The CUbesat Solar Polarimeter (CUSP) for Space Weather and solar flares X-ray polarimetry

Sergio Fabiani [a]
on behalf of CUSP Team

a) INAF-IAPS

CUSP Team

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- Università della Tuscia (Ground Segment)

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- ASI (Project Control)

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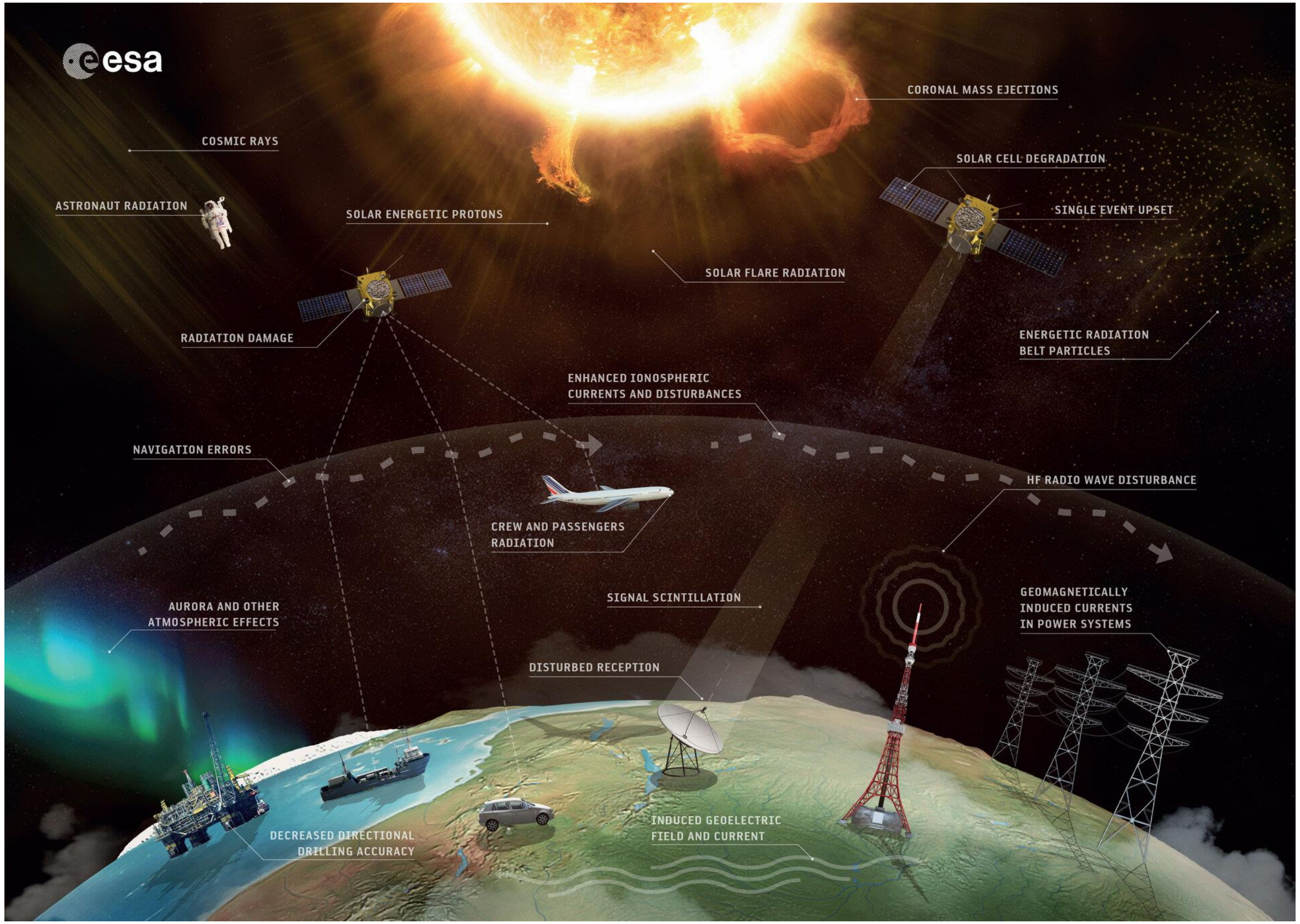
Solar Flares: Heliophysics and Space Weather

