

**СПИНОВЫЕ СПИРАЛИ В МАГНИТНОМ ПОЛЕ
БОЗЕ-ЭЙНШТЕЙНОВСКАЯ КОНДЕНСАЦИЯ
МАГНОНОВ В MnSi**

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ФГБУ ПИЯФ

**Школа
ФКС-2013**

ПРОБЛЕМА

В В20 МАГНЕТИКАХ АНИЗОТРОПИЯ МАЛА И
ОСЬ СПИРАЛИ ОРИЕНТИРУЕТСЯ ПО ПОПЮ

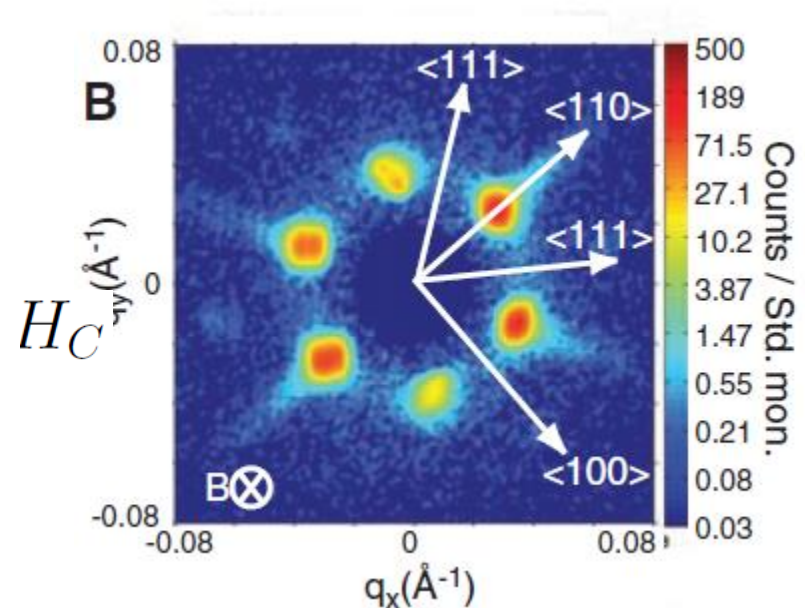


В ИНТЕРВАЛЕ ПОЛЕЙ

$$H_{C1} < H < H_{C2} < H_C$$

ОСЬ ПЕРПЕНДИКУЛЯРНА ПОЛЮ ОБРАЗУЕТСЯ ГЕКСАГОН

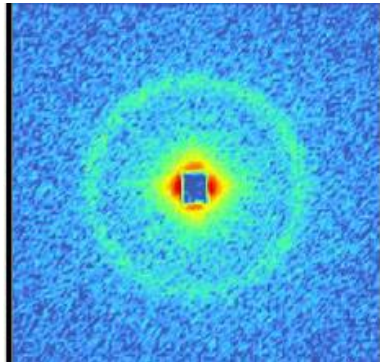
РЕШЕТКА СКРМИОНОВ???



