Report on the Nanomagnetism Workshop

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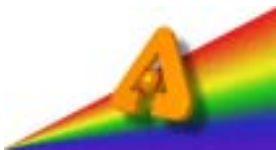
Overview:

- 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

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.

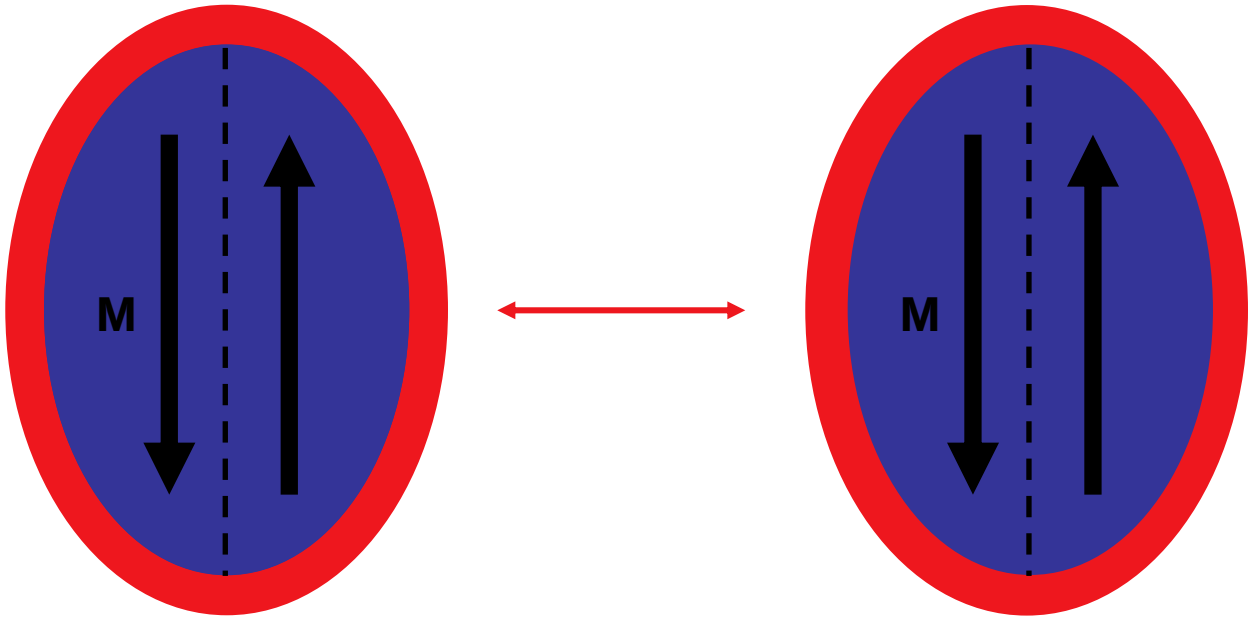
3. **Identify both short- and long-term R&D** to address these grand challenges.

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 economony**: 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!**

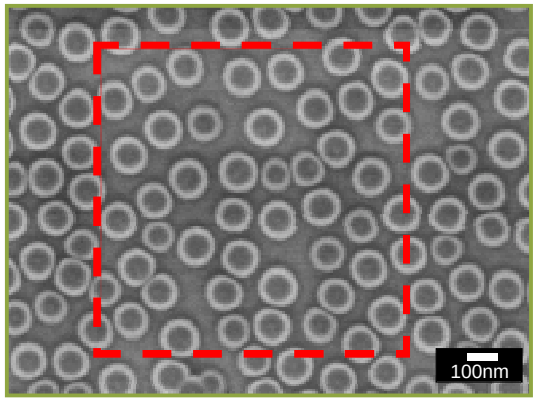


d = 1 - 100 nm

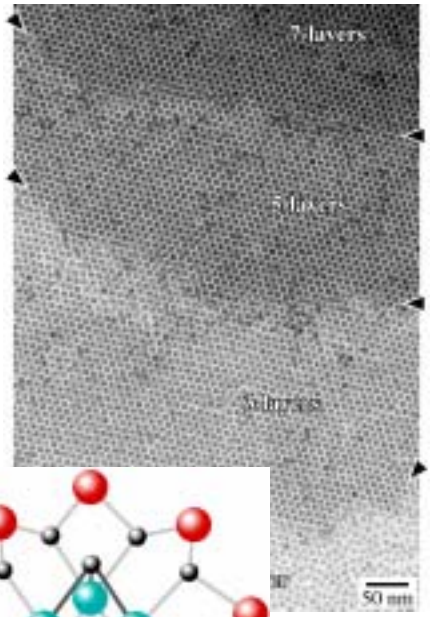
Interactions
Geometry
Fabrication
...

