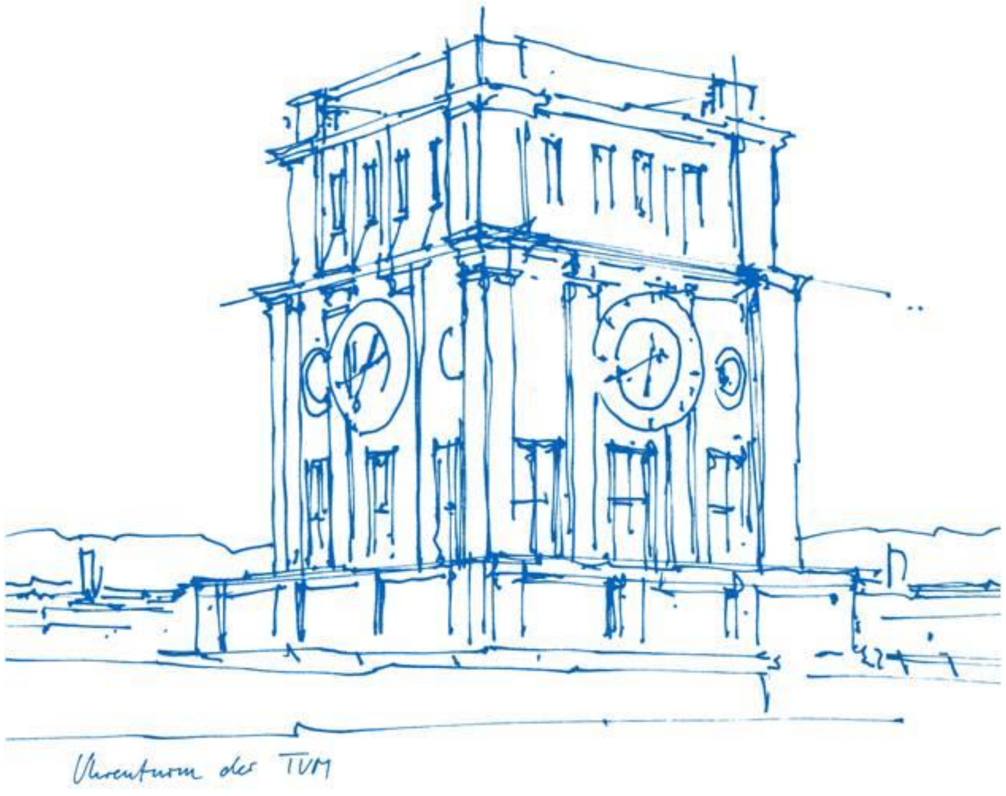
Extraterrestrial Exosphere and Surface Simulations

Lunar Water Exosphere

Alexander Smolka

Lunar and Planetary Exploration
Technical University of Munich



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Researcher, Technical University of Munich, Lunar and Planetary Exploration

Research Topic: *Modelling of the Lunar Water Exosphere and its Interaction with the Surface*

Methodology: *Numerical simulations using our specially developed high-performance Julia code base.*

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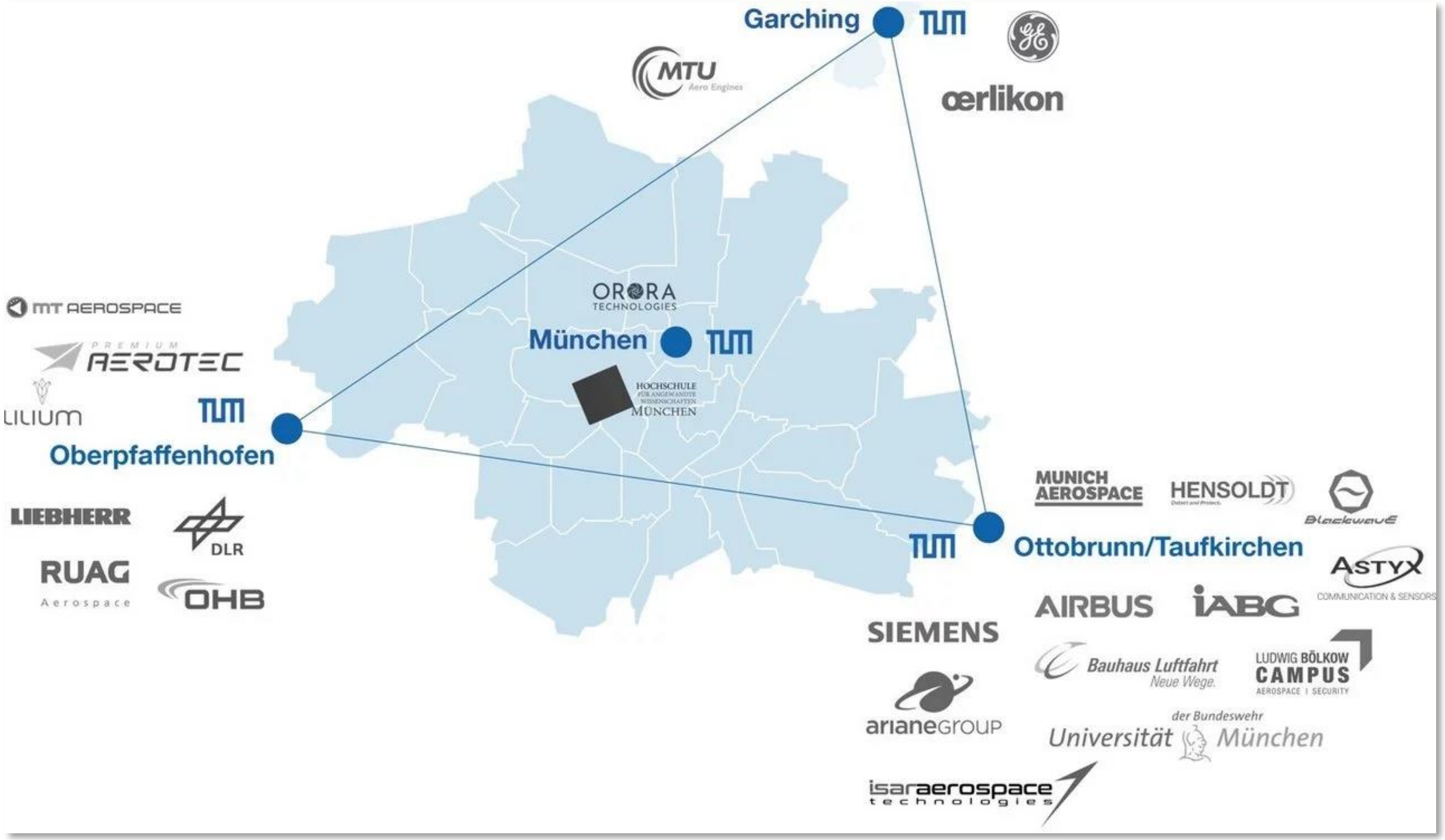
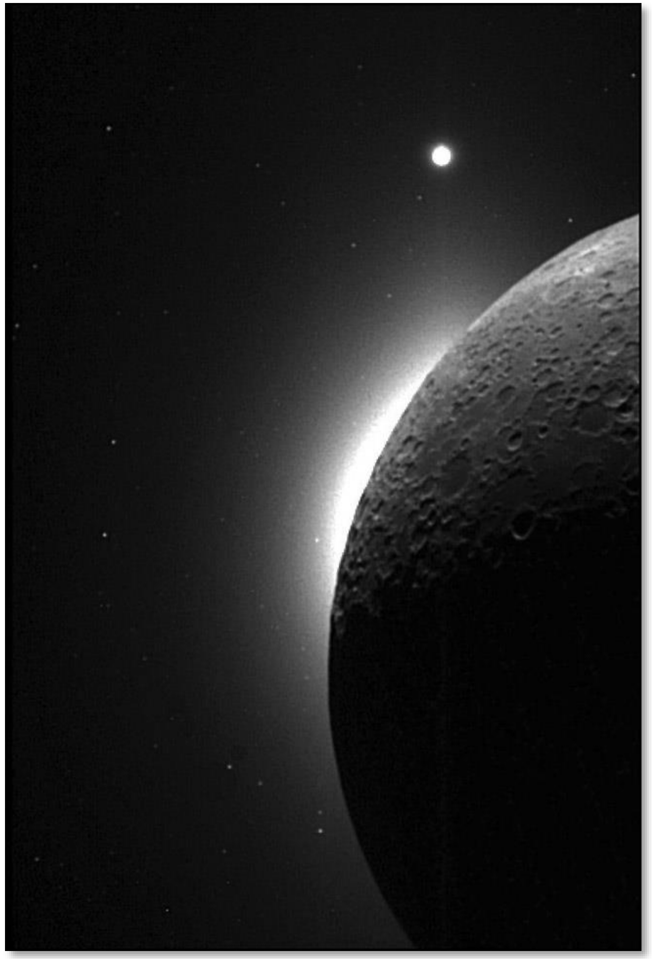


Technical University of Munich

Prof. Dr.-Ing. Philipp Reiss
Lunar and Planetary Exploration

- better understanding of volatiles and space resources
- instrumentation to enable their in-situ characterization
- extract and utilise resources

The Lunar Exosphere



(Image credit: NASA)

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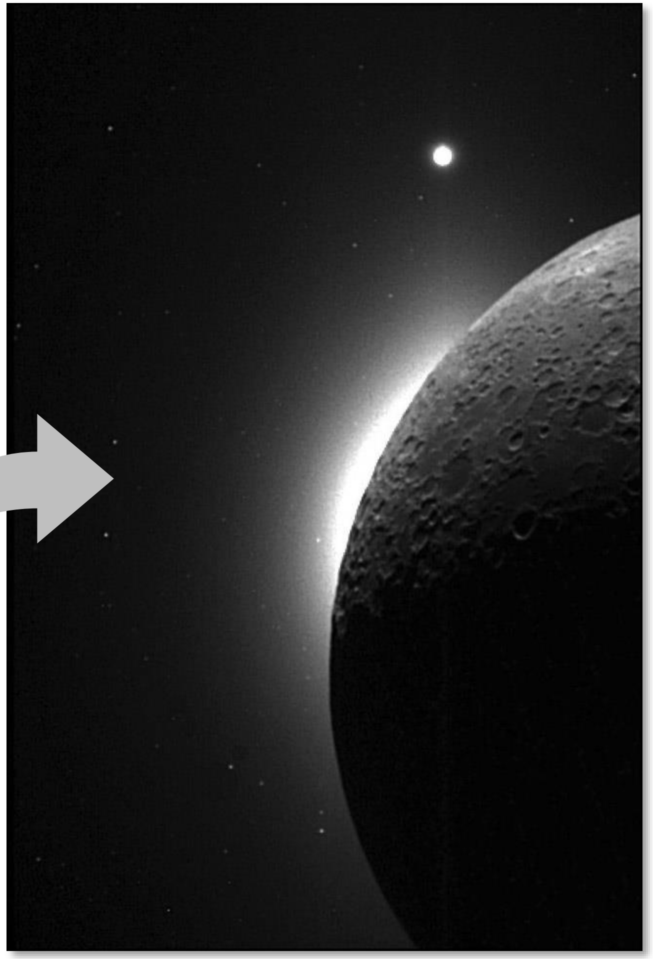

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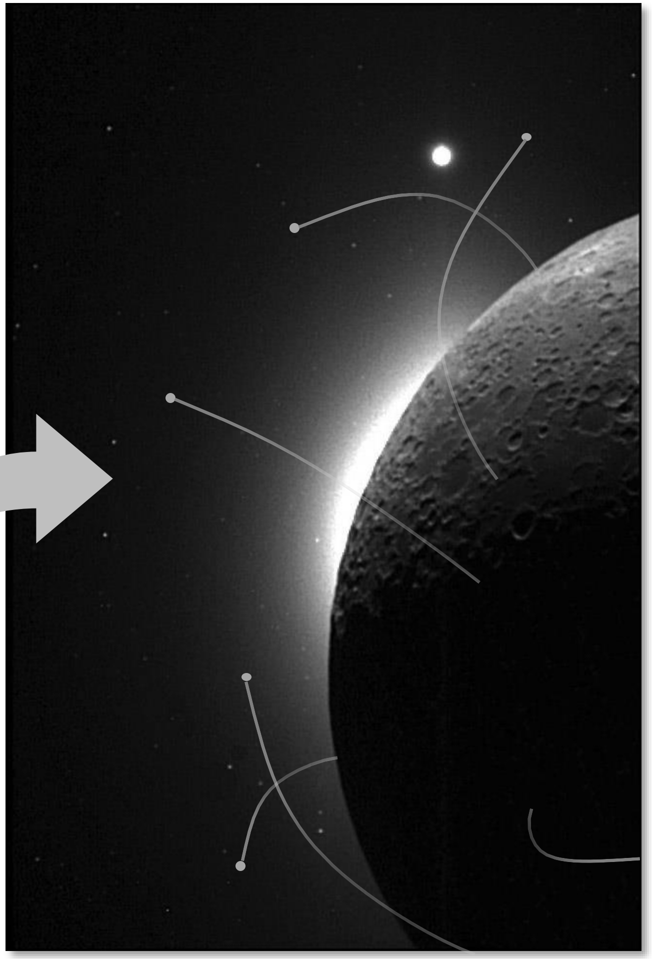
Surface-bounded Exosphere

"[…] atmosphere-like volume surrounding a planet […] where molecules are gravitationally bound to that body, but where the density is so low that the molecules are essentially collision-less."

The Lunar Exosphere



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We can simulate them individually!

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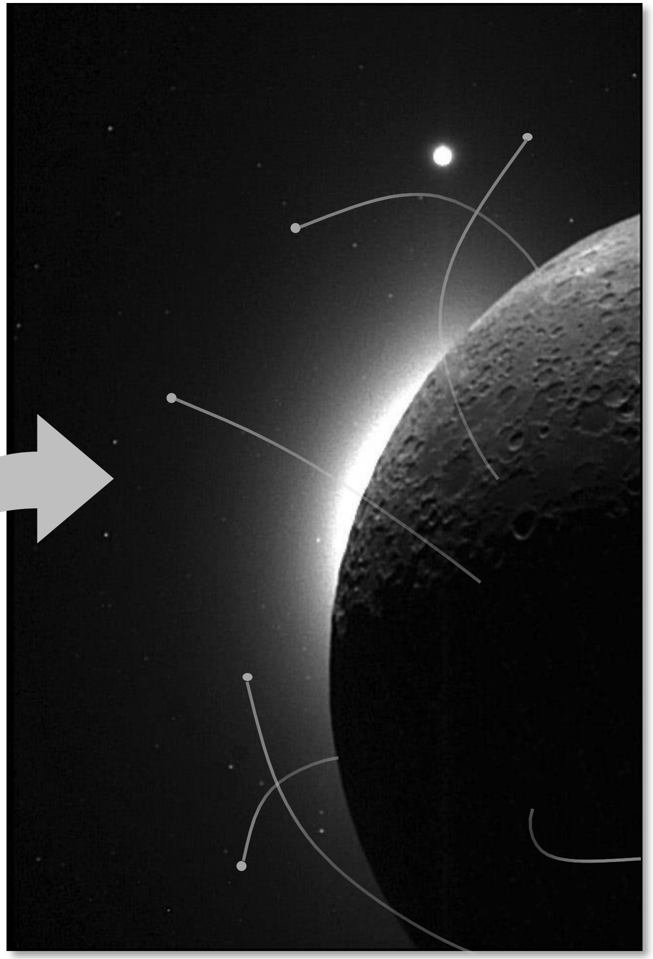

(Image credit: NASA)

The Lunar Exosphere

Densities are highly dependent on the position (equatorial/polar) and time (day/night)!

H	$\sim 1 - 10\ cm^{-3}$
H_2	$\sim 100 - 10^4\ cm^{-3}$
He	$\sim 100 - 5 \times 10^4\ cm^{-3}$
OH	$\sim 1\ cm^{-3}$
H_2O	$\sim 1 - 10^3\ cm^{-3}$
Ne	$\sim 10^3 - 10^5\ cm^{-3}$
…	…

Comparison with Earth's atmosphere:
$$2.687 \times 10^{19}\ cm^{-3}$$

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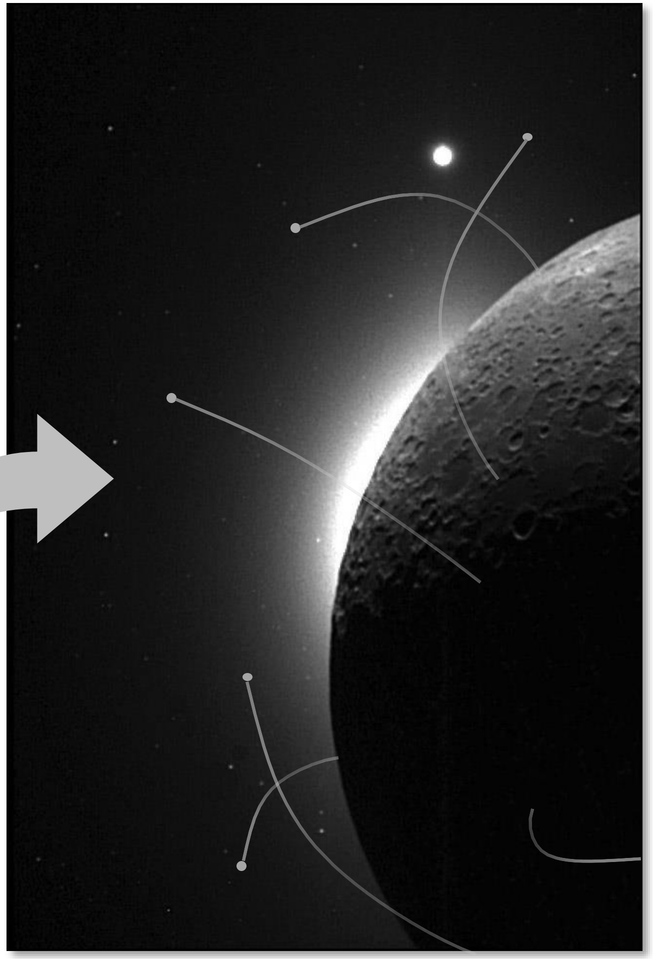

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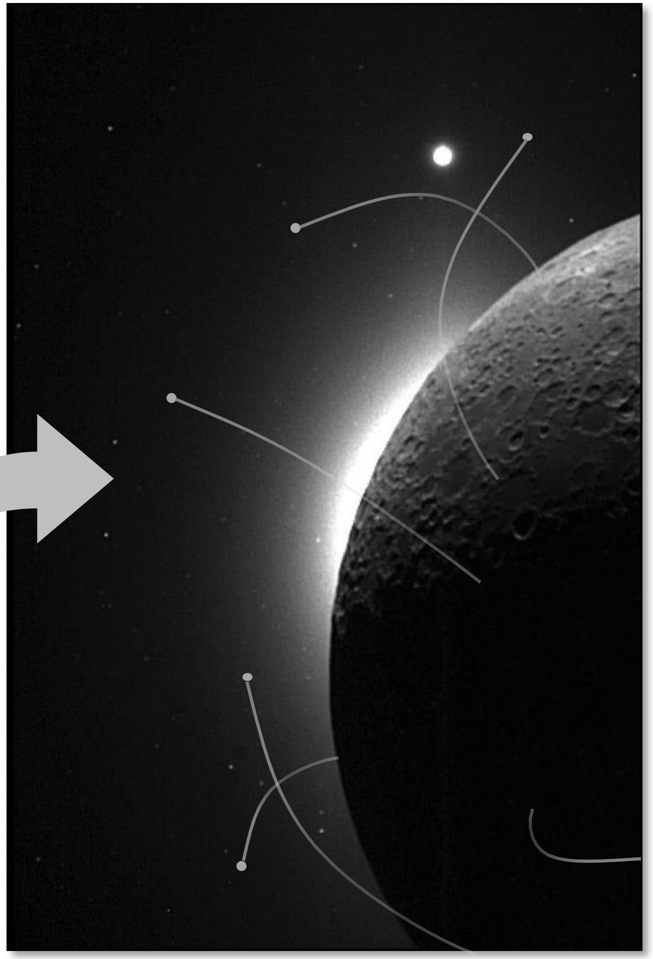

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Monte Carlo simulation

We can simulate them individually!

