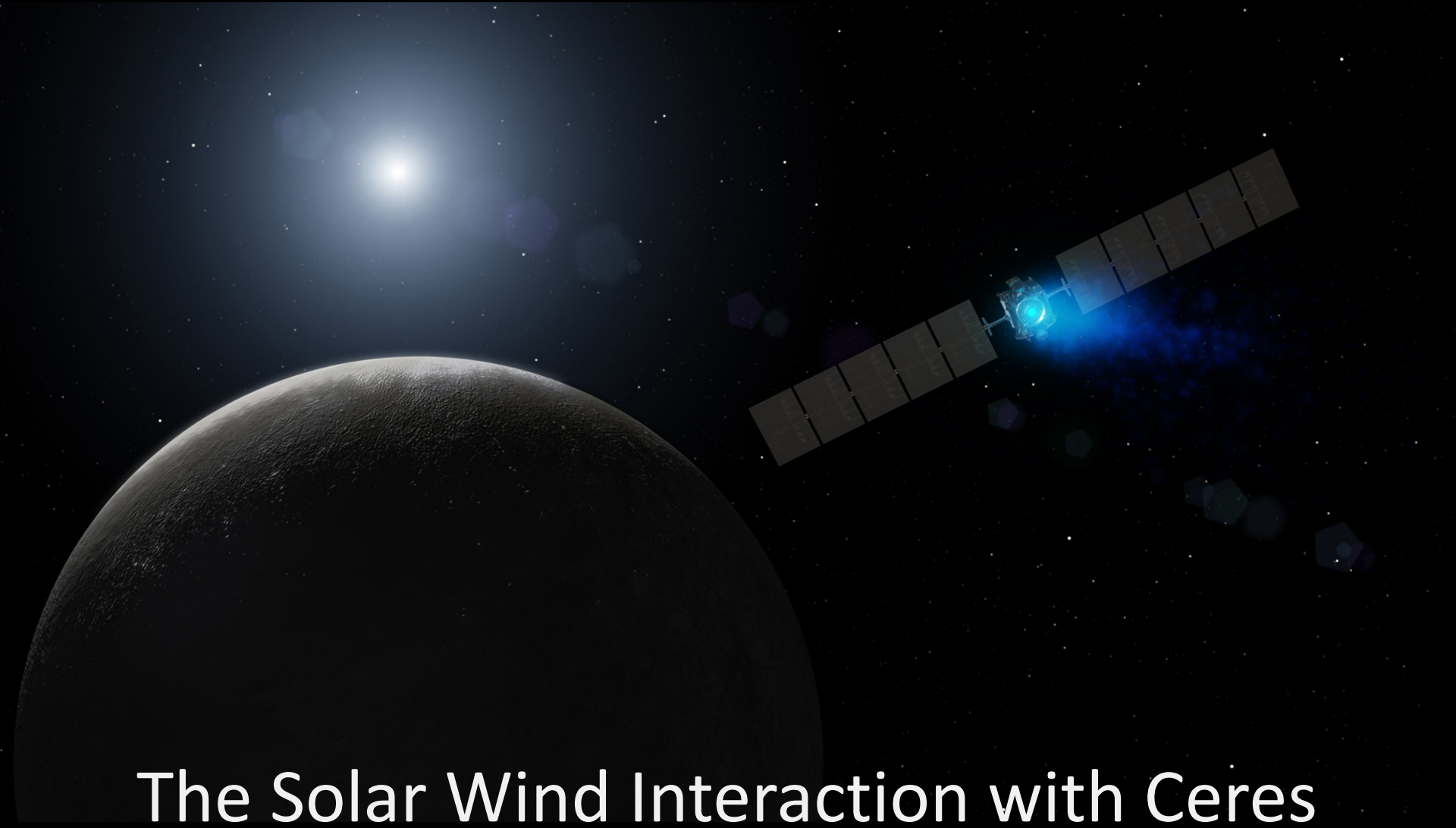
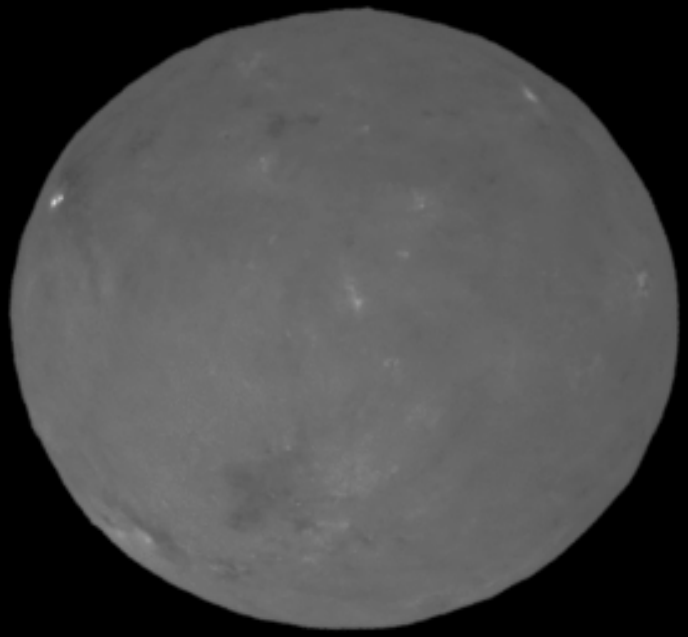


The Solar Wind Interaction with Ceres

M. N. Villarreal, C. T. Russell, Y. D. Jia, T. H. Prettyman, N. Yamashita, C. A. Raymond, J. C. Castillo-Rogez, J. G. Luhmann, M. L. Mays, and C. O. Lee

May 16th, 2018

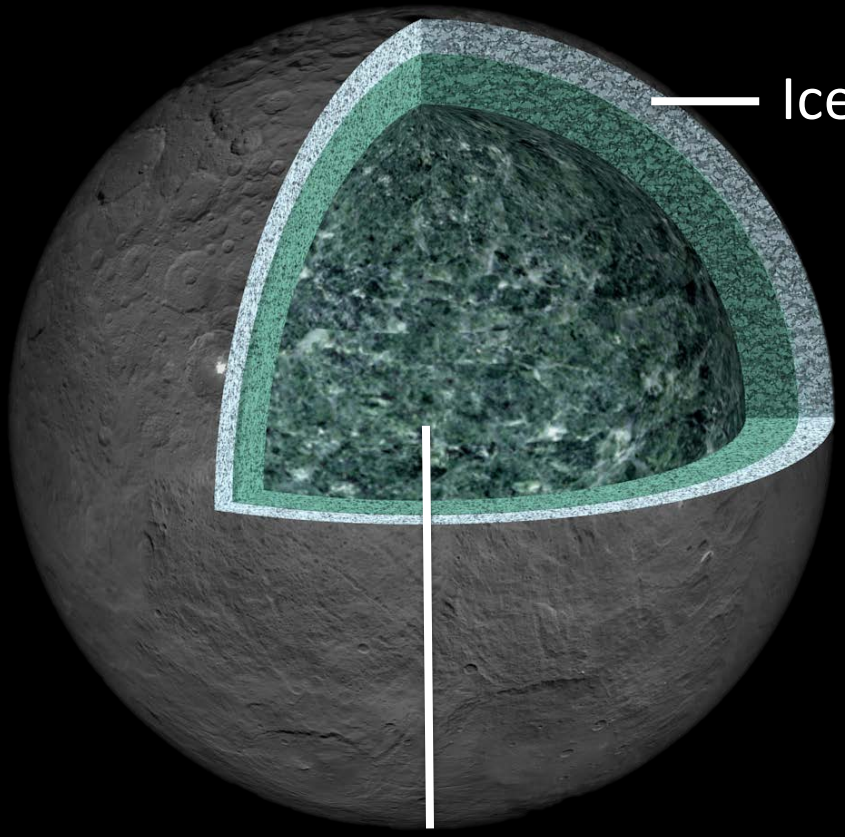
Ceres: An Icy Dwarf Planet



JPL

- Located at ~2.8 AU with ~470 km radius
- Indications of water:
  - Low mean density at 2,160 kg/m^3 [Russell et al., 2016].
  - Exposed ice patch at Oxo Crater [Combe et al., 2016].
  - Bright deposits in cold traps [Platz et al., 2016].
  - Global ice table within 1 m depth (>40 deg) of the surface [Prettyman et al., 2016].
- Ceres is known to have a transient exosphere. [A'Hearn & Feldman (1992), Rousselot et al. (2011), Küppers et al. (2014)].