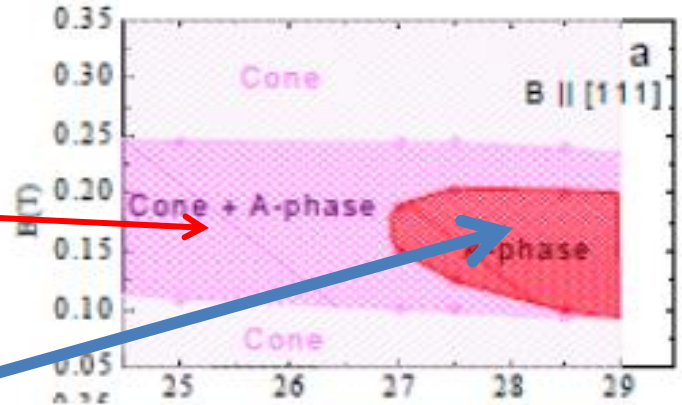
**ВЕКТОР k РЕШЕТКИ ТАКОЙ ЖЕ ПО ВЕЛИЧИНЕ КАК И
ВЕКТОР СПИРАЛИ ПРИ $H = 0$**

**В ОБОИХ СЛУЧАЯХ k ПЕРИОД ОПРЕДЕЛЯЕТСЯ
ОТНОШЕНИЕМ ОБМЕНА К ВЗАИМОДЕЙСТВИЮ
ДЗЯЛОШИНСКОГО-МОРИА**

**ПЕРПЕНДИКУЛЯРНАЯ ФАЗА ГЕКСАГОНАЛЬНОЙ
(С.В. ГРИГОРЬЕВ И ДР.)**



**НЕУПОРЯДОЧЕННАЯ
ПЕРПЕНДИКУЛЯРНАЯ
← ФАЗА**



ГЕКСАГОН

ФАЗОВАЯ ДИАГРАММА

**РАССЕЯНИЕ
НЕЙТРОНОВ**

ЧТО ПОВОРАЧИВАЕТ ОСЬ СПИРАЛИ ПЕРПЕНДИКУЛЯРНО ПОЛЮ?

ПОЧЕМУ ГЕКСАГОН ВОЗНИКАЕТ С РОСТОМ ТЕМПЕРАТУРЫ?

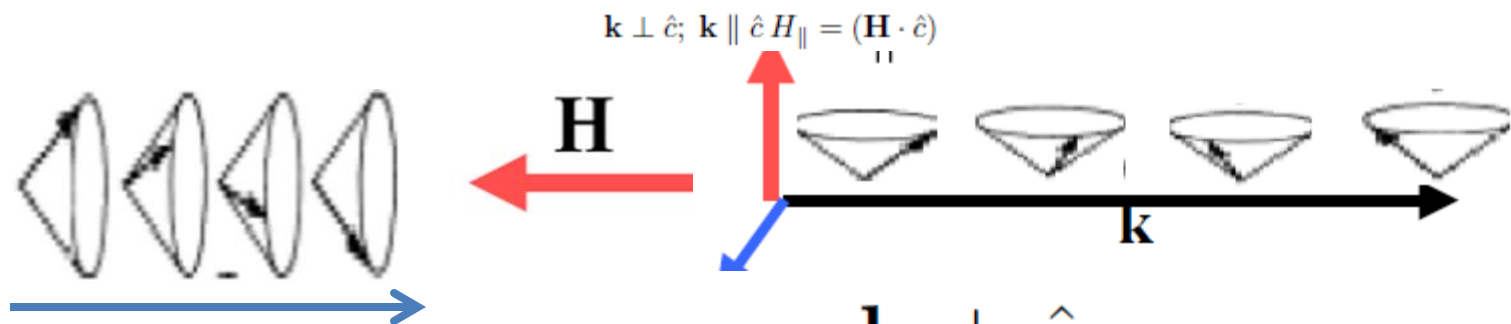
KAPLAN HEIX

$$S_{\mathbf{R}} = \mathbf{A} S_{\mathbf{R}}^A e^{i\mathbf{k} \cdot \mathbf{R}} + \mathbf{A}^* S_{\mathbf{R}}^{A*} e^{-i\mathbf{k} \cdot \mathbf{R}} + \hat{c} S_{\mathbf{R}}^c,$$

$$\mathbf{A} = (\hat{a} - i\hat{b})/2 \quad \hat{a} \times \hat{b} = \hat{c}$$

CORRECT COMMUTATION IN EACH LARRUC POINT

TWO INDEPENDENT VECTORS: \mathbf{k} AND \hat{c}



$\mathbf{k} \parallel \hat{c}$ **MnSi**

**CYCLOID
MULTIFERROICS**

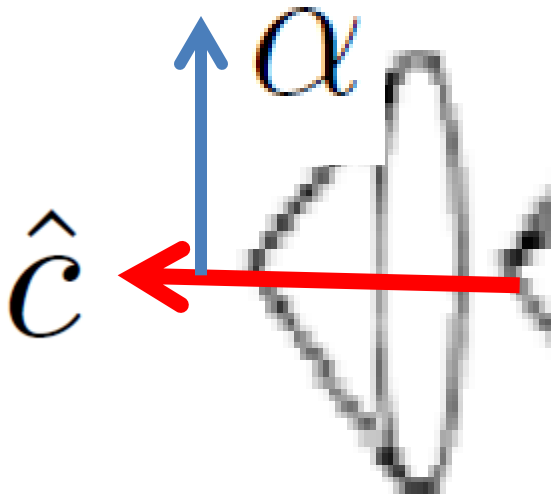
ZEEMAN ENERGY

$$]H_Z = (\mathbf{H} \cdot \mathbf{S}_{q=0} = H_{\parallel} S_0^c + S_{-\mathbf{k}}^A (\mathbf{H} \cdot \mathbf{A}) + S_{\mathbf{k}}^{A^*} (\mathbf{H} \cdot \mathbf{A}^*)$$