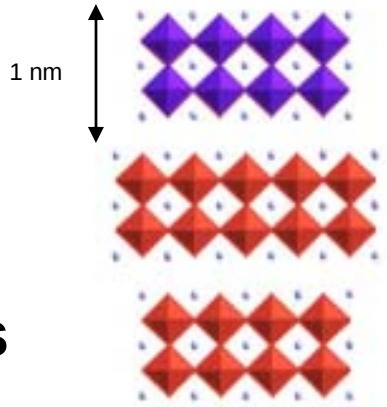
Scientific Themes: Unique Needs

- **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





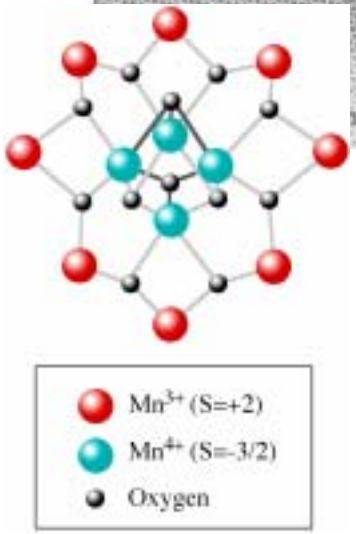
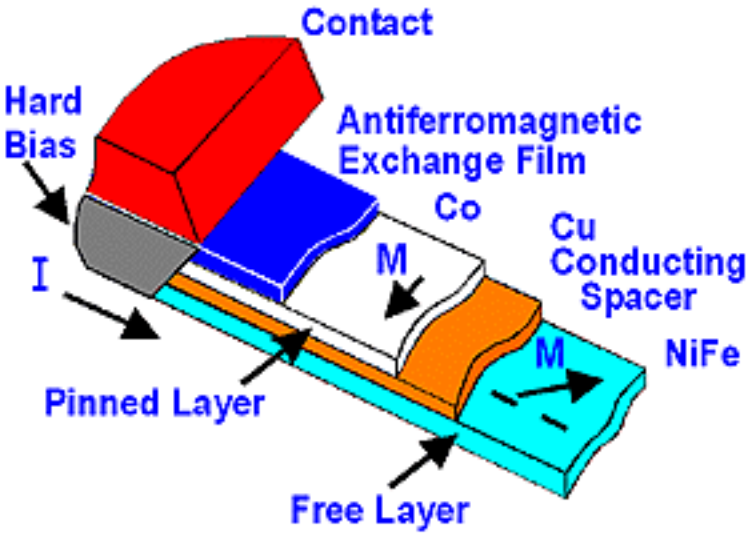


Figure 1 Schematic of layered manganite showing 1 nm thick modified surface layer.

