Experimental report

05/06/2024

Proposal: **5-54-408** **Council:** 4/2023

Title: Probing Multi-q Order in a Eu Triangle Lattice with CryoPAD at THALES

Research area: Physics

This proposal is a new proposal

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Samples: EuAg4Sb2

Instrument	Requested days	Allocated days	From	To
THALES	4	7	26/10/2023	30/10/2023
			05/12/2023	08/12/2023
ORIENTEXPRESS	1	2	25/10/2023	26/10/2023
			04/12/2023	05/12/2023

Abstract:

We have recently synthesized and characterized a centrosymmetric europium triangle lattice material, EuAg4Sb2, which displays evidence of multi-q incommensurate magnetic structures in preliminary small angle neutron scattering (SANS) measurements. The magnetic textures in this material are complex and evade characterization with standard probes of such skyrmion-like textures such as Lorentz transmission electron microscopy (LTEM). In order to investigate the complex multi-q textures in the magnetic phases in EuAg4Sb2, we propose four days of measurements at THALES with CryoPAD to perform spherical neutron polarimetry measurements at several key points in the temperature-field phase diagram.

Experimental report for Proposal 5-54-408

Probing Multi-q Order in a Eu Triangle Lattice with CryoPAD at THALES

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Orient Express: 1 day – 25/10/2023 to 26/10/2023

ThALES + CryoPAD: 4 days – 26/10/2023 to 30/10/2023

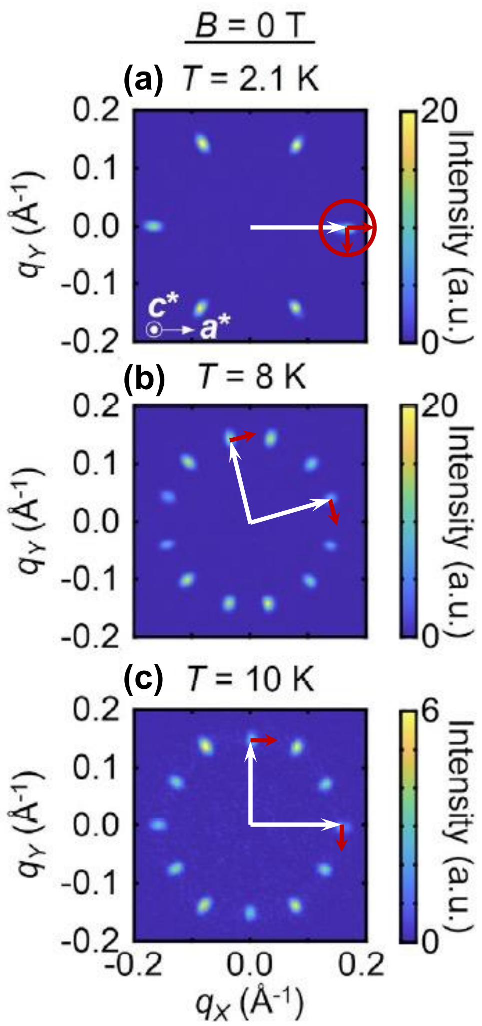

***Figure 1:** (a-c) SANS of ICM1, ICM2, and ICM3 at 0 T and 2.1 K, 8 K, and 10 K, respectively. White arrows represent one single-q domain for ICM1 and one double-q domain for ICM2 and ICM3. Red arrows indicate spin orientation for each q vector as inferred from polarized neutron measurements during this experiment. ICM1 is an in-plane cycloid.*

Overview

For this experiment, two samples of approximate size 5x5x0.1 mm^3 of an Eu triangle lattice compound were prepared on aluminum plates with GE varnish. Both samples were aligned within 1 degree of the desired scattering plane, falling within the vertical divergence of ThALES, as CryoPAD does not permit adjustment of the sample angle. The first sample was loaded first in the H0L scattering plane, then the second sample was loaded rotated about the c axis by 16 degrees to access an incommensurate magnetic peak in ICM2 that does not lie in a high symmetry plane. Finally, the first sample was reoriented to the HHL scattering plane to observe additional magnetic peaks in ICM3.

1.3 meV neutrons were used with a 40' collimator for all measurements. Only elastic measurements were made. The c-axis lattice constant is 24.8 angstroms and the a-axis is 4.7 angstroms (spacegroup 166), so the 101, 102, 104, 105, 003, and 006 nuclear peaks were accessible. The incommensurate peaks at ~(0.1,0,0.05) were also accessible in the zeroth zone, 5 to 6 degrees from the direct beam. This allowed measuring spherical neutron polarimetry directly along the principal magnetic propagation vector in all three phases. Measuring the magnetic satellites around 006 was also extremely helpful as it is nearly 90 degrees rotated from the principal vector. Through these two measurements, determination of the full spin vector information along all three directions was possible for all magnetic propagation vectors. Measuring the polarization matrix with sufficient statistics took approximately 4-6 hours per magnetic peak. Additionally, we found that a background measurement at 15 K above the ordering temperature was quite effective.

In ICM1 and ICM3, the peaks in the H0L plane were measured around 000, 101, 102, 104, 105, 003, and 006 enabling various consistency checks. In ICM2 and the ICM3 peak in the HHL plane, the peaks were measured around 000, 003, and 006. Based on these measurements, in zero field ICM2 and ICM3 are (double-*q*) spin density waves with spin close to or aligned perpendicular to *q* and the *c*-axis, and ICM1 is a (single-*q*) proper cycloid with spins close to or within the *ab*-plane.

Primary Results

All following results background subtracted. Statistical (one sigma) errors shown in following. Counts in right column not time-normalized.

