Contribution ID: **7** Type: **not specified**

XFEL-induced iron-volatile reactions and its implication on the formation of reduced atmosphere in the early Earth

Wednesday, August 16, 2023 2:45 PM (30 minutes)

The giant impact-driven redox processes in the atmosphere and magma ocean played a crucial role in the evolution of the early Earth. However, due to the absence of rock records from that time, understanding these processes have proven challenging. Here, we present experimental results that simulate the reaction between iron and volatile components (H2O and CO2) under giant impact conditions using high-brilliance X-ray free electron laser (XFEL) as a fast heat pump and structural probe. Our results show that under XFEL pump on a compressed mixture of iron and volatiles, iron is oxidized to wüstite (FeO), while the volatiles are reduced to H2 and CO. Furthermore, iron oxidation proceeds into the formation of hydrides (γ-FeHx) and siderite (FeCO3), with an indication of a possible redox boundary near 300 km depth. Through quantitative analysis of the reaction products, we estimate theoretical constraints on the mass of the impactor and its heliocentric origin, as well as the volatile and FeO budgets in the bulk silicate Earth, supporting the Theia hypothesis. Our findings shed light on the fast and short-lived process that led to a reduced atmosphere, which is required for the emergence of prebiotic organic molecules.

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Session Classification: Plenary session