Scientists Clarify the Origins of Lunar Metallic Iron

Metallic iron nanoparticles ($npFe^0$) are widespread on the Moon, and their accumulation changes the optical spectra of the lunar surface over time. How the surface color changes largely depends on the size of $npFe^0$: smaller $npFe^0$ reddens the reflectance spectra, while larger $npFe^0$ causes darkening. The resultant color variations greatly complicate remote sensing studies, posing long-term puzzles to astronomers. However, the origins of $npFe^0$ of different sizes have remained elusive.

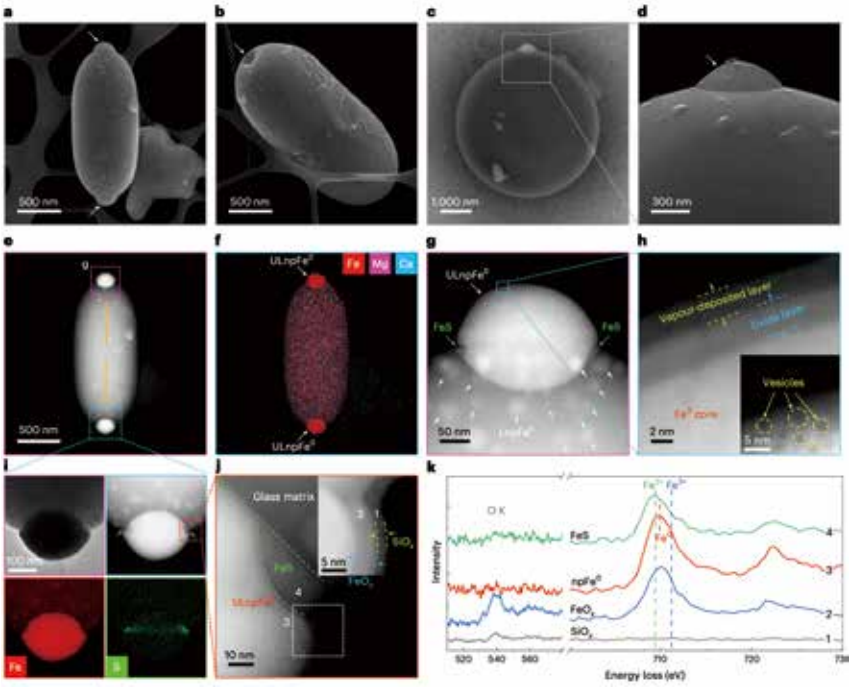
The $npFe^0$ are known as products of space weathering mainly via the two agents: micrometeorite impacts and solar wind irradiation. Yet, the specific roles of these two agents in the formation of different-sized $npFe^0$ have been unclear, hindering our understanding of color variations of lunar surface or asteroids under complex space environments.

Recently, Associate Prof. SHEN Laiquan, Prof. BAI Haiyang, *et al*. from Prof. WANG Weihua's group at the Institute of Physics (IOP), Chinese Academy of Sciences (CAS) clarified the respective effects of irradiation and micrometeorite impacts on $npFe^0$ formation. On the basis of precise observations of glass beads returned by the *Chang'e-5* mission, they revealed that the formation of small and large $npFe^0$ with distinct optical effects is independently governed by solar wind irradiation and micrometeorite impacts.

"We discovered that the glass beads in lunar soil samples returned by *Chang'e-5* can preserve iron particles of varying sizes, from about 1 nanometer to 1 micrometer," said Prof. BAI. "It is generally difficult to distinguish $npFe^0$ of different origins observed together in single samples. Here, leveraging the rotation feature of impact glass beads, we clearly distinguished $npFe^0$ formed before and after the solidification of the host glass beads."

In this study, the scientists found numerous discrete large $npFe^0$, tens of nanometers in size, tending to concentrate towards the extremities of the glass beads. This concentration effect can result in ultra-large $npFe^0$ protruding out from the extremities. Such feature is exactly consistent with the migration phenomenon occurring in rotational glass-forming droplets triggered by hypervelocity impacts. In such scenarios, Fe^0 with higher density than the matrix, migrate to the extremities driven by centrifugal forces, indicating that these large $npFe^0$ formed in the impact-derived melts before the glass beads solidified.

In contrast, they also identified abundant small $npFe^0$, several nanometers in size, densely populating the surfaces of the glass beads. These small $npFe^0$ exhibit similar distribution features to the irradiation-induced vesicle damages. Along the depth direction of the glass beads, both small $npFe^0$



Graphic: IOP

Characterizations of ultralarge $npFe^0$ on extremities of impact glass beads.

