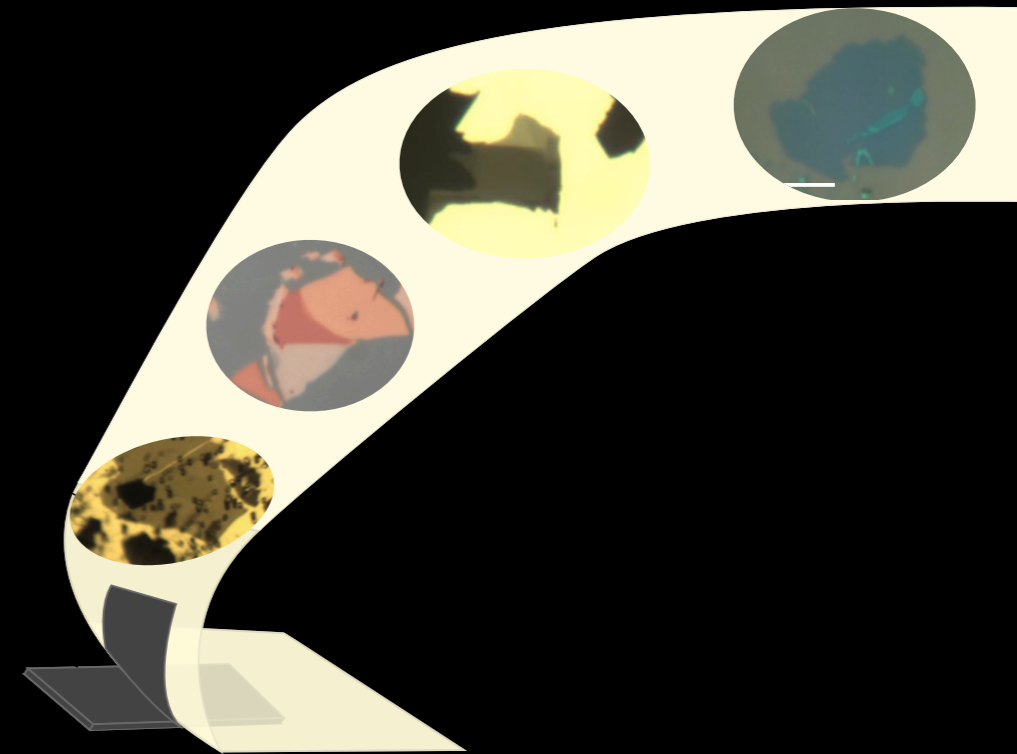


Optics and Scotch Tape: New Discoveries Beyond Carbon



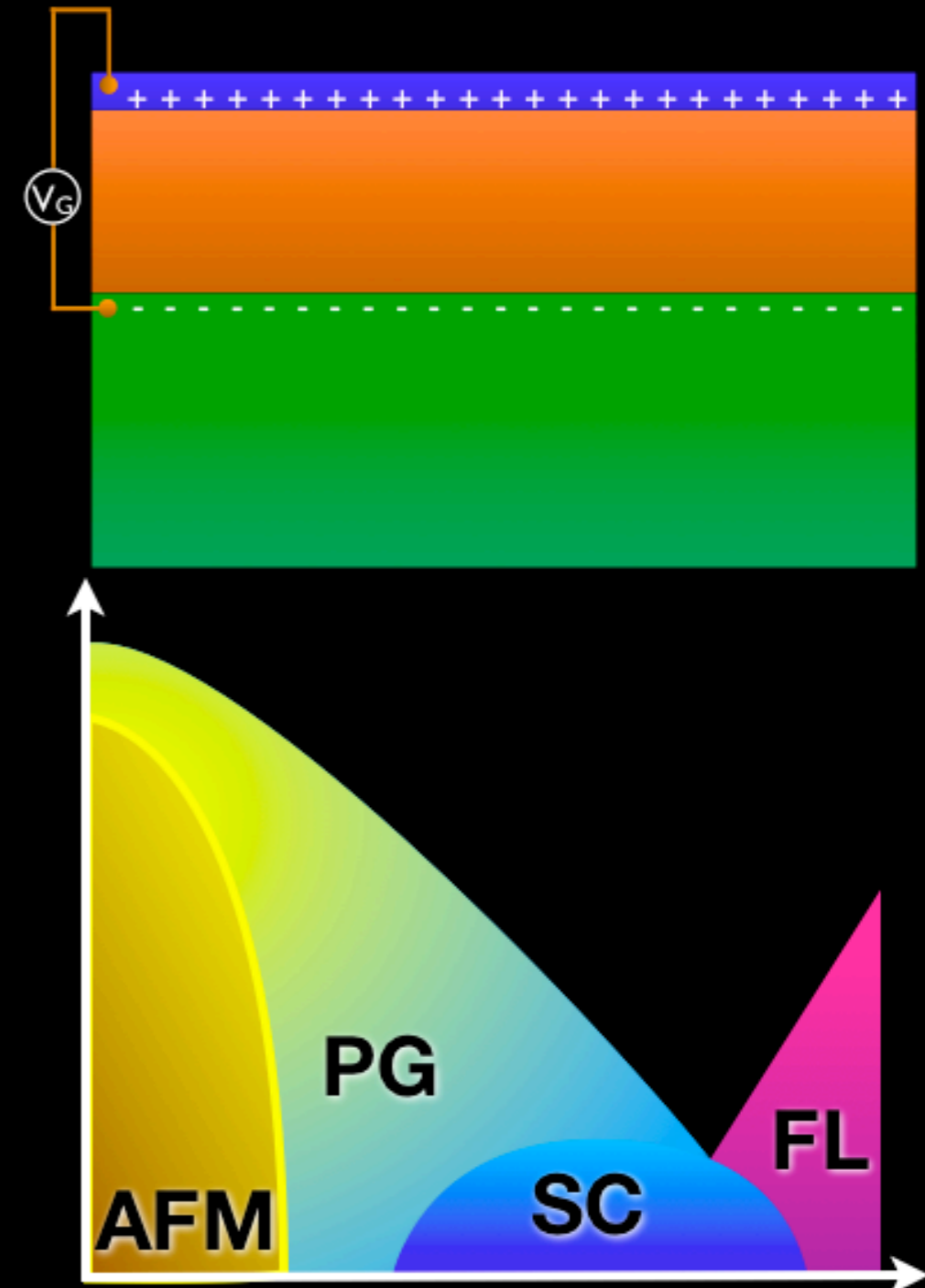
Optics and Scotch Tape: New Discoveries Beyond Carbon



Optics and Scotch Tape:

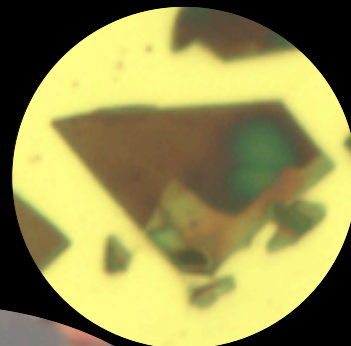
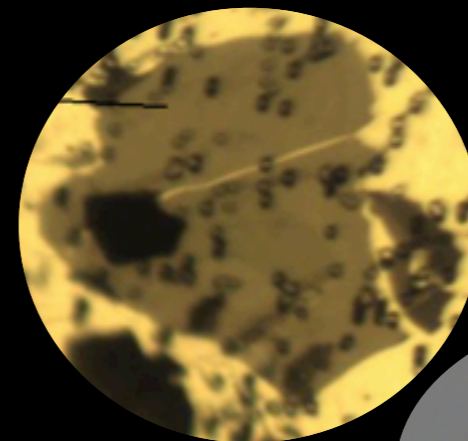
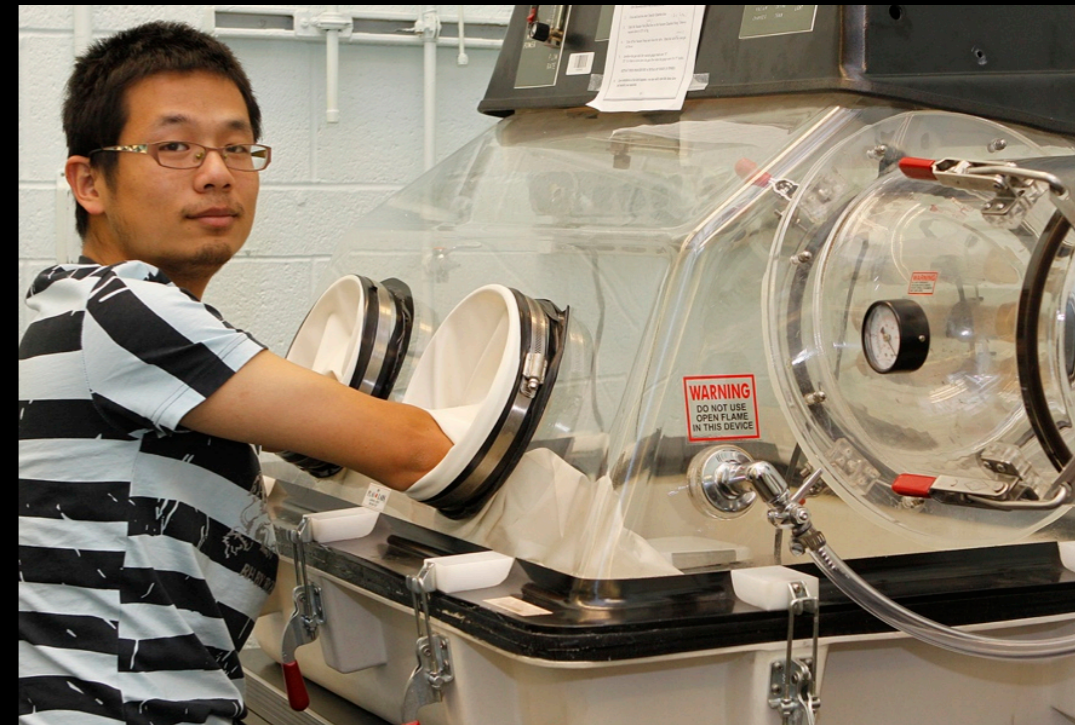
New Discoveries Beyond Carbon

- **Phases**
- **Exfoliation**
- **Optics**
- **Topology**
- **Future Directions**



Optics and Scotch Tape: New Discoveries Beyond Carbon

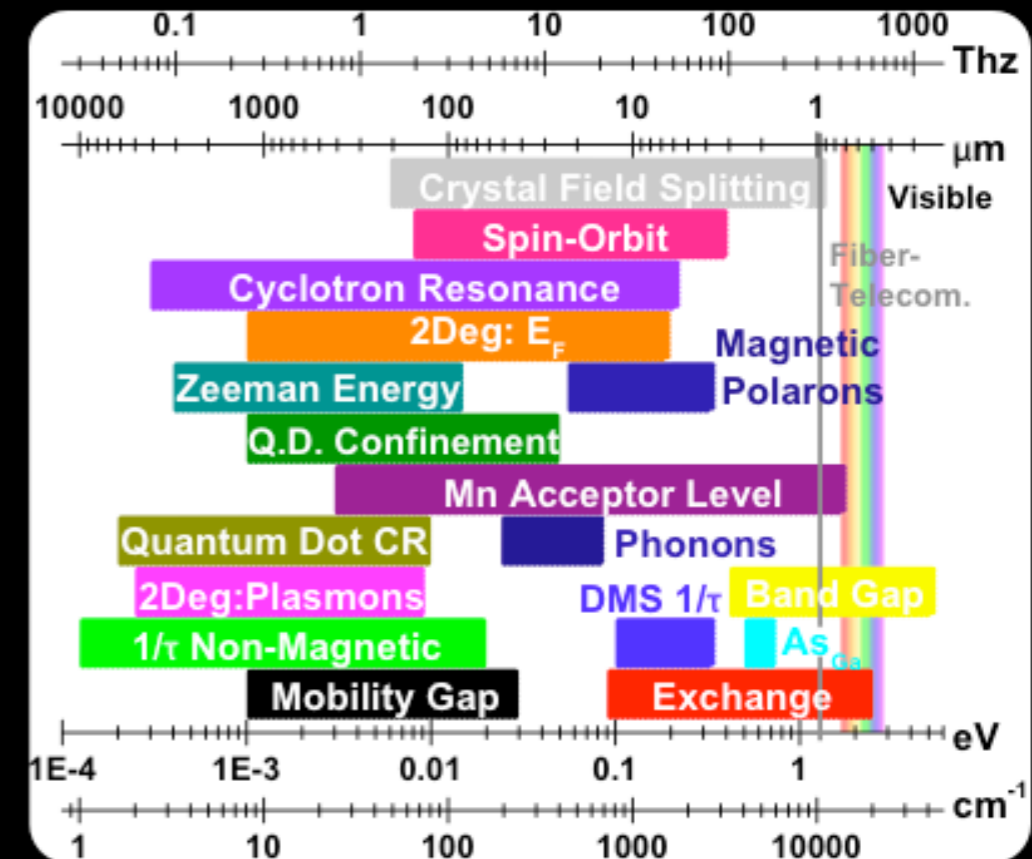
- Phases
- **Exfoliation**
- Optics
- Topology
- Future Directions



Optics and Scotch Tape:

New Discoveries Beyond Carbon

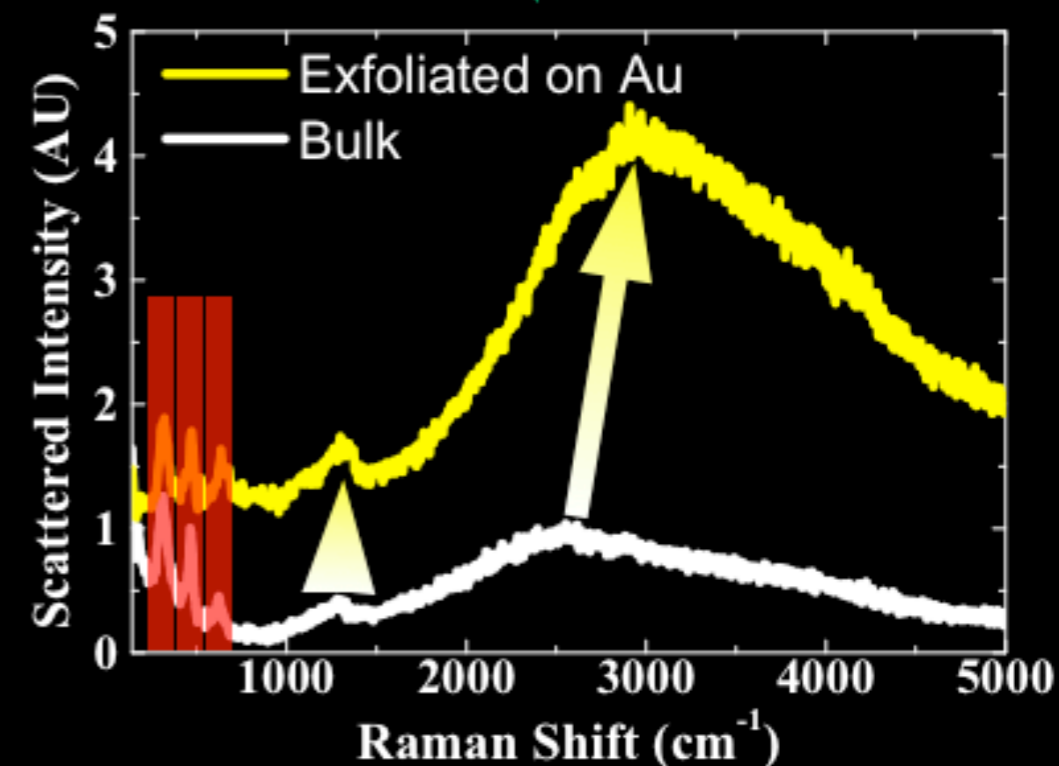
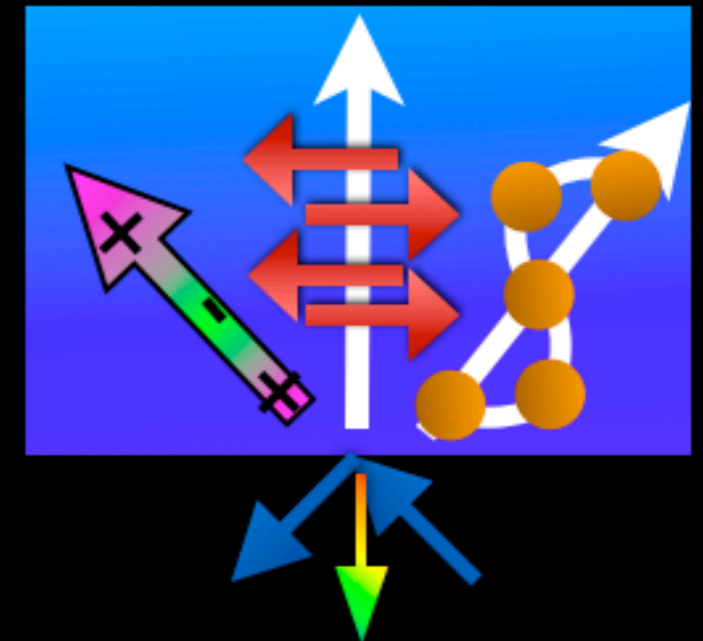
- Phases
- Exfoliation
- **Optics**
- Topology
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Optics and Scotch Tape:

New Discoveries Beyond Carbon

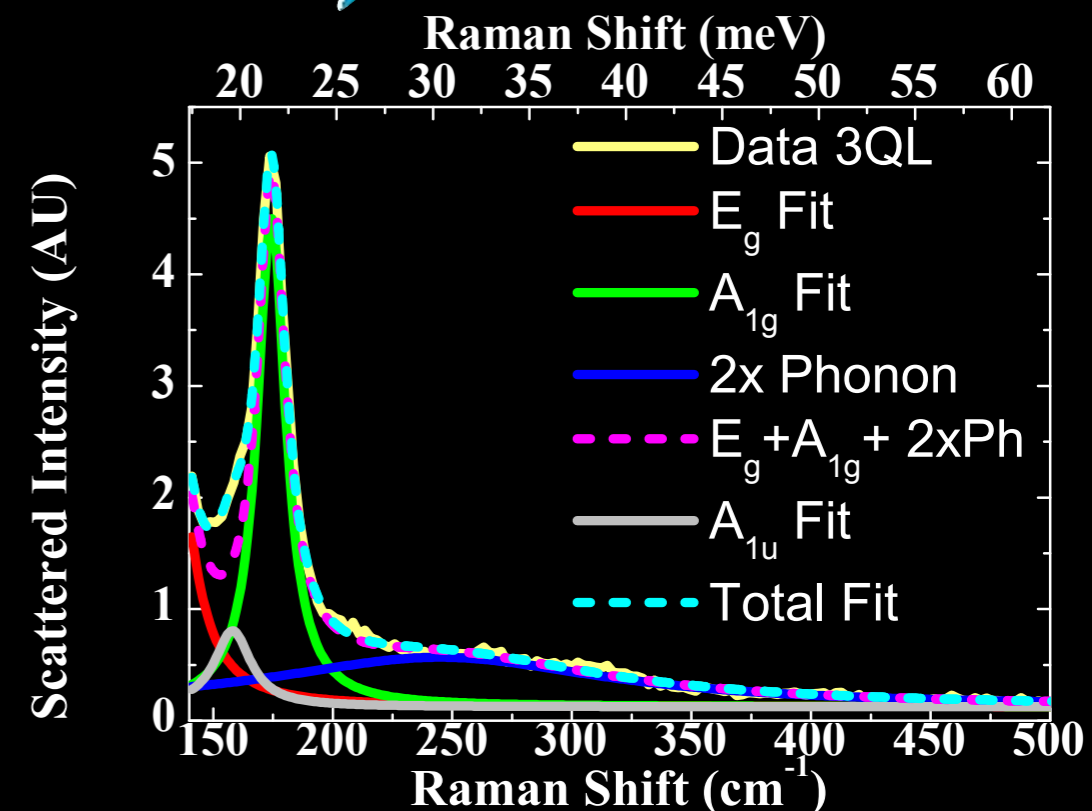
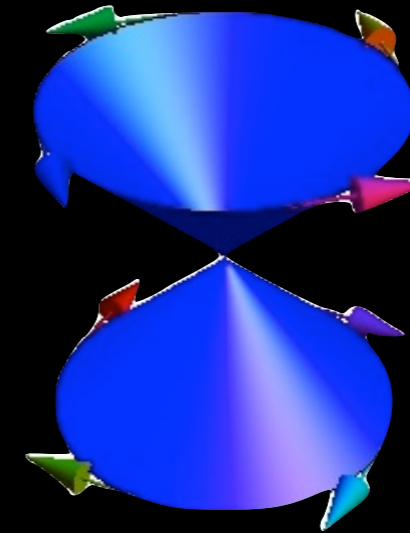
- Phases
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- **Optics**
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Optics and Scotch Tape:

New Discoveries Beyond Carbon

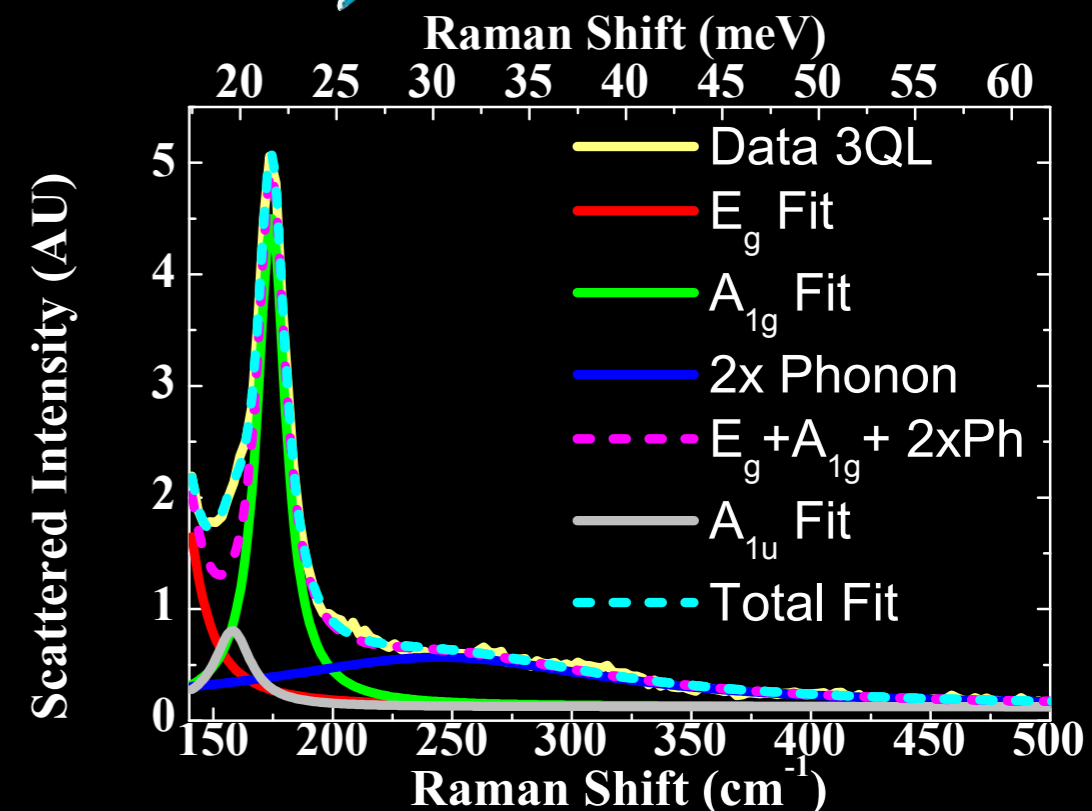
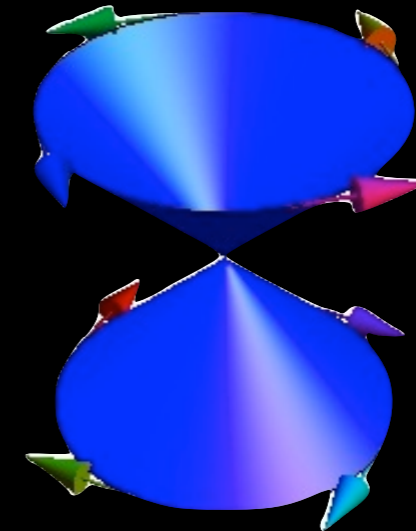
- Phases
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- **Topology**
- Future Directions



Optics and Scotch Tape:

New Discoveries Beyond Carbon

- Phases
- Exfoliation
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- Topology
- Future Directions





Acknowledgements

Y. Ando

Osaka

S. Ono

CREIPI

G.D. Gu

BNL



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Osaka Princeton
S. Ono D. Kwok
CREIPI N. Lee
G.D. Gu S.W. Cheong
BNL Rutgers



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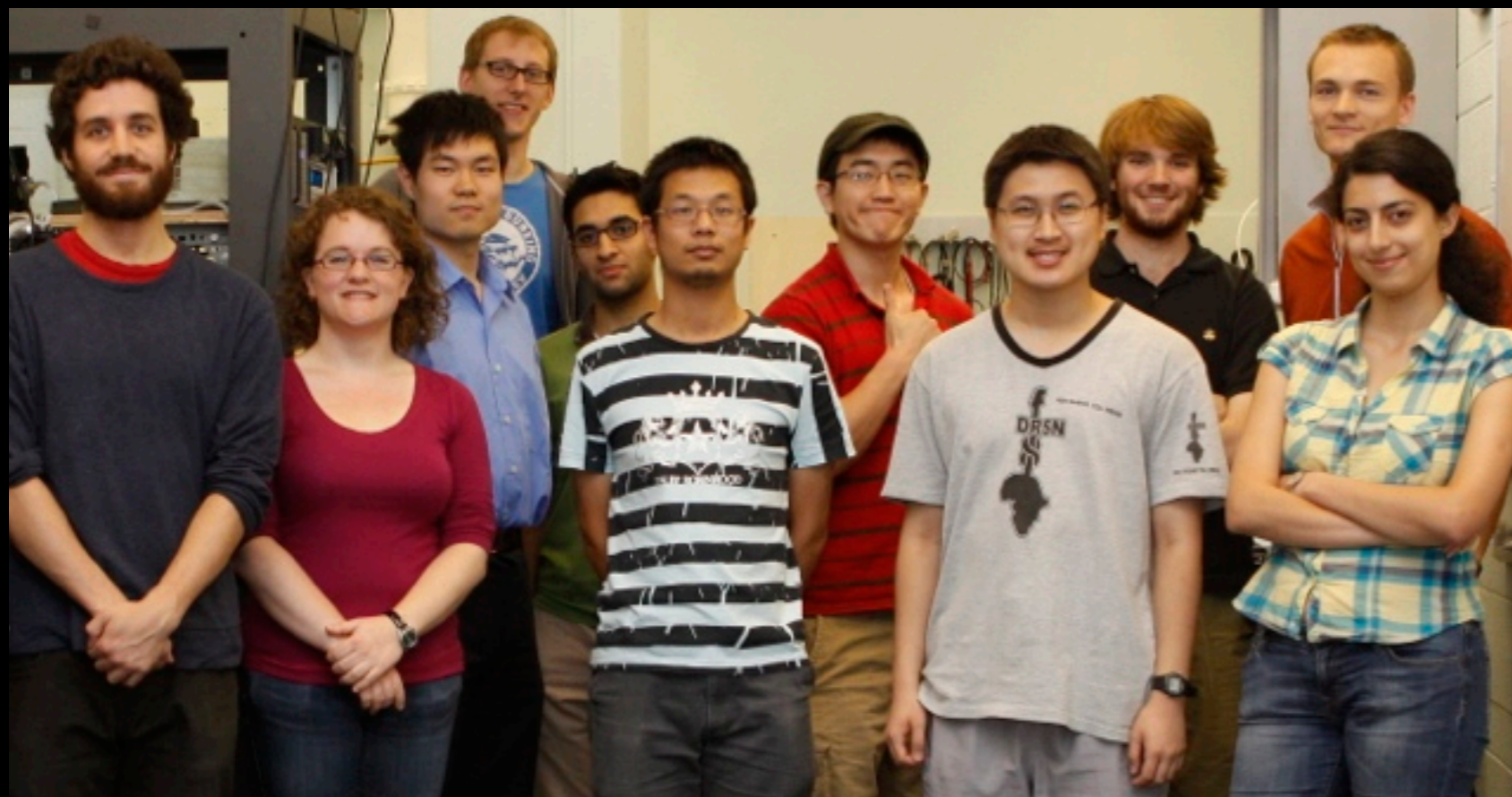


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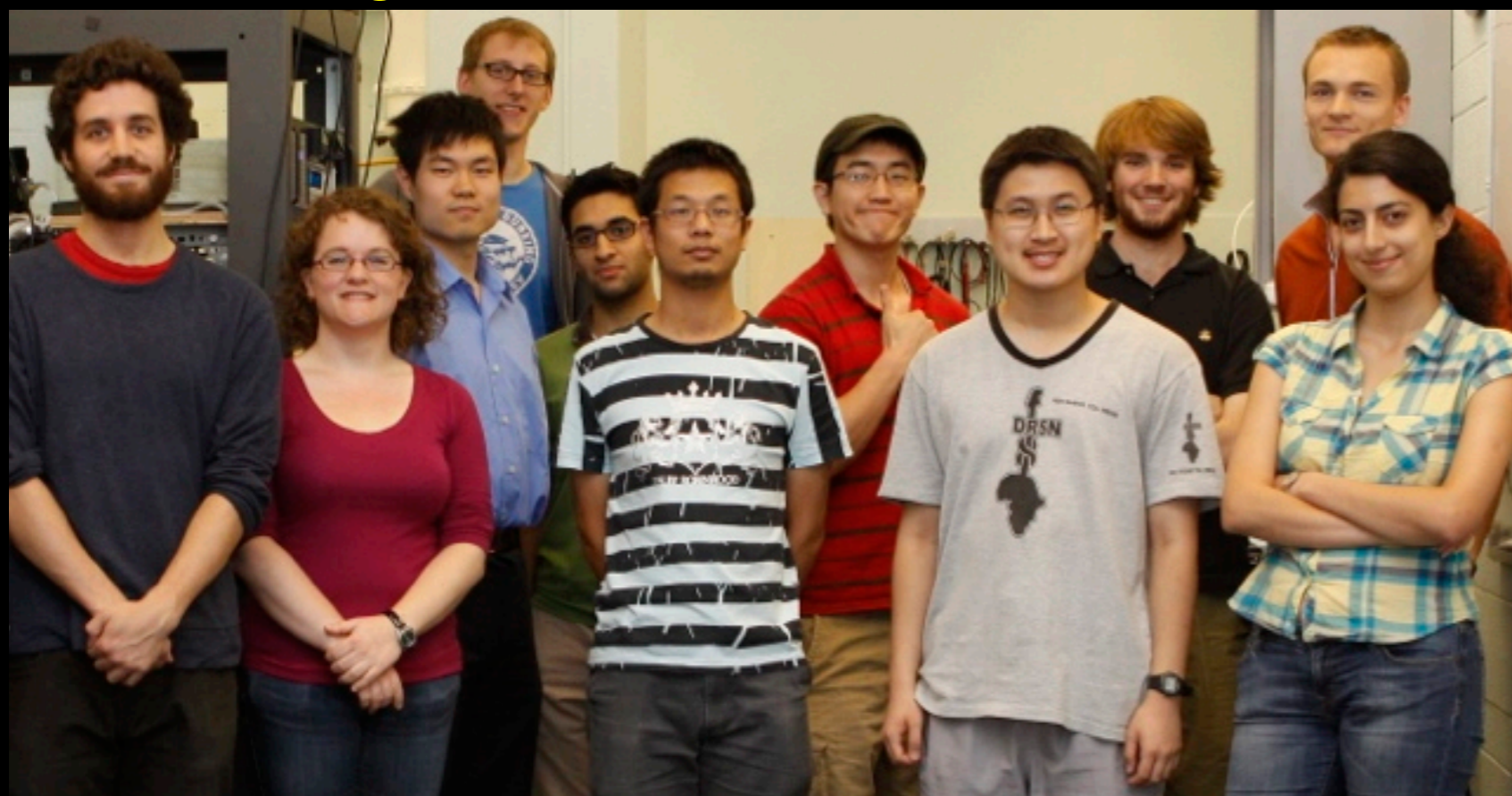
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 P. Zareapour





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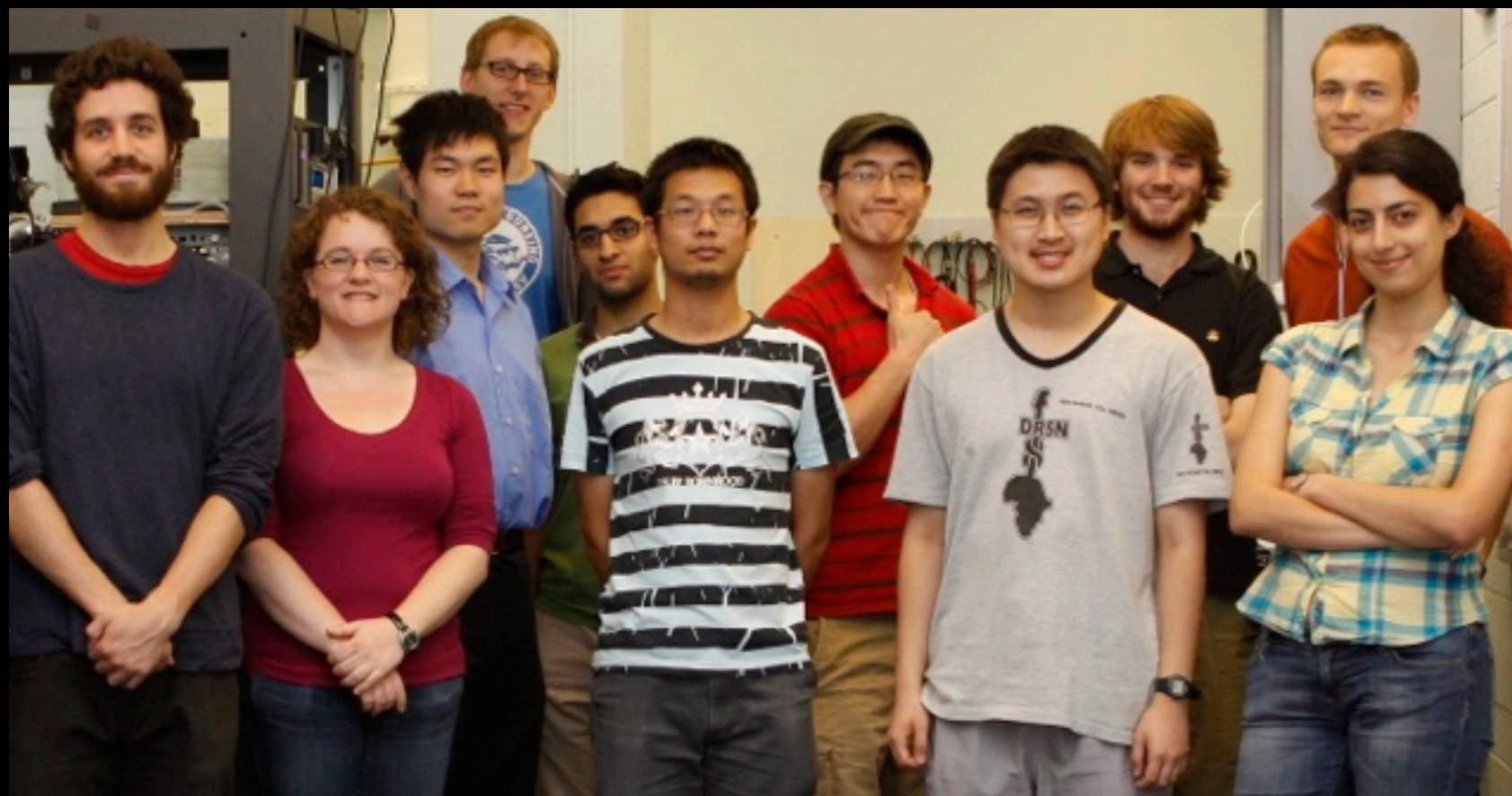


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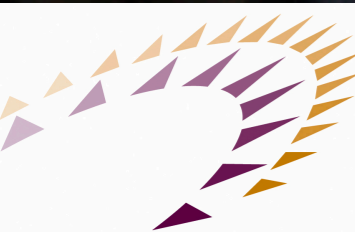


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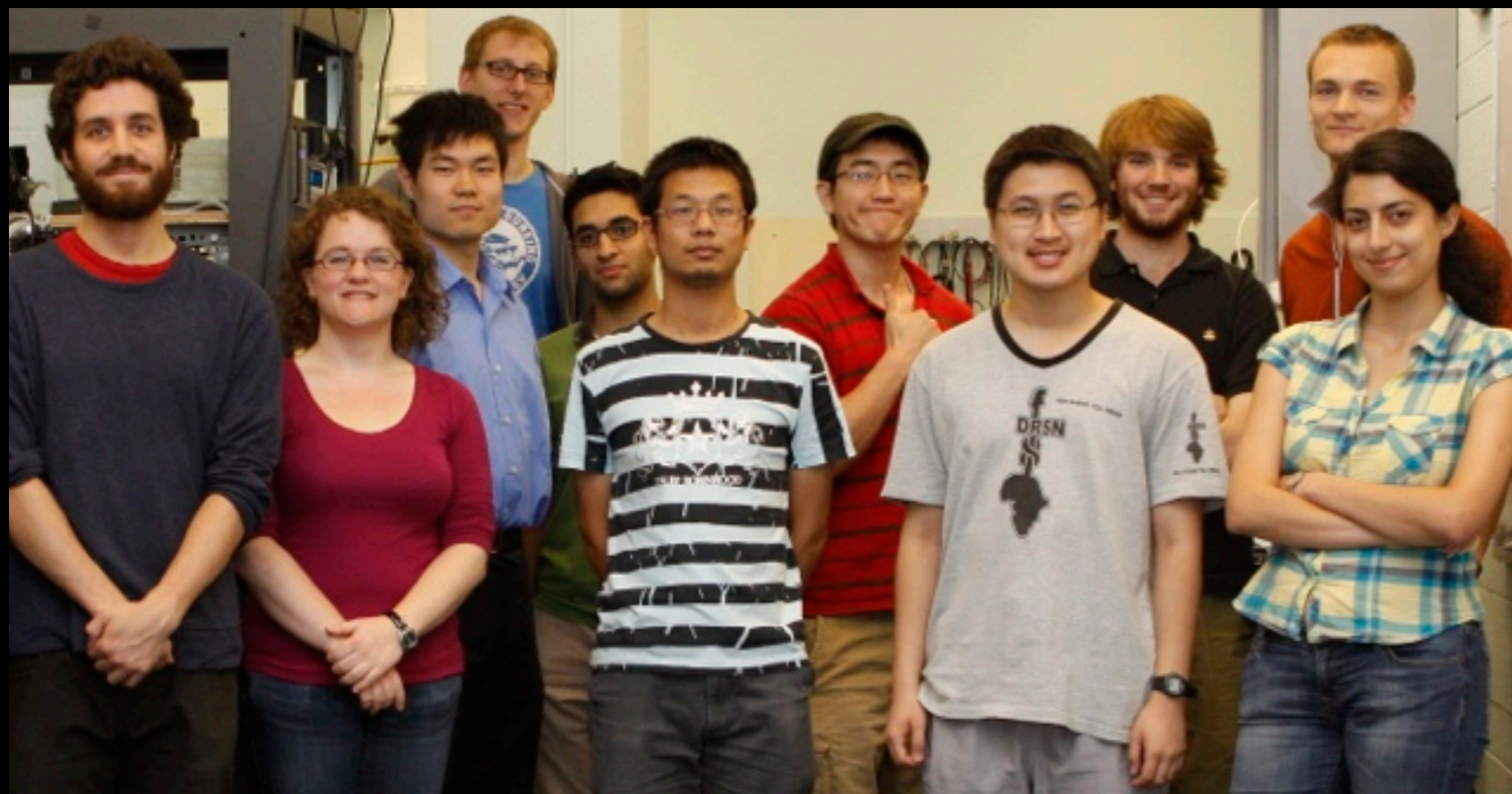


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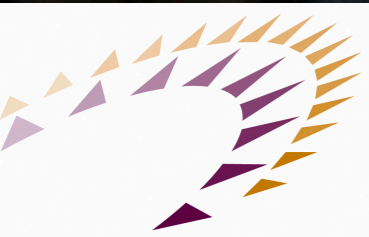


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Research Fund



Phases of Matter

Solids



H_2O

Liquids



Gases



Phases of Matter

Solids



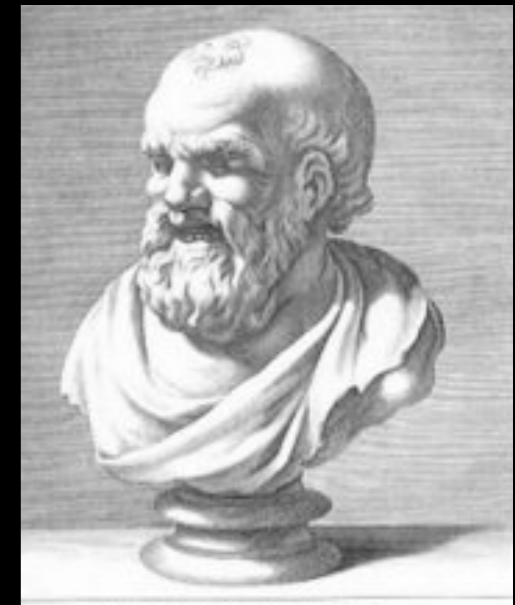
Liquids



Gases



Phases of Matter



Democritus
(~400 B.C.)

Solids



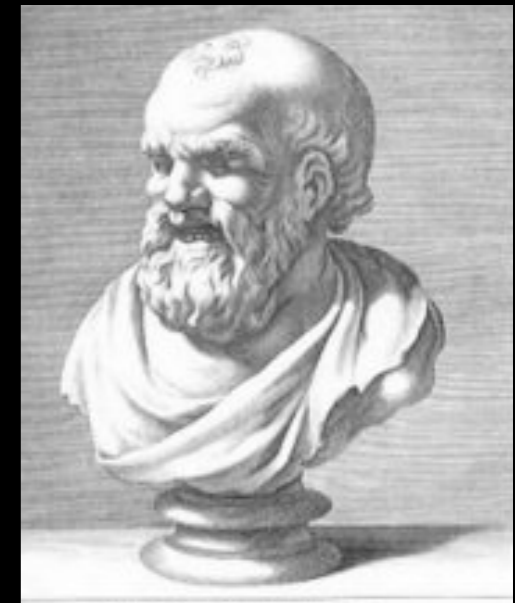
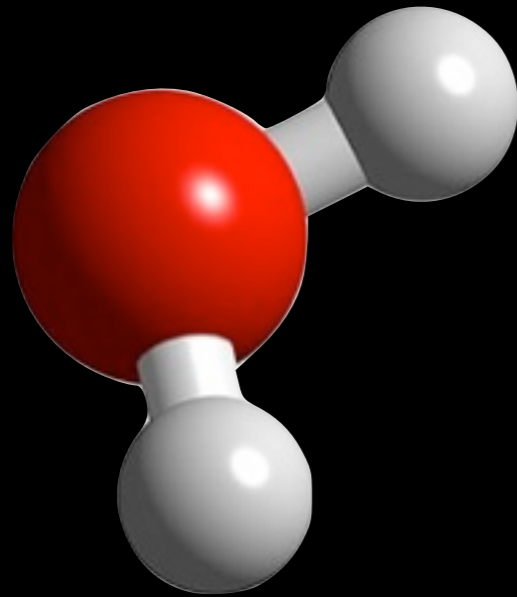
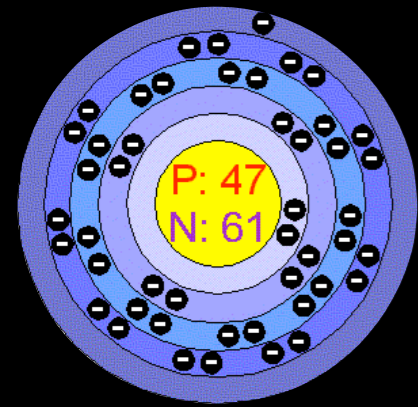
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Gases



Phases of Matter



Democritus
(~400 B.C.)

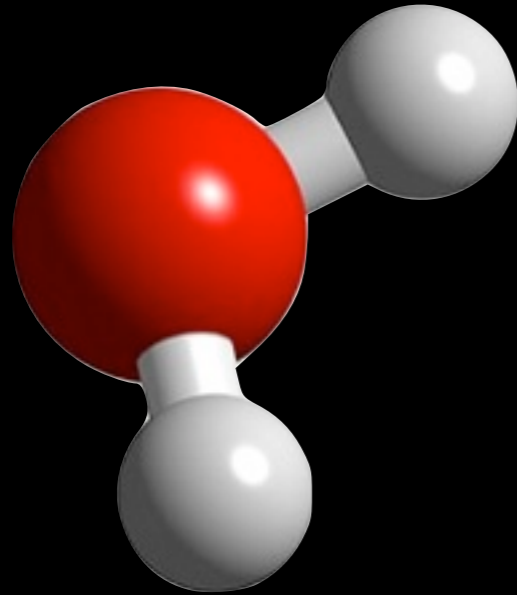
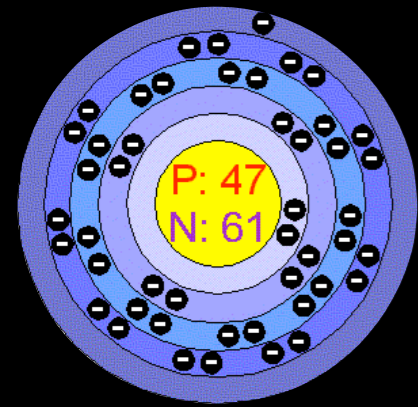
Solids

Liquids

Gases



Phases of Matter



Newton
(1687)

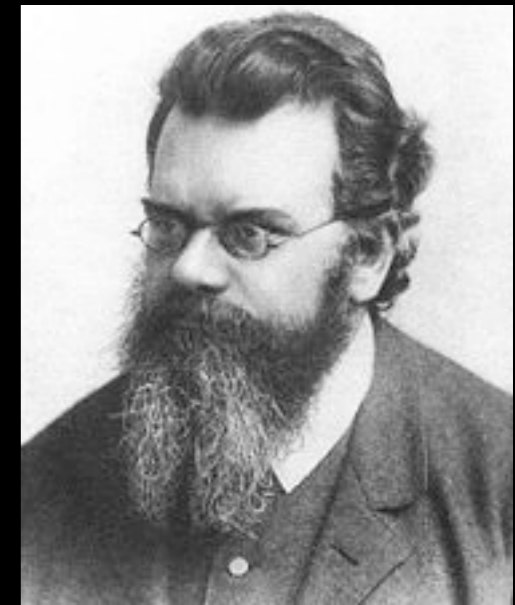
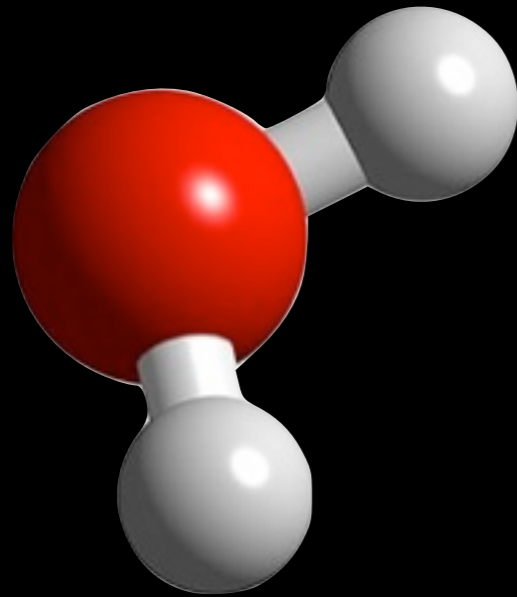
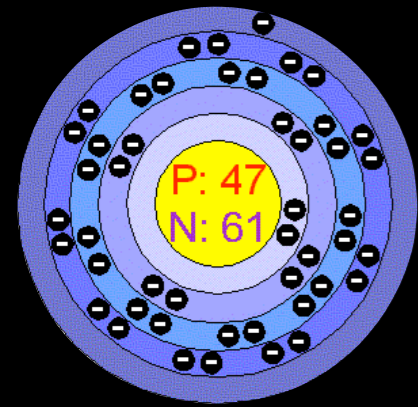
Solids

Liquids

Gases



Phases of Matter



Boltzman
1877

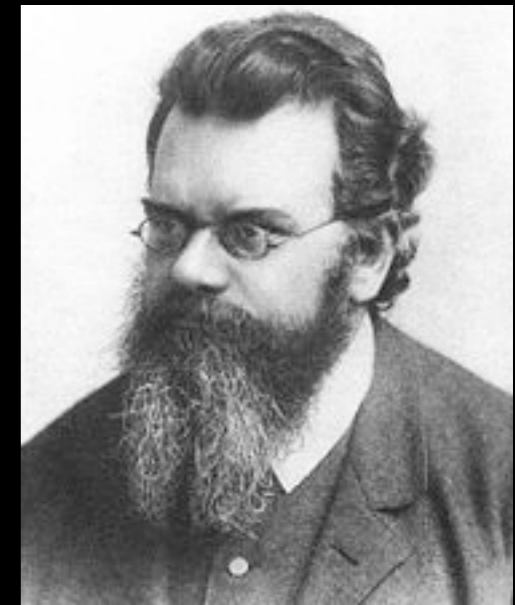
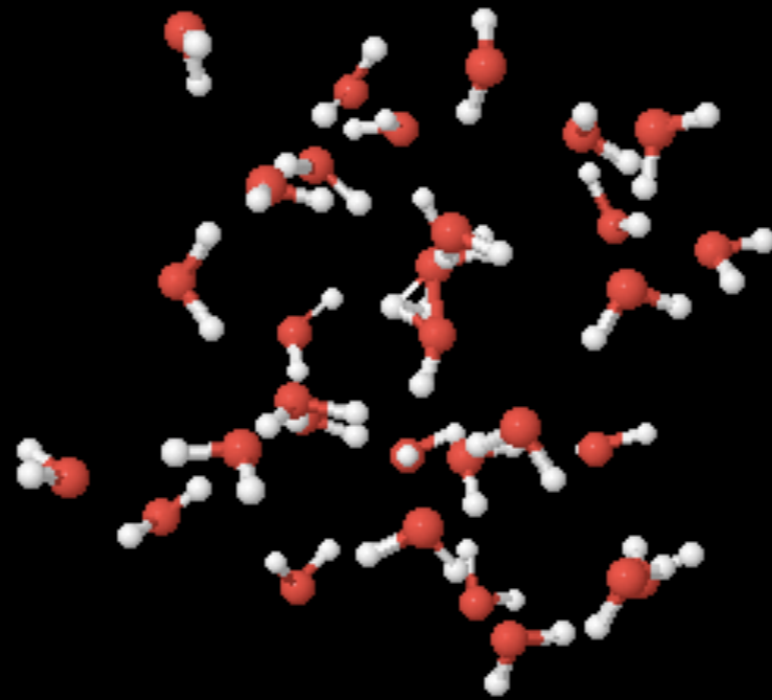
Solids

Liquids

Gases



Phases of Matter



Boltzman
1877

Solids



Liquids

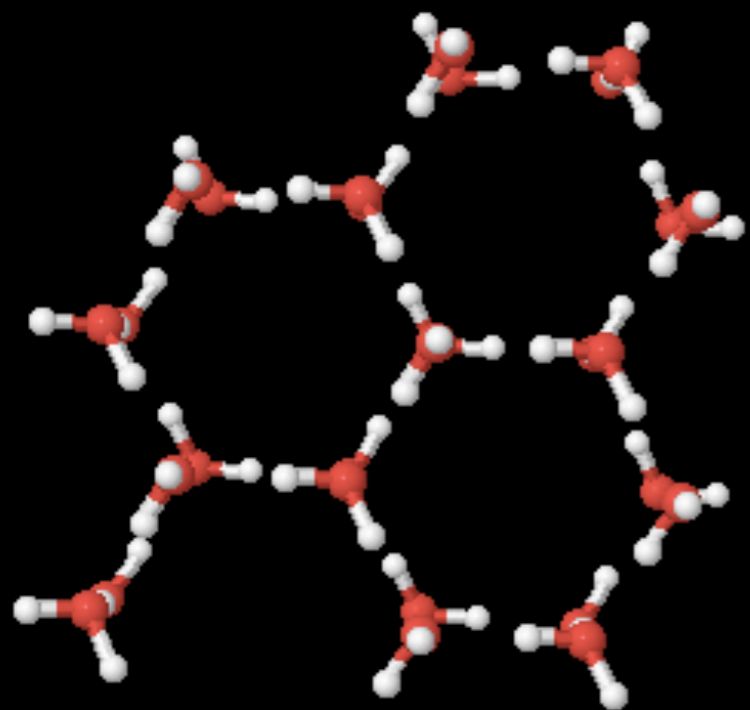


Gases





Phases of Matter

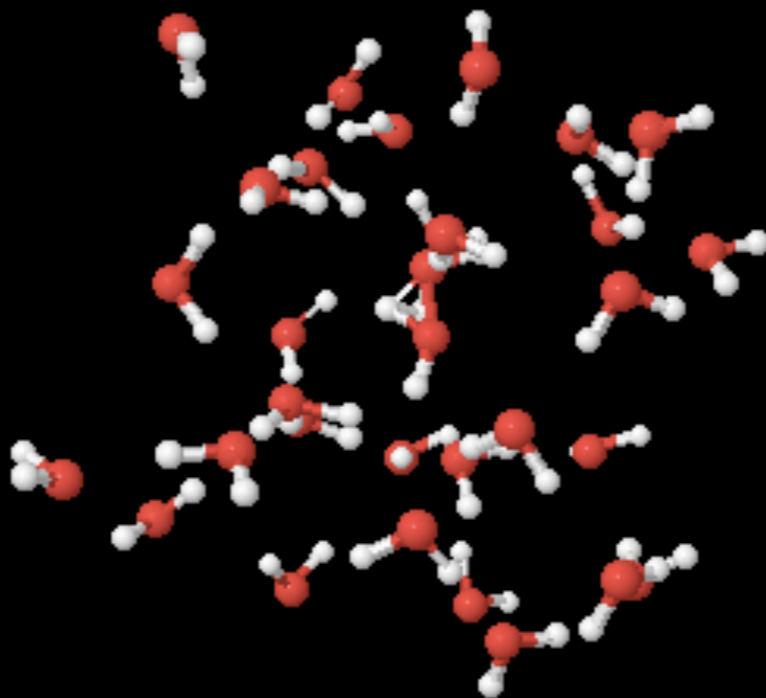


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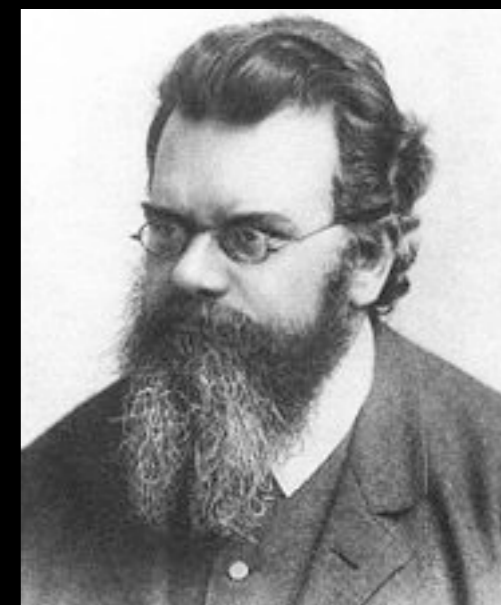


Ag

H₂O



Liquids

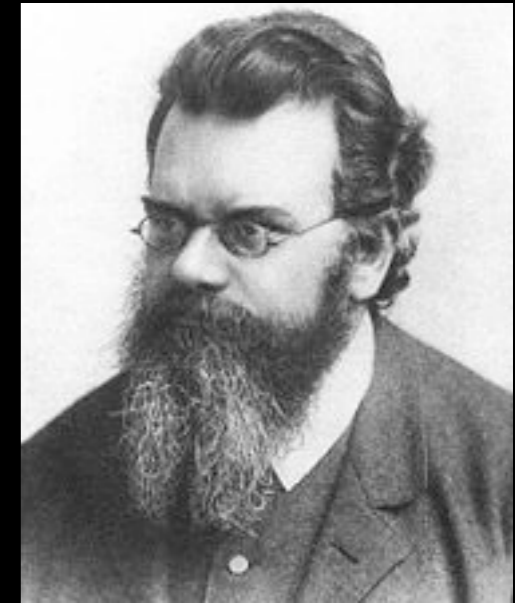


Boltzmann
1877

Gases



Phases of Matter

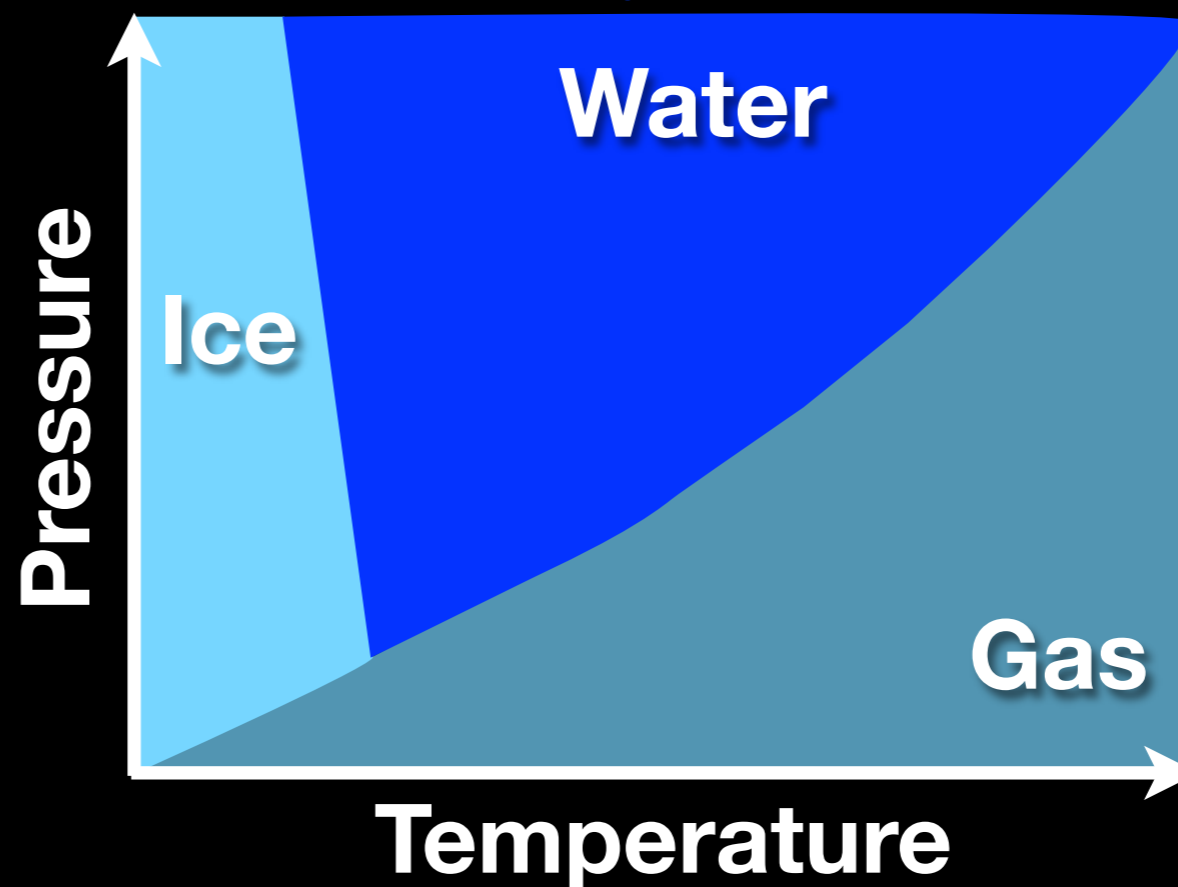


Boltzmann
1877

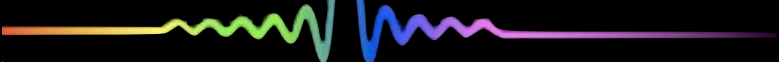
Solids



Liquids



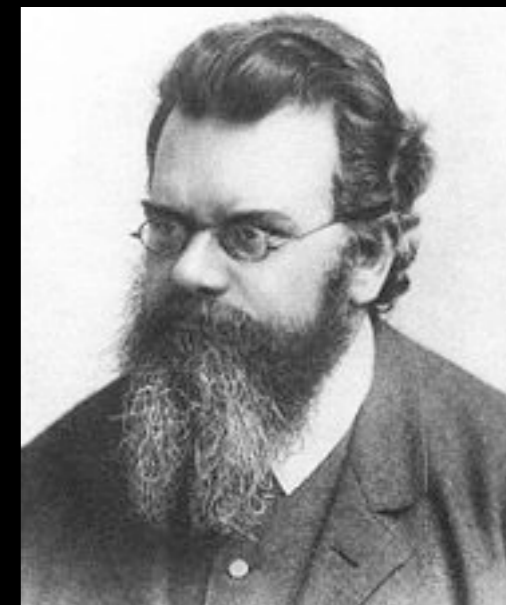
Gases



Phases of Matter



Heat Exchange



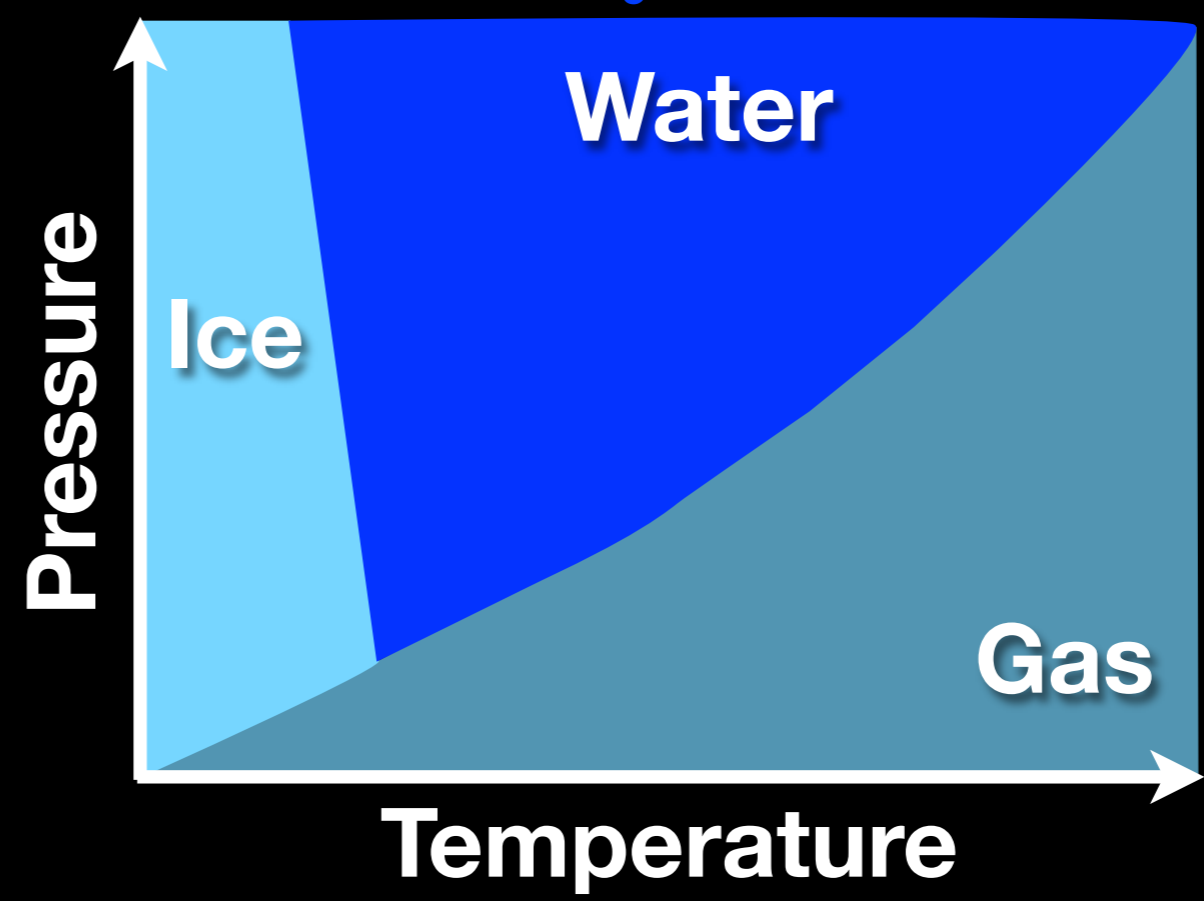
Boltzman
1877

Solids



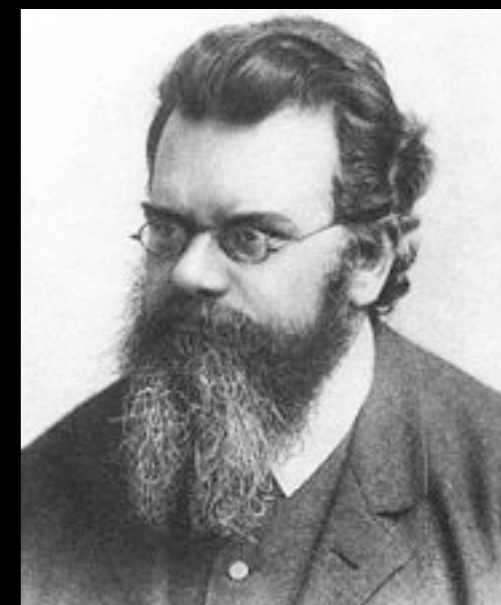
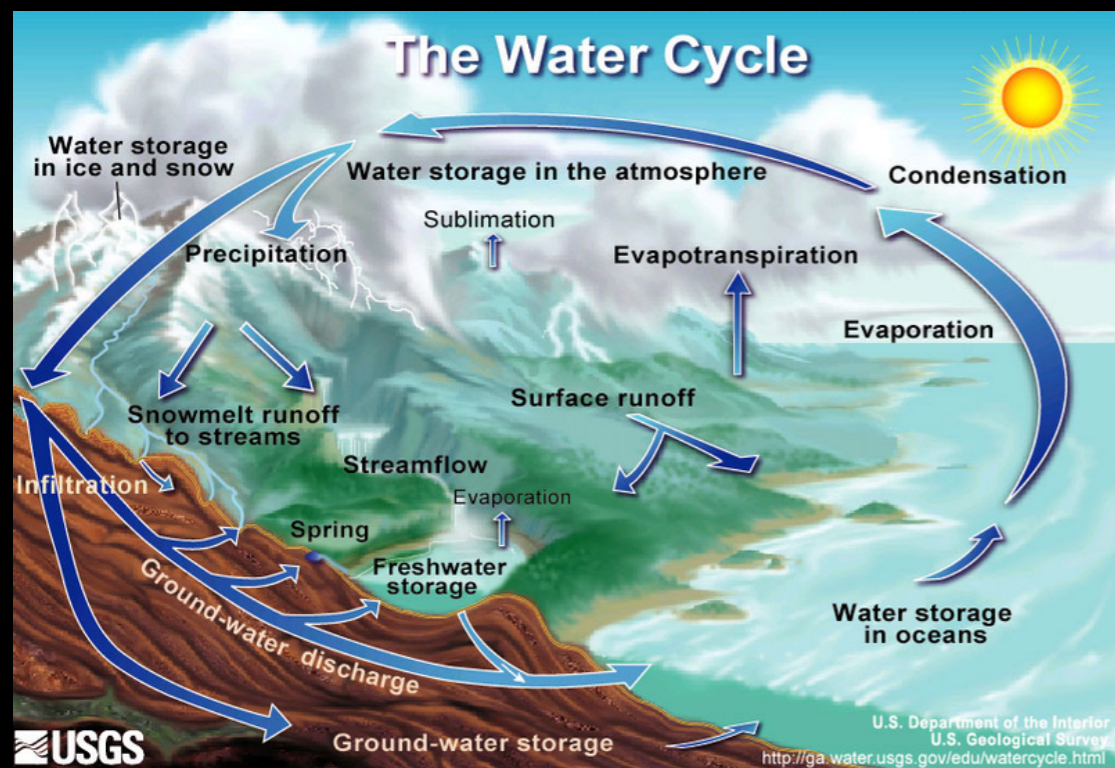
H₂O

Liquids



Gases

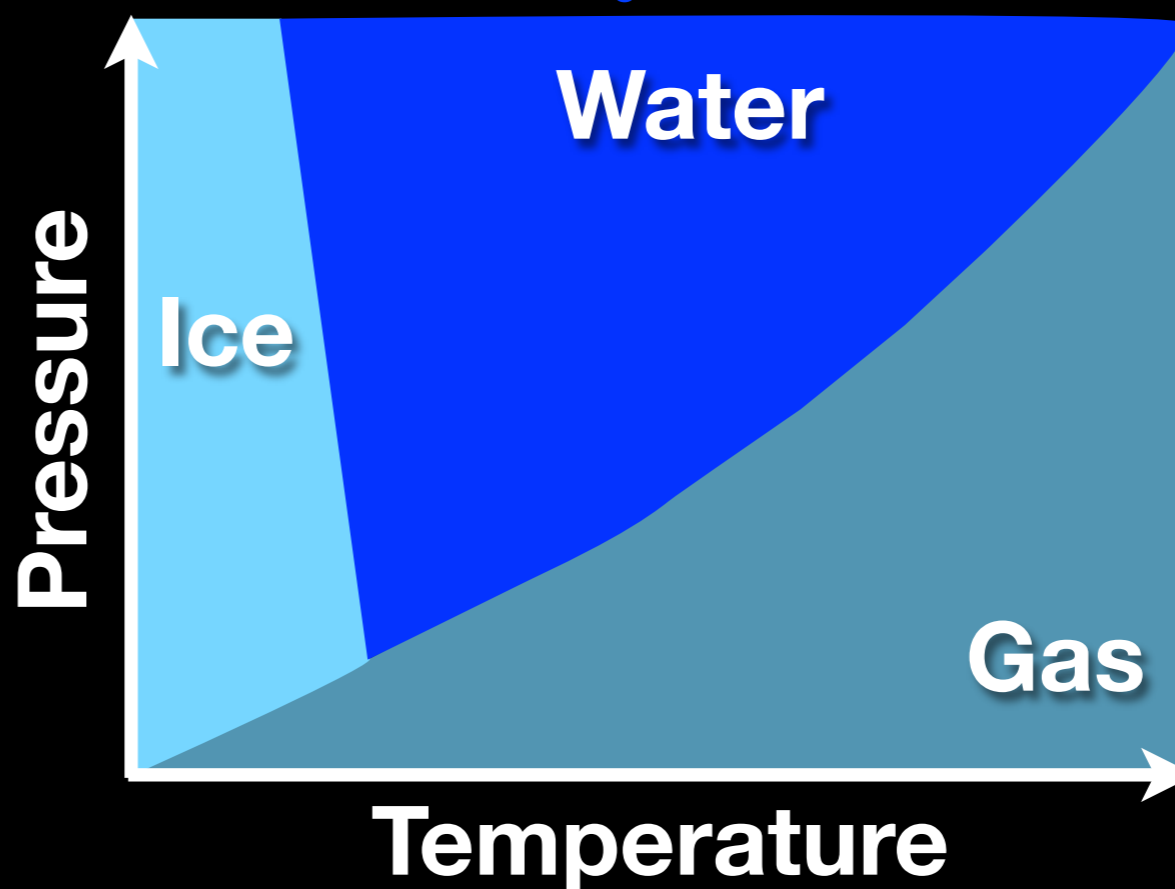
Phases of Matter



Boltzman
1877

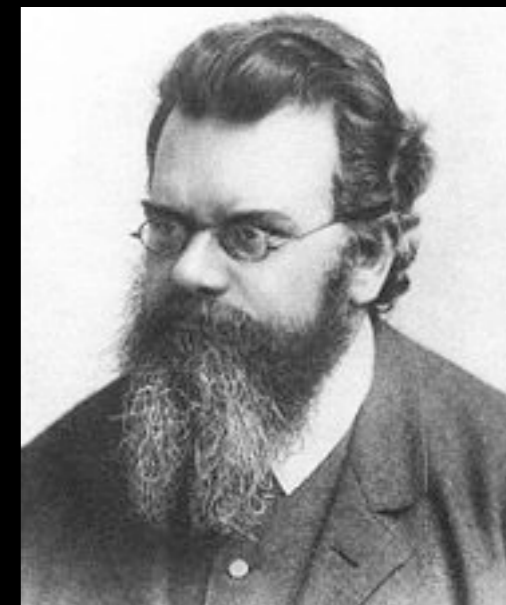
Liquids

Solids



Gases

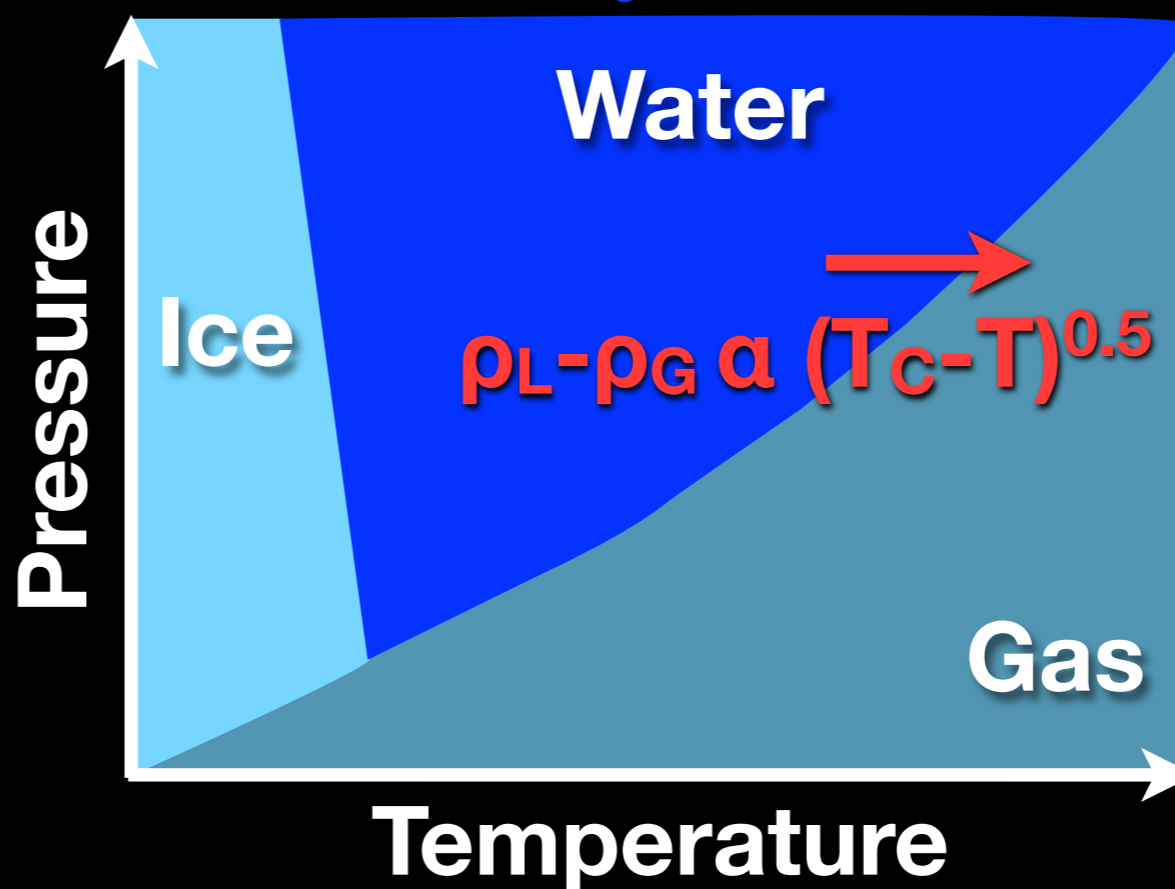
Phases of Matter



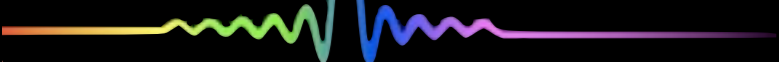
Boltzman
1877

Liquids

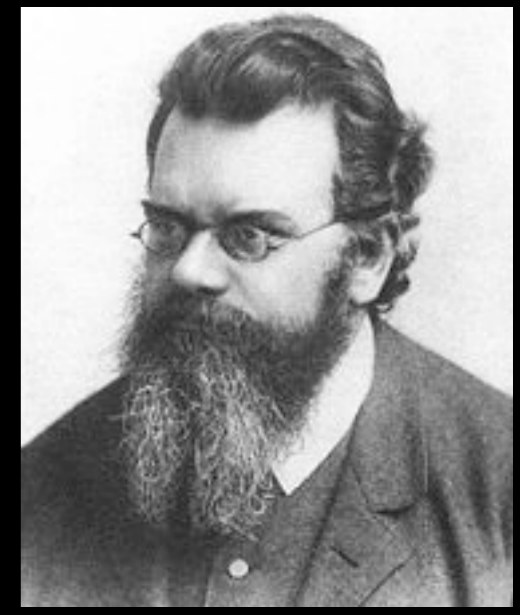
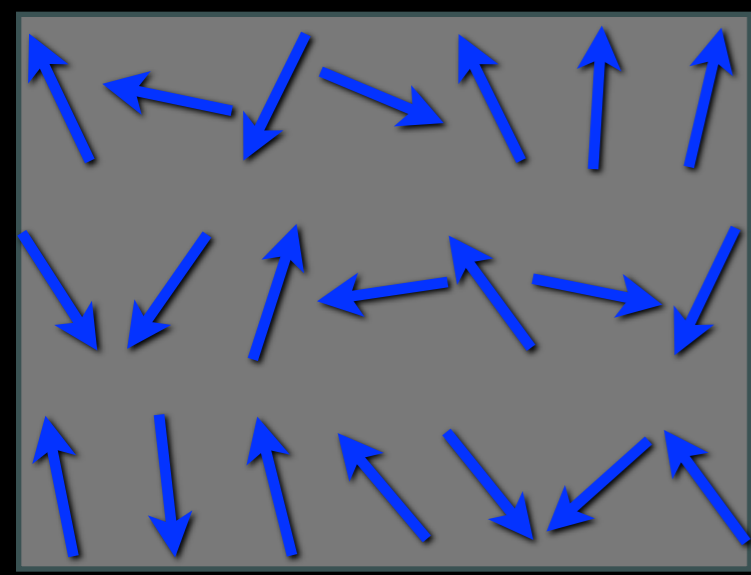
Solids



Gases



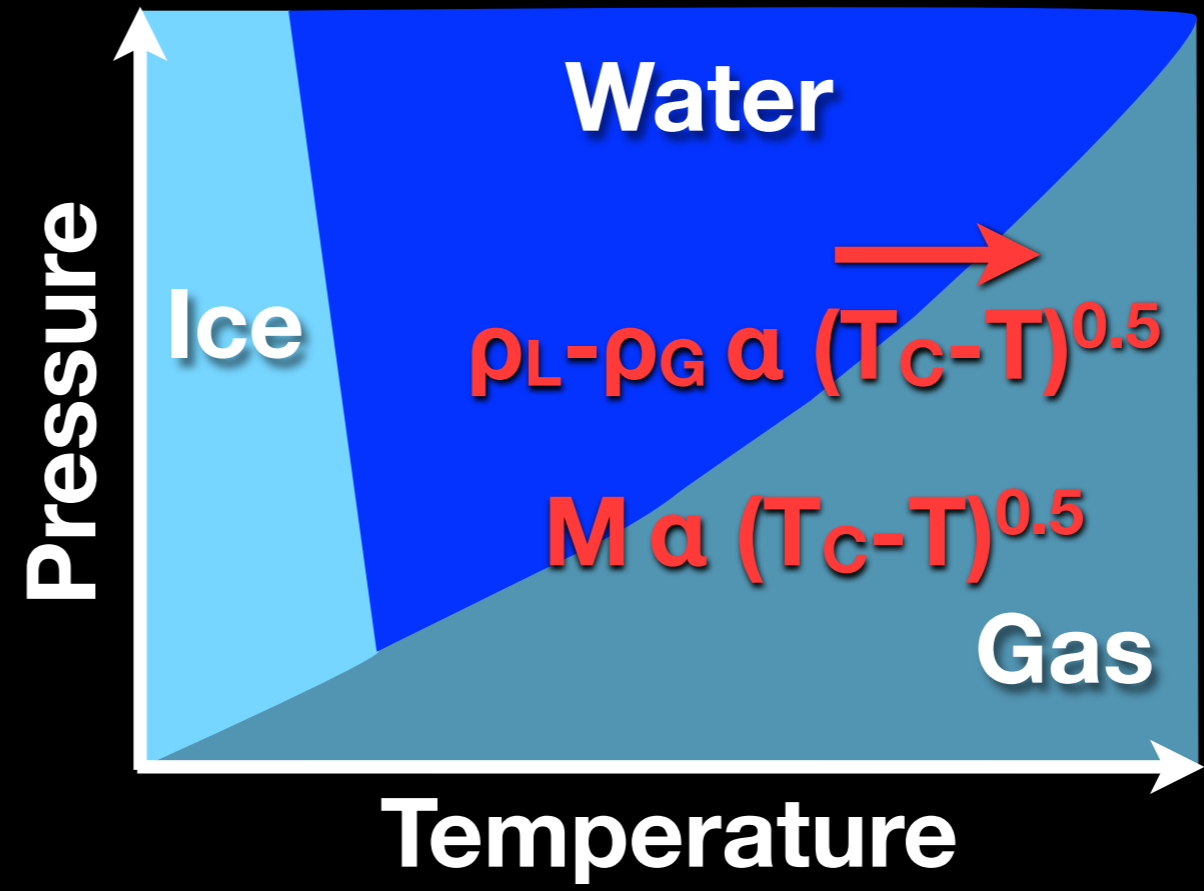
Phases of Matter



Boltzman
1877

Liquids

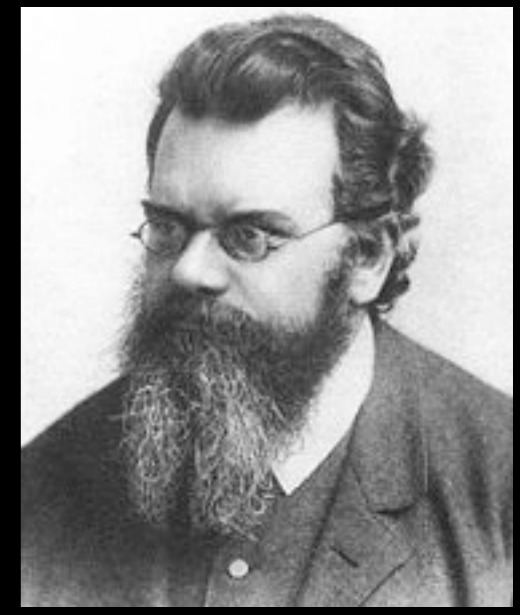
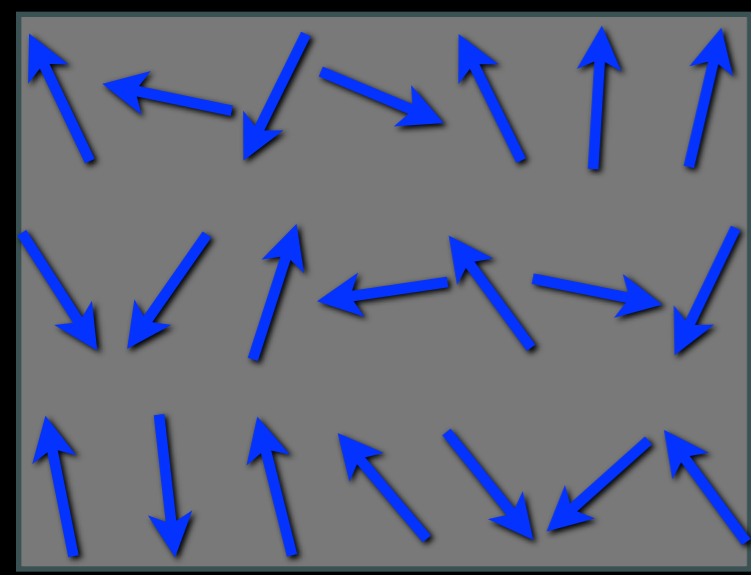
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Gases



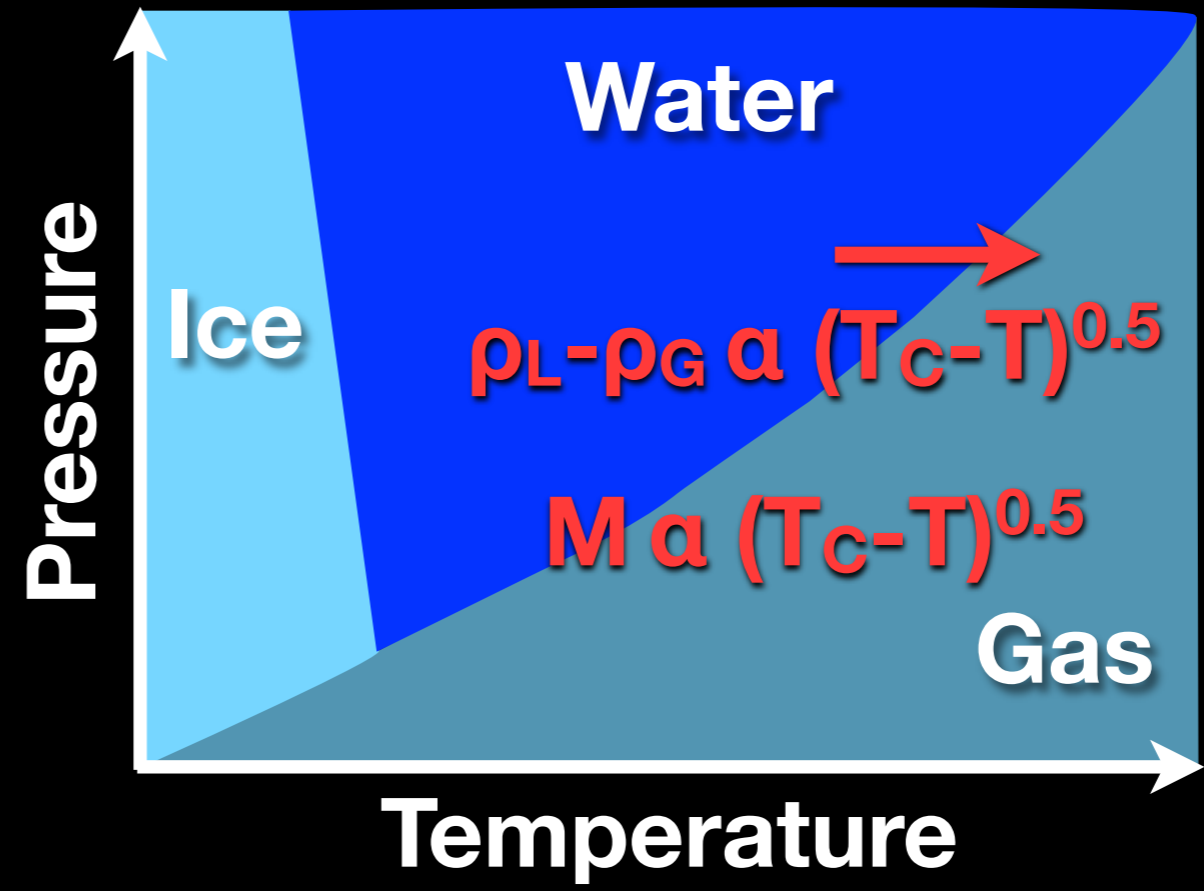
Phases of Matter



Boltzman
1877

Liquids

Solids



Gases

Phases of Matter

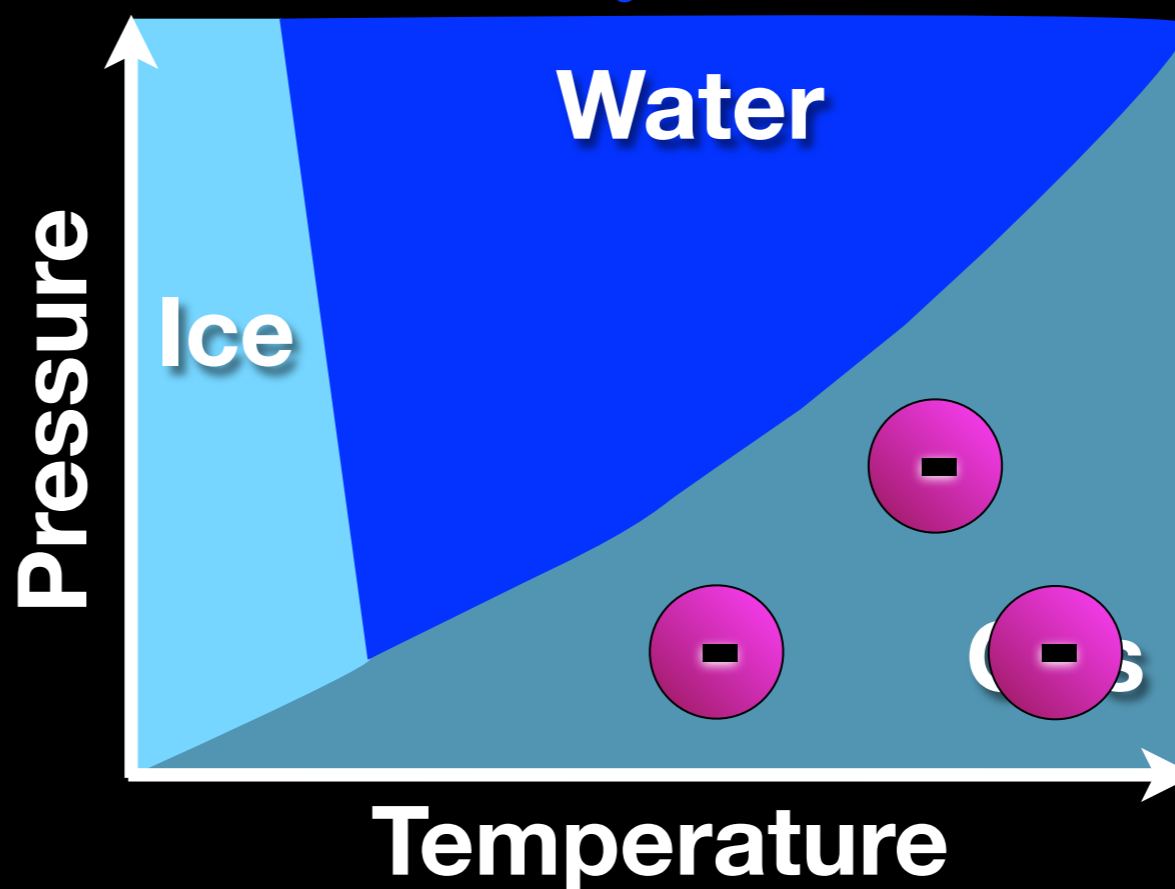


Drude
1900

Solids



Liquids



Phases of Matter

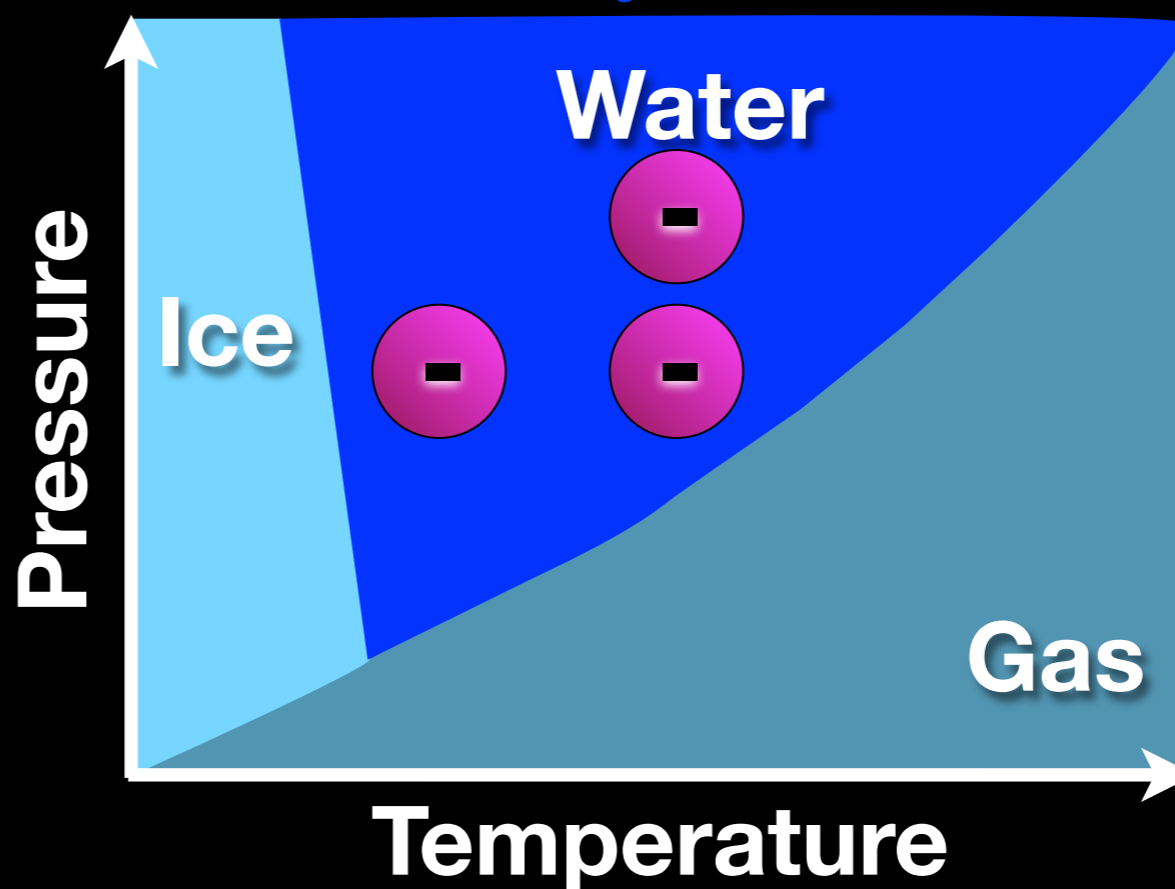


Landau
1956

Metals

Liquids

Solids



Gases

Phases of Matter

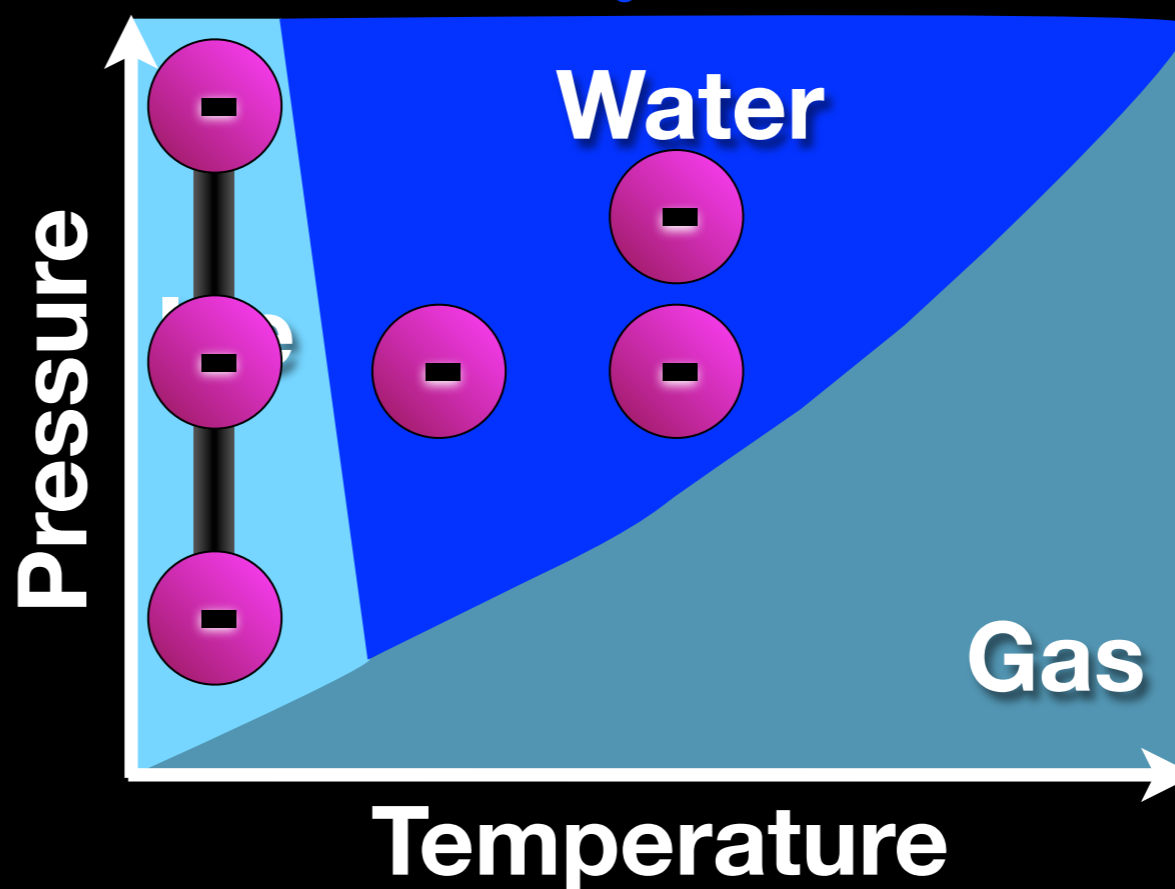


Landau
1956

Metals

Liquids

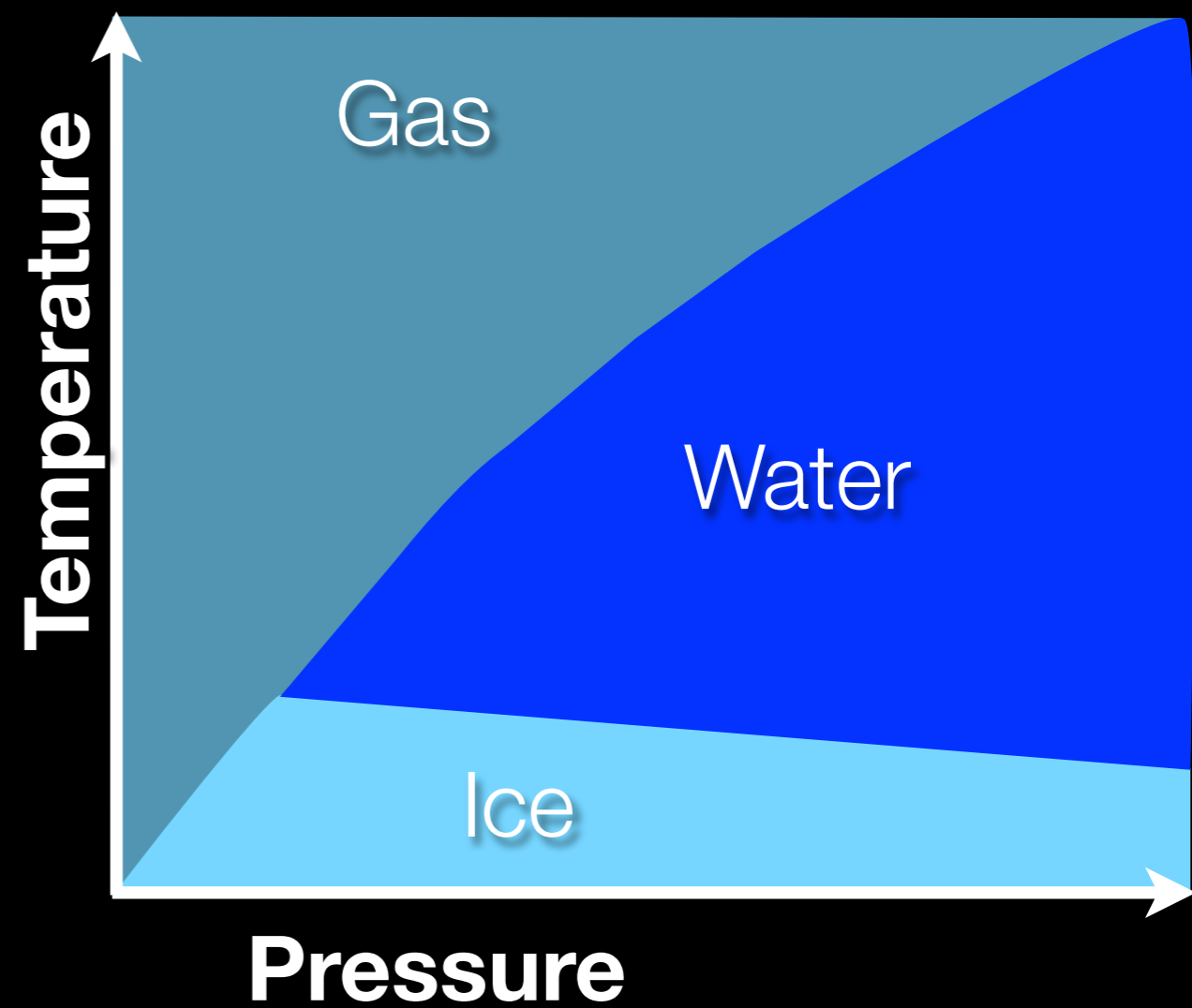
Insulators
Solids



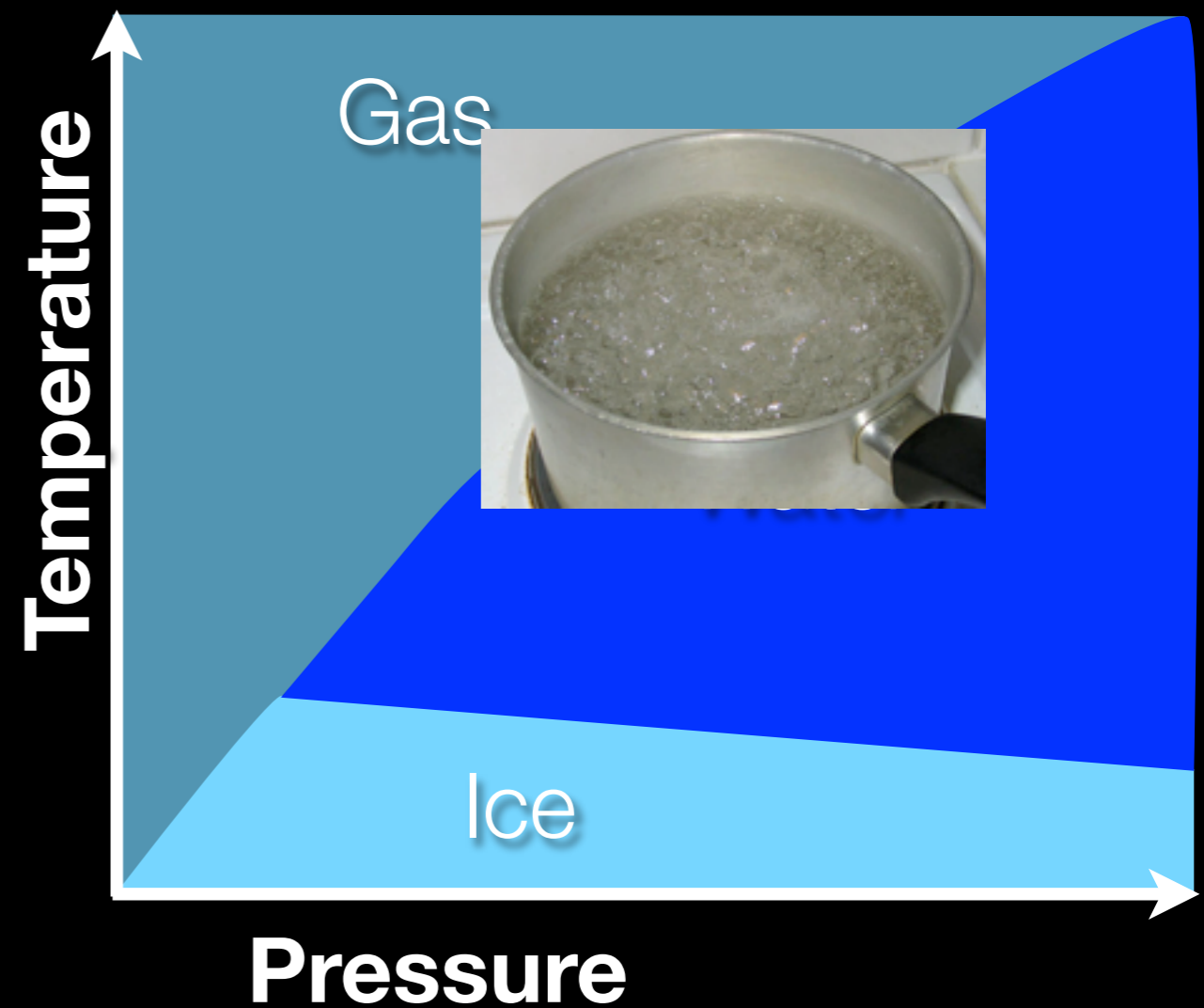
Gases



Phase Transitions

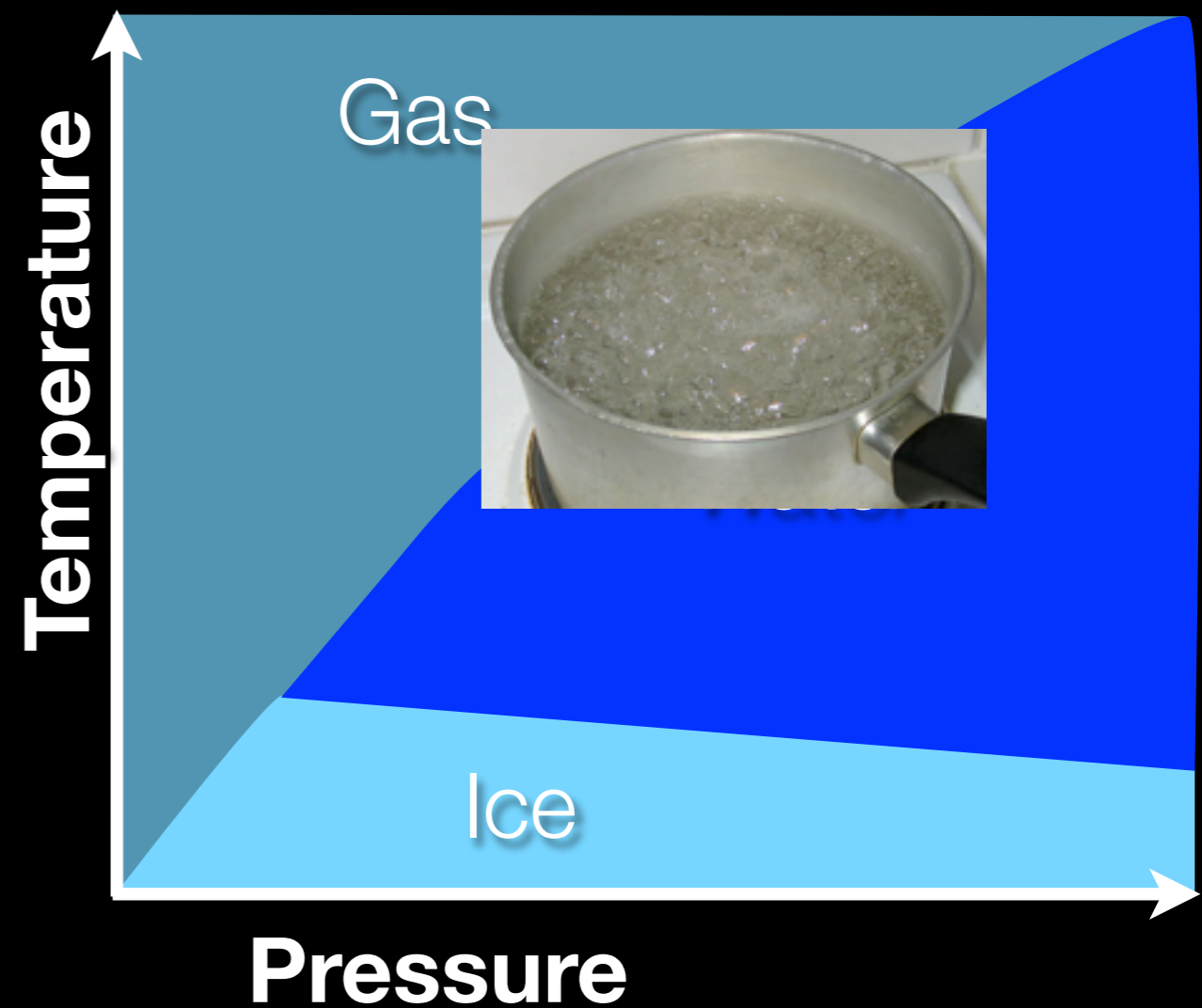


Phase Transitions



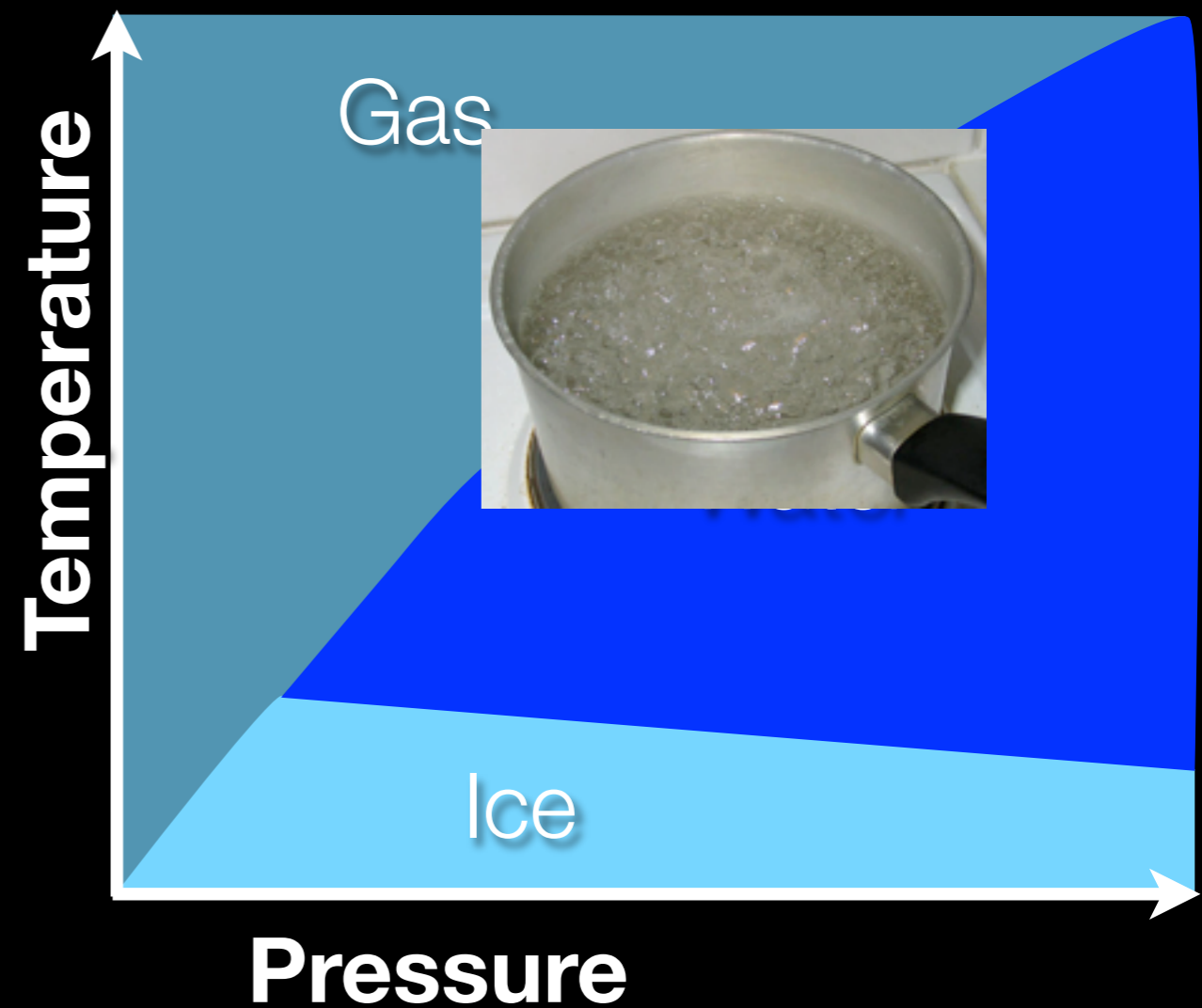
Phase Transitions

Classical Transition: At Transition \rightarrow Coexist



Phase Transitions

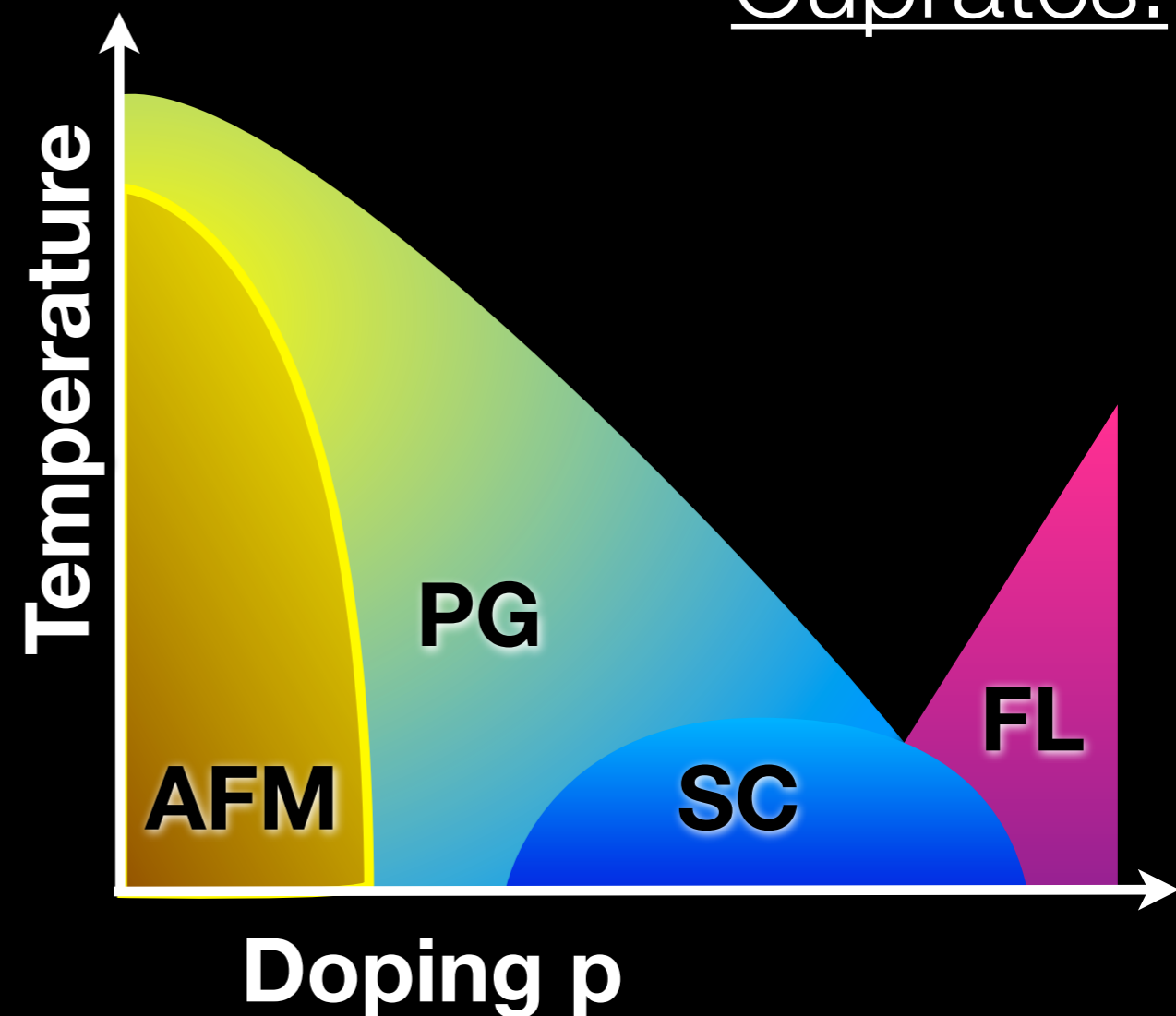
Quantum Phase Transition: New Phases?



Phase Transitions

Quantum Phase Transition: New Phases?

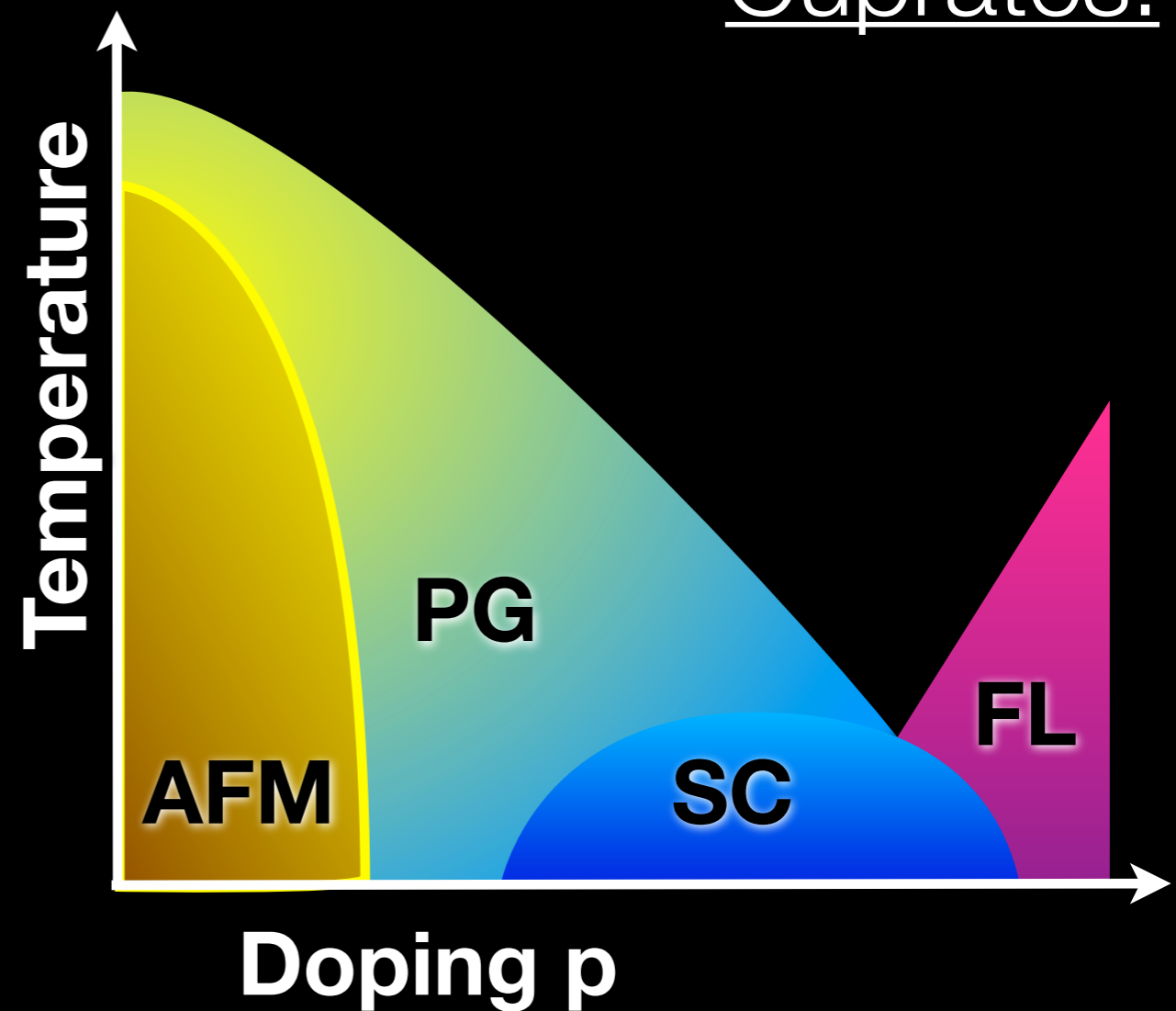
Cuprates:



Phase Transitions

Quantum Phase Transition: New Phases?

Cuprates:



American Superconductor

● Phases

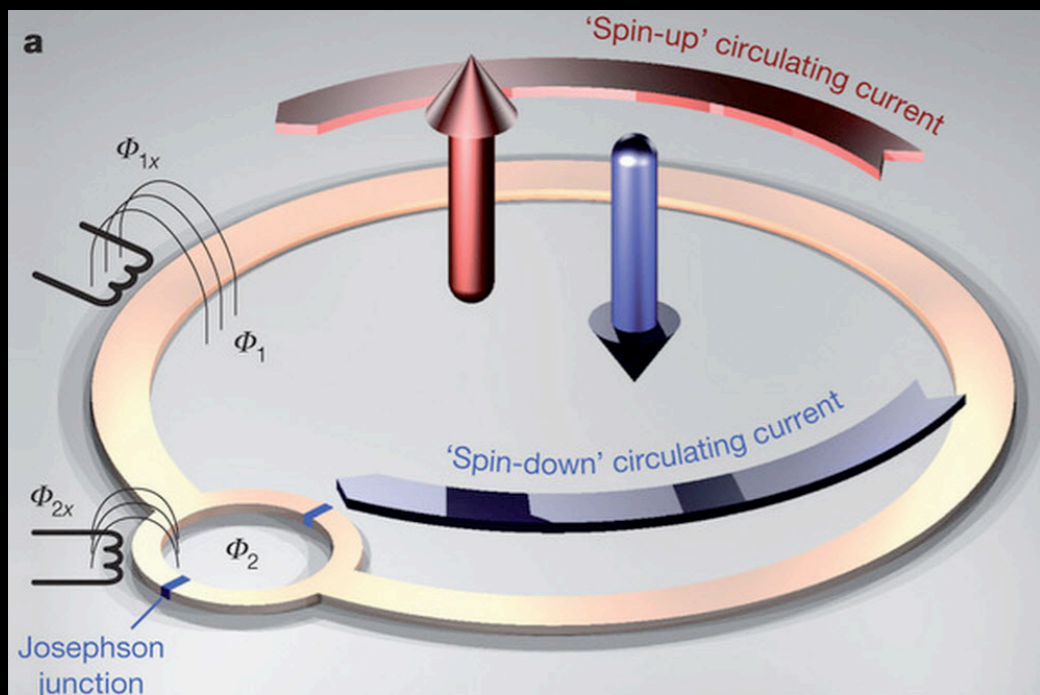
● Exfoliation

● Optics

● Topology

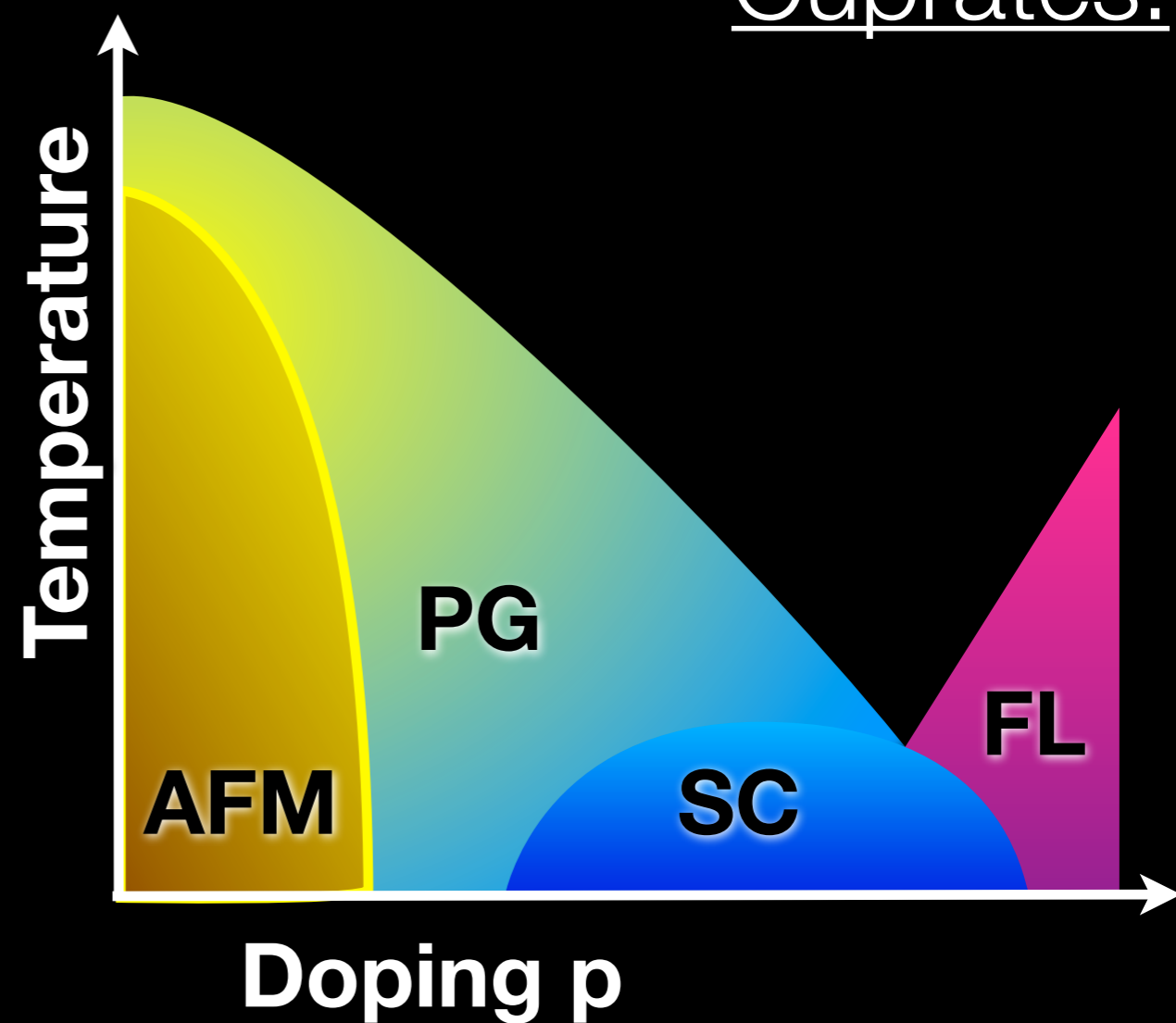
● Future

Phase Transitions



Quantum Phase Transition: New Phases?

Cuprates:



American Superconductor

● Phases

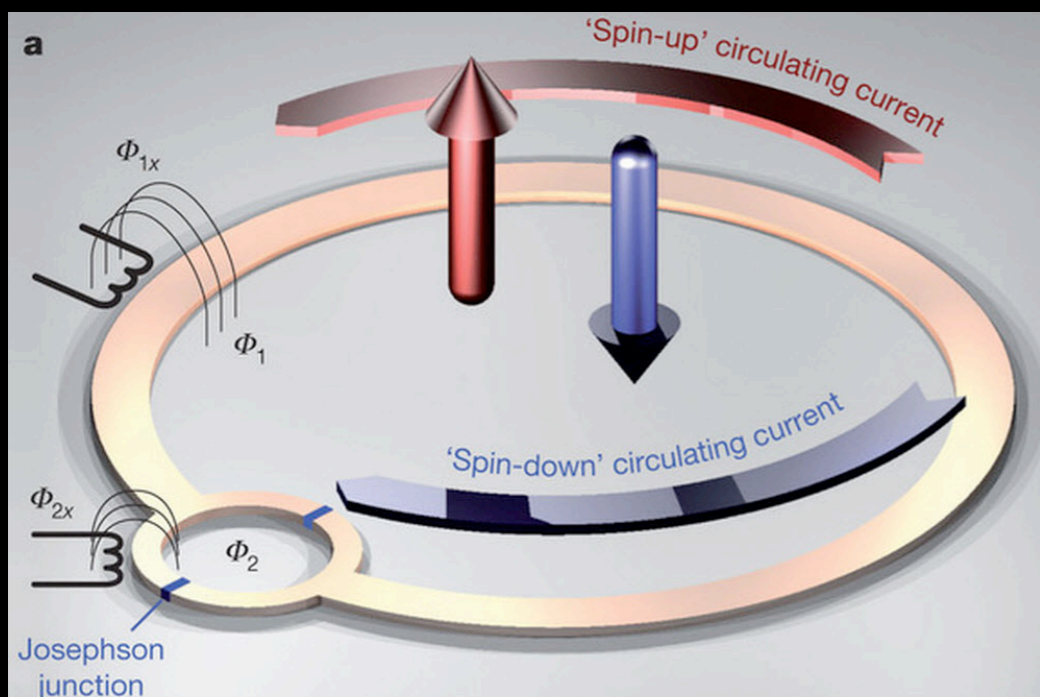
● Exfoliation

● Optics

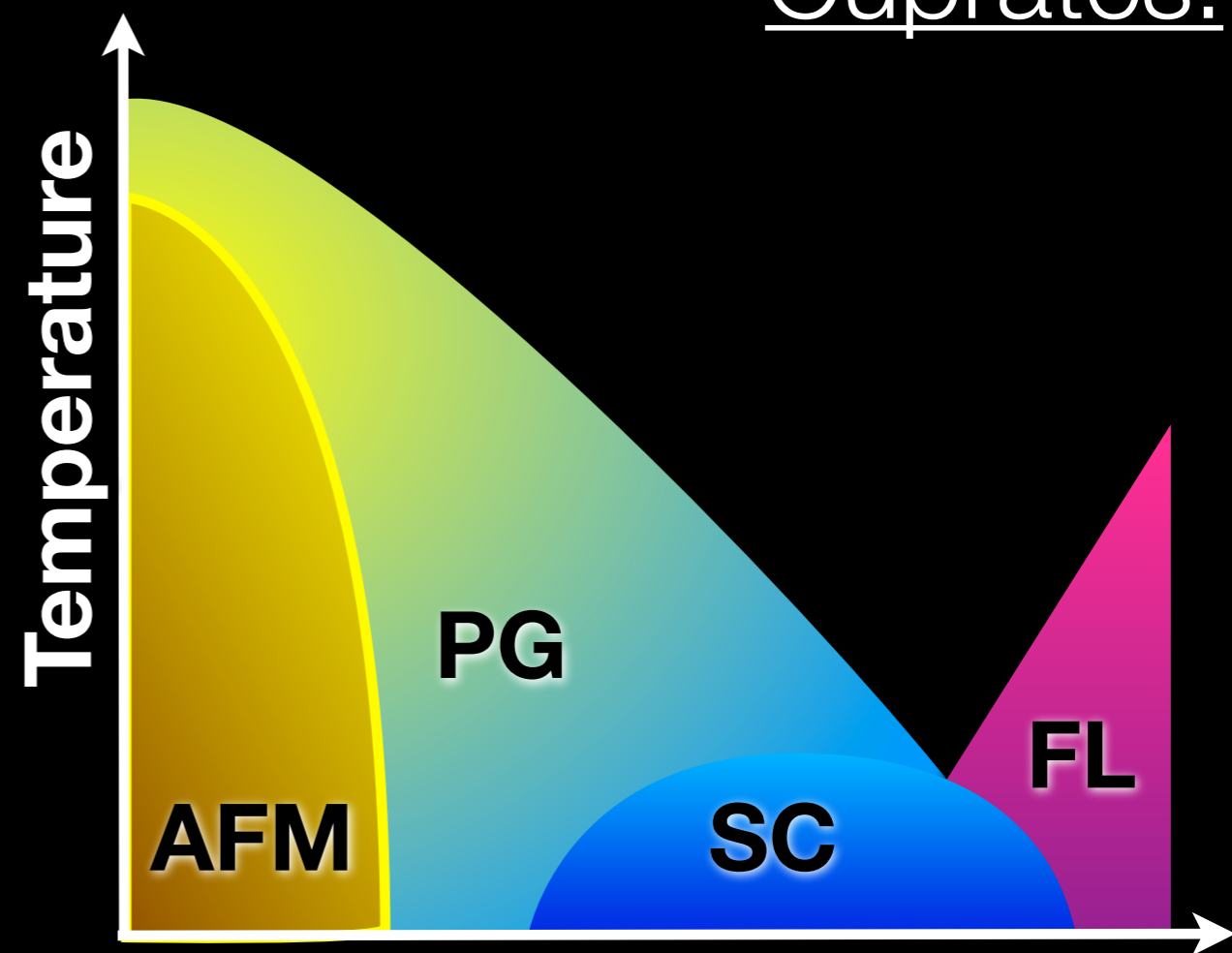
● Topology

● Future

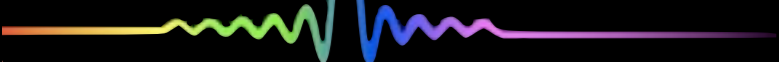
Phase Transitions



Cuprates:

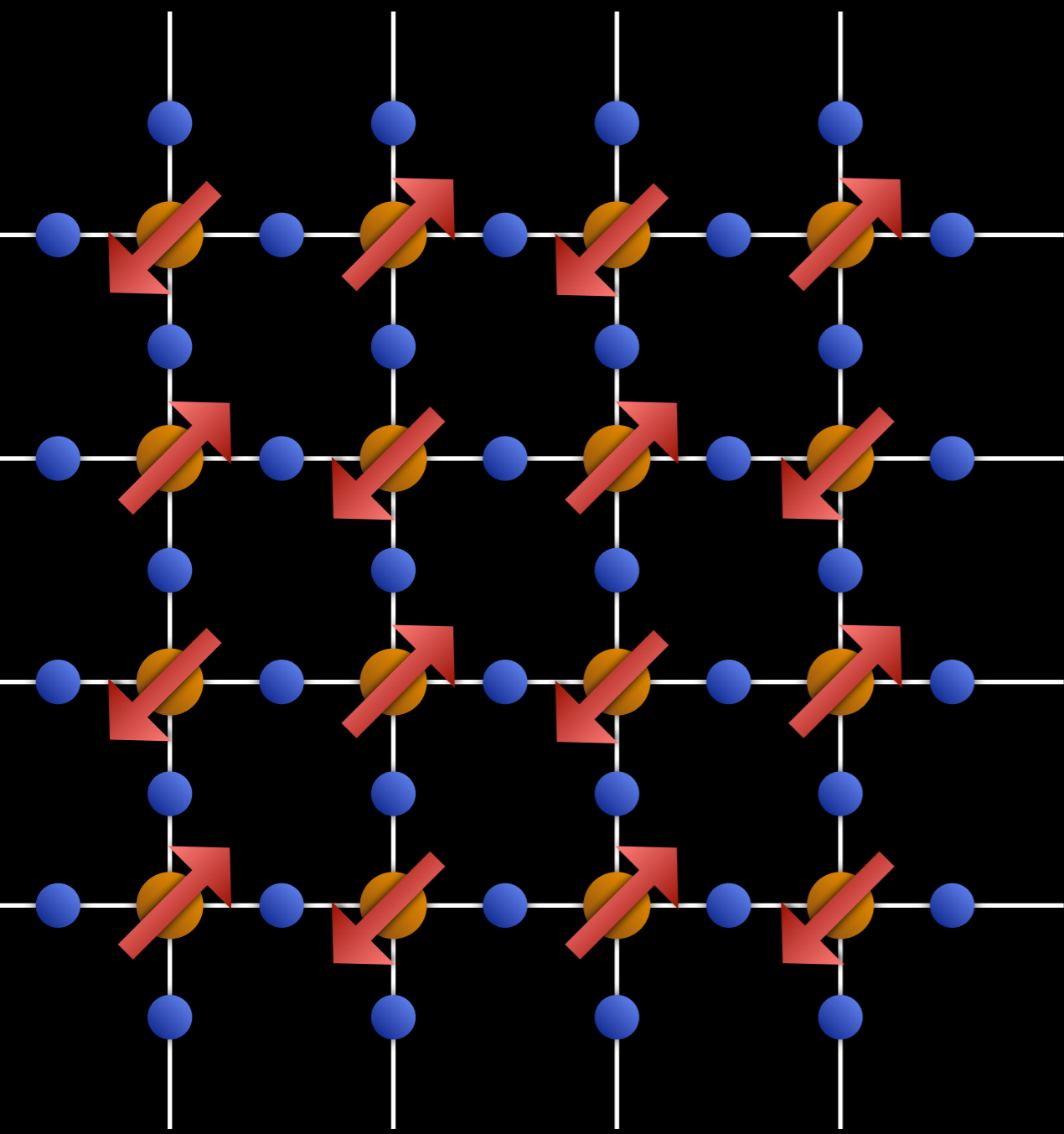


American Superconductor

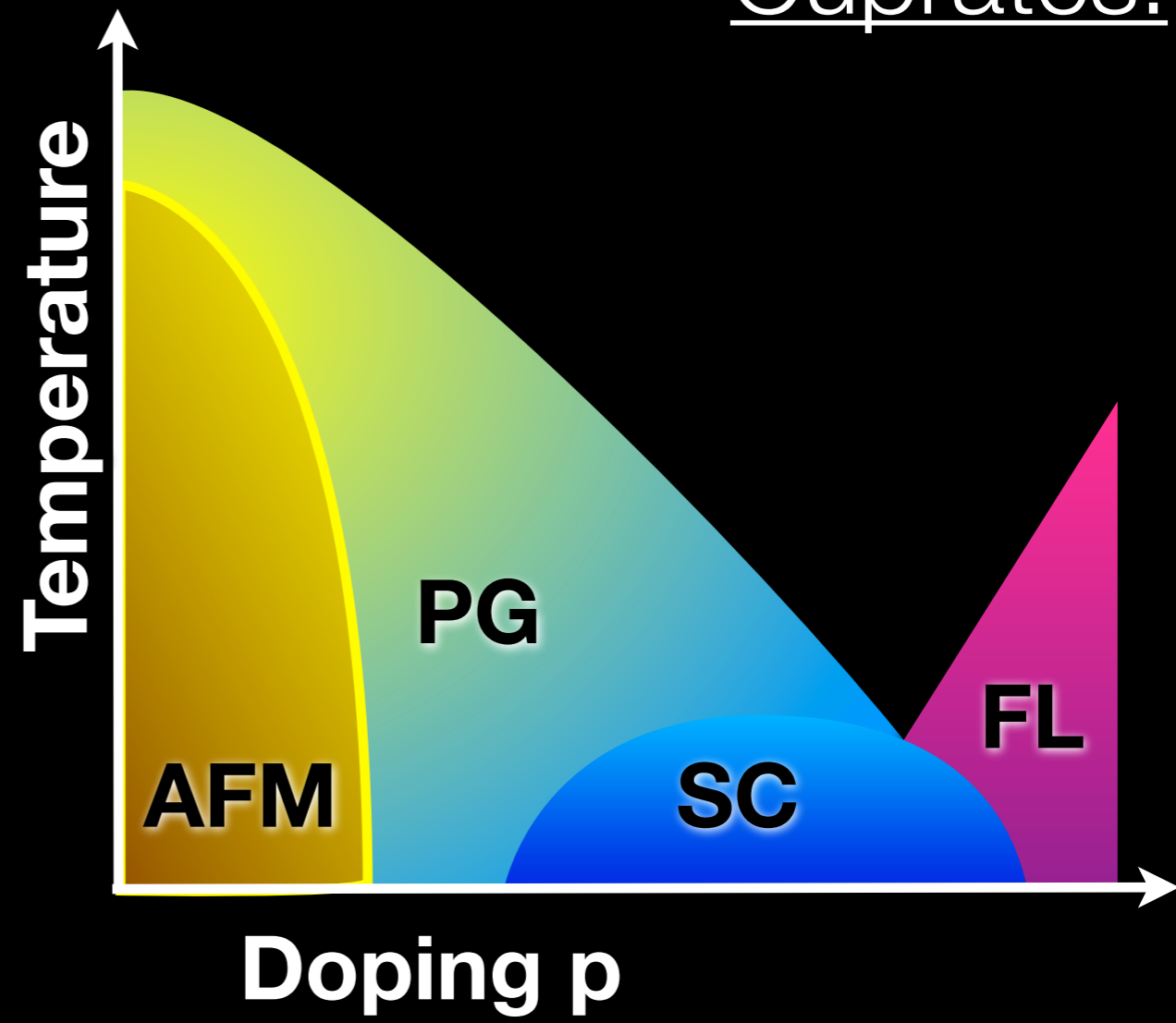


Phase Transitions

Quantum Phase Transition: New Phases?

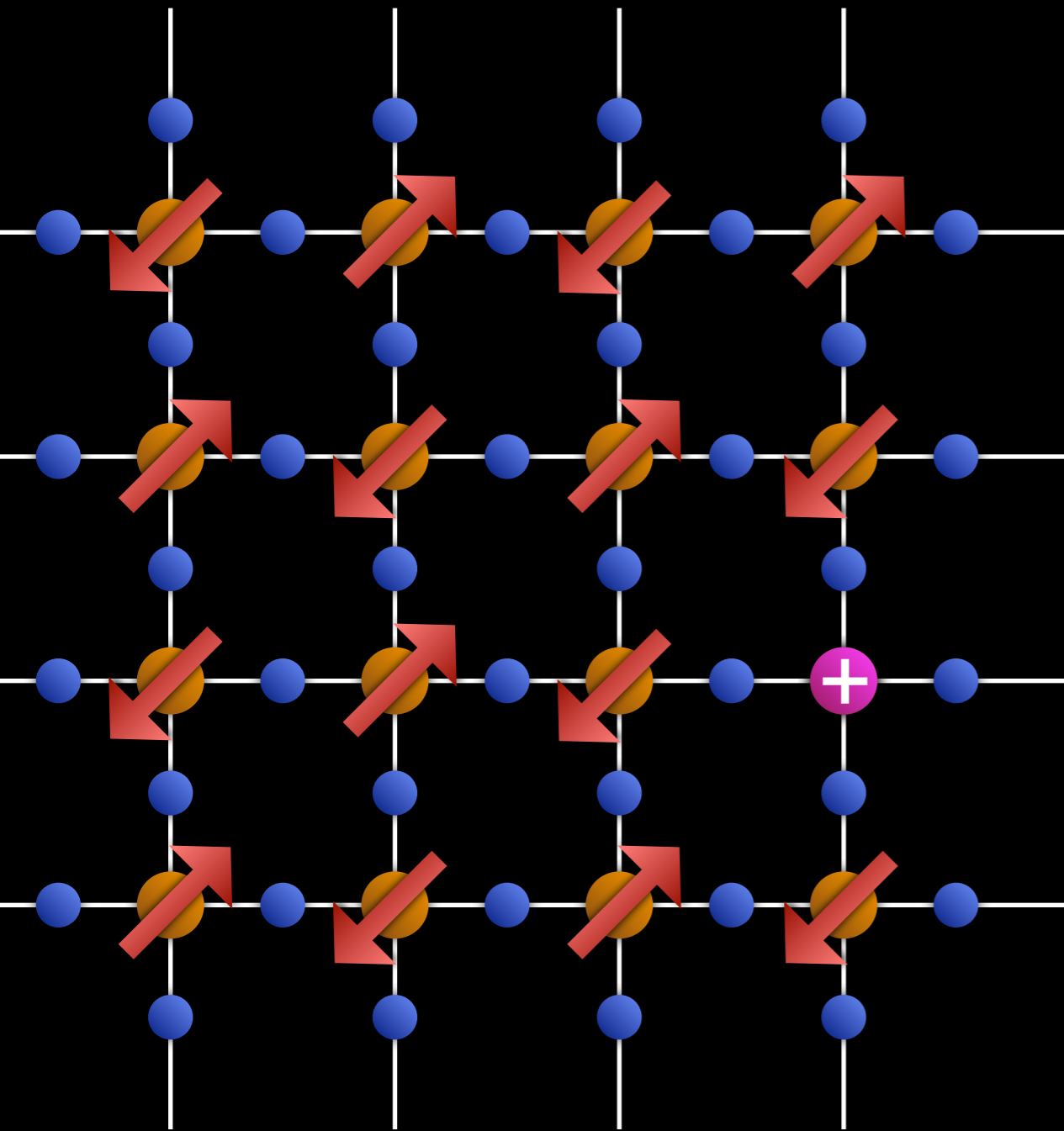


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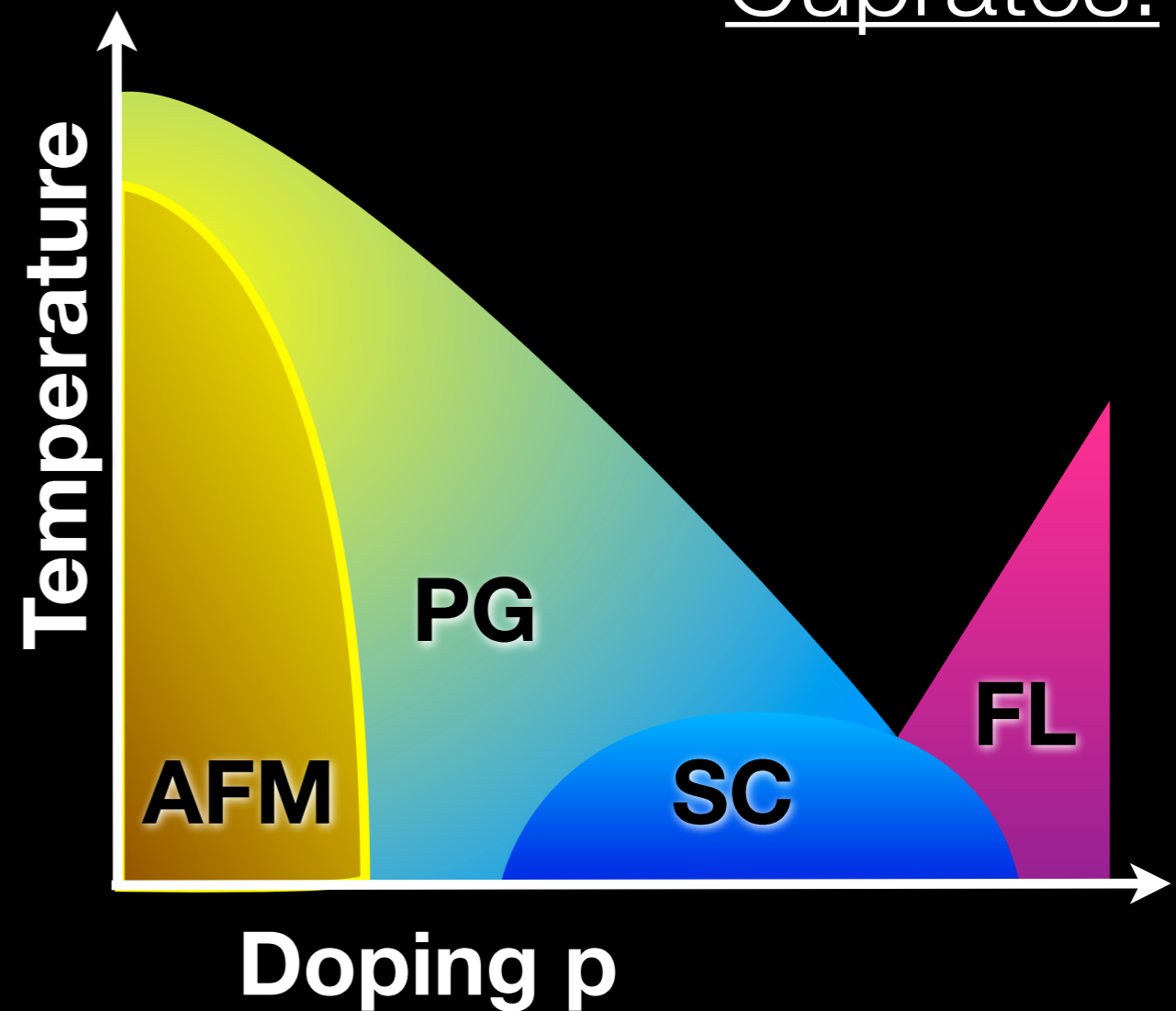


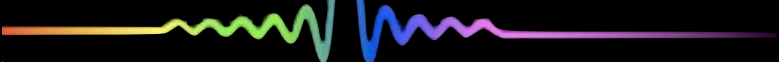
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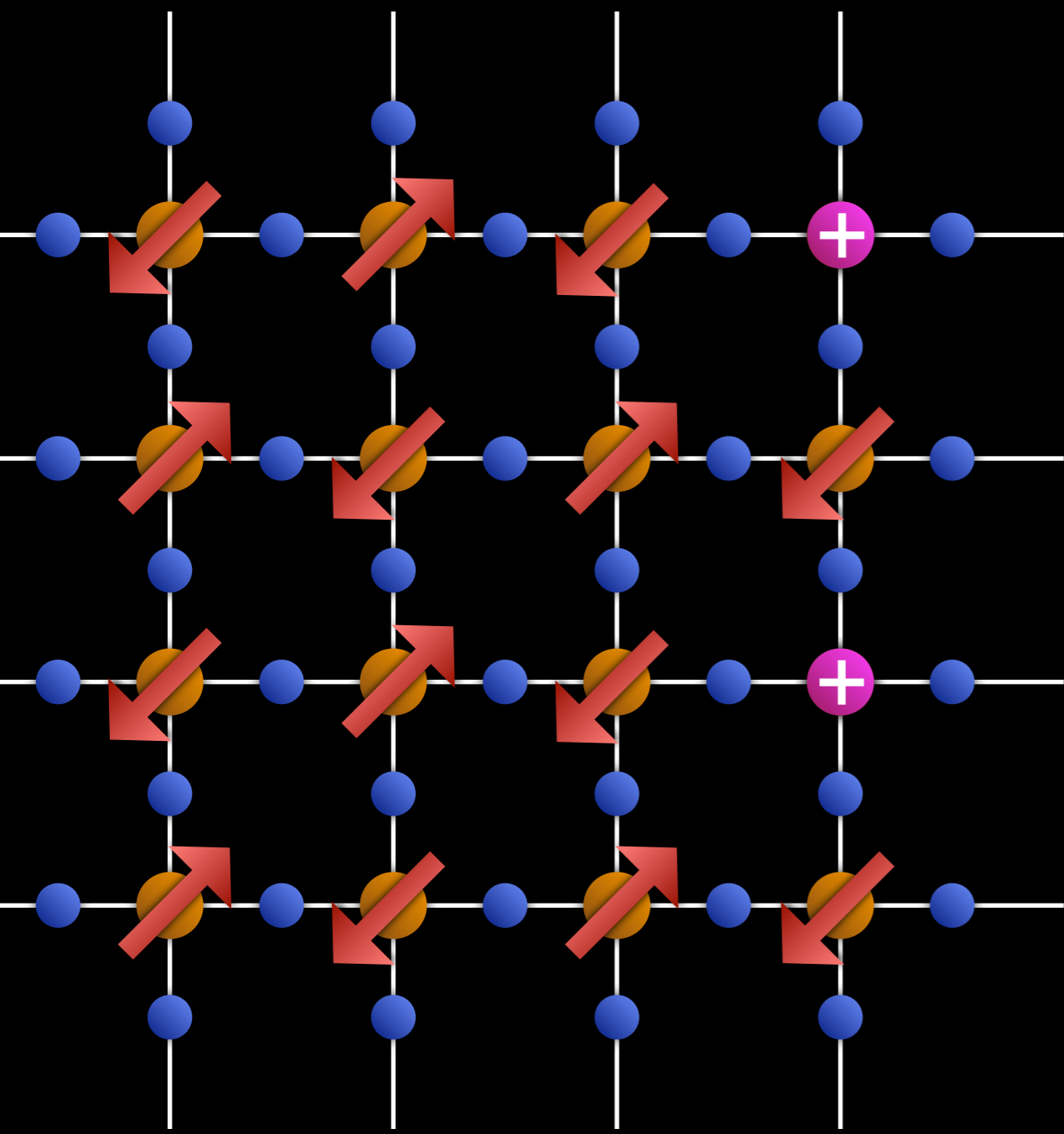
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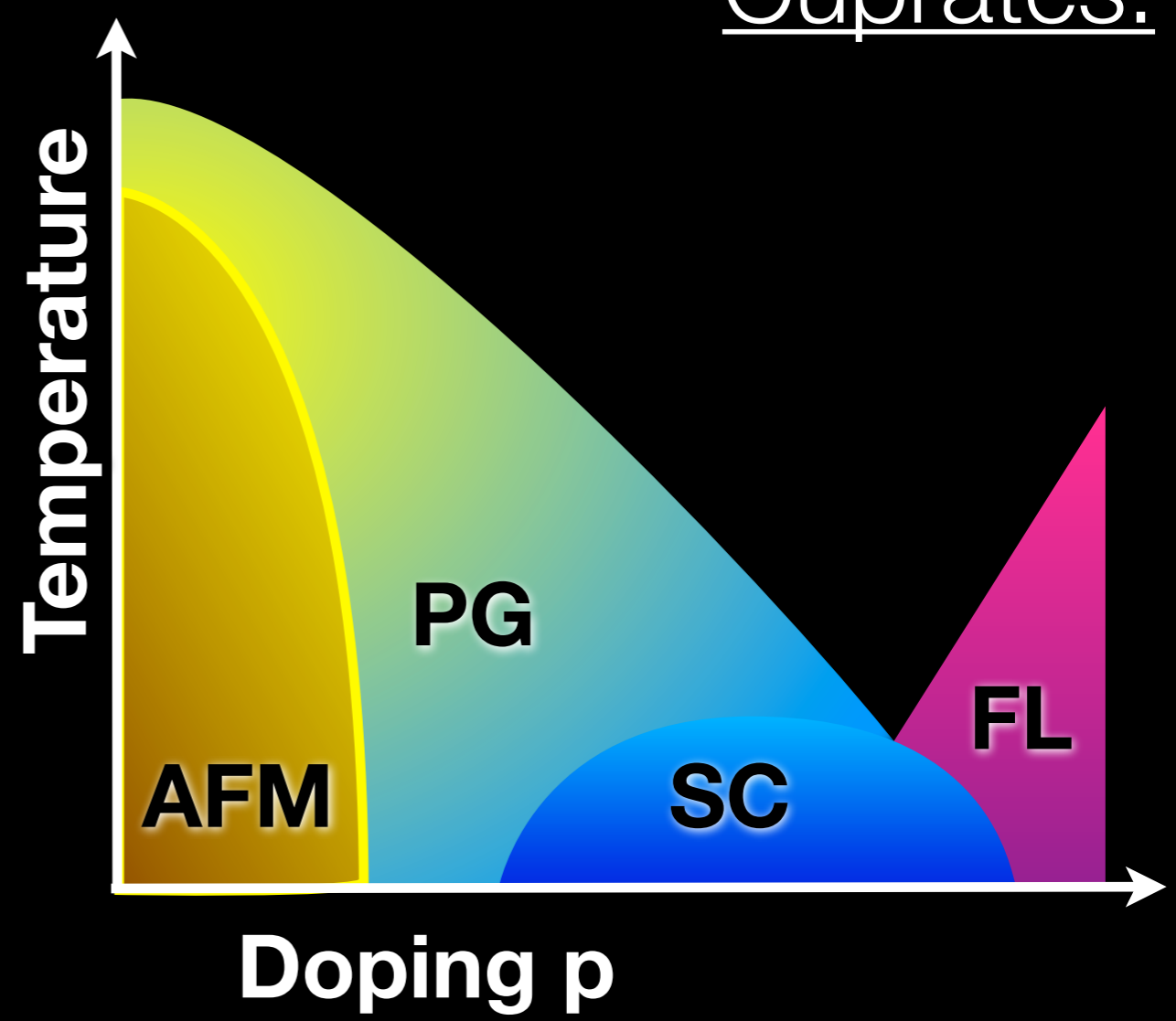


Phase Transitions

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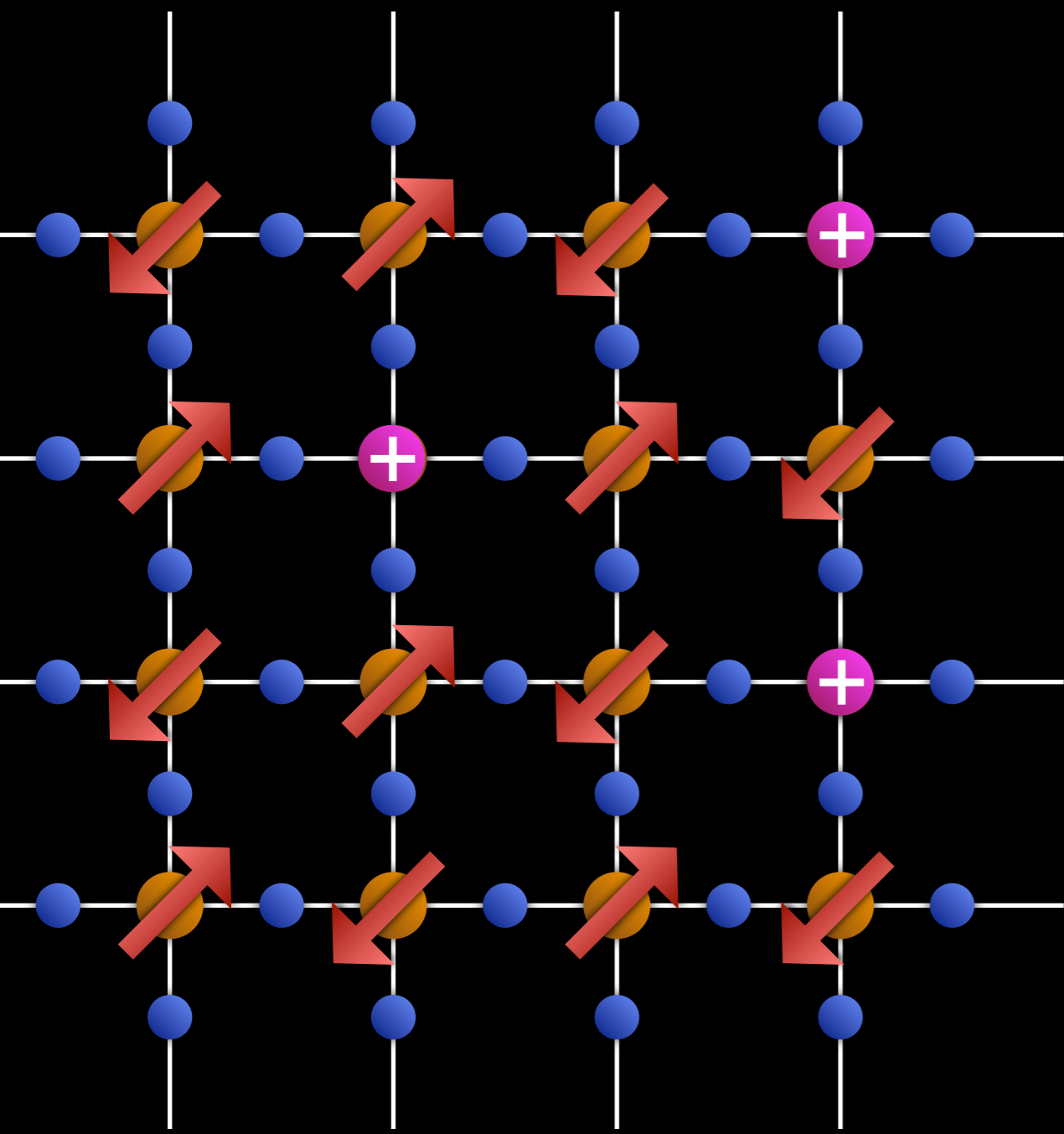
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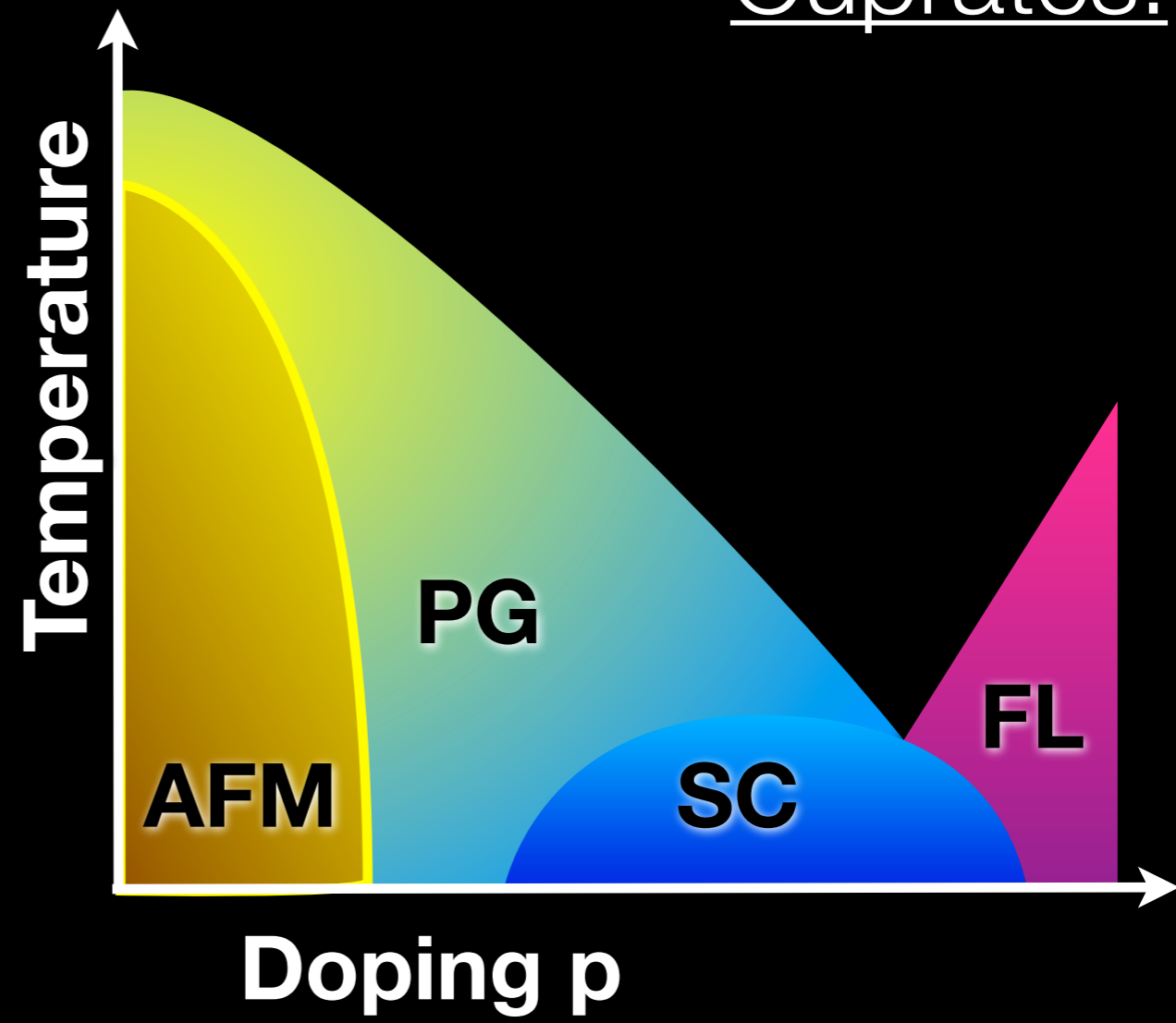


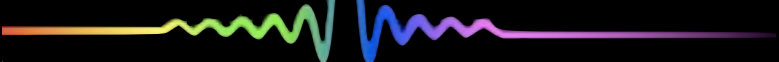
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Quantum Phase Transition: New Phases?



