Sub-psec Magnetic Domain Imaging in Nanoscale Structures Using Photoemission Electron Microscopy

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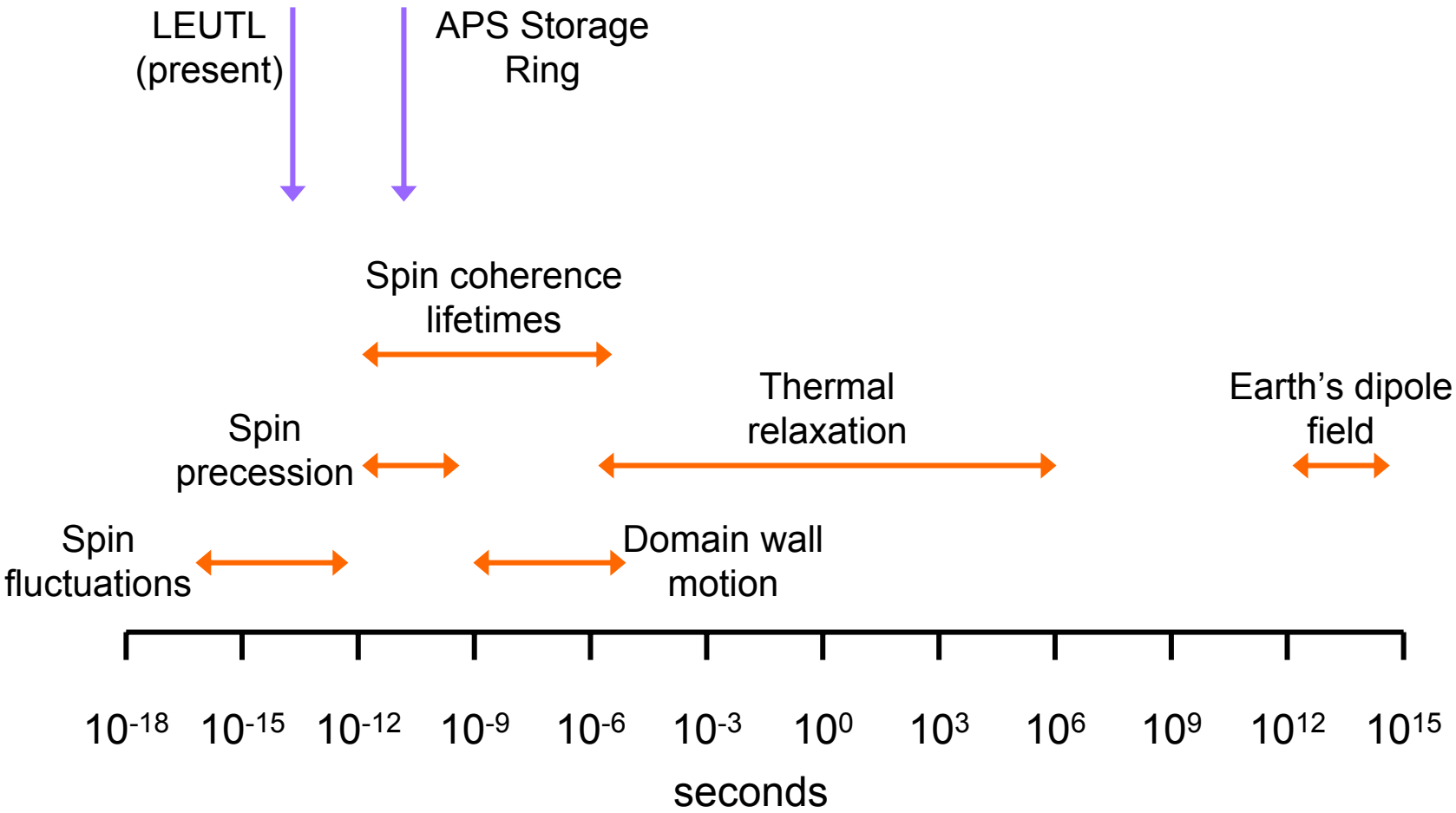
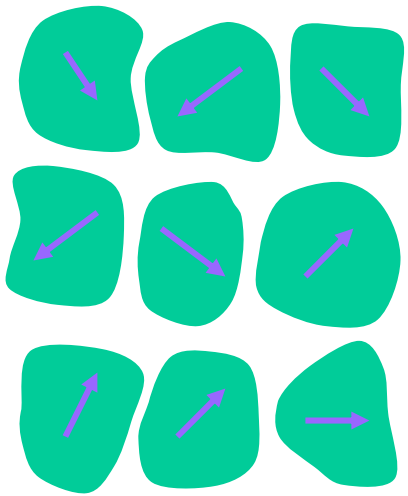
Use of the Advanced Photon Source is supported by the U.S. Department of Energy, Office of Science, under Contract No. W-31-109-ENG-38. Work at the University of Utah is supported by the National Science Foundation ECS under grant No. 0115164.

