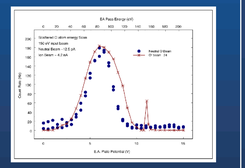
National Aeronautics and Space Administration
Goddard Space Flight Center

The Low Energy Neutral Atom (LENA) Imager on the IMAGE Spacecraft

The Low Energy Neutral Atom (LENA) Imager uses a new atom-to-negative ion surface conversion technology to image the neutral atom flux and measure its composition and energy (10 eV – >1 keV). LENA employs electrostatic optics techniques for energy discrimination and carbon foil time-of-flight techniques for mass discrimination. It has a 90 degree by 8 degree field-of-view in 12 pixels with spacecraft spin providing a total field-of-view of half the sky. LENA has imaged fast neutral particles emitted by the ionosphere, magnetosphere, magnetosheath, solar wind and interstellar medium. LENA is the first instrument to make many of these measurements.

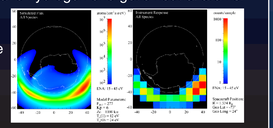
Concept:



The idea for a neutral atom imager operating below 1 keV germinated from experience with neutral mass spectrometers at Goddard Space Flight Center. Some of the unpublished lore suggests that an anomalous signal was observed when a mechanical door was operated in the aperture of such a mass spectrometer. The anomalous signal was believed to be produced by the formation of ions from the grazing incidence interaction of the low energy neutral atoms with the door surface. Laboratory tests suggested that the conversion of neutrals to negative ions could be enhanced significantly through the right choice of surface treatment. During LENA development, a number of surface coatings were considered, the leading candidates having been cesium, diamond, and barium zirconate.

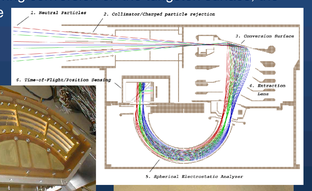
LENA imaging was proposed around 1993 as an augmentation of the planned Inner Magnetospheric Imager mission, which later evolved into a proposal for the IMAGE mission (Imager for Magnetopause to Aurora Global Exploration). The IMAGE proposal included three ENA imaging instruments covering three energy ranges, including LENA (< 1 keV). Further details concerning the instrument that was eventually developed for IMAGE are given in Moore et al., The Low-Energy Neutral Atom Imager for IMAGE, *Space Sci. Rev.*, 91, 155-195, 2000.

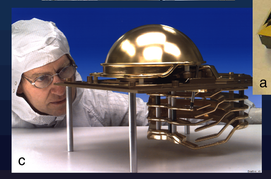
There have been a number of models producing differential fluxes of oxygen and hydrogen energetic neutral atoms. These figures show ENA produced by upflowing ions in the auroral zone, polar cap, and cleft ion fountain. The images on the left were produced by integrating along the line of sight from an observing point just beyond perigee in the nominal IMAGE orbit. The images on the right were constructed from those on the left by folding in the anticipated instrument response, which included the appropriate angular resolution and per pixel sensitivity, and adding random Poisson noise.

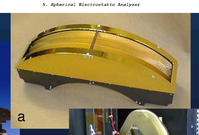


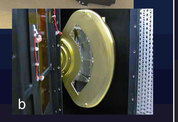
Fabrication:

The top right figure shows a cross section of the LENA instrument. Neutral atoms (1) enter the instrument through a collimator (2/fig. a) which rejects charged particles. The collimator operates by placing alternately positive and negative large (~kilovolt) potentials across consecutive horizontal plates. Neutral particles then hit a tungsten conversion surface (3/fig. b) at a low angle where a small fraction, of the order of a percent, of the incident neutrals pick up an electron and become negative ions. The conversion surface is held at a high negative voltage, run at up to 16.4 kV during calibration and, so far, up to 12 kV in-flight. Following conversion on the tungsten surface, the negative ion "sees" the negative potential of the conversion surface and is accelerated (4/fig. c) through an extraction lens designed to focus particles spatially in one direction dependent on energy and in the other spatial direction dependent on azimuthal angle. The particles then traverse a tuned hemispherical deflection system (5/fig. c) and enter the time-of-flight (TOF) unit, which also has a position sensing capability (6/fig. d). In the TOF/position sensing assembly, the spatial information on azimuthal angle and energy produced by the extraction lens is measured using position sensing on secondary electrons created when the negative ions traverse a carbon foil at the front of the unit. Secondary electrons also form the start signal used for a time-of-flight measurement, which determines mass because the energy is fixed by the extraction lens voltage. The particle itself produces the stop signal by traversing the TOF unit and triggering a stop microchannel plate stack.









