Low dose STEM for everyone using compressed sensing with regular scanning grids

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For many applications of electron microscopy the limiting factor for the achievable data quality is no longer the resolution of the microscope, but the robustness of the sample to exposure to the electron beam. The more sensitive the specimen, the harder it becomes to extract meaningful information from the noisy image. In order to reduce the electron dose needed to acquire STEM images, so that a wider range of samples can be studied, a number of pixels of the image may be intentionally omitted to be later reconstructed (*inpainted*) using compressed sensing (CS) algorithms to solve the inpainting task [1,2].

The key restriction limiting the spread of these CS-STEM measurements has been the need to measure the pixels in a random manner, so that the reconstruction algorithms do not introduce any artifacts to the image. Thus, efforts have so far been focused on the experimental side trying to realize random sampling [3], or approximations thereof [4].

An experimentally far easier strategy to undersampling is the control of the number of pixels per unit area. As shown in Fig.1, by increasing the scanned area, or decreasing the number of pixels per area k-fold, any 1/k undersampling can be achieved on a standard STEM instrument. However, these highly regular sampling grids do not permit the usage of established CS algorithms due to aliasing artifacts of the sampling grid.

In this talk, we will present a new inpainting algorithm [5] applicable to arbitrary sampling grids. By learning a small feature basis from training images, the optimization criterion of basis pursuit compressed sensing algorithms can be simplified to a least square fit over all measured image pixels. By using the recent local low rank (LLR) format [6], we assure a good reconstruction also at low sampling rates and signal to noise ratios.

We demonstrate the new algorithm on experimentally undersampled images of graphene with defects (see Fig.2). Exploring the capabilities of the new algorithm, we achieve a substantial dose reduction of up to two orders of magnitude. By mere improvement of the post-acquisition software, we are thus furhtering the state of the art of CS-STEM measurements and bring the technique to any lab equipped with a standard STEM.

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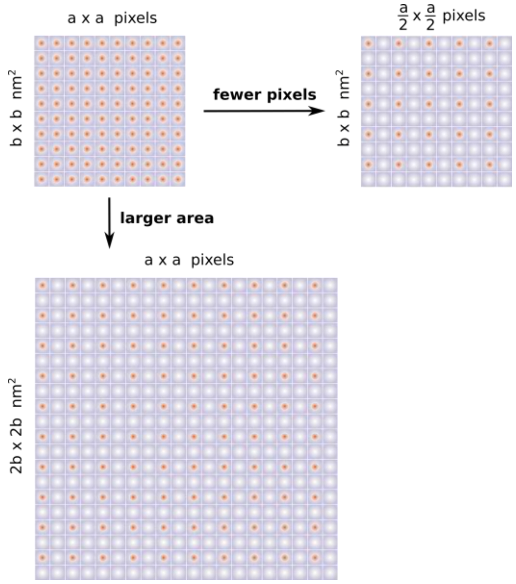

Fig.1 Schematic representation of measurement of an undersampled image by adjustment of the number of pixels per unit area. By doubling the area or halving the number of pixels a 75% undersampling is achieved.

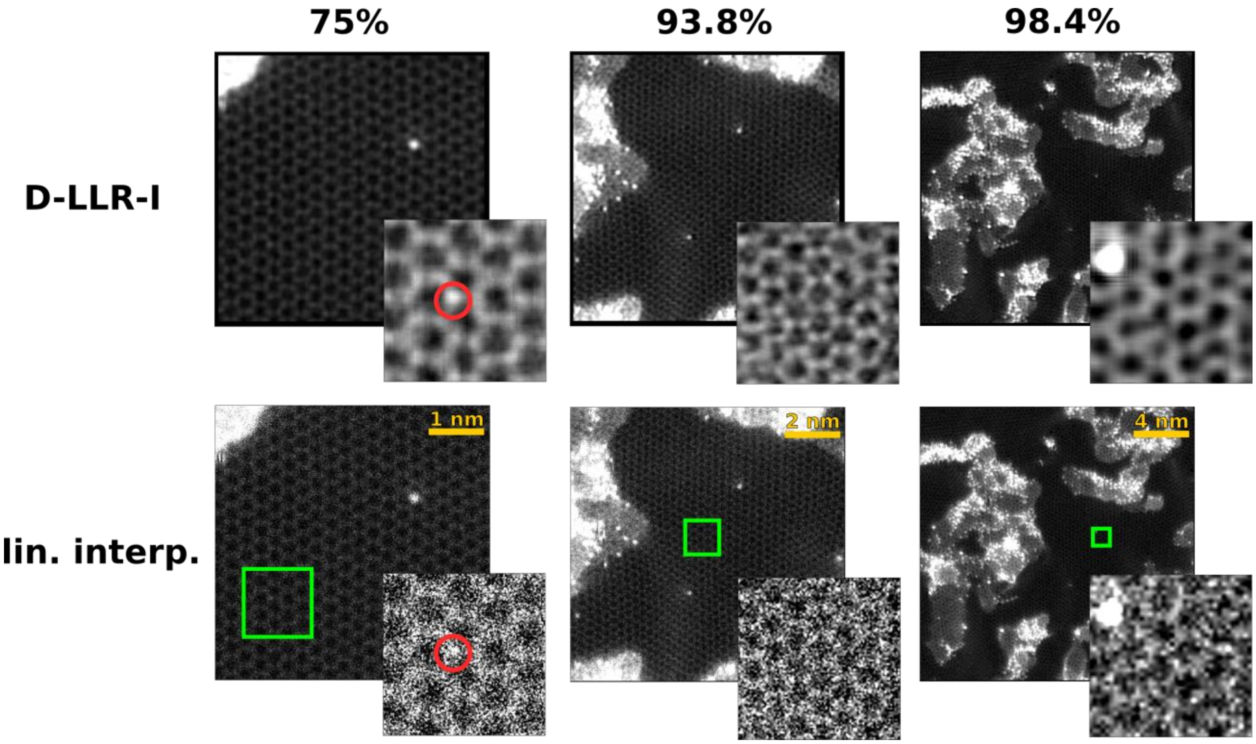

Fig.2 Comparison of reconstructed images of graphene using a linear interpolation and our algorithm. Large field of visions and high undersampling rates are enabled.