Time scales in magnetism

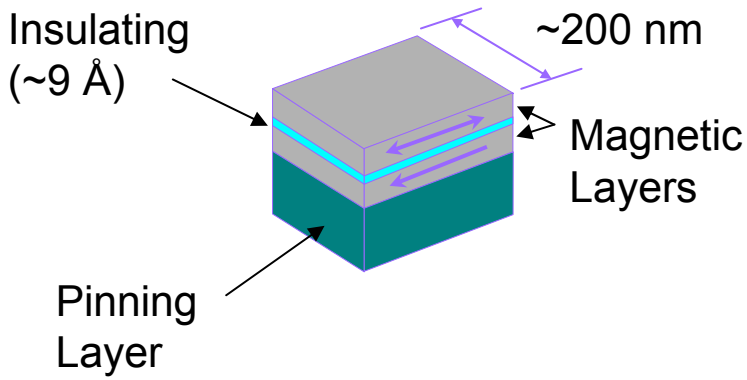


Applications of nanoscale magnets

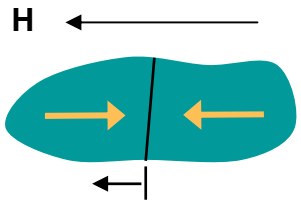
Media



MRAM



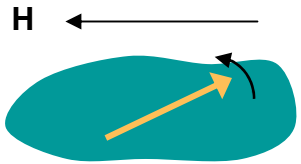
Spin dynamics and time scales



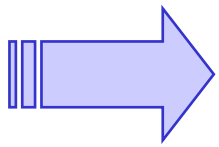
Domain wall propagation

Needed time resolutions:

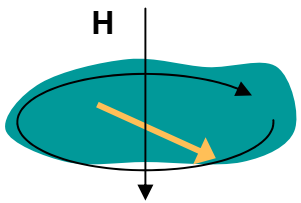
< 200 ps ☑



Coherent Rotation



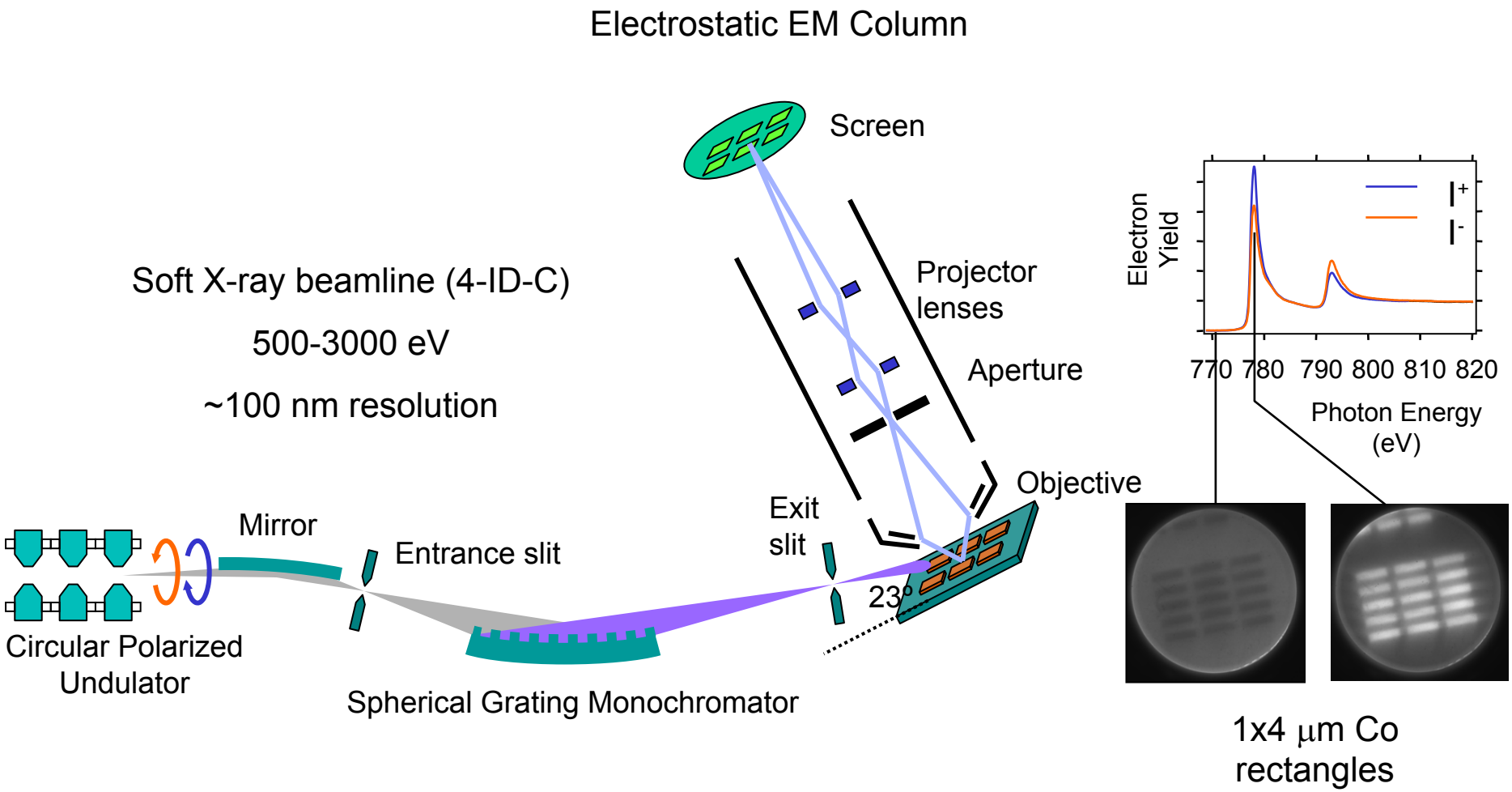
< 1 ps ☐



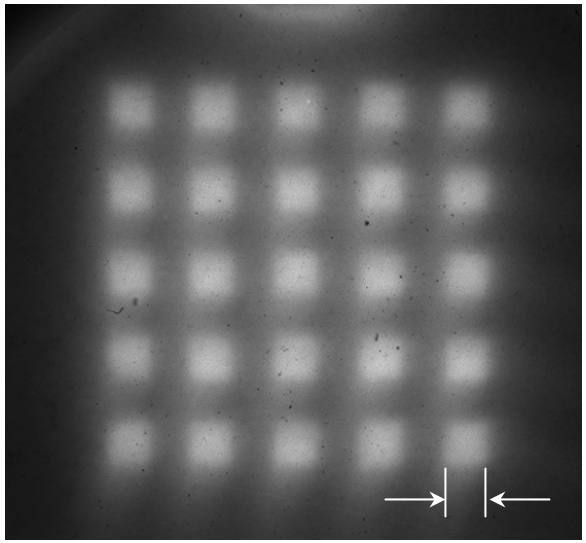
Precession

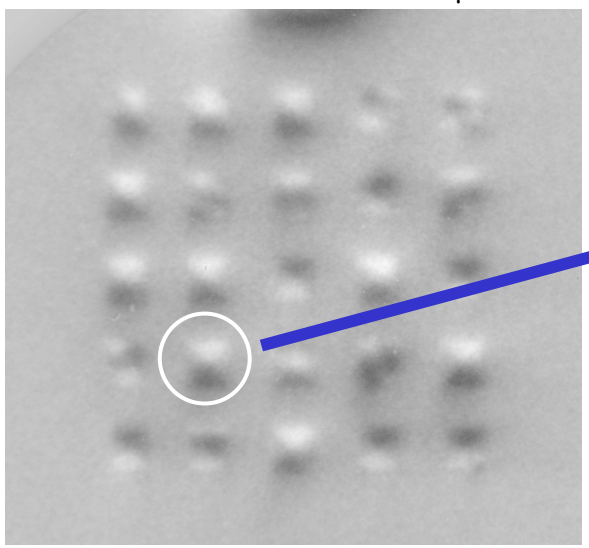
< 1 ps ☐

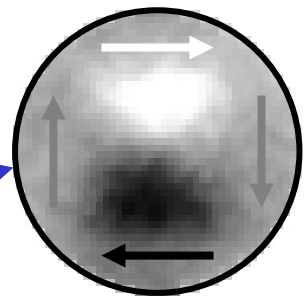
X-ray Photoemission Electron Microscopy at the APS



