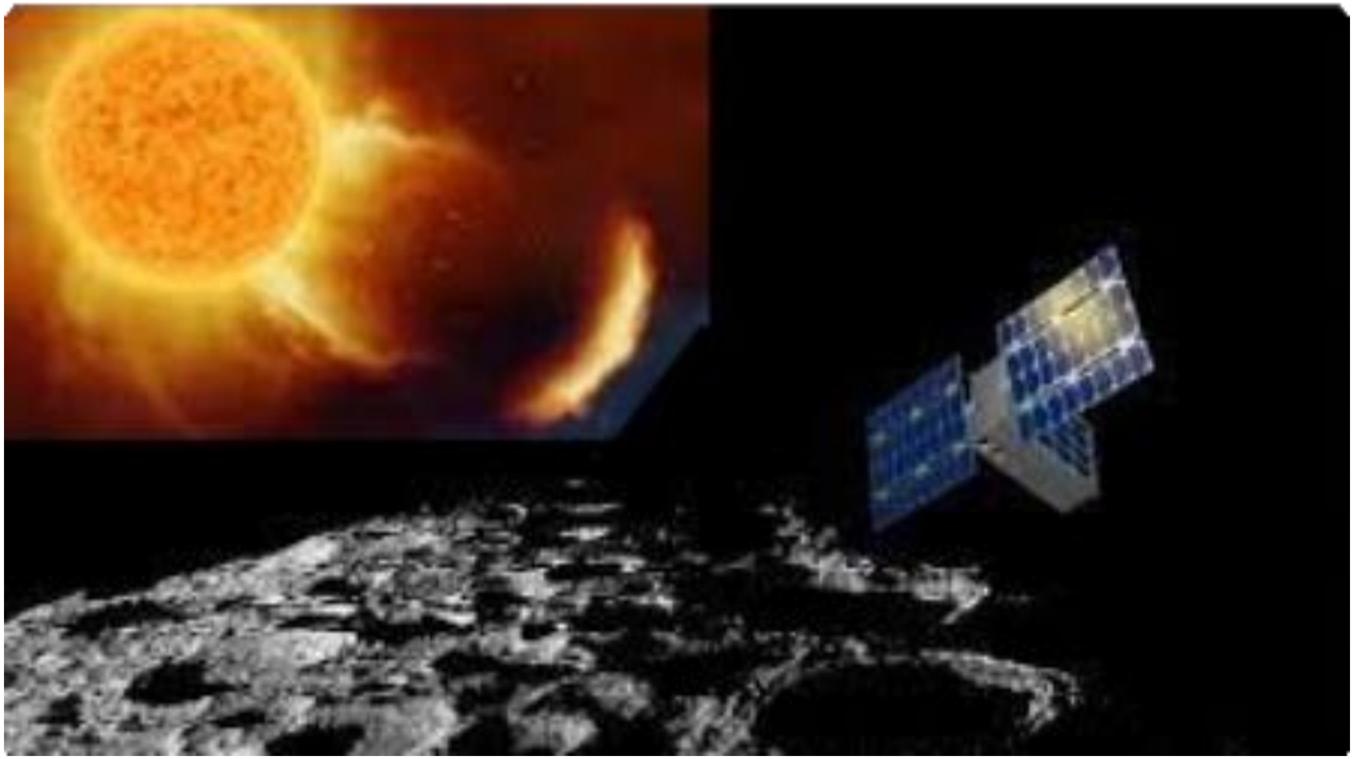
Space Weather Multi-point Monitoring with CubeSat Platforms