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

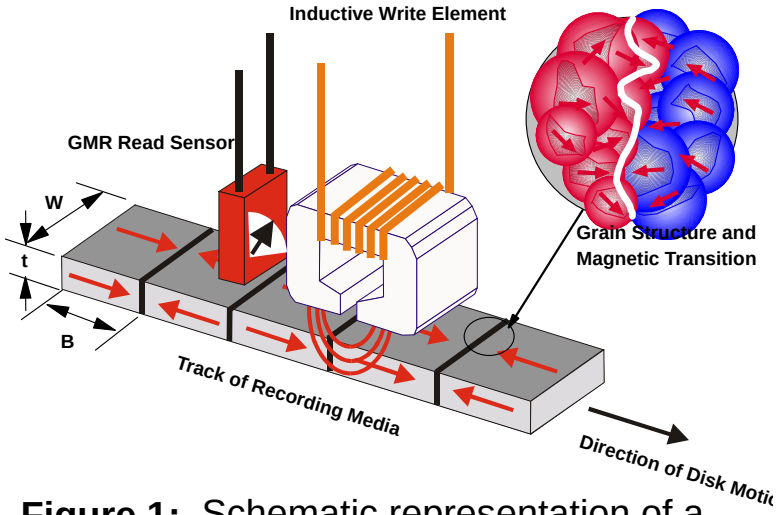
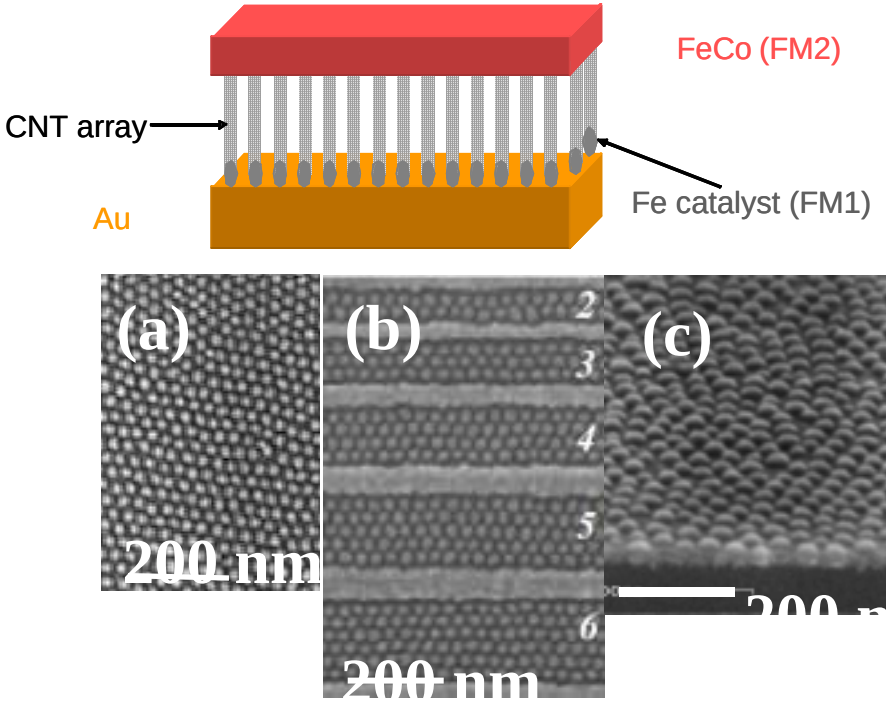


Figure 1: Schematic representation of a longitudinal recording system.

Scientific Destinations

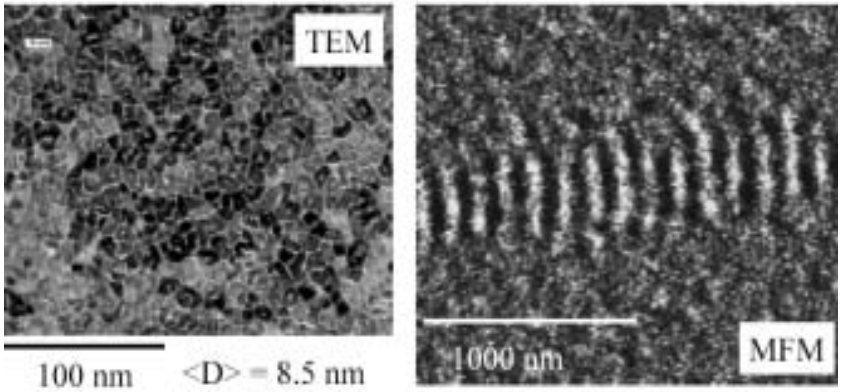
- Sustaining progress in information technology
  - Organic Spintronics
  - Spin-based quantum computing
  - Diblock Copolymer Lithography

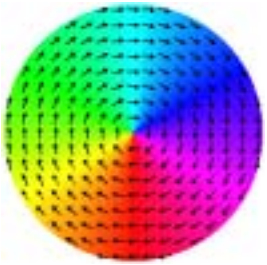


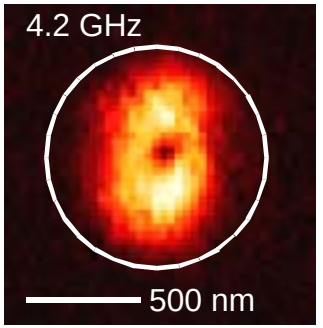
(a) Self assembled block copolymer on a smooth substrate, showing lack of long range order. (b) In shallow grooves, the polymer forms long range ordered structures. (c) Array of Co 'dots' made by block copolymer lithography.

