LENA for Science

Geospace contains a mixture of low-density gases and plasmas of both solar and terrestrial origin. The terrestrial gas and ionospheric plasma is at a base temperature ~1000-3000 K (0.1 - 0.3 eV), depending on solar EUV flux activity. Solar plasma arrives at Earth's magnetosphere, after passing through a bow shock, at ~ 3 x 10^6 K (300 eV). Auroral processes raise ionospheric topside plasma temperatures up to ~ 10^5 - 3 x 10^6 K (10-300 eV). Fast neutral atoms are produced in any volume where energetic ions and relatively cold gas coexist and undergo charge exchange. Low energy neutral atoms (LENA) are defined largely by the observational technique required for their observation. Unlike medium and high energy neutral atoms, those with kinetic energy below 1 keV cannot penetrate the thinnest foils used for secondary electron emission to detect these charge-free particles. Using a conversion surface that produces negative ions from incident neutrals, the LENA Imager makes accessible to observation the energy range from 20-1000 eV, including both arriving solar wind ions and ions escaping the ionosphere owing to acceleration by auroral processes. The LENA Imager aperture contains a collimator/charged particle rejector that suppresses charged particle entry below about 50-100 keV [Moore et al., 1999 SSR].

LENA attained nominal science operations on 5 May 2000. On 6 June, 2000, an intense solar flare was observed on the Sun followed by a full-halo CME. The shock driven by this CME was observed at the L1 point, 235 R_E upstream from the Earth, by the ACE spacecraft, NASA's interplanetary monitor, at about 08:42 on 8 June. About forty minutes later, this disturbance passed the Earth where it and its effects were observed by the IMAGE spacecraft.

Figure 1 is a spin spectrogram (collapsed in polar angle relative to the spin axis) illustrating several features observed by LENA on 8 June, including the period when the CME passed the Earth. The x axis is universal time in hours; the y axis is roll or spin angle away from the nadir; and the color or z axis is the flux of LENA entering the instrument. The pair of yellow lines indicates the apparent angular range of the Earth as a function of time. For positive spin angles the view is generally sunward, while for negative spin angles the view is generally tailward of the Earth during the bulk of this period while the spacecraft is near apogee and North of the ecliptic plane. Periods of significant contamination by penetrating radiation belt particles (mostly MeV electrons) have been blanked from the spectrogram. In Figure 1, the flux feature starting out near 90 degrees spin angle and drifting towards 180 degrees over the first part of the plot is the "Sun pulse" and marks the spin sector of the Sun relative to the Earth as IMAGE makes the transition from apogee towards perigee. (put in some discussion of sun pulse characteristics). A brightening of the Sun pulse occurs at about 09:15 hrs, about the time the shock observed by ACE reaches the Earth.

Figure 2 shows a triplet of individual images from selected times during this pass. The first image shows the LENA flux prior to CME arrival. Here the perspective is from several R_E above the ecliptic plane, looking generally down on the dayside equatorial region. The main feature of interest in the first image is the flux from the direction of the sun, but weak emissions can be seen to emanate from the region around the Earth as well. The next image shows the situation after CME arrival, indicating the increase in the "sun pulse" emissions by a factor of 2-3, and considerable increase of the emissions from the region extending both sunward/southward and tailward/northward from the Earth. [The final image shows a perigee pass perspective of the south polar regions, showing increased LENA emissions on a closeup basis…].

Figure 3 shows, for a TBD hour interval on June 8, 2000, the LENA flux summed over energy and over polar angle within spacecraft spin sectors corresponding to the Sun (left hand y-axis) and Earth (right hand y-axis). At the time the shock passed the spacecraft, there was an enhancement in both the Sun and Earth directions. About 35 minutes later, there was a second brightening from the Earth direction. We interpret the enhancement from the Sun direction as LENA originating from the solar wind and the enhancements from the Earth direction as neutral atom emission from the Earth's ionosphere or other extended plasma regions near the Earth, resulting from the shock's interaction with geospace.

