
Surfaces and Interfaces from Strongly Correlated Materials

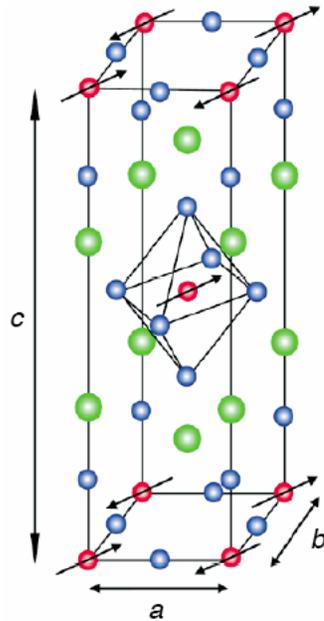
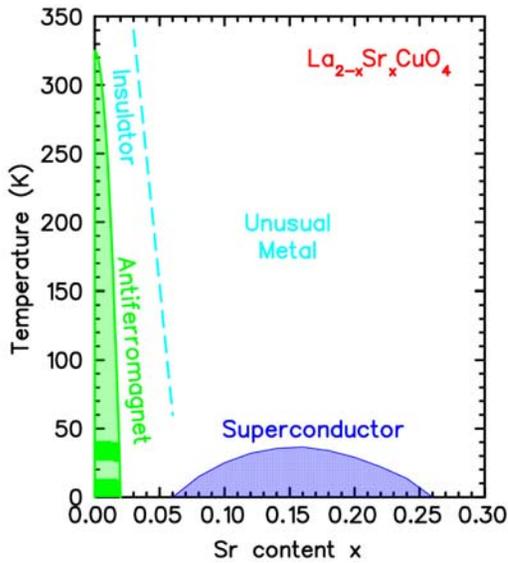
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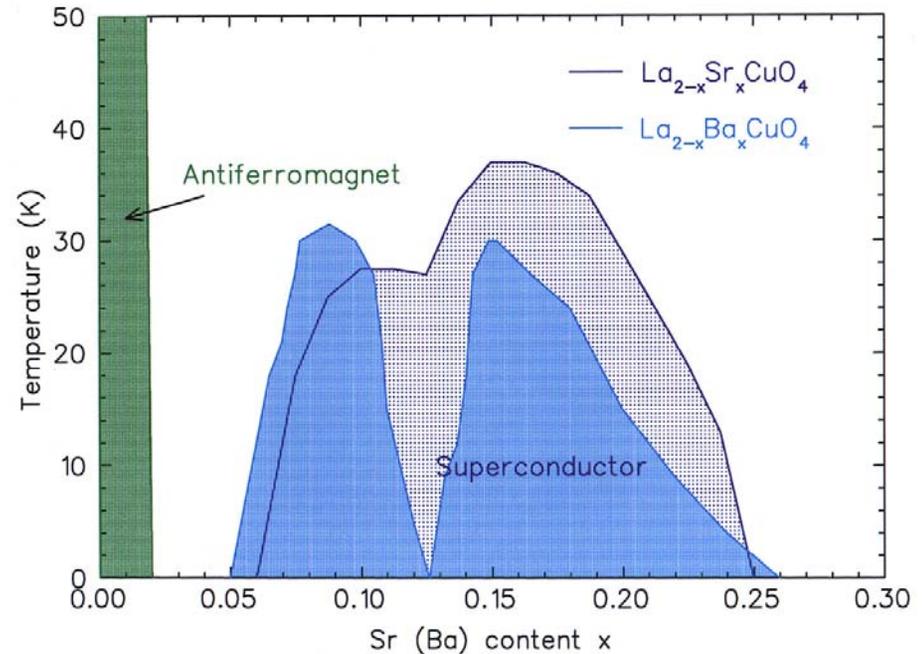
Outline

1. Introduction to Strongly Correlated Systems
2. Why are surfaces and interfaces important?
3. What has been done too date?
4. Our chamber for the future....
5. Future.....