Comparison with Earth's atmosphere:
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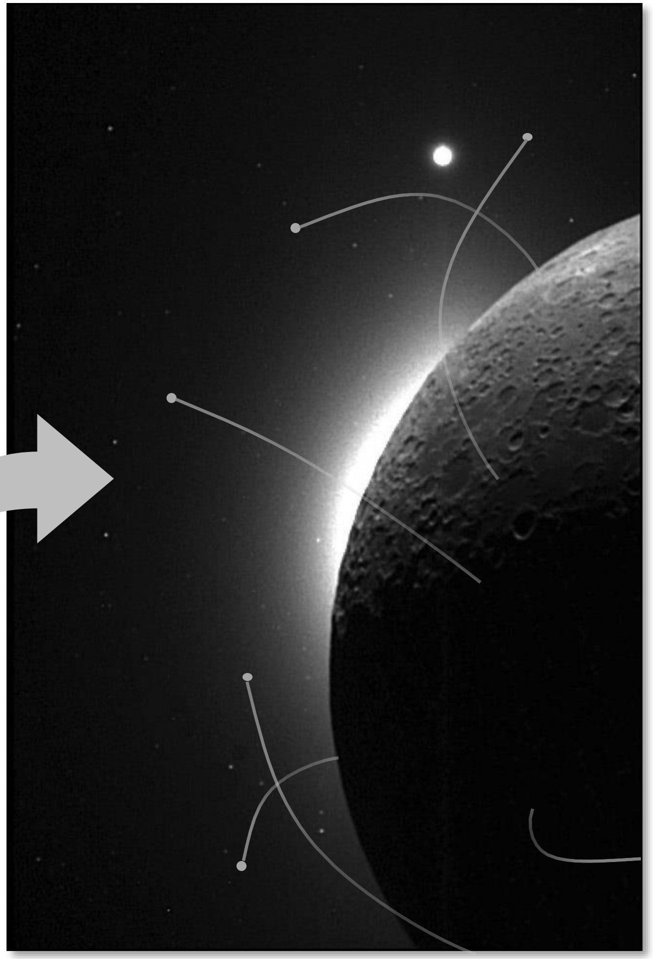
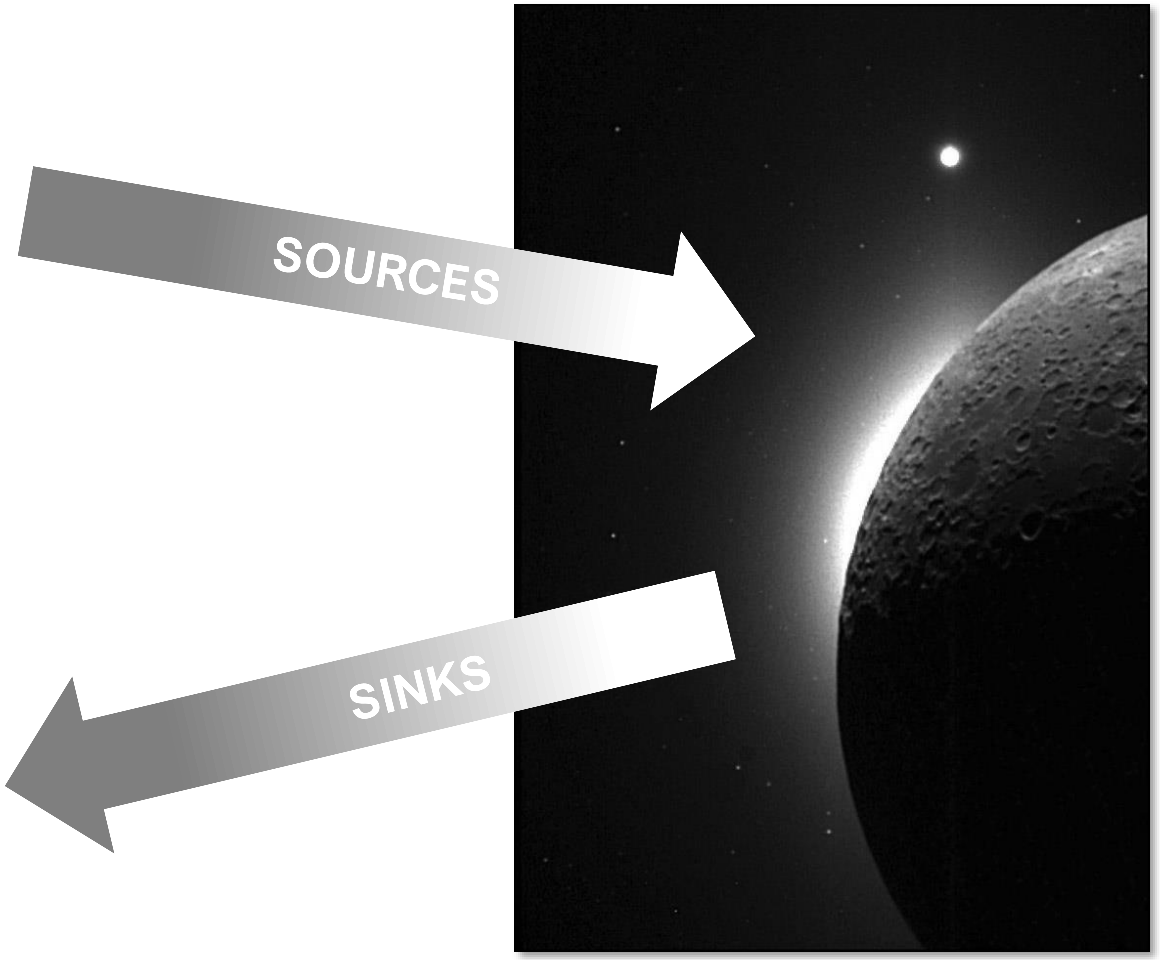


(Image credit: NASA)

The Lunar Exosphere

Sources & Sinks

- Solar wind
- Micrometeoroid Impact
- Micrometeoroid Impact Vaporization
- Sputtering



- Gravitational Escape
- Photolysis
- Sputtering
- Permanent Cold Trapping

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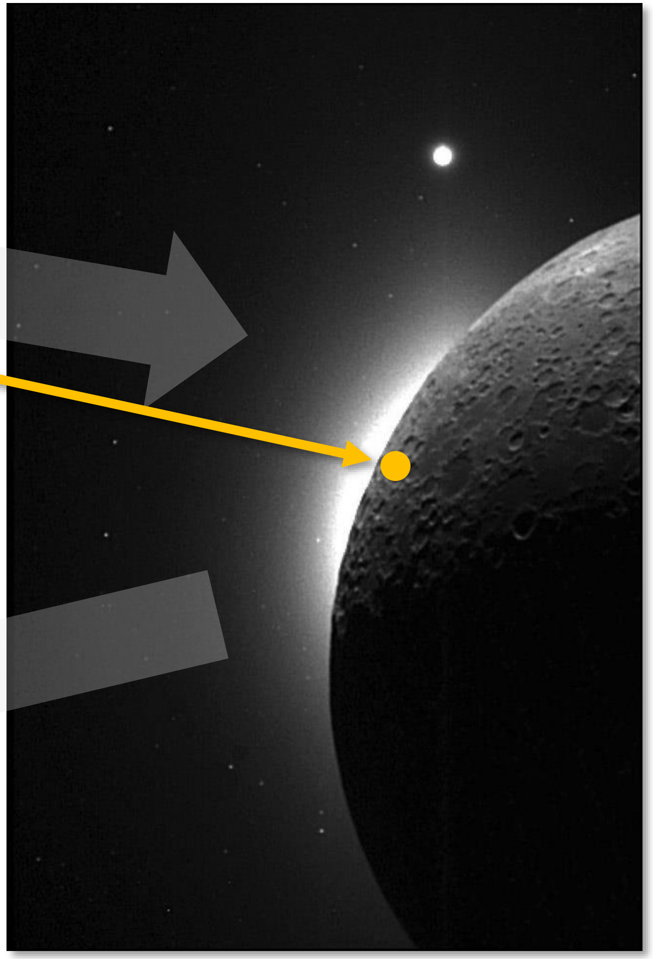

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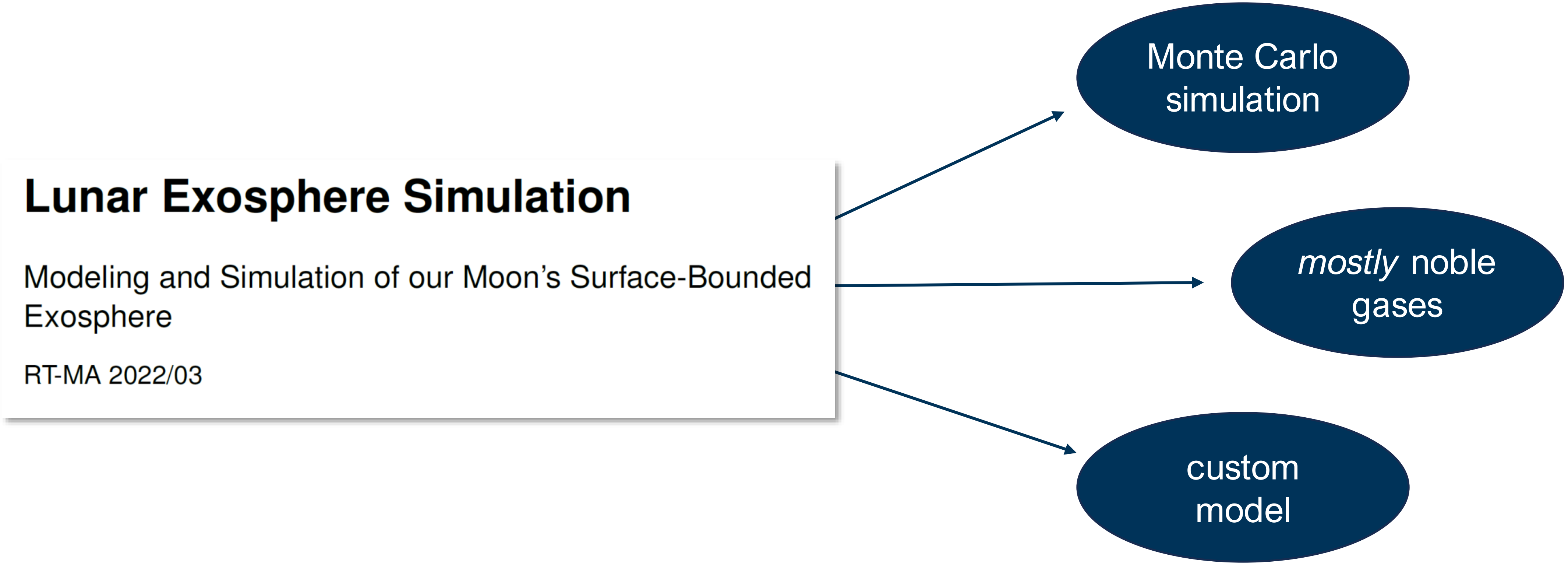
(Image credit: NASA)

Lunar Exosphere Simulation



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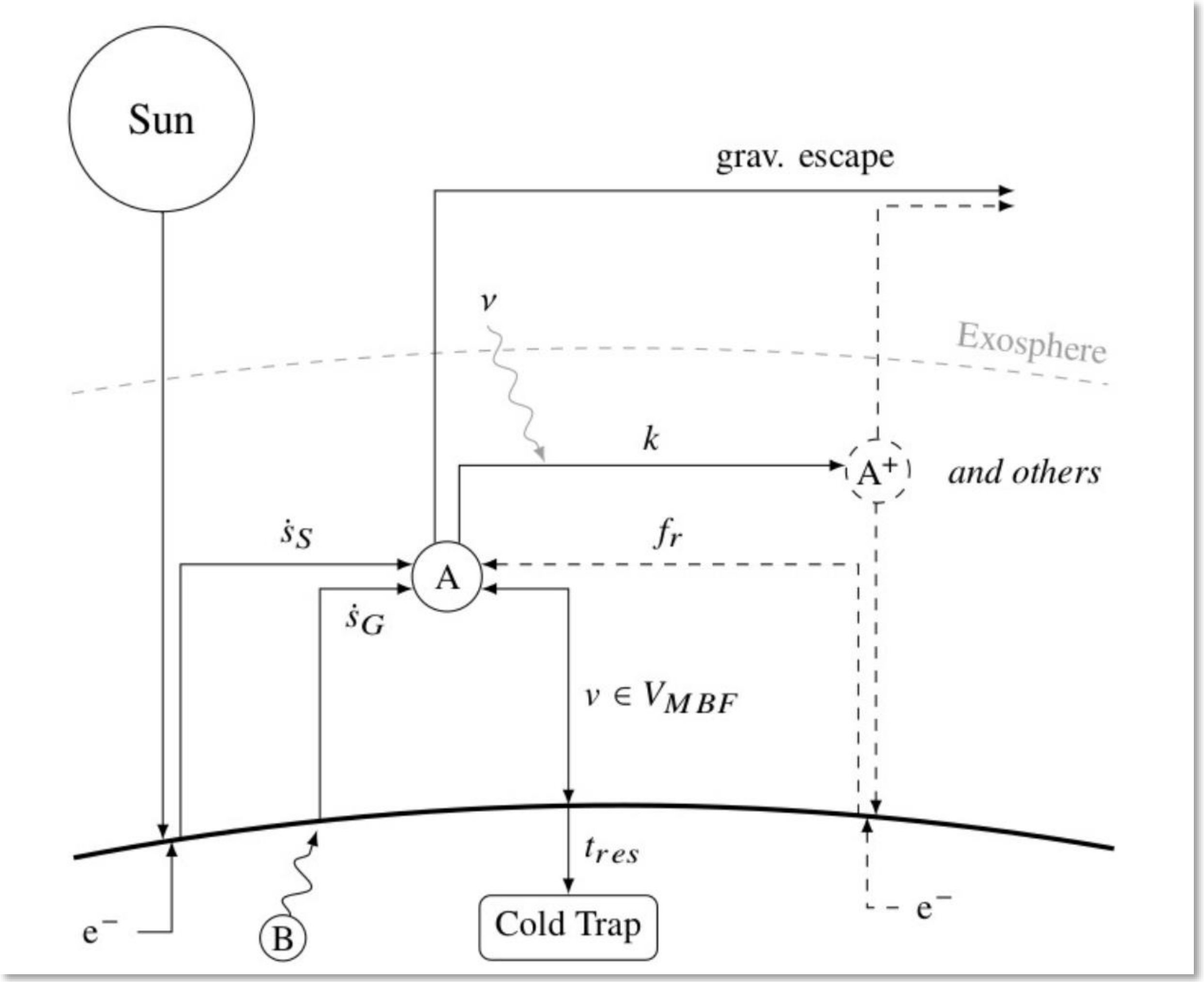
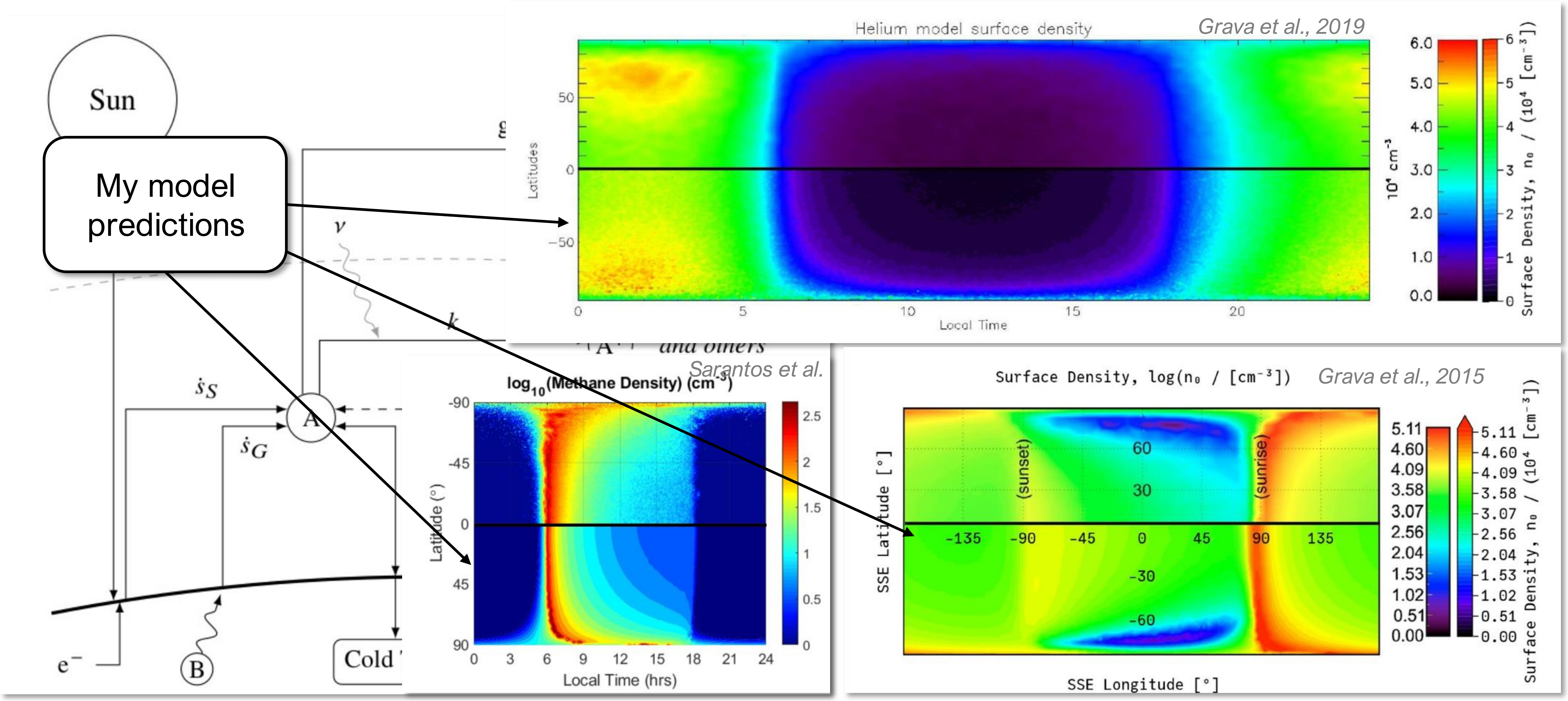


Assumptions:

- 2D landing position calculation instead of 3D ODE trajectory solver
- Only neutral gases
    - Only gravity
- Steady-state conditions without Earth's influence
- ...