- Solar activity, including **Solar flares (SFs)**, can be disruptive for human technological activities in space and on ground
- **The occurrence of SFs** is **very often associated** to Coronal Mass Ejection **(CME)** and Solar Energetic Particle **(SEPs)** events on the ground
- **SF** can also **occur alone** producing a **direct acceleration of particles towards the Earth**

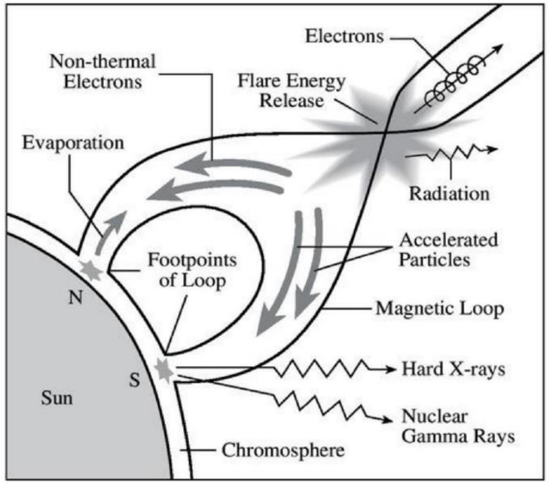


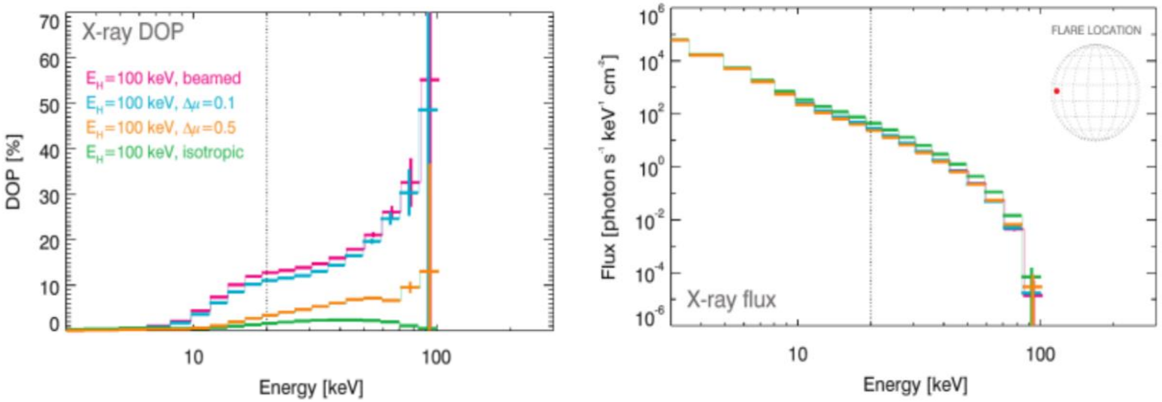
Why Hard X-ray polarimetry of Solar Flares?

