What can we learn from solar wind backscattering off planetary surfaces?

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[2] Max Planck Institute for Plasma Physics (IPP), Greifswald, Germany
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[5] Physics Institute, University of Bern, Bern, Switzerland

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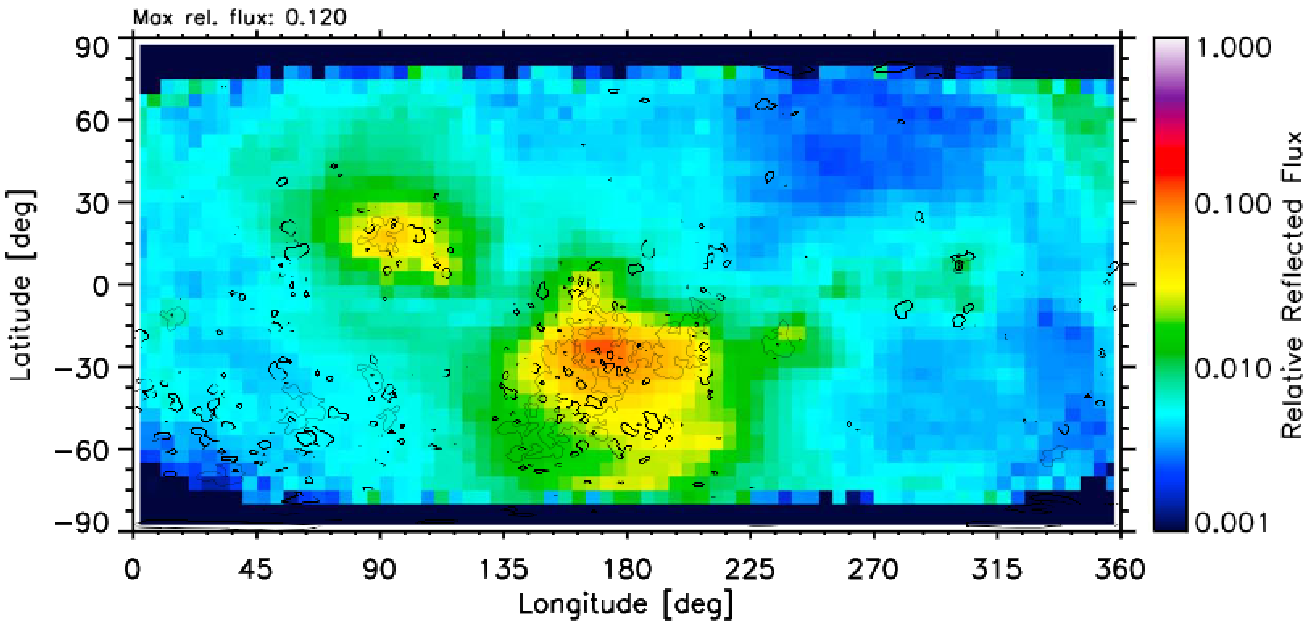
Solar wind backscattering observations from the Moon

Protons backscattered as charged particles:



→ Kaguya & ARTEMIS: < 1% of SW protons get reflected at unmagnetized regions as charged particles

A.R. Poppe, *et al.*, JGR: Planets 122 (2017), 771

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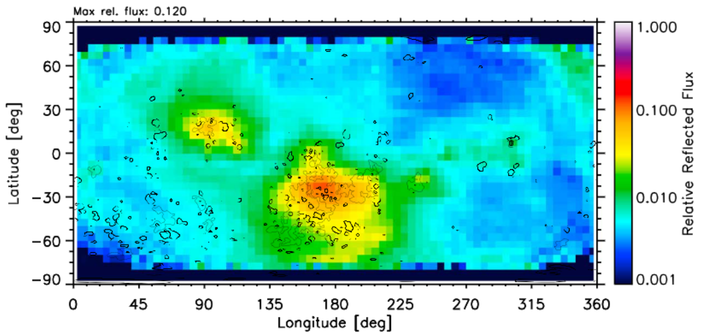
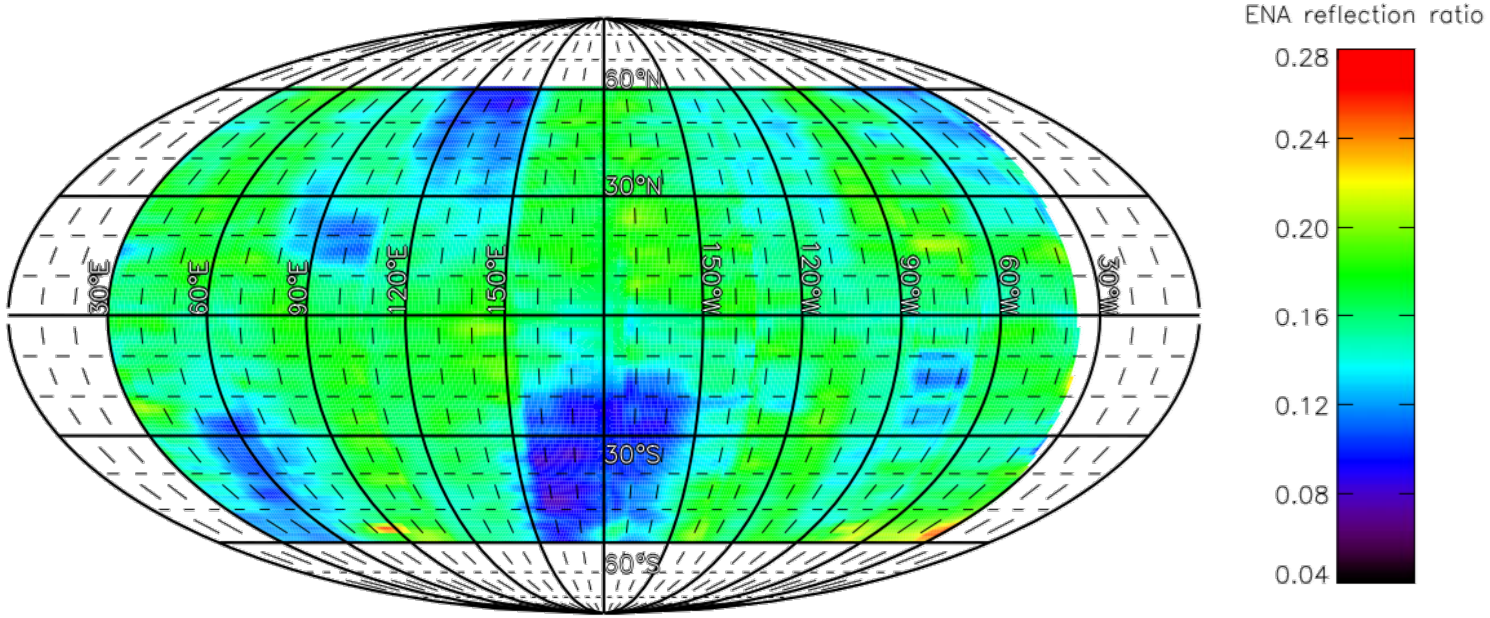


Protons backscattered as neutrals:



→ Kaguya & ARTEMIS: < 1% of SW protons get reflected at unmagnetized regions as charged particles

→ Chandrayaan-1 & IBEX: 10 – 20% of SW protons are reflected as energetic neutral atoms (ENAs)

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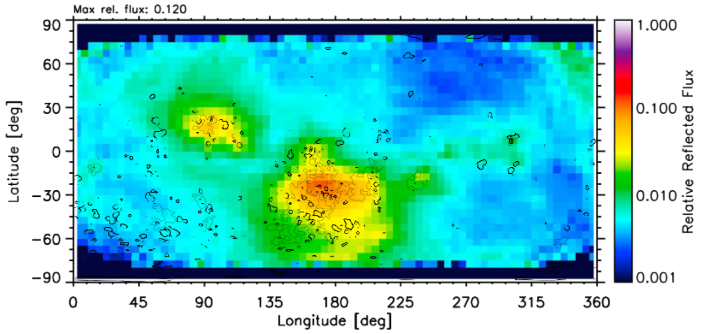

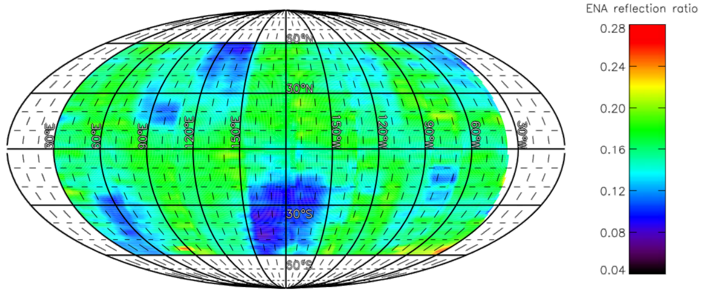

→ Information on precipitating ions and the lunar surface is imprinted in backscattered particles.

→ Studies allow us to learn about properties of both.

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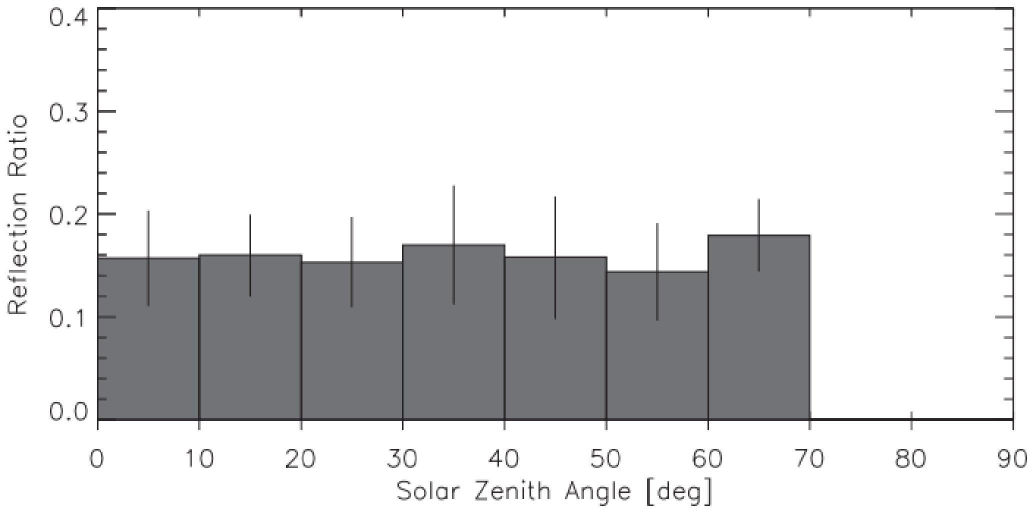
Observations of ENA emission properties

→ reflection coefficients of 10 – 20% had not been expected due to the porous regolith

→ constant reflection coefficients for all solar zenith angles



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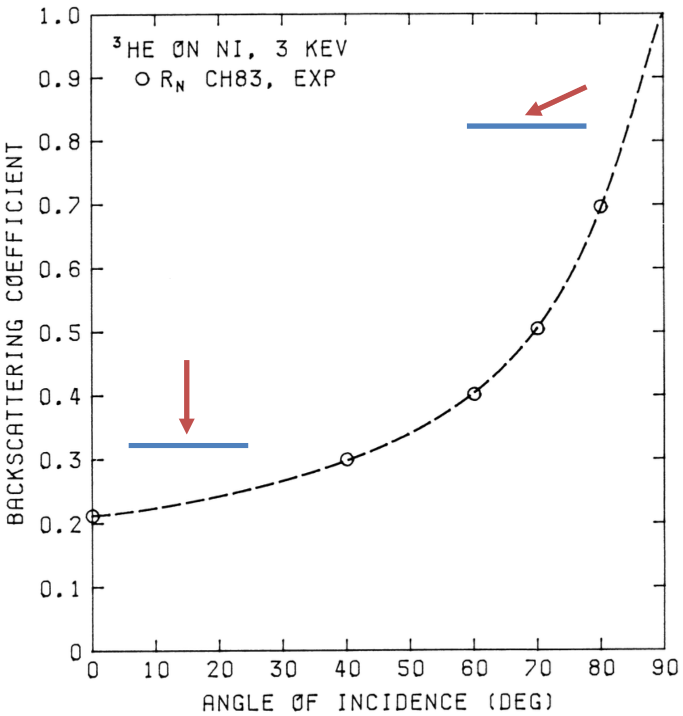
Lab experiments with flat samples:



T. Tabata, *et. al.*, Radiation Effects, 84 (1984), 45

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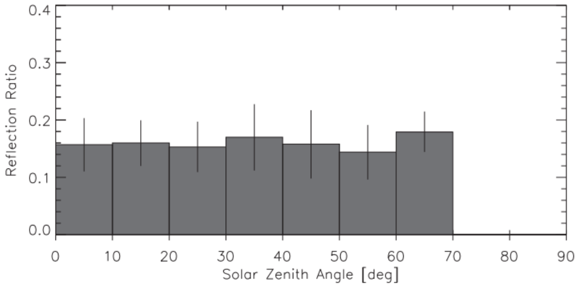

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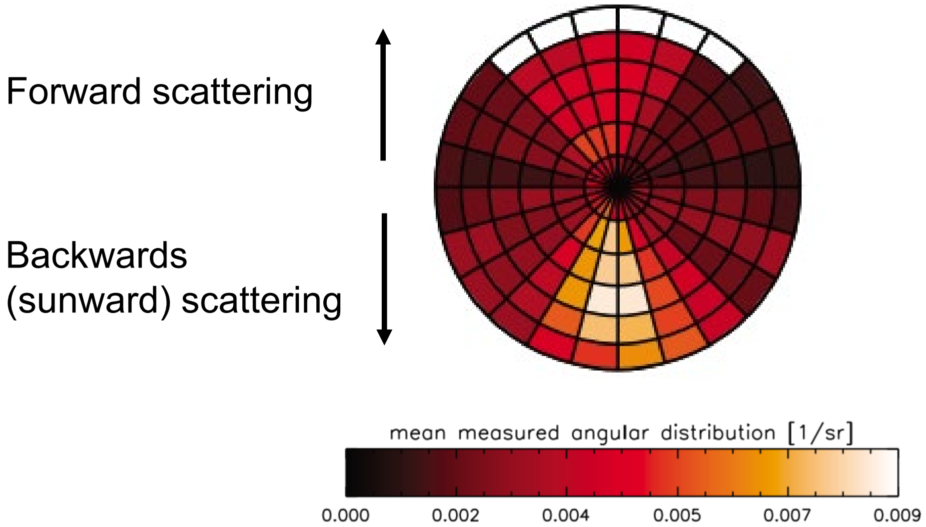
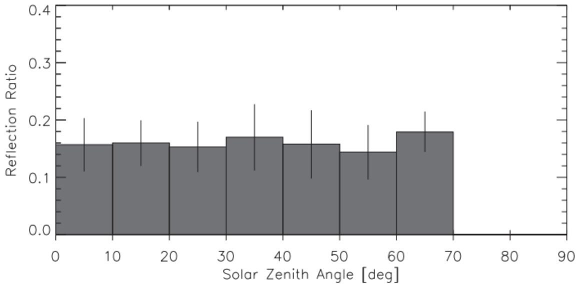


