【Grant-in-Aid for Scientific Research (S)】

Search for snow-lines with high-resolution spectroscopic observations in the mid-infrared

Principal Investigator	Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science, Full-time Professor NAKAGAWA Takao　　Researcher Number:20202210
Project Information	Project Number : 23H05441　　Project Period (FY) : 2023-2027 Keywords : protoplanetary disk, rocky planets, gas giants, immersion grating

Purpose and Background of the Research

●Outline of the Research

The key factor separating rocky and gas planets has been proposed to be the "snow-line", which is the boundary between H_2O gas and solids (Fig. 1). However, no direct observations of it have been done yet. The ultimate goal of this research is to identify the existence of snow-lines observationally by high-resolution spectroscopy of mid-infrared H_2O spectral lines from space. Toward this goal, we will first conduct (1) "technology development." To reduce the size of the spectrometer for space applications, we will work on the "immersion grating" technology, which is essential to reduce the size of the spectrometers. With this new grating technology, we will prototype a high-resolution spectrometer ($R = \lambda/\Delta\lambda \sim 30{,}000$). We will then conduct (2) "test observations" of H_2O spectral lines from protoplanetary disks using ground-based telescopes. Although it is difficult to directly detect the snow-lines by ground-based observations, the validity of the theoretical model can be verified by observing high-temperature H_2O gas, which is closely related to the snow-lines.

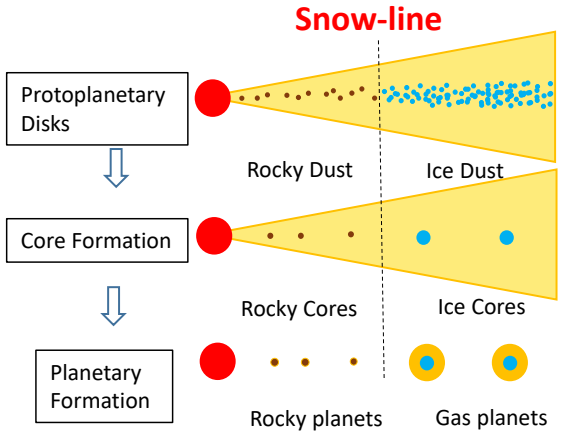

Figure 1: Conceptual view of the evolution of protoplanetary disks. It has been proposed that the "snow-line", the boundary between gas and ice H_2O, characterizes the place of formation of rocky and gas planets.

●The academic "question" at the core of this study: Does the snow-line exist?

It is well known that planets consist of two types: "rocky planets" like Earth and "gas planets" like Jupiter. It has been proposed that rocky planets are formed in the "gas" region of H_2O and gas planets are formed in the "ice" region, and the boundaries between the two regions are considered to be the "snow-lines" (Fig. 1).
However, there have been no direct observations of the snow-line yet, and its existence and position remain theoretical hypotheses. Therefore, the core "question" of this research project is to observationally identify if the snow-line really exists as expected.

Expected Research Achievements

●Uniqueness of this research: Infrared high-resolution spectroscopy

It is challenging to spatially resolve the snow-lines in protoplanetary disks with current technology. Therefore, in this study, we aim to identify the snow-line based on Kepler motion of gas by infrared high-resolution spectroscopy. Figure 2 shows that the H_2O gas decreases sharply around 2 au (depending on the type of the host stars), which corresponds to the snow-line. As in Figure 2 (lower right), we plan to observe weak H_2O spectral lines so that we can see into the protoplanetary disk. We expect to observe double-peak spectral line profiles, which correspond to the snow-line [1][2]. High-resolution spectroscopy of $\Delta v \sim 10$ km/s ($R \sim 30{,}000$) is expected to enable the identification of the snow-lines.

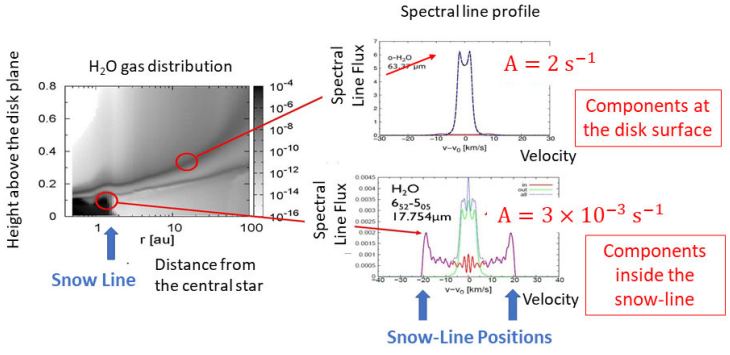

Figure 2: H_2O gas distribution in protoplanetary disks (left). The decrease of gas near 2 au corresponds to the "snow-line." Bright spectral lines (upper right) trace only the surface of the disk, while faint spectral lines (lower right) can see inside the disk and identify the snow-line [1][2].

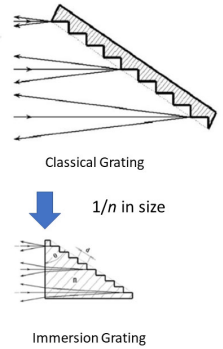

Figure 3: Compared with (top) the classical grating, (bottom) the immersion grating is expected to be much smaller.

●Research Plan

The spectral lines suitable for the snow-line detection cannot be observed from the ground, and high-resolution spectroscopic observations from space are required. In this research, we will proceed step by step toward the realization of snow-line observations from space in the future.

1. We will develop spectroscopic technology that enables high-resolution spectroscopy from space. Observations from space, very limited in weight and volume, require the significant reduction of the size of the spectrometer. Hence, in this research, we will develop the technology "immersion grating" in the mid-infrared. Immersion grating (Fig. 3 bottom) is a technology that uses a medium with a high refractive index n to reduce the grating size to $1/n$ compared to classical one (Fig. 3 top).
2. We will prototype a spectrometer using the above technology and conduct test observations of the H_2O spectral lines of protoplanetary disks from the ground as a part of the performance evaluation test. Although it is difficult to trace the snow-line directly from the ground, we aim to detect the high-temperature H_2O gas, which is closely related to the snow-line.

Through these efforts, we aim to realize (1) technological development and (2) scientific test observations as critical steps toward the final goal to achieve direct observations of snow-lines from space in the future.

●References

[1] Notsu, S., Nomura, H. et al., 2016, ApJ, 827, 113
[2] Notsu, S., Nomura, H. et al., 2017, ApJ, 836, 118

Homepage Address	https://www.ir.isas.jaxa.jp/~nakagawa/research/kiban-S_E.html