$$H_{\parallel} = (\mathbf{H} \cdot \hat{\mathbf{c}})$$

PARALLEL FIELD INCLINES
SOINS TO $\hat{\mathbf{c}}$ PLAIN ON ANGLE α

PERPENDICULAR FIELD FREEZES
SPIN HARMONICS WITH $\pm \mathbf{k}$



SPIN STRUCTURE

ζ η

ζ

H=0, ROTATE ζ AND η SPIN COMPONENTS

ξ REMAINS TABLE

ζ

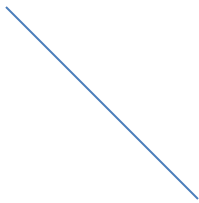
FIELD MIXES ζ AND ξ COMPONENTS

ζ

$$S_{\mathbf{R}}^{\mathbf{A}} = (S_{\mathbf{R}}^{\zeta} \cos \alpha + i S_{\mathbf{R}}^{\eta} - S_{\mathbf{R}}^{\xi} \sin \alpha$$

$$S_{\mathbf{R}}^{\mathbf{A}*} = S_{\mathbf{R}}^{\zeta} \cos \alpha - i S_{\mathbf{R}}^{\eta} - S_{\mathbf{R}}^{\xi} \sin \alpha$$

$$\xi_{\mathbf{R}}^c = S_{\mathbf{R}}^{\zeta} \sin \alpha + S_{\mathbf{R}}^{\xi} \cos \alpha$$



HAMILTONIAN

$$H = -(1/2) \sum J_{\mathbf{R},\mathbf{R}'} \mathbf{S}_{\mathbf{R}} \cdot \mathbf{S}_{\mathbf{R}'} + \sum (\mathbf{D}_{\mathbf{R},\mathbf{R}'} \cdot [\mathbf{S}_{\mathbf{R}} \times \mathbf{S}_{\mathbf{R}'}]) + \mathbf{H} \sum S_{\mathbf{R}},$$

DZYALOSHINSKII VECTOR

$$\underline{\mathbf{D}_{\mathbf{R},\mathbf{R}'} = -\mathbf{D}_{\mathbf{R}',\mathbf{R}}}$$

IN MOMENTUM SPACE

$$H = -(1/2) \sum J_{\mathbf{q}} \mathbf{S}_{\mathbf{q}} \cdot \mathbf{S}_{-\mathbf{q}} + \sum \mathbf{D}_{\mathbf{q}} [\mathbf{S}_{\mathbf{q}} \times \mathbf{S}_{-\mathbf{q}}] + N^{1/2} (\mathbf{H} \cdot \mathbf{S}_0)$$

(0)

MnSi

MnSi

$$J_{\mathbf{q}} = J_0 - Aq^2/S, \quad \mathbf{D}_{\mathbf{q}} = iD\mathbf{q},$$

CLASSICAL ENERGY

$$S_{\mathbf{R}}^{\zeta} = S, \quad S_{\mathbf{R}}^{(\eta \ xi)} = 0$$
$$E_{CL} = -\frac{S^2}{2} \left[J_0 - \frac{Ak^2}{S} + 2D\mathbf{k} \cdot \hat{c} - Ak^2 \sin^2 \alpha \right] + SH_{\parallel} \sin \alpha$$

$$\mathbf{k} = \frac{SD\hat{c}}{A}; \quad \sin \alpha = -\frac{H_{\parallel}}{Ak^2} \quad E_{CL} = -\frac{SH^2}{2Ak^2}$$

FERROMAGNETIC TRANSITION

$$H_C = Ak^2$$

FROZEN HARMONICS

BILINEAR APPROXIMATION

$$S_{\mathbf{k}}^{\zeta} = S\delta_{\mathbf{q},0} - (a_{\mathbf{k}}^+ a_0 + a_0^+ a_{-\mathbf{k}}) - a_{2\mathbf{k}}^+ a_{\mathbf{k}} - \dots;$$