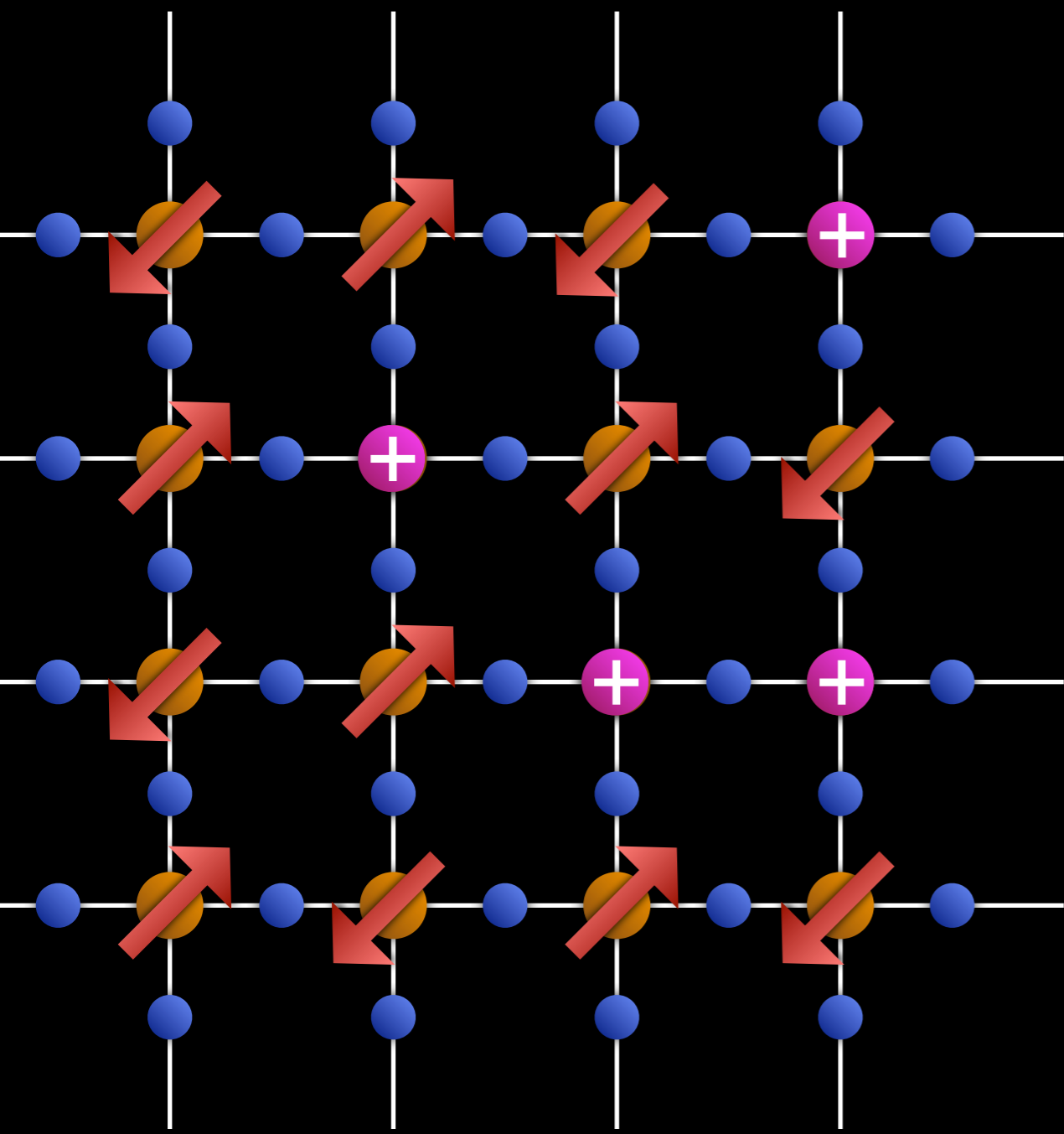
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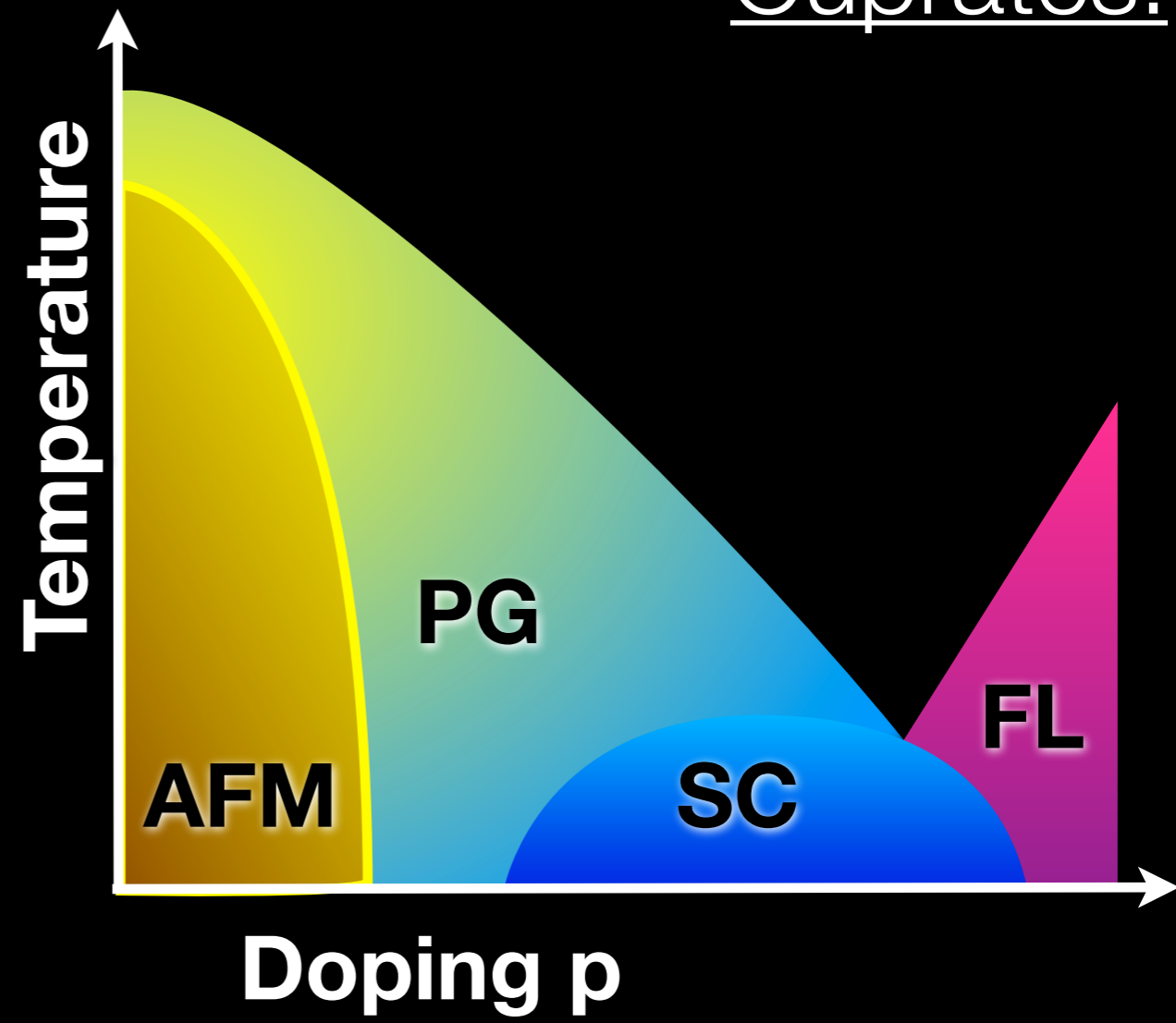


Phase Transitions

Quantum Phase Transition: New Phases?



Cuprates:

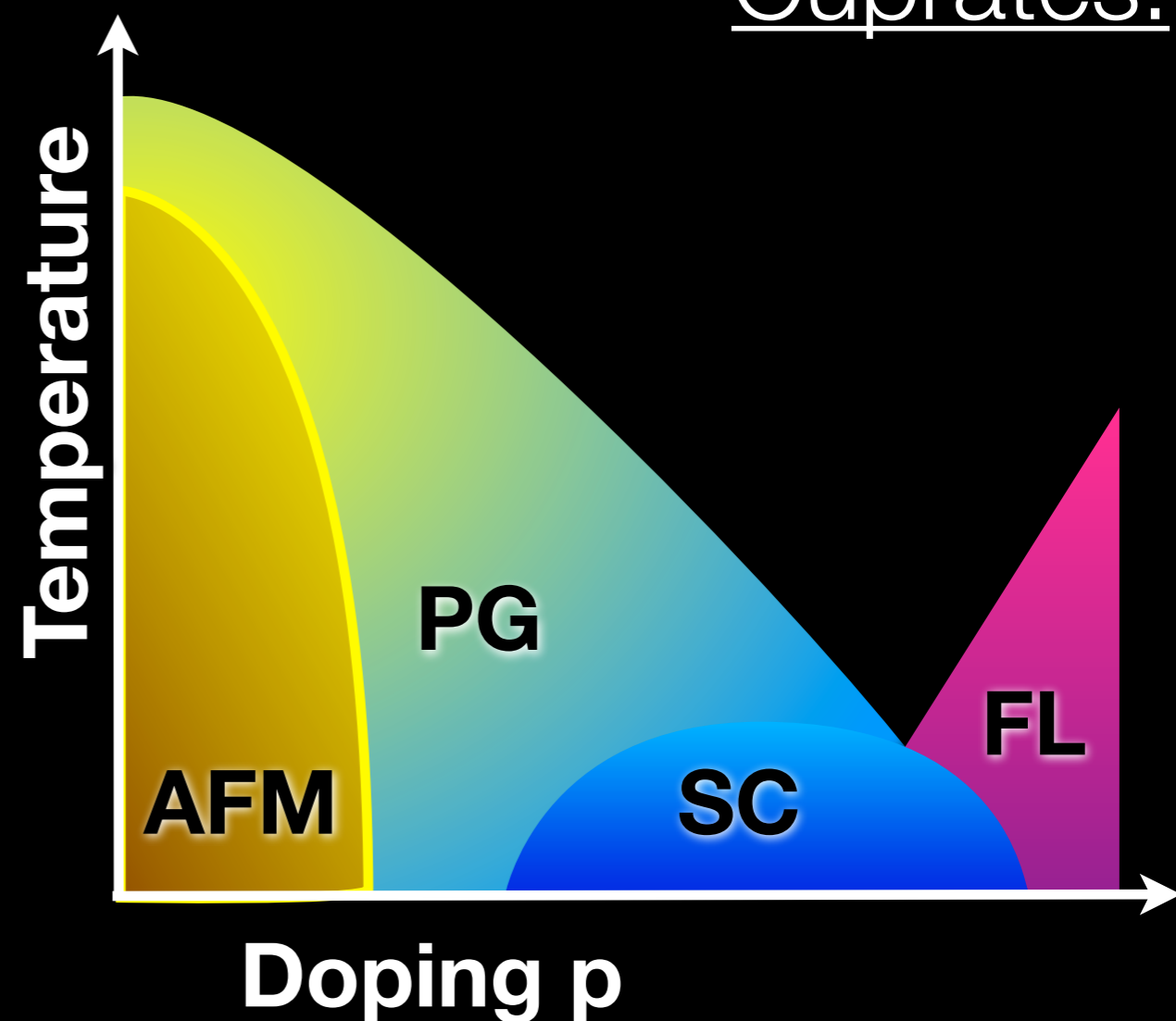


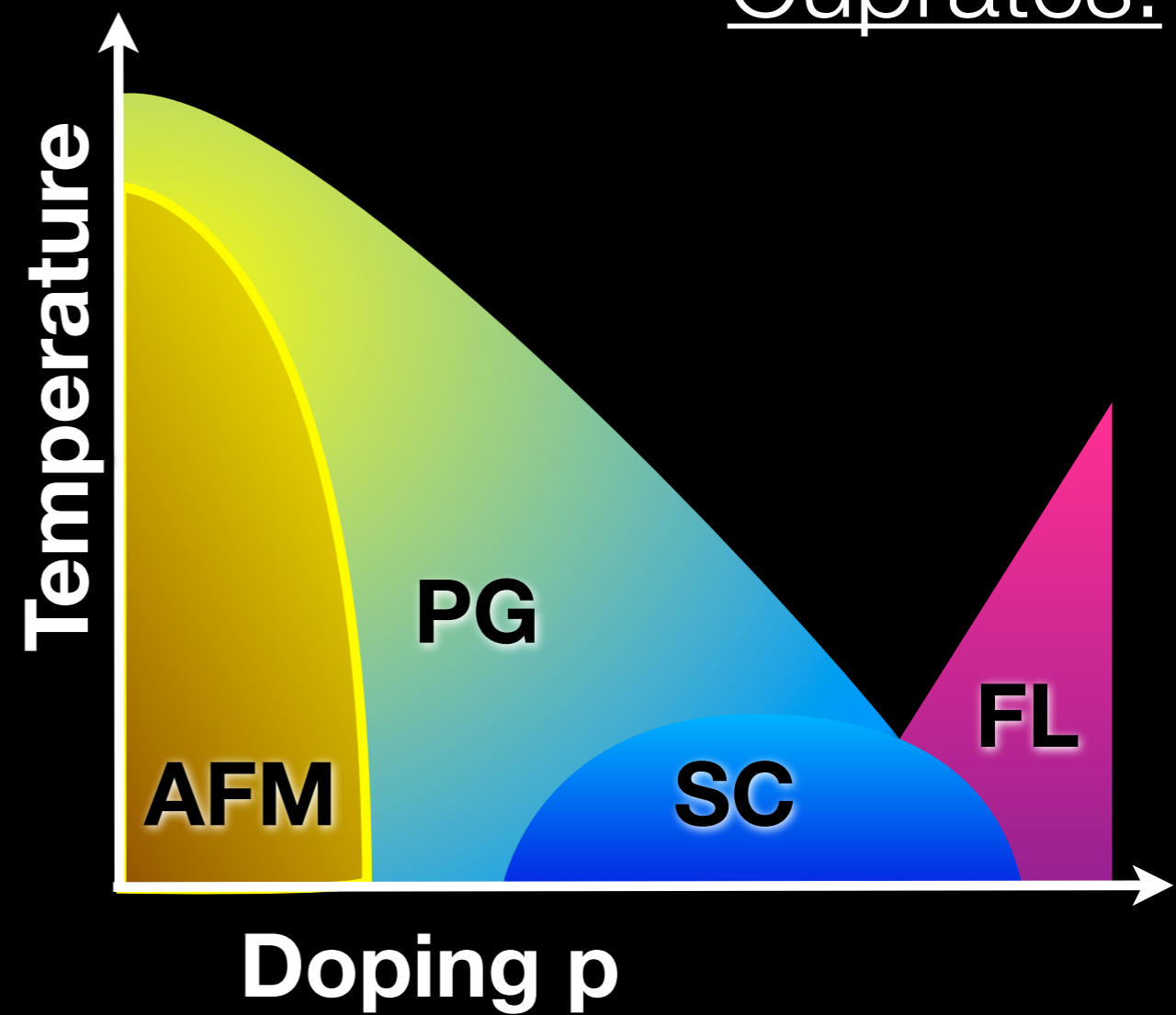
Phase Transitions

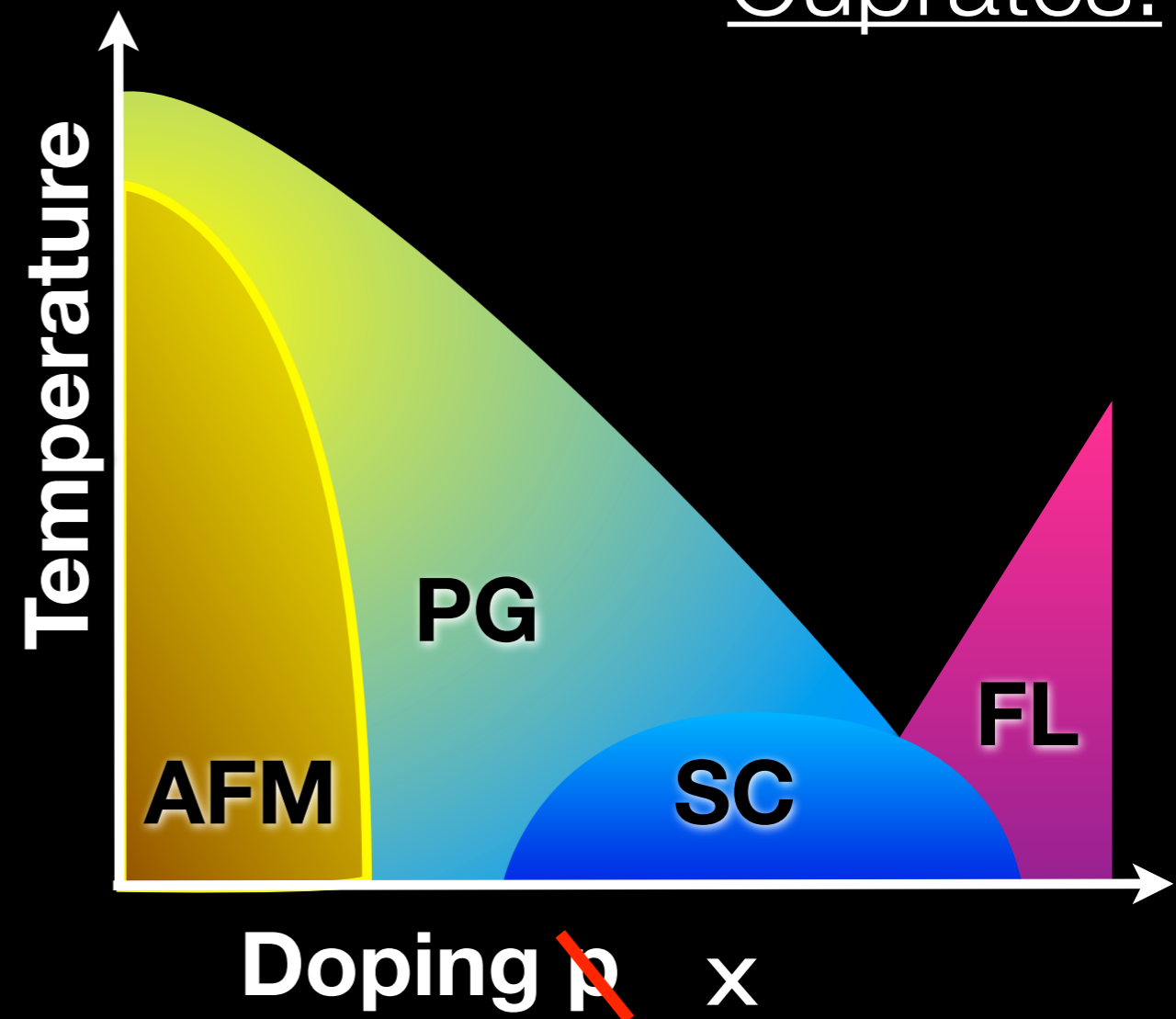
Quantum Phase Transition: New Phases?



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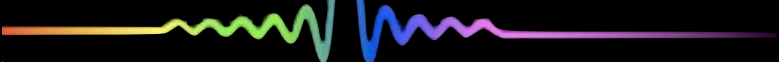






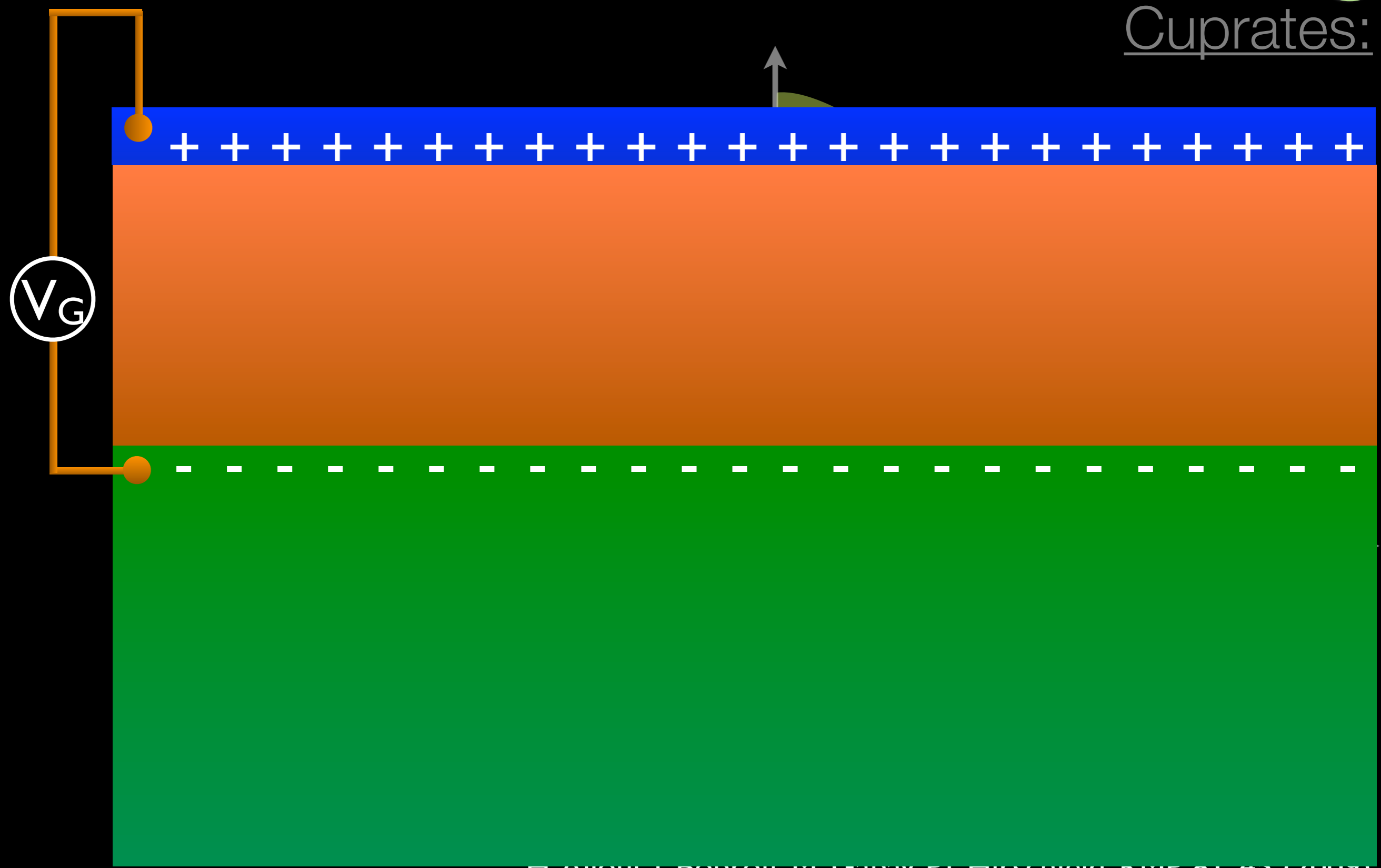
P.A. Lee, N. Nagaosa, X.G. Wen, RMP 78, 17 (2006)

H. Alloul, J. Bobroff, M. Gabay, P.J. Hirschfeld, RMP 81, 45 (2009)



Gating

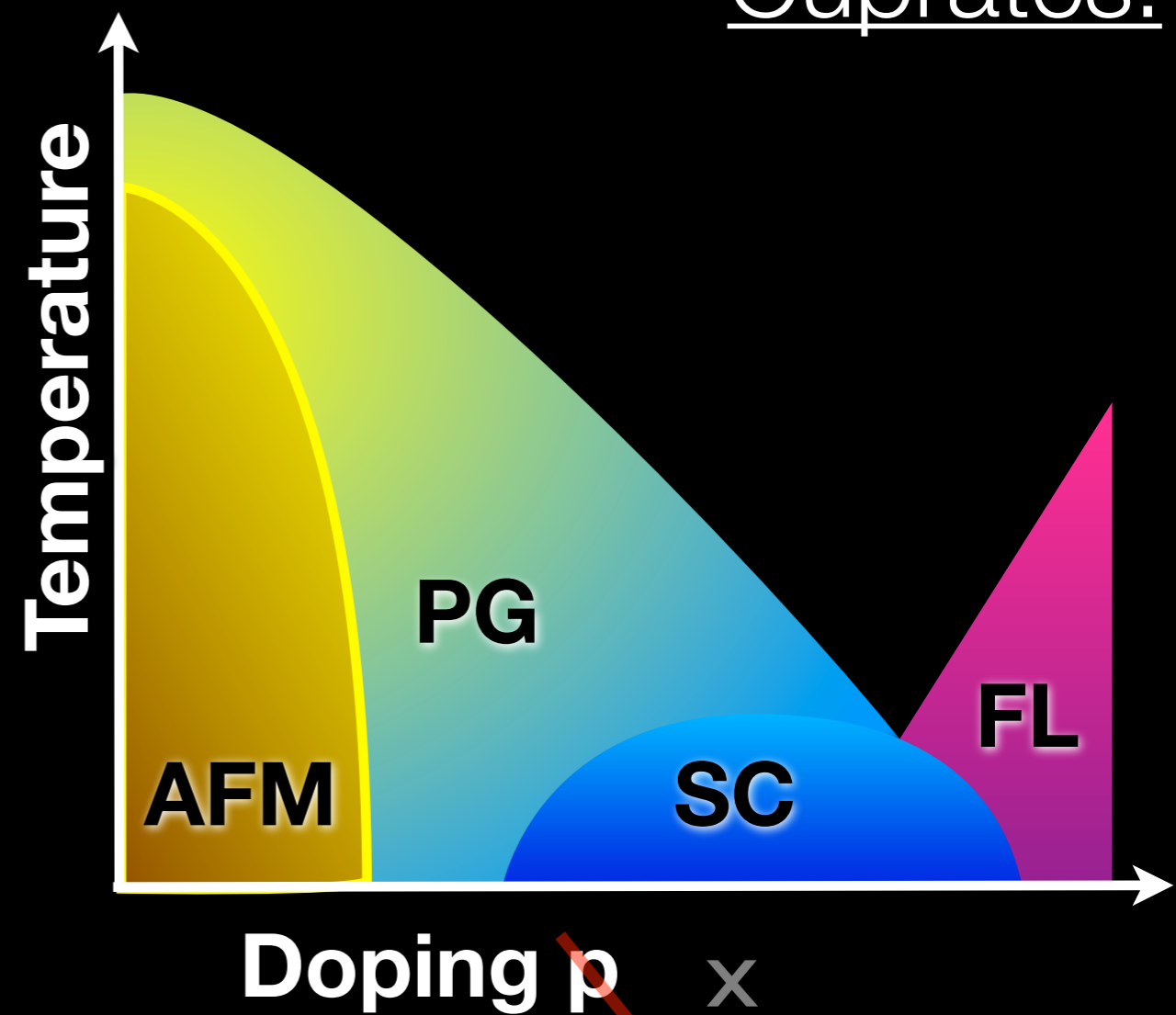
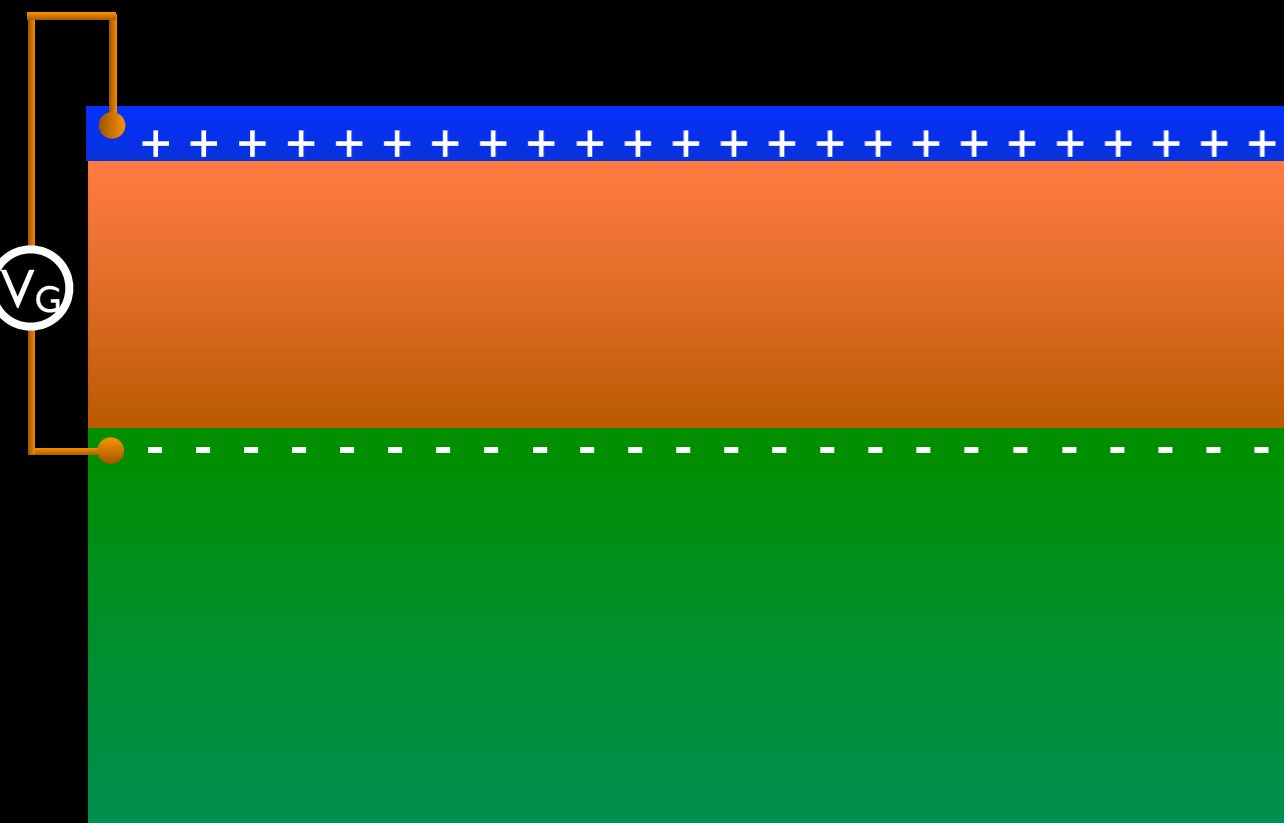
Cuprates:



H. Alloul, J. Bobroff, M. Gabay, F.J. Hirschfeld, *Nature* 41, 45 (2007)

Gating

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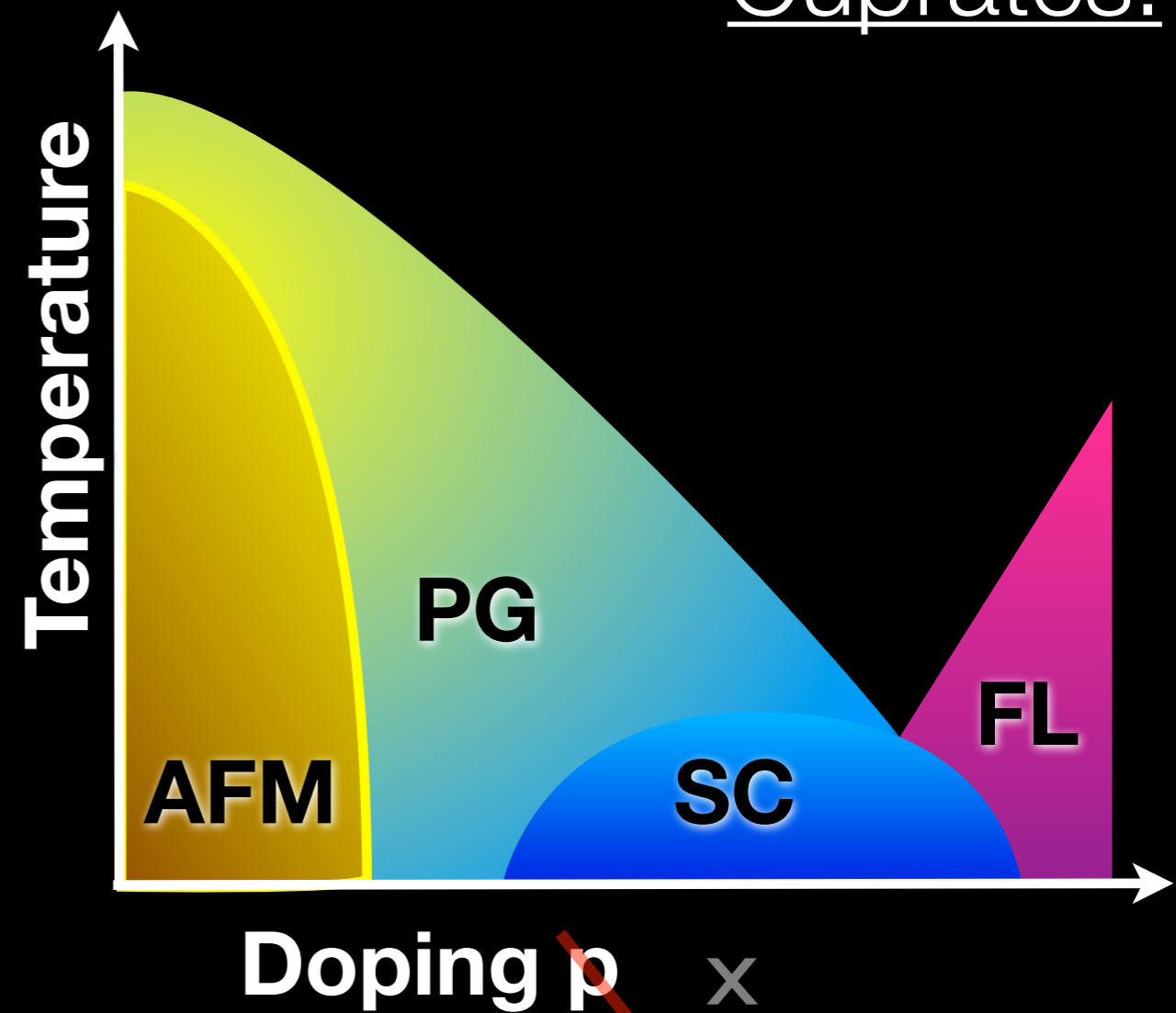
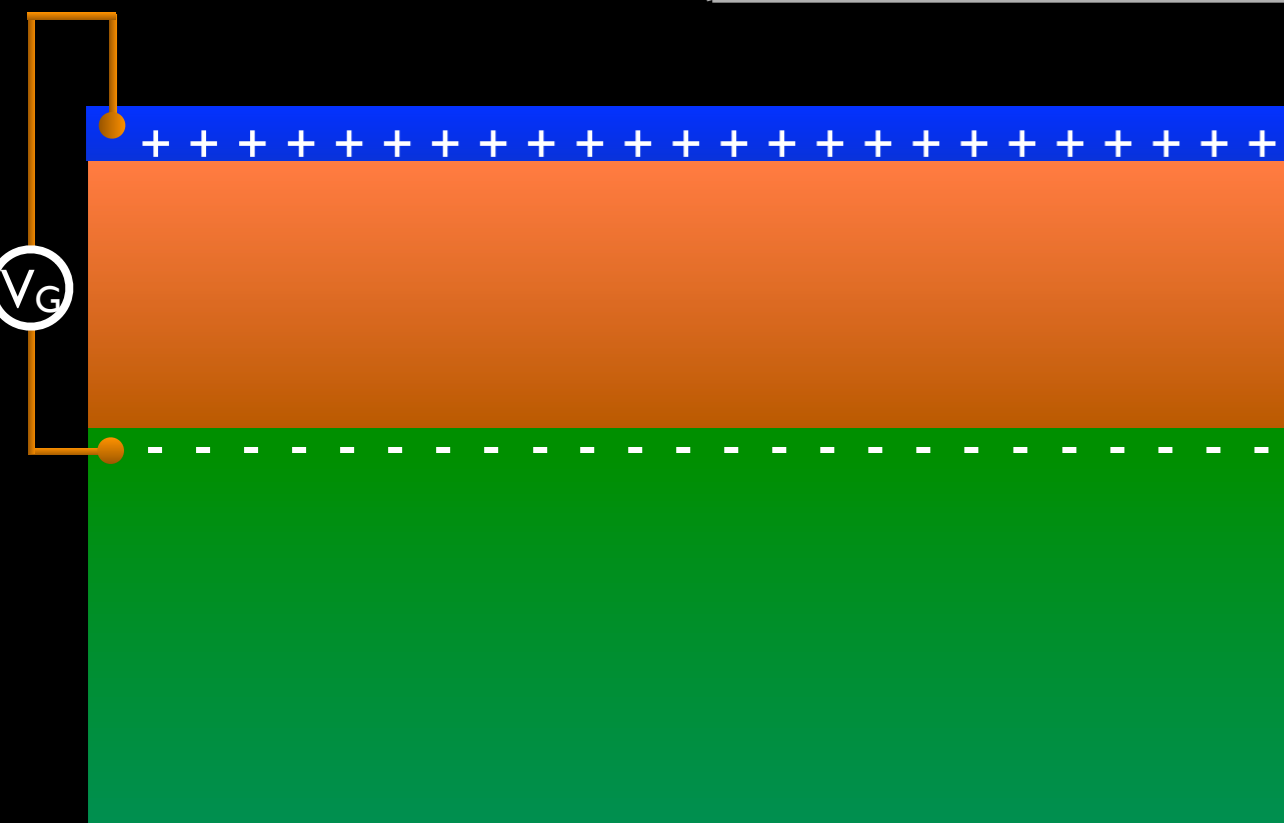
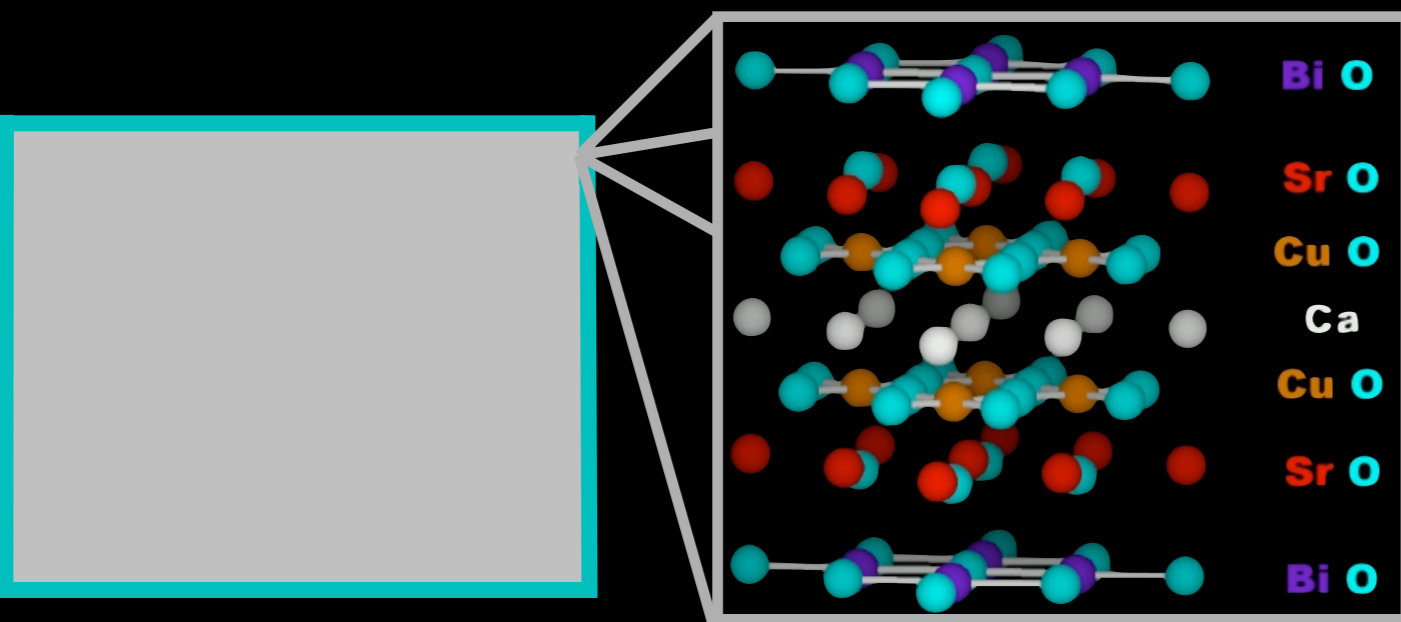


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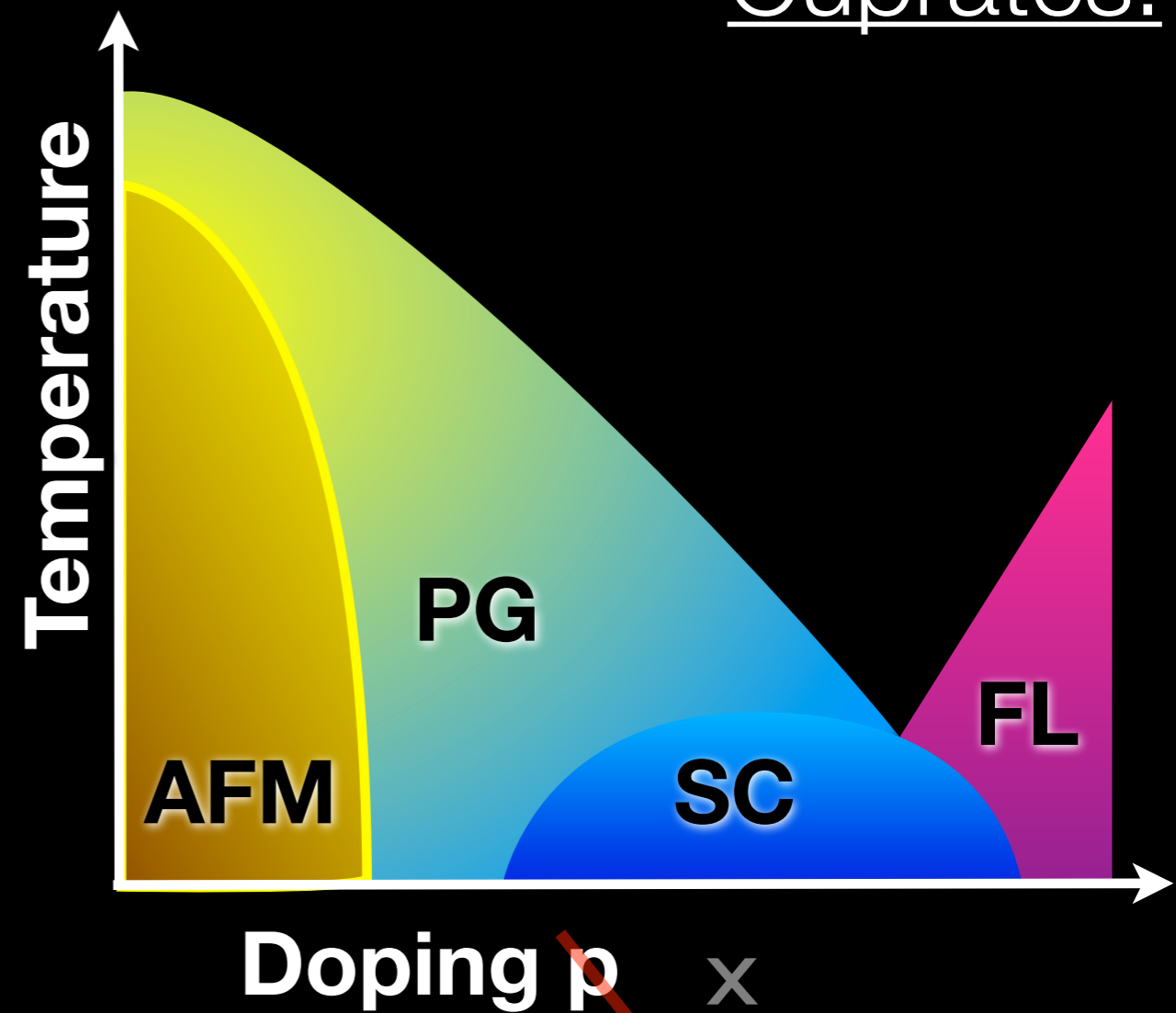
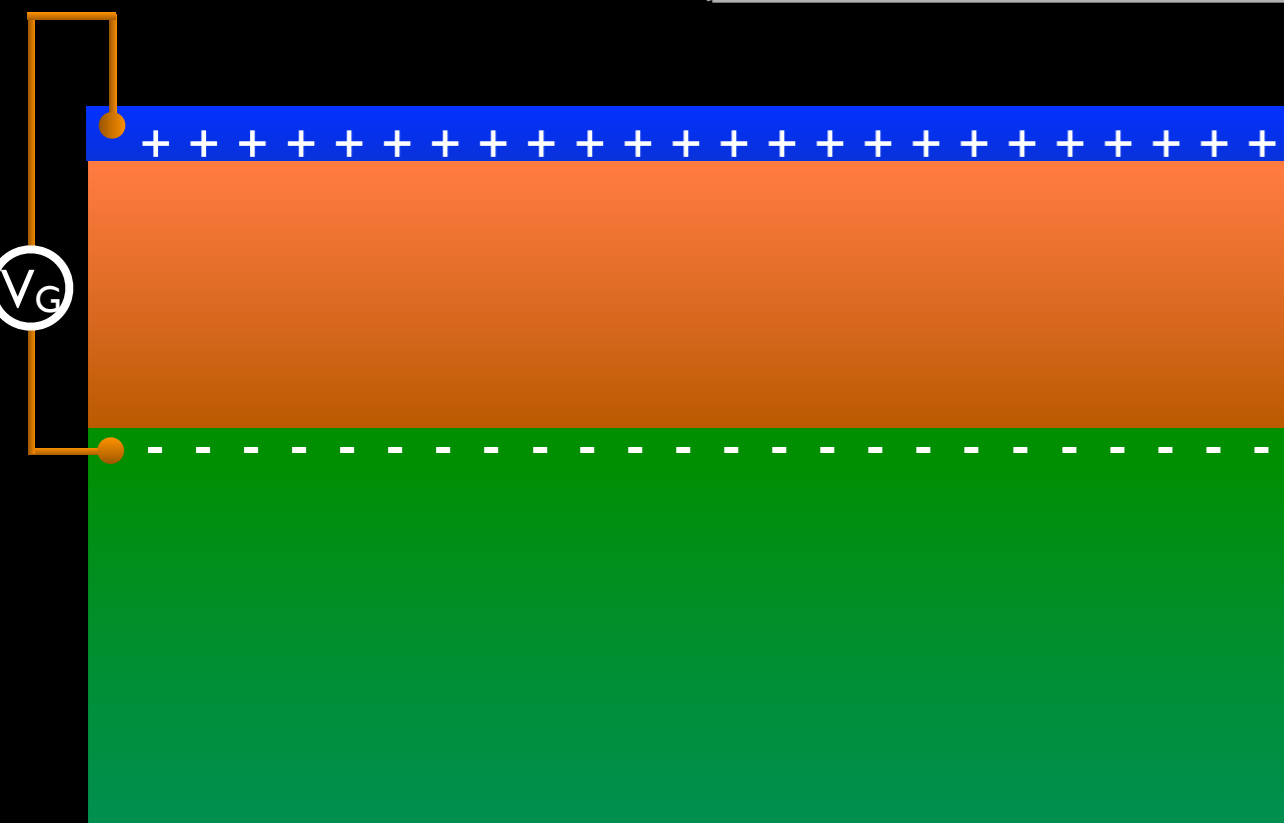
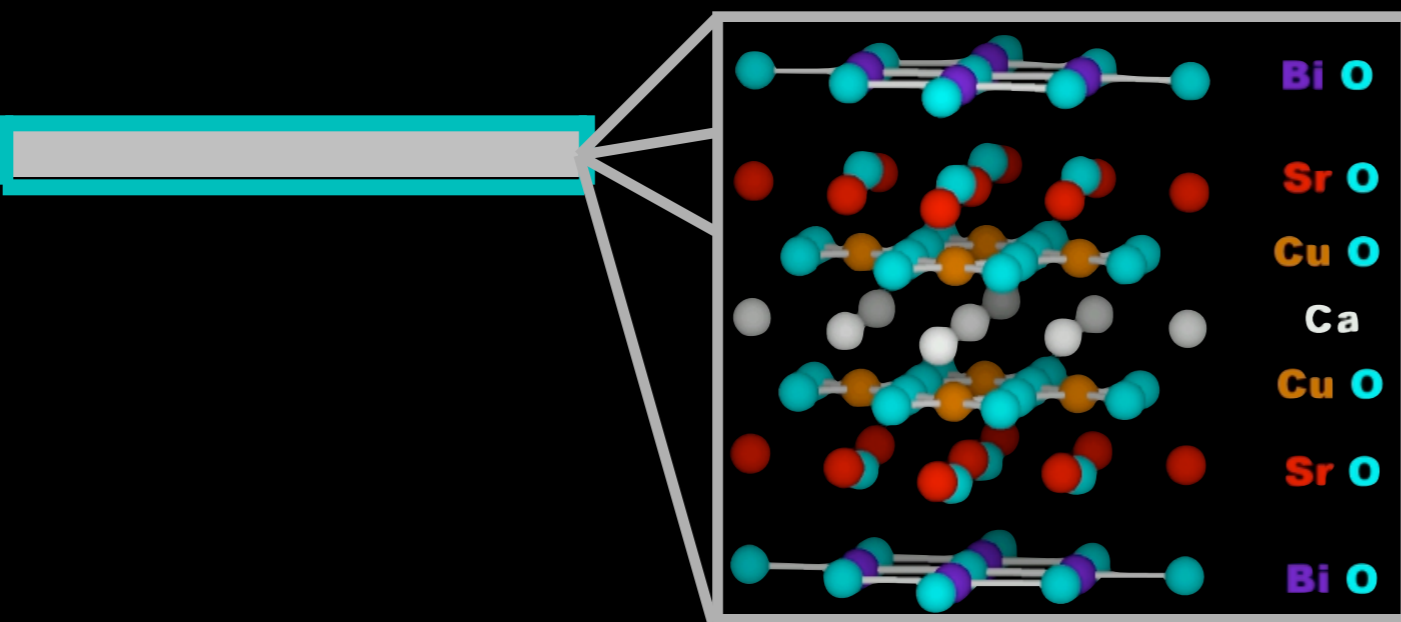


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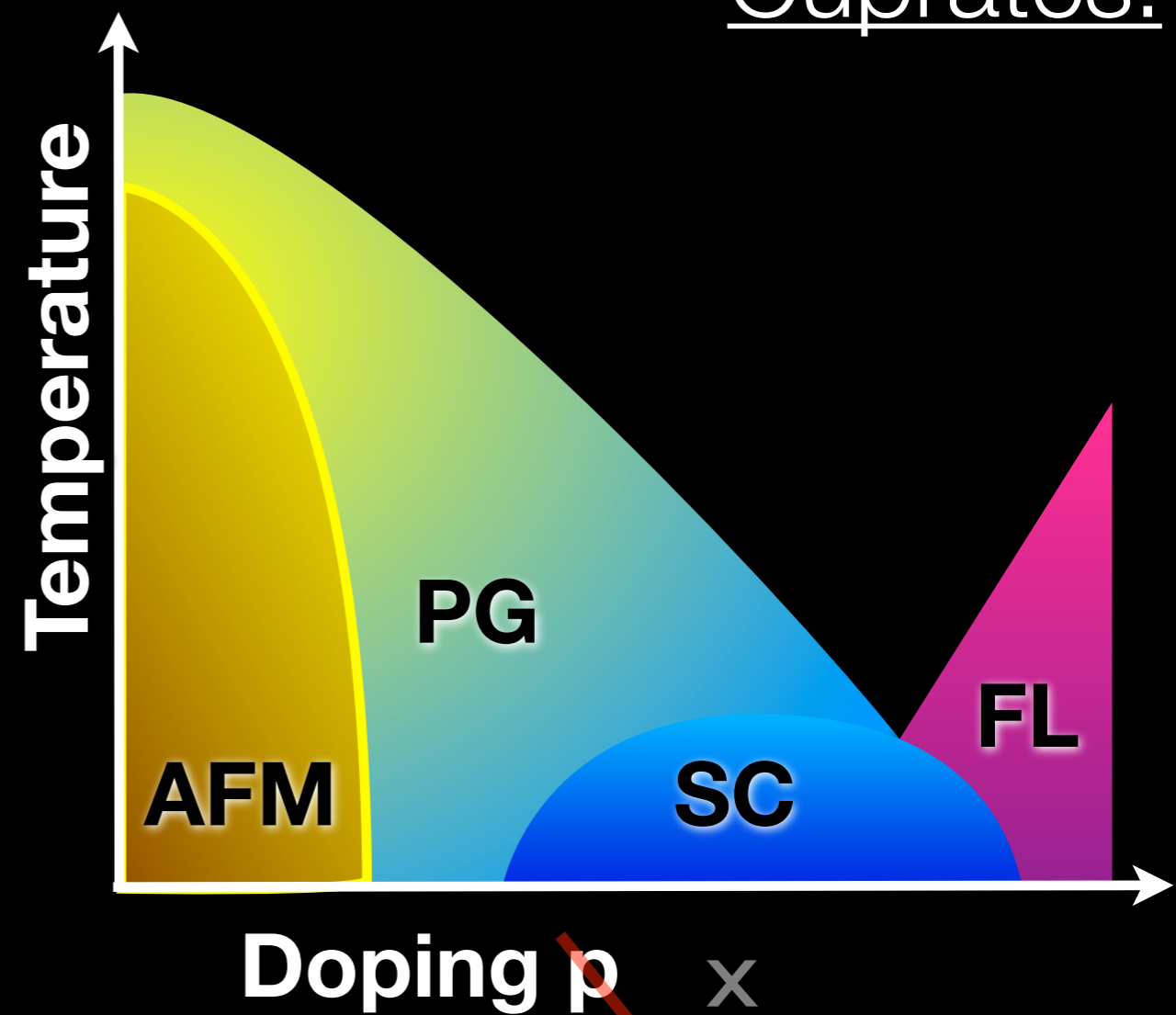
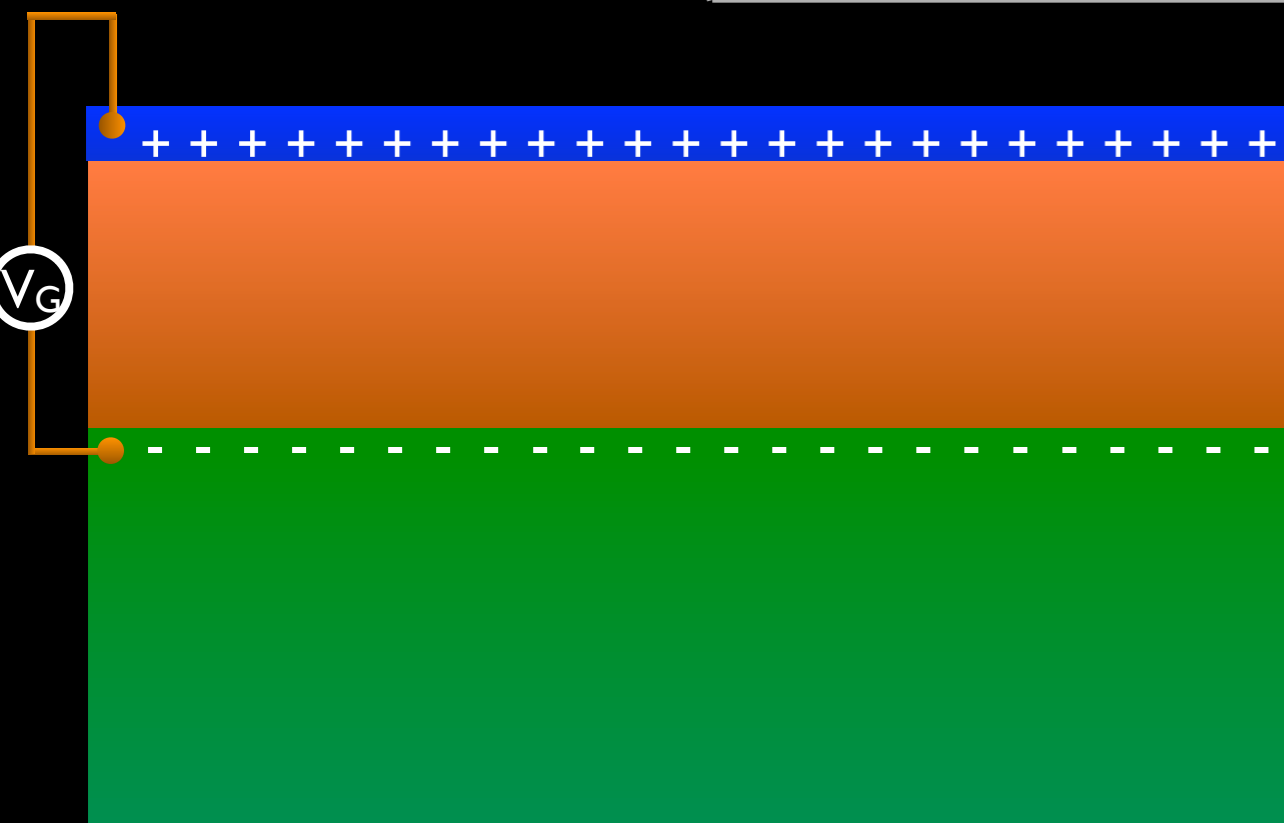
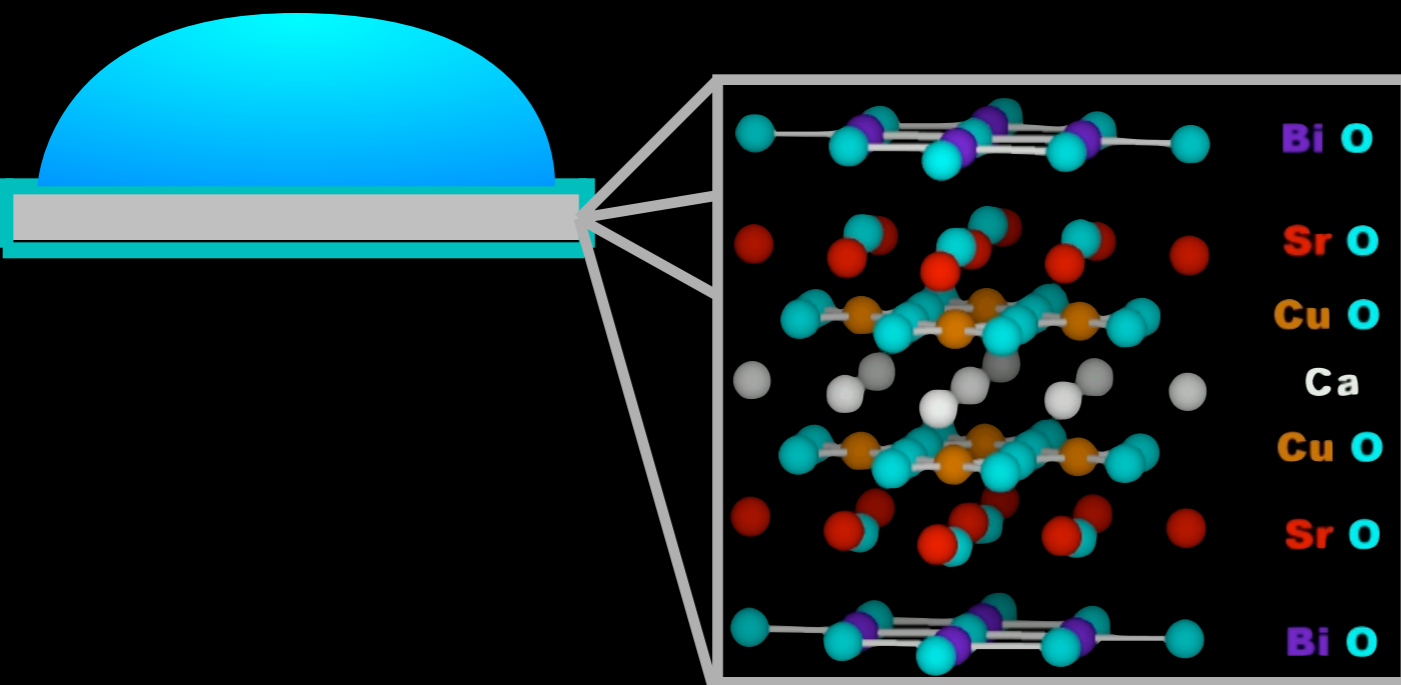


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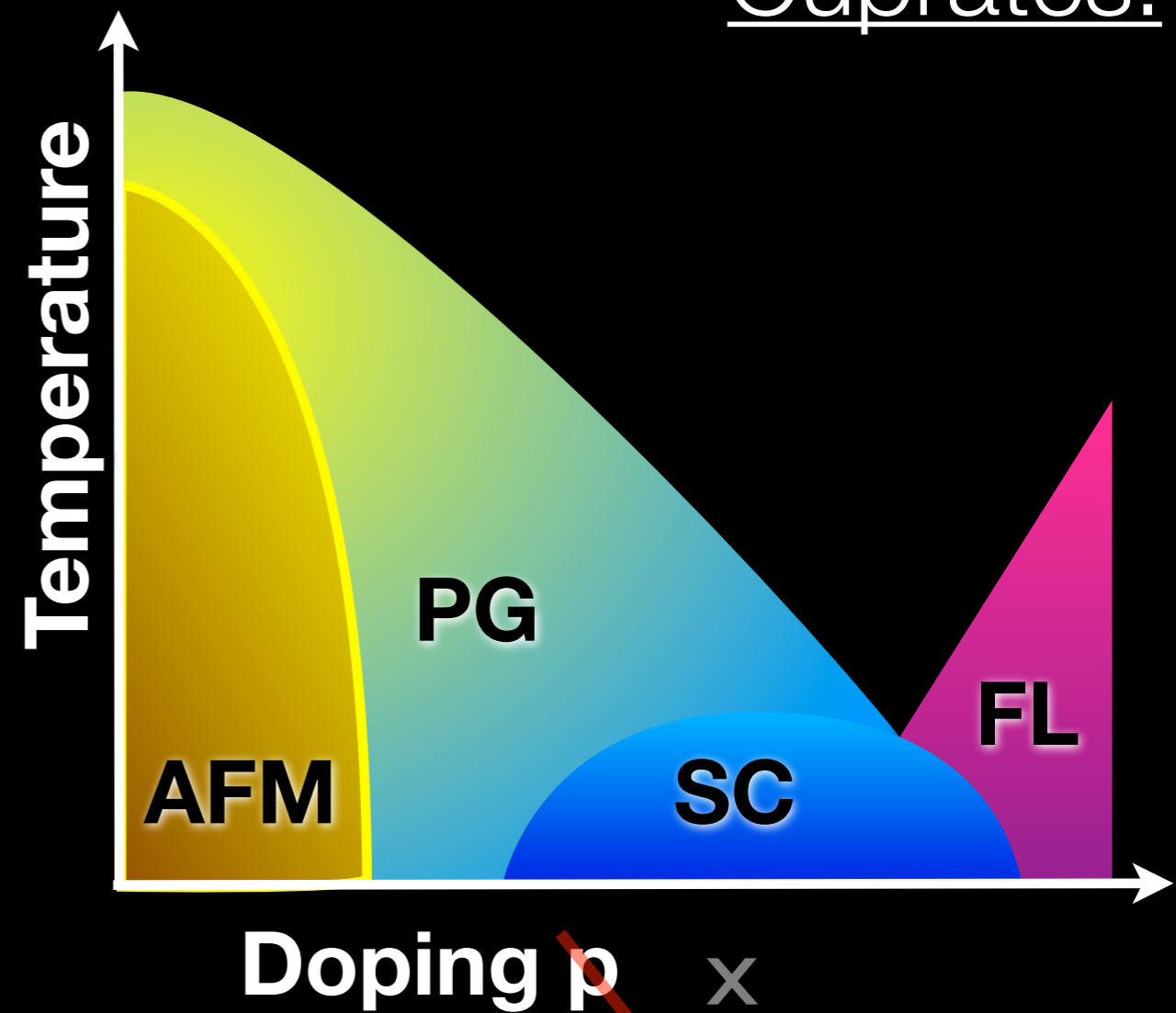
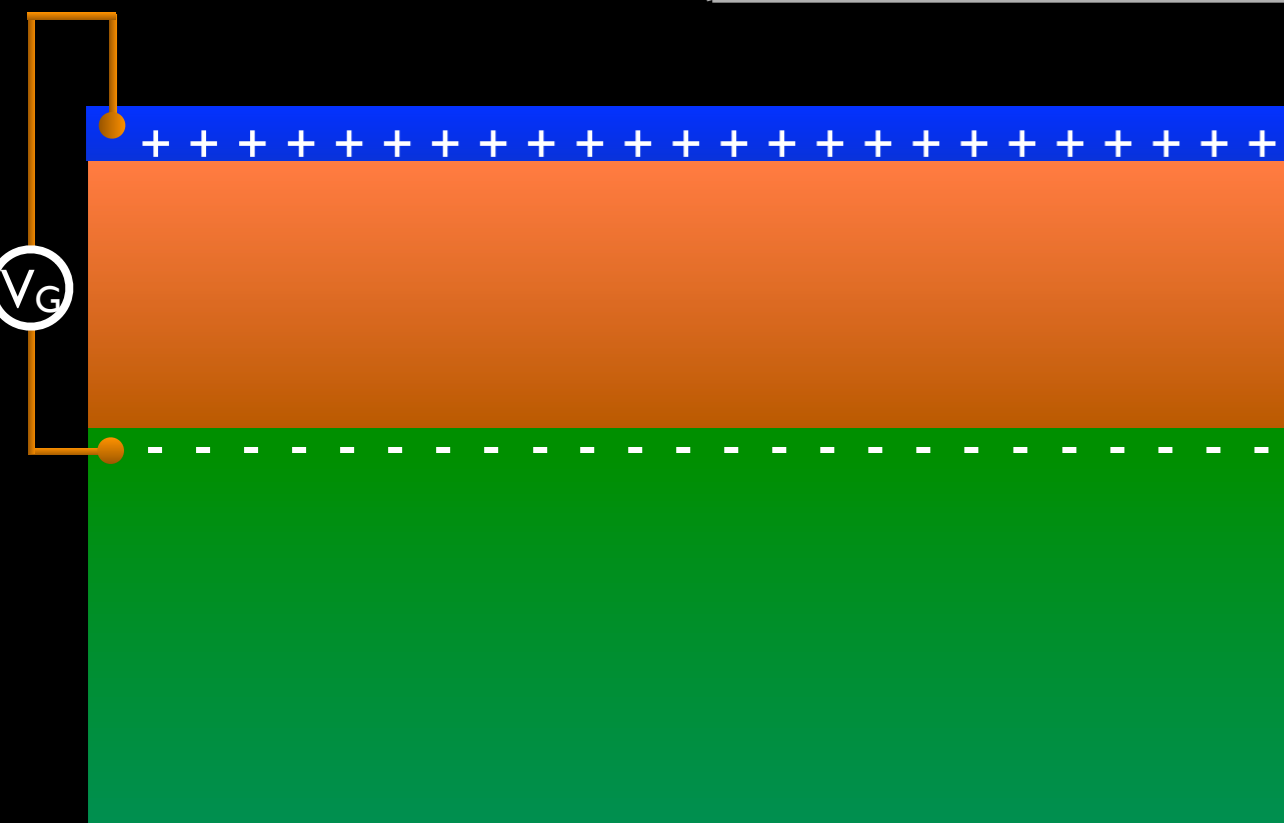
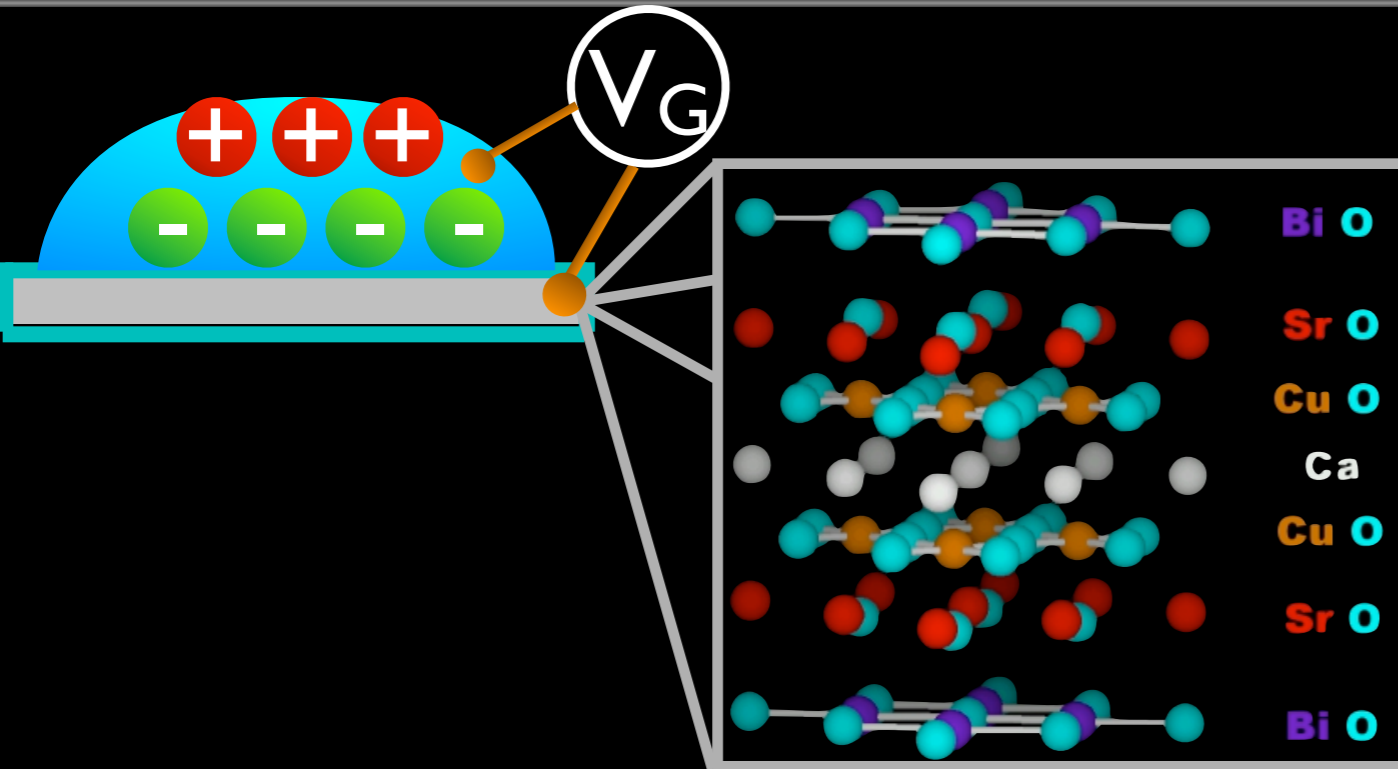


P.A. Lee, N. Nagaosa, X.G. Wen, RMP 78, 17 (2006)

H. Alloul, J. Bobroff, M. Gabay, P.J. Hirschfeld, RMP 81, 45 (2009)

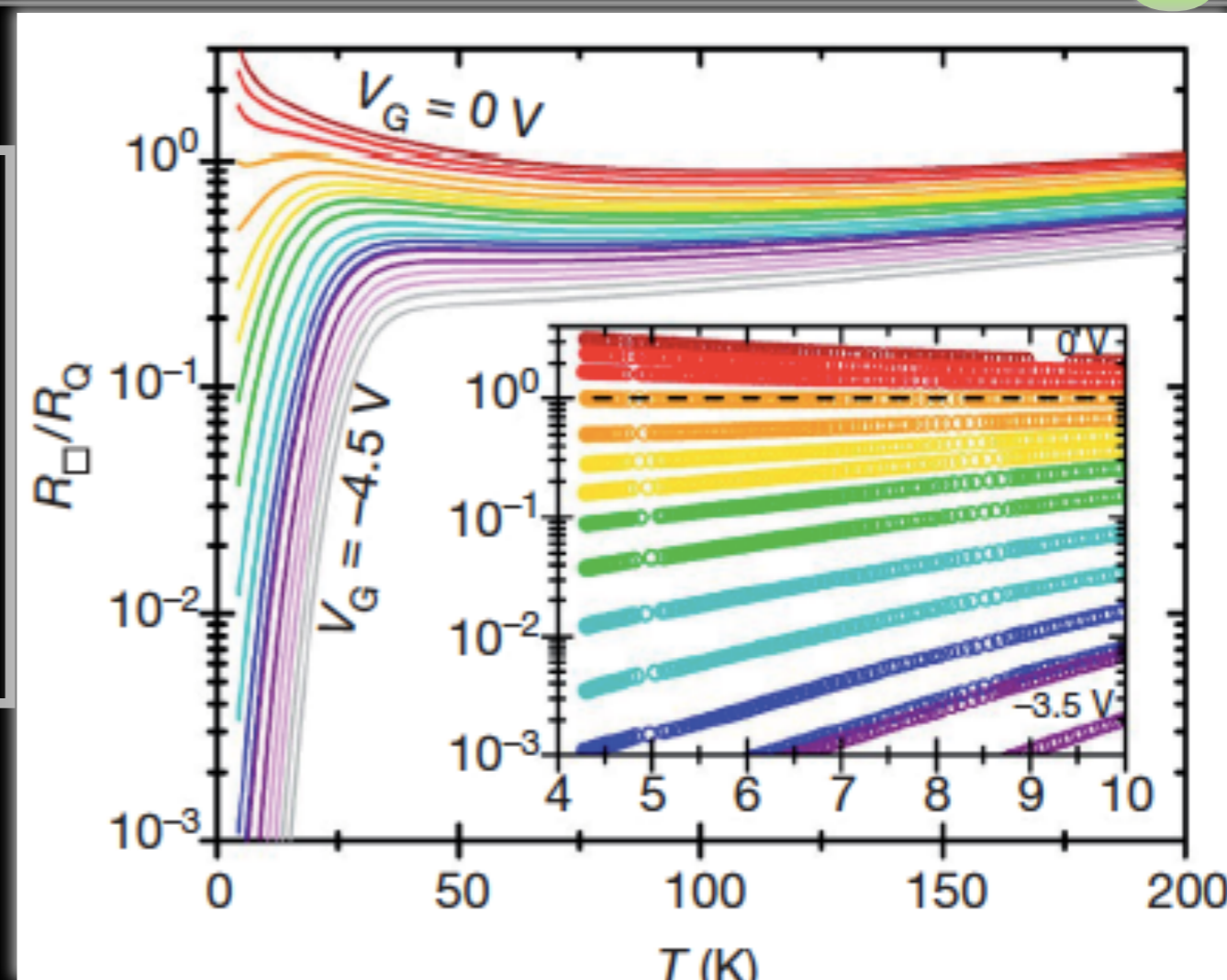
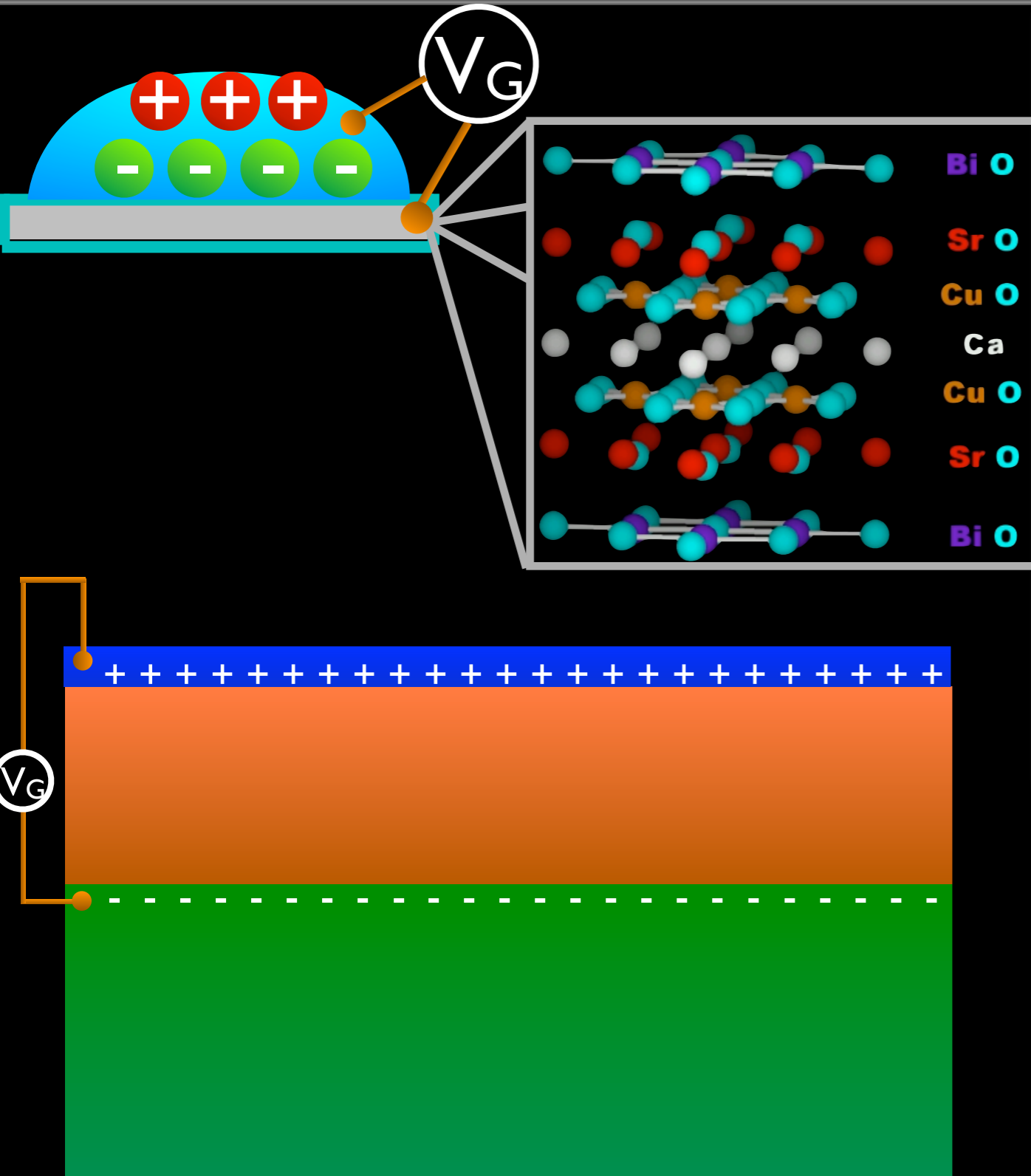
Gating

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P.A. Lee, N. Nagaosa, X.G. Wen, RMP 78, 17 (2006)

H. Alloul, J. Bobroff, M. Gabay, P.J. Hirschfeld, RMP 81, 45 (2009)



X. Lang et al, PRL 107, 027001 (2011)

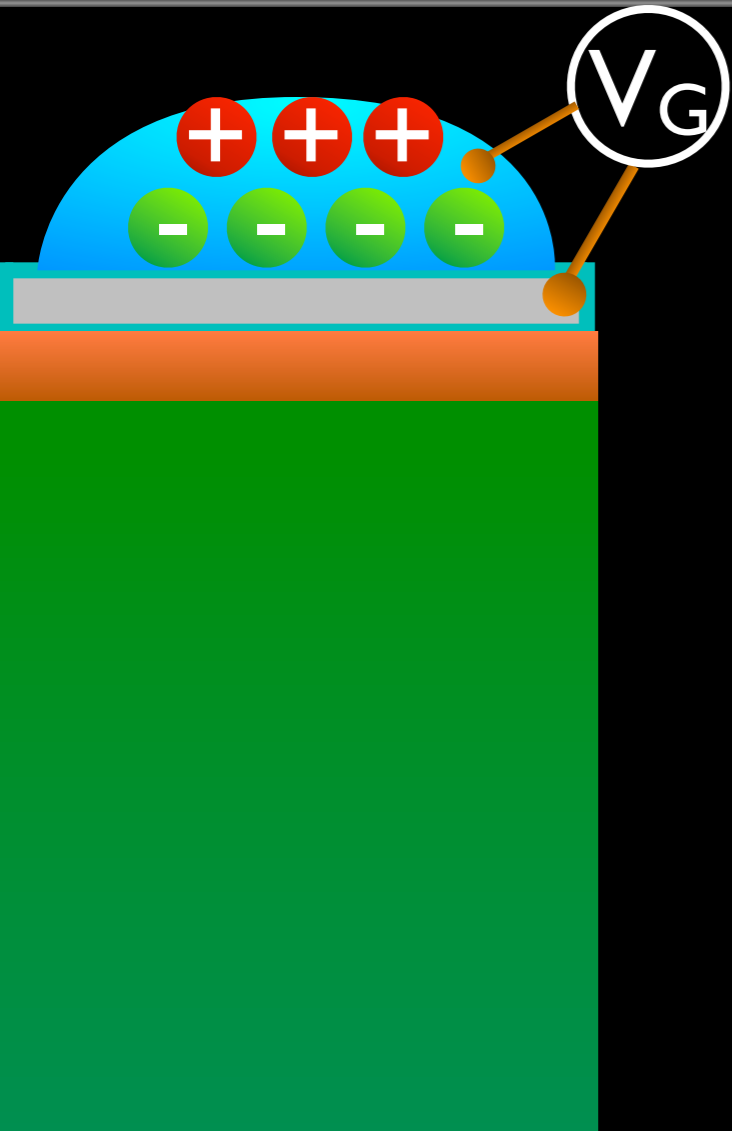
A.T. Bollinger et al, Nature 472, 458 (2011)

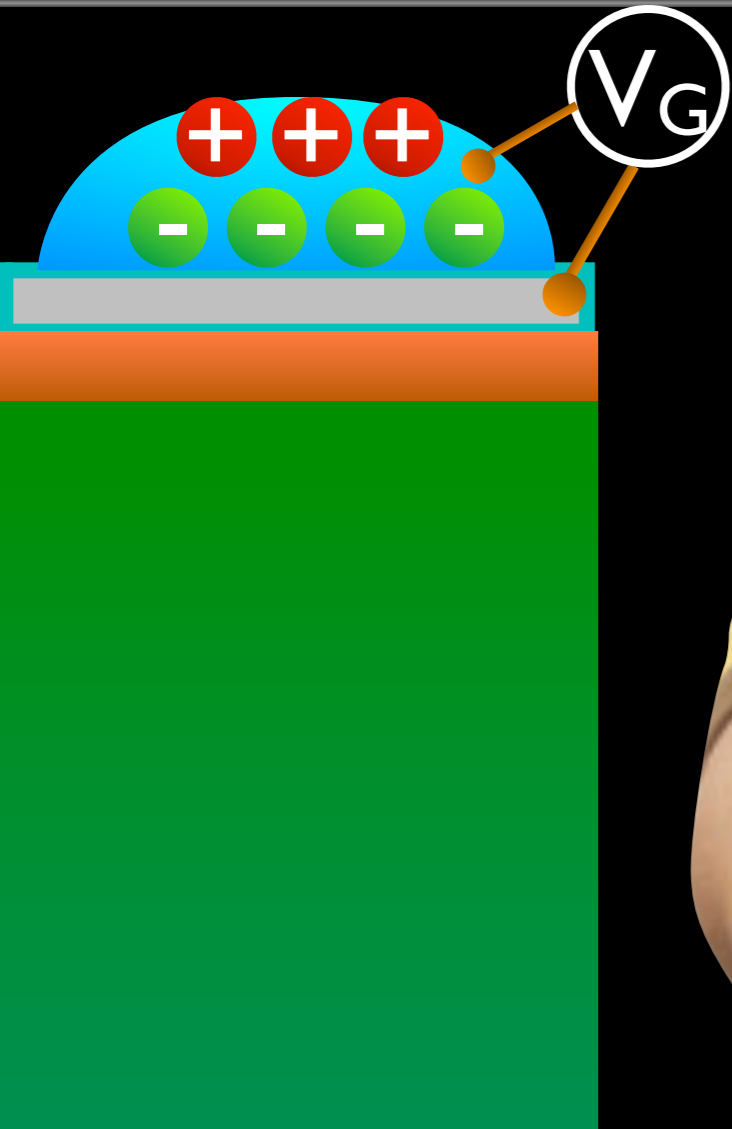
P.A. Lee, N. Nagaosa, X.G. Wen, RMP 78, 17 (2006)

H.Alloul, J. Bobroff, M. Gabay, P.J. Hirschfeld, RMP 81, 45 (2009)



Gating





$\text{LaAlO}_3/\text{LaVO}_3$

M. Takizawa et al., PRL
102, 236401 (2009)

$\text{NdBa}_2\text{Cu}_3\text{O}_{7-\delta}/$
 SrTiO_3

D. Matthey et al., APL 83,
3758 (2003)

$\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$
 $/\text{SiO}_2/\text{Si}$

J.Y. Gu et al., APL 70,
1763 (1997)

$\text{La}_{1.8}\text{Sr}_{0.2}\text{Cu}_3\text{O}_{4-\delta}/$
 $\text{Y}_{1-y}\text{Ca}_y\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}/$
 SrTiO_3

G.Yu. Logvenov et al., APL 86, 202505
(2005)



Exfoliation









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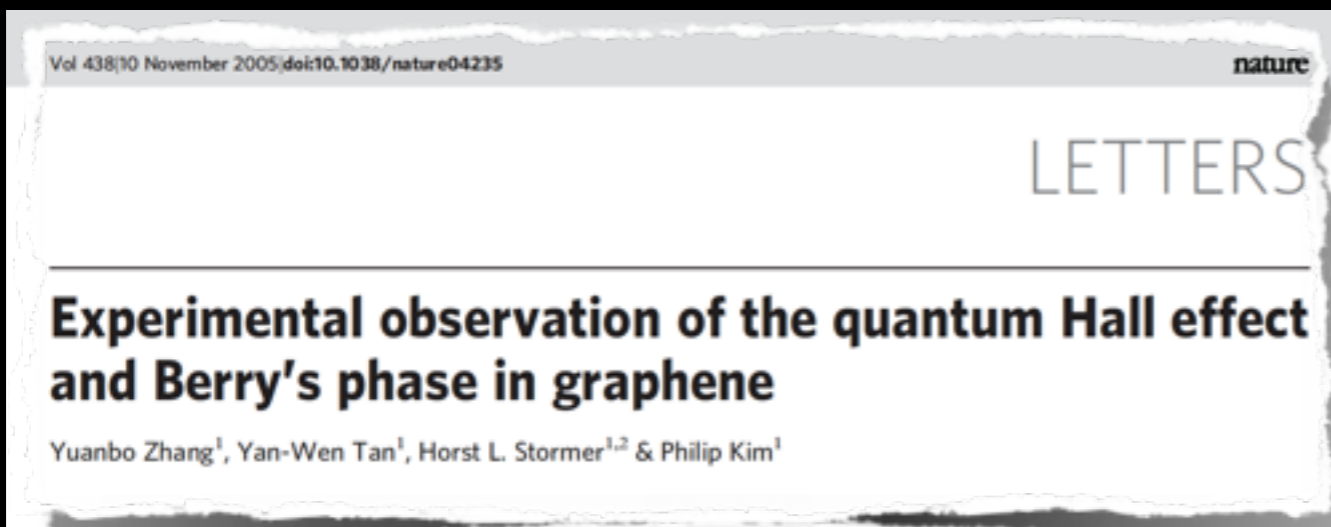
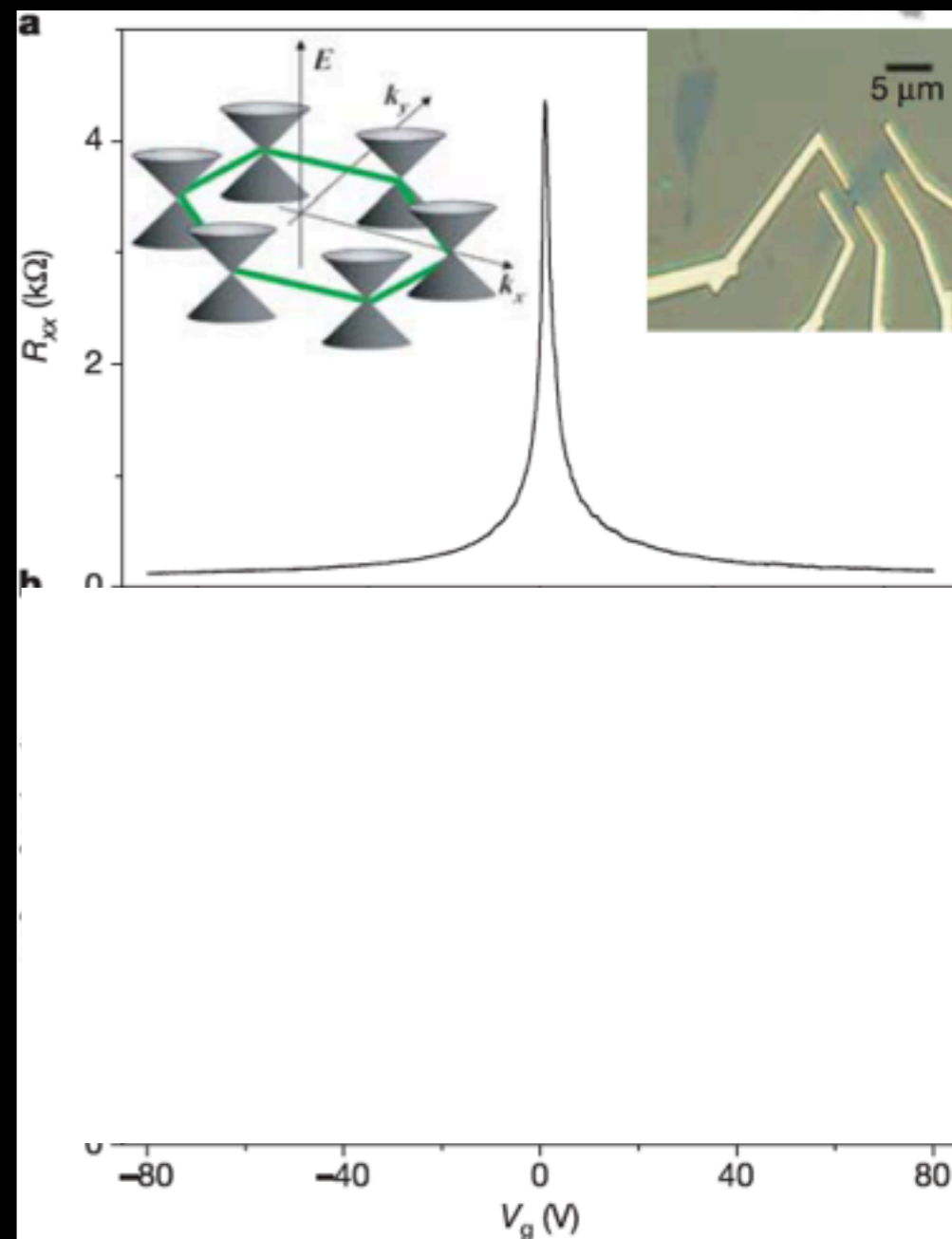
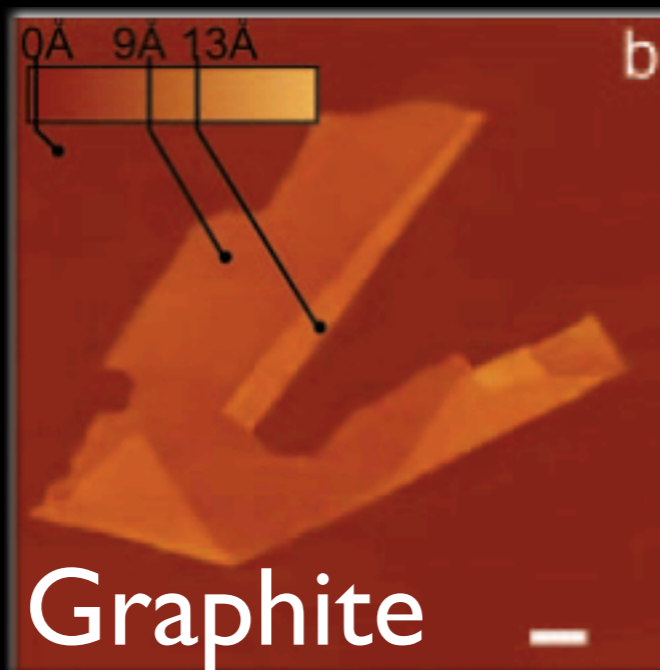




Two-dimensional atomic crystals

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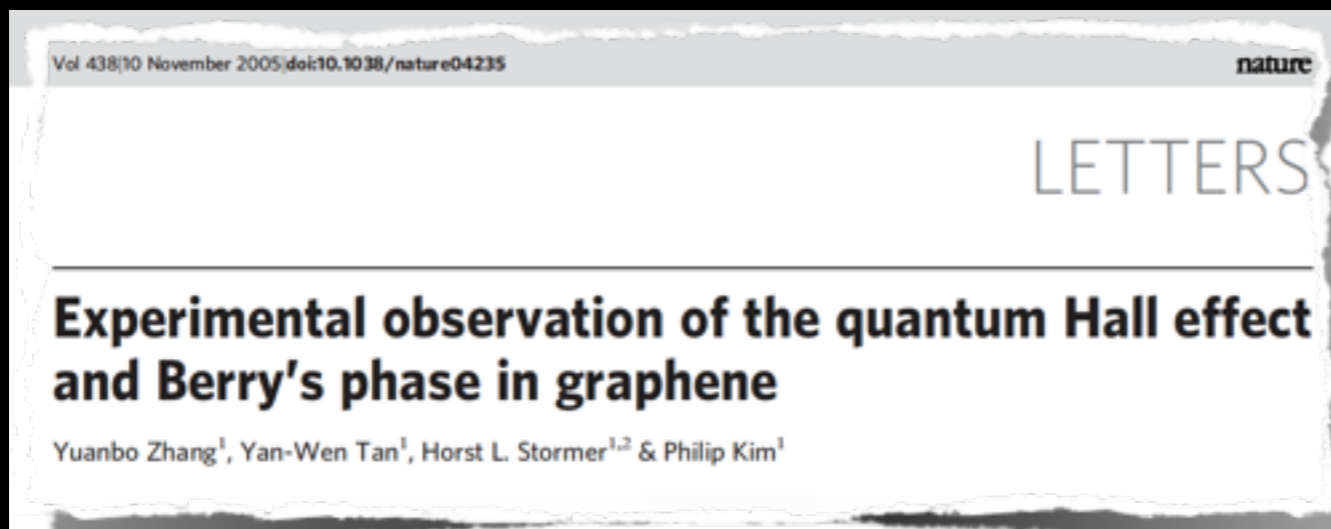
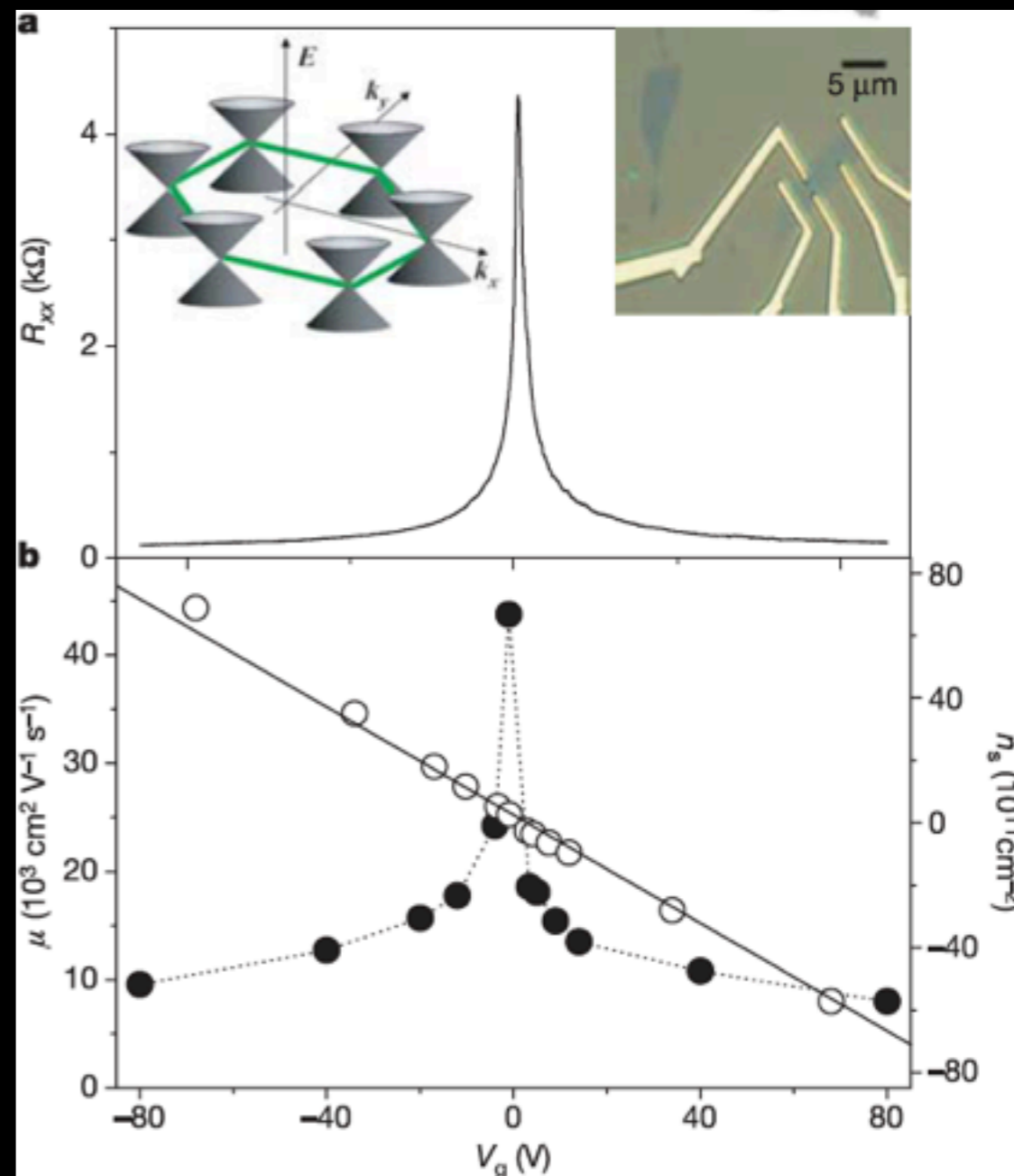
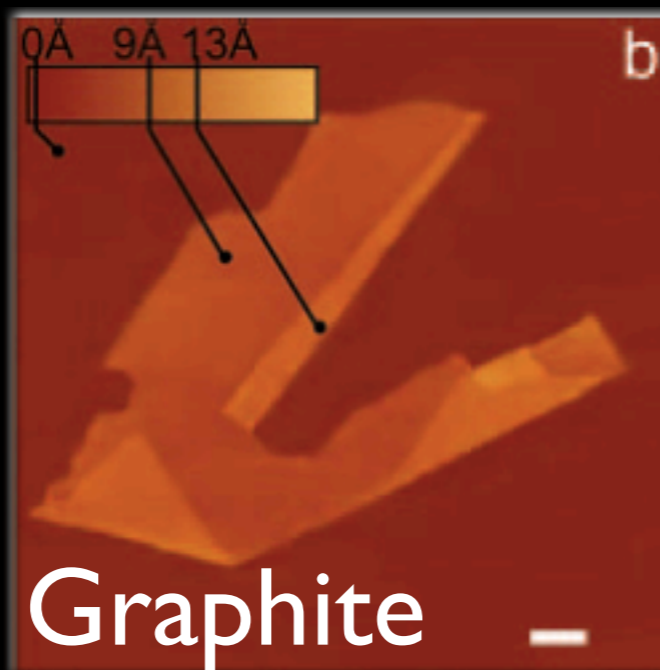




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LETTERS

Ultraflat graphene

Chun Hung Lui¹, Li Liu², Kin Fai Mak¹, George W. Flynn² & Tony F. Heinz¹

PHYSICAL REVIEW B

Spatially resolved spectroscopy of monolayer graphene

A. Deshpande,¹ W. Bao,² F. Miao,² C. N. Lau,² and B. J. van der Geerd¹

¹Department of Physics, University of Arizona, Tucson, Arizona 85724, USA

PHYSICAL REVIEW LETTERS

Electric Field Effect Tuning of Electron-Phonon Coupling in Graphene

Jun Yan,¹ Yuanbo Zhang,¹ Philip Kim,¹ and Aron Pinczuk^{1,2}

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²Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York 10027, USA

PHYSICAL REVIEW LETTERS

Band Structures of Bilayer Graphene Superlattices

Matthew Killi,¹ Si Wu,¹ and Arun Paramakanti^{1,2,3}

¹Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7
²Canadian Institute for Advanced Research, Toronto, Ontario, M5G 1Z8, Canada
³Department of Physics, Indian Institute of Science, Bangalore, India 560 012

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¹Clarendon Laboratory, Physics Department, Oxford University, Parks Road, Oxford OX1 3PU, United Kingdom
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PHYSICAL REVIEW B 82, 125411 (2010)

Graphene and few-layer graphite probed by second-harmonic generation: Theory and experiment

Jesse J. Dean* and Henry M. van Driel

Department of Physics and Institute for Optical Sciences, University of Toronto, Toronto, Ontario, Canada M5S-1A7

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PHYSICAL REVIEW LETTERS

Gate Tunable Infrared Phonon Anomalies in Bilayer Graphene

A. B. Kuzmenko,¹ L. Benfatto,^{2,3,4} E. Cappelluti,^{3,4} I. Crassee,¹ D. van der Marel,¹ P. Blake,⁵

LETTERS

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nature nanotechnology

Controlled ripple texturing of suspended graphene and ultrathin graphite membranes

Wenzhong Bao¹, Feng Miao¹, Zhen Chen², Hang Zhang¹, Wanyoung Jang², Chris Dames² and Chun Ning Lau^{1*}

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PHYSICAL REVIEW LETTERS

Direct observation of a widely tunable bandgap in bilayer graphene

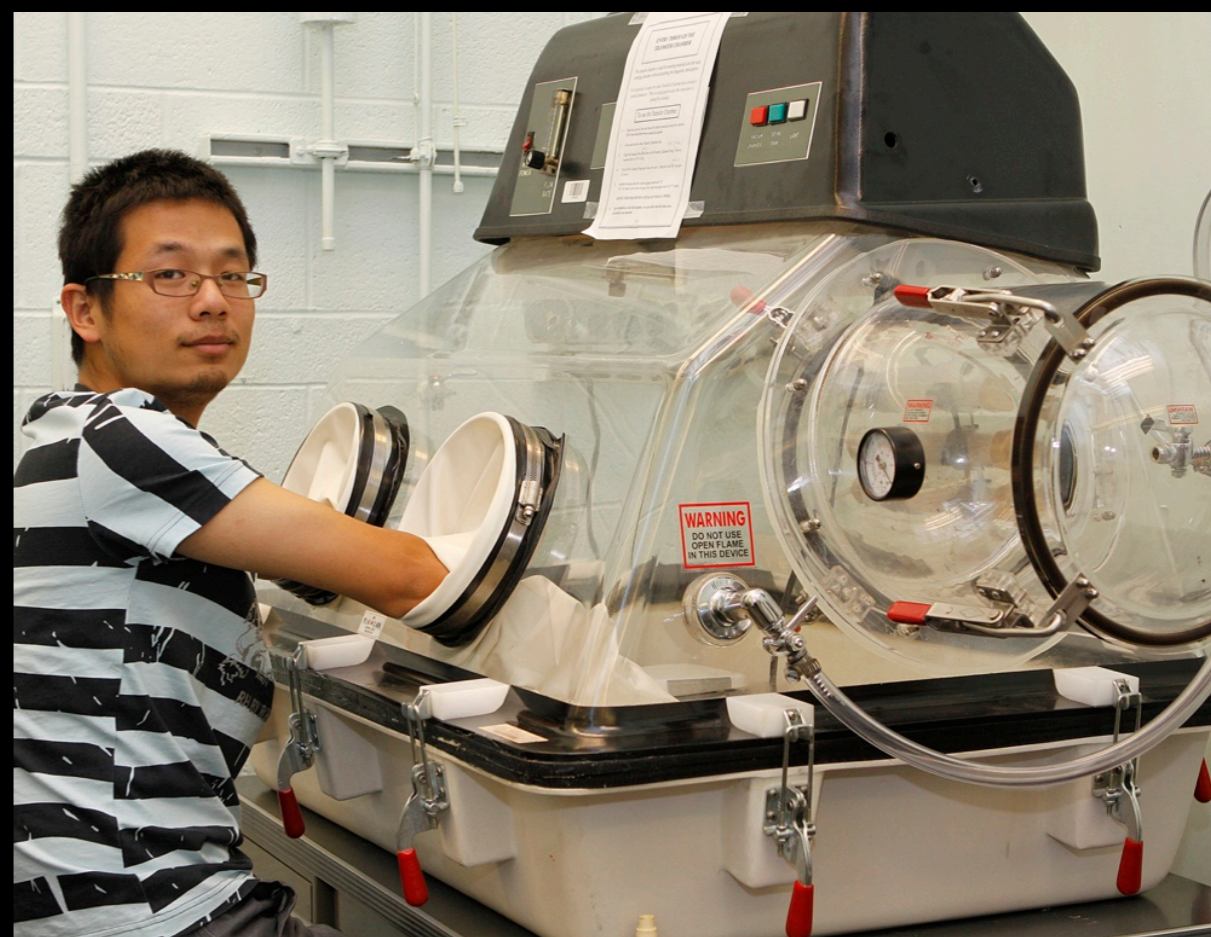
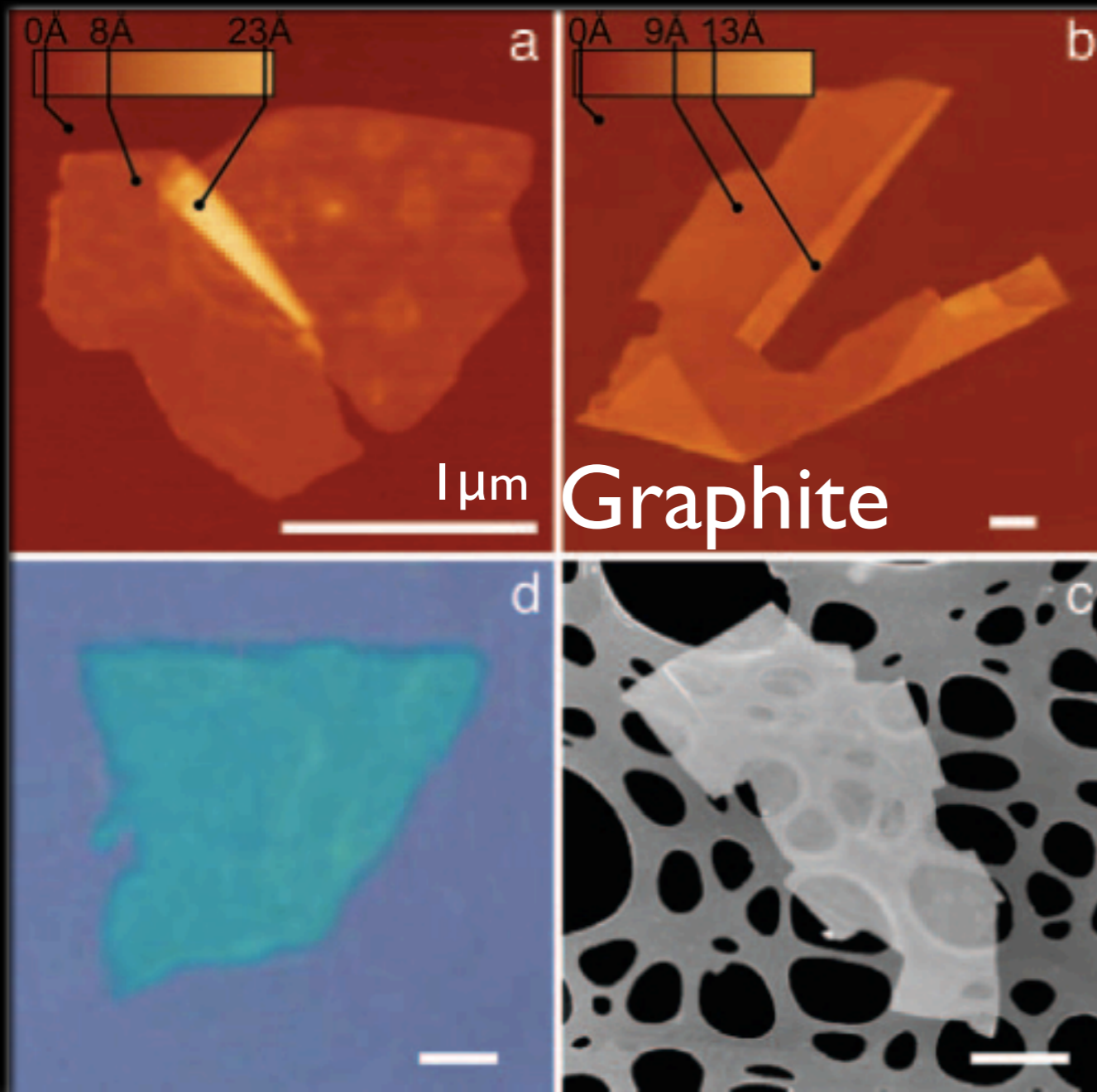
Yuanbo Zhang^{1*}, Tsung-Ta Tang^{1*†}, Caglar Girit¹, Zhao Hao^{2,4}, Michael C. Martin², Alex Zettl^{1,3}, Michael F. Crommie^{1,3}, Y. Ron Shen^{1,3} & Feng Wang^{1,3}



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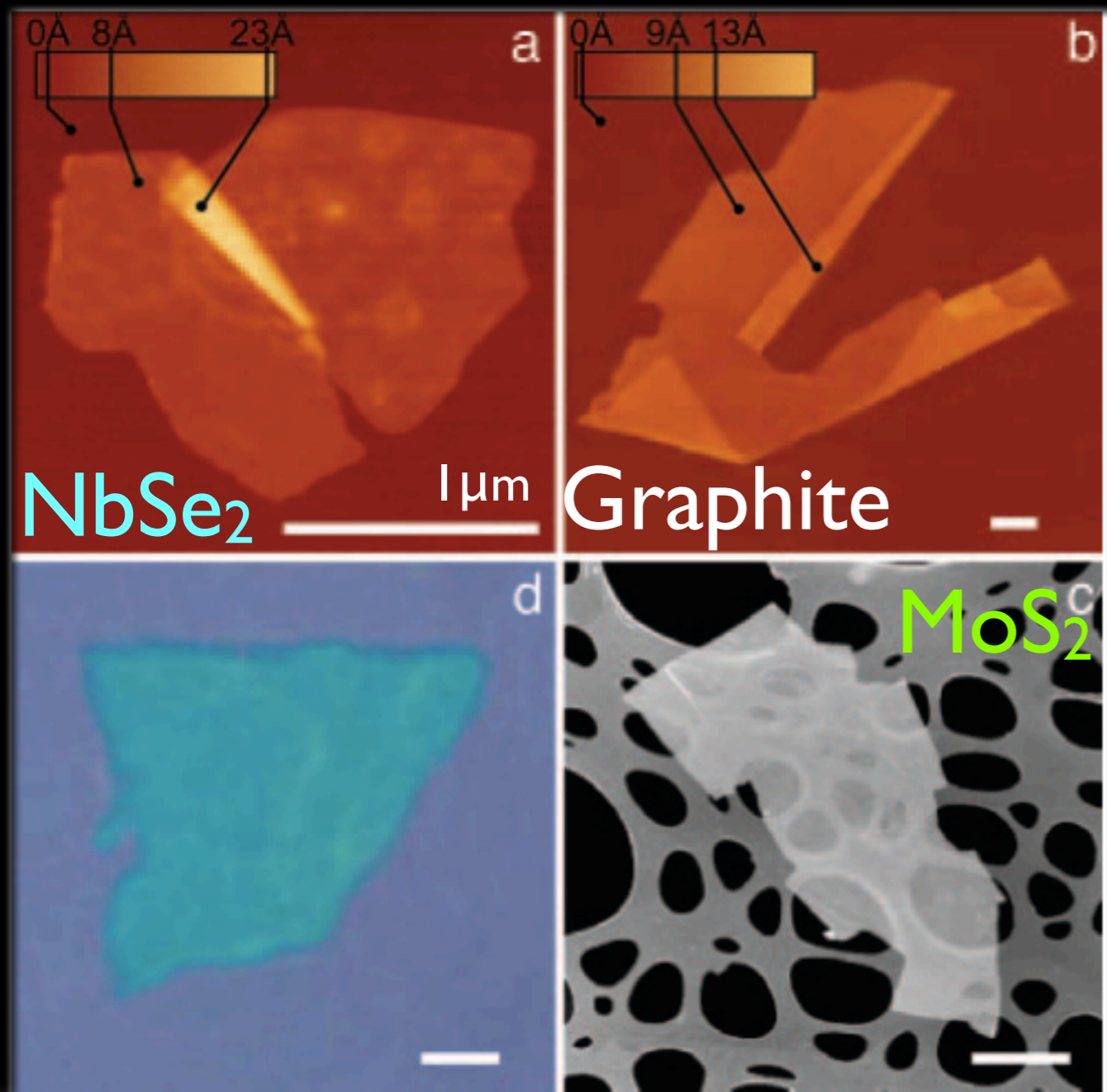




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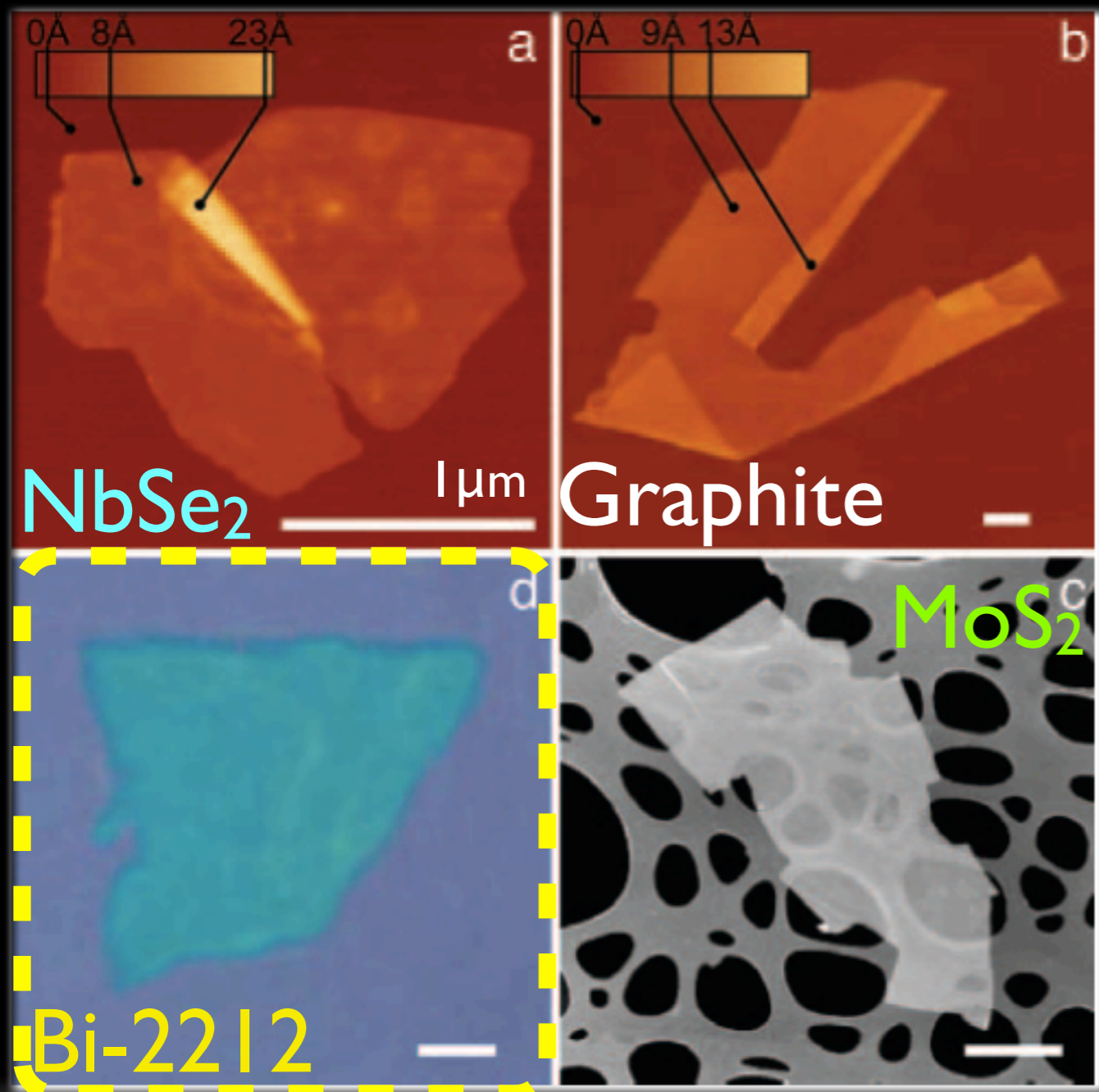
NbSe₂: N.E. Staley, et al., PRB 80, 184505 (2009); Sengupta et al., PRB 82, 155432 (2010)
MoS₂: Radisavljevic et al., Nat. Nano. 6, 147 (2011); Lee et al., Acs Nano 4, 2695 (2010); Splendiani et al., Nano Lett. 10, 1271 (2010)



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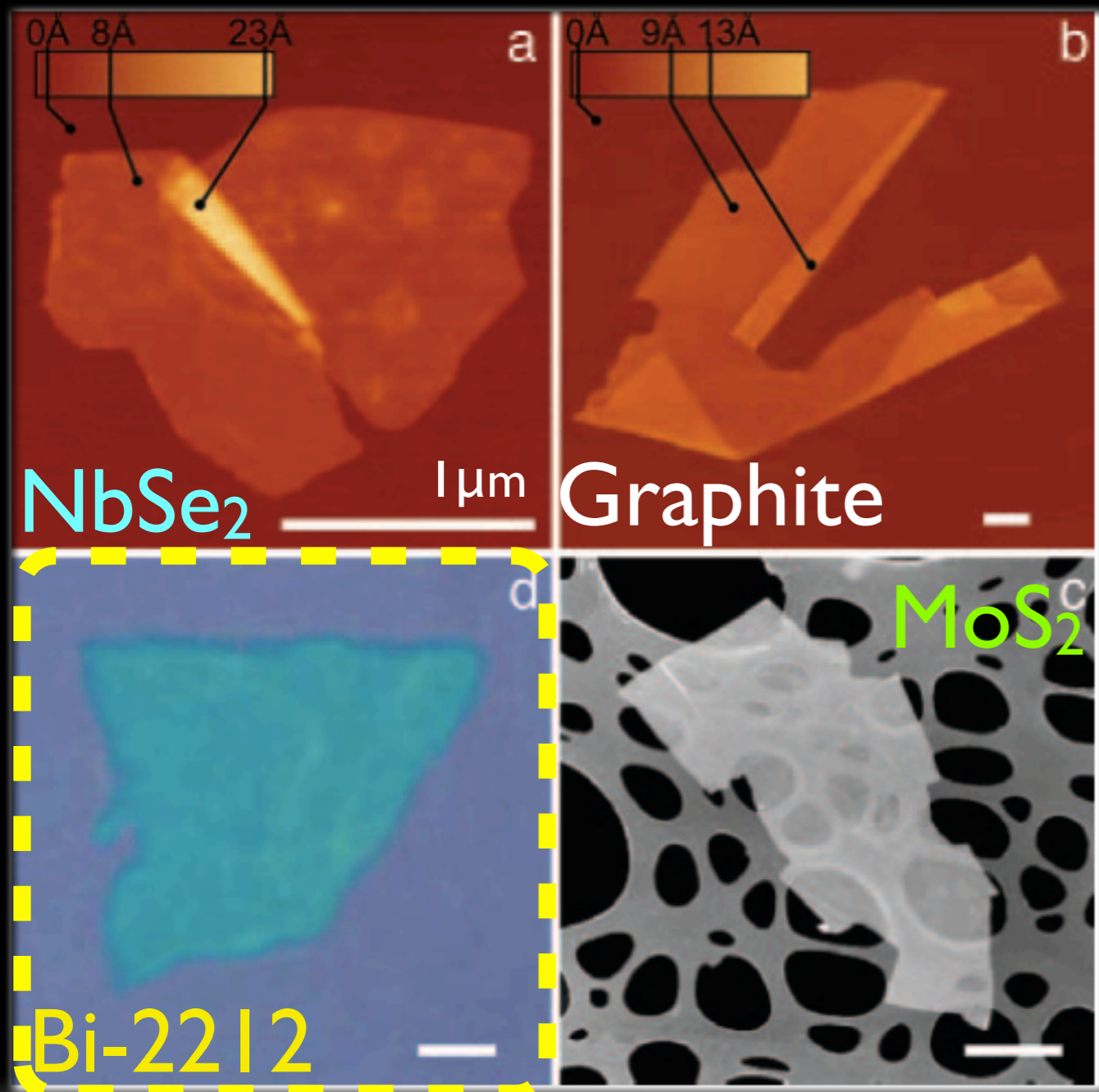
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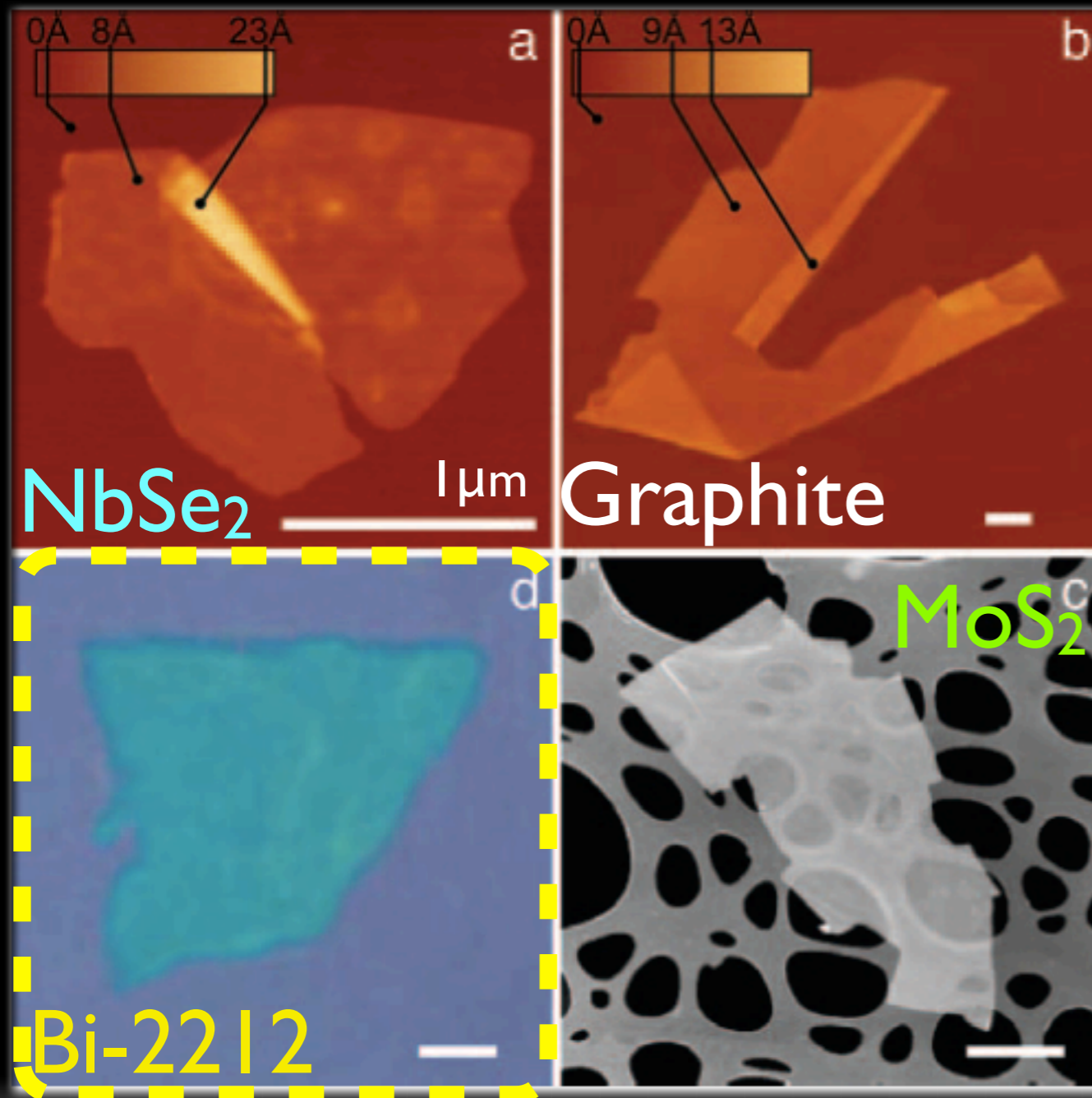
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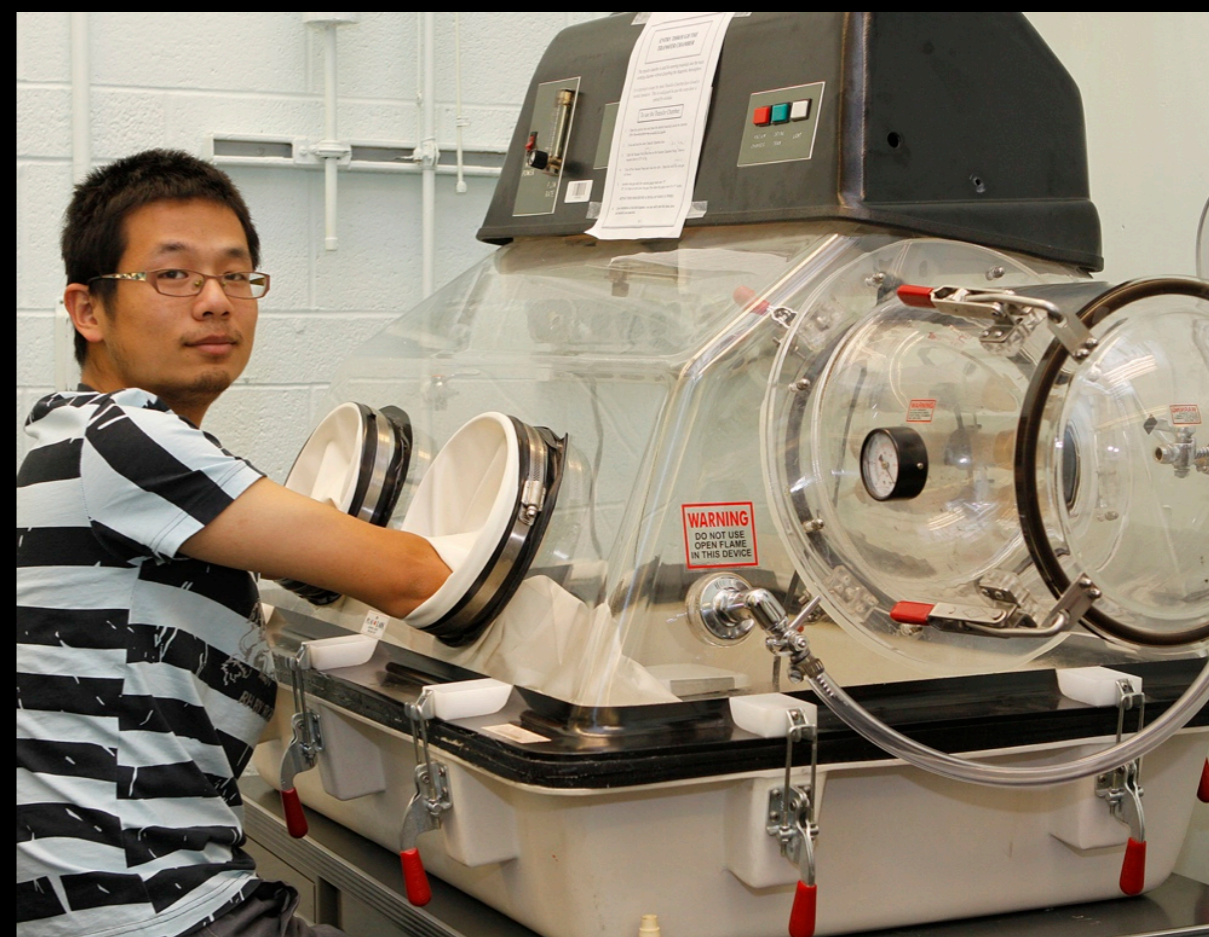
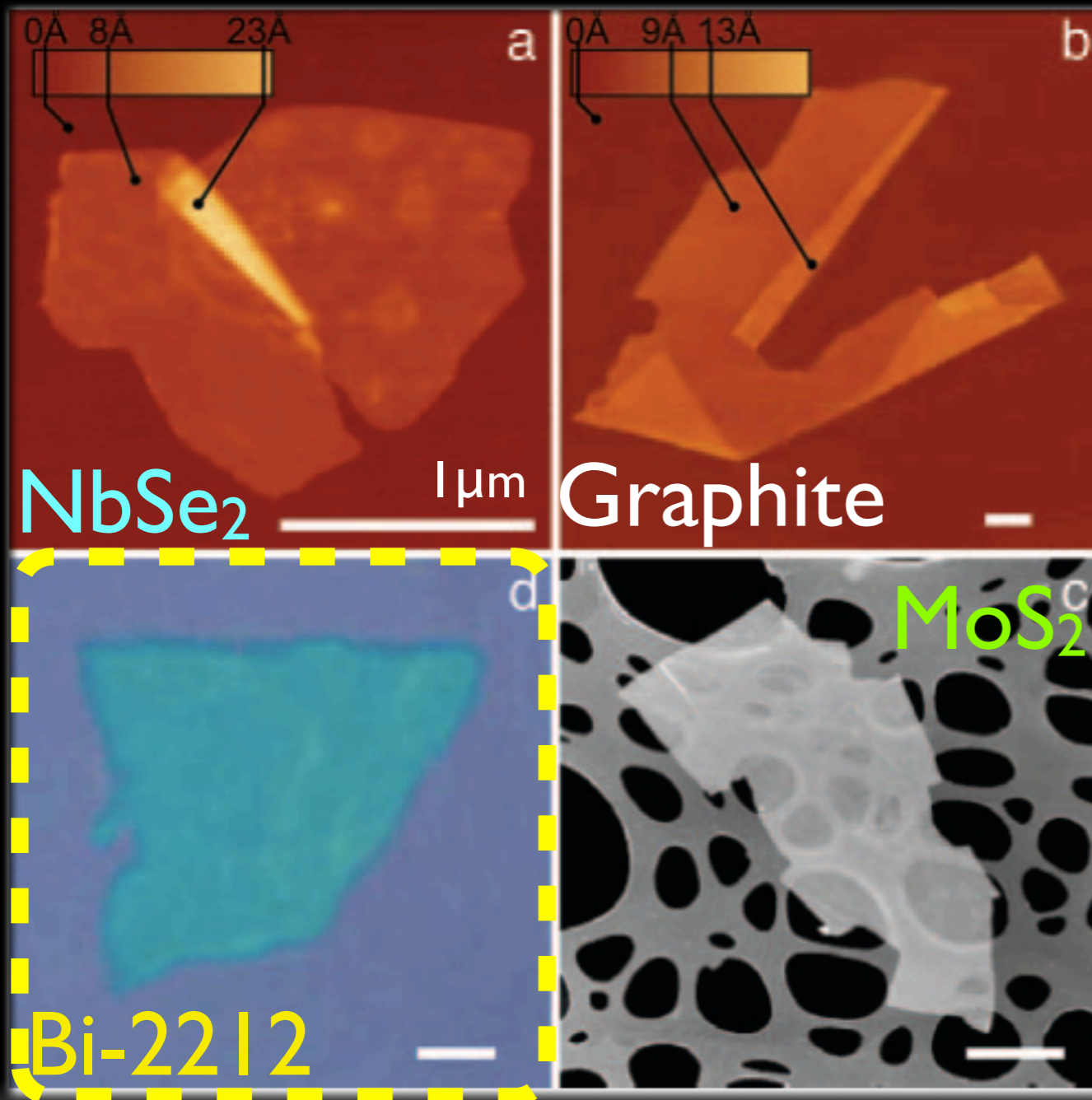
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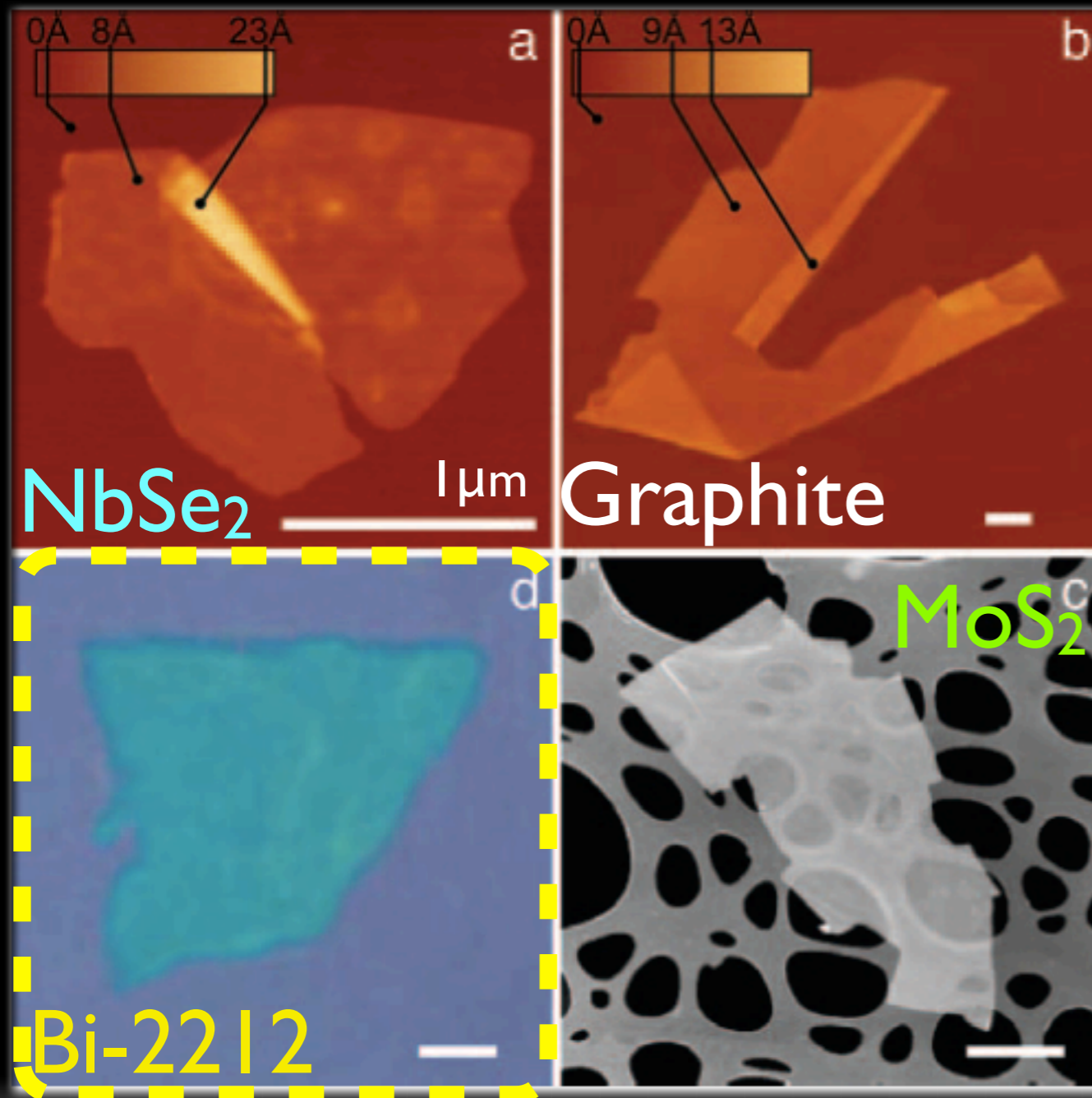
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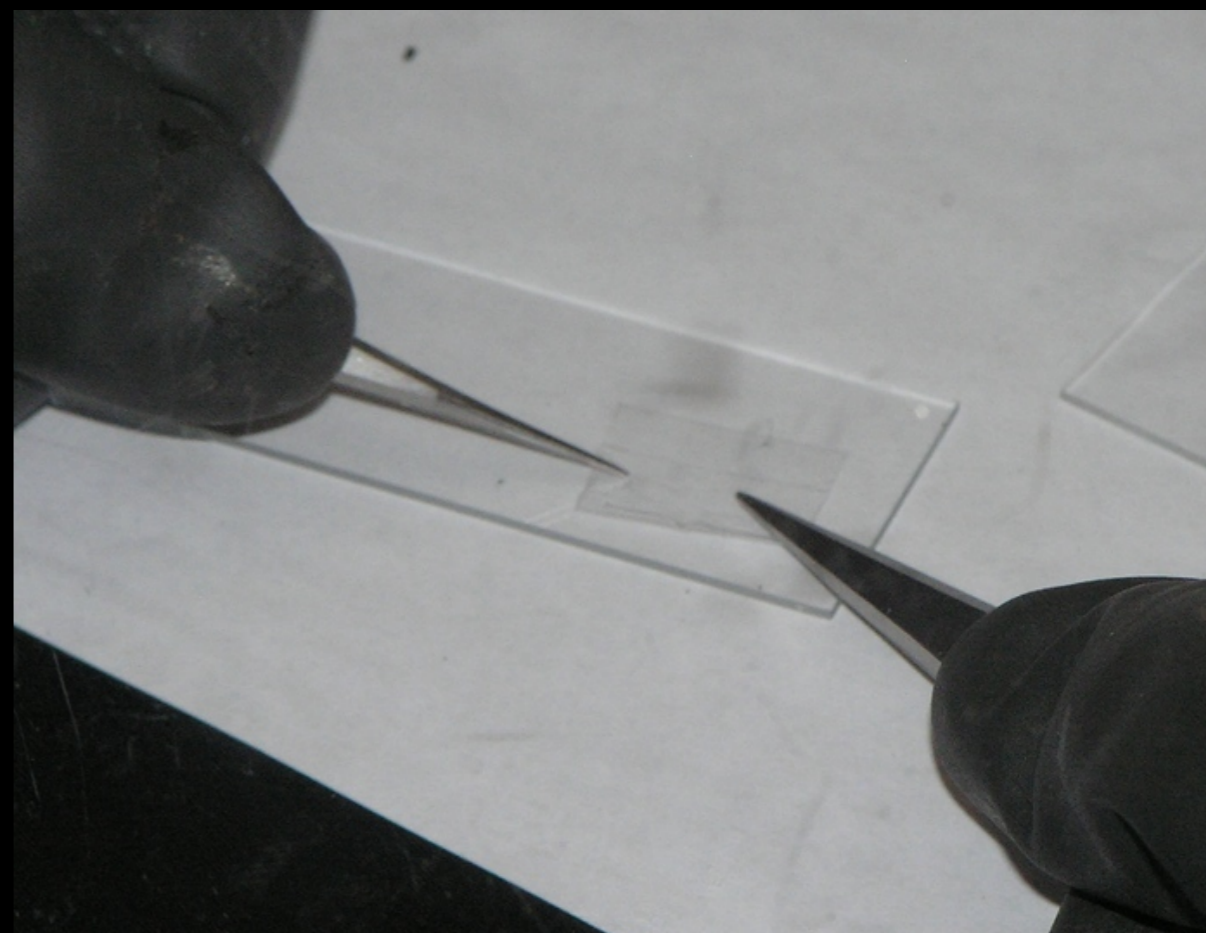
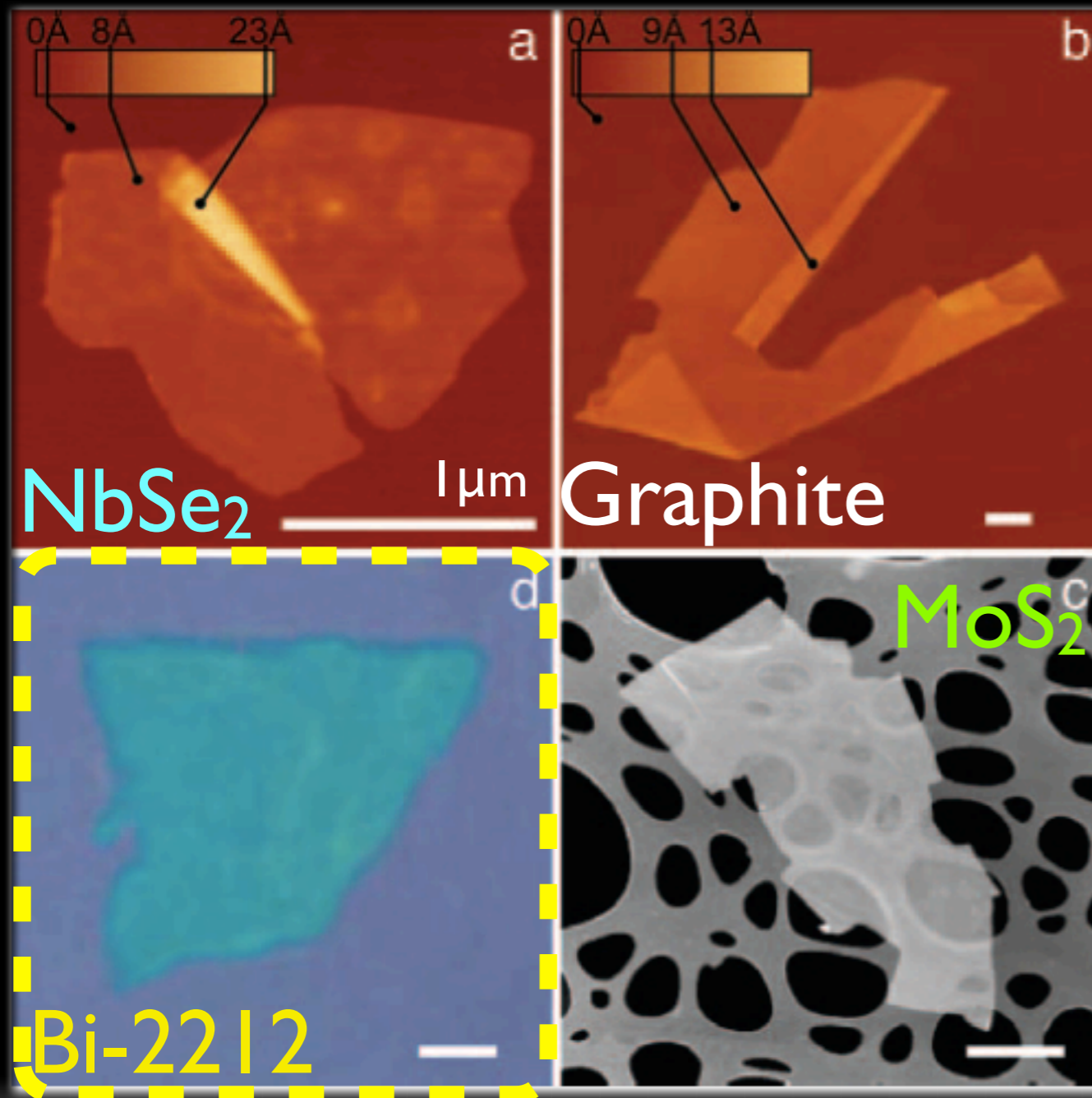
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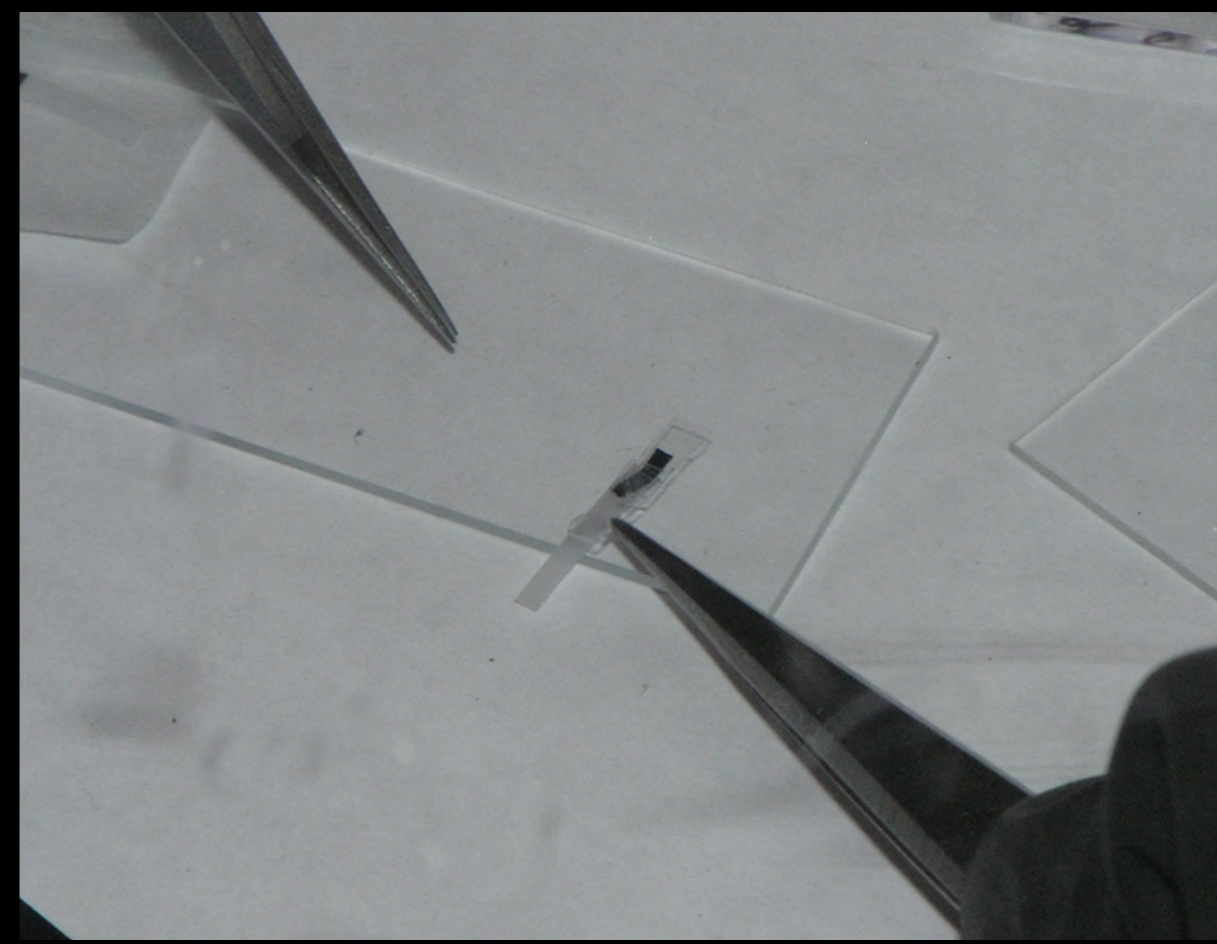
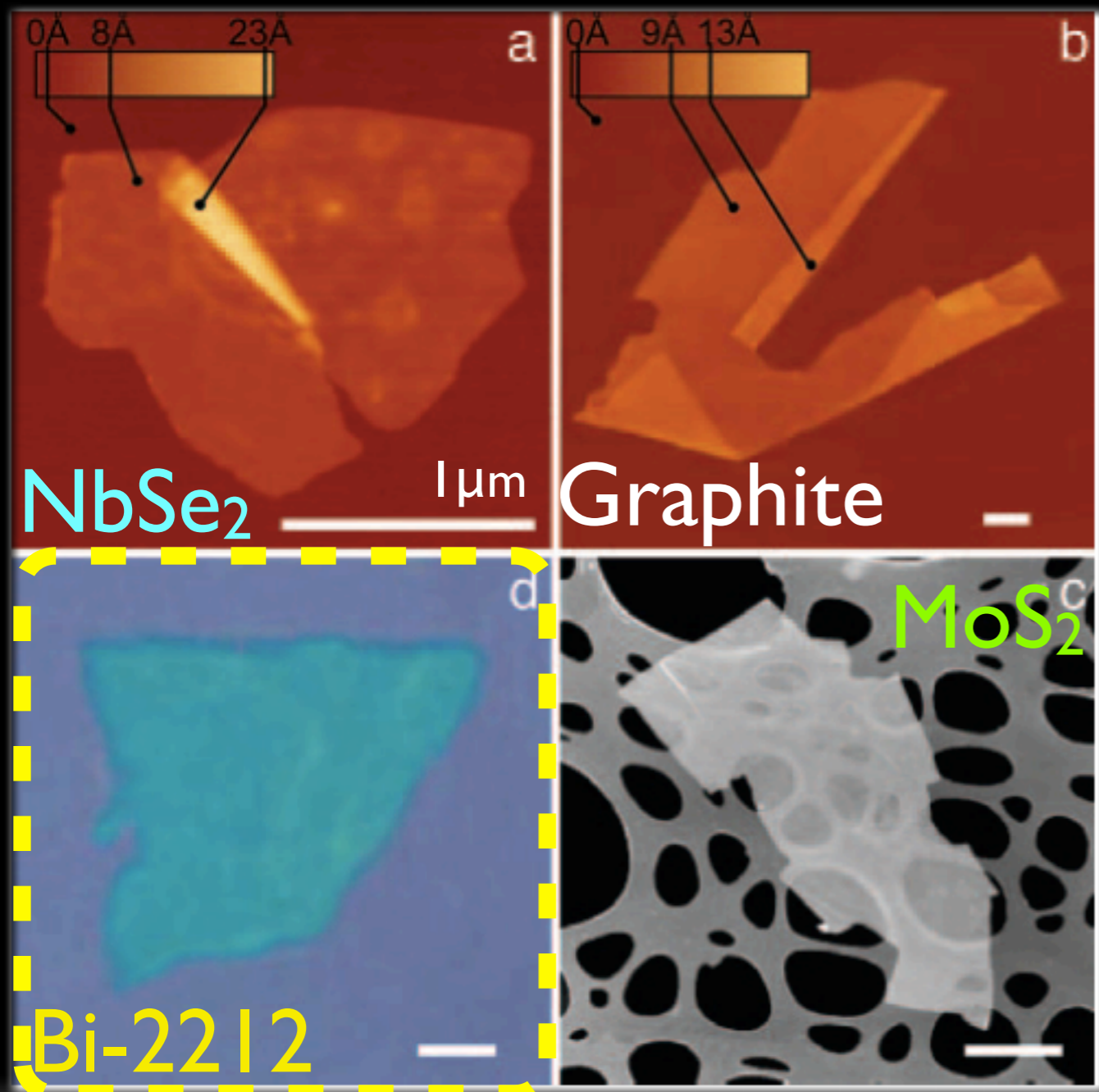
MoS₂: Radisavljevic et al., Nat. Nano. 6, 147 (2011);
Lee et al., Acs Nano 4, 2695 (2010); Splendiani et al.,
Nano Lett. 10, 1271 (2010)



