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Reappraising mantle heavy noble gas isotope systematics and their geodynamical implications - *F.G. Houtermans Award Lecture*

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Being chemically inert, noble gases are key tracers of planetary volatile evolution. Their systematics across mantle reservoirs underpin our understanding of the origin and evolution of terrestrial volatiles (water, carbon, nitrogen), essential for habitability. Several isotopes are produced by nuclear reactions, including the decay of ^{129}I into ^{129}Xe ($T_{1/2}$=16 Myr) and the fission of ^{244}Pu and ^{238}U into ^{131,132,134,136}Xe ($T_{1/2}$=80 Myr and 4.47 Gyr, respectively). These properties allow mantle noble gas isotopes to be used as chronometers to reconstruct volatile reservoir isolation and long-term outgassing that formed the atmosphere. Although Kr and Xe provide valuable information about mantle processes, they are the least abundant noble gases and the most difficult to measure. These analytical difficulties are exacerbated by the protracted recycling of atmospheric Kr and Xe back into the mantle via subduction, which dampens isotopic differences between mantle and atmosphere. Previous studies have used different analytical techniques to detect mantle-derived Kr-Xe signals, yielding conflicting results and interpretations regarding Earth's geodynamical evolution. In this talk, I will show how recently developed noble gas analytical techniques for hydrothermal and volcanic gases using dynamic mass spectrometry (DMS) provide a robust means to address controversies regarding mantle heavy noble gas isotope systematics and geodynamical implications. I will focus on detection of primordial noble gas isotope signatures, the significance of the ^{129}Xe excess to ^{136}Xe excess ratio relative to atmosphere, and the quantification of mantle ^{244}Pu-derived Xe abundances in distinct mantle reservoirs. I will also showcase our improved ability to distinguish between different volatile sources and to monitor hydrothermal and volcanic activity. New DMS data provide insights into the composition and evolutionary history of distinct mantle reservoirs (subcontinental lithospheric mantle, convecting mantle, mantle wedges, and plume mantle sources), opening new avenues for reappraising the implications of heavy noble gases for the geodynamical evolution of Earth's interior. I will conclude this talk with the presentation of a unique DMS instrument, called PRIM'SIRIX, specifically designed to quantify noble gas isotope ratios in hydrothermal and volcanic gas emanations, which will be installed in Nancy in autumn 2026 (PRIMORDIAL - PEPR Origins).