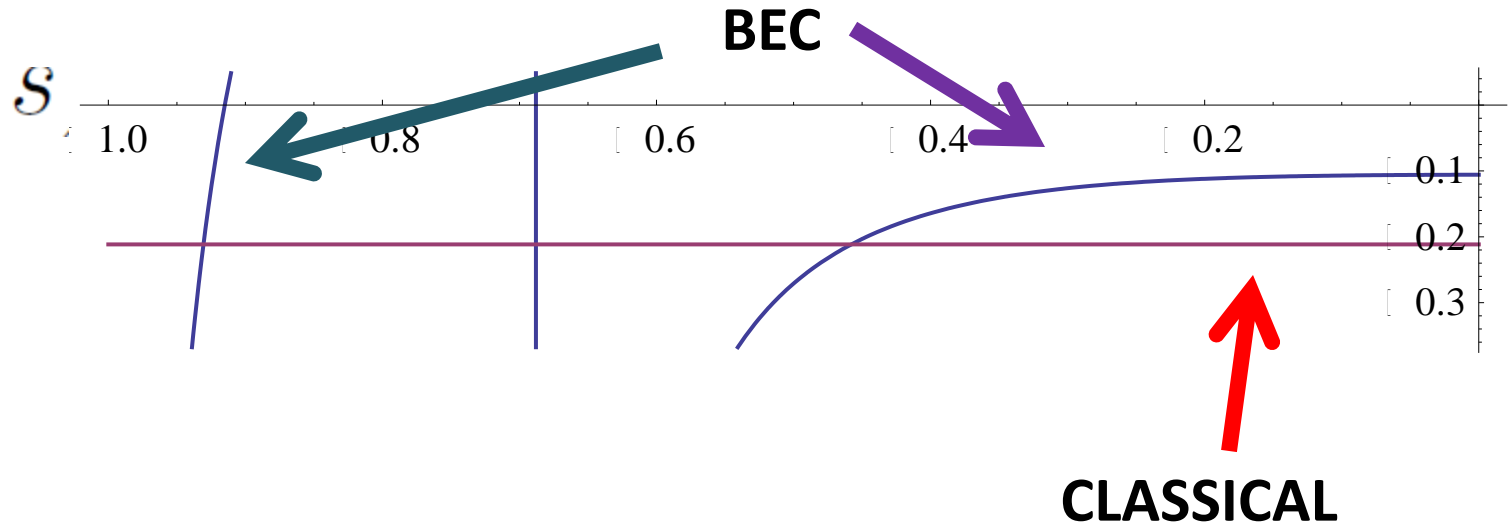
$$S_{\mathbf{k}}^{\eta} = -i\sqrt{S/2}(a_{-\mathbf{k}} - a_{\mathbf{k}}^+);$$

$$S_{\mathbf{k}}^{\xi} = \sqrt{S/2}(a_{-\mathbf{k}} + a_{\mathbf{k}}^+)$$

**BOSE-EINSTEIN
CONDENSATION**

a, a^+ **CLASSICAL VARIABLES**

$$W_{\perp}(H_{C1} = 0.46Ak^2) \quad p = H_{\perp}/H_C$$



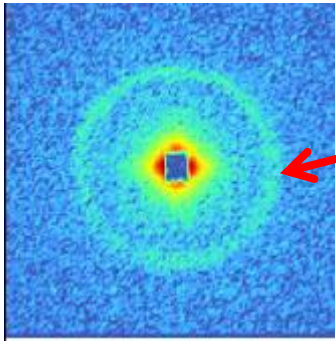
$$W_{\perp} = \frac{p^2}{2 \cos^2 \alpha} - \frac{\sin^4 \alpha (1 - p^2/4 \cos^2 \alpha)}{1 - \underset{\text{POLE}}{2 \sin^2 \alpha} - p^2/4}$$

UPPER CRITICAL FIELD CAN NOT BE FOUND IN LINEAR APPROXIMATION

PERPENDICULAR PHASE STRUCTURE

FIRST ORDER TRANSITION-> PERPENDICULAR CLUSTERS IN
CONE BACKGROUND.

