Mapping the Magnetosphere with Energetic Atoms

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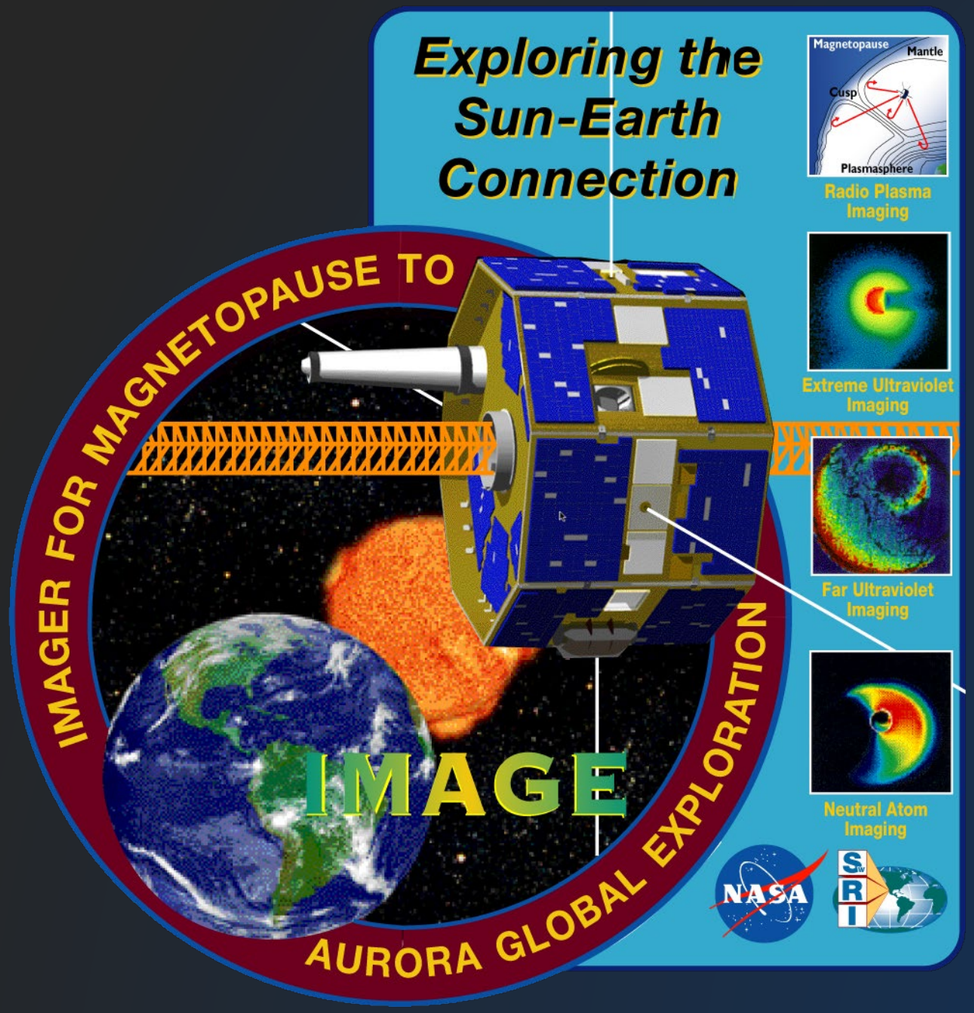

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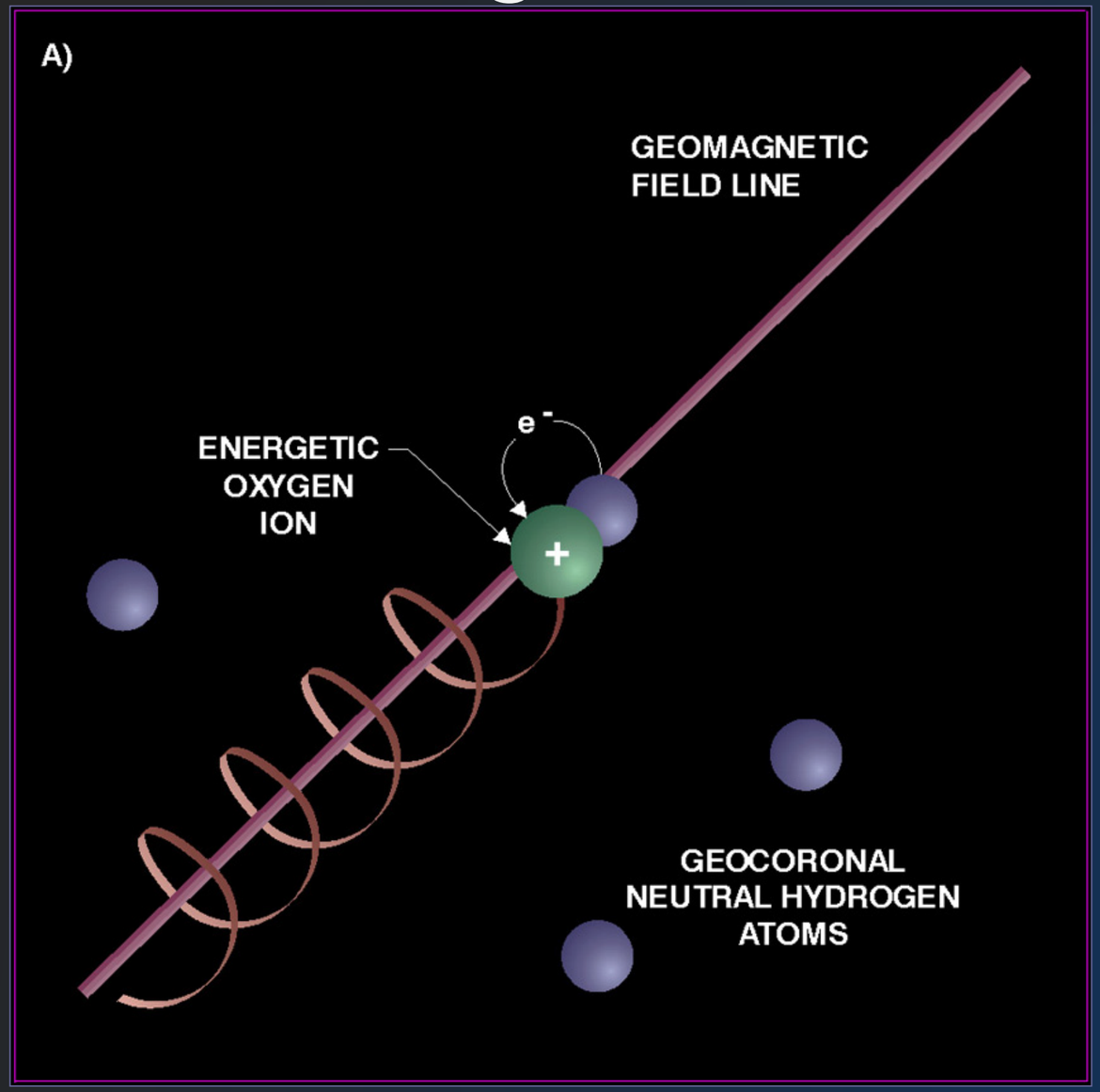
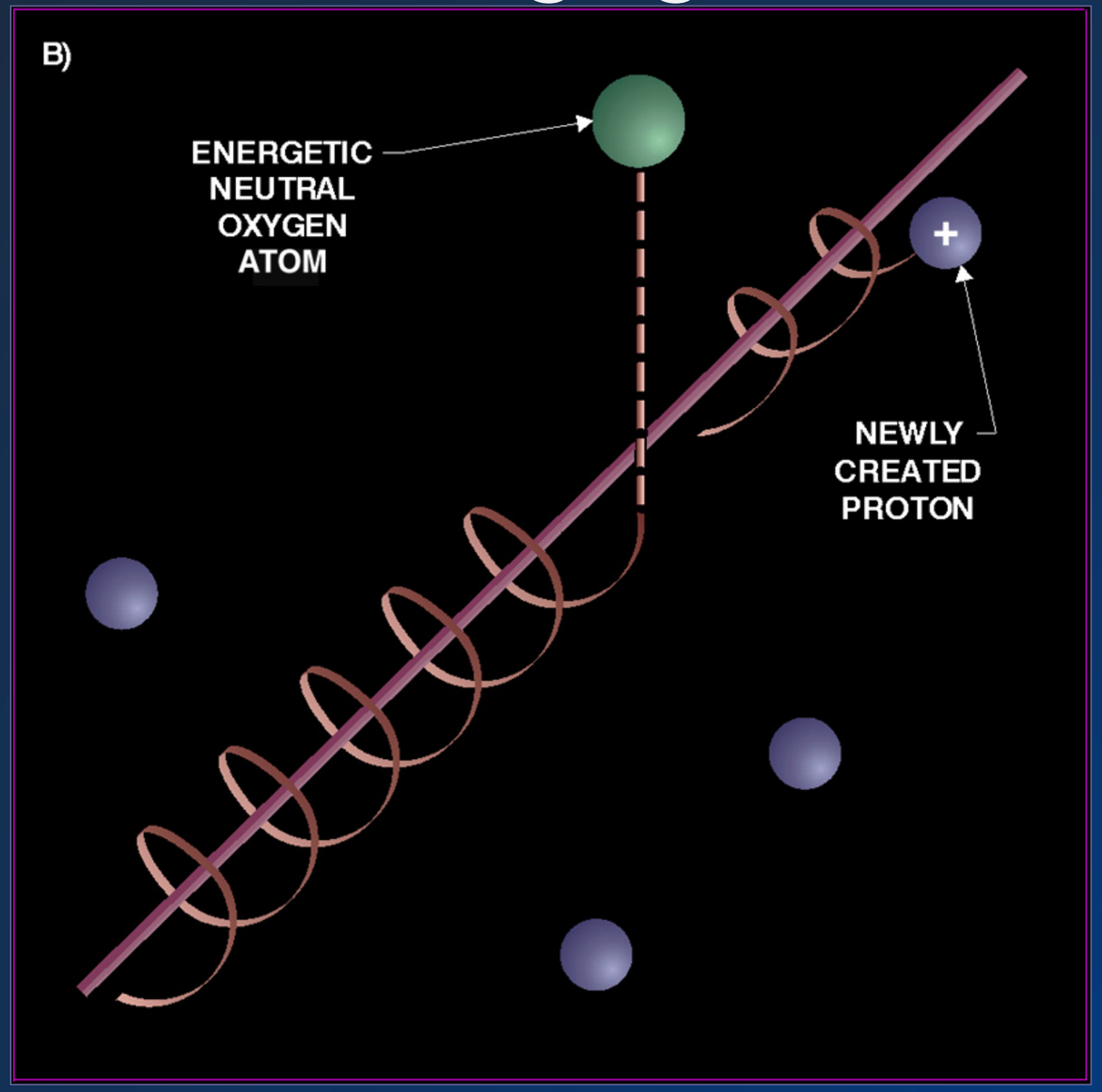
What is Energetic Neutral Atom (ENA) Imaging?





