University of St Andrews

Topological Protection and Non-Equilibrium States in Strongly Correlated Electron Systems

topnes

SUPA

Phase reconstruction near the high-symmetry point of the O(2)xO(2) nonlinear sigma model

Chris Hooley (SUPA, St Andrews)

“New Directions in Theoretical Physics”, Higgs Centre

Thursday 9th January 2014

J.M. Fellows, S.T. Carr, CAH, and J. Schmalian, *Phys. Rev. Lett.* **109**, 155703 (2012);
CAH, S.T. Carr, J.M. Fellows, and J. Schmalian, arXiv:1311.5344 (to appear in JPSJ).

Outline

- Phase transitions at ‘zero’ temperature.
- ‘Phase reconstruction’ near quantum critical points.
- Special features of 2+1 dimensions: topological order and BKT physics.
- Suppression of BKT transitions near high-symmetry points: an alternative route to phase reconstruction.

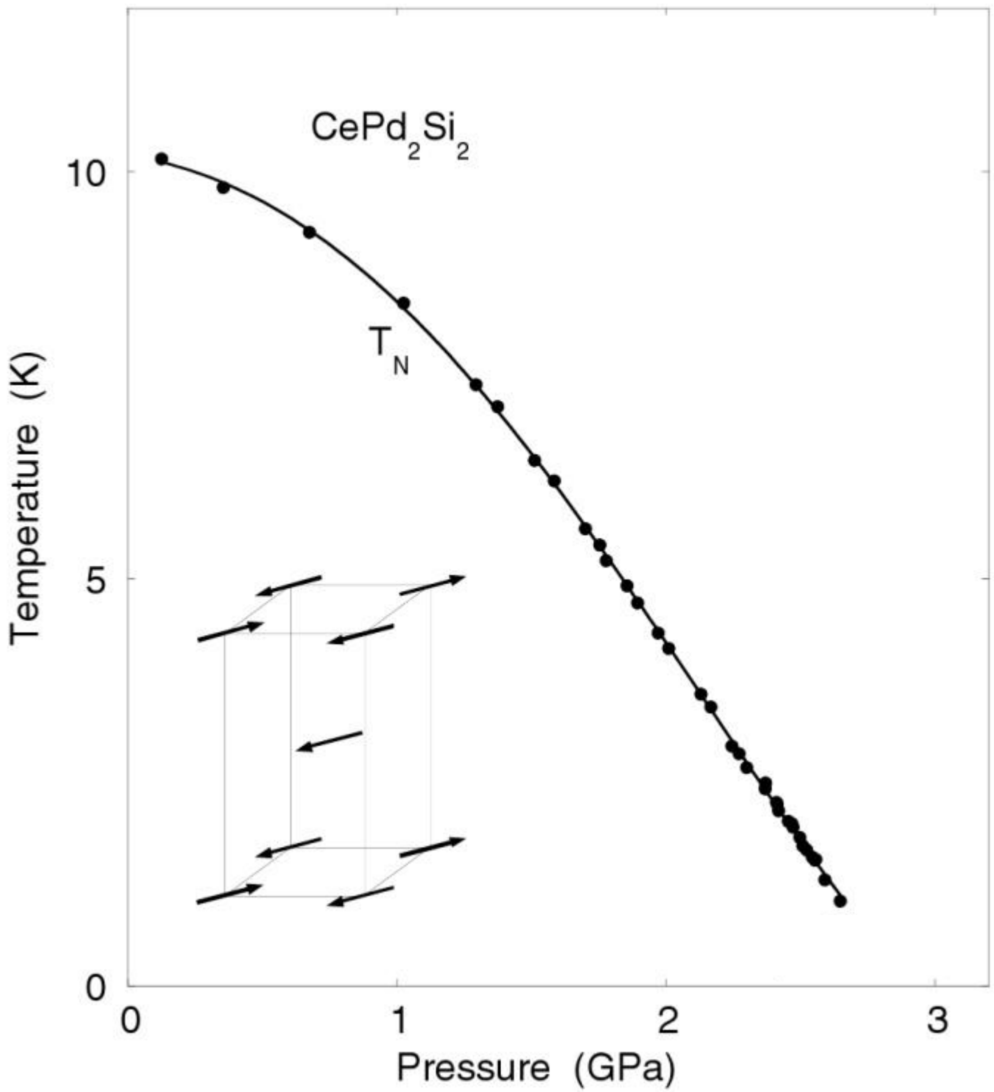
Outline

- Phase transitions at ‘zero’ temperature.
- ‘Phase reconstruction’ near quantum critical points.
- Special features of 2+1 dimensions: topological order and BKT physics.
- Suppression of BKT transitions near high-symmetry points: an alternative route to phase reconstruction.