Lunar Exosphere Simulation



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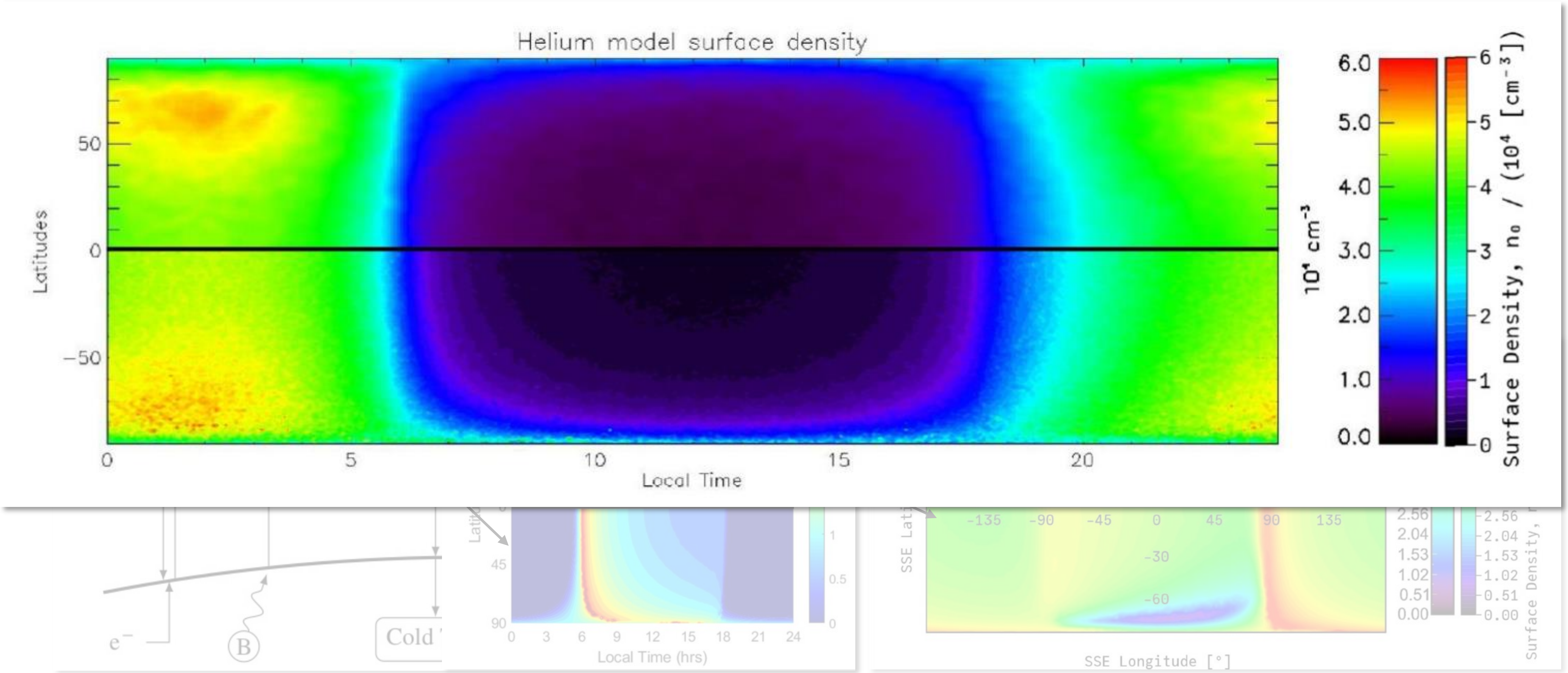

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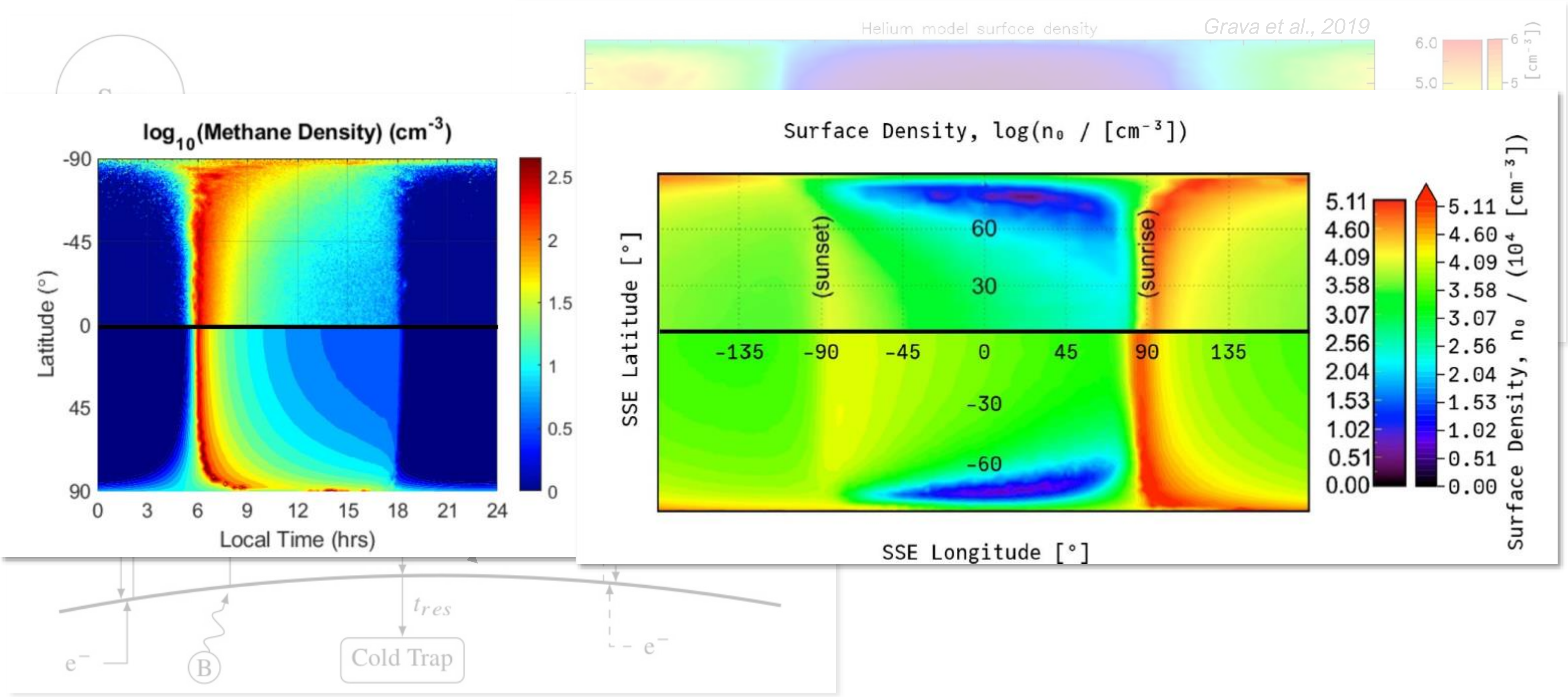

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Lunar Exosphere Simulation

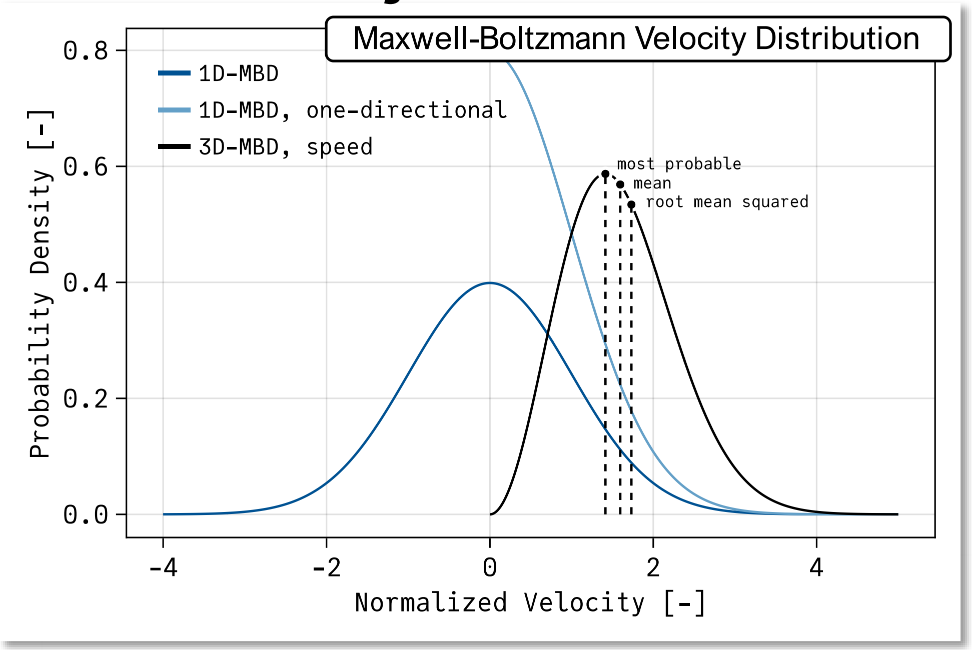
Lunar Exosphere Simulation

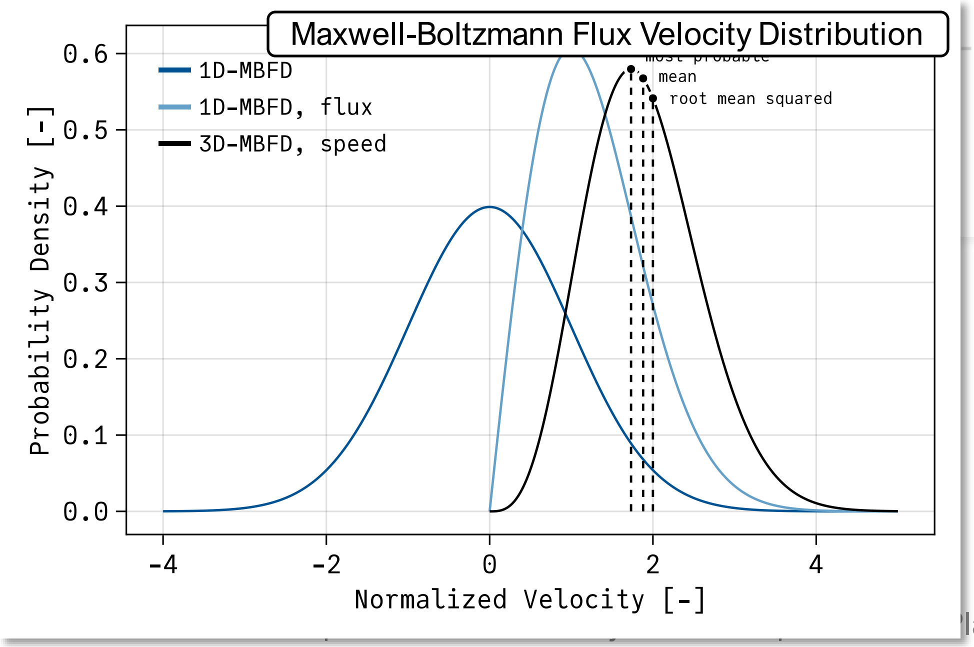
Modeling and Simulation of our Moon’s Surface-Bounded Exosphere

RT-MA 2022/03

ExESS

Velocity distributions





Simulation

-Bounded

ExESS

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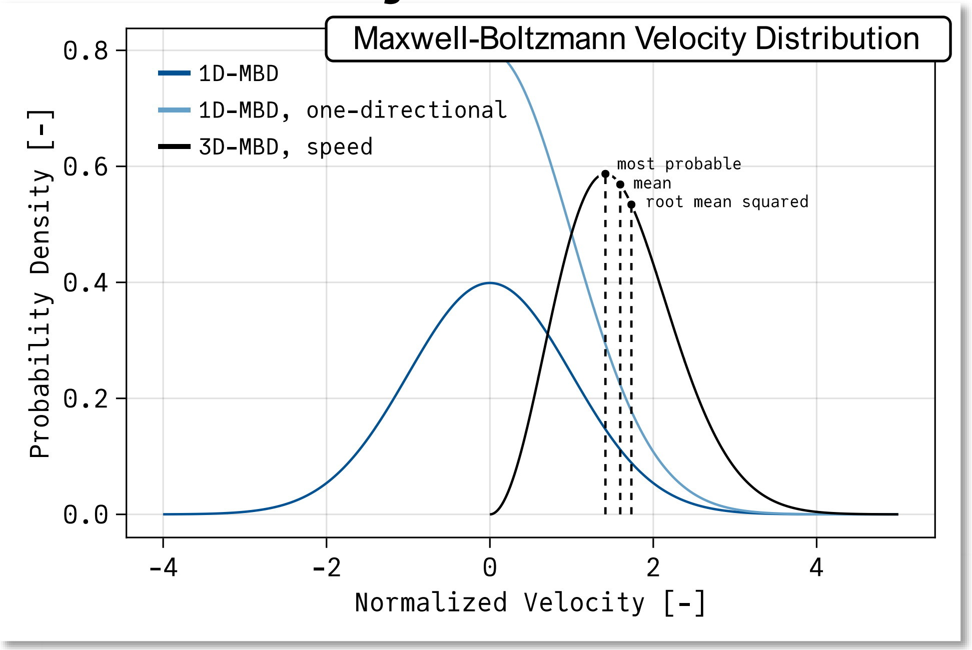
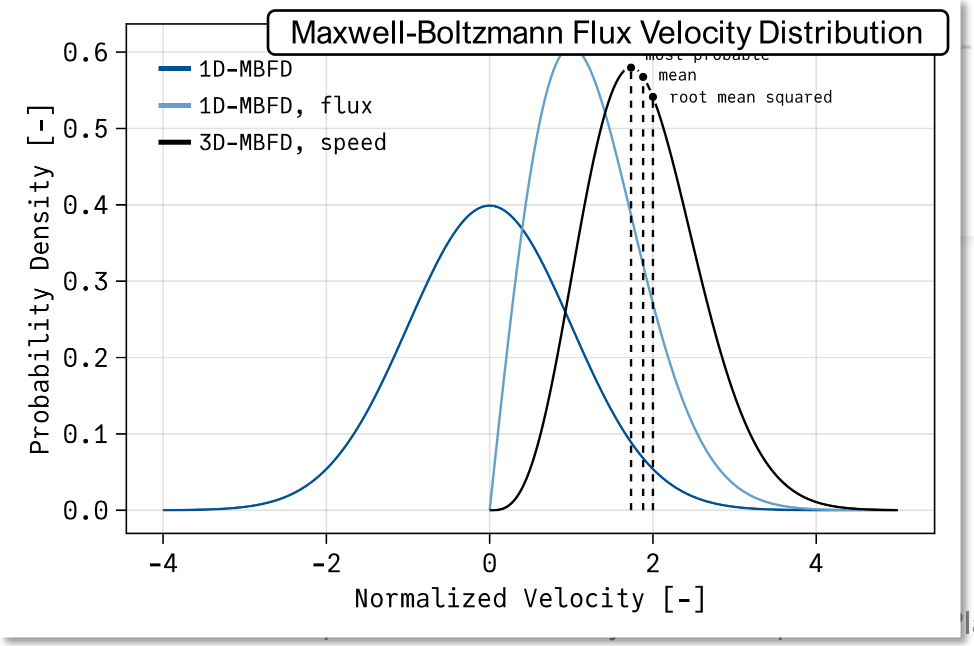
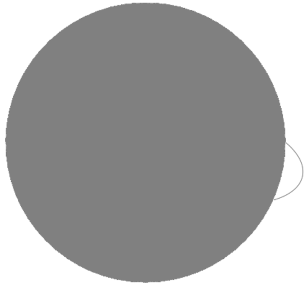
Velocity distributions







2D/3D Trajectories

Velocity distributions

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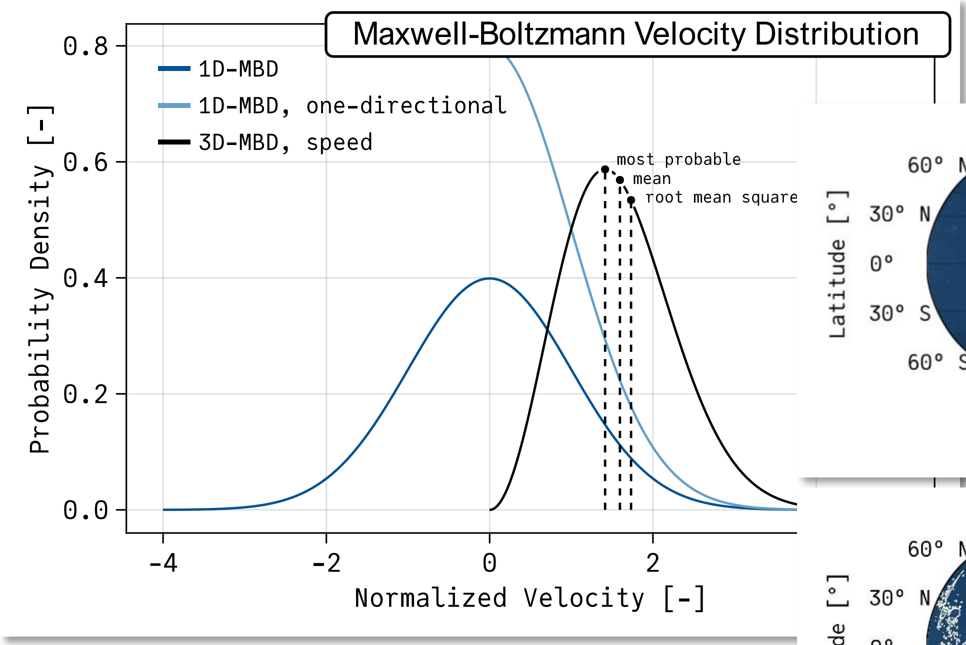
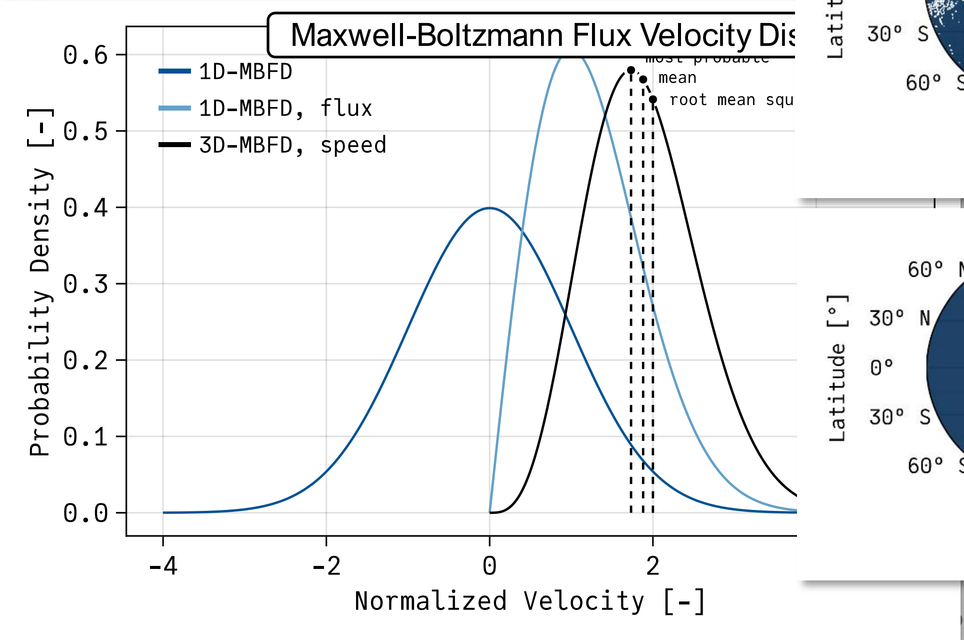
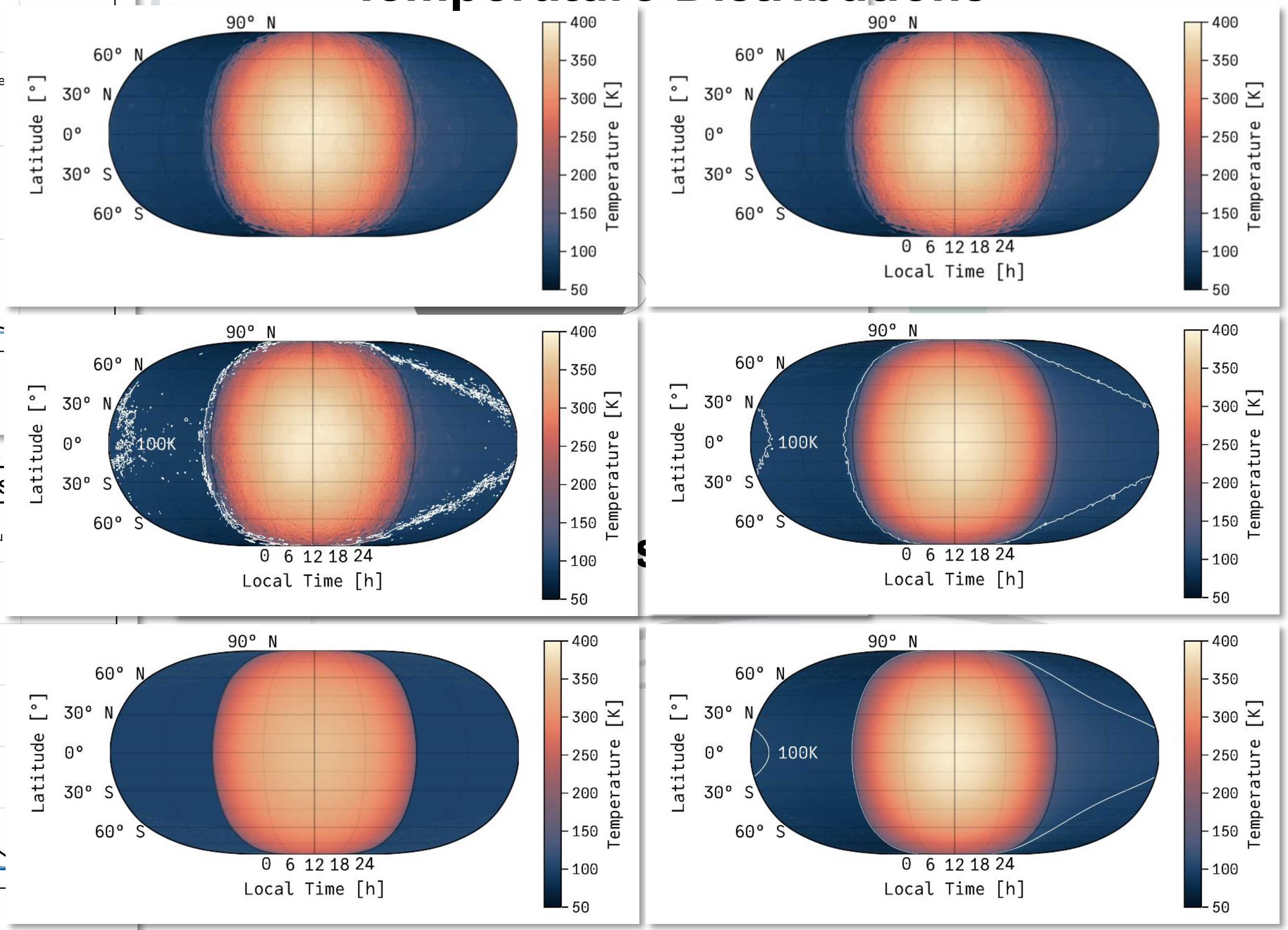
Temperature Distributions







