

# Report on the Nanomagnetism Workshop

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# Overview:

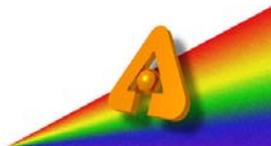
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- Nanomagnetism Past: *where we've been*
- Nanomagnetism Present: *where we are*
- Nanomagnetism Future
- How the APS Can Get Us There



# Introduction: Nanomagnetism

- Understand the magnetic behavior of individual building blocks of matter, which are combined into more complex structures leading to devices with new functionalities.
  - *Emergent behavior* (ex: Multiferroics)
- Components to Success:
  - Creation (e.g.: DOE NSRCs/"Nanocenters")
  - Exploration (National User Facilities)
  - Understanding (Theory/Computation)



# Charge to the Participants

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1. **Identify grand challenge science and technological problems in nanomagnetism** that should be addressed during next 5-10 years.
2. **Identify and justify the technical requirements** to meet the grand challenge problems:
  - New instrumentation, techniques on existing beamlines/facilities to perform a new kind of science;
  - Need for new dedicated beamlines/facilities and instrumentation for this community.
3. **Identify both short- and long-term R&D** to address these grand challenges.



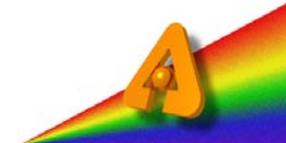
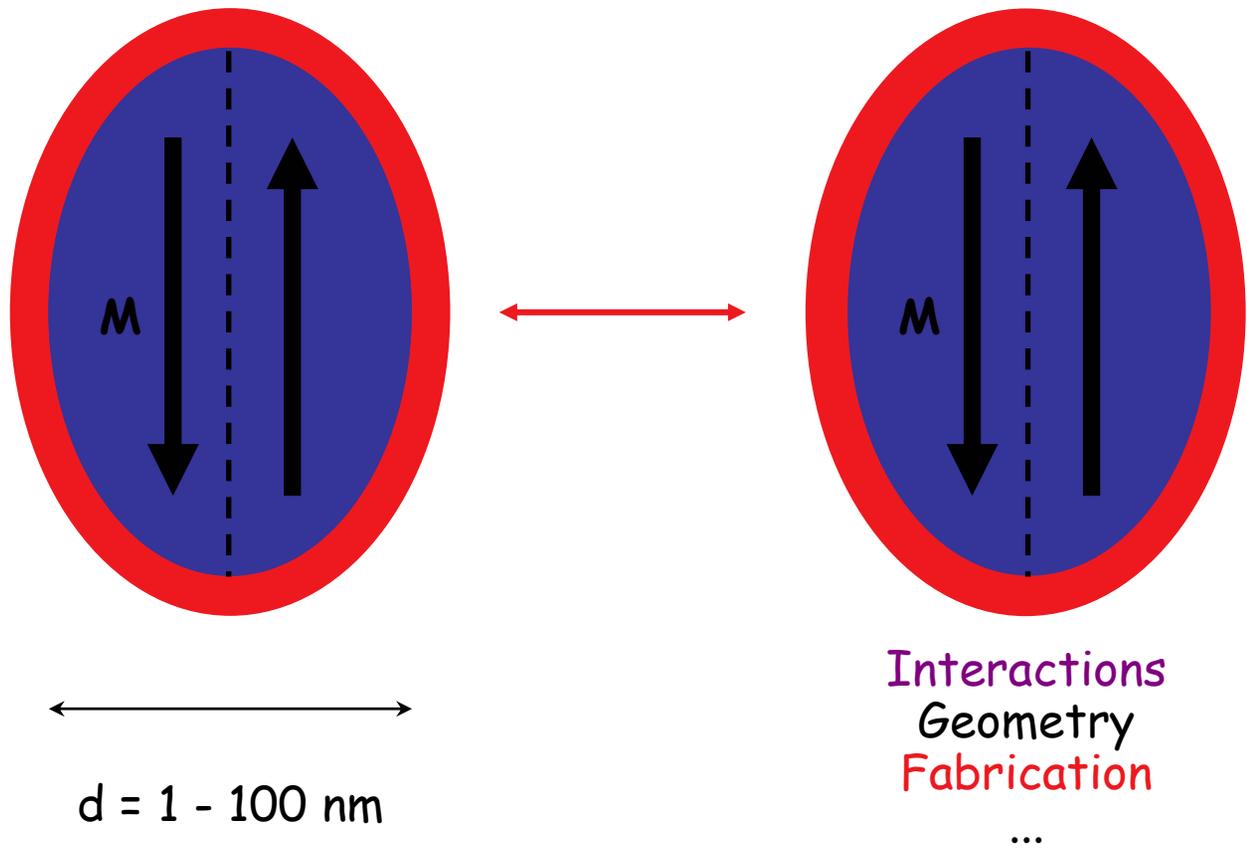
# Context: Why Nanomagnetism?

