Ortho-to-para ratio of water desorbed from ice and its implications for astronomy and planetary science

Tetsuya Hama* [1], **Akira Kouchi,* Naoki Watanabe**† [2],

* Institute of Low Temperature Science, Hokkaido University, Sapporo 060–0819, Japan

Synopsis The ortho-to-para ratio of water photodesorbed from ice at 10 K shows a statistical value of 3, and does not reflect the formation temperature of the ice.

Astronomical observations have recently revealed the ubiquity of H_2O in interstellar regions. Therefore, chemical history of interstellar H_2O provides better understanding the formation of stars and planetary systems, including our solar system.

A key observable is the abundance ratio of nuclear spin isomers (the ortho-to-para ratio, OPR). Because a proton is a fermion with a nuclear spin angular momentum of I = 1/2, nuclear spin isomers exist for H_2O, that is, ortho (I = 1, triplet) and para (I = 0, singlet) molecules. Nuclear-spin conversion between ortho- and para-molecules by radiation or nonreactive collisions is very slow in the gas phase. The different nuclear spin isomers are thus treated as almost entirely separate species. Moreover, the OPR can be related to the spin temperature (T_{spin}) defined at thermodynamic equilibrium. Therefore, the OPR has been often considered as a valuable tracer for the physical and chemical history experienced by H_2O molecules, including their formation temperature on cosmic dust.

Cometary comae, and star- and planet-forming regions have of OPRs for gaseous H_2O (0.1–2.4), which are anomalously lower than the statistical value of 3. The OPR of H_2O in a comet has been proposed as an indicator that gives the past formation temperature (30 K) of the ice nucleus in the solar nebula some 4.6 billion years ago. The low OPR of interstellar H_2O has also been used to determine the formation temperature (<50 K) of water ice on cold interstellar dust. However, the use of the OPR as a temperature probe requires the assumption that the OPR of H_2O desorbed from ice is related to the ice temperature, which has not been validated, indeed. Thus, the significance of the OPR of water is still unknown and remains one of the most problematic issues in astronomy and planetary science.

The present study performed direct measurements of the OPR forwater molecules desorbed after 157 nm photoexcitation of water ice at 10 K, using resonance-enhanced multiphoton ionization (REMPI) detection methods. We found that the OPR of photodesorbed water showed the statistical value of 3, even when the ice is produced in situ by hydrogenation of O_2, a known formation process of interstellar water. Our results indicate that the OPR does not reflect the formation temperature of the ice (10 K, OPR = 0.3), which invalidates the assumed relation between OPR and temperature. Our results indicate that reinterpretation of previous observations is necessary for improving our understanding of interstellar chemistry, as well as the formation of the solar system and comets [1].

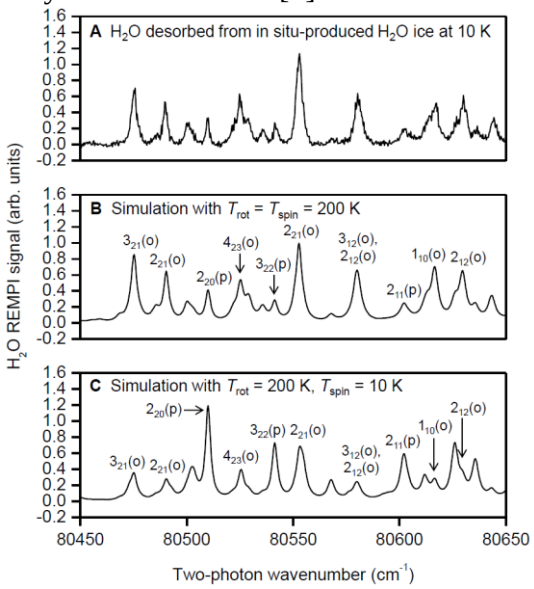

Figure 1. REMPI spectra of photodesorbed H_2O after 157 nm photoirradiation of water ice at 10 K. (A) H_2O ice produced in situ by means of hydrogenation of O_2. (B and C) Simulated spectra with T_{rot} =200 K and (B) T_{spin} =200 K and (C) T_{spin} = 10 K. Indications ($J_{Ka,Kc}$) are rotational assignments, where "o" and "p" denote ortho and para, respectively.

References

[1] T. Hama *et al.* 2016 *Science* ***351***, 65

[1] E-mail: hama@lowtem.hokudai.ac.jp

[2] E-mail: watanabe@lowtem.hokudai.ac.jp