Two-dimensional atomic crystals

K. S. Novoselov*, D. Jiang*, F. Schedin*, T. J. Booth*, V. V. Khotkevich*, S. V. Morozov†, and A. K. Geim**

*Centre for Mesoscience and Nanotechnology and School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom; and †Institute for Microelectronics Technology, Chernogolovka 142432, Russia



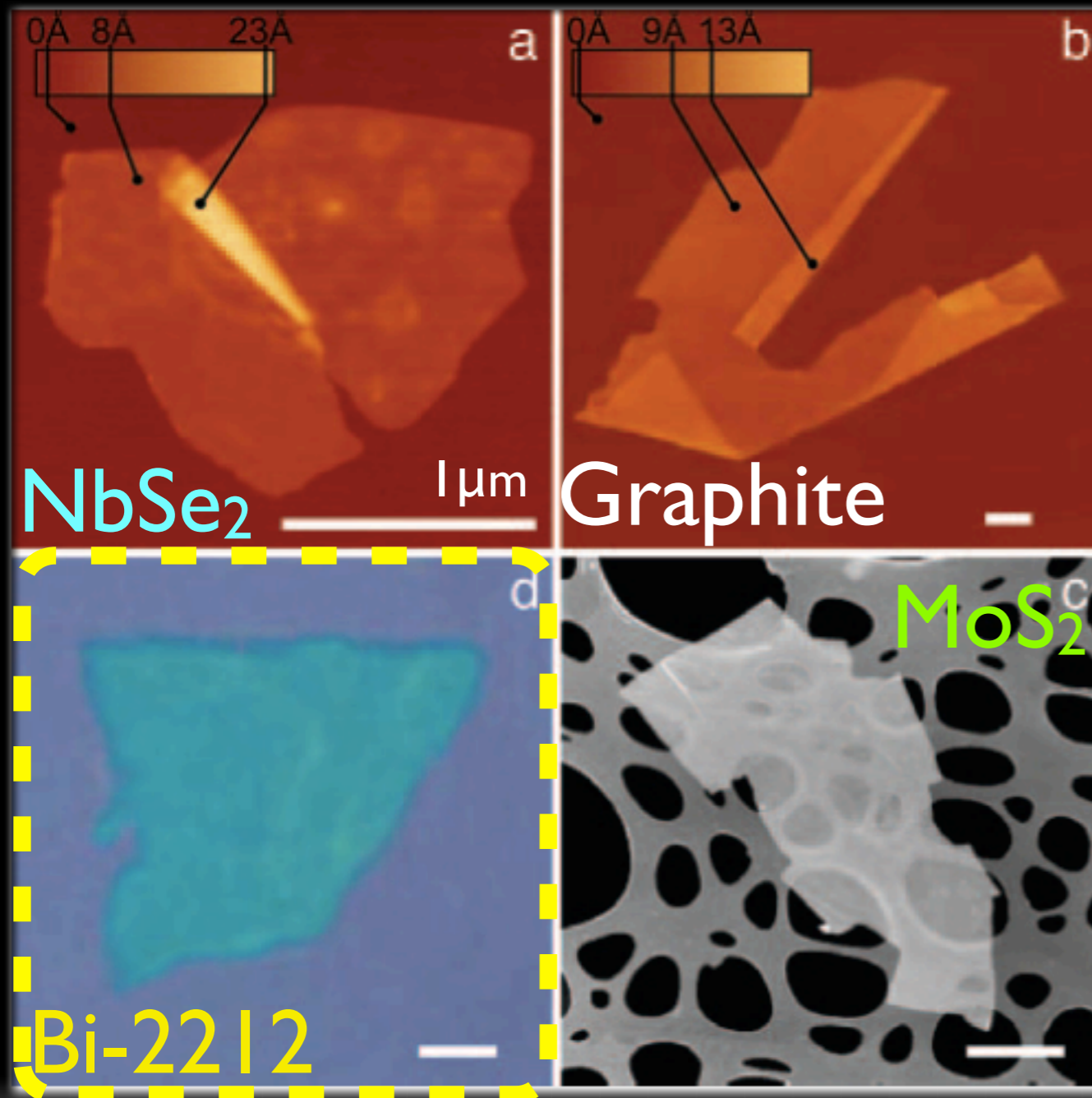
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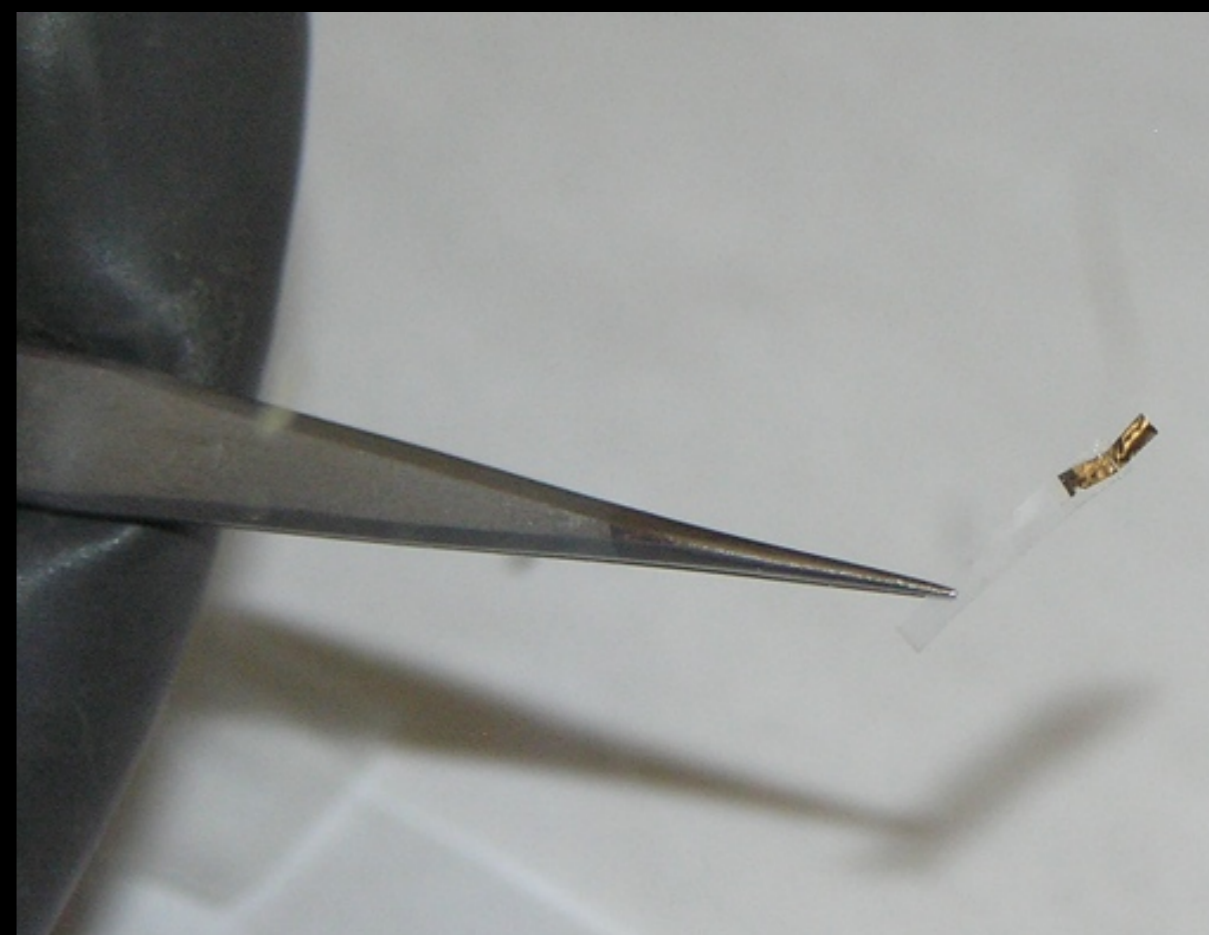
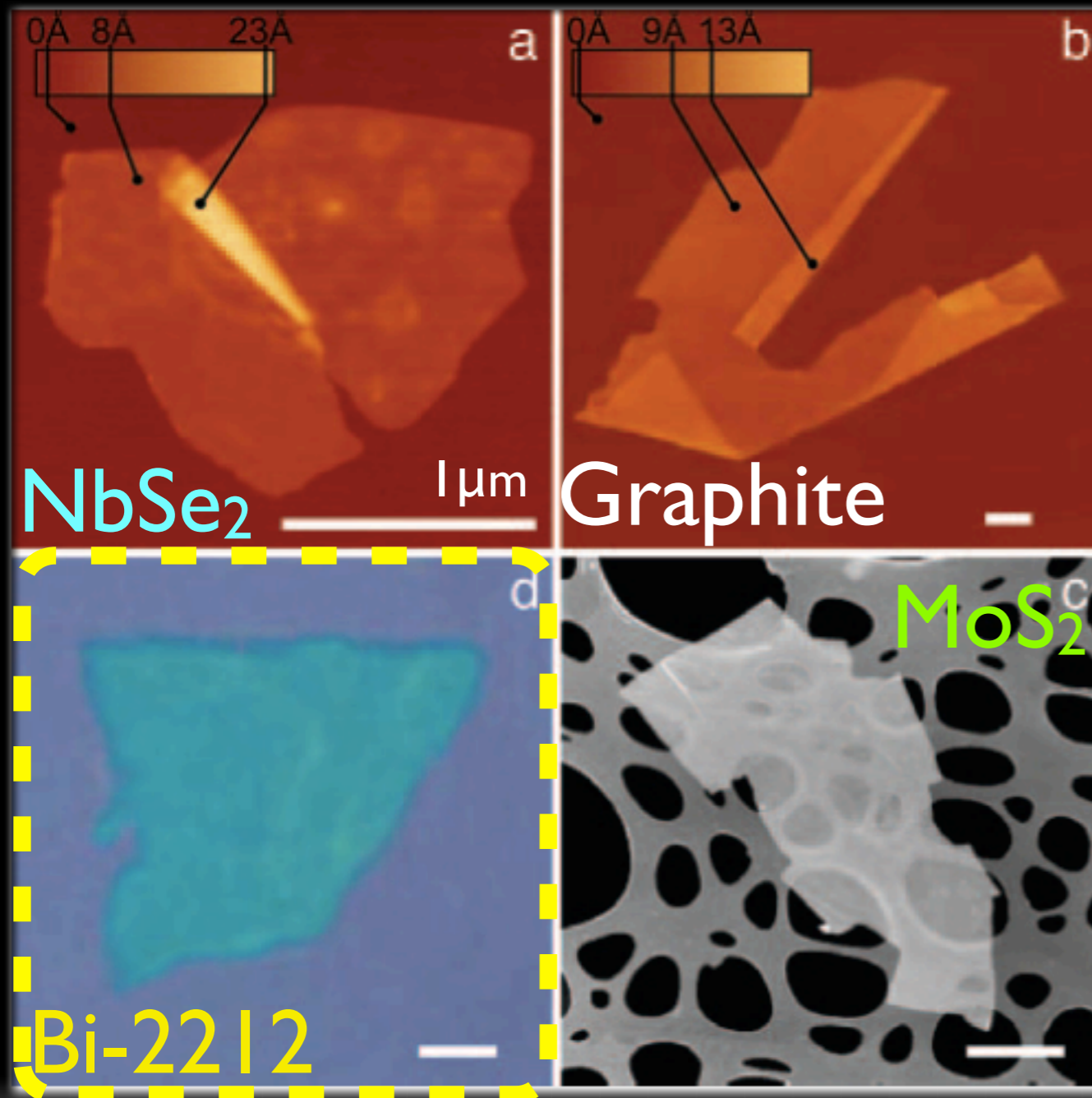
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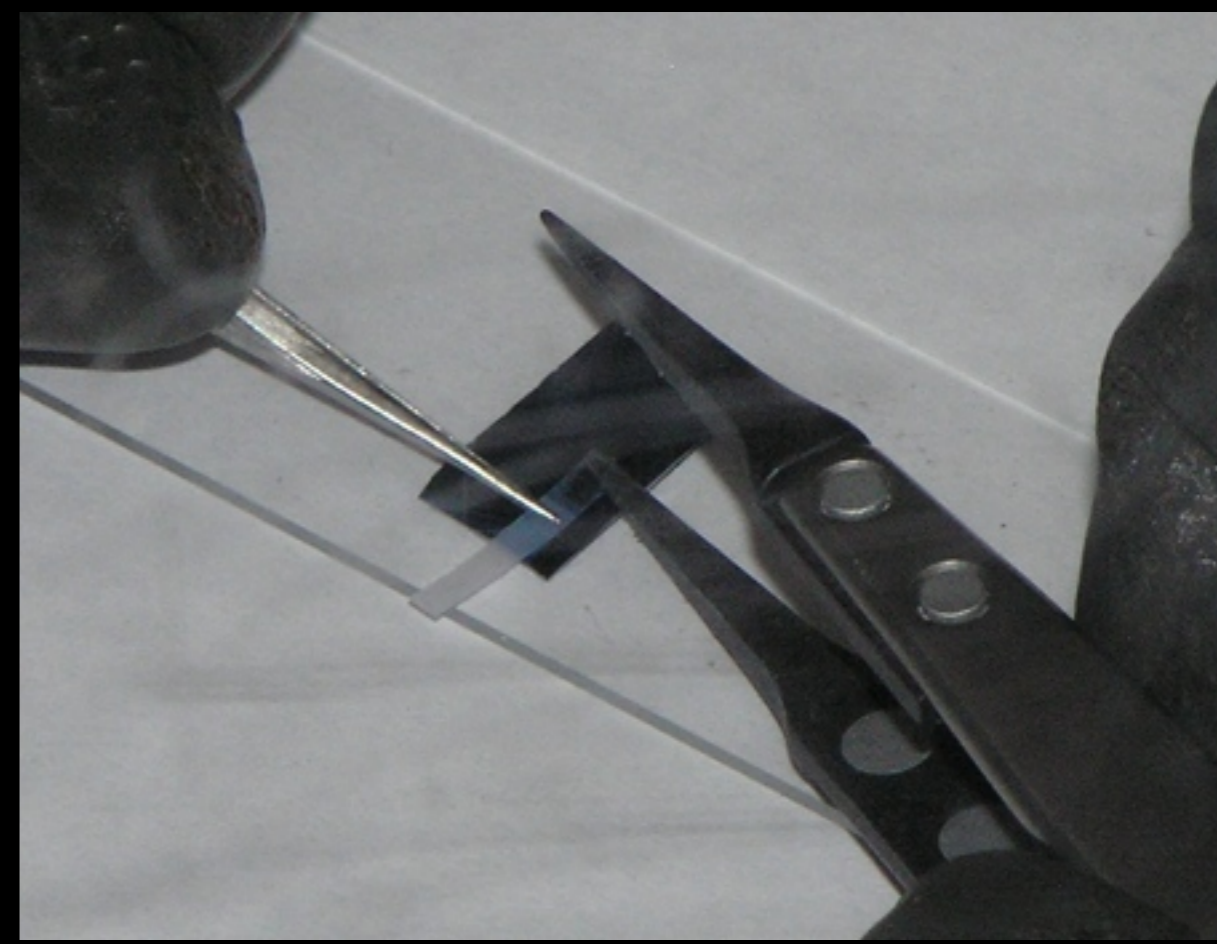
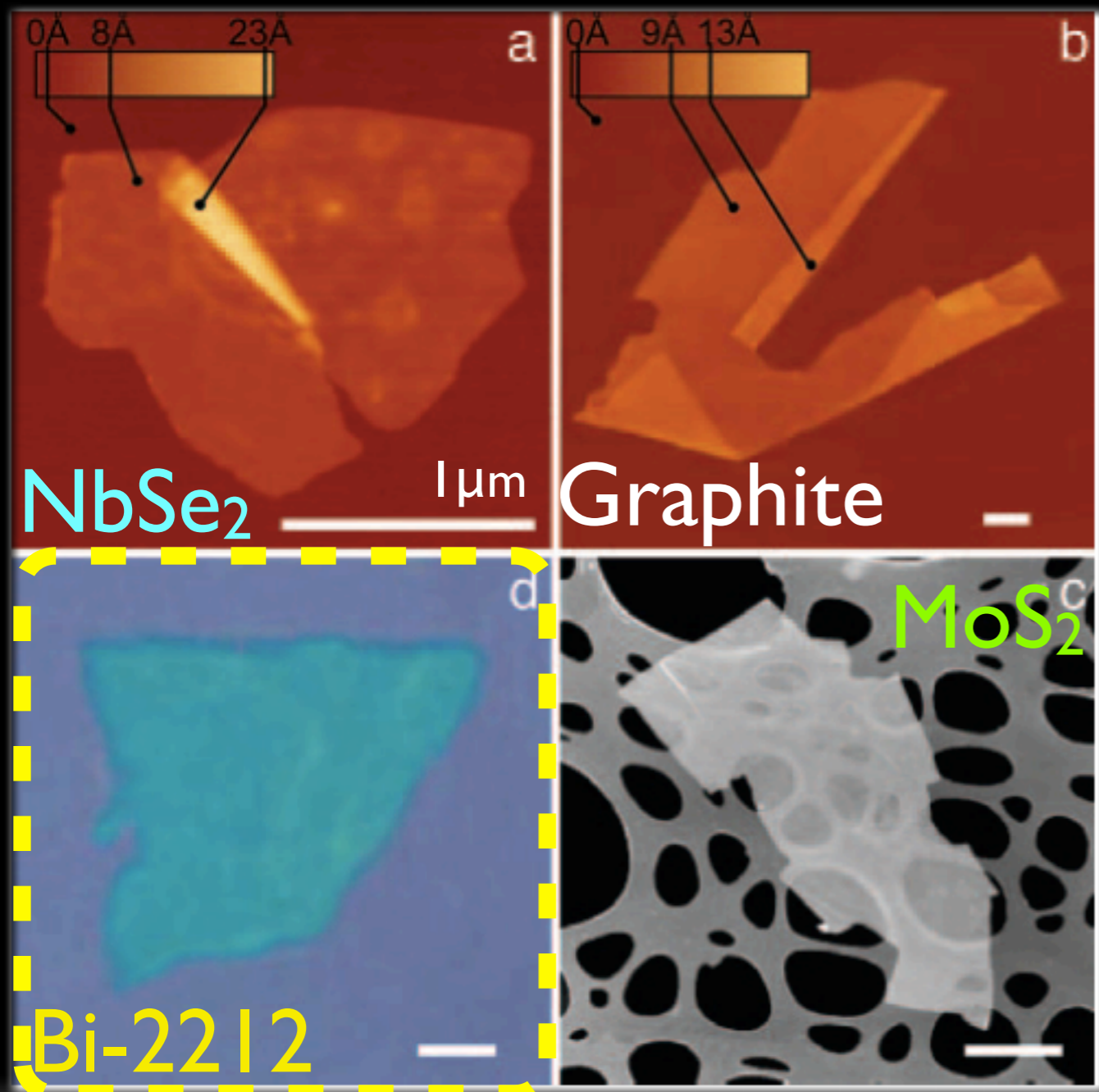
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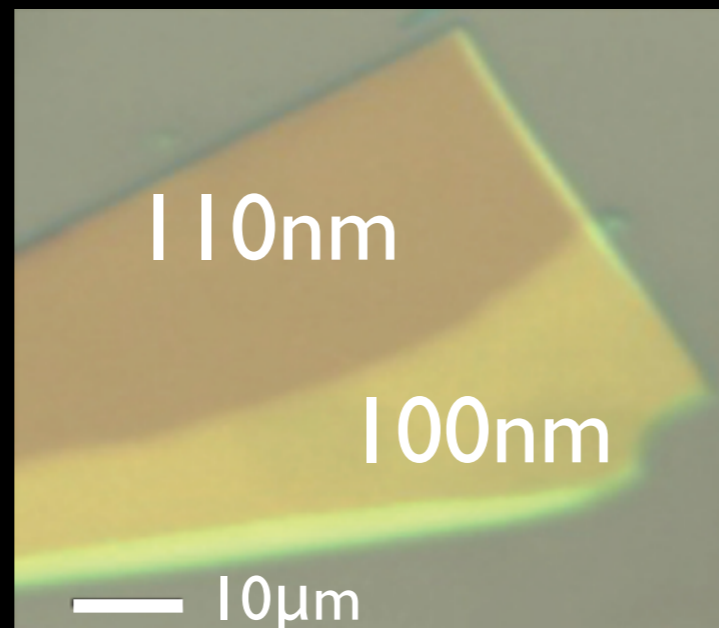
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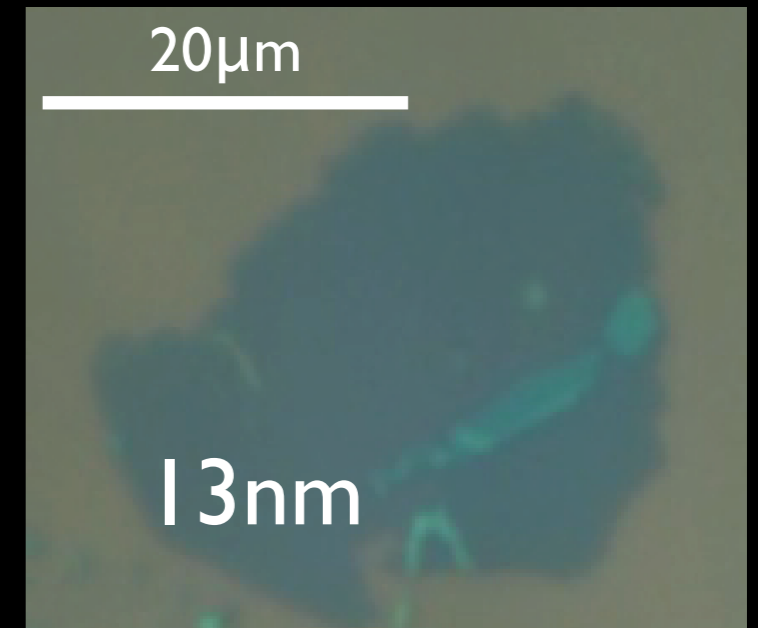
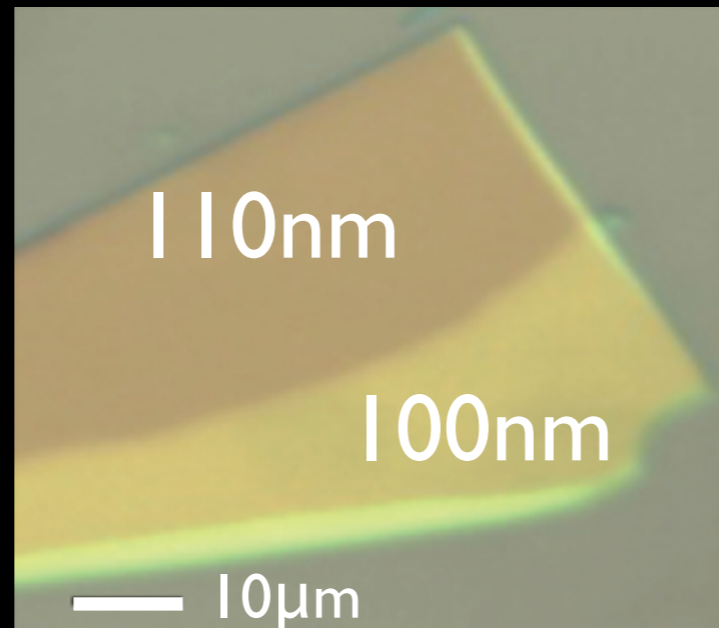
*Centre for Mesoscience and Nanotechnology and School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom; and †Institute for Microelectronics Technology, Chernogolovka 142432, Russia



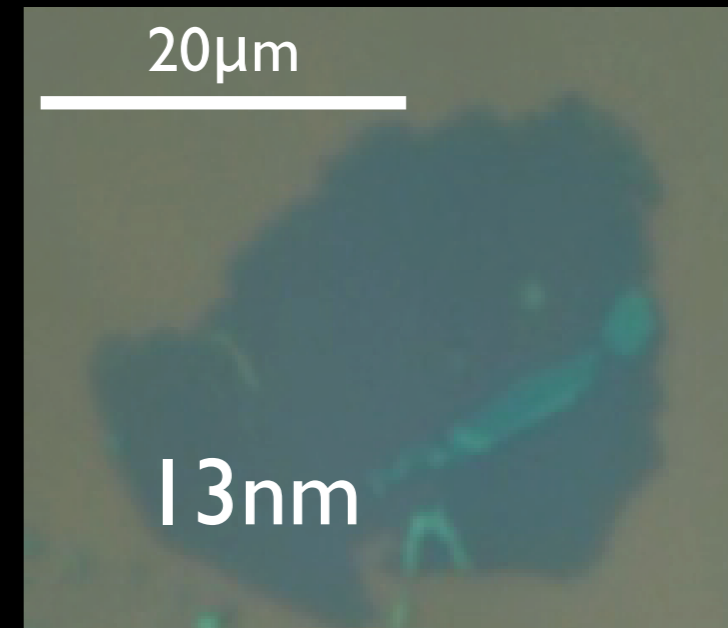
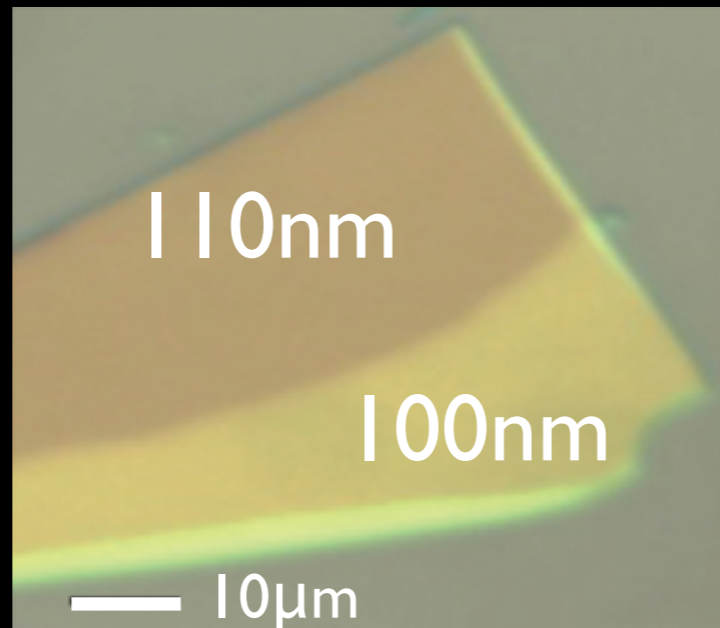
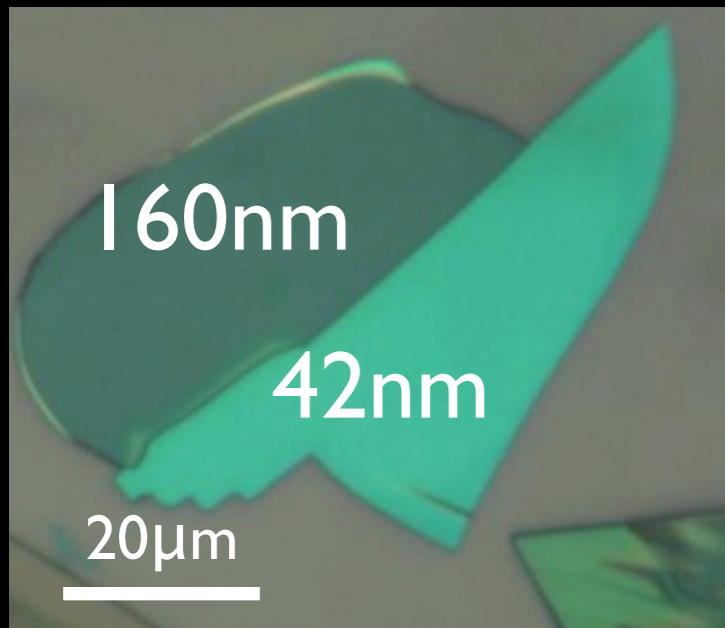
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Visibility

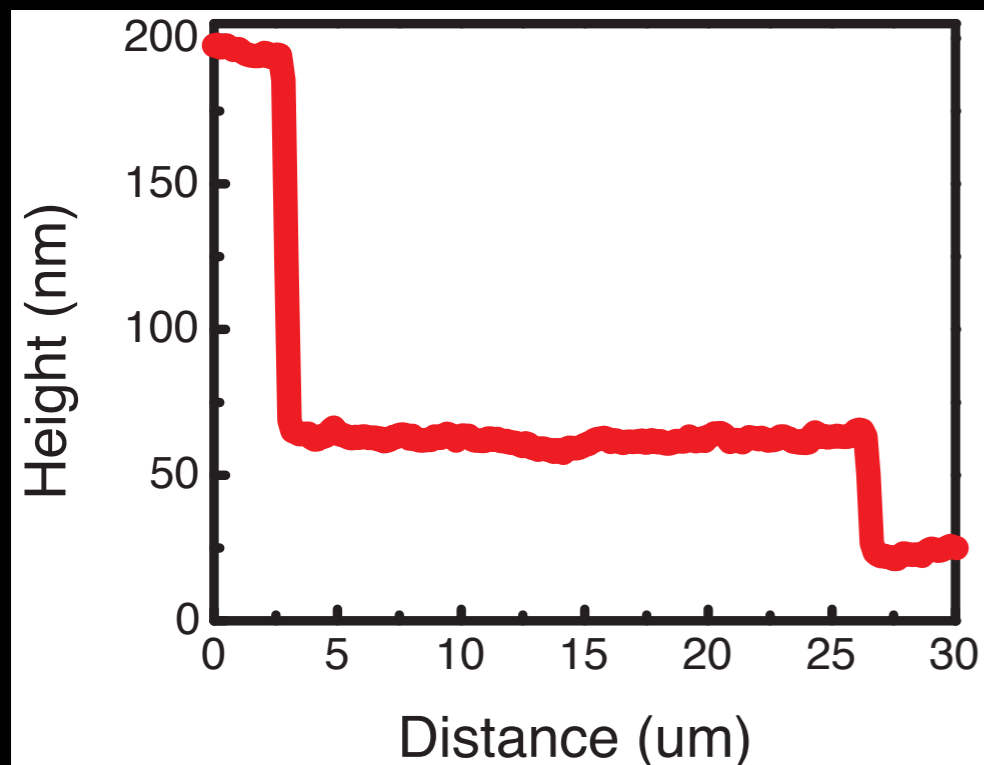
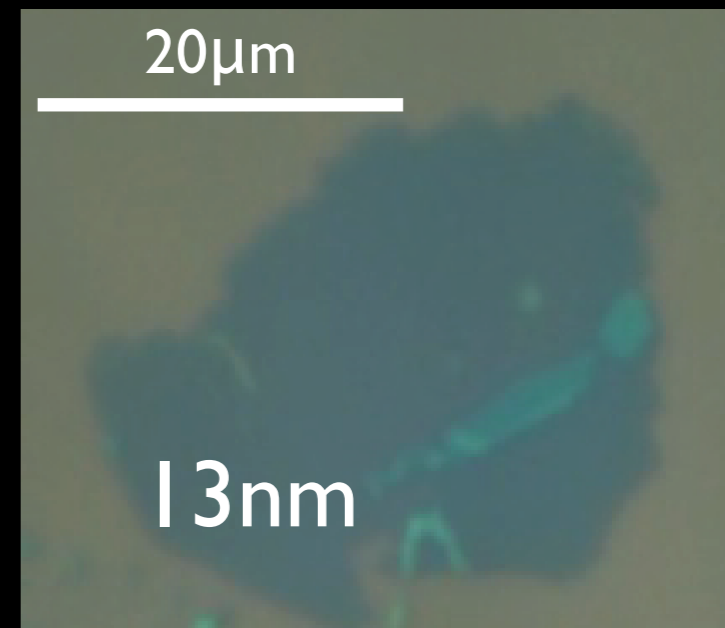
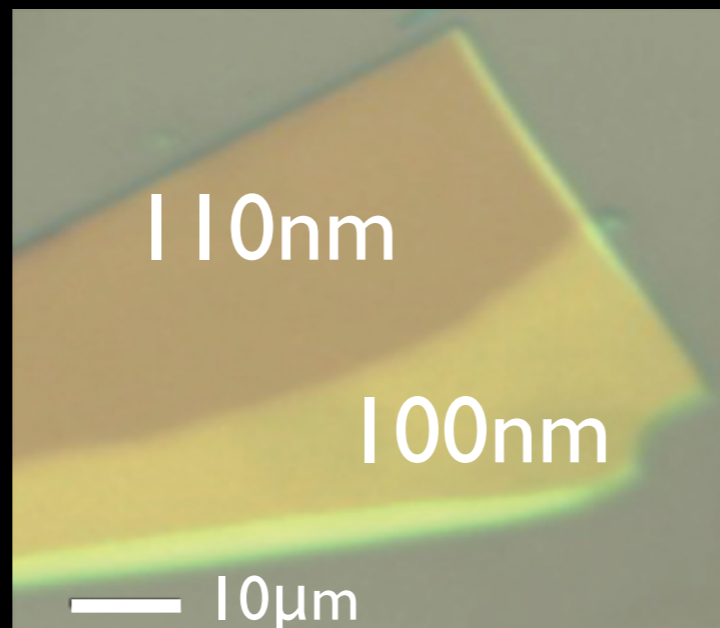
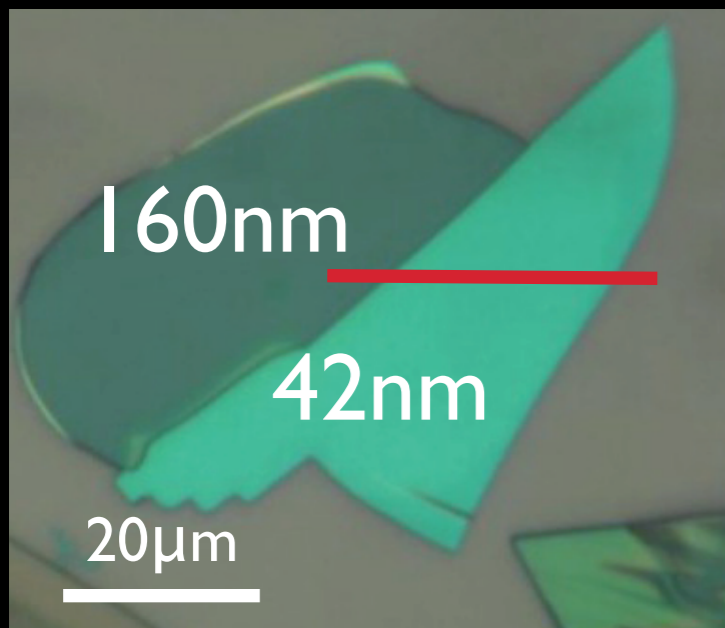


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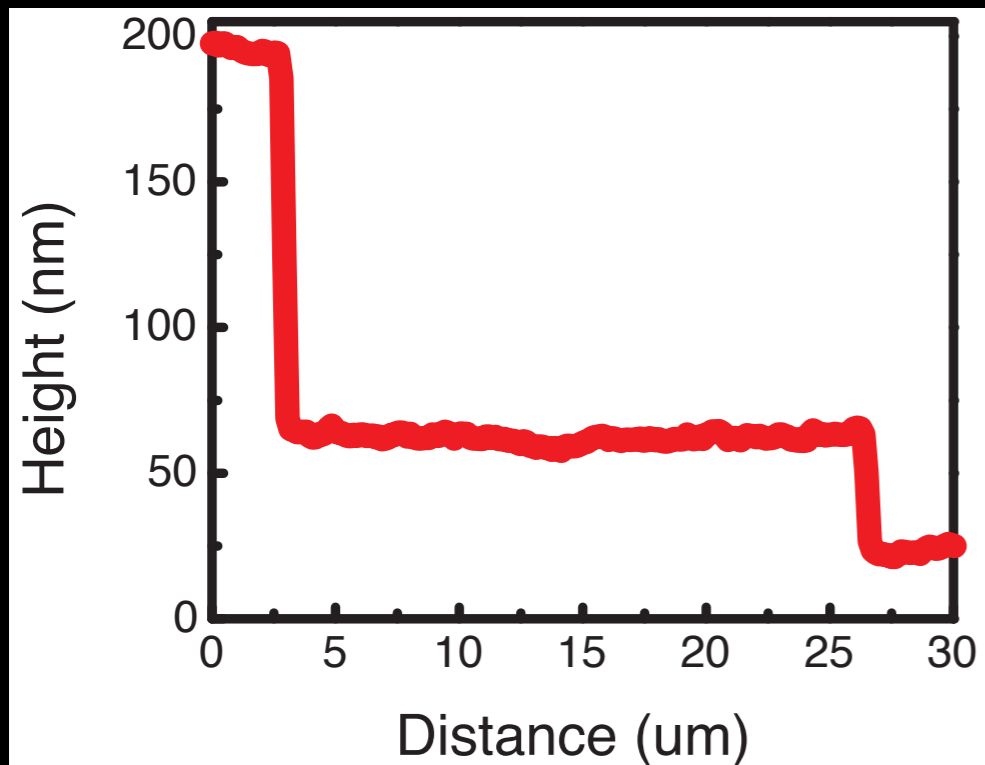
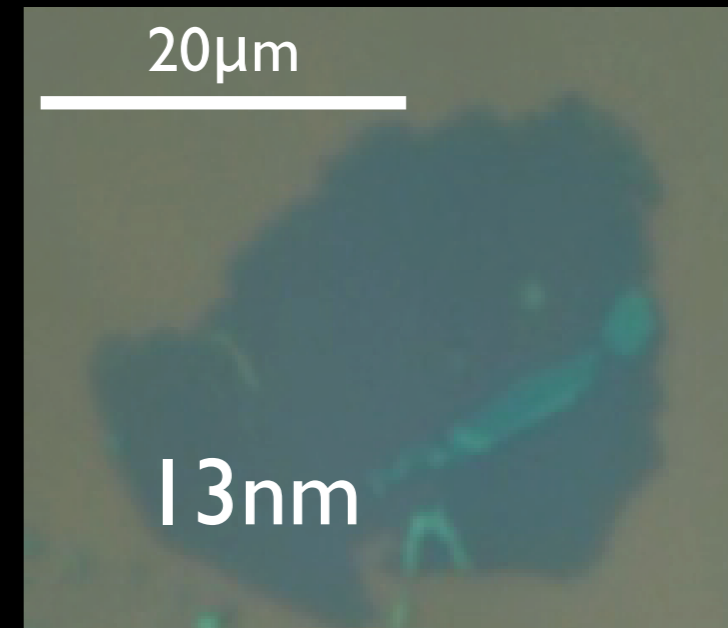
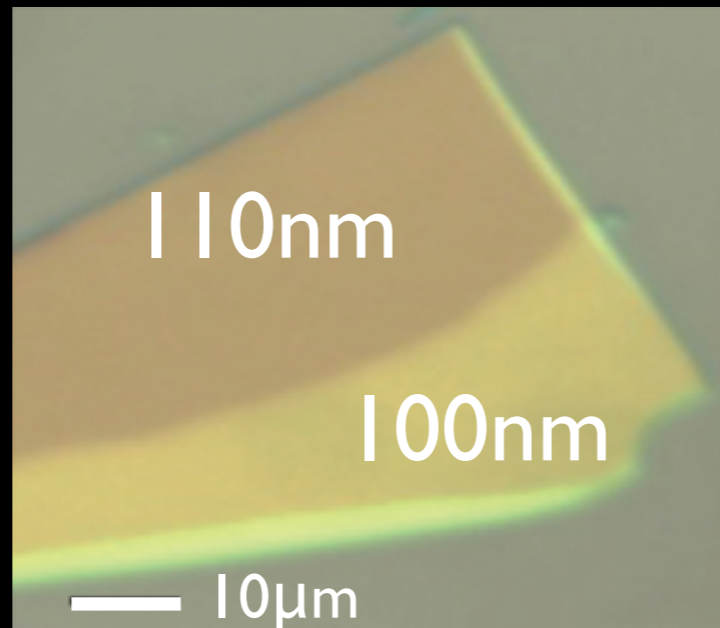
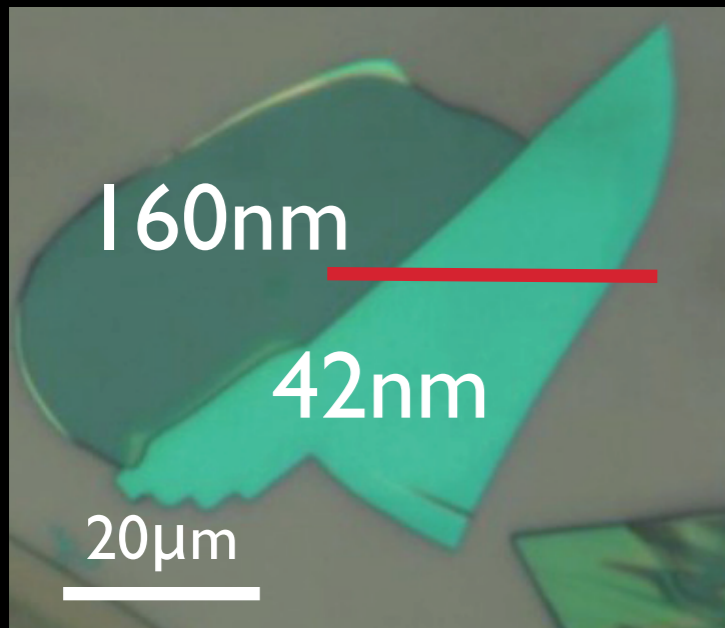




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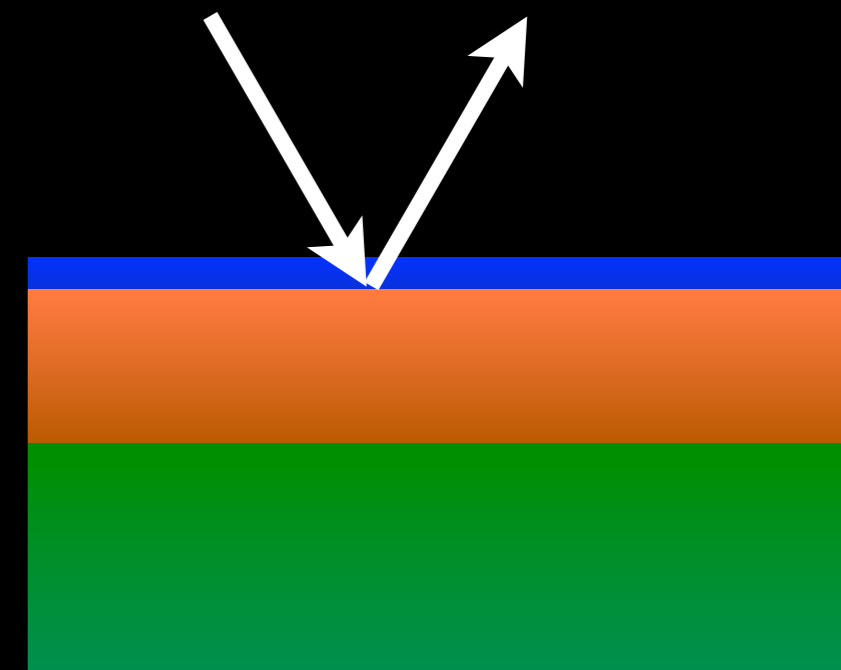
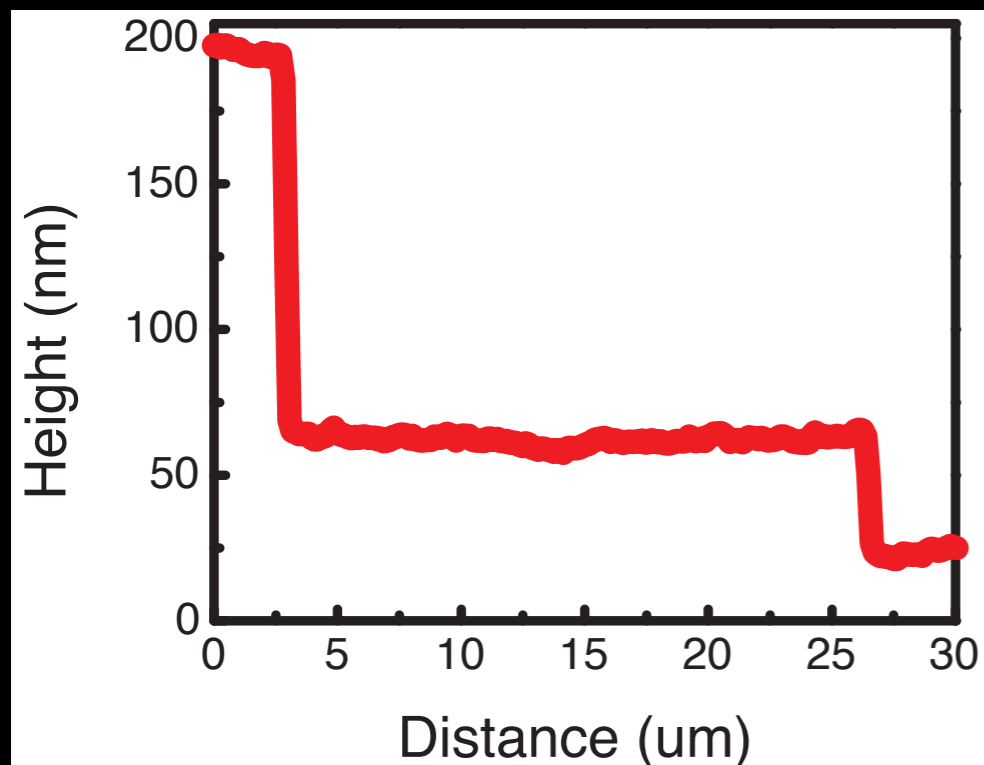
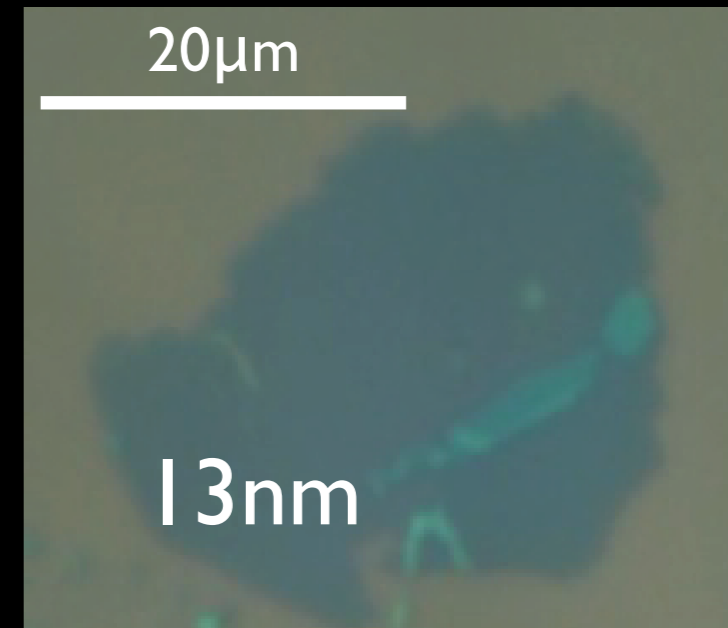
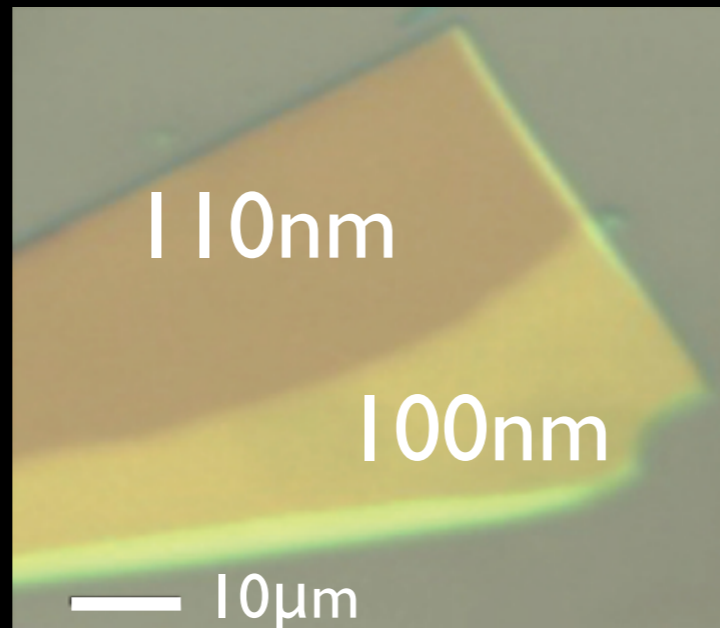
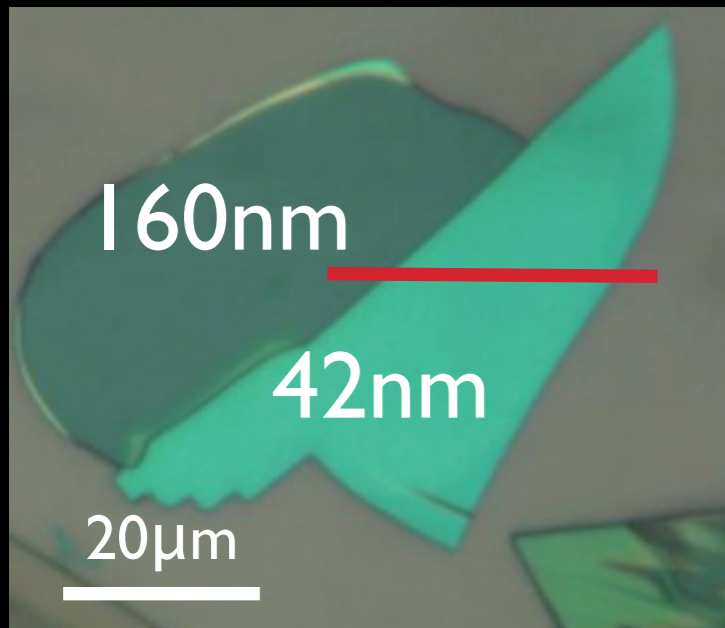


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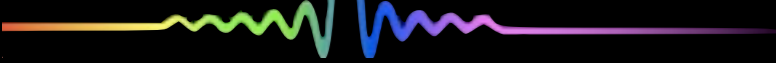


Theory:
A.H. Castro Neto et al.,
APL 91, 063124 (2007)

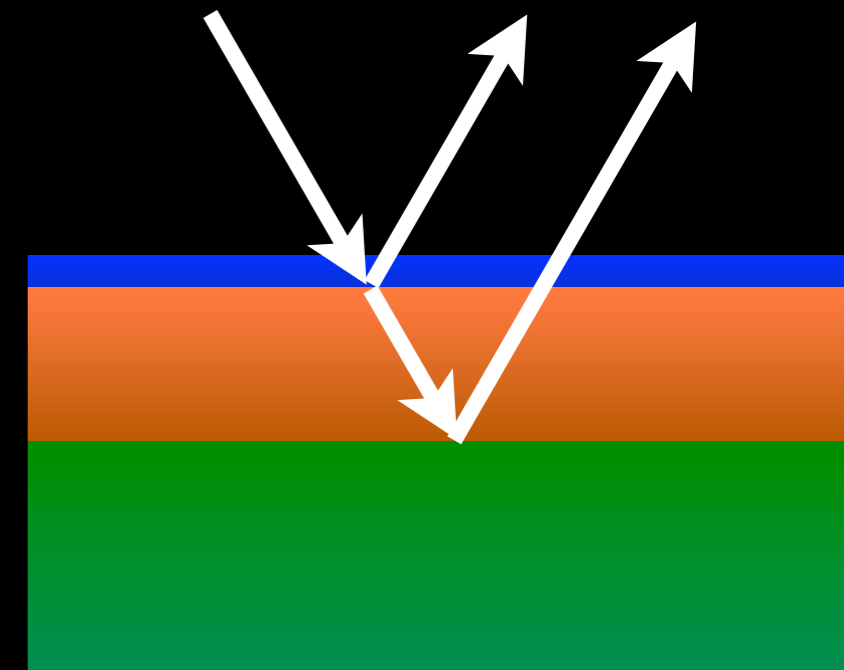
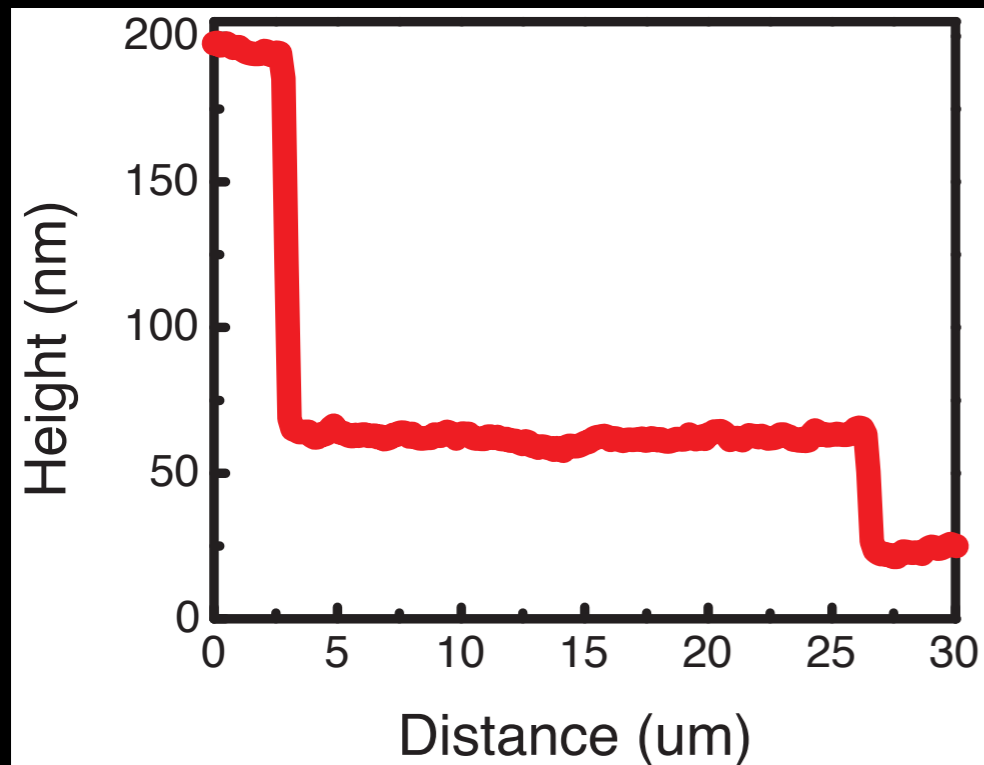
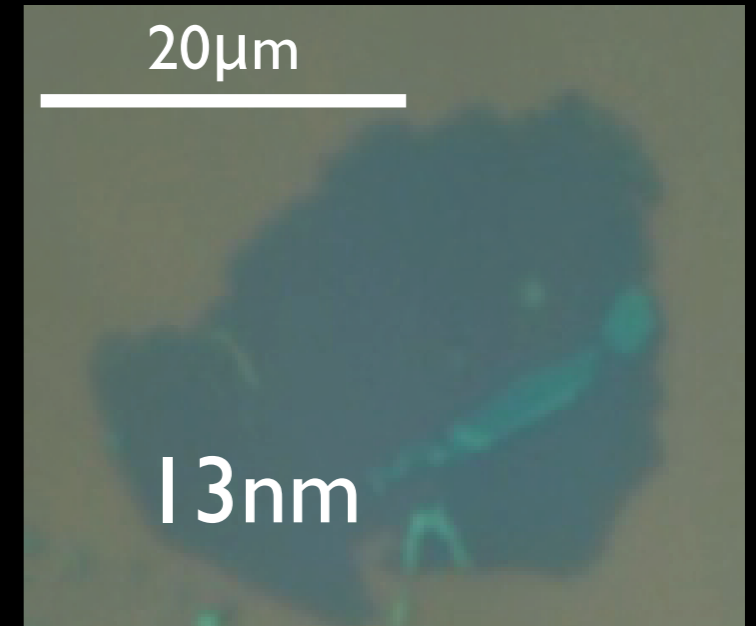
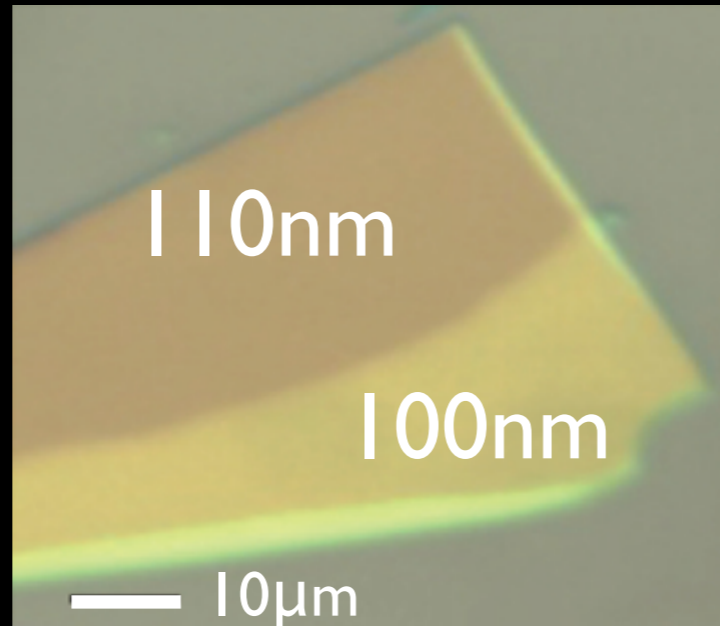
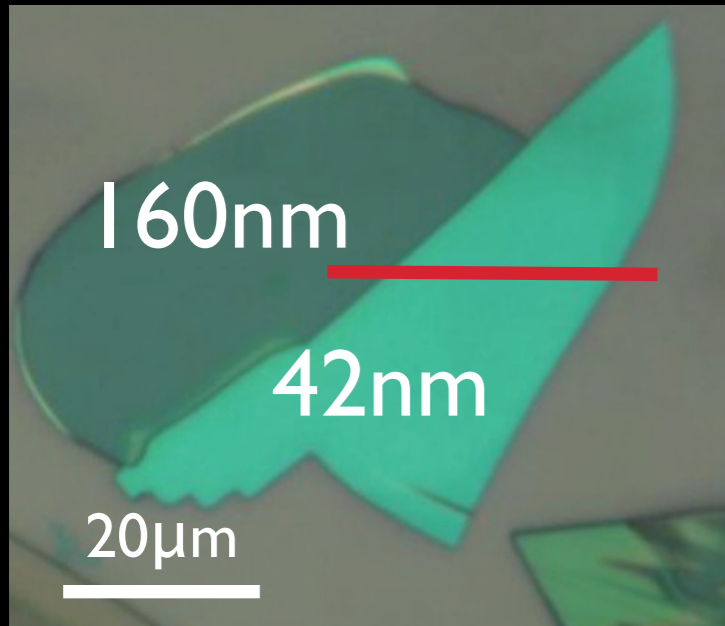
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A.H. Castro Neto et al.,
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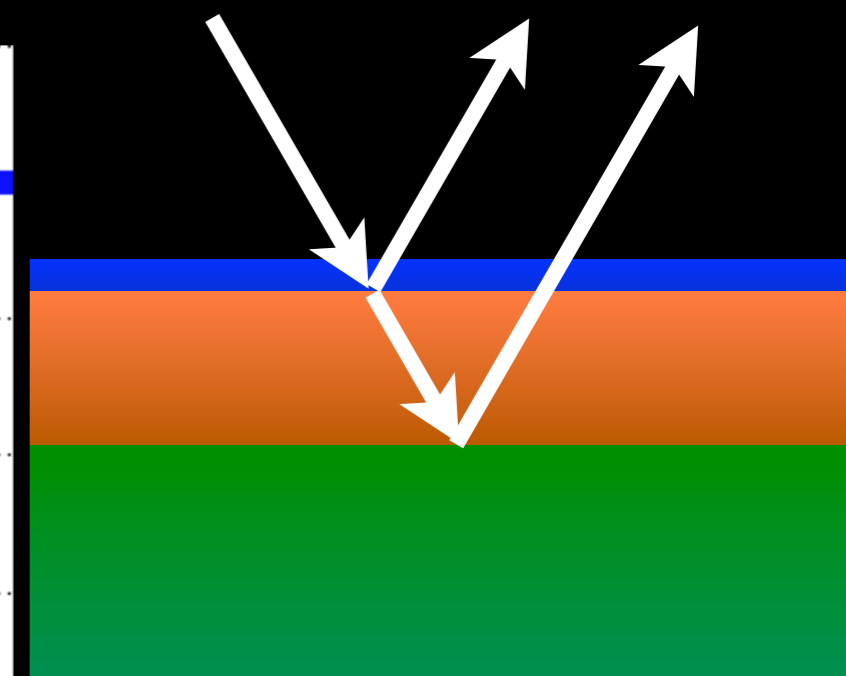
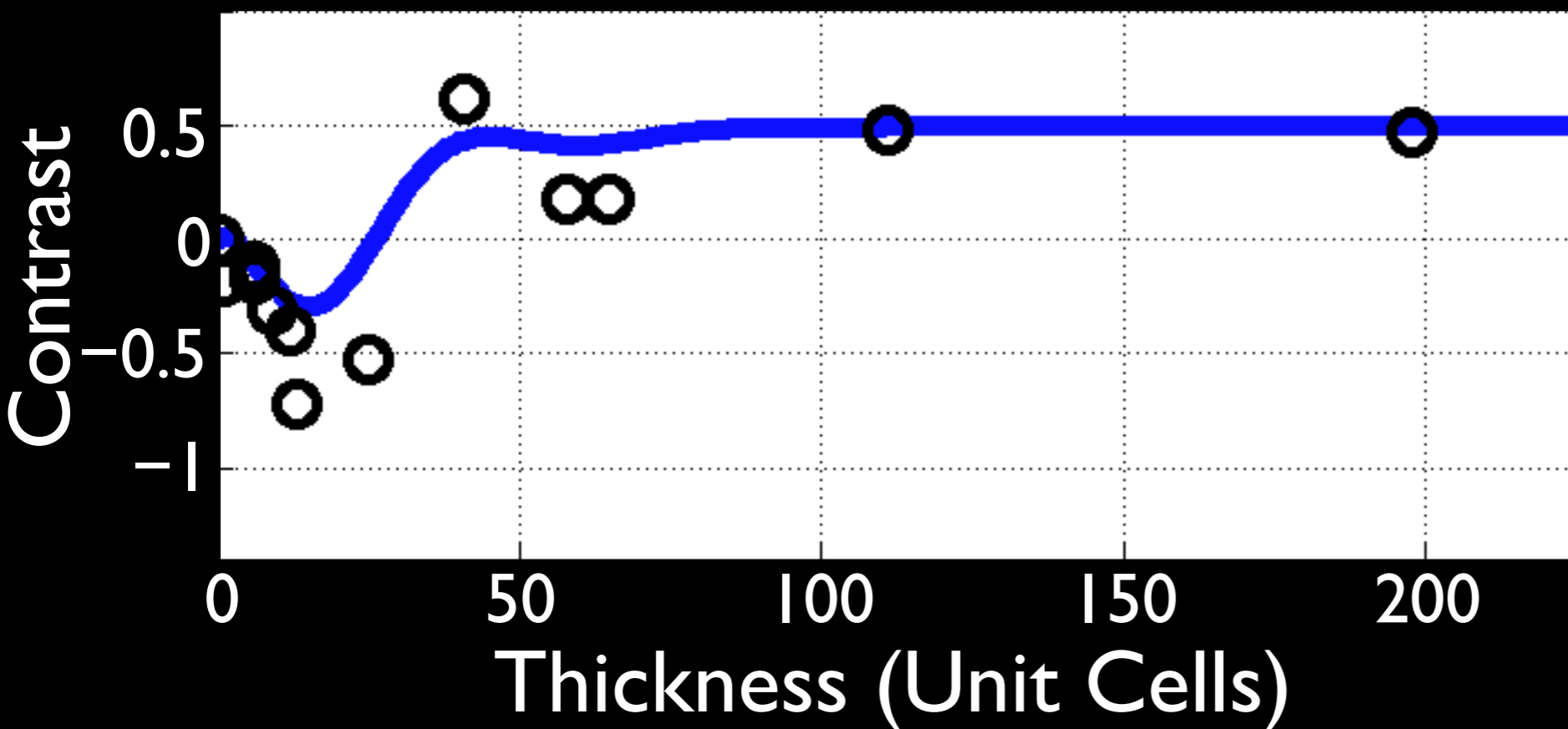
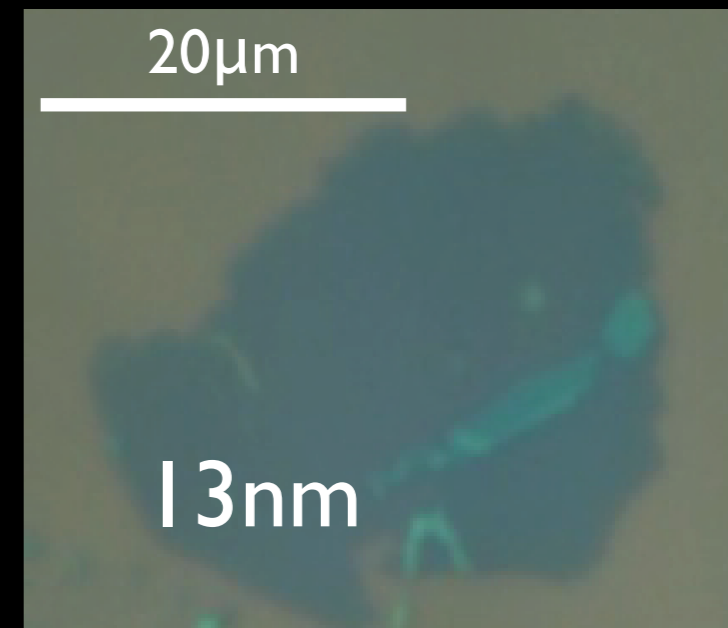
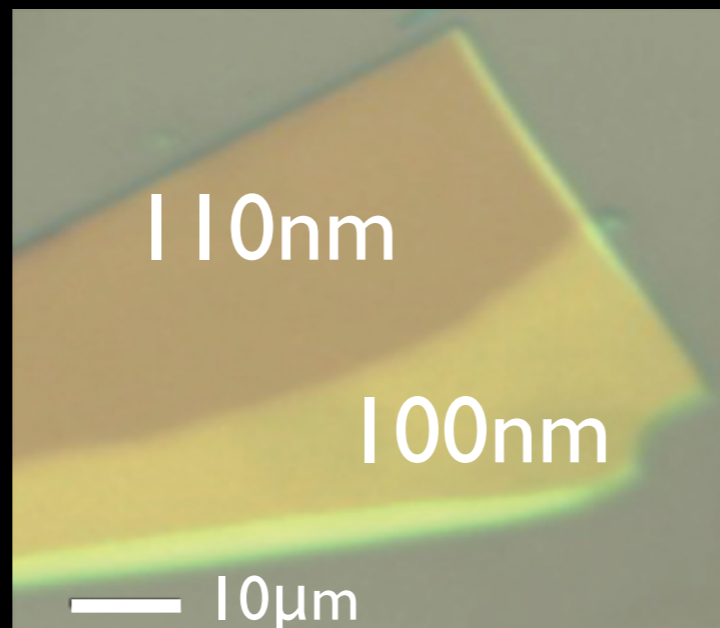
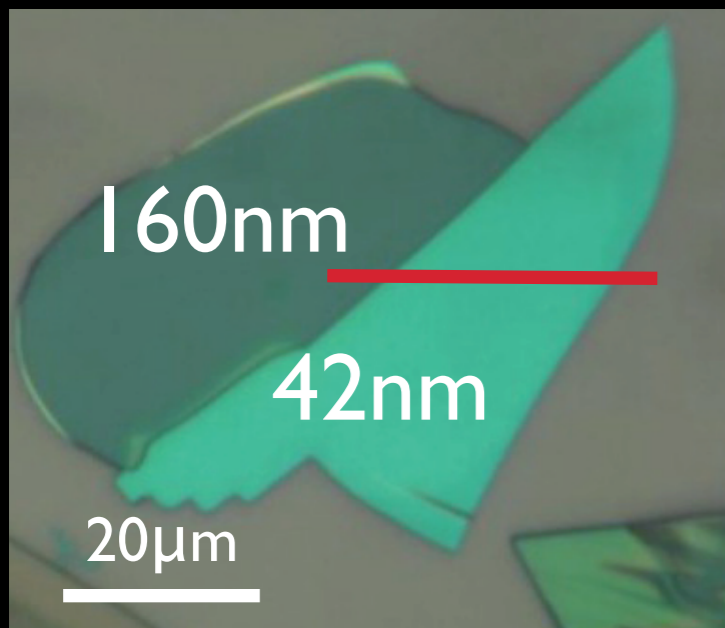
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Theory:
A.H. Castro Neto et al.,
APL 91, 063124 (2007)

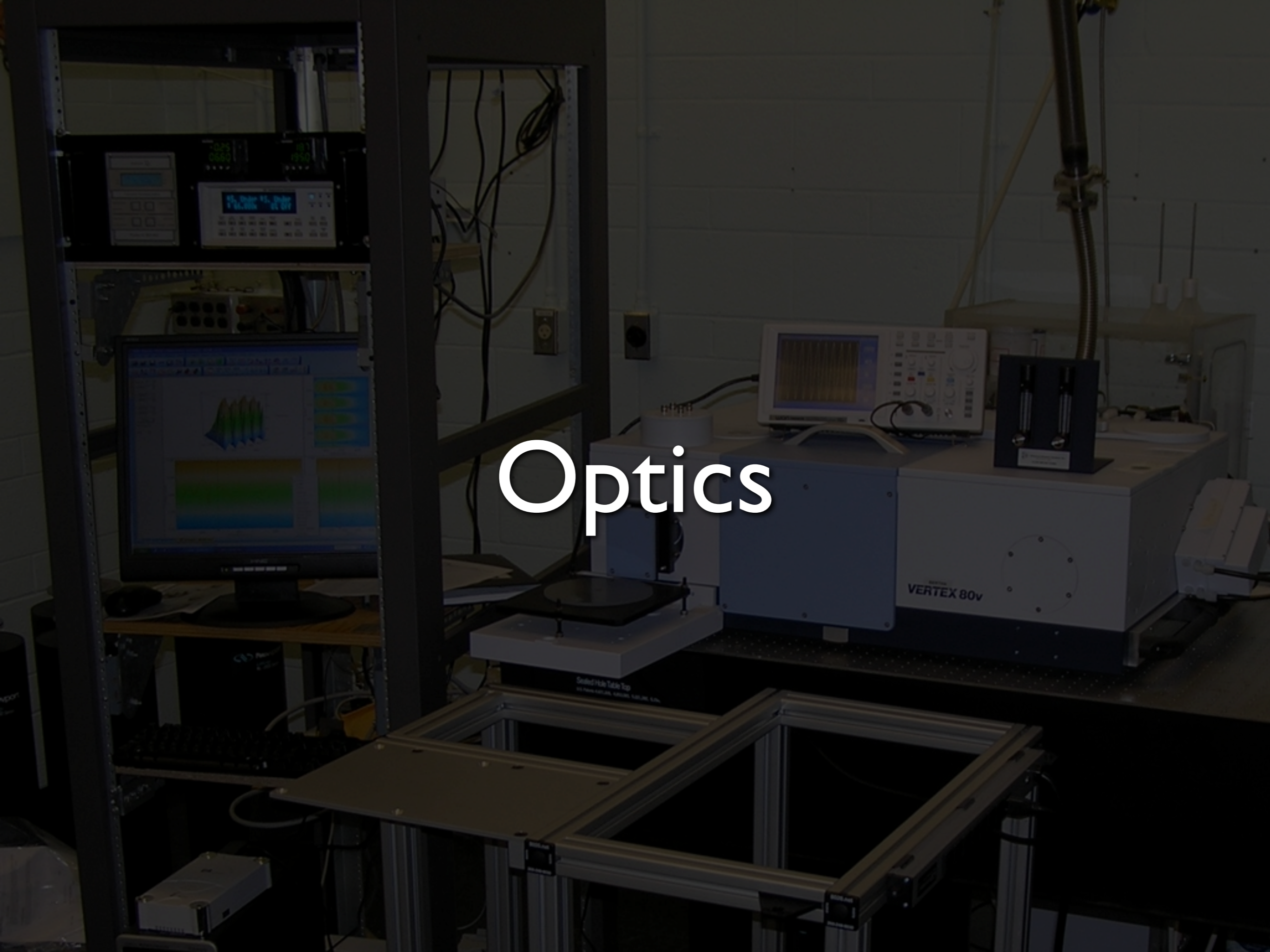


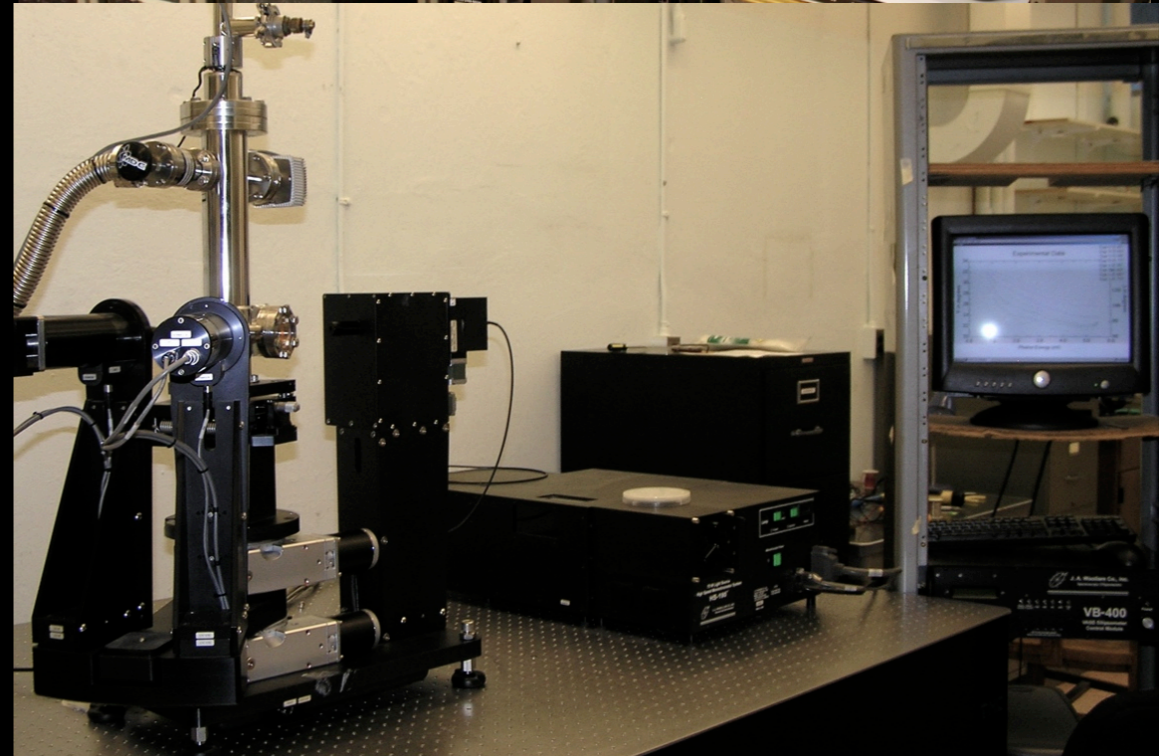
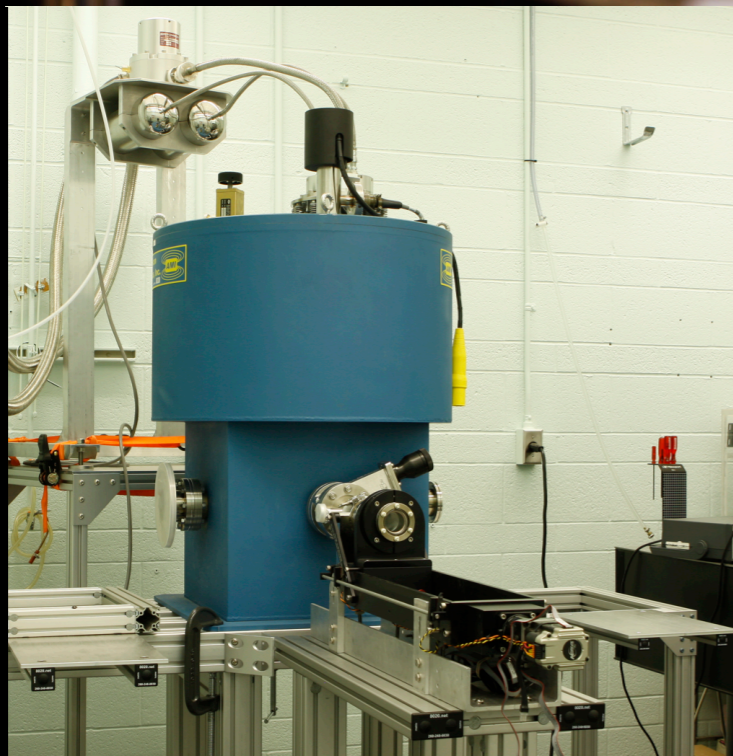
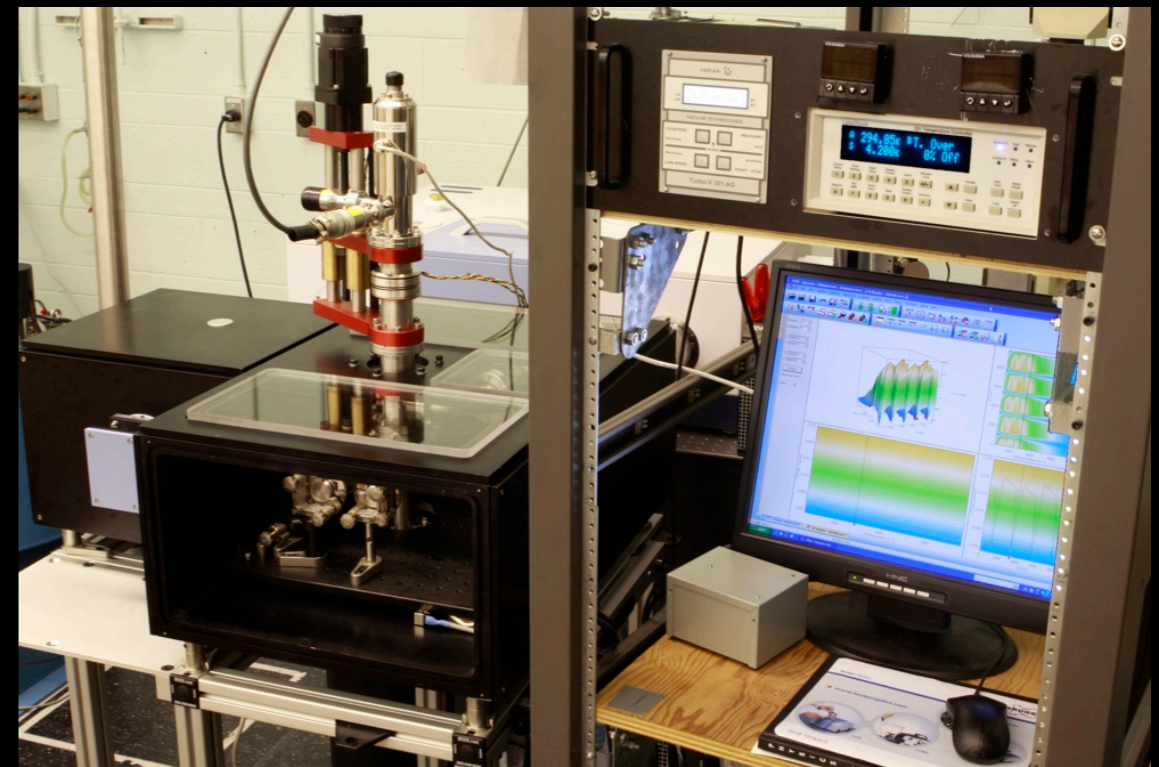
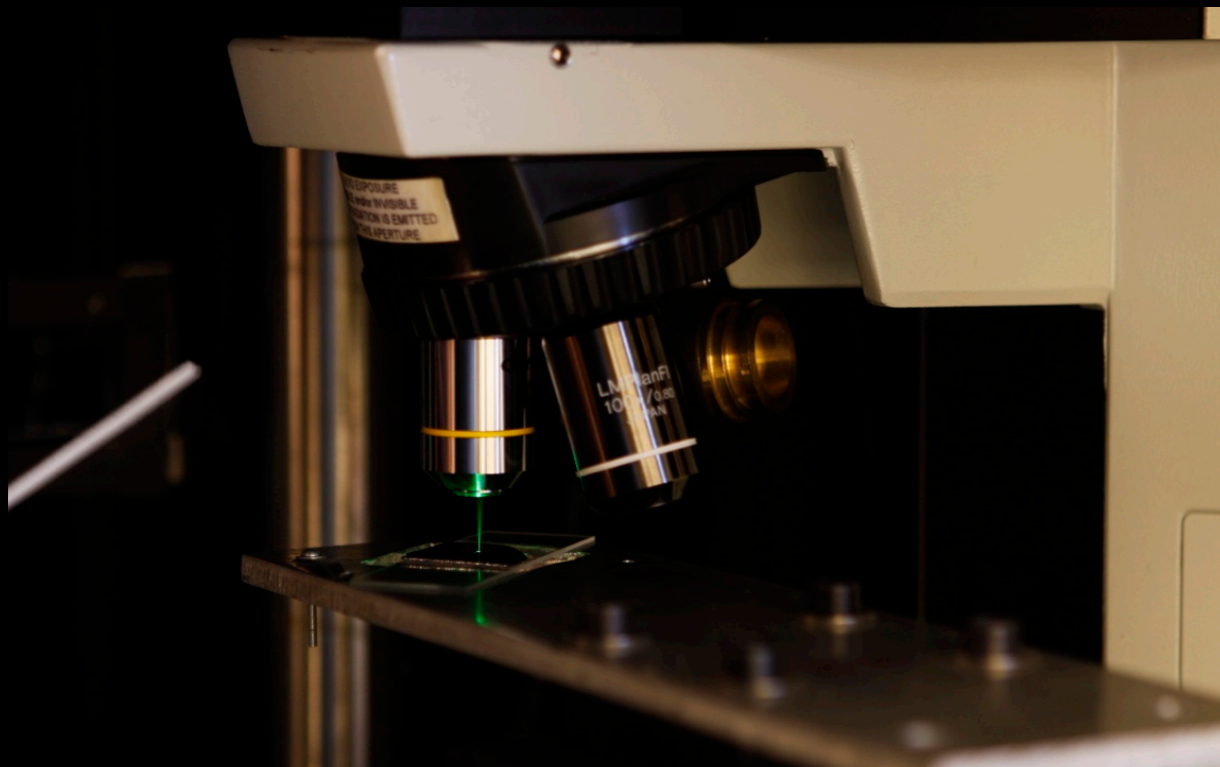
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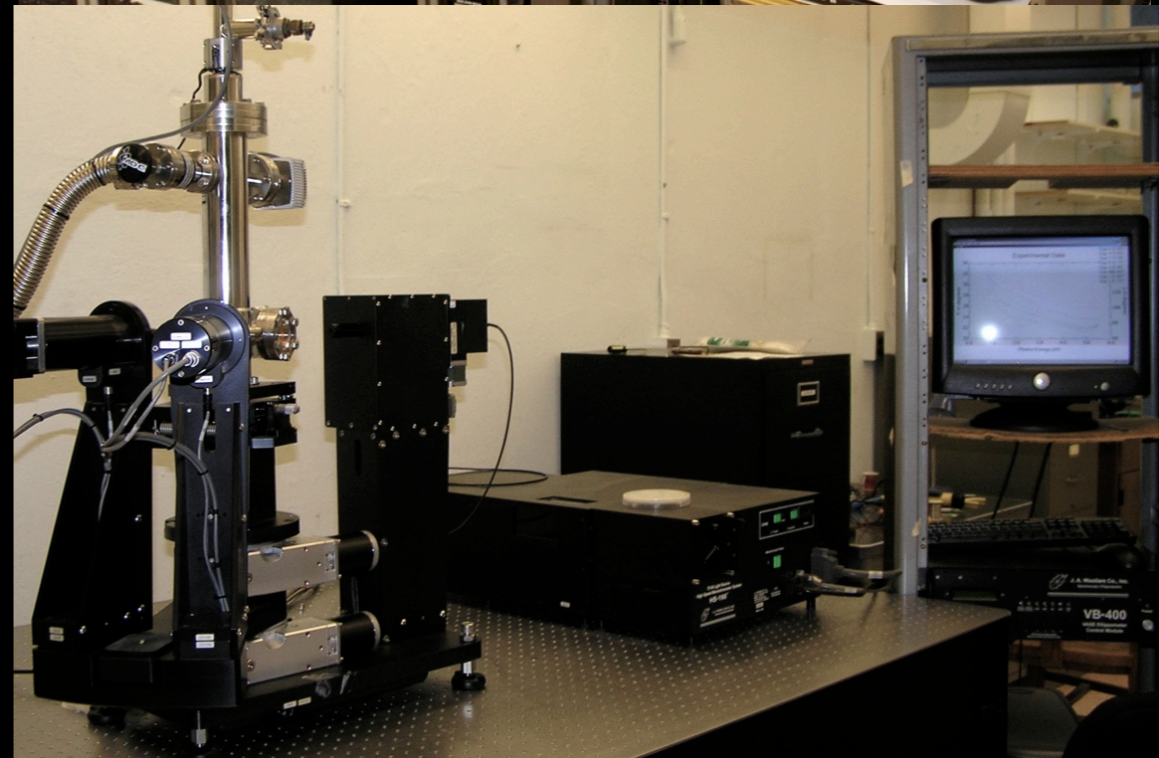
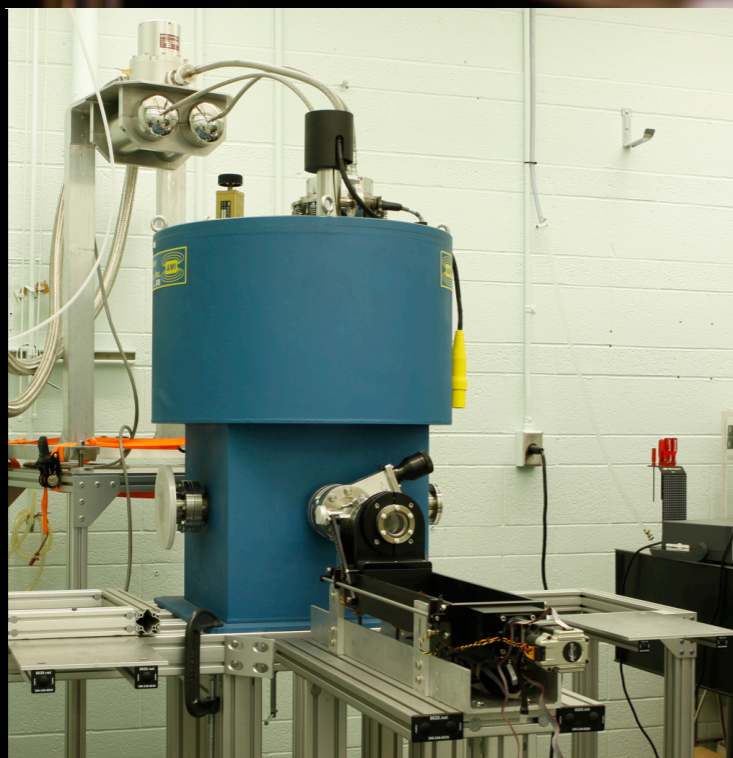
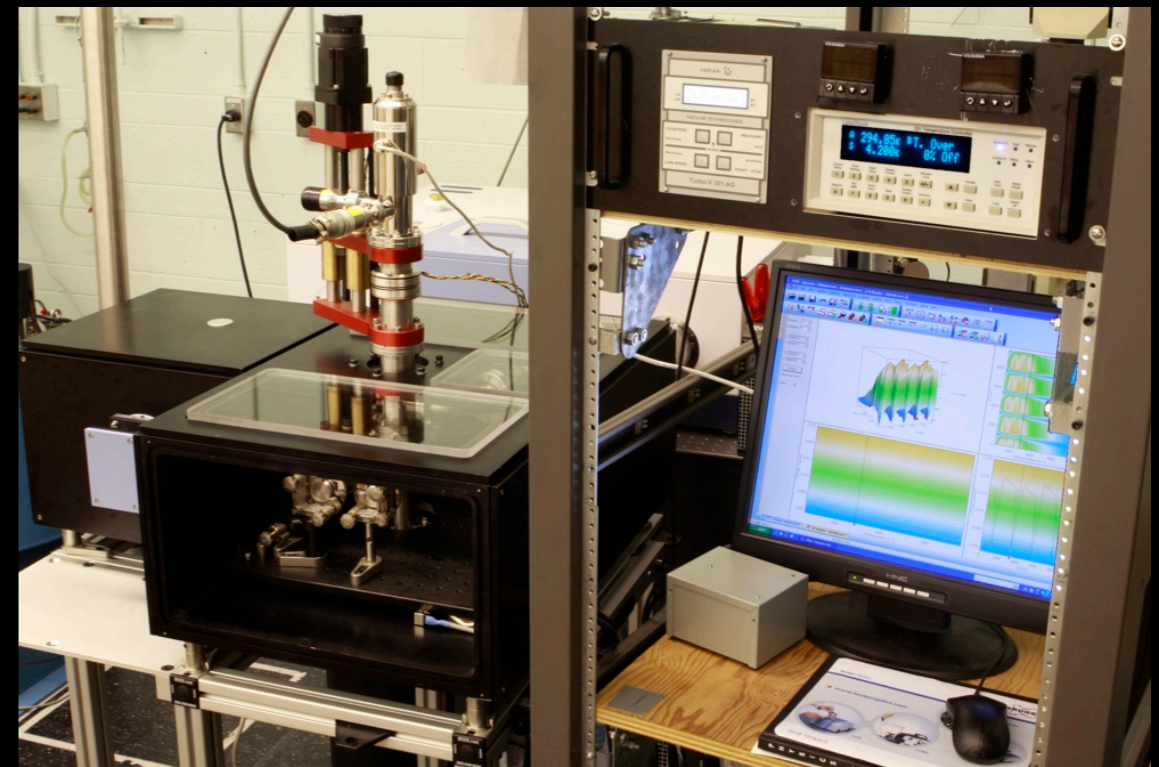
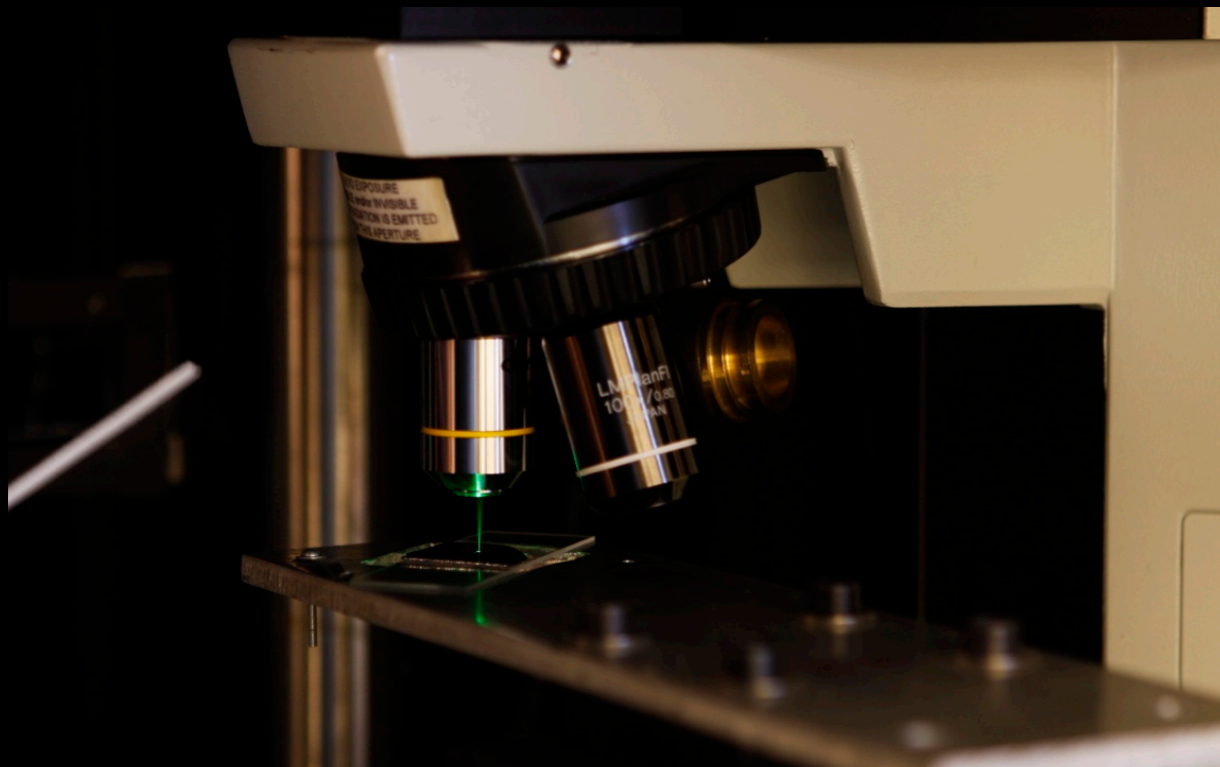


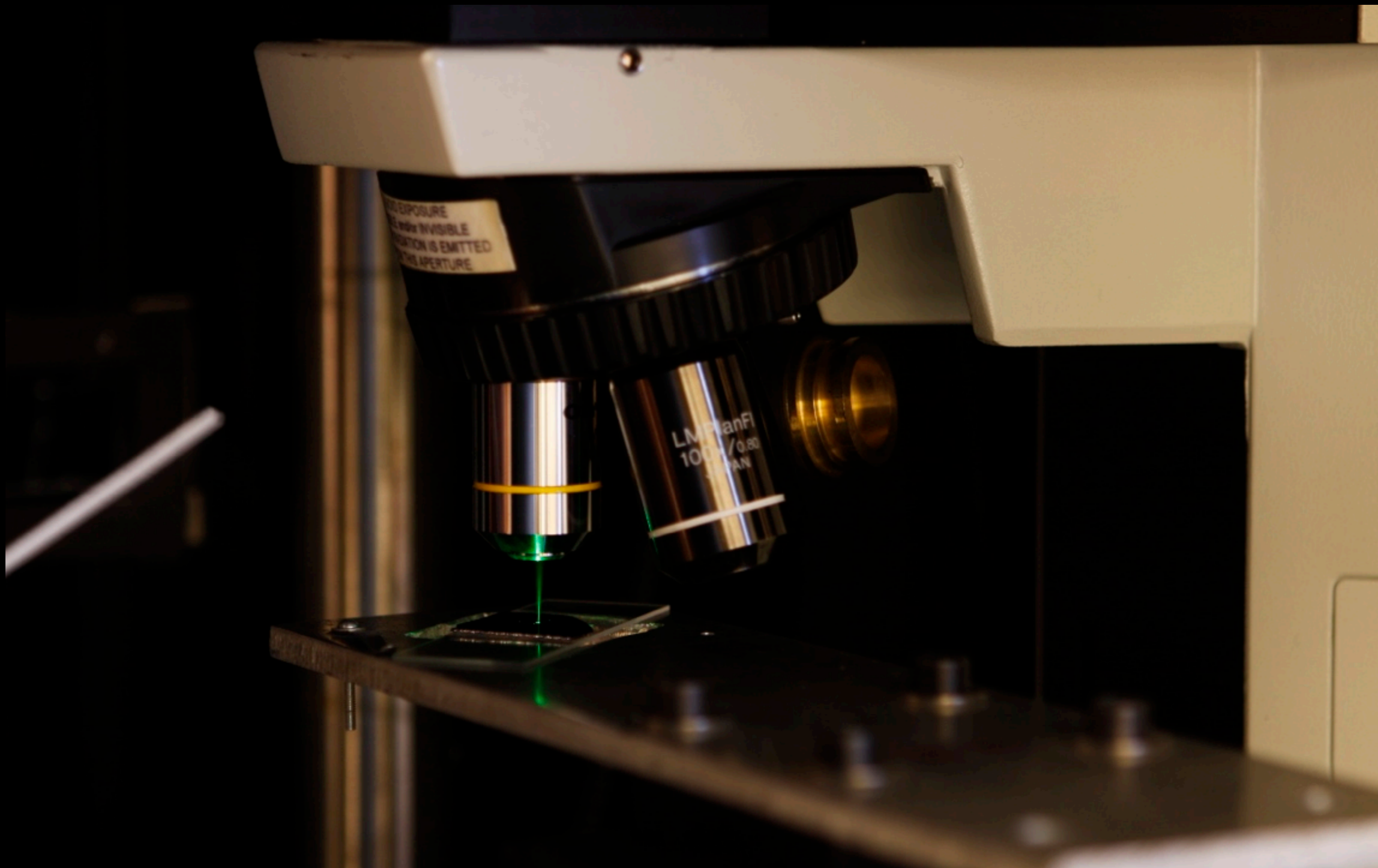
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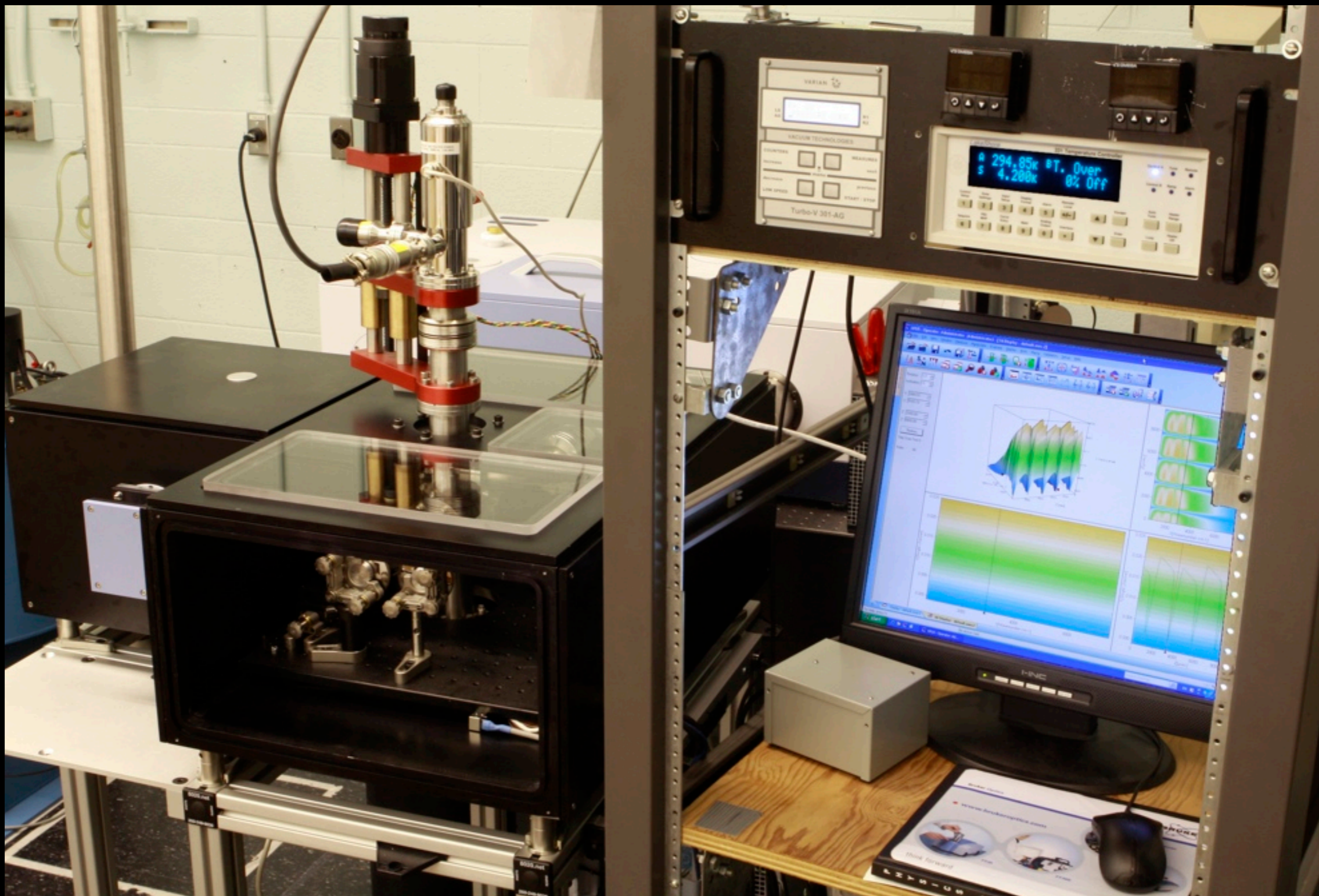
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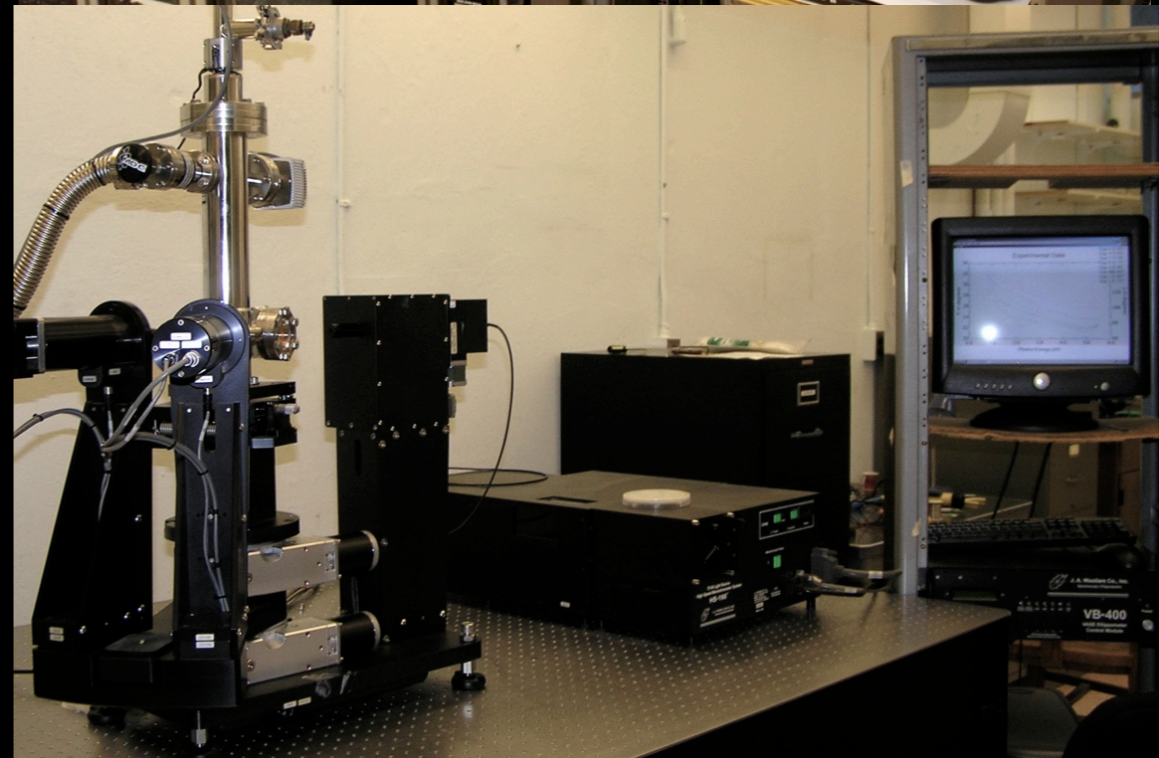
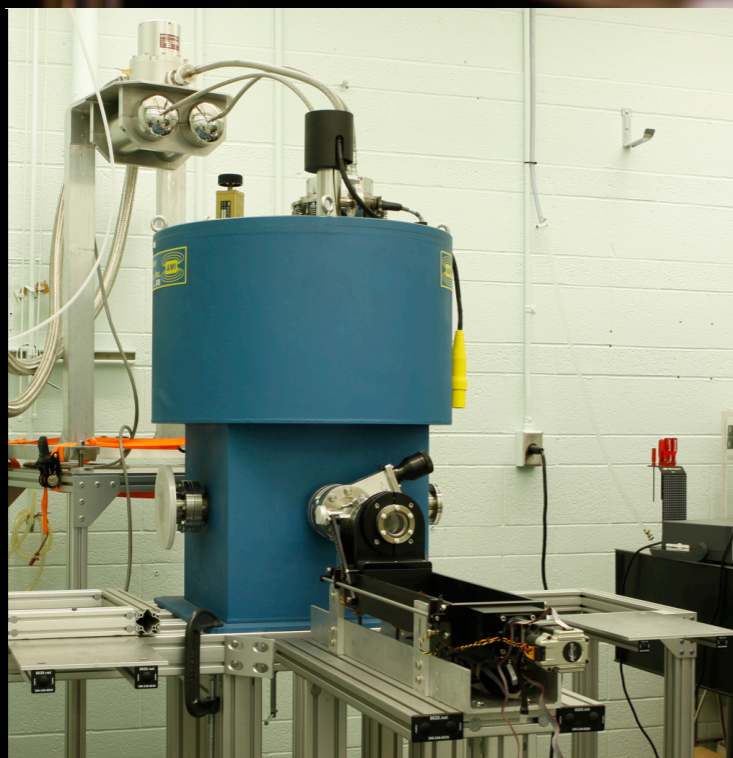
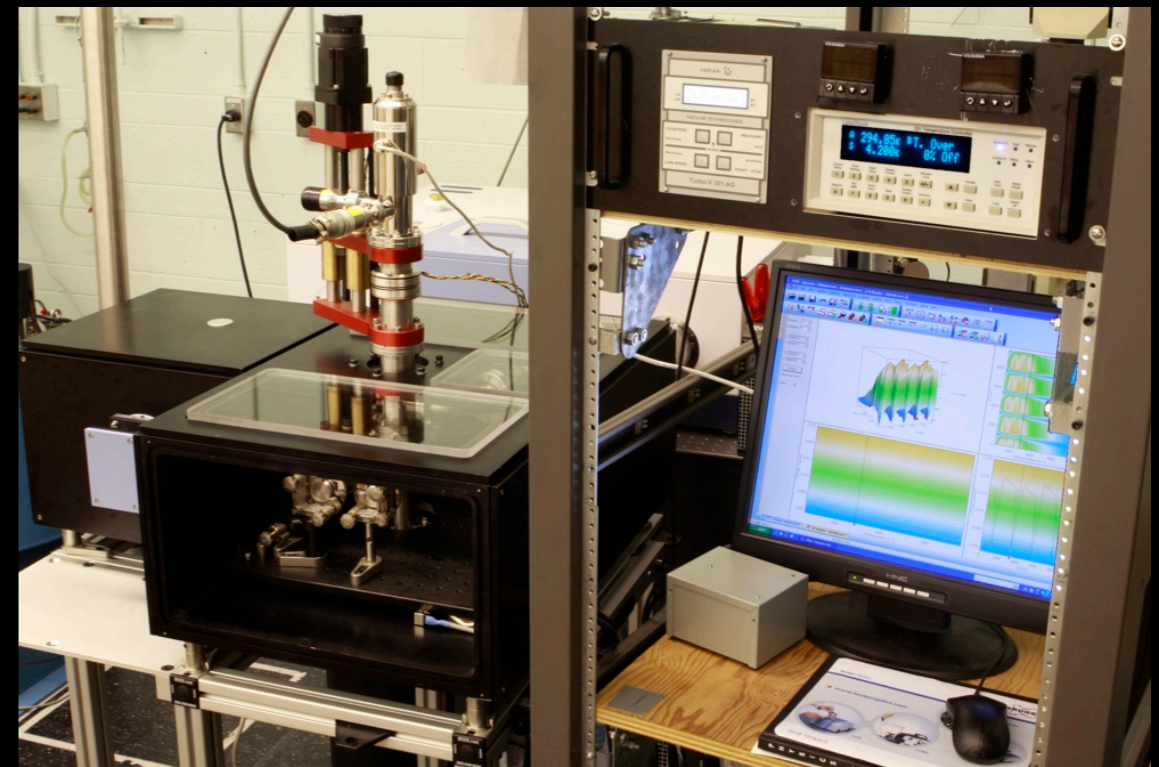
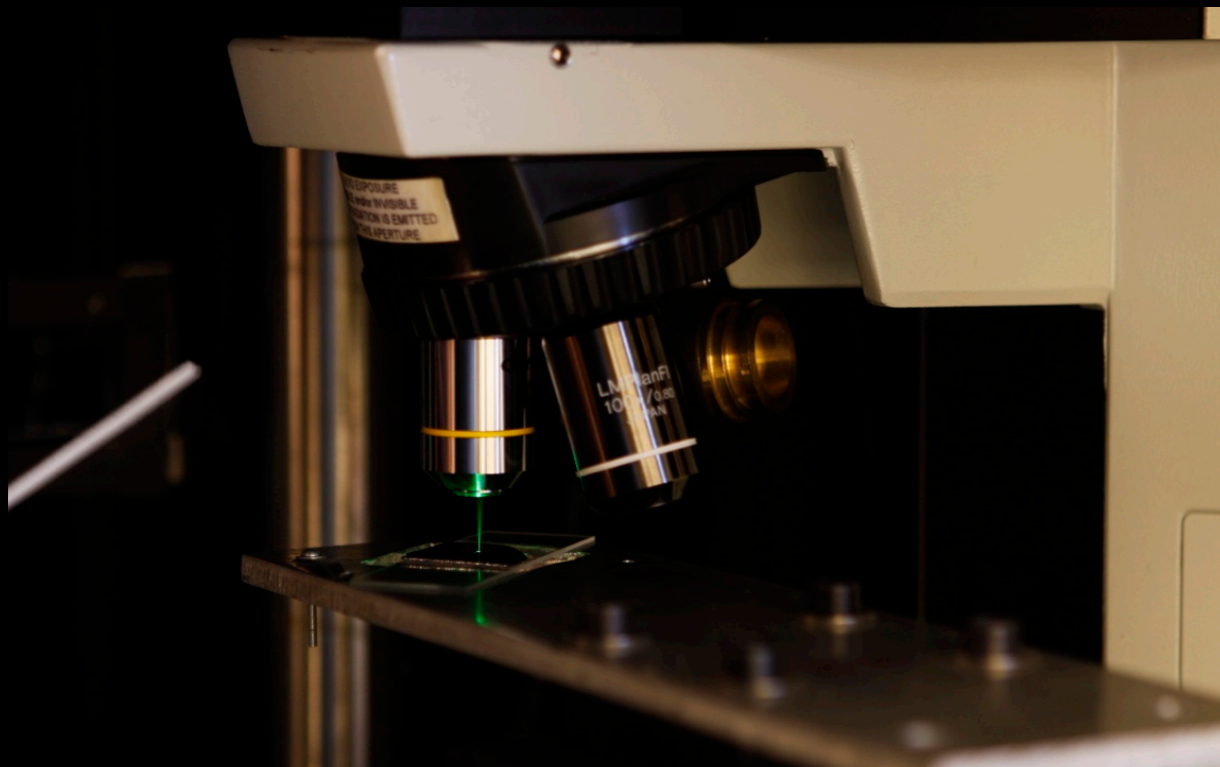


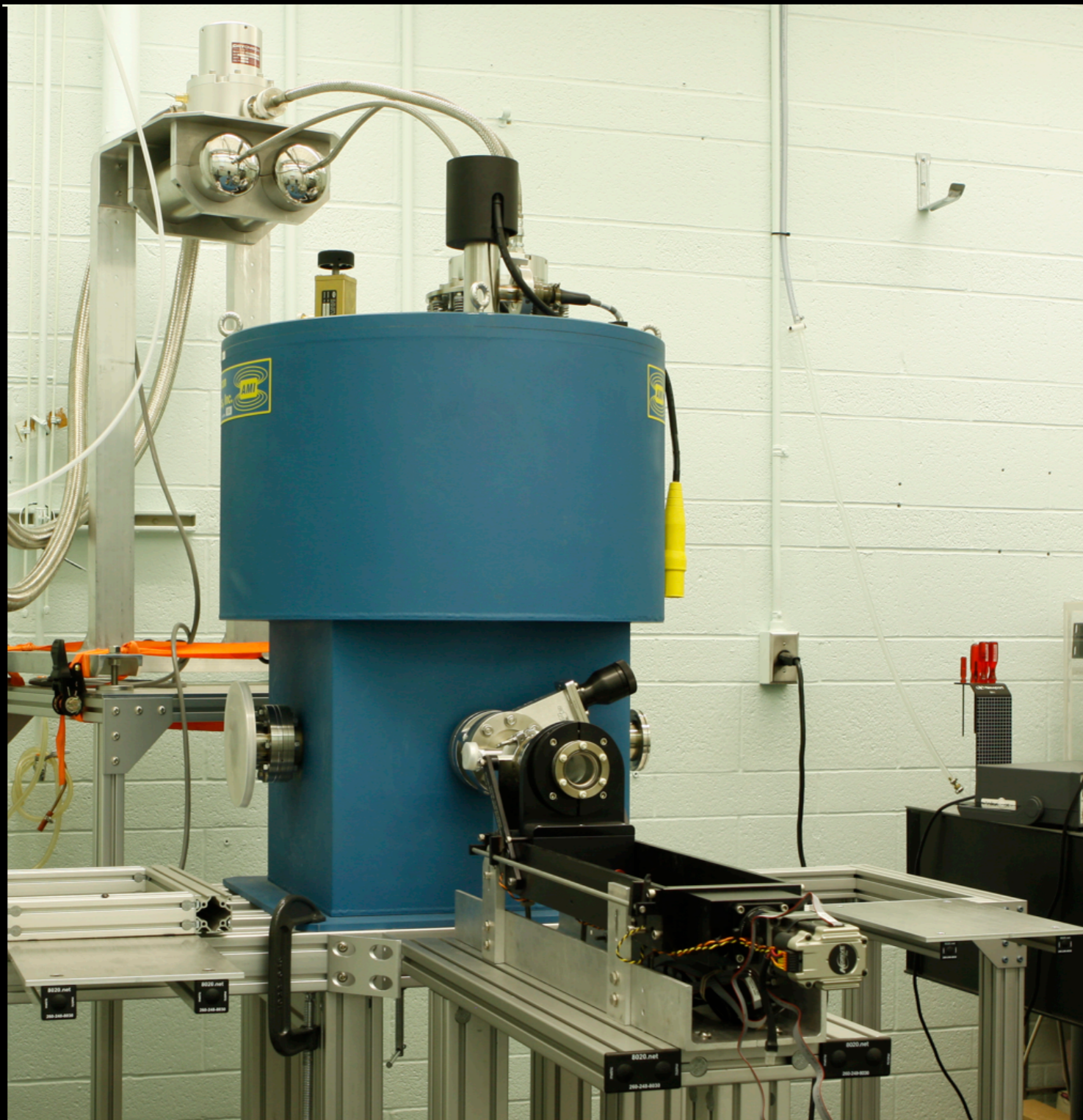


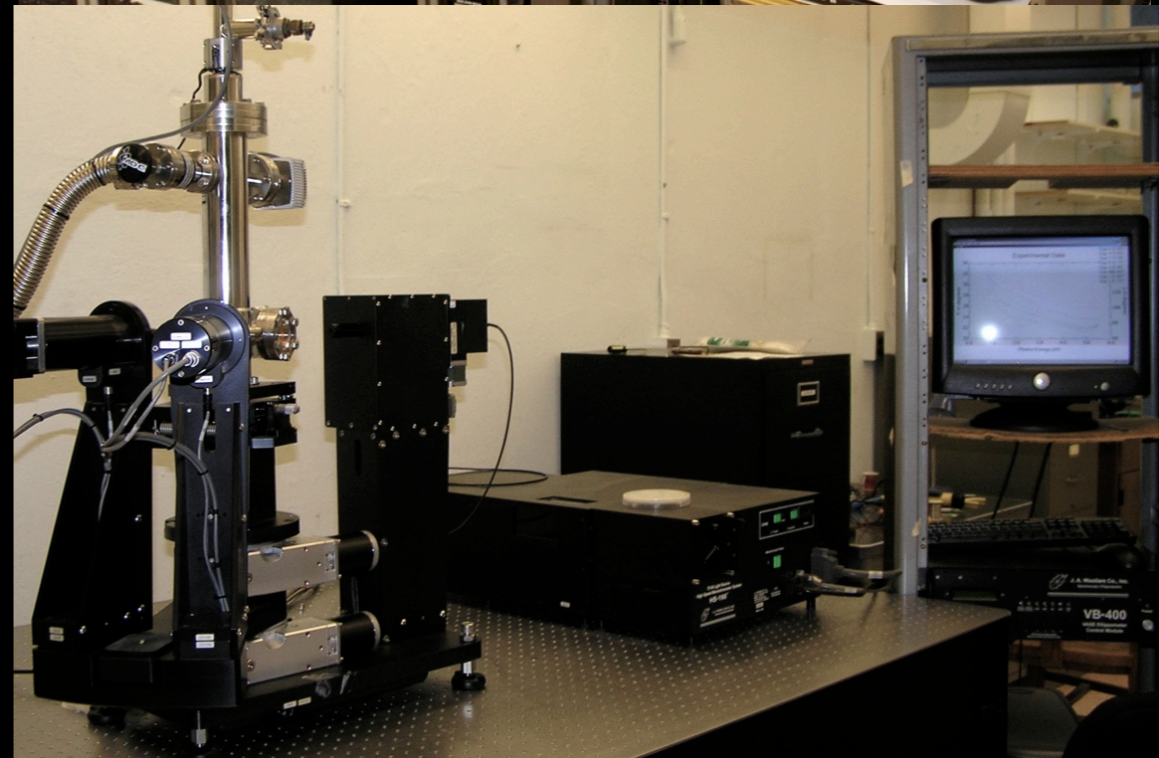
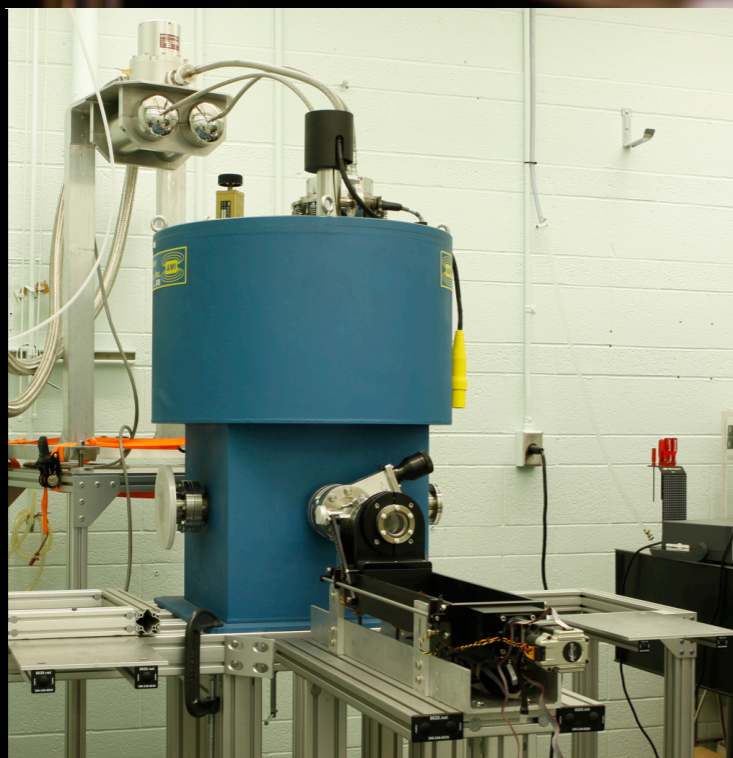
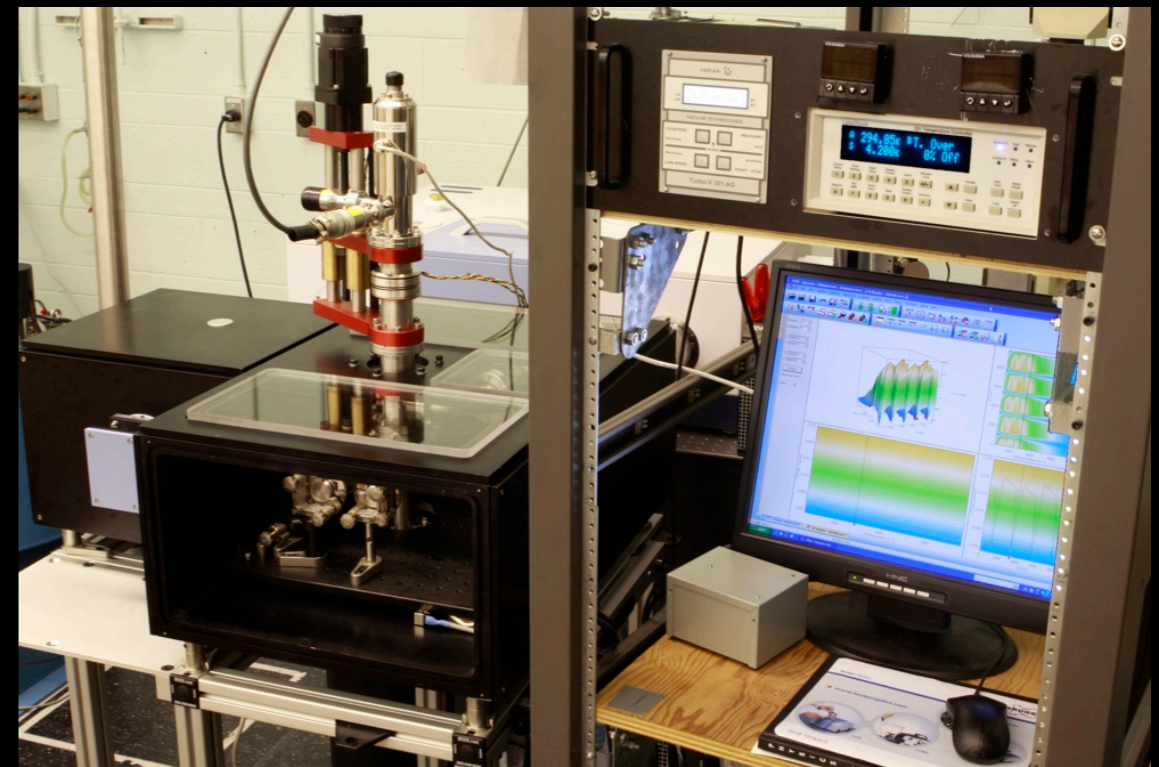
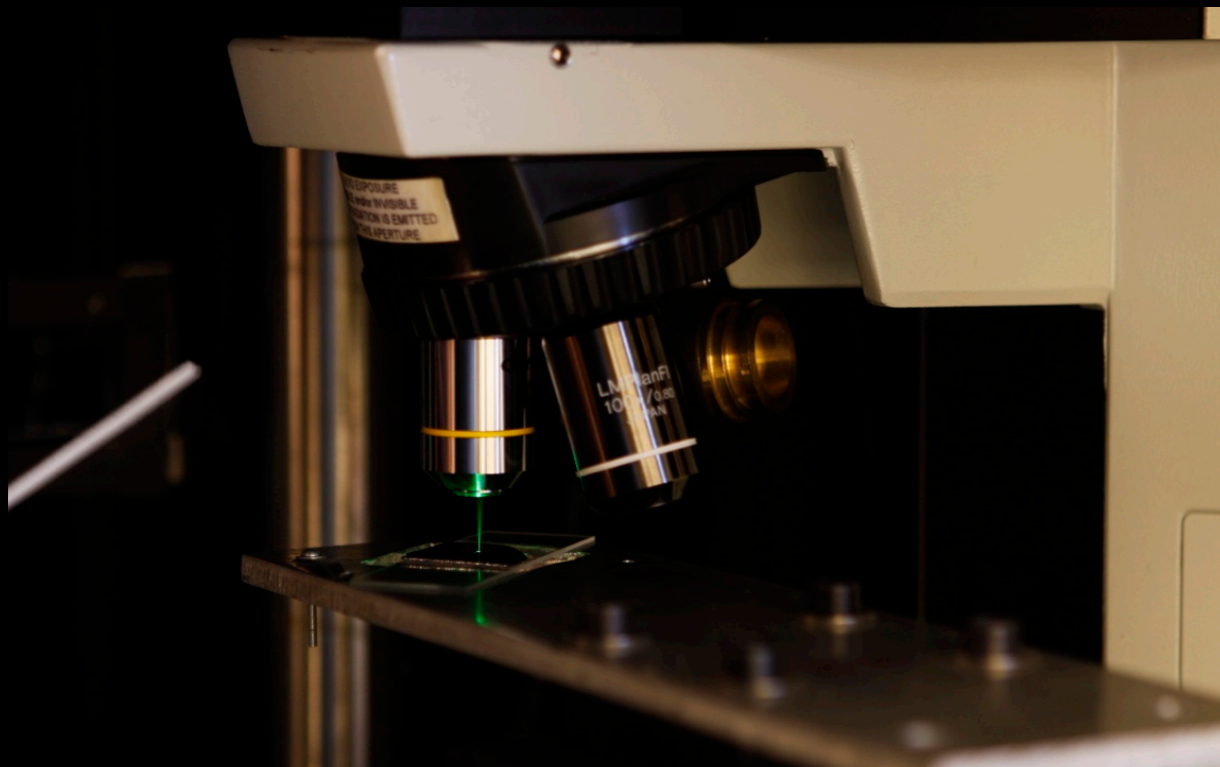


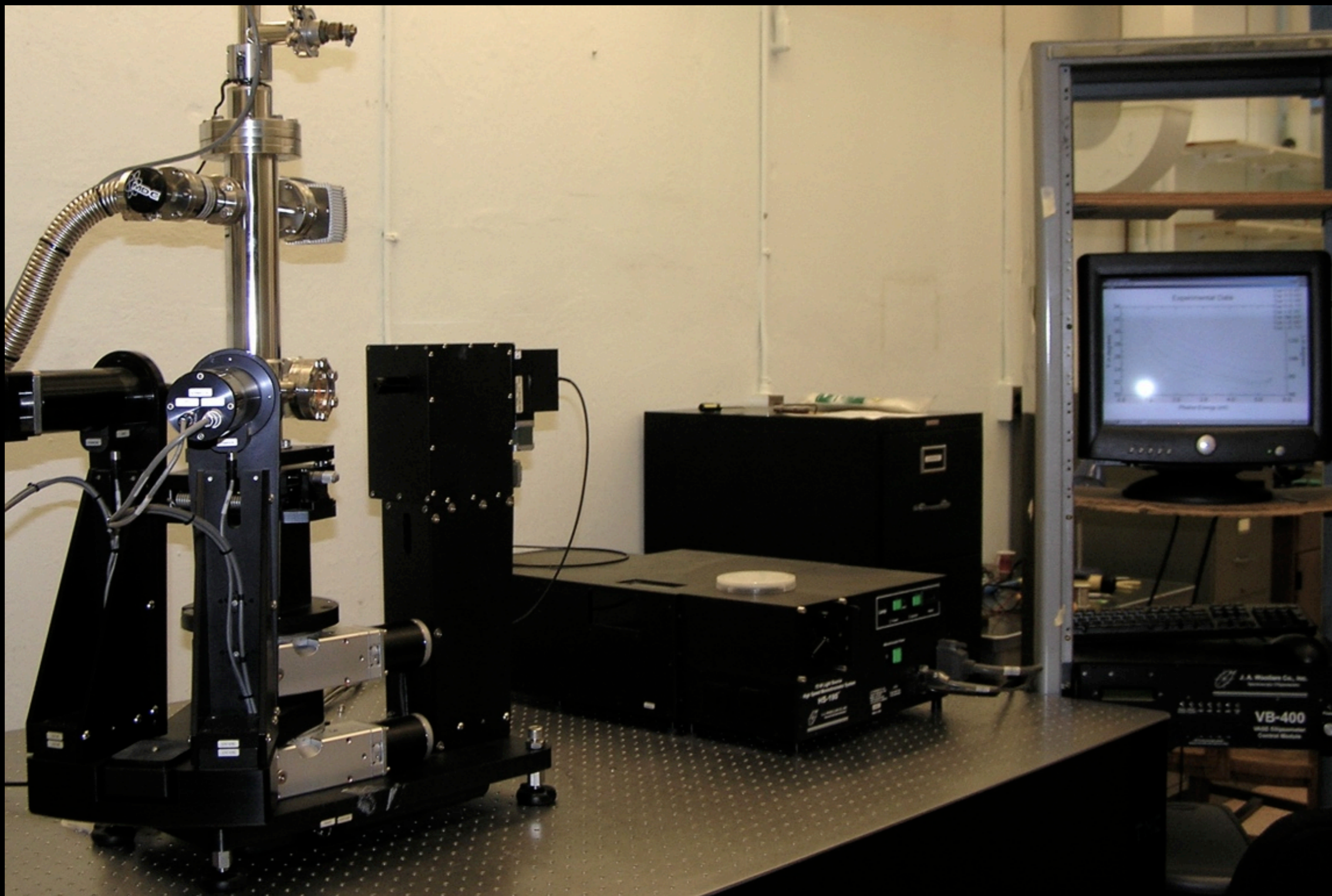
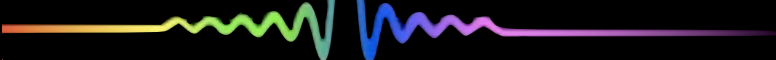


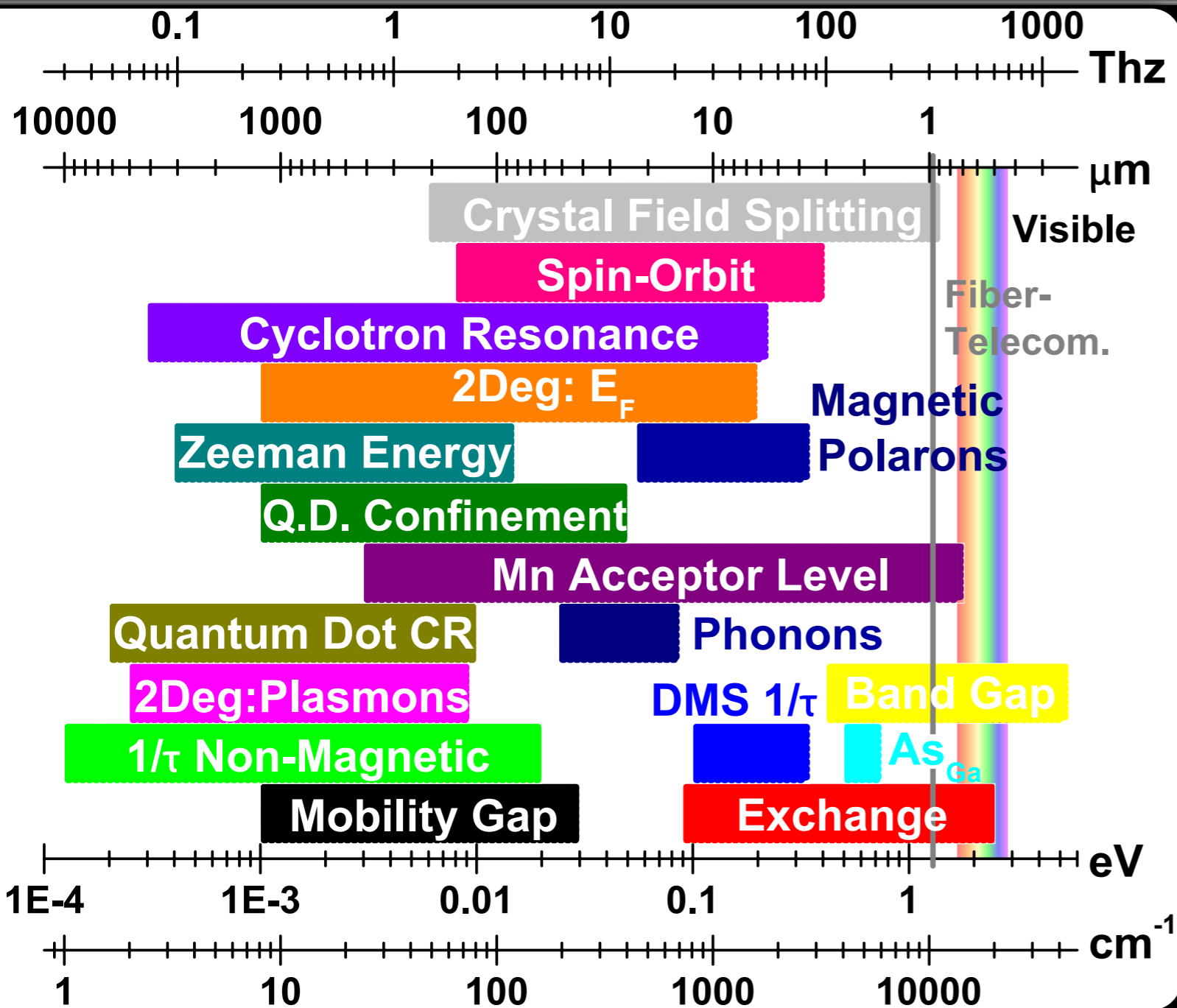




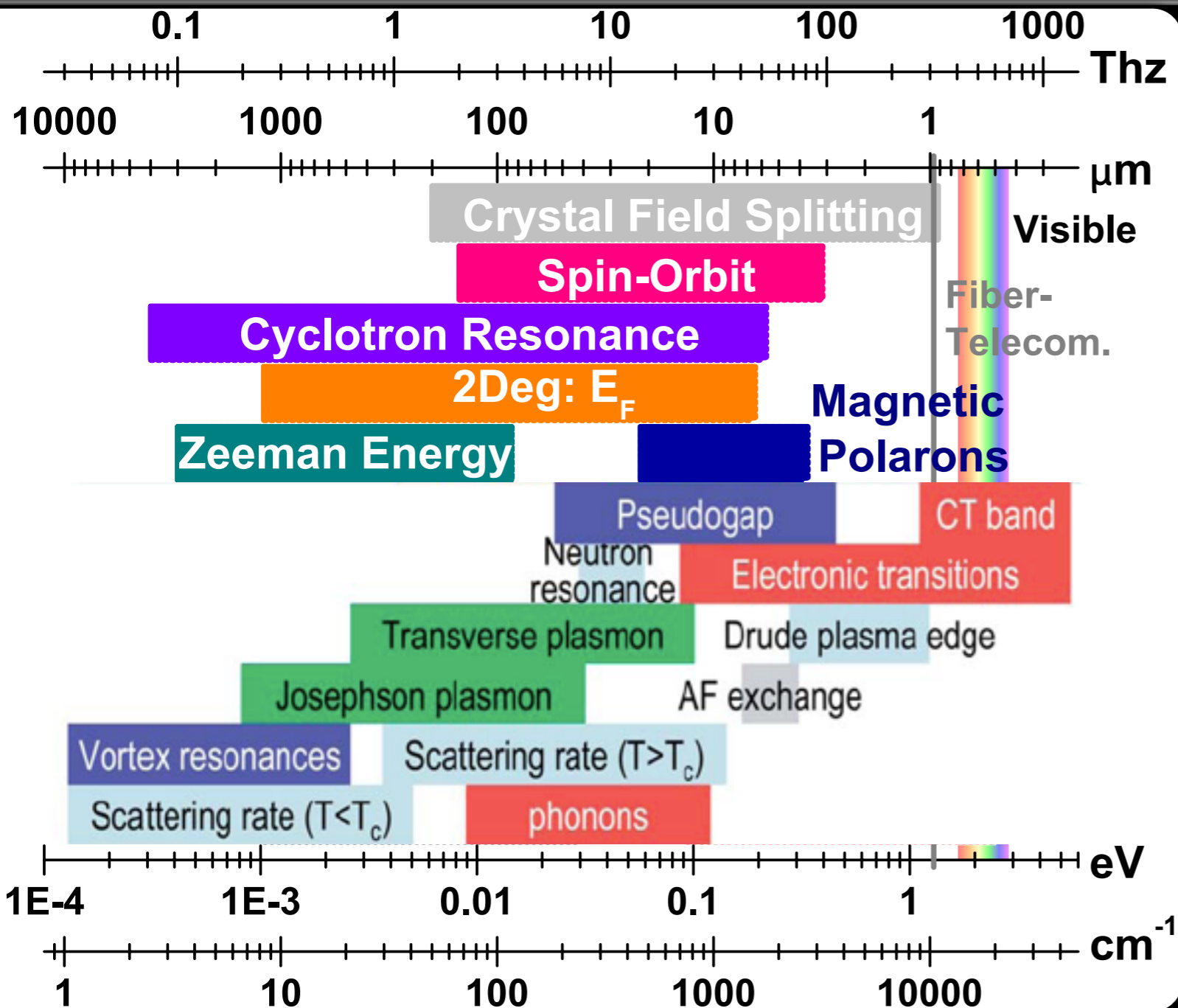






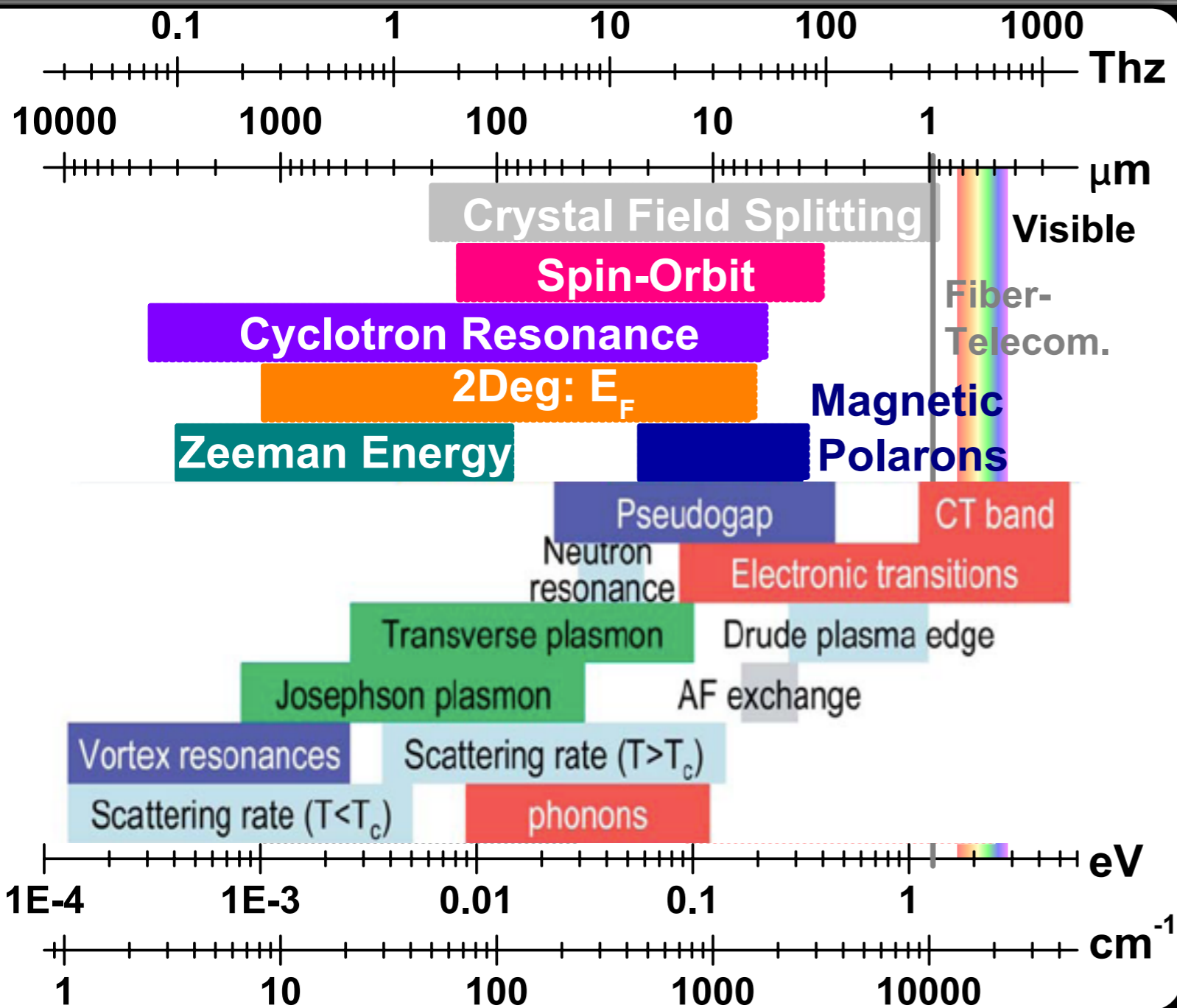


K.S. Burch et al., JMMM 320, 3207(2008)



D.N. Basov & T. Timusk, RMP 77, 721 (2005)

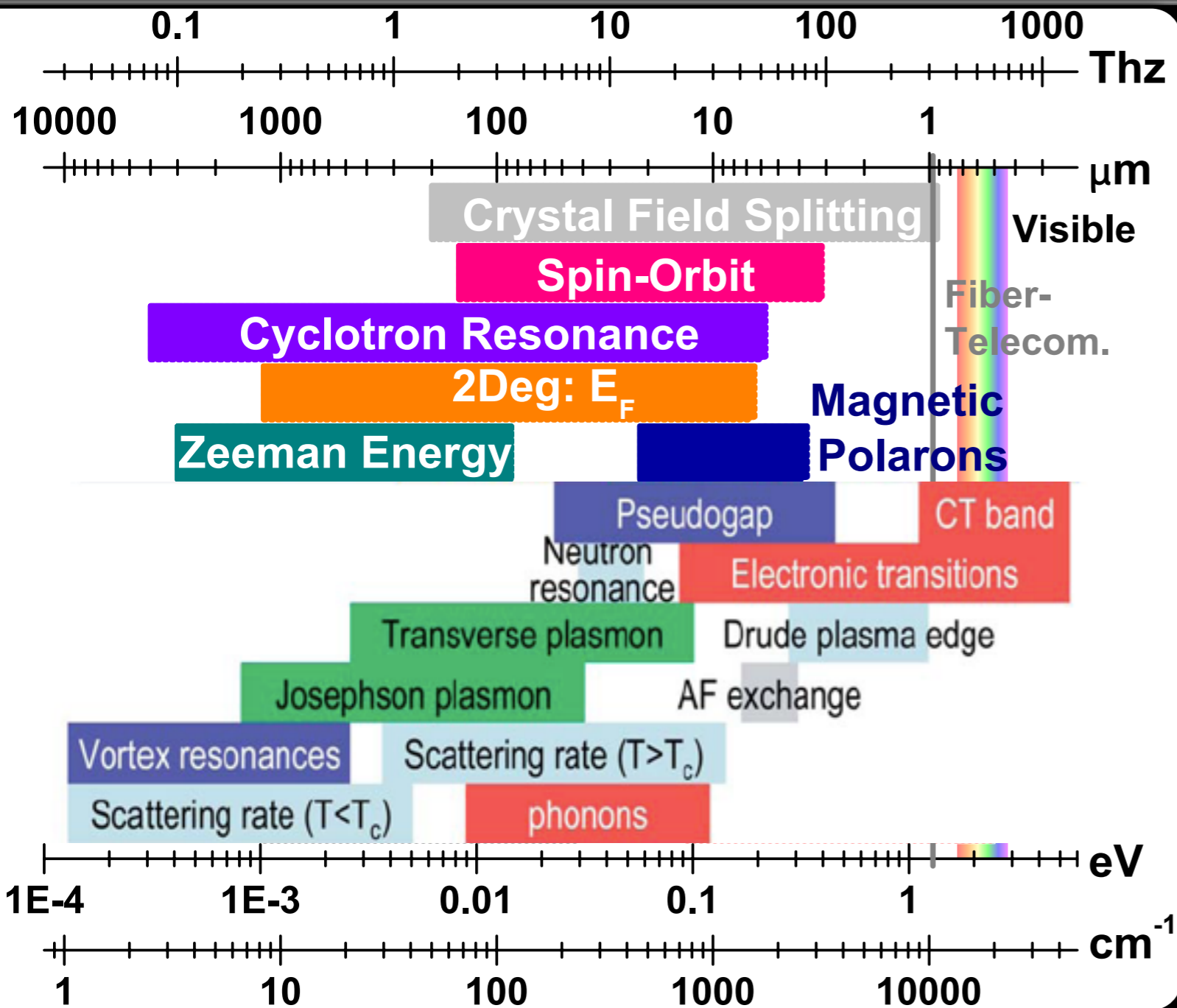
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**GOOD RULES OF THUMB:
8000 cm⁻¹ ~ 1eV (1.5 eV ~ 800 nm)**