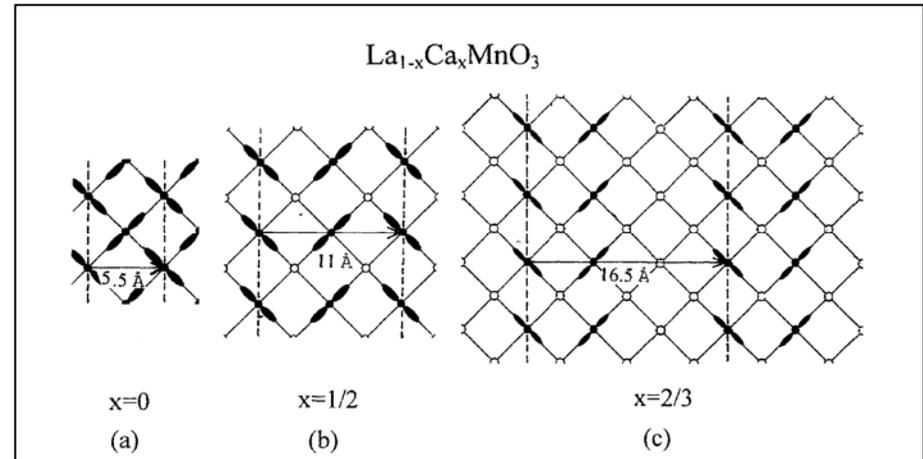
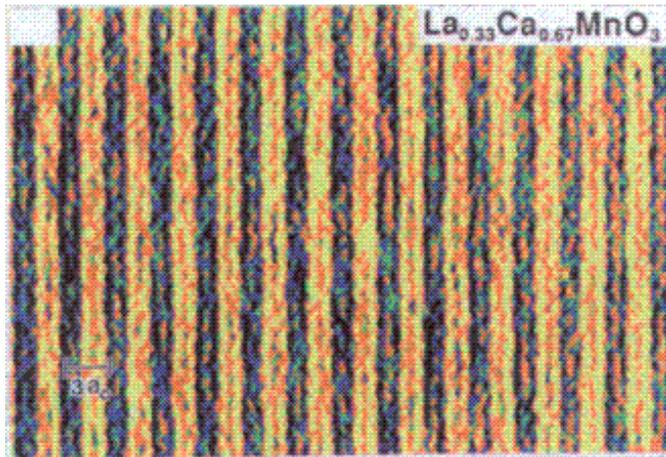
Cuprate Superconductors



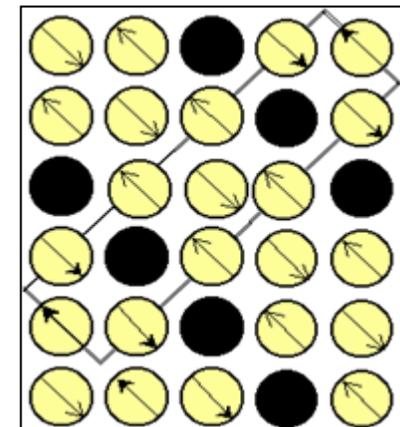
- Cu^{2+}
- O^{2-}
- La^{3+}



Stripes : Controllable Nanostructure Physics



Charge and spin stripes (e.g. $\text{Mn}^{3+}/\text{Mn}^{4+}$) or ordering can be controlled by doping in manganites, nickelates, cuprates, cobaltates, ferrates etc. Strongly linked to CMR, Superconductivity etc.



Why is the surface becoming important?

- Transition from bulk single crystal to nano-scaled device.
 - Nanoscaled devices have a very large surface to volume ratio.
 - Interfacial properties important to functioning of and device and lead to new systems from new properties.

Why are we interested in the surface?

- Electronic Reconstruction?
 - Similar to traditional reconstruction on the surface of materials
 - But strongly correlated materials show electronic phases due to strong electron-electron and electron-lattice interactions: charge/ spin and orbital ordering, High T_c ?
 - *How does the surface / interface electronic phase differ from the bulk?*

Okamoto, S. and Millis, A.J. *Nature (London)* **428**, 630 (2004)
Example: S. Smadici, *Phys. Rev. Lett.* **99**, 196404 (2007)

What about other probes?