Silvano Fineschi – INAF-Osservatorio Astrofisico di Torino

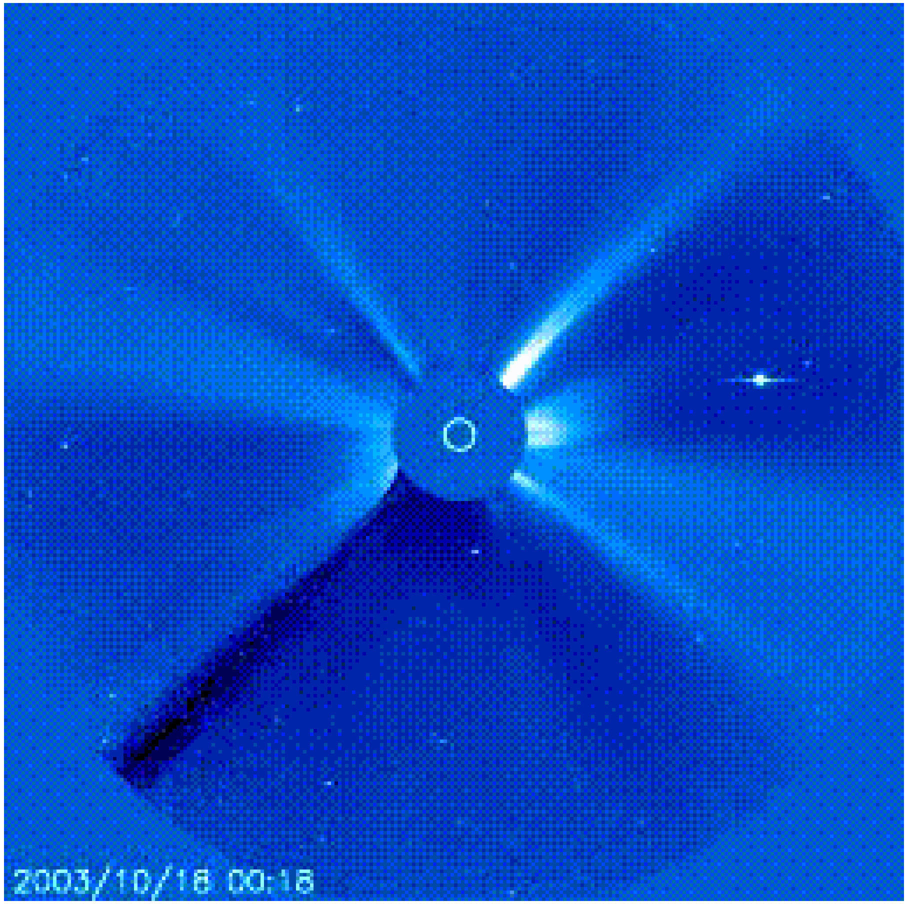


Overview

- **SELENE -** Solar Exploration by Lunar Eclipsing with Nanosatellites Experiment – SWE monitoring from Moon orbit of the heliospheric environment of the Moon-Earth system

- **Helianthus** – SWE monitoring from sub-Lagrangian Point 1with CubeSat with solar photonic propulsion (solar sail)

Motivation: “Affordable” Solar Storms Monitoring



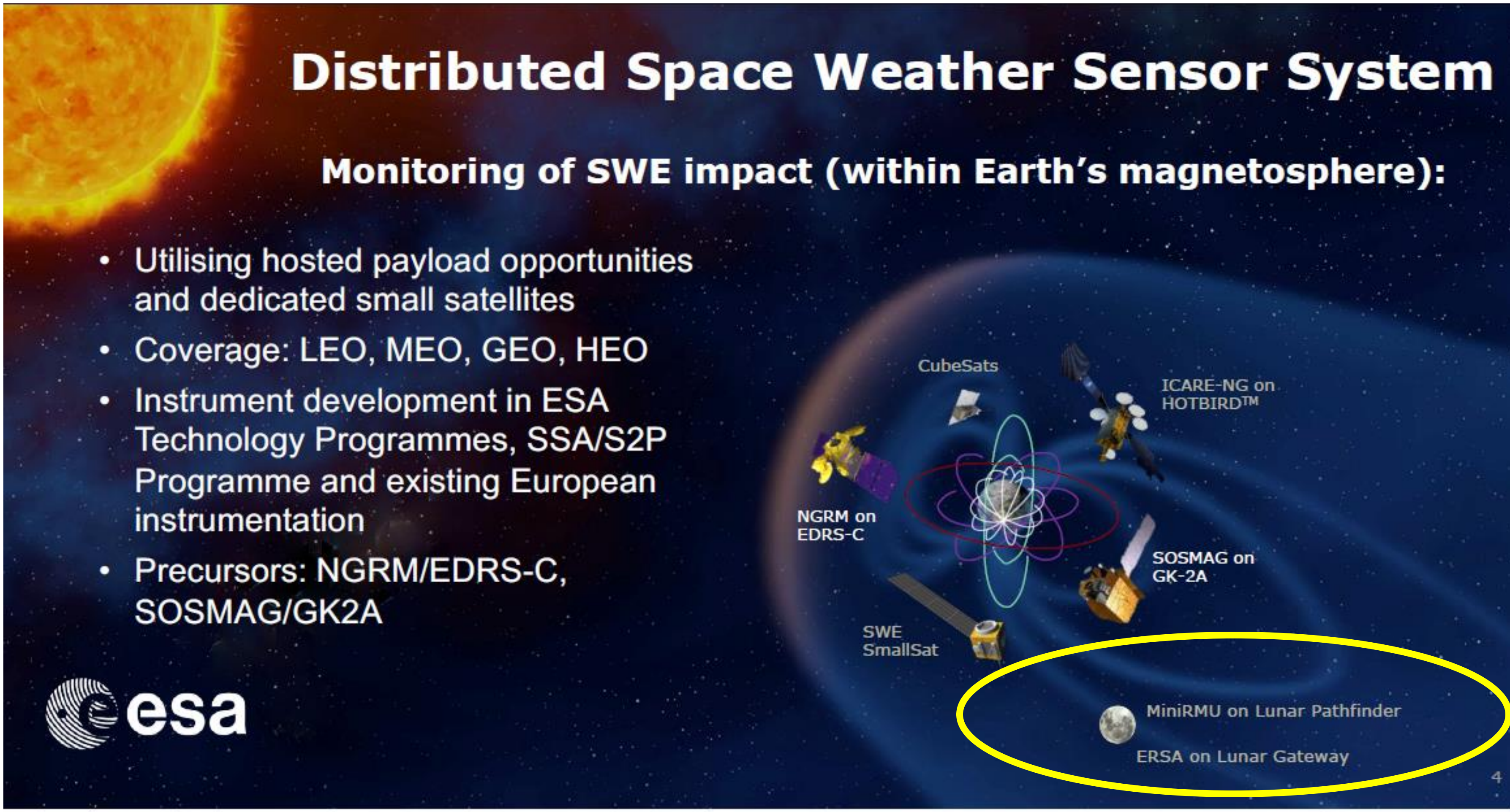
Space Weather Drivers:

Coronal Mass Ejections (CME): remote-sensing imaging of their direction, speed, dimensioni n-situ magnetic configuration