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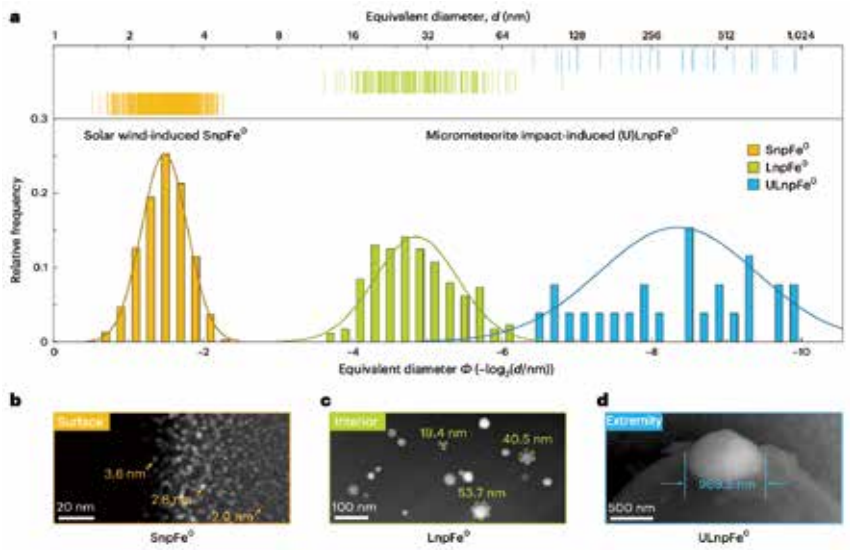

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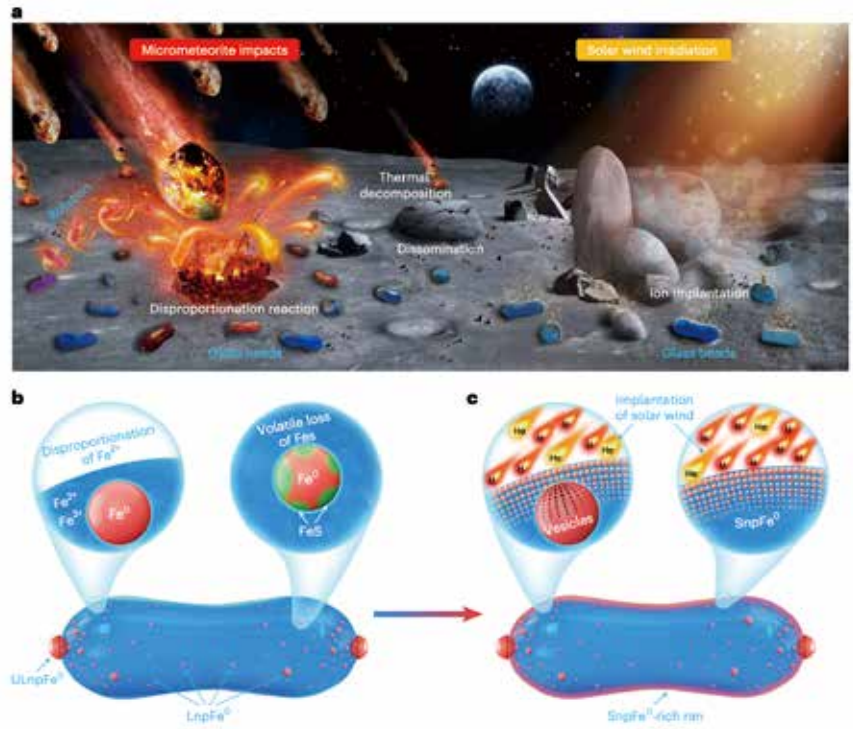
Size distributions of the three different types of $npFe^0$.



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Schematic of space weathering on the Moon and corresponding origins of $npFe^0$.

and vesicles gradually decrease in size and abundance, corresponding to the decreasing amount of implanted solar wind ions with depth. Additionally, when the sizes of the lunar grains are comparable to twice the penetration depth of solar wind ions, small $npFe^0$ can completely fill up the tiny grains. These findings highlight that solar wind irradiation is the primary driver for the formation of the observed small $npFe^0$.

The study demonstrates that solar wind irradiation and micrometeorite impacts both play crucial yet distinct roles in $npFe^0$ formation. The revealed independent growth of small and large $npFe^0$ matches well with many remote sensing measurements, providing valuable insights for understanding and predicting the optical properties of airless bodies exposed to different space environments.

This study entitled "Separate effects of irradiation and impacts on lunar metallic iron formation observed in *Chang'e-5* samples" was published online in *Nature Astronomy* on June 20.

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