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Lyman α Emissions from the Outer Planets: A Comparative Study from Saturn to Neptune

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All the outer planets have much hotter thermospheres than expected from solar heating, a phenomenon known as the *energy crisis*, likely driven by strong energy deposition from their magnetospheres. Since the Voyager era, the upper atmospheres of Uranus and Neptune may both have cooled substantially, which can be driven by evolution of the magnetosphere-atmosphere interaction.

The upper atmospheres of the outer planets, comprised of H_2, atomic H and He, can be probed remotely through ultraviolet emissions, which constrain the composition, temperature, and extent of their thermospheres. The atomic H emission at Lyman α is the brightest UV emission line from the outer planets and has been observed at Uranus, Neptune, Saturn, and Jupiter from the earth orbit and by missions to the respective systems. In particular, the Uranian Lyman α emissions have been observed over 35 years using different platforms, including the Hubble Space Telescope, and can continue to be used to track the evolution of the thermosphere remotely, in preparation for the Uranus Orbiter and Probe mission. The interpretation of Lyman α emissions, however, is challenging due to uncertainties in spectrograph calibration and the potential presence of supplementary emission sources, such as hot hydrogen or electron-excited emissions.

We examine the emissions from Saturn, Uranus and Neptune with observations from Cassini/UVIS, HST, and Voyager 2/UVS, comparing observed brightnesses to modelled emissions from the disk of each planet using a radiative transfer model. We model the scattering of Lyman α photons, from both the Sun and the interplanetary hydrogen background, by atomic H and H_2 in the atmosphere using a model based on the doubling and adding of thin atmospheric layers. The model incorporates partial frequency redistribution which is critical for accurately modelling such optically thick atmospheres ($\tau > 10^4$ at the Lyman α linecenter).

We find that the observed emissions from Saturn and Neptune can be well reproduced by scattering from thermal H. At Uranus, a significant portion of the Lyman α emission arises from Rayleigh scattering by H_2, due to the unusually low mixing rate that places the methane homopause at deeper pressures than at Saturn or Neptune. This leads to an optically significant column of H_2 unique to Uranus. Across all three planets, scattered solar Lyman α flux is the dominant source of emission outside of auroral regions, with an additional 10-15% contribution from scattering of the interplanetary hydrogen background.

Scattering by thermal H and H_2 can replicate the observed disk emissions, without requiring additional emission sources like hot hydrogen or electron-excited emissions. However, the atmospheric model fits based on other observation sets (i.e. UV stellar and solar occultations and IR emissions) are not unique, and we therefore explore how the modeled brightnesses depend on the range of atmospheric parameters allowed by available observations.