Quantum Paramagnet and Frustrated Quantum Criticality in spin-one diamond lattice

Gang Chen, arXiv 1701.05634

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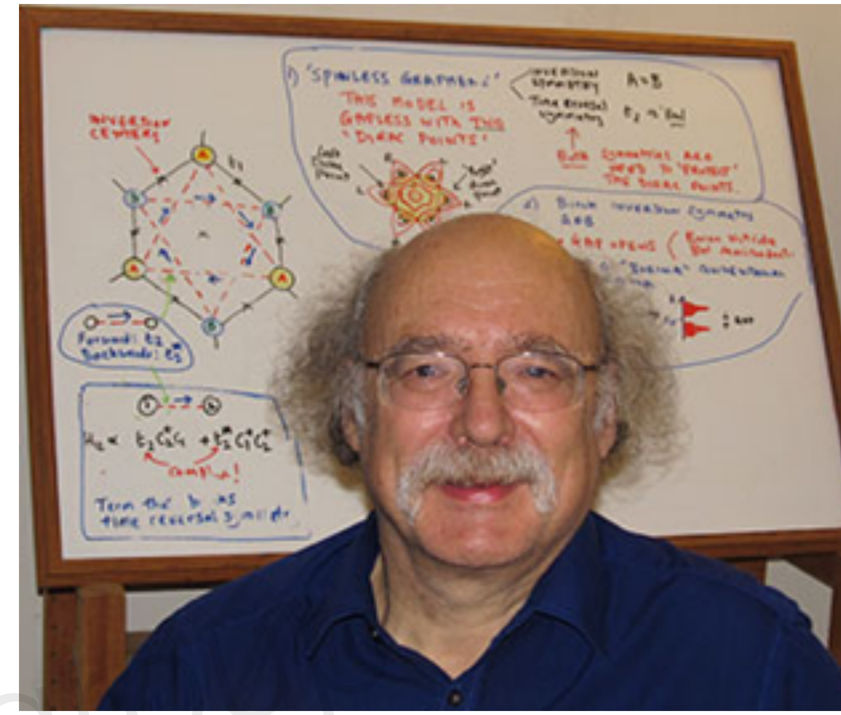
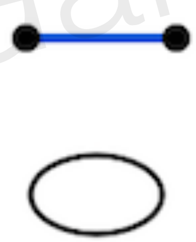
Spin-one Haldane chain

Due to Berry phase effect, spin-1/2 chain is gapless, spin-1 Heisenberg chain is gapped.



Duncan Haldane

S=1 chain



$$= \frac{1}{\sqrt{2}}(\,|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$$

$$= |+\rangle\langle\uparrow\uparrow| + |0\rangle\frac{\langle\uparrow\downarrow| + \langle\downarrow\uparrow|}{\sqrt{2}} + |-\rangle\langle\downarrow\downarrow|$$

AKLT state

Building degree of freedom is S=1, but at there is S=1/2 edge state.

已经被实验证实

Symmetry Protected Topological Phase

Xiao-Gang Wen

Symmetry	$d = 0$	$d = 1$	$d = 2$	$d = 3$
$U(1) \rtimes Z_2^T$	$\mathbb{Z}$	$\mathbb{Z}_2$	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$
Z_2^T	$\mathbb{Z}_1$	$\mathbb{Z}_2$	$\mathbb{Z}_1$	$\mathbb{Z}_2$
$U(1)$	$\mathbb{Z}$	$\mathbb{Z}_1$	$\mathbb{Z}$	$\mathbb{Z}_1$
$SO(3)$	$\mathbb{Z}_1$	$\mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}_1$
$SO(3) \times Z_2^T$	$\mathbb{Z}_1$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2^3$
Z_n	$\mathbb{Z}_n$	$\mathbb{Z}_1$	$\mathbb{Z}_n$	$\mathbb{Z}_1$
$Z_2^T \times D_2 = D_{2h}$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2^4$	$\mathbb{Z}_2^6$	$\mathbb{Z}_2^9$

Table for **boson SPTs**
classified with group cohomology from symmetry and dimension.

It turns out, the well-known topological insulator is a fermion SPT that is protected by time reversal symmetry. Boson SPT must be stabilized by interaction.

重要的问题：理解导致SPT的物理机制，以及在什么物理体系中可以找到。

Senthil's suggestion

PhysRevB, 2015

Topological Paramagnetism in Frustrated Spin-One Mott Insulators

Chong Wang, Adam Nahum, and T. Senthil
Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

(Dated: January 7, 2015)

Time reversal protected three dimensional (3D) topological paramagnets are magnetic analogs of the celebrated 3D topological insulators. Such paramagnets have a bulk gap, no exotic bulk excitations, but non-trivial surface states protected by symmetry. We propose that frustrated spin-1 quantum magnets are a natural setting for realising such states in 3D. We describe a physical picture of the ground state wavefunction for such a spin-1 topological paramagnet in terms of loops of fluctuating Haldane chains with non-trivial linking phases. We illustrate some aspects of such loop gases with simple exactly solvable models. We also show how 3D topological paramagnets can be very naturally accessed within a slave particle description of a spin-1 magnet. Specifically we construct slave particle mean field states which are naturally driven into the topological paramagnet upon including fluctuations. We propose bulk projected wave functions for the topological paramagnet based on this slave particle description. An alternate slave particle construction leads to a stable U(1) quantum spin liquid from which a topological paramagnet may be accessed by condensing the emergent magnetic monopole excitation of the spin liquid.