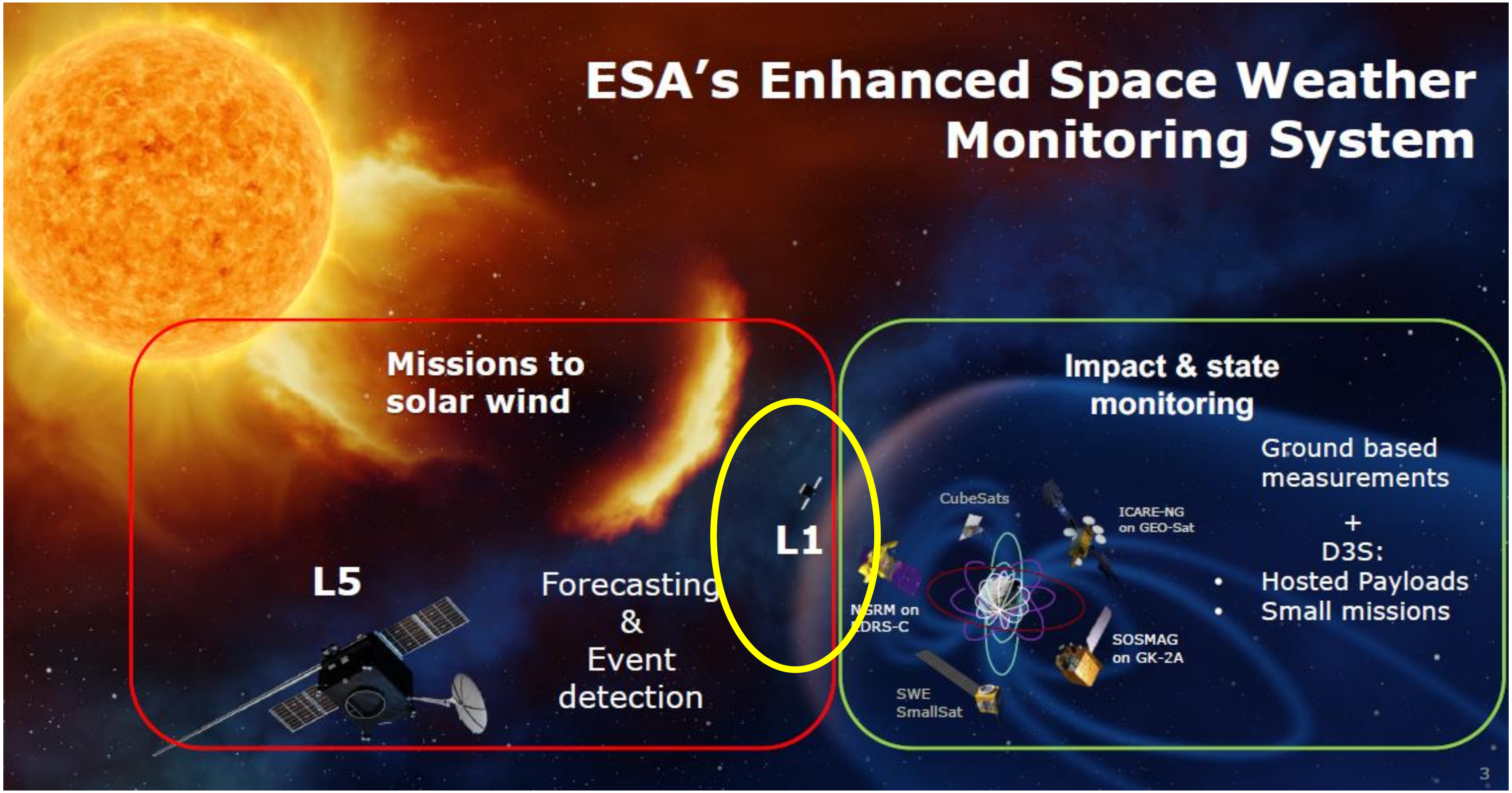
Flares: remote-sensing of x-ray emission intensity, energy