There are a number of potentially important interplanetary sources of neutral particles that could contribute to the neutral solar wind as seen by the IMAGE/LENA Imager. These are neutral solar gas carried along with the solar wind, interstellar gas penetrating the solar system from the local interstellar medium, outgassing from interplanetary dust and, for Earth orbiting satellites, the Earth's exosphere or geocorona (clarify) [Gruntman, M.A., Neutral solar wind properties: Advance warning of major geomagnetic storms, J. Geophys. Res., 99, 19,213-19,227, 1994]. The solar wind neutral flux inferred is similar to that derived in this paper, i.e. ~ .3-1.0 x 10^{-4} x F_{SW}. The uncertainty results from uncertainty in the energy of the observed LENAs. A neutral solar wind component could reach 4keV during the high speed solar wind intervals after shock passage. The LENA Imager (not do this?) was not calibrated beyond 1 keV incident energy. On the other hand, observations of a substantial O response is interpreted as sputtering of O from the conversion surface, which indicates incident energy exceeding about 800 eV. These data show that the LENA flux from the solar wind has been detected and can be a useful monitor of the solar wind flux, even deep within the magnetosphere, from which the direct solar wind is excluded. Further modeling designed to discriminate among the possible sources identified above will be the subject of future publications and studies over time as the Earth moves around the sun and therefore samples a changing environment of interstellar gases [Gruntman, 1994].

Solar wind energy is known to be dissipated in the ionosphere and to produce escaping outflows of energized heavy ions above and beyond the thermal escape of the ionospheric light ions H^+ and He^+, emanating from the narrow auroral zones. Escape fluxes of H+ have been observed to locally exceed 10^{12} $m^{-2}s^{-1}$, while escape fluxes of O+ are known to approach 10^{14} $m^{-2}s^{-1}$ [Pollock et al., 1990; Moore et al., 1999]. As these energized outflows pass through the thermosphere and geocorona, they are expected to produce LENA escape. Data reported here show that the Earth emits a variable flux of LENA in response to solar wind disturbances such as CMEs, reflecting the variations of ionospheric heating and outflow. The LENA flux emitted by the Earth comes mainly from the polar auroral regions. Considerable collisional and gravitational scattering of the LENAs is likely to be responsible for the observed diffuseness of the LENA emissions. In the past, auroral zone outflows could only be sampled locally by in situ spacecraft, perhaps once or twice per few hour orbit. The IMAGE/LENA observations reported here show unambiguously that the outflow response to solar wind pressure fluctuations (a shock in this case) is instantaneous to within fast ion travel times (10's of minutes).

Figure 1. LENA event overview for the 8 June 2000 CME event.