Internal Structure



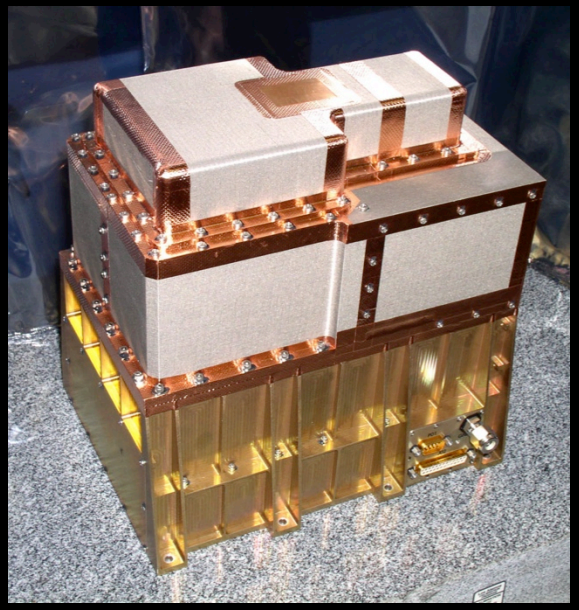
Rocky mantle ~2,400 kg/m^3

Average Density: 2,162 kg/m^3

Dawn Instruments

Framing Camera

SURFACE



Gamma Ray and Neutron Spectrometer

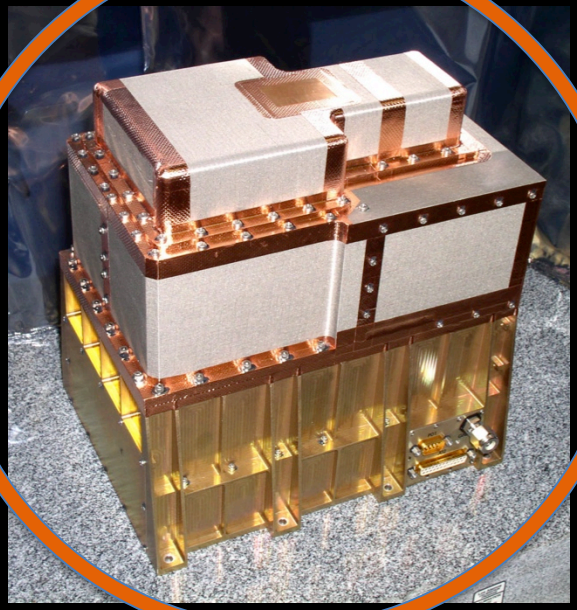
TOP METER

Visible and Infrared Mapping Spectrometer

TOP MILLIMETER

Dawn Instruments

Framing Camera



Gamma Ray and Neutron Spectrometer

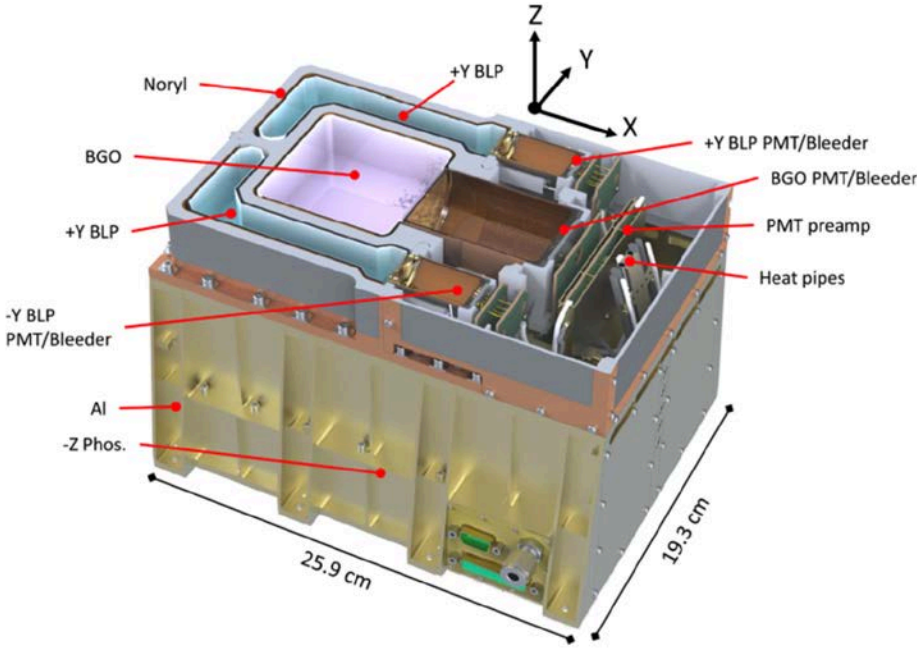
Visible and Infrared Mapping Spectrometer

SURFACE

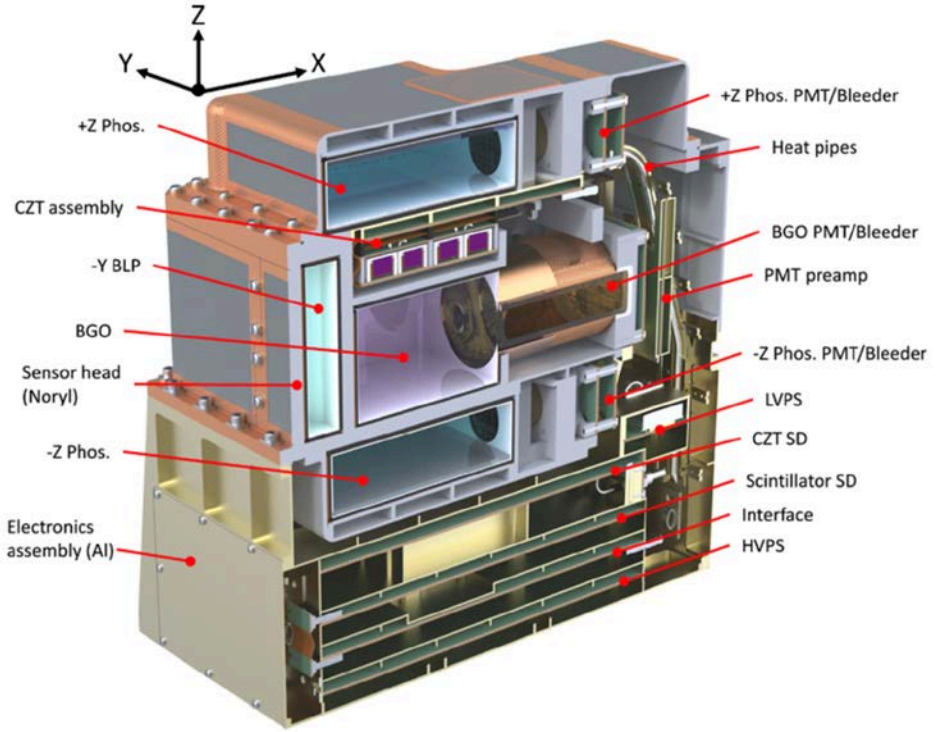
TOP METER

TOP MILLIMETER

Gamma Ray and Neutron Detector

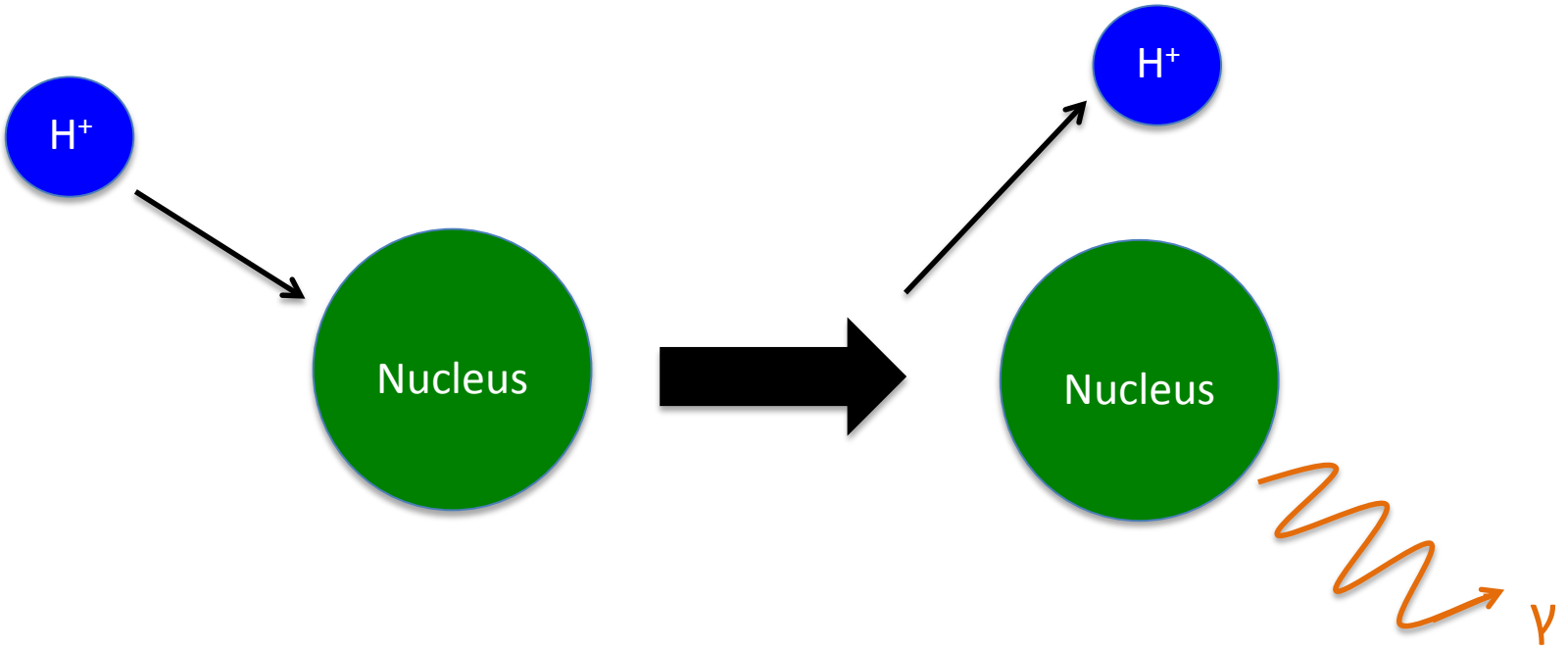


Spacecraft Coordinates

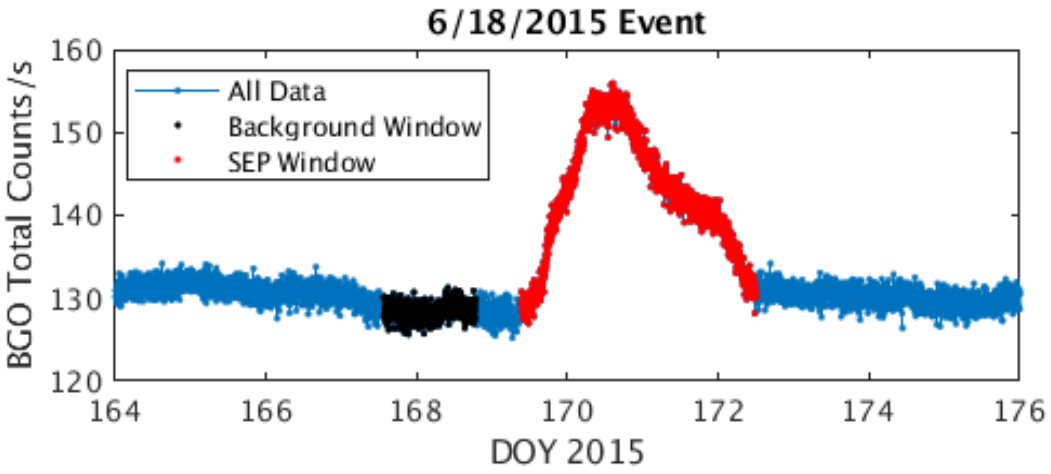


Prettyman et al. (2011)

