CUSP: a two CubeSats constellation for Space Weather and solar flares X-ray polarimetry

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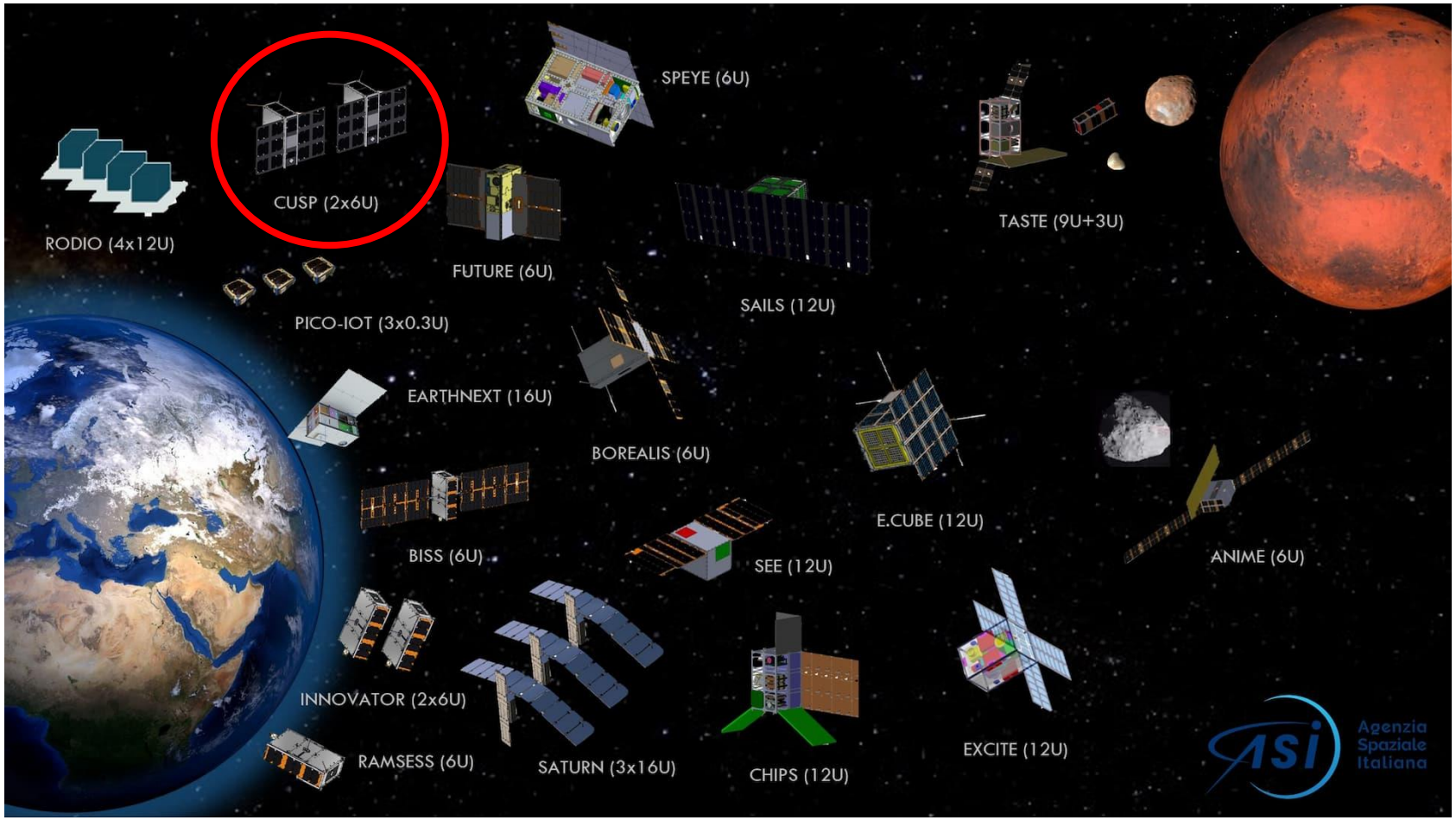
on behalf of CUSP Team

a) INAF-IAPS

The framework

- The **Italian Space Agency** started a new national program named **Alcor** for founding the development of CubeSat technologies and missions
- **CUSP** is one of the 20 selected missions among 49 proposals
  - 22 participants from Research Institutes and Universities and 78 companies, mainly Small and medium-sized enterprises (SMEs)
- Over the next five years, the Agency plans to deploy them in orbit.



CUSP Team

- INAF-IAPS (Prime and Payload)

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- Università della Tuscia (Ground Segment)

