OSU Physics SCANNED PROBE MAGNETIC RESONANCE LAB

Magnetic Resonance Imaging: Interfacial Spin Interaction and Spin Wave Tuning

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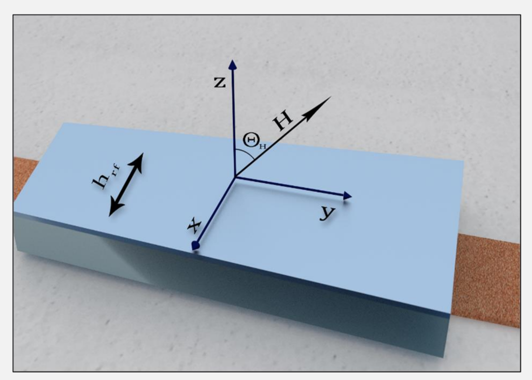
Magnetic Resonance Imaging using Ferromagnetic Resonance Force Microscope

Introduction & motivation

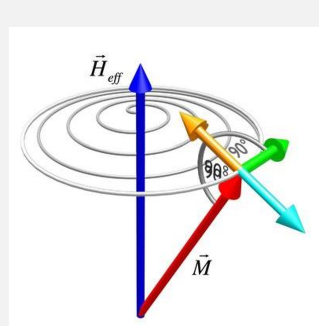
- Understanding interfacial spin interaction in van der Waals (vdW) heterostructure composed of ferromagnet (FM) and two-dimensional (2D) materials
- Explore the novel effect of 2D material and vdW heterostructures on the FM magnetization, including spin pumping, spin torque, Rashba-Edelstein effect and topological surface states etc.
- Tuning spin wave modes generation in FM nanostructures such as internal field step in $Y_3Fe_5O_{12}$ (YIG) thin film, FM/heavy metal(HM) bilayer

Experimental methods

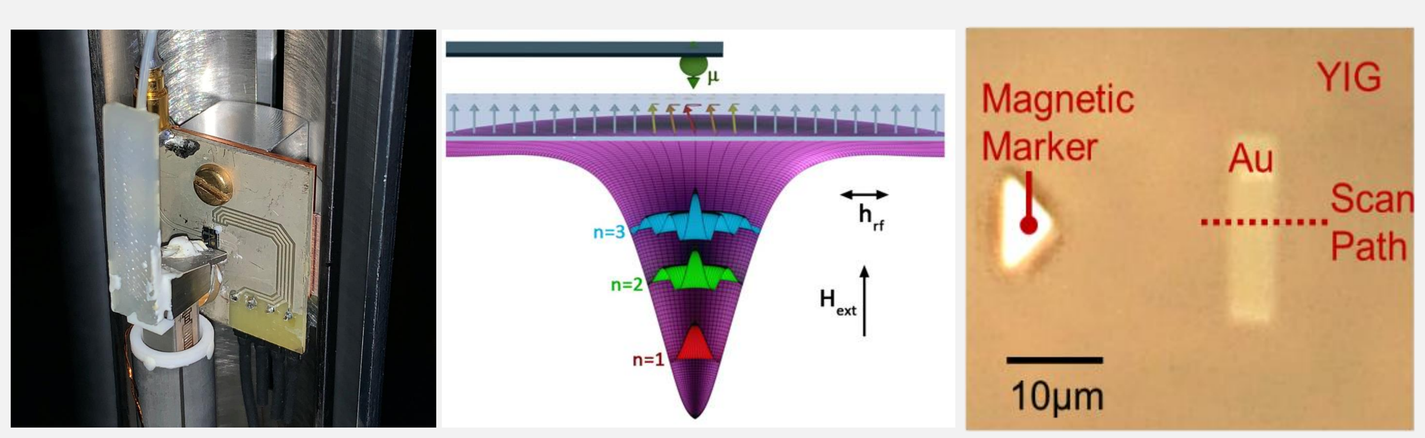
- **Ferromagnetic Resonance (FMR)**
  - Spectroscopically study internal fields of ferromagnet (FM)
  - Examples of FM internal field sources:
    - Exchange interaction
    - Dipolar interaction
    - Crystalline structure
    - External field