Scientific Destinations *(cont'd)*

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

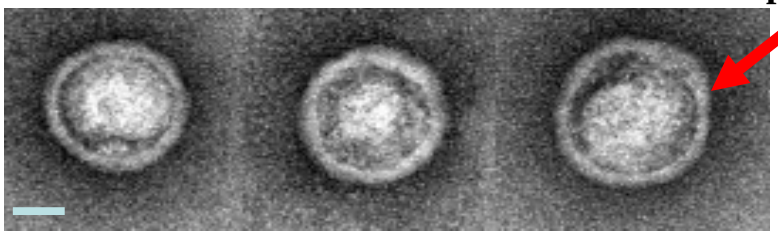






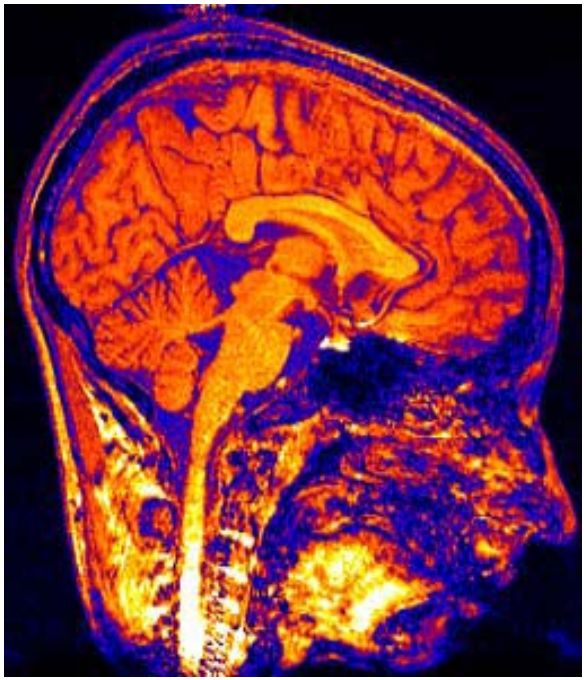
Scientific Marriages

- **Magnetism + Biology**
  - Protein and Viral Templating



20 nm

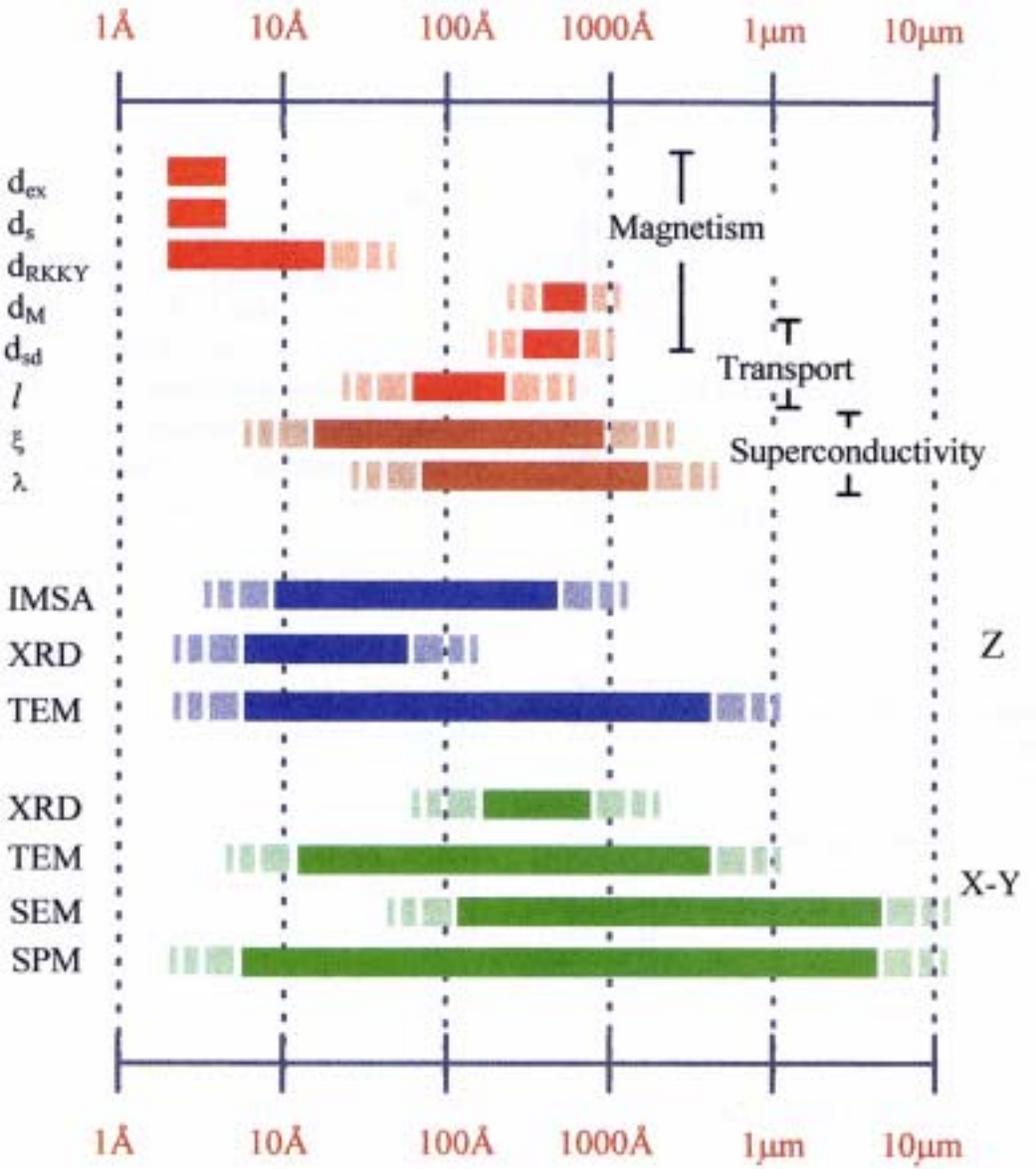
- **Magnetism + semiconductor**
  electronics, transport phenomena