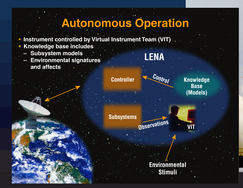
The reason why LENA, unlike other neutral atom imagers, can look directly at the Sun is that for a photon to hit LENA's detectors, it first must reflect off the conversion surface, then pass the hemispherical deflection system by multiple reflections and finally penetrate the carbon foil at the front of the time-of-flight unit. After this, a photon must reflect off some internal surface in the time-of-flight unit to finally hit the start detector.

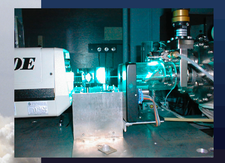
LENA data are available to the general public at the same time they are available to the LENA team at http://goewin.gsfc.nasa.gov/LENA/.

Calibration/Launch/IOC:

For direct testing and calibration, the University of Denver provided one of the only neutral beam facilities in the world that operates in the appropriate energy range. It uses laser photodetachment of electrons from a negative ion beam to produce neutral beams. DU is able to supply a useful neutral beam of either O or H over the entire energy range of primary interest to LENA. LENA was well-calibrated at DU prior to integration onto the IMAGE spacecraft.

With LENA, the team has made great strides in autonomous operation. The LENA flight software is designed to lower the microchannel plate bias levels and the collimator level when the software detects that the spacecraft is traversing the radiation belts or when infrequent sizable solar storms occur and LENA observes unusually high count rates. This feature allows scientists to enjoy more and higher quality data.

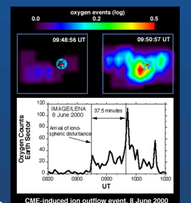




Science:

Ion Outflow

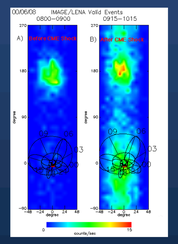
This LENA image shows that there was a localized response in the ionosphere due to the compression of the magnetosphere by a CME shock front. LENA neutral atom observations show a dramatic increase in the oxygen count rate from the general direction of the Earth. The increase occurs about 38 minutes after the disturbance, consistent with the travel time of 30 eV neutral oxygen from the ionosphere to the spacecraft. This suggests that there is no time delay between the ionospheric disturbance and the initiation of ion outflow from the ionosphere.



CME-induced ion outflow event, 8 June 2000

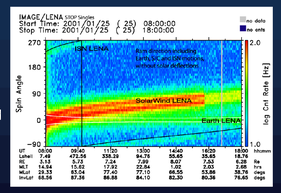
Neutral Solar Wind

On June 6, 2000, an intense solar flare was observed on the Sun followed by a full-halo coronal mass ejection or CME heading towards the Earth. The shock driven by this CME passed the Earth at about 09:11 on June 8. The figure shows two LENA images averaged over a one hour period. These images cover half the sky with the Earth at 0,0 and the Sun pulse in the anti-Earth direction. After the CME shock passes the Earth, the Earth brightens considerably in low energy neutrals. But note that the Sun pulse also brightens, which is inconsistent with the Sun pulse being light since the Sun does not "know" when the CME passed the Earth. At the time of this event, there was no enhancement in the solar EUV. This suggests along with other evidence that LENA is observing neutral atoms from the solar wind.



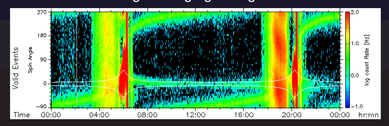
Interstellar Neutrals

Interstellar neutrals (ISN) are a gas of mostly hydrogen and helium streaming into the heliosphere at about 25 km/s. The helium component of these particles is primarily influenced by the Sun's gravitation, so that early in the year the Earth's motion and that of the ISN are about opposite each other. This has the dual effect of increasing the energy of these particles as observed by LENA so the detection efficiency is higher and making the observed direction of the ISN far enough from the direction of the Sun that the signal is not masked by the Sun pulse. LENA is the first instrument on an Earth-orbiting satellite to be able to continuously sense direct interstellar neutral helium. The figure shows a LENA spinogram for a 10 hour period during when interstellar neutral atoms were being detected during January 2001. The black trace shows where the undeflected interstellar wind through the solar system should appear considering spacecraft, Earth, and interstellar wind relative motions. Also evident are the solar wind LENA and the Earth LENA signals.



