

# (Effective) Field Theory without quasiparticles

T. Senthil (MIT)

- **Tuesday afternoon, 4:15-7:15: Field theory**  
**Overview and discussion leader: T. Senthil (MIT)**

4.15 - 4.30 pm:

T. Senthil (MIT)

Session overview and discussion leader

4.30 - 5.05

**Matthew P. A. Fisher** (University of California - Santa Barbara)

Non-Fermi liquid d-wave metal phase of strongly interacting electrons

5.05 - 5.40

**Ribhu Kaul** (University of Kentucky)

Deconfined quantum critical spin systems

5.40 - 6.05: Coffee break

6.05 - 6.40

**Sung-Sik Lee** (McMaster University)

Low energy effective theories for non-Fermi liquids

6.40 - 7.15

**Max Metlitski** (Kavli Institute for Theoretical Physics)

Pairing of critical Fermi surface states

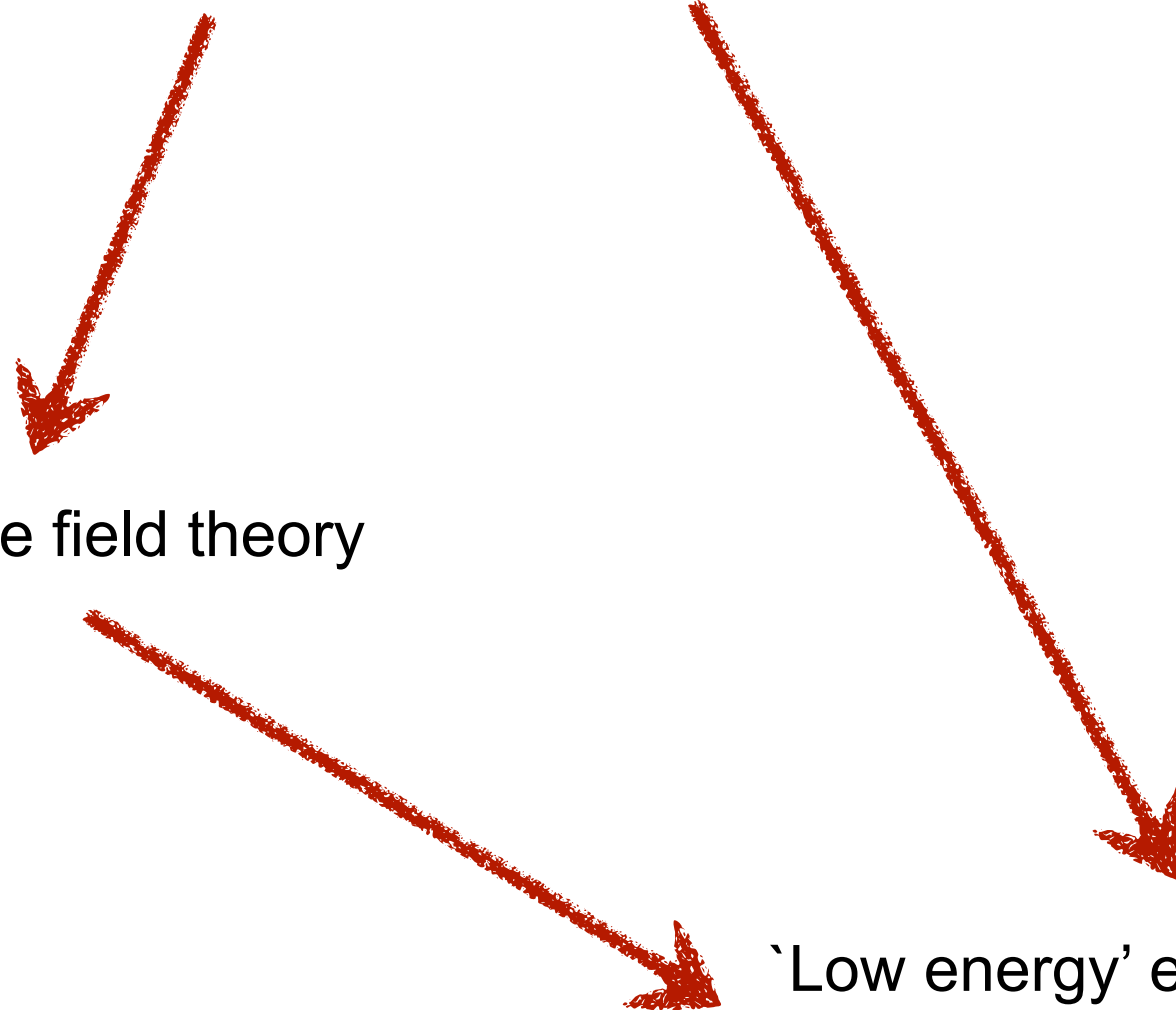
**Tuesday evening, 7.30: Banquet I (Meadows)**

# Effective field theory in condensed matter physics

Microscopic models (e.g, Hubbard/t-J, lattice spin Hamiltonians, etc)

‘Low energy’ effective field theory

‘Low energy’ experiments/  
phenomenology



# Effective field theory:*minimal* requirements/ challenges

1. **`Tractable'**: Must be simpler to understand than original microscopic models and relate to experiments
- continuum field theory often useful (see Lee, Metlitski talks) but not necessarily of the kind familiar from high energy physics.

