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The Importance of Noble Gas Isotopic Composition for Understanding the Origins of the Ice Giants

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The 2023 Planetary Science Decadal Survey recommended a Uranus Orbiter and Probe as the top priority flagship for NASA and encourages collaboration with ESA in this mission. One of the primary science objectives of this mission would be to determine how this class of planets formed. The current composition, particularly the abundances and isotopes of noble gases, in the atmosphere of Uranus will provide information on how the planet formed, and on the origin of the solid building blocks that contributed to its formation.

Noble gas abundances and their isotope ratios are among the most valuable pieces of evidence for tracing the origin of the materials from which the giant planets formed. We will outline the current state of knowledge for heavy element abundances in the giant planets and explain what is currently understood about the reservoirs of icy building blocks that could have contributed to the formation of the Uranus. We then outline how noble gas isotope ratios have provided details on the original sources of noble gases in various materials throughout the solar system. We follow this with a discussion on how noble gases are trapped in ice and rock that later became the building blocks for the giant planets and how the heavy element abundances could have been locally enriched in the protosolar nebula. We then provide a review of the current state of knowledge of noble gas abundances and isotope ratios in various solar system reservoirs, and discuss measurements needed to understand the origin of Uranus. Finally, we outline how formation and interior evolution will influence the noble gas abundances and isotope ratios observed in Uranus today. The measurements required to understand the origin of Uranus can only be made by an atmospheric probe, and include (1) the $^{3}He/^{4}He$ isotope ratio to help constrain the protosolar D/H and $^{3}He/^{4}He$; (2) the $^{20}Ne/^{22}Ne$ and $^{21}Ne/^{22}Ne$ to separate primordial noble gas reservoirs similar to the approach used in studying meteorites; (3) the Kr/Ar and Xe/Ar to determine if the building blocks were Jupiter-like or similar to 67P/C-G and Chondrites; (4) the krypton isotope ratios for the first giant planet observations of these isotopes; and (5) the xenon isotopes for comparison with the wide range of values represented by solar system reservoirs.

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