T. Senthil

The frustrated diamond lattice model appears to describe well [56] the physics of the spinel oxide materials $MnAl_2O_4$ and $CoAl_2O_4$ [58] which belong to a general family of materials of the form AB_2O_4. The A site forms

There is no sharp question in 1D any more. So what is the 3D analogue of Haldane spin-1 phase?

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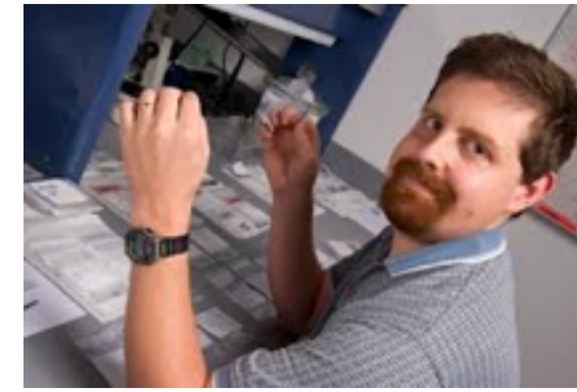

T. McQueen

APS March Meeting 2017

Monday–Friday, March 13–17, 2017; New Orleans, Louisiana

Session B48: Frustrated Magnetism: Spinels, Pyrochlores, and Frustrated 3D Magnets I

11:15 AM–2:15 PM, Monday, March 13, 2017
Room: 395

Sponsoring Units: GMAG DMP
Chair: Martin Mourigal, Georgia Tech

Abstract: B48.00006 : S = 1 on a Diamond Lattice in NiRh2O4

12:15 PM–12:27 PM

Preview Abstract

MathJax ***On*** | *Off*   ← *Abstract* →

Authors:

Juan Chamorro
(Johns Hopkins University)

Tyrel McQueen
(Johns Hopkins University)

An S = 1 system has the potential of rich physics, and has been the subject of intense theoretical work. Extensive work has been done on one-dimensional and two-dimensional S = 1 systems, yet three dimensional systems remain elusive. Experimental realizations of three-dimensional S = 1, however, are limited, and no system to date has been found to genuinely harbor this. Recent theoretical work suggests that S = 1 on a diamond lattice would enable a novel topological paramagnet state, generated by fluctuating Haldane chains within the structure, with topologically protected end states. Here we present data on NiRh2O4, a tetragonal spinel that has a structural phase transition from cubic to tetragonal at T = 380 K. High resolution XRD shows it to have a tetragonally distorted spinel structure, with Ni2+ (d8, S = 1) on the tetrahedral, diamond sublattice site. Magnetic susceptibility and specific heat measurements show that it does not order magnetically down to T = 0.1 K. Nearest neighbor interactions remain the same despite the cubic to tetragonal phase transition. Comparison to theoretical models indicate that this system might fulfill the requirements necessary to have both highly entangled and topological behaviors.