From phases to phase transitions

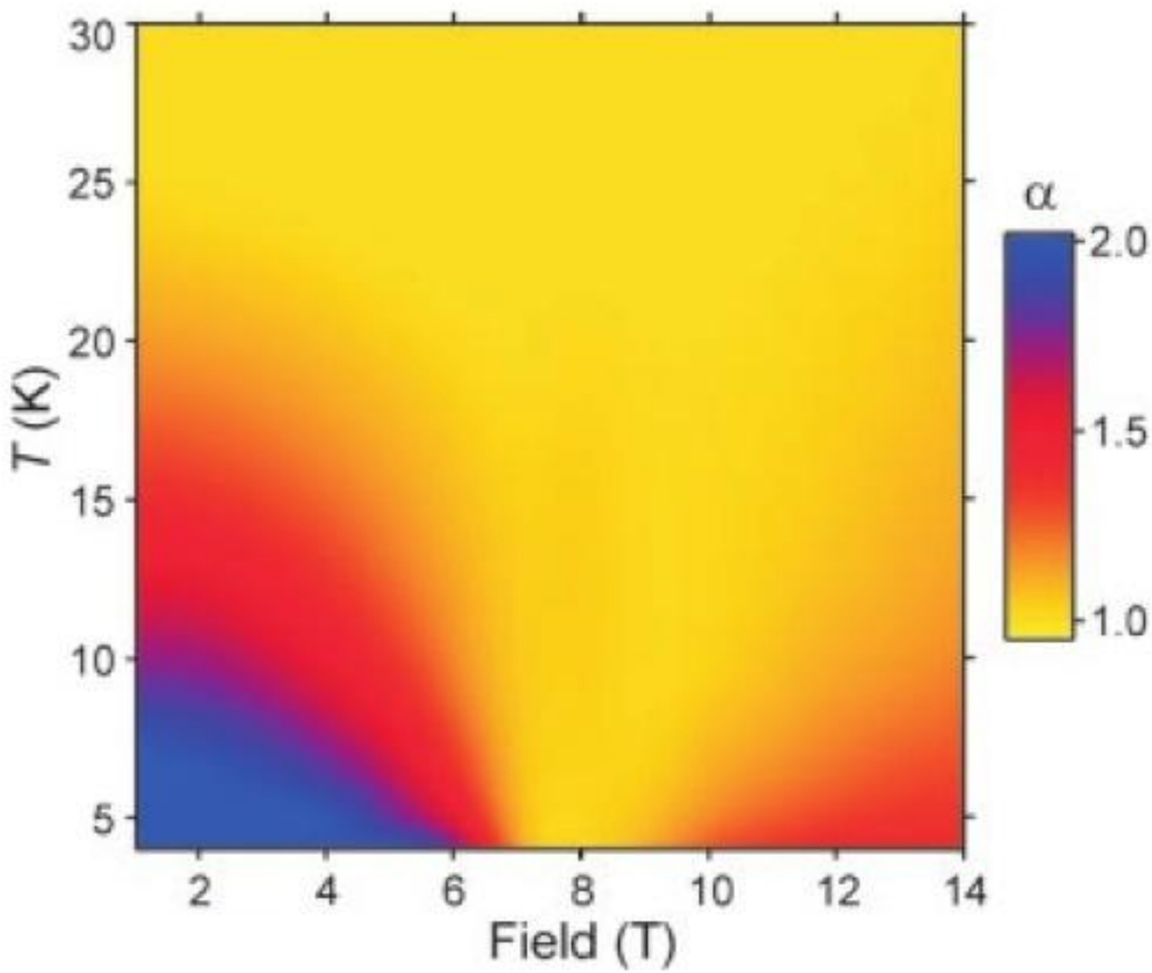
- 1960s and 1970s: shift from classifying phases to classifying phase transitions – particularly continuous phase transitions. (Critical exponents, Widom scaling, etc.)
- Late 1970s, 1980s, and 1990s: shift from thermally ‘driven’ phase transitions to low- (essentially zero-?) temperature phase transitions ‘driven’ by the variation of pressure, magnetic field, or chemical doping.

Pressure: heavy-fermion materials



adapted from
F.M. Grosche *et al.*,
J. Phys.: Cond. Matt. **13**, 2845 (2001).

