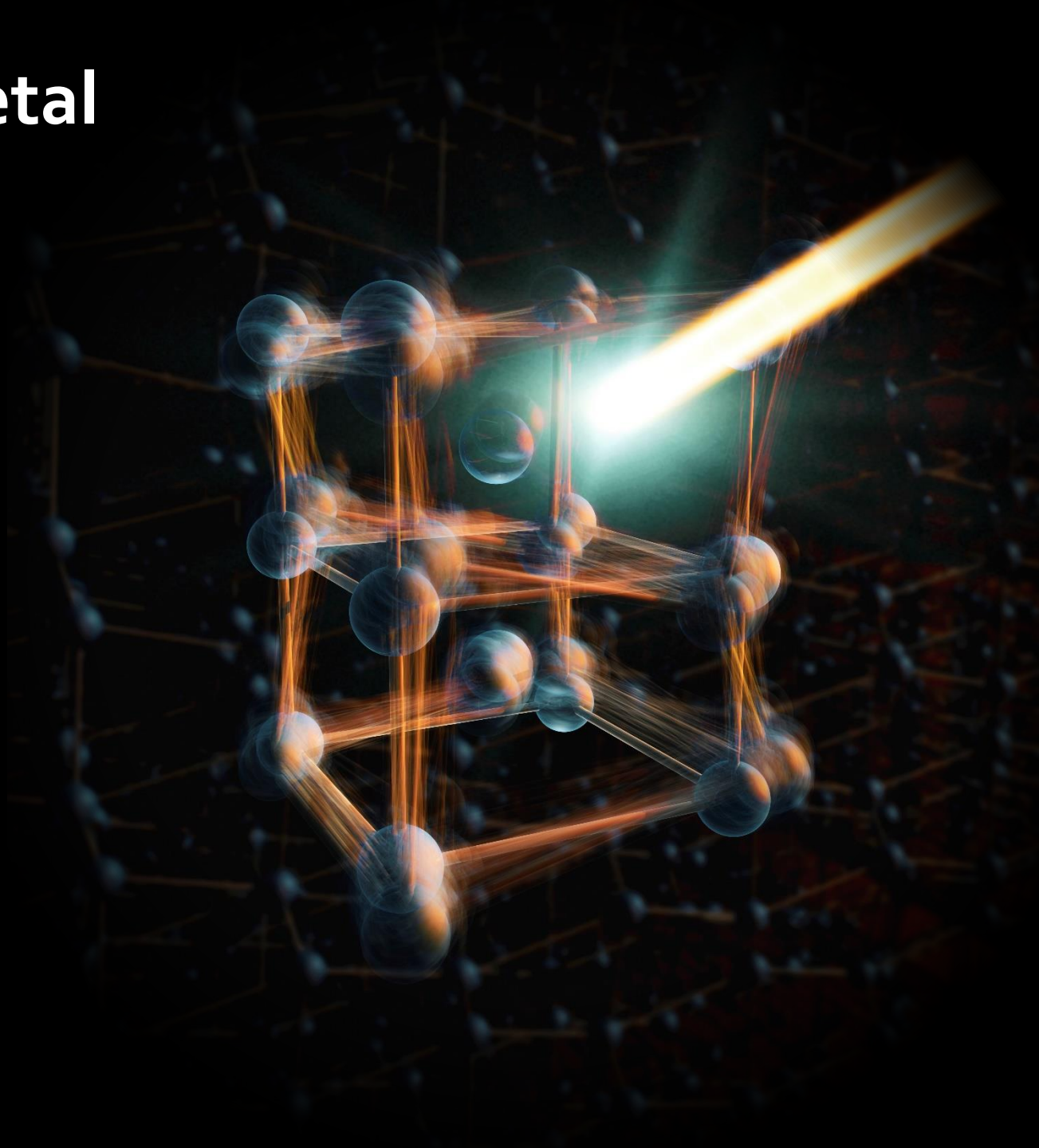
Disorder in the insulator-metal phase transition in VO_2

Simon Wall
ICFO - Barcelona



ICFO

Luciana Vidas
ICFO

Mariano Trigo
PULSE Institute,
Stanford

Olivier Delaire
Duke University
USA

Shan Yang

Inducing new states of matter

nature materials

REVIEW ARTICLE

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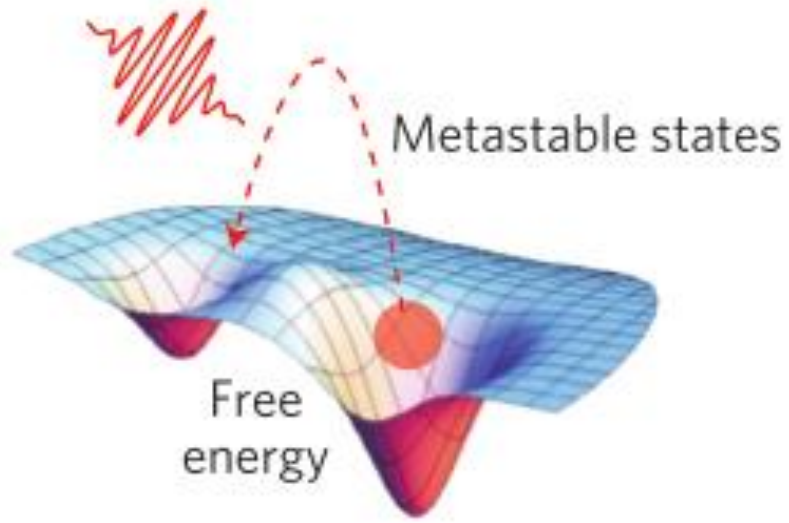
Towards properties on demand in quantum materials

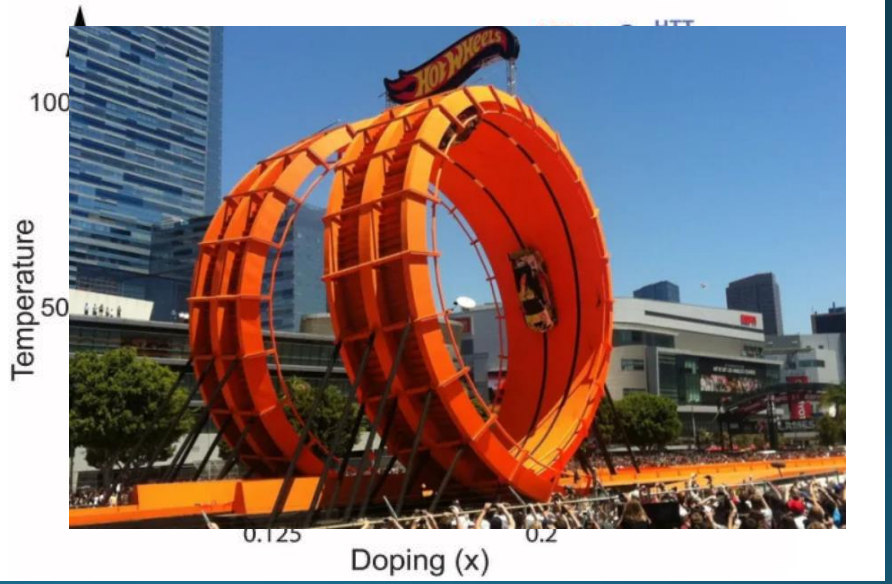
D. N. Basov[1]*, R. D. Averitt[2]* and D. Hsieh[3]*



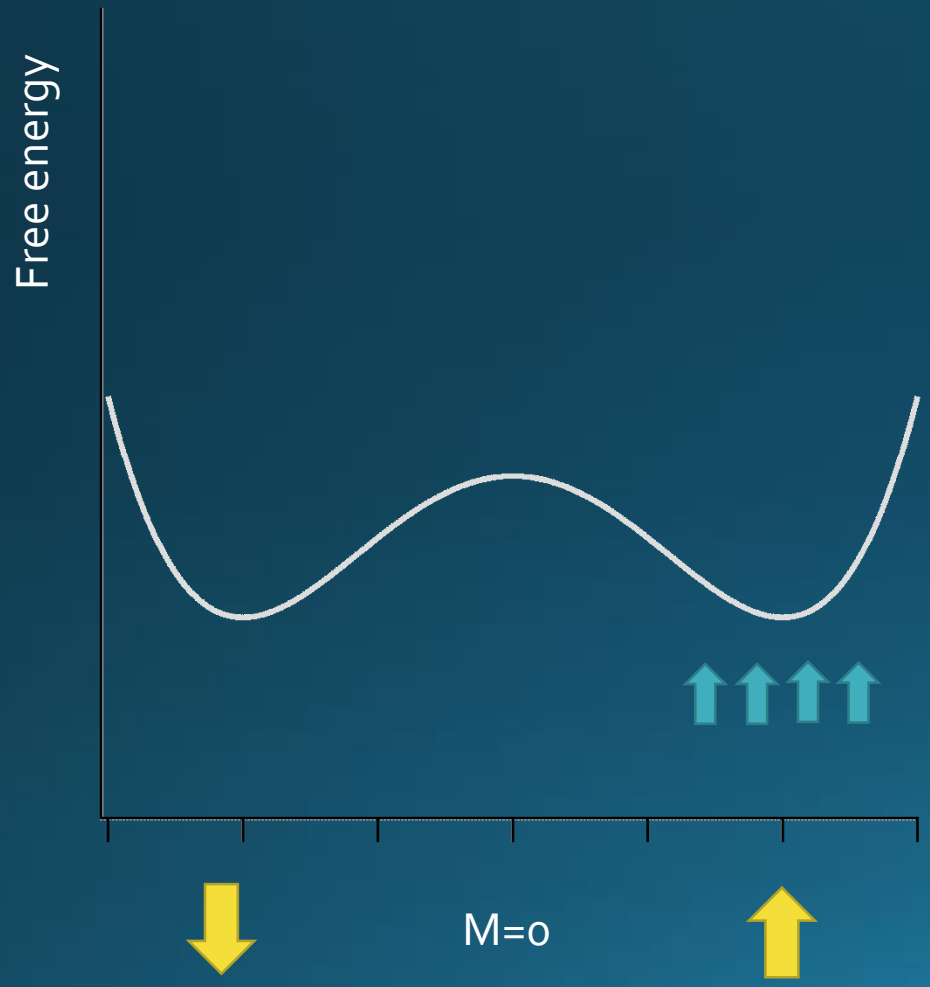
Light-Induced Superconductivity in a Stripe-Ordered Cuprate

