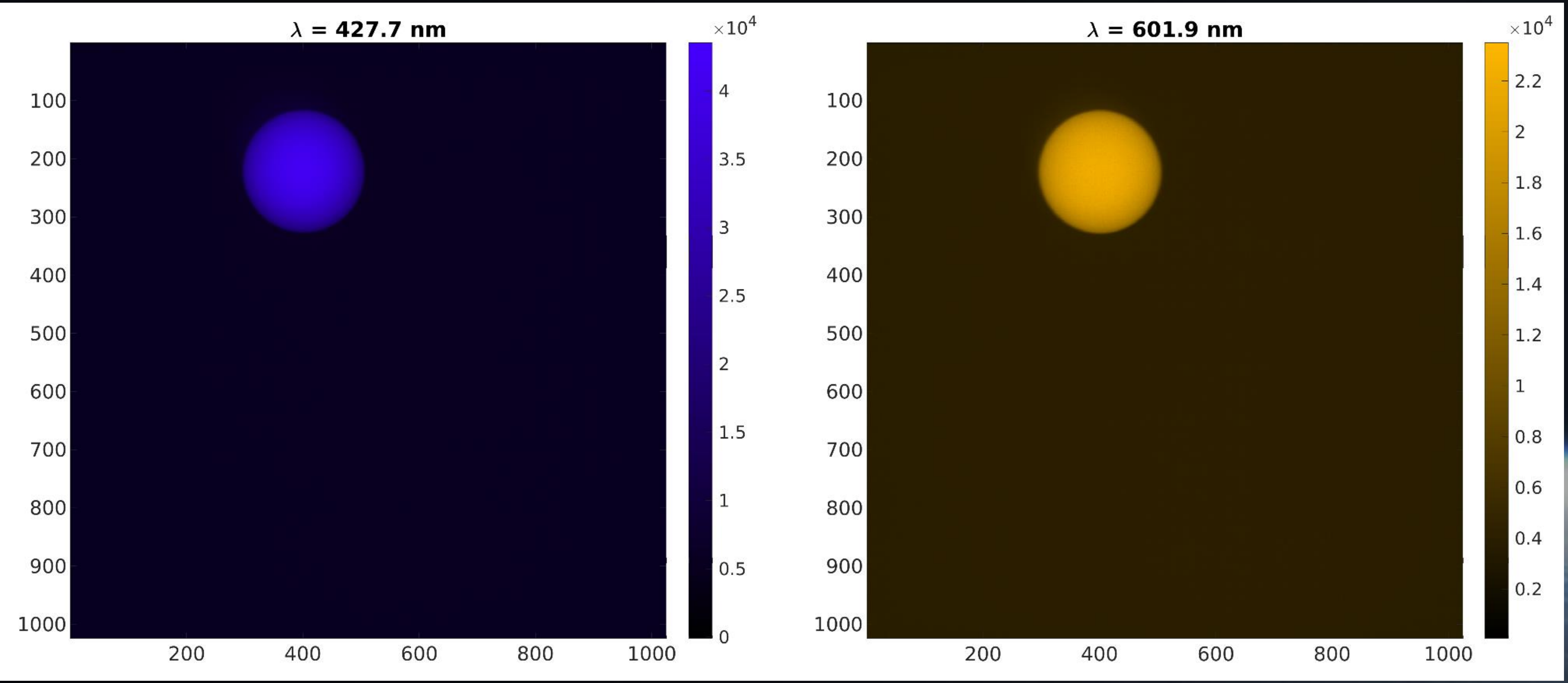
Matching three Fabry-Perot Interferometer orders to color image sensor R, G, and B pixels



Spectral transmission through the Fabry-Perot Interferometer

Measured quantum efficiency of a CMOS color sensor (CMOSIS CMV4000).

VISION: first image of the Sun



- Taken during a test (commissioning) on 27 Feb. 2021
- 2 wavelengths from 1 image
- 601.9 nm = ozone absorption (Chappuis)

SLP: plasma environment

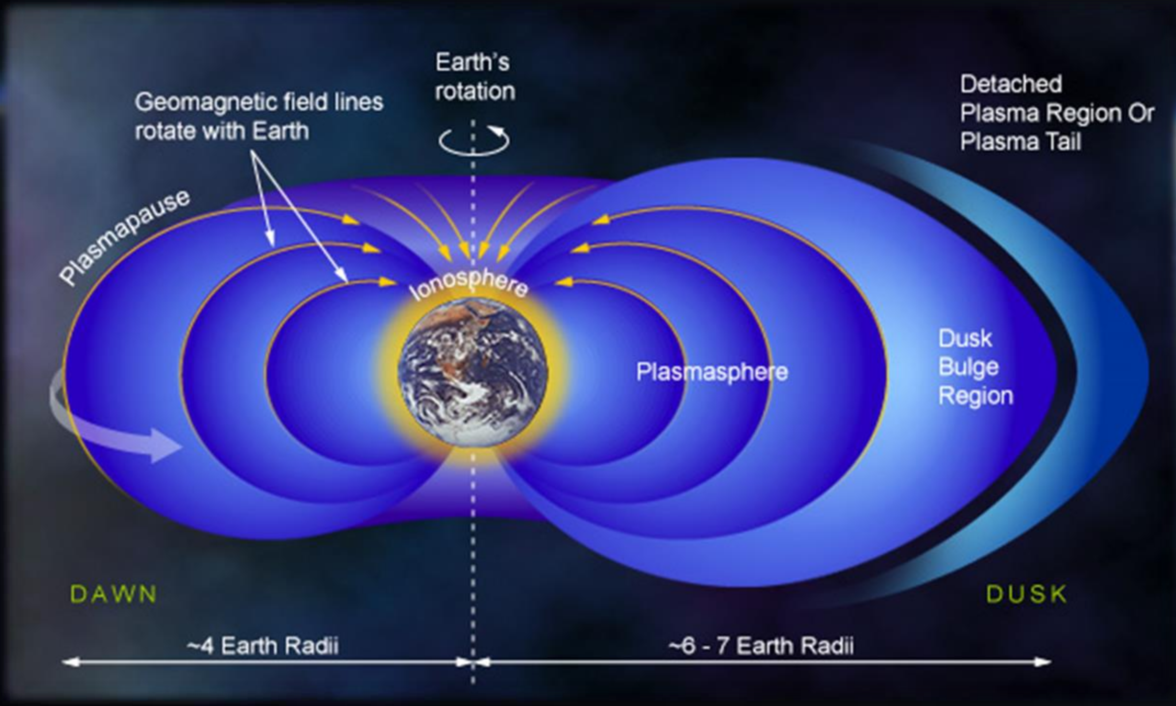
Expected plasma parameters

	Minimum	Maximum
Plasma density (#/m³)	10^8	10^{12}
Electron temperature (K)	600	10 000
Debye length (m)	5.4e-4	0.69

SLP: scientific objectives

1. Ionosphere-plasmasphere coupling

⇒ Study field-aligned density distribution and temperature effects



SLP: scientific objectives

2. Aurora structures

• EISCAT ⇒ ionospheric context

• SLP data ⇒ in situ truth to EISCAT data interpretation algorithms

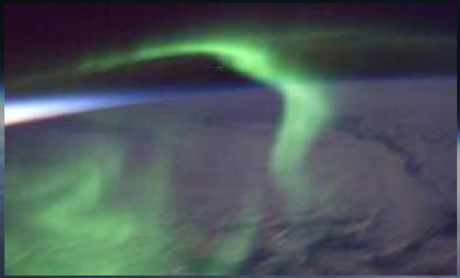
• Goal : identify in what situations density enhancement can be expected at 530 km altitude, and when density depletion is created

SLP: scientific objectives cont.

3. Survey of polar cap arcs

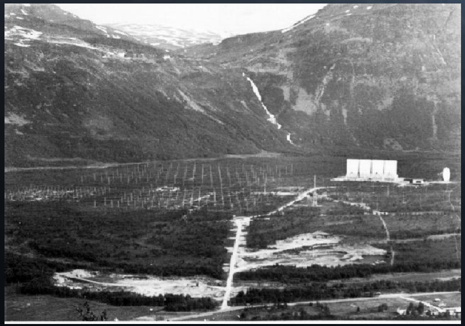
• Monitor density irregularities in polar cap ionosphere and relate those to signatures of polar cap arcs, (e.g. those found in Cluster data).

• Main questions : How often do such features occur? What is their size and motion? What is their relation to the ionospheric conductivity (determined by electron density)?