A. Schaufelberger, *et. al.*, GRL, 38.22 (2011)

Observations of ENA emission properties

- → reflection coefficients of 10 – 20% had not been expected due to the porous regolith
- → constant reflection coefficients for all solar zenith angles
- → preferential sunwards emission observed
- → significant and broad energy loss, related to SW velocity



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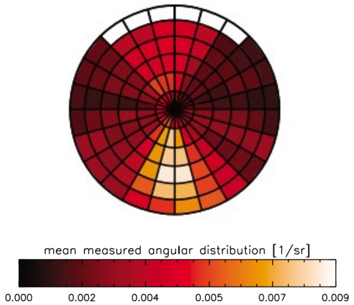

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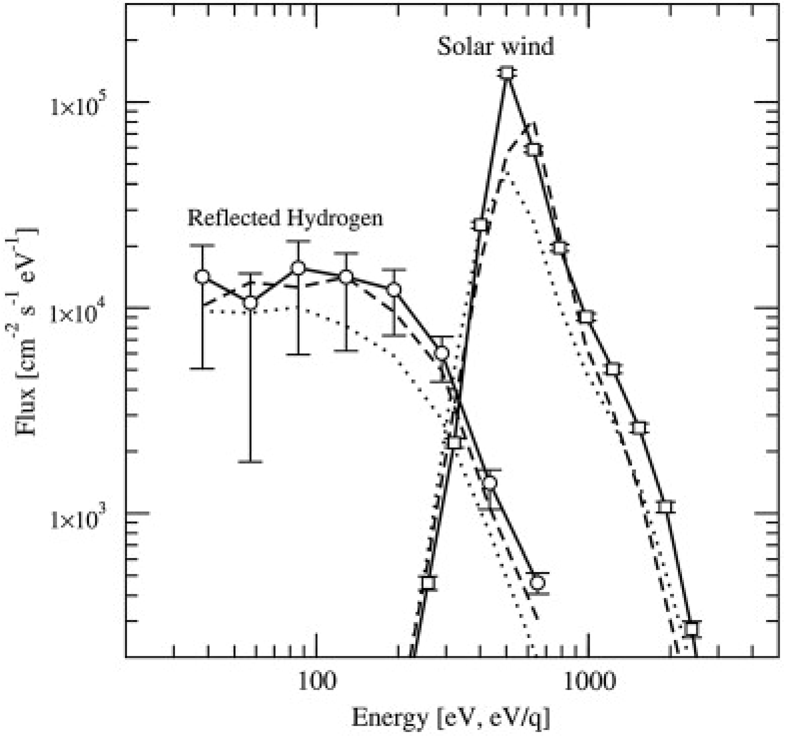

M. Wieser, *et al.*, Planet. Space Sci. 14 (2009), 2132

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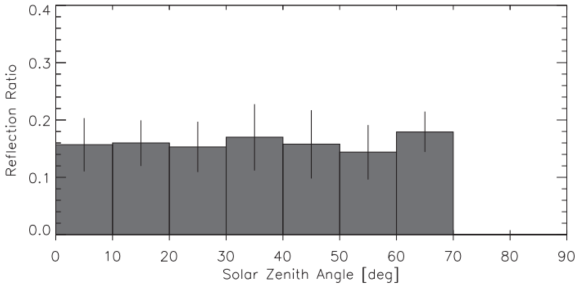
→ constant reflection coefficients for all solar zenith angles

→ preferential sunwards emission observed

→ significant and broad energy loss, related to SW velocity

→ Fundamental understanding of these characteristics has been incomplete.



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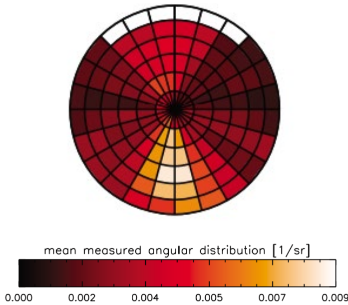

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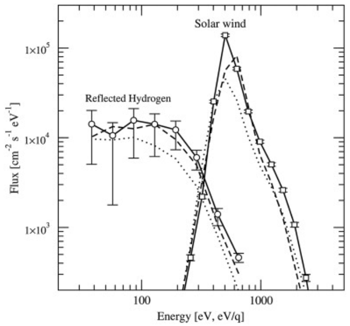

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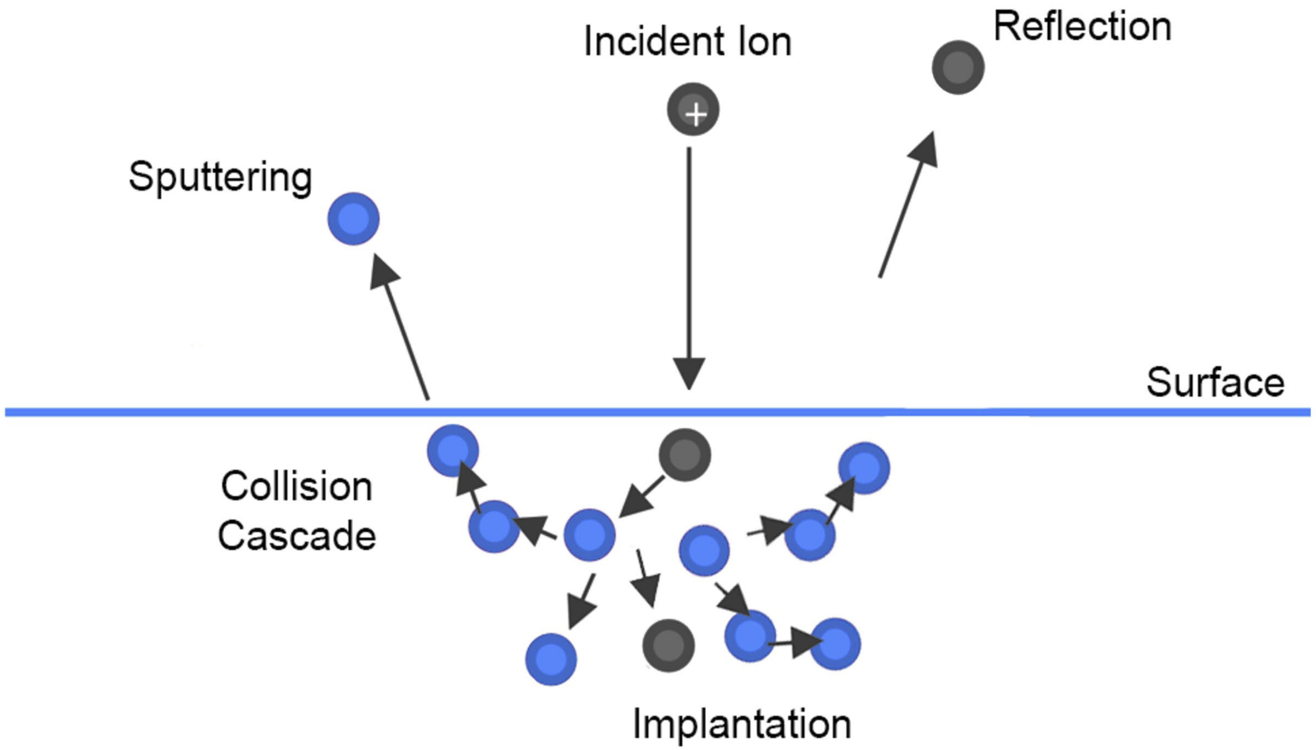
Simulations with SDTrimSP-3D

SDTrimSP-3D

→ Approximates collision cascade as sequence of binary collisions



U. Von Toussaint, et al., Physica Scripta 2017, 014056 (2017)

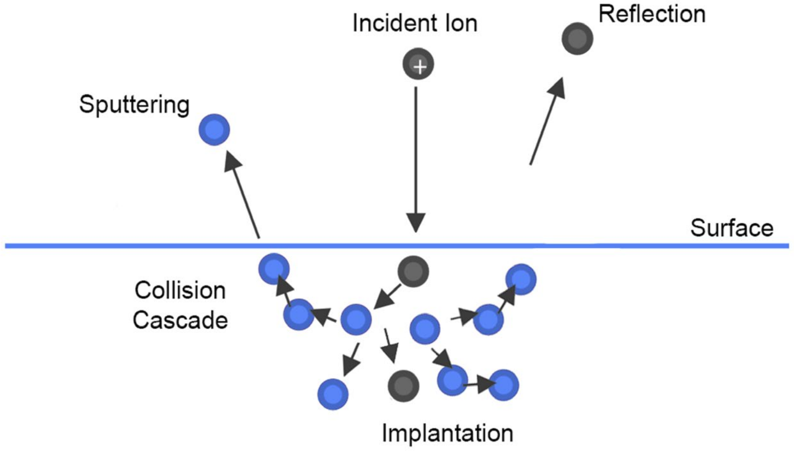
Simulations with SDTrimSP-3D

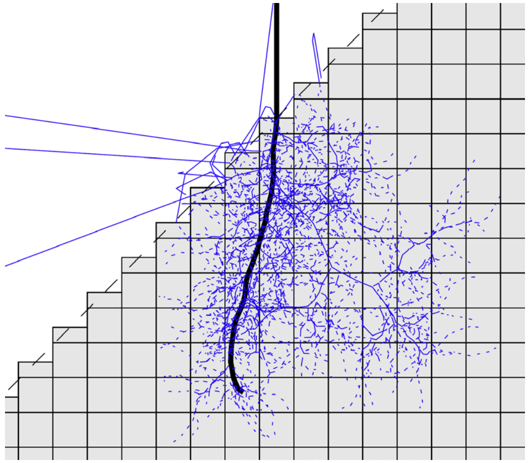
SDTrimSP-3D

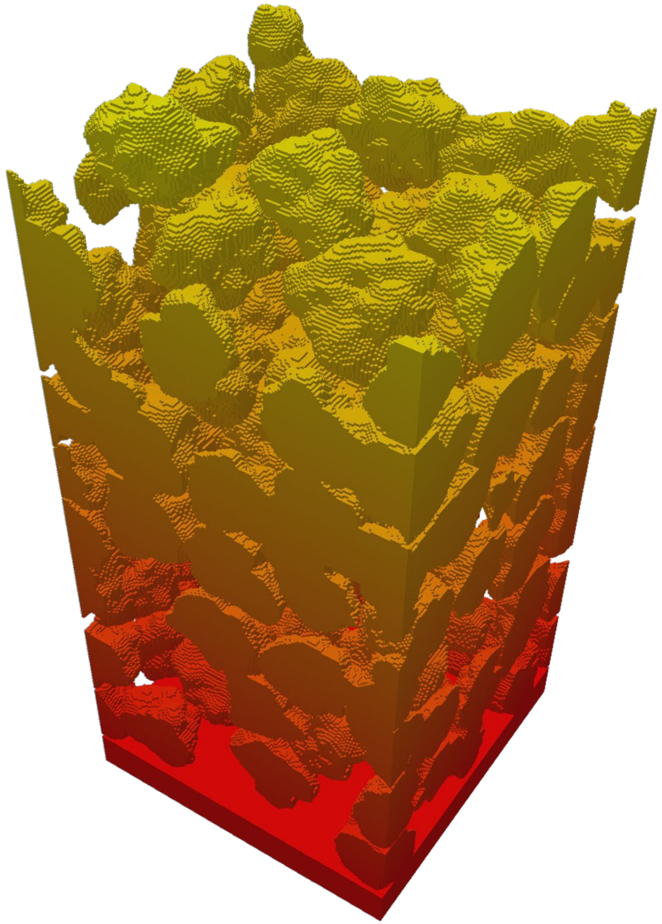
→ Approximates collision cascade as sequence of binary collisions

→ 3D structures with voxel geometry

→ We implement regolith structures with different porosities







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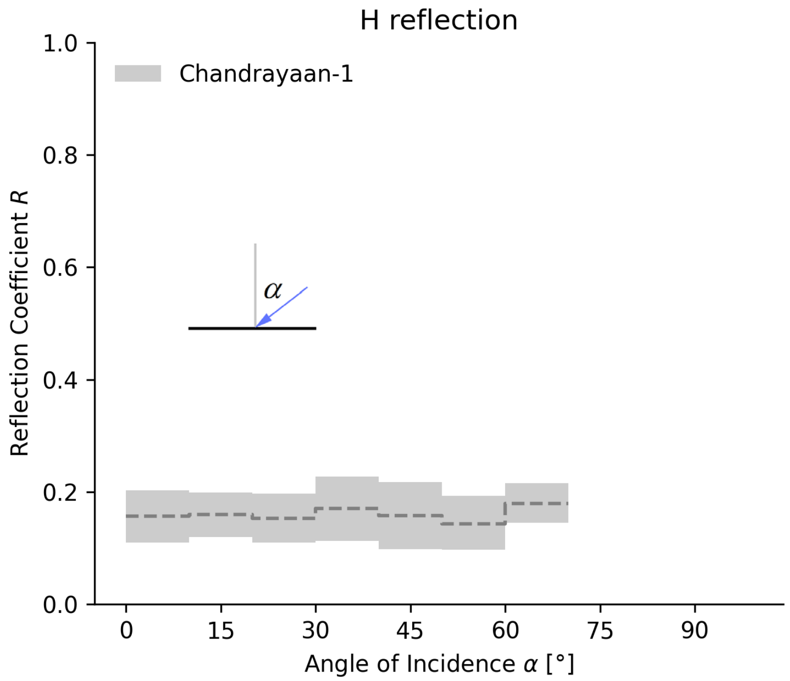
Results for reflection coefficients