neuroregeneration

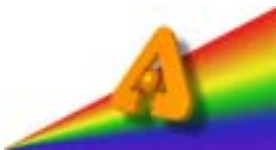
- **Magnetism + optics**

Length Scales

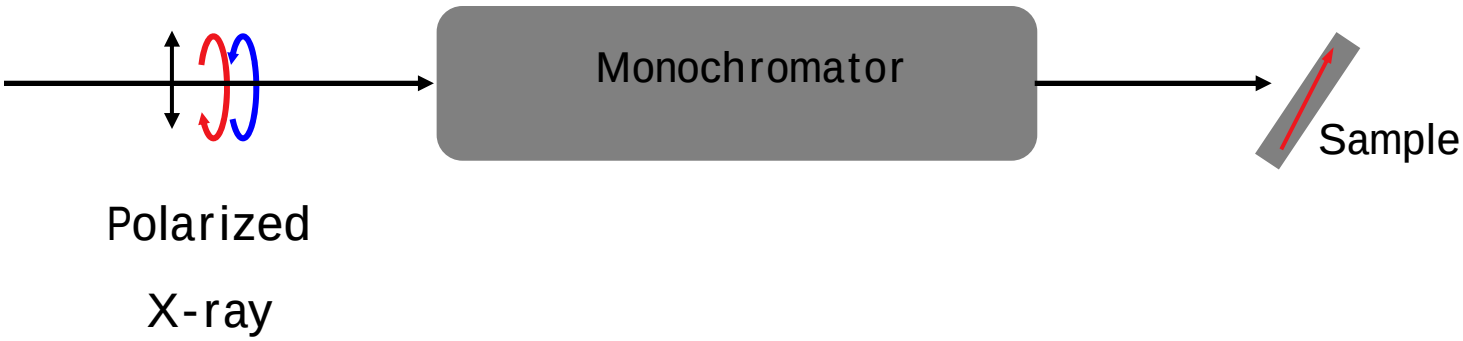


Why APS? Unique dedicated facilities

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



Polarized X-ray Techniques

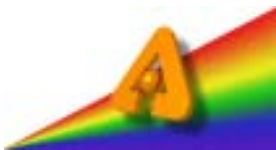


Element specific electronic and magnetic properties

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

