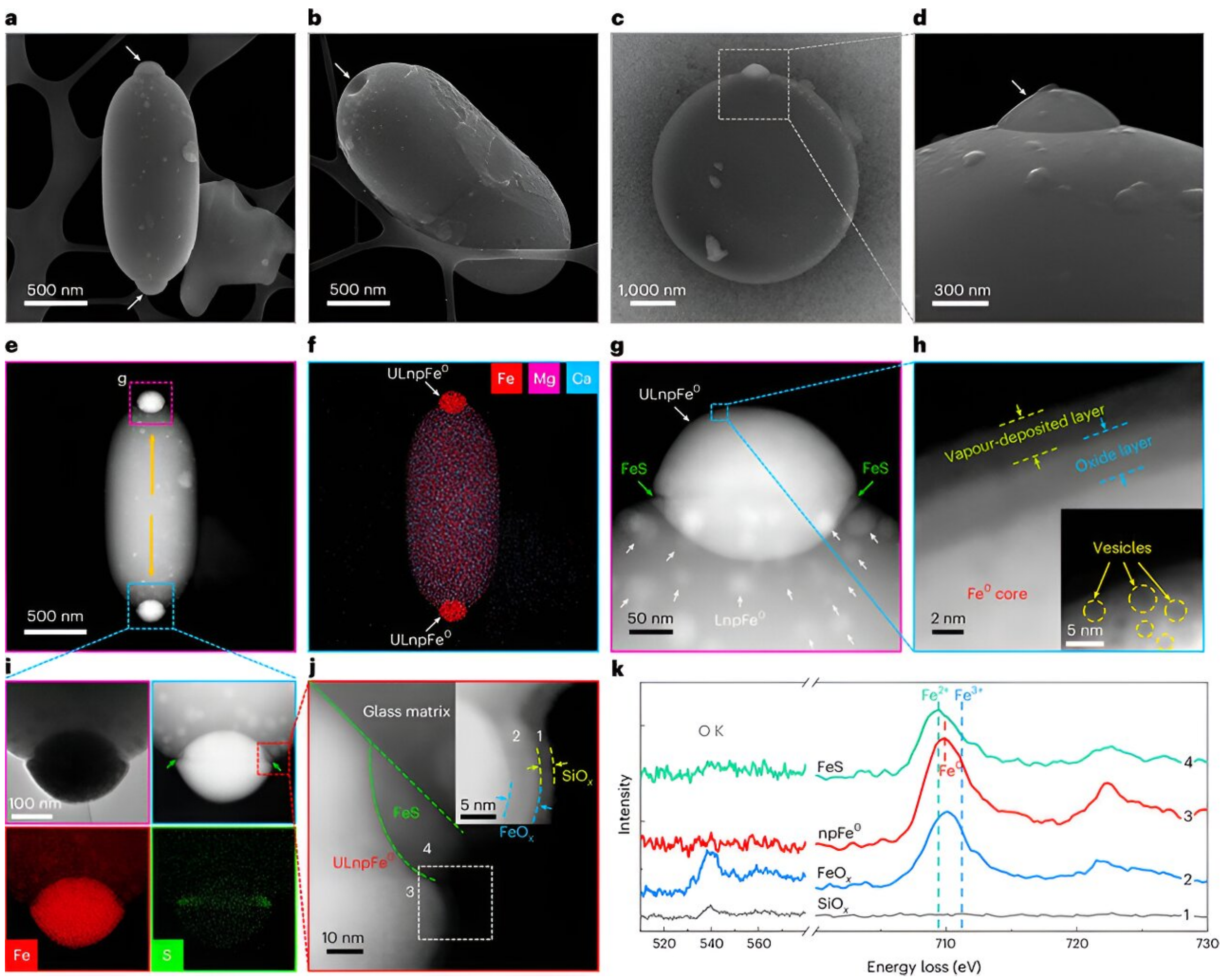
Scientists clarify origins of lunar metallic iron

June 28 2024, by Zhang Nannan



Characterizations of $ULnpFe^0$ on extremities of impact glass beads. Credit: Institute of Physics

In a study published in *Nature Astronomy*, Profs. Shen Laiquan, Bai Haiyang, et al. from Prof. Wang Weihua's group at the Institute of Physics of the Chinese Academy of Sciences have clarified the respective effects of irradiation and impacts on the formation of metallic iron nanoparticles ($npFe^0$).

Based on precise observations of glass beads returned by the Chang'e-5 mission, they showed that the formation of small and large $npFe^0$ with distinct optical effects is independently controlled by solar wind irradiation and micrometeorite impacts.

$npFe^0$ are widely distributed on the moon, and their accumulation changes the optical spectrum of the lunar surface over time. How the surface color changes depends largely on the size of the $npFe^0$: Smaller $npFe^0$ redden the reflectance spectra, while larger $npFe^0$ cause darkening.

