Scientific Activities and Achievements

Ulrich Pöschl is Director at the Max Planck Institute for Chemistry and Professor at the Johannes Gutenberg University in Mainz, Germany. He studied chemistry at the Technical University of Graz, Austria, and he worked as a postdoctoral fellow, research scientist, group leader, and university lecturer at the Massachusetts Institute of Technology, Departments of Chemistry and of Earth, Atmospheric, and Planetary Sciences; at the Max Planck Institute for Chemistry, Atmospheric Chemistry and Biogeochemistry Departments; and at the Technical University of Munich, Institute of Hydrochemistry. Pöschl closely collaborated with Nobel laureates Paul Crutzen and Mario Molina among other internationally leading scientists. Through his pioneering research, dedicated service to the global scientific community, and impactful public outreach, Pöschl is one of the most eminent scholars, successful researchers, and influential international leaders in multiphase chemistry, atmospheric science, and aerosol research. He continues to advance scientific progress, international collaboration, and interdisciplinary exchange at the interface of Earth, life, and materials sciences.

Pöschl's scientific research is focused on multiphase processes, i.e., interactions between gases, liquids, and solids, and their effects in the Earth system, living organisms, and technical applications. His scientific achievements comprise groundbreaking discoveries and major advances in the understanding of mass transport, chemical reactions, and phase changes in aerosols, clouds, epithelial interfaces, and other multiphase systems relevant for air quality, public health, climate, and technology as detailed below. The results and success of Pöschl's research are documented in more than 400 peer-reviewed scientific journal articles that received over 64,000 citations in total and over 5000 citations per year with an h-index of 129 (Google Scholar). Every year since 2014, Pöschl has been honored as one of the world's most highly cited researchers (Web of Science), and he received prestigious awards like the Copernicus Medal, the Pius XI Gold Medal of the Pontifical Academy of Sciences, the Union Service Award of the European Geosciences Union, and the Union Fellowship of the American Geophysical Union (www.mpic.de/3785120/profile-poeschl). In accordance with Pöschl's equitable, open, and inspirational approach to scientific teaching and mentoring, his students, postdocs, and alumni (over 100) come from a wide range of ethnic and societal backgrounds with a fairly even gender balance, and many of them pursue a successful academic career as faculty members or senior scientists in leadership positions at renowned universities and research institutes around the world (over 20, ~50% international, ~50% female; www.mpic.de/5533930/Alumni).

Pöschl is a pioneer in the fields of open science and scientific quality assurance building on transparency and self-regulation. Over 25 years ago, he conceived a groundbreaking new interactive journal concept with transparent peer review and public online discussion (multi-stage open peer review), serving as a cornerstone for an epistemic web to share and show openly what is known, how well it is known, and where the limitations are in accordance with the principles of critical rationalism (Pöschl 2004, 2012; Ervens et al. 2025). Together with Paul Crutzen, Arne Richter and other colleagues from the global scientific community and the European Geosciences Union (EGU, www.egu.eu), Pöschl founded the interactive open access journal Atmospheric Chemistry and Physics (ACP, www.atmospheric-chemistry-and-physics.net), which soon became the leading journal in its field. Serving as division president, council member, and publications committee chair of EGU, Pöschl enabled and promoted the launch of more than a dozen other successful EGU journals adopting the same interactive open access publishing concept. Following this role model, other scientific initiatives and publishers such as SciPost, F1000 Research, and the Nature Publishing Group continue to adopt and develop similar ways of transparent peer review. Moreover, Pöschl initiated, advanced and co-chaired international initiatives, networks, and conferences that are instrumental for the global transformation of the inefficient and profit-oriented subscription oligopoly of the past into a scholarly oriented open access publishing environment for traditional journals as well as new and innovative forms of scholarly publishing (Berlin Open Access Conferences, OA2020, and related networks/projects; openaccess.mpg.de; oa2020.org, www.mpic.de/4123205/open-access).

