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Applying Rosetta Noble Gas Abundances and Xenon Isotopes to Determine the Origin of the Building Blocks of the Ice Giants

Kathleen Mandt (1) and Olivier Mousis (2)
(1) Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, (2) Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France (Kathleen.Mandt@jhuapl.edu)

Abstract

The abundances of the heavy elements and isotopic ratios in the present atmospheres of the giant planets can be used to trace the composition of volatiles that were present in the icy solid material that contributed to their formation. The first definitive measurements of noble gas abundances and isotope ratios at comet 67P/Churyumov-Gerasimenko (67P/C-G) provide new constraints for the source of the Ice Giants building blocks. We outline the method for comparing comet observations with giant planet composition and determine what would be the current composition of the Ice Giant atmospheres based on four potential sources for their building blocks. The primary constraints for building block composition are the bulk abundance of carbon and the noble gases relative to nitrogen, Kr/Ar, Xe/Ar, and the xenon isotopes.

1. Introduction

During formation, each of the giant planets accreted a mixture of gas and solid material that contributed to the current composition of their atmospheres. Because of this, the abundances of the heavy elements and isotopic ratios in the present atmospheres of the giant planets can be used to trace the composition of volatiles that were present in the icy solid material that contributed to their formation. In particular, the abundances and isotopic ratios of carbon, nitrogen and the noble gases are valuable tools for understanding the origin and evolution of heavy elements in the gas giants.

1.1 Observations

Jupiter is the only giant planet where the noble gas abundances have been measured [1], observations that have been valuable for evaluating how Jupiter formed [e.g. 2] and will be necessary for understanding the formation of Saturn [3], and the Ice Giants [4]. The Ice Giants are of particular interest because they are the least explored class of planet in our solar system, and many questions remain about they formed.

Recent measurements in the coma of comet 67P/C-G provide important constraints for the composition of the icy material that contributed to the current composition of the atmospheres of the giant planets. Of particular interest are the noble gas abundances [5] and the xenon isotopes [6]. We found that the most appropriate methodology for applying the ROSINA noble gas abundance observations to determine the origin of the building blocks for the giant planets requires comparing the noble gas abundances with the abundance of nitrogen and then scaling to solar values as shown in Fig. 1 (from [7]). Furthermore, as illustrated in Fig. 2, the xenon isotopes in 67P/C-G are unique compared to other solar system sources [6] providing a valuable tracer for the origin of the Ice Giants' building blocks.

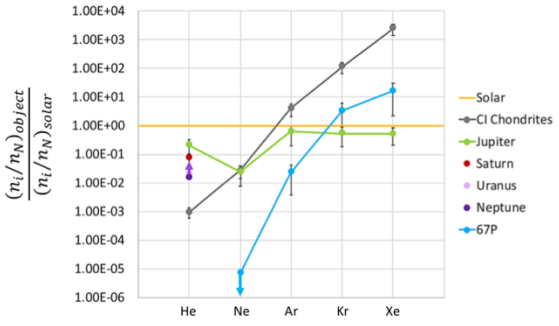

Figure 1: Noble gas abundances relative to bulk nitrogen abundances scaled to the solar values for the giant planets compared to observations in 67P/C-G and CI chondrites (see [7] for references). The ice giants' helium abundance relative to nitrogen is a lower limit because only an upper limit for the bulk nitrogen is available. The 67P/C-G neon abundance is an upper limit.

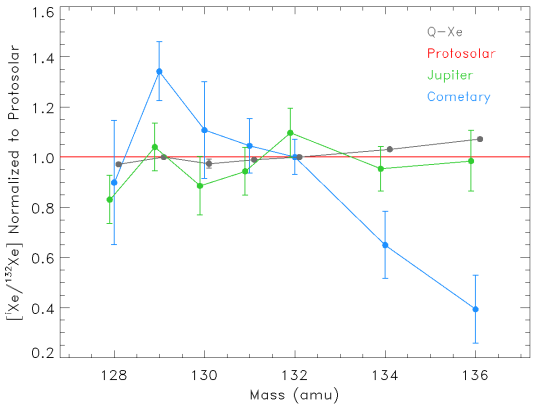

Figure 2: The abundance of each xenon isotope relative to ^{132}Xe and scaled to the solar abundance of each isotope, $(^{i}Xe/^{132}Xe)_{Observed}/(^{i}Xe/^{132}Xe)_{Solar}$ for Jupiter, 67P/C-G and the value representing chondritic xenon, designated as Q-Xe, based on the work of (see [7] and references therein).

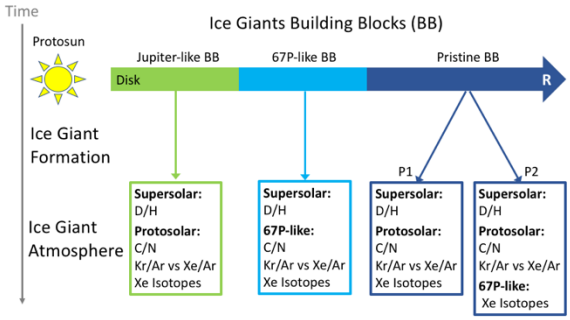

Figure 3: Four scenarios for the origin of the Ice Giants building blocks based on the composition of their current atmospheres. All of the building blocks would have a supersolar D/H from water ice enriched in D/H. Jupiter-like and the 1st category of pristine building blocks, P1, would have protosolar values for all other constraints. The 67P-like building blocks would be similar in all constraints to the observations made for 67-P/C-G. The second category of pristine building blocks, P2, would be protosolar in all constraints except for the xenon isotopes, which would be like those observed in 67P/C-G.

2. Connecting the Atmosphere to the Building Blocks

We have compared the bulk abundance of the noble gases in different solar system boides to nitrogen and find that this comparison is useful for understanding the icy building blocks of the giant planets. We use this and additional constraints of C/N, Kr/Ar, Xe/Ar and the xenon isotopes with the model in Fig. 3 to connect potential future observations in the atmospheres of the Ice Giants with the composition and origin of their building blocks. If the relative abundances of the noble gases Kr/Ar and Xe/Ar are protosolar, the building blocks for the Ice Giants are likely to have been pristine solar-composition ices from the prestellar cloud. If they are supersolar, like has been observed for 67P/C-G, the building blocks for the Ice Giants could have had a composition similar to the building blocks for 67P/C-G. This would mean that the Ice Giants would have formed in a similar region of the PSN as where 67P/C-G formed from reprocessed planetesimals. An important additional constraint is the relative abundances of the xenon isotopes. If the xenon isotopes in the atmospheres of the Ice Giants resemble the xenon isotopes of 67P/C-G, the building blocks of the Ice Giants were either similar to those of 67P/C-G or the pristine version of the 67P/C-G building blocks prior to reprocessing in the PSN.

Acknowledgements

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