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Collisional growth and the evolution of the internal structure of Archean organic haze particles

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The faint young sun paradox has been discussed for almost four decades. While many theories have been suggested regarding temperatures high enough for primitive life and the existence of liquid water despite the lower luminosity of the Sun during the Archean age, the effect of greenhouse gasses such as CH_4 and NH_3 has especially been paid close attention. In order to ascertain how much contribution the greenhouse gasses made to the warming of the early Earth, a more detailed understanding of the properties of the haze on the Archean Earth, such as its shielding and cooling effects, is essential.

The Archean haze is believed to have been similar to that on Titan. The haze is composed of fractal particles, i.e., fluffy aggregates of monomers. Although monomers collide with each other as they fall and grow as large fractal aggregates, this fractal structure had been ignored and a simplified compact aggregate model has been used in the literature. More recently, Wolf and Toon (2010) conducted simulations considering the fractal structure of the aggregates, but they did not consider compression of the particles accurately. Their assumption of compression is based on the experiment conducted by Onischuk (2003), which is considered to be inappropriate to apply to the haze on the Archean Earth.

Our research is aimed at assessing the properties of organic haze on the Archean Earth based on particle dynamics. We calculate collisional growth and compression of haze particles properly taking into account the physics of collisional and static compression. The result reflects the internal structural change of particles as they fall through the atmosphere after they are formed at higher altitudes.

We find that neither static compression nor collisional compression occur, thus the particles fall with its fractal structure maintained. Simulations based on this assumption show that the haze on the Archean Earth were optically thicker in the UV than the results by Wolf and Toon (2010). Thus, the Archean haze may have had a stronger UV shielding effect than previously expected. Also, the simulations showed that the difference in the internal structure of particles affects the haze mass distribution at each altitude. In the Archean organic haze, the haze is optically thin around the altitude where it is formed, and optically thick haze concentrates below the formation layer.

In conclusion, effective UV shielding by the haze likely protected organics from photolysis and may have helped keep the atmosphere from reducing, which are both favorable for primitive life. The difference in altitude between the haze formation layer and the haze residence layer could be the key to sustainable production of haze on early Earth. Although there remain further questions to affirm that CH_4 or NH_3 provided effective warming effect on the early Earth, our result, combined with the result of Wolf and Toon (2010), supports the argument for greenhouse gasses as the key solution to the faint young sun paradox.

Keywords: the early Earth, haze, fractal particle, the faint young Sun paradox, the internal structure change, the Archean