The focal points and key results of Ulrich Pöschl's scientific research can be summarized as follows:

Multiphase chemical kinetics and partitioning

To elucidate the elementary steps in multiphase processes of environmental, physiological and technical relevance, Pöschl initiated and led experimental investigations, numerical simulations, and the development of a universally applicable kinetic multilayer modeling approach that resolves the interplay of mass transport, chemical reactions, and phase changes. This approach helped uncover previously unexplained molecular mechanisms, shielding effects, and kinetic limitations in the formation and transformation of dynamic multiphase systems like atmospheric aerosols, epithelial interfaces, and chemical reactors (Pöschl et al. 1998, 2001, 2005, 2007, 2011, 2015, 2020; Ammann et al. 2003, 2007; Shiraiwa et al. 2009, 2010, 2012, 2014, 2021; Kolb et al. 2010; Berkemeier et al. 2013, 2016, 2017, 2021, 2023, 2024; Knopf et al. 2015, 2024; Lakey et al. 2016, 2017, 2024; Mishra et al. 2023, 2025; Krüger et al. 2022, 2024, 2025).

For example, Pöschl and his team discovered and unraveled how reversible and competitive co-adsorption, the formation of reactive oxygen intermediates, and phase changes in organic coatings limit the atmospheric oxidation rate of hazardous polycyclic aromatic compounds on soot particles. They were able to reconcile environmental observations, laboratory experiments, and numerical simulations of regional to global distribution, transport, and chemical degradation that had previously disagreed by multiple orders of magnitude, highlighting the importance of considering temperature and humidity effects on both the phase state of aerosol particles and the chemical reactivity of particulate air pollutants (Pöschl et al. 2001, 2005, 2011, 2015; Schauer et al. 2003, 2004; Shiraiwa et al. 2009, 2011; Mu et al. 2018; Wilson et al. 2020, 2021). Extending the experimental investigations, mechanistic insights and modeling approach from ambient to high temperatures and concentration levels, Pöschl and collaborators were also able to resolve and predict the chemical kinetics, temperature dependencies, activation energies, reaction pathways, and composition dependence of soot and nanoparticle oxidation under conditions relevant for exhaust gas treatment and syngas production (Messerer et al. 2003, 2004, 2006; Sadezky et al. 2005; Ivleva et al. 2007; Berkemeier et al. 2016, 2017, 2024).

For organic and inorganic atmospheric aerosol particles, Pöschl and colleagues discovered transitions between liquid, semi-solid, glassy and crystalline phase states that depend on ambient temperature, relative humidity, particle size, and chemical composition (Mikhailov et al. 2004, 2009; Virtanen et al. 2010; Koop et al. 2011; Cheng et al. 2015). These phase transitions and related changes in diffusivity can strongly influence the uptake and partitioning of water, reactive trace gases, and condensable vapors as well as the formation, chemical aging, lifetime, and long-range transport of atmospheric aerosols and hazardous pollutants, influencing their effects on climate and health (Pöschl et al. 2011, 2015; Shiraiwa et al. 2011, 2014, 2017; Berkemeier et al. 2013, 2014, 2016; Cheng et al. 2015; Mu et al. 2018; Su et al. 2020). Moreover, Pöschl helped elucidate how the multiphase chemistry of reactive nitrogen in aerosol water contributes to sulfate production and severe haze formation; that pH buffering is dominated by the mass concentration and water content of atmospheric aerosols; and that ammonia from anthropogenic sources regulates aerosol acidity at regional and global scales (Cheng et al. 2016; Zheng et al. 2020, 2024).

Atmosphere-biosphere exchange and aerosol-cloud interactions

In the context of Earth system science, Pöschl investigated, characterized, and quantified atmospheric trace constituents and multiphase processes involved in atmosphere-biosphere exchange and aerosol-cloud interactions, which are essential for air quality, climate, life, and the biogeochemical cycling of aerosols, water, carbon, nitrogen, and organic matter (Pöschl et al. 2005, 2015, 2020).

