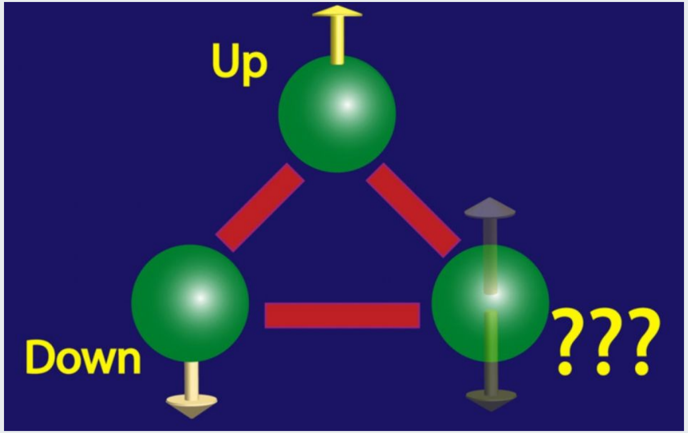
Magnetic Frustration and Spin Liquids

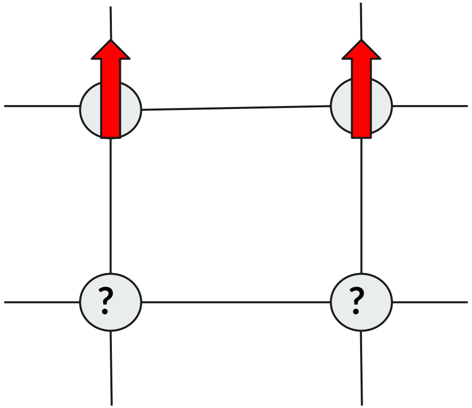
James Saslow
Phys 175a Final Presentation



Let's Play a game!

If the Ising Model favors **Ferromagnetism,**

What spins should the question marks have?

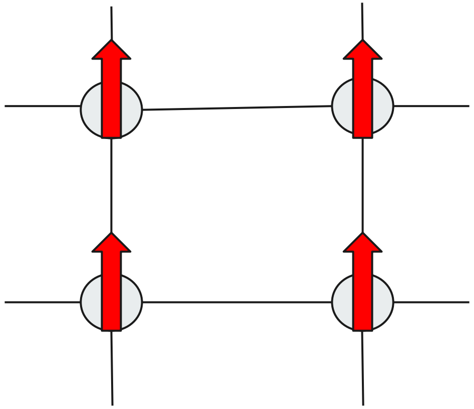


Let's Play a game!

If the Ising Model favors **Ferromagnetism,**

What spins should the question marks have?

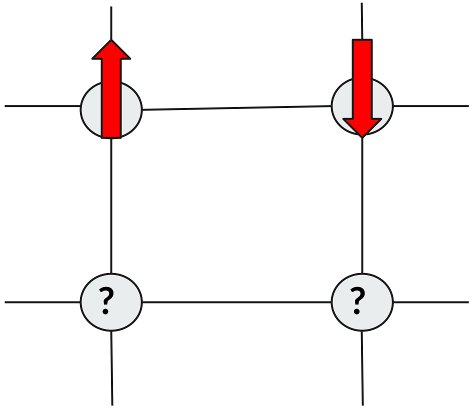
SAME SPIN !



Let's Play a game!

If the Ising Model favors **Antiferromagnetism,**

What spins should the question marks have?

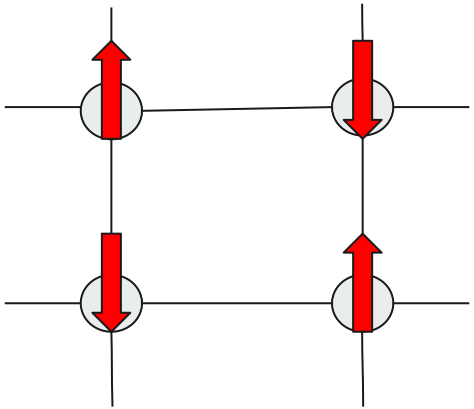


Let's Play a game!

