THERMAL EVOLUTION OF URANUS WITH CONDENSATION OF ICE CONSTITUENTS IN THE ATMOSPHERE: IMPLICATIONS FOR THE N/O AND C/O RATIOS.

K. Kurosaki[1] and M. Ikoma[2], [1]Nagoya University (kurosaki.kenji.k0@a.mail.nagoya-u.ac.jp), [2]National Astronomy of Japan.

Introduction: The luminosity of Uranus is lower than that of Neptune, though their masses and radii are similar. As previous studies of the thermal evolution of the ice giants showed, Uranus's faintness cannot be explained by a simple three-layer model composed of a H/He-dominated envelope, an ice mantle, and a rocky core from top to bottom [1, 2]. Since the timescale of the thermal evolution is determined by the atmospheric structure, the evolution of the atmospheric structure and composition is important.

The interior structure of the ice giant remains uncertain. The gravitational moment observation implies that the envelope is polluted by heavy elements [3,4]. The difference in the interior structure implies the difference in thermal evolution. There are two kinds of ideas to explain the low luminosity of Uranus. One is the thermal boundary layer. The thermal boundary layer between H/He-rich and ice-rich shells prevents heat transport, and the planetary luminosity becomes small. The other is the gradual composition distribution, which also prevents heat transport. Those ideas are focused on the property of the interior structure.

On the other hand, the planetary luminosity should be controlled by the atmospheric structure. If the atmosphere contains ice constituents such as water, ammonia, and methane, those constituents are condensed and removed from the atmosphere [7,8]. Here we focused on the thermal evolution of the ice giants with significant amounts of ice constituents in the atmosphere.

Methods: In this study, we investigate the effect of the condensation of ice constituents in the atmosphere. We simulate the thermal evolution of Uranus based on the four-layer model with an ice-rich H/He atmosphere, a water-rich H/He envelope, a water mantle, and a rocky core from top to bottom, including the effect of the condensation of water, ammonia, and methane in the atmosphere.[5] We investigate the sensitivity of the evolution timescale to the initial mole fraction of ice constituents and the NH_3/H_2O and CH_4/H_2O ratios.

Results: We demonstrate the effect of the condensation makes the timescale of the thermal evolution shorter than that without the effect of the condensation. Moreover, the NH_3/H_2O and CH_4/H_2O values are also important. We find that the NH_3/H_2O value should be larger than the solar N/O value, while the CH_4/H_2O value should be smaller than the solar C/O value to explain Uranus's luminosity. Our conclusions suggest that the disk temperature at the Uranus-forming region would have been higher than the condensation temperature of CO but allows H_2O, NH_3, and CH_4 to condense into the solid phase.

Discussion: Our study suggests that Uranus is required to have the atmosphere with more than 50-mol % of condensable constituents immediately after the formation. To make such initial condition, we need to discuss the giant impact event that would have significant influence on its origin.

References:

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