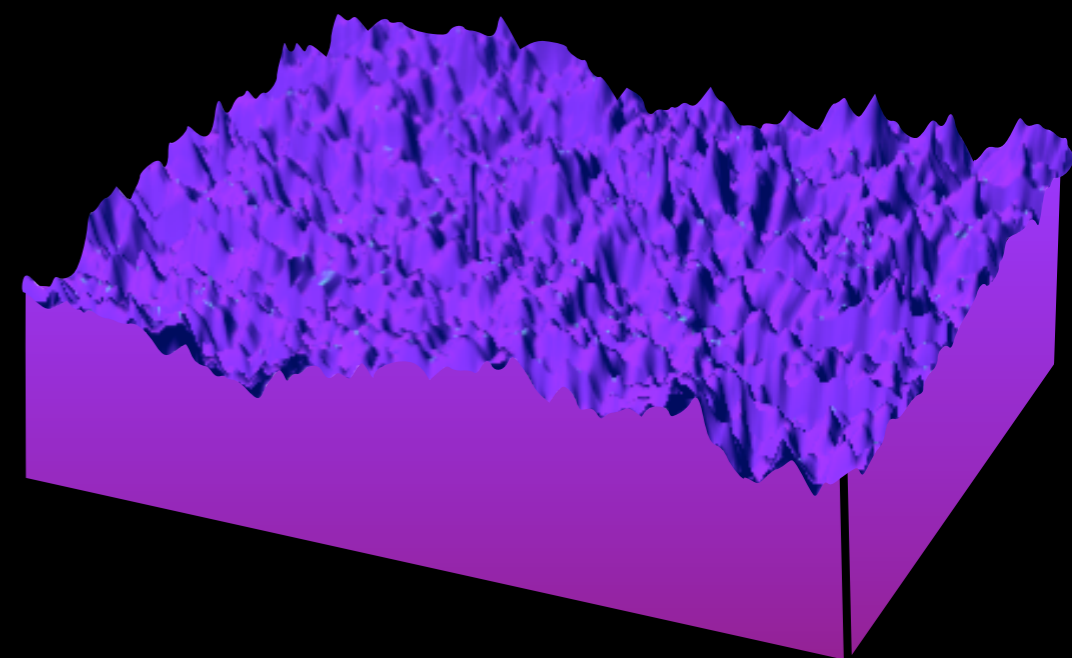
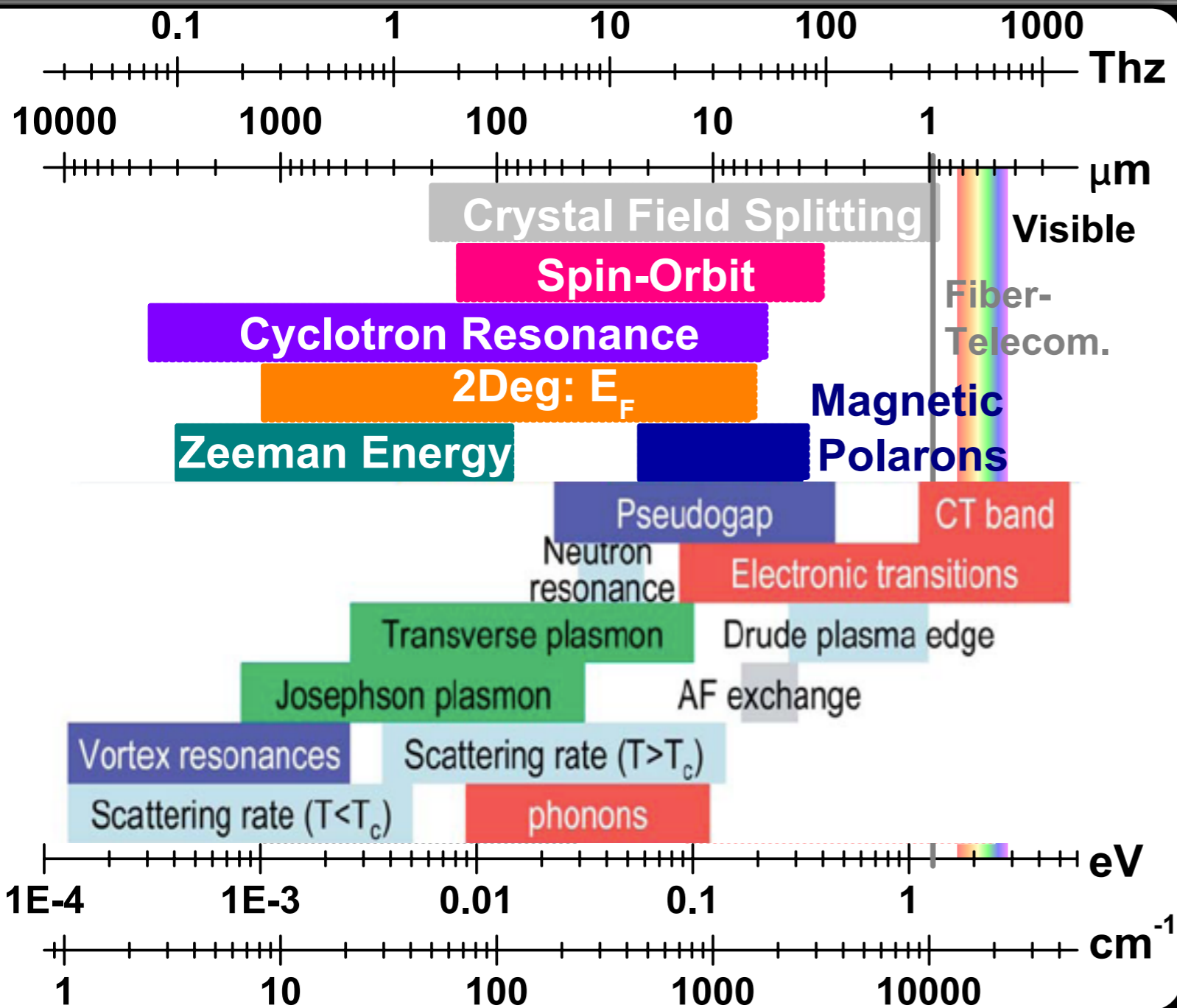
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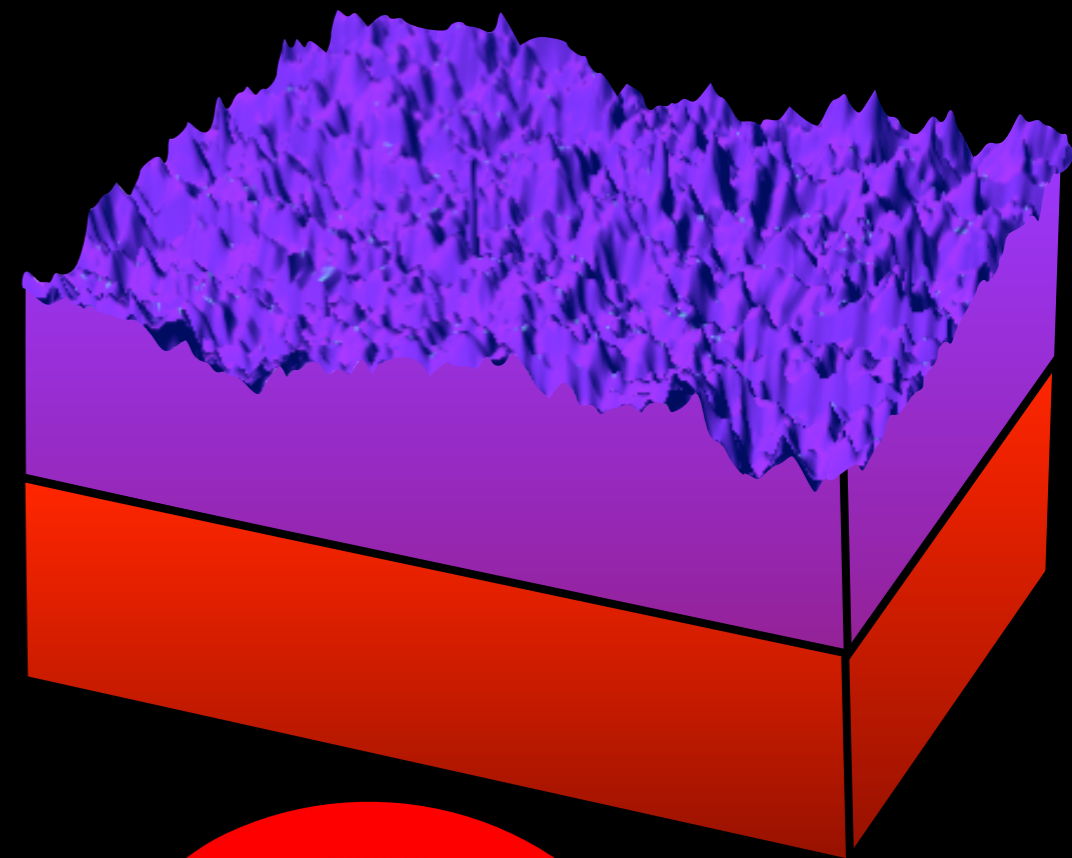
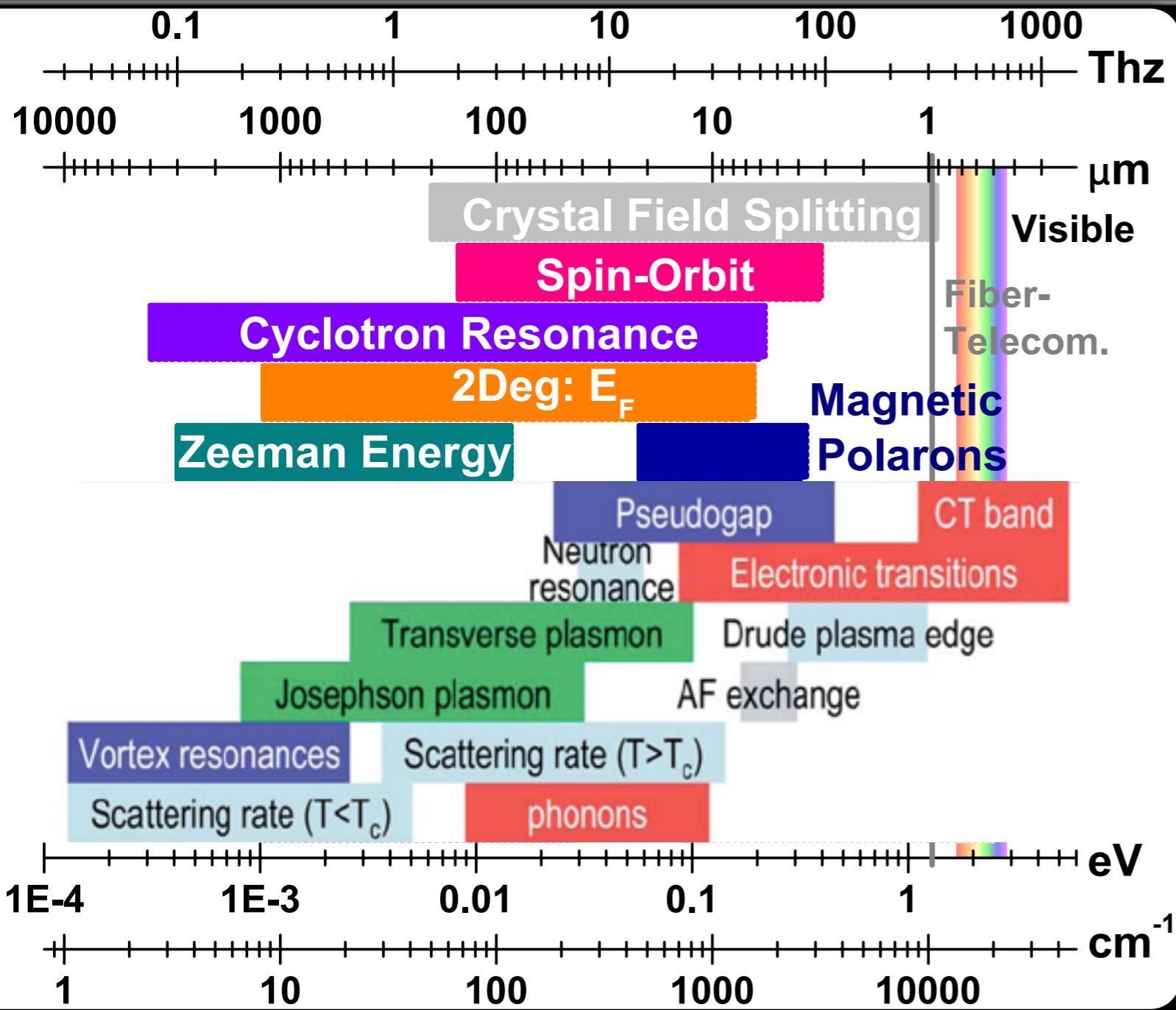
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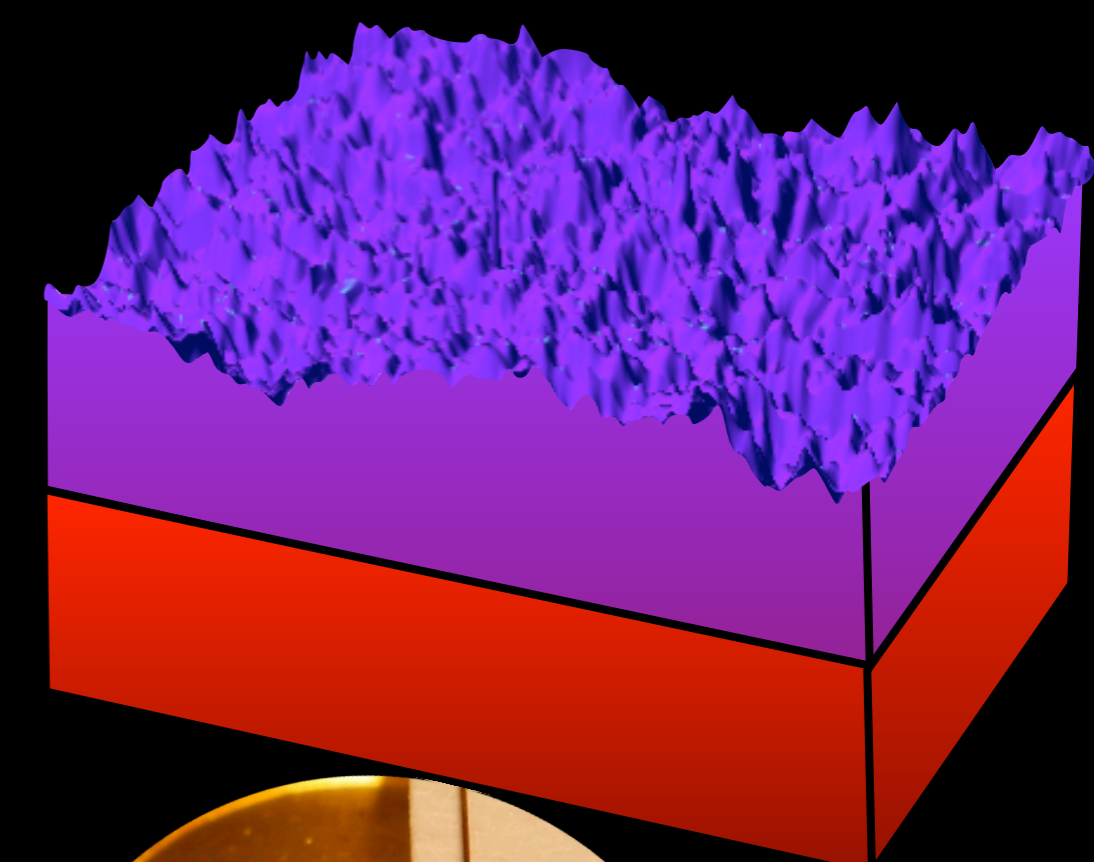
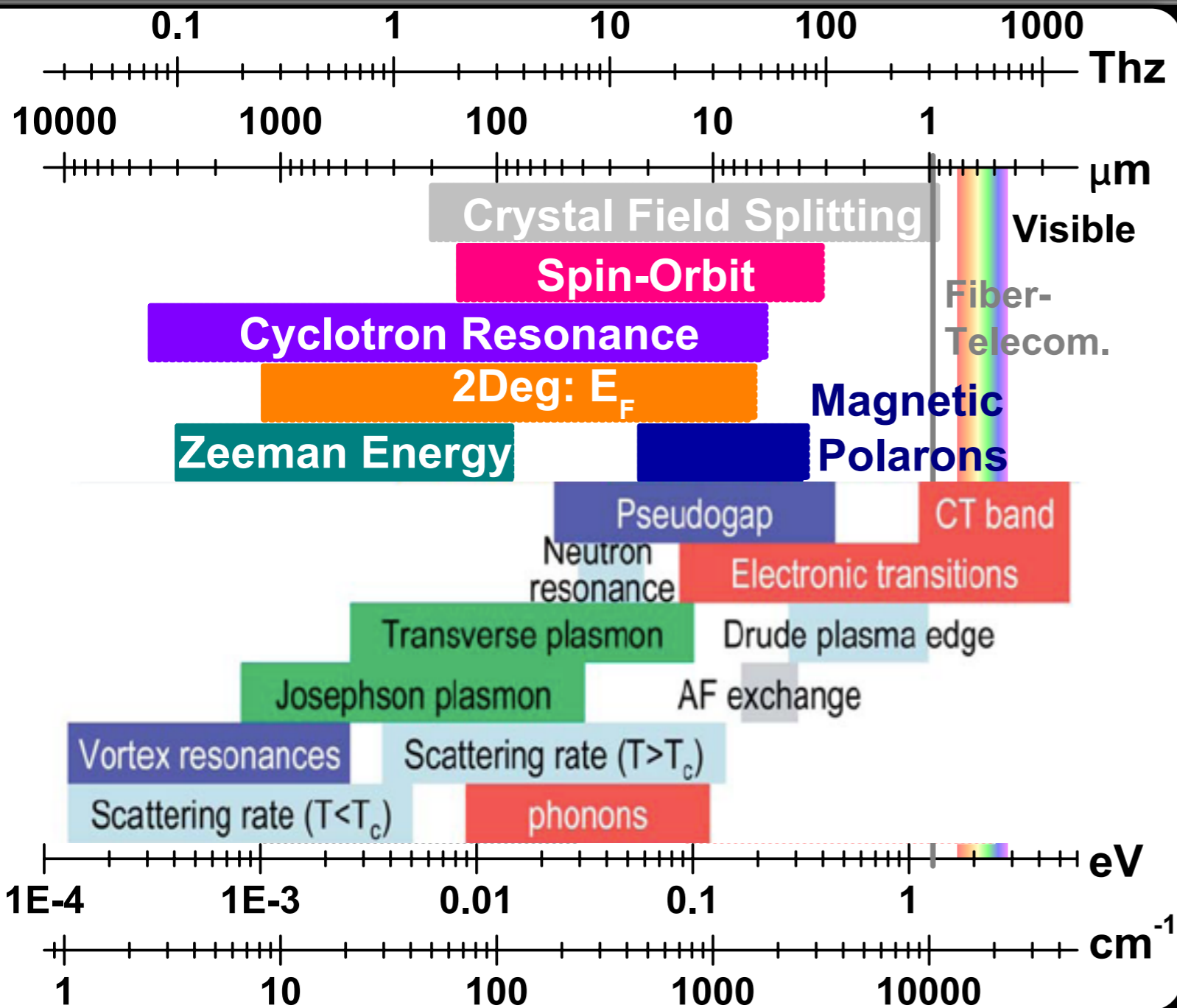
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Raman Scattering



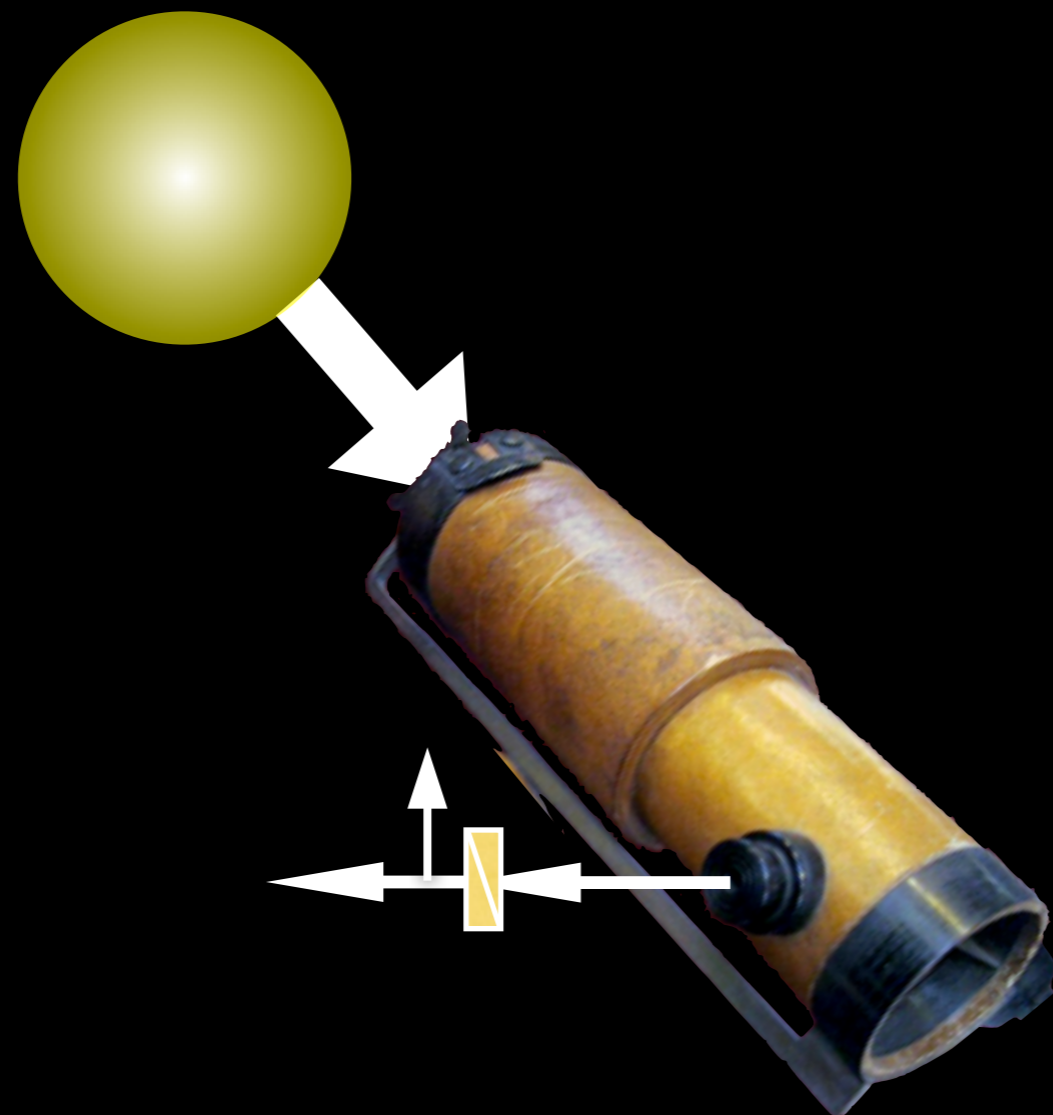


Raman Scattering



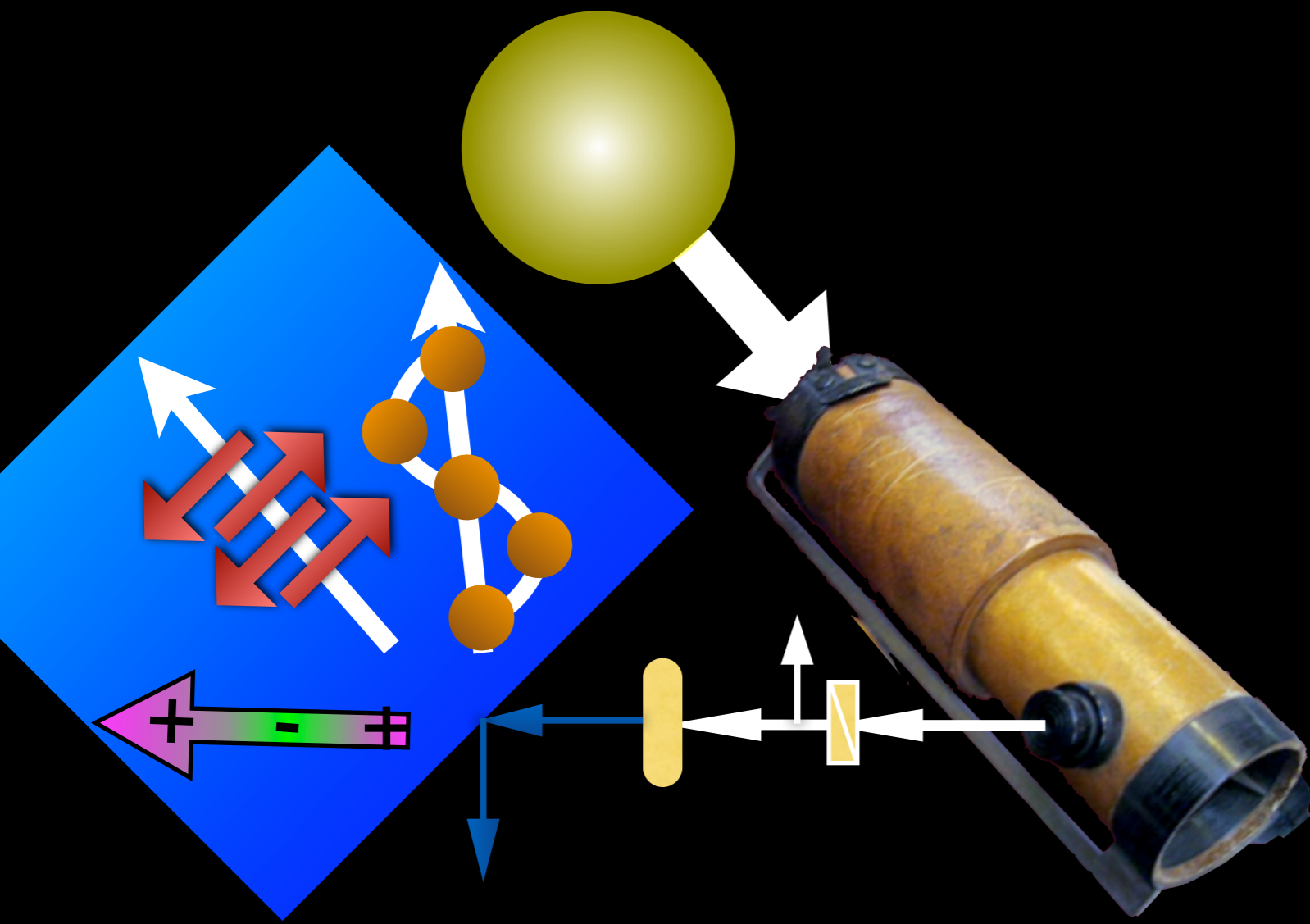


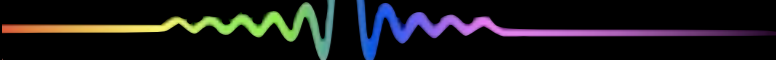
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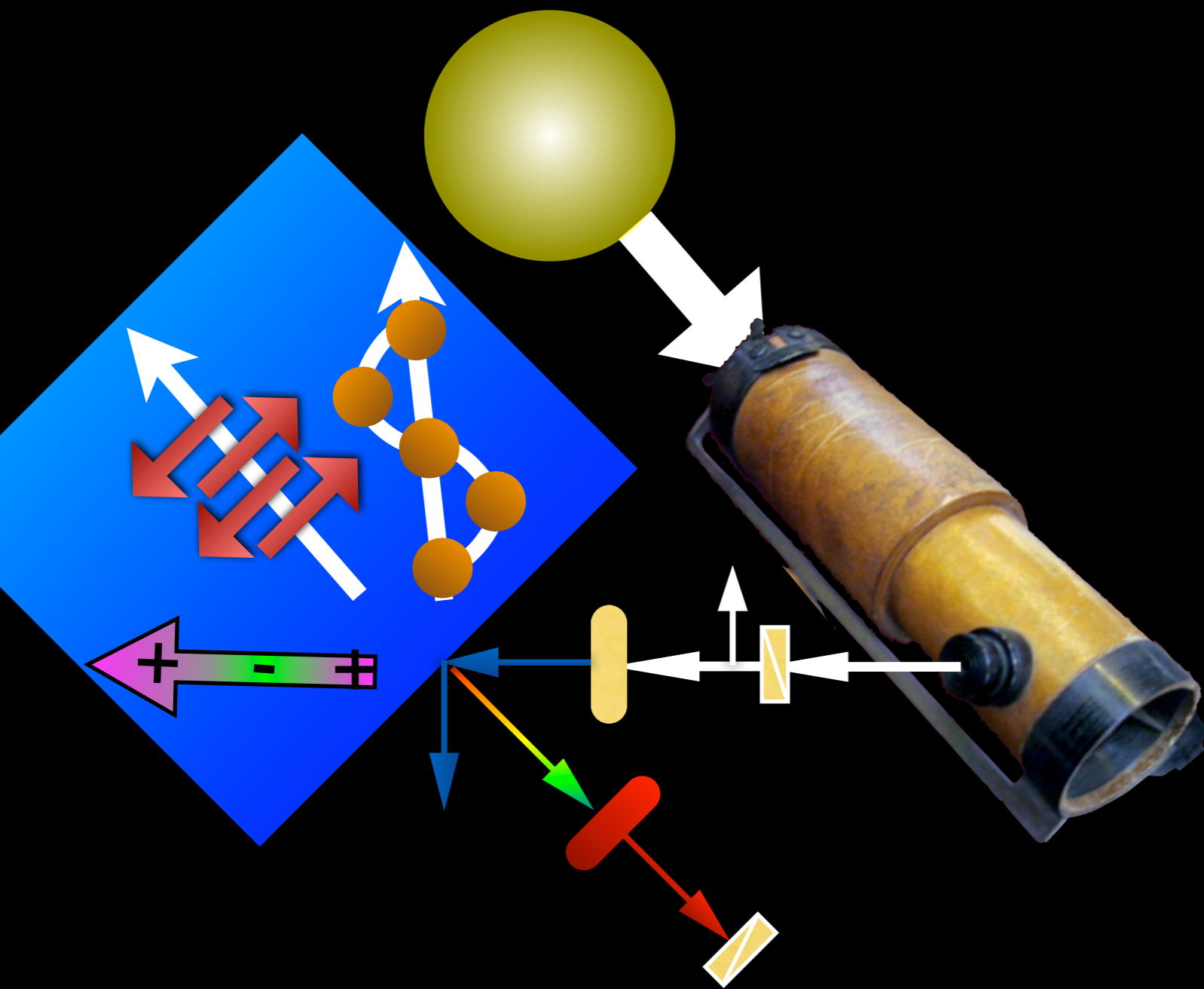


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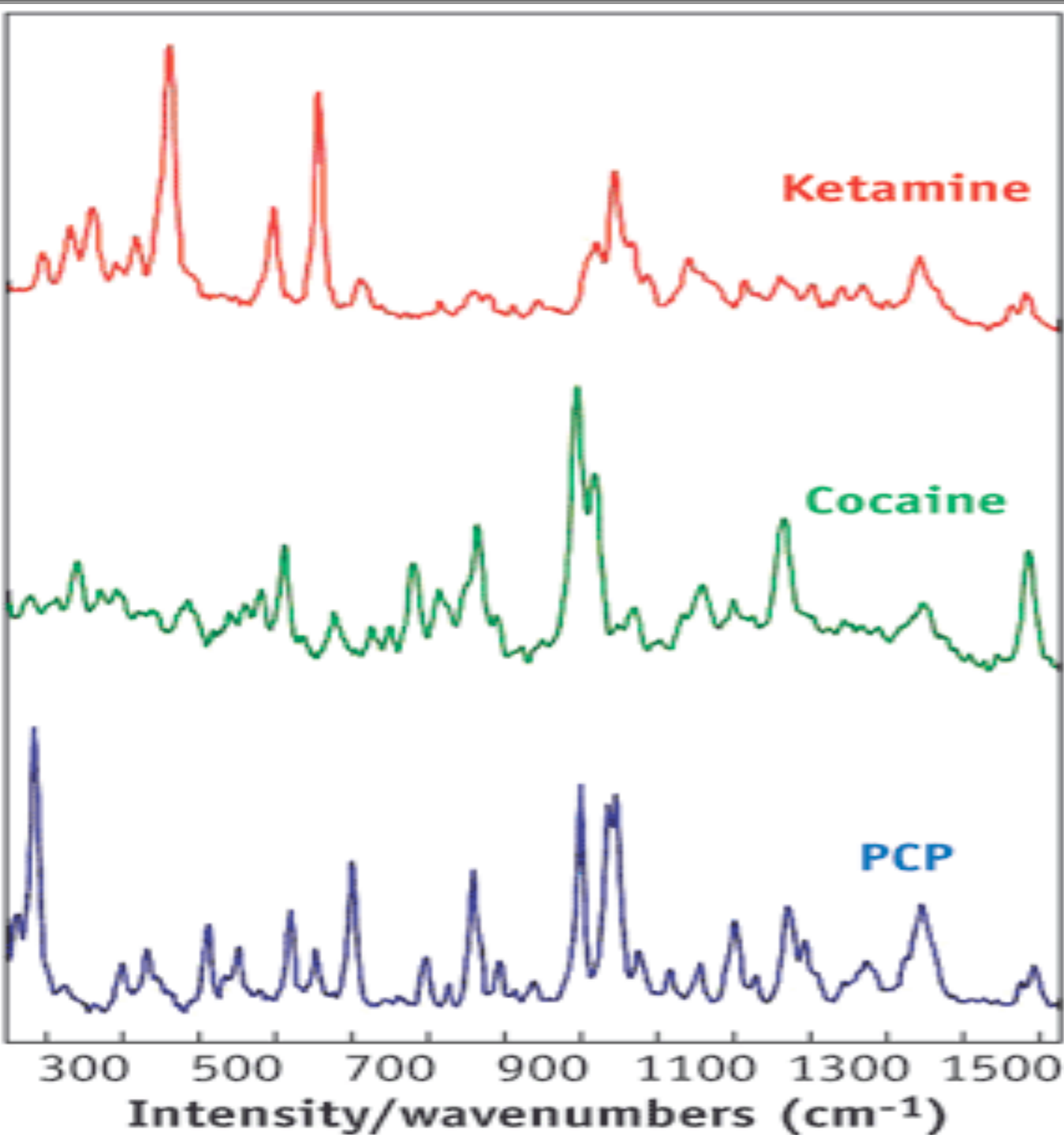


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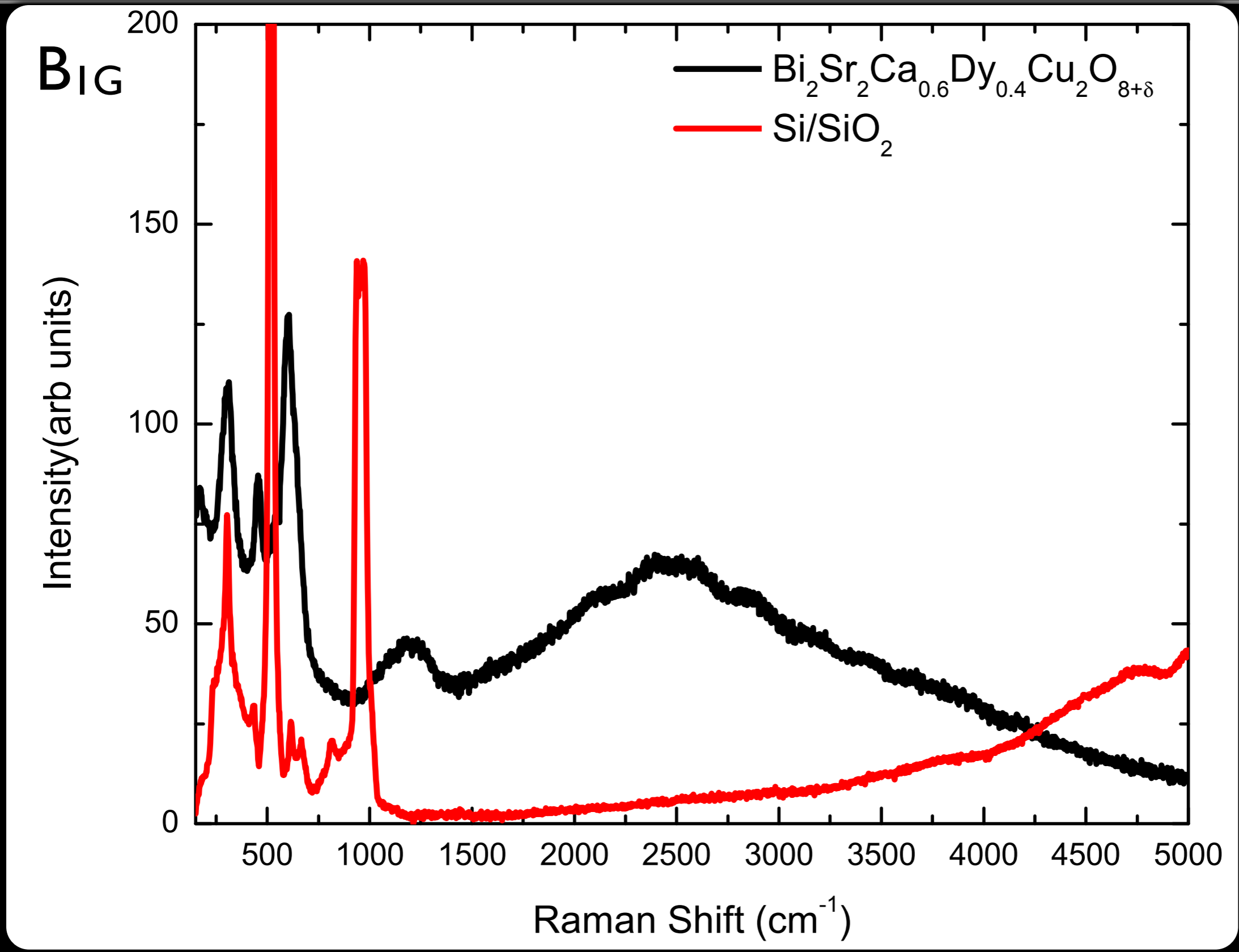




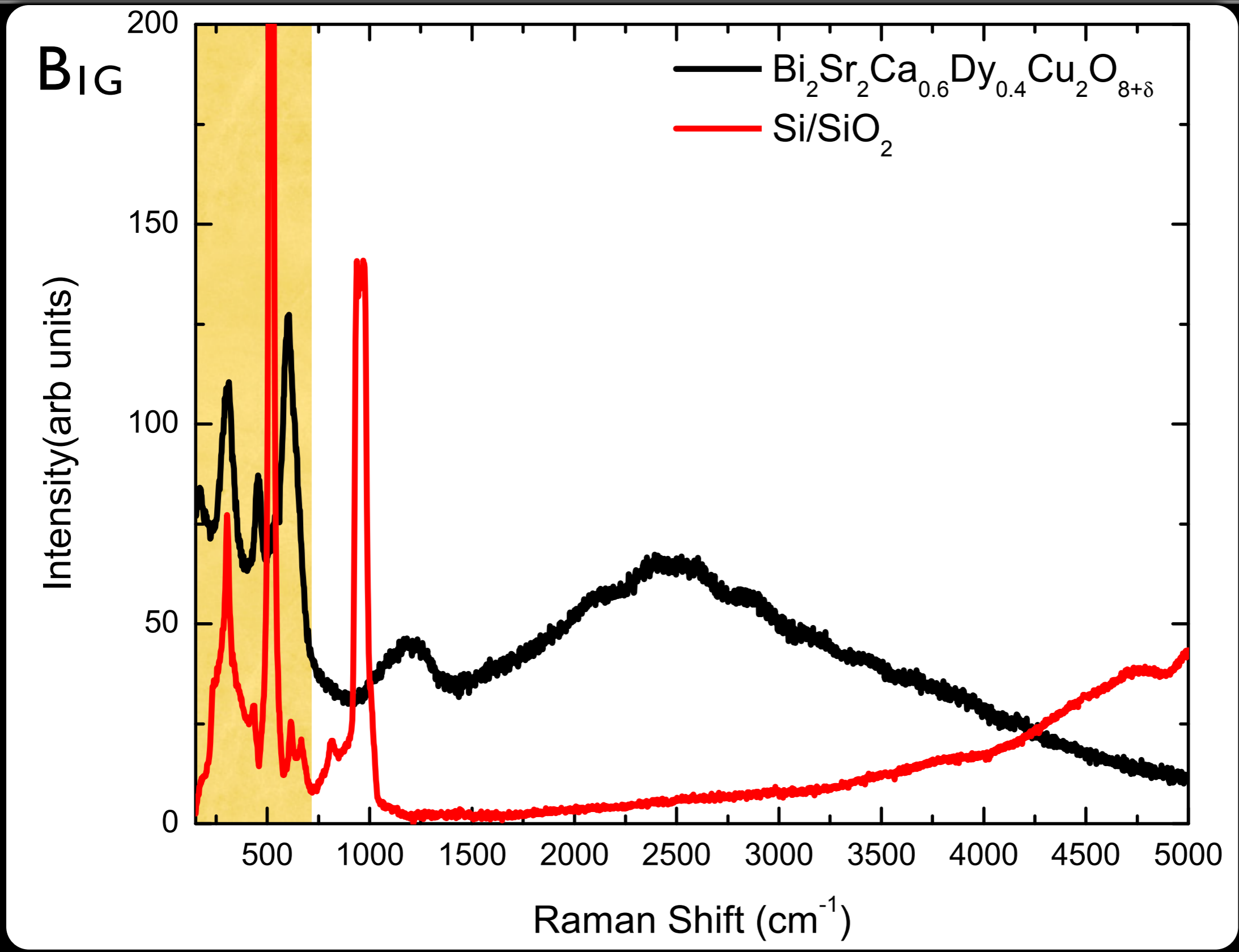
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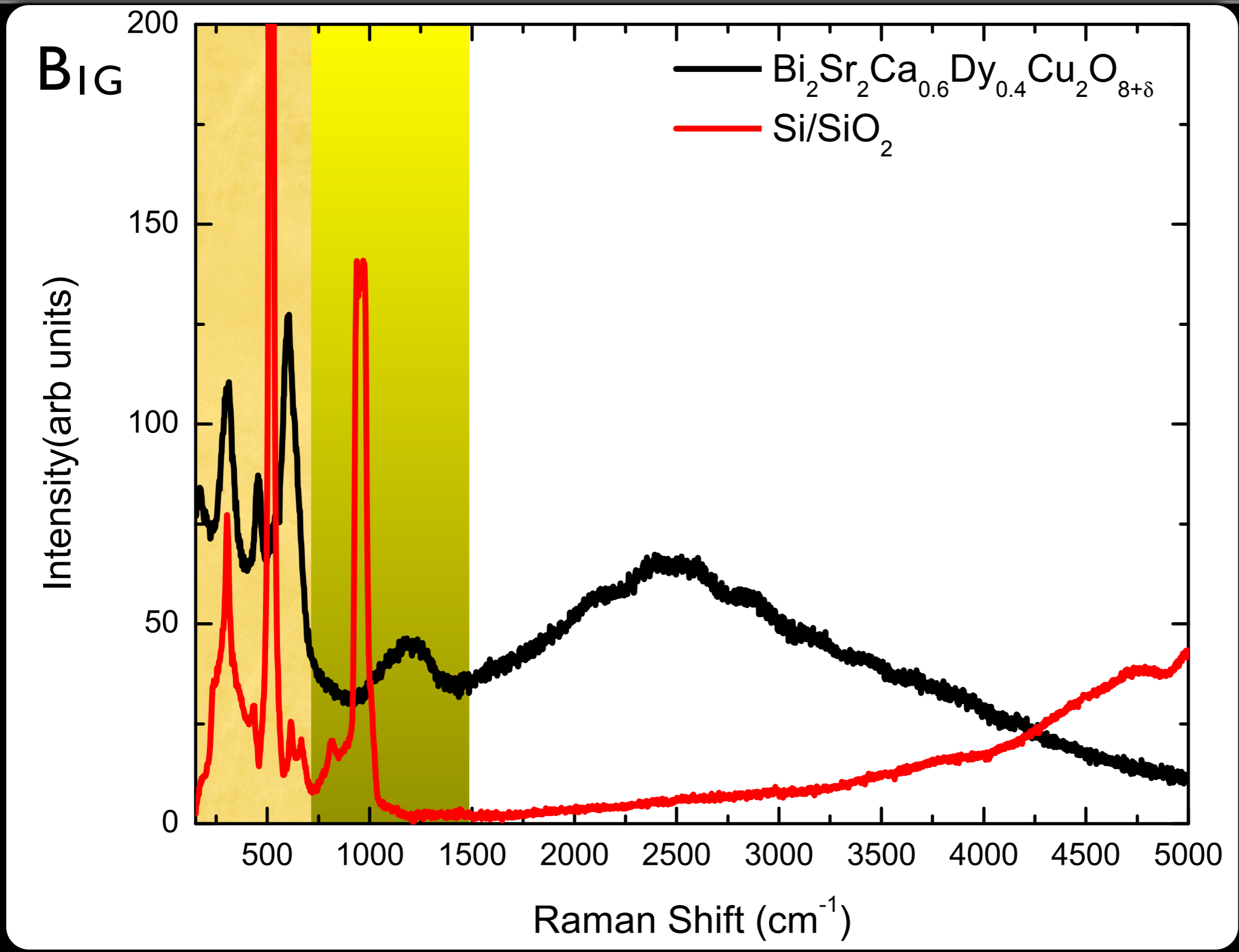
Raman Scattering



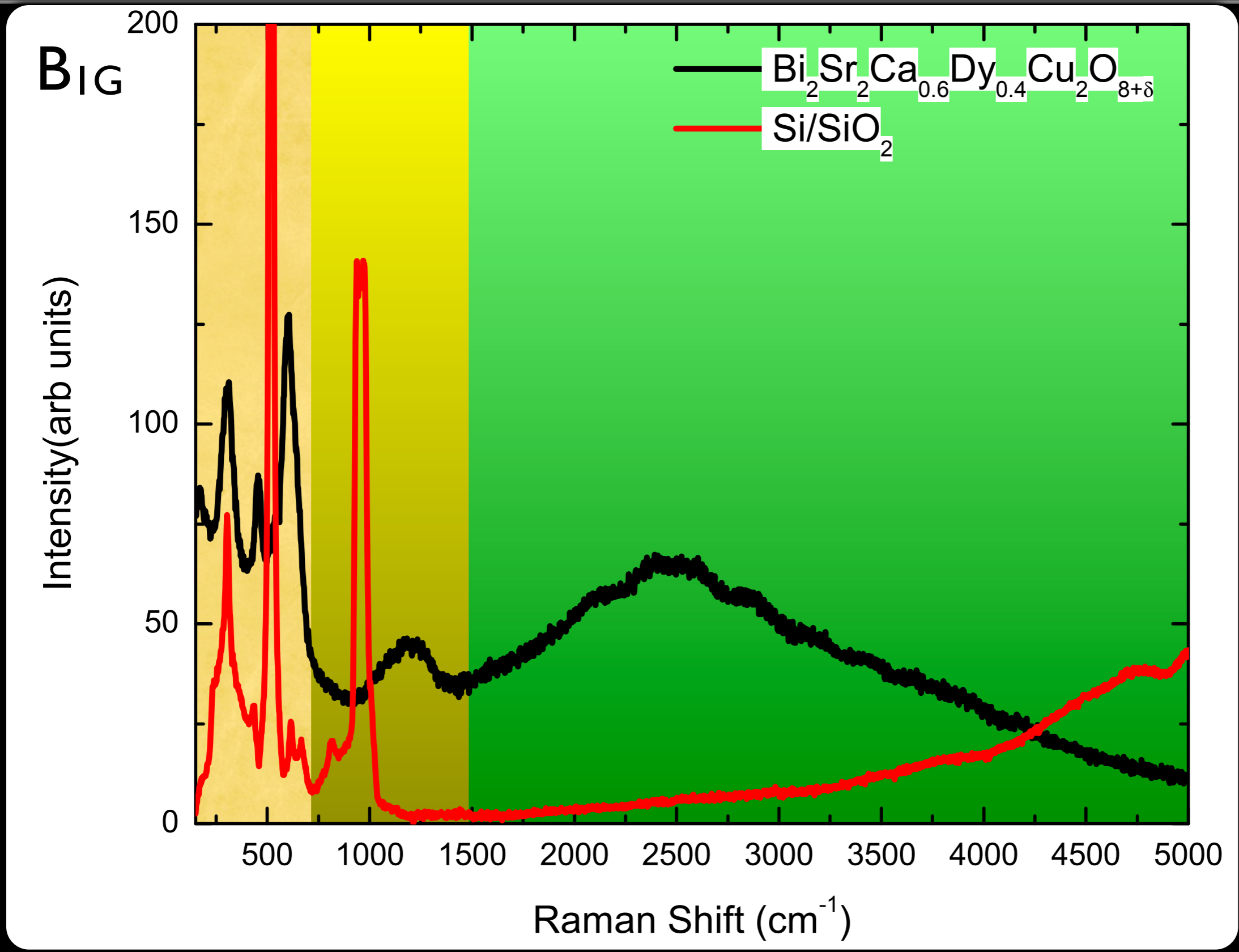
Raman Scattering



Raman Scattering



Raman Scattering





Two Magnon

Review:

T.P. Devereaux and R. Hackl RMP 79, 175 (2007)

W. Weber and R. Merlin *Raman Scattering in Materials Science* (2000)

Experiment:

S. Sugai et. al, Phys. Rev. B 68, 184504 (2003)

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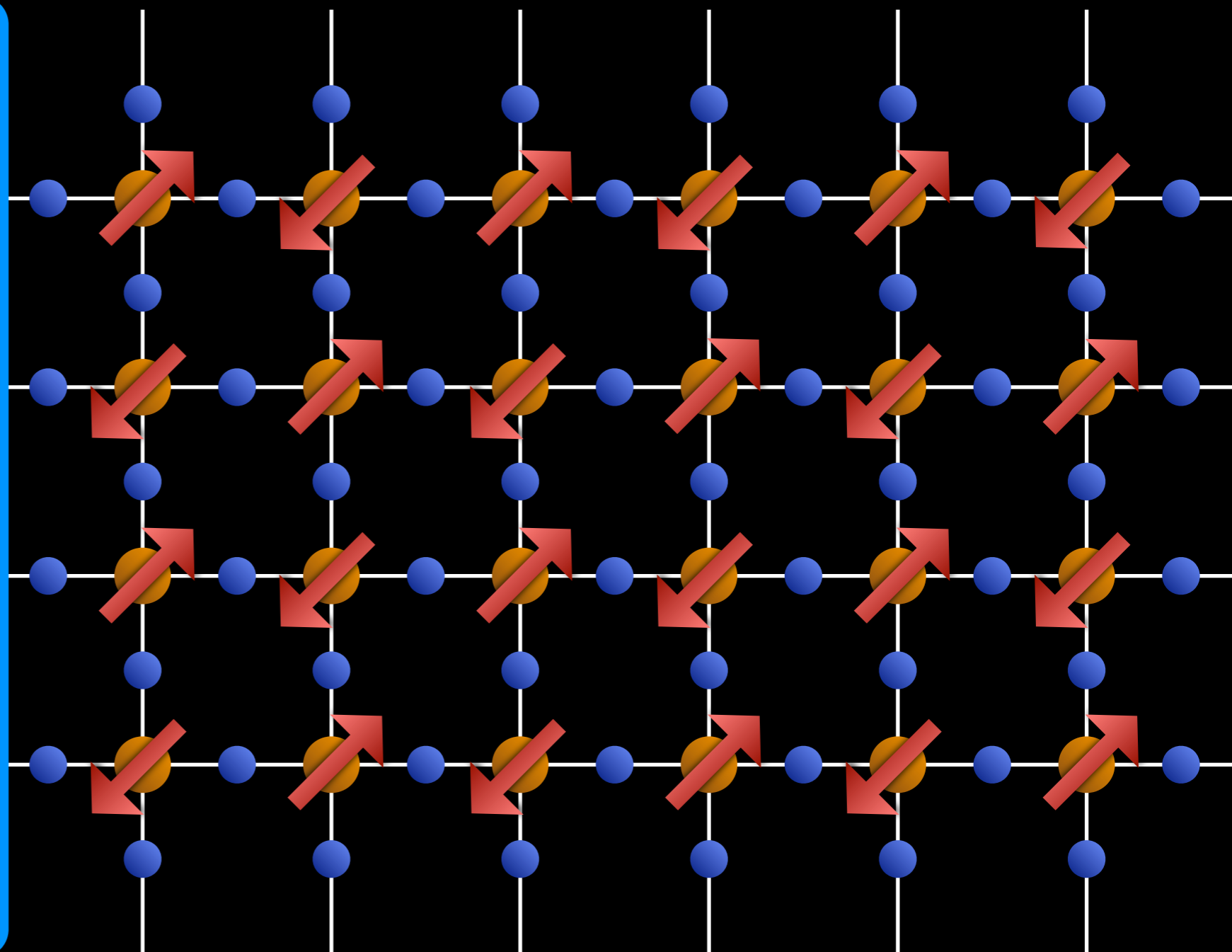
R.R.P. Singh et. al, PRL 62, 2736 (1989)

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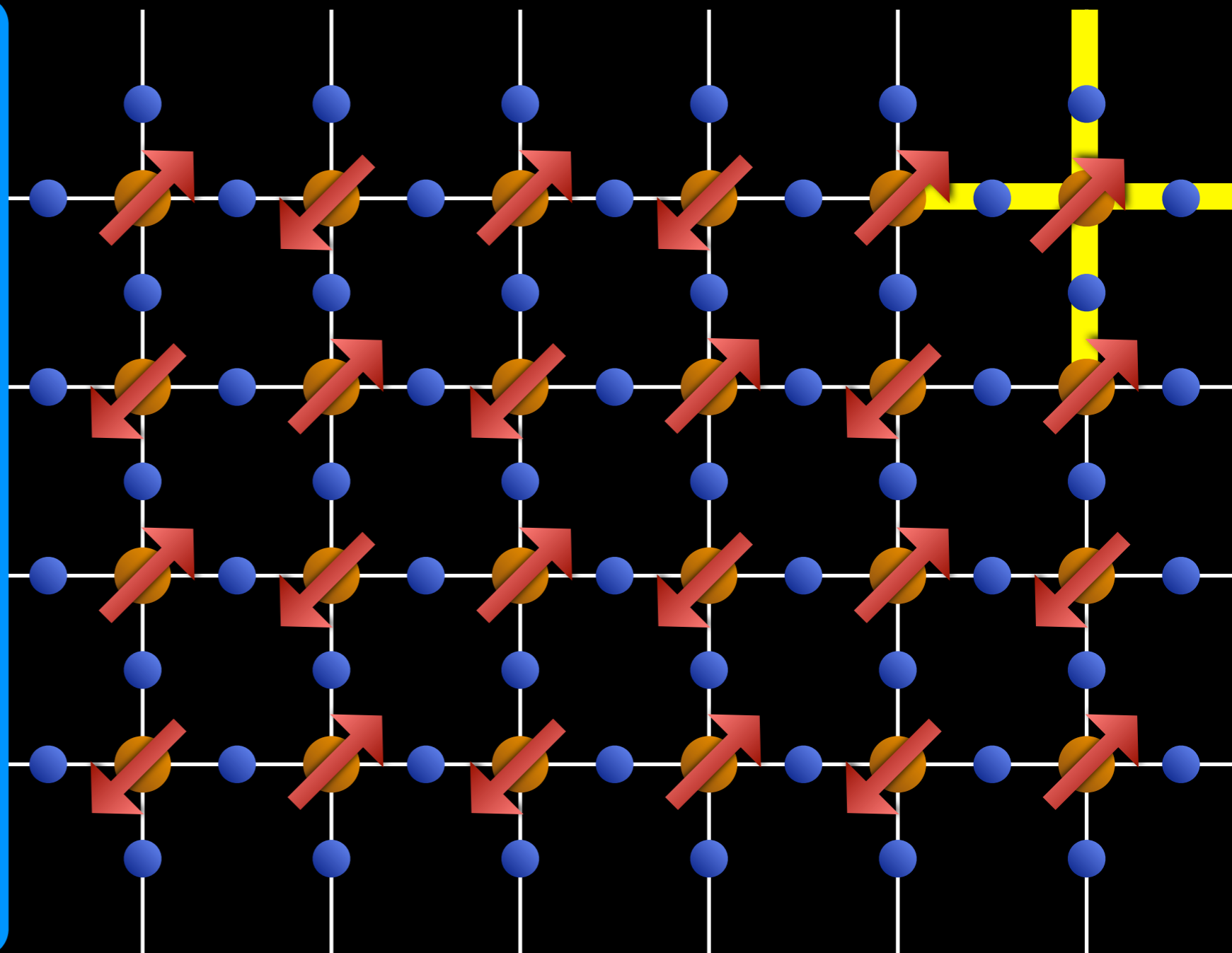
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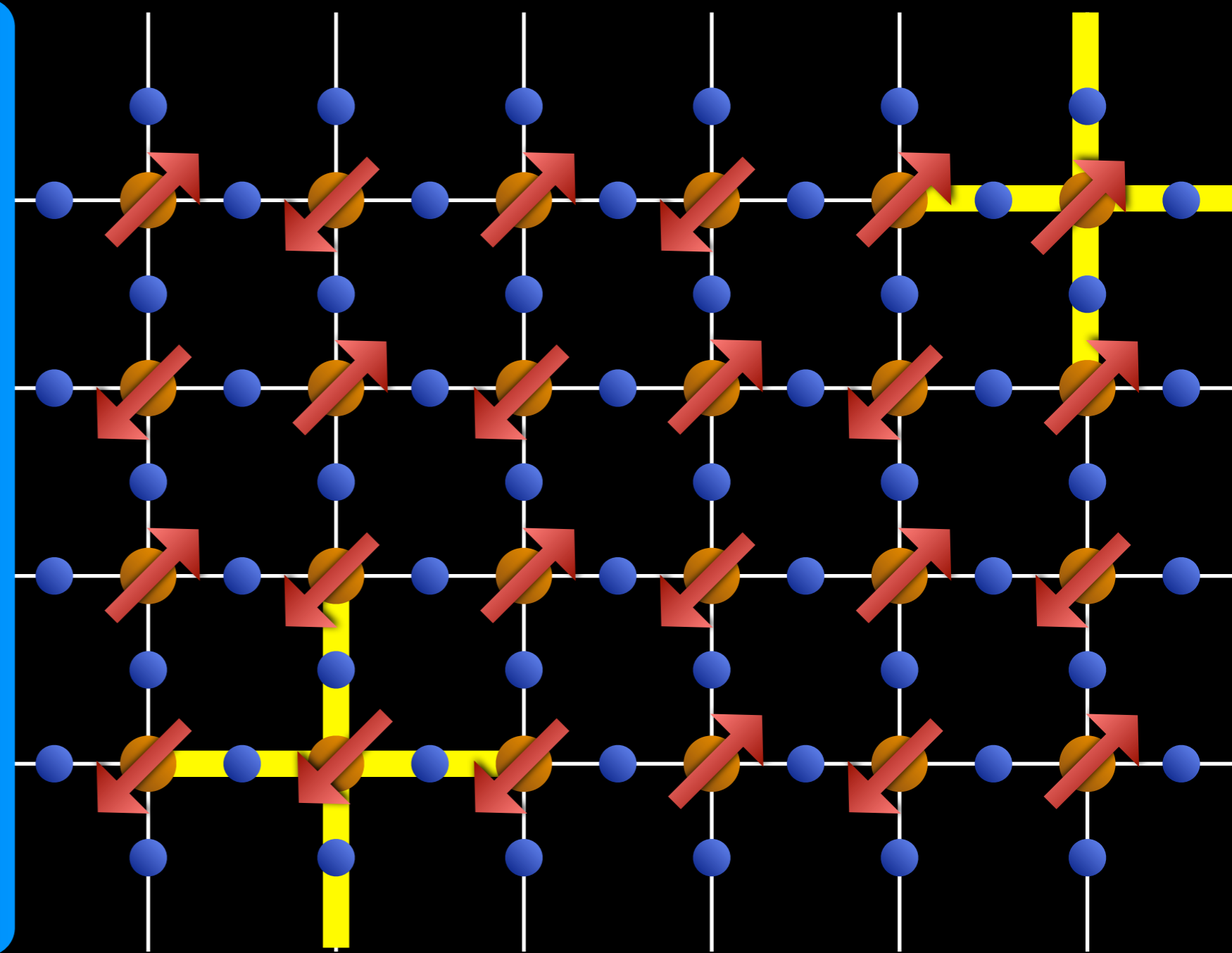
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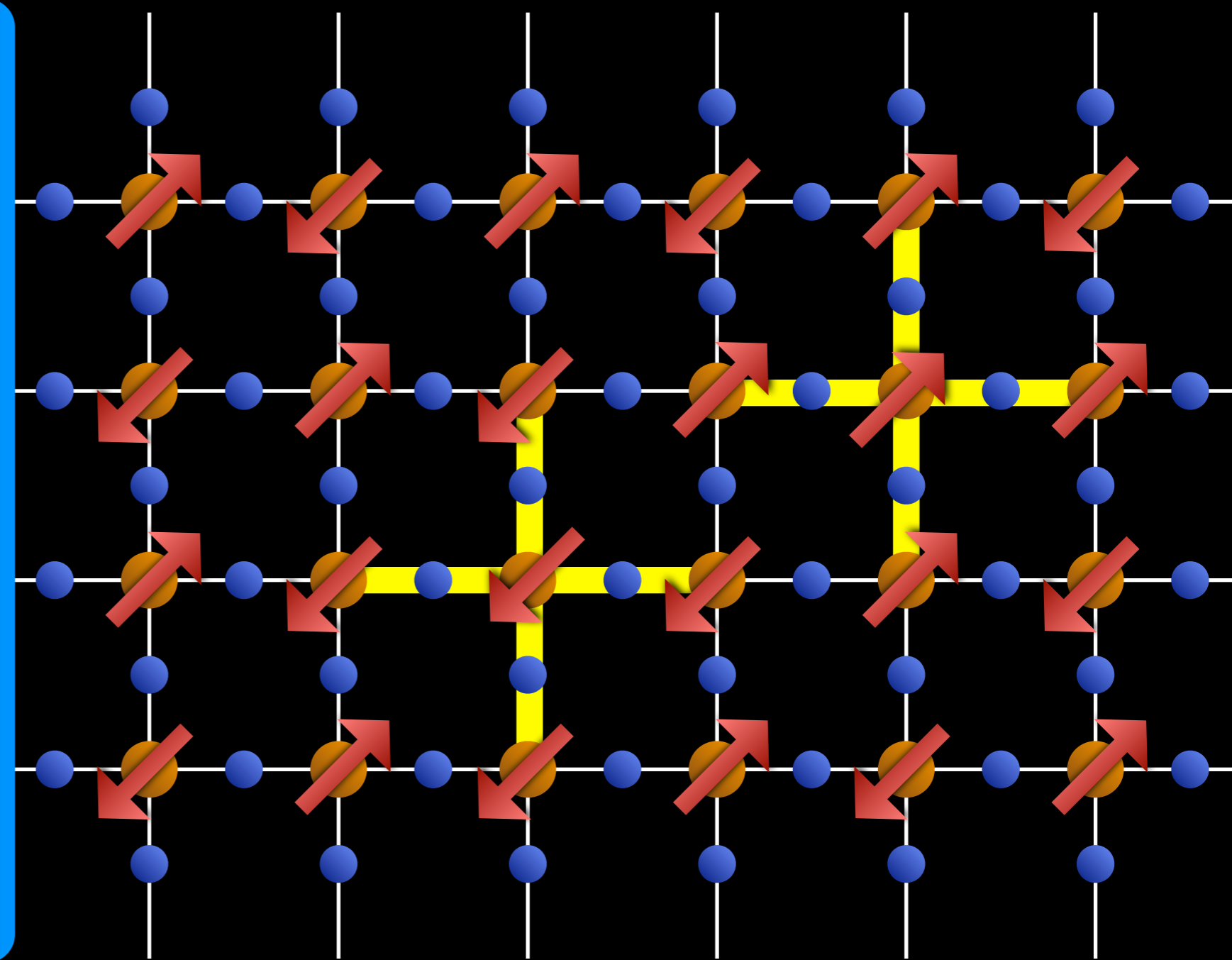
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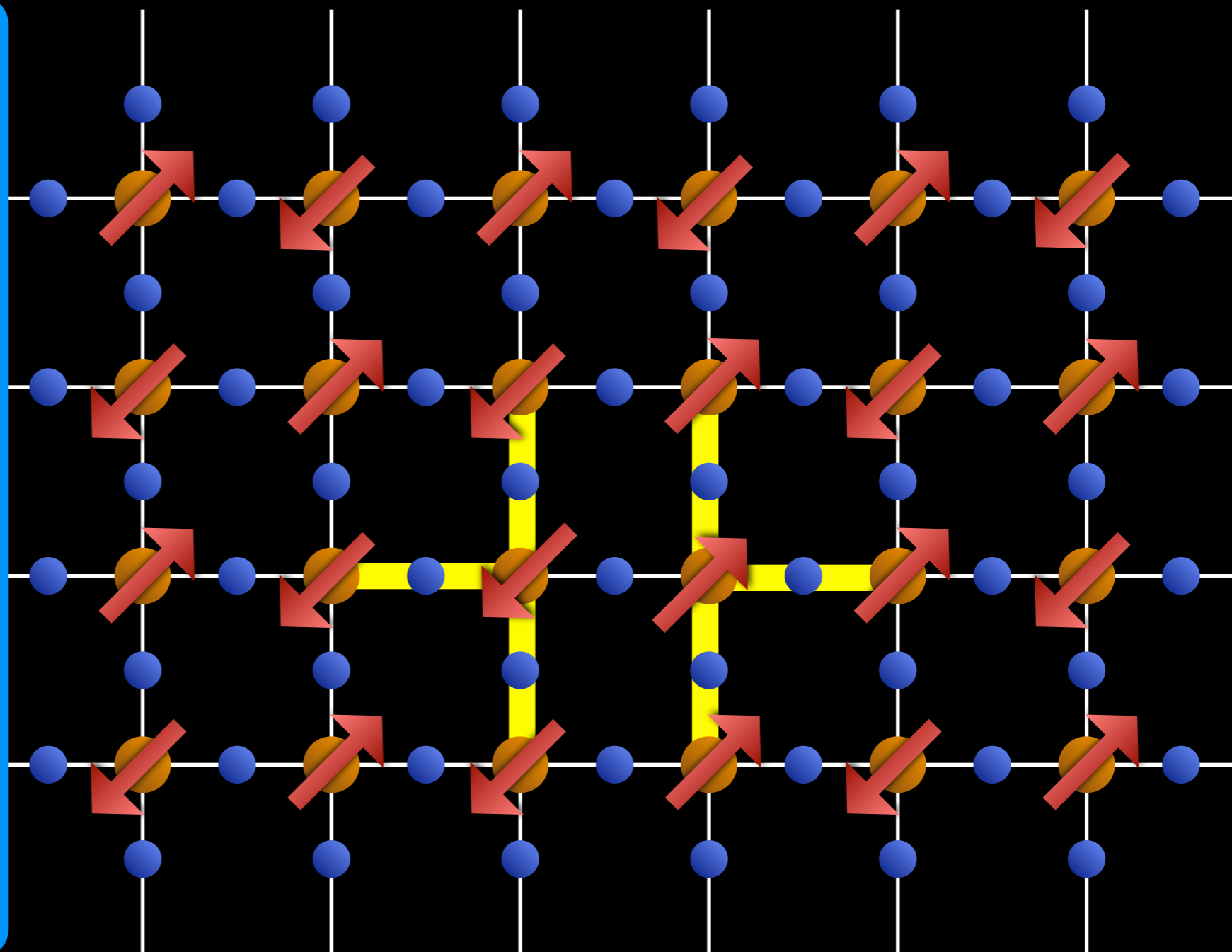
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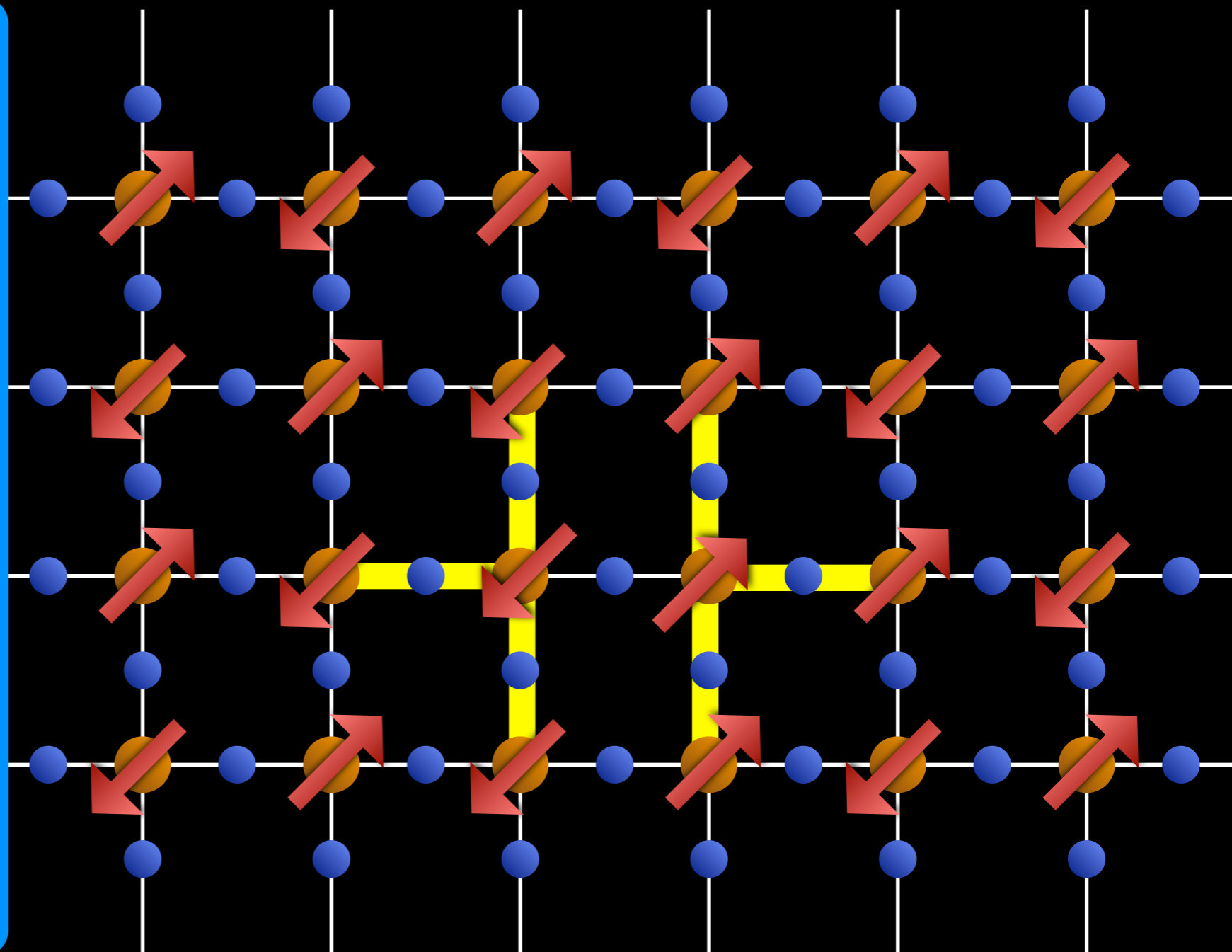
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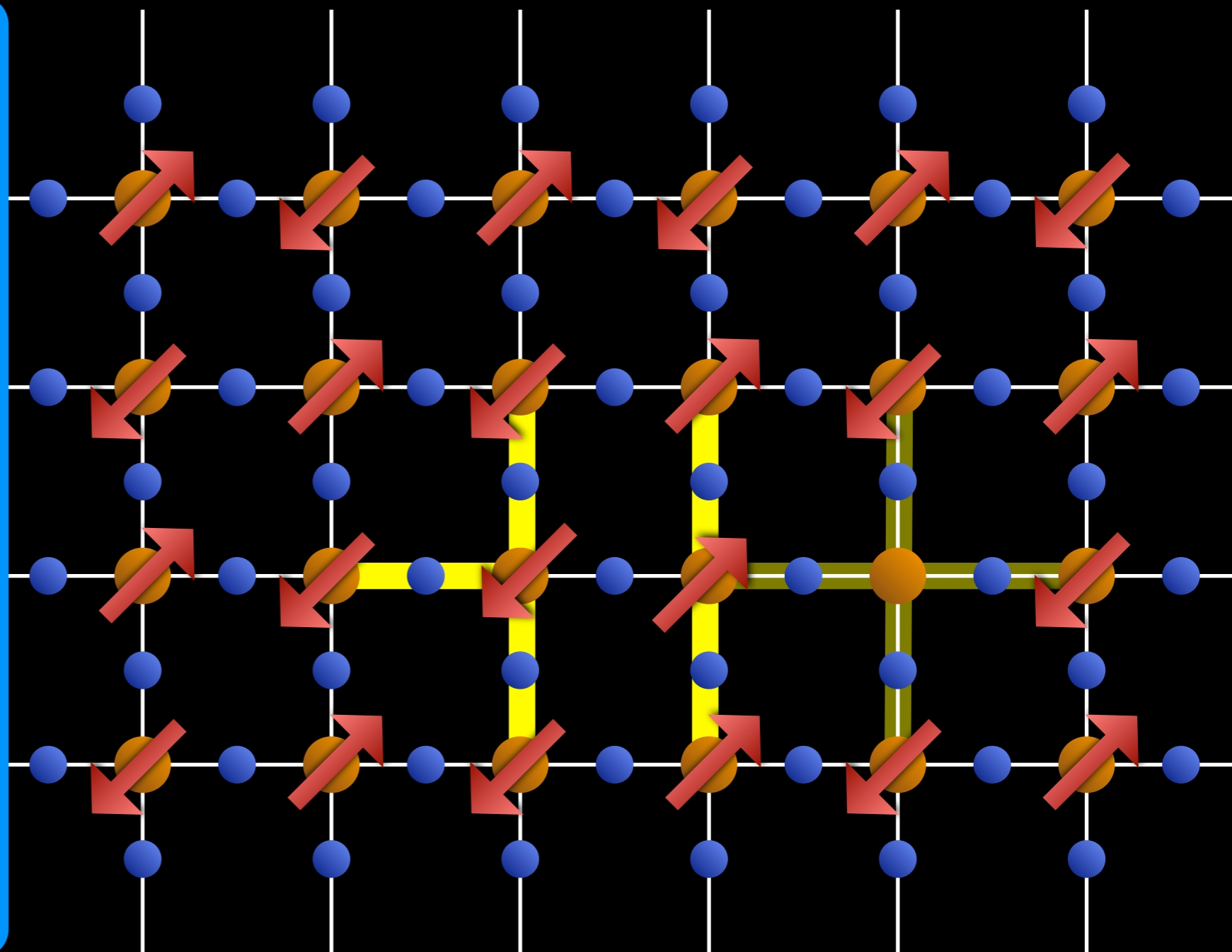
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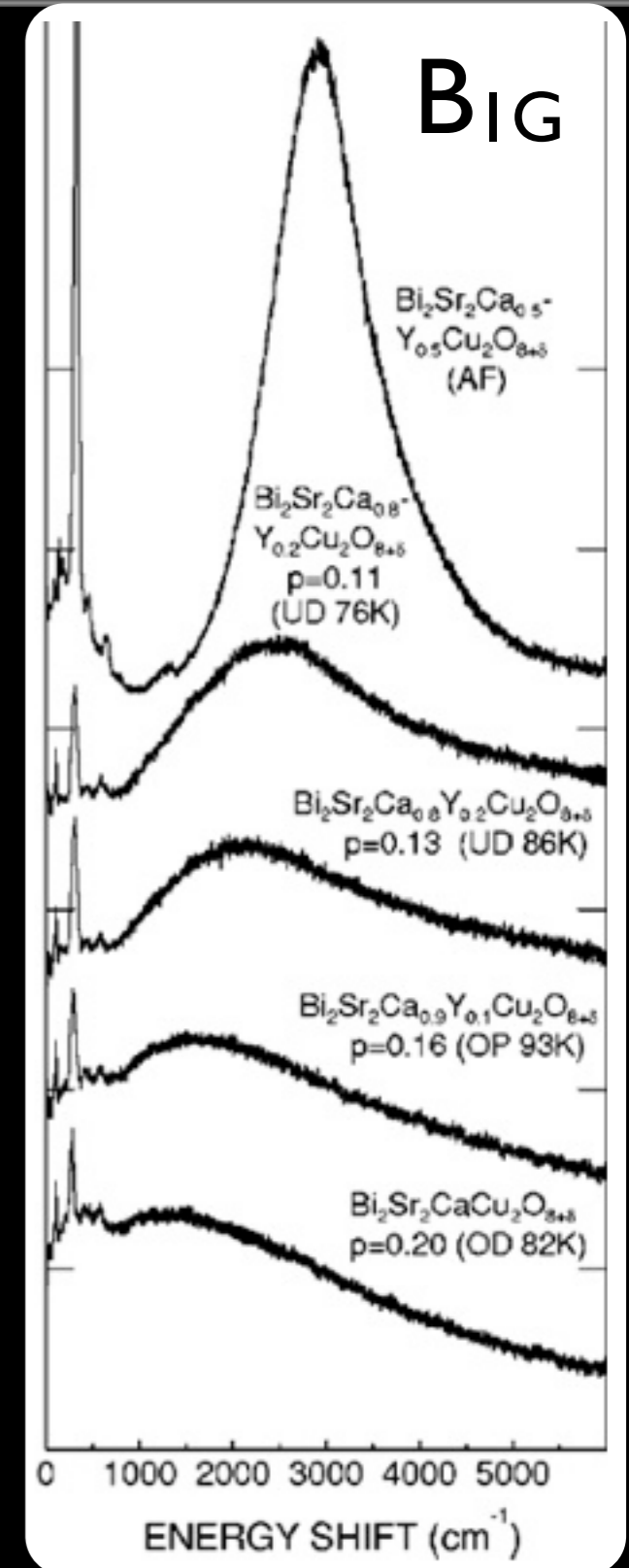
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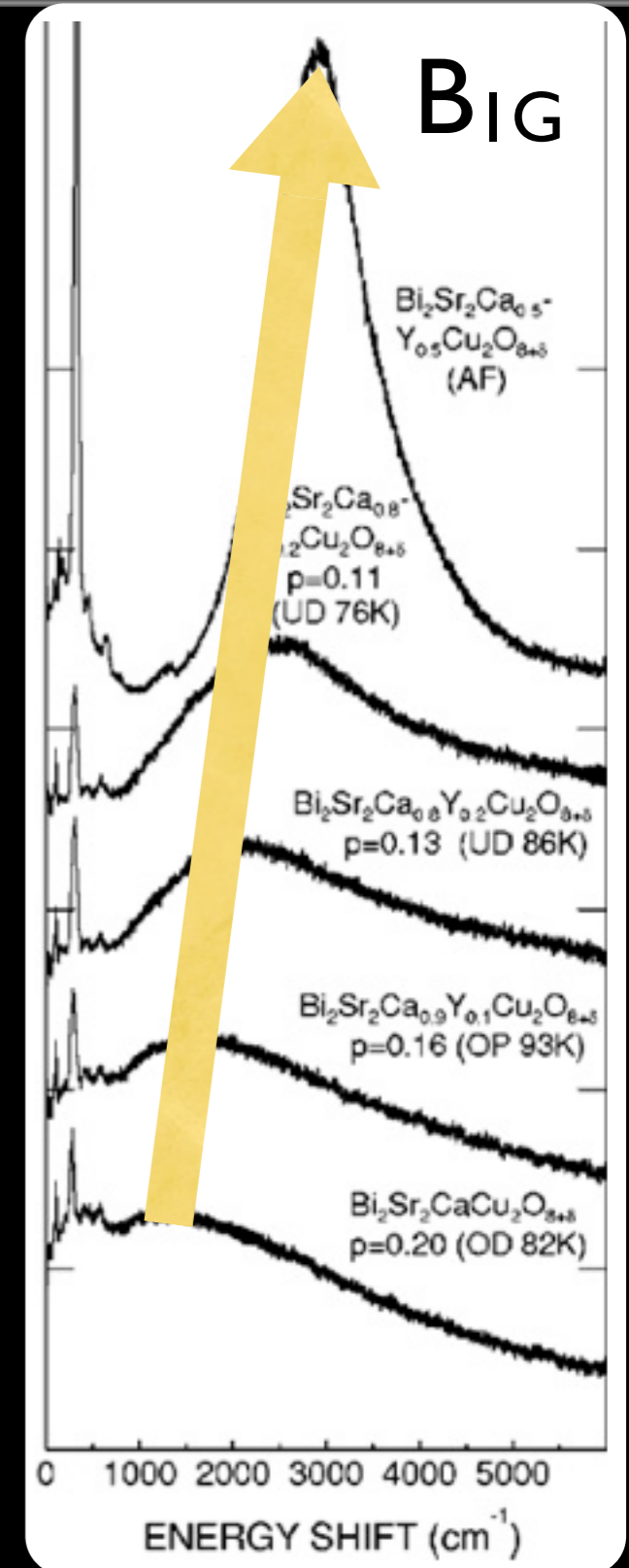
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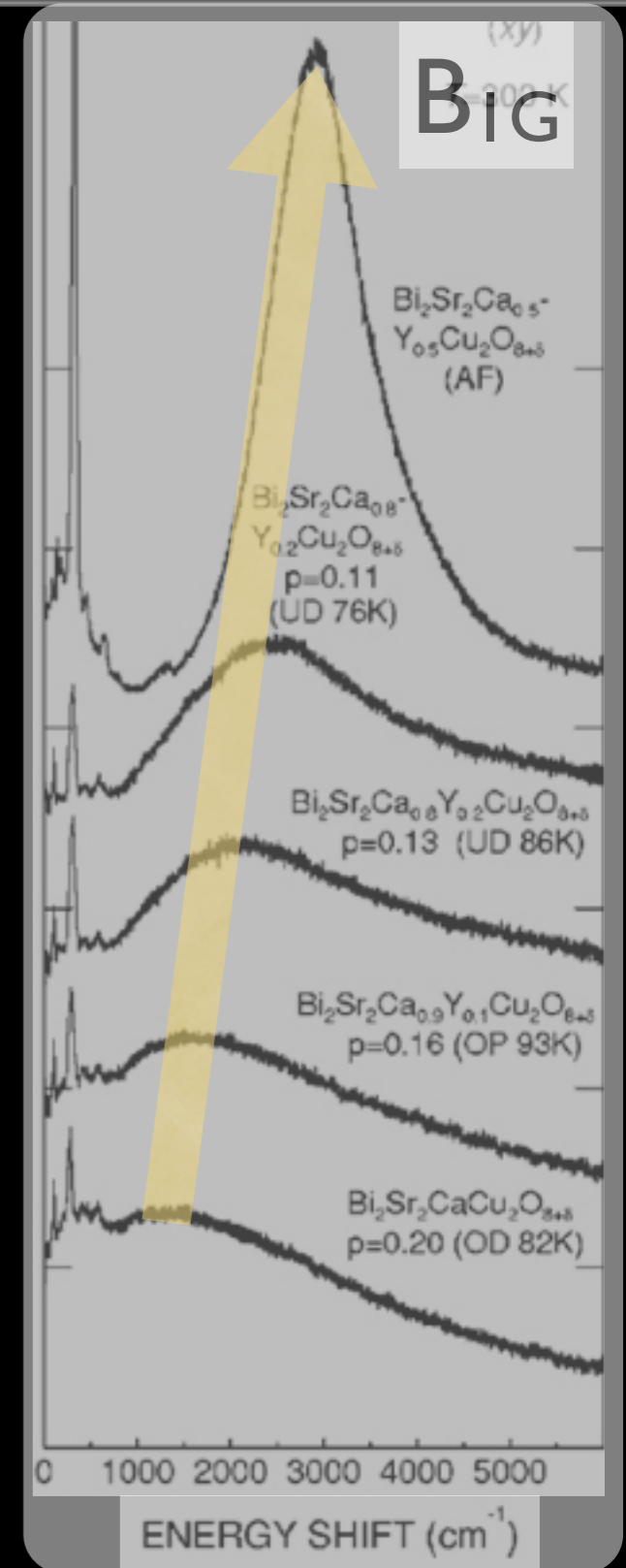
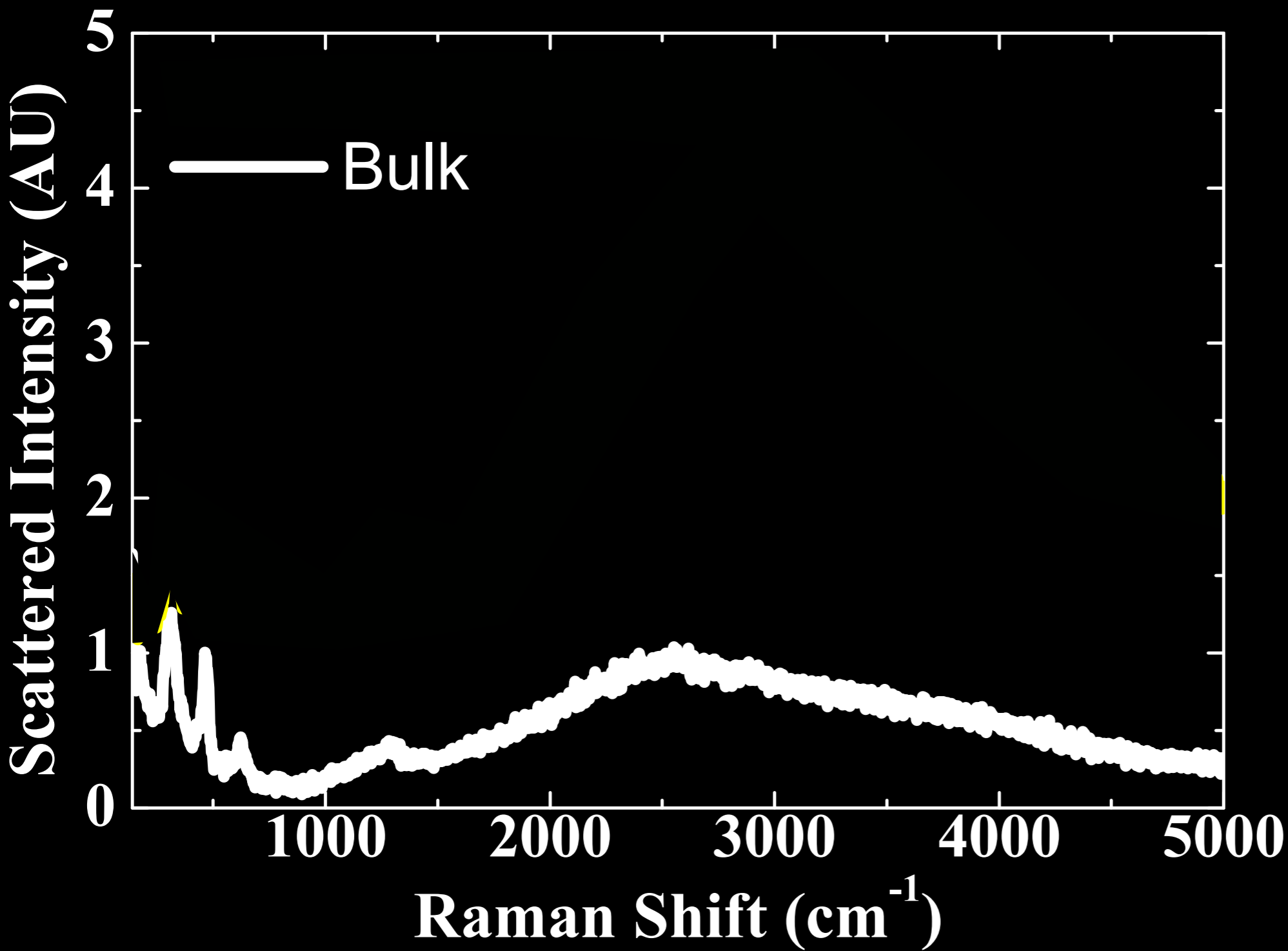


Two Magnon



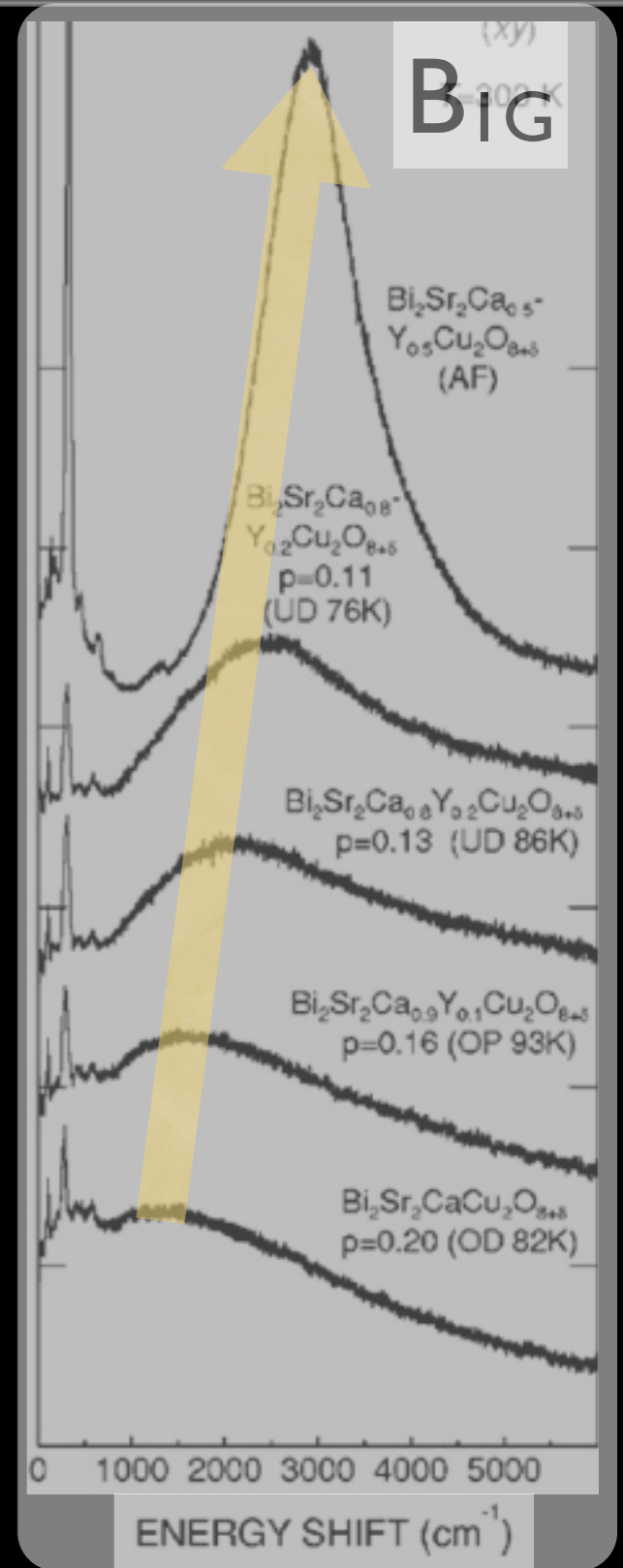
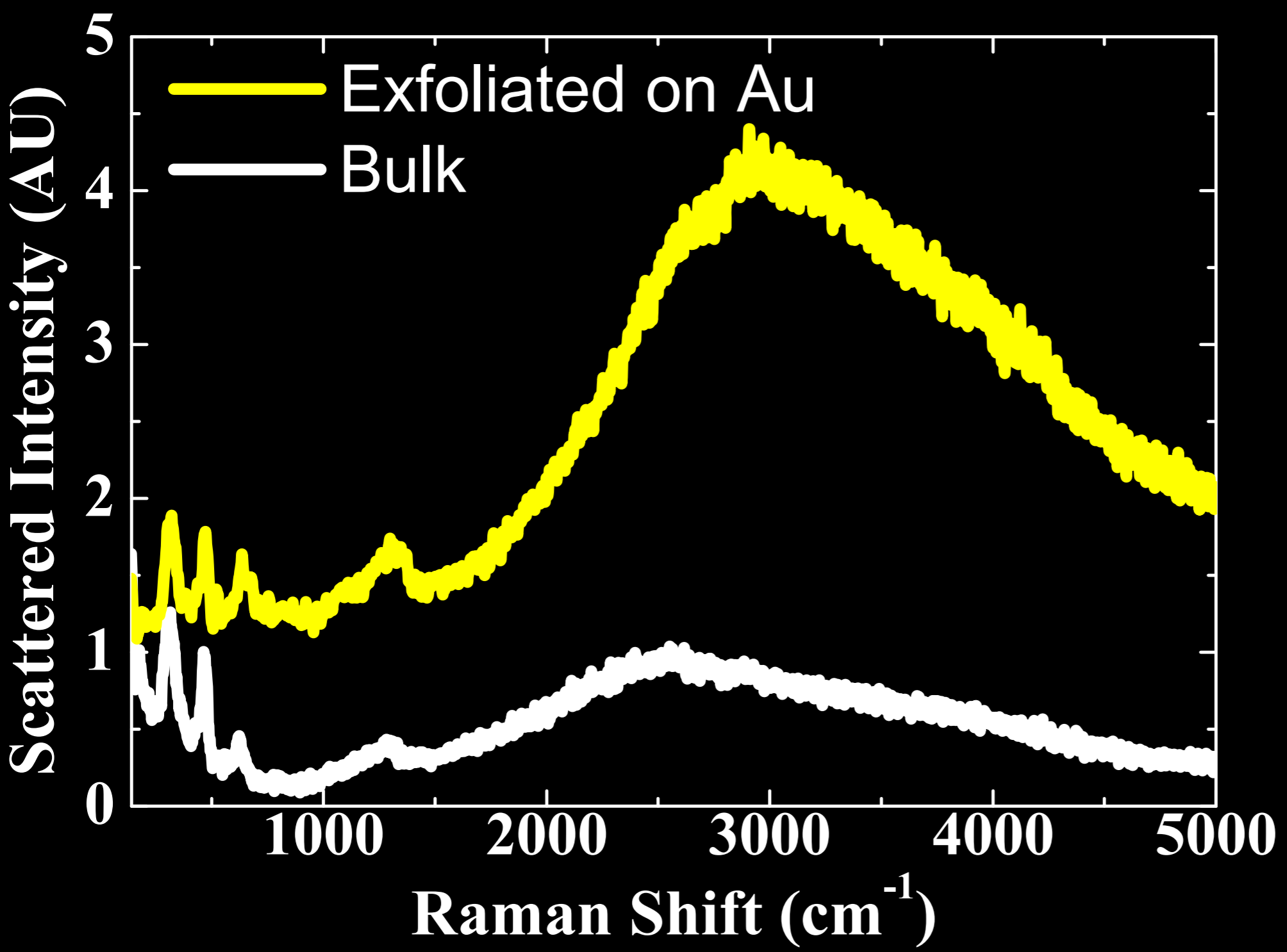
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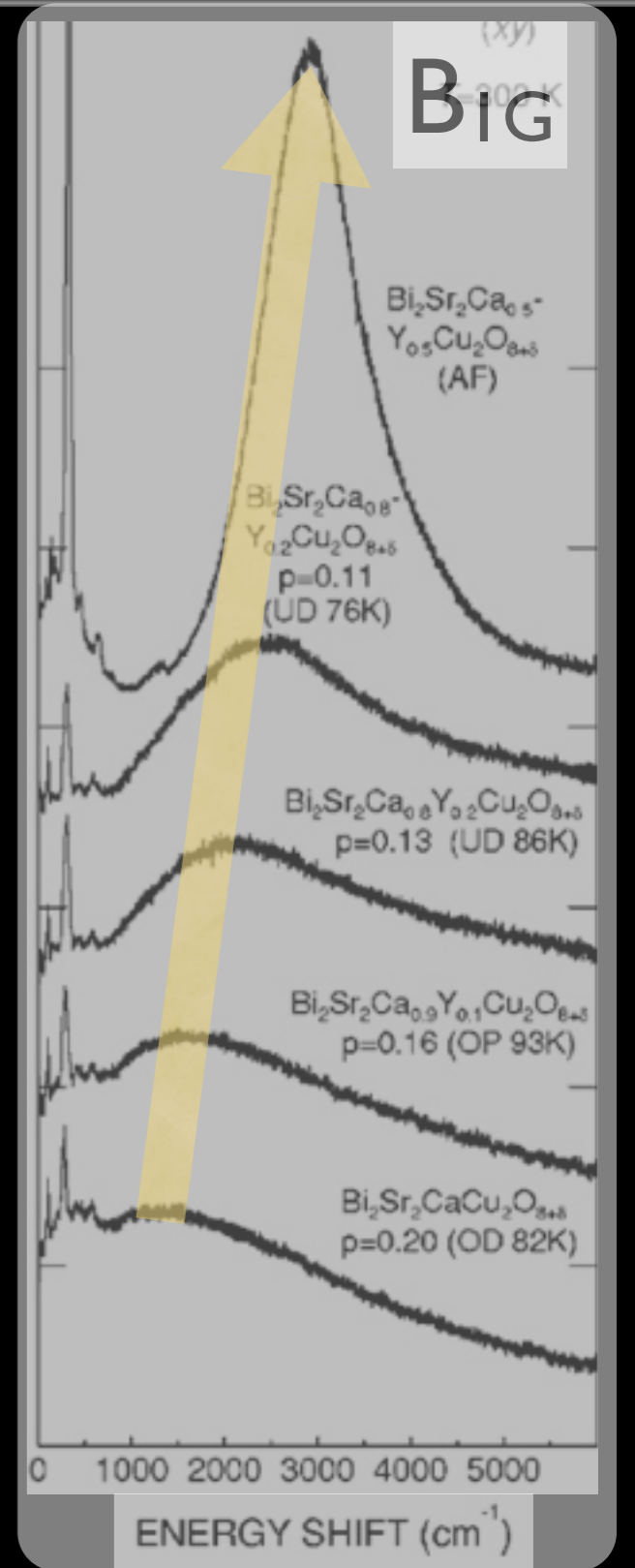
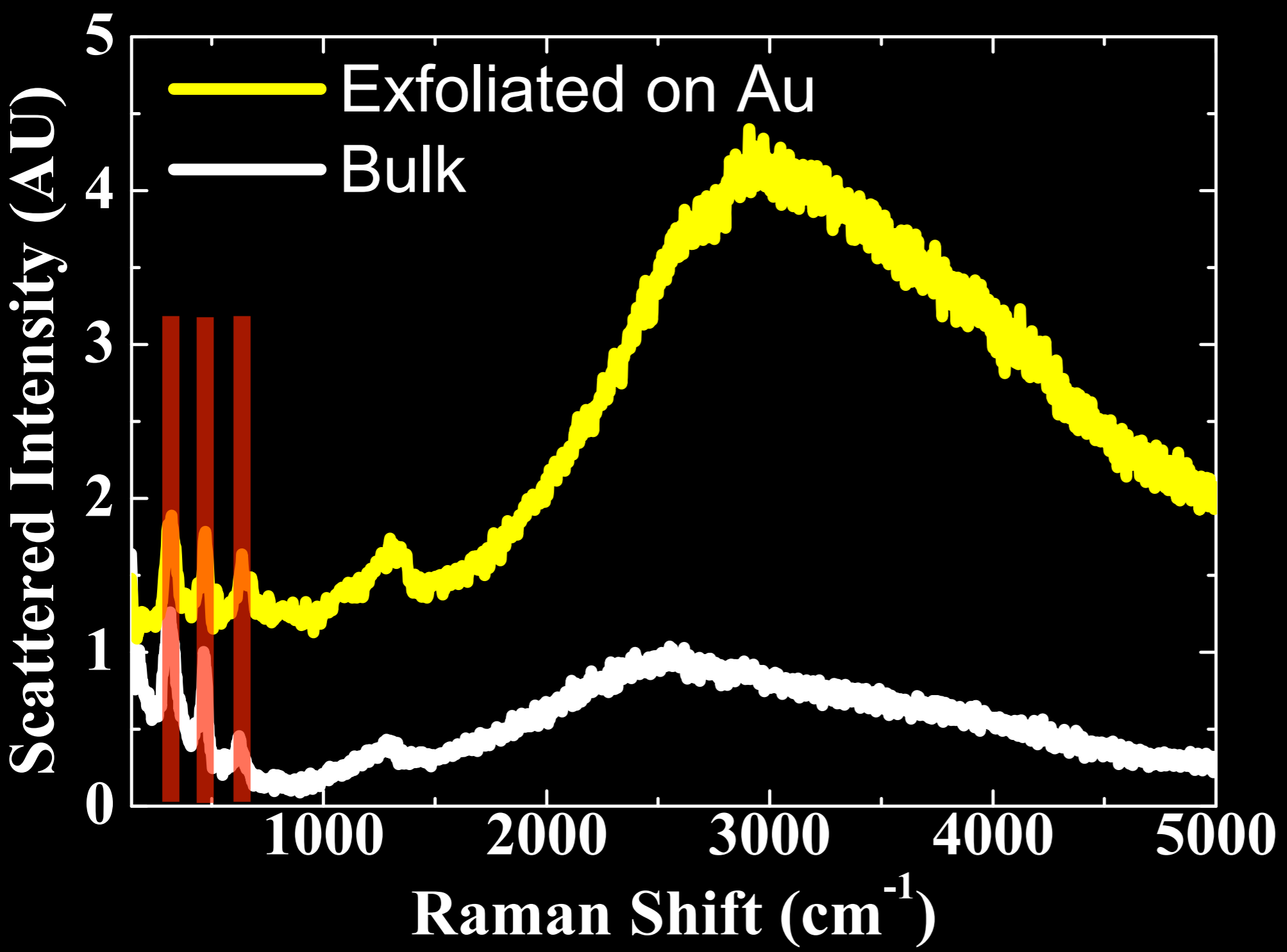
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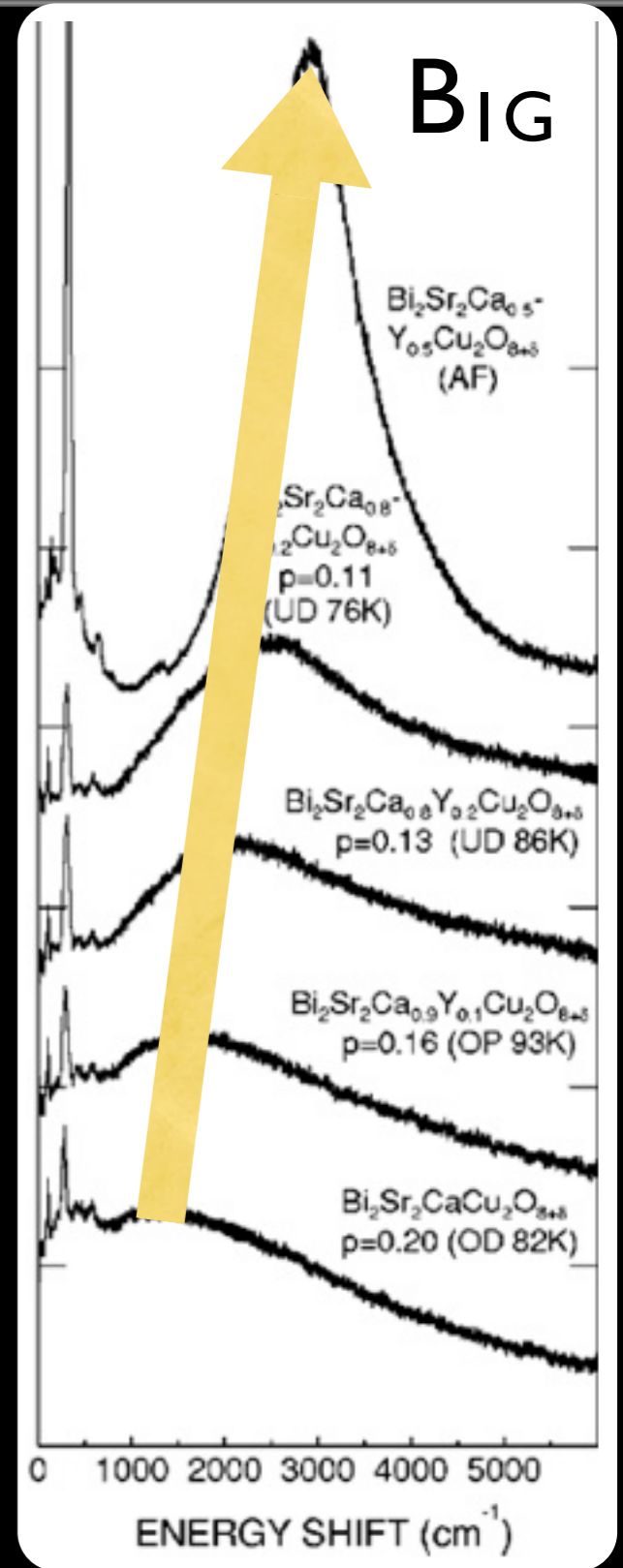
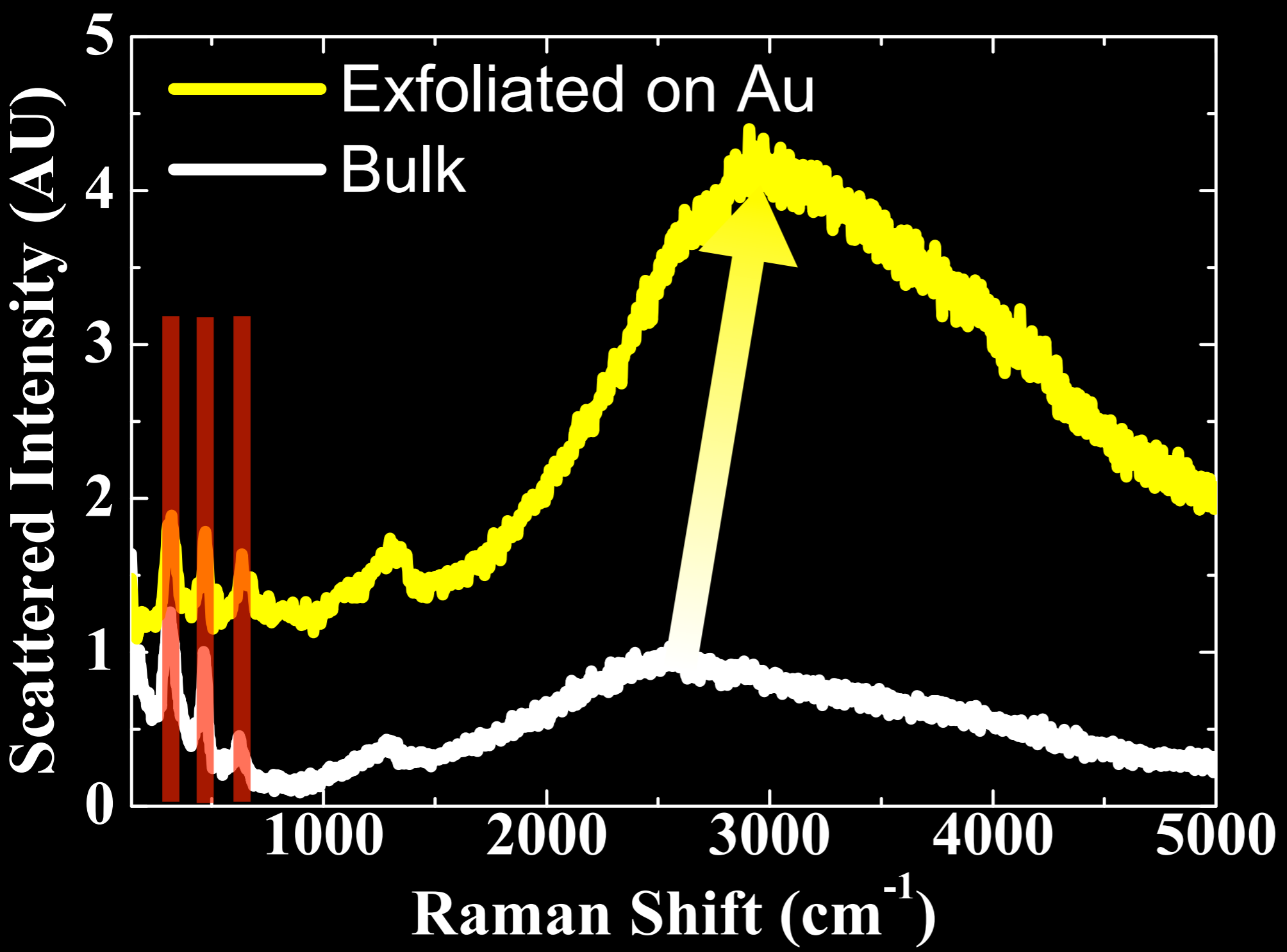
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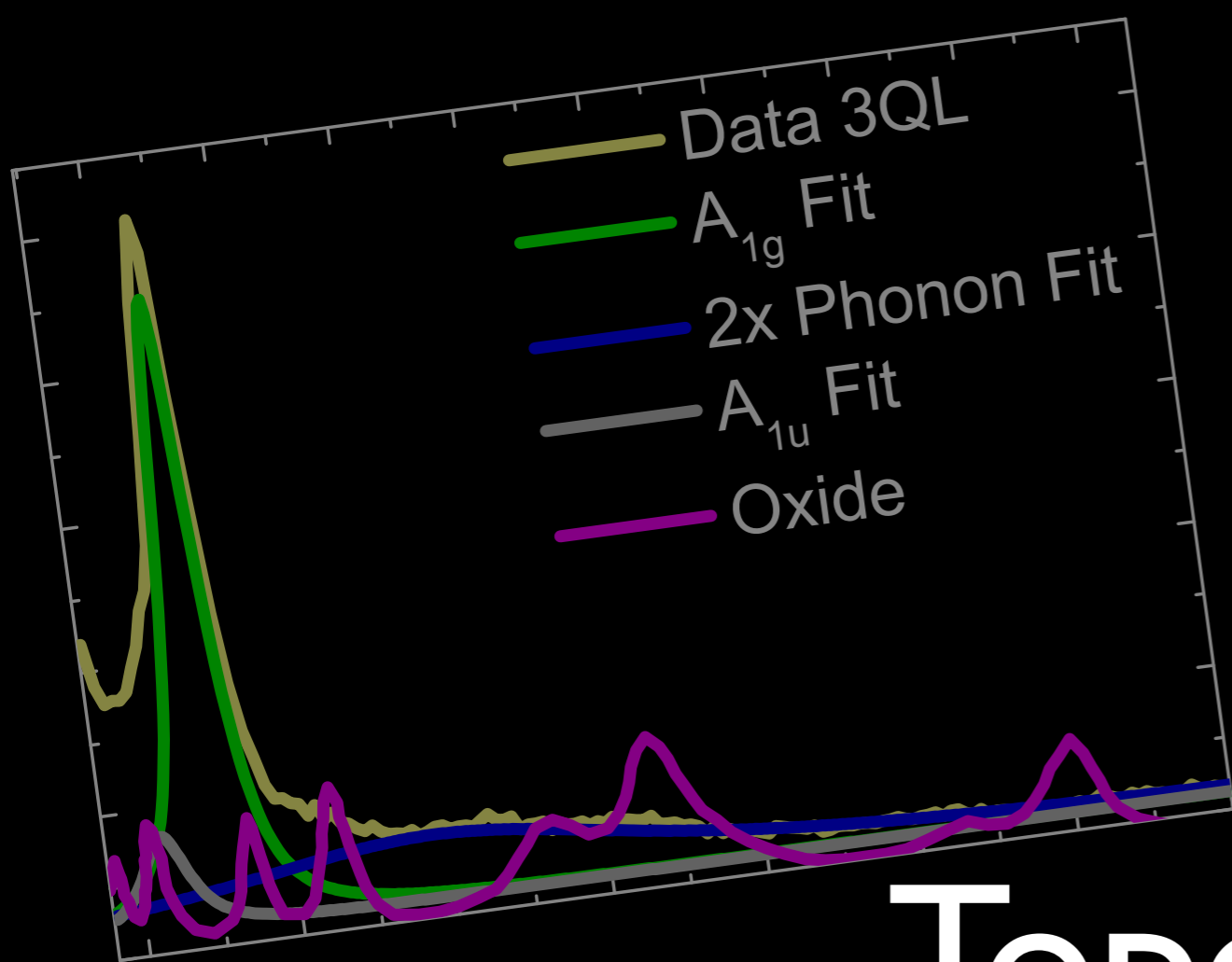


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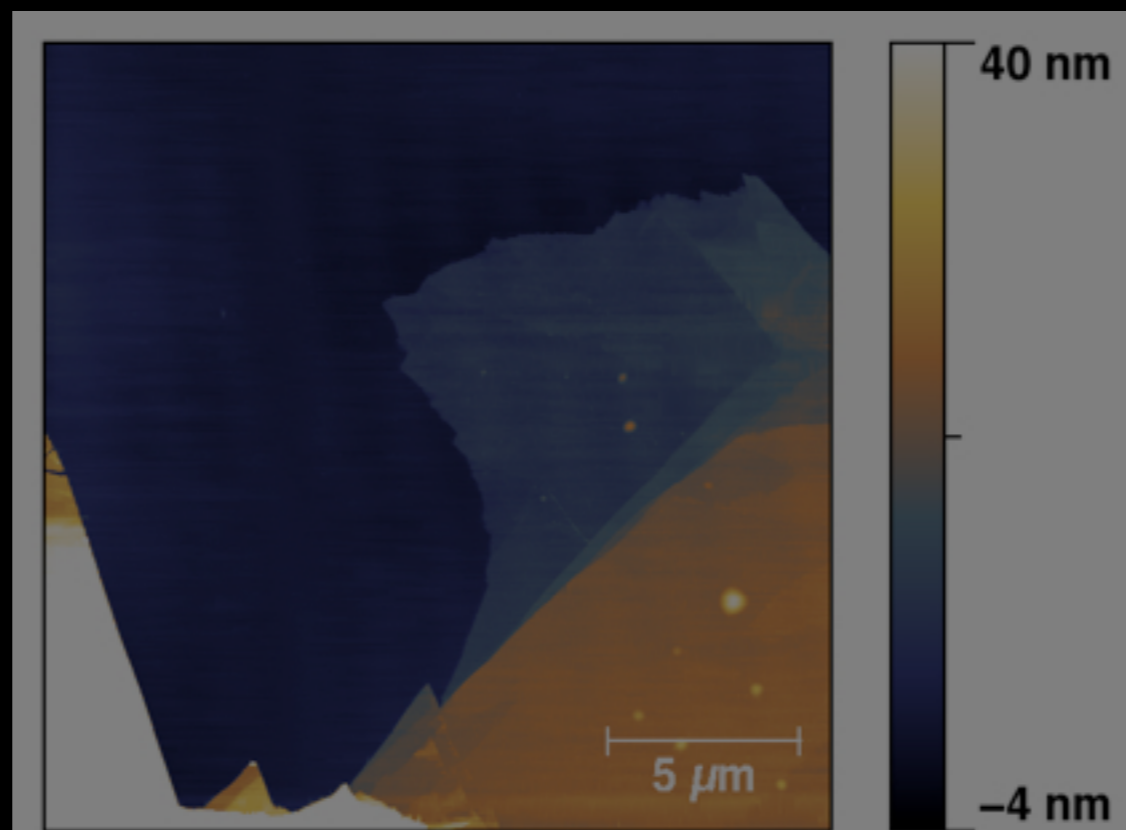
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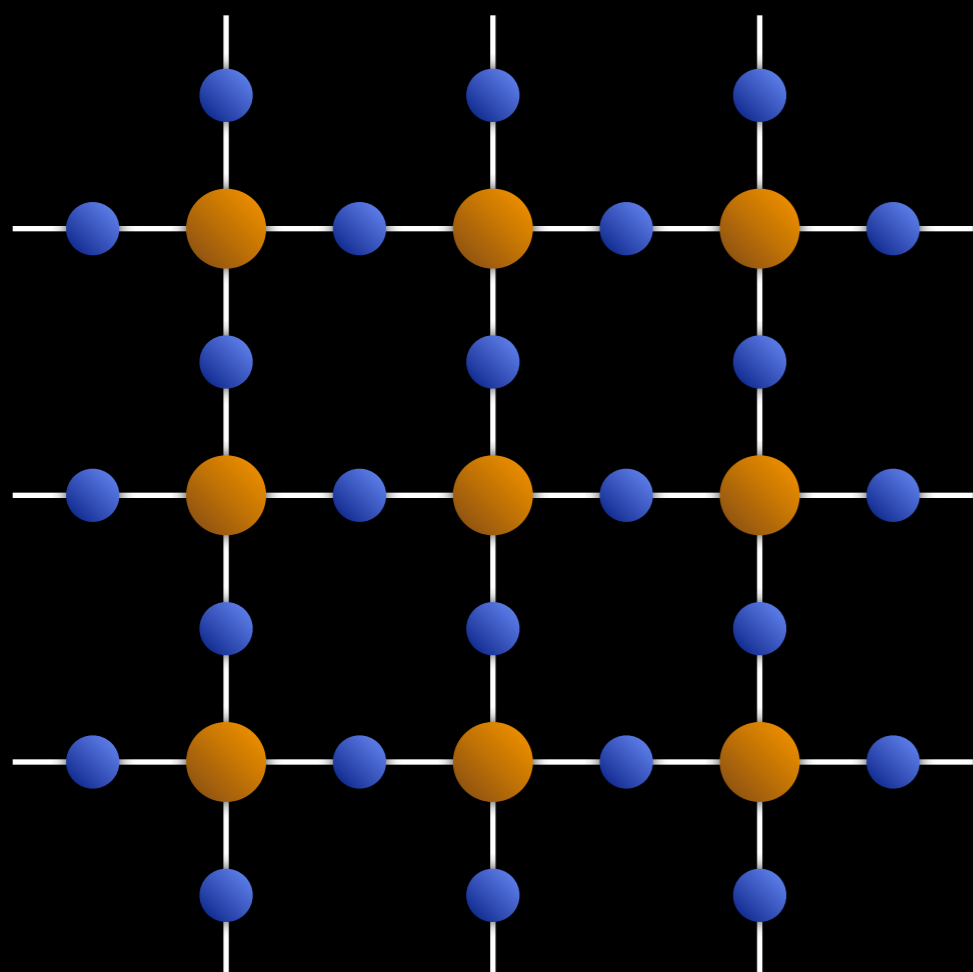


Topology



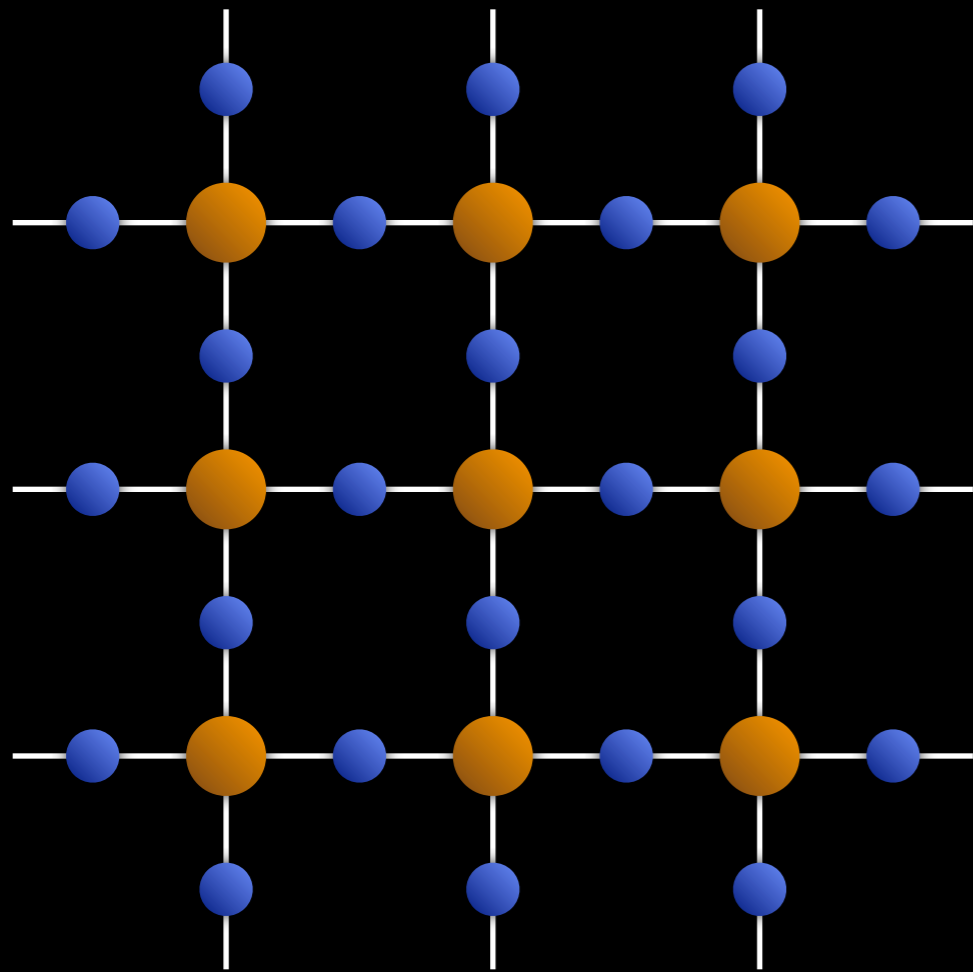


Band Theory



D. Xiao, et al. RMP 82, 1959 (2010)

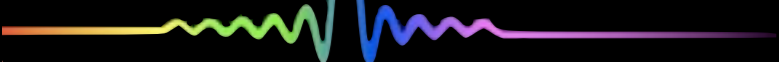
Band Theory



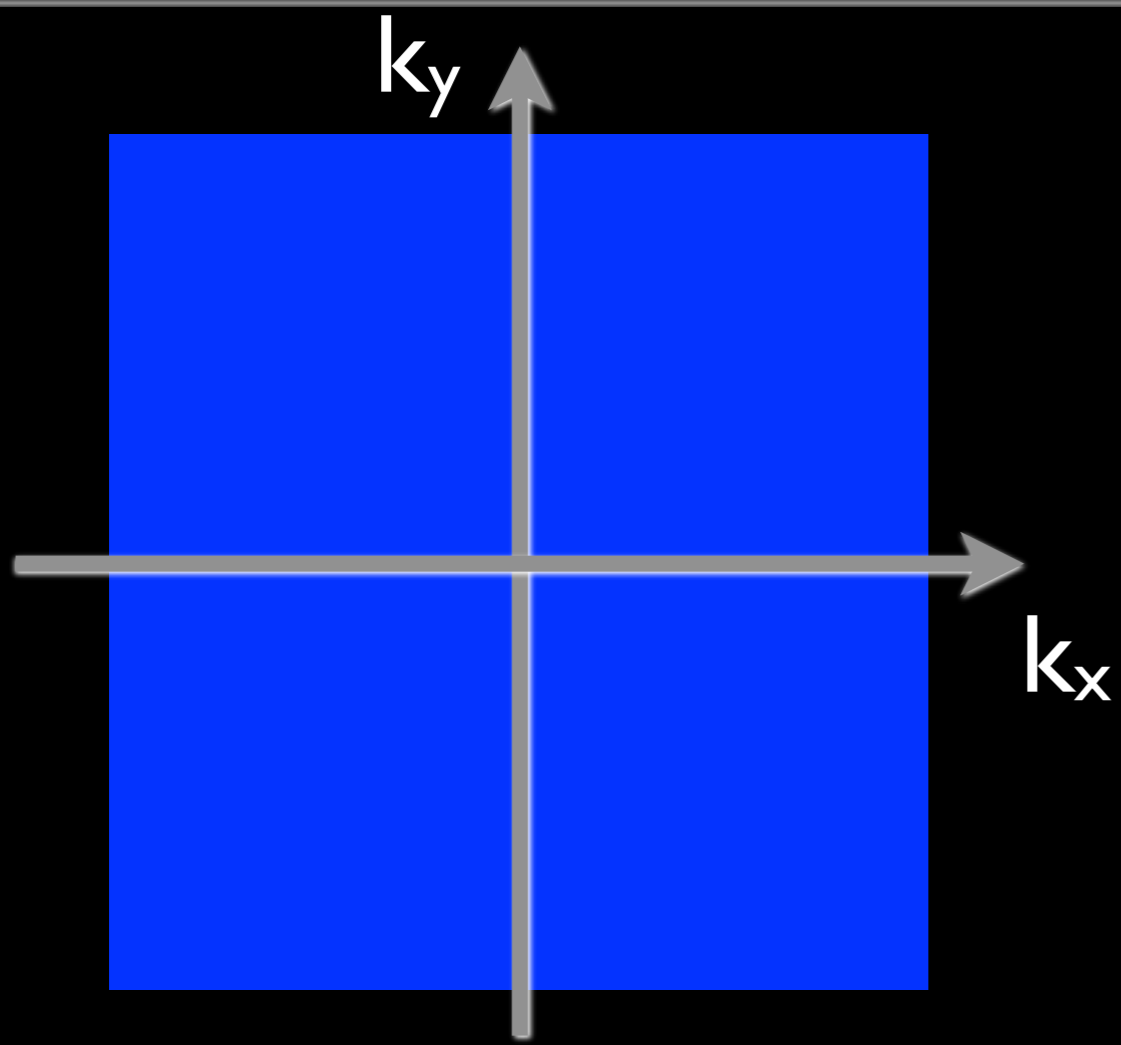
$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



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Band Theory



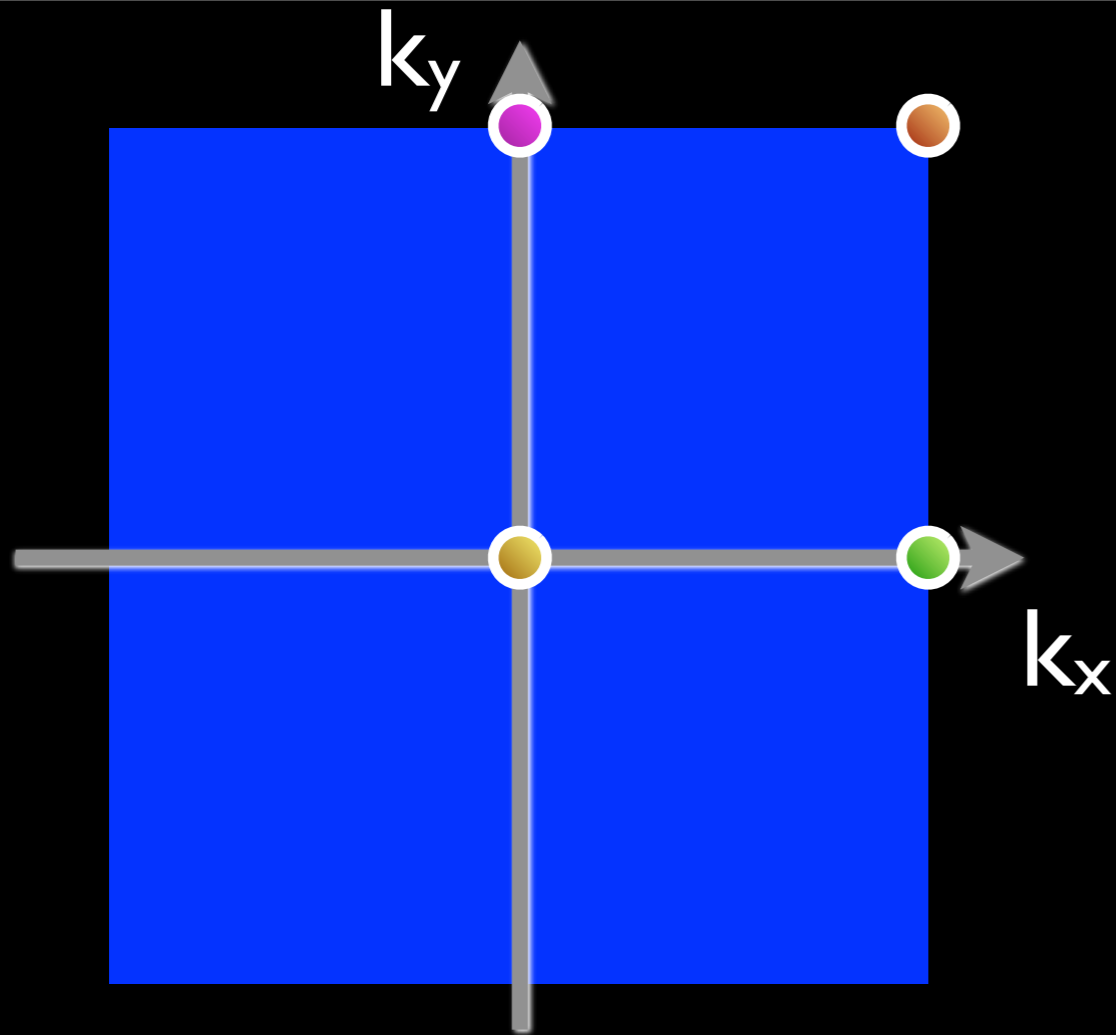
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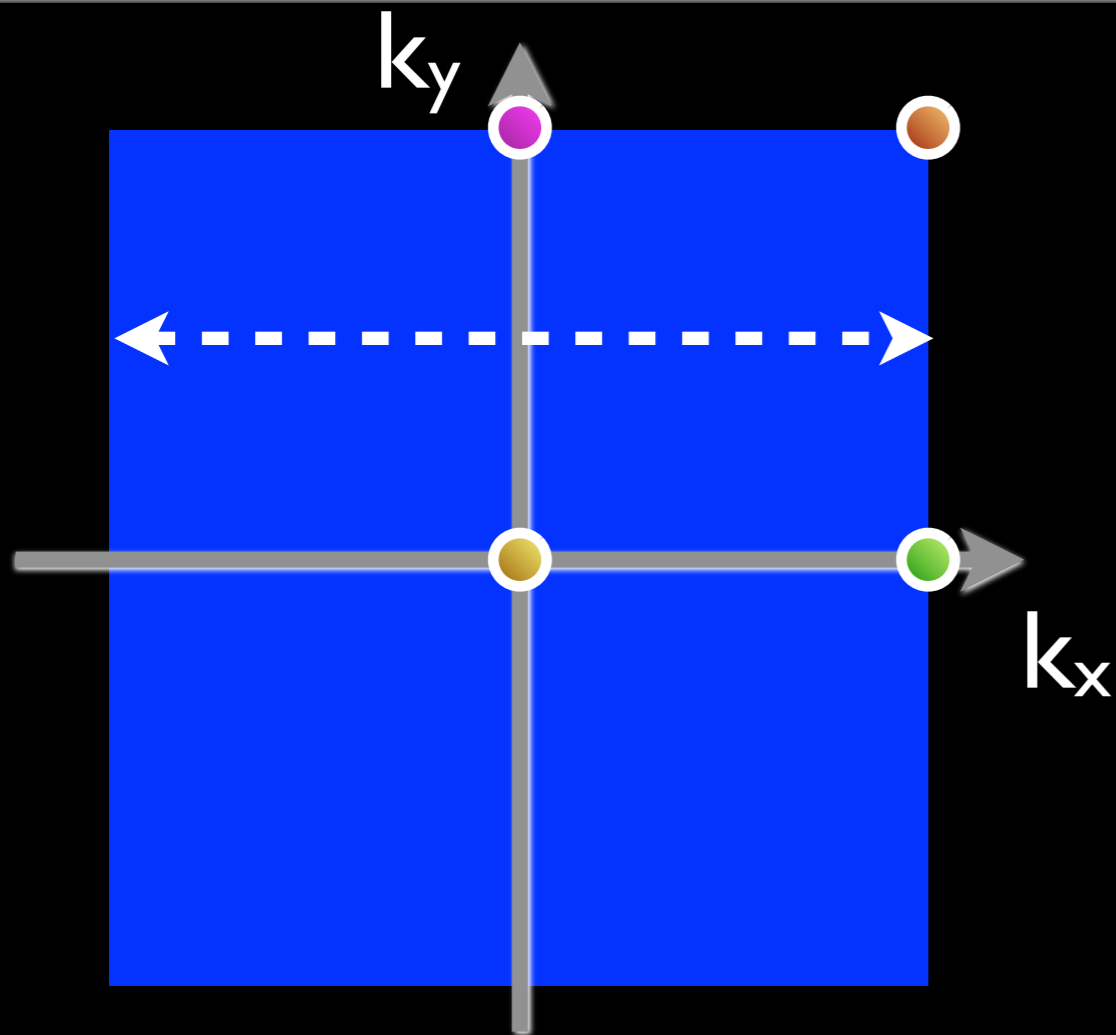
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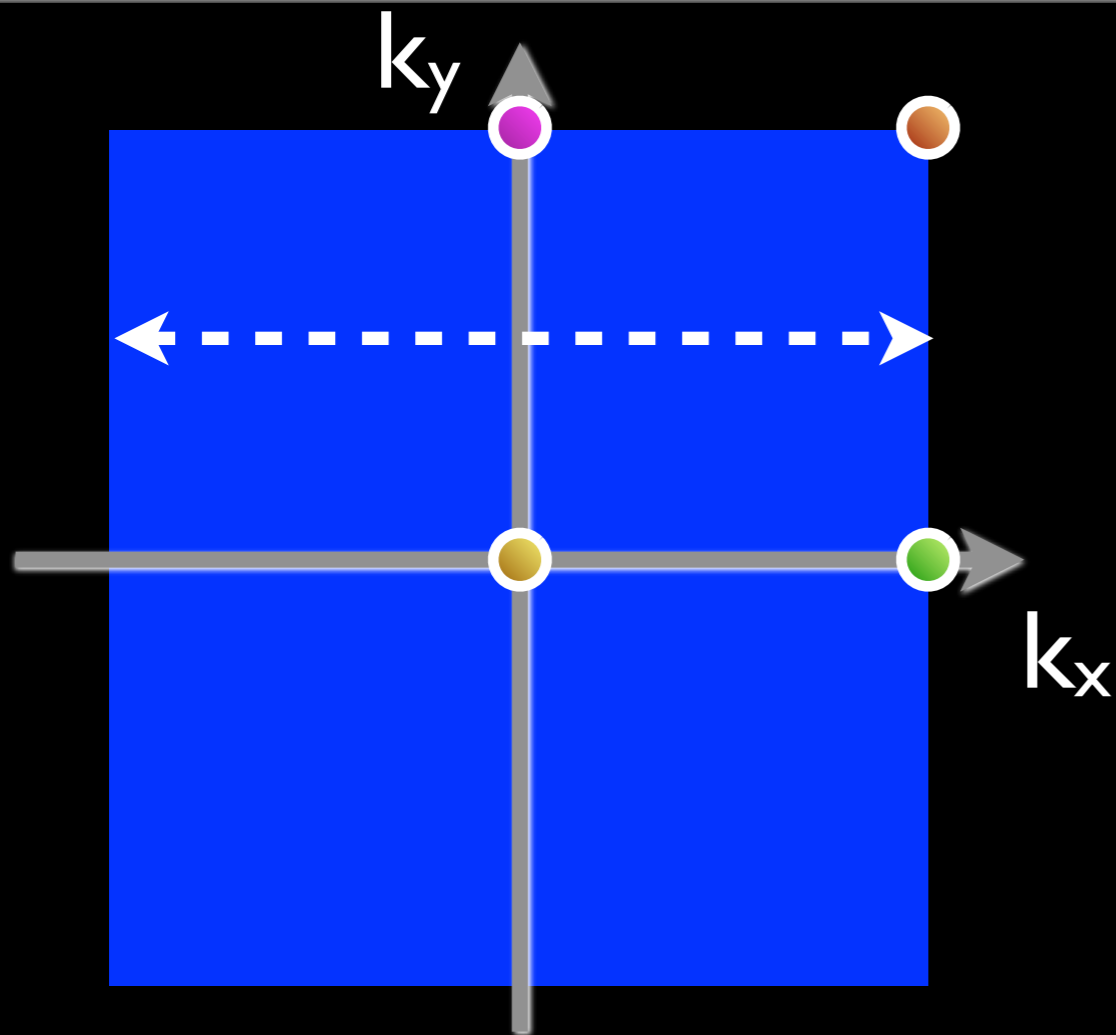
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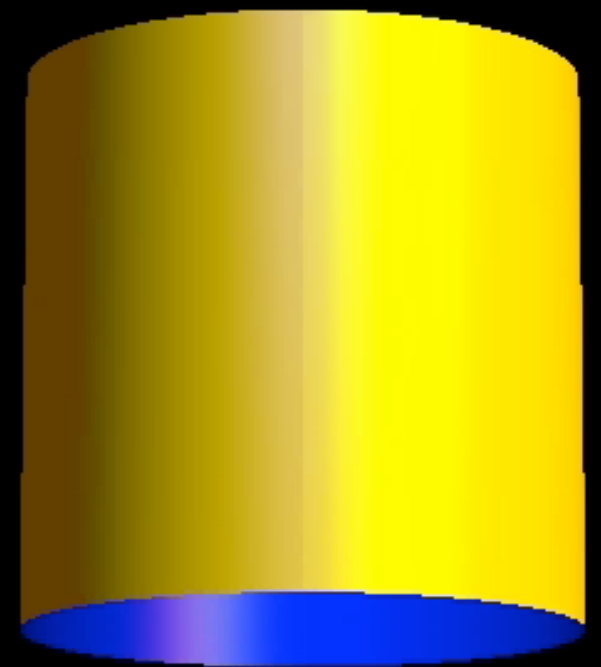
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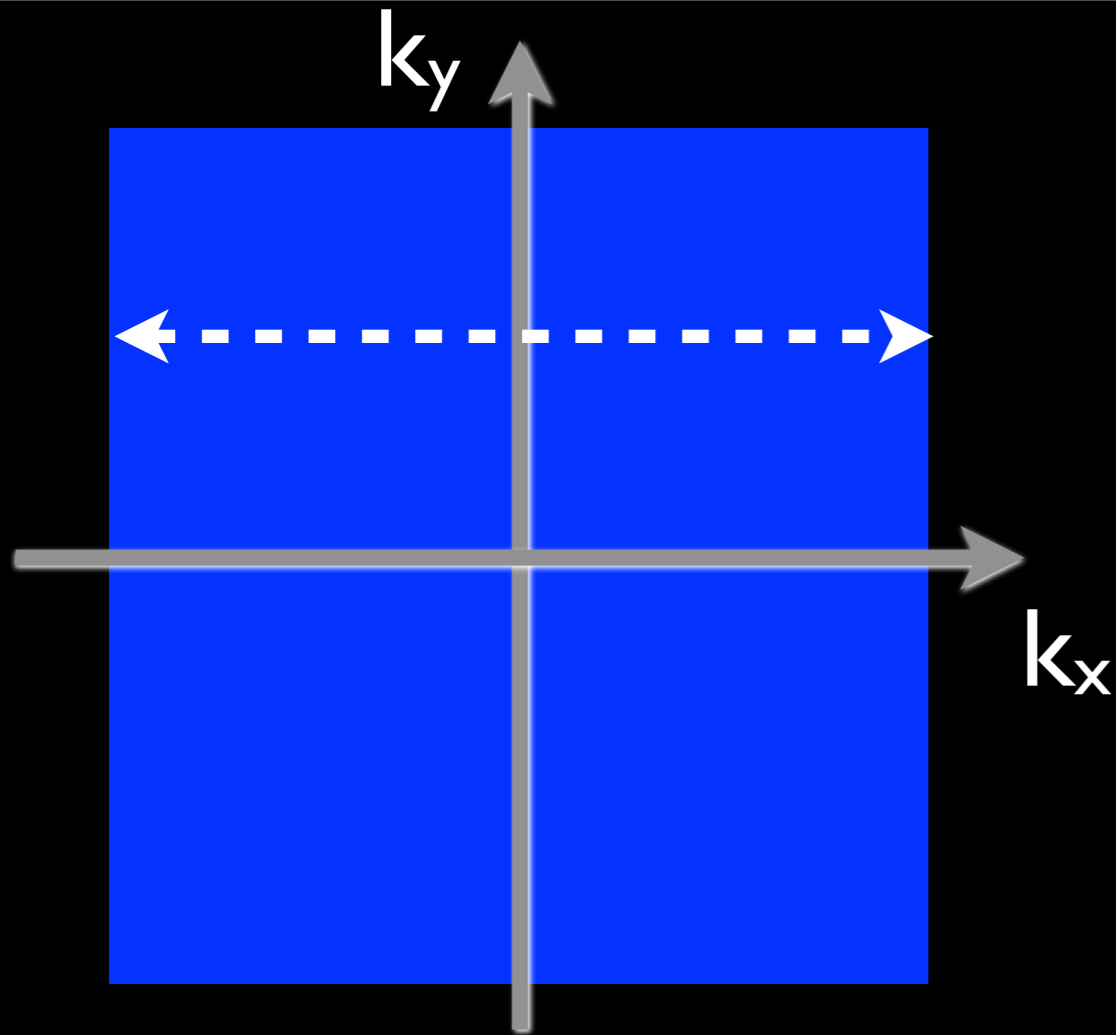


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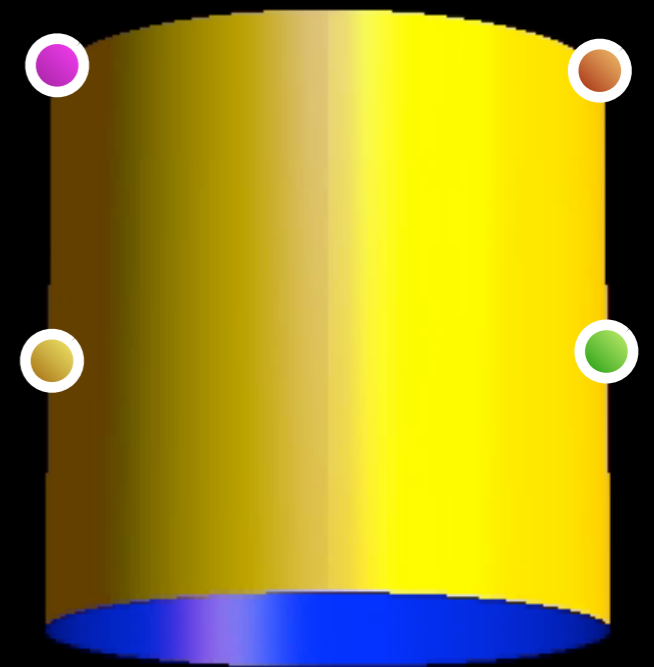


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Band Theory

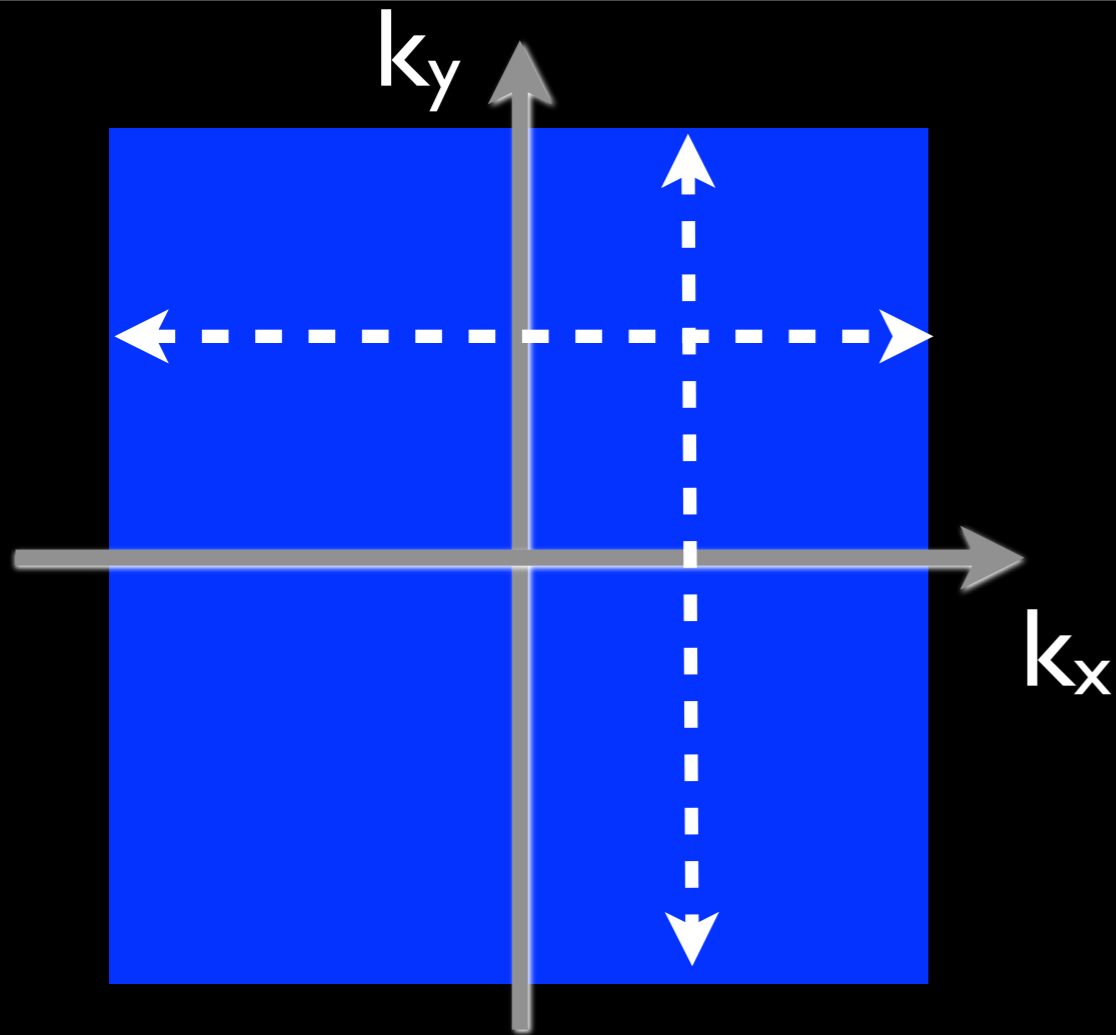


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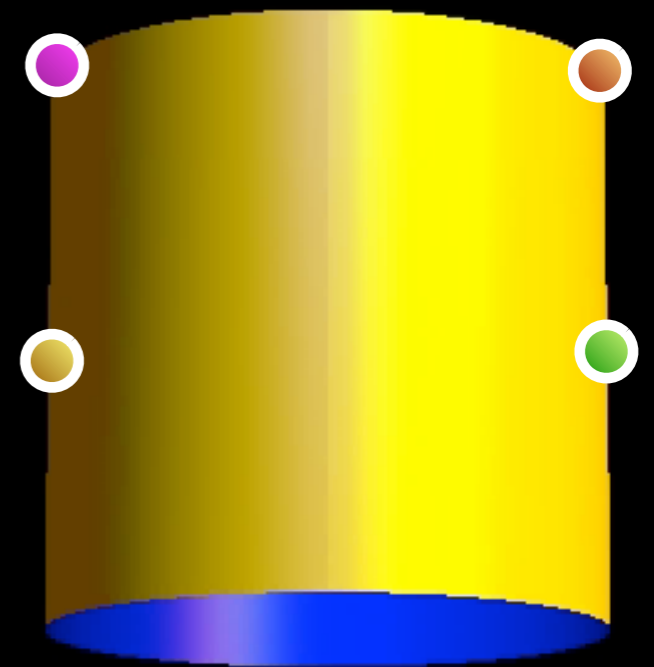


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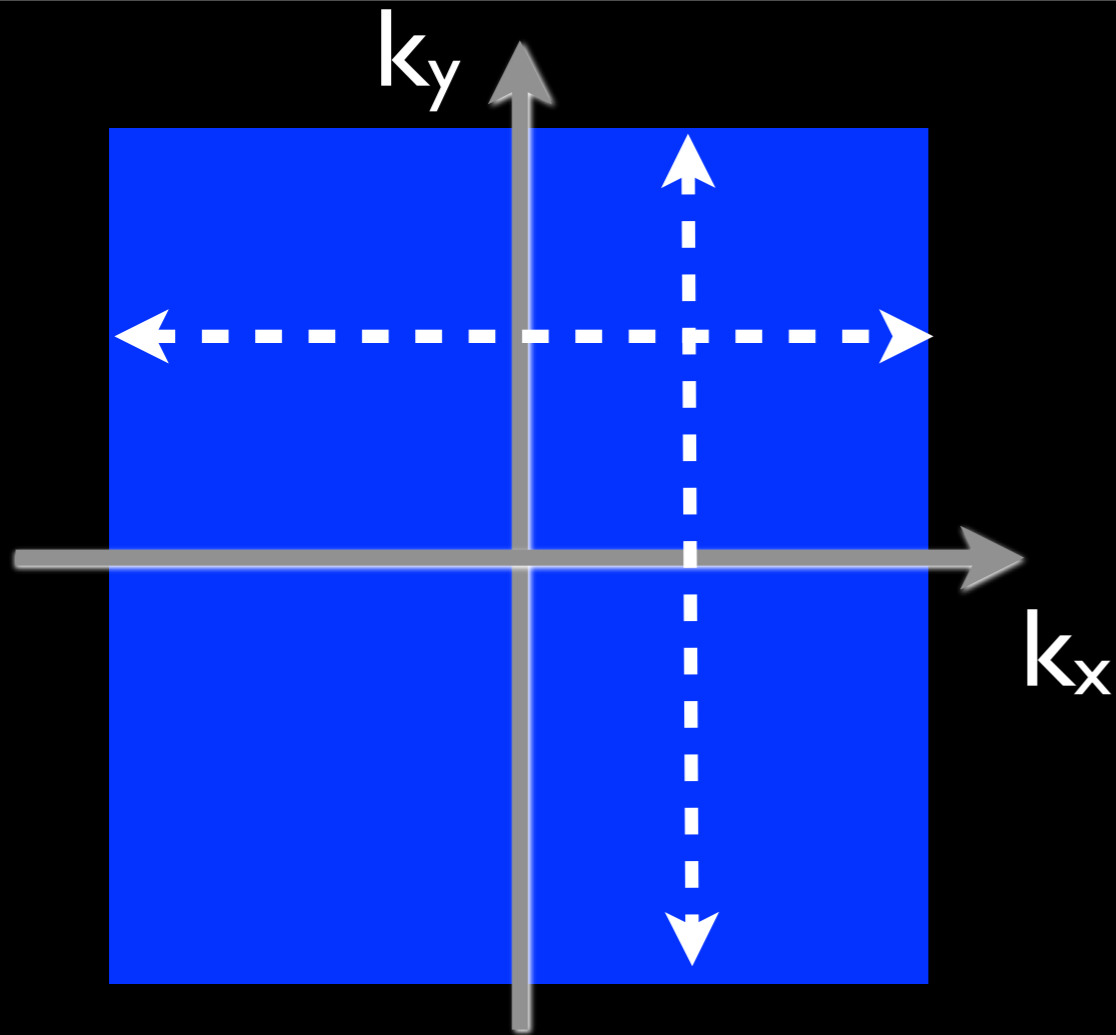


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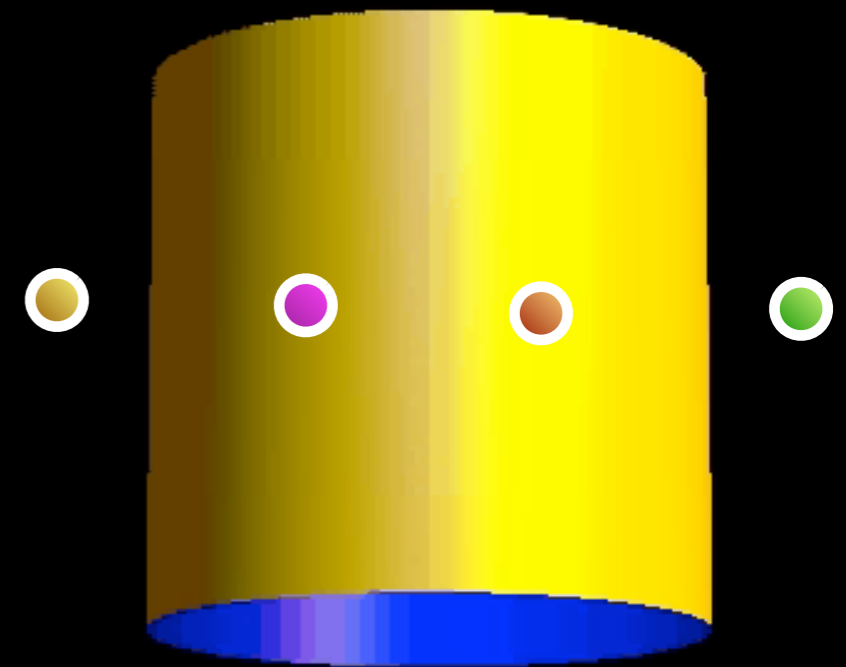


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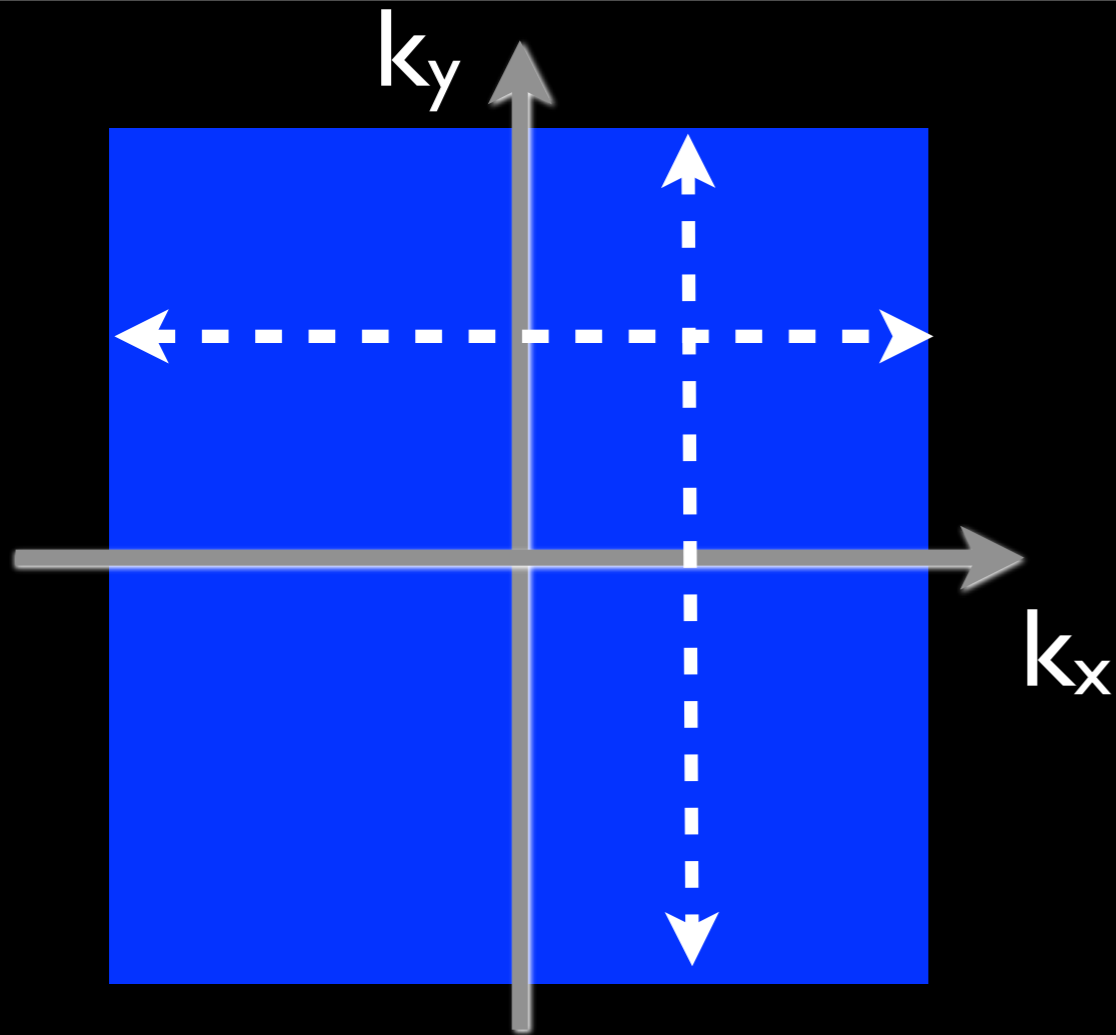


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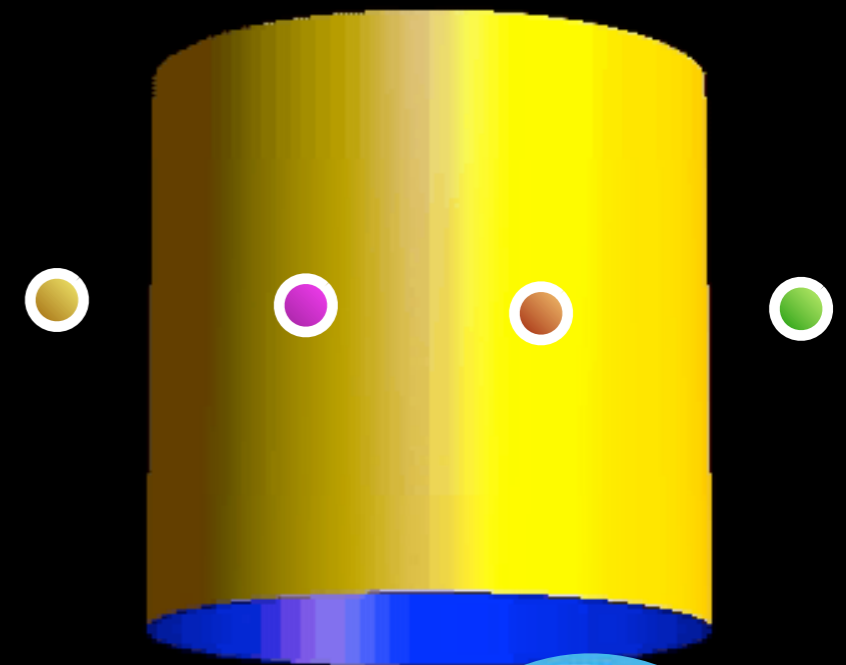