Magnetic field: strontium ruthenate



$$\rho(T) = \rho_0 + AT^\alpha$$

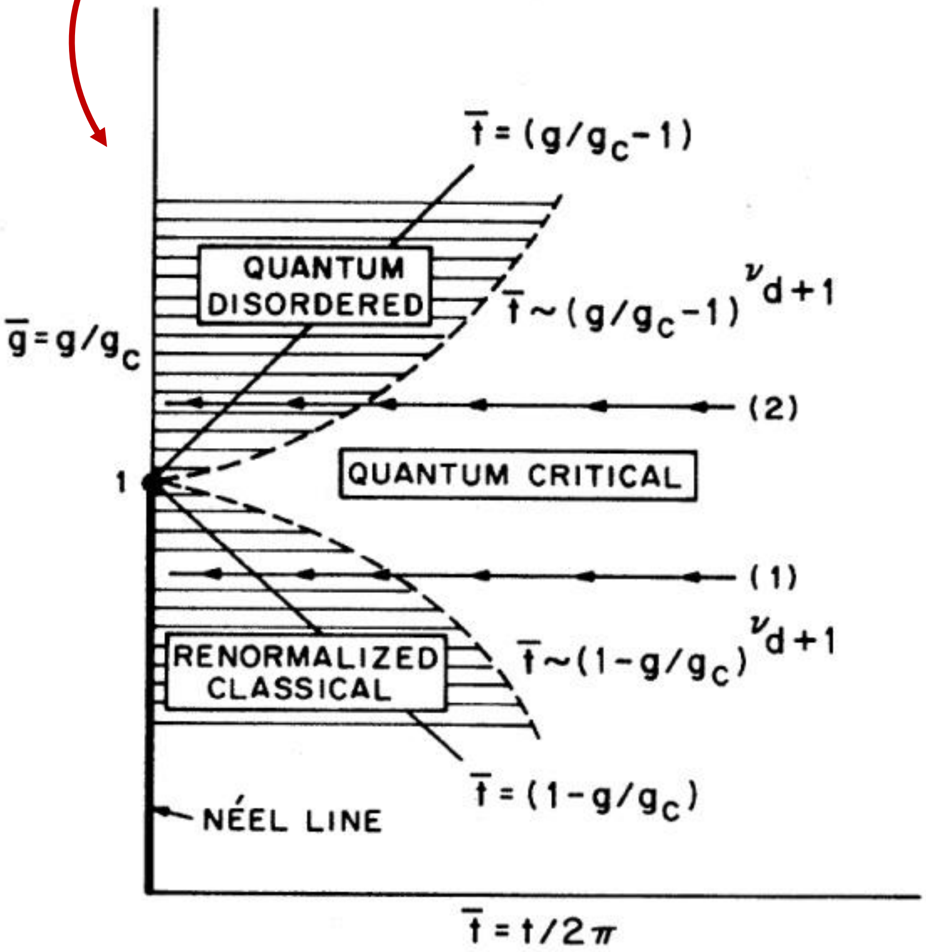
(Well, really it's

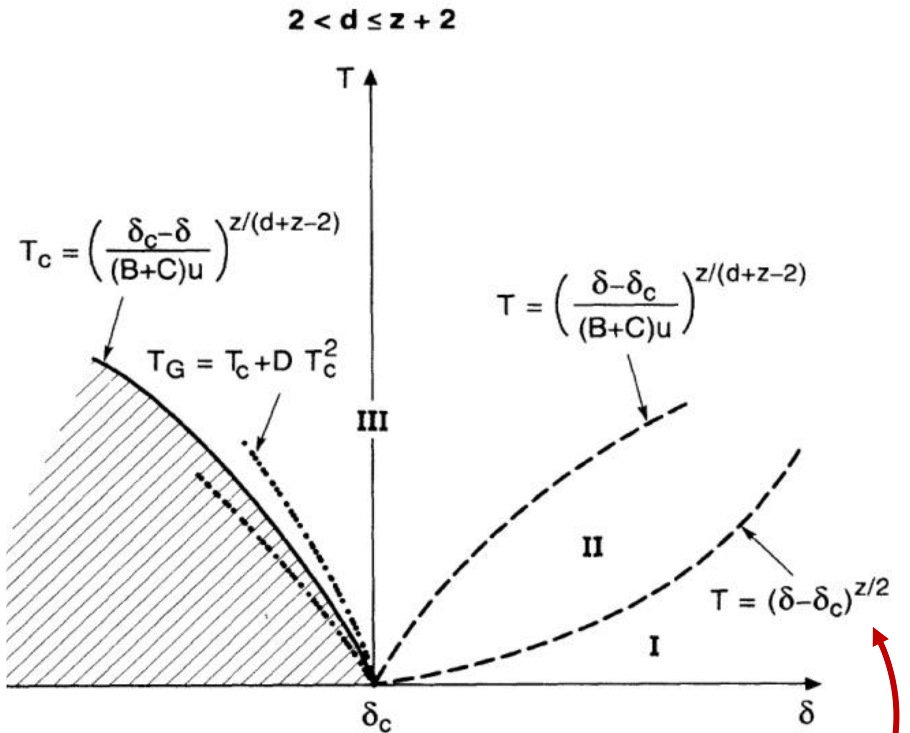
$$\alpha = \frac{d\ln\left(\rho(T) - \rho_0\right)}{d\ln T}$$.)

S.A. Grigera *et al.*,
Science **294**, 329 (2001).

Theories of quantum criticality

Insulators: S. Chakravarty, B.I. Halperin, and D.R. Nelson, *PRB* **39**, 2344 (1989).