- SFs produced by **magnetic reconnection** in loop structures in solar corona

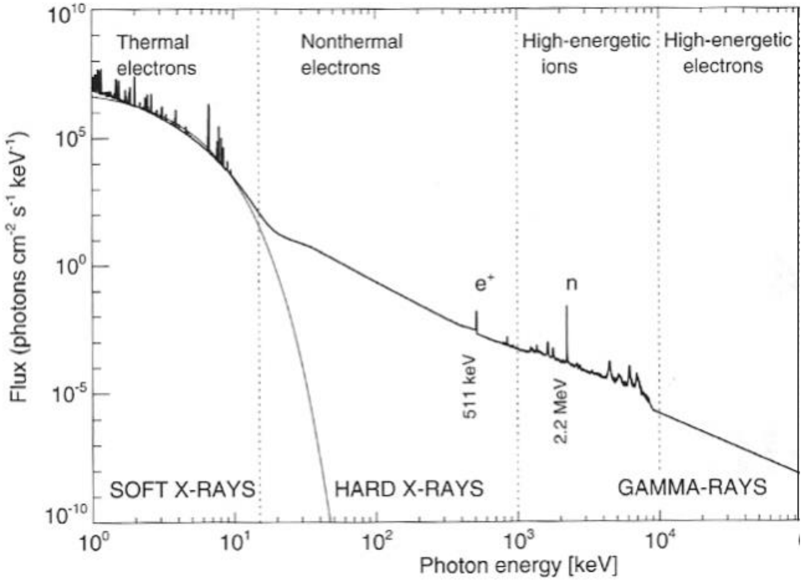
- SFs energy spectrum in the X-rays is dominated by:
  - **thermal Bremsstrahlung** (due to plasma heating, expected weakly polarized by Emslie & Brown 1980) + emission lines < 10 keV
  - **non-thermal Bremsstrahlung** (at the loop top and footprint, due to particle acceleration along magnetic field lines) expected highly polarized [Zharkova+ (2010)] >10-20 keV

- **X-ray polarimetry** (linear) would allow to **disentangle degeneracies** in **models** of particle beaming and magnetic field structure (also without imaging of the SF)





Jeffrey+ 2020 (A&A)

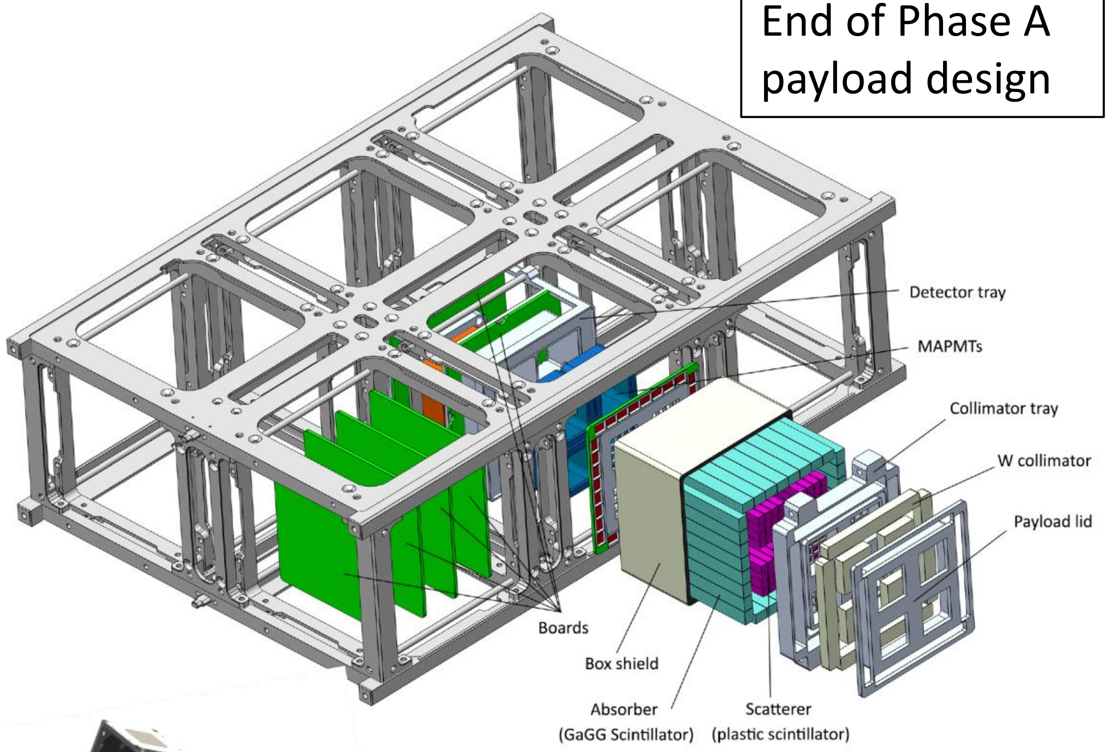


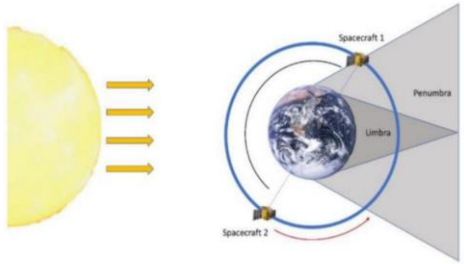
Aschwanden (2005)