→ Reflection coefficient 0.16±0.05 from Chandrayaan-1



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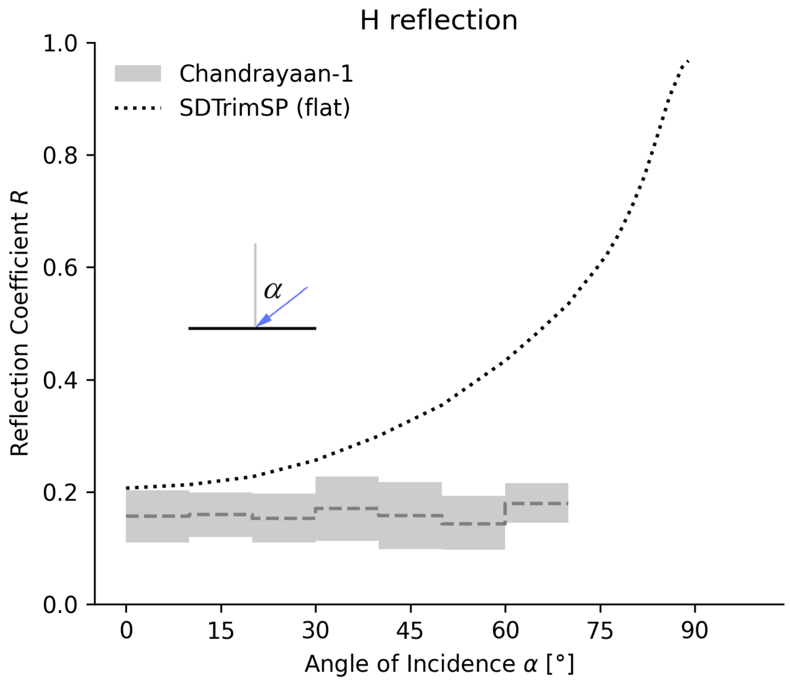

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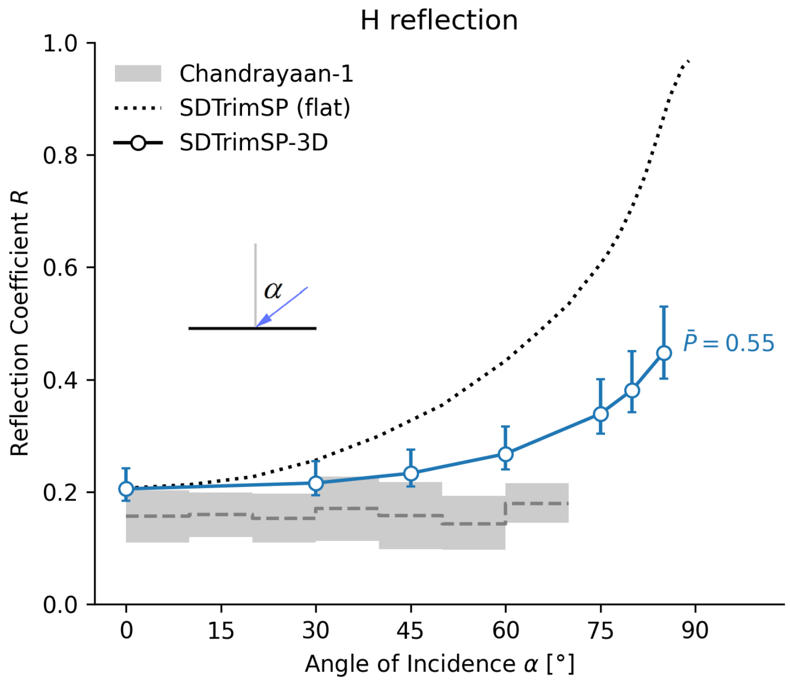

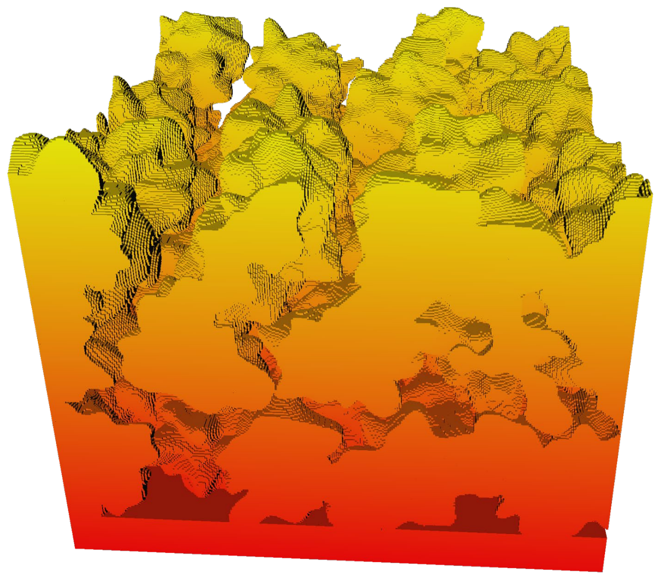

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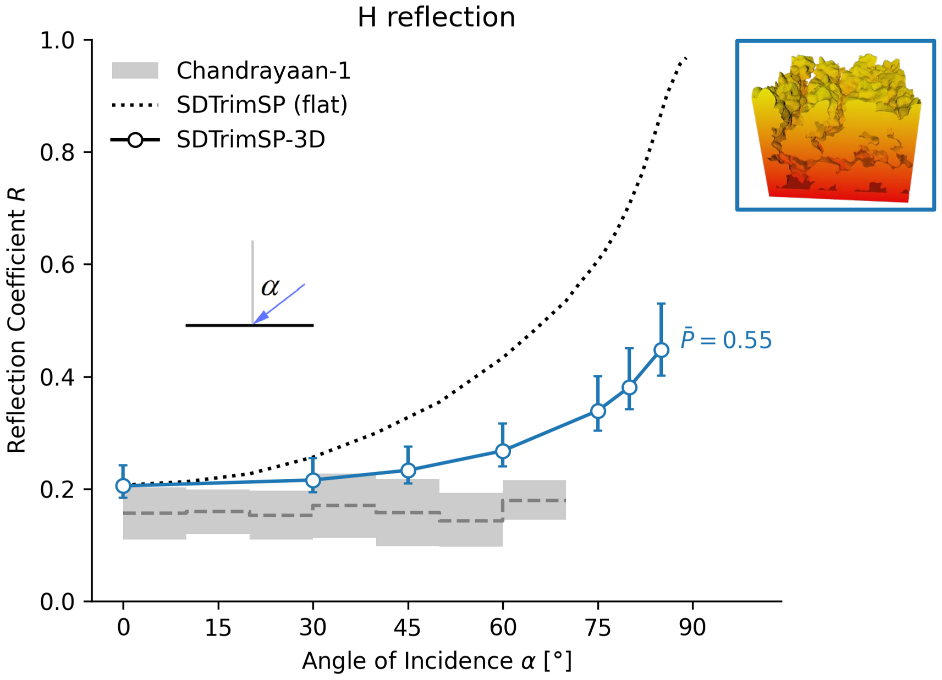

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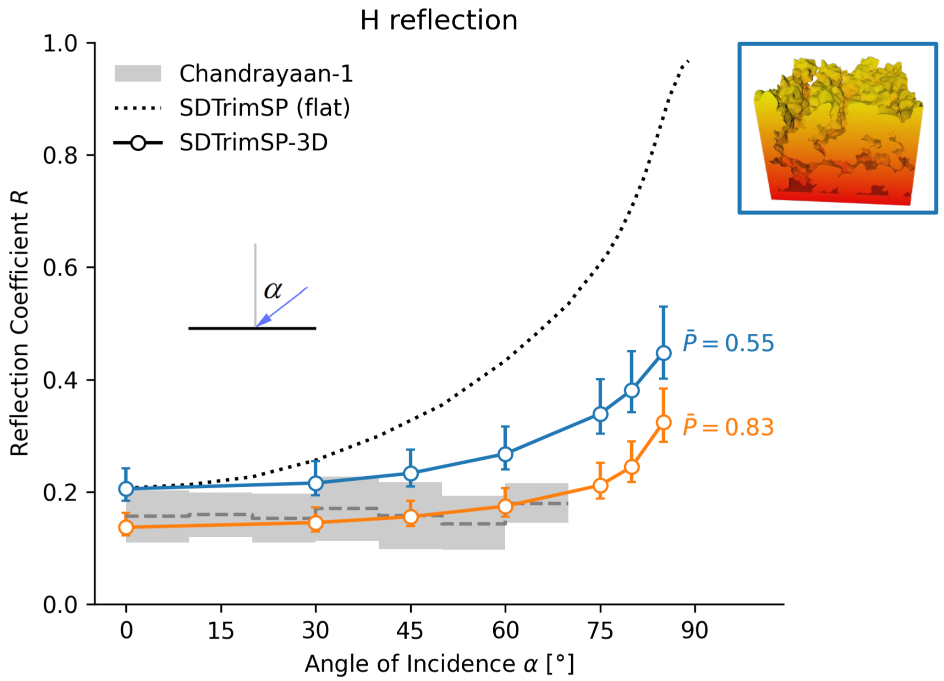

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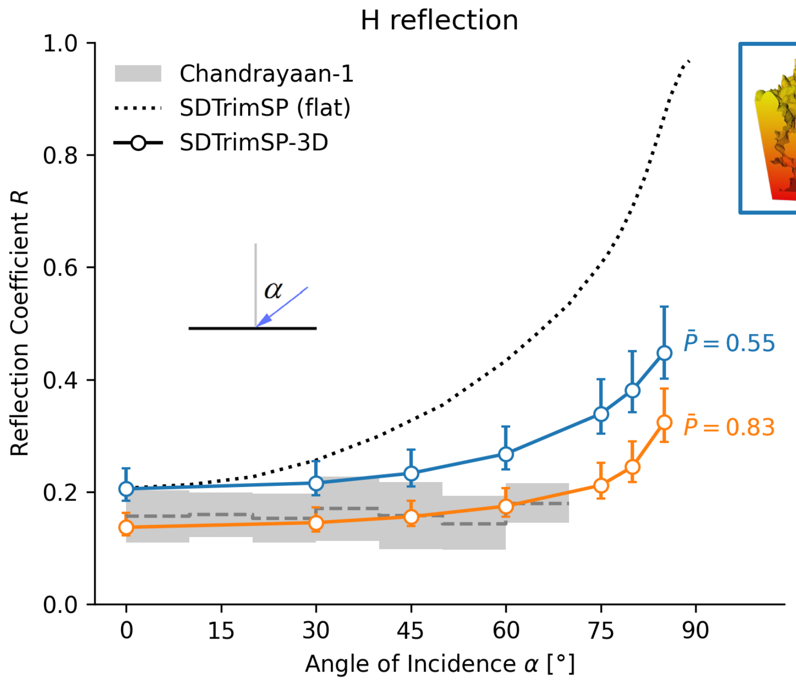

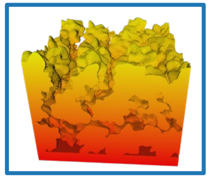

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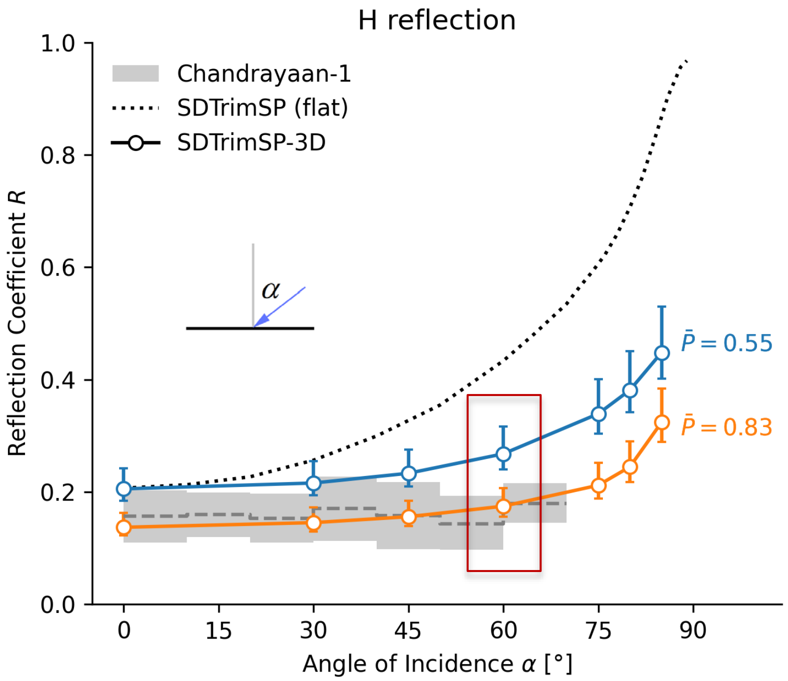