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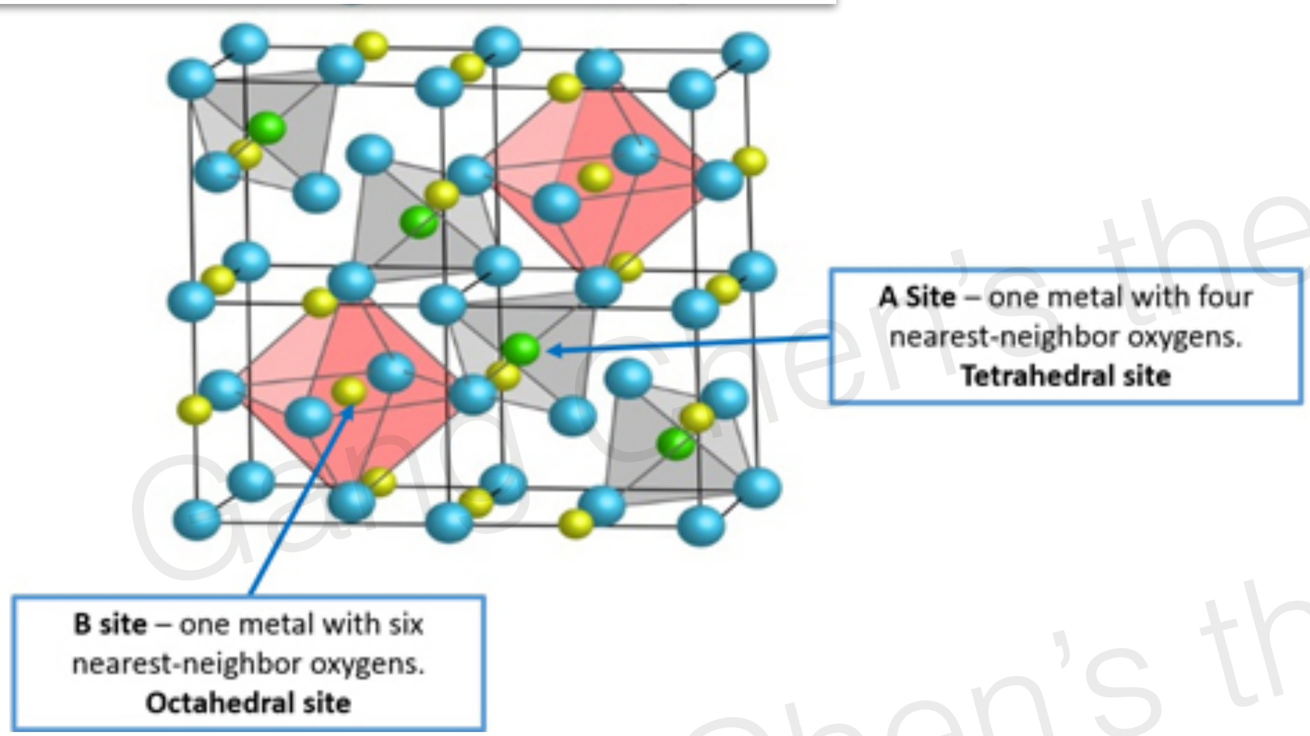
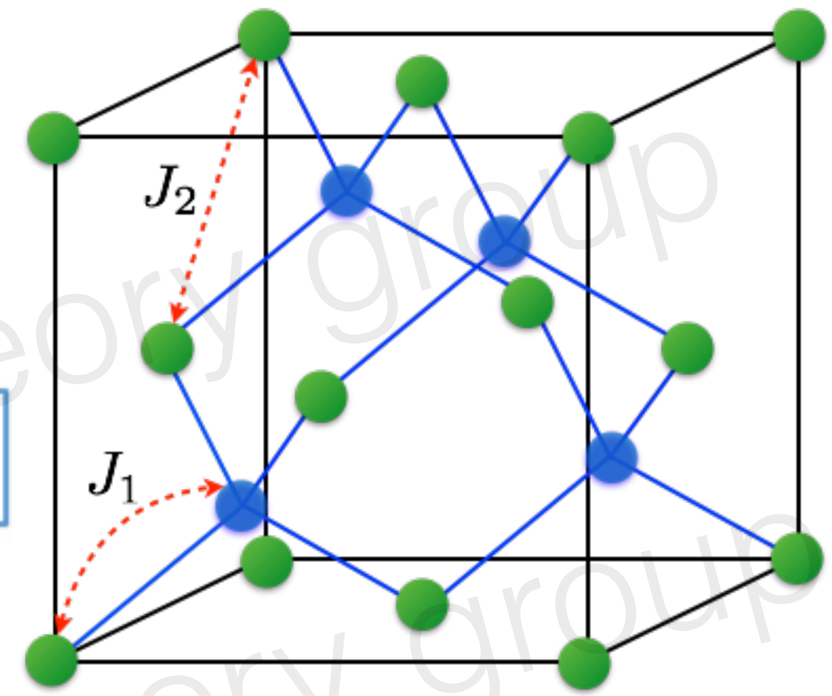
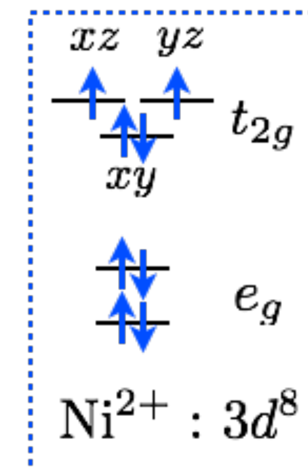
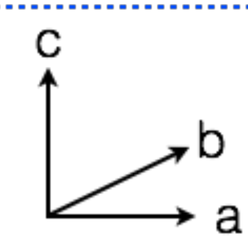
Minimal spin model