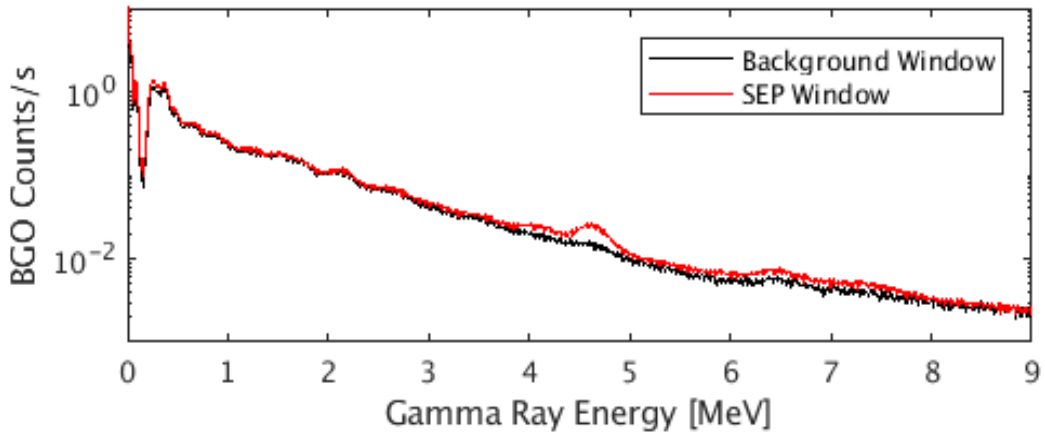
Sensitivity to Energetic Protons

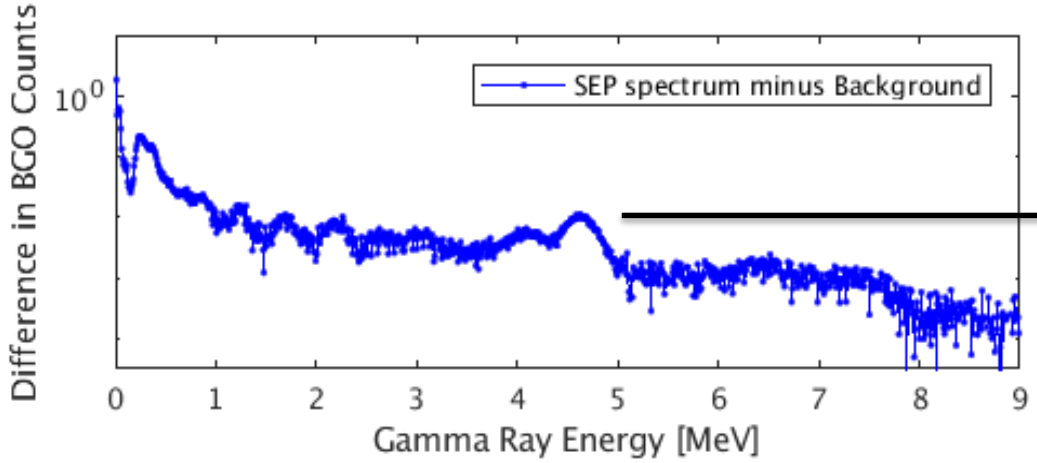


Inelastic collisions of energetic protons with spacecraft material leave nuclei in an excited state. The nuclei then emit gamma rays which are detected by the exterior scintillators and the center BGO. Specifically, the protons will cause an increase in counts in the 4.6 and 6.1 MeV energy channels (C and O peaks) of the BGO due to the composition of the spacecraft which can be used to identify SEP events. The incoming protons must have energies greater than 4.6 and 6.1 MeV to produce gamma rays of this energy through inelastic scattering.



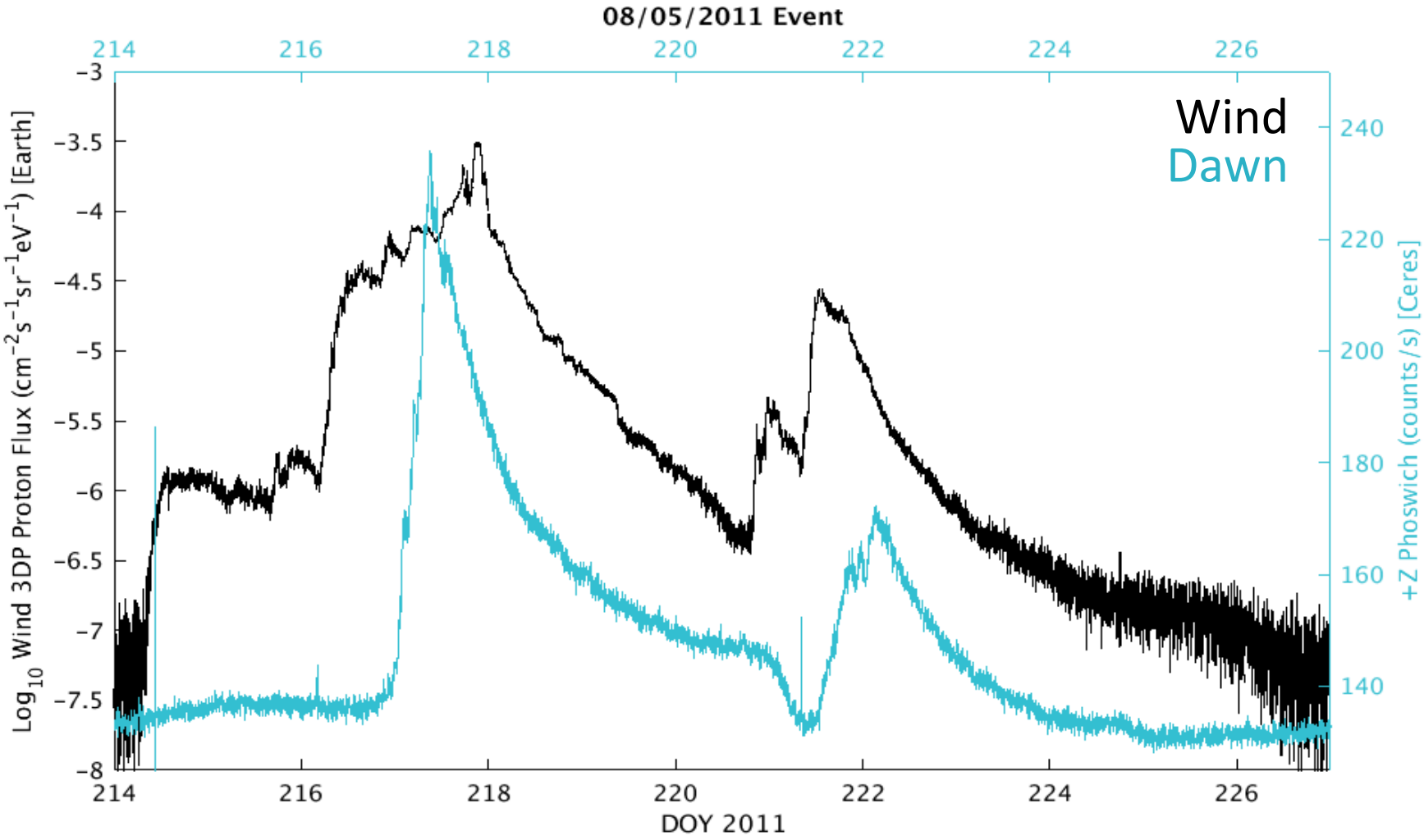
The enhancement in the BGO spectrum is used to identify the presence of energetic protons. Specifically, the protons will cause an increase in counts in the 4.6 and 6.1 MeV energy channels (O and C peaks) of the BGO.