  - Resonance condition: $\omega = \gamma H_{\mathrm{eff}}$
  - Damping: magnetization relaxing to equilibrium
    - Spin-phonon relaxation
    - Spin-magnon relaxation
    - Spin-electron relaxation
    - Spin pumping



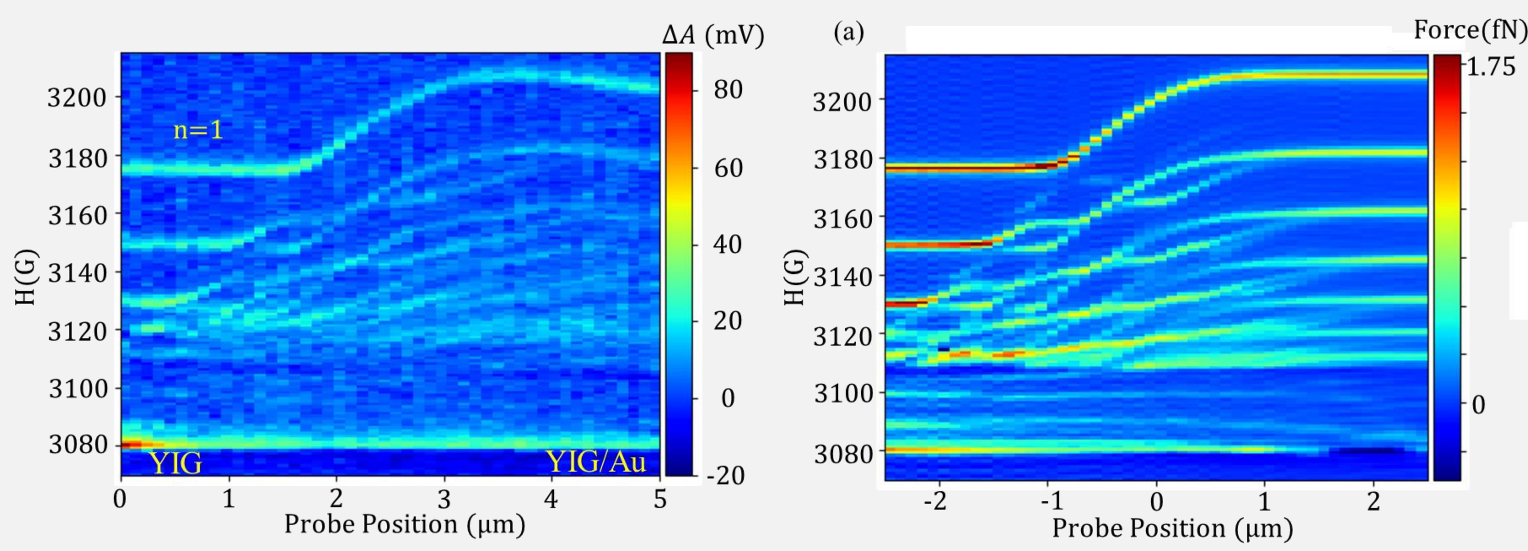
- **Ferromagnetic Resonance Force Microscopy (FMRFM)**



  - Cantilever affixed with high coercivity micromagnetic particle
    - Sensitive force detector of magnetic resonance
  - Strong dipolar field of micromagnetic particle can localize spin wave mode (LMs) underneath probe
    - analogous to particle in a box (quantum mechanics)
    - High spatial resolution (100nm)
  - Measurement procedure:
    - Constant height spatial scan of across the boundary separating two regions with different magnetic properties Track amplitude changes of cantilever when sample undergoes resonance