4. Ionospheric dynamics

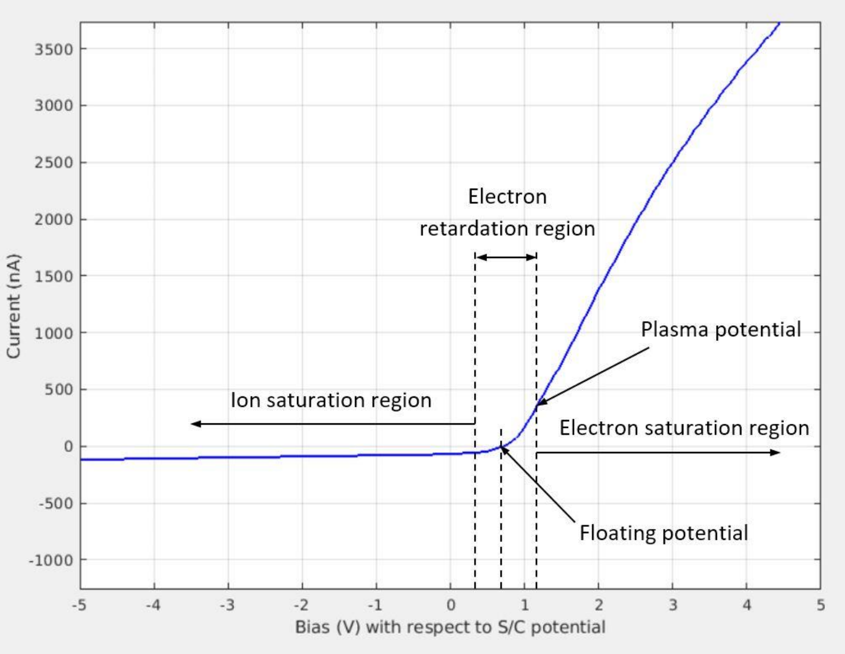
Coordinated observations with EISCAT's heating radar



SLP: Measurement principle

- Based on conventional Langmuir probe theory
- Sweep potential while measuring current => current-voltage characteristic

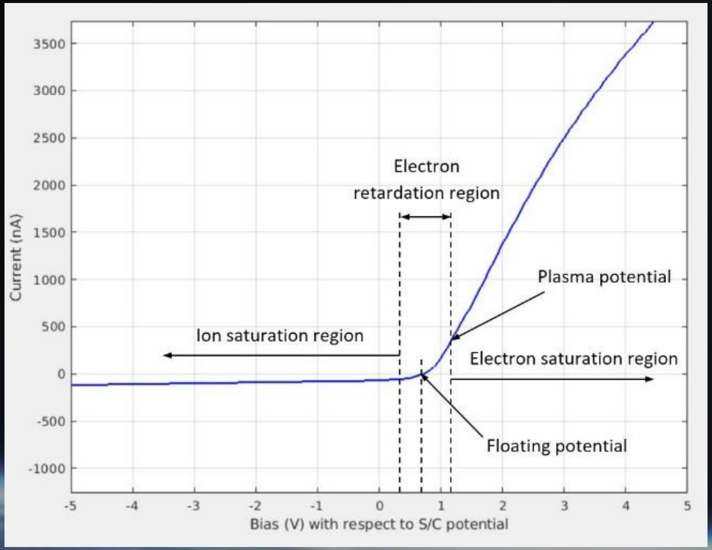
=> **Electron density and temperature, ion density and S/C potential**



3 regions:

- **Ion density** derived from ion saturation region
- **Electron T° and S/C potential** retrieved from electron retardation region
- **Electron density** derived from electron saturation region

SLP: Measurement modes



Nominal mode

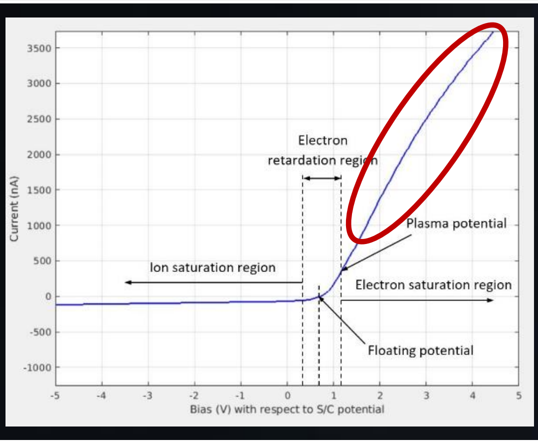
- Sweep: -5 V to +5 V wrt S/C potential
- ~ 25 sweeps / s
- Limited downlink bandwidth

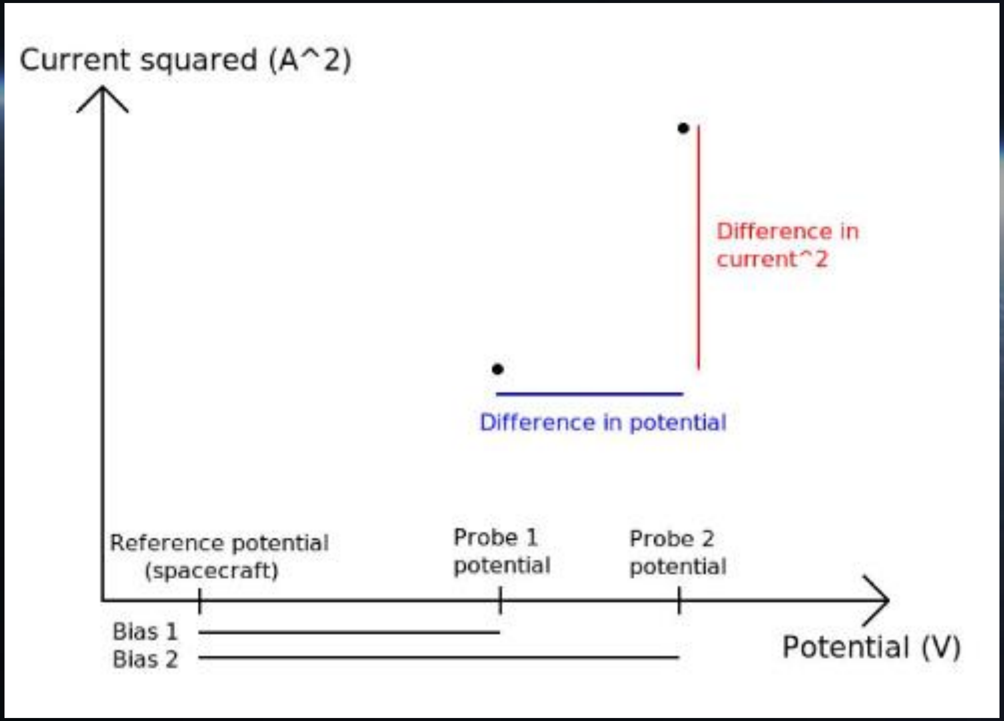
  => not possible to perform linear sweeps with fine steps during normal operation
- 3 regions measured with different step sizes adapted dynamically
    - Ion and e- saturation regions: large voltage step size
    - e- retardation region: smaller step size, varying according to e- T°

SLP: Measurement modes

Fixed bias mode (fast mode)

- Constant bias in e- sat. region
- At least 2 probes simultaneously
- Retrieve only e- density
- Sampling freq.: 5 KHz
- Spatial resolution ~ 1,5 m
- Can be used to study turbulence
- Significant data volume !!



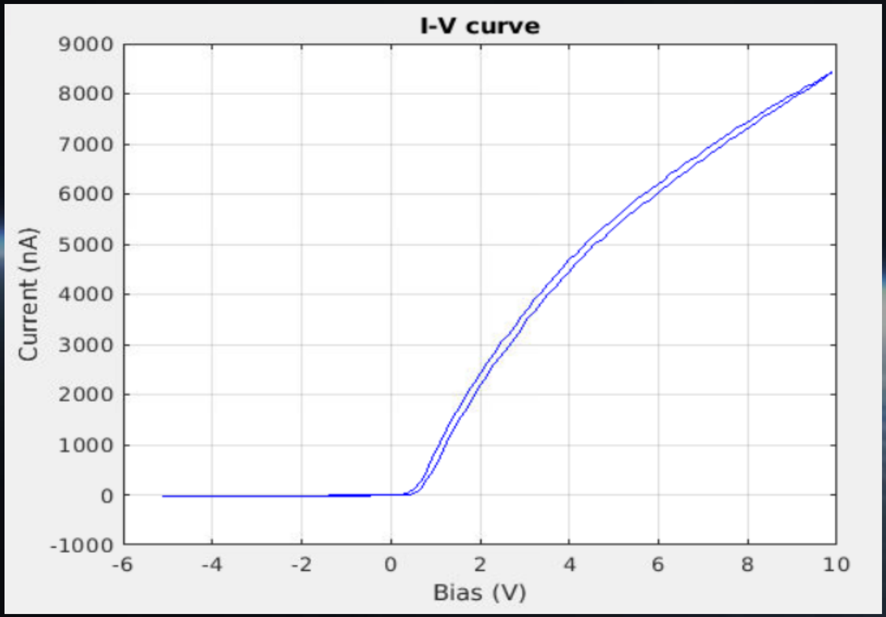


From *T.A., Bekking, University of Oslo*

SLP: Measurement modes

Monitoring mode

- Assess the amount of contamination of probe surface
- Sweep in both directions
- Different sweep durations