D. Fausti,[1,2]*†‡ R. I. Tobey,[2]†§ N. Dean,[1,2] S. Kaiser,[1] A. Dienst,[2] M. C. Hoffmann,[1] S. Pyon,[3] T. Takayama,[3] H. Takagi,[3,4] A. Cavalleri[1,2]*

SCIENCE VOL 331 14 JANUARY 2011



A phase transition with temperature



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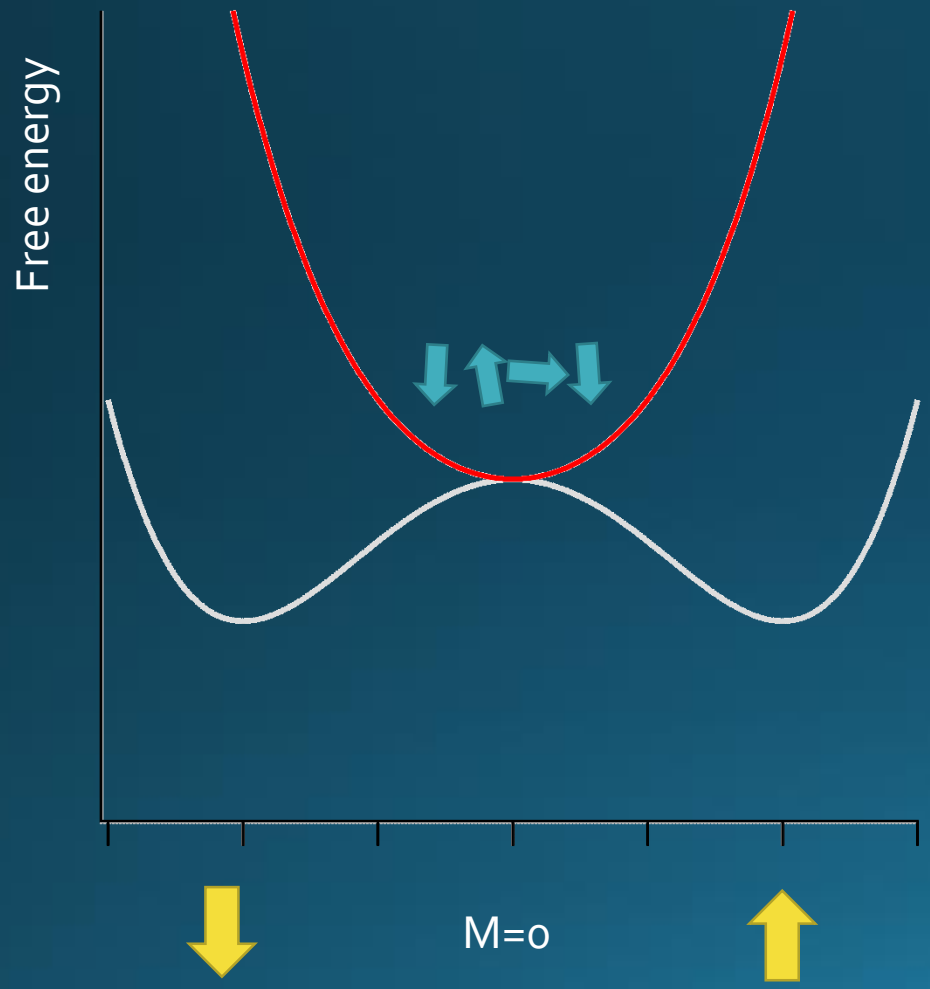

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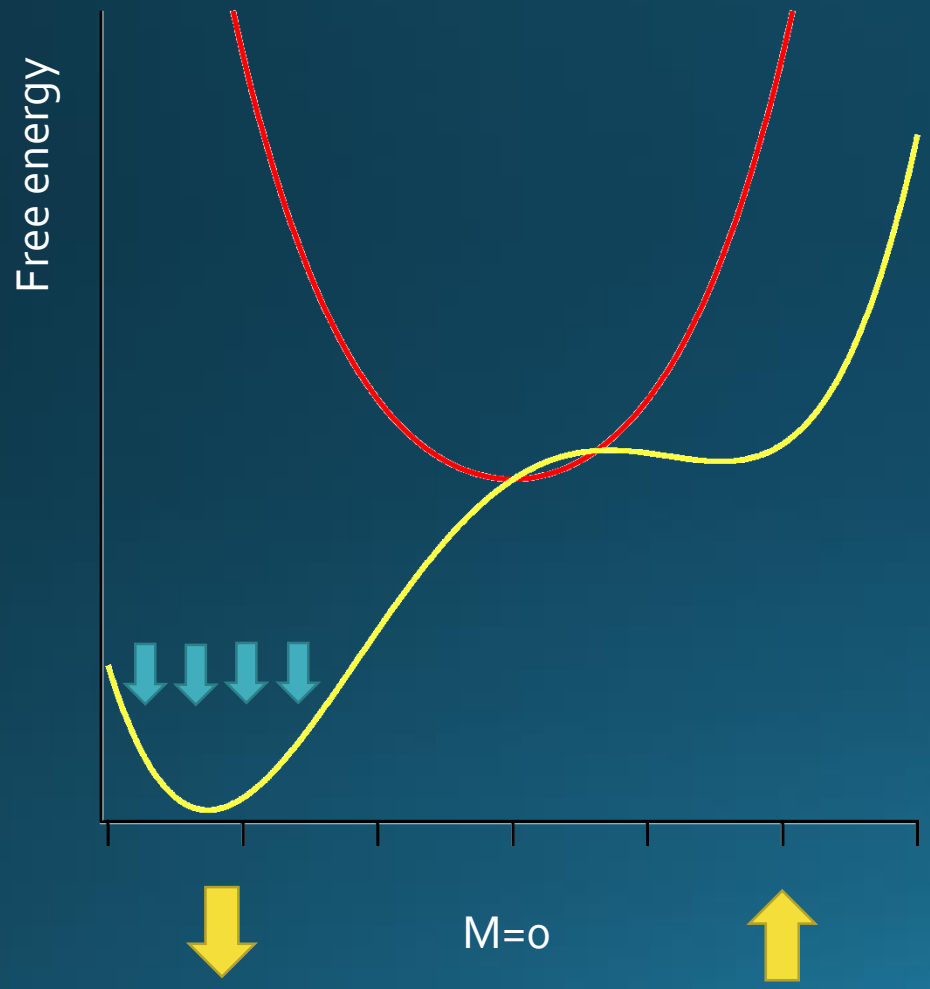
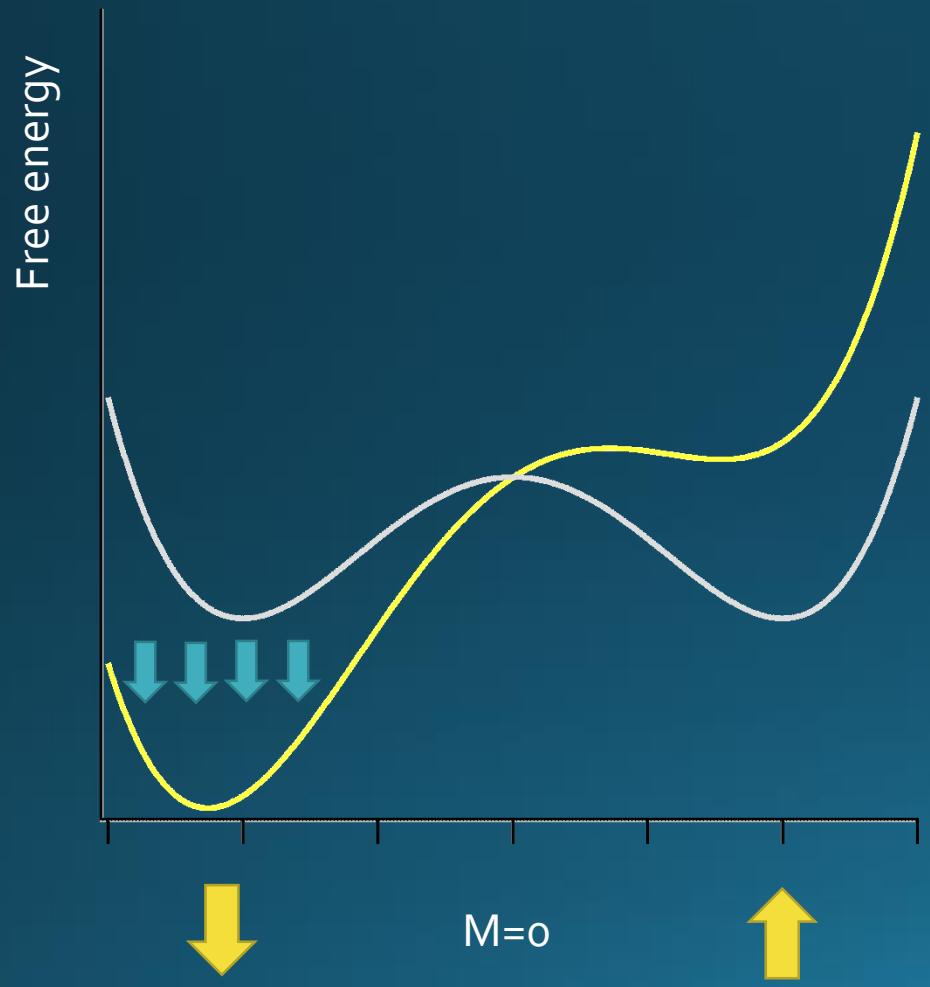
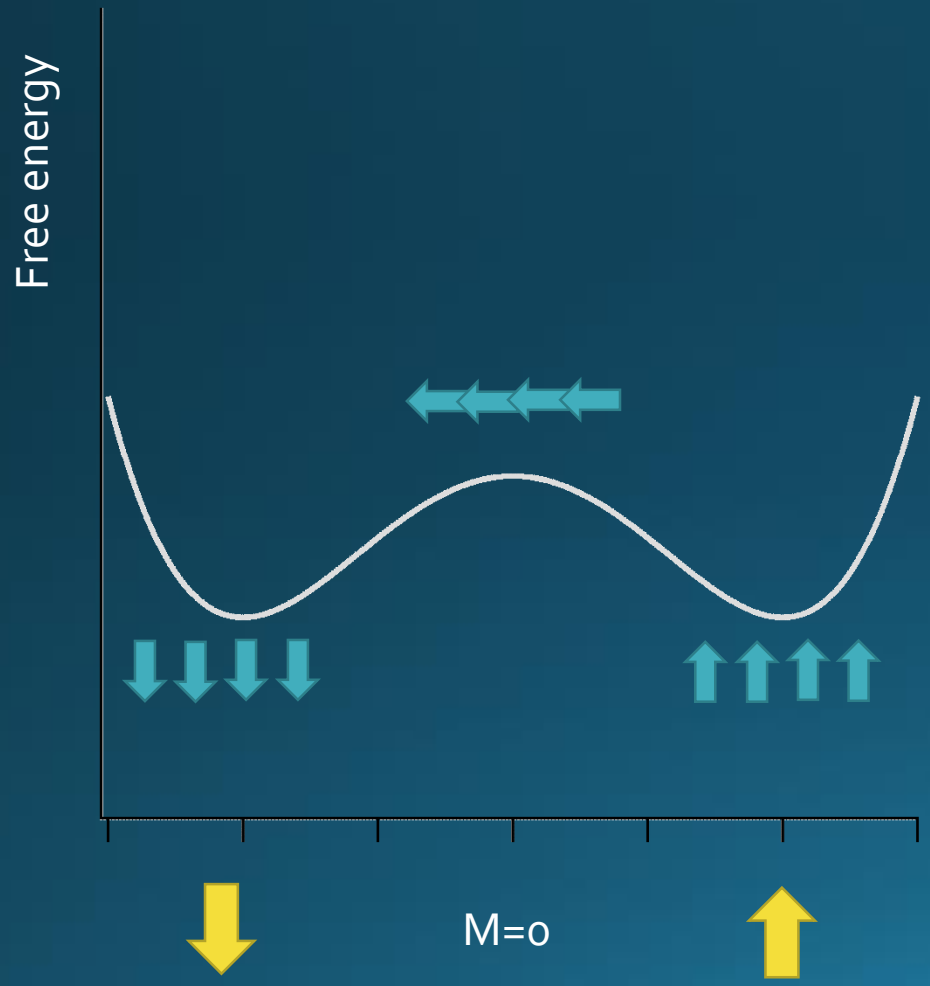
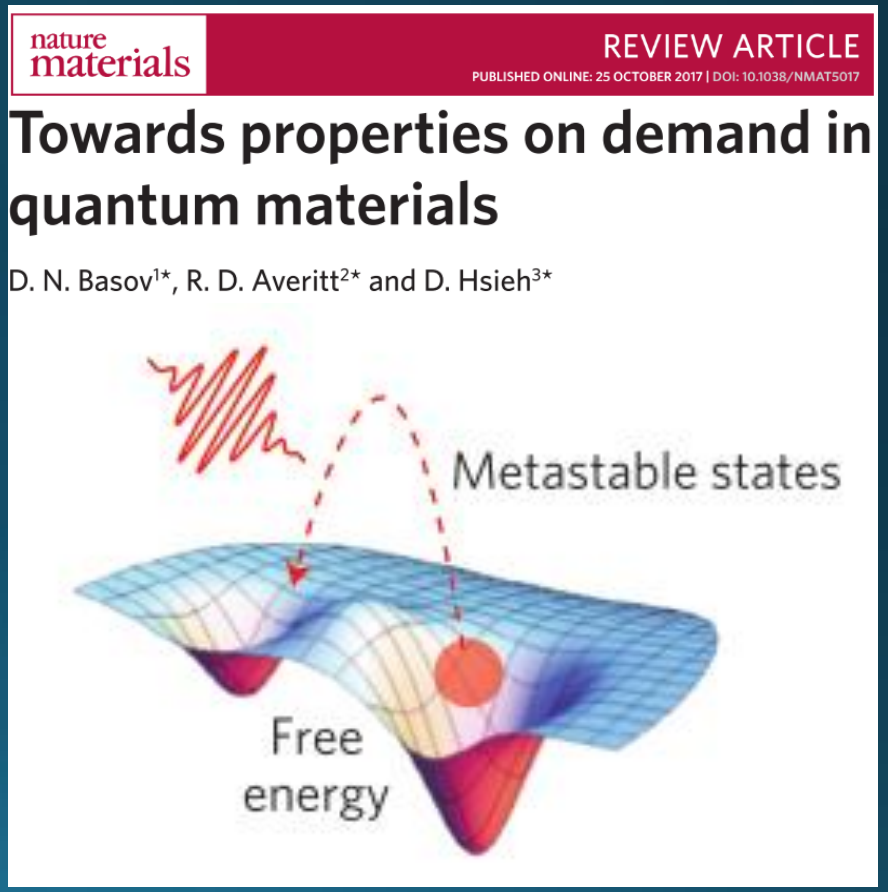