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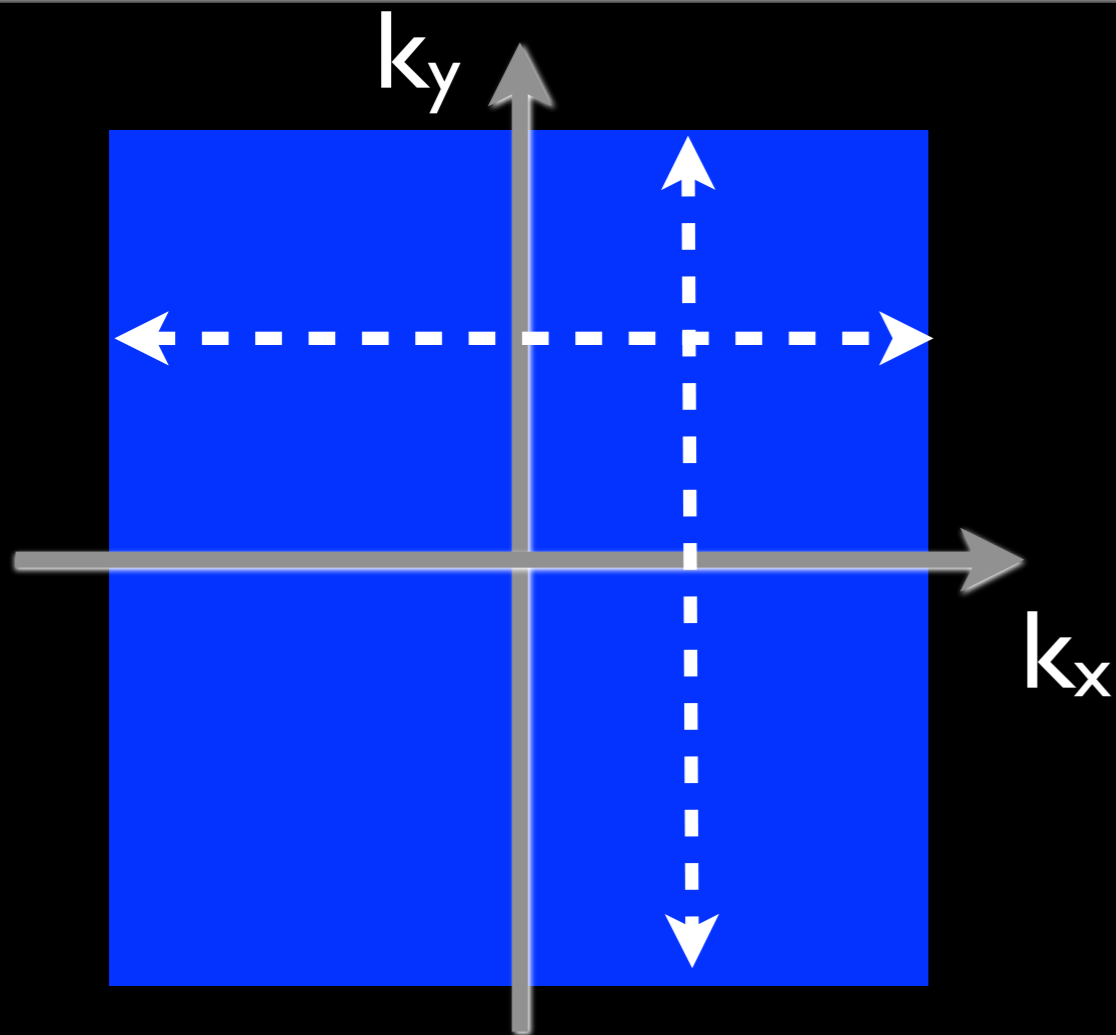
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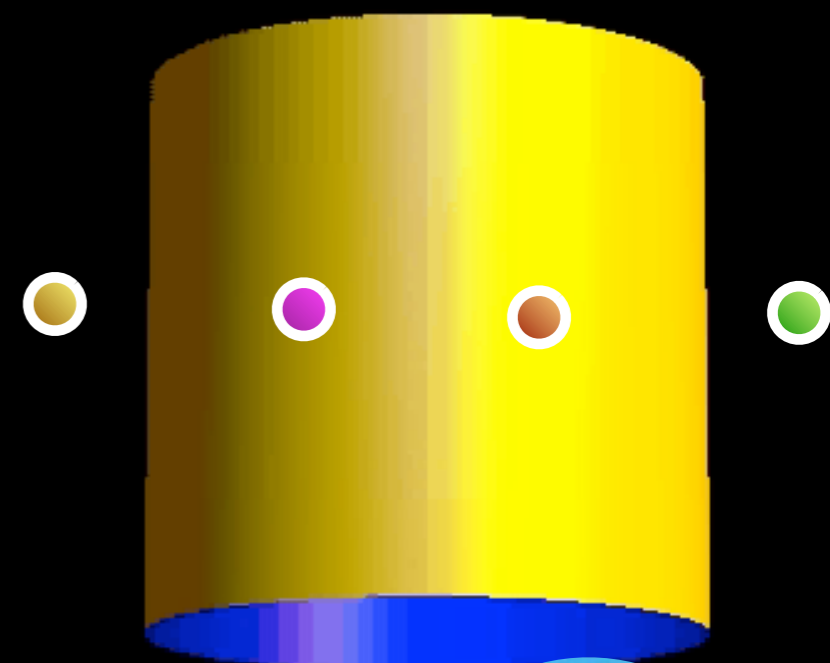
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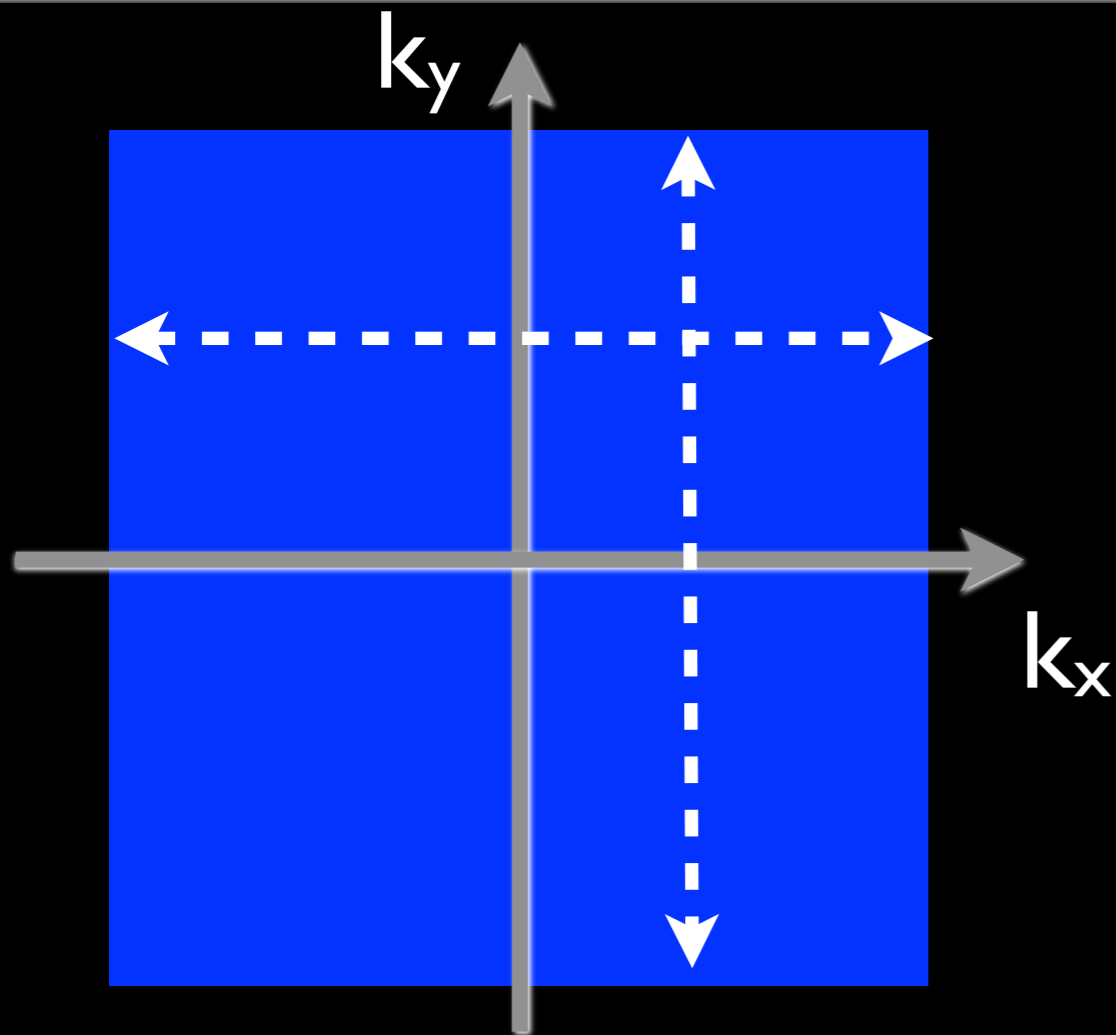
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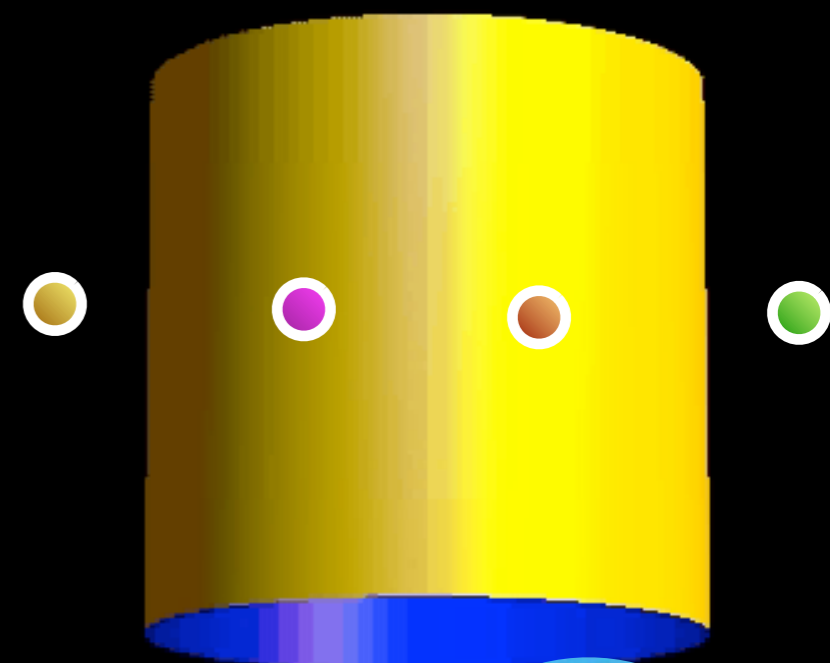
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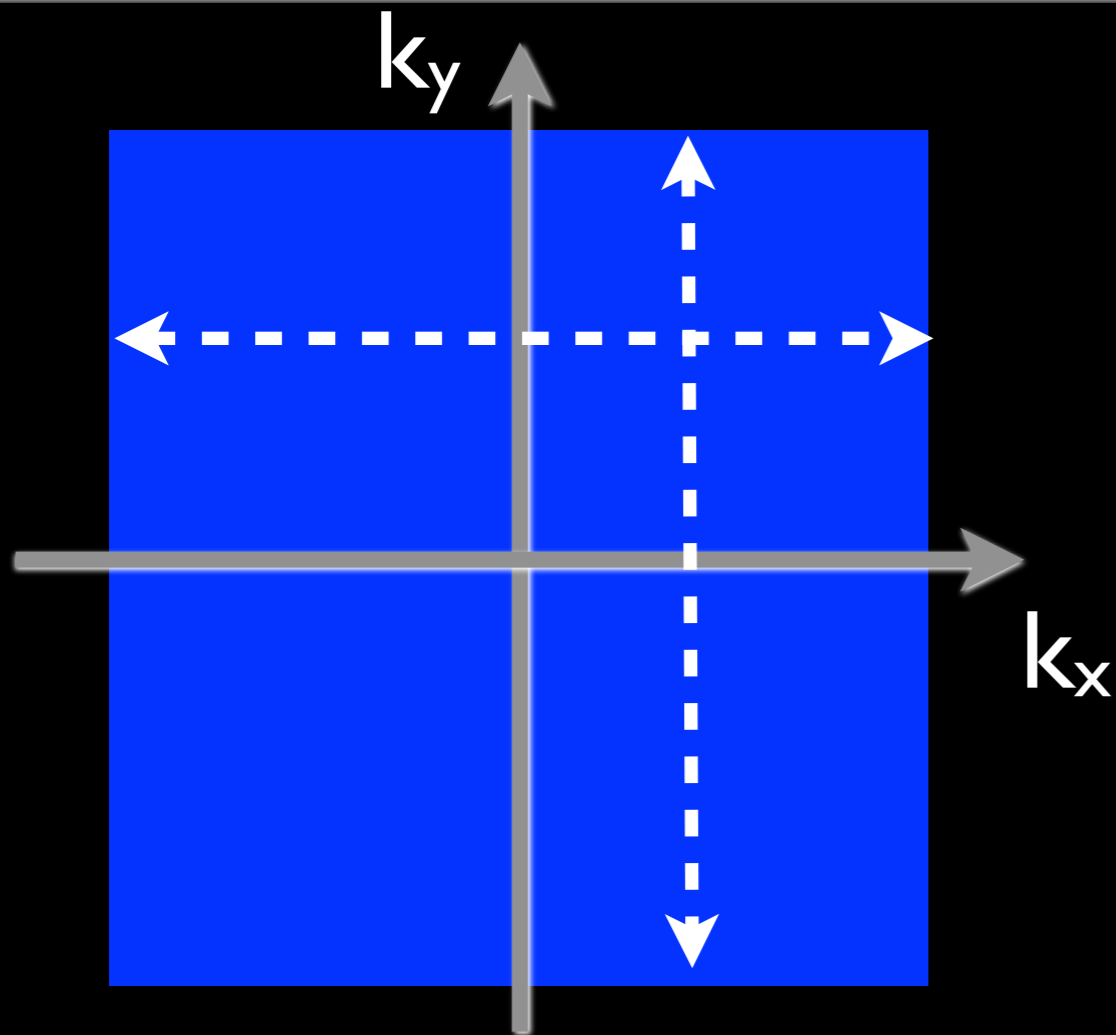
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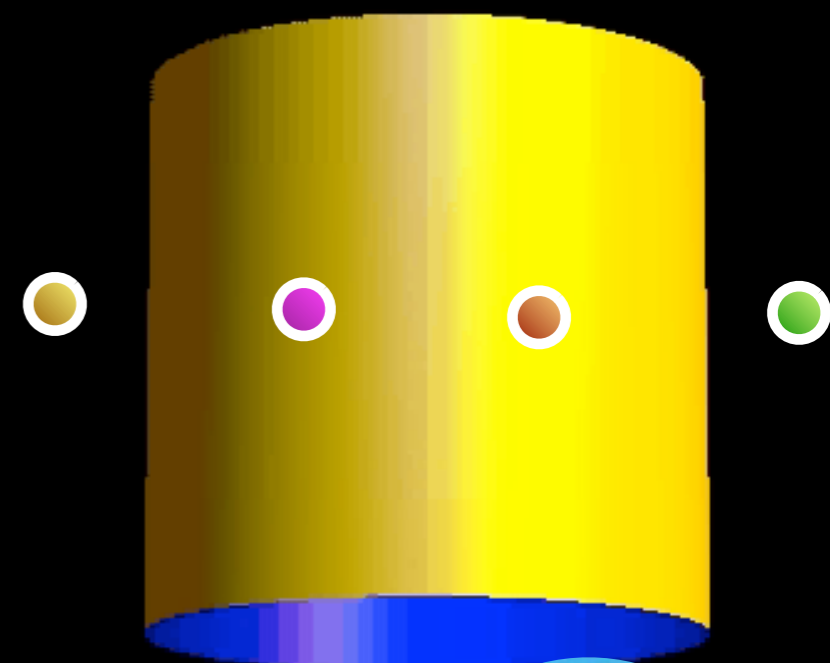
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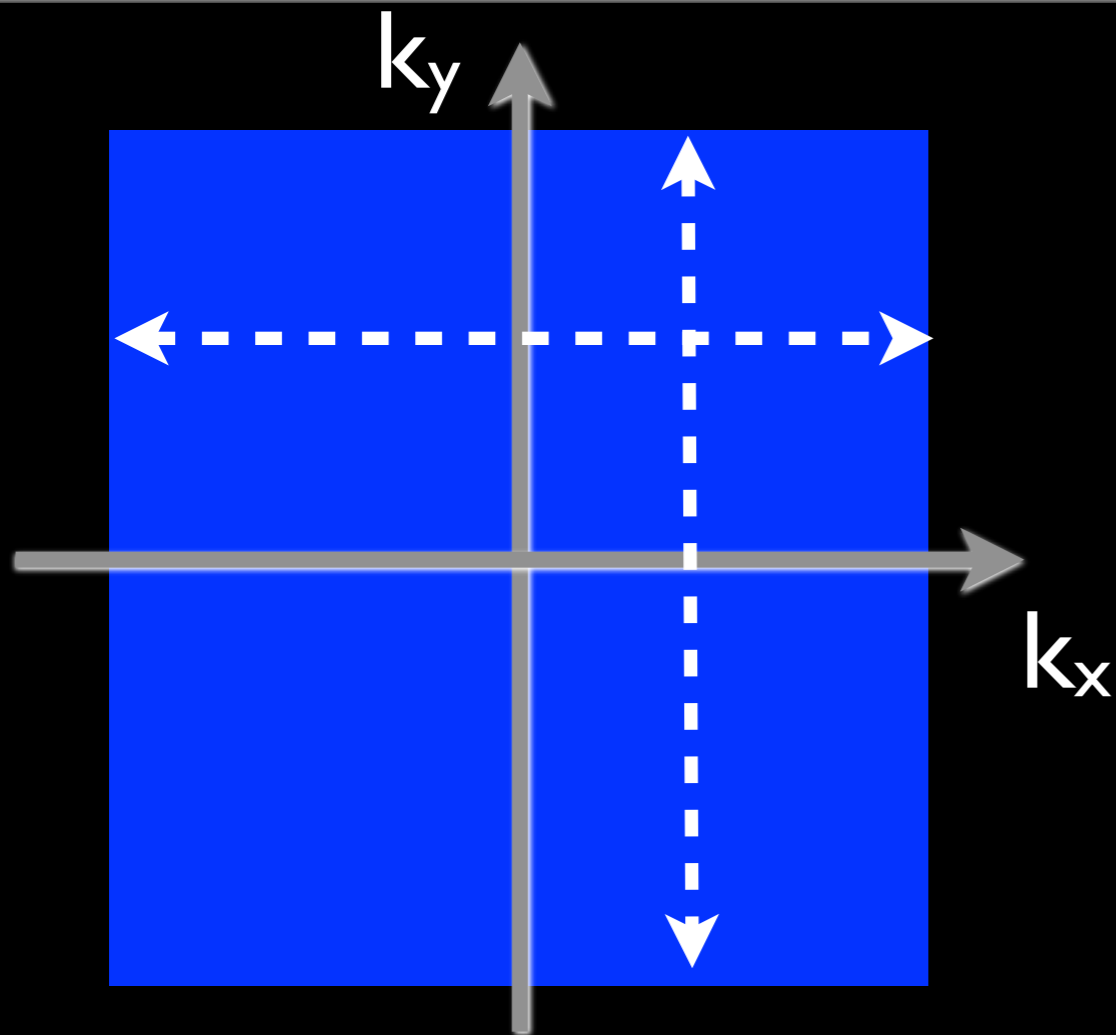
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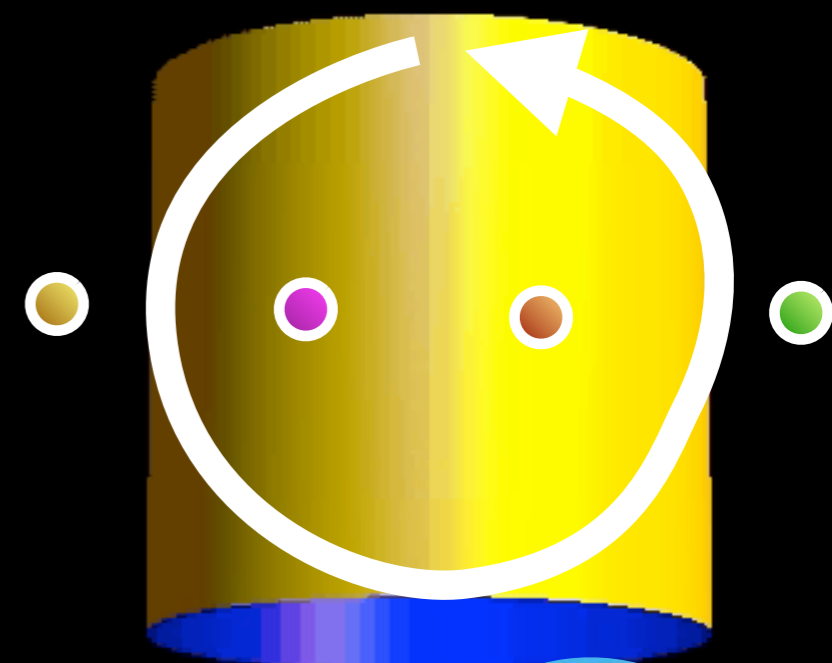
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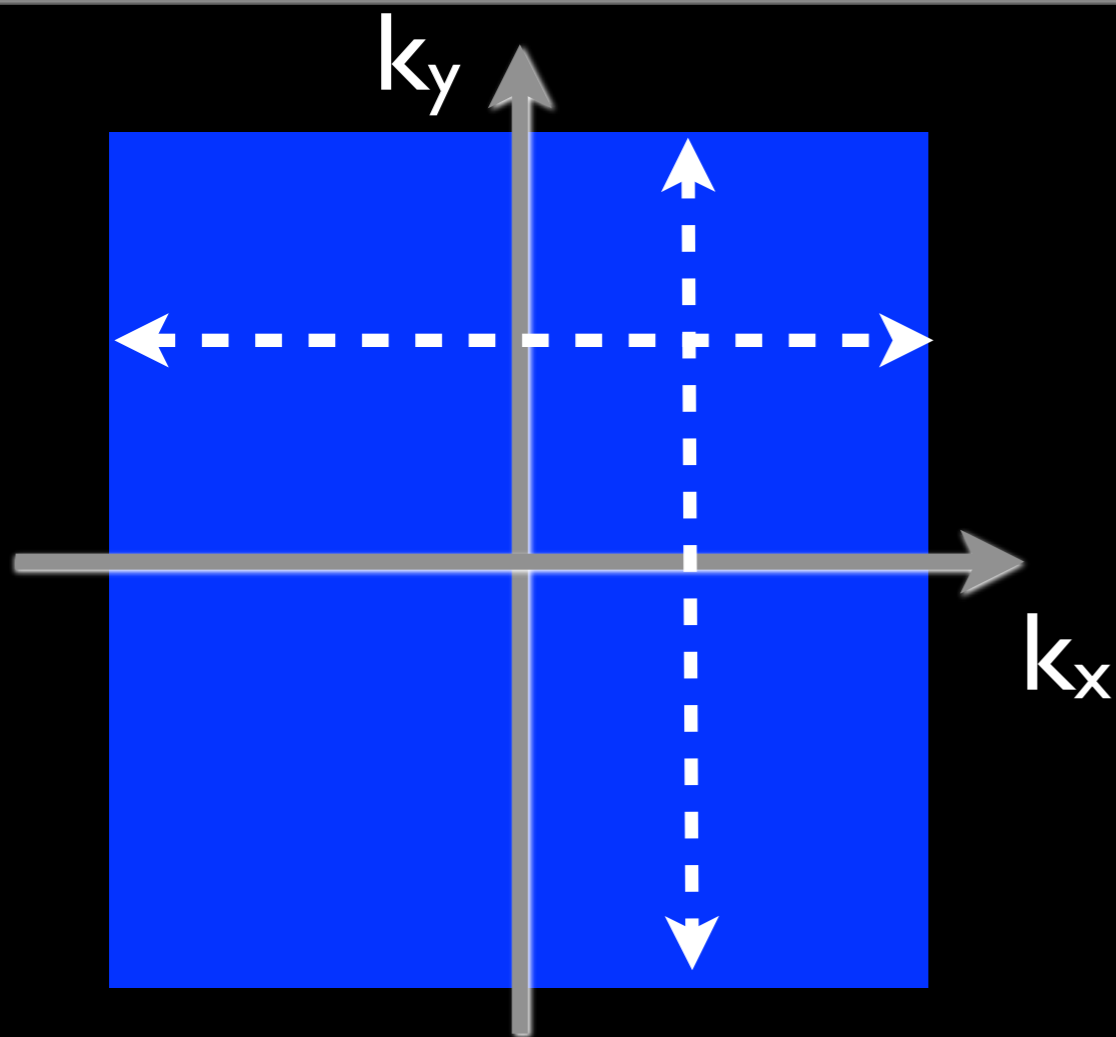
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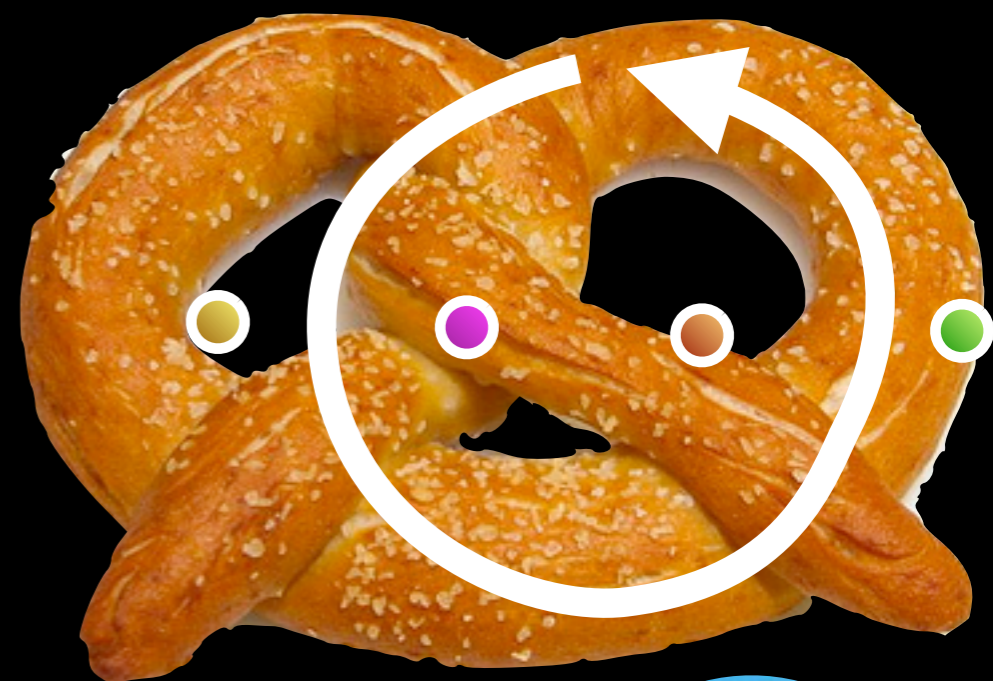
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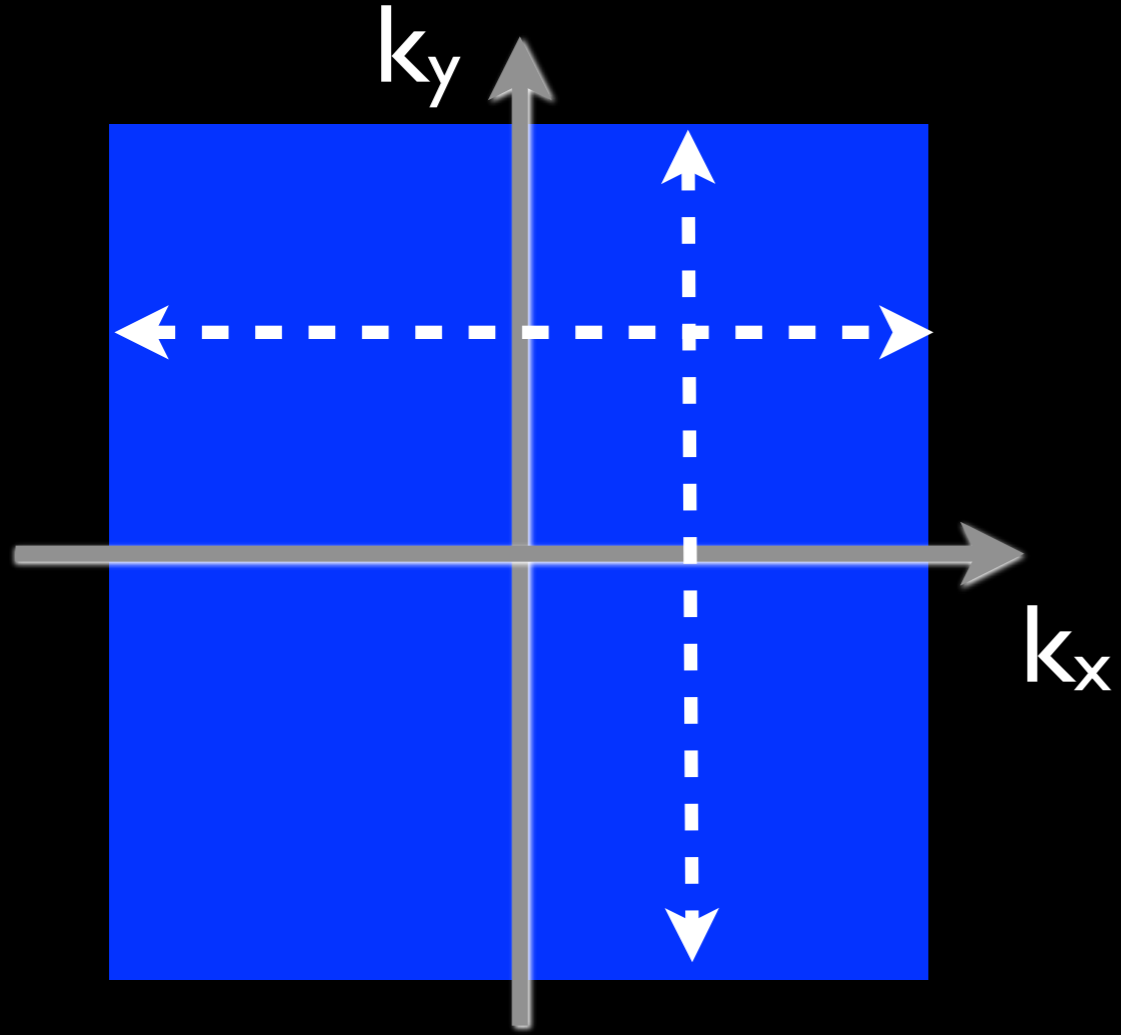
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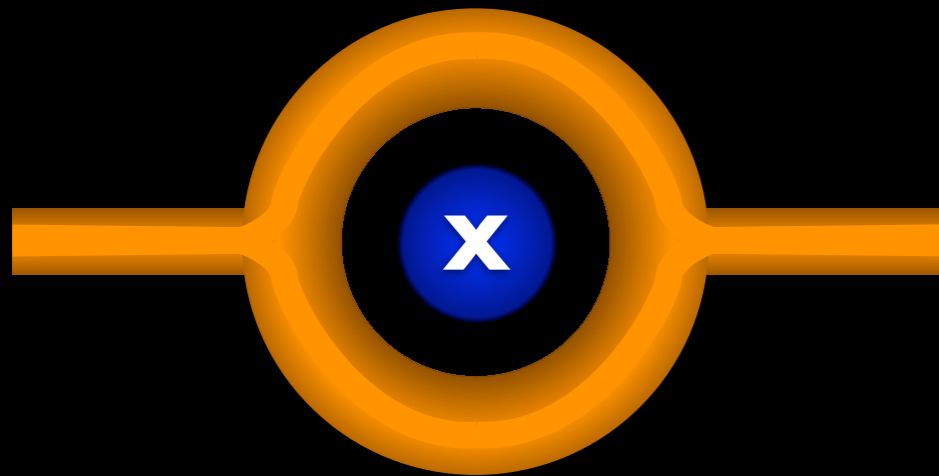
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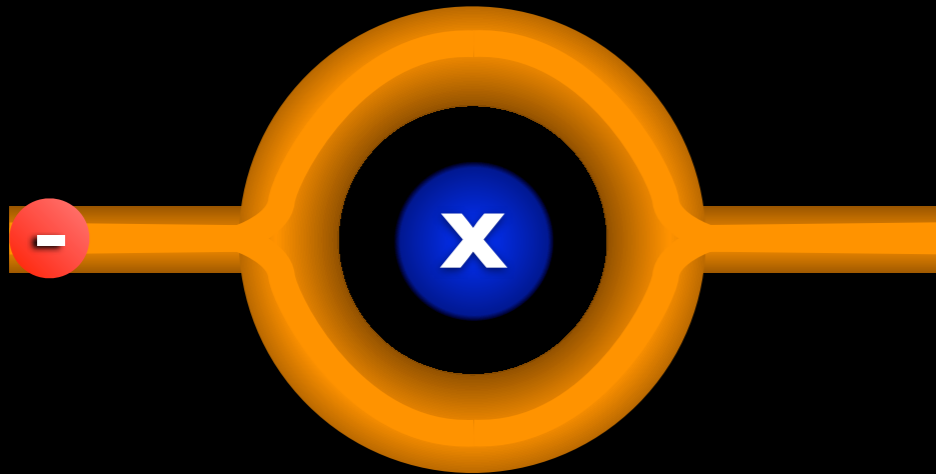
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Aharonov - Bohm



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Aharonov - Bohm

$$\Psi(\mathbf{r}, t) = e^{\frac{i\mathbf{E}(\mathbf{r})t}{\hbar}} \Psi(\mathbf{r}, 0)$$



Berry Phase: $\gamma = \oint_C d\mathbf{R} \cdot \mathbf{A}(\mathbf{k})$

D. Xiao, et al. RMP 82, 1959 (2010)

Aharonov - Bohm

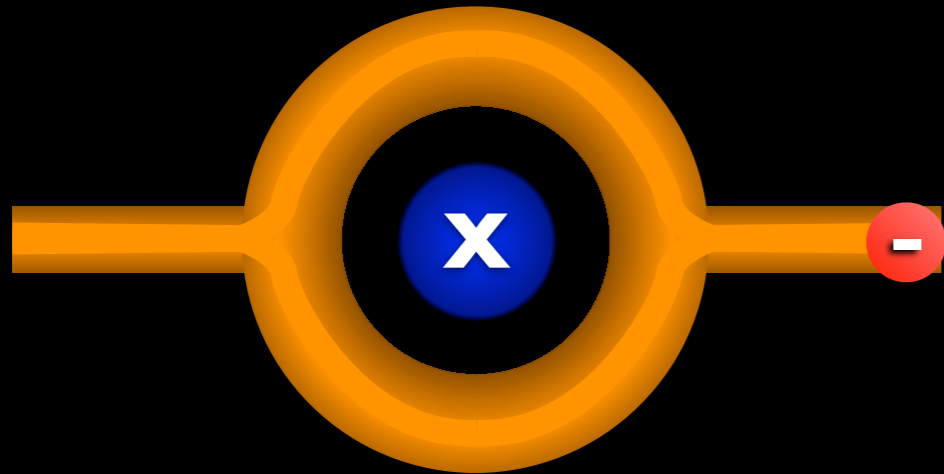


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Aharonov - Bohm



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2 Cases

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“Transparent”

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D. Xiao, et al. RMP 82, 1959 (2010)

Aharonov - Bohm



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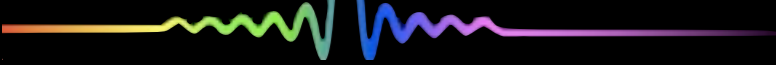
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“Reflective”

Topological

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D. Xiao, et al. RMP 82, 1959 (2010)



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Theory:

M.Z. Hasan & C.L. Kane, RMP 82, 3045 (2010)

J. Moore, Nature 464, 194 (2010).

XL Qi & SC Zhang arXiv:1008.2026



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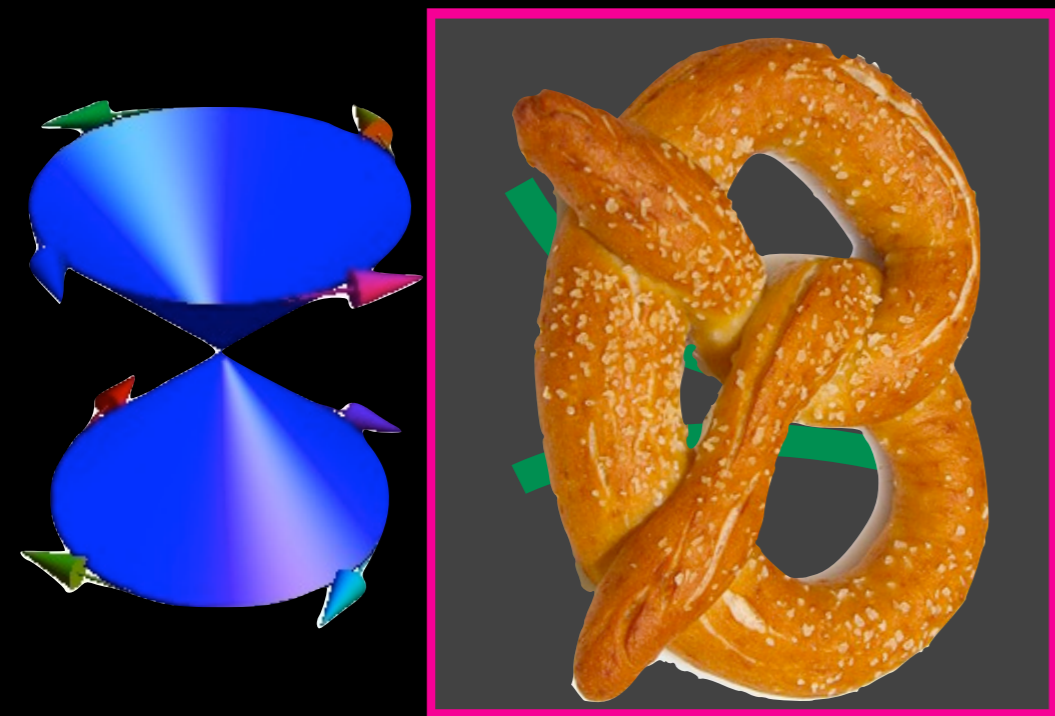
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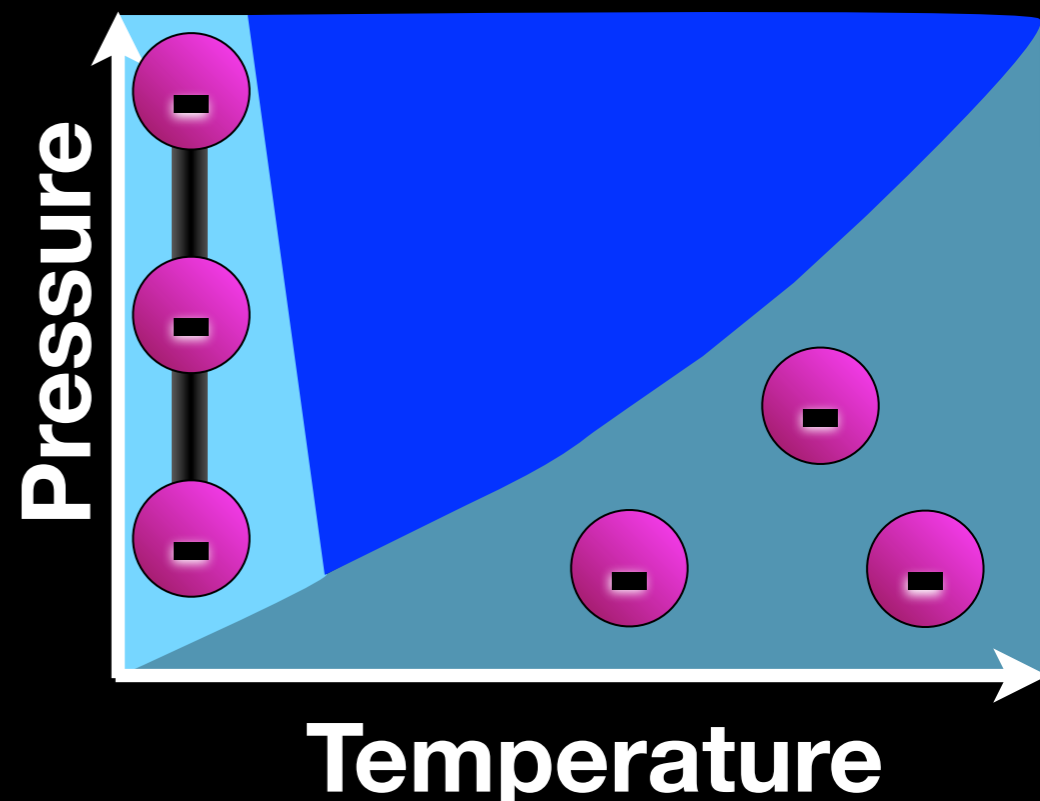
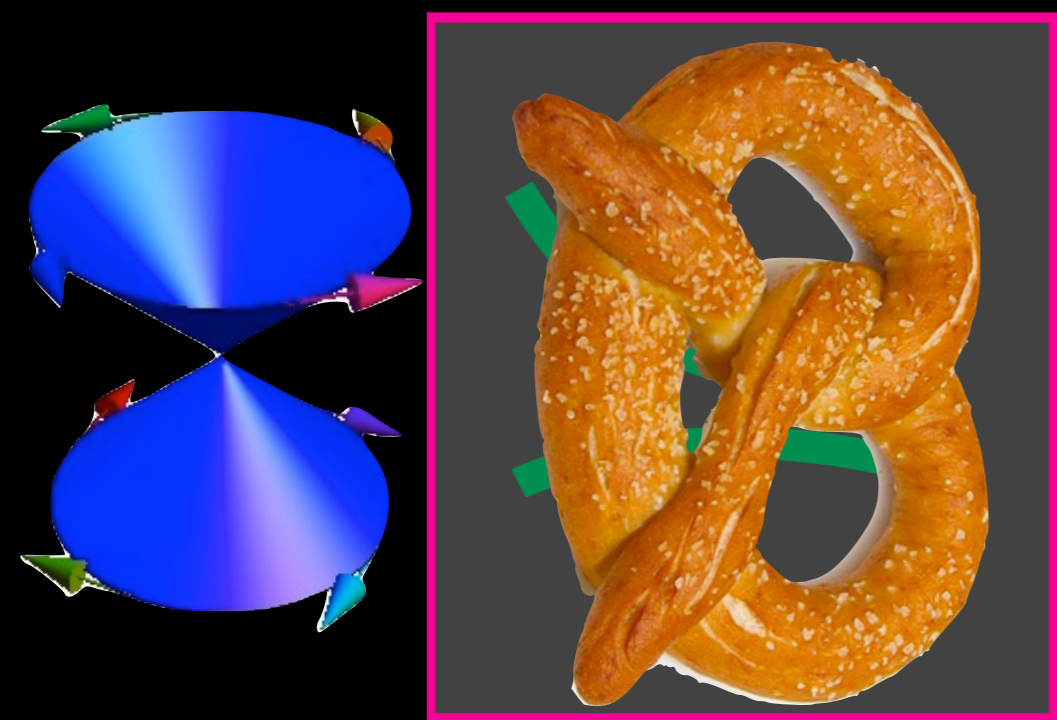
“Transparent”

Ordinary

$$\Delta\phi = \pi + \mathbf{n} \times 2\pi$$

“Reflective”

Topological

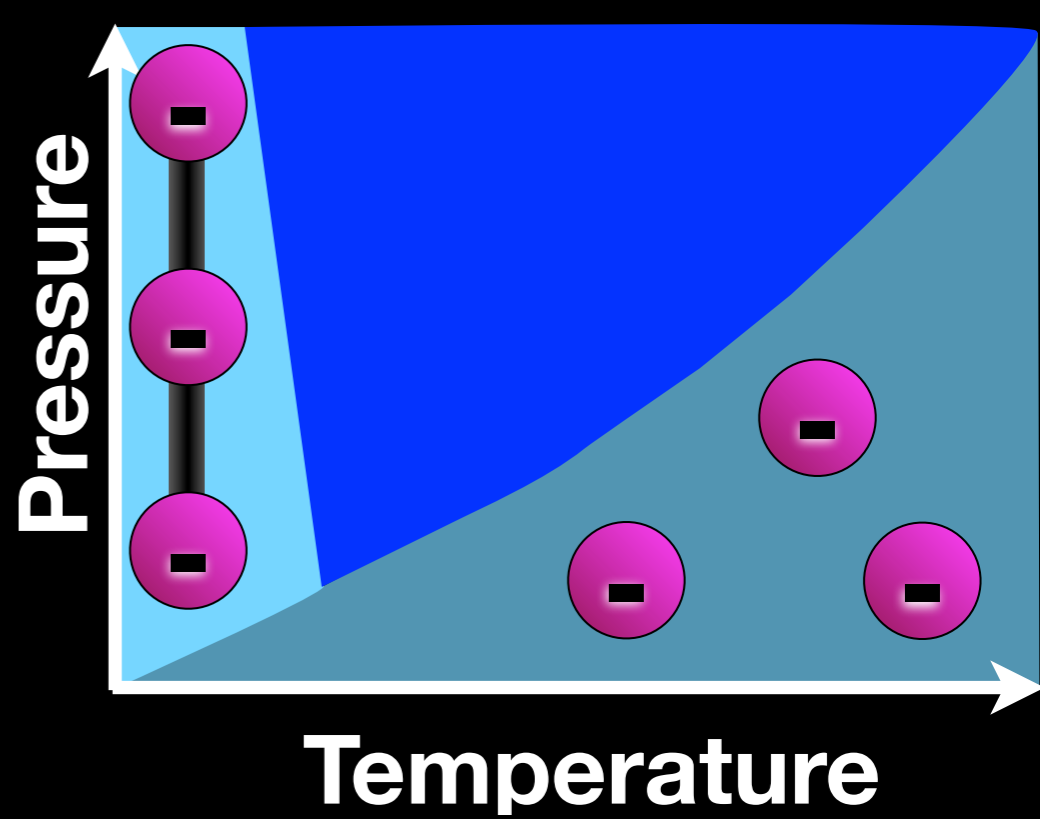


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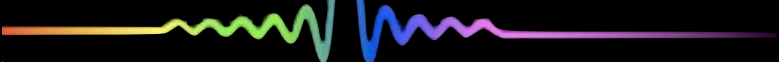
M.Z. Hasan & C.L. Kane, RMP 82, 3045 (2010)

J. Moore, Nature 464, 194 (2010).

XL Qi & SC Zhang arXiv:1008.2026

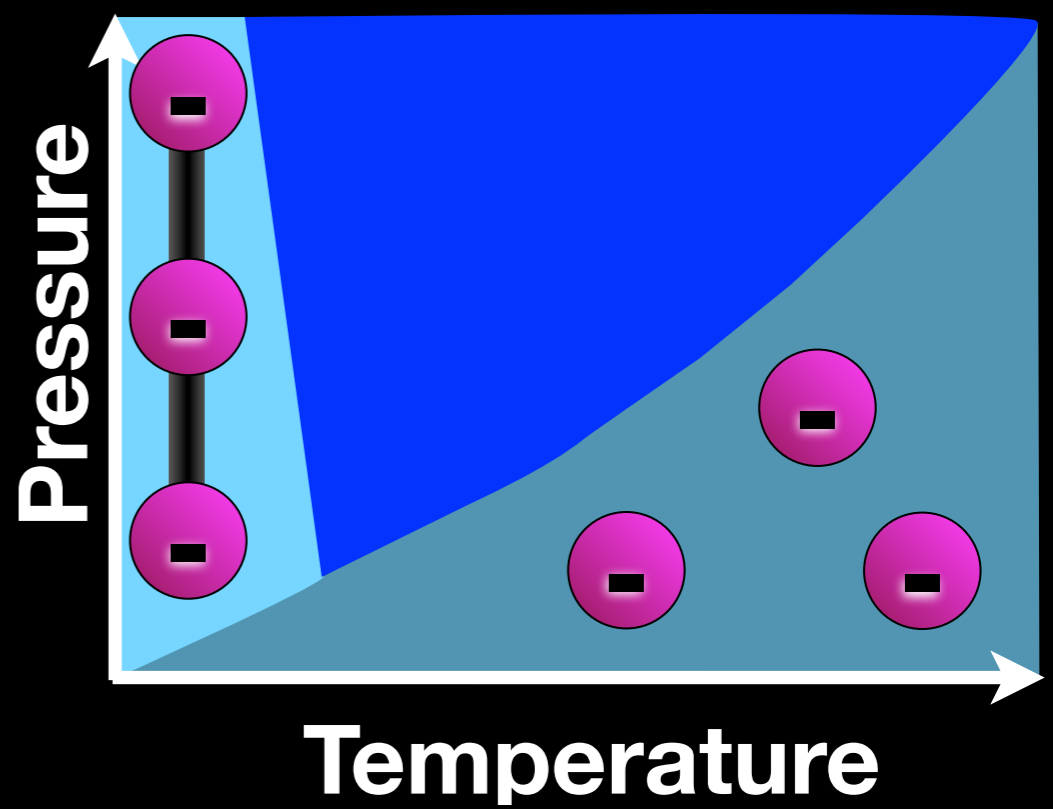
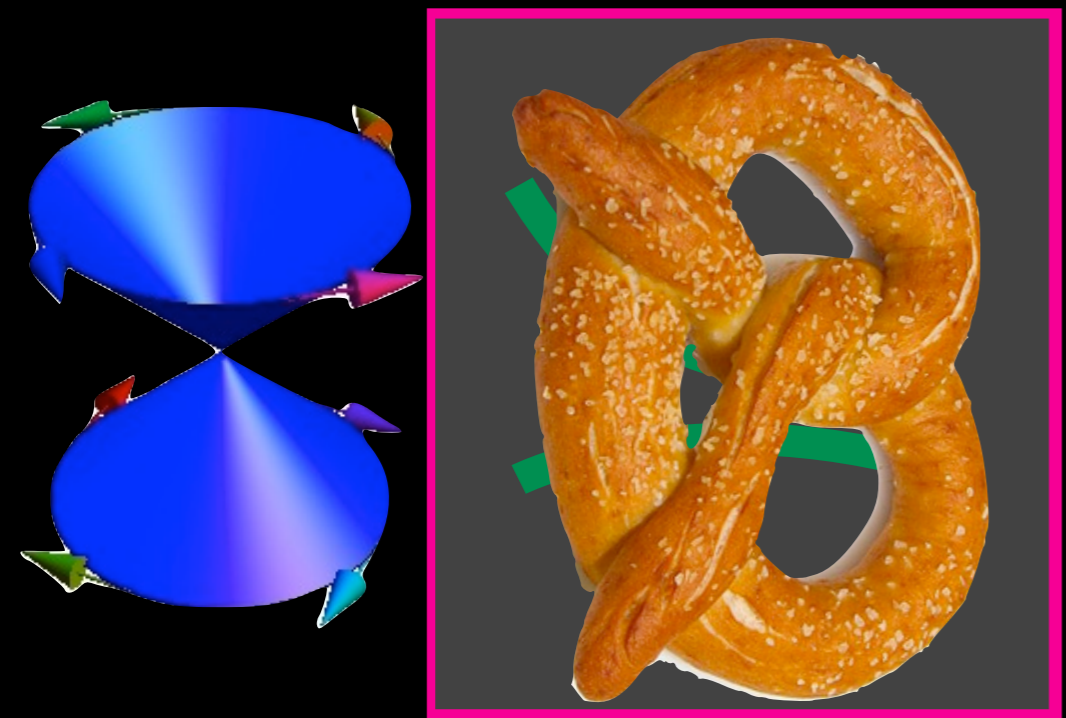
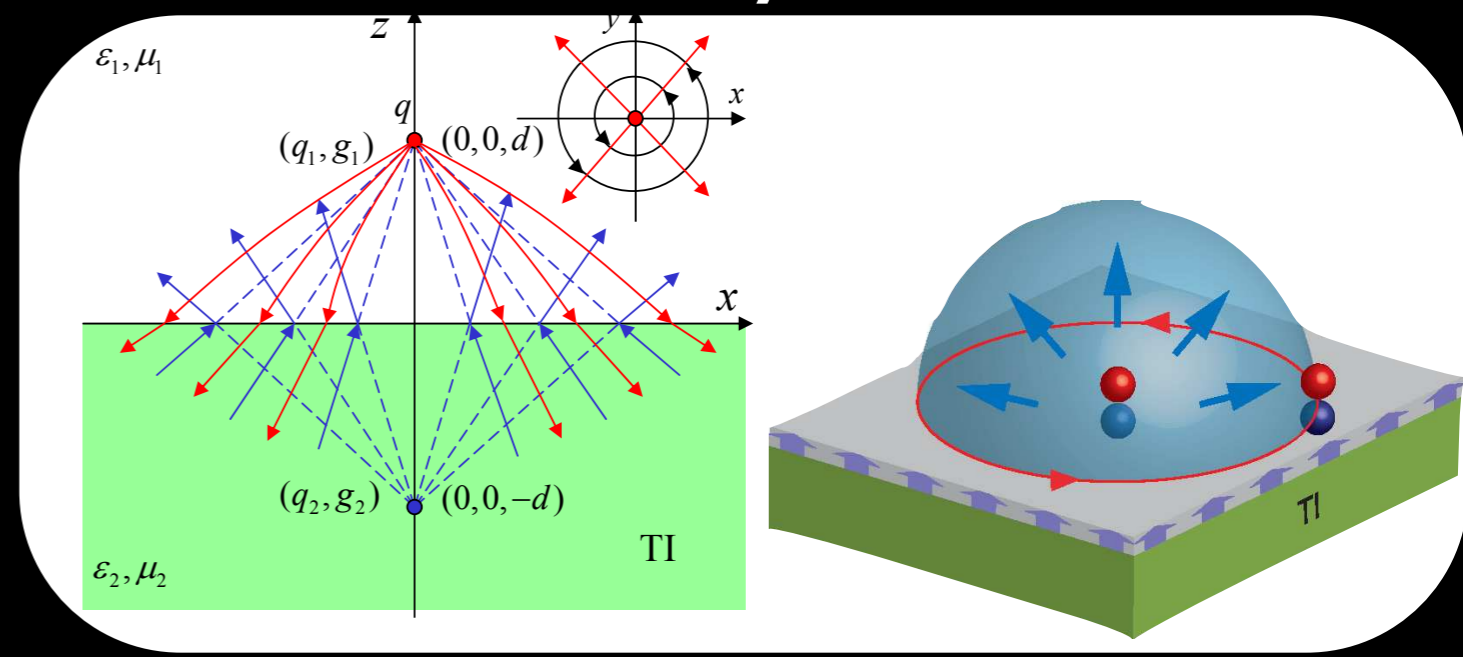


Theory:
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Topology

Anyons



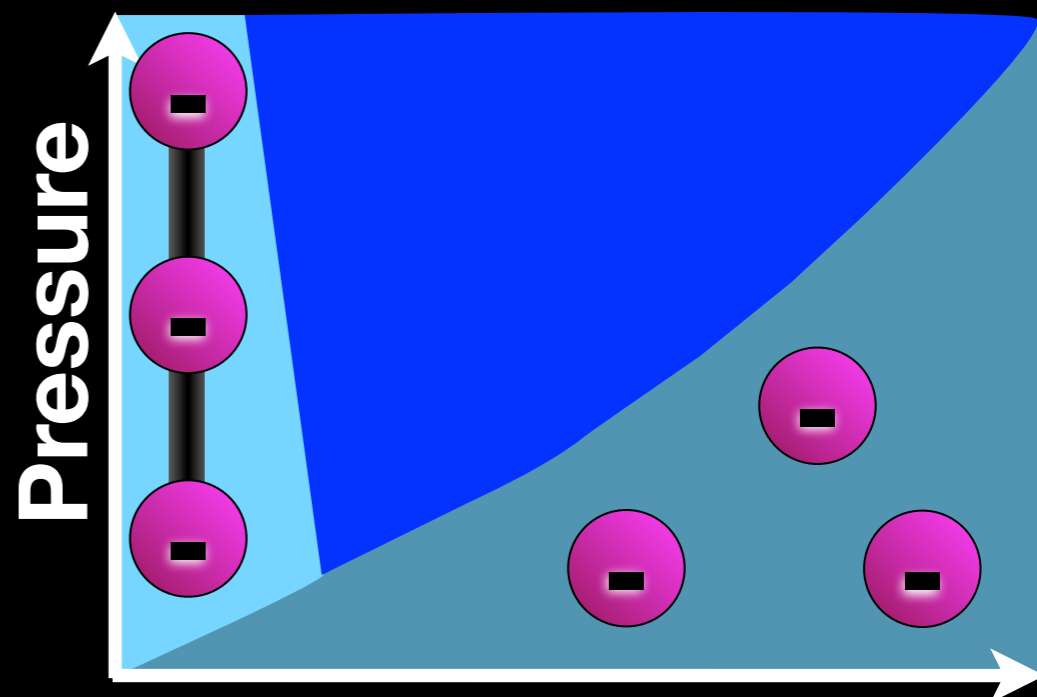
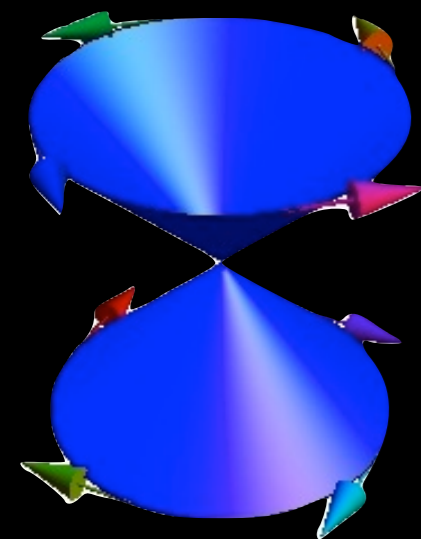
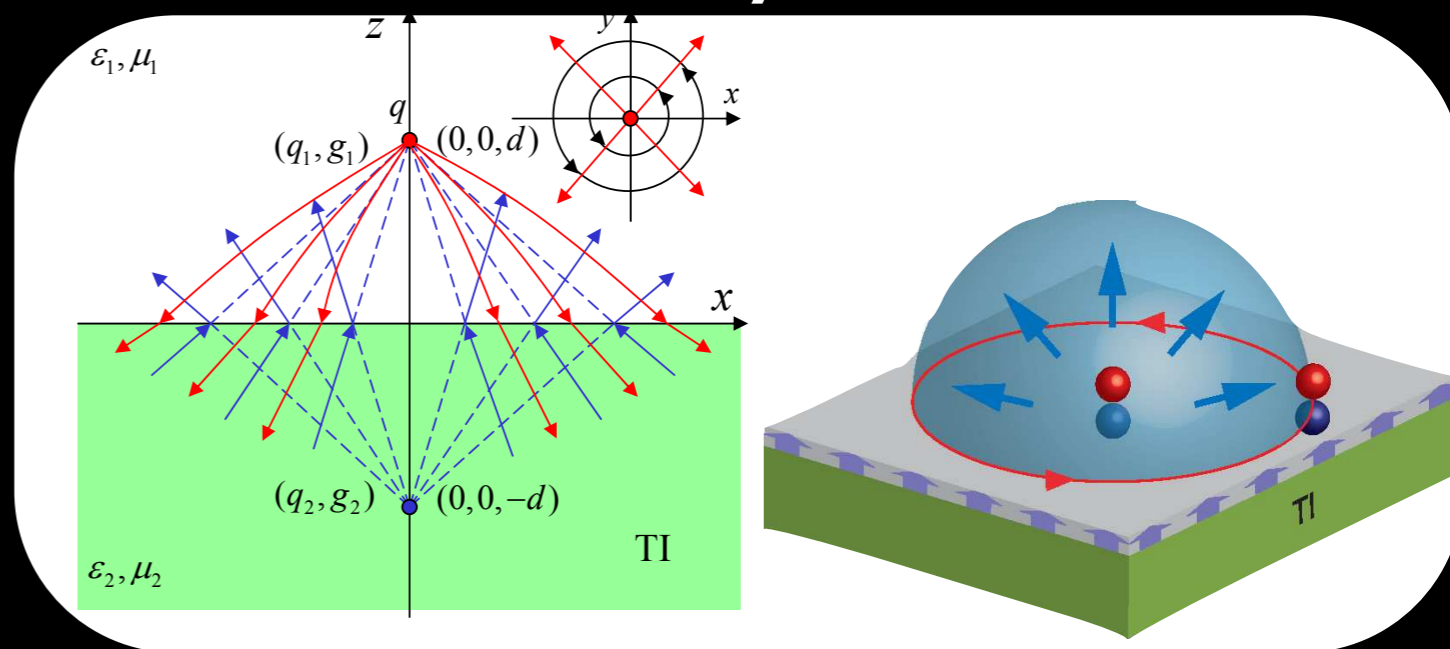
Theory:
 M.Z. Hasan & C.L. Kane, RMP 82, 3045 (2010)
 J. Moore, Nature 464, 194 (2010).
 XL Qi & SC Zhang arXiv:1008.2026



Marijuana Fermions



Anyons



Pressure

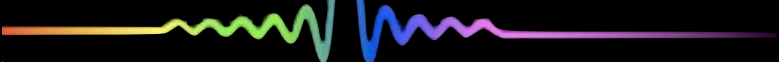
Temperature

Theory:

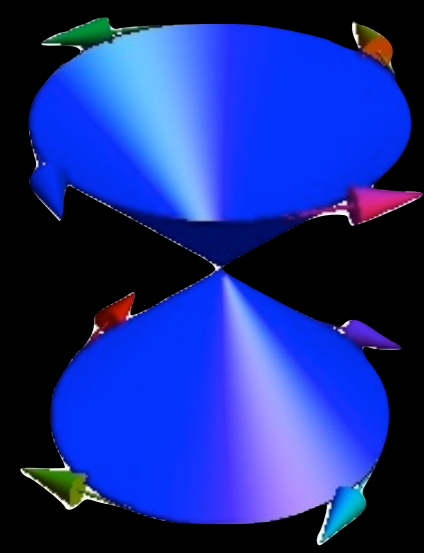
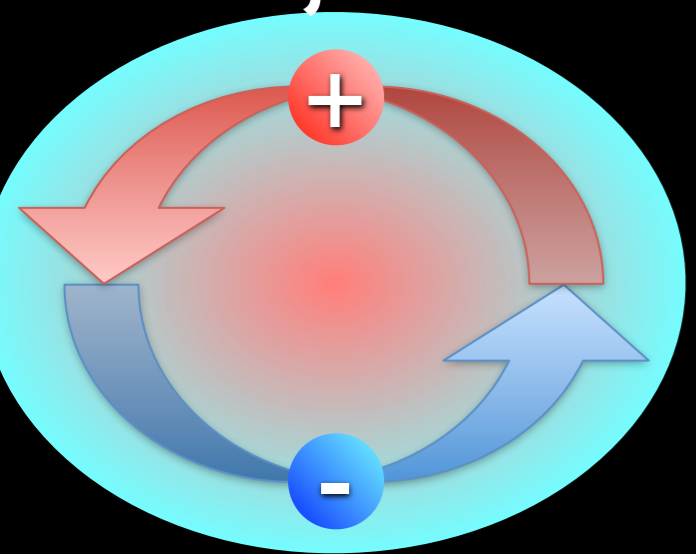
M.Z. Hasan & C.L. Kane, RMP 82, 3045 (2010)

J. Moore, Nature 464, 194 (2010).

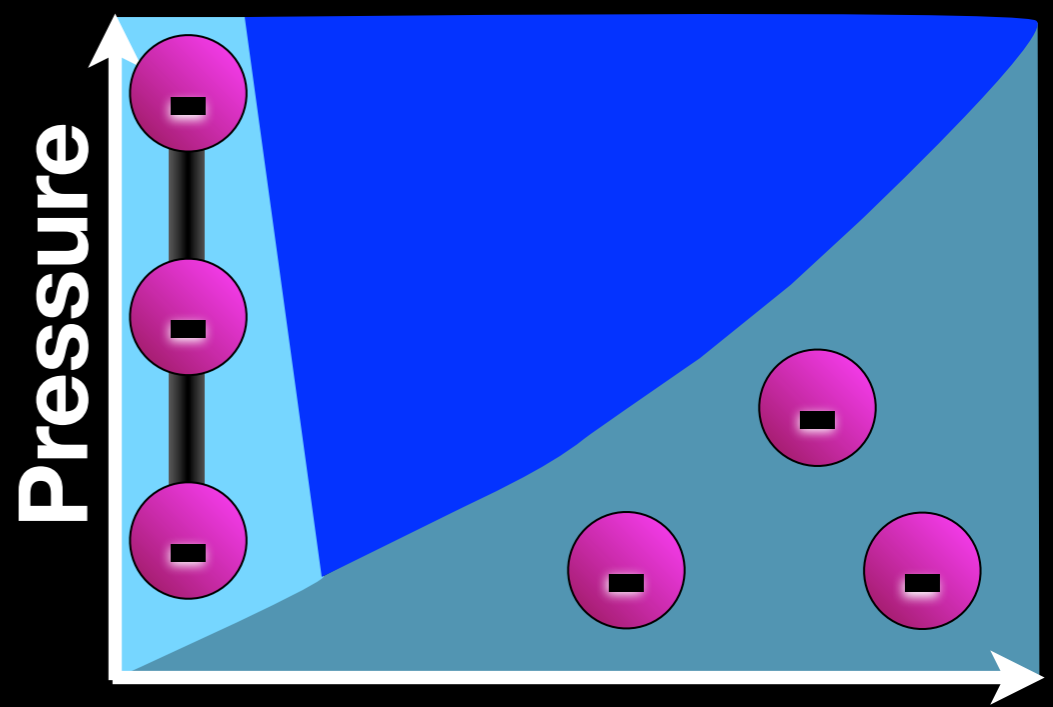
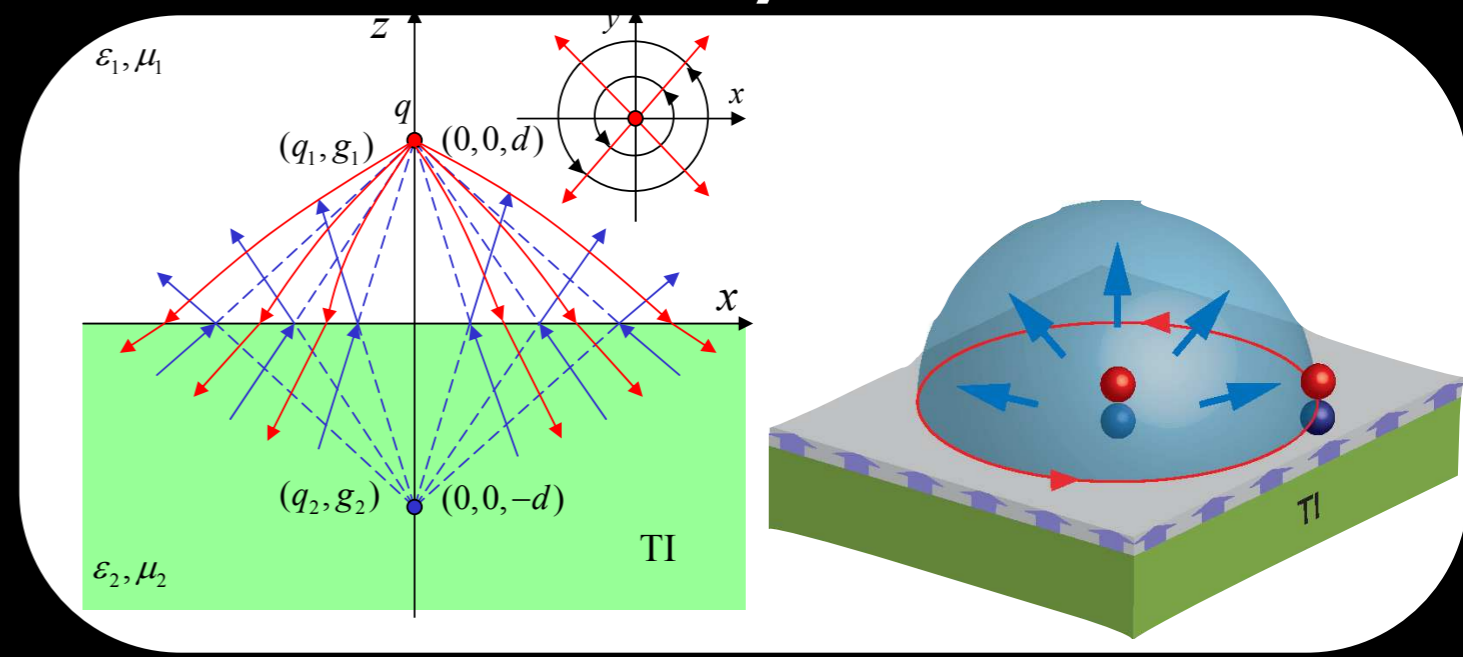
XL Qi & SC Zhang arXiv:1008.2026



Majoranna Fermions



Anyons



Temperature

Theory:
 M.Z. Hasan & C.L. Kane, RMP 82, 3045 (2010)
 J. Moore, Nature 464, 194 (2010).
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Towards the Surface

3500K Gap - Bi_2Se_3

S.Y.F. Zhao et al., APL 98, 141911 (2011)

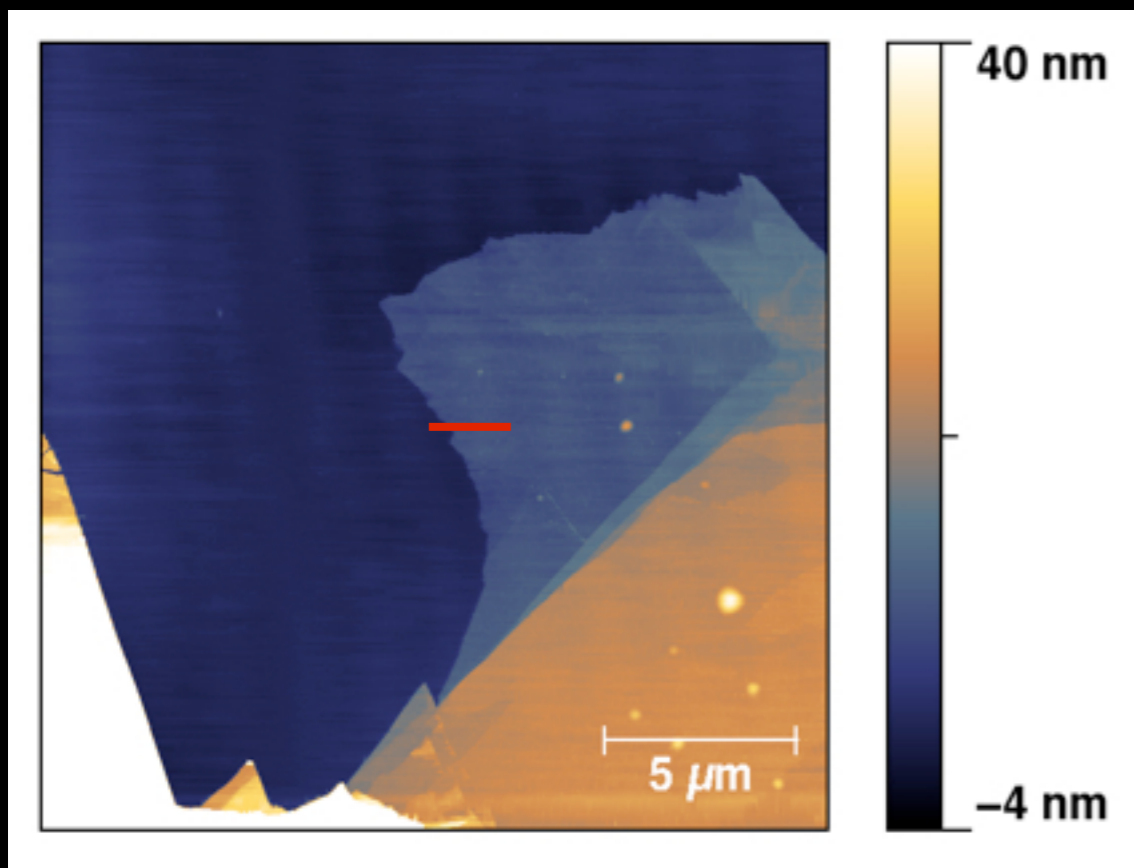




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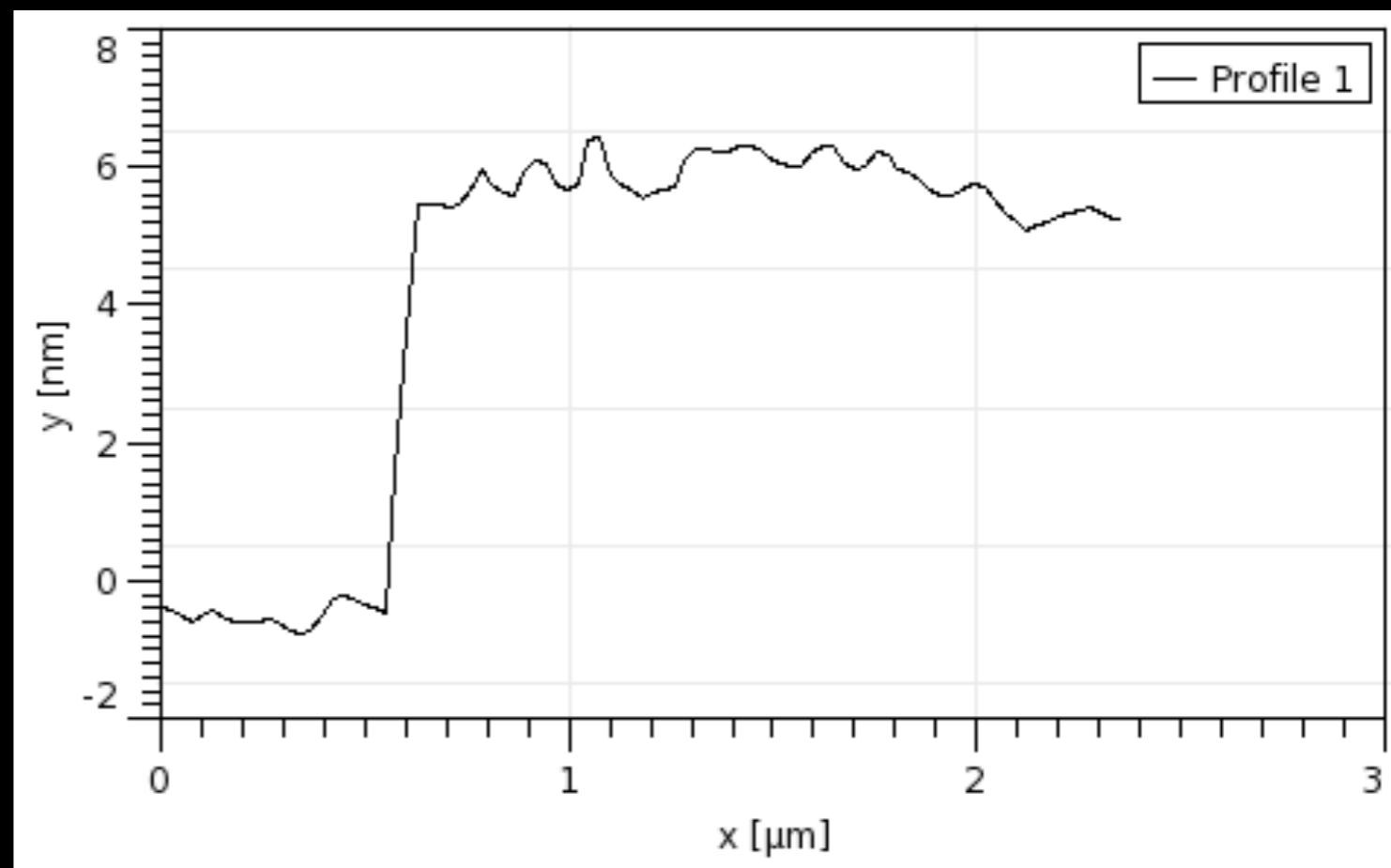
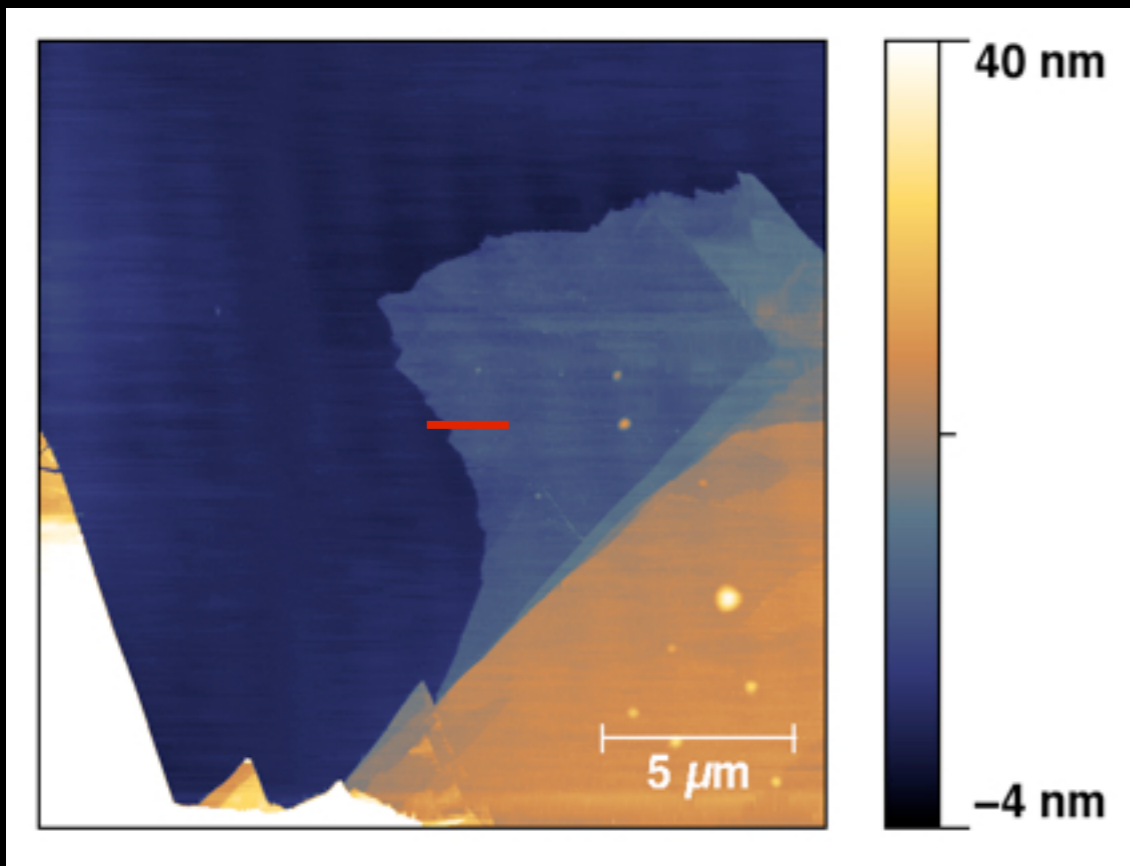




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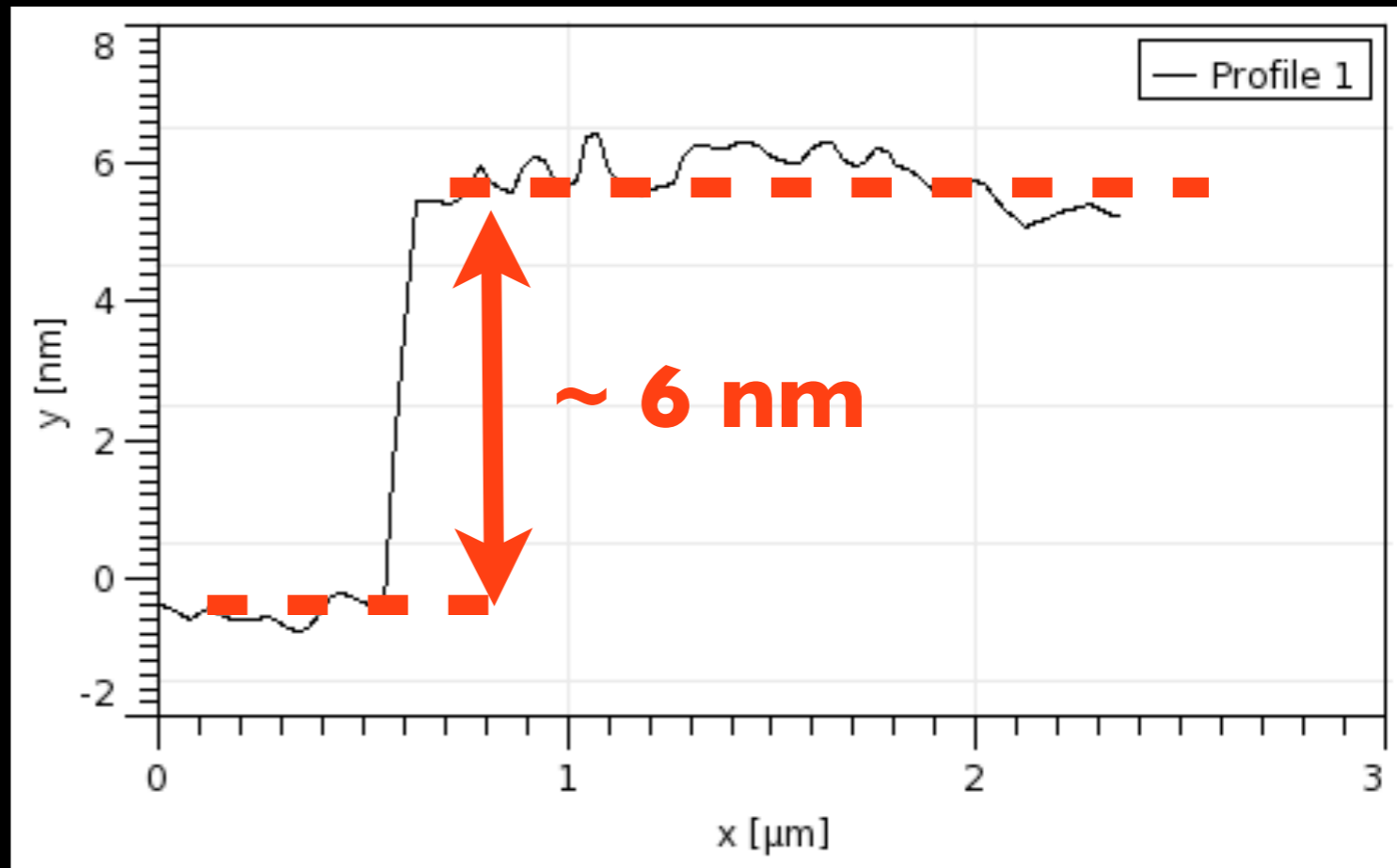
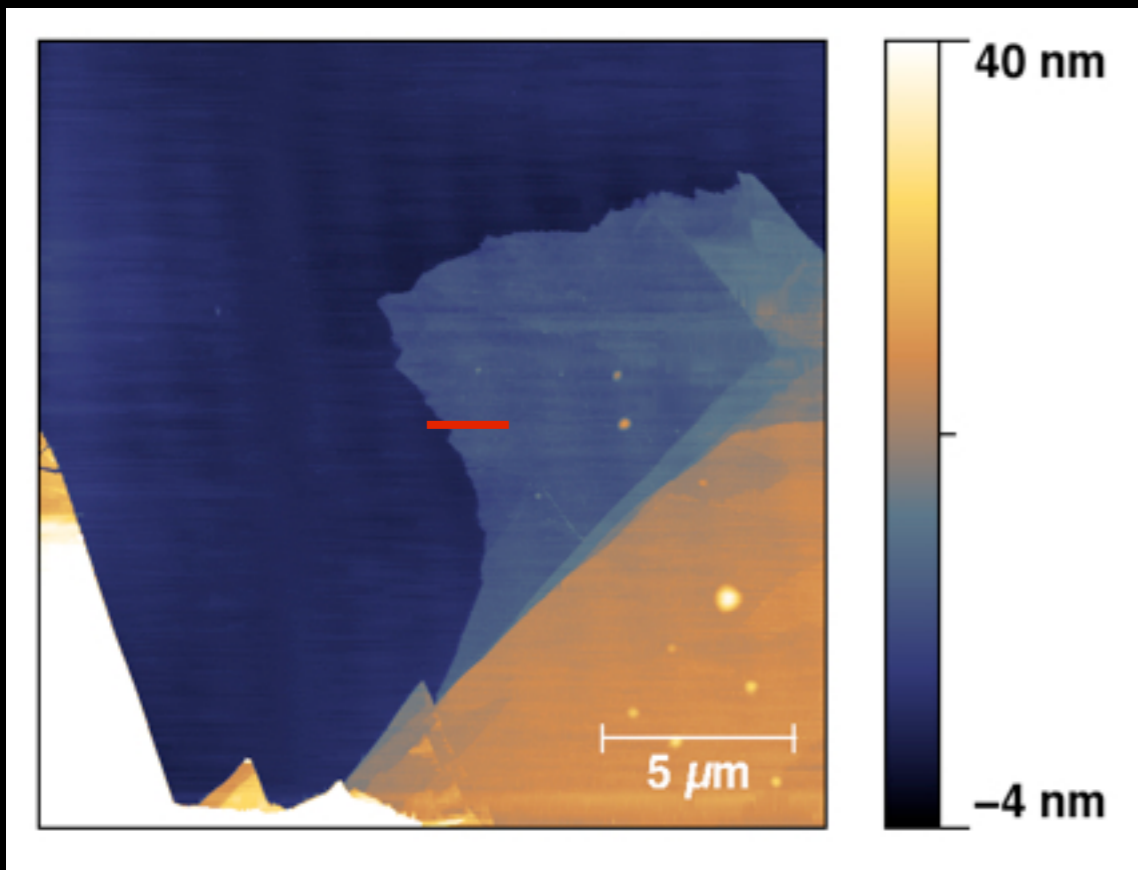




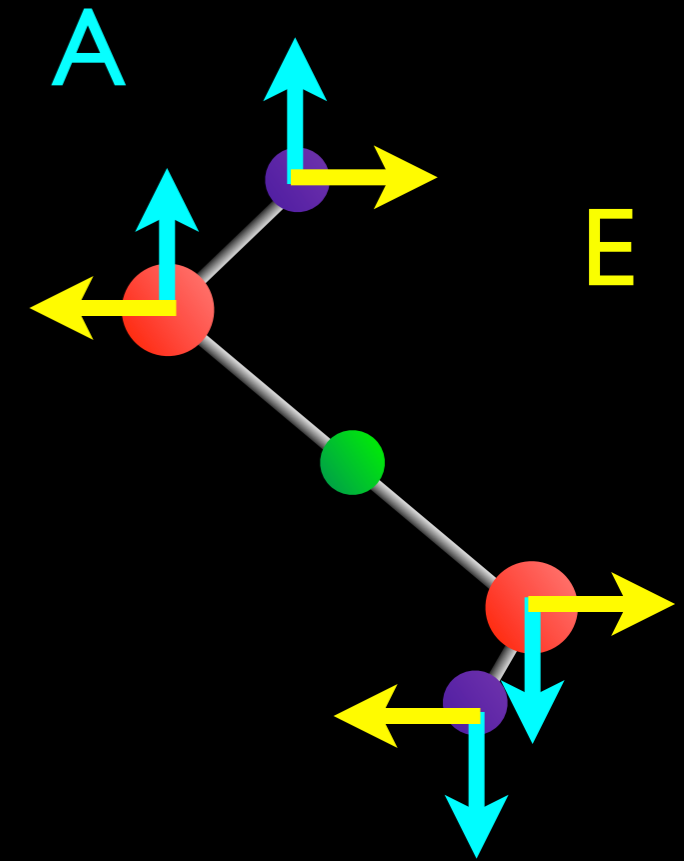
Towards the Surface

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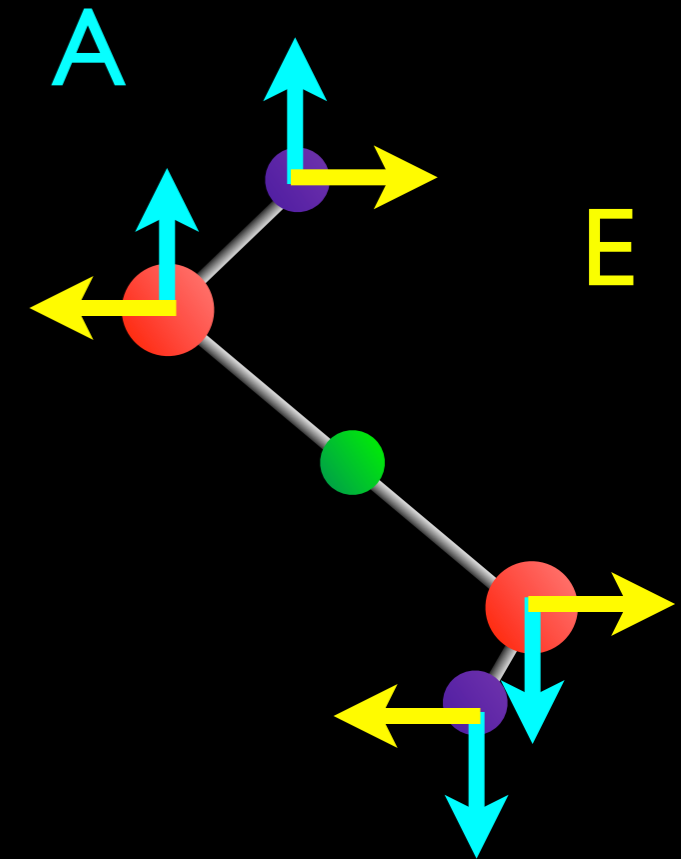
Raman



	Ir	Raman
A_{1G}		72,174.5
E_G		131.5
A_{1u}	135,161.5	
E_U	65,129	

S.Y.F. Zhao et al., APL 98, 141911 (2011)

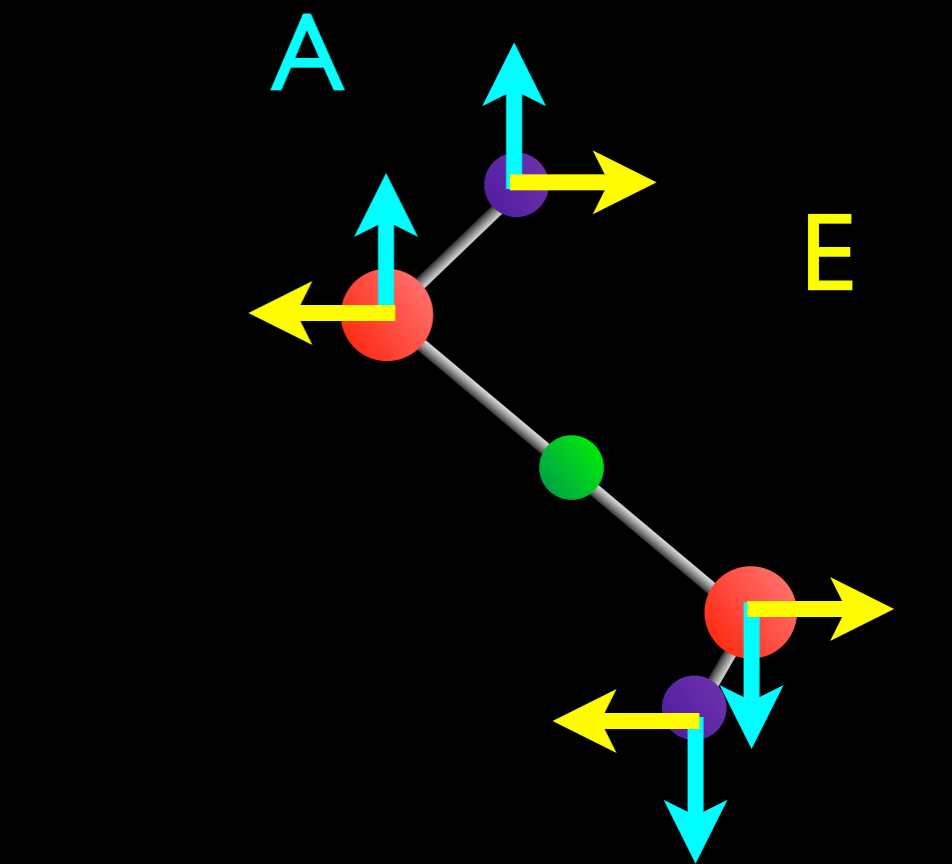
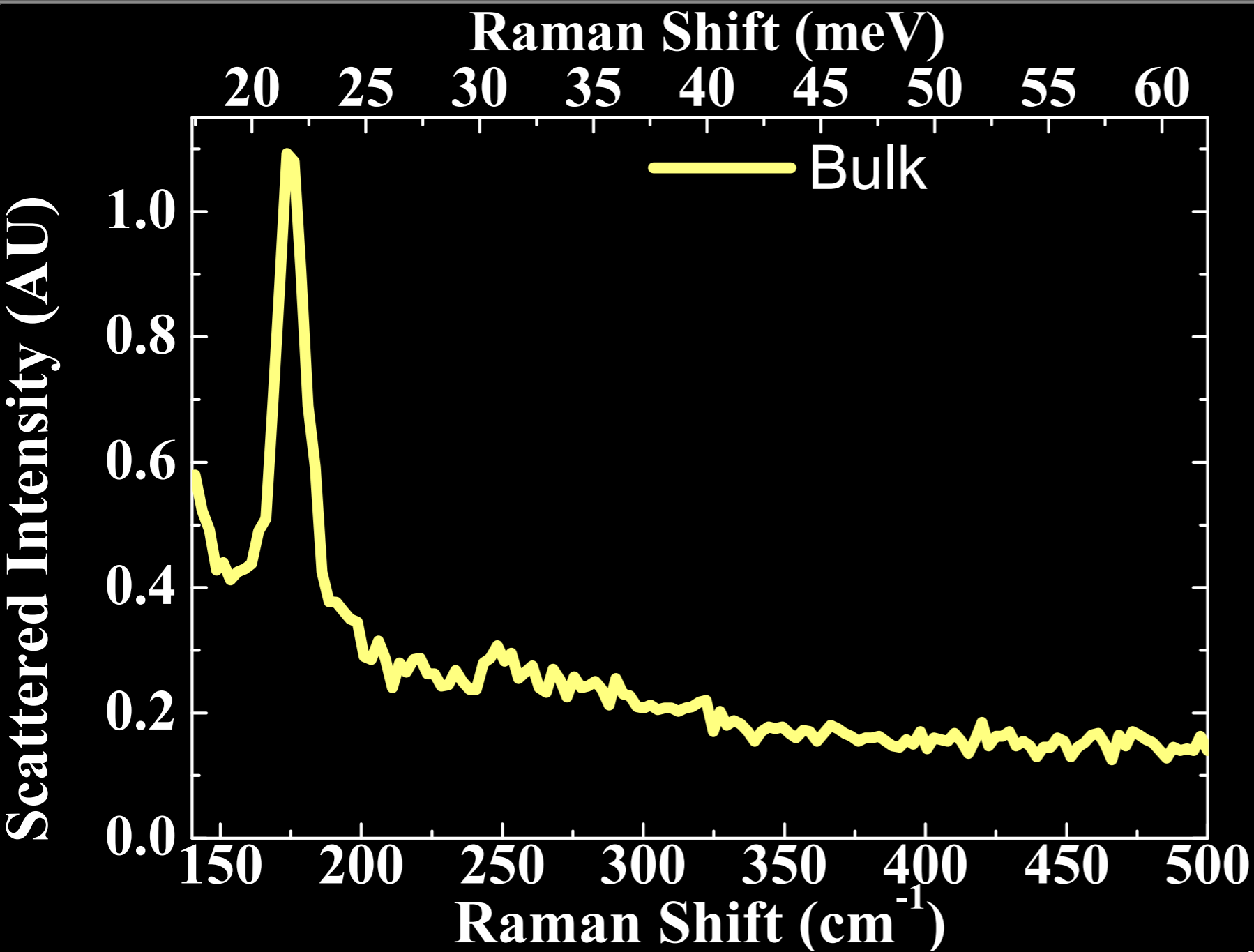
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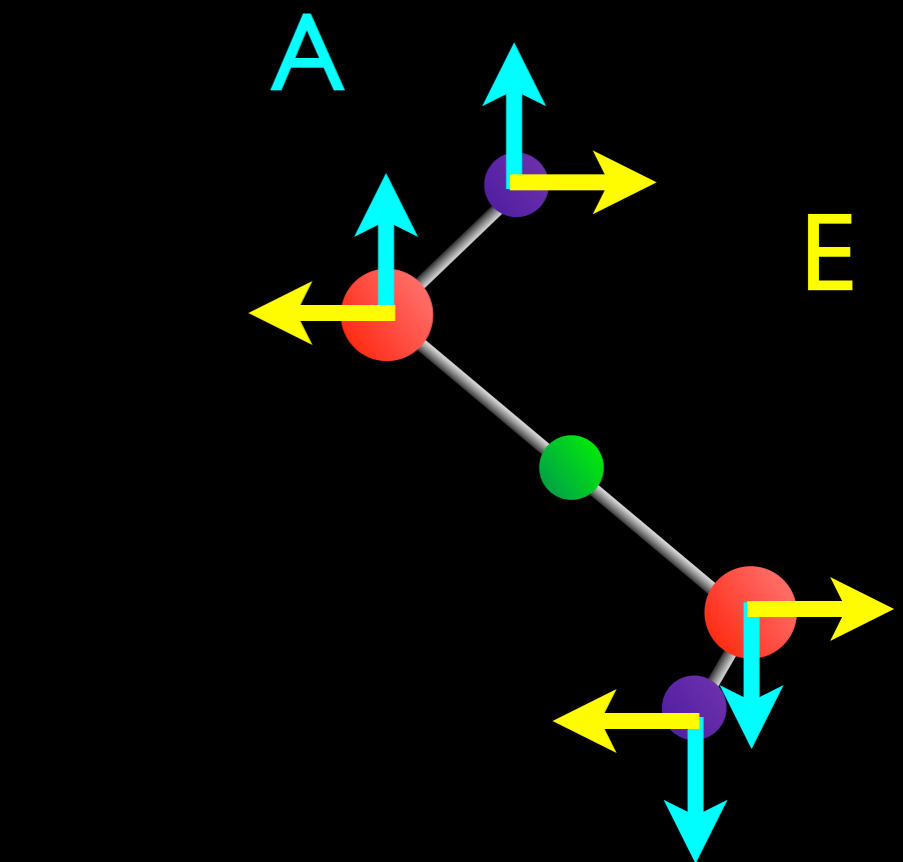
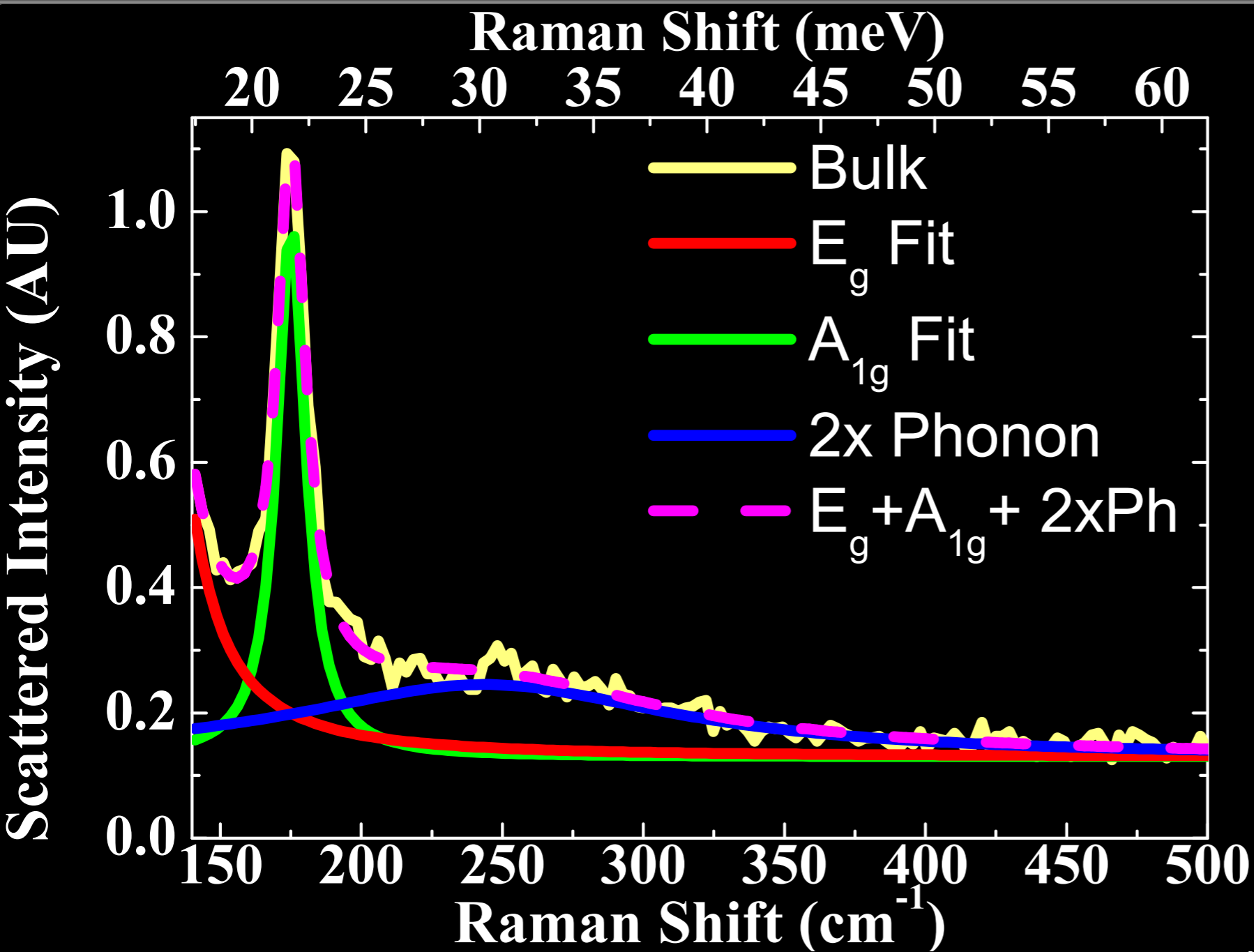
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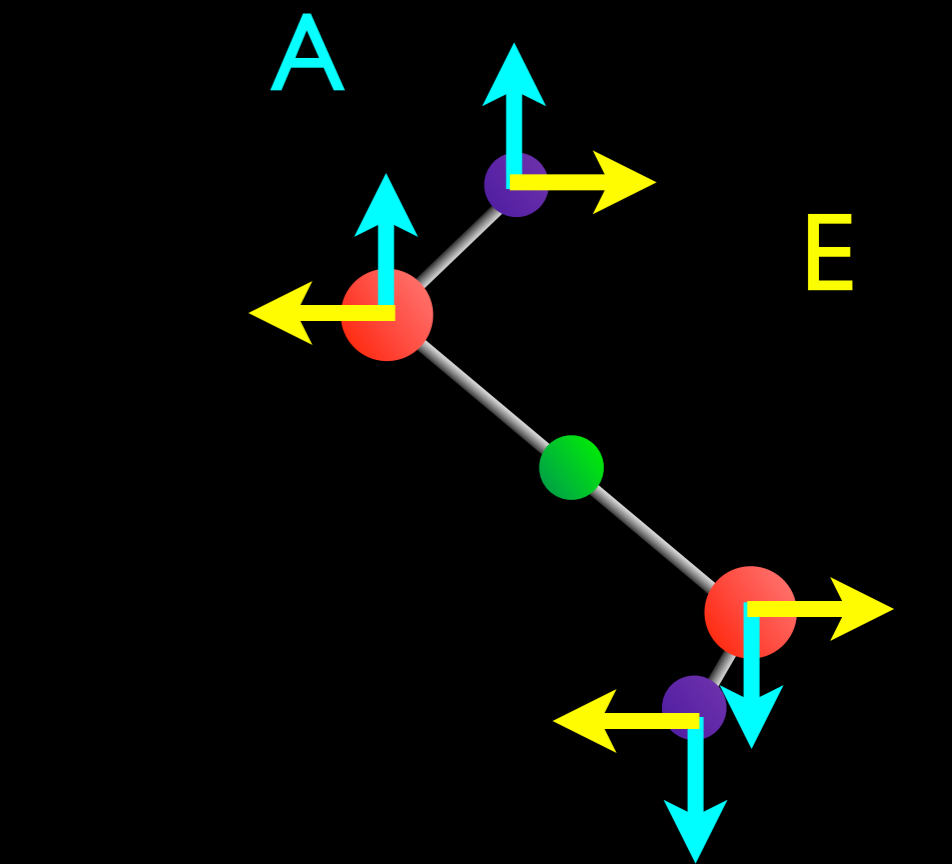
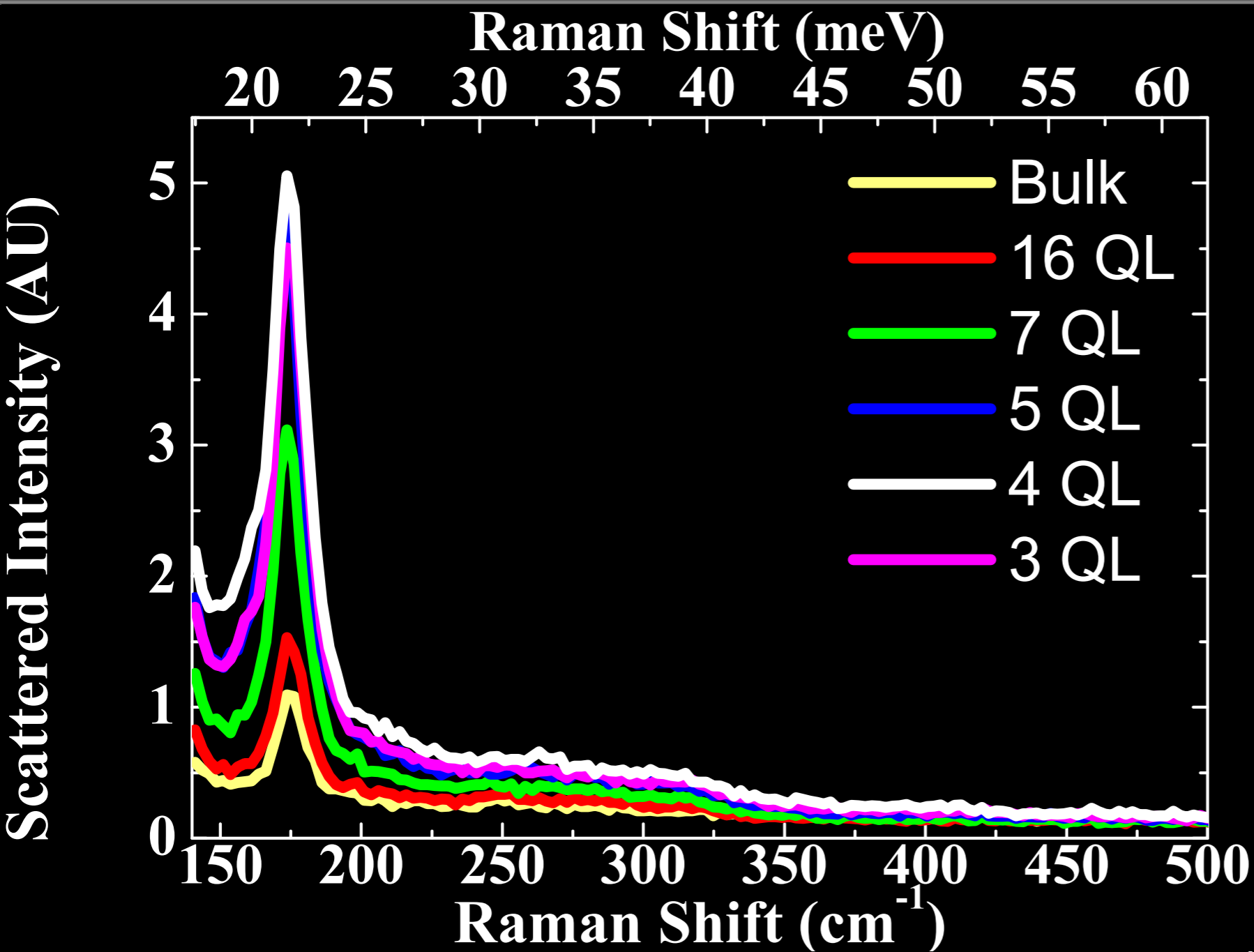
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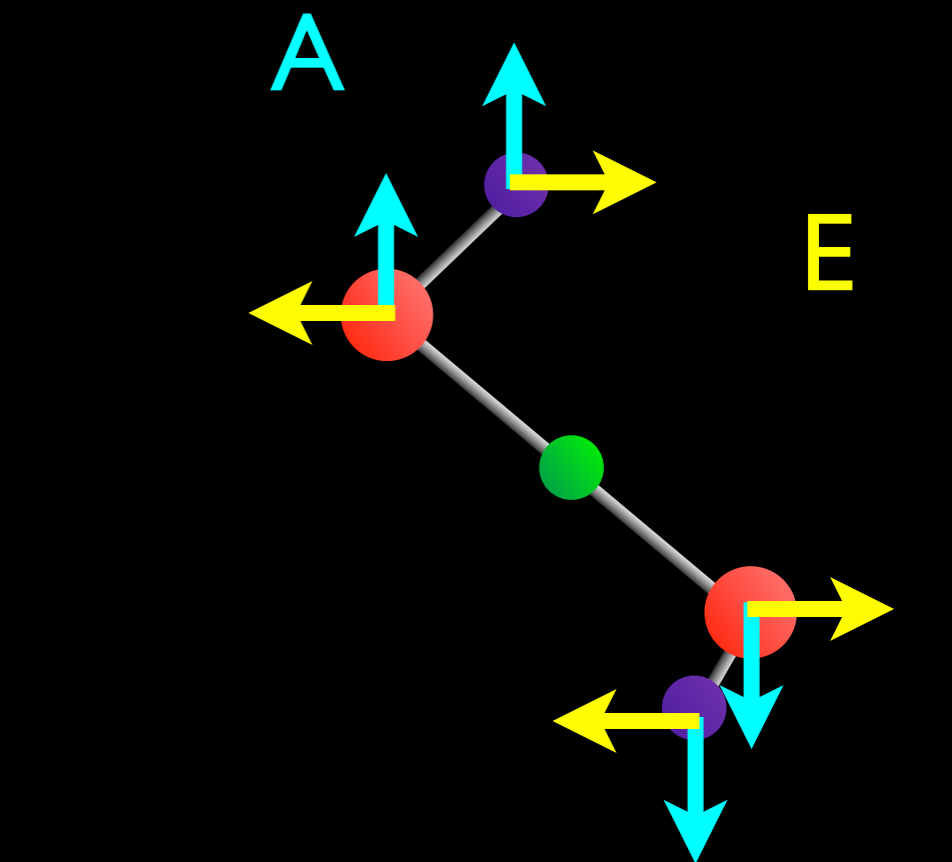
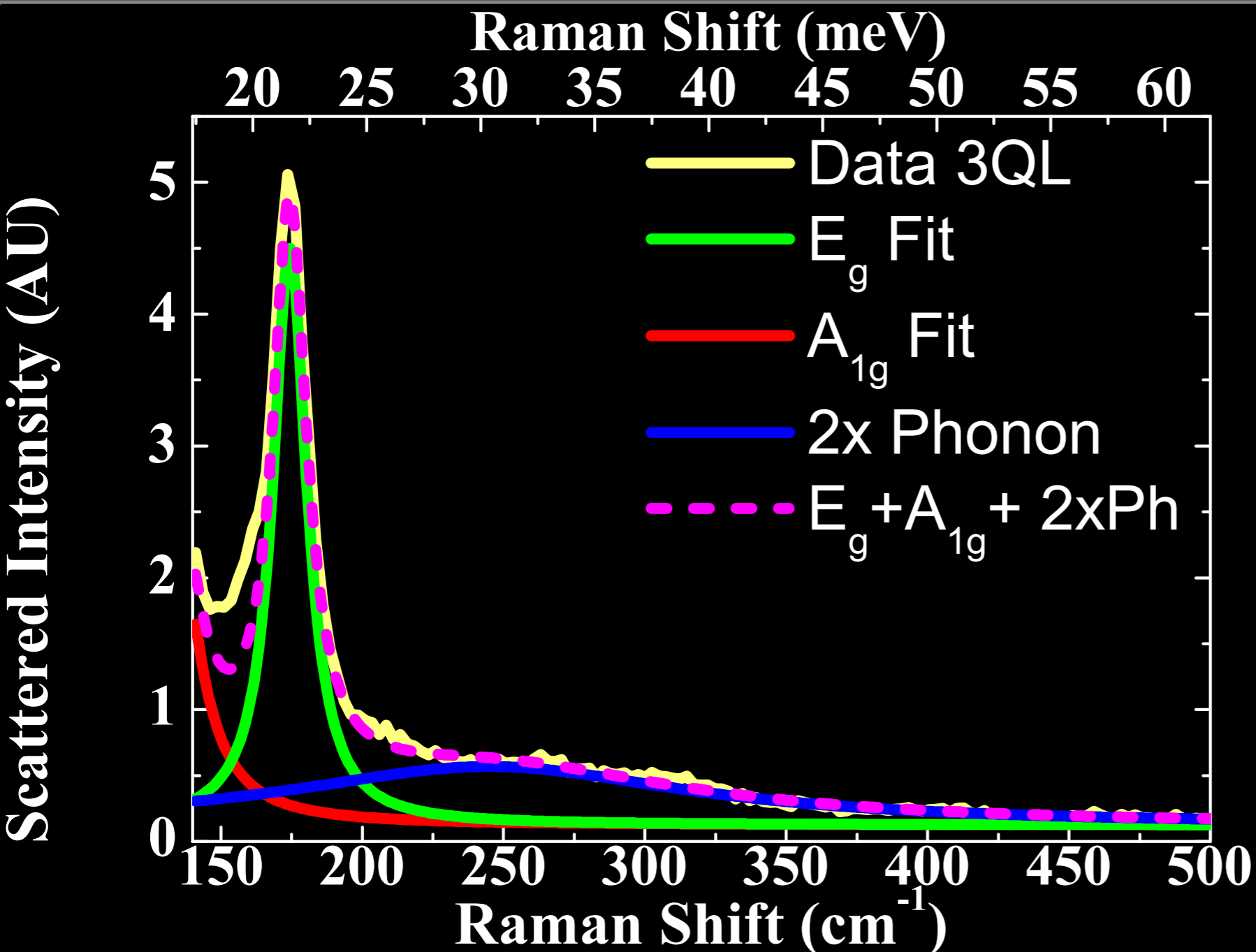
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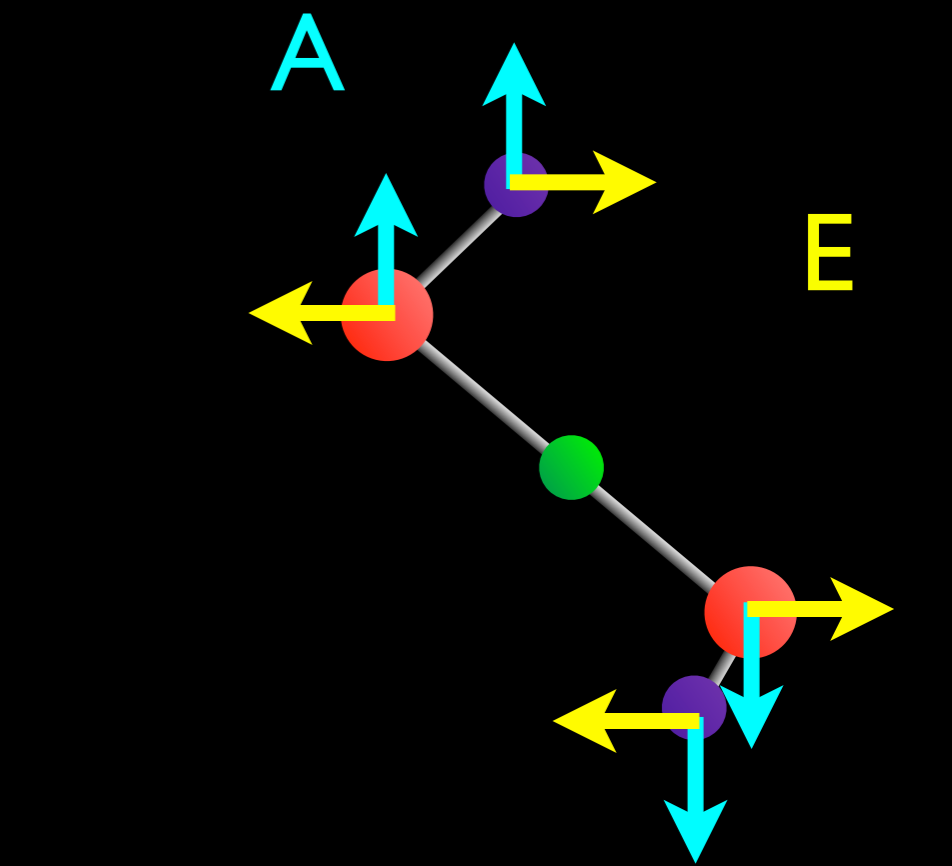
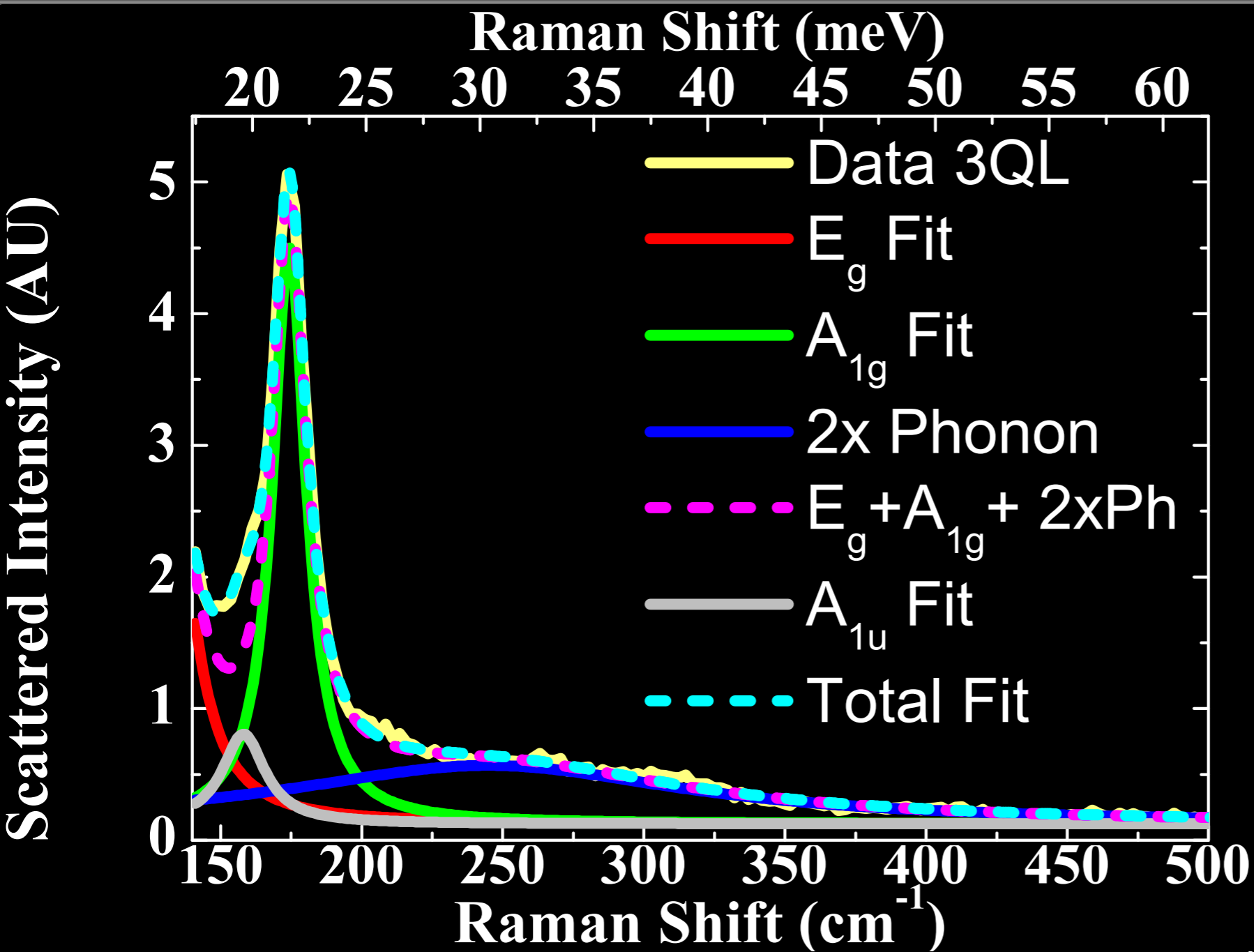
Raman



S.Y.F. Zhao et al., APL 98, 141911 (2011)

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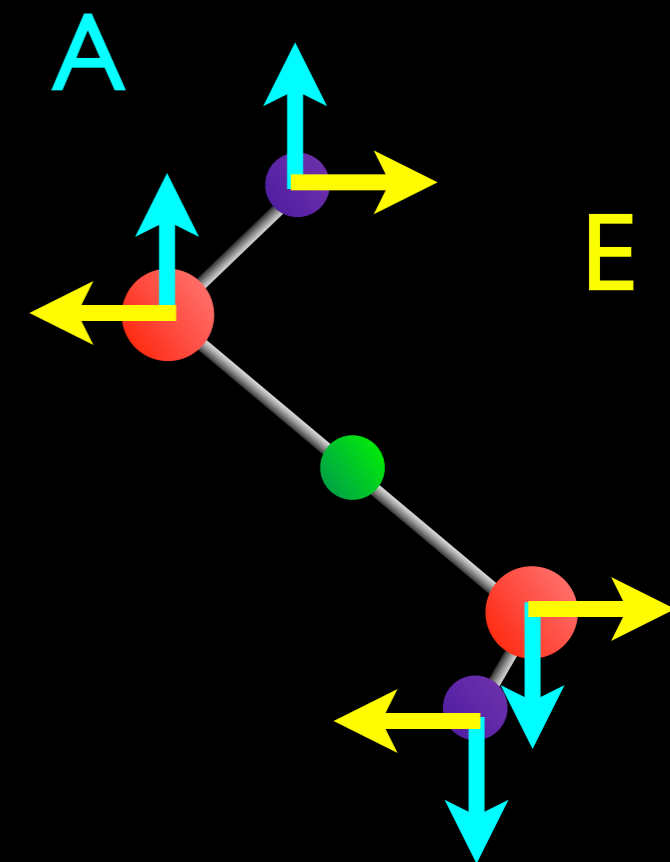
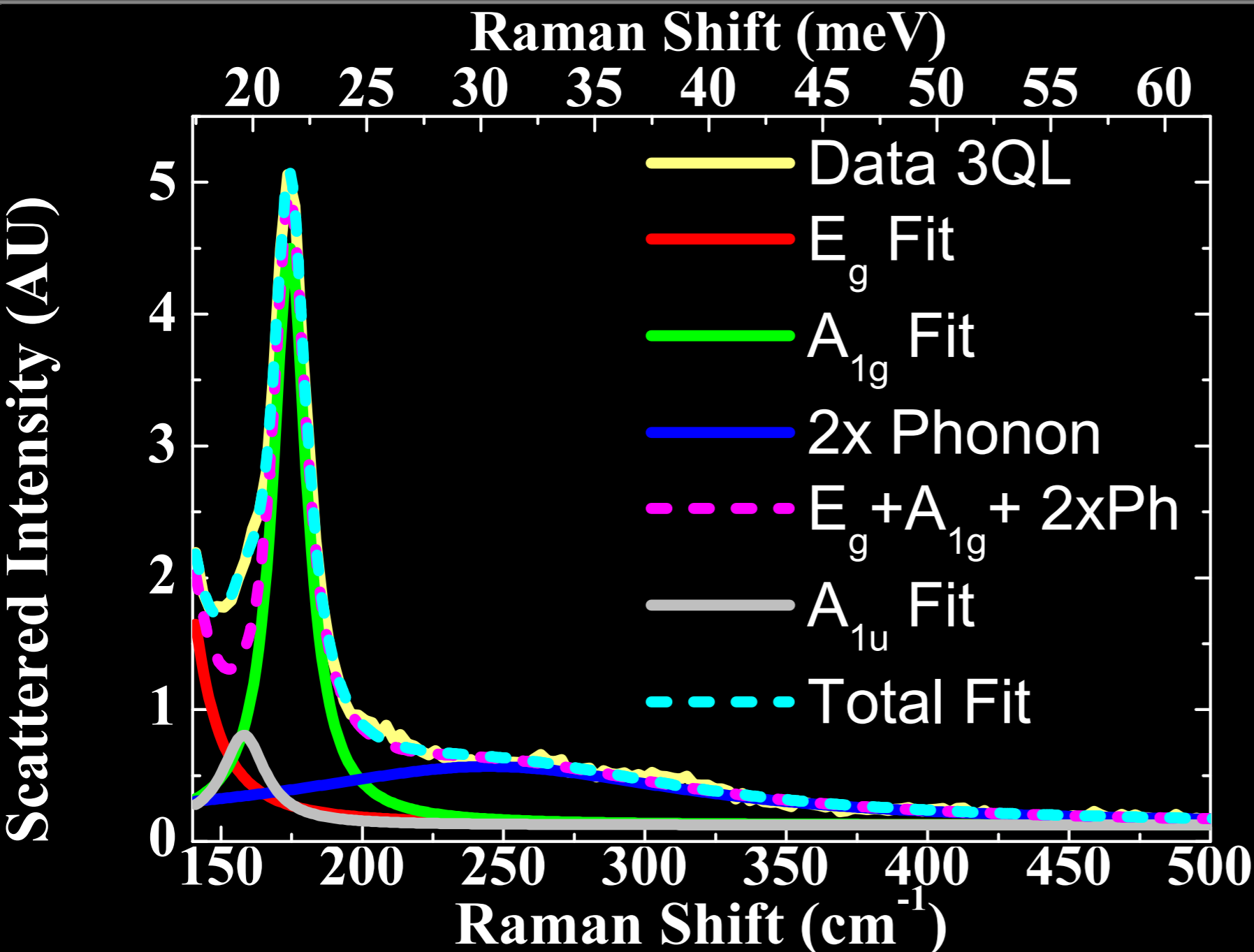
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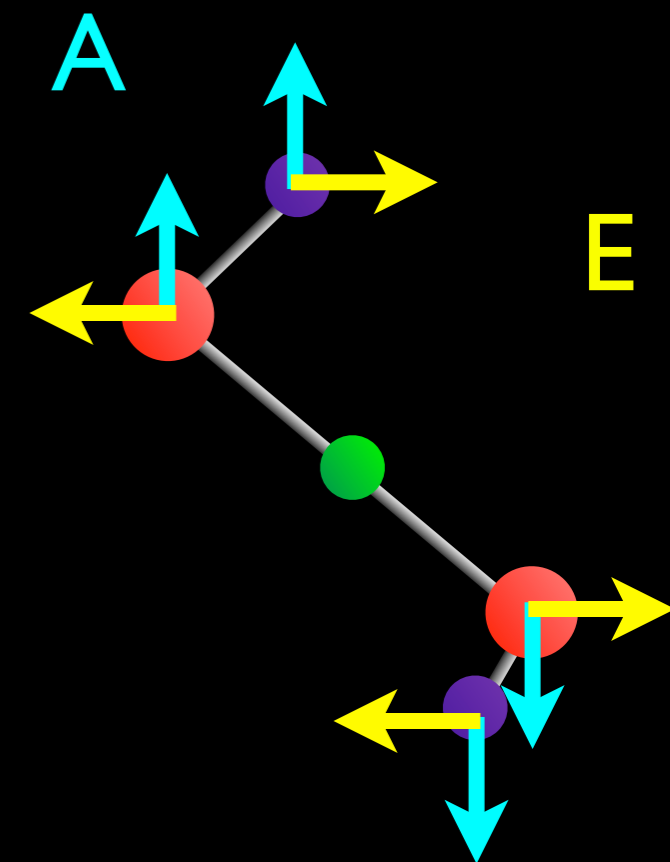
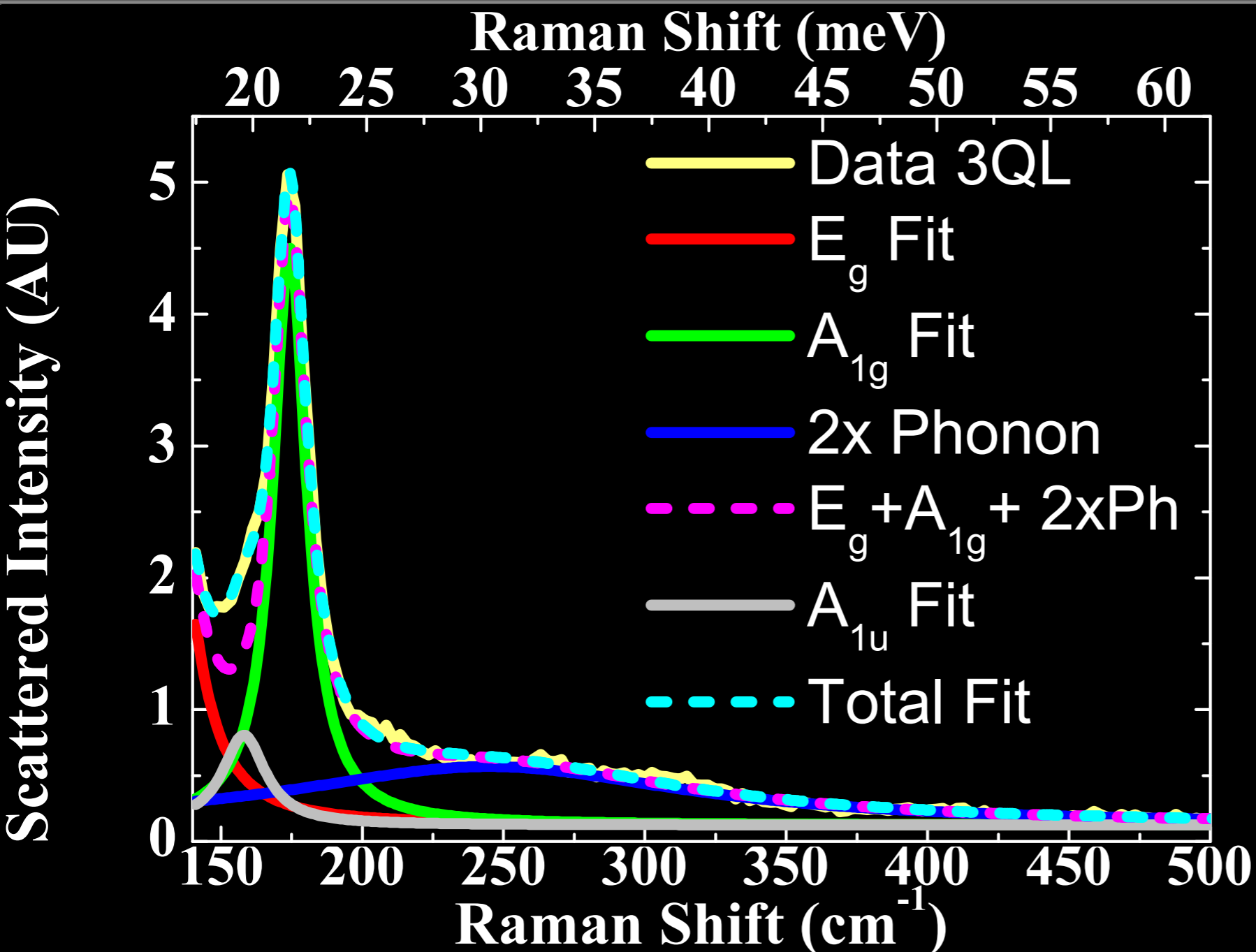


Ir (LO) Mode

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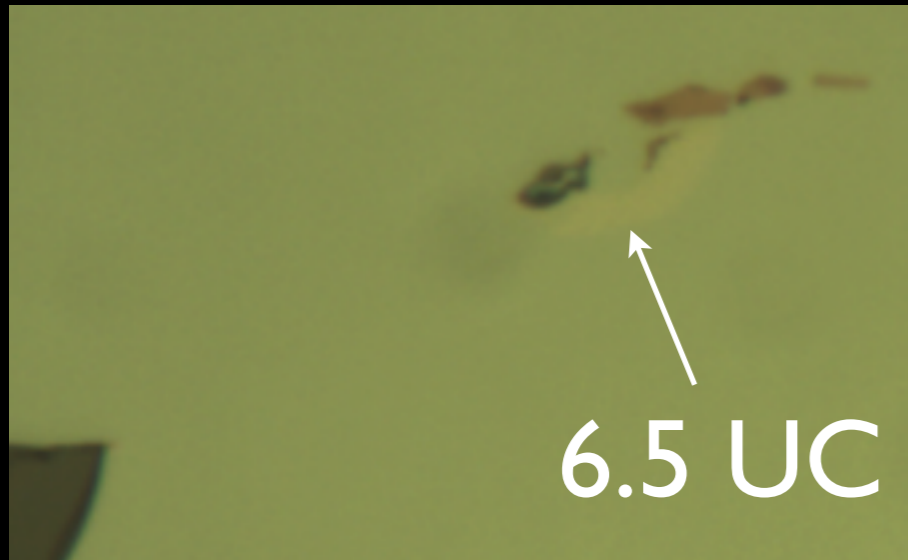
X. Zhu et al., arxiv 1108.2470

THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR
ALL AUDIENCES
BY THE MOTION PICTURE ASSOCIATION OF AMERICA

www.filmratings.com

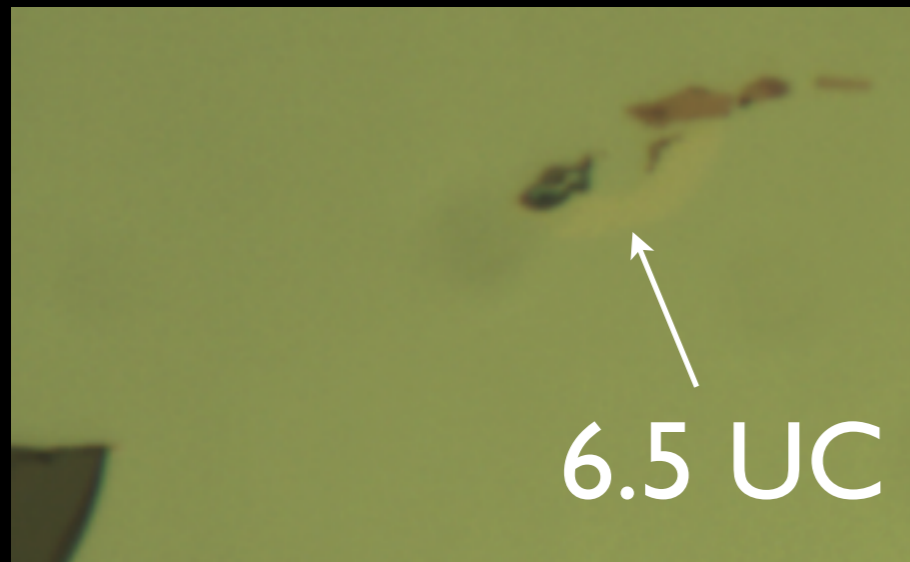
www.mpa.org

Bi-2212 on SrTiO₃/Si

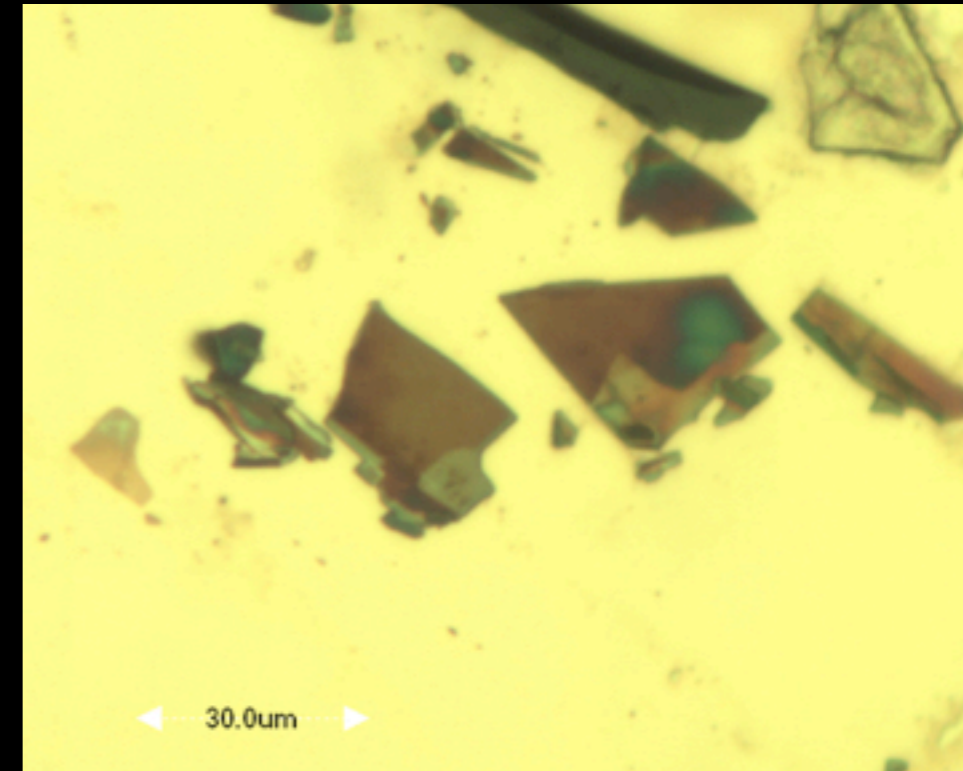


Substrates

Bi-2212 on SrTiO₃/Si

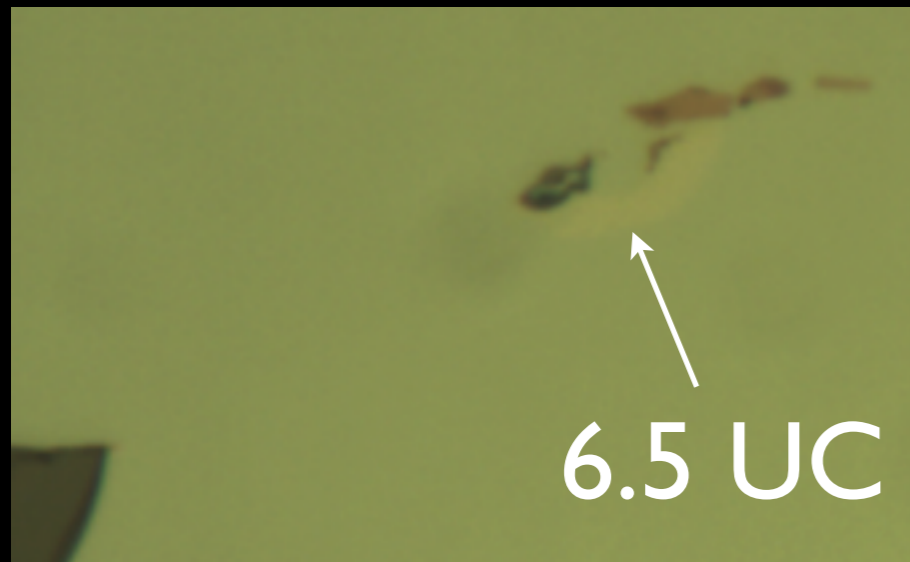


Bi-2212 on Au/Si

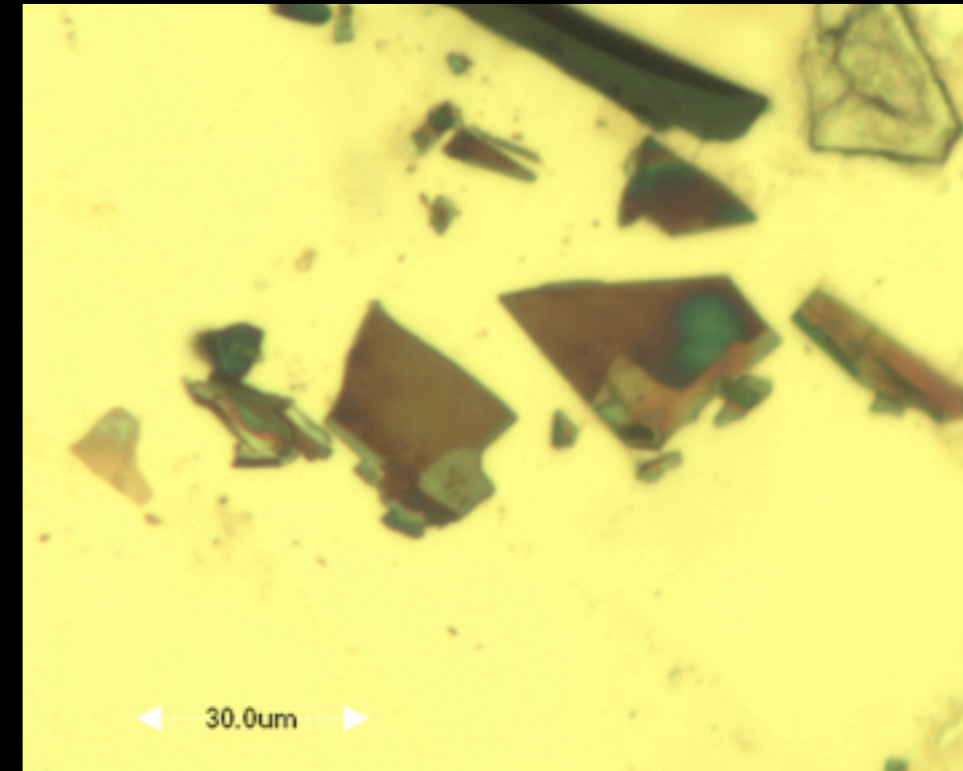


Substrates

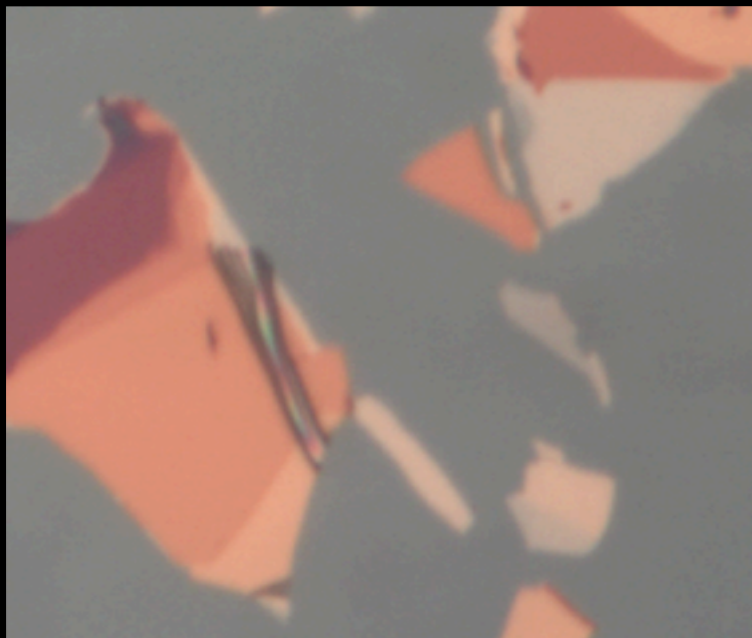
Bi-2212 on SrTiO₃/Si



Bi-2212 on Au/Si

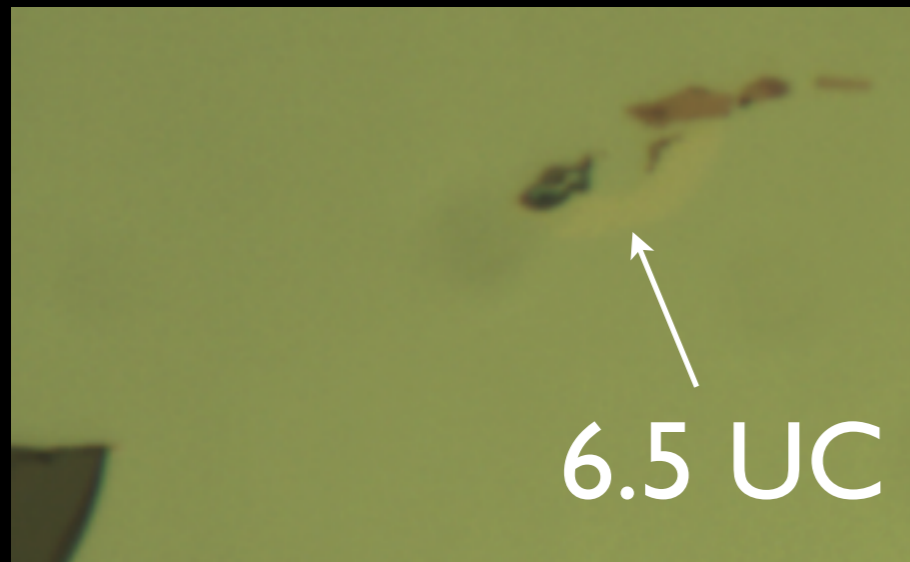


Bi-2212 on HfO₂/Si

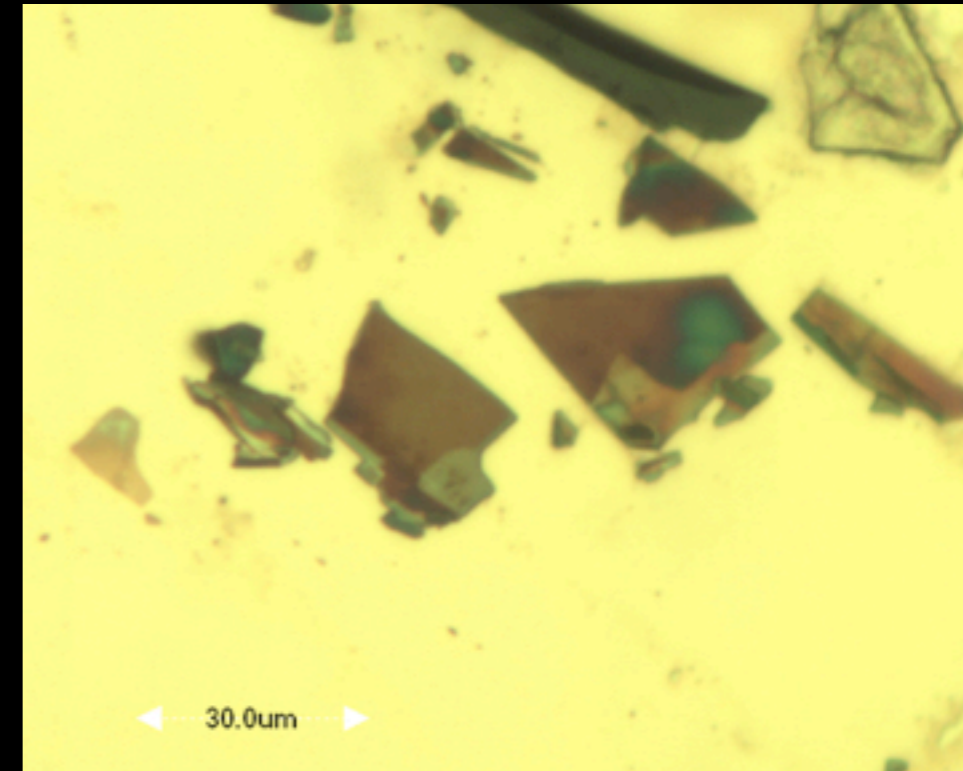


Substrates

Bi-2212 on SrTiO₃/Si

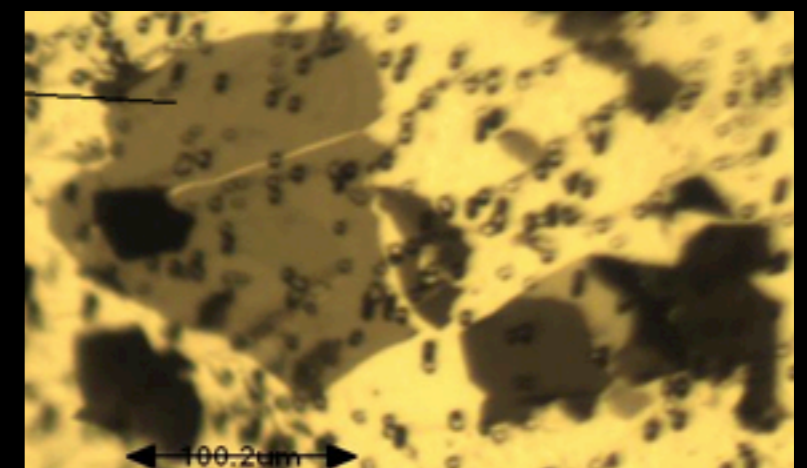
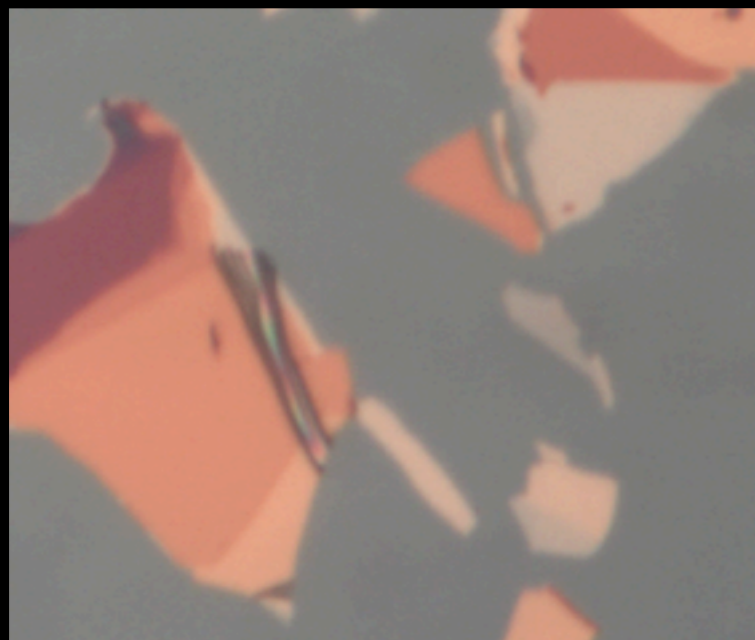


Bi-2212 on Au/Si



Porous Polycarbonate

Bi-2212 on HfO₂/Si



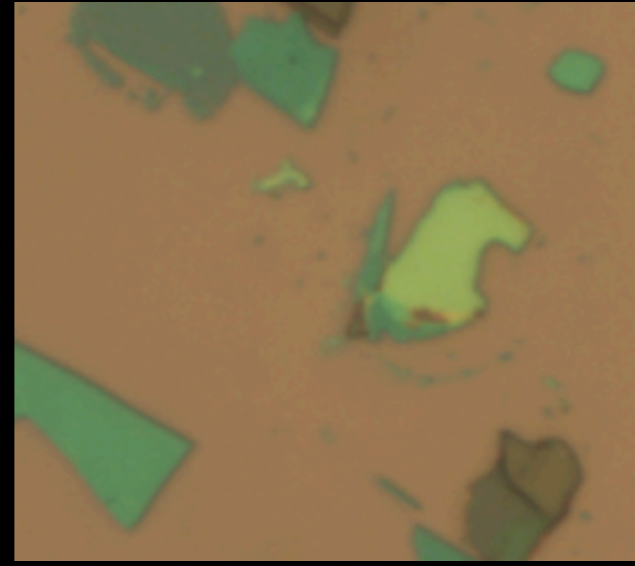
Bi-2212 on SrTiO₃/Si vs SiO₂/Si

Visibility

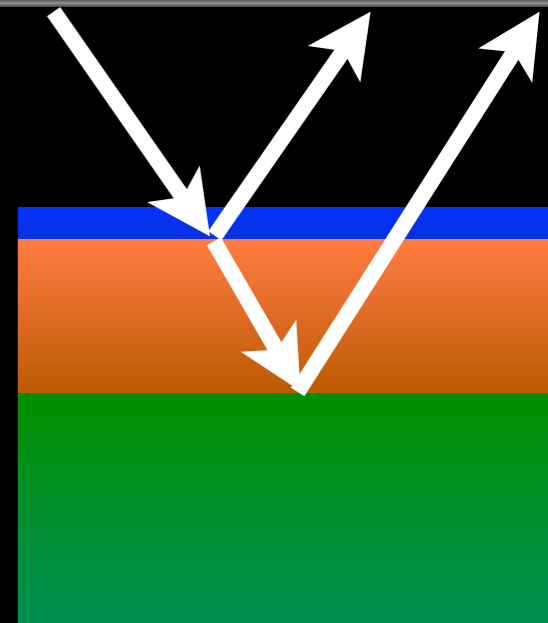


Challenges

Bi-2212 on SrTiO₃/Si vs SiO₂/Si



Visibility



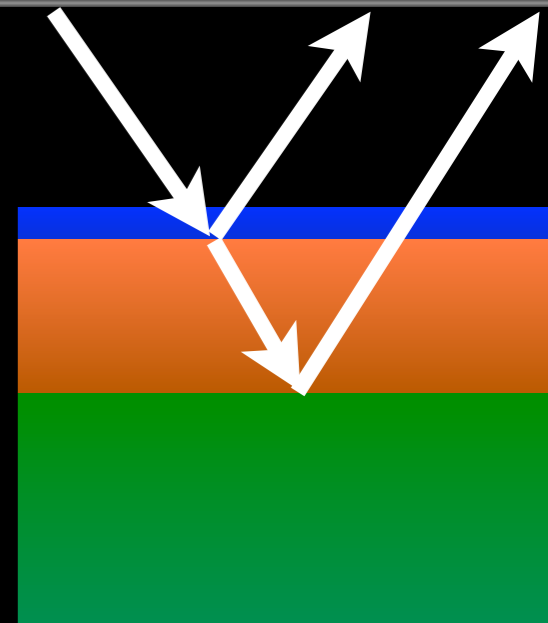
Challenges

Bi-2212 on SrTiO₃/Si vs SiO₂/Si



Visibility

“Sticky”



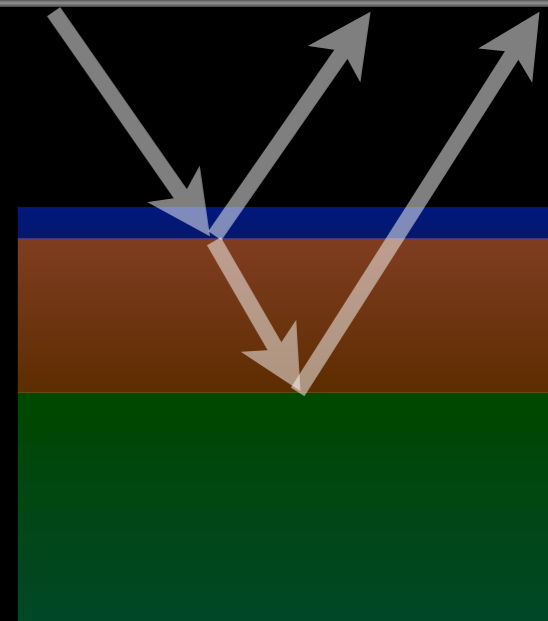
Challenges

Bi-2212 on SrTiO₃/Si vs SiO₂/Si

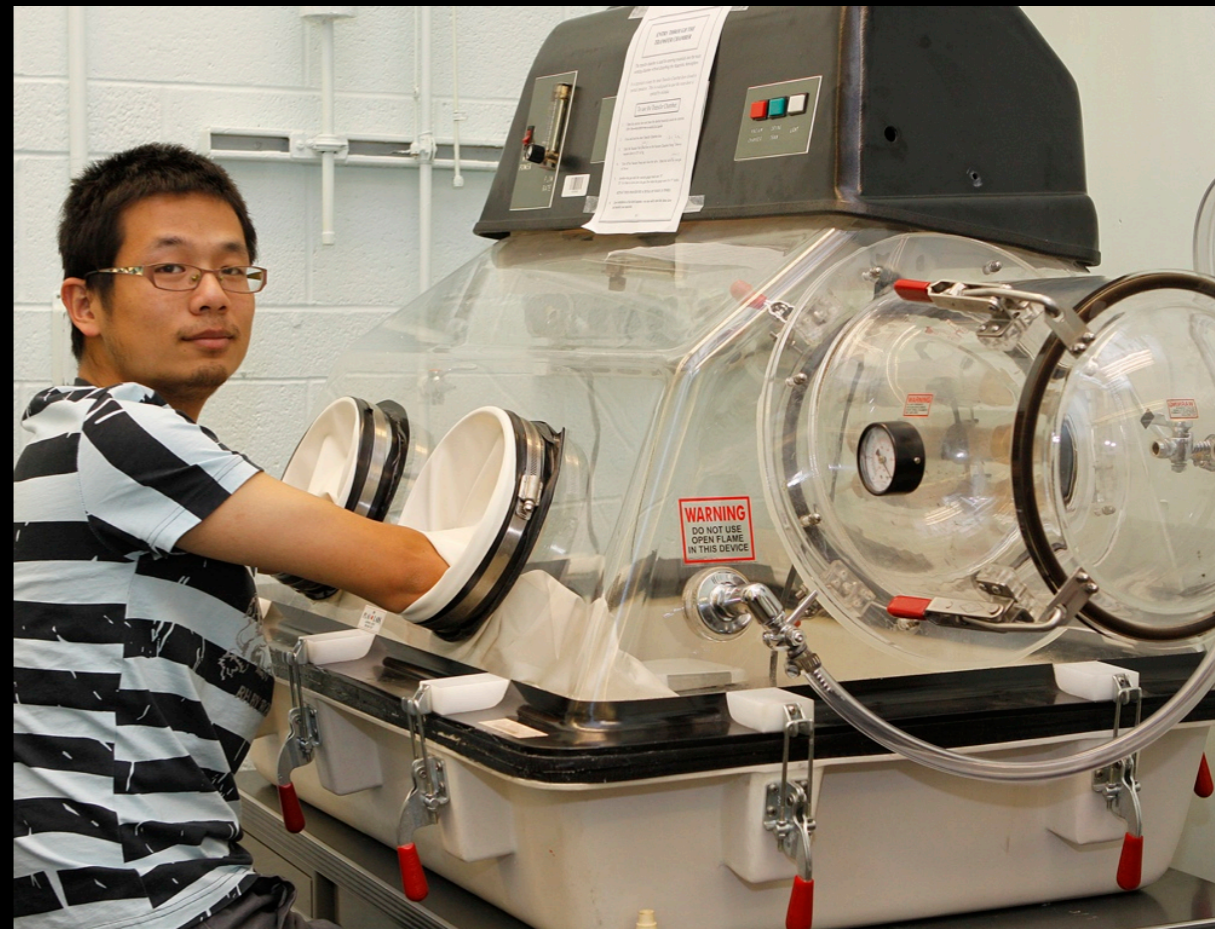


Visibility

“Sticky”



procedures



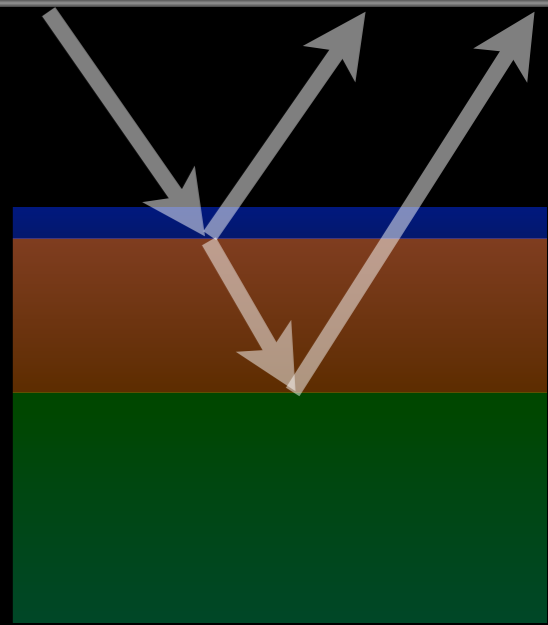
Challenges

Bi-2212 on SrTiO₃/Si vs SiO₂/Si



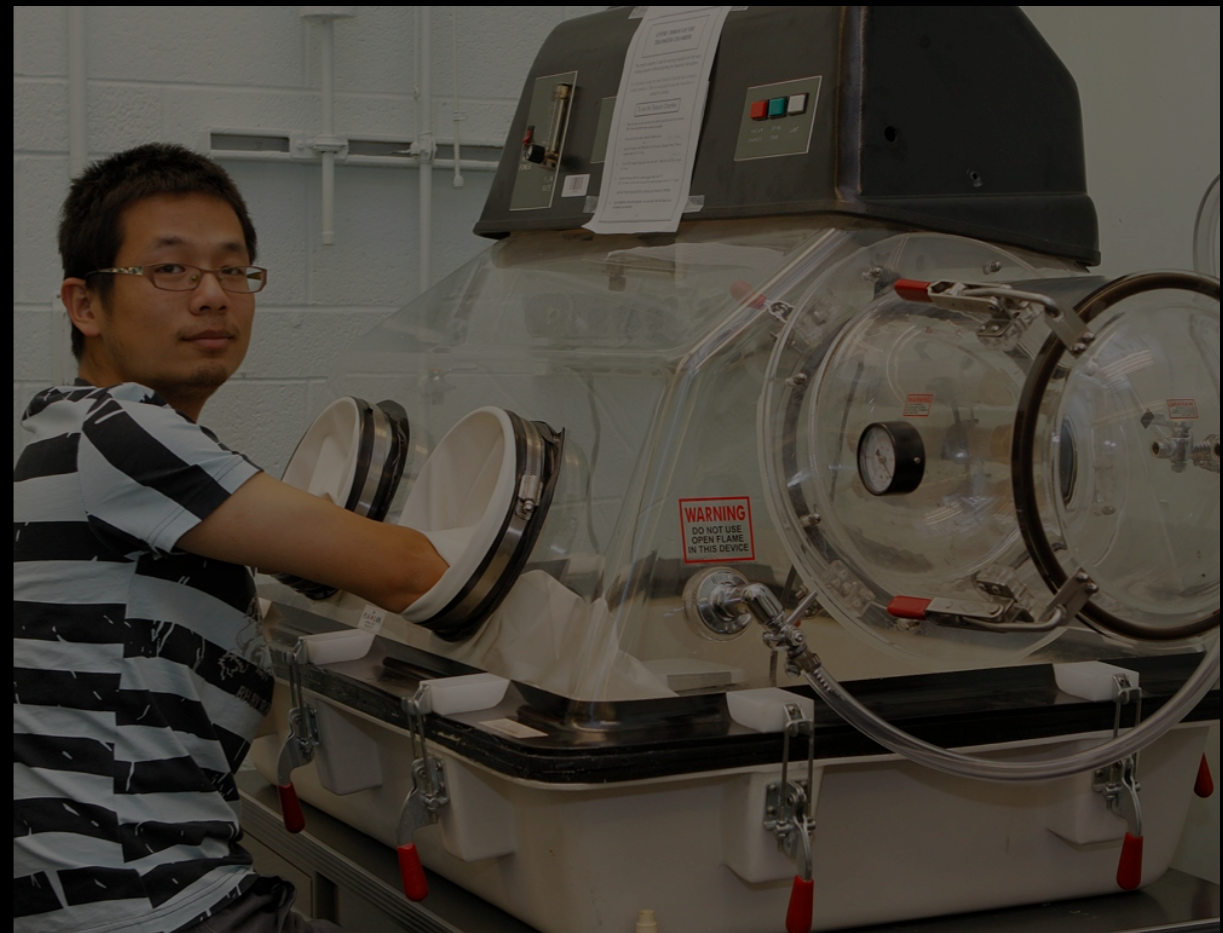
Visibility

“Sticky”



procedures

Good Combinations?