S/C charging

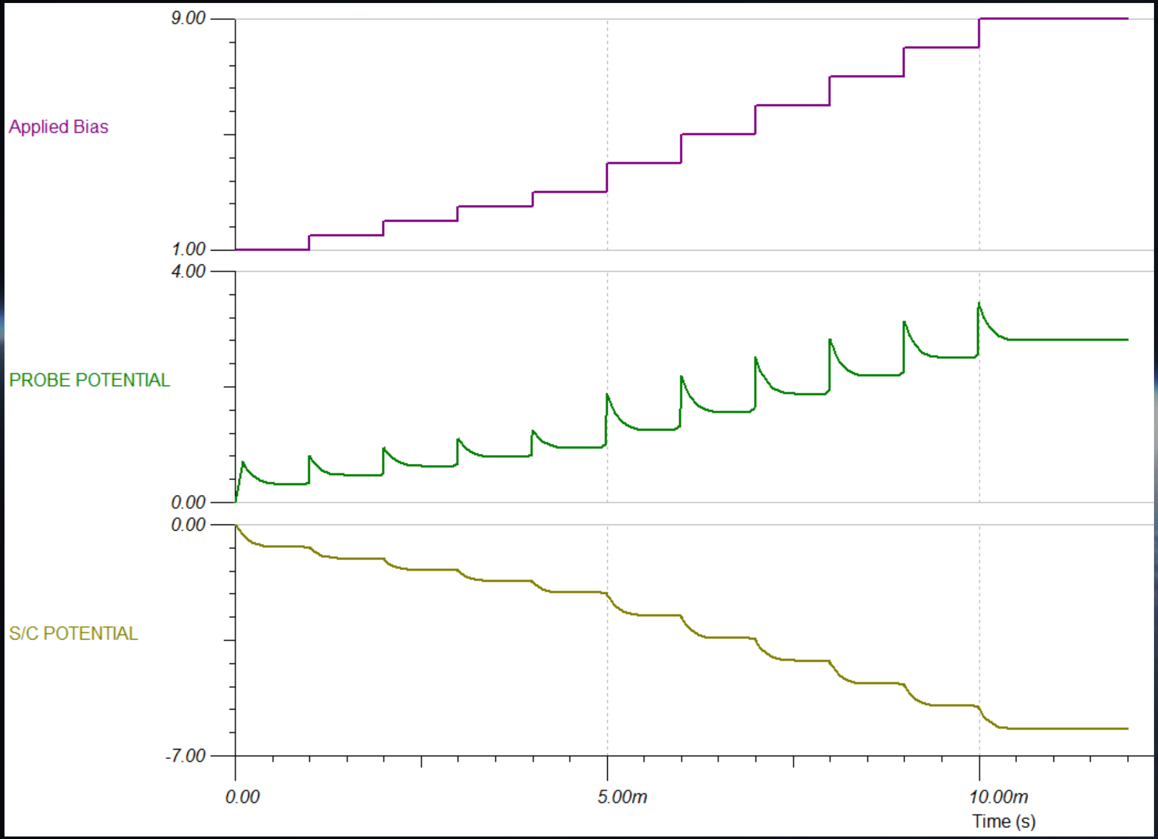
Challenge of using LP on board CubeSat:

Limited conducting area of the S/C with respect to the area of the probe

=> **Spacecraft charging** (e- sat. region)

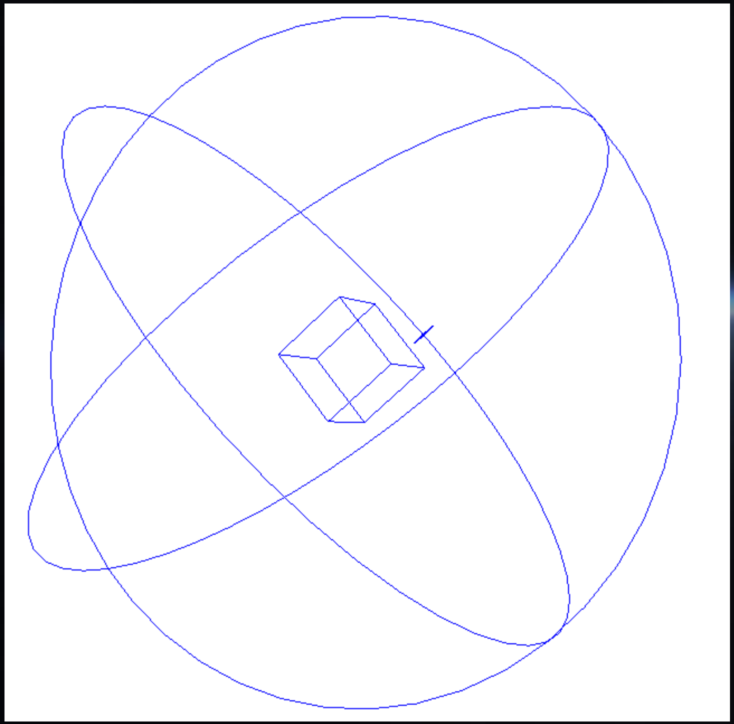
=>Drift of the instrument's electrical ground during the measurement

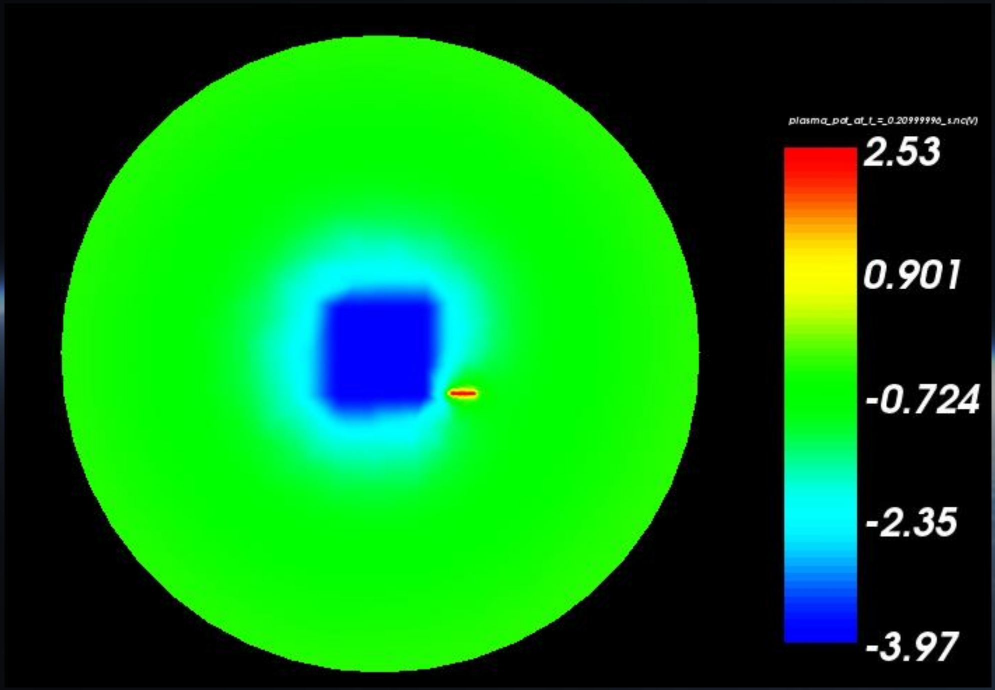
=>Unusable data



S/C charging

Particle-in-cell (PIC) modelling and simulations (SPIS)





Applied Bias: 6.5 V

S/C charging

Proposed solution

- Increase conducting surface of the S/C (at least 200 cm^2 on all sides of the S/C, incl. solar panels)
- **Measure the floating potential** of one probe while measuring the I-V curve with another probe
  => The 2 probes that are in the same environment (light/shadow)

Advantages

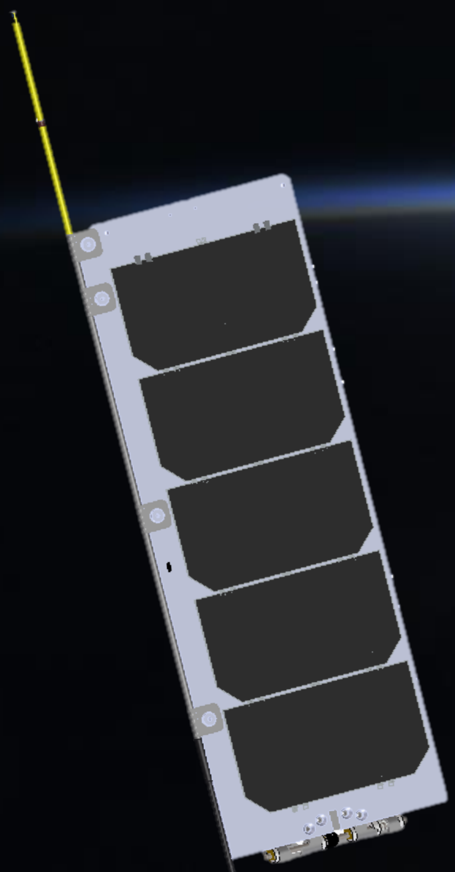
- Robust: no filament
- No risk of electron collection from e-gun
- Provides information on S/C charging