A phase transition with temperature



A phase transition with temperature





Ultrafast phase transitions

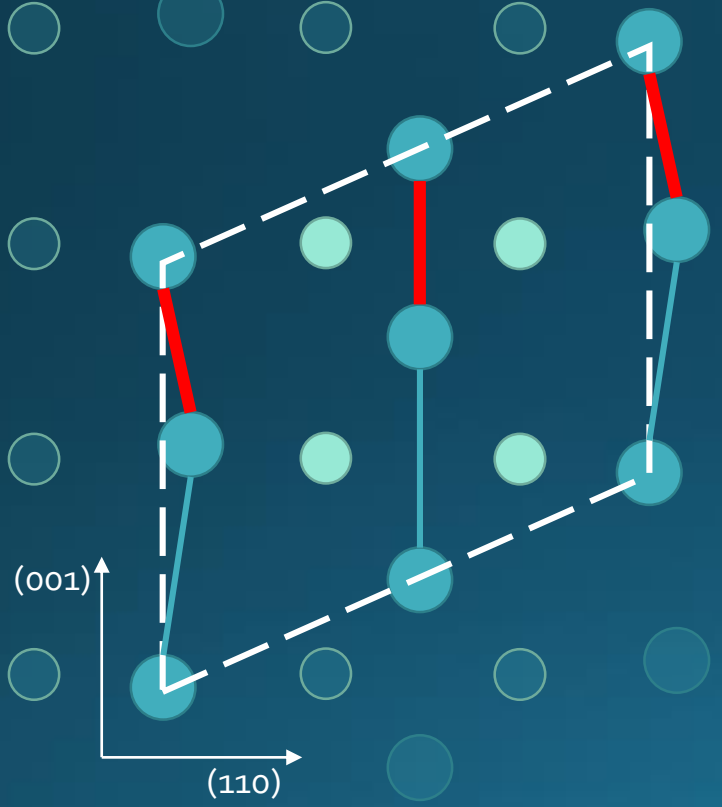
- Are ultrafast phase transition “coherent” or disorder processes?
- How can we distinguish coherent vs disorder-like processes?