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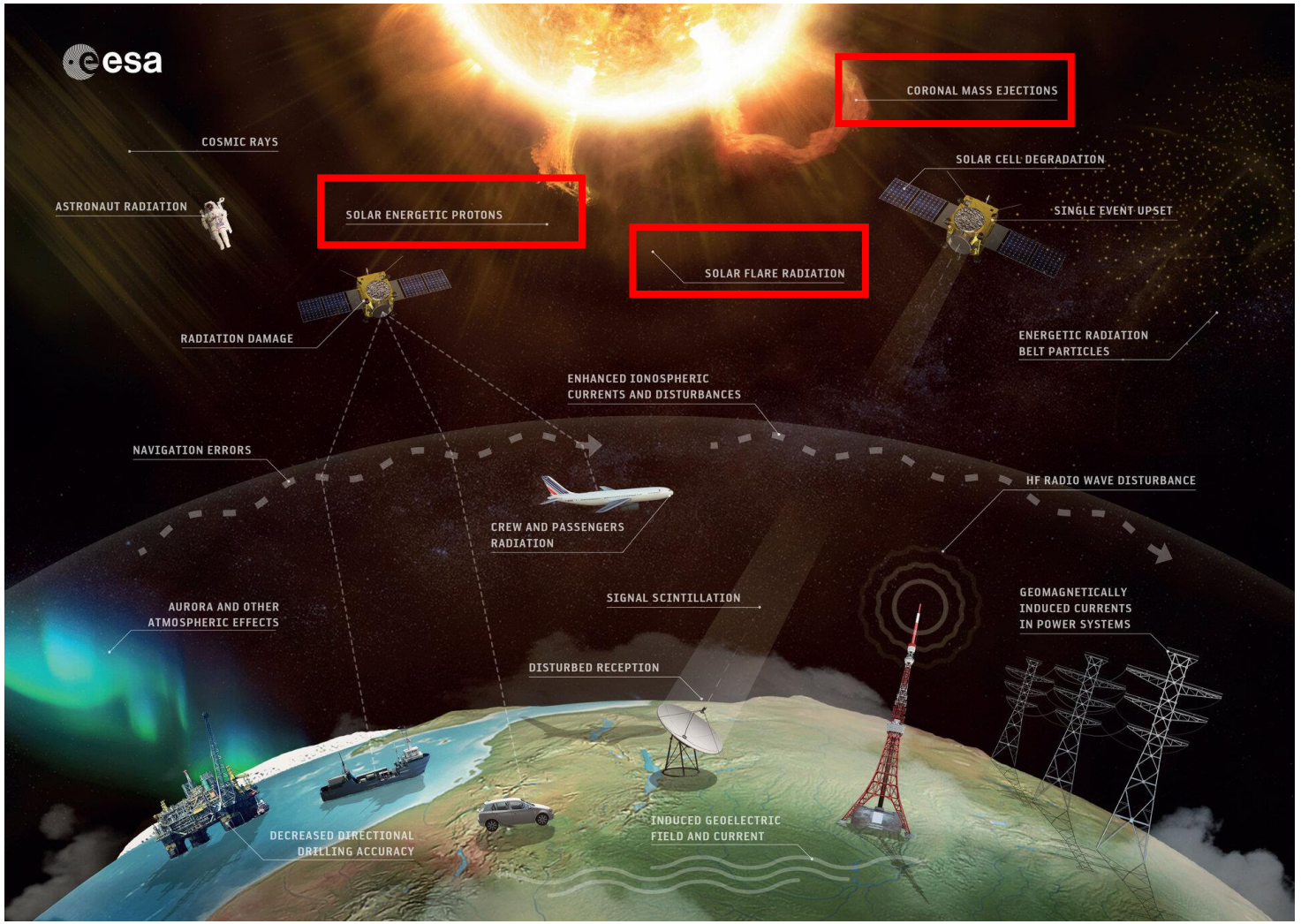
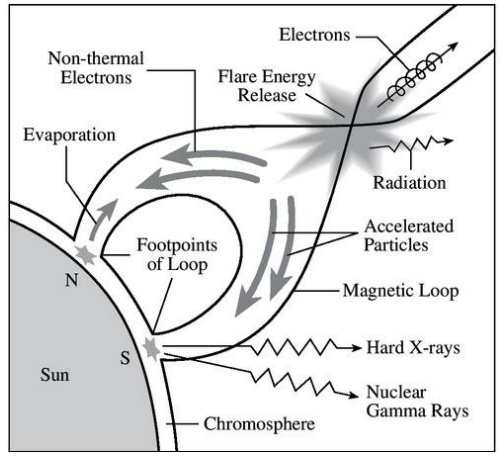
Solar Flares: Heliophysics and Space Weather

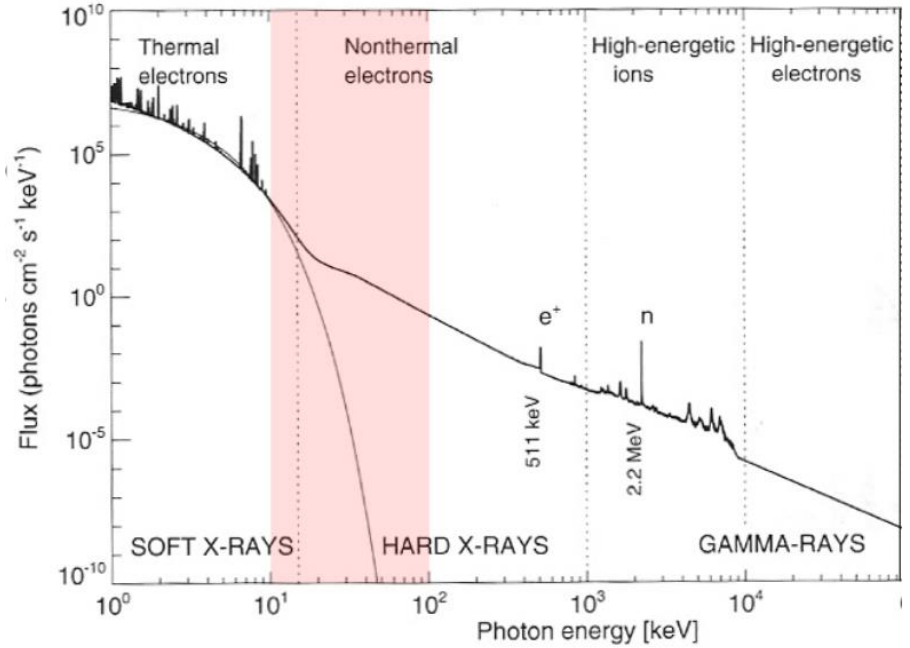
- Solar activity, including Solar flares (SFs), can be disruptive for human technological activities in space and on ground
- The occurrence of SFs is linked also to Coronal Mass Ejection (CME) and Solar Energetic Particle (SEPs) events on the ground
- CUSP outcomes are intended to contribute to the present and future networks for Space Weather, inlcuding the future ASI SPace weather InfraStructure (ASPIS)