Chemical and Magnetic Imaging





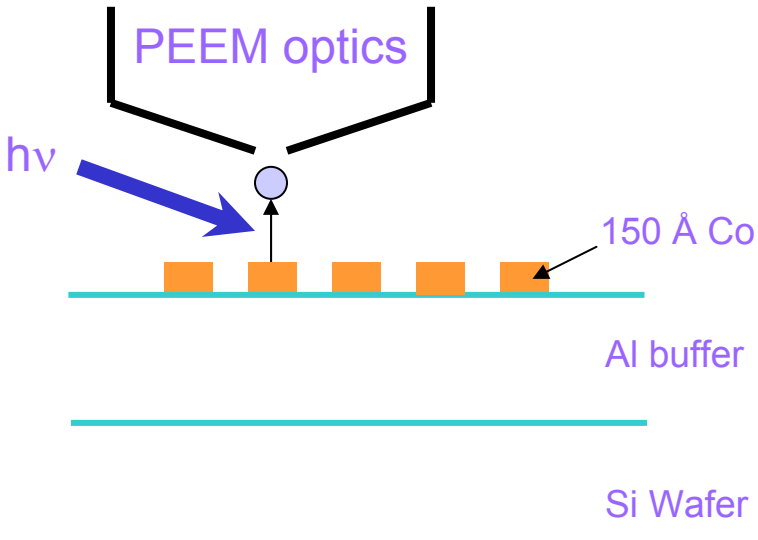


- Simultaneous chemical + magnetic contrast
- High magnetic contrast
- Full field
- No interaction with sample
- 100-120 nm resolution
    - 20 nm target

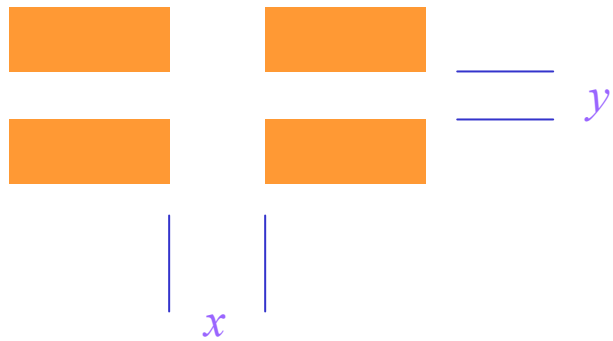
- Domain imaging
- Buried layers (~5 nm)
- Finite size effects
- Self-assembled systems
- Ground states in nanoscale systems
- Interactions in particle arrays

Co nanodot arrays

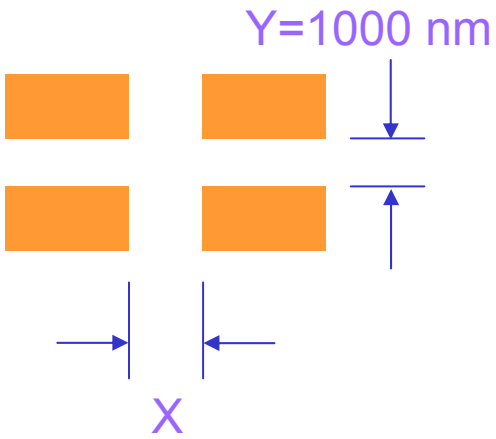
e-beam lithographic lift-off process:
University of Utah