Advantages of Synchrotron Sources

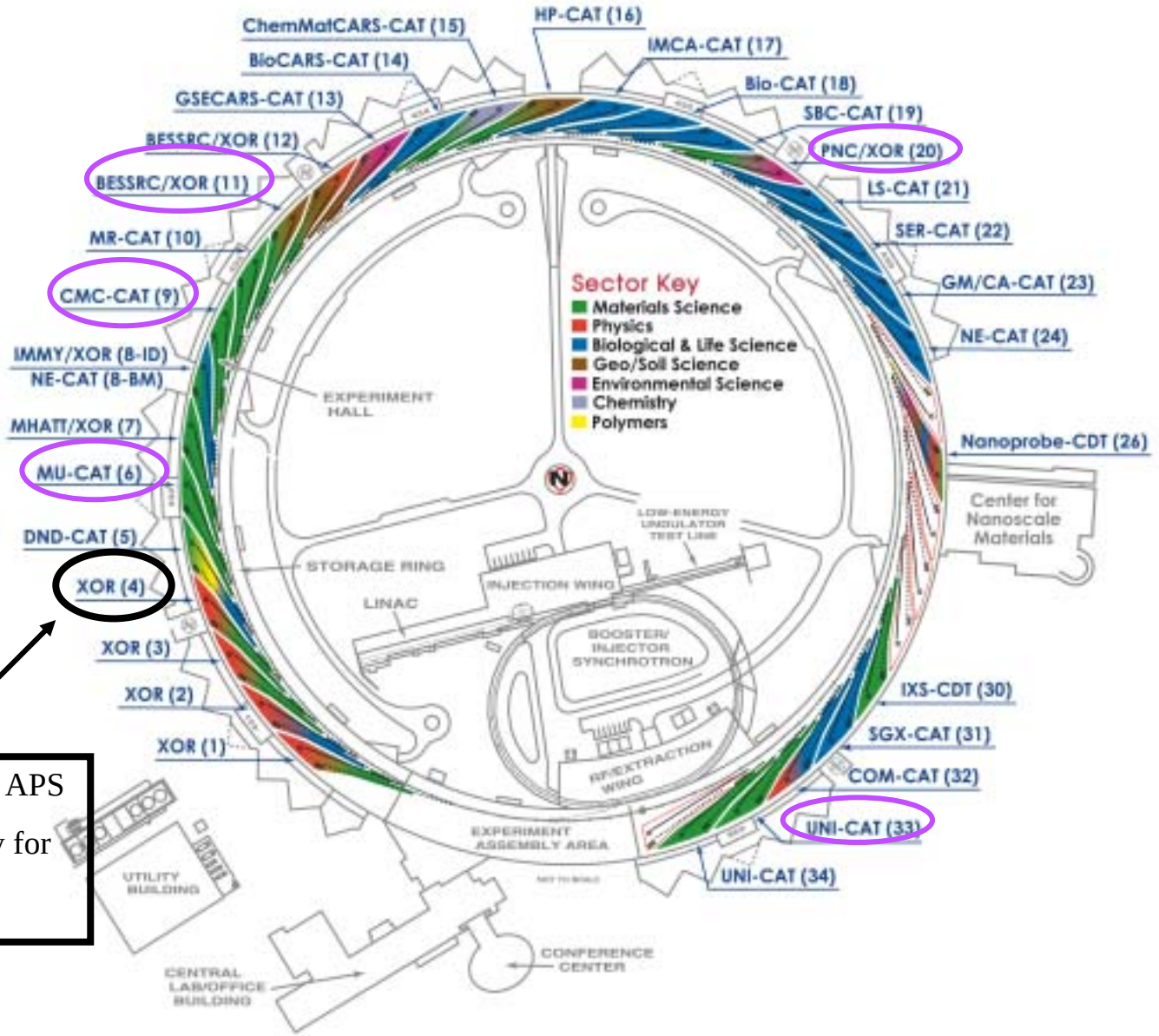
- ***Energy tunability → Element specificity***
  - ***Enables studies of heterogeneous systems***
- ***High brilliance → High flux density***
  - ***Enables studies of small and dilute samples***
- ***High momentum resolution → High spatial resolution***
  - ***Enables studies of surfaces and interfaces***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