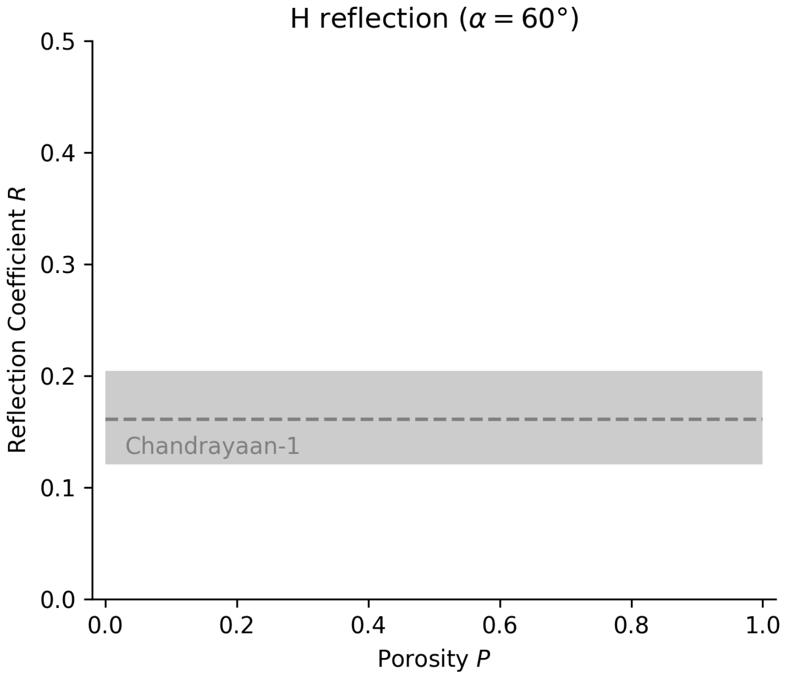

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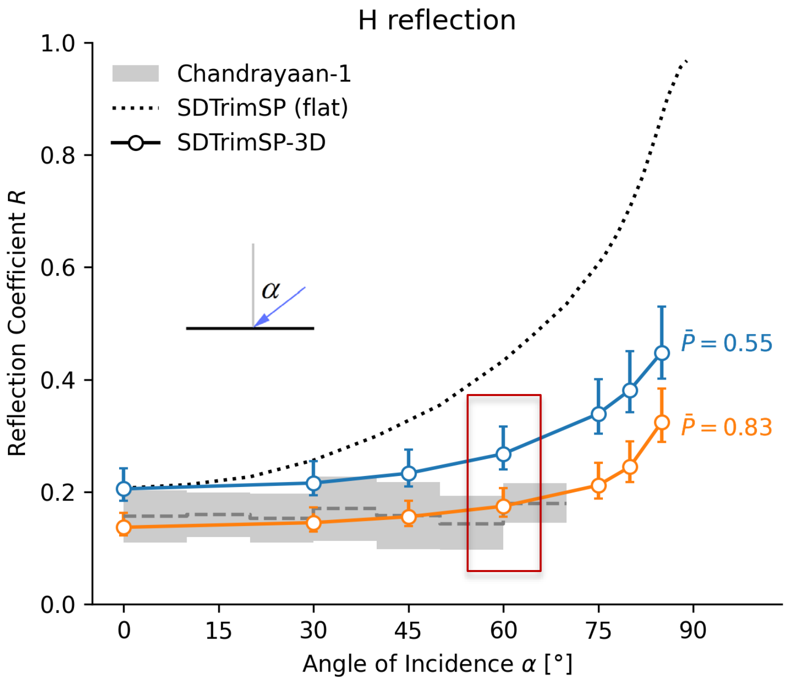

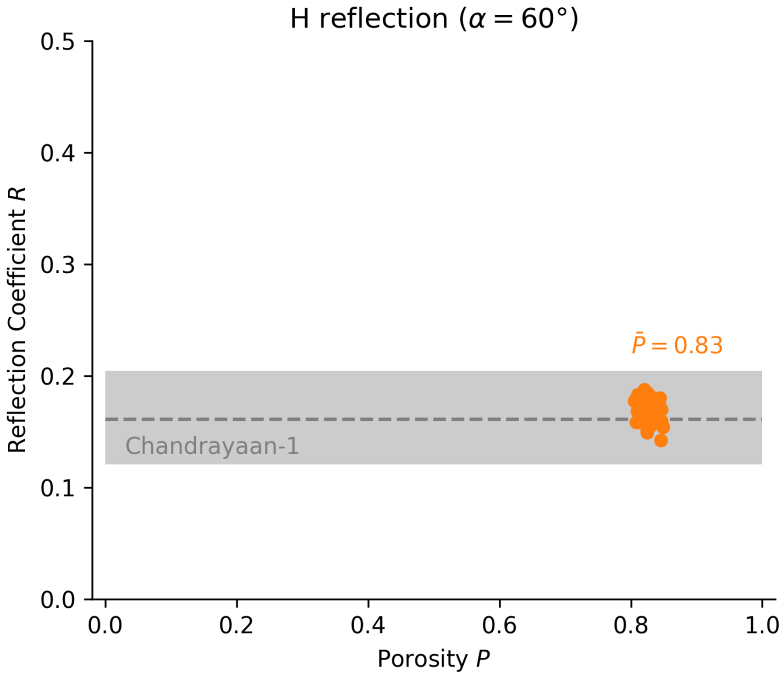

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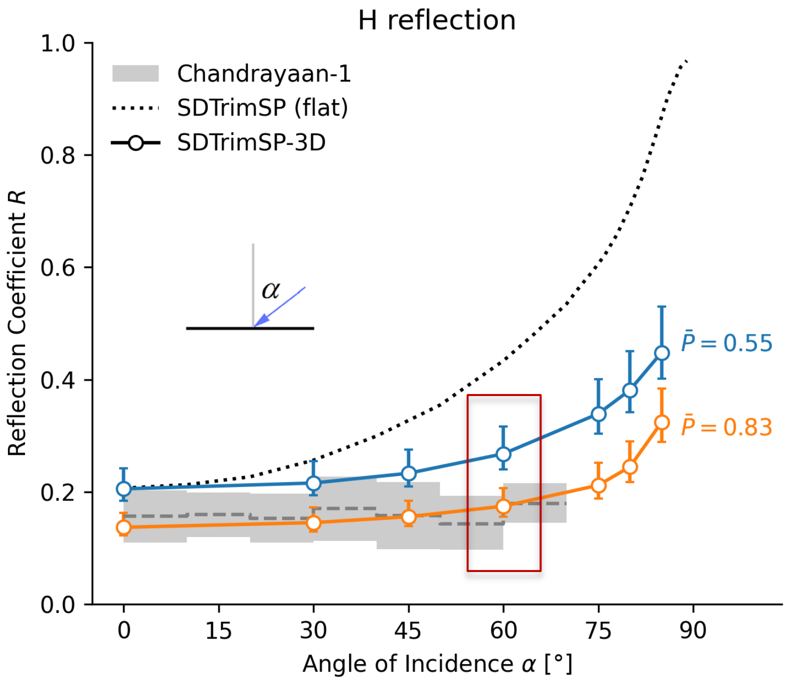

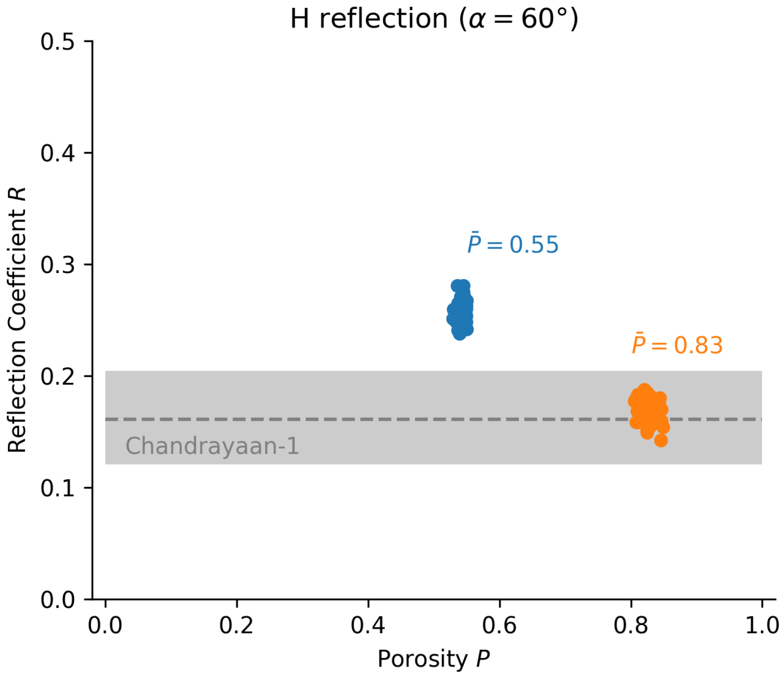

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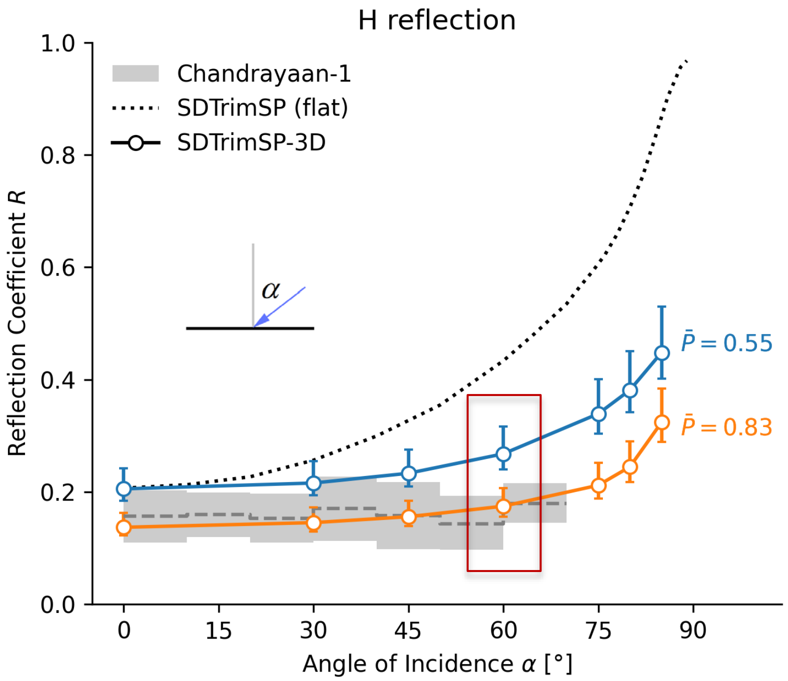

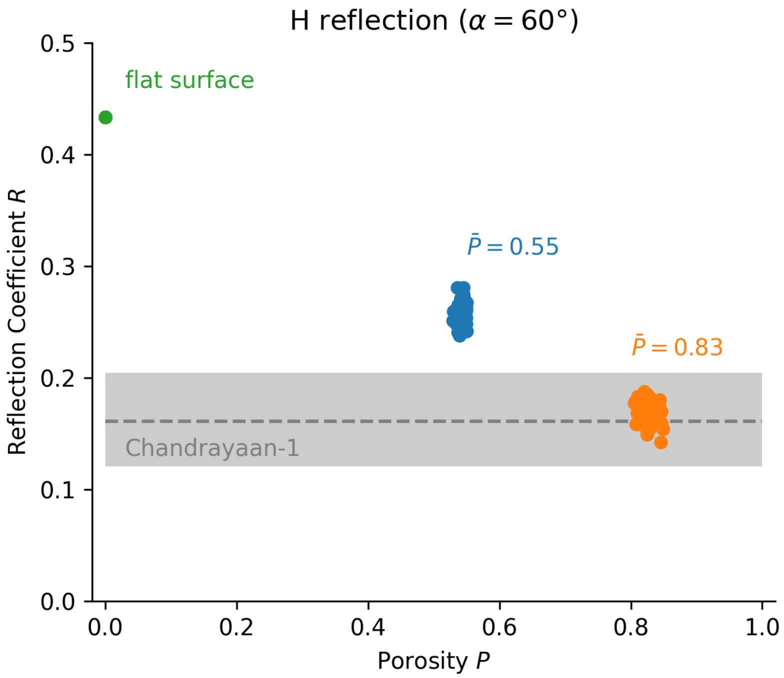

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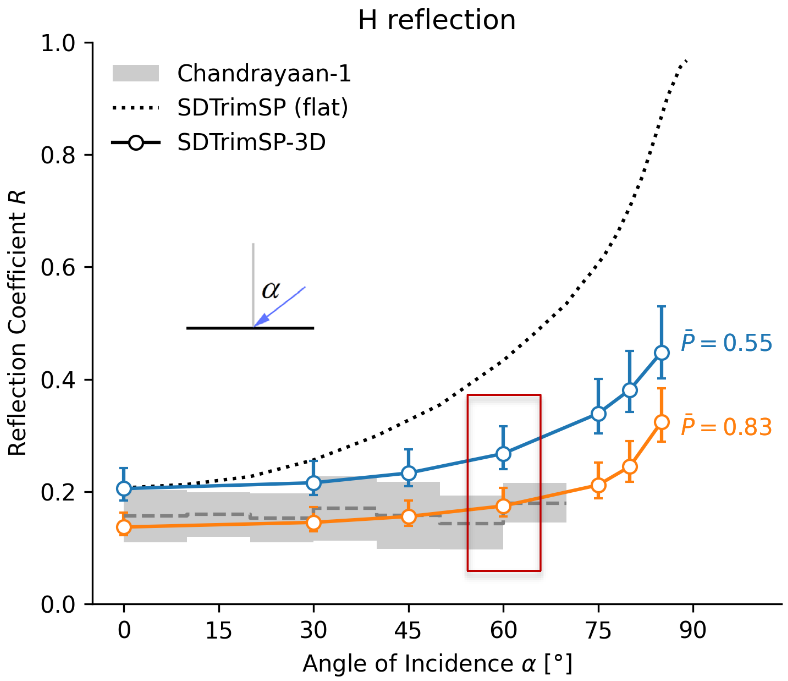

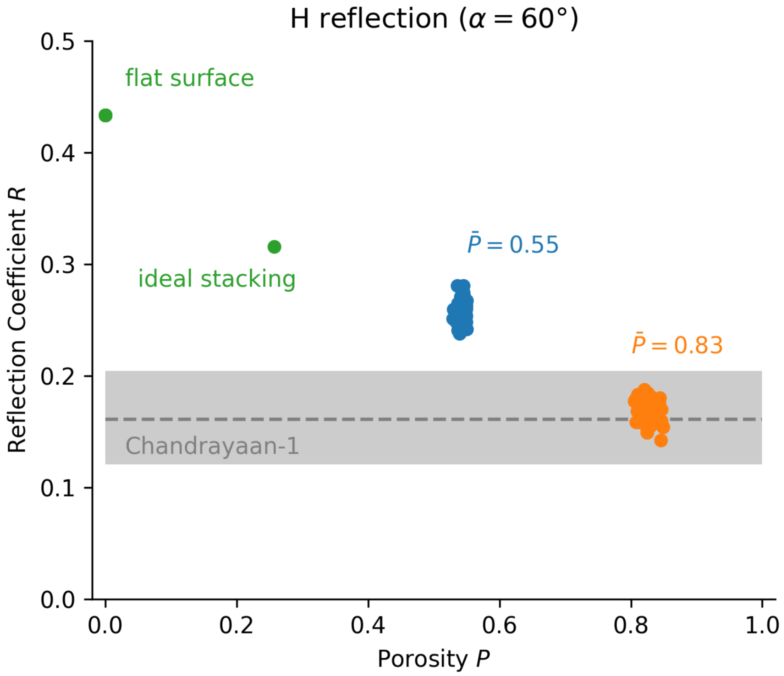

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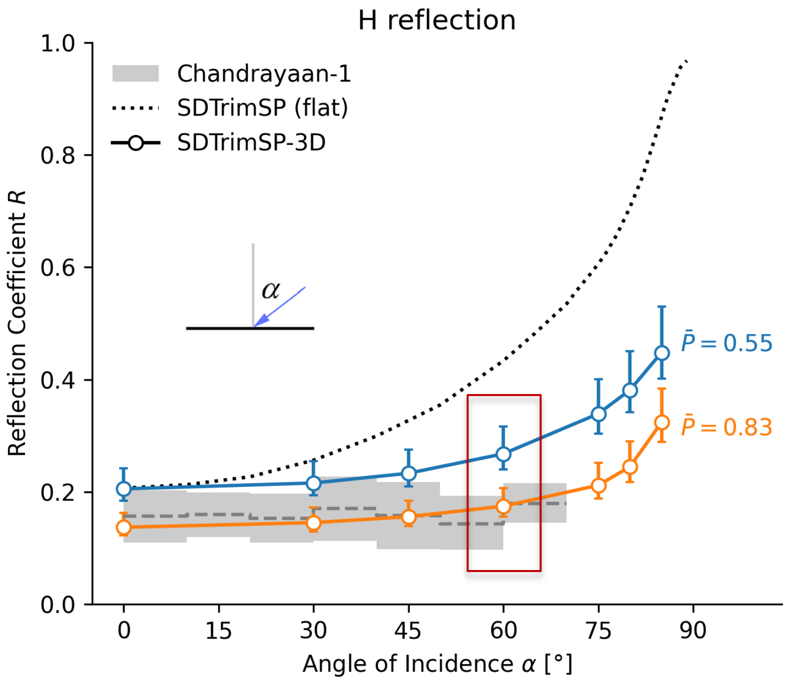