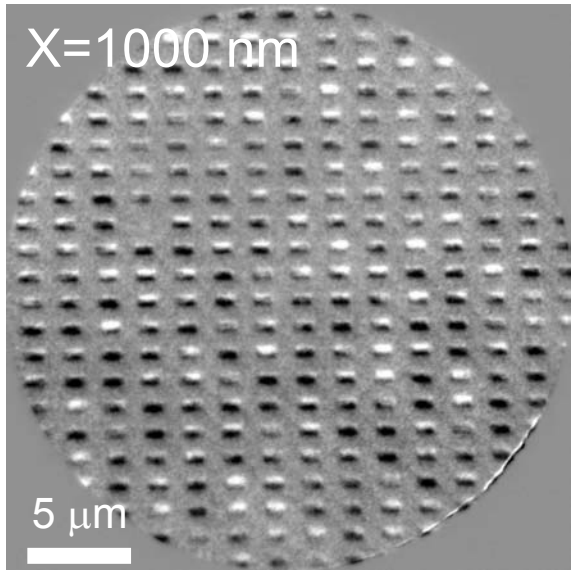
500x1000nm, 200x600nm

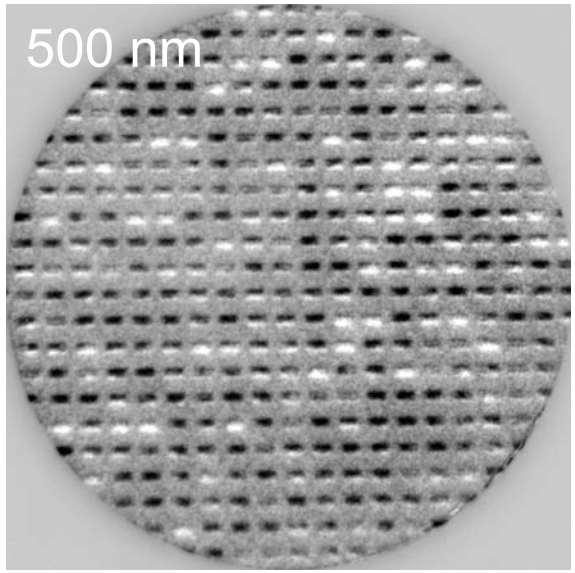


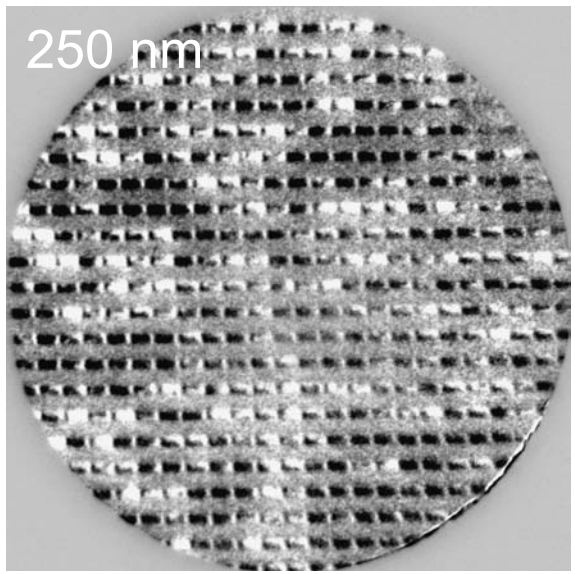
Magnetostatic interactions between Co dots