ENA imaging takes advantage of charge-exchange collisions

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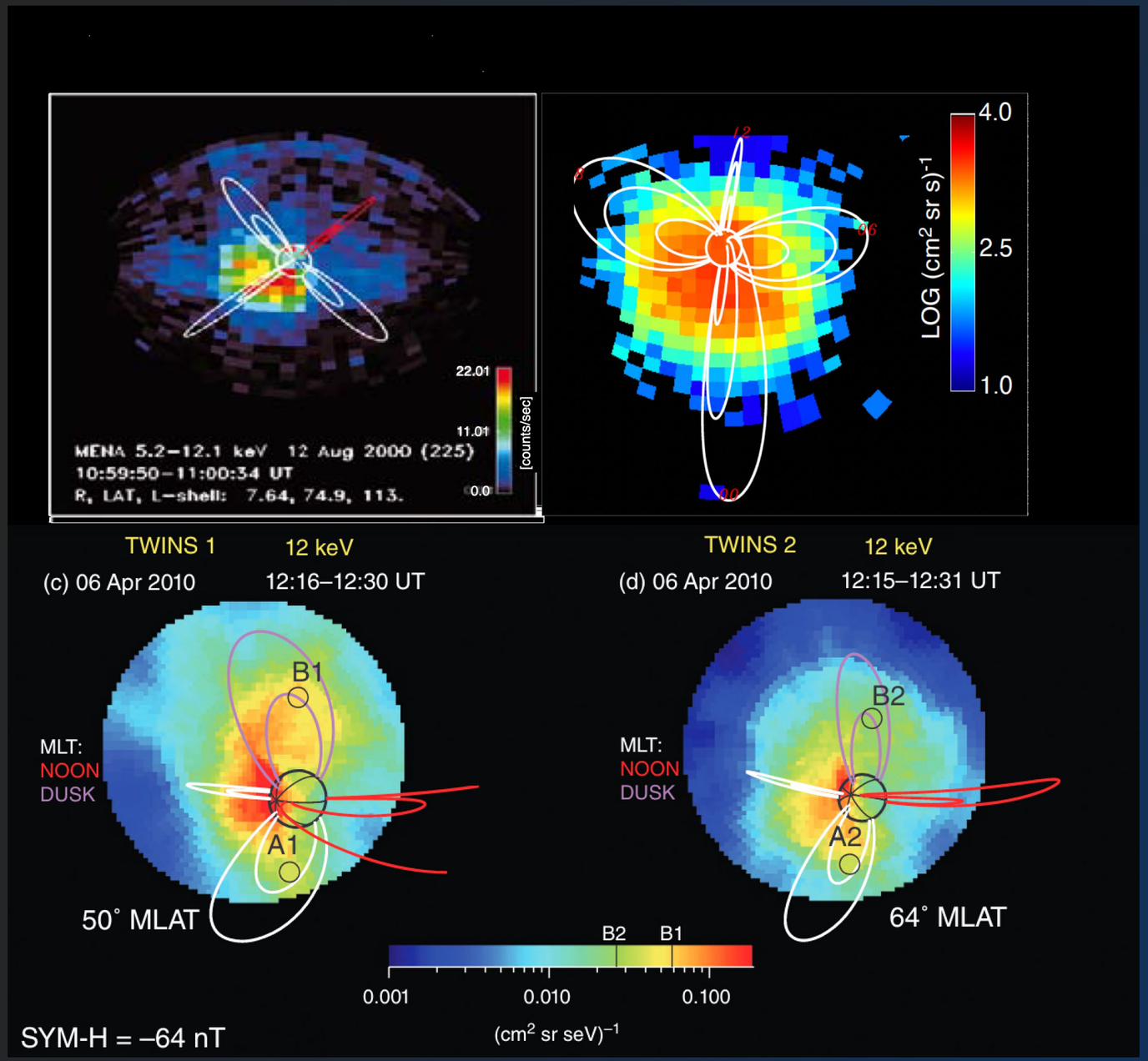
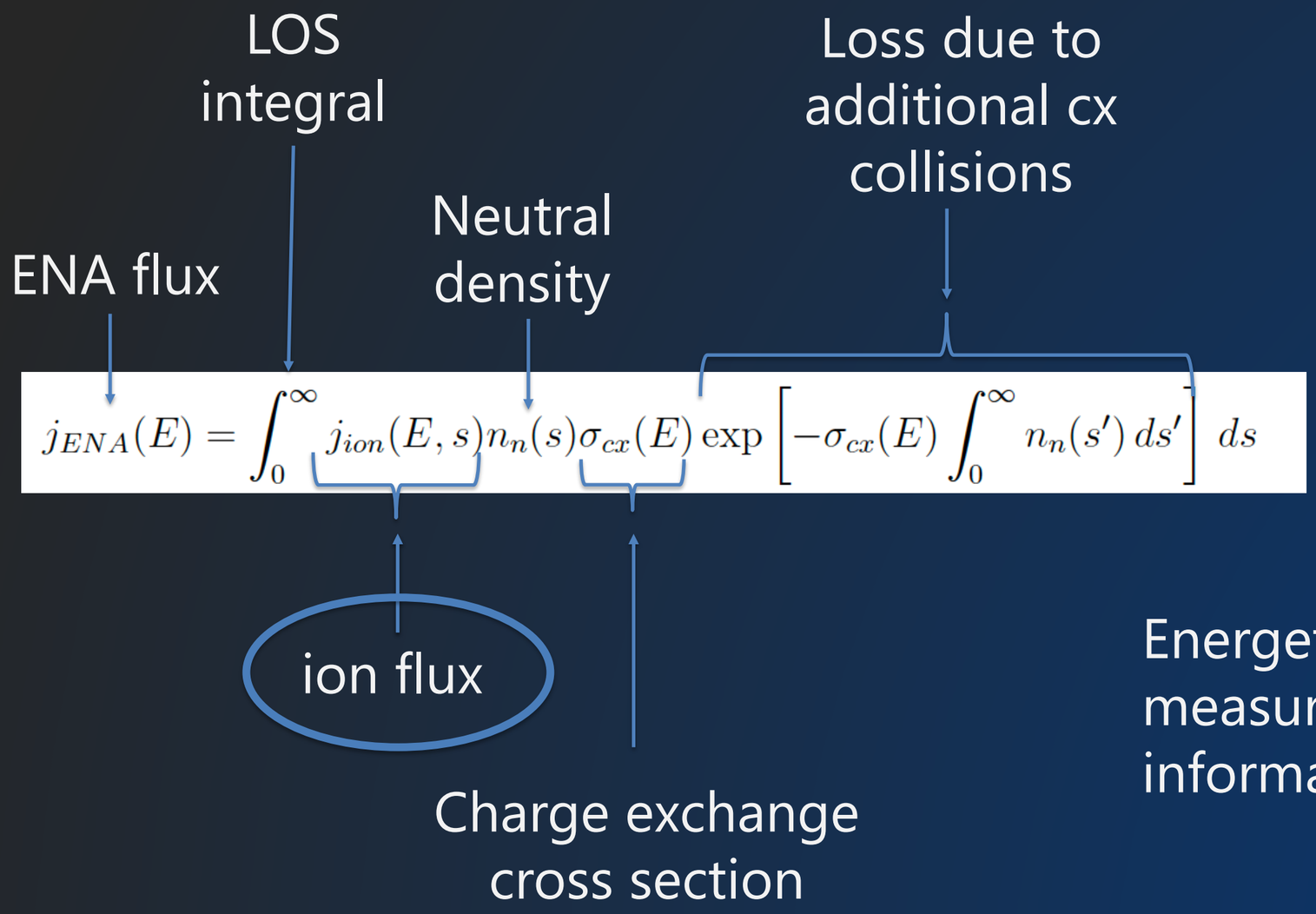
What are the benefits of ENA Imaging?



