

Small, Innovative Missions for Planetary Exploration
NNH14ZDA001N-SIMPLEX

**LUNAR HYDROSPHERIC EXPLORER
(HYDROX)**

Principal Investigator

Dr. John F. Cooper

**Heliophysics Science Division
NASA Goddard Space Flight Center
Greenbelt, Maryland
United States of America**

Goal: Definitively confirm existence of exospheric water and hydroxyl molecules, and determine their sources.

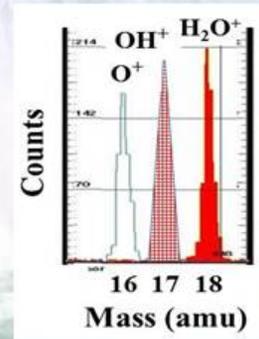
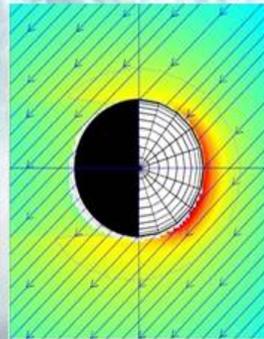
Participating Institutions

*NASA Goddard Space Flight Center
University of Maryland Baltimore
County
University of Maryland College Park
George Washington University
University of California at Los Angeles
University of New Hampshire*

150 MT of lunar water in multi-billion-year polar ice deposits is equivalent to fifty seconds of Niagara Falls peak flow at 3 MT/s (100,000 cf/s)

HYDROX will measure the lunar ionospheric component of water flow ~ 40 kg/s in 4 Gyr from global sources to poles.

Where in the world did all that water come from?



The Scientific Context for the Exploration of the Moon [2007]

LADEE was designed to determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity. *But it did not carry a hot ion mass spectrometer allowing wider FOV, full energy coverage, or angular resolution of surface and exospheric sources. LADEE has internal background water response, HYDROX measures only hot external ions.*

Visions and Voyages [2011]

The Moon is less dry than once thought. Evidence is mounting that lunar surface and interior are not completely dry as previously believed. Some beads of lunar volcanic glass and minerals from mare basalts contain concentrations of hydrogen high enough to suggest that their parent magma contained as much water as Earth's mantle.

Remote sensing of the Moon by Lunar Prospector and Lunar Reconnaissance Orbiter (LRO) has shown that *broad areas near the poles contain significant hydrogen;* radar data suggest some of this hydrogen is present as water ice.

Other remote observations from LRO, LCROSS, Cassini, and Chandrayaan-1 suggest *small, but significant, quantities of water near or on the Moon's surface.*

→ *HYDROX provides orbital analysis of lunar ionospheric hot ion composition.*

HYDROX Objectives

- **Objective 1:** Definitively detect and resolve the global abundances of **water group** pick-up and related ions.

O⁺ {CH₄⁺}, **OH⁺**, **H₂O⁺**, H₂⁺, He⁺, C⁺, N⁺, **H₃O⁺** {plume}

M/ΔM ≥ 30 → M = H⁺ to O₂⁺ {S⁺}

- **Objective 2:** Determine source process contributions through in-situ measurement of spatial and temporal variations expected in water group and other ions from those processes {see next slide}

- **Objective 3:** Track water group and other hydrospheric ion trajectories back to surface source sites to correlate site-specific geophysical characteristics to source processes.

➤ Single WIMS measurement: 25°x 2°angular beam source

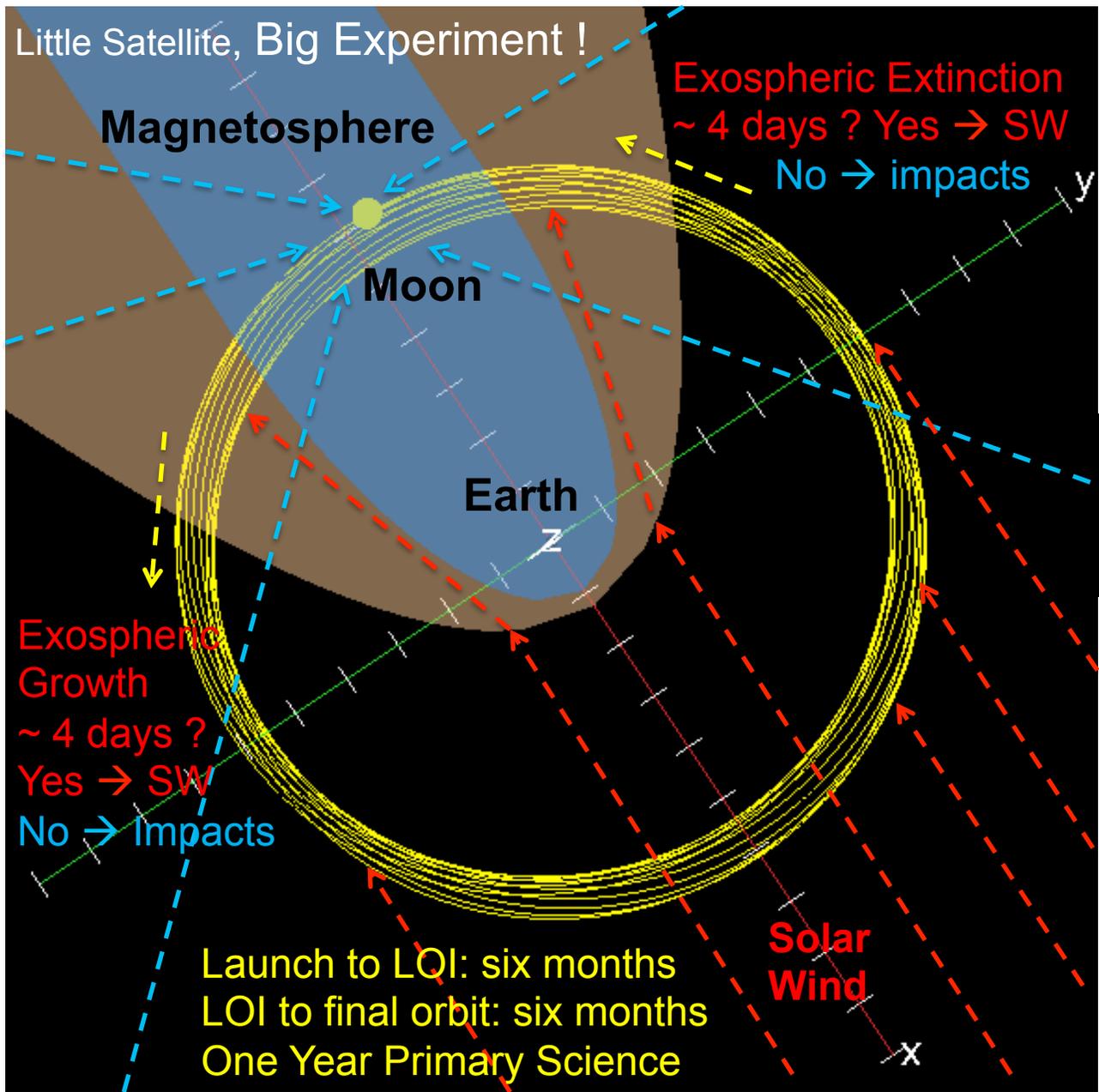
➤ Rotated multiple measurements: 2°x 2°angular beam source

➤ Resolve nadir surface sources at 600 – 50 km² resolution

Lunar Water Group Sources

- Photo-Stimulated Desorption (PSD) by solar ultraviolet irradiation
 - lunar dayside (no dust stream, solar wind, SEP correlations?)
- Meteoritic Impact Vaporization (MIV) from continuous to transient dust impacts
 - lunar global (time correlations to known dust streams ?)
- Solar Wind Sputtering (SWS) from surface bombardment by solar wind ions
 - lunar dayside in solar wind (response to fast/slow SW ?)
- Energetic Particle Radiation (EPR) from solar, heliospheric, and galactic energetic particle irradiation and resultant effects on regolith chemistry and deep dielectric charging
 - lunar global (enhancements from buried ice deposits ?)

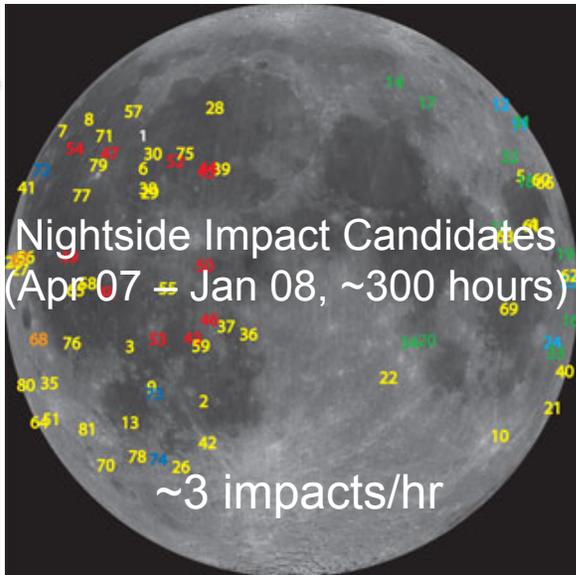
HYDROX Approach: Source flux deconvolution over at least six lunations (6 x 29.53 days) in lunar orbit.