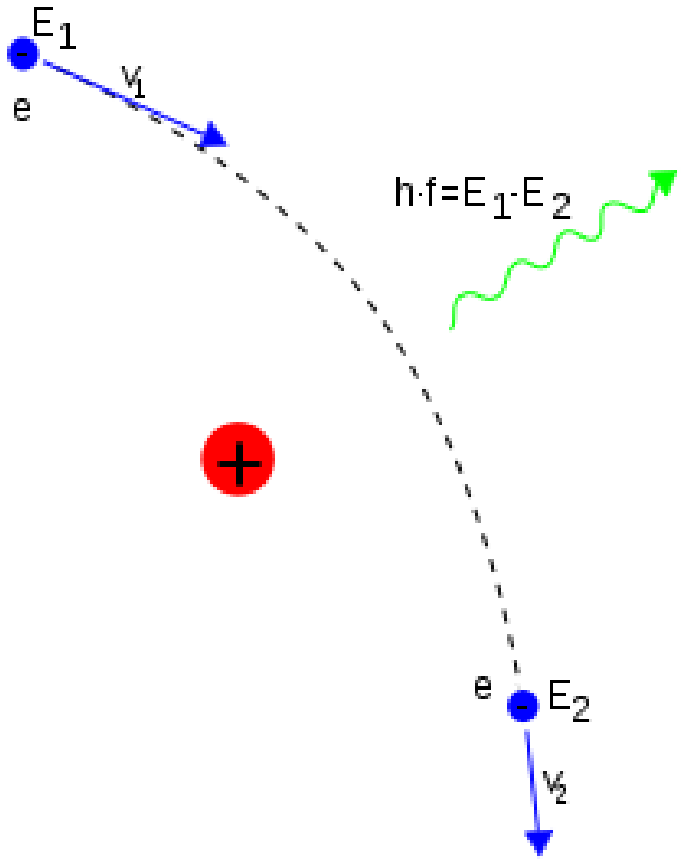


Clear enhancement in elemental peaks

Sensitivity to Energetic Protons



Sensitivity to Energetic Electrons

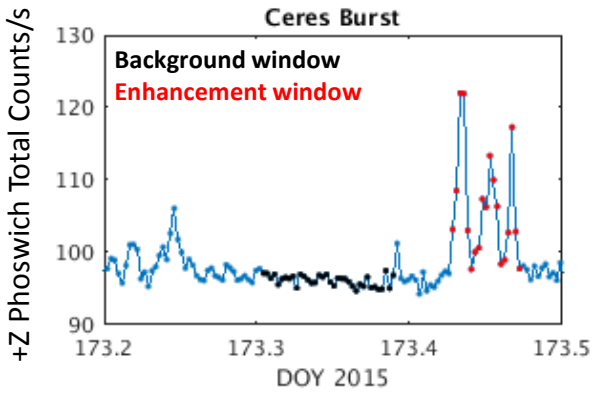


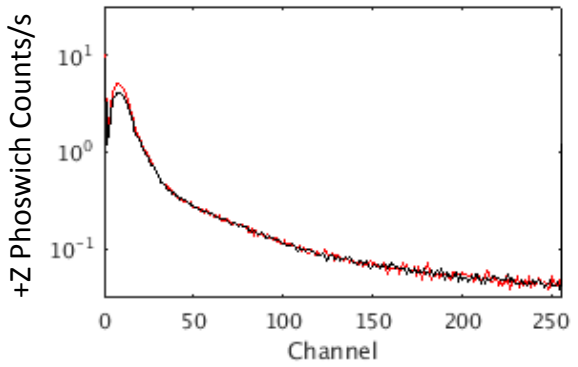
Electrons impacting the spacecraft material are forced to decelerate, causing them to emit bremsstrahlung. The radiation is fully absorbed in the exterior scintillators.

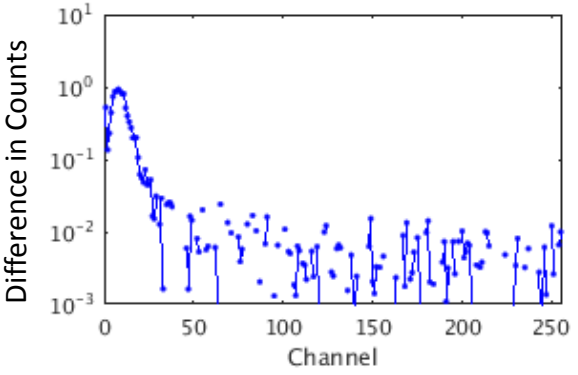
Sensitivity to Energetic Electrons

Subtraction of the background spectrum from the spectrum due to bursts indicates which energy bins the enhancements in counts reside.

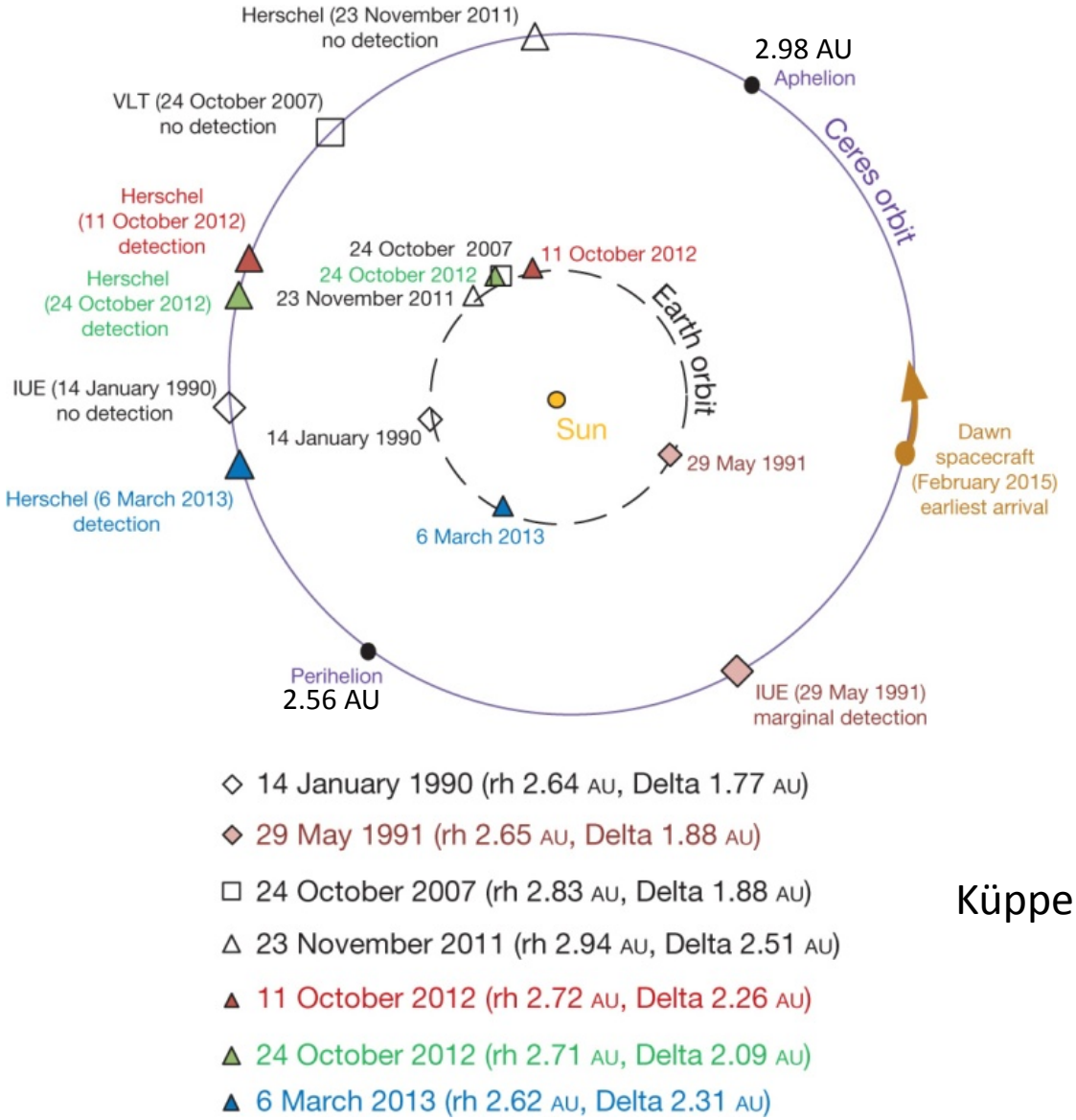
Method was successfully used by Lawrence et al. (2015) to identify energetic electrons with MESSENGER's Gamma Ray and Neutron spectrometer.