If the Ising Model favors **Antiferromagnetism,**

What spins should the question marks have?

CHECKERBOARD PATTERN

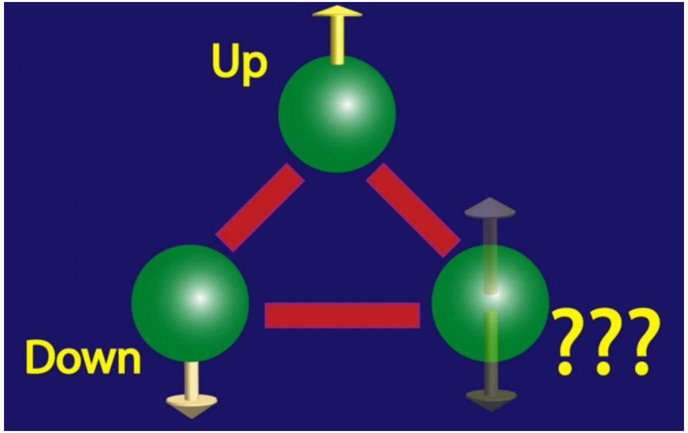


Let's Play a game!

If the Ising Model favors **Antiferromagnetism,**

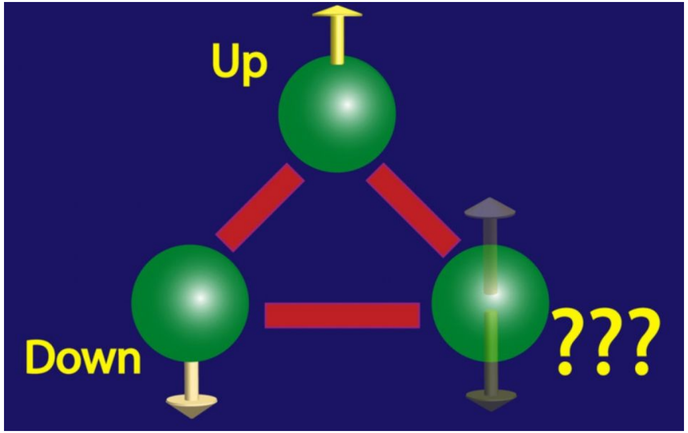
What spins should the question marks have?

Triangular Configuration



Let’s Play a game!

Triangular Configuration



If the Ising Model favors **Antiferromagnetism,**

What spins should the question marks have?

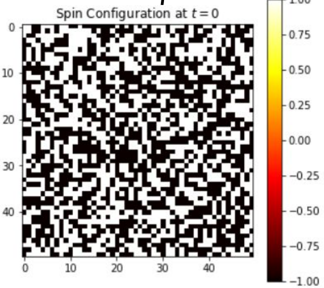
There is no spin we can pick that would satisfy antiferromagnetism

This is called frustrated magnetism

Spin Liquids

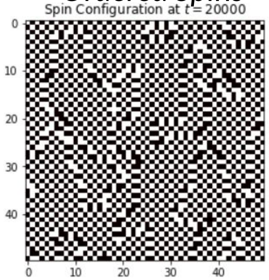
Antiferromagnetic Behavior (AFM) For a Square Lattice