Monoclinic Insulating phase $T < 60\ C$

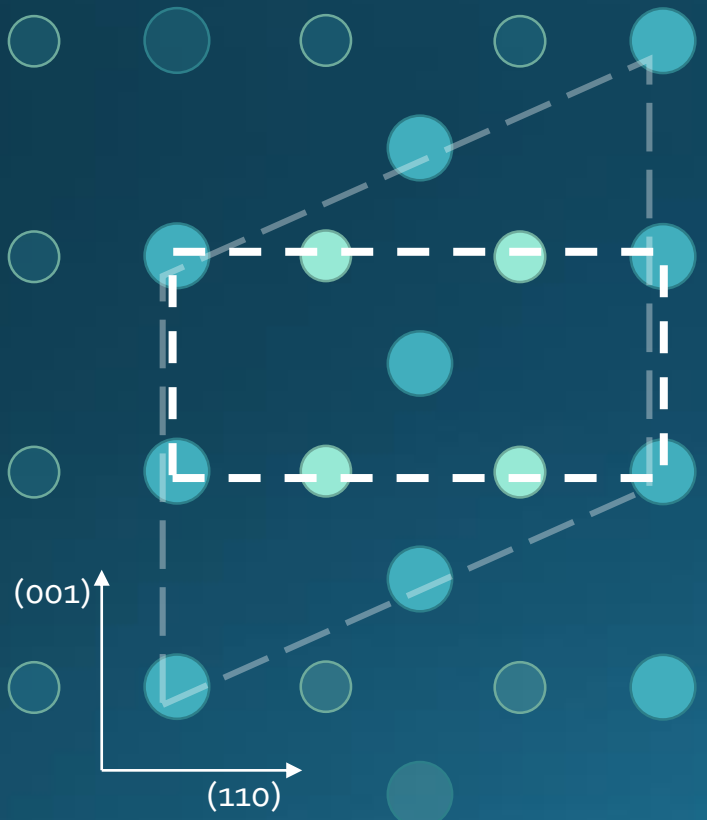
V

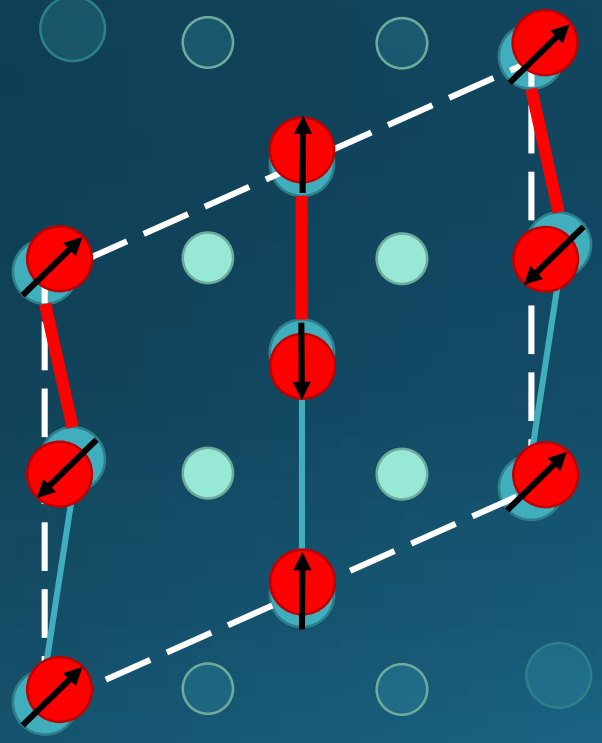
O

Monoclinic Insulating phase $T < 60\ C$

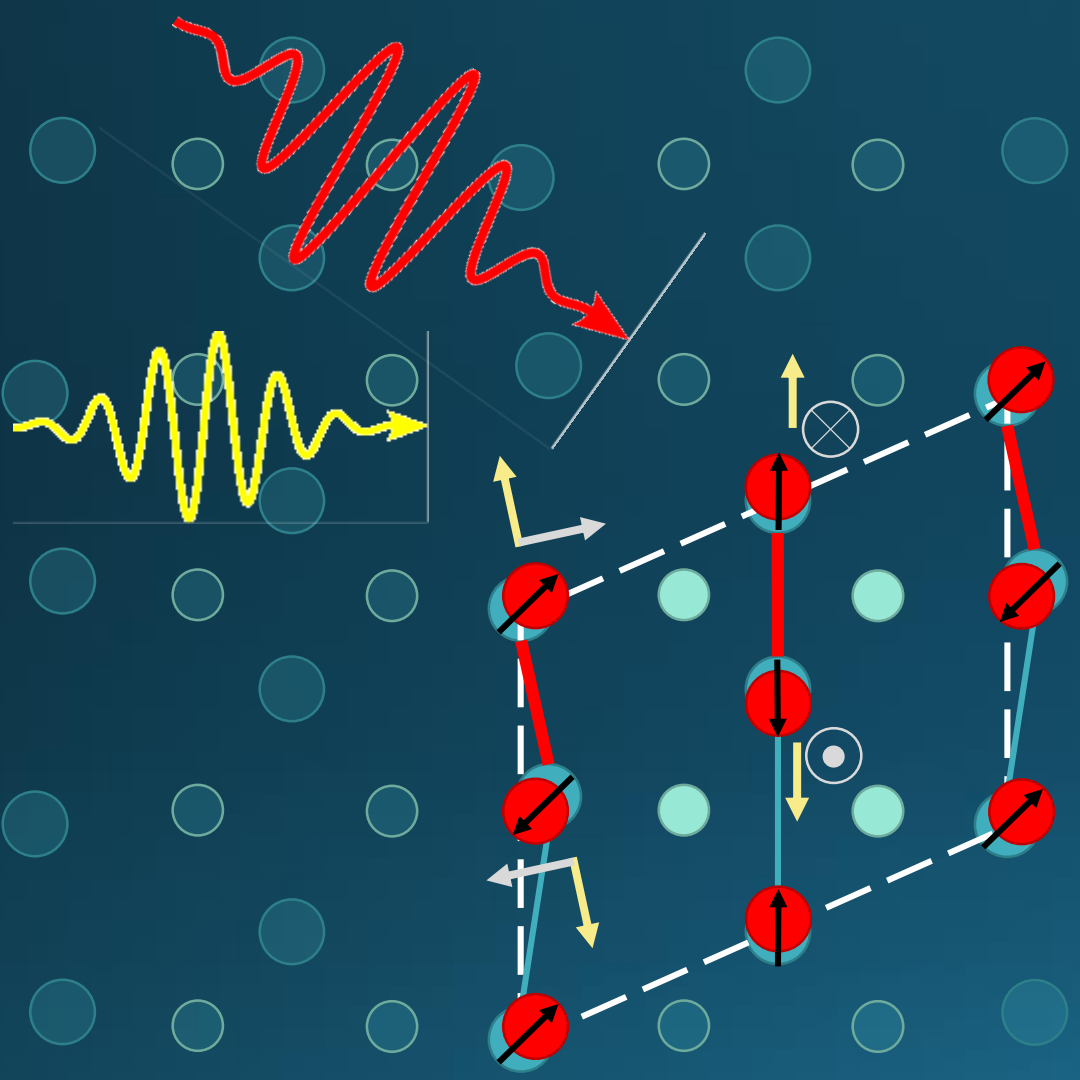


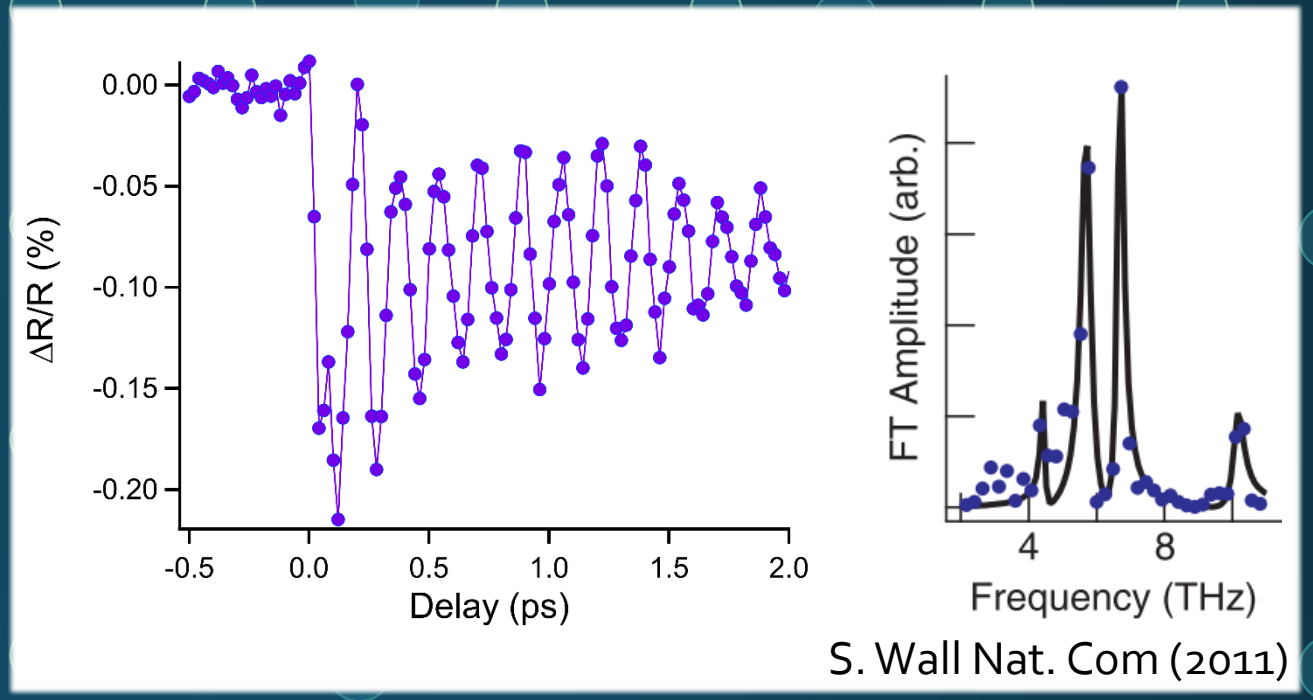
Rutile Metallic phase *T* < 60 C





- There is a displacement that maps the low temperature phase onto the metallic phase
- The displacement is at the Brillouin zone centre





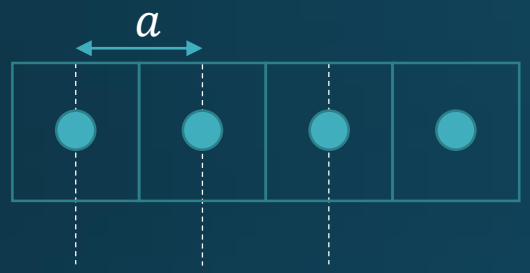
S. Wall Nat. Com (2011)

- The displacement is made up of multiple optical phonons
- These phonons are excited coherently at low laser intensities

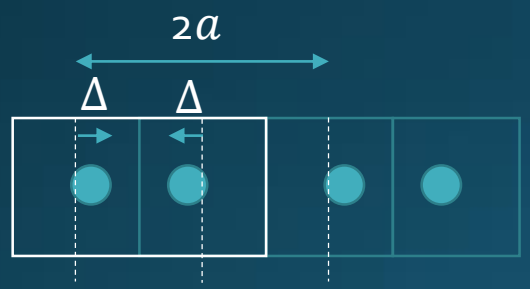
Transition by an optical phonon

How do we measure structure?

High Temperature phase



Low Temperature phase

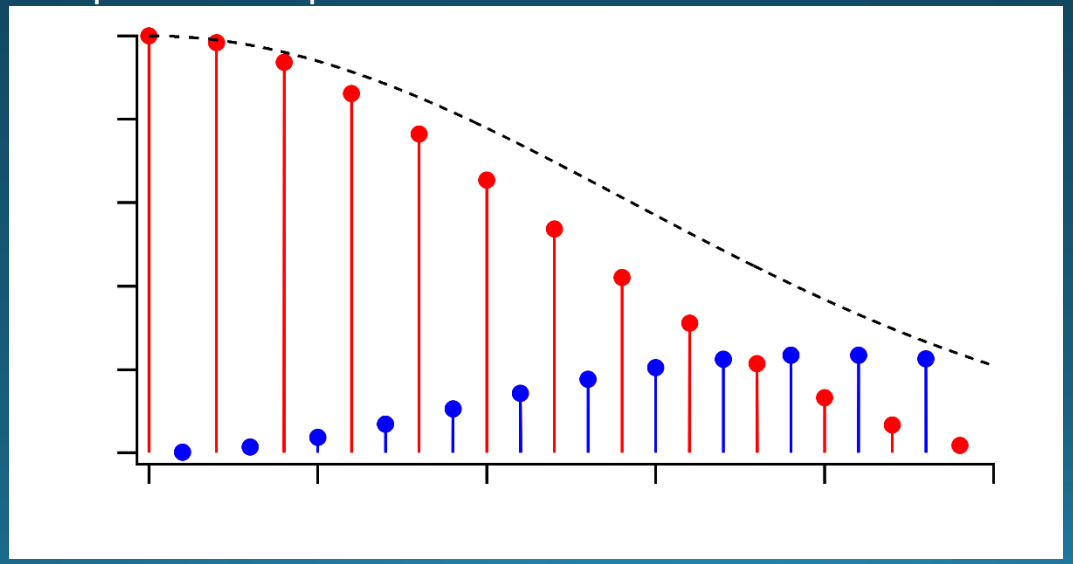


Scattered intensity goes as

$$I_e = |F_e|^2 \propto \cos^2\left(\frac{\pi\Delta l}{2a}\right) \propto 1 + \cos\left(\frac{\pi\Delta l}{a}\right) \approx 2 - \left(\frac{\pi\Delta l}{a}\right)^2$$

