Systems with competing interactions: from high-T_c to new types of order

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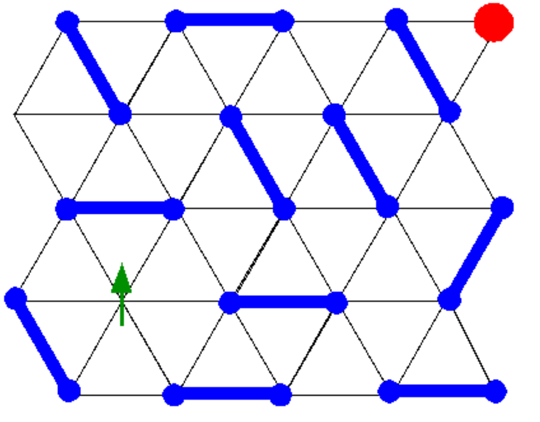
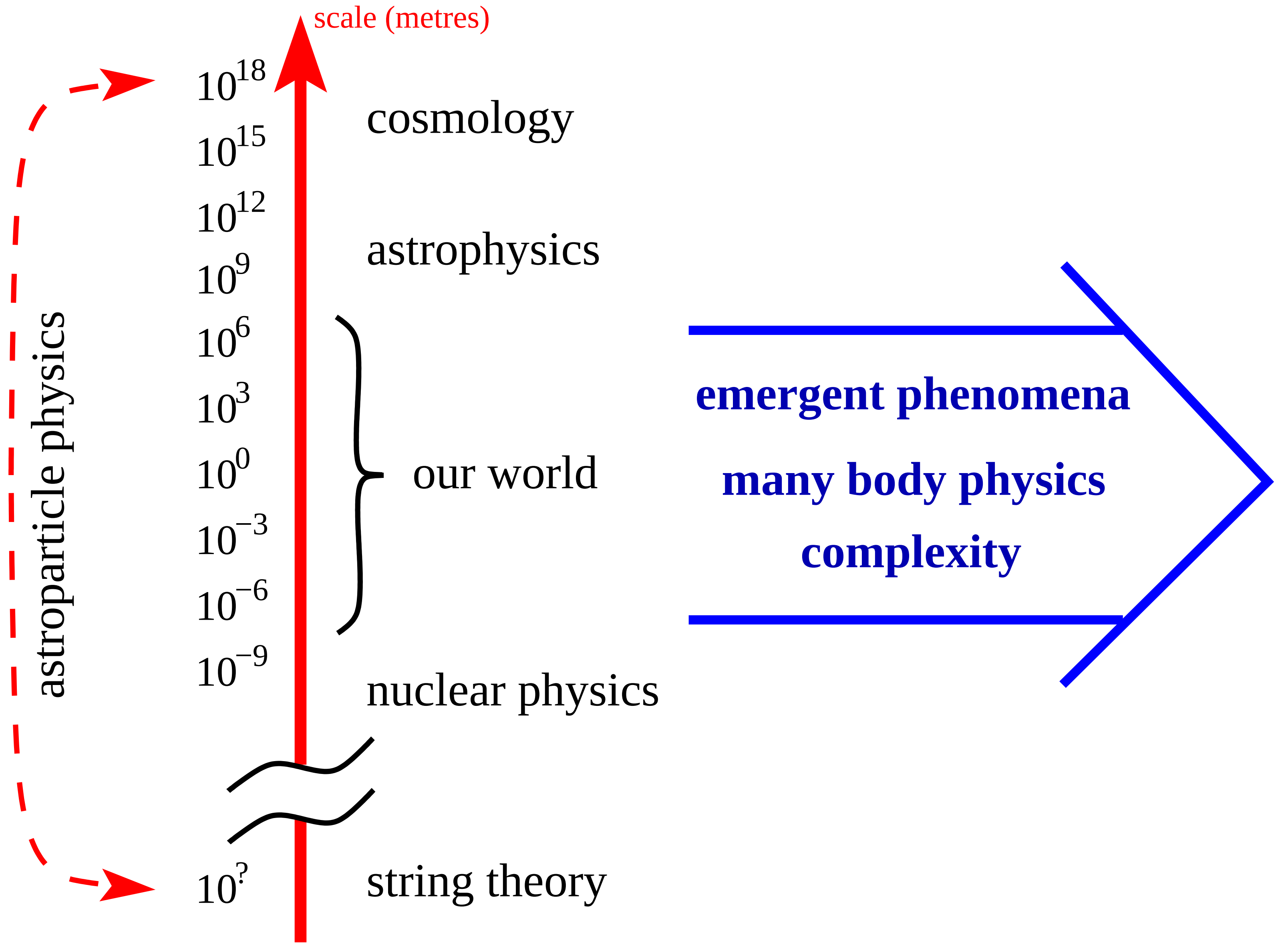