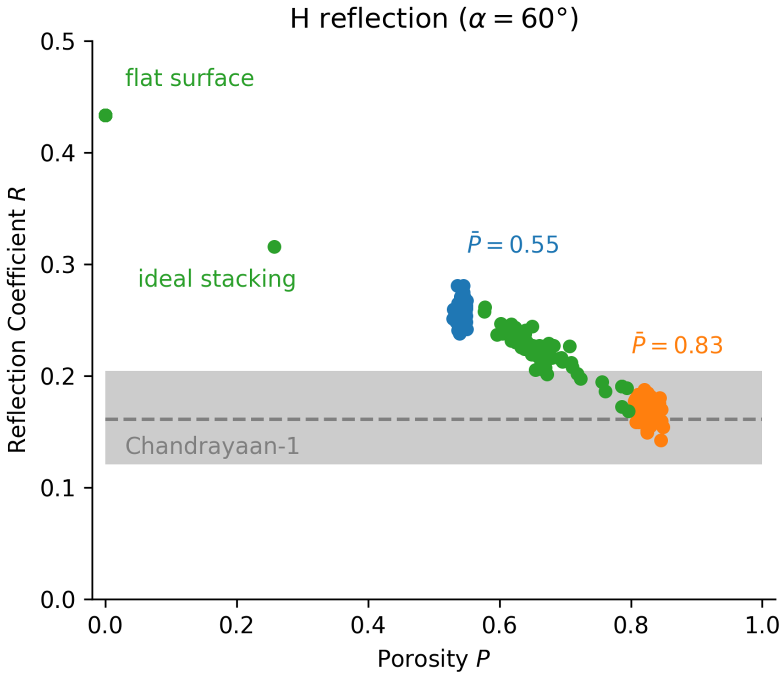

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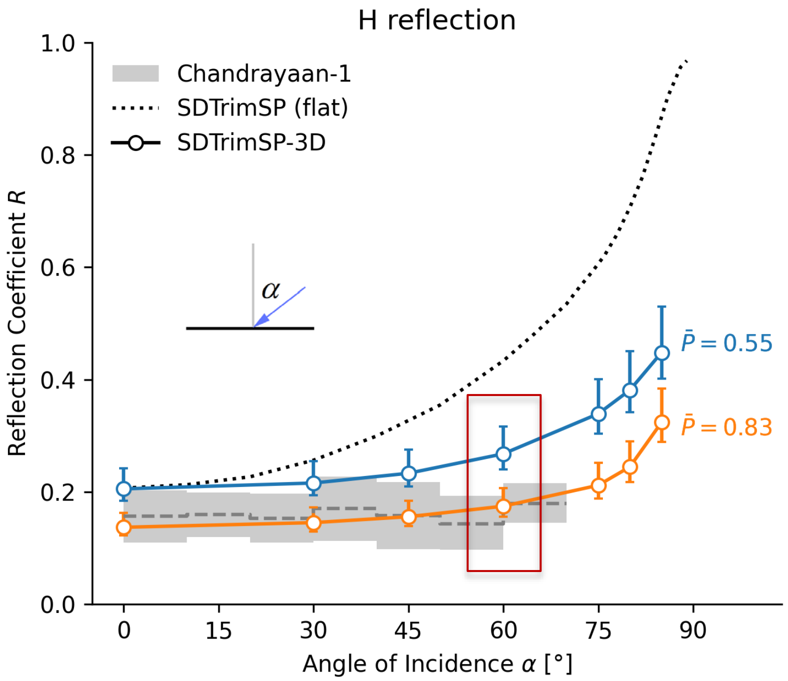

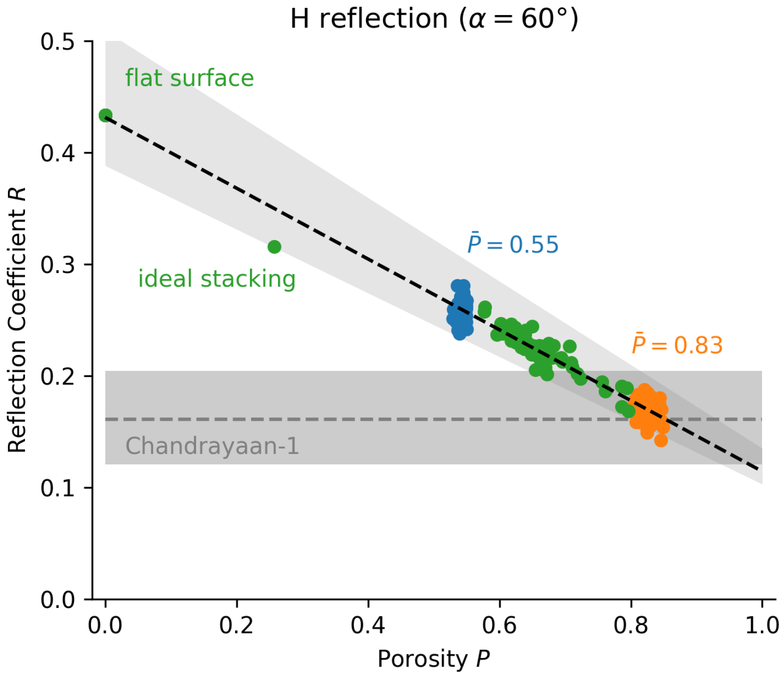

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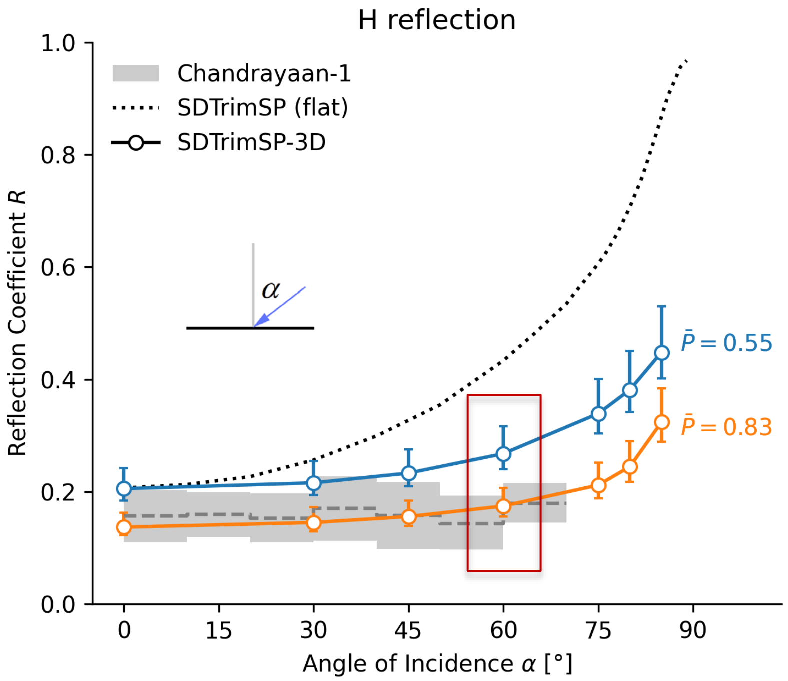

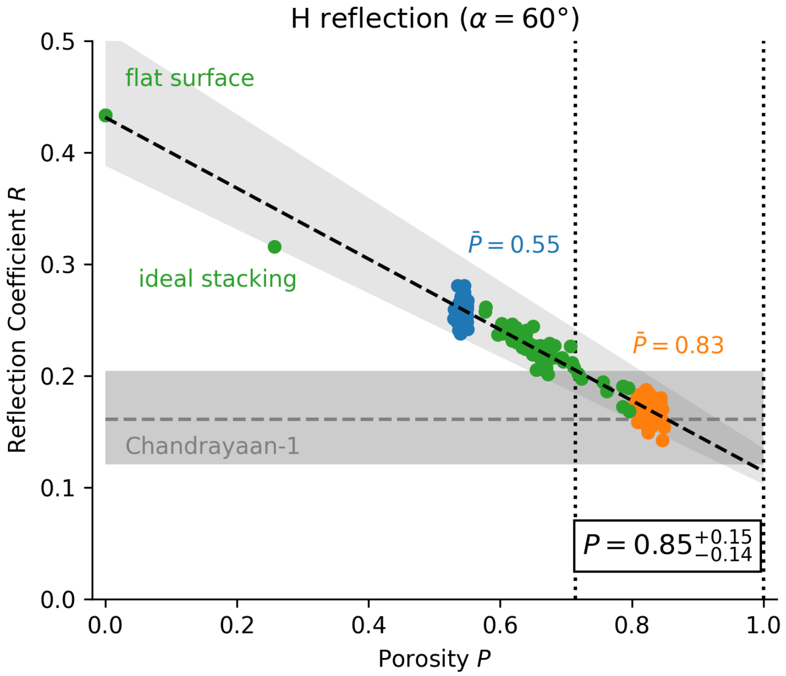

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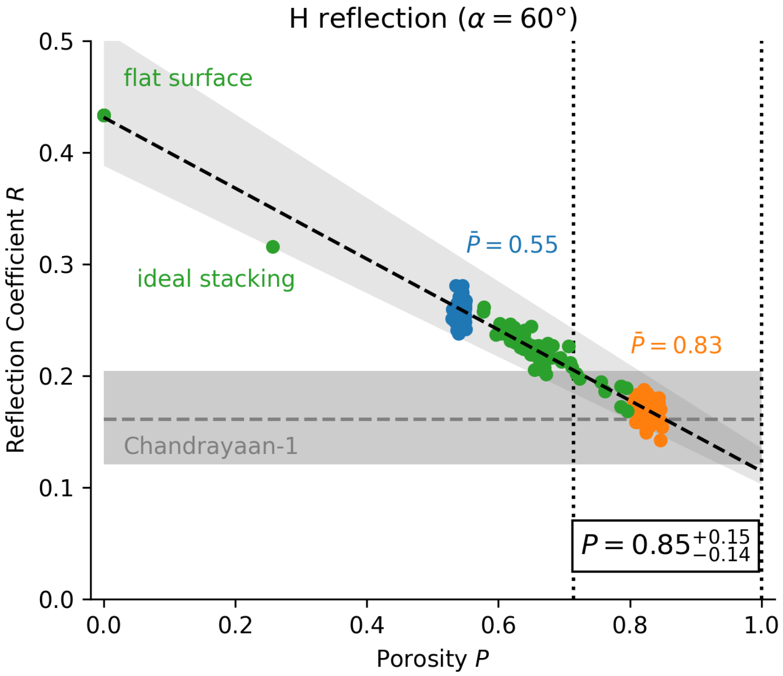
Porosity from reflection coefficients



→ Porosity is a key regolith parameter, affecting thermal and optical properties

→ different porosities reported for the Moon:

- Returned samples: 0.52 ± 0.02 for the upper 15 cm
- Infrared (Apollo 16 site): 0.83 ± 0.03 for upper mm to cm

→ ENA reflection gives porosity for the whole lunar surface

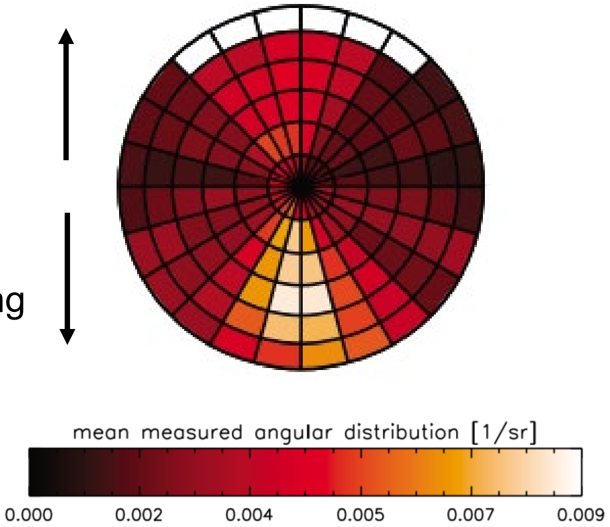
P.S. Szabo, et al., Geophys. Res. Lett. 49, e2022GL101232 (2022).
W. Carrier III, *et. al.*, Cambridge Univ. Press (1991)
B. Hapke and H. Sato, Icarus, 273 (2016), 75