X-ray polarimetry and Solar Flares

- Classical picture of a solar flare originating from a magnetic reconnection at the top of a magnetic loop
- The dominant components of the energy spectrum are:
  - thermal Bremsstrahlung (expected weakly polarized (Emslie & Brown 1980) + lines < 10 keV
  - non-thermal Bremsstrahlung >10-20 keV. It is expected to be highly polarized [Zharkova et al. (2010)]
- In 20-100 keV energy band the non-thermal component is dominant

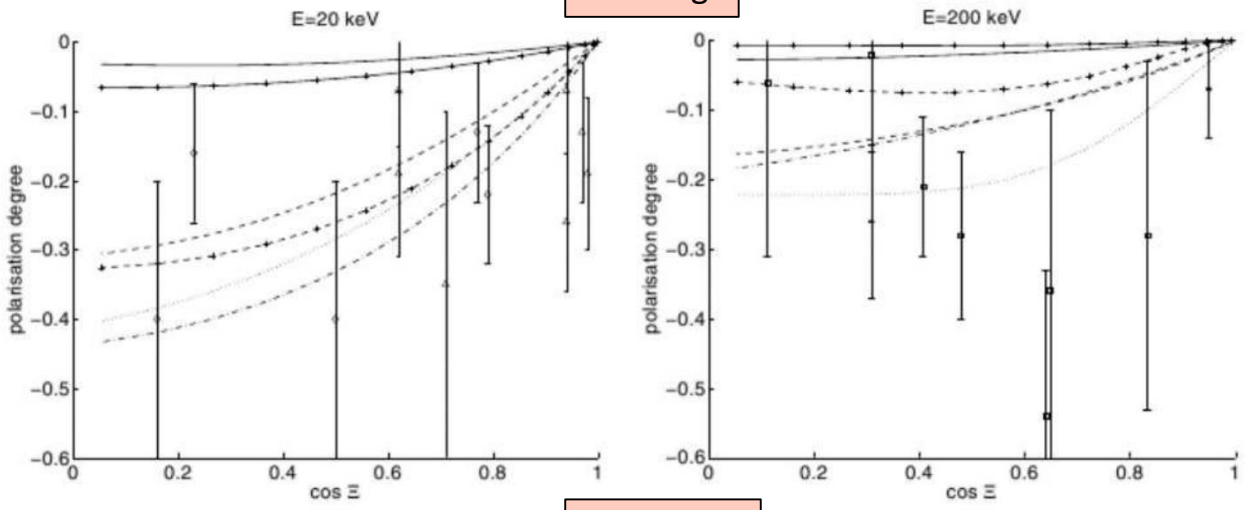




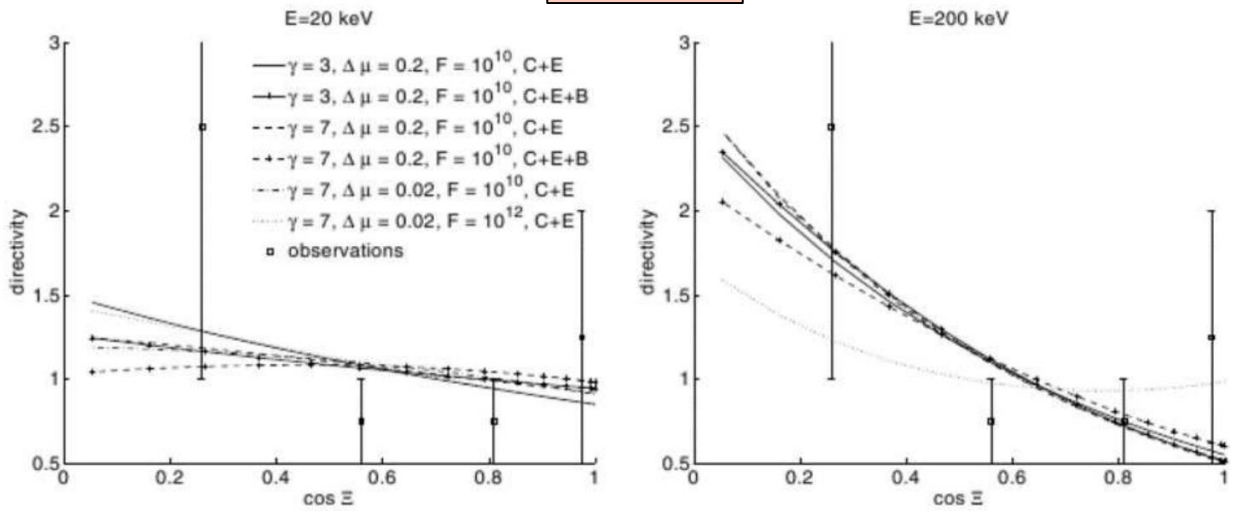
X-ray polarimetry and Solar Flares

- Theoretical models predict high linear polarization in the X-rays, depending on the particle beaming and magnetic field properties [Zharkova et al. 2010 (A&A), Jeffrey et al. 2020 (A&A)]
- Particle directivity can be derived from polarization measurements
- Until now few measurements with, moreover, low significance
- Data:
  - 20 keV plots: diamonds - Tindo et al. (1970, 1972a,b) at 15 keV, triangles - Tramiel et al. (1984) at 16-21 keV,
  - 200 keV plots: squares – Suarez-Garcia et al. (2006) at 100−350 keV, and asterisks - Boggs et al. (2006) at 200−400 keV.

