

Multi-Element Lunar Exosphere Simulation to Improve the Prediction of Ballistic Migration of Water.

¹A. Smolka, ¹P. Reiss

¹Professorship of Lunar and Planetary Exploration Technologies, Technical University of Munich

Introduction

- New numerical model of the lunar exosphere based on the Monte-Carlo method, simulates individual, weighted particles in thermal equilibrium with the Moon surface (Smolka, 2022; Tucker et al. 2019).
- Simultaneously simulates H, H₂, OH, and H₂O, connected through conversion reactions like photo-dissociation and geochemical surface reactions.

Method

- The model takes advantage of a nested-loop architecture that iteratively solves for the surface number density while calculating particle conversions to be applied as source rates in the following iteration.
- Assumes pseudo-stationary surface-bounded exosphere in thermal equilibrium with a Maxwell-Boltzmann flux distribution of energies and full thermal accommodation (Brinkmann, 1970; Smith et al., 1978).
- The loss and source mechanisms of all four species are connected through particle conversion, based on dissociation rates (Huebner et al., 1992) and surface reaction probabilities (Crider and Vondrak, 2002).
- Uncertain parameters are modelled with probability distributions (like in Tucker et al., 2018), allowing a statistical analysis of the uncertainty propagation.

Results

- Adsorption during the night and desorption at sunrise leads to OH and H₂O accumulating at the morning-terminator, exhibiting a “snowplow” effect stretching from pole to pole.
- While H does not adsorb or desorb, its peak must originate from the connection to OH and H₂O.
- Conversions act as efficient recycling of particles, leading to generally higher densities compared to single-element studies.
- Confirms expected surface number densities of H: $\sim 1200 \pm 400 \text{ cm}^{-3}$ (LAMP, Hurley et al., 2017)
- OH: $\sim 10^4 \text{ cm}^{-3}$ (Wang et al., 2015)
- but cannot reproduce expectations for H₂O: $\sim 60 \text{ cm}^{-3}$ (Jones et al., 2018).

Hydrogen bearing species require multi-element models and simultaneous simulations to predict the ballistic transportation of water. For accurate description of OH/H₂O accumulations, a more sophisticated geochemical lunar regolith model is needed.