Energetic neutral atom (ENA) imaging is a remote measurement that can provide a global view of the ions in the magnetosphere

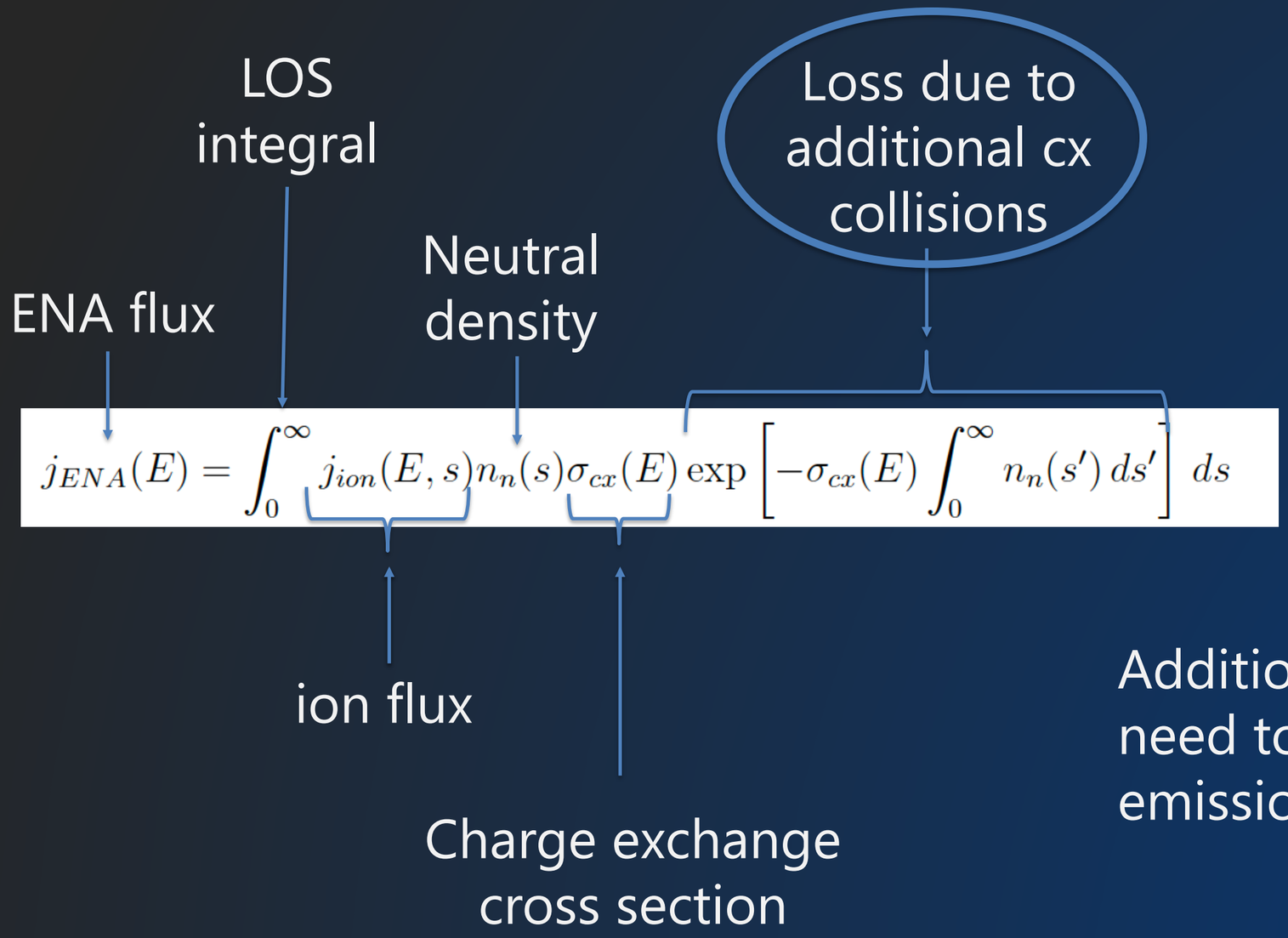
Skymap images of ENA flux from MENA (upper left) (Fok et al, 2003), HENA (upper right) (Brandt et al, 2002), and both TWINS (bottom) (Maggiolo et al, 2021)

What do ENA instruments measure?



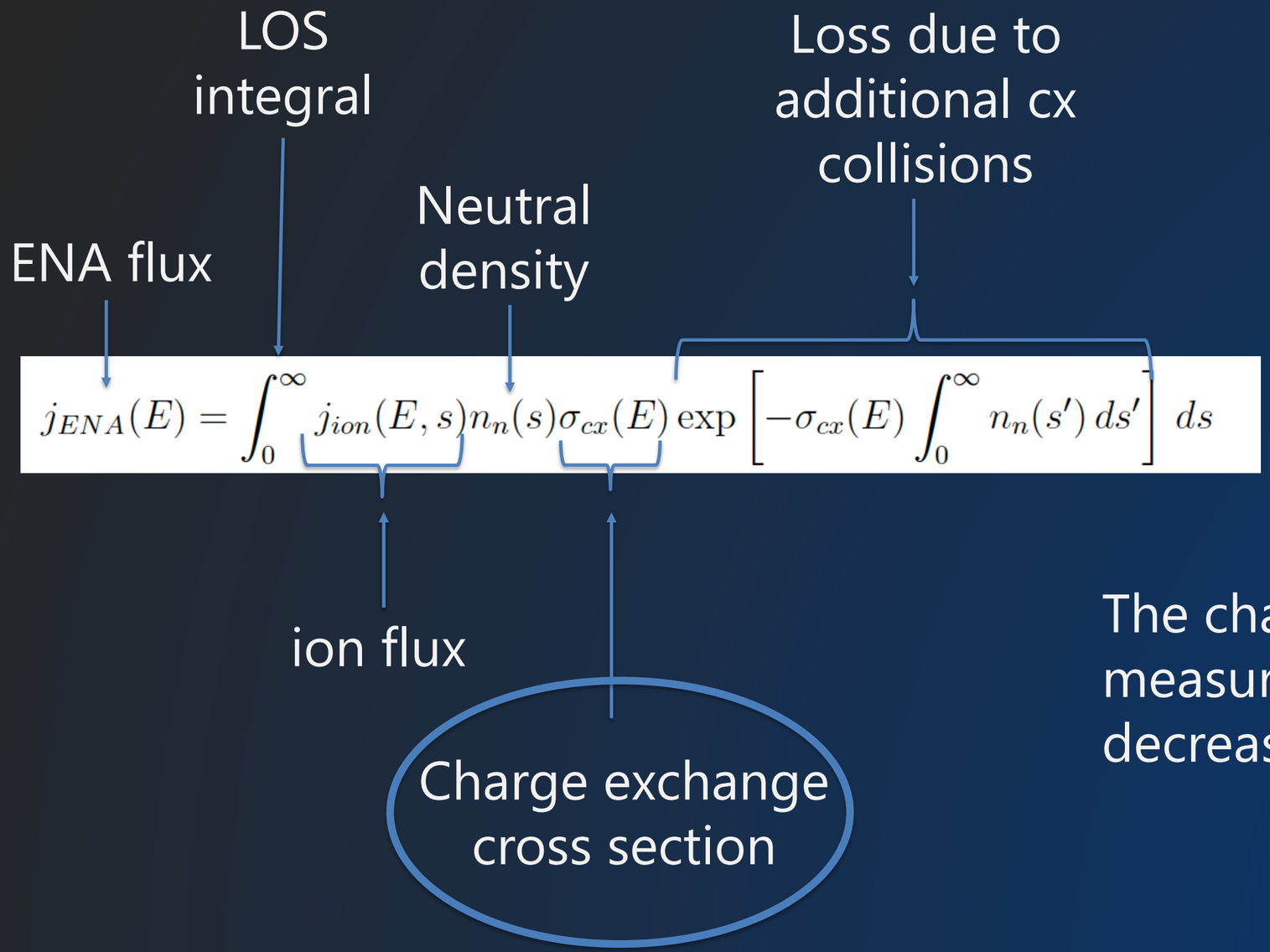
Energetic neutral atom (ENA) measurements help us get information about the ion population

What else do we have to consider?



