Exospheric hydrogen density determined from Lyman-α irradiance

J. Machol1,2, P. Loto’aniu1,2, R. Viereck3, M. Snow4, D. Woodraska4, A. Jones4, R. Redmon2, J. Bailey5, M. Gruntman6

1NOAA NCEI, Boulder, Colorado; 2CIOPE, University of Colorado, Boulder, Colorado; 3NOAA SWPC, Boulder, Colorado; 4LASP, University of Colorado, Boulder, Colorado; 5LASP, University of Colorado, Boulder, Colorado; 6Space Environment Technologies, Palisades, California; 7Dept. of Aeronautical Engineering, USC, Los Angeles, California.

Introduction

The exosphere is the outermost layer of the atmosphere and consists of mostly hydrogen (H). Here we present a technique to estimate the exospheric H density distribution using Lyman-α irradiance measurements from the GOES satellites. The Lyman-α line at 121.6 nm is the strongest solar line in the far and extreme ultraviolet (EUV). Satellite ultraviolet image of the glow from H in the earth’s atmosphere and the auroral oval. (Measurements from Dynamics Explorer-1 taken in 1981)

Hydrogen in the exosphere

The exosphere is where atomic densities are so low that atomic collisions seldom occur. The exobase for H is ~500 km.

Atmospheric conditions

The H escape flux is limited by the rate of replenishment of H from the H2O in the lower atmosphere and solar activity. Knowledge of the exospheric H density (nH) distribution will improve understanding of the solar-outer atmosphere coupling and benefit whole atmosphere and satellite drag models.

Existing techniques to derive nH

Models

• Spherically symmetric + harmonics + asymmetries (e.g., Bishop, Chamberlain, Raiden et al., Nass et al., Bailey and Gruntman)

Measurements

• Lyman-α scattering measured from rockets and satellites such as TWINS LADS (Bailey and Gruntman, Zoonchen et al.) and TIMED GUVI limb measurements (Waldrop and Paxton)

• Geocoronal H Balmer α observations (Nossal et al.)

Results

• Models inconsistent with observations (e.g., MSIS at exobase)

• nH values of ~600 cm⁻³ at 3 Re

• Enhance nH (geotail) in anti-sunward direction

GOES Lyman-α measurements

• GOES: geocentric orbit

• EUV irradiance measurements since 2006

• Measures 10-nm band around Lyman-α line

• Nighttime dips are observed due to H scattering in exosphere. Can H density be estimated from these dips?

Method to obtain nH from GOES

Extract the scattering loss using a baseline during dips. The variability of Lyman-α makes this difficult.

Assume a power law H density:

\[ n_H(r) = \rho r^{-\alpha} \]

where \( r \) is in distance from the center of the earth.

Solar irradiance loss due to scattering along the line of sight between GOES and the sun:

\[ I_{loss} = \int g' r^{-\alpha} dx \]

where \( g' \) is the local scattering rate and \( x \) is distance along the line of sight.

Fit \( I_{loss} \) integral to find \( \rho \) and \( \alpha \) values for each dip, thus defining \( n_H \) for each day.

Details:

• Rediscerned irradiance – negligible, not included.

• Interplanetary Lyman-α scattering – negligible, not included.

• Irradiance 1 nm band is estimated to be 88% of full GOES band.

• Baselines

  • Average for 4 hours.

  • 3rd baseline interpolated dipole GOES measurements.

  • 3rd baseline from scaled measurements from GOES EUV at 26.5 nm, GOES CH A and B, and SORCE SOLSTICE Lyman-α.

• Fits

  • Exclude high points in the dips to exclude flares from fits.

  • Excludes post-midnight GOES data during eclipse (thermal effect).

• Satellite location – interpolate to 1 nm from 3 nm data.

• Scattering rate:

\[ g'(\text{photos} \text{ cm}^{-2} \text{ s}^{-1}) = \frac{3.47 \times 10^{-7} \times \left( \frac{\text{EUV flux at 3 R}_{	ext{e}}}{\text{EUV flux at 1 R}_{	ext{e}}} \right)^2}{\text{day} \text{ cm}^{-2} \text{ s}^{-1}} \]

Here \( \text{EUV flux at 3 R}_{	ext{e}} \) is the transition probability between the ground state and the lowest solar-excited state (data from thesis p. 20), \( \text{EUV flux at 1 R}_{	ext{e}} \) is the full irradiance of the solar Lyman-α line (i.e., the baseline GOES measurement at each time), and \( C_{\text{e}} = 1.388e-12 / \text{J/cm}^2 \) for wavelength 1/km is the unit conversion factor from (photos/cm² s) to (W/m²).

Space weather and nH

During a geomagnetic storm, when disturbances coming from the sun via the solar wind perturb the earth’s magnetosphere, there is enhanced interaction of the ring current and exospheric plasma. Often during solar storms there is increased solar Lyman-α irradiance which causes the upper atmosphere to warm and expand, resulting in higher densities at higher altitudes and losses to the ring. We are currently examining correlations between \( n_H \) during storm conditions and enhanced ring currents.

Summary

Initial results are somewhat consistent with previous studies and we are working to refine the technique. If successful, this technique could provide a daily (or better) exospheric H density distribution which could be used as an input to or to improve upper atmospheric chemistry models under different solar, geomagnetic and atmospheric conditions. Improved models may help with the understanding of the solar-outer atmosphere coupling, global changes in the atmosphere, and the decay of the ions in the magnetospheric ring current.

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