Les Houches, May 2009

The fundamental question



How to look for new phenomena

Serendipity

- look for something else

New systems

- cold atoms
- graphene
- quantum chemistry (the periodic table has many elements!)

Destablise ‘boring’ known states – strong fluctuations

- low dimensionality (spin chains, quantum Hall physics)
- quantum fluctuations
- thermal fluctuations (partial order)
- competing interactions (‘frustration’)
- coupled degrees of freedom (electrons+phonons)

What one hopes to find

Unconventional order parameters (‘states of matter’)

- hexadecupolar order; supersolids; multiferroics; . . .

New types of order

- topological order
- quasiparticle fractionalisation
- exotic phase transitions

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Dual aim:

- Search for underlying principles
  - How is the world around us organised?
- New applications
  - quantum computers; magnetoelectric switches; . . .

This lecture course

Basic outline:

Motivation+history: the high-T$_c$ problem

$\longrightarrow$ strong correlations and spin liquid physics

$\longrightarrow$ new types of order and their manifestations

High-dimensional systems ($d > 1 + 1$)

$\Rightarrow$ G. Mussardo, Th. Giamarchi for low-d

Periodic Hamiltonians

- some disorder physics if time permits

Analytical methods

$\Rightarrow$ A. Laeuchli for numerics

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Feedback gratefully received

Recommended overview literature

Textbooks:

- P. C. Chaikin , T. Lubensky: Principles of cond. mat. phys.
- A. Auerbach: Interacting electrons and quantum magnetism

Articles:

- G. Misguich, C. Lhuillier: Two-dimensional quantum antiferromagnets, cond-mat/0310405
- R. M., S. L. Sondhi: Ising models of quantum frustration, cond-mat/0011250
- R. M., K. Raman: Quantum dimer models, arxiv:0809.3051
- M. Gingras: Spin ice, arxiv:0903.2772
- C. Laumann,...: Random quantum satisfiability, arxiv:0903:1904

Quantum magnetism: spin liquids etc. (lectures I-III)

The high-T$_c$ problem

- what is the parent state of the superconductor?

The resonating valence bond scenario

- desired properties
- the Rokhsar-Kivelson quantum dimer model: derivation etc.

Order and disorder

- valence bond solids
- a quantum spin liquid
- topological order and fractionalisation
- deconfined critical points

Spin ice – lecture IV

Classical frustration and ground-state degeneracy

- Ice and spin ice

Projective equivalence and the dumbbell model

$\Rightarrow$ monopole excitations with irrational charge

Monopole properties

- in principle detectable in monopole search
- monopole liquid-gas transition

Magnetic field effects

- magnetisation plateau
- Kasteleyn transition
- hybrid dimensionality

Random quantum satisfiability – lecture V

Motivation

- quantum complexity theory
- disordered quantum magnets

classical k-SAT

- graph theory
- ensembles and organisation of solution space

quantum 2-SAT

- Bravyi transfer matrix and transfer basis
- SAT-unSAT transition

quantum k-SAT

- bounds on SAT and unSAT phases
- geometrisation

Collaborators+discussions

Theory:

- C. Castelnovo (Oxford)
- John Chalker (Oxford)
- Eduardo Fradkin (UIUC)
- Karol Gregor (Caltech)
- Sergei Isakov (ETHZ)
- Andreas Laeuchli (MPIPKS)
- Chris Laumann (Princeton)
- Didier Poilblanc (Toulouse)
- Kumar Raman (UIUC)
- A. Scardicchio (ICTP)
- Shivaji Sondhi (Princeton)
- Adam Willans (Oxford)

Experiment:

- Steve Bramwell (UCL)
- Zenji Hiroi (Tokyo)
- Art Ramirez (Alcatel-Lucent)
- Peter Schiffer (Penn State)
- Alan Tennant (HMI)

+ many more