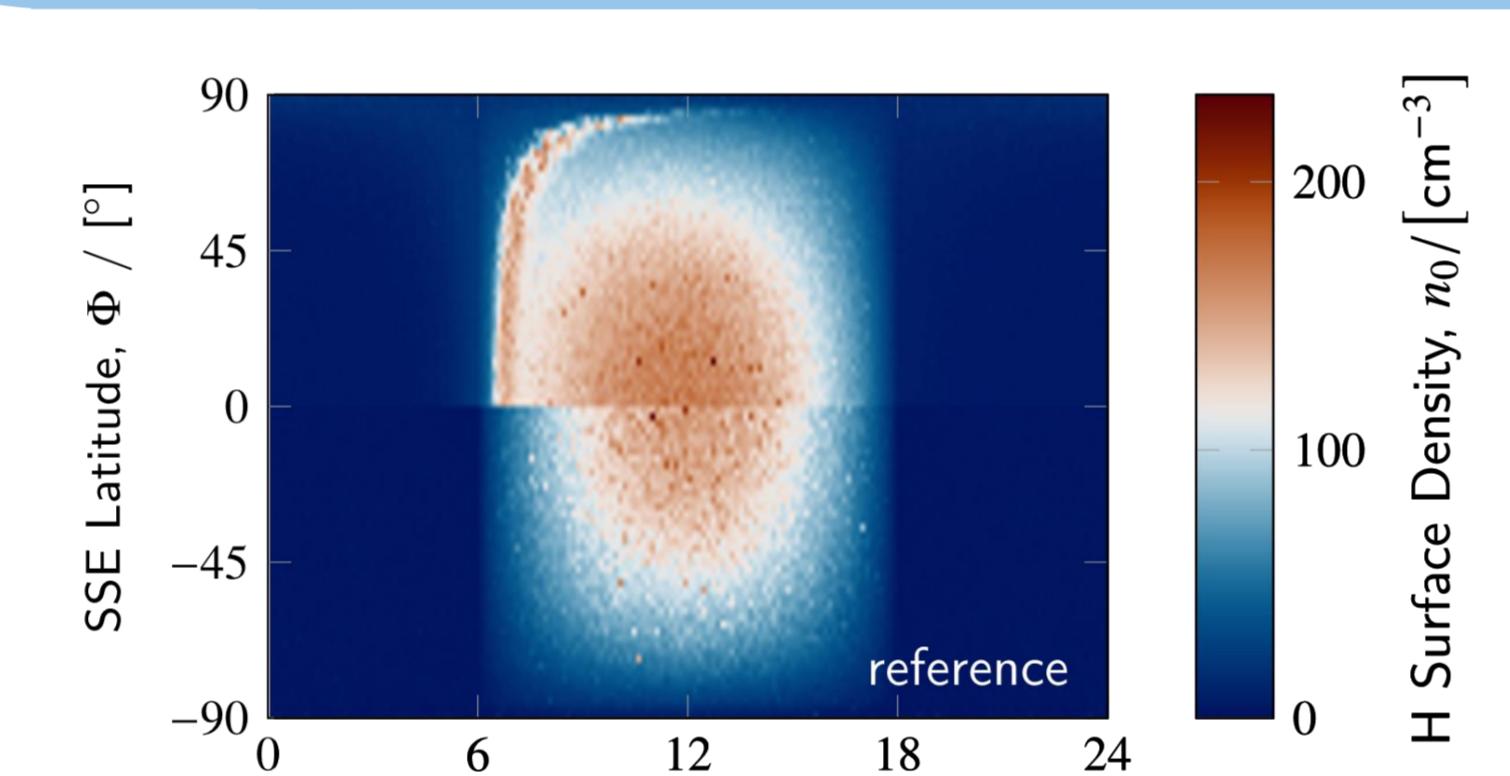


Figure 1
Comparison of exospheric atomic hydrogen predictions of the multi-element study with a reference single-element simulation.

Conclusion

Clear changes in the surface number densities are visible once the species were connected in a multi-element model respecting particle conversions. Non-condensable species, like H, develop a morning-terminator peak due to heavy OH and H₂O desorption and dissociation. Globally increased densities suggest that conversion acts as a recycling mechanism.

Large uncertainty intervals and density increases strengthen the need for a more sophisticated geochemical model to better describe the lunar water cycle. Models of Jones et al. (2018), Tucker et al (2019), and Grumpe et al. (2019) will be used as guidelines in future iterations of the numerical model, especially focussing on better descriptions of the OH/H₂O behavior.