- Fundamental understanding of natural length scale of magnetism.
- To serve our **National Strategic Missions**:
  - **energy independence**: ultrastrong permanent magnets, ultra low-loss transformers
  - **medical applications**: image contrast, cancer treatment
  - new technologies to **stimulate the economy**: spintronics
  - **sensors** to support homeland security: biomagnetic approaches, communication systems
  - **environment friendly approaches**: efficient, light-weight motors, organic functional devices; magnetocaloric devices



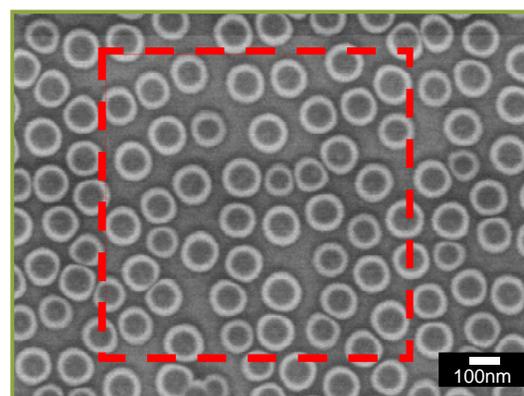
# Nanomagnetism: Physics at the Nanoscale

- Confinement
- Domains
- Surfaces
- Dynamics!



# Scientific Themes: Unique Needs

- **Confined Magnetism:**  
Layered and artificially structured systems
- **Cluster Magnetism:**  
Molecular magnets, spin ice and spin glasses
- **Phase Separated Systems/Complex Oxides**



1 μm x 1 μm

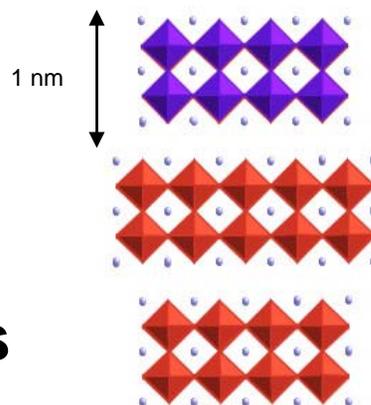
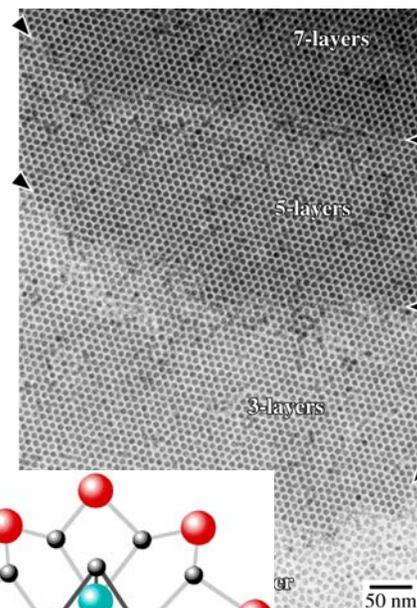
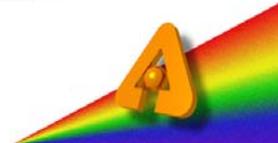
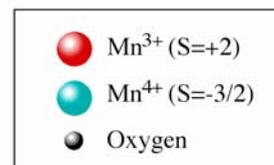
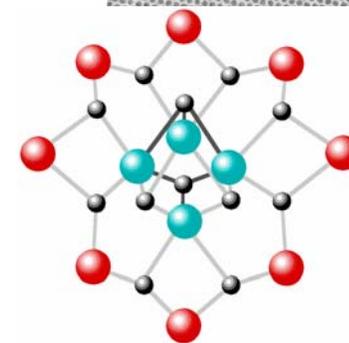
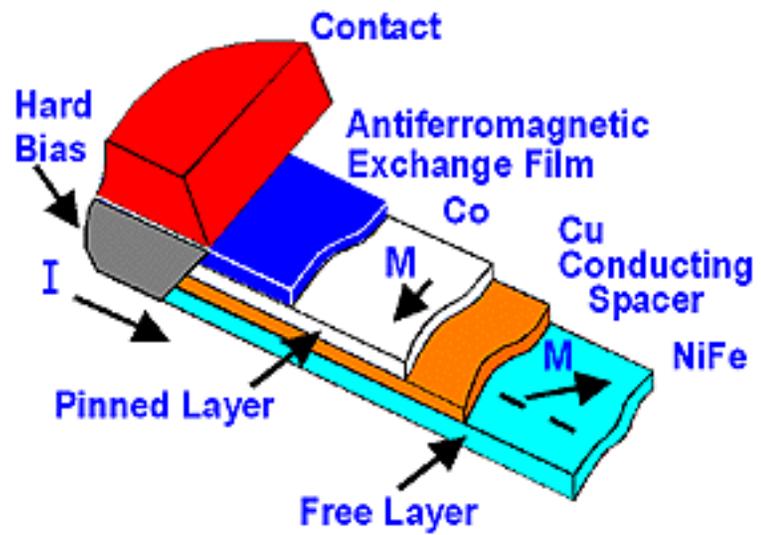


Figure 1 Schematic of layered manganite showing 1 nm thick modified surface layer.