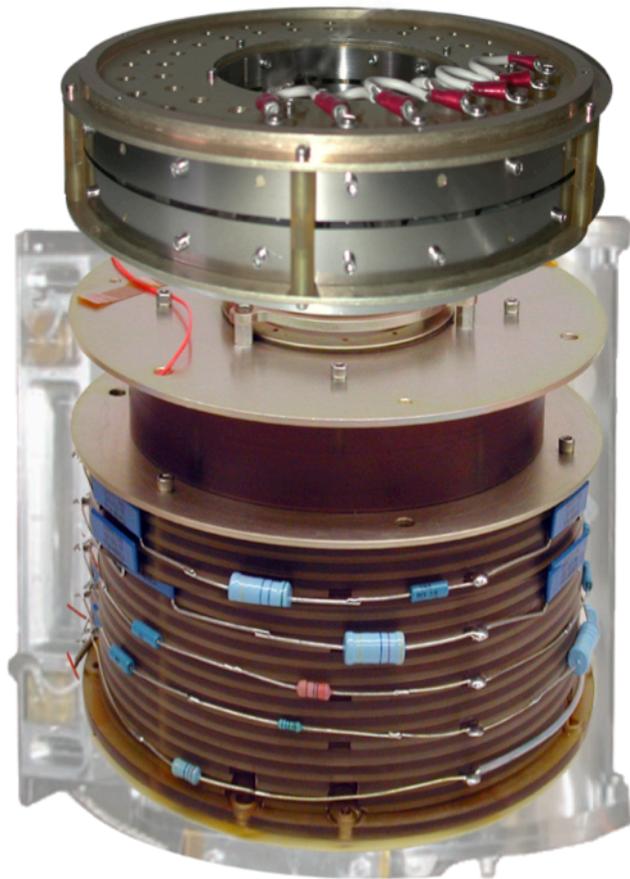
What is primary surface source for detected lunar water group ions?

1. Surface sputtering by solar wind ions (Kaguya) ?
2. Meteoritic impact vaporization (LADEE) ?

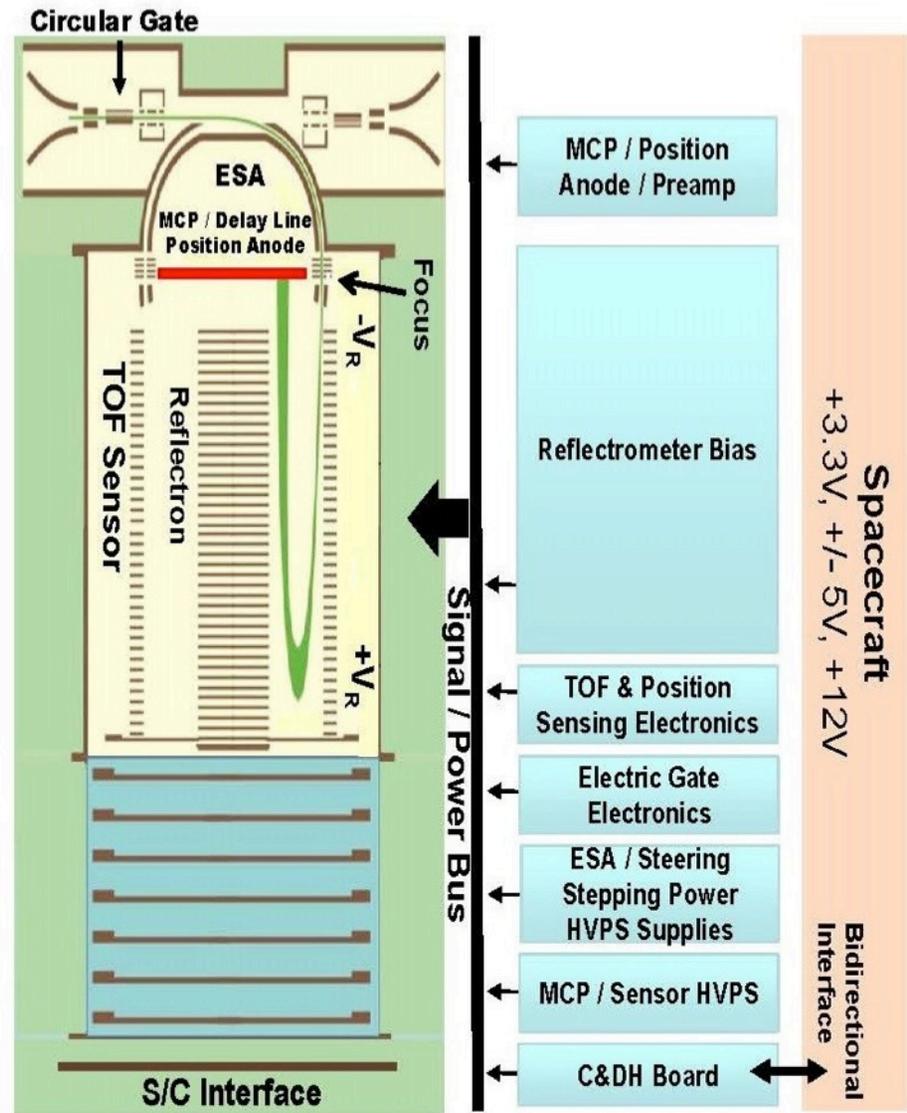
Meteoroid Sources
Sporadic background
Taurids Geminids
Leonids Lyrids etc.



Wide-FOV Ion Mass Spectrometer
 Field of View $200^\circ \times 60^\circ$
 240 $25^\circ \times 2^\circ$ Angular Sectors



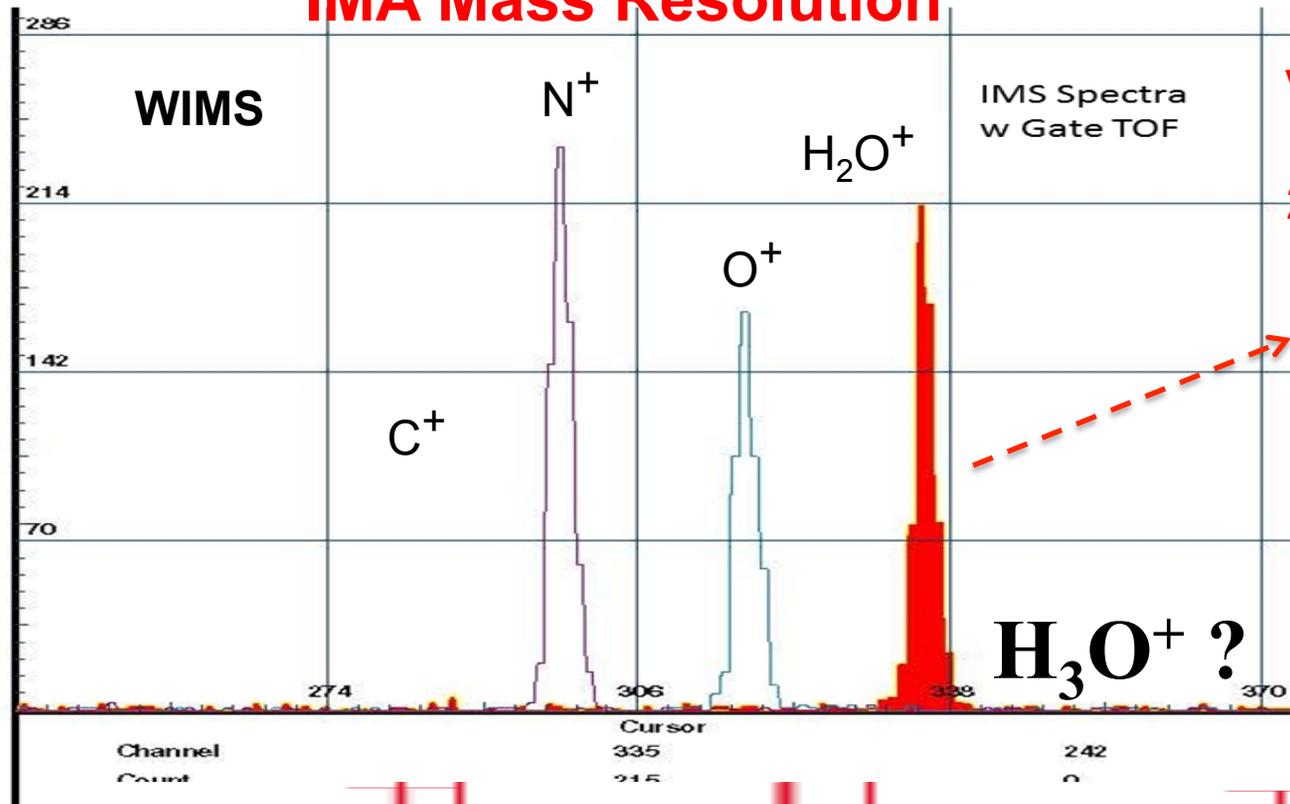
Laboratory WIMS prototype with cylindrical steering lens and aperture (top) section and ESA/TOF section (bottom)



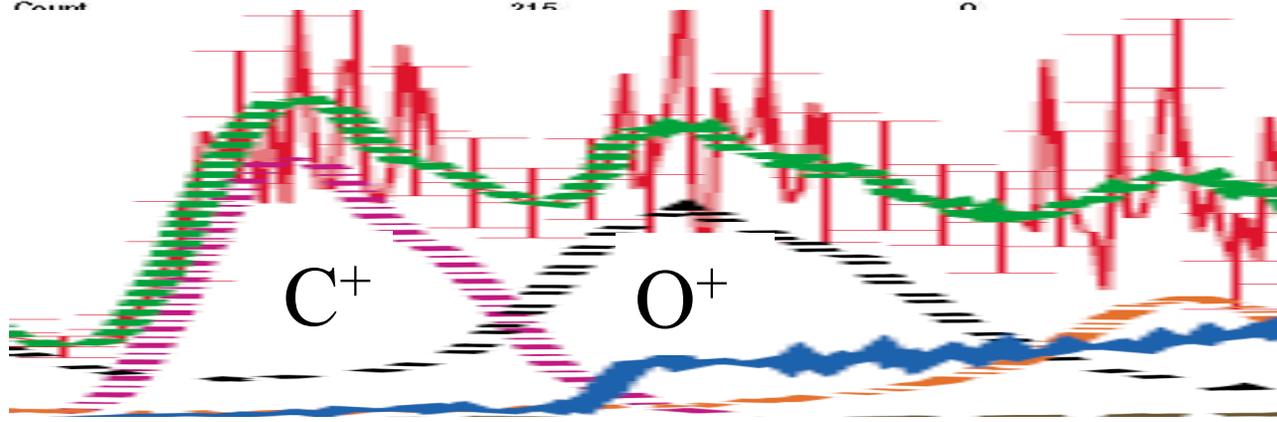
WIMS design, including circular electric gate replacement for carbon foils, dramatically increases ion mass resolution to $M/\Delta M \geq 30$ (10% rule), 100 @ FWHM, energy resolution to 2%, angle $2 - 25^\circ$

WIMS Laboratory Calibration Comparison to Kaguya IMA Mass Resolution

WIMS would be the highest resolution W⁺ IMS ever flown in lunar orbit as natural follow-on to LADEE and Kaguya !