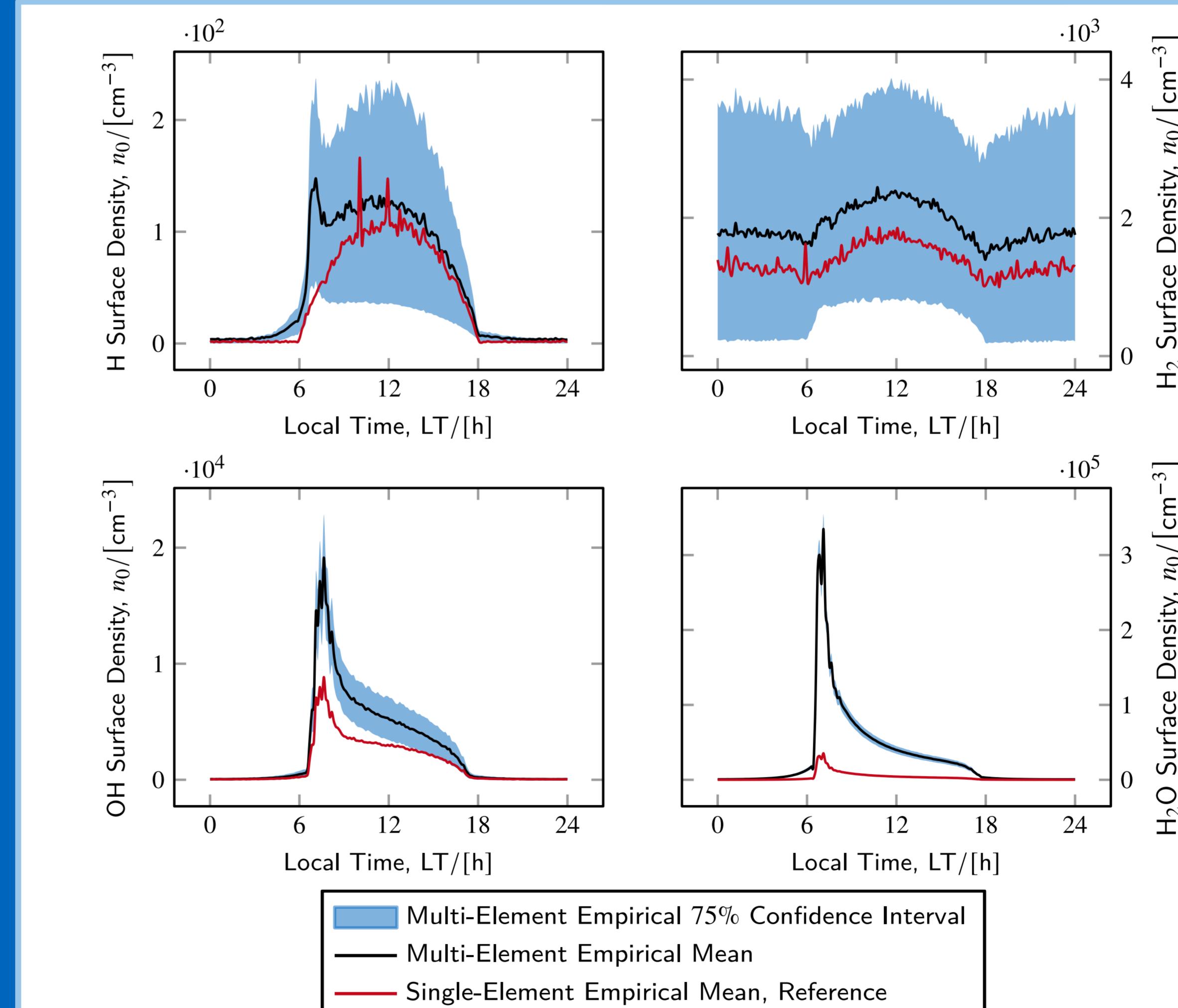


Figure 2
Surface number densities of H, H₂, OH, and H₂O of the multi-element study including its empirical 75% confidence interval, and a reference density as a result of a single-element study with the same parameter setup.