# Where we've been: GMR: (Giant Magnetoresistance) a driver of the nano era...

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



Schematic GMR device

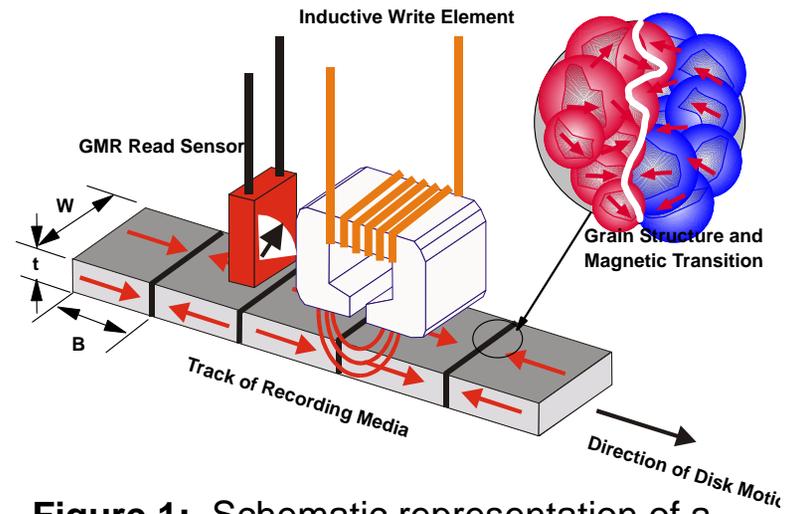
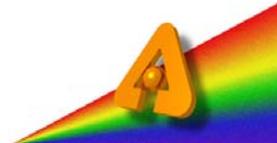
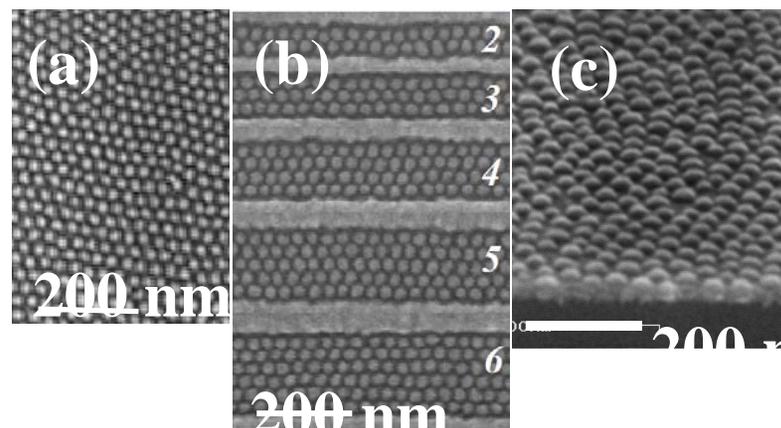
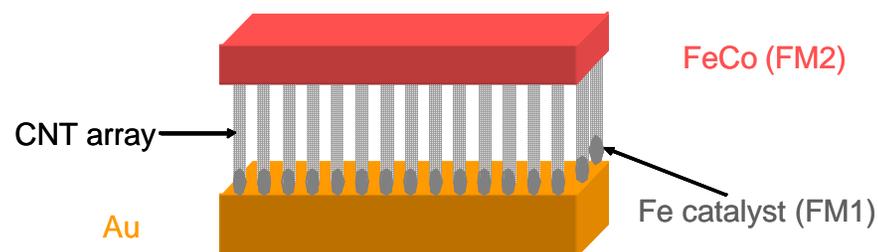


Figure 1: Schematic representation of a longitudinal recording system.