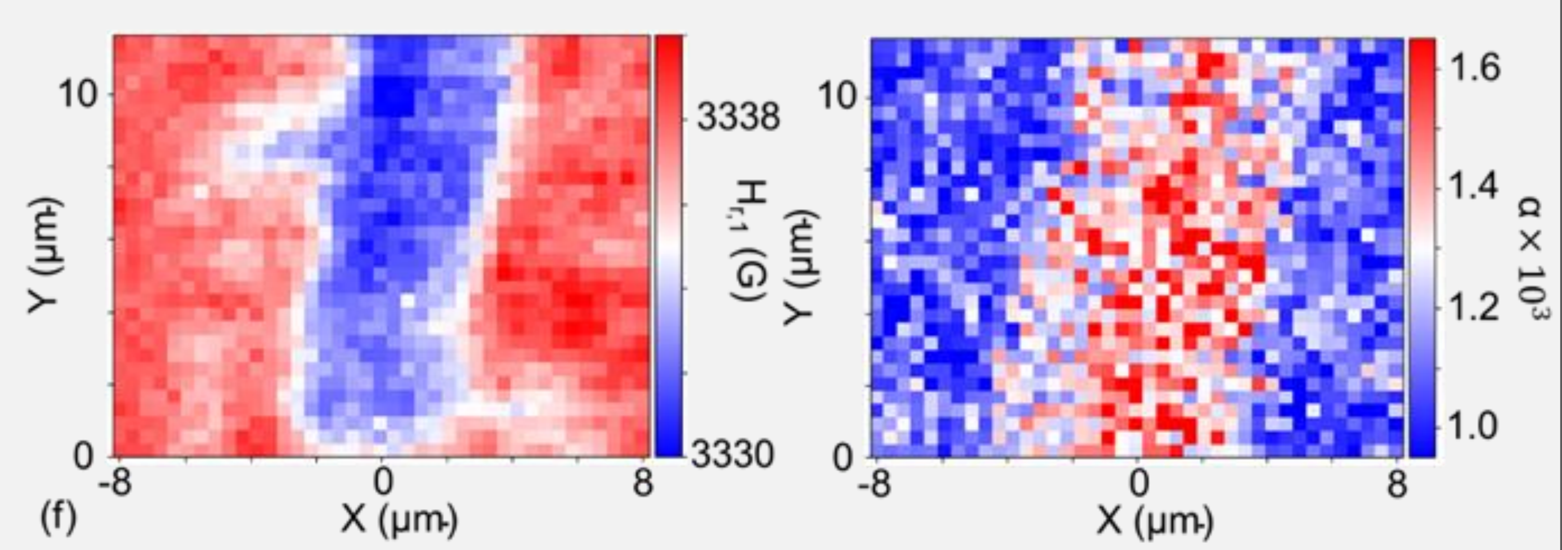
Results

- **Au Overlayer Induced Surface Anisotropy**



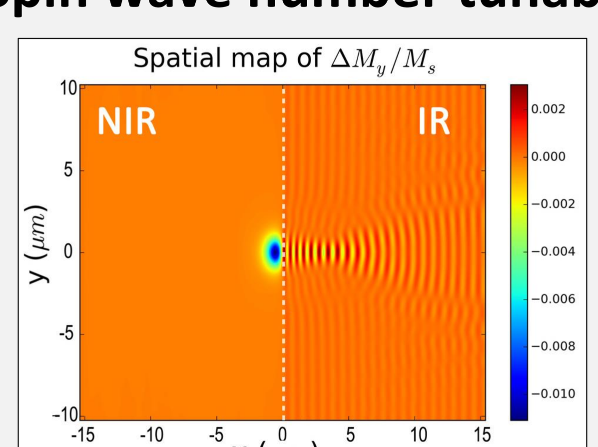
  - Spatial FMRFM scans across a boundary separating bare YIG and YIG/Au bilayer resolves a 32 Gauss Resonance field increase in the out-of-plane geometry.
  - Experimental results can be repeated with high accuracy using micromagnetic simulation if we set a 32 Gauss decrease of H_u in the region of YIG/Au bilayer