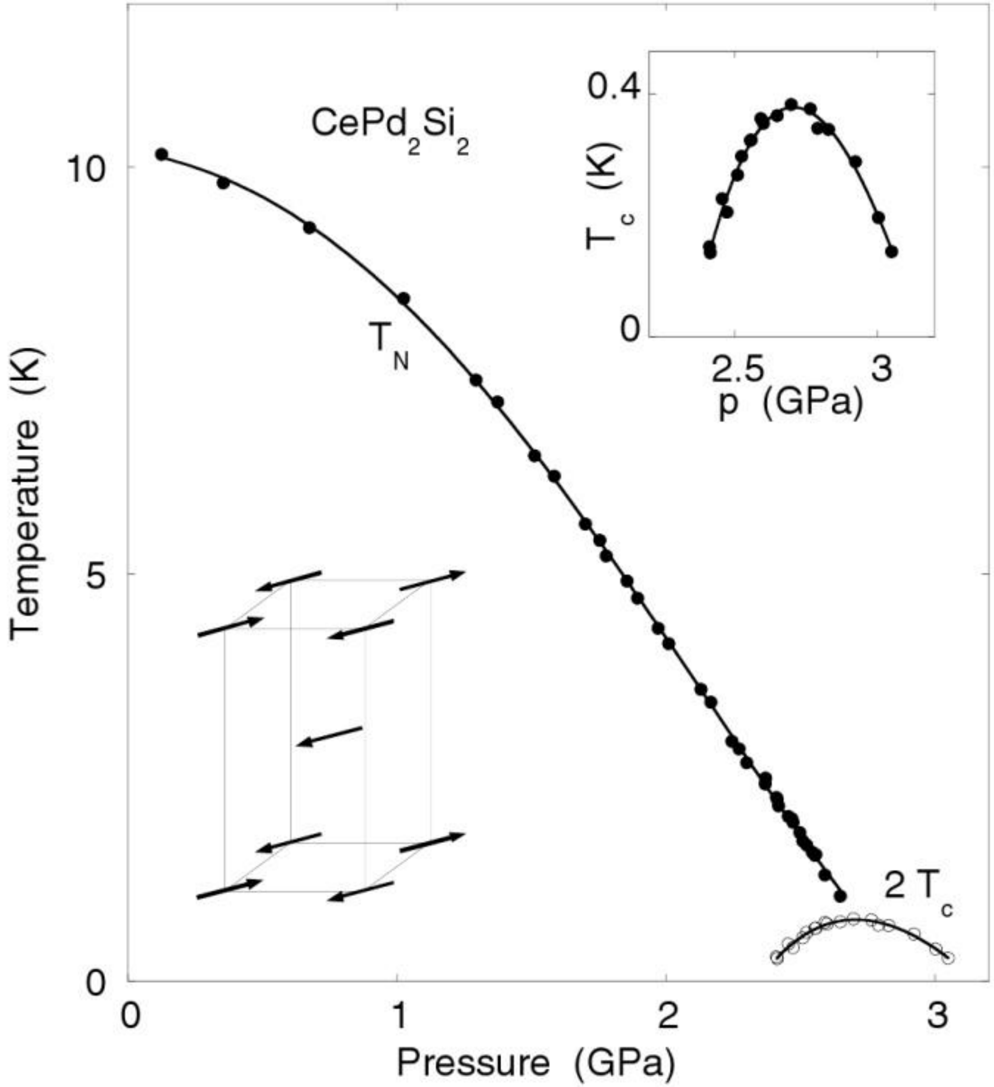


Metals: J.A. Hertz, *PRB* **14**, 1165 (1976); A.J. Millis, *PRB* **48**, 7183 (1993).

Outline

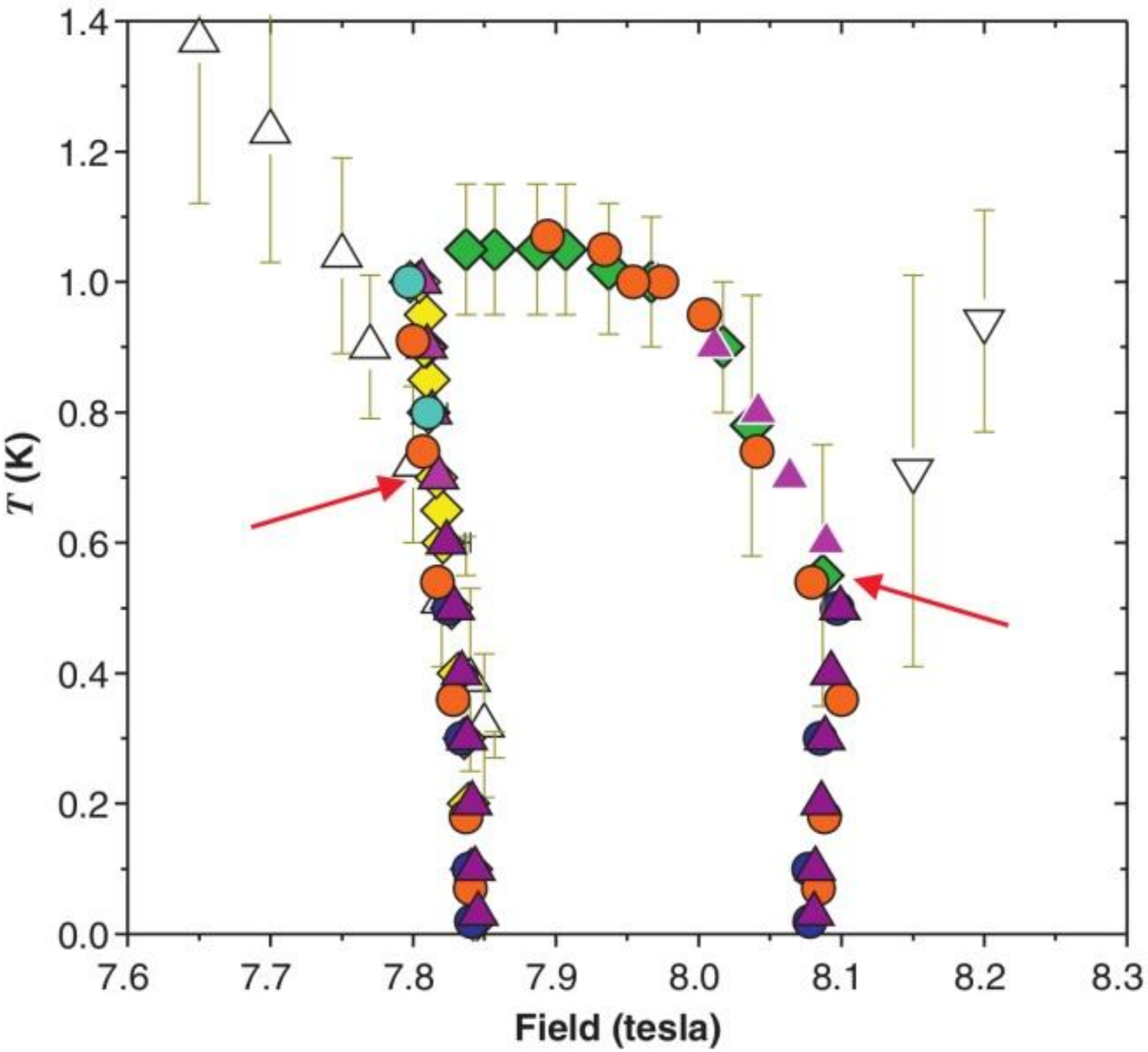
- Phase transitions at ‘zero’ temperature.
- ‘Phase reconstruction’ near quantum critical points.
- Special features of 2+1 dimensions: topological order and BKT physics.
- Suppression of BKT transitions near high-symmetry points: an alternative route to phase reconstruction.