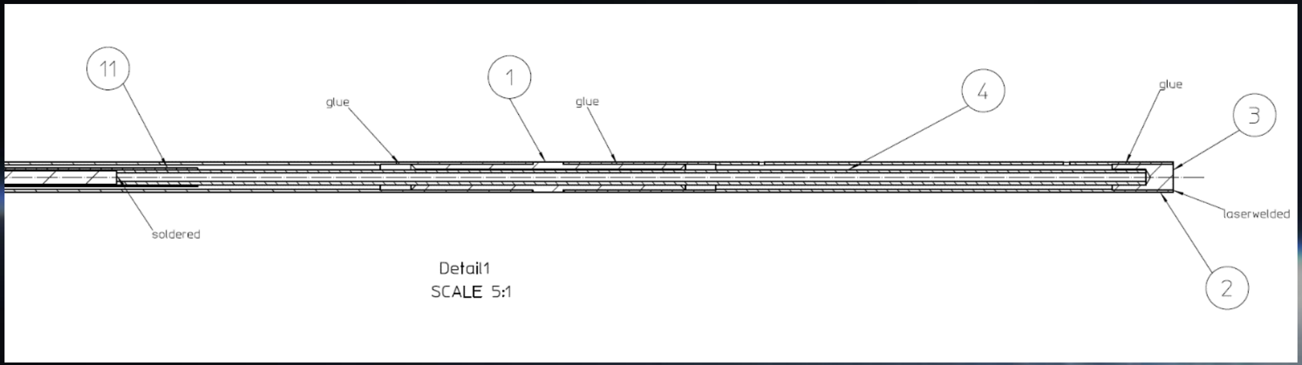
Disadvantage

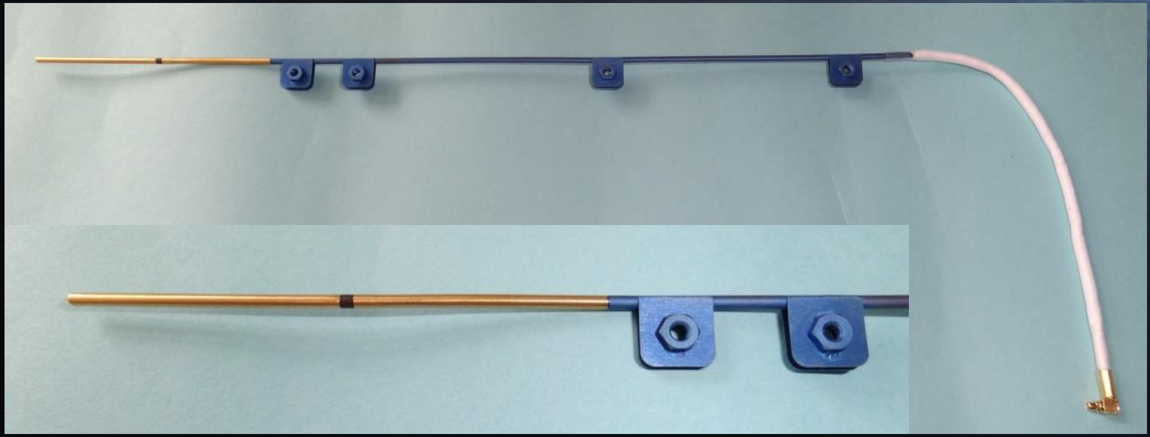
- Increase data volume

HW: probes

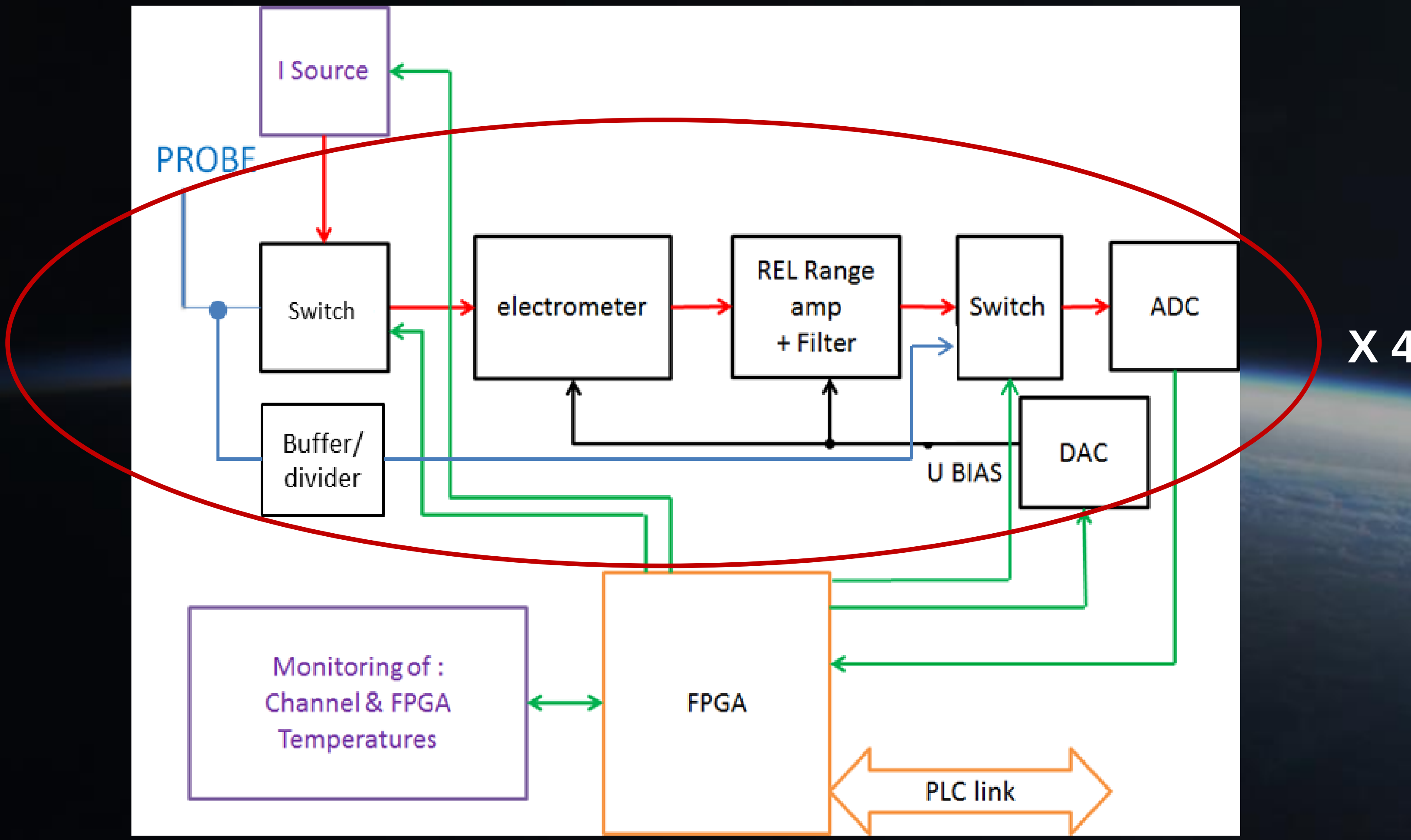
- Probes: 40 mm Ti tubes of 2 mm diameter
- Attached to the extremity of the solar panels via 40 mm boom
- Gold plated (protection against ATOX)







HW: electronics



HW: electronics

2 boards:

- PSU (20V, -10V, 5V, 3,3V, 1,8V, 0,9V)
- Main board (FPGA, front end)

Dimensions:

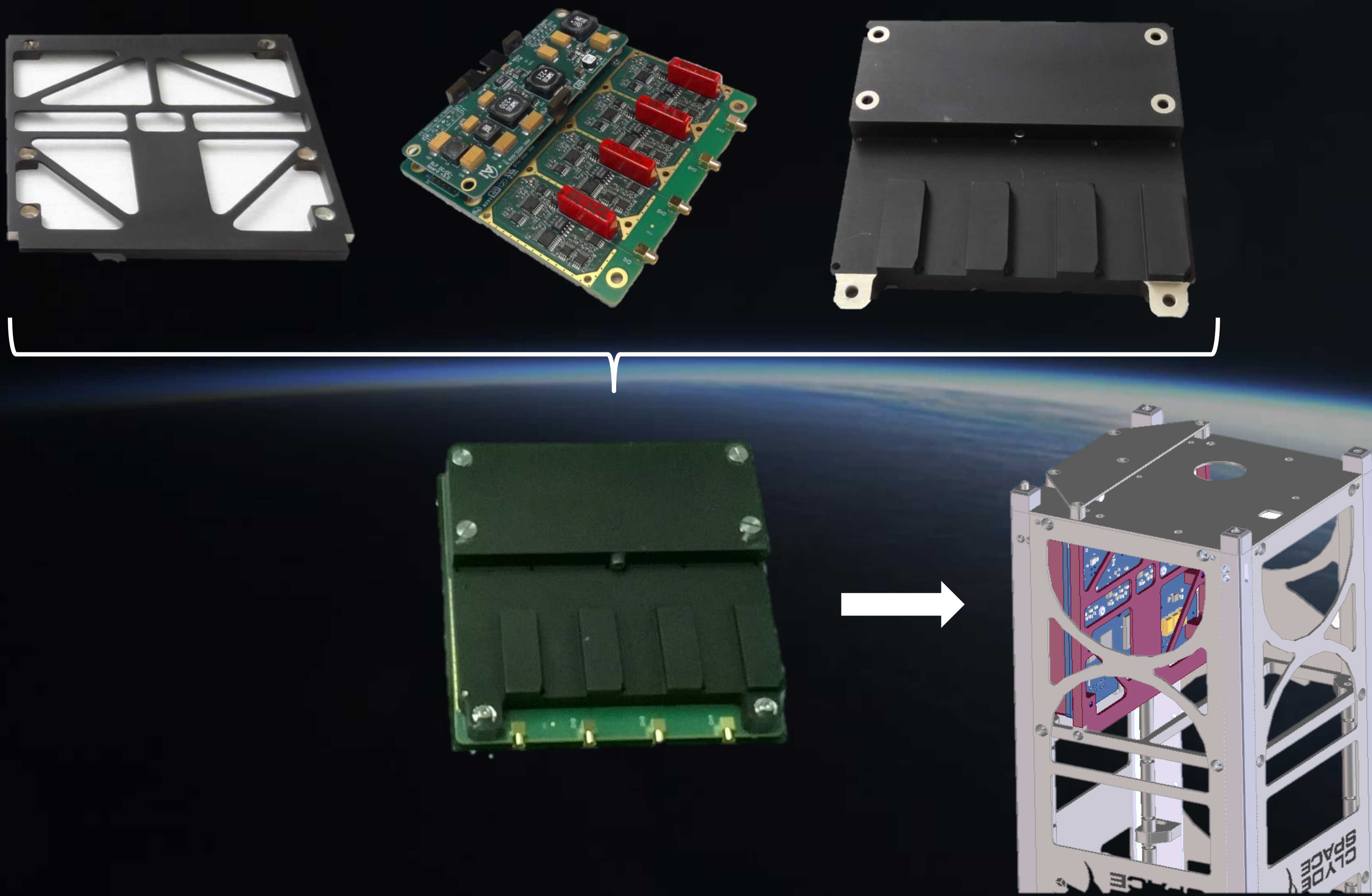
- 36 x 90.6 x 11 mm (PSU)
- 92 x 95 x 12 (main)
- 104 x 98 x 25 (envelope, incl. shielding cover and mounting bracket)

Mass:

SLP Electronics	87 g
Shielding cover	41 g
4 SLP booms/probes **Incl. interface and harness**	24 g
TOTAL SLP MASS	152 g