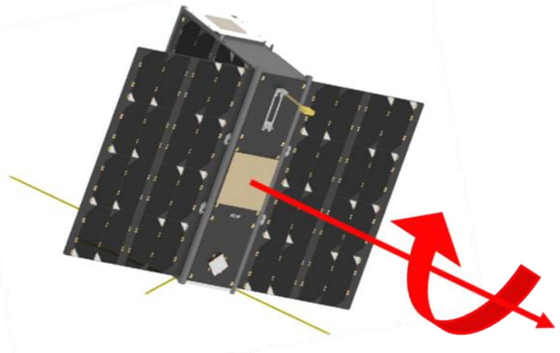
The payload

- **Constellation** of **2 CubeSats** orbiting the Earth on SSO orbit (~500-600 km) to observe the Sun
- Monitoring of the Sun with a time fraction >68% during the 3 years nominal life time
- X-ray polarimetry of Solar Flares in the 25-100 keV energy band
- Each satellite hosts a **dual-phase Compton scattering polarimeter** that exploits **coincidence measurements** between plastic (scatterer) and inorganic (absorber) scintillator rods
- **1 RPM rotation of the spacecraft** around the polarimeter symmetry axis pointing the Sun allows to reduce the systematic effect known as spurious polarization

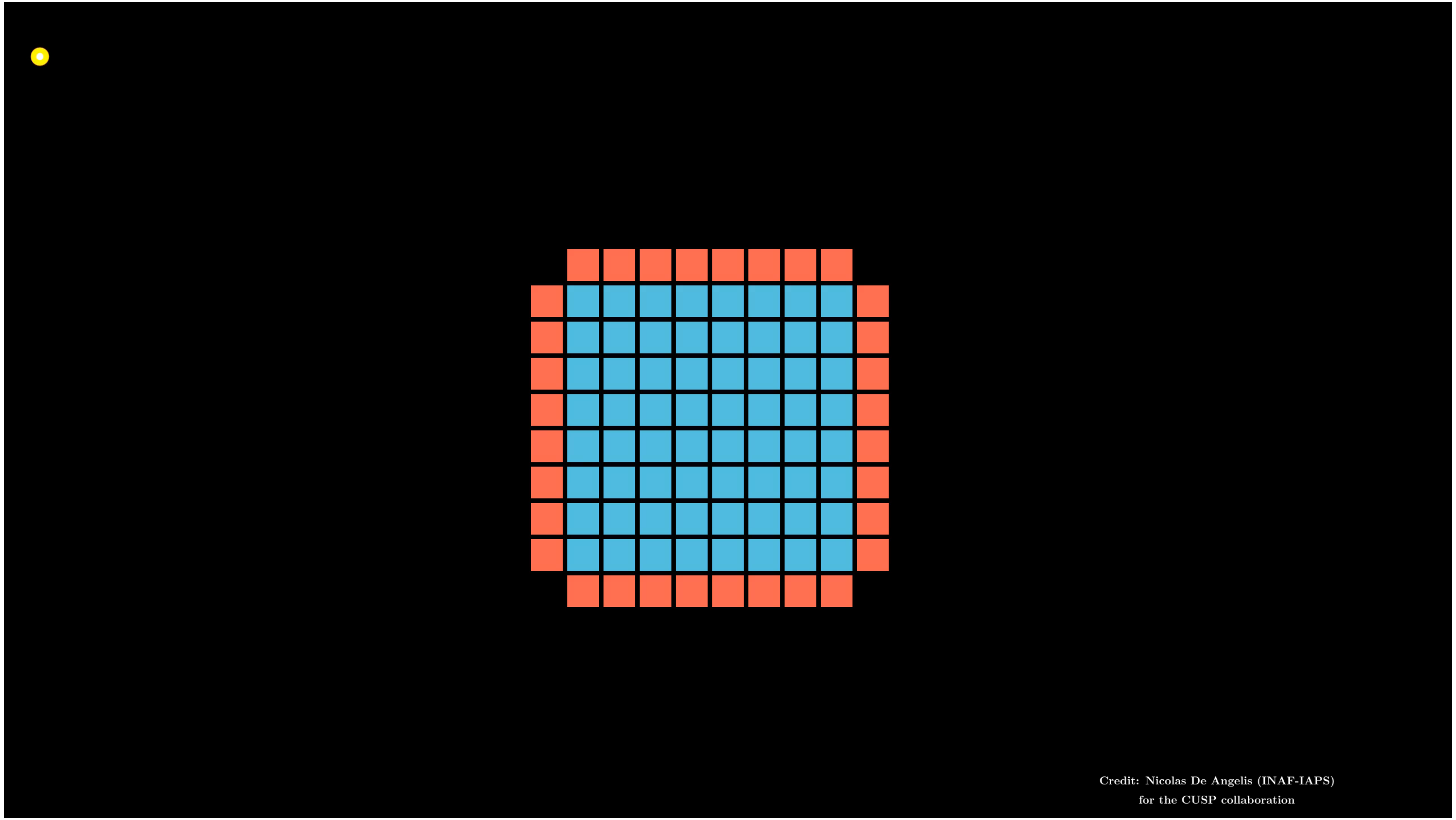
End of Phase A payload design







How a dual-pahse Compton polarimeter works



The payload sensitivity

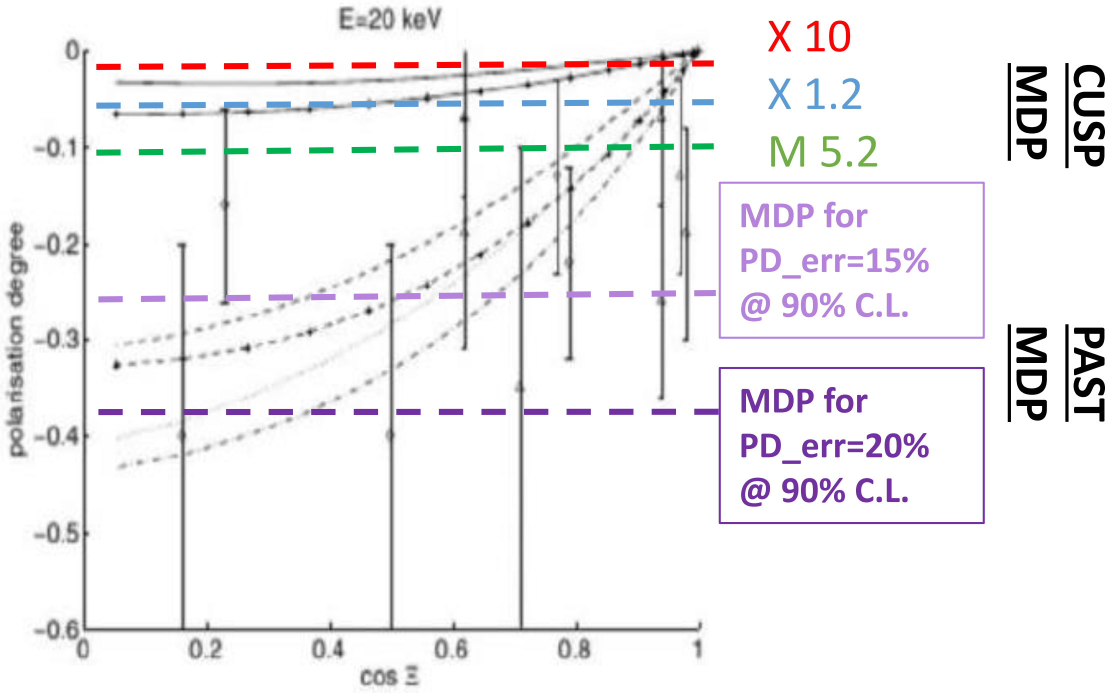
- **Minimum Detectable Polarization (@99% C.L.)** (Weisskopf+ 2010, SPIE) in the 25-100 keV energy band (CBE based on benchmark SFs from Saint-Hilaire et al. (2008), Sol. Phys. 250, 53–73)