Pol. Deg.



Directivity

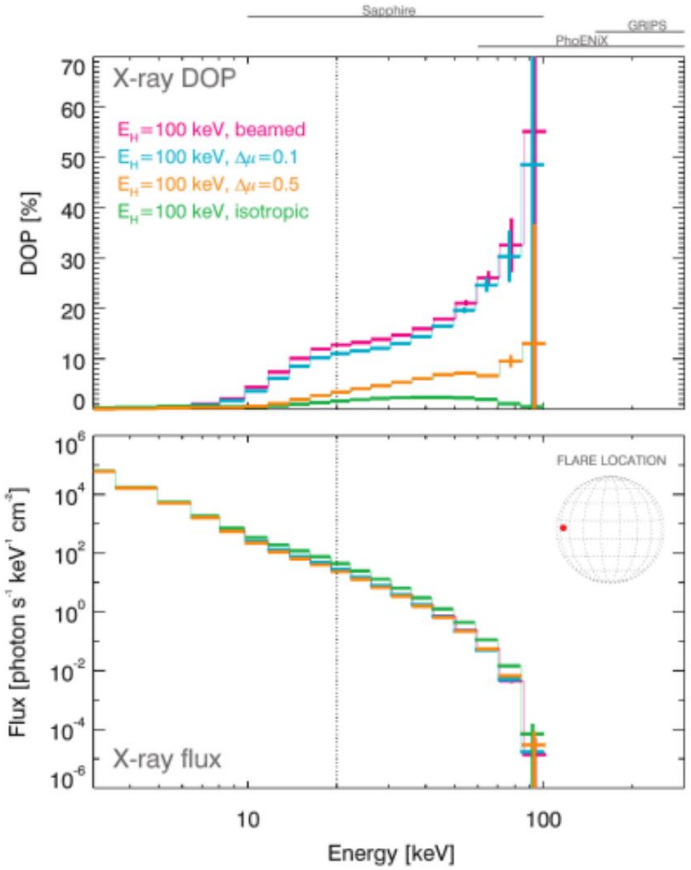


[Zharkova et al. 2010 (A&A)]

X-ray polarimetry and Solar Flares

- X-ray polarimetry of Solar Flares (SFs) allows to assess:
  - **magnetic configuration** of the flaring site on the Sun
  - **magnetic reconnection** at the magnetic loop top
  - **particle acceleration**, including particle **directivity**
- Polarimetry allows to **overcome degeneracies in particle beaming models** from other observables like energy spectra
- Polarimetry gives instantaneous clues about the flaring event

- **Which scientific requirements?** (to be properly assessed during phase A and B):
  1. Measure the linear polarization of the non-thermal component
  2. Minimum Detectable Polarization < 10% at least for SFs most relevant in terms of SpaceWeather (X class)
  3. SFs are dynamical events (time scales from minutes to hours), thus capability to study polarization as a funciton of time



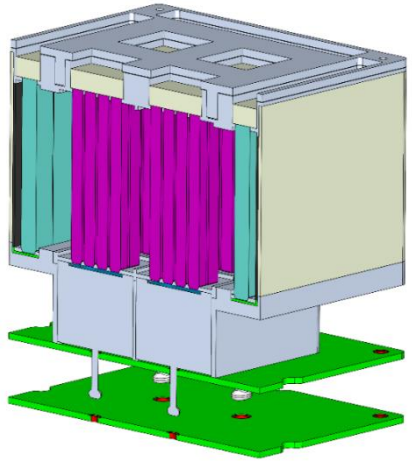
Jeffrey et al. 2020 (A&A)

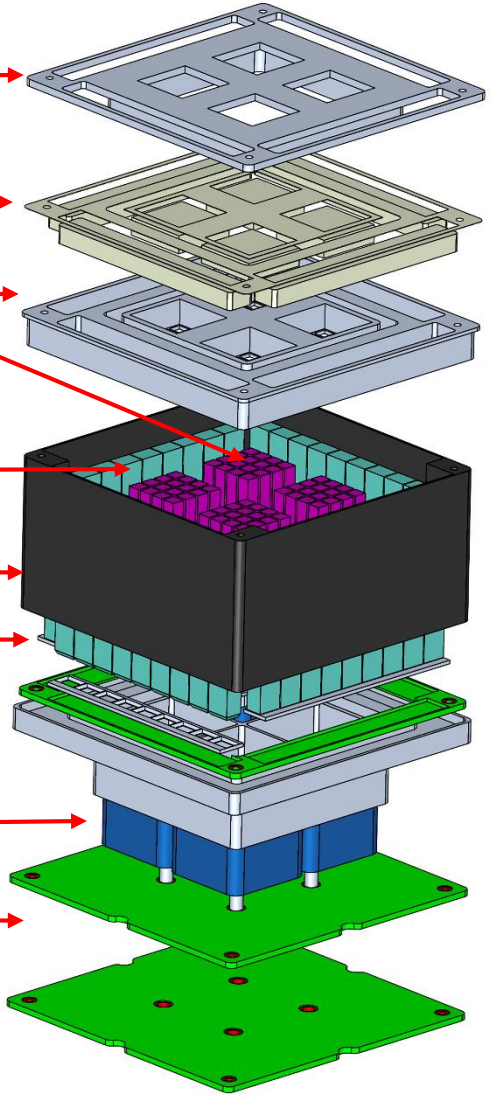
Ancillary science

- CUSP can detect intense X-ray astrophysical sources falling in the Field of View during the year while observing the Sun (F.O.V. +/- 21 deg around the Sun):
  - Gamma Ray Bursts:
    - Based on the SWIFT/BAT catalog, CUSP is expected to detect 16 GRBs/yrs with a peak flux over the absorber background
  - Other possible sources:
    - Crab Nebula (PWN), Sco X-1 (LMXB), A0535+26 (HMXB)

