Lunar Observatories and Solar Wind-Magnetosphere Interactions

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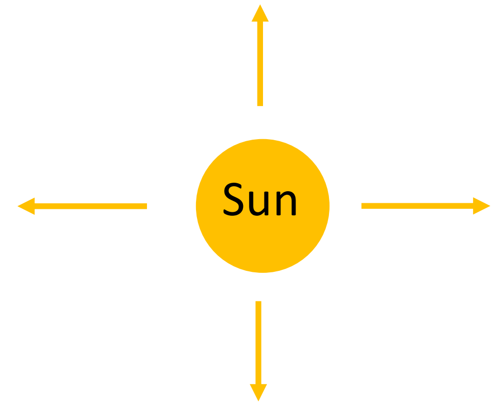
BOSTON UNIVERSITY

A journey of energy

- Not to scale -

A journey of energy



In our solar system (and at Earth) the bulk of the energy comes from the sun

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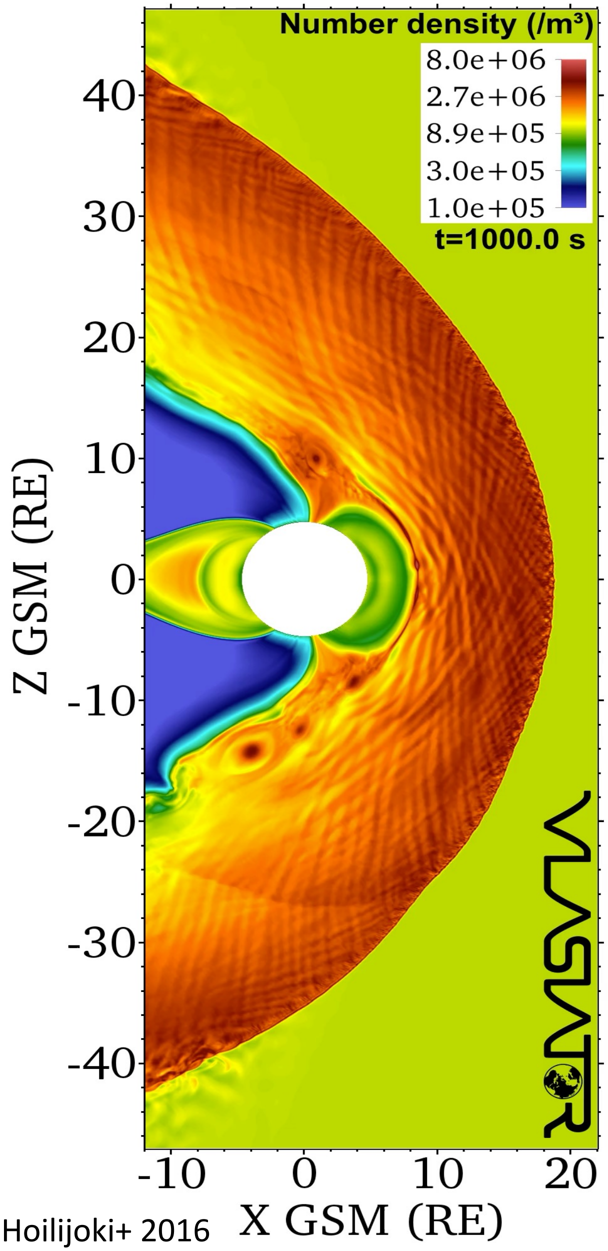
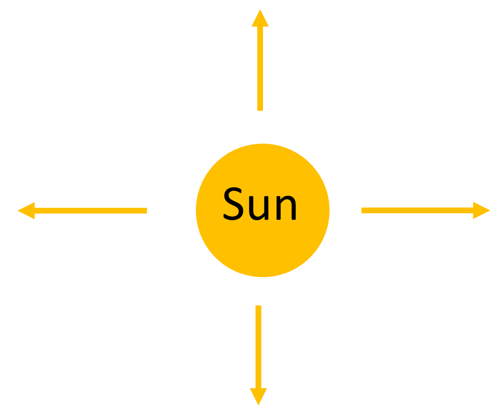


Hoilijoki+ 2016



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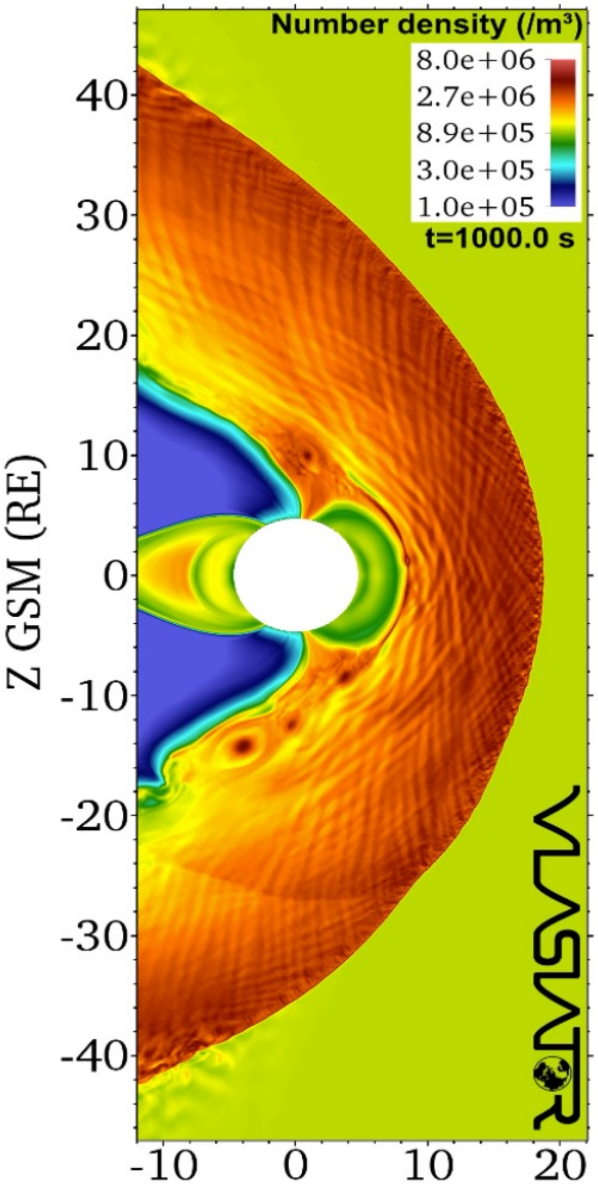

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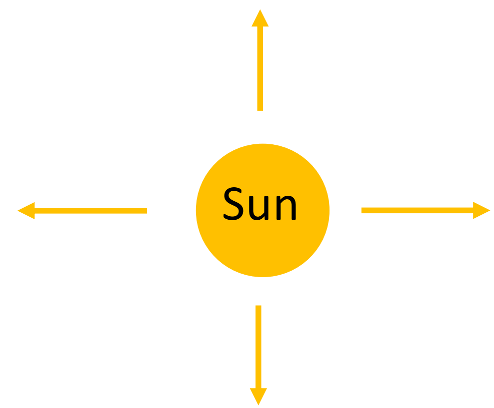
Energy transfer from solar wind can vary from <1% to ~15% without appreciable change in the solar wind *[Palmroth+ 2003; Ala-Lahti 2022]*