Solar Energetic Particles (SEP): in-situ particle intensity, energy

SWE Monitoring ESA Context



SWE Monitoring ESA Context

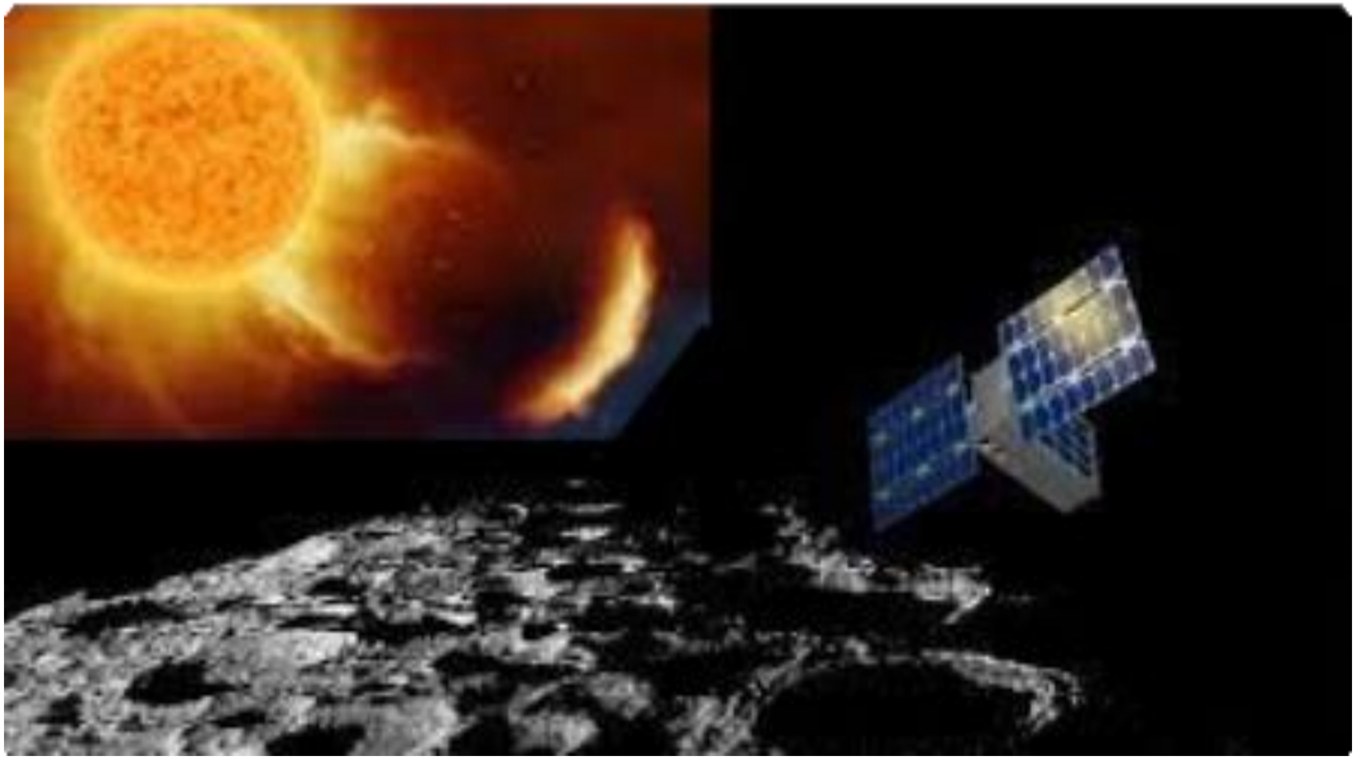


SELENE – Solar Exploration by Lunar Eclipsing with Nanosatellites Experiment

Silvano Fineschi – INAF-OATo

Sabrina Corpino - Politecnico di Torino-DIMEAS

Giovanni Scarfizzi – ALTEC, Torino



Mission Objectives

The Solar Exploration by Lunar Eclipsing with Nanosatellites Experiment–SELENE– is a Space Weather (SWx) mission

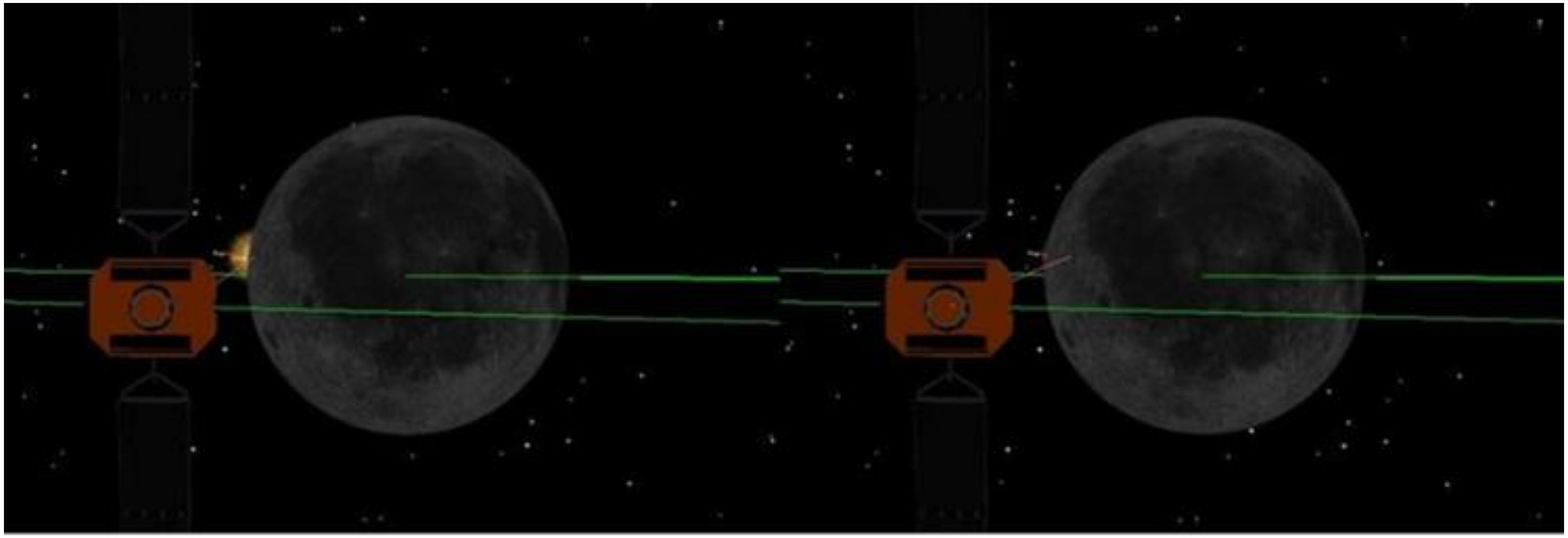
- with Moon orbiting observatories utilizing lunar limb occultation of the solar disk for detection and propagation prediction of Earth-directed coronal mass ejections (CMEs);
- At the same time, SELENE will monitor the heliospheric particle radiation (electron, ions) and magnetic field environment of the Earth-Moon system

Submitted in Nov. 2021 to ESA OSIP Campaign: "Nanosatellites for Space Weather Monitoring"

