Geocoronal Hydrogen Density Estimates Using Solar Absorption in the Exosphere

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What is the Geocorona?

- A hydrogen cloud that surrounds Earth
- Transition between Earth’s atmosphere and interplanetary space
- Extends from 500 km to >10,000 km in the exosphere
- Scatters solar irradiance at 121.6 nm (Lyman-α)
GOES satellites make continuous measurements of EUV solar irradiance at 6.6 $R_E$ (42,000 km)

Lyman-α irradiance exhibits a multi-hour decrease when satellite is on anti-solar side of Earth

Plot shows daily absorption dips as well as fluctuations due to solar variability

**Without the geocorona, there would be no absorption dips**
Use extreme ultraviolet (EUV) measurements of solar irradiance from GOES satellites to derive daily hydrogen density distributions of the terrestrial upper atmosphere by using absorption dips to map out the geocorona and observe short term variability.
Geocorona varies with space weather

Geocoronal hydrogen density distributions are important for...
- Satellite operations
- Magnetospheric ring current models
- Energetic Neutral Atom (ENA) imaging
- Photochemical modeling

Geocoronal variations are currently not well understood

URL: http://www.ospo.noaa.gov/Operations/GOES/index.html
Research Plan

1. Create an IDL program to read in satellite location data and compare data sets.
   - Data set 1: NASA Satellite Locator
   - Data set 2: Rob Redmon’s Location Propagator

2. Create an IDL program to read in EUV irradiance data.

3. Estimate the total absorption loss using the GOES EUV irradiance data.

4A. Determine local hydrogen number density along the line of sight by testing different integral fits.

4B. Determine local hydrogen number density along the line of sight with a differential fit.

5. Identify further refinements and future work.
**STEP 1: Create an IDL program to read in satellite location data and compare data sets.**

**GOES 15  2011 Orbit (GSE coordinates)**

**Geocentric Solar Ecliptic Coordinate System**

- x-axis: earth-sun line
- z-axis: projection of Earth’s magnetic dipole axis

Satellite Location Comparison

2 Different Data Sets:

**NASA Satellite Locator**
- Lower precision
- 3 minute resolution
- Well verified
- Propagations for all times are based on the nearest TLE value
- Does not provide real time location information

**Rob Redmon’s Location Propagator**
- Higher precision
- 1 minute resolution
- Uses new routine
- Propagations for each day are based on the TLE value that is closest to noon of that day
- Provides real time satellite location information for space weather purposes

Provide GOES satellite location data
Satellite Location Comparison: Total X, Y, Z Coordinate Error

Total XYZ Error for 2011 Between Data Sets

Day 1- Day 10

Day 210- Day 220
Satellite Location Comparison: X-Coordinate Error

Total X-Coordinate Error

Day 1- Day 10

Day 210- Day 220
Satellite Location Comparison: Y-Coordinate Error

Total Y-Coordinate Error

Day 1- Day 10

Day 210- Day 220
Satellite Location Comparison: Z-Coordinate Error

Total Z-Coordinate Error

Day 1 - Day 10

Day 210 - Day 220
STEP 2: Create an IDL program to read in EUV irradiance data.

Lyman – α Irradiance for 2011
EUV Data Analysis

Seasonal Variability:

- **Solstice:**
- **Equinox:**
- **Solstice:**

Angle of the Sun relative to the ecliptic and angles/dates when eclipse occurs.
EUV Irradiance Method

1. Lyman-α irradiance data from the GOES15 satellite for 2011

2. 5 day view of the Lyman-α irradiance data from June 15 – June 20, 2011
A baseline value for the daytime irradiance with no absorption

Nighttime absorption dips created by subtracting baseline

*Baseline value includes an 8-hour interpolation over midnight
STEP 3: Estimate the total absorption loss using the GOES EUV irradiance data.

- Total scattering loss along the line of sight through the atmosphere:

  \[ F = c \int n(r) \, dx \]

  - Constant \( c \):
    - Local scattering rate
    - Angular-dependence of scattering
    - Contribution of resonantly scattered Lyman-\( \alpha \) from interplanetary glow

  - \( n(r) \) = local H number density along line of sight (x) in terms of \( r \) (the radius to Earth’s center)

- Assumed a simple spherical power law for the H distribution: \( n(r) = ar^b \)

- Fit the data to determine \( a \) and \( b \) by using the non-linear least squares fitting algorithm
Density Fit Part 1
Integral Method

STEP 4A: Determine local hydrogen number density along the line of sight by testing different integral fits.

- Tested integral fits for $b = -1, -2, \text{ and } -3$
  \[ n(r) = ar^b \]
  
  - $\int_{1/r}^{\infty} dx = \ln|x+r|$  
  - $\int_{1/r^2}^{\infty} dx = 1/y \tan -1 x/y$  
  - $\int_{1/r^3}^{\infty} dx = x/y^2 r$

- Regimes that were considered:
  - Local times between ±3 hours of midnight
    - Any radius
    - Radius $> 3 R_E$
    - Radius $< 3 R_E$

**The single scattering approximation is only valid at radii greater than $3R_E**
Fit type: $n(r) \sim r^{-2}$ and $> 3 \, R_E$
STEP 4B: Determine local hydrogen number density along the line of sight with a differential fit.

Total Absorption: \[ F = c \int n(r) \, dx = c \sum n(r) \Delta x \]

Change in Absorption:
\[ \Delta F = F[1] - F[0] \]
\[ \Delta F = c \left[ \sum n(r1) \Delta x - \sum n(r0) \Delta x \right] \]
\[ \Delta F \approx c \left[ \sum n(r) \Delta x_{\text{center}} - n(r) \Delta x_{\text{edge}} \right] \]
or:
\[ \Delta F \approx n(y \downarrow \text{GOES}) \cdot \Delta x_{\text{center}} - n(r \downarrow \text{GOES}) \cdot \Delta x_{\text{edge}} \]
Preliminary Results

Results showed that the exponents were fairly consistent for the years of 2011 and 2012.

Calculated density is reasonably accurate for ≥3R_E.

![Graph showing b vs. y_GOES coordinate](image)

- Expected value (>3 R_E)
Location data sets are very similar with an overall discrepancy of ~45 km and had three major error spikes for 2011.

For the integral method, three integer values were tested for \( n(r) = ar^b \) (\( b=-1, -2, -3 \)). The preliminary results for this method showed the best fit \( b = -2 \) for a regime of \( >3 \) \( R_E \), but still did not provide a good fit.

Preliminary results for the differential method were somewhat consistent for the years of 2011 and 2012 and agreed with expected values from Bailey’s thesis.

The results that were obtained from this study are encouraging, but there are still many refinements that can be made.
Future Work

STEP 5: Identify further refinements and future work.

Possible next steps:
- Determine source of phase shift between satellite location data.
- Test $b$ from second fit by numerical integration of $n(r) = ar^b$
- Try other improvements on integral fit, such as better smoothing.
- Estimate how close to the Earth can we get good estimates.
- Include measurements from other satellites.
- Try to fit data with a 2D model.
References