- Traditional probes

- Neutrons
- X-ray Scattering
- “Bulk” Lab Tech.

QuickTime™ and a decompressor are needed to see this picture.

- In the field of SCES much information is obtained from such techniques as STM, Photoemission which are surface sensitive
- For example, in cuprates STM measurements show checkerboard ordering, not stripes!

Magnetism at the surface

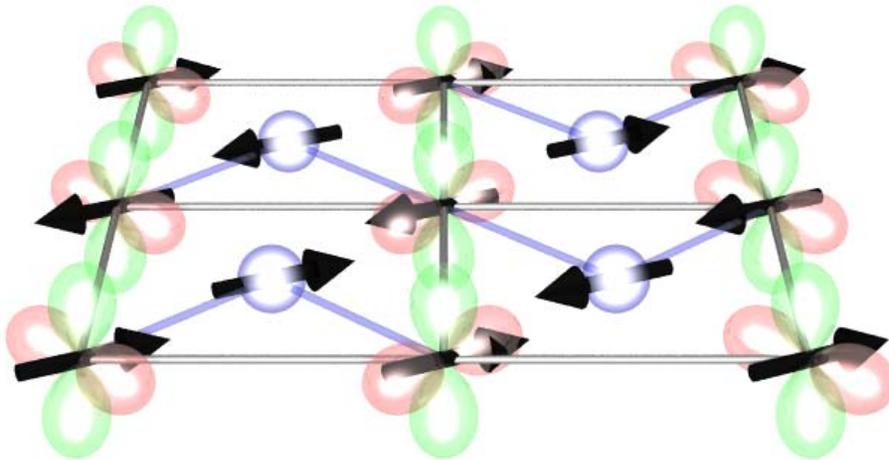
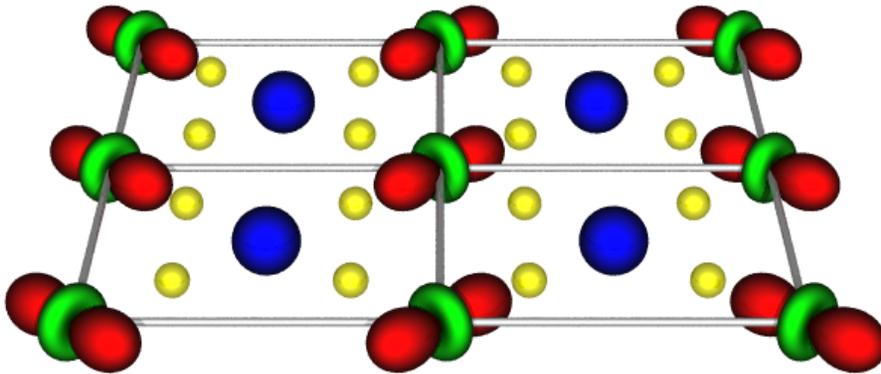
- Nickel oxide. AF order at a surface
- Nonresonant - HARD
- NiO (111) Surface spins remain ordered at a higher temperature than the bulk.

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Barbier et al. Phys. Rev. Lett. **93**, 257208 (2004)