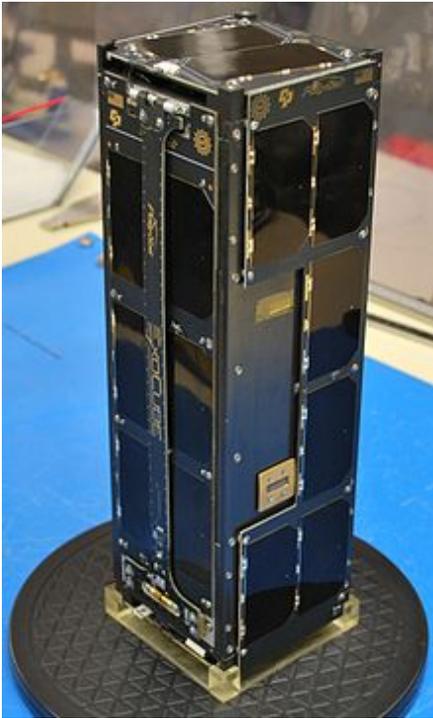


- observation
- He⁺
- C⁺
- O⁺
- Na⁺
- K⁺
- Ar⁺
- simulation

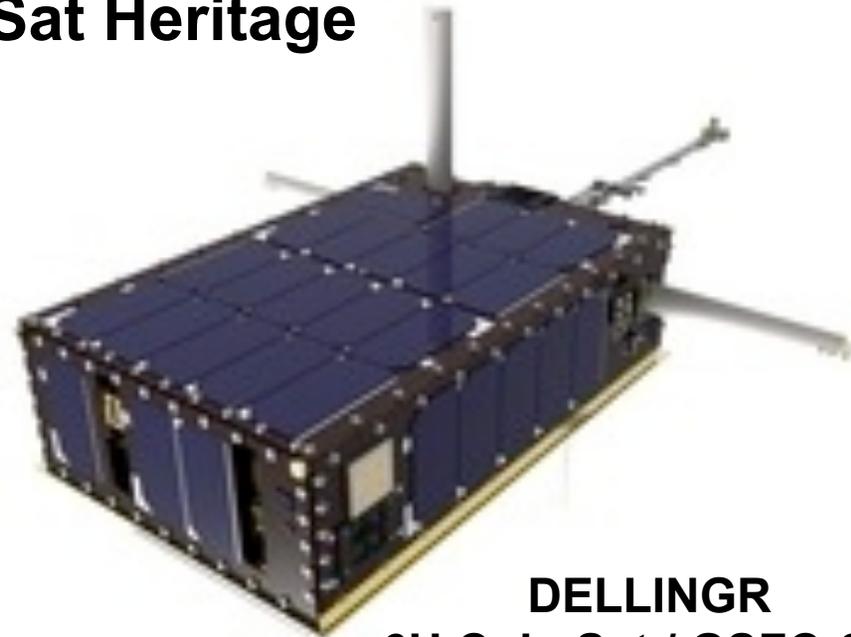


Kaguya Ion Mass Analyzer [Tanaka et al., GRL, 2009]

