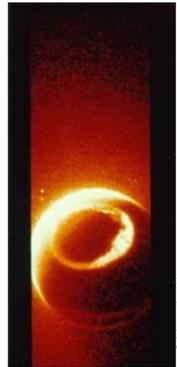


# Exospheric hydrogen density determined from Lyman- $\alpha$ irradiance

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## 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- $\alpha$**  irradiance measurements from the GOES satellites. The Lyman- $\alpha$  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)

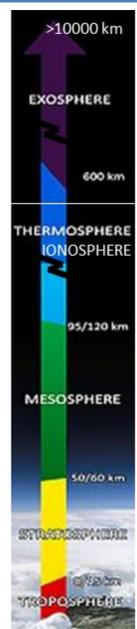
## Hydrogen in the exosphere

The exosphere is where atomic densities are so low that atomic collisions seldom occur. The **exobase** for H is  $\sim 500$  km.

Atoms with upward velocities greater than the escape velocity exit the atmosphere. Most exospheric H escapes in about a day, but heavier particles, such as He and O, usually return to earth.

The H escape flux is limited by the rate of replenishment of H from the H<sub>2</sub>O in the lower atmosphere and solar activity.

**Knowledge of the exospheric H density ( $n_H$ ) distribution will improve understanding of the solar-upper atmospheric coupling and benefit whole atmosphere and satellite drag models.**



## Existing techniques to derive $n_H$

### Models

- spherically symmetric + harmonics + asymmetries (e.g., Bishop, Chamberlain, Rairden et al., Nass et al., Bailey and Gruntman),

### Measurements

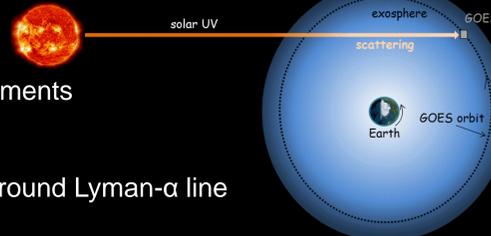
- Lyman- $\alpha$  scattering measured from rockets and satellites such as TWINS LADS (Bailey and Gruntman, Zoennchen et al.) and TIMED GUVI limb measurements (Waldrop and Paxton)
- geocoronal H Balmer  $\alpha$  observations (Nossal et al.)

### Results

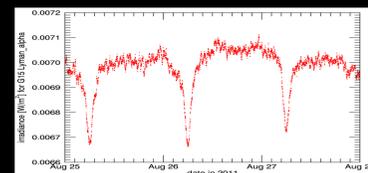
- models inconsistent with observations (e.g., MSIS at exobase)
- $n_H$  values of  $\sim 600$  cm<sup>-3</sup> at 3 R<sub>E</sub>
- enhance  $n_H$  (geotail) in anti-sunward direction

## GOES Lyman- $\alpha$ measurements

- GOES: geocentric orbit
- EUV irradiance measurements since 2006
- Measures 10-nm band around Lyman- $\alpha$  line
- Nighttime dips are observed due to H scattering in exosphere. **Can H density be estimated from these dips?**



Cartoon shows how solar UV at the Lyman- $\alpha$  wavelength is scattered by exospheric H.



Three days of Lyman- $\alpha$  irradiance measurements. Nighttime dips due to H scattering are observed. Data is from GOES-15, channel E and has 1-min cadence. Dips vary seasonally from 2-7% with the largest dips at the equinoxes.

## Method to obtain $n_H$ from GOES

Extract the scattering loss using a **baseline** during dips. The variability of Lyman- $\alpha$  makes this difficult.