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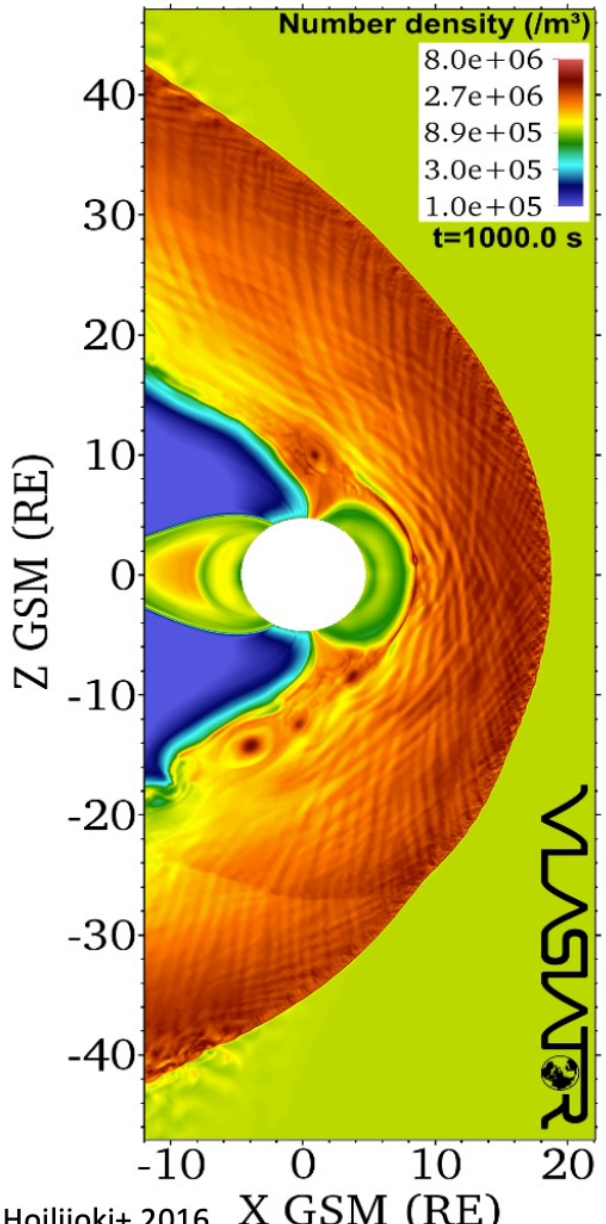

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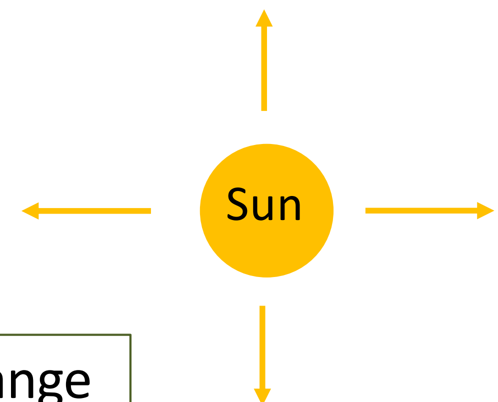
- How does energy transfer change with time?
- What are the macro-scale properties of reconnection?
- How does Earth's magnetosphere saturate with strong driving?



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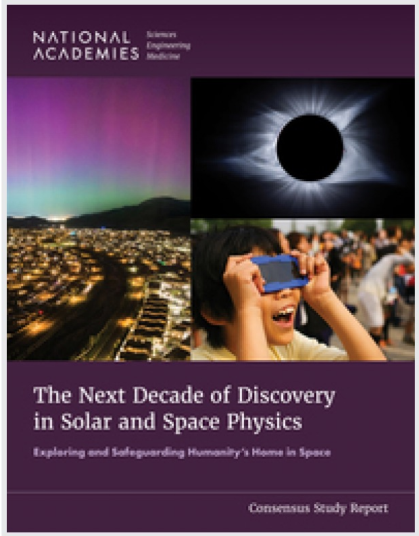
NASA and Decadal Survey Objectives

The Next Decade of Discovery in Solar and Space Physics - 2024

Priority Science Goal (**PSG-1**): How is the solar wind energy input to the magnetosphere transmitted between different regions and across different scales?

Priority Science Goal (**PSG-4**): What Are the 3D Global Properties of Turbulence, Magnetic Reconnection, and Shocks, and What Is Their Role in Coupling Energy in the Magnetosphere?

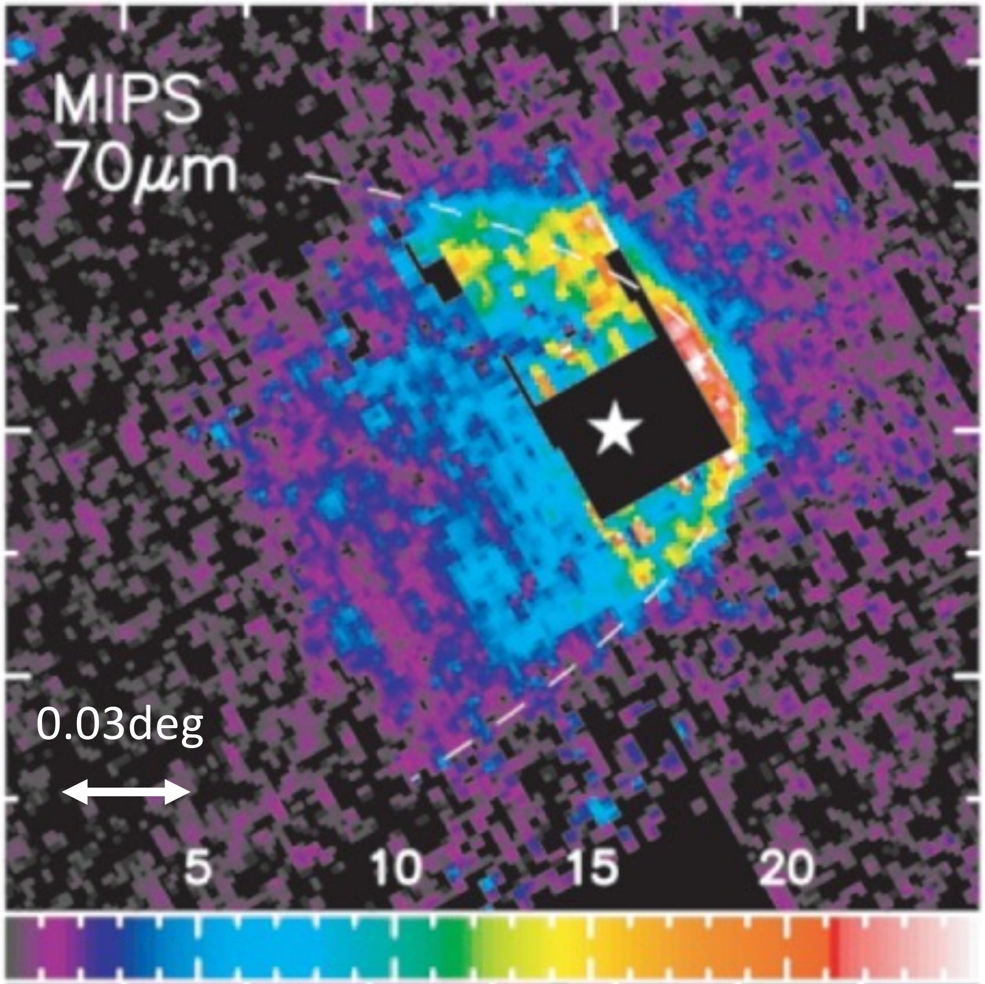


NASA's Moon to Mars Objectives - 2022

HS-3: Investigate and characterize fundamental plasma processes, including dusk-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.