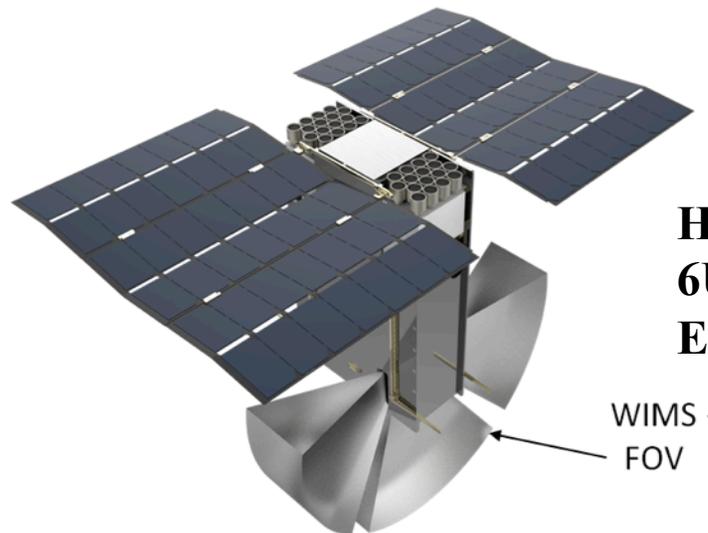
HYDROX CubeSat Heritage



ExoCube (CP-10)
3U CubeSat / NSF-CalPoly
Launched Jan. 2015



DELLINGR
6U CubeSat / GSFC-670
ISS Jan. 2016

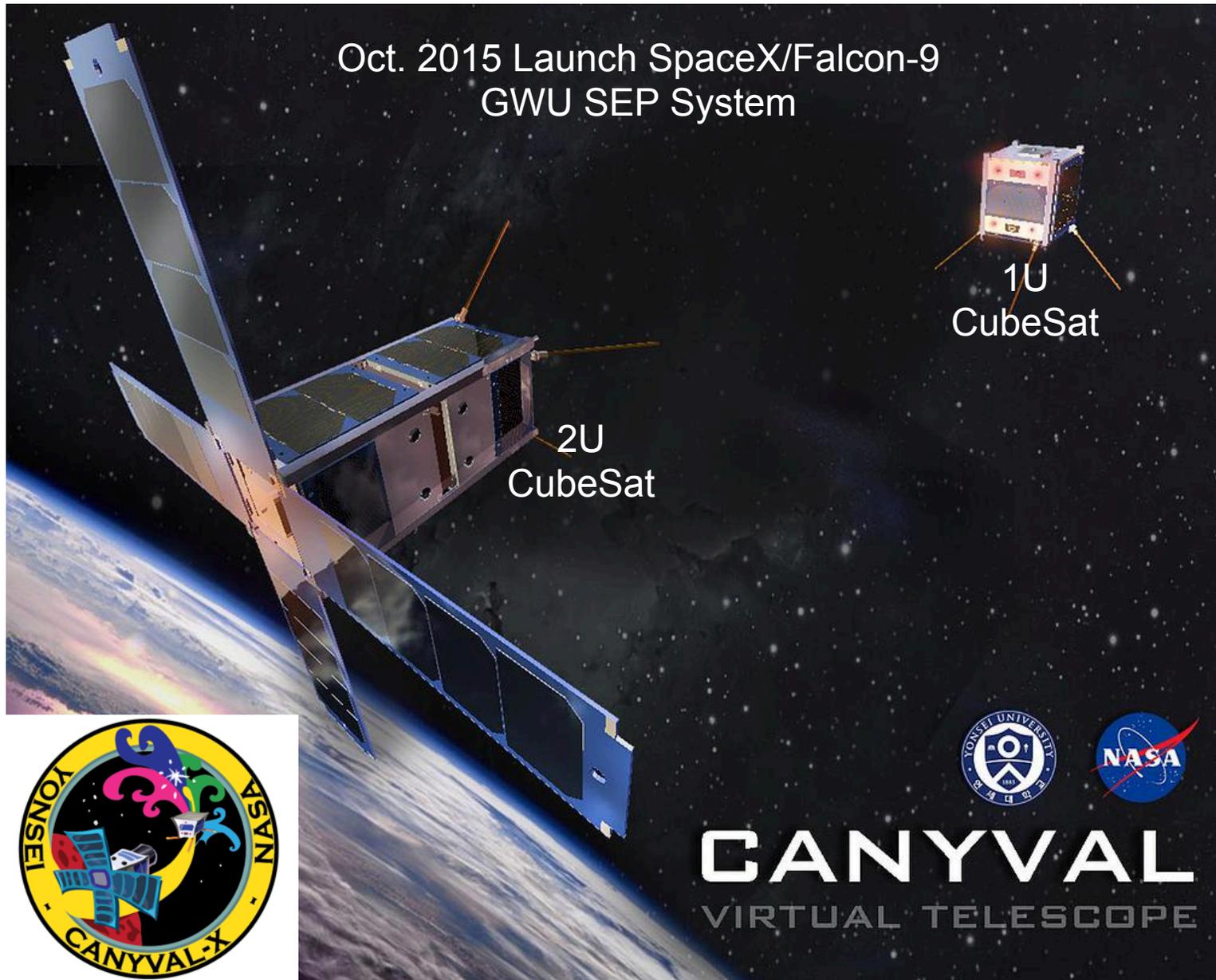


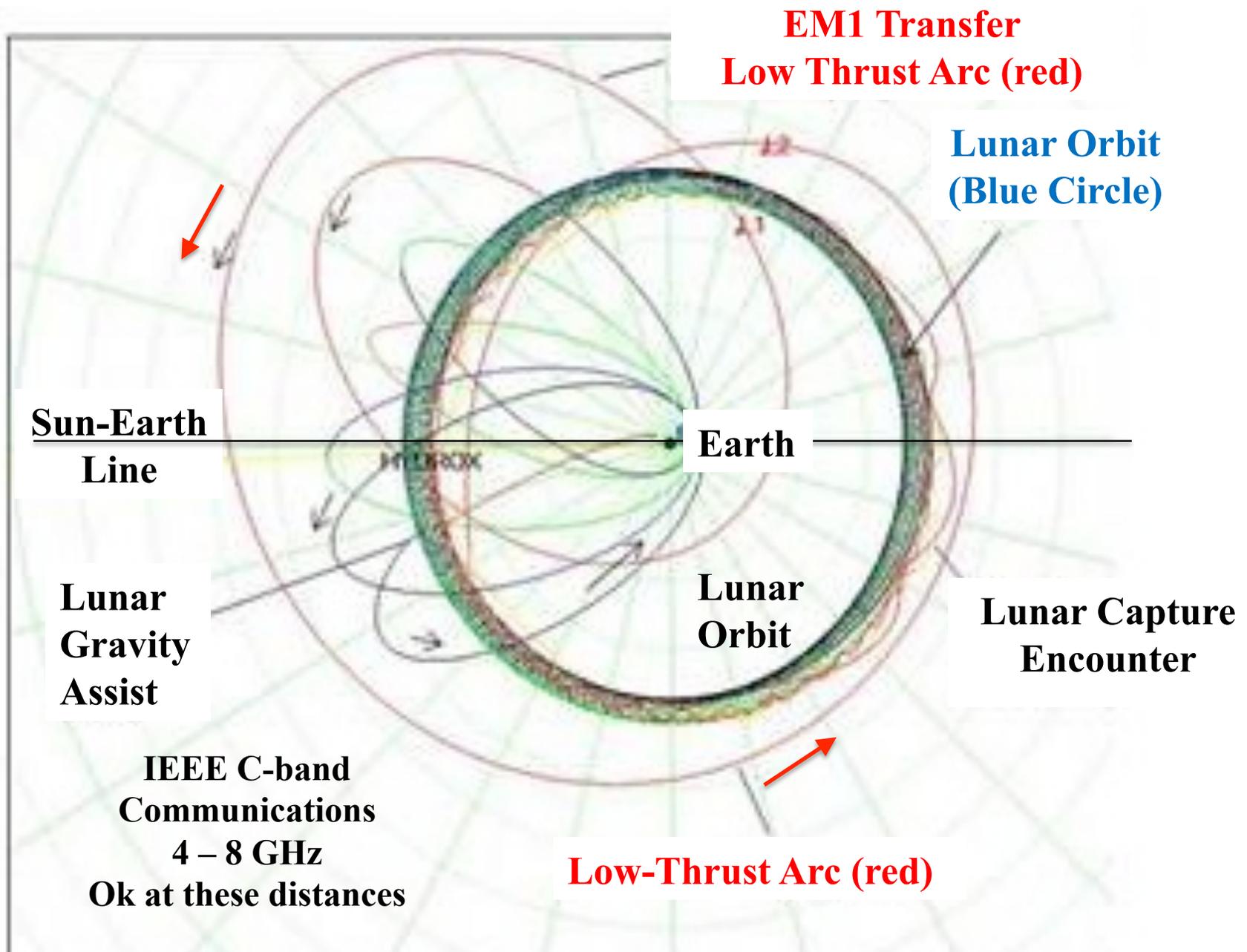
HYDROX
6U CubeSat / 670
EM-1 July 2018

WIMS -
FOV

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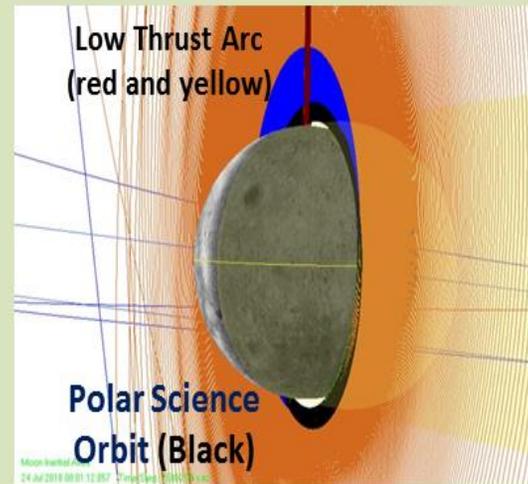
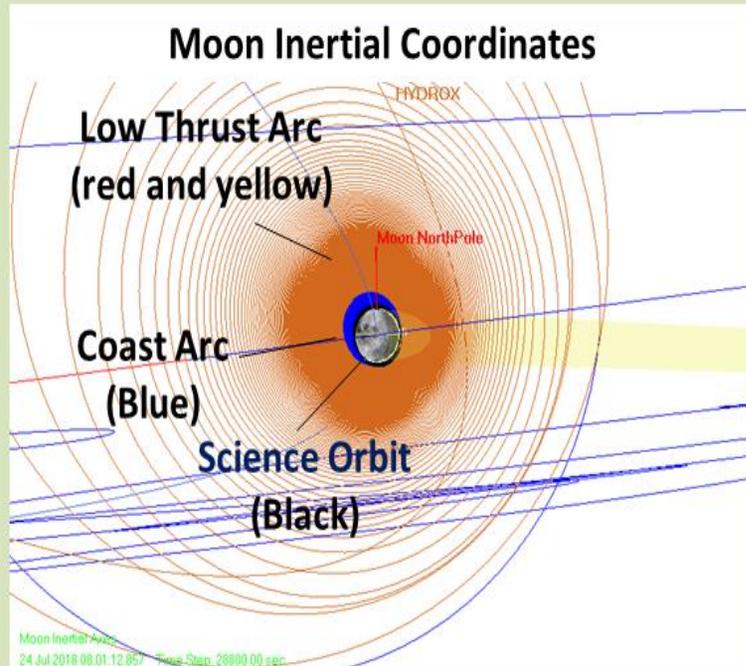
HYDROX SEP Heritage from 2U-1U CANYVAL (George Washington University)





413 day transfer time from EM-1 release to lunar science orbit
 Including 207 days of active SEP thrusting in total of 10 low-thrust arcs

Low Thrust Insertion and Polar Science Orbit

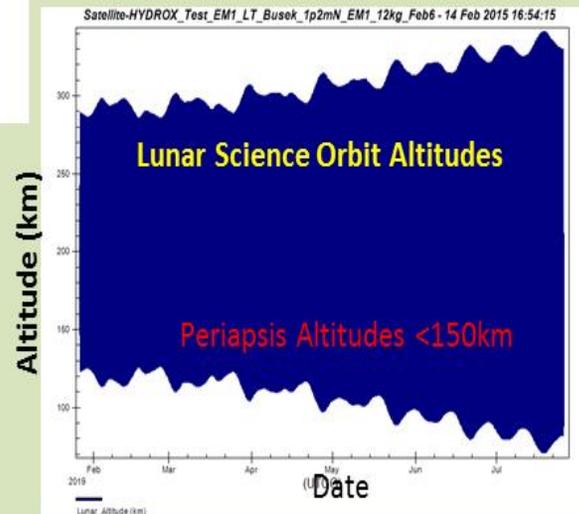


Full science operations in Coast Arc and Polar Science Orbit phases

Most power goes to SEP system during active thrusting

Could extend mission lifetime in “frozen” lunar orbits, e.g. for collaborative observations with ARTEMIS, LRO

- *Stable Low Polar Circular Orbit*
- *Periapsis altitude below ~150 km for > 1 year*
- *A variety of Science Orbits can be achieved from the low thrust capture and insertion trajectory*