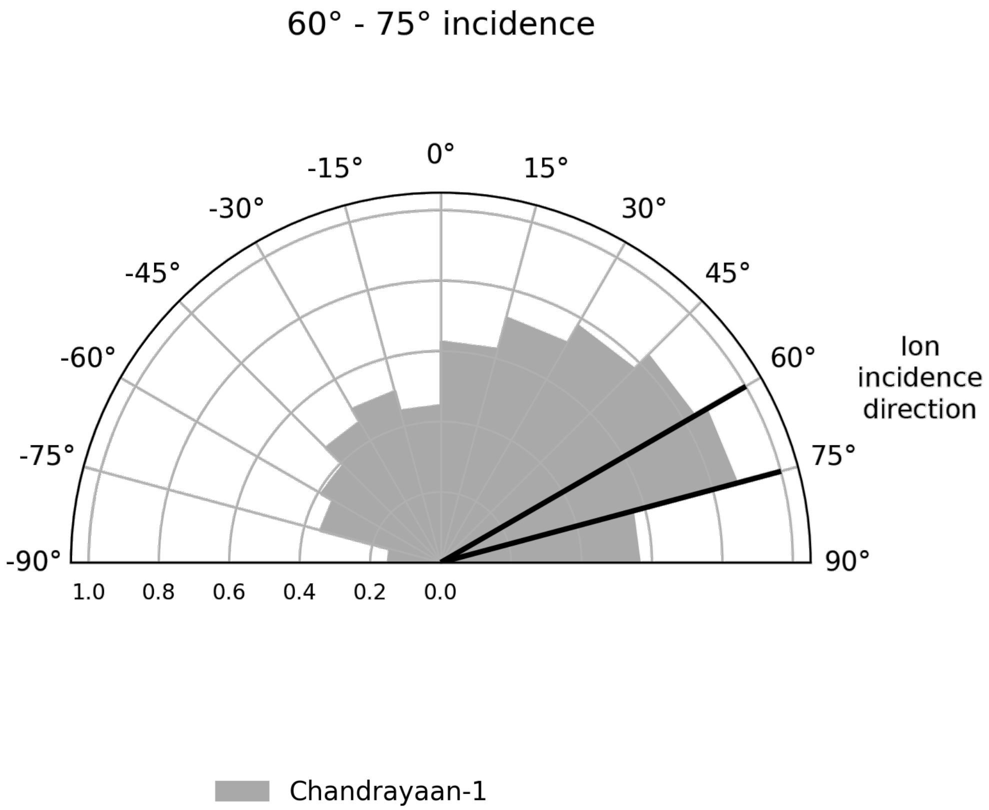
ENA scattering angles

→ Preferential backwards scattering:

Forward scattering

Backwards (sunward) scattering





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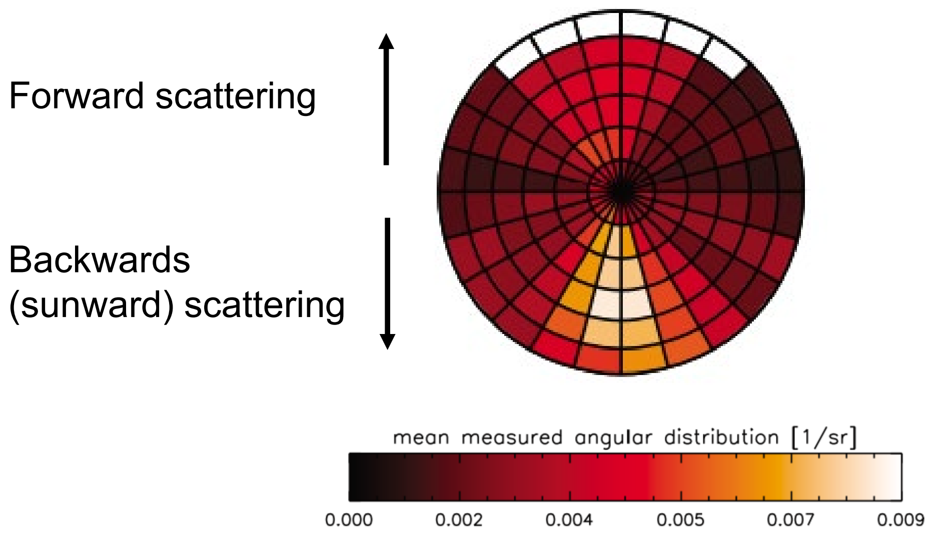

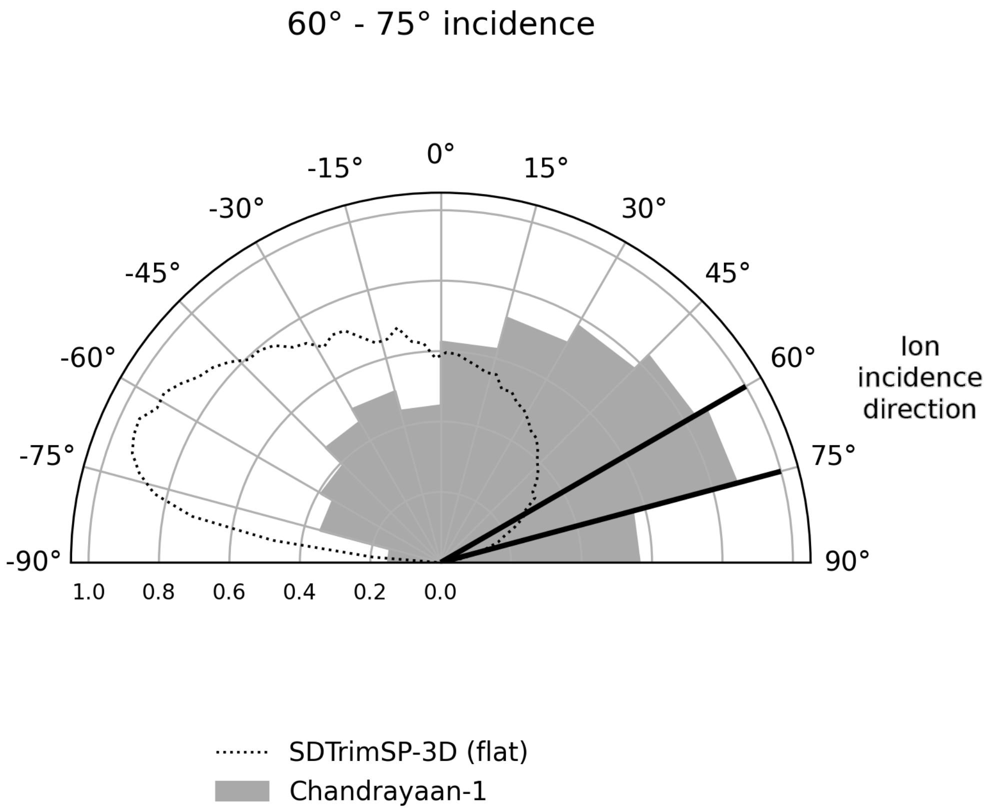

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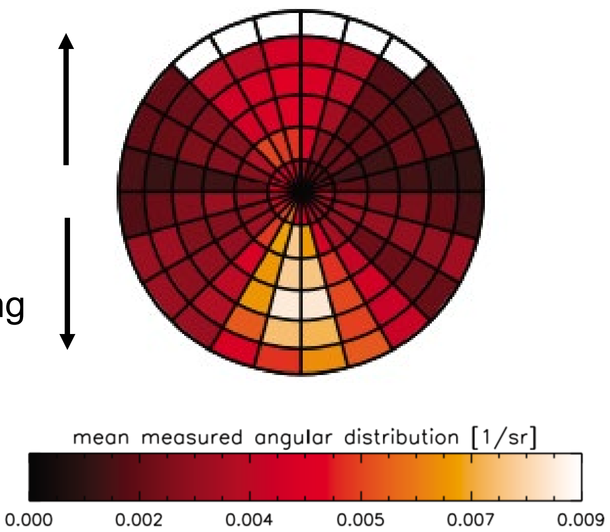

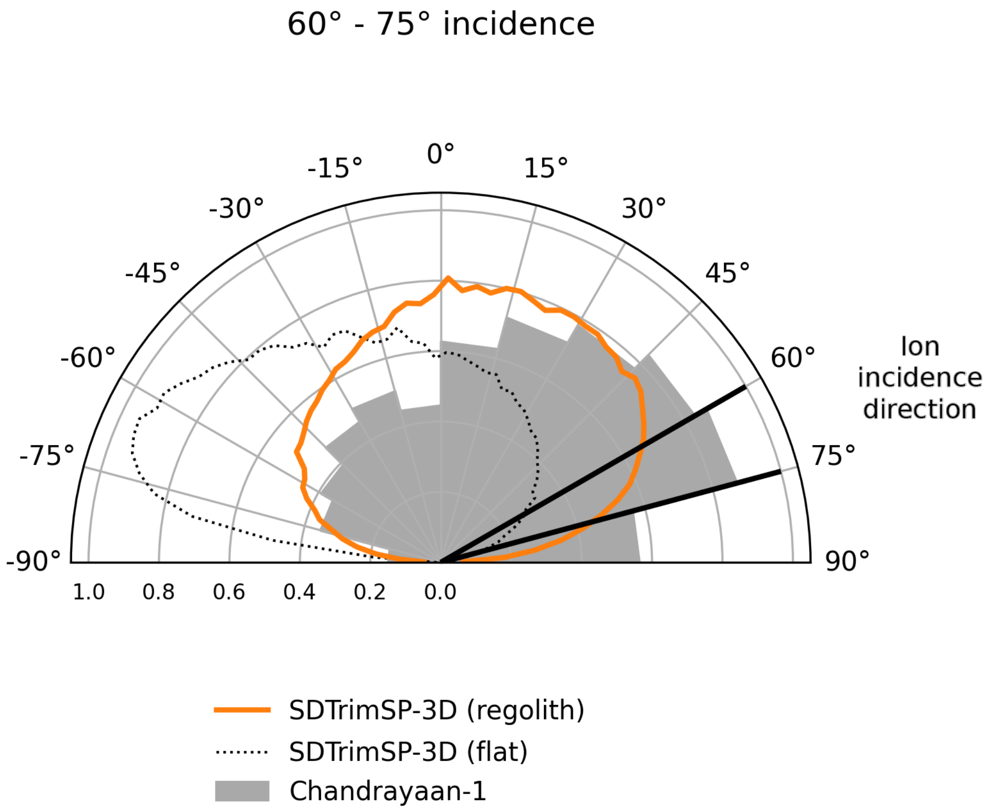

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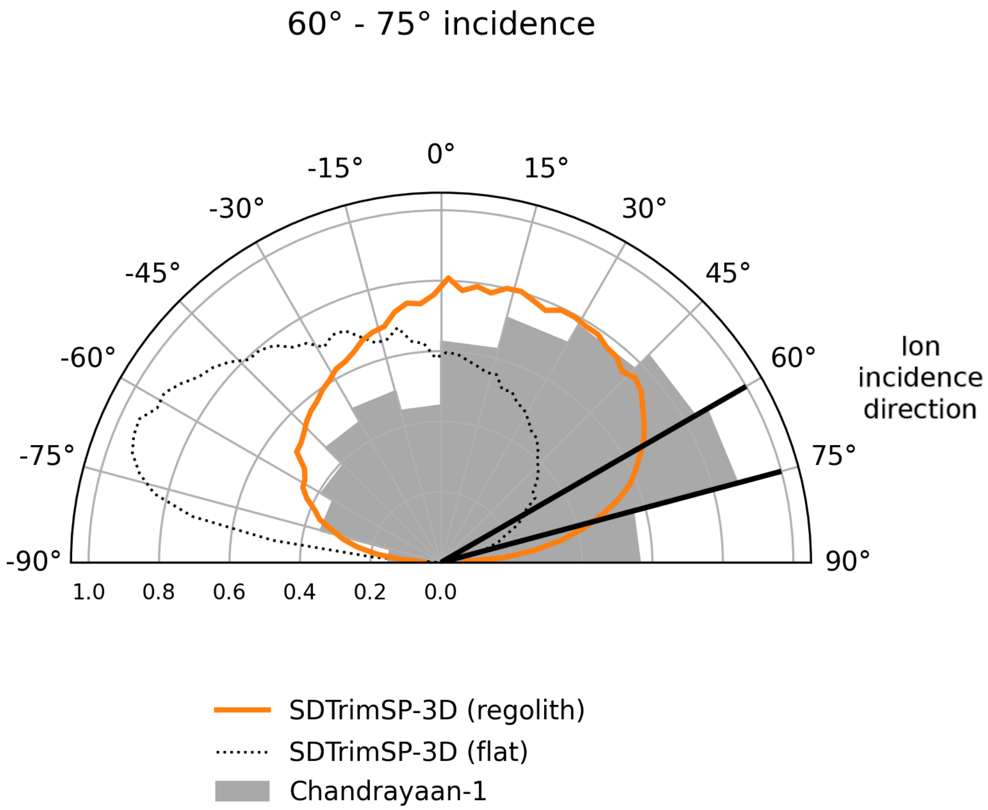

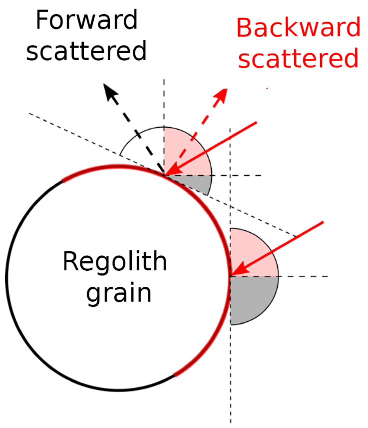

→ regolith geometry explains the observed scattering directions

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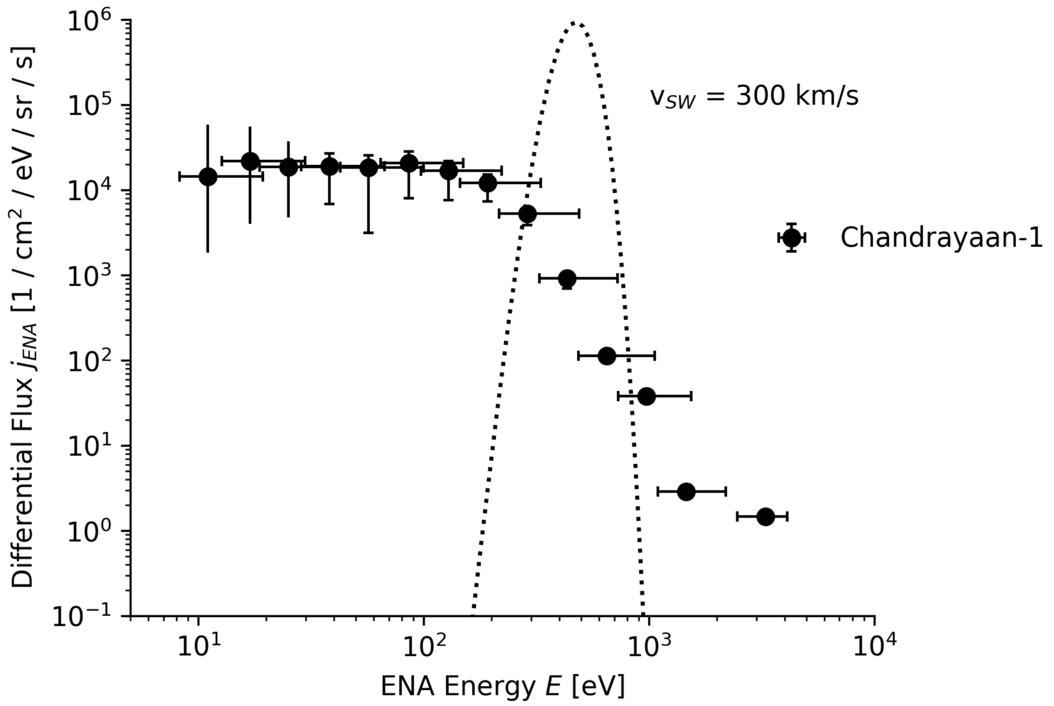
ENA scattering energies

