EUV observation for Earth’s plasmasphere from EML2 by nano-spacecraft

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EQUULEUS will be launched by SLS

- EQUULEUS is one of the CubeSat boarded on the SLS#1.
- SLS#1 will be launched in 2020.
- 3 science instruments
  - **PHOENIX**
    - EUV telescope for Earth’s plasmasphere
  - **DELPHENUS**
    - Impact flash camera for Moon surface
  - **CLOTH**
    - Dust monitor (MLI)

| Max. Dimension (X direction) | 239 mm |
| Max. Dimension (Z direction) | 366 mm |
| Max. Dimension (Y direction) | 113 mm |
PHOENIX on EQUULEUS (6U, 14kg sc)

- **EQUULEUS** will be launched in 2021 by NASA’s SLS.
- **PHOENIX** is an EUV (30.4nm) telescope for He⁺ emission in Earth’s plasmasphere.
- **EML2 is suitable for continuous monitoring** of the plasmasphere from equatorial plane.
PHOENIX telescope (Science objective)

- Plasmasphere
  - Earth is surrounded by plasmas
    - $H^+$, $He^+$, and etc.
  - $He^+$ can be observed remotely by emission line
    - Wavelength at 30.4 nm.

- Observation geometry
  - By flying far from the Earth, the entire image of $He^+$ distribution can be obtained.
  - The image from the equatorial plane help understanding the dynamics of plasmas along the magnetic field.
PHOENIX: 0.5kg EUV telescope

- A mirror and detector are optimized for He\(^+\) emission line 30.4nm.
- Only one reflection by a spherical mirror (not parabolic).

Incoming light (From Earth’s plasmasphere)

PHOENIX mechanical design

Optical design of PHOENIX

Focal length = 69.4mm
PHOENIX: 0.5kg EUV telescope

Mass (FM, measured) | 537.7g (with cables)
Power (FM, measured) | 1.5~1.8W (during observation)
*Temperature dependent
Size (outer envelope) | 6.6 cm x 6.6 cm x 10cm
Field of view | 8deg. x 8deg. (8R_E x 8R_E)
Spatial resolution | < 0.1 deg. (0.1R_E)
Temporal resolution | 10~60 minutes.

Optical design of PHOENIX

FM of PHOENIX with FPGA
Wavelength selection (Mirror)

- Elimination of lights from another sources.
  - HI 121.6nm: \(> x10^4\)
  - OI 83.4nm: \(> x10^2\)
  - HeI 58.4nm: \(> x10\)

- Wavelength is selection by...
  - **Multilayer mirror**
  - Metallic thin filter
  - Photon detector

Multilayer of Mg/SiC
Wavelength selection (Metallic thin filter)

- Elimination of lights from another sources.
  - HI 121.6nm: > x10^4
  - OI 83.4nm: > x10^2
  - HeI 58.4nm: > x10

- Wavelength is selection by...
  - Multilayer mirror
  - Metallic thin filter
  - Photon detector
Wavelength selection (Photon detector)

- Elimination of lights from another sources.
  - HI 121.6nm: > x10⁴
  - OI 83.4nm: > x10²
  - HeI 58.4nm: > x10

- Wavelength is selection by...
  - Multilayer mirror
  - Metallic thin filter
  - **Photon detector**
Wavelength selection (Overall)

- Elimination of lights from another sources.
  - HI 121.6nm: > x10^4
  - OI 83.4nm: > x10^2
  - HeI 58.4nm: > x10

- Wavelength is selection by...
  - Multilayer mirror
  - Metallic thin filter
  - Photon detector

Optimized for 30.4nm
Optical performance (FM)

Sky-tree from UT Kashiwa campus
Distance from Kashiwa to Sky-tree: 24km

Defocus analysis (calc.)

Shim vs width (meas.)

0.1 $R_E$ from moon: ~0.1 deg.
Sky-tree width viewed from Kashiwa: ~0.023 deg.

Shim (0.5~1.2mm)
Shutter system for PHOENIX

• Shutter system is needed to avoid...
  • Pollution for the mirror, filter, and detector during the ground operations.
  • Incoming solar light during the flight. (Everything is fully damaged!!)

• Former missions (BepiColombo, ISS/IMAP, Hisaki/EXCEED) adopted the 1-axis door open/close system.

• However... No space for such system in nano-spacecraft missions.

FM shutter in vacuum  close  open

Bepi/MPO/PHEBUS

Sensor system

O/C sensor
PHOENIX telescope (on board nano-spacecraft, EQUULEUS) will observe Earth’s plasmasphere by using He+ emission.

The side view image of the He+ plasmasphere (from Earth-Moon L2 point) will tell us the plasma dynamics (especially) along the magnetic field.

We are trying to develop the key techniques for nano-spacecraft.

- Small photon detector and electronics.
- Shutter system (with bio-metal fiber springs).

FM (PHOENIX and EQUULEUS) is now under the construction.
Development status of PHOENIX (and EQUULEUS)

• System Kick off meeting [2016.6.16]

• Mission PDR (Preliminary Design Review) [2016.8.25]

• System EM thermal vacuum test [2017.5.20]
  • PHONEIX electronics works (some modification is needed)

• System EM Shock and Vibration test [2017 June]

• PHOENIX FM integration on EQUULEUS [2019 Oct.~]

• System environment test for FM [2019 Dec.~]

• Launch (by SLS) [2021 TBD]