Random Spins



After a long time

Ordered Spins

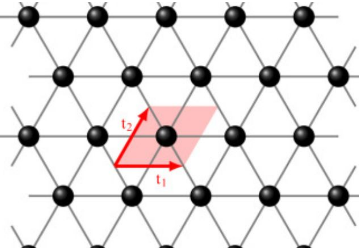


Magnetic Ordering

- Checkerboard
- obvious ground state solution

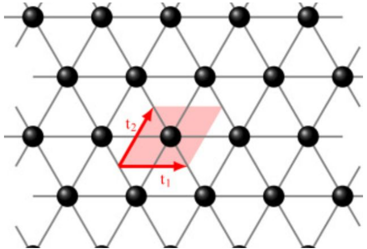
AFM Behavior for Triangular Lattice

Random Spins



After a long time

Random Spins



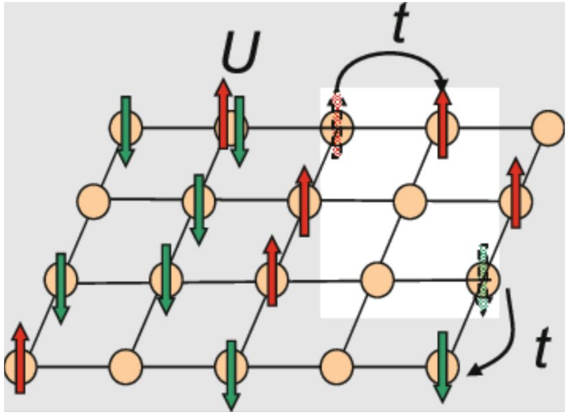
<u>A spin Liquid</u>!

- A Spin Liquid has no magnetic ordering
- No obvious ground state solution

Review Of the Hubbard Model

- We can use the Hubbard Model to describe the phase space of spins

$$\mathcal{H} = -\sum_{i,j,\sigma} t_{ij} c^{\dagger}_{i,\sigma} c_{j,\sigma} + \text{h.c.} + U \sum_{i} n_{i,\uparrow} n_{i,\downarrow}$$

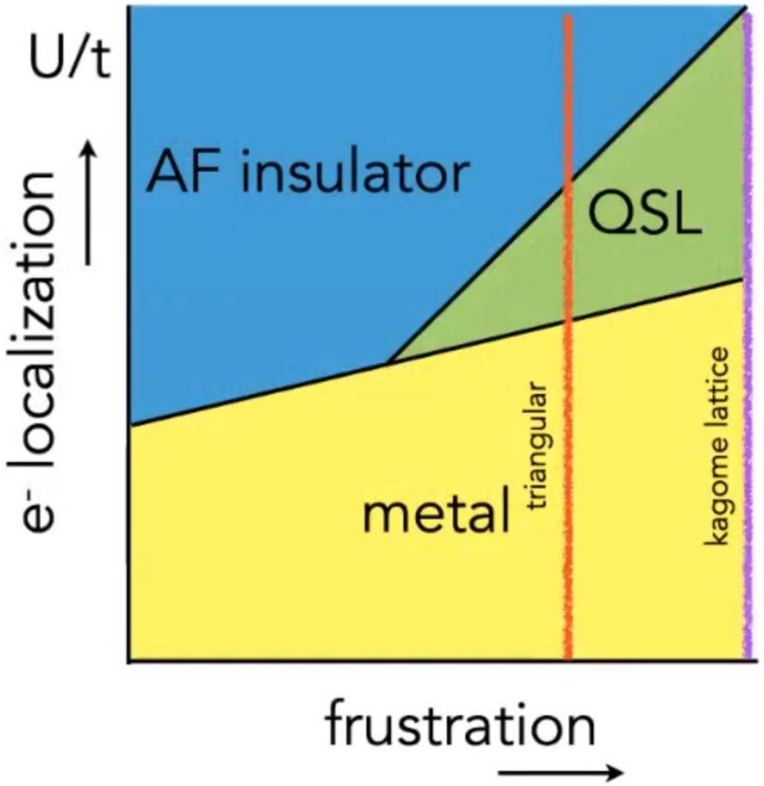


H Is the Hamiltonian of the system
t is the cost of quantum tunneling
U is the coulomb repulsion energy