Geomagnetic Storms

LENA detected a strong signal of ENAs flowing upward from the Earth during the large geomagnetic storm of August 12, 2000. These neutral atoms are produced by the charge exchange of upflowing ions that eventually form the Earth's ring current and produce the geomagnetic storm. The figure shows a LENA spin angle spectrogram for August 12, 2000 showing a strong signal centered on the Earth (around zero degrees) beginning about 0700.



LENA Future Flight Opportunities:

The LENA imager is a large instrument on a spacecraft dedicated to imaging, with resources for LENA of about 20kg, 10W, and 1kbps. This was quite an ambitious effort for the first demonstration of a concept, but worked out quite well by having sufficient aperture and sensitivity to detect the interstellar neutrals, which were among the weakest signals observed to date. In the future, we can expect that many opportunities may require a more focused instrument with lower resource requirements, the minimum being of course those needed for a single pixel "atometer", possibly spectrographic. The following represents a list of future opportunities that can be anticipated on the basis of known mission planning efforts:

- BepiColombo (ESA 3 s/c mission to Mercury). Mercury has no sensible ionosphere, but does have an exosphere that is rich in sodium, among other species. Solar wind interactions are likely to produce considerable sputtering and escape of materials from Mercury, and ENA diagnostics are thought to be quite important for this mission. It is not yet clear how well the low energy range will be covered, but a LENA-based atometer appears to be obligatory.
- Heliospheric Imager Galactic Gas Sampler mission. The SEC roadmap shows that this mission would image the heliopause and the termination shock using global sky maps of 83.4nm photons and energetic atoms, measure the isotopic and elemental composition of the interstellar gas and anomalous cosmic rays, and determine the flow and temperature of interstellar atoms. A LENA-like instrument is mandatory for such a mission.
- Local interstellar medium, Discovery Program mission. The LENA development team has been invited to participate in a Discovery-class mission proposal with similar goals.
- Mars/Venus Aeronomy Missions. The SEC roadmap includes both Mars and Venus Aeronomy Probe missions, designed to improve our understanding of all the terrestrial planets and in particular the evolution of their atmospheres. Solar wind driven atmospheric escape is thought to be important on Mars and may also be important for Earth, Venus and even Mercury. Emission of low energy neutral atoms is certainly a significant factor in this atmospheric escape, and again, a LENA-like instrument appears essential to such missions.
- Geospace System Response Imagers. The SEC roadmap also includes a mission designed as a successor to the IMAGE mission, but based on advanced propulsion technologies (e.g. solar sails) that will permit station keeping high above the poles of the magnetosphere. Here it will be possible to make uninterrupted observations of the storm response of the Sun-Earth connection in geospace.

Conclusion:

With only one year's worth of science data under her belt so far, LENA already has notched a plethora of accomplishments including imaging ionospheric outflow and its response to CMEs, observing the neutral solar wind, detecting interstellar neutrals, and examining neutral emissions during geomagnetic storms. In the upcoming years and with a hoped-for extended mission, LENA will certainly increase her already impressive resume of scientific accomplishments.

Acknowledgements:

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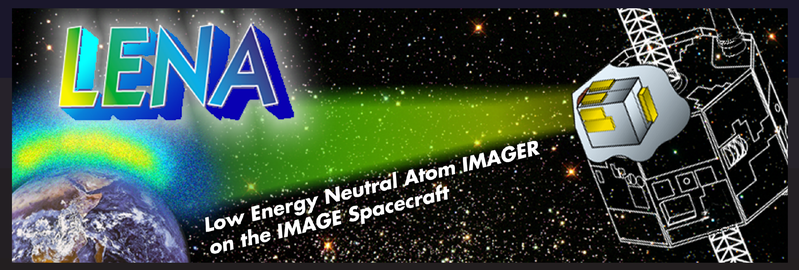
LENA is one of six scientific instruments on the Imager for Magnetopause to Aurora Global Exploration or IMAGE spacecraft which was launched March 25, 2000 from Vandenberg AFB on a Delta rocket. The LENA instrument is a collaborative effort involving six institutions: Goddard Space Flight Center where Tom Moore is the instrument lead; the University of Maryland, College Park; Lockheed Martin Advanced Technology Center; the University of New Hampshire; Denver University; and The University of Bern. The instrument is designed to look at atomic, that is neutral, hydrogen and oxygen with energies from as low as about 10 electron volts to above 1 keV and to determine their energy and direction.