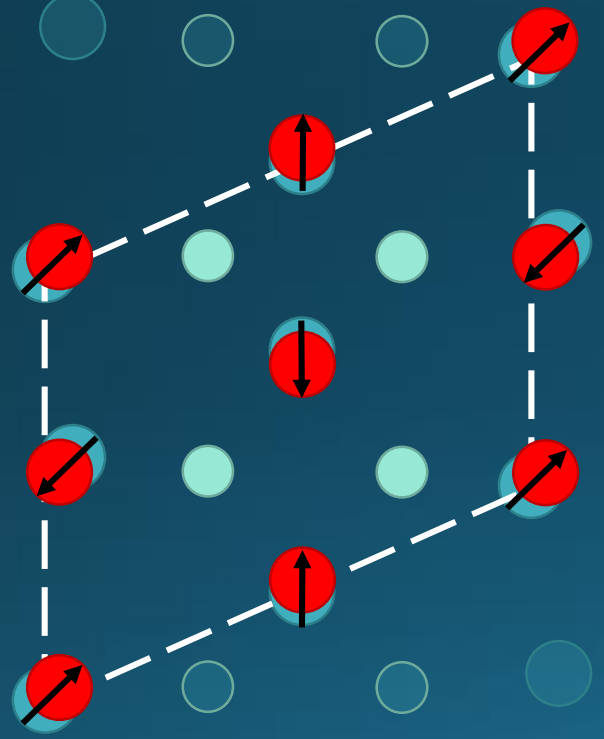
$$I_{odd} = |F_e|^2 \propto \sin^2\left(\frac{\pi\Delta l}{2a}\right) \propto 1 - \cos\left(\frac{\pi\Delta l}{a}\right) \approx \left(\frac{\pi\Delta l}{a}\right)^2$$

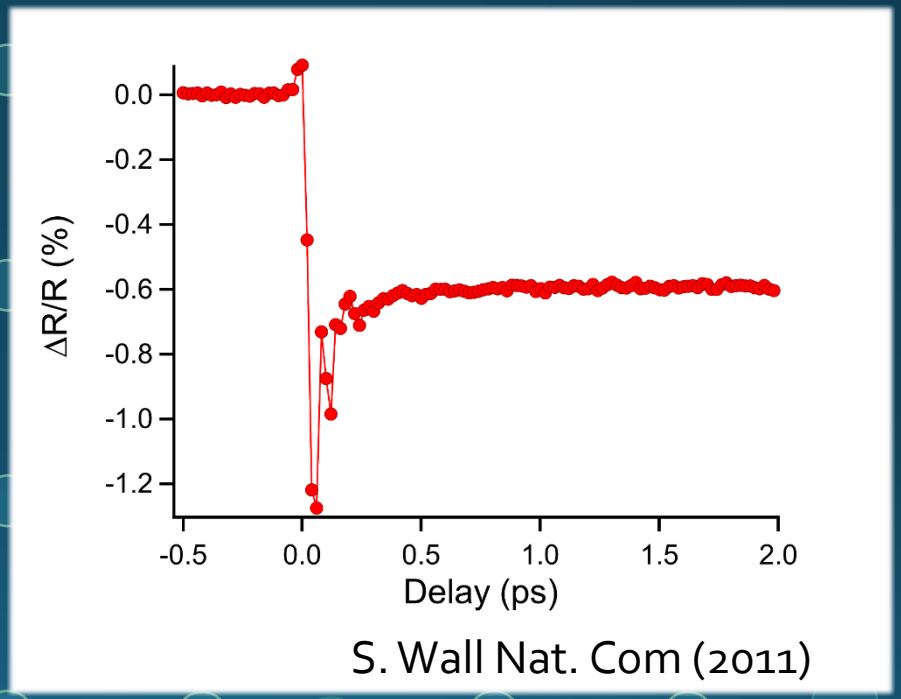
"odd" peaks decrease as Δ^2
"even" super-lattice peaks increase as Δ^2



What if the transition doesn’t follow the optical phonon?

Above the phase transition threshold optical phonon dynamics are lost





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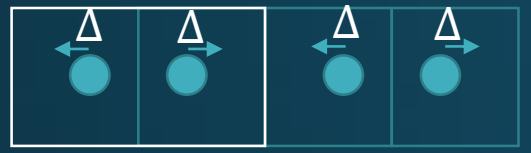
The Nature of the Phase Transition

Low temperature phase (T=o)

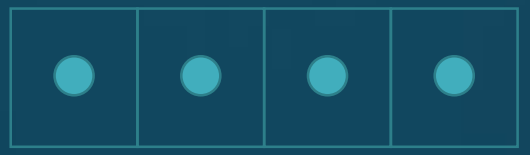


$$< Q > = \Delta$$
$$< Q^2 > = \Delta^2$$
$$\sigma = 0$$

$\Delta_{q=0}$

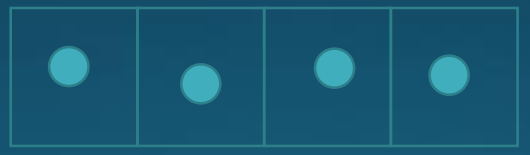
$\sum_q \Delta_q$

$\Delta = 0$ state

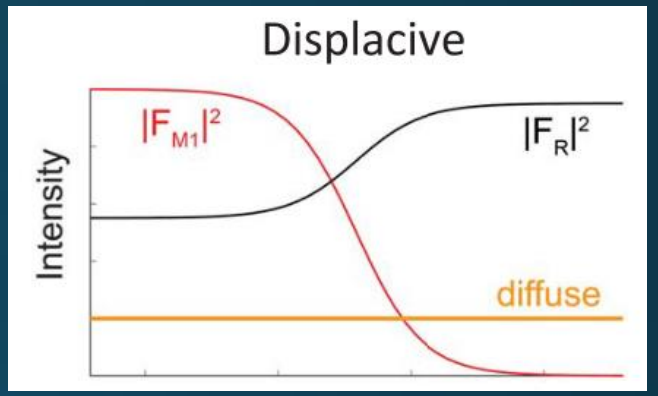


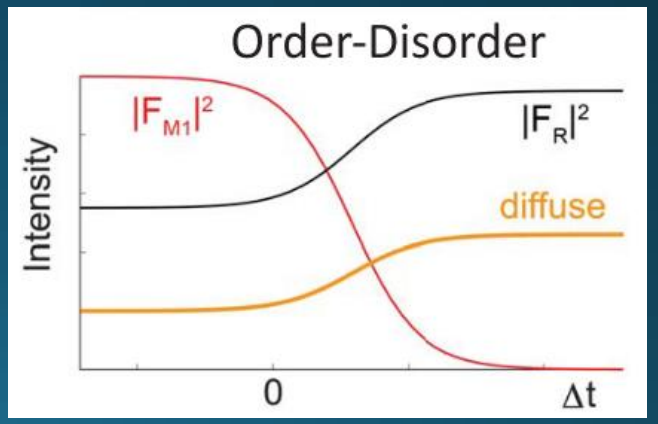
$$< Q > = 0$$
$$< Q^2 > = 0$$
$$\sigma = 0$$