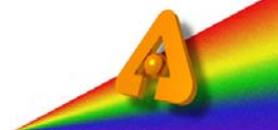


# Scientific Destinations

- Sustaining progress in information technology
  - Organic Spintronics
  - Spin-based quantum computing
  - Diblock Copolymer Lithography

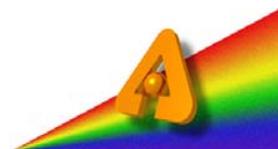
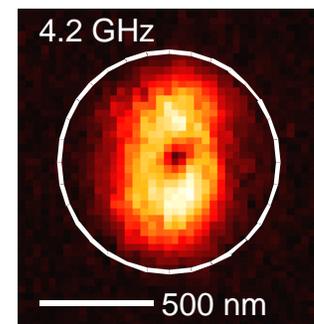
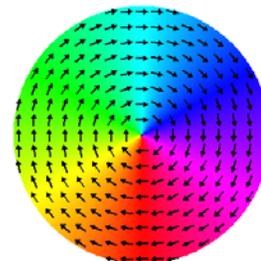
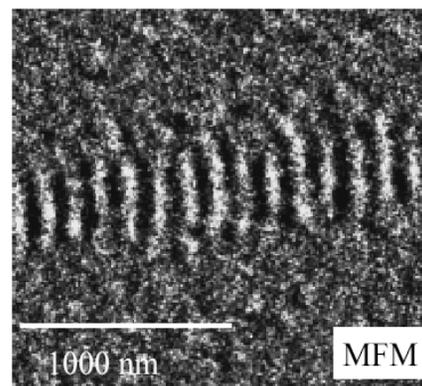
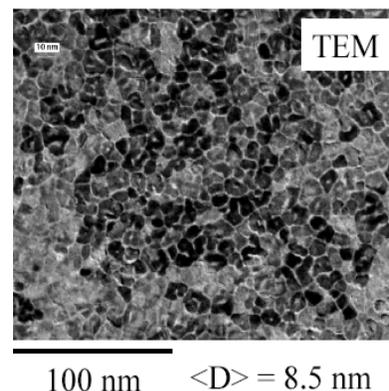


(a) Self assembled block copolymer on a smooth substrate, showing lack of long range order. (b) In shallow grooves, the polymer forms long range ordered structures. (c) Array of Co 'dots' made by block copolymer lithography.



# Scientific Destinations (*cont'd*)

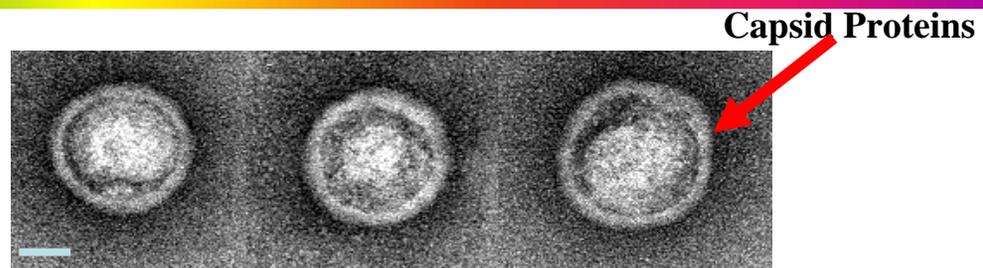
- Self-assembled nanocomposite magnets
- MRAM: Magnetoresistive Random Access Memory & dynamics
- Ultra-high density media
- Spin Torque effects;
- Vortex spin dynamics