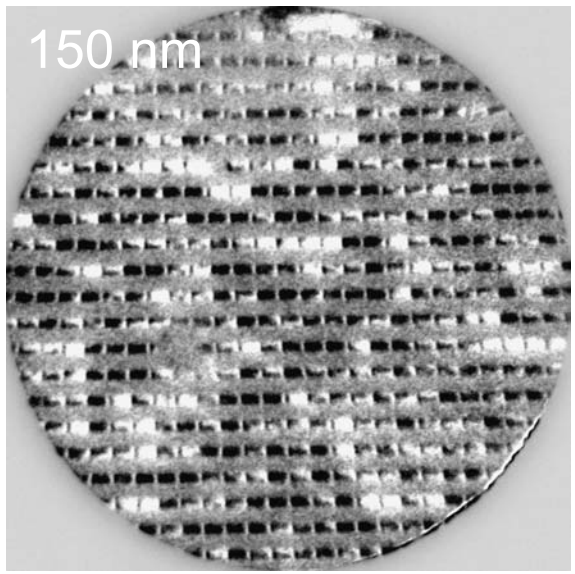


500 x 1000 nm dots



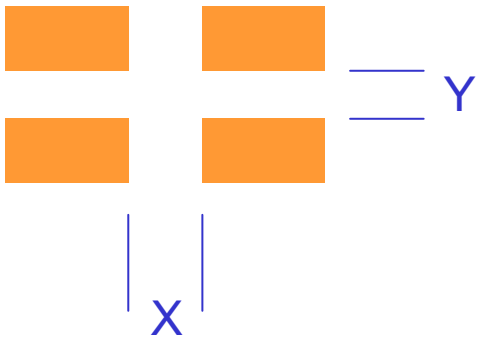


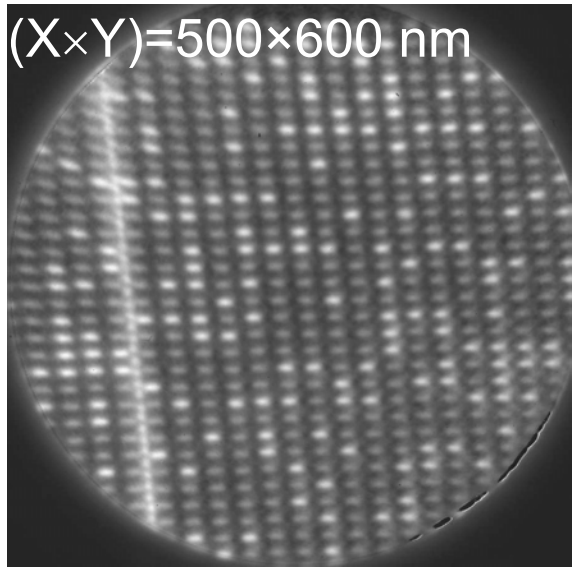


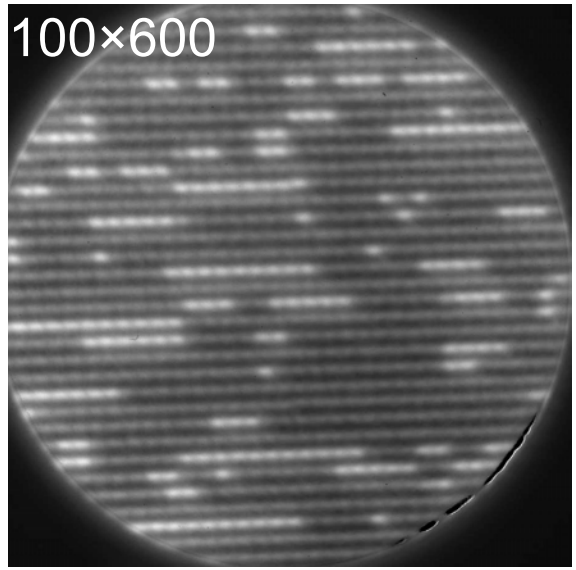


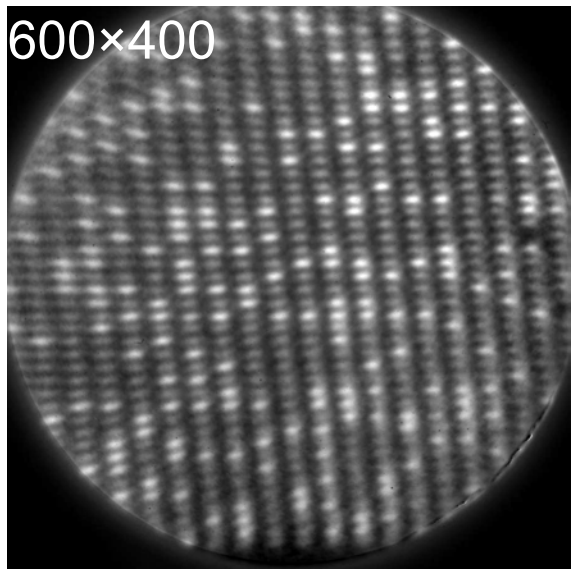
Magnetostatic interactions between Co dots