Spinel AB_2O_4







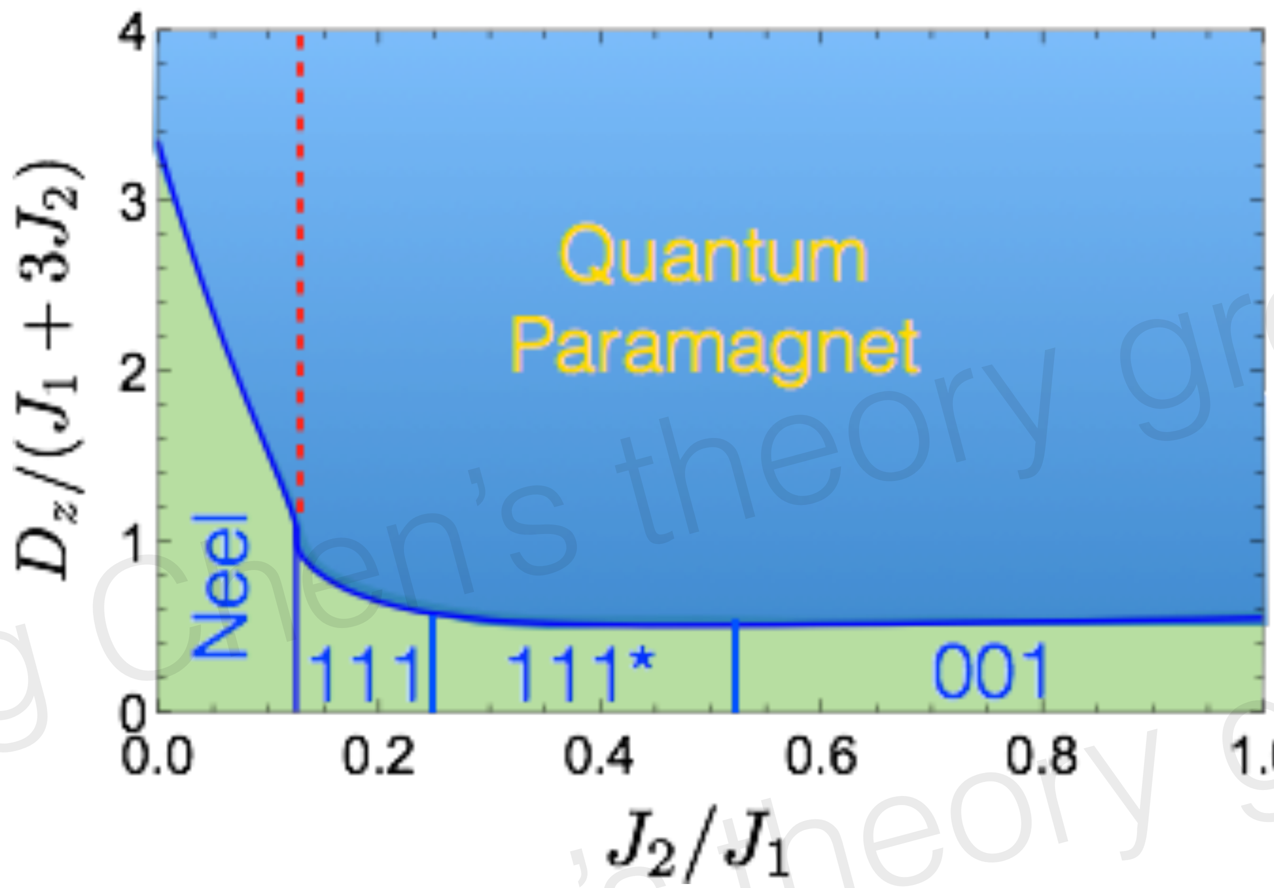


$$H = J_1 \sum_{\langle \boldsymbol{r}\boldsymbol{r}' \rangle} \boldsymbol{S}_{\boldsymbol{r}} \cdot \boldsymbol{S}_{\boldsymbol{r}'} + J_2 \sum_{\langle\langle \boldsymbol{r}\boldsymbol{r}' \rangle\rangle} \boldsymbol{S}_{\boldsymbol{r}} \cdot \boldsymbol{S}_{\boldsymbol{r}'} + D_z \sum_{\boldsymbol{r}} (S^z_{\boldsymbol{r}})^2,$$

Immediate experimental consequence

$$\Theta^z_{\text{CW}} = -\frac{D_z}{3} - \frac{S(S+1)}{3}(z_1 J_1 + z_2 J_2),$$
$$\Theta^{\perp}_{\text{CW}} = +\frac{D_z}{6} - \frac{S(S+1)}{3}(z_1 J_1 + z_2 J_2),$$