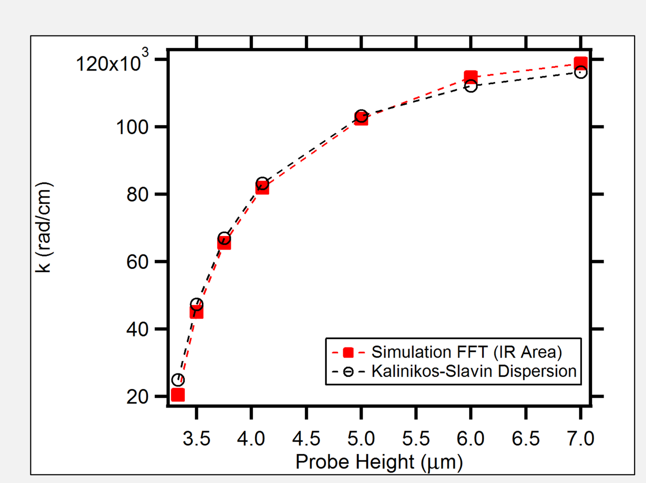
- **Gilbert Damping Real Space Imaging of YIG/Au Spin Pumping**



  - Real space imaging of $\mathrm{n}=1$ LM can simultaneously provide the information of internal field and Gilbert damping
  - 5nm Au overlayer induce damping increase of ~2×10^{-4} due to spin pumping effect .
  - Actively working on imaging internal field and damping variation in YIG/2D heterostructures

- **Spin wave number tunability**

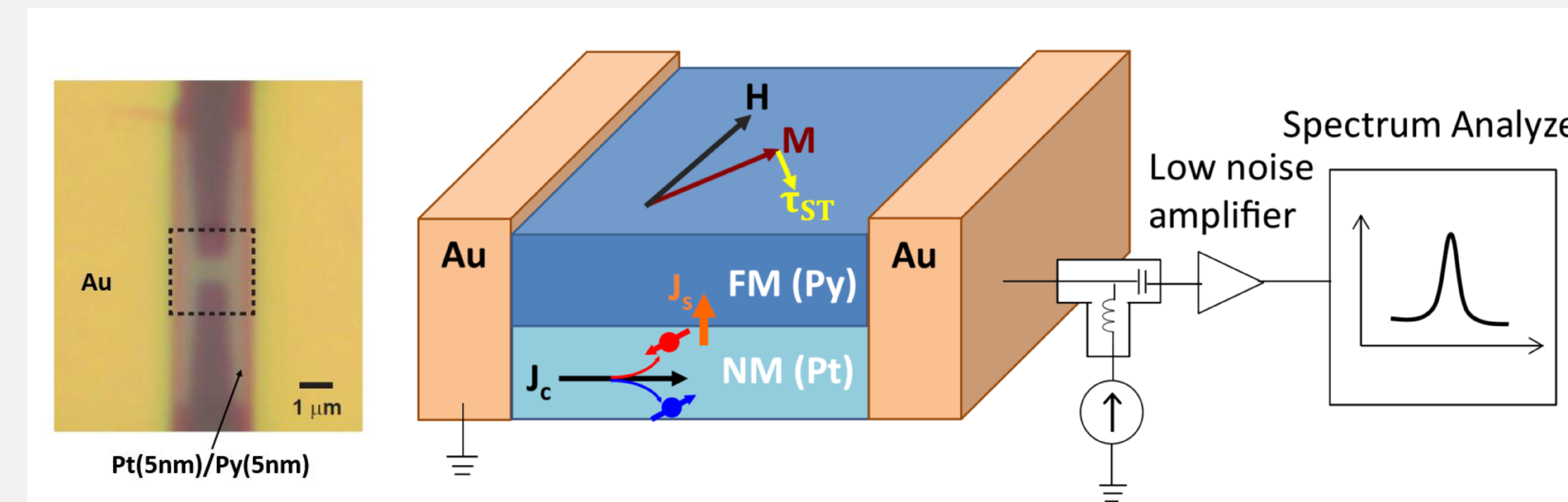




  - Transmitted wave vector depends on internal field step height
  - Can tune wave vector by changing particle-sample separation