# Scientific Marriages

- **Magnetism + Biology**

- Protein and Viral Templating

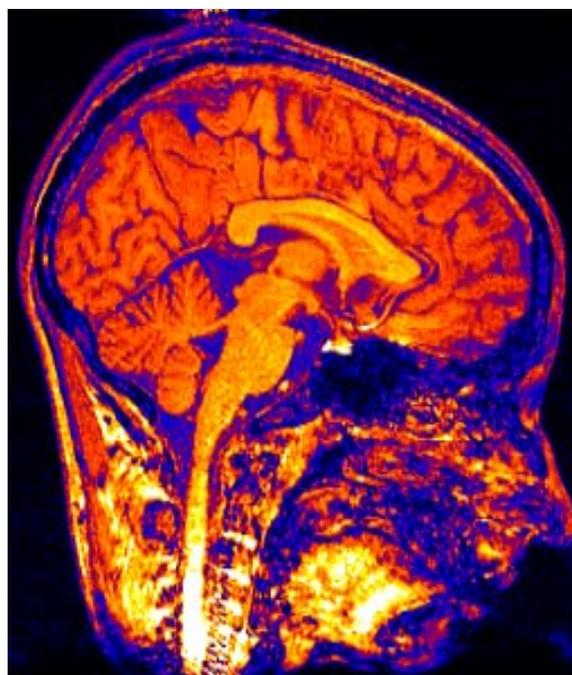


20 nm

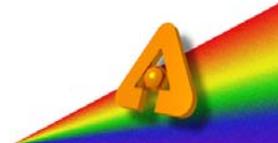
- **Magnetism + semiconductor**

electronics, transport phenomena

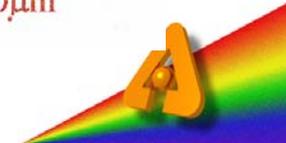
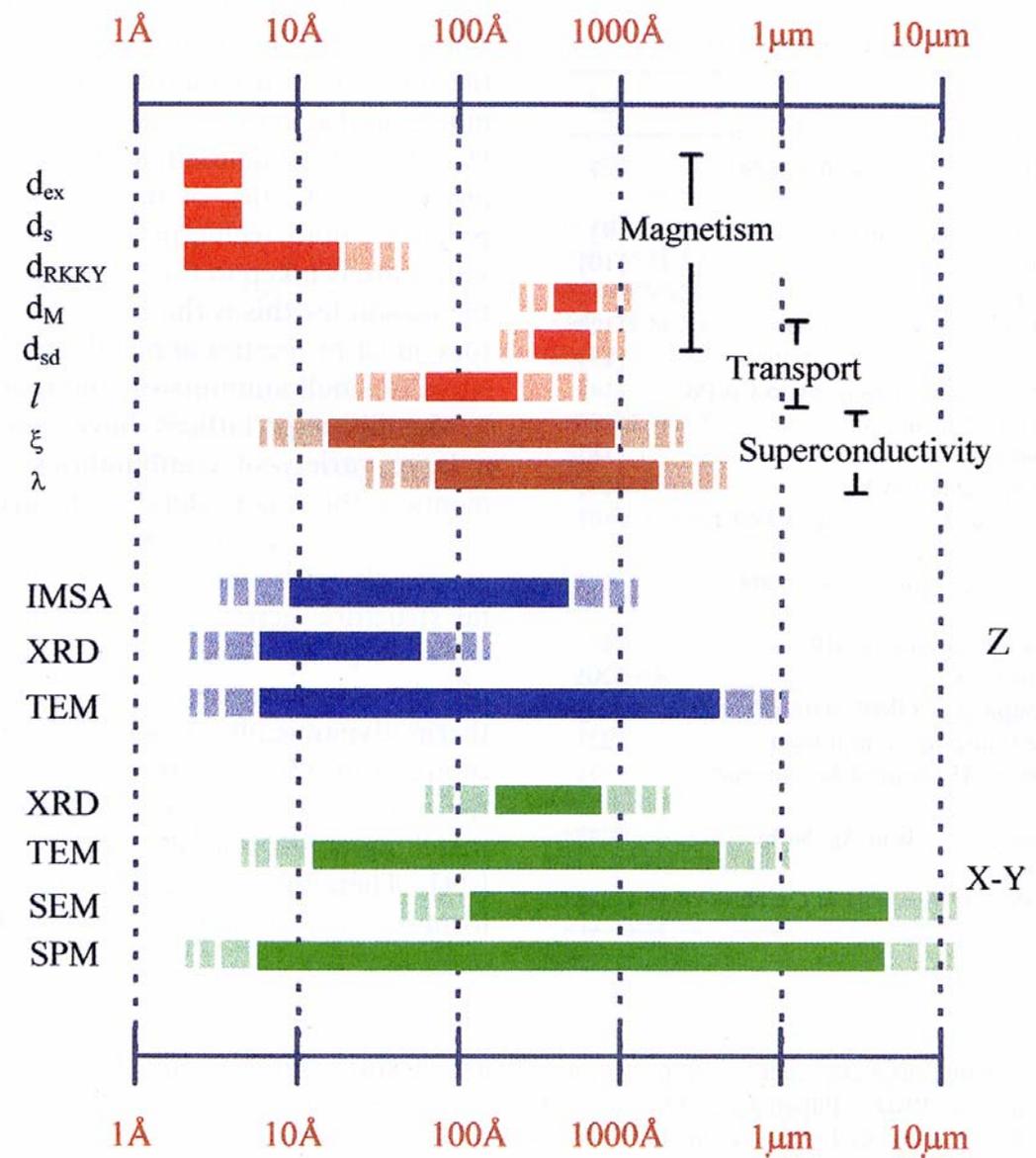
- **Magnetism + optics**