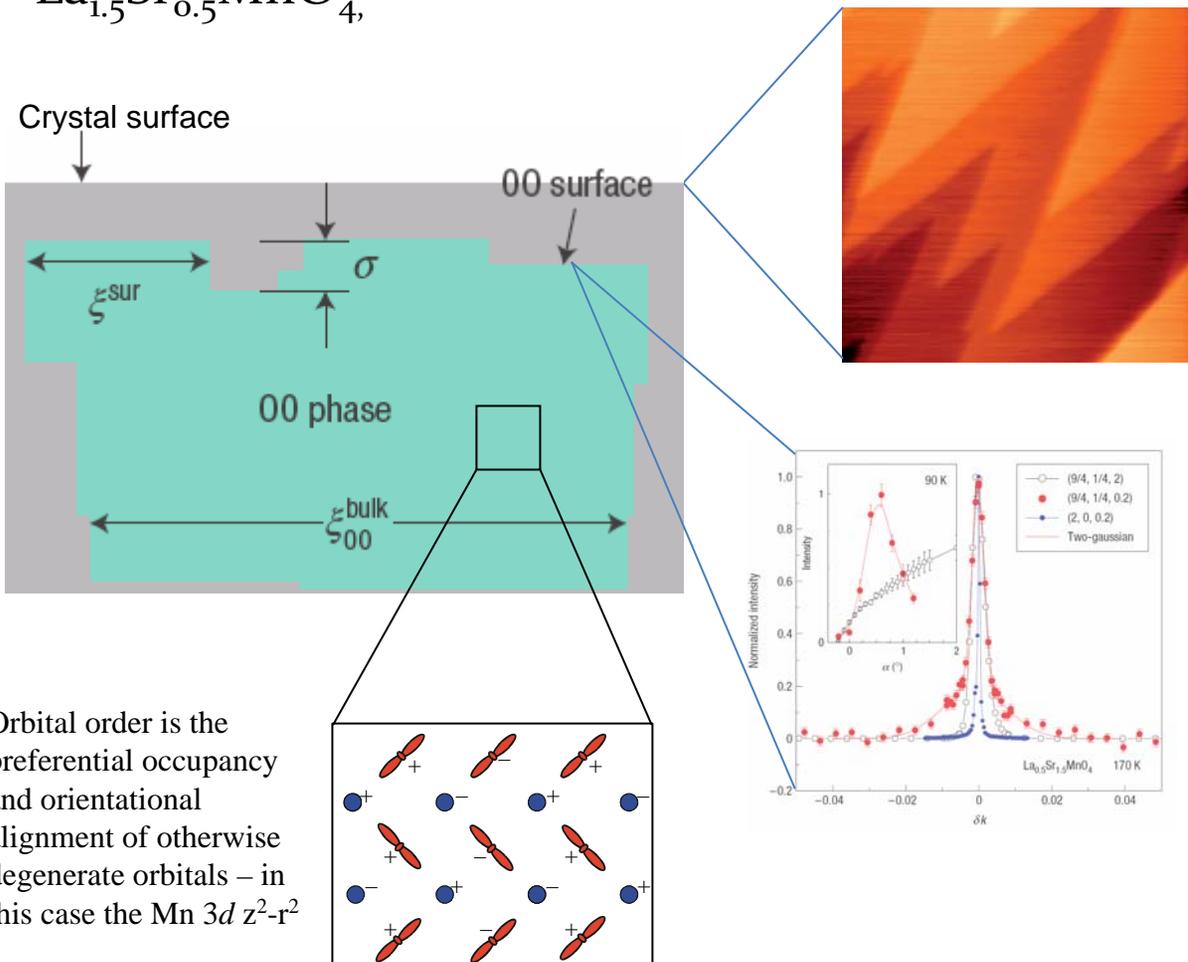
Orbital + Magnetic order ($\text{La}_{0.5}\text{Sr}_{1.5}\text{MnO}_4$)



- Superstructure reflections from both magnetic and orbital order
- Orbitals are ferro-ordered along c but magnetic moments are anti-ferro ordered along c

Electronic Roughness at a Surface

The x-ray group looked at the electronic **orbital order** at the surface of $\text{La}_{1.5}\text{Sr}_{0.5}\text{MnO}_4$,



Grazing incidence x-ray diffraction and AFM show that the crystallographic surface is **atomically smooth**, and La terminated.

