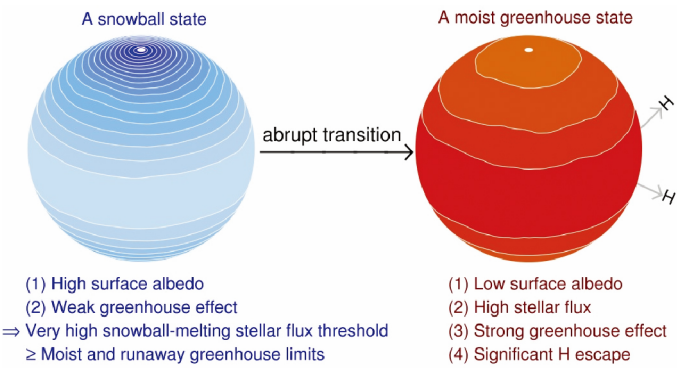
Icy planets and moons bypassing the habitable state

Profs. Yang Jun (**杨军**) and Hu Yongyun (**胡永云**) at the Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, and their collaborators recently published a paper in *Nature Geoscience* (http://www.nature.com/ngeo/journal/v10/n8/pdf/ngeo2994.pdf). They show that icy planets and moons shall bypass the habitable stage and jump from the icy state to the runaway greenhouse state. This result is fundamentally important for searching for habitable exoplanets.

Liquid water is the most important condition for life. Thus, a planet's habitability greatly depends on whether its surface temperature allows the existence of permanent liquid water. In our own solar system, Venus is too hot (about 500℃) to be habitable, Mars is too cold (−60℃), while Earth's surface temperature (15℃) is just right. Forouter solid planets/satellites, such as Mars, Pluto, Jupiter's moon—Europa and Saturn's moon—Enceladus, water is all frozen due to low surface temperatures.

According to the standard theory of star evolution, stars become brighter and brighter with time, due to stronger and stronger nuclear fusion. Therefore, the traditional view is that icy planets/moons shall receive more radiation energy as time progresses, their surface ice would eventually start melting, and that these icy worlds would become habitable. With theoretical analysis and numerical simulations, Yang *et al*. demonstrated that icy planets/moons would directly transit to the moist greenhouse or the runaway greenhouse states, as illustrated by the figure below. In both states, planetary surface temperatures are above the boiling point (100℃), and all water evaporates to the atmosphere and escapes to the space. Thus, these planets will become uninhabitable. This study greatly changes the traditional view on the climate and habitability evolution of icy planets and moons.



Yang *et al*. pointed out that the mechanisms leading to such an abrupt climate transition are ice albedo feedback and water vapor feedback. Melting ice requires very high stellar radiation because ice has very high albedo. As stellar radiation is sufficiently strong to melt the icy worlds, surface albedo suddenly becomes very low, so that more stellar radiation is absorbed by these planets, causing surface temperature to increase rapidly. Moreover, a large amount of water vapor gets into the atmosphere after ice melting. The greenhouse effect of water vapor and its feedback further warm planets and lead to runaway greenhouse state.

Prof. Ingersoll at the California Institute of Technology, a world-wide leading planetary scientist, was invited by *Nature Geoscience* to write News and Views. He commented "…making an icy planet habitable is not as simple as melting its ice; many icy bodies swing from too cold to too hot, bypassing just right." (https://www.nature.com/ngeo/journal/vaop/ncurrent/pdf/ngeo2996.pdf). The paper was also highlighted by *Nature* magazine (https://www.nature.com/articles/d41586-017-02003-9).

Prof. Yang and Hu are both supported by the National Natural Science Foundation of China.