Ferromagnetic insulators are extremely valuable components of novel devices based on spin (rather than charge) transport. The lack of conductivity means that spin waves can propagate more freely in ferromagnetic insulators, as those spin waves are undamped by eddy currents. However, there are a limited number of ferromagnetic insulators commonly found in nature. As such, a large fraction of research done on ferromagnetic insulator based devices involve one specific ferromagnetic insulator compound, yttrium iron garnet, Y3Fe5O12 (YIG). Despite being so commonly used, researchers continue to learn more about the fundamental properties of YIG, and how it interacts with other materials. An excellent example came from a recent study of the nature of the magnetic exchange coupling between YIG and the commonly used metallic ferromagnet permalloy, Ni80Fe20 (Py) [1]. In this work, the authors used polarized neutron reflectometry to characterize the magnetization of individual YIG and Py thin film layers in a multilayer stacks. They found very surprising results, and we'll reproduce their polarized neutron reflectometry (PNR) experiment for our NCNR summer school PBR experiment. It's an excellent paper, but SPOILER ALERT - don't read it ahead of time if you want to be surprised by the results!

The thin-film multilayer sample to be studied in our experiment was grown by magnetron sputtering in Luqiao Liu's lab at the Massachusetts Institute of Technology. The layer structure, as well as key results from initial characterization measurements are shown in Figure 1.
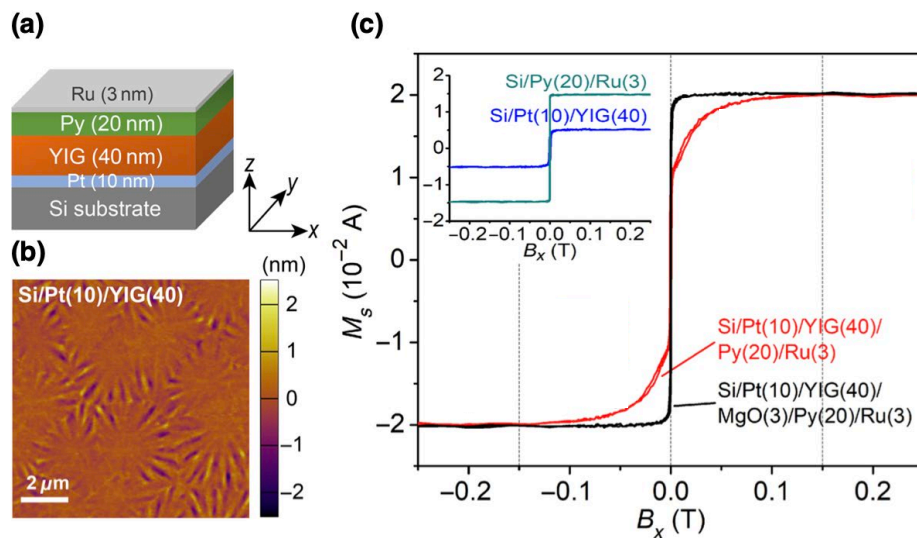

Figure 1. (a) Sample layer structure. (b) AFM image indicating low surface roughness. (c) VSM hysteresis loops for our sample (red) and control samples (black, blue, and green).

The atomic force microscopy (AFM) image in Fig. 1(b) shows a local surface roughness of about 1 nm, suggesting that the sample is smooth enough for PNR measurements. Fig. 1(c) shows

room temperature vibrating sample magnetometry (VSM) measurements of the applied field dependent magnetization of our YIG / Py experiment sample (red), as well as those for various control samples: no YIG (green), no Py (blue), and with a non-magnetic MgO spacer layer in between the YIG and Py layers. Notably, the hysteresis loop for our sample with adjacent YIG and Py layers looks qualitatively different than that of the other three. Instead of a tight, square, ferromagnetic loop, the net magnetization of the sample with a YIG/Py interface is qualitatively different. When the applied field drops below about 0.1 T, the magnetization starts to relax, slowly dropping before switching rapidly upon application of negative field. Can you guess what might be happening here?

The VSM measurements are only sensitive to the net magnetic moment associated with the samples. To understand this strange hysteresis loop, we'll need characterize the magnetizations of the individual layers using PNR. We will conduct room temperature specular PNR measurements at applied fields of 0.5 T (magnetic saturation), and 0.01 T (near-remanence). By model fitting this data, we will be able to deduce the depth profiles of the in-plane magnetization, and the nuclear composition (which will allow us to reference how the depth-dependent magnetization correlates with the chemical composition). These depth profiles will reveal fascinating magnetic coupling between the ferromagnetic insulator YIG and the ferromagnetic metal Py.

[1] Yabin Fan, P. Quarterman, et. al, PHYSICAL REVIEW APPLIED **13,** 061002 (2020).