Interestingly, the orbital “surface”, is not defined by the atomic surface and is much rougher than the crystallographic surface. It also has a correlation length much shorter than that in the bulk (120 Å cf 400 Å)

Wakabayashi et al. Nature Materials, 2007

Resonant X-ray Scattering

- What we need is an enhancement of scattering from charge, orbital and spin ordering.
 - RESONANT X-RAY SCATTERING!
- X-ray Photon In / Photo Out technique
- Sensitive to superstructure due to magnetic and orbital order through the ATS or Templeton² scattering.
- Closely related to absorption techniques such as XMCD, XMLD

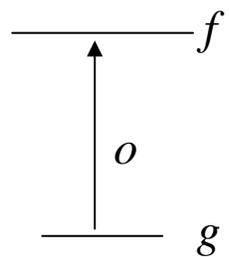
Resonant X-ray Scattering

The signal depends on the transition matrix (Fermi golden rule)

$$\langle f | \vec{\epsilon} \cdot \vec{r} \left(1 - \frac{i}{2} \vec{k} \cdot \vec{r} \right) | g \rangle = \langle f | \vec{\epsilon} \cdot \vec{r} | g \rangle - \frac{i}{2} \langle f | \vec{\epsilon} \cdot \vec{r} \vec{k} \cdot \vec{r} | g \rangle$$

dipole

quadrupole



XANES case: real absorption

$$\sigma(\omega) = 4\pi^2 \alpha \hbar \omega \sum_{f,g} |\langle f | o | g \rangle|^2$$

The density of states is in f

RXS case: virtual absorption

$$f'(\omega) + if''(\omega) = -m_e \omega^2 \int_{E_{Fermi}}^{\infty} \frac{\sum_{f,g} \langle g | o_o^* | f \rangle \langle f | o_i | g \rangle}{E - E_g - \hbar\omega + i\frac{\Gamma}{2}} dE$$

Summation over the atoms with Bragg factor + Thomson term :

$$I = \frac{K}{V^2} \left| \sum_{atoms} e^{i\vec{Q} \cdot \vec{R}_a} (f_{0a} + f'_a(\omega) + if''_a(\omega)) \right|^2$$

XANES and RXS are very sensitive to the 3D environment !

Resonant Scattering

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decompressor
are needed to see this picture.

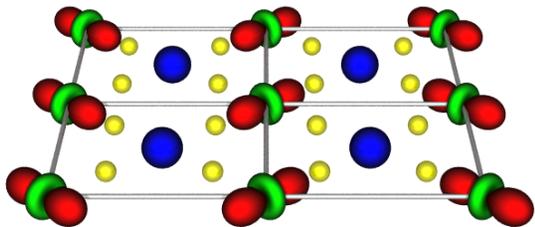
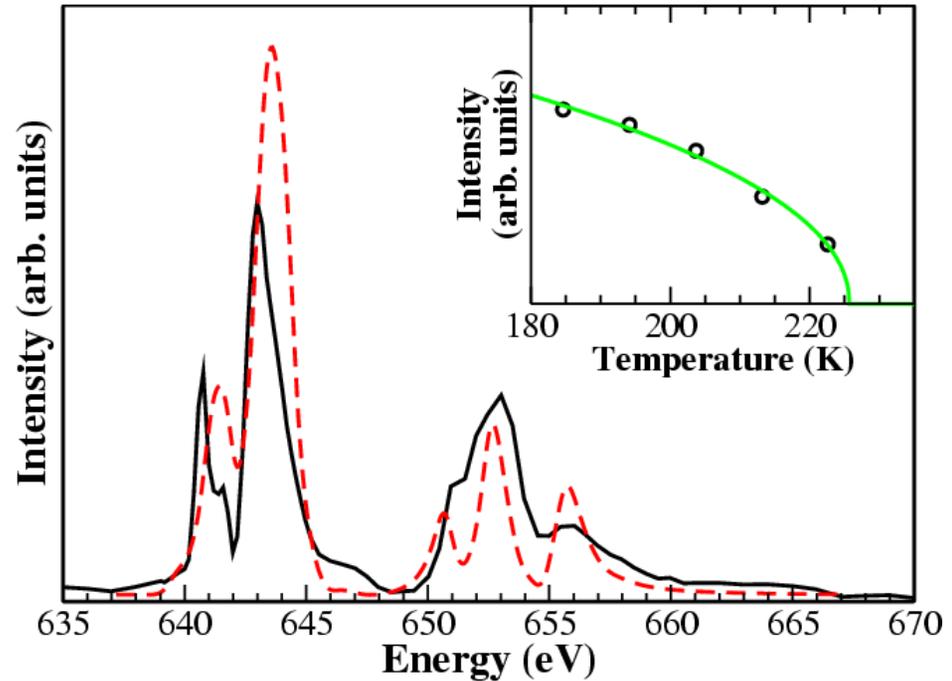
QuickTime™ and a
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- Surface scattering from
3-k magnetism at the
surface (X22C)