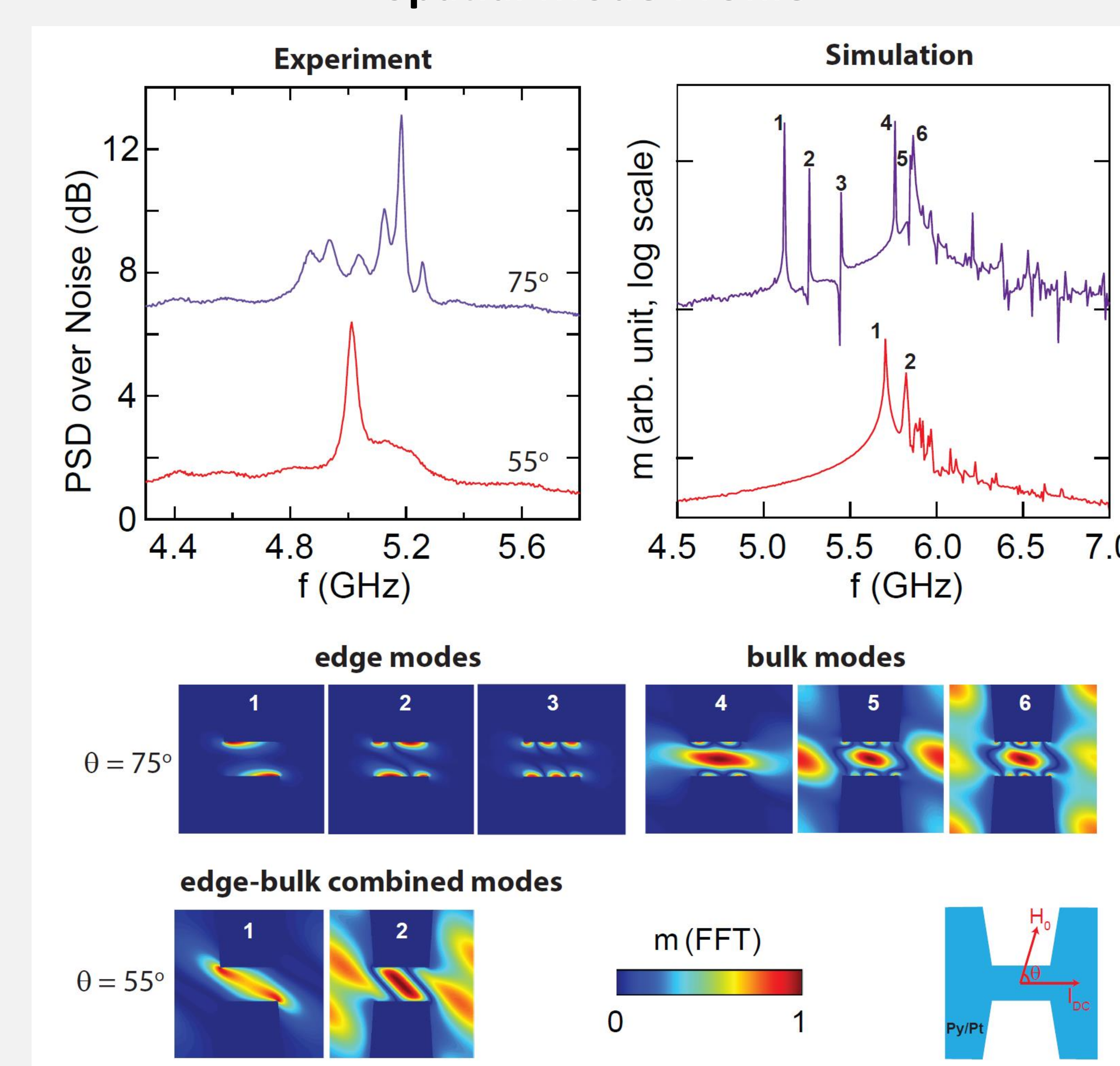
Spectral and Spatial Tuning of the Edge and Bulk Auto-Oscillation Modes

2D Constriction Based Spin-Orbit Torque Driven Auto-Oscillators



- The strong spin-orbit interaction allows the charge current to be converted into a spin current.
- The spin current exerts a spin transfer torque on the magnetization, generating coherent magnetic oscillations at microwave frequencies by compensating the damping of the system.

Angle Dependence of FMR Spectrum and its Corresponding Spatial Mode Profile



- In 2D constriction based structure, there are edge modes arising from the demagnetizing field as well as the bulk modes defined by the sample geometry and applied magnetic field.
- We tune the spectrum and spatial distribution of edge and bulk modes by altering the field orientation relative to the drive current.

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