neuroregeneration



# Length Scales



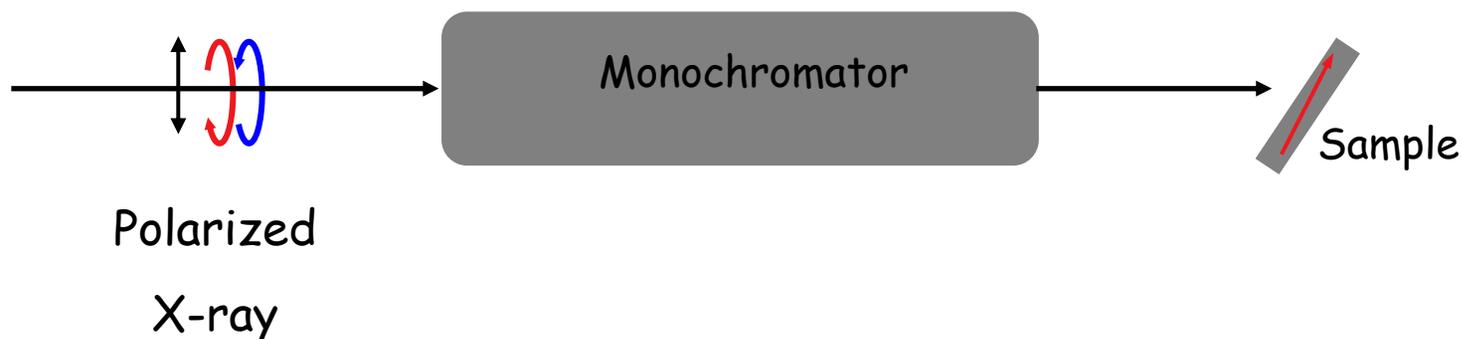
# Why APS? Unique dedicated facilities

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**Simultaneously probe where the atoms are and what the electrons and spins are doing.**



# Polarized X-ray Techniques



## Element specific electronic and magnetic properties

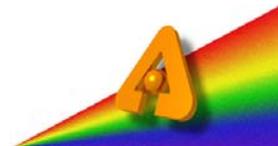
- X-ray magnetic circular dichroism (XMCD)
- X-ray magnetic linear dichroism (XMLD)
- X-ray resonant magnetic scattering (XRMS)



# Advantages of Synchrotron Sources

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- ***Energy tunability → Element specificity***
  - ***Enables studies of heterogeneous systems***
- ***High brilliance → High flux density***
  - ***Enables studies of small and dilute samples***
- ***High momentum resolution → High spatial resolution***
  - ***Enables studies of surfaces and interfaces***
- ***Timing structure***
  - ***Enables studies of time-dependent processes***