The resultant color variations greatly complicate remote sensing studies, posing long-term puzzles to astronomers. Furthermore, the origin of $npFe^0$ of different sizes was not well understood before this study.

$npFe^0$ are known as products of space weathering, which includes the two main 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 the lunar surface or asteroids in complex space environments.

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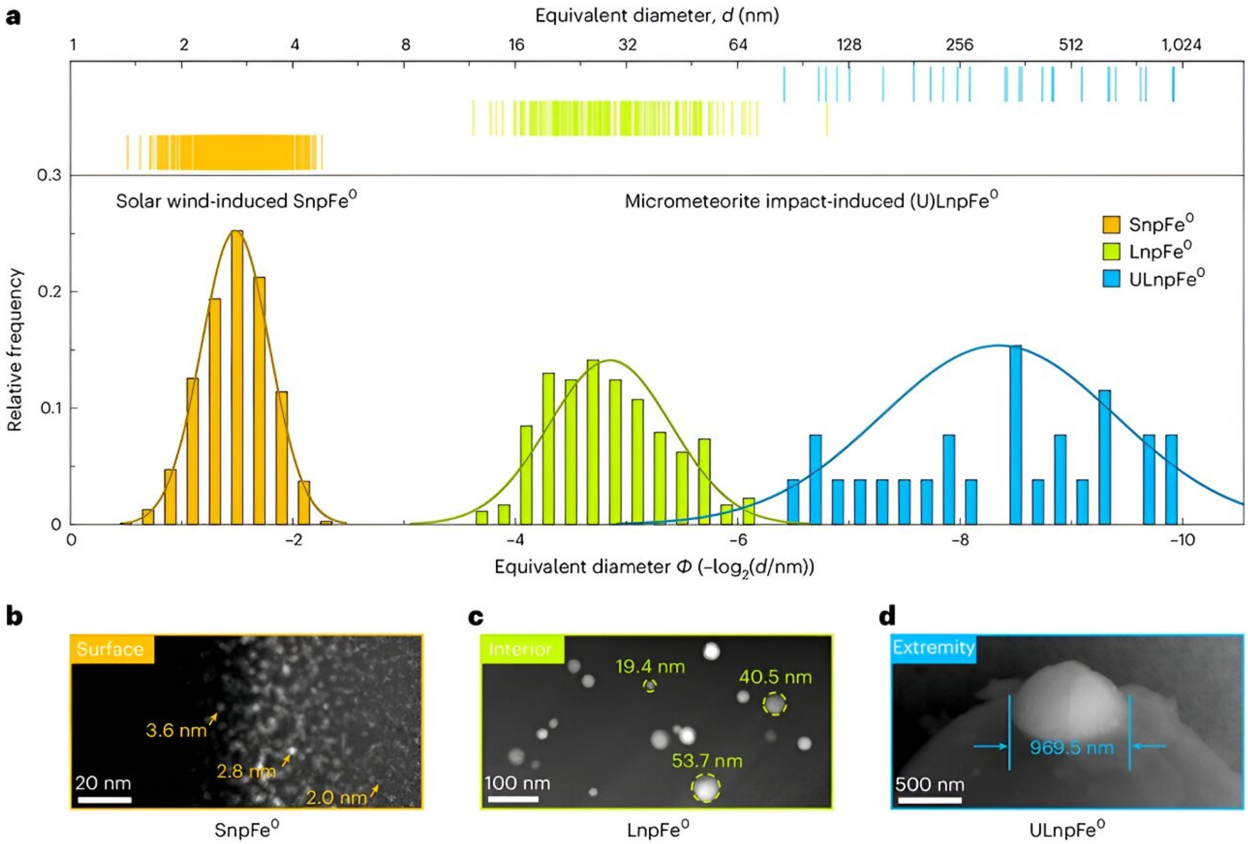


Size distributions of the three different types of $npFe^0$. Credit: Institute of Physics

"We discovered that the glass beads in the Chang'e-5 lunar soil can preserve iron particles of different 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 we used the rotation feature of the impact glass beads to clearly distinguish $npFe^0$ formed before and after the solidification of the host glass beads."

