Tomographic estimation of exospheric hydrogen density distributions

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Abstract

For the past decade, the Lyman-alpha detectors (LADs) onboard NASA’s Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) mission have obtained routine measurements of solar Lyman-alpha photons (121.6nm) resonantly scattered by atomic hydrogen (H) in the terrestrial exosphere. This data has been used to derive global, 3D models of exospheric H density beyond 3R_e, which are needed to understand the influence of solar activity and ion-neutral coupling throughout the terrestrial environment as well as to assess its long-term evolution through atmospheric escape. These historical models are based on parametric fitting of assumed functional forms which may be inaccurate or invalid, thus limiting confidence in conclusions drawn from analysis of the resulting distributions. In this work, we present a new means of global, 3D reconstruction of exospheric H density through a tomographic inversion of the scattered H Lyman-alpha emission. Our approach avoids the conventional dependence on ad hoc and arbitrary parametric formulations and enables a more accurate characterization of the global structure of this region.

Methodology: Data pre processing stage and tomographic approach

Step 1: Data filtering 1
Fig. 2: To assess validity of the linear emission model, we omit data along LOS's that (1) point away from the source, (2) are located in the Earth’s shadow, and (3) pass within 2R_e of Earth’s surface.

Step 2: Data filtering 2
Fig. 3: Calculating the α’ factor
The α’ factor or Lyman-alpha resonant scattering rate is defined in terms of (i) the spectral density at the center of the solar Ly-α line flux [f], (2) the inter-state transition probability of H atoms, and (3) the g-factor or Lyman-alpha resonant scattering rate. The natural reference is the solar Ly-α line flux [f].

Step 3: Subtracting the Interplanetary background
Fig. 4: The interplanetary background (IP) is derived from SWAN measurements for day 145 of 2008. LOS's from both LADs have been located in the ecliptic plane in order to minimize IP.

Step 4: Calculating the photon scattering intensity by H atoms
Fig. 5: The Lyman-alpha photon are scattered astrophotically by H atoms. Its angular dependence was studied by [Wisniewski et al., 1999].

Step 5: Inverse problem and Regularization
Fig. 6: Since the observation matrix, L, is not of full rank, a regularization technique must be used to solve the system. The selected regularization method is presented in the following equation:

Reconstruction results

Monaco Carlo theoretical evaluation
Parameteric fitting
Tomographic inversion

Discussions

H-density profile

(1) Previous work [Hodges, 1994] work describes the H-density profile in the radial direction as an exponential decaying signal.
(2) Previous work has shown asymmetries in the dusk and dawn longitudes. Our work aims to correct for this.
(3) Interplanetary background

Quantitative comparison with parametric fitting model

For each shell of constant radius we used the same LOS's, identified with more than 100 LOS (experimental value) through them. The relative difference was calculated between the tomographic inversion and the parametric fitting model.

Conclusions

We demonstrate that tomographic inversion of optically thin Ly-alpha emission is a promising technique to obtain the 3D structure of the exospheric H.

The azimuthal dependence of our H reconstruction results exhibits superior agreement with Monte Carlo simulations, while the radial dependence agrees best with parametric estimation results.

Future work will focus on applying the new technique systematically to both TWINS and IMAGE Ly-alpha emission data in order to obtain comprehensive spatial and climatological characterization of exospheric structure and variability while avoiding ambiguities of conventional parametric density estimation techniques.

References


Acknowledgments

The authors gratefully thank Dr. J. Bailey and Dr. M. Graumann for providing the interplanetary background map. We especially thank Dr. Farzand Kamalabadi and Dr. Mark Butala for discussions.