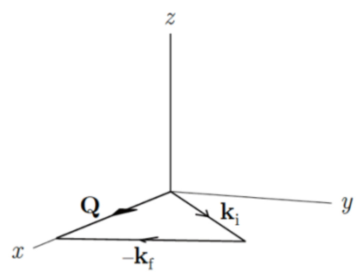

Figure 2: *Convention for polarization x, y, and z axes relative to scattering plane. From Boothroyd 2020.*

<u>ICM1</u>

P_{ab} and polarized scattering rates in ICM1 000+q_{ICM1} magnetic peak:

-1.001(36)	-0.069(23)	0.024(33)
0.089(25)	-0.922(30)	-0.065(34)
0.081(21)	-0.091(19)	0.987(25)

S_y^{NM}: -8(31)
S_z^{NM}: 121(75)
S_{yy}^{M}: 66(55)
S_{zz}^{M}: 3981(67)
T_{yz}^{M}: -89(58)

P_{ab} and polarized scattering rates in ICM1 006+q_{ICM1} magnetic peak:

-0.900(45)	-0.103(48)	-0.006(47)
0.151(38)	-0.012(37)	0.013(41)
0.093(37)	-0.013(36)	0.063(39)

S_y^{NM}: 23(19)
S_z^{NM}: -26(22)
S_{yy}^{M}: 596(24)
S_{zz}^{M}: 672(25)
T_{yz}^{M}: -205(28)

Notes: Proper cycloid close to or within the ab-plane. Note finite T_{yz} term in 006+q_{ICM1} peak consistent with multiple domains of cycloid, also marginally present in off-diagonal (bold) components of P_{ab} which should equal $-T_{yz}^M/(S_{yy}^M+S_{zz}^M)=0.16$.

<u>ICM2</u>

P_{ab} and polarized scattering rates in ICM2 000+q_{ICM2} magnetic peak:

-1.32(27)	0.207(46)	-0.039(56)
-0.099(61)	-0.96(18)	-0.015(58)
0.081(45)	0.078(50)	0.81(12)

S_y^{NM}: 52(59)
S_z^{NM}: 70(100)
S_{yy}^{M}: 58(73)
S_{zz}^{M}: 1878(90)
T_{yz}^{M}: -63(57)

P_{ab} and polarized scattering rates in ICM2 006+q_{ICM2} magnetic peak:

-1.009(68)	-0.123(56)	0.078(78)
0.164(64)	-0.993(57)	-0.019(85)
-0.005(49)	0.062(48)	0.876(63)

S_y^{NM}: 16(80)
S_z^{NM}: 5(22)
S_{yy}^{M}: 6(19)
S_{zz}^{M}: 681(21)
T_{yz}^{M}: -4(22)

Notes: Spin density wave with spin close to or within the ab-plane perpendicular to q_{ICM2}.

<u>ICM3</u>

P_{ab} and polarized scattering rates in ICM3 000+q_{ICM3} magnetic peak:

-0.911(76)	0.037(33)	0.080(40)
0.024(36)	-0.869(70)	-0.068(47)
0.116(32)	-0.085(32)	0.915(59)

S_y^{NM}: 124(42)
S_z^{NM}: -113(75)
S_{yy}^{M}: 36(56)
S_{zz}^{M}: 2121(67)
T_{yz}^{M}: -13(50)

P_{ab} and polarized scattering rates in ICM3 006+q_{ICM3} magnetic peak:

			S_y^{NM}: 30(13)
-1.07(28)	0.14(16)	-0.03(17)	S_z^{NM}: 21(32)
-0.05(14)	-0.69(30)	-0.11(18)	S_{yy}^{M}: 9(26)
-0.06(16)	-0.09(11)	0.95(29)	S_{zz}^{M}: 303(34)
			T_{yz}^{M}: 14(28)

P_{ab} and polarized scattering rates in ICM3 000+q'_{ICM3} magnetic peak:

			S_y^{NM}: 54(67)
-0.963(33)	-0.005(18)	-0.002(26)	S_z^{NM}: 130(130)
0.020(21)	-0.895(30)	-0.010(27)	S_{yy}^{M}: -9(96)
0.054(16)	-0.020(17)	0.921(23)	S_{zz}^{M}: 9890(110)
			T_{yz}^{M}: -146(90)

P_{ab} and polarized scattering rates in ICM3 006+q'_{ICM3} magnetic peak:

			S_y^{NM}: -11(11)
-0.934(38)	-0.095(37)	0.059(54)	S_z^{NM}: 6(35)
0.084(37)	-0.921(36)	0.019(54)	S_{yy}^{M}: 32(30)
0.080(33)	-0.043(30)	0.977(38)	S_{zz}^{M}: 2011(33)
			T_{yz}^{M}: -73(36)

Notes: Spin density wave with spin close to or within the ab-plane perpendicular to q_{ICM3} *and* q'_{ICM3}.

Important Conclusions

- In zero field, ICM1 is a (slightly ellipsoidal) cycloid with spins lying close to or within the *ab*-plane.
- In zero field, ICM2 and ICM3 are spin density waves with spin close to or aligned perpendicular to *c* and the propagation vector *q*.
- ICM1 shows some chiral scattering, T_{yz}, around 006 (as is expected for a cycloid in the *ab*-plane). This is visible in the imbalance between $I(X\uparrow \rightarrow X\downarrow)$ and $I(X\downarrow \rightarrow X\uparrow)$, and from the P_{yx} and P_{yz} terms in the full polarization matrix.

Recommended Future Experiments

- Determine evolution of these textures from the solved zero field to finite field to see if any phase transitions or spin texture evolution occur.
- Determine if T_{yz} can be enhanced by field cooling before inserting into CryoPAD to determine if the sense of rotation of the cycloid can be altered.