SOLAR ENERGETIC PROTON EVENTS AS THE SOURCE OF THE TRANSIENT EXOSPHERE OF CERES. M. N. Villarreal[1], C. T. Russell[1], J. G. Luhmann[2], W. T. Thompson[3], T.H. Prettyman[4], M. A'Hearn[5], M. Küppers[6], L. O'Rourke[6], [1]Earth, Planetary and Space Sciences, University of California, Los Angeles, 405 Hilgard Avenue, Los Angeles, CA 90095-1567, USA (mvillarreal@igpp.ucla.edu), [2]Space Sciences Lab, University of California, Berkeley. [3]Goddard Space Flight Center, Greenbelt, MD. [4]Planetary Science Institute, Tucson, AZ. [5]University of Maryland, College Park, MD. [6]European Space Astronomy Centre, Eropean Space Agency, Villaneuva de la Canada.

Introduction: Detections of water vapor near Ceres have shown the exosphere to be time varying. The International Ultraviolet Explorer (IUE) first detected OH emission in 1991, but not on its first attempt in 1990 [1]. A later observation in 2007 with the Very Large Telescope (VLT) was unsuccessful at detecting OH [2]. The launch of the Herschel Space Observatory (HSO) enabled a new set of water absorption observations, again the first of which was unsuccessful, the second was successful showing a strong signal, and the third and fourth resulted in detections with a weaker signal [3]. The apparent random variations in exospheric production rates seen by IUE, VLT, and HSO cannot be explained by the variation of the sublimation rate on Ceres due to its heliocentric distance. Estimates of the photon-induced sublimation rate of Ceres' ice table show it to be orders of magnitude below the reported production rates [4]. However, a clue to the controlling factor of the Cerean exosphere has been provided by the Dawn mission.

While Dawn was not instrumented to detect an exosphere, it can detect one indirectly when the exosphere interacts with the solar wind. This interaction slows down the supersonic solar wind abruptly, forming a bow shock. Solar wind electrons can be reflected and accelerated at the bow shock surface, forming a beam. Dawn detected this beam on two occasions [5] with its Gamma Ray and Neutron Detector (GRaND) [6]. Magnetohydrodynamic models of the observed interaction show the water vapor production rate implied by the size of the shock to be comparable to that observed by IUE and HSO [7].

The electron bursts seen by Dawn occurred shortly after GRaND had sensed strong solar proton events at Ceres [5]. This is important because water ice can be sputtered by these very energetic protons, the flux of which are highly variable. A solar proton event could produce a transient atmosphere that would last on the order of a week before it disappeared [8].

We analyze the correlation between the observed production rates and the energetic proton flux preceding each observation using space-based measurements near 1 AU. Since Solar Energetic Particle events extend over a broad range in longitude and the remote observer and Ceres are never on opposite sites of the sun,(Figure 1), the Earth provides a good monitor for solar disturbances at the time of the IUE, VLT, and HSO observations. We have examined the records of solar energetic proton data for both positive and negative detections of water in Ceres' atmosphere and conclude that solar proton events occurred in conjunction with positive detections, and were absent during negative detections. Since Dawn has seen the same correlation and has not detected evidence for active plumes, optically or thermally, we conclude that the solar protons' variability explains the transient behavior of the Ceres water exosphere.

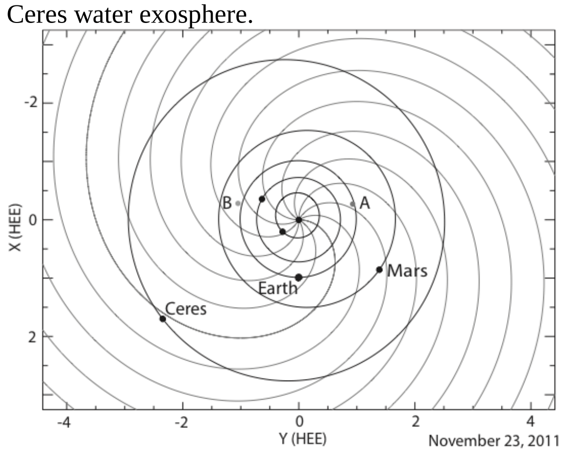

Figure 1. Locations of the planets and solar satellites relative to Ceres for November 23, 2011. All attempts to detect water vapor at Ceres were around the time of Earth's closest approach to Ceres.