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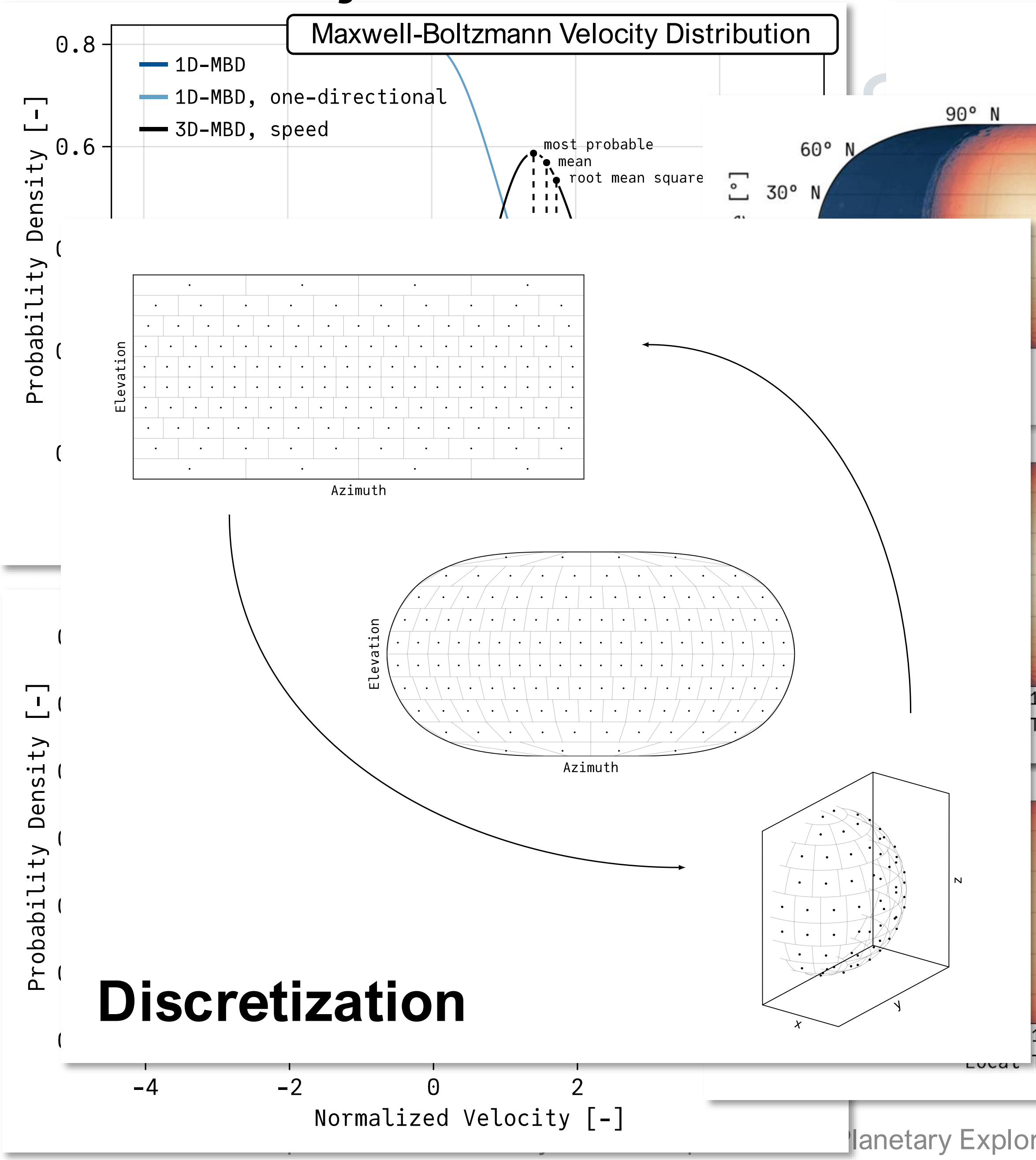

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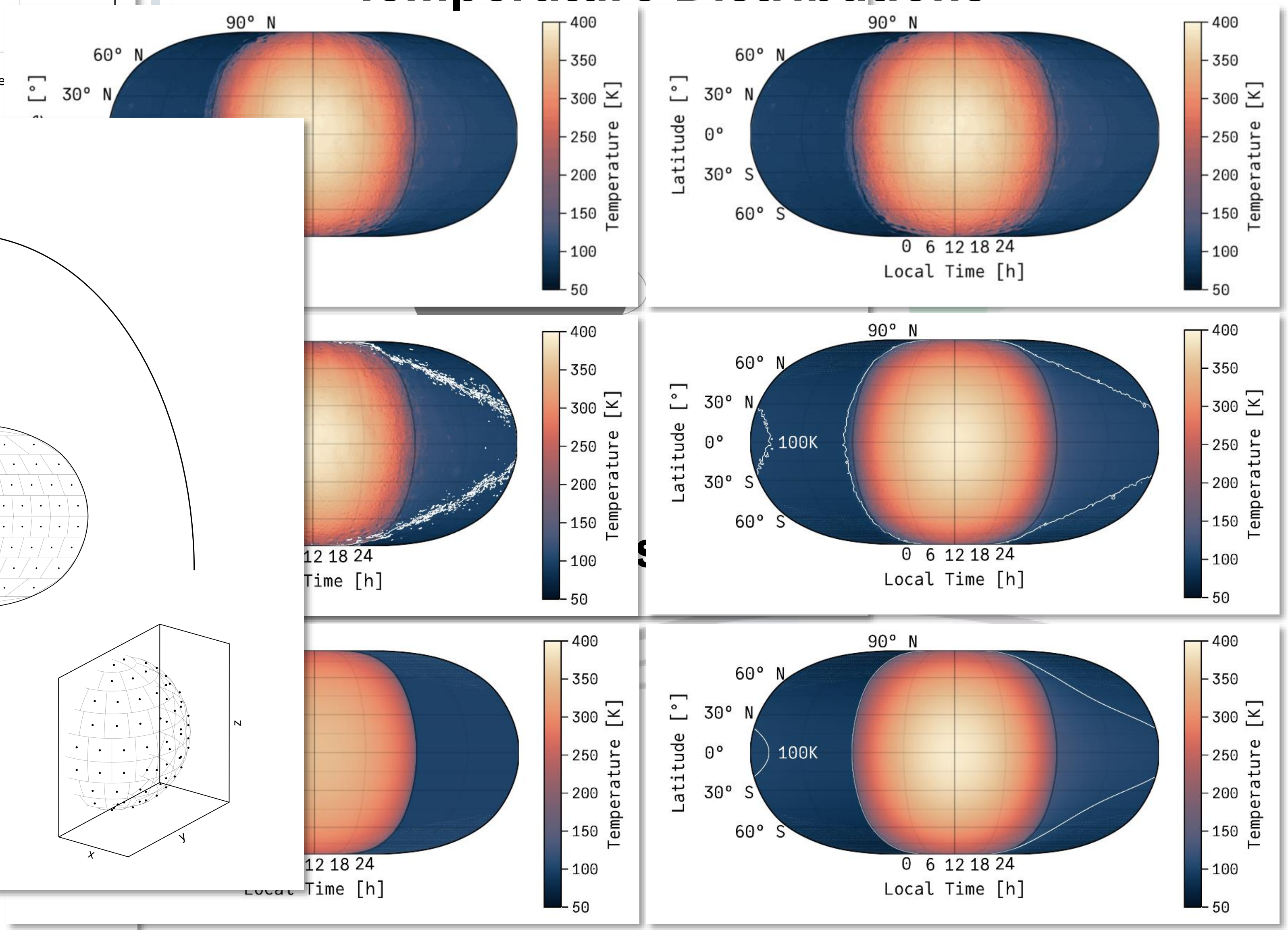
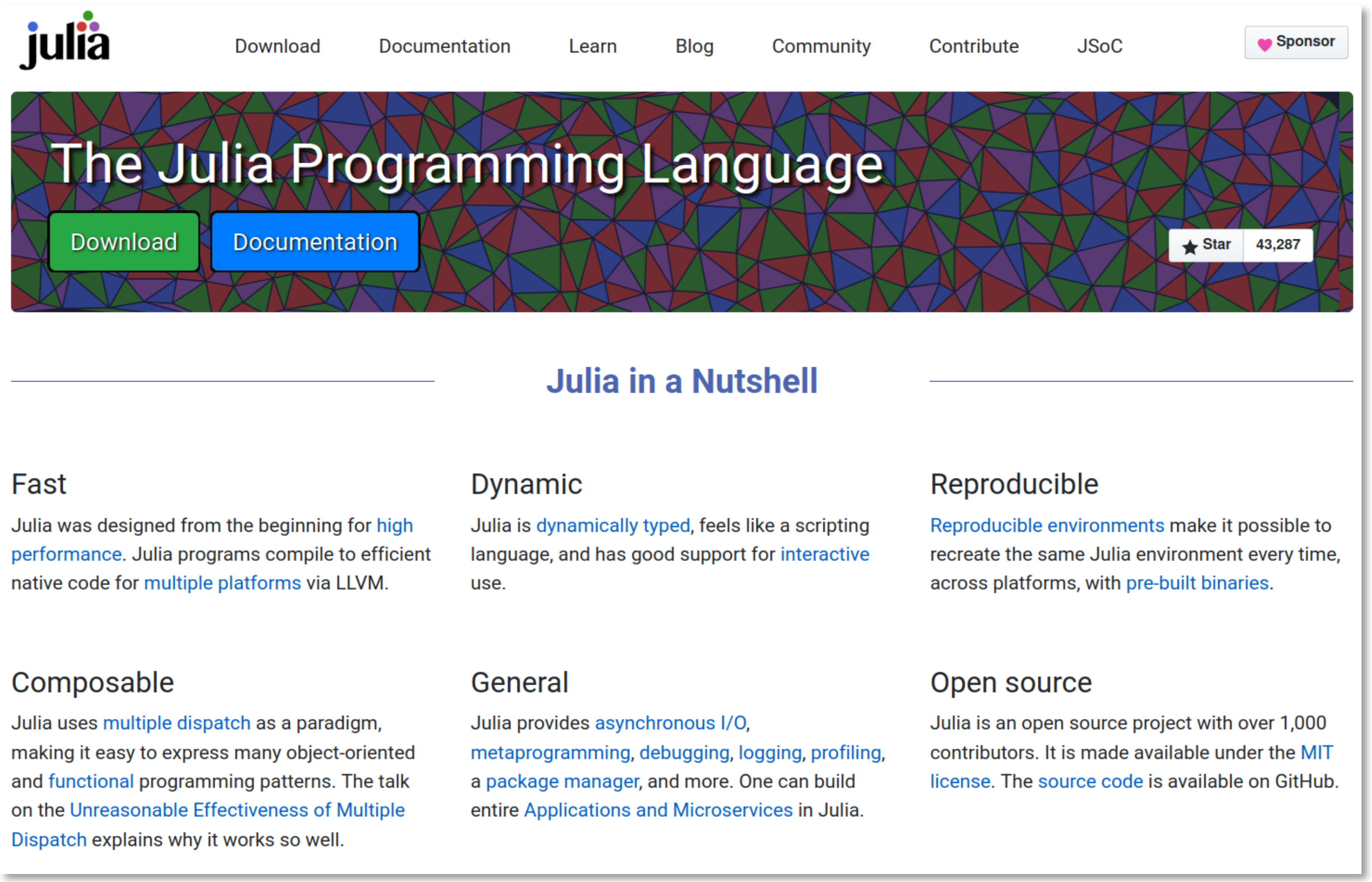


Discretization

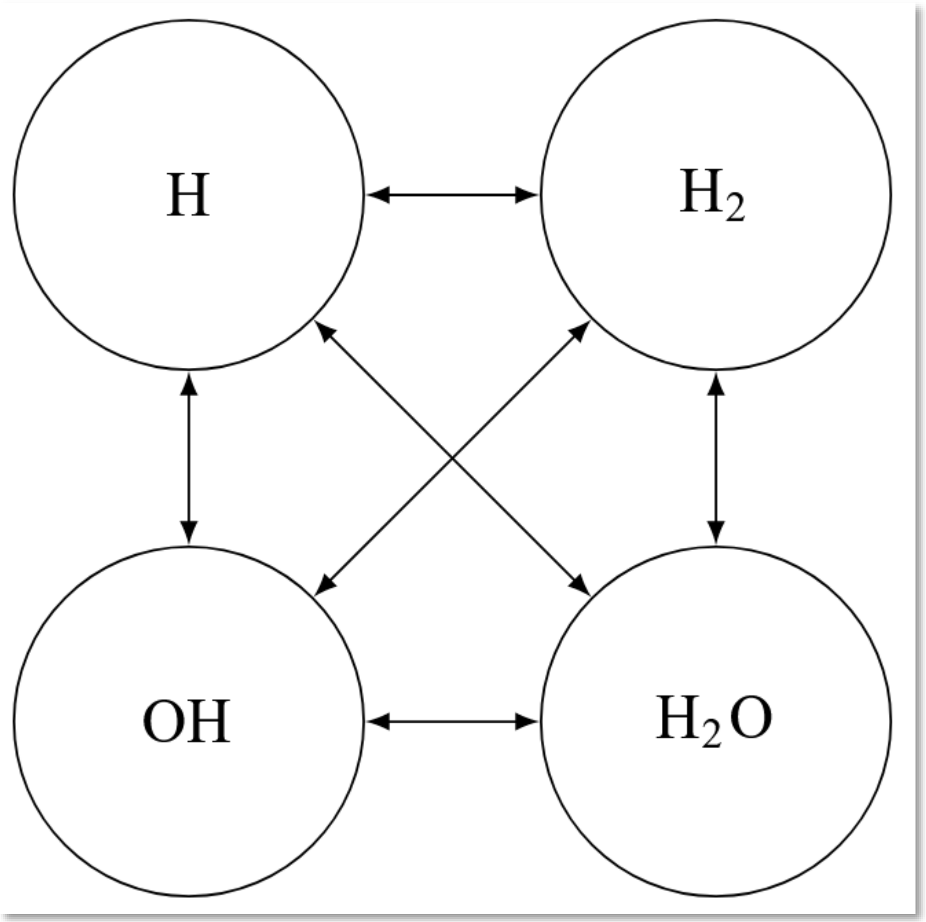
Lunar Exosphere Simulation



https://julialang.org/

Lunar Water Exosphere Simulation

Conversion Reactions

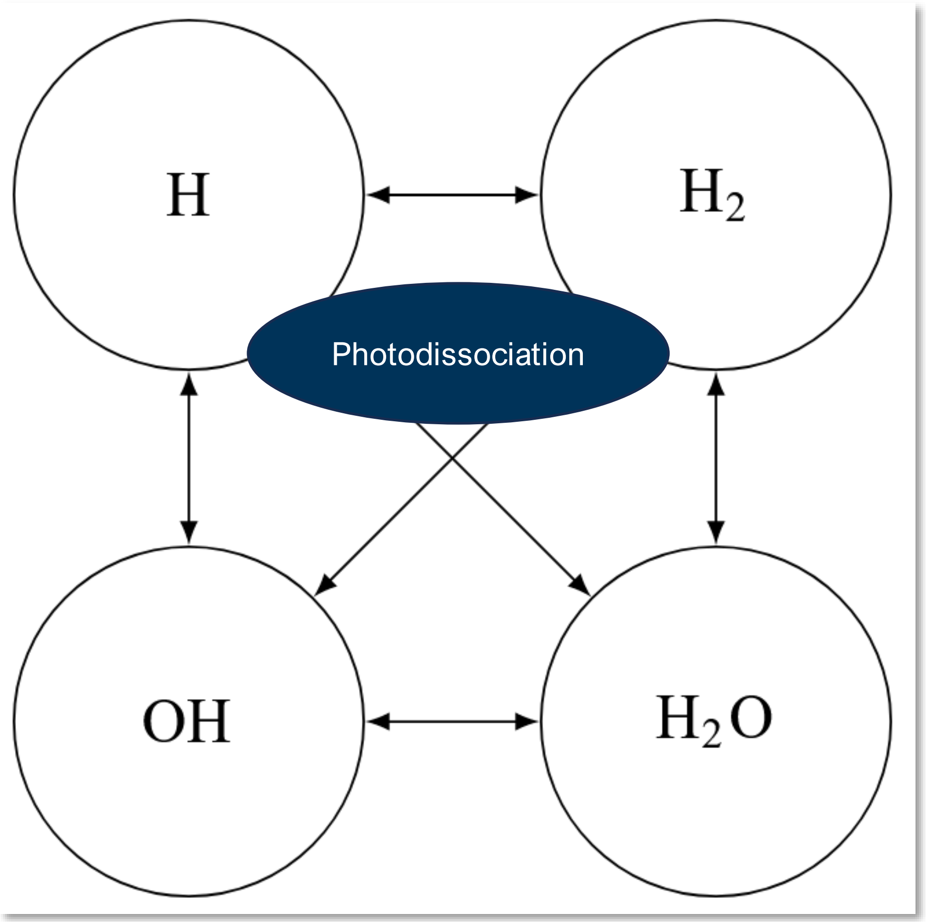


Lunar Water Exosphere Simulation

Conversion Reactions

	Reaction	Quiet Sun Photoreaction Rate in 10^{-7} s^{-1}	Active Sun Photoreaction Rate in 10^{-7} s^{-1}
1	$H + \nu \longrightarrow H^+ + e^-$	0.726	1.720
2	$H_2 + \nu \longrightarrow H(1s) + H(1s)$	0.480	1.090
	$H_2 + \nu \longrightarrow H(1s) + H(2s\ or\ 2p)$	0.344	0.821
	$H_2 + \nu \longrightarrow H_2^+ + e^-$	0.541	1.150
	$H_2 + \nu \longrightarrow H + H^+ + e^-$	0.095	0.279
17	$OH + \nu \longrightarrow O(3p) + H$	(120.00) 65.400	(138.00) 71.700
	$OH + \nu \longrightarrow O(1d) + H$	(70.10) 6.350	(176.00) 15.100
	$OH + \nu \longrightarrow O(1s) + H$	(8.33) 0.671	(21.10) 1.640
	$OH + \nu \longrightarrow OH^+ + e^-$	(2.43) 2.470	(6.43) 6.520
18	$H_2O + \nu \longrightarrow OH + H$	103.000	176.000
	$H_2O + \nu \longrightarrow H_2 + O(1d)$	5.970	14.800
	$H_2O + \nu \longrightarrow H + H + O$	7.550	19.100
	$H_2O + \nu \longrightarrow H_2O^+ + e^-$	3.310	8.280
	$H_2O + \nu \longrightarrow H + OH^+ + e^-$	0.554	1.510
	$H_2O + \nu \longrightarrow H_2 + O^+ + e^-$	0.059	0.221
	$H_2O + \nu \longrightarrow OH + H^+ + e^-$	0.131	0.407