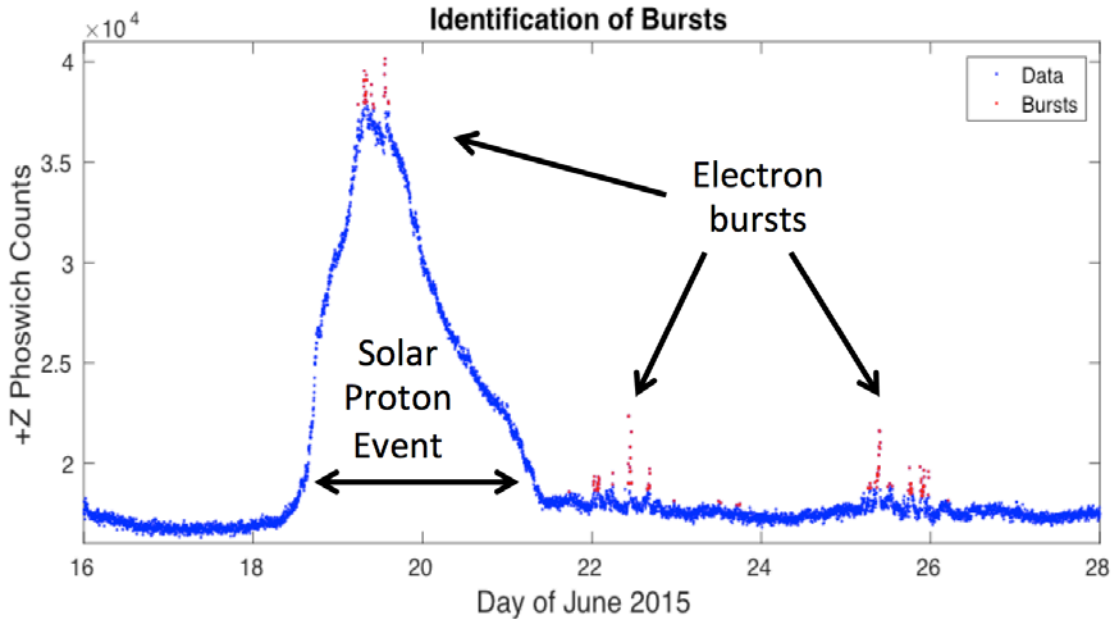


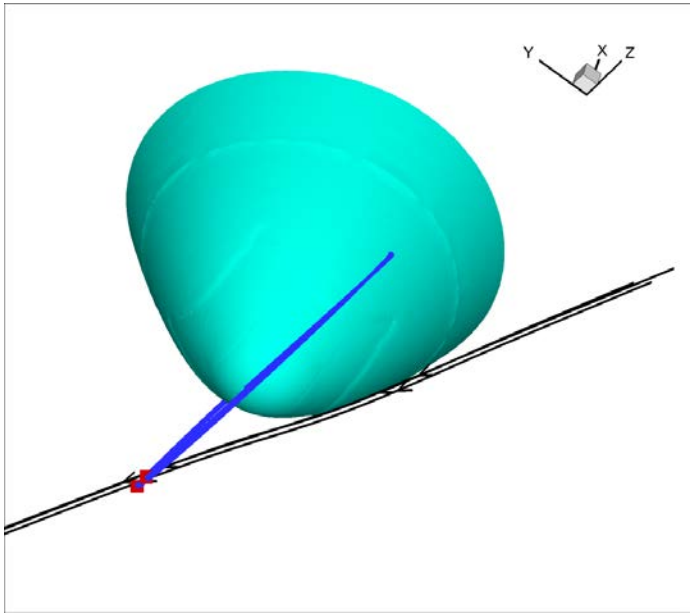
Previous detections of Ceres' Exosphere



Küppers et al. (2014)

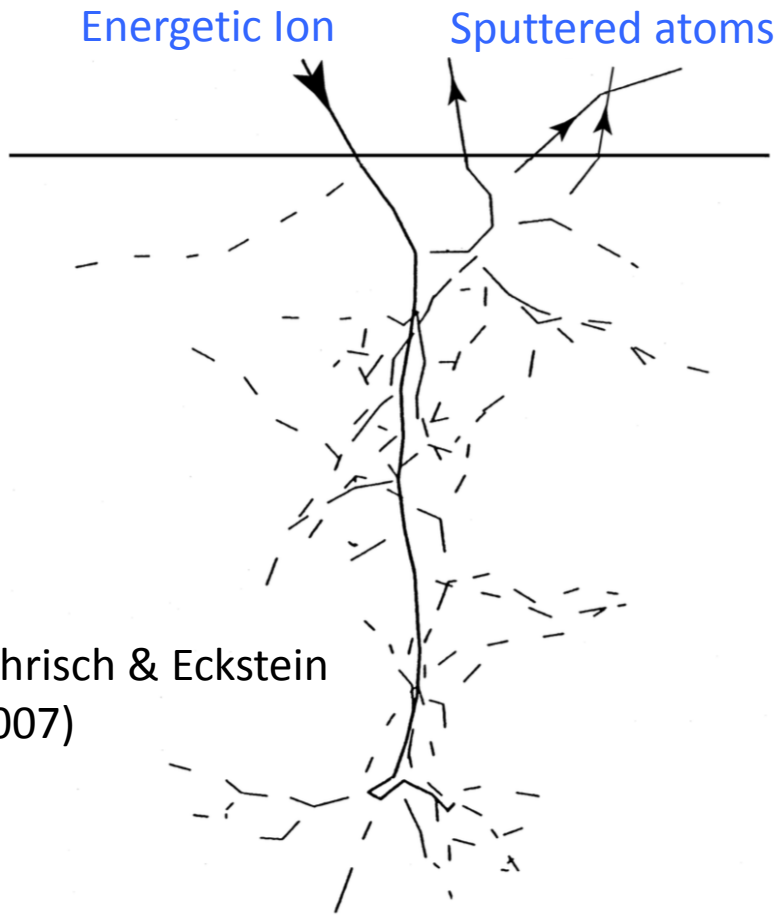
Evidence of an Exosphere following a SEP Event



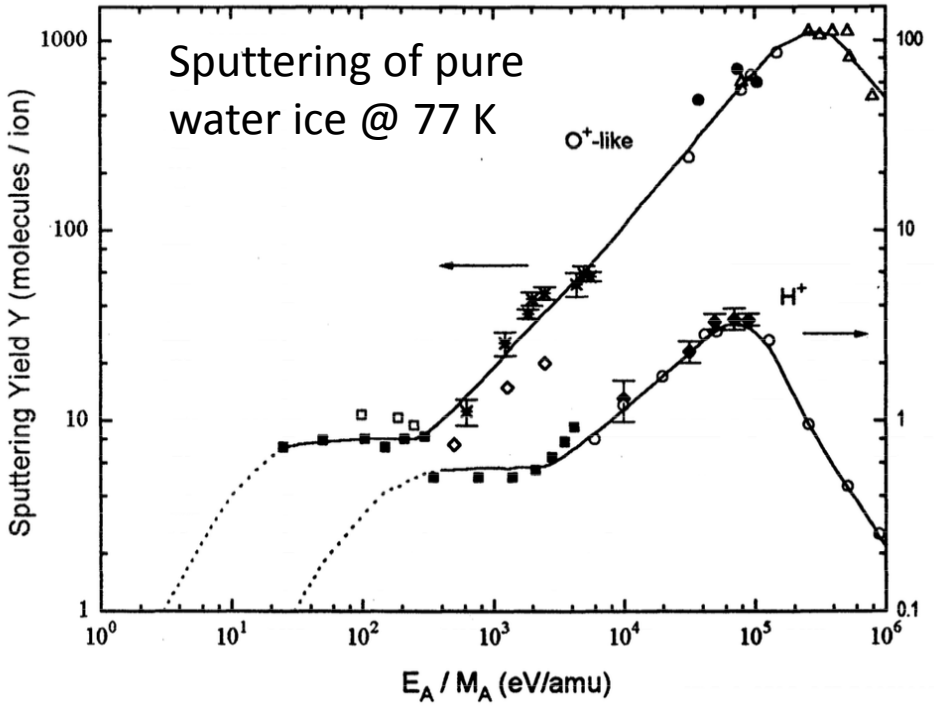


- During Survey orbit, GRaND saw distinct bursts in its exterior scintillators between June 18th-26th
- Dawn was at a distance of ~10 R_C away from Ceres (4,400 km alt)
- First appearance of spikes concurrent with a solar energetic particle event

Can Solar Energetic Particle Events Create an Exosphere?

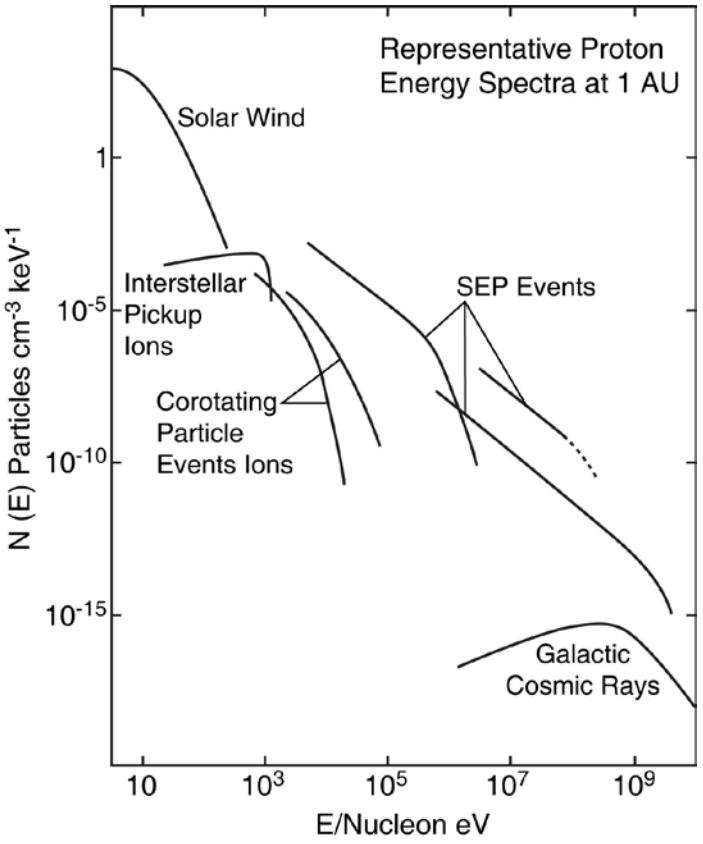


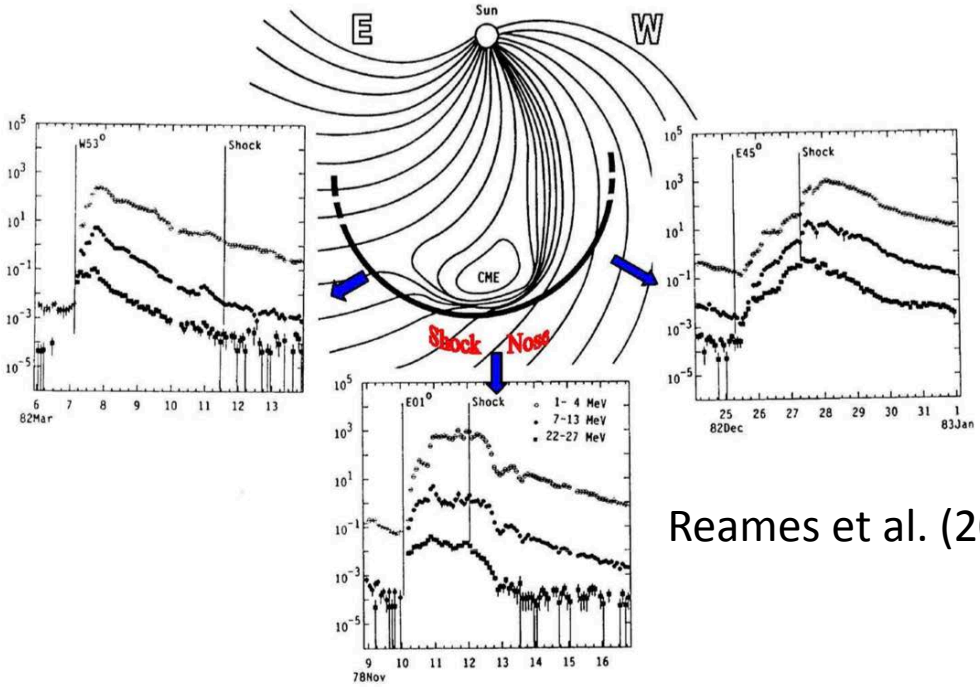
Behrisch & Eckstein (2007)