Supplemental Materials

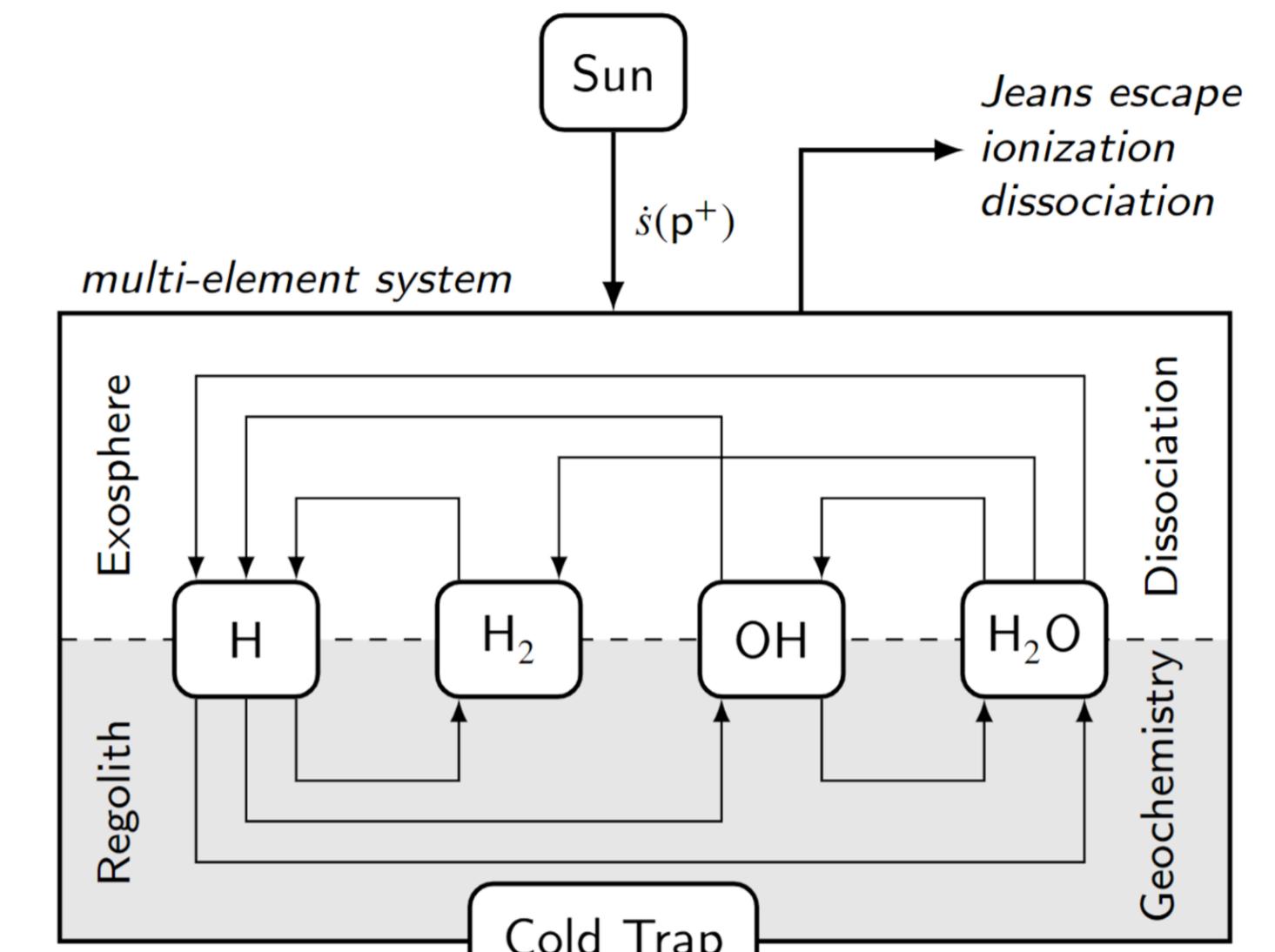


Figure 3
Schematic of the implemented conversion processes in both the exosphere and the lunar surface.