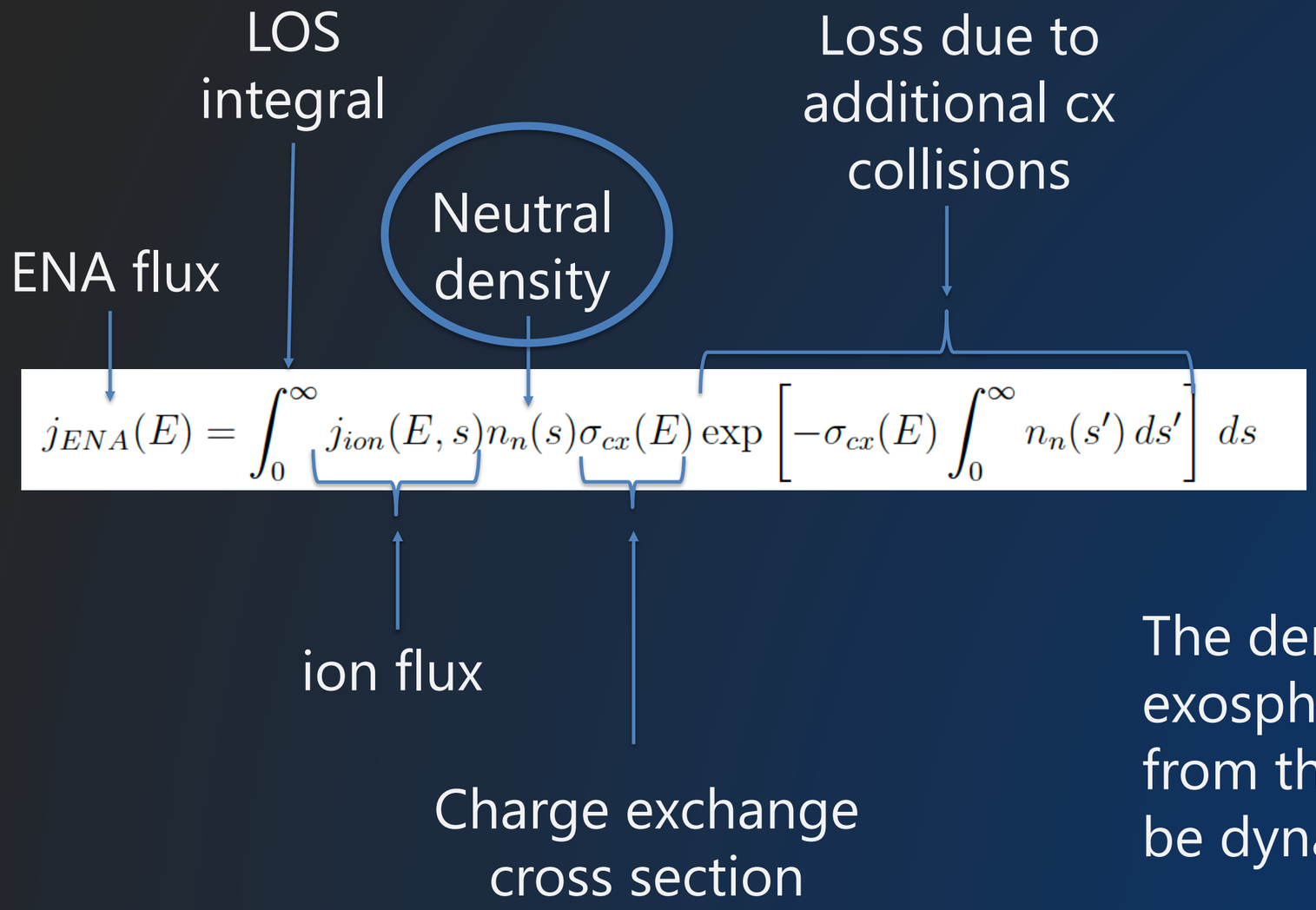
Additional charge exchange collisions need to be considered for low altitude emissions (LAE)

What else do we have to consider?

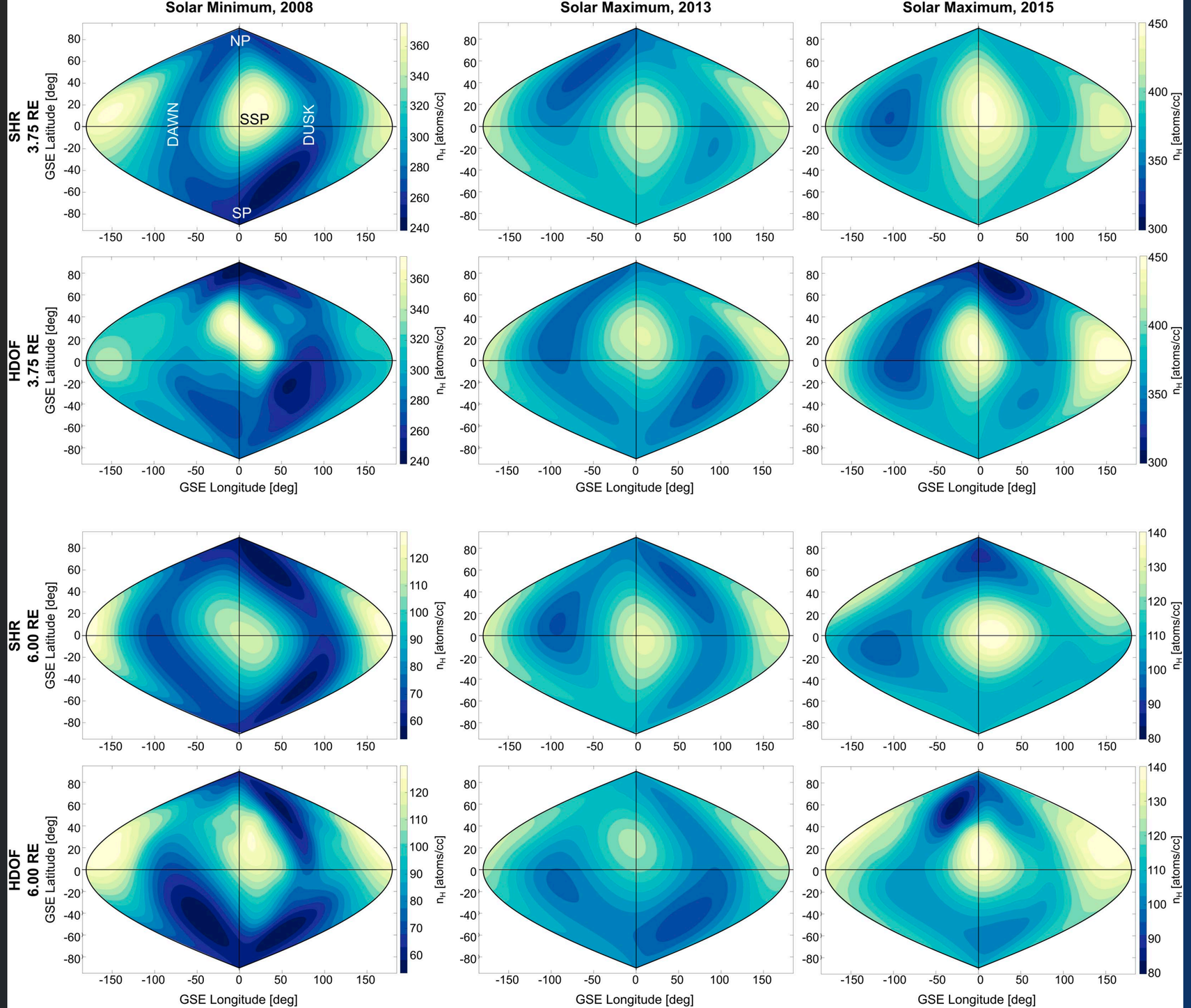


The charge exchange cross section, measured in laboratory experiments, decreases with increasing energy

What else do we have to consider?