The phase diagram

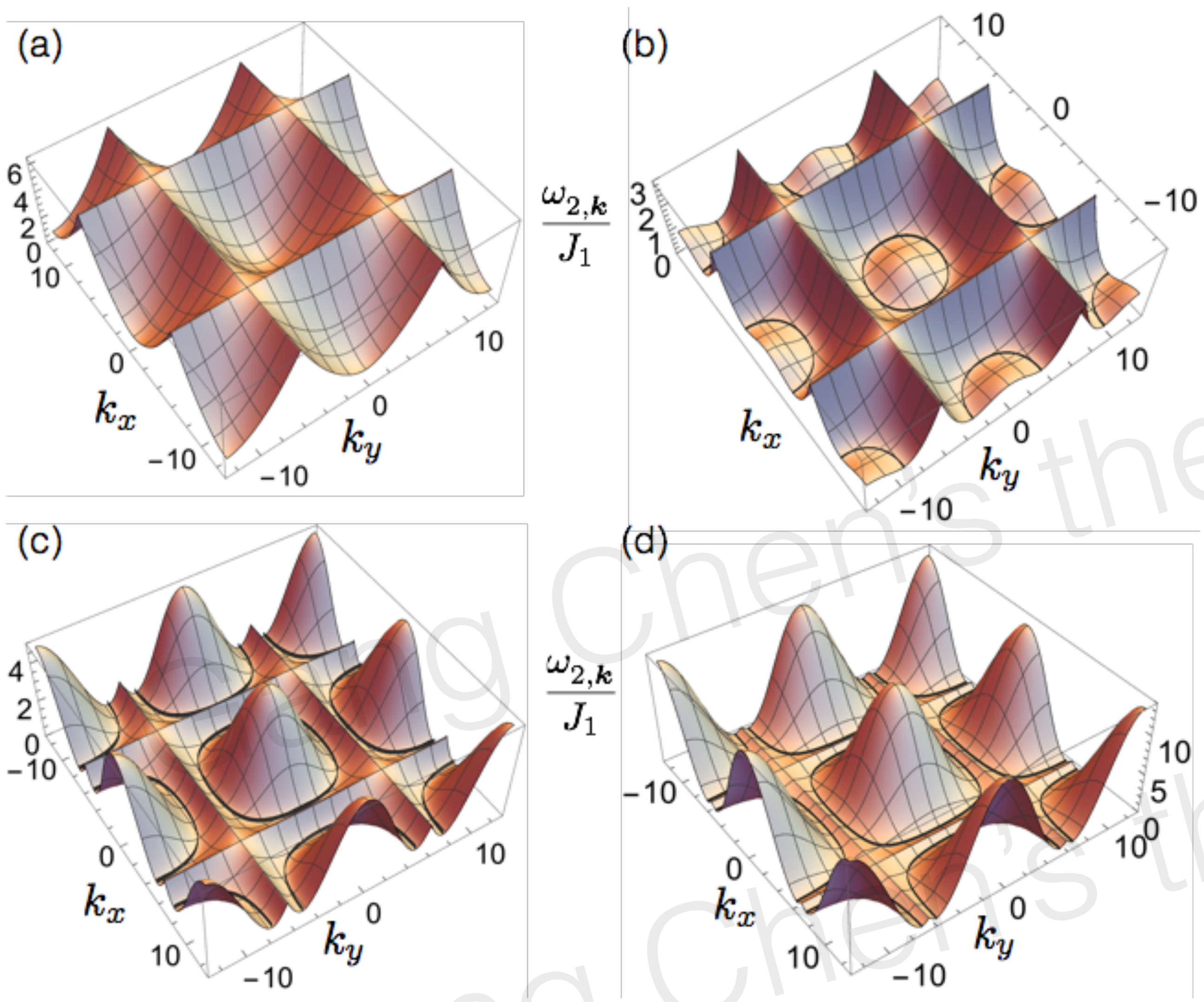


Deep in quantum paramagnet, the ground state is a trivial product state.
The state is trivial, but excitation and phase transition out of it can be non-trivial.

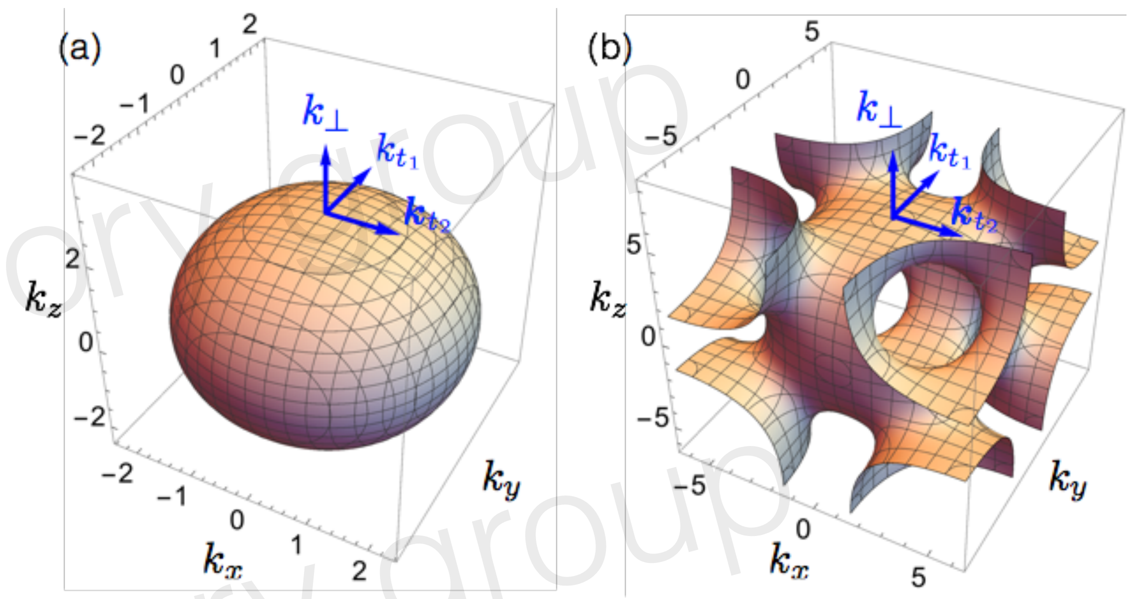
$$|\Psi\rangle = \prod_{\boldsymbol{r}} |S^z_{\boldsymbol{r}} = 0\rangle$$