If t >> U , tunneling is more favorable… so we get a **metal**

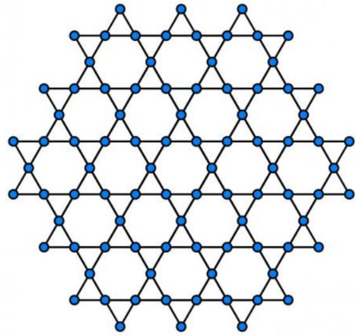
If U>> t, Coulomb repulsion is strong, each spin occupies its own site … we get an **insulator**

Phase Diagram

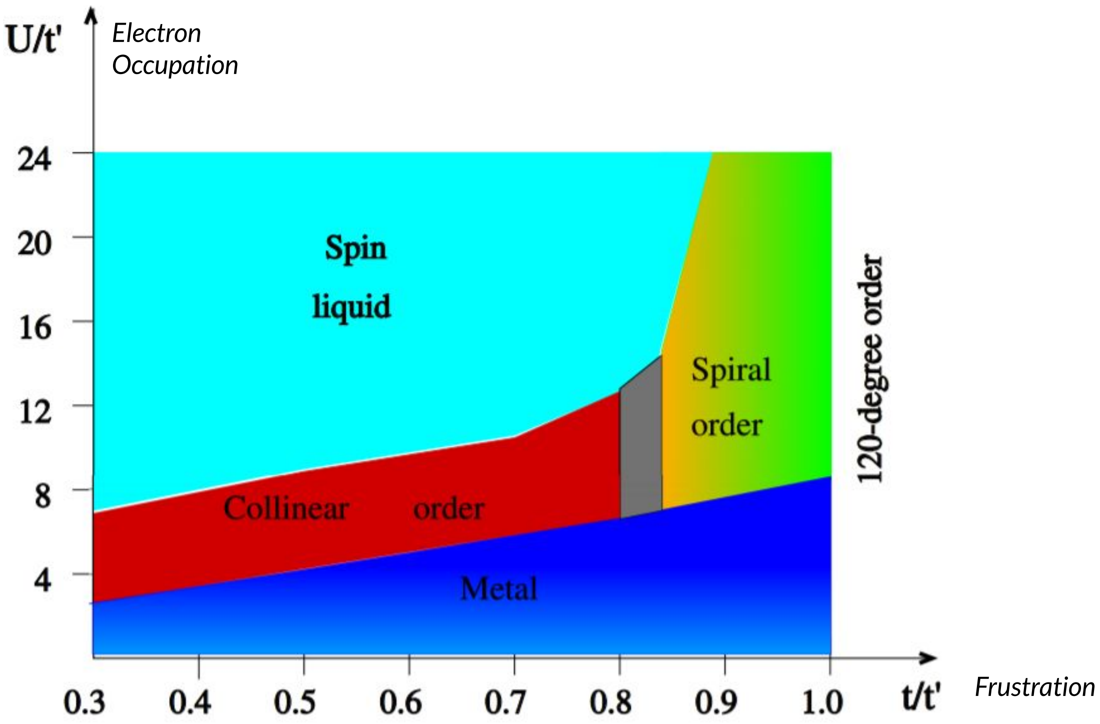


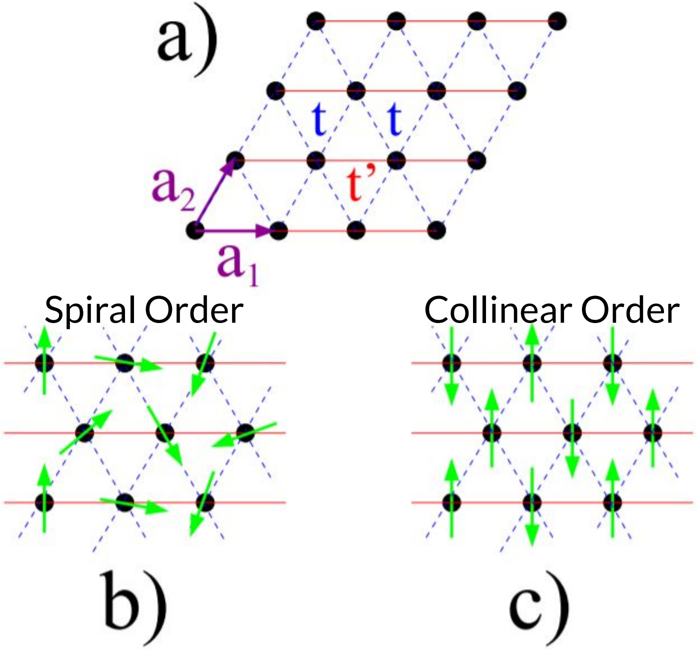
- Frustration is dependent on the geometry of the lattice
- Electron localization is proportional to the number of isolated spins

Kagome Lattice

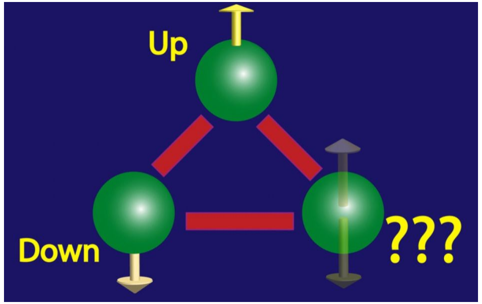


Phase Diagram of Magnetic Ordering on a Triangular Lattice



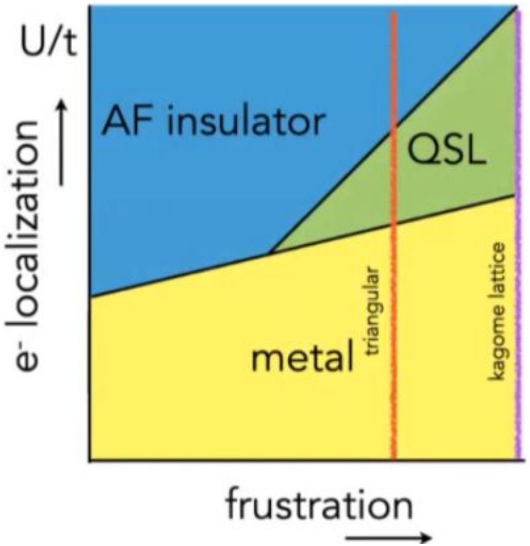


Conclusion



- Quantum Spin Liquids are a phase that a lattice can take on under appropriate frustration and electron occupation conditions

