# Nuclear Quantum Imaging

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Accelerator-driven free-electron lasers have opened new avenues for high-resolution structure determination that go beyond conventional X-ray crystallography [1-3]. While these techniques rely on coherent scattering, incoherence due to wavefront distortions or incoherent fluorescence emission - often the predominant scattering mechanism - is generally considered a detrimental effect. It has been demonstrated recently that methods from quantum imaging, *i.e.*, exploiting higher-order intensity correlations [4-6], can be used to image the full 1D, 2D and possibly even 3D arrangement of sources that scatter or emit incoherent X-ray radiation [7,8]. This type of structure determination has been coined incoherent diffraction imaging IDI, see Fig. 1. A key requisite for these techniques is that the integration time of photon detection is in the range of or shorter than the coherence time of the emission process. It is the virtue of radiation sources like X-ray lasers that their femtosecond pulse length can be in the range of the core-hole lifetime of atomic emitters, so that fluorescence radiation, *e.g.*, from transition metal atoms, can be used for IDI.

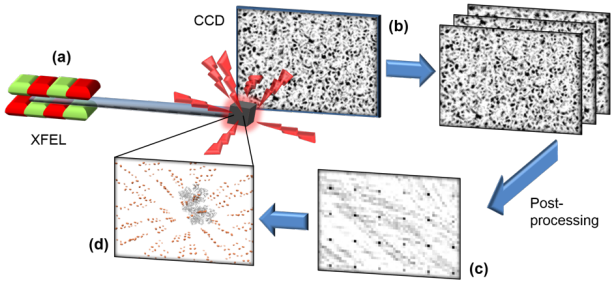


Figure 1: Illustration of IDI: A large number of snapshots of incoherent X-rays emitted by a 3D source arrangement is recorded by a CCD; the intensity correlations of each snapshot are determined individually; averaging over many snapshots leads to a pattern that yields the initial 3D distribution of the sources [7]

In this contribution, IDI with nuclear resonant fluorescence radiation from Mössbauer nuclei like $^{57}$Fe or $^{119}$Sn is proposed. In this way, a novel regime of coherence times is accessible since the lifetime of the involved nuclear levels (140 ns in case of $^{57}$Fe) is much longer than the duration of the exciting FEL pulses (10 fs) or even synchrotron X-ray radiation (100 ps). The nuclear resonance signal can thus be efficiently discriminated against the non-resonant background by time-resolving detectors with very low noise and quantum efficiency of essentially 100%. This would immediately reduce many sources of background from non-resonant events that are not correlated. If successful, this approach would not only allow exploration of the foundations of IDI in a novel regime of parameters but open up the perspective for imaging of metal clusters in active centers of biological macromolecules.

## References

[1] H N Chapman, A Barty, M J Bogan, *et al.*, Nat. Phys. **2**, 839 (2006)

[2] H N Chapman, P Fromme, A Barty, *et al.*, Nature **470**, 73 (2011)

[3] A Barty, J Küpper and H N Chapman, Annu. Rev. Phys. Chem. **64**, 415 (2013)

[4] C Thiel, T Bastin, J Martin, E Solano, J von Zanthier and G S Agarwal, Phys. Rev. Lett. **99**, 133603 (2007)

[5] S Oppel, T Büttner, P Kok and J von Zanthier, Phys. Rev. Lett. **109**, 233603 (2012)

[6] A Classen, F Waldmann, S Giebel, R Schneider, D Bhatti, T Mehringer and J von Zanthier, Phys. Rev. Lett. **117**, 253601 (2016)

[7] A Classen, K Ayyer, H N Chapman, R Röhlsberger and J von Zanthier, Phys. Rev. Lett. **119**, 053401 (2017)

[8] R Schneider, T Mehringer, G Mercurio, *et al.*, Nat. Phys. **14**, 126 (2018)