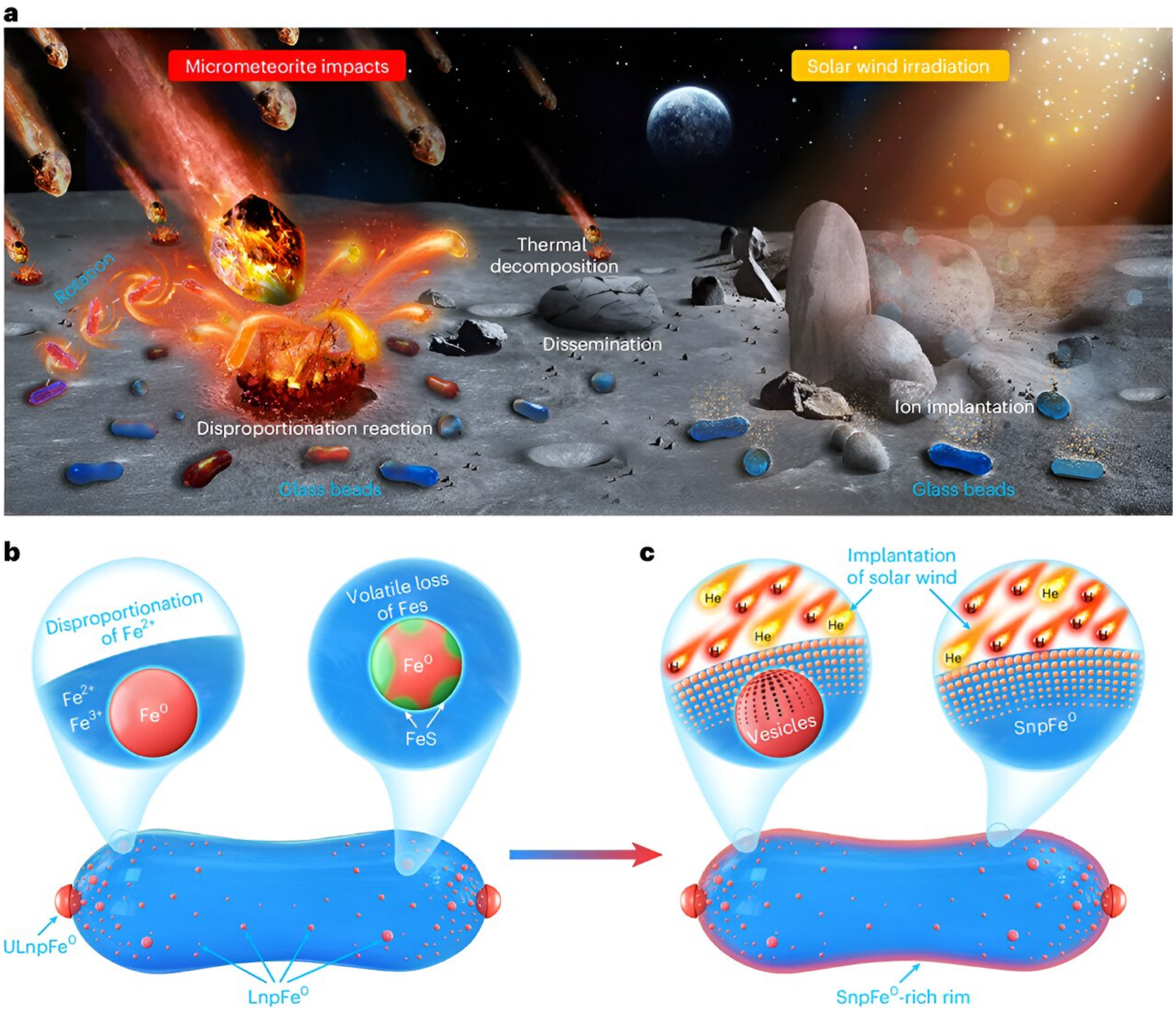
In this study, the scientists found numerous discrete large $npFe^0$, tens of nanometers in size, which tended to concentrate towards the extremities of the glass beads. This concentration effect can cause ultralarge $npFe^0$ to protrude from the extremities.

Such a feature is exactly consistent with the migration phenomenon occurring in rotational glass-forming droplets triggered by hypervelocity impacts. In such scenarios, Fe0 with higher density than the matrix migrates to the extremities driven by centrifugal forces, indicating that these large $npFe^0$ were formed in 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 distribution characteristics similar to irradiation-induced vesicle damage.

Along the depth direction of the glass beads, both small $npFe^0$ and vesicles gradually decrease in size and abundance, corresponding to the decreasing amount of implanted solar wind ions with increasing depth.

Furthermore, when the size of the lunar grains is smaller than twice the penetration depth of the solar wind ions, small $npFe^0$ can completely fill up the tiny grains. These results emphasize that solar wind irradiation is the primary driver of the observed small $npFe^0$.



Schematic of space weathering on the Moon and corresponding origins of npFe^{0}. Credit: Institute of Physics

The study demonstrates that solar wind irradiation and micrometeorite impacts both play important but distinct roles in npFe^{0} formation. The independent growth of small and large npFe^{0} revealed in this research 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.

More information: Laiquan Shen et al, Separate effects of irradiation and impacts on lunar metallic iron formation observed in Chang'e-5 samples, *Nature Astronomy* (2024). DOI: 10.1038/s41550-024-02300-0

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