Heavy-fermion materials (again)



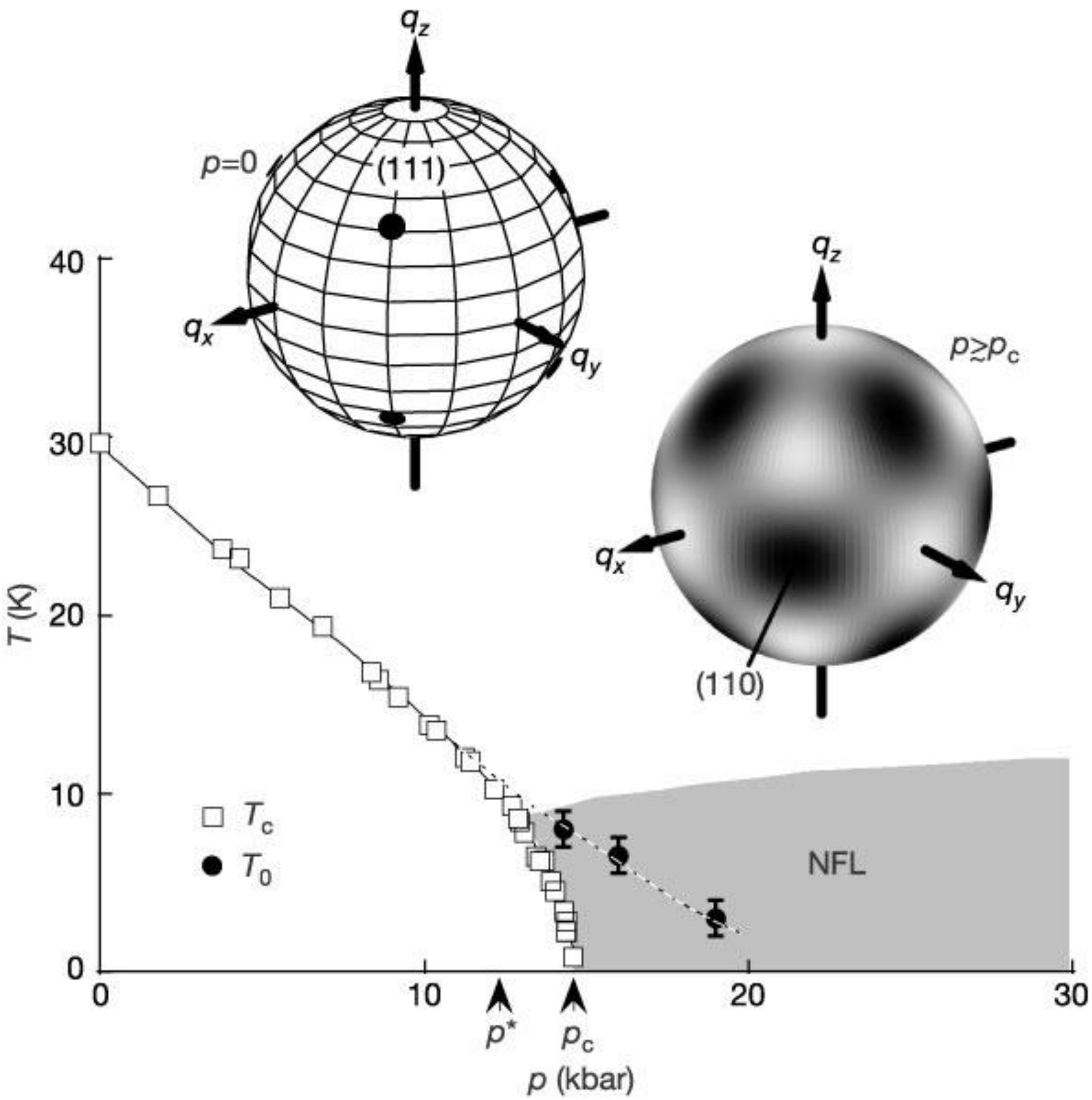
F.M. Grosche *et al.*, *J. Phys.: Cond. Matt.* **13**, 2845 (2001).

Strontium ruthenate (again)



S.A. Grigera *et al.*, *Science* **306**, 1154 (2004).

Manganese silicide



C. Pfleiderer *et al.*, *Nature* **427**, 227 (2004).

Outline

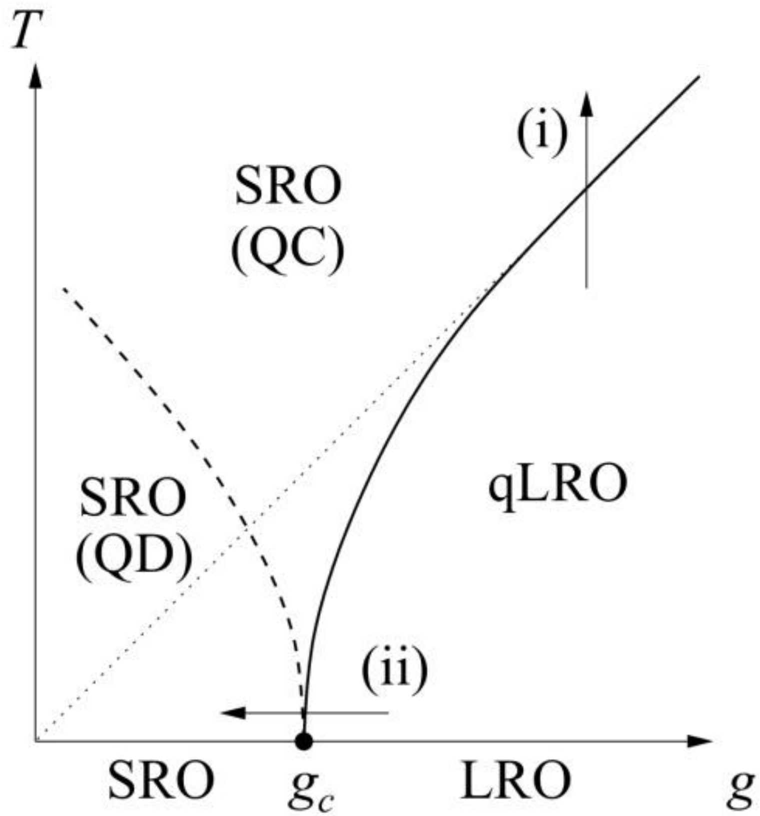
- Phase transitions at ‘zero’ temperature.
- ‘Phase reconstruction’ near quantum critical points.
- Special features of 2+1 dimensions: topological order and BKT physics.
- Suppression of BKT transitions near high-symmetry points: an alternative route to phase reconstruction.