- ➢ Preselected in Dec. 2021 (43 proposal -> 11 preselected)
- ➢ Final Selection 11-> 5 did not include SELENE

2024 Phase-0 Study in the ASI-funded "Space-It-Up" – Spoke 6: SWE

Mission Profile



SELENE Mission Profile will be carried out with small platforms orbiting the Moon

Mission Profile (2)

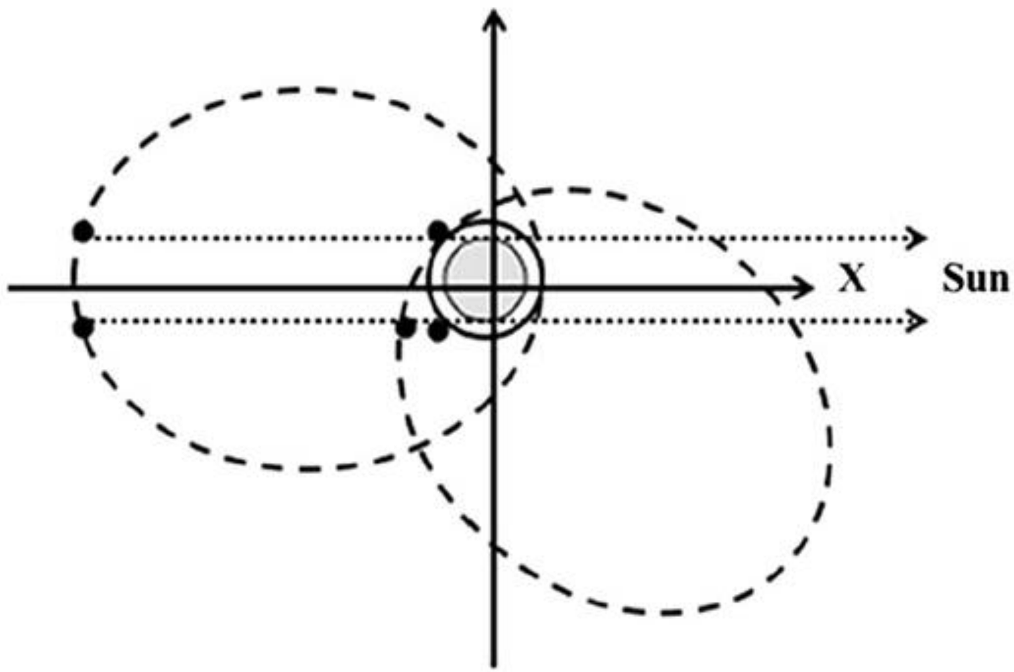


Fig. 1 Three orbits in selenocentric coordinates with lunar equatorial *X*-axis towards the Sun and the *Y* -axis in the dawn-dusk direction. The two elliptical orbits have the same low-altitude perilune 100 km and same apolunes at 10 RM from the center of the Moon. These and the one low-altitude 100-km circular orbit are in the equatorial plane. The ecliptic pole is pointing out of the page. The solid circles indicate the locations of occultation events for solar coronal observations.

SELENE Strawman Payload

Remote -sensing instrumentation

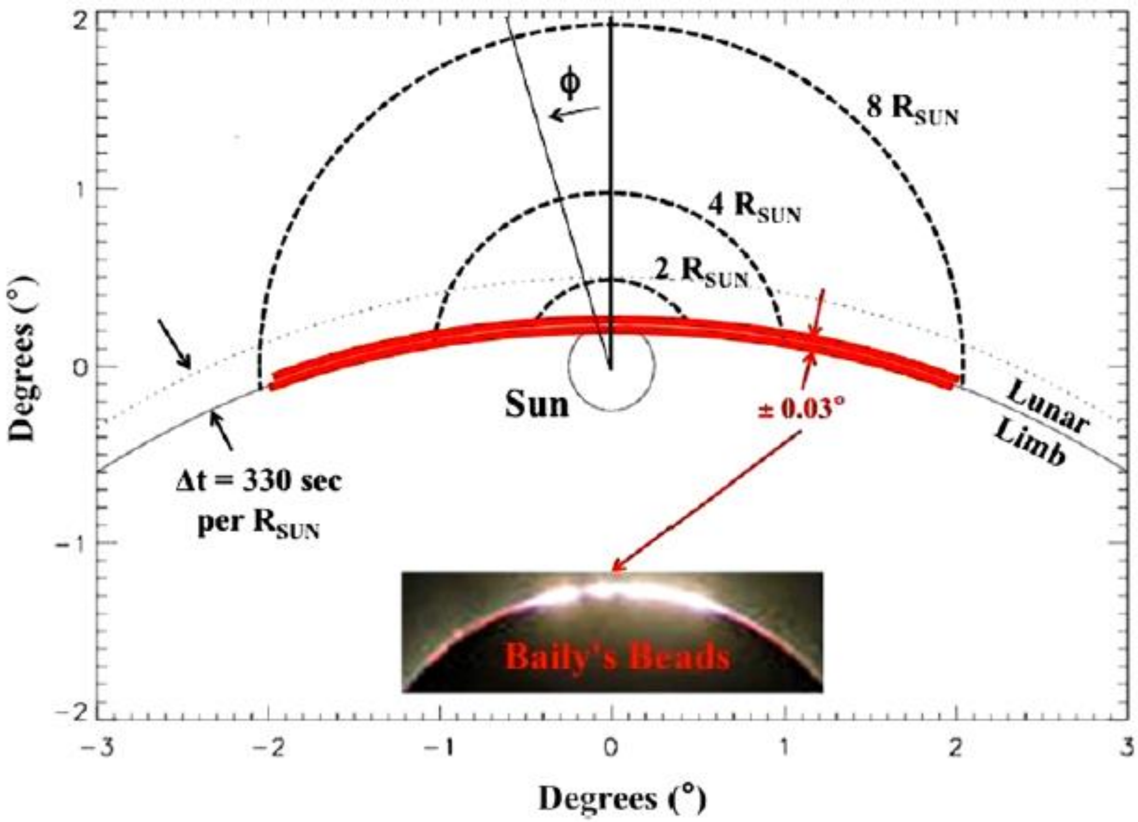
- Coronal Wide-Angle Camera with wide field-of -view objective lens and CMOS sensor
- X-ray sensor for solar flares detection