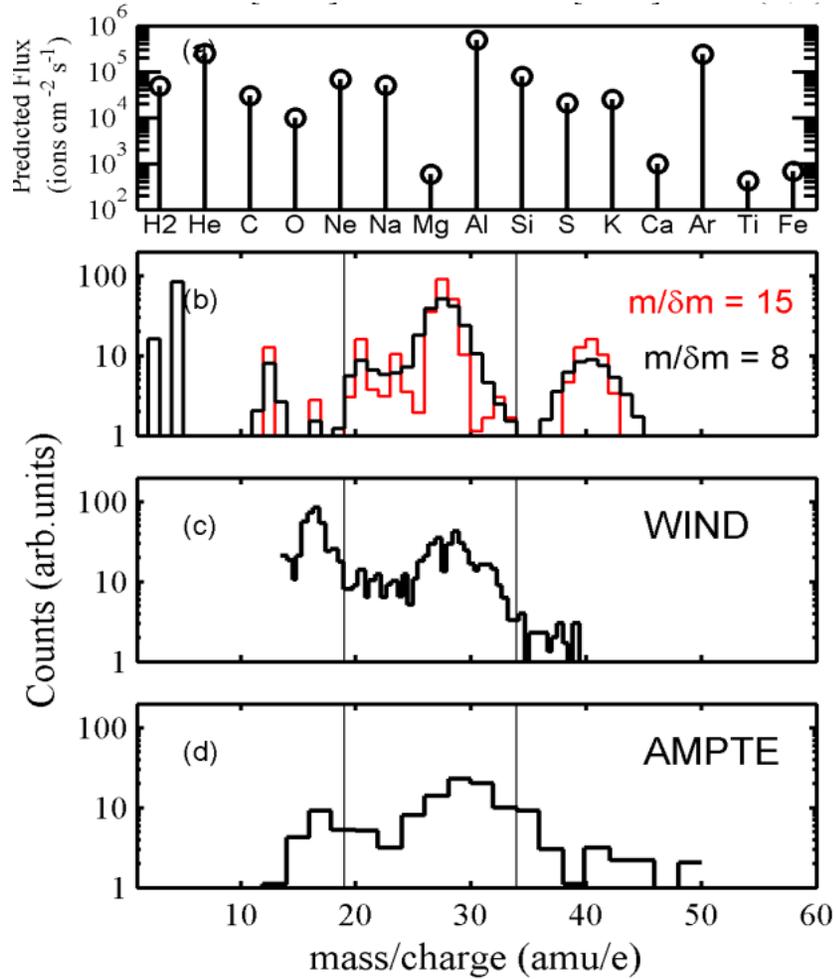


Key Points

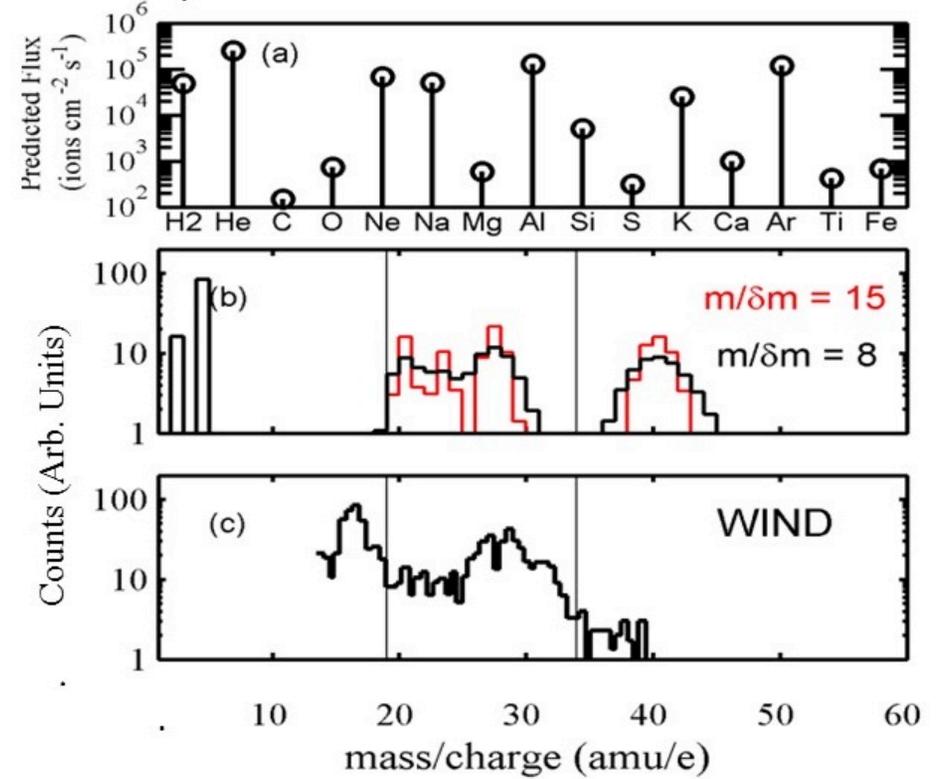
- EM-1/SLS launch in July 2018 provides *fantastic near-term opportunity* to put multiple CubeSats in lunar orbit
- Water deposited over billions of years in polar shadowed regions transported through neutral atmospheric and ionospheric environments accessible to orbiters
- WIMS avoids problems of LADEE internal instrument outgassing by measuring only hot ions from lunar/SW sources
- Six months in lunar orbit covers six lunations and all local times for deconvolution of lunar water group ion sources
- 240 angular sectors within wide FOV on rotatable 3-axis CubeSat allow determination of surface source locations and well-defined separation from solar wind background
- Science Enhancement opportunity for extended mission to one year or more, collaborative observations with ARTEMIS P1 & P2 spacecraft, LRO

Backup

Sarantos et al. [2012] Model Stern [1999] limits (C,S)

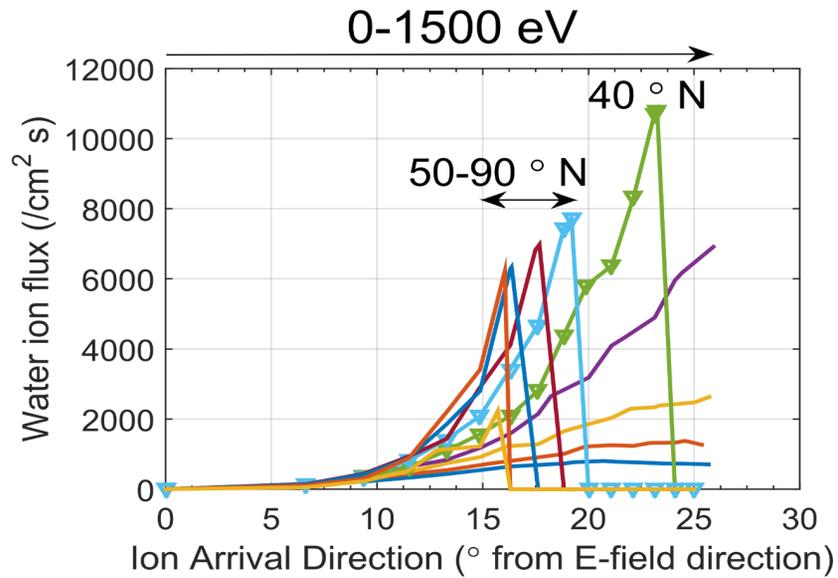
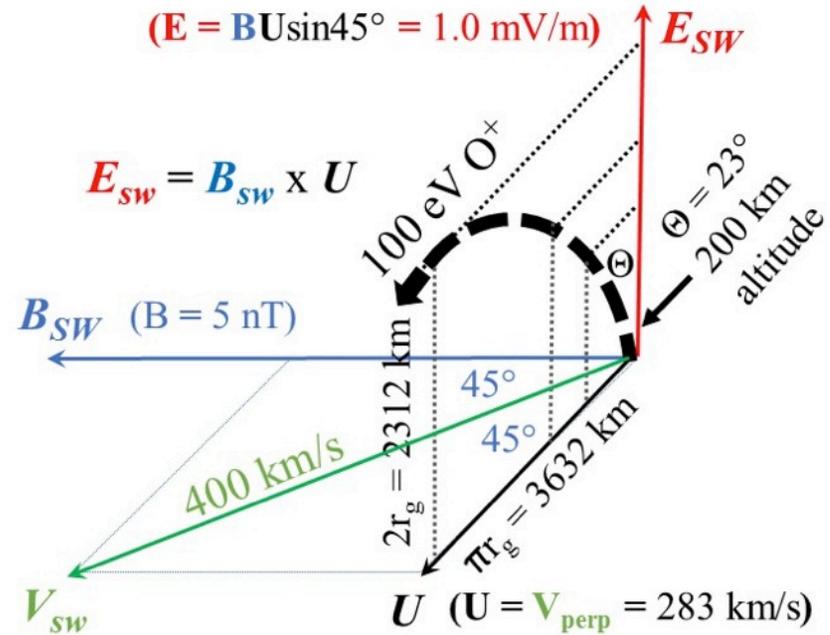
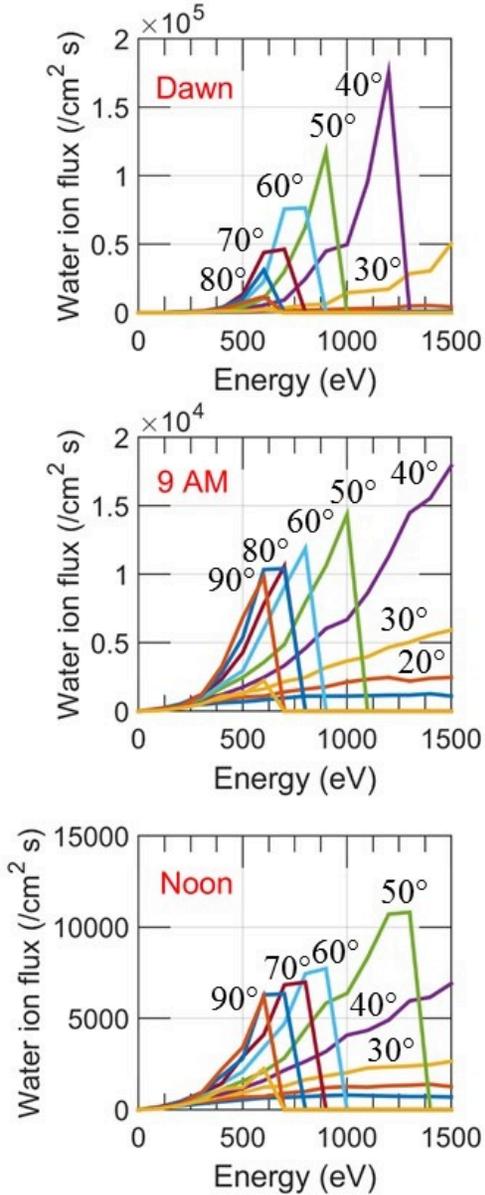