The density of neutrals in the exosphere decreases with distance from the Earth, but has been shown to be dynamic



Lyman-α measurements of Hydrogen geocorona using TWINS show spatial and temporal variations

Zoennchen JH et al. (2024)
doi: 10.3389/fspas.2024.1409744

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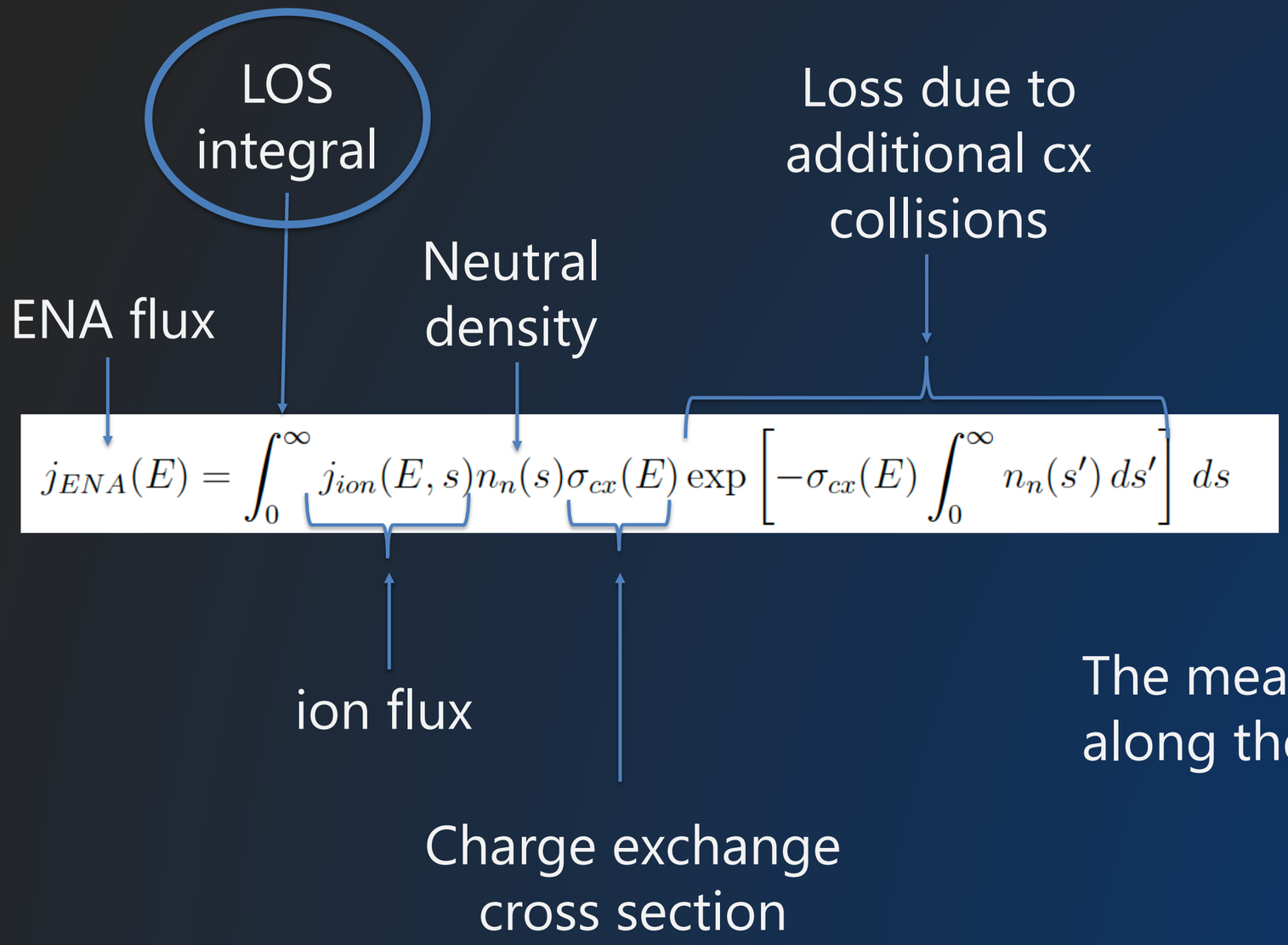
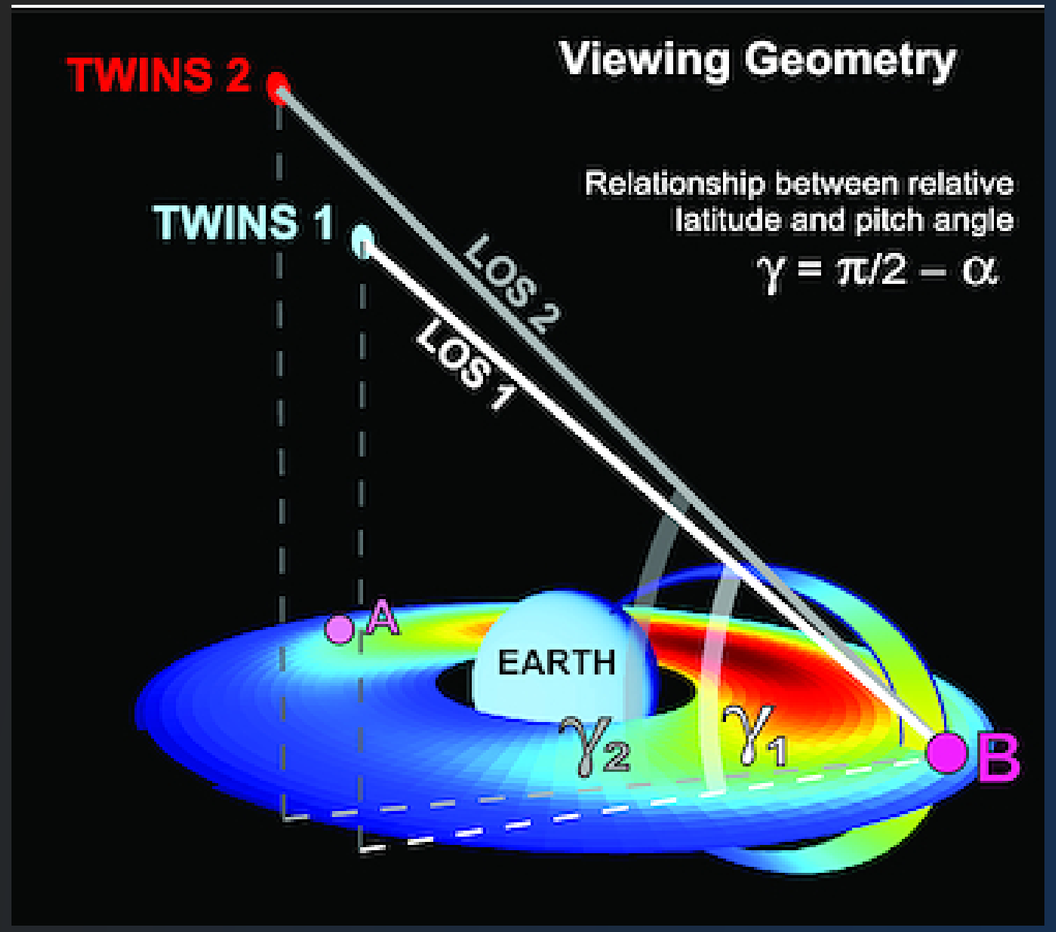
What else do we have to consider?