Topological order and BKT

- Mermin-Wagner theorem: no spontaneous breaking of a continuous symmetry at $T>0$ in $d\geq 2$.
- 'Loophole' in $d=2$: can have a finite-T transition from quasi-long-range (or "topological") order (algebraically decaying correlations) to short-range order (exponentially decaying correl'ns).
- Mechanism: vortex-antivortex unbinding.

O(2) nonlinear sigma model

$$S = \frac{g}{2} \int_0^\beta d\tau \int d^2x \left[(\partial_\tau \mathbf{n})^2 + (\partial_\mu \mathbf{n})^2 \right] \qquad \mathbf{n}^2 = 1$$



Outline

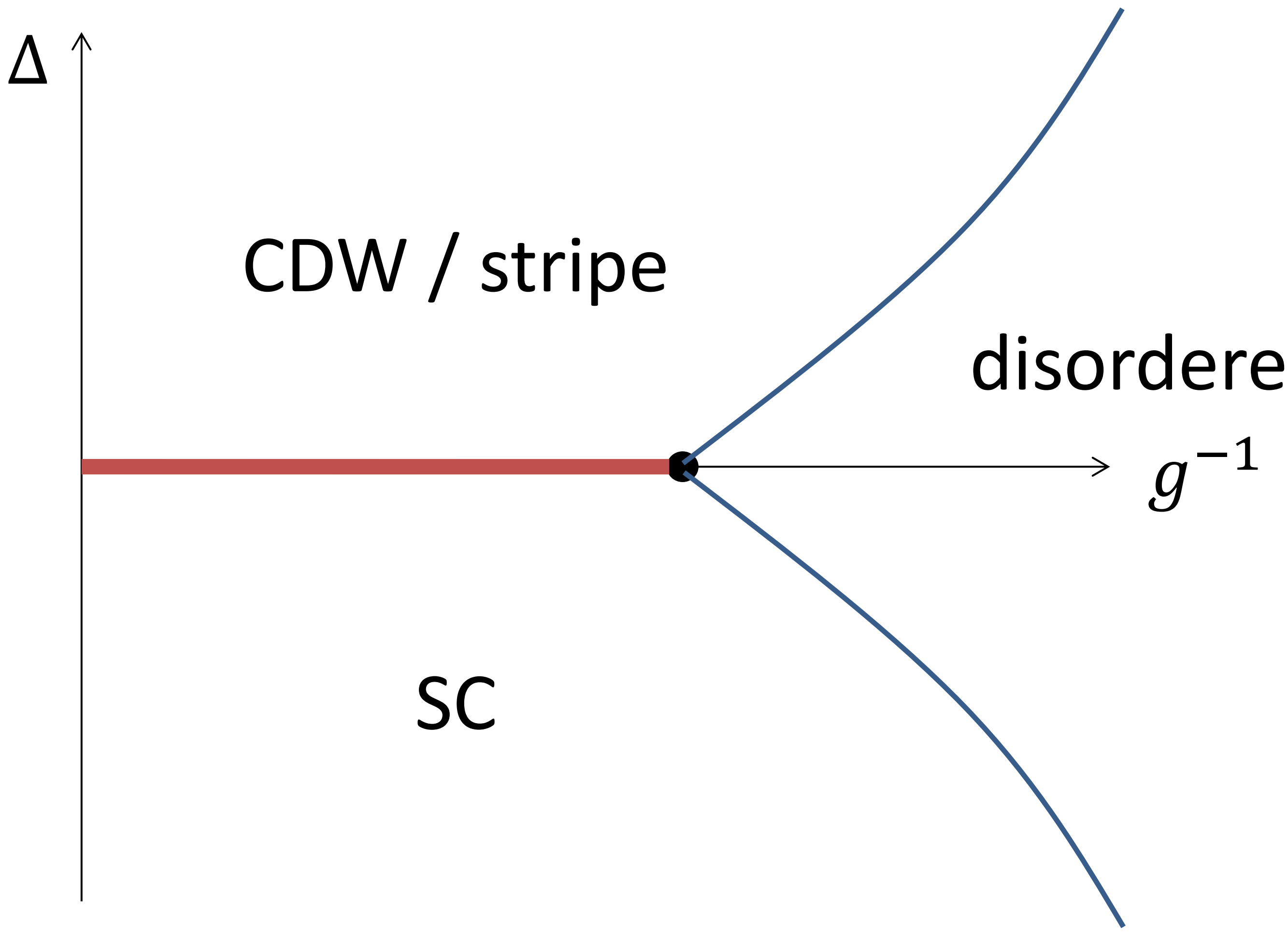
- Phase transitions at ‘zero’ temperature.
- ‘Phase reconstruction’ near quantum critical points.
- Special features of 2+1 dimensions: topological order and BKT physics.
- Suppression of BKT transitions near high-symmetry points: an alternative route to phase reconstruction?