Shi et al. (1995)

Ceres' Solar Wind Environment

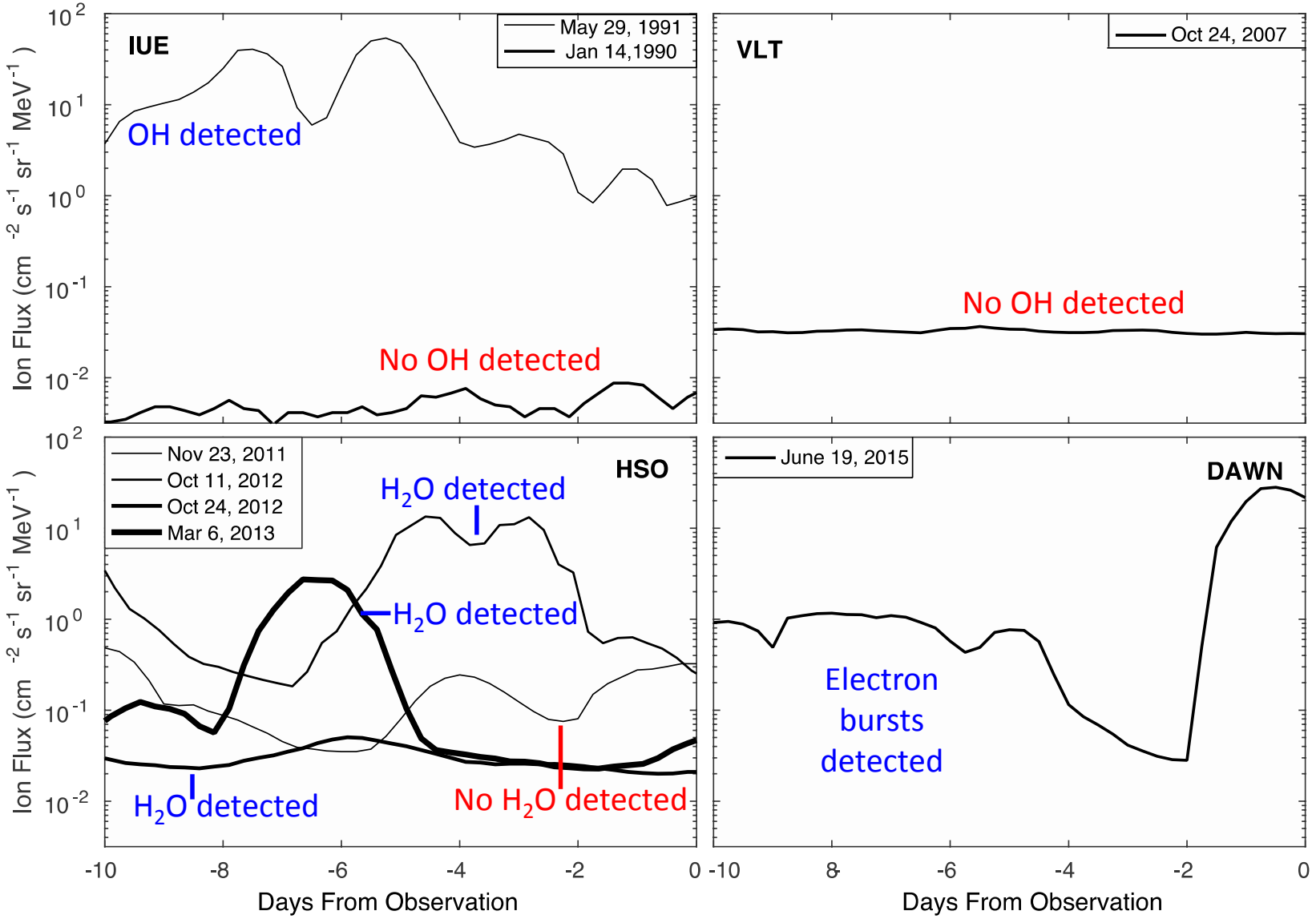




Reames et al. (2013)

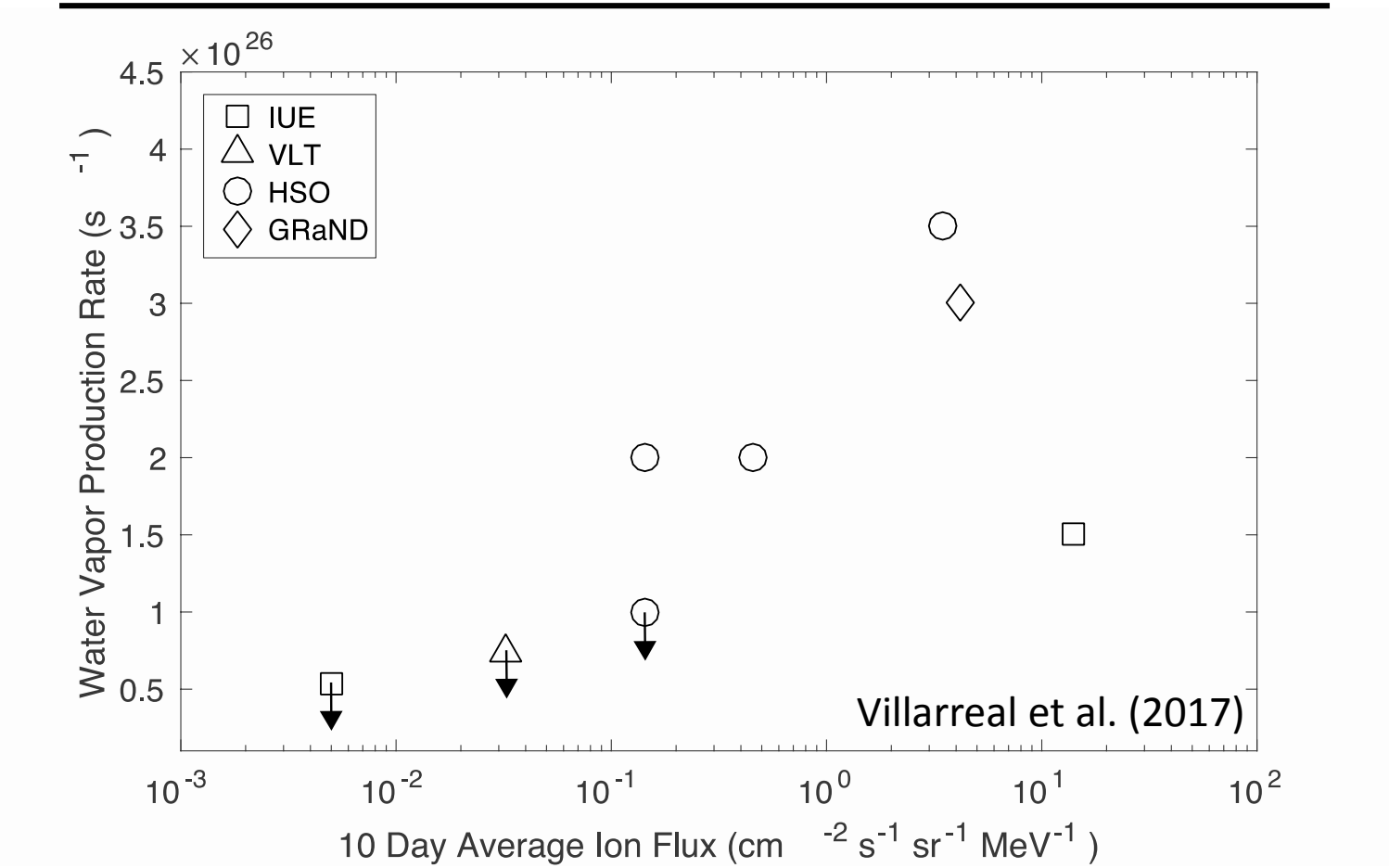
Energetic protons >1 keV are capable of sputtering water molecules from the surface. Particles of this energy jump by orders of magnitude during solar energetic particle (SEP) events. SEPs can be produced by solar flares or coronal mass ejections, so their occurrence is sporadic.

Solar Wind Conditions Prior to Observing



Proton fluxes 2-5 MeV at 1 AU during each exospheric observation.