The Payload – The Hard X-ray Polarimeter
The heart of CUSP

- Paylod:
  - Compton scattering polarimeter operating in the 20-100 keV energy band
  - W collimator
  - A/D Conversion
  - Micro HVs (0.5" x 0.5" x 0.5")
  - HK handling
  - Payload computer based on microcontroller
- Absorber / scatterer coincidences (dual-phase scattering polarimeter)
- Scattering stage:
  - Multi-anode Photomultipler Tube (MAPMT R7600 rugged by Hamamatsu) coupled with plastic scintillator elements
  - ASIC for MAPMT readout is MAROC 3A by WEEROC
- Absorption stage:
  - Gd3Al2Ga3O12 (also known as GAGG) readout with APD silicon sensors S8664 by Hamamatsu)
  - ASIC for APDs readout is SKIROC 2A by WEEROC





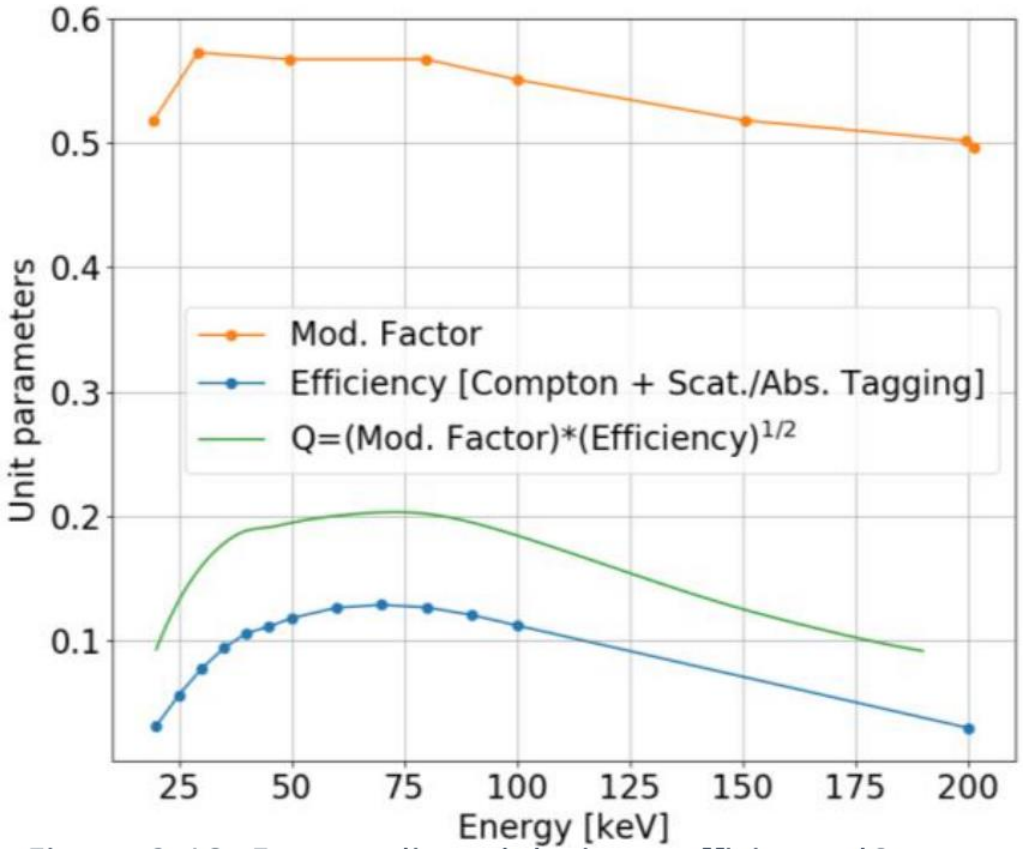
The Payload – The Hard X-ray Polarimeter The heart of CUSP

- Minimum Detectable Polarization in the 20-100 keV energy band

(CBE based on benchmark SFs from Saint-Hilaire et al. (2008), Sol. Phys. 250, 53–73):