To elucidate the abundance, diversity, sources, and interactions of atmospheric bioaerosols including airborne fungal spores, bacteria, archaea, proteins, amino acids and related substances, Pöschl and his team developed and applied a wide range of advanced analytical methods including fluorescence microscopy and spectroscopy, liquid chromatography coupled to UV/VIS and mass spectrometry, chemical tracer and molecular genetic analysis, immunoassays, and ice nucleation assays (Pöschl 2003, 2005, 2010; Franze et al. 2003, 2004, 2005; Després et al. 2007, 2012; Elbert et al. 2007; Fröhlich-

Nowoisky et al. 2009, 2012, 2014, 2015, 2016; Huffman et al. 2010, 2012, 2013; Pöhlker et al. 2012, 2013; Reinmuth-Selzle et al. 2014, 2017, 2022, 2023; Liu et al. 2016, 2017; Kunert et al. 2018, 2019; Lang-Yona et al. 2018, 2019; Könemann et al. 2019; Prass et al. 2021; Zhang et al. 2019, 2021). They obtained first estimates for the mass concentrations of airborne proteins and DNA in fine particulate matter (Franze et al. 2005; Despres et al. 2007) and groundbreaking molecular genetic insights into the biodiversity of fungi, bacteria, and archaea in continental and marine air (Fröhlich-Nowoisky et al. 2009, 2012, 2014; Valsan et al. 2016; Schiebel et al. 2024). Moreover, they discovered new fungal ice nuclei and relations between atmospheric bioparticle and ice nuclei concentrations (Prenni et al. 2009, 2013; Huffman et al. 2013; Tobo et al. 2013; Fröhlich-Nowoisky et al. 2015; Kunert et al. 2019; Tang et al. 2022), helping to elucidate the interplay of bioaerosols, ecosystems, and the hydrological cycle (bioprecipitation cycle; Burrows et al. 2009, 2013; Morris et al. 2014; Fröhlich-Nowoisky et al. 2016). Pöschl and collaborators also gained fundamental new insights into the chemical mechanisms of ice nucleation by biological particles and macromolecules (Pummer et al. 2015; Pandey et al. 2016; Lukas et al. 2019, 2020; Schwidetzky et al. 2020, 2021; Eufemio et al. 2025; Wieland et al. 2025).

To disentangle aerosol-cloud interactions and determine the sources and properties of aerosol particles acting as cloud condensation nuclei (CCN), Pöschl and his team performed comprehensive laboratory experiments, field observations, and model calculations for clean and polluted conditions ranging from the Amazon rainforest to Asian megacities and from the planetary boundary layer to the upper troposphere (Rose et al. 2008, 2010, 2011; Garland et al. 2009, 2010; Gunthe et al. 2009, 2011, 2021; Su et al. 2010, 2016; Mikhailov et al. 2013, 2015, 2017, 2021; Andreae et al. 2015, 2018; Braga et al. 2017, 2021; Pöhlker et al. 2016, 2018, 2021, 2023; Holanda et al. 2020, 2023; Liu et al. 2020; Singh et al. 2023, 2025). Besides characterizing spatiotemporal patterns of CCN number concentrations and size distributions, they discovered distinctly different regimes of aerosol- and updraft-limited CCN activation and cloud droplet formation under clean and polluted conditions, respectively (Reutter et al. 2009, 2014; Chang et al. 2015; Fan et al. 2018; Liu et al. 2020; Pöhlker et al. 2021). They found and demonstrated that the hygroscopicity of CCN can be efficiently predicted as a function of organic and inorganic aerosol mass fraction and particle size distribution, constraining a critically important aspect of global climate modelling (Pöschl et al. 2009, 2011; Gunthe et al. 2009, 2011; Pringle et al. 2010; Pöhlker et al. 2023).

Pöschl and collaborators discovered that biological soil crusts play a major role in the global biogeochemical cycling of carbon, nitrogen, and aeolian dust (Elbert et al. 2012; Porada et al. 2013, 2014, 2016, 2017, 2019; Rodriguez-Caballero et al. 2018, 2022), and how microbes in soil and biocrusts release large amounts of photochemically active nitrous acid and nitrogen oxides to the atmosphere (Su et al. 2011; Oswald et al. 2013; Lenhart et al. 2015; Weber et al. 2015; Kratz et al. 2022). Moreover, Pöschl helped elucidate and quantify the interplay of volatile organic compounds, nitrogen oxides, and ozone in atmospheric gas phase chemistry (Crutzen et al. 1999, 2000; Waibel et al. 1999; Pöschl et al. 2000, 2001; Warneke et al. 2001; Williams et al. 2001; Kuhlmann et al. 2004; Kuhn et al. 2007; Li et al. 2016, 2018, 2019; Wang et al. 2022, 2024; Crowley et al. 2025) as well as in new particle formation and secondary organic aerosol production from the rainforest canopy to the upper troposphere over the Amazon (Pöschl et al. 2010, 2011, 2015; Martin et al. 2010, 2016, 2017; Pöhlker et al. 2012, 2019; Shiraiwa et al. 2014, 2017; Andreae et al. 2015, 2016; Machado et al. 2018, 2021, 2024; Franco et al. 2021, 2024, 2025; Curtius et al. 2024; Unfer et al. 2024, 2025; Brill et al. 2025; Cecchini et al. 2025; Leppla et al. 2025; Meller et al. 2025; Valiati et al. 2025).