# Effective field theory: *minimal* requirements/ challenges

1. **`Tractable'**: Must be simpler to understand than original microscopic models and to relate to experiments
  - continuum field theory often useful (see Lee, Metlitski talks) but not necessarily of the kind familiar from high energy physics.
  
2. **`Emergable'**: A proposed low energy field theory must (at the very least) be capable of emerging from microscopic lattice models in the *`right' physical Hilbert space* with the *right symmetries*.
  - demonstrate by calculations on *`designer' lattice Hamiltonians* (see Kaul, Fisher talks).

Designer Hamiltonians do not need to be realistic to serve their purpose.

# Conventional condensed matter physics

Hartree-Fock + fluctuations

Structure of effective field theory:

Landau quasiparticles + broken symmetry order parameters (if any).

Phase	Field Theory	Sample designer Hamiltonian
Metals	Fermi Liquid Theory	Eg, Jellium
Superconductors	Landau-Ginzburg + Bogoliubov quasiparticles	Reduced BCS Hamiltonian
Antiferromagnets	Nonlinear sigma model	Eg, Nearest neighbour Heisenberg

# Beyond quasiparticles

Non-fermi liquid metals, quantum critical points, some (gapless) quantum spin liquids.....

What are the useful degrees of freedom for formulating an effective field theory?

Field theory not necessarily in terms of electrons + Landau order parameters.

A powerful approach (all talks in this session):

Slave particles (partons): Fractionalize spin/electron into partons which are then gapless

# Beyond quasiparticles: Slave particle paradigm

Examples:

1. Quantum spin system

$$\vec{S}_r = \frac{1}{2} f_r^\dagger \vec{\sigma} f_r \quad (1)$$

Field theory: Fermionic spinons  $f_{r\alpha}$  gapless, and coupled to fluctuating emergent gauge fields.

2. Electronic systems

$$c_\alpha = b f_\alpha \quad (2)$$

Effective field theory in terms of  $(b, f)$  + gauge fields.

Further fractionalize  $b$  as product of 2 fermions to get gapless non-Fermi liquid (Fisher talk)



# Slave particles at work: Field theories of `exotic' phases

Phase	Field Theory	Sample designer Hamiltonian	Comments
Metals	Fermi Liquid Theory	Eg, Jellium	Conventional quasiparticles
Superconductors	Landau-Ginzburg + Bogoliubov quasiparticles	Reduced BCS Hamiltonian	
Antiferromagnets	Nonlinear sigma model	Eg, Nearest neighbour Heisenberg	
Fractional quantum Hall	Chern-Simons	Many solvable models	Exotic quasiparticles (fractional statistics/ quantum numbers)
Gapped quantum spin liquids	Deconfined discrete gauge theory	Eg: ``Toric code''	
Gapless quantum spin liquids	Gauge theory + gapless charge neutral `matter'	Eg: Ring exchange model, Sandvik J-Q model (Kaul talk), Kitaev honeycomb model	Beyond quasiparticles
Non-fermi liquid metals	Gauge theory + gapless charged `matter'	Solvable models (Nandkishore, Metlitski, TS 2012), ``t-J-K'' model (Fisher talk)	

# Comments on slave particle framework

1. **Conceptually important** construction of effective field theories of a class of quantum phases/phase transitions that are beyond standard quasiparticles

2. Often slave particle effective field theories are both tractable and emergable.

Theoretical demonstration of many unusual phenomena; some successful contact with experiments (eg, FQHE, 1/2-filled Landau level, some quantum spin liquids)

Essentially only available framework for field theory 'beyond quasiparticles'.

# Beyond (standard) slave particles?

Some examples:

1. Are there quantum spin liquids that cannot be understood easily within the slave particle framework?

Apparently yes.

(i) Quantum vortex liquid phases of quantum XY magnets/frustrated boson systems

Chong Wang, TS, to appear; see poster.

(ii) Quantum liquid of fluctuating spiral magnetic orders (inspired by MnSi).

A. Vishwanath, TS, to appear.

2. Holographic liquids: Tractable but are they emergable?