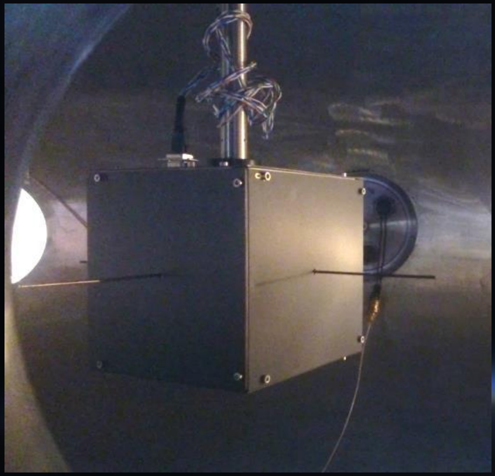
Power consumption (ave.): 2,2 W

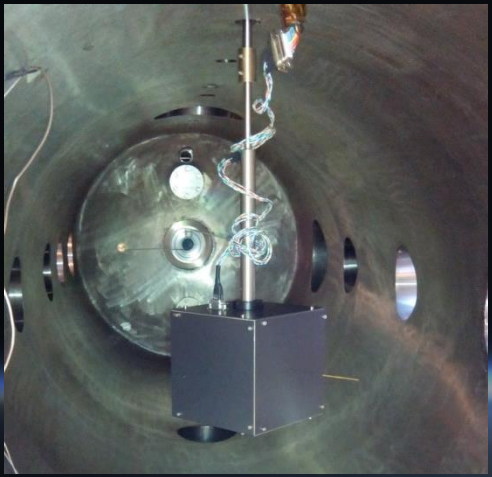
HW: integration

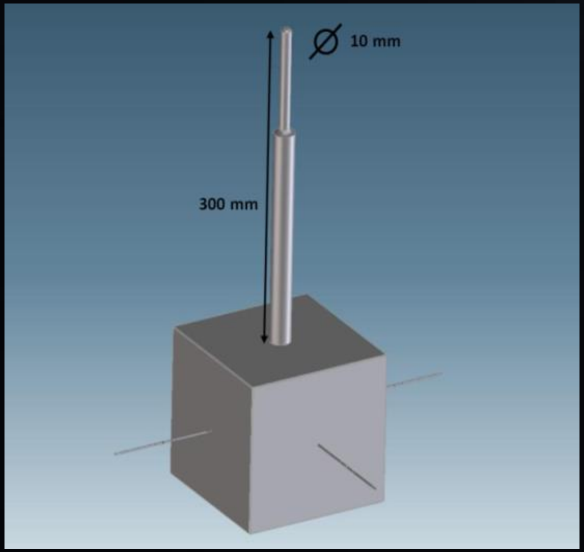


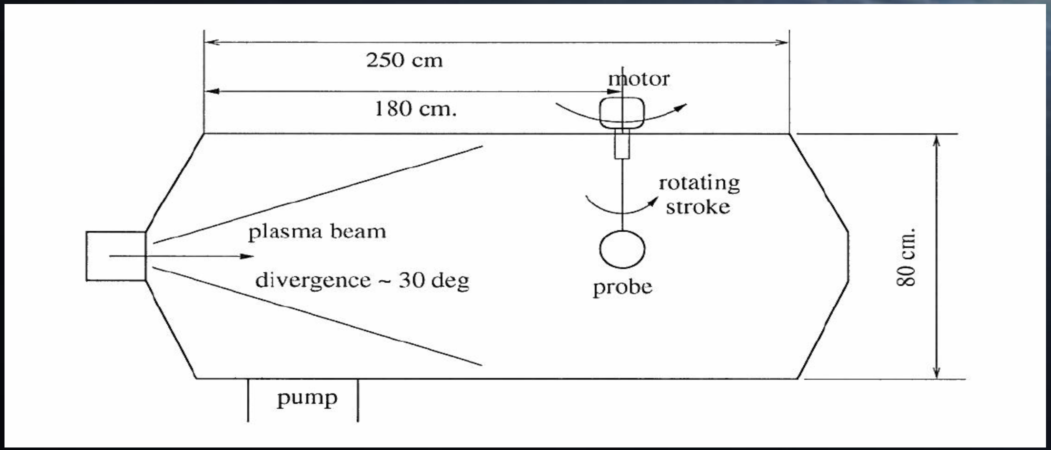
Functional test in plasma chamber

Test at ESTEC in July 2015, February 2017 and February 2019



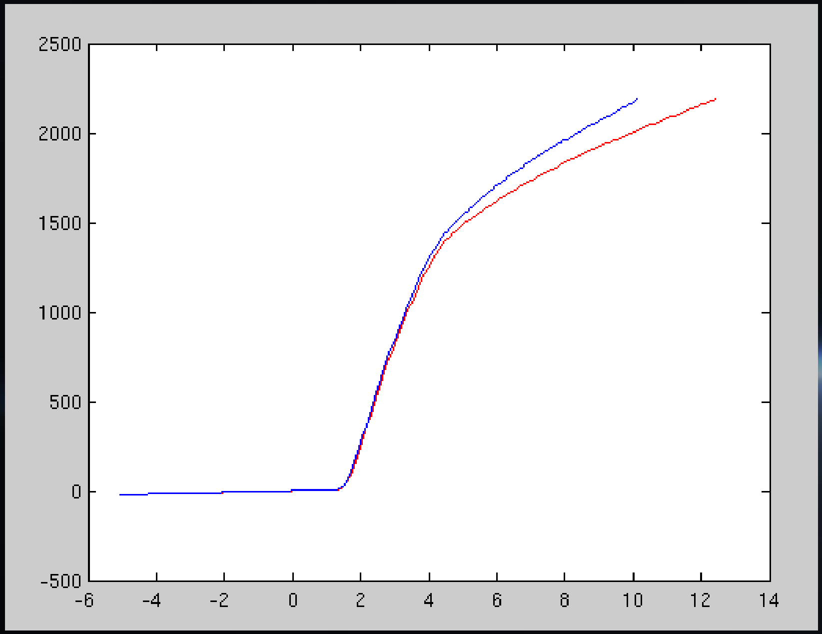




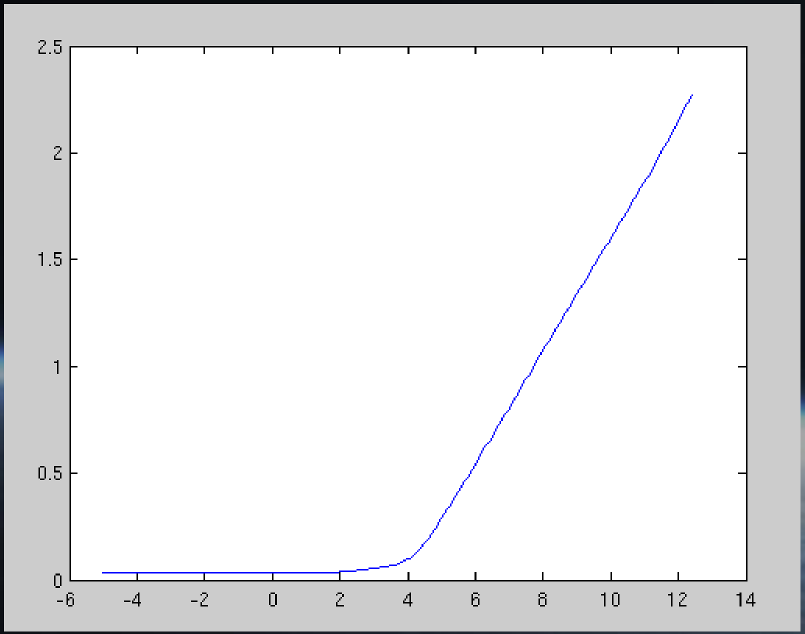


Functional test in plasma chamber

Validation of measurement principle



Red: I as function of bias (wrt to S/C GND)
Blue: I as function of bias (wrt to plasma pot.)



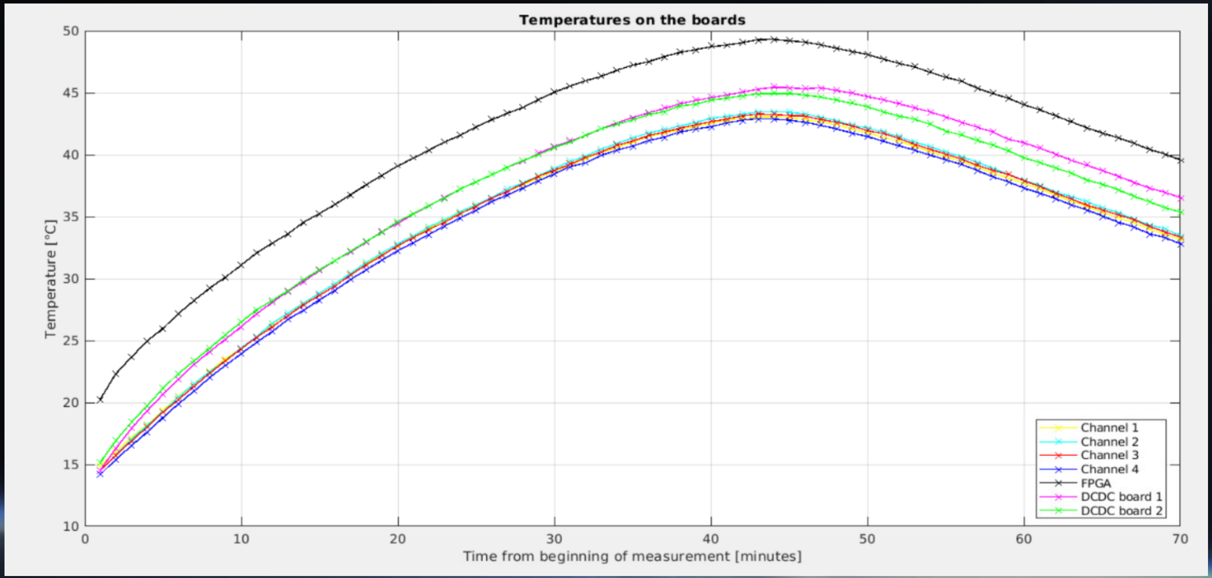
Floating pot. As function of applied bias

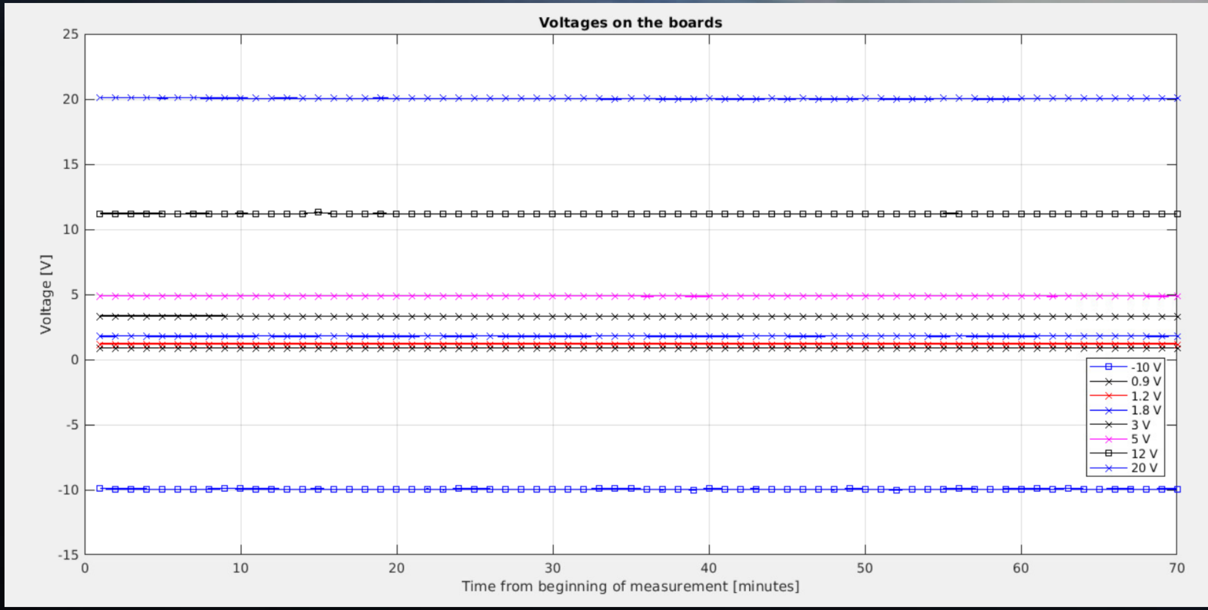
First results: internal temperature and voltages

- Temperature of all channels between 14 °C and 43 °C
- Temperature of PSU between 15 °C and 46 °C
- Temperature of FPGA between 20 °C and 49 °C

=> Very reasonable

=> Voltages are nominal



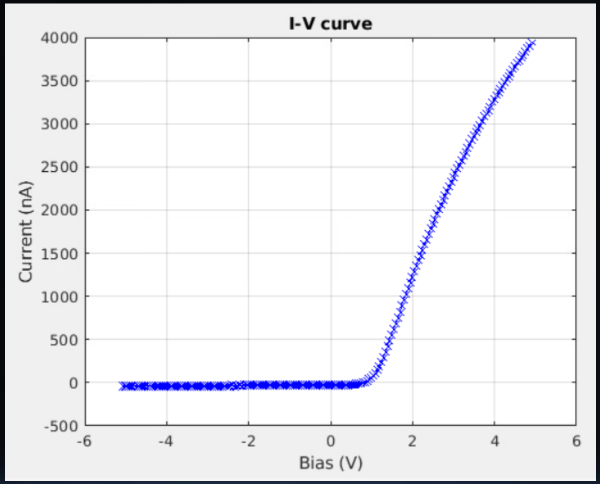


First results: linear sweep

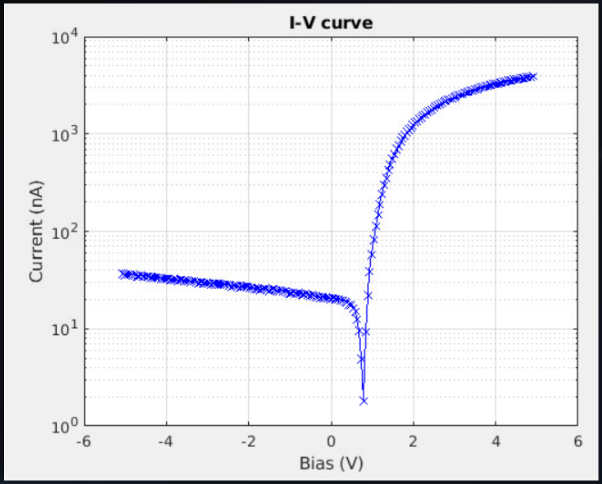
Example of linear sweep with equidistant steps:

- -5 V to + 5 V
- 200 samples
- I-V sweep : probe #1
- Floating probe: probe #3

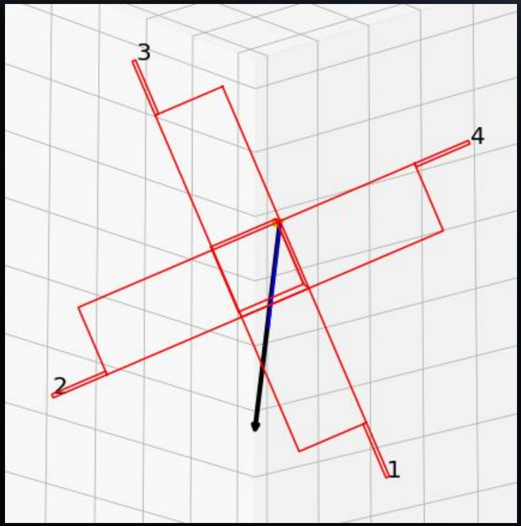
⇒ **Clean data**



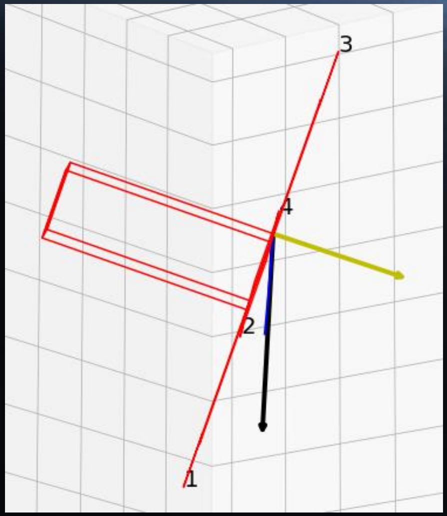
I-V curve. Linear scale



I-V curve. Semi-log scale



Attitude of PICASSO wrt velocity vector (black arrow) and Sun direction (yellow).



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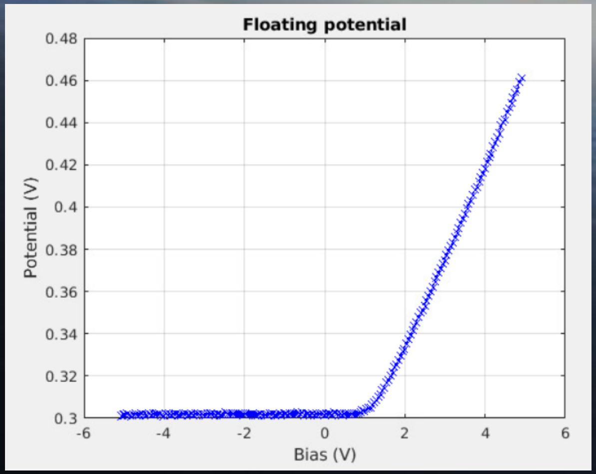


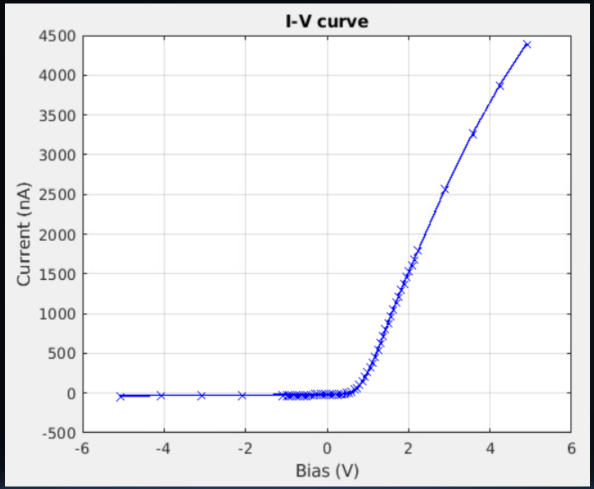
Potential measured with floating probe

First results: adaptive sweep

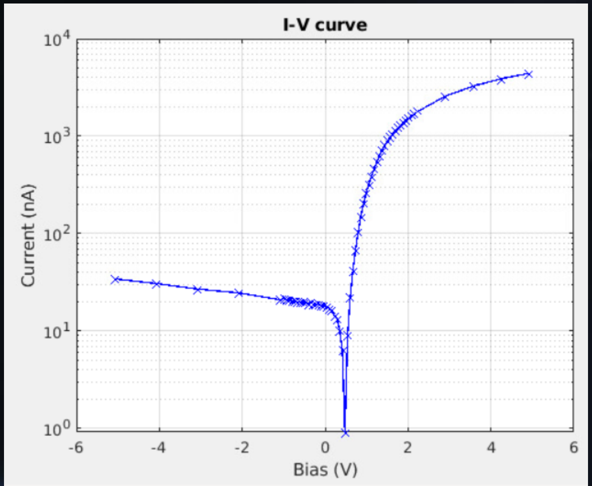
Example of adaptive sweep:

- -5 V to + 5 V
- 60 samples:
  - 5 in ion saturation region
  - 50 in e- retardation region
  - 5 in e- saturation region
- I-V sweep : probe #1
- Floating probe: probe #3

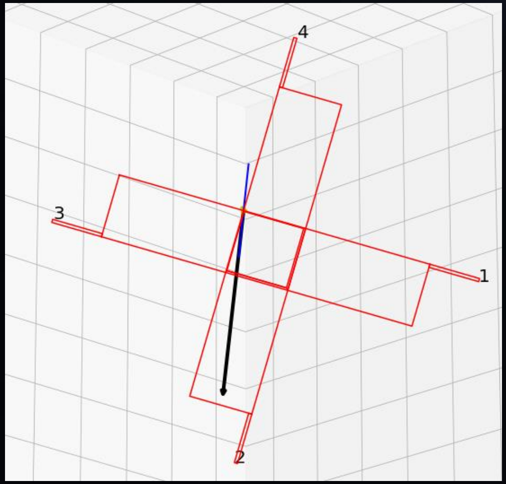
⇒ **e- retardation region well resolved**



I-V curve. Linear scale.



I-V curve. Semi-log scale.



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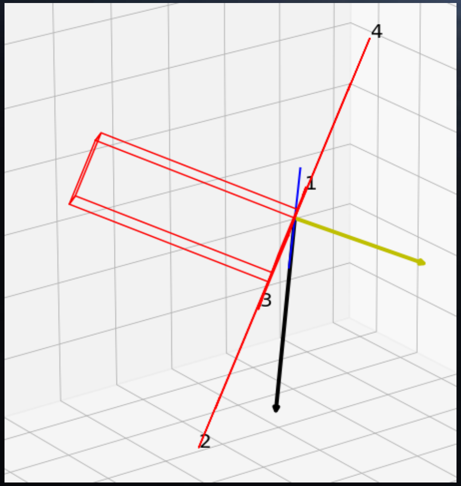

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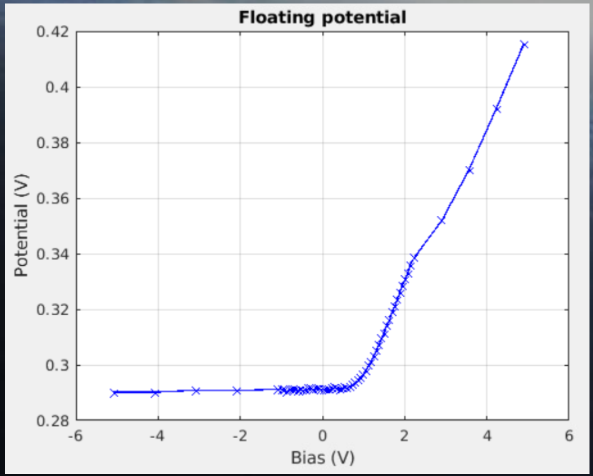
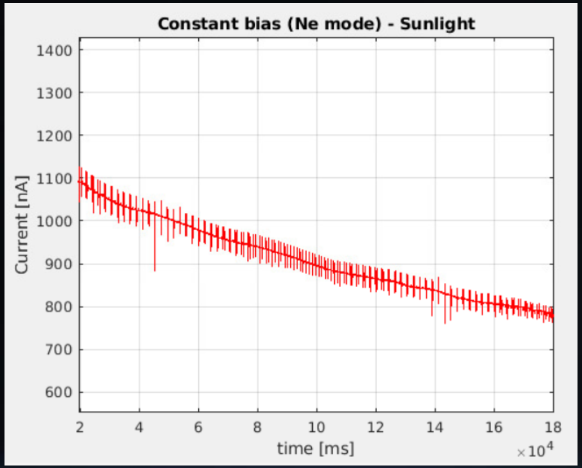


Potential measured with floating probe.