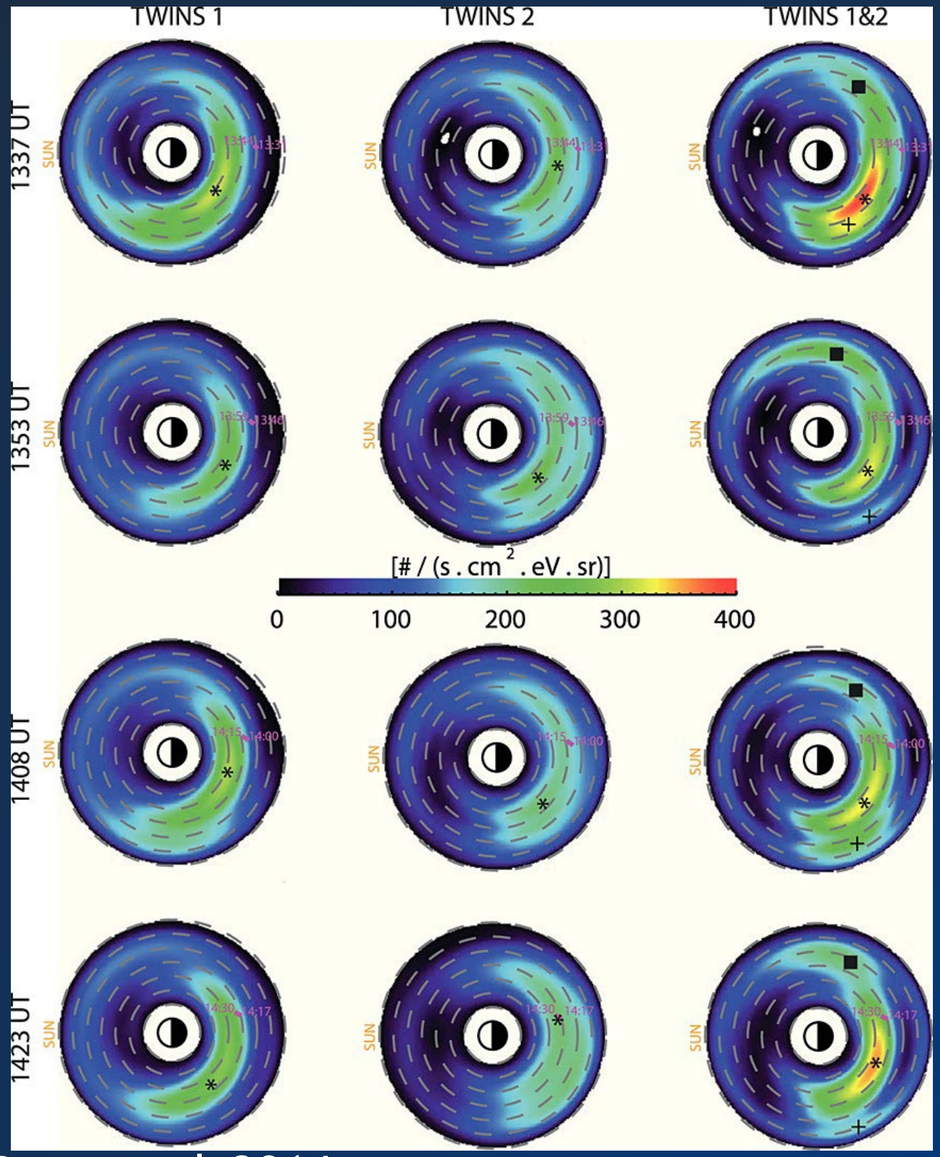


The measurement combines everything along the line of sight (LOS)

TWINS studies utilized dual vantage points



Goldstein et al, 2012
https://doi.org/10.1029/2012JA017804



Perez et al, 2014
https://doi.org/10.1002/2014JA020662

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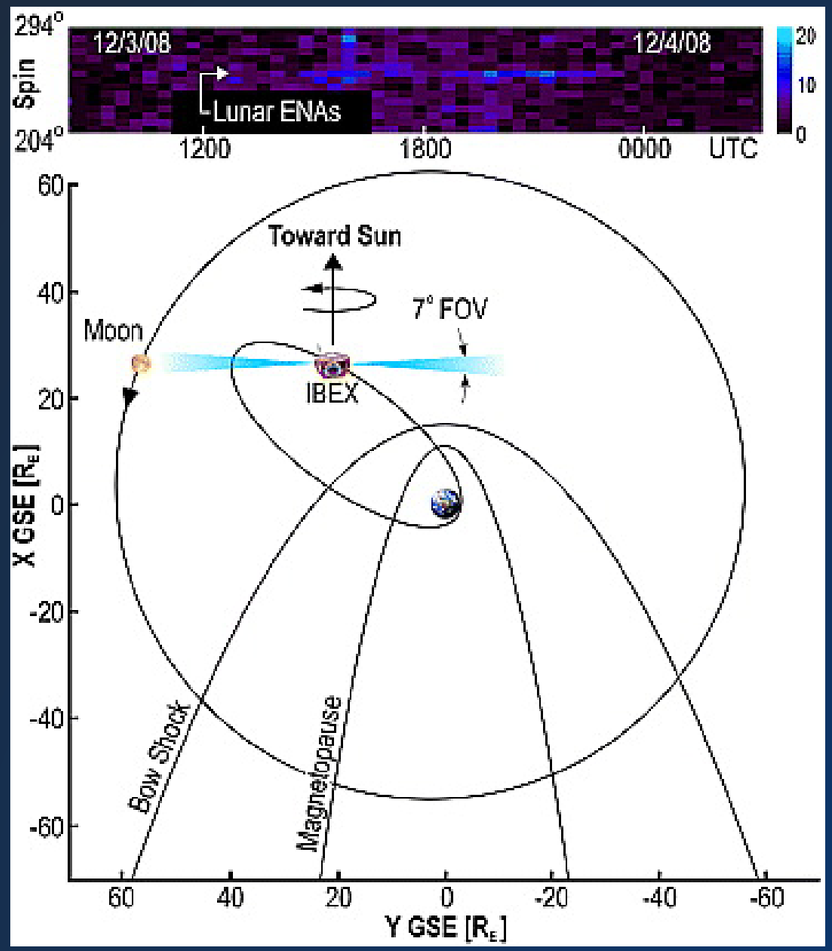
What if we put an ENA imager on the moon?

What did the Interstellar Boundary EXplorer (IBEX) do?

- Designed to observe ENAs from ~100 AU

- Observed ENAs of lunar origin
- Relevant to solar wind-moon interactions throughout solar system and other space plasma/small body interactions
- A consideration as background signal in moon-based measurements



McComas et al, 2009
https://doi.org/10.1029/2009GL038794

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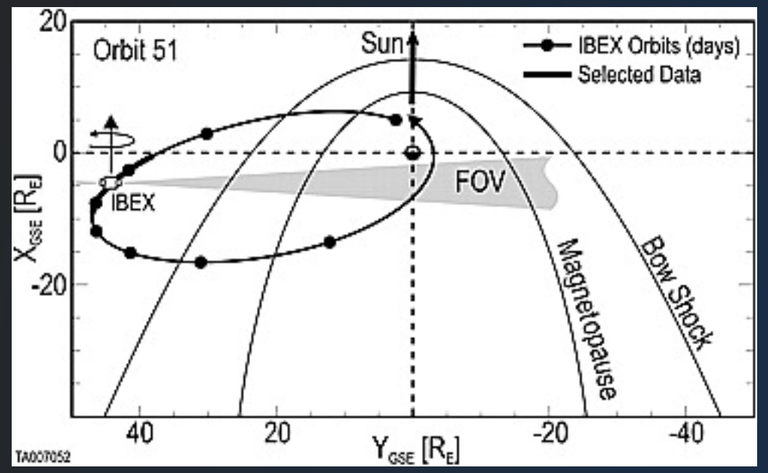
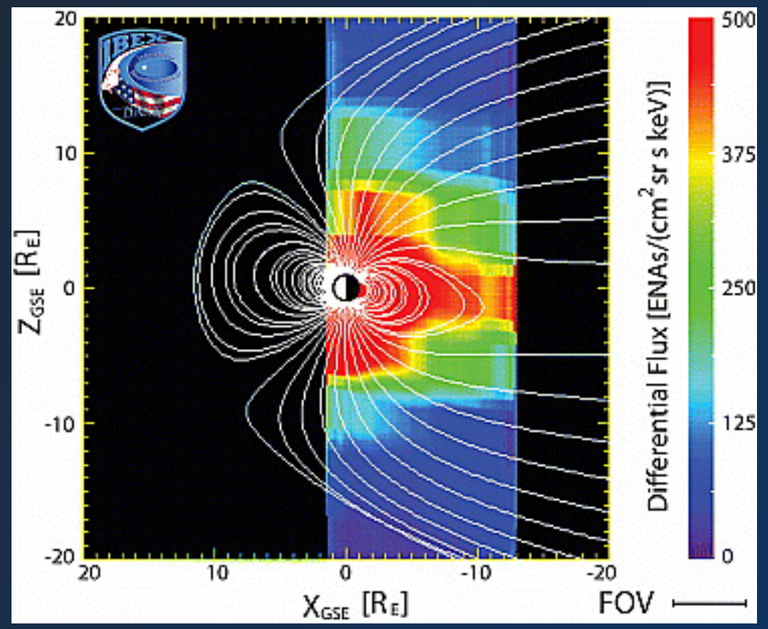
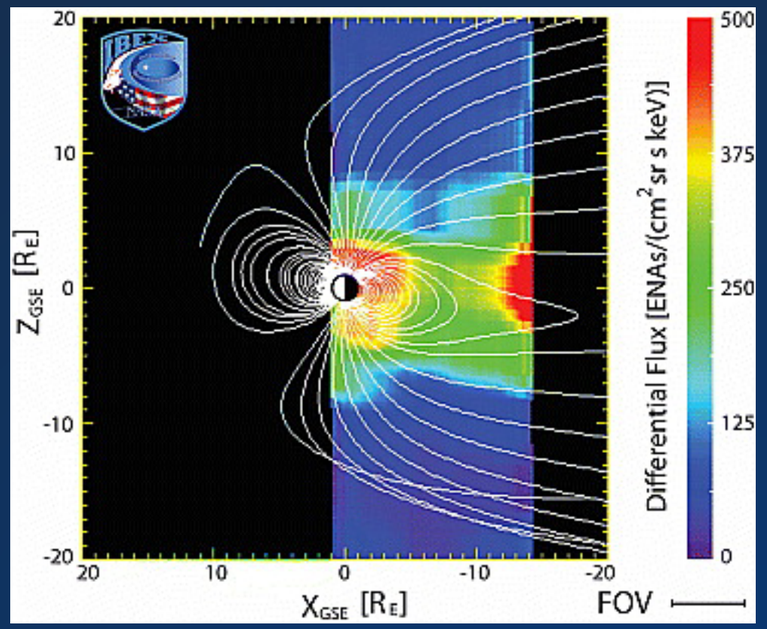
What did the Interstellar Boundary EXplorer (IBEX) do?