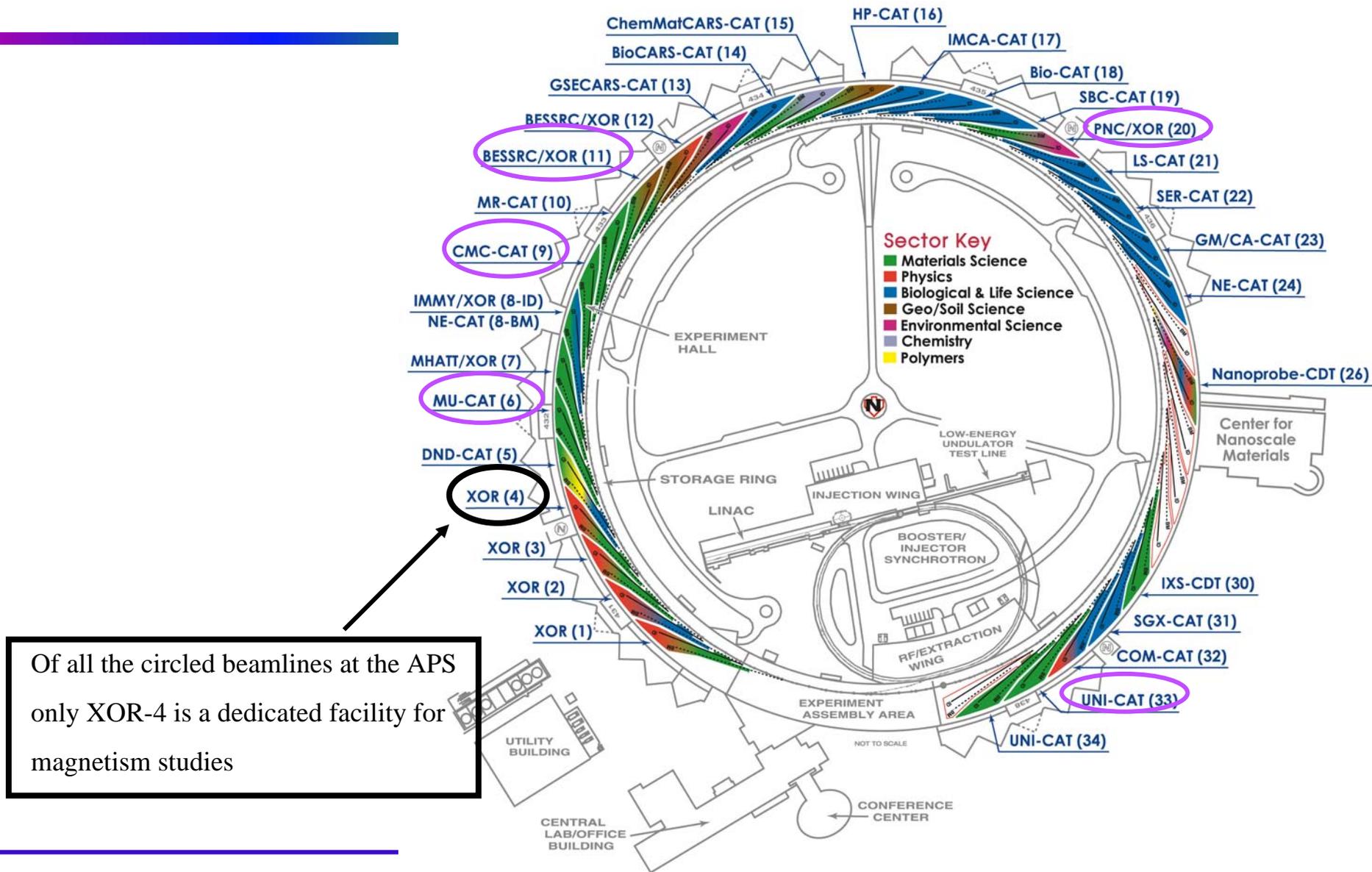
# Specific Magnetism Capability

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***Separate orbital and  
spin contributions***