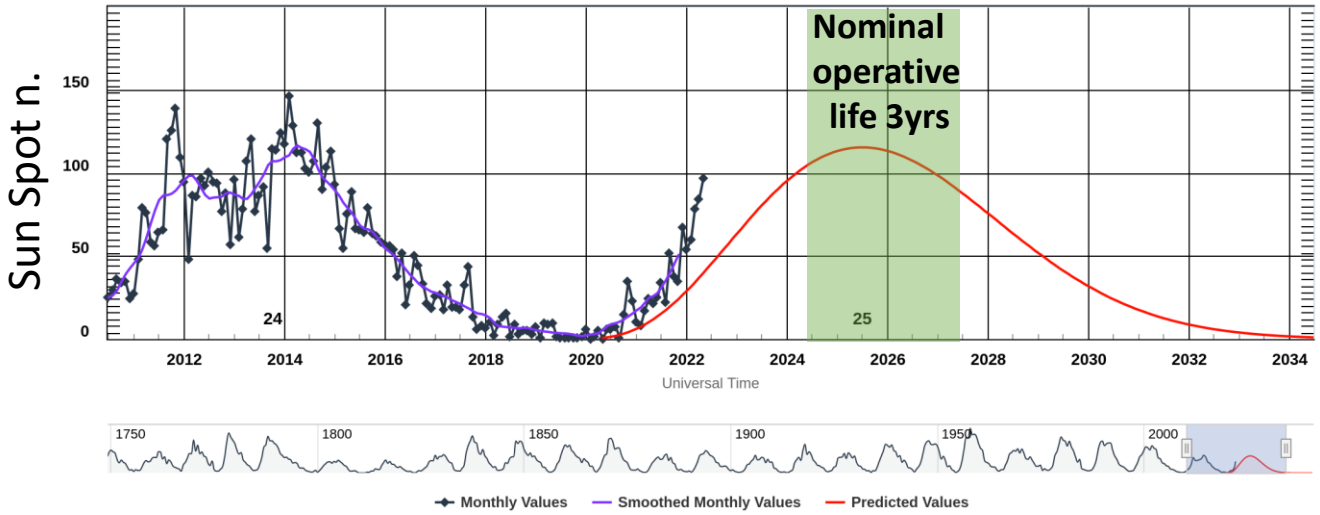
Flare Class	Integration time (s)	MDP
M 5.2	284	9.2%
X 1.2	240	4.8%
X 10	351	0.9 %

- Few minutes of integration time allows to measure polarization of SFs expected at a level of some tens of %

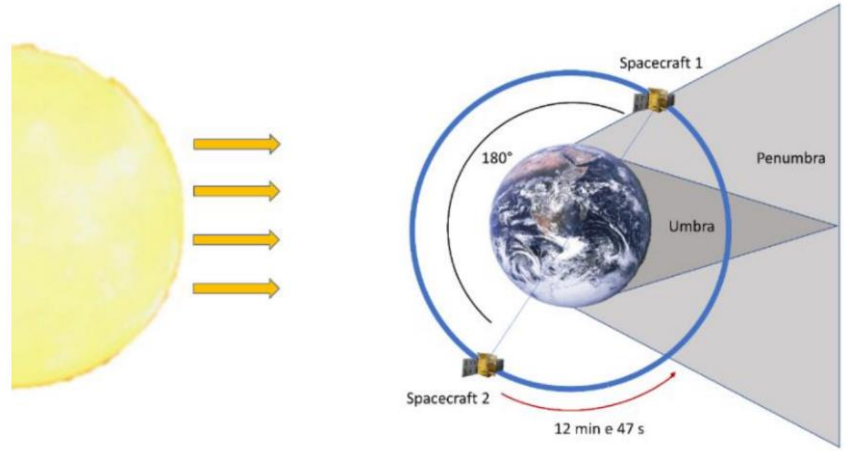


The Mission Concept

- 2 CubeSats at 180° phase difference along the orbit.
- Continuous monitoring of the Sun (at least 1 satellite observing), regardless of the mutual orientation between the orbital plane and the Sun direction (i.e. the beta angle)



- Target orbit is polar 500-600 km of height:
  - To maximize launch opportunity: low eccentricity Solar Synchronous Orbits (SSO)
  - Satellites with same orbital period and nodes precession
  - Maximum contemporary daylight for both satellites is ≈16 min. in case of SSO Mid-Morning (LTAN = 9:30) at 600 km



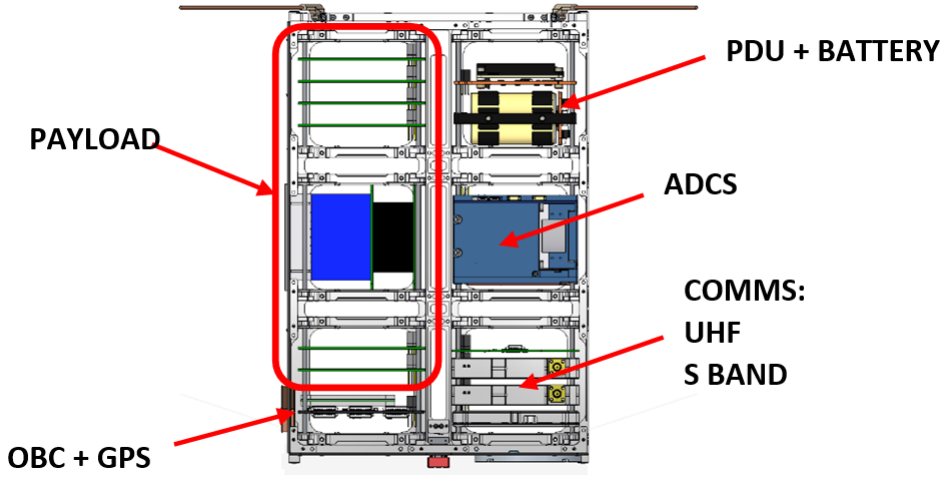
- Operative modes:

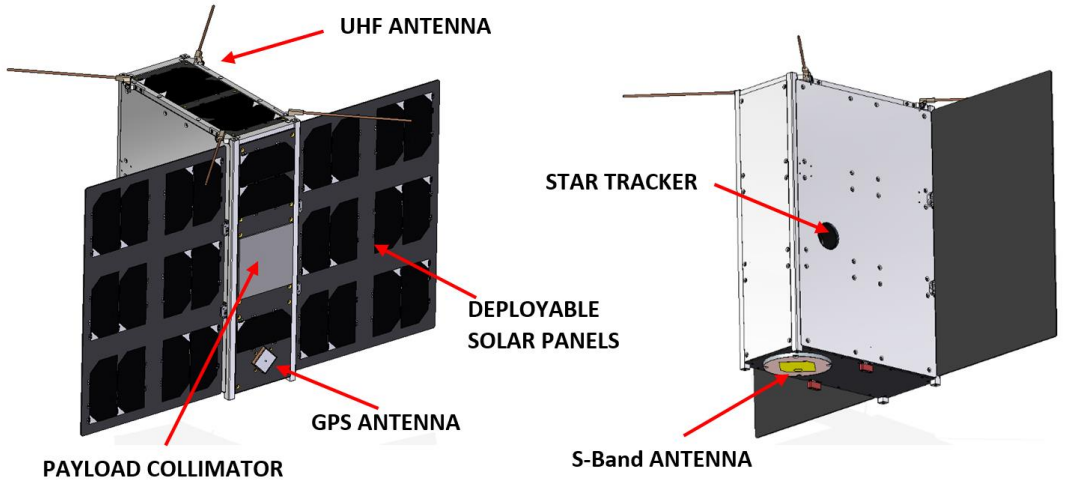
  Sun Pointing: satellite rotation 1 RPM along Sun pointing for data collection (polarization is a geometrical property, rotation allows to significantly reduce detector systematic effects due to geometry, 30 s is the integration period relevant for polarimetry)

  Data downlink: 3 axes stabilized

The Platform

- 6 U CubeSat
- IMT s.r.l. heritage from platforms HORTA (funds POR/FESR 2014-2020 by Lazio region) and EOSS (funds POR/FESR 2014-2020 by Puglia region)
- Compatible with CDS(CubeSat Design Specification) and internal architecture with CubeSat Kit Bus (CSKB)

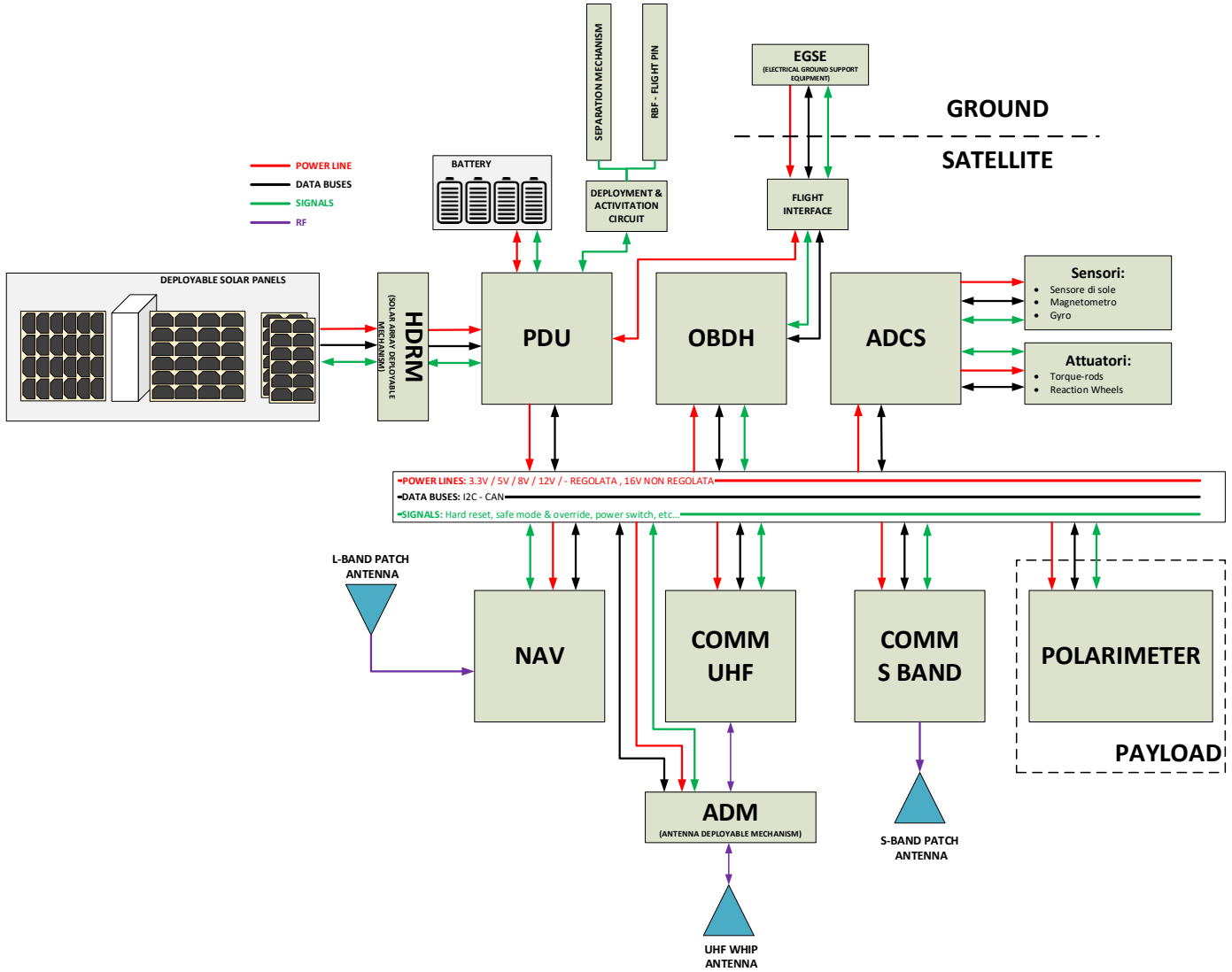




Preliminary performance	
Peak Power	30W with deployable panels
Battery	> 75Wh
Pointing accuracy	< 1° (down to 0.1°)
Operative frequencies	S / UHF
Downlink throughput	Up to 5 Mbps
Available interfaces	CAN Bus, I2C, UART, RS422
Regulated bus	3,3V, 5V e 12V
Not regulated bus	32V (24V-33.6V) or 16V (12V-16.8V)
Available valume for the payload	2.5U
Nominal life time	3 years in LEO