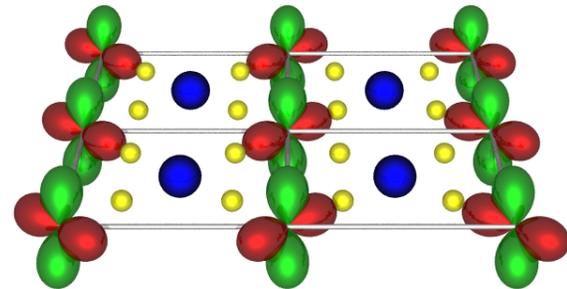
“Orbital” Scattering

Orbital order reflection shows strong energy dependence. More scattering observed at L_2

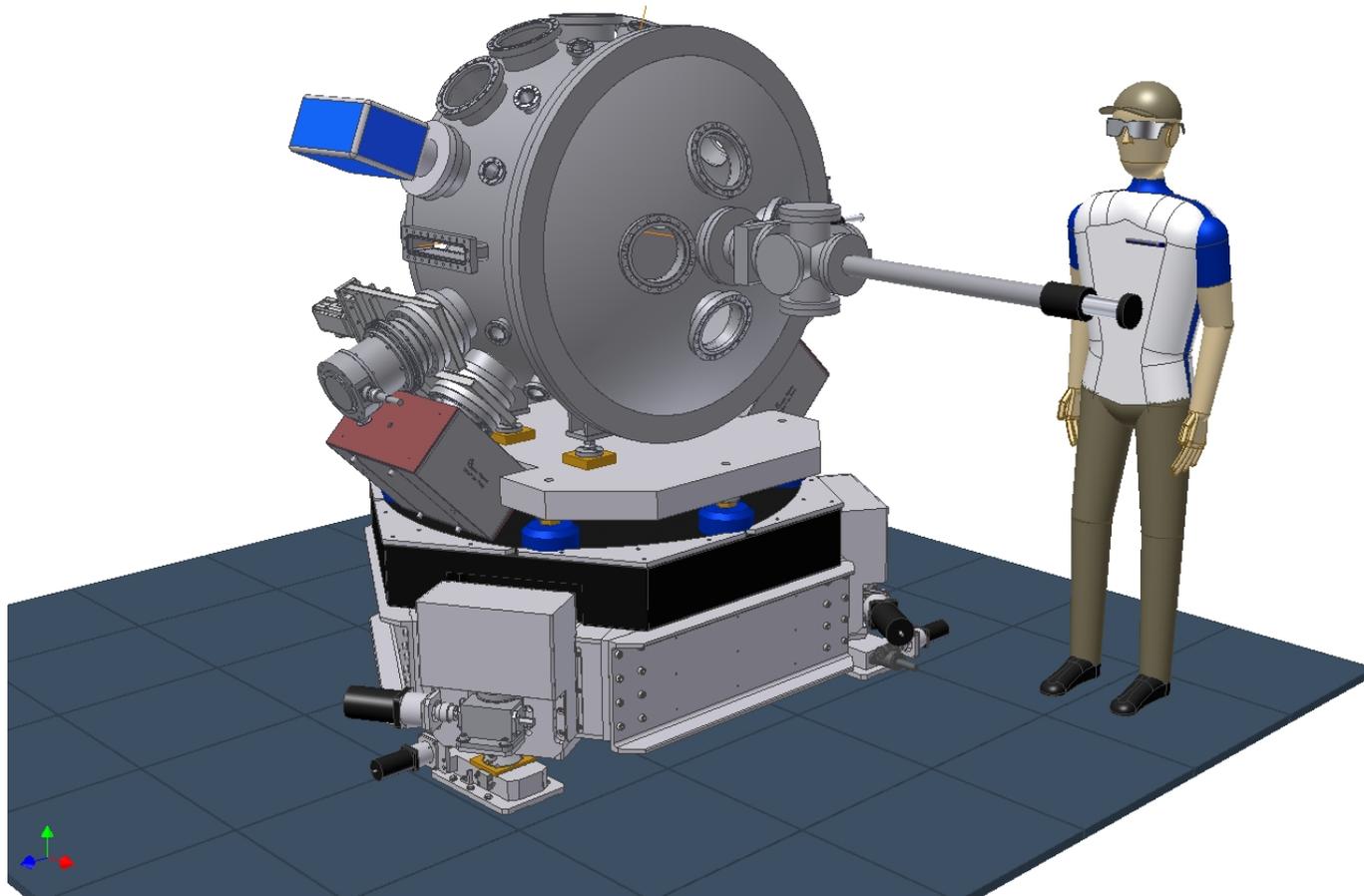
Comparison with multiplet calculations shows that in $\text{La}_{0.5}\text{Sr}_{1.5}\text{MnO}_4$ system is strongly Jahn-Teller ordered.