Flare Class	Integration time (s)	MDP (%) (25-100 keV)
M5.2	284	10.2
X1.2	240	5.0
X10	351	1.1

$$MDP = \frac{4.29}{\mu \cdot R} \cdot \sqrt{\frac{R+B}{T}}$$

$$Q = \mu\sqrt{\varepsilon}$$

R: source rate
B: background rate
T: integration time
µ: modulation factor
ε: quantum efficiency



Zharkova et al. 2010 (A&A)

CUSP will reduce significantly the MDP wrt past observations

Towards Phase B

Just presented @

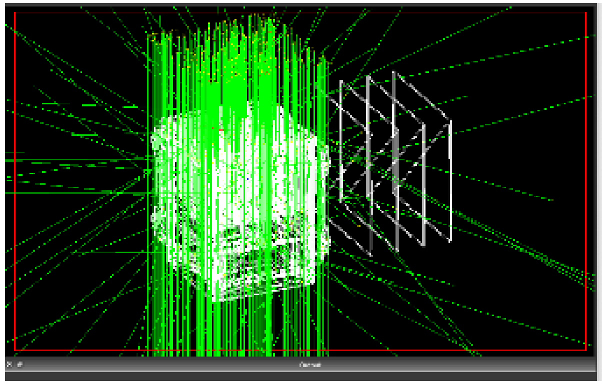
SPIE. ASTRONOMICAL TELESCOPES+ INSTRUMENTATION

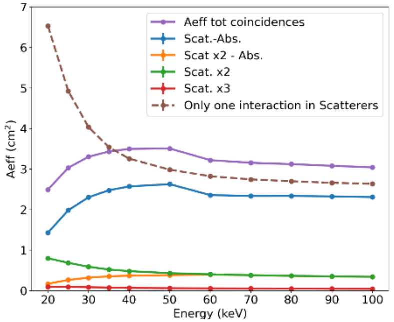
16-21 June 2024

Yokohama (Japan)

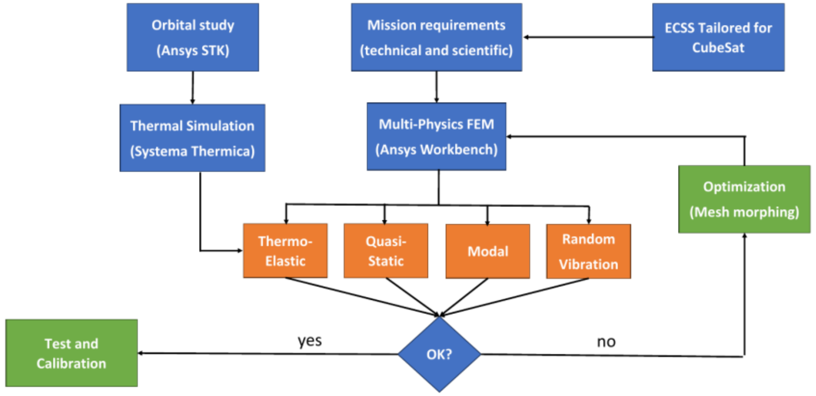
Geant4 detector simulator developement

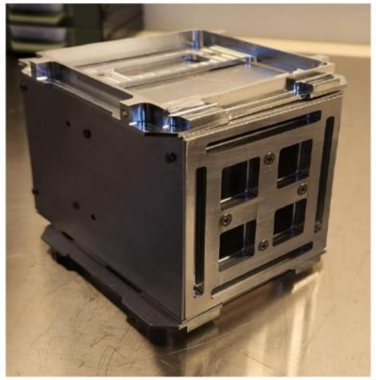
- Estimation of the MDP requires:
  - effective area, modulation factor (spurious modulation)
- Background estimation