In-situ instrumentation

- Plasma Analyzer
- Magnetometer

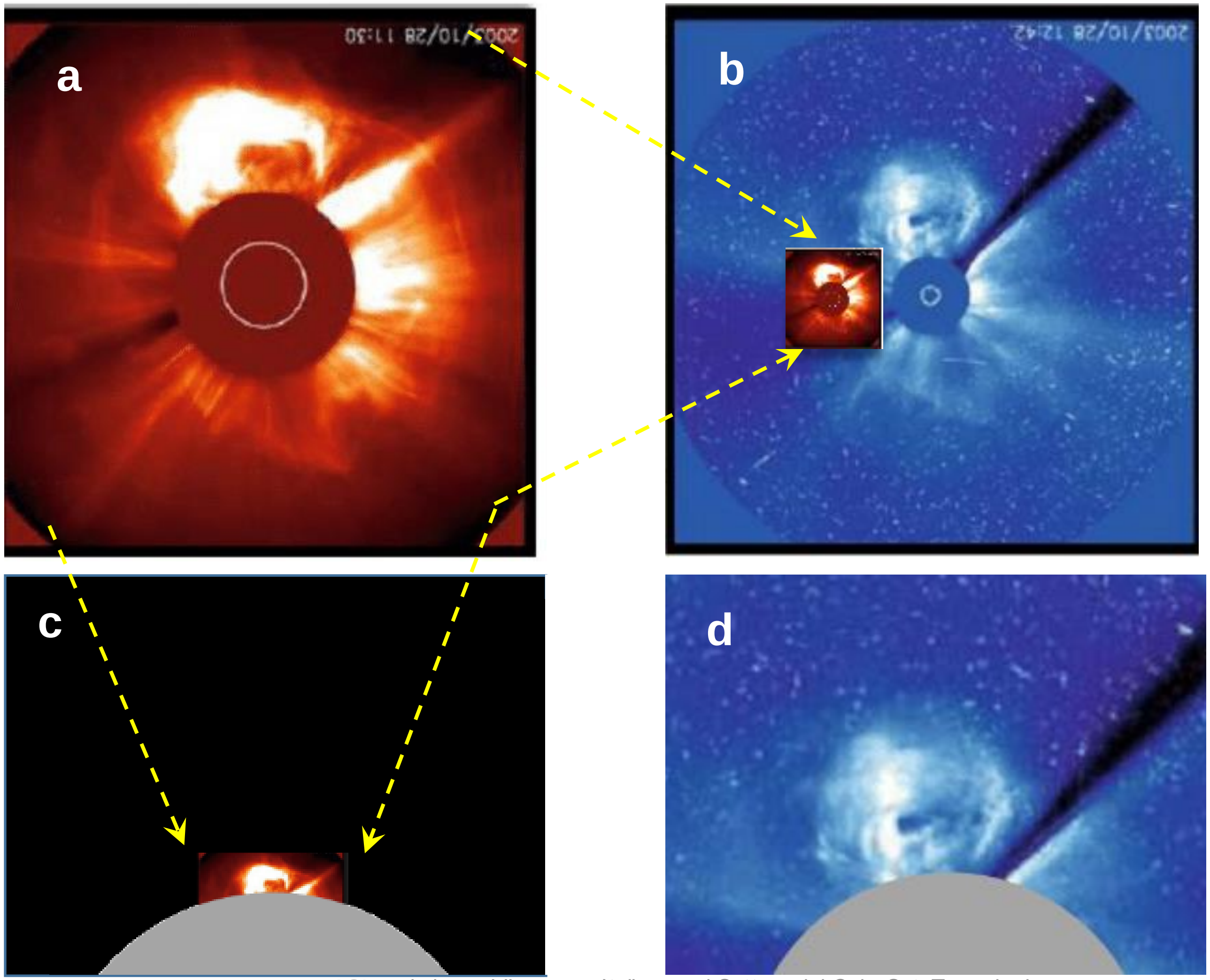
Fig. 3 Left. Solar Flares X-ray sensor is a compact (7.6cm×4.4cm×2.9cm) diode (Amptek XR100FASTSDD) covering the 1-100 keV x-ray range.
Right. Ion and Electron Sensor flown on Rosetta for measurements of thermal and Supra-thermal Electrons and Ions 1 -22 keV

Remote Sensing Observations



Lunar limb view at the beginning or end of a solar occultation event with the solar disk just at the limb, roughly defined in indicated view angle by surface topography of ± 8 km. From the perspective of an occultation observation point nearly 10 RM behind the Moon. The Sun and the solar corona are shown in a 2° (8 solar radii) conical field of view. The circular arcs show meridional exposure of the corona at 2 – 8 solar radii radial distances vs angle west (rightward) or east (leftward) from the local limb zenith.