Aerosol health effects, oxidative stress and physiological responses

To explore, understand and help mitigate the adverse health effects of aerosols and hazardous pollutants, Pöschl pursued and obtained groundbreaking mechanistic insights into relevant multiphase processes in ambient air and in the human respiratory tract (Pöschl et al. 2002, 2005, 2015, 2020; Shiraiwa et al. 2012, 2017; Lelieveld et al. 2017, 2019, 2020, 2021; Berkemeier et al. 2017, 2023; Cheng et al. 2021; Pöhlker et al. 2024).

For example, Pöschl and collaborators discovered that proteins are efficiently nitrated and oligomerized by ozone and nitrogen oxides in polluted air and that the chemically modified proteins can trigger and enhance pro-inflammatory signaling pathways and feedback loops in the immune system, providing a tentative answer to the enigmatic question how air pollutants may contribute to the widely observed but unexplained increase of allergic and inflammatory diseases (Franze et al. 2005; Gruijthuisen et al. 2006; Yang et al. 2010; Zhang et al. 2011; Selzle 2013; Reinmuth-Selzle 2014, 2017, 2023; Ziegler et al. 2021; Backes et al. 2021; Fröhlich-Nowoisky et al. 2023). They also explored chemical interventions that can influence and mitigate inflammatory processes and signaling pathways by antioxidant and antagonistic interactions (Schink et al. 2018; Rosch et al. 2021).

To unravel and quantify the mechanisms by which individual air pollutants contribute to oxidative stress in the human respiratory tract, Pöschl and his team performed laboratory investigations of aqueous phase radical reactions and environmentally persistent radicals, assessed the oxidative potential of fine particulate matter (PM2.5) from different sources and regions, and developed novel multilayer models describing the uptake and chemical reactions of PM2.5 and reactive trace gases at epithelial interfaces (Arangio et al. 2015, 2016; Lakey et al. 2016, 2017; Tong et al. 2016, 2017, 2018, 2019, 2021, 2025; Filippi et al. 2019, 2022; Berkemeier & Pöschl 2023). They found that the main effects of PM2.5 in epithelial lining fluid are related to the catalytic conversion of H_2O_2 into OH radicals rather than the production of H_2O_2, which differs from widespread earlier assumptions and may imply a paradigm shift for the methods commonly used to assess the oxidative potential and adverse health effects of PM2.5 and its redox-active compounds (Dovrou et al. 2023). Moreover, they found that the oxidative stress caused by air pollutants can be exacerbated by enhanced levels of endogenous nitric oxide, which provides a tentative explanation for the previously unexplained observation that individuals with pre-existing inflammatory disorders are more susceptible to air pollution (Lelieveld et al. 2024).

During the COVID-19 pandemic and beyond, Pöschl and colleagues took extra efforts to quantify and explain the benefits as well as the limitations of protective measures like face masks and room ventilation against aerosol and droplet transmission of infectious diseases, which helped administrative and political decision makers, was taken up by mass media, and was well received in the broader public as confirmed by positive feedback from many sides (Lelieveld et al. 2020; Cheng et al. 2021; Pöschl & Witt 2021; McLeod et al. 2022; Helleis et al. 2023; Pöhlker et al. 2023). Pöschl also engaged in other community efforts to carefully assess, discuss, and explain scientific and societal issues related to air quality, health, climate, and sustainability in the Anthropocene in accordance with the open-minded and open-ended principles of the scientific method and critical rationalism (e.g.: Clean Air, Leopoldina 2019; Health of People, Health of Planet, Pontifical Academy 2020; Politics in the Anthropocene, Brauch et al. 2025).

References

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