Unconventional magnetic excitation

$J_2 = 0.05J_1$, $D_z = 3J_1$ $J_2 = 0.18J_1$, $D_z = 1.5J_1$



$J_2 = 0.4J_1$, $D_z = 1.5J_1$ $J_2 = 0.8J_1$, $D_z = 2J_1$

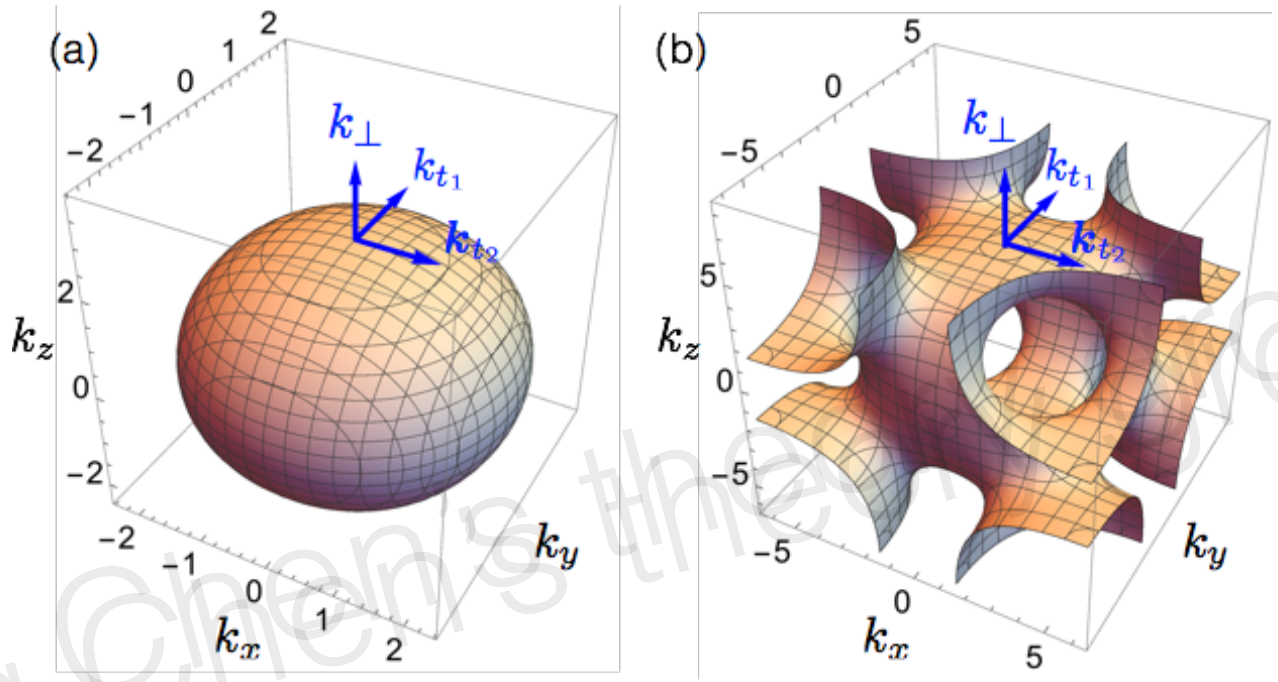


$J_2 = 0.18J_1$ $J_2 = J_1/3$

These are bosonic excitations. What is relevant for bosons is the lowest energy mode. Usually, the lowest energy modes occur at certain discrete momenta. But here, the lowest energy modes occur at a surface in the reciprocal space.