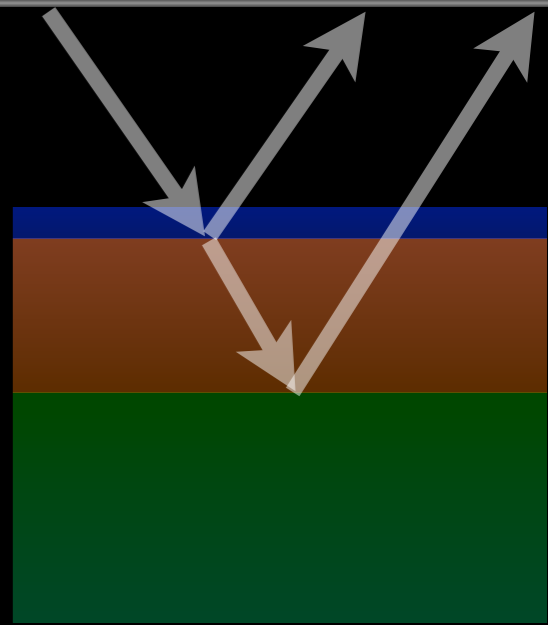
Challenges

Bi-2212 on SrTiO₃/Si vs SiO₂/Si



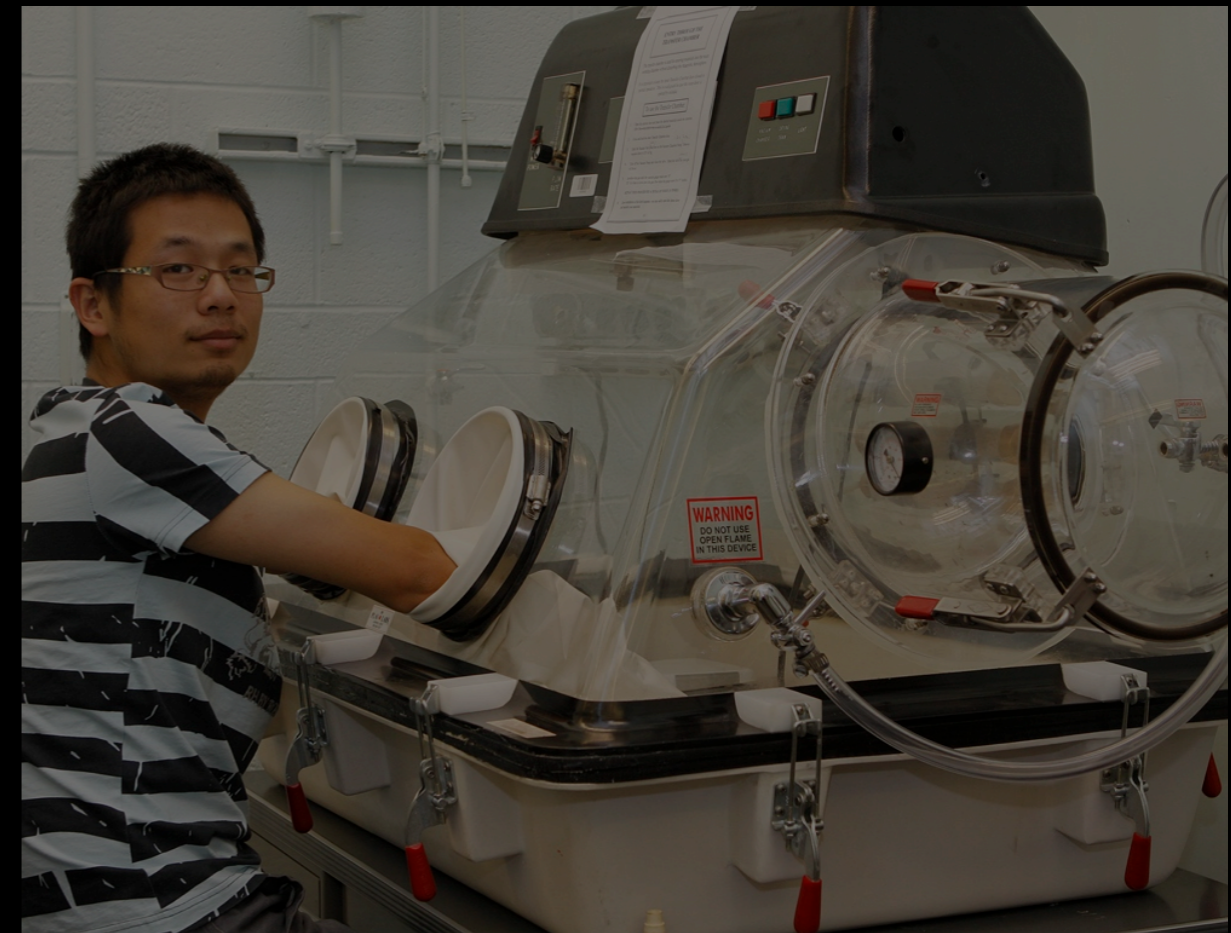
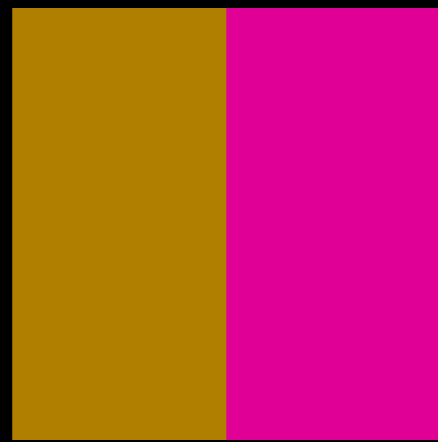
Visibility

“Sticky”



procedures

Good Combinations?





Spectroscopy



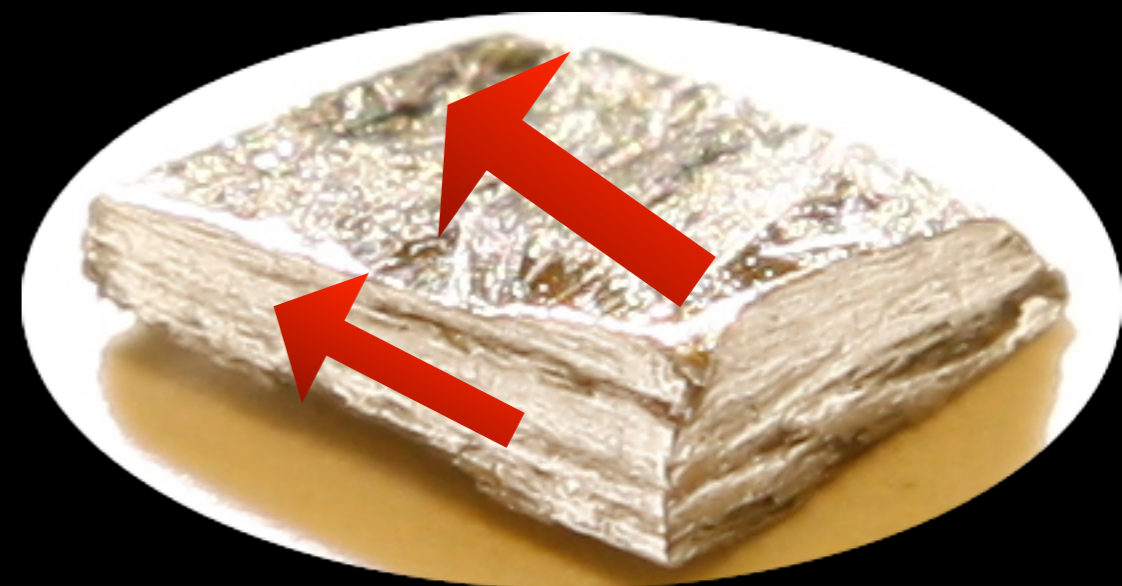


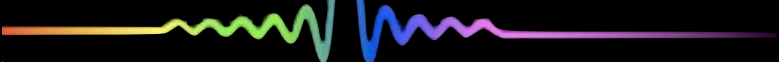
Spectroscopy



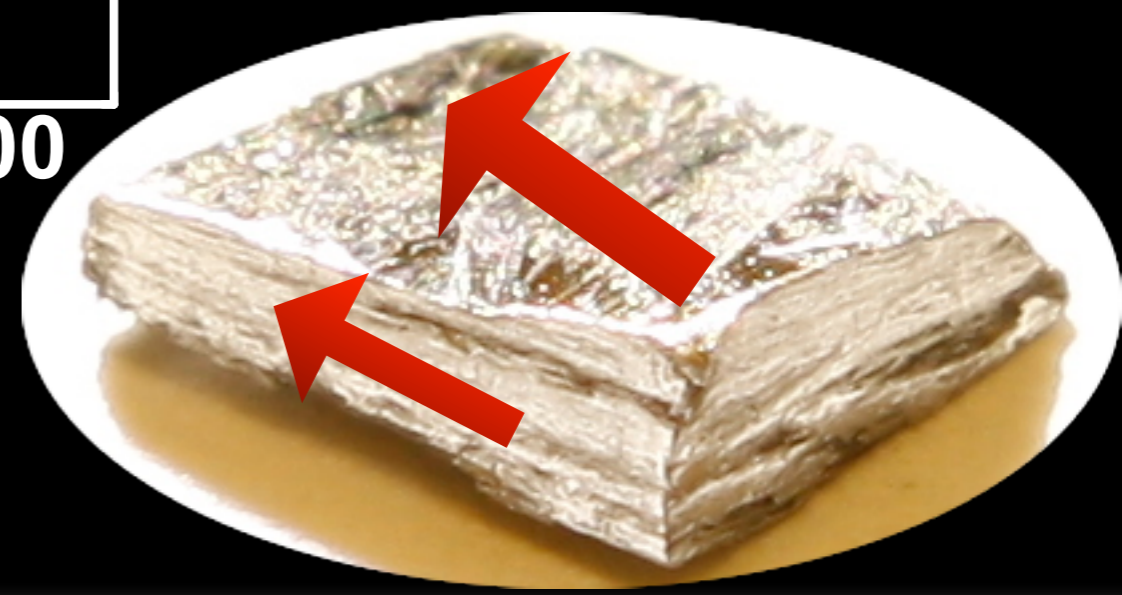
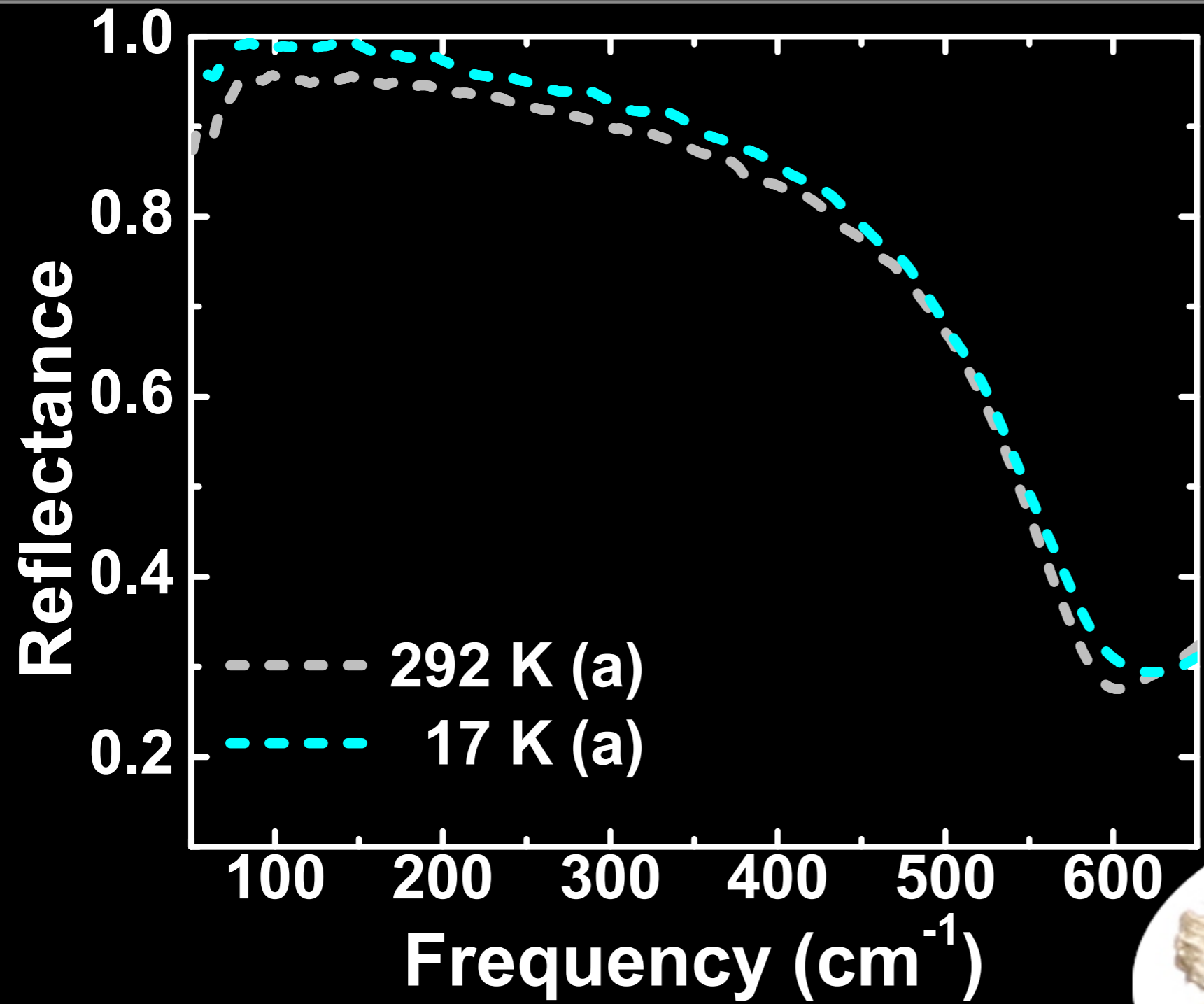


Spectroscopy



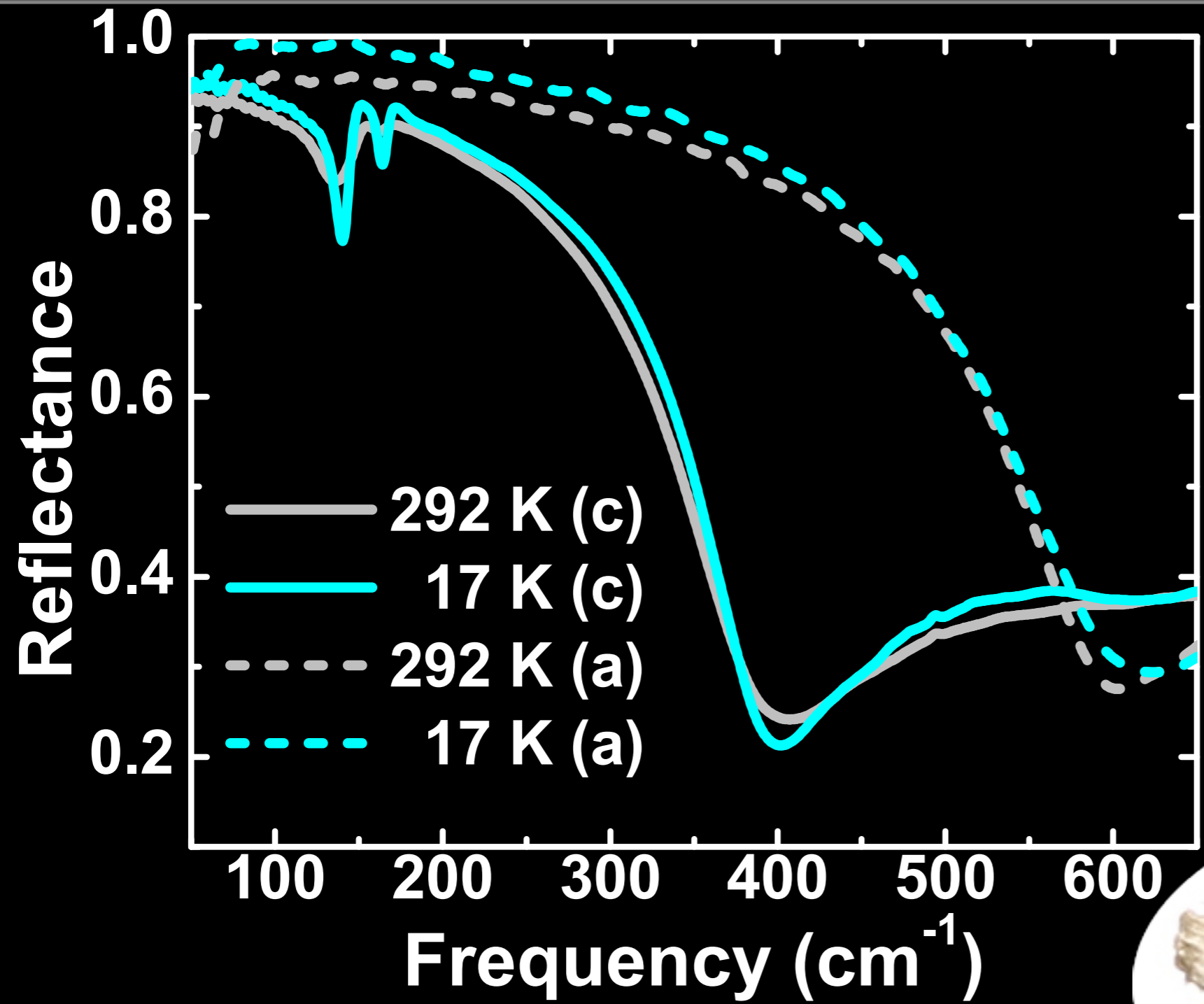


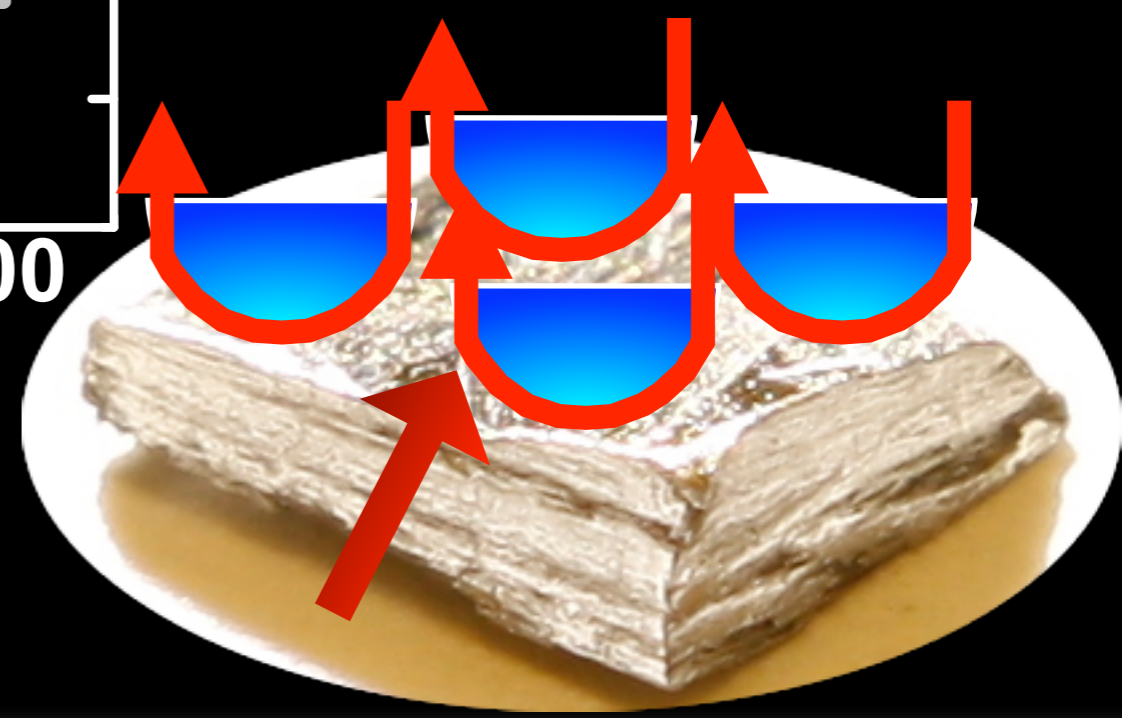
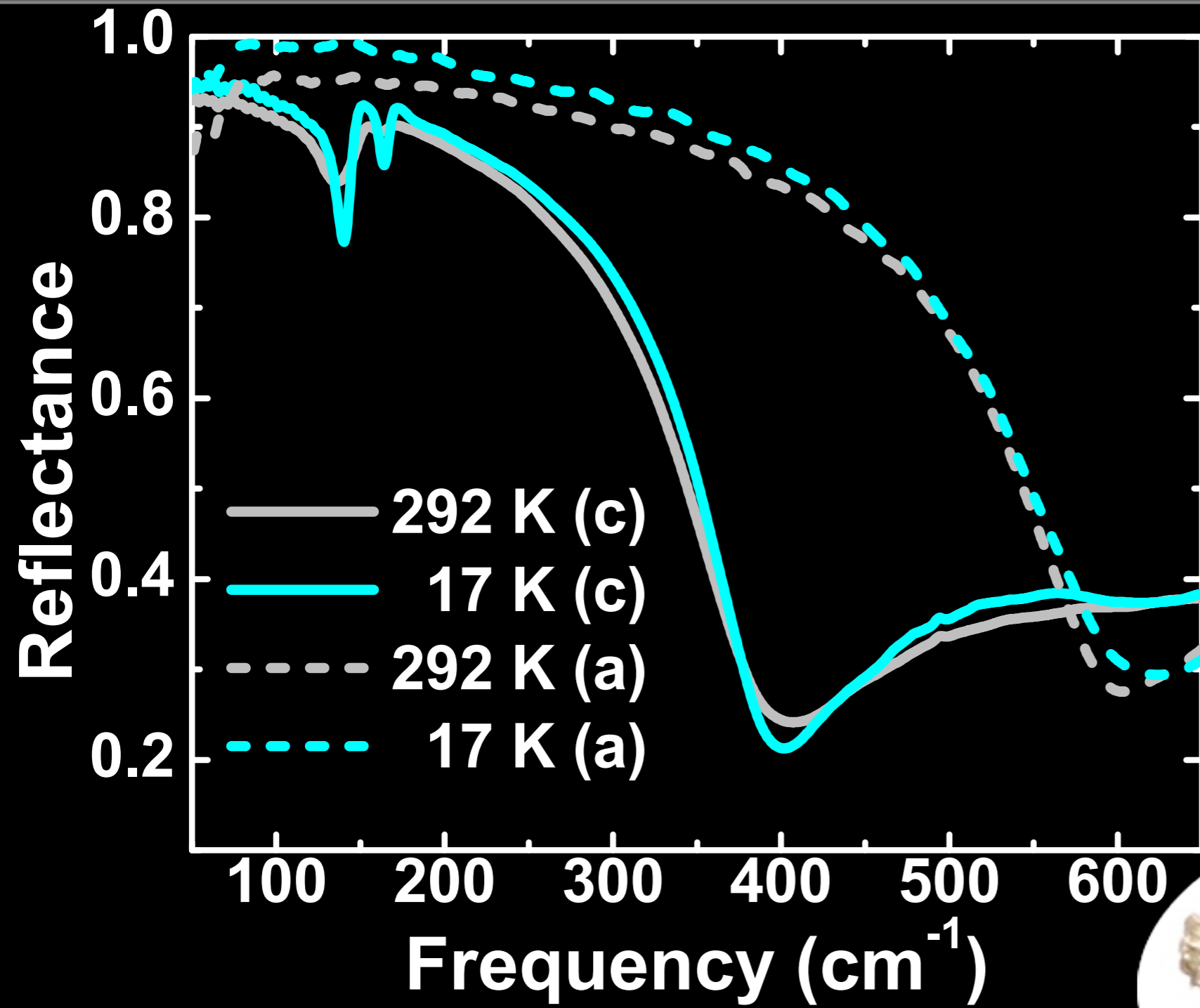
Spectroscopy

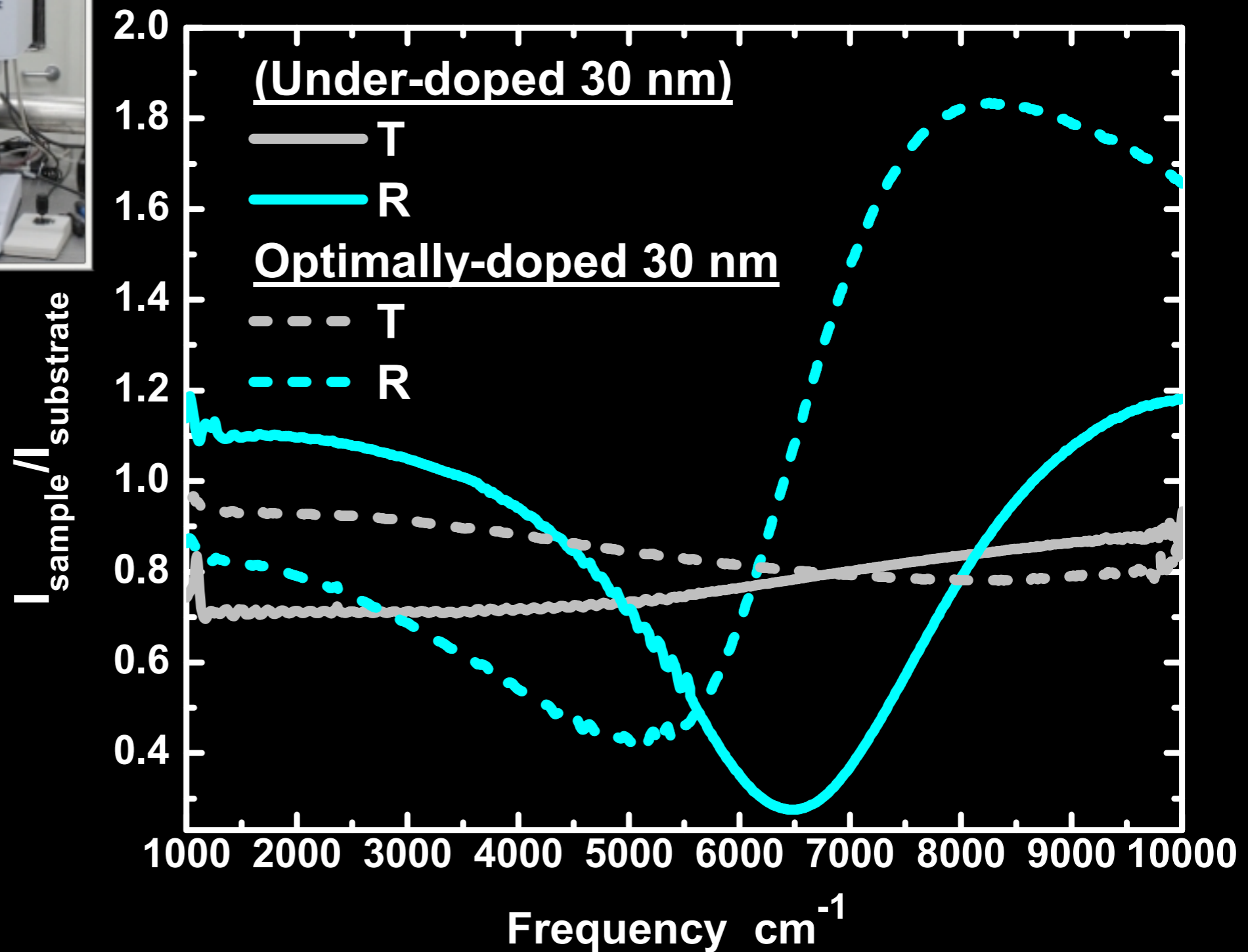
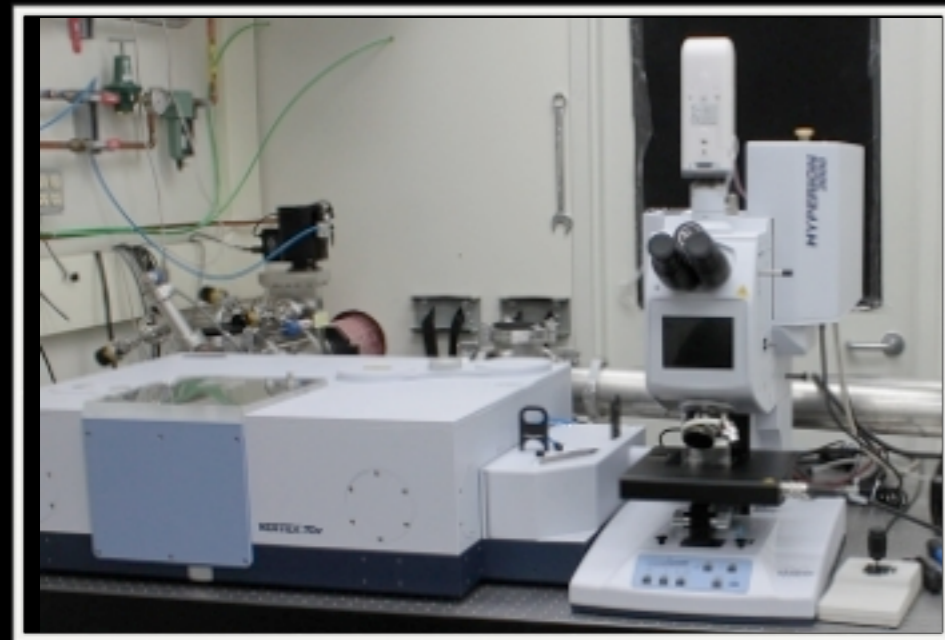




Spectroscopy





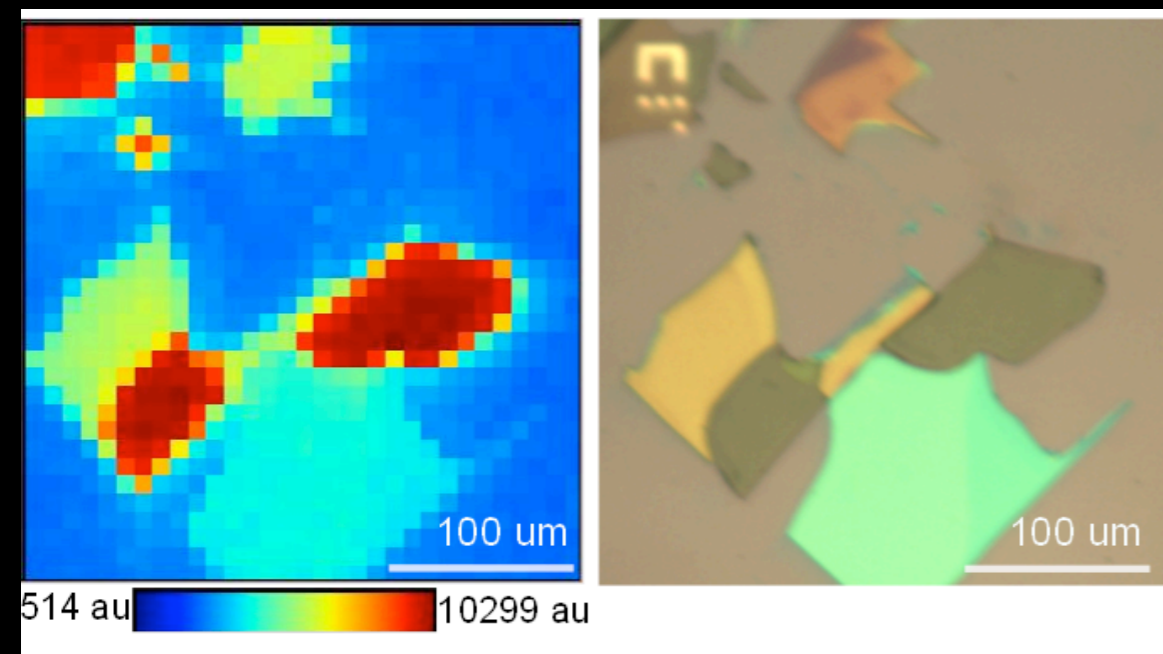




Laue Diffraction

~10 nm

Bi-2212



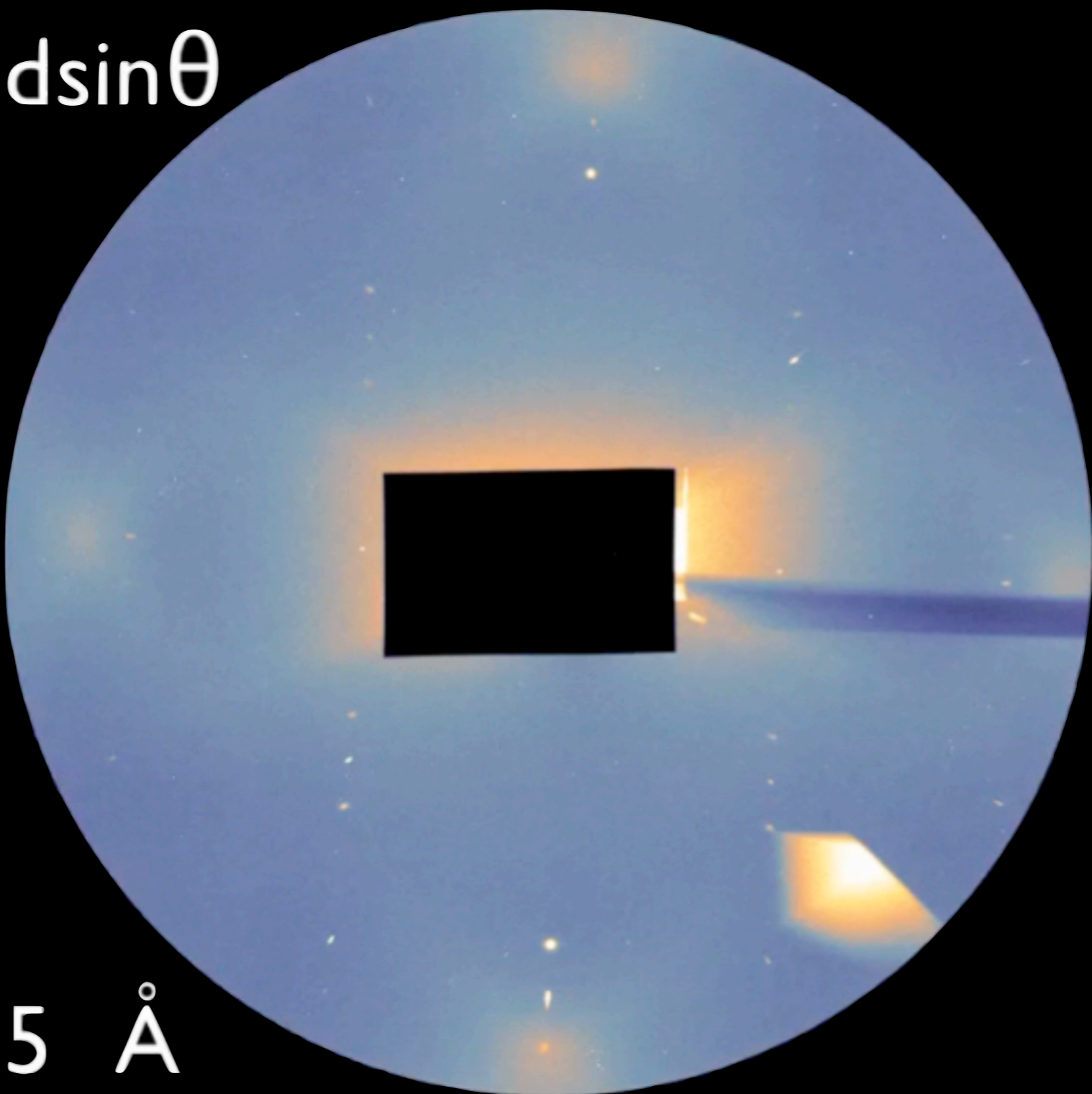


Laue Diffraction

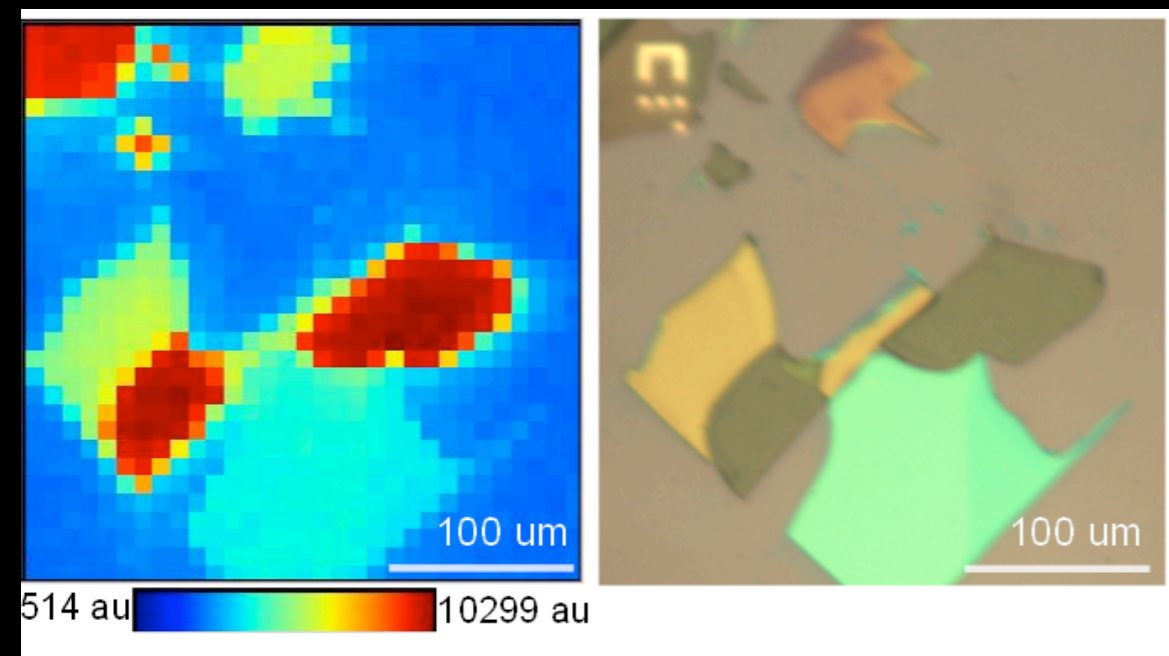
~10 nm

Bi-2212

$$n\lambda = 2d\sin\theta$$



0.095 Å



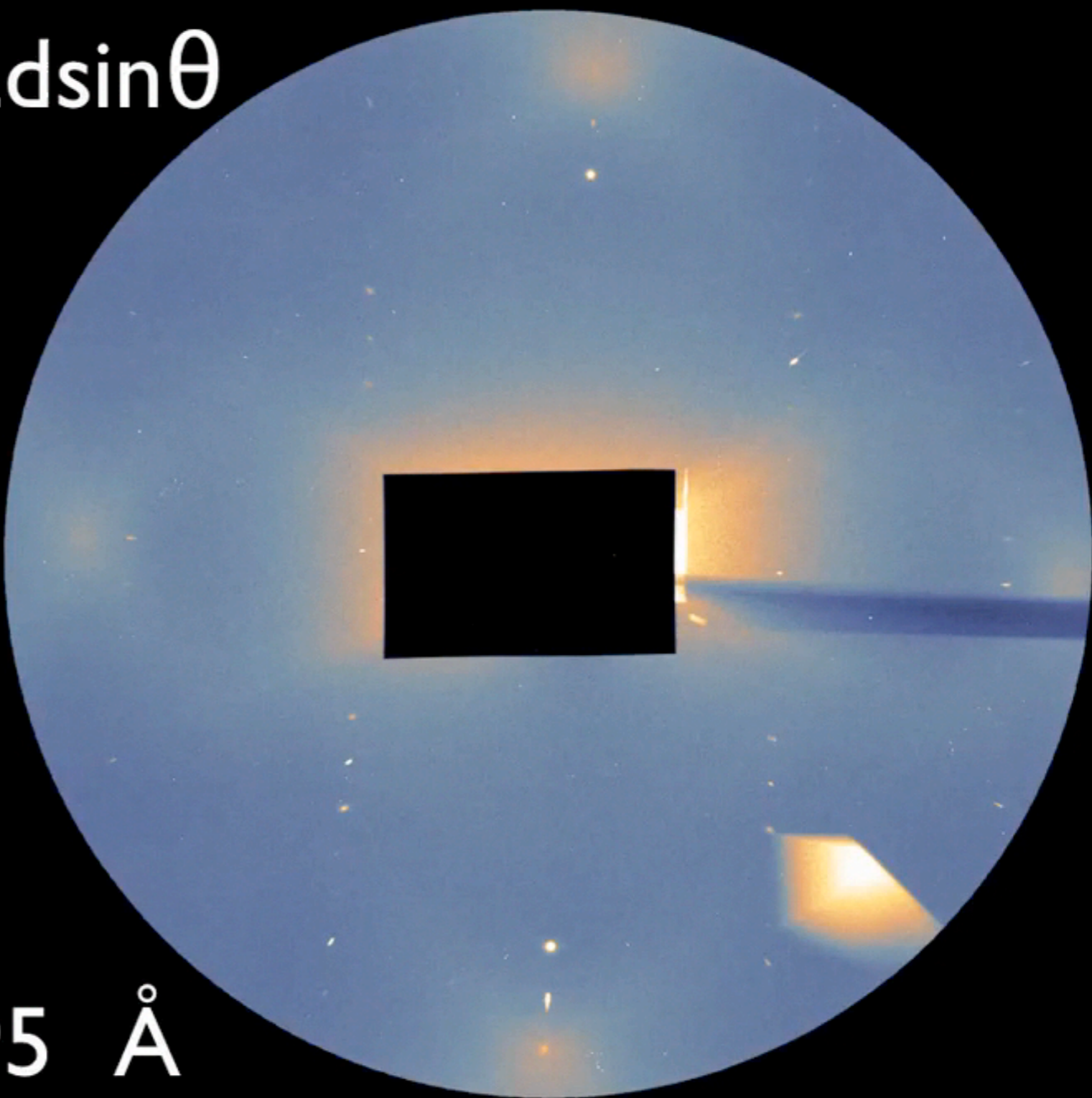


Laue Diffraction

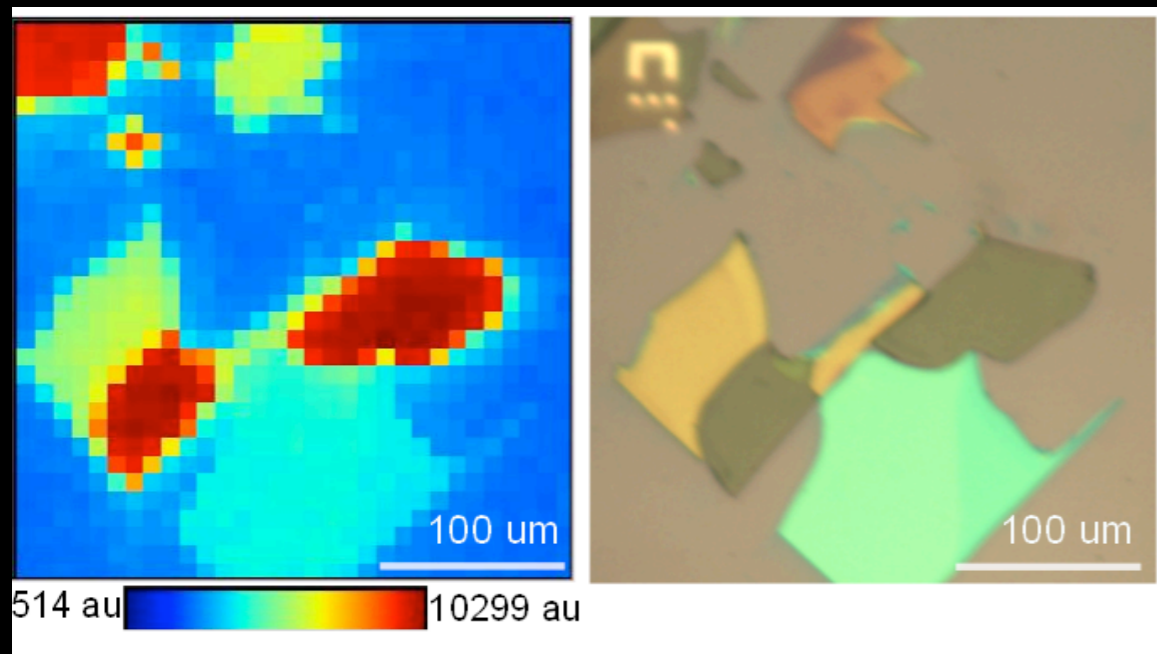
~10 nm

Bi-2212

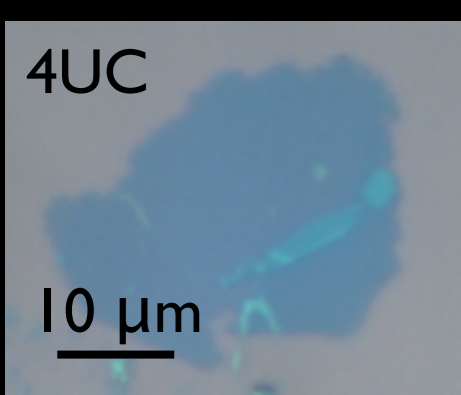
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0.095 Å

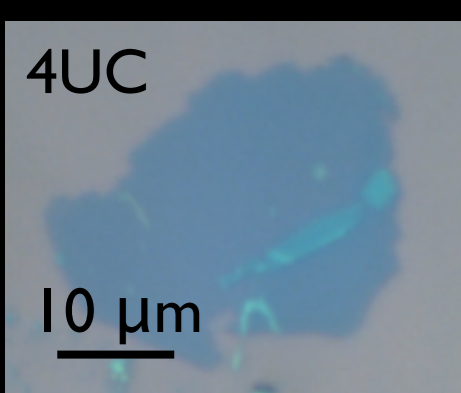


Summary



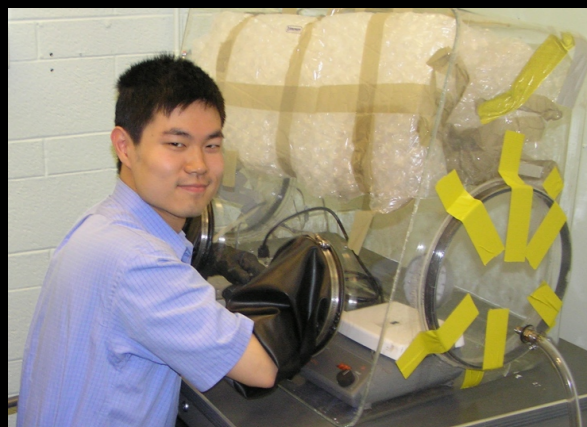
Summary

Exfoliation



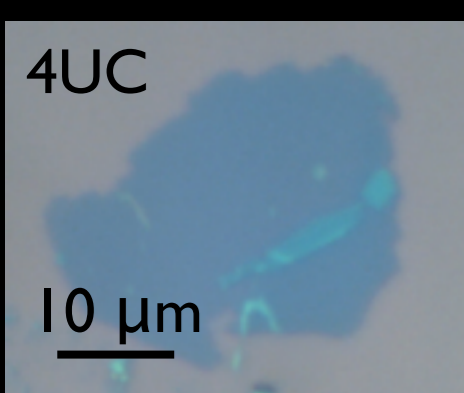
Summary

Exfoliation



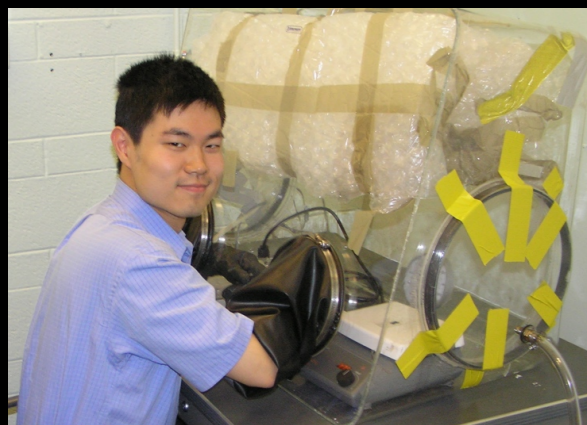
VS





Summary

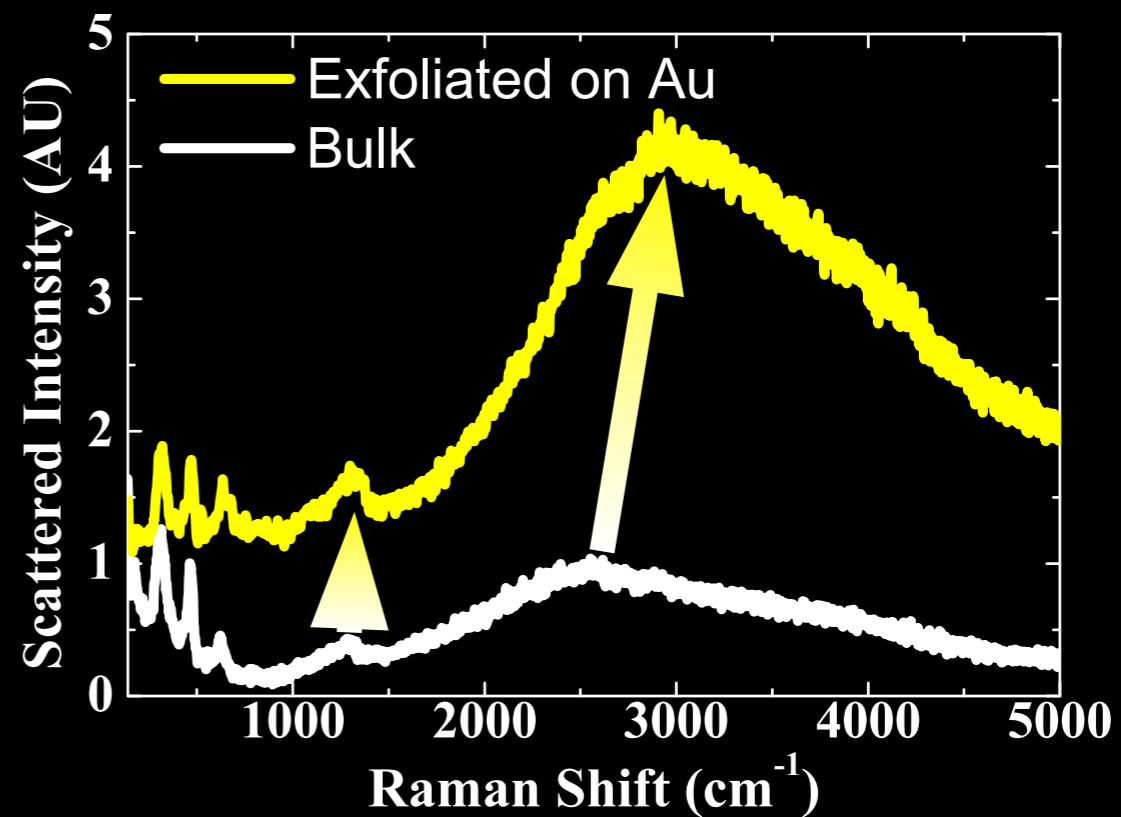
Exfoliation

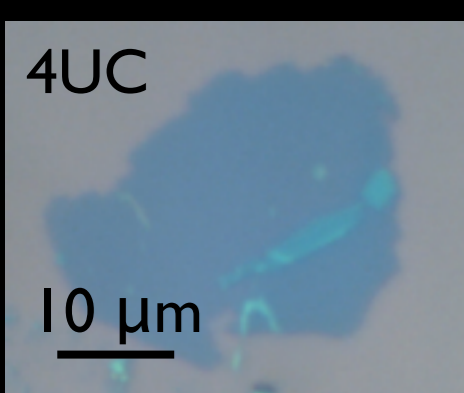


VS



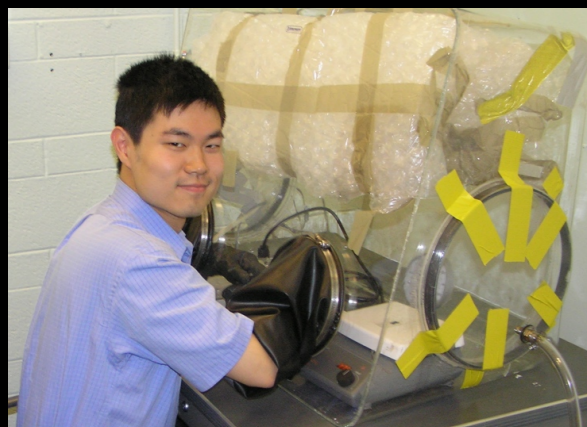
Raman





Summary

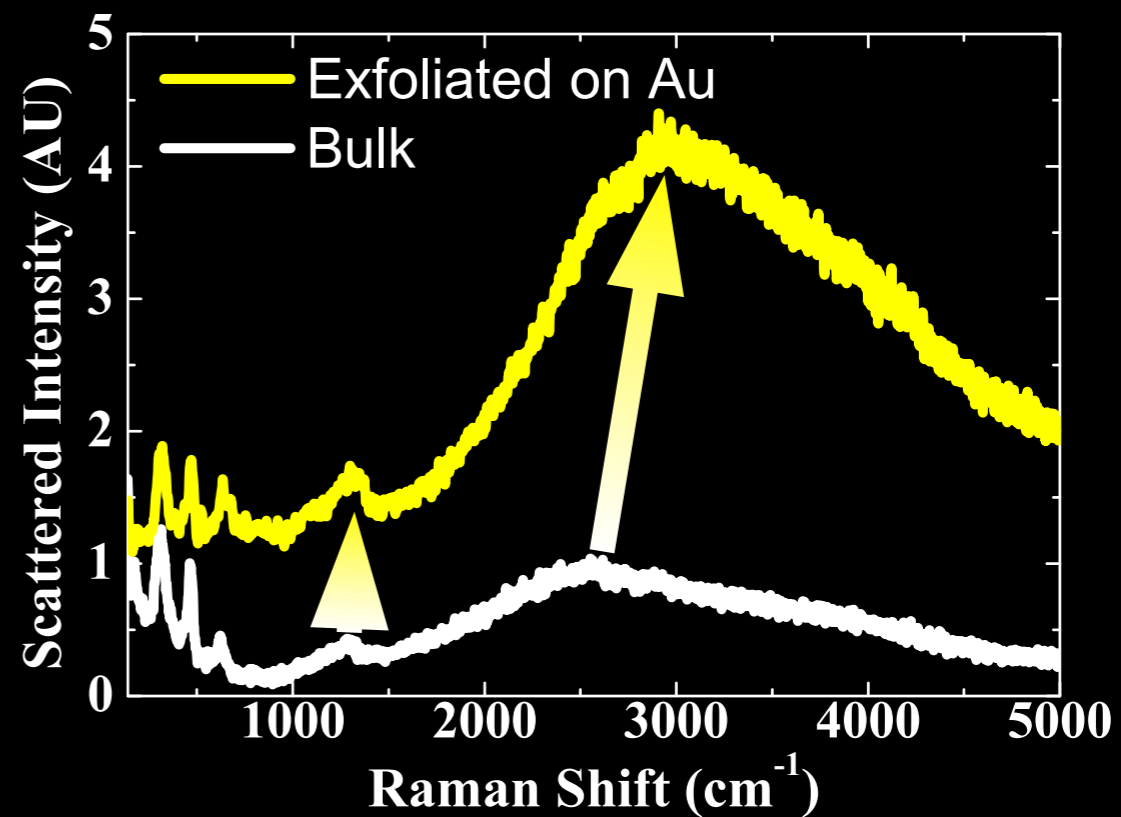
Exfoliation



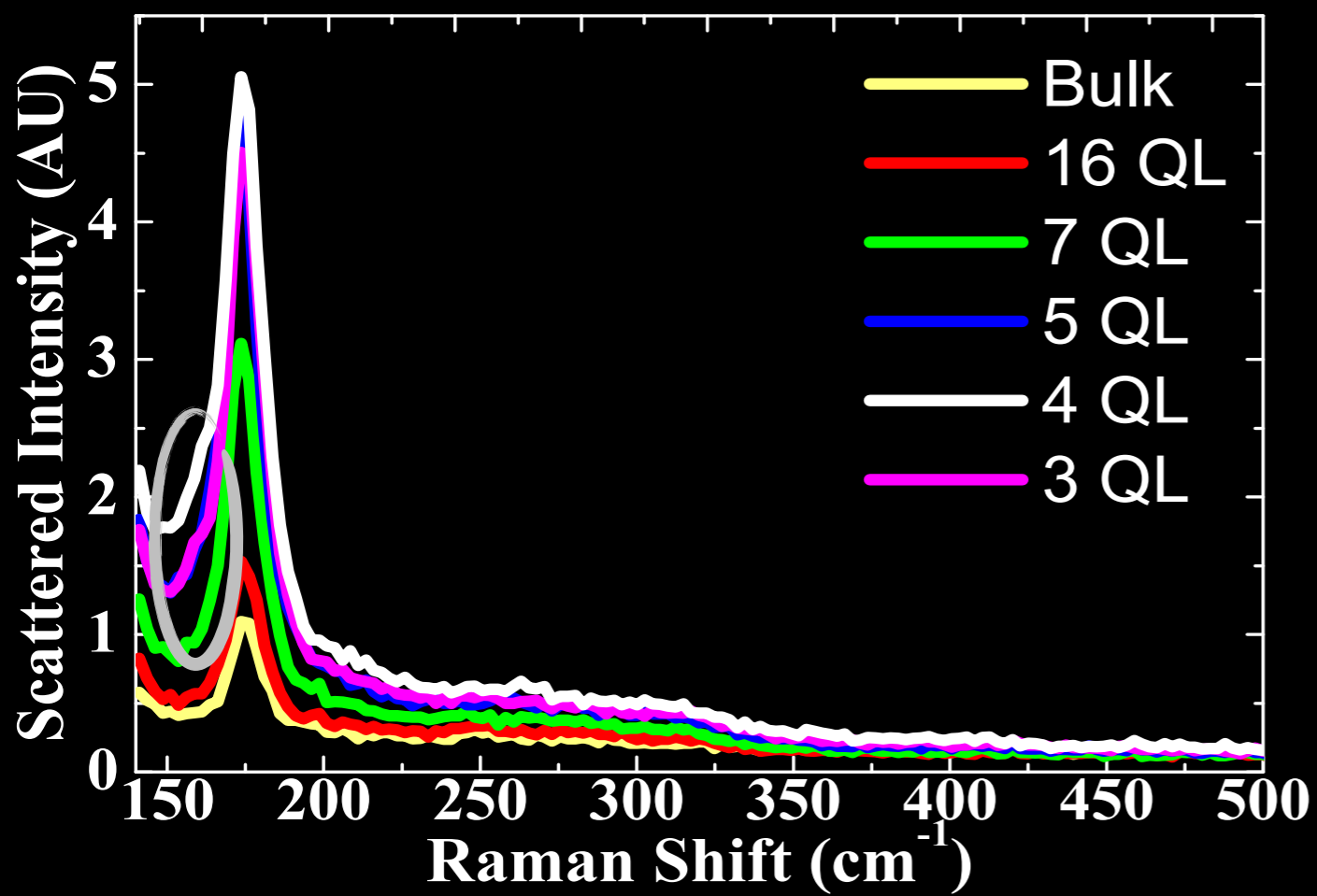
vs

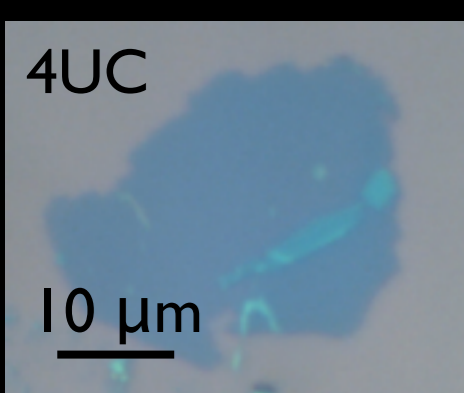


Raman



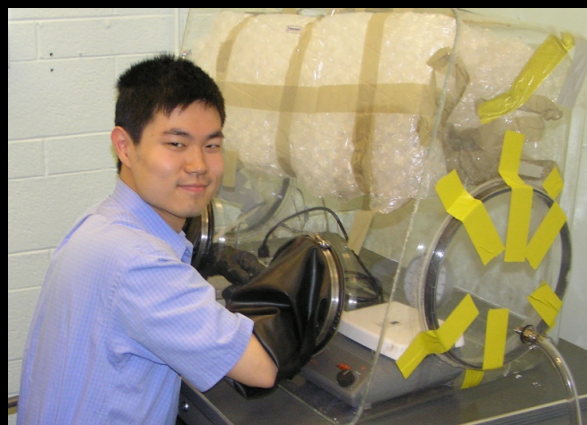
Topological Insulators





Summary

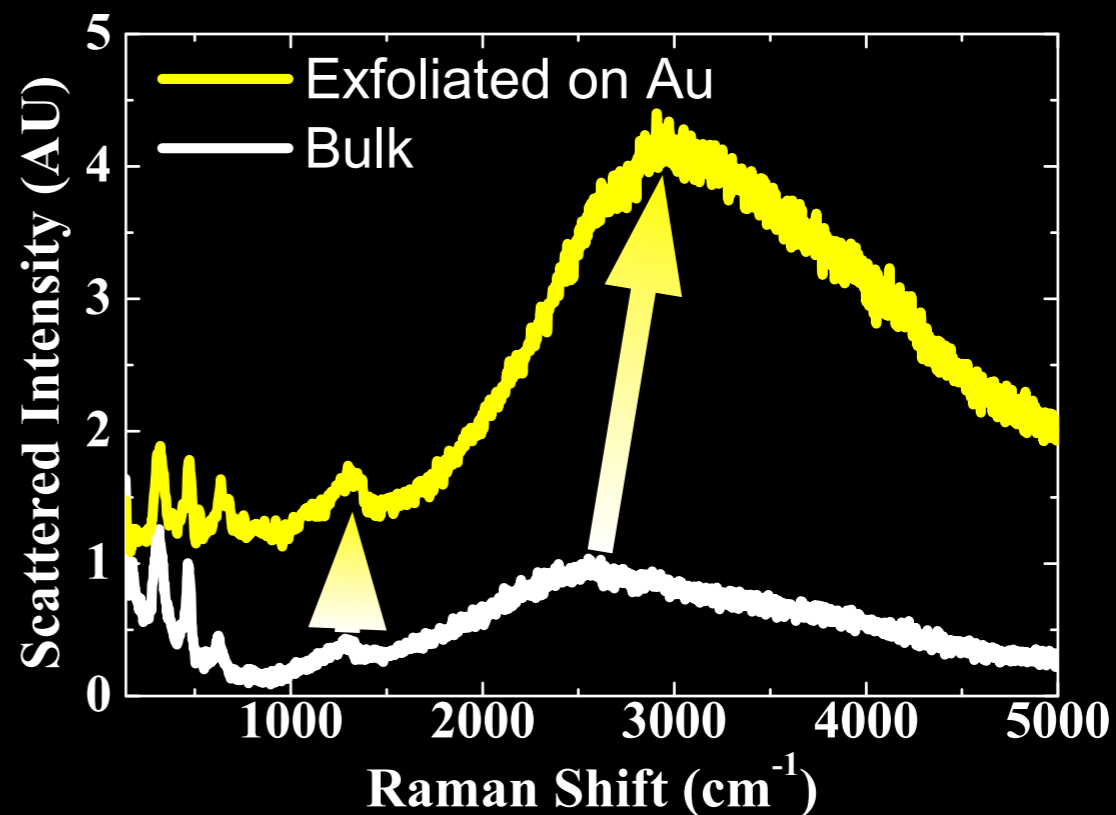
Exfoliation



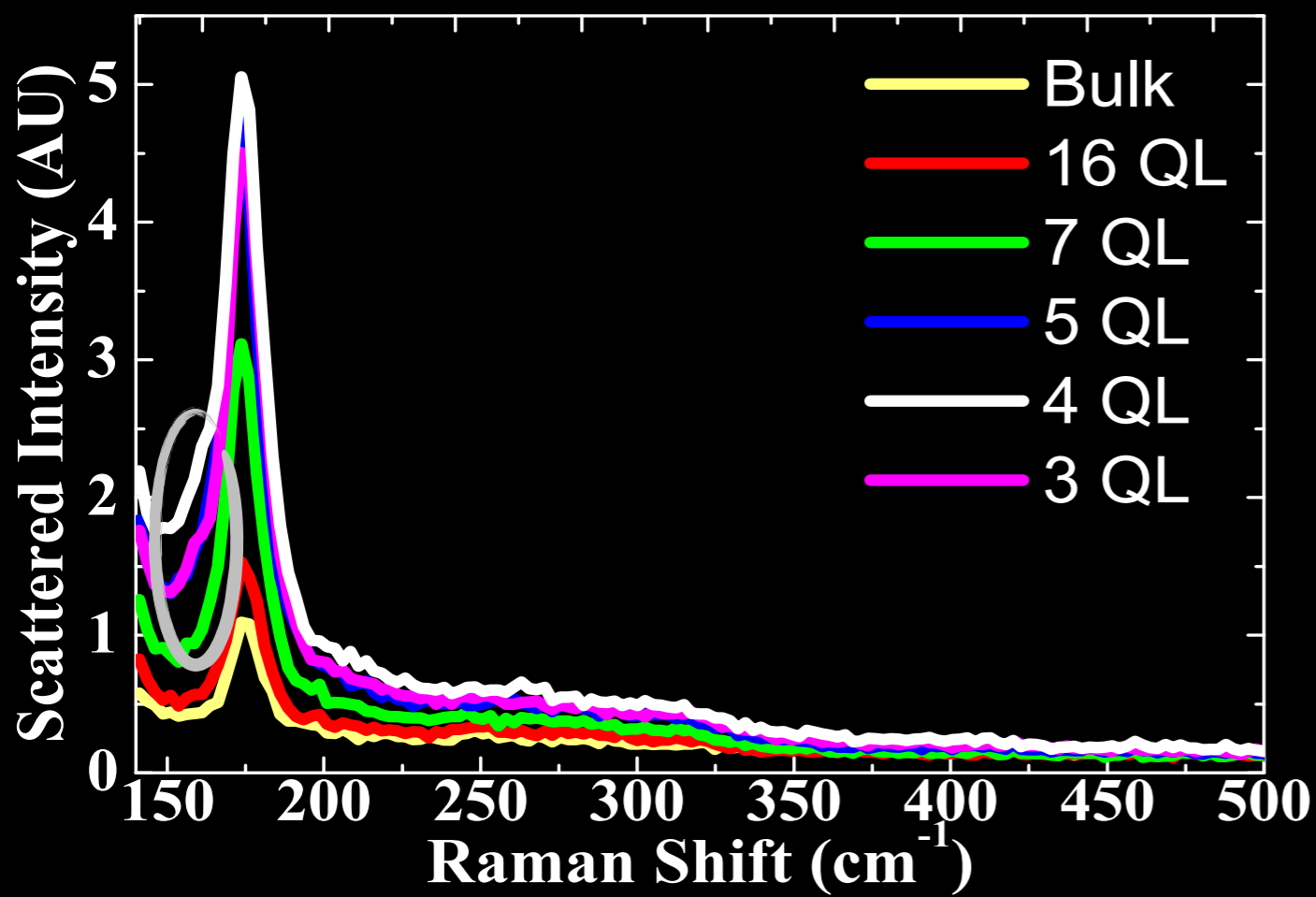
vs



Raman



Topological Insulators



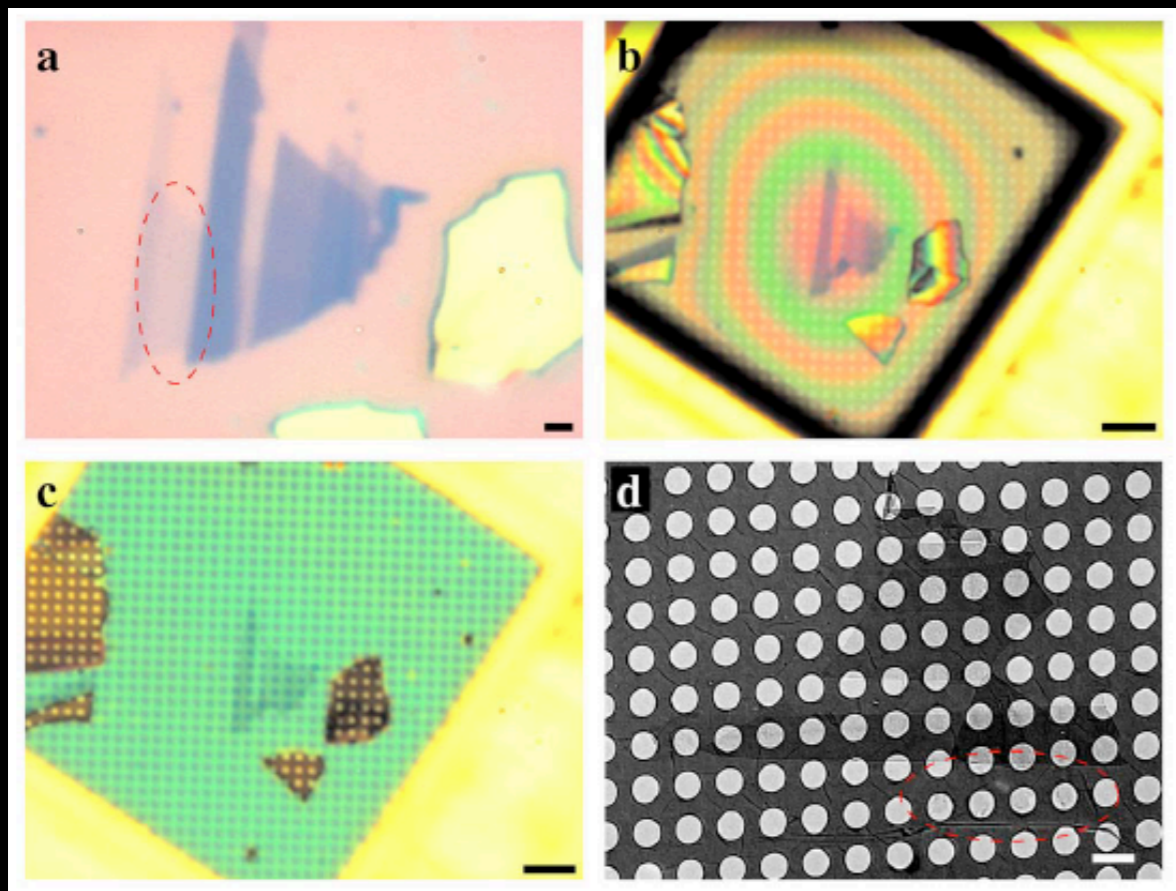
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Hydrocarbon lithography on graphene membranes

Jannik C. Meyer,^{a)} C. O. Girit, M. F. Crommie, and A. Zettl
 Department of Physics, University of California at Berkeley and Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

(Received 3 January 2008; accepted 3 March 2008; published online 28 March 2008)



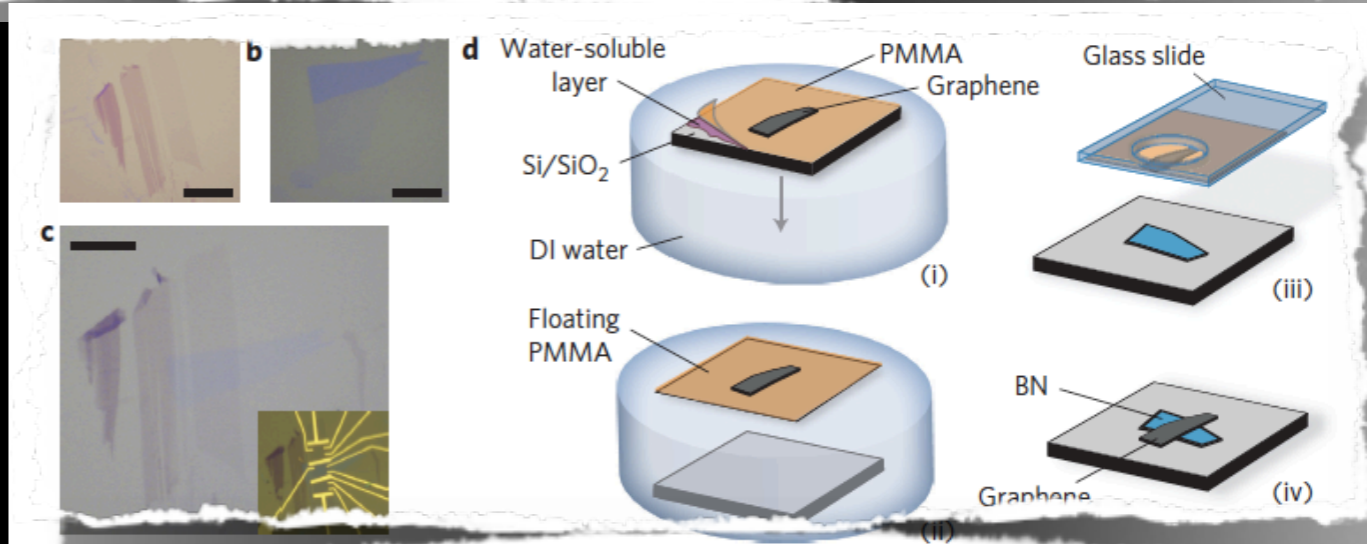
nature nanotechnology

LETTERS

PUBLISHED ONLINE: 22 AUGUST 2010 | DOI: 10.1038/NNANO.2010.172

Boron nitride substrates for high-quality graphene electronics

C. R. Dean^{1,2*}, A. F. Young³, I. Meric¹, C. Lee^{4,5}, L. Wang², S. Sorgenfrei¹, K. Watanabe⁶, T. Taniguchi⁶, P. Kim³, K. L. Shepard¹ and J. Hone^{2*}



Toys vs Tools



Toys vs Tools

Toy



Toys vs Tools

Toy



Toys vs Tools

Toy



Tool

Toys vs Tools

Toy



Tool

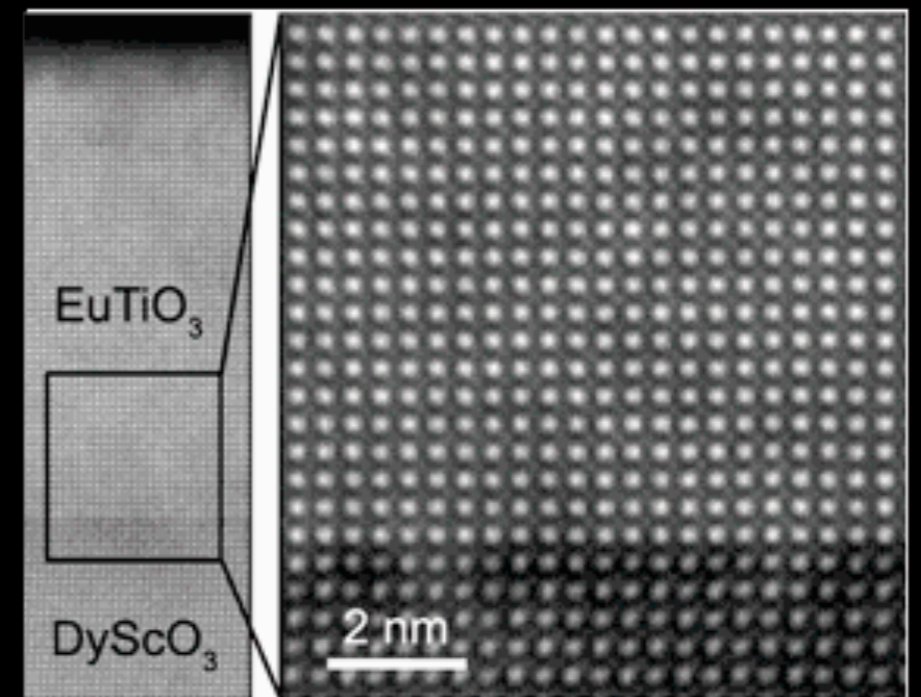


Toys vs Tools

Toy



Tool



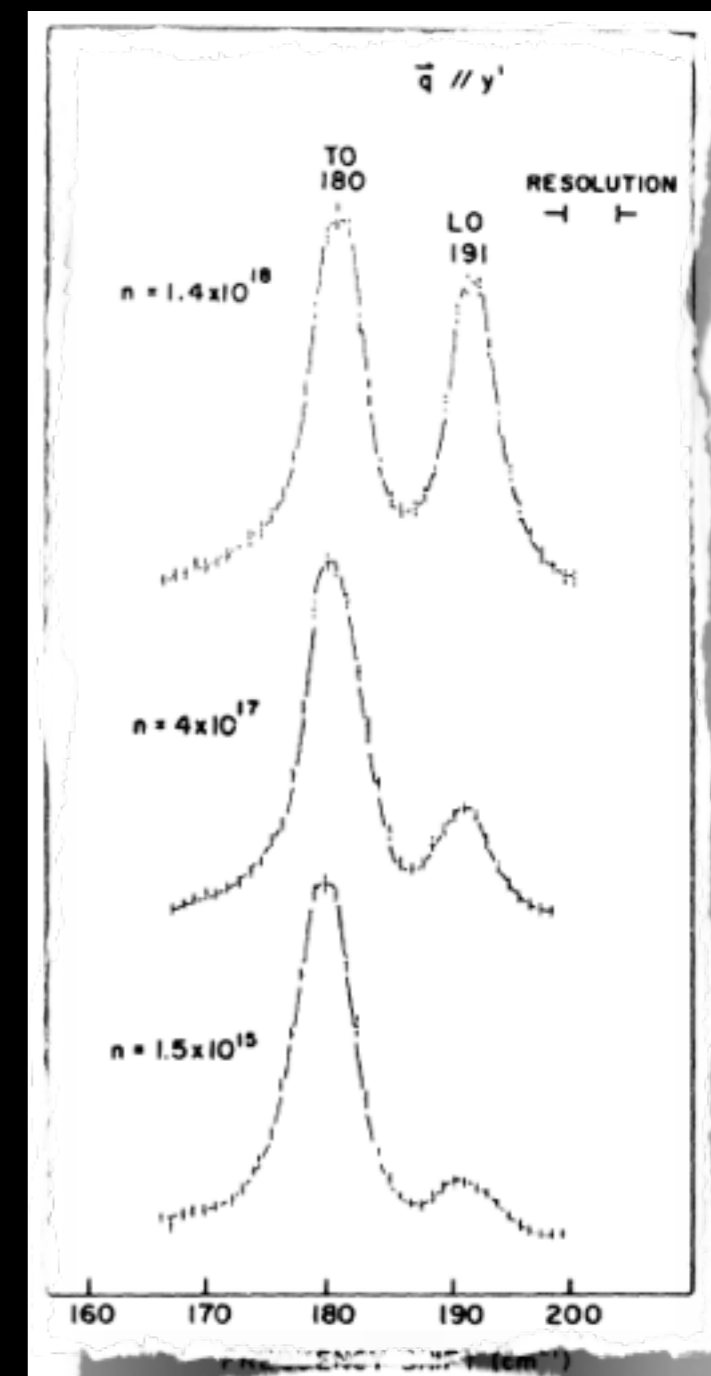
J.H. Lee et al., Nature 466, 954 (2010)



Band Bending

Electric Field Induced Raman Scattering (EFIRS)

LO modes can become Raman-active due to band-bending



A. Pinczuk and E. Burstein, Phys. Rev. Lett. 21, 1073 (1968)

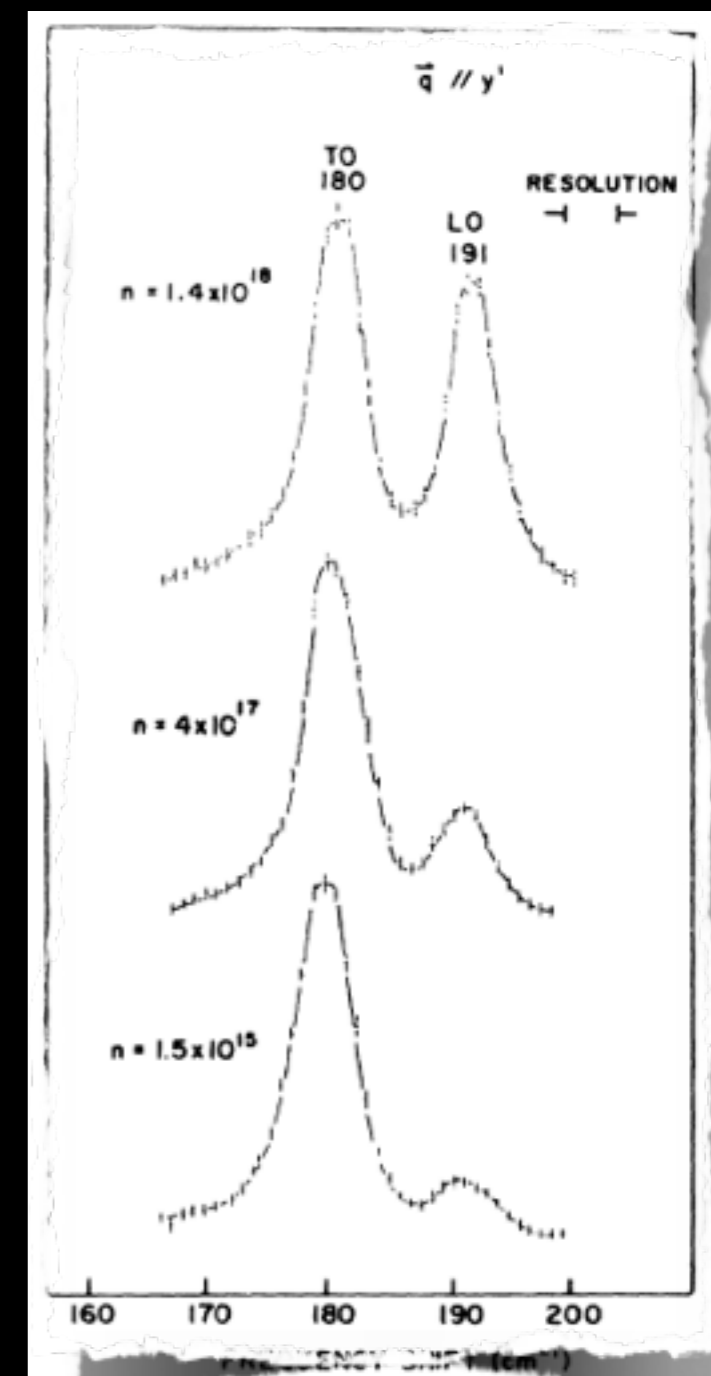
F. Schaffler and G. Abstreiter, PRB 34, 4017 (1986)



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- ARPES vs. SdH
(Analytis, PRB 81 205407 (2010))
- Interface effects
(Steinberg, Nano Lett., 10 ,5032 (2010))
- SHG in Bi₂Se₃
(Hsieh, PRL 106, 057401 (2011))



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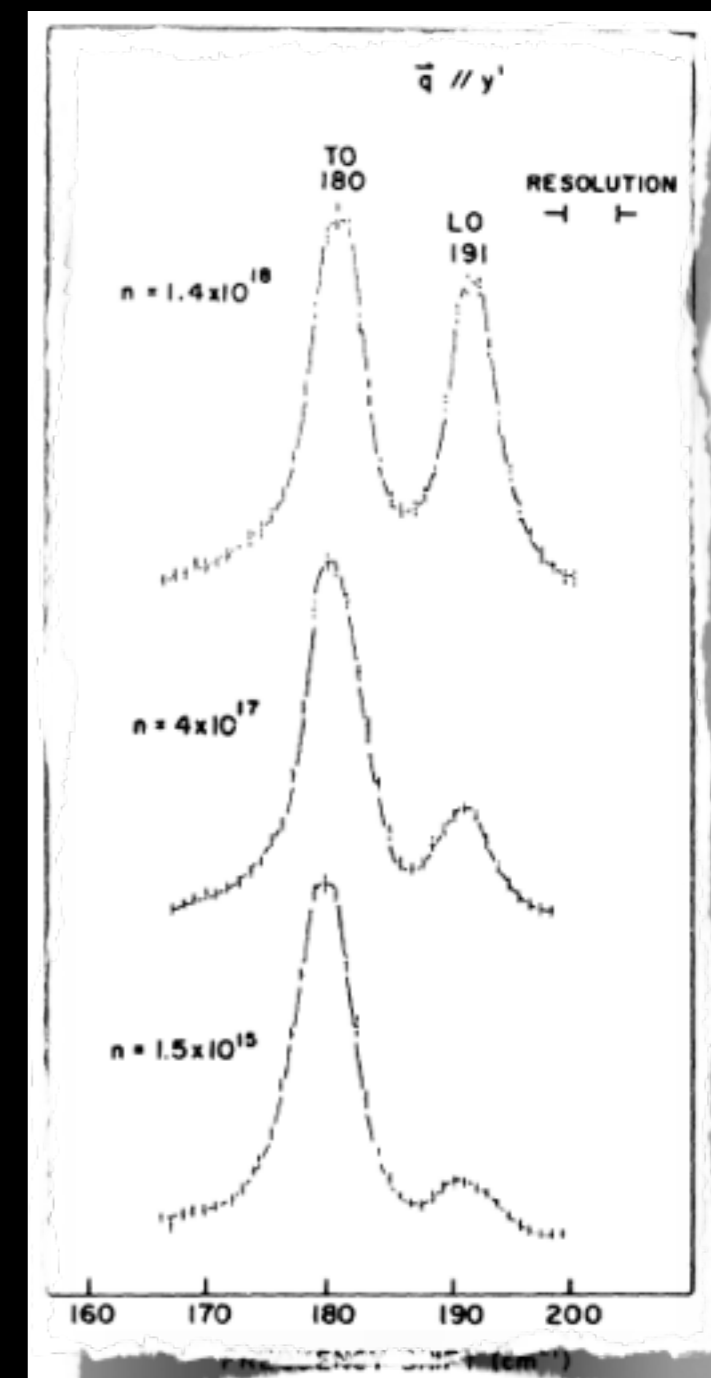
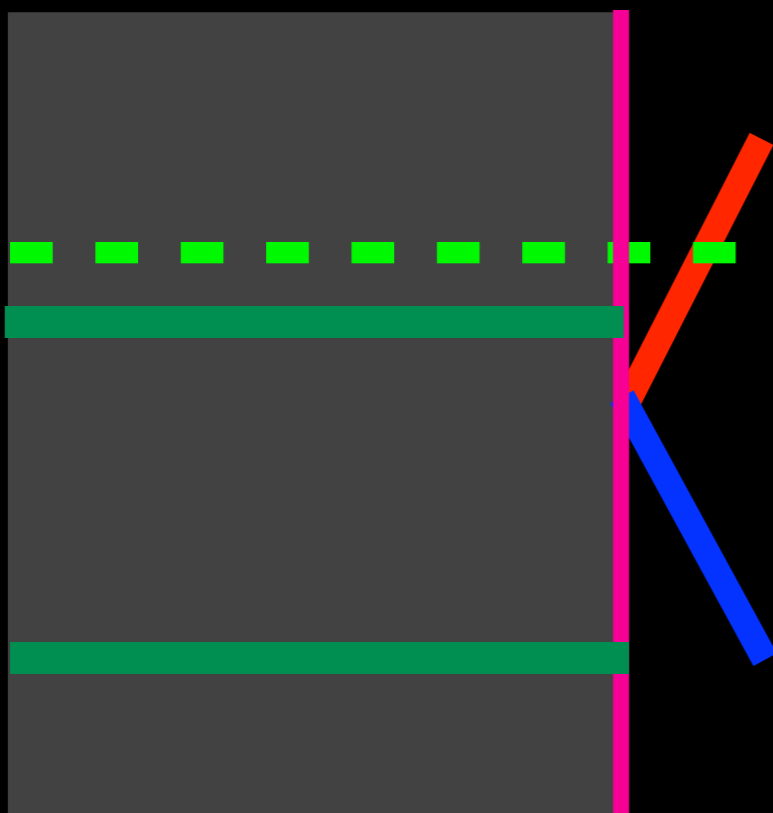


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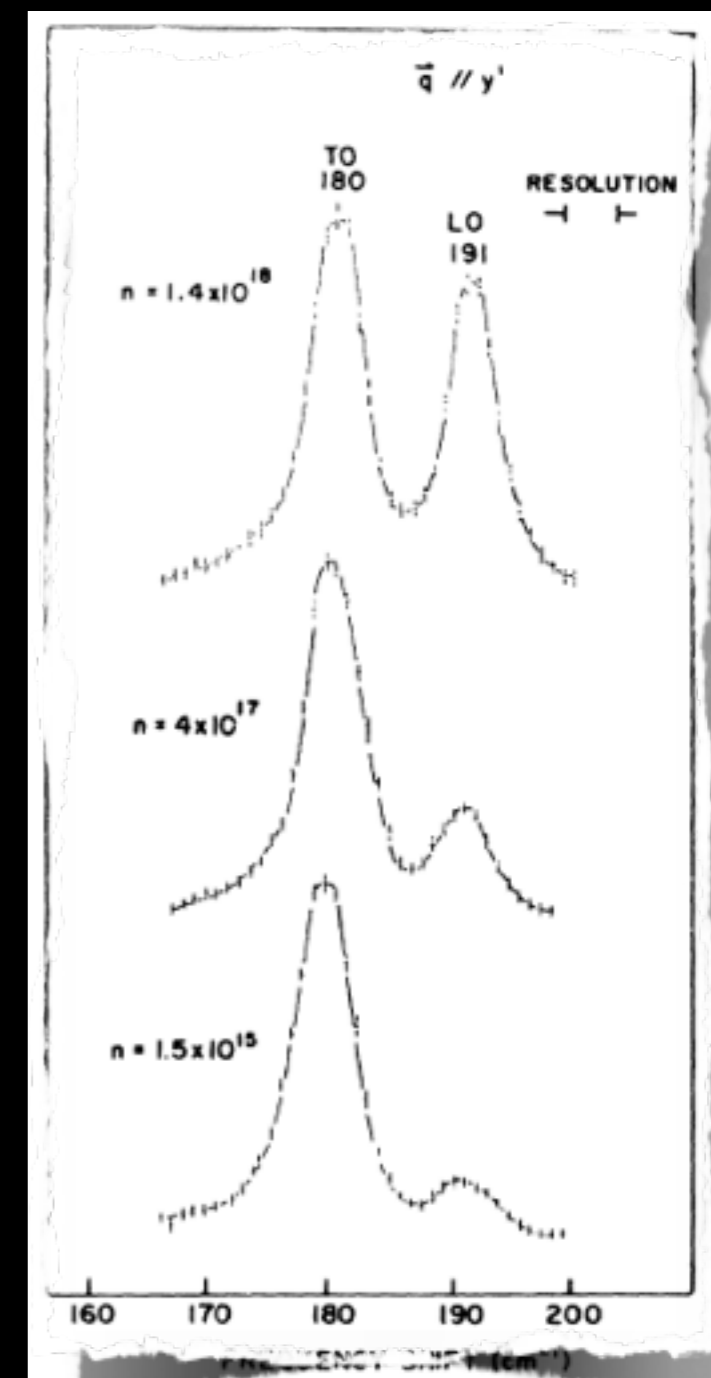
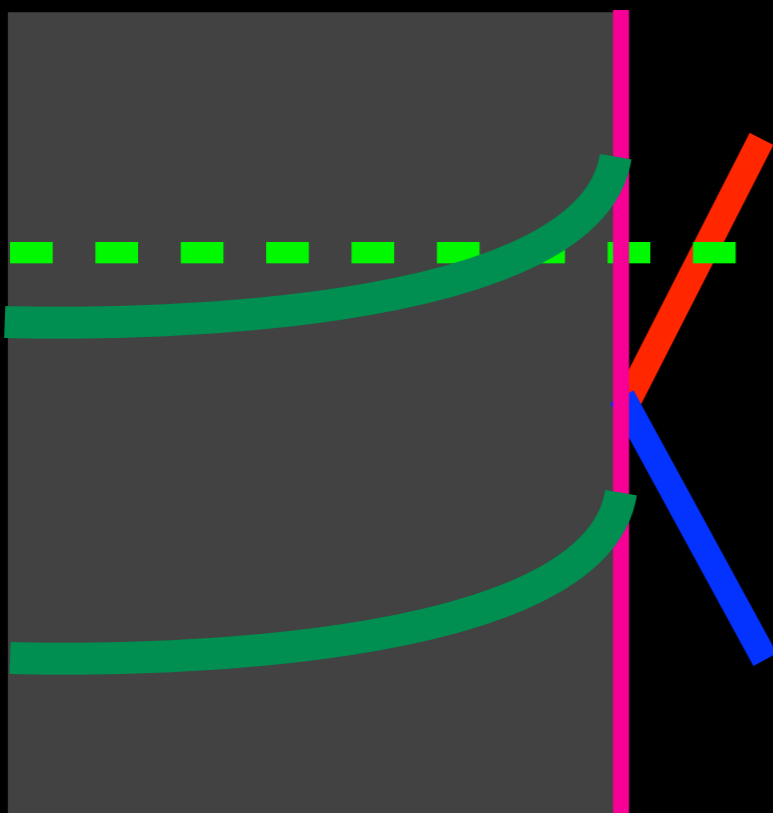


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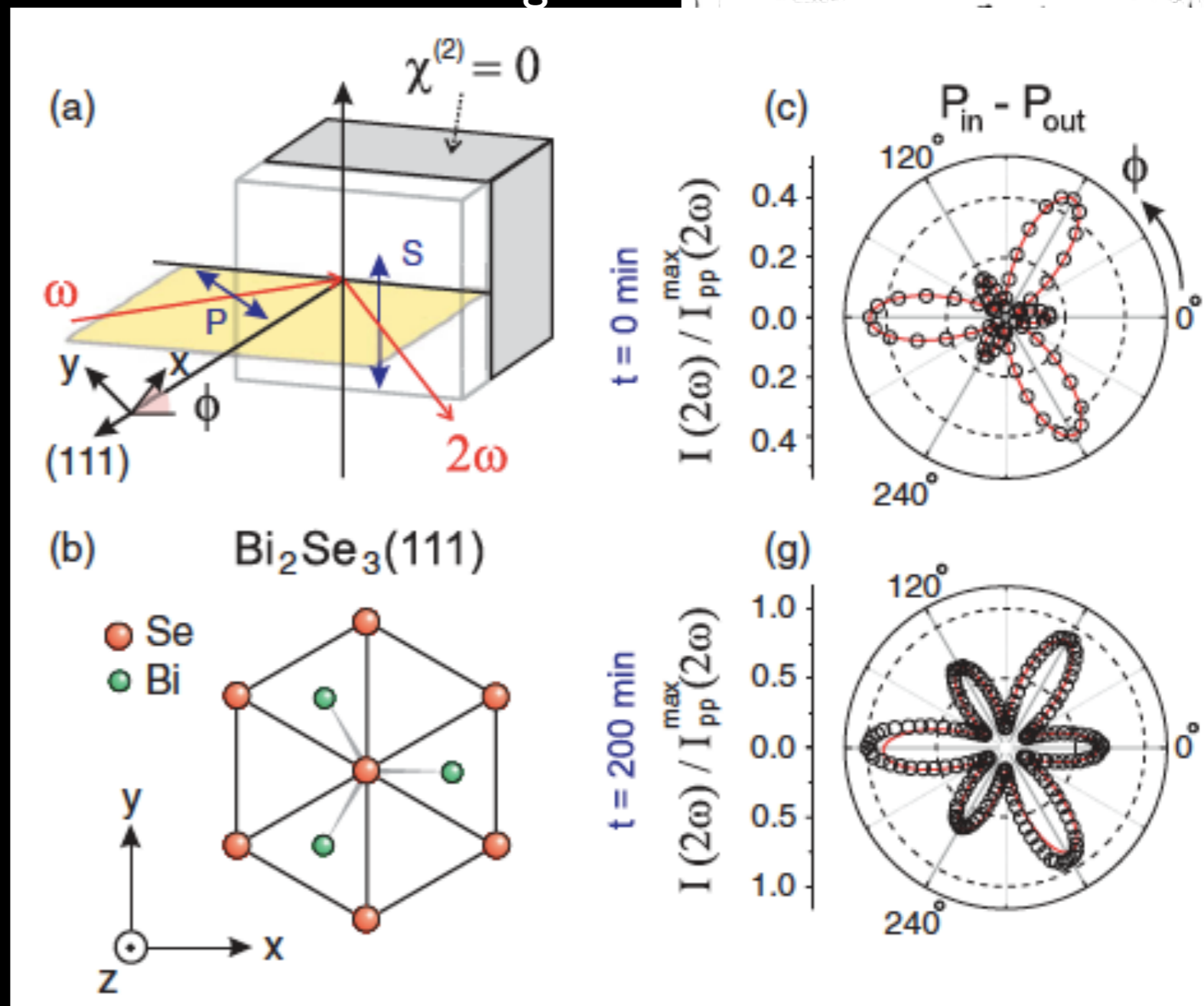
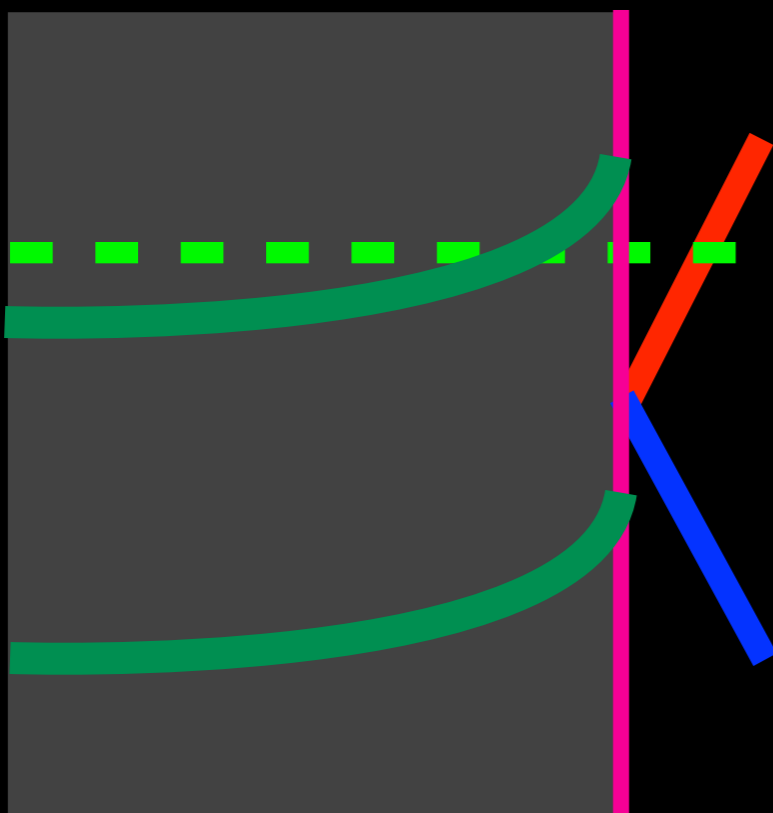
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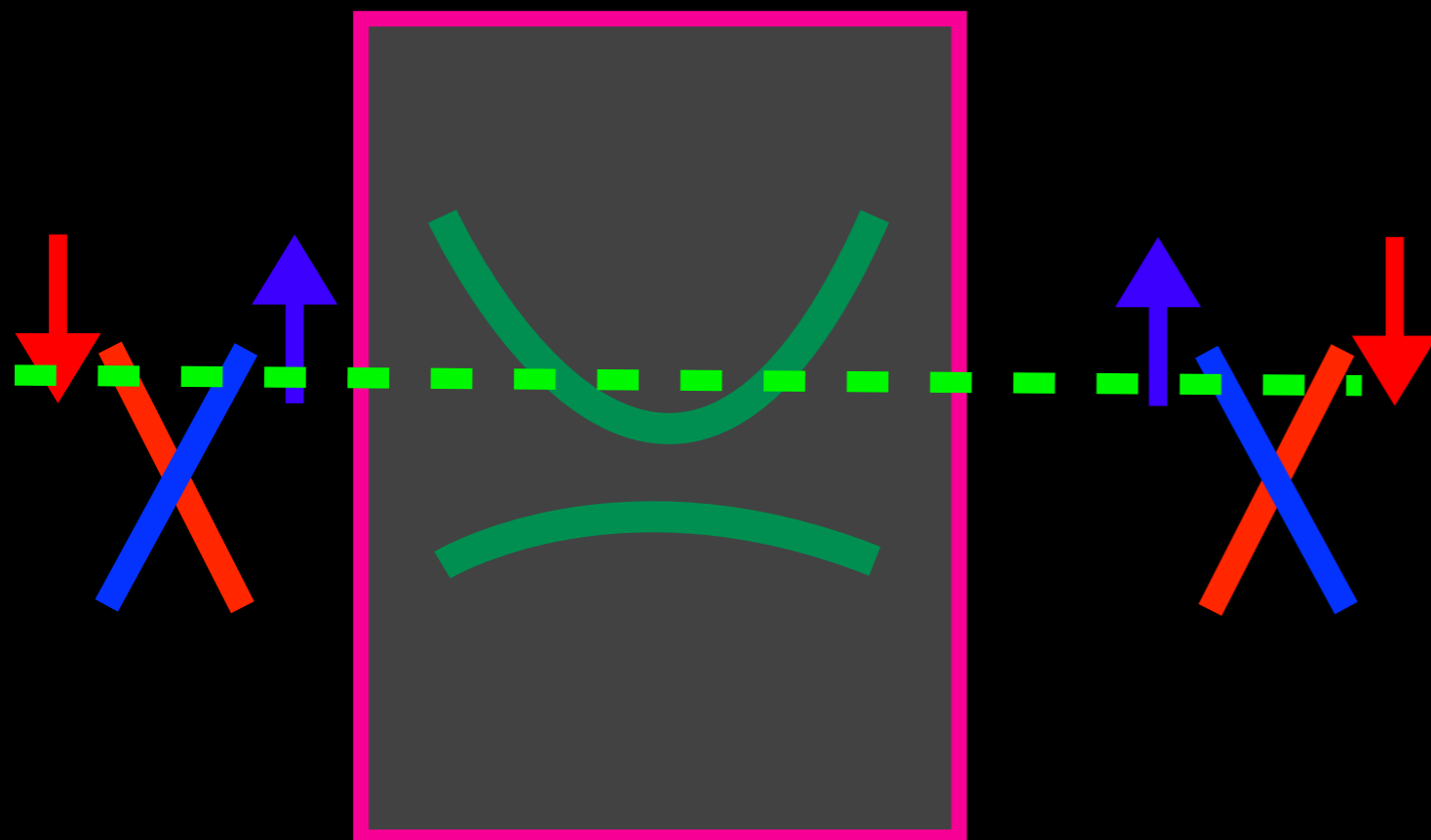
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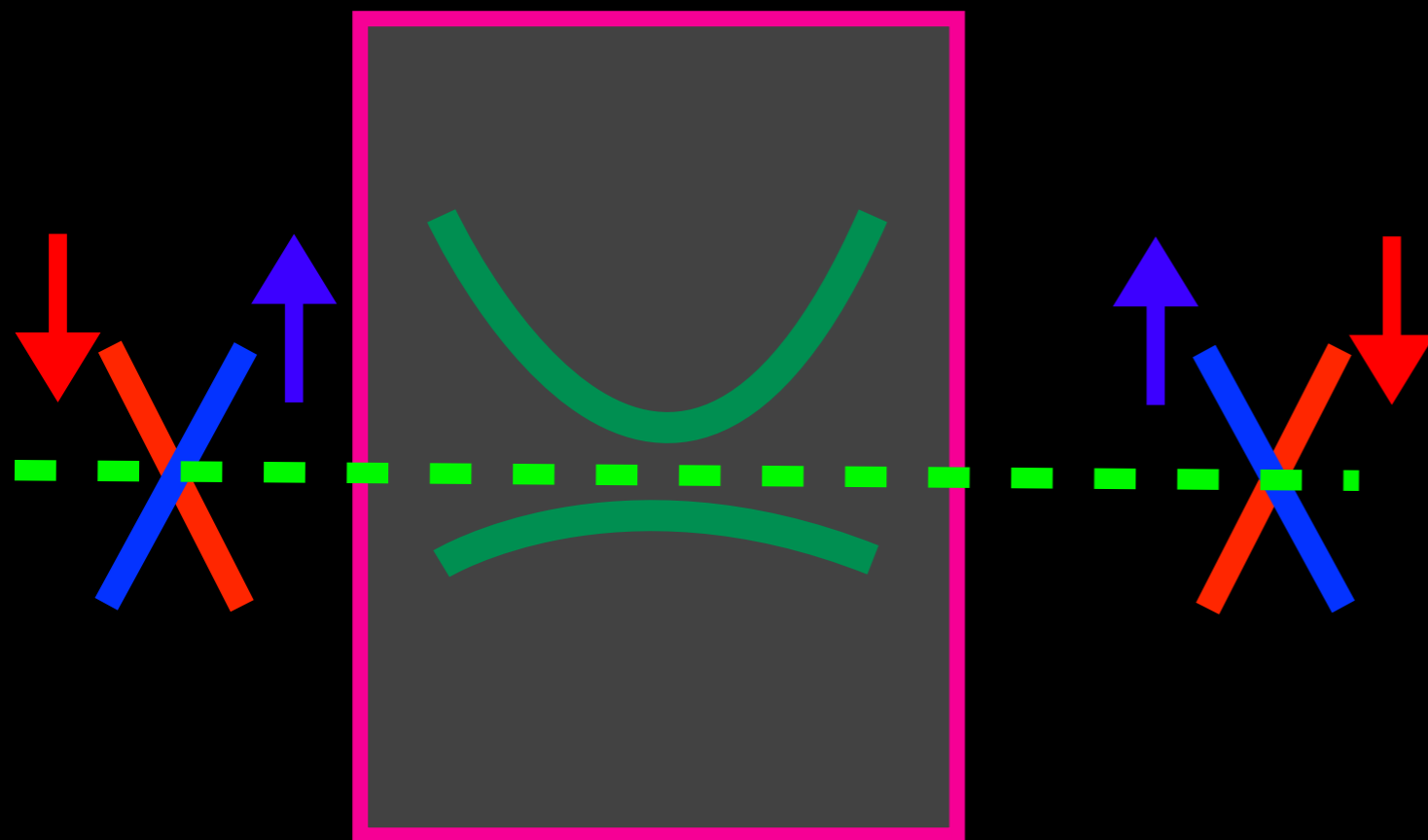
A. Pinczuk and E. Burstein, Phys. Rev. Lett. 21, 1073 (1968)

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Towards the Surface

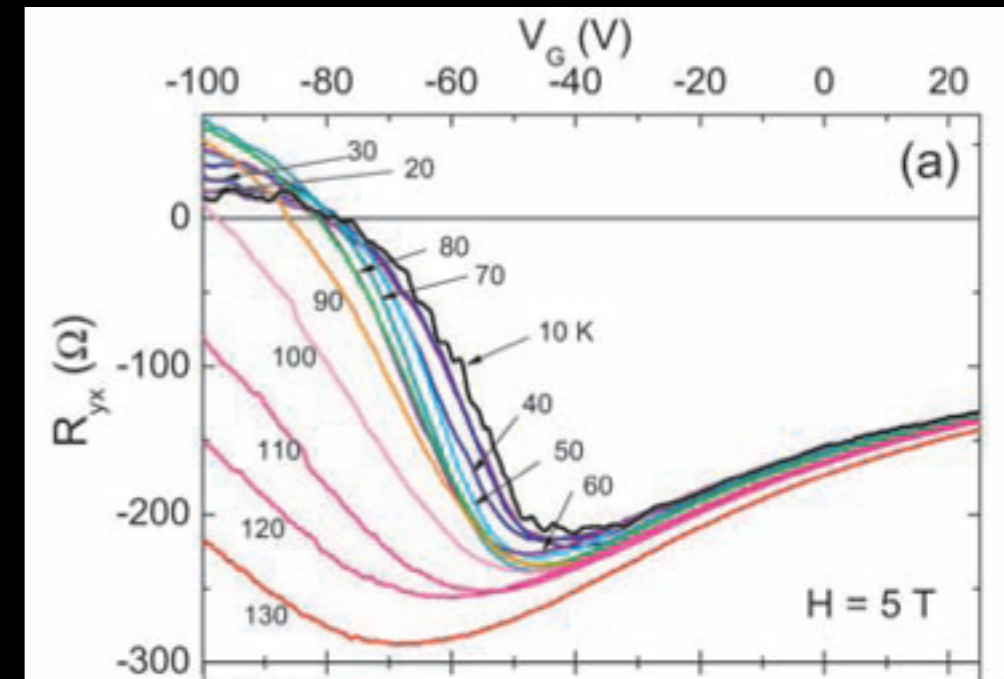
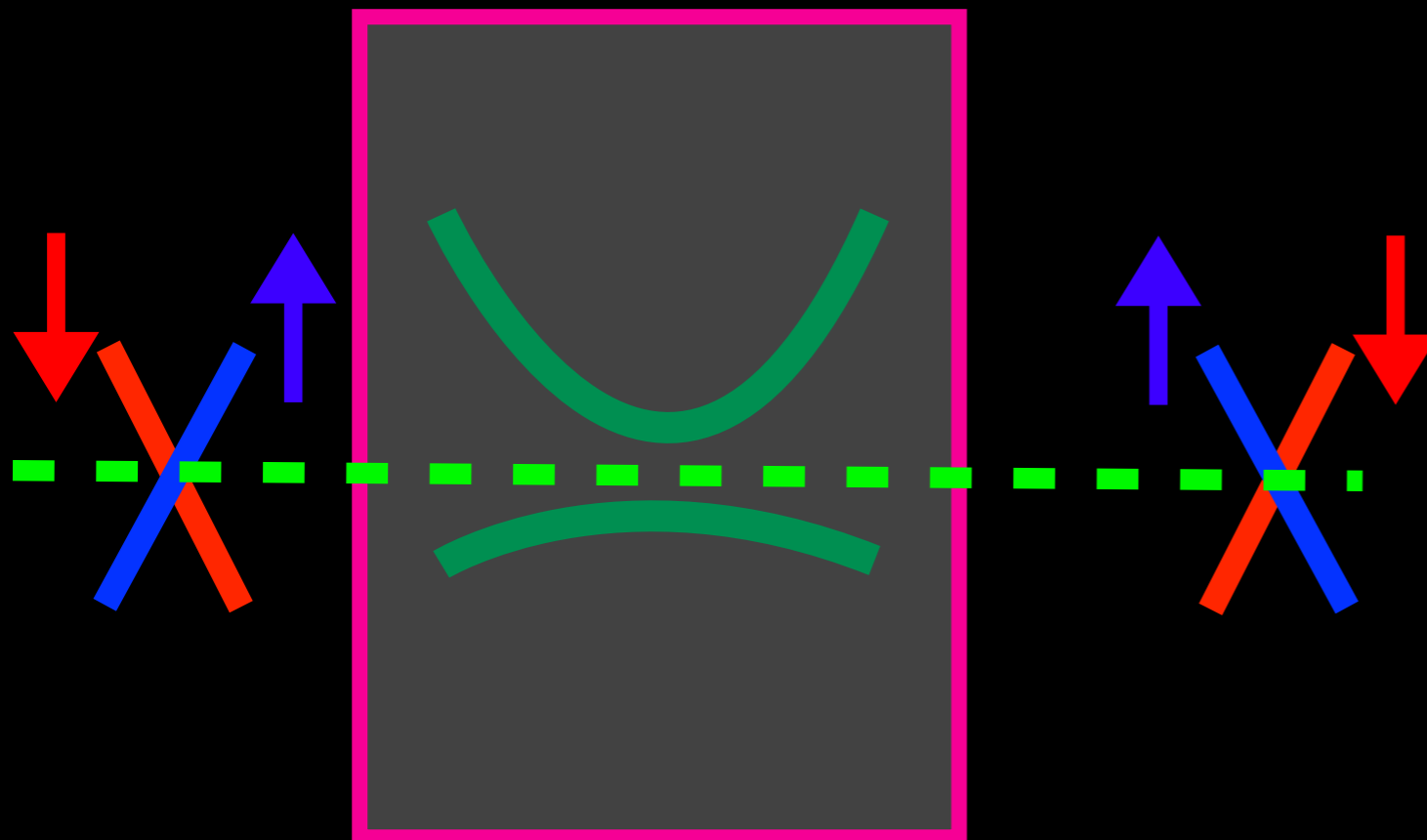


Towards the Surface



Towards the Surface

3500K Gap - Bi_2Se_3



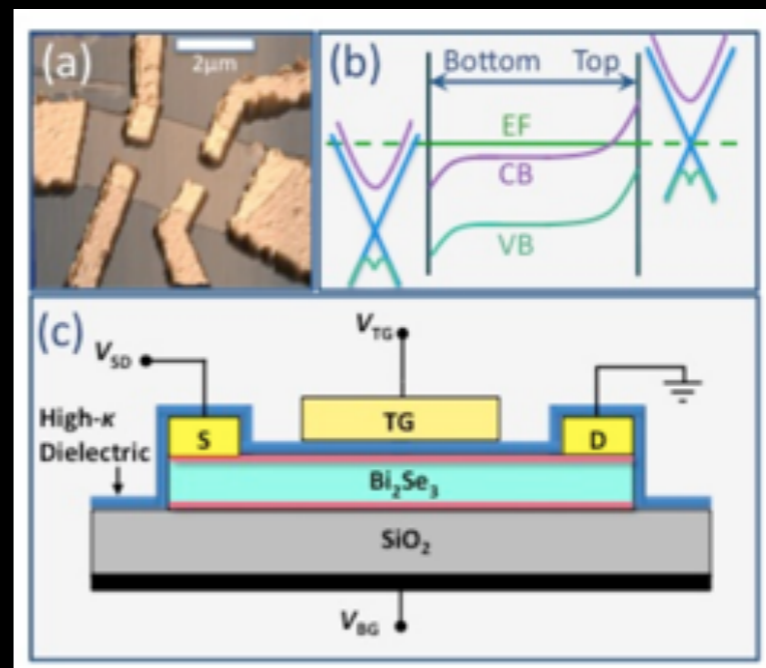
J. G. Checkelsky et al., arxiv 1003.3883

$d \sim 20 \text{ nm}$

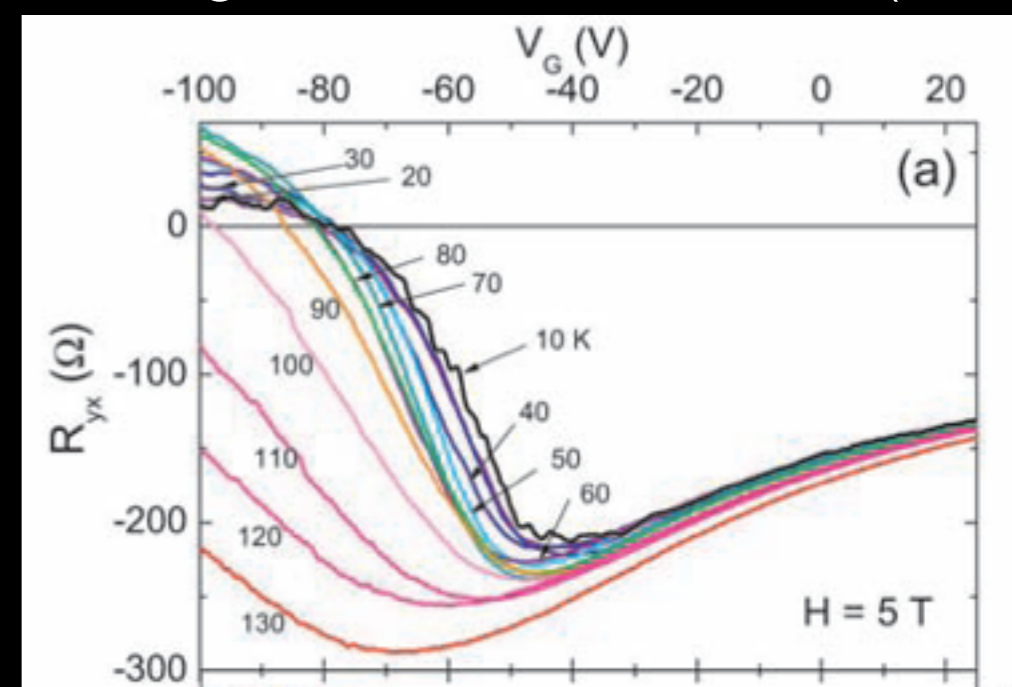
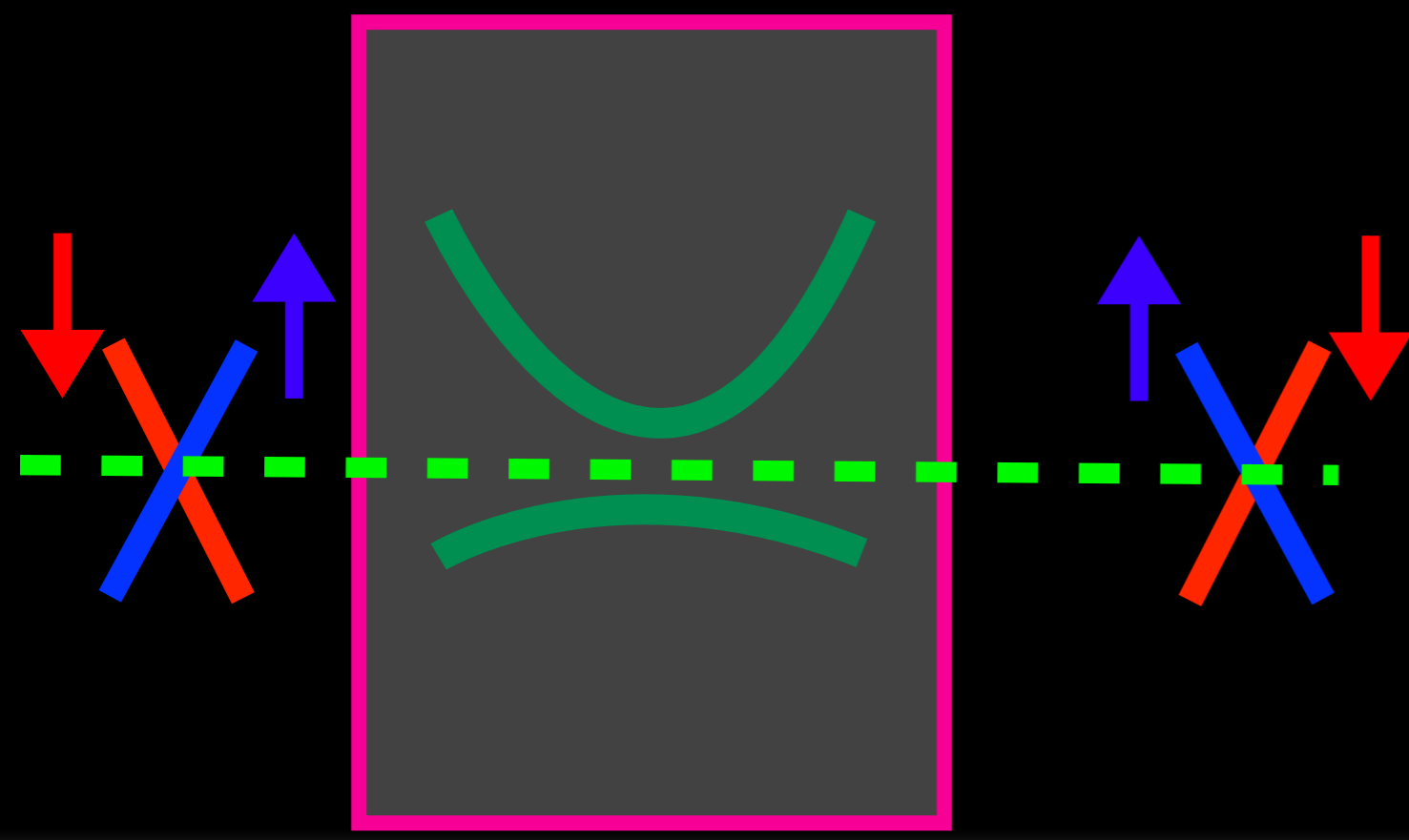
Towards the Surface

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H. Steinberg et al., NanoLett 10, 5032 (2010)



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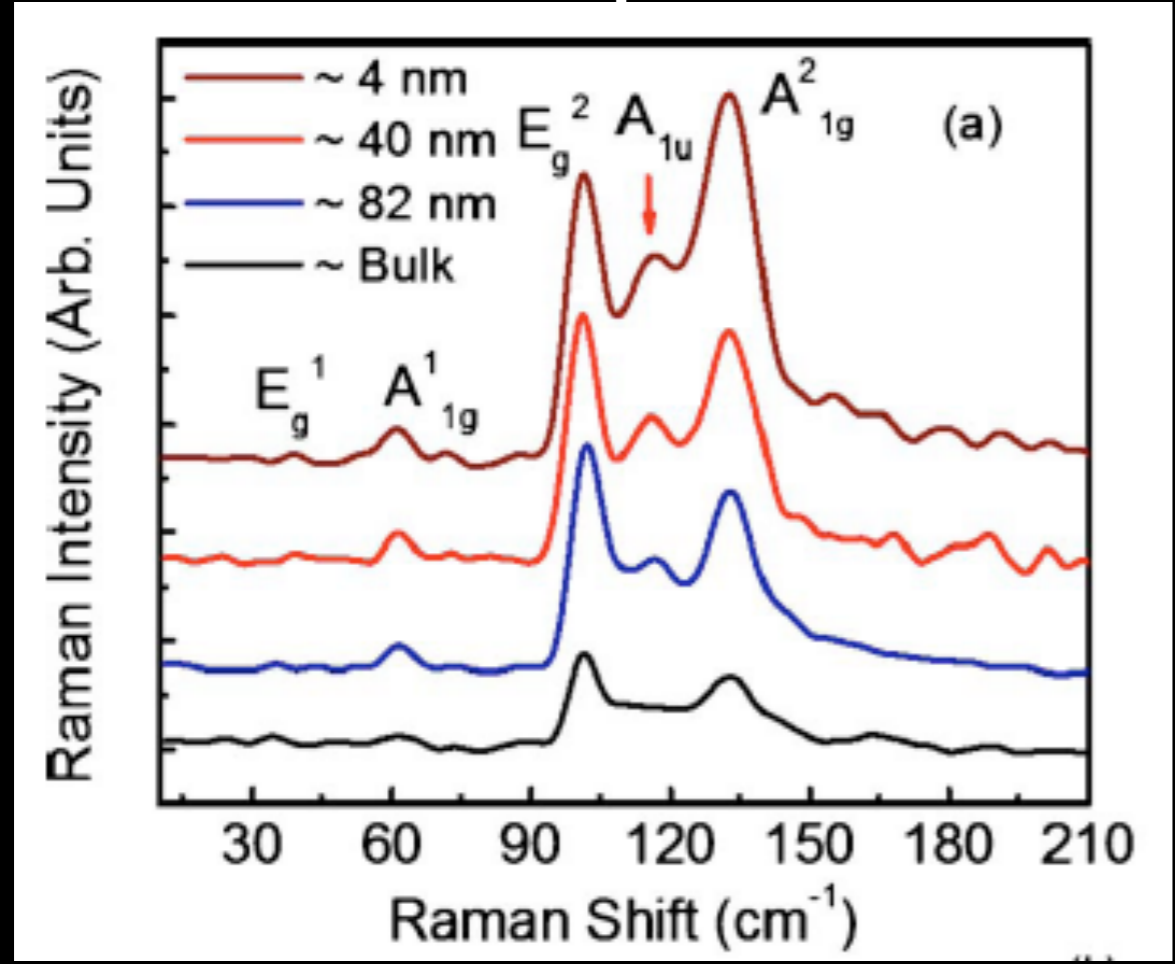


Towards the Surface

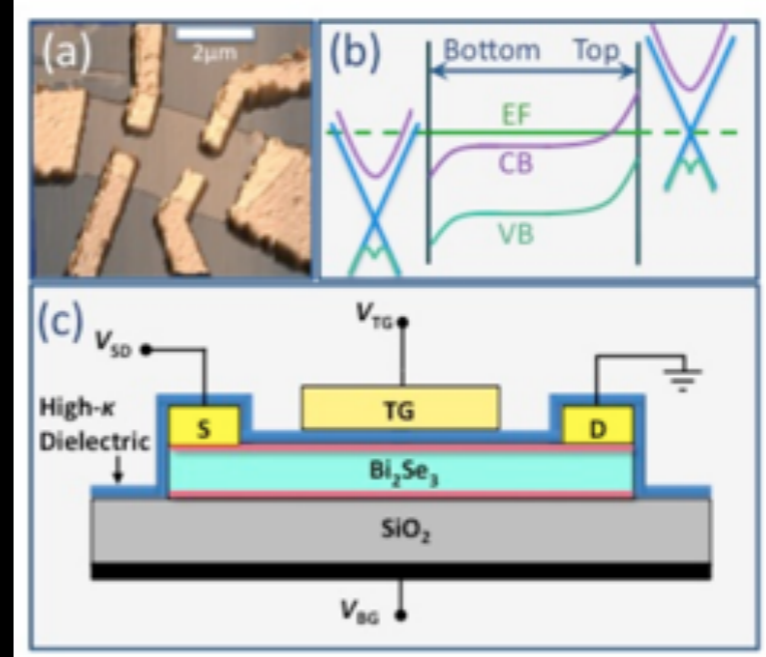
2300K Gap - Bi_2Te_3

3500K Gap - Bi_2Se_3

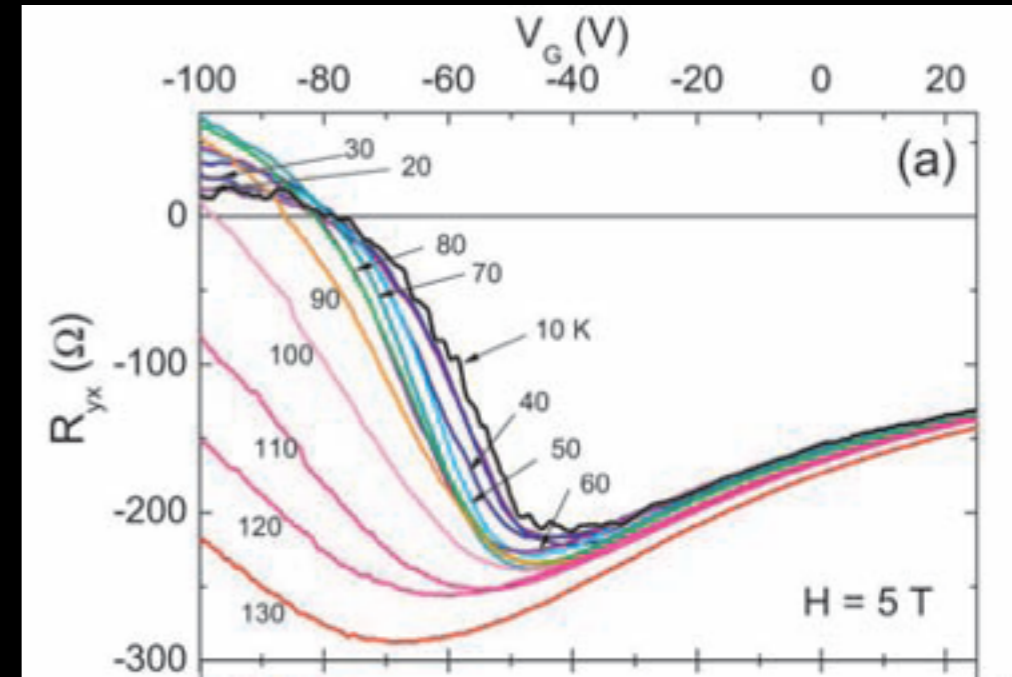
$d \sim 10 \text{ nm}$



K.M.F. Shahil et al., APL 96, 153103 (2010)



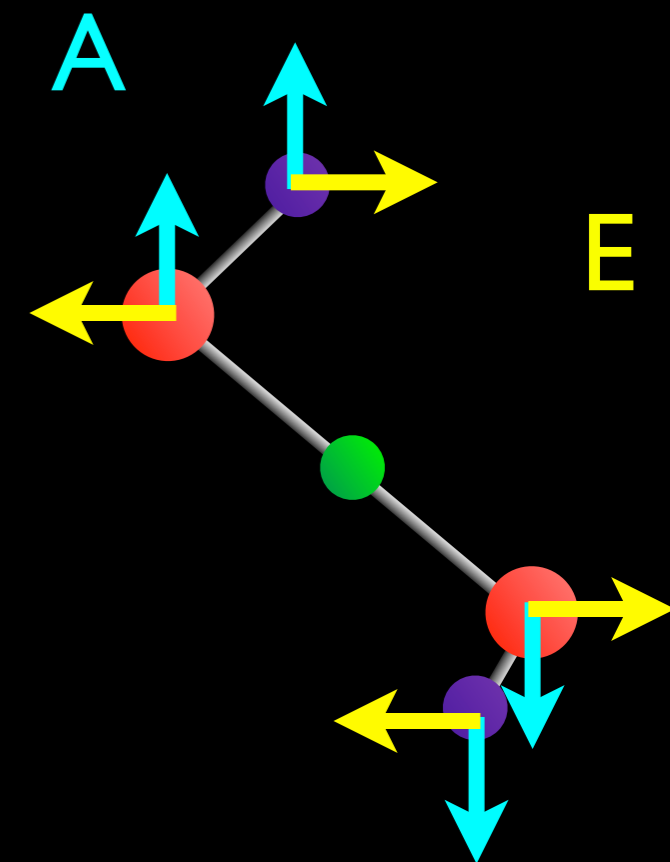
H. Steinberg et al., NanoLett 10, 5032 (2010)



J. G. Checkelsky et al., arxiv 1003.3883

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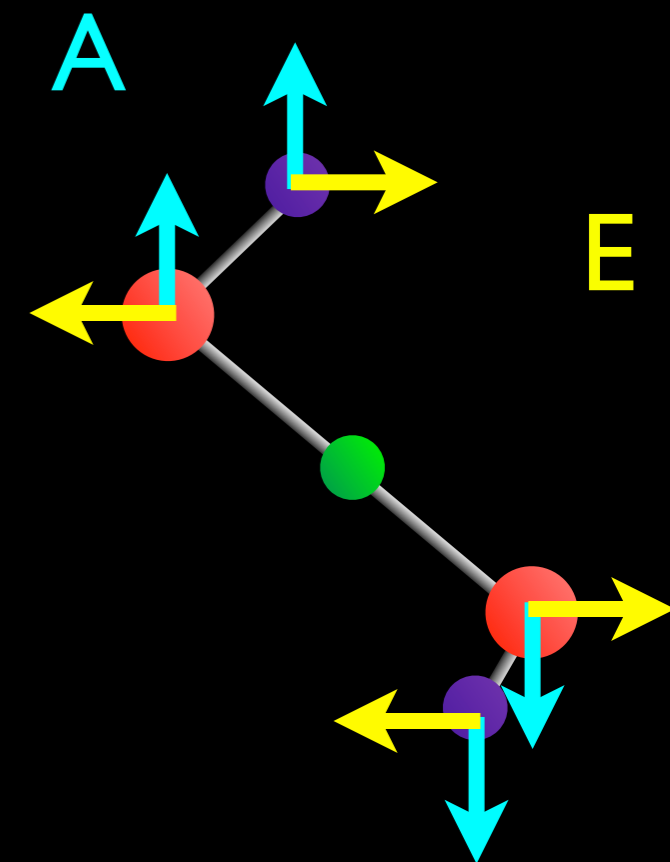
Raman



S.Y.F. Zhao et al., APL 98, 141911 (2011)