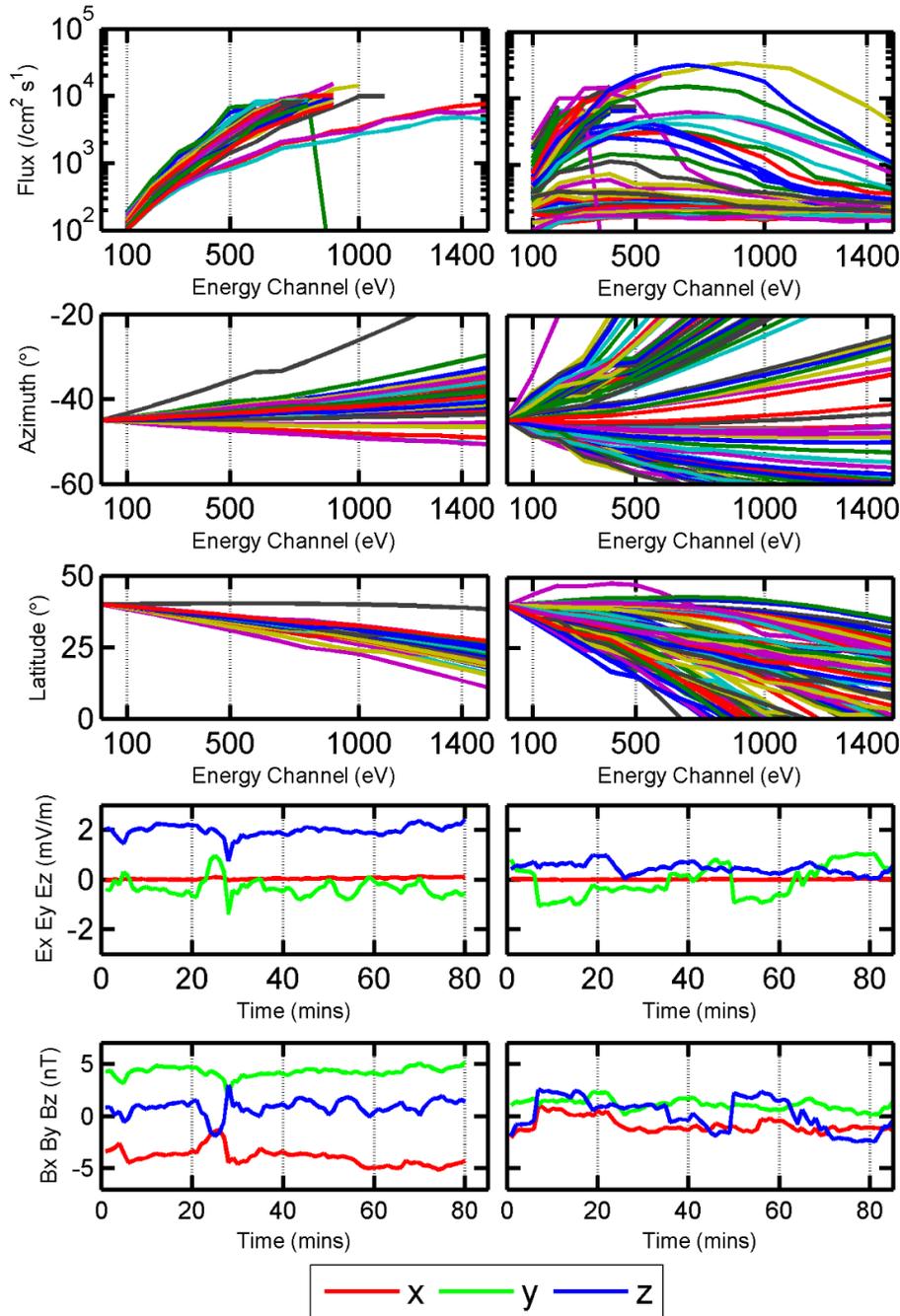
LRO Limits [Cook et al., 2013]



Latitude Dependence of O⁺ Flux Spectra

Water Binding Energy = 0.5eV



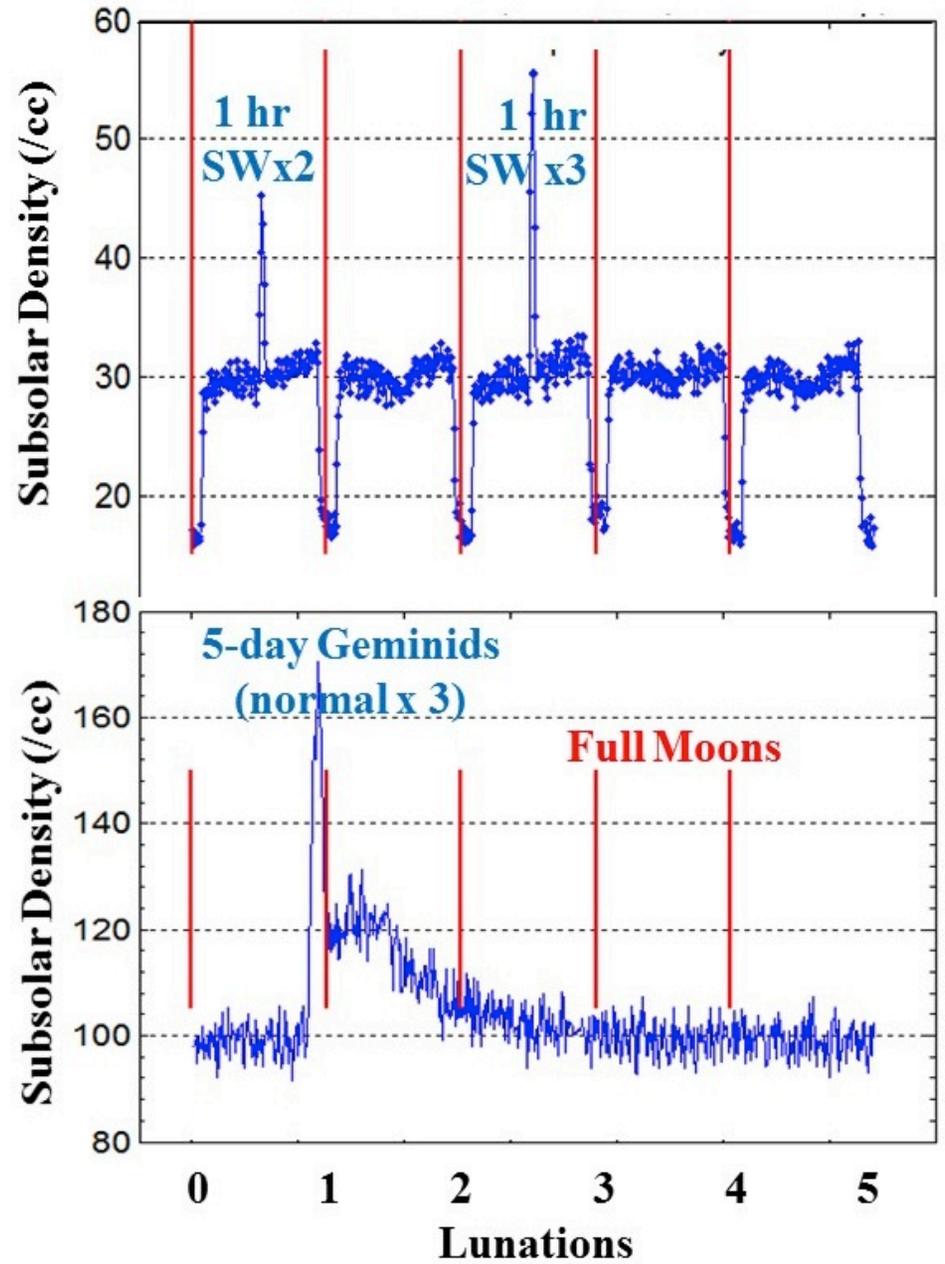
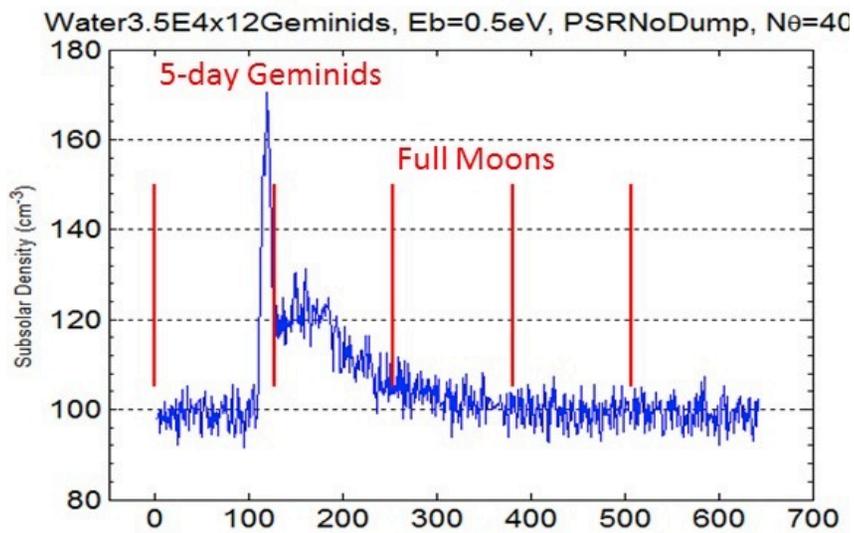
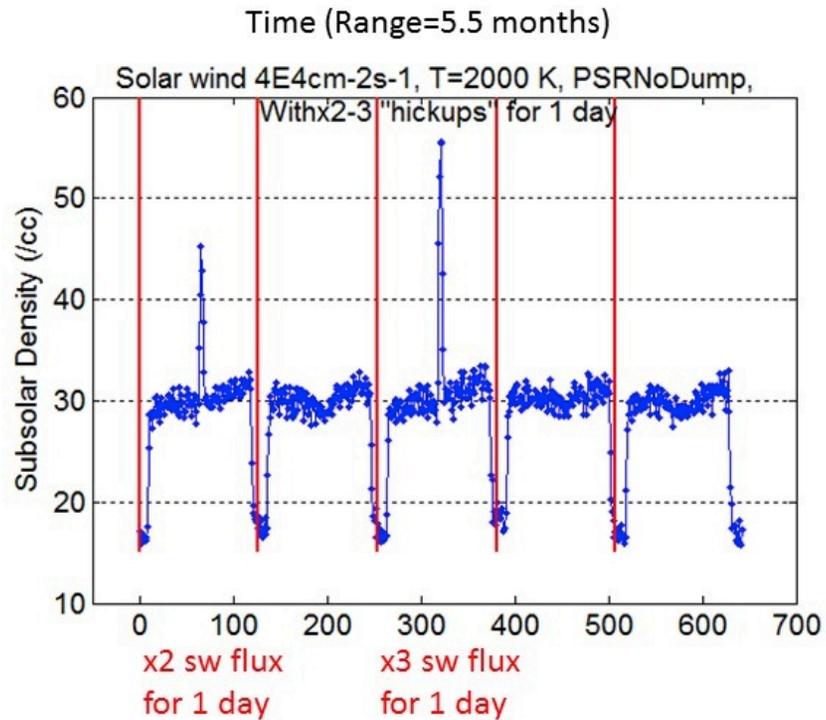


