MIP: PARADIM at Cornell University, DMR-1539918
In-House Project - 2021

Cryo-STEM Unveils Electronic Order on the Atomic Scale

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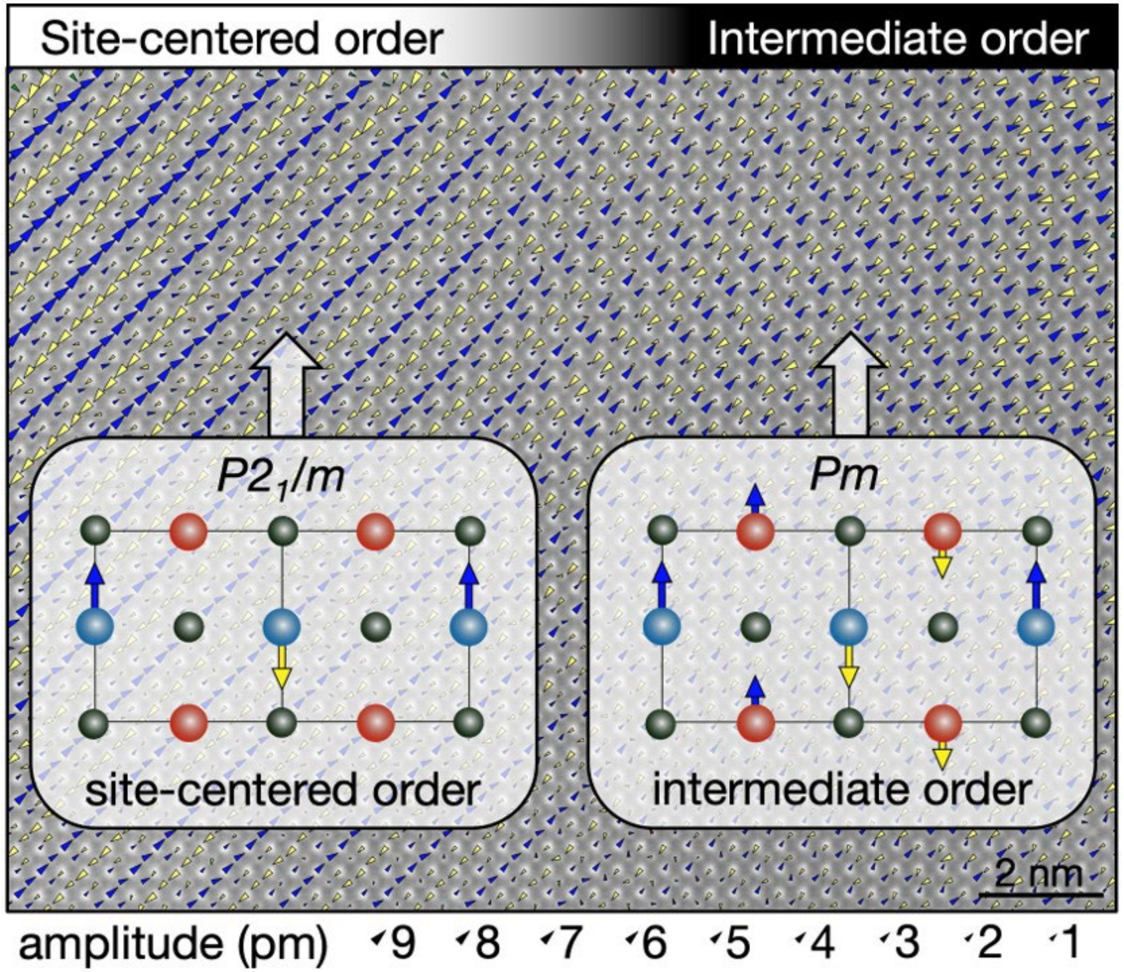
In quantum materials, electrons can interact strongly with each other and with the atomic lattice, giving rise to novel electronic states with functionalities not achievable in conventional materials. At the atomic scale, the local crystal symmetries are governed by variations in the charge distribution and subtle atomic displacements, dramatically affecting the material's properties.

Here, **members of PARADIM's in-house research team demonstrate the capabilities of cryogenic scanning transmission electron microscopy (cryo-STEM)**. When pushed to sub-Angstrom resolution and picometer precision, cryo-STEM provides a unique path to answering fundamental questions about the microscopic arrangement within charge-ordered states. Using a half-doped manganite as a model system, they achieve a direct, atomic-scale visualization of the prototypical site-centered charge order, a model proposed over 60 years ago. They also discover an exotic intermediate charge-ordered state that breaks inversion symmetry and coexists at the nanoscale within the same material. Combining cryo-STEM to visualize lattice order with crystal symmetry analysis and density functional theory calculations, reveals a nonlinear coupling mechanism behind the formation of distinct ordered states providing a potential path to controlling electronic phases in these materials. More broadly, the results demonstrate that cryo-STEM is a powerful technique for understanding low temperature phenomena in quantum materials at the atomic scale.



I. El Baggari *et al.* [Nat. Commun. **12**, 3747 (2021)].