Specific Magnetism Capability

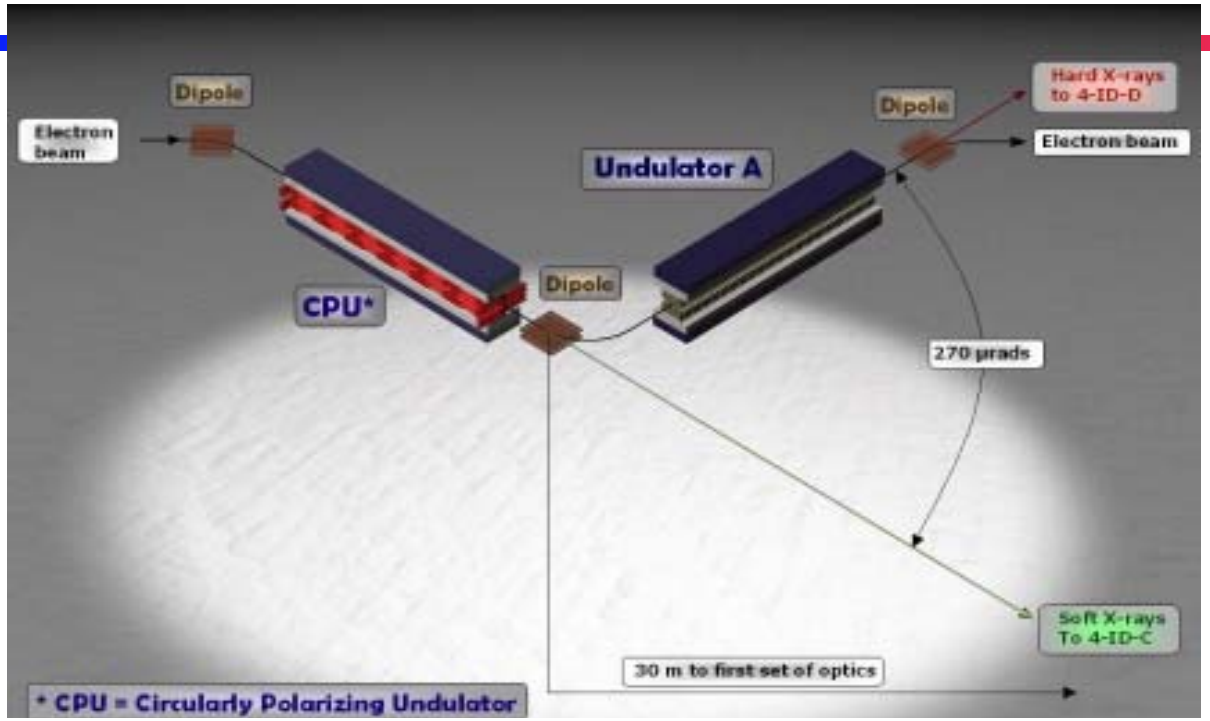
Separate orbital and spin contributions

Beamlines with Magnetism Capabilities

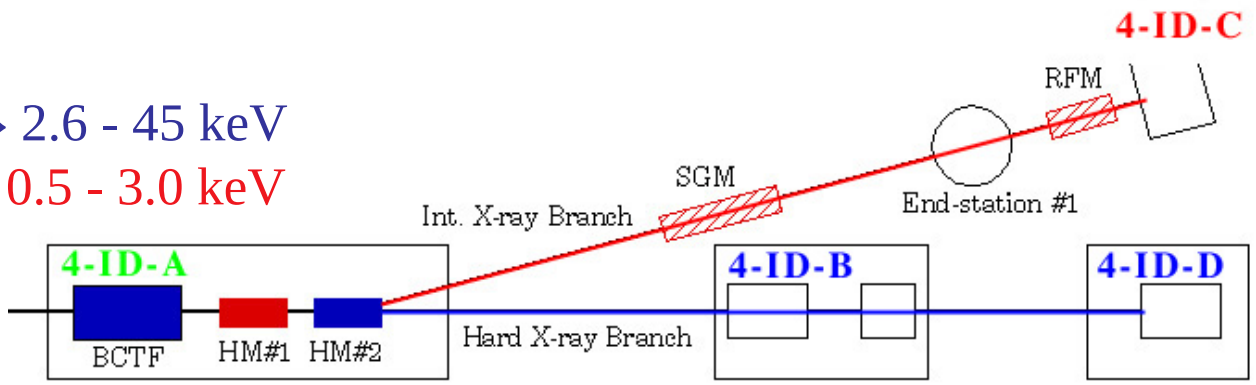


Of all the circled beamlines at the APS only XOR-4 is a dedicated facility for magnetism studies

