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Hydrogen atoms near the exobase are cold: independent observations do not support the hot exosphere concept

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1 Introduction

Atomic hydrogen (H) near the exobase (above ~500 km) is the primary source of neutral and charged particles for the two largest systems of near-Earth space–the geocorona and plasmasphere.

The H atoms near the exobase have long been considered to be in thermal equilibrium with the dense ambient atomic oxygen thermosphere. However, in their analysis of the GUVI satellite observations of dayside Lyman-α emission at low solar activity, Qin and Waldrop (2016) concluded that the exobase hydrogen atoms are extremely hot (~20,000 K), which is more than 20 times hotter than the oxygen thermosphere. This result contradicts the fundamental assumptions of existing geocoronal theories. Qin and Waldrop listed several possible sources of the hot H atoms and postulated that the high temperature is a consequence of incomplete collisional thermalization due to the low thermospheric oxygen density at solar minimum.

Here, we question the Qin and Waldrop conclusions on the basis of comparison with results from numerous different independent observations of temperature and density of atomic hydrogen and of hydrogen ion and electron densities. We show that those observations provide comprehensive evidence in favour of validity of classic cold hydrogen concept.

2 Comparison to observations by independent techniques

Obviously, the most solid evidence pro or contra hot hydrogen concept could be provided by independent measurements of the hydrogen atoms temperature near the exobase. Such observations were conducted for typical mid-latitudes during magnetically quiet periods and medium-to-high solar activity conditions by Mierkiewicz et al. (2012). The authors retrieved the atomic hydrogen temperatures near the exobase from the Balmer-α spectra data within 2 years for all the seasons. Their hydrogen temperature estimates (range from 710 K to 975 K) are two to three times smaller than one of Qin and Waldrop (~2200 K) and are close to the temperature of the ambient oxygen provided for the same location, dates, and altitudes by the well-tested NRLMSISE-00 model (Picone et al., 2002). This closeness evidences against the existence of a notable amount of much hotter H atoms near the exobase during medium-to-high solar activity conditions with a caveat that Mierkiewicz et al. temperatures were obtained for dawn and dusk while Qin and Waldrop estimates are for near-noon time. It should be noted that no significant change of the H atoms temperature is expected from the noon towards dusk because (1) the ambient oxygen thermosphere changes are small from the noon towards the dusk (the temperature and density decrease by only several tens percent) and (2) lifetime of the exospheric H atoms is ~ 1 day as estimated by Hodges (1994) for the daytime hydrogen temperatures of the same order of magnitude as the estimates of Qin and Waldrop. These imply that, even if the hypothetical hotter H atoms are originated during the daytime, they do not leave the exosphere through the night and their chance to be cooled is not larger than during the day.

Another sensitive indicator of the correctness or incorrectness of the hot hydrogen concept is the H density at high altitudes in the exosphere. It is seen from Figure 2 b, e of the Qin and Waldrop paper that change of the classic cold hydrogen concept on the hot hydrogen concept increases the H density at an altitude of 20,000 km by a factor of ~ 5 for medium-to-high solar activity. For such conditions, H density at altitudes of ~ 20,000 km was retrieved from Lyman-α observations by the Dynamics Explorer 1 satellite (Rairden et al., 1986) and TWINS satellite (Zoennchen et al., 2015) and those estimates are close to ones obtained by Qin and Waldrop using cold hydrogen approach. It should be noted that both the analyses by Rairden et al. and Zoennchen et al. were also conducted assuming the cold hydrogen concept, i.e., the equality of the exobase hydrogen temperature to the temperature of oxygen thermosphere. Since this equality is supported by the above discussed H temperature observations of Mierkiewicz et al., the Dynamics Explorer 1 and TWINS H density estimates provides further support for correctness of the classical cold hydrogen concept.

For the solar minimum, for which Qin and Waldrop retrieved the largest temperatures of the H atom (~20,000 K), there are no independent observations of the H temperature. Thus, despite extreme sensitivity of the high-altitude exospheric H density to change of cold hydrogen assumption to hot one (see Figure 2 b, e of Qin and Waldrop paper), comparison with other observations employing cold hydrogen approach (Zoennchen et al., 2011; Zoennchen et al., 2013) cannot be useful to refute or support hot hydrogen concept.

Indirect support of validity of the classic cold hydrogen concept for solar minimum comes from numerous comparisons of the observed H^+ ion and electron densities in the topside ionosphere and plasmasphere with the results of simulations using physical model of the ionosphere-plasmasphere system (Kotov et al., 2015; Kotov et al., 2016; Kotov et al., 2018; Kotov et al., 2019; Panasenko et al., 2021; Kotov et al., 2023). Those plasma densities are quite sensitive to the H density near the exobase (Kotov et al., 2023) but insensitive to the H temperature because the O^++H reaction responsible to the densities is near thermo neutral (Fox and Sung, 2001). Comparison of the plasma density observations conducted using independent techniques and facilities for all seasons of two solar minima with the simulations shows that the physical model which uses the near-exobase H density corresponding to the classic cold hydrogen approach provides excellent agreement with the observations. Applying the hot hydrogen concept reduces the near-exobase H density by a factor of a ~ 3 to 4 at solar minimum (Figure 2 b, e of Qin and Waldrop paper). As follows from Kotov et al. (2023), with such small H density, simulated H^+ ion and electron density in the topside ionosphere and plasmasphere would be at least twice smaller than the observations.

3 Conclusion

The existence of large amounts of hot H atoms near the exobase is not supported either by independent observations of H atom temperature and density or by numerous observations of hydrogen ion and electron densities conducted with different independent techniques.

Conducted near the exobase, in the exosphere, ionosphere, and plasmasphere for various levels of solar activity, seasons, and geographical regions, these independent observations provide comprehensive support for the classic cold hydrogen concept.

Author contributions

DK proposed the idea and wrote the first draft of the manuscript. OB participated in the manuscript editing. All authors contributed to the article and approved the submitted version.

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greatly improved the paper and made it more convincing and interesting.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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