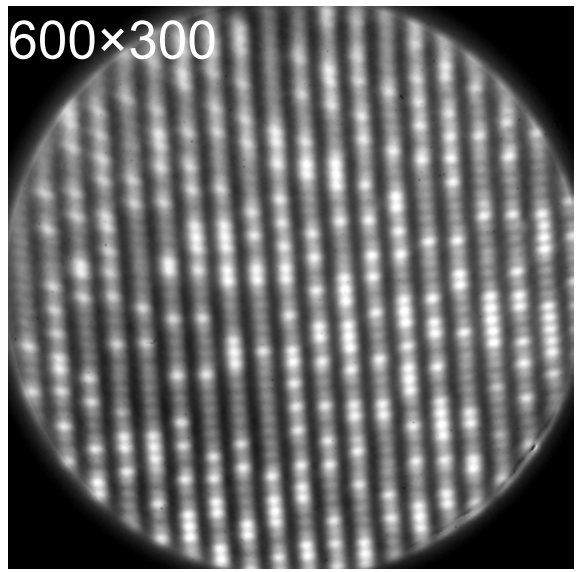
200 x 600 nm dots





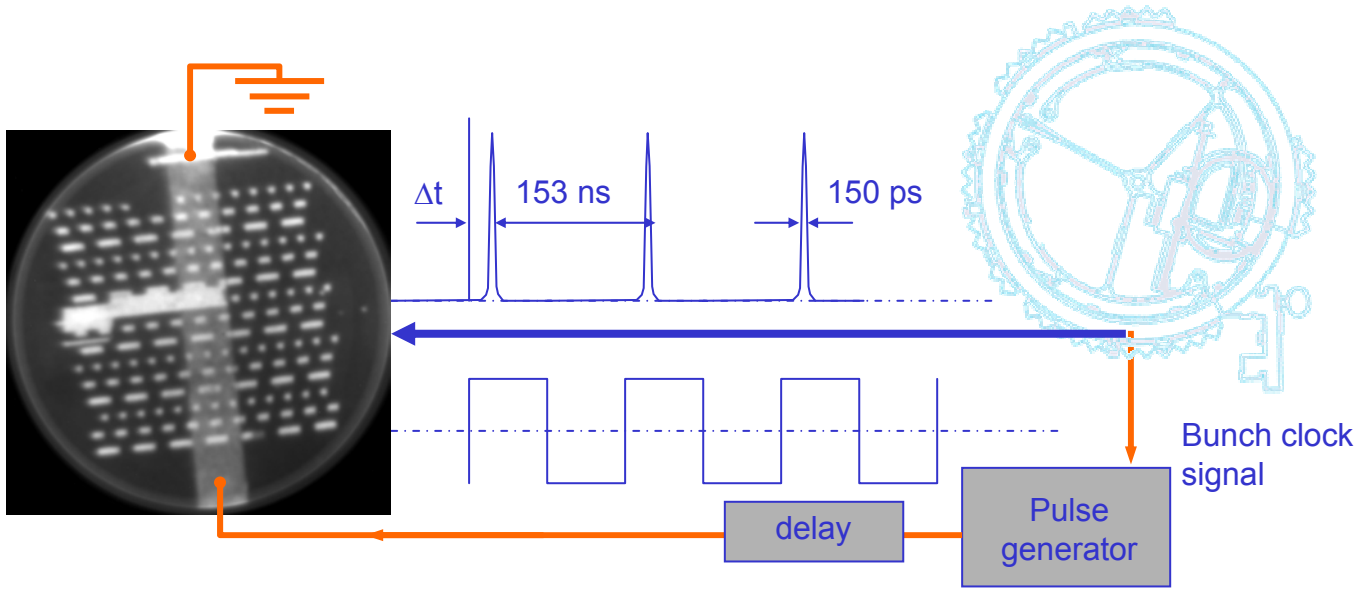


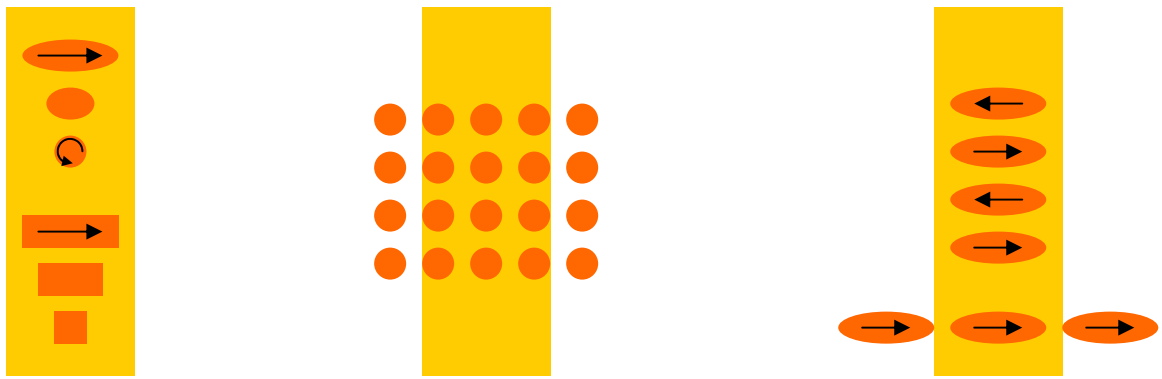




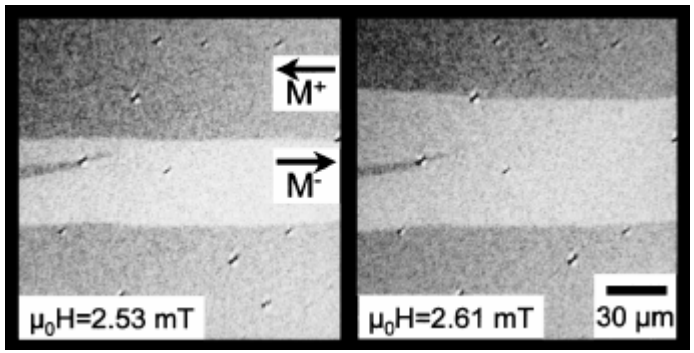
Time resolved imaging

Pump-probe experiments using the APS ring timing structure

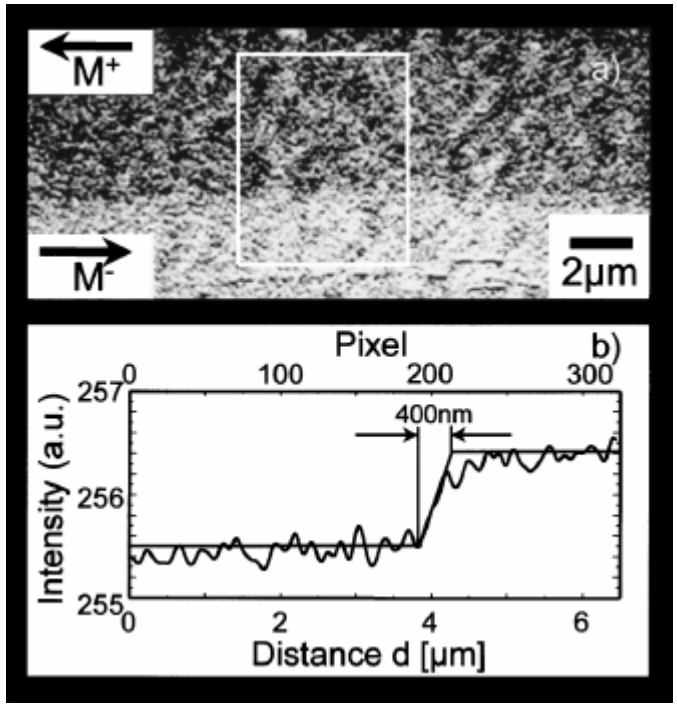




Magnetic linear dichroism in threshold photoemission



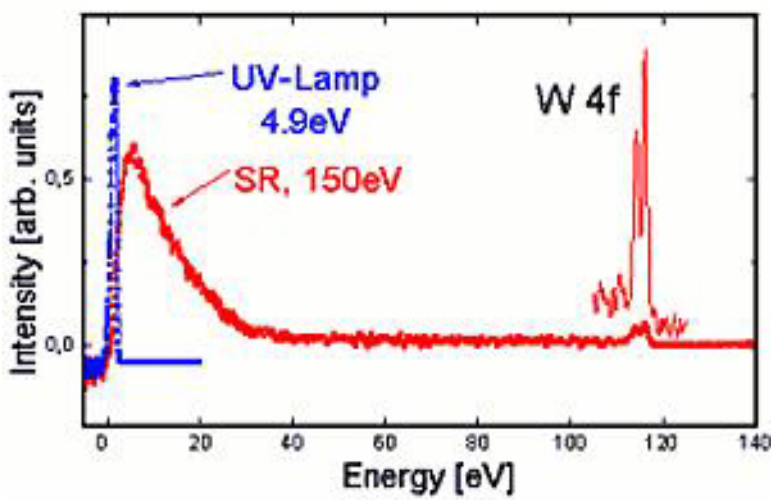
100 W Hg lamp
(4.9 eV)

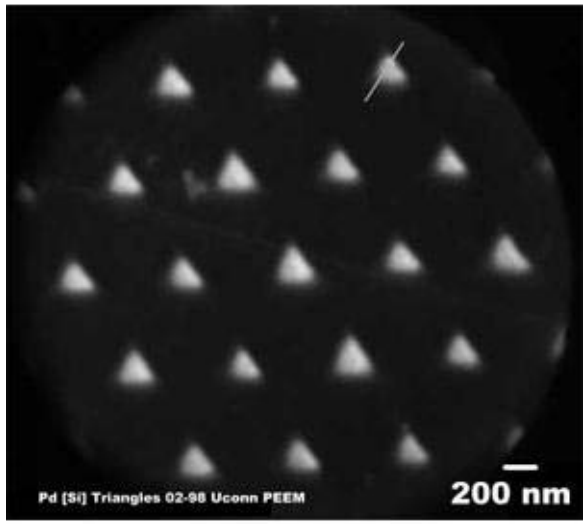


0.37% asymmetry

Spatial Resolution at threshold

Chromatic aberrations limit the spatial resolution





Pd on Si

Spherical aberration limit ~ 20 nm