Huebner et al., 1992



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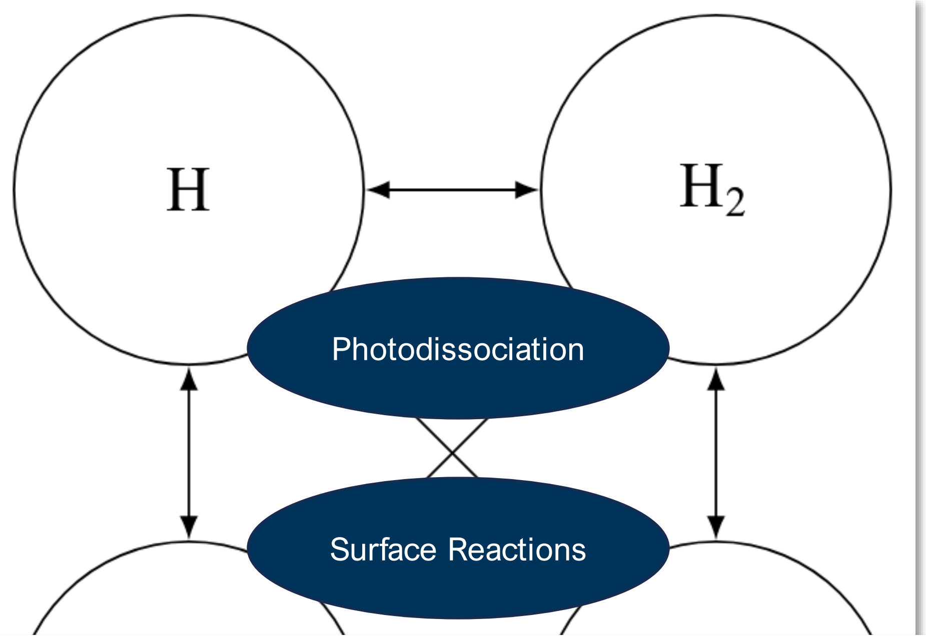
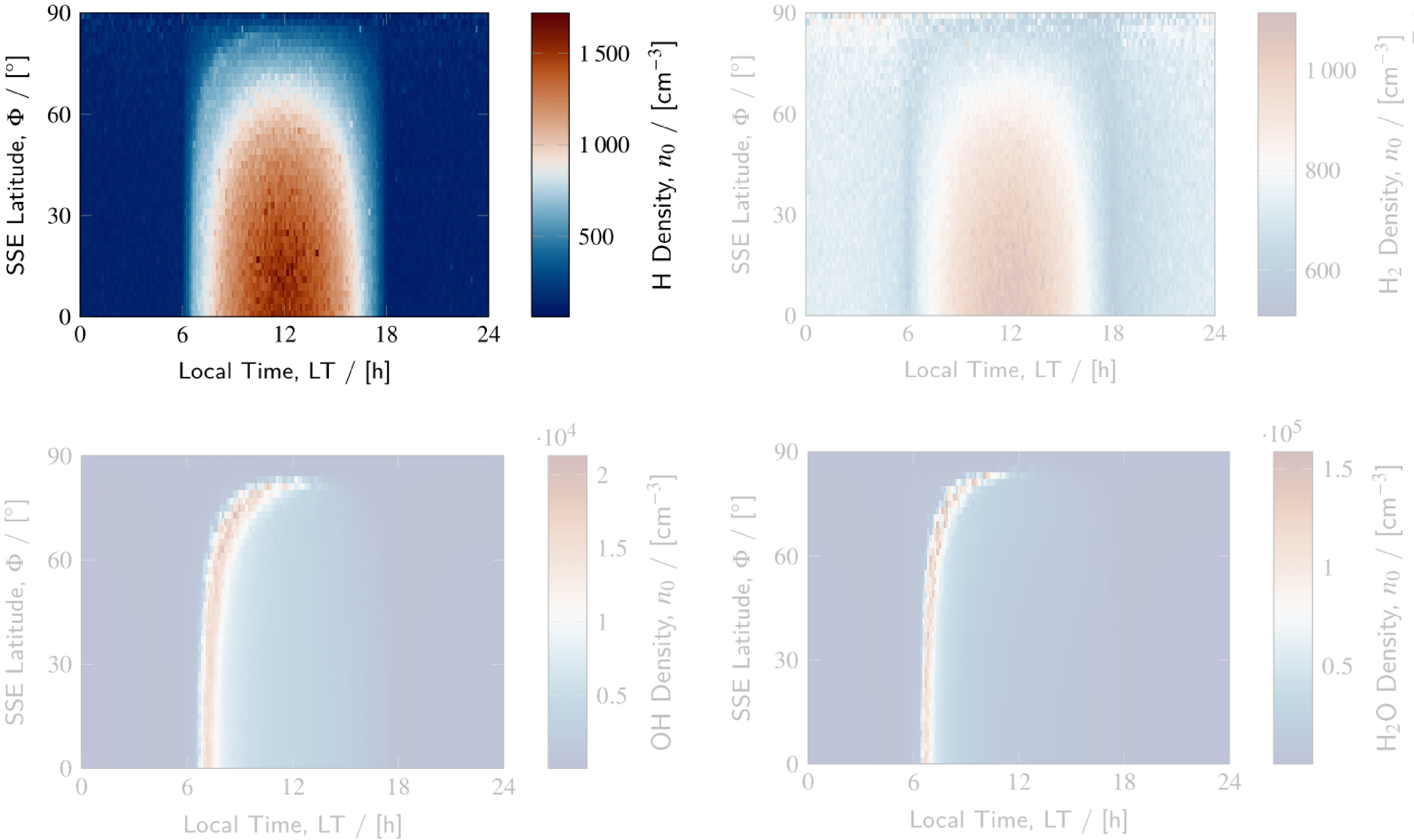


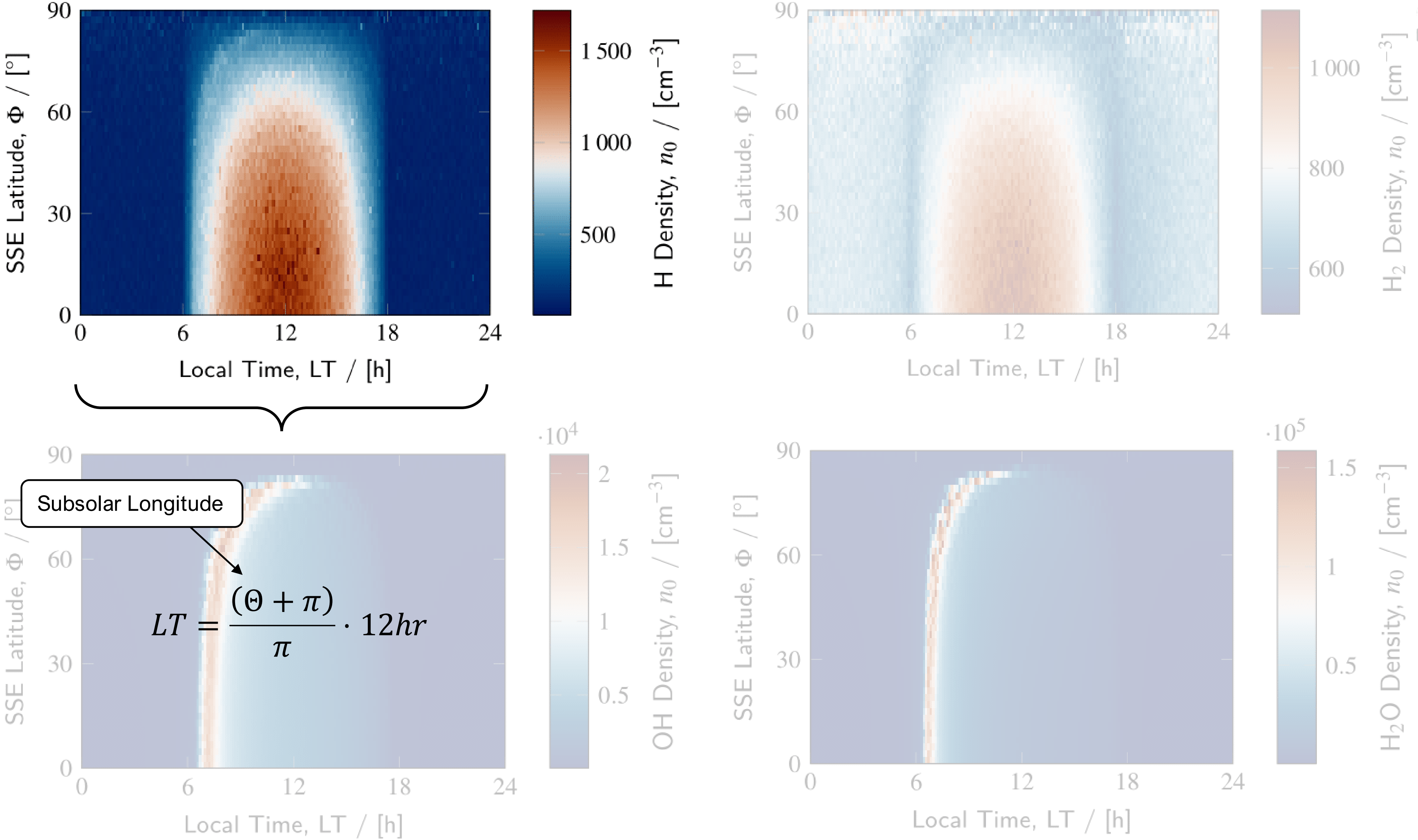
Table 1. Fractions of Incident Protons Entering Each Branch After Surface Interaction

Backscatter H	Sputtered H	Desorbing H	Convert to H_2	Convert to OH	Convert to H_2O
.01	.0001	.27	.6	.1	.02

Crider and Vondrak, 2002

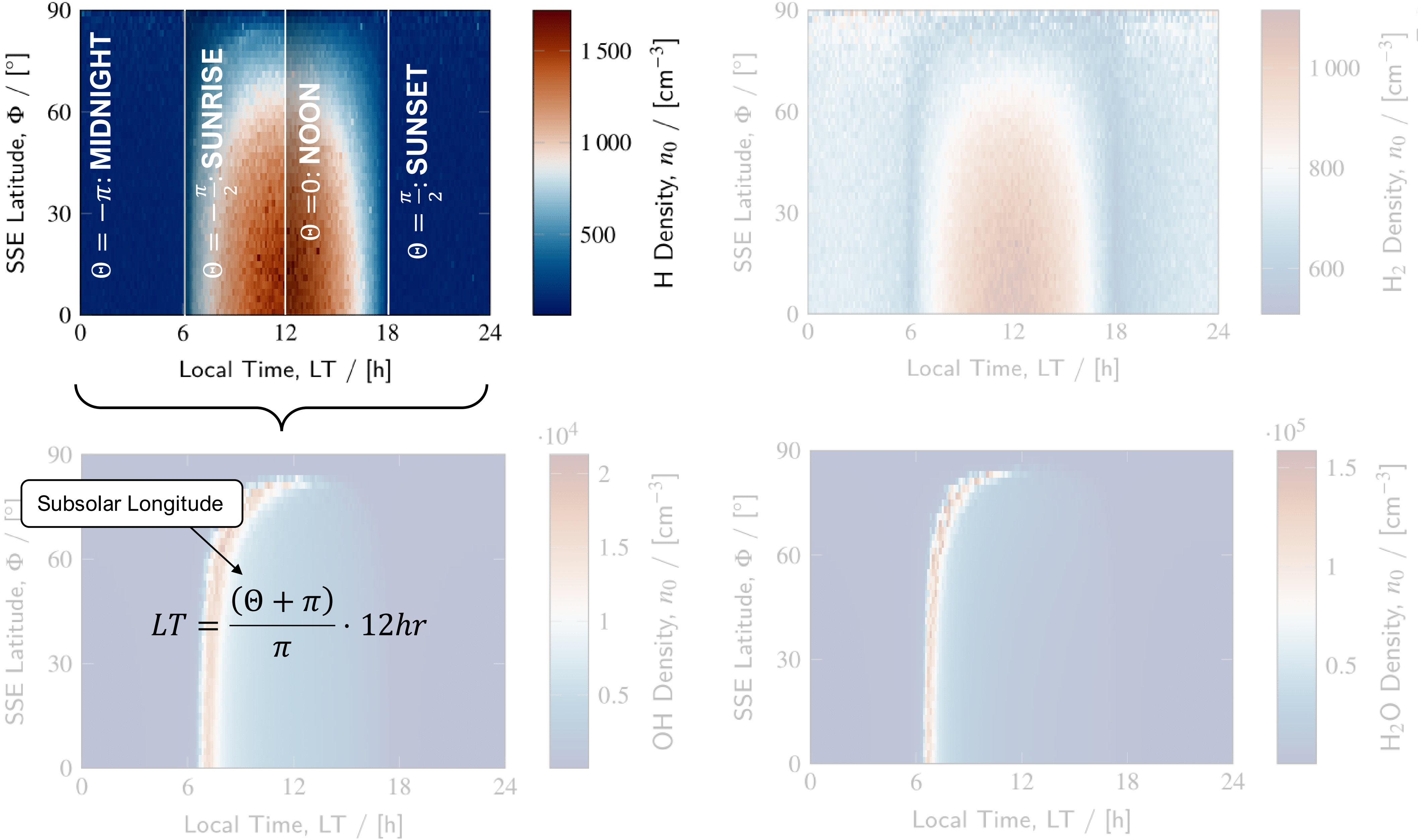


Smolka et al. 2023



$$LT = \frac{(\Theta + \pi)}{\pi} \cdot 12hr$$

Smolka et al. 2023



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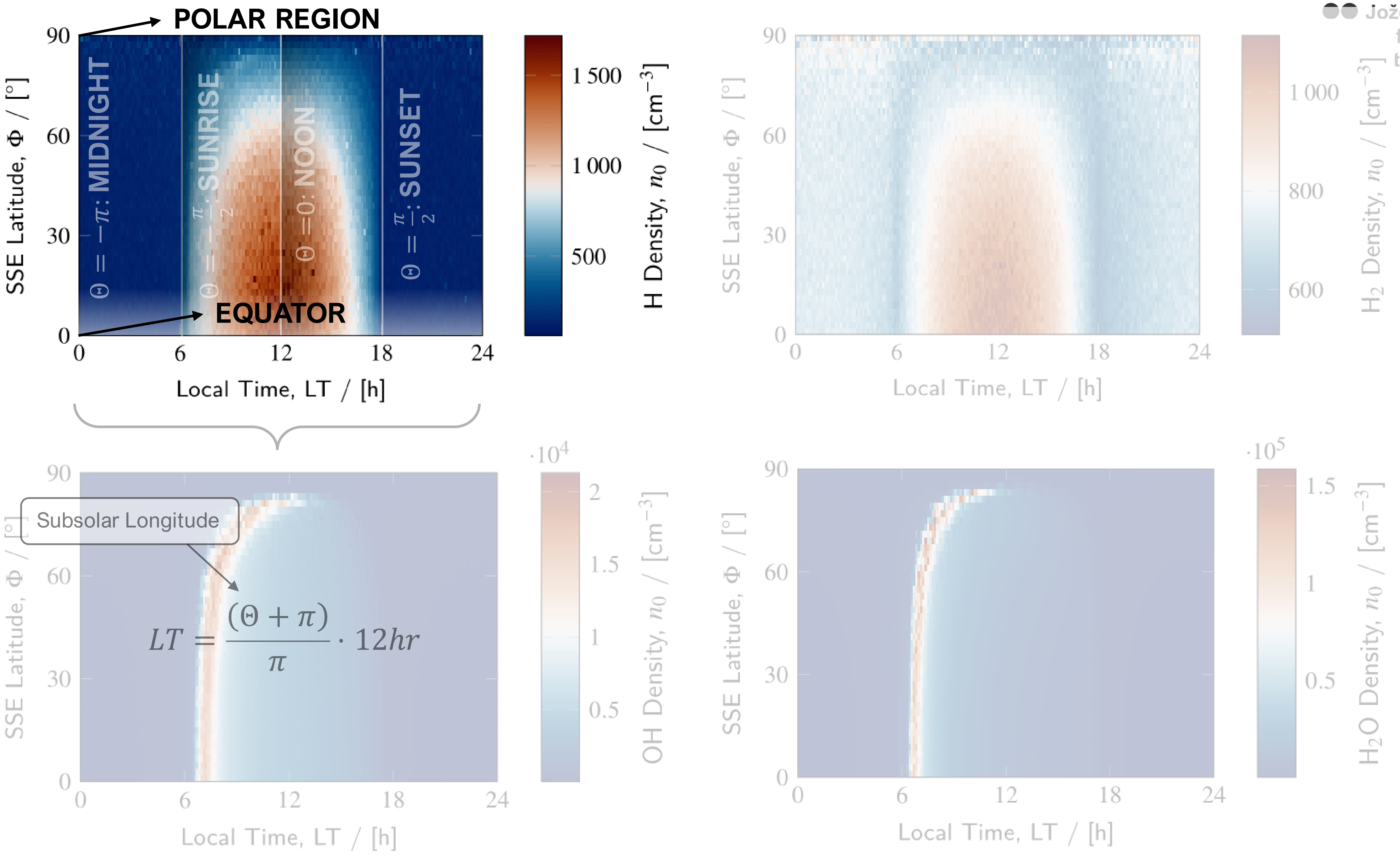

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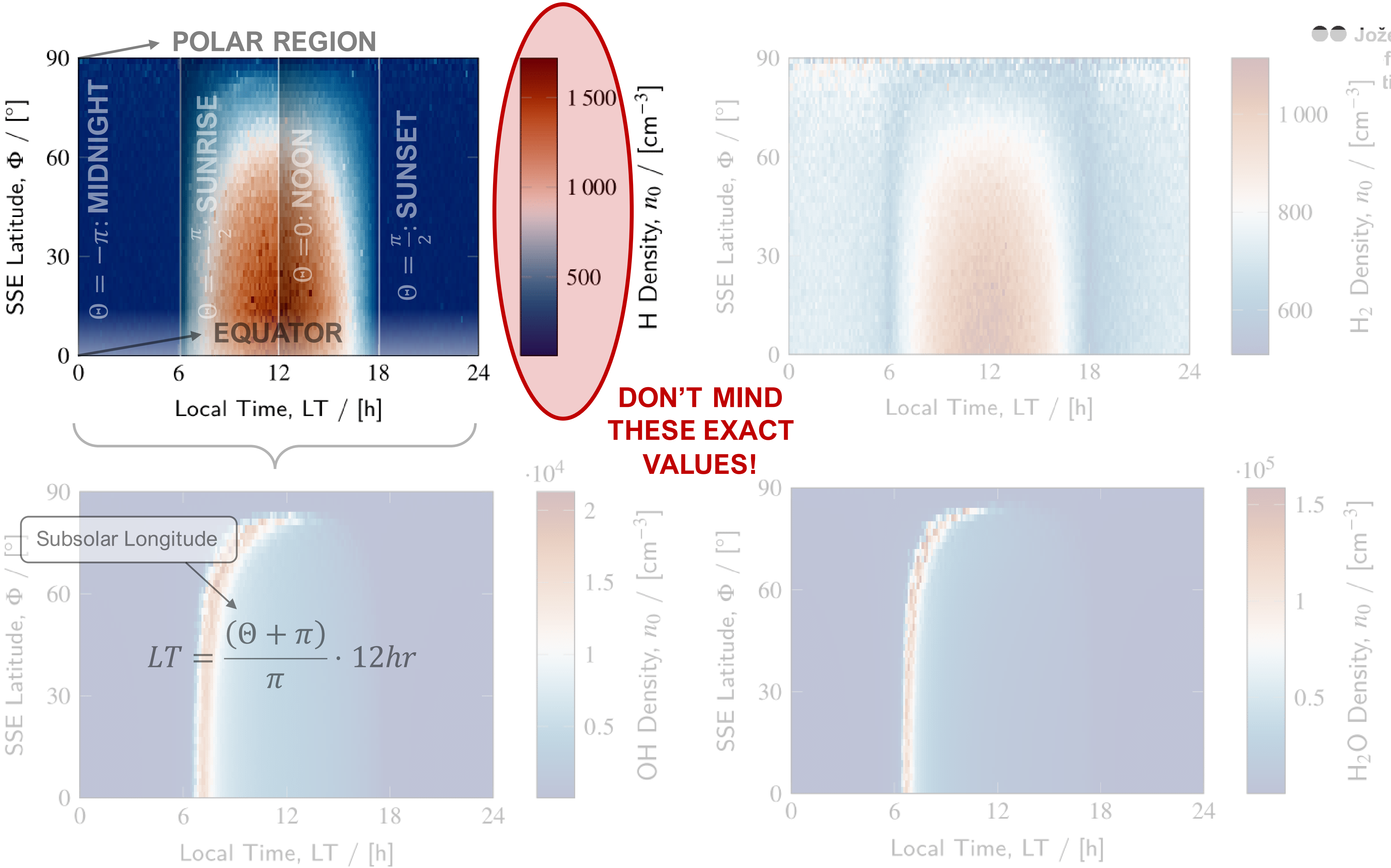