PPS-2: Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

Imaging from outside Earth's magnetosphere: X-ray, ENA



20,578s (5.5 hrs) of integration

Bow Shock, R Hya *Ueta+ 2006*

Spitzer Space Telescope

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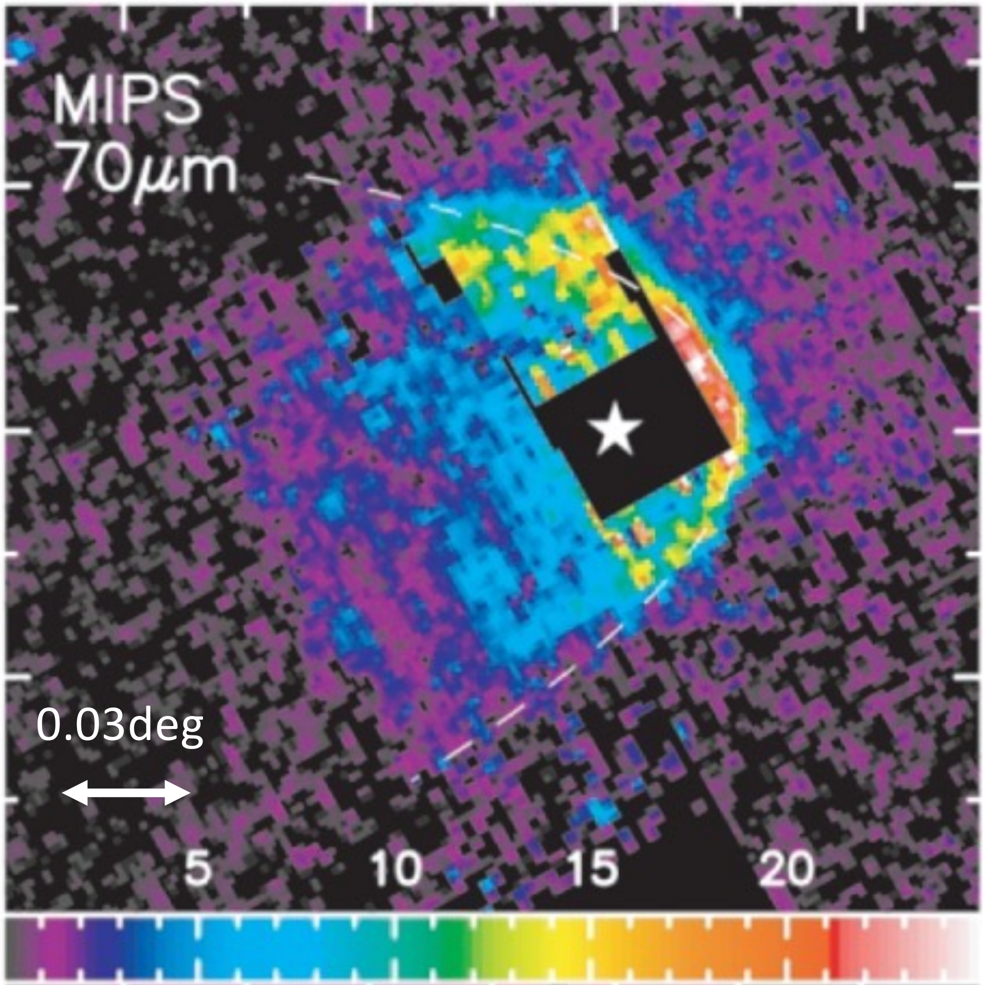

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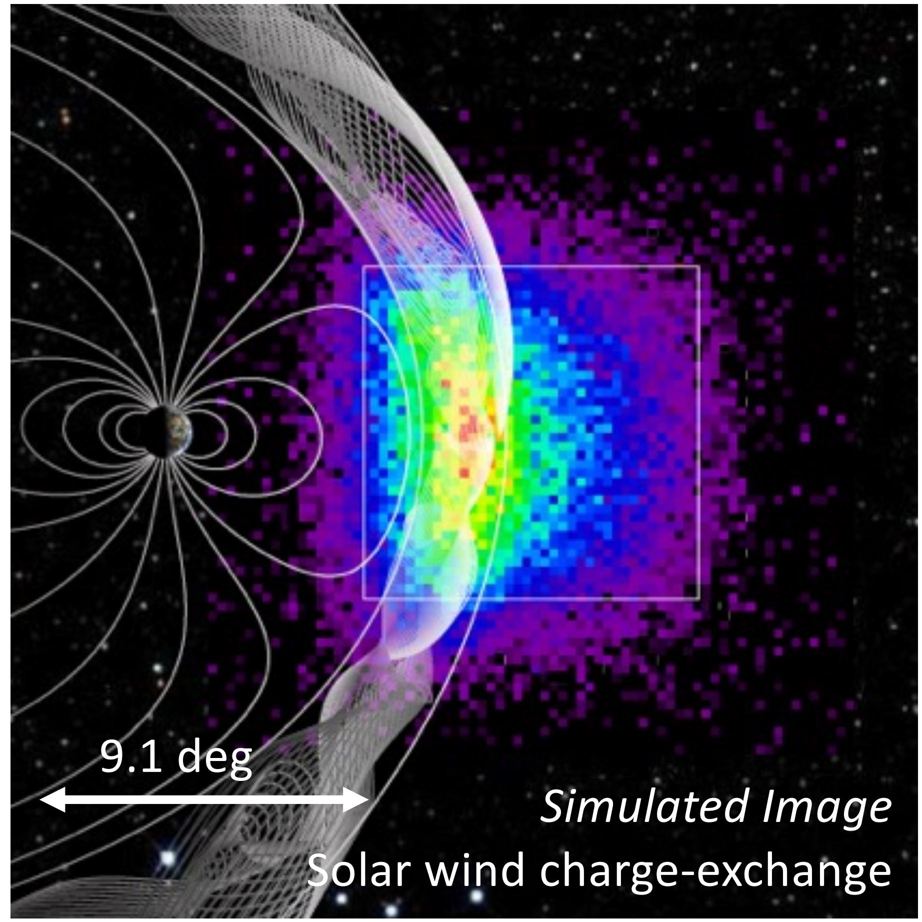
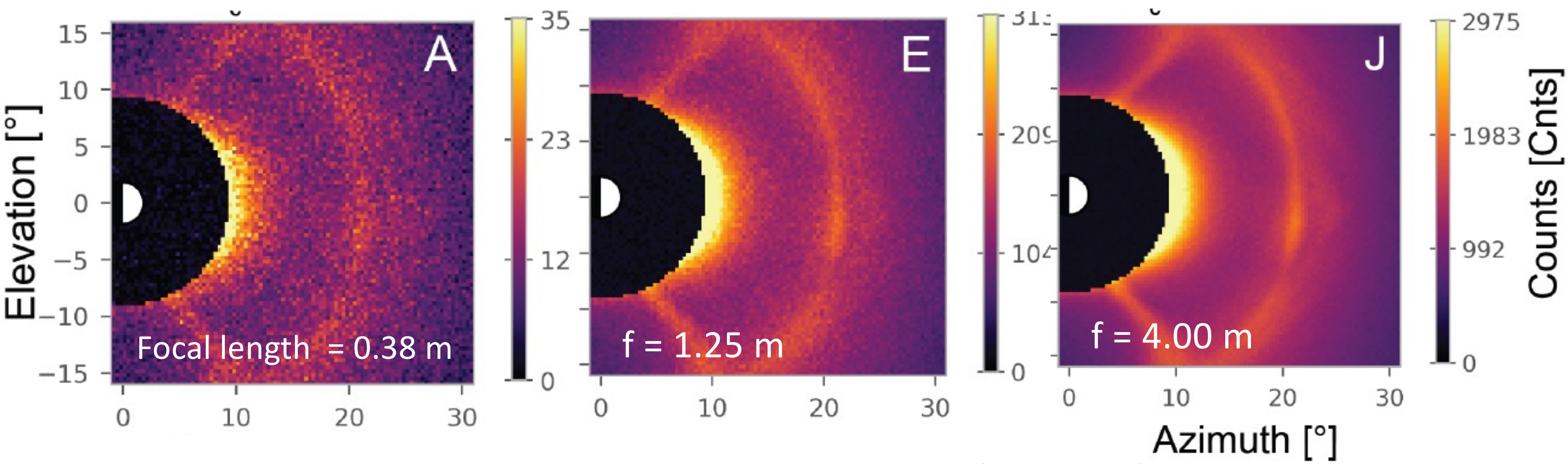


300 s (5 min) of integration

Magnetopause, Bow Shock, Earth

Imaging from outside Earth’s magnetosphere: X-ray, ENA

Soft X-ray photons from solar wind charge-exchange (Atz et al., Submitted)