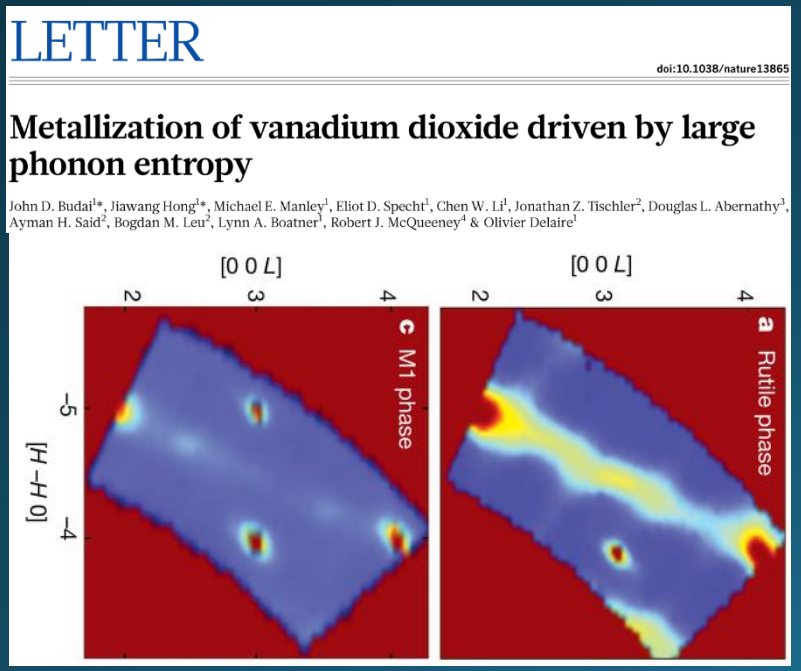
High temperature phase



$$< Q > = 0$$
$$< Q^2 > \neq 0$$
$$\sigma \neq 0$$







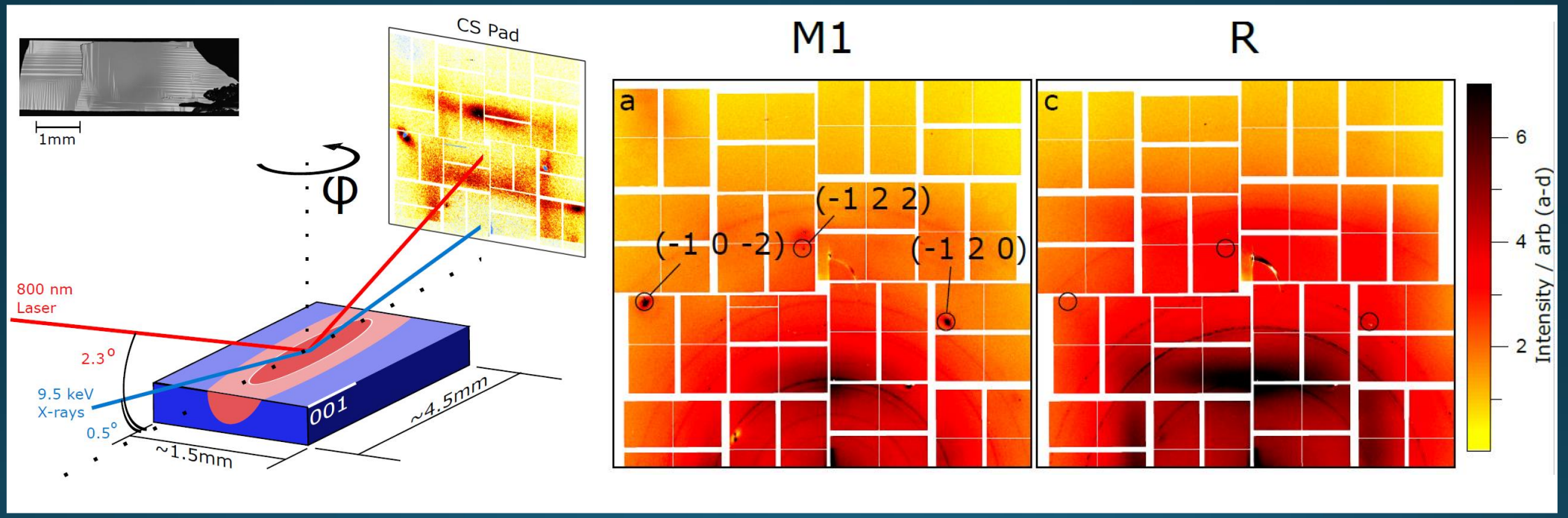
LETTER

doi:10.1038/nature13865

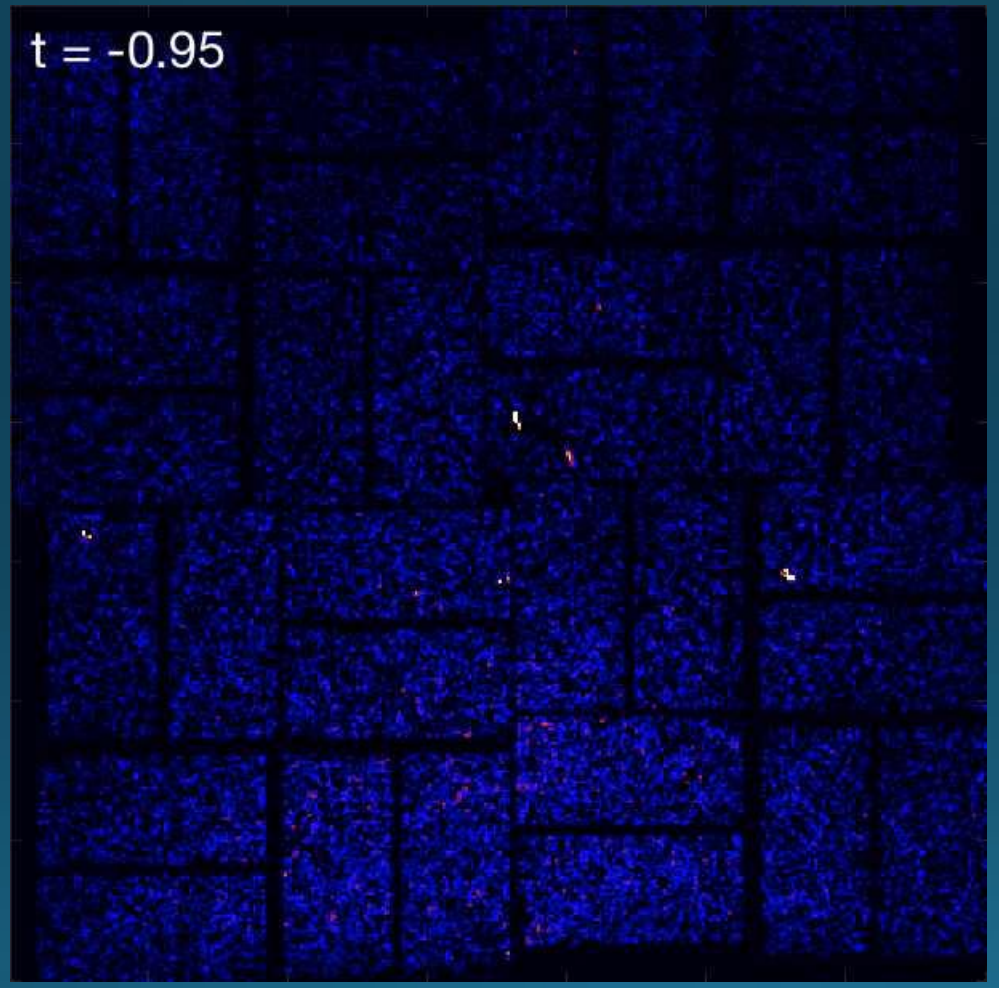
Metallization of vanadium dioxide driven by large phonon entropy

John D. Budai[1]*, Jiawang Hong[1]*, Michael E. Manley[1], Eliot D. Specht[1], Chen W. Li[1], Jonathan Z. Tischler[2], Douglas L. Abernathy[3], Ayman H. Said[2], Bogdan M. Leu[2], Lynn A. Boatner[1], Robert J. McQueeney[4] & Olivier Delaire[1]