CLUSTERS INTERACT AS MAGNETIC DIPOLES.



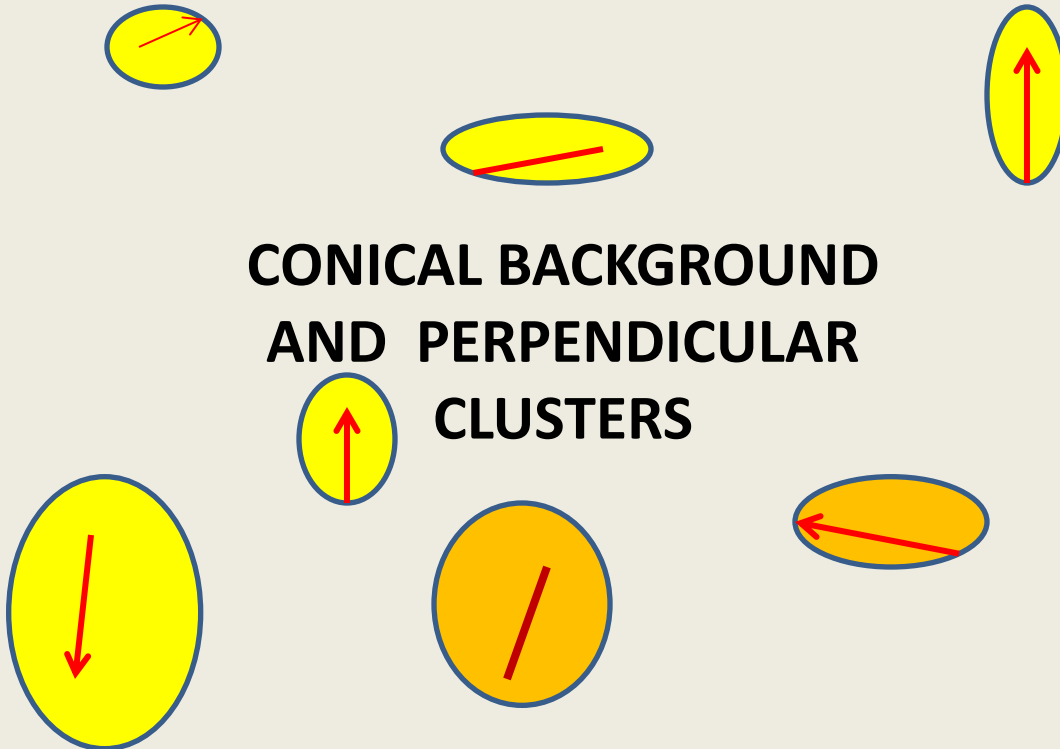
RING RADIUS λk
THICKNESS $\delta k \sim 0.1 - 0.2k$

CLUSTER
SCATTERING

CLUSTER SIZE N PERPENDIQUALAR TO FIELD
DIRECTION

$$D \sim (2\lambda k)(k/\delta k) \sim 90 = 180nm$$

**CONICAL BACKGROUND
AND PERPENDICULAR
CLUSTERS**



CLUSTER SIZE AND CONCENTRATION INCREASE WITH T AND H

LOW T BIPOLAR GLASS

$T \rightarrow T_C$ **REENTRANT TRANSITION TO
MAGNETICALLY ORDERED STATE**

**HEXAGONAL STRUCTURE (SKYRMION LATTICE) HAS
MINIMAL MAGNETIC ENERGY**

**NATURAL EXPLANATION: LATTICE PERIOD IS THE SAME AS
THE HELIX ONE AT T=0**

CONCLUSIONS

IN CLASSICAL APPROXIMATION THE HELIX ENERGY DEPENDS ON THE FIELD PERPENDICULAR TO THE SPIN ROTATION PLANE (ALONG k FOR MnSi).

OTHER FIELD COMPONENT LEADS TO MAGNON BEC

IN MnSi BEC GIVES RISE TO THE FIRST ORDER TRANSITION TO PERPENDICULAR k ORIENTATION

REENTRANT PHASE TRANSITION IN PERPENDICULAR STATE ALLOW TO UNDERSTAND QUALITATIVELY ORIGIN OF THE SO CALLED SKYRMION LATTICE

**THANKS FOR
YOUR
ATTENTION!**