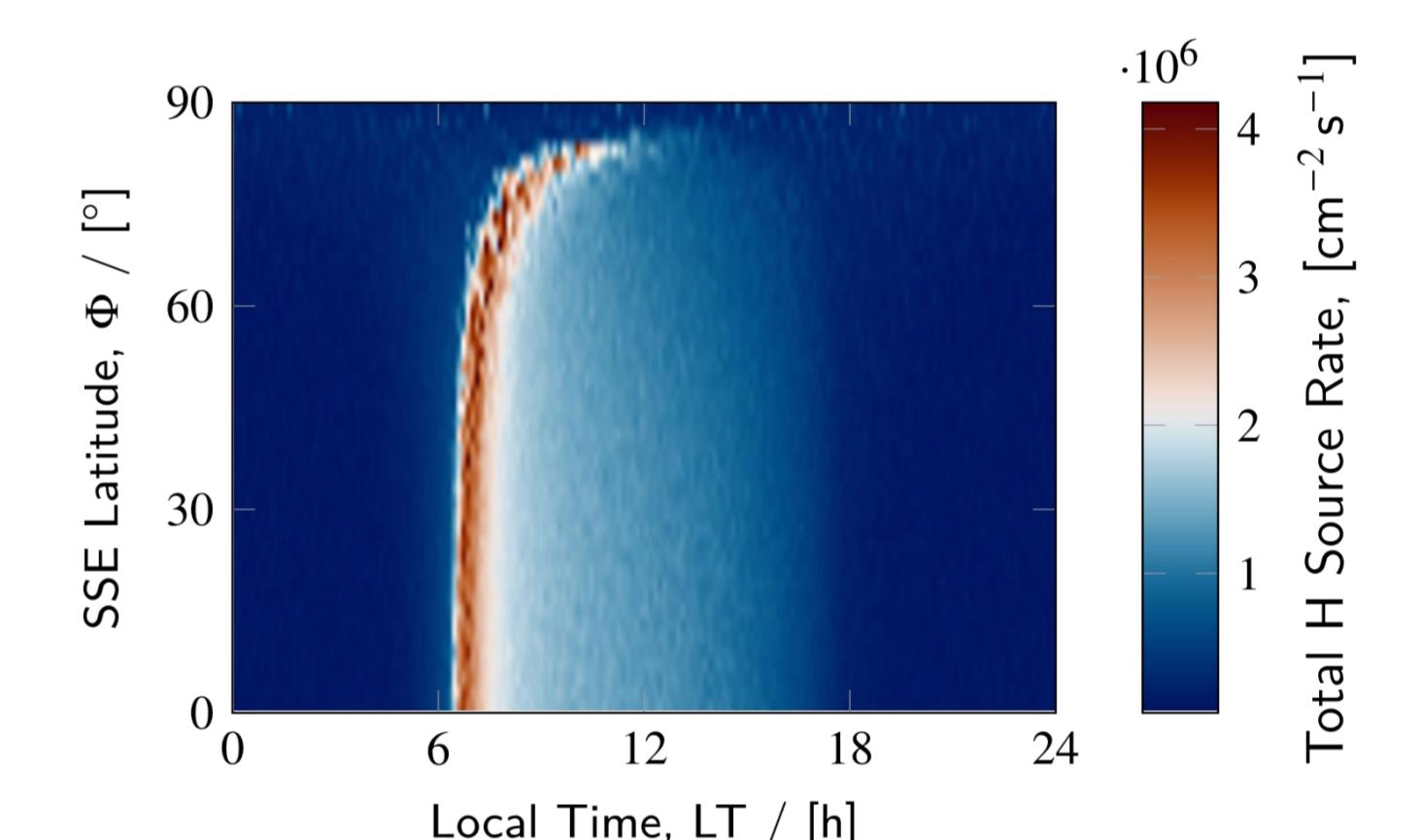


Figure 4
Total source for H particles based on conversions from H₂, OH, and H₂O through photo-dissociation.

