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Coherent soft x-ray imaging: Uncovering emergent physics with unprecedented spatial and temporal resolution

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Nanometer-scale textures, such as stripe domains and magnetic skyrmions, are ubiquitous in materials in which interactions compete at different length scales. Remarkably, such textures can exist even in a perfectly homogeneous underlying material. Since their energy is translationally invariant, they can move within the hosting material. It is of great fundamental and applied interest to image the emergent dynamics of such textures.

However, the grand challenge in such studies is that they require exceptional spatial and temporal resolution, often beyond the reach of established imaging techniques. Here, I will highlight several scenarios in which holographically-aided coherent x-ray imaging has allowed us to uncover previously inaccessible physics of emergent spin textures at the nanometer scale.

The first example is static magnetic imaging with deep sub-10 nm spatial resolution. Reaching this resolution presents a change of paradigm in x-ray magnetic imaging because it allows to resolve domain walls and not just domains. Thanks to this, we make some highly surprising discoveries in a supposedly well-explored Pt/Co-type material, including the emergence of 3D spin textures near pinning sites.[1]

In my second example I will demonstrate that coherent x-ray magnetic imaging can also be performed with x-ray magnetic linear dichroism contrast, which allows to directly capture the chirality of domain walls and which is also suitable for imaging of antiferromagnetic materials. At beamline BOREAS at ALBA, this technique has allowed us to directly image Bloch line defects in skyrmions in bulk DMI DyCo films.[2]

Finally, I will show that coherence also allows to massively enhance the temporal resolution. The example I will show is the direct imaging of thermal fluctuations between highly degenerate magnetic stripe domain states. Such fluctuations are very common in nature, especially in disordered or imperfectly ordered systems at the nanometer scale. Yet, they are notoriously difficult to access by direct imaging because pump-probe techniques cannot be employed. The challenge can be traced back to seemingly a fundamental dilemma between temporal and spatial resolution. I will show that coherent imaging can overcome this dilemma, by allowing to identify the underlying state of a scattering pattern at much lower photon count as required for the reconstruction of a real-space image. This approach, which we coin Coherent Correlation Imaging, allows us to uncover an intricate network of more than 30 recurring magnetic states and dynamics that is governed by a surprising interplay of attractive and repulsive pinning.[3]

I will conclude with a wish list for new high coherence sources such as ALBA-II.

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