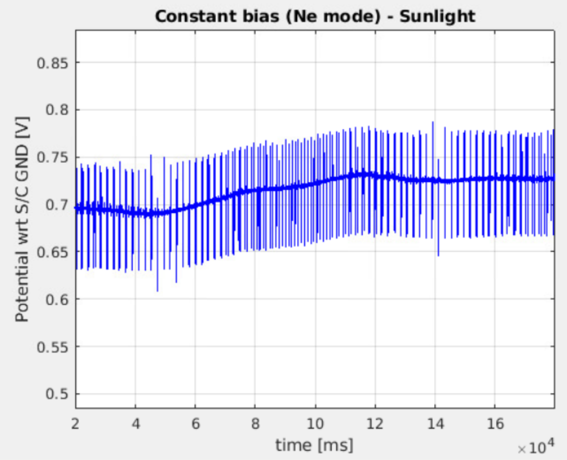
First results: fixed-bias mode in sunlight

- 1k sample / s

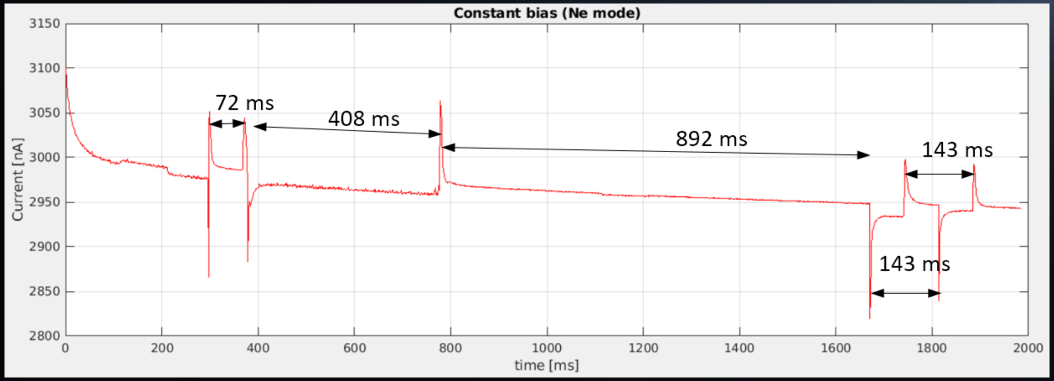
  ⇒ **Noise structures from the platform**



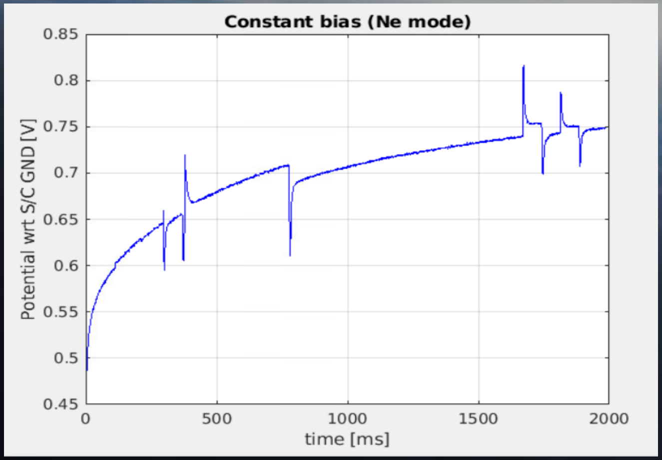
Current from probe



Potential measured with floating probe



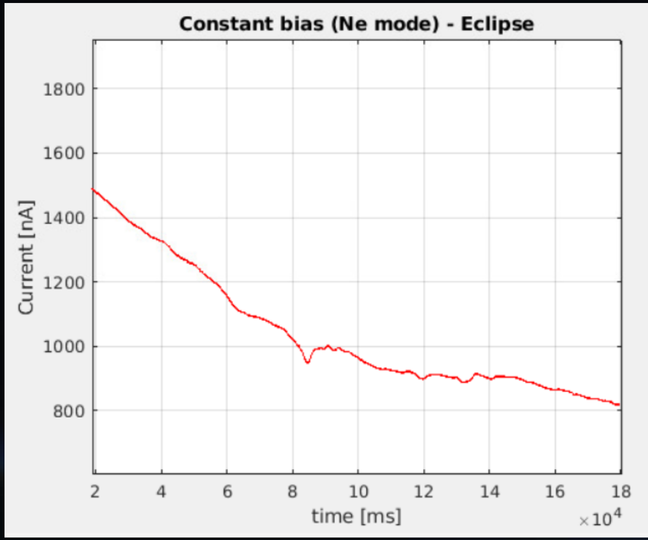
Current from probe



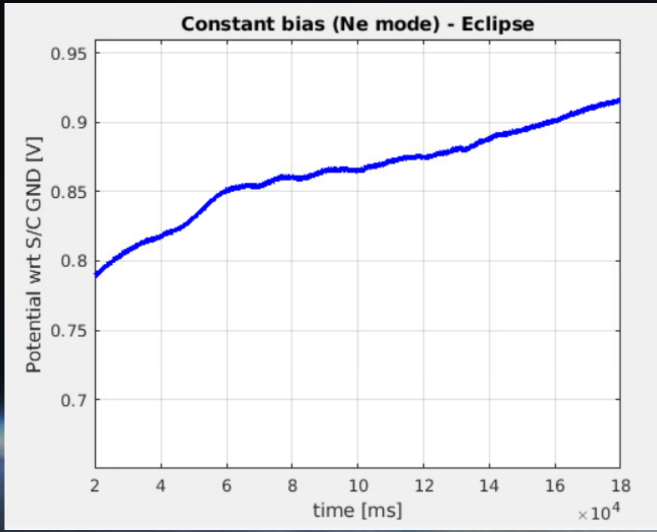
Potential measured with floating probe

=> Timing and duration of noise structures compatible with BCR-originated noise

First results: fixed-bias mode in eclipse



Current



Potential measured with floating probe

$\Rightarrow$ **No noise structures in eclipse**

$\Rightarrow$ **Noise attributed to Battery Charge Regulator (BCR)**

=> More tests on going

Status of the mission

- **PICASSO platform** still in commissioning phase (16 months)
  ⇒ Main issue: ADCS (star tracker)
  ⇒ Other issues: GPS, platform resets, battery
  ⇒ Limited number of payload measurements

- **VISION**
  ⇒ Still in commissioning (acquired only 1 image of the Sun)
  ⇒ Health indicators are nominal
  ⇒ Requires full pointing accuracy to finalise commissioning and start science mode

Status of the mission cont.

- **SLP**

⇒ Health indicators and operations are nominal except that one probe seems to be disconnected (not critical since there is full redundancy)

⇒ All modes have been successfully tested

⇒ Both linear and adaptive sweeps produce clean I-V curves

⇒ Noise structures attributed to the Battery Charge Regulator (BCR) of the platform

⇒ Still possible to perform I-V sweeps in sunlight, even if some curves are perturbed by the noise

⇒ More of a problem for fixed-bias mode

⇒ Assessment of probe surface contamination on going

Next steps:

- Validation of SLP data with EISCAT data (coordinated campaign)
- When platform commissioning completed: start science mode

Lessons learned

- Philosophy to develop ESA CubeSat different from university CubeSat
- Requires several qualification tests (SLP: 2 SEE, 2 vib., 2 TVAC, 3 func. in plasma chamber)
- Strong constraints due to CubeSat platform (envelop/dimensions, power consumption, mass, telemetry, processing power)
- Difficulties not linearly scaled with budget of the mission

Is a CubeSat-based scientific mission a viable approach ?

YES !

- Platforms are becoming more reliable
- Instruments are getting smaller, lighter with reduced power consumption
- Space agencies, industrial actors, universities, research institutes, etc. have increasing experience with Cubesats
- Development time reduces
- Offers opportunity to fly scientific instruments for limited budget

BUT …

- Platform provider should be selected carefully
- Allocate sufficient time for testing, especially once integrated
- If platform also developed by university => great opportunity for students but increased risk (delay, failure)
- No redundancy on platform => inherently higher risk than for traditional scientific missions
- Funding for operations and support should be in line with scientific objectives

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Thank you for your attention !