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Numerical Study of Multi-Component Hydrodynamic Escape: Application to the Fractionation of Noble Gases on Venus

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Hydrodynamic escape is one of a few mechanisms that can change the composition of a planetary atmosphere irreversibly. So far, several numerical models have been developed to solve the hydrodynamic escape problem. Previous models, however, is unsatisfactory to apply actual atmospheric evolution quantitatively because they cannot solve transonic solutions or multi component solutions. Here we present the first study on the multi-component time-dependent hydrodynamic equations for transonic neutral gas escape from planetary atmospheres.

The numerical model is the one-dimensional time-dependent non-viscous Euler equations with thermal conduction in spherical geometry. The effects of collisions with other species are included in the momentum equation to solve the multicomponent hydrodynamic escape. We develop the numerical code of hydrodynamic escape using CIP method, which is well suited to solve the transonic flow. A two-dimensional energy deposition calculation method is adapted to provide an accurate approximation of the complicated radiative transfer processes in an extended spherical atmosphere. We also use the power-law fits of solar fluxes against solar age to estimate the energy deposition by solar EUV heating in numerical calculations; the emission of the younger Sun in all wavelength intervals is orders of magnitude larger than the current solar flux.

In this study, we apply the developed numerical model to the escape of hypothetical early Venusian atmosphere to consider the fractionation of noble gases on Venus. Venus may have lost some Ne, since it is enriched about 10% in ^{22}Ne/^{20}Ne with respect to solar abundances. On the other hand, Venus appears to have lost no Ar, as indicated by near solar ^{36}Ar/^{84}Kr and ^{38}Ar/^{36}Ar ratios. The fractionation of Ne and Ar, would not be explained simply by mass-dependent hydrodynamic escape of primordial Venusian atmosphere. So, we consider the CO rotational cooling to realize the fine tuning of hydrogen escape flux, which make Ne escape and Ar unescape. We apply the numerical code with CO cooling to examine the possibility of Ne/Ar fractionation on Venus atmosphere.

When carbon monoxide is the same amount as hydrogen at the homopause in the early Venusian atmosphere, the Ne/Ar fractionation by hydrodynamic escape with CO cooling efficiently occurs. However, even in this case, quantitatively appropriate Ne/Ar fractionation cannot be achieved by hydrogen hydrodynamic escape. The results indicates that the present Venus' Ne/Ar abundance ratio cannot be explained by hydrodynamic escape of early Venusian atmosphere with solar-composition. Other possibilities of achieving noble gas patterns of present Venusian atmosphere are also discussed.