Observations of the magnetotail/plasma sheet: Observations of downtail intensification





1048 UT on 5 November - 0223 UT on 7 November 2009



2121 UT on 27 October - 1340 UT on 29 October 2009

McComas et al, 2011
https://doi.org/10.1029/2010JA016138

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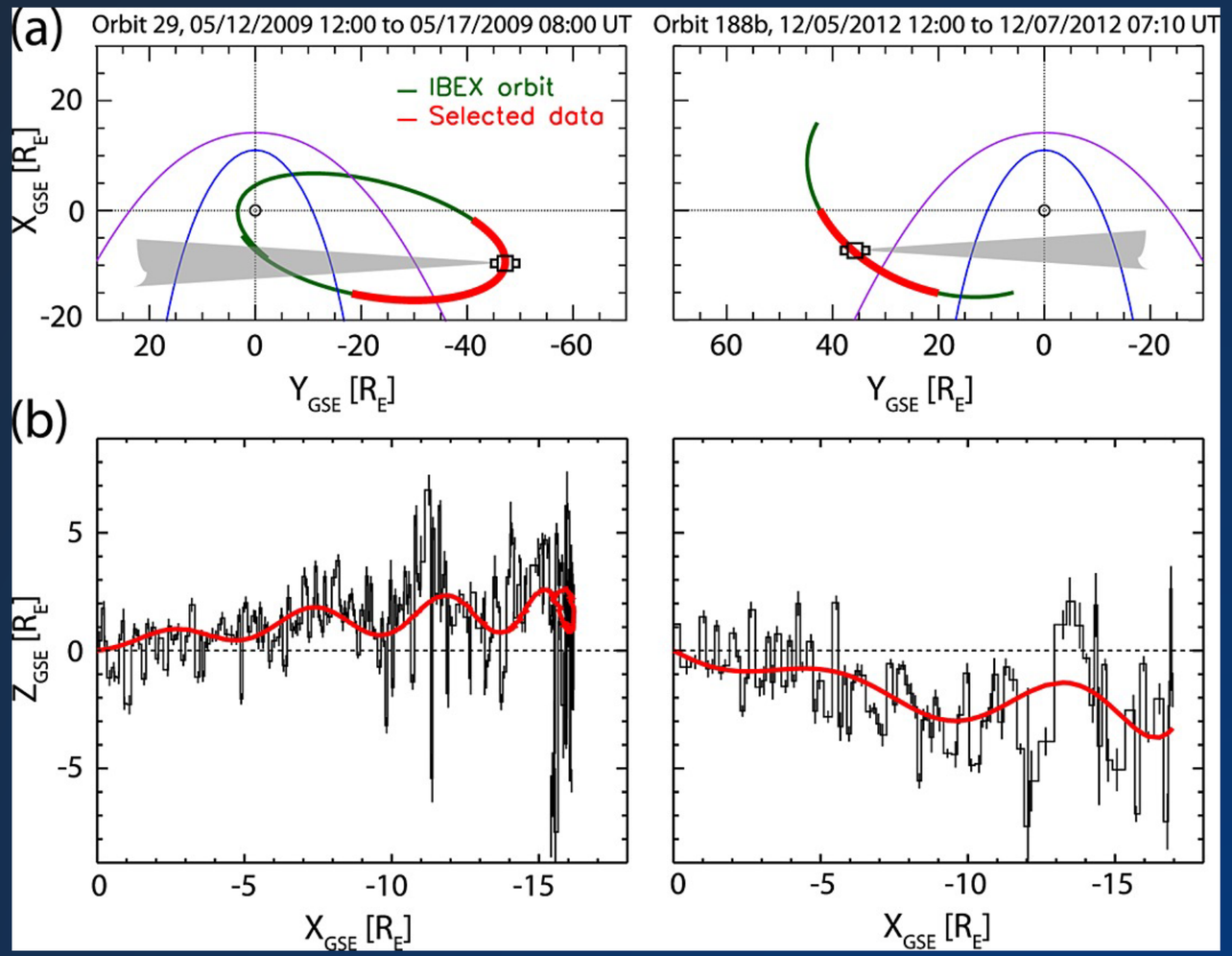
What did the Interstellar Boundary EXplorer (IBEX) do?

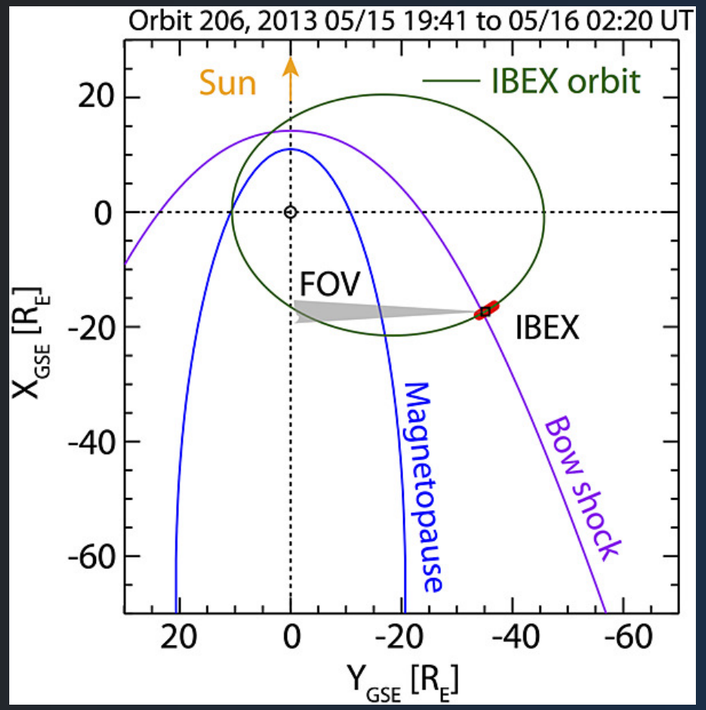
Observations of the magnetotail/plasma sheet: Observations of plasma sheet diurnal motion and short time-scale flapping

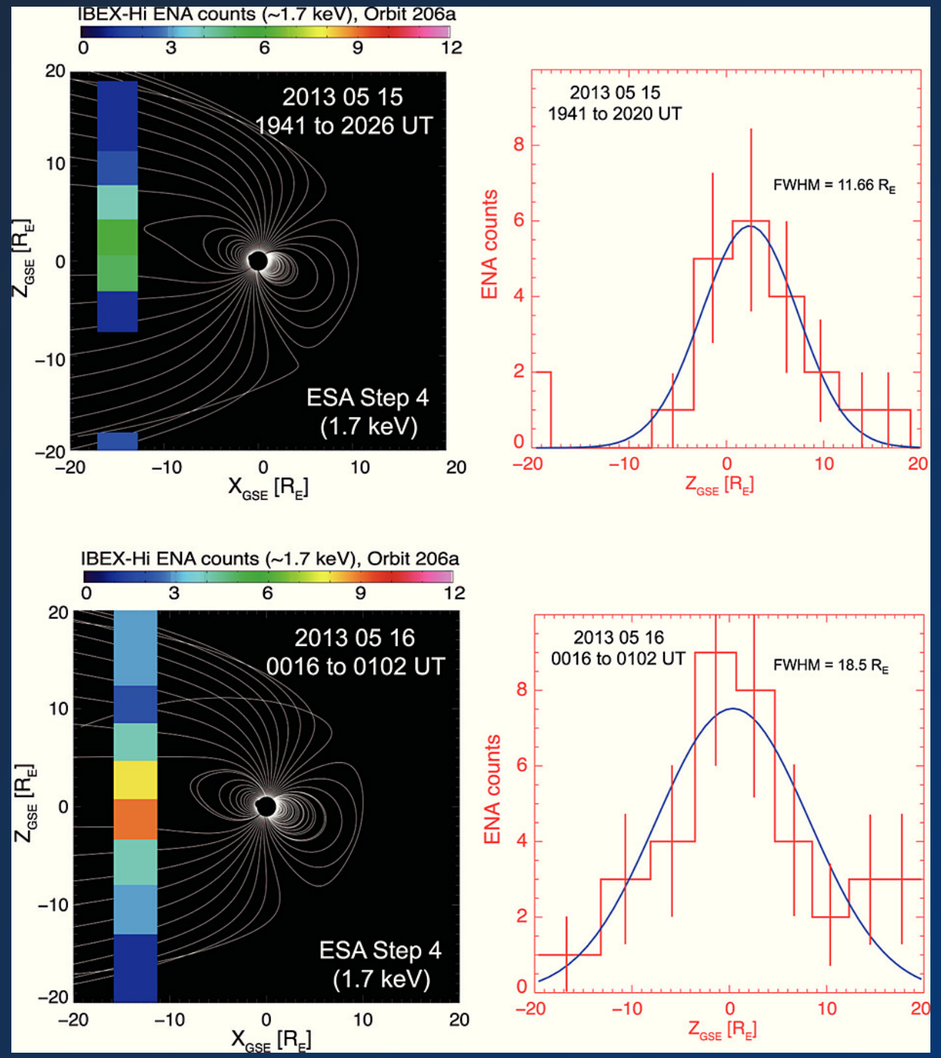


Dayeh et al, 2015
https://doi.org/10.1002/2015GL063682

What did the Interstellar Boundary EXplorer (IBEX) do?