Results: Water ice can be sputtered by protons with energies ~1 keV-1 MeV [9]. In the solar wind, it is the higher energy protons that are the most variable. We inspect the proton fluxes for energies between ~100 keV-4 MeV for a 10 day period prior to each observation, the timescale for which an exosphere is expected to last at Ceres [8]. We use the Solar Terrestrial Relations Observatory (STEREO) Low Energy Telescope (LET) [10], the Advanced Composition Explorer (ACE) Electron, Proton, and Alpha Monitor (EPAM) [11]; Wind 3DP [12]; and the OMNI data provided by the Space Physics Data Facility [13]. Figure 2 shows examples of ~2-4 MeV protons present during the IUE and HSO detections. The energetic proton flux during the 1991 IUE observation is about three orders of magnitude larger than the 1990 detection. Similarly, the October 11, 2012 observation has a flux about an order of magnitude greater than that of the November 23, 2011 non-detection.

The strongest absorption feature seen by HSO [3] on October 11th, 2012 corresponds to the period with the highest ion flux bombardment. After the ion flux drops back to its normal value, the water signal observed significantly becomes weaker by October 24th, 2012. Likewise, the water absorption feature was smaller during the March 6th, 2013 detection [3], when the energetic ion flux was less than that prior to the October 11th, 2012 detection.

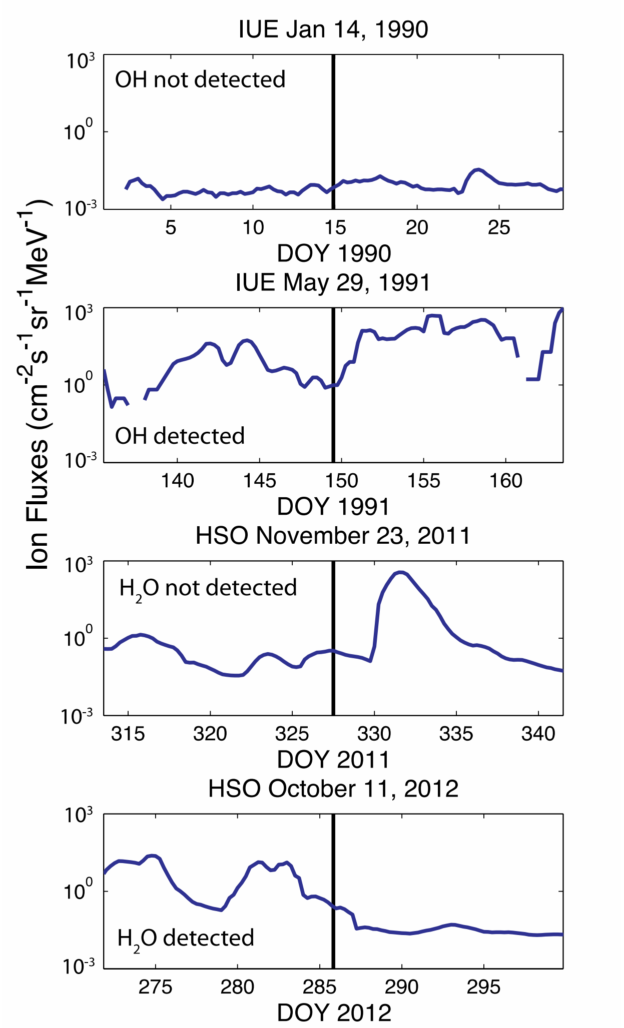

Figure 2. Month long Ion Fluxes vs Time for four Ceres observations centered on the observations. Solid black line indicates time of observation [1,3]. Proton fluxes with energies capable of sputtering water from the surface are noticeably higher during periods of positive water detection. The IUE data are for protons 2-4 MeV [11] and the HSO data are for protons 1.91-4.75 MeV [9].

Conclusions: Sublimation by solar photons is inconsistent with the IUE observations as Ceres was equidistant from perihelion during these observatons. The increased sputtering rate during the 1991 detection provides a reasonable explaination for the difference in the estimated water production rate. Similarly, for the positive water detections by HSO, the water signature decreased, rather than increased, with distance from the sun, again inconsistent with sublimation produced by solar heating. Our results show that solar proton sputtering provides the strongest evidence for control of the Ceres' exospheric production. These protons may be sputtering water ice from exposed ice patches on the surface [14], water ice in polar cold traps [15, 16], or water ice near the surface.

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