or

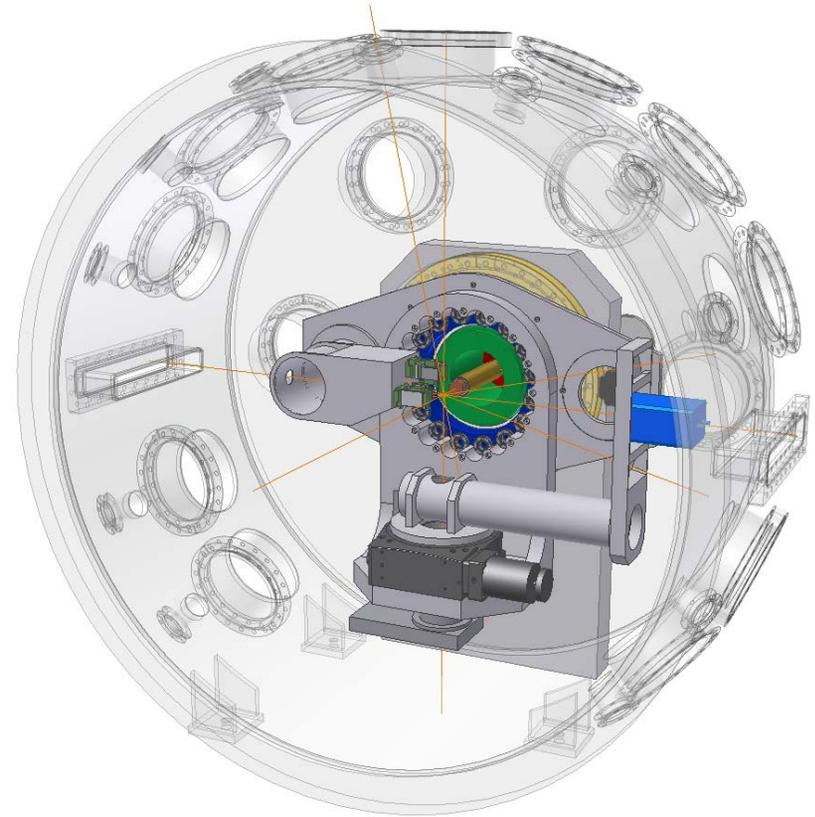


Soft X-ray Diffraction + Imaging



Chamber specifications

- Soft X-ray Diffraction (Pseudo sixc geometry)
- Sample cooling
 - 5 K (on sample)
- GIXD + Imaging
- Zone Plate focusing
 - NSLS 100nm
 - NSLS-II 30nm ???



Chamber specifications