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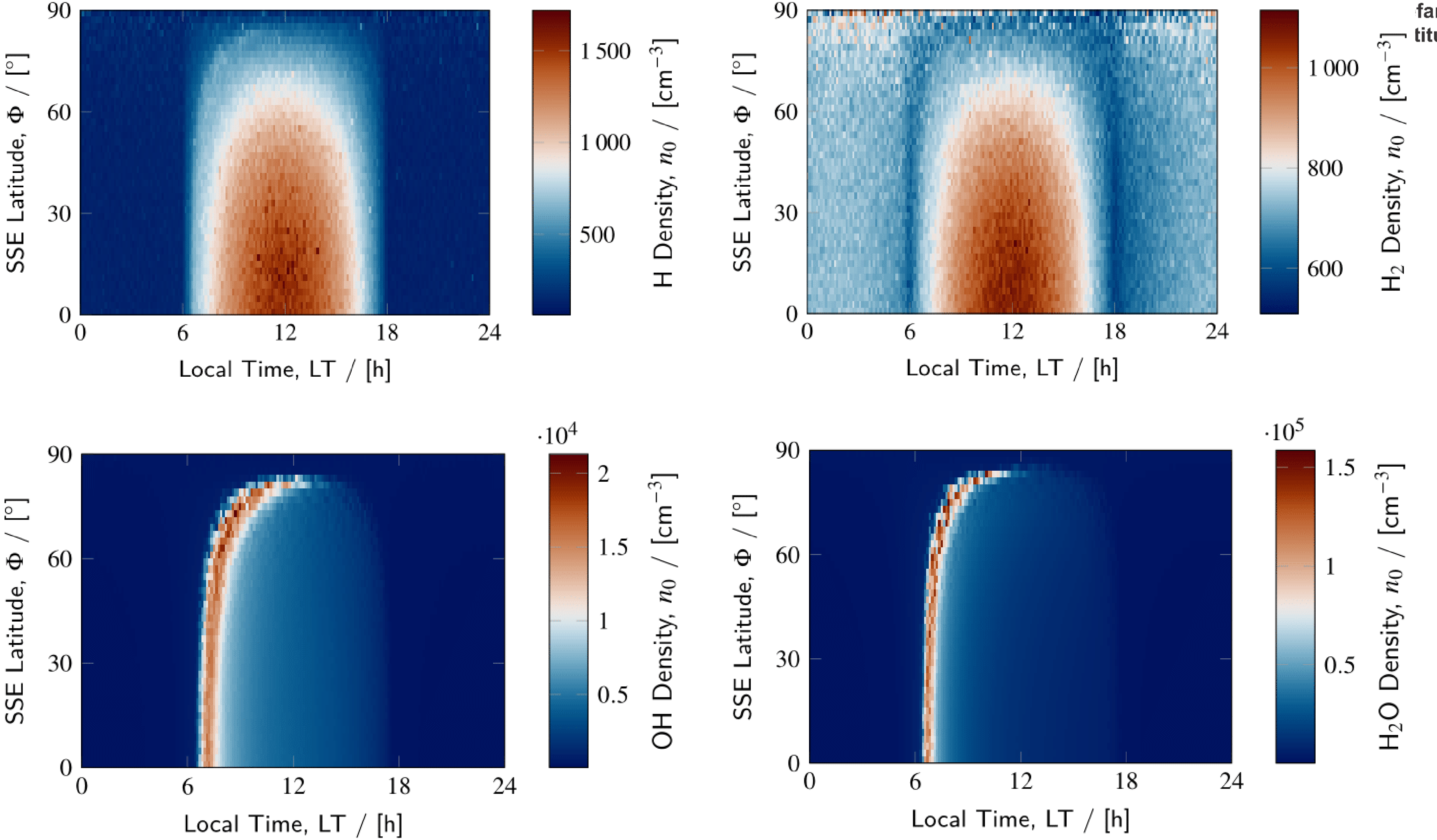

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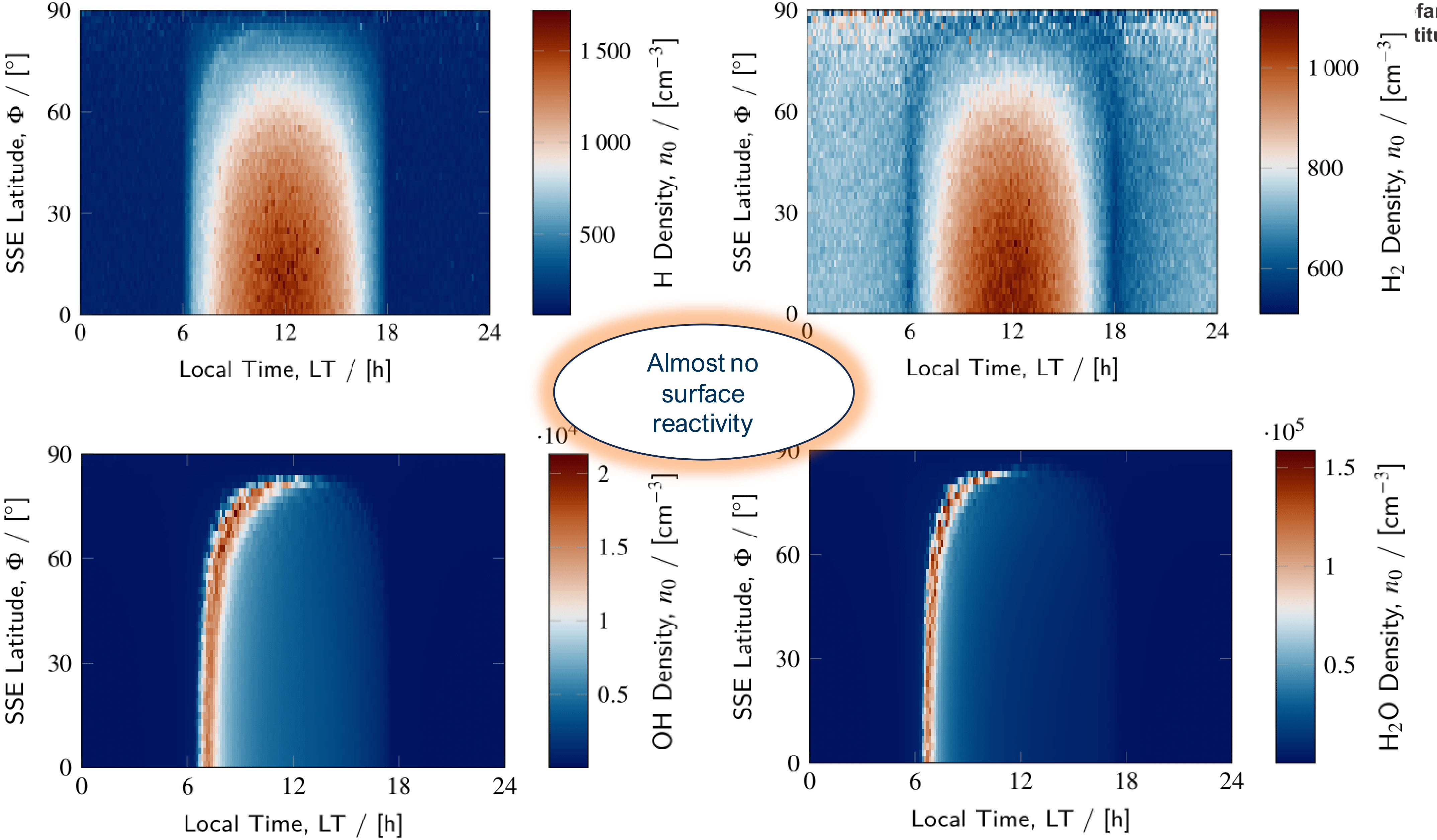

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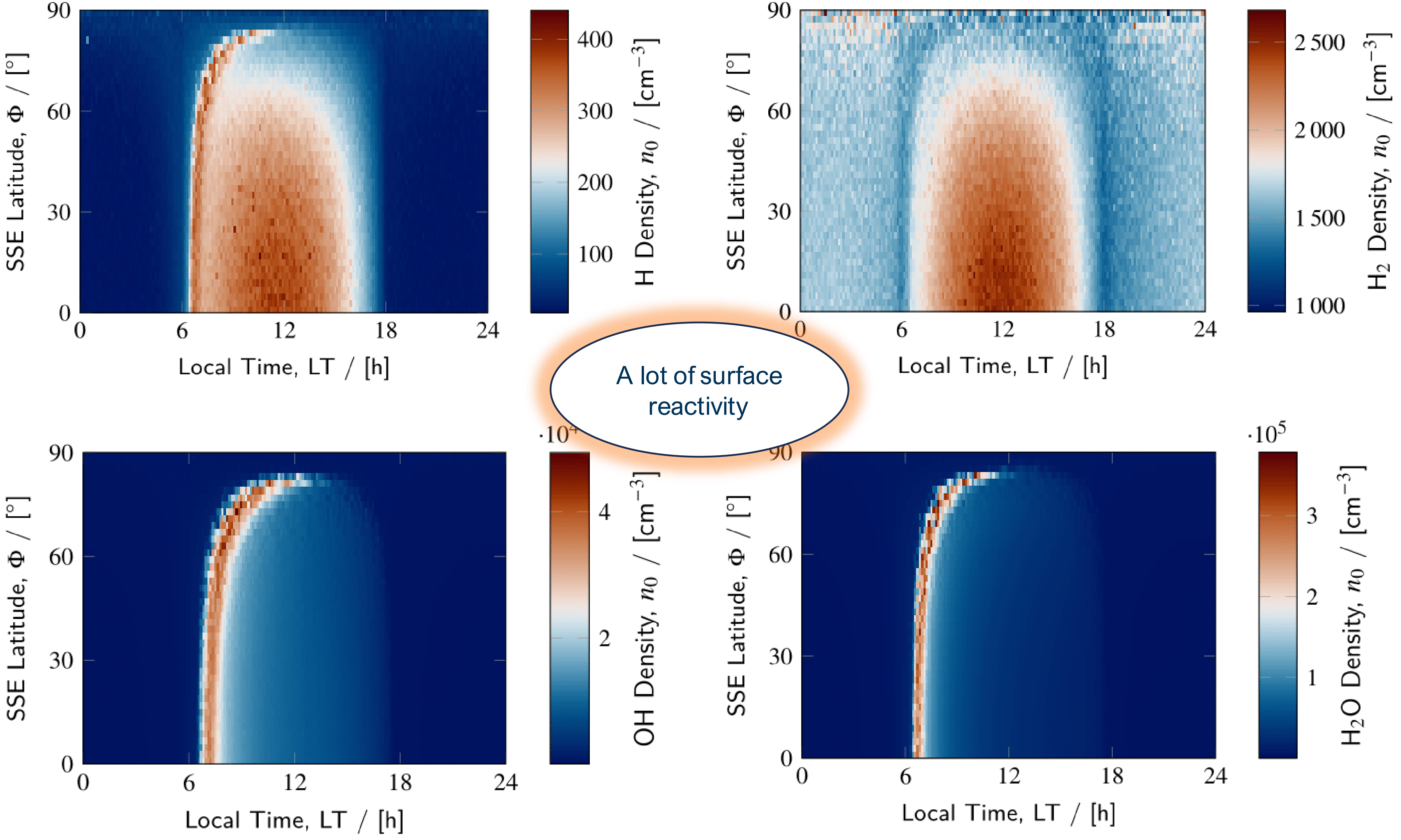
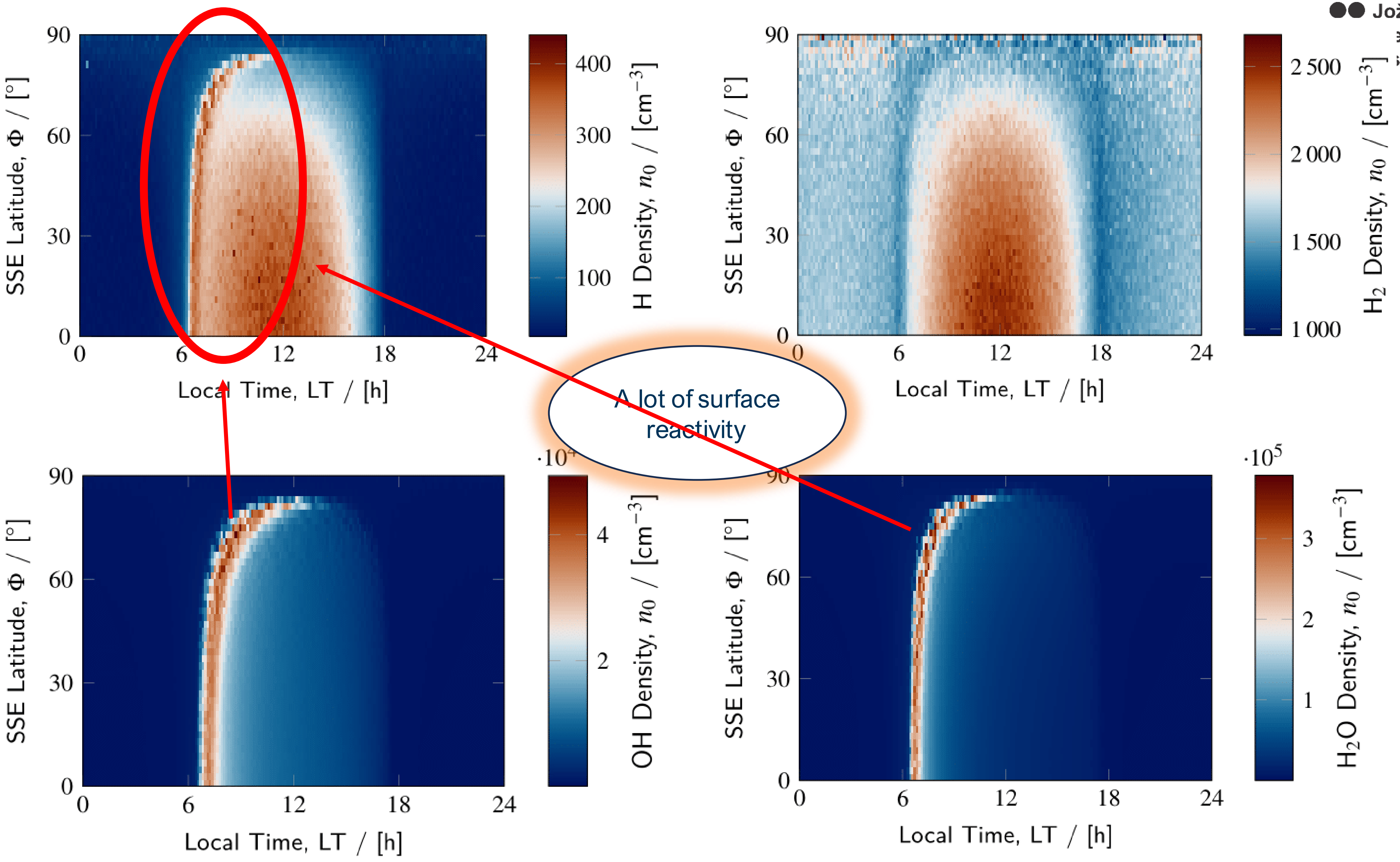


Smolka et al. 2023



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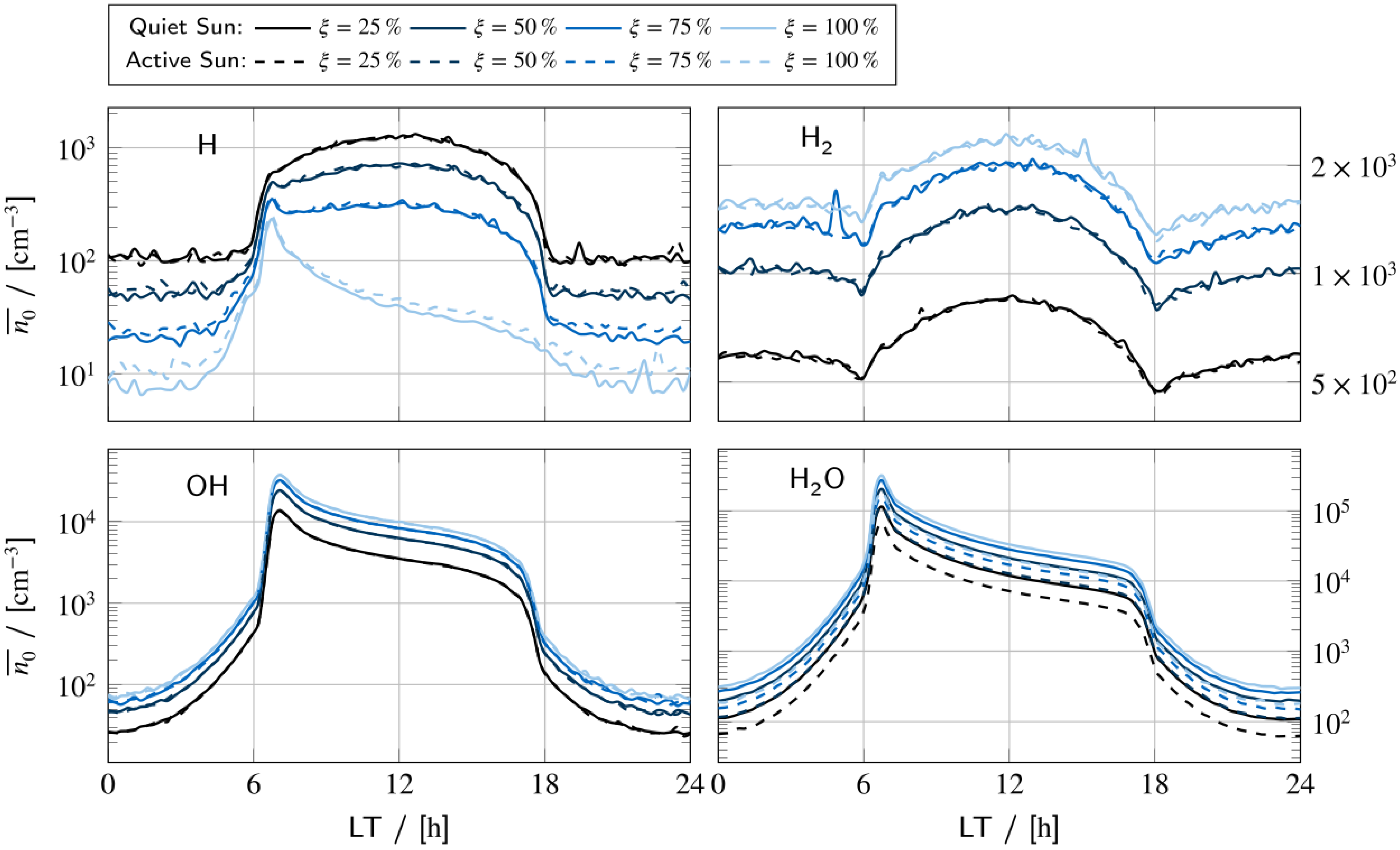
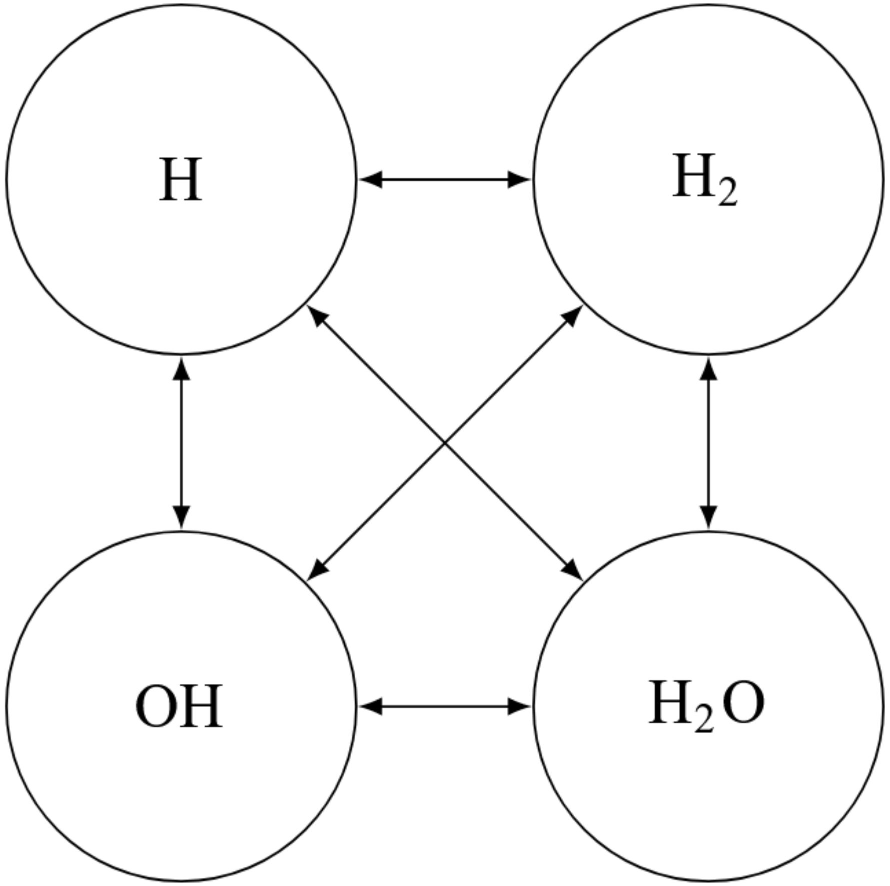