Remote Sensing Observations



From a lunar orbit there would be major advantages over solar eclipse observations from the ground at Earth:

i) High cadence observations, dependent on the time-variable orbit for occultation frequency, duration, and spatial section (east, west, north, south) of the viewable solar corona.

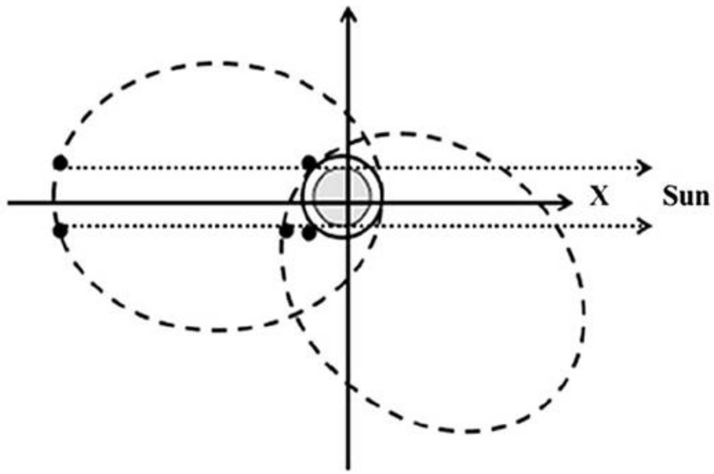
ii) Very low atmospheric scattering of sunlight in the orbital exospheric gas and dust environment of the Moon as compared to the strong atmospheric scattering at Earth.

iii) Very low stray light within the instrumentation, since light from the solar disk is completely occulted by the lunar limb, therefore, **there is no need of complex external- and internal-occulters,** and

iv) In near-equatorial orbit the spacecraft sees per orbit, and in sequence, the east and west extensions of the solar corona above the respective east and west limbs of the Moon.

v) Stereoscopic view of Earth directed CMEs with ESA Vigil L4 space weather mission

CubeSat Platform for SELENE: Challenges



- **Propulsion**: Orbit insertion and keeping ⇒ Priod few hours to 1 day
- **Pointing: ~**10 arcsec
- **Data storage & downlink** ⇒ Requirement for SWE forecast: 500MB/day

Helianthus: Early Warning Sailcraft Mission

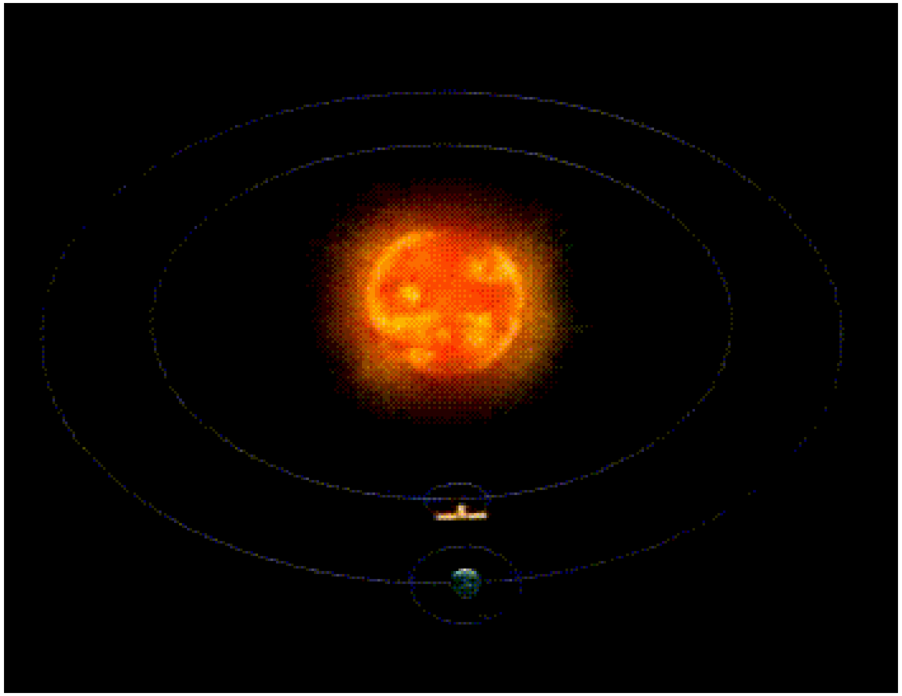
2019 - 2023 ASI-funded Study – PI: Christian Circi Univ. La Sapienza

Payload study: INAF

CME speed ~ 1000 km/s

Earth-L1: 1.5 e6 km
In-situ warning time: ~ 0.5 hours

Earth-sub-L1: 6.8 e6 km
radiation pressure ⇔ gravity
In-situ warning time: ~ **2 hours**