Simulations: 60s integration – observer 35 R_E away from Earth (0.1 – 3keV)

Soft X-rays for magnetospheric imaging

[Walsh+2016; Sibeck+ 2018; Kuntz+2019; Sun+2021; Connor+2021; Guo+ 2022; Ng+2023; Wang+2023; Jorgensen+ 2022; Zhang+2023; Xu+2024; Grandin+2024; Ishi+ 2024; Cucho-Padin+ 2024; Kim+2024]

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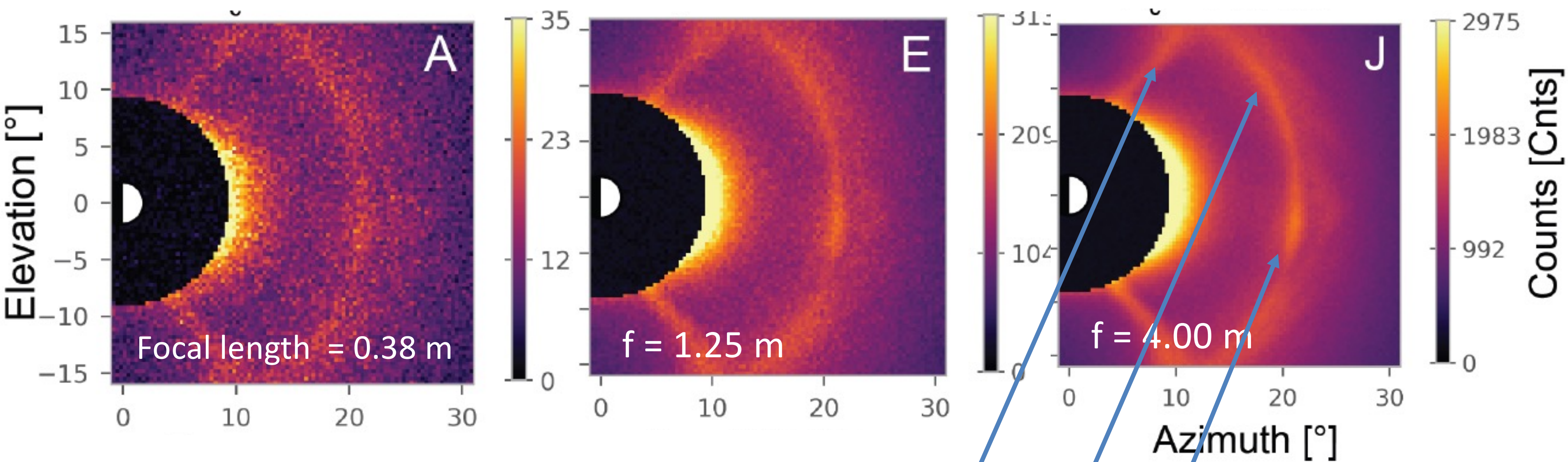

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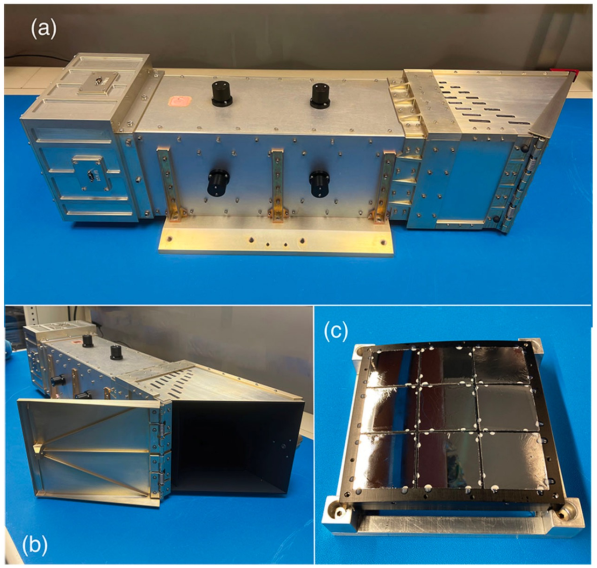
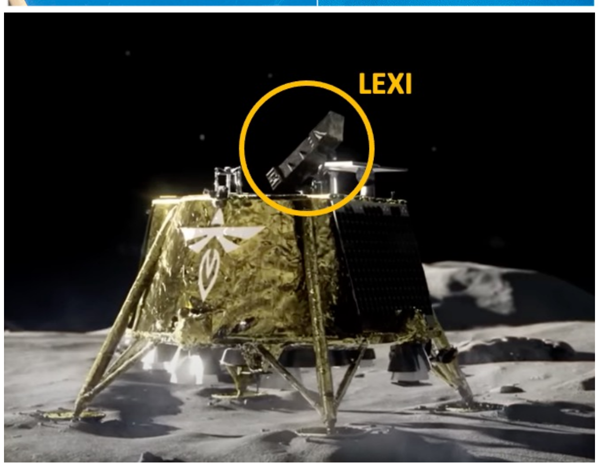
Flux transfer event dynamics

Magnetopause position and motion

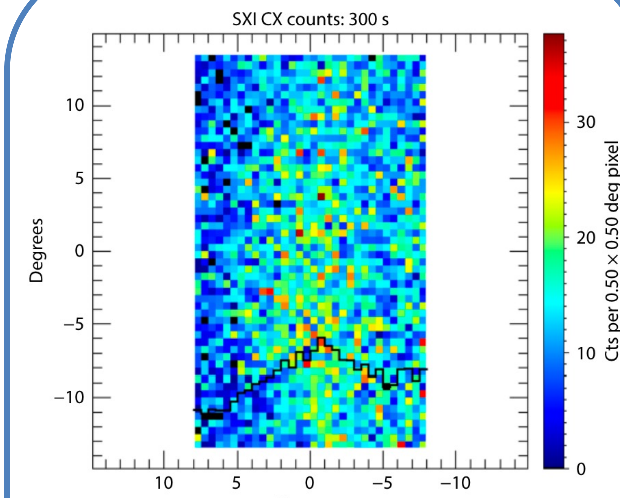
Cusp position and motion

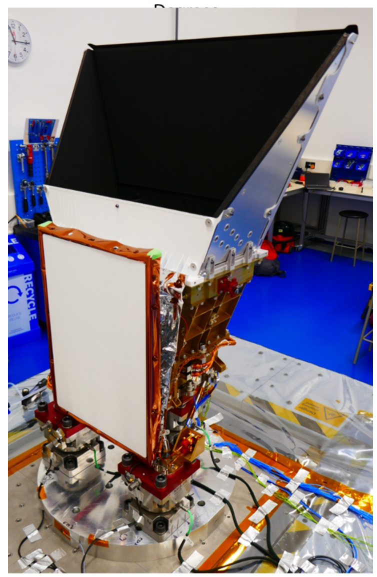
High maturity technology



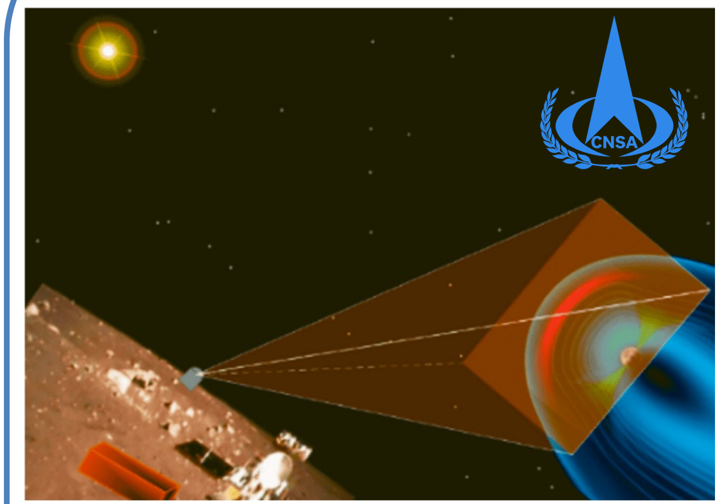


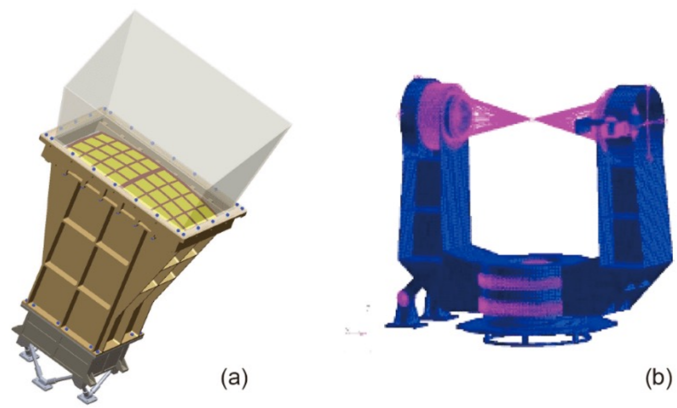
LEXI [Walsh+2024]
(Launch 2025)