Smolka et al. 2023

Lunar Water Exosphere Simulation

Conversion Reactions



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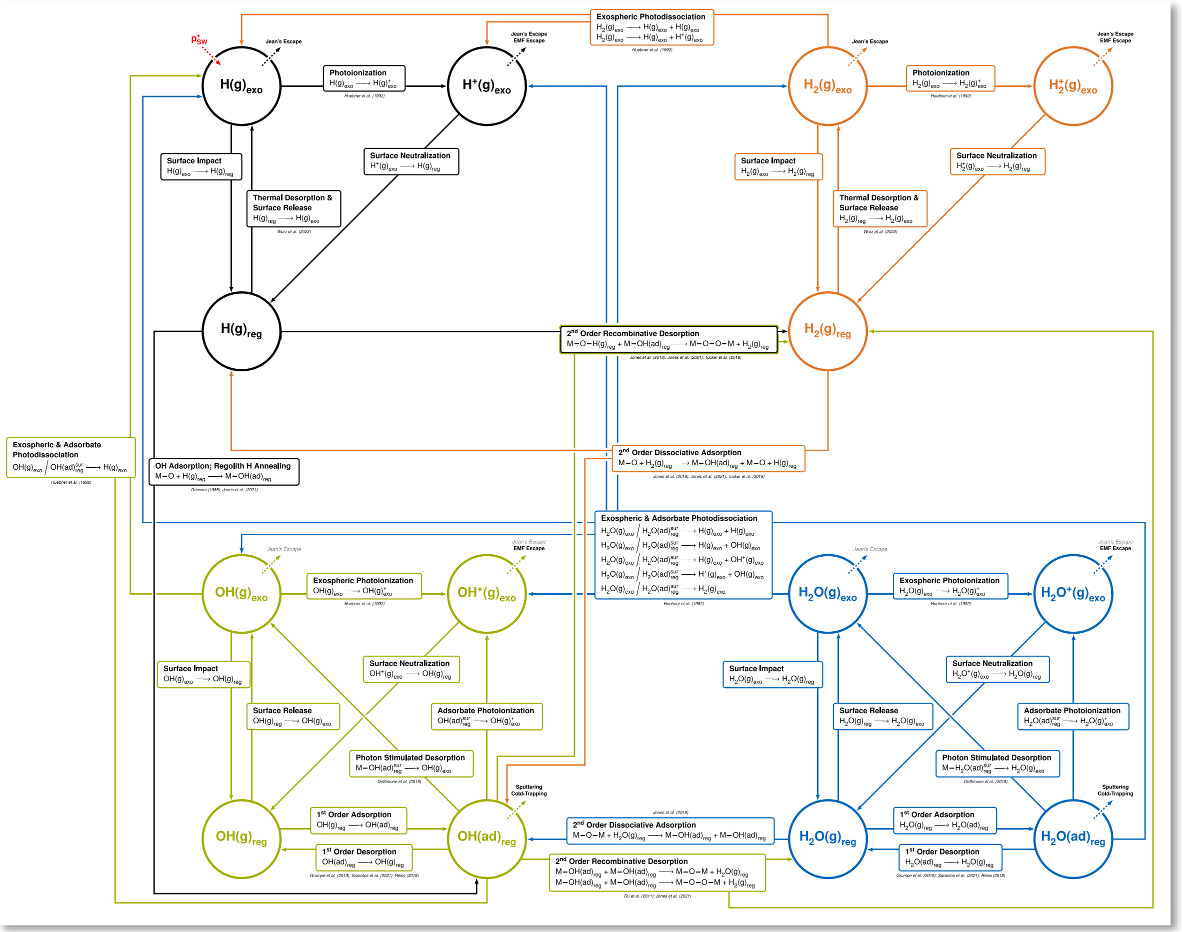
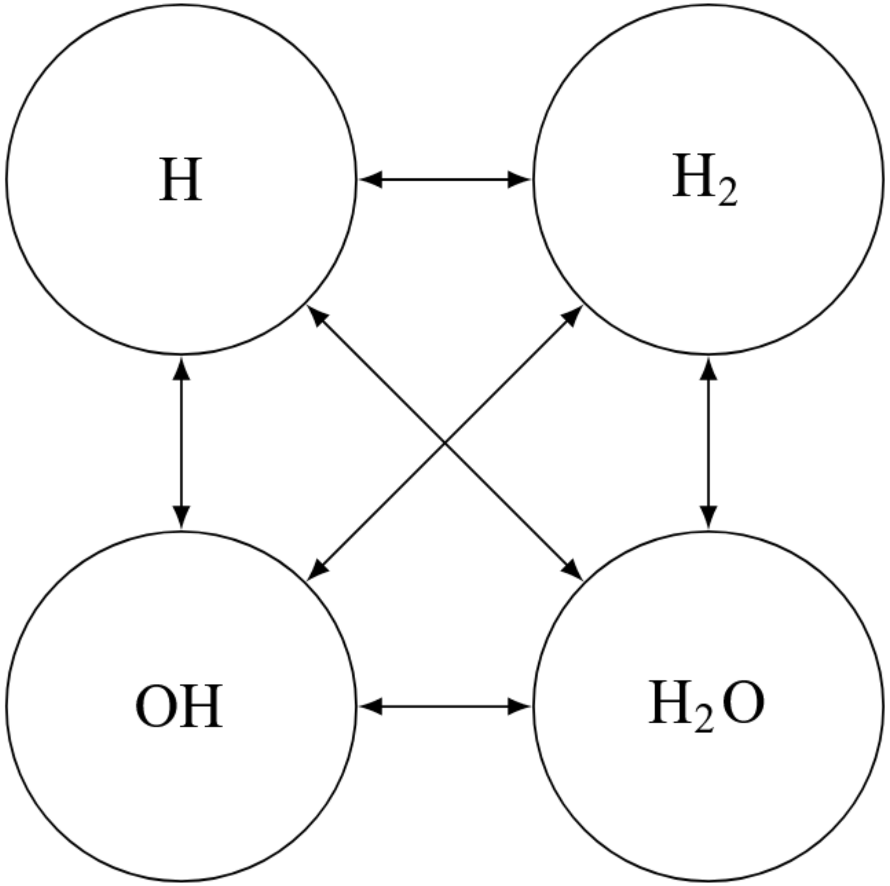


Smolka, 2023 (LPSC)



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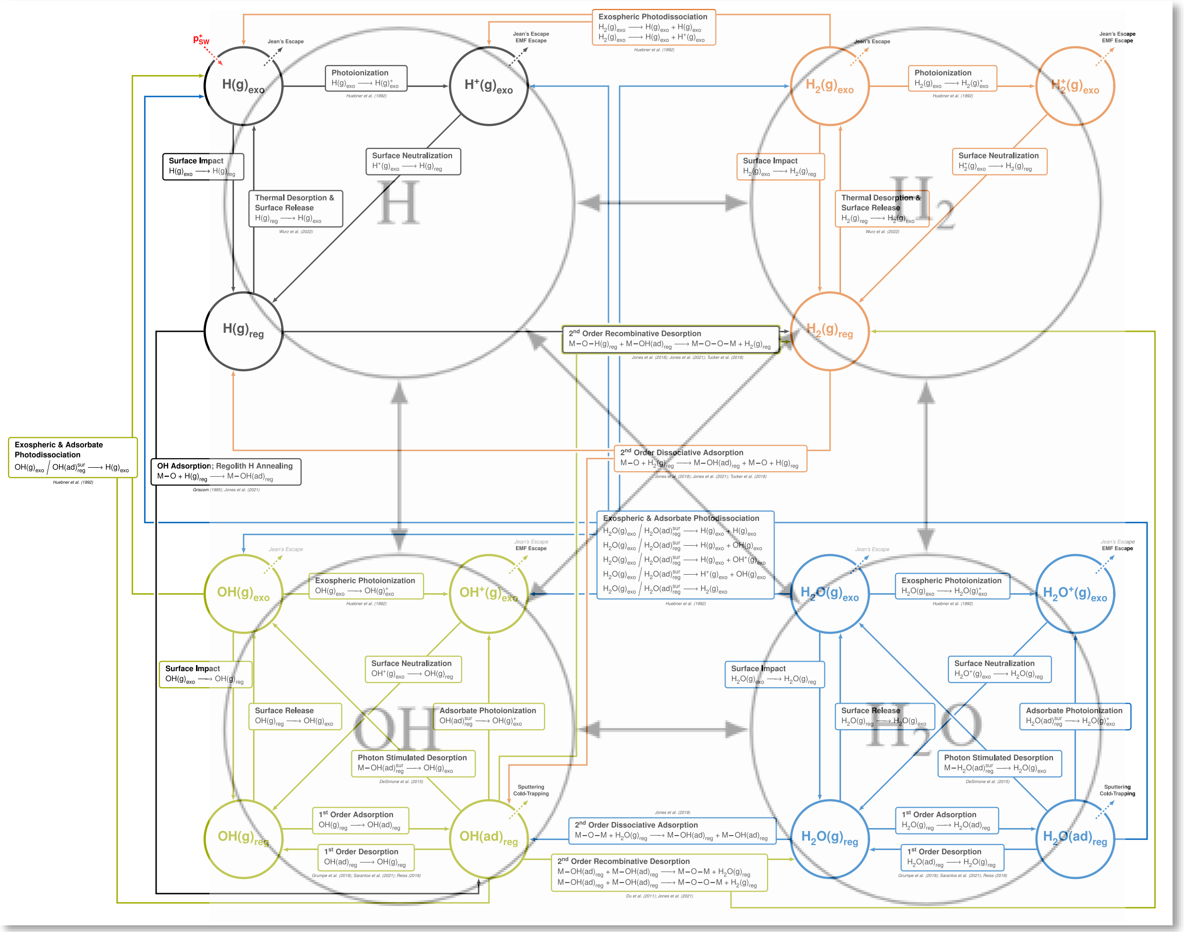

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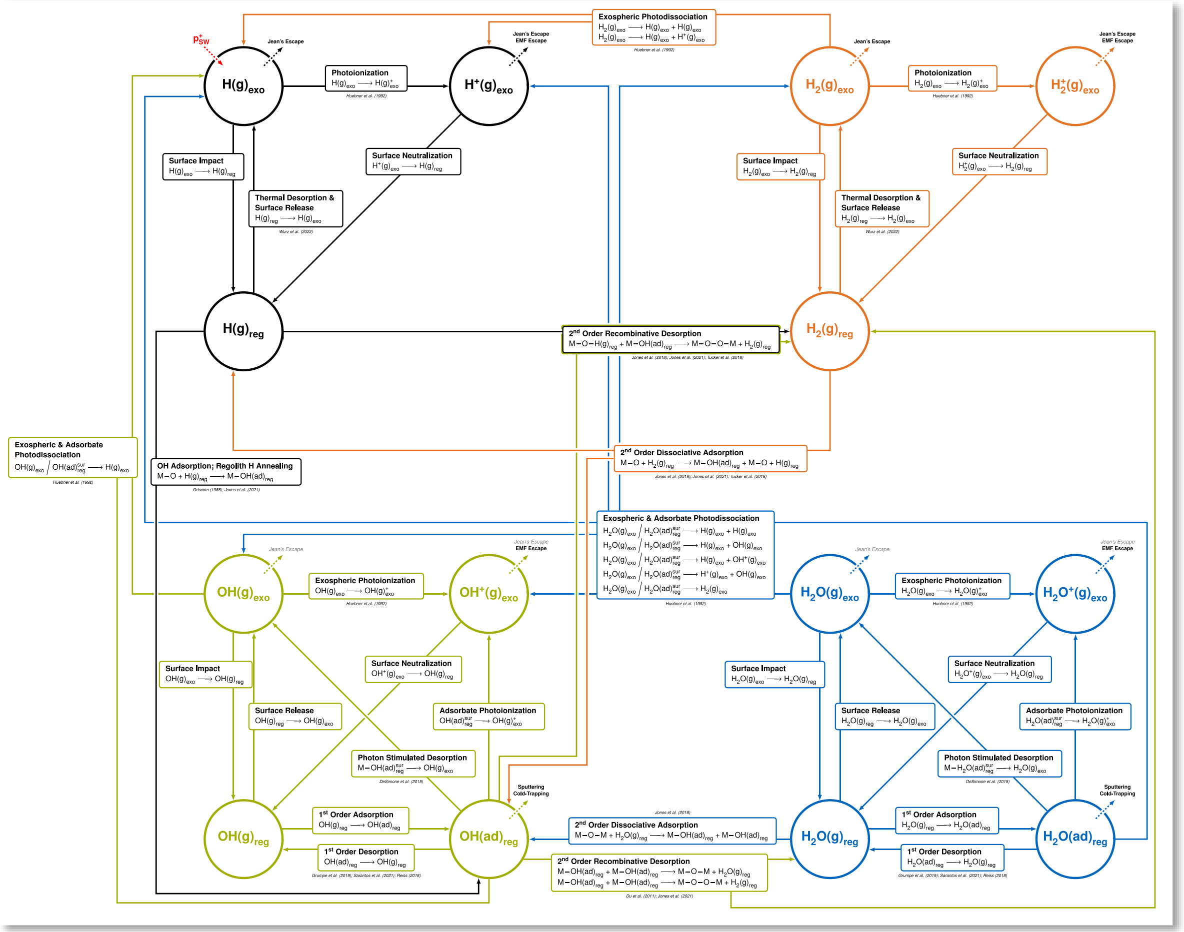

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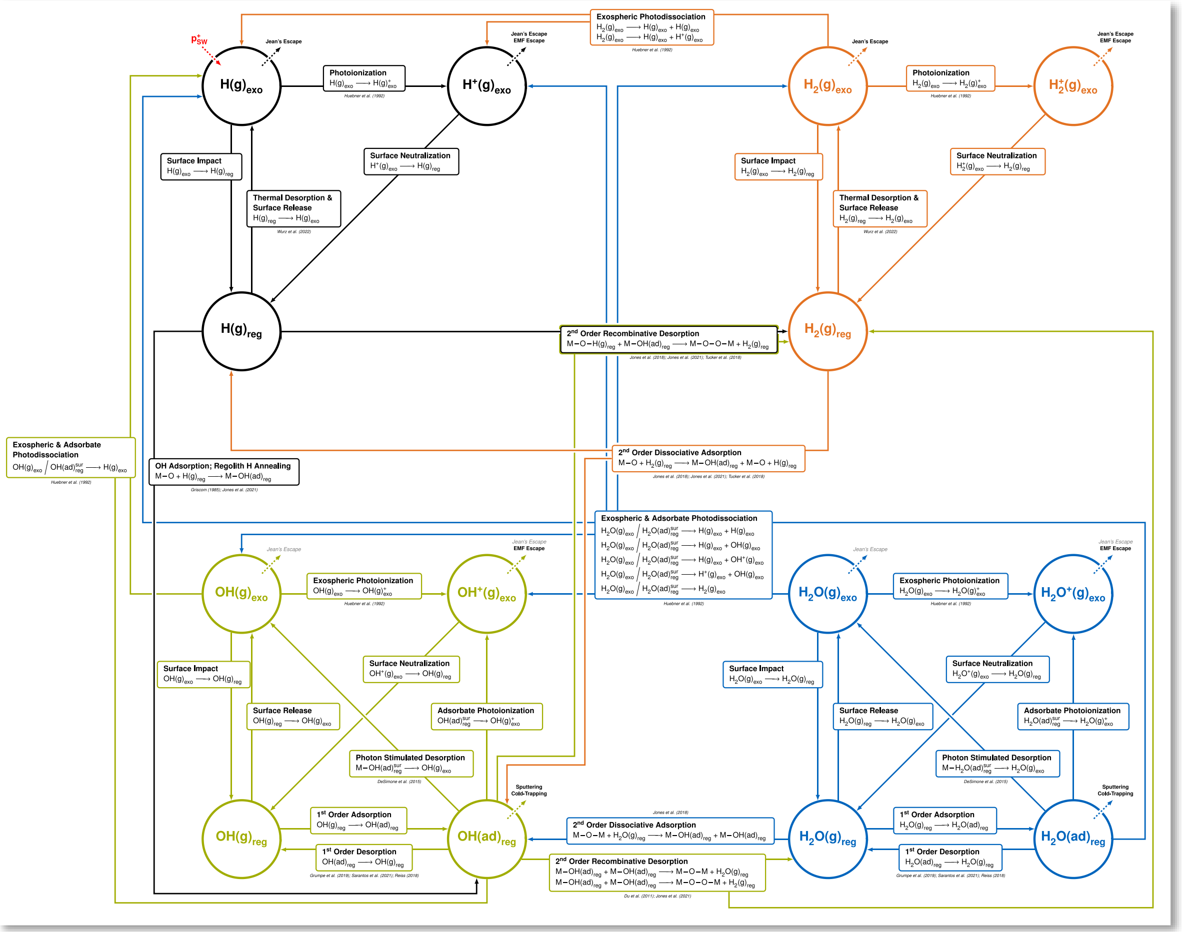