Frustrated Quantum Criticality: collapse of boson surface

$J_2=0.18J_1$



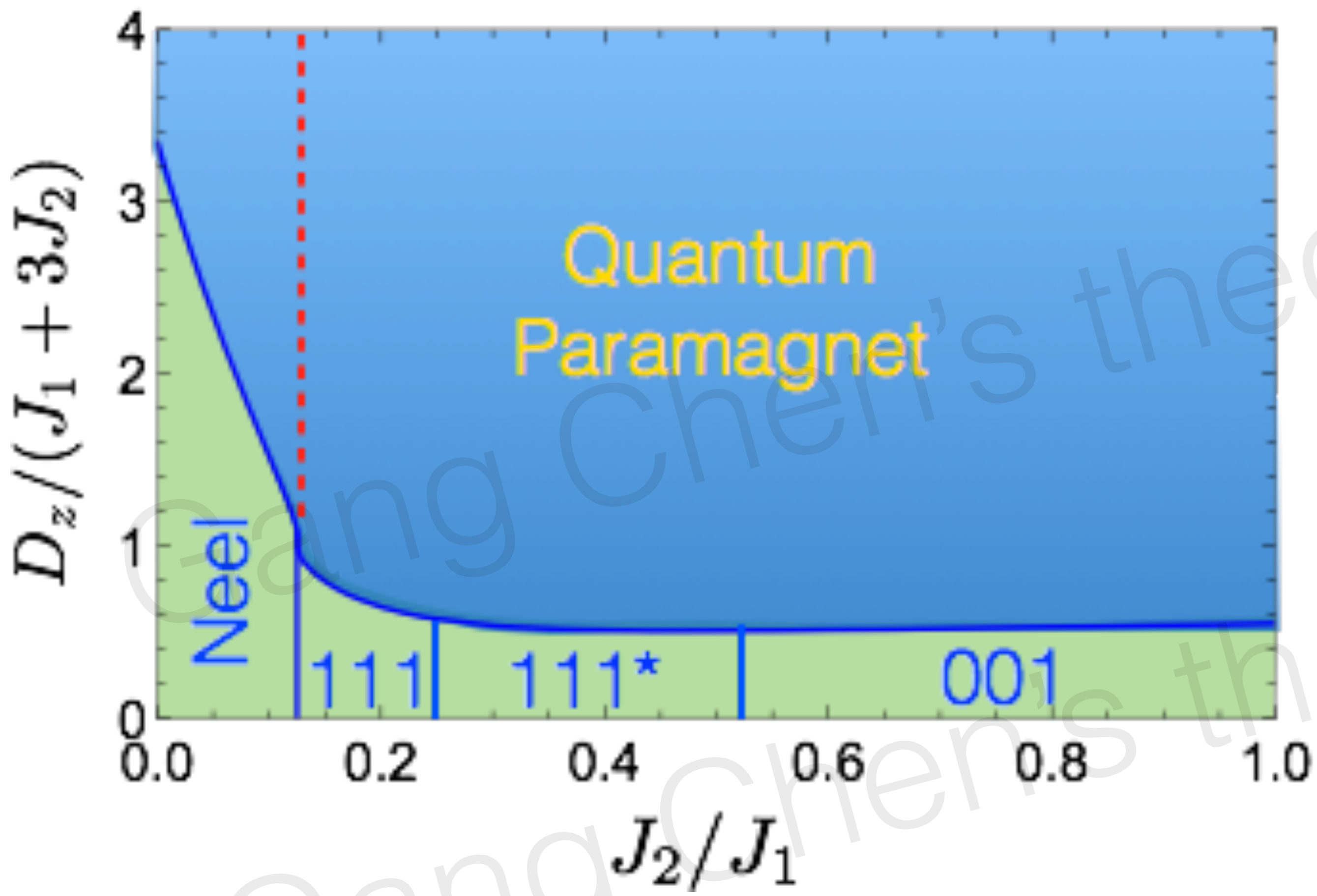
$J_2=J_1/3$

$$\cos\frac{k_x}{2}\cos\frac{k_y}{2}+\cos\frac{k_x}{2}\cos\frac{k_z}{2}+\cos\frac{k_y}{2}\cos\frac{k_z}{2}=\frac{J_1^2}{16J_2^2}-1$$

These degenerate surfaces are NOT Fermi surface !

But at low temperature, the fluctuation of the system is governed by the surface, i.e. low-energy fluctuations are near the 2D surface.
We obtain a linear-T heat capacity **$C_v \sim T$,** which is like a Fermi surface.

Degeneracy breaking in the ordered side



Here, because infinite number of boson modes are condensed, the system does not know which order to select.

So quantum fluctuation will pick up the order that gives the lowest quantum zero-point energy.

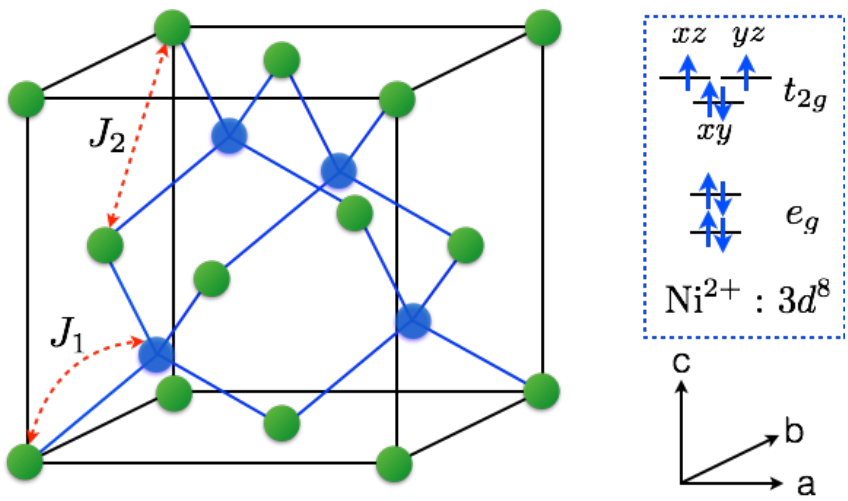
Summary

1. We point out that $NiRh_2O_4$ spin-1 diamond lattice antiferromagnet is NOT the topological quantum paramagnet.

2. Through a minimal model, we find that the ground state can be a trivial quantum paramagnet. But due to the frustrated interaction, the excitations with respect to this trivial state develop an extensively degenerate minima in the reciprocal space.

3. Moreover, as the system approaches the phase transition to a magnetic order, these extensively degenerate low-energy bosonic modes condense at the same time, leading to an unusual critical behavior.

Quantum Paramagnet and **Frustrated Quantum Criticality** in spin-1 diamond lattice