SXI-SMILE [Sembay+2023]
(Launch 2026)



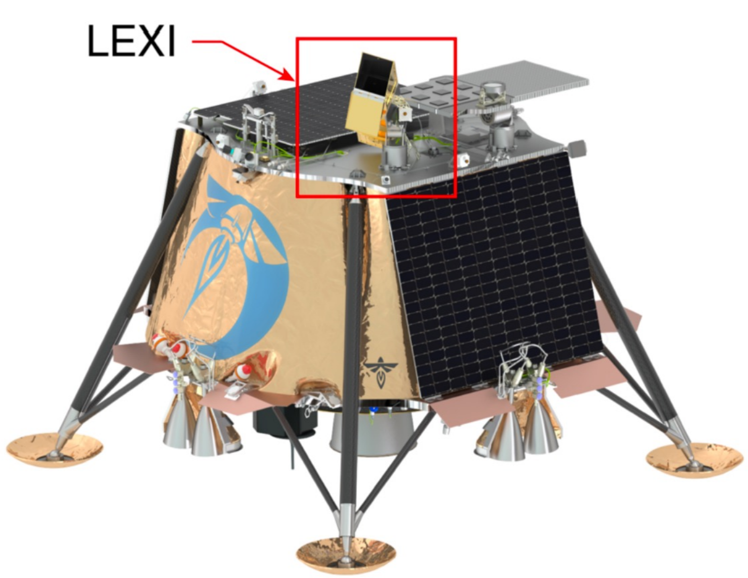


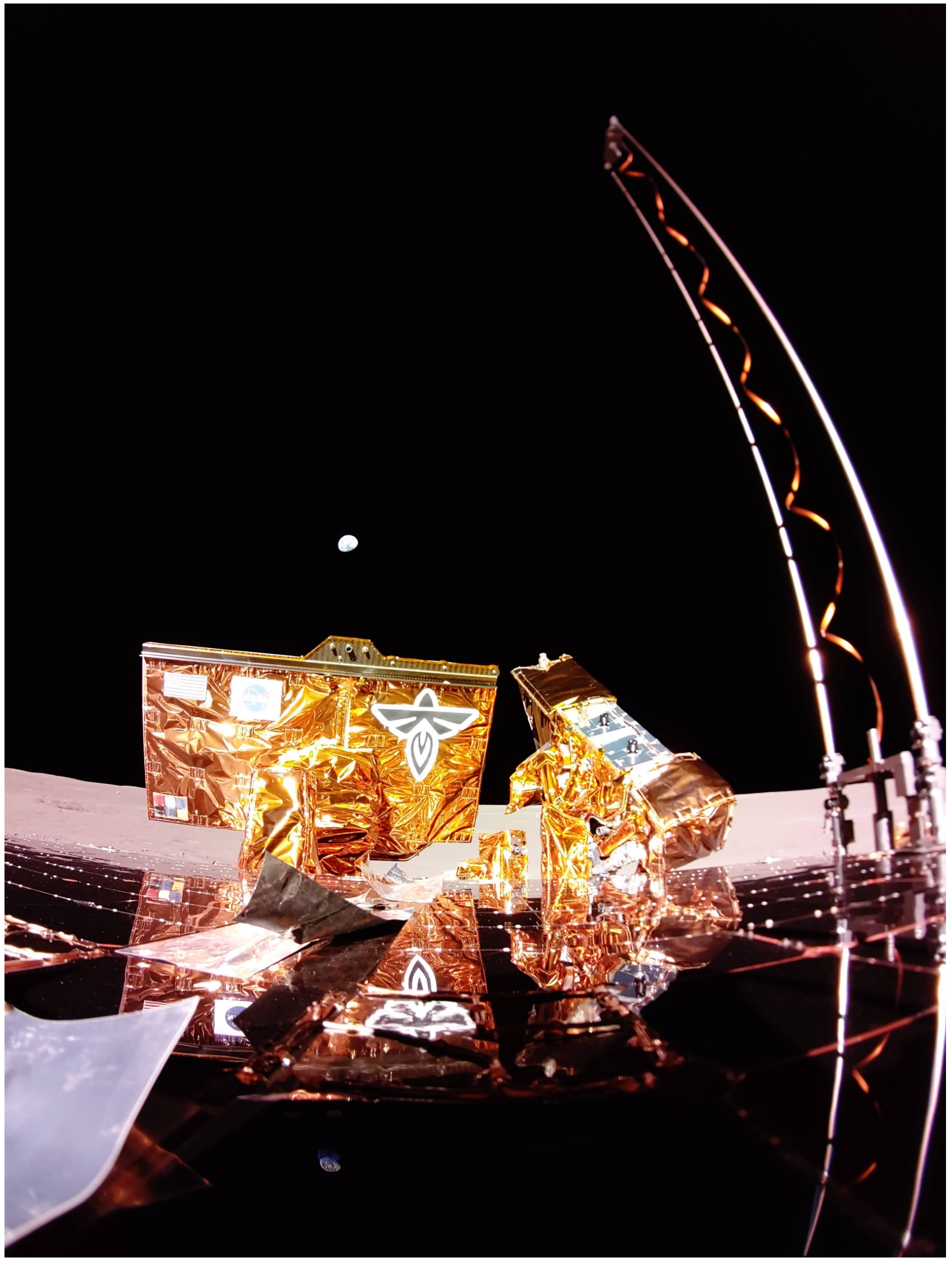
LSXI – Chang’e 8 [Guo+ 2021]
(Launch 2029)

Preliminary LEXI results

Lunar Environment heliospheric X-ray Imager (LEXI)

- 9x9deg FOV, Micropore optics
- 0.1 – 2keV
- Monitor solar wind charge-exchange
- Operations: 2-16 March 2025





