Lensless coherent imaging of nanoscale magnetic domains in 2D van-der-Waals materials

J. Llobet[1,8], D. Pérez-Salinas[1], J. Pérez-Grau[2], D. Elvira[2], X. Borrisé[3], R. Saha[4], N. Schammelt[4], P. Gargiani[1], F. Büttner[5], R. Battistelli[5], A. Johnson[6], S. Wall[7], H. L. Meyerheim[4], Stuart S. P. Parkin[4], F. Pérez-Murano[8], E. Navarro-Moratalla[2], M. Valvidares[1]

1- ALBA Synchrotron Light Source, 08290 Cerdanyola del Vallès, Catalonia, Spain
2- University of Valencia, Molecular Science Institute (ICMOL), 46980 Paterna, Valencia, Spain
3- Catalan Institute of Nanoscience and Nanotech. (ICN2) & BIST, 08193 Bellatera, Catalonia Spain
4- Max Planck Institute for Microstructure Physics, D-06120 Halle (Saale), Germany
5-University of Augsburg, 86159 Augsburg, Germany and Helmholtz-Zentrum Berlin, 14109 Berlin, Germany
6- IMDEA Nanoscience, Calle Faraday 9, 28049 Madrid, Spain
7- Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark
8- Institute of Microelectronics of Barcelona (IMB-CNM CSIC), 08193 Bellaterra, Catalonia, Spain
*presenting author: dpsalinas@cells.es

Here, we present lensless coherent soft X-ray imaging of magnetic domains [1] in two-dimensional (2D) van der Waals (vdW) materials[2] at low temperatures and under strong magnetic fields. By integrating micron-scale flakes of 2D materials onto nano-fabricated holography masks—either through deterministic transfer in an inert-air glove box or via focused ion beam lamella preparation—we expand the applicability of soft X-ray holography to this emerging class of materials. This robust and versatile approach, illustrated in Figure 1, also enables the study of air-sensitive systems. We apply it to probe complex magnetic domain structures and non-collinear spin configurations in various 2D vdW compounds at temperatures as low as 20 K and magnetic fields up to 2 T. In addition to Fourier transform holography, we utilize holography-assisted phase retrieval [3] to enhance spatial resolution. Our results highlight the potential of lensless soft X-ray imaging—leveraging circular and linear dichroism, as well as element-specific contrast—to reveal nanoscale magnetic and electronic phenomena in 2D magnetic materials and related device architectures.

References:

[1] Eisebitt, S. et al. Nature, 432 (2004) 885–888
[2] Huang, B. et al. Nature 546 (2017) 270–273
[3] Battistelli, R. et al, Optica 11, (2024) 234-237

Acknowledgements:
AMaChaS – Advanced Materials Characterization System, MSCA-IF EU project # 101018445.
Stemin2D-Sync – MINECO project MCIN/AEI PID2023-146354NB-C43,C41

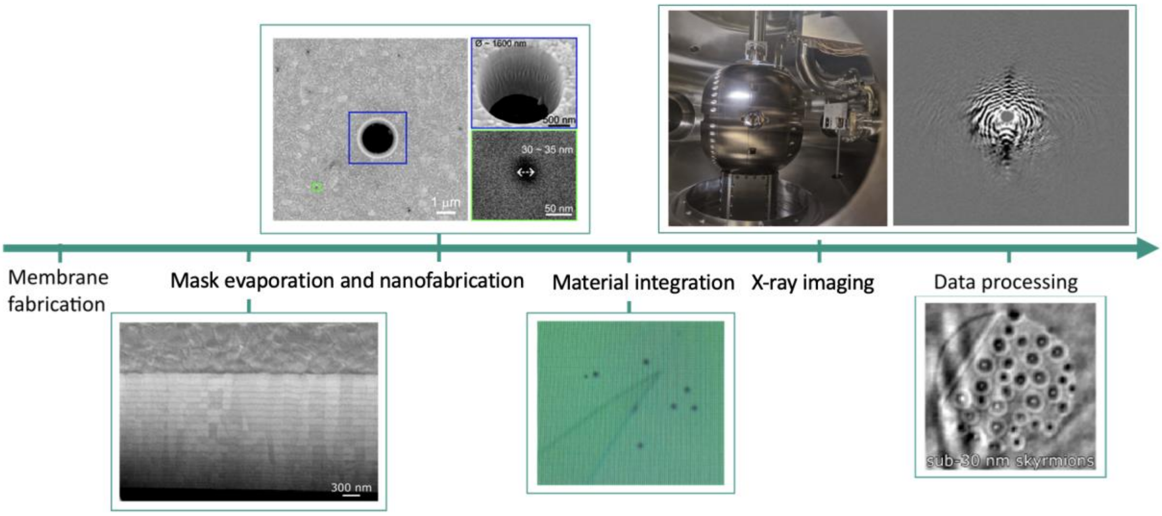

Figure 1: Methodology flow for lensless coherent imaging of nanoscale magnetic domains in 2D materials. Starting from x-ray transparent substrates such as Si_3N_4 membranes, the main steps are illustrated: (1) Preparation of holography masks by evaporation of Au:Ti or Au:Cr multilayers and clean-room FIB patterning of the imaging mask; (2) preparation of sample specimen by exfoliation or lamella preparation, and its integration onto the masks by deterministic transfer; (3) synchrotron x-ray experiments; and (4) image reconstruction by Fourier transform and/or iterative phase retrieval algorithms.