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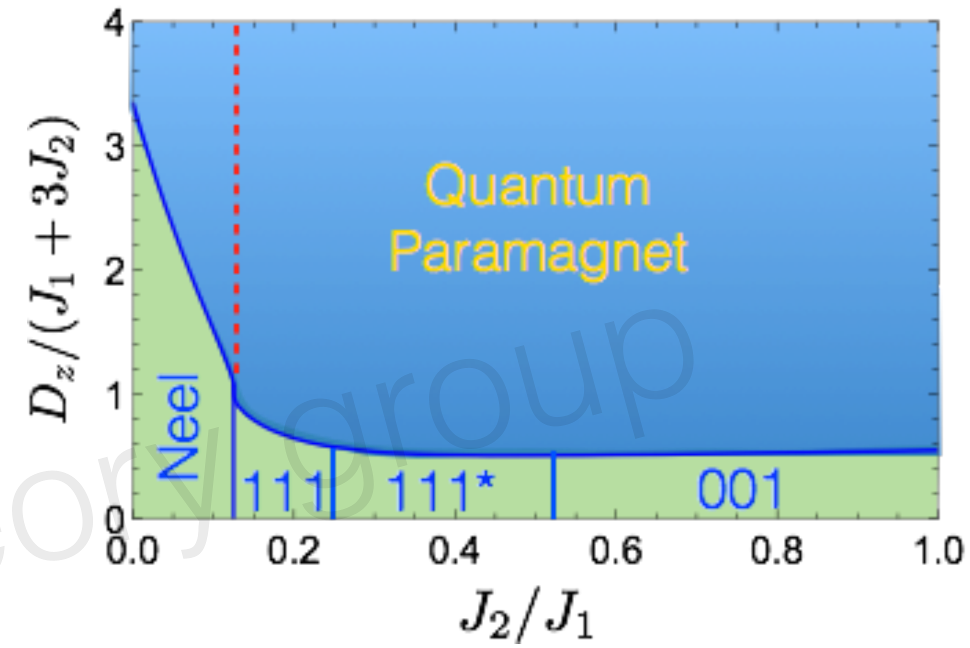
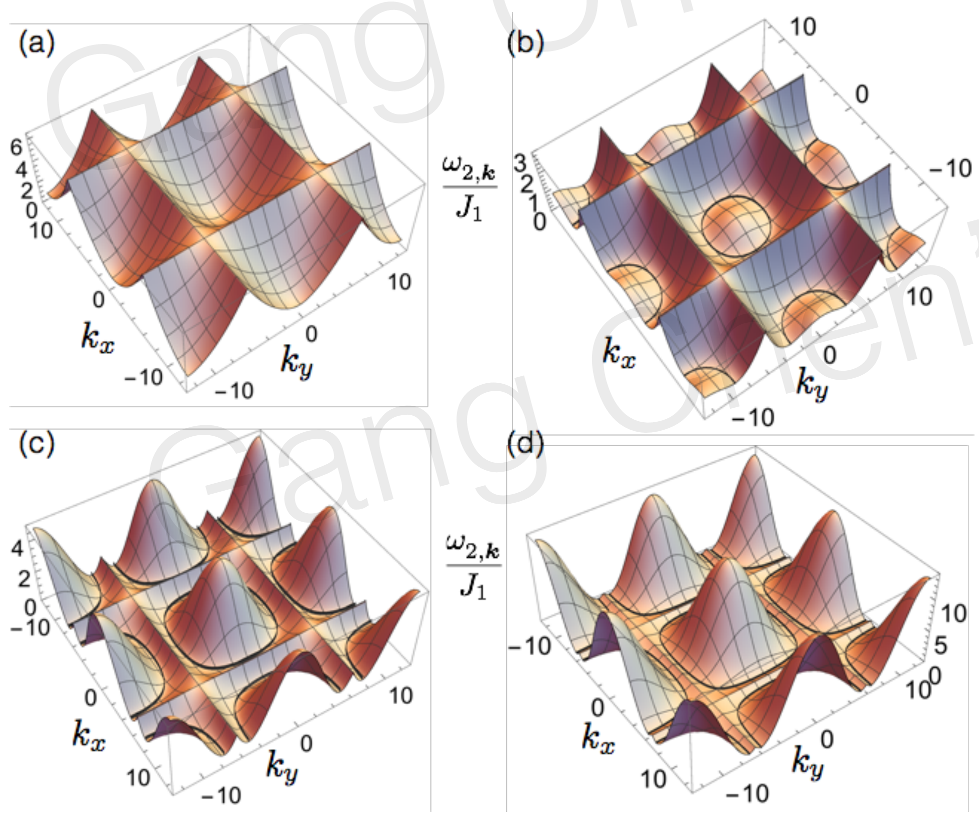
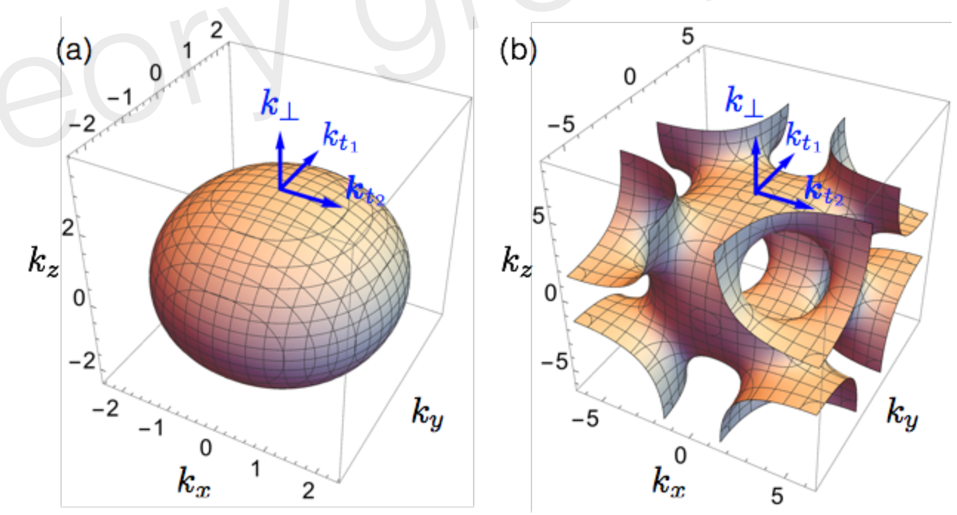


Phase diagram



Magnetic excitation in the kx-ky plane



degenerate minima of the excitations
in quantum paramagnet

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