Inhomogeneous phases driven by competing orders

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Inhomogeneous states and glassiness may occur spontaneously in systems without disorder as a result of competing interactions or competing orders.

Inhomogeneous ordered states

- Coexistence and competition of different orders: manganites, heavy fermions, cuprates, ...
- Inhomogeneities on the micro-meso-nano-scale
- Microscopic origins: disorder, competing interactions, competing orders
- Description at the level of effective theories (Ginzburg-Landau)?
Competing orders: a reminder

\[ F_0 = \frac{r_1}{2} |\Phi_1|^2 + \frac{u_1}{4} |\Phi_1|^4 + \frac{r_2}{2} |\Phi_2|^2 + \frac{u_2}{4} |\Phi_2|^4 + \frac{c}{2} |\Phi_1|^2 |\Phi_2|^2 + \frac{1}{2} (\nabla \Phi_1)^2 + \frac{1}{2} (\nabla \Phi_2)^2 \]

Disorder-induced glass

Disorder + competing orders

E. Dagotto et al. 2001-2005;

Can we obtain inhomogeneous states in a uniform system?
Gradient couplings

- System has a preferred wave vector:
  
  \[ F_1 = a |\Phi_2|^2 |\Phi_1|^2 (\nabla \varphi_2 - q_0), \text{ where } \Phi_2 = |\Phi_2| \exp(i\varphi_2) \]

  manganites, G. Milward, M. Calderon, P. Littlewood, 2005

- System selects the wave vector from interactions
  
  \[ F_1 = a |\Phi_2|^2 |\nabla \Phi_1|^2 + \text{higher}, \ a < 0 \]

  ZN, IV, and AVB, 2004-05

  e.g. stripes: charges like to sit at magnetic domain walls

- Inhomogeneity only in the coexistence region

  \[ F_0 = \frac{r_1}{2} |\Phi_1|^2 + \frac{u_1}{4} |\Phi_1|^4 + \frac{r_2}{2} |\Phi_2|^2 + \frac{1}{4} |\Phi_2|^4 + \frac{c}{2} |\Phi_1|^2 |\Phi_2|^2 \]

  \[ F_1 = \frac{a}{2} |\Phi_2|^2 |\nabla \Phi_1|^2 + \frac{1}{4} |\nabla \Phi_1|^4 + \frac{1}{2} |\nabla \Phi_1|^2 + \frac{1}{2} |\nabla \Phi_2|^2 + \text{higher} \]
• Example: mean field $T_{c2} > T_{c1}$:

$$F_{11} = -\frac{|a|}{4} |\Phi_2|^2 q^2 |\Phi_1|^2$$

• Modulated phase with weakly $T$-dependent $q_0 \propto \Phi_2$

• Effective model similar to surfactants in liquids

• Complicated inhomogeneous states

M. Laradji et al. 1992

Inhomogeneous; Slow dynamics; Glassy?
Effective theory

S. Brazovskii, 1975

\[
H = \frac{1}{2} \sum_k v(k) \Phi_1(k) \Phi_1(-k) + \frac{u}{4} \sum_{k_1+k_2+k_3+k_4=0} \Phi_1(k_1) \Phi_1(k_2) \Phi_1(k_3) \Phi_1(k_4)
\]

\[
v(k) \approx r_0 + (k^2 - q_0^2)^2, \quad r_0 \equiv \xi_0^{-2} = a(T - T_c)
\]

• Isotropic model - shell of modes |k|=q_0.

• Large phase space for fluctuations:
  classical dynamics or quantum dynamics

\[
\langle \Phi^2 \rangle = bTq_0^2 / \sqrt{r_0}
\]

\[
\langle \Phi^2 \rangle = bq_0^2 \log \frac{E_0}{r_0}
\]

• Drives system away from transition

on the shoulders of giants 1
1st order transition

*Brazovskii transition*: S. Brazovskii, 1975

- Self-consistency (large N)

\[ r = r_0 + u \left\langle \Phi^2 \right\rangle = r_0 + ubTq^2_0 / \sqrt{r} \]

2nd order transition impossible (large N); real transition may occur at \( 0 < T_c << T_{c1} \)

- Fluctuation driven 1st order transition
- Mean field: lamellar phase

\[ \Phi_1 = A_1 \cos(q_0r) \]
Two length scales and glassiness

• Competition between
  
  \[ \xi^{-2} = r(T) + q_0^2 \]
  
  \[ l^{-2} = q_0^2 - r(T) \]
  
  – correlation length
  
  – modulation length
  
  – at \( q_0^2 = r \) short range correlations
  
  – at \( r + q_0^2 = 0 \) long range order

• Glass emerges when
  \[ \frac{\xi}{l} > 2 \]

  \[ N \propto \exp(q_0^3 V) \] metastable states below \( T_A(q_0) \)
  
  Low cost of creating regions of order parameter \( (\xi^{-2}) \)
  correlated over short distance of order \( l \)

on the shoulders of giants 3
• If $T_{c2} > T_{c1}$: fluctuation-induced first order transition into inhomogeneous or glassy phase at $T_{c2} > T_1 > T_{c1}$ possibly followed by a strongly first order transition to a uniform phase at $T^* << T_{c1}$.
• For mean field $T_{c2} \approx T_{c1}$: 1st order into modulated phase
• Reason: $q_0$ depends on $T$
• Under investigation

Basic question: is it enough to reach glassy limit?
It depends…
Summary

• You can get modulated and inhomogeneous states of different orders in nominally uniform systems. Disorder need not be there.
• These states may exhibit glassy dynamics.
• For glassiness details matter (unfortunately?)

Open question:

• Hamiltonian from which such GL follows?
• Plan: use mean field microscopic theories (see talks by G. Alvarez and W. Atkinson), and check the relevant Ginzburg-Landau theories.