	Ir	Raman
A_{1G}		72,174.5
E_G		131.5
A_{1u}	135,161.5	
E_U	65,129	

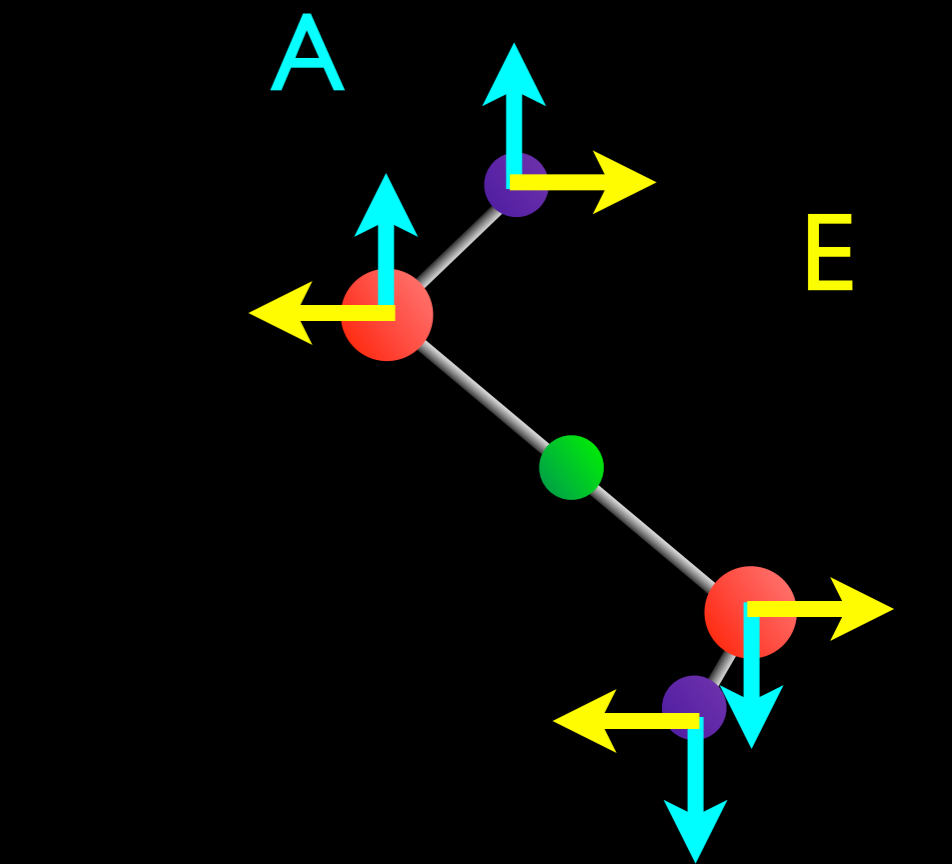
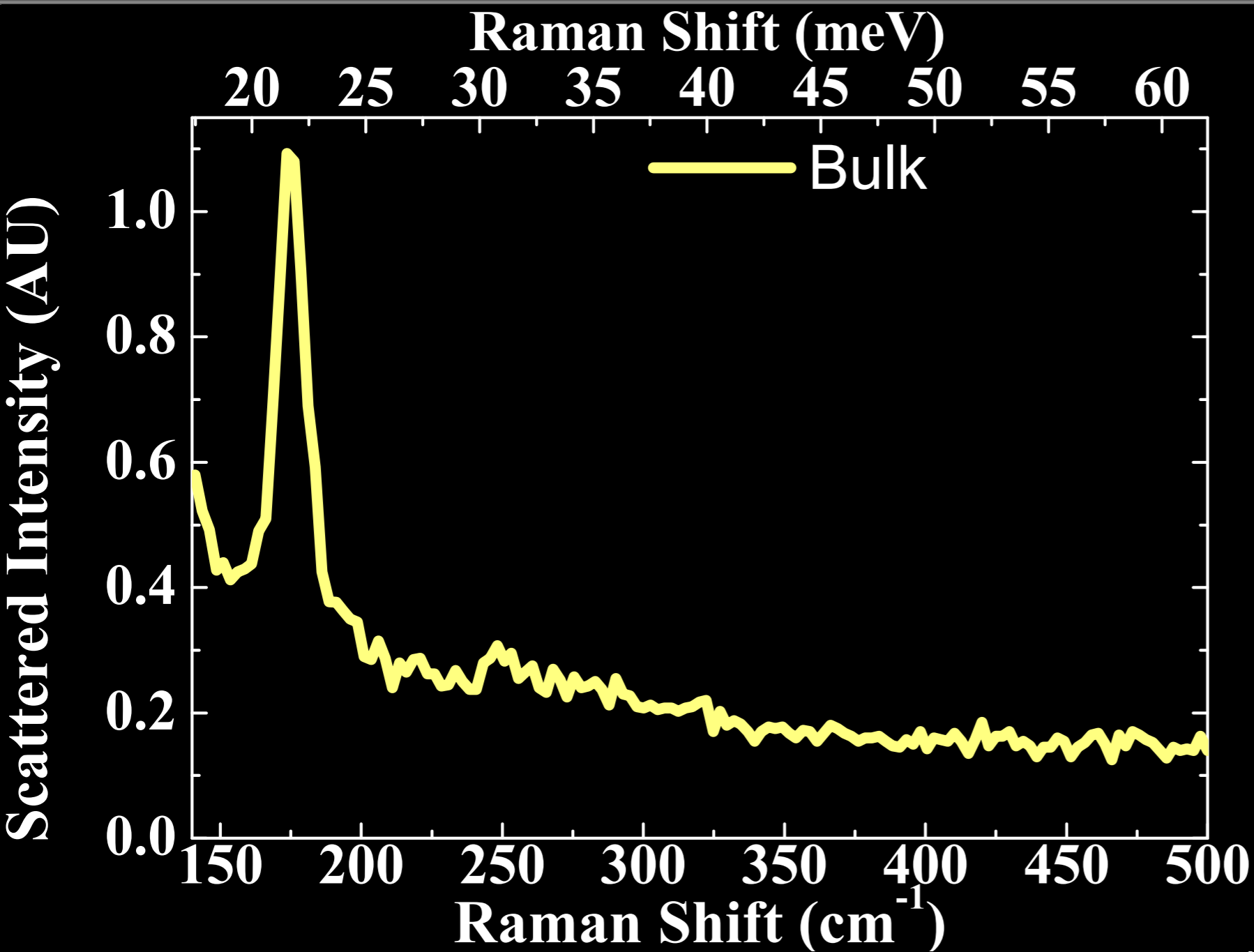
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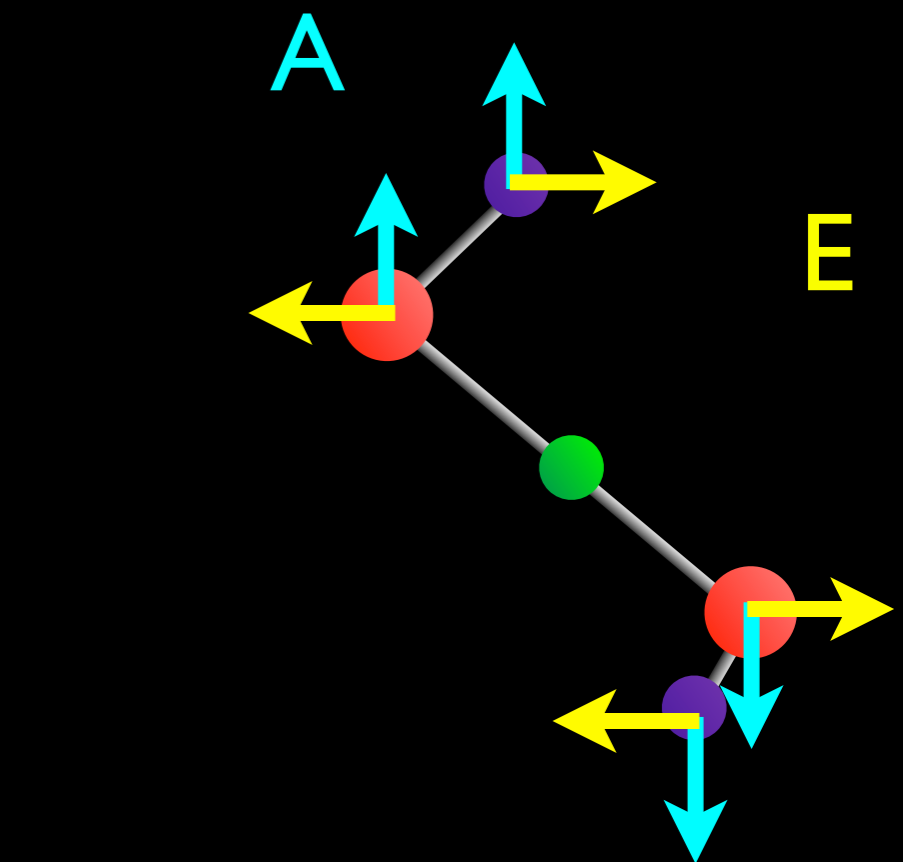
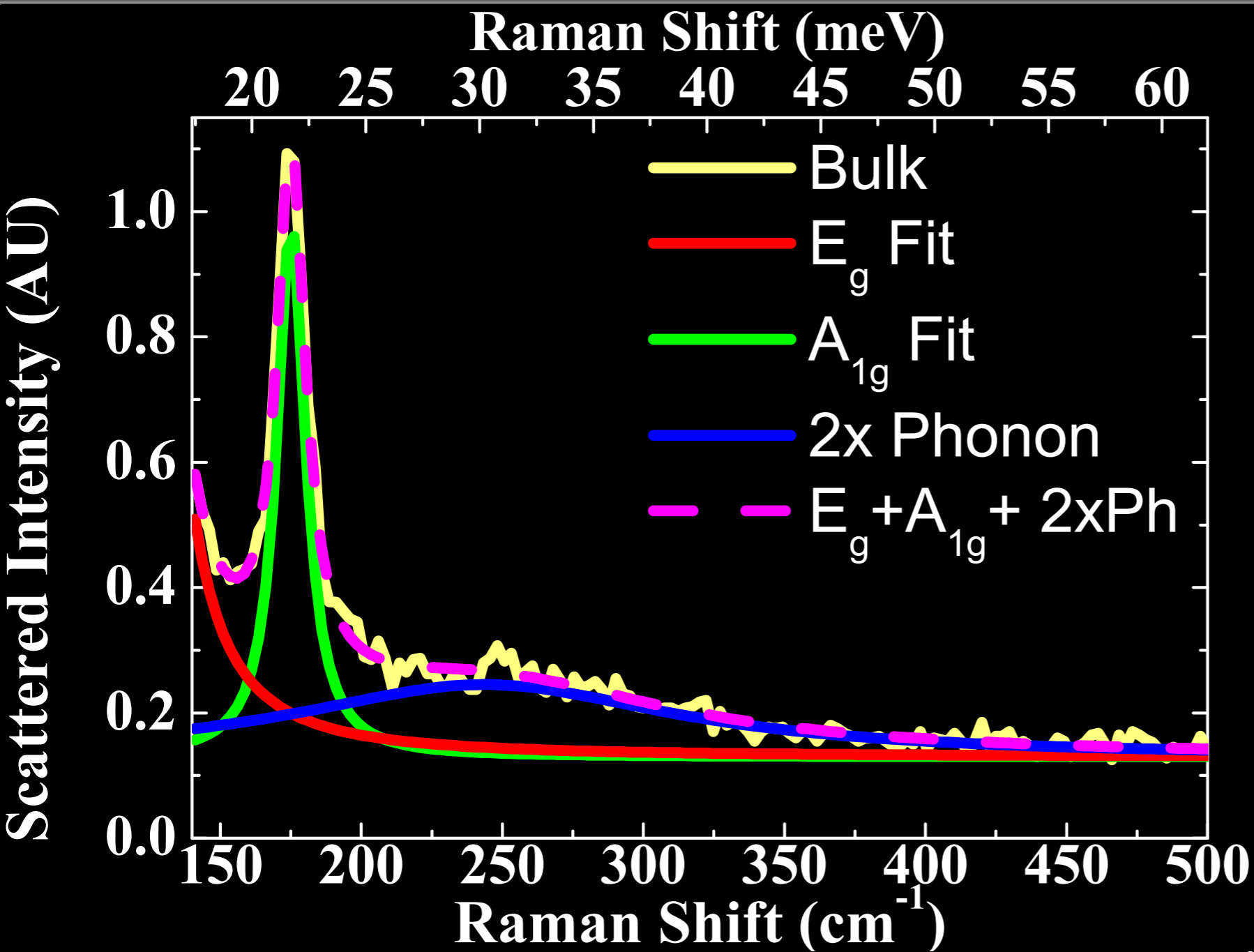
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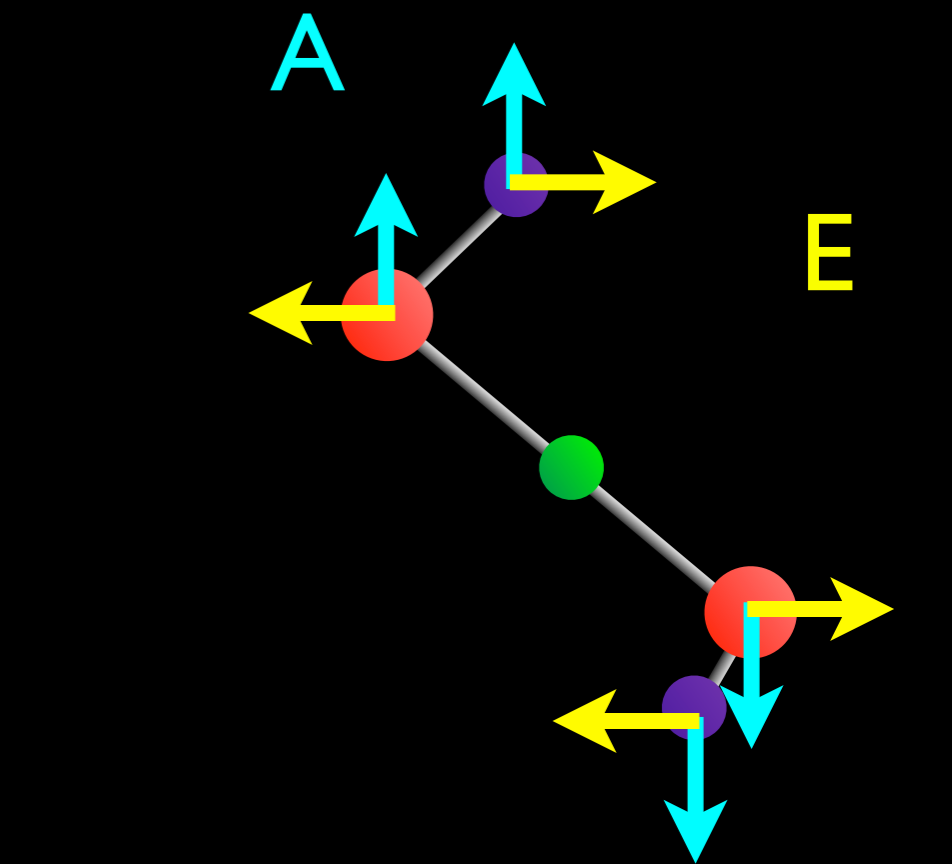
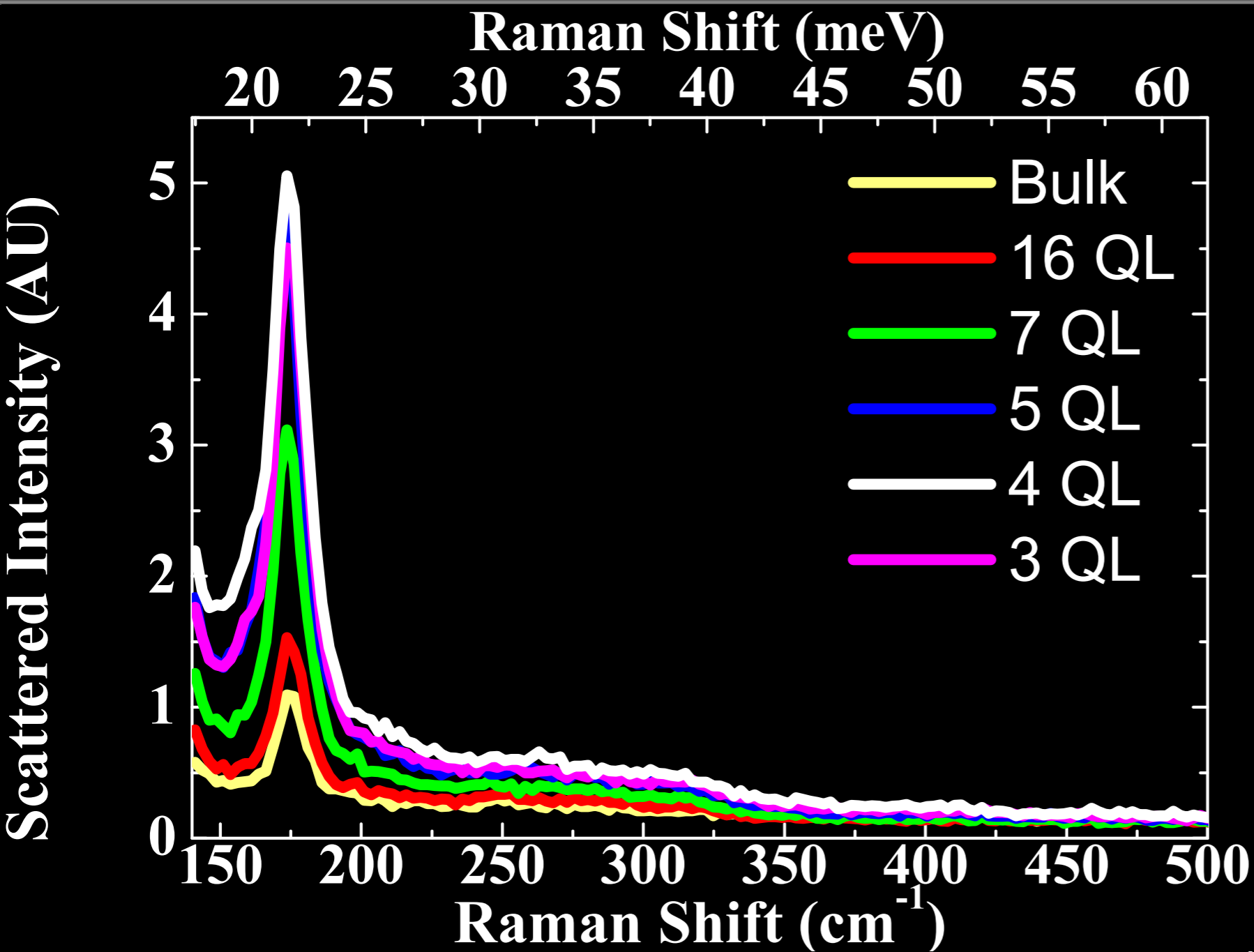
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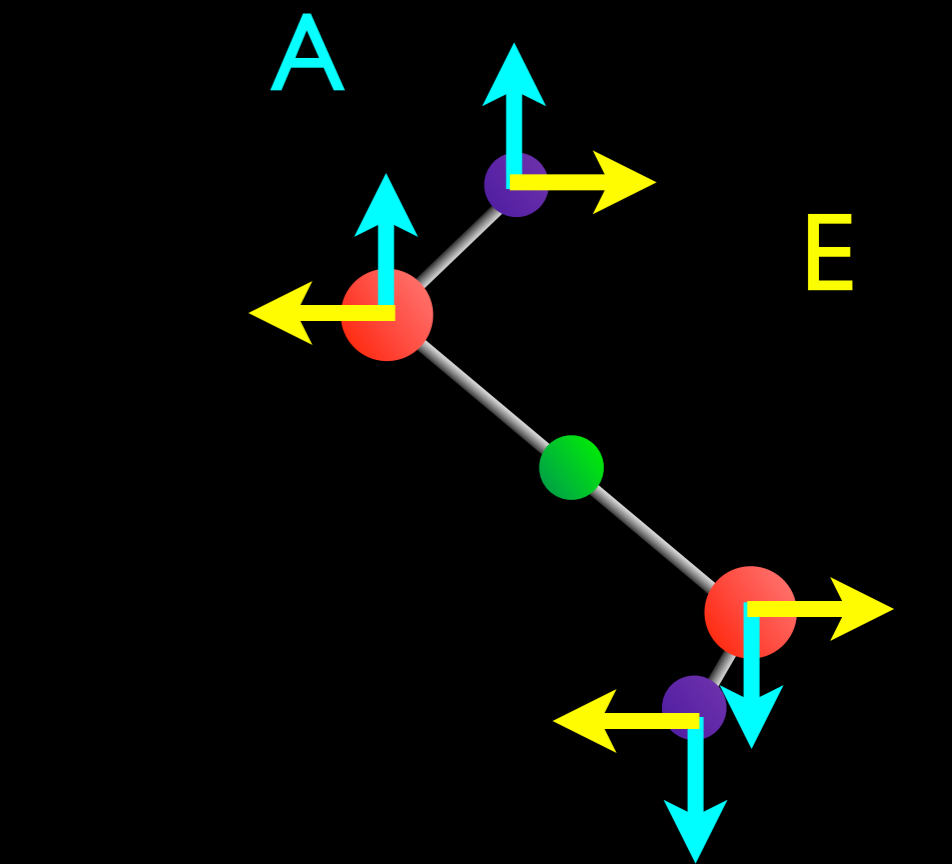
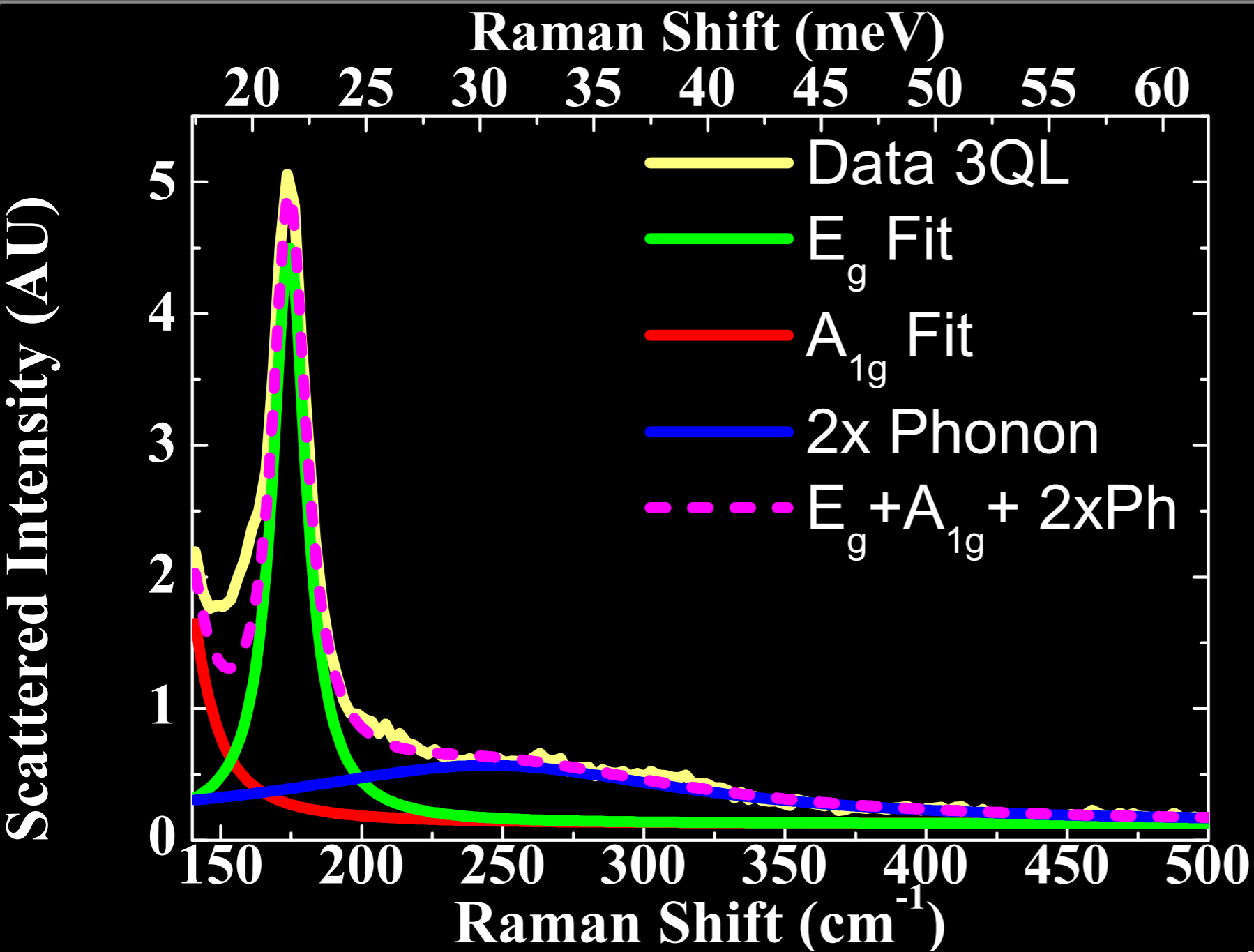
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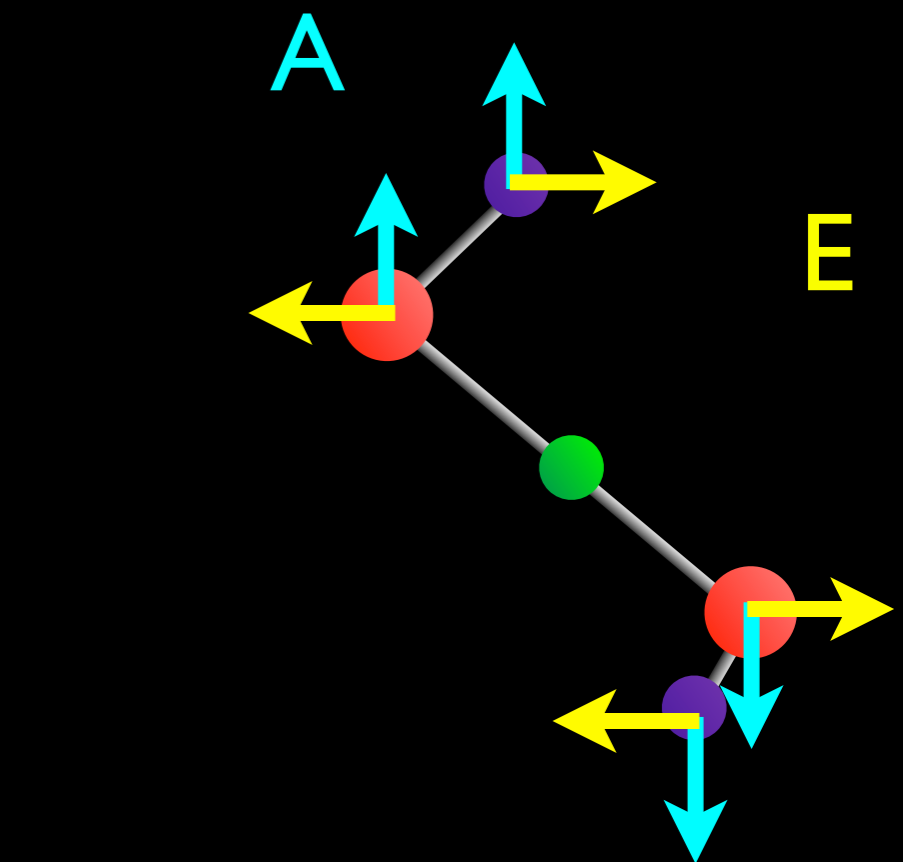
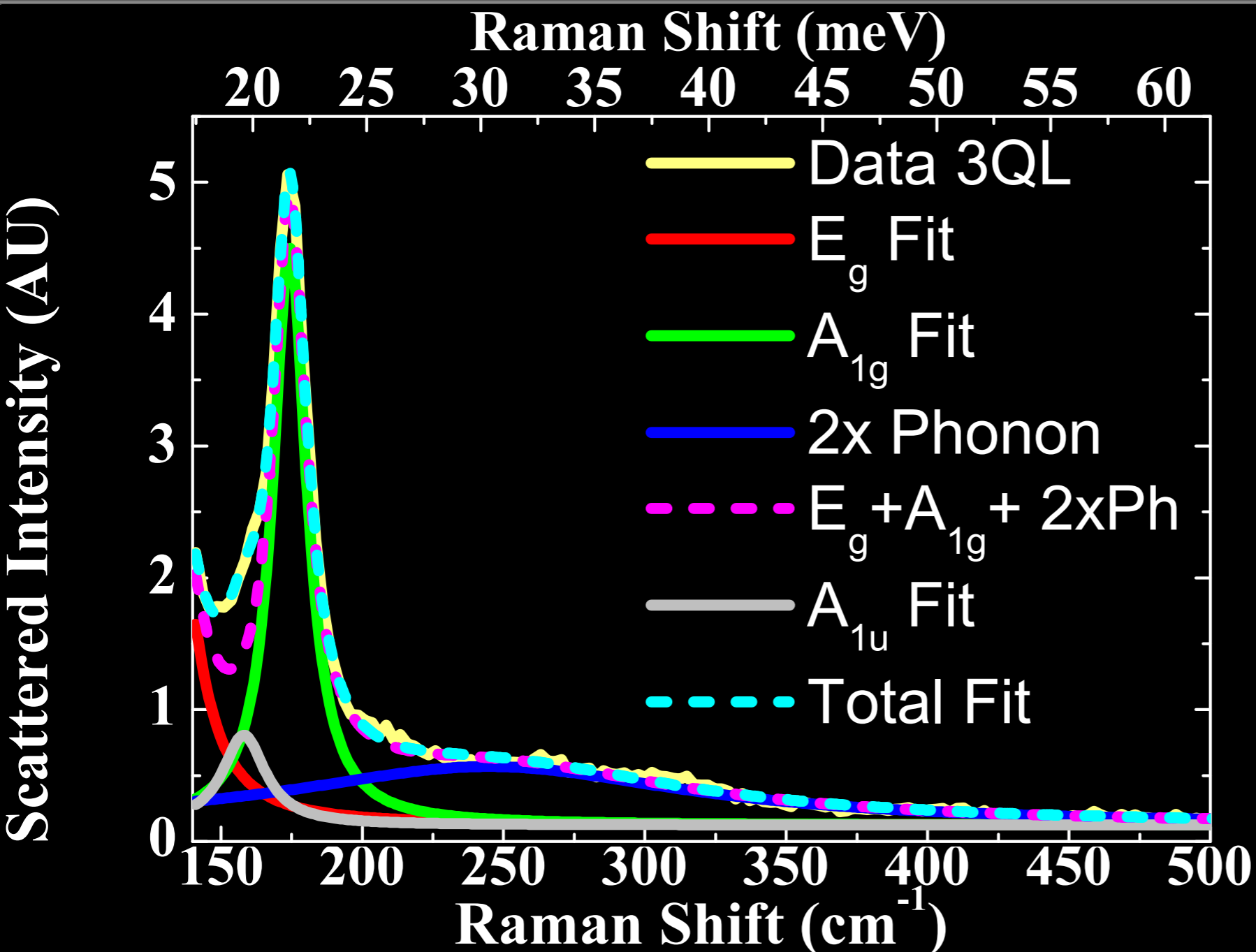
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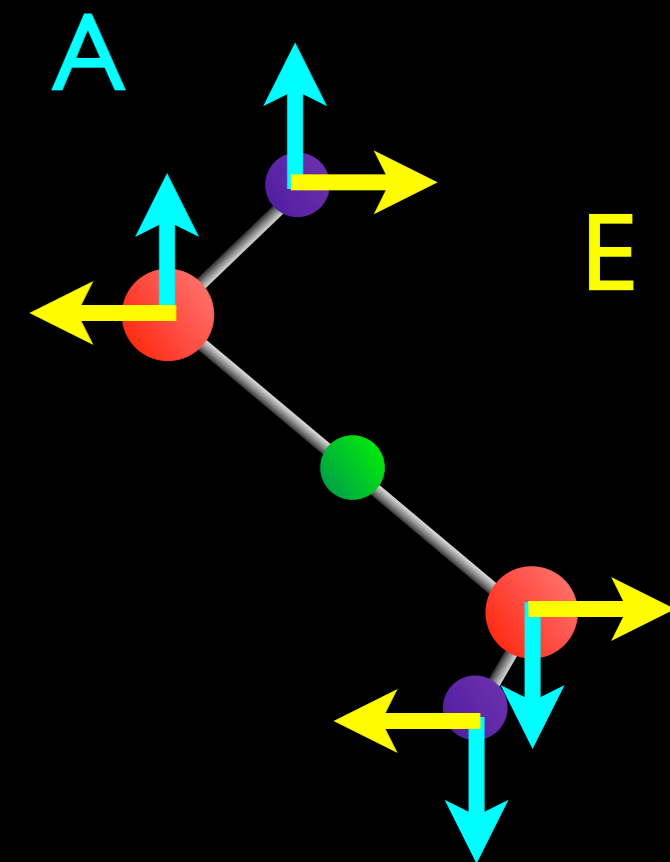
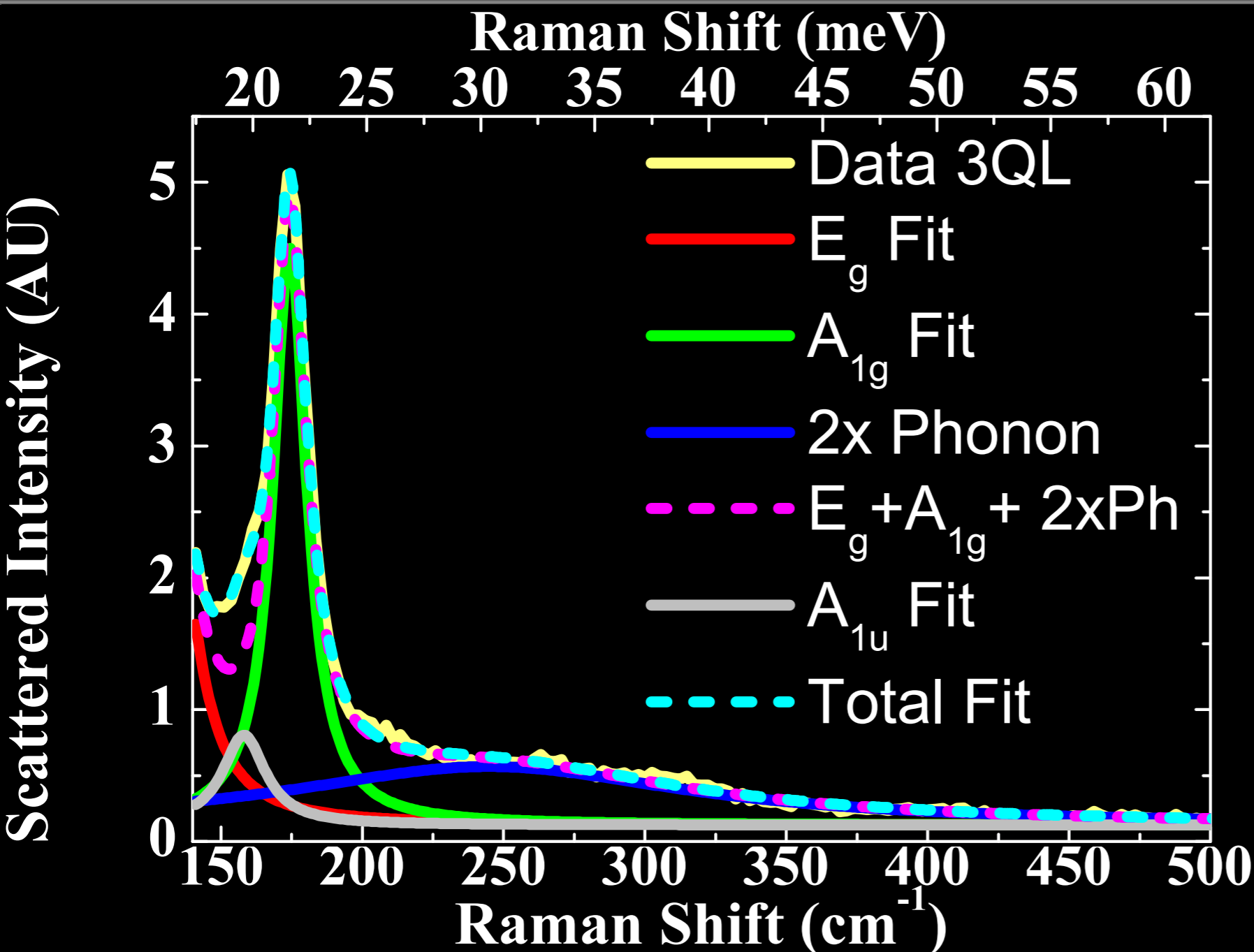
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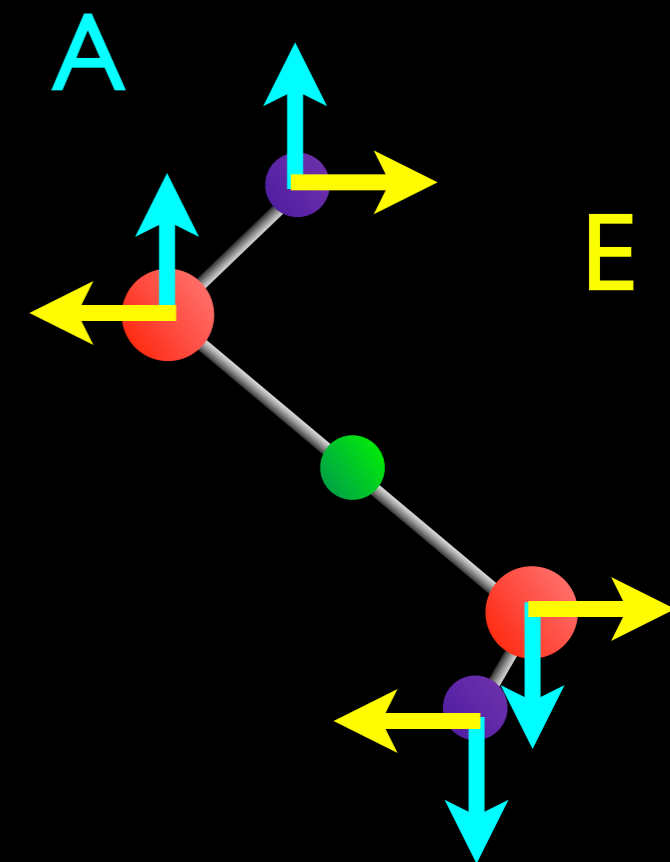
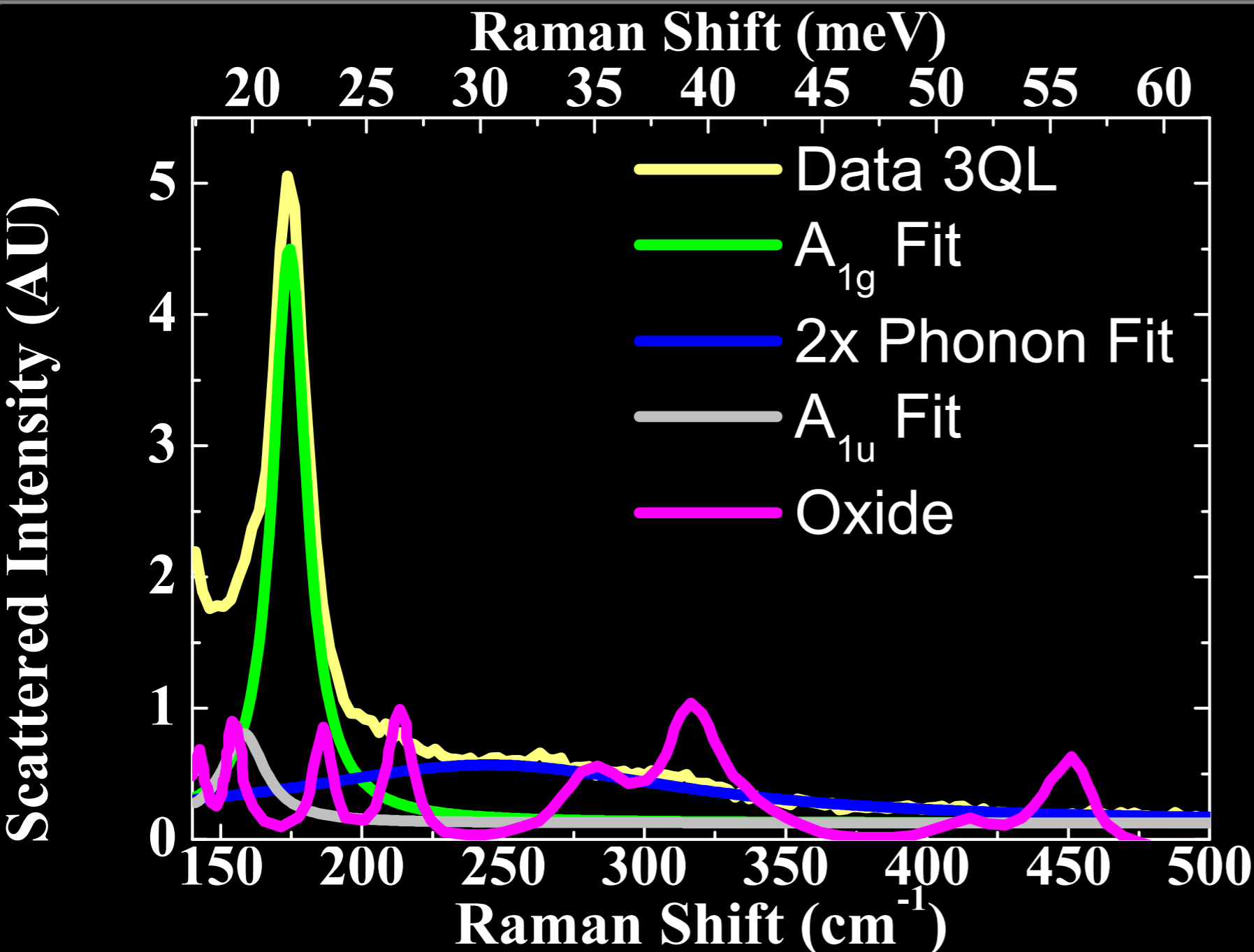
Raman



	Ir	Raman
A_{1G}		72,174.5
E_G		131.5
A_{1u}	135, 161.5	
E_U	65, 129	

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Raman

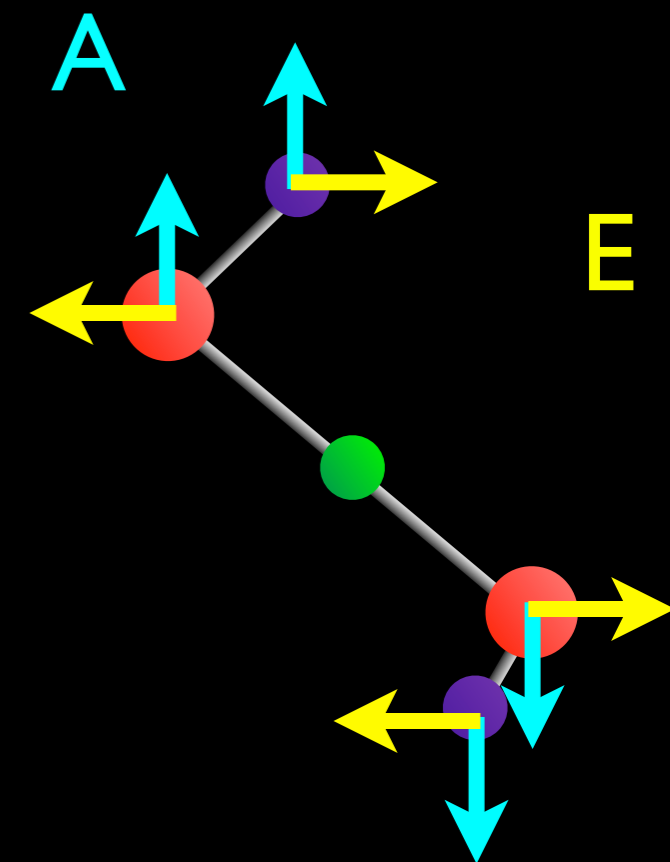
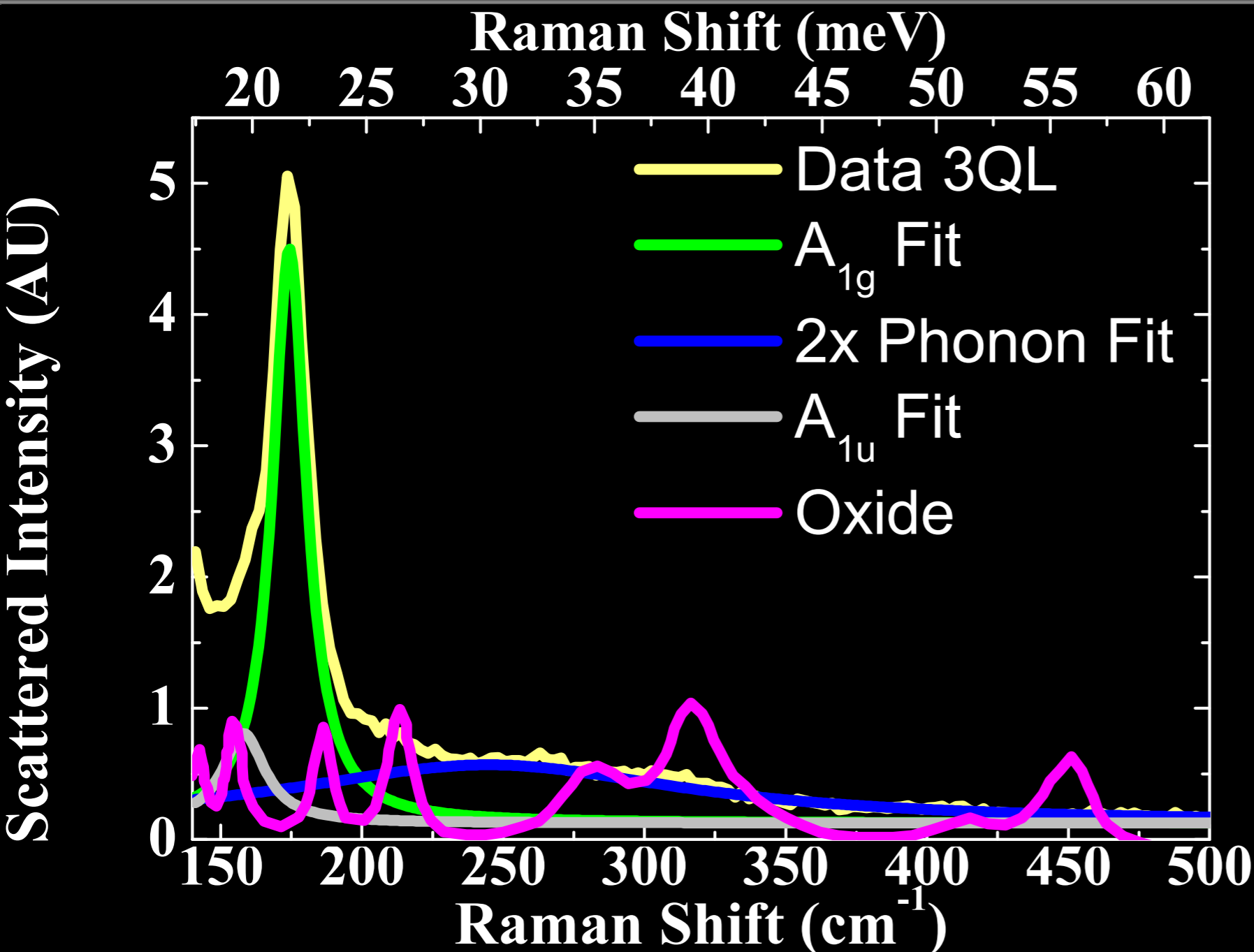


Ir (LO) Mode

	Ir	Raman
A _{1G}		72,174.5
E _G		131.5
A _{1u}	135, 161.5	
E _U	65, 129	

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Raman



Ir (LO) Mode

	Ir	Raman
A _{1G}		72,174.5
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A _{1u}	135, 161.5	
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S.Y.F. Zhao et al., APL 98, 141911 (2011)

X. Zhu et al., arxiv 1108.2470

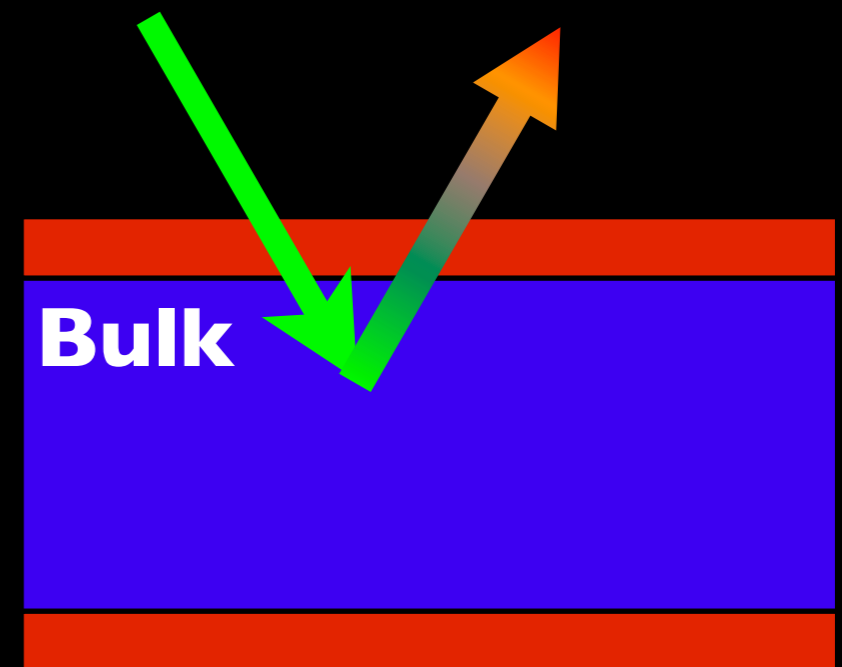


Thickness

Ir (LO) Mode

S.Y.F. Zhao et al., APL 98, 141911 (2011)

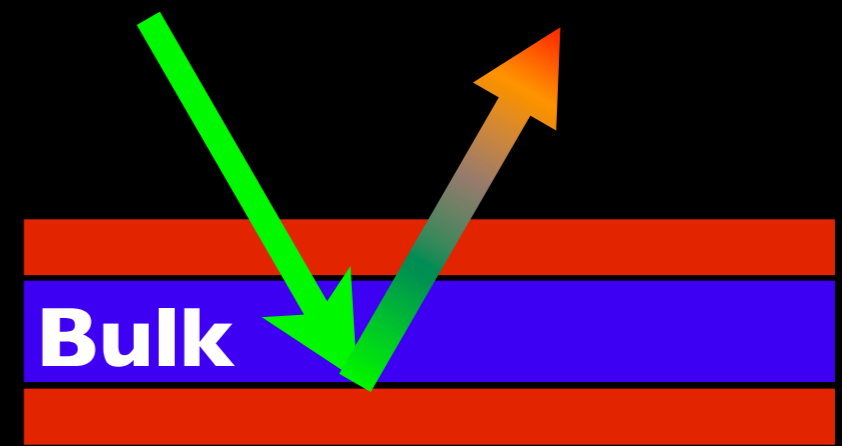
Thickness



Ir (LO) Mode

S.Y.F. Zhao et al., APL 98, 141911 (2011)

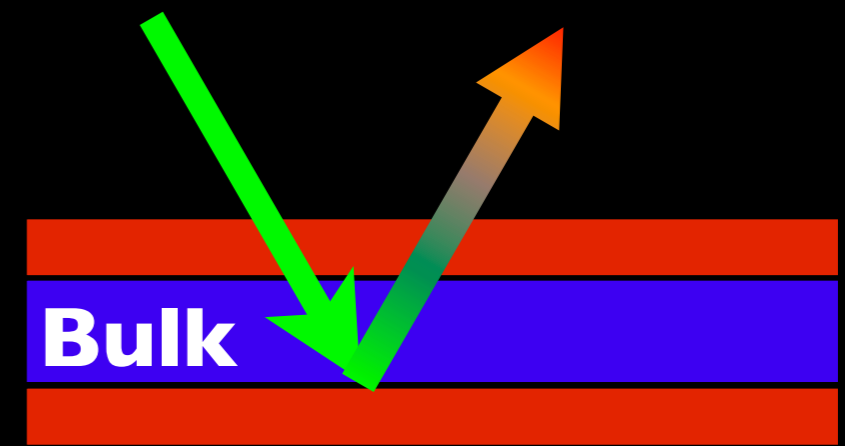
Thickness



Ir (LO) Mode

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Thickness

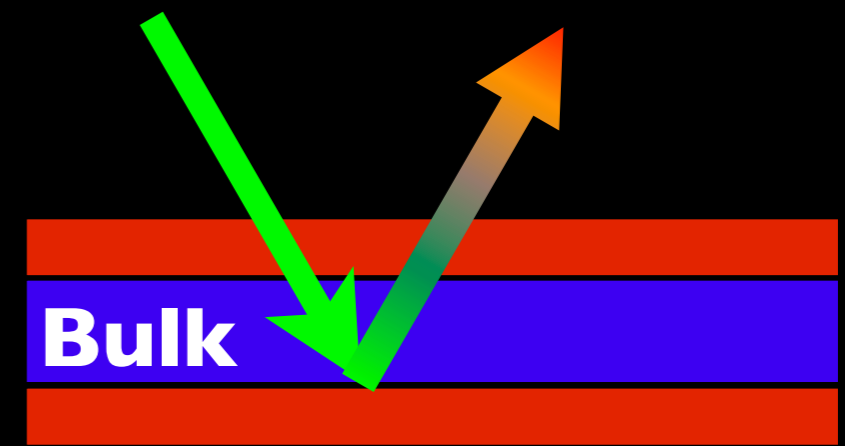


Ir (LO) Mode

Surface volume probed ~ 2

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Thickness

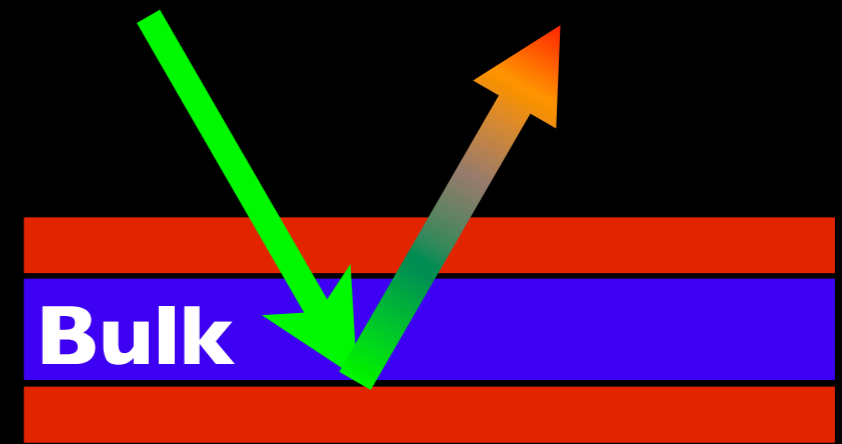


Ir (LO) Mode

Surface volume probed ~ 2
Bulk volume probed $\sim QL - 2$

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Thickness



Ir (LO) Mode

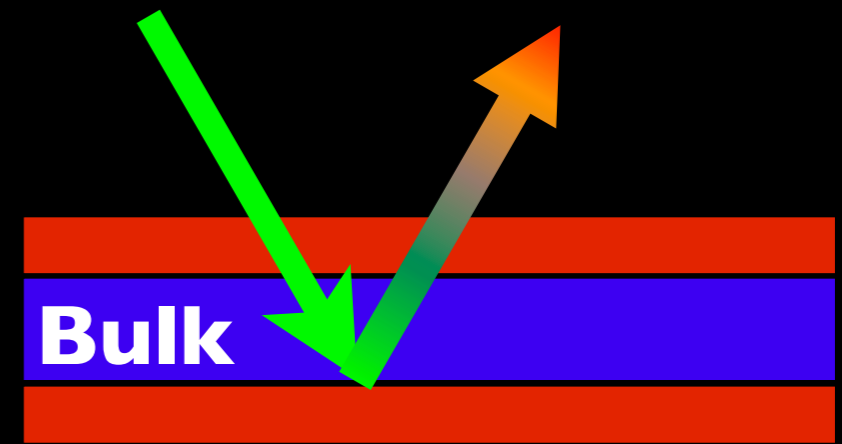
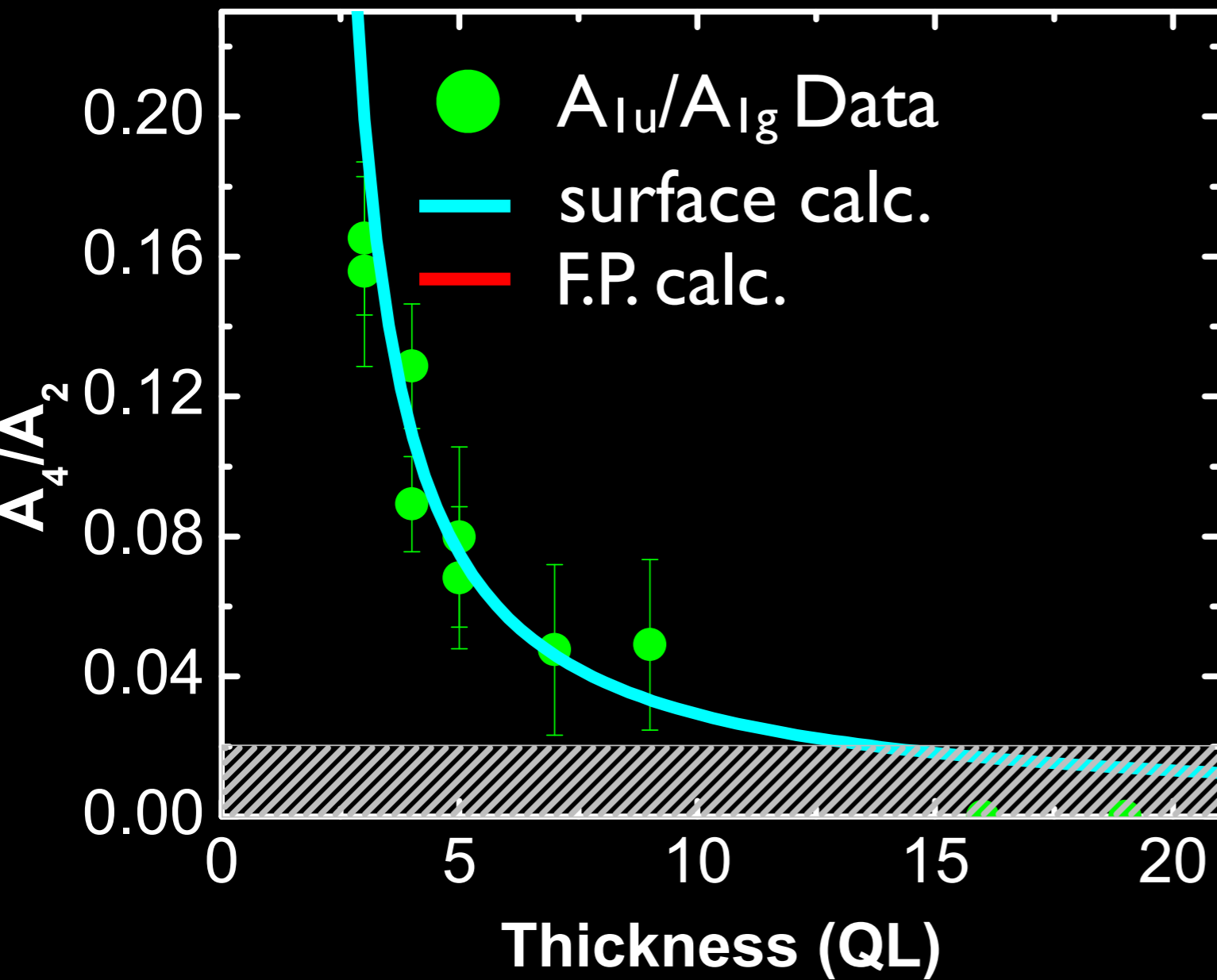
Surface volume probed ~ 2

Bulk volume probed $\sim QL - 2$

$$\text{Ratio} \sim \frac{\alpha}{QL - 2}$$

S.Y.F. Zhao et al., APL 98, 141911 (2011)

Thickness



Ir (LO) Mode

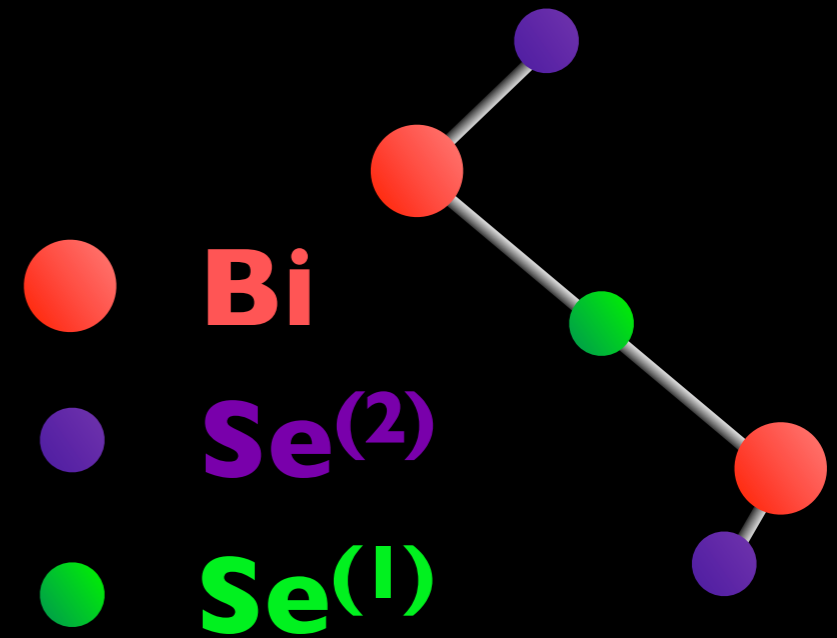
Surface volume probed ~ 2

Bulk volume probed $\sim QL - 2$

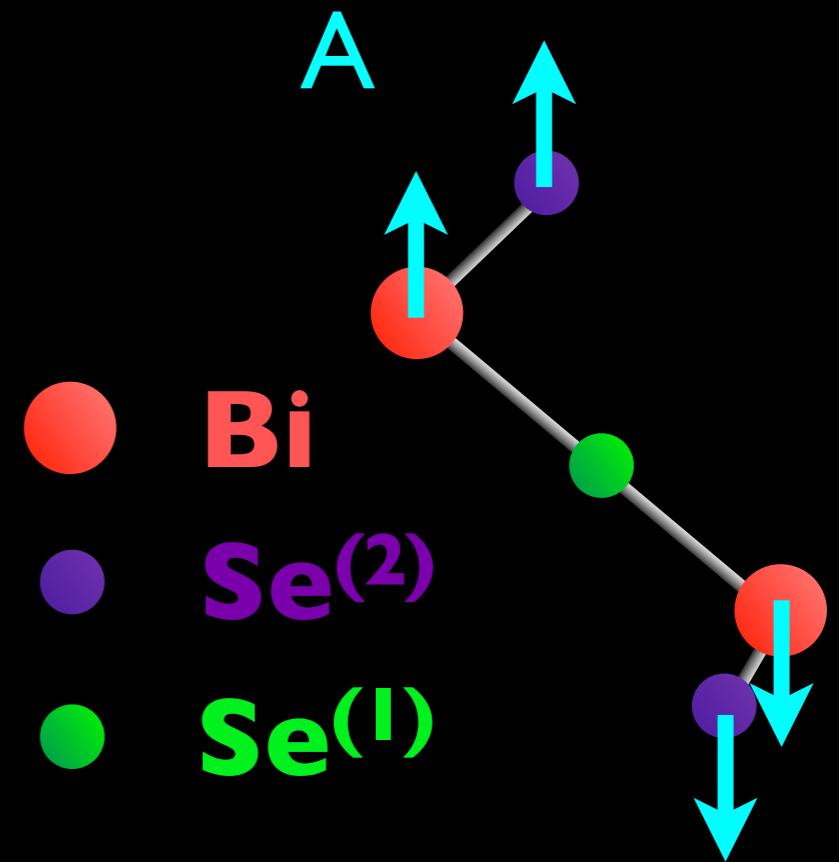
$$\text{Ratio} \sim \frac{\alpha}{QL - 2}$$

S.Y.F. Zhao et al., APL 98, 141911 (2011)

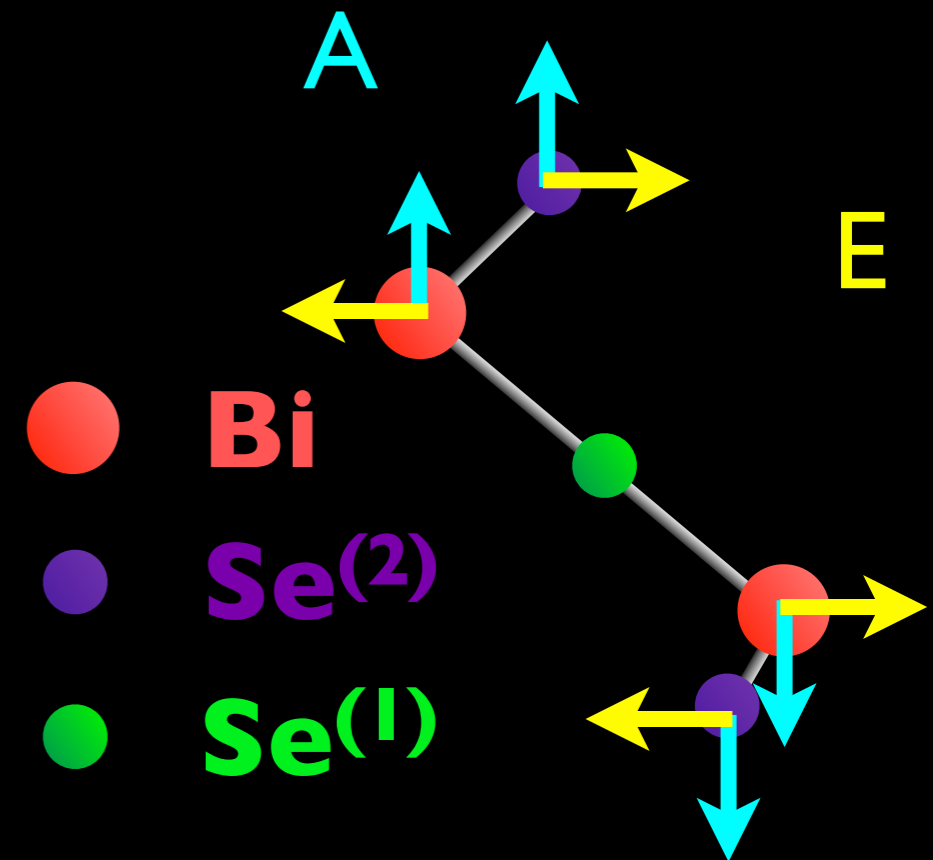
Phonons



Phonons



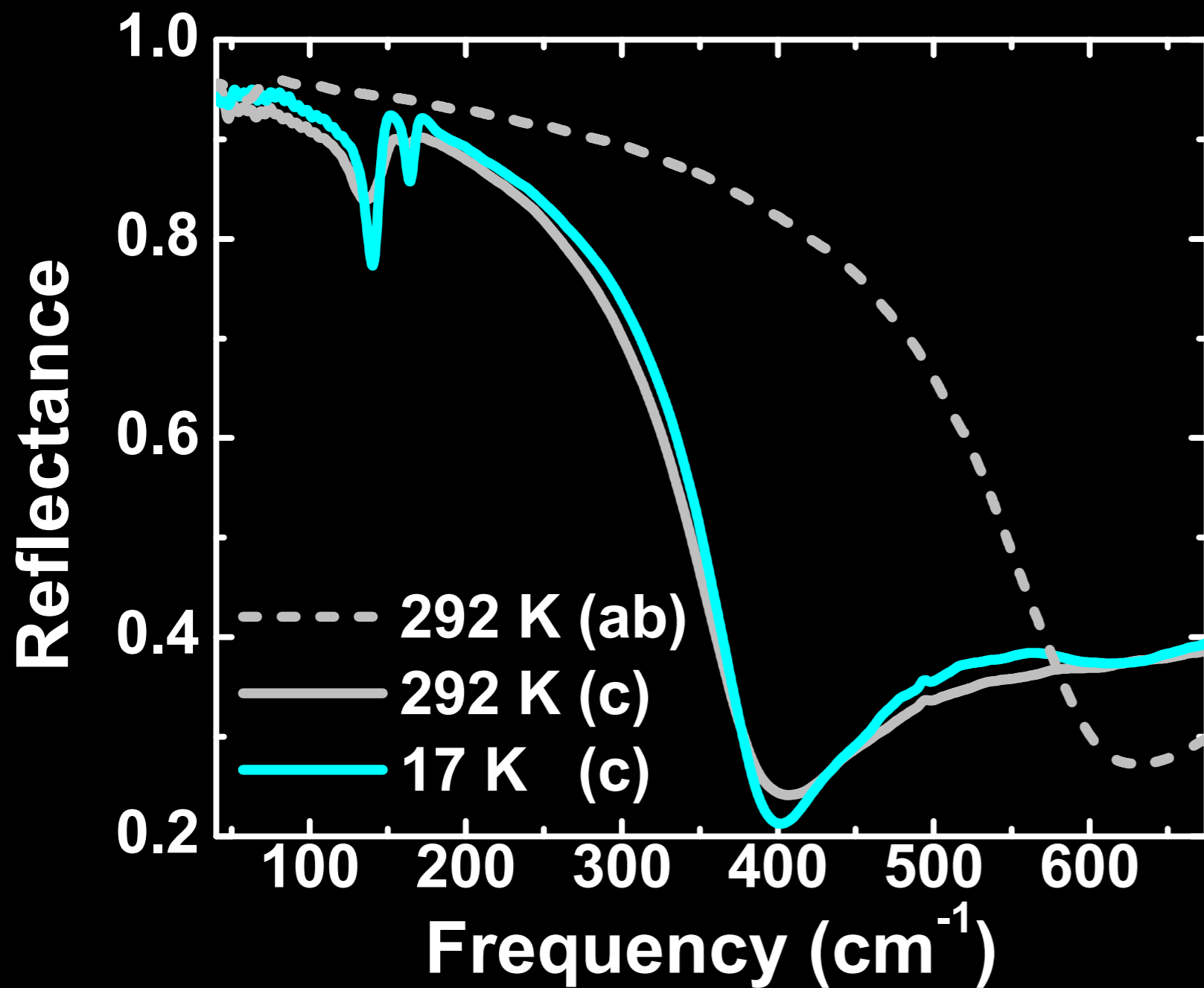
Phonons



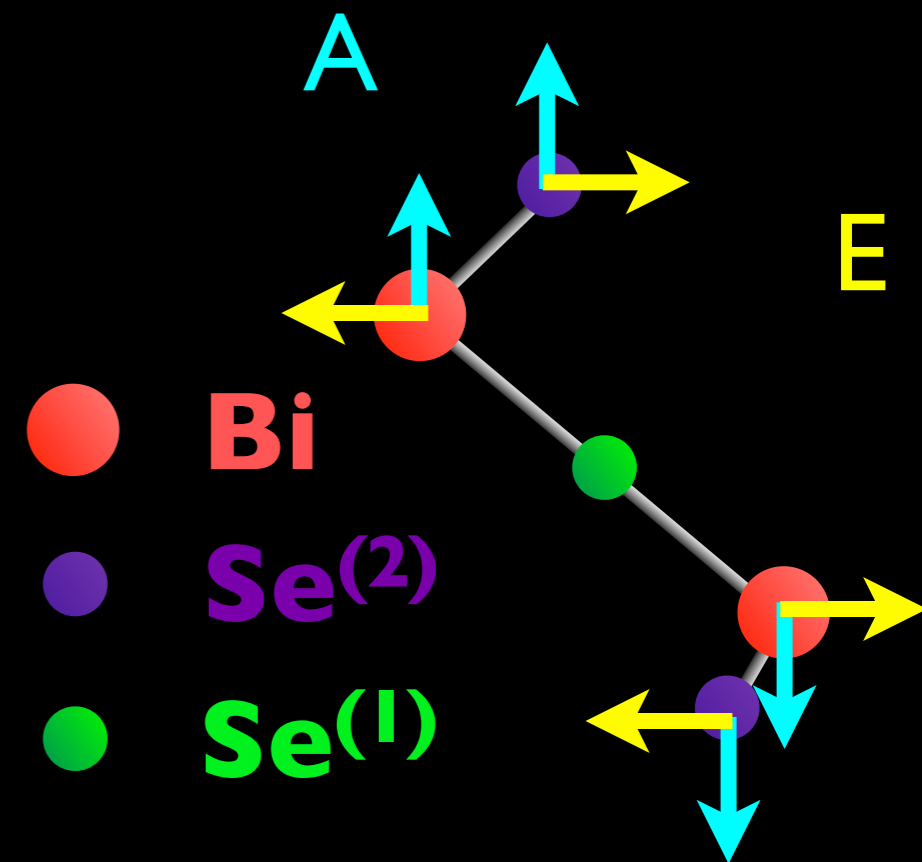
W. Richter et al., phys. stat. sol. b 84, 619 (1977)
 A. D Laforge et al., PRB 81 125120 (2010)
 A.B. Sushkov et al., PRB 82 125110 (2010)

	Ir	Raman
A _{1G}		72,174.5
E _G		131.5
A _{1u}	?	
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Phonons

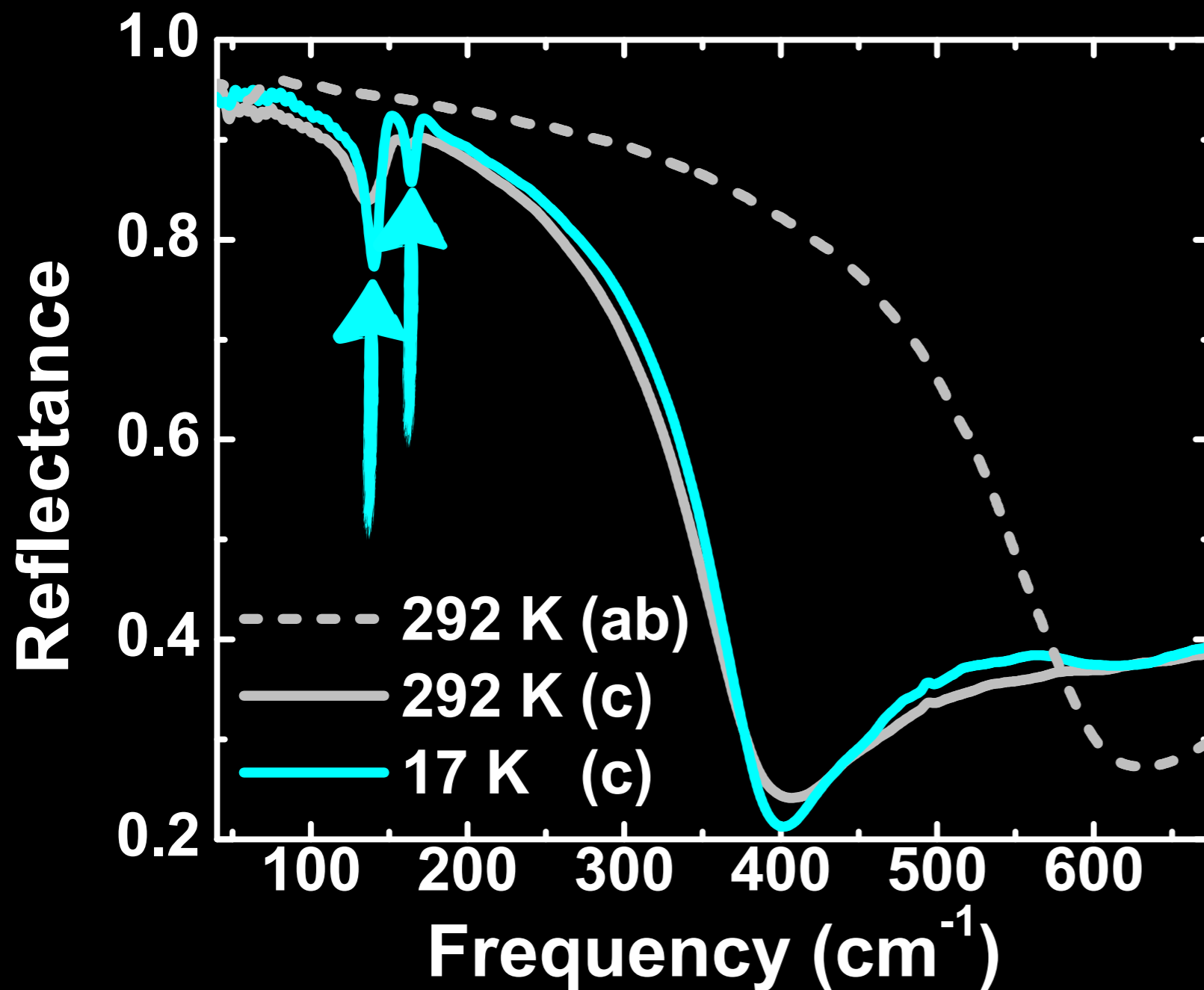


W. Richter et al., phys. stat. sol. b 84, 619 (1977)
 A. D Laforge et al., PRB 81 125120 (2010)
 A.B. Sushkov et al., PRB 82 125110 (2010)

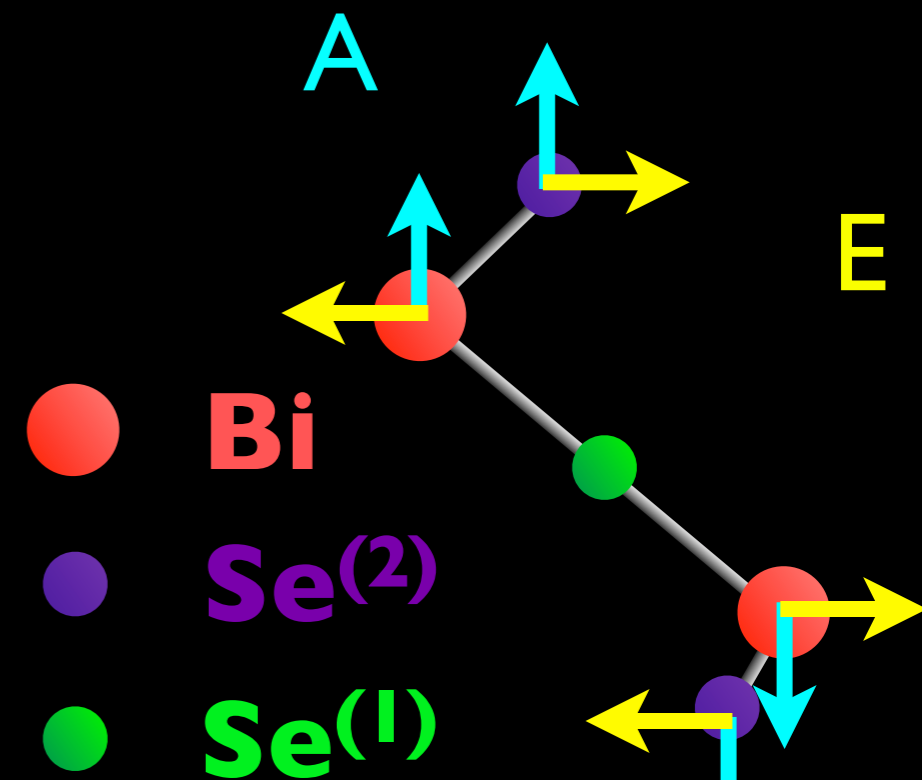


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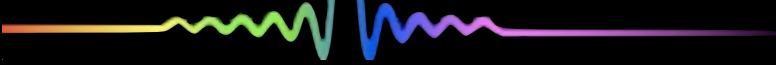
Phonons



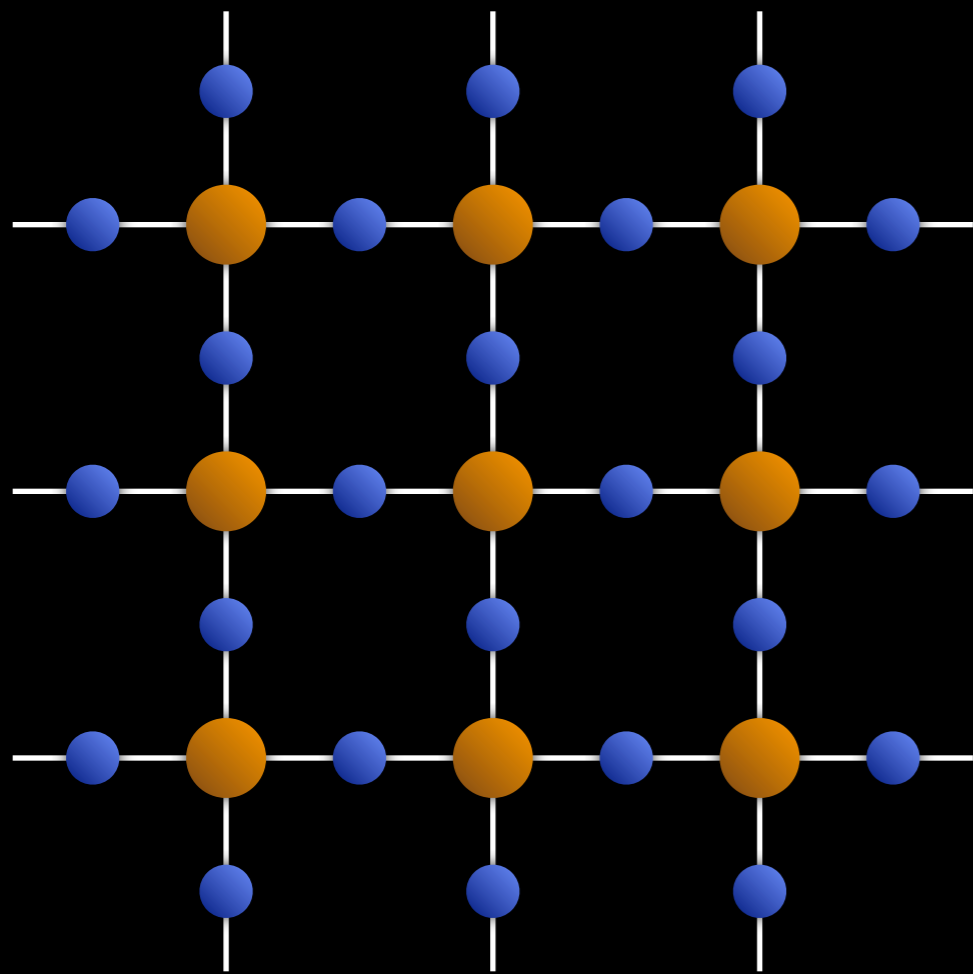
W. Richter et al., phys. stat. sol. b 84, 619 (1977)
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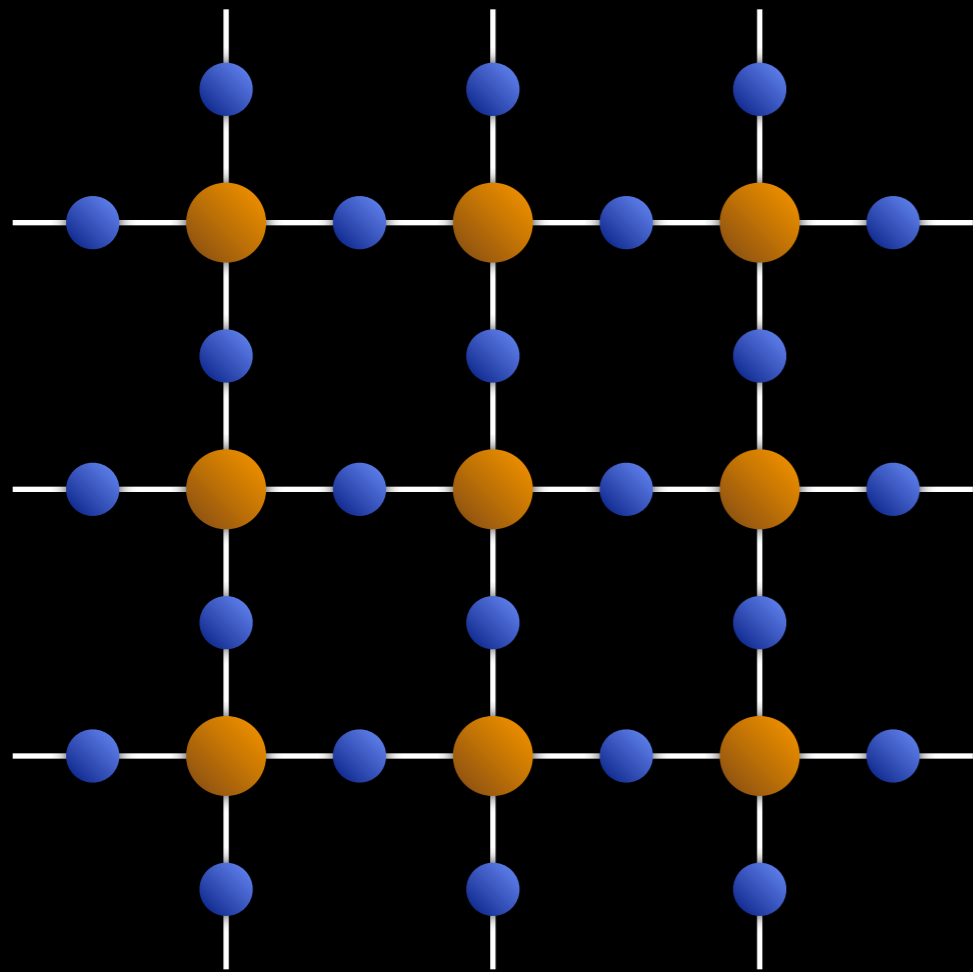


Band Theory



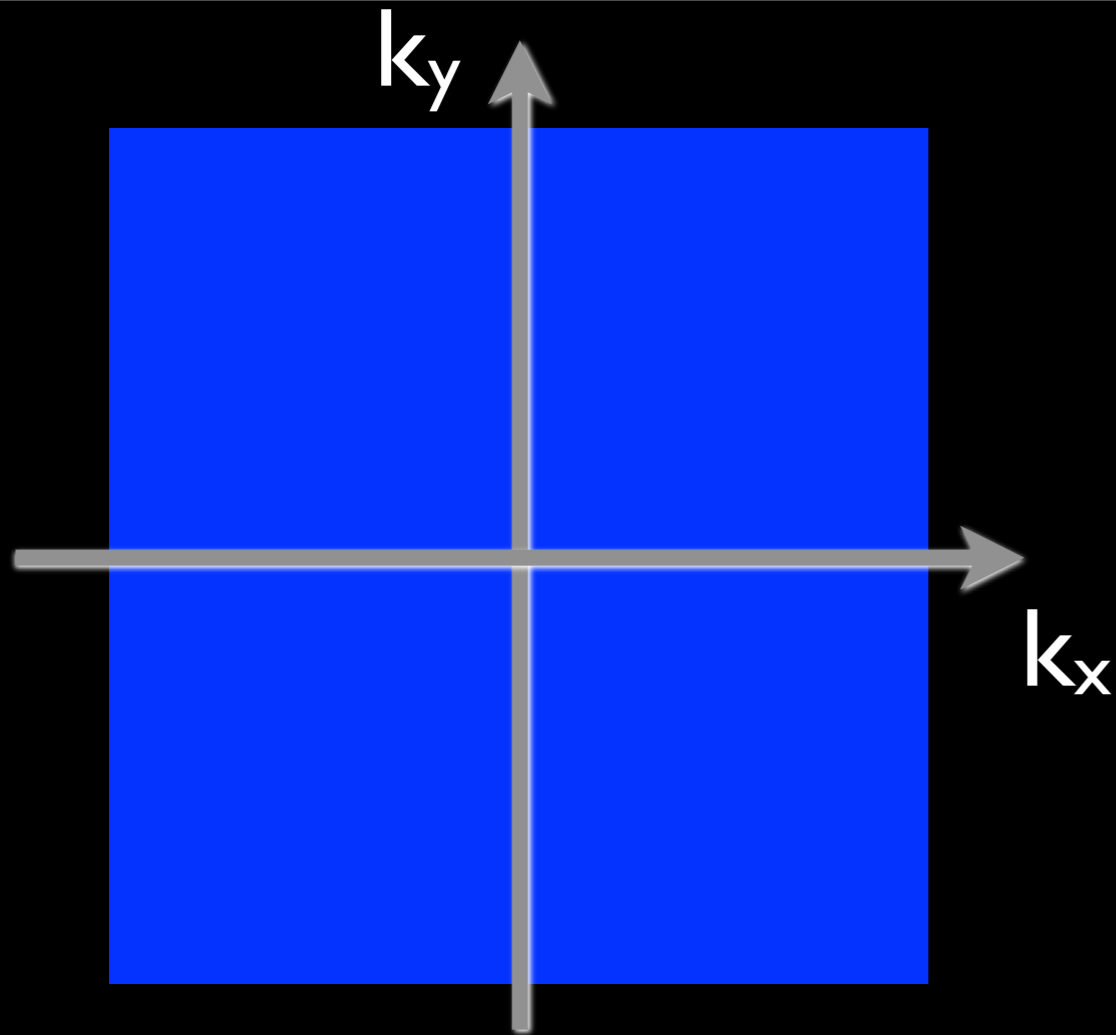
D. Xiao, et al. RMP 82, 1959 (2010)

$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



D. Xiao, et al. RMP 82, 1959 (2010)

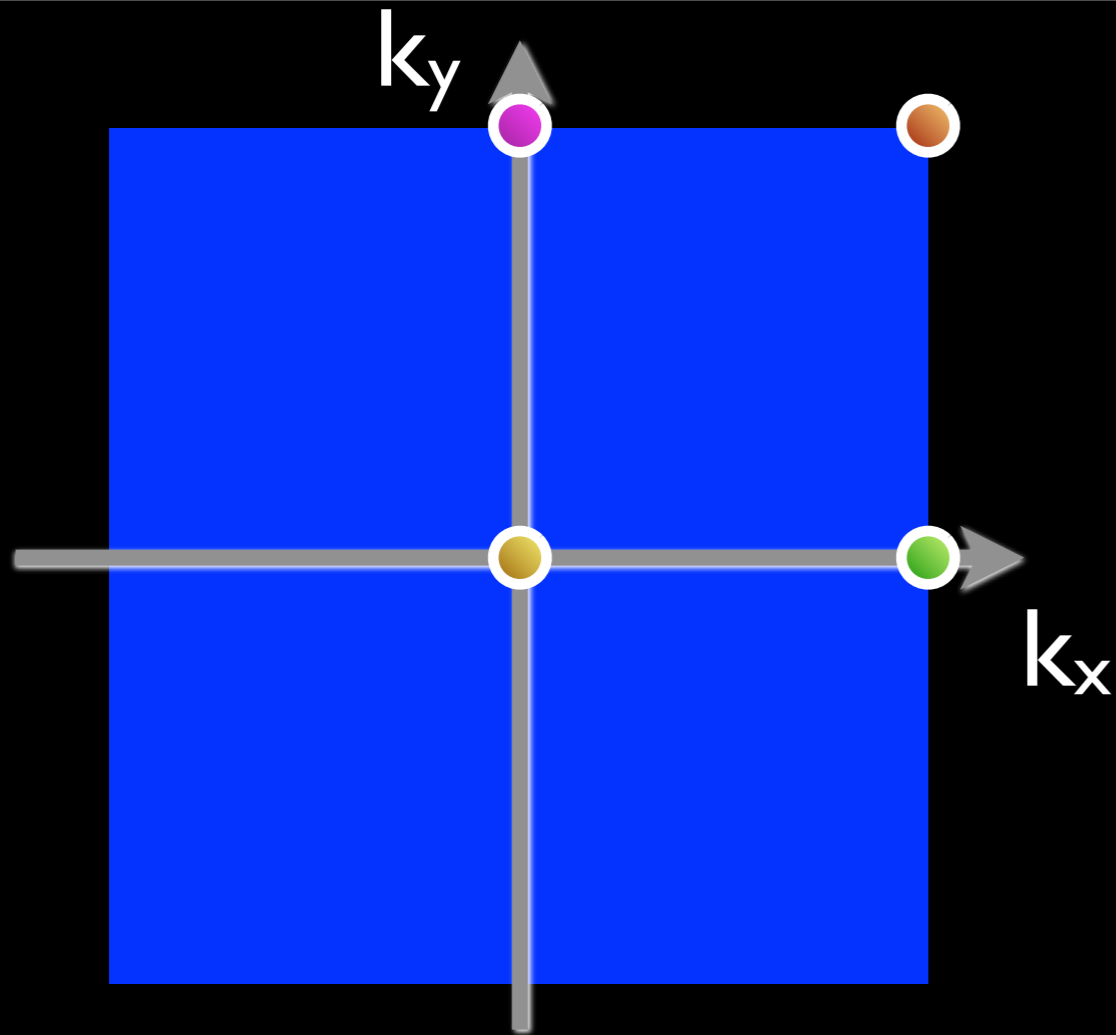
Band Theory



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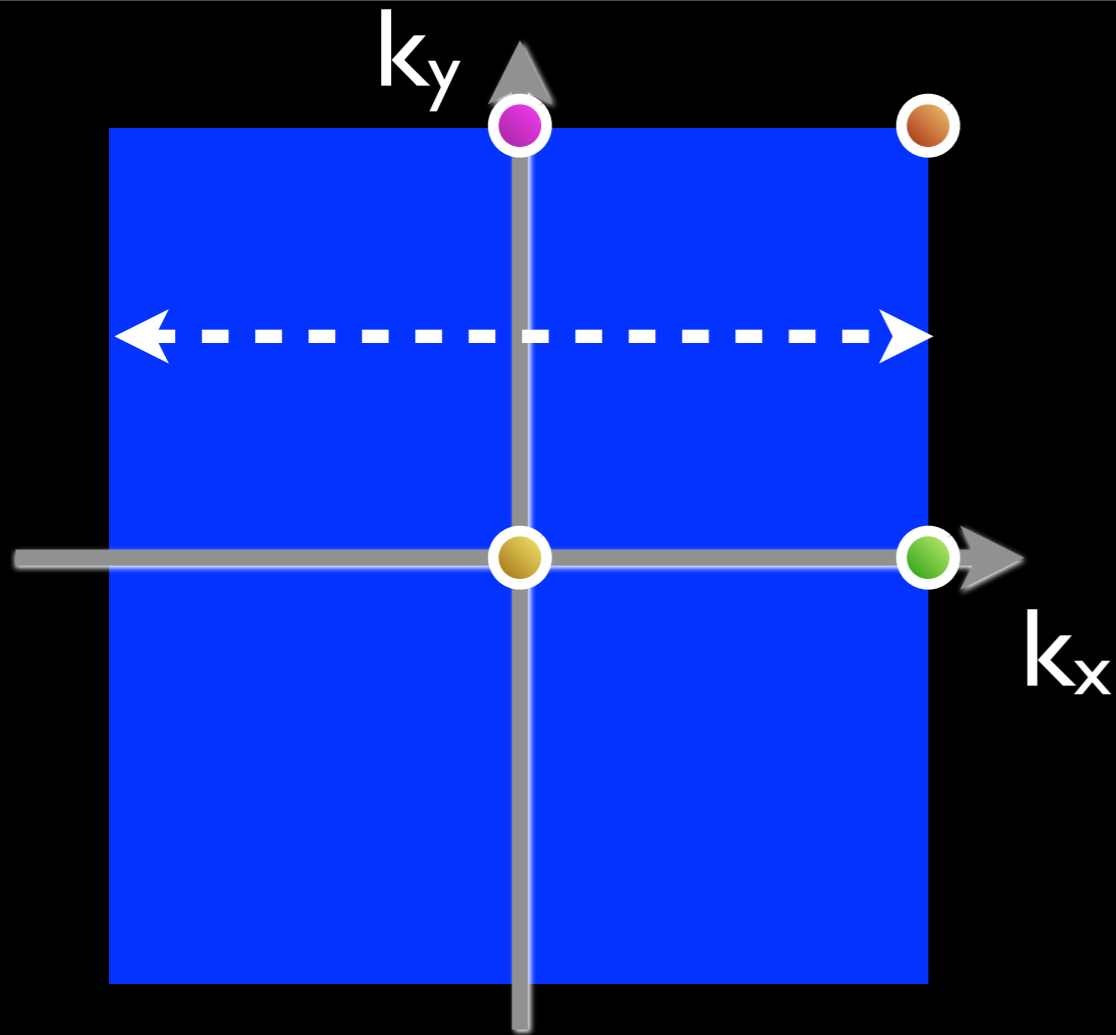
Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$

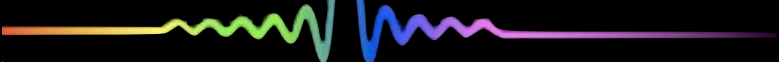
D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory

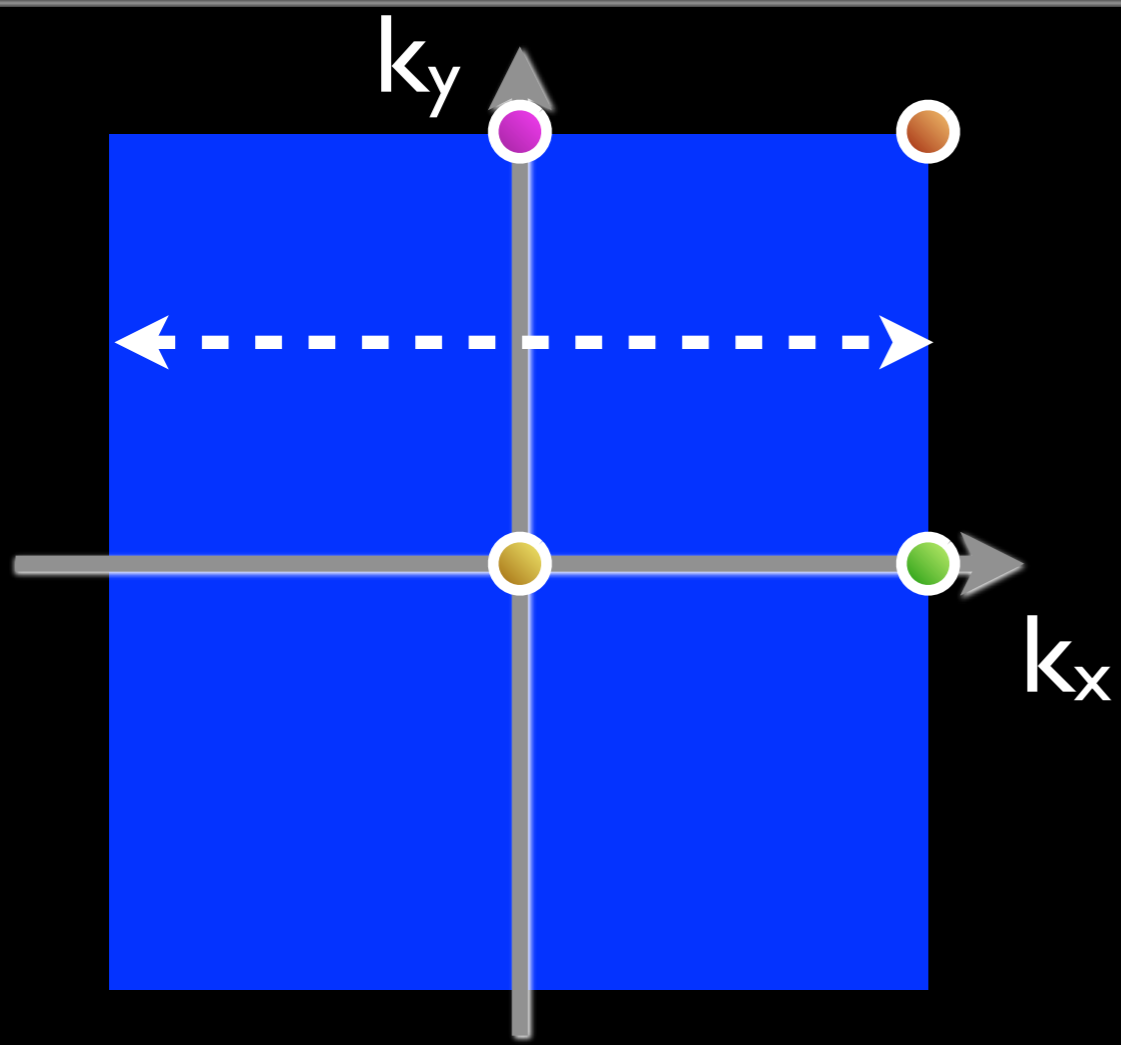


$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$

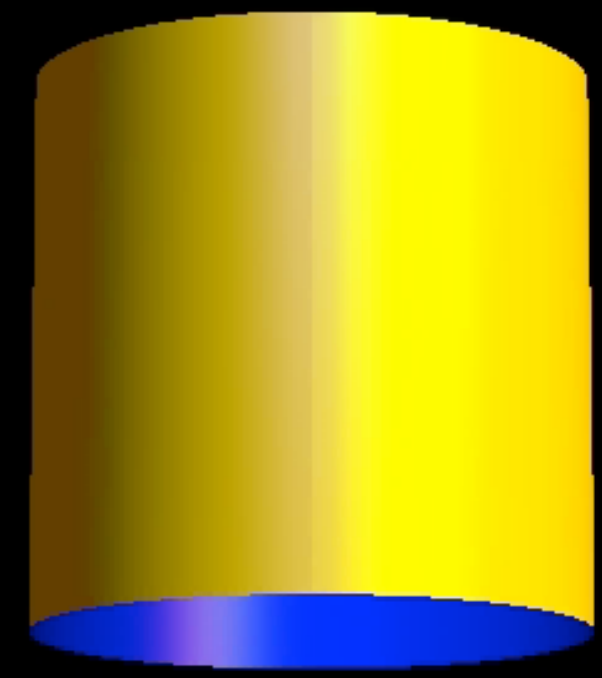
D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory

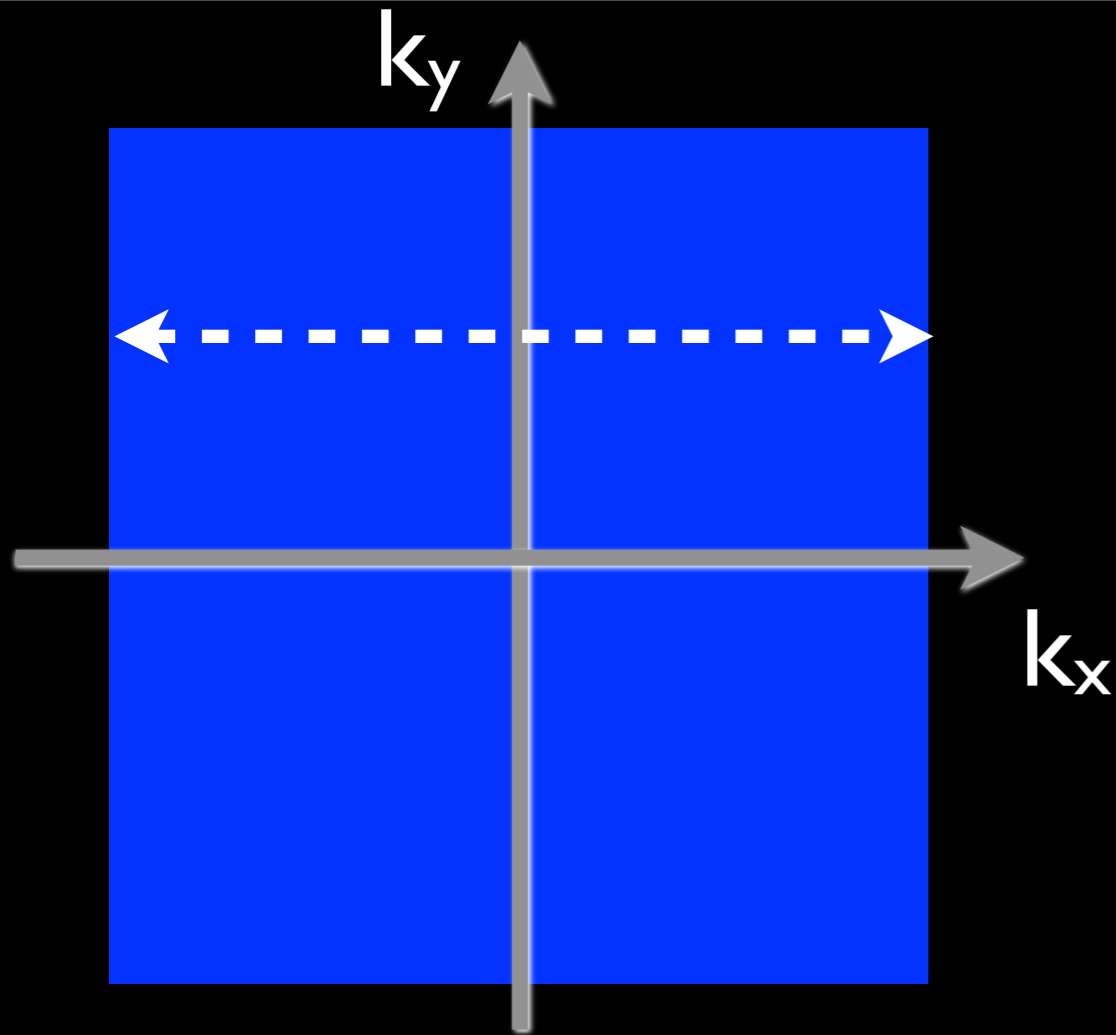


$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$

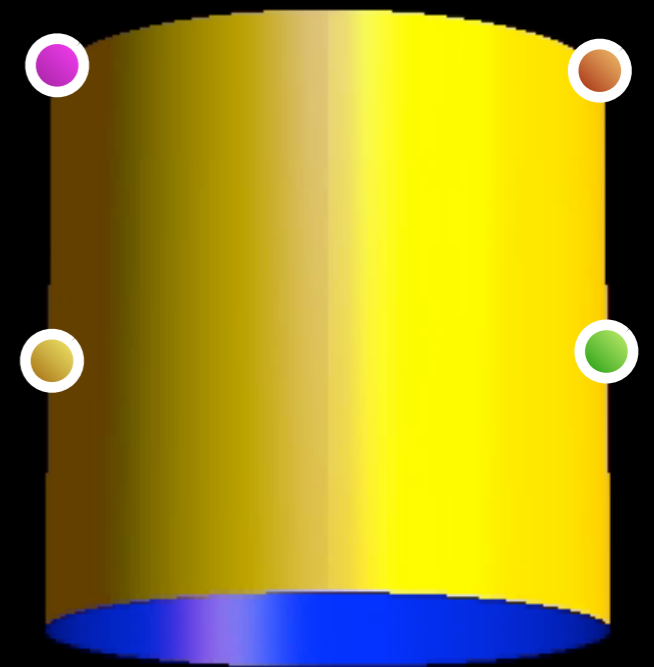


D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory

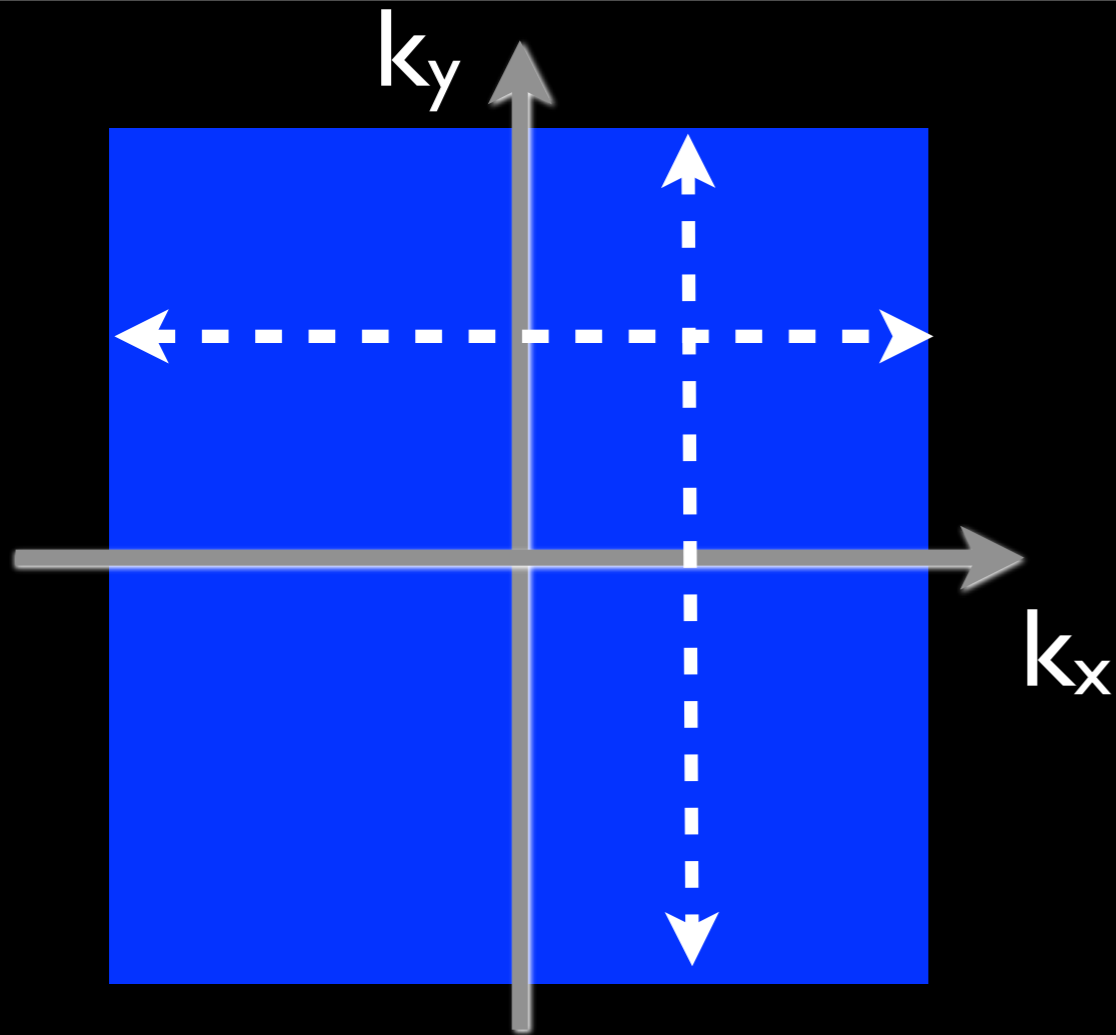


$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$

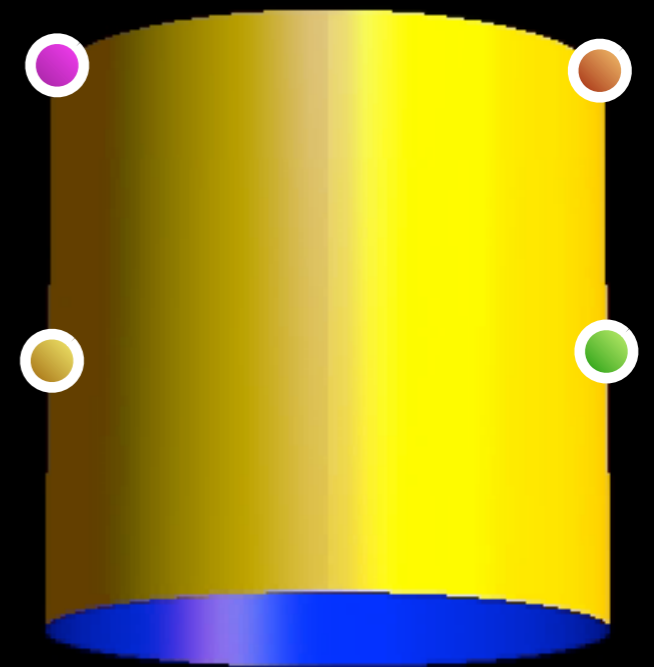


D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory

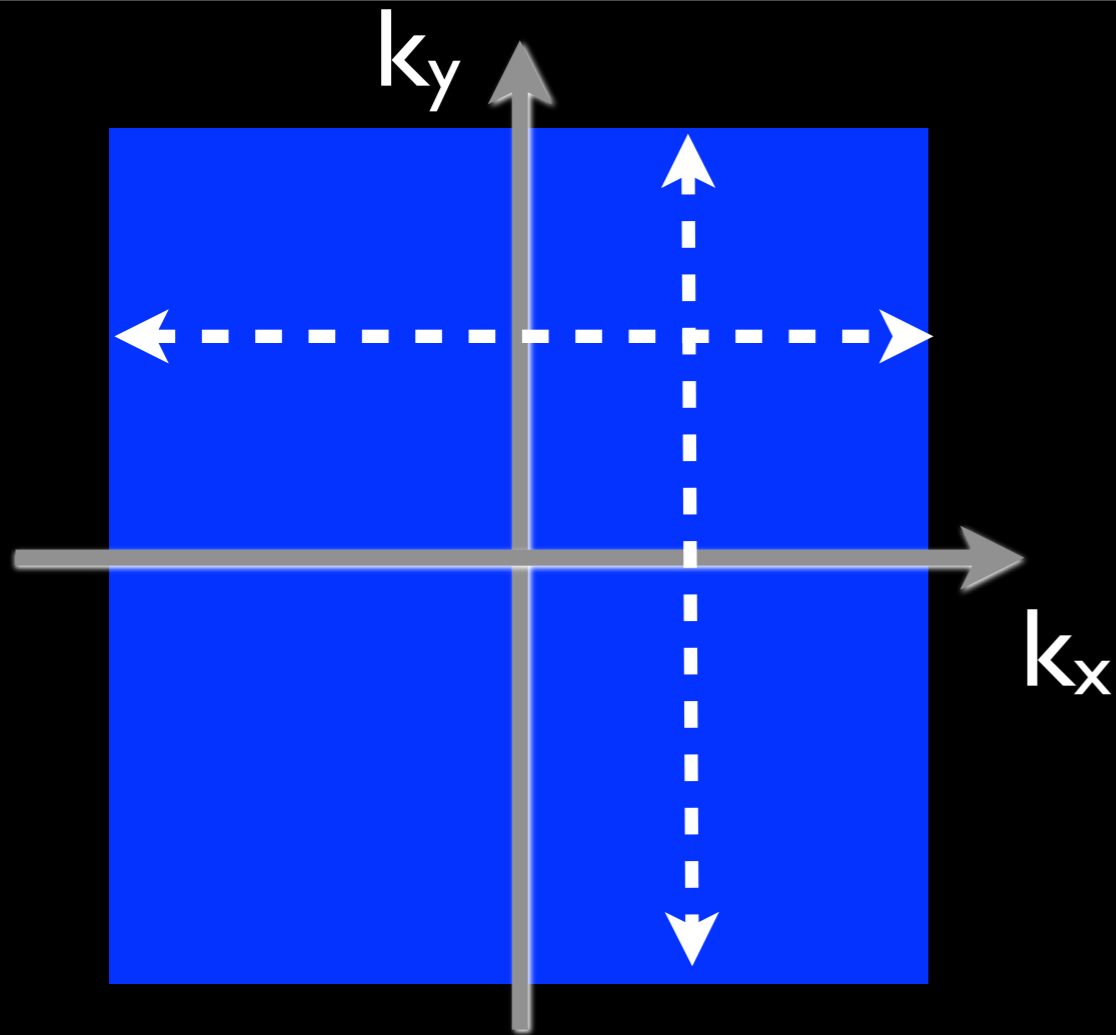


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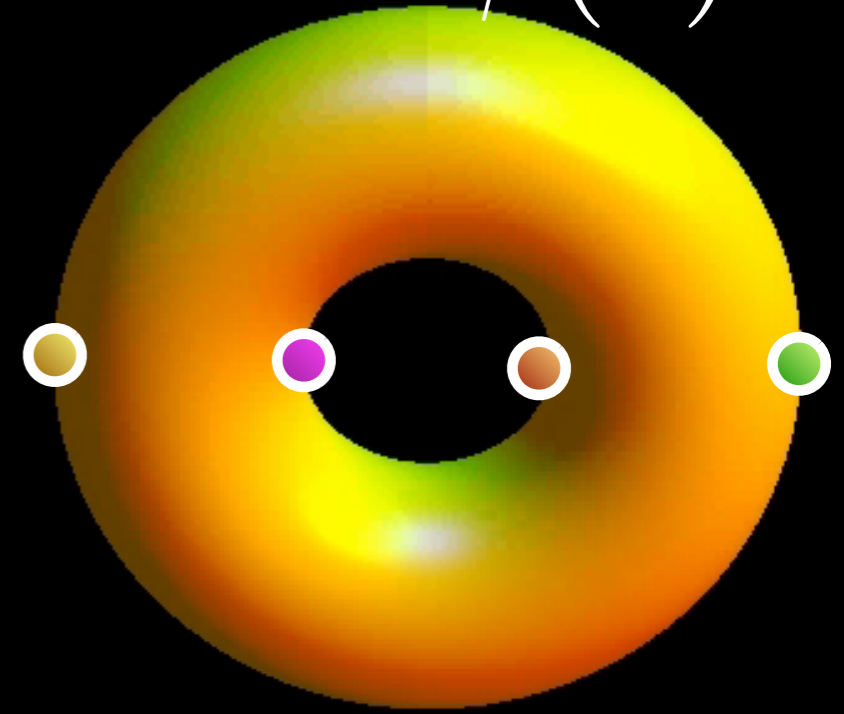


D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory

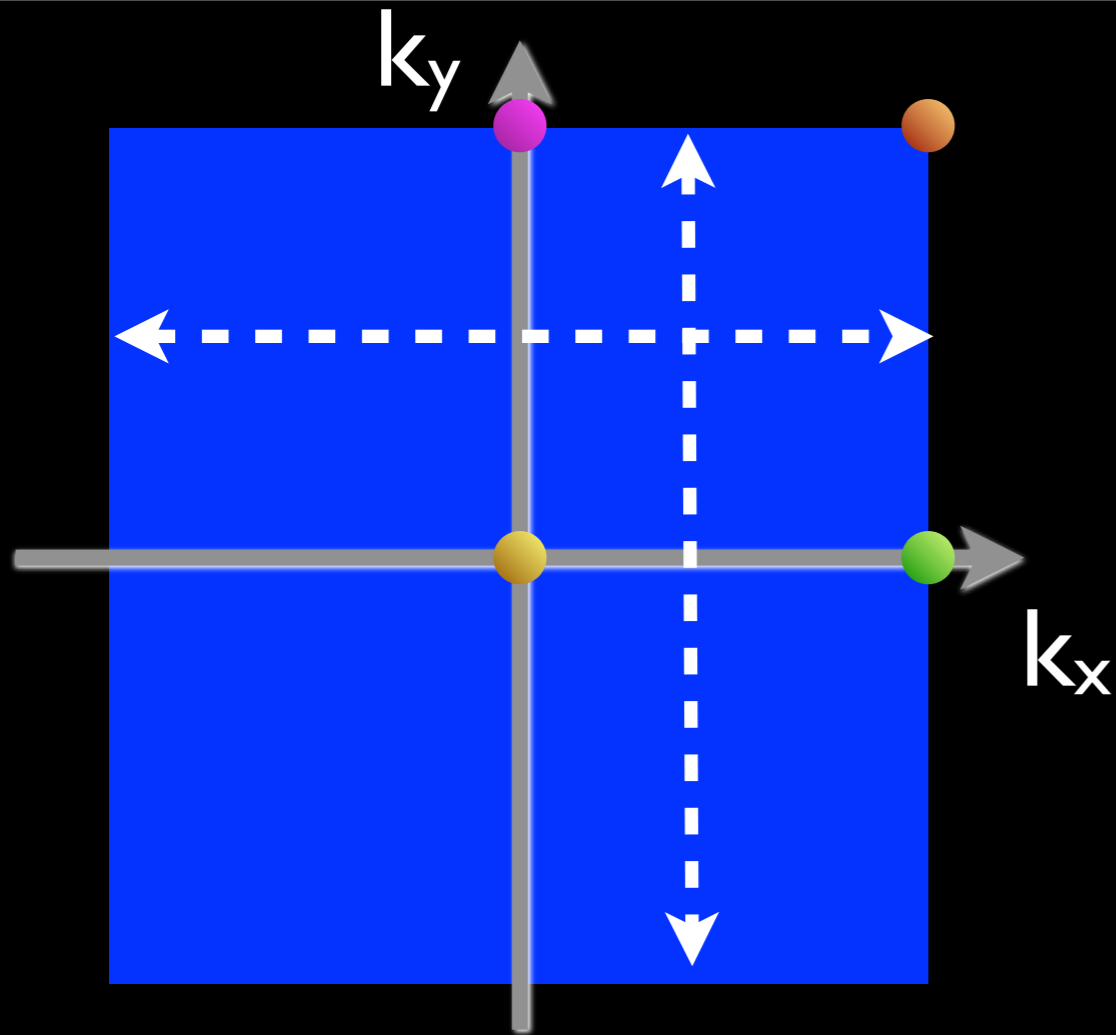


$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$

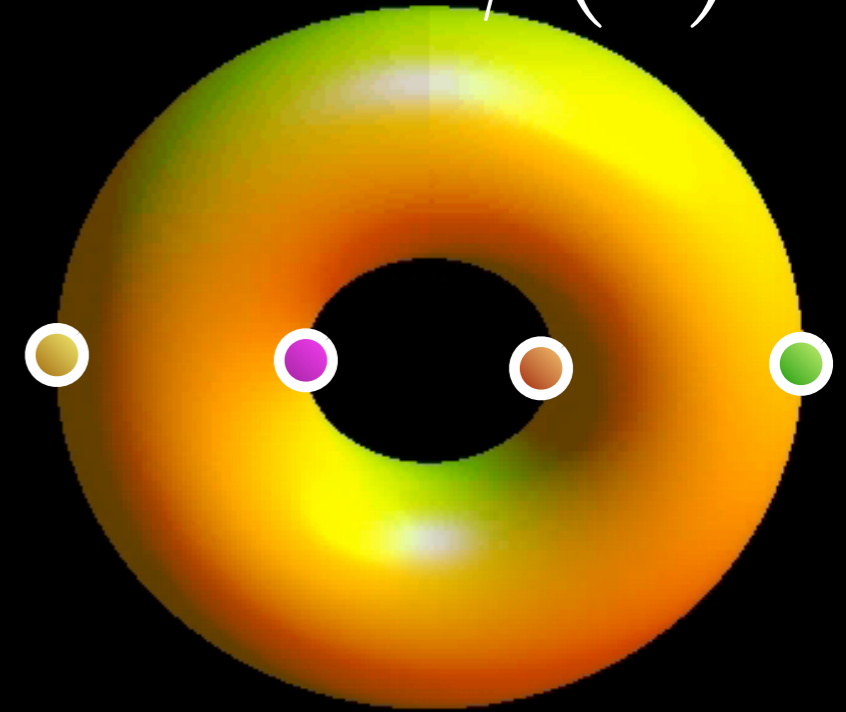


D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory

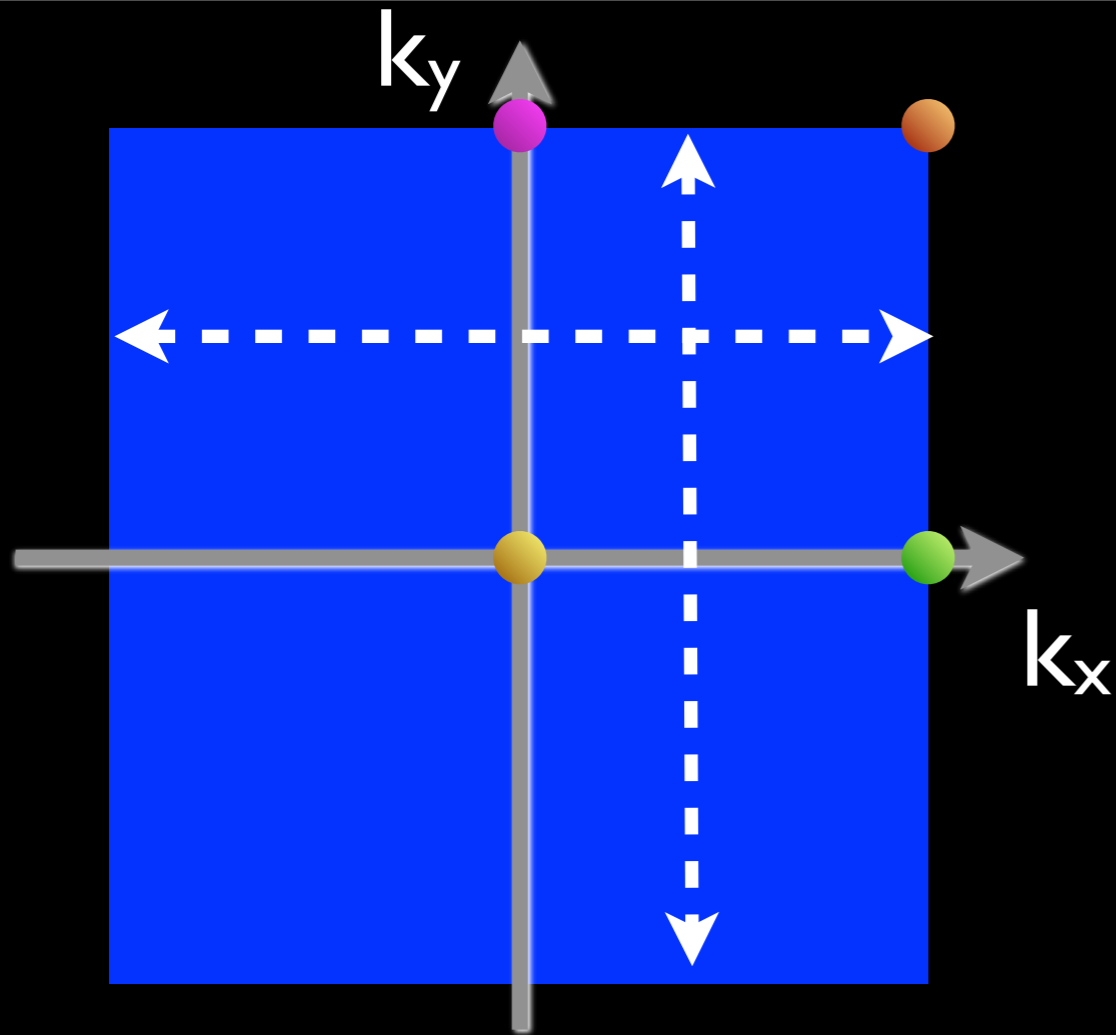


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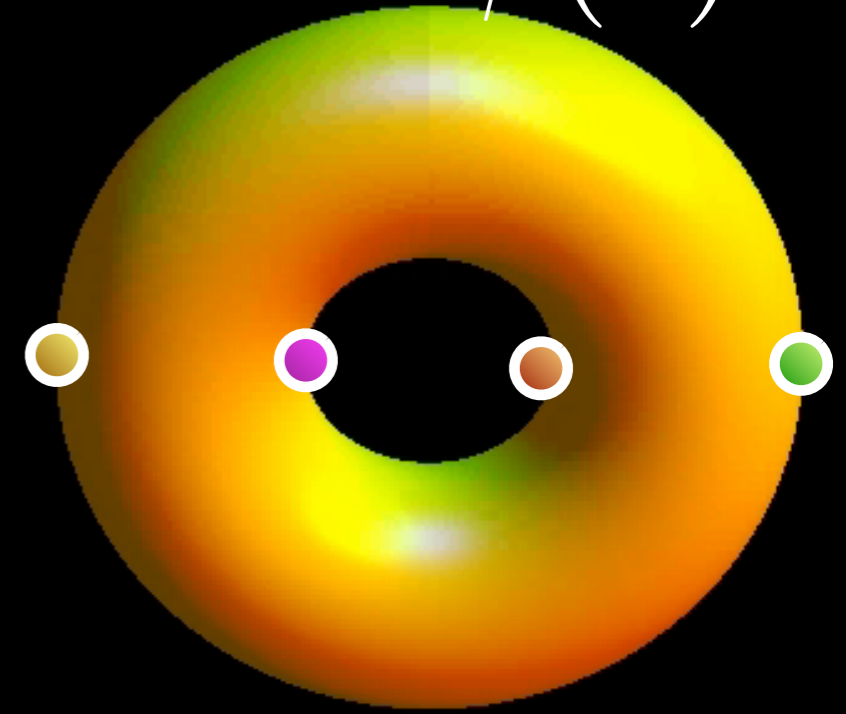


D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory



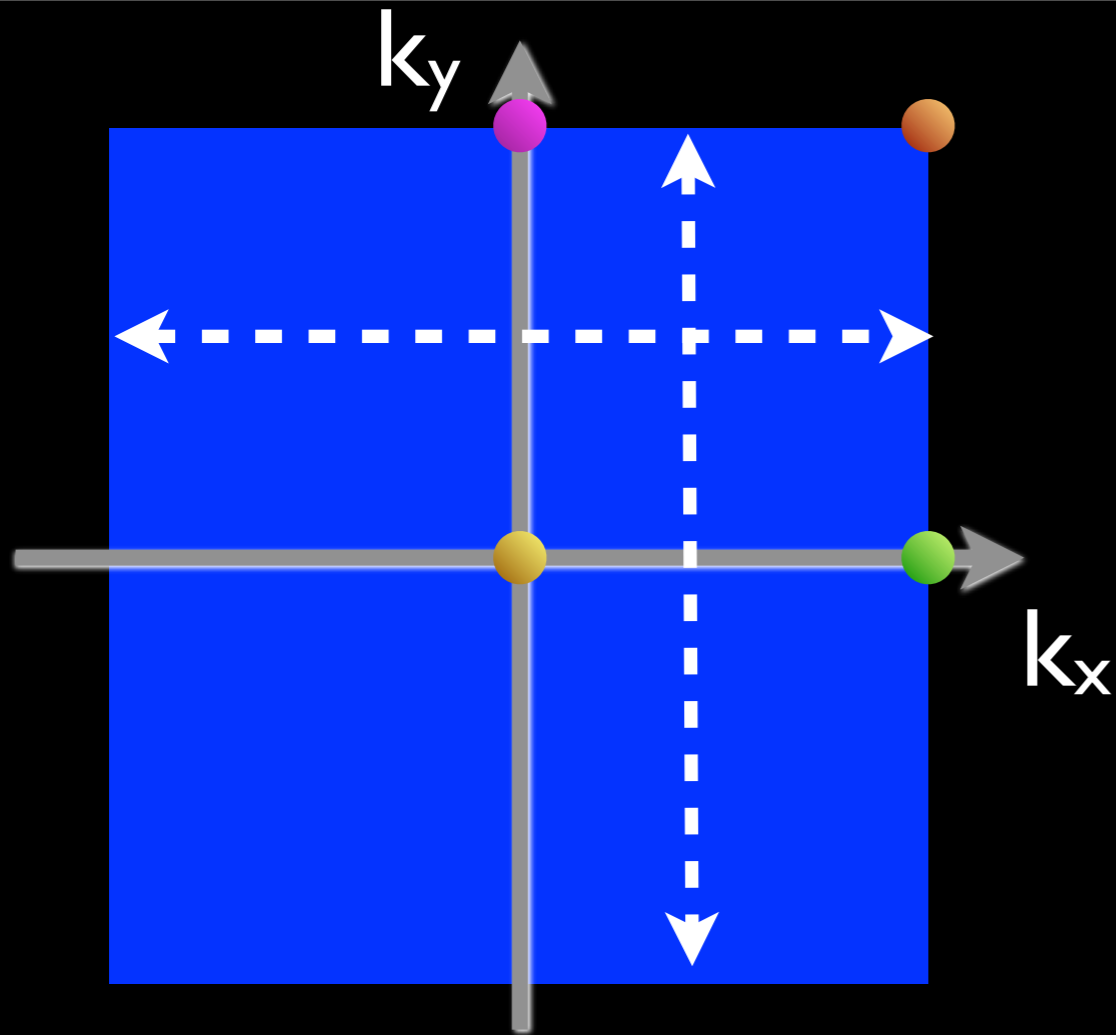
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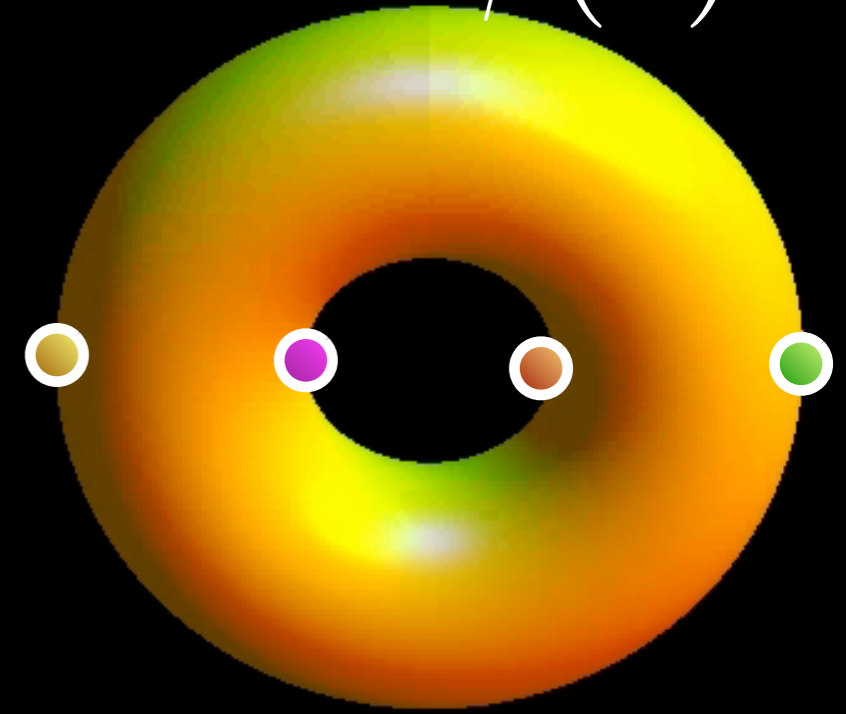
$$\mathbf{A}(\mathbf{k}) = i\psi(\mathbf{k})\nabla_{\mathbf{k}}\psi(\mathbf{k})$$

D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



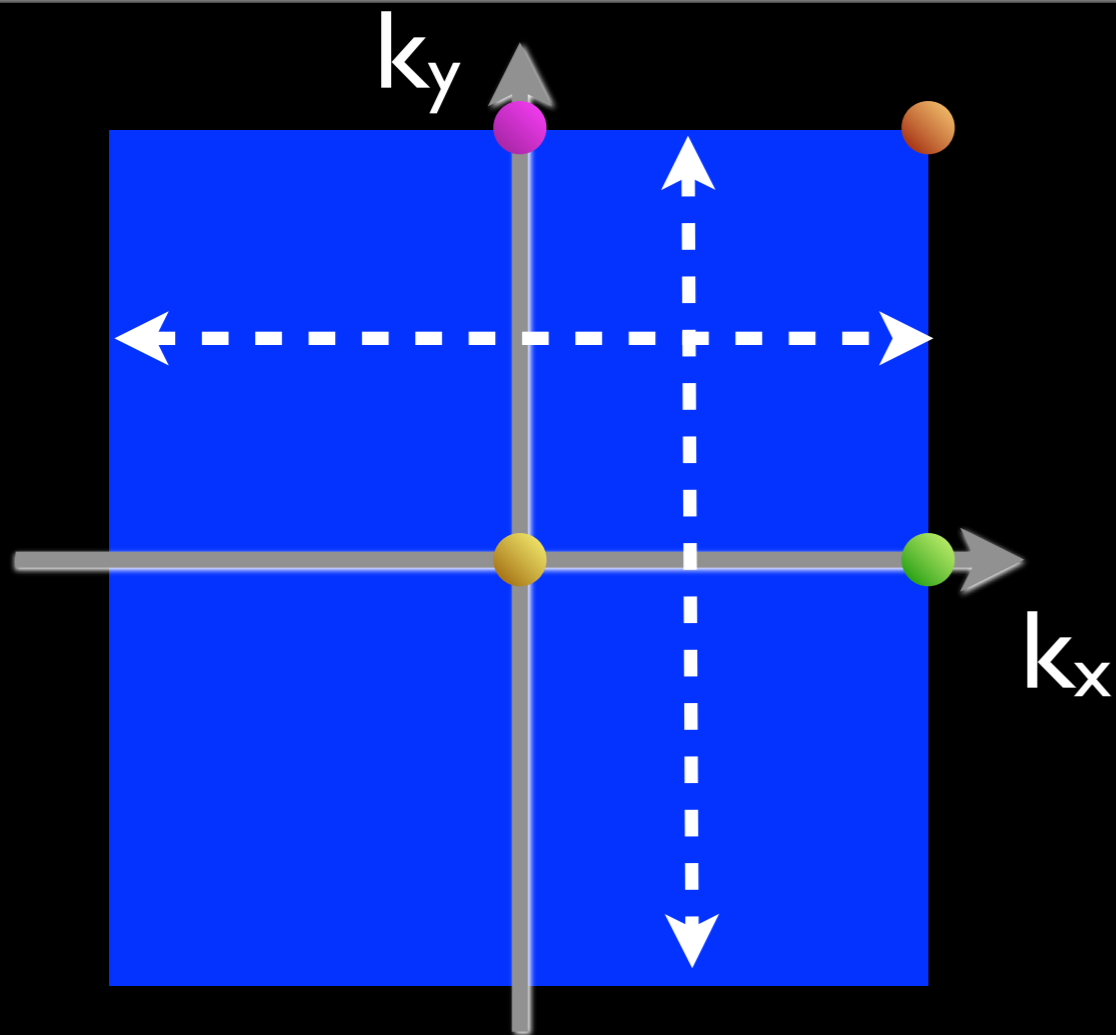
$$\mathbf{A}(\mathbf{k}) = i\psi(\mathbf{k})\nabla_{\mathbf{k}}\psi(\mathbf{k})$$

$$\mathbf{\Omega}(\mathbf{k}) = \nabla_{\mathbf{k}} \times \mathbf{A}(\mathbf{k})$$

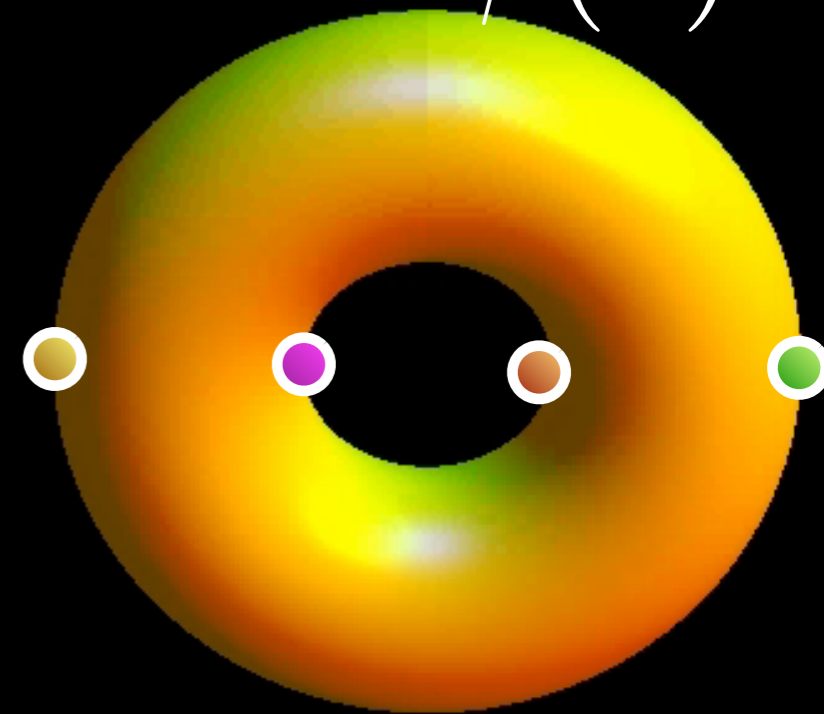
D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



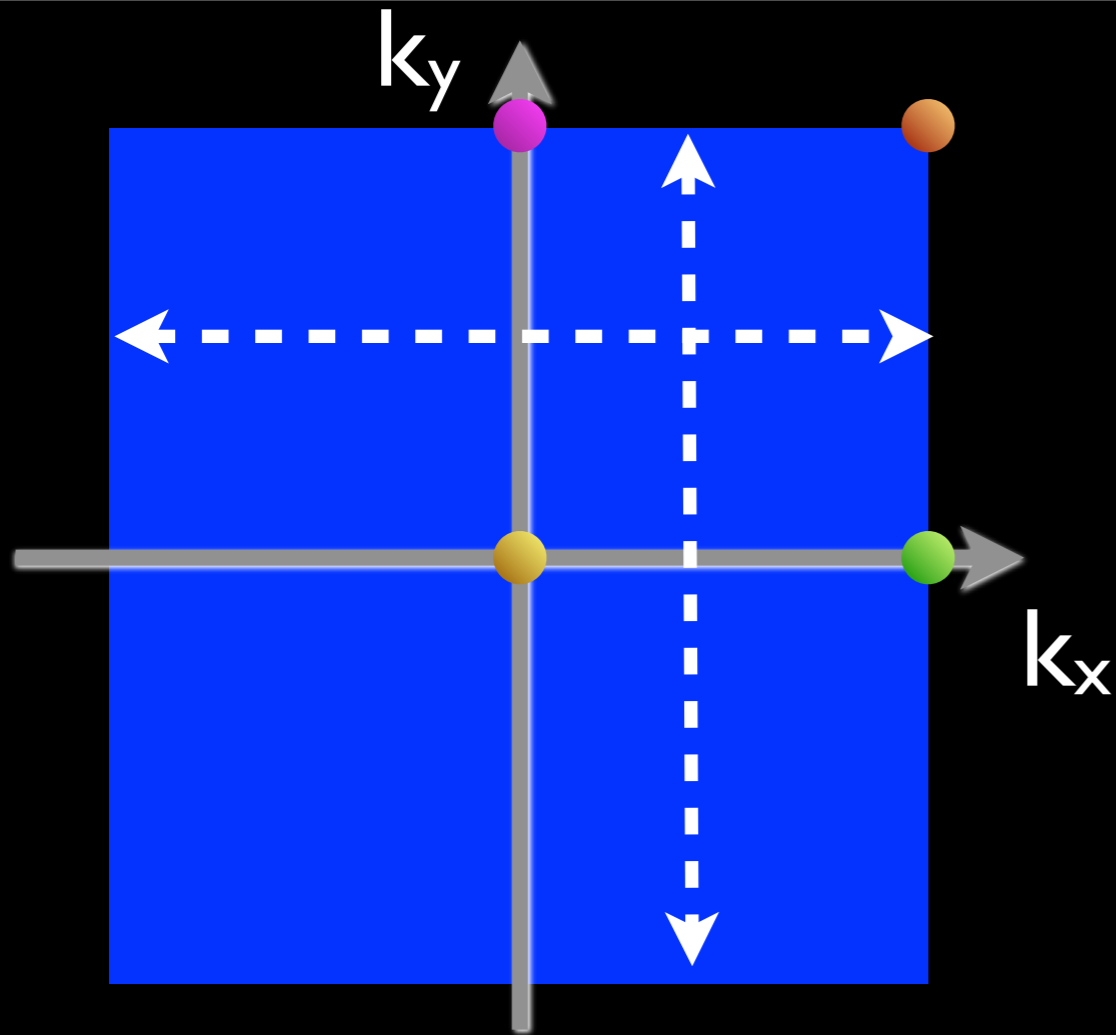
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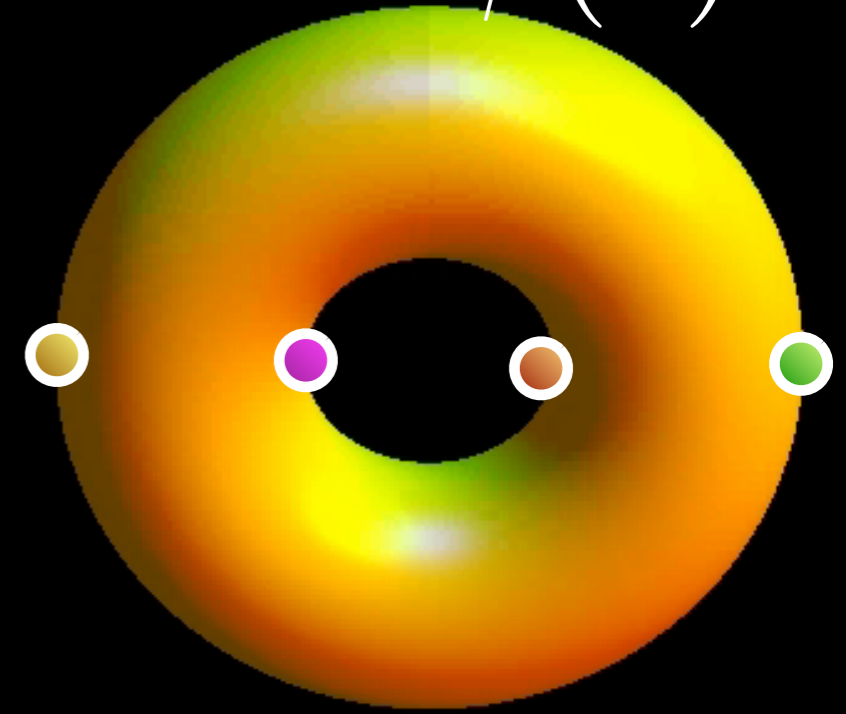
Berry Phase: $\gamma = \int_{\mathcal{S}} d\mathbf{S} \cdot \mathbf{\Omega}(\mathbf{k})$

D. Xiao, et al. RMP 82, 1959 (2010)

Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



$$\mathbf{A}(\mathbf{k}) = i\psi(\mathbf{k})\nabla_{\mathbf{k}}\psi(\mathbf{k})$$

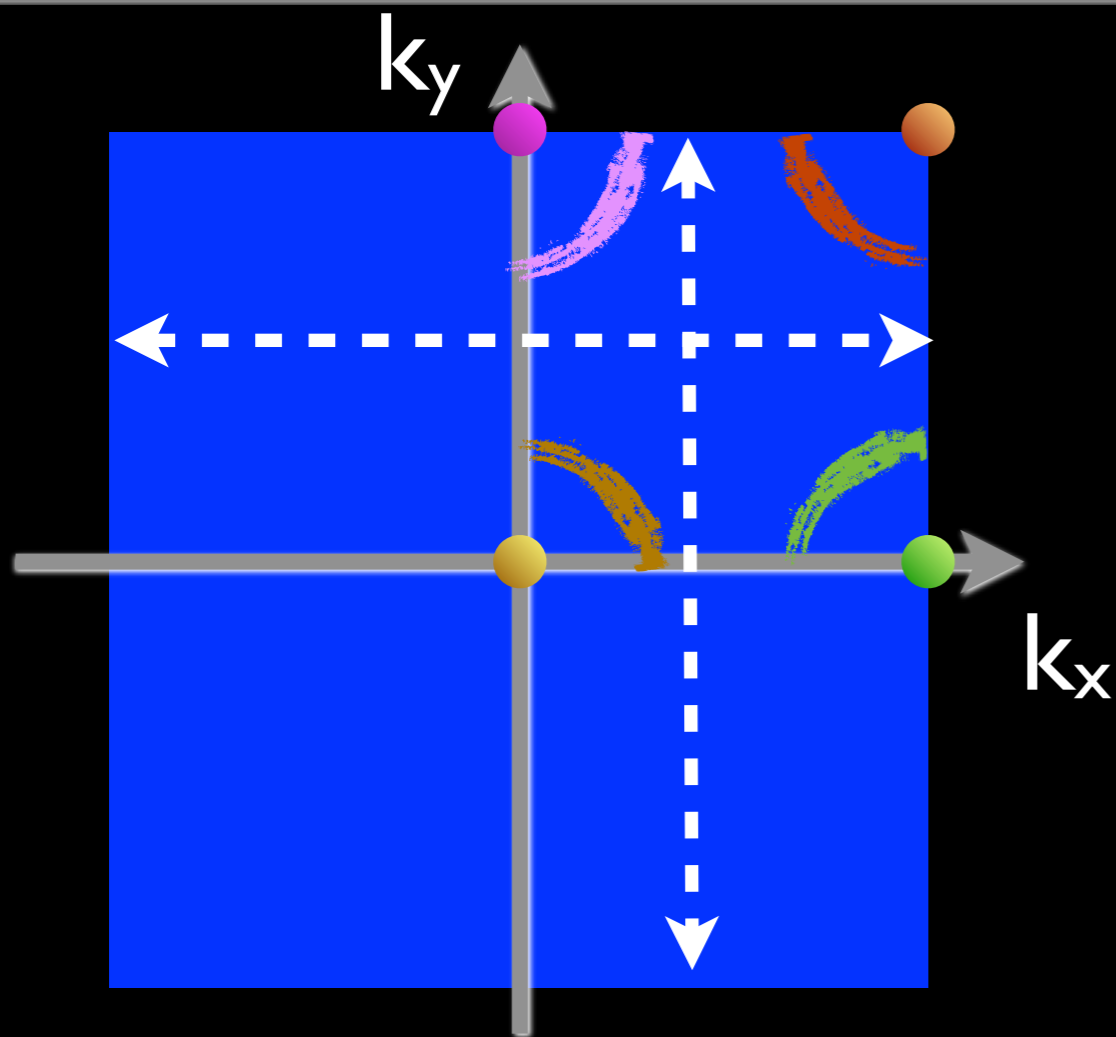
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Berry Phase: $\gamma = \int_{\mathcal{S}} d\mathcal{S} \cdot \mathbf{\Omega}(\mathbf{k}) = \oint_{\mathcal{C}} d\mathbf{R} \cdot \mathbf{A}(\mathbf{k})$

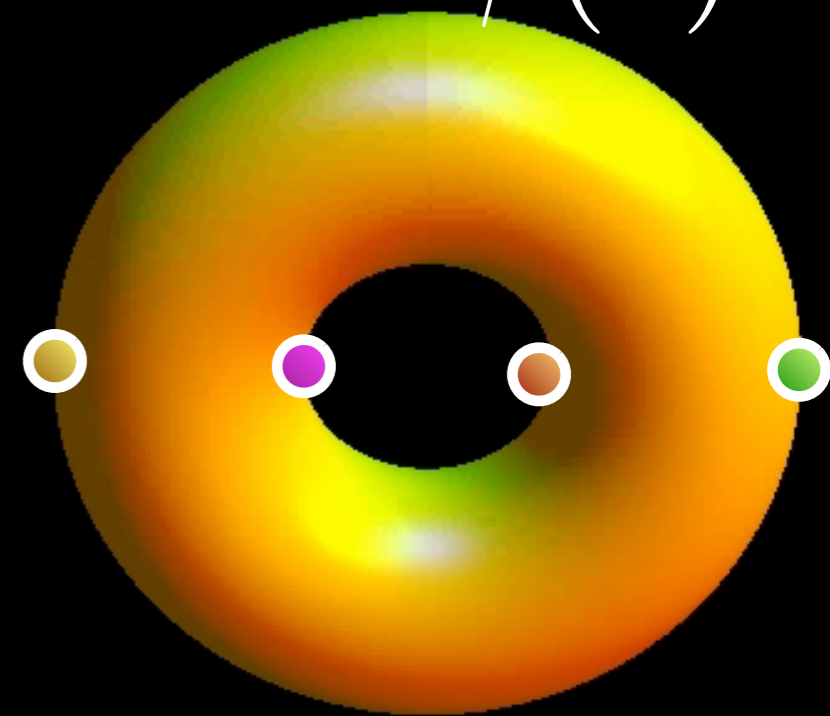
D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory



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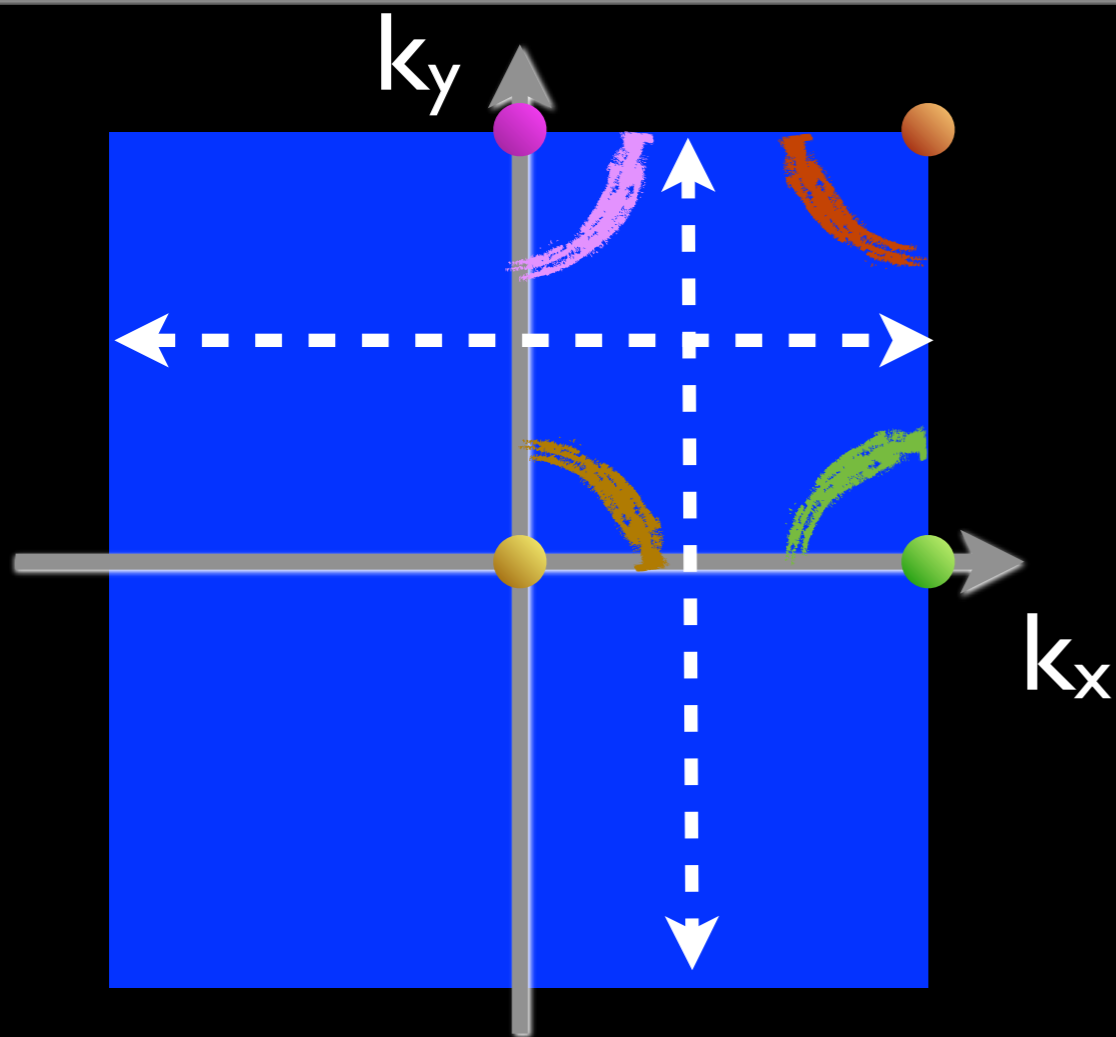
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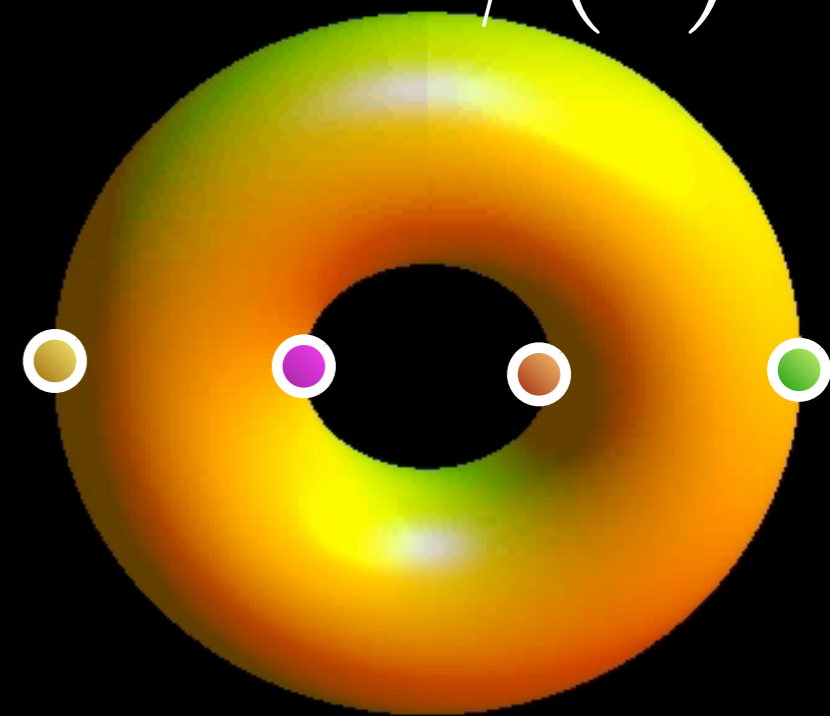
D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



Vector Potential: $\mathbf{A}(\mathbf{k}) = i\psi(\mathbf{k})\nabla_{\mathbf{k}}\psi(\mathbf{k})$

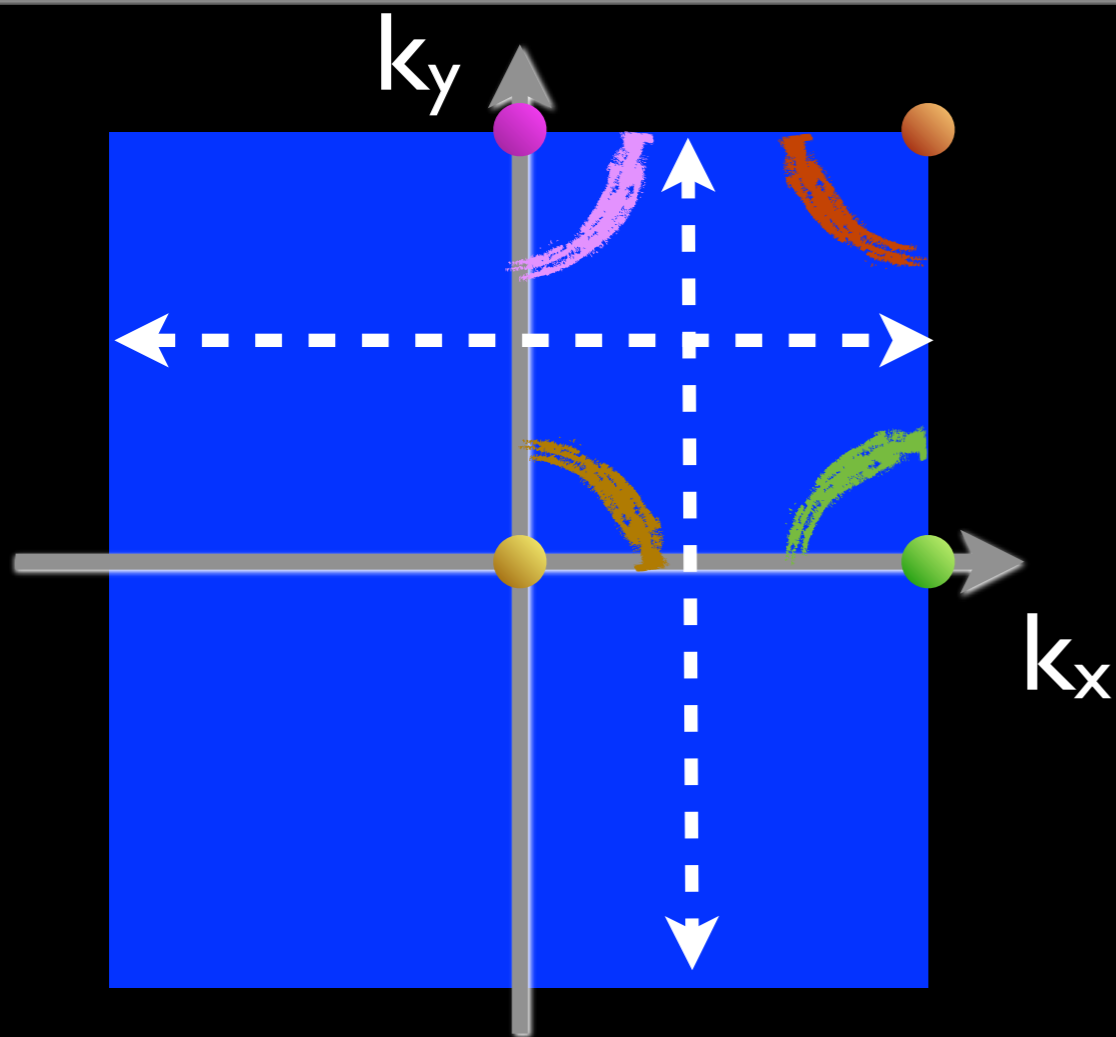
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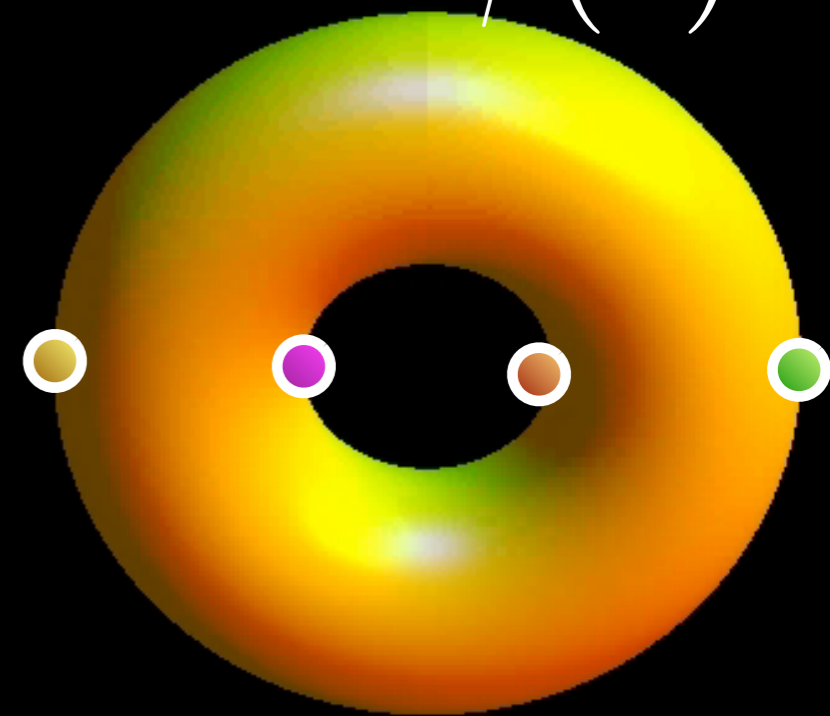
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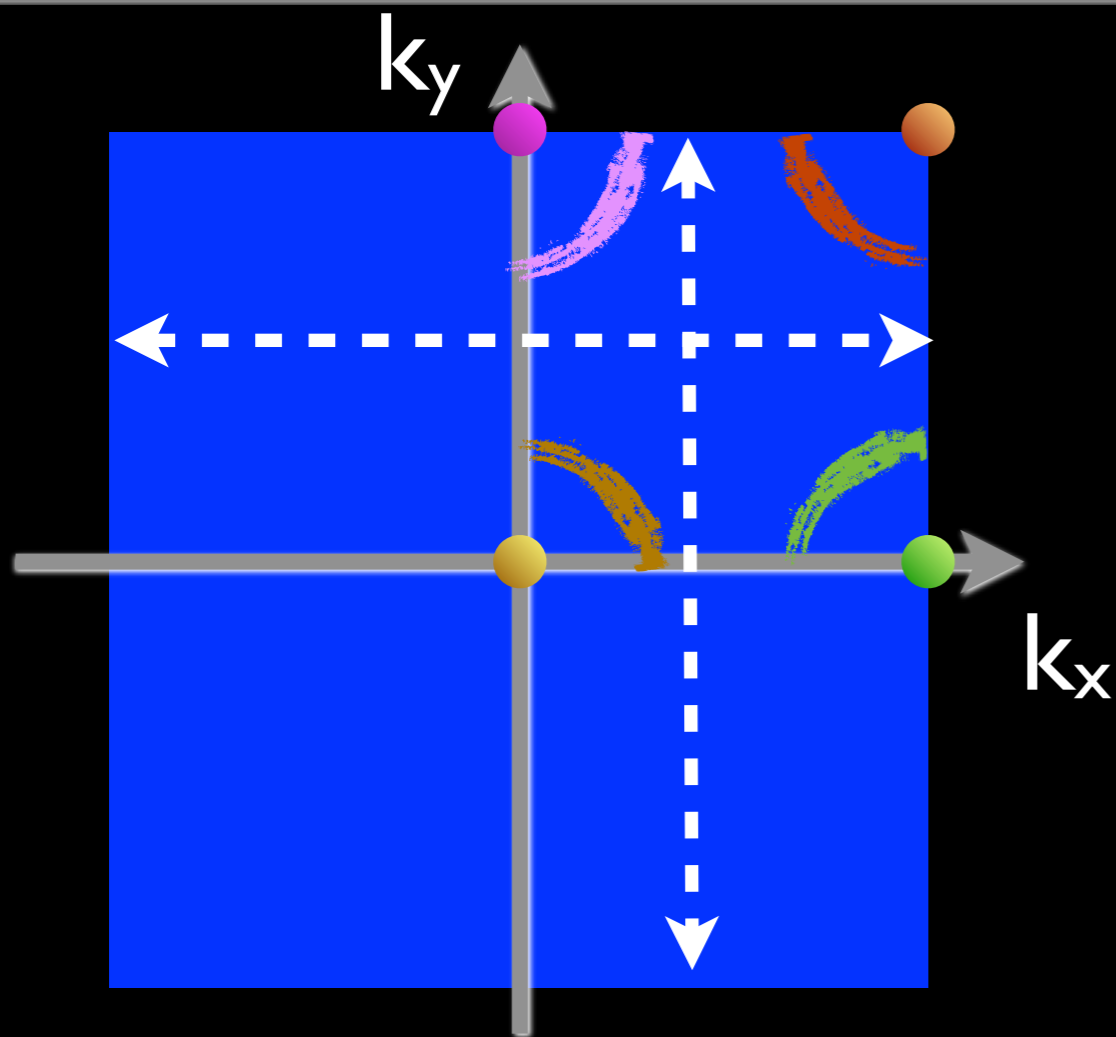
Curvature: $\Omega(\mathbf{k}) = \nabla_{\mathbf{k}} \times \mathbf{A}(\mathbf{k})$

Berry Phase: $\gamma = \int_{\mathcal{S}} d\mathcal{S} \cdot \Omega(\mathbf{k}) = \oint_{\mathcal{C}} d\mathbf{R} \cdot \mathbf{A}(\mathbf{k})$

D. Xiao, et al. RMP 82, 1959 (2010)



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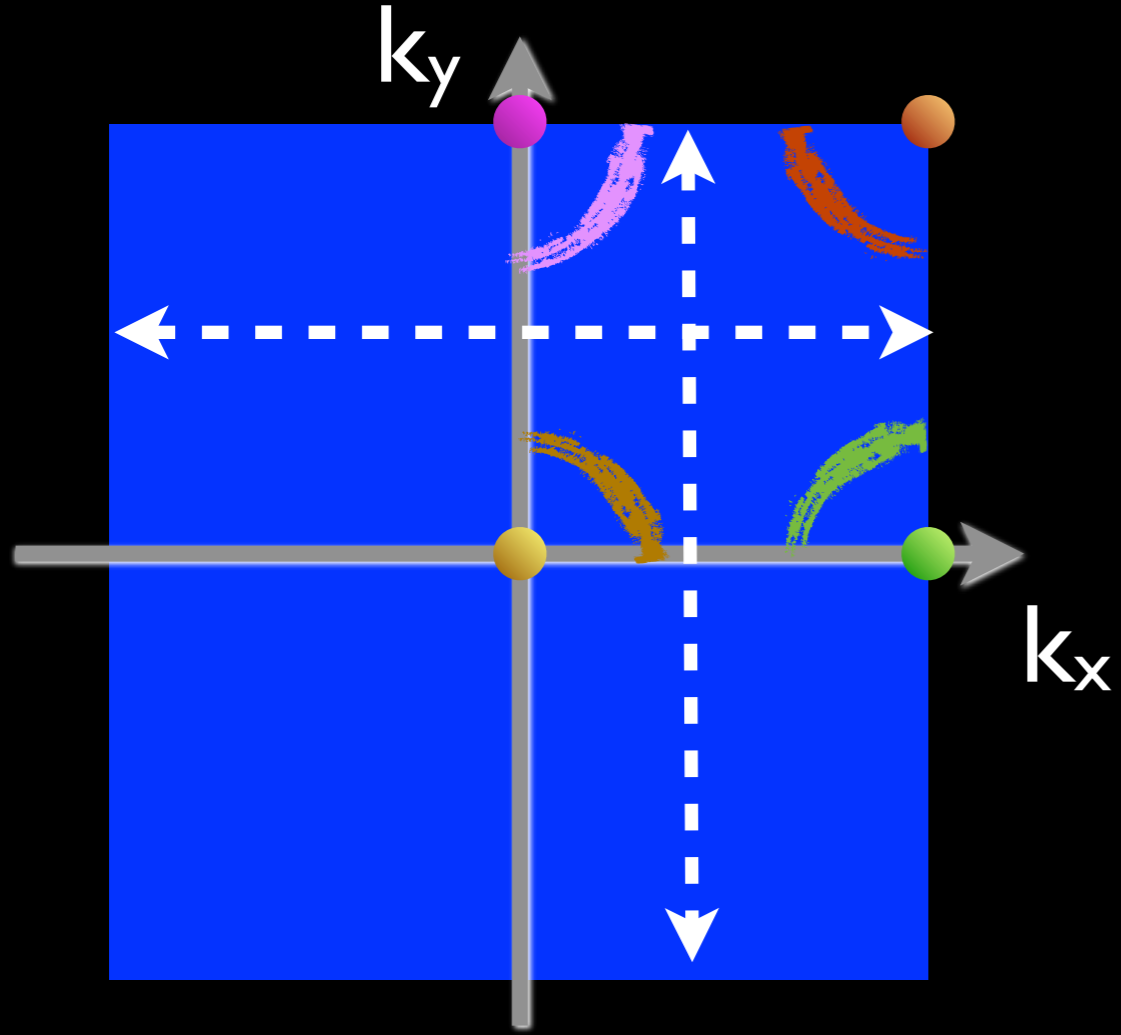
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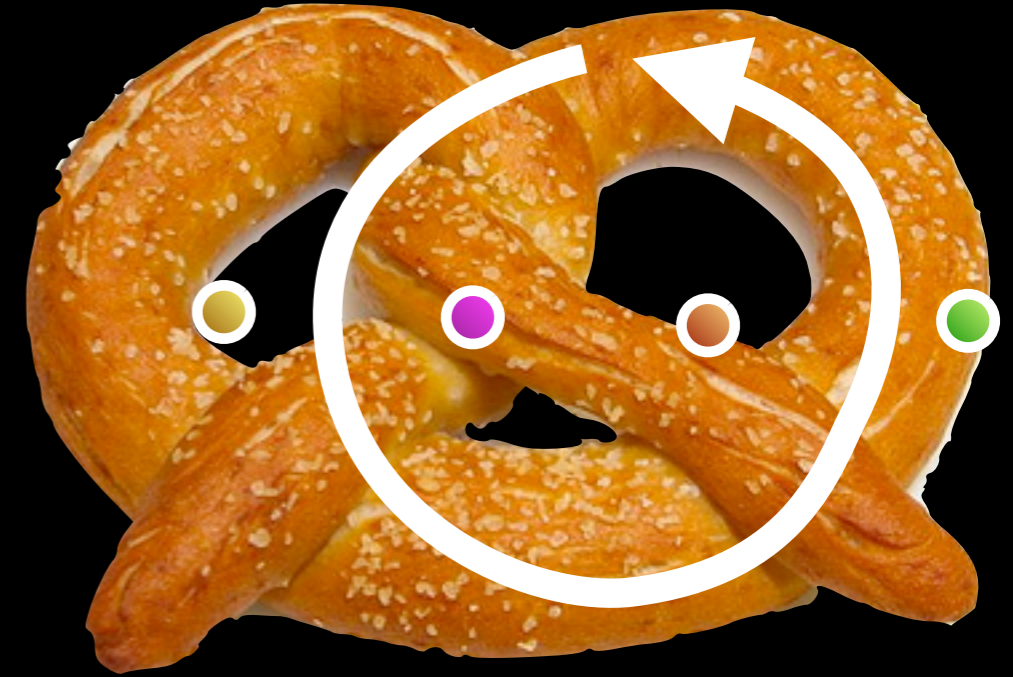
D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory



$$\psi(\mathbf{r} + \mathbf{a}) = e^{i\mathbf{k} \cdot \mathbf{a}} \psi(\mathbf{r})$$



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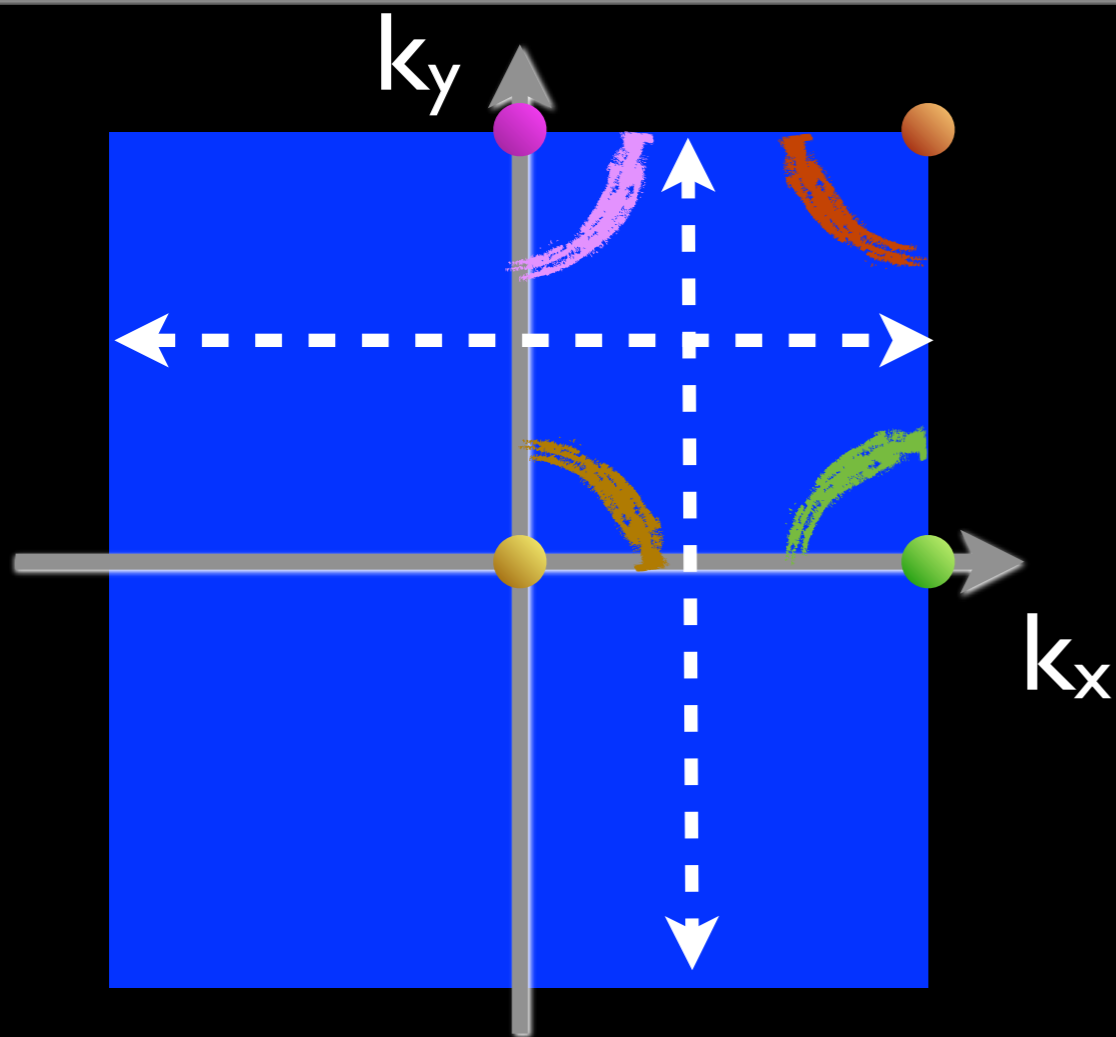
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D. Xiao, et al. RMP 82, 1959 (2010)



Band Theory



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D. Xiao, et al. RMP 82, 1959 (2010)



Exfoliation



Exfoliation

- X-Ray



Exfoliation

- X-Ray
- Infrared & Visible Microscopy



Exfoliation

- X-Ray
- Infrared & Visible Microscopy
- New substrates



Exfoliation

- X-Ray
- Infrared & Visible Microscopy
- New substrates
- Devices

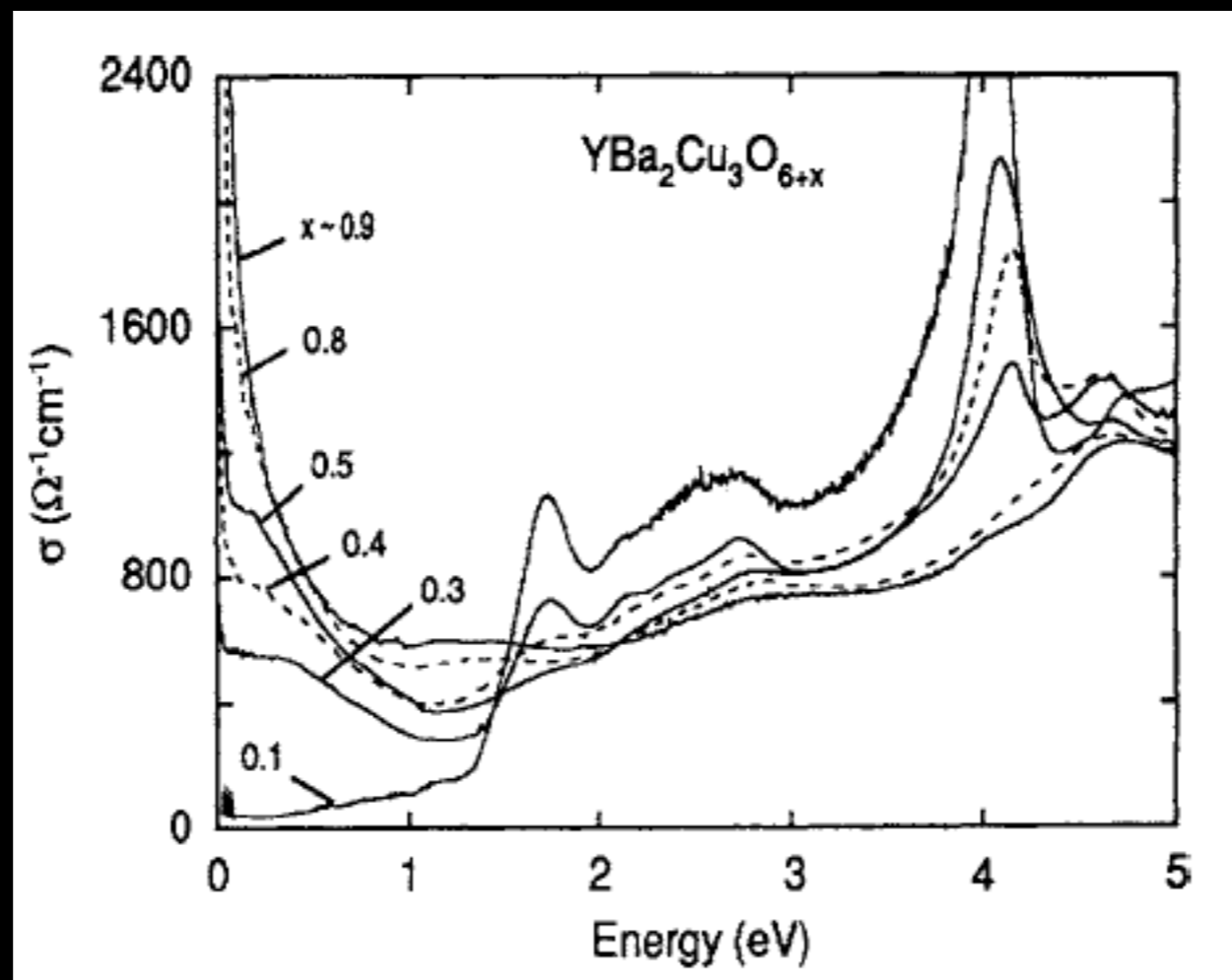


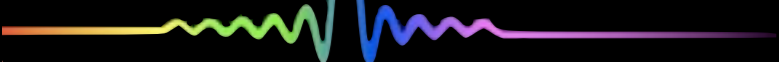
Exfoliation

- X-Ray
- Infrared & Visible Microscopy
- New substrates
- Devices
- Other Materials



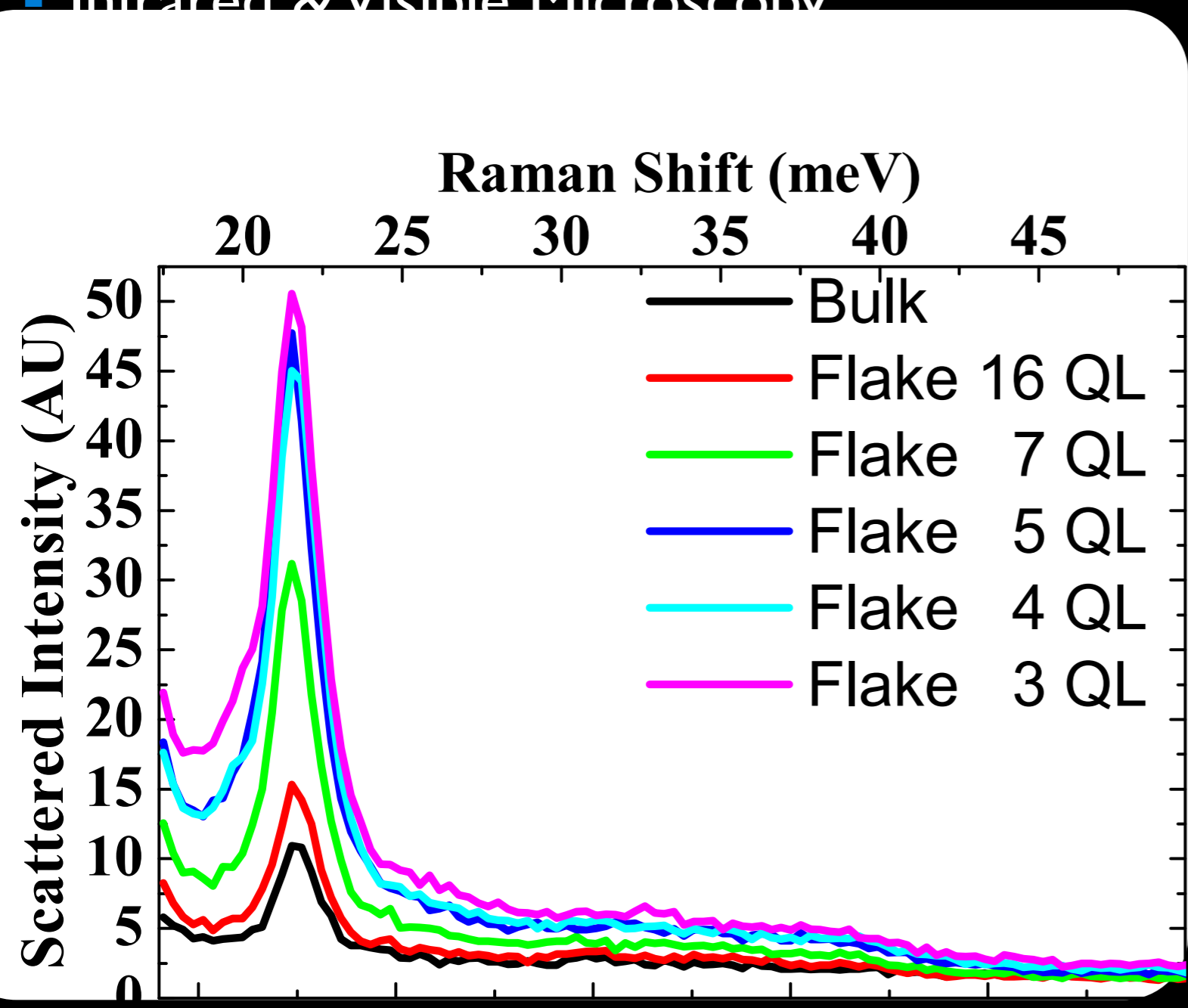
- X-Ray
- Infrared & Visible Microscopy
- New substrates
- Devices
- Other Materials
- New Interfaces?