Assume a power law H density:

$$n_H(r) = p r^{-k}$$

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:

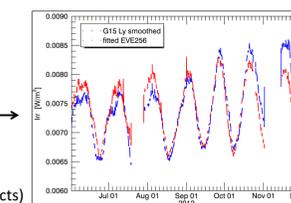
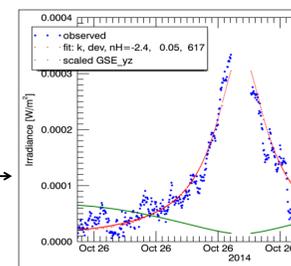
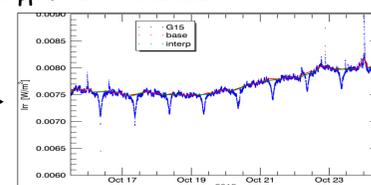
$$I_{loss} = g^* \int p r^{-k} dx$$

where  $g^*$  is the local scattering rate and  $x$  is distance along the line of sight.

Fit  $I_{loss}$  integral to find  $p$  and  $k$  values for each dip, thus defining  $n_H$  for each day.

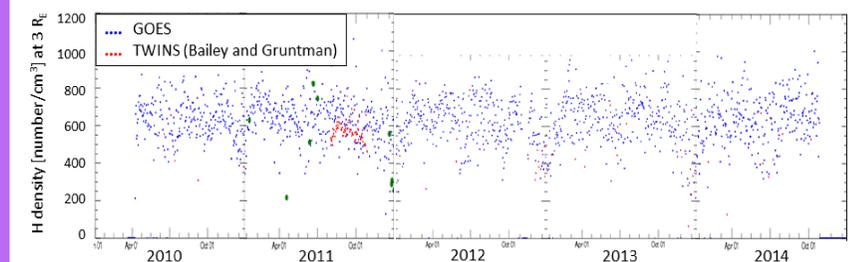
### Details:

- Backscattered irradiance – negligible, not included.
- Interplanetary Lyman- $\alpha$  scattering – negligible, not included.
- Irradiance in 1 nm band is estimated to be 88% of full GOES band.
- Baselines
  - Average for 4 hours.
  - Tried baseline interpolated dayside GOES measurements.
  - Tried baselines from scaled measurements from SDO EVE at 26.5 nm, GOES Ch A and B, and SORCE SOLSTICE Lyman- $\alpha$ .
- Fits
  - Exclude high points in the dips to exclude flares from fits.
  - Excludes post-midnight GOES data during eclipses (thermal effects)
- Satellite location -- interpolate to 1 min from 3 min data.



Scattering rate:  $g^* [\text{photons s}^{-1}] = A_{10}^2 \cdot \frac{A^3}{4\pi c} f_{\lambda} = 3.47 \cdot 10^{-4} \left( \frac{I_{Ly} [W/m^2] / C_{y-w}}{10^{11} m^{-2} s^{-1}} \right)^{1.21} s^{-1}$   
 Here  $A_{10}^2$  is the transition probability between the H ground state and the lowest level excited state <ref from thesis p. 20>,  $f_{\lambda}$  is the irradiance at the center of the Lyman- $\alpha$  line,  $I_{Ly}$  is the full irradiance of the solar Lyman- $\alpha$  line (i.e., the baseline GOES measurement at each time), and  $C_{y-w} = 1.988e-12 / \lambda [nm]$  for wavelength  $\lambda = 121.6$  nm is the unit conversion factor from [photons/cm<sup>2</sup> s] to [W/m<sup>2</sup>].

## Results



Daily  $n_H$  at 3 RE derived from GOES data and compared with TWINS measurements.

- Correct magnitude for the density values, about 600 cm<sup>-3</sup> at 3 R<sub>E</sub>.
- More variability -- due to averaging in other techniques?
- No solar cycle variability.
- Seasonal variability - artifact from small dips at solstices?

### Advantages of technique

- Continuous (operational) measurements.
- High signal relative to pure scattering measurements.

### Disadvantages/Challenges

- Need a better way to fit background variability.
- Measurements only in one plane and only at night.

## Space weather and $n_H$

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 also increased solar UV 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-upper atmospheric coupling, global changes in the atmosphere, and the decay of the ions in the magnetospheric ring current.

## Acknowledgements

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