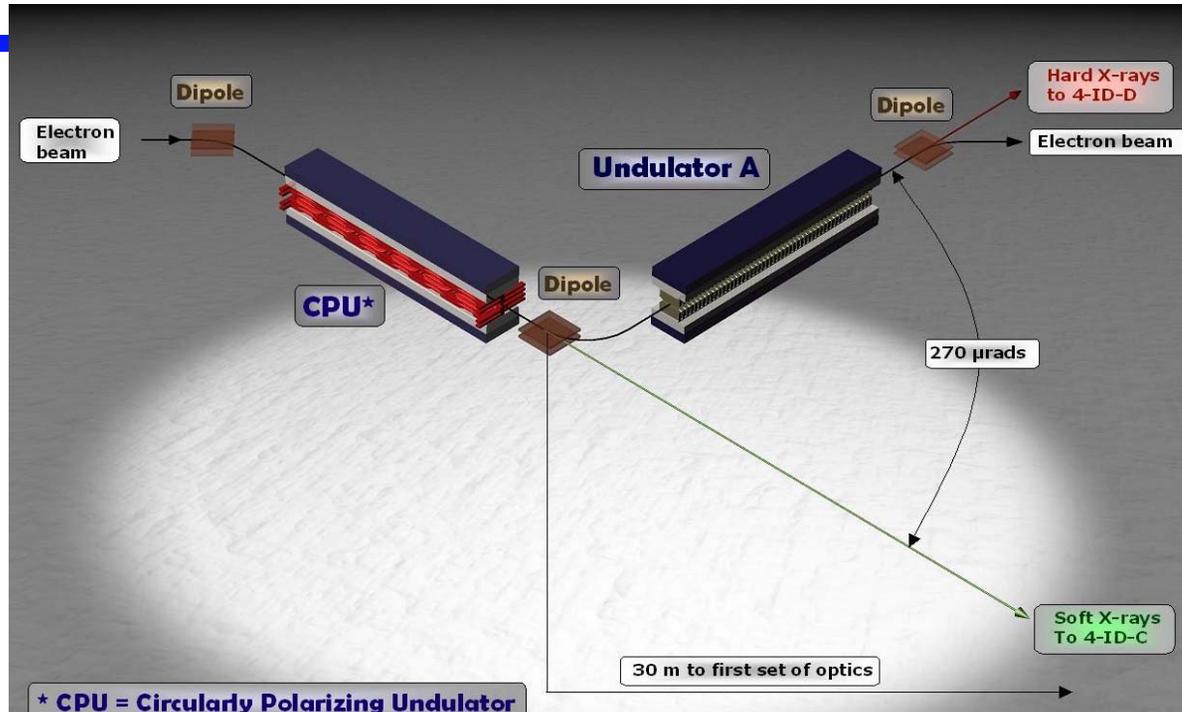


# Beamlines with Magnetism Capabilities

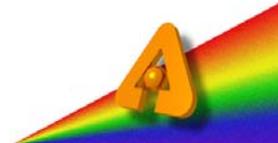
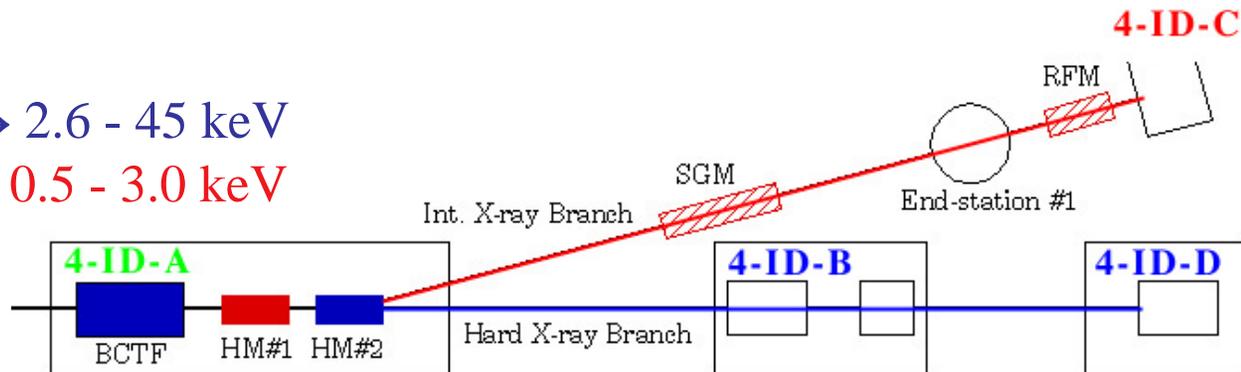


Of all the circled beamlines at the APS only XOR-4 is a dedicated facility for magnetism studies

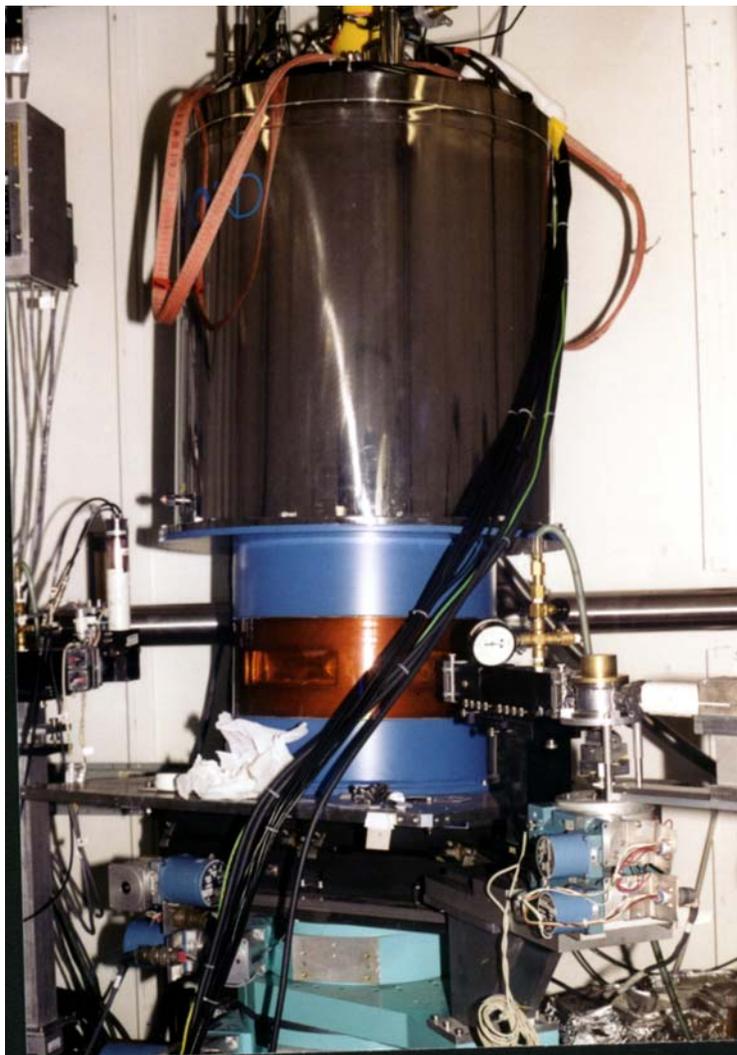
# Beamlines with Magnetism Capabilities



- hard → 2.6 - 45 keV
- soft → 0.5 - 3.0 keV

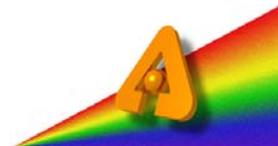


# High Field Capabilities (current: 13 T magnet)



Long term future plans:

Build a new ( $> 20$  T)  
facility



# Frontier Technical Requirements

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- Probe new physics at nanometer length scales -the length scale of exchange interaction.
- Time-resolution of  $< 1$  ps opens spin dynamics studies on scales characteristic of the exchange interaction.
  - Combination of  $< 5$  nm and  $< 1$  ps - even better
- High magnetic field opens new science in a wide range of fields: biology to highly-correlated electron systems.



## Recommendation: New facilities, New Resources

- Provide capabilities to study 2 nm length scales in elemental and magnetism-specific manners
  - Provide high-magnetic (20 T and beyond) facilities
  - Temporal Res. ps/fs realm
  - Thermal: mK
- 
- **Provide theoretical support for the APS facility**