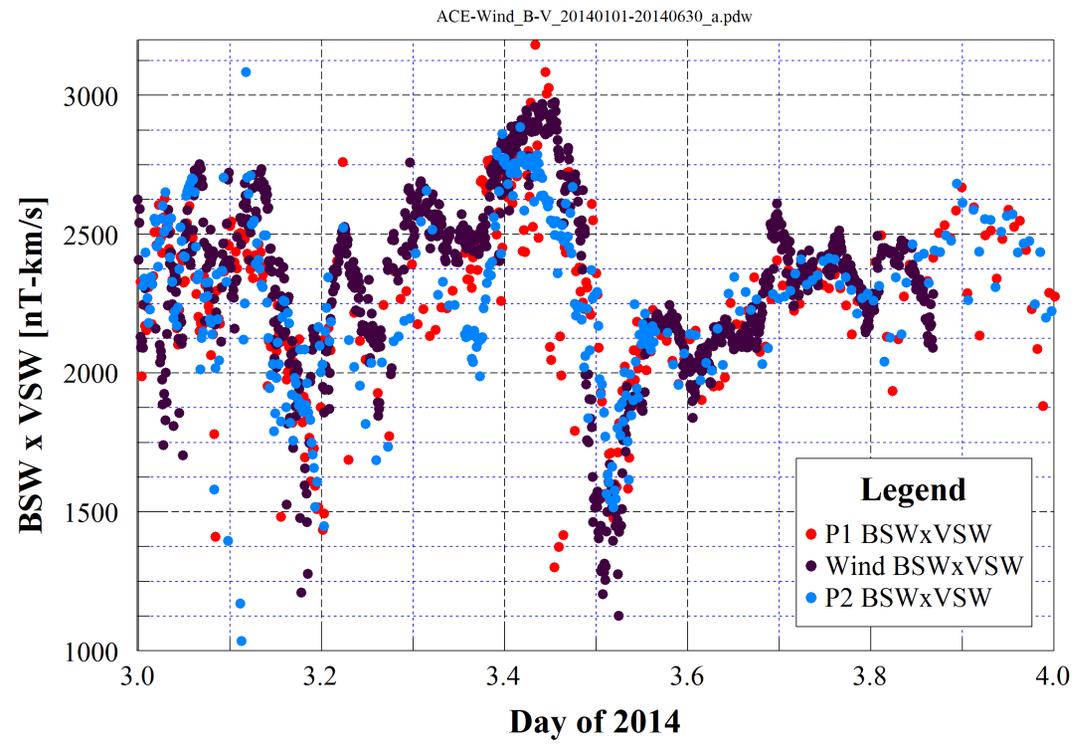
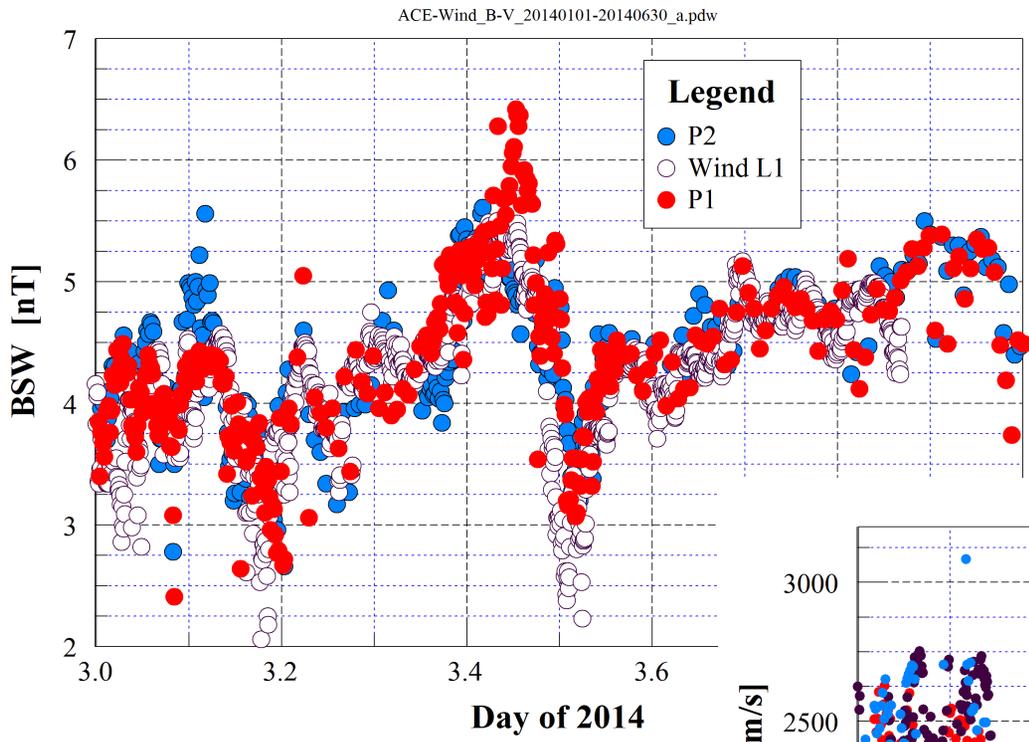
Model O^+ ion beam trajectories (flux vs energy) for strong Bx-By (left) and weak Bx-By (right).

Ion beams are more coherent from localized sources for high Bx-By

Ion sources more widely dispersed for low Bx-By.

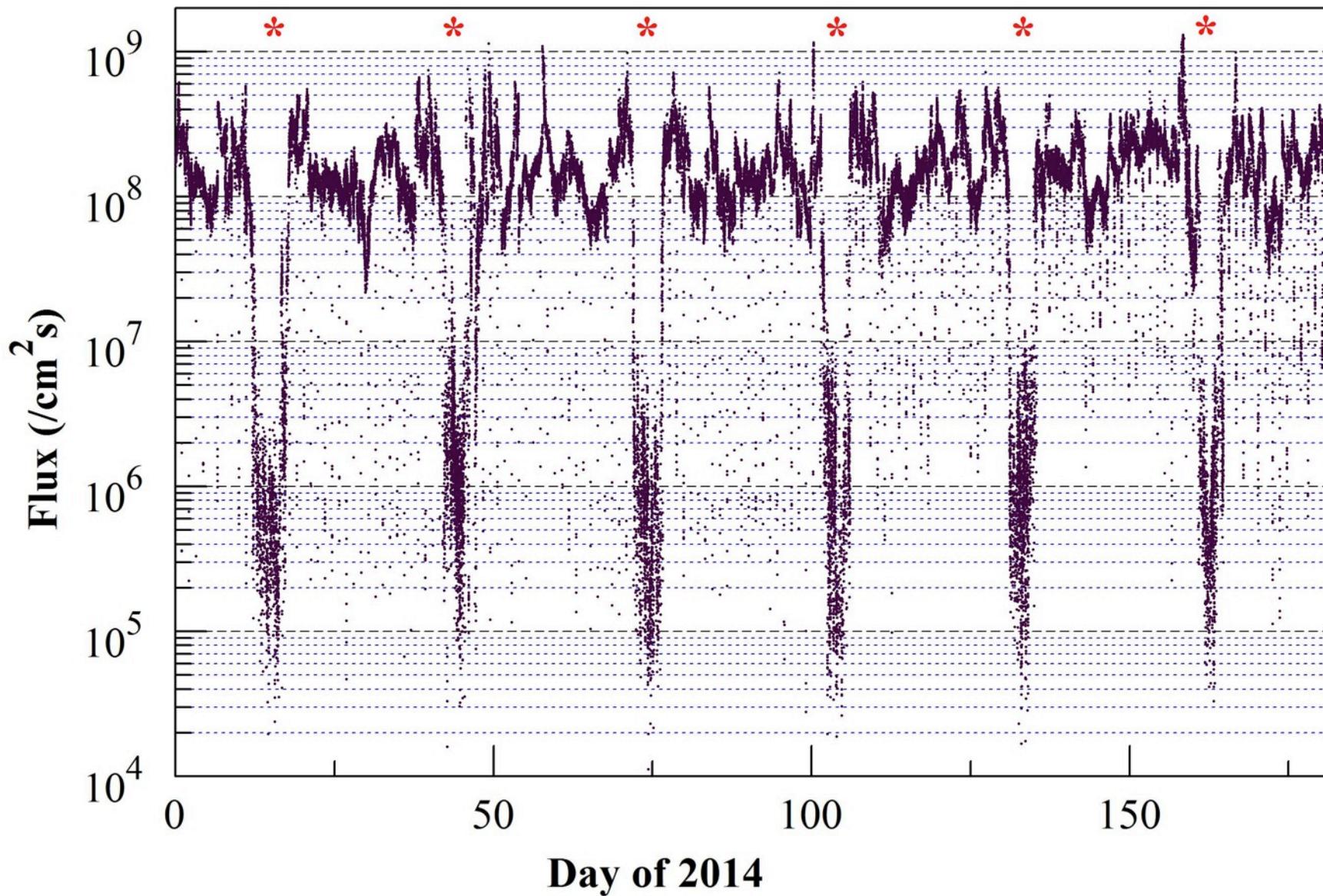
WIMS solar wind fluxes as correlated to upstream solar wind monitors and ARTEMIS P1 & P2 can be used to define best times for highest angular resolution of surface sources



