Accumulation of Primordial Atmospheres: Effects of Enrichment in Heavy Elements

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I have simulated structure of protoplanetary atmospheres. The atmosphere considered in this work originates basically from a circumstellar disk. Subjects of particular interest are the formation of the envelopes of giant planets and the primordial atmospheres of terrestrial planets.

Planets are formed in the circumstellar disk. The disk is the remnant of star formation and is composed of hydrogen, helium, and a small amount of dust. Solid protoplanets grow through accumulation of planetesimals, which are aggregates of dust particles. Once the protoplanet becomes larger than a few percent of Earth mass, it attracts the surrounding disk-gas gravitationally to form an atmosphere. If the mass of the solid part of the protoplanet reaches a critical mass, considerable contraction of the atmosphere and inflow of a large amount of the disk gas happen, resulting in the giant planet formation.

The focus of this work is on effects of enrichment in heavy elements such as oxygen and carbon. Almost all of the workers assumed that the atmospheric composition was similar to that of the disk gas, that is, the atmosphere consisted of hydrogen and helium. However, the atmospheres would probably be rich in heavy elements. Because of ablation and evaporation, planetesimals deposit part of their mass in the atmosphere, before reaching the solid surface of the protoplanet. Even if planetesimals reach the solid surface, the volatile components such as water and carbon dioxide are added to the atmosphere through impact degassing. Furthermore, Fe-bearing silicate melt (i.e., magma ocean) probably oxides the hydrogen-rich atmosphere.

In this work, I have considered hydrogen, helium, oxygen, carbon, and their compounds as the constituents of the atmosphere and performed chemical-equilibrium calculations among them. Using the equation of state obtained from the calculations, I have simulated the structure of the atmospheres and calculated the atmospheric masses for different mixtures. I have found that the atmospheric mass increases with increasing amount of heavy elements. This means that the critical mass is small for a protoplanet with a heavy-element-rich atmosphere. Based on this result, I will discuss the formation and current compositions of giant planets. Furthermore, considering mixing the solar-type component with the degassed component, I will also discuss the possibility of existence of the solar-type component in the ancient Earth's atmosphere and the environment in which the Earth was formed.