Observations of the magnetotail/plasma sheet: Development of cold dense plasma sheet during northward IMF





Fuselier et al, 2015
https://doi.org/10.1002/2015GL065716

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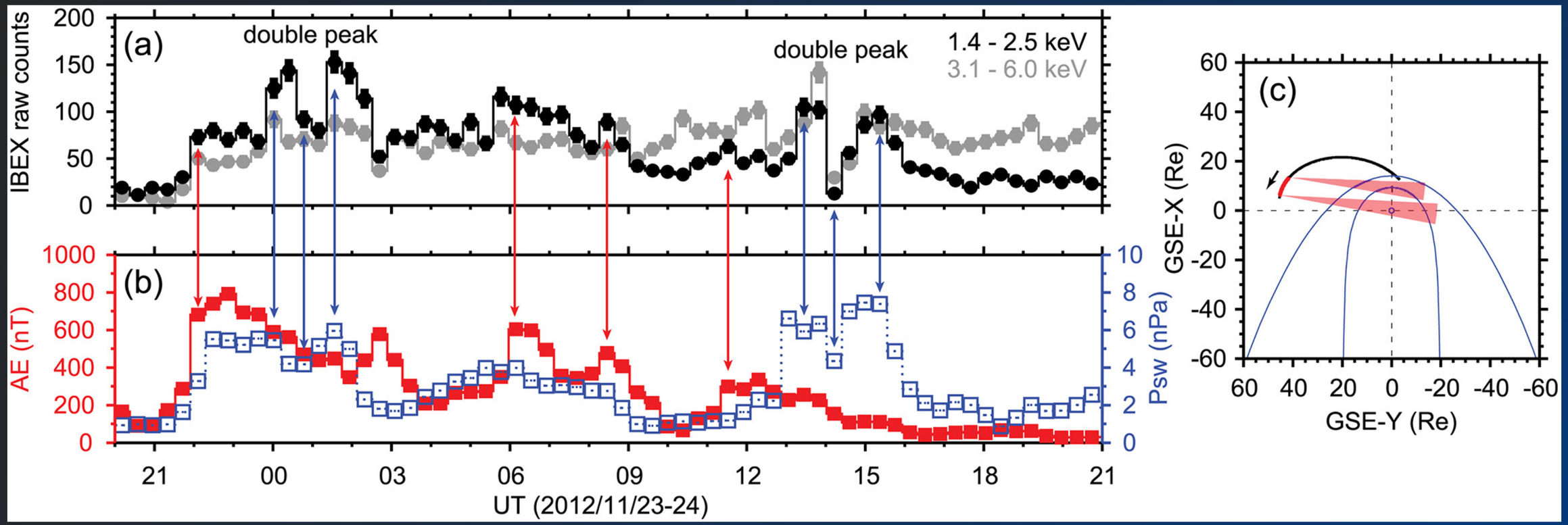
What did the Interstellar Boundary EXplorer (IBEX) do?

Observations of the inner magnetosphere:
Correlations with the AE index indicating strong emission during FAC formation



Ogasawara et al, 2019
https://doi.org/10.1029/2019JA026976

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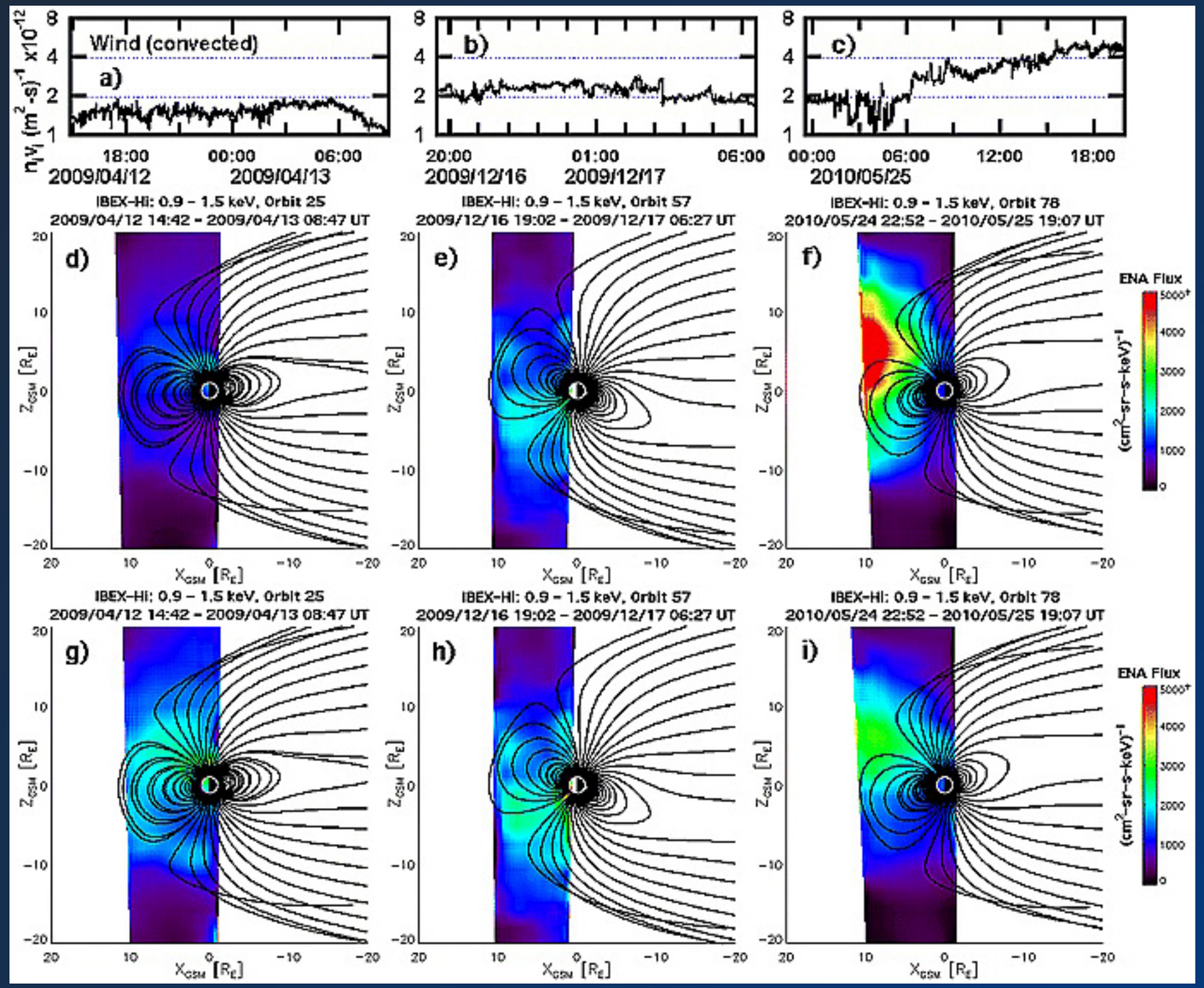
What did the Interstellar Boundary EXplorer (IBEX) do?

Observations of the dayside cusps:
Cusp ENA emission related to magnetopause reconnection locations



Petrinec et al, 2011
https://doi.org/10.1029/2010JA016357

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What should be considered for a lunar ENA imager?

- Spatial and temporal resolution
- Energy range
- Time delays

Increase counts with active ENA experiments

- Artificially increase neutral density to increase ENA flux
- Release could be at a modulated frequency for improved detection
- Releases of unused fuel from rockets could be used for such experiments

ENA flux

Neutral density

$$j_{ENA}(E) = \int_0^\infty j_{ion}(E,s) n_n(s) \sigma_{cx}(E) \exp\left[-\sigma_{cx}(E) \int_0^\infty n_n(s')\, ds'\right] ds$$

Scime and Keesee, 2019
https://doi.org/10.3389/fspas.2019.00009

What should be considered for a lunar ENA imager?

- Spatial and temporal resolution
- Energy range
- Time delays

- Combine with measurements from other sources