Correlation with SEP events



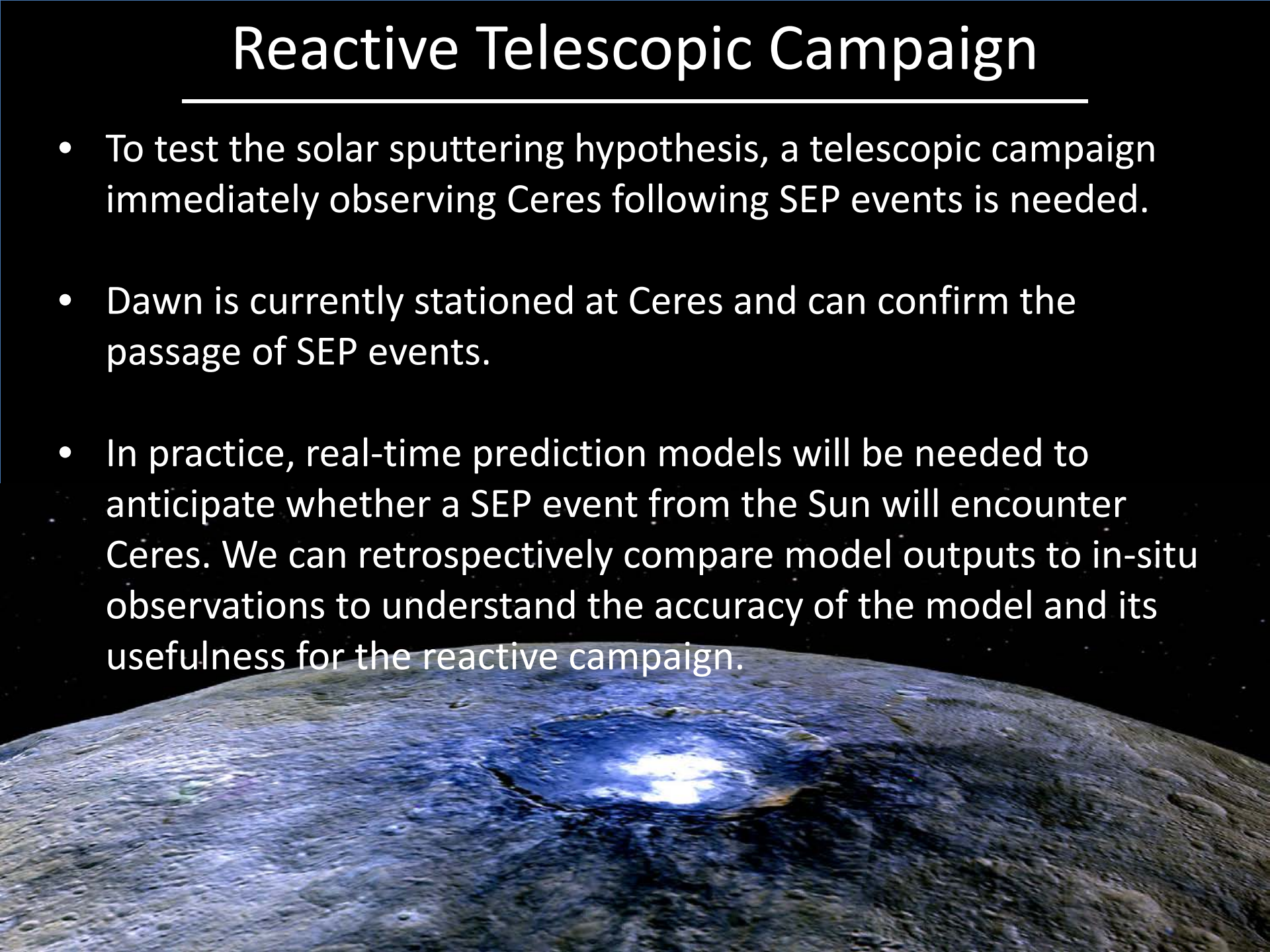
This figure shows the correlation of the proton flux at 1 AU with the published water vapor production rates. Larger production rates are present after the occurrence of an SEP event.

Reactive Telescopic Campaign

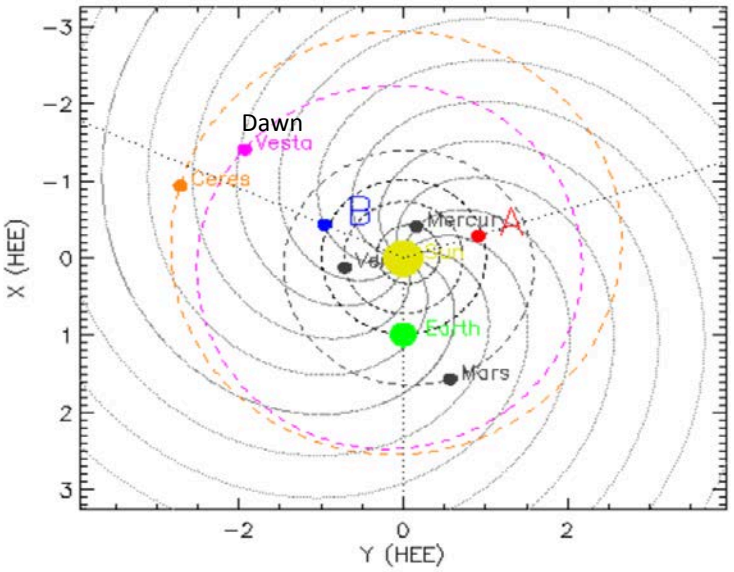
- To test the solar sputtering hypothesis, a telescopic campaign immediately observing Ceres following SEP events is needed.

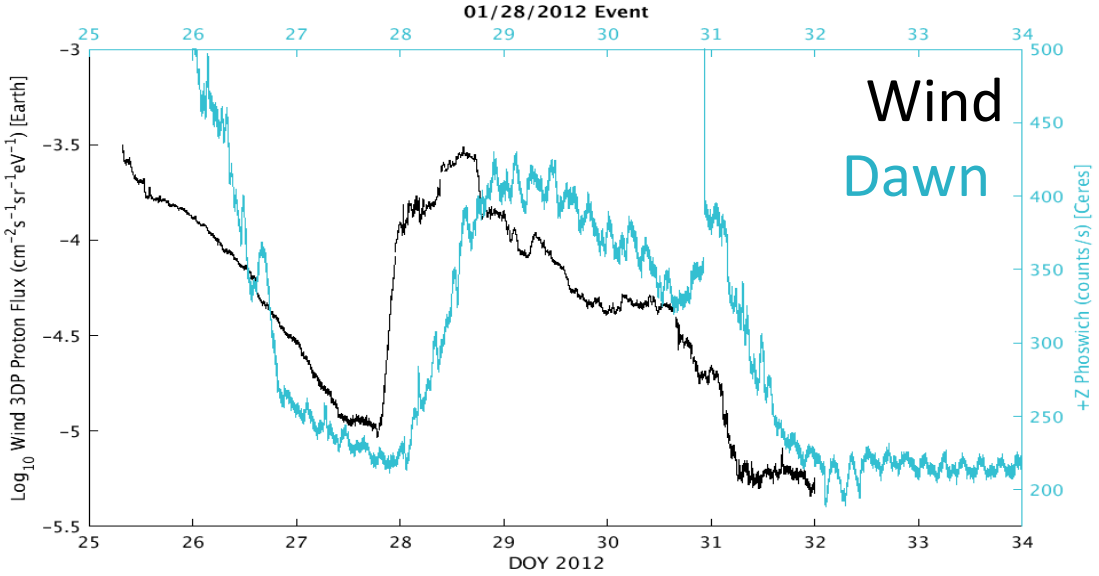
- Dawn is currently stationed at Ceres and can confirm the passage of SEP events.

- In practice, real-time prediction models will be needed to anticipate whether a SEP event from the Sun will encounter Ceres. We can retrospectively compare model outputs to in-situ observations to understand the accuracy of the model and its usefulness for the reactive campaign.