→ Broad energy spectra observed:



Y. Futaana, *et. al.*, JGR Planets, 117.E5 (2012)

P.S. Szabo, *et. al.*, submitted to JGR Planets (2023)

ENA scattering energies

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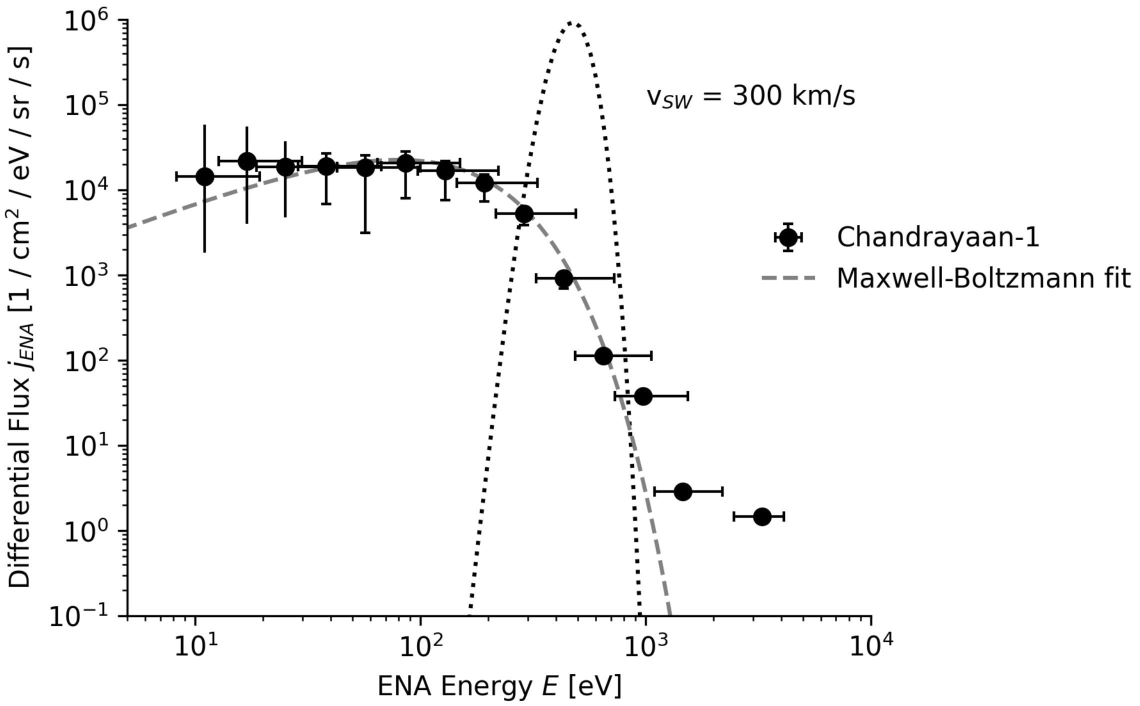

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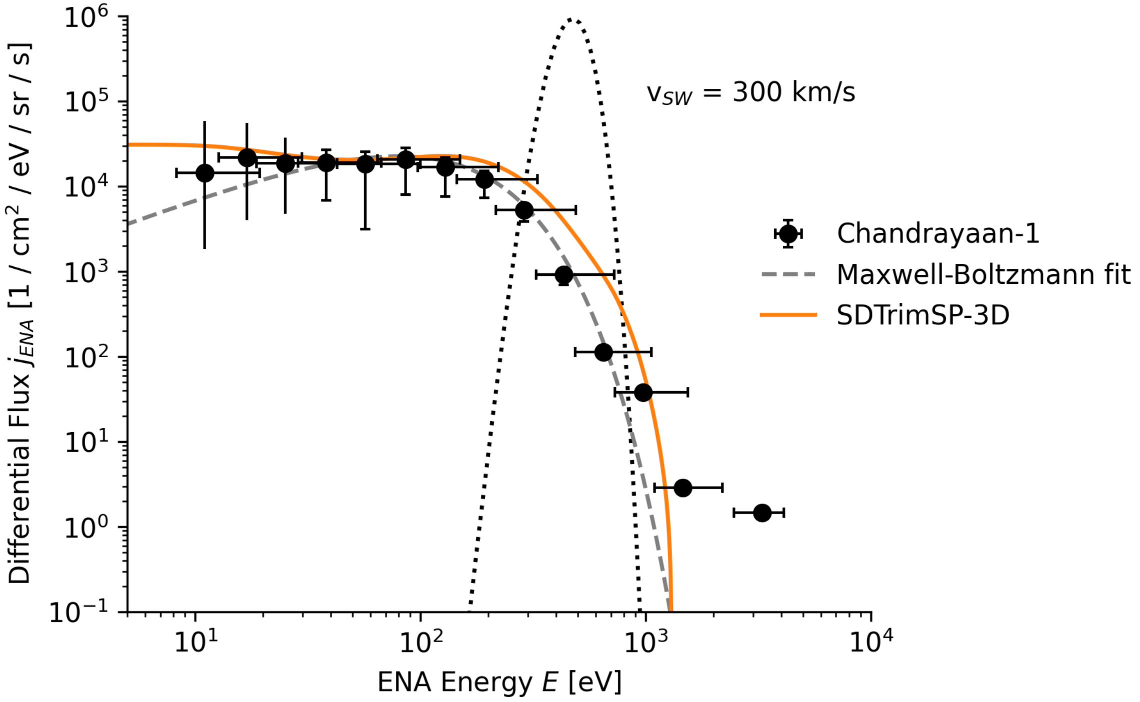

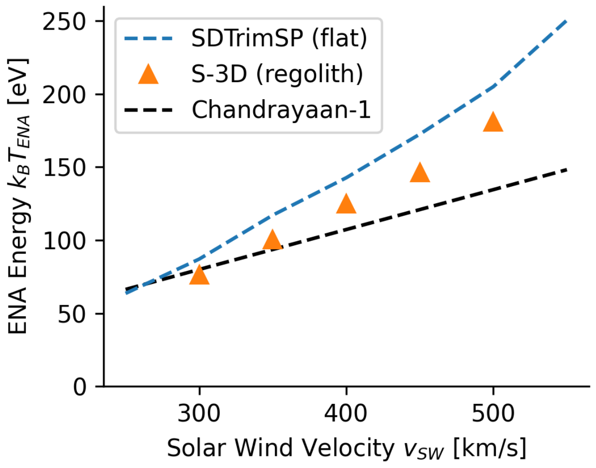

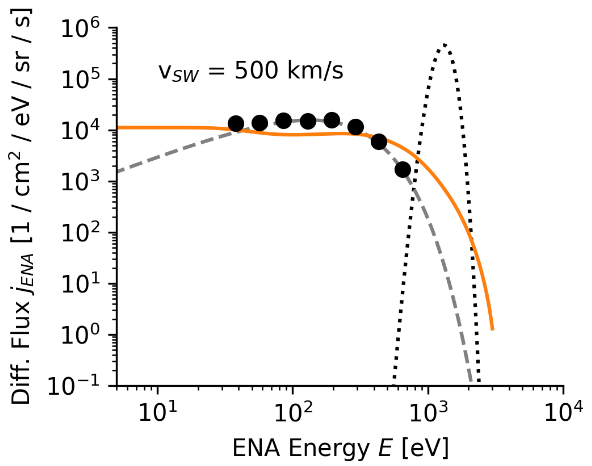

→ Energy spectra of ENAs from backscattering are mostly well reproduced

Y. Futaana, *et. al.*, JGR Planets, 117.E5 (2012)

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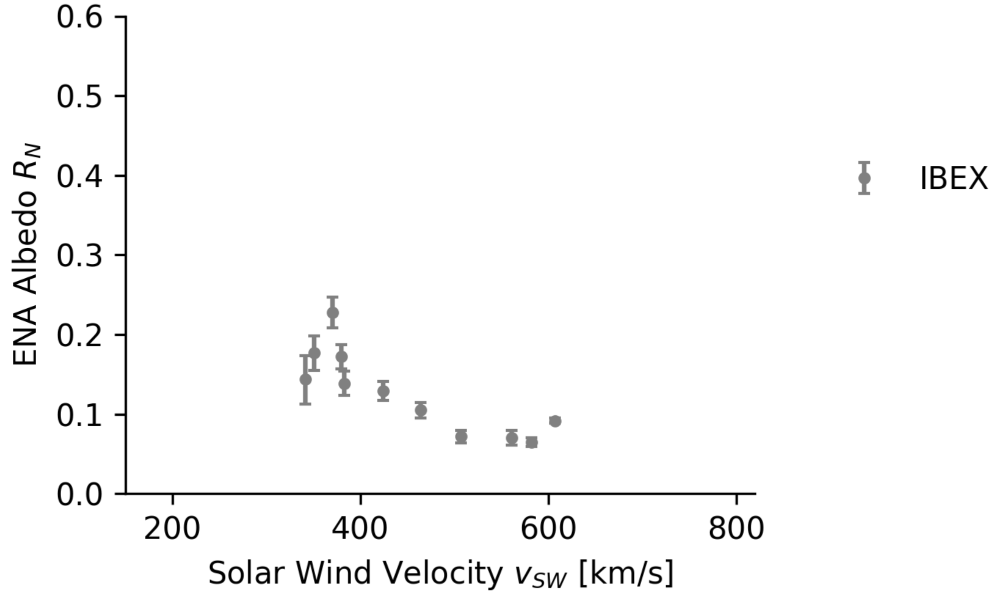
Solar wind velocity effect on the ENA albedo

→ IBEX reported reduced ENA emission for faster SW velocities:



H.O. Funsten, *et. al.*, JGR Planets, 118.2 (2013), 292

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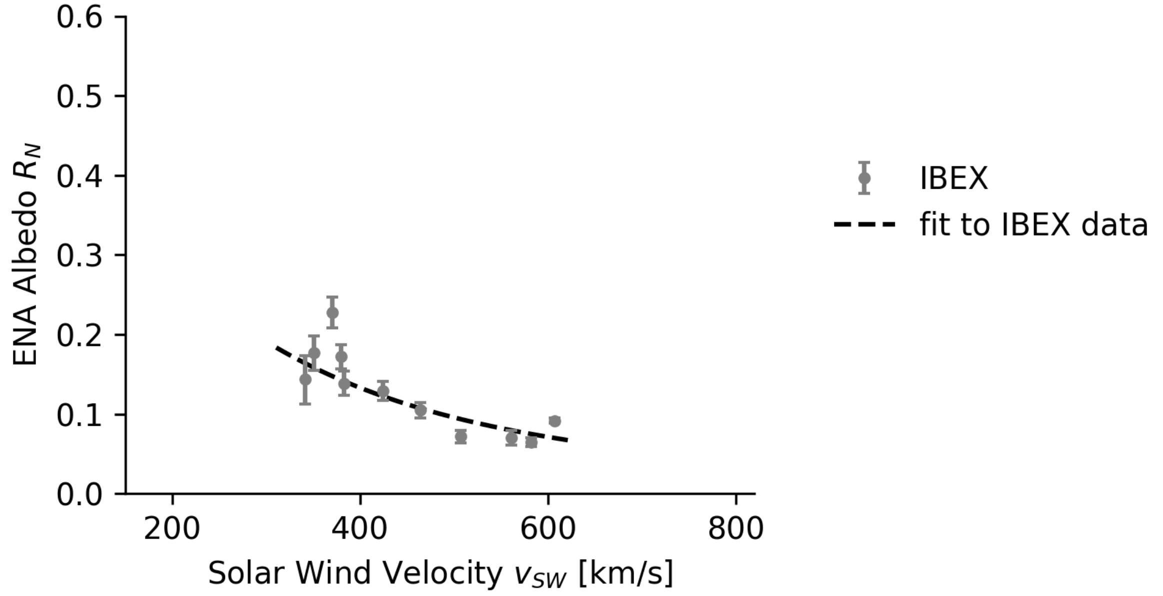

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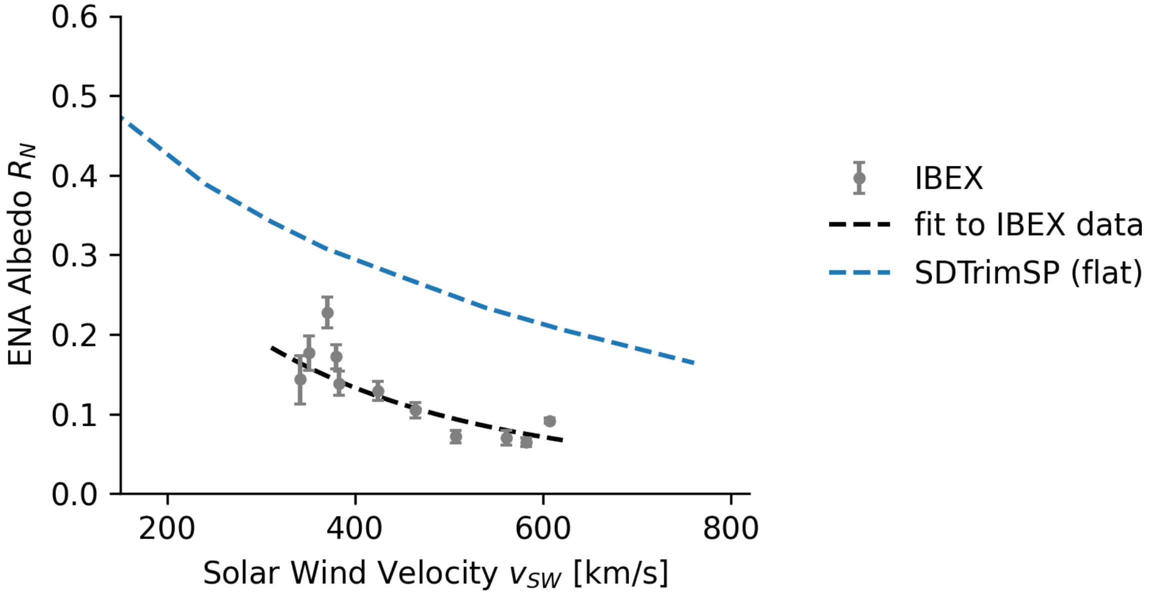