Definition of the thermo-mechanical analysis method and hypotesys of payload mechanical optimization



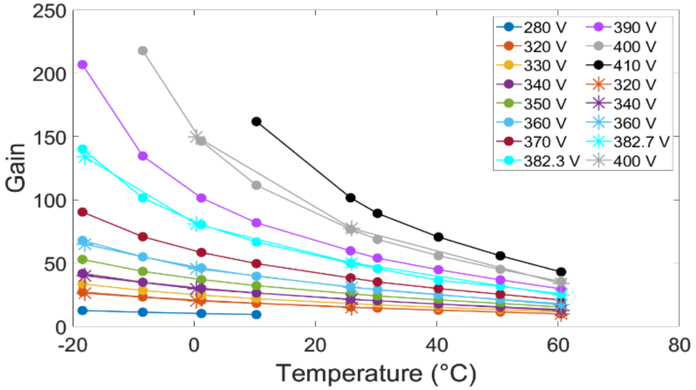


See exposition desk 14B

- **Mechanical model**
- **Meta Quest visor**

Test @ INAF-IAPS

- Tests on the Avalanche Photodiodes to readout GAGG absorbers scintillators

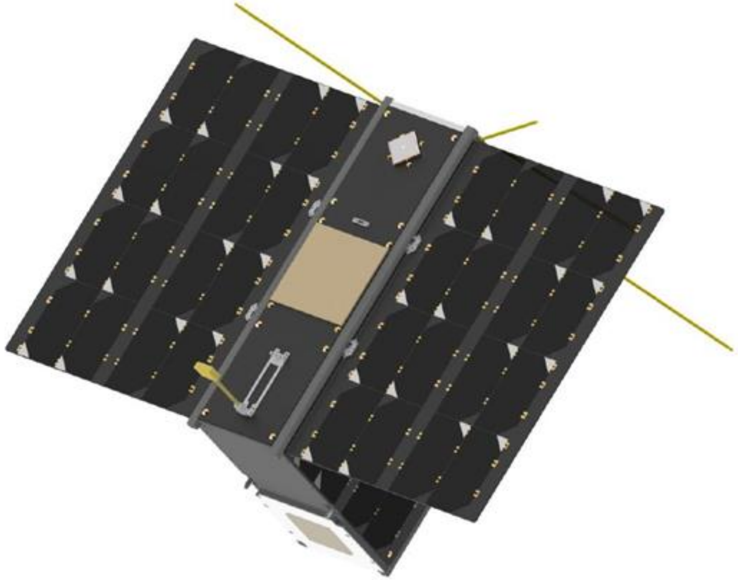


Sergio Fabiani - “L’impegno italiano nel settore dei CubeSat: tecnologie e missioni future” - 2° edizione – 2-4 July 2024 – Roma (Italia)