- Triangular Lattices have different magnetic ordering
    - Spin Liquid, Collinear, Spiral, Metal, Unknown regime



References

https://arxiv.org/pdf/1403.4497.pdf

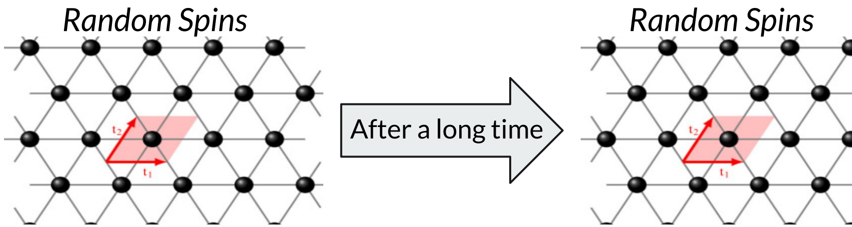
https://guava.physics.uiuc.edu/~nigel/courses/569/Essays_Spring2018/Files/johnson.pdf

https://www.youtube.com/watch?v=CUg-sGeuJA8

Ground State Solution of Triangular Lattice

- Nontrivial
  - A spin liquid configuration does not converge

AFM Behavior for Triangular Lattice



- Superposition of configurations
  - Superposition of different valence band solids (VBS)
  - Each bond has 0 spin

Valence Band Solid