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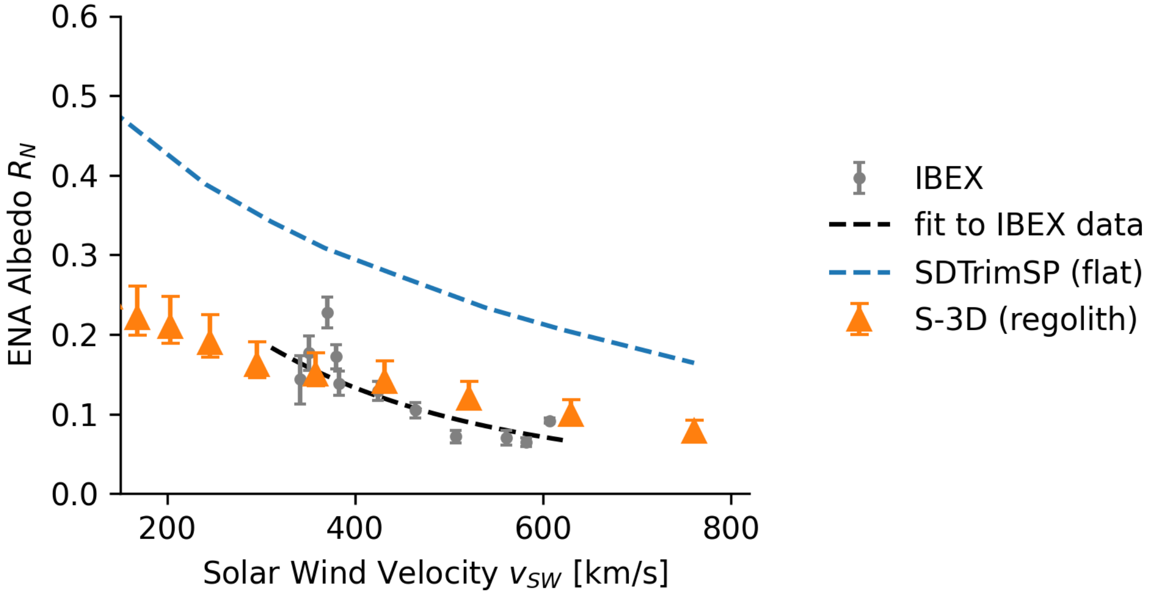


→ We can reproduce the observed ENA albedo.

→ Overall, our model is very well suited for describing the solar-wind-regolith interaction.

H.O. Funsten, *et. al.*, JGR Planets, 118.2 (2013), 292

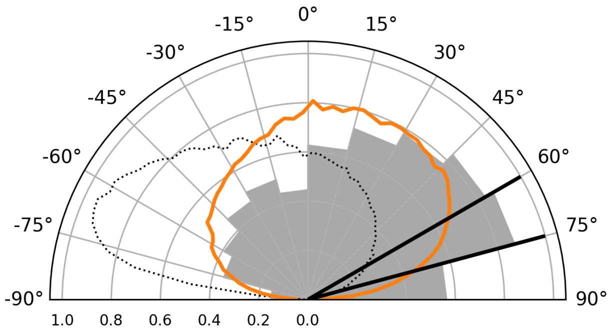
P.S. Szabo, *et. al.*, submitted to JGR Planets (2023)

Outlook for future lunar ENA studies

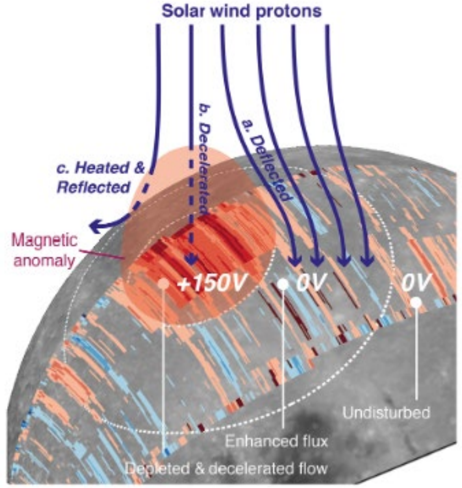
→ Scattering angles possibly connected to further regolith properties

→ Laboratory measurements use ion backscattering to analyze surface composition

→ ENA studies will help to better understand how the solar wind interacts with magnetic anomalies



P.S. Szabo, *et. al.*, submitted to JGR Planets (2023)



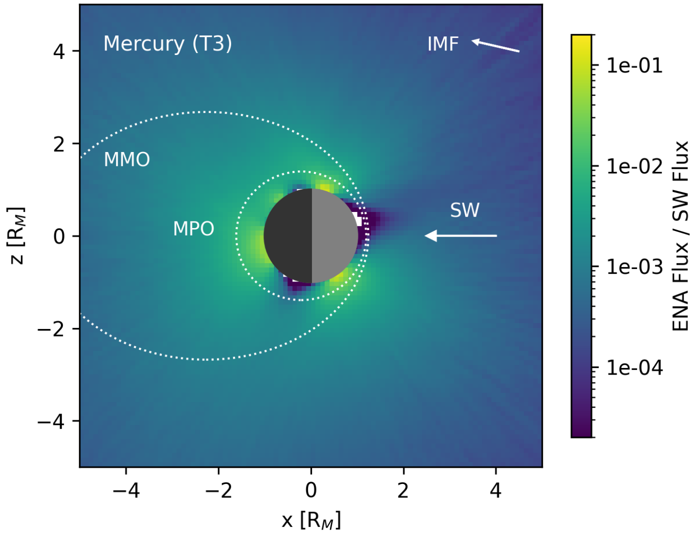
Y. Futaana, *et. al.*, GRL, 40.2 (2013), 262

Outlook for other planetary bodies

→ BepiColombo will investigate surface precipitation with backscattered ENAs

→ Proton scattering from Phobos is uncertain, ENA measurements could be helpful

→ ENA studies applicable for any airless body



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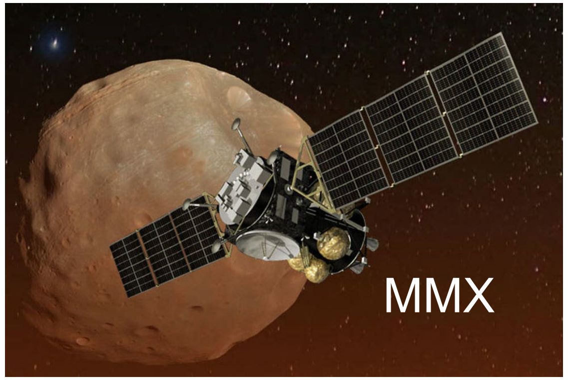

Summary

→ We performed SDTrimSP-3D simulations of ion interaction with lunar regolith.

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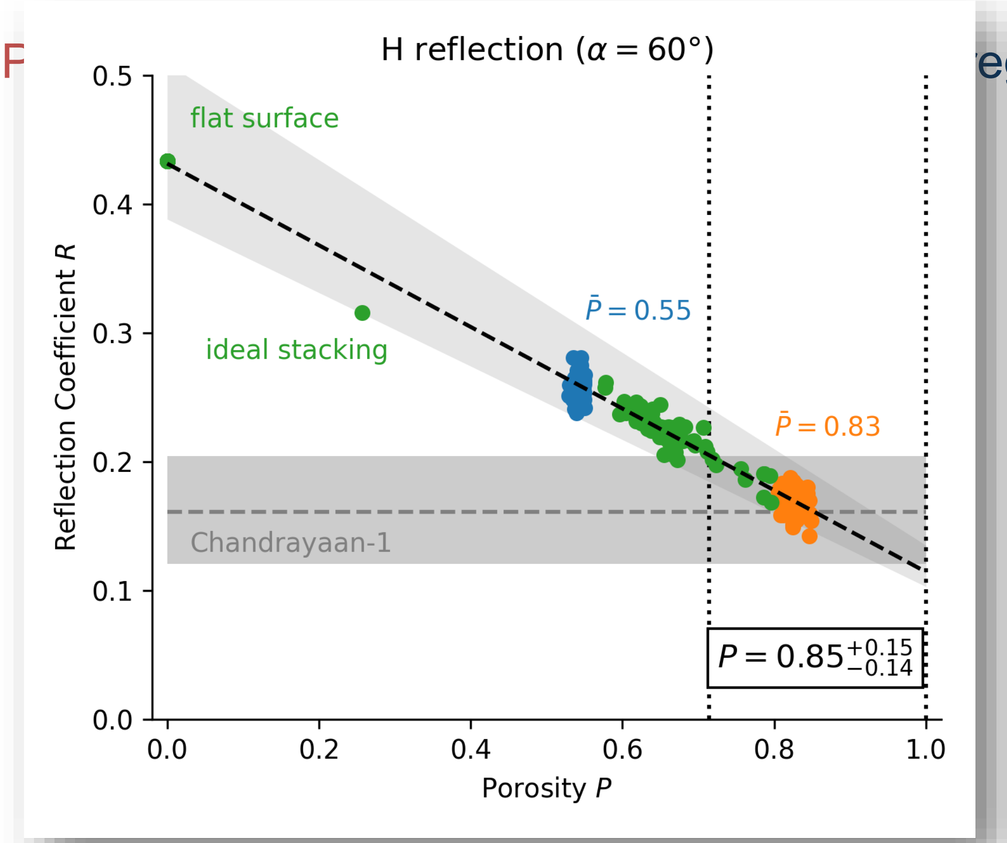

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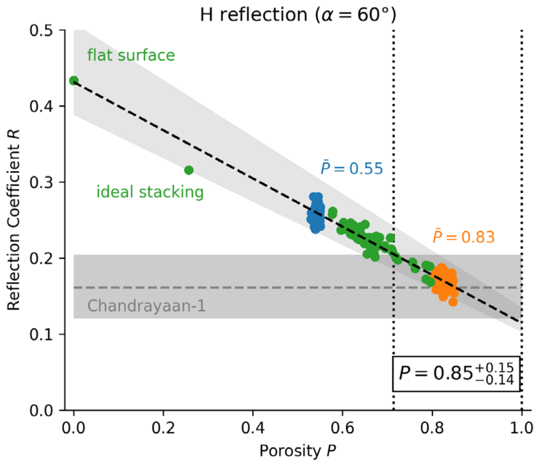
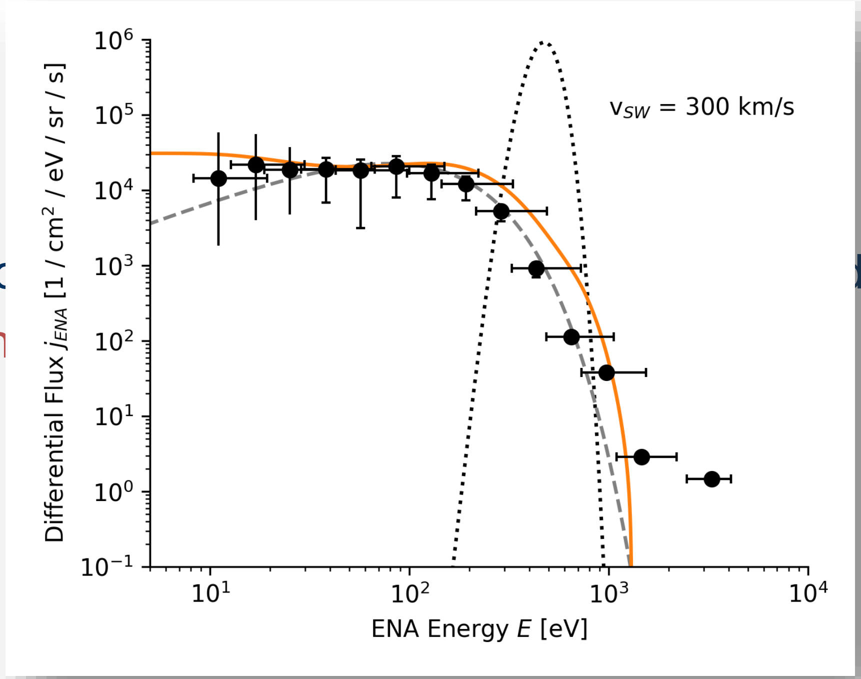


→ Fr… determine the lun…



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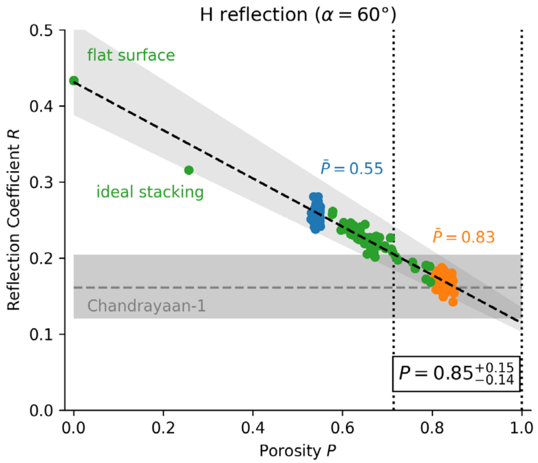

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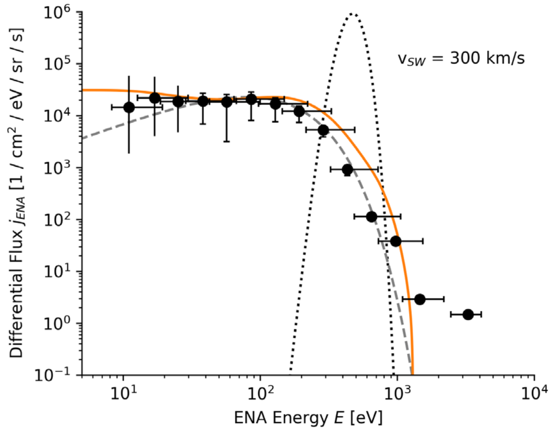

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