The platform

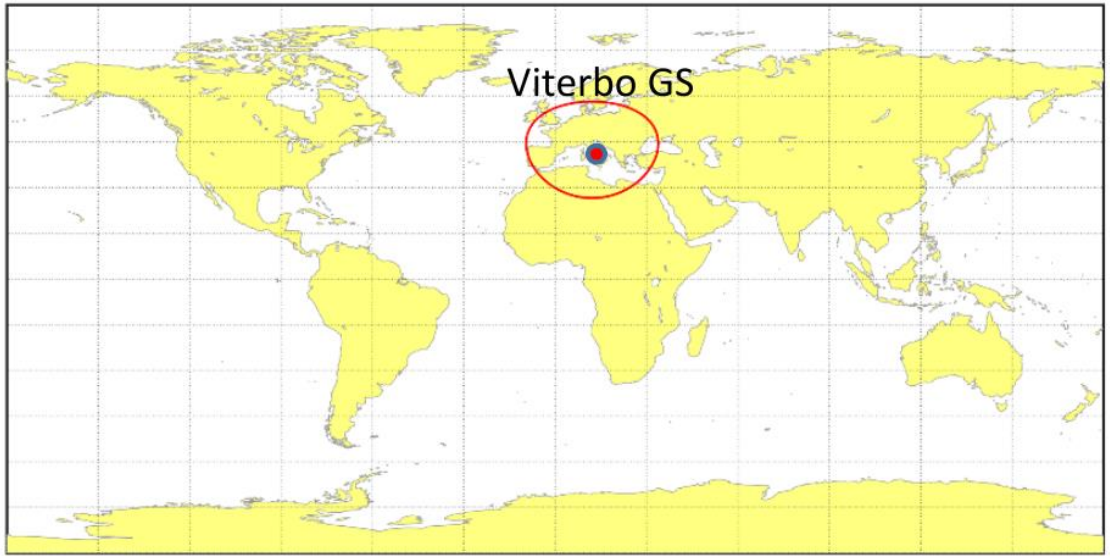
- Designed and prduced by **IMT s.r.l.** Italian company
- **6U CubeSat** platform based on the heritage of the HORTA and EOSS platforms (funded by Italian regional POR / FESR 2014-20 projects of Lazio and Puglia regions, respectively).

Peak Power	$\sim$ 30 W with Deployable Panels in Sun Pointing
Battery	Up to 84 Wh (baseline 42 Wh)
Pointing accuracy	$\pm 2^\circ$ @ 1σ
Operative frequencies	S-Band downlink; UHF-Band uplink / downlink
Downlink throughput	Up to 5 Mbps
Available interfaces	CAN Bus, I2C, UART, SPI, RS485
Regulated bus	3,3V, 5V e 12V
Not regulated bus	16V (12V-16.8V)
Available volume for the payload	2.5U
Nominal life time	3 years in LEO



The Ground Station

- Located on a building of the **Università della Tuscia in Viterbo (Lazio, Italy)**
- Built in 2019 for the HORTA project (funds POR/FESR 2014-2020 by Lazio Region)
- Available antennas and bands:
  - VHF: Uplink and Downlink
  - UHF: Uplink and Downlink
  - S-band: Downlink
- UHF/VHF bandwith:
  - Downlink: default 9.6 kbps (available also 1.2/ 2.4 / 4.8 kbps)
  - Uplink: default 1.2 kbps (available also 2.4 / 4.8/ 9.6 kbps)
- S-band bandwith:
  - Downlink: up to 1 Mbps



Planning

- **Model Philosophy:**
  - Payload:
    - 1 detector prototype at the end of Phase B. Representative of the detector front-end (from TRL 3 to TRL 4)
    - 1 payload subsystem Structural Model at the end of Phase B (scintillator bars holding system)
    - 1 payload EQM (design phase B, production and test phase C). Representative of the payload (from TRL 4 to TRL 7)
  - Trade-off assessment to allow ASI to decide if to continue with a 2 CubeSats constallation or with a 1 CubeSat
  - Depending on the trade-off 1 or 2 CubeSats:
    - 1 Proto-flight Model (PFM). To qualify at proto-qualification level.
    - 1 additional Flight Model (FM). To qualify at acceptance level.

- **Next Phases:**
  - Phase B will start soon (12 months)
  - Proposed phase C/D 15 months

- **Calibration** of the Hard X-ray Polarimeter of each CubeSat will be carried out at INAF-IAPS calibration facility (possibly also measurements at Synchrotron facilities)

Conclusions

- **CUSP** will measure linear X-ray polarization of solar flares for **Heliophysics** and **Space Weather**

- **CUSP** will perform X-ray polarimetry with a **better sensitivity** with respect to **past missions**

- **CUSP** is going to start **soon** a **12 months Phase B** to define a preliminary design and deliver a prototype of the polarimeter, representative of the detector front-end