# Experimental report

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**Proposal:** 5-54-410 **Council:** 4/2023

**Title:** Noncollinear magnetism in hexagonal MnPdGa thin films

**Research area:** Physics

**This proposal is a new proposal**


**Main proposer:** Rebeca IBARRA

**Experimental team:** Bachir OULADDIAF

**Local contacts:** Bachir OULADDIAF


**Samples:** MnPdGa

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| D10 | 10 | 10 | 11/09/2023 | 21/09/2023 |


## Abstract:

Complex noncollinear magnetic structures attract great attention due to various associated emergent phenomena, such as the (anti)skyrmions lattice, a magnetic structure of topologically protected spin vortices. The formation of these nano-objects is usually associated to non-centrosymmetric materials, where the Dzyaloshinsky-Moriya interaction plays a crucial role. However, the recent discovery of biskyrmions up to room temperature in the centrosymmetric hexagonal MnPdGa magnet, opens the door to potential spintronic applications of the centrosymmetric materials, given that the control and manipulation of skyrmions/biskyrmions will be crucial in the development of high-density magnetic storage devices. In this proposal, we will quantify the spin canting of a 60 nm MnPdGa thin film by means of single-crystal neutron diffraction. At the moment, there are no reported studies of the magnetic properties of this compound in thin single-crystalline films. Our previous SCND experiments performed at D10 (ILL) proves that this methodology is successful for the quantification of spin canting in thin films.

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*Noncollinear magnetism in hexagonal MnPdGa thin films.*

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## Introduction

Magnetic systems exhibiting spin-canted states have lately garnered much attention, promising rich exotic properties driven by their real space spin-textures and competing magnetic orders. In this work, we study the magnetic ground state of hexagonal $h$-MnPdGa epitaxial thin films (40 nm thickness) grown by magnetron sputtering on $Al_2O_3(0001)$ single crystalline substrate. The MnPdGa film crystalizes in the centrosymmetric $P6_3/mmc$ (no. 194) space group, displaying perpendicular magnetic anisotropy and a second order phase transition at the Curie point ($T_C = 312$ K). A second transition is identified by SQUID-VSM magnetometry at $T_sr \approx 140$ K. In order to examine the temperature evolution of the magnetic structure, we performed single-crystal neutron diffraction in the D10 four-circle diffractometer at the Institut Laue-Langevin.

## Performed Experiment

Thermal neutrons of incident wavelength 2.36 Å were selected employing a vertically focusing pyrolytic graphite (PG) (002) monochromator and collected in a $96 \times 96\,mm^2$ 2D microstrip detector. Given the higher flux of the updated intrument, the triple-axis configuration in elastic mode was not implemented. The measurements were performed in the temperature range of 320 K to 2 K and no magnetic field was applied.

## Data Analysis

The crystal structure of the 40 nm $h$-MnPdGa in the paramagnetic (PM) state was analyzed through the collection of 37 Bragg peaks at 320 K. The refinement of the nuclear and magnetic structures were performed by the Rietveld method implemented within the FullProf software [1].

A similar set of Bragg reflections were collected below $T_C$, in the collinear FM state at $T = 200K$. At this temperature, an increase in the intensity of the (-100) Bragg reflection is observed, which signals the appearance of an additional ferromagnetic contribution to the scattering. Accordingly, the nuclear and magnetic structures were refined and analyzed at this temperature.

Reducing the temperature to 2 K, well below the spin reorientation temperature $T_{sr} \approx 140$ K, we observe that the intensity of the (-100) Bragg reflection was further increased, accompanied by the onset of a sizeable (001) Bragg reflection. The observation of the structurally forbidden (001) Bragg reflection for the $P6_3/mmc$ space group, of therefore purely magnetic origin, is a signature of the existence of a component of the magnetic moment in the basal plane. The magnetic order in the spin canted state (SC) is found to be commensurate with the lattice, and characterized by a propagation vector $\boldsymbol{k}$ = (0,0,0). This type of magnetic ordering was previously reported by our group in $h$-MnPtGa thin films [2].

The refinement of the nuclear and magnetic structures at 2 K were performed including both a FM coupling in the basal plane, with the moment along the $c$-axis, and an AFM in-plane component (staggered in the out-of-plane direction). Figure (a) and (b) shows the temperature dependence of the integrated intensities of the (-100) and (001) Bragg reflections, where both transitions to the

collinear FM state and spin-canted state can be observed.

## Conclusions

Hexagonal MnPdGa thin film undergoes a spin reorientation transition at $T_{sr} \approx 140K$. We investigate the magnetic groundstate and find the emergence of the (00l) purely magnetic Bragg reflection below $T_{sr}$. This structurally forbidden reflection evidences the emergence of a spin-canted state, where the magnetic moments align ferromagnetically in the basal plane and a non-zero in-plane component exhibits an antiferromagnetic ordering along the $c$-axis.

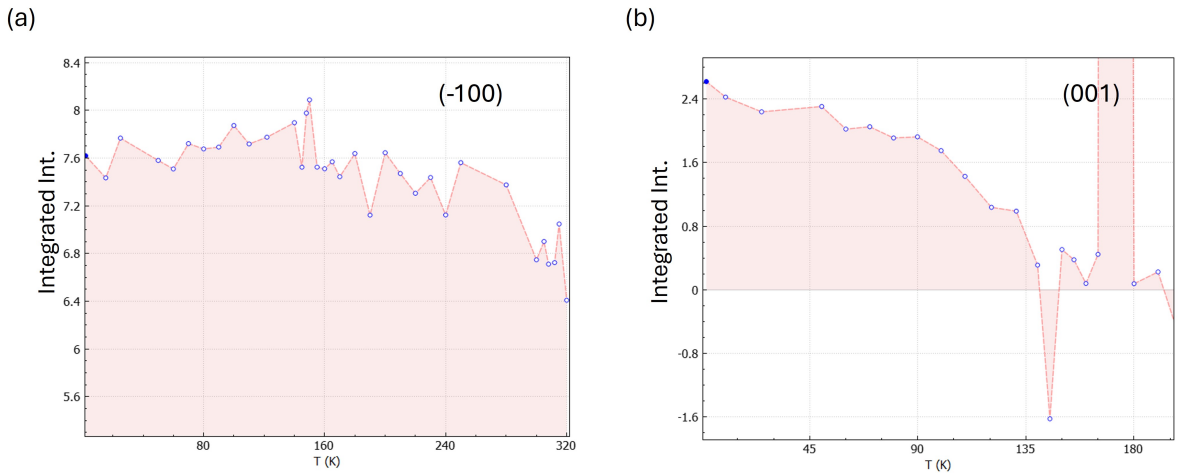


Figure 1: Single-crystal neutron diffraction of $h$-MnPdGa epitaxial thin film. (a) Temperature dependence of the (-100) Bragg reflection, due to the FM component of the magnetic structure. (b) Temperature dependence of the purely magnetic (001) Bragg reflection, evidencing the emergence of the spin canted state below $T = 140K$.


[1] J. Rodríguez-Carvajal, "Fullprof," *CEA/Saclay, France*, vol. 1045, pp. 132–146, 2001.

[2] R. Ibarra, E. Lesne, B. Ouladdiaf, K. Beauvois, A. Sukhanov, R. Wawrzyńczak, W. Schnelle, A. Devishvili, D. Inosov, C. Felser, and M. A, "Noncollinear magnetic order in epitaxial thin films of the centrosymmetric mnptga hard magnet," *Applied Physics Letters*, vol. 120, no. 17, 2022.