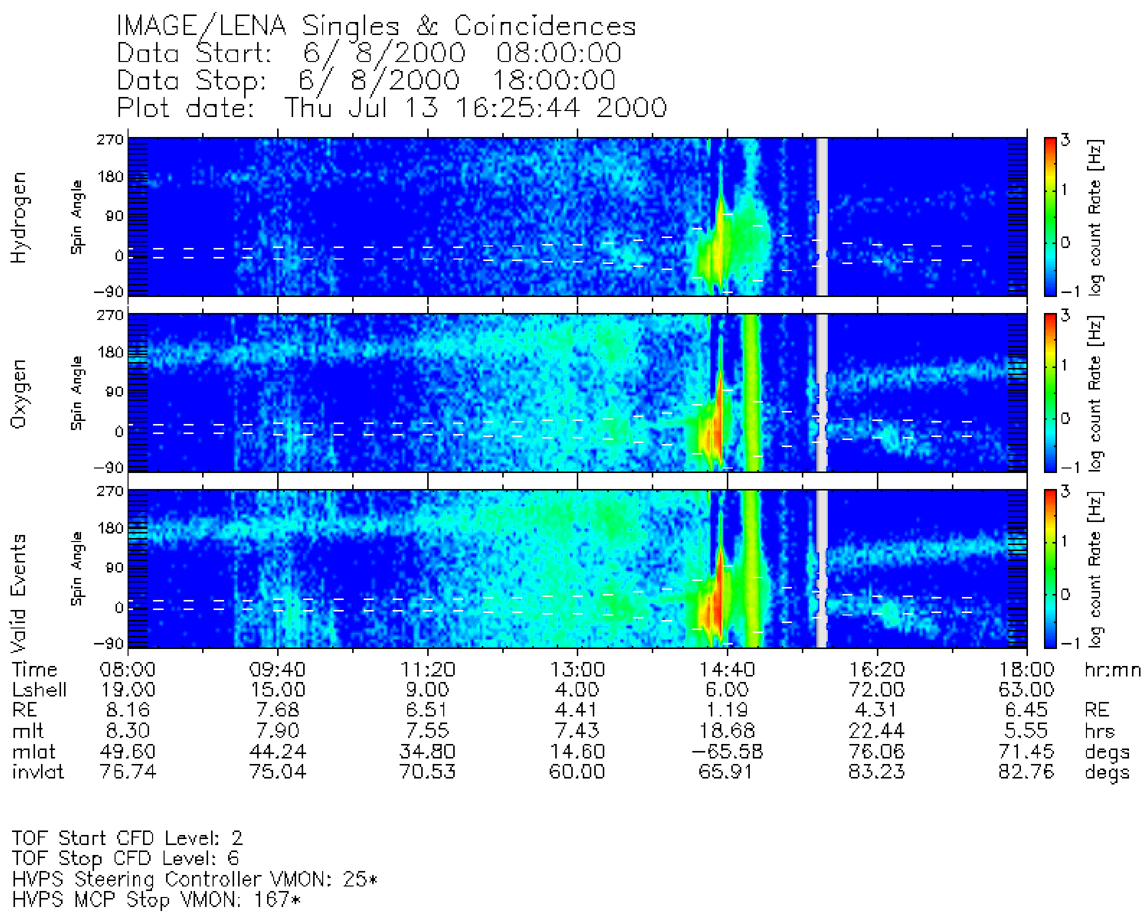

Figure 2. Three selected O images from before CME arrival, after CME arrival, and perigee view, from left to right. The earth is indicated in each image for perspective.

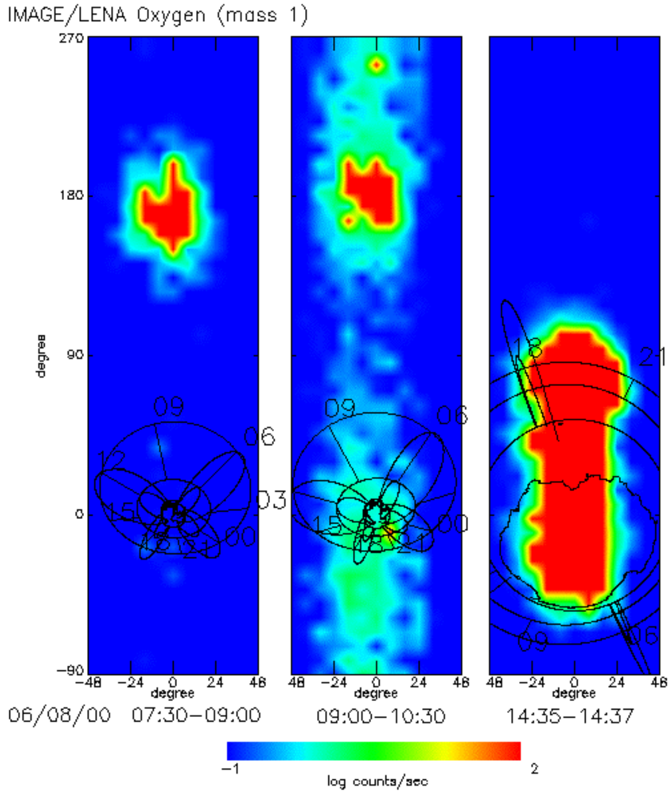

Figure 3. Time series of LENA fluxes vs. time for the 8 June 2000 CME event.