The aberration corrected scanning transmission electron microscope (STEM) is able to probe materials down to the atomic scale. Often images are created using either small on-axis detectors (bright-field) or large annular detectors with a fixed size (dark-field). However, far more information is available in the diffraction plane than these simple detectors record (Figure 1). By using a pixilated detector (camera) the entire diffraction pattern can be recorded for every probe position yielding a four-dimensional dataset [1]. Once acquired, any number of virtual detectors can be created and images synthesised without the need for pre-configured fixed detector angles [2].

Recording speeds are however slower than conventional STEM detectors with the examples shown in Figures 3 and 5 having 256x256 real-space probe positions recorded at 1000 diffraction patterns per second (264x264 camera pixels, Δt≈6s total recording time).

### Hardware Setup on JEOL 200CF

- **New PN Monitor Screen**
- **JEOL PC**
- **Gatan PC**
- **EDX PC**
- **Existing Computers**

#### figure 1. Installation of PN detector setup on a JEOL 200CF

Sensor is installed in the Ustarcag part below the viewing screen about the G2. Data is transferred to a server rack by fiber optic cable and the chip is cooled during a closedlarge chiller water circuit.

An additional collection is setup for the camera operator with a top view of the sensor image required to an additional monochromatic position and the microscope operator.

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### Synthesising BF, ABF, ADF & PACBED

By separating the processes of data-acquisition and image-processing, the 4D-data-block can be evaluated interactively to optimise the synthetic-detector geometry. Figure 3 shows some of the example images that can all be synthesised from the same experimental scan.

#### figure 3. Examples of the possible images that can be reconstructed using different synthetic detectors or modes. The sample is a 100nm carbon/UTP, angle with maximum increasing from left to right. The panels above show spindle bright-field (BF), annular bright-field (ABF) and low, medium, and high-angle annular dark-field images.

The BF image shows clearly the metal containing columns, while ABF also shows the oxygen column positions. The transmission function plane (as retrieved by ptychography [2]) is also shown for comparison, this has a higher resolution but shows diffraction propagation effects.

The LAADF images show atomic columns on the left edge (this region) clearly but little atomic number contrast between the 10 and 14 columns. The HAADF image shows the interelement s contrast difference between the metal containing columns but overall image quality is poorer due to the large incident electron range. The HAADF image offers a good compromise between contrast information and image speed.

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### Nanoparticle Dark-field Optimisation

Precious metal nanoparticles are used widely in catalysis. Improving their design and performance requires high resolution imaging, but their small size makes them incredibly sensitive to electron beam damage. Using a pixilated detector allows for every scattered electron to be recorded with 100% efficiency and for the incoming beam current to be reduced.

Figure 4 shows an example detector lane image exhibiting single electron sensitivity; the detector sensitivity is so great a beam-blanker was used here to improve the dynamic range in the dark-field regime. After reducing the electron dose, no sample damage was observed and sample and instrument stability was sufficient to produce an atomic resolution image of the nanoparticle supported only on amorphous carbon black (Figure 5).

Having acquired the 4D data-block of detector images at every probe position, the data were rehashed into a three dimensional volume of x-y and ‘scattered intensity as a function of angle’. This three-dimensional volume can then be treated similarly to a spectrum image and inspected for optimised detector angles to reveal certain features [4].

Integrating the whole dark-field region gives a high signal-noise ADF image (Figure 5 left), but inspecting the low and medium angle scattering reveals detail within the twinned region at the left edge of the particle.

#### figure 5. Left: Atomic resolution synthetic-ADF image of PACBED nanoparticle formed using the whole dark-field regime. The red arrows indicate the position of a twin boundary, the black and yellow superlattice spots from the ordering of the aly, Right: Low-angle and medium-angle synthetic dark-field images where the surface layer appears first inset, then dark.

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### Conclusions

Recording all the electrons scattered during STEM imaging on a pixilated camera yields a highly sensitive and rich dataset. This dataset can be analysed offline from the microscope using virtual detectors optimised to deliver the peak SNR for a given imaging mode. Additional data can be extracted about sample thickness from PACBED patterns or about sample composition from scattering curves such as those in Figure 3.

Operating the camera in an electron counting mode delivers single electron sensitivity (Figure 4) which allows maximally efficient dark-field STEM to be performed. This is especially useful for imaging fragile beam-sensitive materials such as nanoparticles.

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### References


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