Helianthus Team

Compito	Ente
Analisi di missione traiettoria	**Uniroma1-DIAEE** (Giovanni Vulpetti, Christian Circi, Tommaso Pino)
Analisi di missione assetto	**Uniroma1-DIAEE** (Giovanni Vulpetti, Christian Circi, Tommaso Pino) **UniPisa** (Giovanni Mengali, Alessandro Quarta, Lorenzo Niccolai)
Antenna	**Uniroma1-DIAEE** (Gabriele Mocci, Christian Circi)
Sensore per Early Warning	**INAF – Osservatorio di Torino** (Silvano Fineschi)
Materiali fotonici (per ACS)	**CSM** (Stefano Lionetti)
Misure ottiche membrana	**ENEA-Casaccia** (Salvatore Scaglione, Danilo Zola)
Misure meccaniche	**Uniroma1-DIAEE** (Christian Circi, Tommaso Pino)
Boom tubolari (materiali compositi a matrice resinosa)	**Uniroma1-DIAEE** (Susanna Laurenzi)
Boom piatti a memoria di forma (materiali compositi a matrice polimerica)	**KET Lab – Uniroma 2** (Loredana Santo, Fabrizio Quadrini)
Materiali polimerici per membrane sottili	**Uniroma1-DICMA-DIAEE** (Gabriella Santonicola, Susanna Laurenzi)

Solar Sail

Solar Sail

Parametri	Valori
Sail area	926.735 m^2
Sail side length	30.44 m
One boom length	21.52 m
Sailcraft mass	10.393 kg
Al reflective layer	90.0 nm
CP1 membrane	2.0 um
Boom linear density	20.0 g/m
Lightness number	0.1273
Distance from Earth	0.04558 AU (6800000 km)
Advance warning	**140-150 min**.

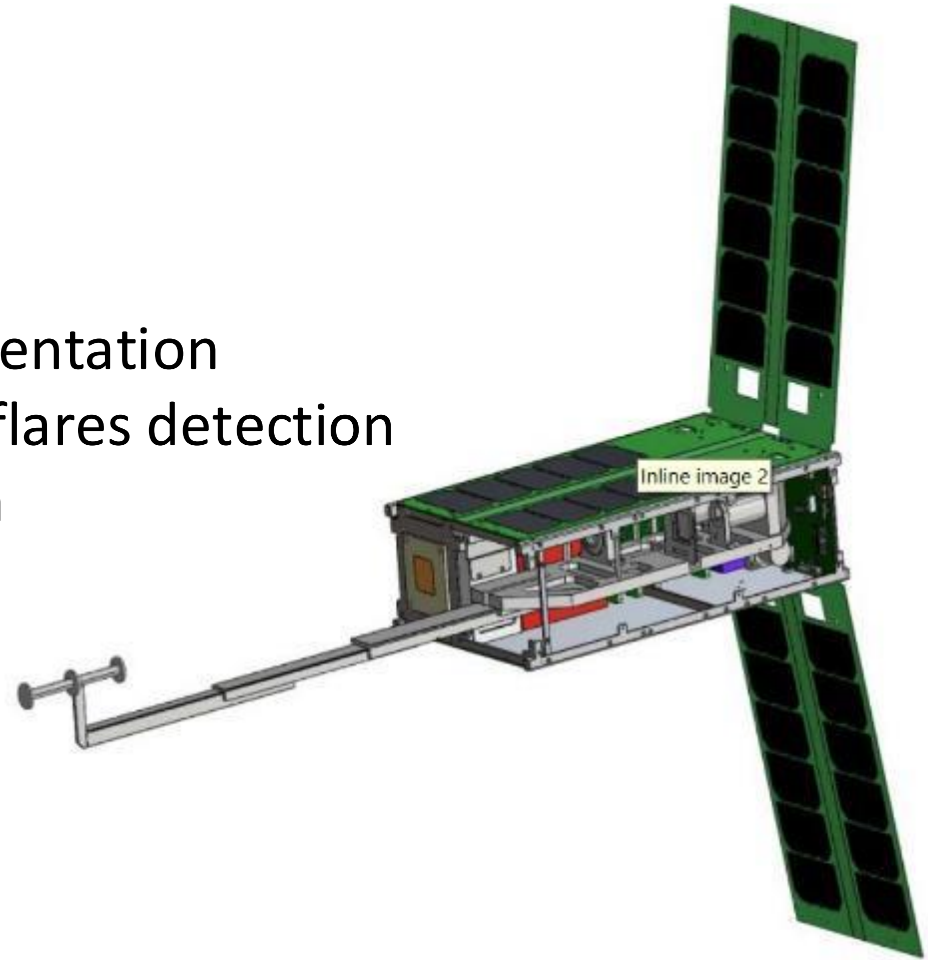
Helianthus Strawman Payload

In-situ instrumentation

- Plasma Analyzer
- Magnetometer

Remote -sensing instrumentation

- X-ray sensor for solar flares detection
- Compact Coronagraph
  (CubeSat 6U)



CubeSat Platform for Helianthus: Challenges

- **Accommodation**: Sail-FoV clearance;
- **Stability:** Sail & extendable boom
- **Pointing**: ~ 1 arcmin
- **Data storage and downlink** ⇒ Requirement for SWE forecast: 500MB/day
- **Data storage and downlink** ⇒
  - 400 Mb/day (patrol)
  - 2 Gb/day (burst x 2 CME/day) ⇒ Compression (x 10): = 0.2 Gb
- **TLM rate** ≤ 0.5 Gb/8-hour

Summary

SELENE is a Space Weather mission concept utilizing nanosatellites in Lunar Orbit

- Simple remote sensing wide-angle imager
- In-Situ monitoring of the heliospheric plasma in the Moon-Earth system

Helianthus is a Space Weather mission study utilizing nanosatellites with in solar photonic propulsion at the sub-L1 halo orbit (6.8 e6 km from Earth)

- Early warning (2 hours) of in-situ heliospheric conditions
- Continuous remote-sensing monitoring of halo CMEs.
- **Concept extendable to L5** (“behind Earth”) for strereoscopic remote-sensing tracking of CMEs.