Magnetic imaging at 300 fs, 20-30 nm!

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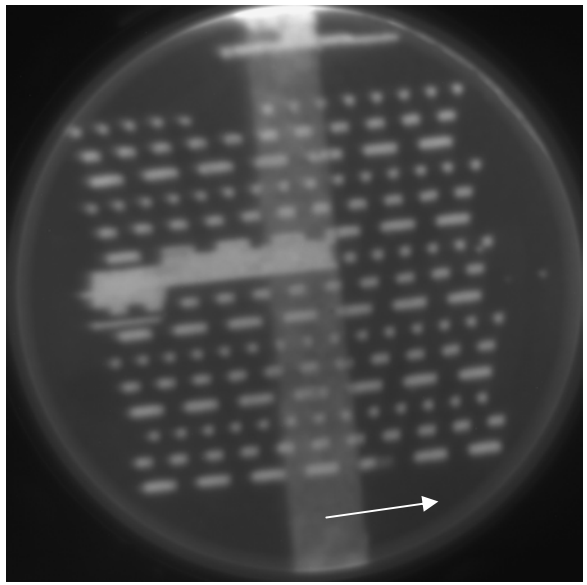
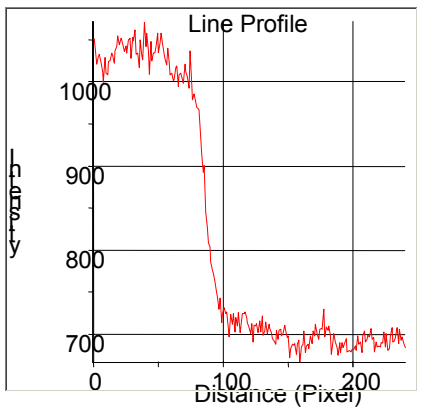
Beyond stroboscopic imaging



30s exp (~3x10^{14} photons)



2-3% noise

4.9 eV @ 30 μJ = 3.8x10^{13} photons

200 μJ = 2.5x10^{14} photons

Enhancements:

Asymmetry (energy/polarization dependence?)

Flux (2mJ/pulse?)

Single-shot mode?

Summary

- Significant improvement in state of the art magnetic imaging possible with existing parameters
  - Magnetic nanostructures
  - Spin populations in semiconductors
- Possible single-shot imaging mode
  - Spin fluctuations