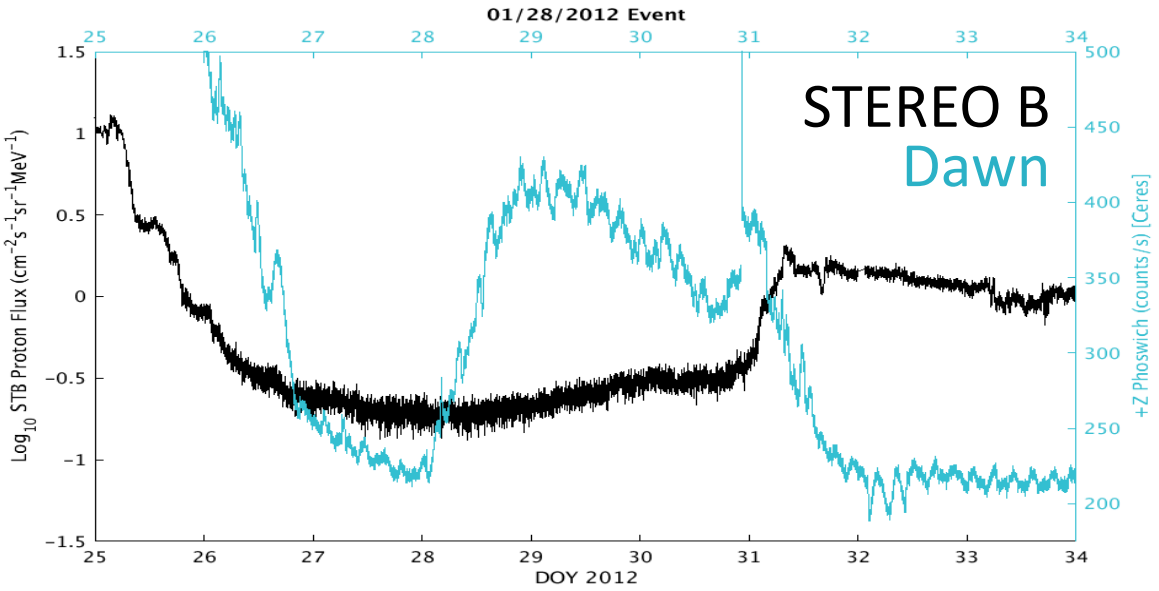


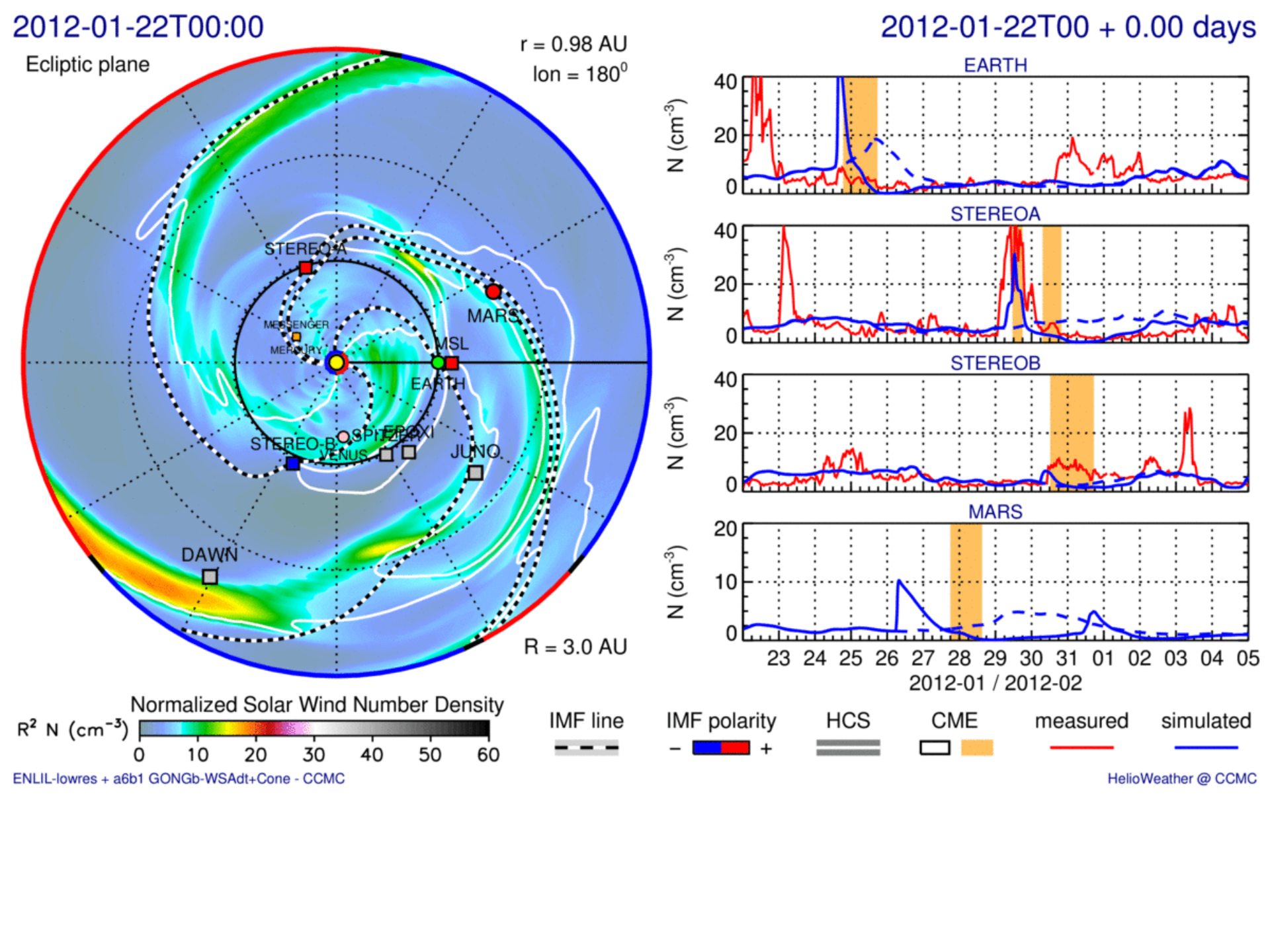
January 28, 2012 Event

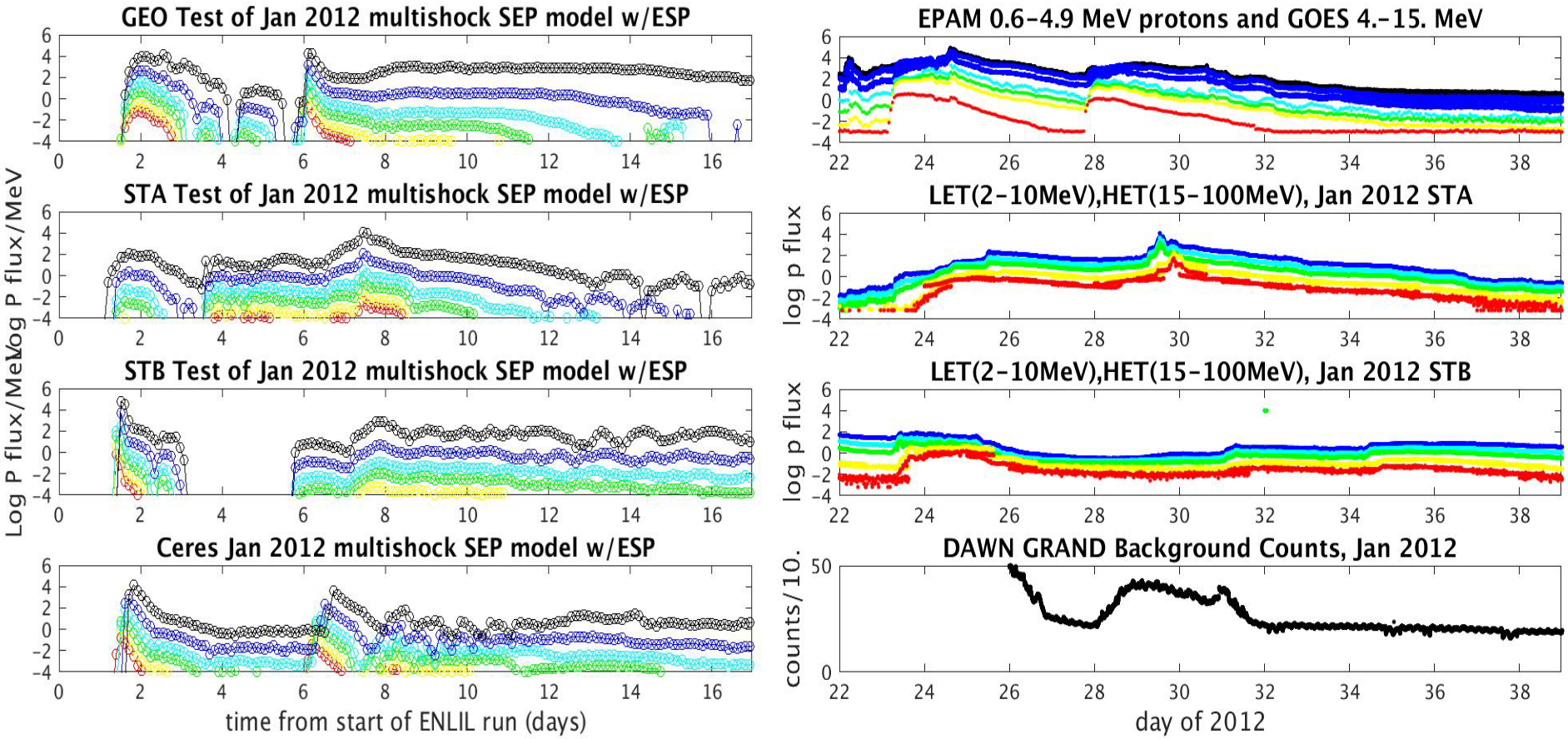




Relative locations 1/28/2012. Dawn (at Vesta) is near radial alignment with STEREO B; Dawn's magnetic footprint is in between that of STEREO B's and Earth's. The responses recorded by Wind and Dawn are very similar while STEREO B does not experience an event on the 28th.




2012-01-22T00:00
Ecliptic plane
r = 0.98 AU
lon = 180⁰
STEREOA
MARS
MESSENGER
MERCURY
MSL
EARTH
STEREO-B
SPITZER
VENUS
EPOXI
JUNO
DAWN
R = 3.0 AU
2012-01-22T00 + 0.00 days
EARTH
STEREOA
STEREOB
MARS
N (cm-3)
23 24 25 26 27 28 29 30 31 01 02 03 04 05
2012-01 / 2012-02
Normalized Solar Wind Number Density
R² N (cm⁻³)
0 10 20 30 40 50 60
IMF line
IMF polarity
HCS
CME
measured
simulated
ENLIL-lowres + a6b1 GONGb-WSAdt+Cone - CCMC
HelioWeather @ CCMC



1.2 MeV 8.6 MeV
2.6 MeV 17 MeV
5.1 MeV 26 MeV

Left: SEPMOD predictions for the arrival of SEPs at various observer locations for the January 2012 event. Right: SEPs measured by in-situ spacecraft. Day 0 of Enlil corresponds to DOY 22 on the right hand side.

Summary

- Evidence shows Ceres' transient exosphere may be produced by Solar Energetic Particles sputtering water ice at or near Ceres' surface.
- Dawn is currently at Ceres and is capable of monitoring and confirming the passage of SEP events.
- We are currently assessing how spacecraft at 1 AU can be used as a proxy for the arrival of SEPs at Ceres for a future reactive campaign.