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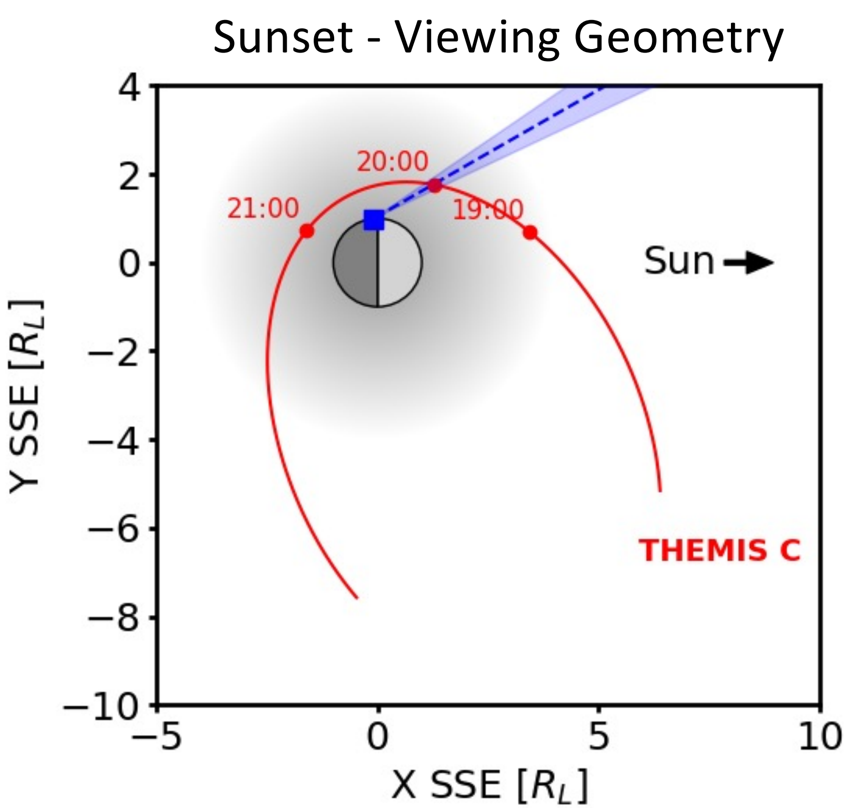
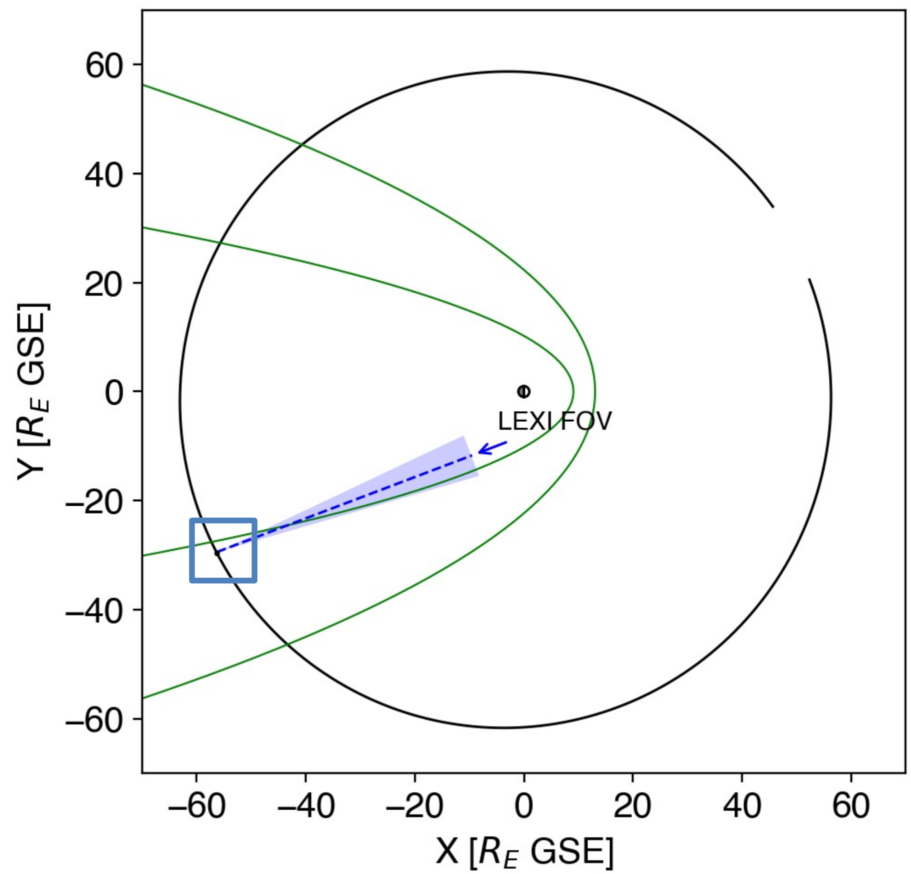
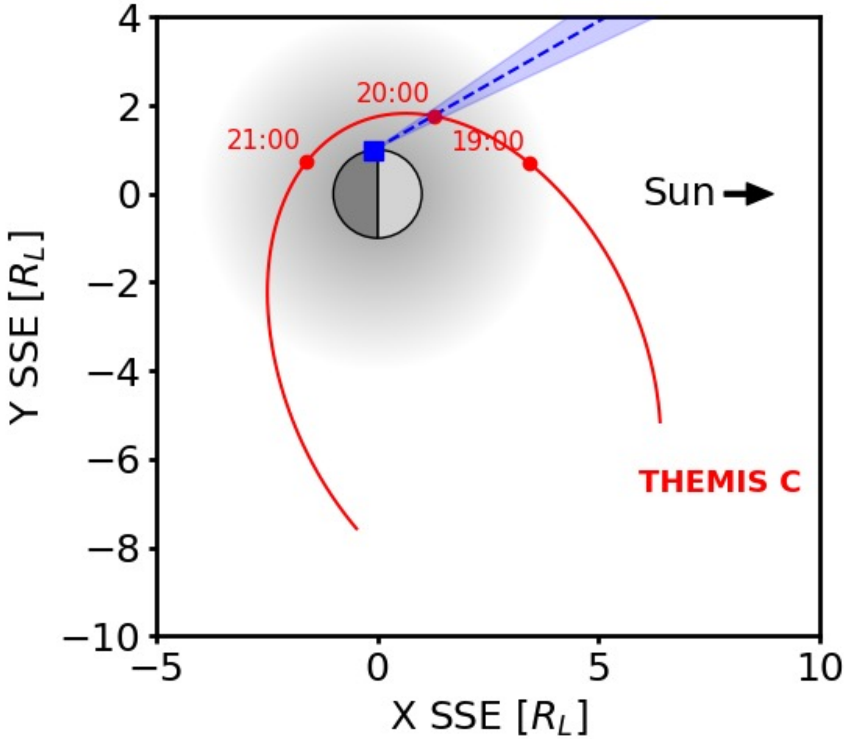