The Platform

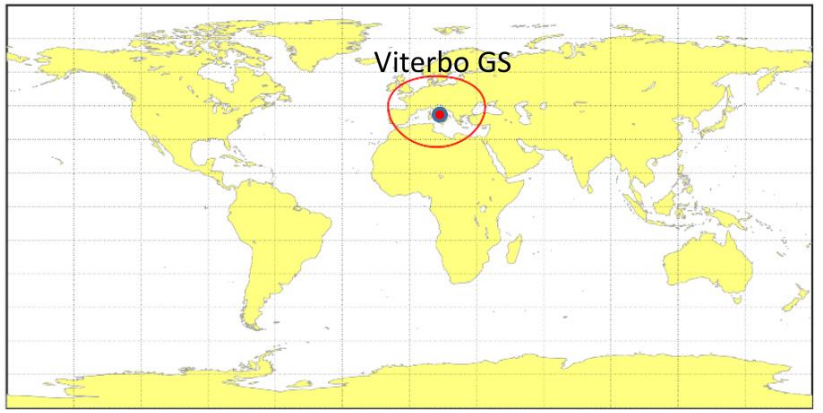
- OBC based on micro controller with RTOS operative system
- OBC qulified >20 krad, architecture for SEU/SEL mitigation with anti-latchup circuitry and TMR (Triple Modular Redundancy)
- UHF engineering telemetries and telecommands, S-band mainly scientific data

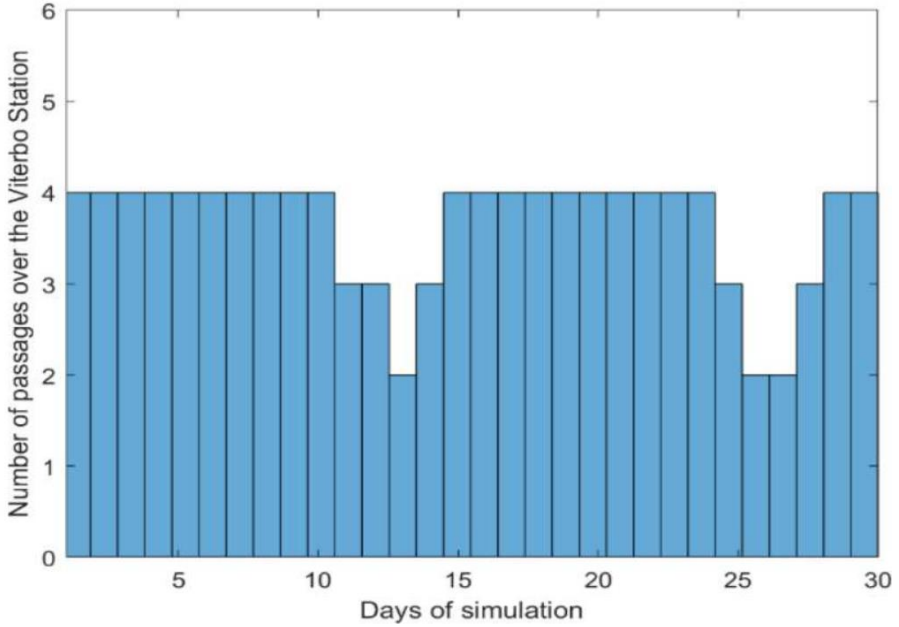


The Ground Station

- Located at 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
- Pointing accuracy 0.1° (both azimuth and elevation)
- Minimum tracking speed 2°/sec in azimuth, 1.8°/sec in elevation





Planning

Subsystem	TRL	Notes
Spacecraft	7	Many platform components have TRL 9
Payload	3	Components like MAPMT, APD, ASICs have a high TRL (7-9)
Ground Segment	7	Ground station already operative, but HW and SW to be adapted to the new mission

- **Model Philosophy:**
  - 1 detector prototype at the end of Phase B. Representative of the detector front-end (from TRL 3 to TRL 4)
  - 1 payload EQM (design phase B, production and test phase C). Representative of the payload (from TRL 4 to TRL 7)
  - 2 CubeSats:
    - 1 Proto-flight Model (PFM). To qualify at proto-qualification level.
    - 1 Flight Model (FM). To qualify at acceptance level
- **Phases:**
  - Proposed 15 months for a phase A/B, approved phase A then B (3+12 months)
  - Proposed phase C/D 15 months
  - Phase A nearly to start
- **Calibration** of the Hard X-ray Polarimeter of each CubeSat will be carried out at INAF-IAPS calibration facility (already employed for calibrating the IXPE Detector Units)

Conclusions

- Solar flares (SFs) are correlated to many damages and disruptions related to human technological activities in the space and on ground
- Solar Energetic Particles Events (SEPs) at the Earth are correlated with SFs and Coronal Mass Ejections (CMEs), which may also be triggered by SFs
- SFs are relevant phenomena for Space Weather
- X-ray polarimetery is a direct probe of particle acceleration on the Sun
- X-ray polarimetry allows to measure particle directivity and magnetic filed structure of the flaring loop
- X-ray polarimetry will allow to assess magnetic reconnection that is thought to originate SFs
- CUSP will contribute in the understanding of these solar violent phenomena also participating to the present and future networks for Space Weather, inlcuding the ASI SPace weather InfraStructure (ASPIS)