O(2) x O(M) quantum NLσM: a simple model of phase competition

$$S = g \int_0^\beta d\tau \int d^d x \left[(\partial_\tau \mathbf{n})^2 + (\nabla \mathbf{n})^2 + \frac{\Delta}{a^2} \mathbf{n}^T \mathbf{D} \mathbf{n} \right]$$

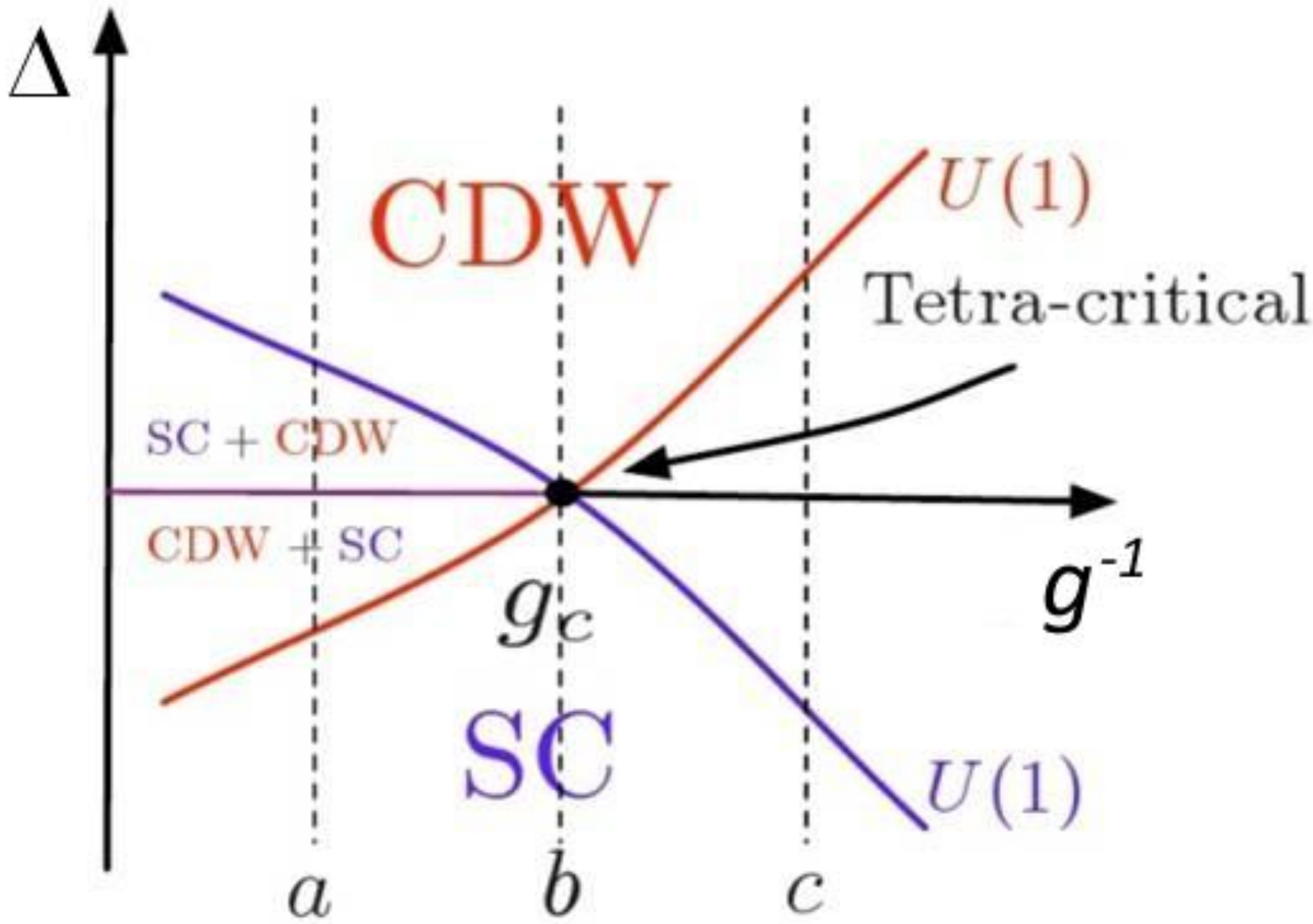
$$\mathbf{n} = \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_{M+2} \end{pmatrix} \qquad \mathbf{n}^2 = 1 \qquad \mathbf{D} = \begin{pmatrix} 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \end{pmatrix}$$