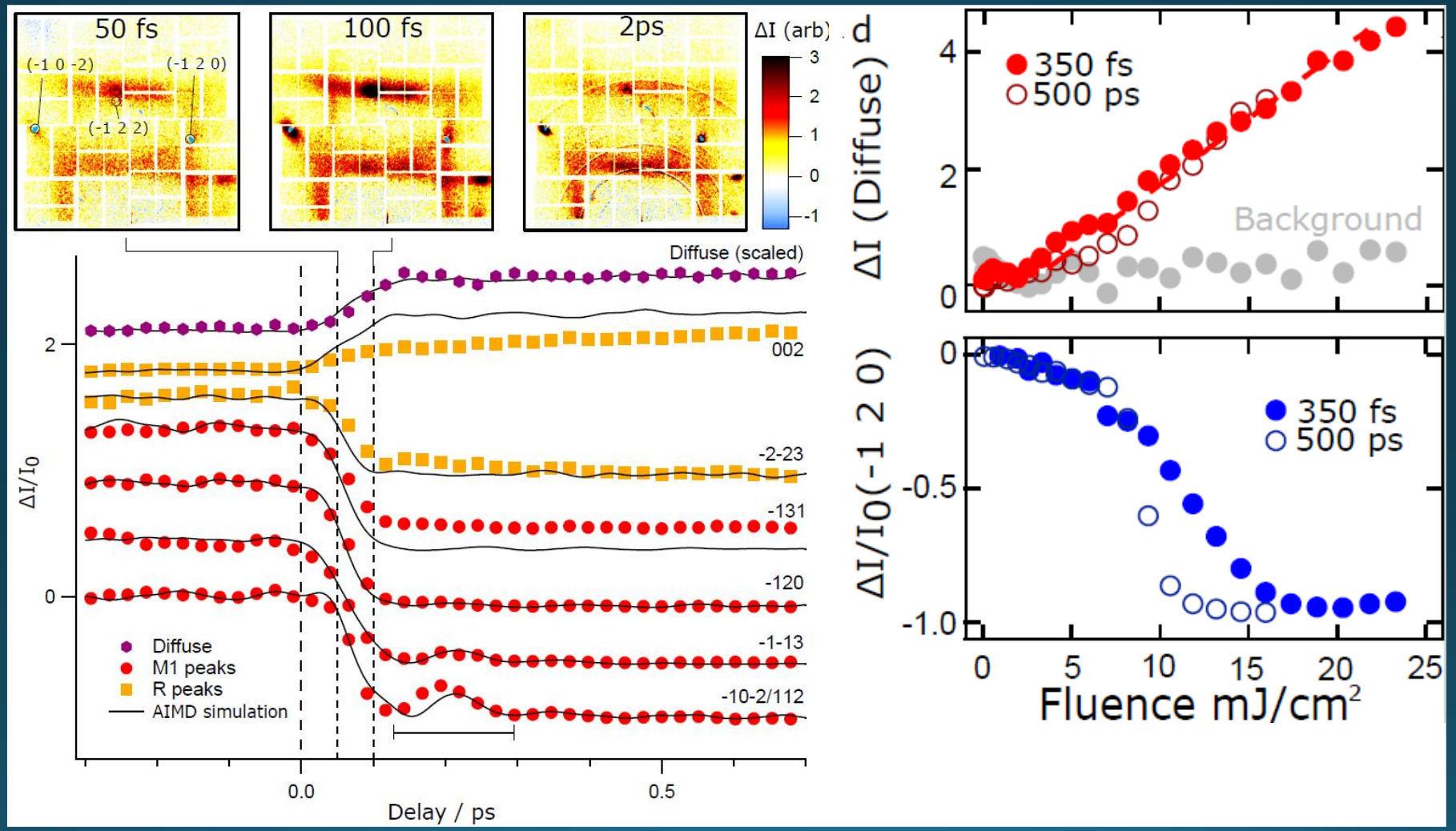
Total scattering of VO_2



S. Wall *et al. Science* (2018)

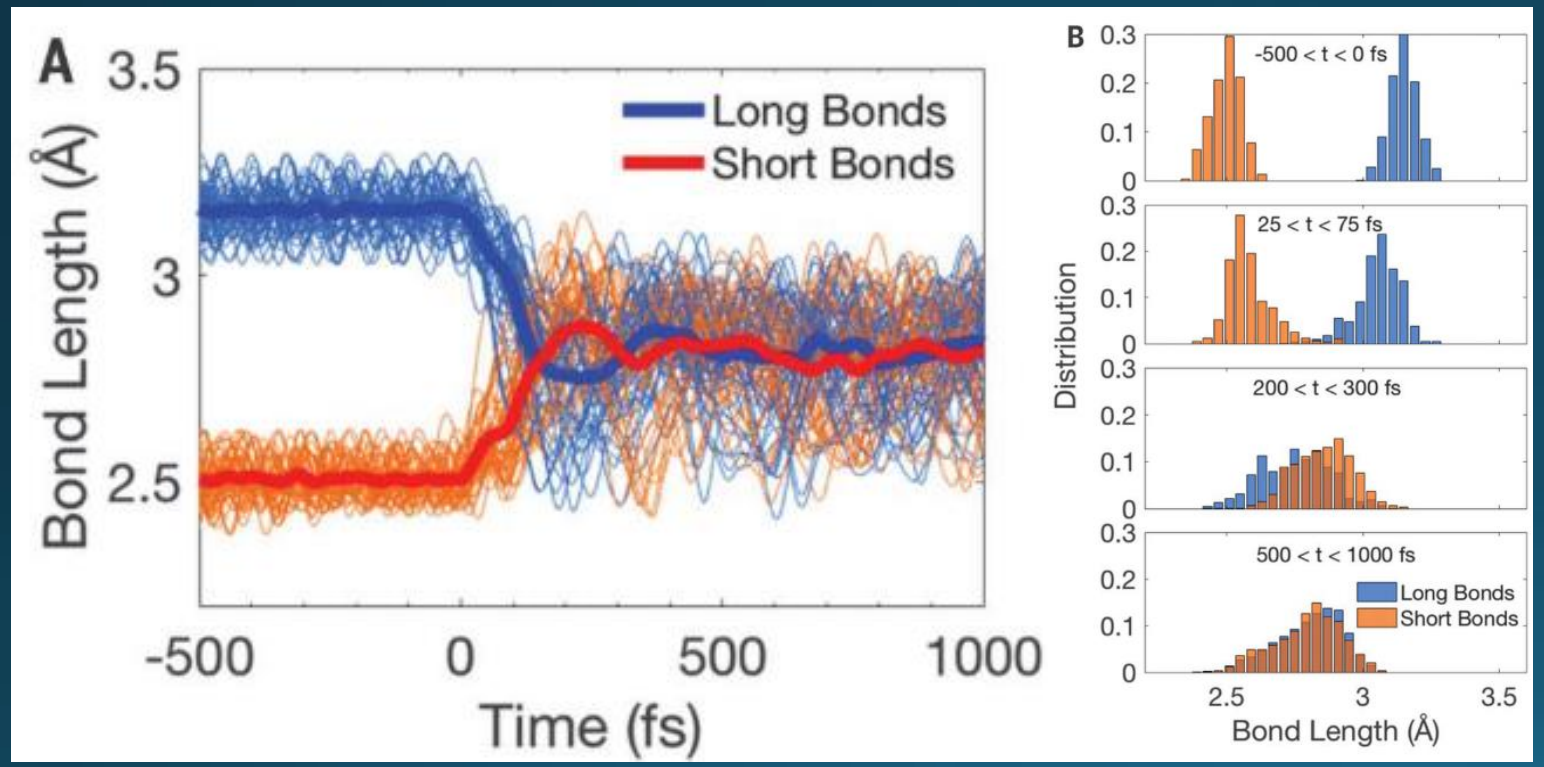


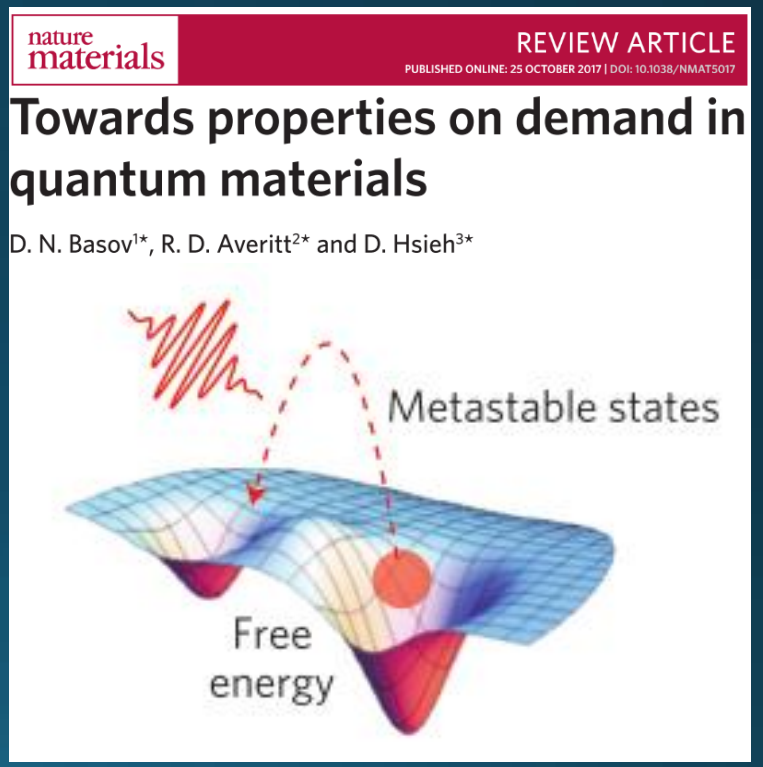
S. Wall *et al. Science* (2018)



S. Wall *et al. Science* (2018)

Dynamics of the phase transition





VO_2 is a disorder transition even on the ultrafast timescale!

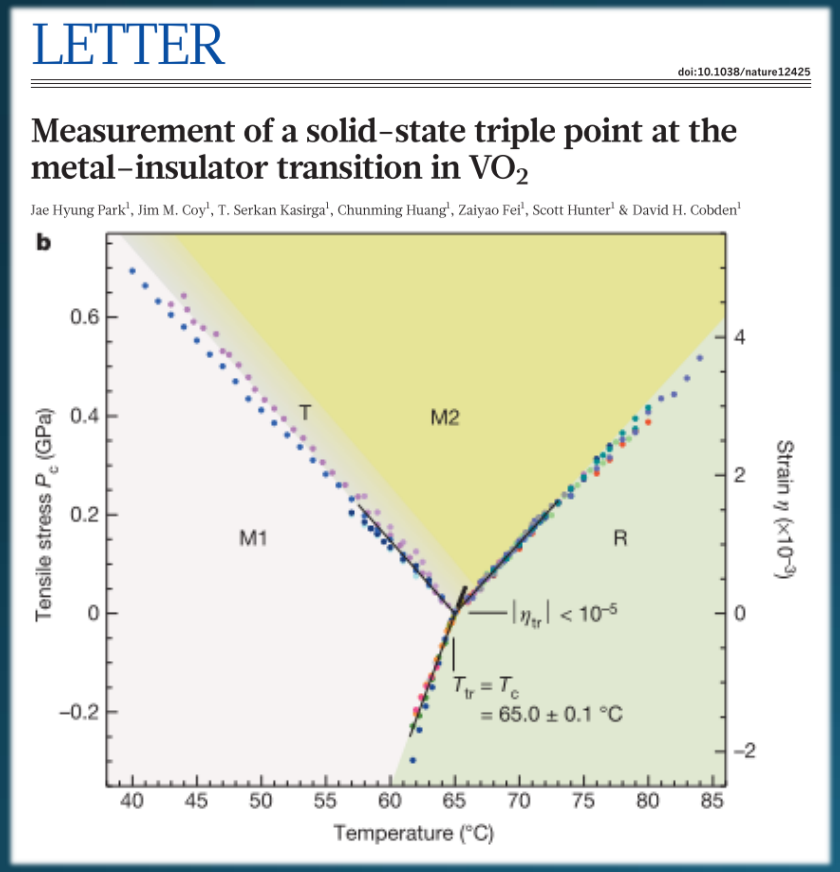
Summary and Outlook

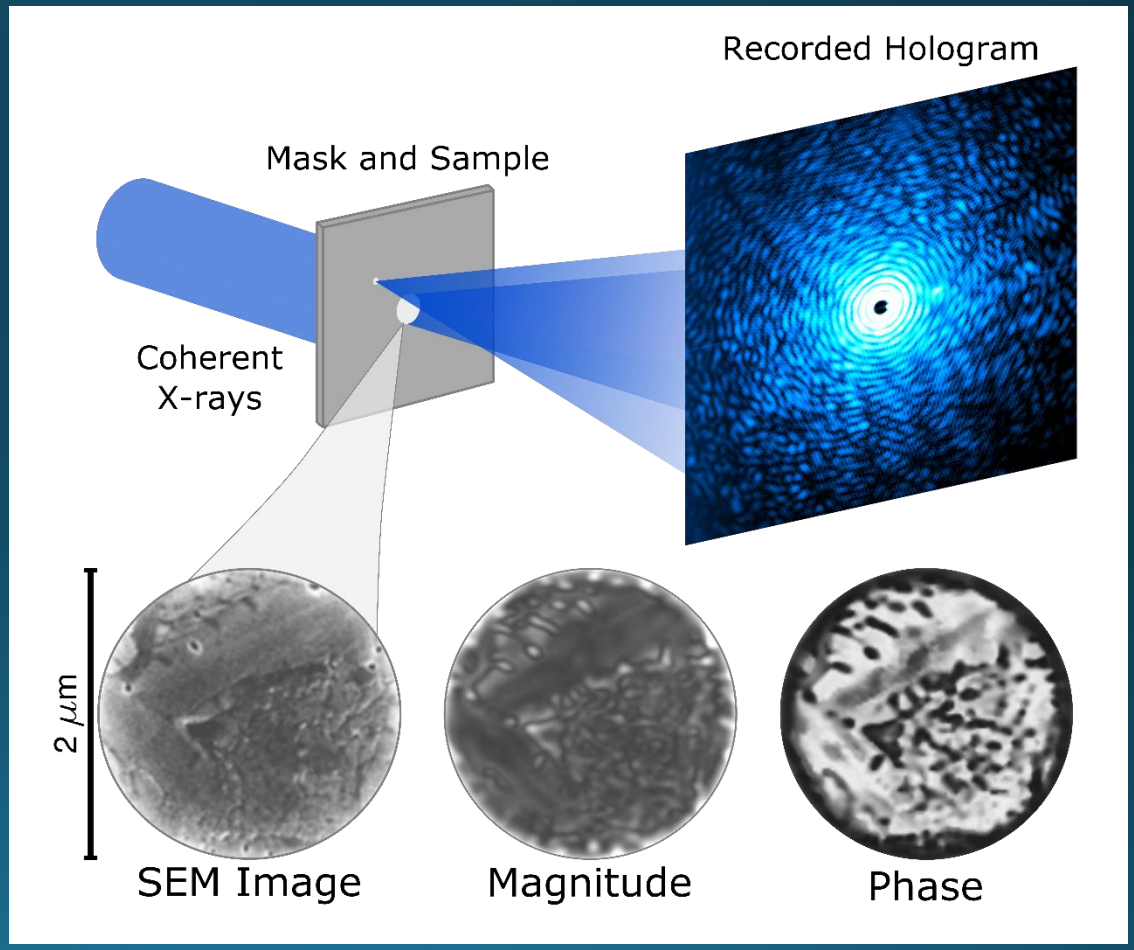
- A range of techniques are required to understand the properties of quantum materials – and these are being developed all the time
- Intrinsic "disorder" dominates the phase transition pathway in VO_2 and explains why the transition is not reversible on the ultrafast timescale
- Disorder originates from either initial thermal distribution or electron-phonon scattering on sub 100 fs timescale

Next Steps

- How typical is VO_2 ?
- Do spin systems behave differently?
- What properties should a system have in order for us to be able to control it with light?
- Can we exploit disorder/inhomogeneity to generate new properties?

