Editorial: Heterogeneous processes on dust and ice surfaces in planetary atmospheres: Mars, Venus, Titan, and perspectives for exoplanets

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Editorial: Heterogeneous processes on dust and ice surfaces in planetary atmospheres: Mars, Venus, Titan, and perspectives for exoplanets

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Editorial on the Research Topic
Heterogeneous processes on dust and ice surfaces in planetary atmospheres: Mars, venus, titan, and perspectives for exoplanets

Heterogeneous processes at the surface of suspended particles (both solid - dust, soot and ice - and liquid - water) play a crucial role in planetary atmospheres. In the atmosphere of Earth, they modify the planetary albedo, perturb stratospheric ozone chemistry, and provide a platform for secondary organic chemistry during smog events in the troposphere.

Recent exciting detections in planetary atmospheres, such as methane on Mars, or phosphine on Venus, call for a thorough investigation of all chemical formation and destruction routes of these species, including heterogeneous processes on solid surfaces. Currently, new data from space observation (JWST) and planetary exploration missions (Curiosity, Hope, Tianwen-1, TGO) are blossoming. Forthcoming missions to Venus (EnVision, DAVINCI+, VERITAS) and Mars (Rosalind Franklin), space observation missions (ARIEL, OST, HabEx, LUVOIR), and proposed exploration missions to the icy moons of the Solar System will surely bring unexpected new detections. Heterogeneous interactions with solid particles will be needed for a complete map of planetary atmospheric chemistry to be drawn, bringing an unbiased understanding of observations.

This small collection of papers represents a tentative step in exploring such heterogeneous processes in other planetary atmospheres.

The review by Tielens offers a detailed top-down view into the chemical nature of dust grains likely to infall from space into planetary atmospheres, and their formation in astrophysical environments. Dust grain formation is explained well by thermodynamical models in dense, hot environments. However, as pressure and temperature decrease, the activation barriers become greater obstacles to dust formation. At this point, kinetics begins to play a pivotal role, as discussed in this contribution which explores the inventory of dust particulates and their observation, and provides a strong foundation on which to explore the chemistry of dust (inorganic solids - silicates and oxides) and soot (carbonaceous solids) surfaces. As such, it provides answers to the key question often posed by those interested in surface interactions with dust: what is the chemical nature of dust?

Potapov & Bouwman extend this discussion to silicate materials and the importance of their morphology on the chemistry of exoplanetary atmospheres. The authors review the optical, morphological (porosity) and chemical (gas-grain surface reactions) properties of silicate materials. They highlight the aggregate nature of such dusts, and postulate on the impact of the extended surface area of such materials on the nature and rates of chemical processes. In cold environments, where icy or liquid films might accrete on the grains, this extended surface may mean that we over-estimate the thickness of these films, and under-estimate the potential role of bare grain chemistry, which is greatly favored by the variety of binding sites available for adsorbing species. The variety of binding sites due to the great porosity of silicate grains grants them a catalytic activity of importance for exoplanetary atmospheres and provides sites where adsorbed species remain stable over longer timescales, and at higher temperatures. Further in this direction, the authors stress the need to develop new laboratory setups allowing measurements at high temperatures for characterization of hot planetary atmospheres.

The paper of Sameera et al. demonstrates the power of combining experimental measurements with computational investigations when exploring the chemistry of heterogeneous processes; especially those involving reactive species, such as radicals. Quantum chemical calculations working in tandem with laboratory experiments on large water clusters highlight a broad range of binding energies of radicals to surface sites of ice. The key role of quantum tunneling in OCS + H and PH_3 + D reactions on ice at low temperatures is highlighted in this work, where reaction products and kinetics are determined. The choice of OCS and PH_3 for this case study is particularly meaningful because OCS connects the chemical cycles of carbon and sulfur, and phosphine bears a phosphorus atom crucial for life, and its hotly debated detection was proposed as a potential proof for exobiological activity in the atmosphere of Venus.

Finally, Iannarelli et al. identify the importance of Knudsen Flow Reactors operating in the stirred-flow regime as an important tool for exploring both simple physical processes and more complex kinetic processes. The systems studied involve model atmospheres interacting with dust at pressures higher than are achievable using complementary high- and ultrahigh vacuum-based methods, making such experimental setups ideally suited for exoplanetary atmospheres. The methodology described allows determination of adsorption and desorption kinetics, and of quantitative uptake coefficients under relevant conditions for a planetary atmosphere. Mapping the reactivity of the surface of ice and dust with up to ten gases selected to probe different properties of the surface is made possible, and calls for the development of this type of reactor, and for more studies to be conducted with them.

While we had hoped to attract a wider range of contributions on this Research Topic, those authors who have submitted papers have provided us with a strong foundation on which to build this young and increasingly important Research Topic area. The high quality and impact of these contributions gives the Guest Editors hope for further development of the field of heterogeneous atmospheric chemistry in planetary and space sciences. In all areas where surface science has been applied in the past, it has proved to be more than the last refuge of the scoundrel.

Author contributions

JL, MM, and AR-F wrote the first draft of the manuscript. All authors approved the submitted version.

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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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