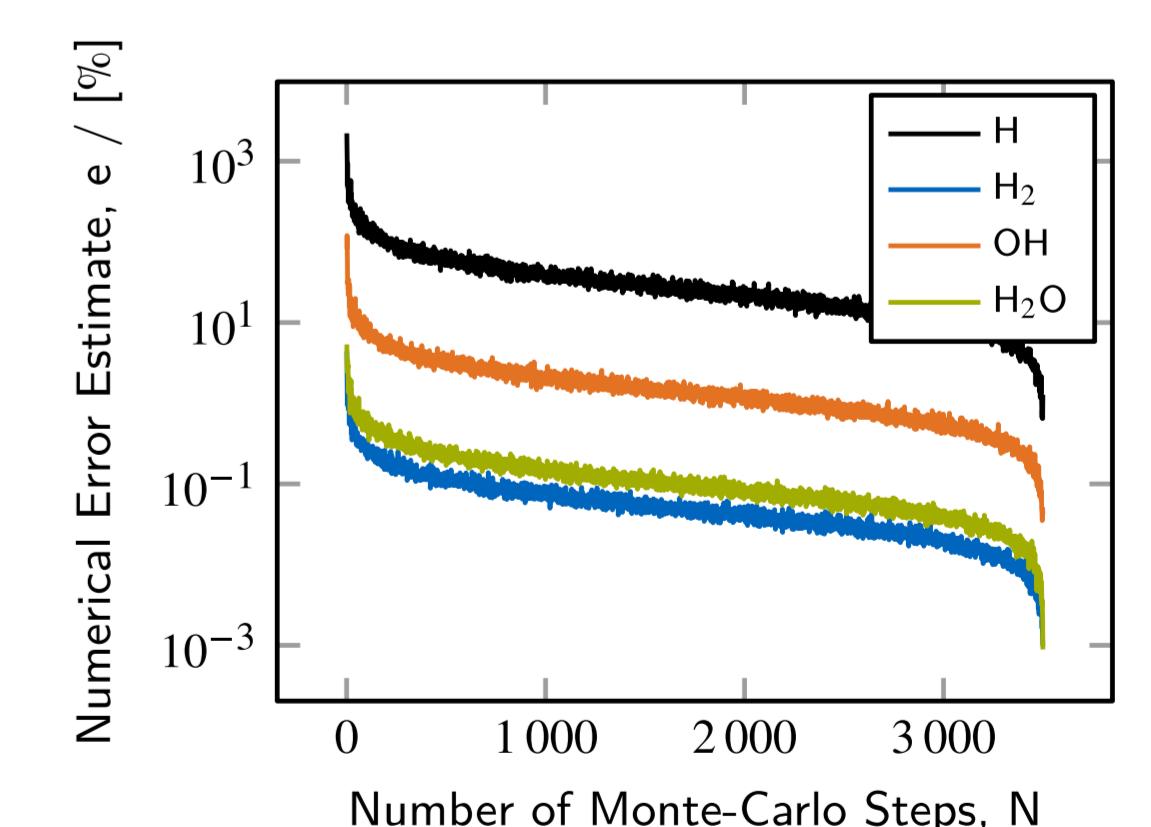


Figure 5
Numerical error estimation for all four constituents over the number of Monte-Carlo steps. Measured at a reference point on the day-side.

Brinkmann, R., 1970, Departures from jeans' escape rate for h and he in the earth's atmosphere. *Planetary and Space Science*, Vol. 18.

Crider, D., Vondrak, R., 2000, The solar wind as a possible source of lunar polar hydrogen deposits. *Journal of Geophysical Research*, Vol. 105.

Huebner, W. et al., 1992, Solar photo rates for planetary atmospheres and atmospheric pollutants. *Astrophysics and Space Science*, Vol. 195.

Hurley, D.M. et al., 2017, Contributions of solar wind and micrometeoroids to molecular hydrogen in the lunar exosphere. *Icarus*, Vol. 283.

Jones, B.M. et al. 2018, Solar wind-induced water cycle on the Moon. *Geophysical Research Letters*, Vol. 45.

Smith, G et al., 1978, Monte Carlo modeling of exospheric bodies: Mercury. *Journal of Geophysical Research*, 83.

Smolka, A., 2022, Lunar Exosphere Simulation: Modeling and Simulation of our Moon's Surface-Bounded Exosphere. Thesis, Technical University of Munich.

Tucker, O.J. et al., 2019, Solar wind implantation into the lunar regolith: Monte-Carlo simulations of H retention in a surface with defects and the H₂ exosphere. *Journal of Geophysical Research: Planets*, Vol. 124.

Wang, J. et al., 2015, An unprecedented constraint on water content in the sunlit lunar exosphere seen by Lunar-based Ultraviolet Telescope of Chang'e-3 mission. *Planetary and Space Science*, Vol. 109-110.

Data availability

For data and model access, please contact Alexander Smolka (alexander.smolka@tum.de).

Previous work: <https://mediatum.ub.tum.de/node?id=1658109>