Holographic imaging





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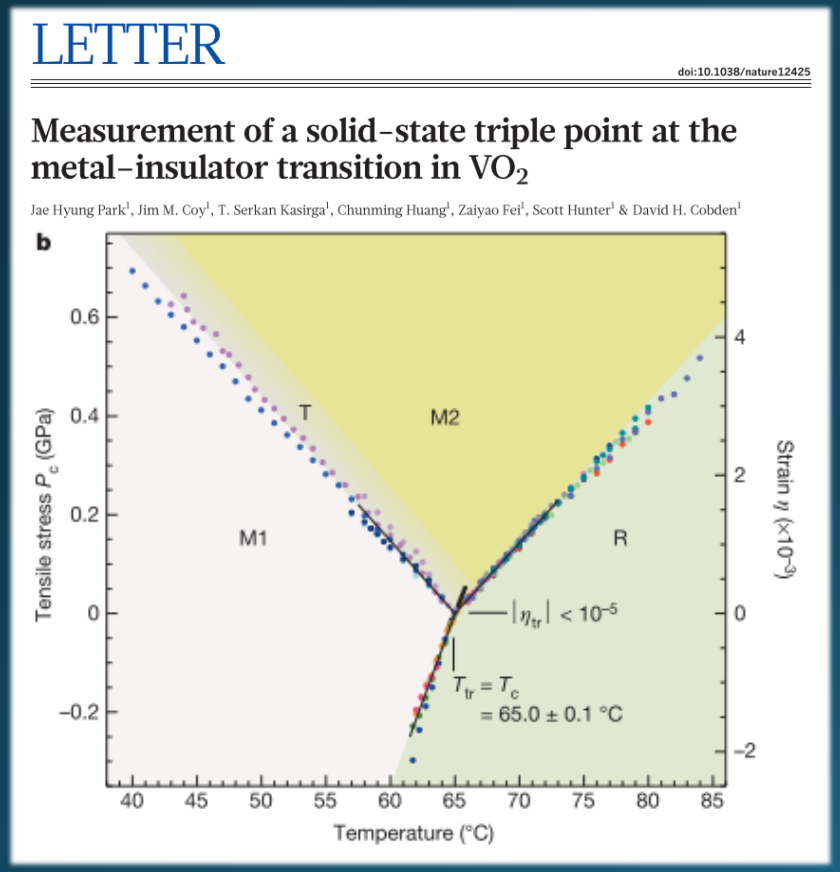
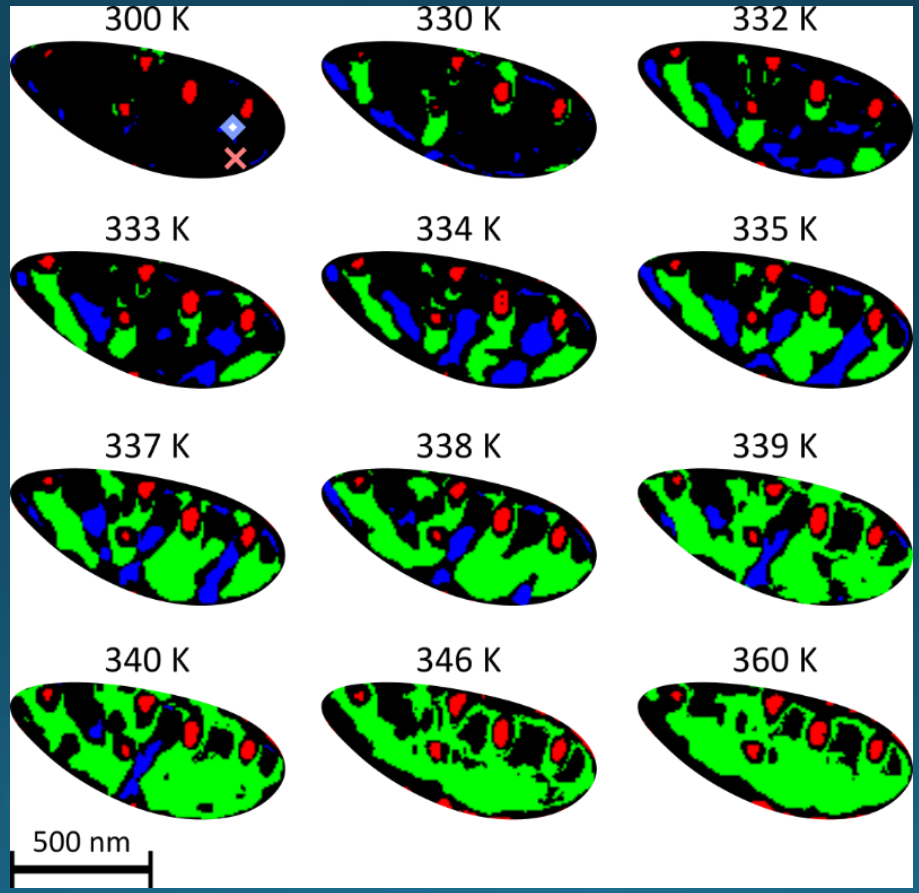
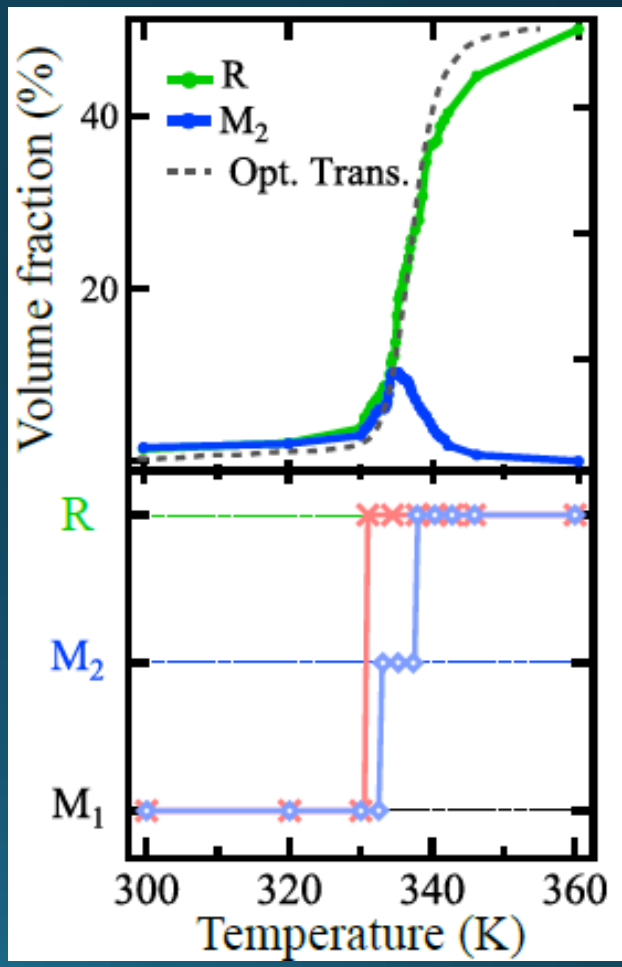
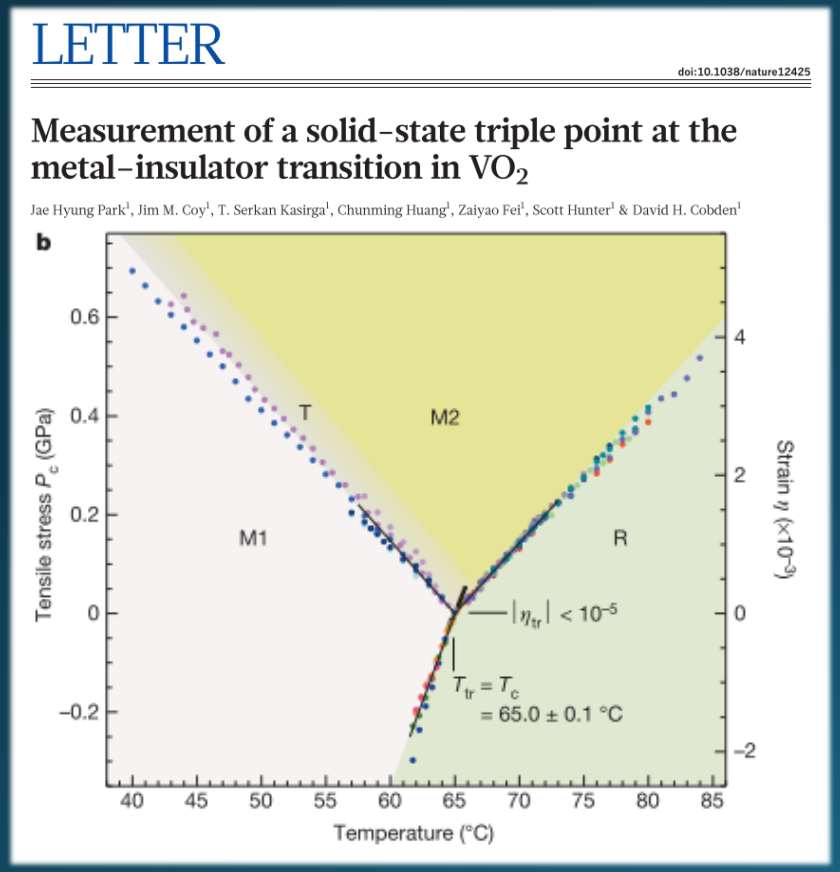






L. Vidas et al. Nano Letters (2018)

VO2 The Prototypical Quantum Material



Diamond 9th September (2019)

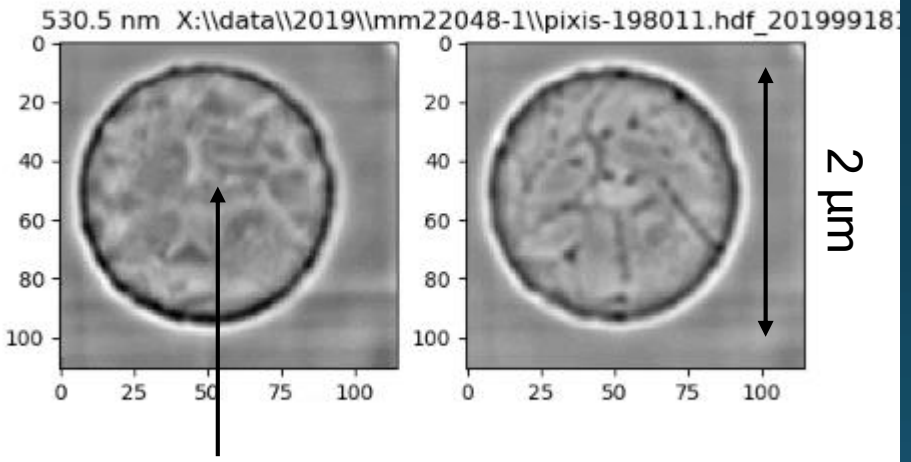


Photo-induce metallic domains

VO2 The Prototypical Quantum Material