NASA STORM mission: Overview and contributions from the Lyman Alpha Imaging Camera (LAICA)

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Abstract

This paper introduces the NASA's Solar-Terrestrial Observer for the Response of the Magnetosphere (STORM) mission, which was under a Phase-A study of the 2019 Heliophysics Medium-Class Explorer (MIDEX), Announcement of Opportunity, with the launch readiness date scheduled for July 1, 2026. The focuses are the general introduction of the STORM mission and the important roles played by the Lyman Alpha Imaging Camera (LAICA) in addressing primary science topics of the mission. Possible collaborations with in-situ and ground-based observations are also presented.

STORM was planned to image the near-Earth plasma environments, namely the dayside magnetosphere, the cusp, the near-Earth plasma sheet, the ring current, and aurorae to quantify their responses to the variations of the solar wind. Imaging with multi-wavelength and neutral atom measurements was expected on a ~30 Re circular orbit, comprehensively tracking the end-to-end circulation of energy throughout the solar wind-magnetosphere system. High inclination of the orbit (~90 deg.) enables the mission to image the magnetosphere from both the equatorial and polar regions. The imaging based on soft-X ray emissions, which originate from charge-exchange collisions of solar wind high-charge-state heavy ions (O^{6+}, O^{7+}) and cold neutral hydrogen (Geocorona), covers both northern and southern hemisphere to determine the location and motion of the entire dayside magnetopause. The far ultraviolet (FUV) imaging captures spatial and temporal variations of electron and proton aurora. The measurements of energetic neutral atoms (ENAs), which are the products of charge-exchange interactions between singly-charged ring current ions and Geocorona, determine the global distributions of the near-Earth plasma sheet and the ring current ions, and in turn ion pressure. Imaging by LAICA provides spatial distributions and temporal variations of the Geocorona density, which is required to extract the density of the solar wind from the soft-Xray imaging and the fluxes of ring current ions from the ENA imaging.

NASA STORM mission

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STORM (Solar-Terrestrial Observer for the Response of the Magnetosphere)

PI: David Sibeck (NASA/GSFC)

under Phase-A study of Heliophysics MIDEX; will be launched in summer 2026

Images the dayside magnetosphere and the ring current to quantify their response to solar wind drivers.

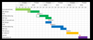
Comprehensively tracks the end-to-end circulation of energy throughout the solar wind-magnetosphere system.

Images Geocorona (exospheric hydrogen atmosphere) to determine spatio-temporal evolution of the Earth's exosphere.

Schedule

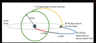
Sep. 2019, Submitted the proposal to MIDEX AO
Aug. 2020, Selected for Phase-A concept study
Jan. 2021, JAXA/ISAS WG approved

Jul. 2021, Submitted CSR (Concept Study Report)
Mar. 2022, Phase-B selection decision to be made
will be launched in Summer 2026

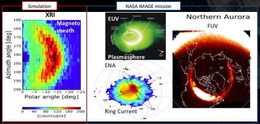


Comprehensive Imaging Studies for Geospace

- ✓ Solar wind monitor : in-situ obs. of solar wind plasma and IMF
- ✓ Soft X-ray images : magnetosheath, cusp
- ✓ ENA images : ring current, magnetotail
- ✓ FUV images : electron aurora, proton aurora
- ✓ All-sky imagers : Ground-based obs. over US and Canada
- ✓ **Lyman alpha images : geocorona**

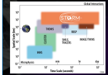


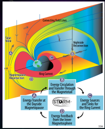
Images a broad area of the magnetosphere from both the equatorial and polar regions via multi-spectral and neutral atom imaging with in-situ monitoring of the solar wind and interplanetary magnetic field.



What is new?

- Image the entire magnetosphere
  - in a broad area, every few minutes
  - from the side (as well as polar)
- Soft-X ray imaging that covers both northern and southern cusps
- Continuous (>a few days) imaging and simultaneous solar wind monitoring
- Simultaneous Geocorona imaging





Primary Science Topics: Dynamics of Earth's Magnetosphere

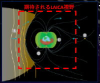
Energy transfer at the dayside magnetopause, and its response to solar wind variations

Energy circulation and transfer through the magnetotail
- From dayside through plasma sheet to inner magnetosphere, ionosphere

Energy sources and sinks for the ring current
- Magnetotail – inner magnetosphere coupling, Ring current ion loss

Energy feedback from the inner magnetosphere
- Contributions from ring current and plasmasphere to dayside reconnection

LAICA Contributions to STORM



Field of view (FOV): 64° x 64°
(equivalent to 37.5 x 37.5 (Re) @30 Re)
Spatial resolution: <1 Re

Time resolution of image: ~5min

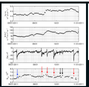
- Geocorona (Hydrogen geocorona) spatial distributions are required to extract ion density and flux.
  - Soft-Xray emissions are proportional to high charge-state heavy ion fluxes and neutral hydrogen density.
  - Fluxes of energetic neutral atoms (ENAs) are proportional to ion fluxes and neutral hydrogen density.
- Geocorona spatial distributions are asymmetric and dependent on solar wind activity.
  - LAICA can make a significant contribution to the main science topics to be addressed by STORM.

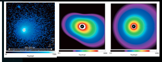
$O^{7+} + H \rightarrow O^{6+} + H^{+}$ (soft X-ray)
$H^{+} + H \rightarrow H^{*} + H^{+}$ (ENA)

LAICA Science: Spatial distributions and temporal variations of Geocorona

- Provides Geocorona density distributions, for the deconvolution of magnetosheath plasma density and ring current ion fluxes.