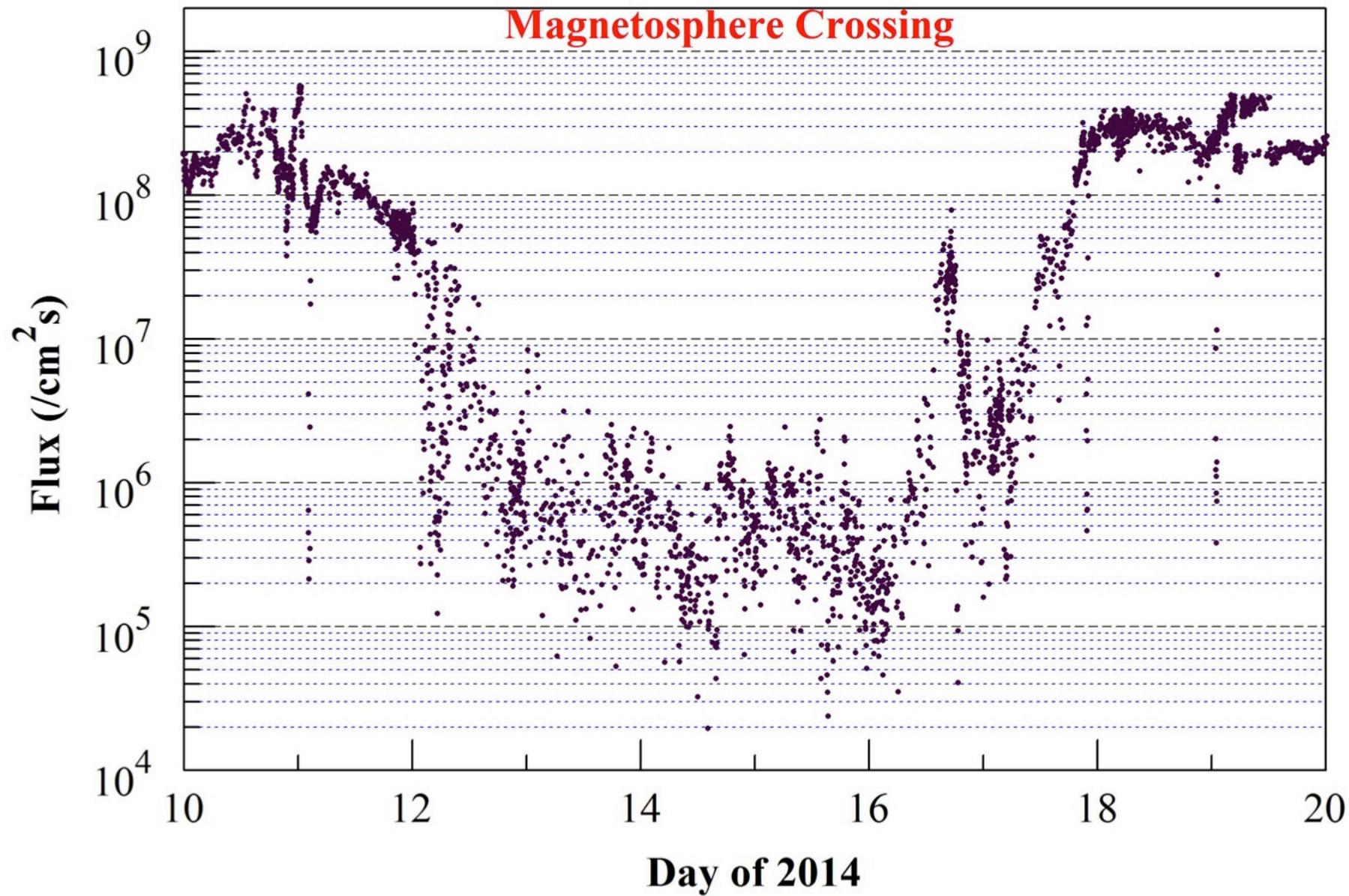


ARTEMIS P1 Proton Flux

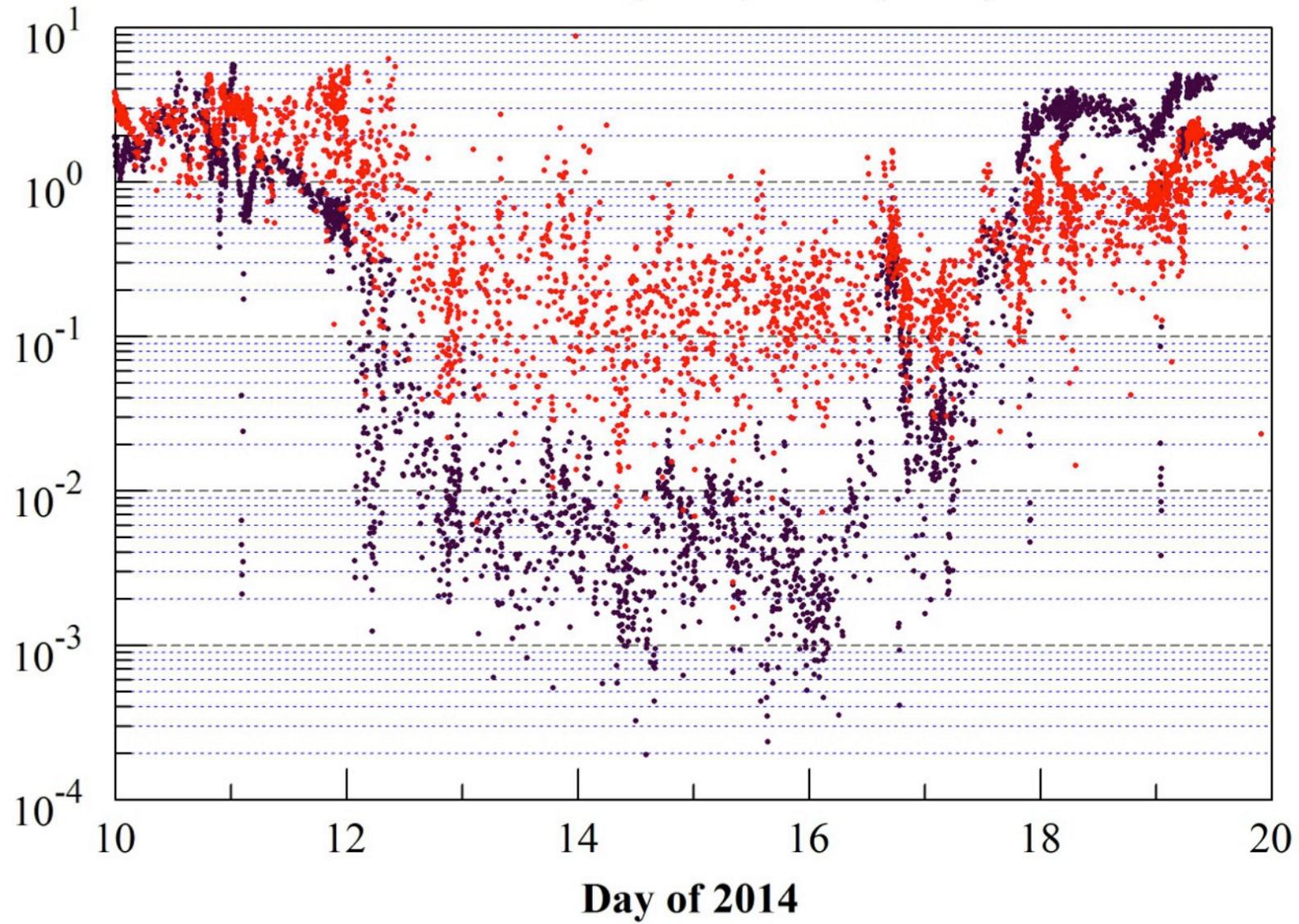
* Magnetosphere Crossings



ARTEMIS P1 Proton Flux



ARTEMIS P1 96s Data
Electric Field Magnitude (mV/m) (red)
Proton Flux (/cm²s) * 10⁻⁸ (black)



ARTEMIS P1 96s Data
Electric Field Magnitude (mV/m) (red)
Proton Flux (/cm²s) *10⁻⁸ (black)
Proton Density (/cc) (green)
Proton Bulk Speed [km/s] /400 (blue)