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

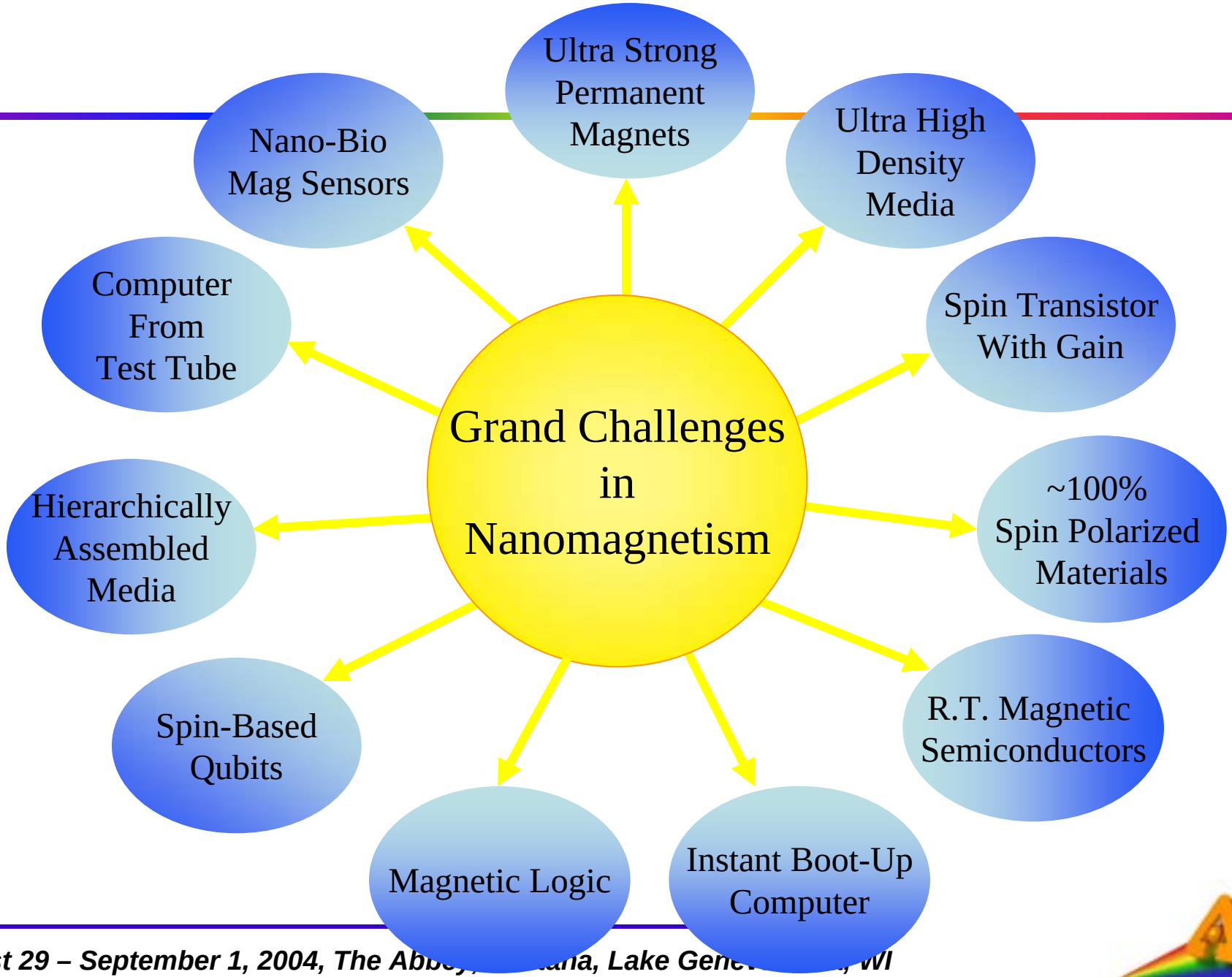
Frontier Technical Requirements

- 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**


Grand Challenges in Nanomagnetism
Ultra Strong Permanent Magnets
Ultra High Density Media
Spin Transistor With Gain
~100% Spin Polarized Materials
R.T. Magnetic Semiconductors
Instant Boot-Up Computer
Magnetic Logic
Spin-Based Qubits
Hierarchically Assembled Media
Computer From Test Tube
Nano-Bio Mag Sensors