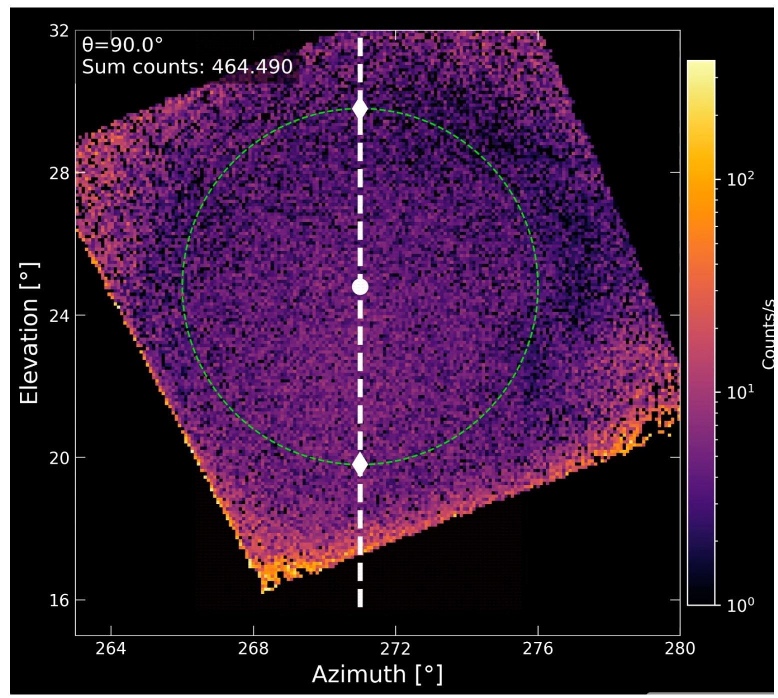


Preliminary LEXI results

Sunset - Viewing Geometry



X-ray Imaging



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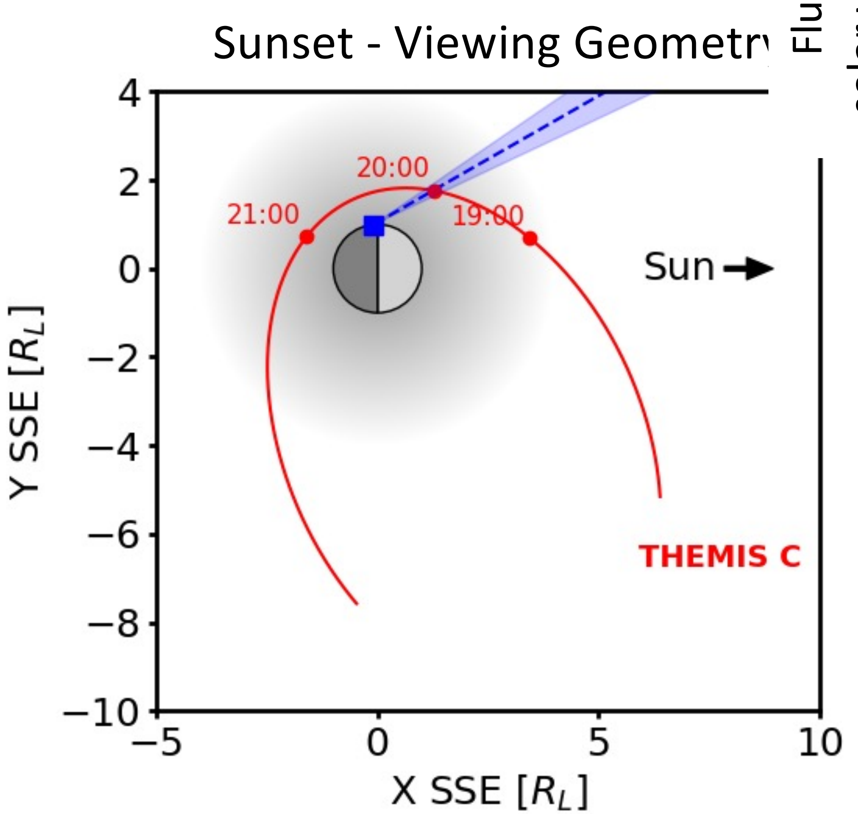