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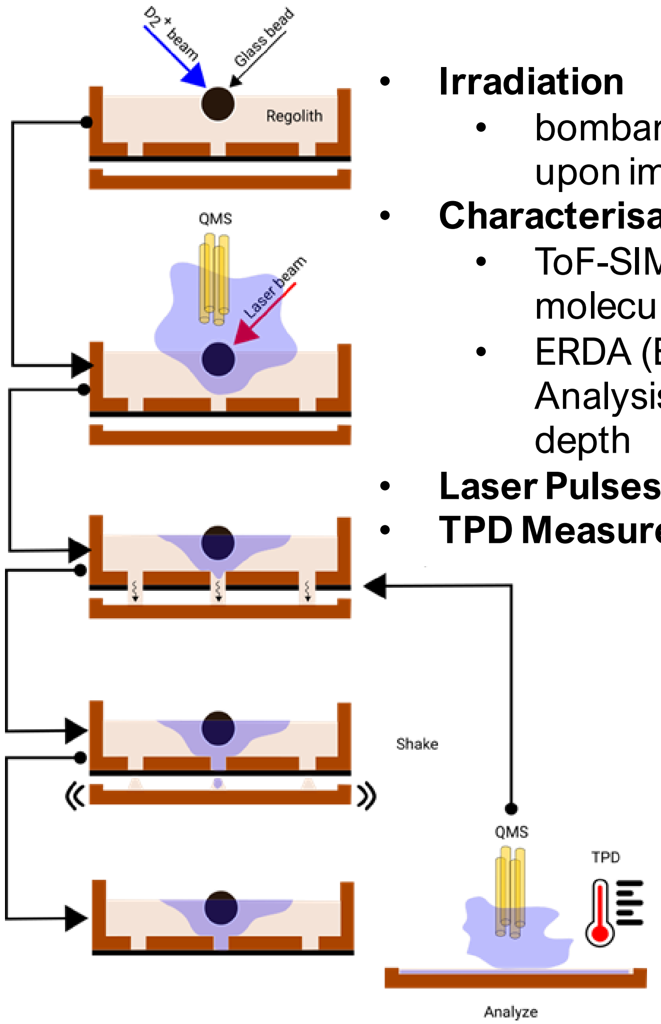

- **Irradiation**
  - bombardment with D+; dissociation upon impact
- **Characterisation of Irradiated Samples**
  - ToF-SIMS to measure water group molecule concentration
  - ERDA (Elastic Recoil Detection Analysis) to determine deuterium depth
- **Laser Pulses to Simulate MMI**
- **TPD Measurements**

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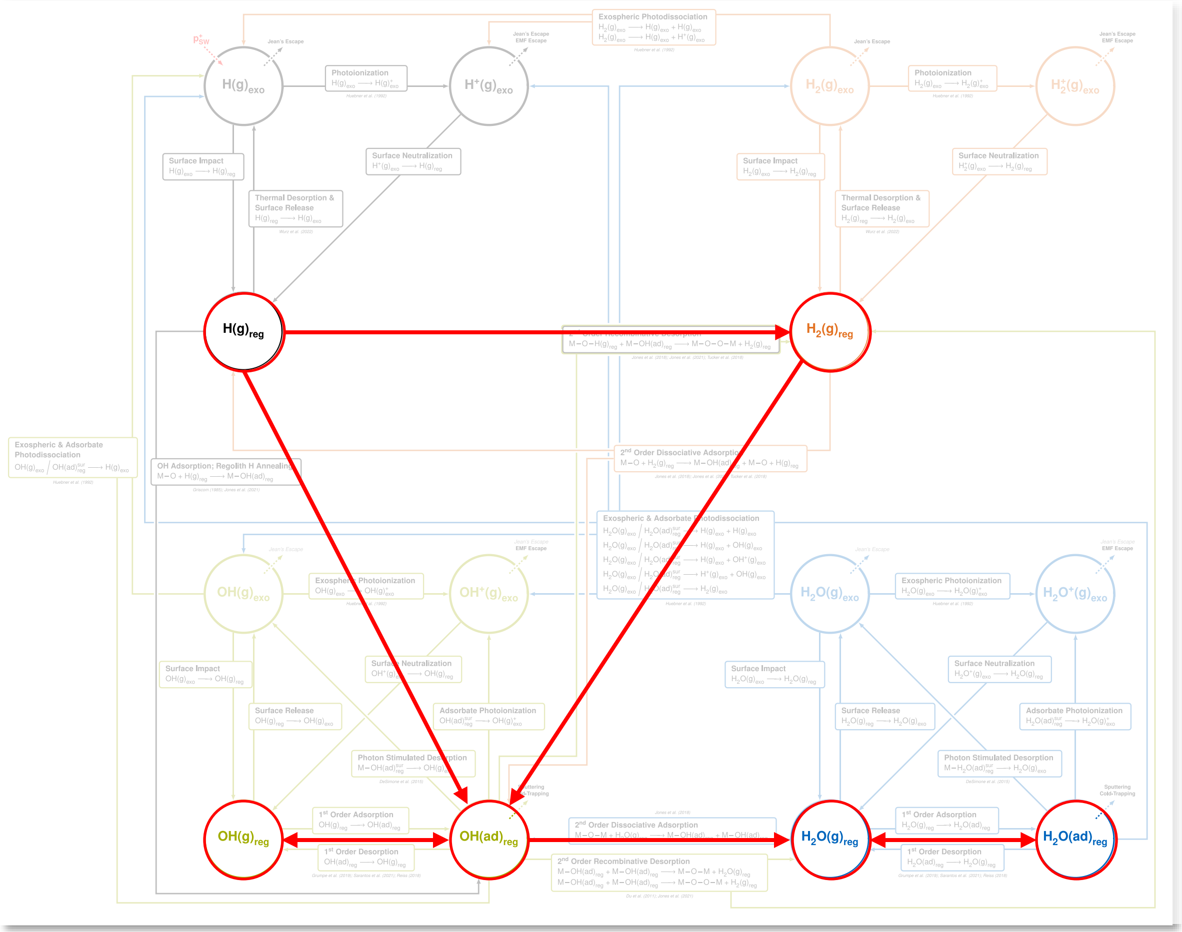

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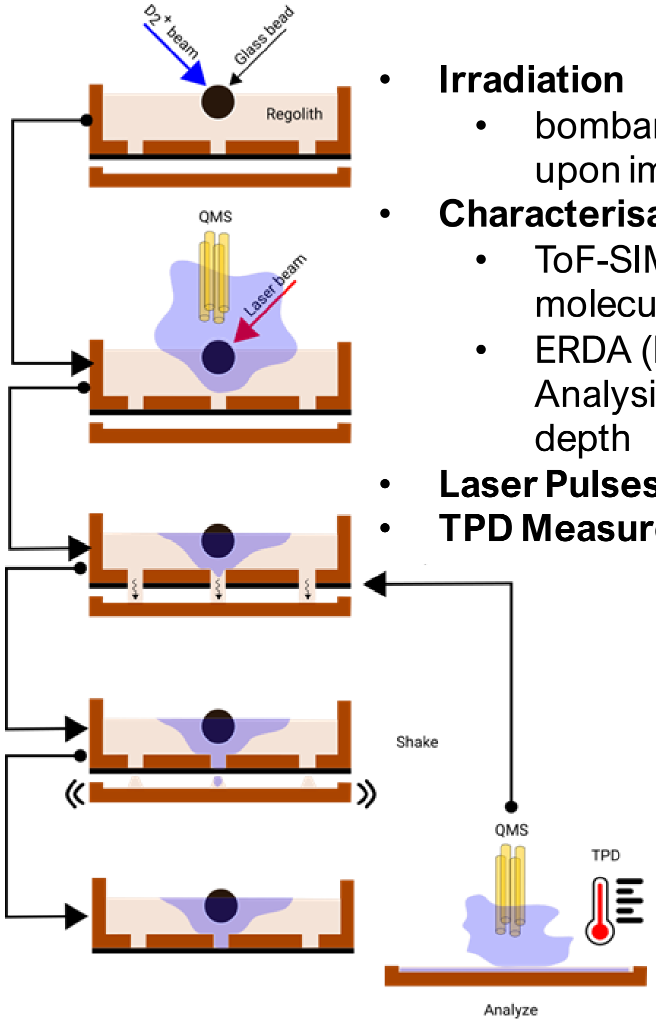

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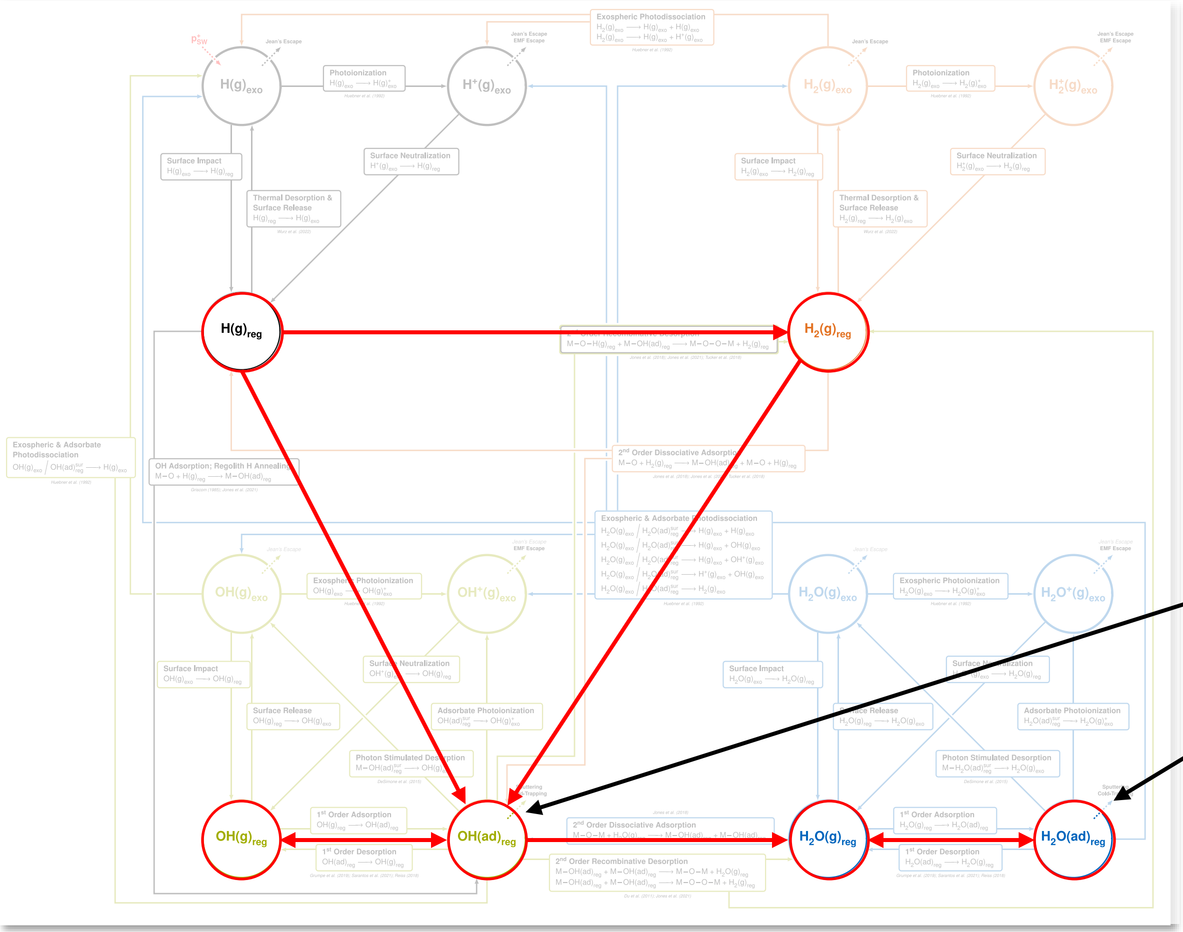
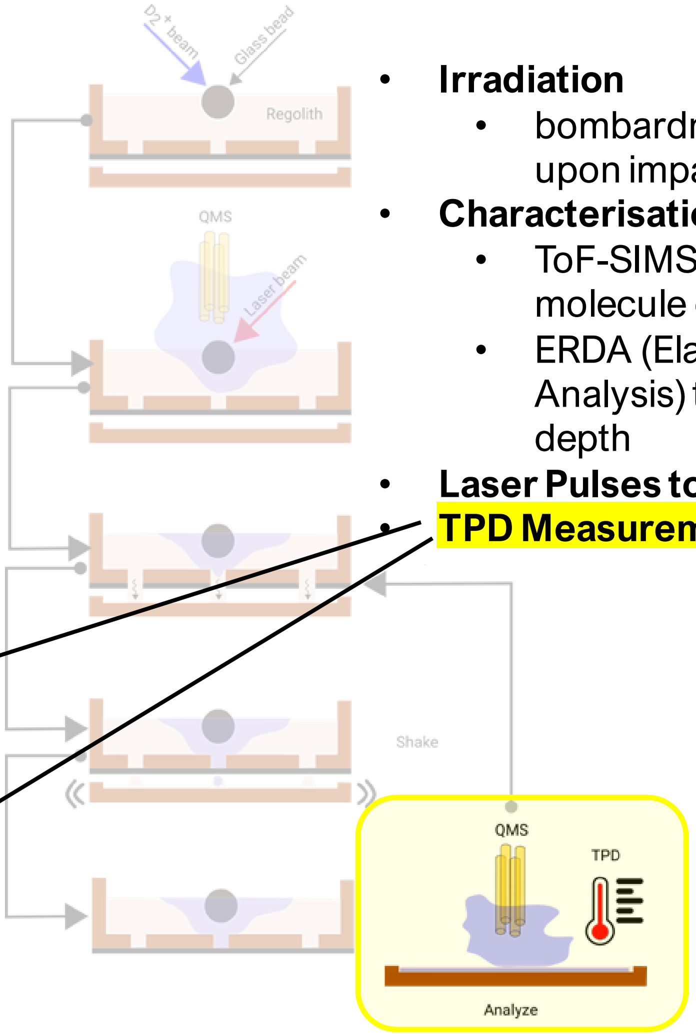
Lunar Water Exosphere Simulation

Conversion Reactions



Smolka, 2023 (LPSC)



- **Irradiation**
  - bombardment with D+; dissociation upon impact
- **Characterisation of Irradiated Samples**
  - ToF-SIMS to measure water group molecule concentration
  - ERDA (Elastic Recoil Detection Analysis) to determine deuterium depth
- **Laser Pulses to Simulate MMI**
- **TPD Measurements**

Jožef Stefan Institute

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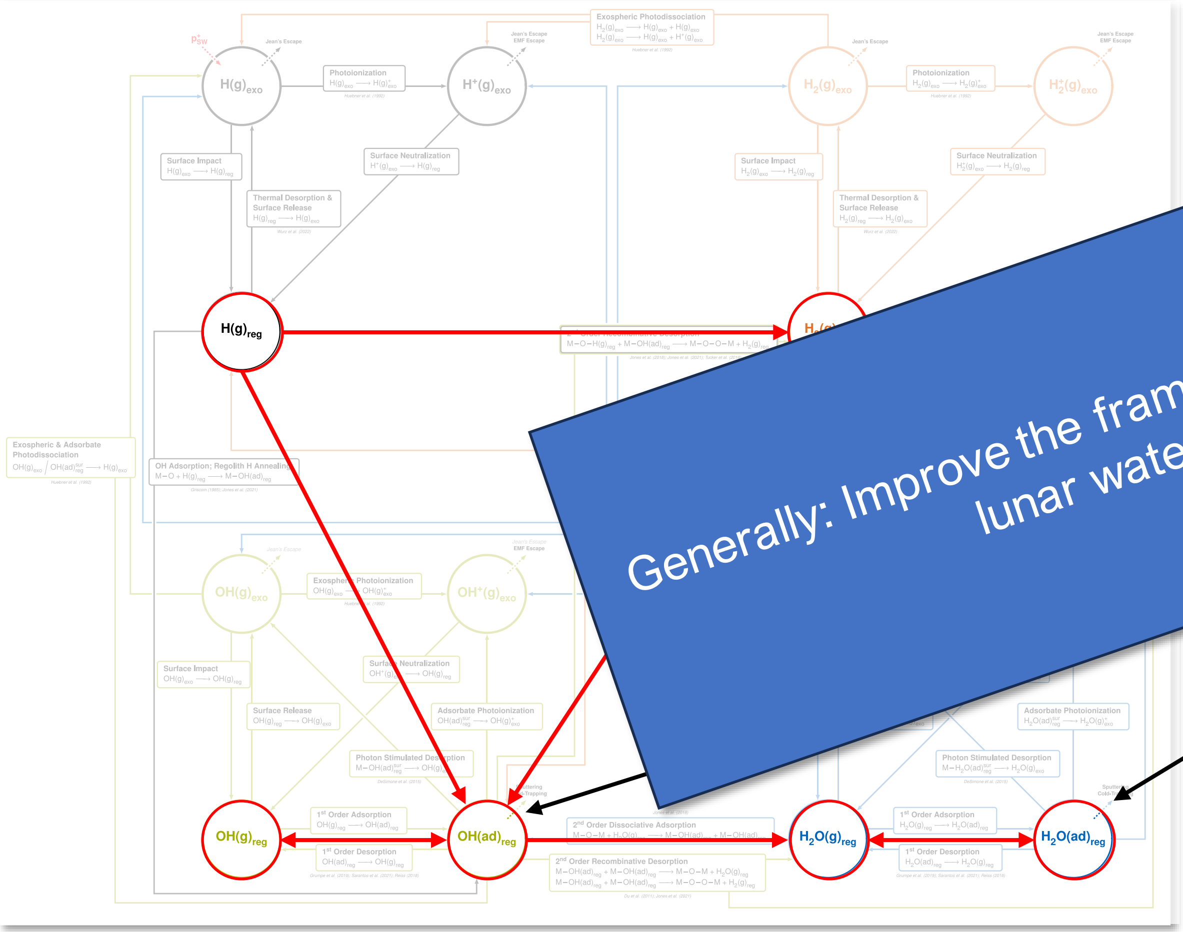
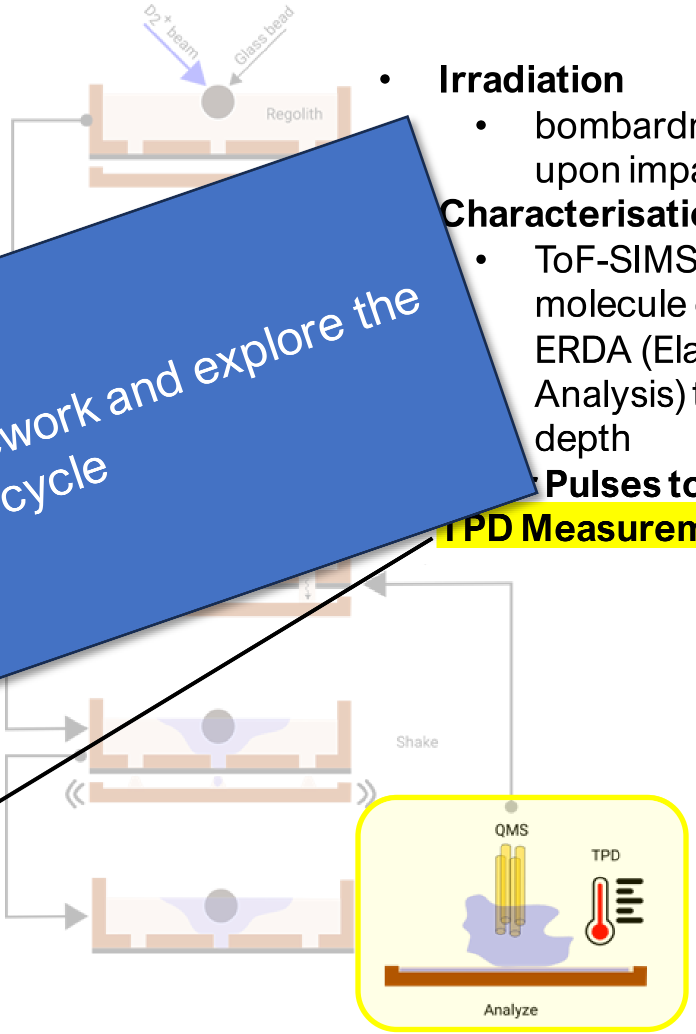


Smolka, 2023 (LPSC)

Generally: Improve the framework and explore the lunar water cycle



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