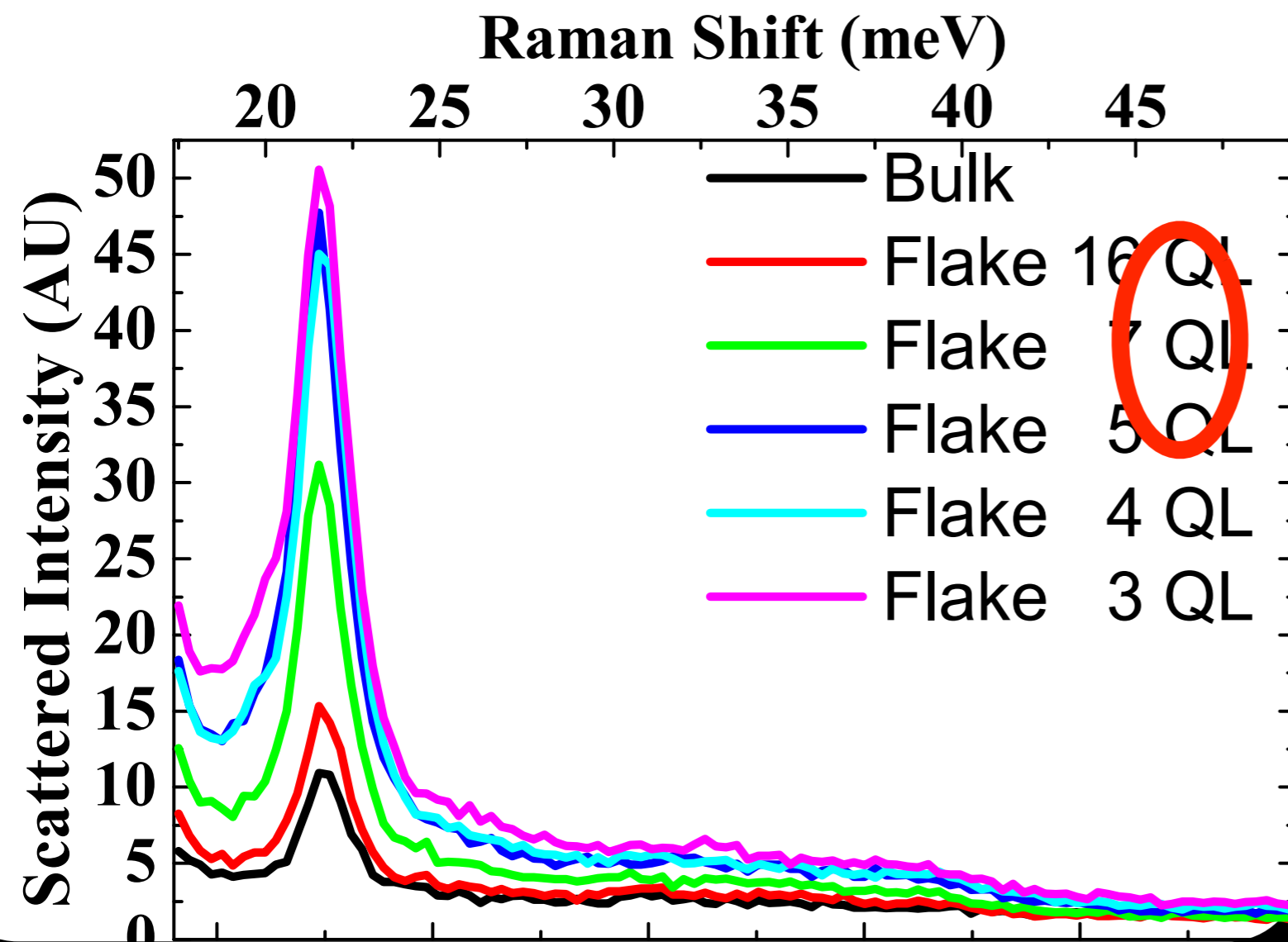
Exfoliation

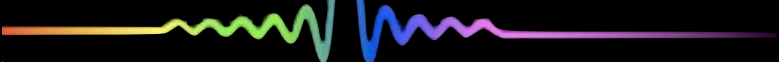
- X-Ray
- Infrared & Visible Microscopy





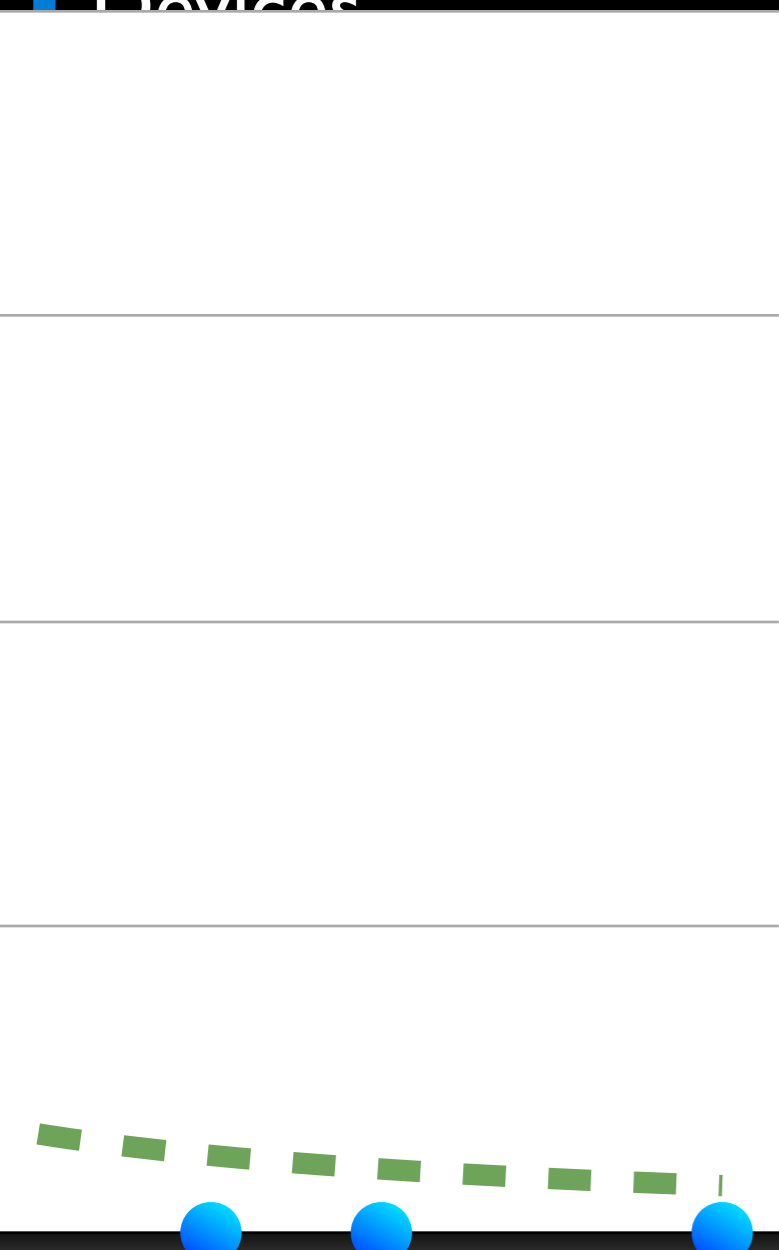
- X-Ray
- Infrared & Visible Microscopy





Exfoliation

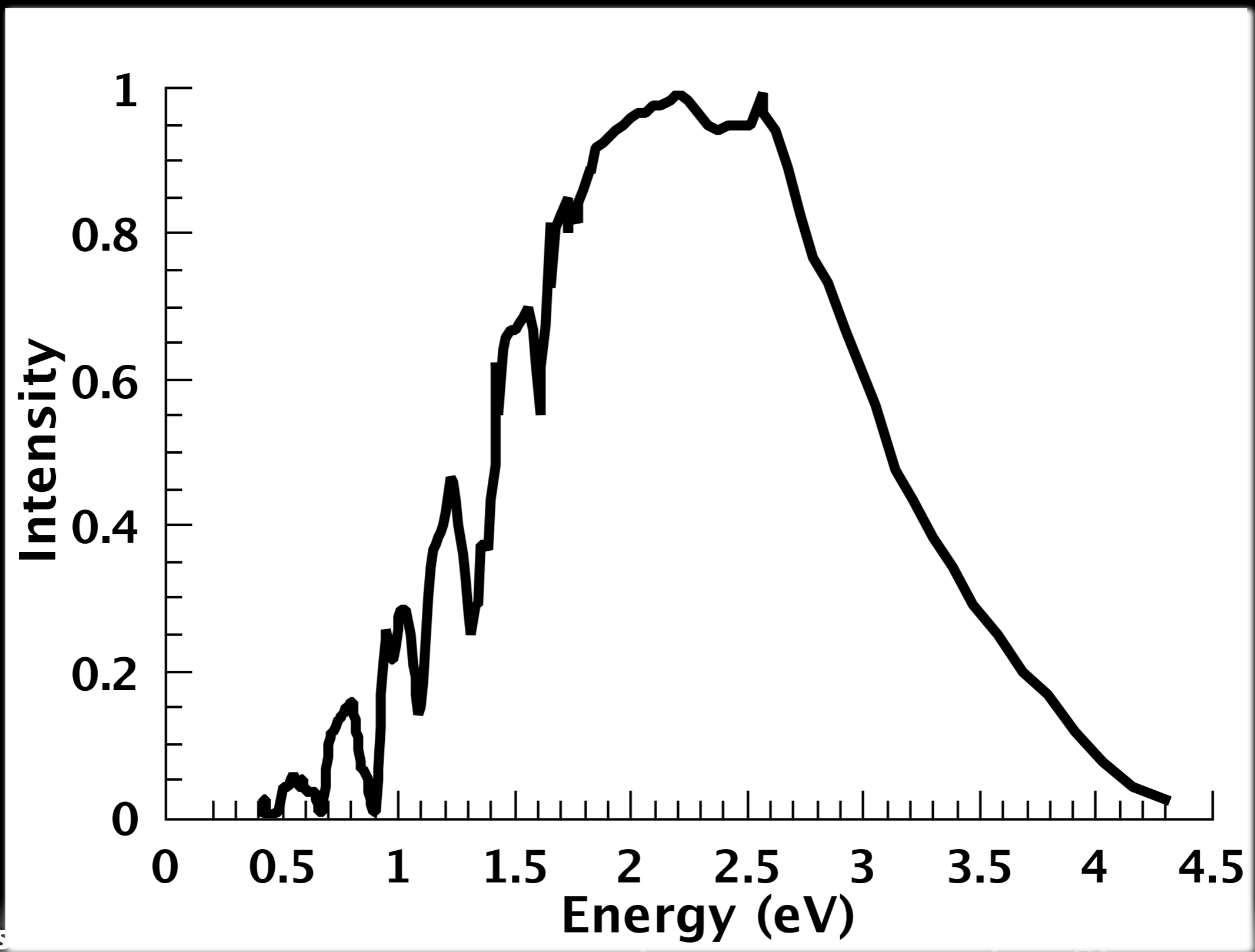
- X-Ray
- Infrared & Visible Microscopy
- New substrates
- Devices





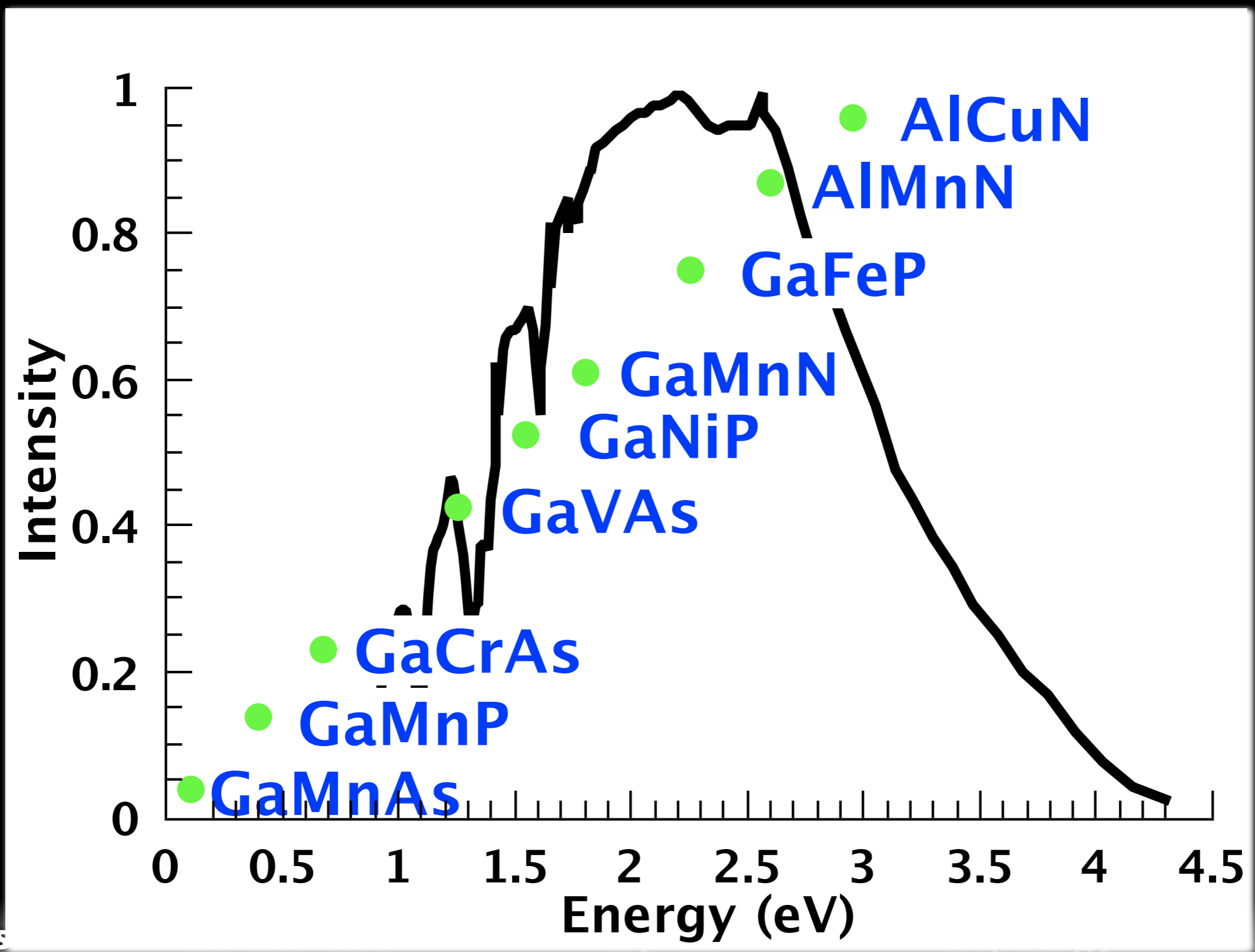
Future Directions

- Dilute Magnetic Semiconductors



Future Directions

- Dilute Magnetic Semiconductors





Two Magnon

L.J. Sandilands et al., PRB 82, 064503 (2010)

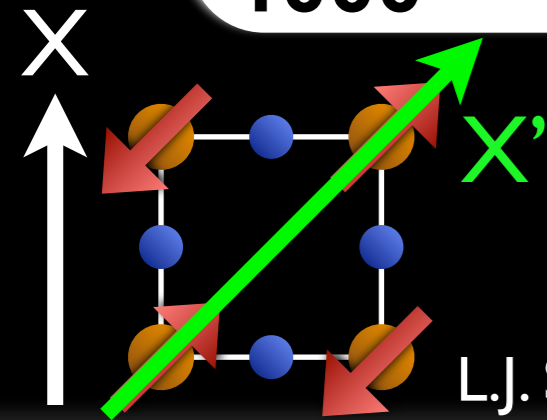
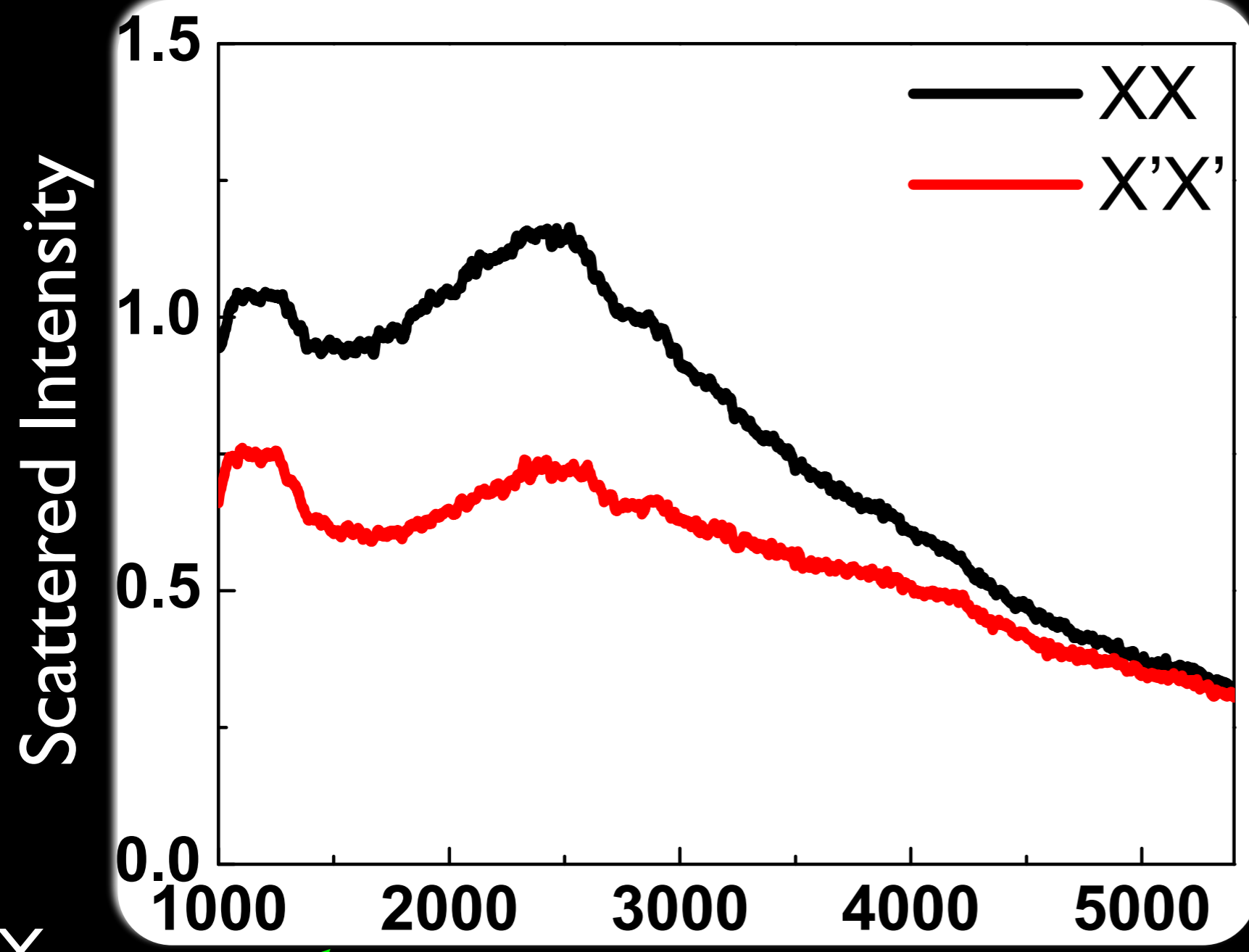
● Phases

● Exfoliation

● Optics

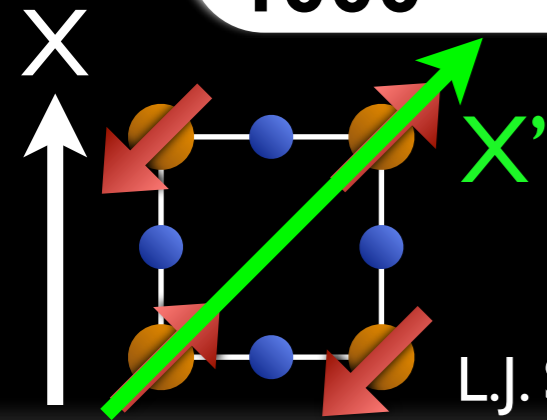
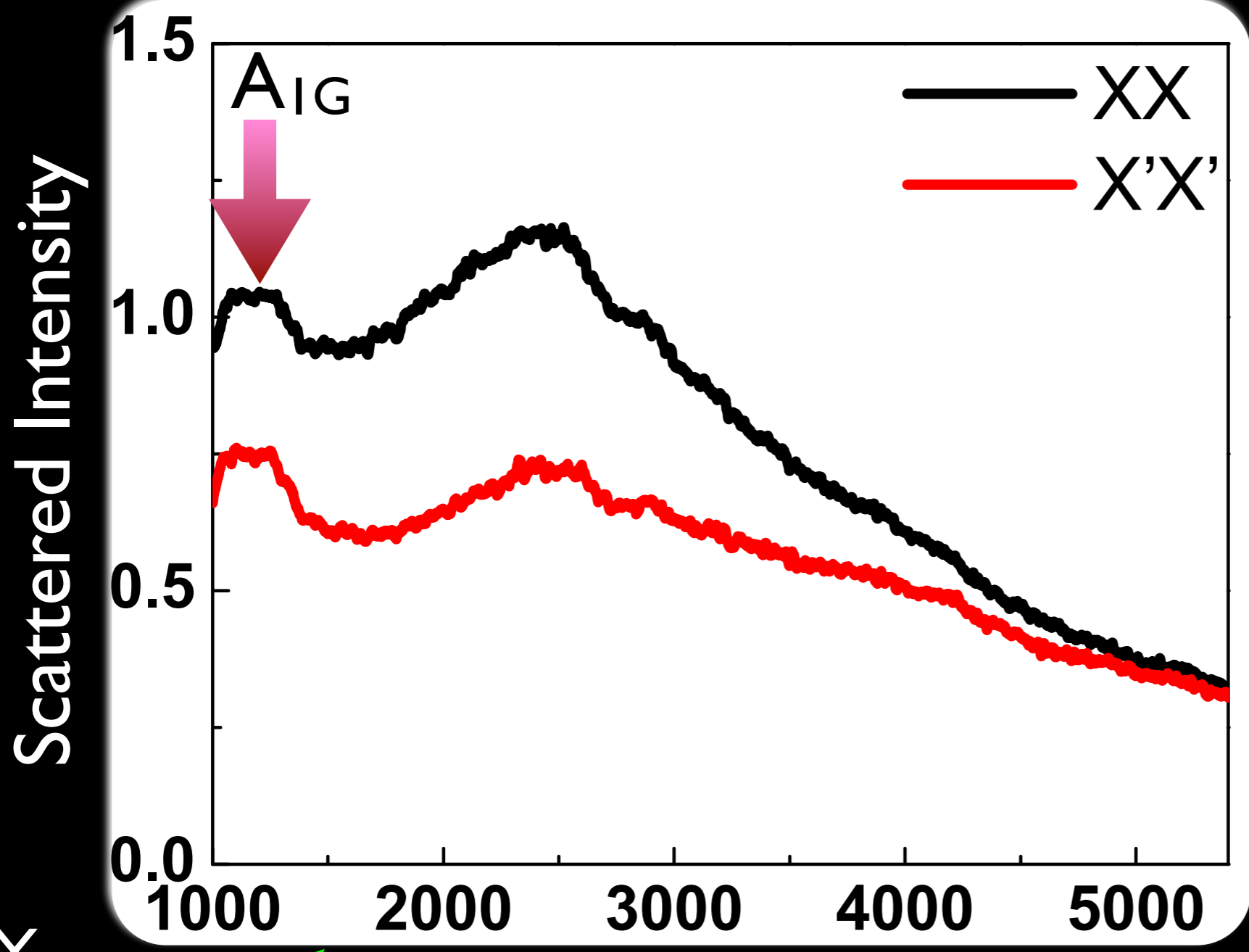
● Topology

● Future



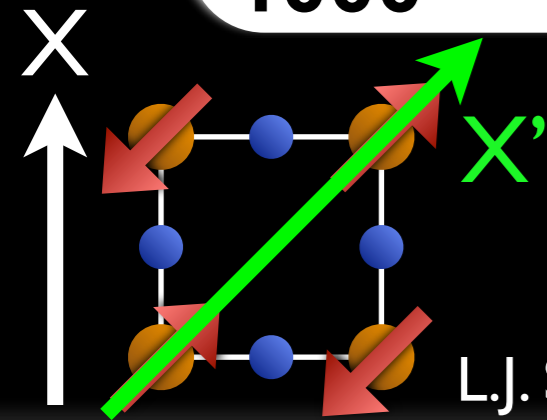
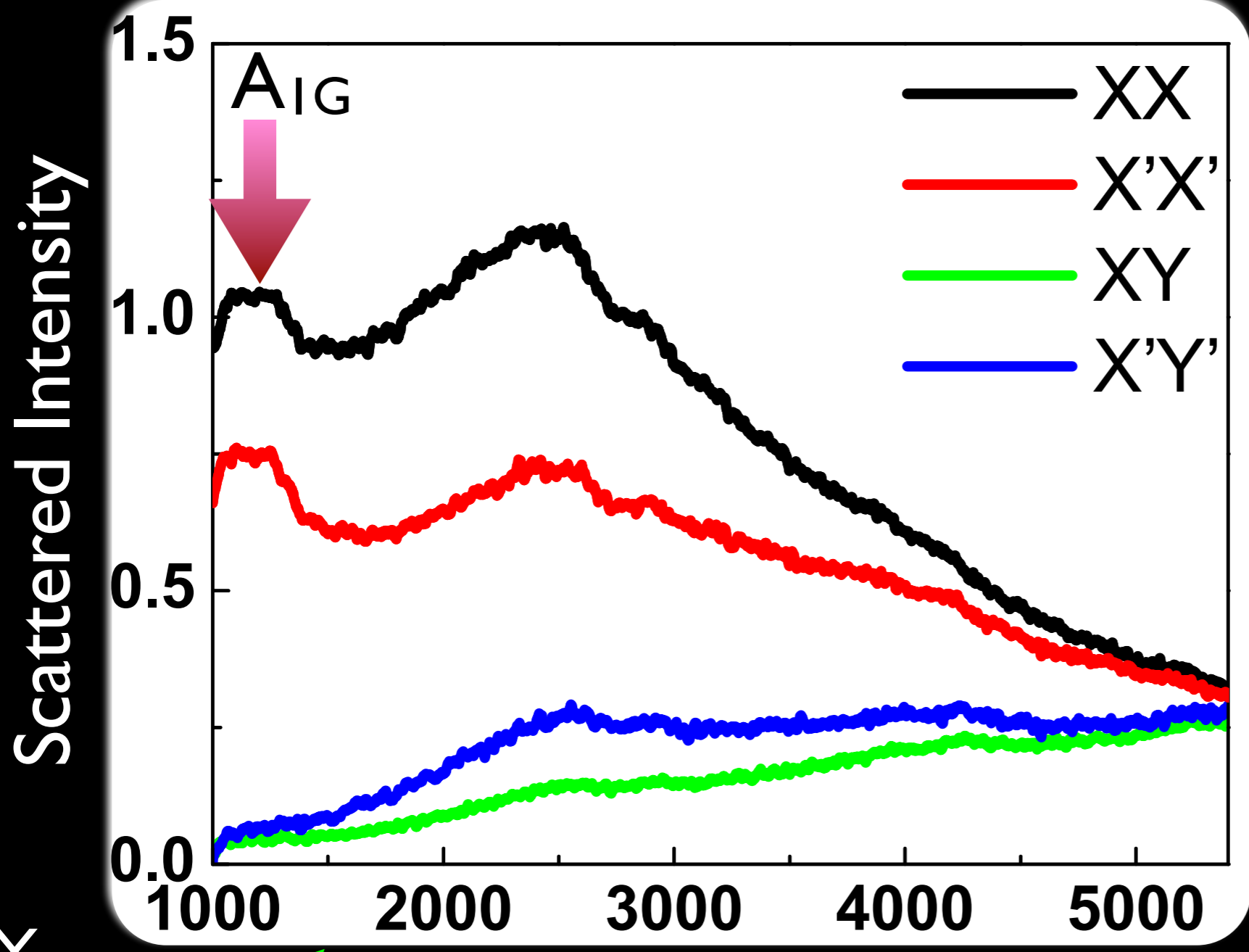
Raman Shift (cm^{-1})

L.J. Sandilands et al., PRB 82, 064503 (2010)



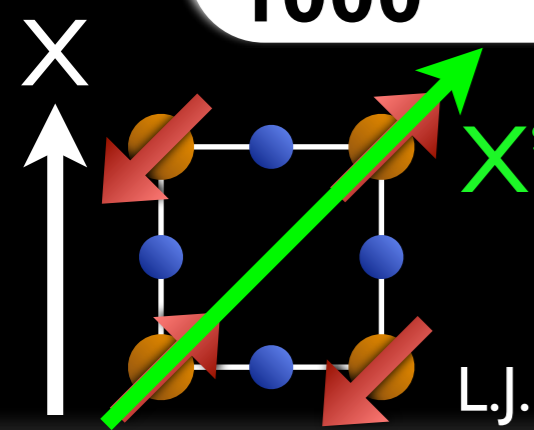
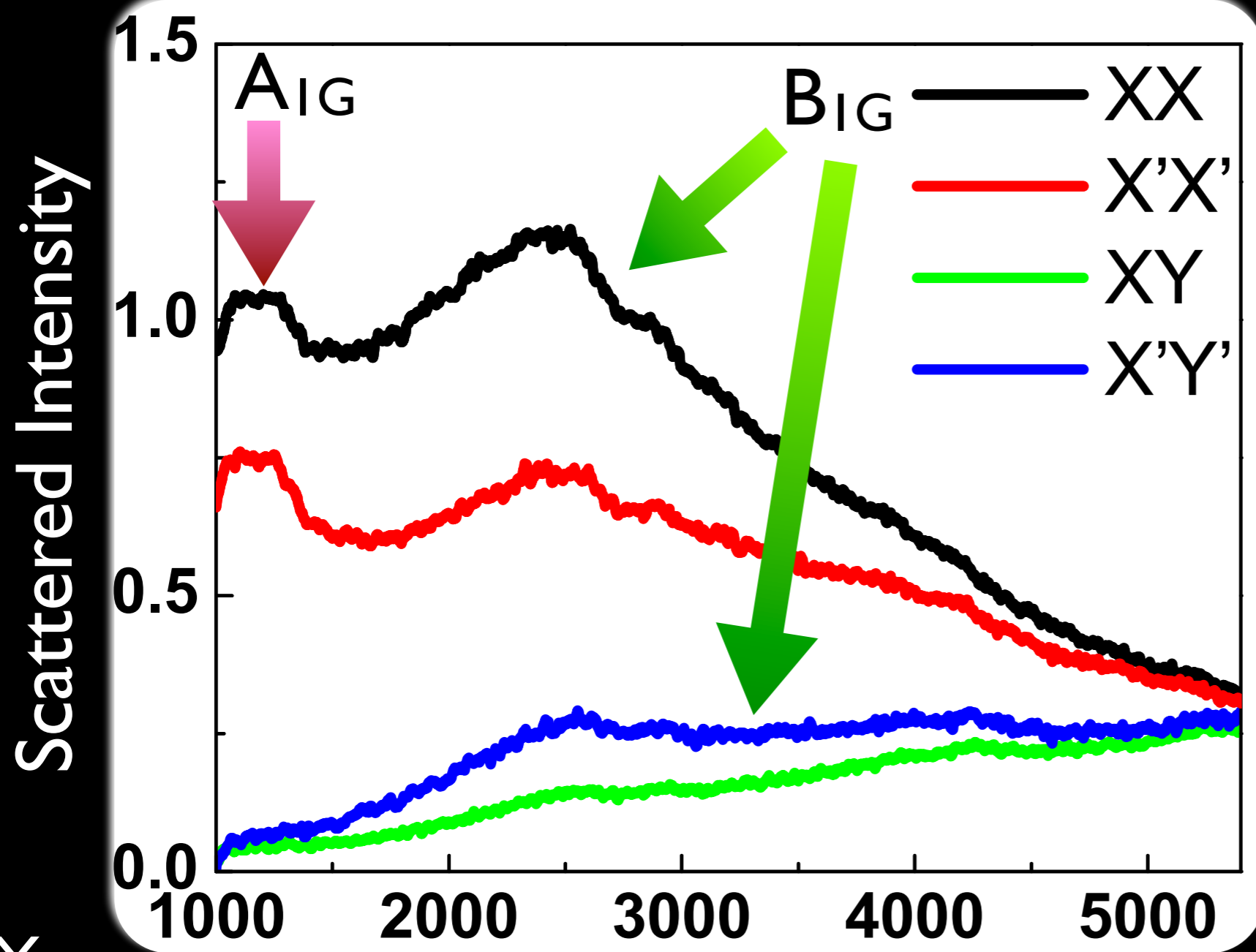
Raman Shift (cm^{-1})

L.J. Sandilands et al., PRB 82, 064503 (2010)



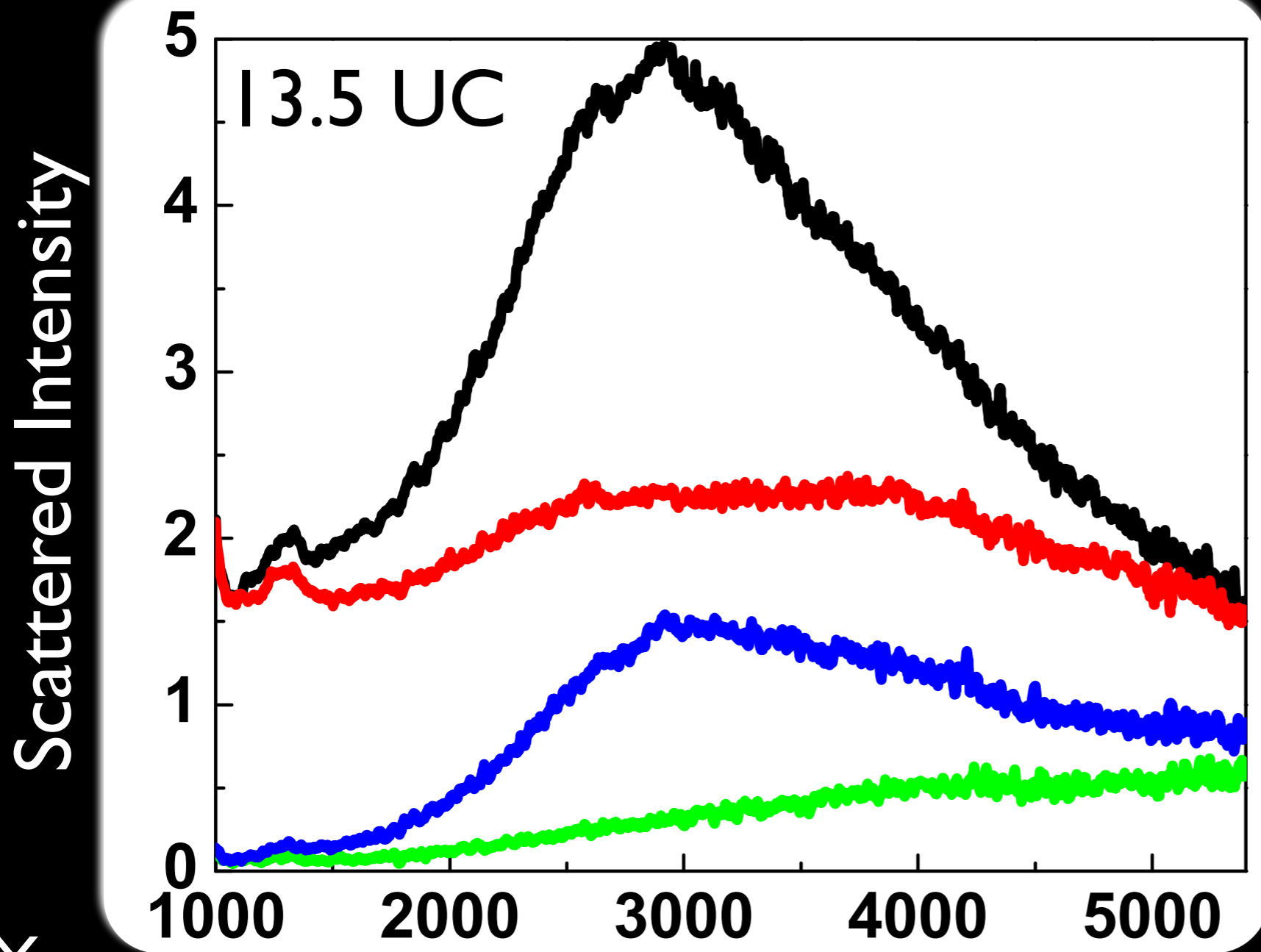
Raman Shift (cm⁻¹)

L.J. Sandilands et al., PRB 82, 064503 (2010)

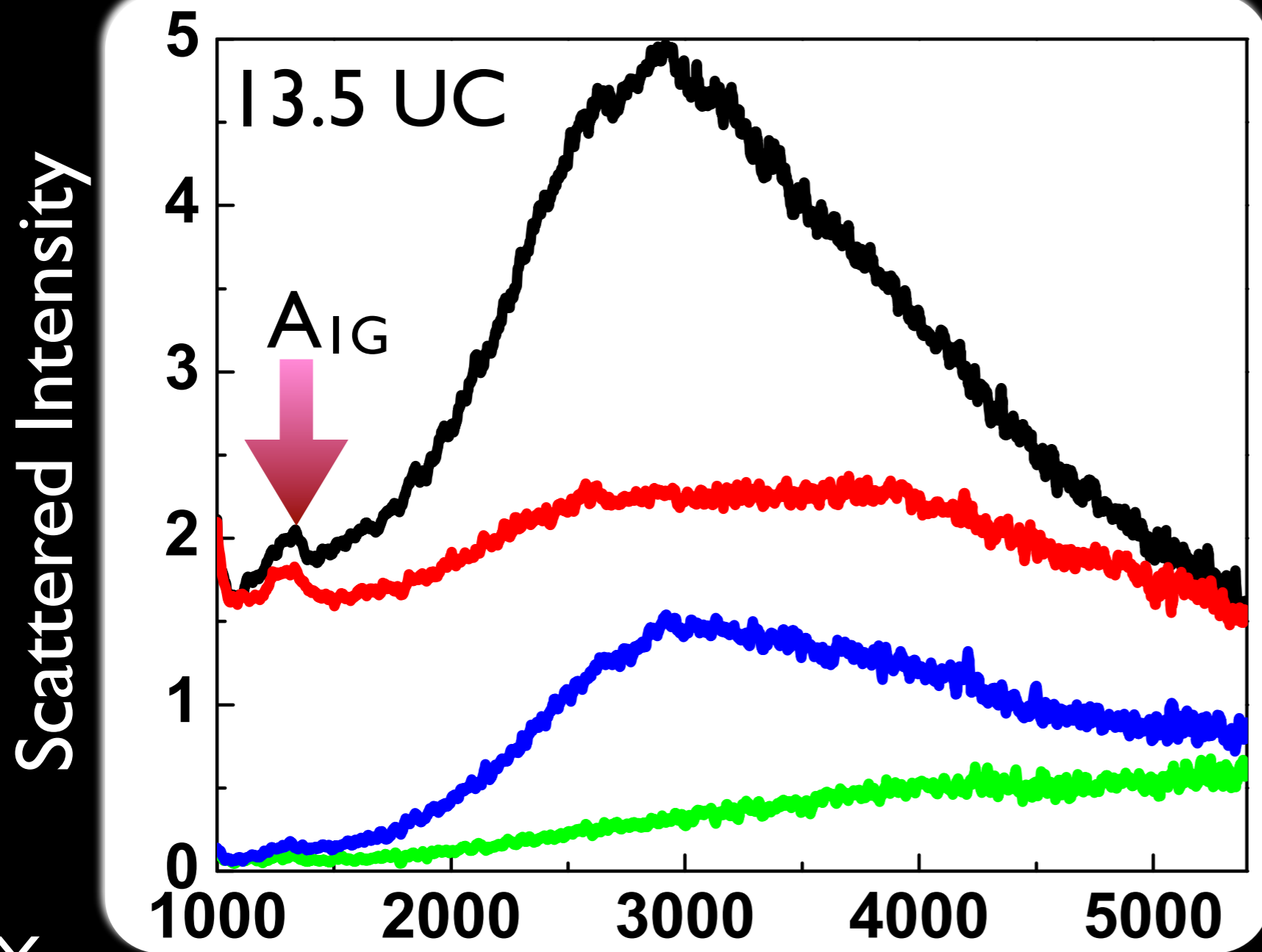


Raman Shift (cm⁻¹)

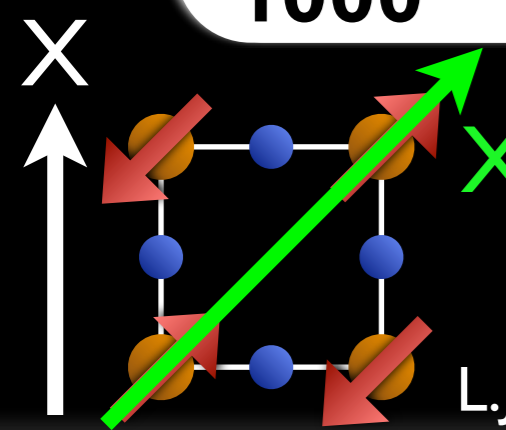
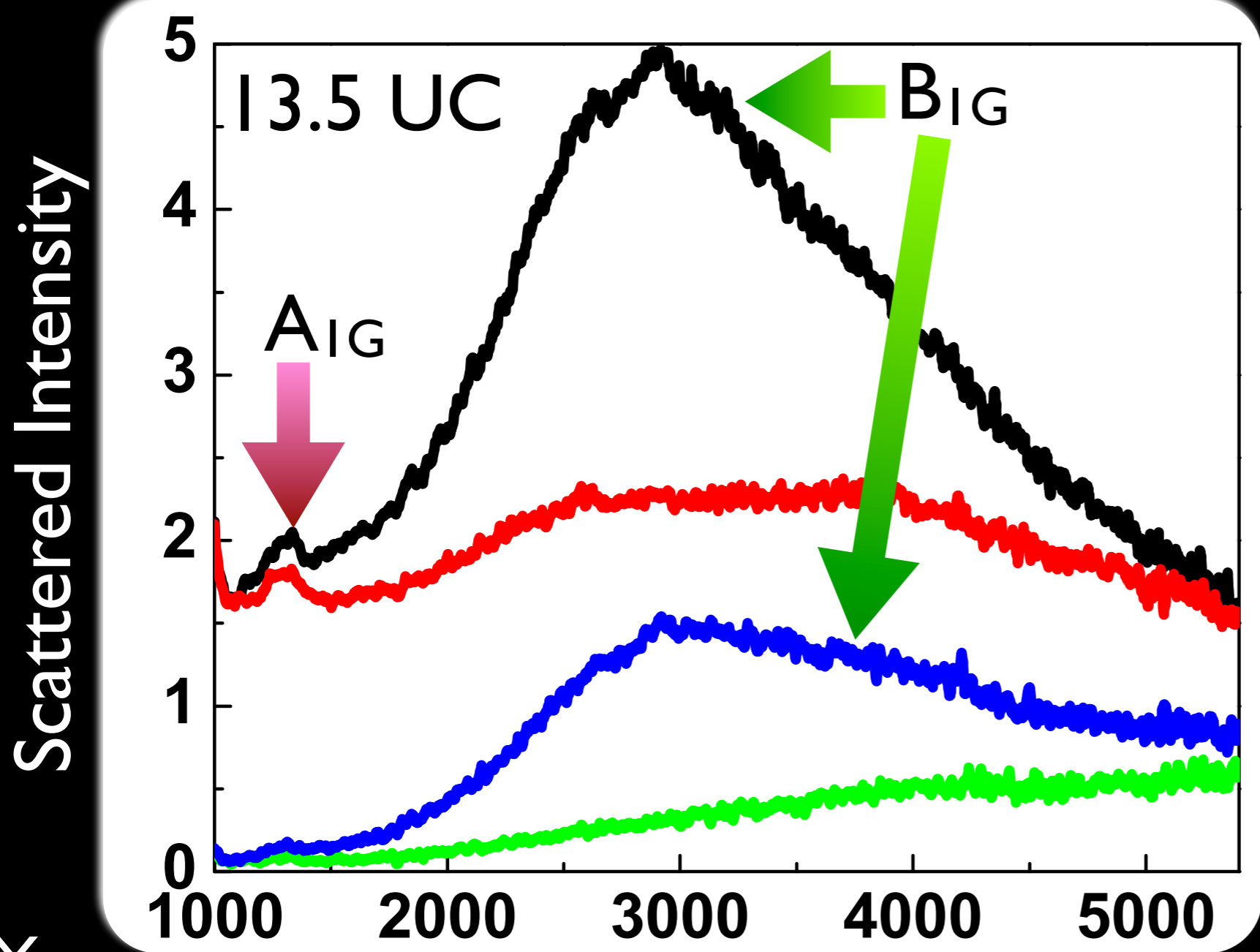
L.J. Sandilands et al., PRB 82, 064503 (2010)



L.J. Sandilands et al., PRB 82, 064503 (2010)

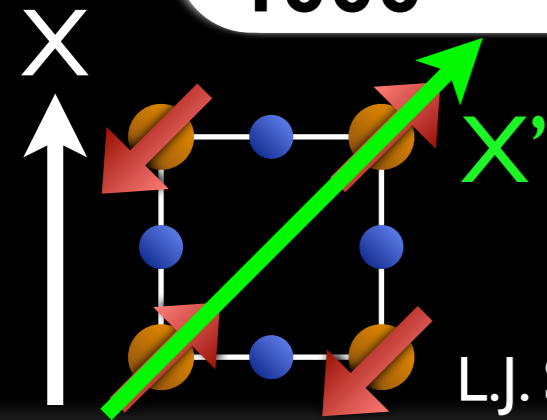
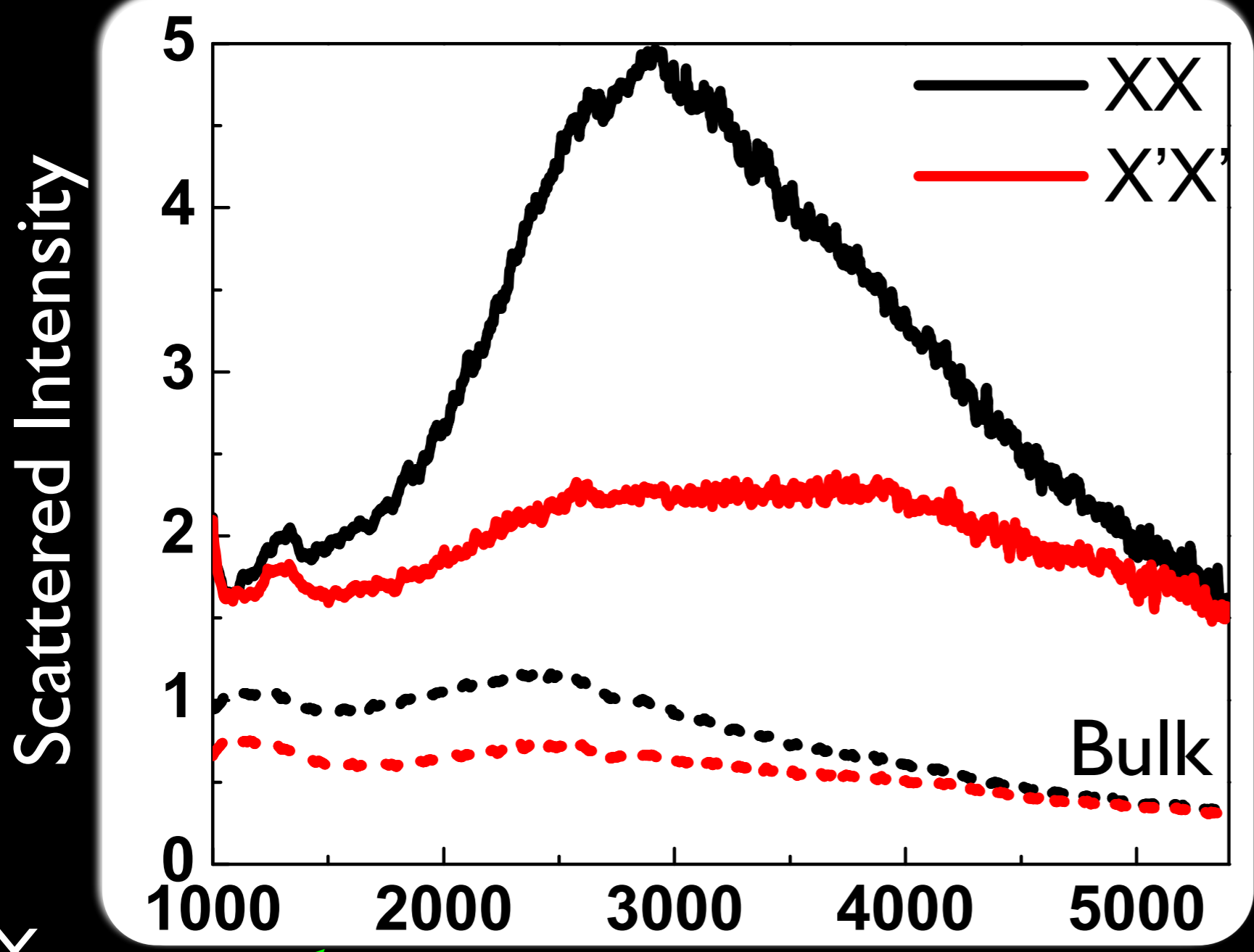


L.J. Sandilands et al., PRB 82, 064503 (2010)



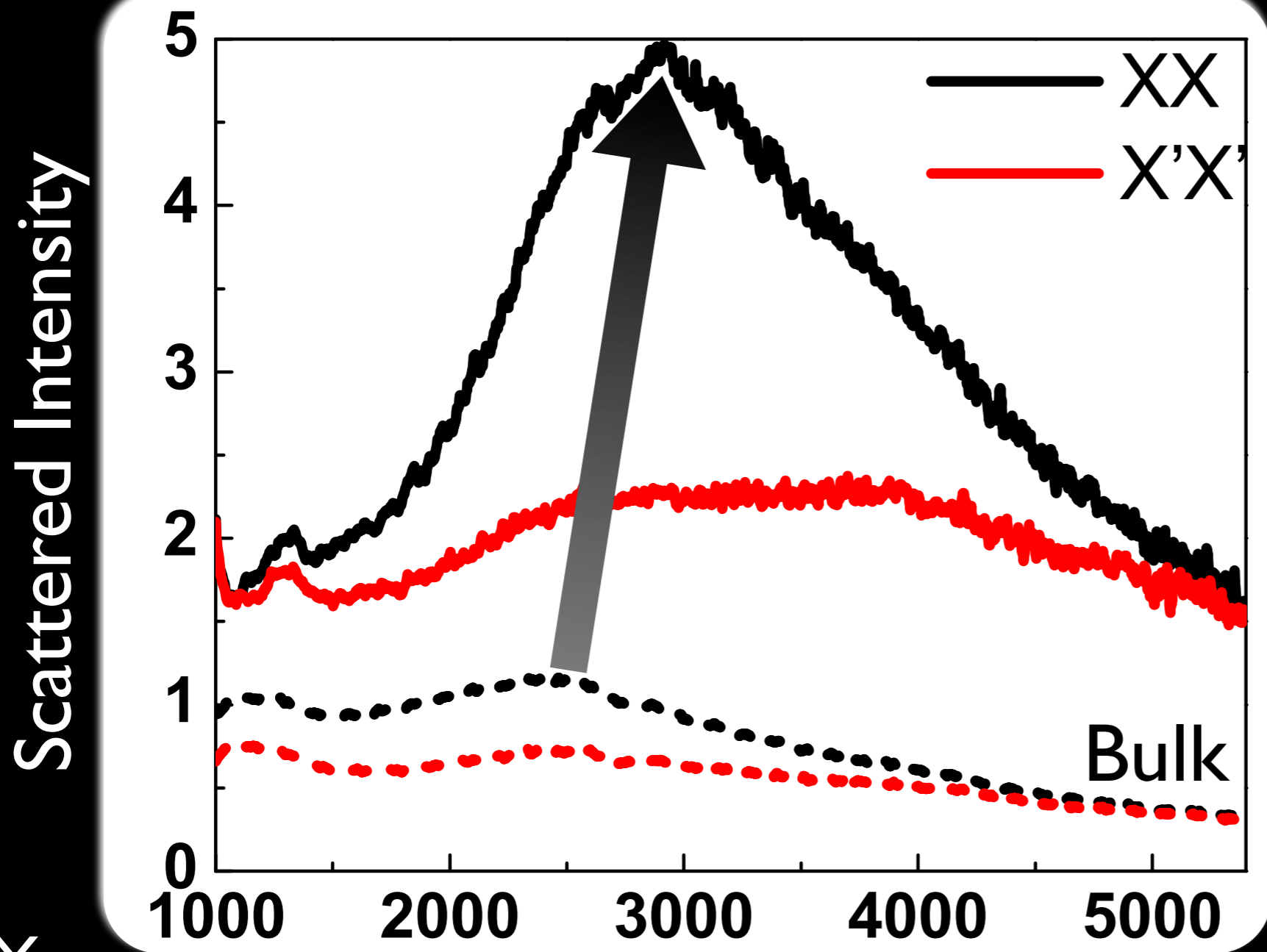
X', Raman Shift (cm⁻¹)

L.J. Sandilands et al., PRB 82, 064503 (2010)



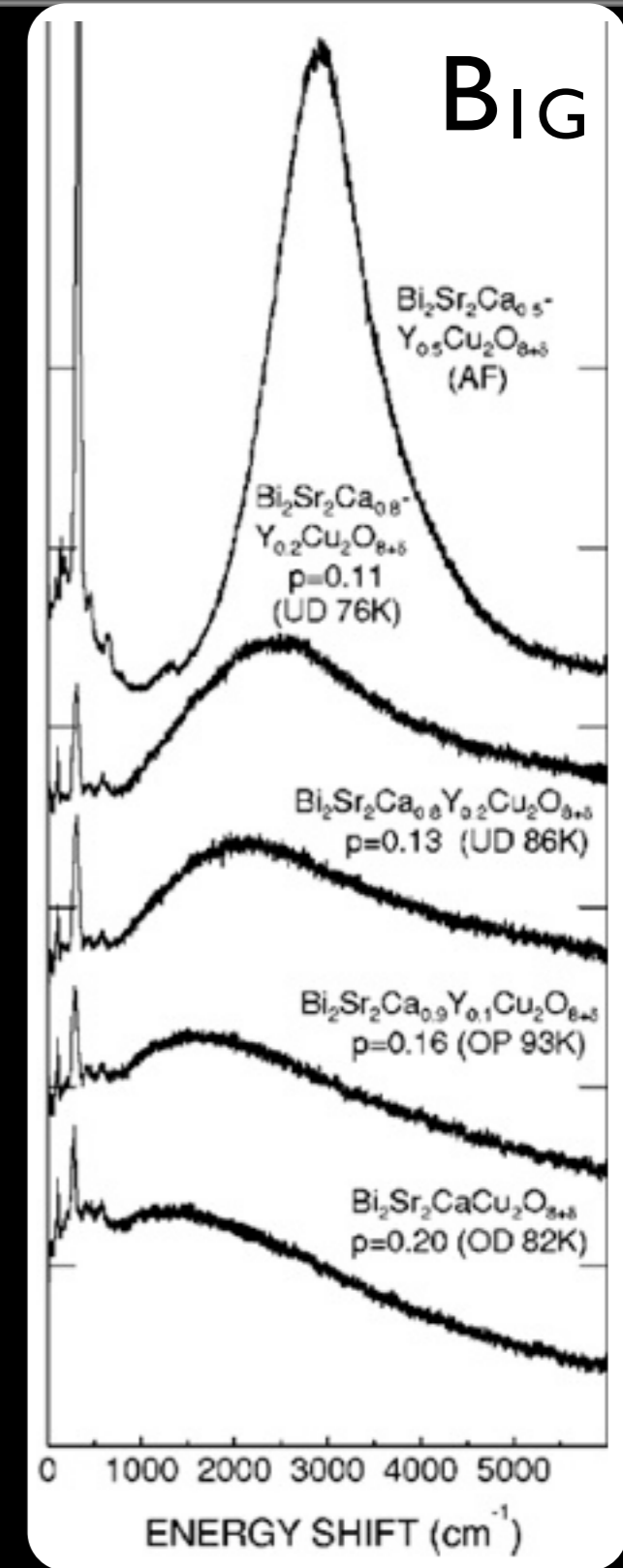
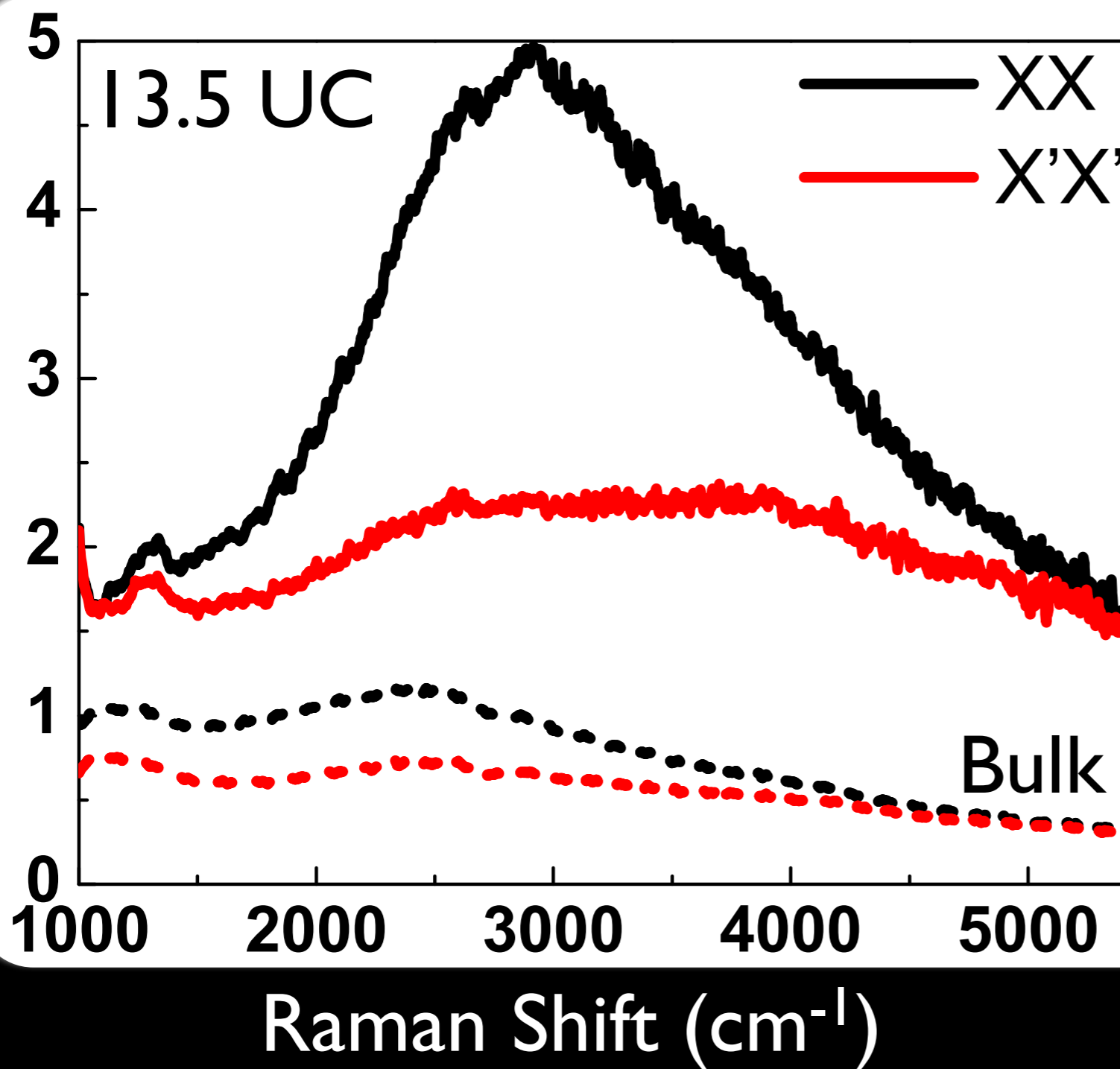
Raman Shift (cm⁻¹)

L.J. Sandilands et al., PRB 82, 064503 (2010)



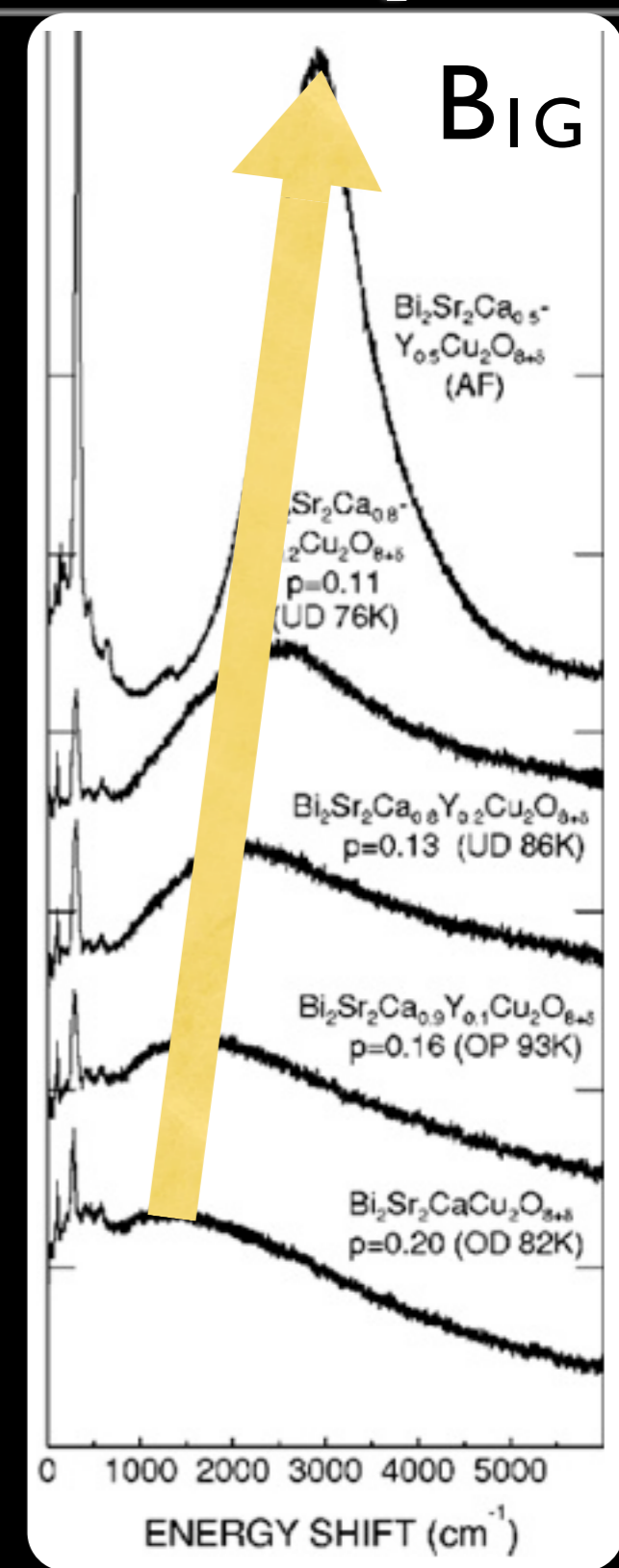
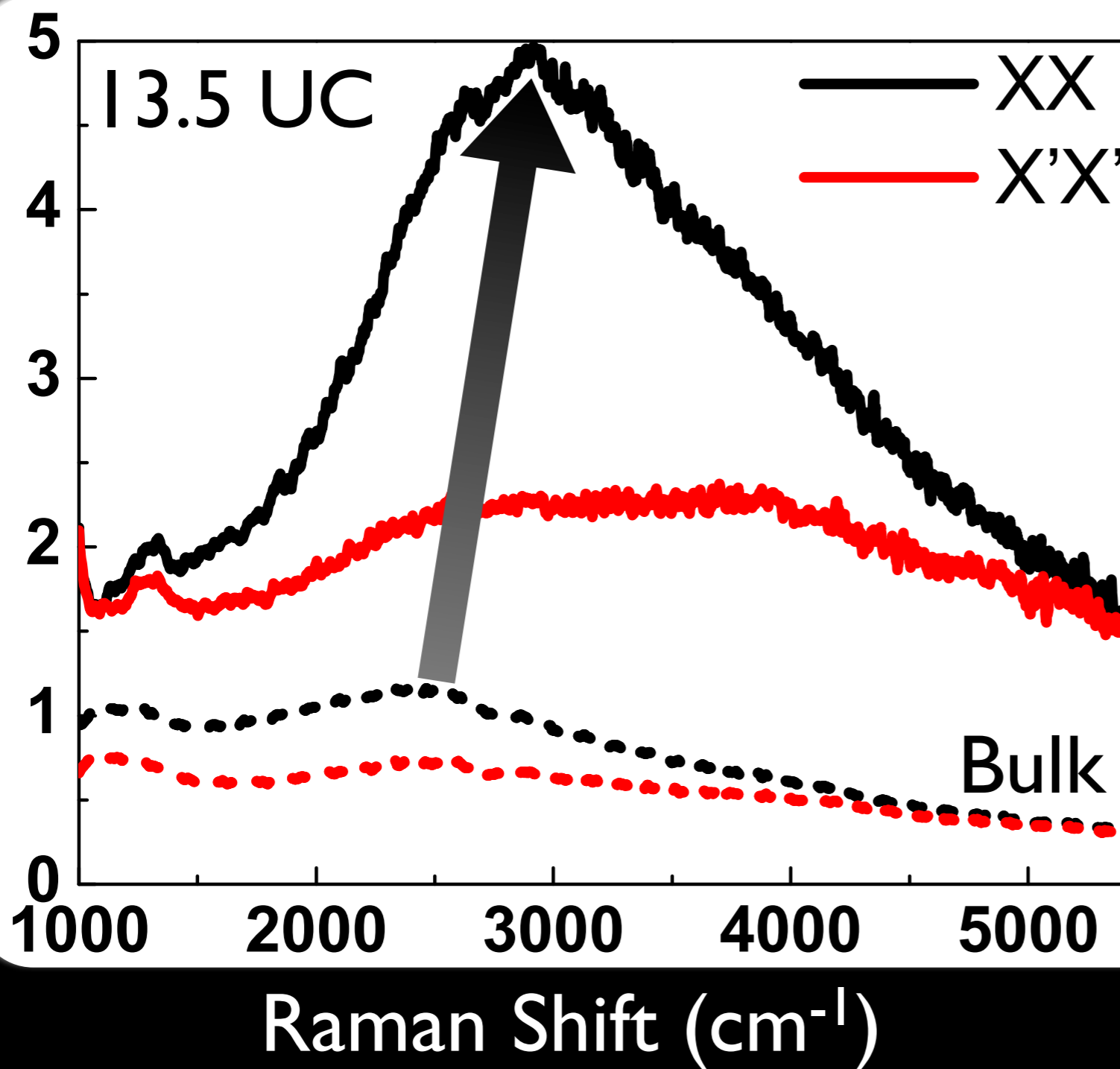
L.J. Sandilands et al., PRB 82, 064503 (2010)

Scattered Intensity



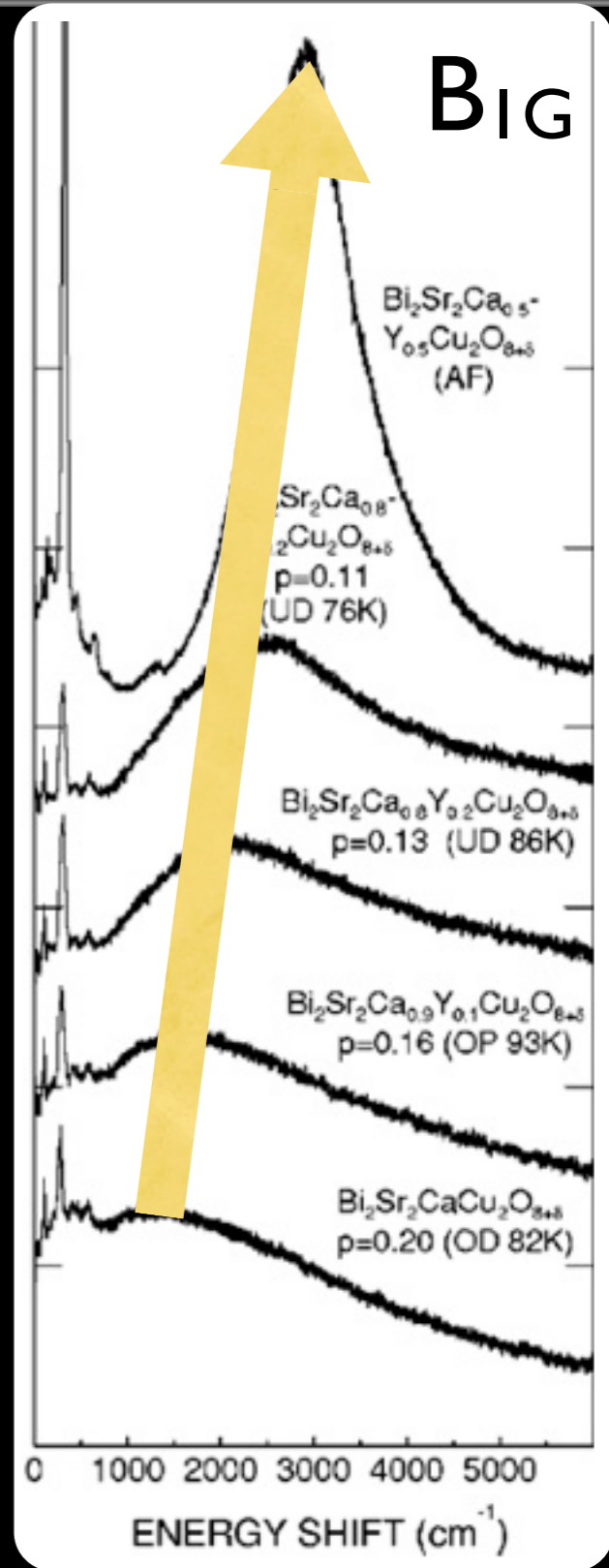
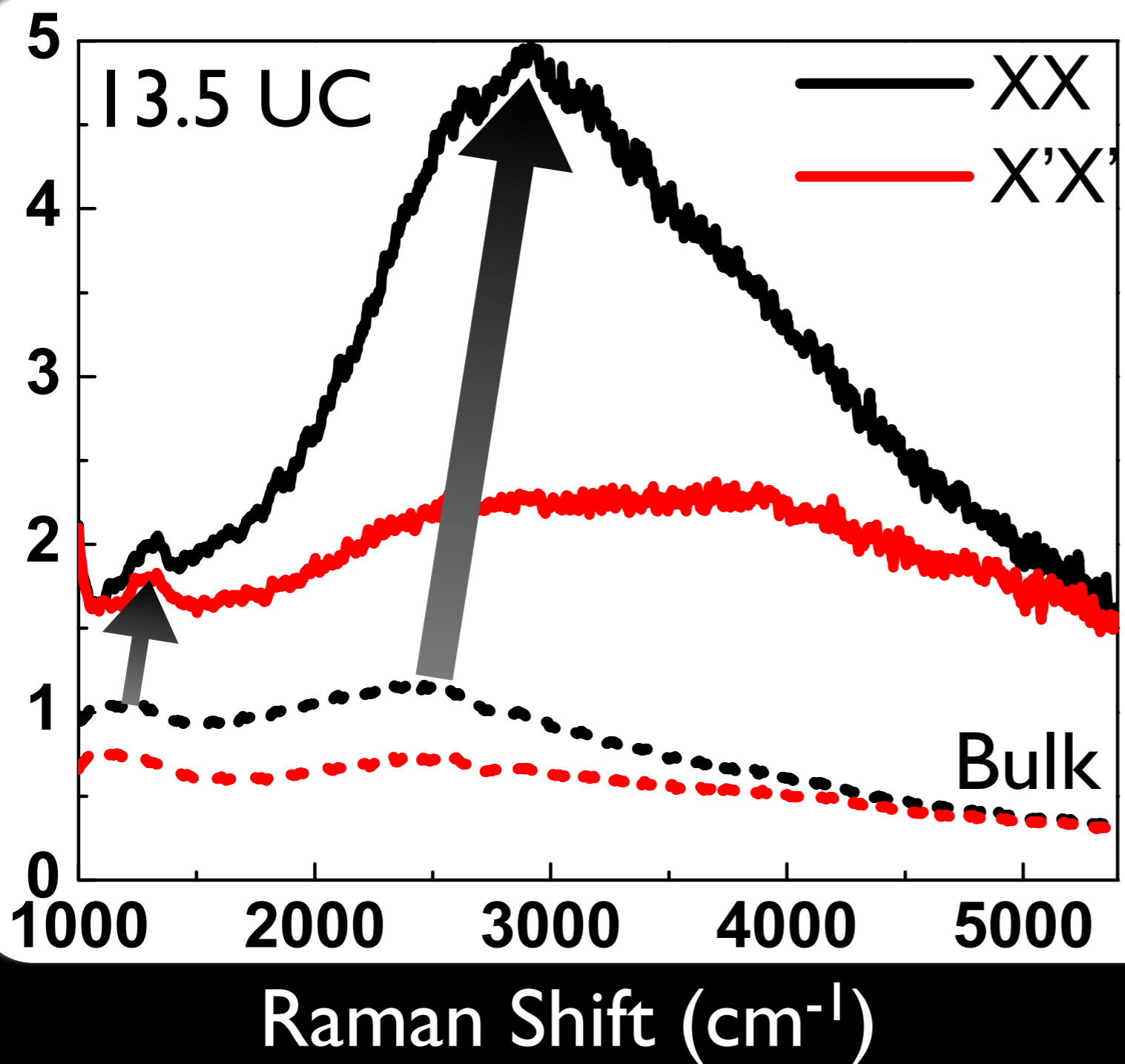
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



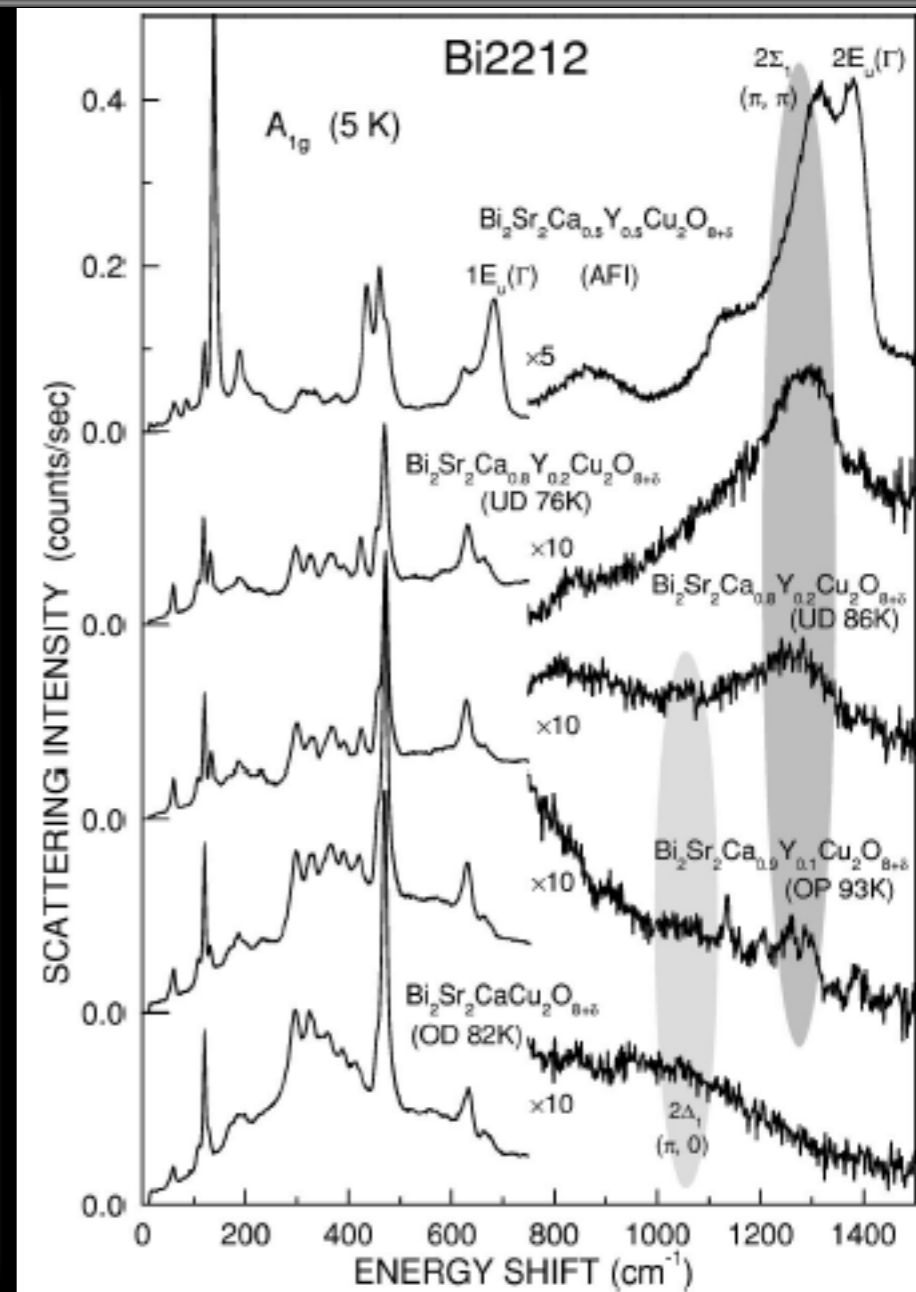
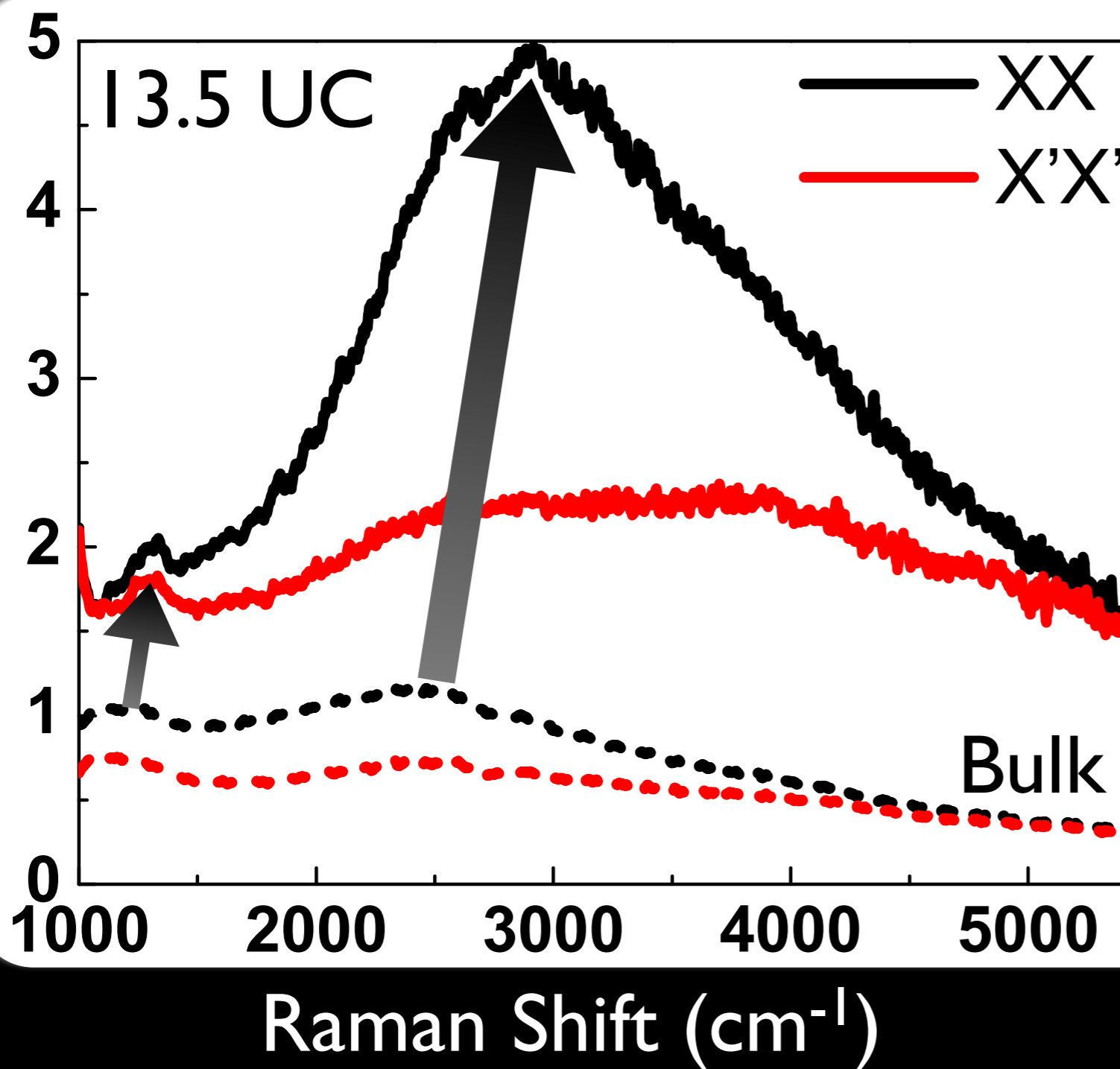
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



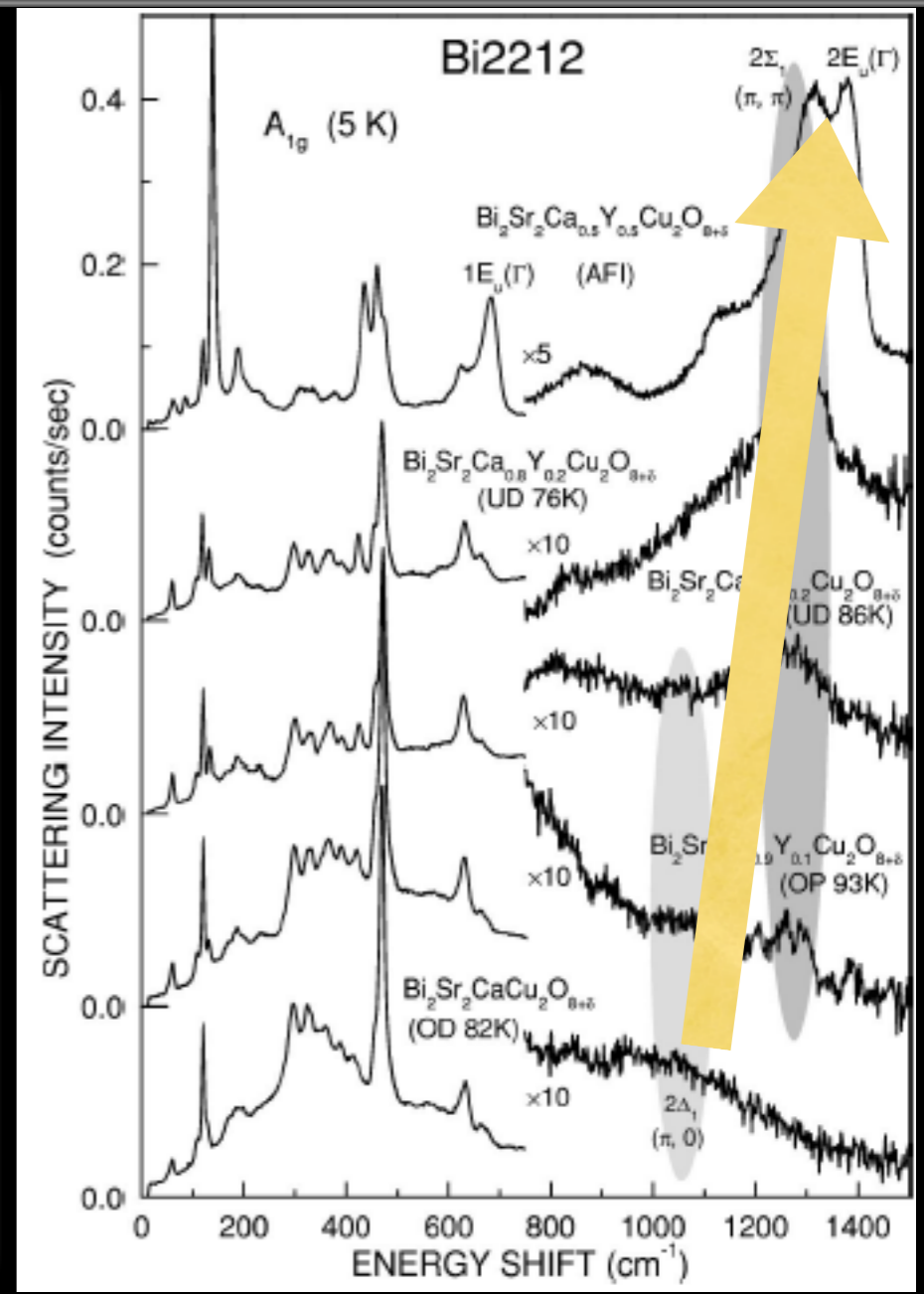
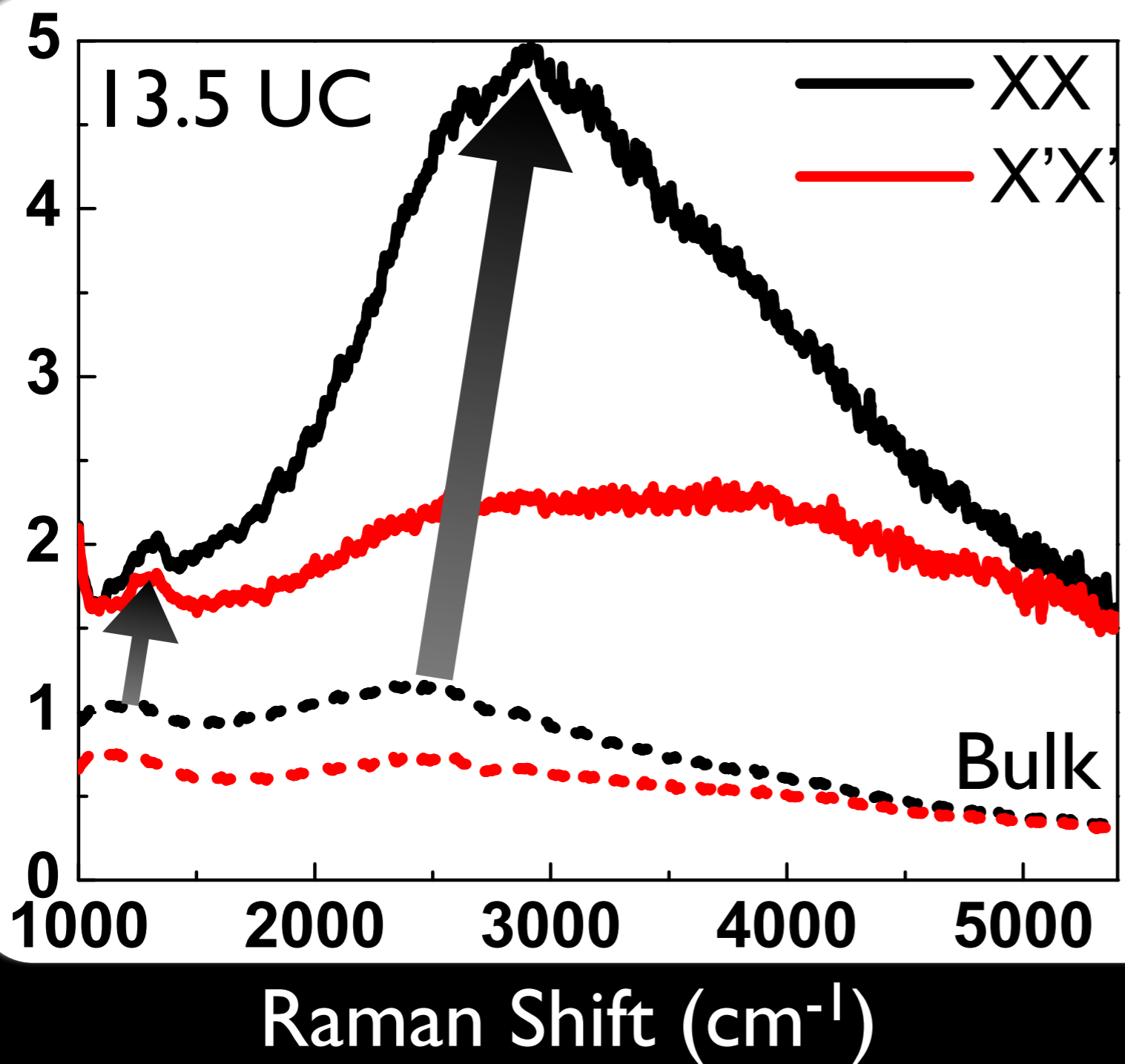
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



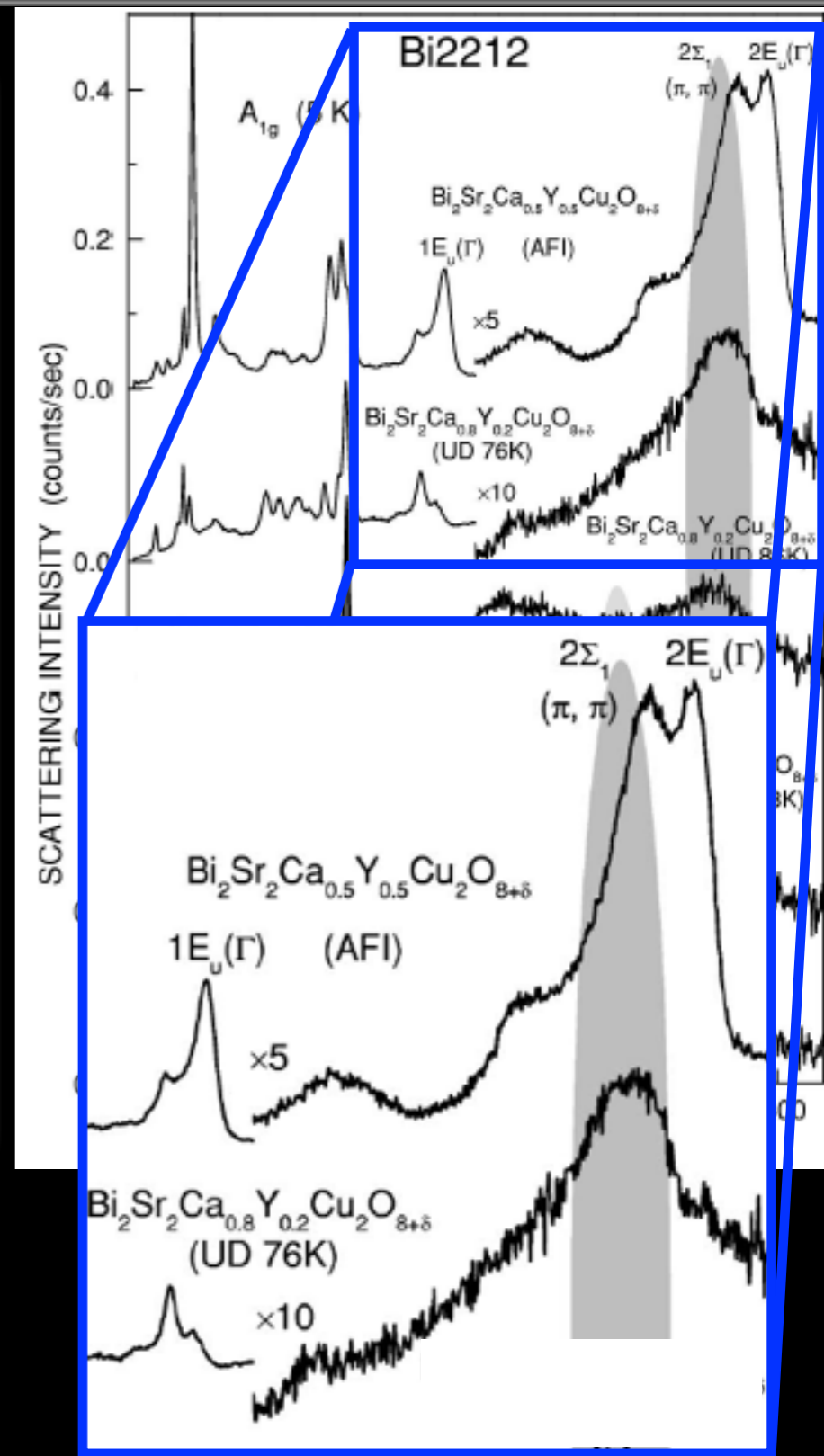
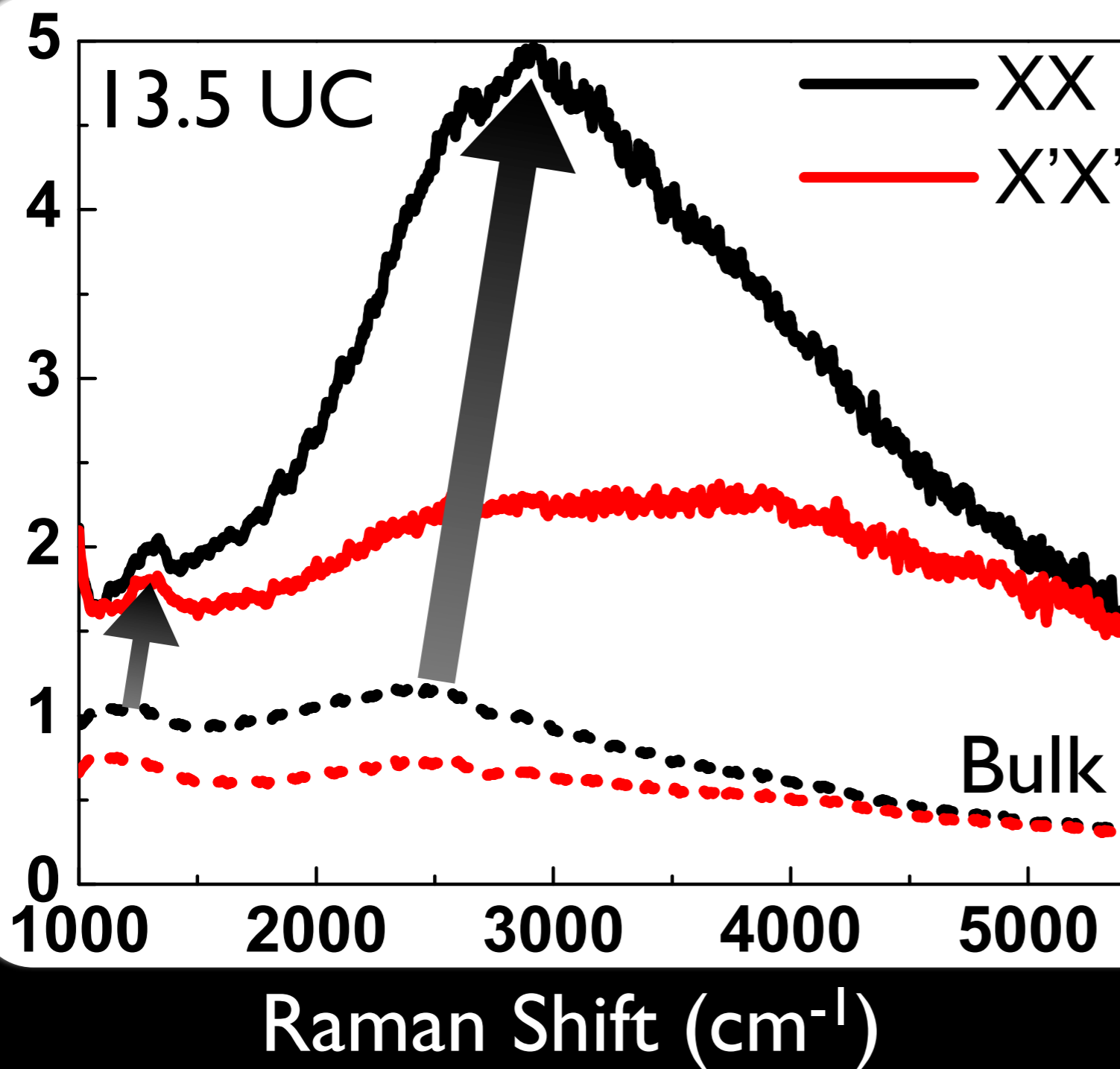
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



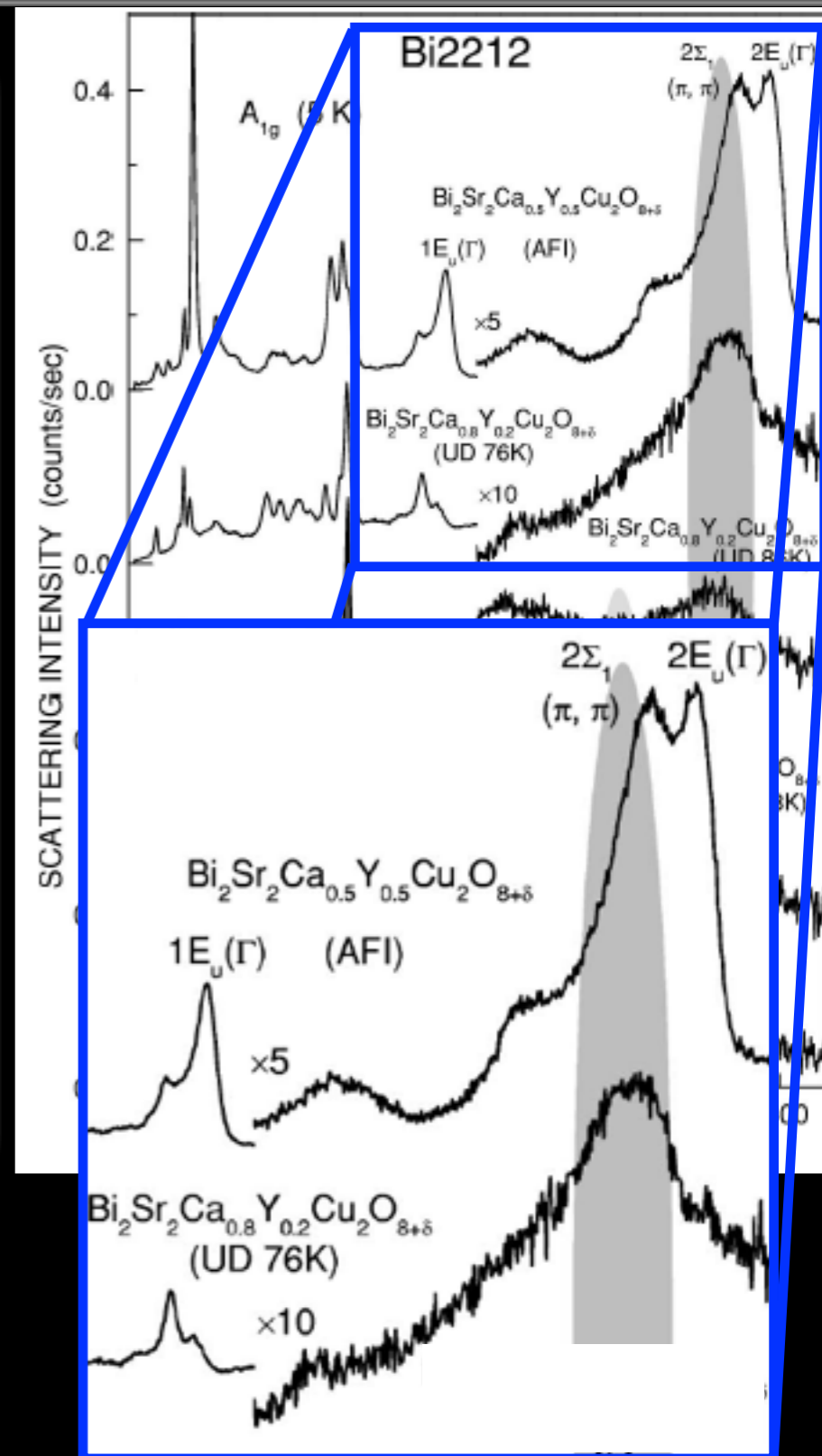
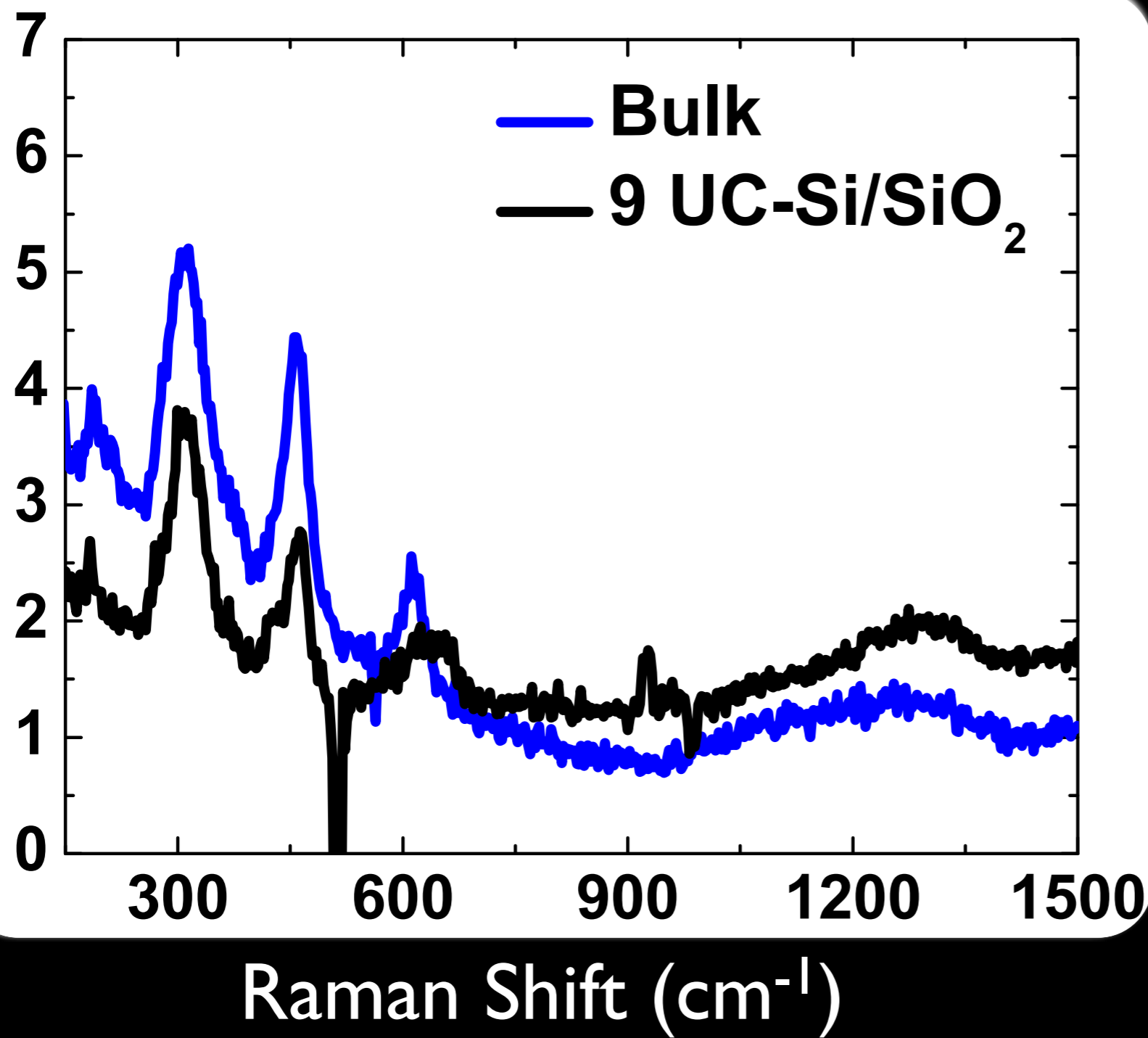
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



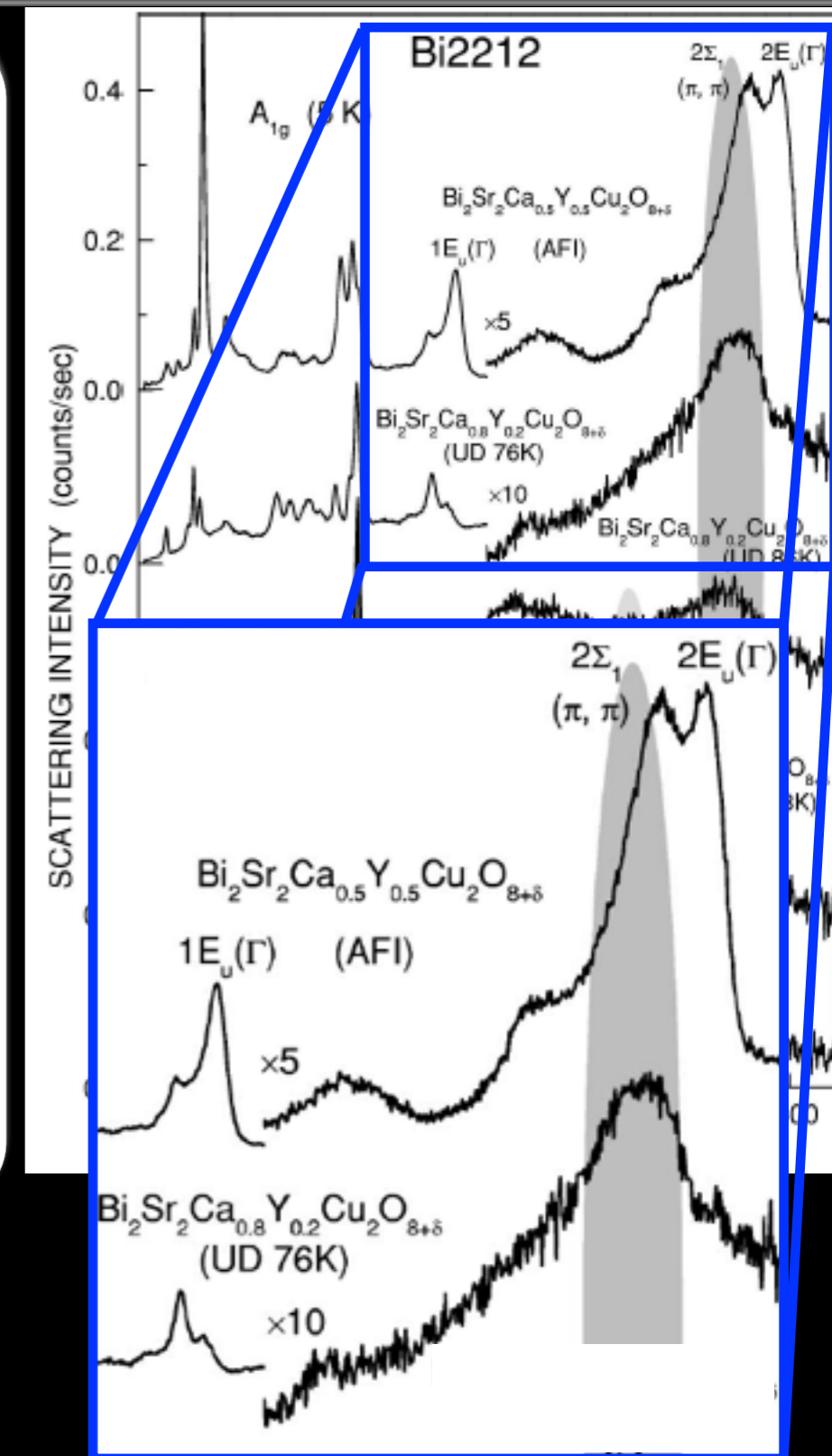
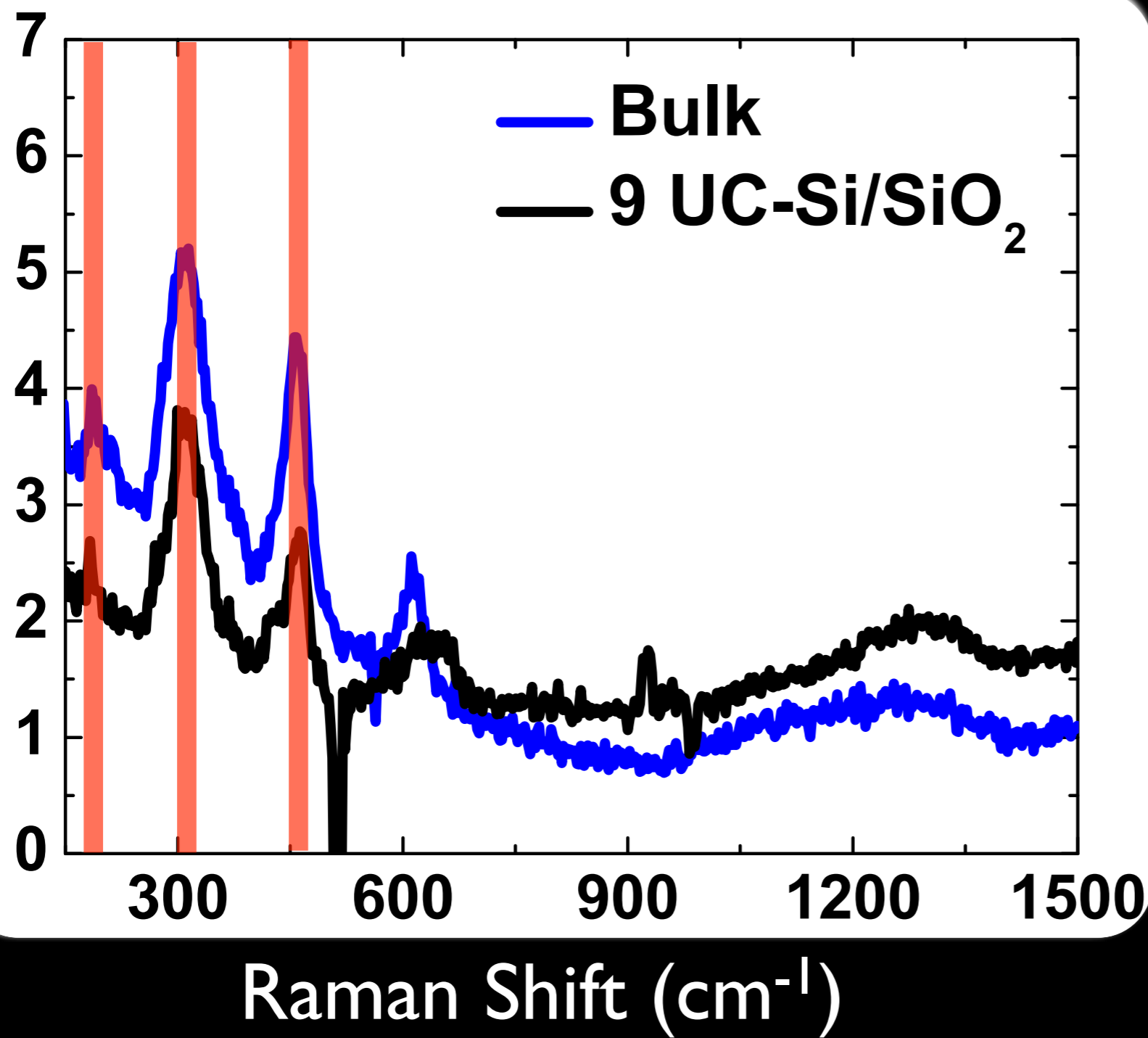
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



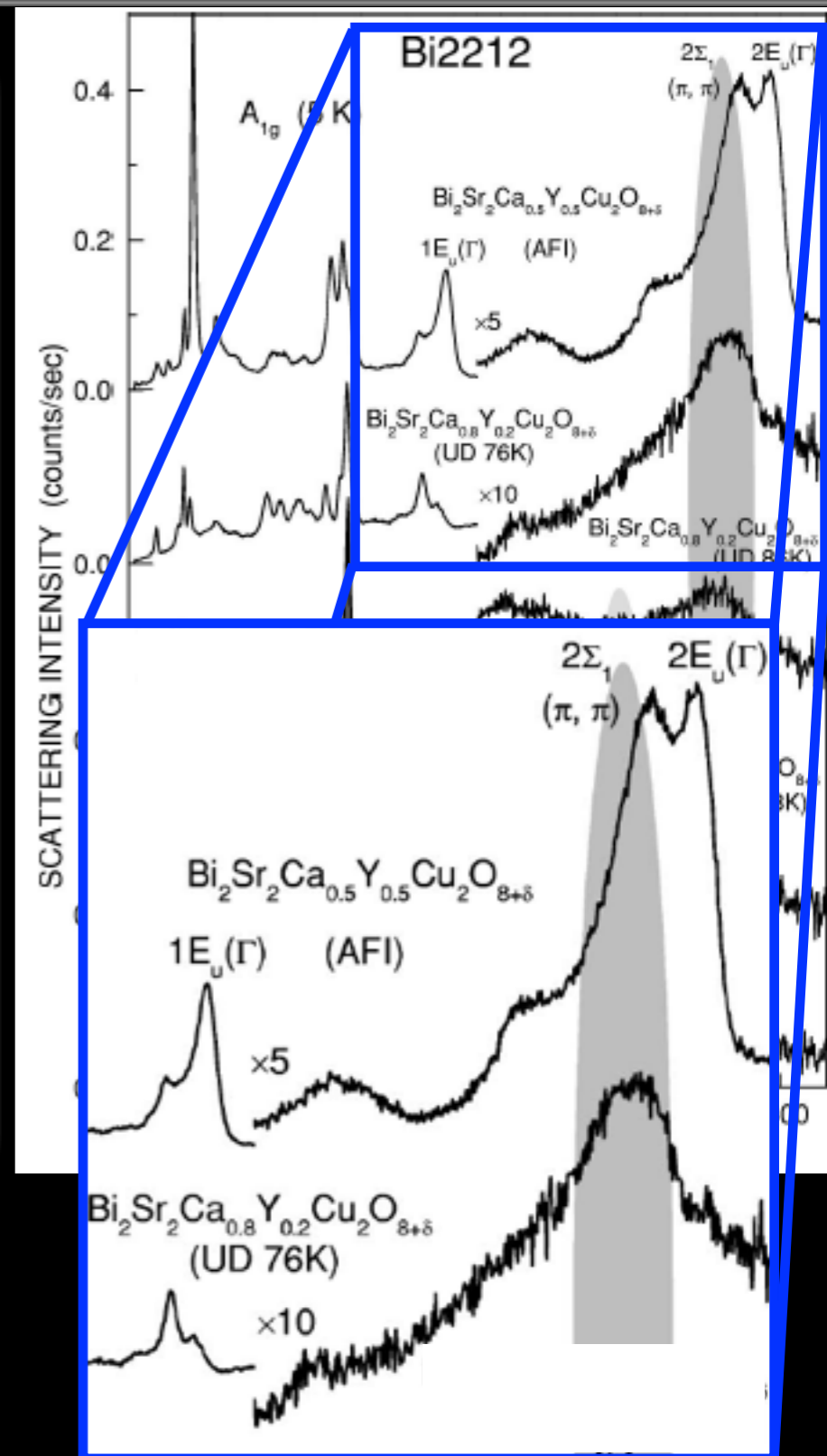
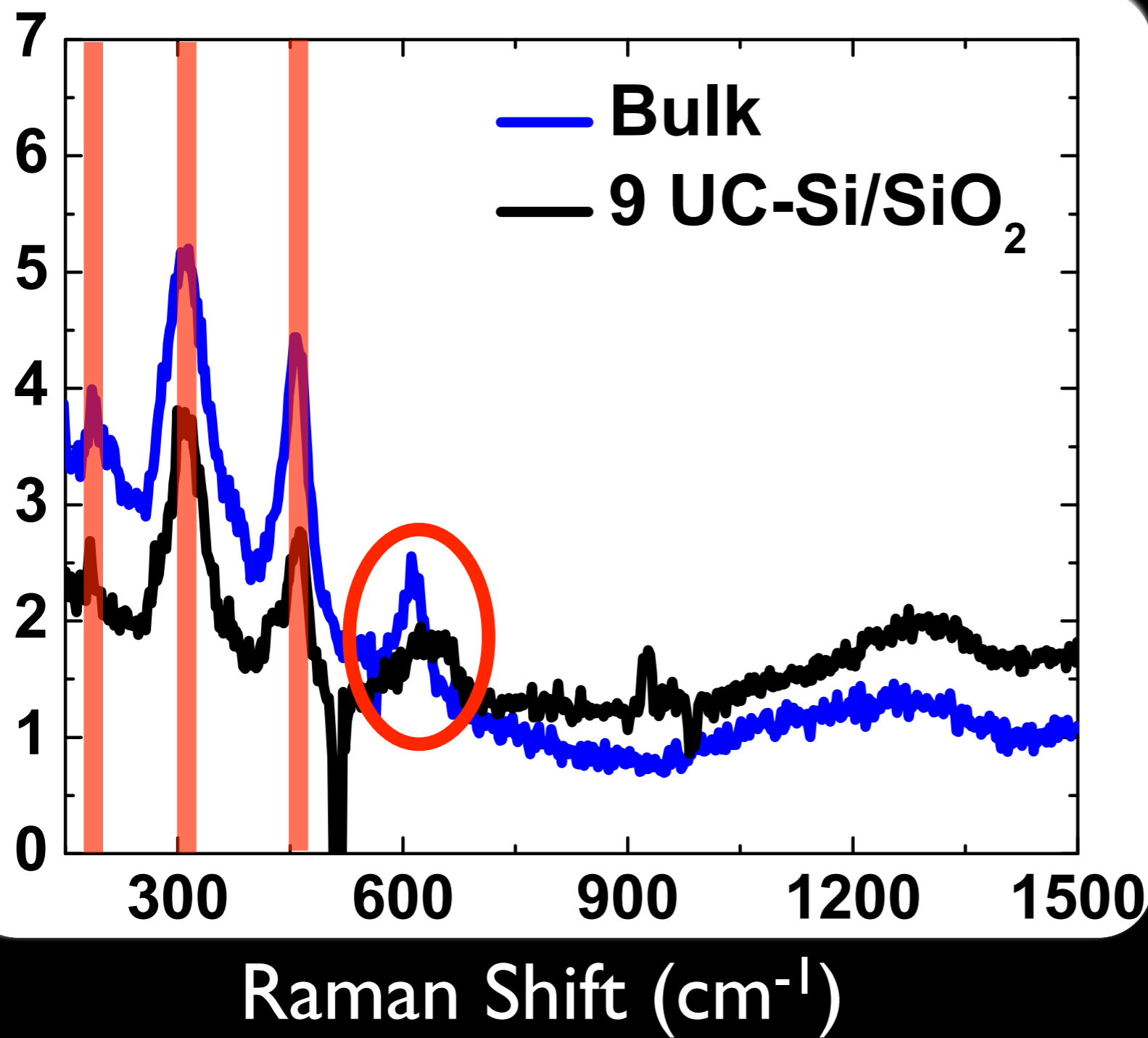
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



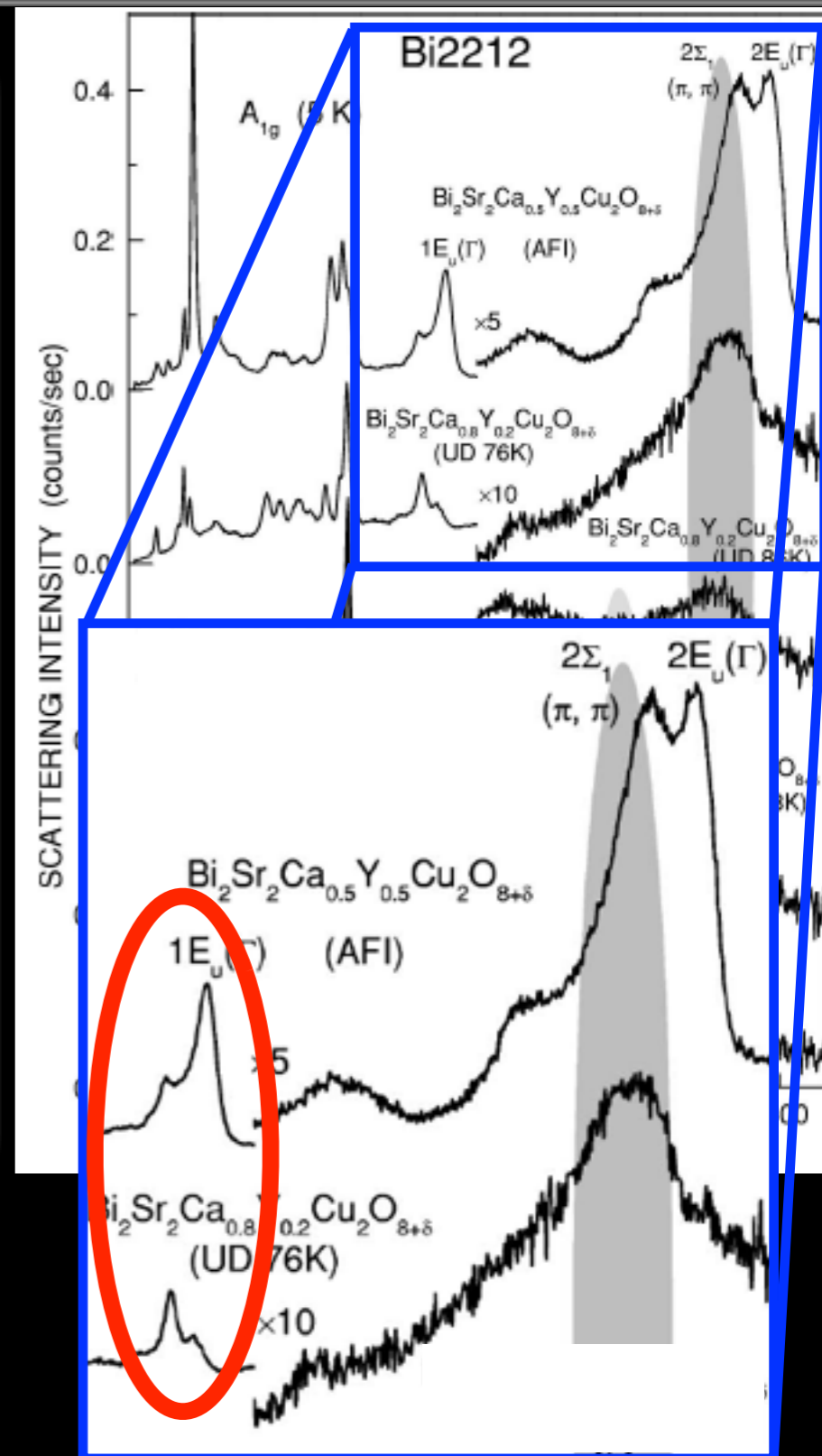
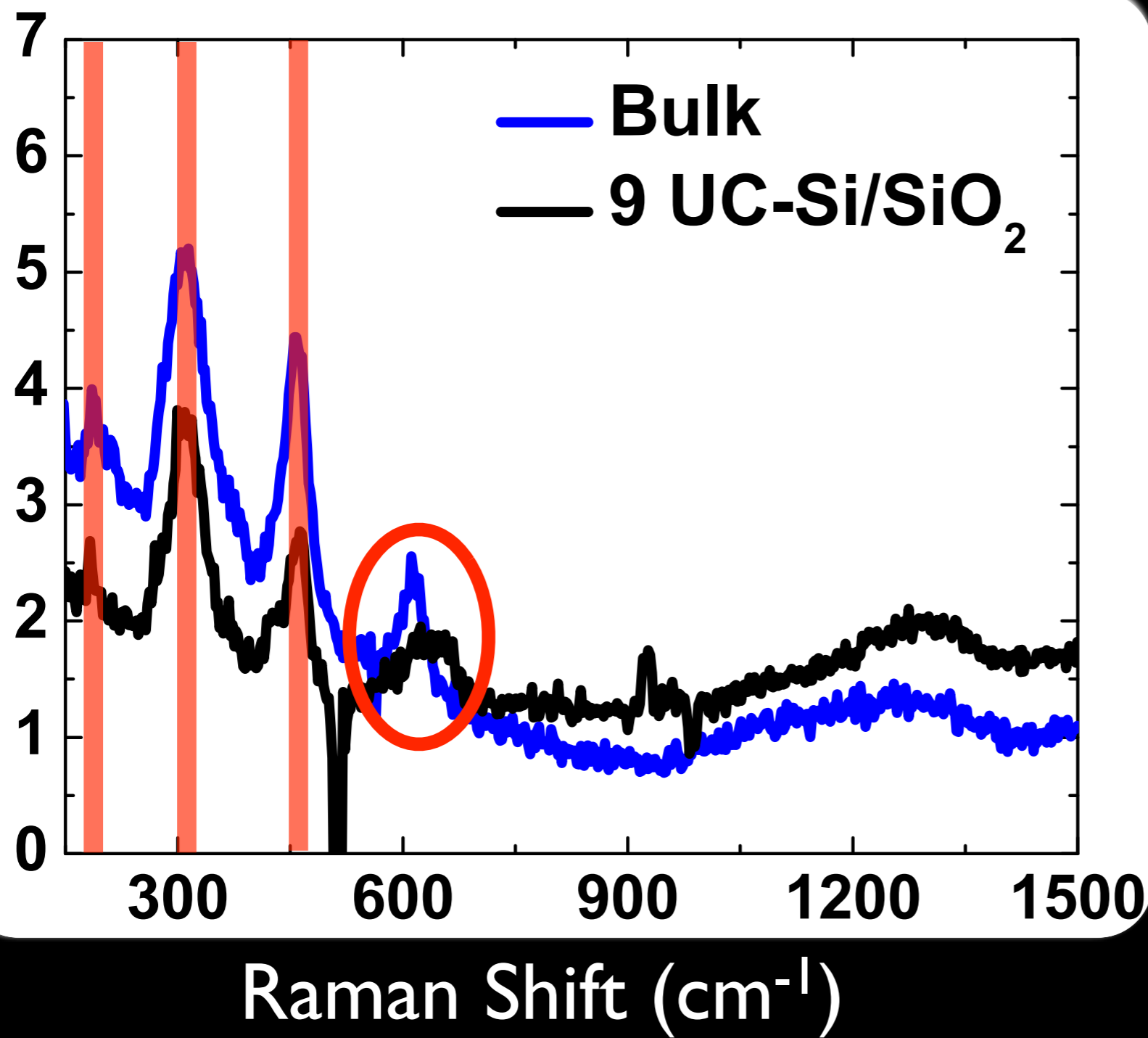
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



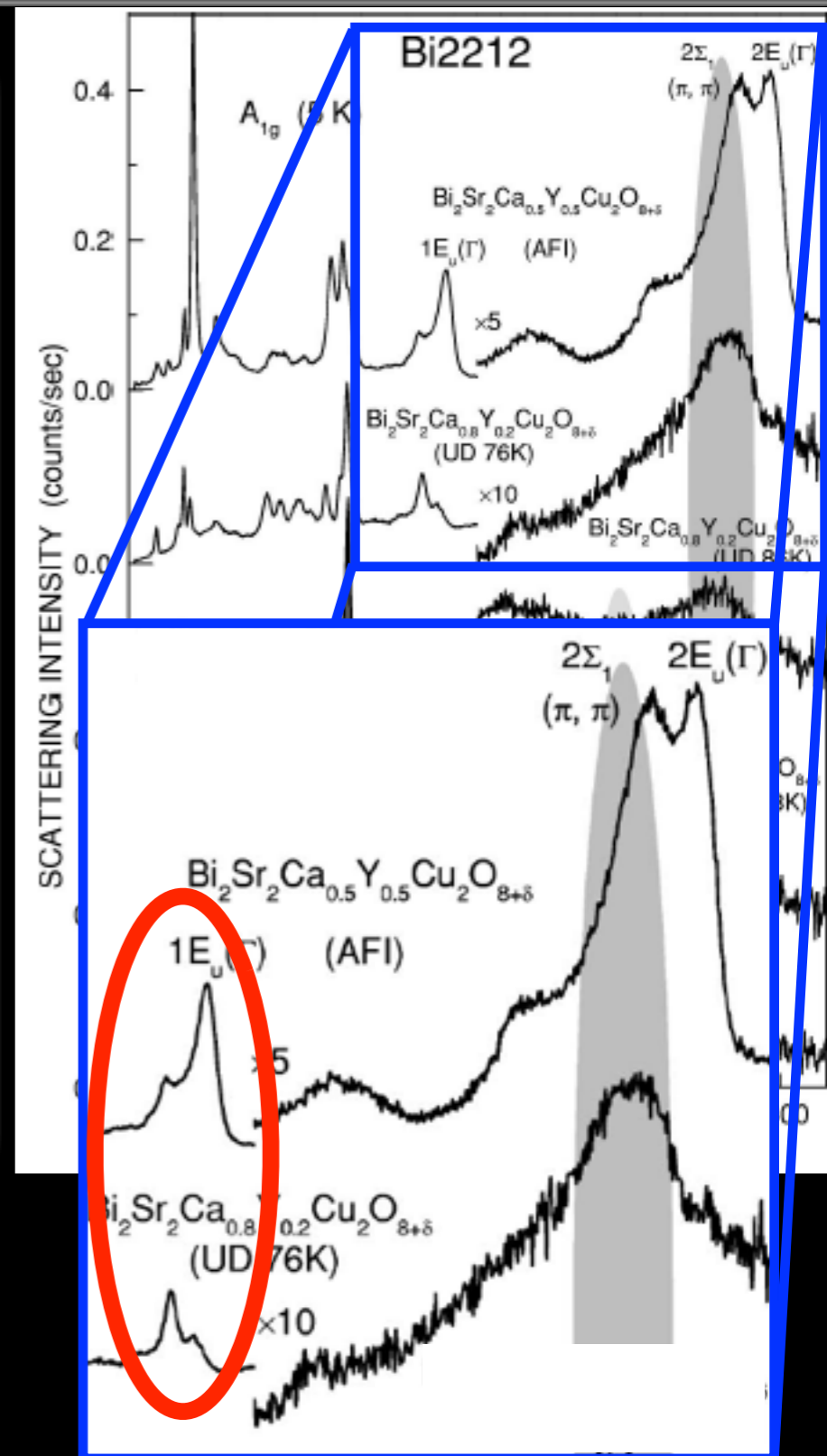
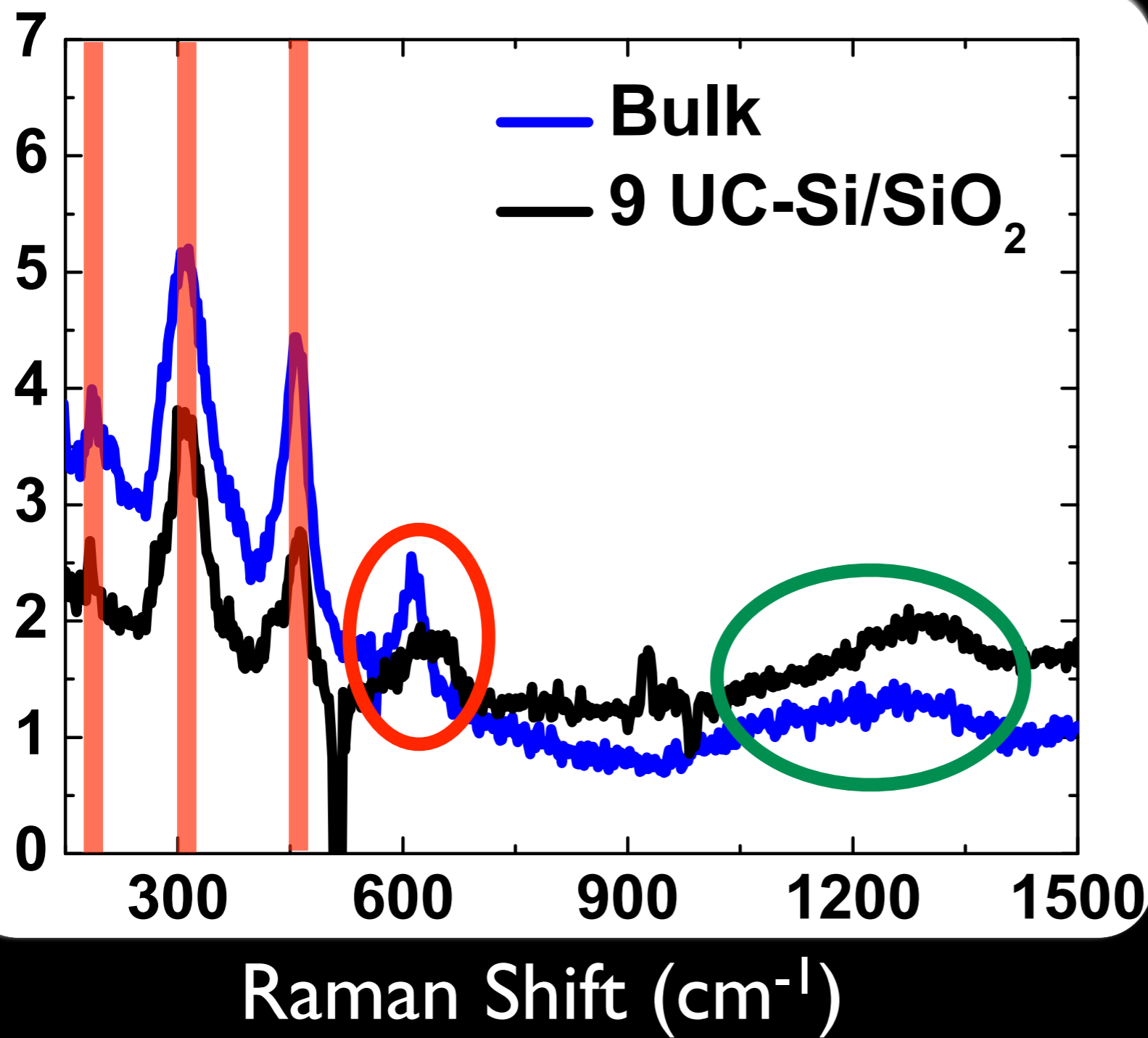
S. Sugai et al., PRB 68, 184504 (2003)

Scattered Intensity



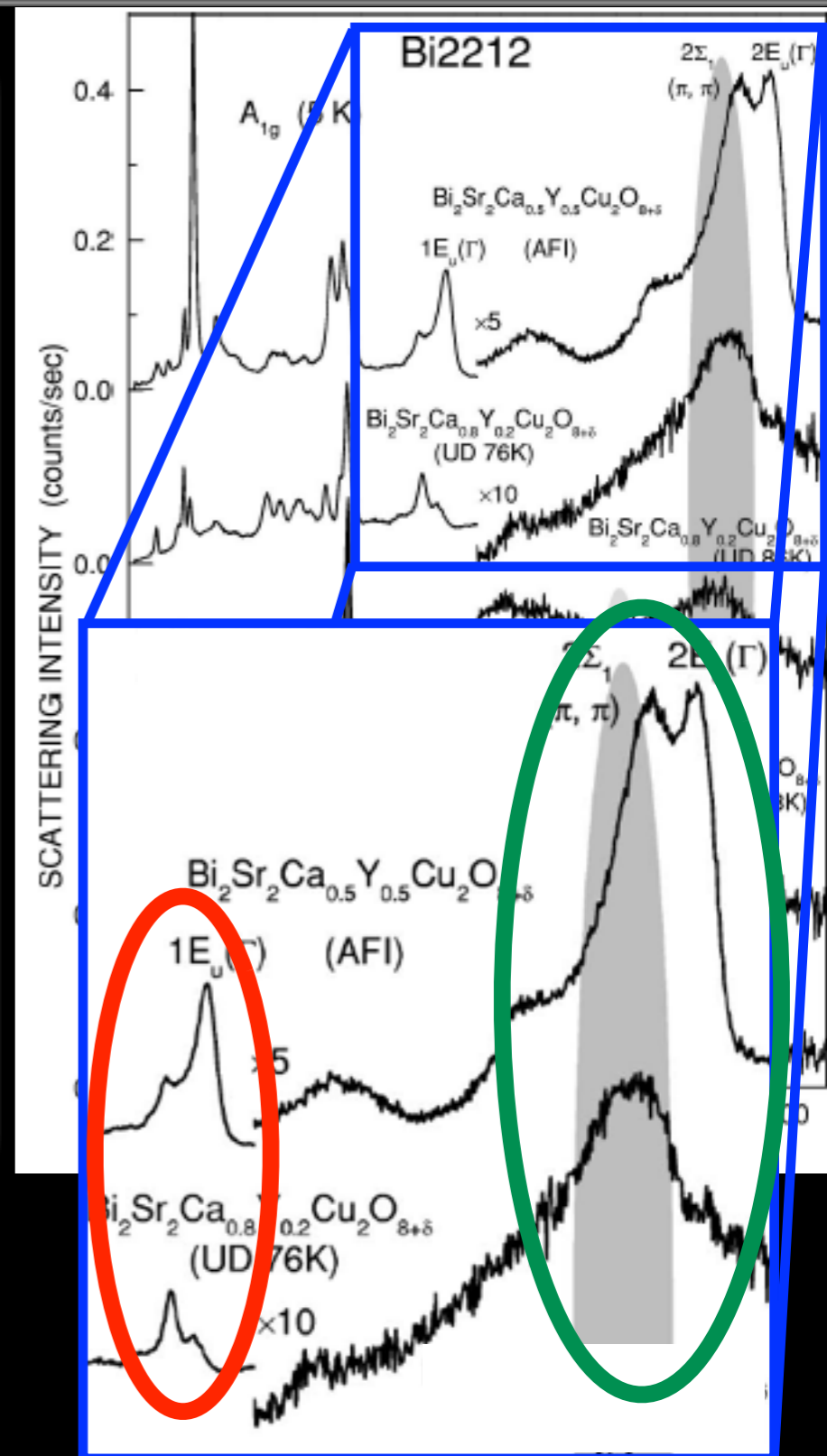
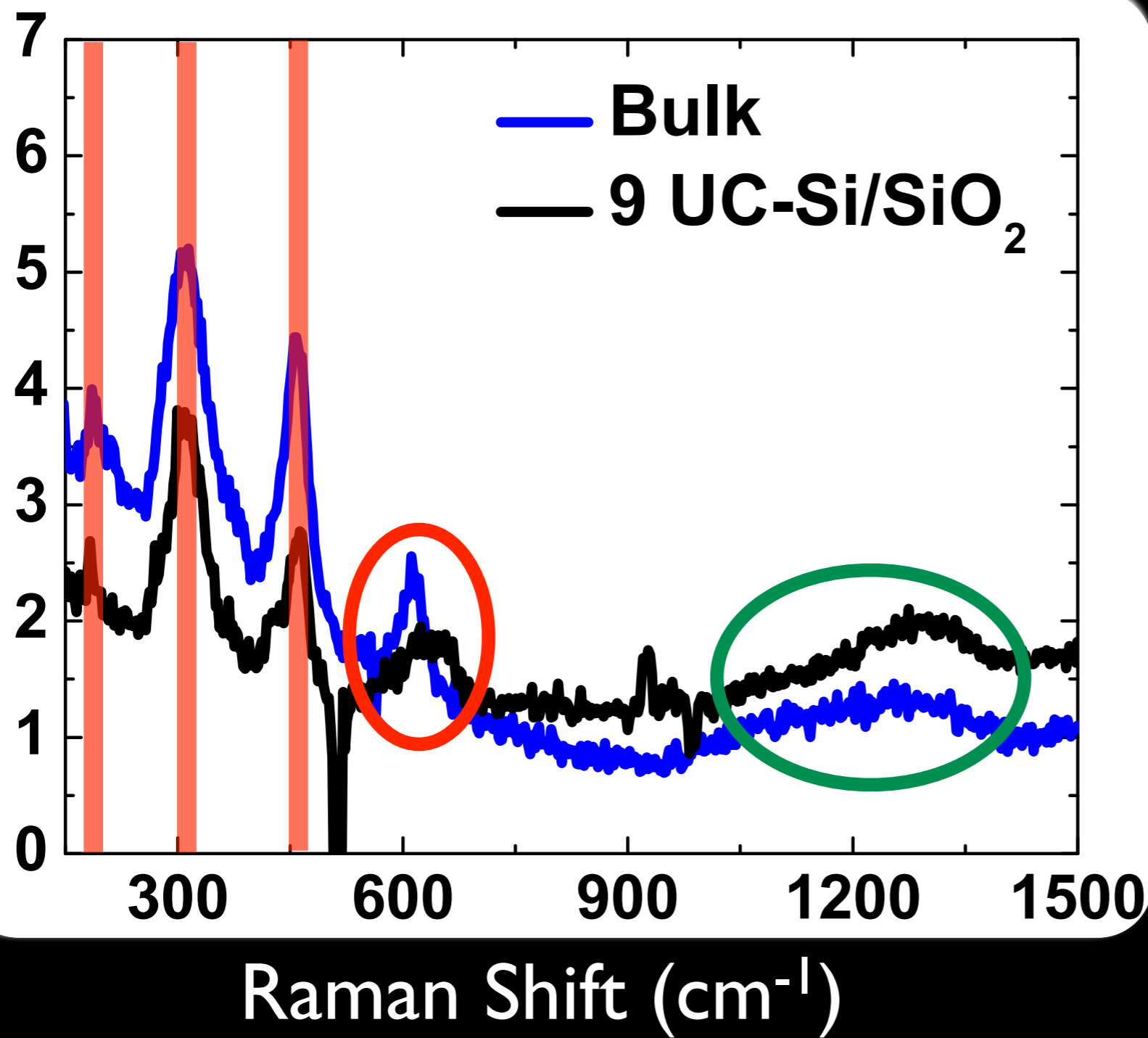
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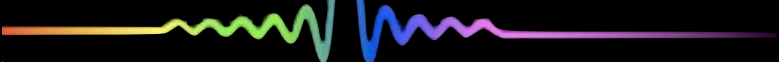
S. Sugai et al., PRB 68, 184504 (2003)



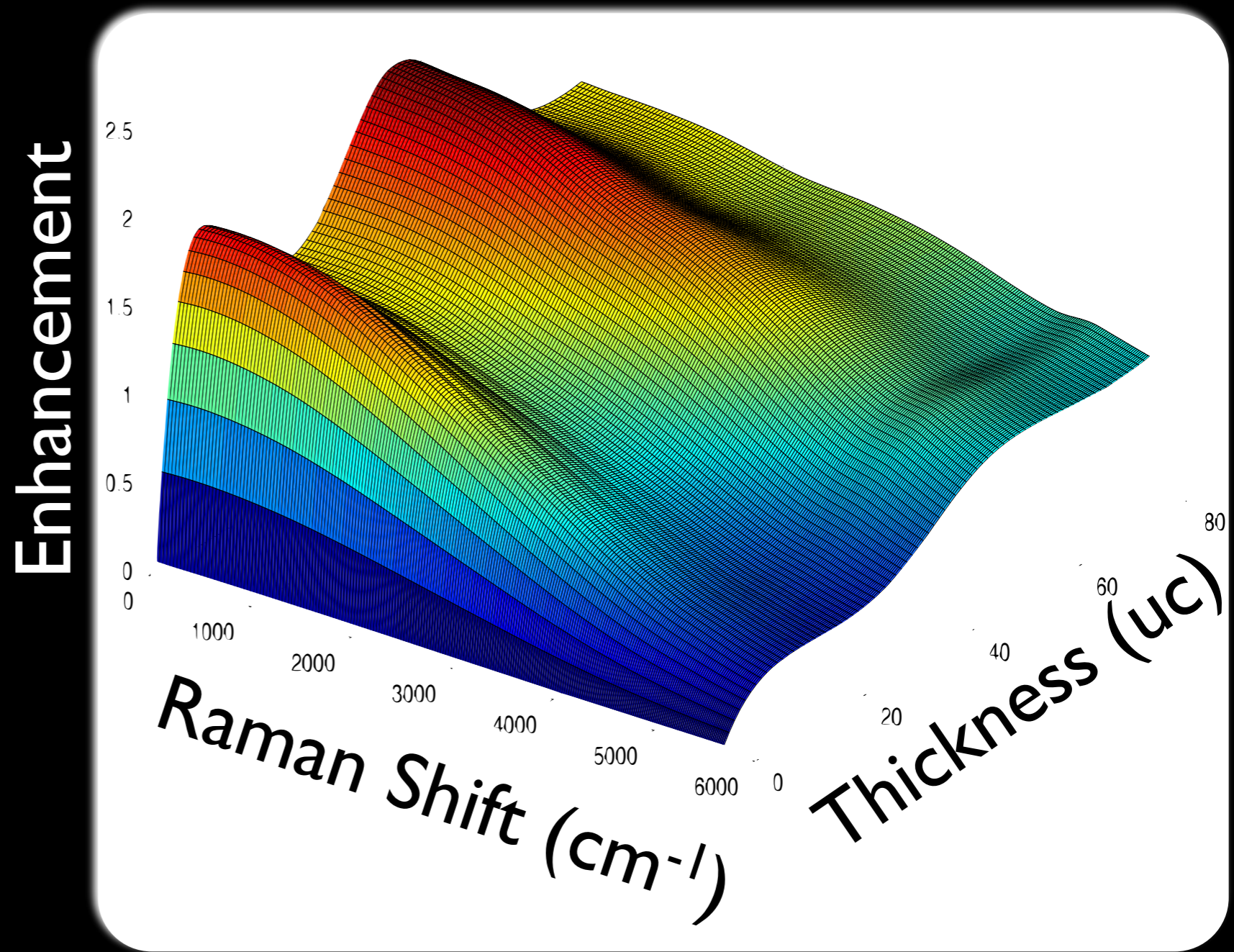
Interference

Interference Correction:

Y.Y. Wang et al., APL 92, 043121 (2008)



Interference



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Y.Y. Wang et al., APL 92, 043121 (2008)



Interference

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