Dynamics of exospheric neutrals at exobase up to ~10 Re.
- Long-term variations of spatial distributions
- Seasonal dependence
- Solar activity dependence
- Short-time variations
  - Particularly, the response of these variations and dependence to solar wind and magnetospheric conditions.





左図：TWINS観測 (Bailey and Gruntman, 2013)　上図：Procyon/LAICA観測 (Kameda et al., 2017)

Science objectives and requirements related to exospheric neutrals

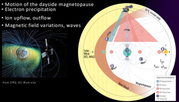
Mission topics and Science questions	Measurement requirements	Instrument requirements	Projected instrument performance
Spatial distributions of Geocorona at r < 10 Re ·What causes/determines north-south and dawn-dusk asymmetries? ·What determines the expansion or length of the exospheric tail (geotail)?	·Altitude profile of Geocorona density, with Δr < 2 Re, up to r = 8 Re ·Latitudinal profile of Geocorona density, with Δlat < 30° ·Longitudinal profile of Geocorona density, with ΔLT < 6h	·53°x 53° FOV ·1 Re resolution	·64° x 64°FOV ·0.23 Re/pix ·~1 cps/kR/pix ·122±10 nm bandwidth ·<5 min/frame
·How does Geocorona evolve during space storms? ·Where does the dominant evolution occur? What controls the evolution?	·Temporal variations of Geocorona density, ΔT < 1h ·Altitude profile of Geocorona density, with Δr < 2 Re, up to r = 6 Re ·Latitudinal profile of Geocorona density, with Δlat < 45° ·Longitudinal profile of Geocorona density, with ΔLT < 1h	·53°x 53°FOV ·1 Re resolution ·1 hr resolution	

Collaboration: In-situ and ground-based observations

Collaborations/Coordinations with in-situ measurements and ground-based observatiories/networks are expected.

In-situ measurements (by Arase, MMS, GOES, etc.)
Capture local phenomena and solar wind response
- Electron precipitation into the ionosphere
- Variations of plasma sheet and ring current plasma
- Configuration of the magnetic and electric fields
- Plasma waves (magnetic and electric fields)

Ground-based obs. (EISCAT, SuperDARN, Aurora, Geomagnetic field, etc.)
Simultaneously image global phenomena mainly at high latitudes
- Motion of the dayside magnetopause
- Electron precipitation
- Ion upflow, outflow
- Magnetic field variations, waves



from ERG-SC Web site

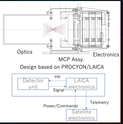
Design & Block Diagram

Refractive Optics for Hydrogen Lyman Alpha emission line (121.6 nm)
- A singlet spherical lens and a bandpass filter (Δλ~20 nm)

5-stage micro-channel plates assembly
- Vacuum sealed, CsI Photocathode (solar (visible) blind), Resistive anode encoder

Electronics (Readout, HV (5 kV), Storage (1 GB), Communication (RS422))

Specification
- Focal length: 16 mm (D2mm, F#8)
- FoV: 64 deg x 64 deg (37.5 Re x 37.5 Re @ 30 Re)
- iFoV: ~0.5 deg/pix (~0.26 Re/pix)
- Bandwidth: 122 ± 5 nm
- Sensitivity: ~0.23 cps/kR (/pix)



MASS, Power, Telemetry, and Data rate

Mass
- 2.5 kg (3 kg Max) (PROCYON/LAICA 2.145 kg)
- To be confirmed
  - Space qualified Electronical parts (+)
  - Smaller optics (-)

Power
- 3 W (Max 5W) (PROCYON/LAICA 2.8 W)
- To be confirmed
  - DC/DC efficiency (+)

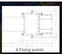
Telemetry and Data rate
- Data size: 32 kB/frame,
- Exposure (interval): 5 min -> 9 MB/day (Max)

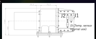
for typical storms,
- Main Phase (~1 day) : 1 image/hour (768 kB/day)
- Recovery phase (~3 days): 1 image/3 hours (256 kB/day)

The total data budget for 4 days is 1536 kB.

Interfaces and Accommodation

- Dimension
  H130mm × W160mm × D300mm
- Temperature
  -30 to 50 degC (Operation)
  -30 to 60 degC (Storage)
- Thermal dissipation: 3W (5W max)
- 2 Connectors for E. I/F
  J1 Dsub15 for Power and Temp
  J2 Dsub9 for RS422

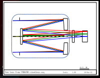




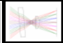
Contamination requirement

GN2 purge:
- Whether GN2 purge is necessary or not is still to be discussed.
- No GN2 purge in PROCYON/LAICA and no degradation was confirmed (within error) but note that LAICA was installed to S/C just 4 month before launch.
- The weakest in PROCYON/LAICA is UV mirror but we don't have a mirror but a MgF2 lens (w/o coating) in STORM/LAICA.
- Even if GN2 purge is necessary for long term storage, 4 month without purging would be acceptable.

Heritage and TRL Assessment, Plan to TRL 6



PROCYON/LAICA optics (telescope)



STORM/LAICA optics (1 spherical lens + filter)

Focal length of PROCYON/LAICA: 400 mm
STORM/LAICA: 30 mm

HERITAGE: PROCYON/LAICA, BepiColombo/PHEBUS
- TRL 9 ("flight proven through successful mission operations" in PROCYON/LAICA) but with commercial electronical parts. These should be changed to space-qualified ones for STORM/LAICA, utilizing heritage of BepiColombo/PHEBUS with the same type detector (TRL 9).
- Above is except for optics. STORM/LAICA optics' focal length is 16 mm, shorter than LAICA's. No new technology development is necessary. Prototype of optics will (can) be manufactured and tested in (or before) Phase A to TRL6.