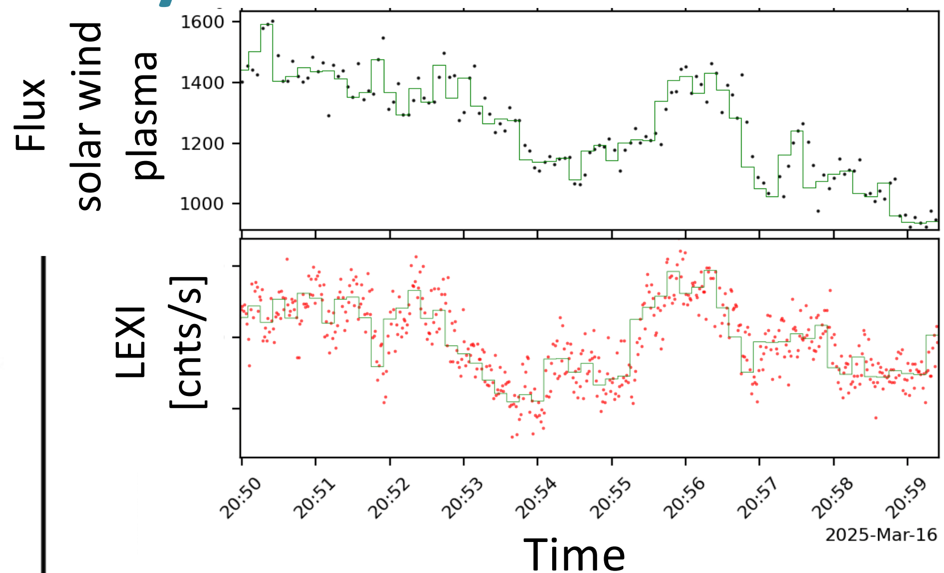

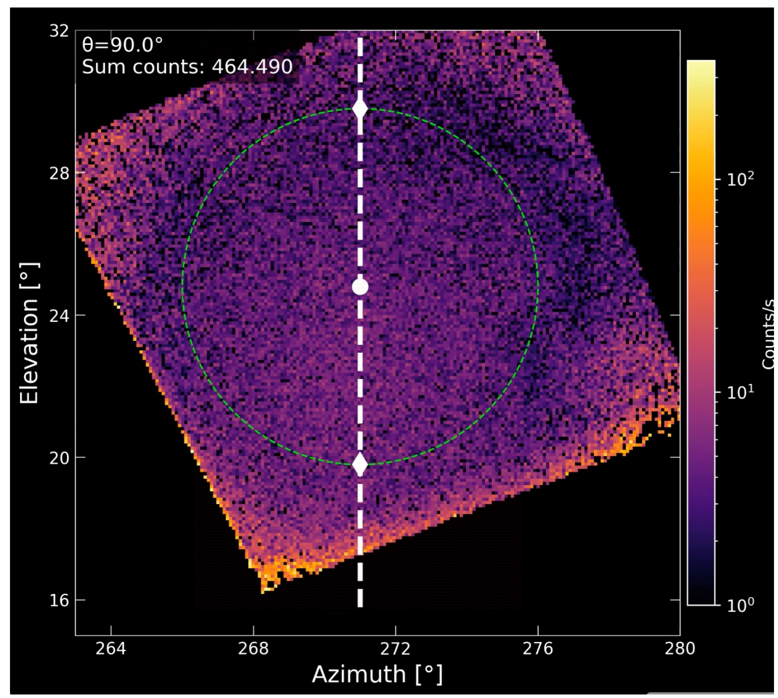

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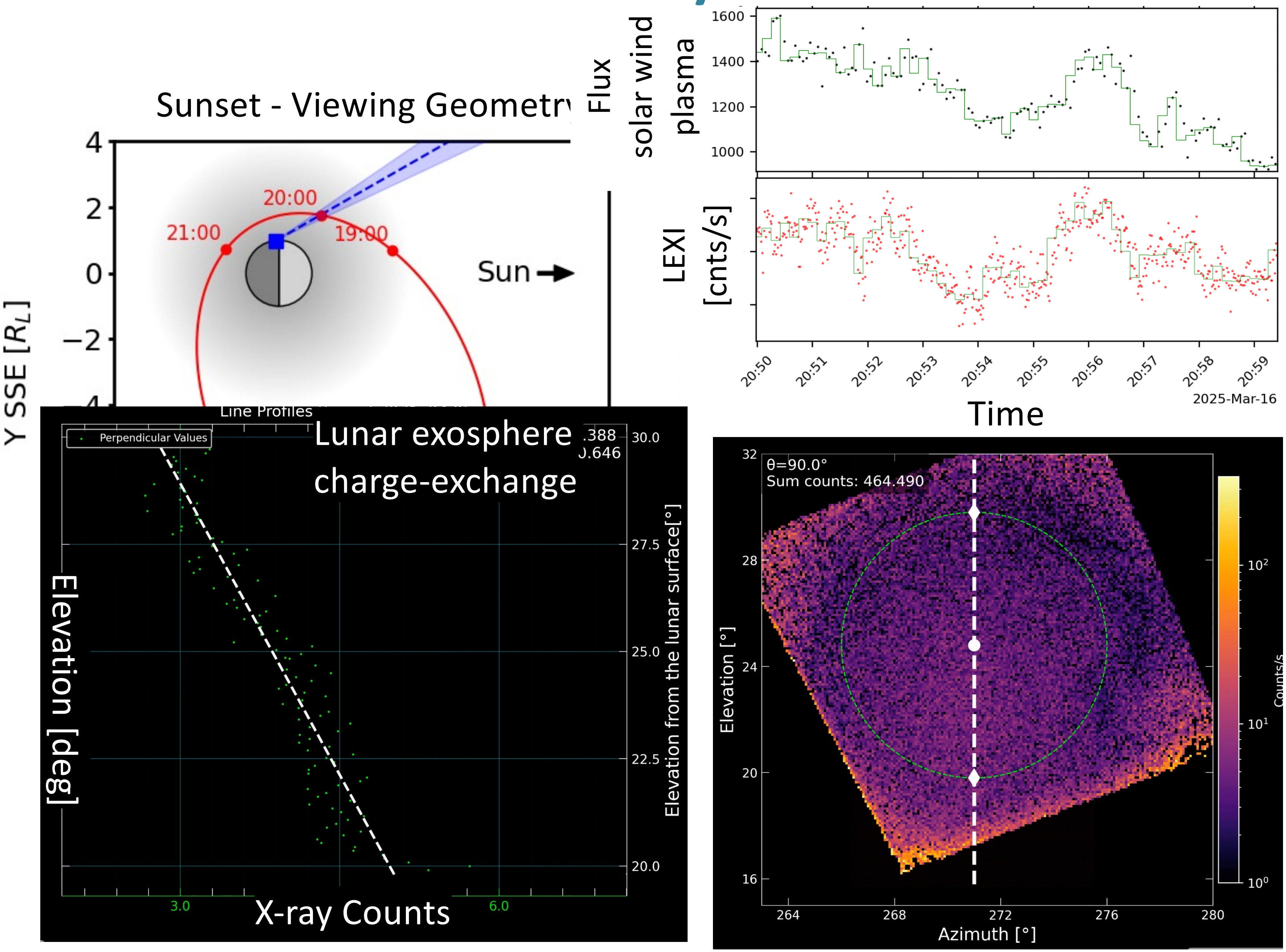
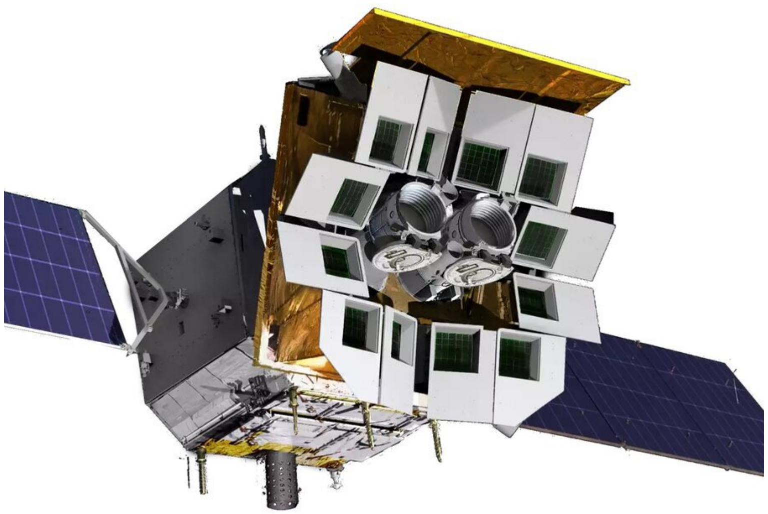


Opportunity for Cross-Disciplinary Discovery: *Lunar-Based Observatories*

Lunar X-ray Station



Einstein Probe – Jan 2024. Combination of Wide-field X-ray Telescope (WXT) 60x60deg, and the Follow-up X-ray Telescope (FXT) ~6arcmin [0.5–4.0 keV]

Not configured to do heliophysics pointing

Lunar Opportunity

Wide FOV: 40x40deg (Micropore optics)
Narrow FOV: 6arcmin (Wolter optics)
Pointing stage, near-side operations, lunar equatorial (+/- ~60deg)

Science:

Heliophysics: Magnetopause/cusp imaging

Astrophysics: X-ray transient survey and follow-up. Electromagnetic counterpart of events triggering gravitational waves such as merging neutron stars

Technology Development:
3-6 month lunar operational periods

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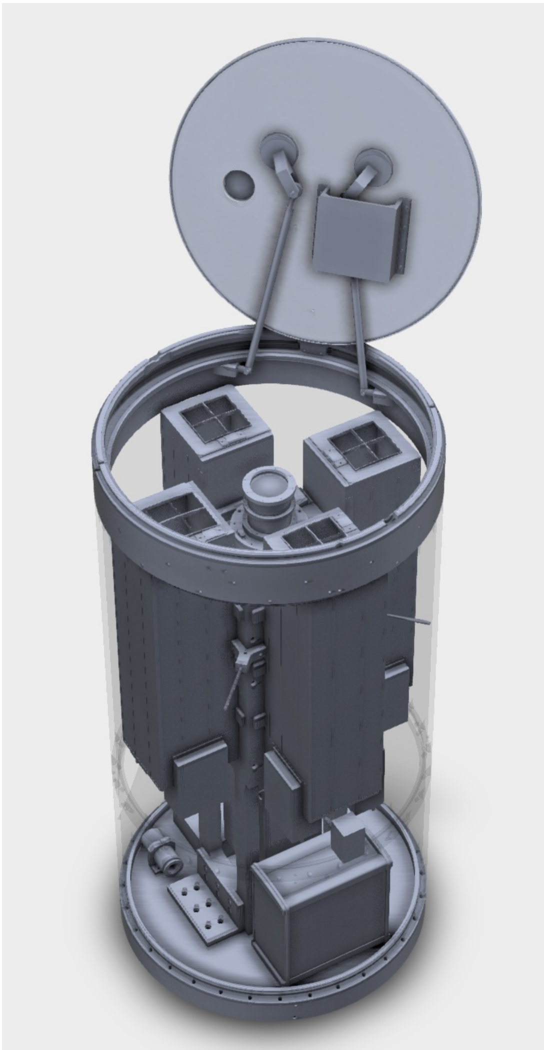

LXT Sounding rocket APRA:
[Courtesy of M. Galeazzi]

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Summary

1. Opportunity for system-level discovery of Earth's plasma physics and solar wind-magnetosphere coupling
   – With current optics, x-ray imaging can occur with 0.2RE spatial resolution and 60s time resolution from the moon.
   – The moon offers large land-mass. This could support large telescopes built "module by module" in multiple flights or landings
2. Opportunity for macro-scale imaging with local in-situ physics (Solar Space Physics 2024 Decadal – STP-Links concept for a fraction of the cost)
3. Opportunity for cross-disciplinary high-impact science (astro/helio/planetary) through a lunar X-ray observatory
   – Opportunity for international collaboration

Technical and Considerations I

How can this science be accomplished on the Moon? Are there particular advantages to a non-polar lunar site?

- For x-ray instruments or those impacted by lunar exospheric emission, non-polar means less column to view through

What measurements are needed to accomplish the objective?

- Wide FOV (~10deg) X-ray sensing
- Potential follow-up – high spatial resolution telescope

Does this science require a specific site, multiple sites, or can it be done anywhere on the lunar surface?

- Near-side is necessary for imaging of geospace
- Longitudes near (+/- ~45deg) 0 deg longitude so the imager doesn't need to look through large cords of the exosphere

What will the site, or site type, need to ensure that the science objective can be accomplished (e.g. radio quiet, geological properties, other)?

- Dark environment. No glint or reflections from astronauts or other experiments

Technical and Considerations II

Is there a pathfinder to advance the scientific objective?

- Experiment to test modular telescopes being combined for coaligned measurements
- System is highly sensitive to charged particle background. Enhancement of particle rejection systems for the electrostatic trapping layer on the lunar surface
- A pathfinder should include complimentary science payloads to allow for human teaming to begin for future projects as well. In the past several CLPS landers the teams have had diverse and sometimes unconnected science objectives

How does a human onsite enable or improve the quality of the measurement(s)? (e.g., Judgement? Reaction? Adaptability?)

- Humans could support in-situ assembly of modular telescopes. Could be shipped to lunar surface in parts.
- Alignment is often a large task on the ground prior to launch. If the telescope would be installed by astronauts on the moon, some Earth-based alignment could be replaced with alignment by astronauts on the moon.

Are new capabilities and/or pre-placed assets necessary to ensure the human can do the measurement or collect the sample? If so, what?

- There is need for an observing platform that can last longer than 14 days.
- Total data volume is manageable with current communication systems (X-Band)