d=2 O(2) x O(2) NLσM: pre-2010 wisdom



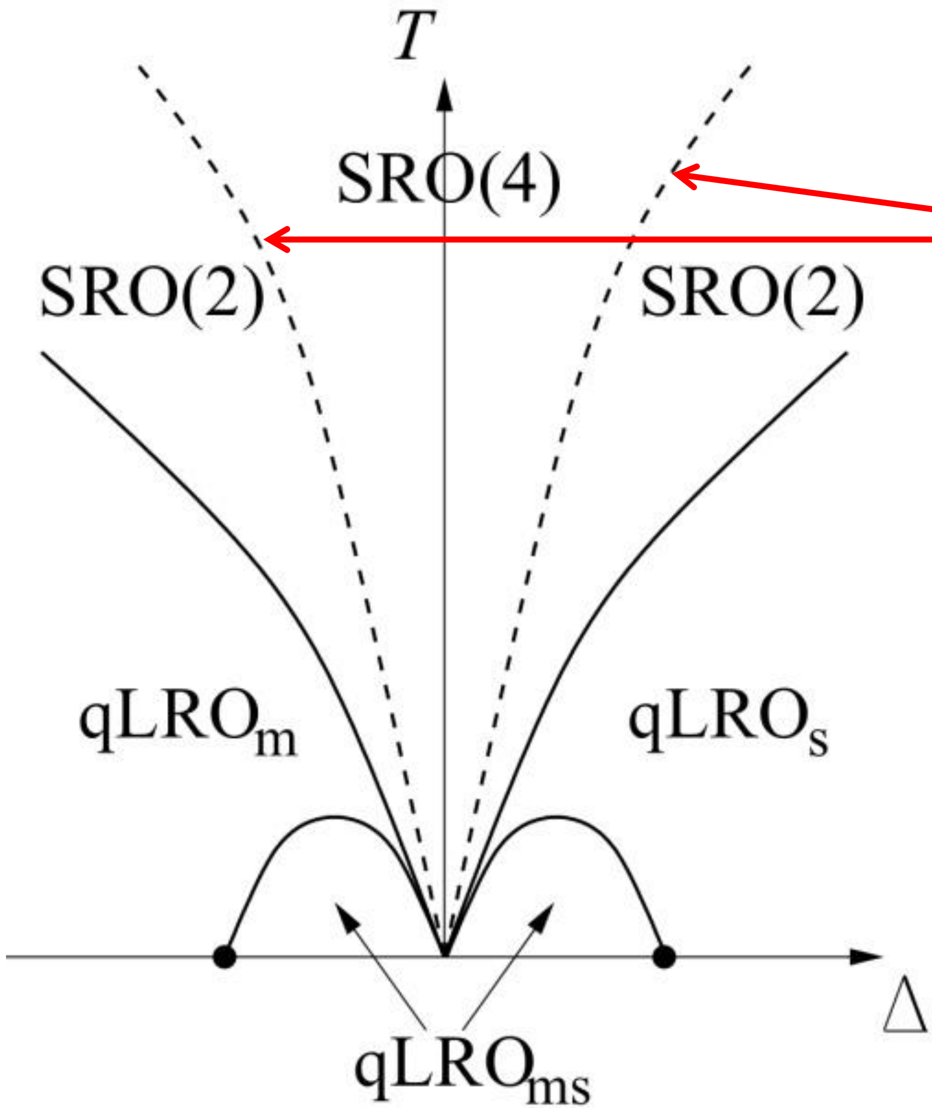
see: D. J. Scalapino, Y. Imry, and P. Pincus, *Phys. Rev. B* **11**, 2042 (1975);
E. W. Carlson, D. Orgad, S. A. Kivelson, and V. J. Emery, *Phys. Rev. B* **62**, 3422 (2000);
F. H. L. Essler and A. M. Tsvelik, *Phys. Rev. B* **65**, 115117 (2002).

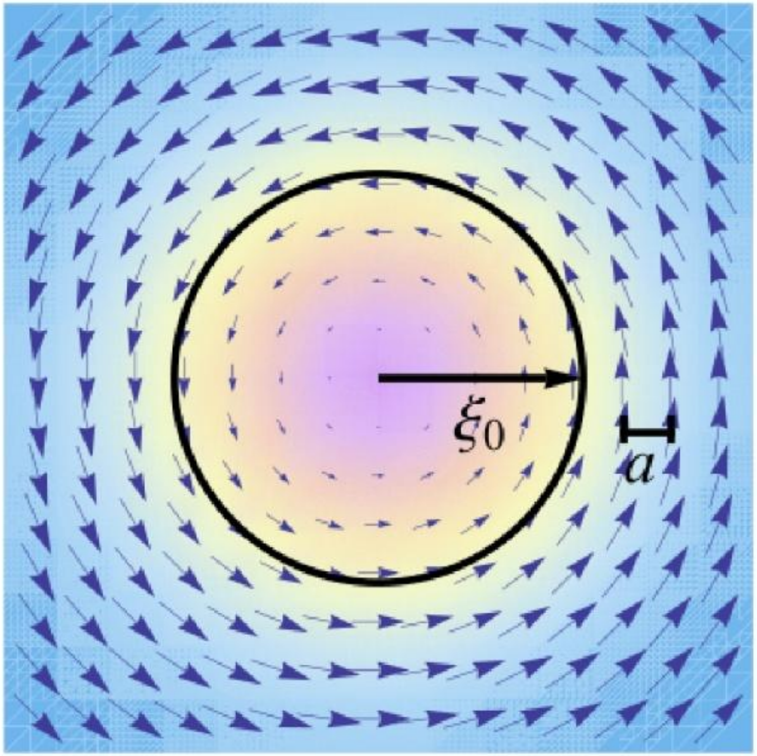
O(2) x O(2) NLσM: Jaefari, Lal, and Fradkin



adapted from A. Jaefari, S. Lal, and E. Fradkin, *Phys. Rev. B* **82**, 144531 (2010)

O(2)xO(2): conjectured phase diagram





Conclusions

- It is possible, at least in (2+1)-dim. systems, for finite-temperature phase transitions to be suppressed to T=0 without connecting to a quantum critical point.
- The O(2)xO(2) nonlinear sigma model is probably an example of this.
- Conjecture: in 2+1 dimensions, even when a finite-temperature line connects to a quantum critical point, it may not necessarily be ‘controlled’ by it.